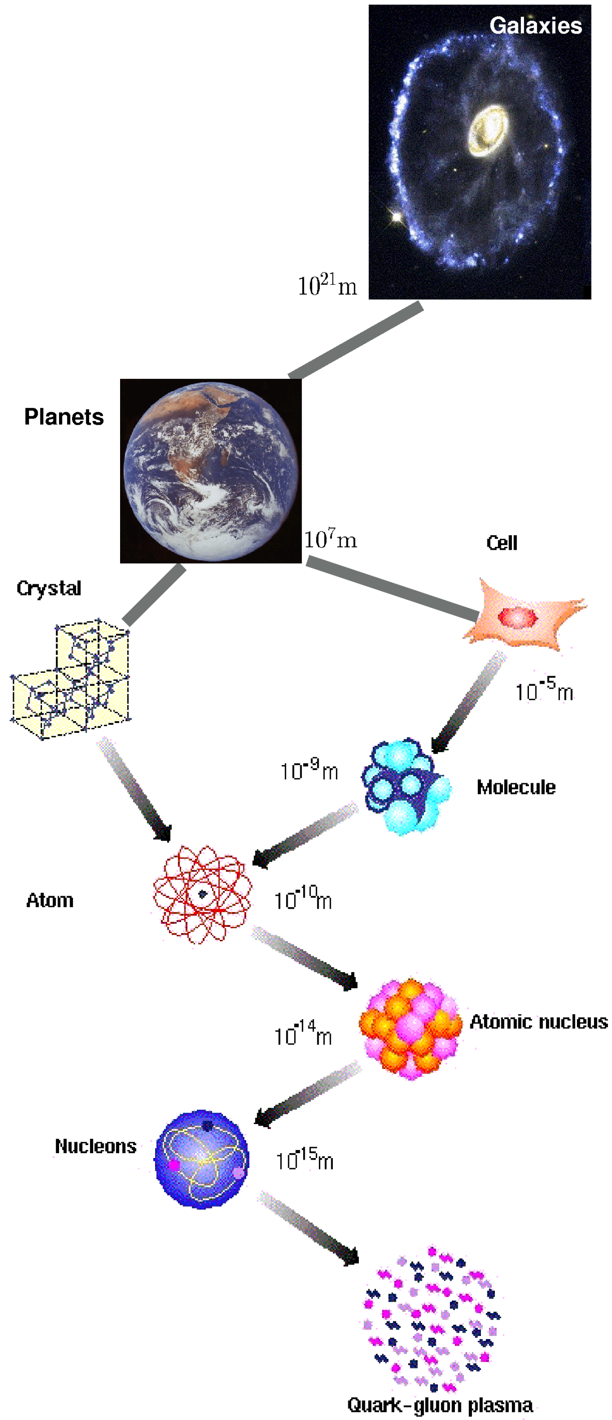
Detection and Identification Methods in Nuclear and Particle Physics

Why Physics ?

Basic Research



Applied Research & Technological Development

Space Science

Earth Science

Material Science

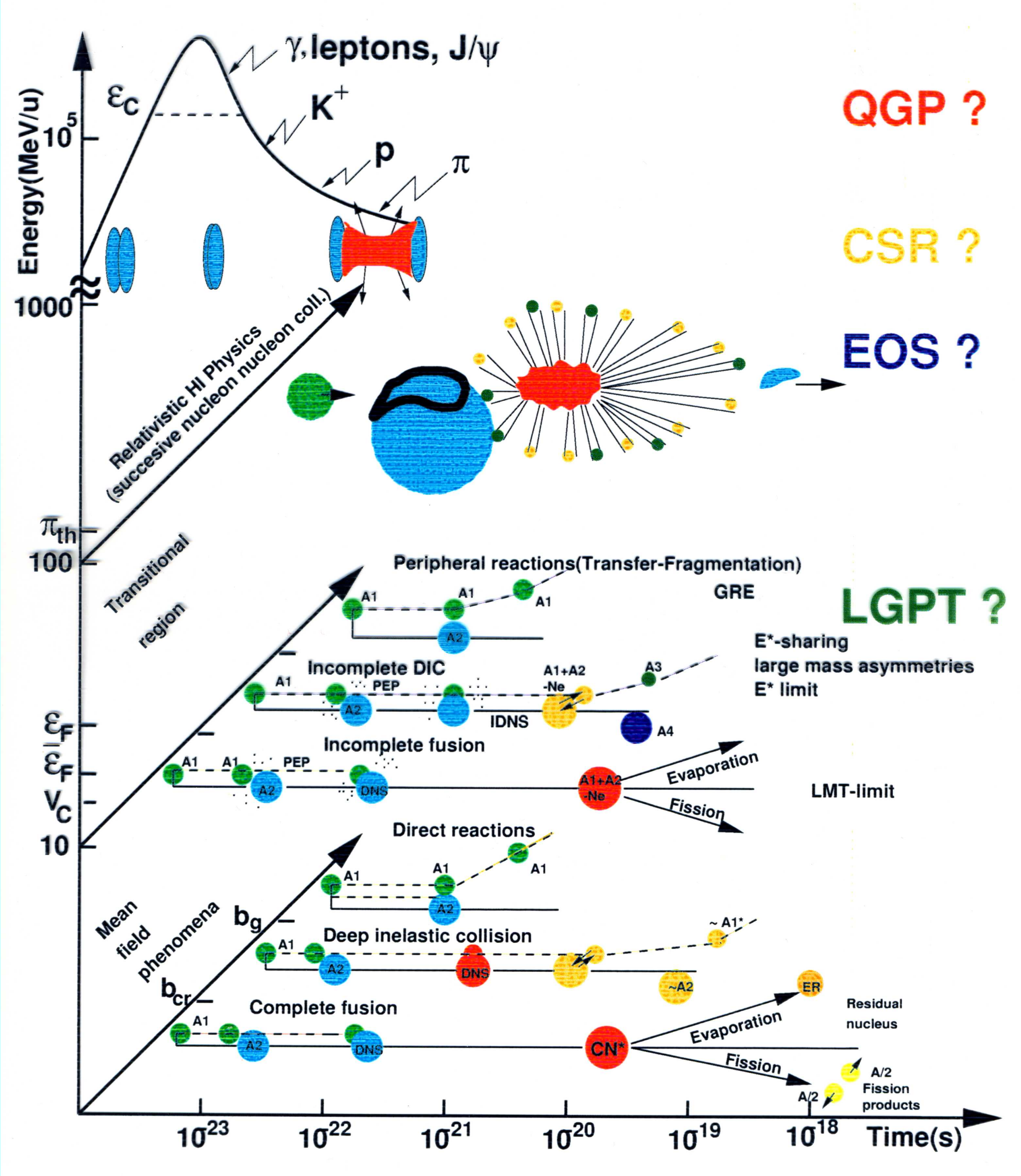
Radiation Medicine
Biophysics
Cancer Therapy

Plasma Physics

Inertial Confinement Fusion

Who knows ?

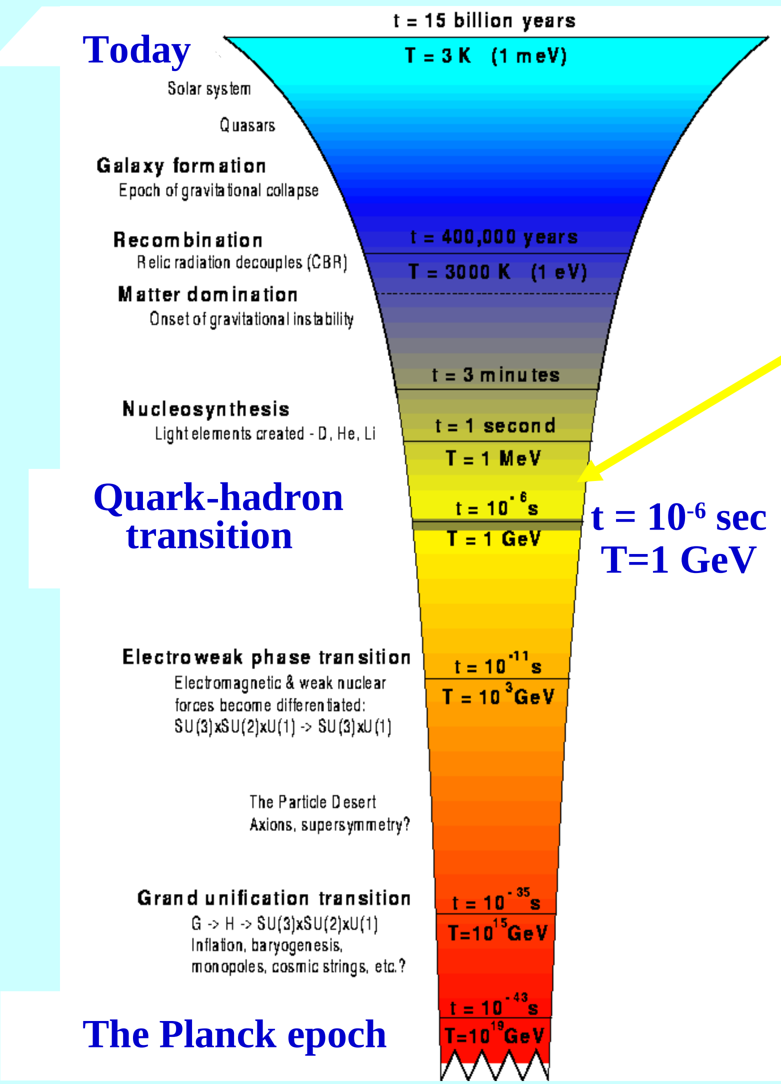
Heavy Ion Physics motivation

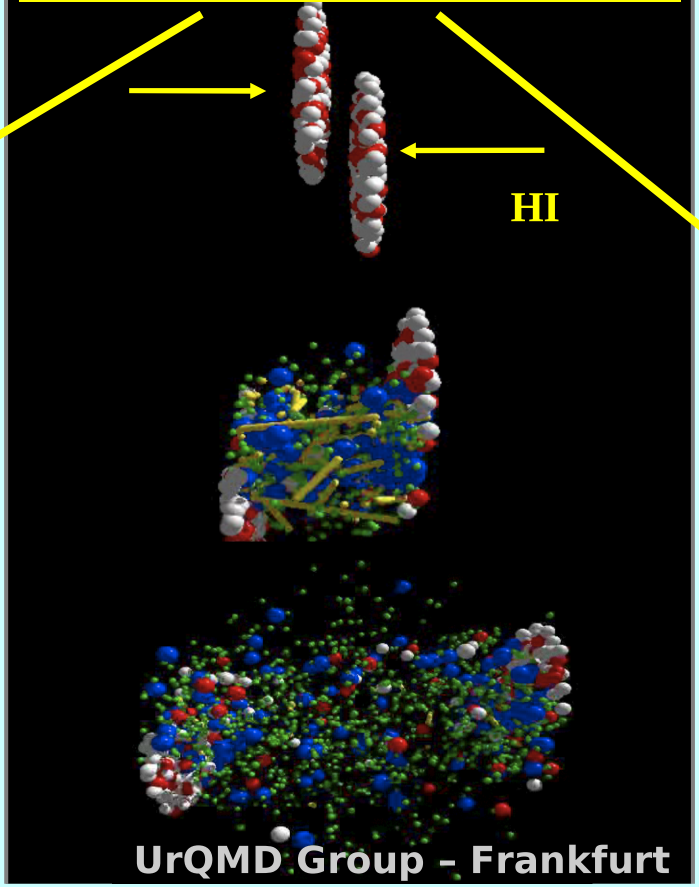


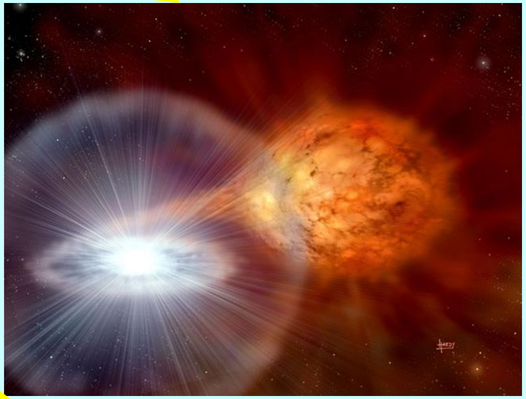
Motivation

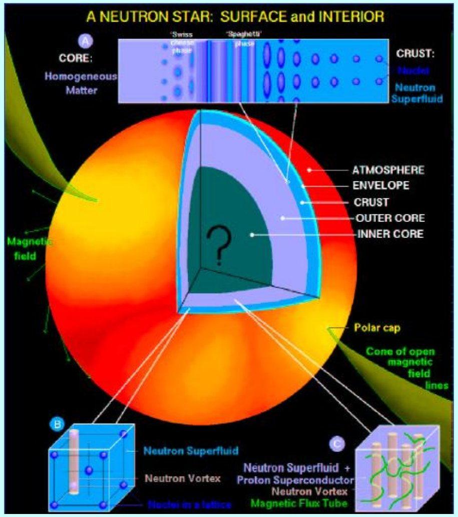
Exotic nuclear structure & dynamics relevant for nuclear astrophysics

May nucleus-nucleus collisions probe the physics of this epoch
this epoch & neutron stars

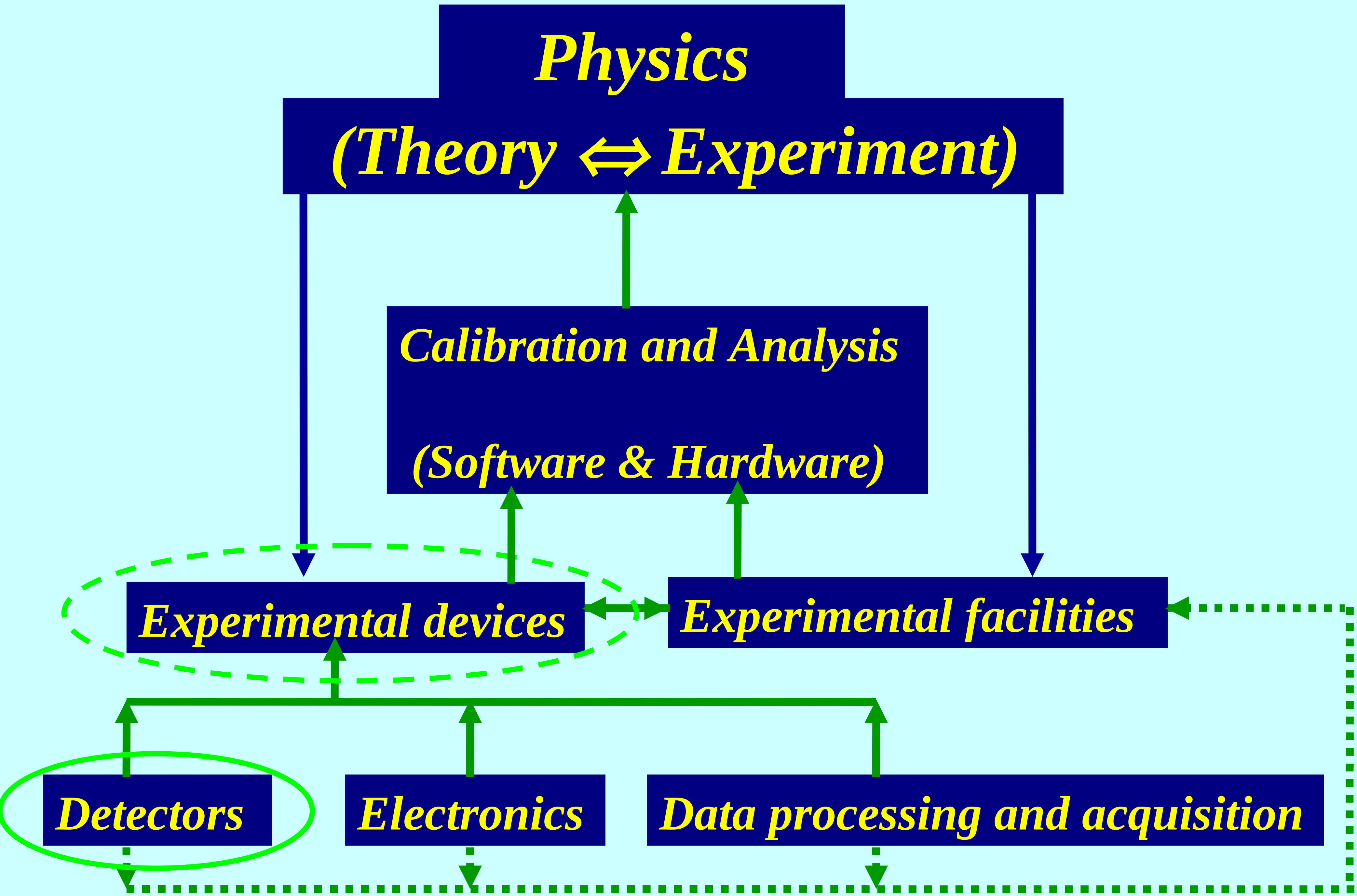








Theory ⇔ Experiment


Physics
(Theory ⇔ Experiment)
Calibration and Analysis
(Software & Hardware)
Experimental devices
Experimental facilities
Detectors
Electronics
Data processing and acquisition

Detectors' aim

Determination of:

- ***position***
- ***energy***
- ***momentum***
- ***particle identification (charge & mass)***

Experimental techniques in high-energy nuclear and particle physics

T. Ferbel, World Scientific 1991

A. Detectors relying on ionization and excitation:

- ***Gaseous detectors:*** - *Ionization Chambers,*
  - *Proportional Counters,*
  - *Drift Chambers*
  - *Streamer chambers*
  - *Spark chambers*
  - *Flash tubes*
  - *Avalanche Counters (PPAC)*
  - *Resistive Plate Counters (RPC)*

- ***Liquid detectors:*** - *Bubble chambers*
  - *Ionization chambers*

- ***Semiconductor detectors** - hodoscopes, pixel, drift, microstrips and CCDs*

$\Rightarrow$ ***ΔE, E, Z, A, position, Time-of-Flight measurements, momentum measurements in a magnetic field***

- ***Scintillator counters and photomultipliers***

$\Rightarrow$ ***PID, n-γ discrimination, Time-of-Flight measurements***

B. Coherent effects for charged particles:

- ***Cherenkov radiation and Cherenkov detectors:***
  - ***threshold***
  - ***ring imaging***
- ***Transition Radiation Detectors (TRD)***

C. Interaction of electrons and photons with matter:

- ***Bremsstrahlung***
- ***Photo-electric effect***
- ***Compton scattering***
- ***e^+e^- pair production***

D. Electromagnetic calorimetry:

- *Electromagnetic showers and energy measurement*

E. Hadronic calorimetry:

- *Hadronic showers*

Interaction of charged particle with the matter

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

- Energy loss due to ionization depends on $\beta\gamma$

typically ~ 2 MeV/cm ρ/(g cm^{-3})

⇒liquids, solids: few MeV/cm

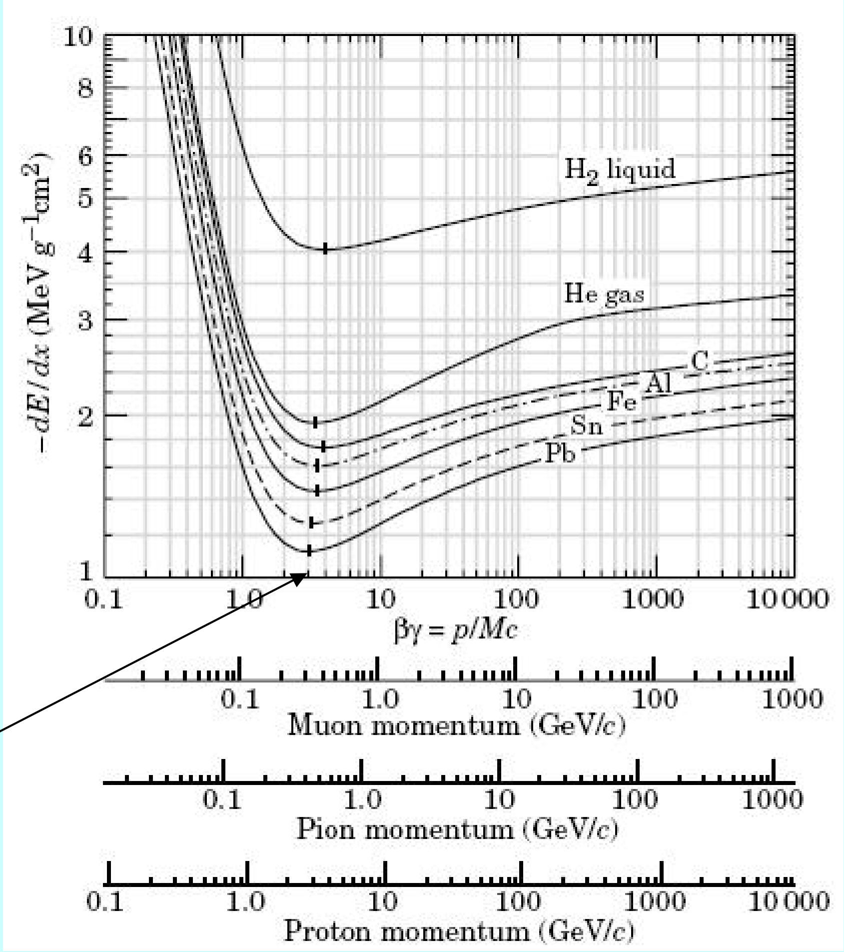
⇒gases: few keV/cm

- Primary ionization: charged particle kicks electrons from atoms
- In addition: excitation of atoms (no free electron)

⇒On the average W_i (ionization energy) needed to to create a e^- - ion pair

W_i typically 30 eV

⇒~ 2000eV/30eV = 60 e^--ion pairs/(cm of gas)



minimum ionizing particles MIP

- ***Gaseous detectors:***

- *are based on the ionization process produced by charged particles as they pass through matter*

- *free electrons and positive ions are produced along their tracks*

- *The strength of applied field determines the working regime, therefore the detector type, i.e:*

- ***Ionization Chambers (IC)*** - *small electric field* $\Rightarrow$ *the collected signal is the original produced charge*
- ***Proportional Counters (PC)*** - *larger electric field* $\Rightarrow$ *secondary ionizations but the final charge is still proportional with the initial one*

- ***Drift Chambers (DC)***
- ***Time Projection Chambers (TPC)***

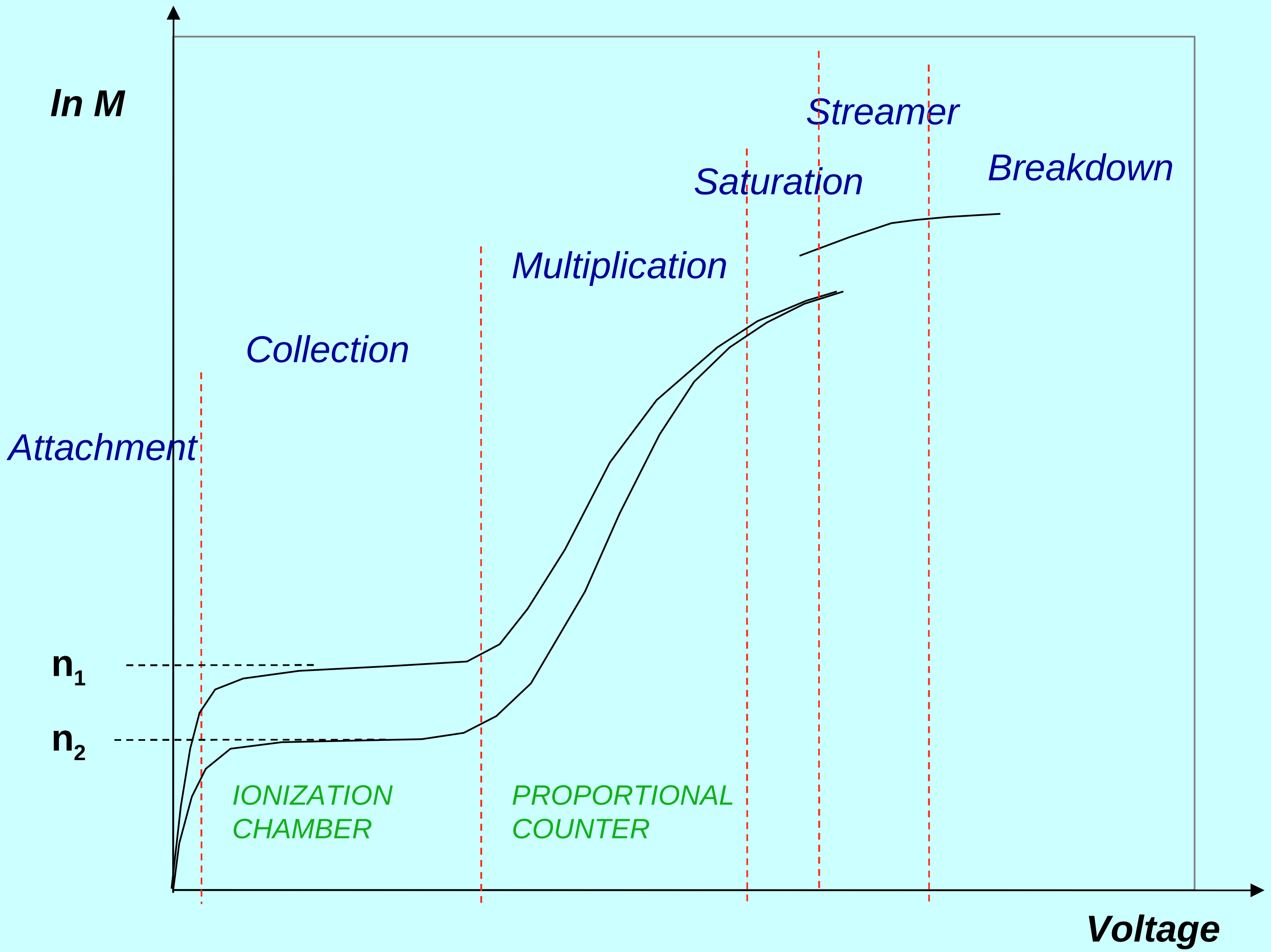
- ***Gaseous detectors (cnt'd):***

- ***Streamer chambers (SC)*** - *electric field further increased*
  - *secondary ionization increase ⇒ saturation*
  - *electrons-ions recombination ⇒ visible streamers*

- ***Spark chambers*** - *electric field very large and longer voltage pulse the photons produced by recombination produce secondary avalanches ⇒ discharge spreads over the whole counter*

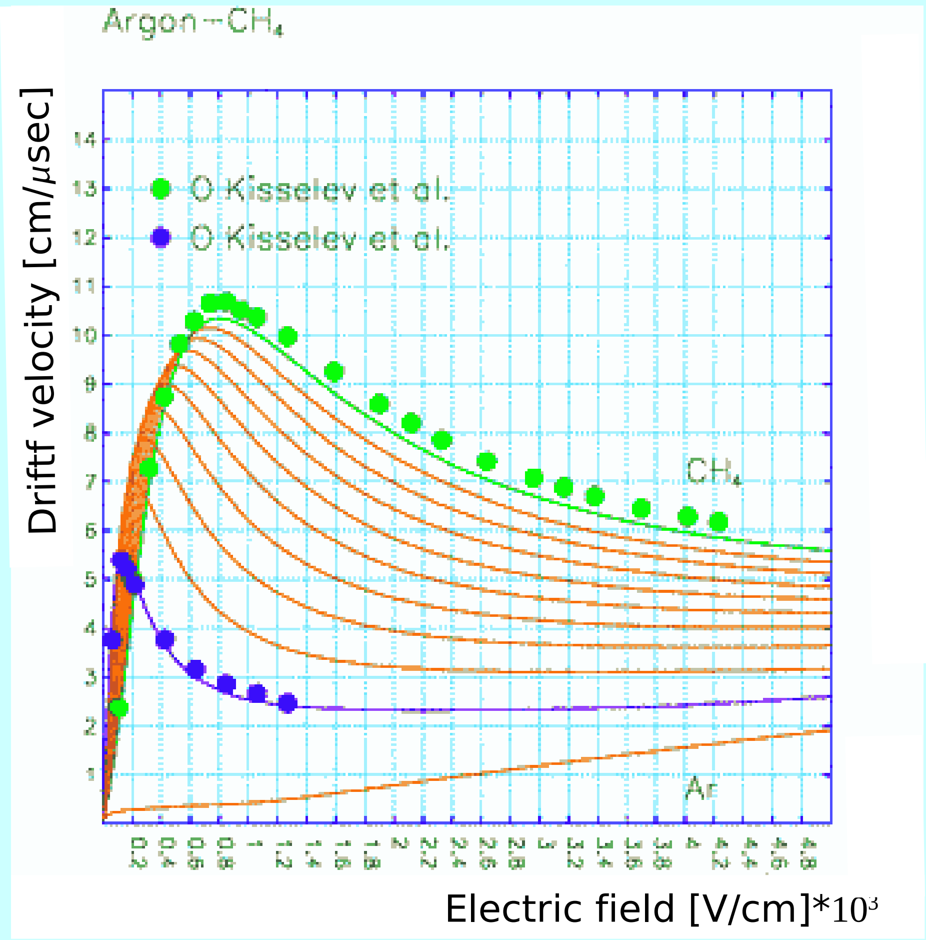
- ***Flash tubes*** – *spark mode maintaining the spatial resolution*

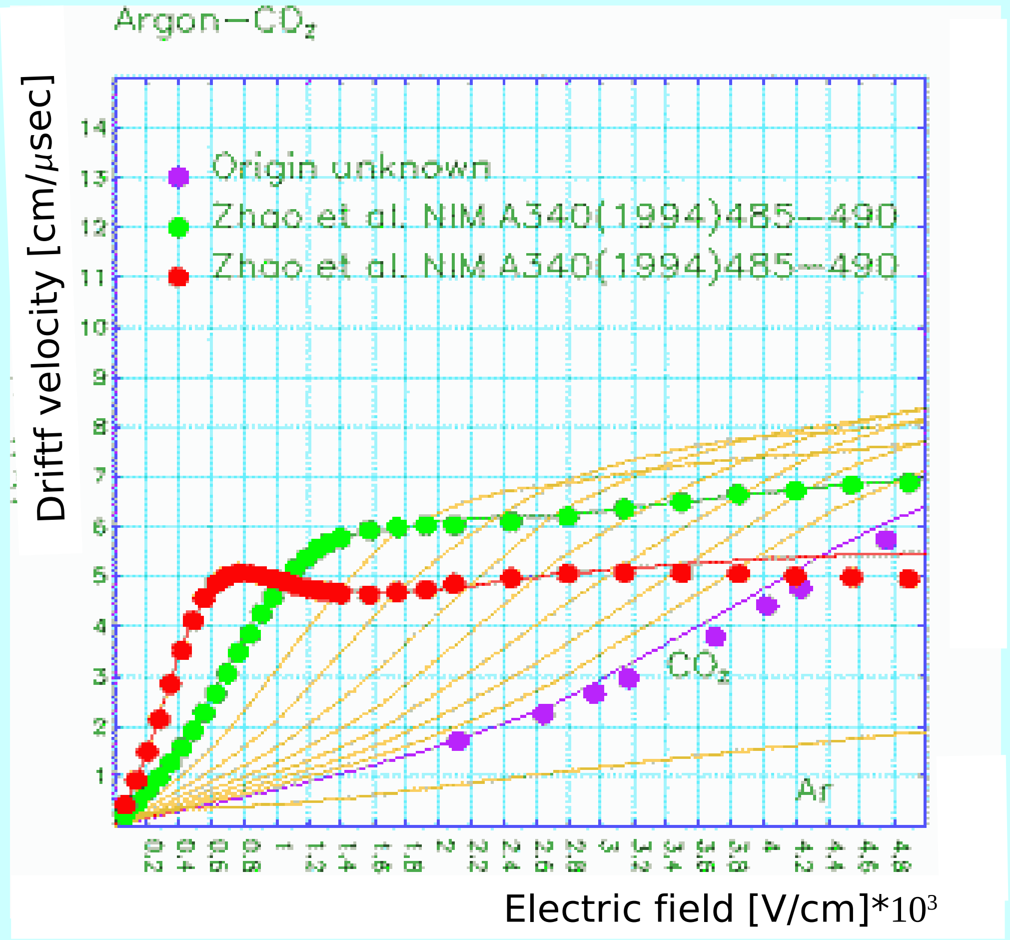
Gain characteristics



Produced signal $\Rightarrow \delta V = (q/CV_0)\cdot E\cdot\delta x$

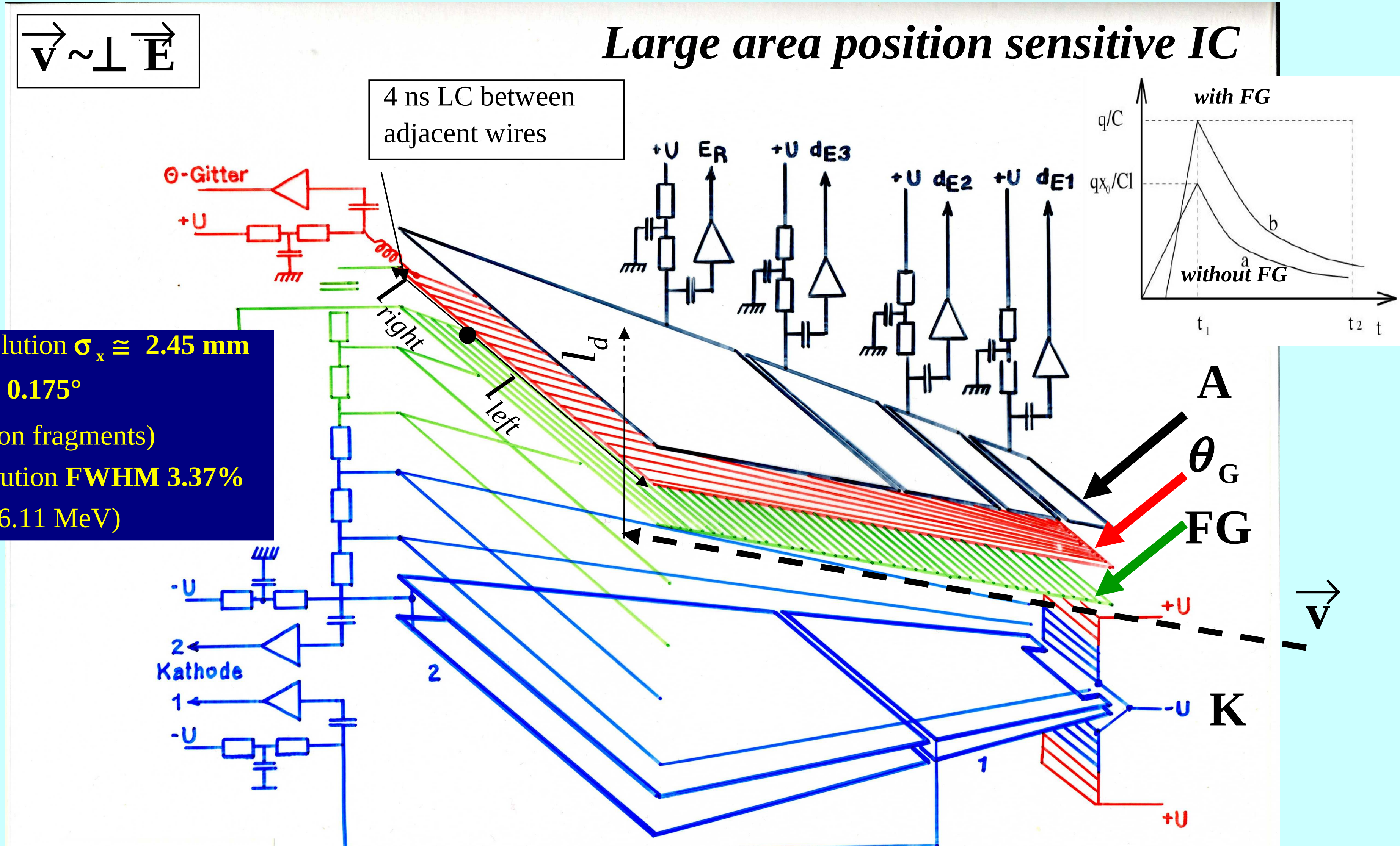
Electron drift velocity





http://consult.cern.ch/writeup/garfield/examples/gas/trans2000.html#elec

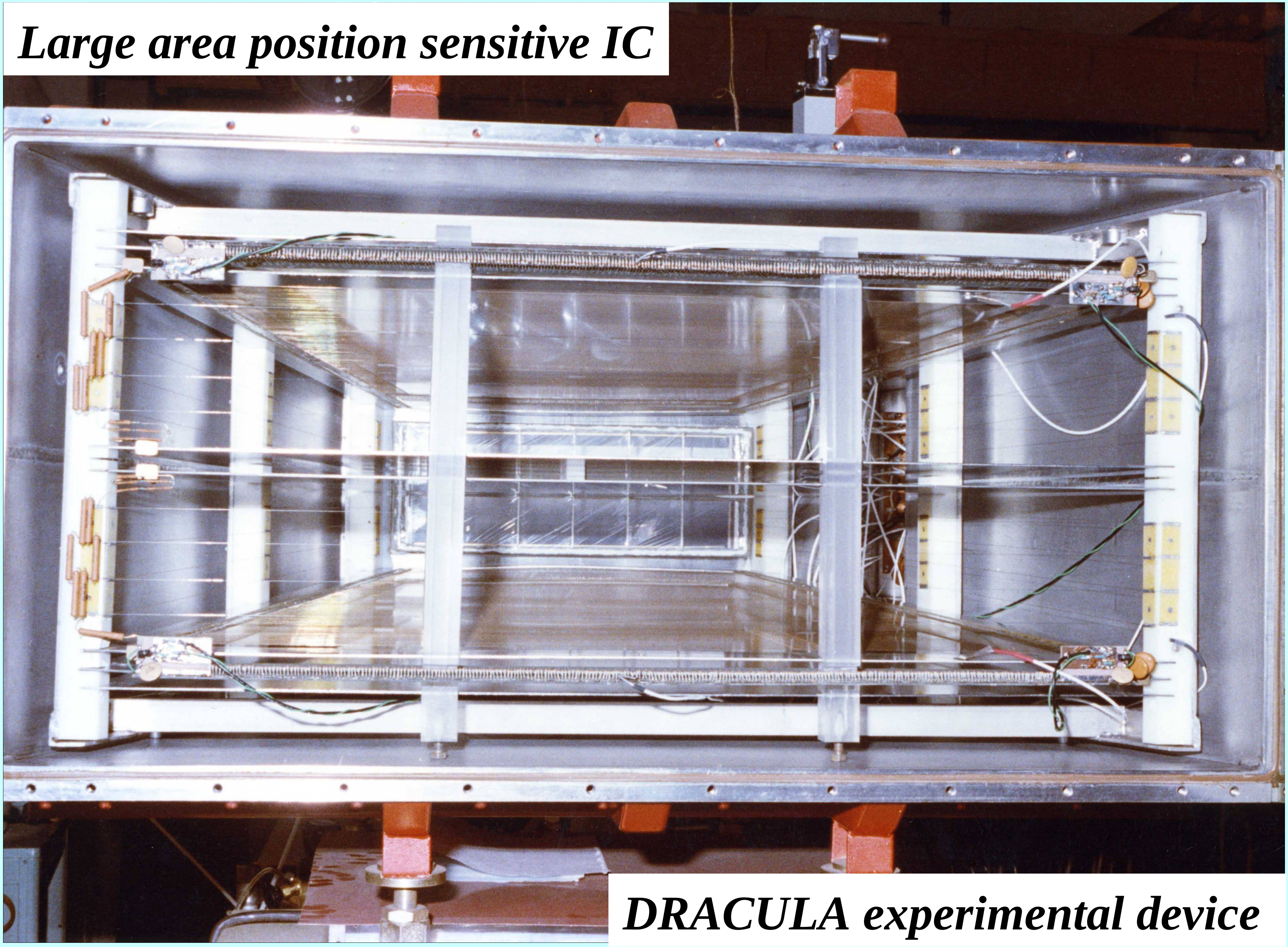
IC-Examples



- position resolution $\sigma_x \cong$ **2.45 mm**
  $\Rightarrow \sigma_\theta \cong$ **0.175°**
  (^{252}Cf – fission fragments)
- Energy resolution **FWHM 3.37%**
  (^{252}Cf - Eα=6.11 MeV)

$l_{left}-l_{right} \sim (t_{left}-t_{right}) \Rightarrow \theta_{lab}$; $l_d \sim (t_{drift}-t_{start}) \Rightarrow \varphi_{lab}$

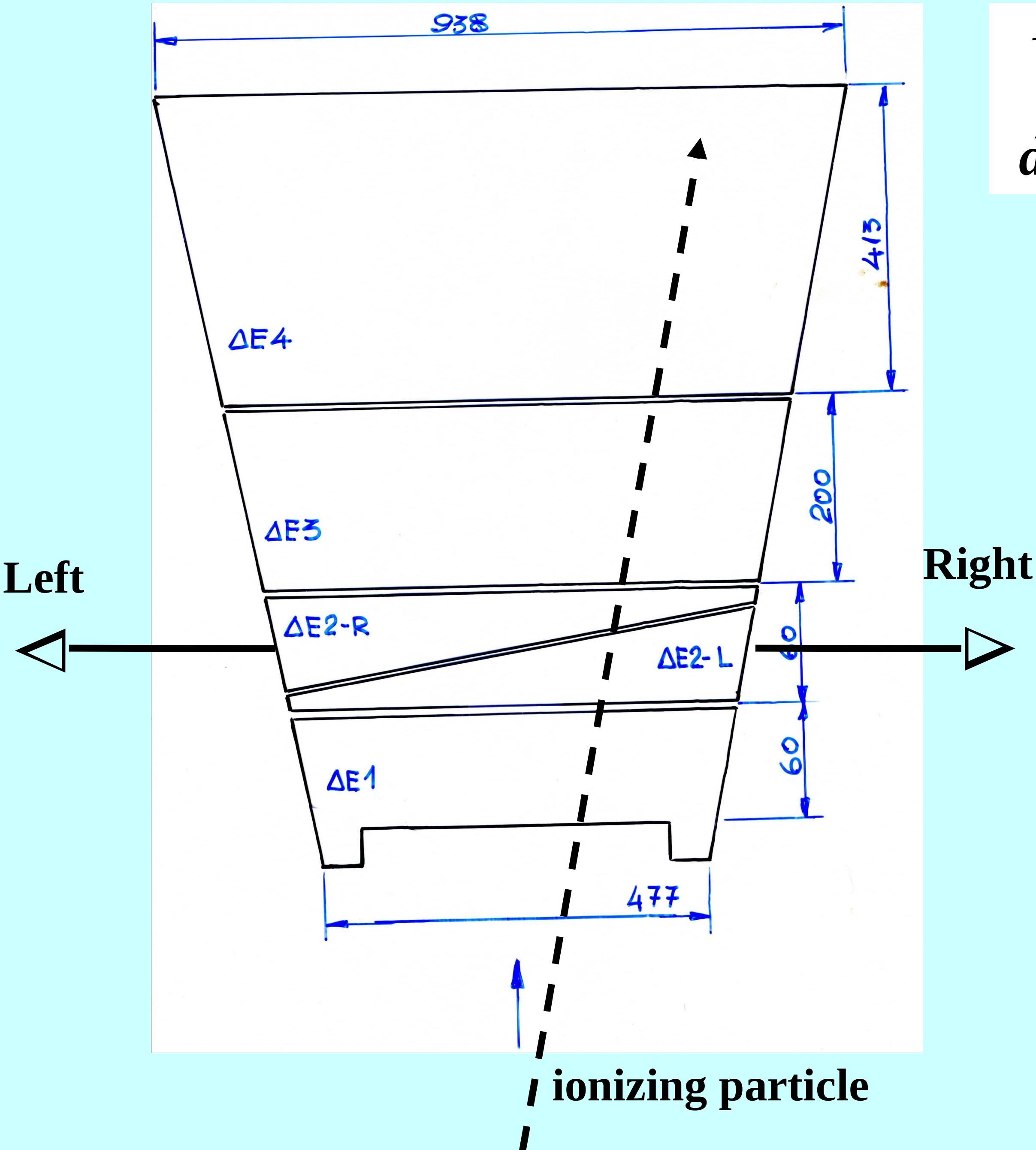
IC-Examples



Large area position sensitive IC
DRACULA experimental device

IC-Examples

Position information using diagonally split anodes



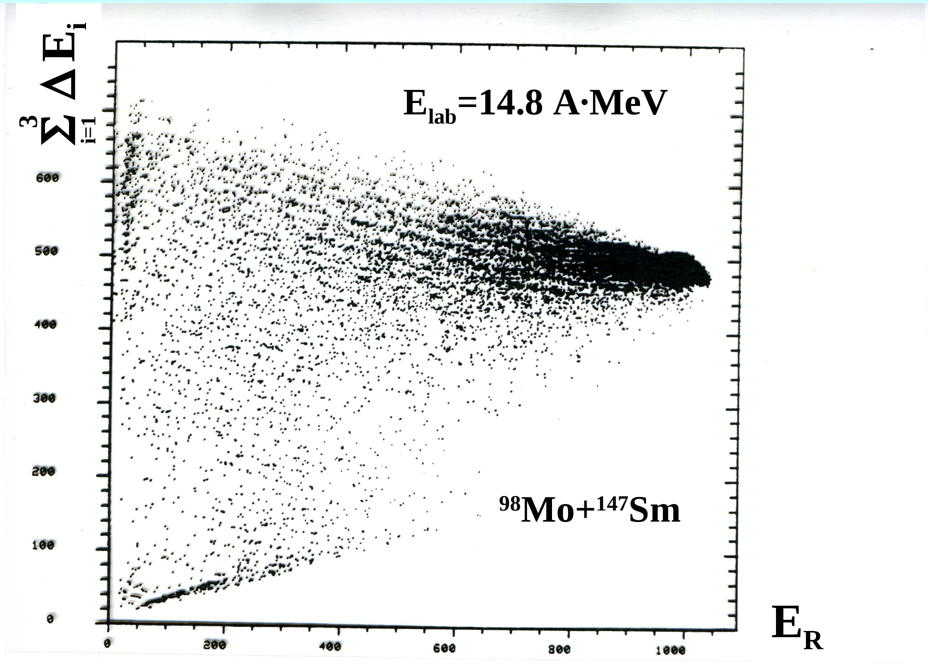
$(\Delta E_L - \Delta E_R) \sim x \sim \theta_{lab}$

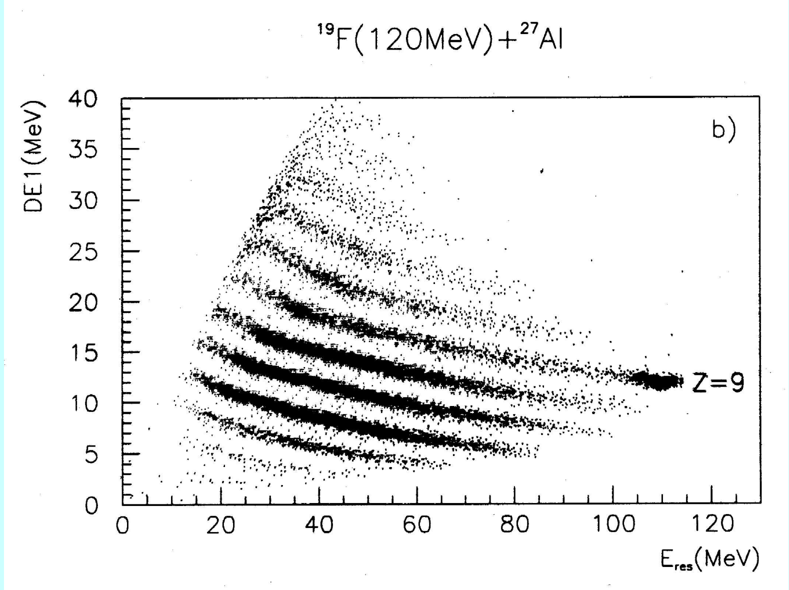
IC performance - Examples

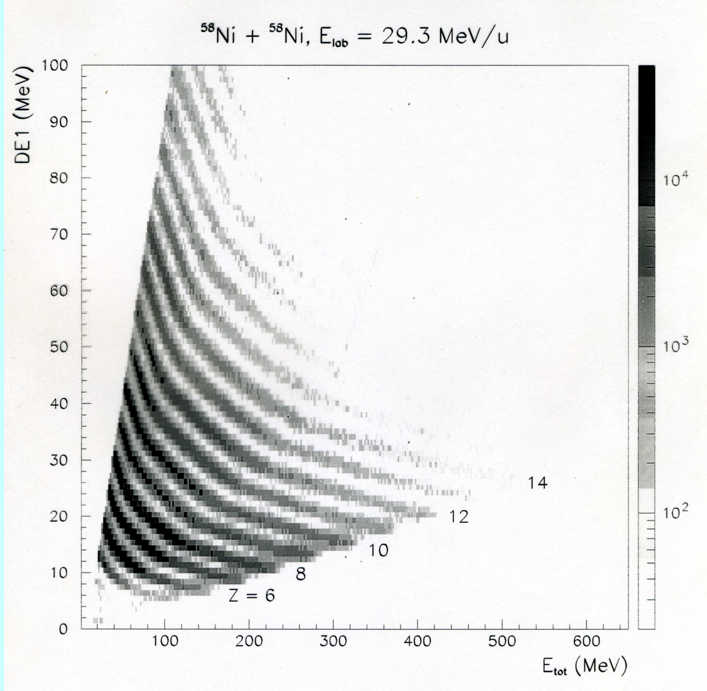
$$-dE/dx = (aZ^2c^2/v^2)\ln[bv^2/(c^2-v^2)]$$

since the logarithmic term varies slowly with energy (velocity)

$$\Rightarrow dE/dx \sim MZ^2/E$$







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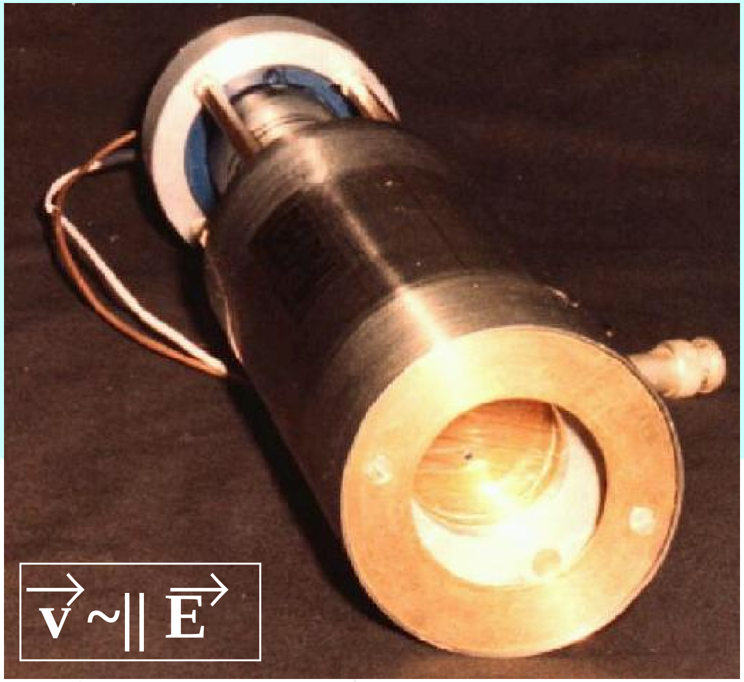
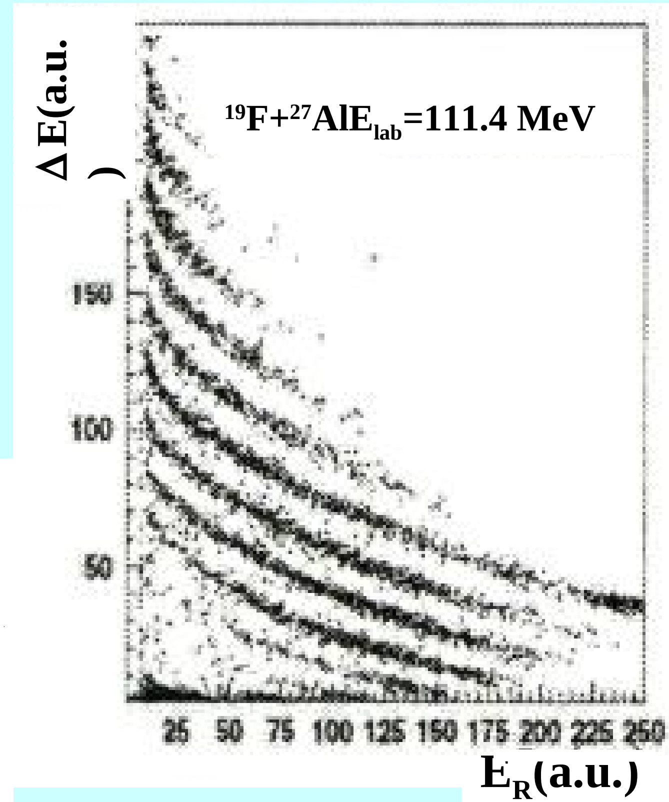
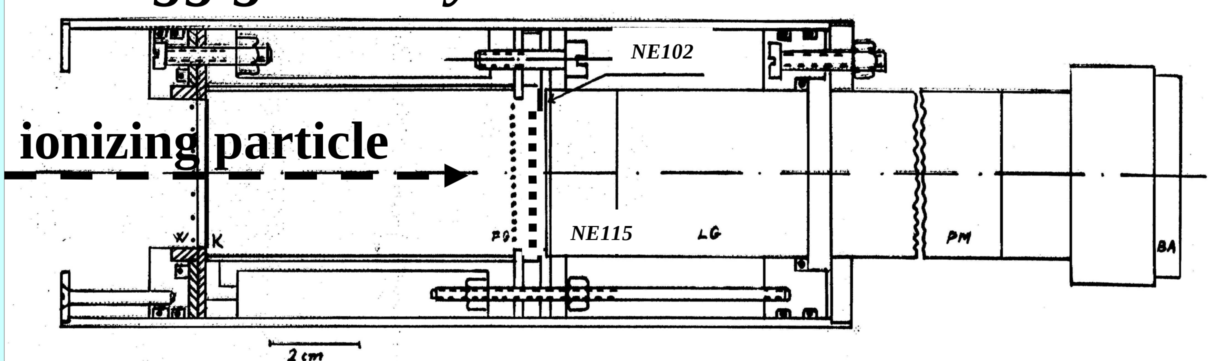
IC-Examples





Bragg geometry IC



CH_4

p=300 torr

U_A=1100 V

U_{FG}=525 V

- Energy resolution **FWHM 3.1%**
  (^{239}Pu - Eα=5.114 MeV)

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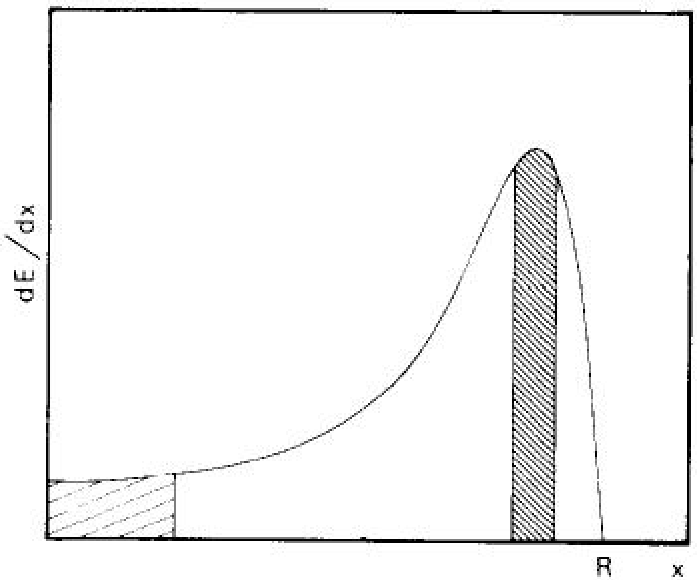
IC-Examples

Sampling mode



~ $(T_d - t_d)$

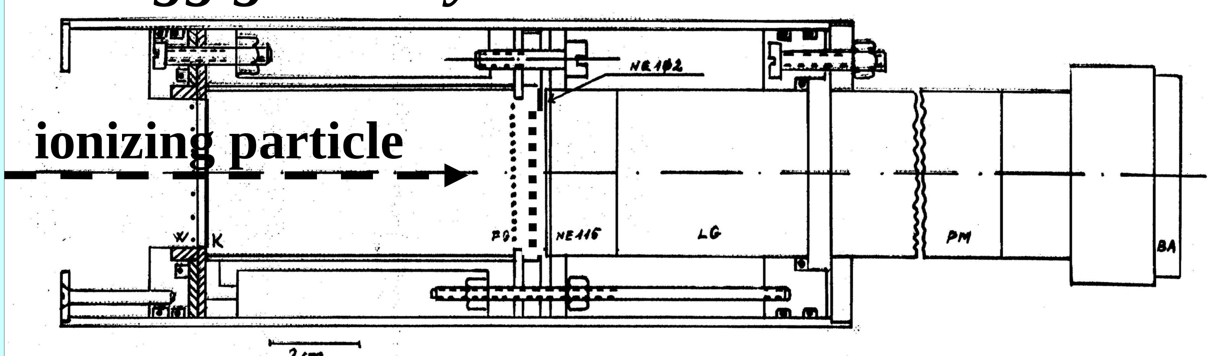
R ⇒ Heavy ion range (A,Z,β)

⇒ Bragg peak amplitude (Z)

⇒ Specific ionization (Z,β)

E ⇒ Integral over the curve

Bragg geometry IC



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Bibliography:

- ***Nucl. Instr. and Meth. in Phys. Research A495(2002)121***

  L.M. Pant et al

  & references therein
- ***Nucl. Instr. and Meth. in Phys. Research A238(1985)347***

  G.D.Westfall et al

  & references therein
- ***Nucl. Instr. and Meth. 204(1982)109***

  J.M. Asselineau at al

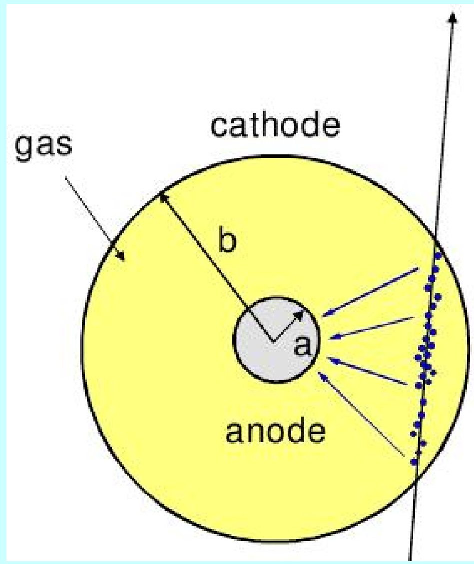
PC-Signal development

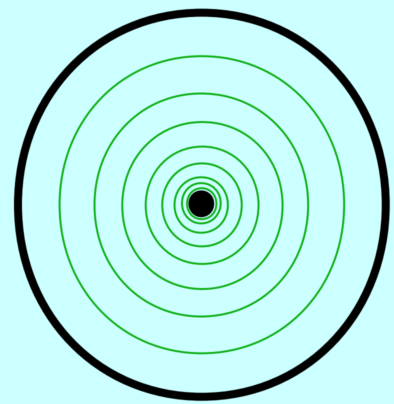
Axial symmetry
Cathode coaxial with the thin anode wire

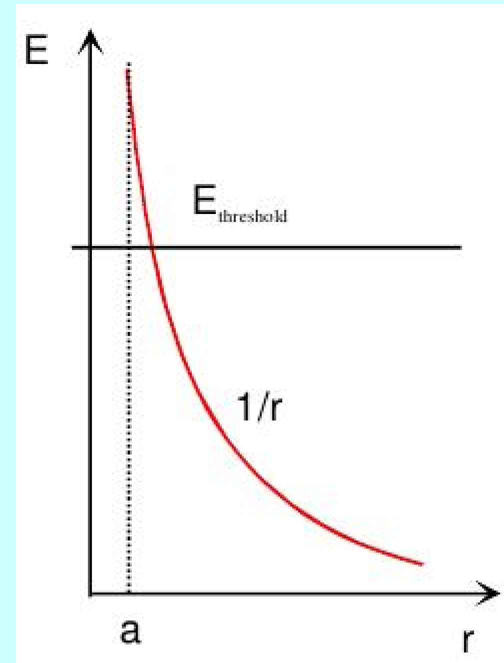
Electric field:

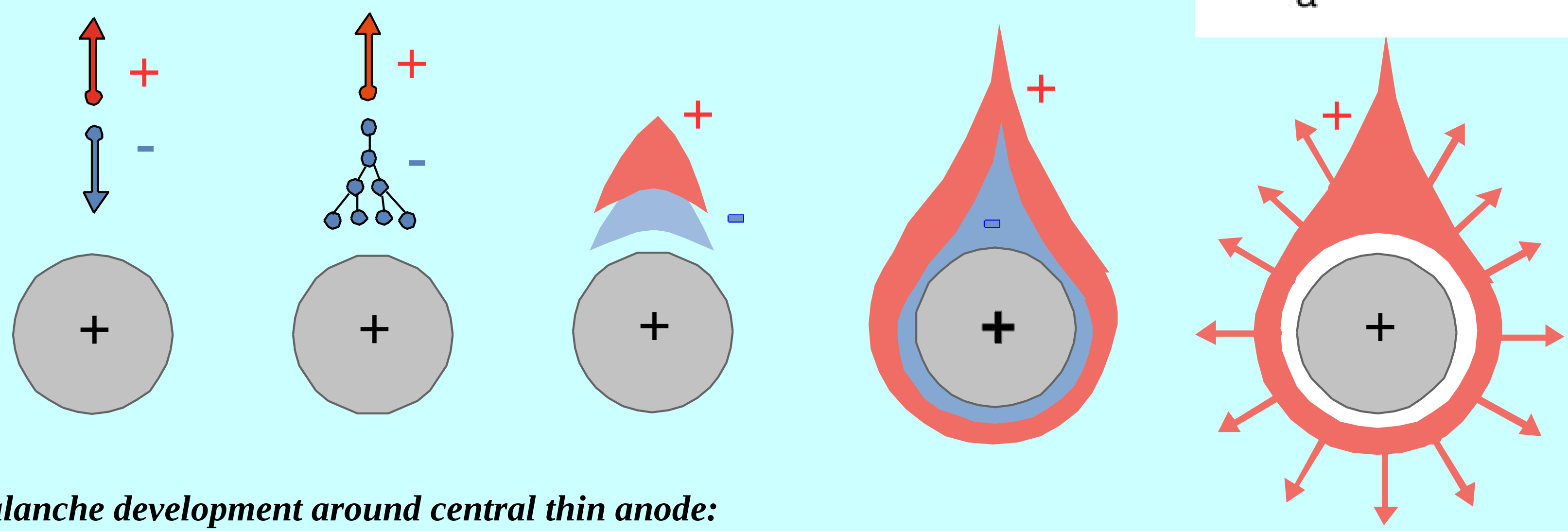
$$E(r) = \frac{CV_0}{2\pi\varepsilon_0}\frac{1}{r}$$

$$C = \frac{2\pi\varepsilon_0}{\ln(b/a)}$$









Avalanche development around central thin anode:

F. Sauli, IEEE-NSS 2002 lecture

PC-Signal development

- *Close to the anode wire the field is high ~ some kV/cm*

  $\Rightarrow e^-$ *gain enough energy* $\Rightarrow$ *further ionization*

  $\Rightarrow$ *exponential increase of* e^-*-ion pairs*

$dn = \alpha n dx$

$n = n_0 e^{\alpha(E)x}$ *or* $n = n_0 e^{\alpha(r)x}$ α: *first Townsend coefficient*

(e^- - ion pairs/cm)

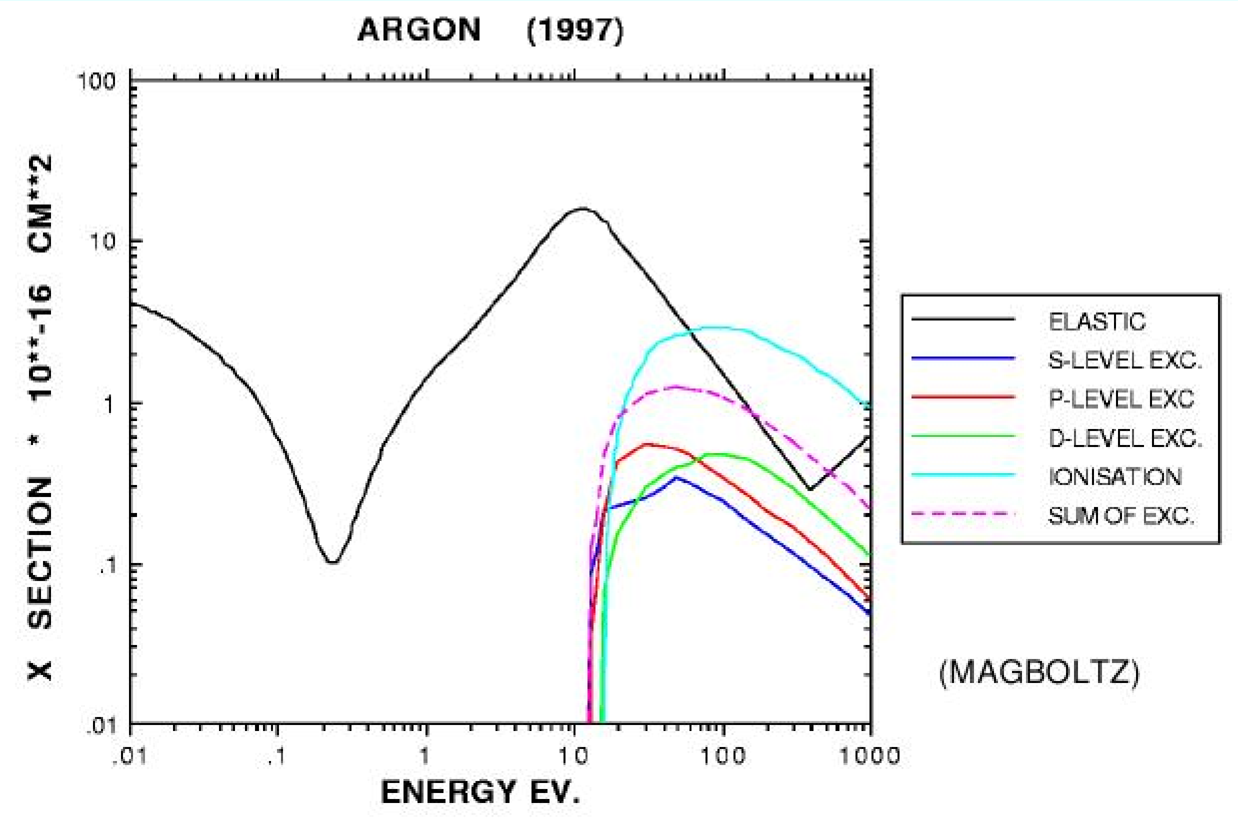
$\alpha = 1/\lambda$ λ: *mean free path*

$M = n/n_0 = \exp\left[\int_a^{r_C} \alpha(r)dr\right]$ - *Gain*

PC-Signal development

Gas selection:

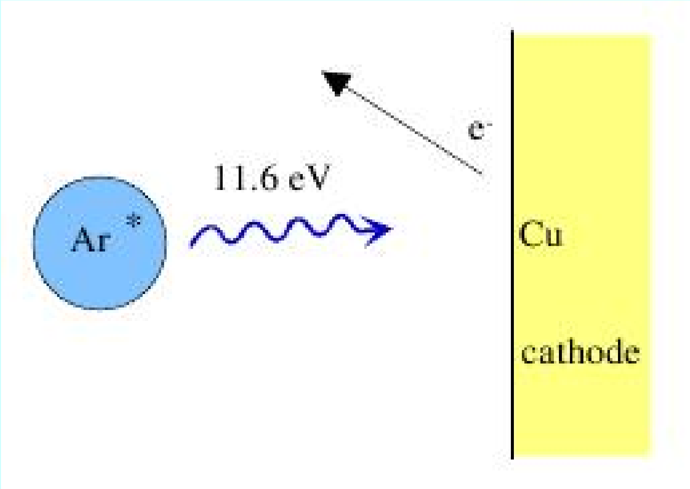
Dense noble gases – energy dissipation mainly by ionization – high specific ionization



De-excitation possible only via photon emission, e.g. 11.6 eV Ar

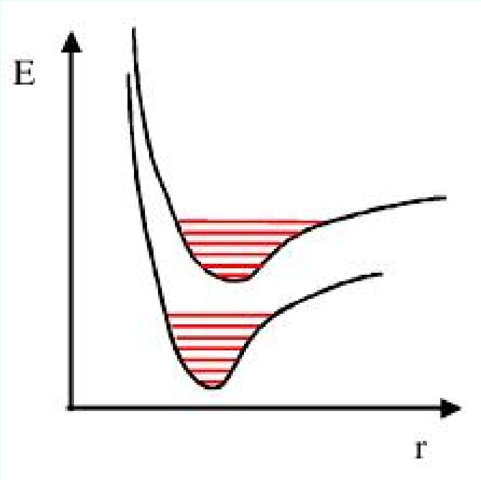
This is above the ionization threshold of metals, e.g. Cu 7.7 eV !!!

PC-Signal development



⇒new avalanches ⇒permanent discharges !!!

Solution:



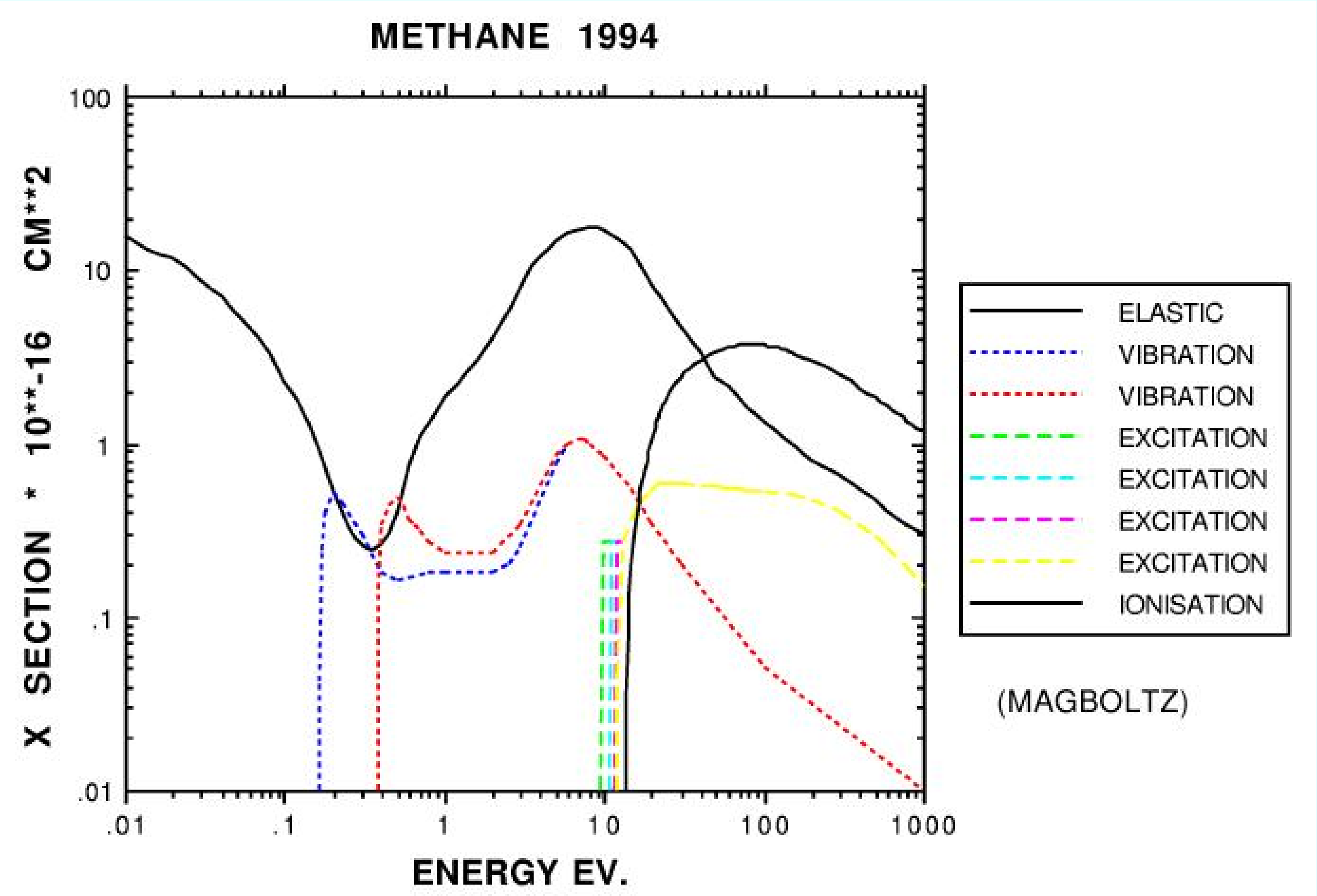
Add poly-atomic gases as quenchers

Photons absorption in a large energy range (many vibrational and rotational energy levels)

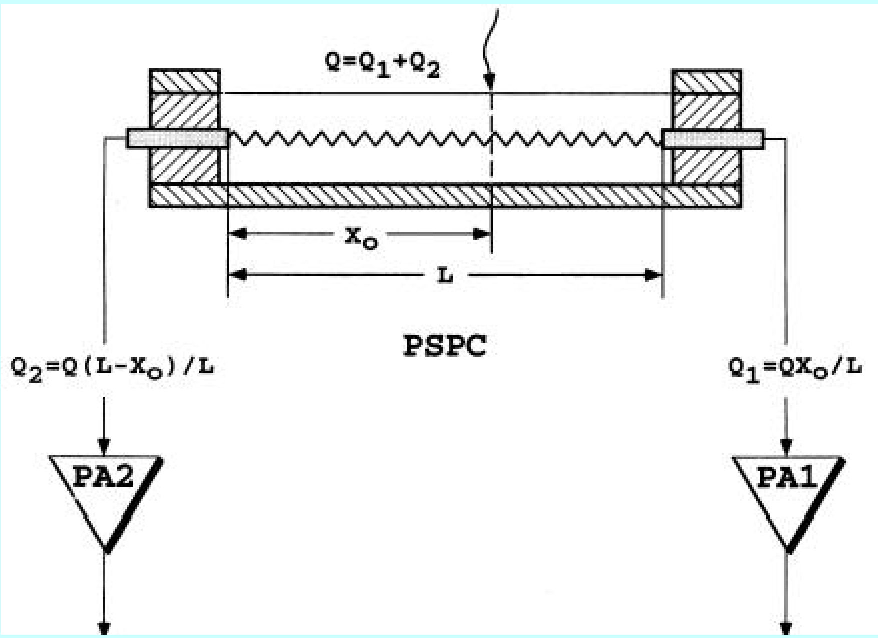
Energy dissipation by collisions or dissociation into smaller molecules

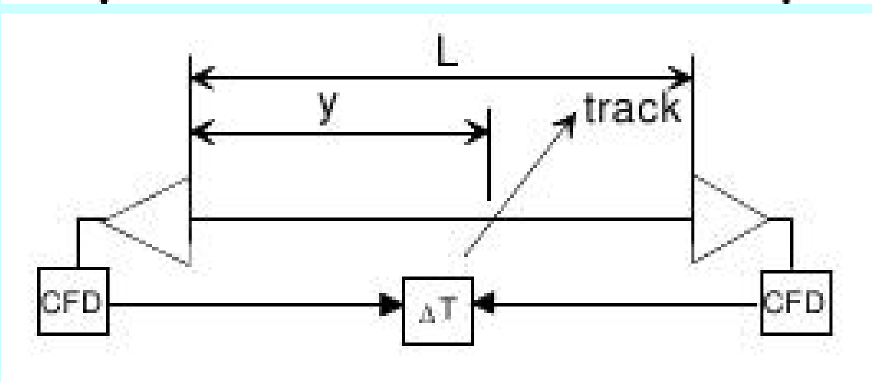
PC-Signal development

Methane – absorption band 7.9 – 14.5 eV



PC-position sensitive





$$\frac{y}{L} = \frac{Q_B}{Q_A + Q_B} \qquad \sigma\left(\frac{y}{L}\right) \text{ up to } 0.4\%$$

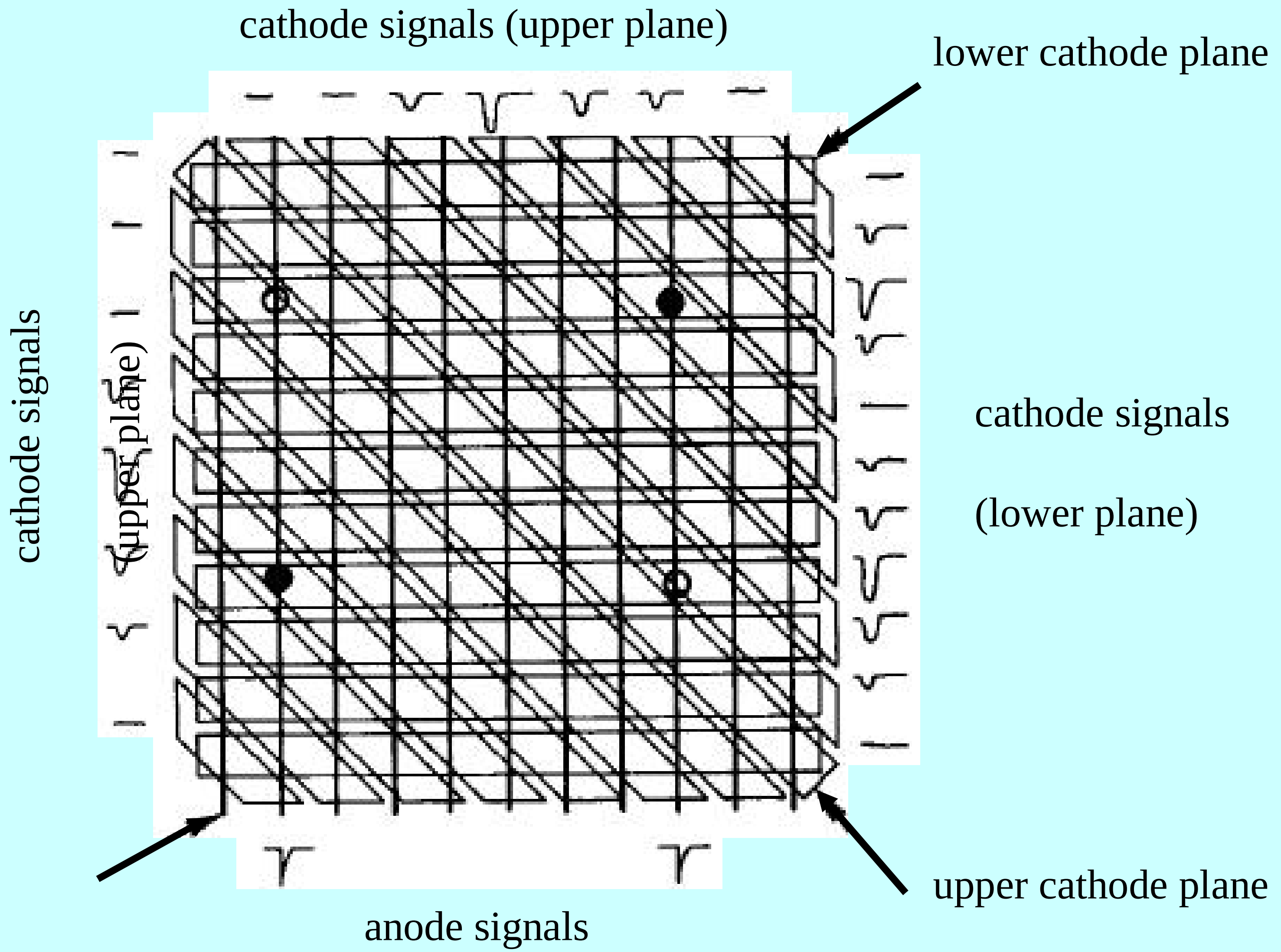
$$\sigma(\Delta T) = 100\,ps$$
$$\rightarrow \sigma(y) \approx 4cm \qquad \text{(OPAL)}$$

Applied Radiation and Isotopes 52(2000)943

D. Ohsawa et al.

PC-position sensitive

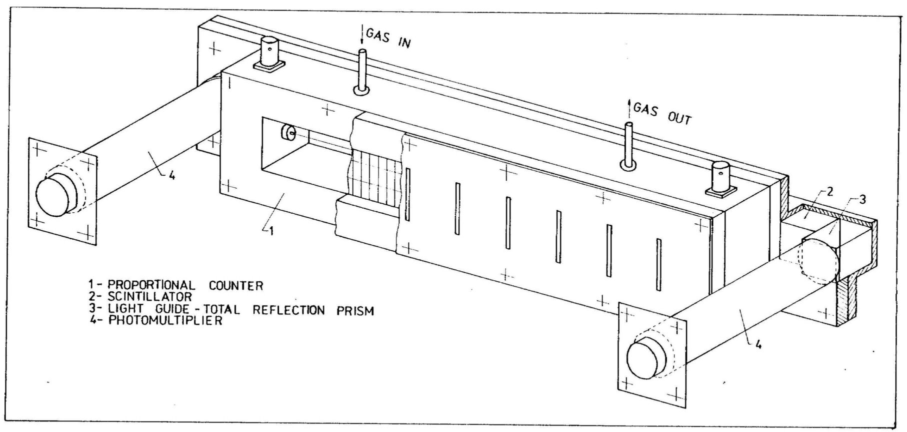
1 wire plane + 2 segmented cathode planes

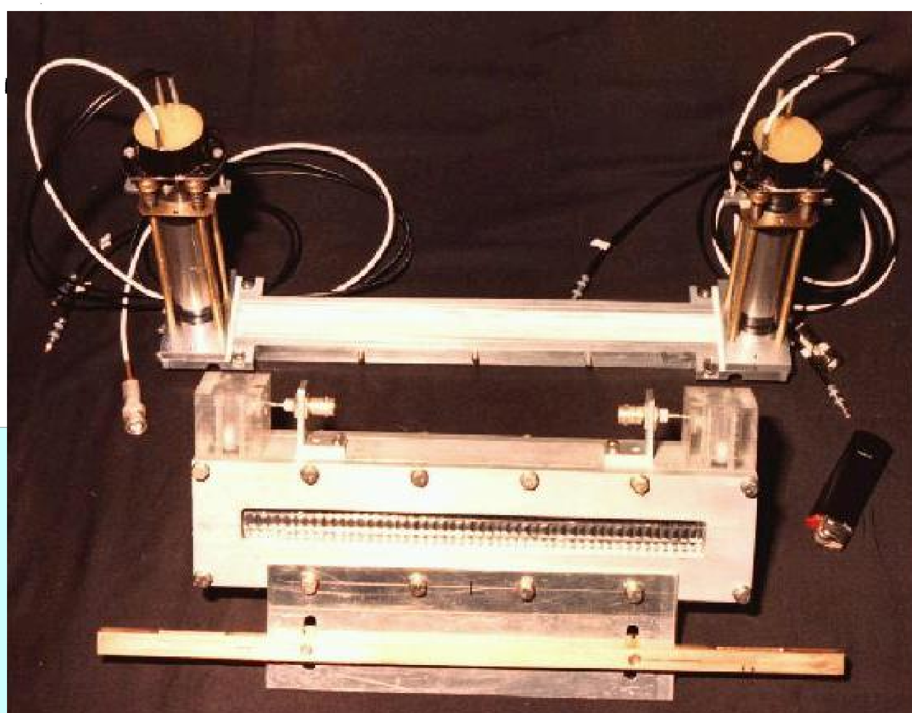


analog readout of cathode planes ⇒ $\sigma \cong$ 100 μm

PC-Examples

Position sensitive ***- resistive anode wire***
- charge division method





Ni-Cr 12 μm wire - ~10 kΩ/m

- position resolution **FWHM ~ 300 μm**

  (^{241}Am - E_α=5.479 MeV)

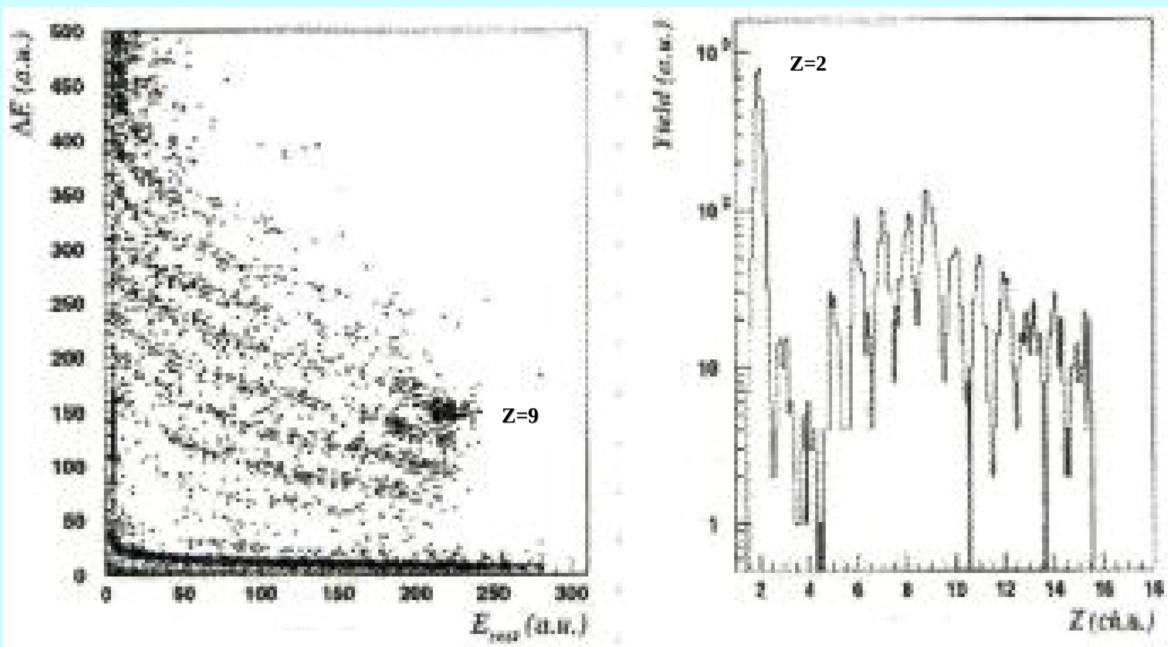
- Energy resolution **FWHM 15.7%**

  (^{55}Fe X ray – 5.9 keV)

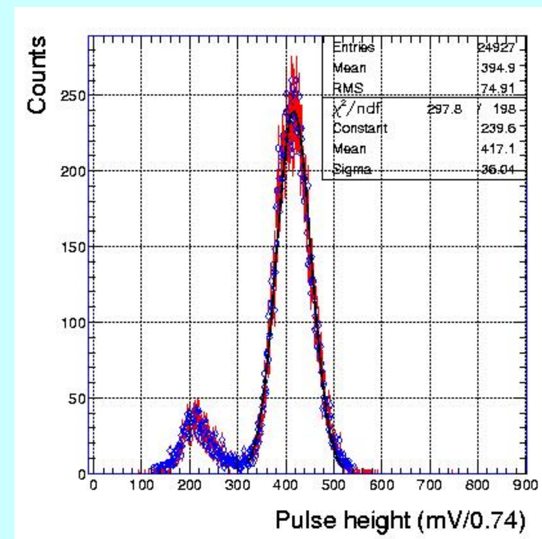
DRACULA experimental device

PC-Examples

$^{19}F+^{27}Al$ E_{lab}=111.4 MeV



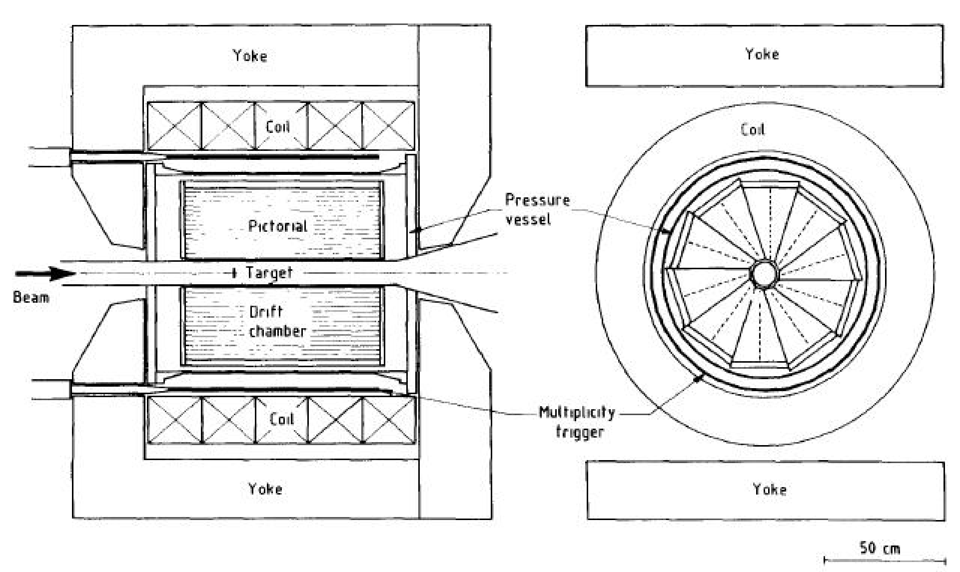
X-ray, ^{55}Fe E=5.9 KeV



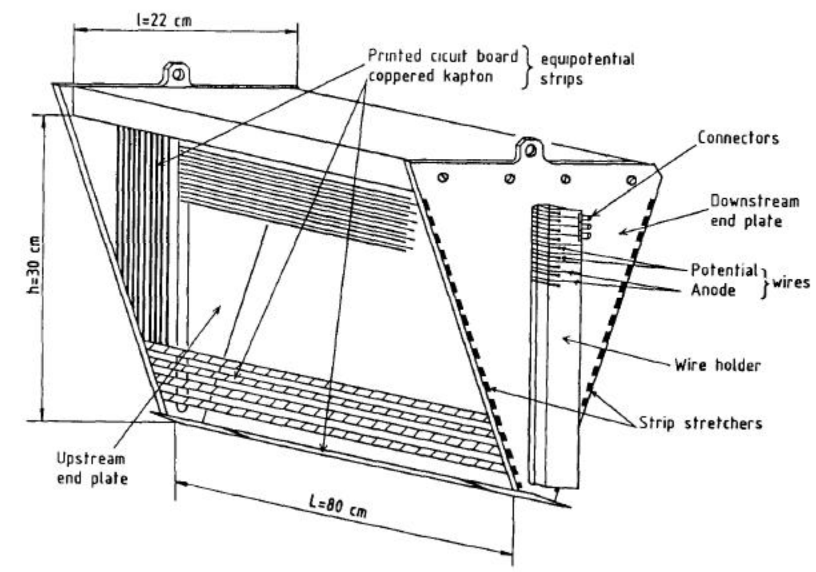
DRACULA experimental device

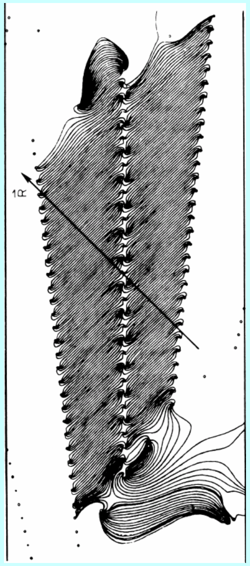
DC-Examples

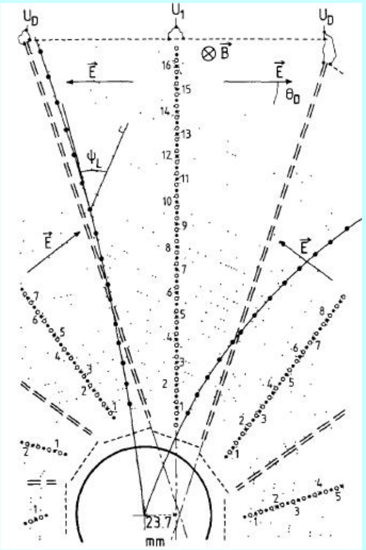
DIOGENE – Pictorial Drift Chamber



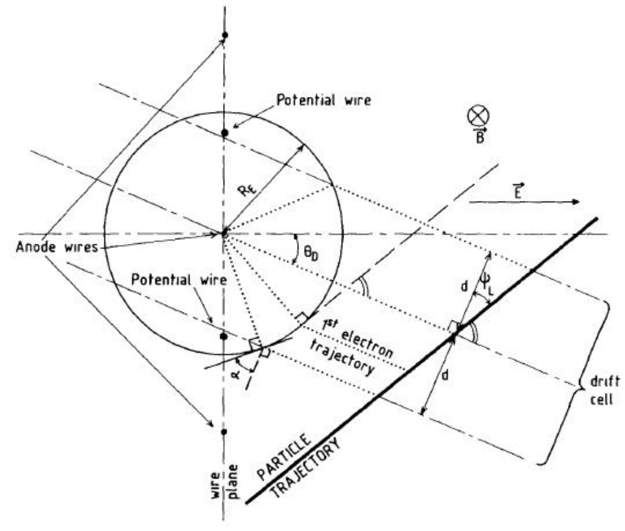
Sector structure





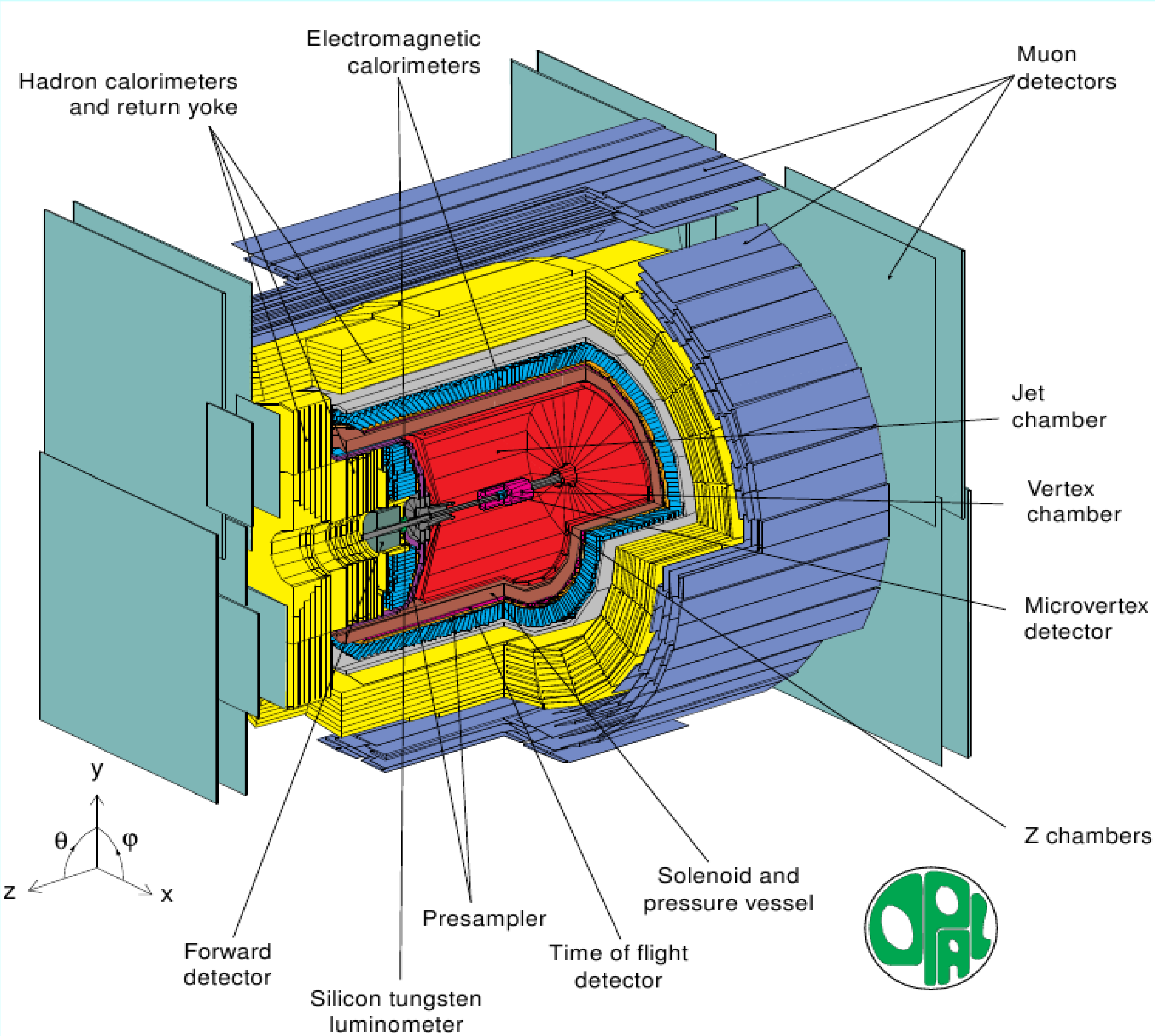


Drift cell

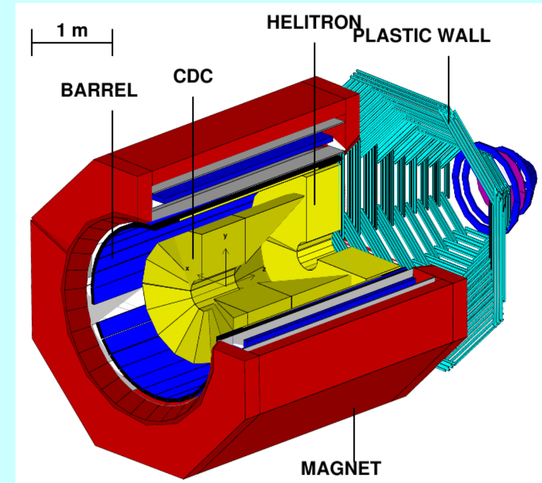


Nucl. Instr. And Meth. A261(1987)379

DC-Examples



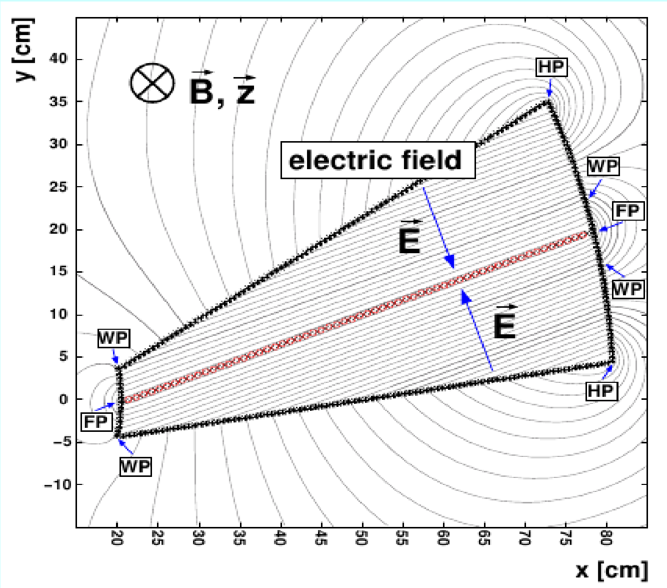
24 sectors
R_{out}=185 cm, R_{in}=25 cm
L=400 cm
160 sens wires W(Au), 25 μm
160 pot wires Cu-Be, 100 μm
cathod wires (3.3mm sp) Cu-Be 100 μm,
88%Ar, 9.4% CH_4, 2.6% $i-C_2H_6$
p_{start}=10^{-6} bar
$gas_{exch.rate}$=60 m^3/day
Stable cond. after 10 compl. circ. of the gas vol !
O_2 content few ppm

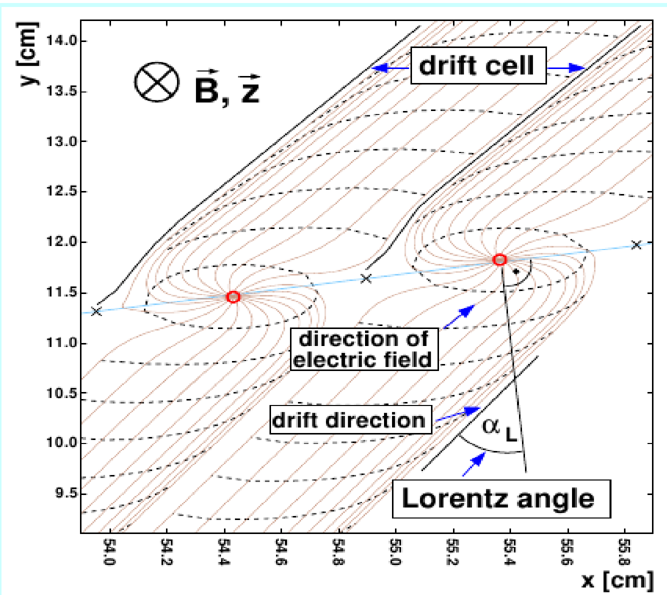


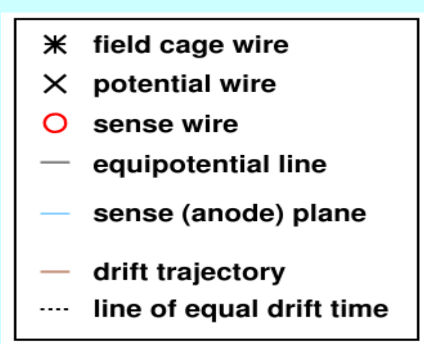
16 sectors
R_{out}=90 cm, R_{in}=20 cm
L_{out}=192 cm L_{in}=76 cm
60 sens wires W(Au), 20 μm
60 pot wires Cu-Be, 100 μm
100μm,(6.8mm sp) Cu-Be100μm
88%Ar, 2% CH_4, 10% $i-C_2H_6$
p_{start}=outside atm. cond.
$gas_{exch.rate}$=1.44 m^3/day
?
O_2 content 10*few ppm

DC-Examples

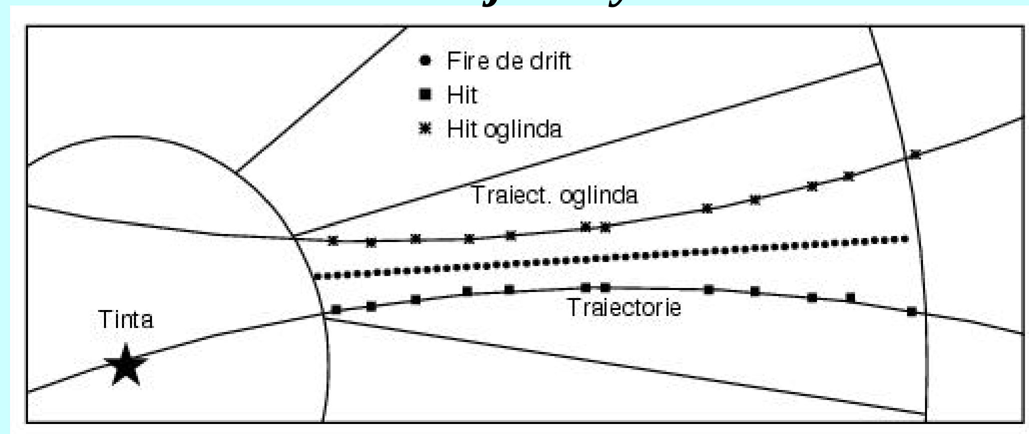
FOPI CDC



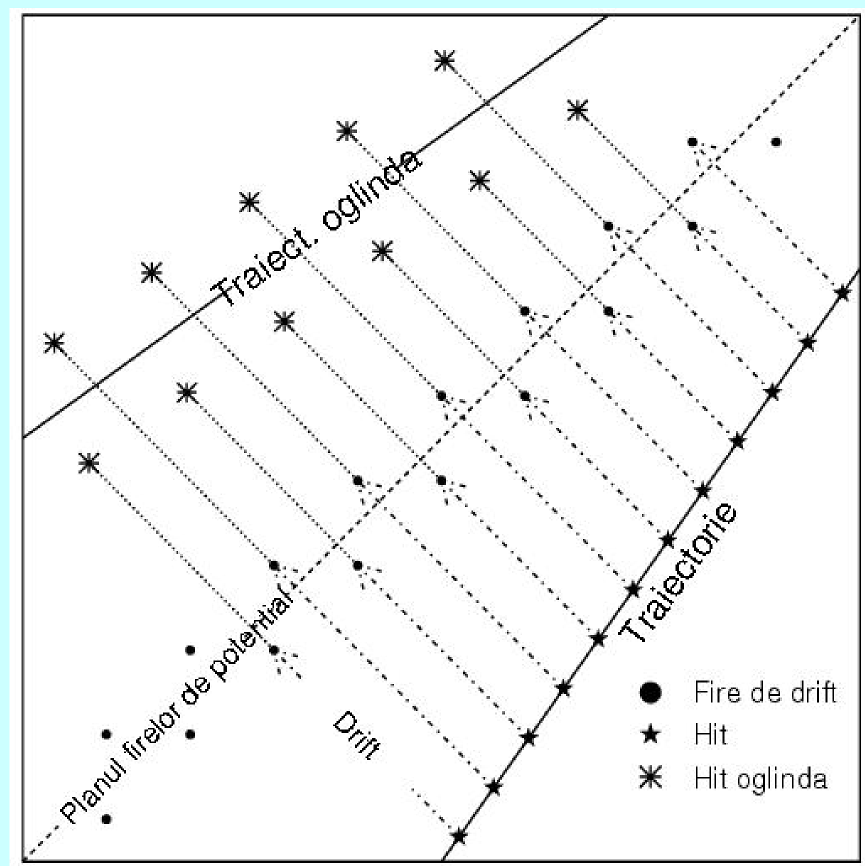




Real - mirrored trajectory discrimination

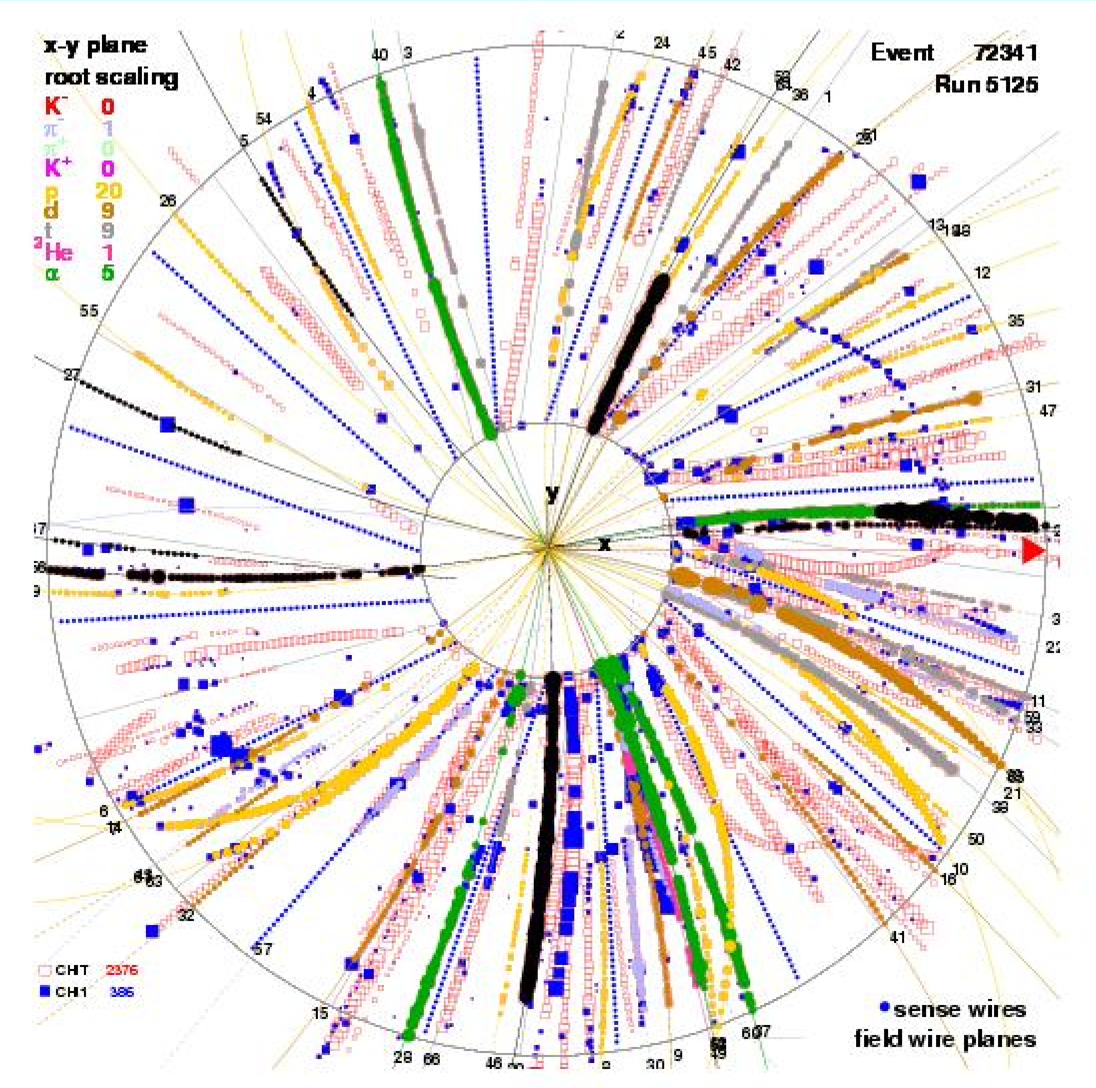


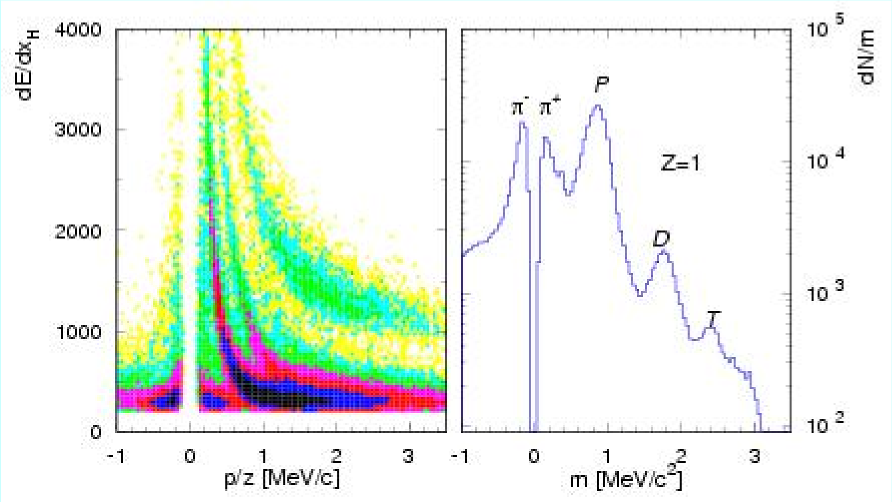
U_p = -1.5 kV
U_{sw} = 0.0 kV
U_k =-15.0 kV

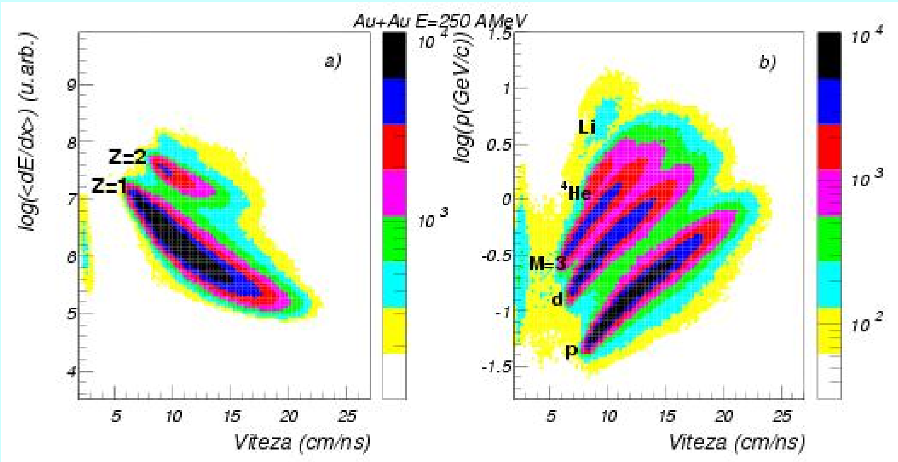


DC-Examples

FOPI CDC



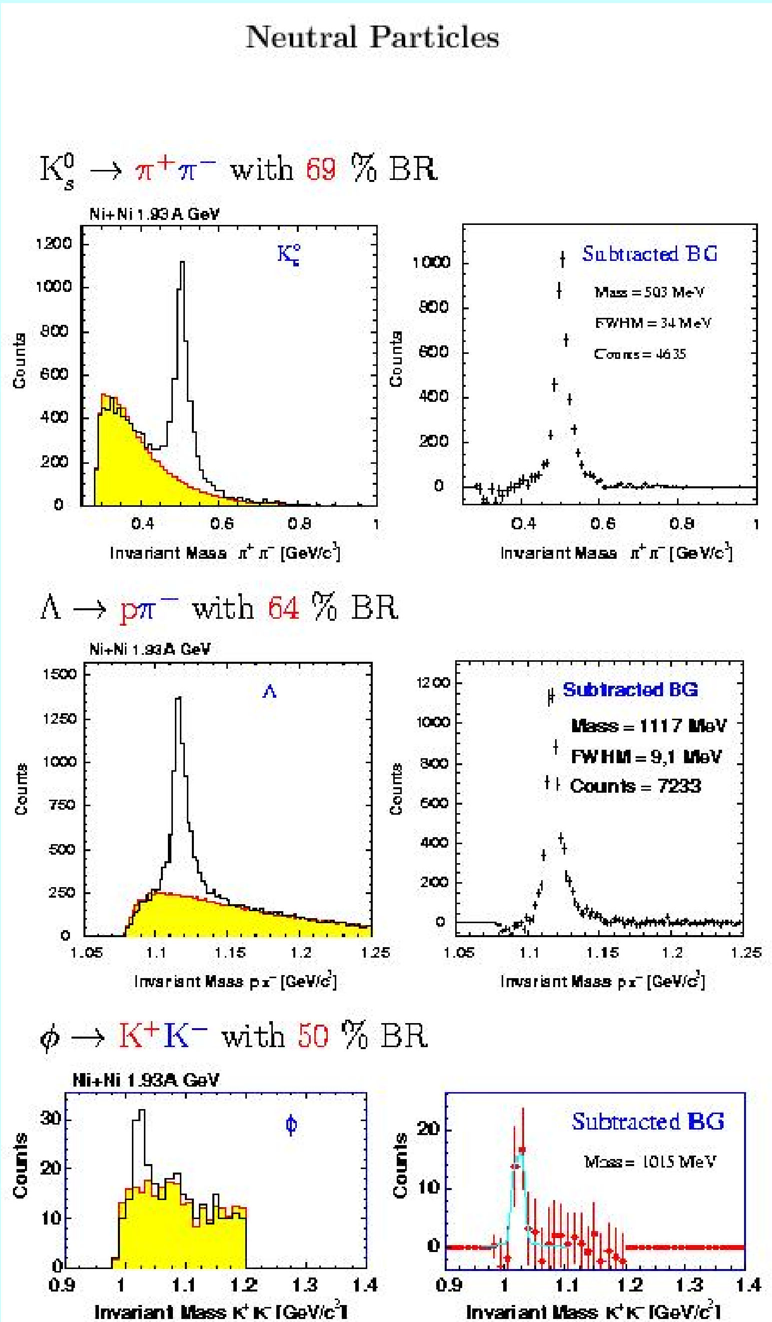


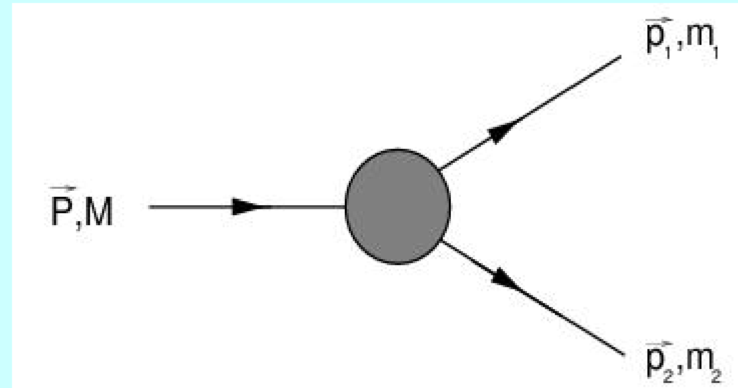


$$B\rho \sim Mv/q$$

FOPI

DC-Examples





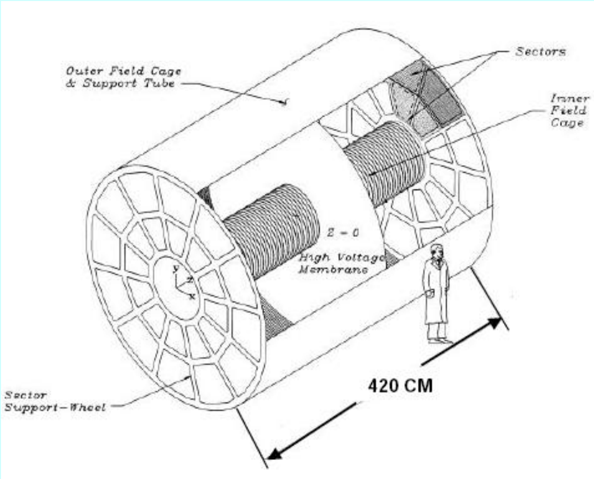
$$\begin{aligned} E &= E_1 + E_2 \\ \vec{P} &= \vec{P}_1 + \vec{P}_2 \end{aligned}$$

$$E^2 = \vec{P}^2 + M^2$$

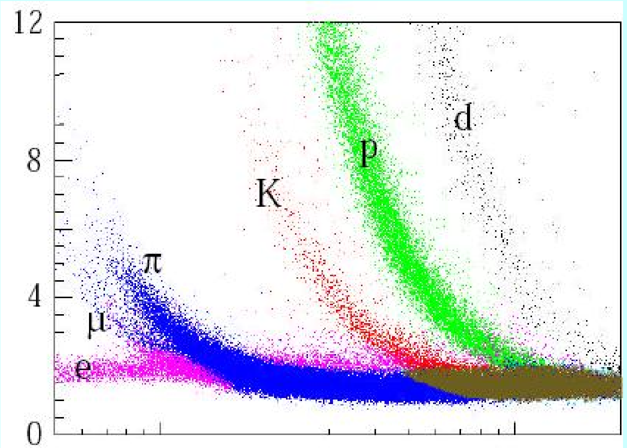
$$M_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

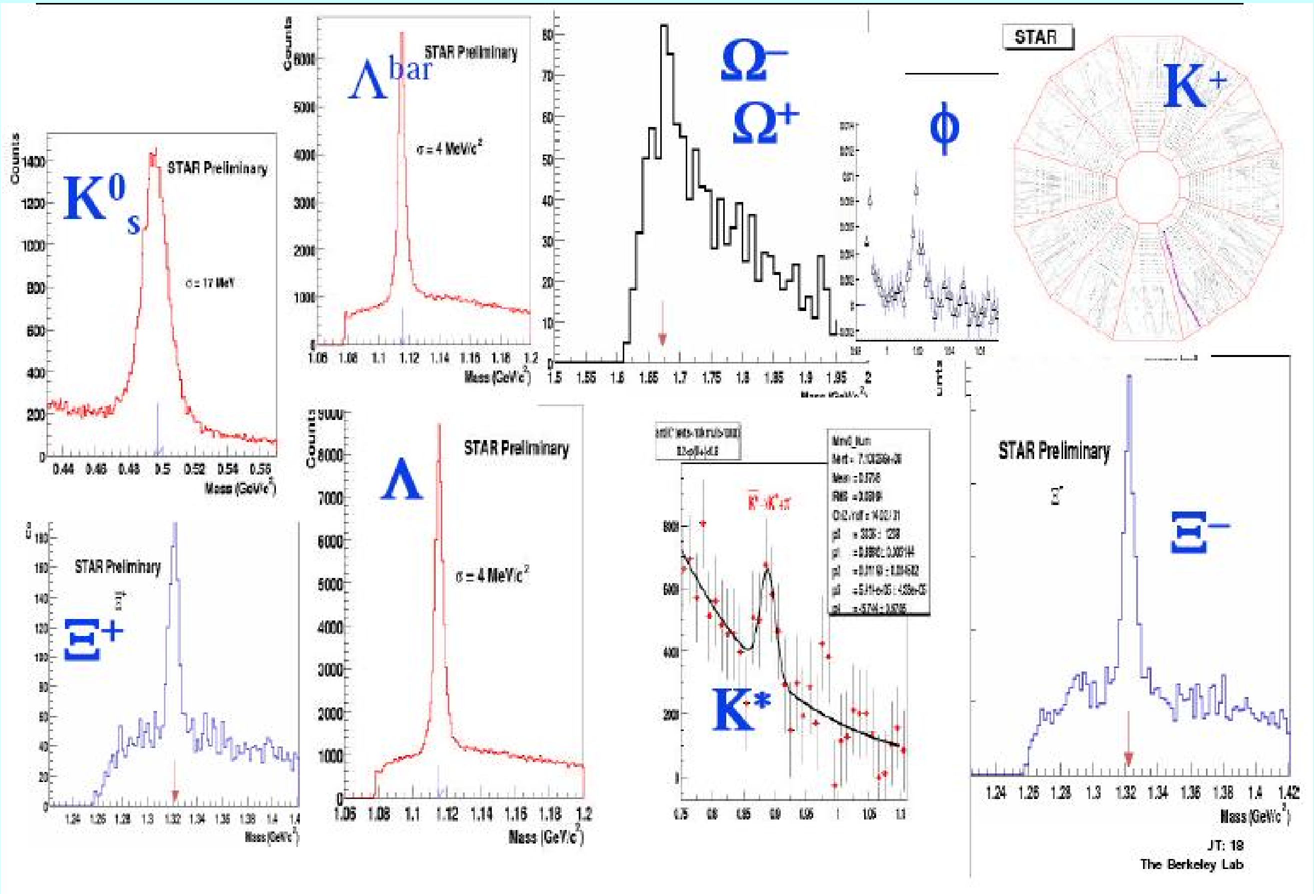
$$f_{BW}(E, E_R) = \frac{P_{Fit}}{(E - E_R)^2 + (\Gamma/2)^2}$$

TPC-Examples



STAR TPC





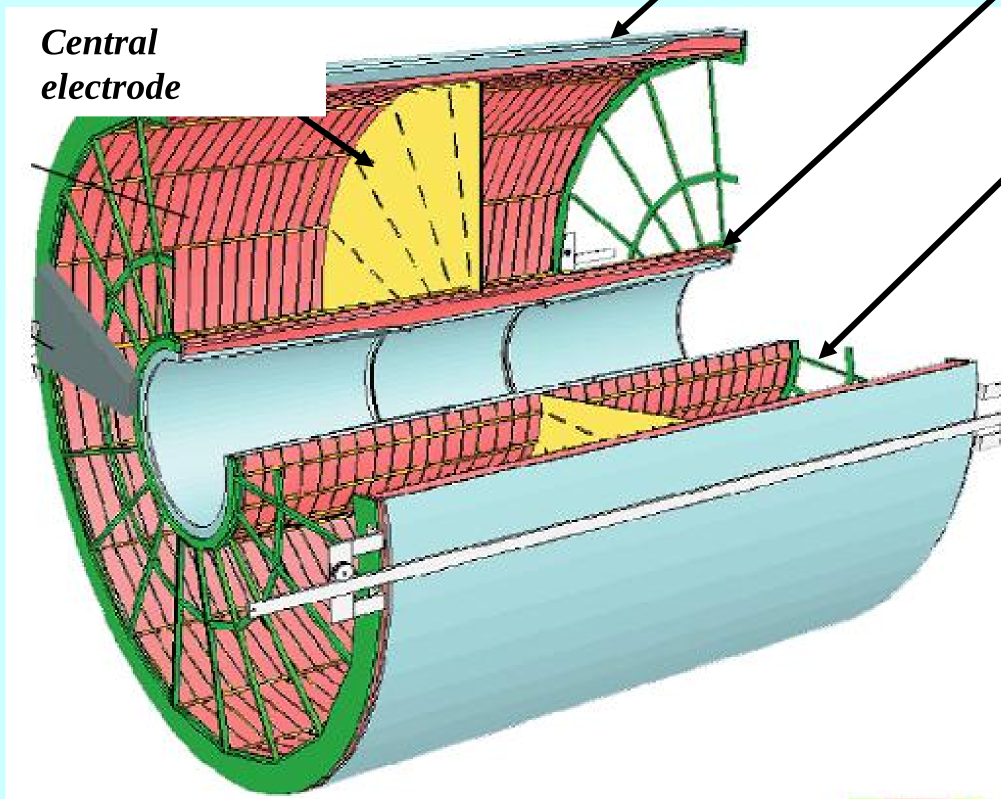
ALICE TPC

TPC-Examples

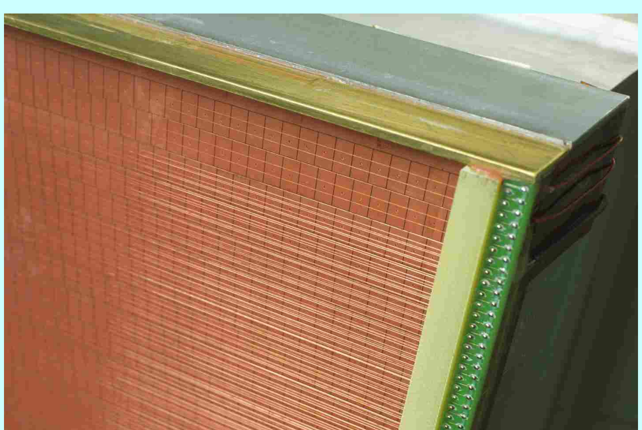
Outer containment volume

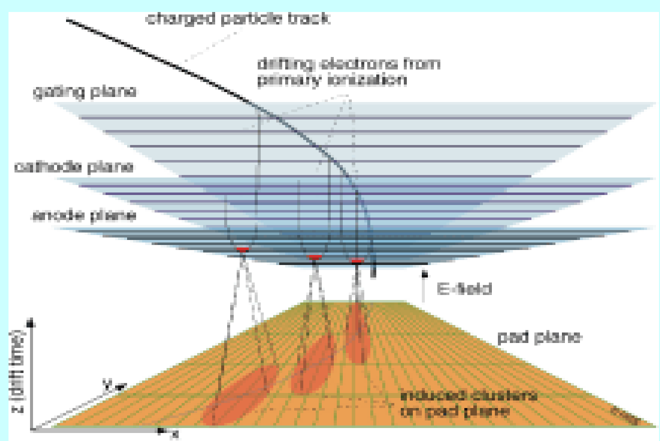
Inner containment volume

End-plate



Read-out chamber

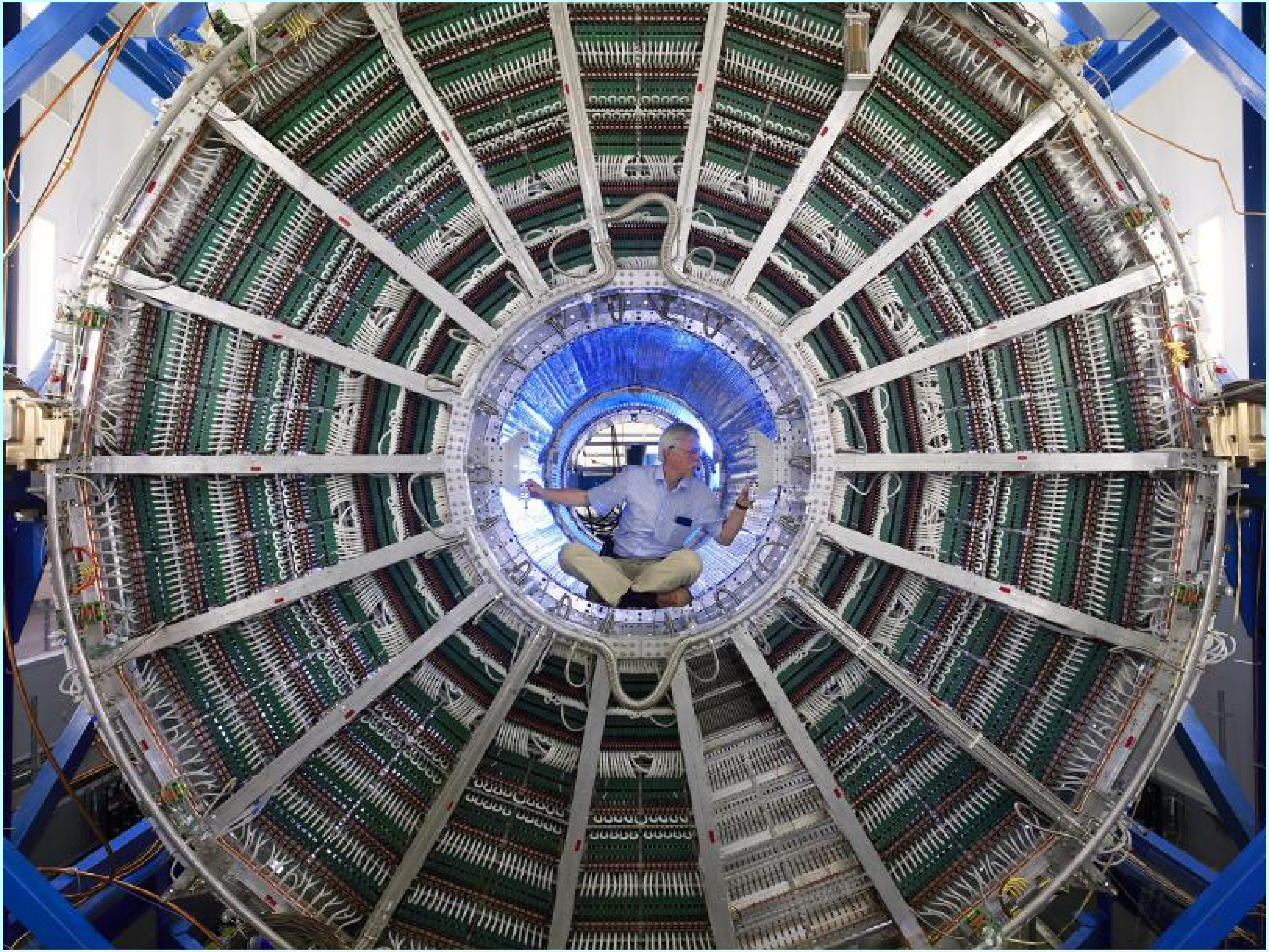




- 18 sectors on two sides.
- MWPC read out.
- 2 types of chambers: Inner (IROC) and outer (OROC).
- IROC + OROC = sector.
- Drift length: $2 \times 2.5\,\mathrm{m}$.
- $845 < r < 2466\,\mathrm{mm}$.
- $\approx 92\,\mathrm{m}^3$ of gas: Ne, CO_2, N_2 (90/10/5).
- Drift Field: 400 V/cm.
- 557 568 readout channels.

https://edms.cern.ch/document/398930/1

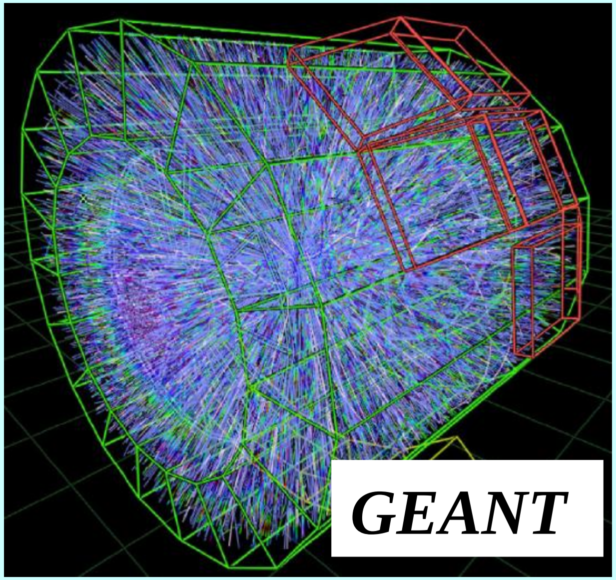
TPC-Examples

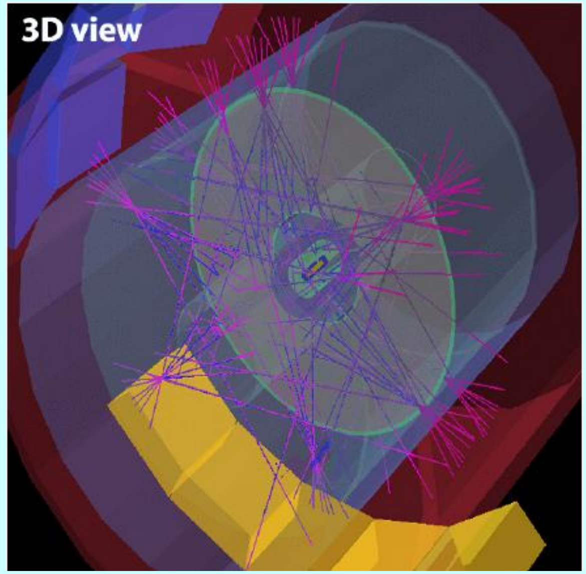


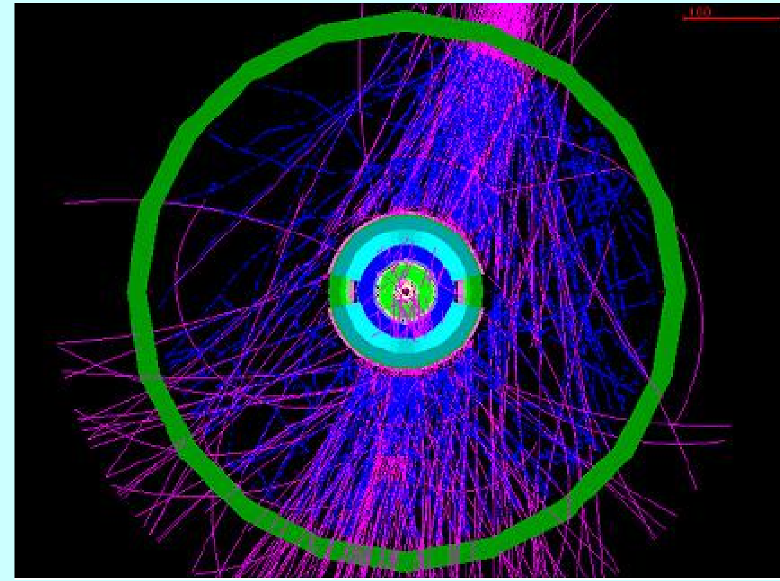
ALICE TPC

TPC-Examples ALICE TPC

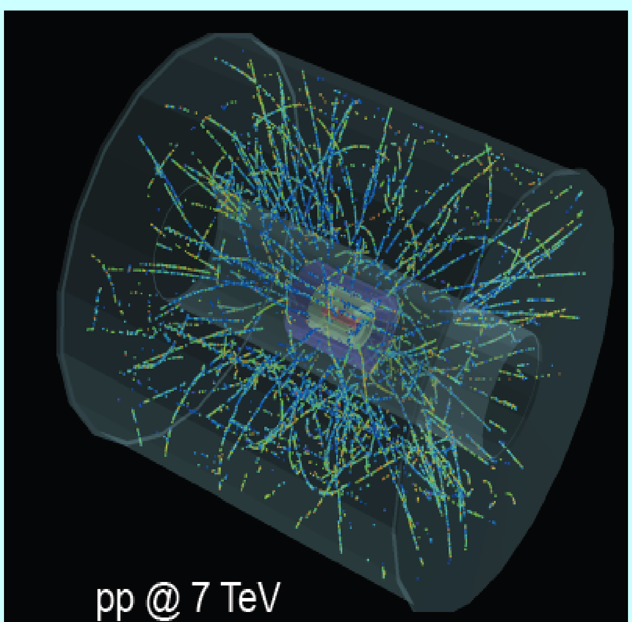
Pb+Pb 5.5 TeV | **Laser tracks** | **Cosmic shower**

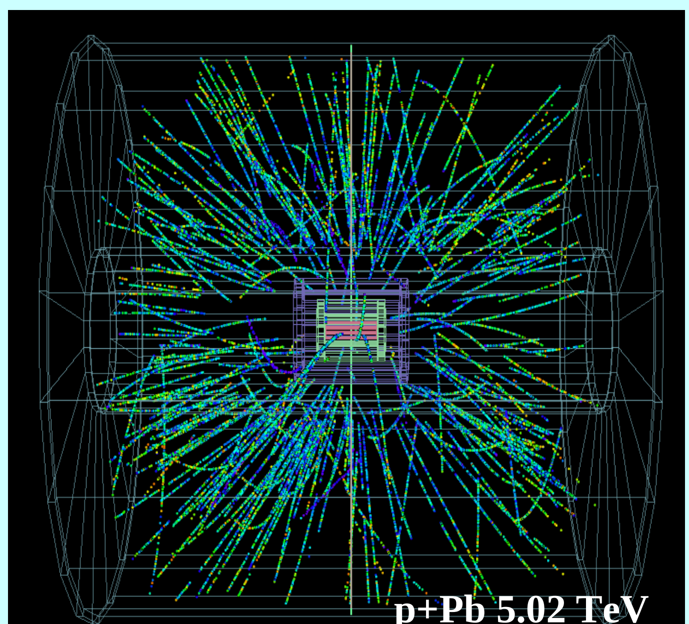


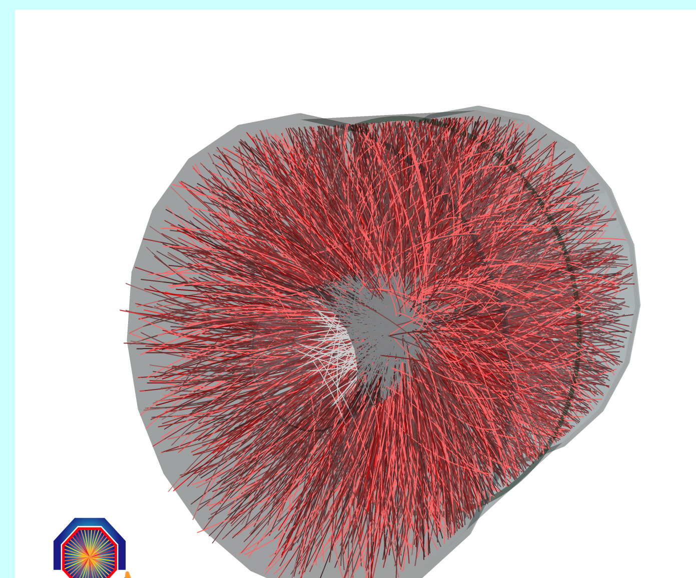




Real collisions



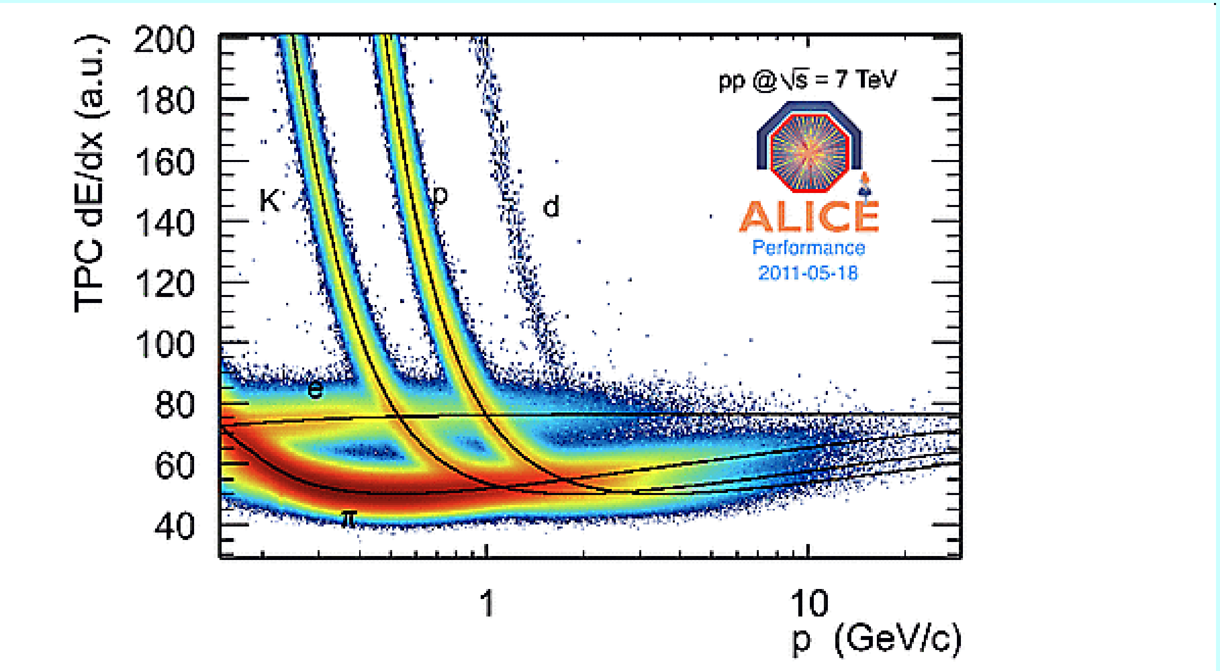




Pb+Pb 2.76 TeV

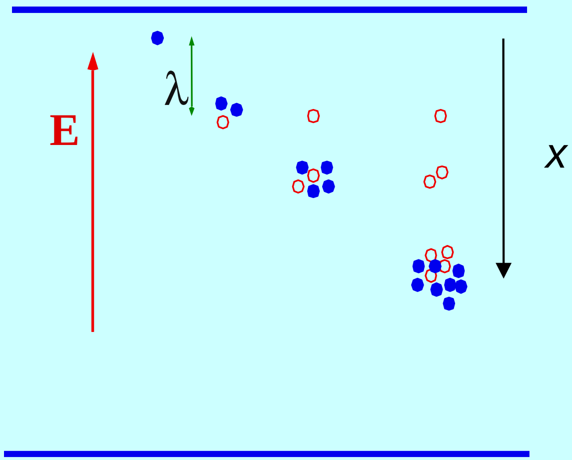
TPC-Examples *ALICE TPC*

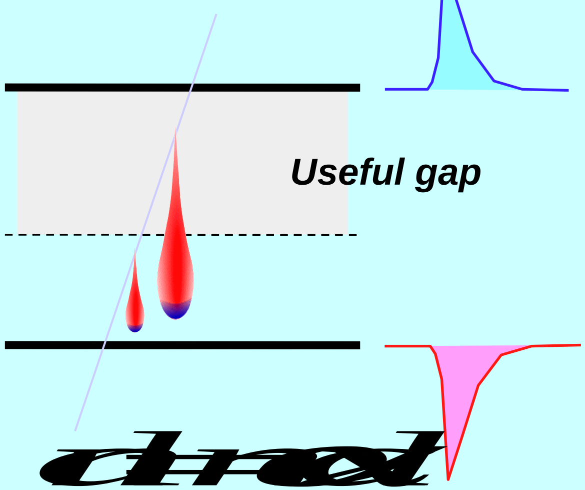
Example of PID performance of ALICE ITS subdetector



p+Pb 5.02 TeV

Low pressure PPAC-Examples



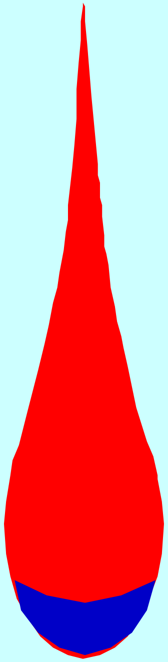


$$dn = n\alpha\,dx$$

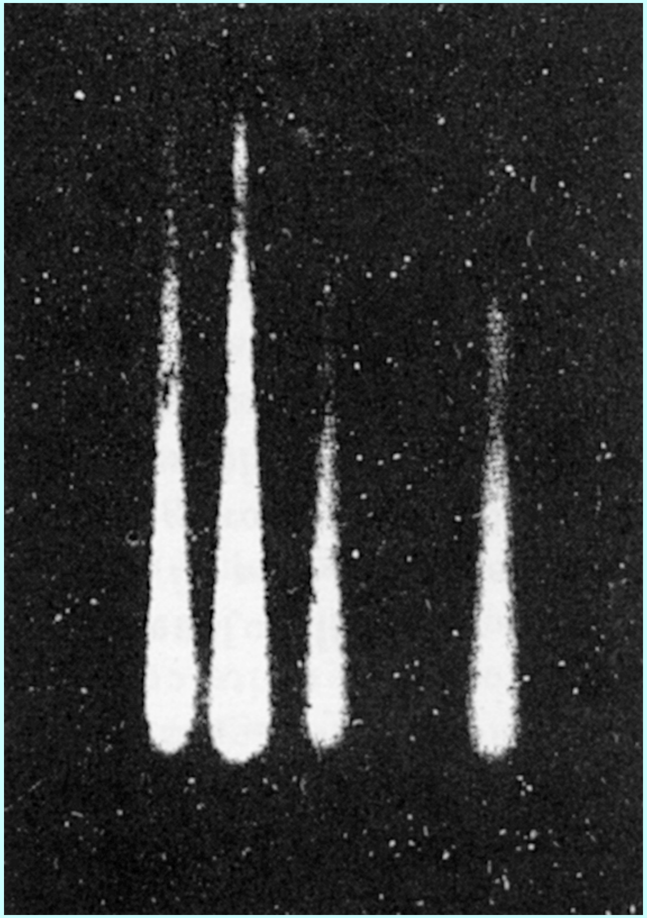
$$n(x) = n_0 e^{\alpha x}$$

$$M(x) = \frac{n}{n_0} = e^{\alpha x}$$

- *Multiplication factor* or ***Gain***



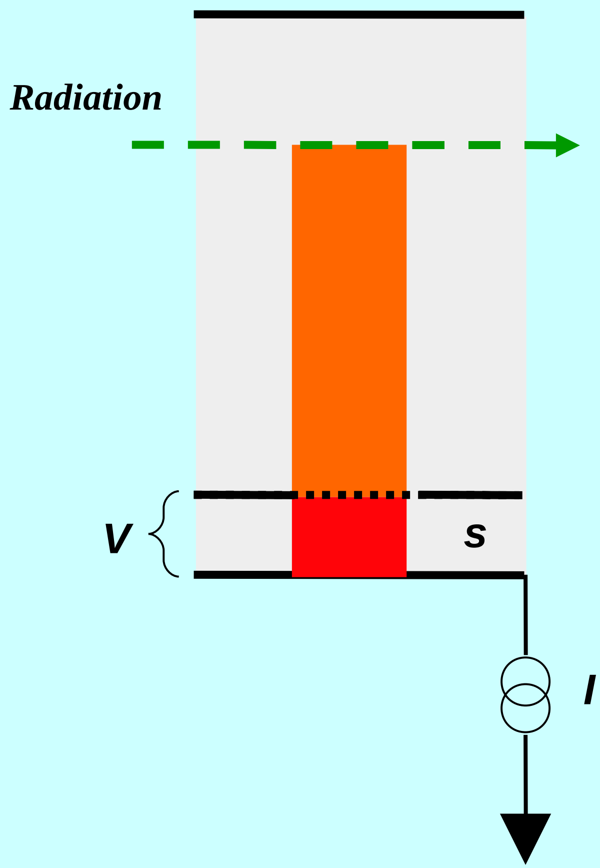
cloud chamber-avalanche chamber:

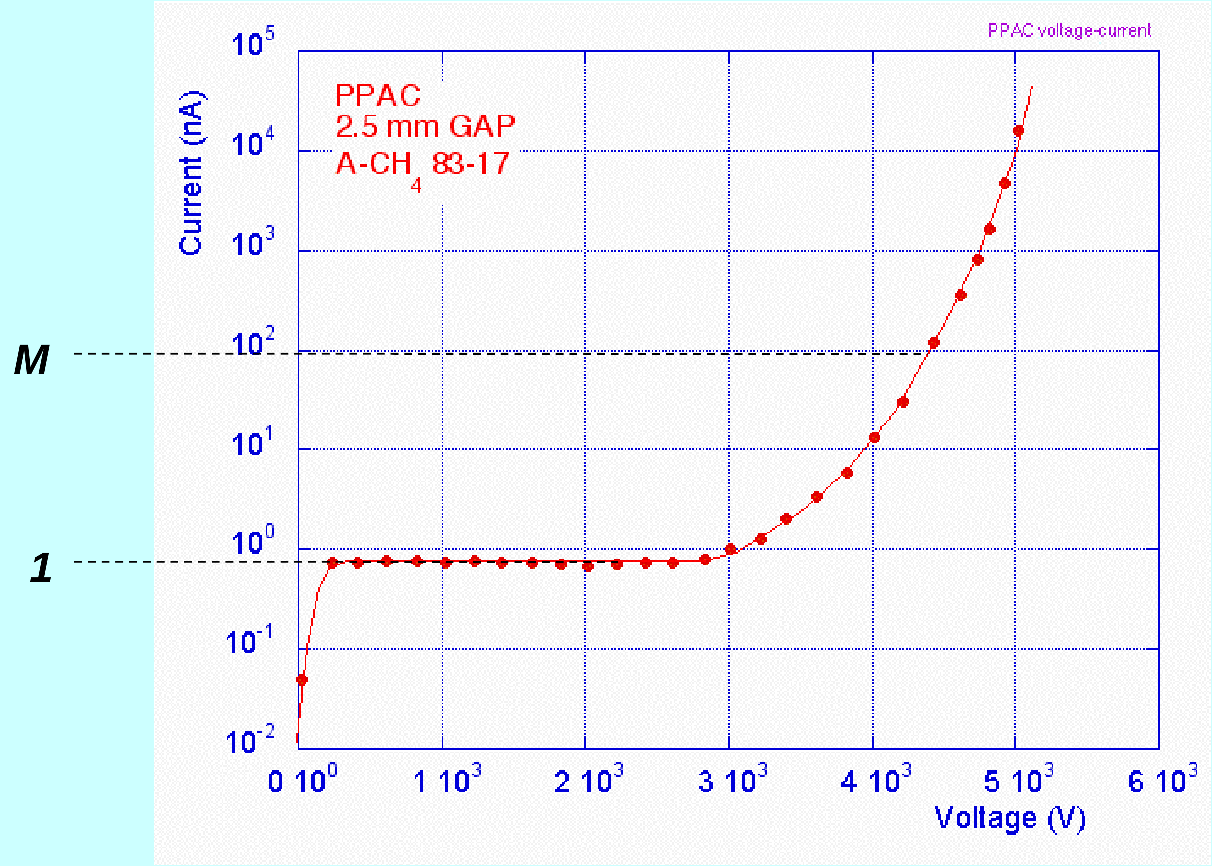


H. Raether
Electron avalanches and breakdown in gases
(Butterworth 1964)

Low pressure PPAC-Examples

How to measure the Townsend coefficient ?

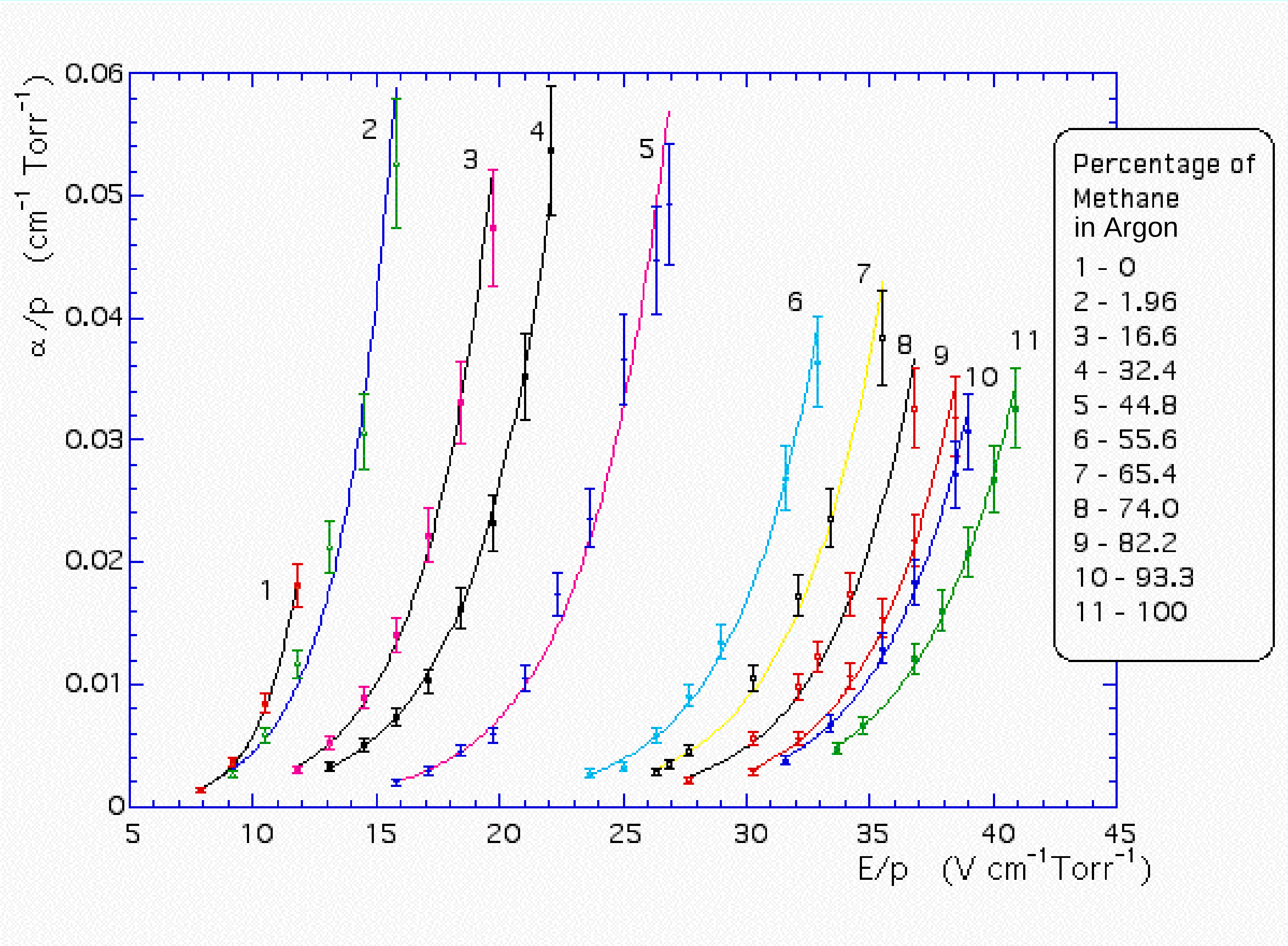




$$\alpha = \frac{\ln M}{s}$$

F. Sauli lecture IEEE-NSS 2002

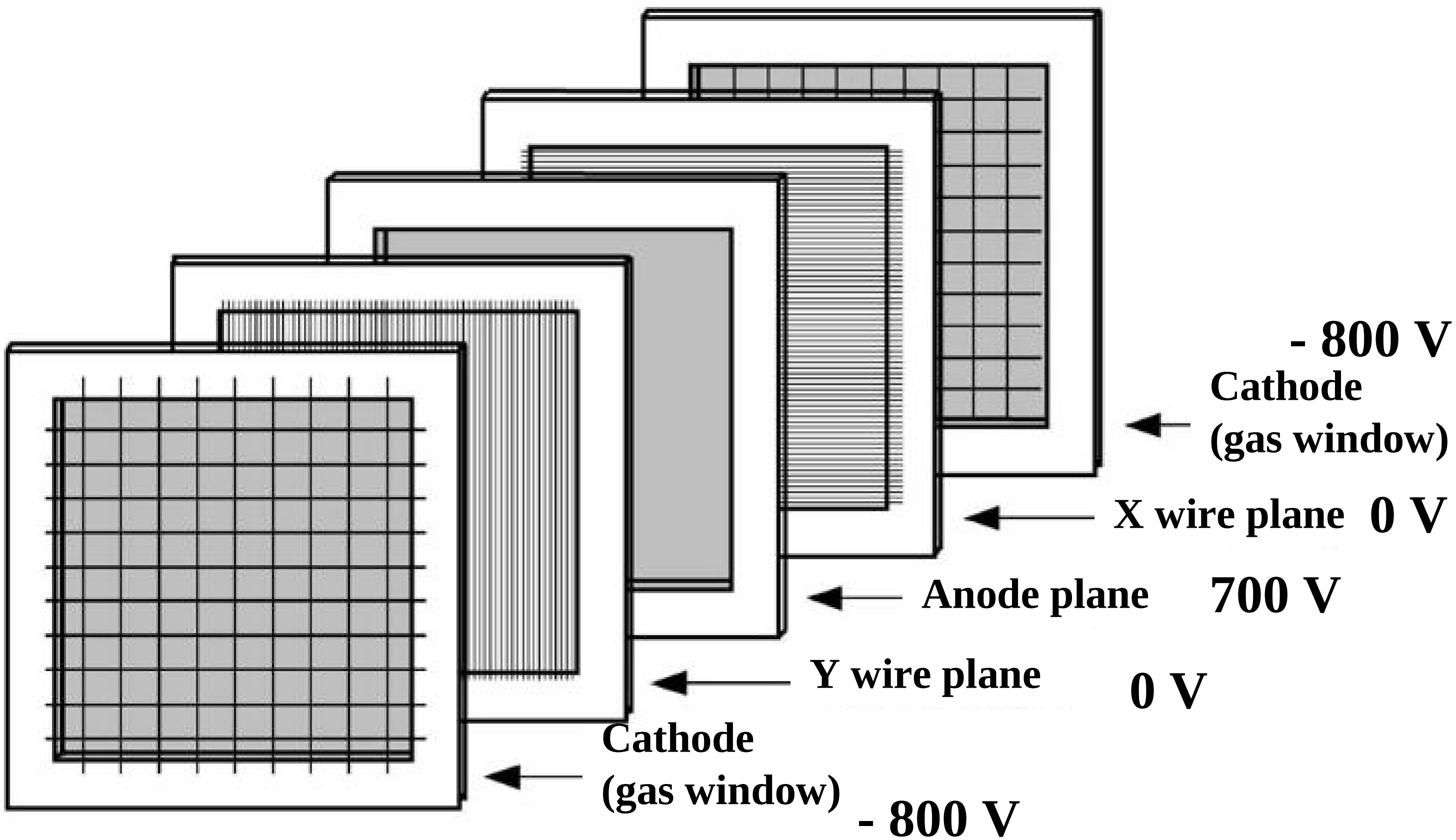
Low pressure PPAC-Examples



A. Sharma and F. Sauli, Nucl. Instr. and Meth. A334(1993)420

Low pressure PPAC-Examples

-Two thin metalized foils - parallel to one other
- close distance – 1-2 mm
- strong homogenous electric field ~ 500 V/mm
- 5 – 10 torr gas pressure
- ⇒very high reduced field strength E/p (several hundred V/cm·torr)
- ⇒ FWHM ~ 180 psec ⇒ σ ~ 75 psec



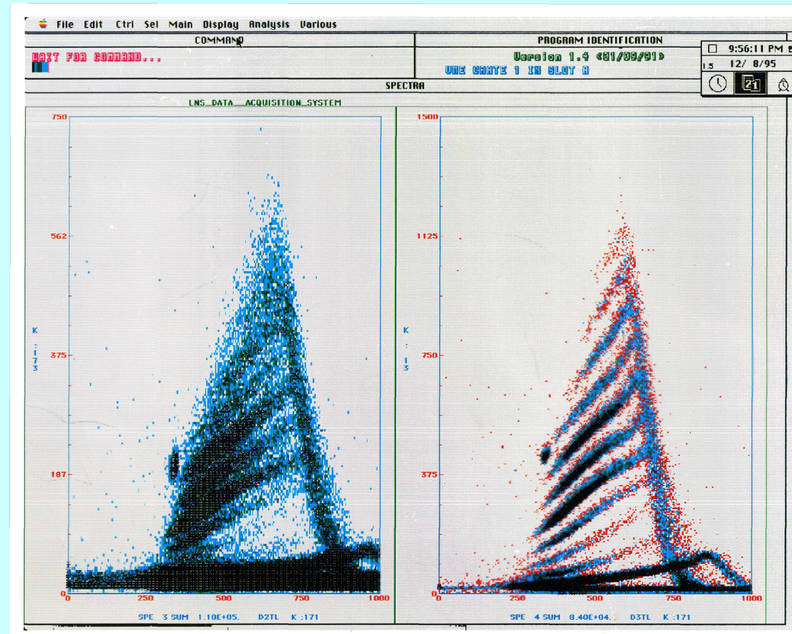
Structure of a position sensitive PPAC

Nucl. Instr. and Meth. in Phys. Research A481(2002)160

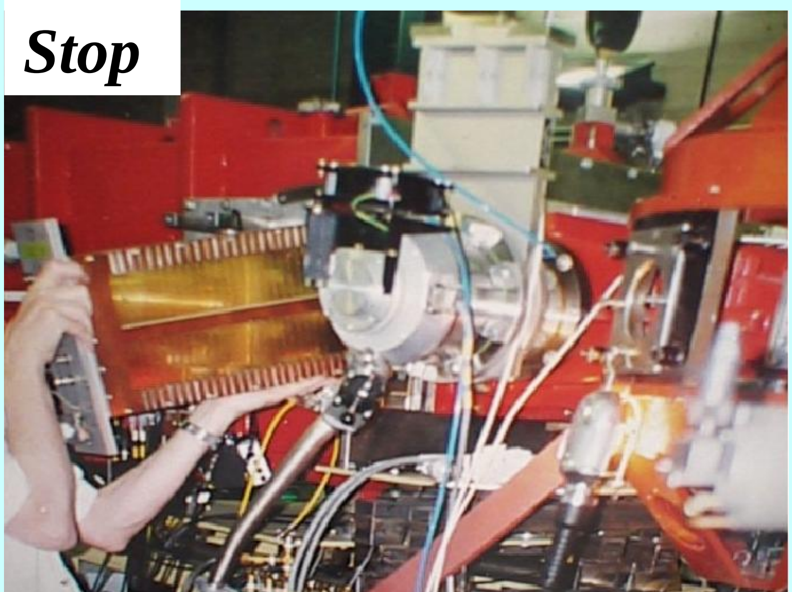
PPAC-Examples

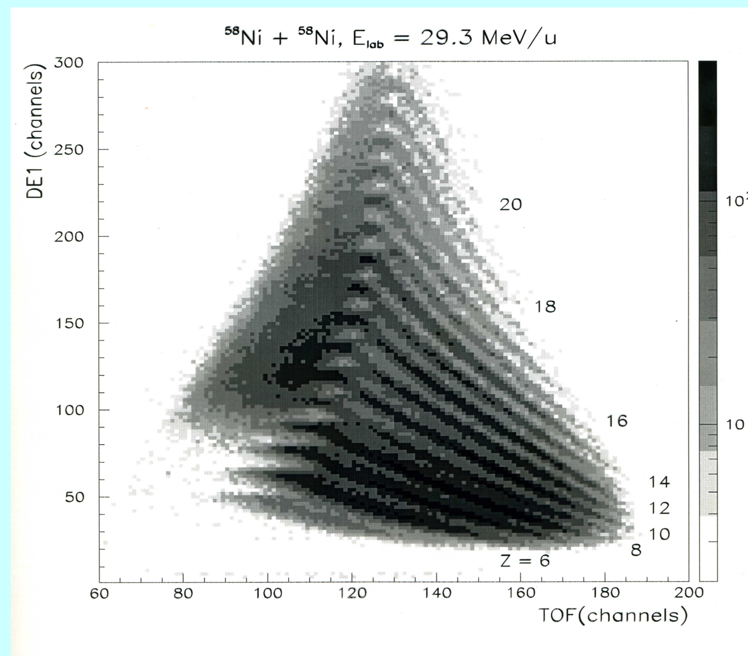
$^{19}F + ^{27}Al E_{lab} = 111.4$ MeV

Start



Stop



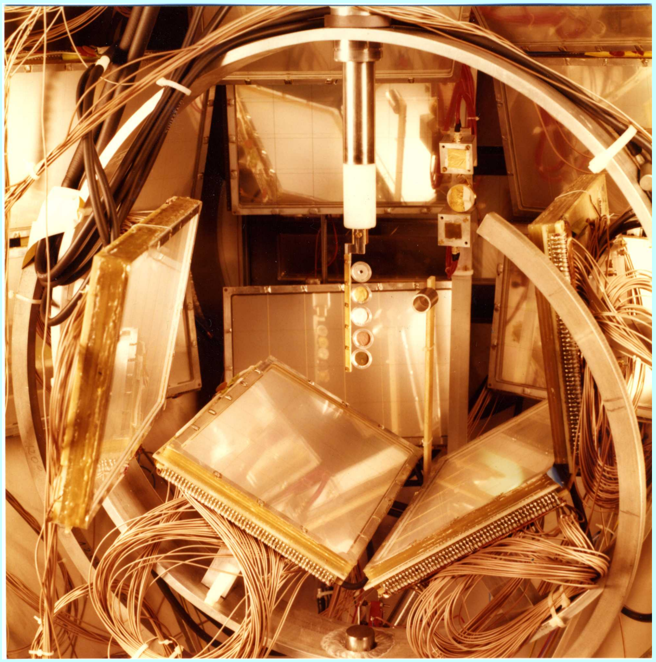


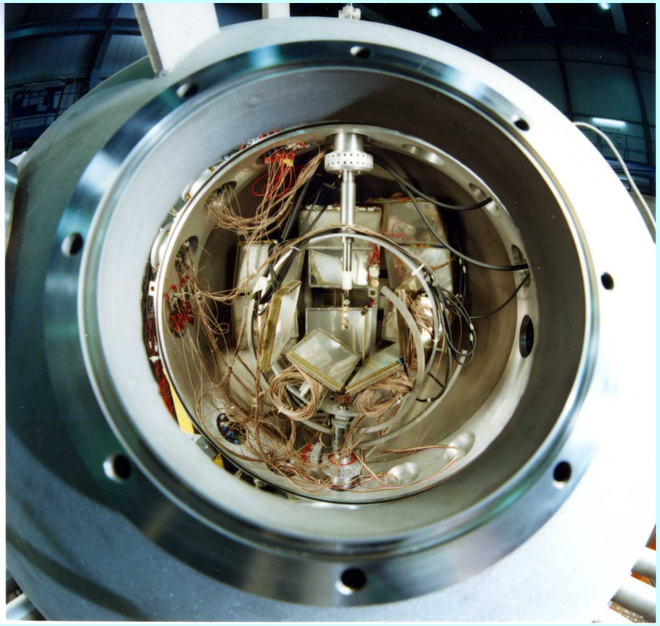
dE/dx ~ MZ²/E

$v^2 = 2E/M$

***DRACULA** experimental device*

PPAC-Examples



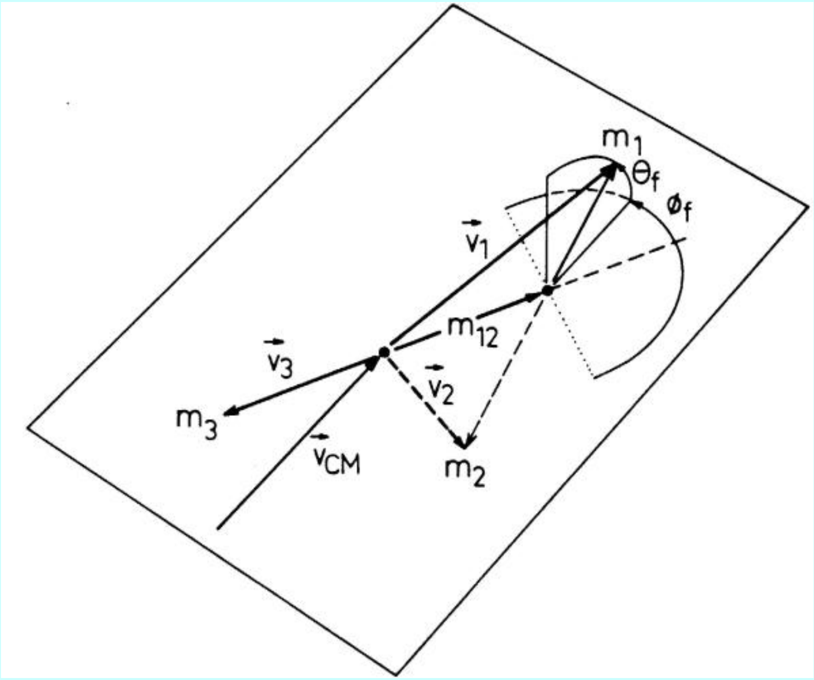


- ToF

- Position information ⇒ flight path

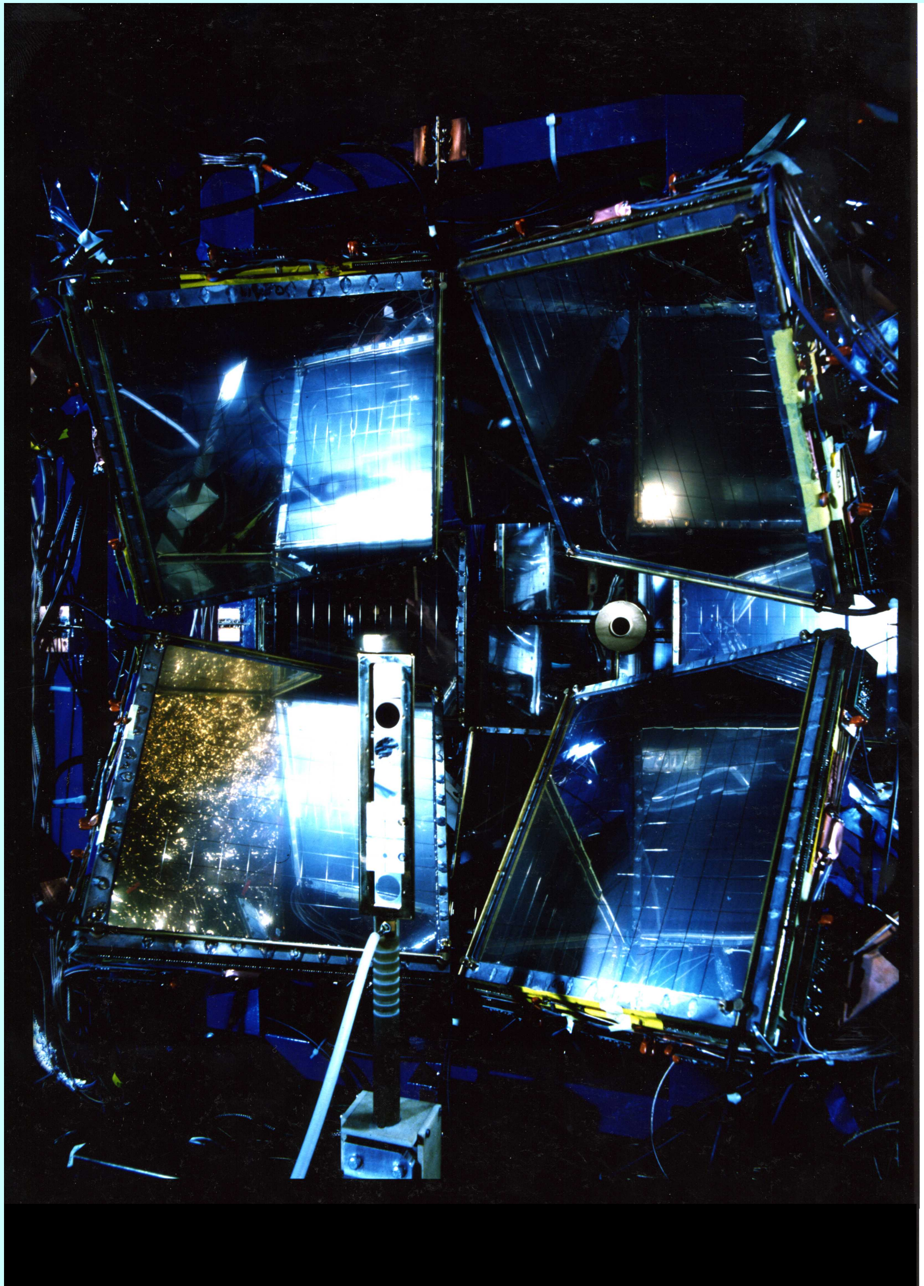
⇓

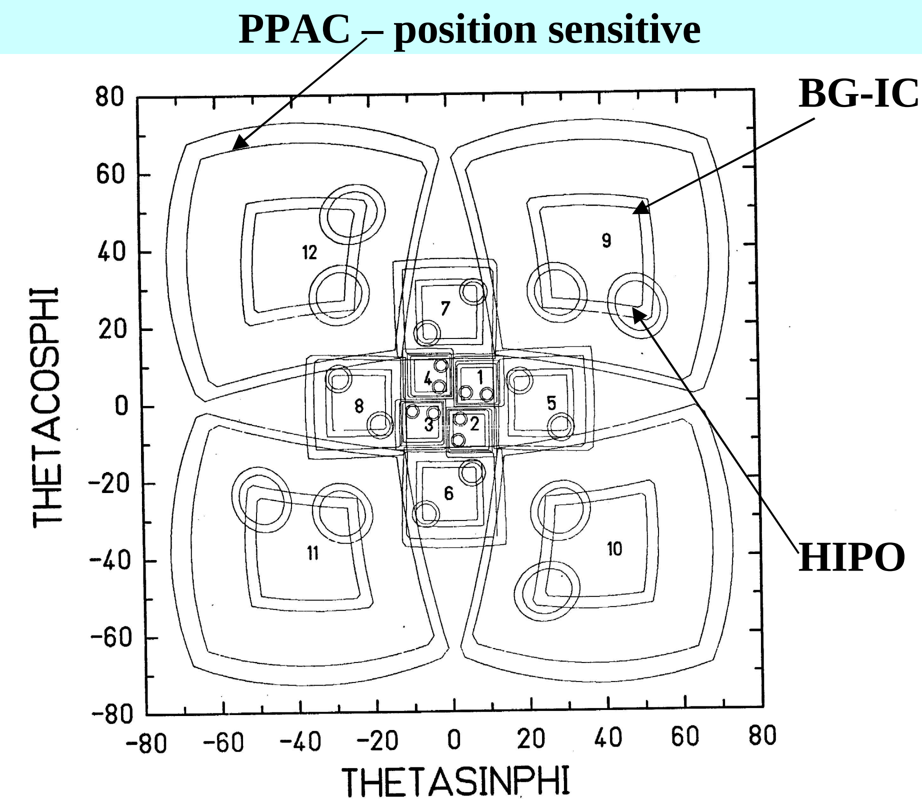
$\vec{V}(m_i)$ (i=1,4)

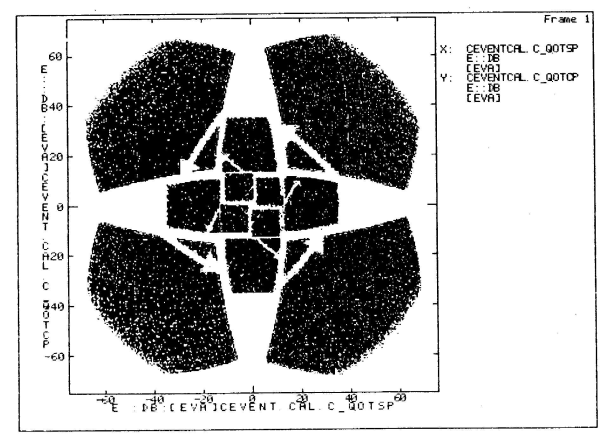


Kinematic coincidence set-up **UNILAC**

PPAC-Examples



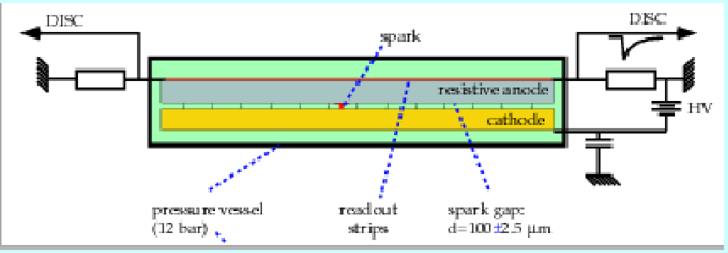




Kinematic coincidence set-up ***UNILAC***

RPC-Examples

Pestov Counter



Y.V.V. Pachomchuck et al. ,
Nucl. Instr. And Meth. A
93(1971) 269

Advantages:

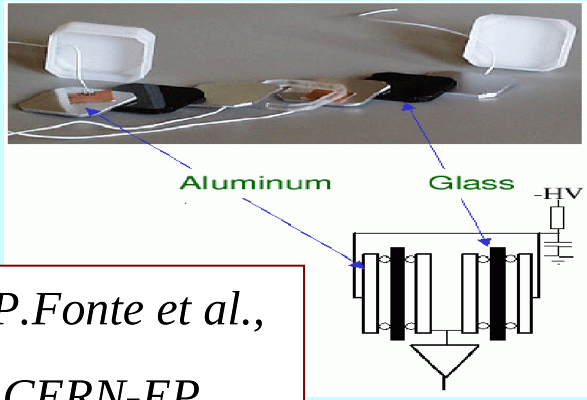
-Very good σ_t (~25 ps)

- Position information: x, y

Drawbacks:

- high pressure operation
- tails in the time spectrum
- needs special glass

Single Cell RPC



P.Fonte et al.,

CERN-EP

27/9/99

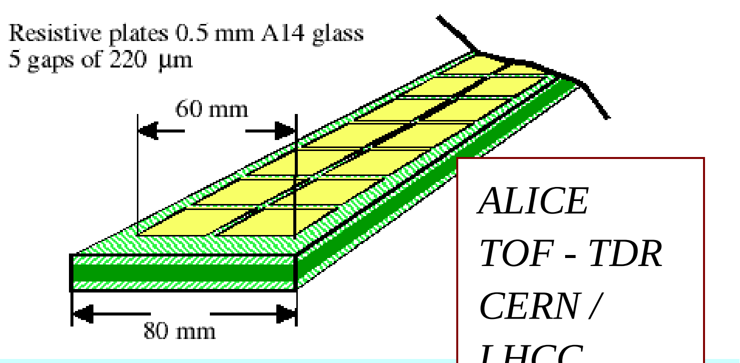
Advantages:

- Very good σ_t (~44 ps)
- commercial glass
- 1 atm pressure operation

Drawbacks:

- edge effects
- unrealistic for large area configuration

MGRPC - pad rows readout



ALICE
TOF - TDR
CERN /
LHCC
2000-12

Advantages:

- Very good σ_t (~60 ps)
- commercial glass

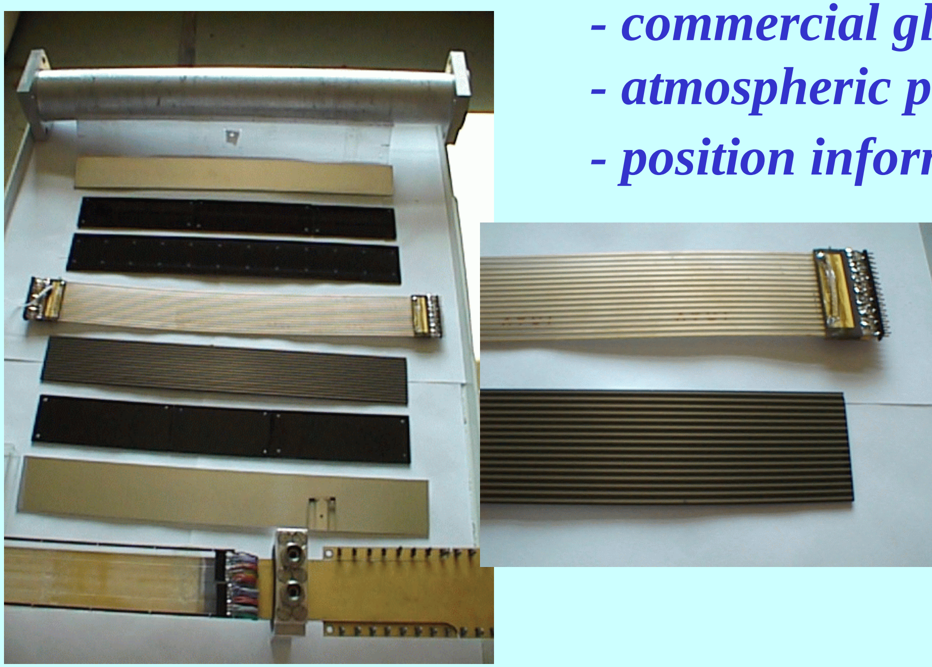
-1 atm pressure operation

Drawbacks:

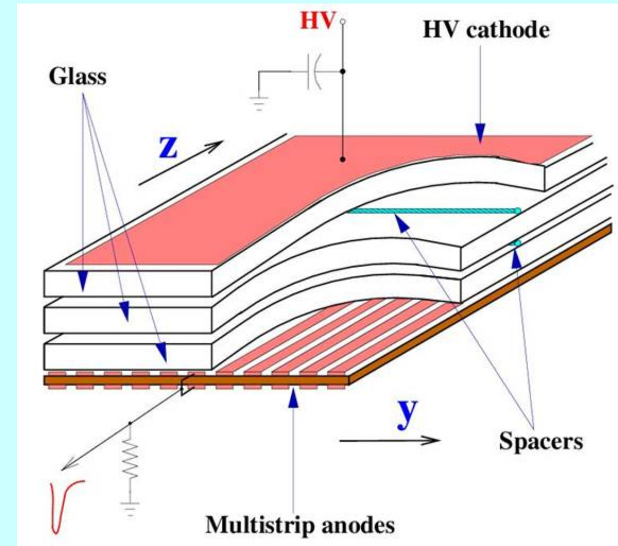
- edge effects, cross talk
- no position information over the pad sizes; tracking device is needed for position dependence correction

RPC-Examples

First prototype , 30 cm length, built and tested in 2000 with ^{60}Co source



- *commercial glass*
- *atmospheric pressure operation*
- *position information: x, y*



•*Amplitude measurements*

FEE

- *Fast Charge Amplifier + Shaping Amplifier (0.25 μ s)*

Digitization

- *Ortec AD811 ADC*

•*Time measurements*

FEE

- *FTA (GSI 80's generation) +CF4000 Discriminator*

Plastic scintillator (NE102)

- *XP2020 PM+ - CF4000 Discriminator*

Digitization

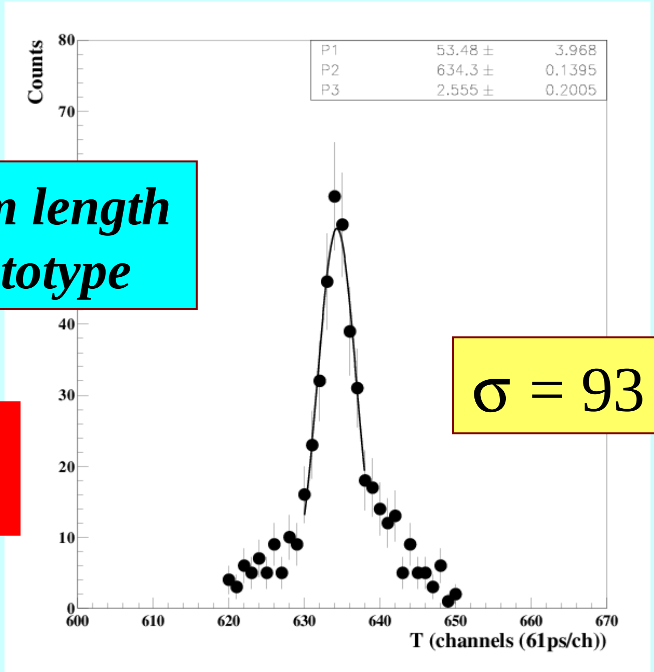
- *LeCroy 2228A TDC*

NIHAM

RPC-Examples

30 cm length prototype

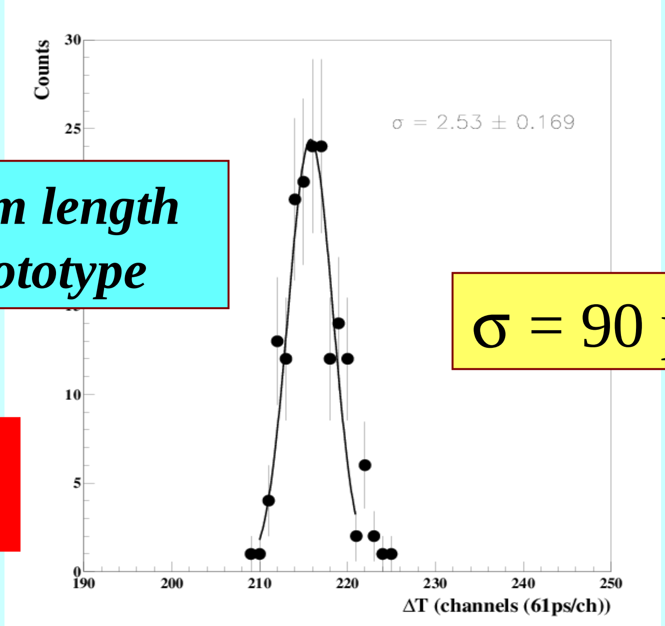
FEE FTA420



σ = 93 ps

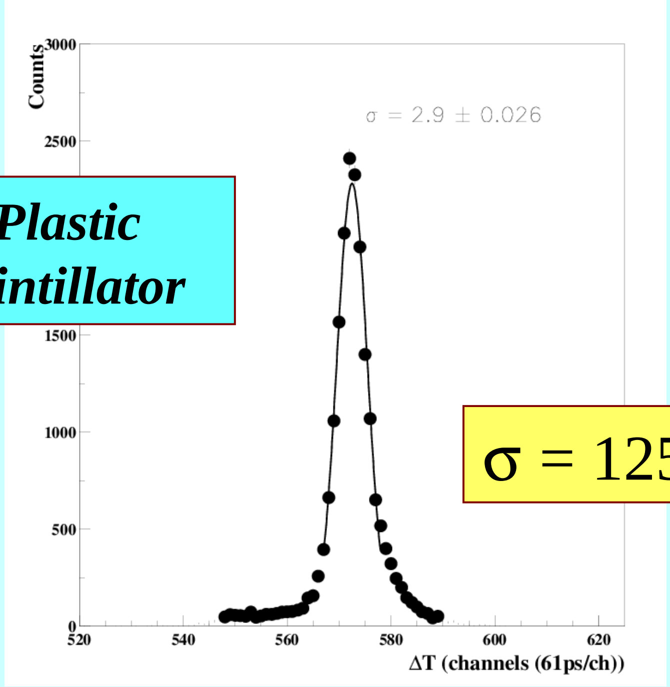
90 cm length prototype

FEE FTA810



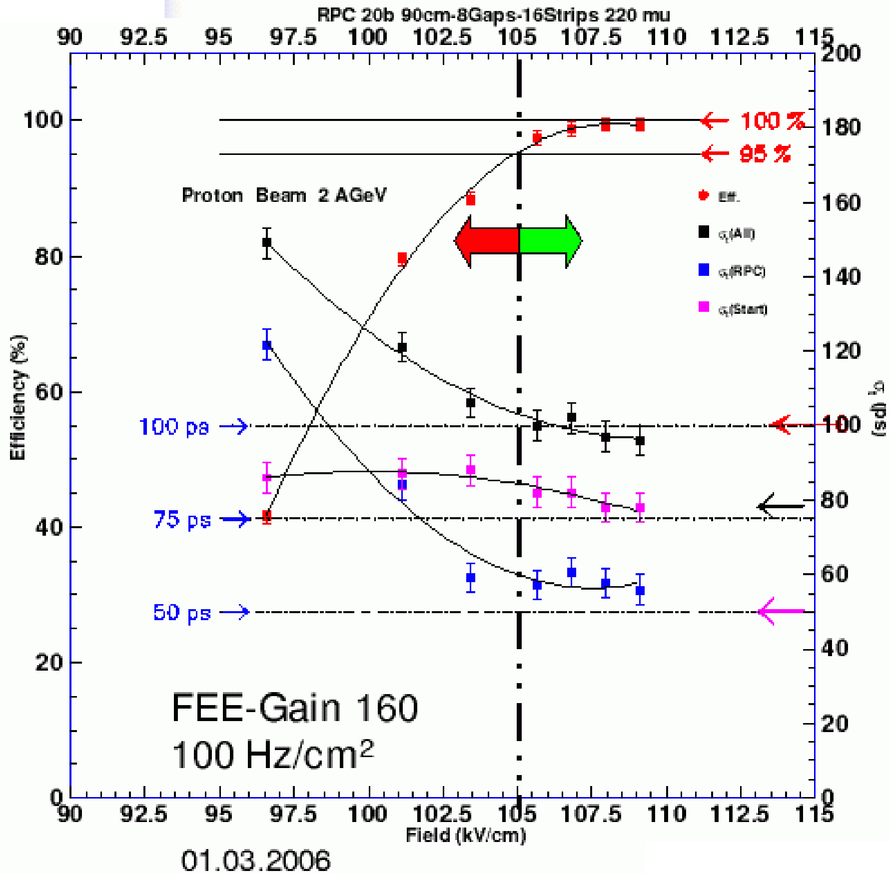
σ = 90 ps

Plastic scintillator



σ = 125 ps

RPC-Examples



Double hit 100 ps

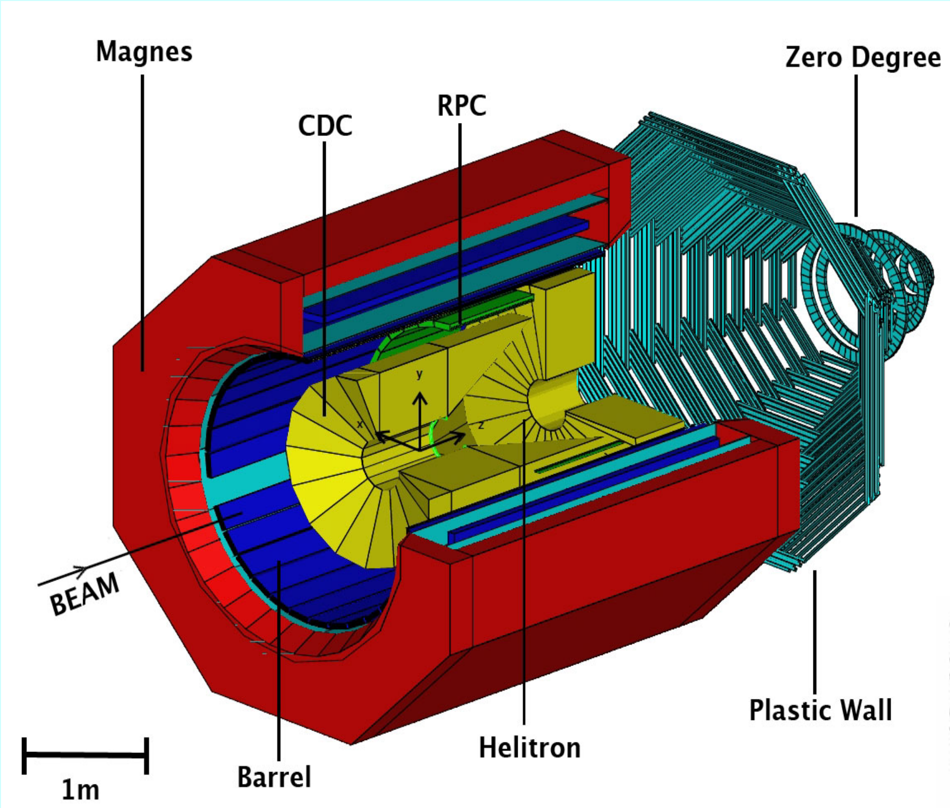
Single hit 78 ps

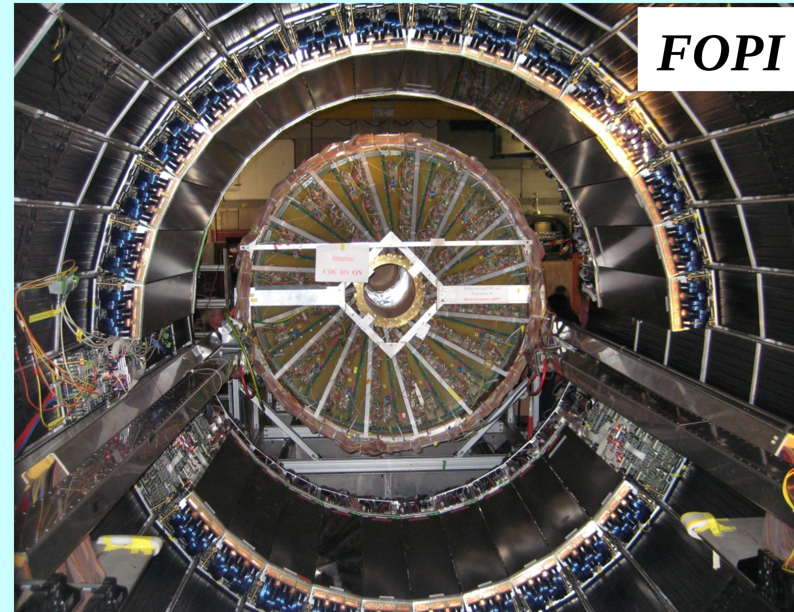
Start 50 ps

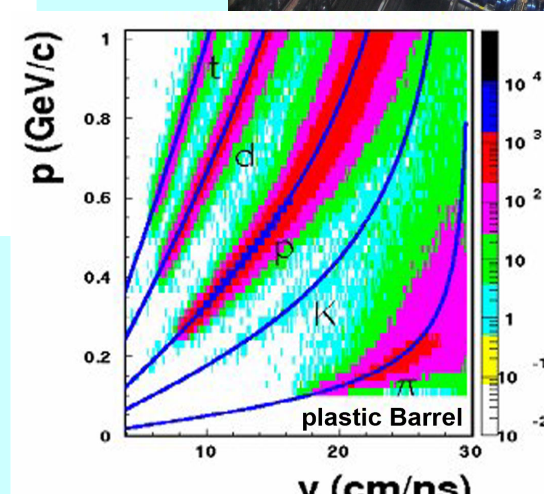
RPC_b + Start	$_t$< 96 ps
Start	$_{ts}$< 78 ps
RPC	$_{RPC}$< 56 ps

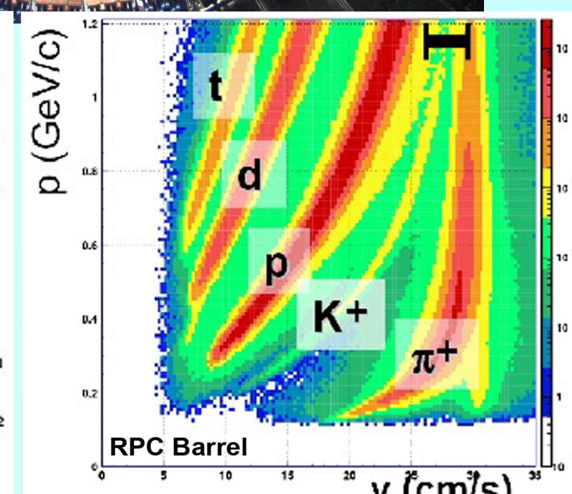
A. Schüttauf et al. NIM, A533(2004)65
M. Kiš et al, NIM, A646(2011)27

RPC-Examples



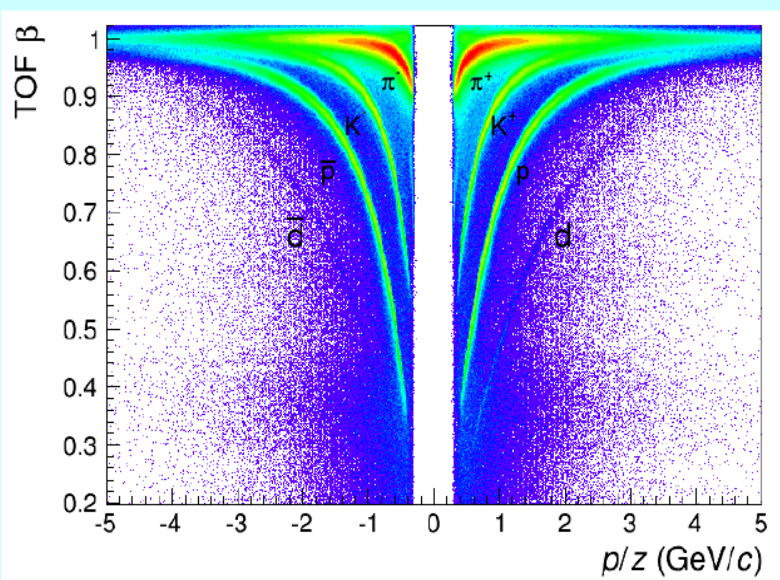






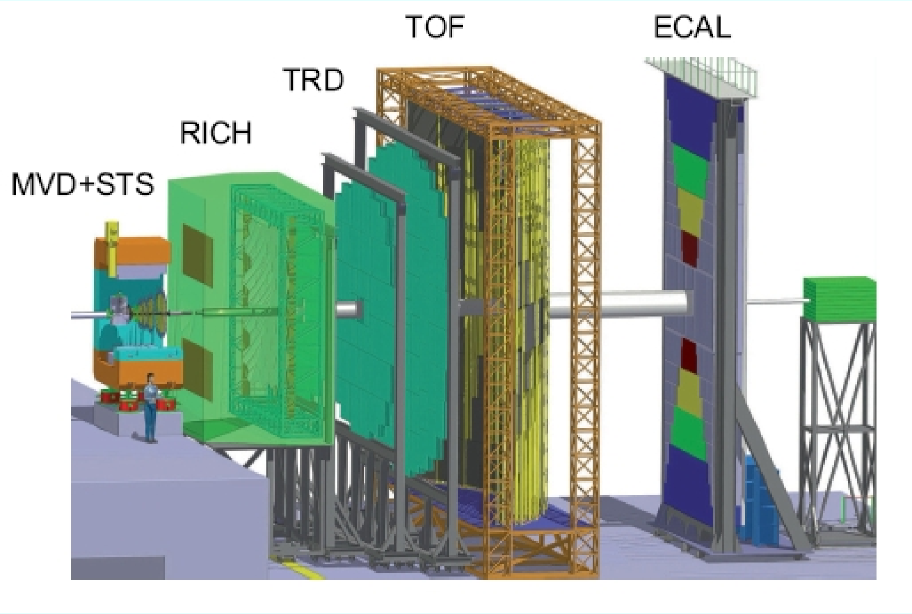
- M.Petrovici et al., NIM 487A(2002)337

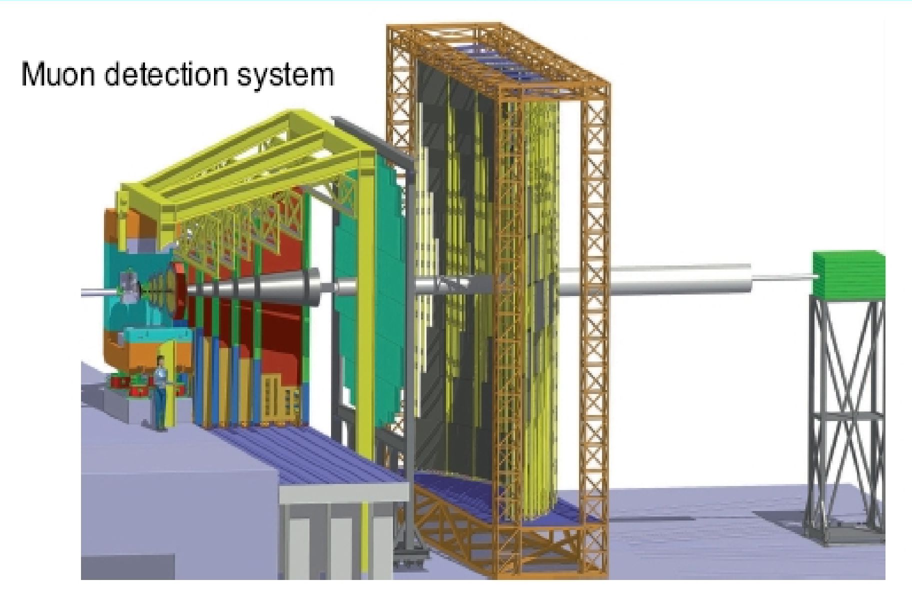
- M.Petrovici et al., NIM 508A(2003)75



⇐ ***Example of PID performance of ALICE TOF subdetector***

High counting rate RPC-Examples
Compressed Barionic Matter (CBM) – Experiment @ FAIR





- *Interaction rate 10^7Hz (~1000 tracks/event)*
- *TOF wall at 10 m from 3º to 27º*
  - *⇒ large area (~150 m²)*
- *Rate from 1 kHz/cm² (27º) to 20 kHz/cm² (3º)*
  - *⇒ large counting rate*
- *Hit density from $6\cdot10^{-2}$/dm² to 1/dm²*
  - *⇒huge number of cells for <5% occupancy*

particle	S/B ratio	Efficiency %	S/B ratio	Efficiency %
ω	0.13	1.8	0.3	1.6
φ	0.05	3.8	0.11	3.5
η	0.002	0.9	0.008	0.8

CBM Experiment Technical Status Report,
Darmstadt, February 2005

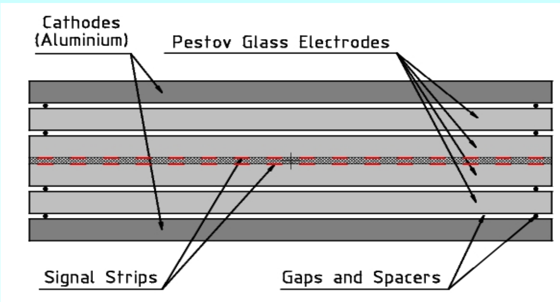
http://www.fair-center.eu/for-users/experiments/cbm.html

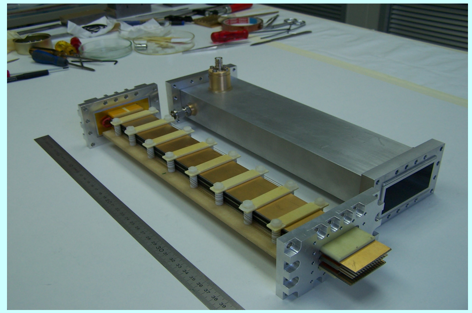
High counting rate RPC-Examples
Compressed Barionic Matter (CBM) – Experiment @ FAIR

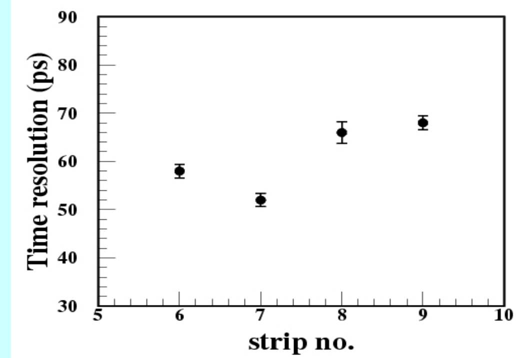
Single-ended – strip readout Pestov glass RPC

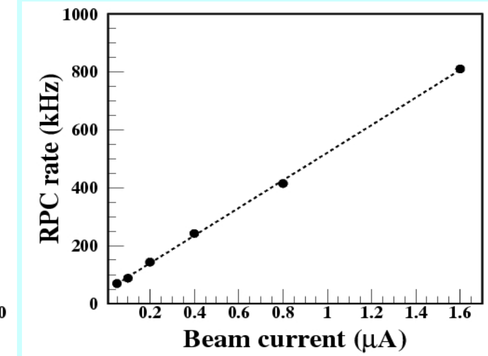
Construction Details

Gap size = 300 μm
Active area 300 mm x 40.6 mm



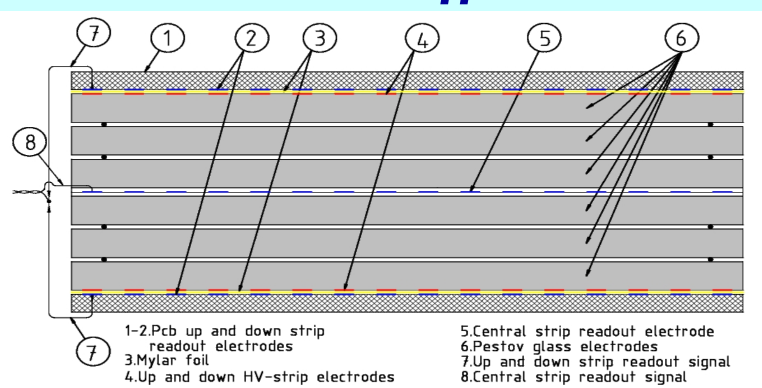




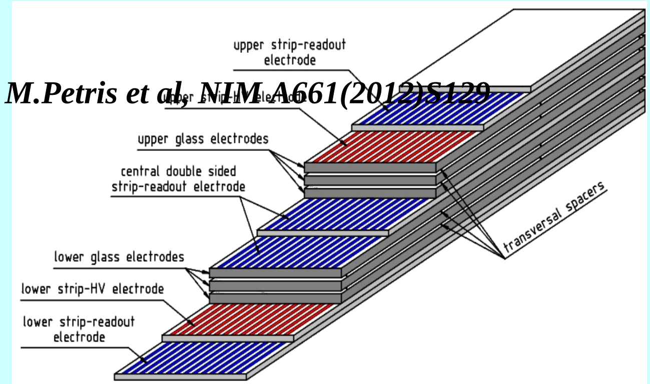


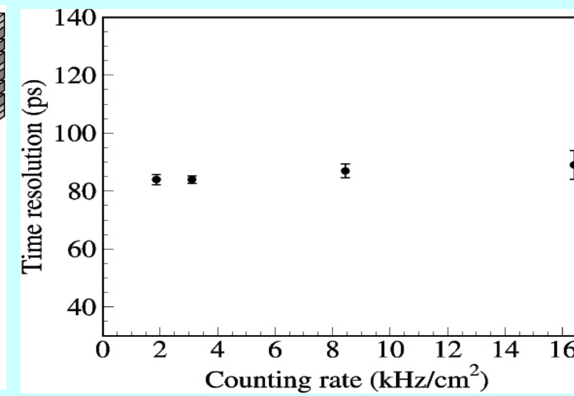
pitch: 2.54 mm, 1.10 mm width, 1.44 mm gap

Differential – strip readout Pestov glass RPC



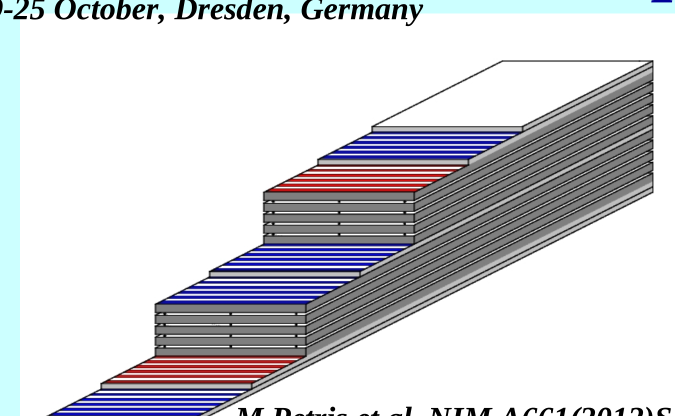
M.Petris et al, NIM A661(2012)S129



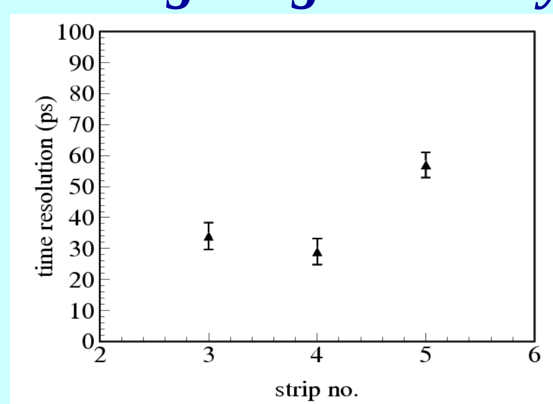


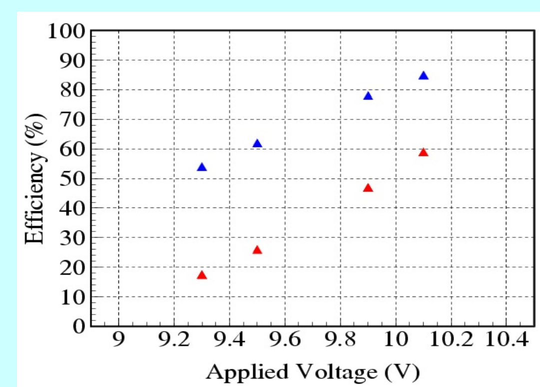
D. Bartos et al., 2008 Nuclear Science Symposium
19-25 October, Dresden, Germany

Towards higher granularity

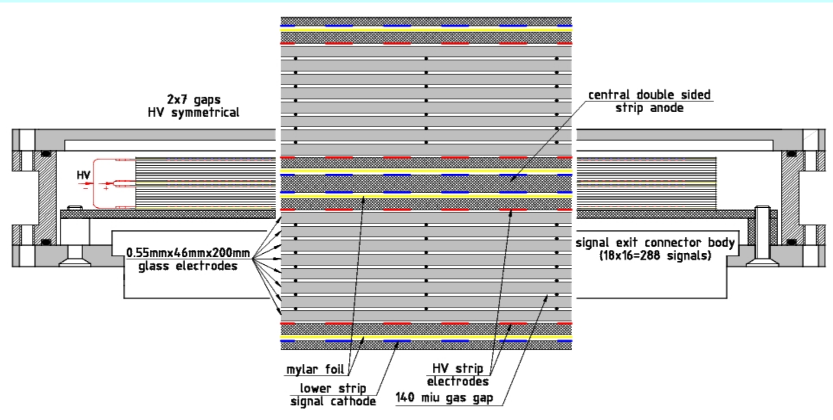


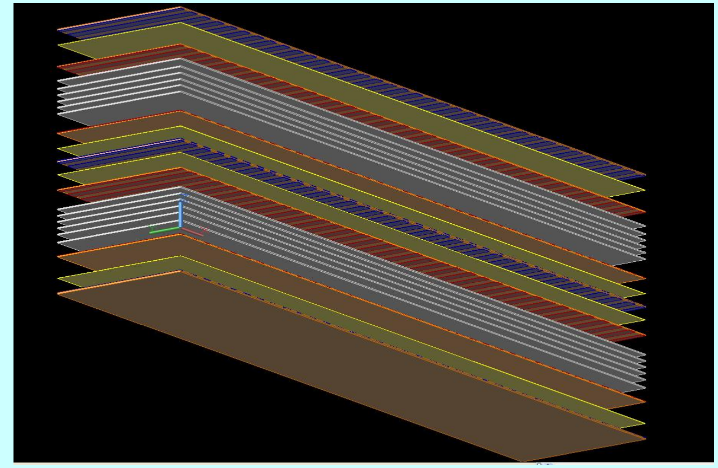
M.Petris et al, NIM A661(2012)S129

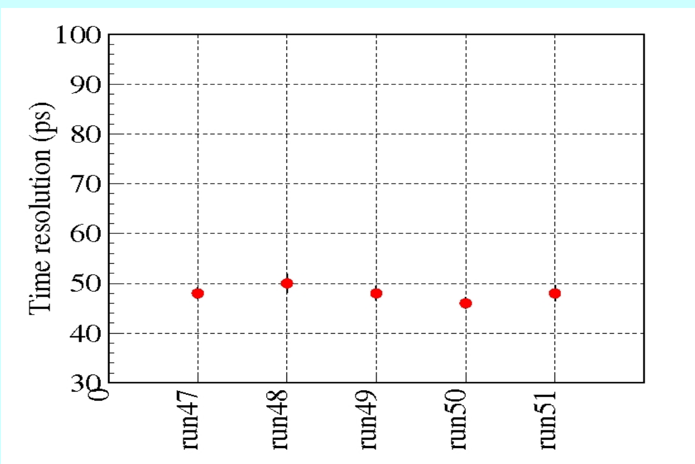


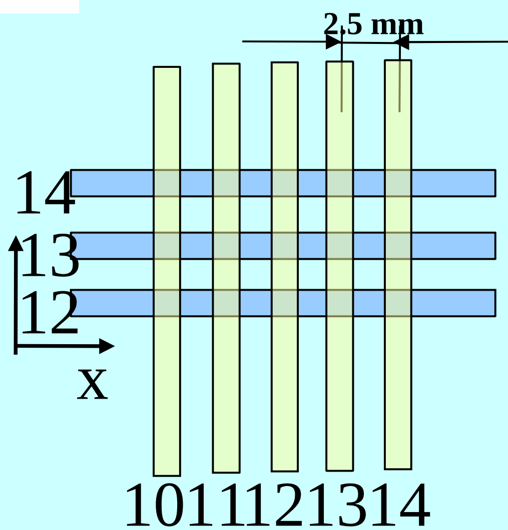


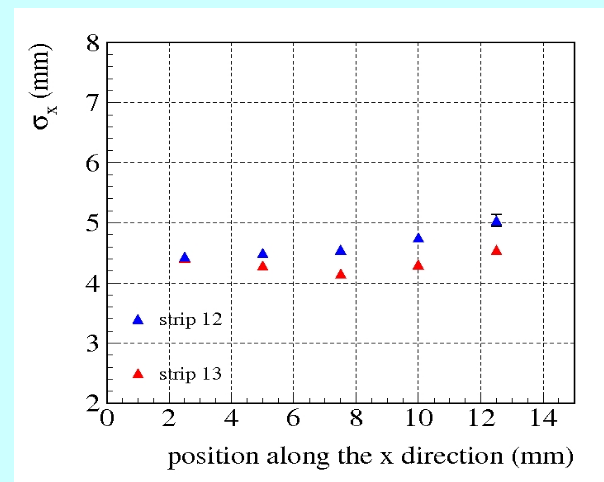
High granularity, differential, strip read-out, multi gap, timing RPC











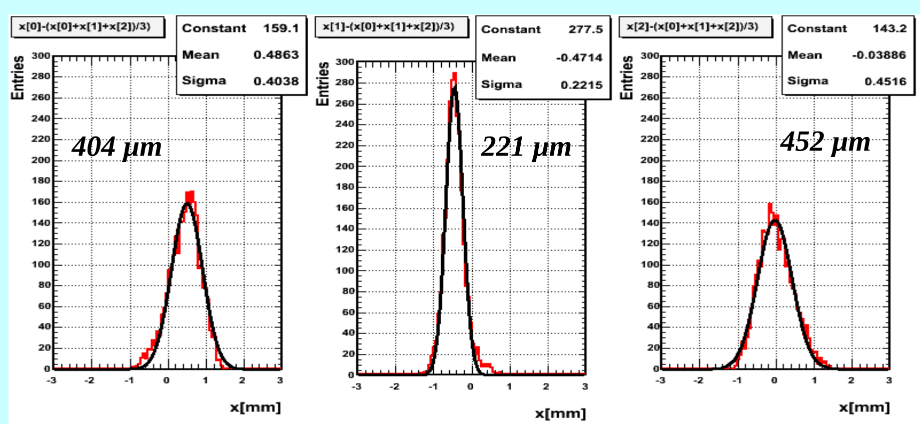
$$x = w\frac{\ln Q_{L-1} - \ln Q_{L+1}}{2(\ln Q_{L-1} - 2\ln Q_L + \ln Q_{L+1})}$$

where:

(ToT)Q_L = the charge of the most significant strip

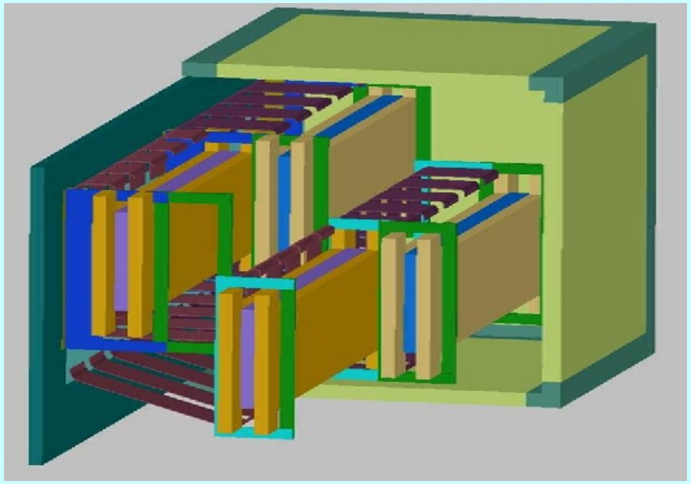
(ToT)Q_{L-1} = the charge of the left adjacent strip

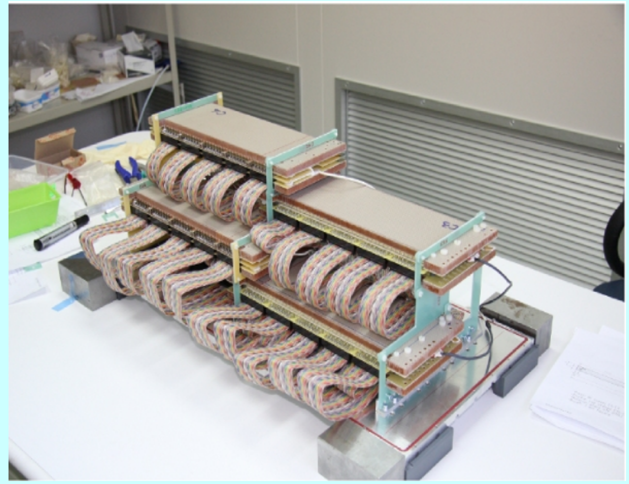
(ToT)Q_{L+1} = the charge of the right adjacent strip

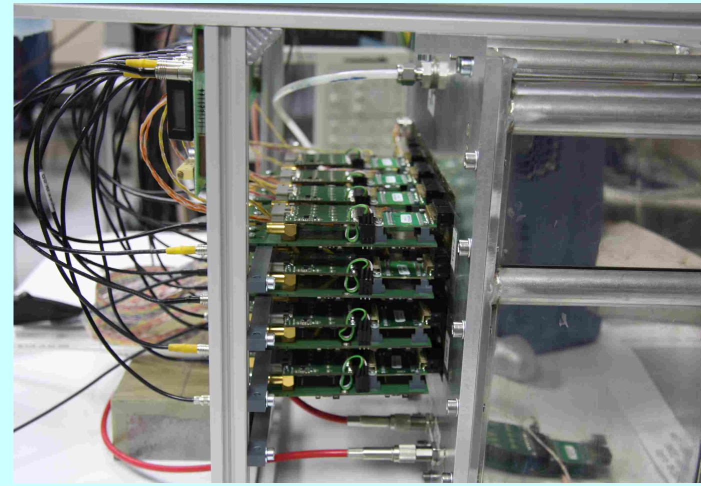


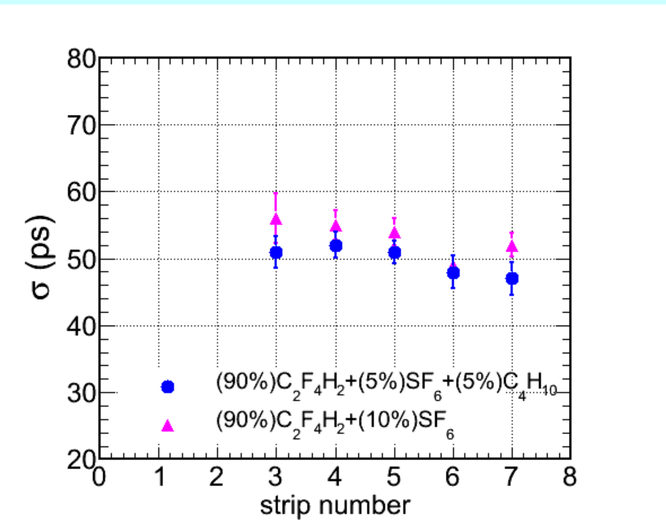
M.Petrovici et al, JINST 7(2012)P11003

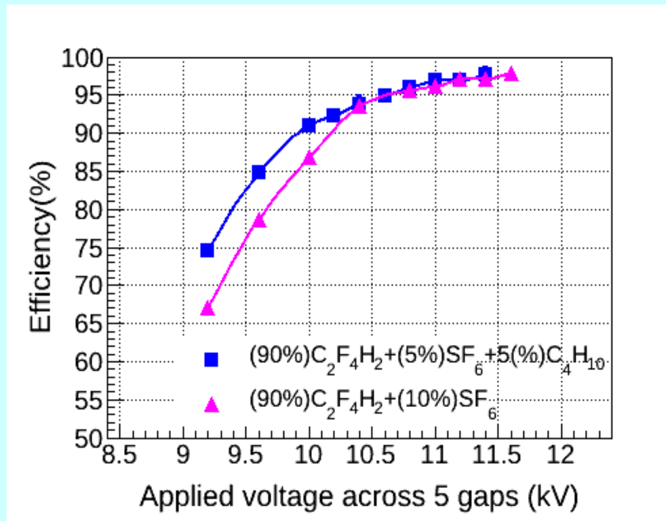
Towards real geometry

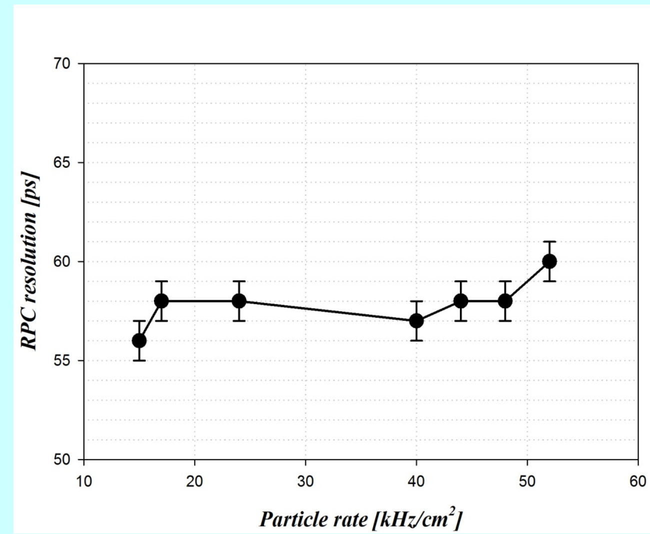




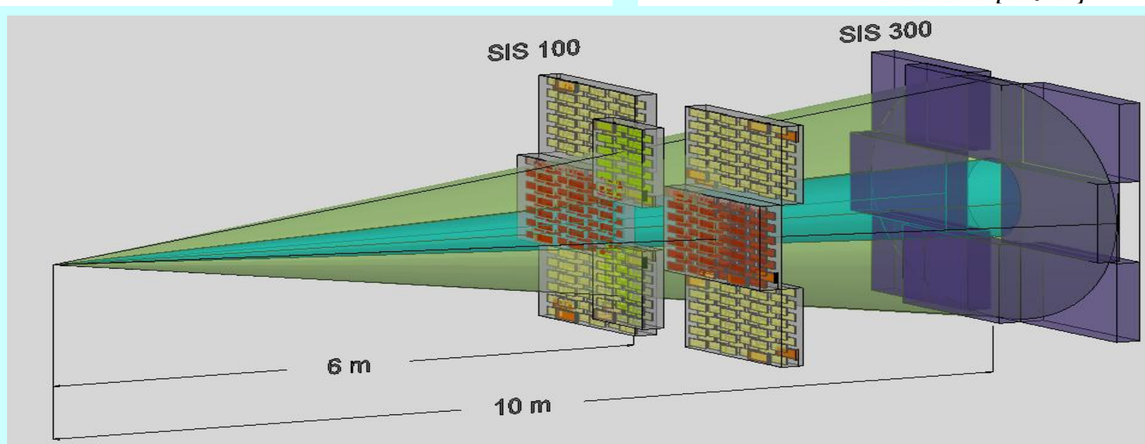








CBM-TOF
inner zone architecture

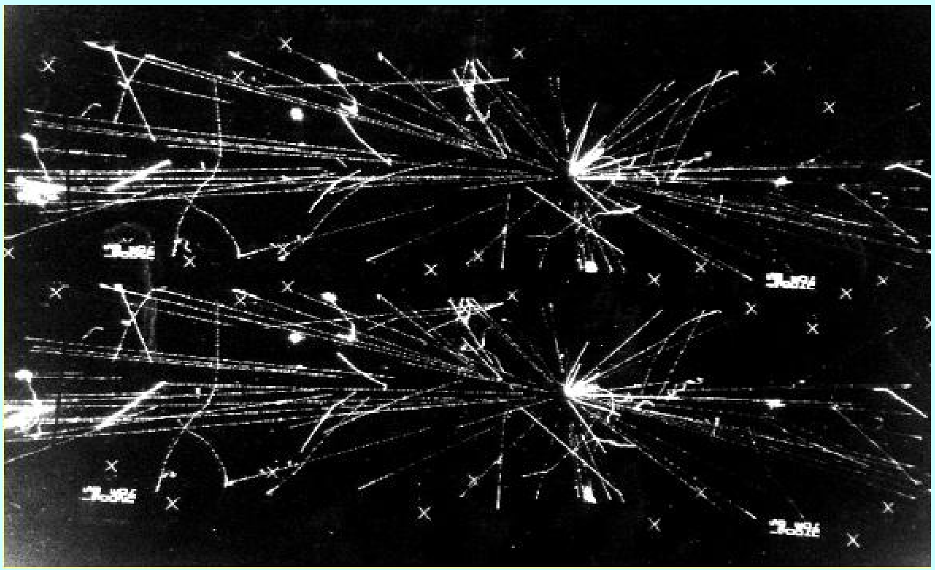


More details:

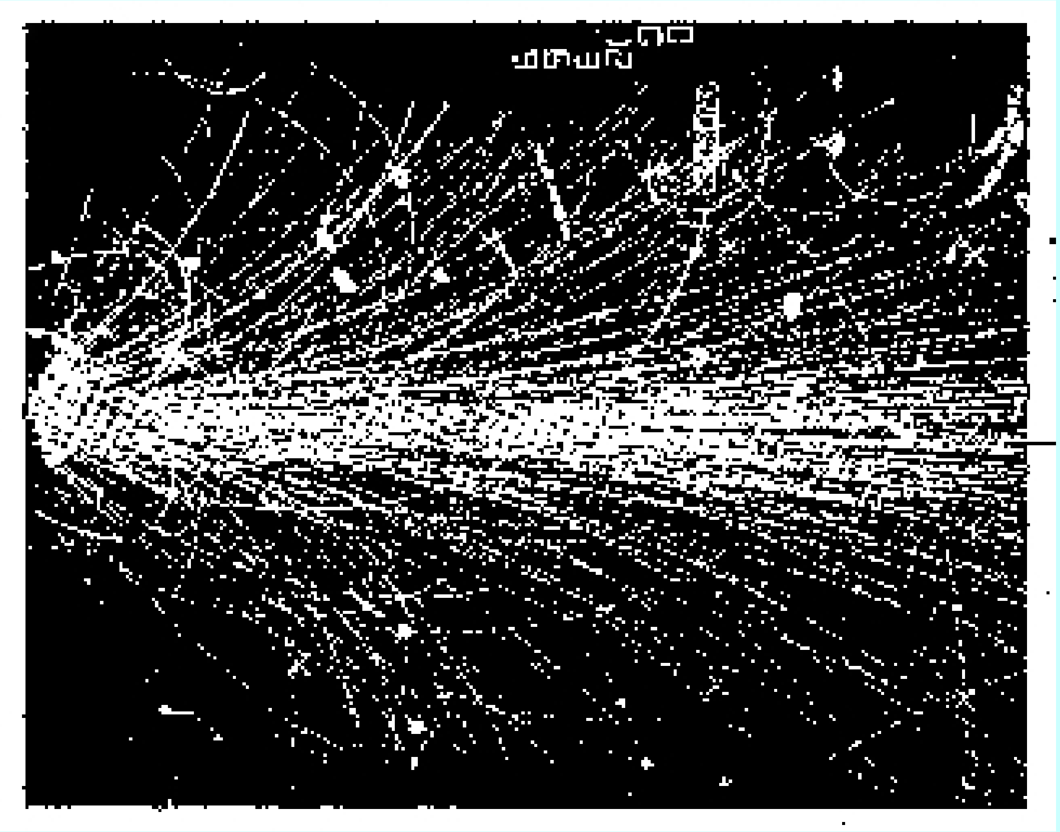
CBM – Progress Reports:
http://www.fair-center.eu/en/for-users/experiments/cbm/cbm-documents.html

CBM – Collaboration Meetings:
https://indico.gsi.de/categoryDisplay.py?categId=134
Time table (Idico view) – especially TOF sessions

SC-Examples



UA5 – SPS experiment
$p\bar{p}$ collision



NA35 – SPS experiment
16O + Pb 200 GeV/u

Acta Physica Polonica B19(1988)307
H.G. Pugh

- ***Liquid detectors:*** - ***Bubble chambers :***

- super heated, above boiling point - liquid hydrogen
- nucleation centers are formed along the particles' trajectories
- via a piston the pressure is slightly decreased, bubbles develop along the particle tracks
- after a couple of msec, bubbles a large enough that a flash photograph can be taken by several

cameras for stereo information
- the piston moves back to collapse the bubbles and prevent the boiling
- ~0.1 mm spatial resolution
- bubble density ~ primary ionization
⇒Poison rather than Landau distribution with long tail
⇒π and K separation up to ~0.9 GeV/c and π and p up to ~1.6 GeV/c
- 6 μm space resolution can be achieved with holographic recording for small chambers

• ***Liquid detectors: - Bubble chambers (cnt'd):***

Performances:

⇒ π and K separation up to ~0.9 GeV/c and π and p up to ~1.6 GeV/c

⇒ 6 μm space resolution can be achieved with holographic recording for small chambers

• *Liquid detectors: - Bubble chambers (cnt'd):*

Drawbacks:

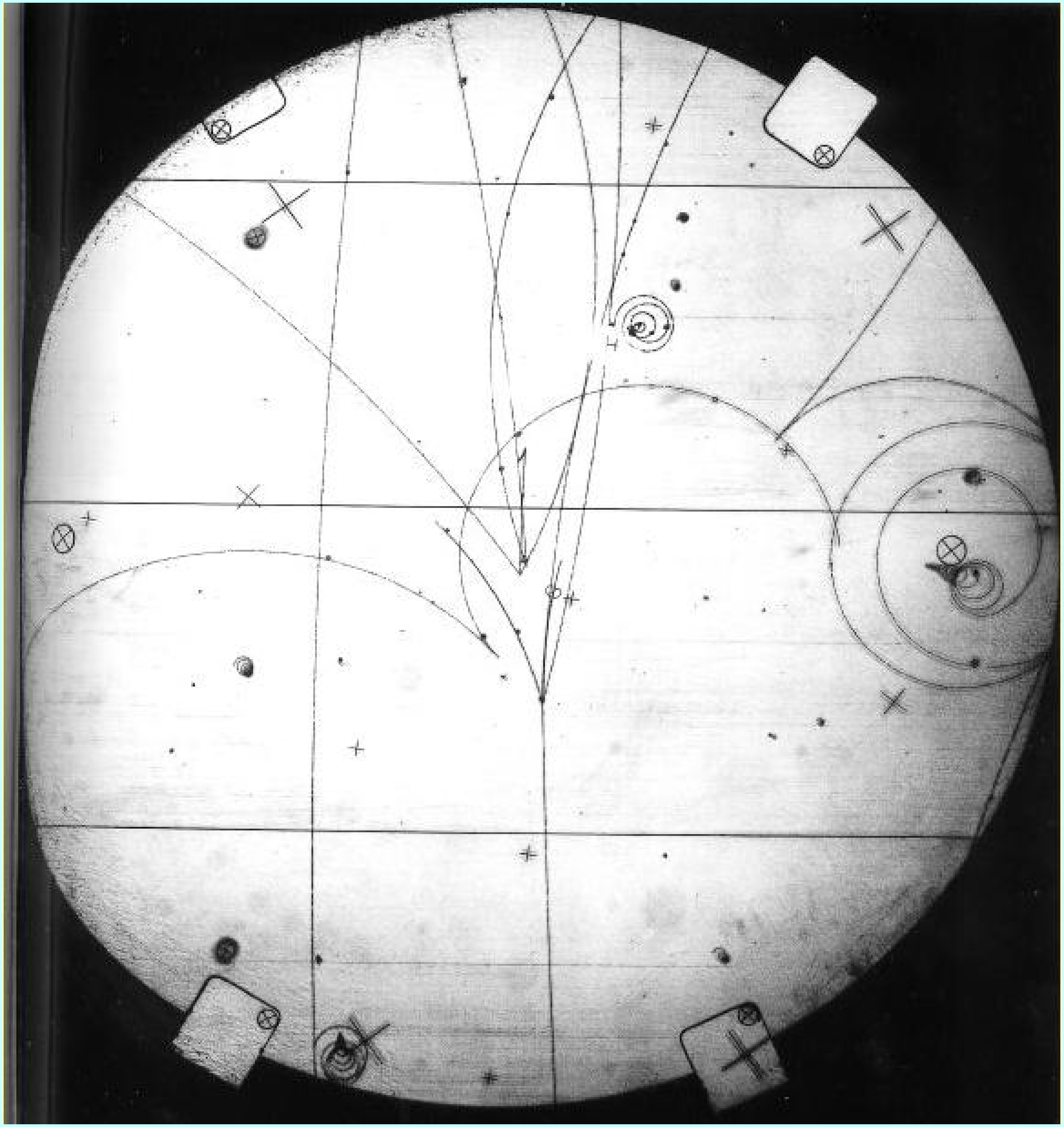
- *film measurement and event reconstruction is slow (this limits experiments to 10^5 to 10^6 events)*

- *The sensitive period is quite long ⇒ the beam intensity must be limited*

- *⇒difficult to search for and study very rare events*

- *the liquid in the chamber acts as target and detector ⇒bubble chambers cannot be used with modern colliding-beam machines.*

Bubble chambers (cnt'd):

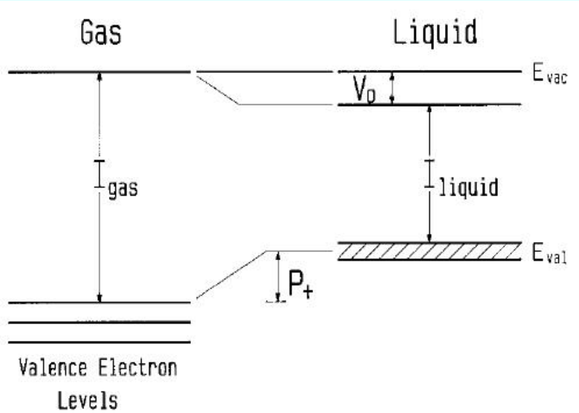


$$\bar{p}\,p \rightarrow p\,\pi^{+}\,K^{-}\,\pi^{-}\,\pi^{0}\,K^{0}\,\bar{n}$$

Stanford 1 m hydrogen bubble chamber, 8.8 GeV/c antiprotons

Liquid detectors (cnt'd):

Liquid **A**rgon **N**eutrino and **N**ucleon **D**ecay **D**etector



$V_{\text{positive ions}} \sim 6.1 \cdot 10^{-4}\, cm^2 V^{-1} sec^{-1}$

$V_{\text{electrons}} \sim 500\, cm^2 V^{-1} sec^{-1}$

⇒Relaxation time required

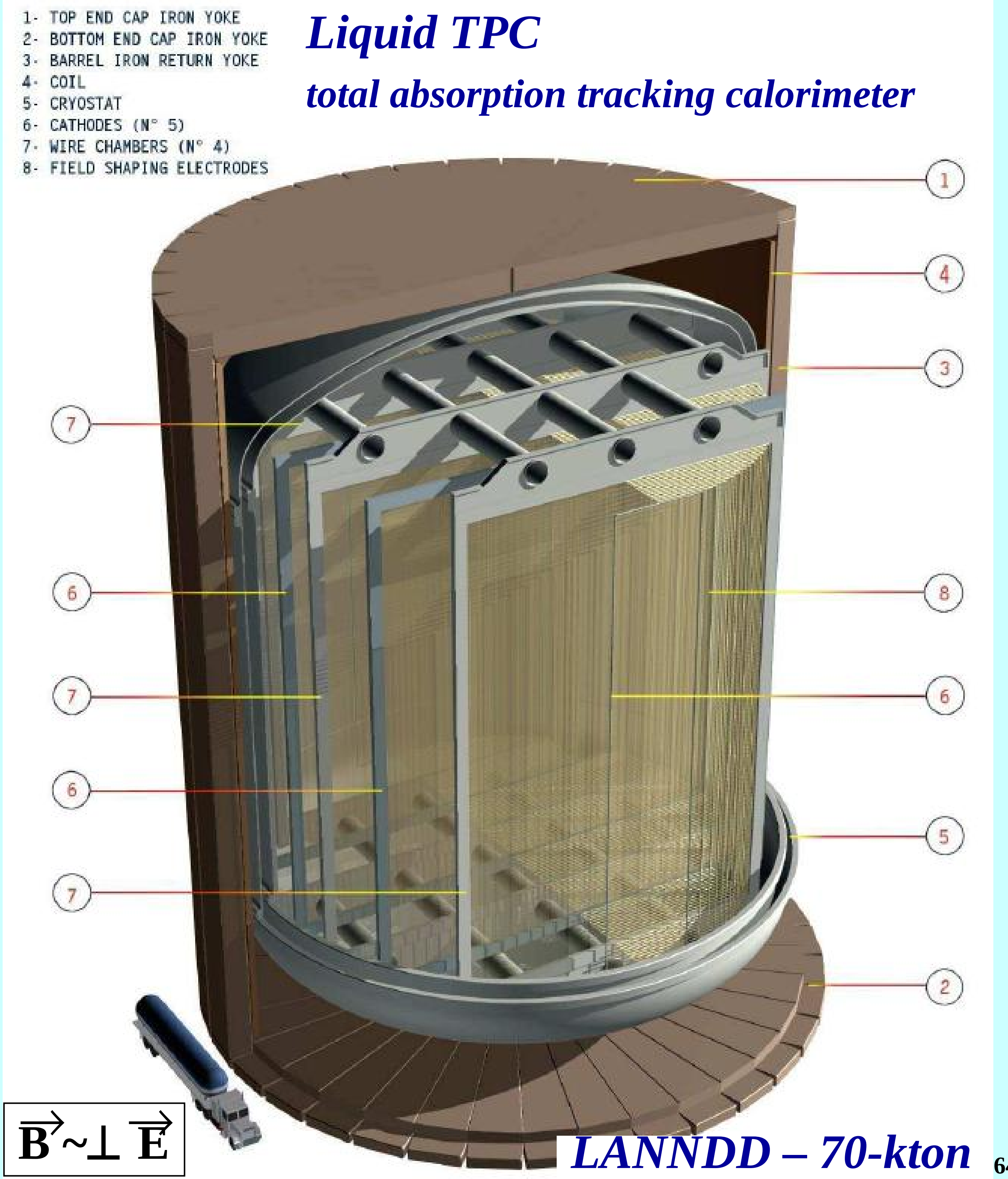
to avoid space charge effect

0.1 ppb O_2

arXiv:astro-ph/0105442v1

Liquid TPC

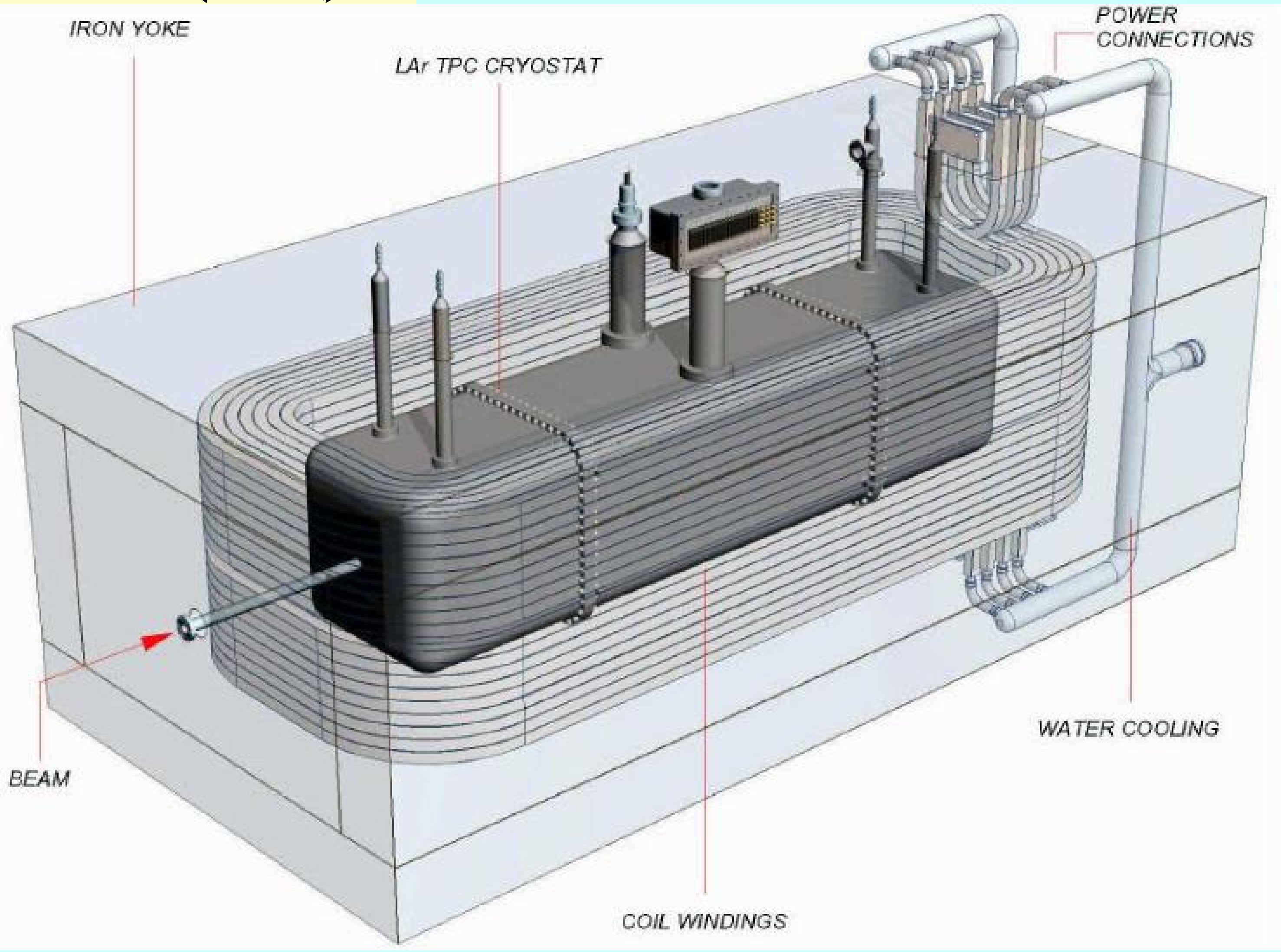
total absorption tracking calorimeter



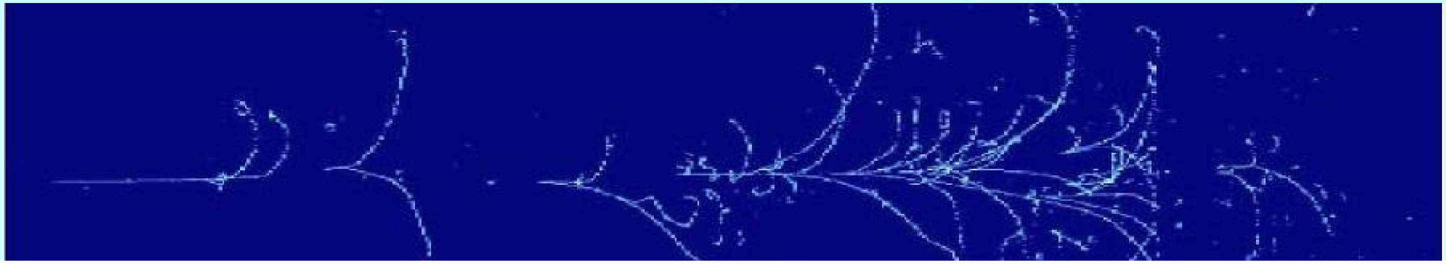
$\vec{B} \sim \perp \vec{E}$

LANNDD – 70-kton

Liquid detectors (cnt'd):



Simulation of electromagnetic showers of 2.5 GeV electrons 1T transverse magneticfield



μLANNDD – 60x60x280 cm^3, horizontal 38 cm drift 1-T magnetic field

http://www.hep.princeton.edu/~mcdonald/nufact/uL@CERN_LOI.pdf

http://www.hep.princeton.edu/~mcdonald/nufact/bnl_loi/argonprop.pdf

http://neutrino.kek.jp/jhfnu/loi/loi_JHFcor.pdf

• *Semiconductor detectors*

Silicon

- velocity: μ_e=1450 cm2/Vs,

  μ_h=505 cm2/Vs,

- 3.63eV per e^--h pair ⇒~11000 e^--h pairs/100µm of silicon.

- however:

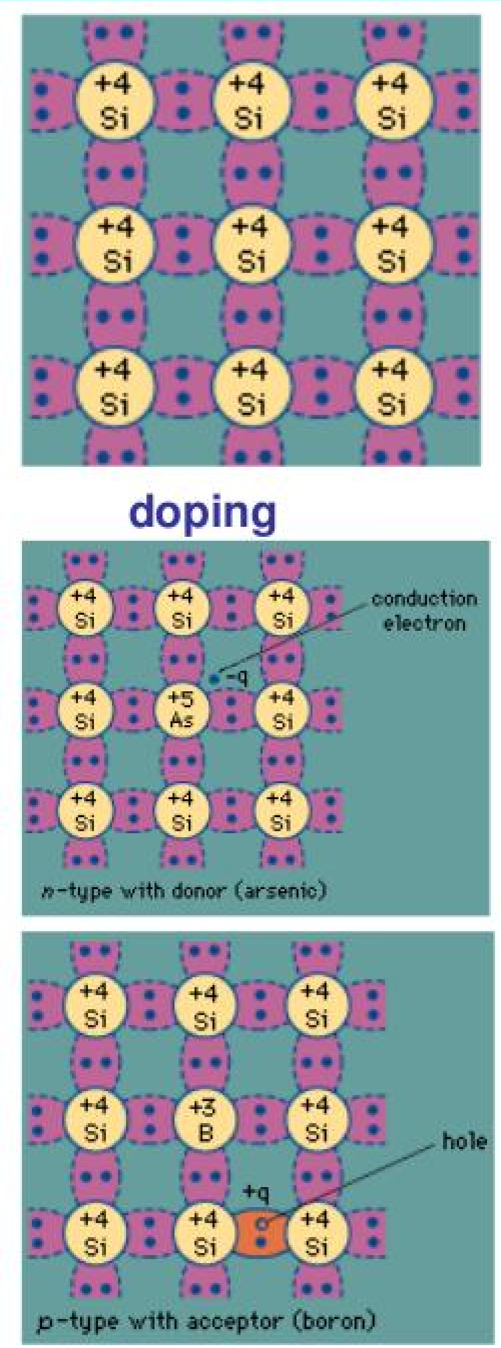
  - free charge carriers in Si @ T=300 K: n = 1.45 x 10^{10}/ cm^3

  - only 33000 e^--h in 300 µm produced by a high energy particle

⇓

Why do we use Si as a solid state detector ?

• Semiconductor detectors



current can flow due to movement of electrons and holes

increase concentration of free electrons

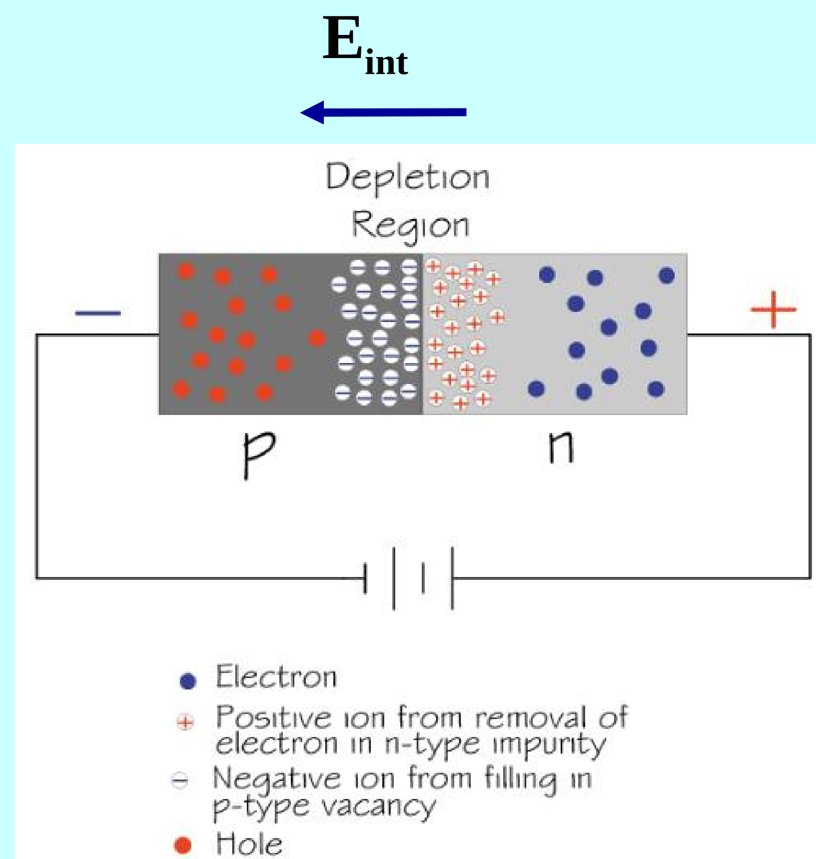
⇒ reduces holes concentration

n-type silicon

increase concentration of holes

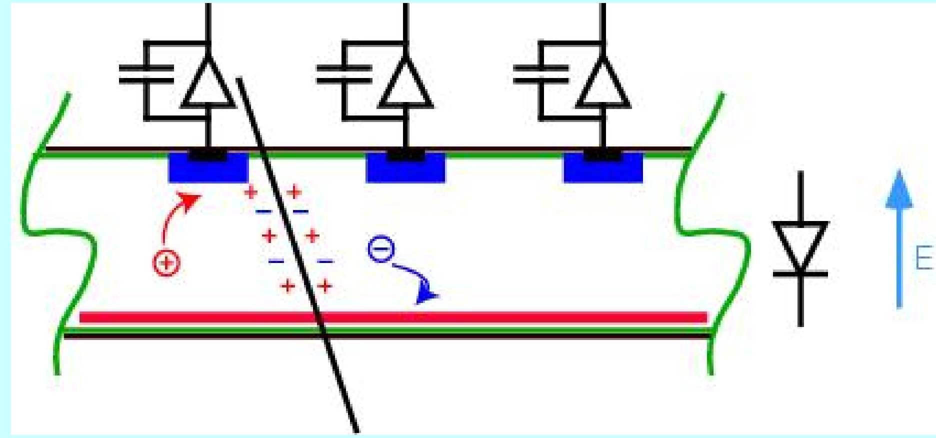
⇒ reduces concentration of free electrons

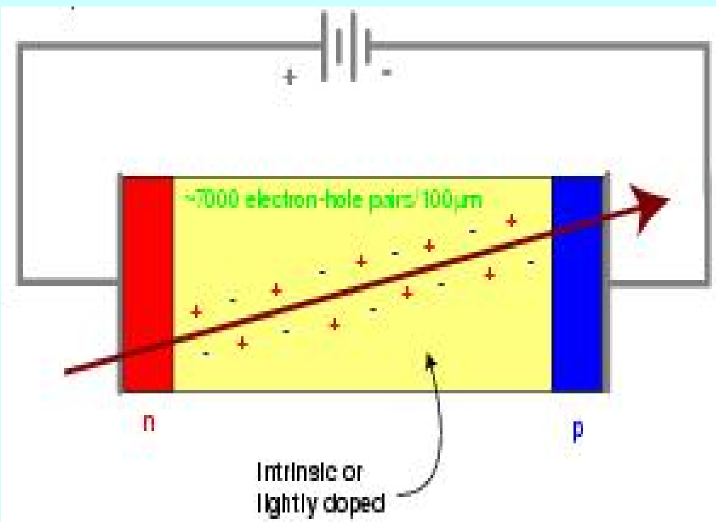
p-type silicon



Reversed bias increases the barrier potential – more difficult for electrons and holes to diffuse across junction

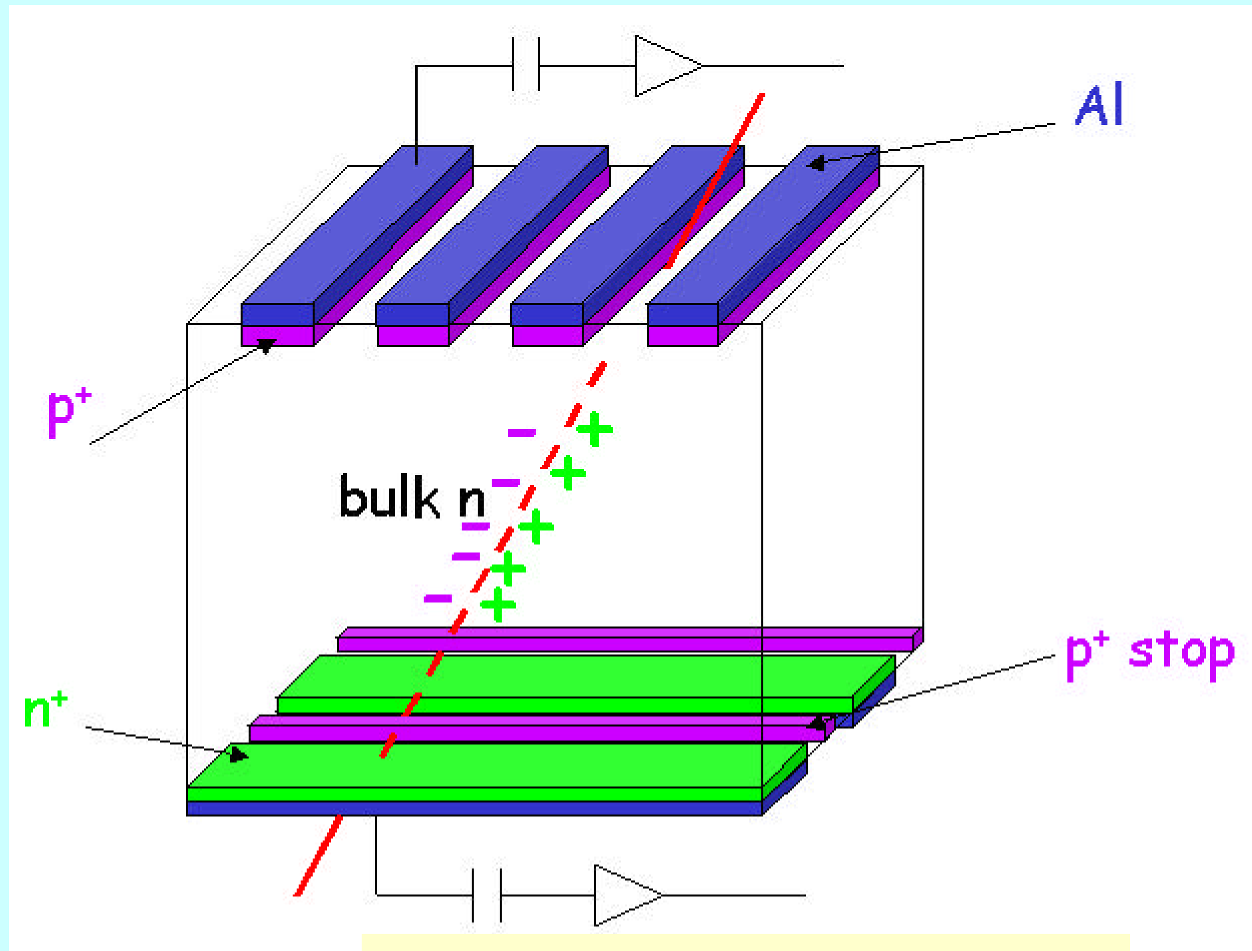
• Semiconductor detectors





Single detector

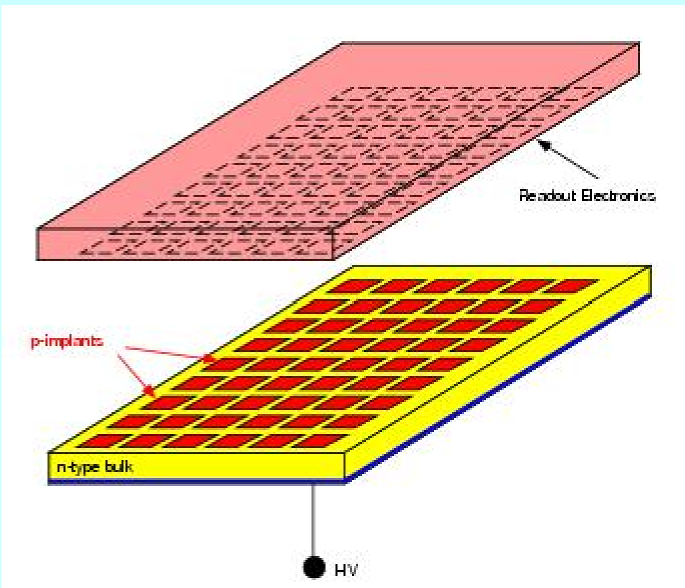
semiconductor ionization chamber

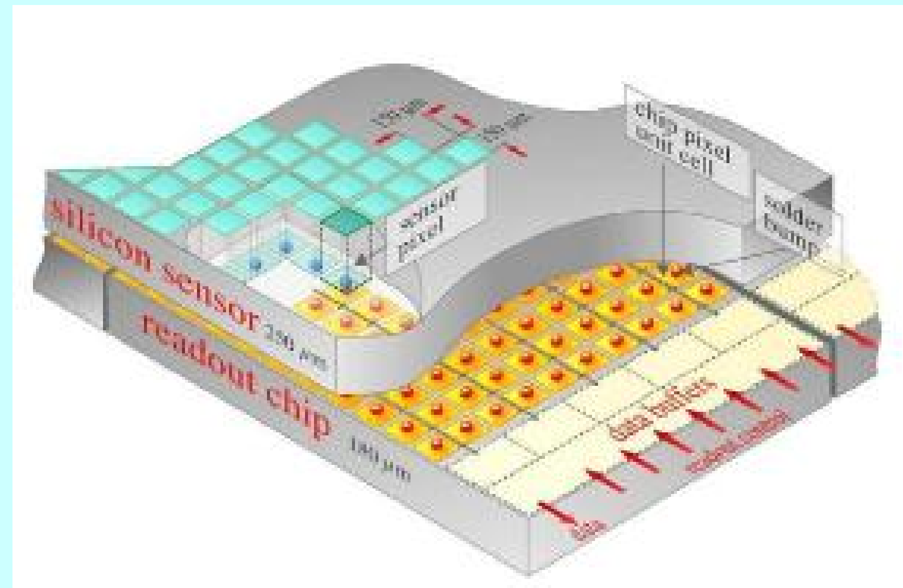


Double sided strip detector

• *Semiconductor detectors*

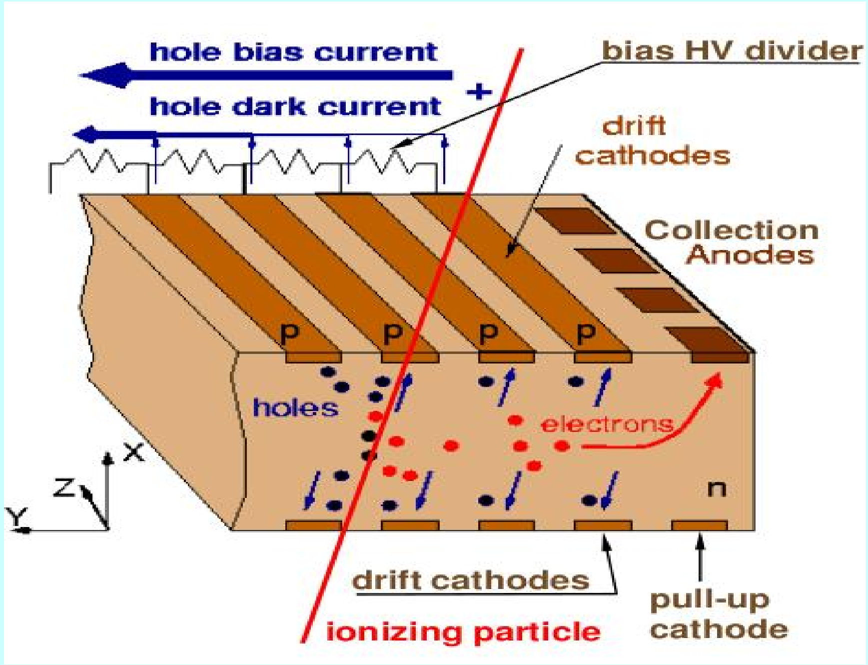
Pixel detector

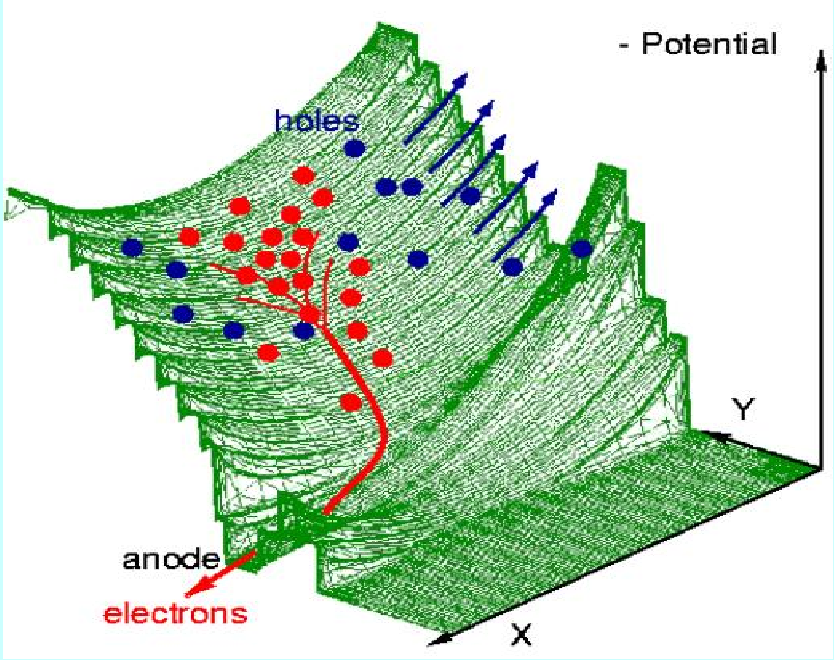




• *Semiconductor detectors*

Drift detector

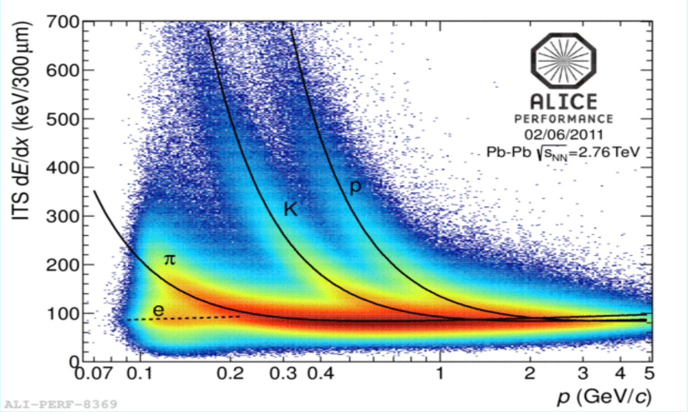




semiconductor TPC

Silicon Detectors for Particle Physics
P. Hopman, 1997 IEEE NSS Short Course
On Detectors for High Energy Physics

Example of PID performance of ALICE ITS subdetector



• ***Scintillator counters and photomultipliers***

⇒PID, n-γ discrimination, Time-of-Flight measurements

Scintillator counters are based on atomic and molecular excitations produced by the passing charged particle

De-excitation ⇒emission of light – ***"fluorescence"***

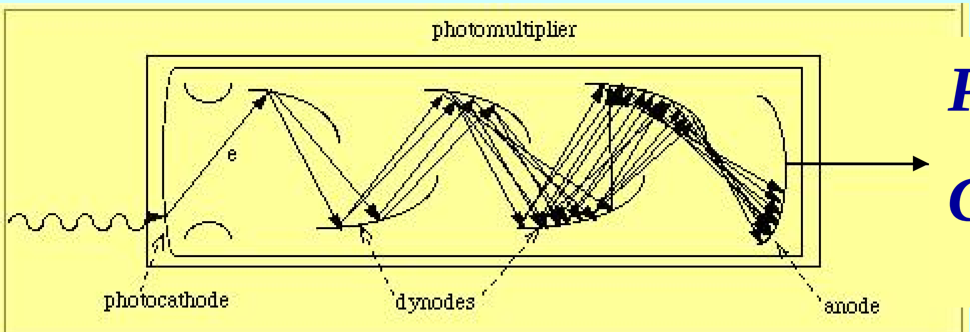
- inorganic, i.e. NaI – doped with Thallium activator

- organic, plastic – polystyrene or plexiglass $(C_5H_8O_2)_n$

doped with wavelength shifter (WLS)

u.v photons ⇒longer wavelength light

greatly reduced absorption



Photomultiplier:

Converts optical signal ⇒electrical one

Scintillator counters: reference time – start detector

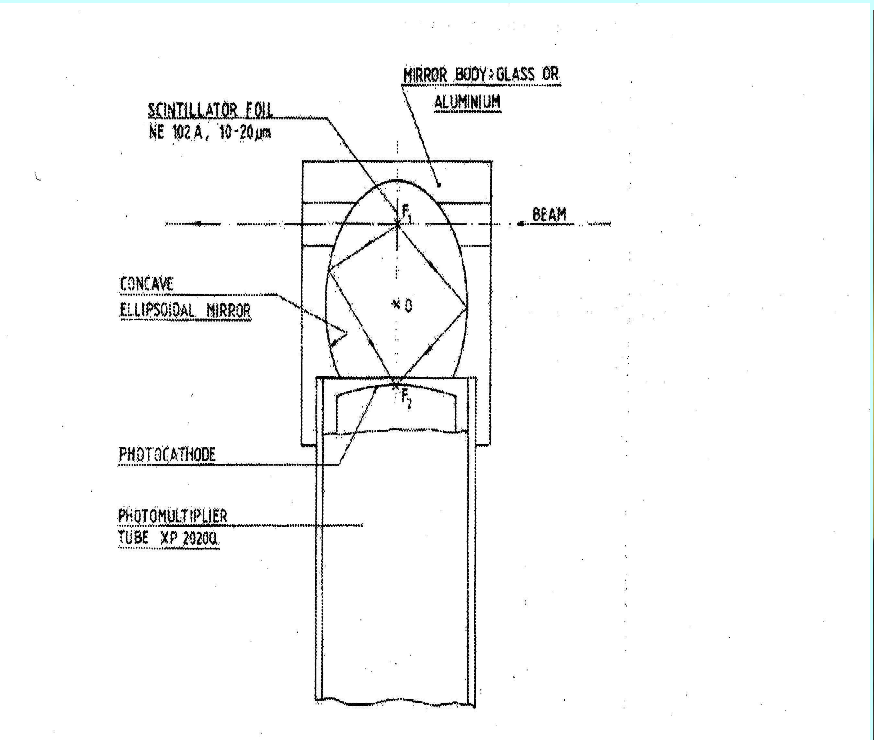
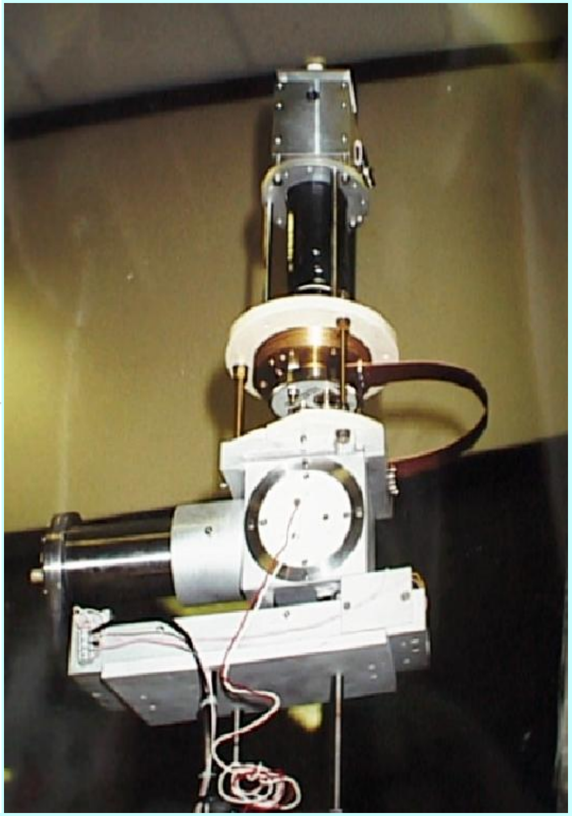
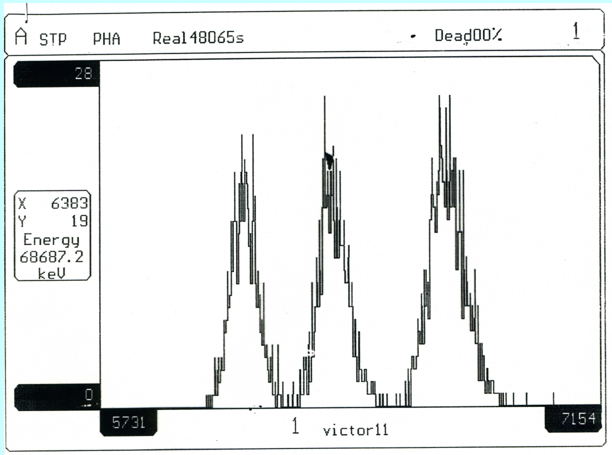


Figure 1: Schematic view of the detector.





printing hardcopy... press any key to stop

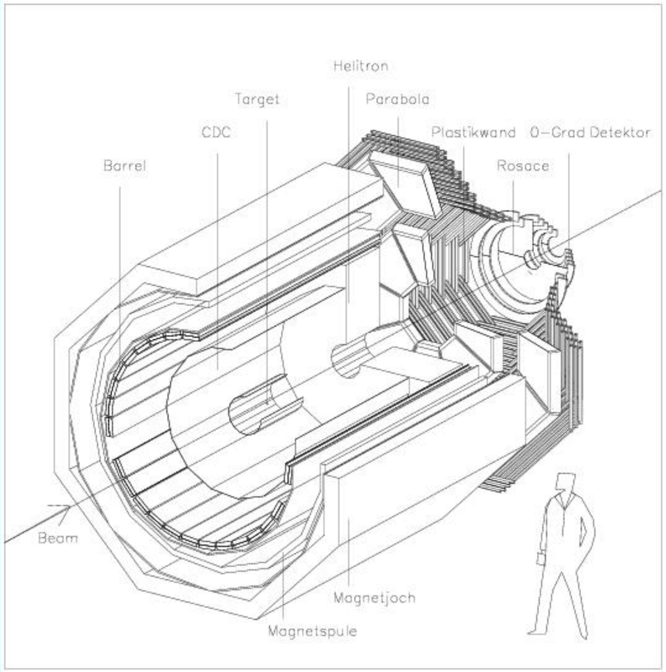
Scint. Start : NE 102 A (Spessore 20μm)
Rivelatore : Specchio Vetro
PM Start : EMI 9814 B (Bias = - 1800 V)
Distanza : 66 cm
Distanza 1° - 2° : [redacted] σt = 286 ps
Distanza 2° - 3° : [redacted]
FWHM 2° : [redacted] 400 ps ; 480 ps ; 558 ps
PM Stop : EMI 9954 QA (Bias = - 1800 V)
Scint. Stop : NE 102 A , diam. = 2"; Spess. = 2 mm
Sorgente : Alfa Tre Picchi : (^{239}Pu , ^{241}Am, ^{244}Cu; 5155, 5484, 5806 Kev)

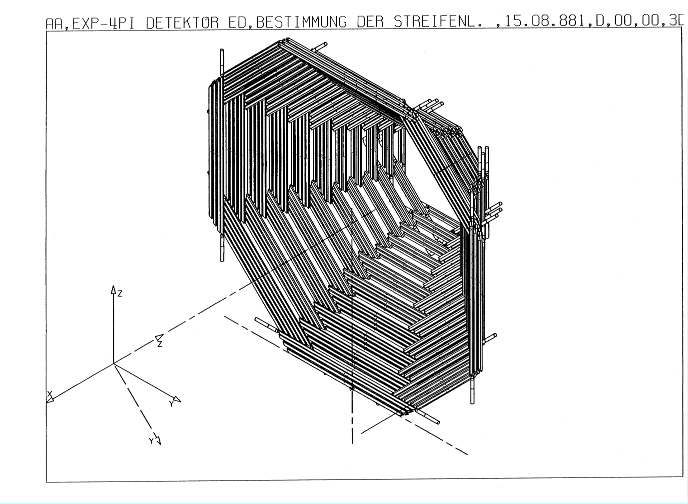
Perdita Energ. : NE 102 A 20 um 1° 5.155 Mev - 2.126 Mev = 3.029 Mev
2° 5.484 Mev - 2.001 Mev = 3.483 Mev
3° 5.806 Mev - 1.897 Mev = 3.909 Mev

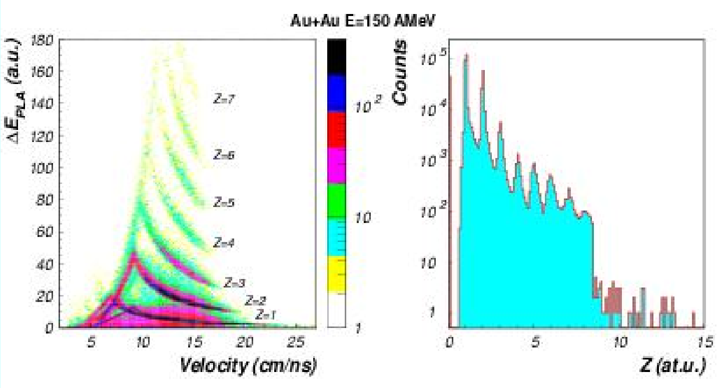
Lab Rivel.

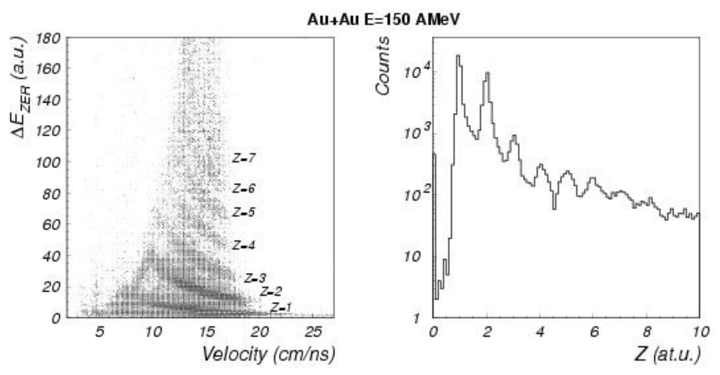
Scintillator counters: Time-of-Flight measurements

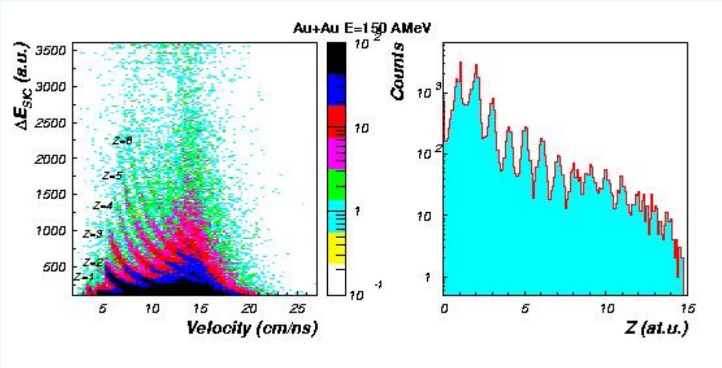
FOPI – Plastic Wall & Plastic Barrel

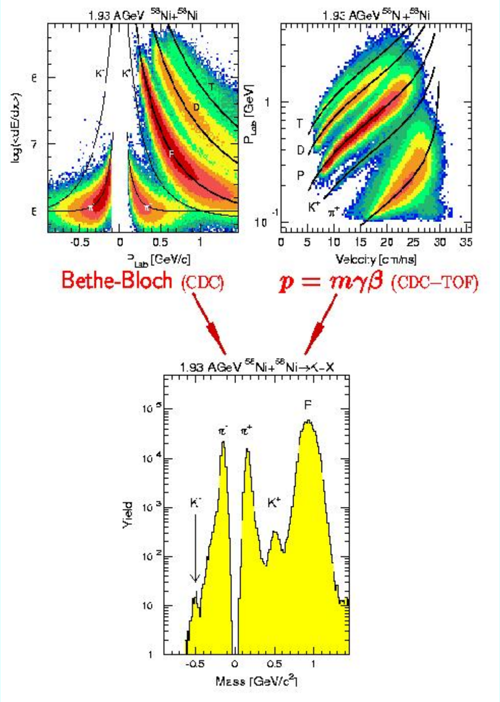








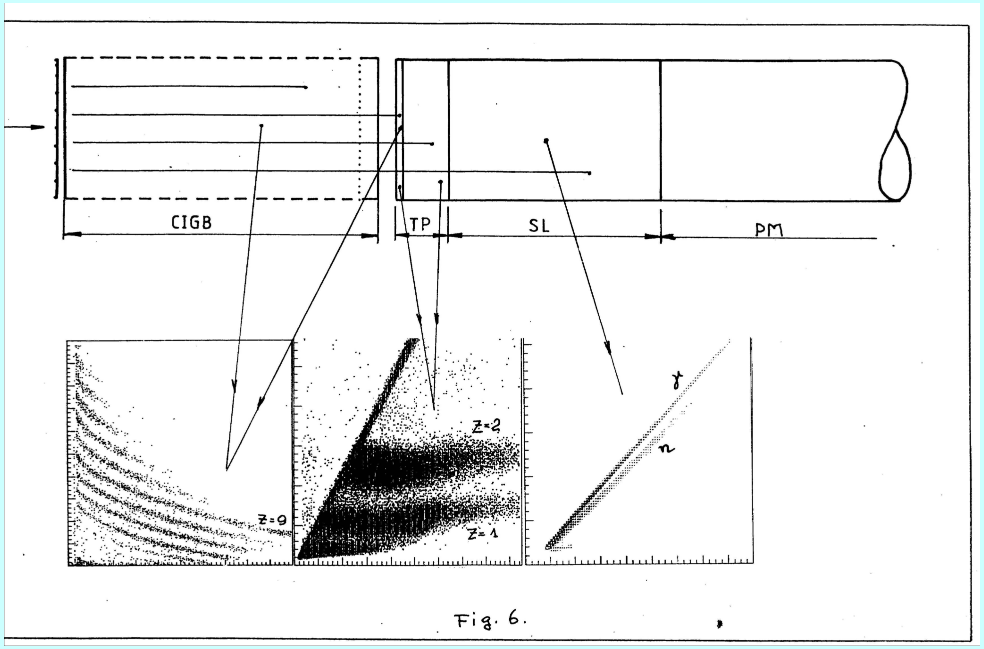




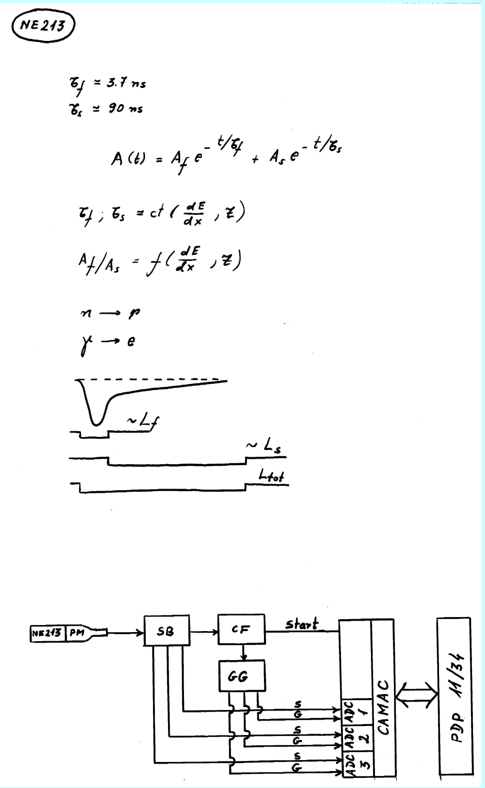
Nucl. Instr. and Meth. A324(1993)156
A. Gobbi et al.

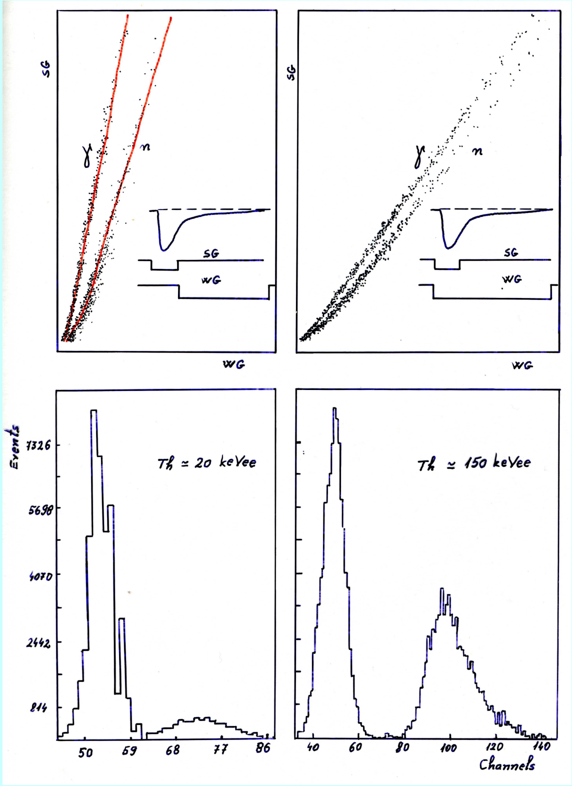
• *Scintillator counters and photomultipliers*

⇒PID, n-γ discrimination, Time-of-Flight measurements



$^{19}F+^{27}Al$ E_{lab}=111.4 MeV





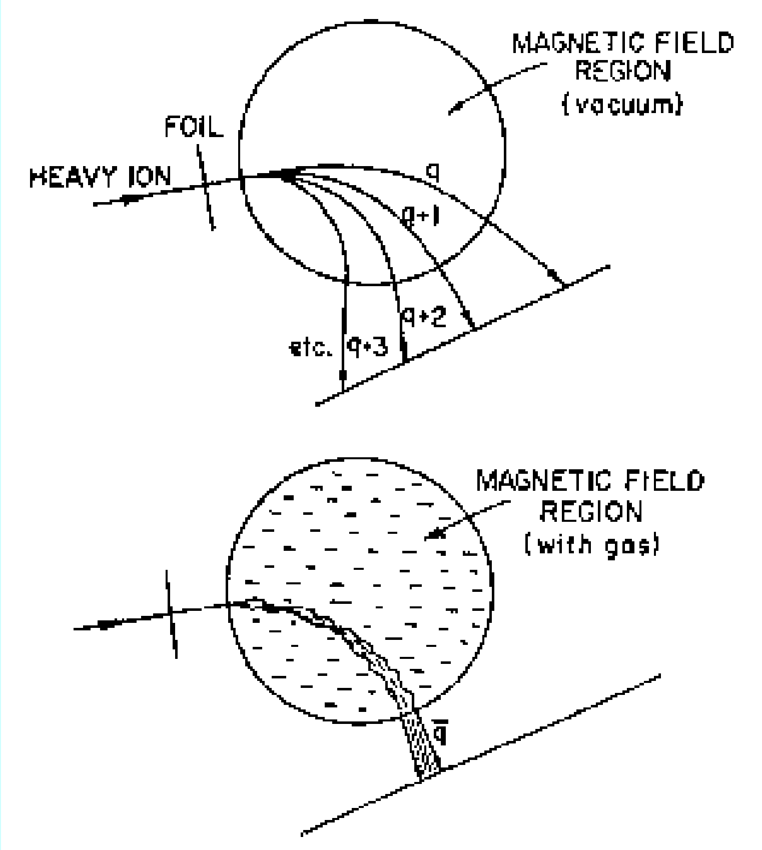
^{252}Cf

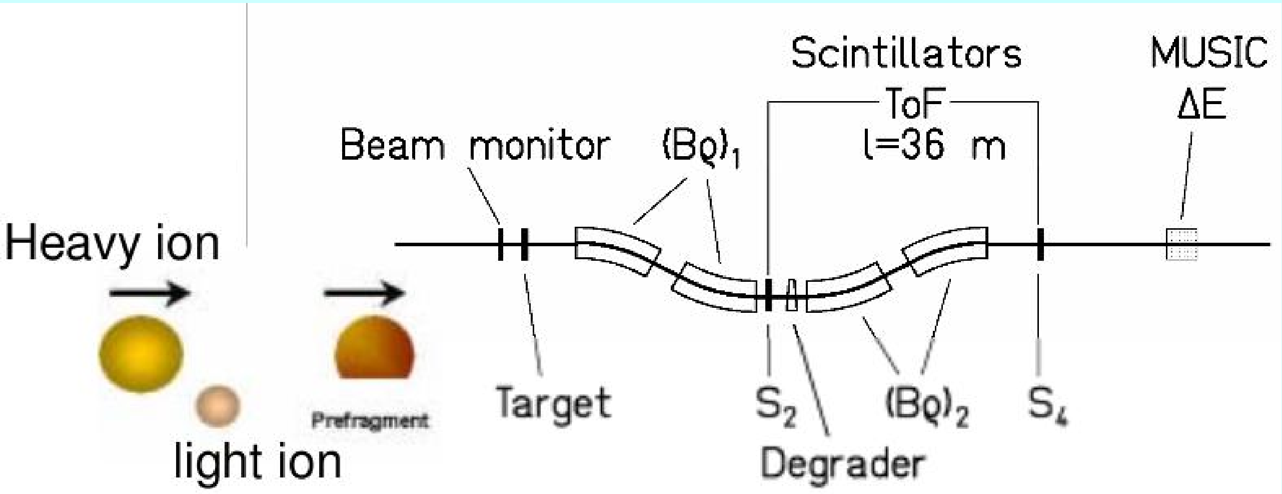
DRACULA

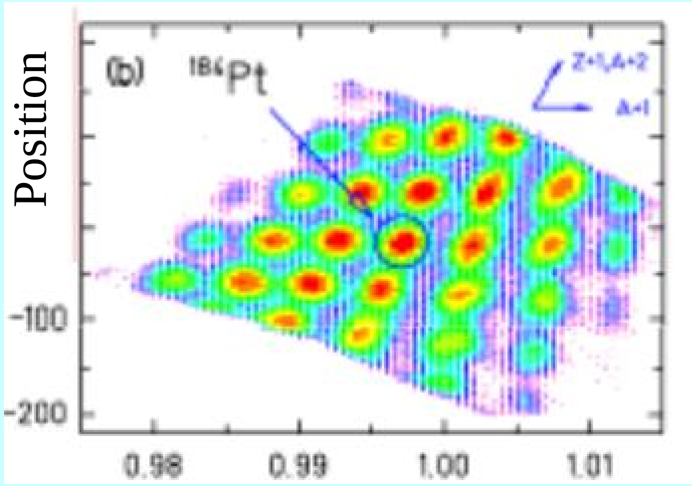
• *Magnetic spectrometers :*

$B\rho_B \sim mv/q$

Working principle:







$(A/Q)_{rel}$

•*Lect.Notes Phys. 178(1982)80*
•*Ann.Rev.Nucl.Sci 25(1975)167*

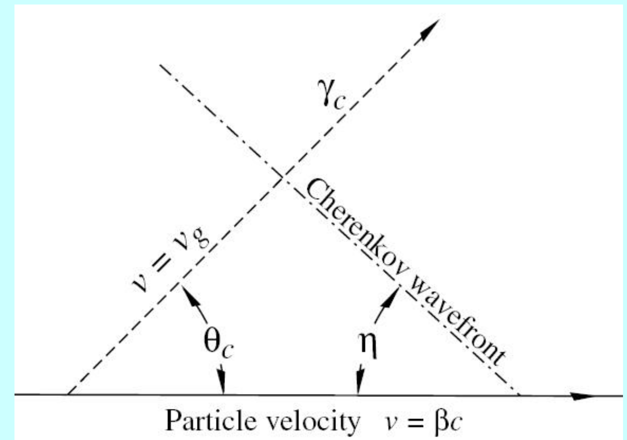
B. Coherent effects for charged particles:

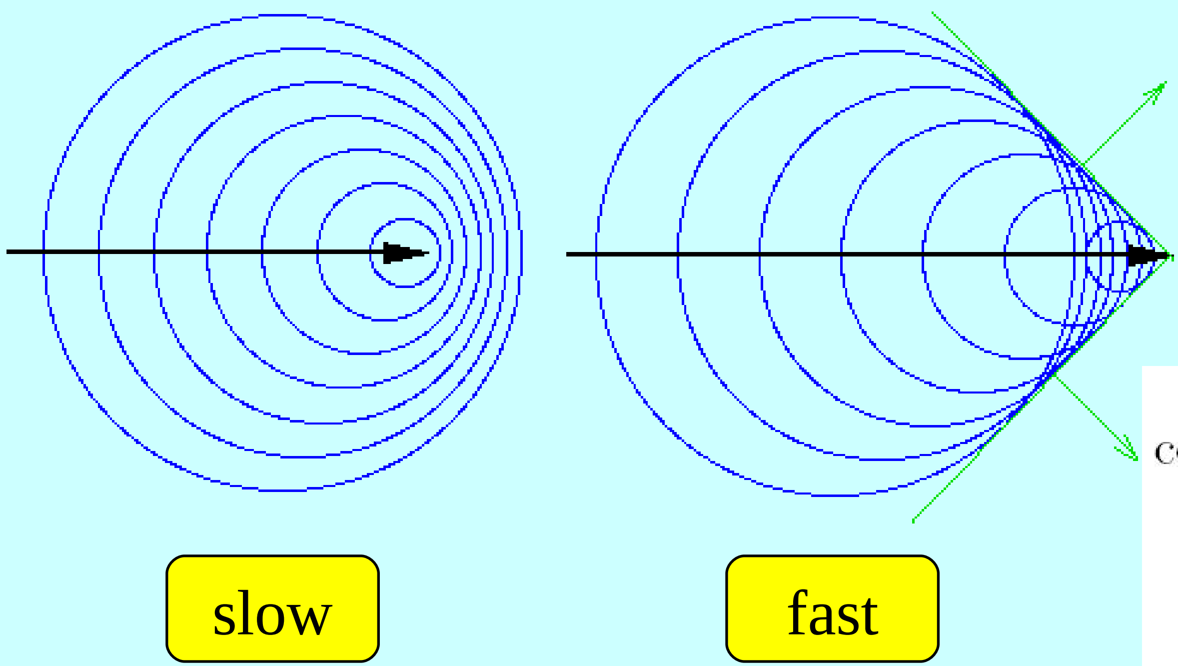
• *Cherenkov radiation and Cherenkov detectors:*

-Moving charge in dielectric medium

-Wave front comes out at certain angle

$$\cos\theta_c = (1/n\beta)$$
$$\tan\theta_c = \sqrt{\beta^2 n^2 - 1}$$
$$\approx \sqrt{2(1 - 1/n\beta)}$$





$$\cot\eta = \left[\frac{d}{d\omega}(\omega\tan\theta_c)\right]_{\omega_0}$$
$$= \left[\tan\theta_c + \beta^2\omega\, n(\omega)\,\frac{dn}{d\omega}\cot\theta_c\right]_{\omega_0}$$

Cherenkov radiation and Cherenkov detectors:

How many Cherenkov photons are produced ?

$$N_\gamma = L \frac{\alpha z^2}{r_e m_e c^2} \quad \varepsilon(E) \sin^2 \theta_c (E) \mathrm{d}E$$

$$= L \frac{\alpha z^2}{r_e m_e c^2} \quad \varepsilon(E) \quad 1 - \frac{1}{\beta^2 n^2} \quad \mathrm{d}E$$

$$L N_0 \quad 1 - \frac{1}{\beta^2 \langle n^2 \rangle}$$

with $\varepsilon(E) =$ Efficiency to detect photons of energy E

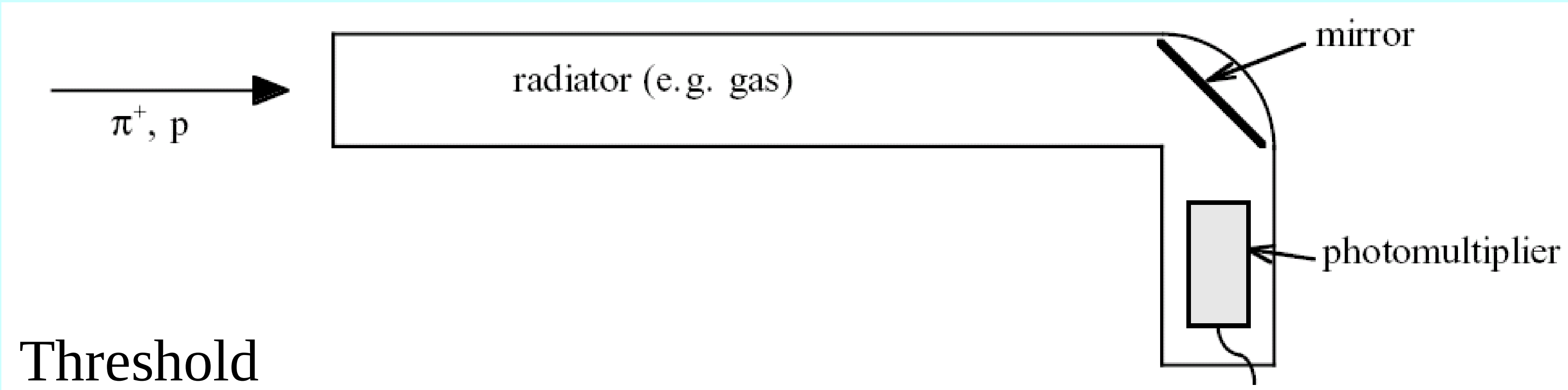
$L =$ radiator length

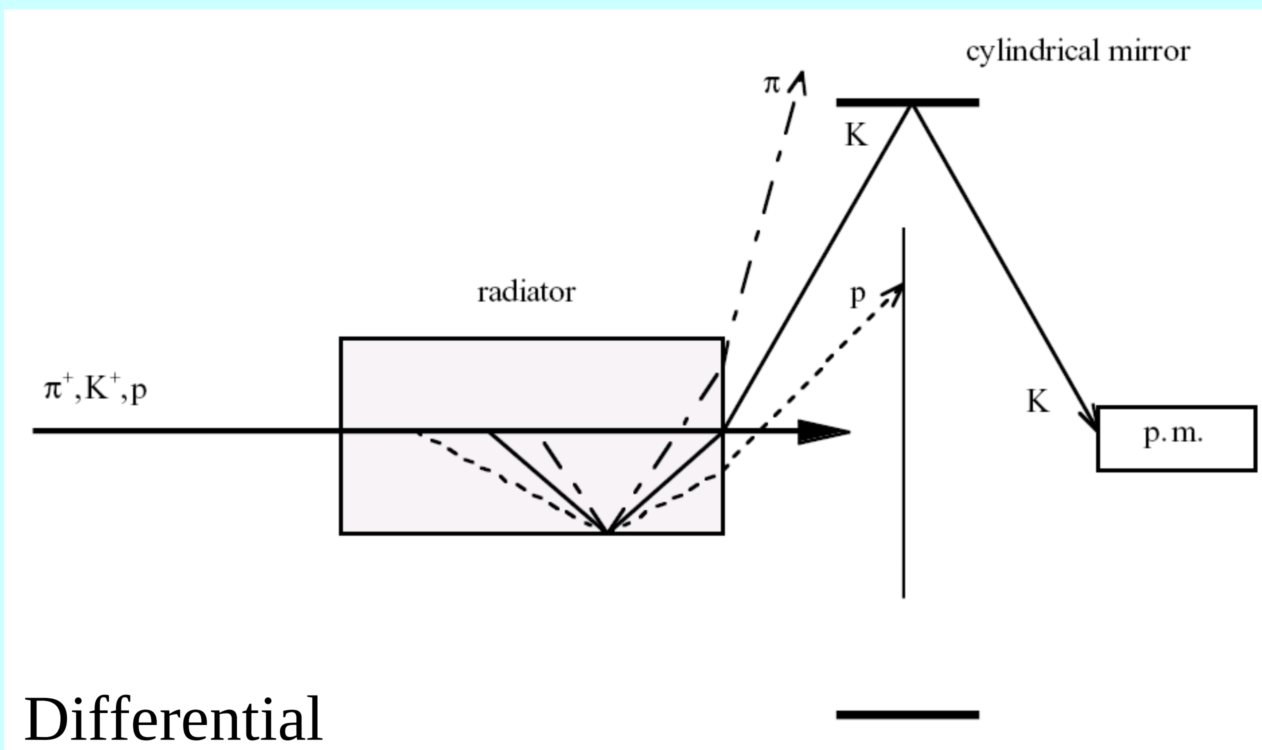
$r_e =$ electron radius

Cherenkov radiation and Cherenkov detectors:

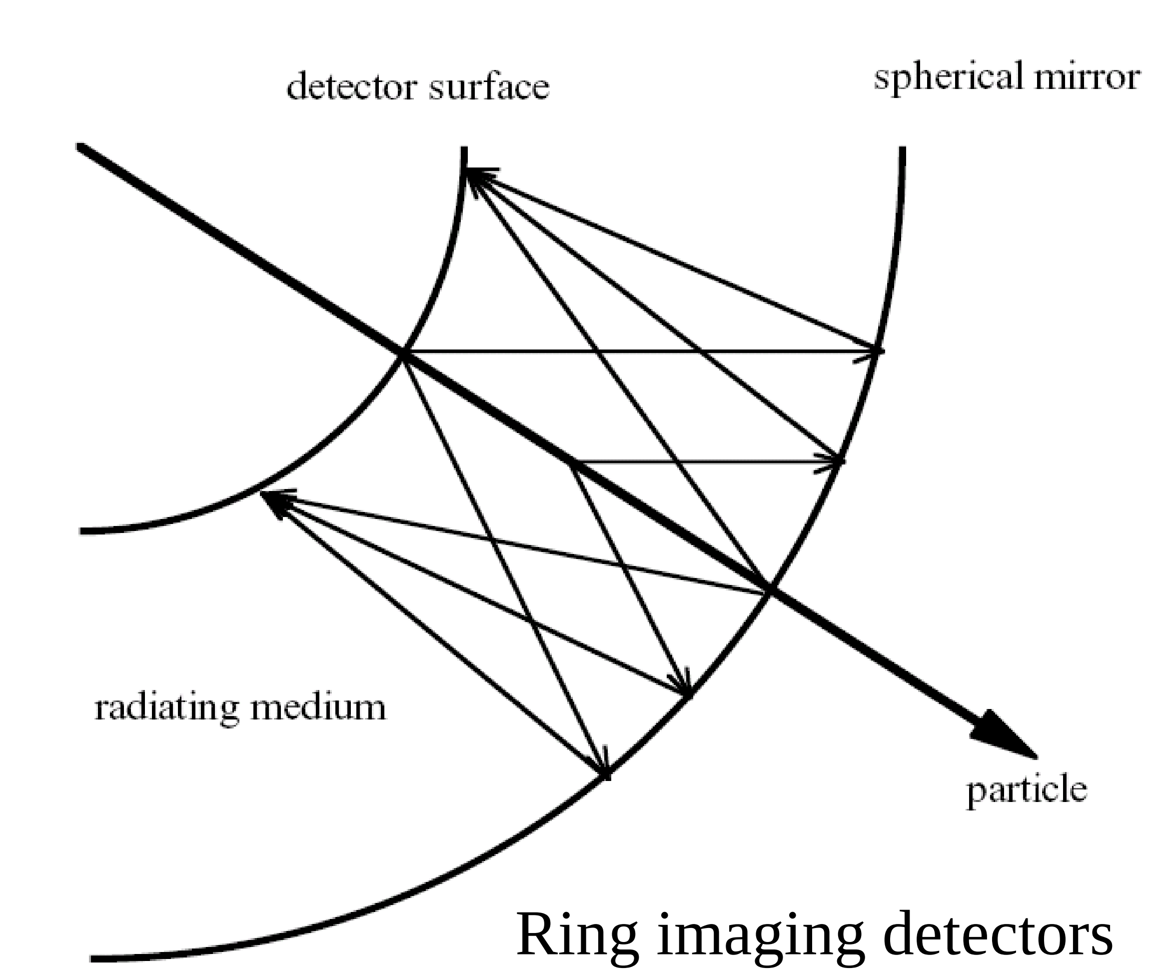
- *Threshold Detectors*
  - *Yes/No on whether the speed is* $\beta > 1/n$
- *Differential Detectors*
  - $\beta_{max} > \beta > \beta_{min}$
- *Ring-Imaging Detectors*
  - *Measure* β

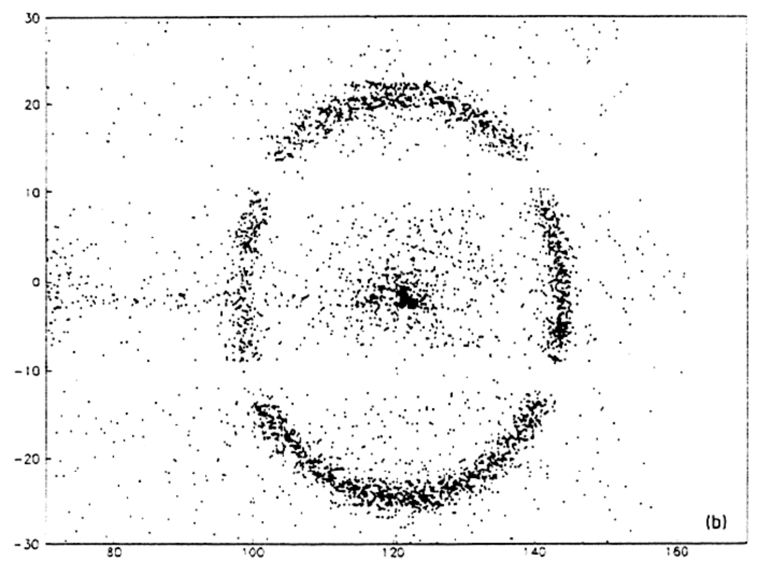
Cherenkov radiation and Cherenkov detectors:





Cherenkov radiation and Cherenkov detectors:

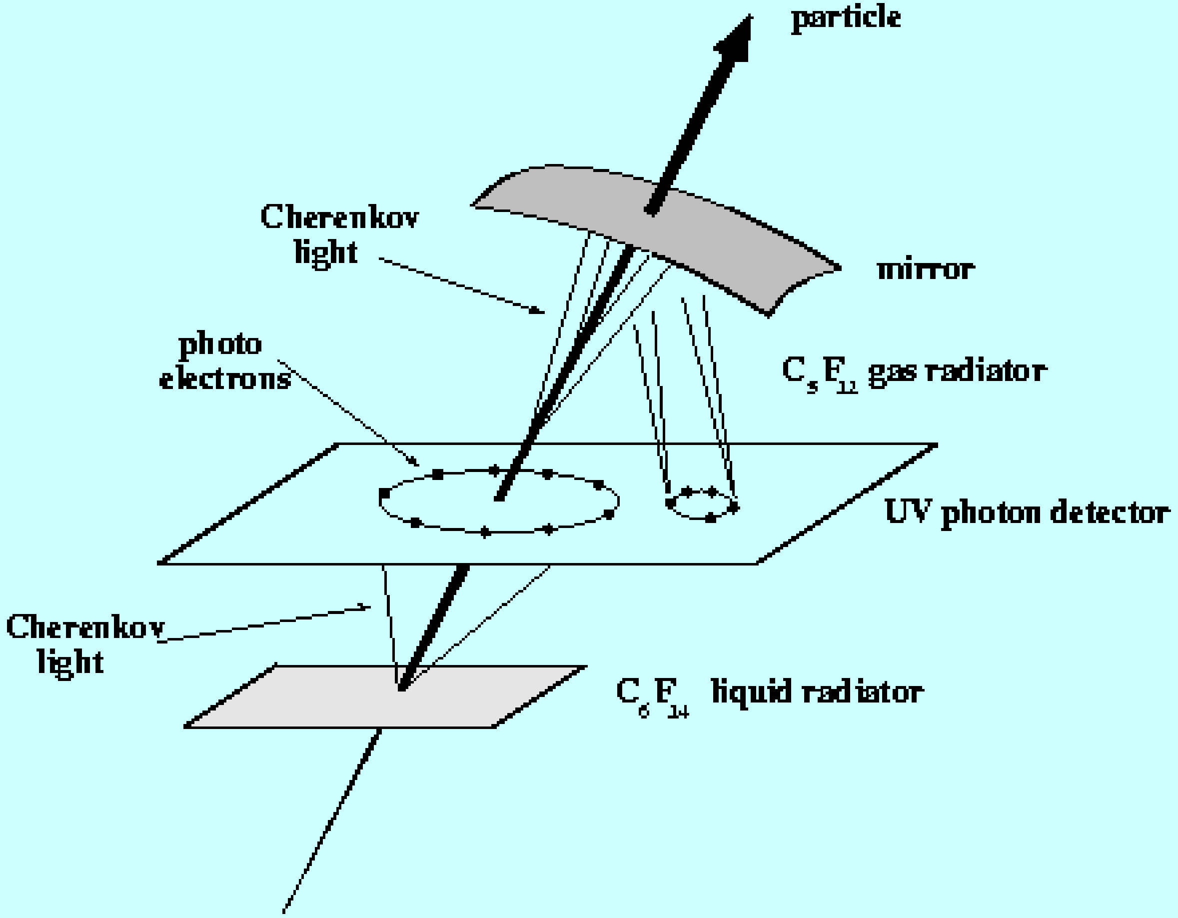




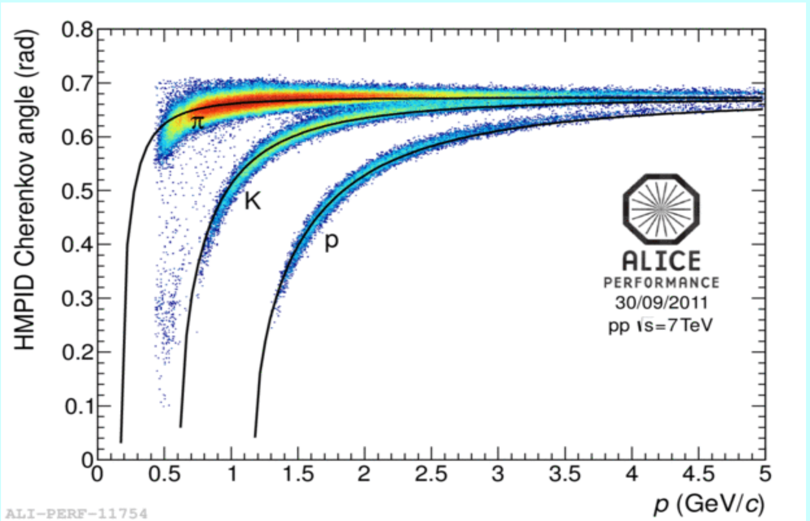
Cherenkov radiation and Cherenkov detectors:

Complex geometry:

two radiators – one photon detector



Example of PID performance of ALICE HMPID subdetector

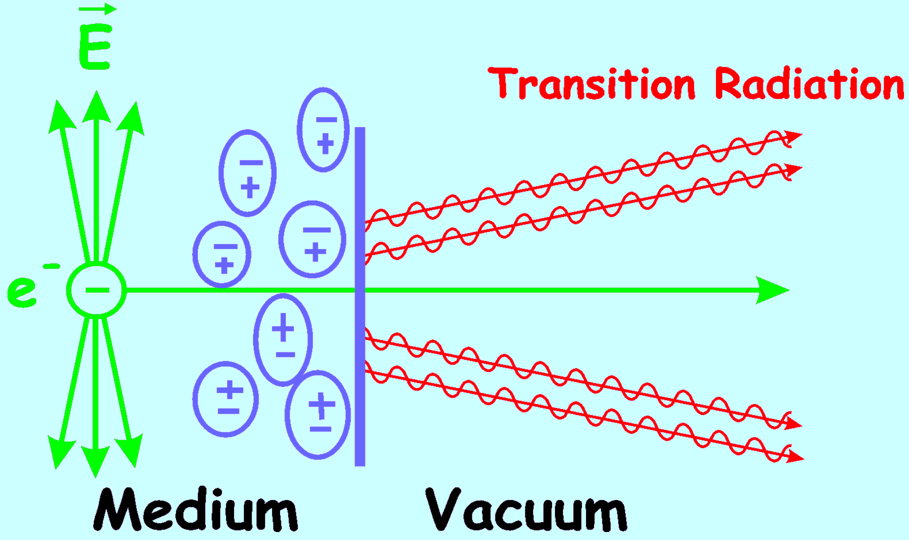


B. Coherent effects for charged particles:

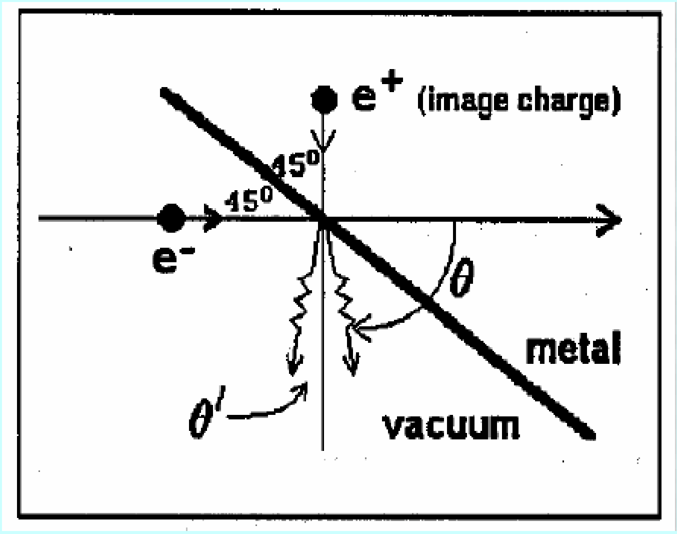
Transition Radiation Detectors (TRD)

- TR is created when a charged particle crosses boundary of different dielectric constants

- fields have to be reajusted
⇒ some are emitted as TR



similar with:



B.Dolgoshein, NIM A326 (1993) 434
P. Piot, PHYS 571 – Fall 2007
Chitrlada Settakorn, SLAC-Report-576, August 2001
X1-Experiment – Mainz
R. Agustsson, UCLA Part.Beam Phys. Lab.

B. Coherent effects for charged particles:

Transition Radiation Detectors (TRD)

$I = m\gamma = m/(1-\beta^2)^{1/2}$ *- intensity of produced TRD*

$\theta = 1/\gamma$ *- angular distribution*

$E \cong (2/3)\alpha\gamma\hbar\omega_{plasma}$ *- total energy radiated by a single foil*

$\langle N \rangle \cong \alpha\gamma\hbar\omega_{plasma} / (\hbar\langle\omega\rangle)$ *– the average number of radiated photons*

α *-fine structure ct. - 1/137*

B. Coherent effects for charged particles:

Transition Radiation Detectors (TRD)

Radiators:

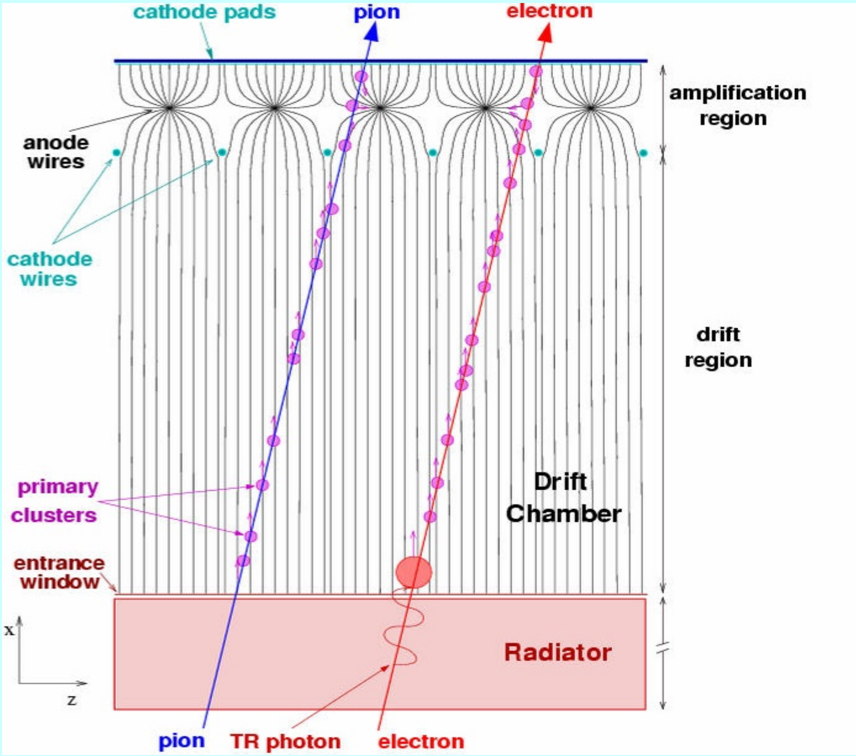
- ***periodically arranged*** *of large number of foils – gaps*

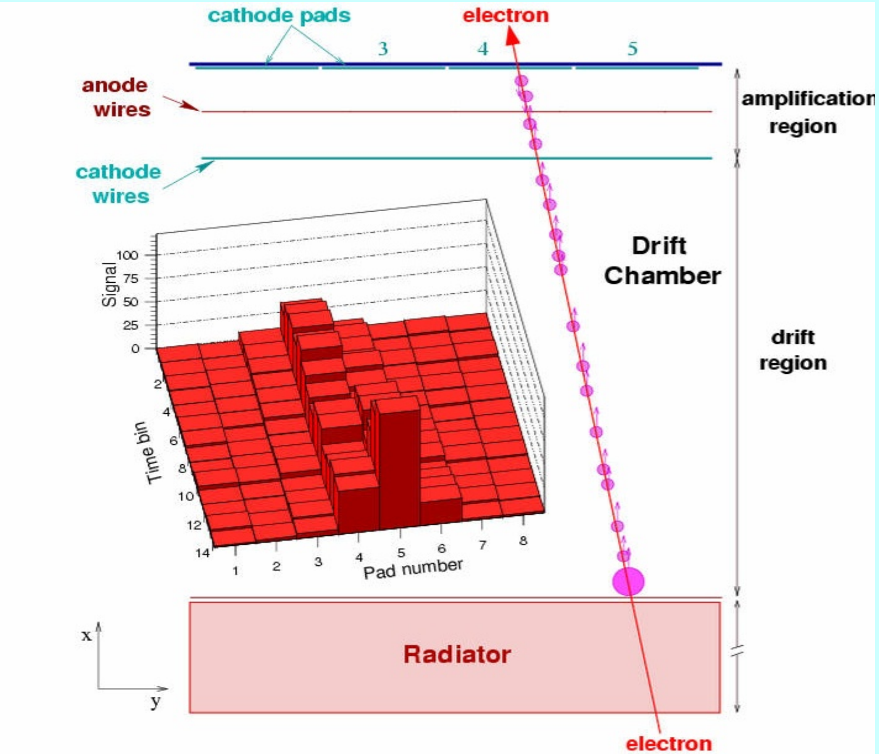
  lithium, polyethylene or carbon

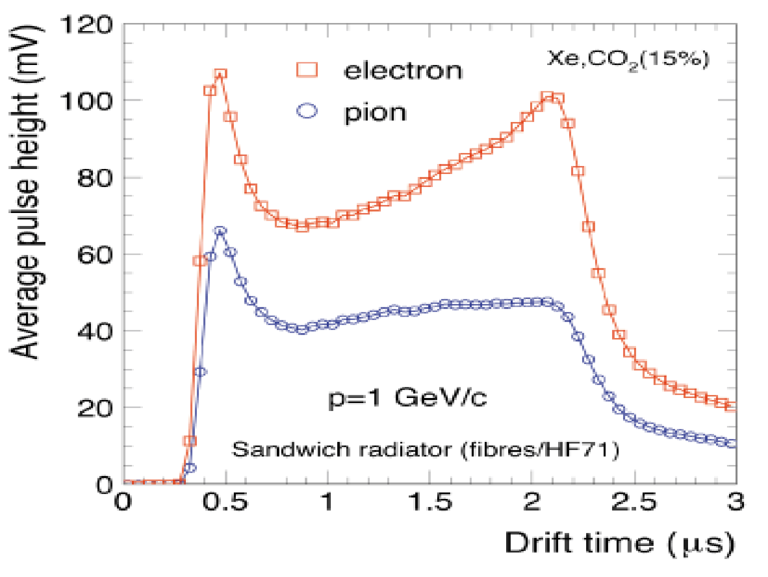
- ***randomly spaced*** *radiators*

  foams, granules or fibre mats

TRD-Examples

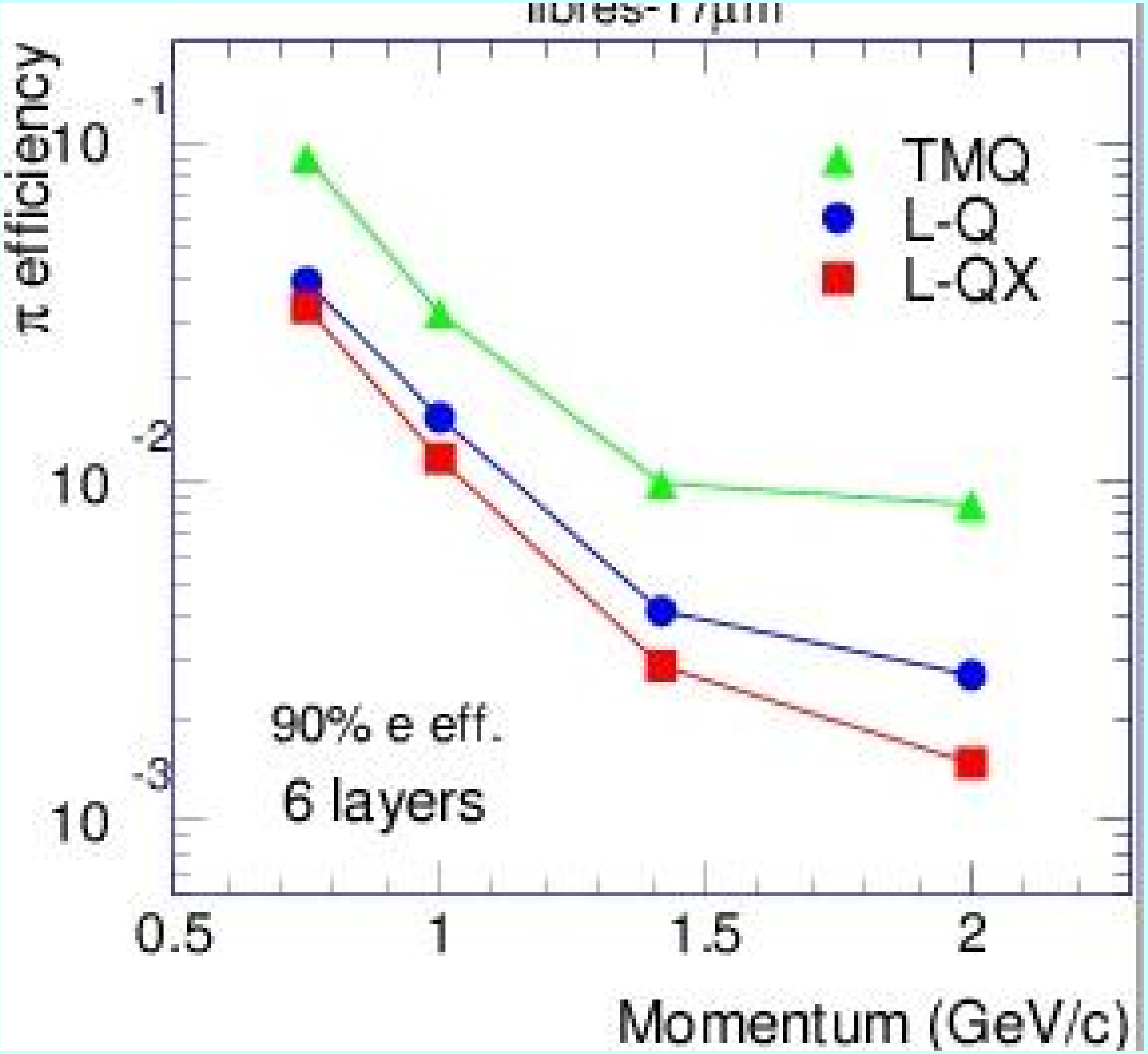




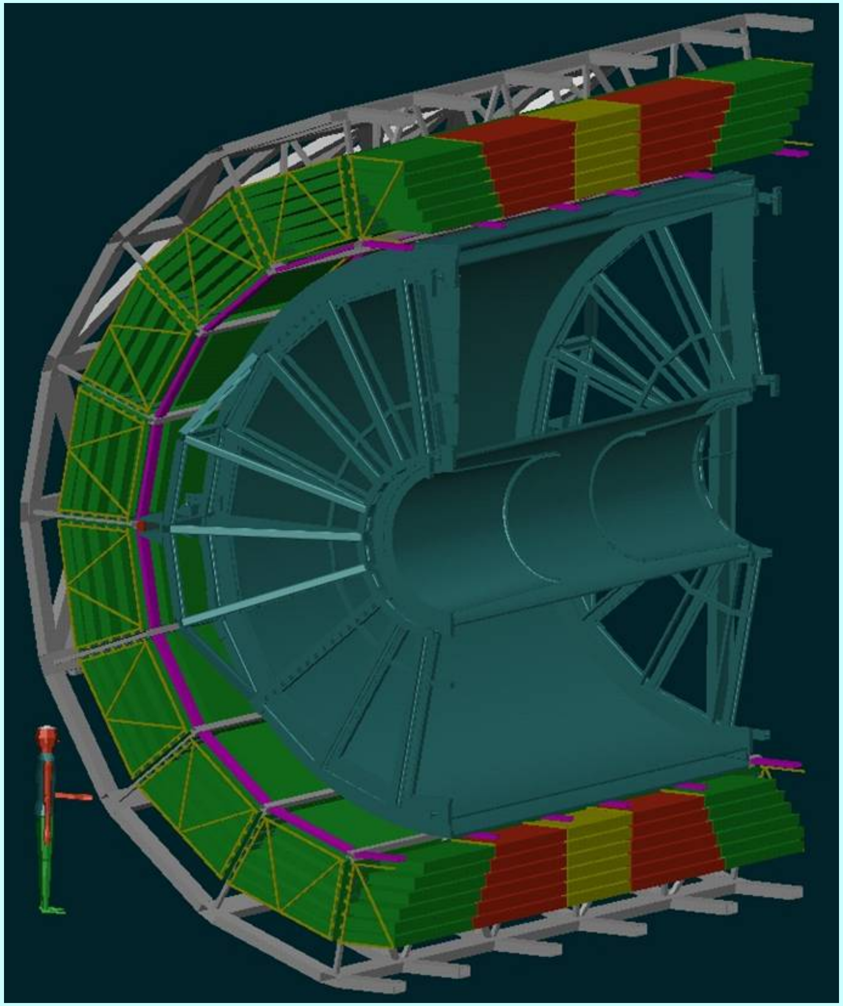


ALICE

TRD-Examples



TRD-Examples



Purpose:

- electron ID in central barrel p>1GeV/c

Parameters:

- 18 supermodules segmented in

6 layers, 5 stacks

- 540 modules ~ $750m^2$

- Lenghth: 7m

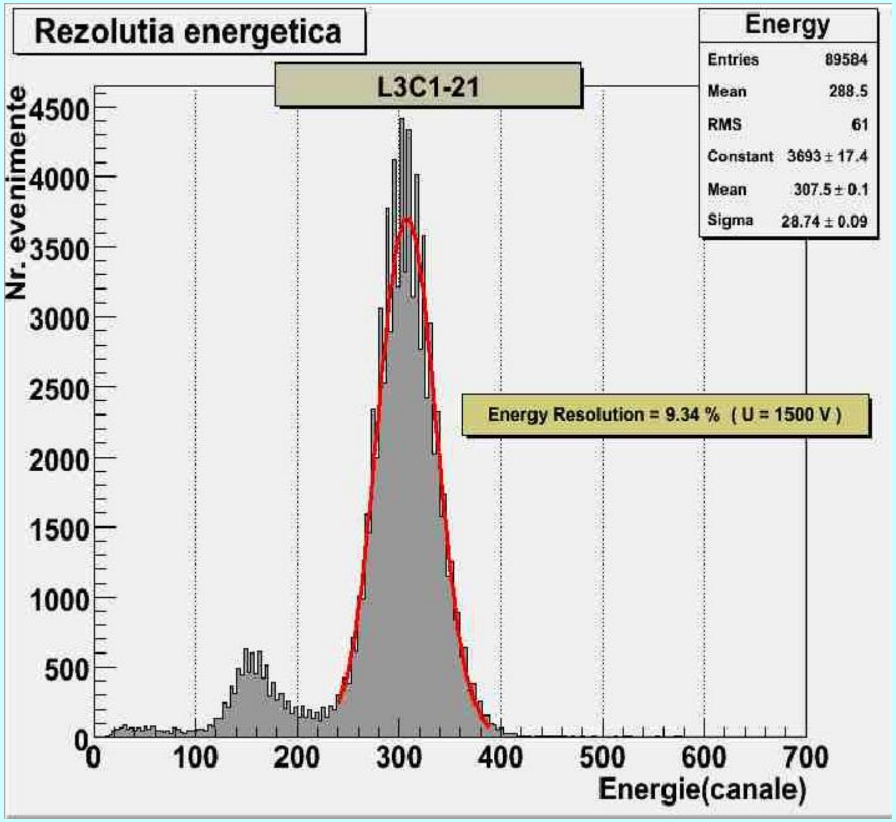
- X/X_0 ~ 15%

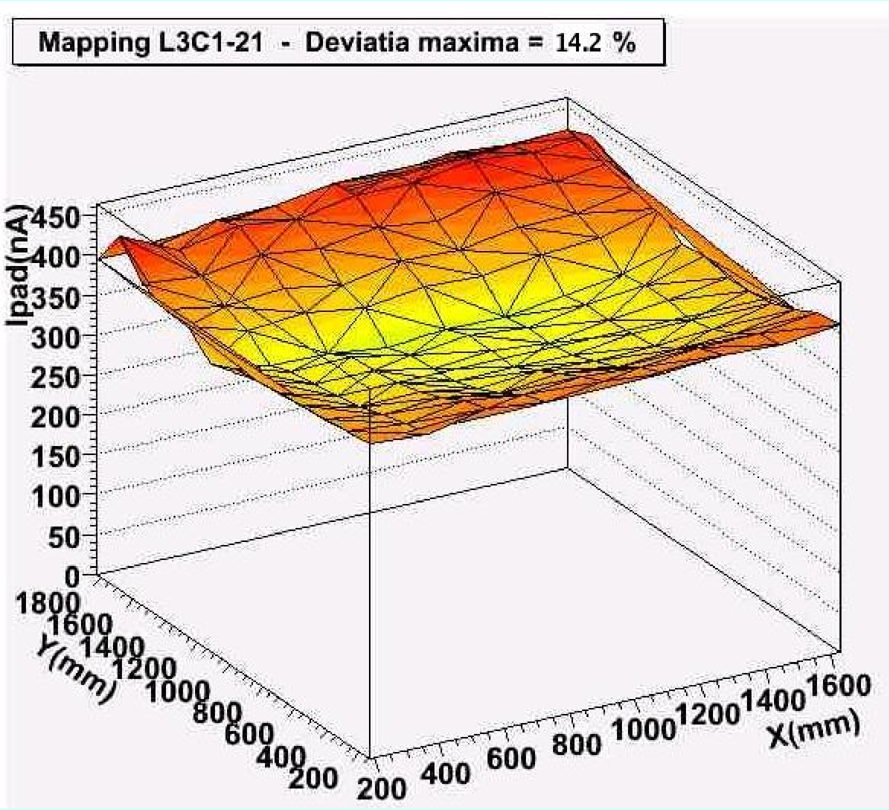
- 28 m^3 Xe/CO_2 (85:15)

- 1.2 million channels

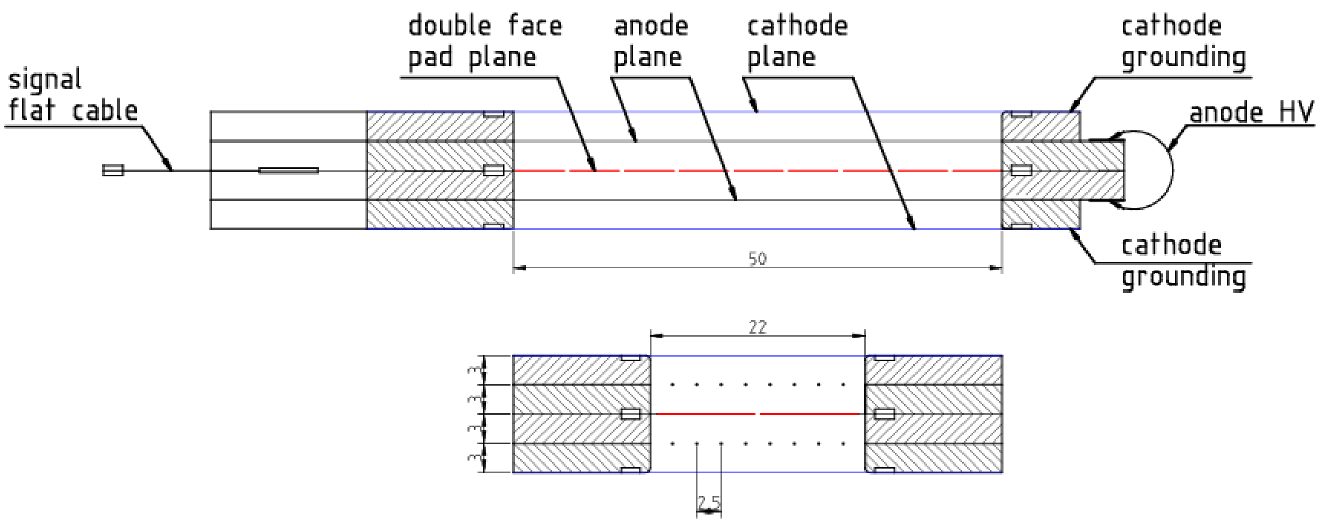
- 15 TB/s on-detector badwidth

TRD-Examples

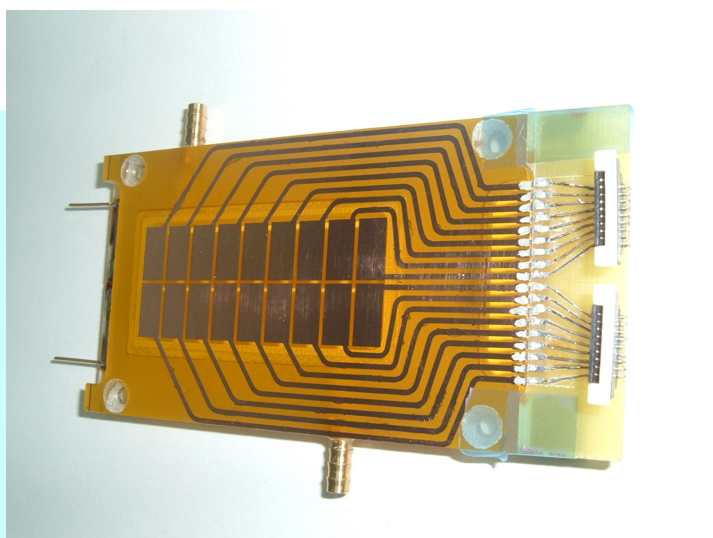




High counting rate TRD-Examples

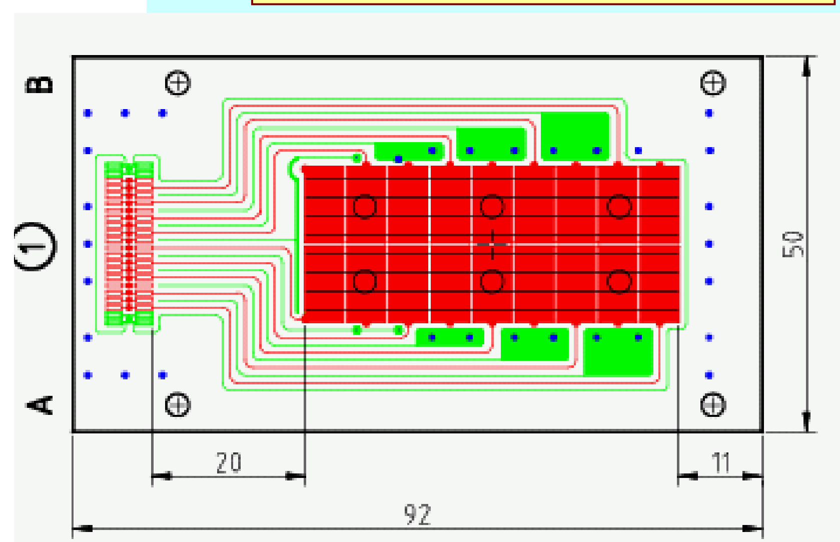


-pad plane: 250 miu pc board;
-anode plane: 20 miu Wo+Au wire;
-cathode plane:Alu covered 25 miu Kapton foil;
-frames: 3 mm thick pc board



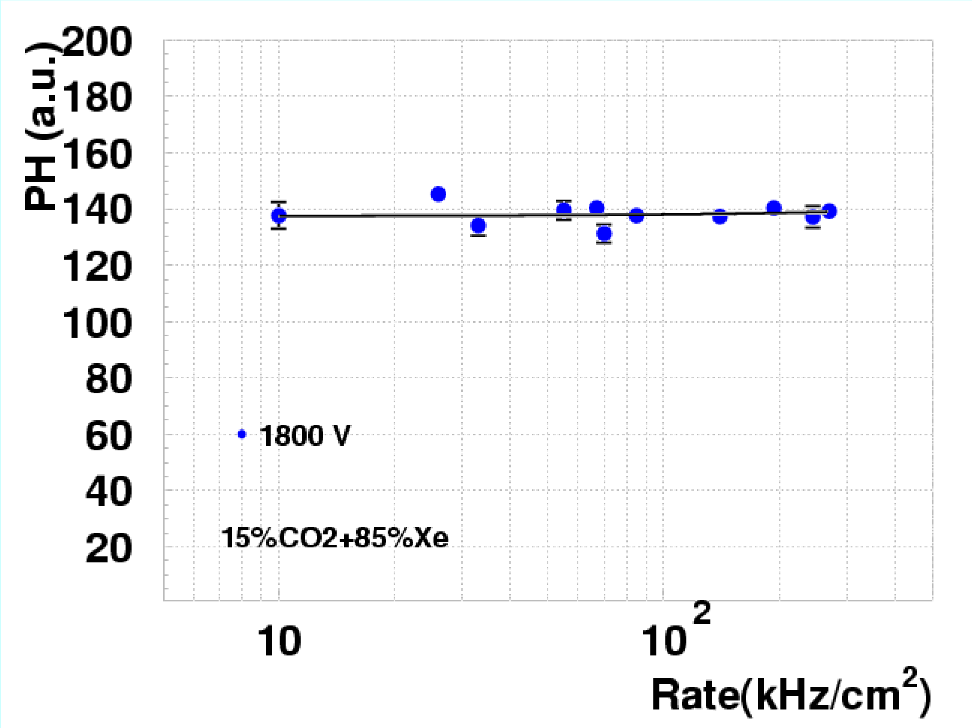
Readout electrode

pad size: 5 x 10 mm²

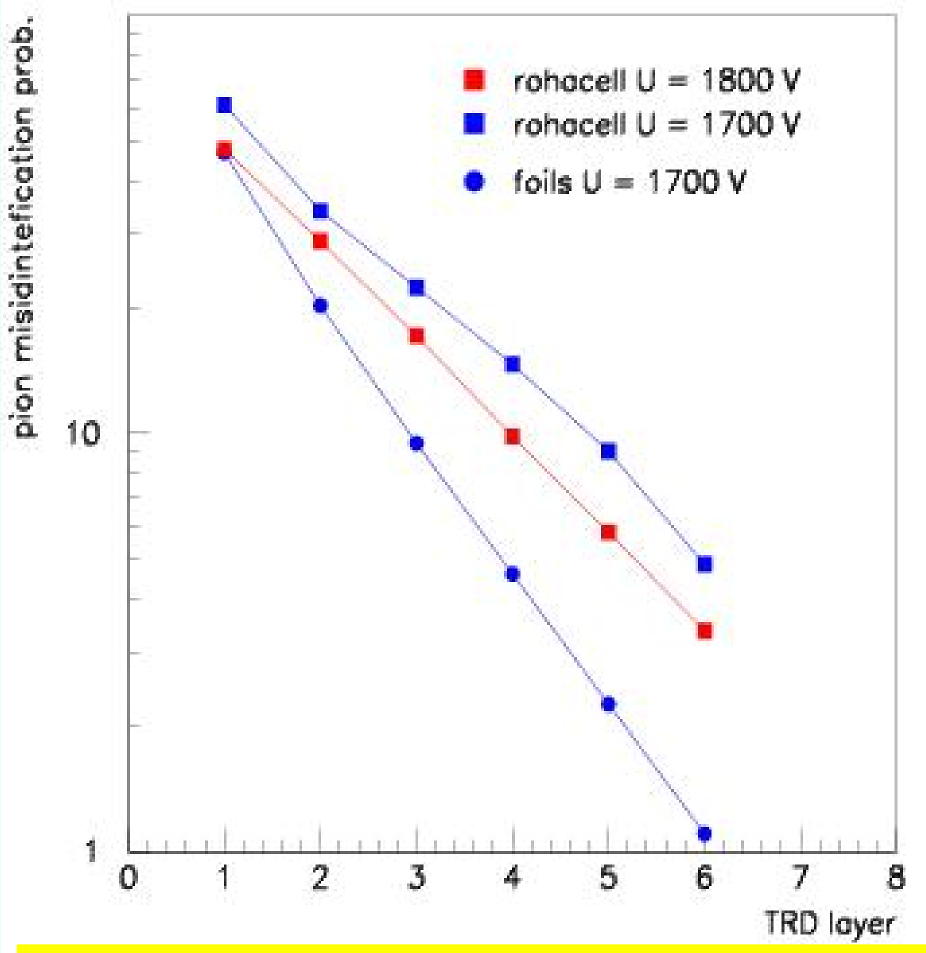


High counting rate TRD-Examples

High Counting Rate Effect
Xe,CO_2(15%), p-1.5 GeV/c



log(p_e/p_π)

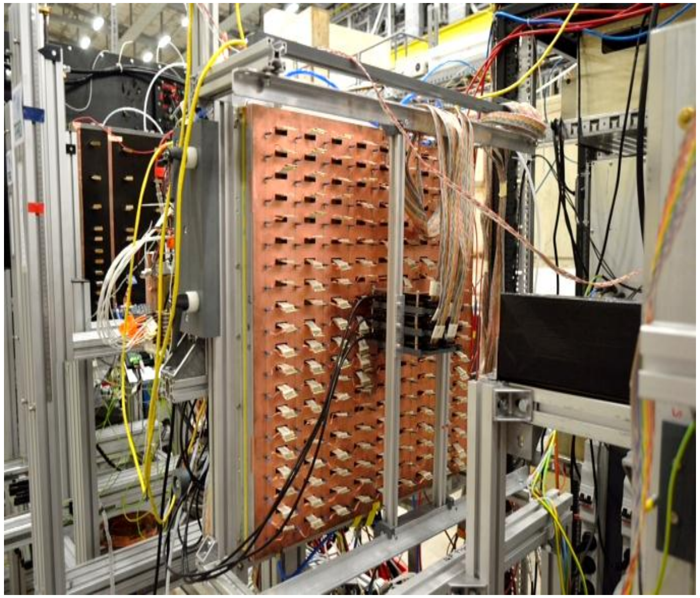


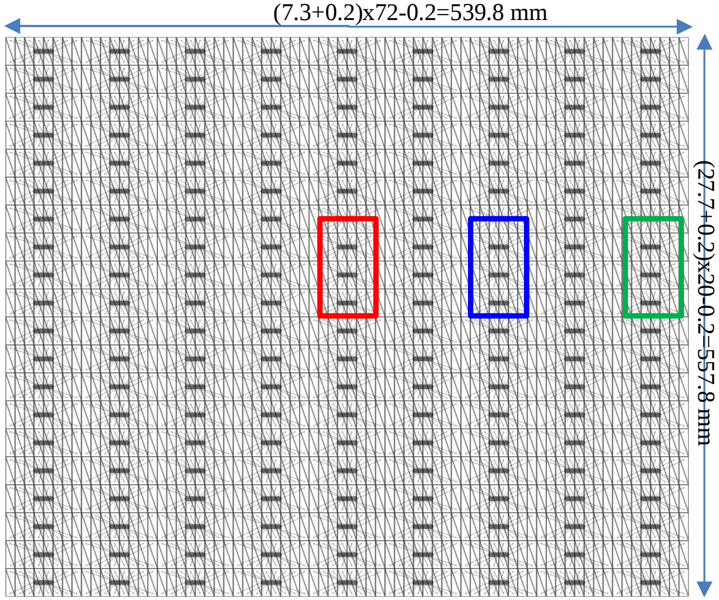
⇒ 1800 V, foils, ~ 0.7 % π rejection
20/500/120 ⇒ 20/200/220, 1.4 better

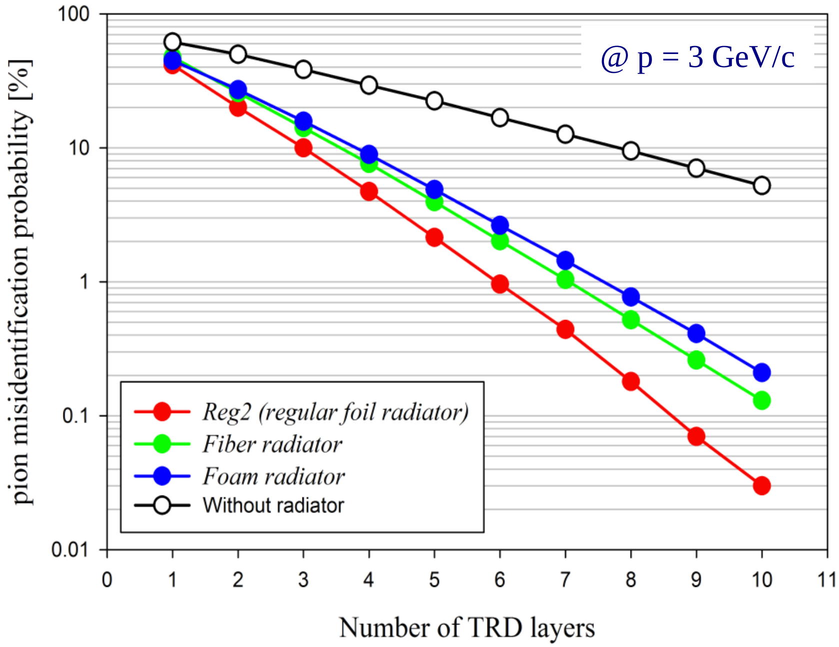
Nucl. Instr. and Meth. in Phys. Research A579(2007)961
Nucl. Instr. and Meth. in Phys. Research A581(2007)406
Nucl. Instr. and Meth. in Phys. Research A585(2008)83

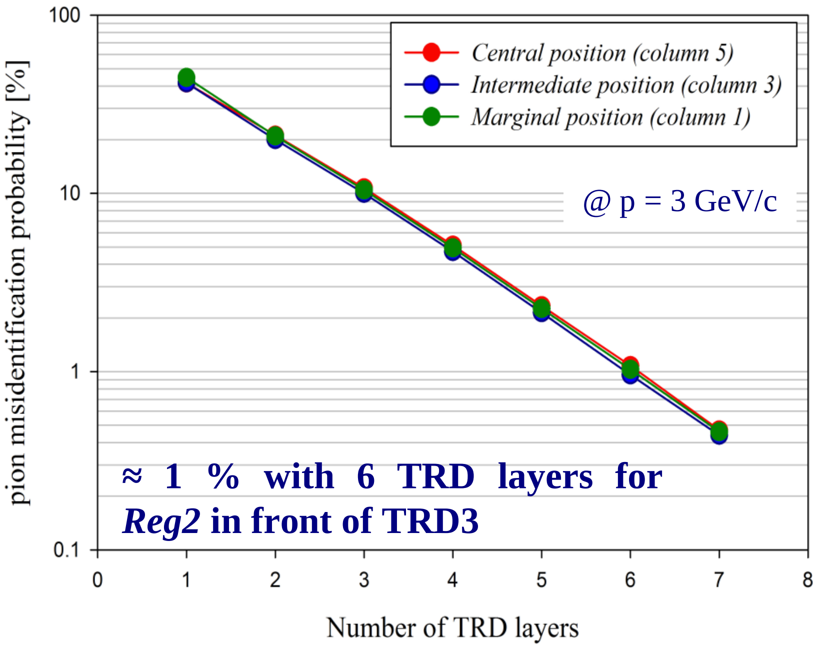
NIHAM

High counting rate TRD-Examples





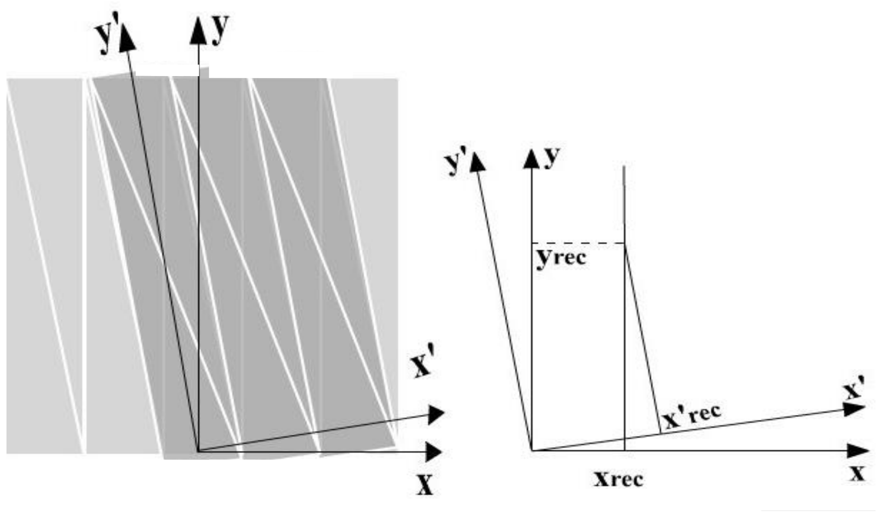


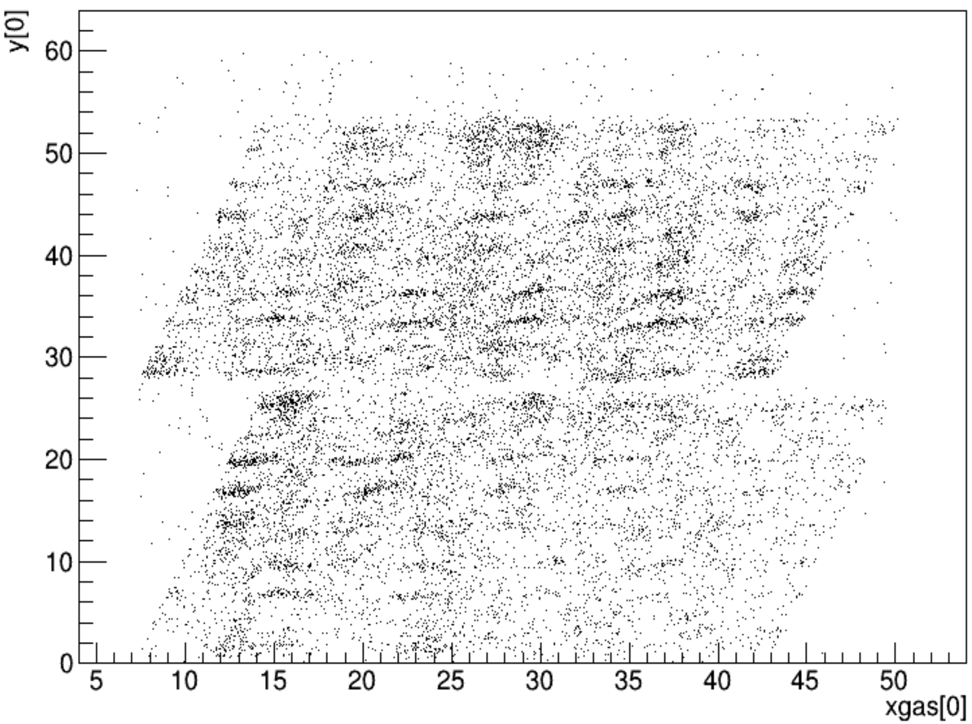


≈ 1 % with 6 TRD layers for *Reg2* in front of TRD3

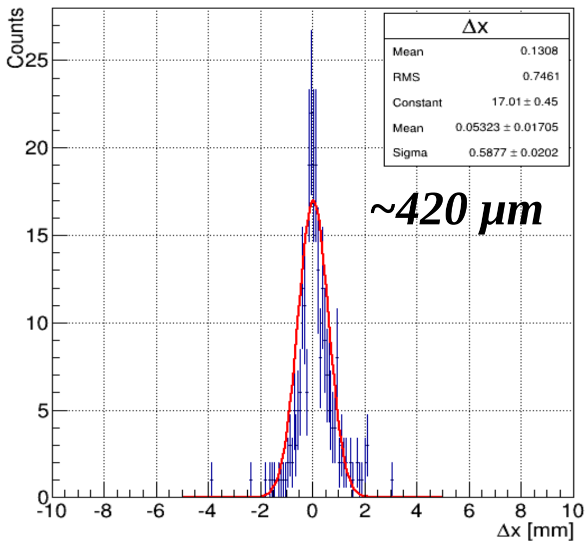
High counting rate TRD-Examples

x-y position reconstruction

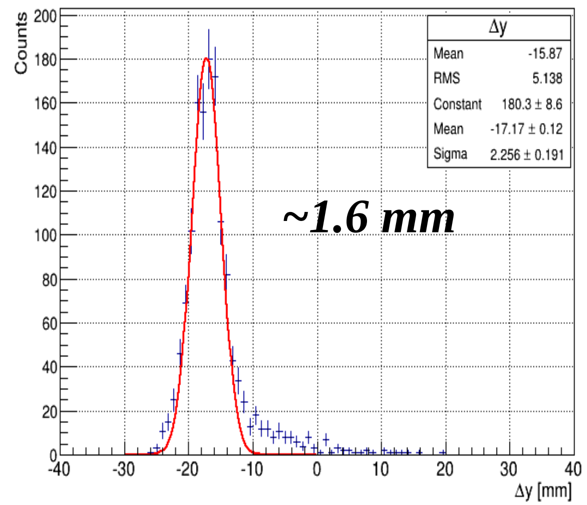




across the pads



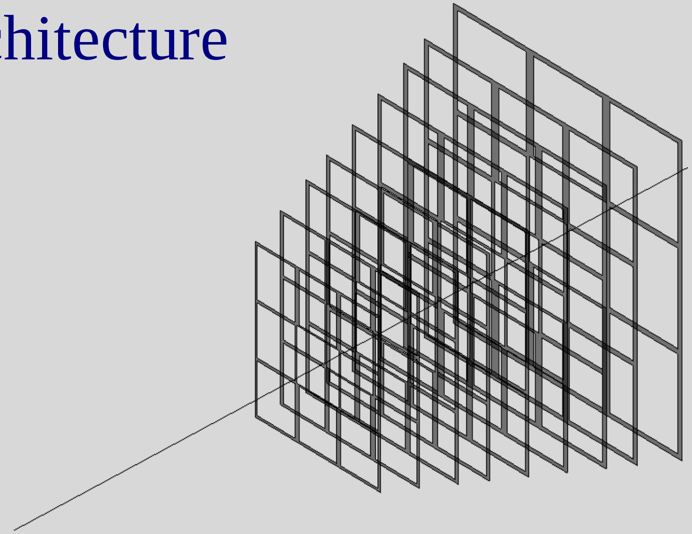
along the pads

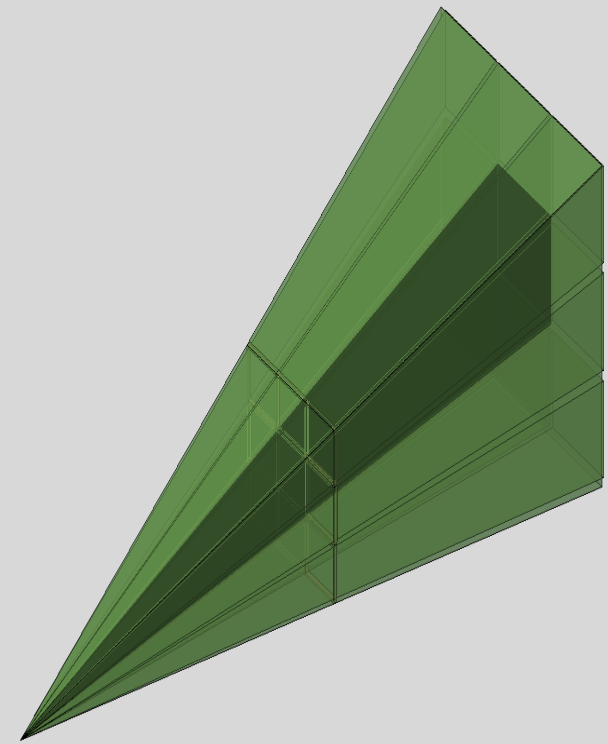


M. Tarzila et al., https://indico.gsi.de/conferenceOtherViews.py?view=standard&confId=2054

High counting rate TRD-Examples

CBM-TRD
inner zone architecture





More details:

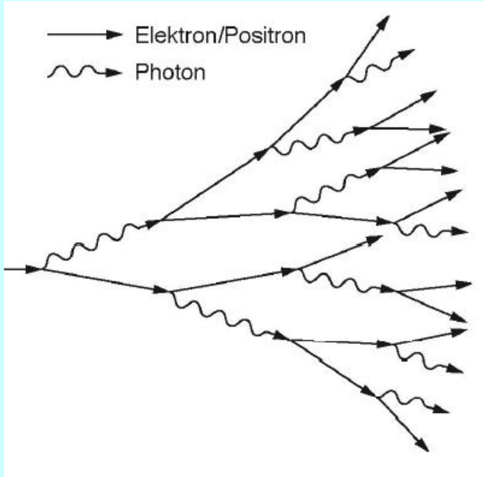
CBM – Progress Reports:
http://www.fair-center.eu/en/for-users/experiments/cbm/cbm-documents.html

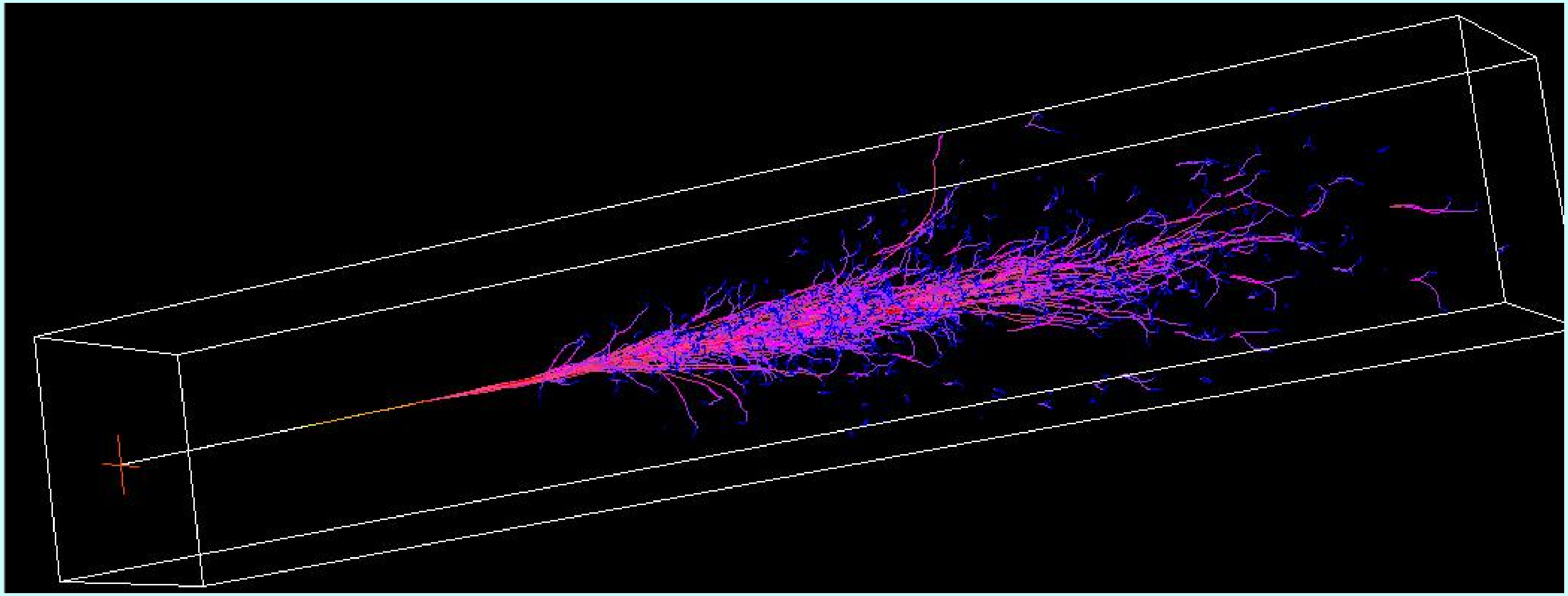
CBM – Collaboration Meetings:
https://indico.gsi.de/categoryDisplay.py?categId=134
Time table (Idico view) – especially TRD sessions

Electromagnetic Calorimetry

-electrons undergo bremsstrahlung producing photons

-photons undergo pair production ⇒ electrons and positrons



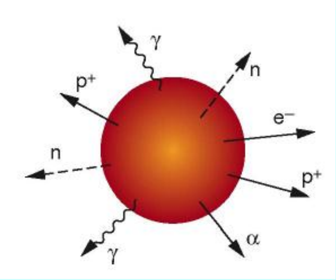


OPAL lead glass 80 GeV electrons

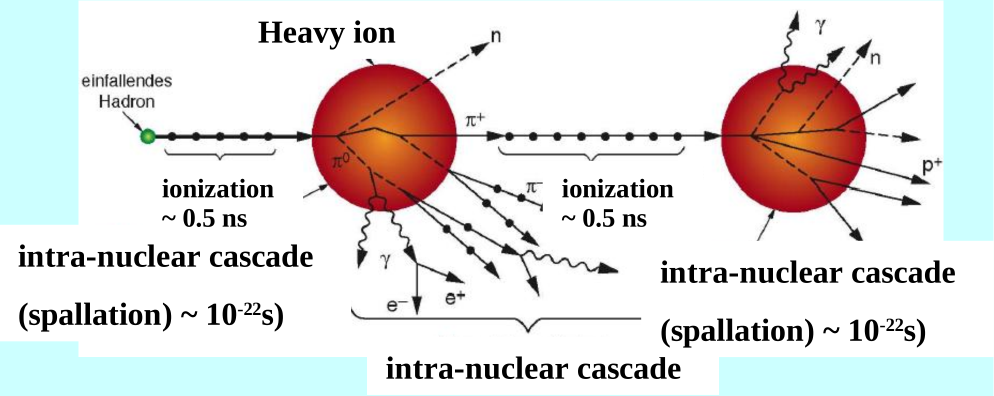
Hadronic Calorimetry

Involved processes:

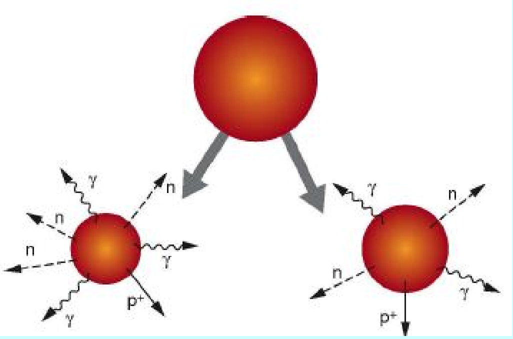
- spallation
(most probable for high energy hadrons)



- core excitation



- production of mesons
(->decay into two photons->em shower)



- fission

Calorimetry

-Homogeneous Detectors:

- **lead glass** (55% PbO, 45% $SiO2$), radiation length of 2.36 cm
  resolution σ/E is about $5^{\%}/E^{1/2}$ ([E] GeV)
- **sodium iodide** crystals, radiation length of 2.6 cm
  resolution σ/E of about $1.5^{\%}/E^{-1/4}$
- **crystal calorimeters,** i.e. BGO

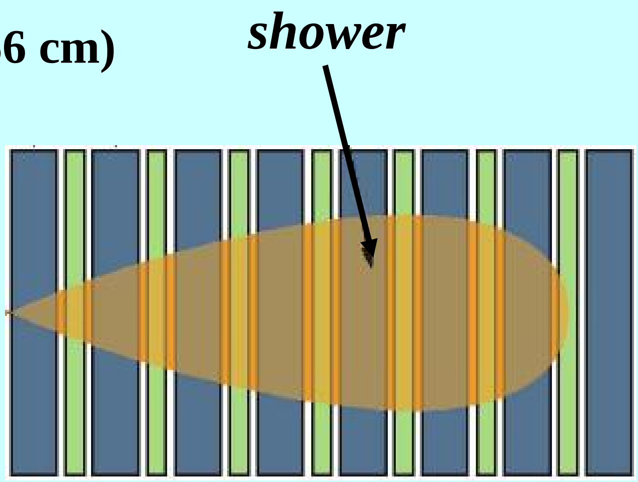
-Heterogeneous or Sampling Calorimeters Detectors:

medium responsible for the showering is separate from that used in detection – sandwich

alternate high-Z passive layer of converter, i.e. lead ($X0$ of 0.56 cm)

and

active detecting layers:

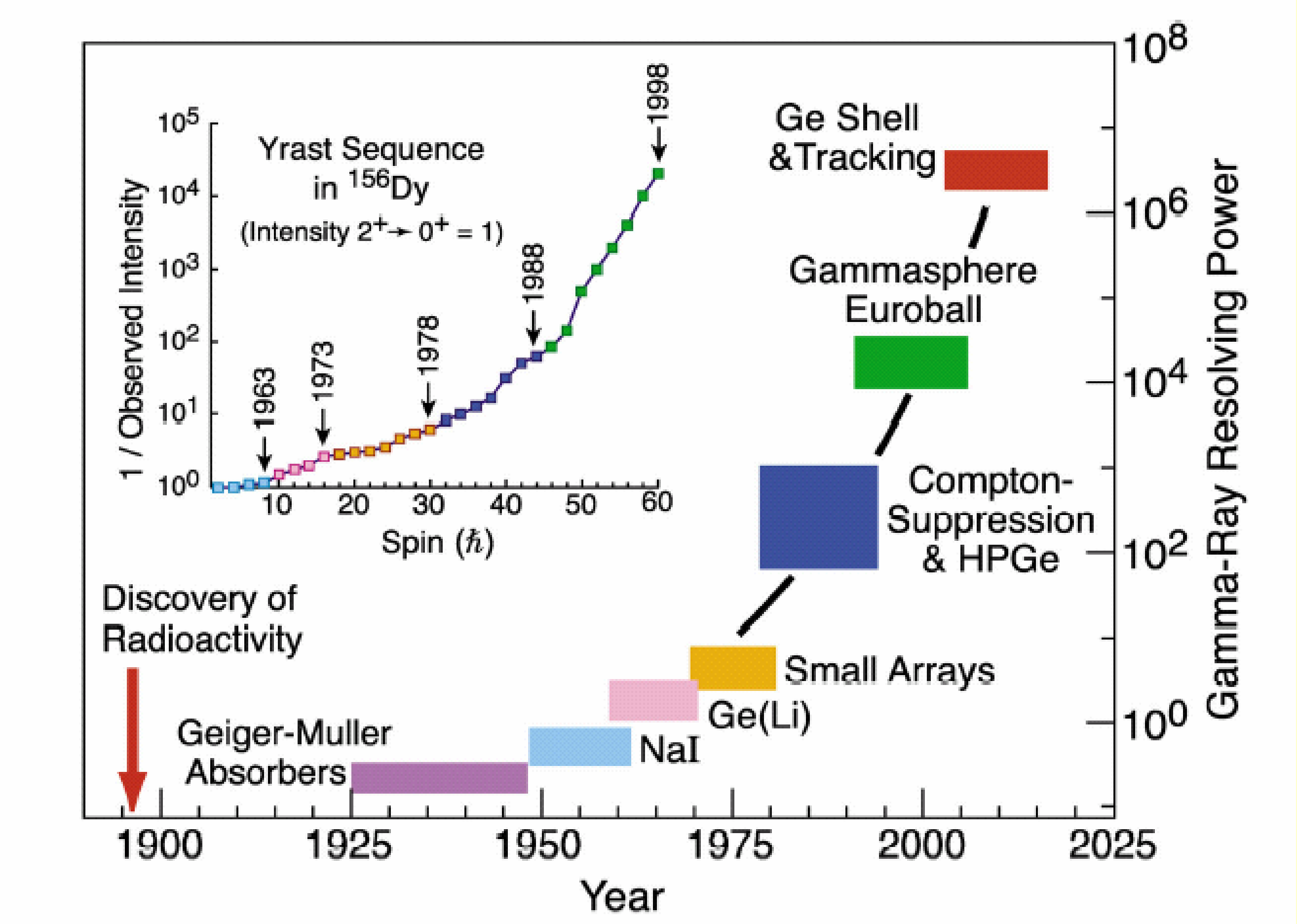


- **plastic scintillator**
- **liquid ionisation chambers**
- **proportional wire chambers**

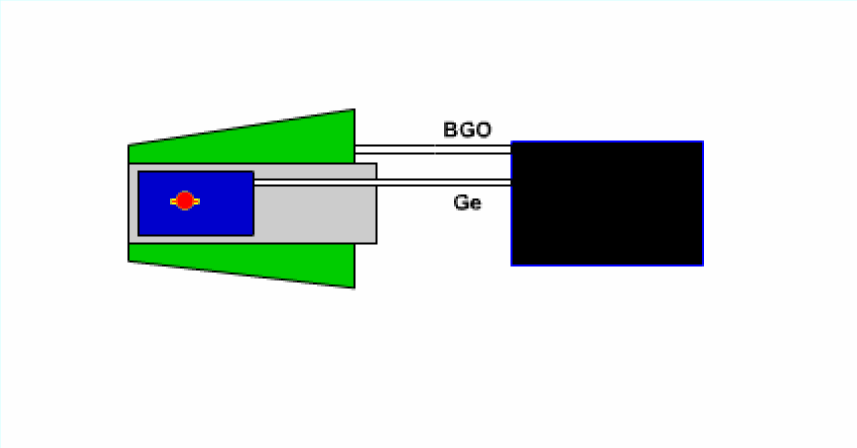
$$\sigma/E \sim (5\text{-}15)^{\%}/E^{1/2}$$

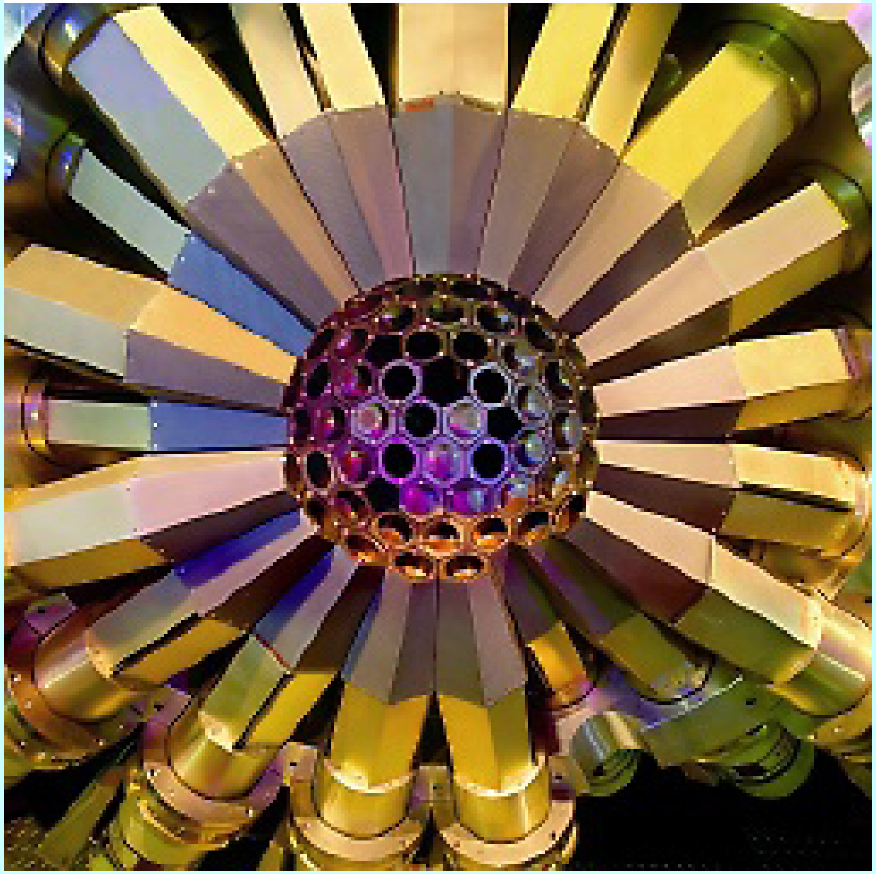
C. Interaction of electrons and photons with matter:

- ***Bremsstrahlung***
- ***Photo-electric effect***
- ***Compton scattering***
- ***e^+e^- pair production***



C. Gamma ray spectrometry:





$\varepsilon \sim 10 — 7$ %

(M_γ=1 —M_γ=30)

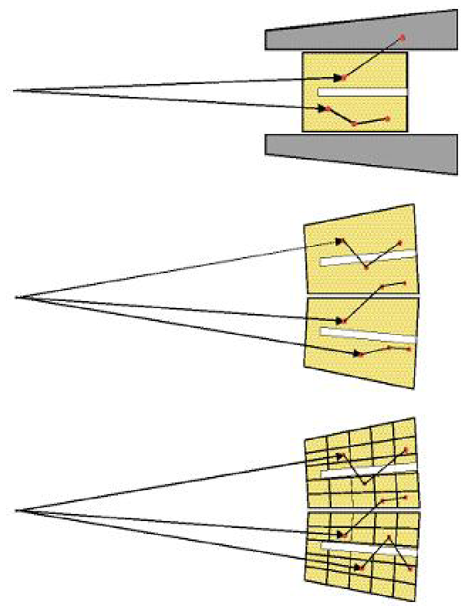
C. Gamma ray spectrometry:

Gamma ray tracking principle

Compton shielded Ge

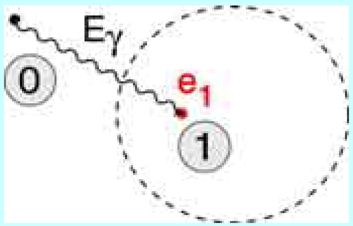
Ge sphere

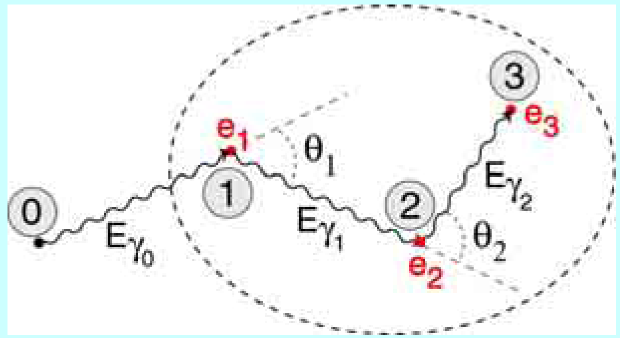
Ge tracking array

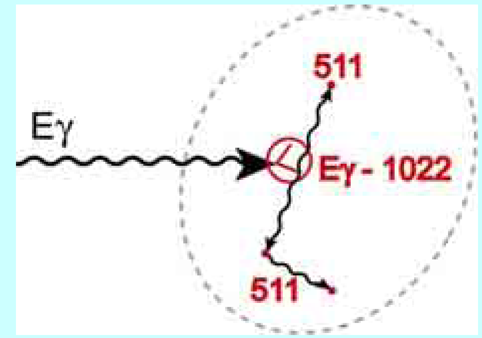


C. Gamma interaction/reconstruction mechanisms:

~ 100 keV ~ 1 MeV ~ 10 MeV γ-ray energy







Photoelectric

isolated hits

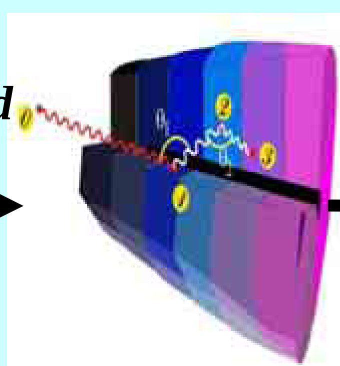
Compton scattering

angle/energy

Pair production

patern of hits

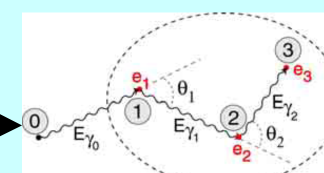
Highly segmented HPGe detectors



Pulse shape analysis

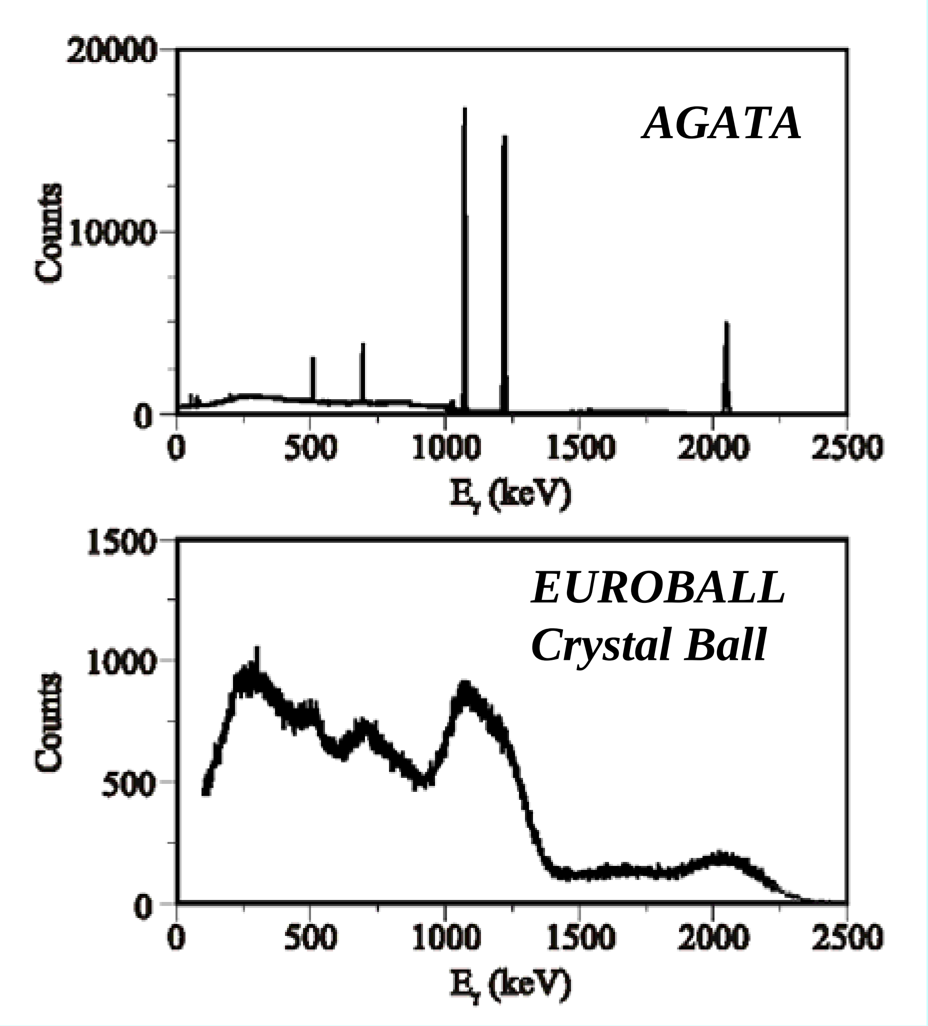
(x,y,z,E,t)

Track reconstruction



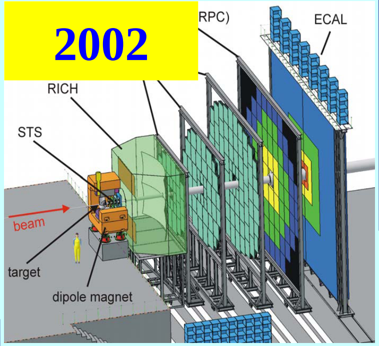
C. Gamma interaction/reconstruction mechanisms:

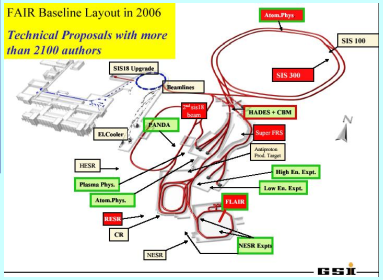
Improved resolution for fast moving source v~0.5c



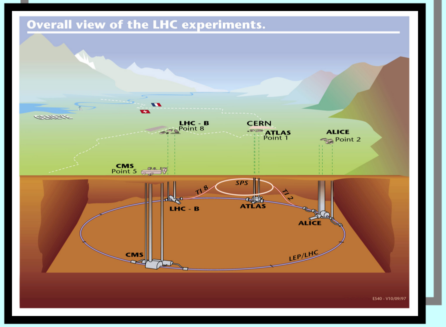
A few examples of exprimental dvices based on the detection and identification methods presented above

2002

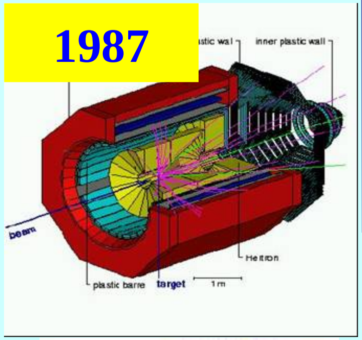


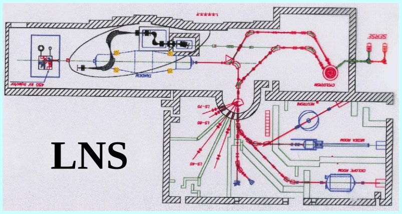


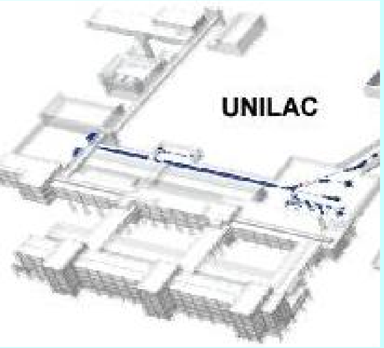
1999



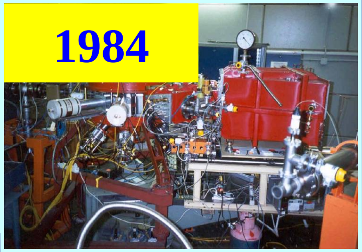
1987



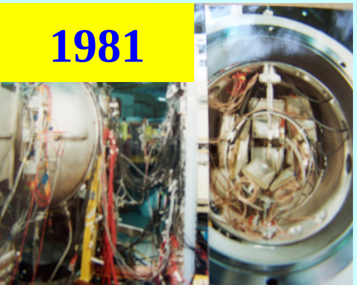


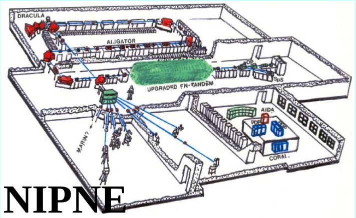


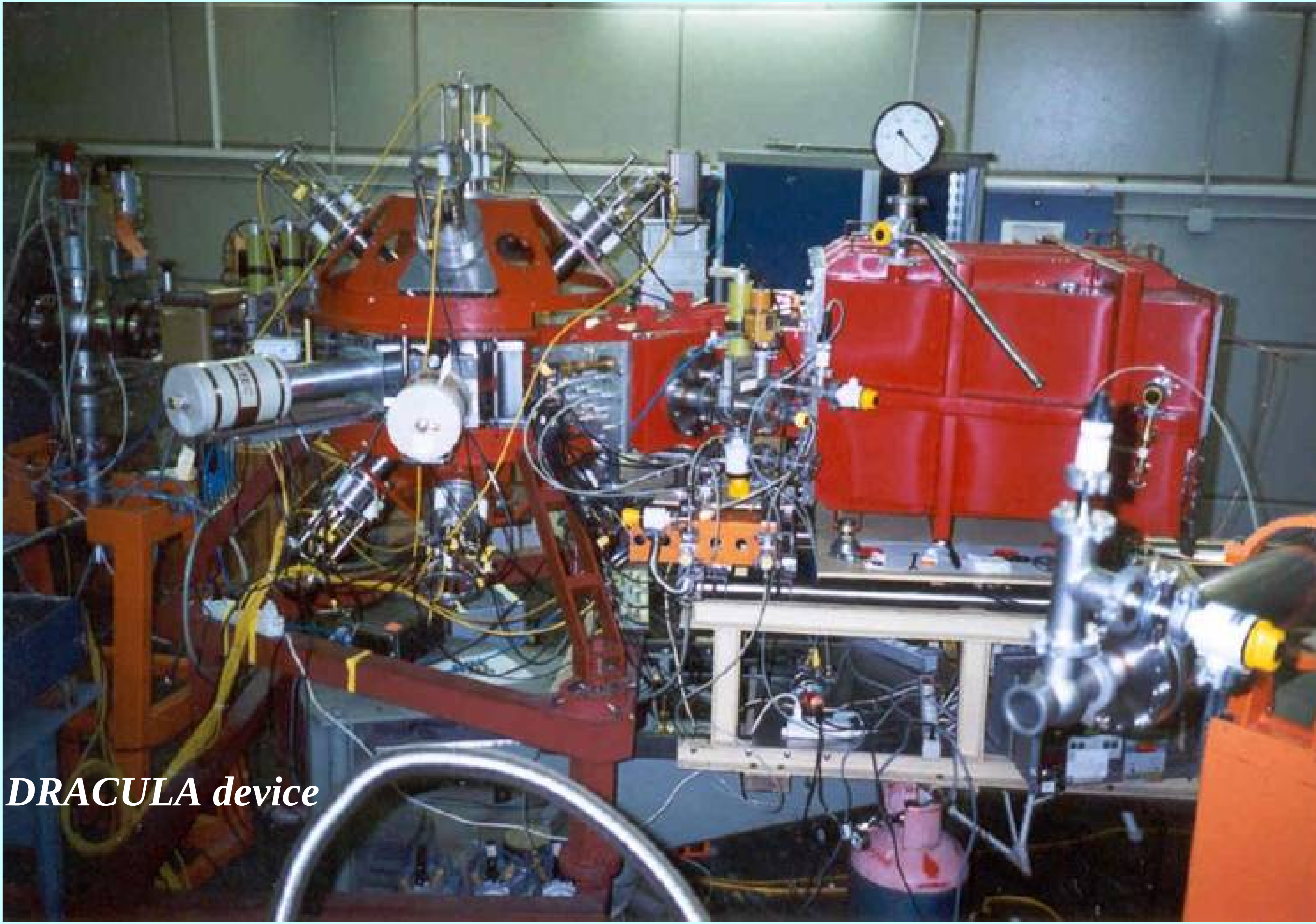
1984



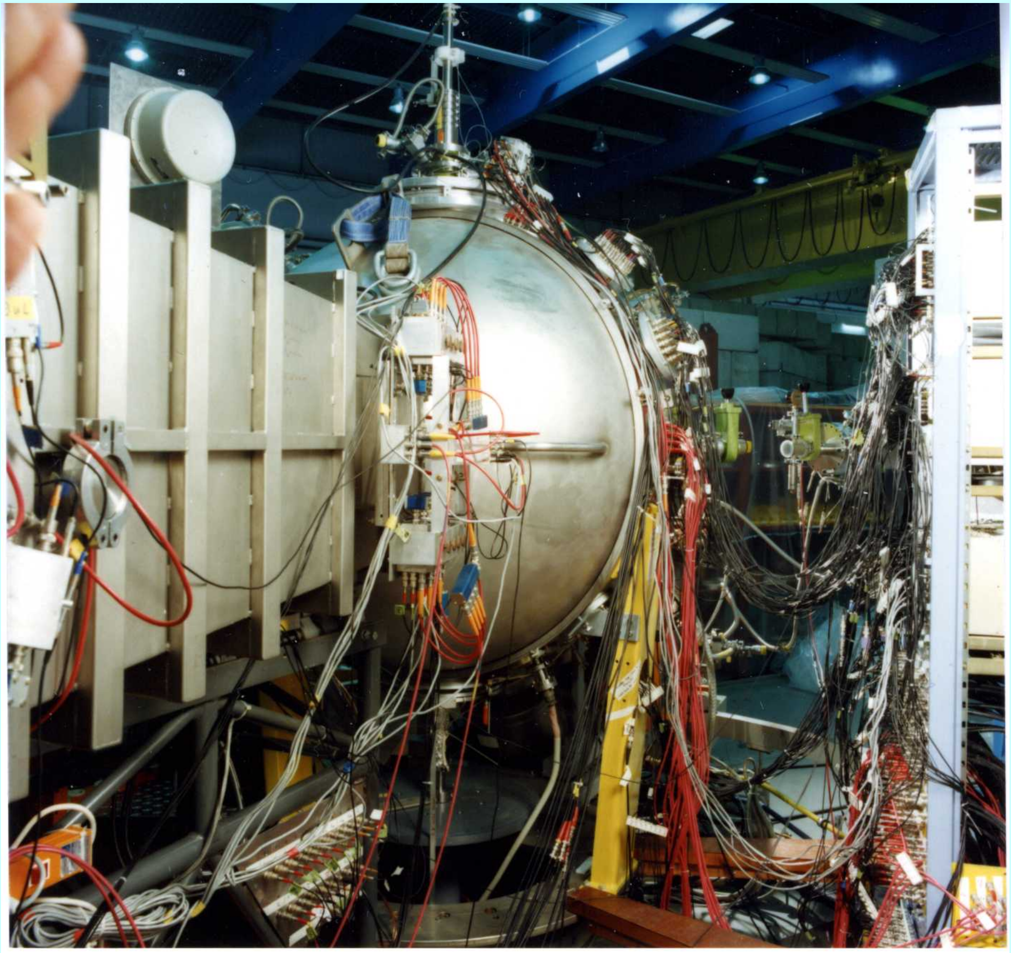
1981

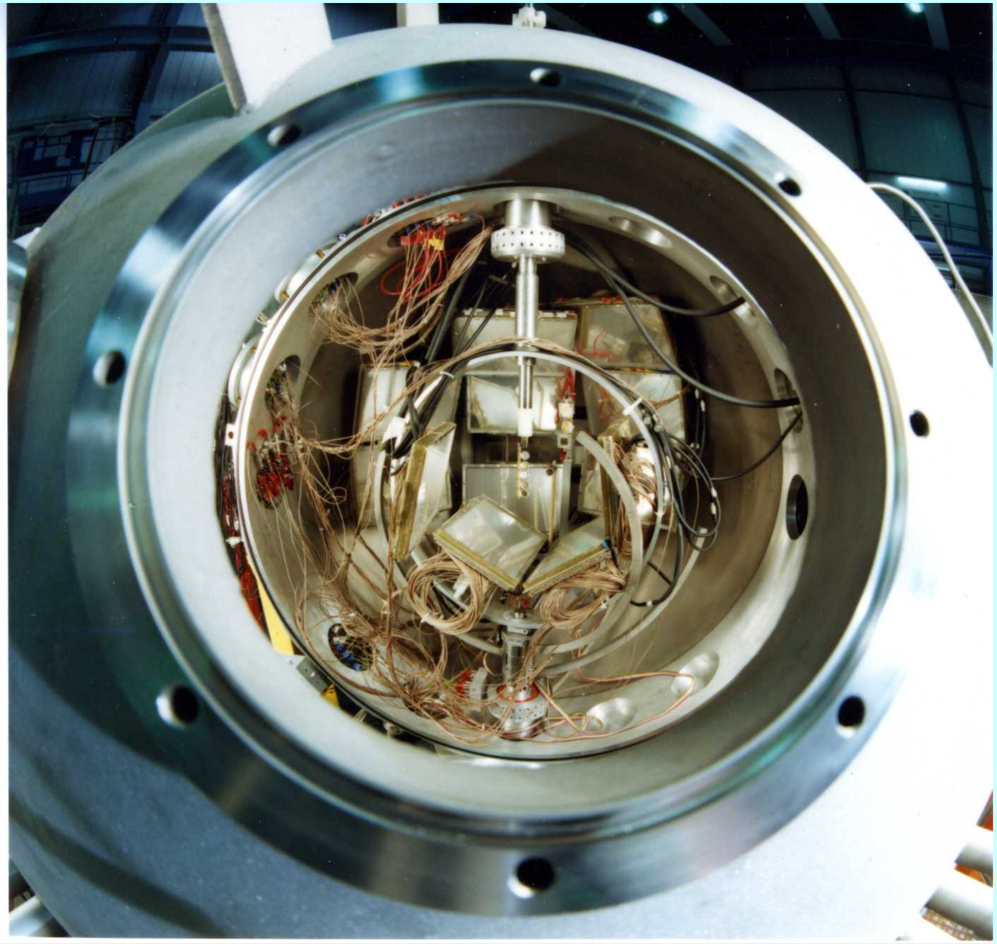





DRACULA device

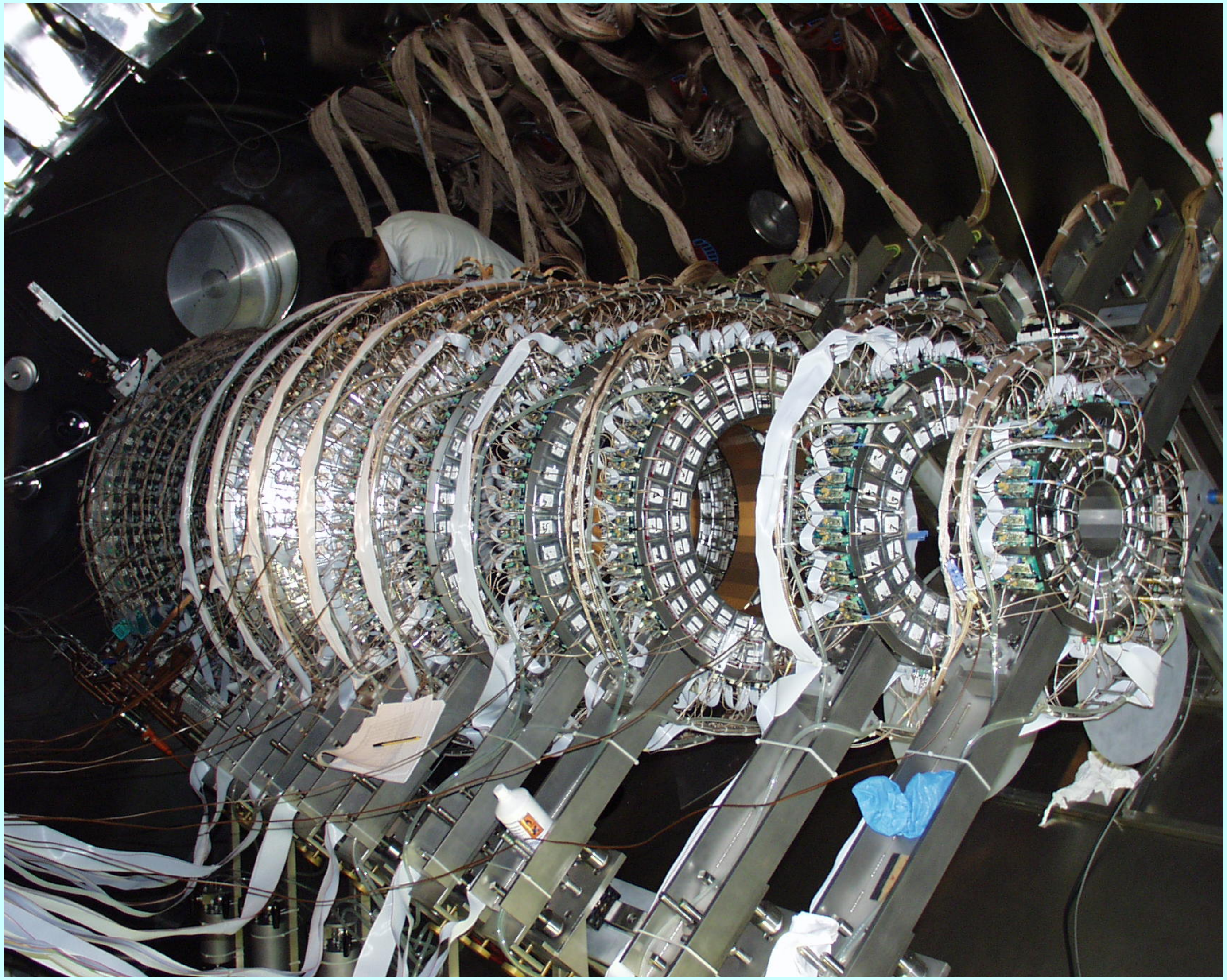
Kinematical coincidence experiment - UNILAC



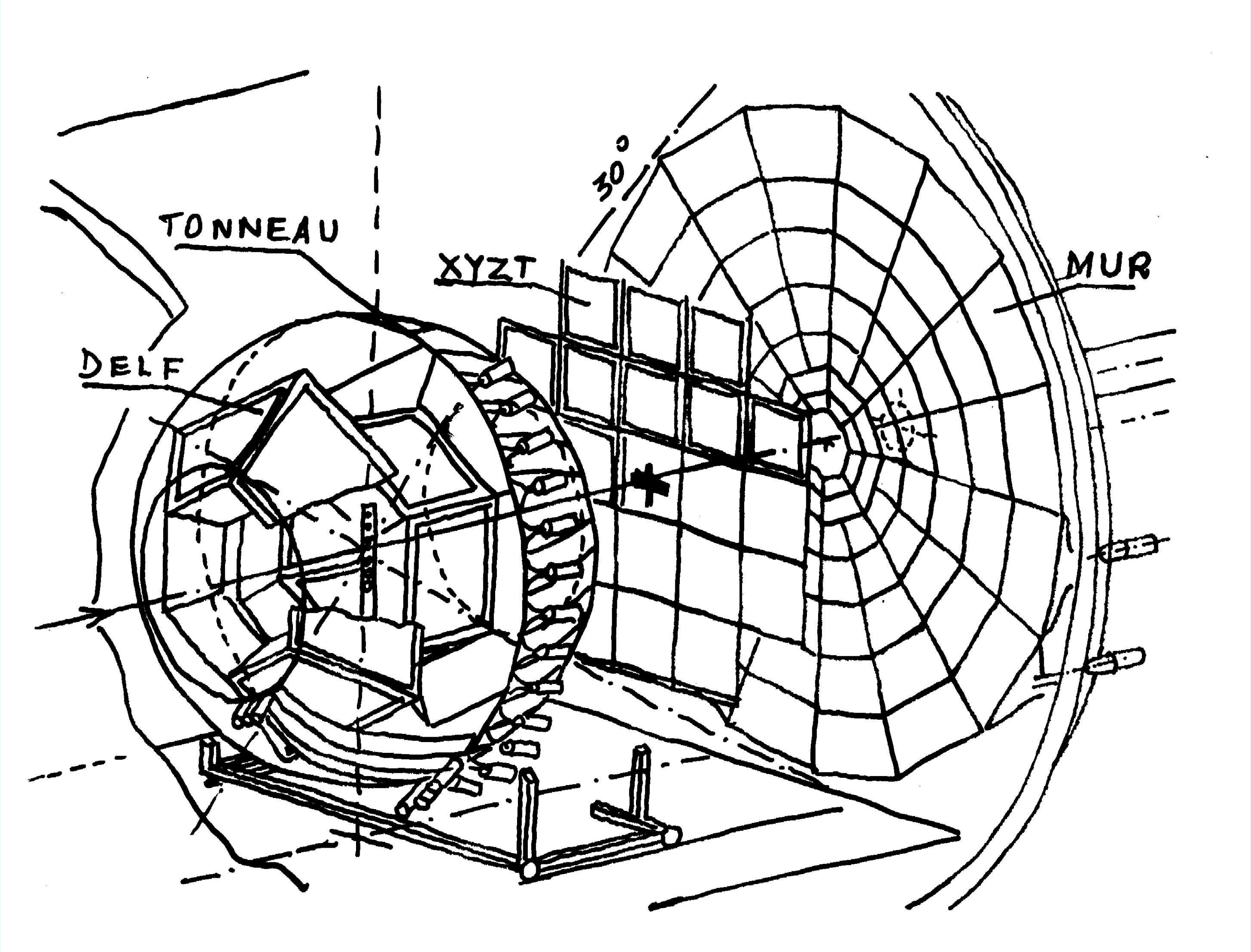


CHIMERA – LNS

a 4π experiment based on Si & CsI telescopes



A 4π experiment based on PPAD, IC and plastic scinillators GANIL



AMPHORA - SARA

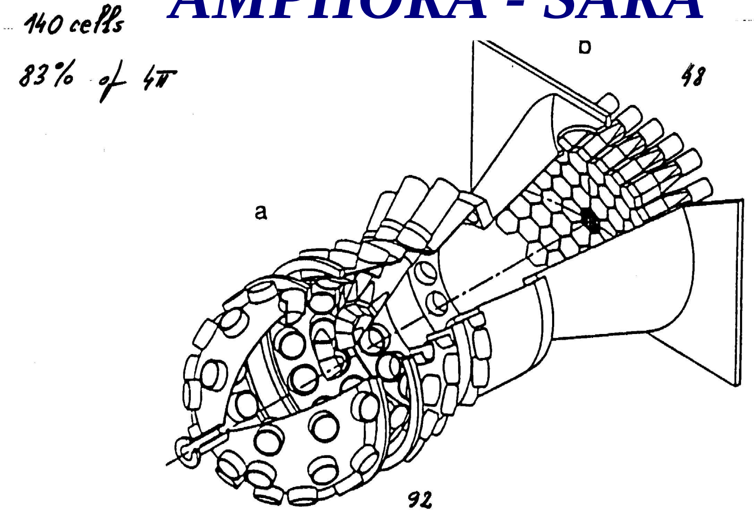


Figure 1 : *Schematic view of the 4π detector*

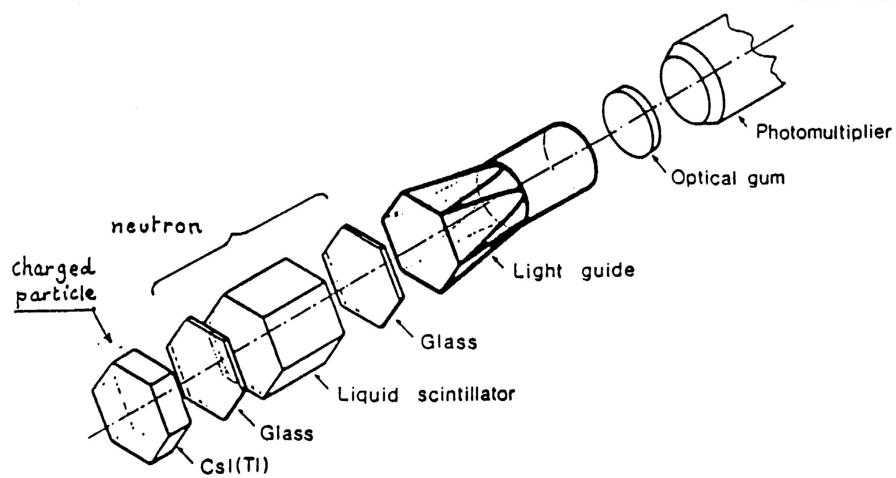


Figure 2 :
Exploded view of one of the forward wall cell, as mounted for light particle and neutron detection

4π MiniBall - NSCL

188 phoswich detectors

40 - 100 μm ps
20 mm CsI(Tl)

50 ns
60 - 400 ns
1-2 μs

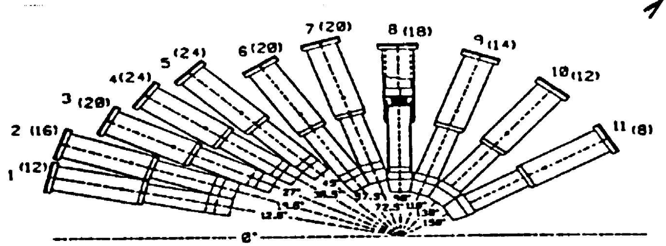


FIG. 1: Half-plane section of the Miniball array. Individual detector rings are labeled 1 through 11; numbers of detectors per ring are given in parentheses.

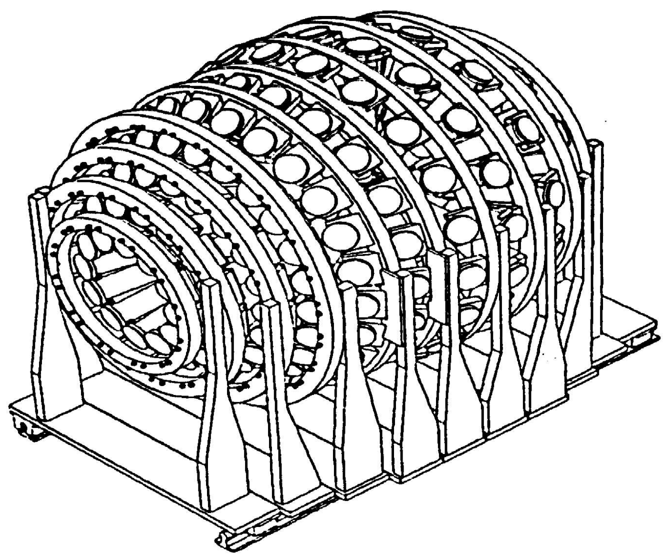


FIG. 2: Schematic of three-dimensional detector geometry.

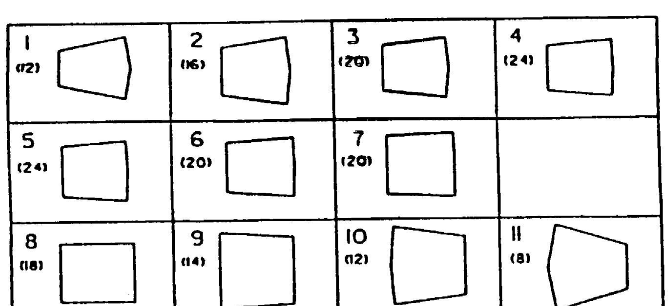
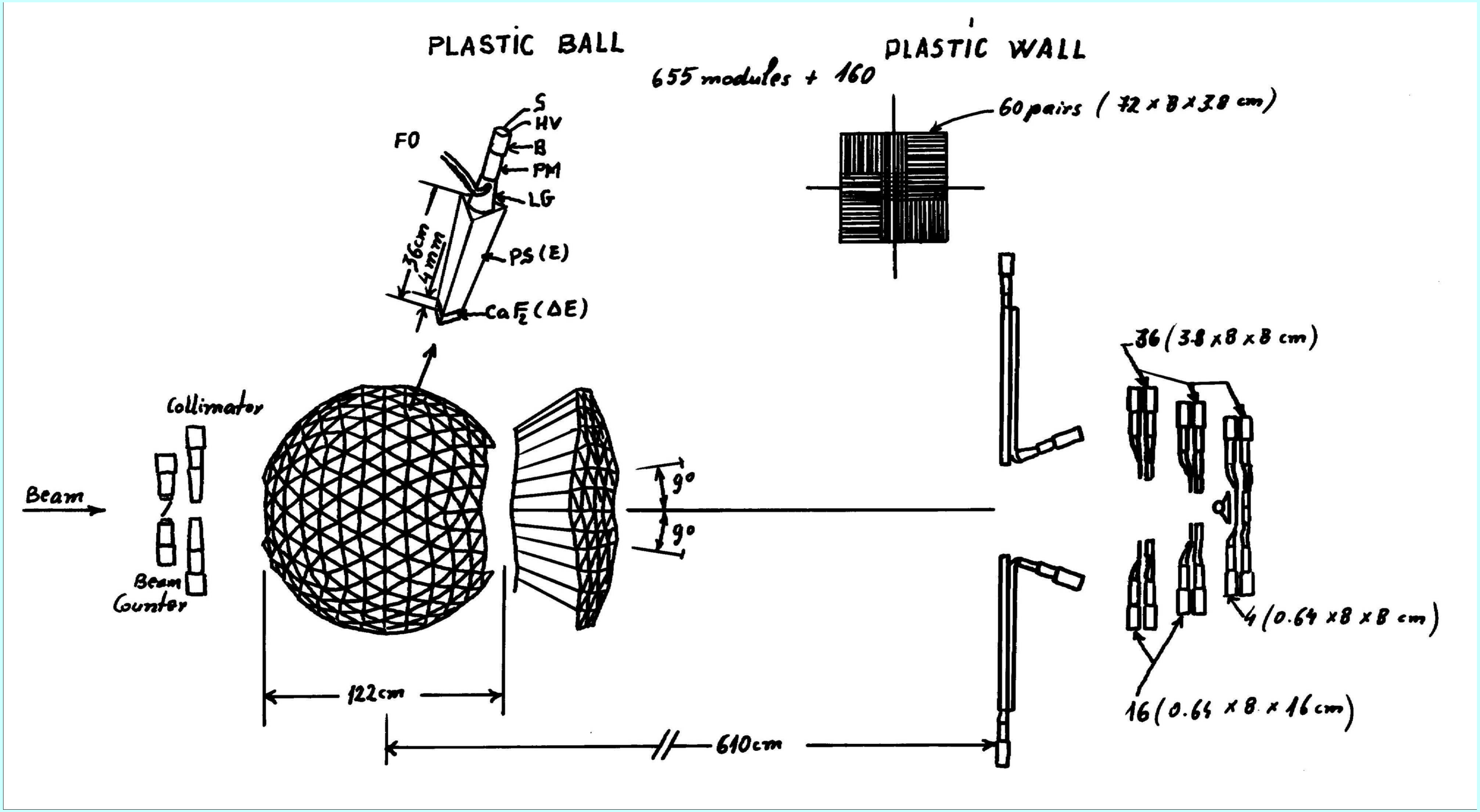
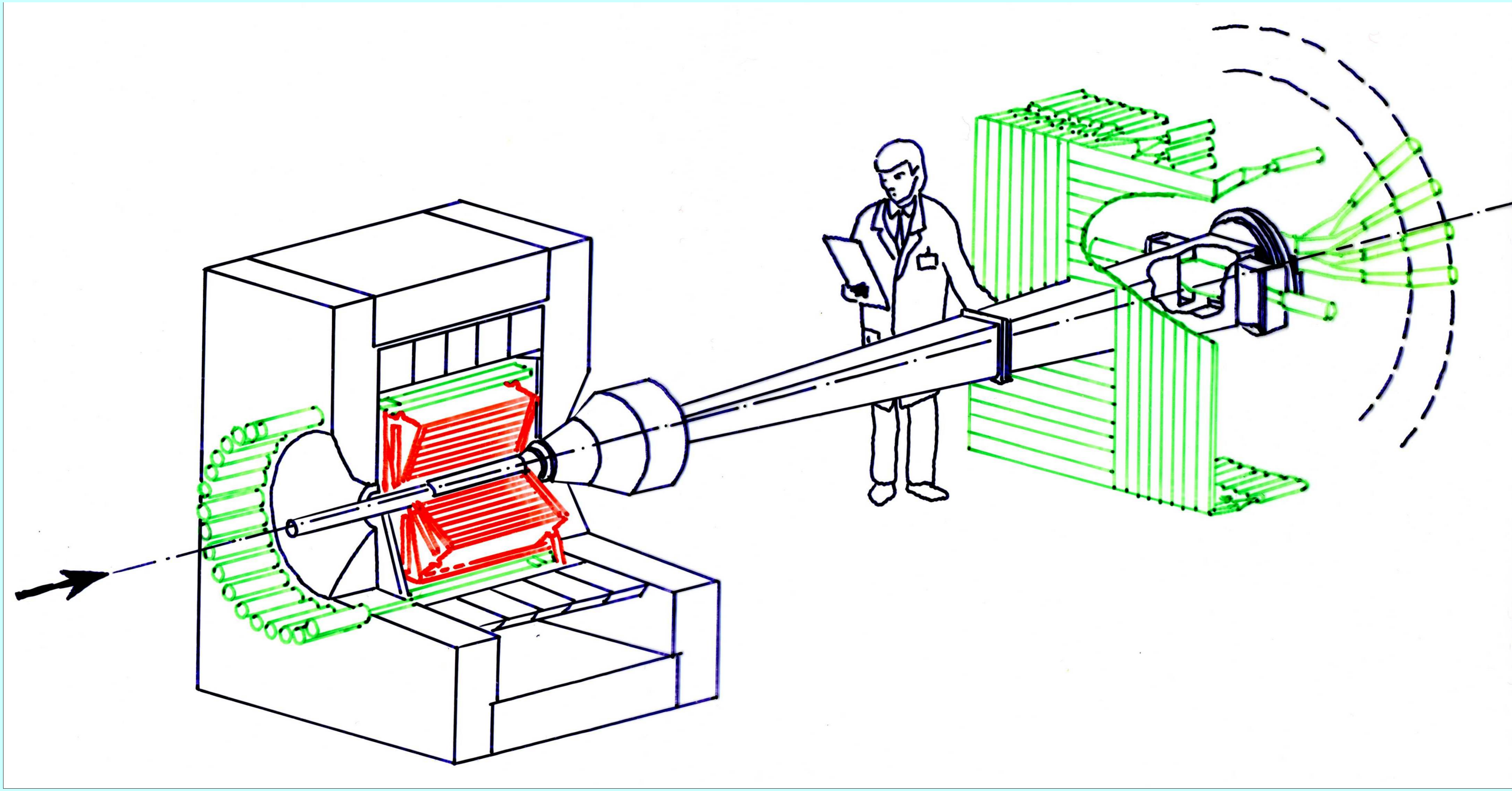


FIG. 3: Front views of different detector shapes. The detectors are labeled by their ring number; numbers of detectors per ring are given in parentheses.

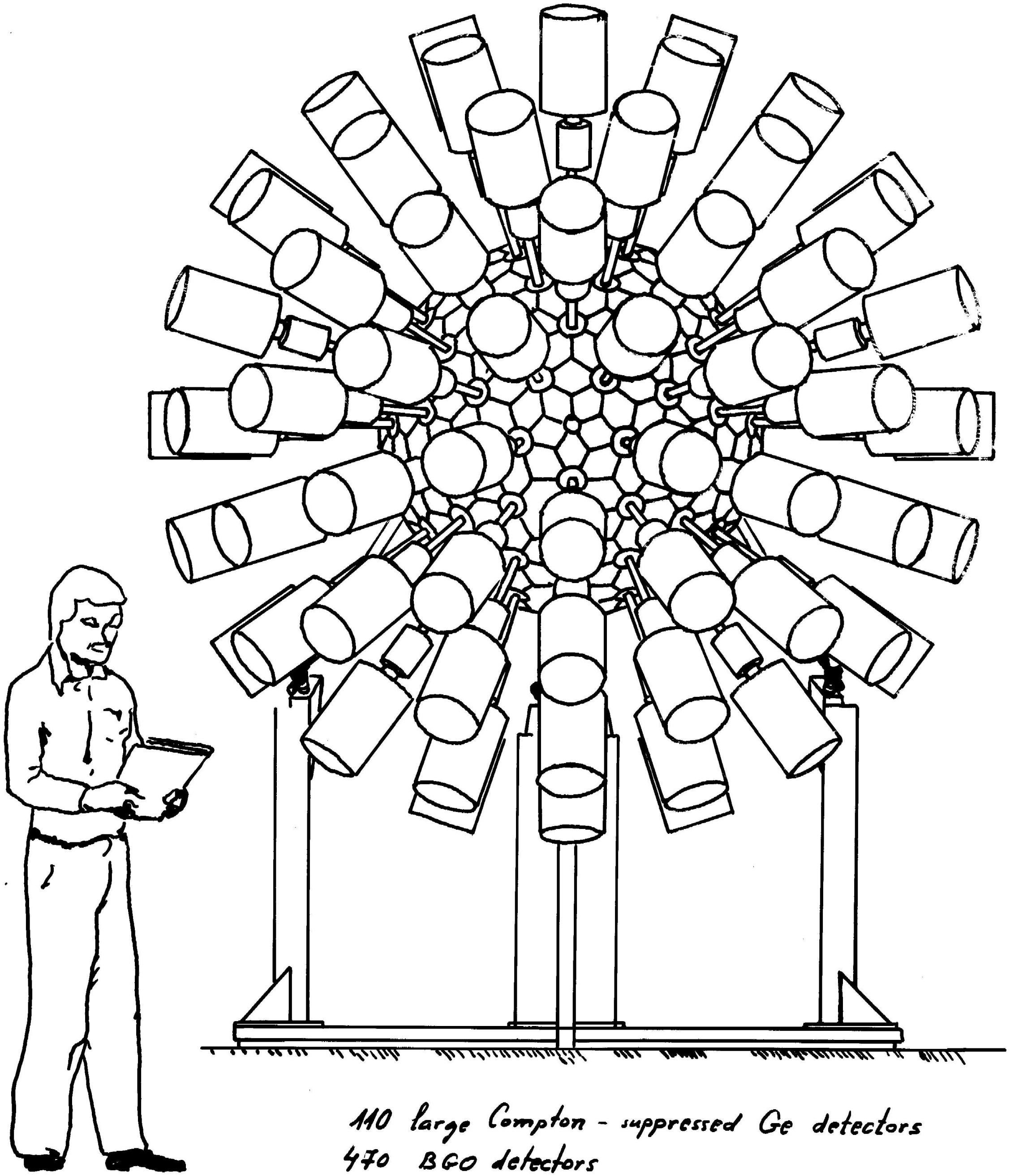
4π Detector - Bevalac



4π Detector – DIOGENE - Saturne

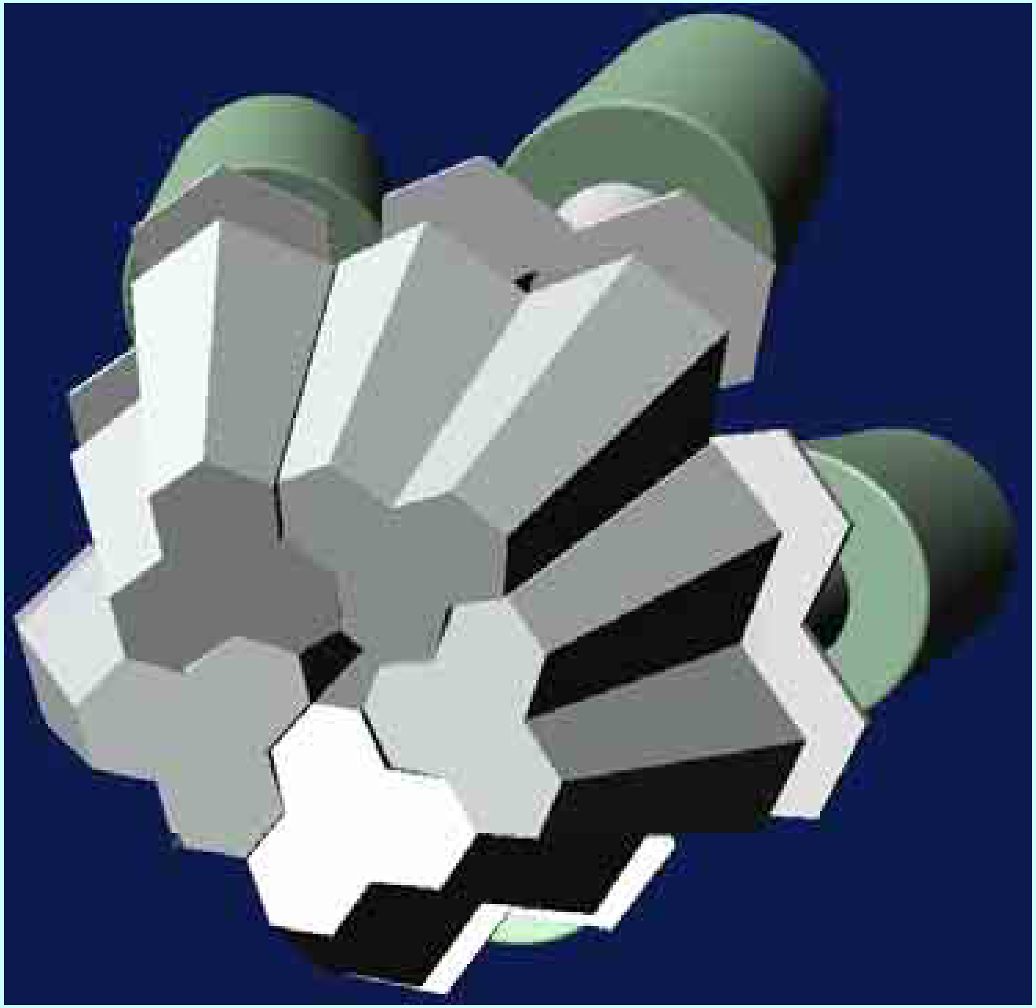


GAMMASPHERE

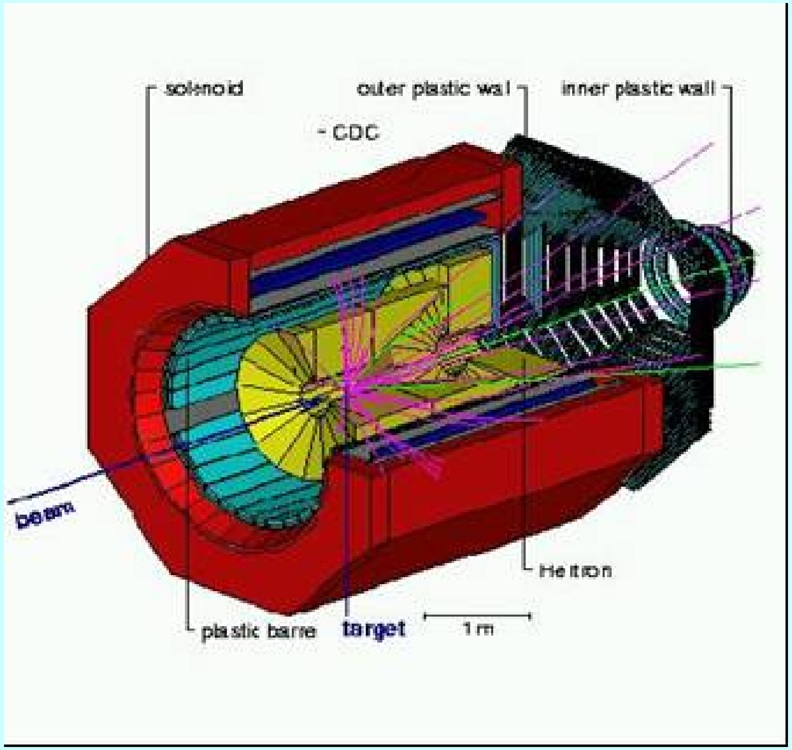


110 large Compton - suppressed Ge detectors
470 BGO detectors

AGATA Demonstrator

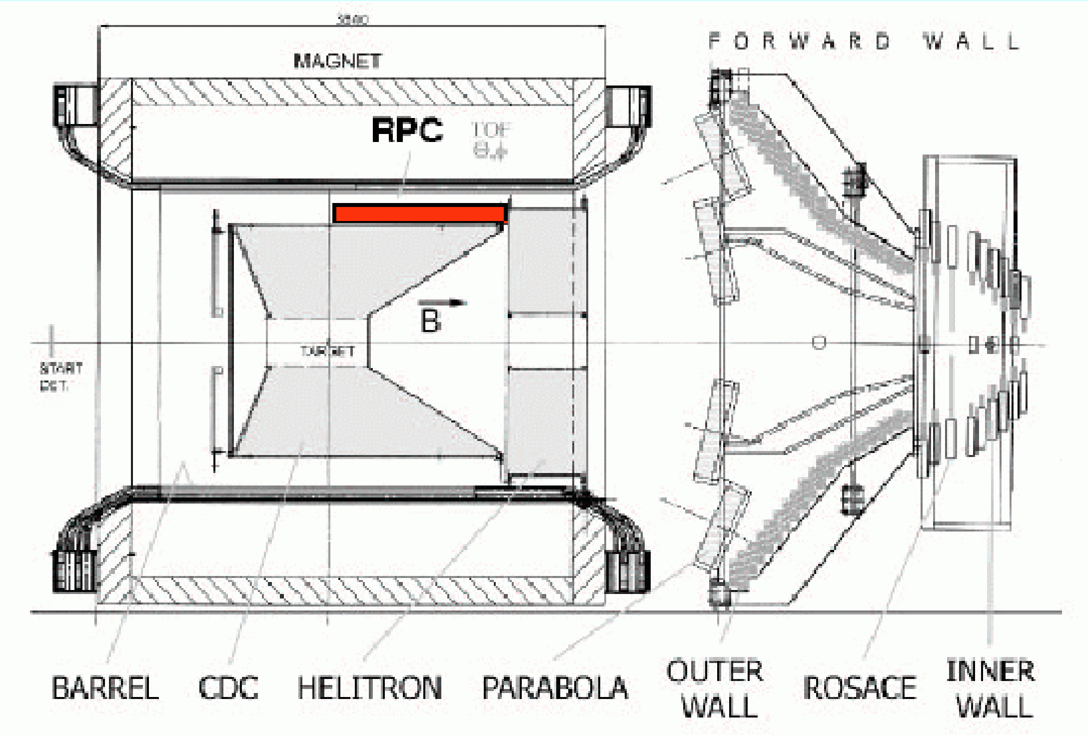


1 symmetric cluster
4 asymmetric clusters
36-fold segmented crystals
540 segments
555 digital-channels
Eff. 3 –8 % @ Mγ= 1
Eff. 2 –4 % @ Mγ= 30
Full ACQ
with on-line PSA and γ-ray tracking
Operational in 2007
Cost ~ 5 M€

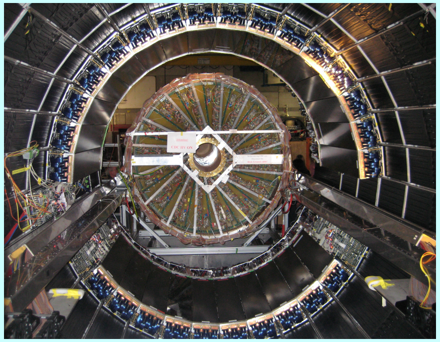


solenoid
outer plastic wall
inner plastic wall
CDC
beam
Helitron
plastic barrel
target
1 m

FOPI

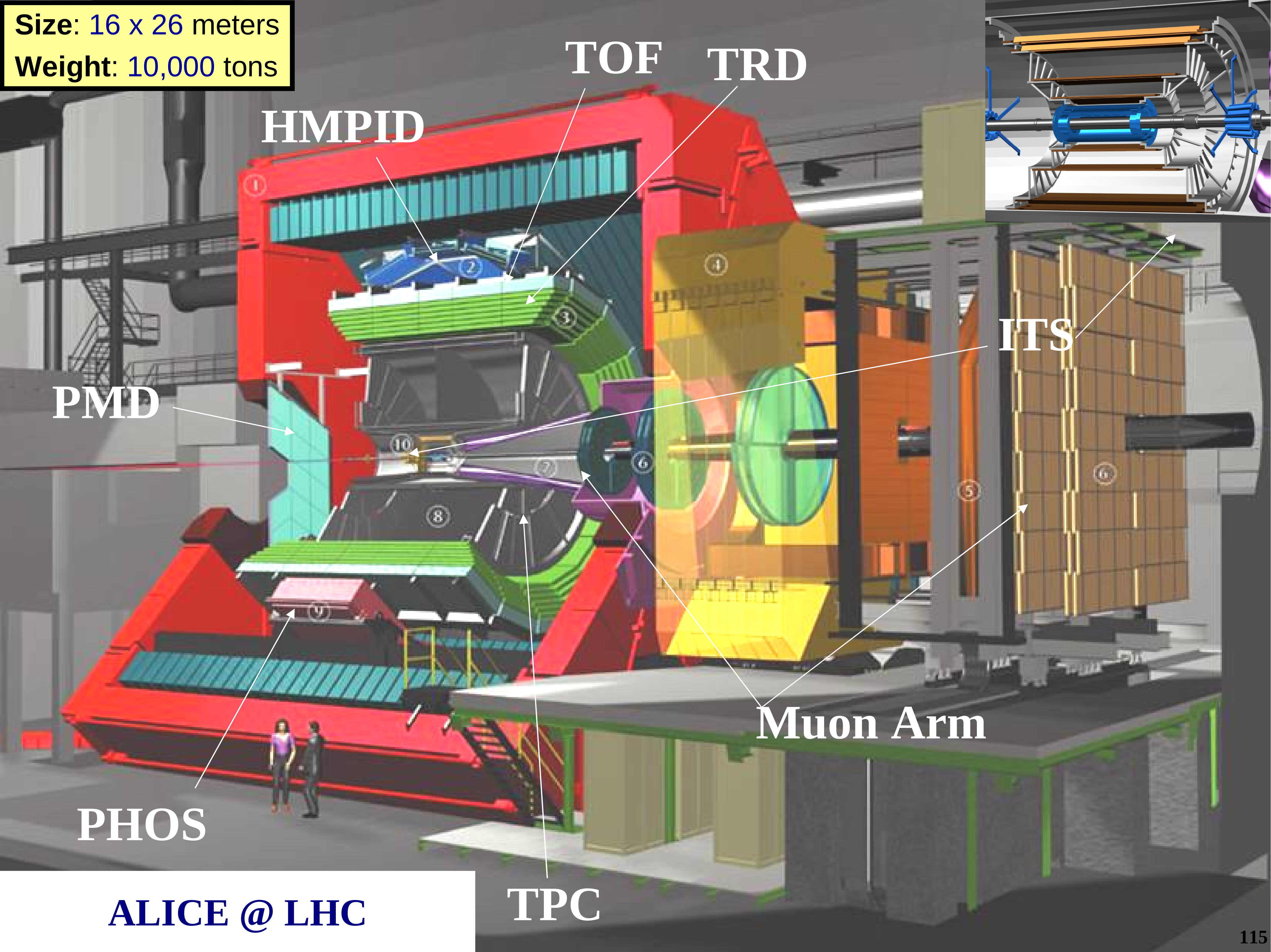


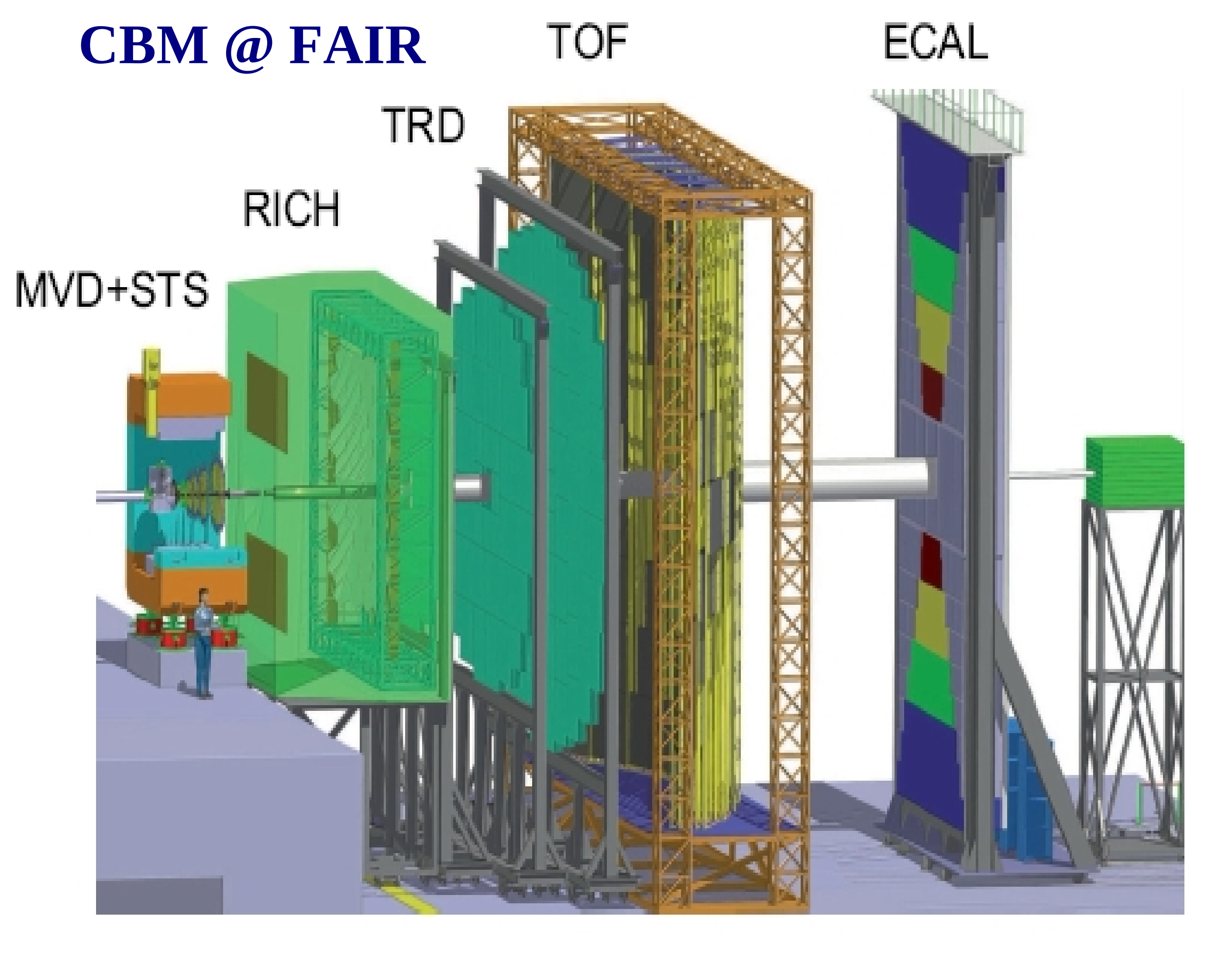
MAGNET
RPC
TOF
FORWARD WALL
B
TARGET
START DET.
BARREL
CDC
HELITRON
PARABOLA
OUTER WALL
ROSACE
INNER WALL



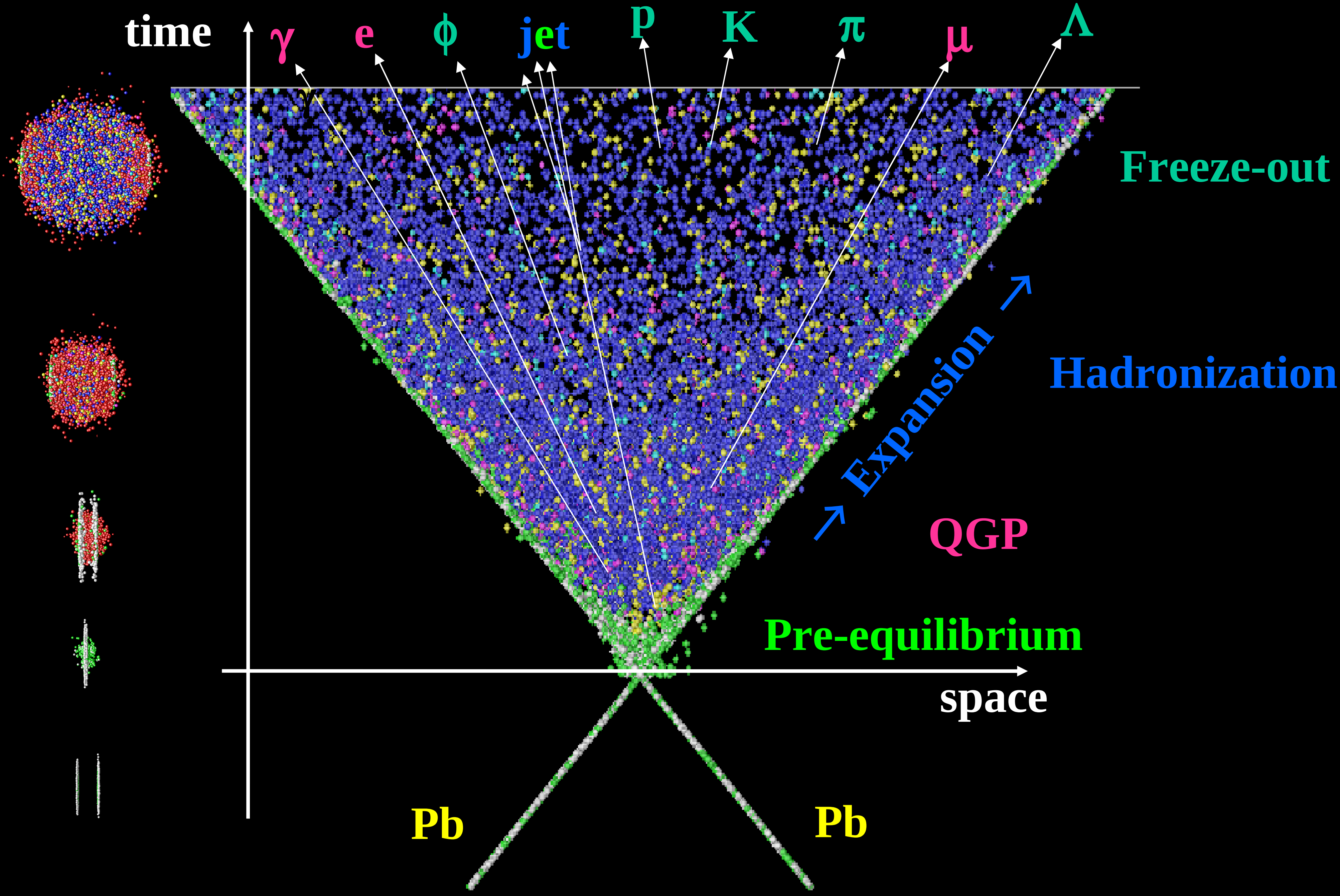
ALICE @ LHC

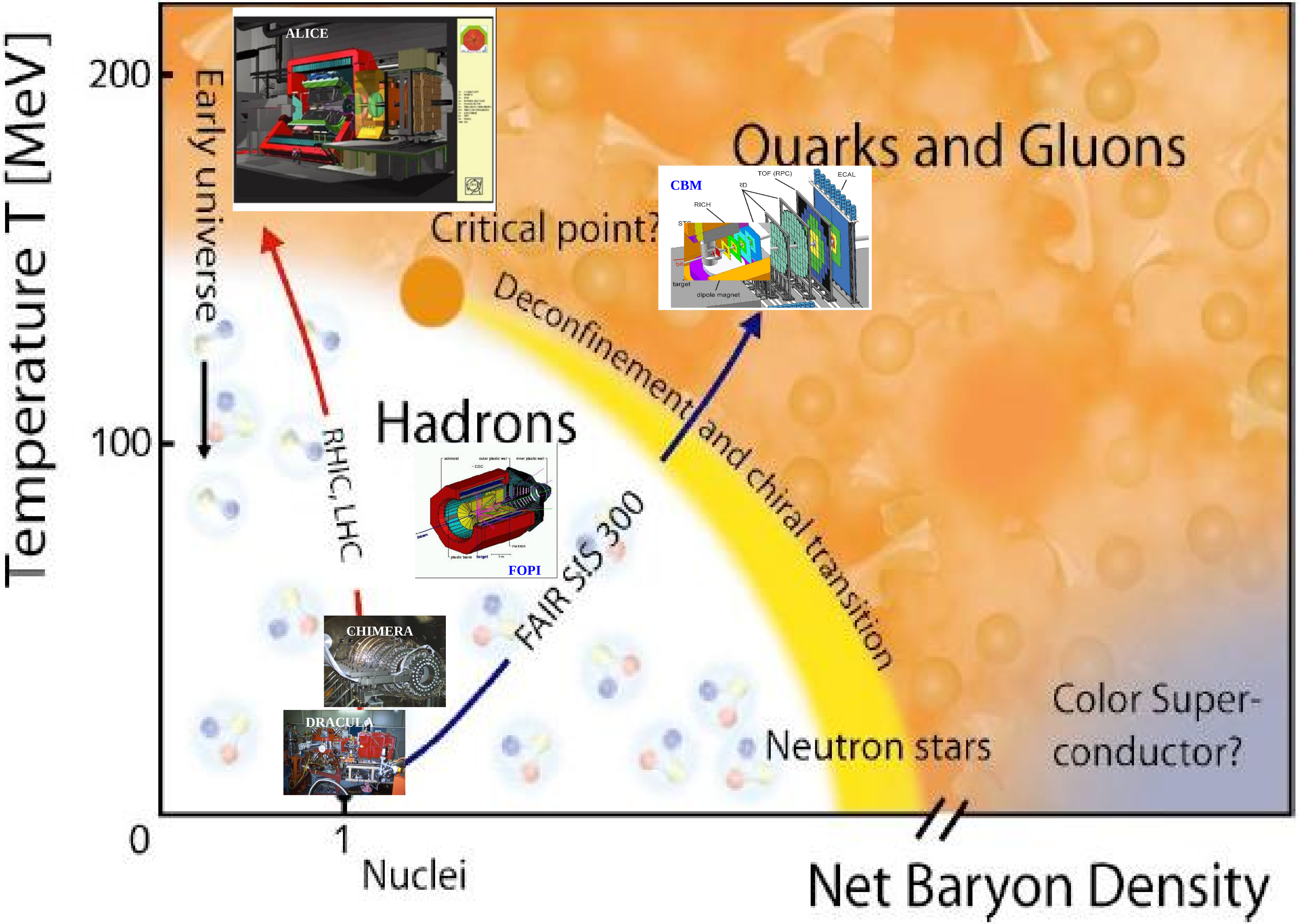
Size: 16 x 26 meters
Weight: 10,000 tons




CBM @ FAIR
TOF
ECAL
TRD
RICH
MVD+STS

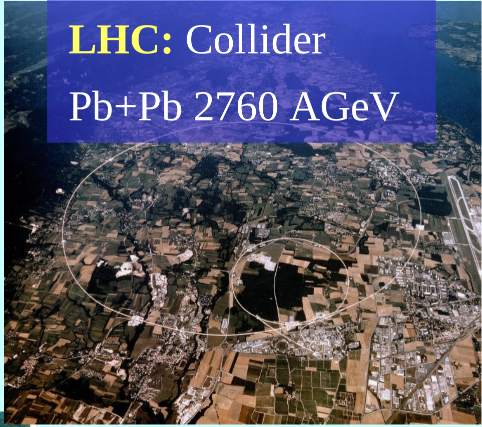
Space-time Evolution of the Collision



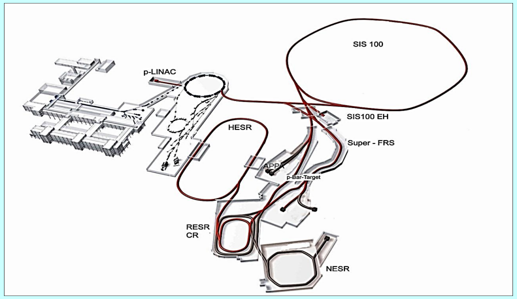

Temperature T [MeV]
200
100
0
1
Nuclei
Net Baryon Density
Early universe
RHIC, LHC
FAIR SIS 300
ALICE
CBM
TOF (RPC)
ECAL
RICH
target
dipole magnet
Quarks and Gluons
Critical point?
Deconfinement and chiral transition
Hadrons
FOPI
CHIMERA
DRACULA
Neutron stars
Color Super-
conductor?

Dedicated Facilities

LHC: Collider
Pb+Pb 2760 AGeV

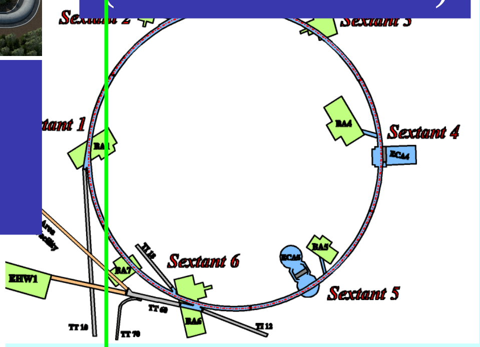


FAIR: Fixed Target
(Ec.m.=2.7-8.3AGeV)



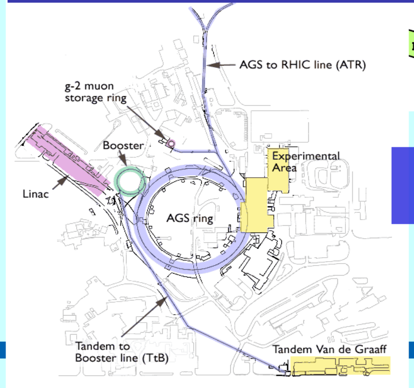
NICA: Collider
(Ec.m.=4-11 AGeV)

SPS: Fixed Target
Pb at 158 AGeV
(Ec.m.=17.3 AGeV)



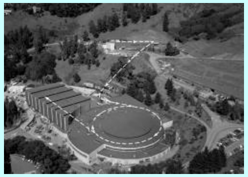
RHIC: Collider
Au+Au 200 AGeV

AGS: Fixed Target
Au at 11.7 AGeV
(Ec.m.=4.86 AGeV)



Fixed Target
1–2 AGeV

Bevalac



UNILAC

RHIC BES: Collider