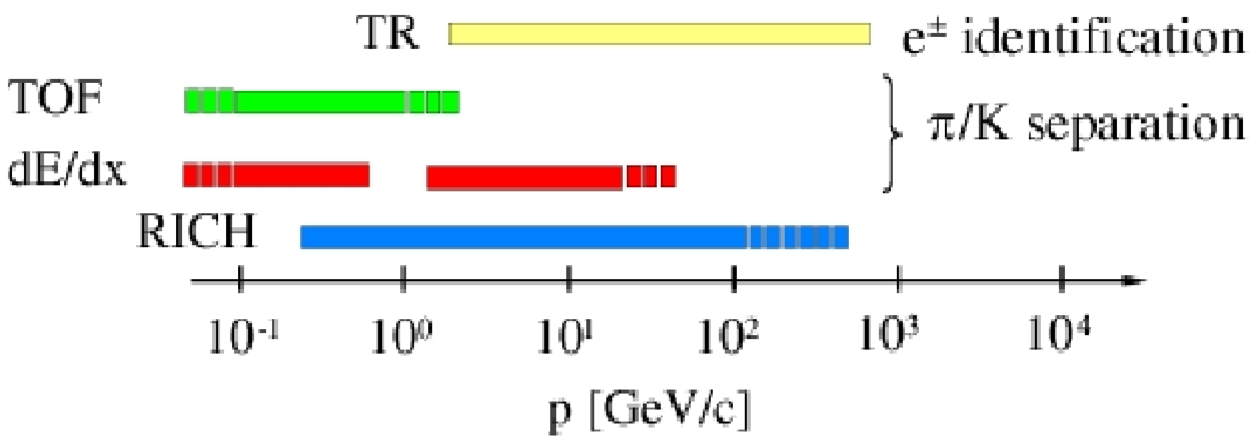
RPC - general presentation

Mariana Petris, DFH Seminar, July 14, 2010

Time of Flight (TOF) method



One of the most common methods of

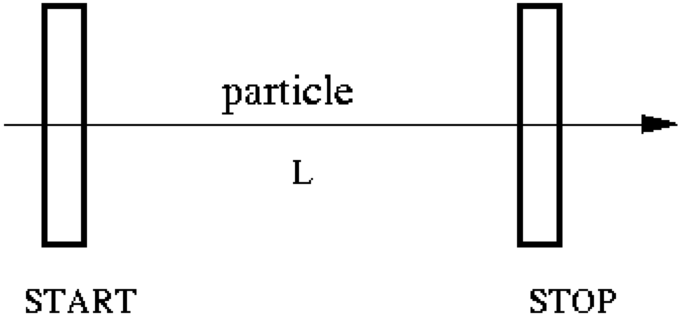
***Particle identification** (at low momenta) is the Time of Flight.*

*- If the time of crossing is known for two points on the particle trajectory, then the **velocity** can be determined.*

*- If the momentum (p = mv) is also known (by measuring the curvature in a magnetic field), then the **mass** of the particle can be determined.*

Time of Flight method

Precision time measurements can determine the mass differences of particles with the same momentum.



$$v = \frac{L}{t} = particle\ speed \rightarrow m = \frac{p}{\gamma\beta c} = \frac{p}{c}\sqrt{\frac{c^2t^2}{L^2} - 1}$$

$$\Delta t_{1-2} \approx \frac{Lc}{2p^2}\left(m_1^2 - m_2^2\right)\ \ for\ relativistic\ particles\ (\beta \rightarrow 1)$$

$$Particle\ \ separation\ \ capability:$$

$$N_{\sigma_{ToF}} = \frac{\Delta t_{1-2}}{\sigma_{ToF}} \approx \frac{Lc}{2\sigma_{ToF}\,p^2}\left(m_1^2 - m_2^2\right)$$

Time of Flight (TOF) resolution

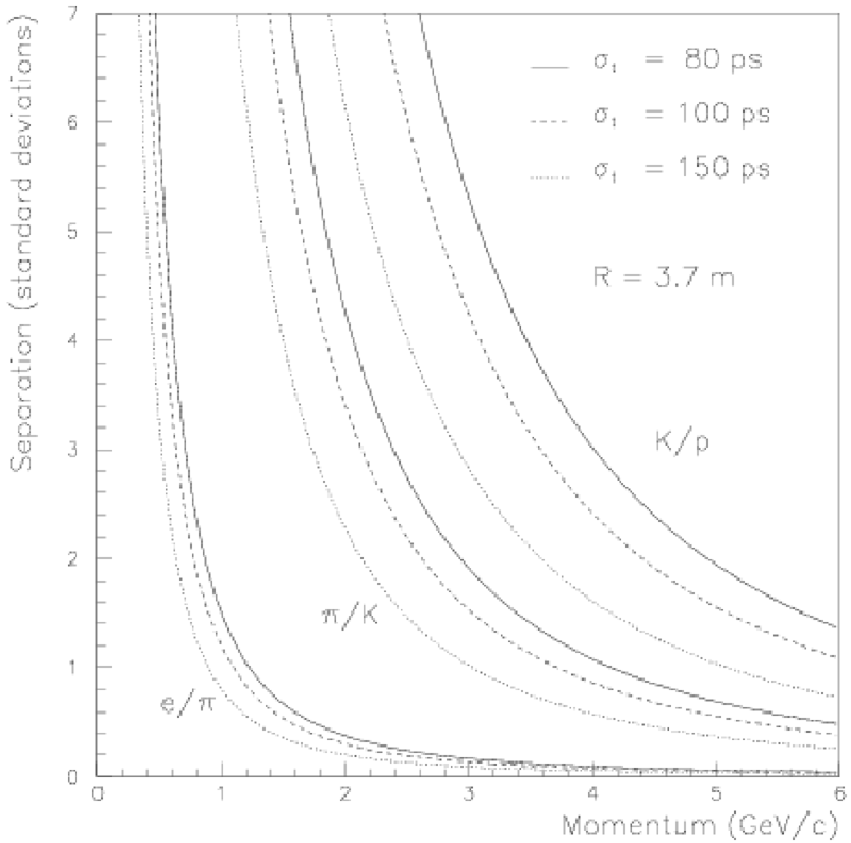
$$\sigma_{ToF} = \sqrt{\sigma^2_{START} + \sigma^2_{STOP}}$$

σ_{ToF} :Time of Flight method resolution

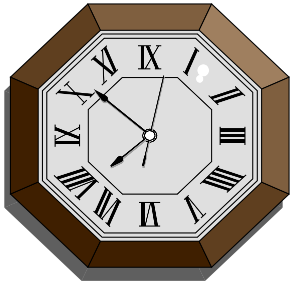
$\sigma_{ToF} \leq 100$ ps for 4σ K/π

σ_{START} :Start counter resolution < 100 ps

σ_{STOP} :Stop counter resolution <100 ps



Time of Flight detector:



- time resolution < 100 ps

- detection efficiency >95%

- high granularity

- cheap detector

Scintillators coupled to photomulipliers (usually):

- the main drawback: large costs needed to built large area time of flight detectors.

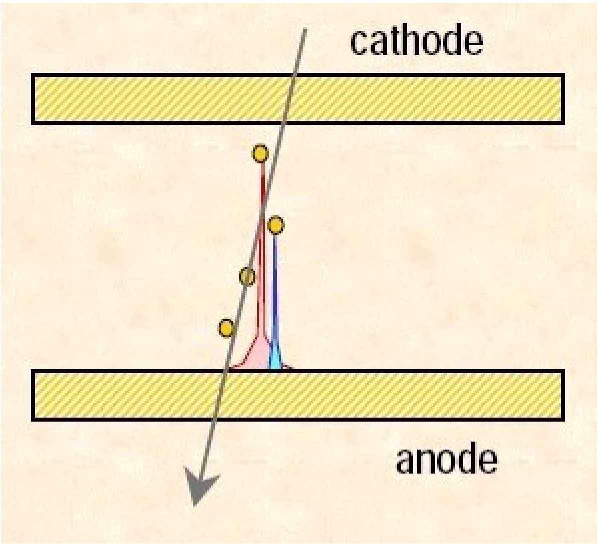
Gaseous detectors:

- much cheaper for large area configurations

- for a good time resolution needs a strong uniform electric field to set in instantly the avalanche amplification for all primary clusters.

See next slide

Parallel Plate configuration



- simple device: a gas volume bounded by two parallel plates
- through – going charged particles create clusters of positive ions and electrons in the gas
- electrons avalanche in the high electric field as they move towards the anode: $N = N_0 exp(\alpha x)$
- the avalanche induces a signal on the external electrodes
- only avalanches initiated in the region of first 25% of gas gap produce detectable signals on pickup electrodes

- a large gap: higher detection efficiency but worse time resolution (large time jitter)
- small gap: a better time resolution but a lower detection efficiency

See

Nuclear Instruments and Methods A 373 (1996), 35;

Nuclear Instruments and Methods A 374 (1996), 132.

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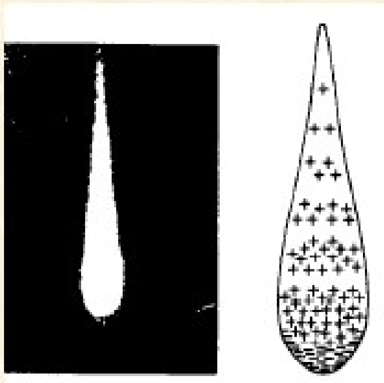
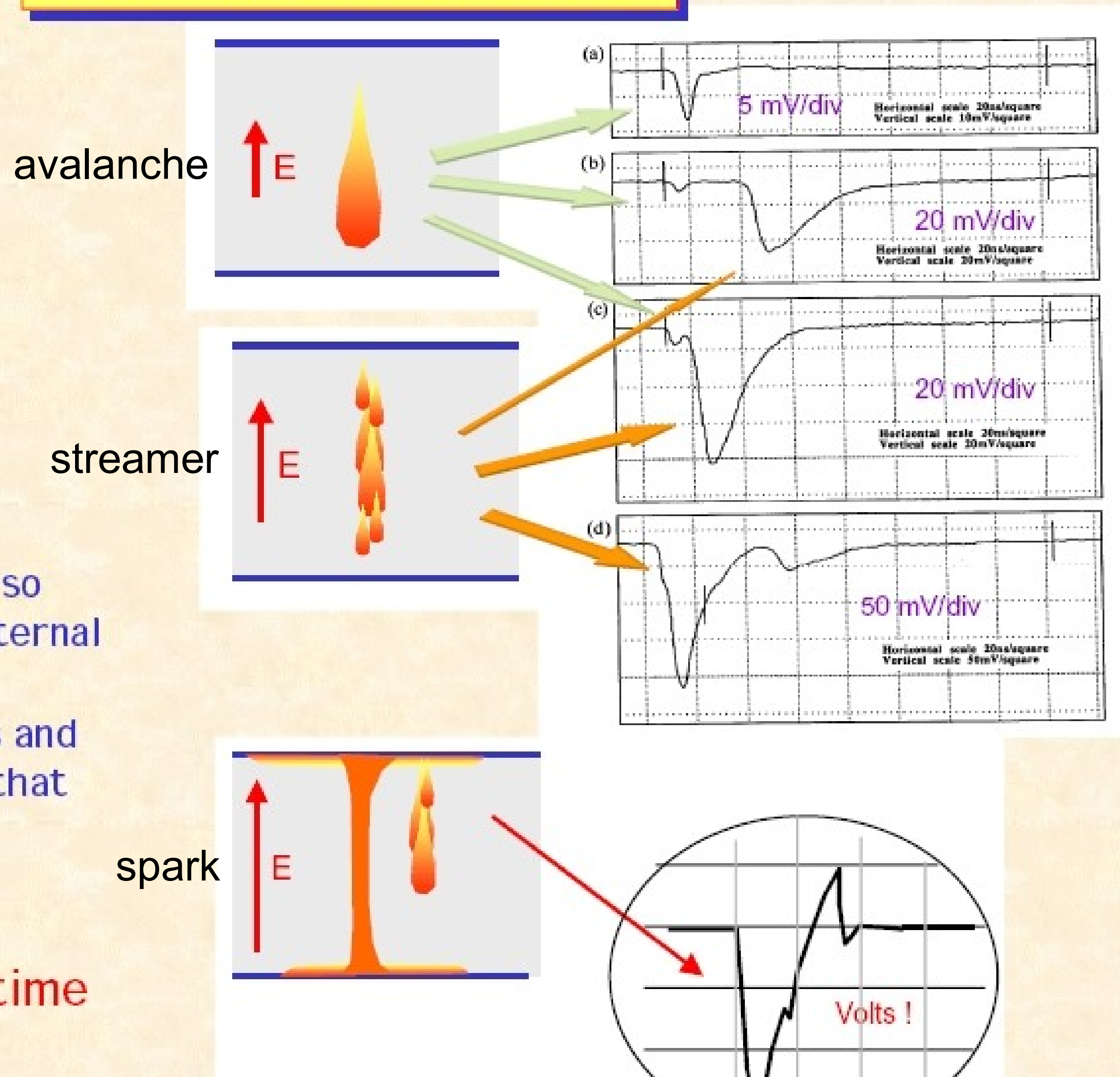
From Avalanche to Spark



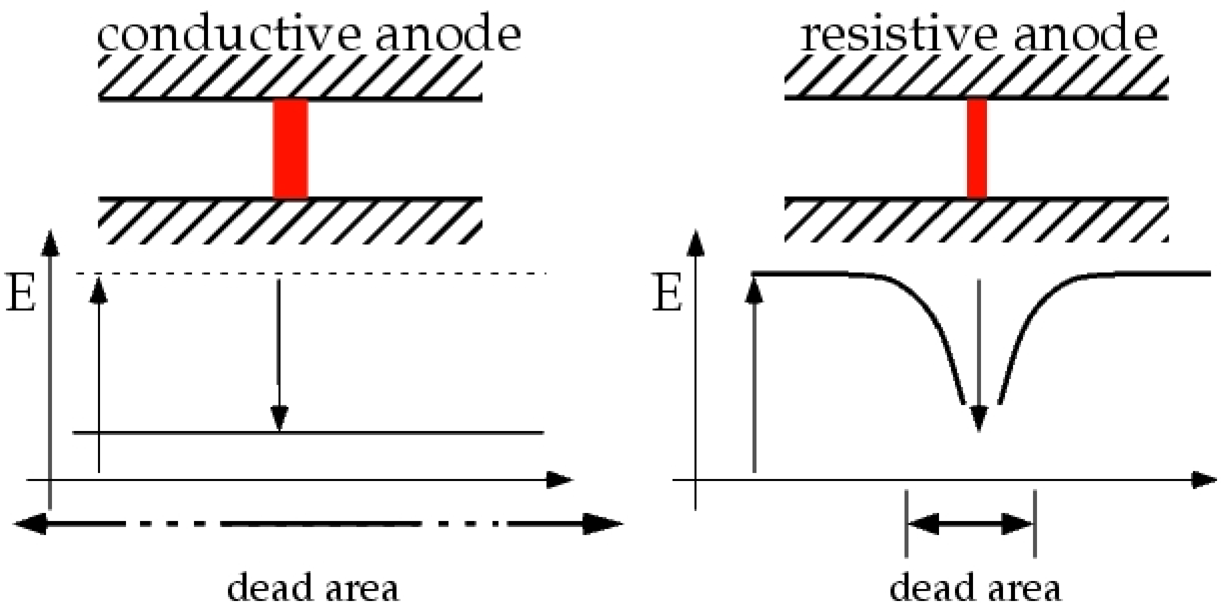


As soon as the number of electrons in the avalanche reaches ~10^8 (Raether's criterium):
the space charge becomes so relevant to balance the external field, the subsequent recombination of electrons and ions generate UV photons that initiate other avalanches (streamer) up to the spark regime

FAST but high dead time

Resistive Electrode principle

Pestov idea:
use as anodic electrode
a high resistivity glass !!
Concept extended to RPCs
with both electrodes with
high resistivity



Principle: a charge Q_0 that enters the resistive electrode surface 'decomposes' with time t following an exponential:

$Q(t) = Q_0 exp(-\tau/t)$ with $\tau = \rho\varepsilon_0\varepsilon_r$

ρ = volume resistivity of the material,

ε_0 = dielectric constant,

ε_r = relative permittivity of the material

$$\tau_{streamer/spark} \ll \tau_{recovery} = \rho\varepsilon \sim 10 \text{ ms}$$

Recovery time long→ electrodes behave as insulators while electrons of the spark reach the anode → the electrical field is quenched only locally (a small region of almost 0.1 cm^2 will appear "dead" for ~ 10 ms)

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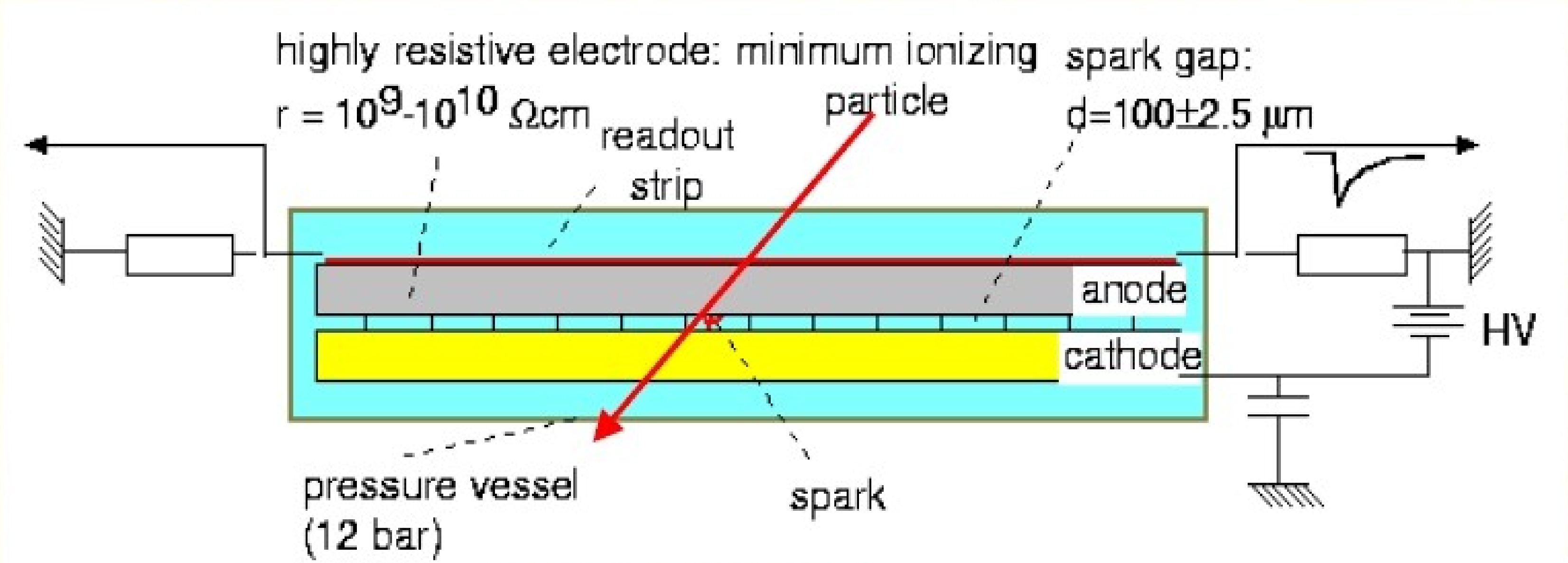
TOF with fast gaseous detectors

1970: Y. Pestov

1st example of resistive plate chamber: glass electrode (Pestov glass)+ metal electrode



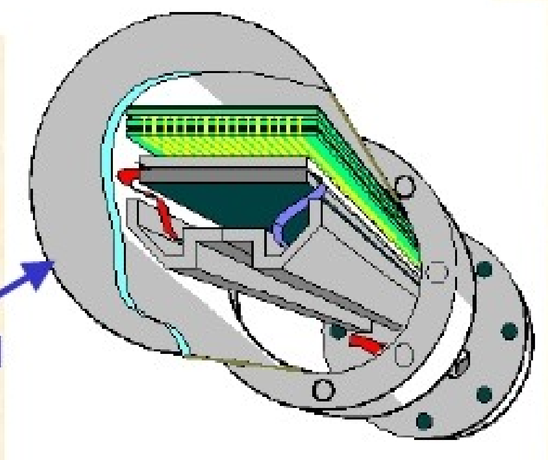
Excellent time resolution ~ 50 ps or better!

Many drawbacks:

- long tail of late events
- mechanical constraints (high pressure)
- non-commercial glass
- nasty gas composition

ALICE R&D
test beam: $\sigma_t \approx 40$ ps !

pressure vessel



Resistive Plate Chamber

- *it was developed in 1981 by R. Santonico & R. Cardarelli (Nuclear Instruments and Methods 187 (1981) 377 - 380)*
- *two parallel plate electrodes; at least one of the electrodes is made of a material with high volume resistivity.*
- *atmospheric pressure operation*
- *lower requirements of mechanical precision*

- *RPC operation*
  - *streamer (discharge mode) – large charge pulses which simplifies the read-out: 2 x 2 mm gaps reach 99 % efficiency and 1 ns time resolution limitation of the rate capability: tens of Hz/cm^2.*
  - *avalanche mode – lower charge pulses, need further amplification*
  - *larger rate capabilities*

Resistive Plate Chamber

Avalance mode RPC operation has two different design:

- ***Trigger RPC***
  - ***Time resolution: ~ 1 ns***
  - ***Spatial resolution: mm ÷ cm***
  - ***Detection efficiency: >95%***

ALICE muon trigger RPCs

- Trigger on high p_T muons from heavy flavour and quarkonia decay
- Two stations of two ~ 6×6 m^2 planes each, 72 RPCs total

- ***Timing RPC***
  - ***Time resolution: < 100 ps***
  - ***Spatial resolution: 200 – 400 µm***
  - ***Detection efficiency: >95%***

Timing RPC –in present: intensive R&D activity for time resolution better than 100 ps , high efficiency (> 95%) at high counting rate (>1 kHz/cm²) .

http://www-aix.gsi.de/conferences/rpc2010/Program_RPC_2010_Linked.html

Designing a Fast Gaseous Detector

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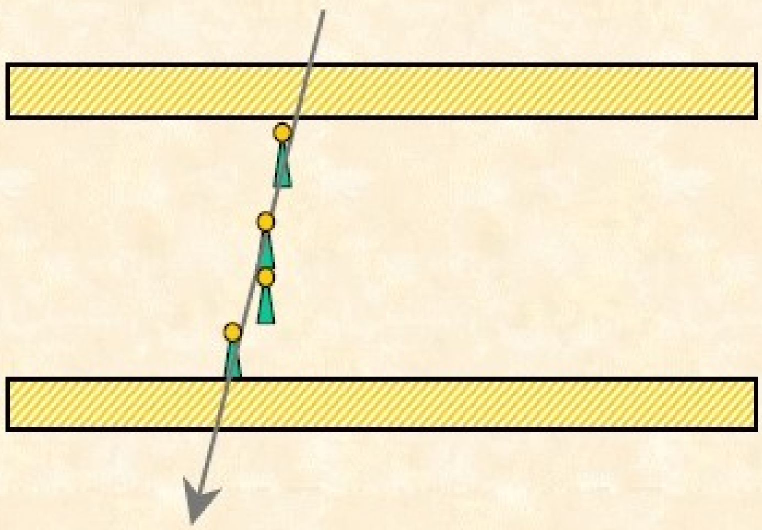
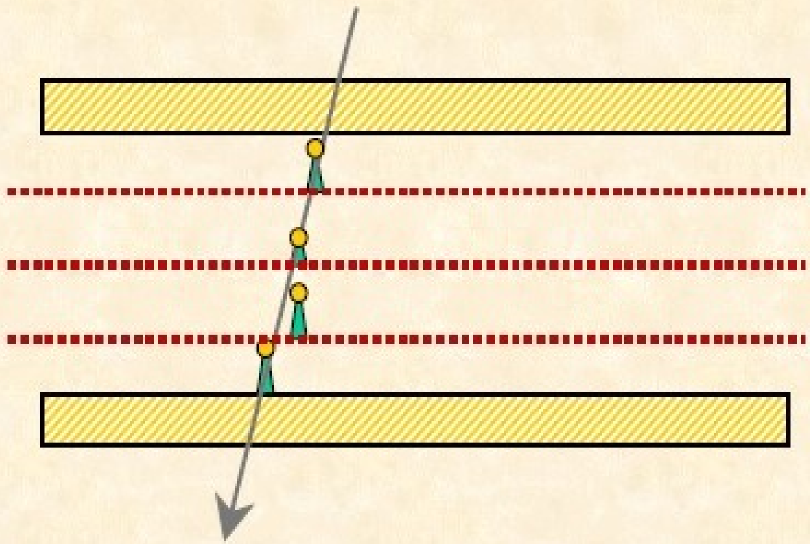
Requirements:

(a) Small gaps to achieve a high time resolution

(b) Very high gas gain (immediate production of signal)

(c) Possibility to stop growth of avalanches (otherwise streamers/sparks will occur)





C. Williams – INFN Bologna (1999):
add boundaries that stop avalanche development. These boundaries must be invisible to the fast induced signal - external pickup electrodes sensitive to any of the avalanches

MULTIGAP RESISTIVE PLATE CHAMBER

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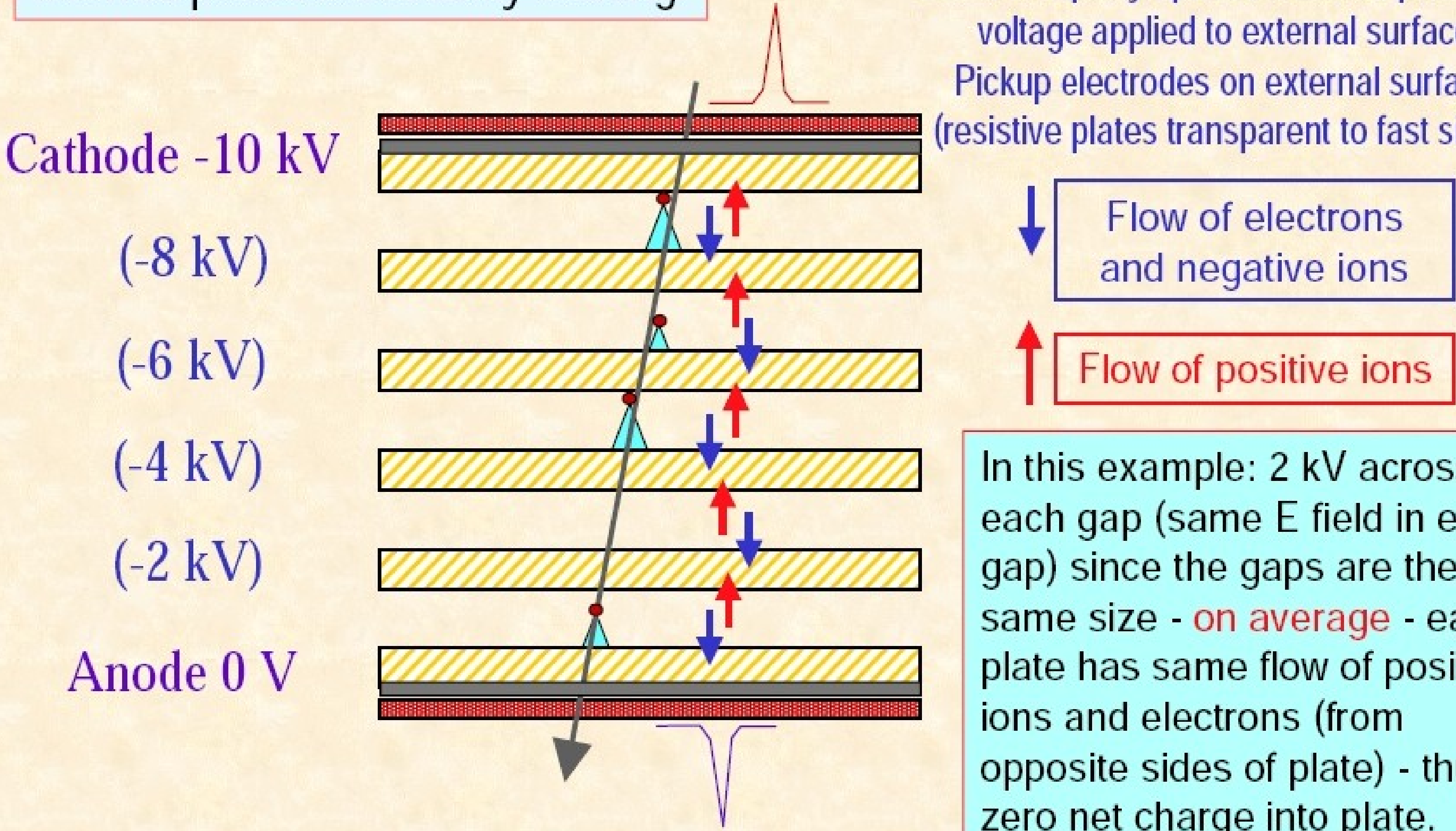
Internal plates electrically floating!

Stack of equally-spaced resistive plates with voltage applied to external surfaces
Pickup electrodes on external surfaces
(resistive plates transparent to fast signal)



In this example: 2 kV across each gap (same E field in each gap) since the gaps are the same size - on average - each plate has same flow of positive ions and electrons (from opposite sides of plate) - thus zero net charge into plate.
STABLE STATE

MGRPC: OPERATIONAL STABILITY

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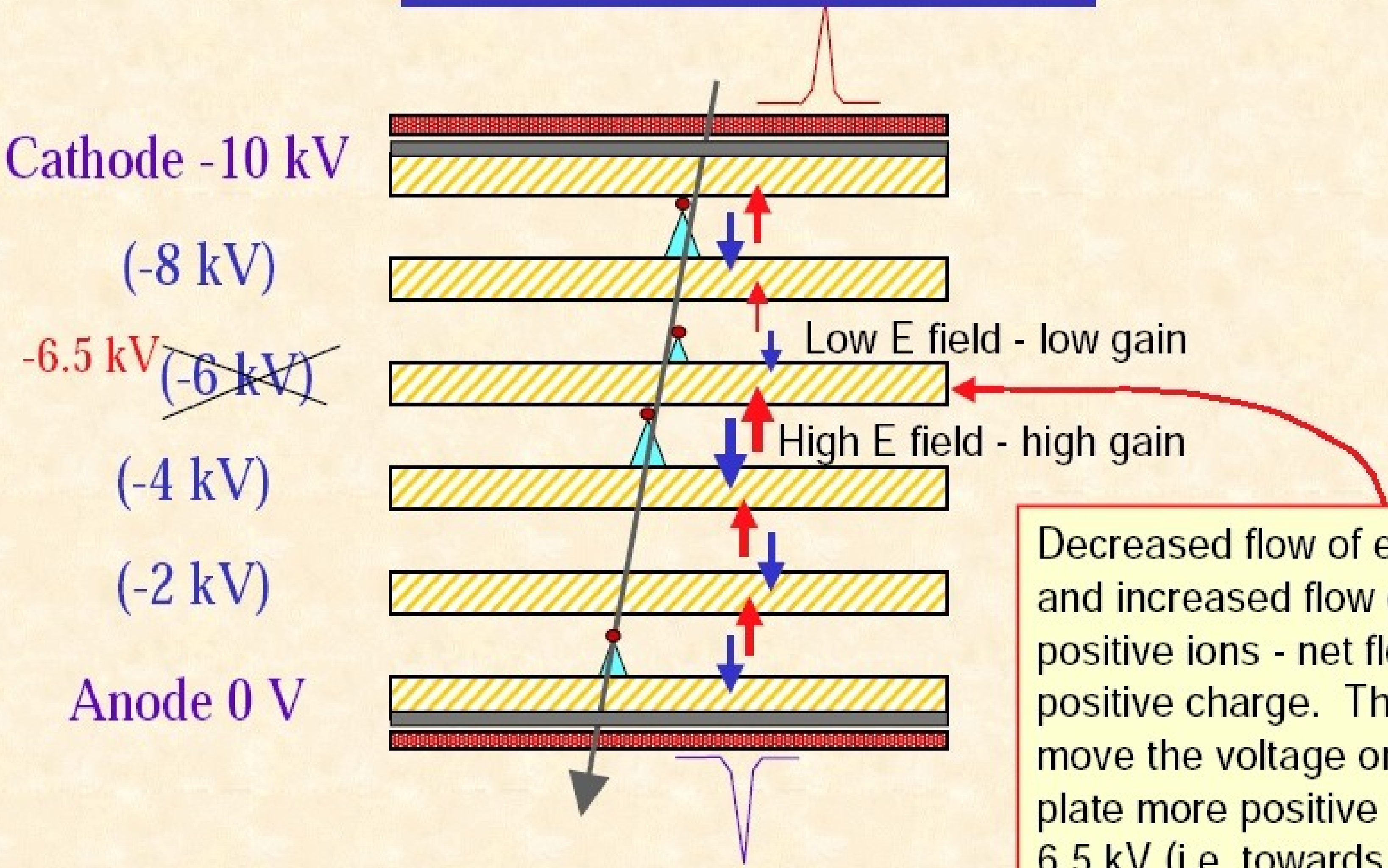


Decreased flow of electrons and increased flow of positive ions - net flow of positive charge. This will move the voltage on this plate more positive than -6.5 kV (i.e. towards 6 kV)

Internal plates take correct voltage - initially due to electrostatics but kept at correct voltage by flow of electrons and positive ions - feedback principle that dictates equal gain in all gas gaps

Gas mixture

Choice of suitable gas mixture is governed by :

- low working voltage

- high gain

- high rate capability

- Need gas mixing unit capable of mixing individual components and control the mixed gas flow through the detector chamber

Gas mixture

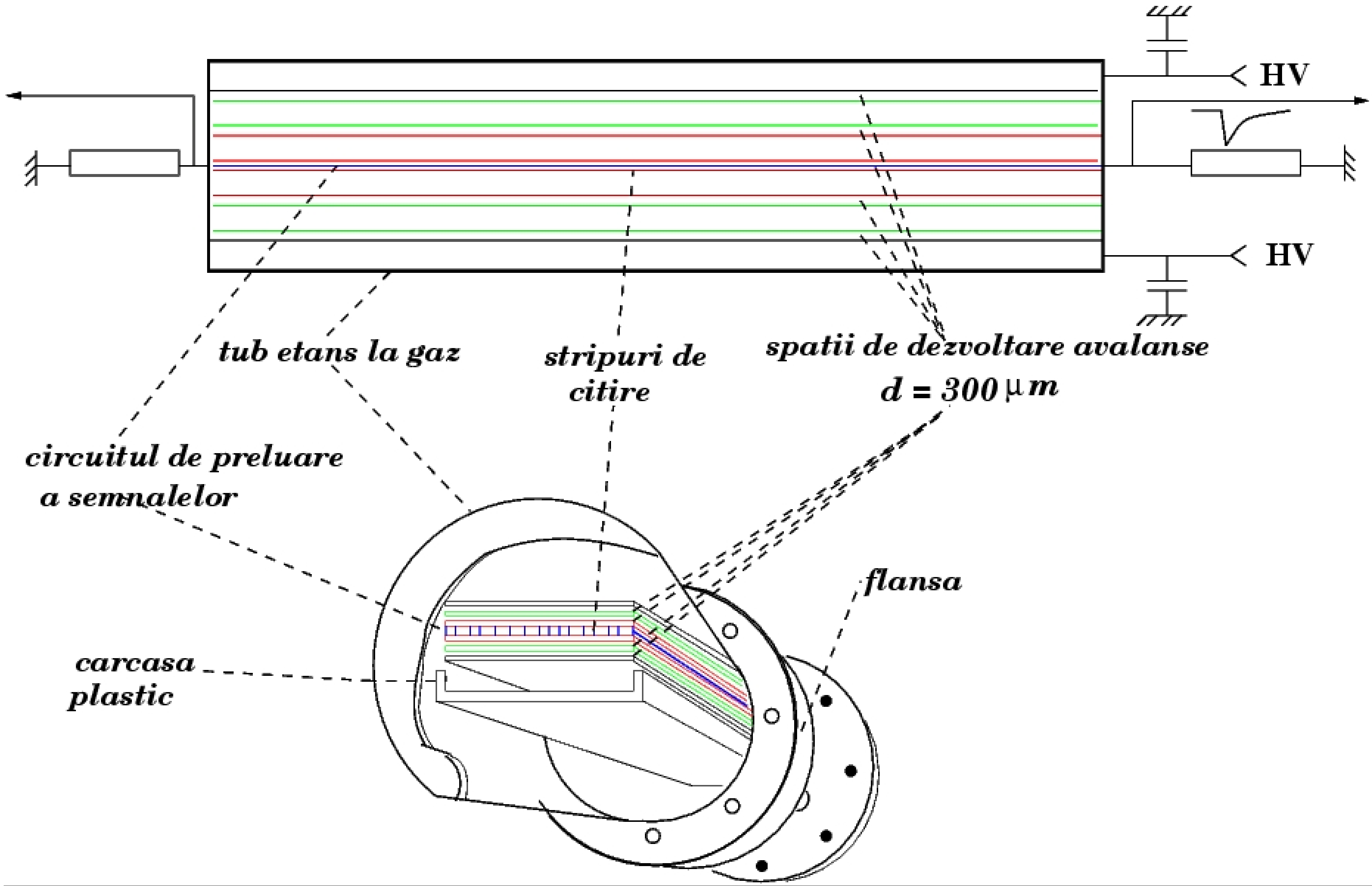
- ***$C_2F_4H_2$ (freon) - high primary ionization:***
  - *high electron affinity*
  - *low operating HV,*
  - *reduced probability of discharges,*
  - *environmentally safe gas*

- ***SF_6(hexafluoride) – electronegative gas:***
  - *high electron affinity*
  - *reduced discharges probability*
  - *large HV operation plateau*

- ***C_4H_{10}(izo-butan) - quencher:***
  - *aborbtion of UV photons which are radiated from the de-excitation of the molecules*

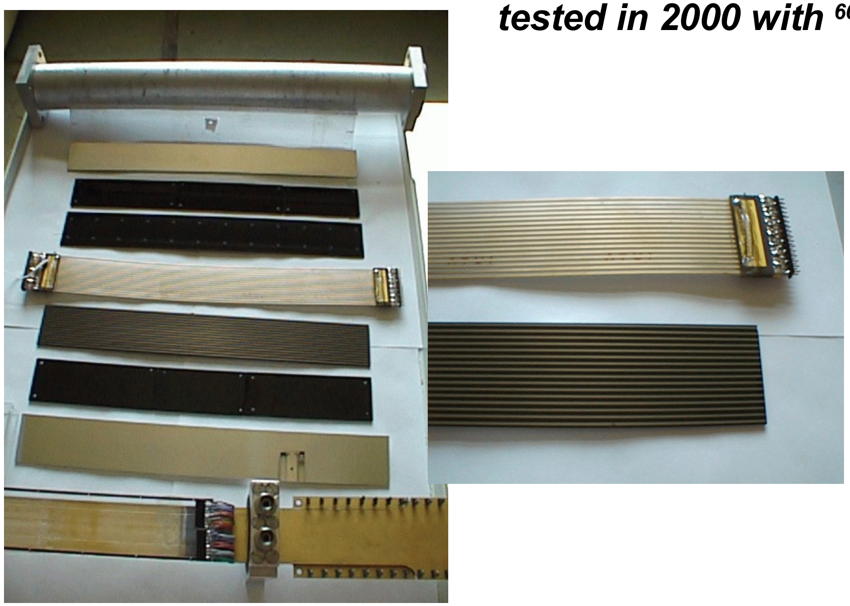
85% $C_2F_4H_2$ + 10%SF_6+5%C_4H_{10}
circulated at atmospheric pressure

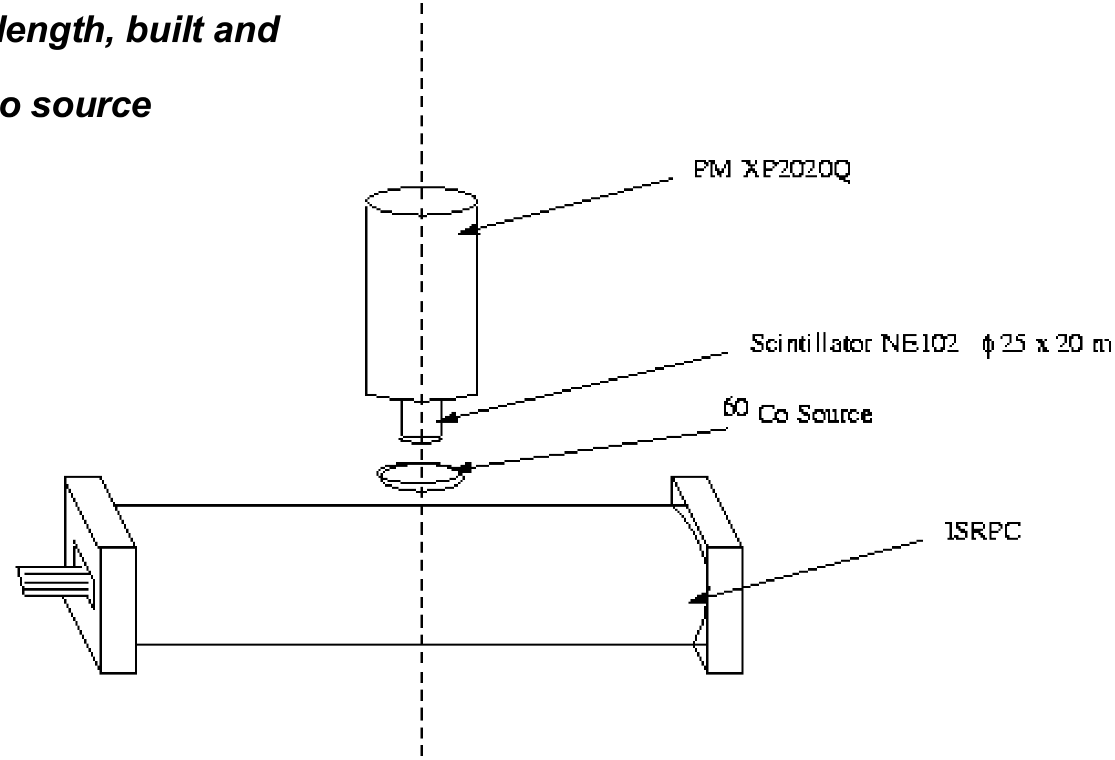
Our proposal for a MSMGRPC

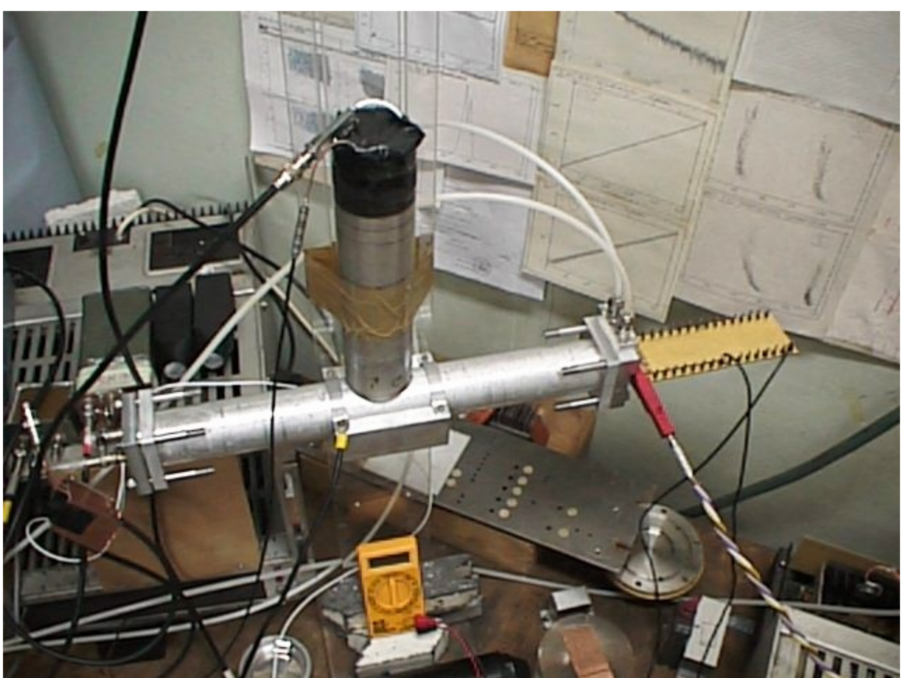


Our proposal for a MSMGRPC

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



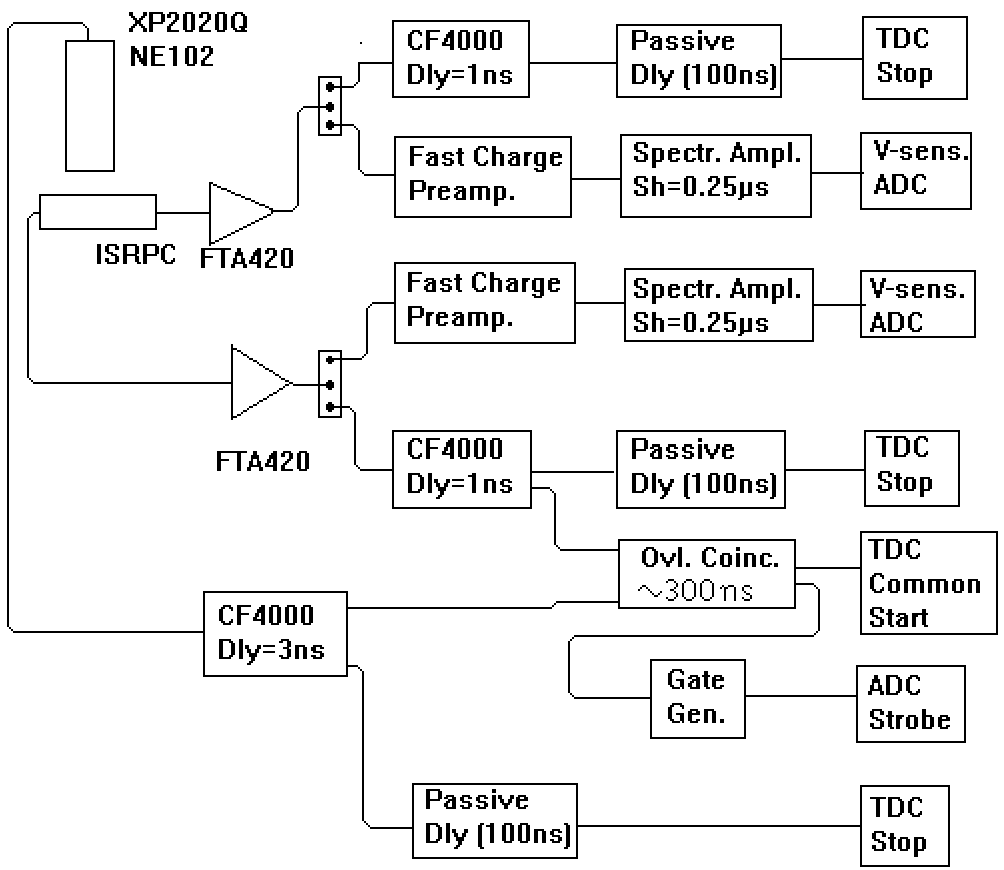




$$85\%C_2F_4H2 + 10\%SF_6 + 5\%C_4H_{10}$$

Applied HV = 5800 V → 2900 V/gas gap

Block diagram for time of flight measurements with ^{60}Co for a single strip readout at both ends



- *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*

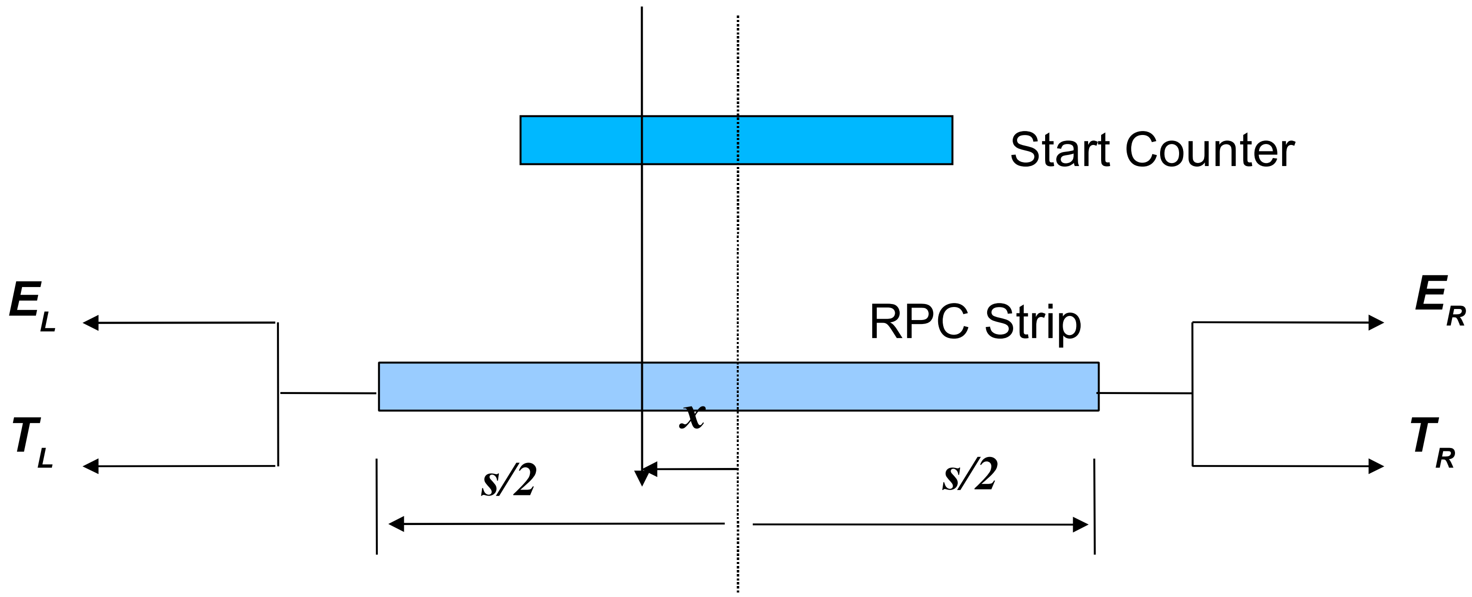
  Plastic scintillator (NE102)

  - *XP2020 PM + CF4000 Discriminator*

  Digitization

  - *LeCroy 2228A TDC*

Strip Readout Information



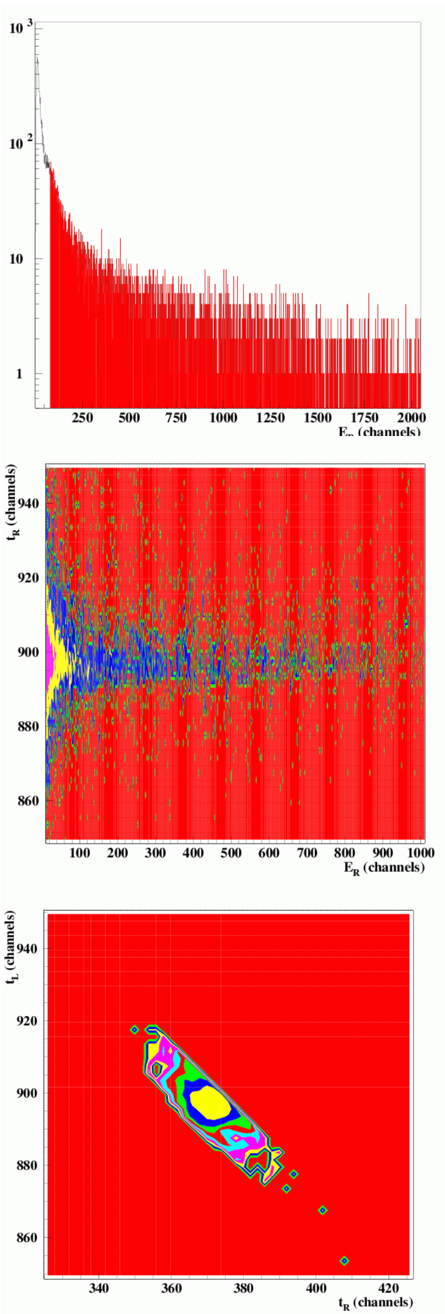
$$T_L = ToF + (s/2 - x)/v_s$$

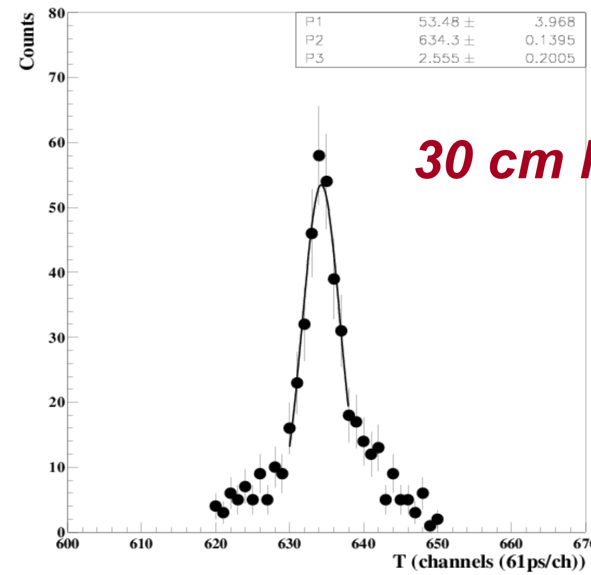
$$T_R = ToF + (s/2 + x)/v_s$$

$$T_{mean} = (T_L + T_R)/2 = ToF + s/v_s$$

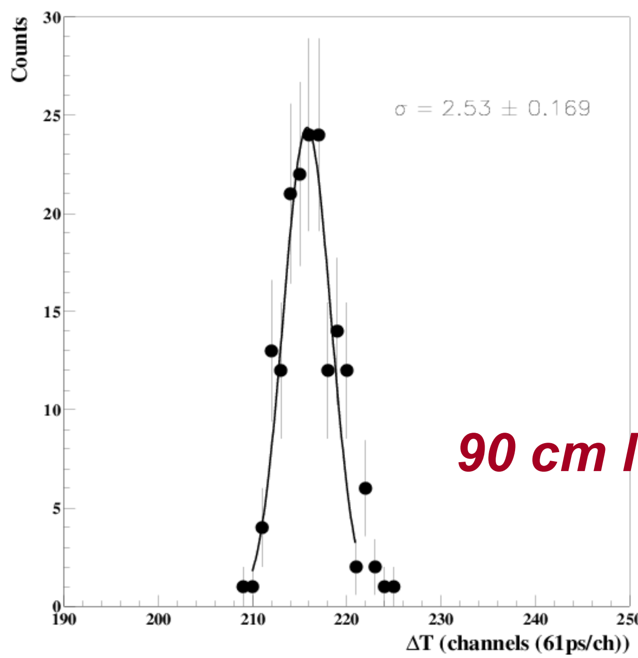
$$T_{diff} = (T_R - T_L) = 2x/v_s$$

First Results



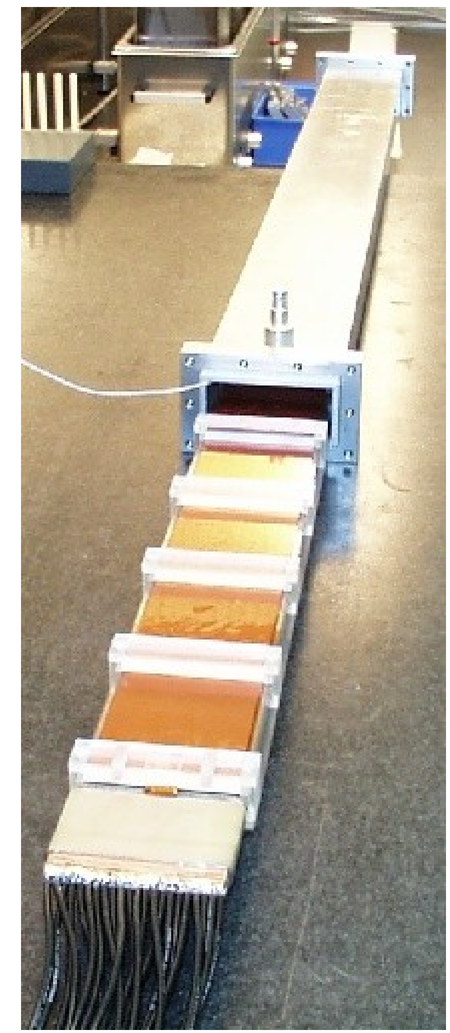


30 cm length

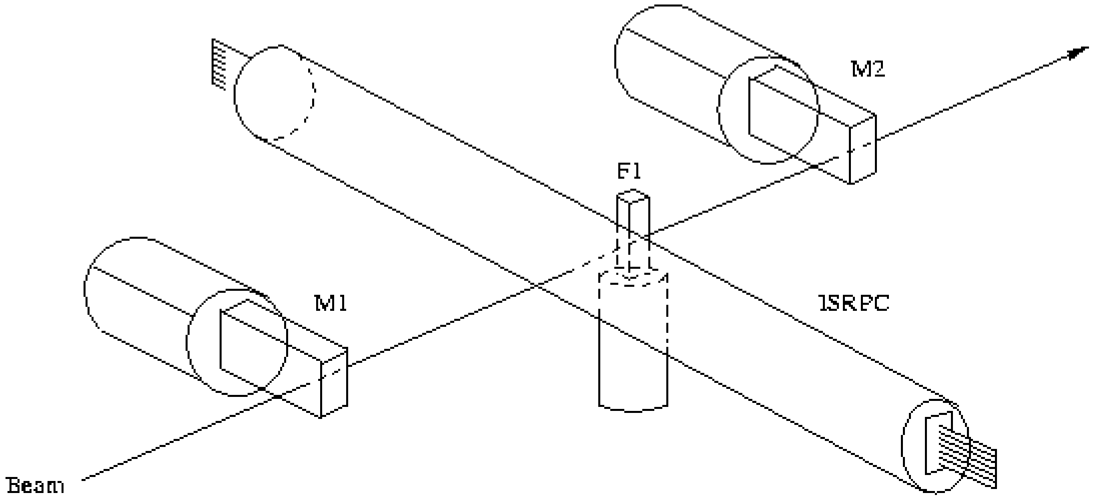


90 cm length

Subtracting the contribution of the plastic scintillator (125 ps), the intrinsic time resolution was 93 ps for 30 cm length counter and 90 ps for 90 cm length counter



In Beam Tests at the SIS Accelerator of GSI - Darmstadt



Beam: MIPs (p,d 1.5 GeV)

Time reference: 2 crossed scintillators (M1 and M2)

·*Time measurements*

FEE

- DBA +LE CES-510 (CERN)

Discriminator

Plastic scintillator

- CF4000 Discriminator

Digitization

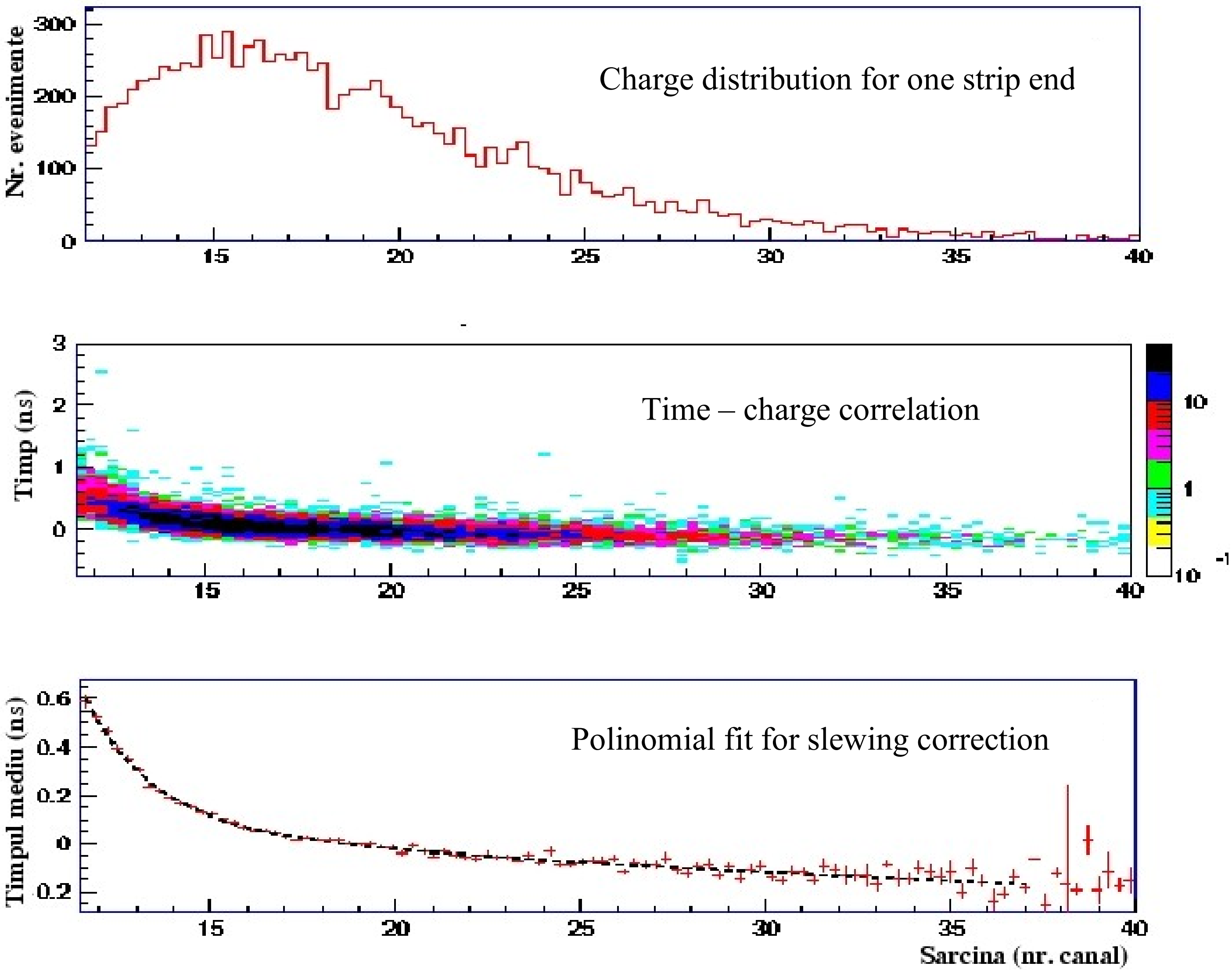
- LeCroy 2228A TDC

·*Amplitude measurements*

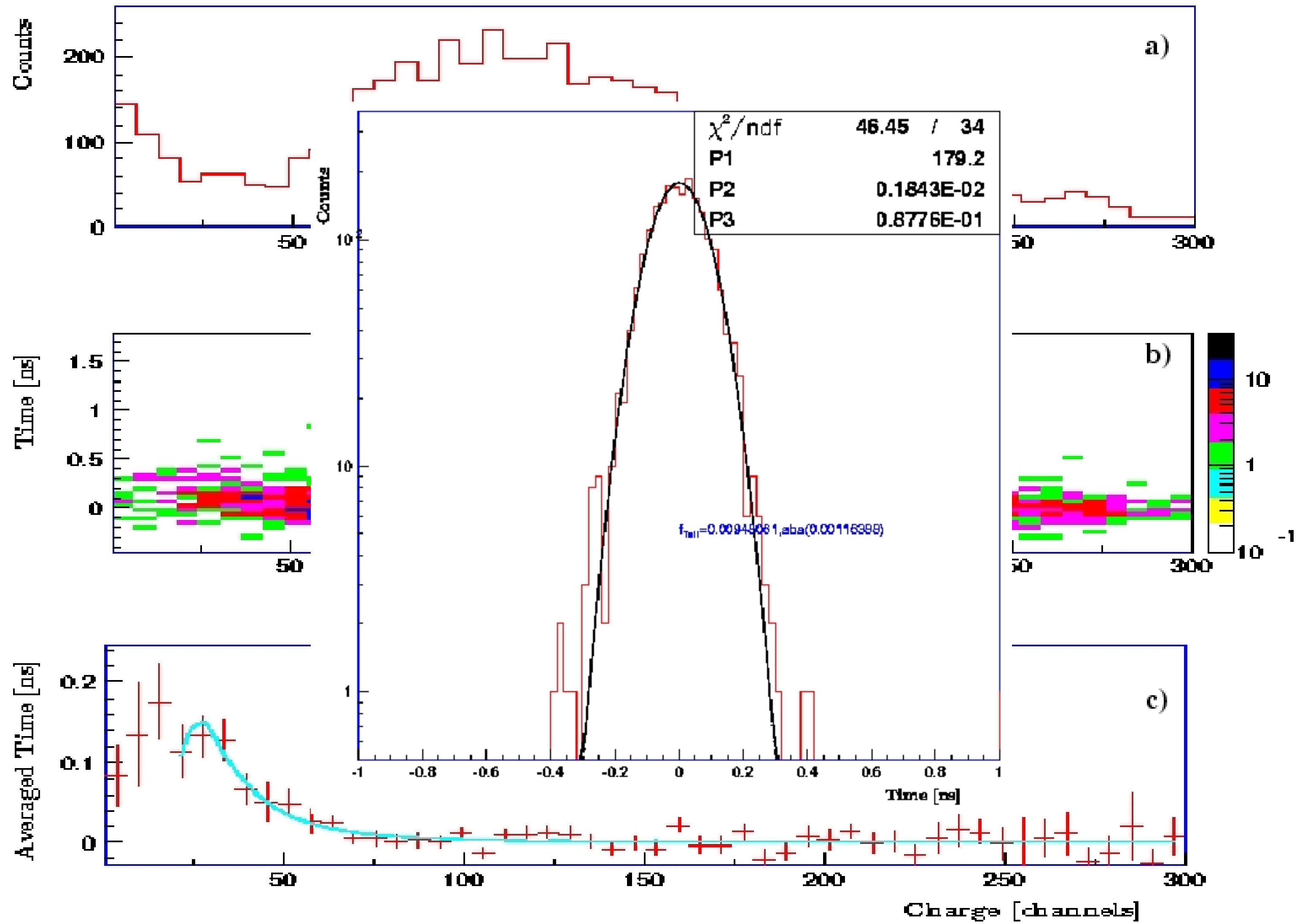
Digitization

- LeCroy ADC 2249W

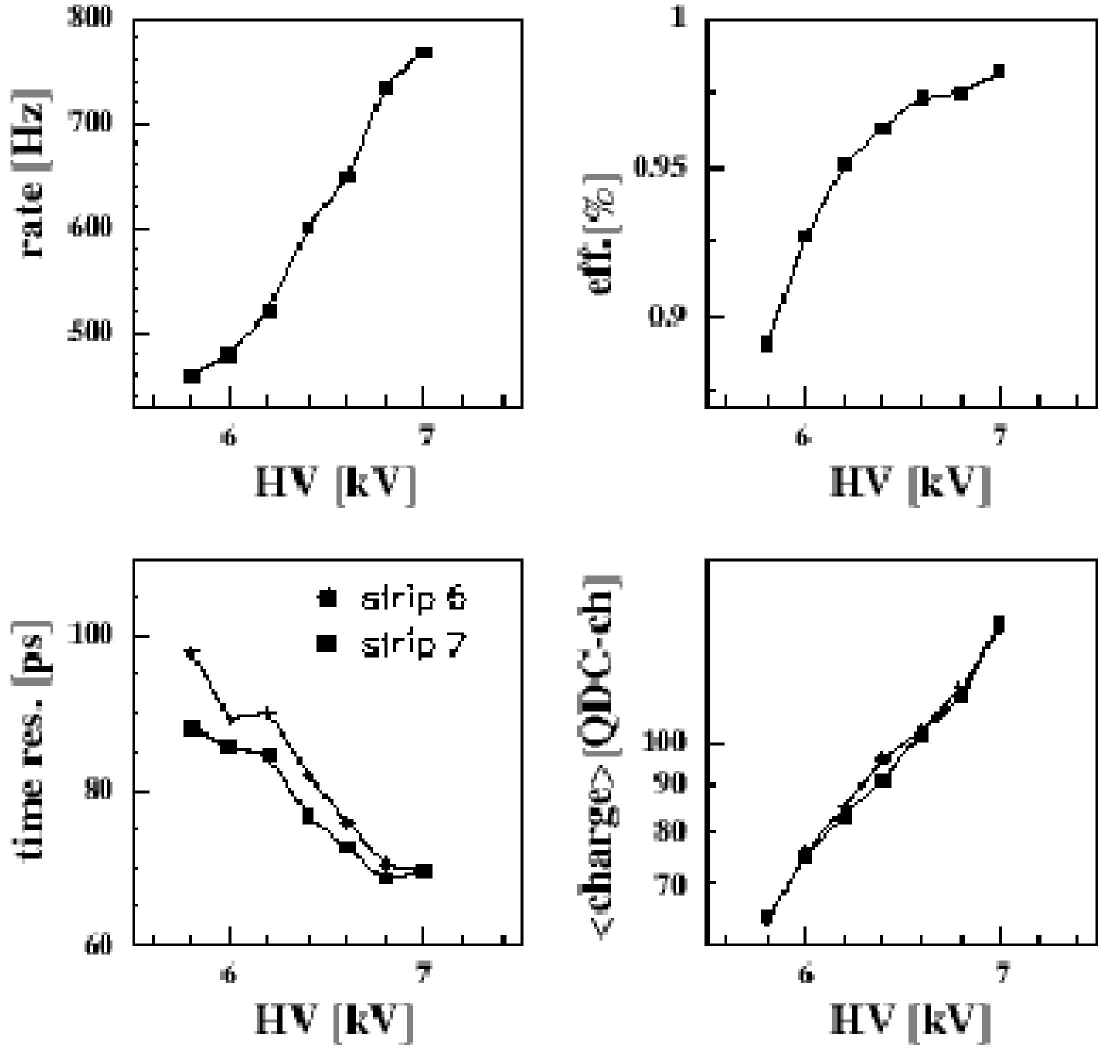
Typical Data Analysis



Typical Data Analysis



Typical Data Analysis for MGMSRPC

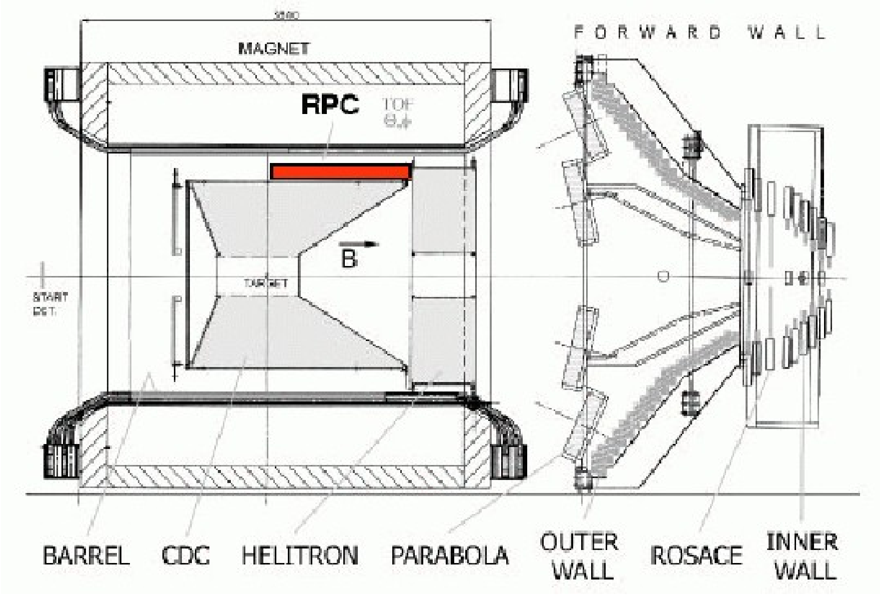


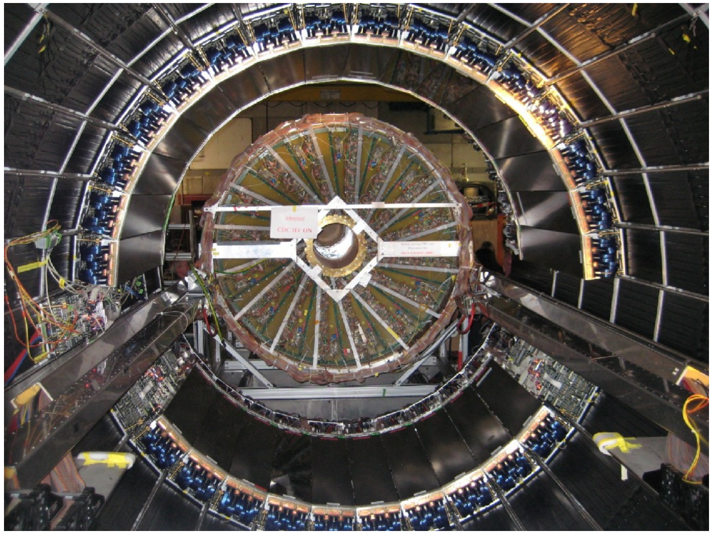
Position resolution:

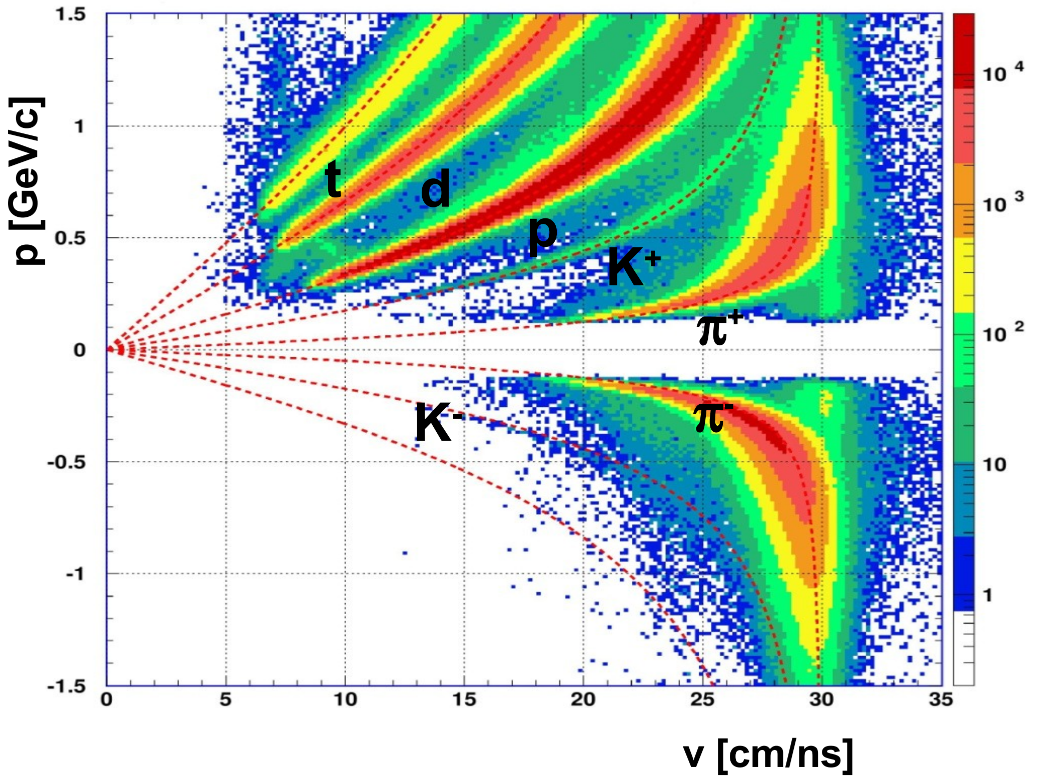
- along the strip: 5-6 mm
- across the strips: 300 – 400 µm (estimated).

- *M. Petrovici et al., Nucl. Instr. And Methods, A508 (2003), 75*
- *M. Petrovici et al., Nucl. Instr. And Methods, A487 (2002), 337*

The upgrading of the FOPI-TOF barrel is based on this type of architecture



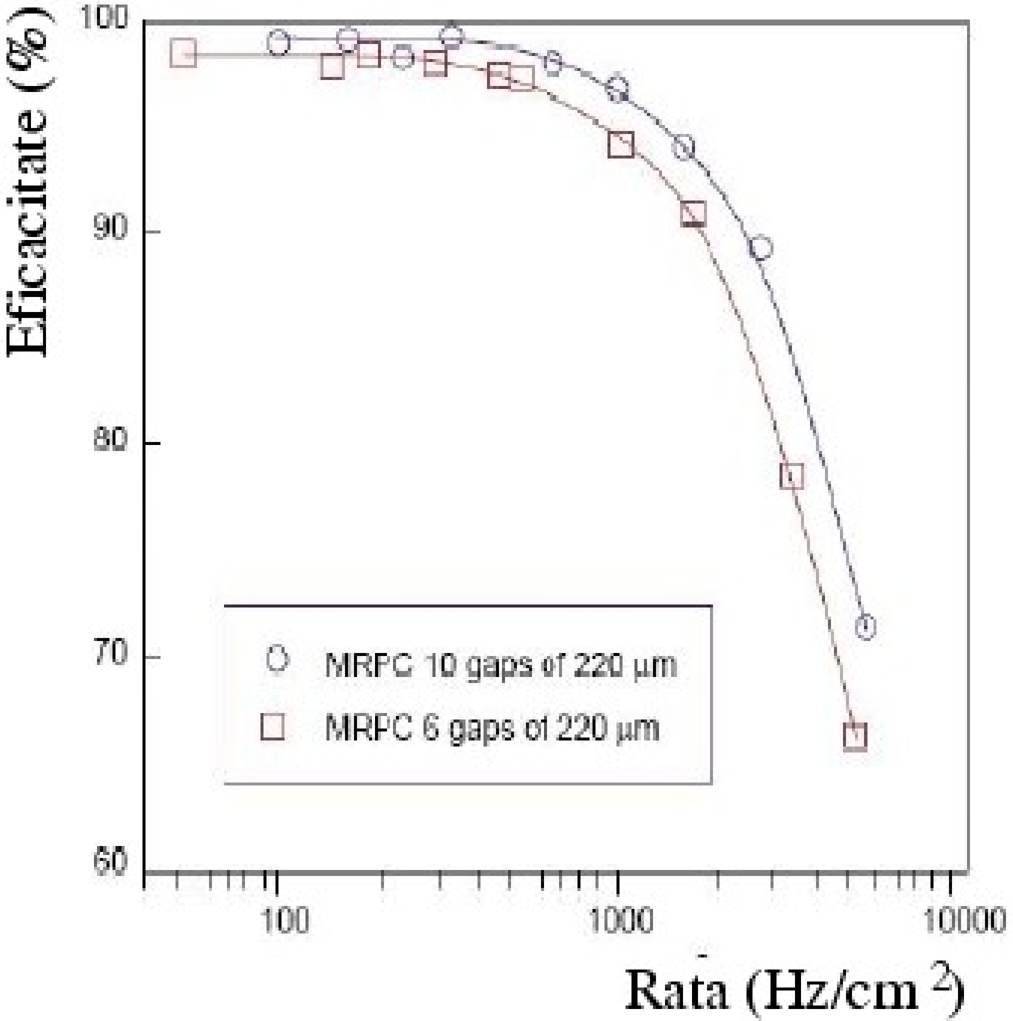




A. Schuttauf et al., Nucl.Phys. B – Proc. Suppl. 158(2006), 52

Rate Capability

Resistive electrodes – float glass of 10^{12} – 10^{13} Ωcm resistivity



CBM-TOF wall requirements

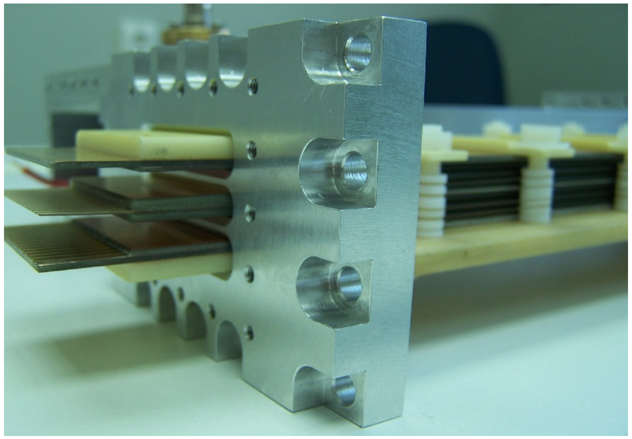
- ***Interaction rate 10^7Hz (~1000 tracks/event)***
- ***TOF wall at 10 m from 3º to 27º***
- ***Rate from 1 kHz/cm² (27º) to 20 kHz/cm² (3º)***
- ***Hit density from $6 \cdot 10^{-2}$/dm² to 1/dm²***

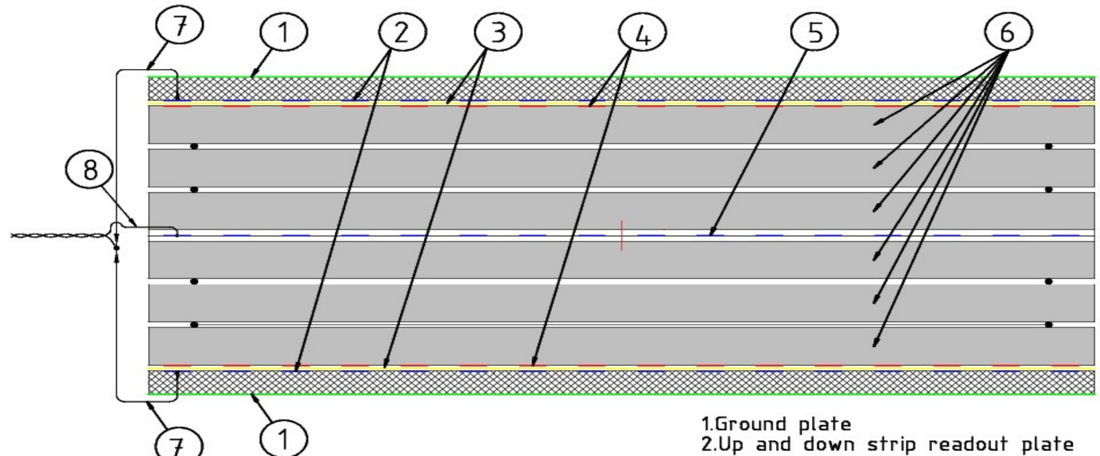
  ⇒ more than 60,000 cells for <5% occupancy
- ***Total area > 60 m²***

RPC Counting Rate Performance

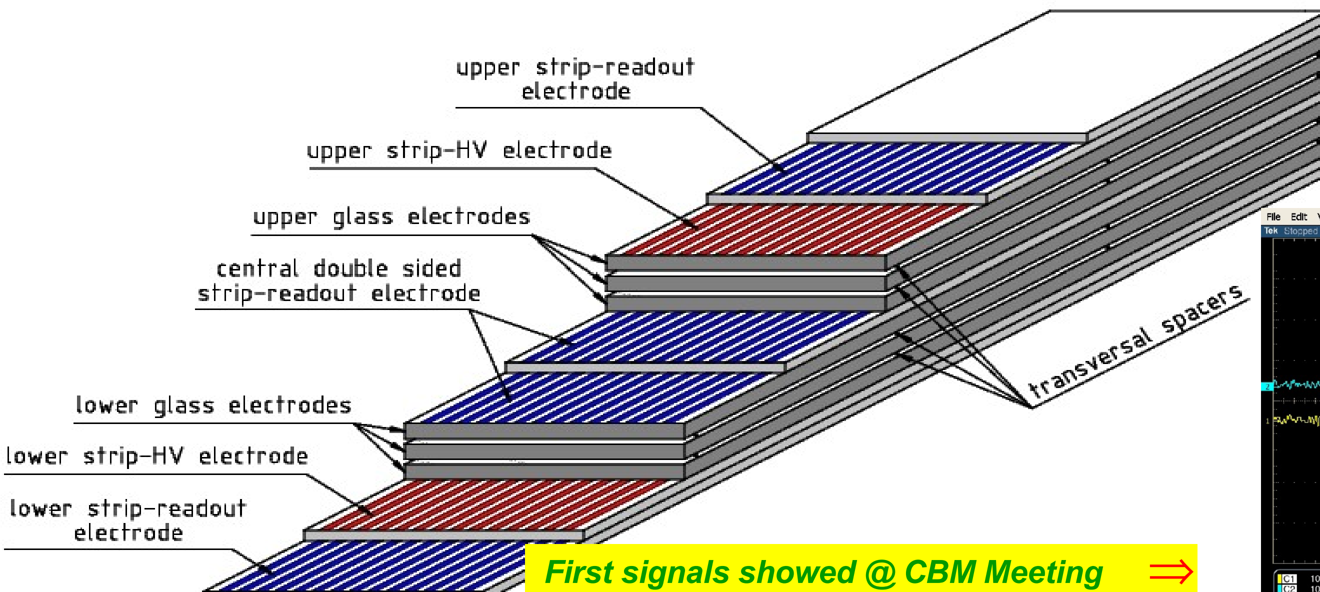
- MSMGRPC based on commercial float glass ($\rho_{glass} \sim 10^{12}\ \Omega cm$) keeps the performances up to ~1 kHz/cm^2 ; this type of RPC could be a solution for a major part of the CBM - TOF subdetector.
- CBM - TOF subdetector at small polar angles – high counting rate environment (up to 20 kHz/cm^2).
- Solutions:
  - Electrodes with lower resistivity
  - Smaller and many gaps
- Our prototypes were built using Pestov glass with $\rho \sim 10^{10}\ \Omega cm$.

Differential Strip – Readout Pestov Glass RPC Prototype



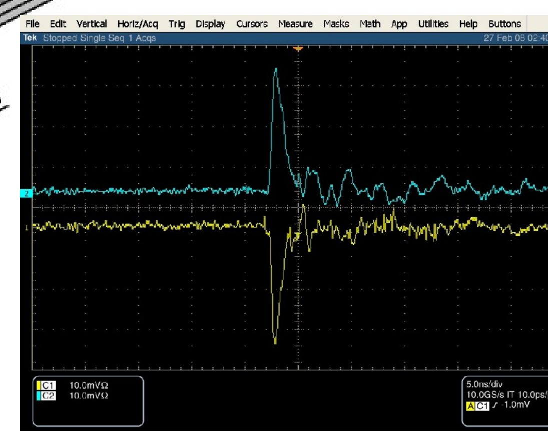


1.Ground plate
2.Up and down strip readout plate
3.Mylar foil
4.Up and down HV plate
5.Central strip readout plate
6.Pestov glass electrodes
7.Up and down strip readout plate signal
8.Central strip readout plate signal

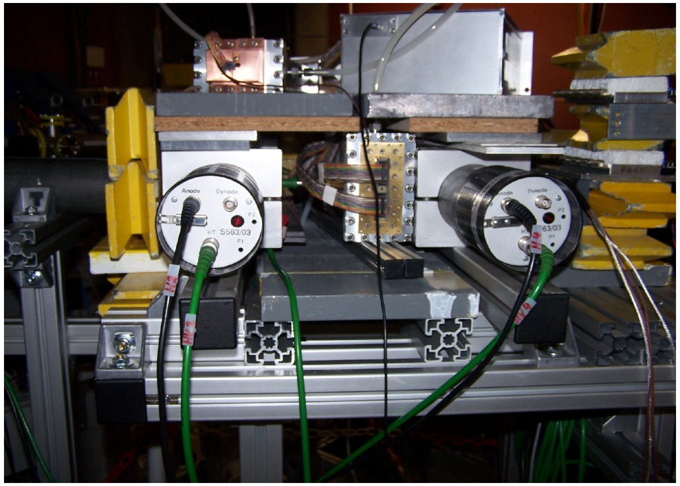


Gap size = 300 μm

First signals showed @ CBM Meeting Feb. 2008, GSI ⇒

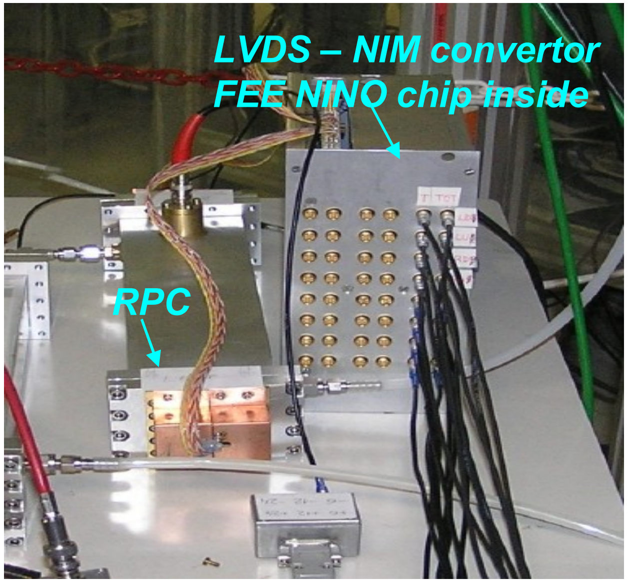


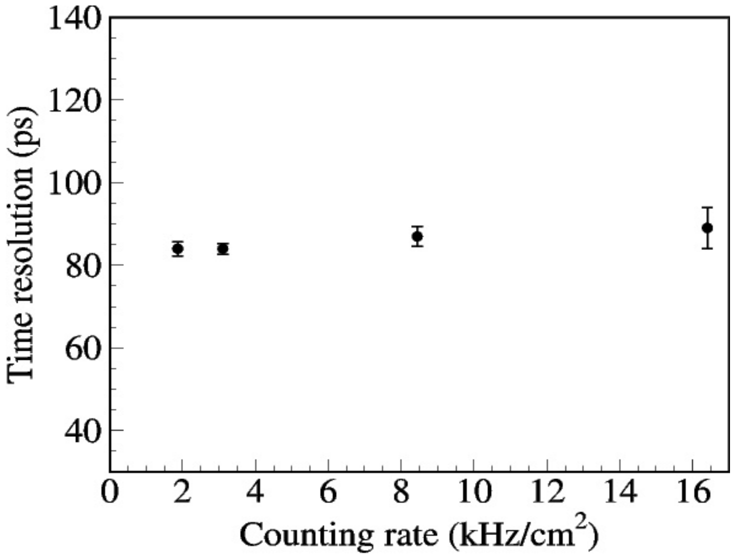
In-Beam Tests @ ELBE



Experimental set-up:

- ***electron beam, 28 MeV, scattered @ 45^0 by a 18 μm Al foil***
- ***plastic scintillators S5(XP2972), S12(XP2020), S34(XP2020), (2×2 cm^2) used for active collimation***
- ***signal amplification: differential readout based on NINO chip developed within ALICE Collaboration***
- ***digital converters: CAEN TDC V1290N***
- ***DAQ – MBS***
- ***information recorded for 2 central strips***





M. Petris et al. CBM Collaboration Meeting, 13-18 October, 2008, Dubna, Russia

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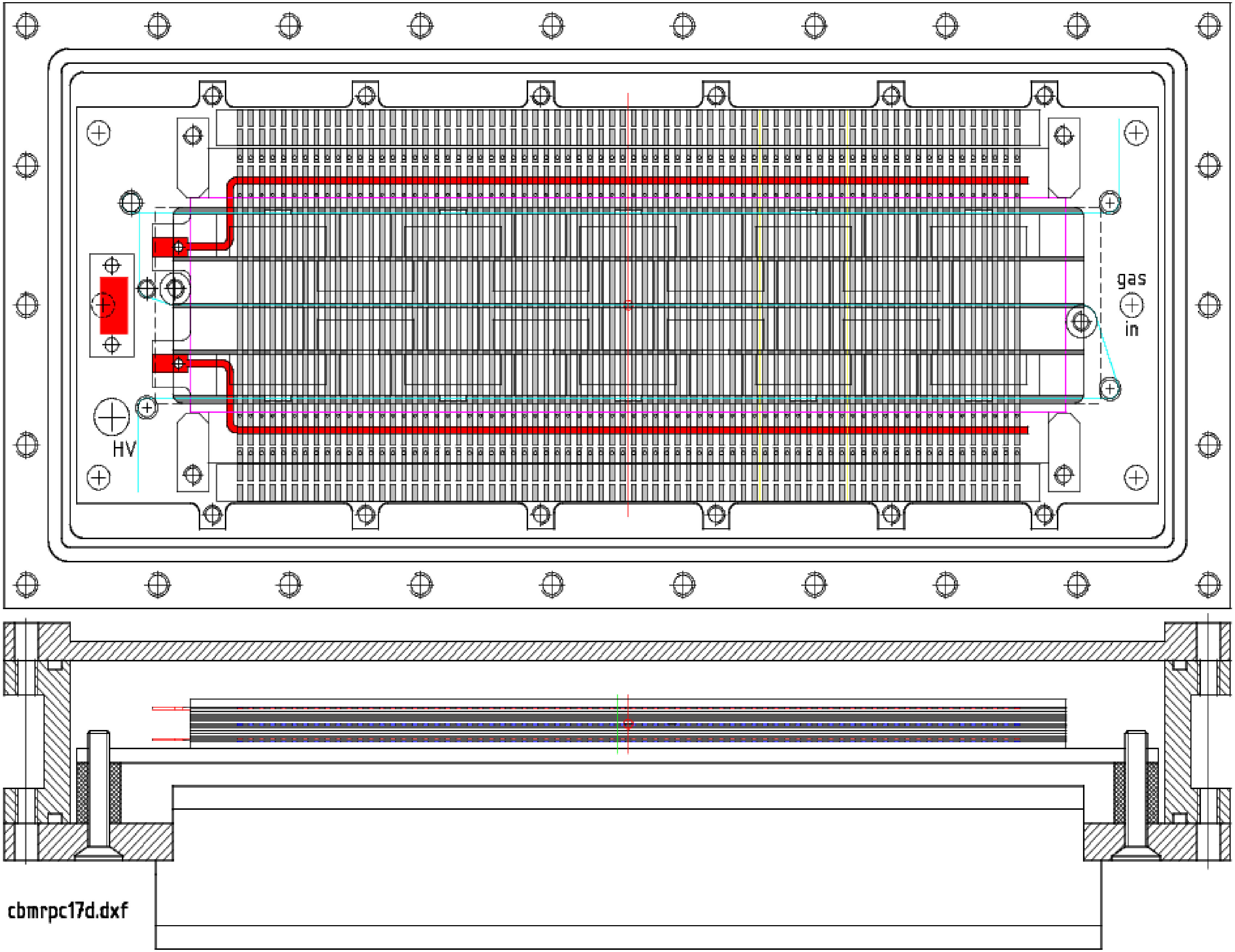
⇒ more than 60,000 cells for <5% occupancy

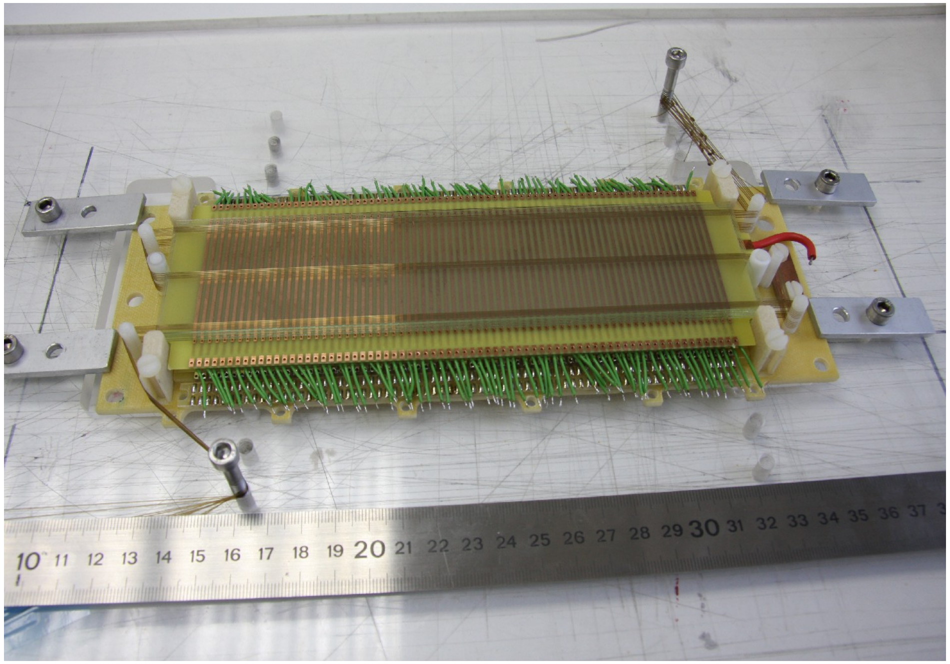
- *Total area > 60 m²*

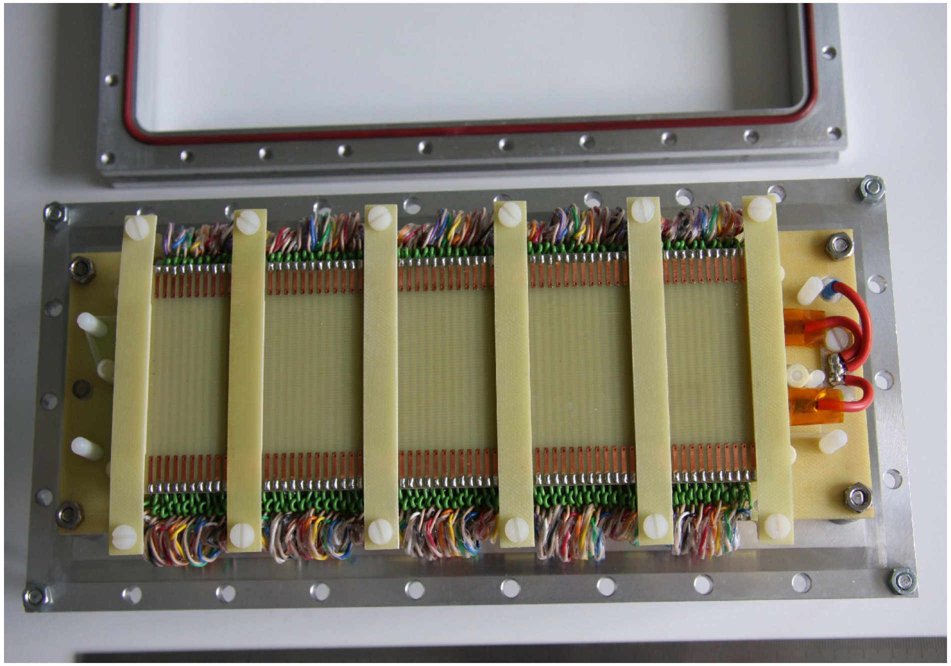
High granularity HCRRPC

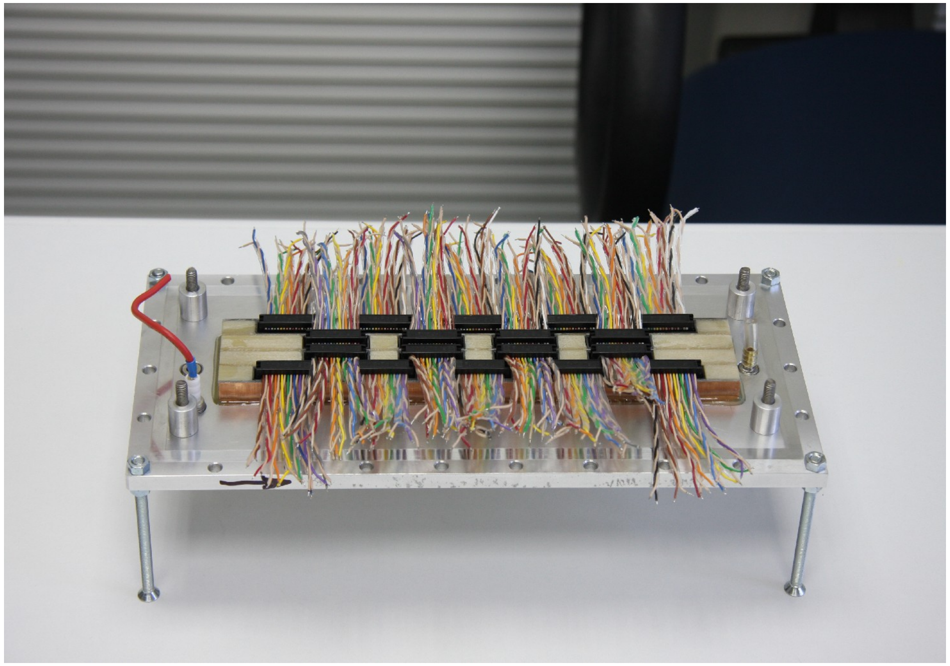


HV distribution

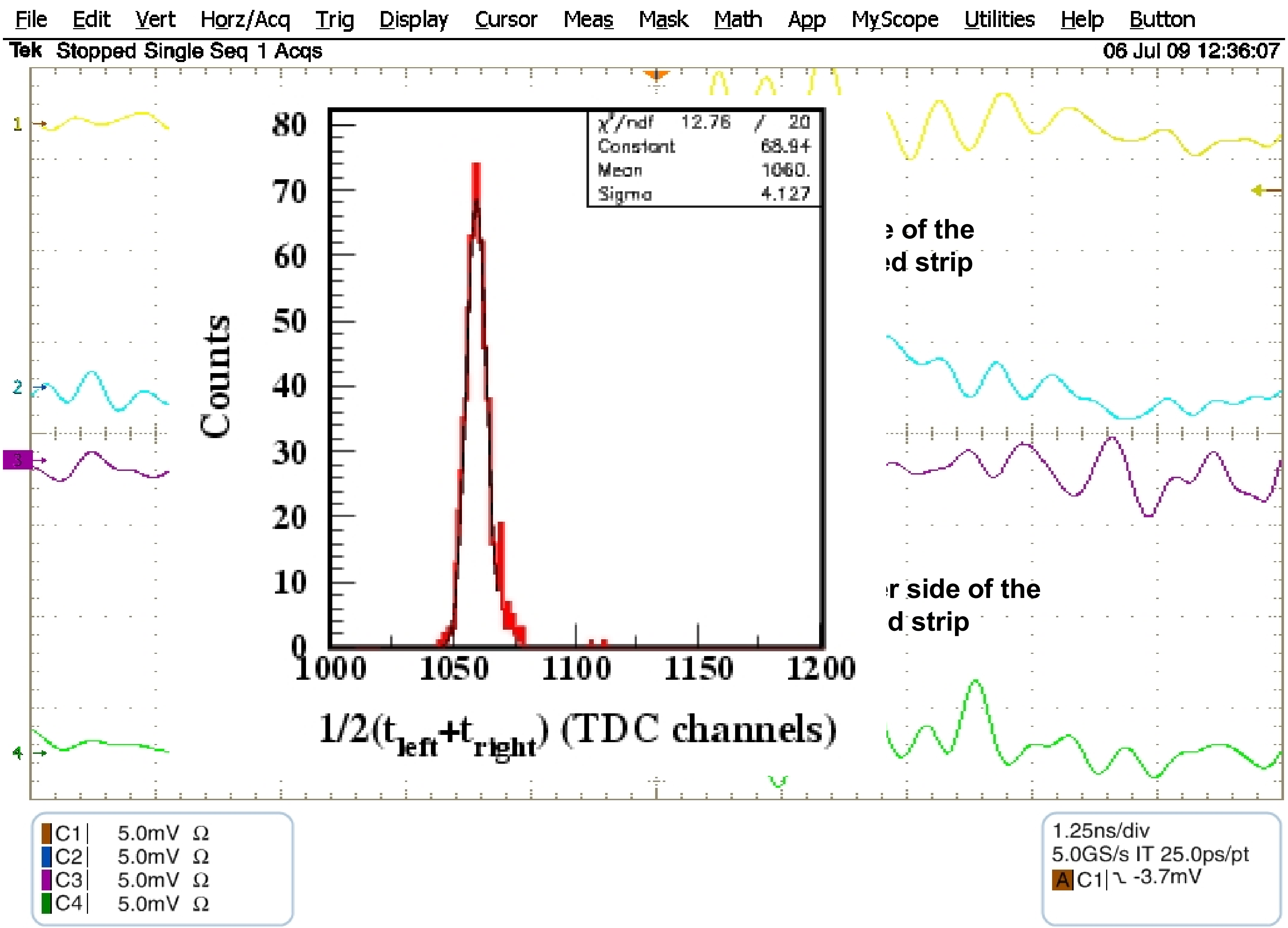
Construction Details



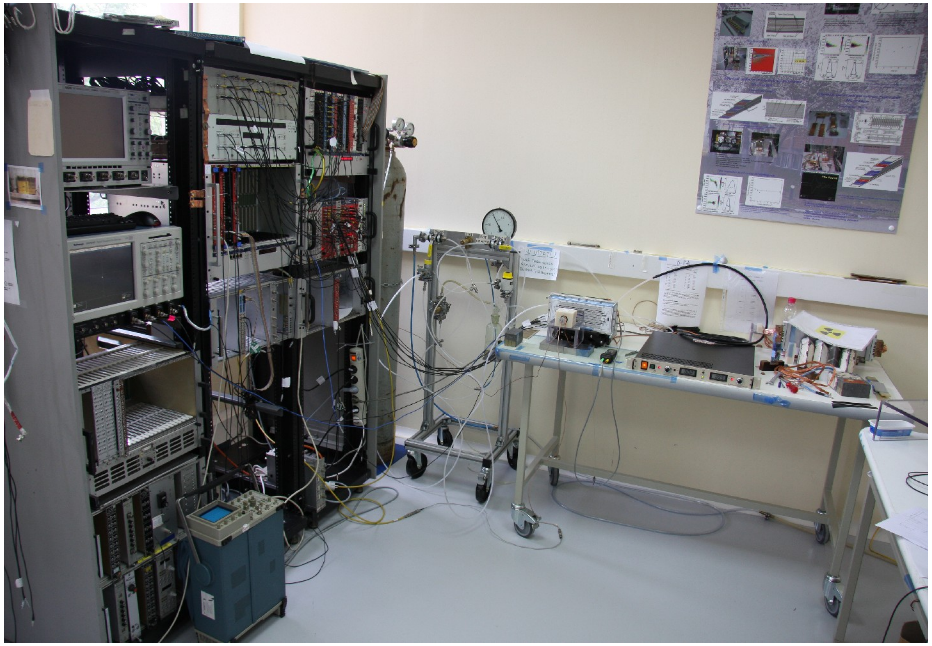


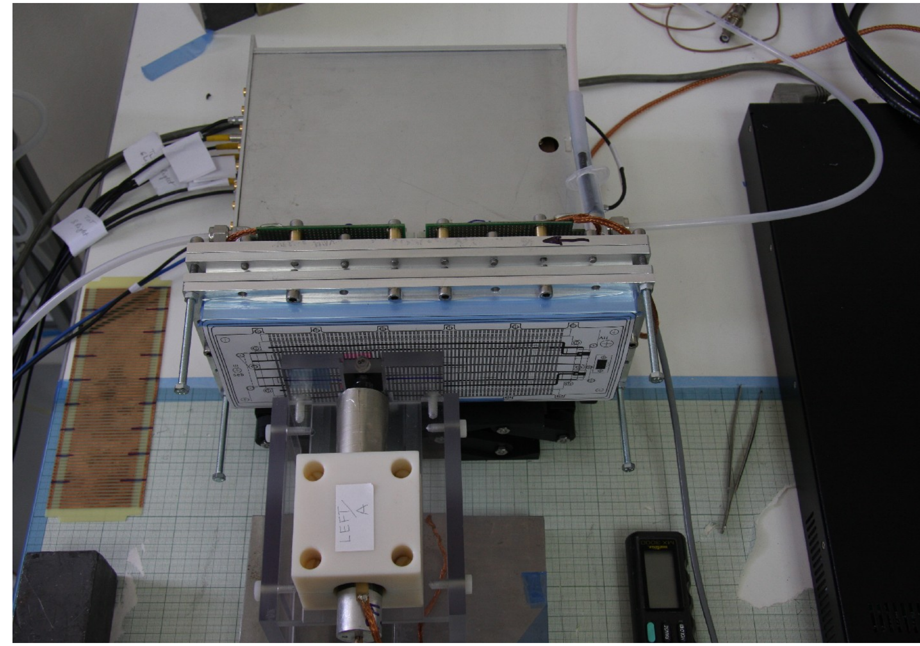


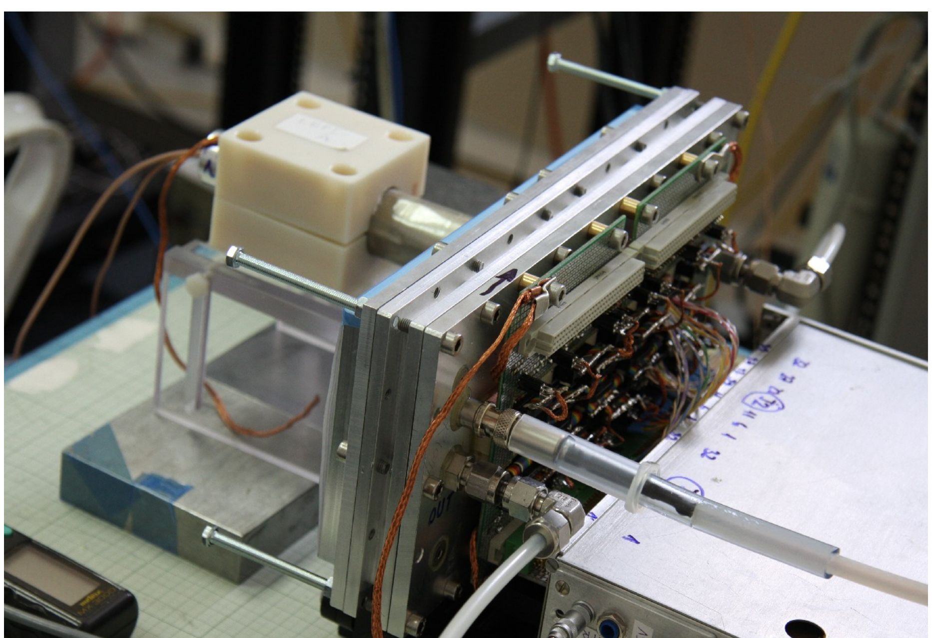
^{60}Co signals recorded from one strip without any amplification

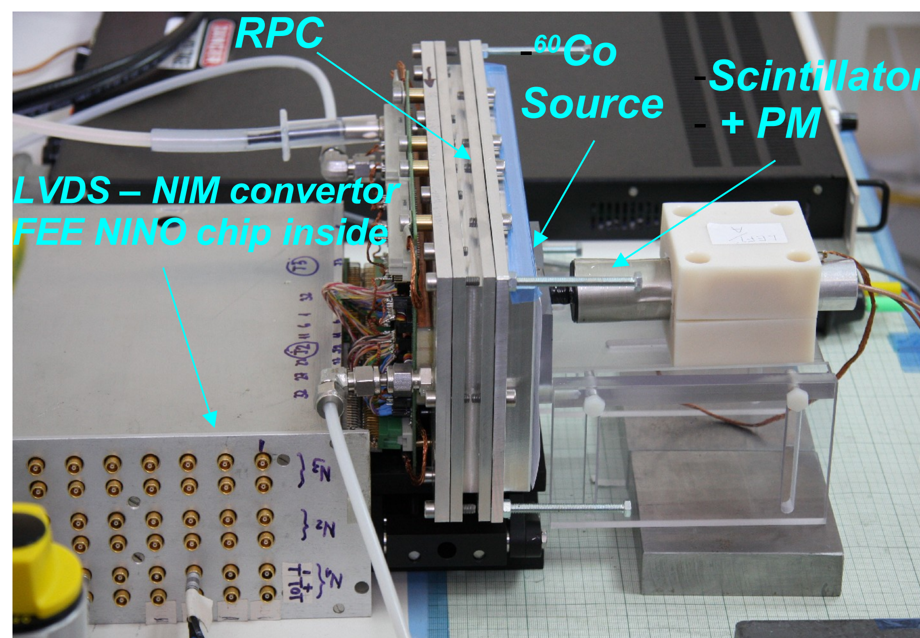


^{60}Co source test set-up

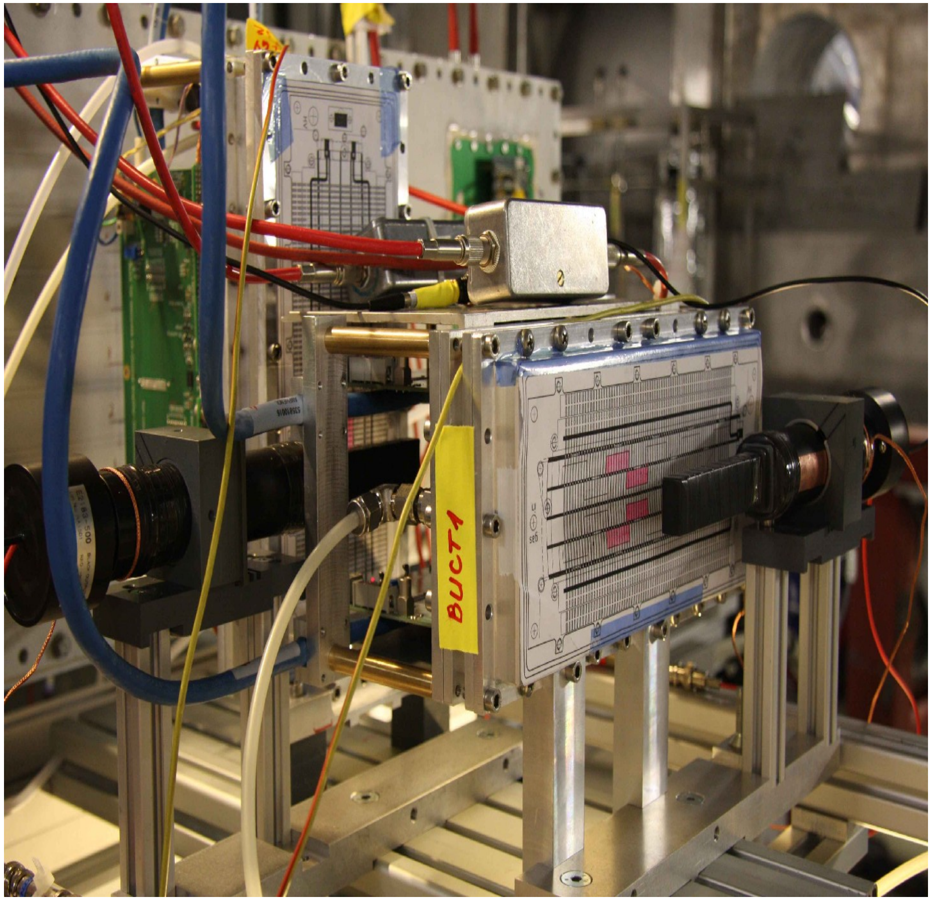


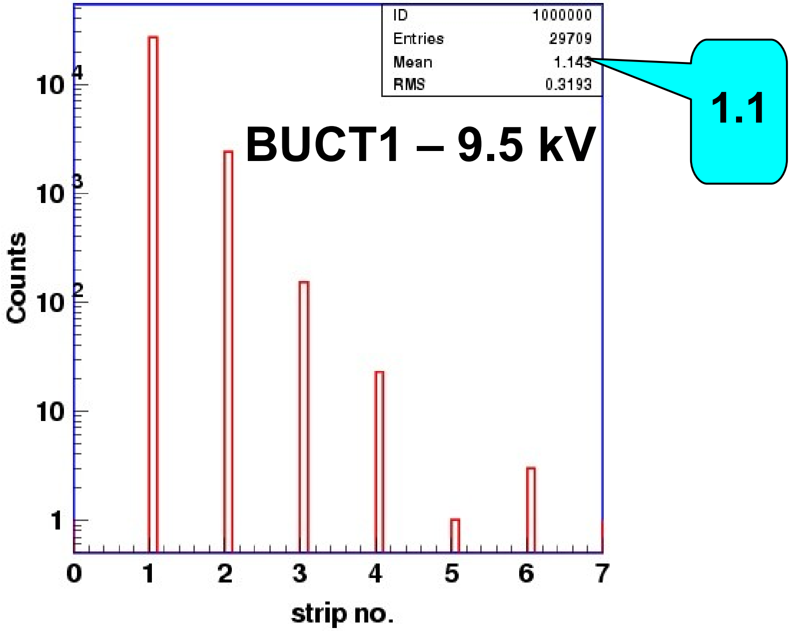


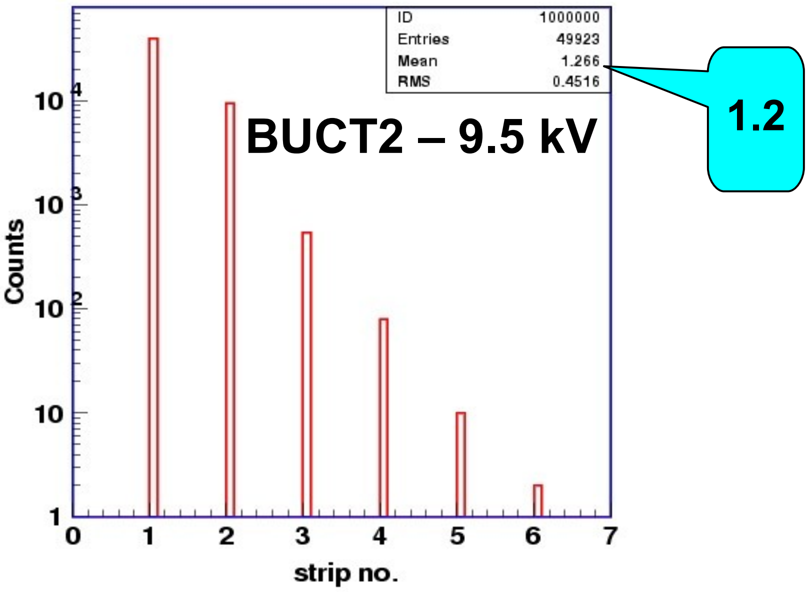




Cluster size

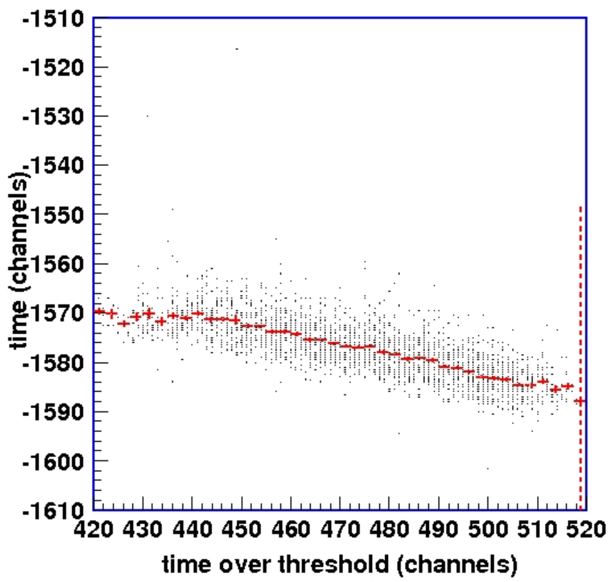


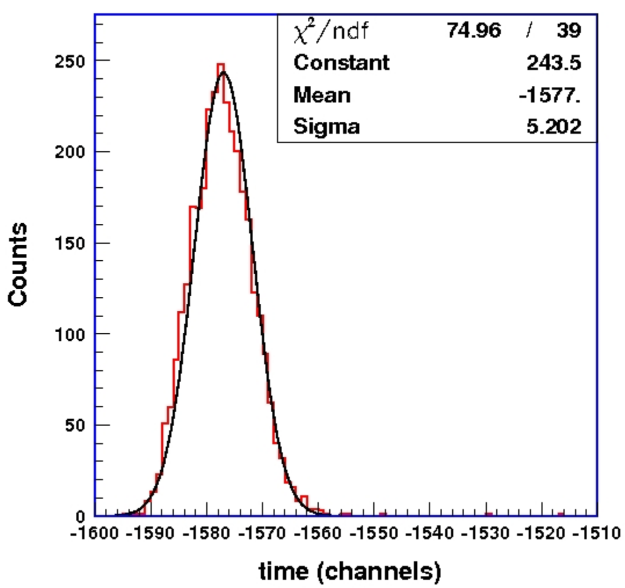




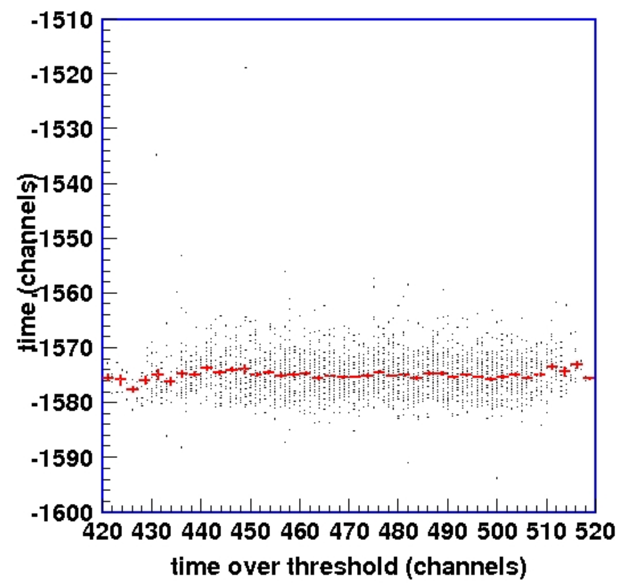
Time resolution

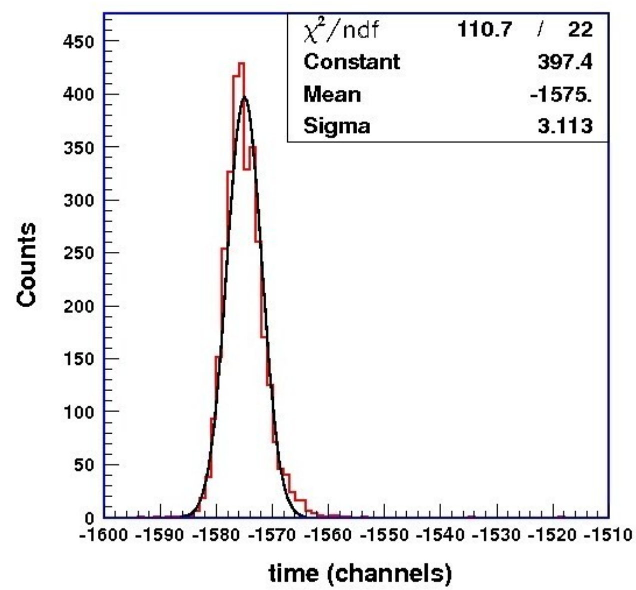
Before the slewing correction





After the slewing correction





How to improve the rate capability?

- Golden rule: reduce the charge delivered in the gas per detector count (as we have learned when we switched from streamer to avalanche mode

- This means to transfer to the front end electronics a substantial part of the gas amplification and requires an adequate front end improvement

- Thinner gaps exhibit intrinsically lower charge: multigap RPCs indeed have achieved a significant rate capability even with a high resistivity material like standard glass. This looks very promising for high rate applications

RPCs "visibility" in basic science and practical applications

- A number of very relevant experiments presently working use RPCs as an important sub-detector or even as the main detector
- To pursue the target of achieving relevant physics results with them is crucial for communities who spent huge efforts for preparing detectors; detector building and data analysis should not be seen as mutually exclusive activities
- Reliability and stable performance are necessary crucial conditions for a detector but its "visibility" depends mainly on the quality of the physics that can be produced with it
- Fully exploit the RPC potential both in basic research and in industrial applications such as imaging, PET, muon tomography…

http://www-aix.gsi.de/conferences/rpc2010/Program_RPC_2010_Linked.html