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Do we really need low p_T measurements with CBM ?

Work done in collaboration with Amalia Pop

HADRON PHYSICS DEPARTMENT

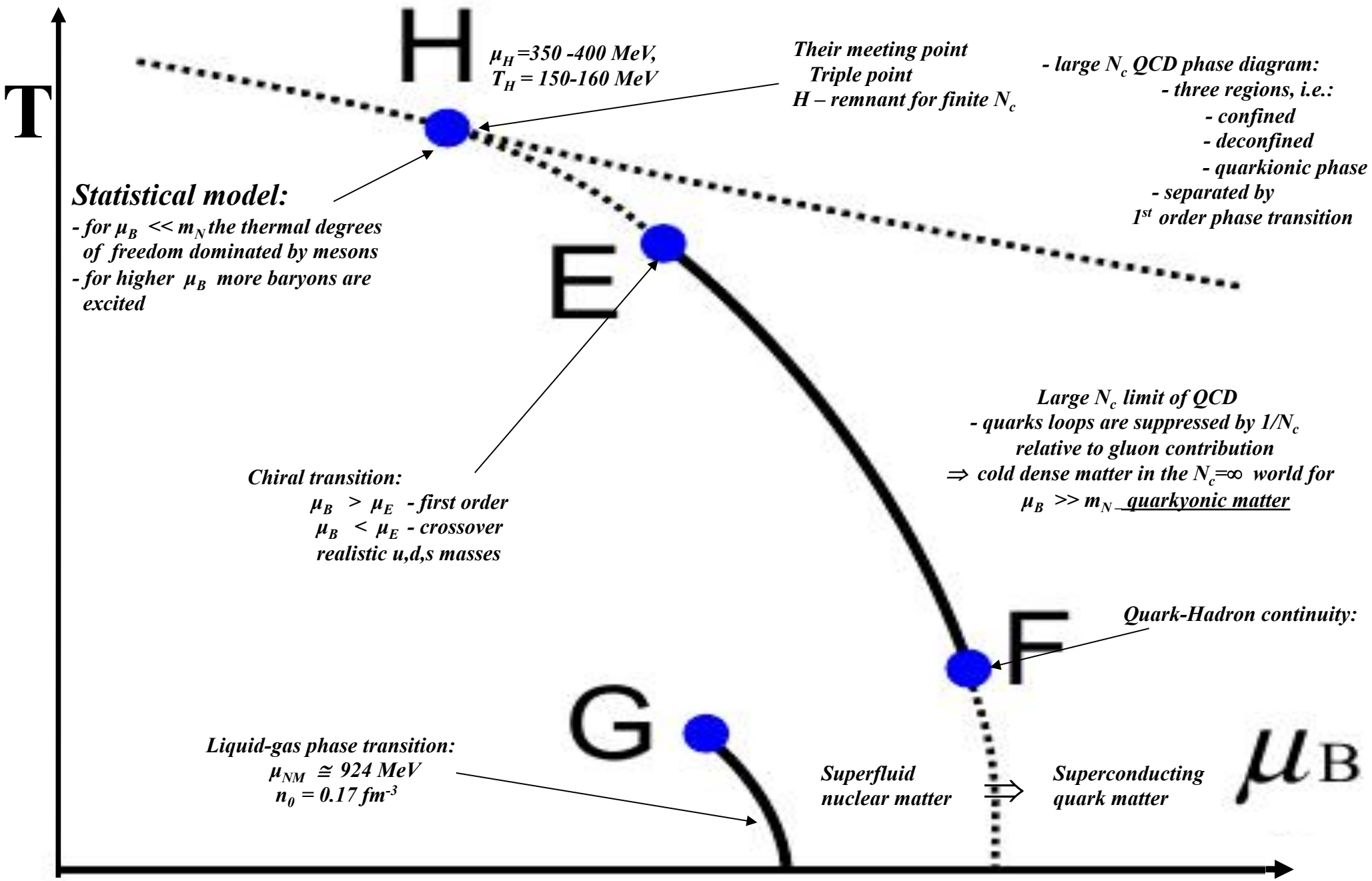
M. Petrovici, CBM PWG-COM meeting, April 9, 2021

Outline

- ***Introduction - a few general considerations***
- ***Examples of multi-differential analysis***
- ***Examples of p_T range for different experiments***
- ***Some observables worth being scanned by CBM***
- ***Latest ideas on the potential new information at low p_T values***
- ***Outlook***

Expectations based on QCD

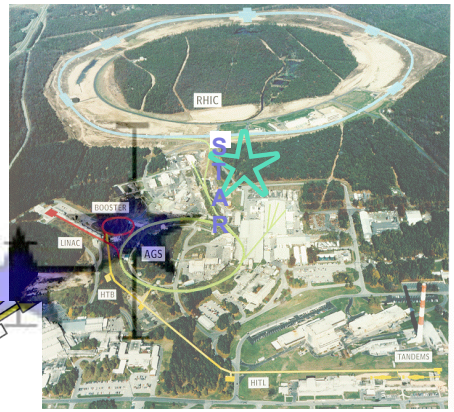
QCD Critical Points



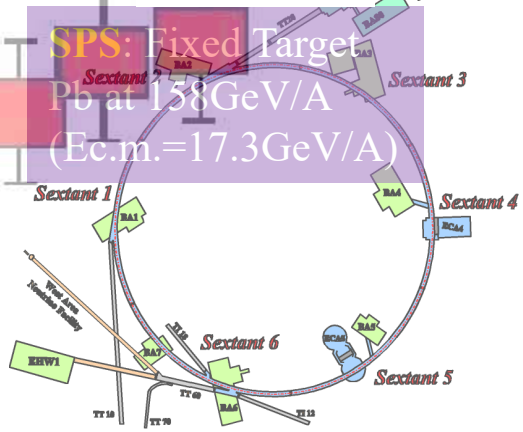
Experimental facilities

LHC: Collider
Pb+Pb @5020GeV/A

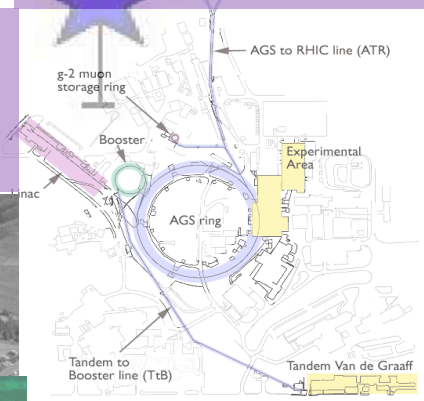
RHIC: Collider
Au+Au @ 200GeV/A



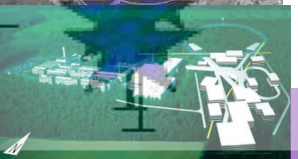
SPS: Fixed Target
Pb at 158GeV/A
(Ec.m.=17.3GeV/A)



AGS: Fixed Target
Au at 11.7GeV/A
(Ec.m.=4.86GeV/A)



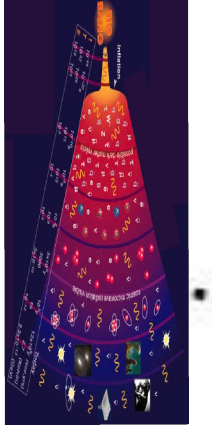
Bevalac
Fixed Target
1-2GeV/A



SIS 18

Expectations based on QCD

QCD Critical Points



LHC: Collider
Pb+Pb @5500GeV/A

RHIC: Collider
Au+Au @ 200GeV/A

μ_H =350 -400 MeV,
T_H @ 150-160 MeV

H

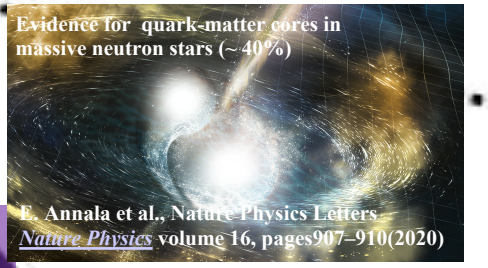
T

Their meeting point
Triple point
H – remnant for finite N_c

- large N_c QCD phase diagram:
- three regions, i.e.:
- confined
- deconfined
- quarkionic phase
- separated by
1st order phase transition

SPS: Fixed Target
Pb at 158GeV/A
(Ec.m.=17.3GeV/A)

E



Statistical model:

- for μ_B << m_N the thermal degrees of freedom dominated by mesons
- for higher μ_B more baryons are excited

AGS: Fixed Target
Au at 11.7GeV/A
(Ec.m.=4.86GeVA/A)

Large N_c limit of QCD
- quarks loops are suppressed by $1/N_c$ relative to gluon contribution
⇒ cold dense matter in the N_c=∞ world for μ_B >> m_N quarkyonic matter

Chiral transition:
μ_B > μ_E - first order
μ_B < μ_E - crossover
realistic u,d,s masses

SIS 18

Bevalac
Fixed Target
1-2GeV/A

Quark-Hadron continuity:

F

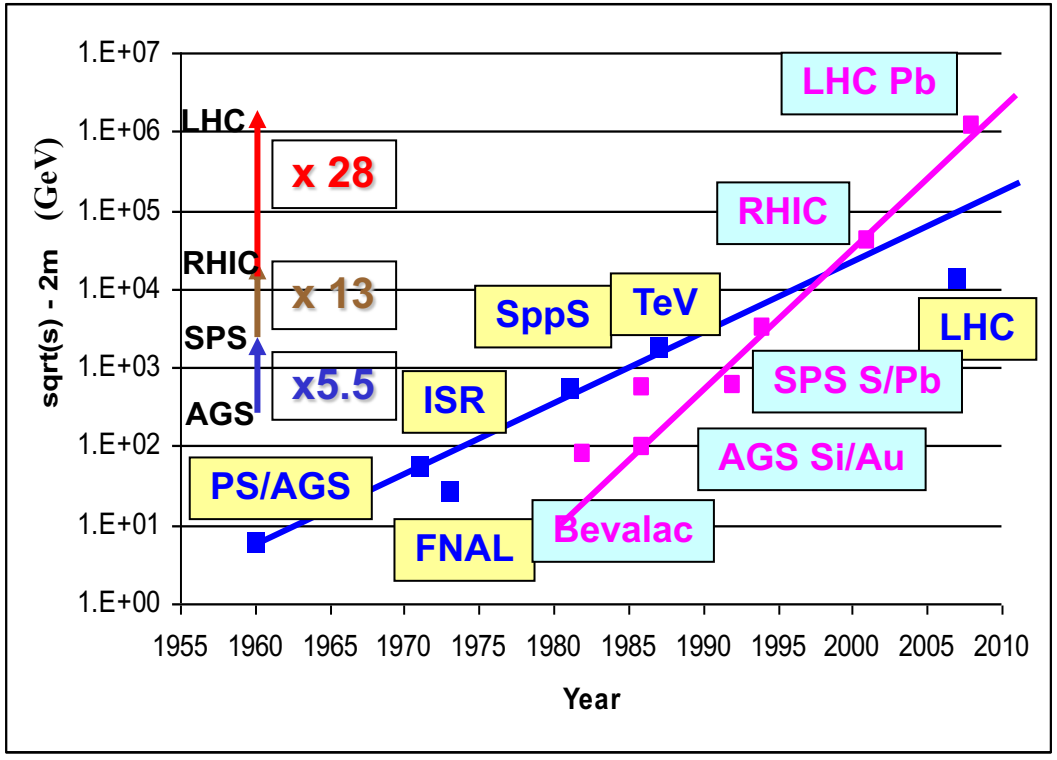
G

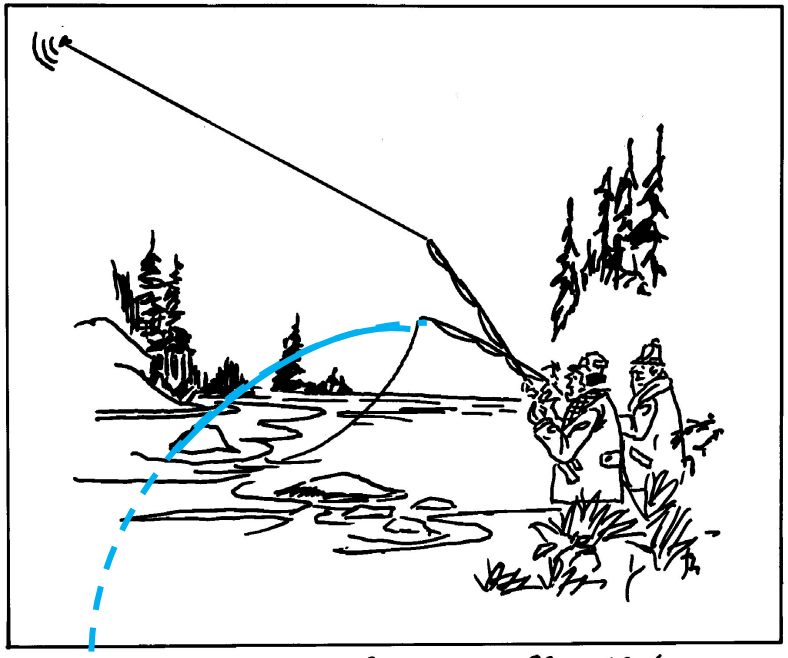
Liquid-gas phase transition:
μ_{NM} ≅ 924 MeV
n_0 = 0.17 fm^{-3}

Superfluid nuclear matter ⇒ *Superconducting quark matter*

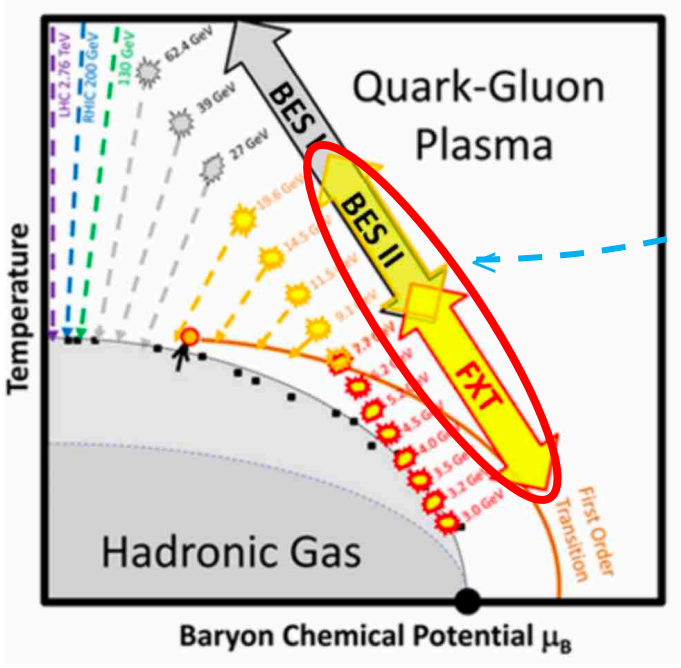
μ_B

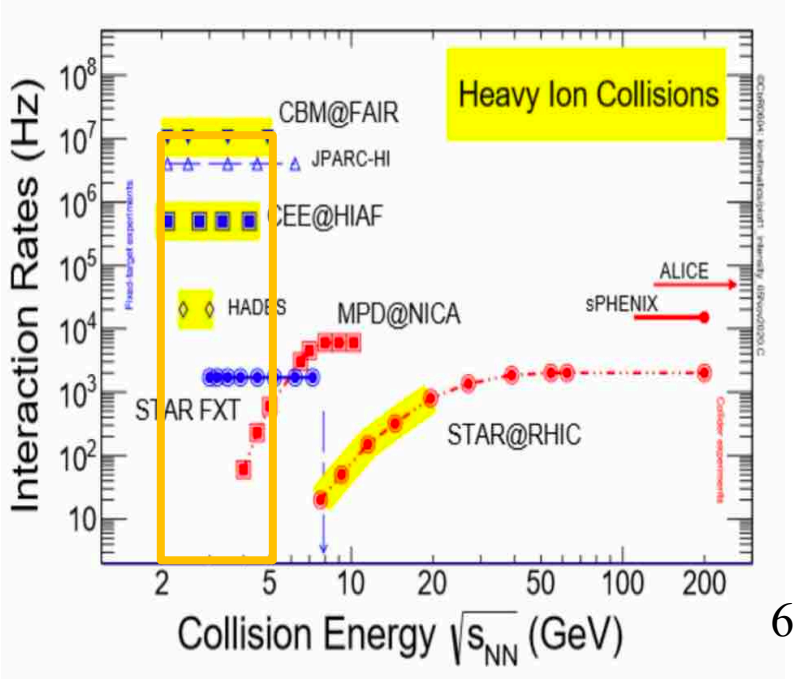
QCD phase diagram covered by CBM





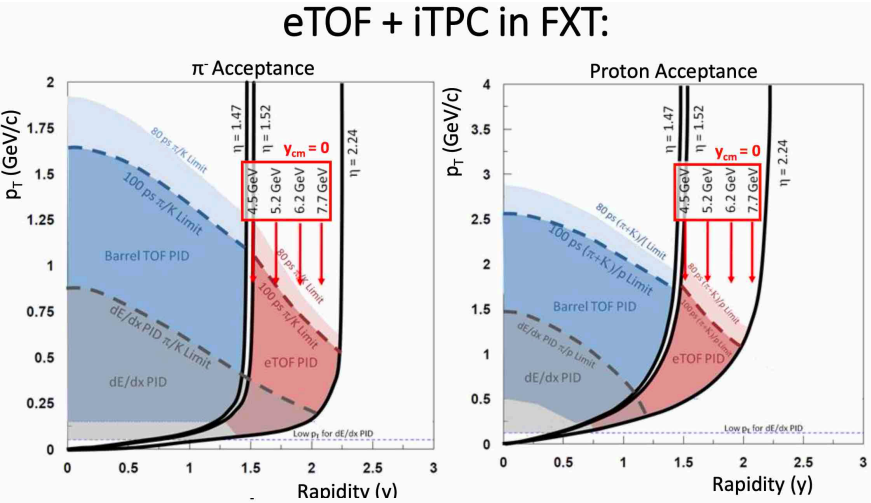
Try one's with a smaller fly!

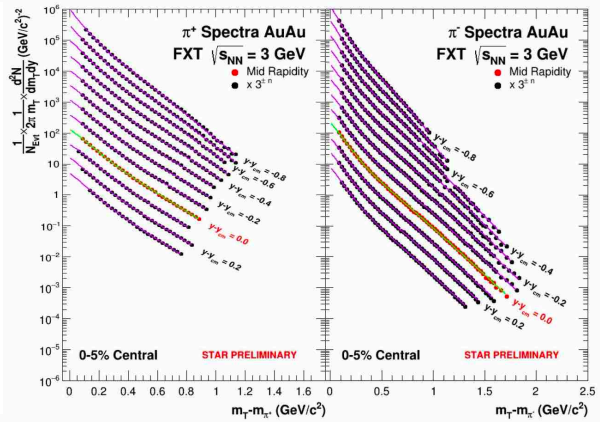


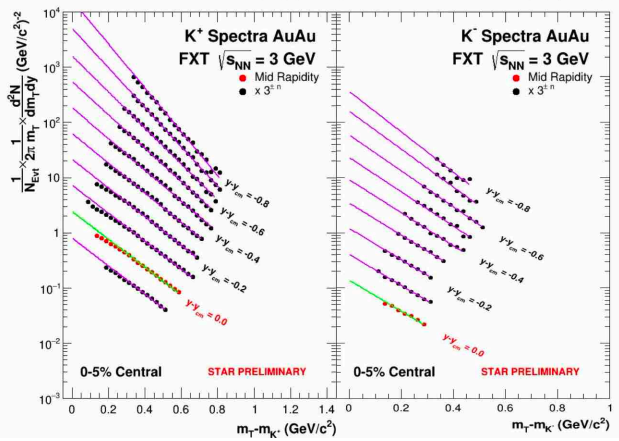


Phase space coverage

STAR

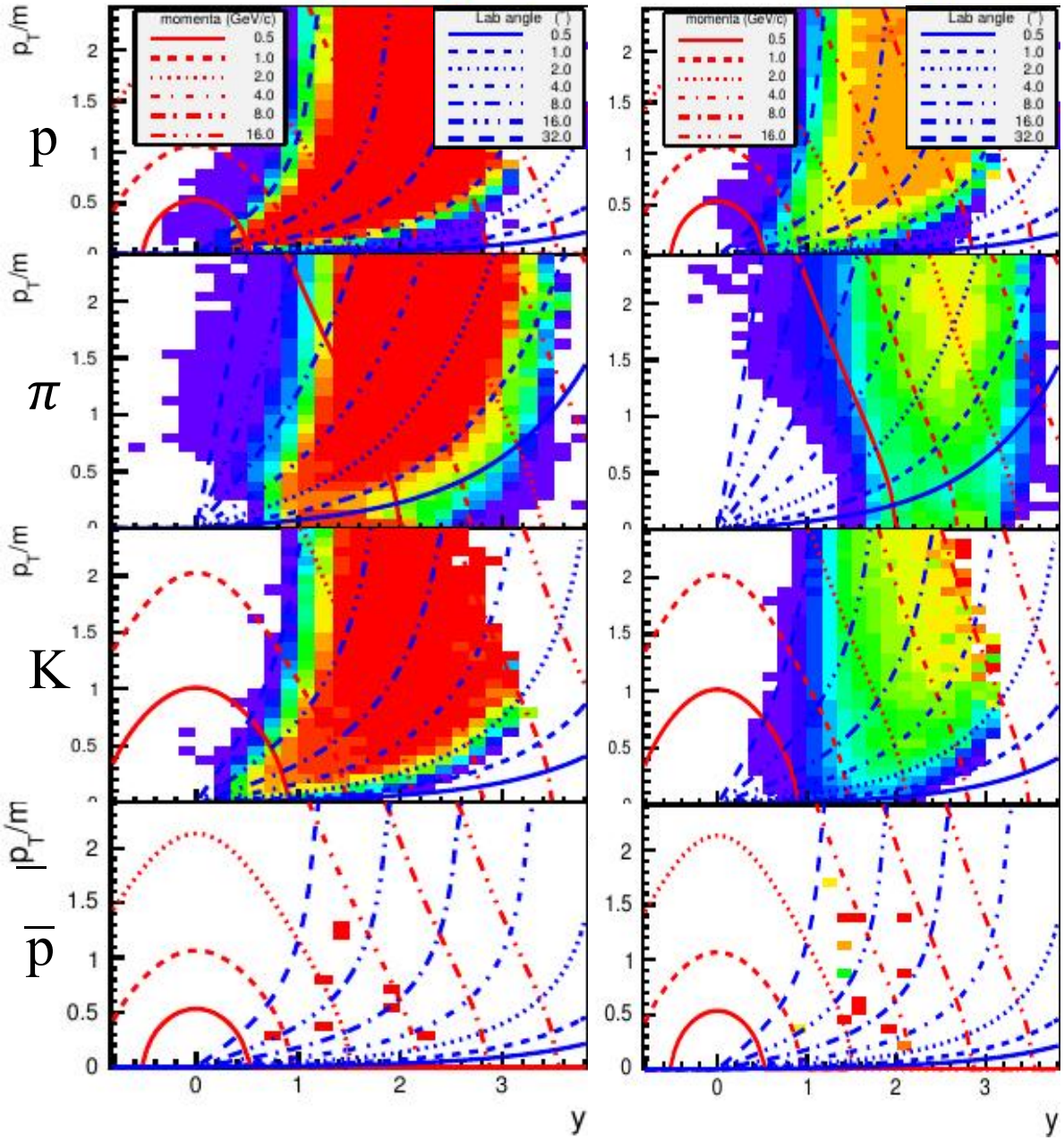






CBM

Au-Au 4 A·GeV



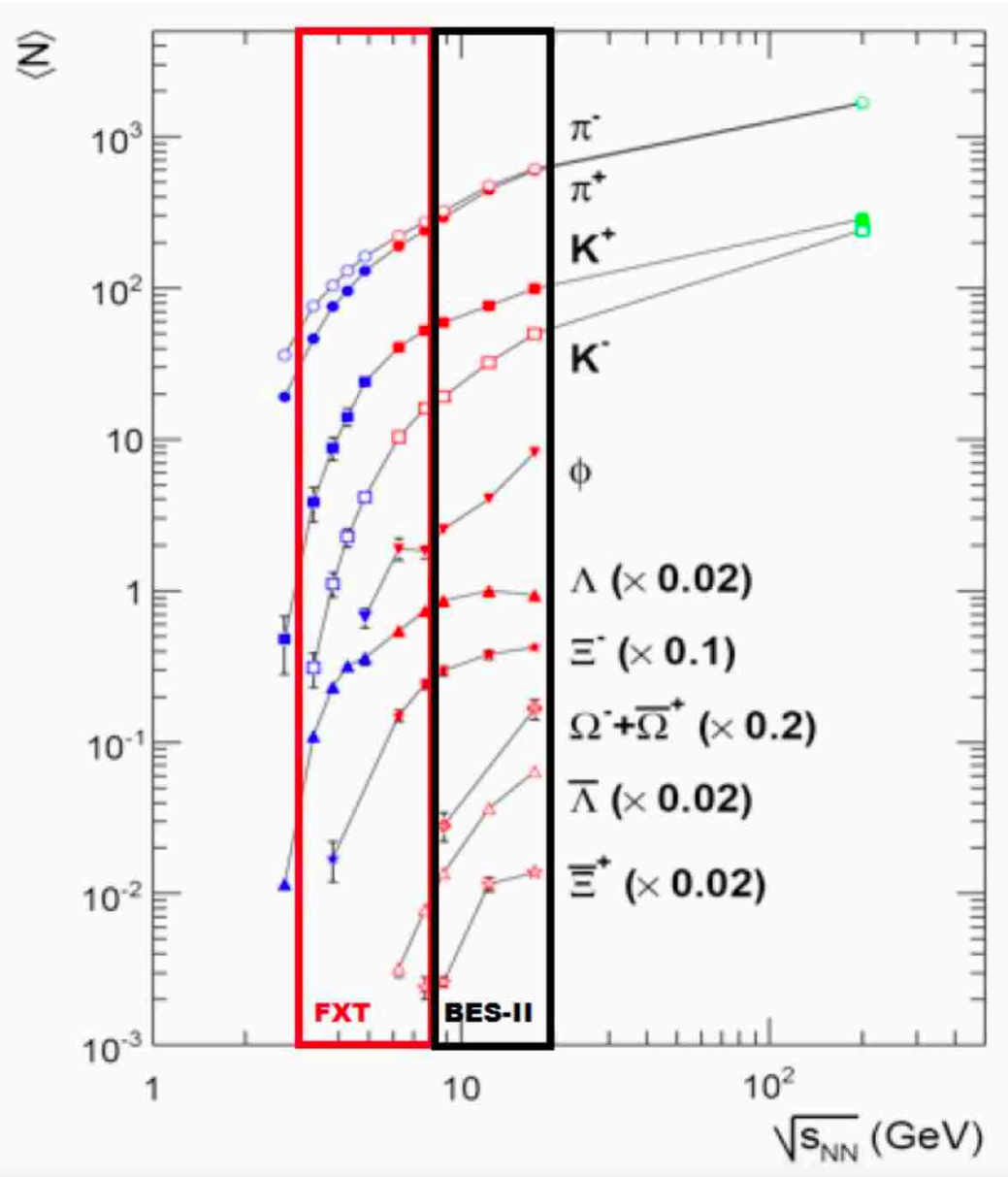
STS **ToF - 10m from target**

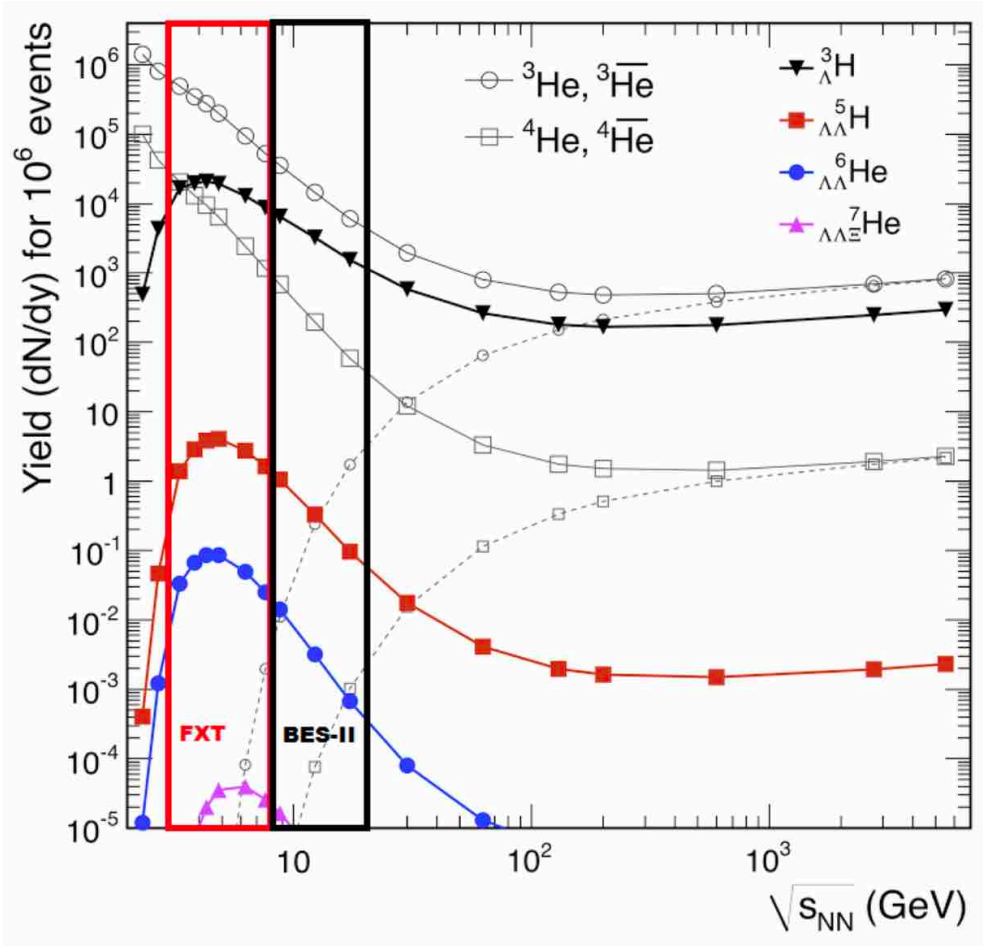
K.Meehan, STAR Collaboration, RHIC&AGS Users Meeting 2016

B. Kimelman, STAR Collaboration, CPOD 2021

CBM-ToF TDR

STAR


⟨N⟩
π⁻
π⁺
K⁺
K⁻
φ
Λ (× 0.02)
Ξ⁻ (× 0.1)
Ω⁻+Ω̄⁺ (× 0.2)
Λ̄ (× 0.02)
Ξ̄⁺ (× 0.02)
FXT
BES-II
√sNN (GeV)

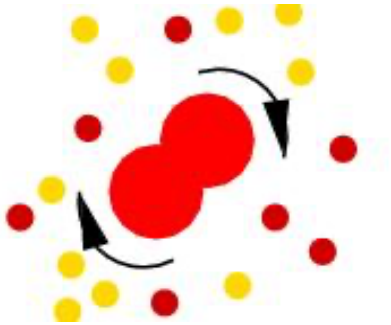

Yield (dN/dy) for 10⁶ events
³He, ³H̄e
⁴He, ⁴H̄e
³ΛH
⁵ΛΛH
⁶ΛΛHe
⁷ΛΛΞHe
FXT
BES-II
√sNN (GeV)

What remains for CBM ?

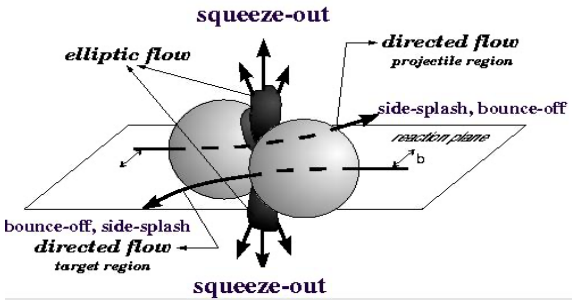
- ***much higher statistics:*** ***- multi-differential analysis***
  - rare probes
- ***larger dynamical range***
- ***better data quality***
- ***new ideas***

Azimuthal distributions

What should be expected as a function of incident energy ?



< 100 A•MeV



100 A•MeV - ~400 A•MeV

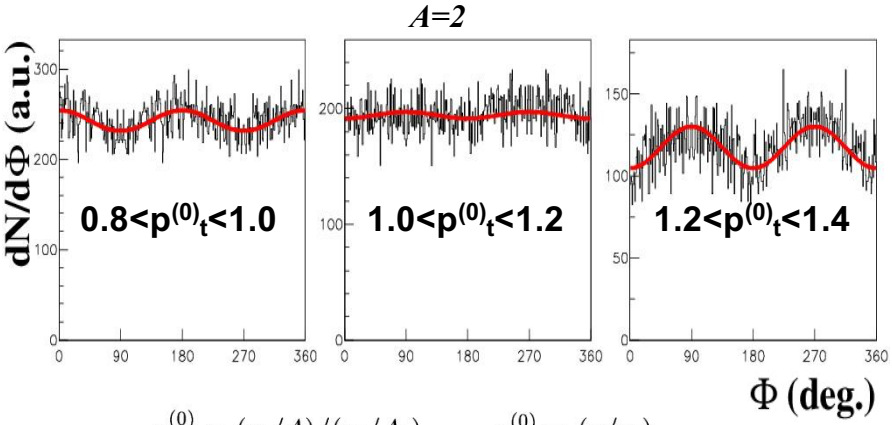
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos\left(n(\phi-\Psi_r)\right)\right)$$

$$v_2 = \langle \cos 2(\phi - \Psi_r)\rangle, \quad \phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

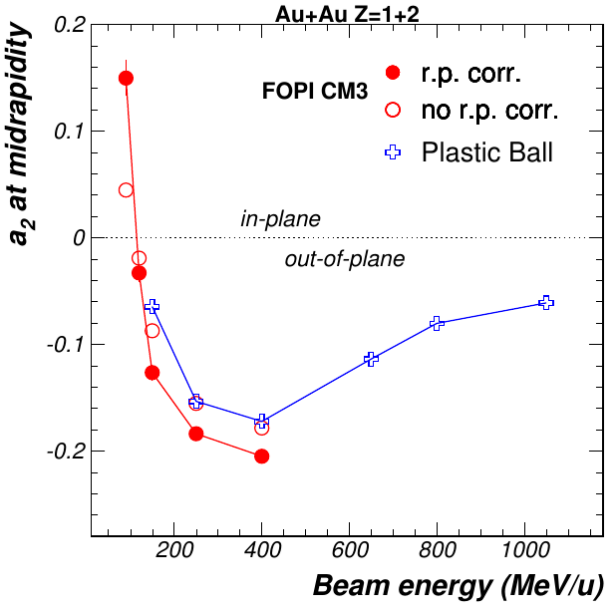
The experimental evidences

$$\frac{dN}{d\phi} = a_0 \cdot [1 + a_1 cos\phi + a_2 cos(2\phi)]$$

Au+Au 120 Mev/u, CM3



$$p_t^{(0)} = (p_t/A)/(p_b/A_b), \qquad y^{(0)} = (y/y_b)_{cm}$$

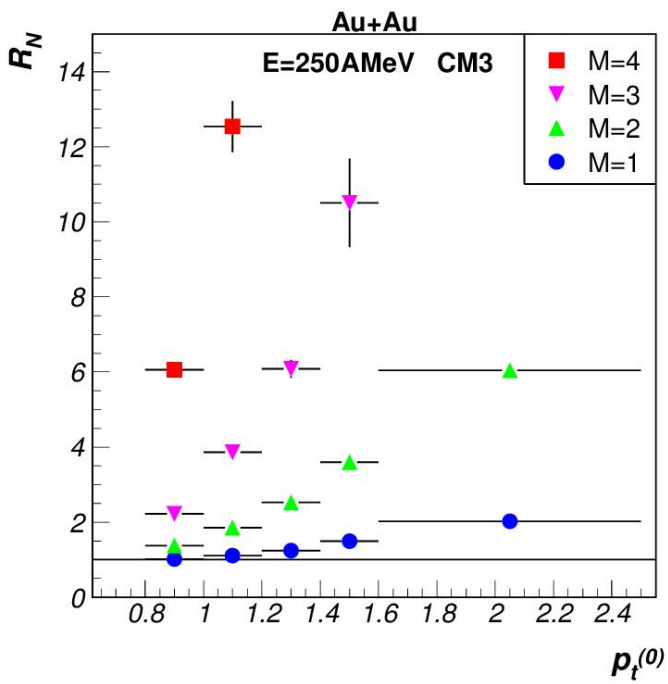


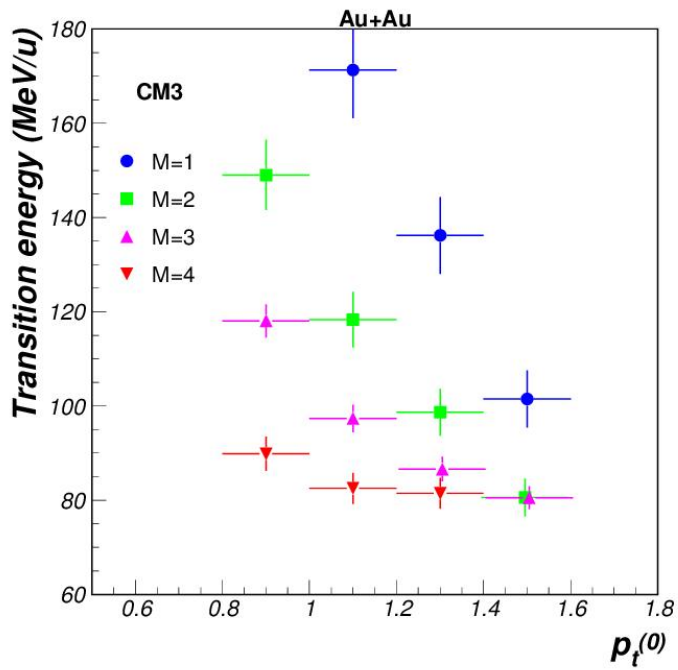
A.Andronic, G.Stoicea, M.Petrovici &FOPI Coll. NPA679(2001)765

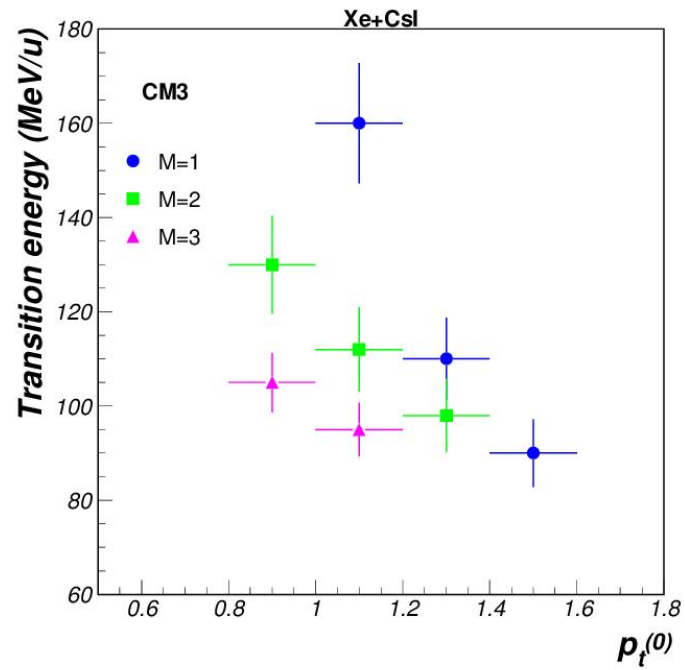
Transition energy - multi-differential analysis

FOPI Collaboration

$$R_N = \frac{dN/d\phi(90^o) + dN/d\phi(270^o)}{dN/d\phi(0^o) + dN/d\phi(180^o)} = \frac{1 - a_2}{1 + a_2} \qquad \frac{dN}{d\phi} = a_0 \cdot [1 + a_1 cos\phi + a_2 cos(2\phi)]$$

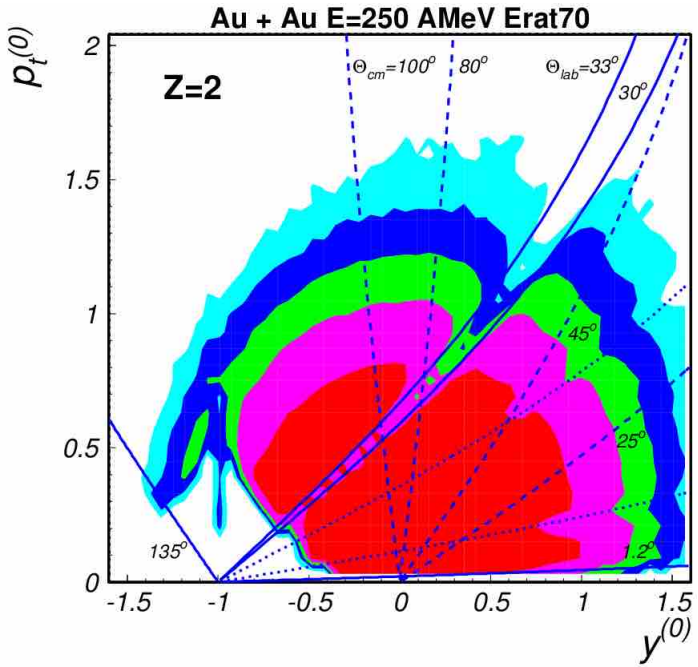


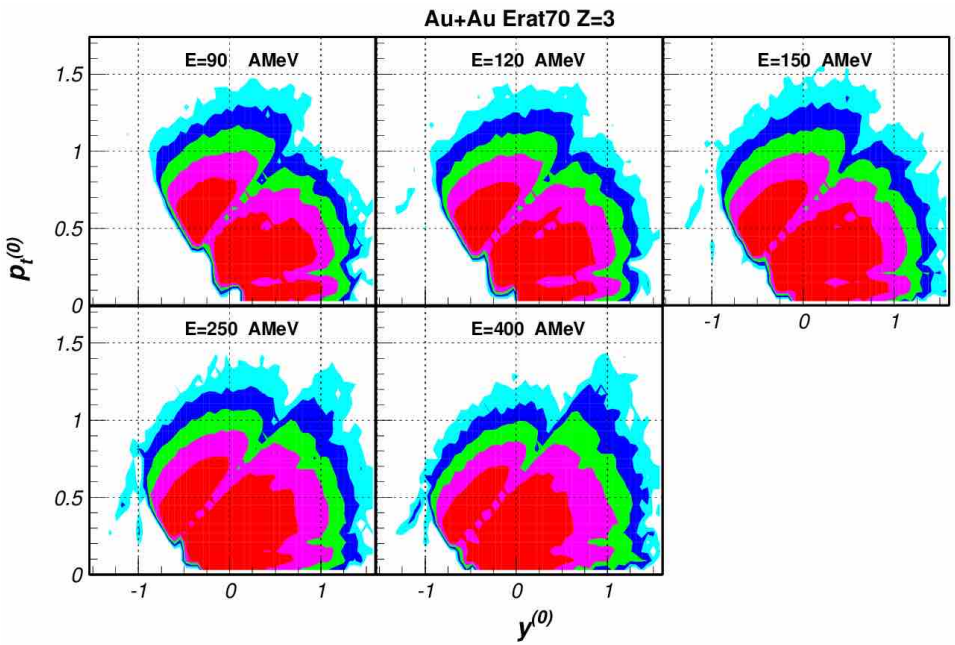




A.Andronic PhD Thesis

FOPI - phase space coverage





A.Andronic PhD Thesis

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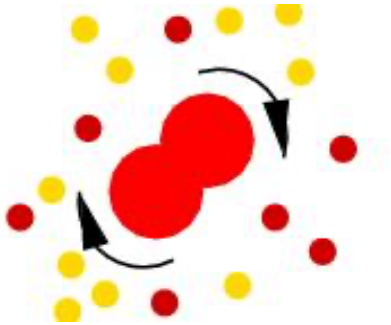
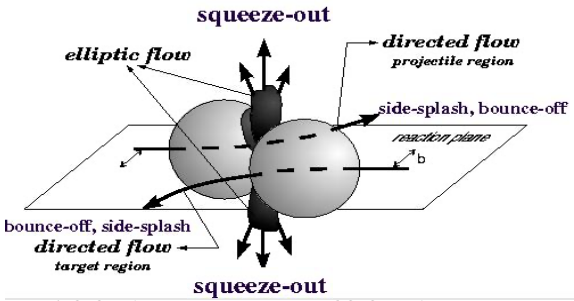
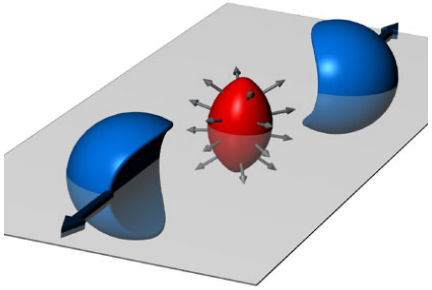


< 100 A•MeV



100 A•MeV - ~600 A•MeV



~4 A•GeV

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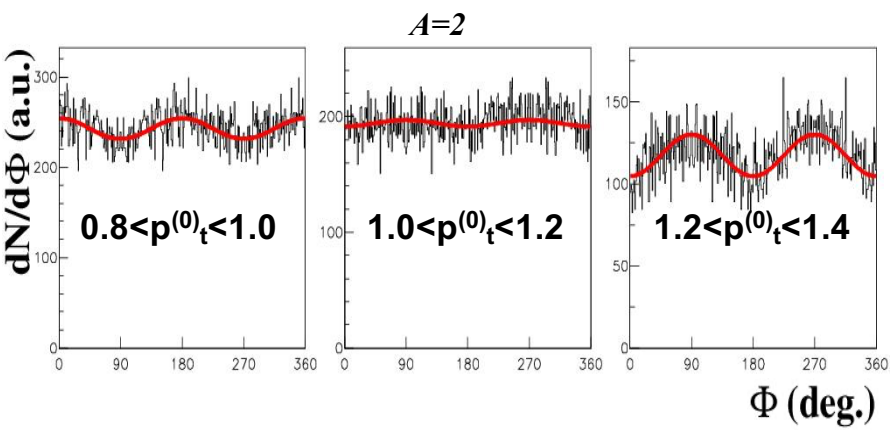
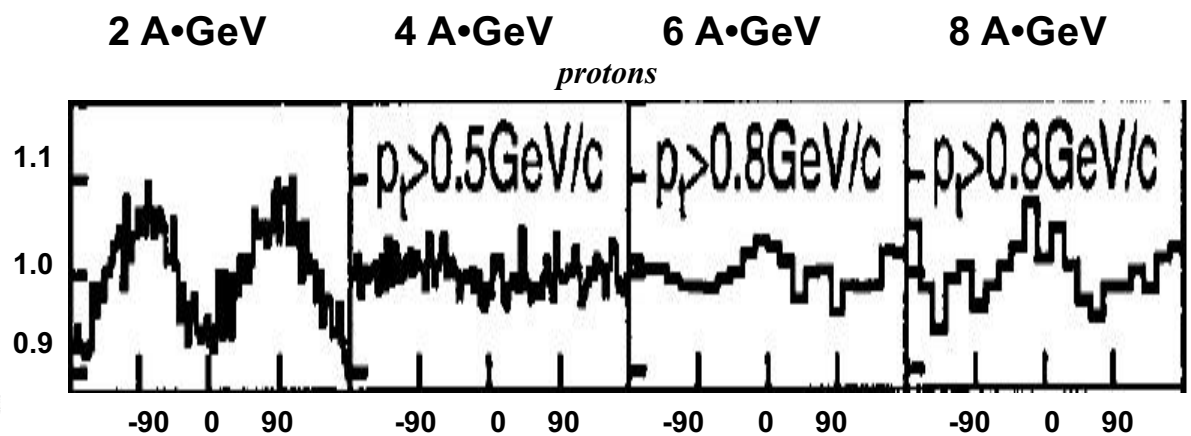
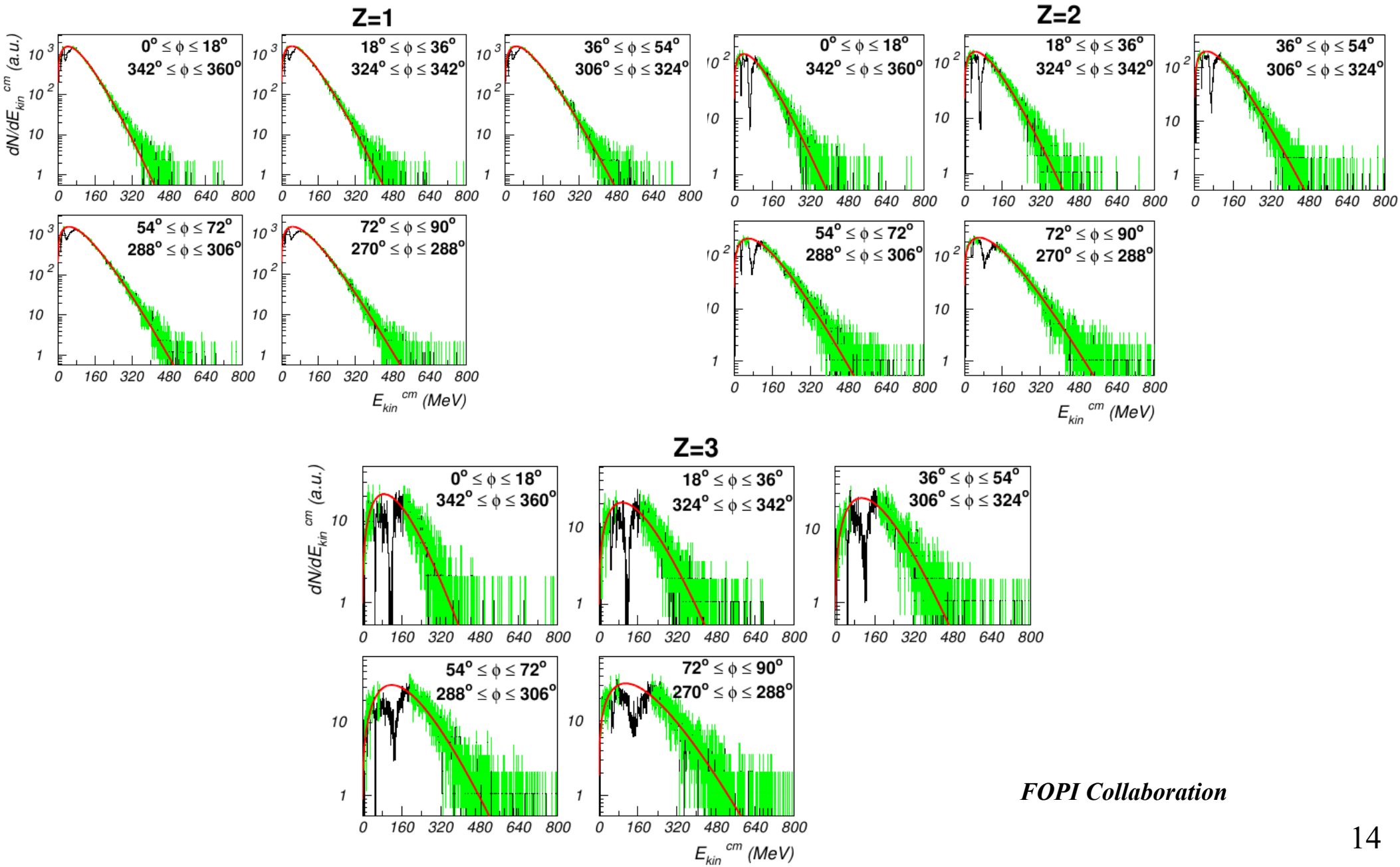


A.Andronic, G.Stoicea, M.Petrovici et al., FOPI Coll. NPA679(2001)765



C.Pinkenburg et al., EOS Coll. Phys.Rev.Lett. 83(1999)1295

E_{kin} spectra
Au-Au 250 A·MeV

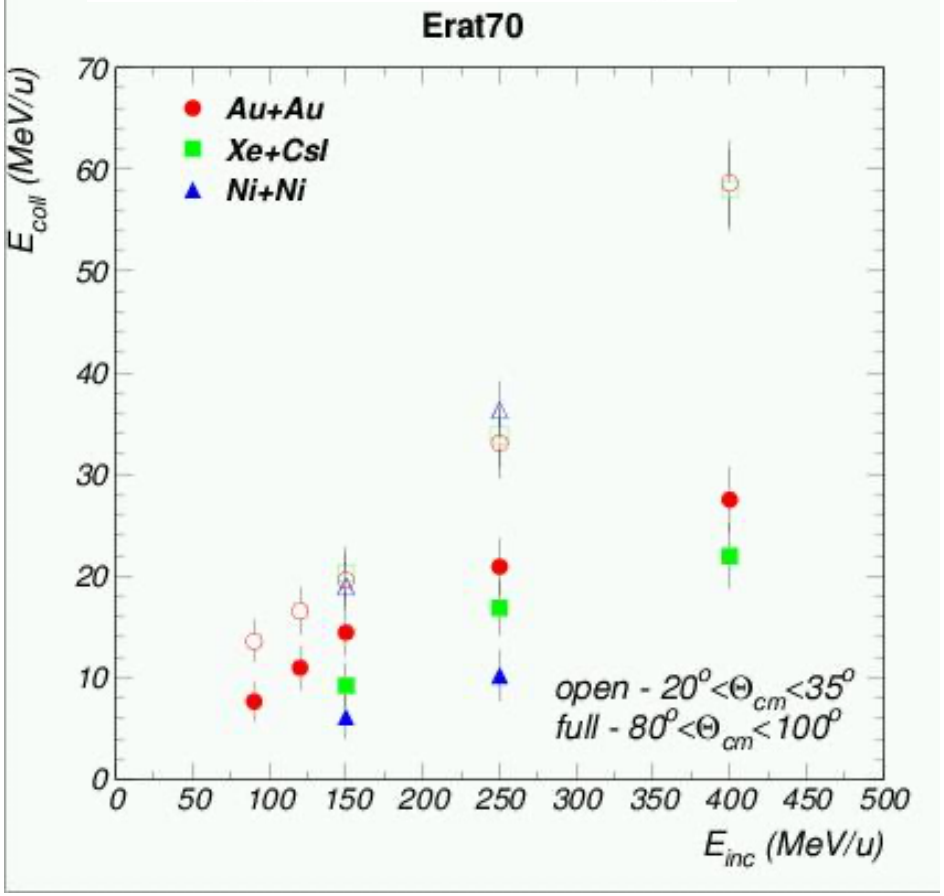


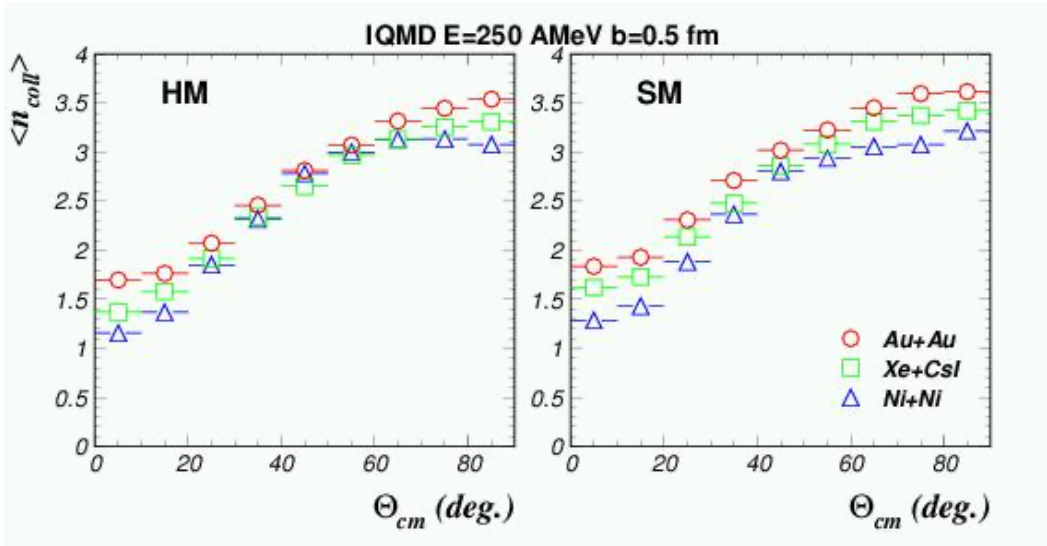
FOPI Collaboration

Radial expansion of compressed baryonic matter

Highly central A-A collisions

$$\langle E_{kin}^{cm} \rangle \approx \frac{1}{2} m_0 < \beta_{flow}^2 > A_{IMF} + \frac{3}{2} "T"$$

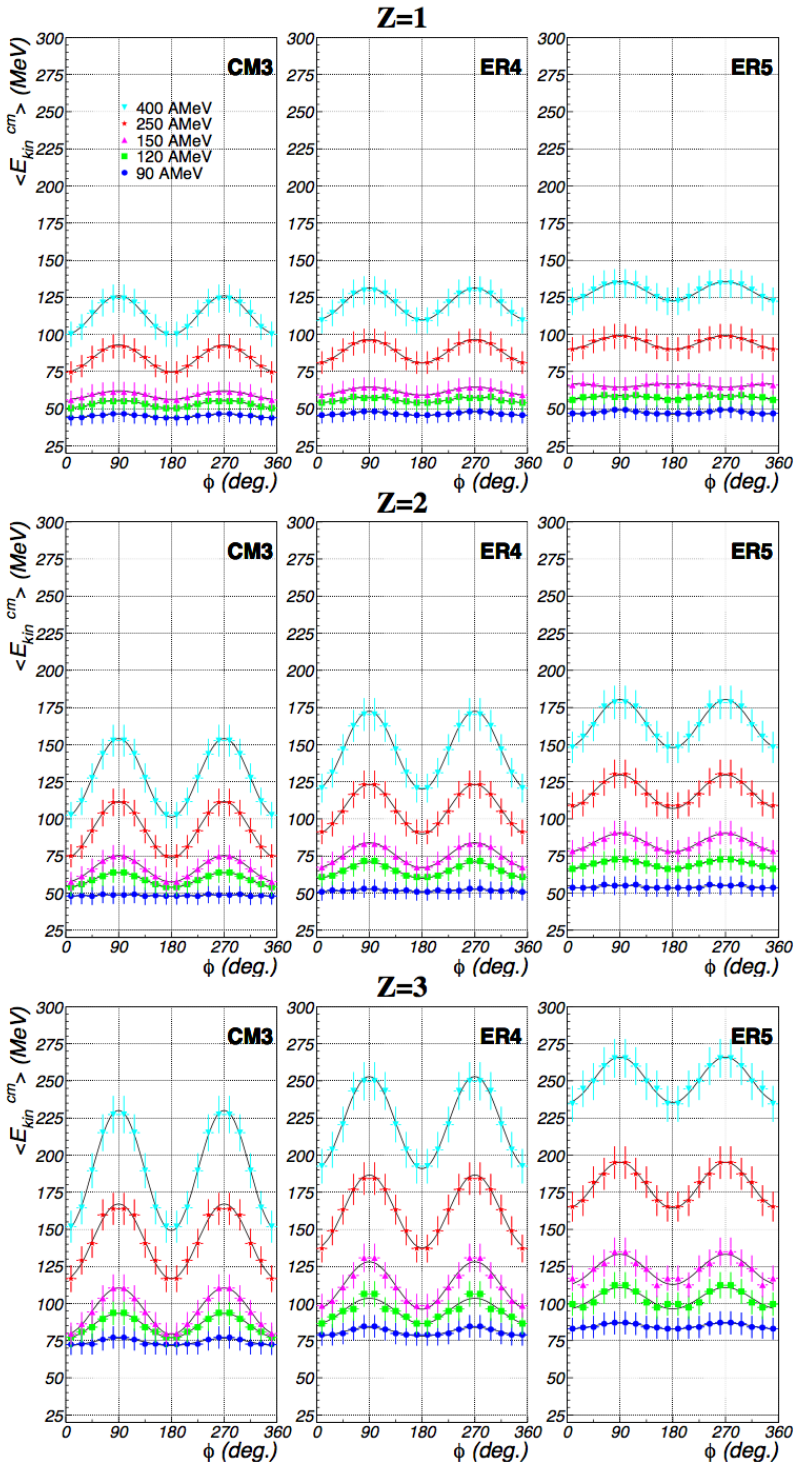




M.Petrovici, "Exotic Nuclei and Nuclear/Particle Astrophysics", AIP Conf.Proc. 972(2004)072303

A.Andronic PhD Thesis

Mean kinetic energy azimuthal distributions



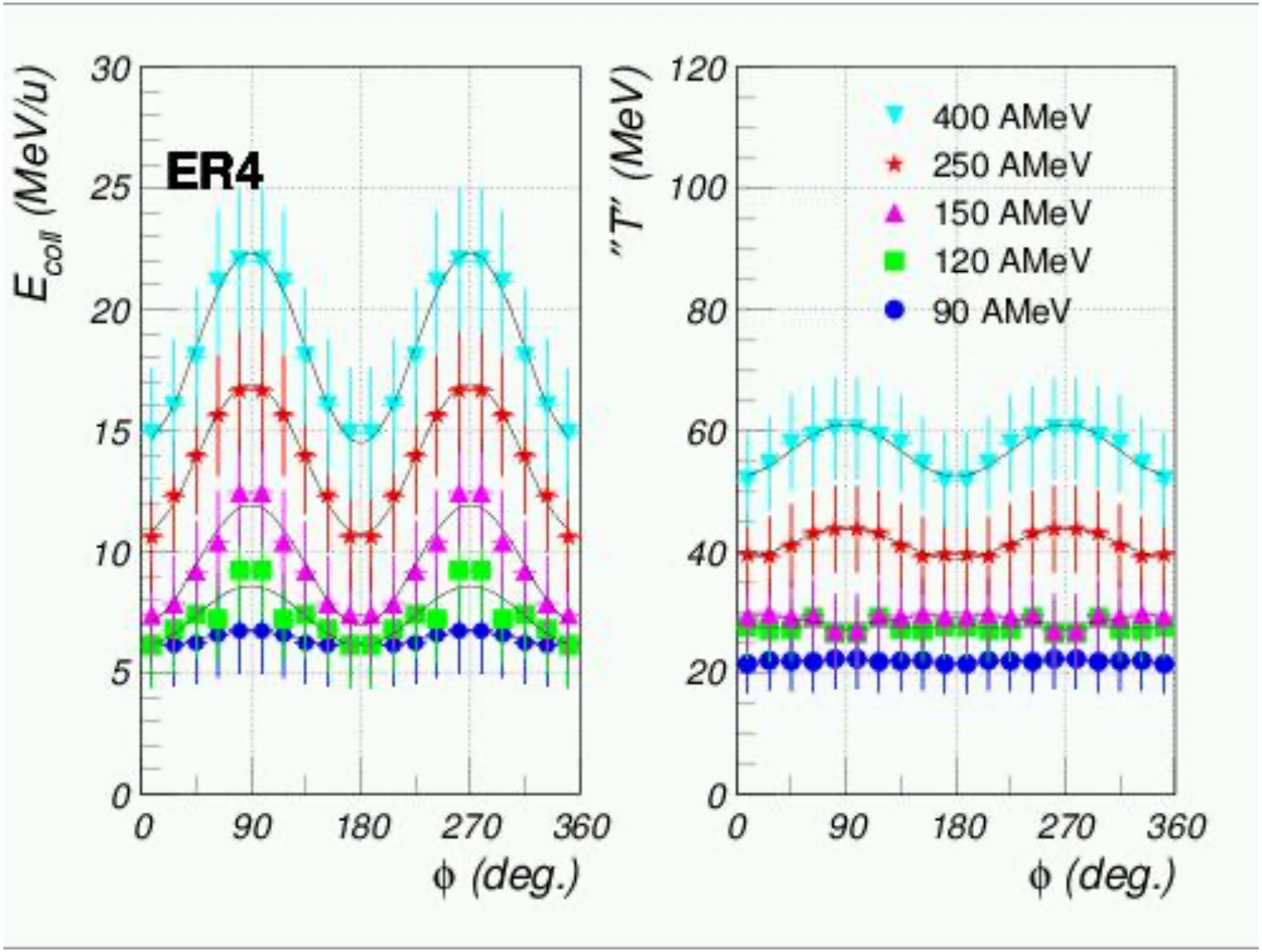
$$\langle E_{kin}^{cm} \rangle \approx \frac{1}{2} m_0 < \beta_{flow}^2 > A_{IMF} + \frac{3}{2} \text{"}T\text{"}$$

$$E_{coll} = \frac{1}{2} m_0 \langle \beta_{flow}^2 \rangle$$

G.Stoicea, M.Petrovici & FOPI Phys.Rev.Lett. 92(2004)072303

G.Stoicea PhD Thesis

E_{coll} & "T" azimuthal distributions

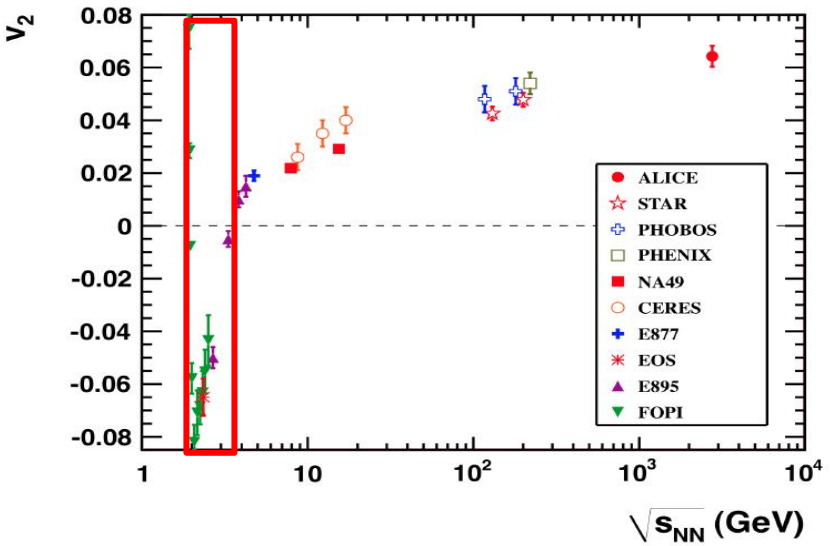


$$E_{coll} = E^0_{coll} - \Delta E_{coll} \cdot \cos 2\Phi$$

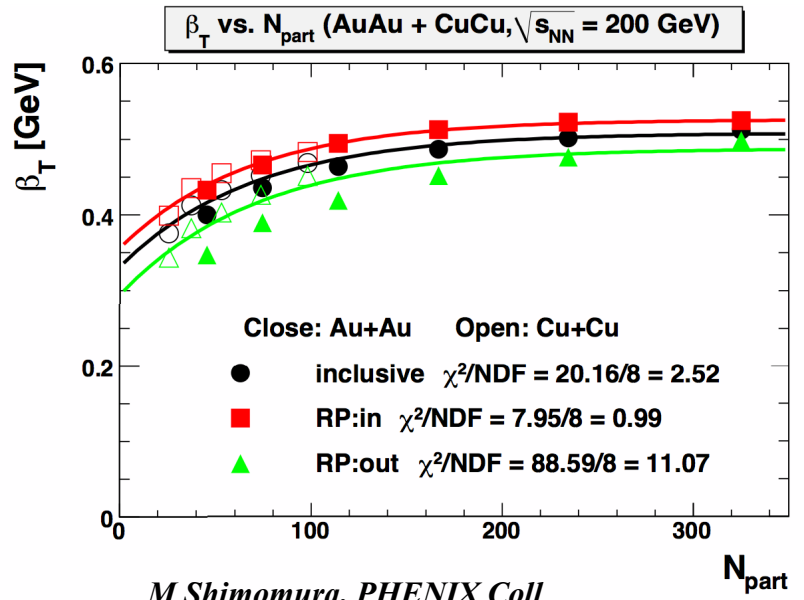
$$"T" = "T"_0 - \Delta "T" \cdot \cos 2\Phi$$

G.Stoicea, M.Petrovici & FOPI Coll., Phys.Rev.Lett. 92(2004)072303

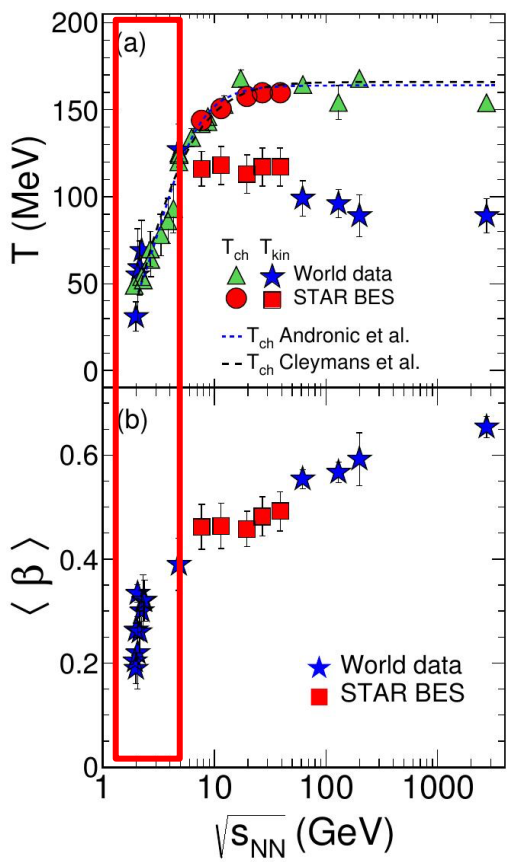
Towards highly compressed baryonic matter



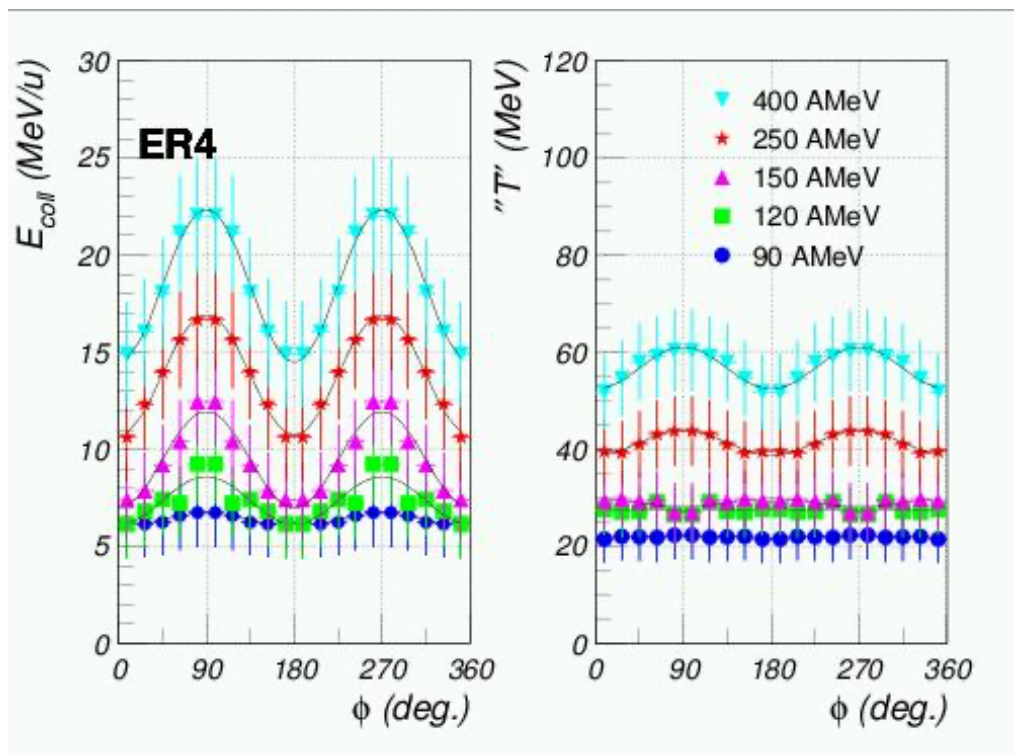
K. Aamodt et al, ALICE Collaboration PRL105(2010)252302



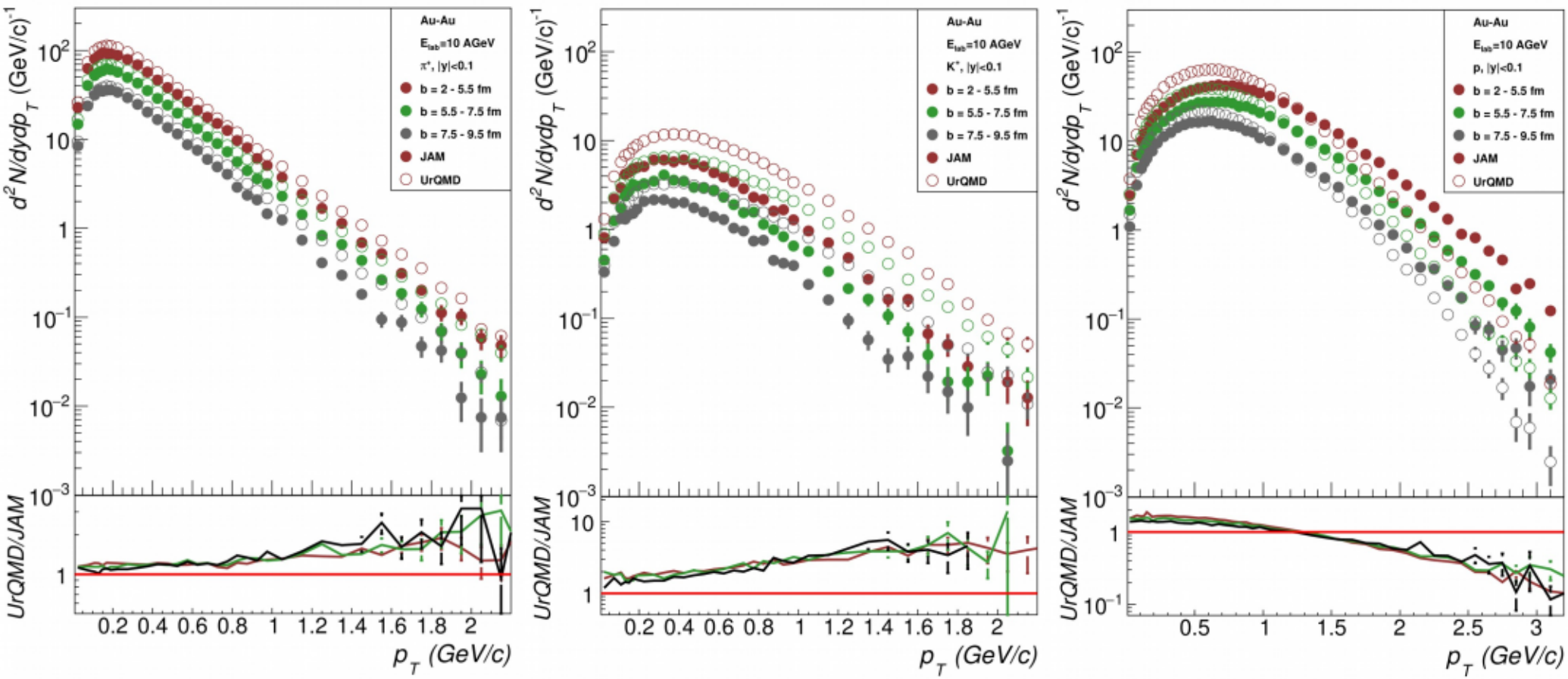
M.Shimomura, PHENIX Coll.
J. of Phys. Conf. Series 270(2011)012041



L.Adamczyk et al,
STAR Collaboration,
Phys.Rev.C96(2017)044904

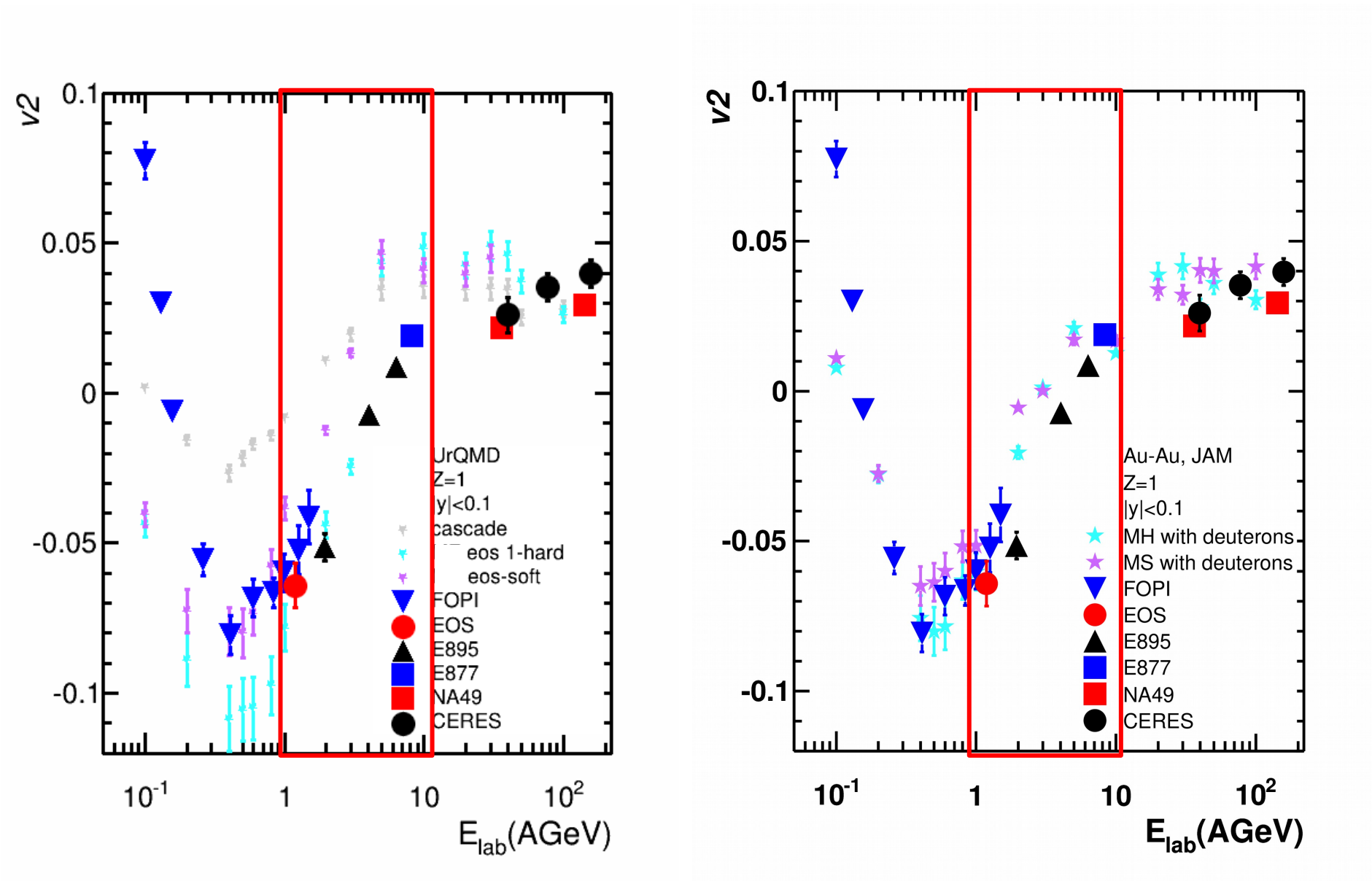


Towards highly compressed baryonic matter



- *A. Pop and M. Petrovici based on:*
- *J.C. Beicher et al., J.Phys. G325(1999)1859*
- *Y. Nara et al., Eur.Phys.J. A20(2018)1*

Towards highly compressed baryonic matter



- A. Pop and M. Petrovici based on:

- J.C. Beicher et al., J.Phys. G325(1999)1859

- Y. Nara et al., Eur.Phys.J. A20(2018)1

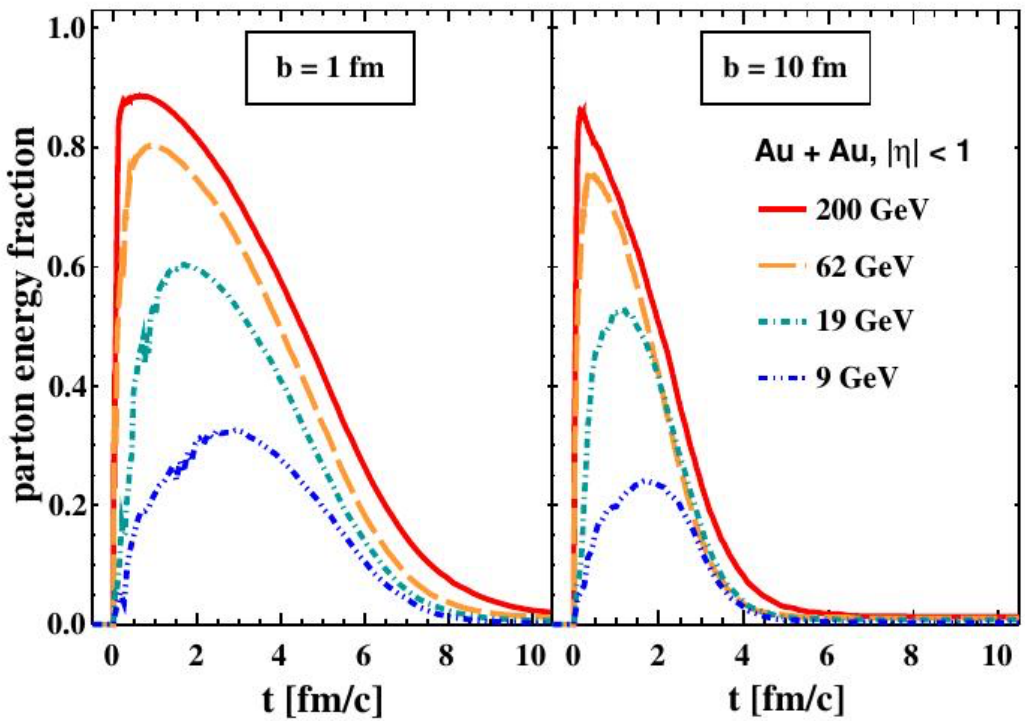
Towards highly compressed baryonic matter

- transition from baryon-dominated to meson-dominated matter - UrQMD, QGSM ?

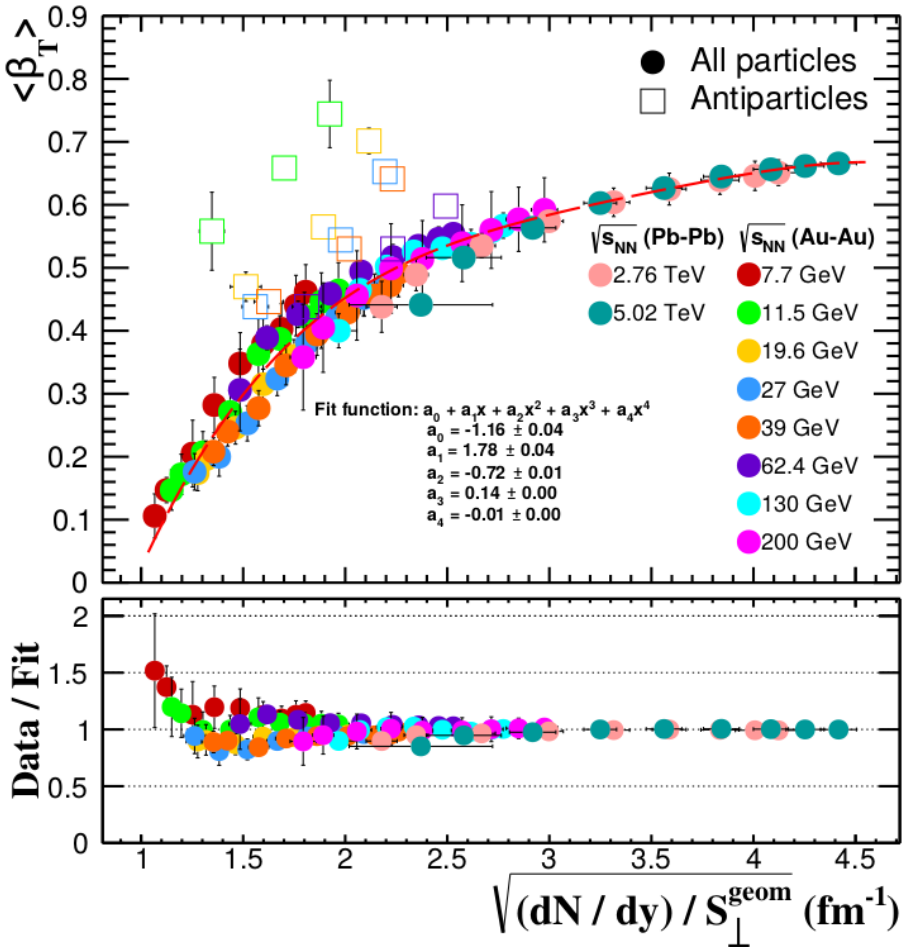
L.V.Bravina et al., Phys.Rev. C78(2008)014907

- evolution of parton fraction in the total energy density - PHSD ?

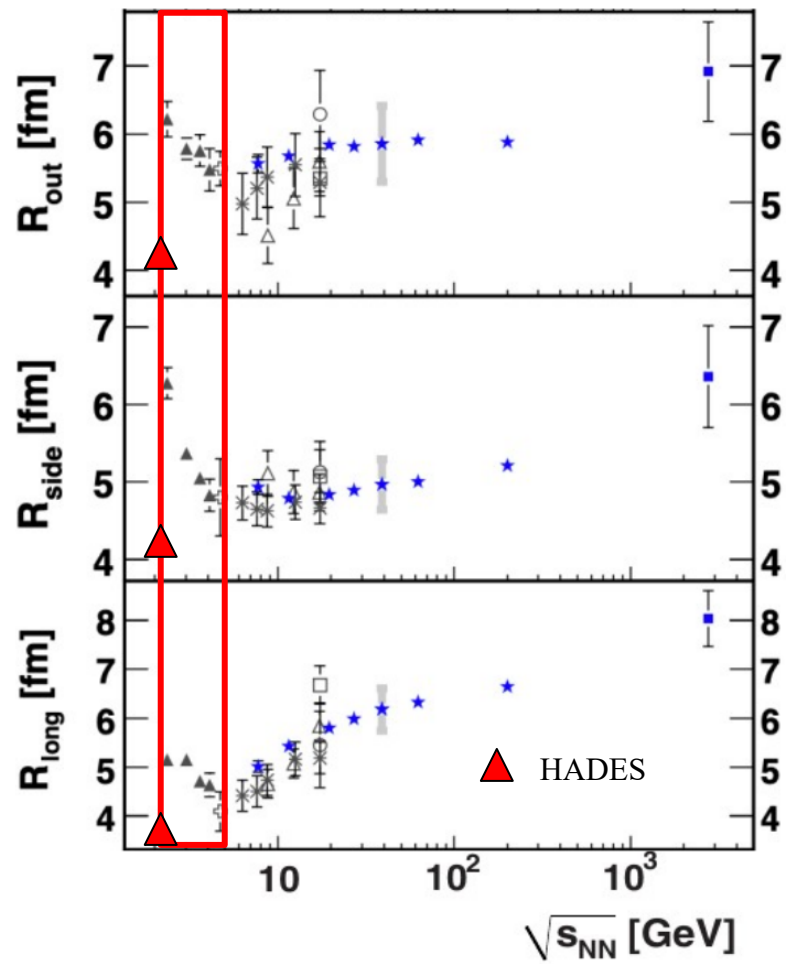
V.P.Konchakovski et al., Phys.Rev. C85(2021)044922



Towards highly compressed baryonic matter



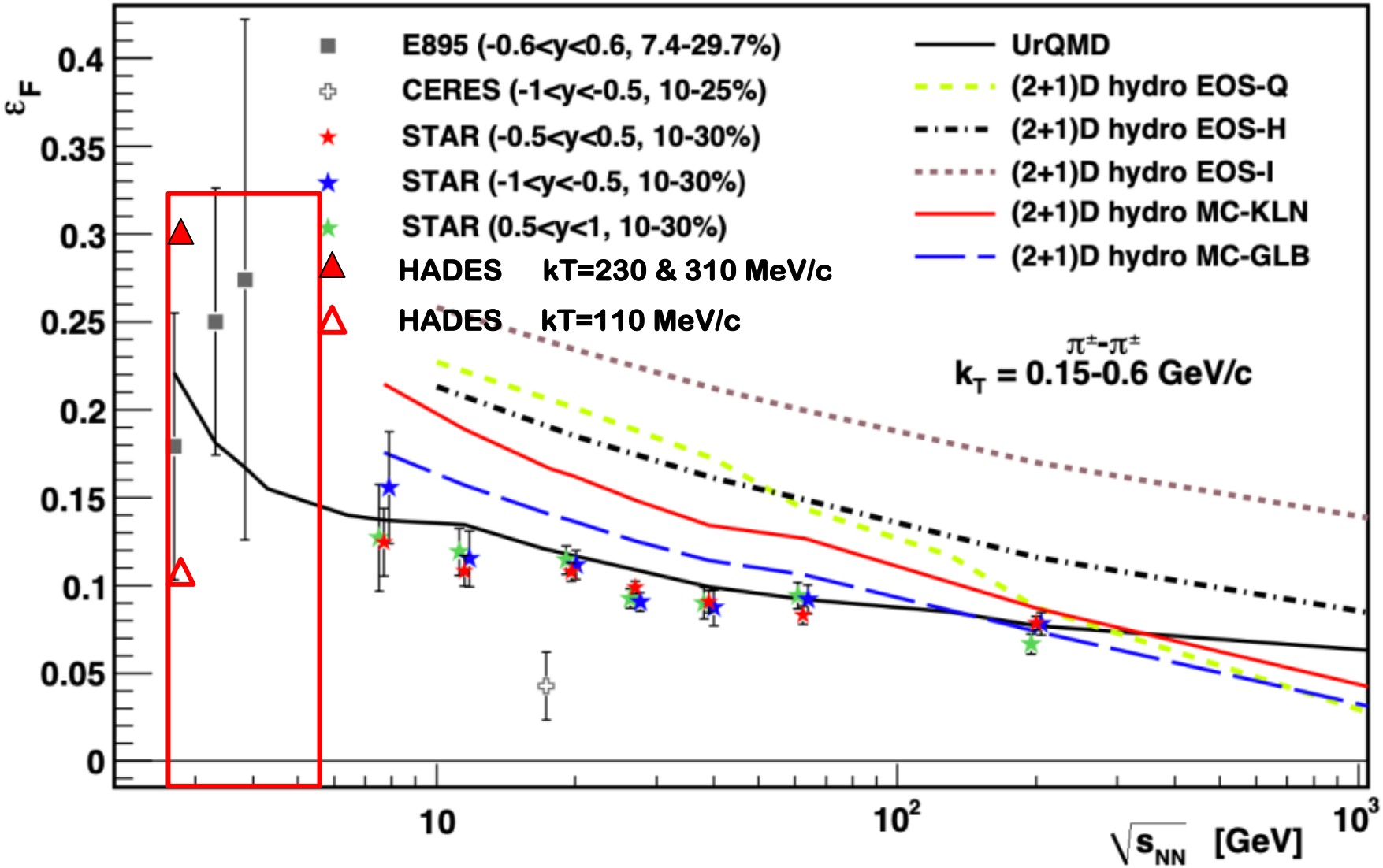
- *M. Petrovici et al., Phys.Rev. C98(2018)024904*



- *S.A. Adamczyk et al., STAR Collaboration, Phys.Rev. C92(2015)014904*

Towards highly compressed baryonic matter

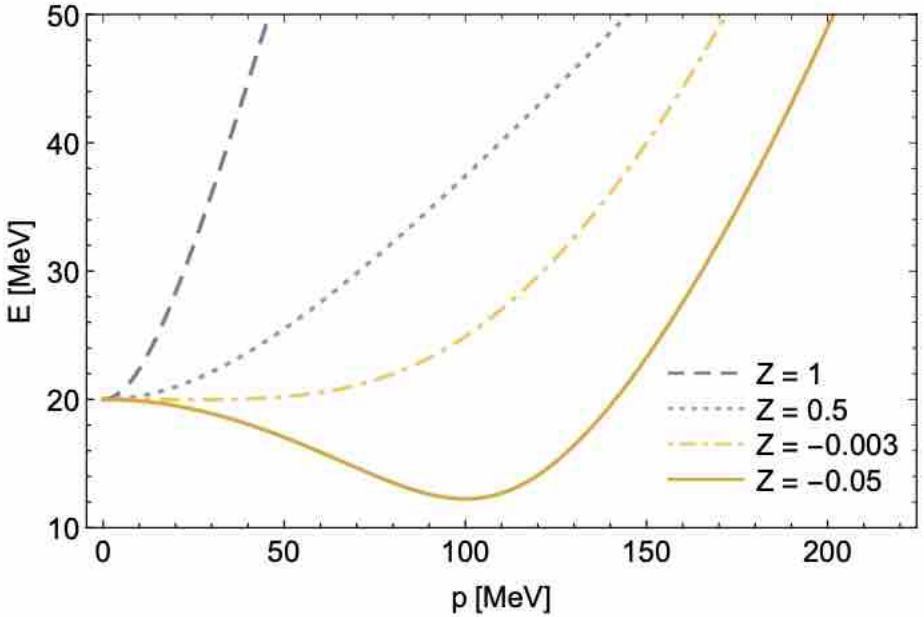
- pions' kinetic freeze-out eccentricity

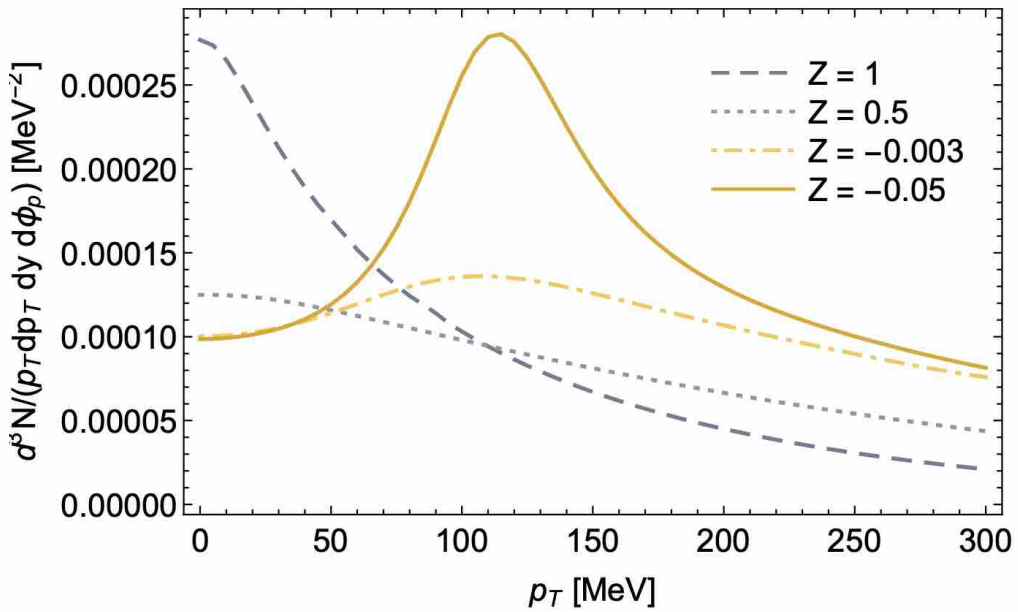


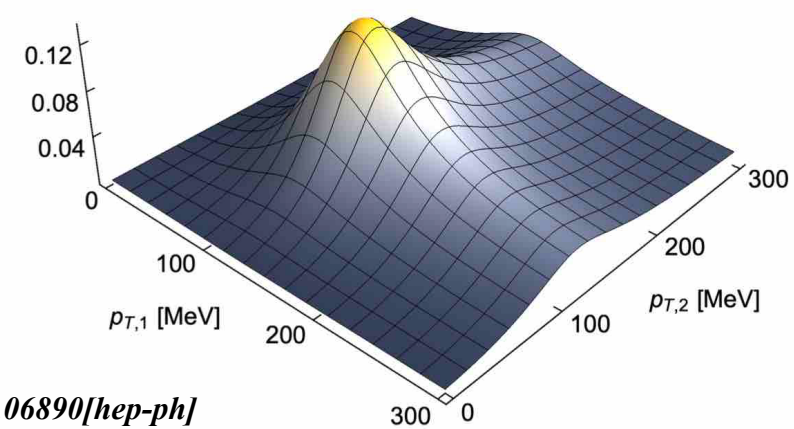
- *S.A. Adamczyk et al., STAR Collaboration, Phys.Rev. C92(2015)014904*

Signatures of Moat Regimes in Heavy-Ion Collisions

Regimes which feature periodic modulations of the spatial structure, where the energy spectrum is shaped like a moat, with the minimum of the energy over a sphere at nonzero momentum.



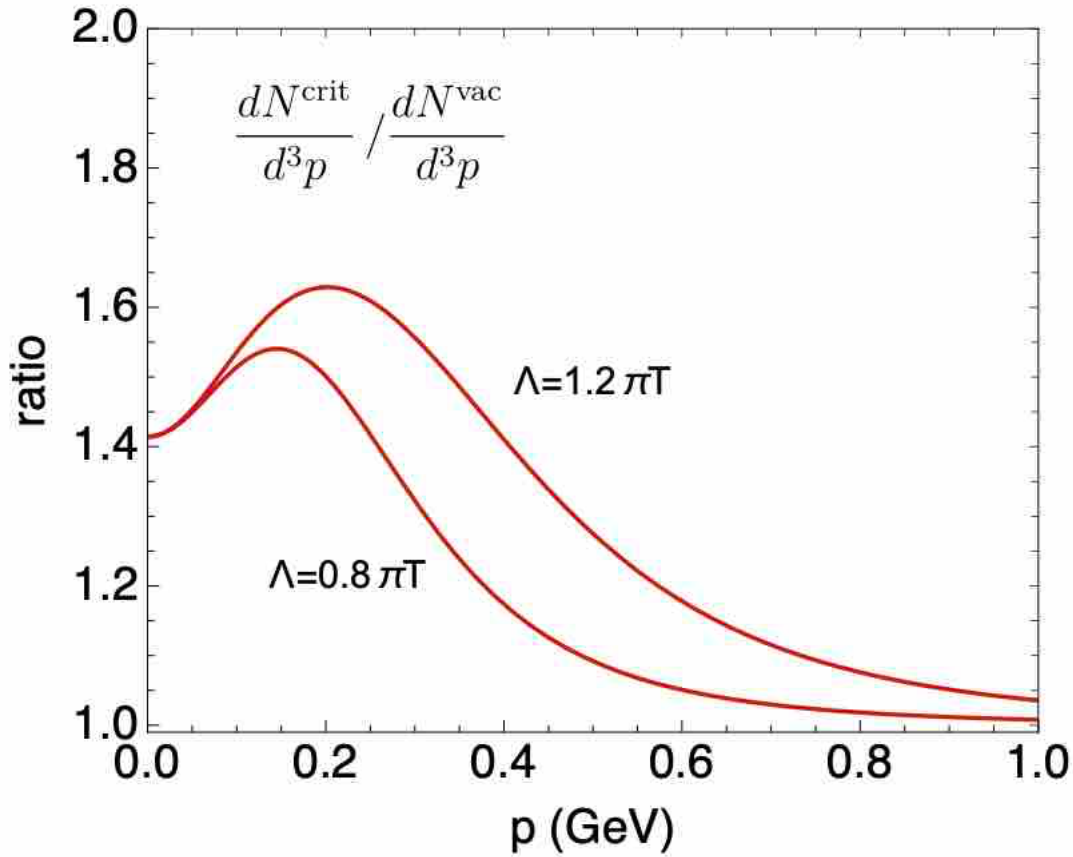




R.D. Pisarski and F. Rennecke, arXiv:2103.06890[hep-ph]

Soft pions and transport near the chiral critical point

- *The hydrodynamic theories at high and low temperatures are separated by the chiral critical point, which is somewhat analogous to the critical point separating the normal and superfluid phases of helium*
- *phenomenological estimate for how chiral fluctuations could effect the momentum spectrum of soft pions*



The yields for soft pions due to a critical modification of the dispersion curve, relative to an expectation based on the vacuum dispersion curve

E.Grossi et al., arXiv:2101.10847[nucl-th]

Outlook

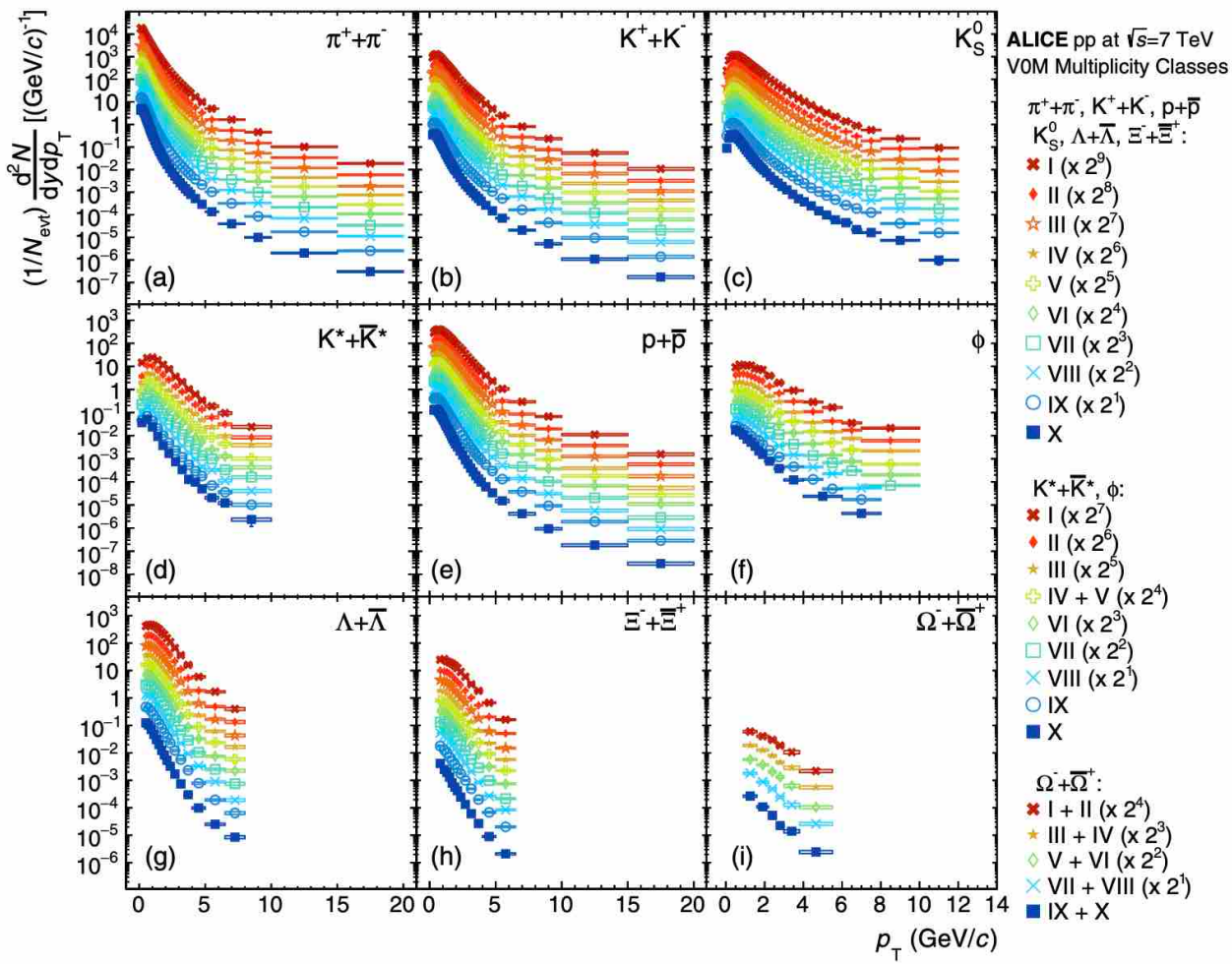
- *Model predictions are mandatory for guiding the experiment and data analysis*

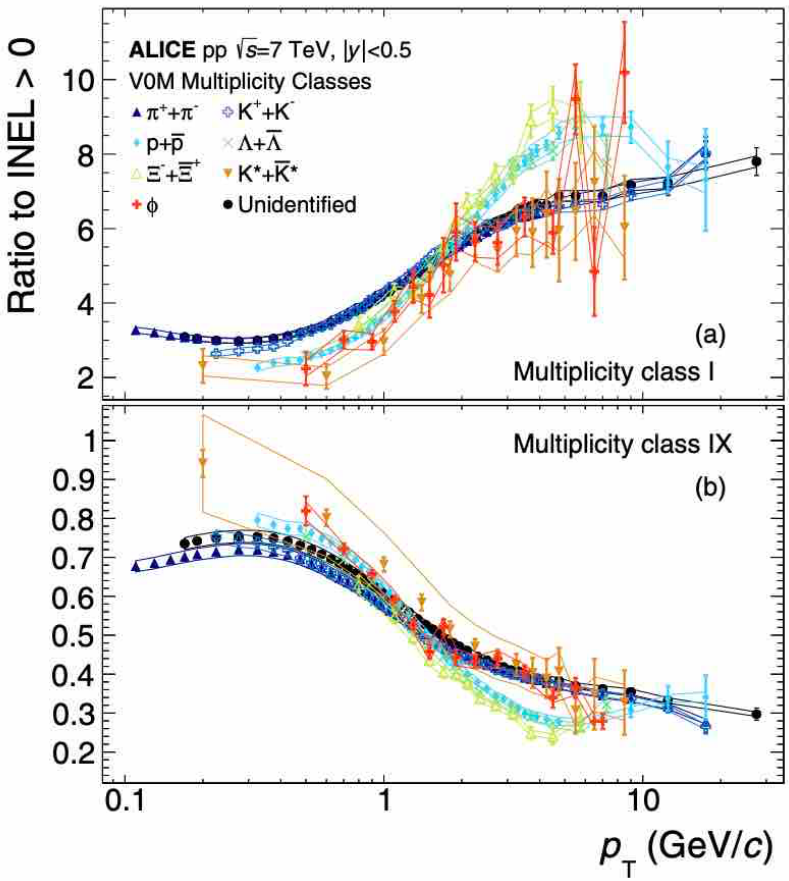
- *The confirmation/support for underlying physics and validation of different approximations used by the models require detailed complementary multi-differential analyses*

- *Independent of how challenging the models are, a careful analysis should not exclude new findings*

- *How to reach low p_T measurement in CBM - see next presentation*

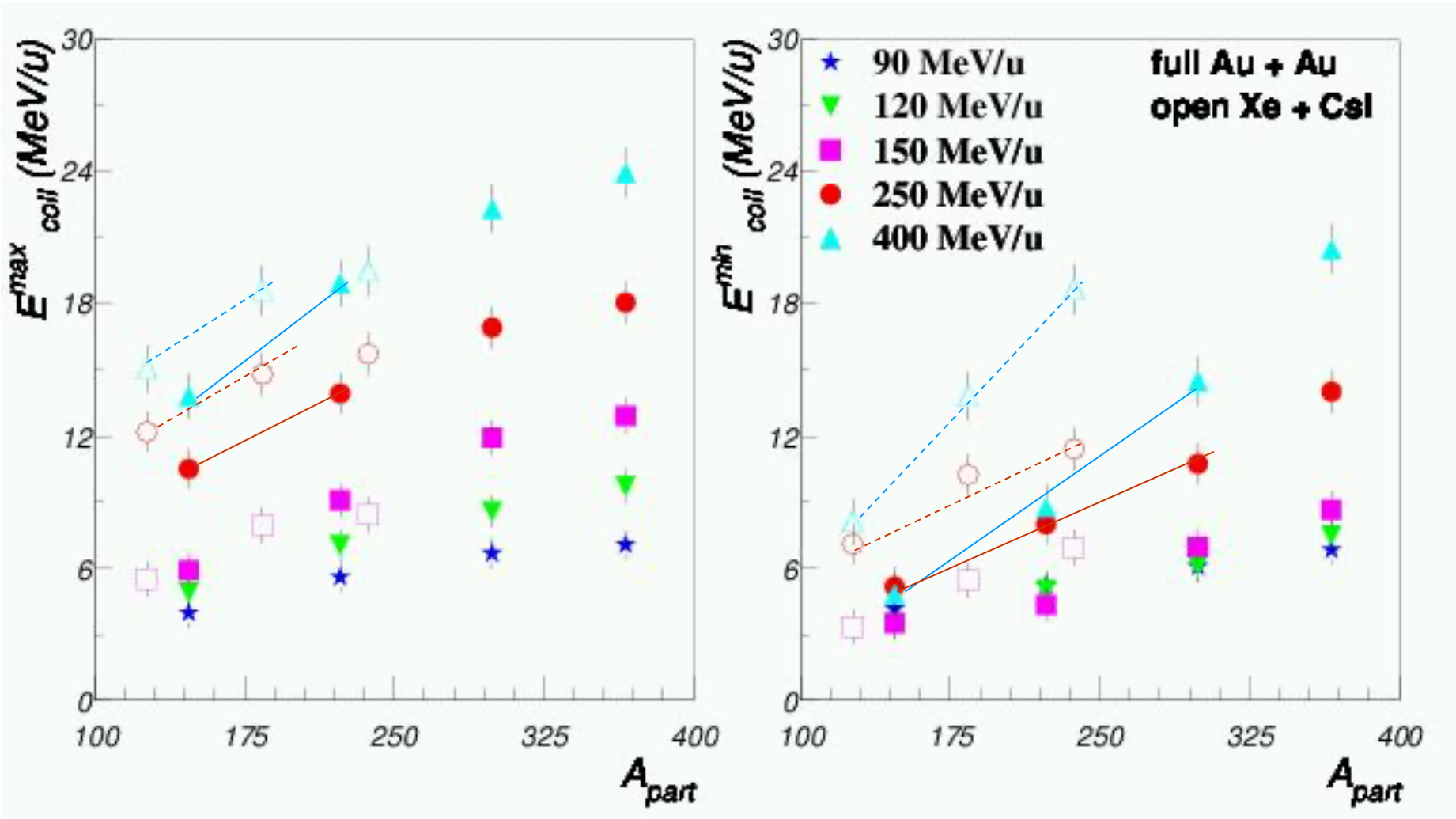
Back-up slides





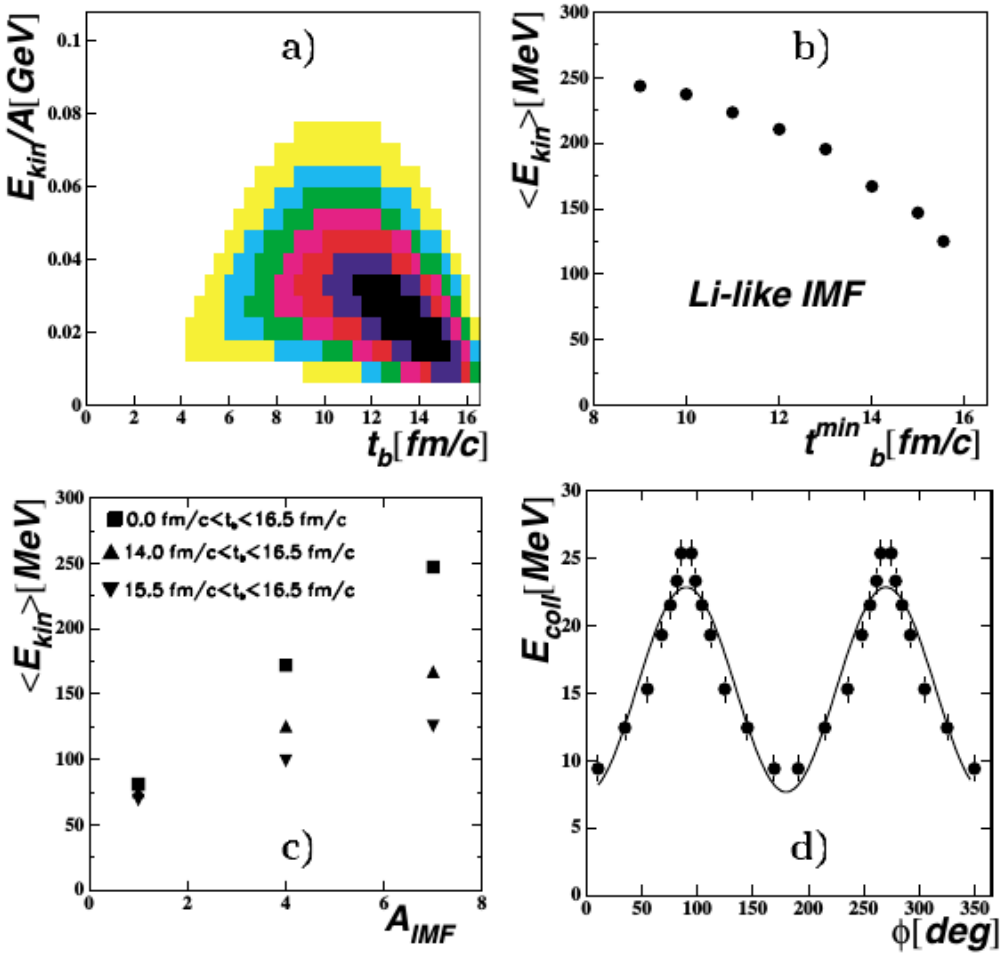
ALICE Collaboration, Phys.Rev. C99(2019)024906

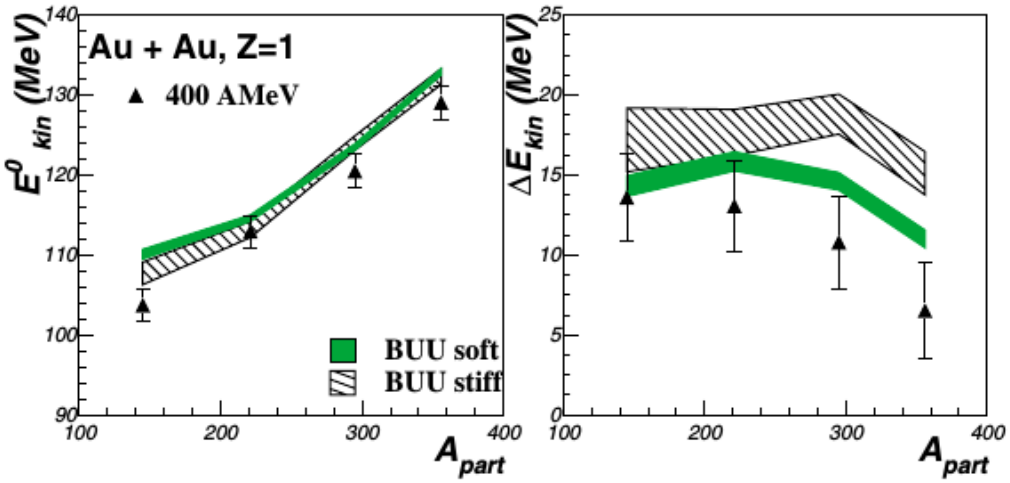
Fireball shape & shadowing effects at SIS18



G.Stoicea, M.Petrovici & FOPI Coll., Phys.Rev.Lett. 92(2004)072303

Shadowing effects - EoS





M.Petrovici et al., Phys.Rev.Lett. 74(1995)5001

G.Stoicea, M.Petrovici & FOPI Coll., Phys.Rev.Lett. 92(2004)072303

P.Danielewicz, Nucl.Phys. A6873(2000)375 and ref. therein