From electromagnetic effects to fire-streaks in heavy ion collisions

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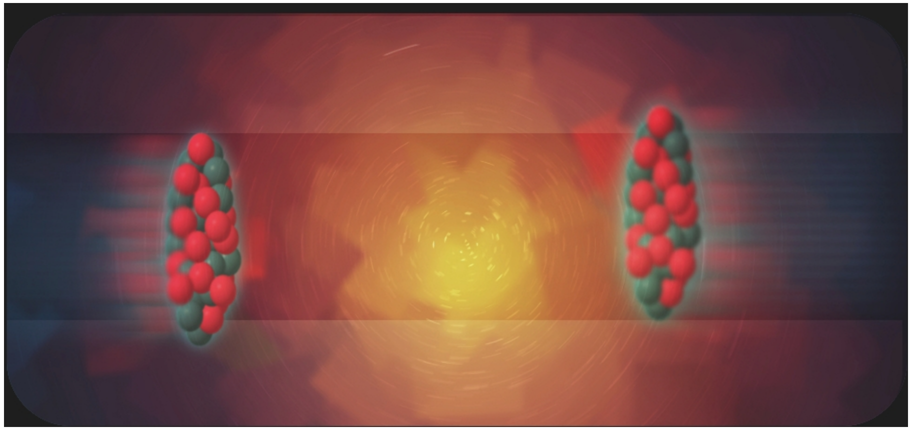
Plot by I. Sputowska

In collaboration with:
Andrzej Rybicki
Antoni Szczurek

Outline

- Introduction.
- Electromagnetic effects in heavy ion collisions.
- Formation distance of π meson from the spectator system, d_E.
- Fire-streaks.
- Conclusions.



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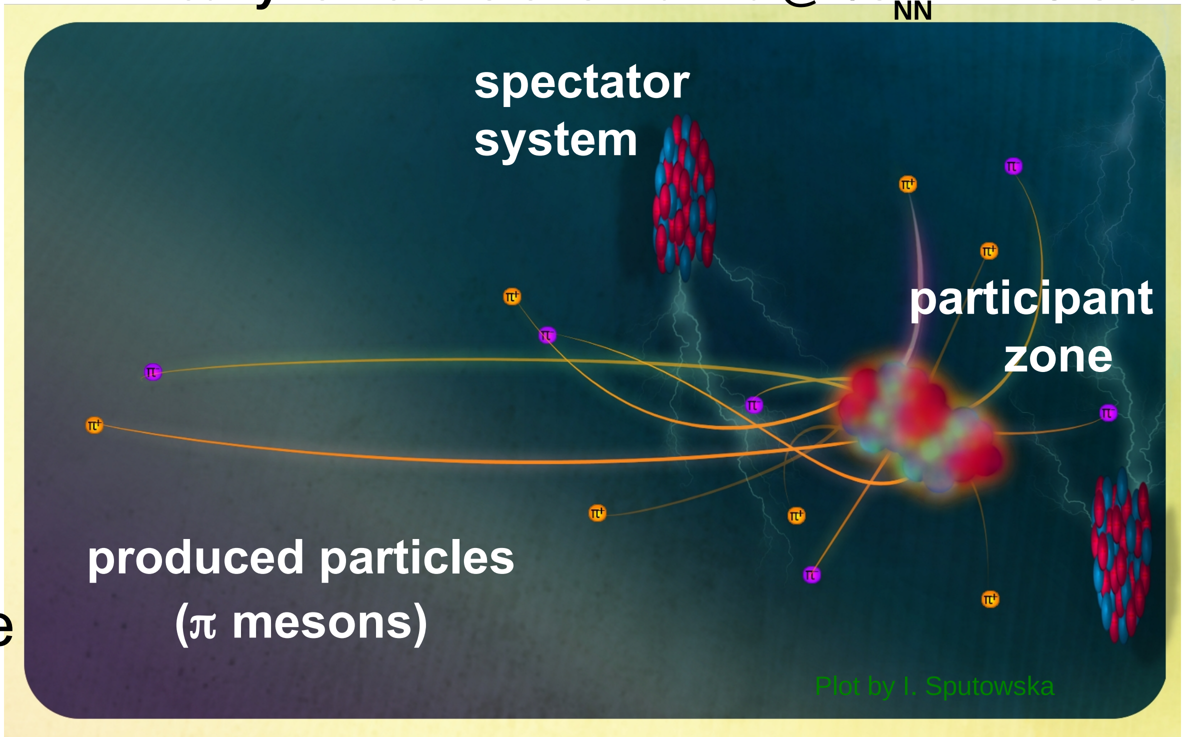
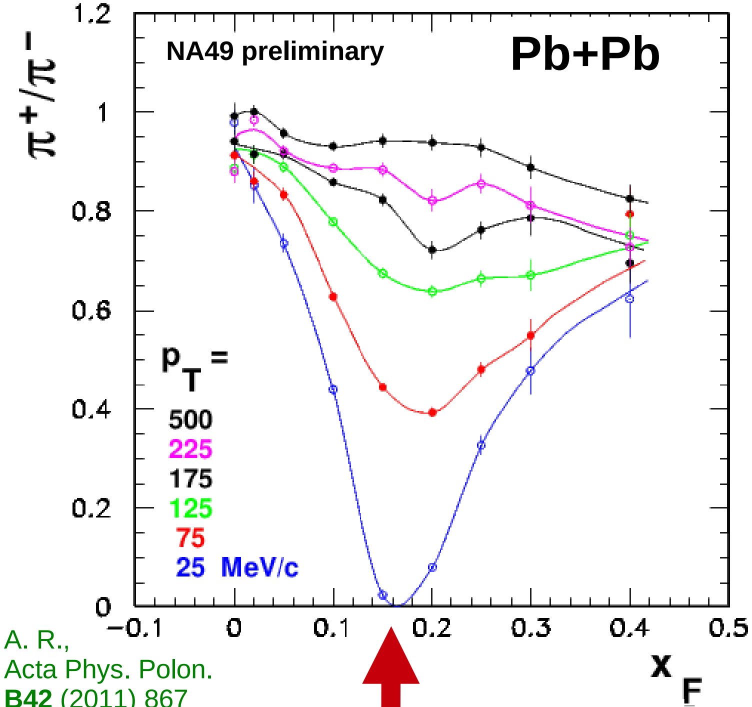
Heavy ion collisions Pb+Pb @ $\sqrt{s_{NN}}$ = 17.3 GeV



Introduction

- Charged spectators generate electromagnetic fields.
- These modify charged pion spectra in the final state.
- We use this effect as a new source of information on the space-time evolution of the system.
- This brings us to a specific energy-momentum conservation picture in the initial stage. → (Fire-streaks)

Electromagnetic effects

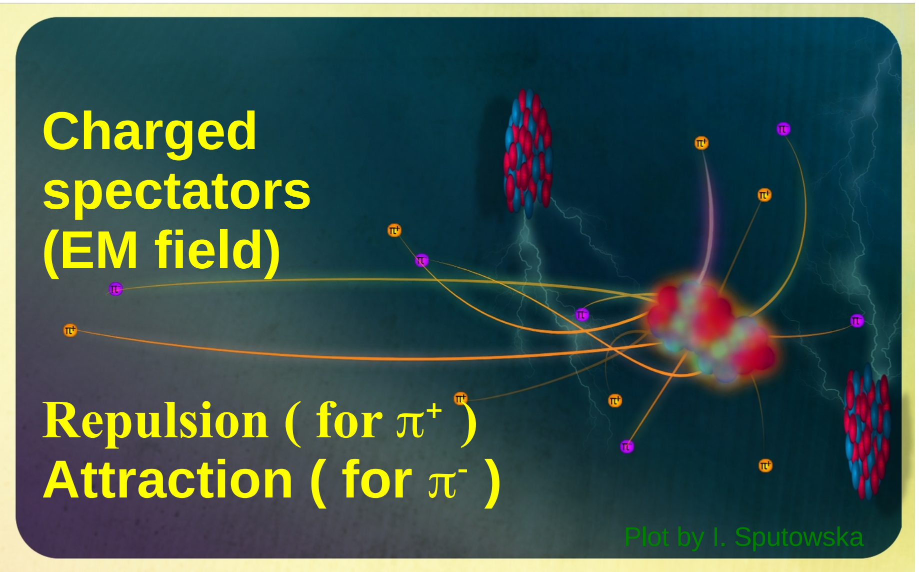


A. R.,
Acta Phys. Polon.
B42 (2011) 867

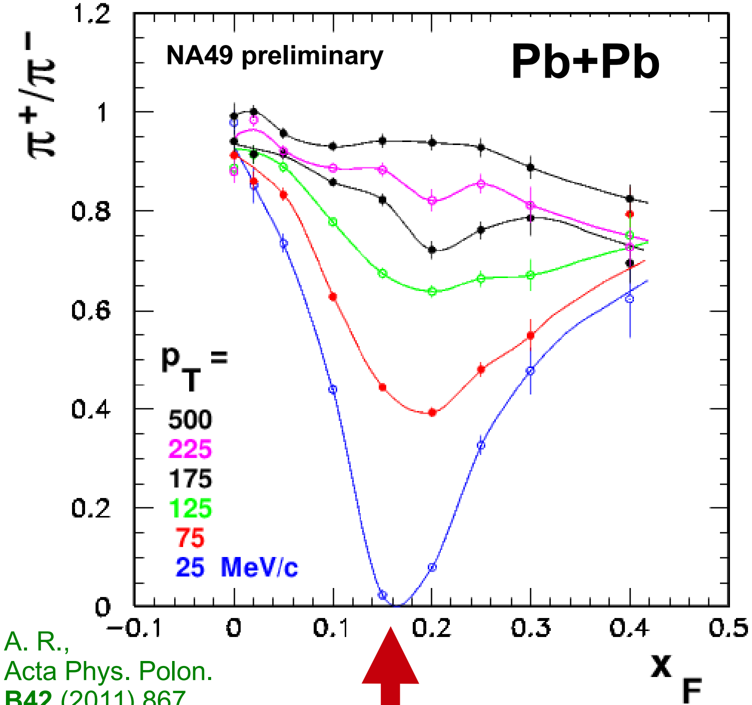
spectator velocity:
$y = y_{beam}$

$$x_F = \frac{p_L}{p_L^{beam}}$$

(c.m.s.)



- EM effects influence the emission of π mesons, namely modify the ratio of π^+/π^-.
- Dependence on p_T.
- Visible as a drop of π^+/π^- ratio at low p_T and pion velocity close to spectator velocity.
- A.Rybicki and A.Szczurek Phys. Rev. C75, 054903 (2007).



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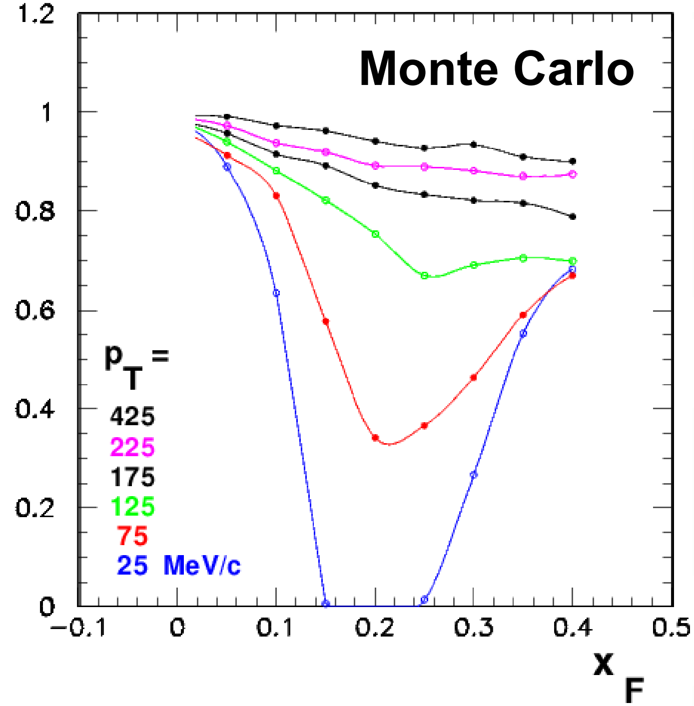

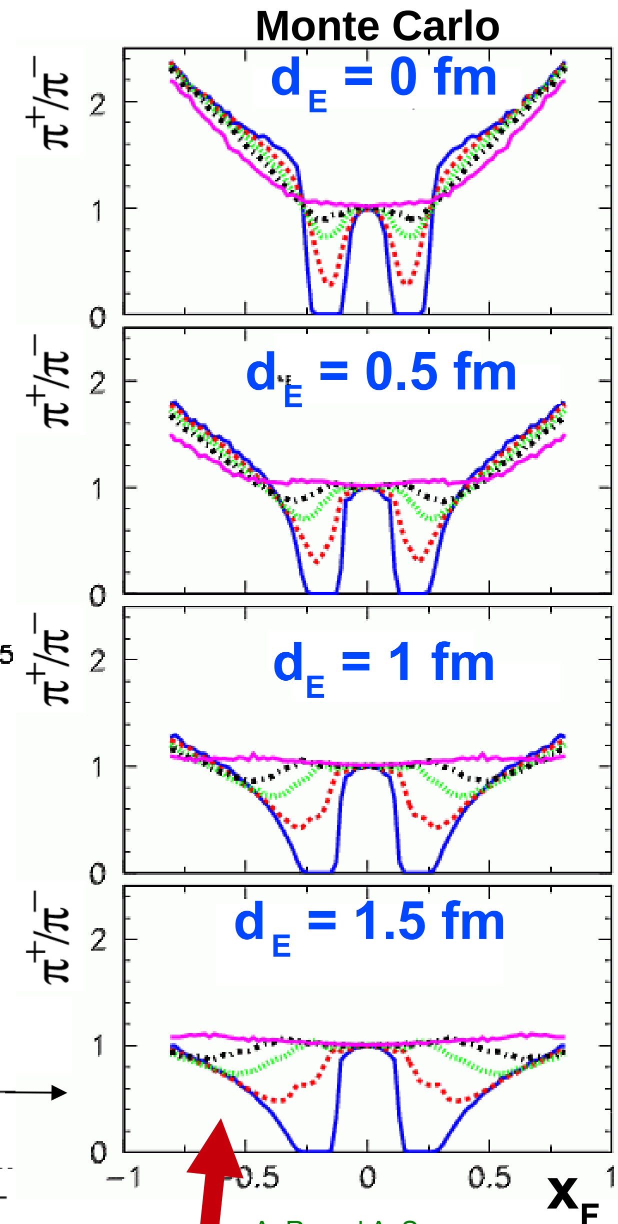

A. R. and A. S.,
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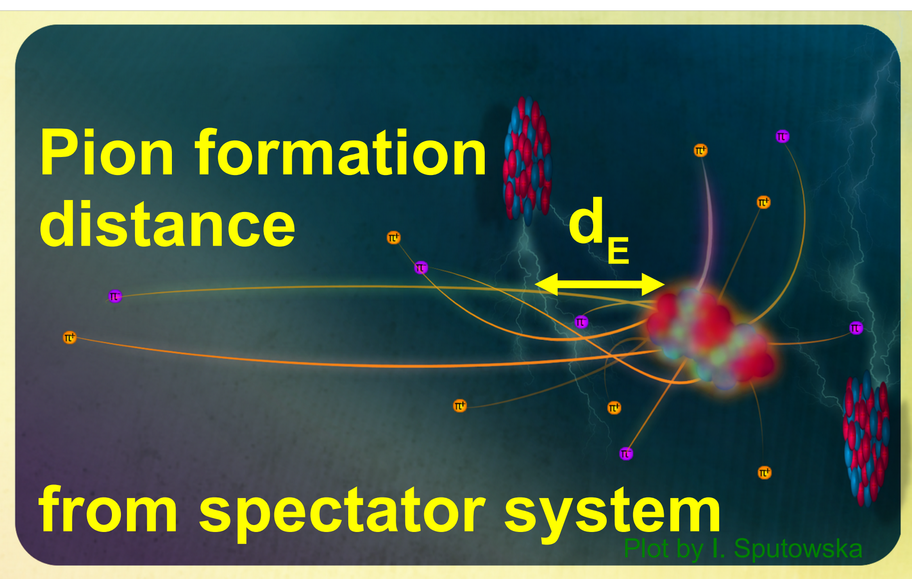
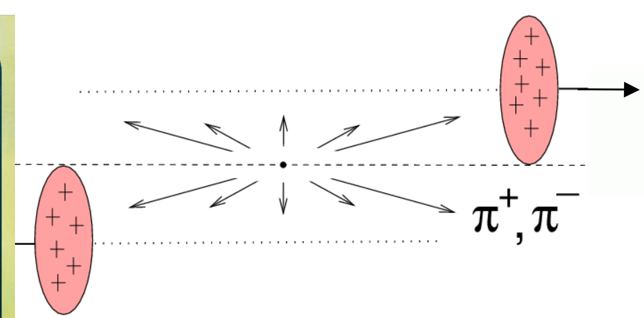
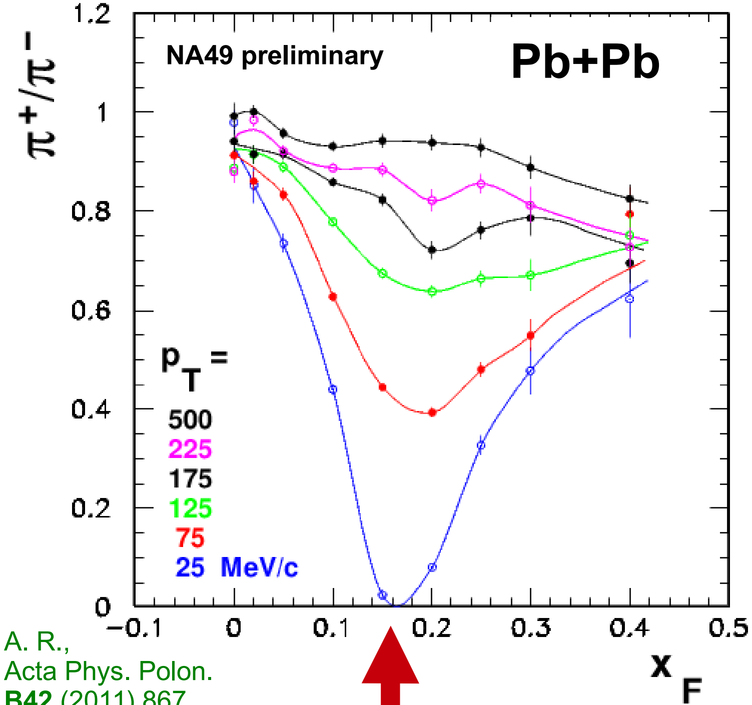




Sensitive to d_E



A. R.,
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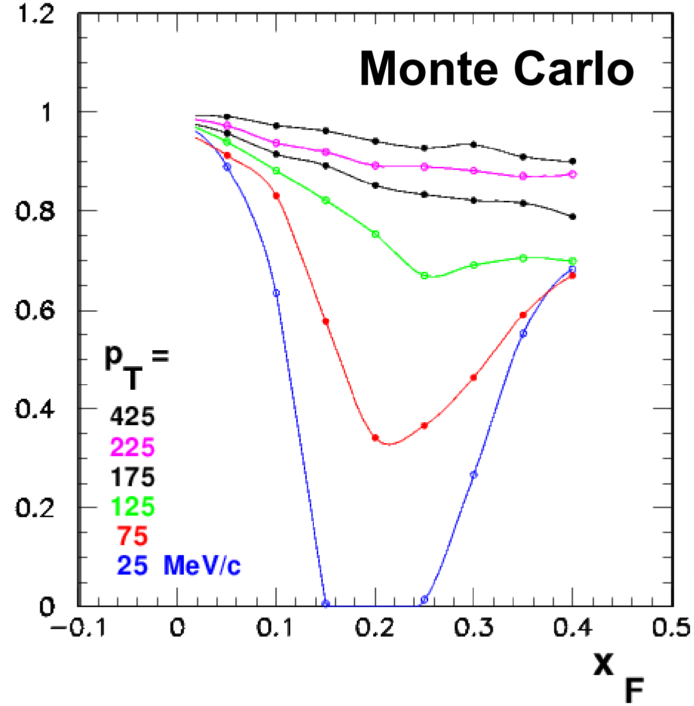

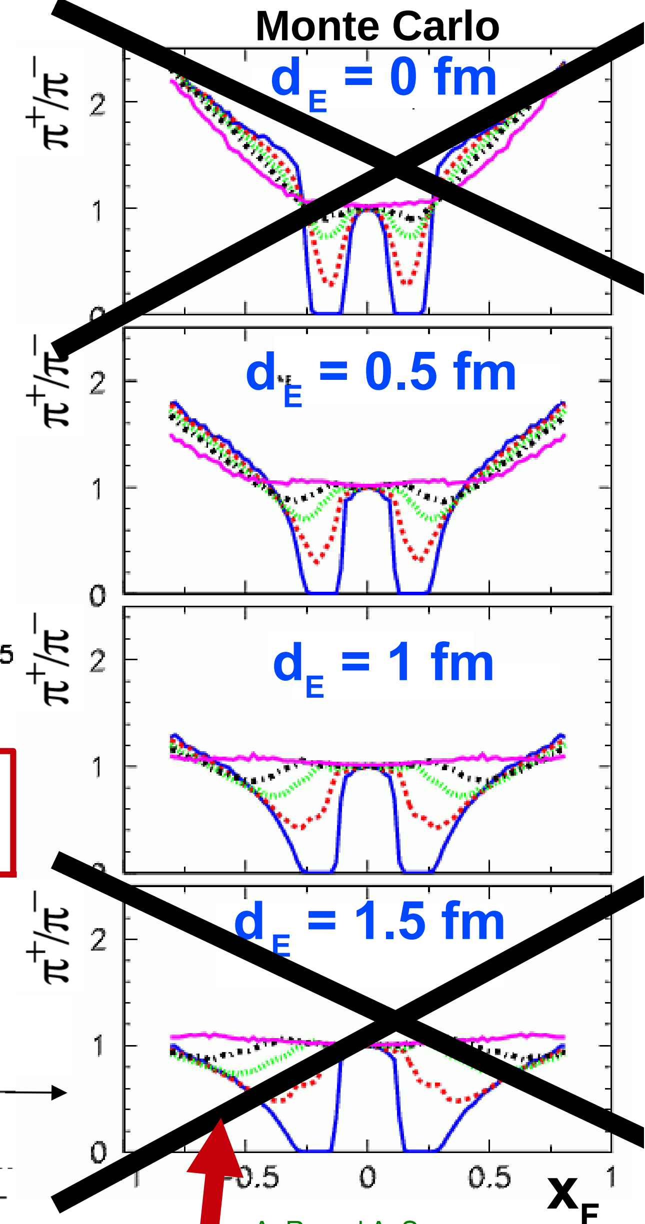

A. R. and A. S.,
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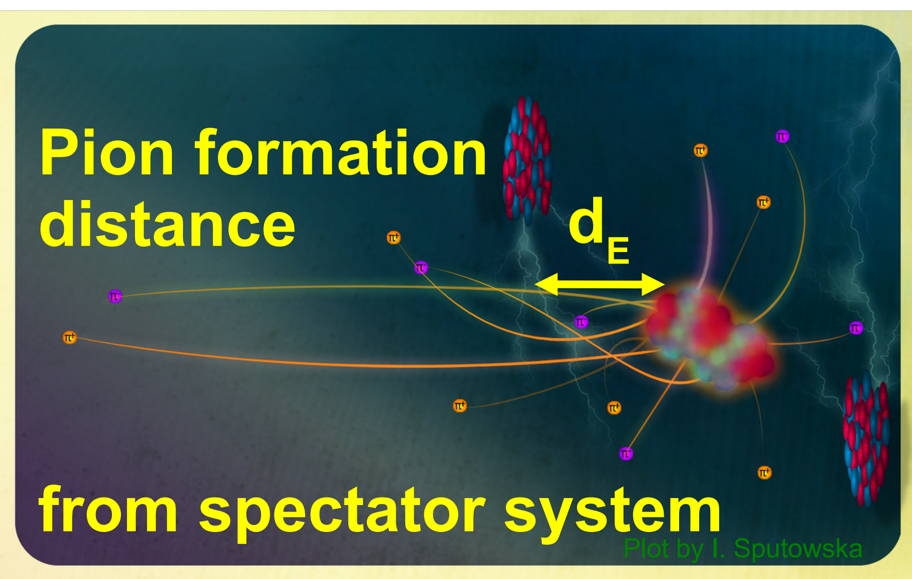
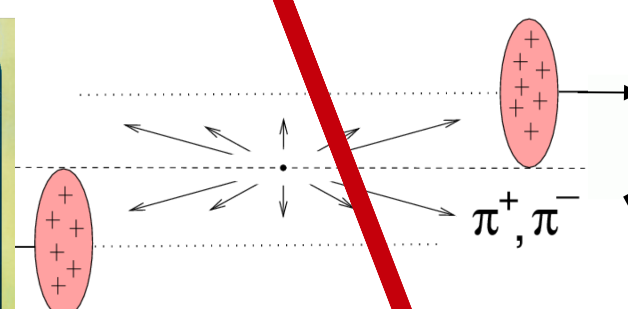
$d_E \approx 0.75$ fm !





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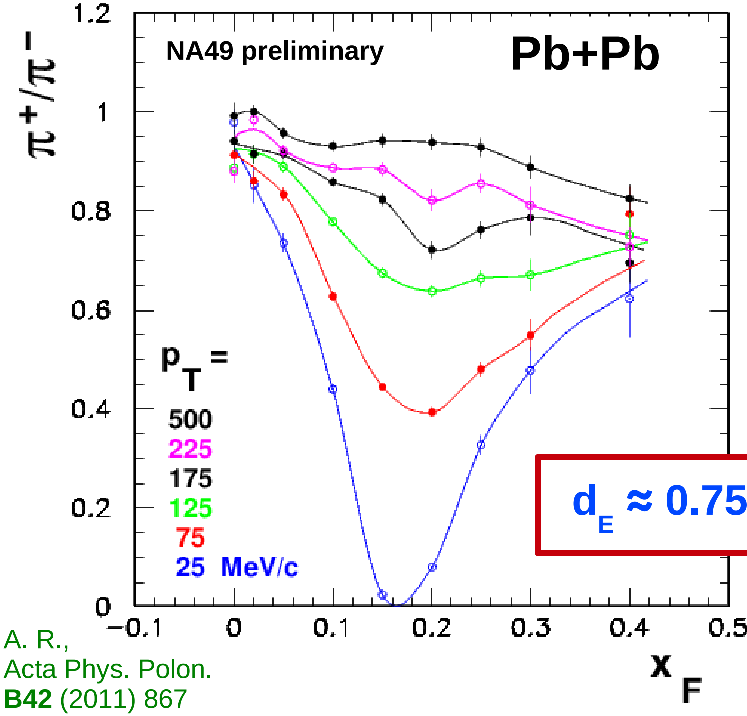

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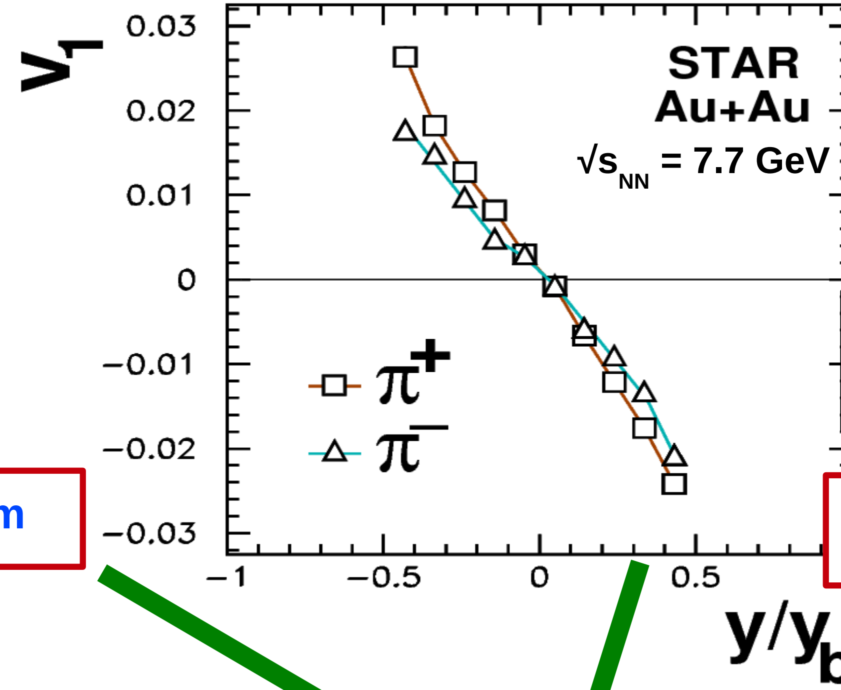


L. Adamczyk et al. STAR, Phys. Rev. Lett. 112, (2014) 162301.

A. R. and A. S., Phys. Rev. **C87** (2013) 054909.

A. R., APPB 46 (2015) 3, 737.

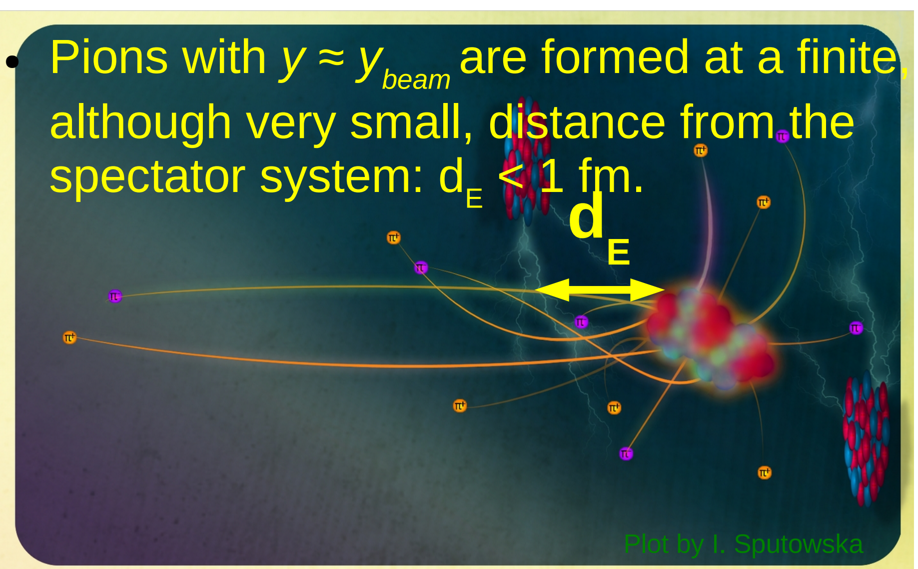
Directed flow:

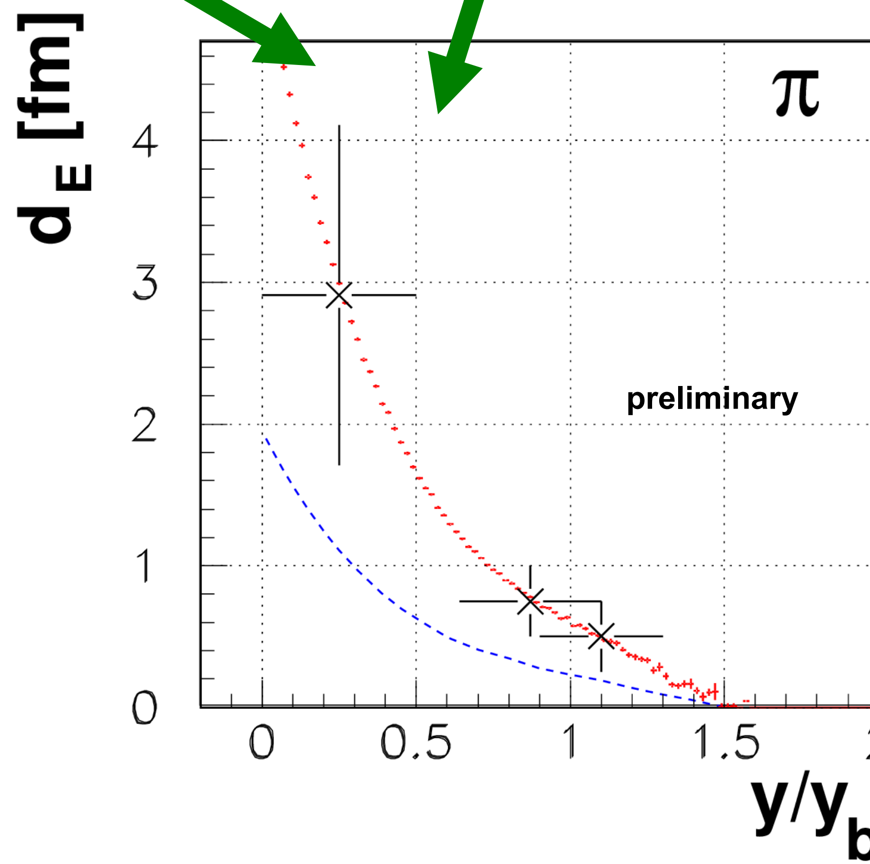
$v_1 = < \cos(\phi - \Psi_{RP}) >$

$d_E \approx 3$ fm

- Formation distance of π meson from spectator system d_E, decreases with increase of rapidity y of emitted pion.

- Pions with $y \approx y_{beam}$ are formed at a finite, although very small, distance from the spectator system: $d_E < 1$ fm.

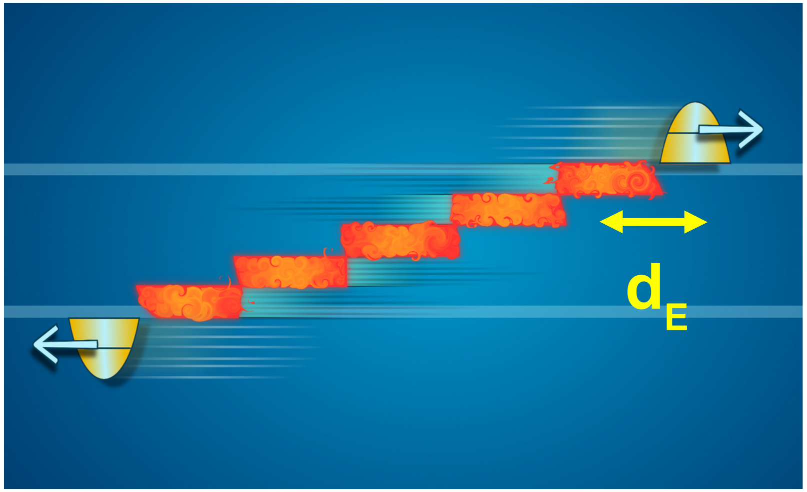




A. R., A. S. et al., APP Supp. 9 (2016) 303

Fire-streaks (1)

- Attempt to use E-p conservation to understand the behavior of d_E as a function of rapidity



Plot by I. Sputowska

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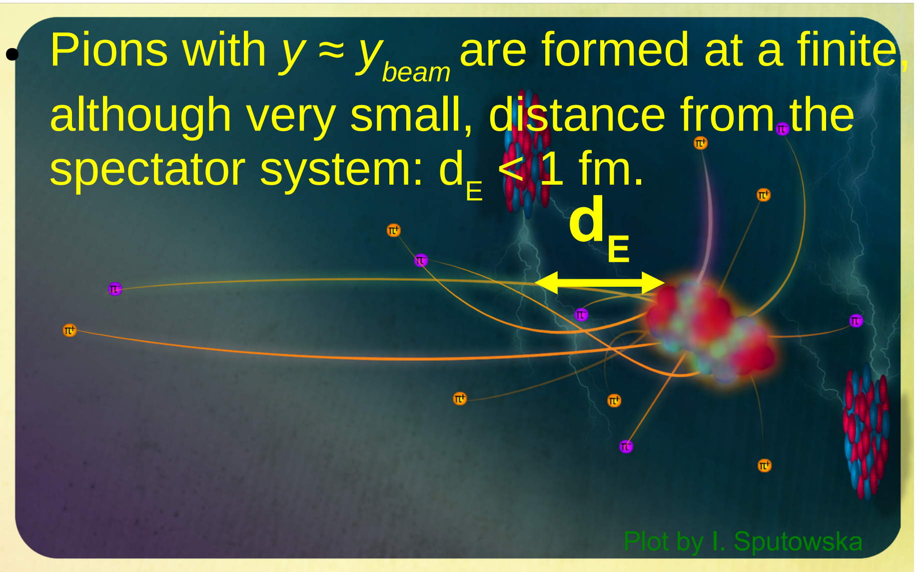
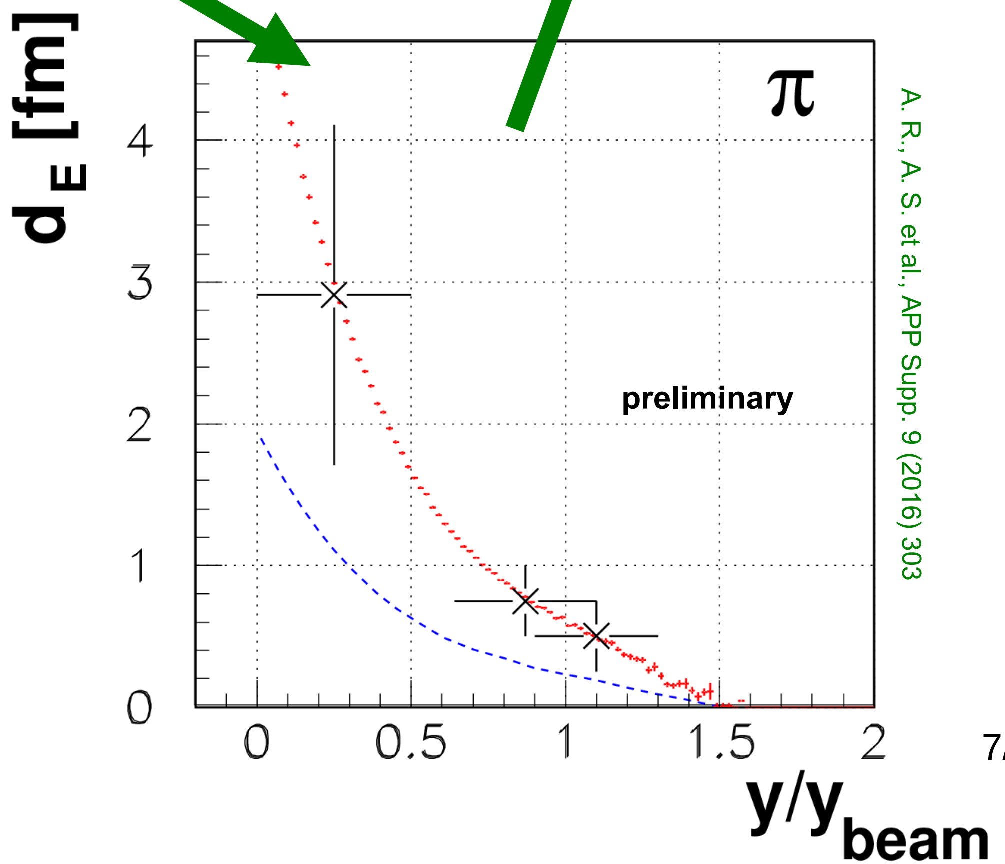
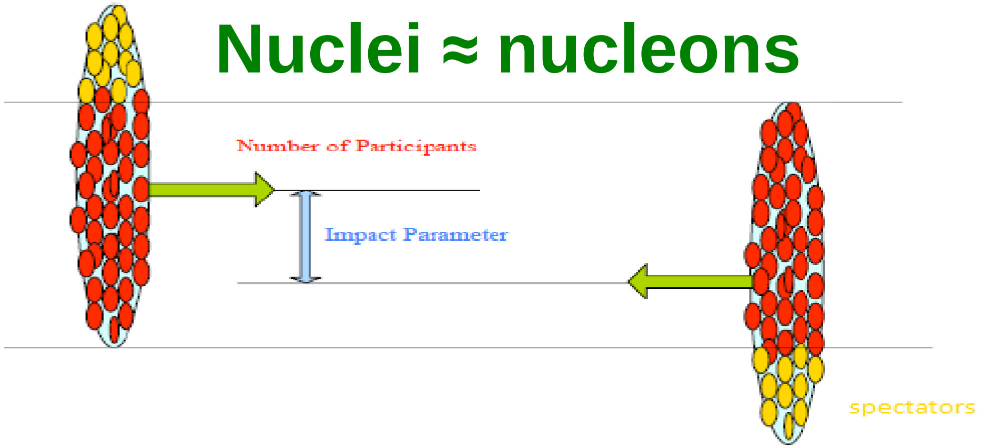


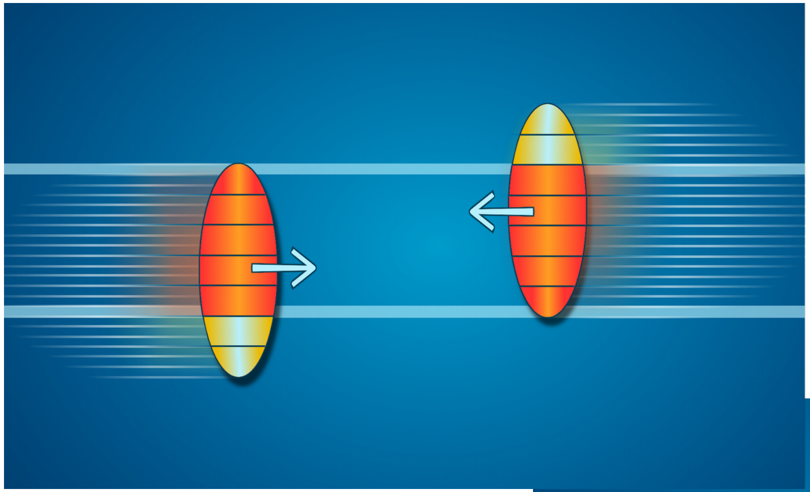


Fire-streaks (2)

- Standard Glauber model, collision divided into participant and spectator zone.

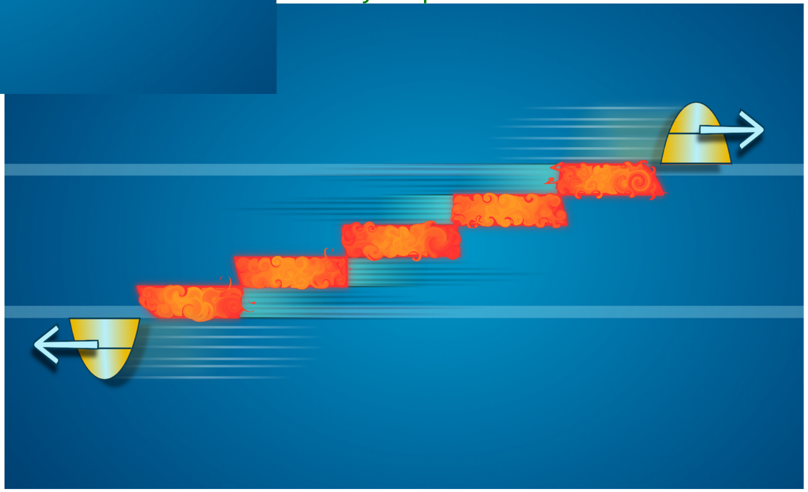


Nuclei ≈ 3D mass distributions



- Different approach to the collision of two nuclei, not by means of nucleon-nucleon collisions (as in the Glauber model) but on the basis of their mass distribution.

Plots by I. Sputowska



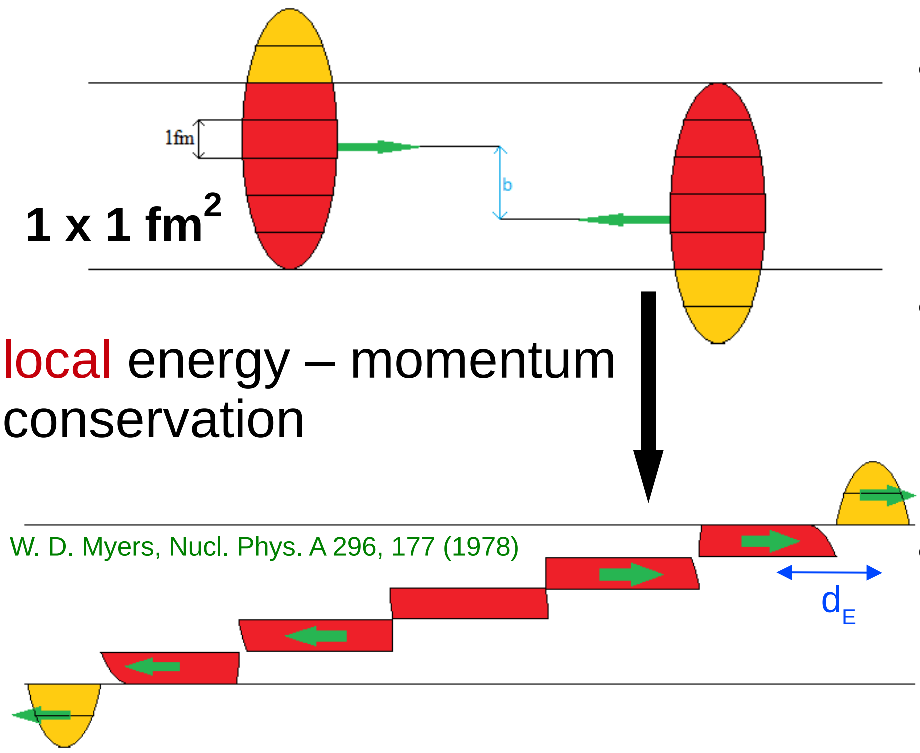
10 May 2017
IFJ PAN press release
Google out: fire streaks

Based on publication:
A. Szczurek, A. Rybicki, M. Kiełbowicz,
Phys. Rev. C95, 024908 (2017)

See also:
W. D. Myers,
Nucl. Phys. A 296, 177 (1978)

Model formulation

- We divide the 3D nucleus mass distribution into "bricks" in the perpendicular plane (brick size: 1 x 1 fm^2).



- Assumption: the colliding bricks "stick together" and can be treated as a single object - called a fire-streak.
- The energy of the fire-streaks is greater (in its c.m.s.) than the rest mass of the two bricks, so there is some kind of excitation!
- The fire-streak excitation energy E^*_S and rapidity y_S can be obtained from E – p conservation.

- Each fire-streak fragments independently into pions

$$\frac{dn}{dy} = A \cdot (E_s^* - m_s) \cdot \exp\left(\frac{-[(y-y_s)^2 + \varepsilon^2]^{\frac{n}{2}}}{n\,\sigma_y^n} \right)$$

excitation energy

summed rest mass of the two bricks

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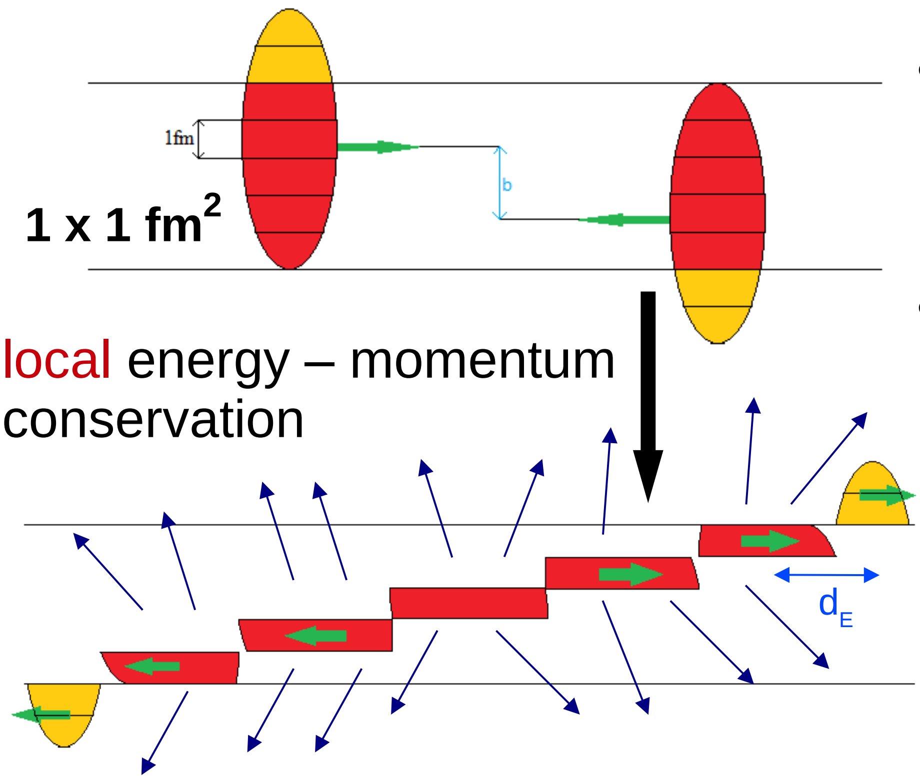

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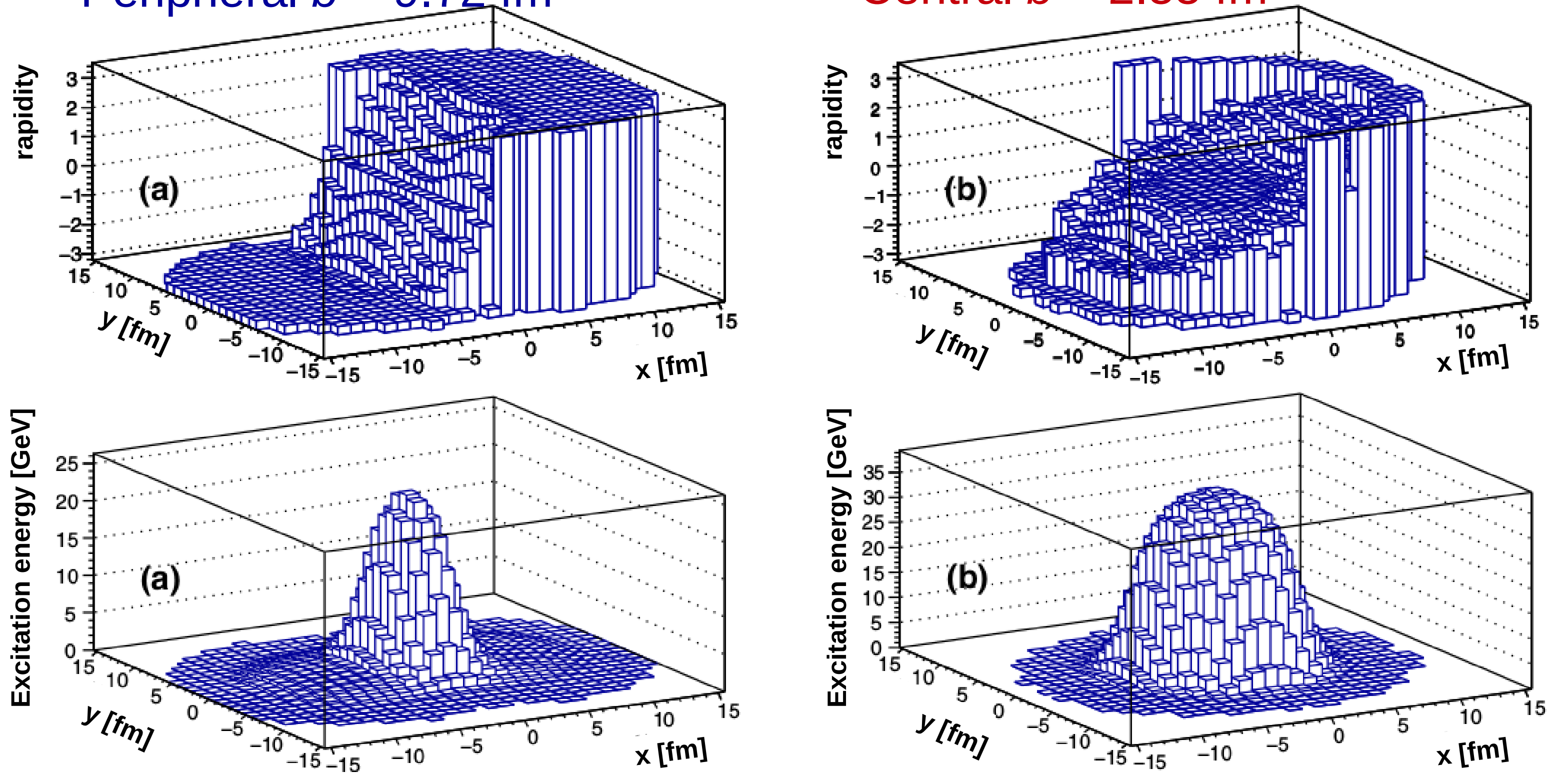
summed rest mass of the two bricks

Fire-streaks characteristics

Pb+Pb @ 158 GeV $\longrightarrow \sqrt{S_{NN}} = 17.3\,GeV$ $y_{beam} = 2.9$

Peripheral *b* = 9.72 fm Central *b* = 2.55 fm



- Very narrow (if any) “stopped” region in peripheral collisions.
- Much smaller spread in rapidity of the fire-streaks in central reactions.

- In peripheral collisions two spectator regions are visible.
- Central reactions: broader “hot” region, with higher excitation energies.

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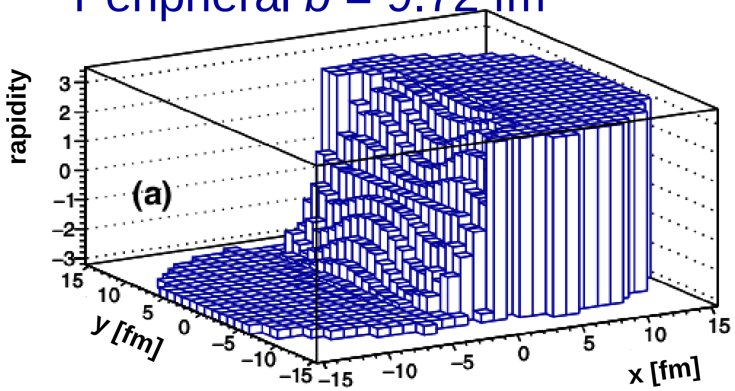
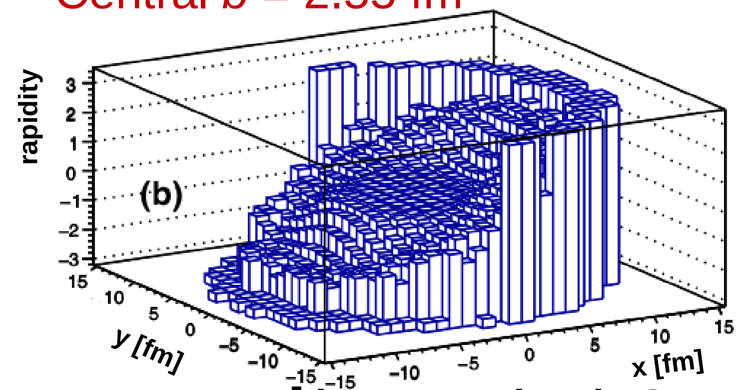


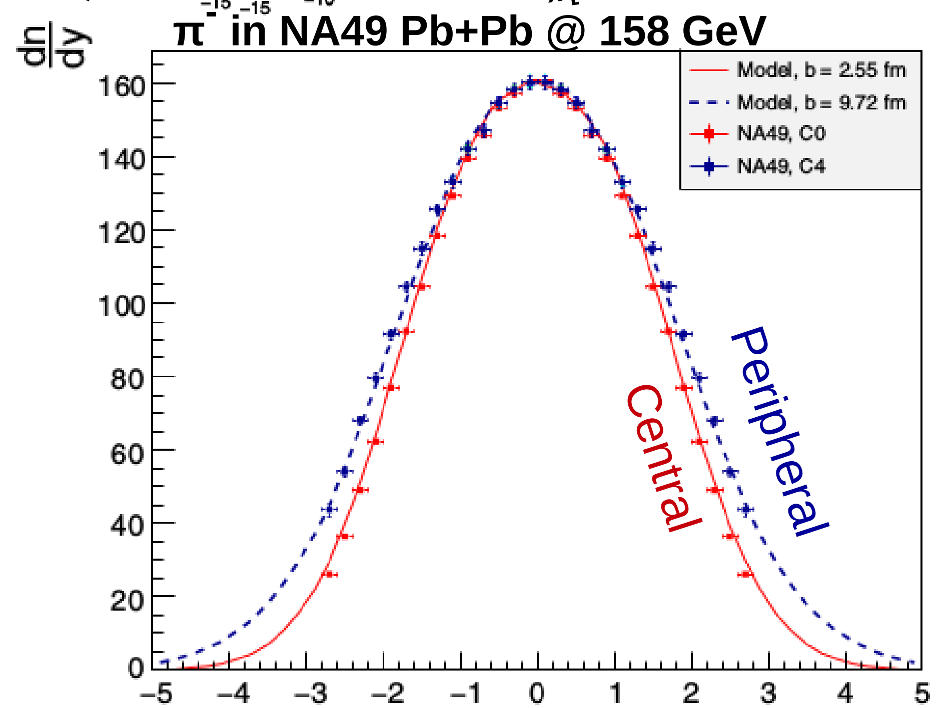
Central *b* = 2.55 fm



Explains the narrowing of the pion rapidity spectrum in central reactions.

- Much smaller spread in rapidity of the fire-streaks in central reactions.

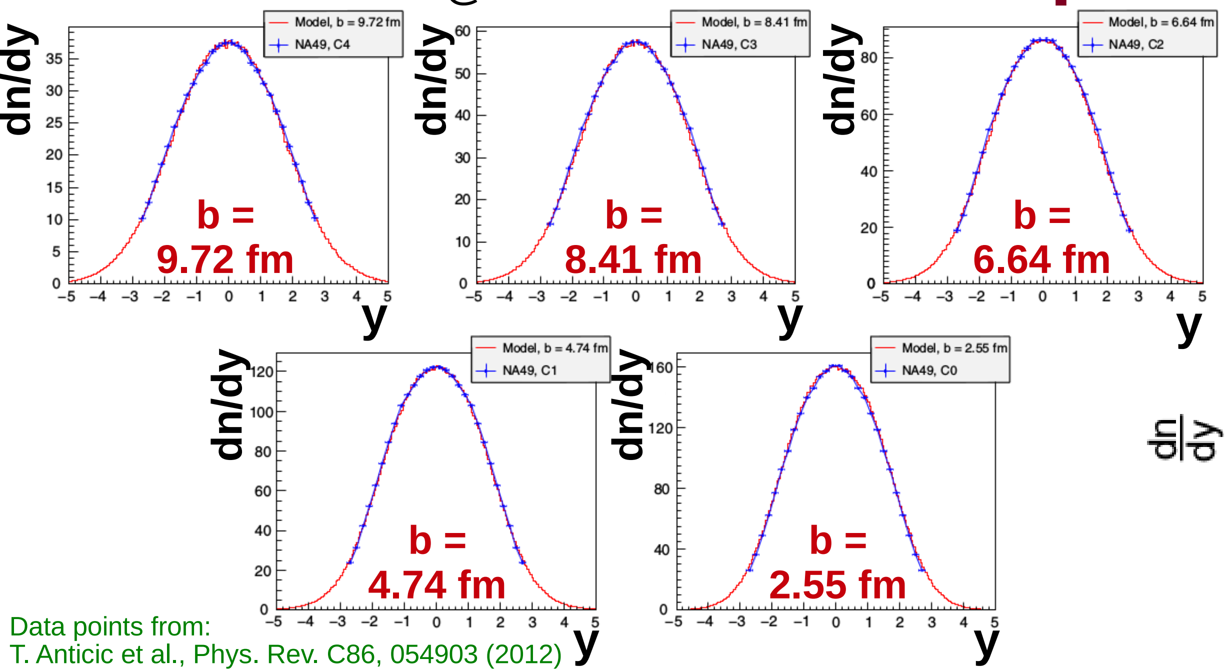
$$\frac{dn}{dy} = A\cdot(E_s^* - m_s)\cdot\exp\left(\frac{-[(y-y_s)^2+\varepsilon^2]^{\frac{n}{2}}}{n\,\sigma_y^n}\right)$$



A. Szczurek, A. Rybicki, M. Kiełbowicz, Phys. Rev. C95, 024908 (2017)
Data points from: T. Anticic et al., Phys. Rev. C86, 054903 (2012)

Centrality dependence of pion production

π^- in NA49 Pb+Pb @ 158 GeV



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Yield and shape of pion *dn/dy* spectrum as function of centrality.

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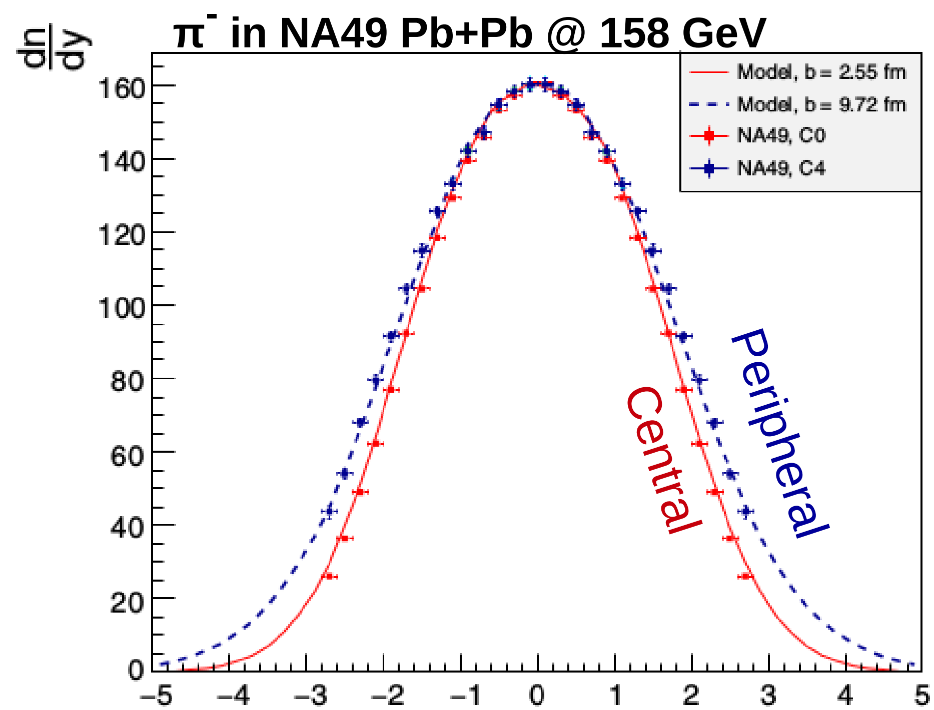

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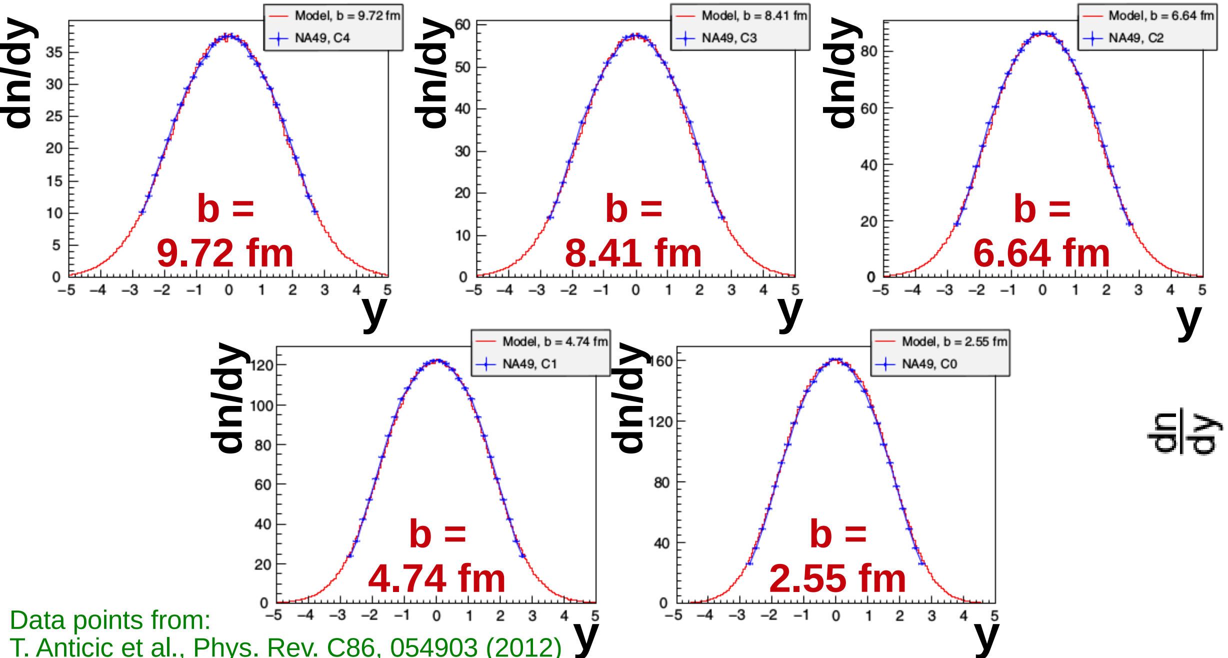

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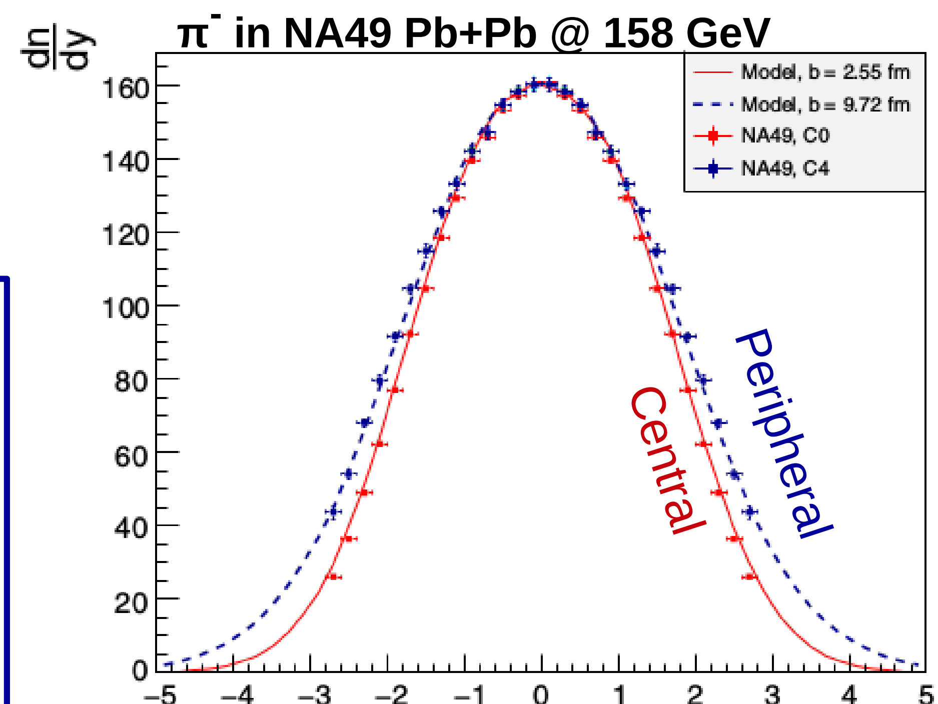

A. Szczurek, A. Rybicki, M. Kiełbowicz, Phys. Rev. C95, 024908 (2017)
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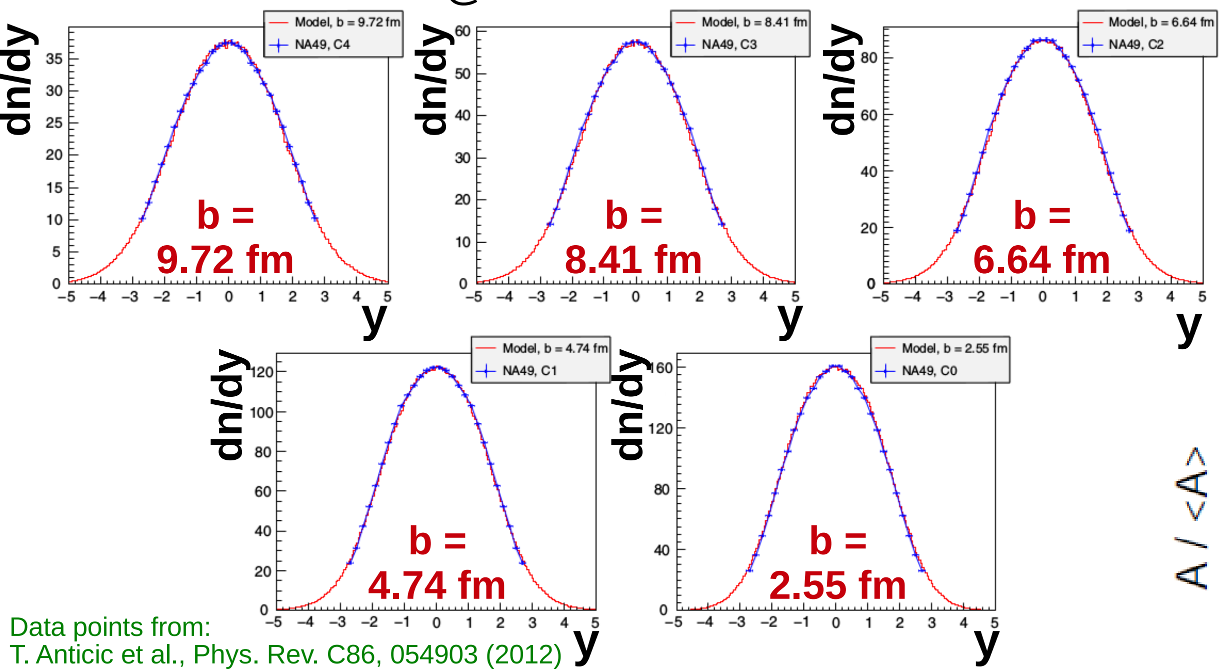
Full centrality dependence of pion dn/dy spectrum:

consequence of E-p conservation!

Parameter stability

π^- in NA49 Pb+Pb @ 158 GeV



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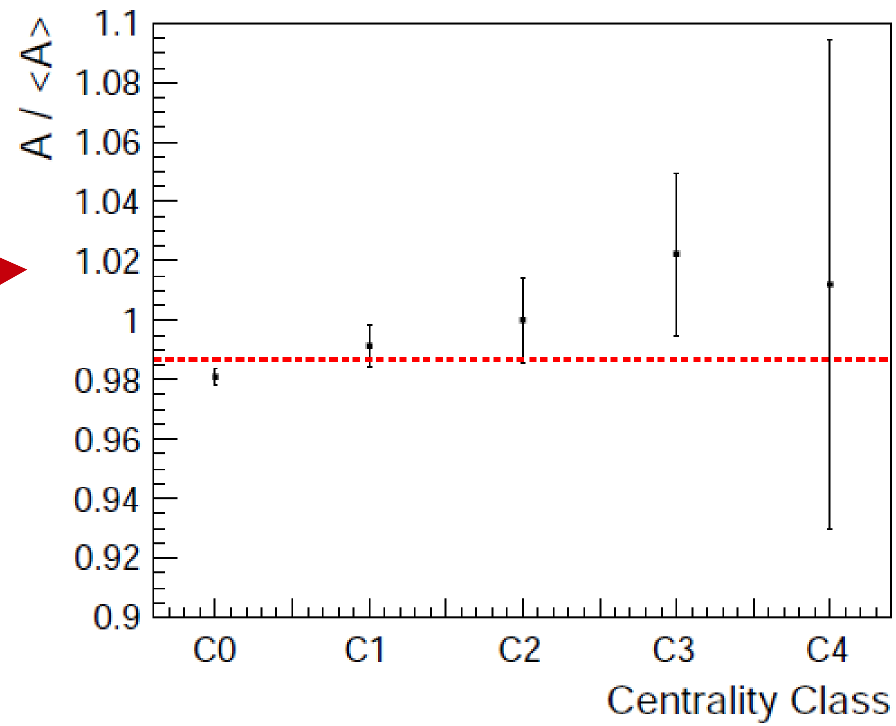

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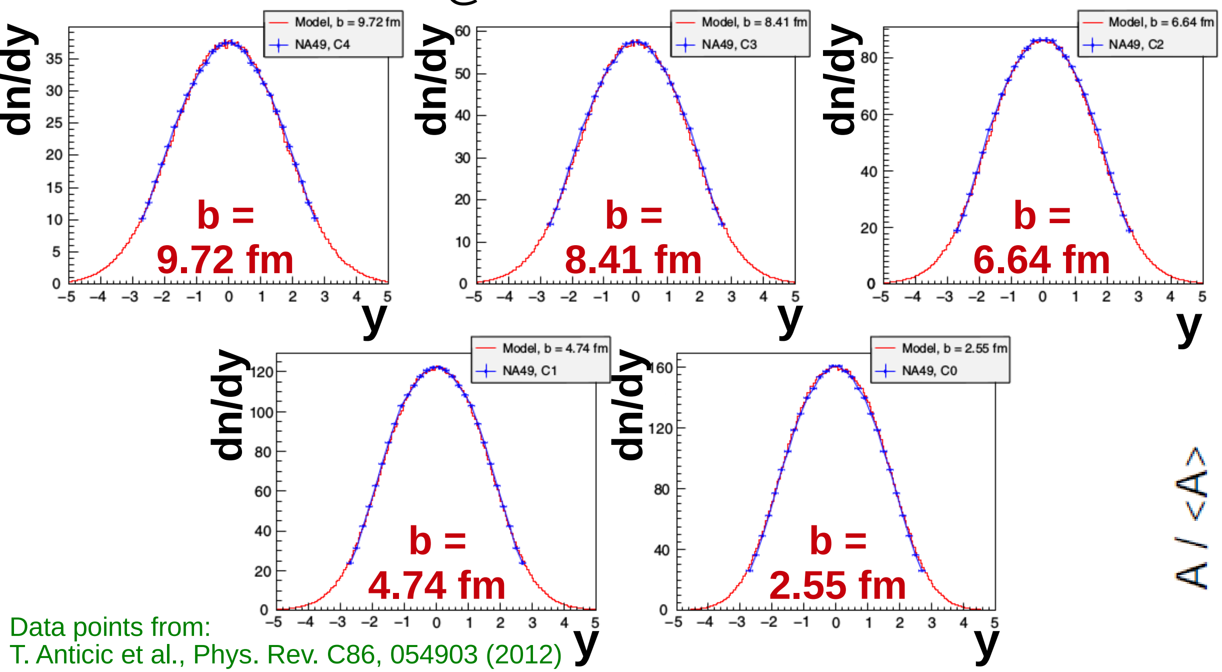

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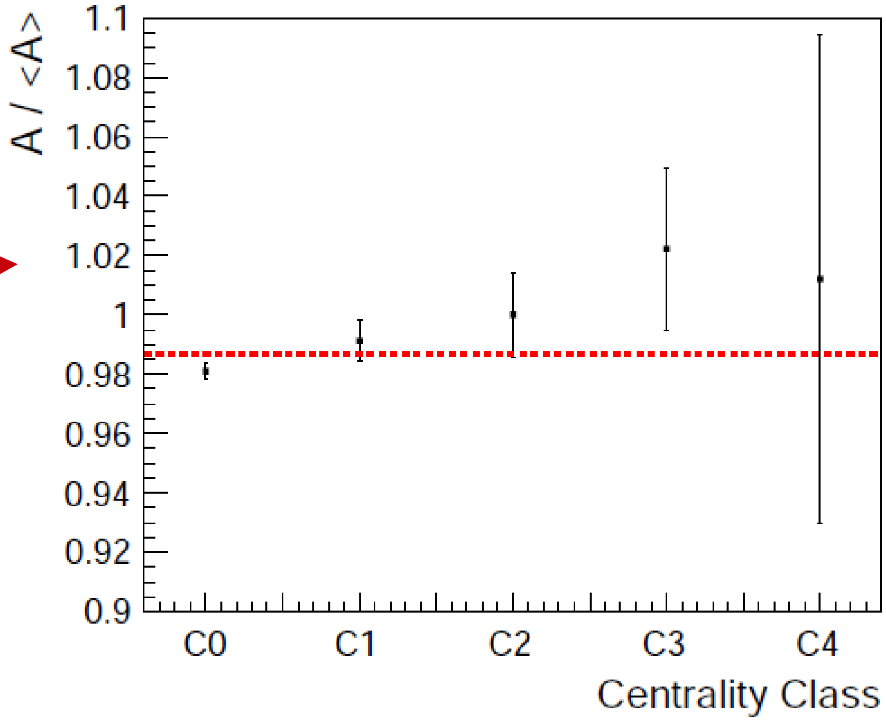

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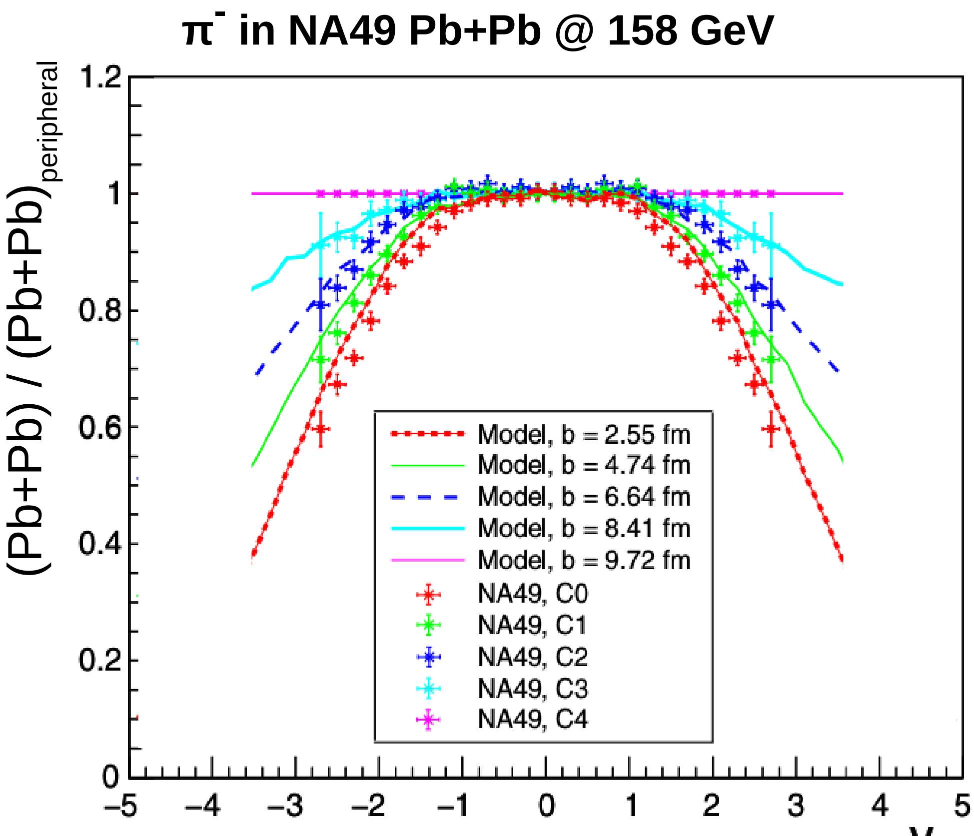
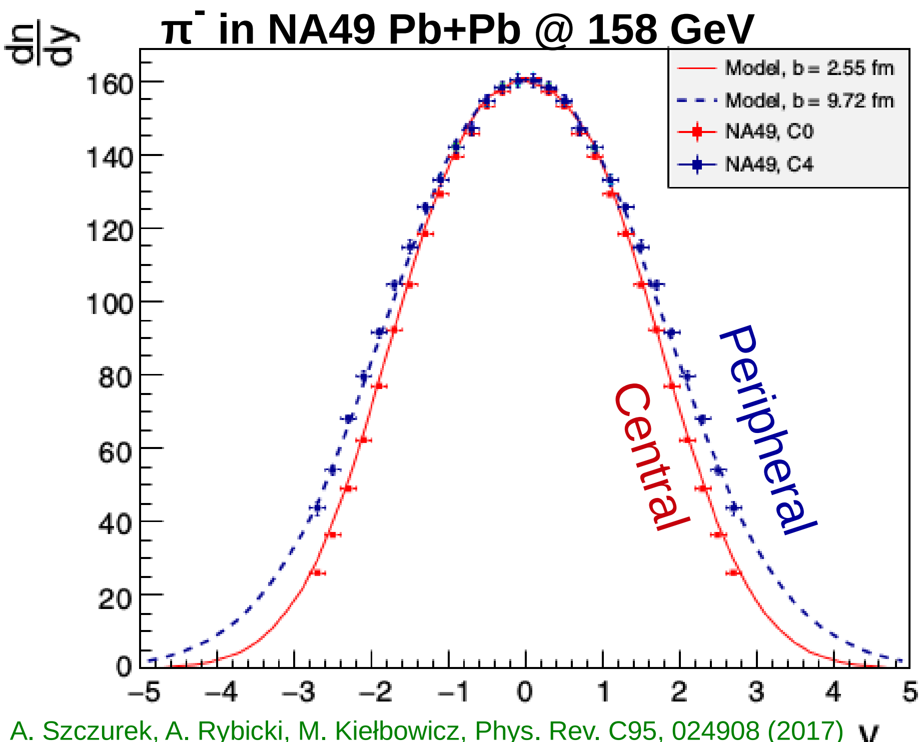
Precision



Shapes of rapidity spectra, normalized to the most peripheral Pb+Pb collisions.



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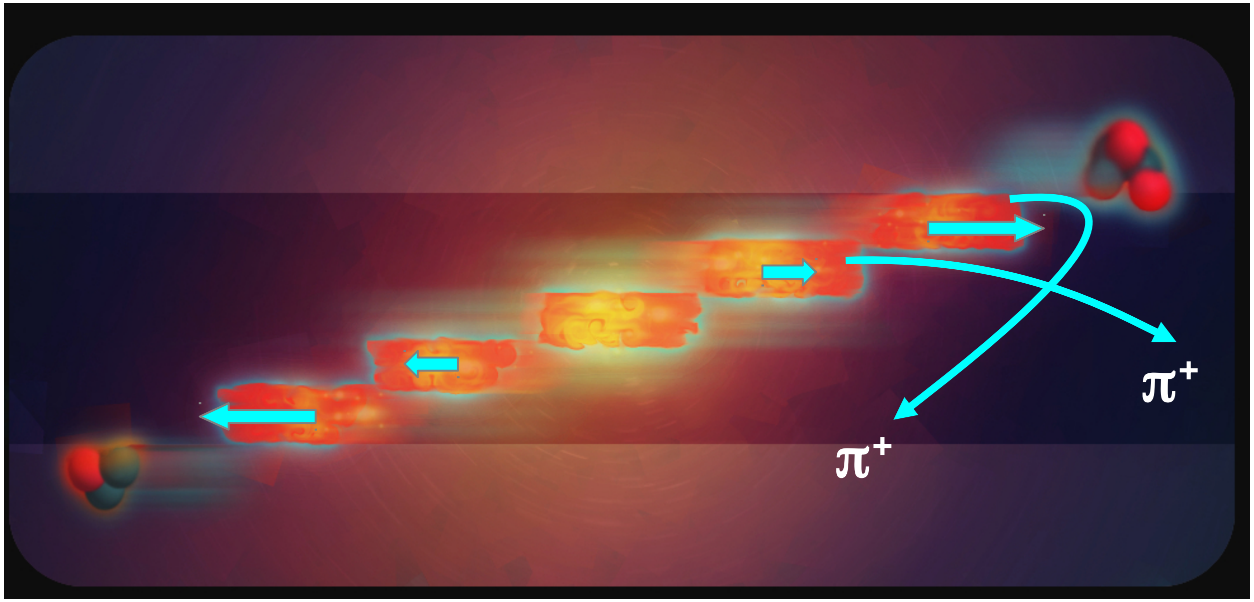
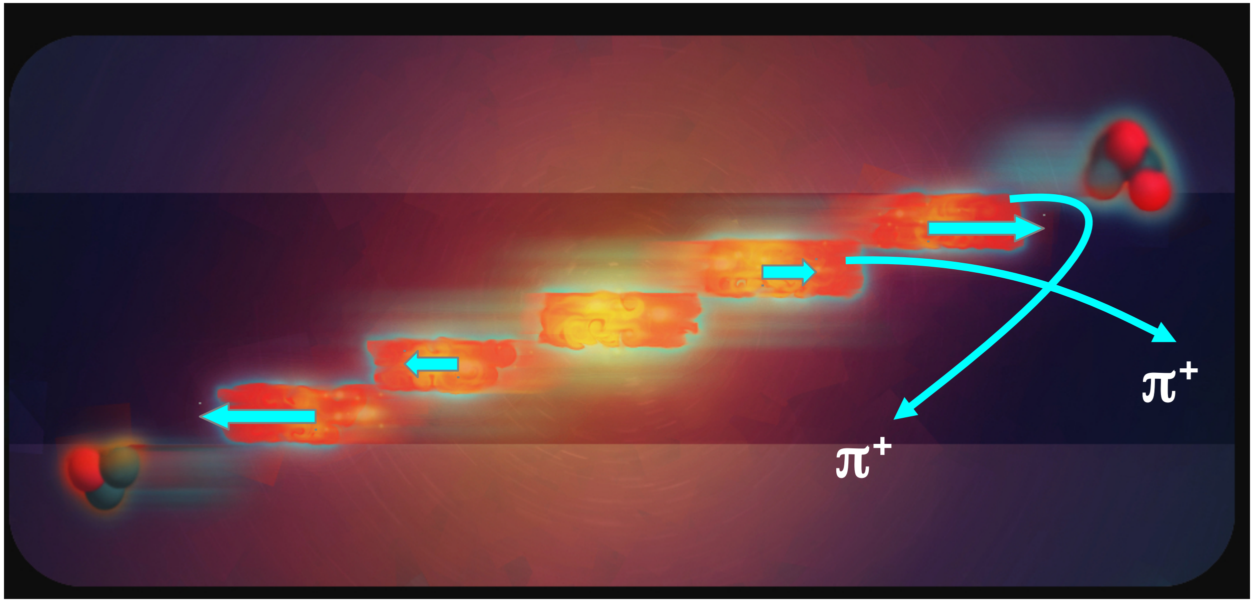
Conclusions and remarks (1)



- Spectator – induced electromagnetic effects brought us from the final state of the reaction…
- ...into a picture of the longitudinal evolution of the system at the initial stage at SPS energies, largely governed by local energy-momentum conservation.

Conclusions and remarks (2)



- Our approach is based on nuclear 3D mass distribution and local E-p conservation.
- The fire-streak model gives a confirmation of what we see in EM effects: emission distance of particles from spectator system decreases with increase of rapidity.
- The fire-streaks concept can be used (again) to study heavy ion collisions.
- On that basis, longitudinal evolution of the system may be interpreted as a consequence of E-p conservation.

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