

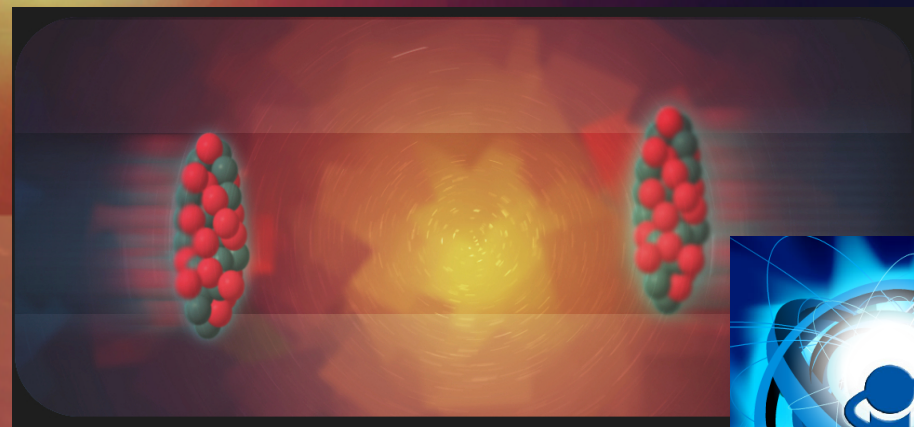
New Results On Energy and Momentum Conservation in Meson Production for A+A Collisions at SPS Energies

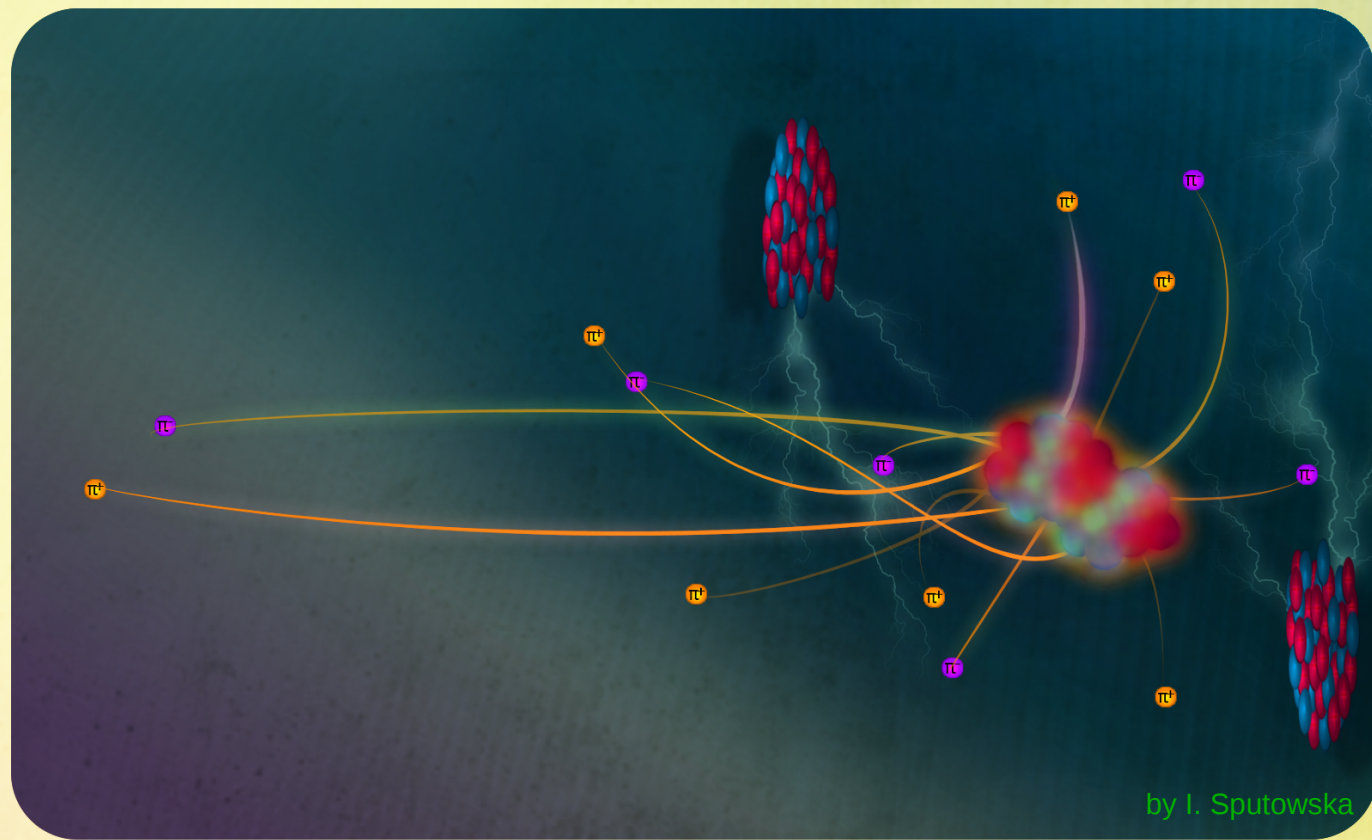
A. Rybicki, A. Szczurek, M. Kielbowicz,
K. Mazurek, V. Ozvenchuk

H. Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

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- 1) Prologue ;
- 2) EM fields ;
- 3) Fire streaks ;
- 4) Summary.

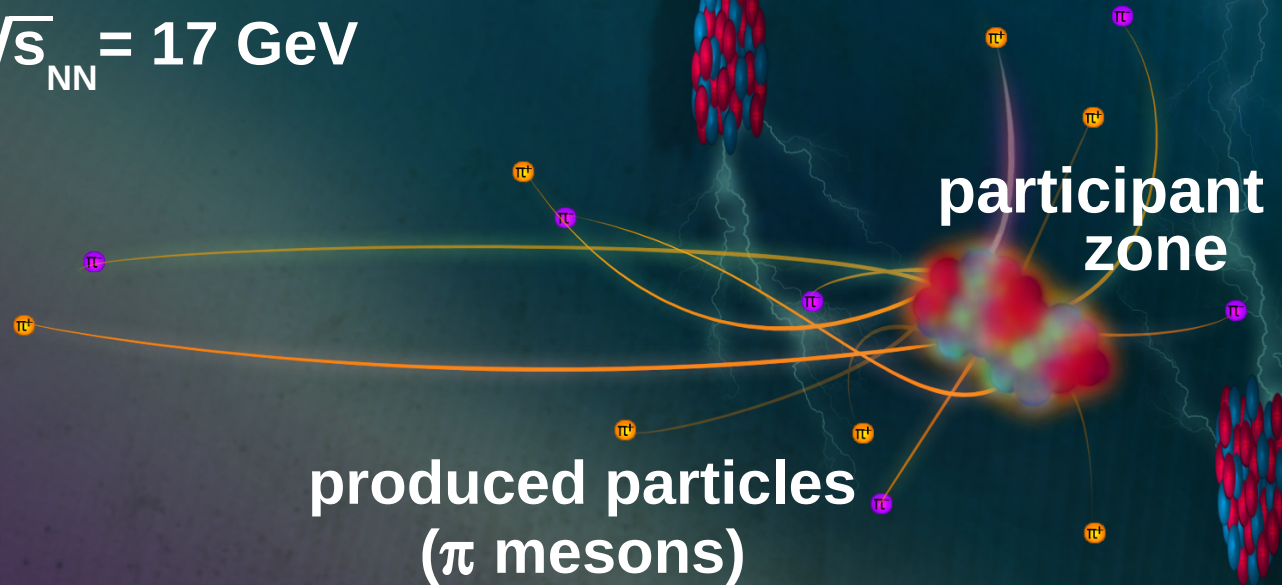




1) Prologue

Nucleus-nucleus collisions:

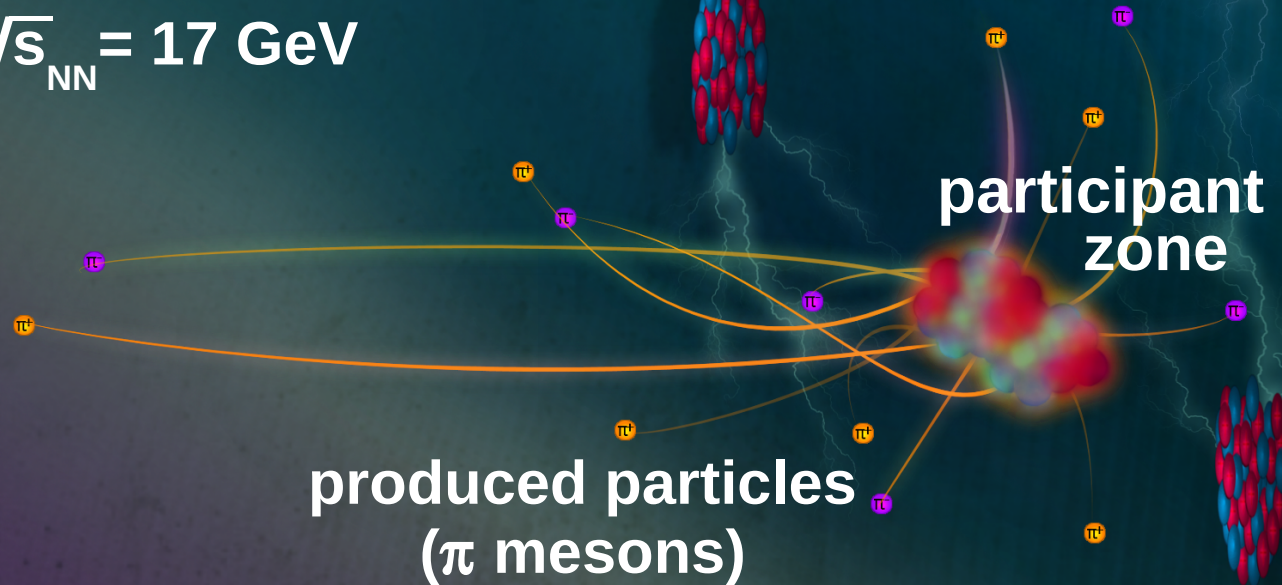
$$\sqrt{s}_{NN} = 17 \text{ GeV}$$



- 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**.

Nucleus-nucleus collisions:

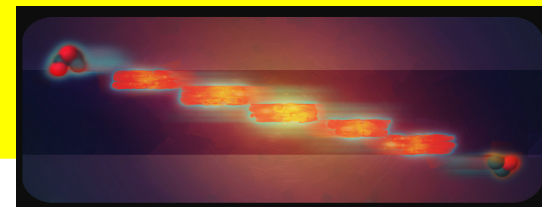
$$\sqrt{s}_{NN} = 17 \text{ GeV}$$



by I. Sputowska

- 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**.
- New, specific **“energy-momentum conservation picture”** of the initial stage of the collision.

- **New exp. data** from NA61/SHINE@SPS.
- New info on the space-time evolution of both **participants** and **spectators**.

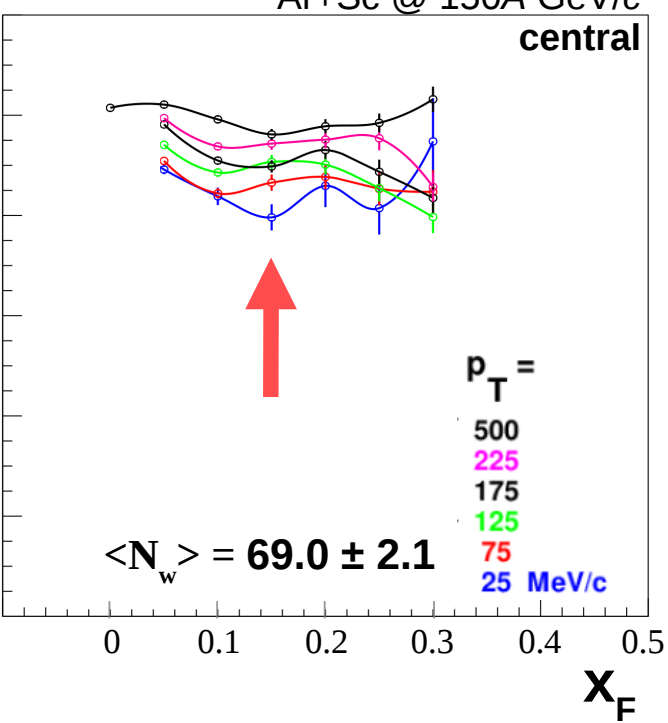
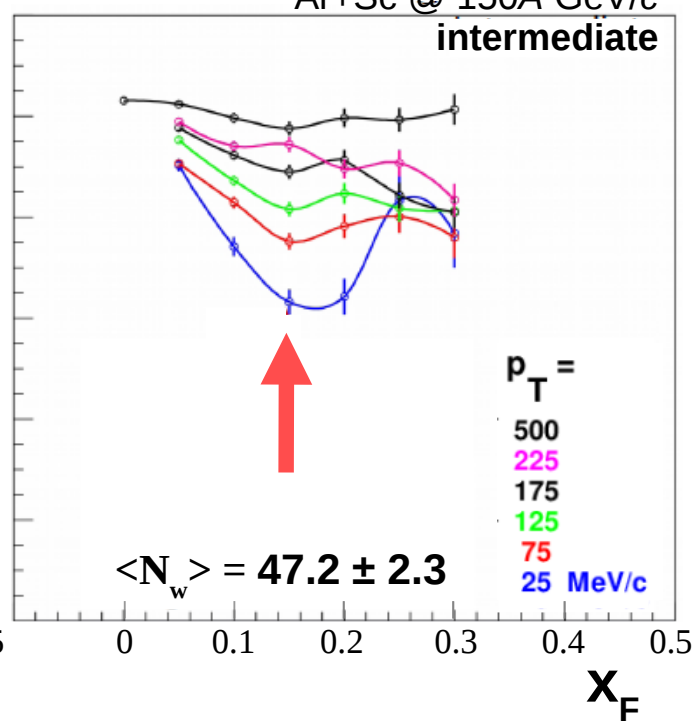
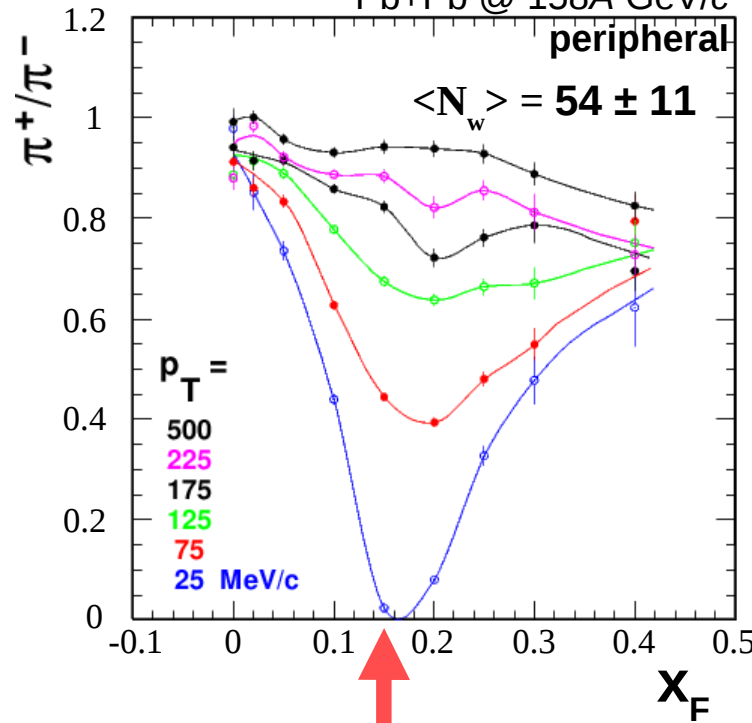


2) electromagnetic fields

NA49 preliminary
Pb+Pb @ 158A GeV/c

NA61/SHINE preliminary
Ar+Sc @ 150A GeV/c

NA61/SHINE preliminary
Ar+Sc @ 150A GeV/c

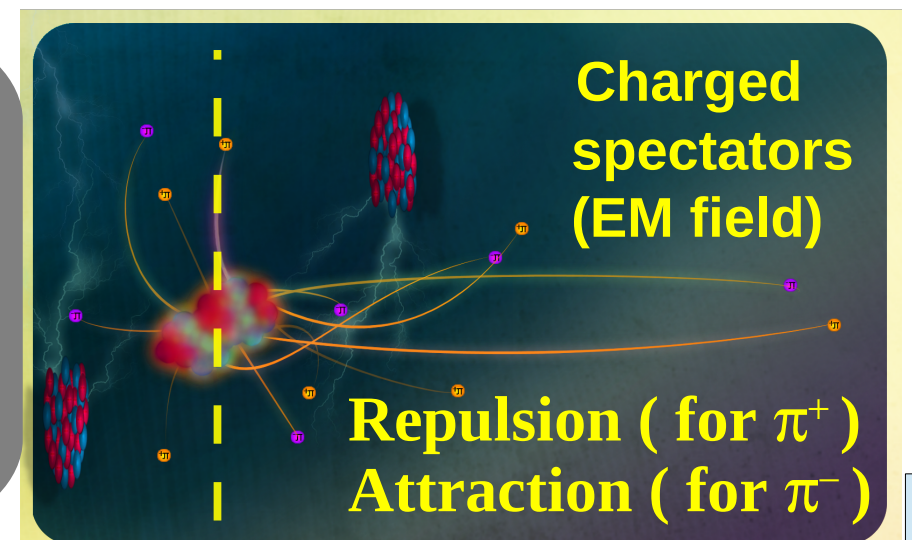


spectator velocity:
 $y = y_{beam}$

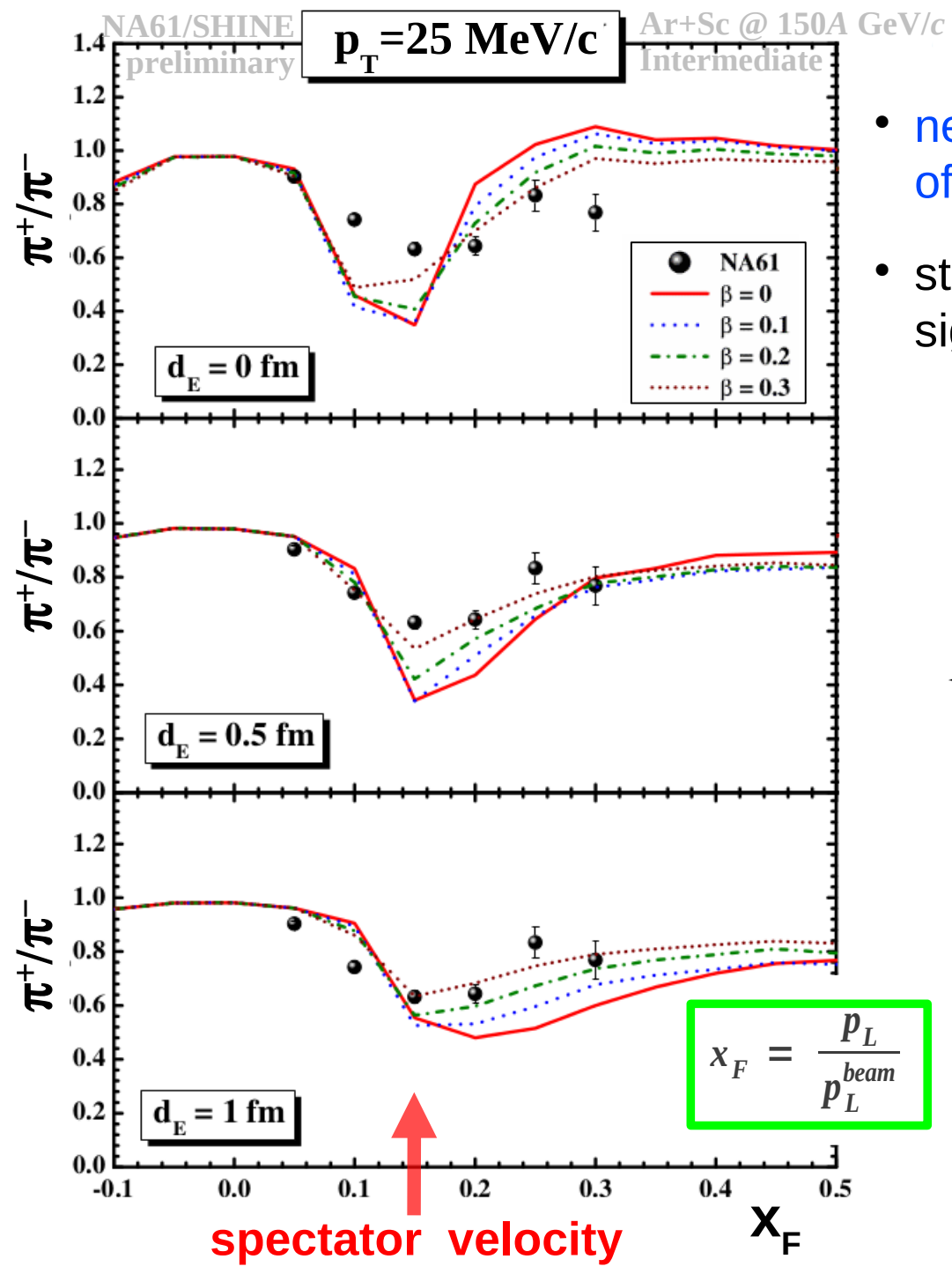
$$x_F = \frac{p_L}{p_L^{beam}} \quad (\text{c.m.s.})$$

A. Marcinek,
MESON 2018,
this session.

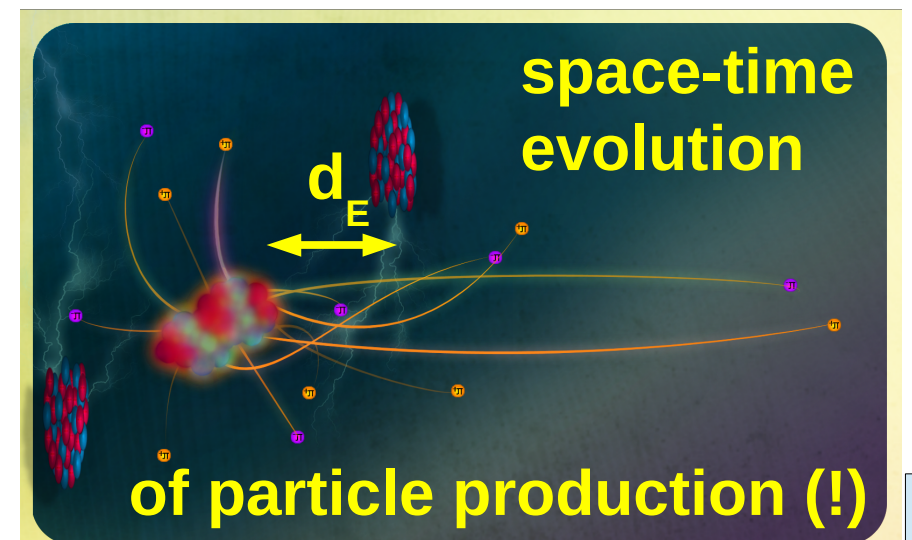
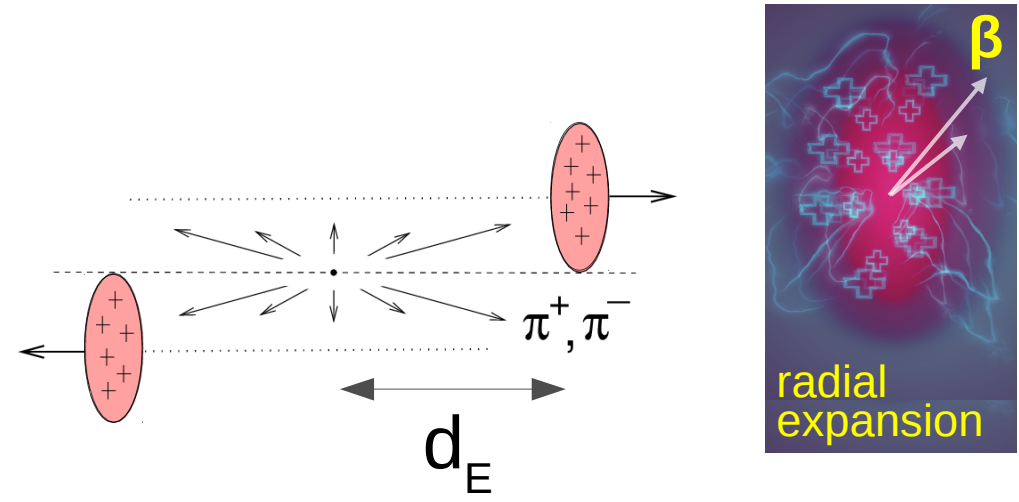
- (a) Peripheral Pb+Pb ($Q_{SPECTATOR} \approx 70 \text{ e.u.}$)
→ large EM effect, $\pi^+/\pi^- \approx 0$.
- (b) Intermediate Ar+Sc ($Q_{SPECTATOR} \approx 8 \text{ e.u.}$)
→ visible EM effect, breaks isospin symmetry.
- (c) Central Ar+Sc ($Q_{SPECTATOR} \approx 3 \text{ e.u.}$)
→ still visible shadow of EM effect.



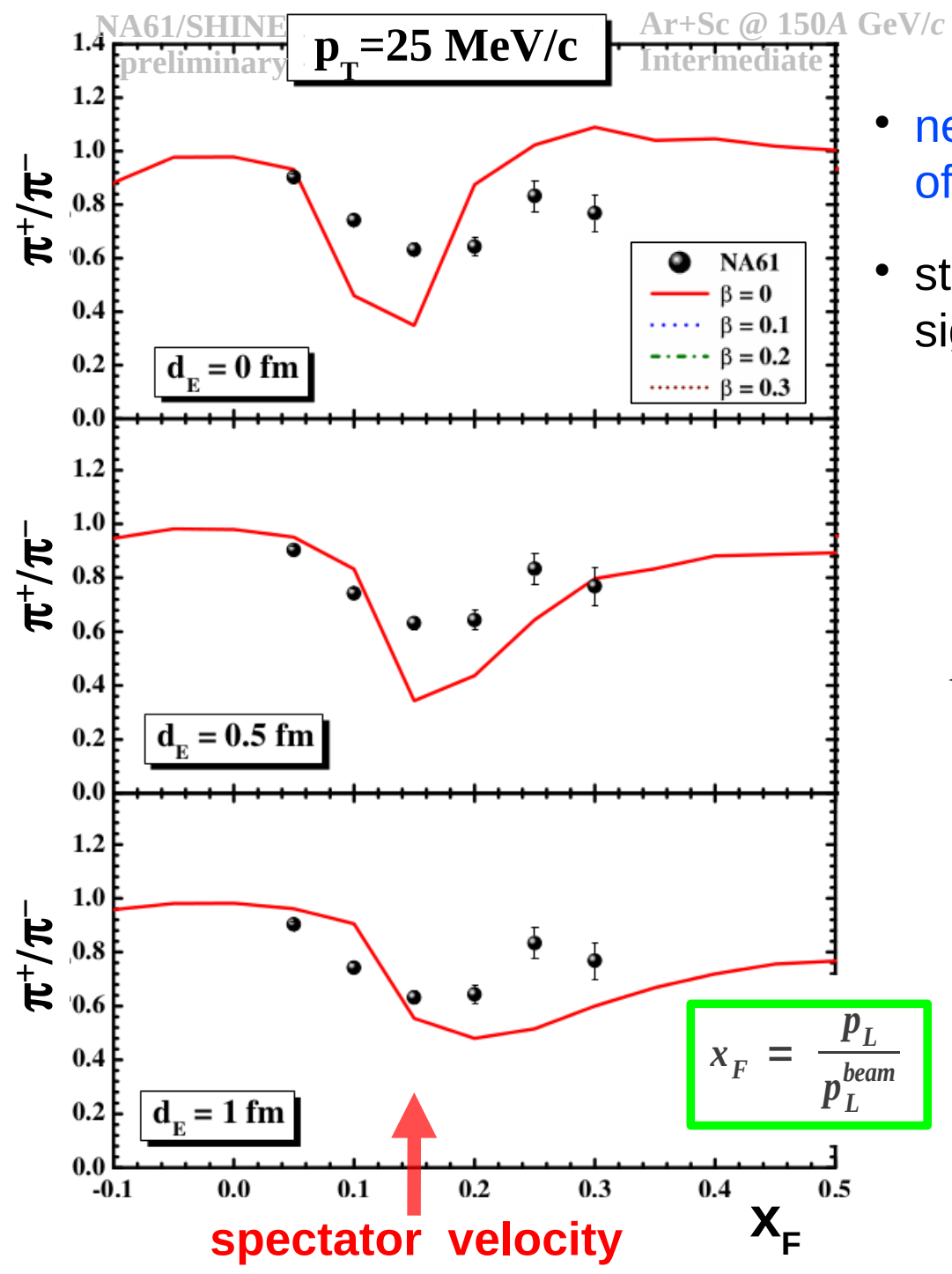
Ar+Sc data compared to MC simulation



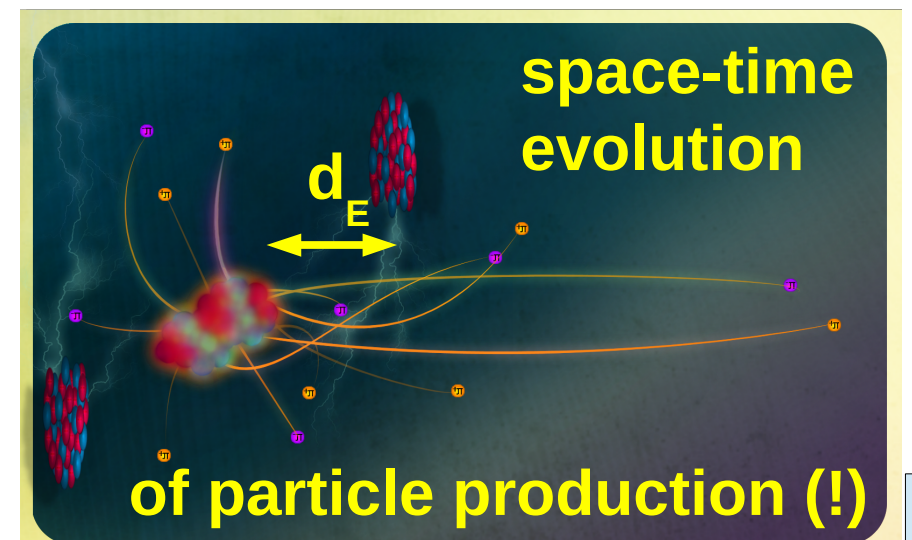
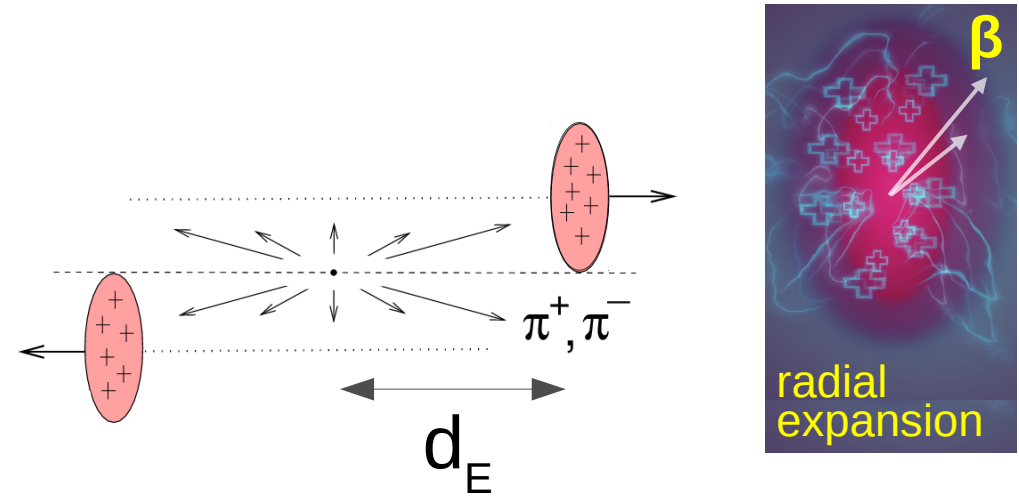
- new information on the space-time evolution of π production in Ar+Sc collisions $\rightarrow d_E$.
- stable spectator cannot describe the data: significant expansion velocity $\rightarrow \beta$.



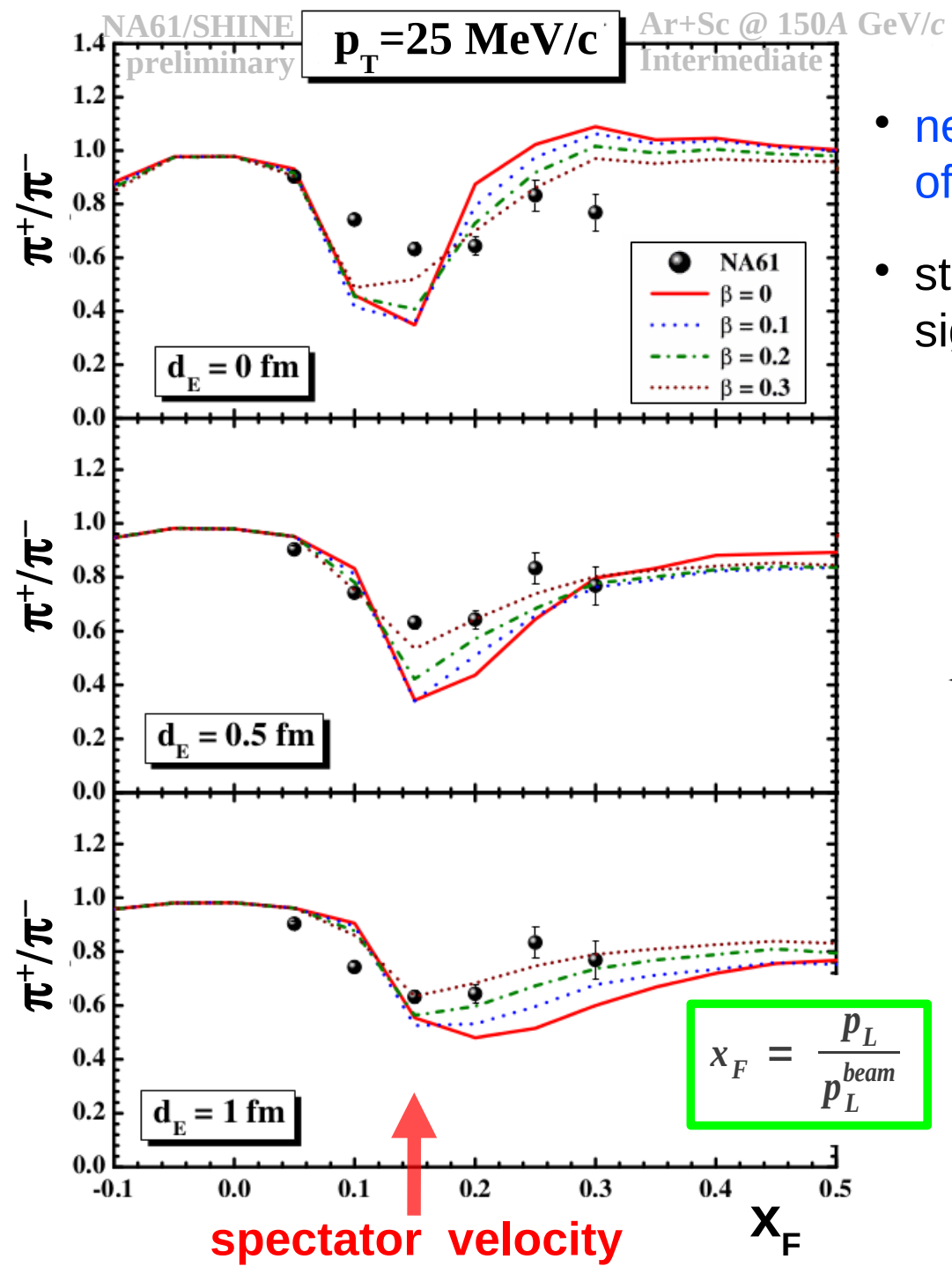
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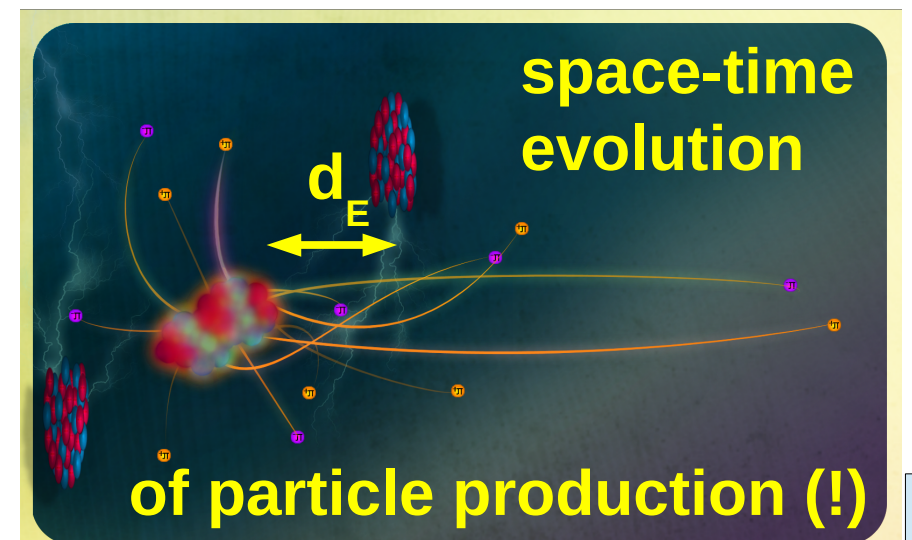
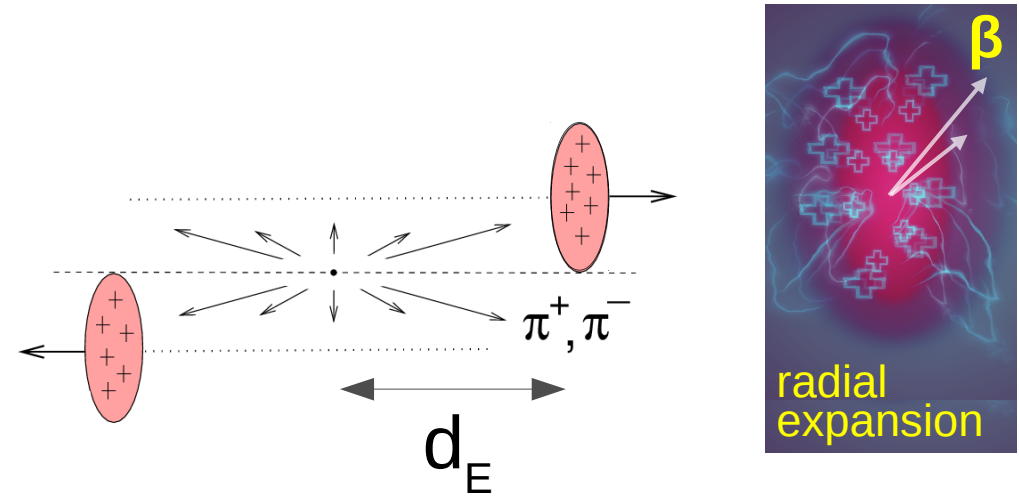
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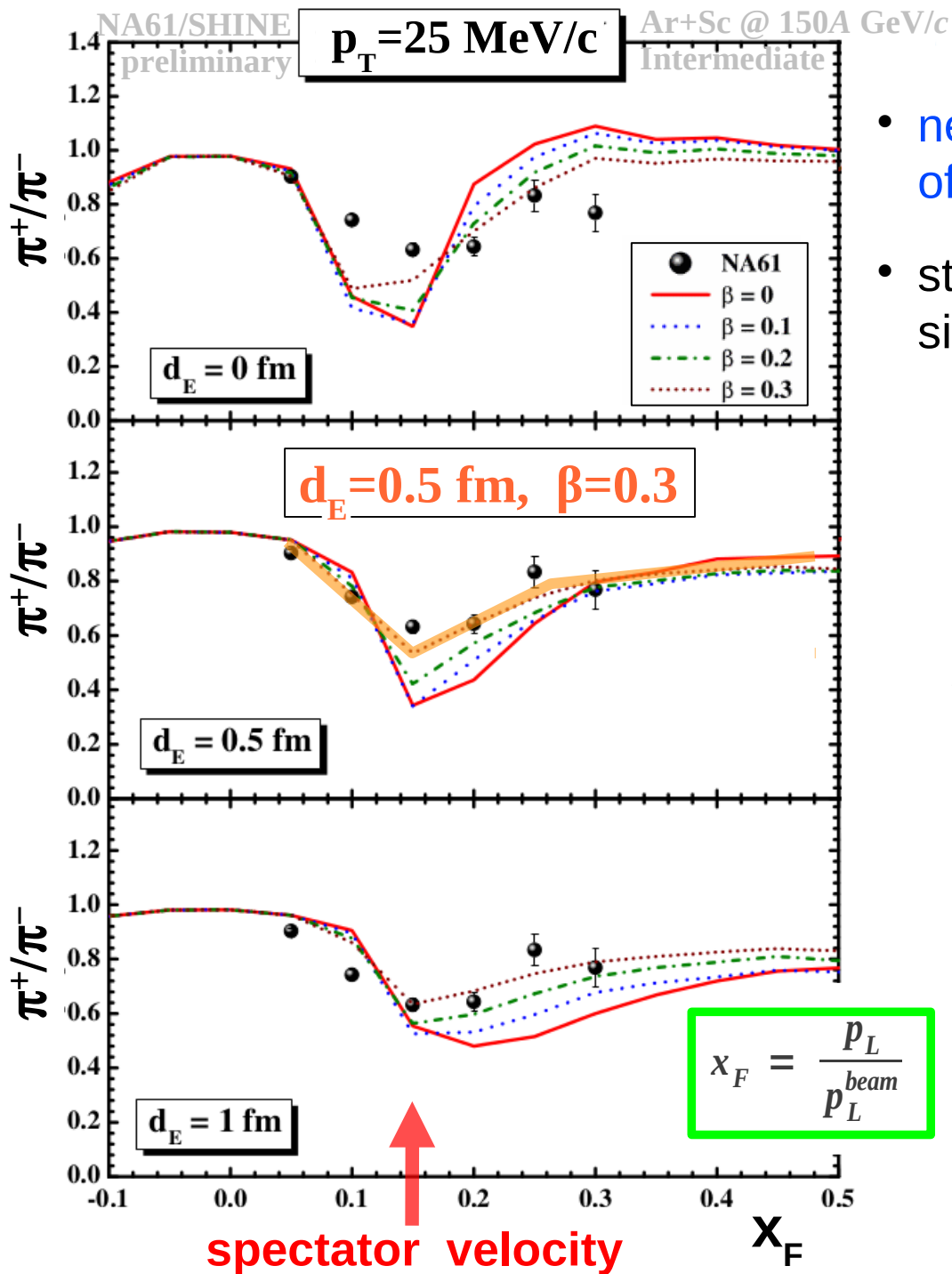
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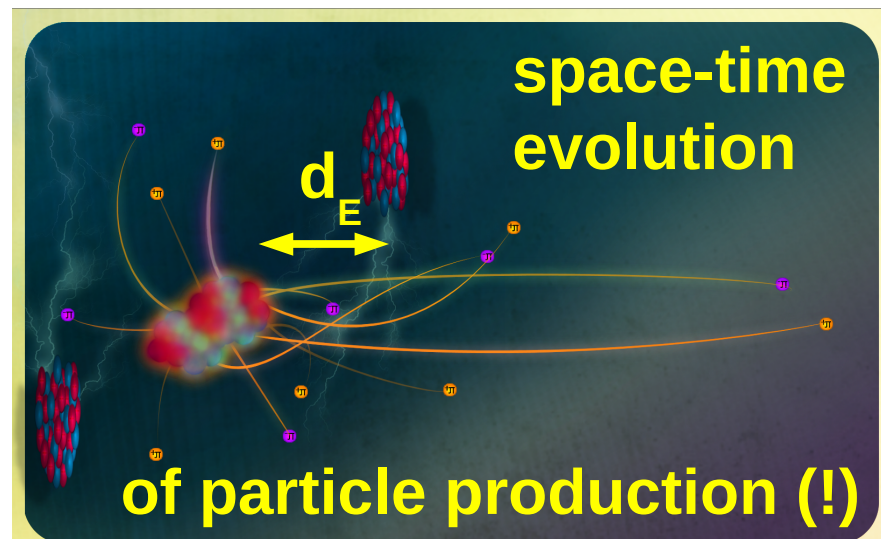
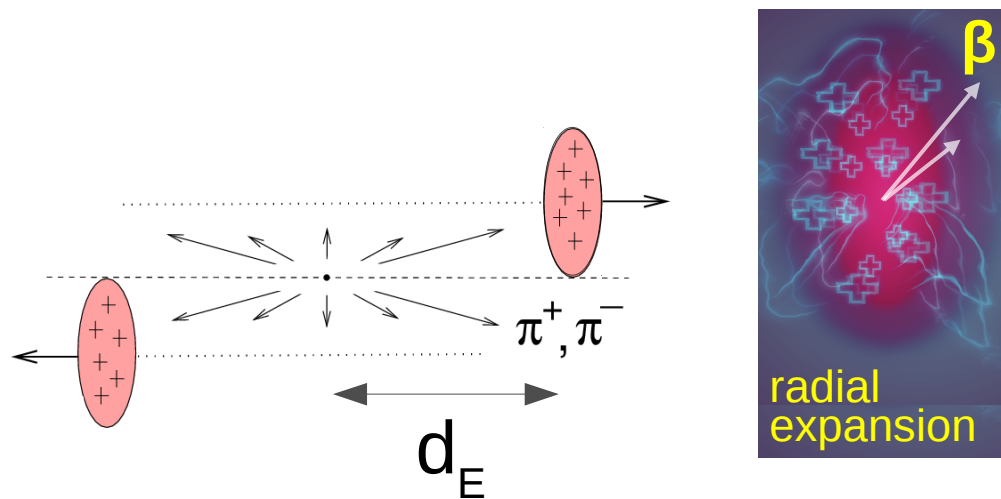
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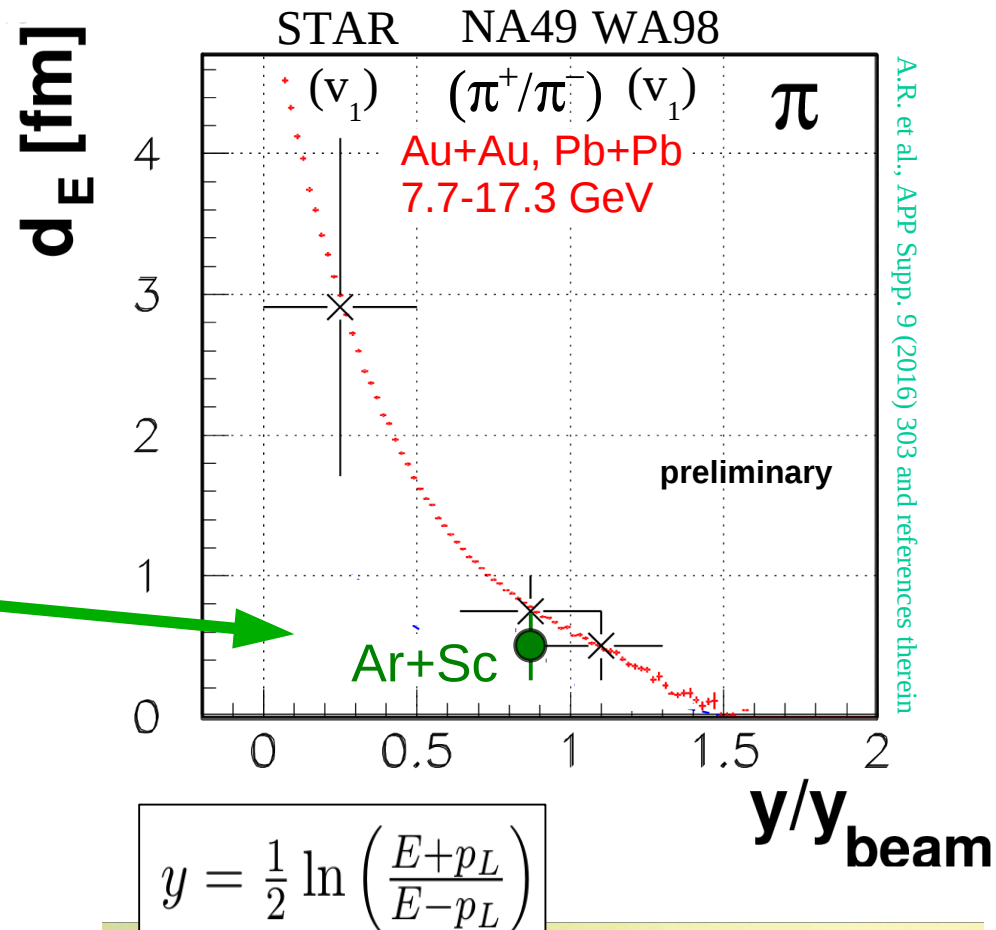
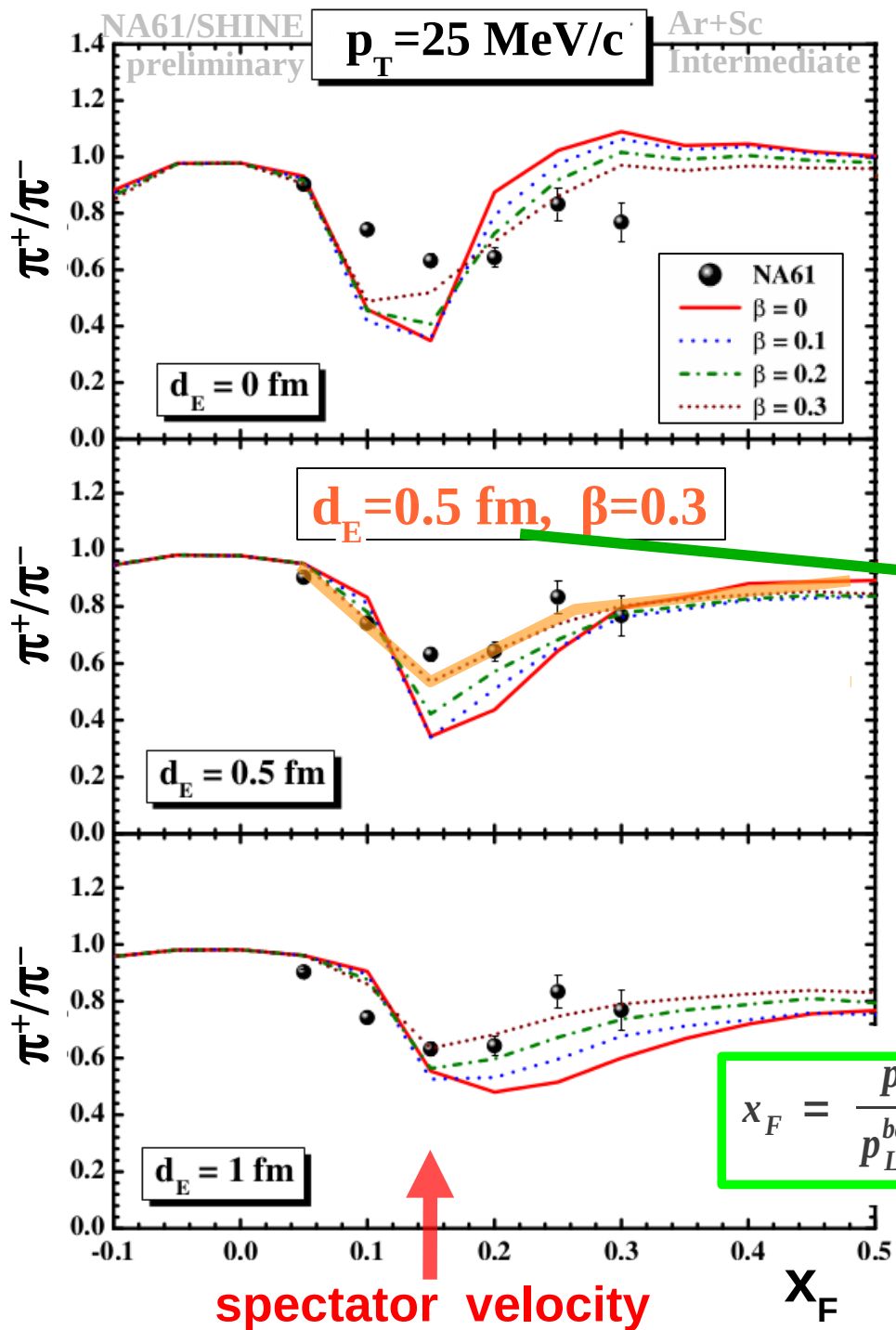
Ar+Sc data compared to MC simulation



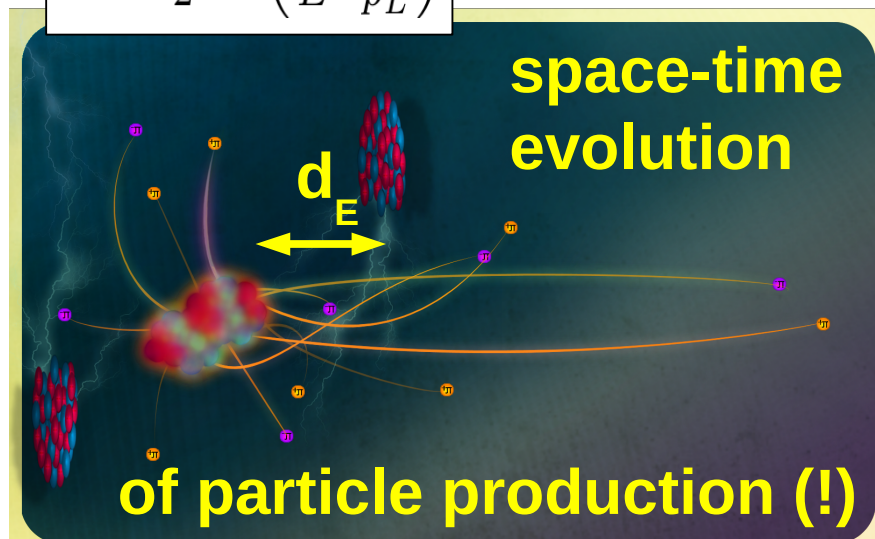
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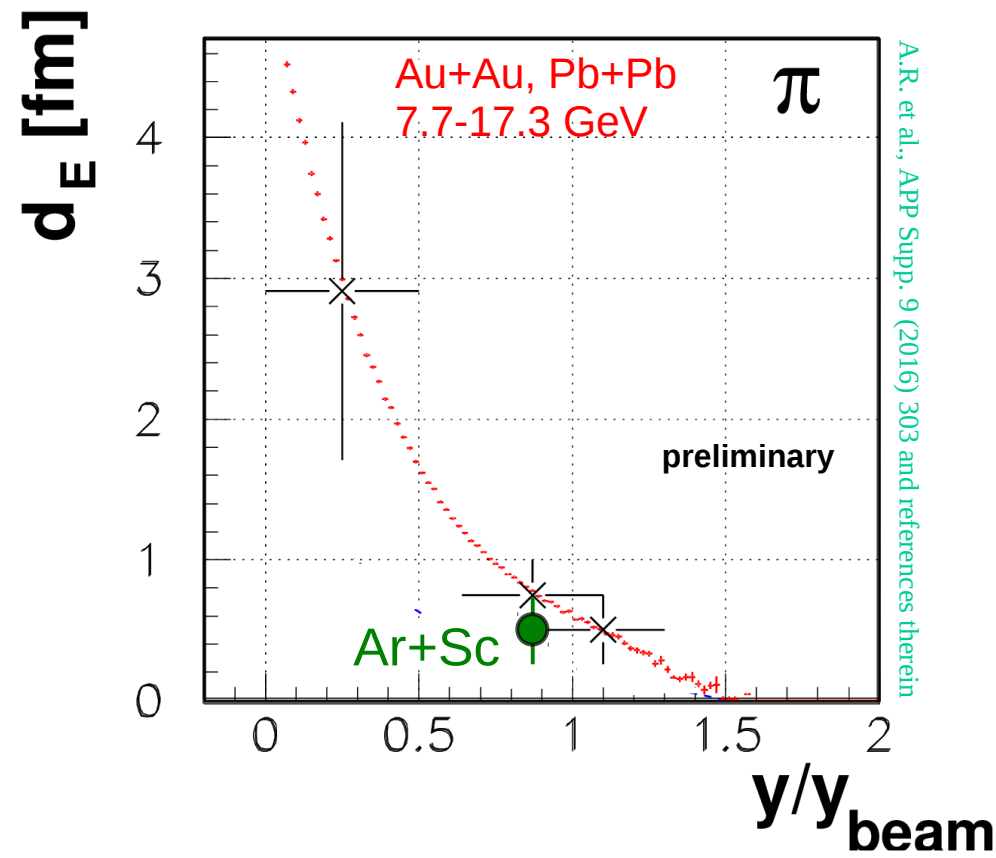


Ar+Sc data compared to MC simulation



A.R. et al., APP Supp. 9 (2016) 303 and references therein

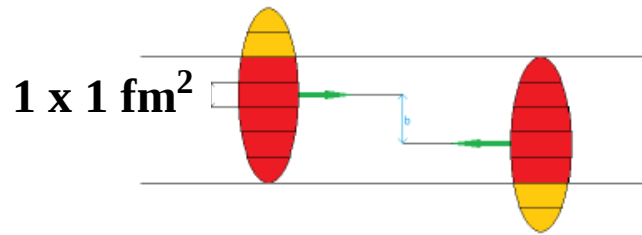




Picture from IFJ PAN press release:
google out "fire streaks in collisions"



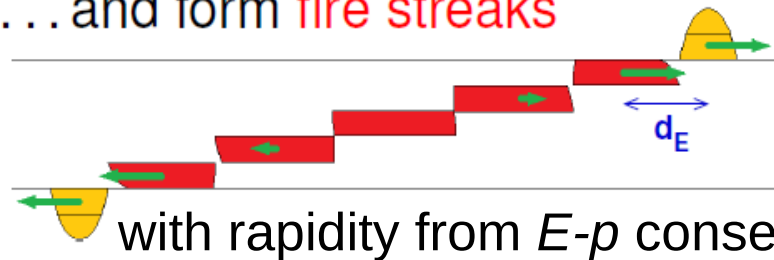
Bricks collide ...



R. Hagedorn, CERN-71-12 (1971)
W.D. Myers, Nucl. Phys. A 296 (1978) 177

(Re)invented by A. Szczurek

... and form fire streaks

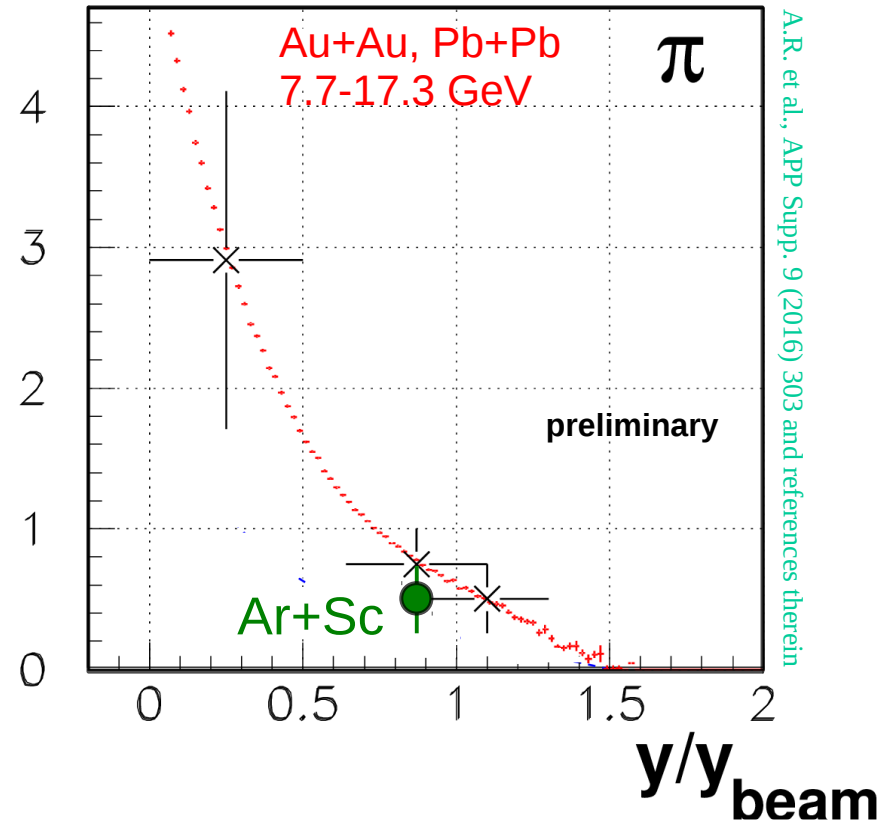


Each fire streak fragments independently into pions

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

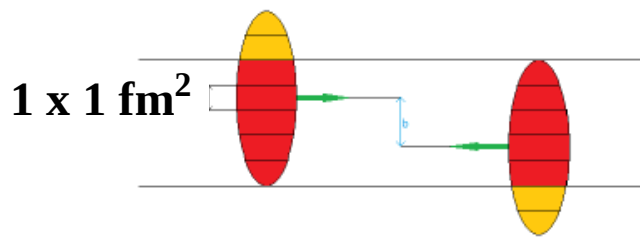
A. Szczurek., A. R., M. Kielbowicz, Phys. Rev. C **95**, 024908 (2017)

d_E [fm]



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with rapidity from $E-p$ conservation

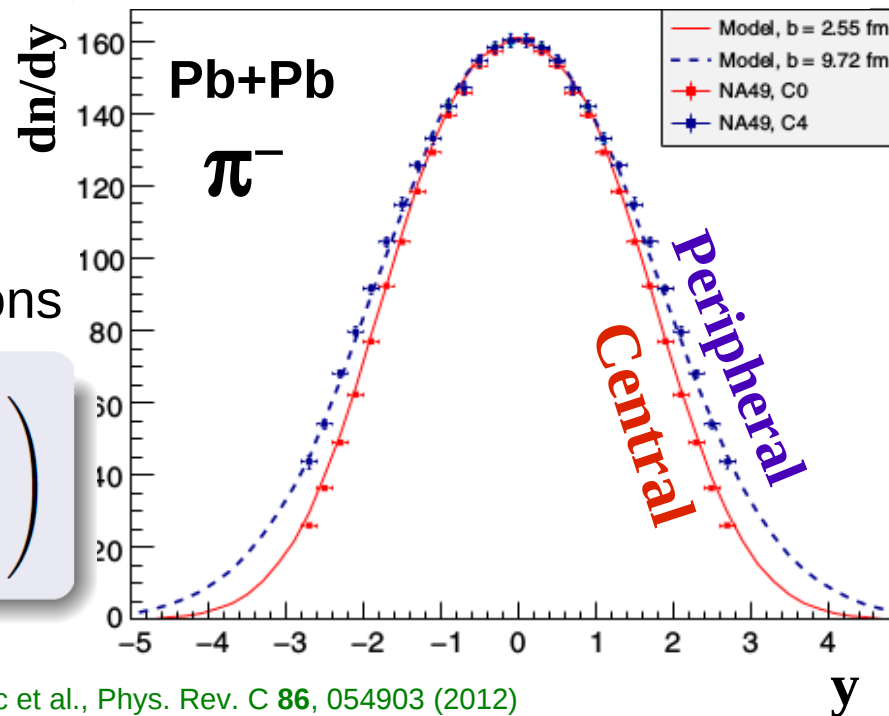
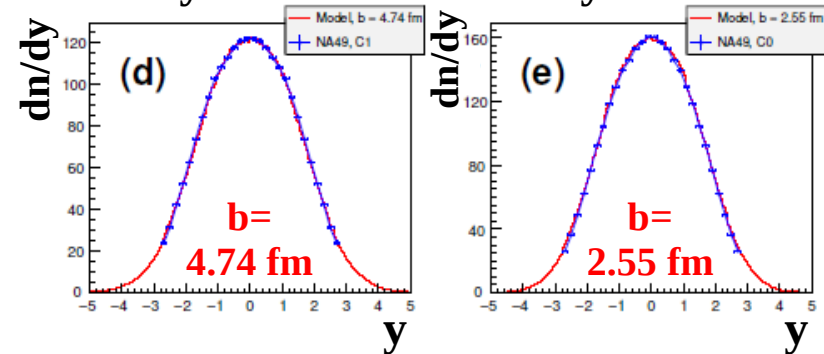
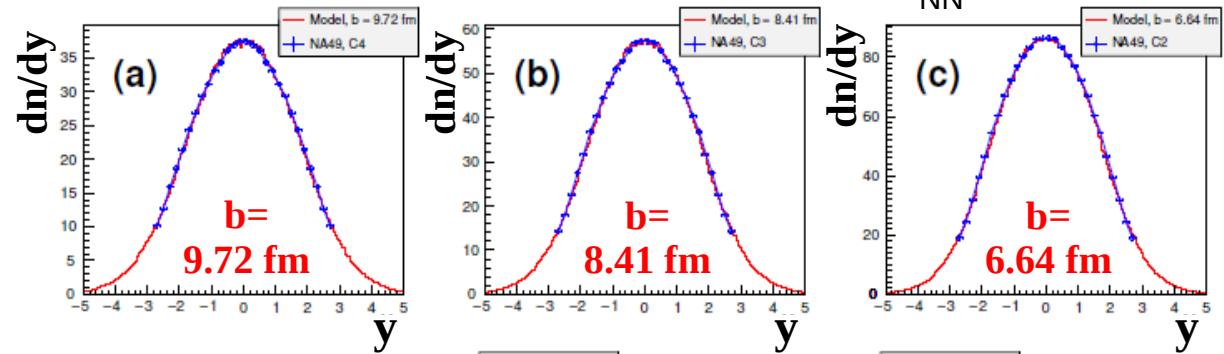
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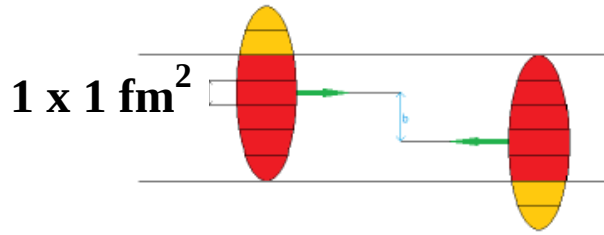
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data points from: **NA49**, T. Anticic et al., Phys. Rev. C **86**, 054903 (2012)

π^- , Pb+Pb, $\sqrt{s}_{NN} = 17.3$ GeV



Bricks collide ...

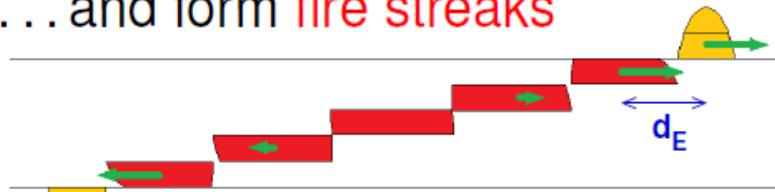


$1 \times 1 \text{ fm}^2$

R. Hagedorn, CERN-71-12
W.D. Myers, Nucl. Phys. A

(Re)invented by A. Szczurek

... and form **fire streaks**



with rapidity from $E-p$ conservation

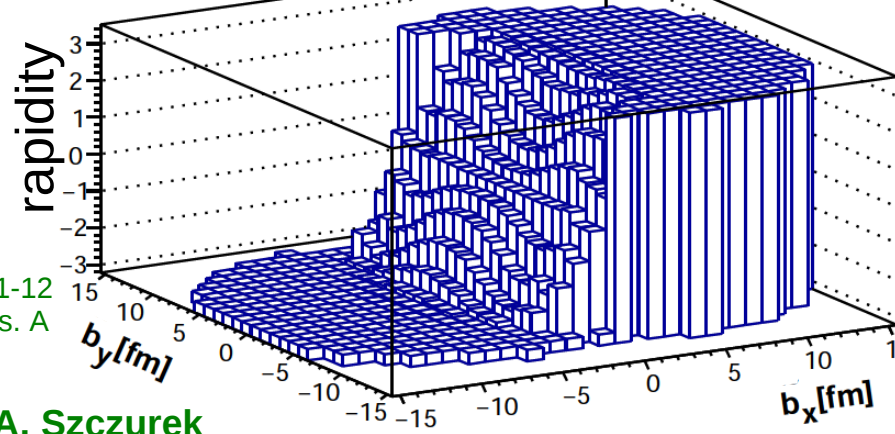
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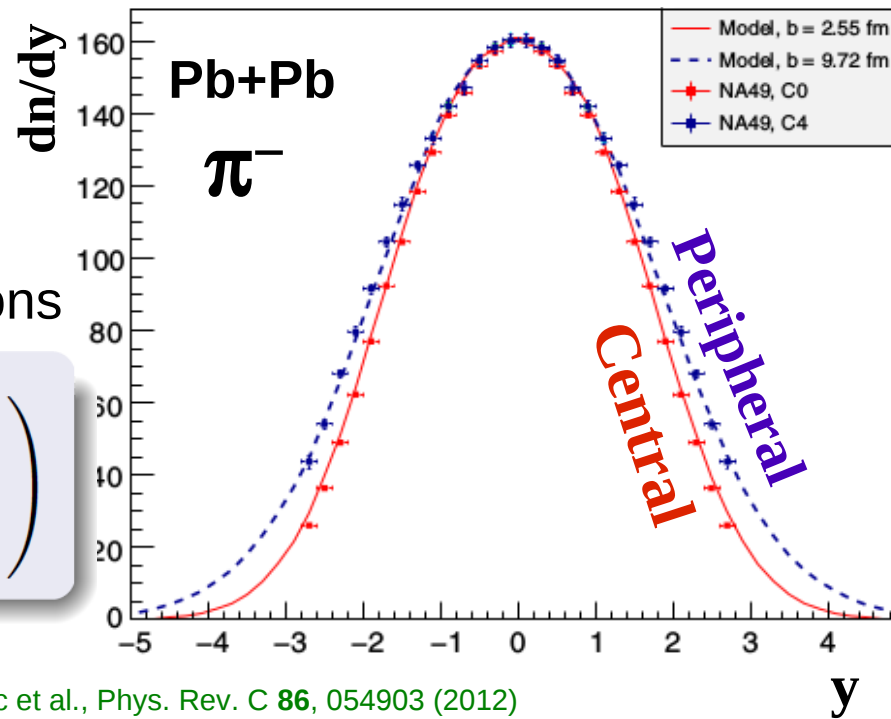
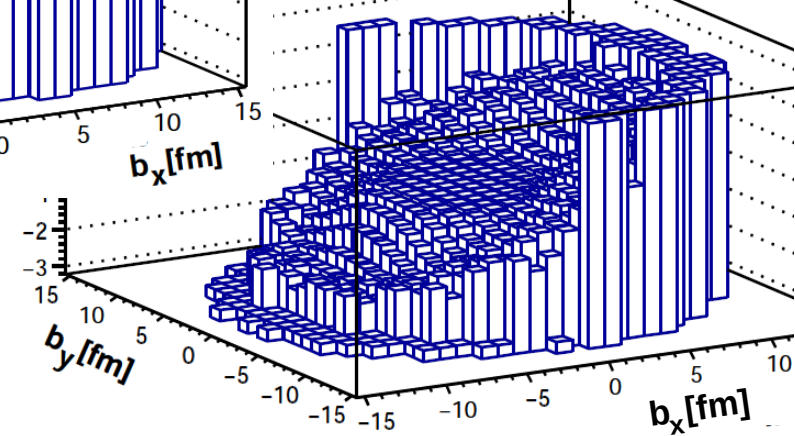
data points from: **NA49**, T. Anticic et al., Phys. Rev. C **86**, 054903 (2012)

Peripheral (b=9.72 fm)



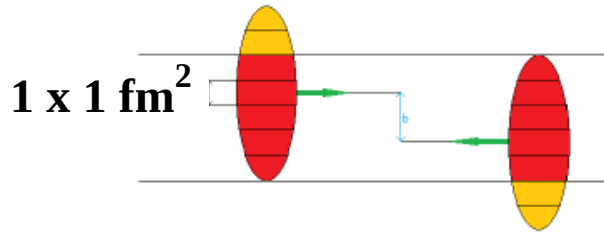
$\sqrt{s}_{NN} = 17.3 \text{ GeV}$
Pb+Pb

Central (b=2.55 fm)



y

Bricks collide ...



$1 \times 1 \text{ fm}^2$

R. Hagedorn, CERN-71-12
W.D. Myers, Nucl. Phys. A

(Re)invented by A. Szczurek

... and form fire streaks



with rapidity

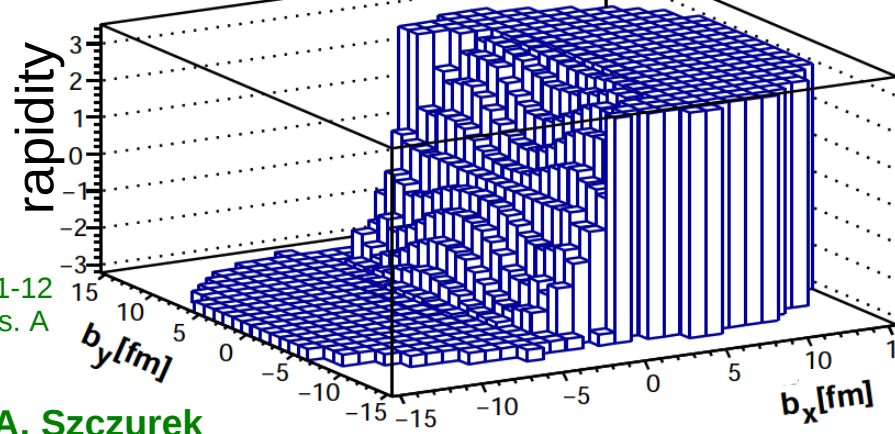
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A. Szczurek., A. R., M. Kielbowicz, Phys. Rev. C **95**, 024908 (2017)

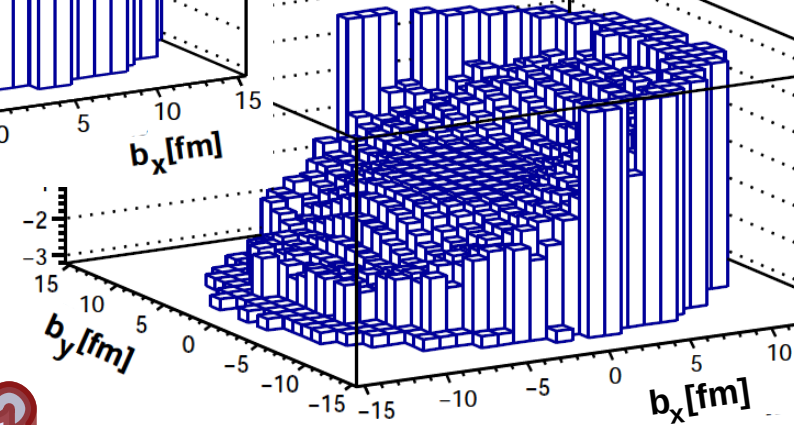
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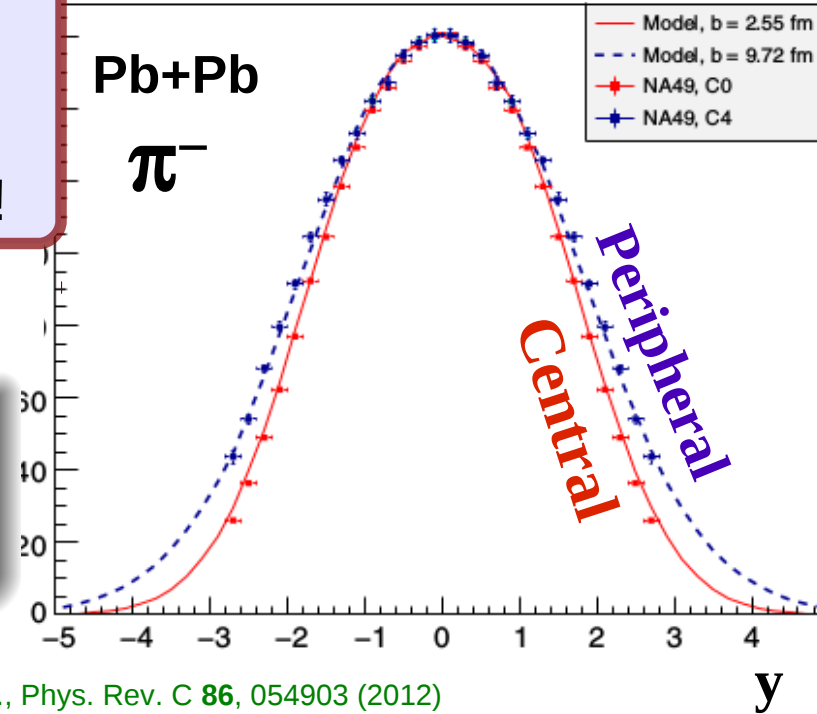
Central
($b=2.55 \text{ fm}$)



Centrality dependence of
pion dn/dy spectrum :
only from E-p conservation !

Pb+Pb

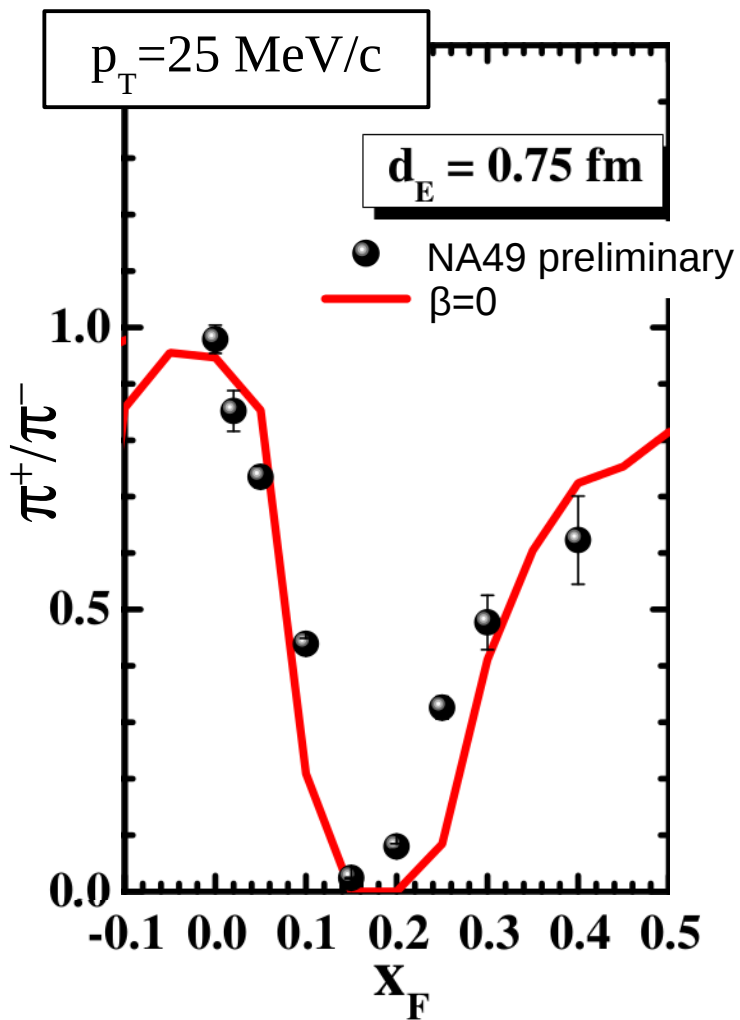
π^-



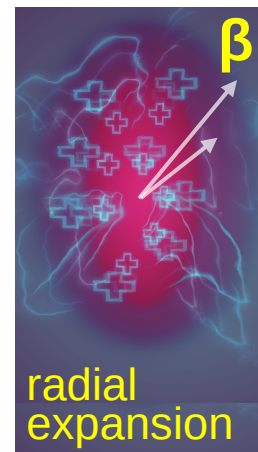
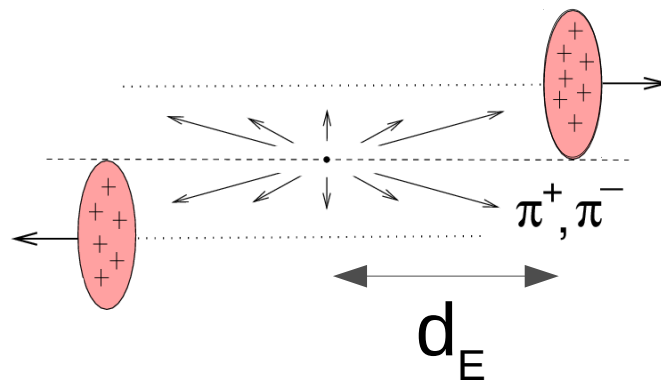
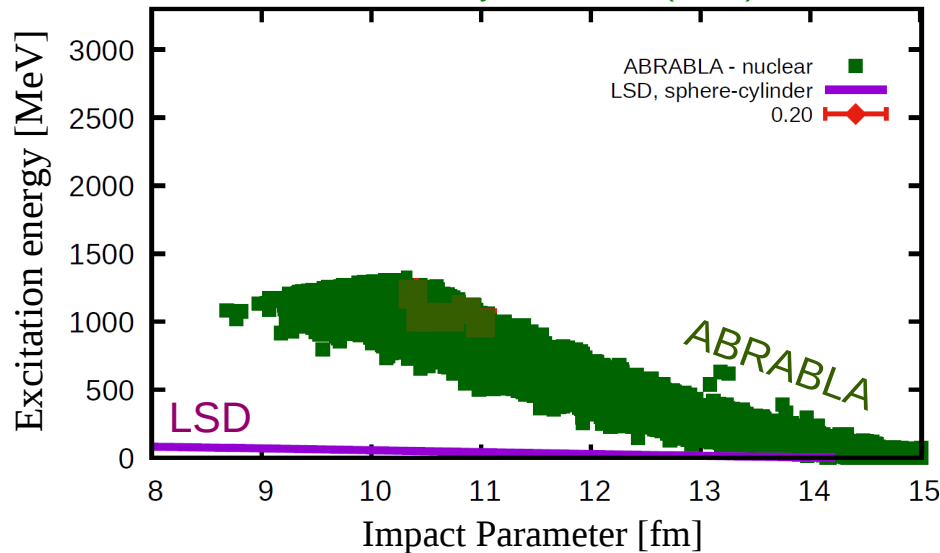
Central
Peripheral

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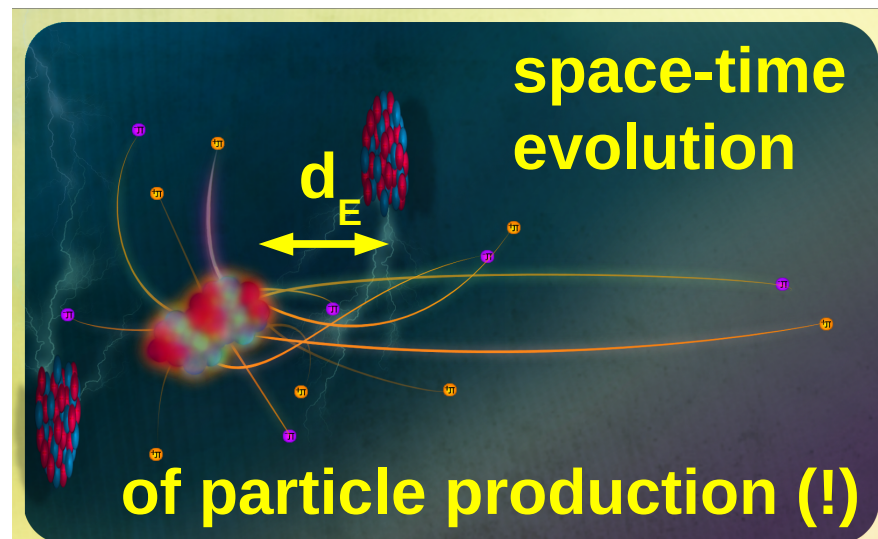
$\sqrt{s}_{NN} = 17.3 \text{ GeV}$, Pb+Pb peripheral



K. Mazurek et al., Phys.Rev. C97 (2018) 024604

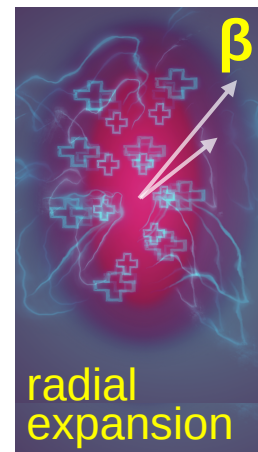
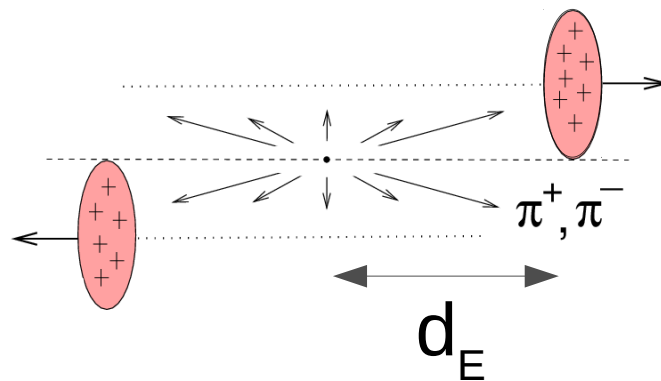
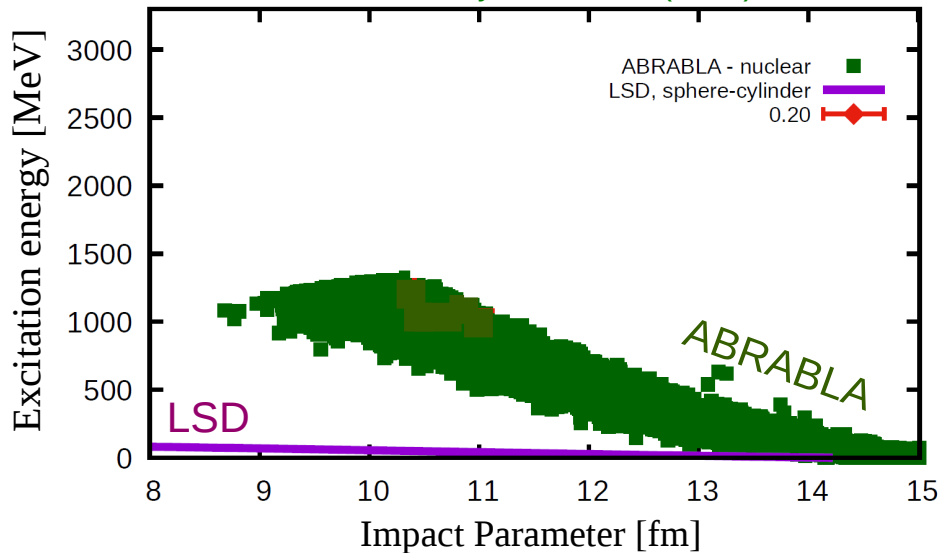
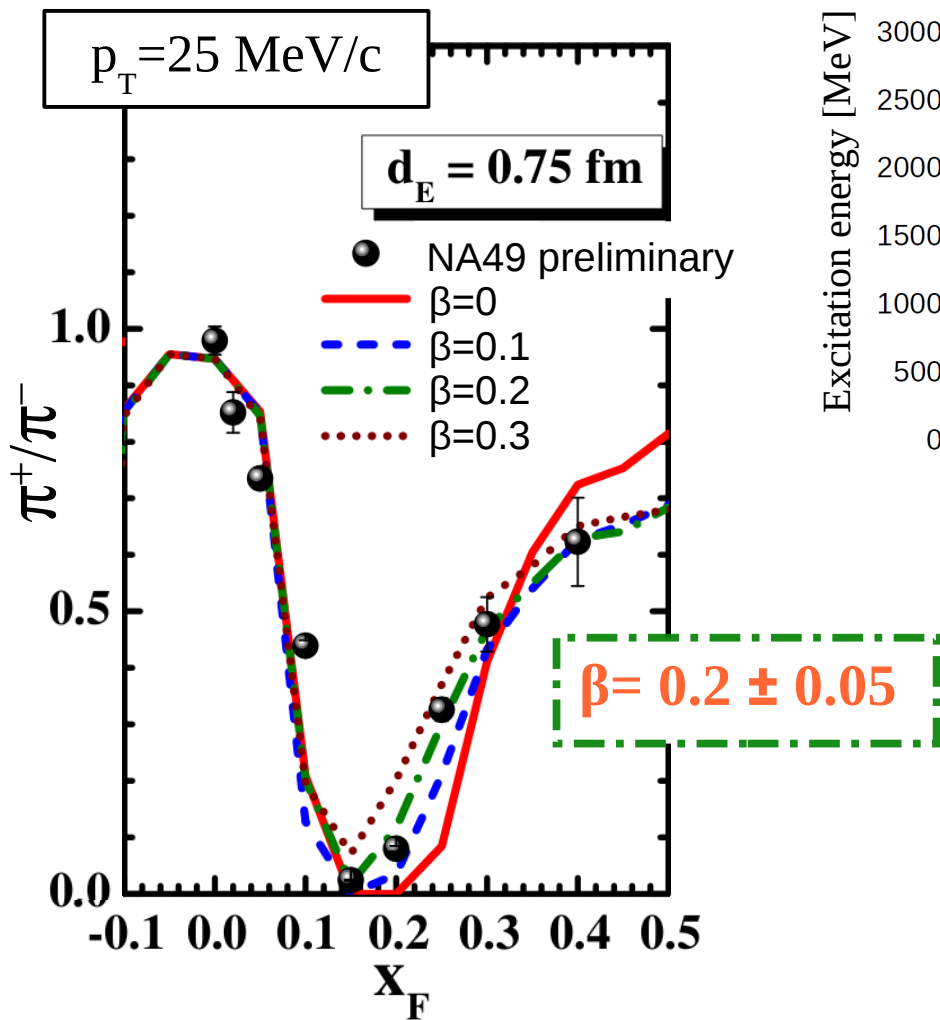


Remark:
 excitation energy
 in the spectator system

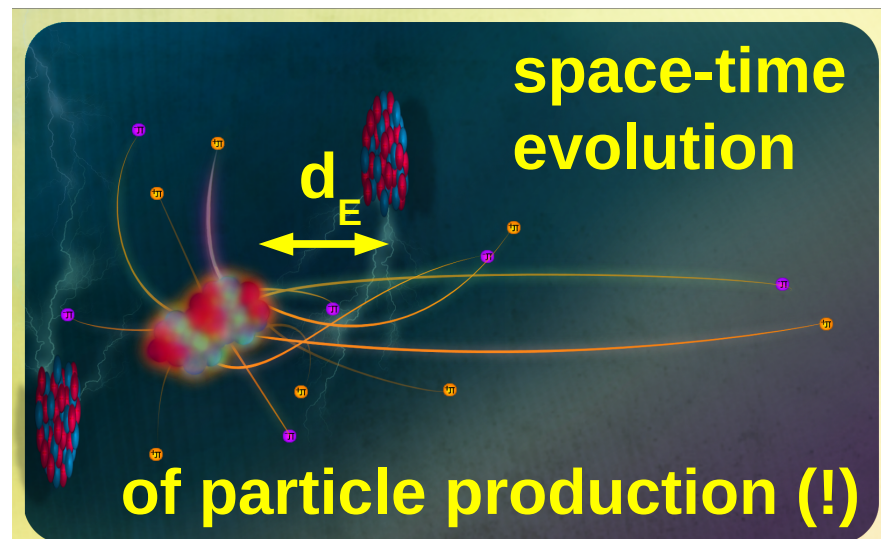


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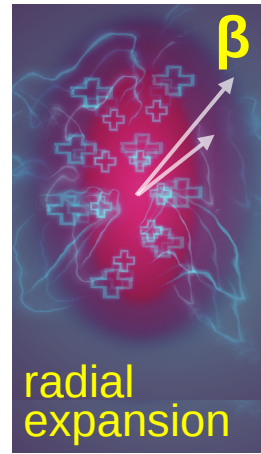
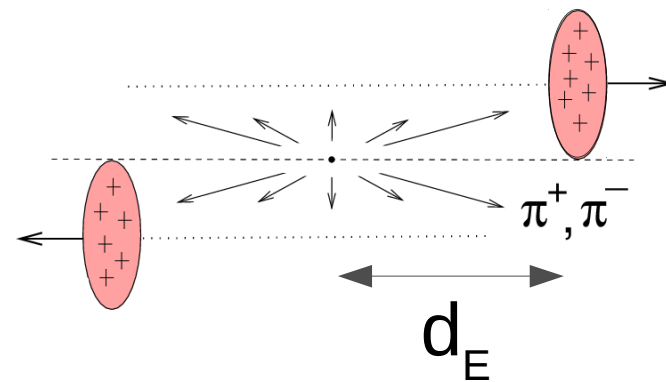
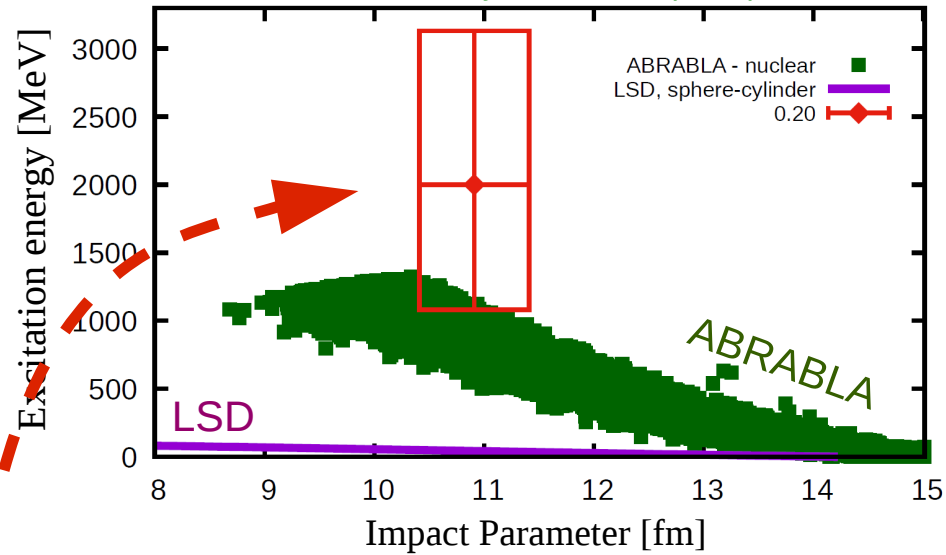
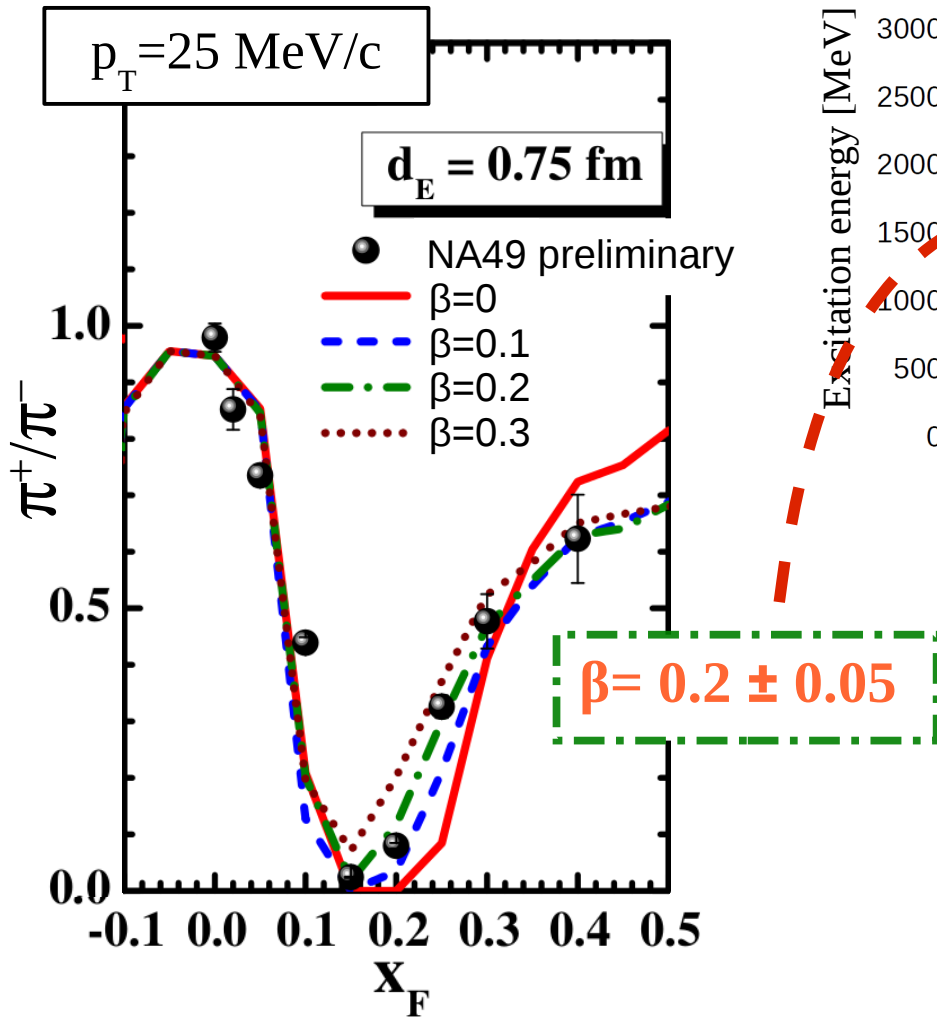


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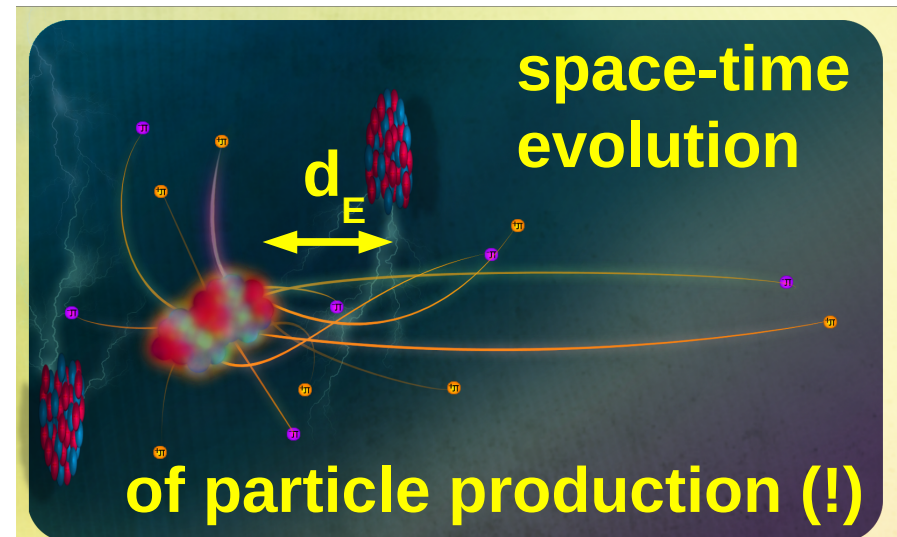


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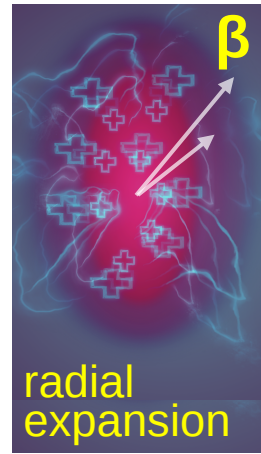
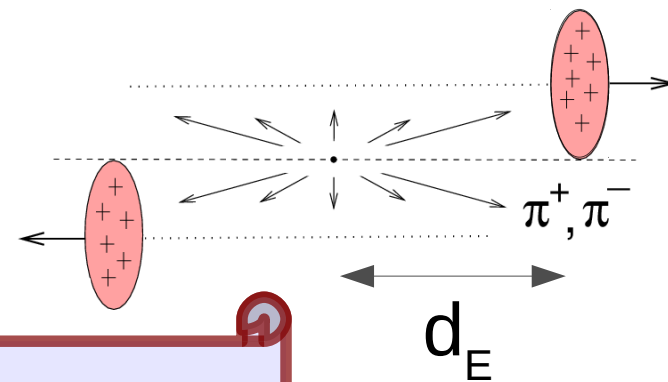
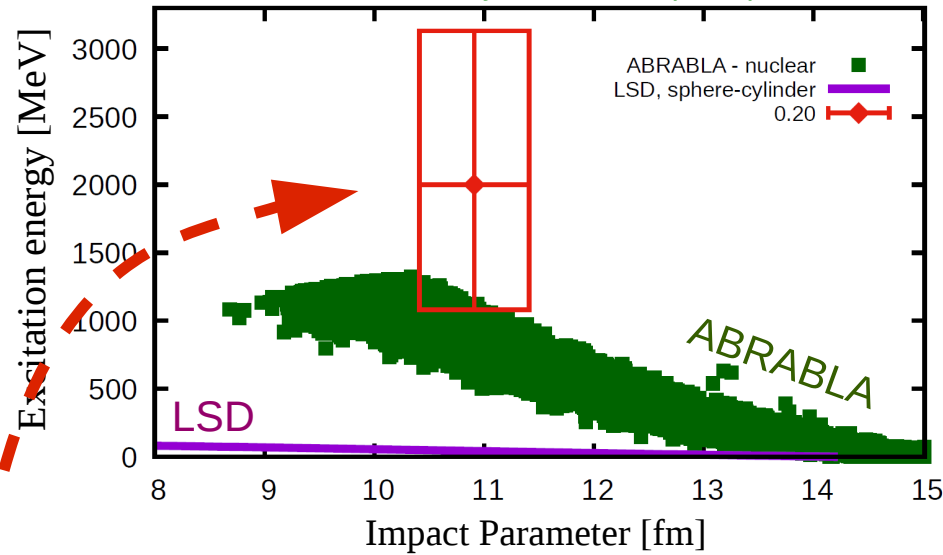
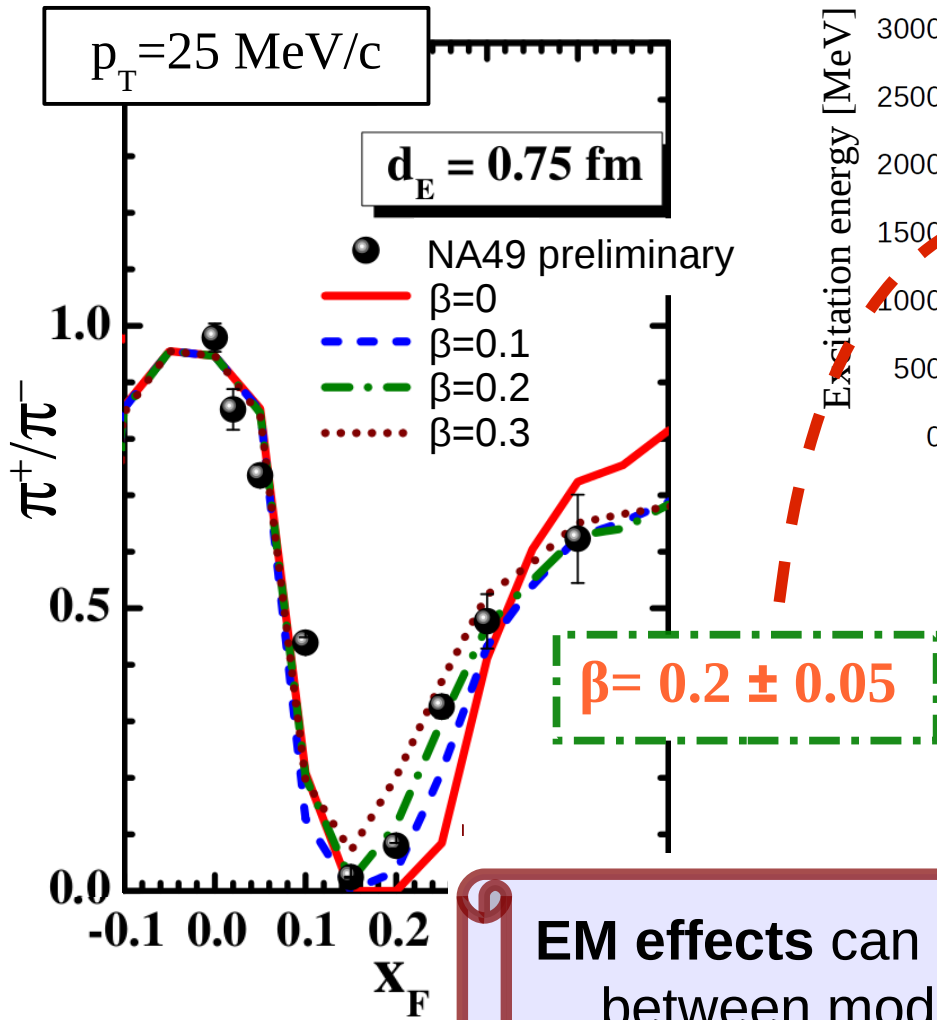


Remark:
*excitation energy
 in the spectator system*



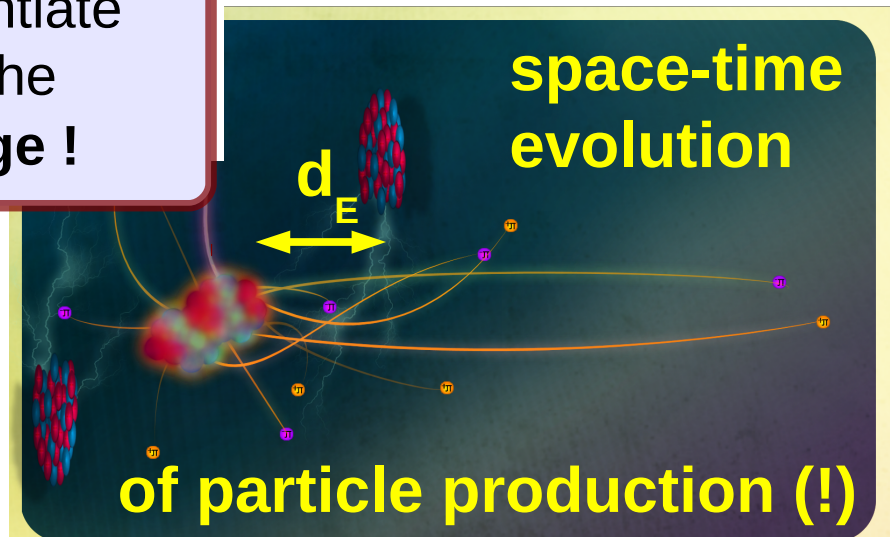
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K. Mazurek et al., Phys.Rev. C97 (2018) 024604

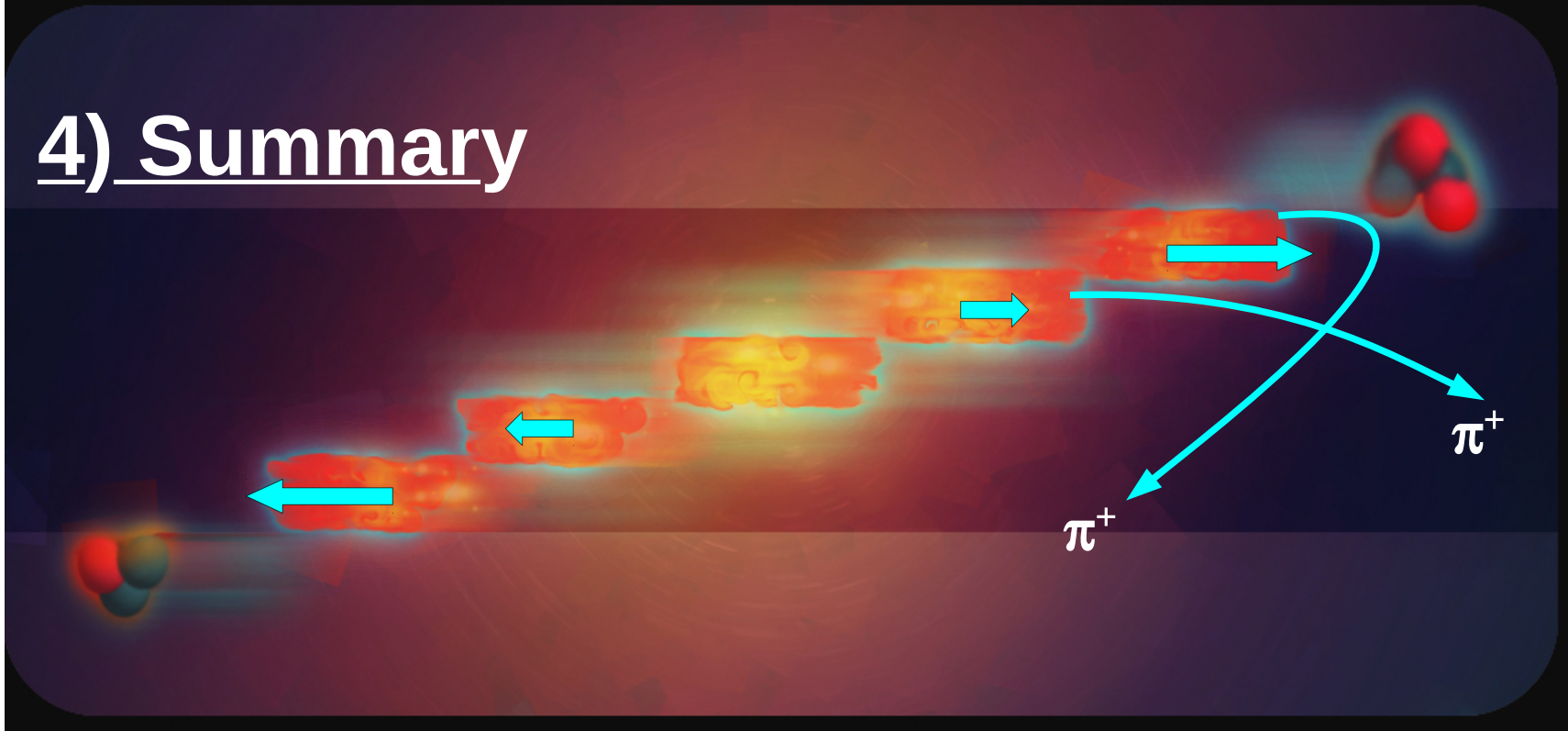


EM effects can differentiate between models of the spectator initial stage !

Remark:
excitation energy
in the spectator system



4) Summary



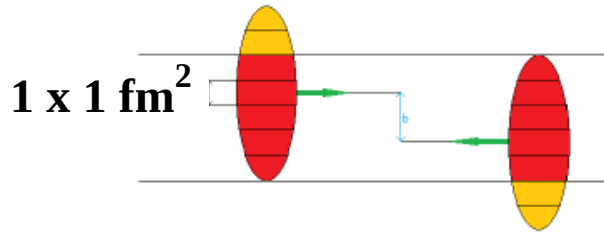
- Spectator-induced EM effects brought us from the final state of the reaction ...
- ... into a picture of the longitudinal evolution of the system at the initial stage at SPS energies, largely governed by energy-momentum conservation...
- ... BUT they also give us a chance to get insight into the spectator system's excitation energy.

Acknowledgments.

This work was supported by the National Science Centre, Poland (grant no. 2014/14/E/ST2/00018).

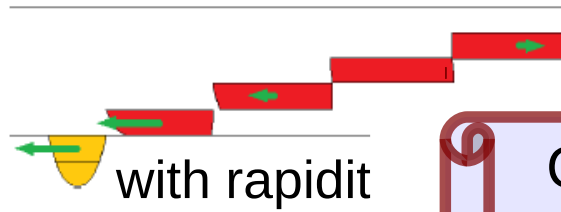
Extra slides

Bricks collide ...



↓
 (Re)invented

... and form fire streaks



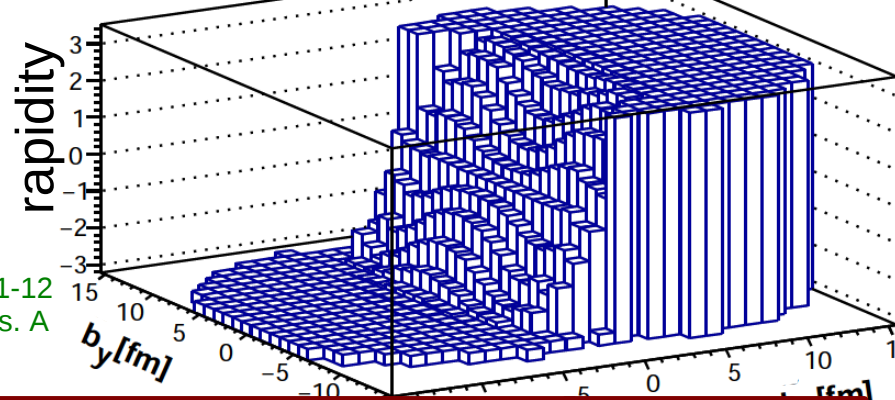
with rapidity
 ↓

Each fire streak

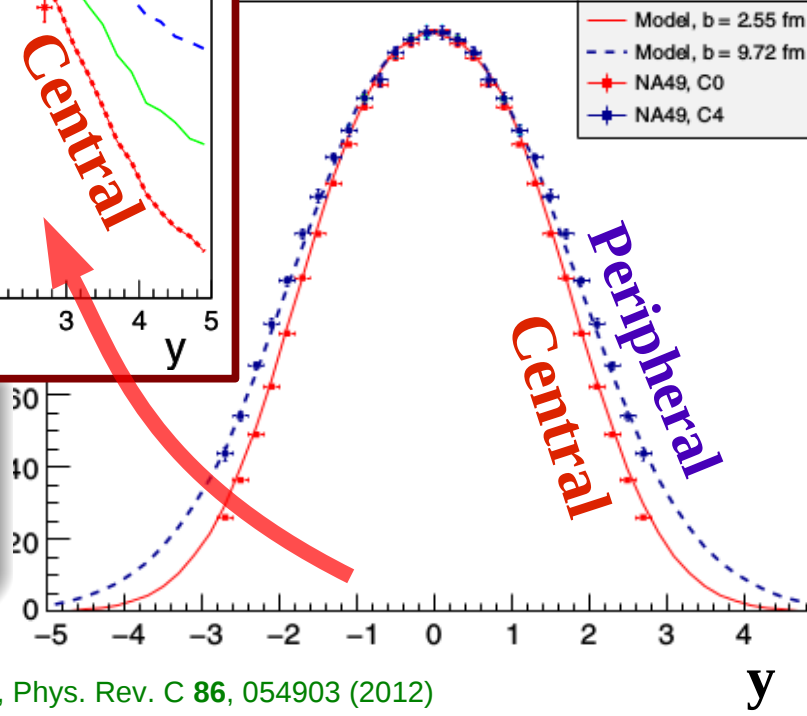
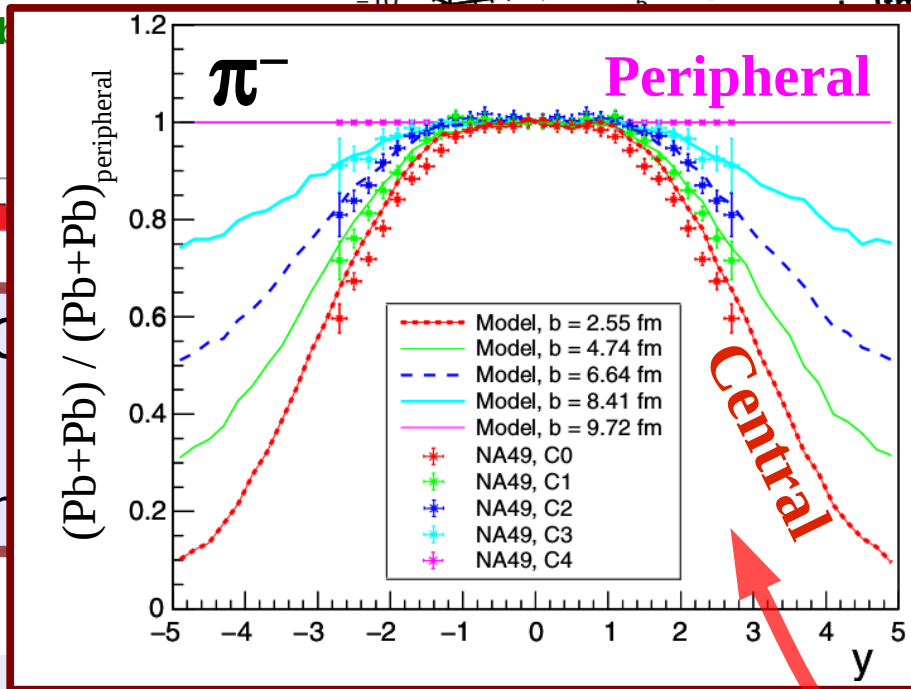
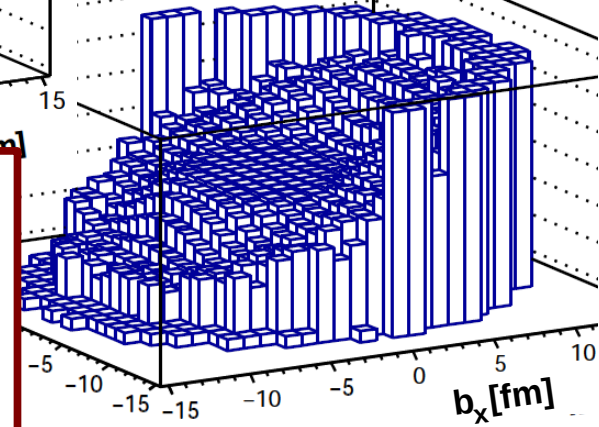
$$\frac{dn}{dy} \sim A \cdot (E_s^* - m_s) \cdot \exp\left(-\frac{[(y - y_s)^2 + \epsilon^2]^{\frac{n}{2}}}{n\sigma_y^n}\right)$$

$\sqrt{s}_{NN} = 17.3 \text{ GeV}$
Pb+Pb

Peripheral (b=9.72 fm)



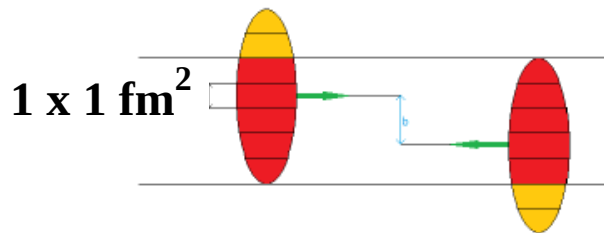
Central (b=2.55 fm)



A. Szczurek., A. R., M. Kielbowicz, Phys. Rev. C **95**, 024908 (2017)

data points from: **NA49**, T. Anticic et al., Phys. Rev. C **86**, 054903 (2012)

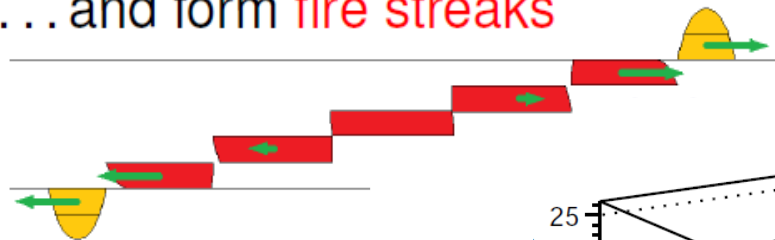
Bricks collide ...



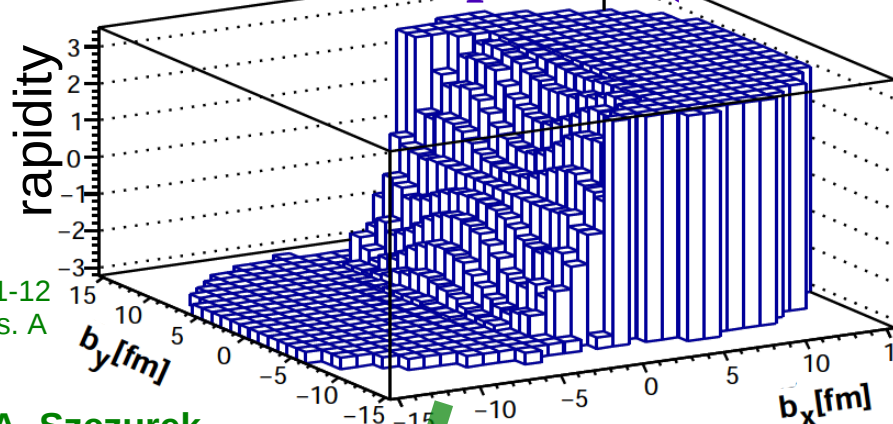
R. Hagedorn, CERN-71-12
W.D. Myers, Nucl. Phys. A

(Re)invented by A. Szczurek

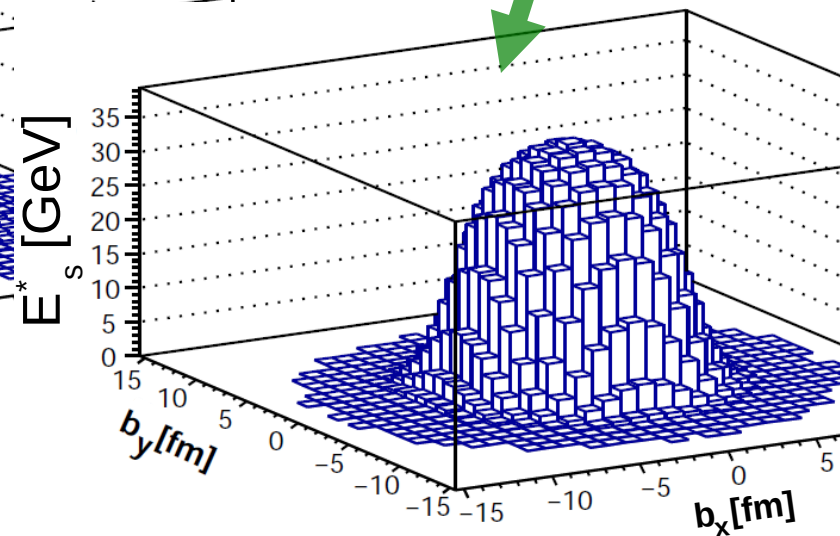
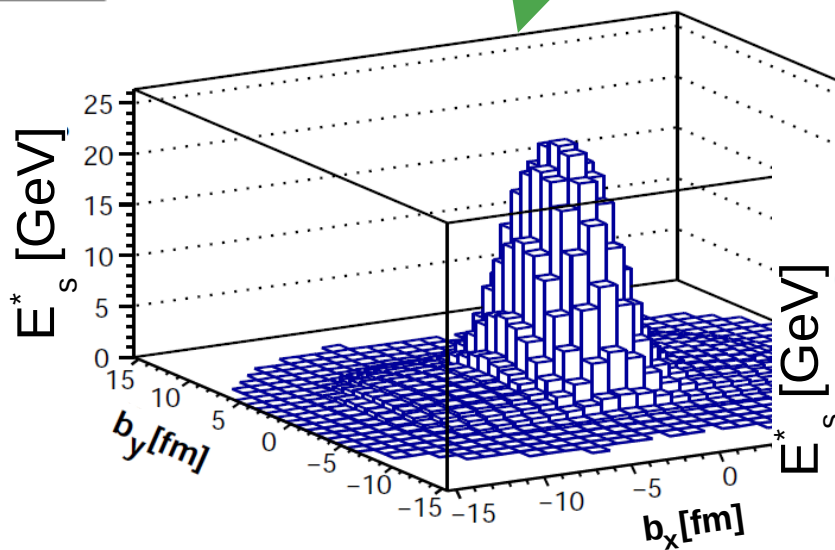
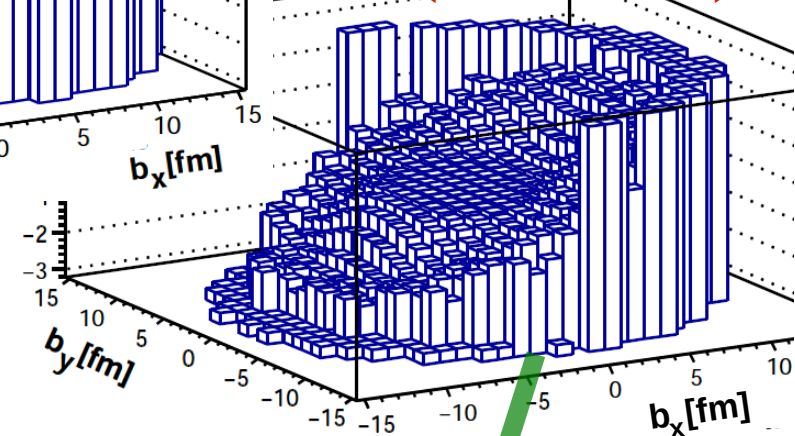
... and form fire streaks



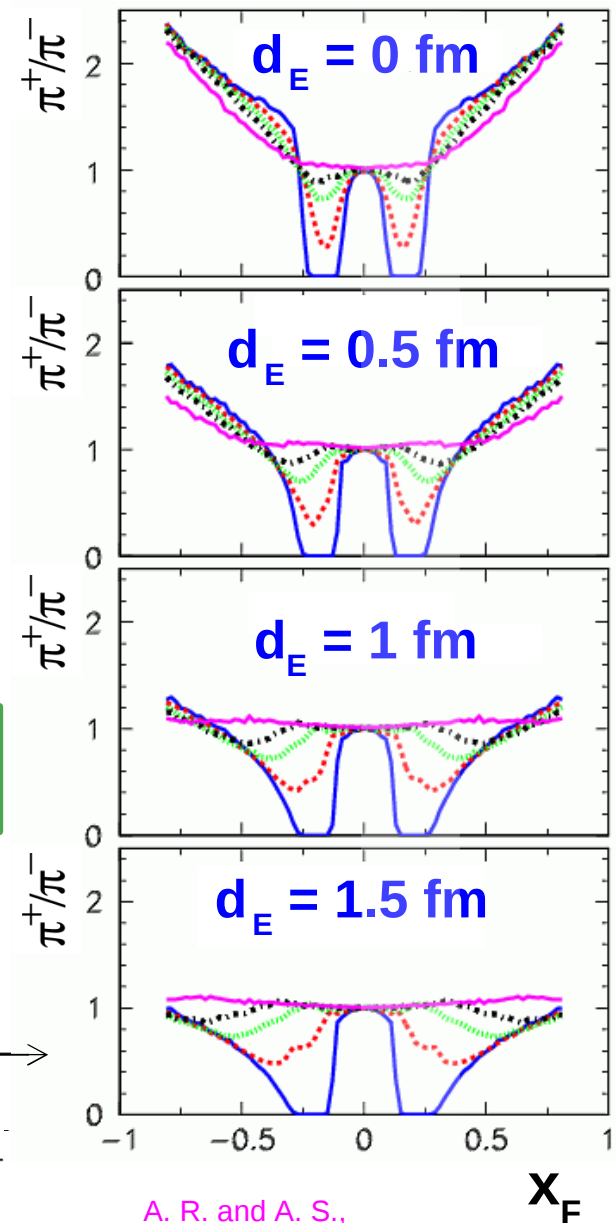
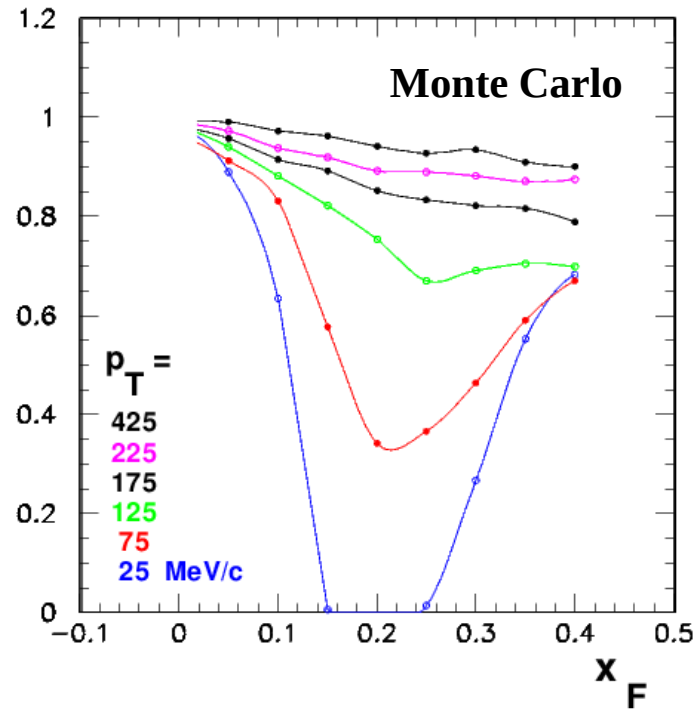
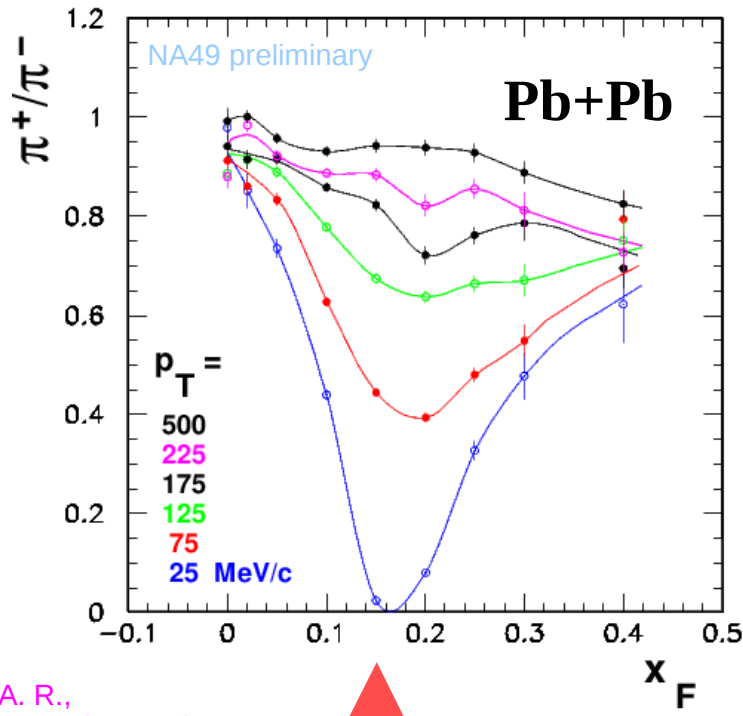
Peripheral (b=9.72 fm)



Central (b=2.55 fm)



**Remark (1):
excitation energy
in the participant zone...**

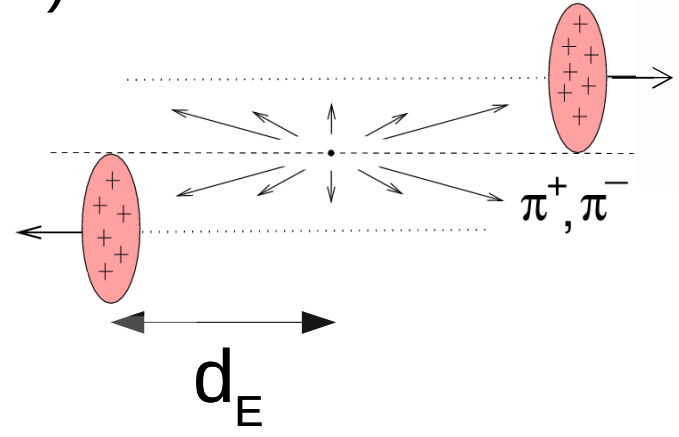
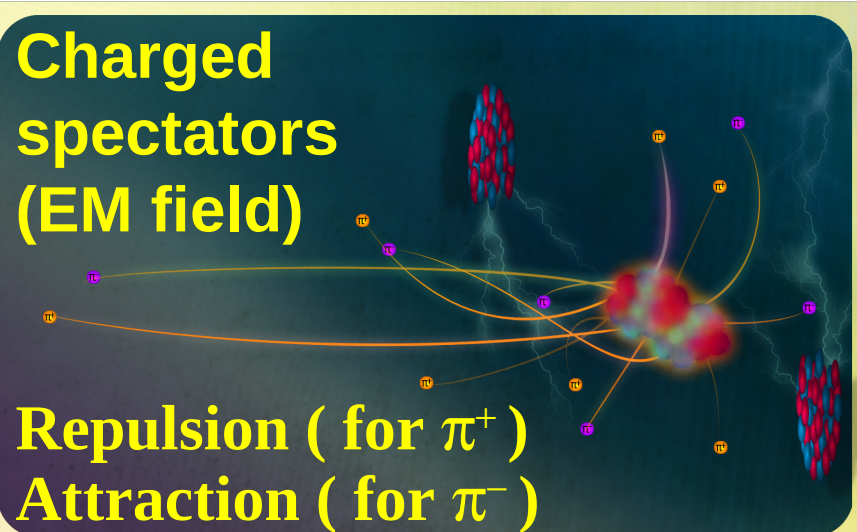


A. R.,
Acta Phys. Polon.
B42 (2011) 867

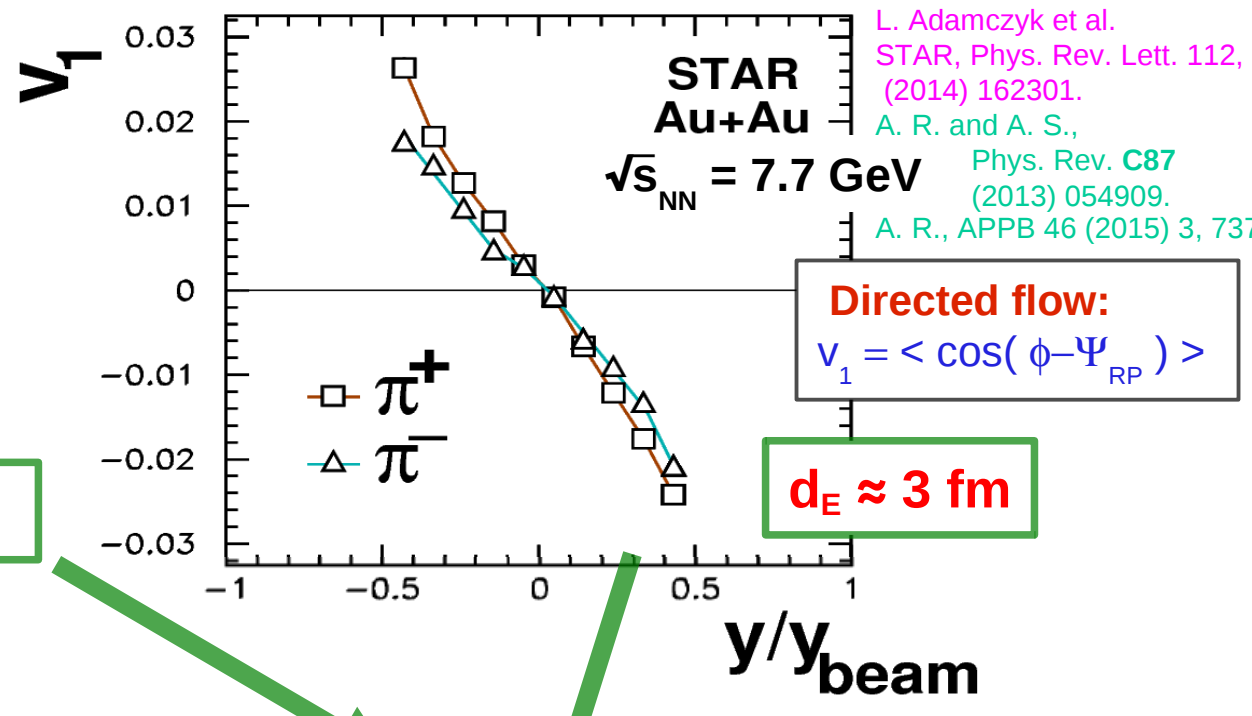
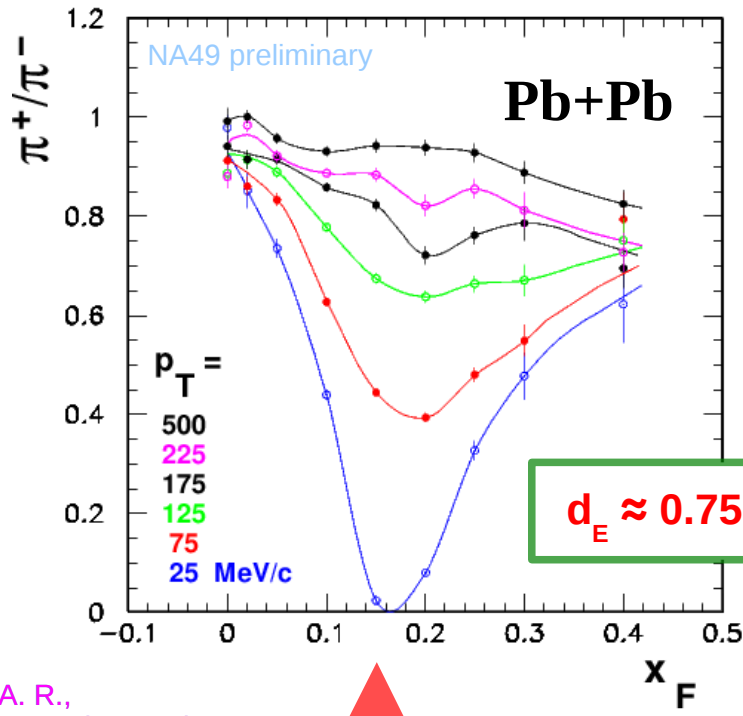
↑
**spectator
velocity:
 $y = y_{\text{beam}}$**

$$x_F = \frac{p_L}{p_L^{\text{beam}}} \quad (\text{c.m.s.})$$

$d_E \approx 0.75 \text{ fm} !$

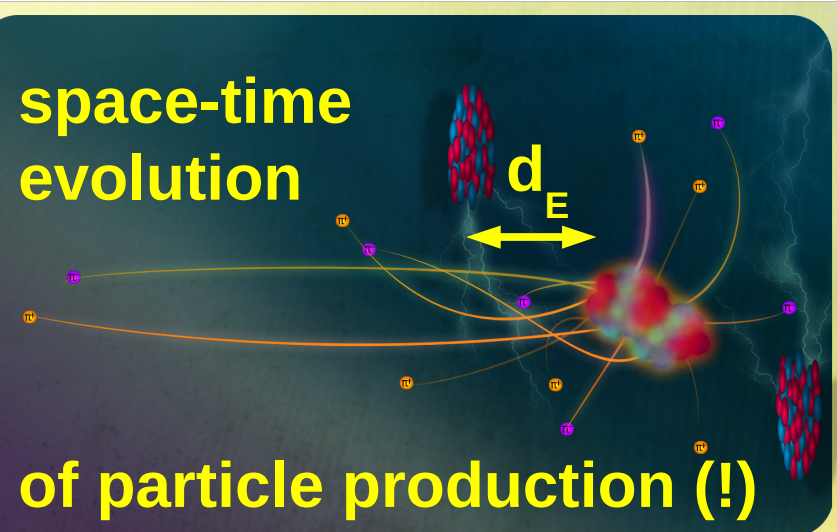
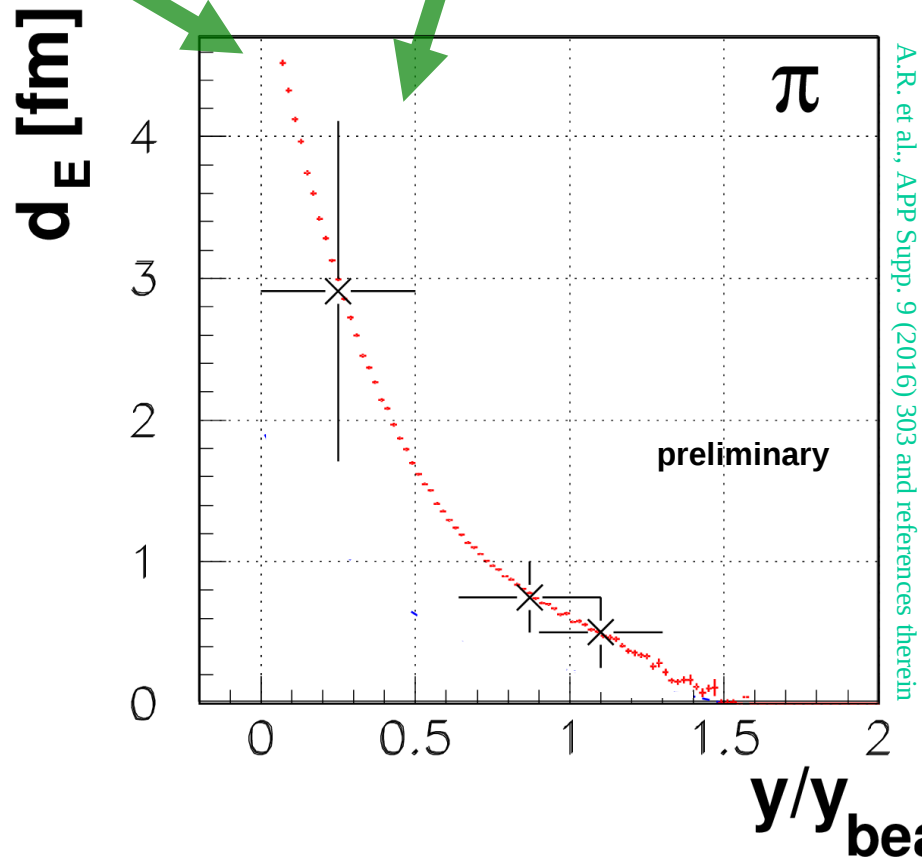


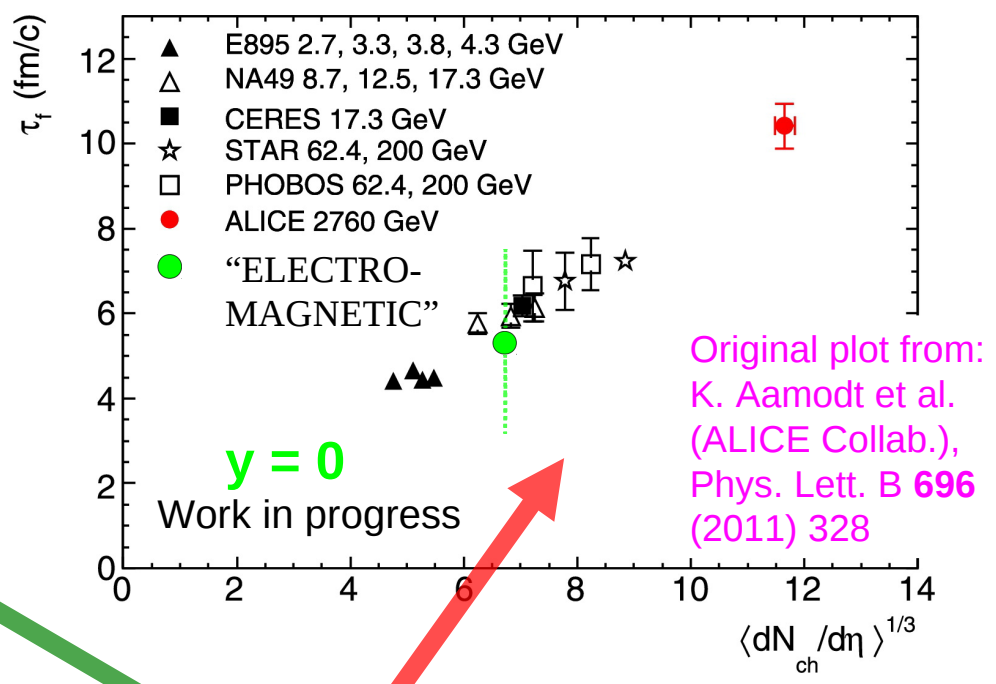
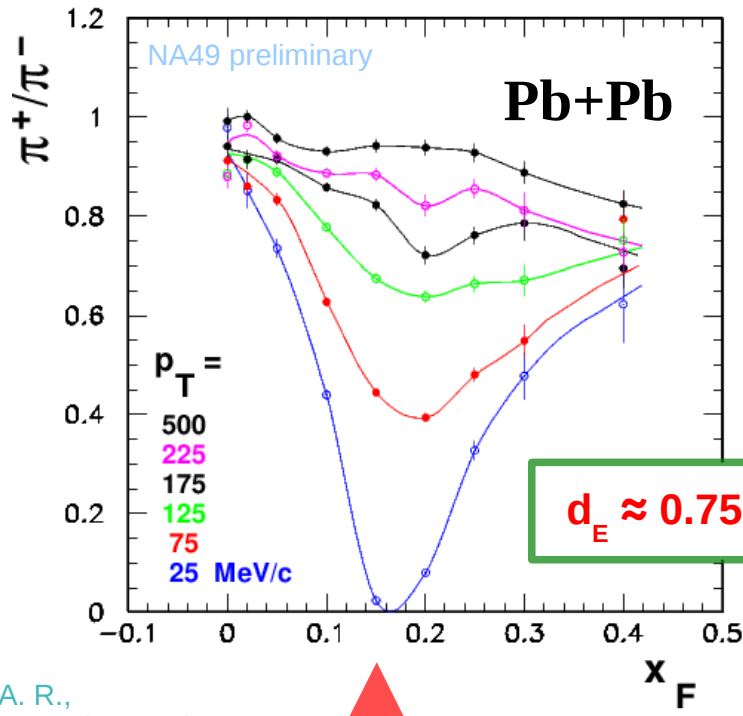
A. R. and A. S.,
Phys. Rev. C75 (2007)
054903



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↑
spectator velocity:
 $y = y_{\text{beam}}$





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↑
spectator
velocity:
 $y = y_{\text{beam}}$

