

Strong and electromagnetic collective effects from NA61/SHINE



Antoni Marcinek for the NA61/SHINE Collaboration

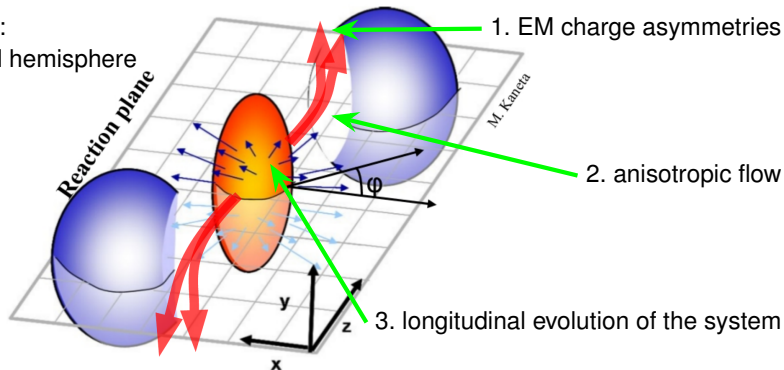
Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland

XXV Cracow EIPPHANY Conference on Advances in Heavy Ion Physics
8 January 2019, Kraków, Poland

Introduction

NA61/SHINE:

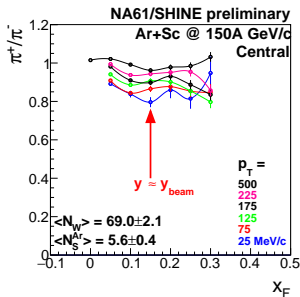
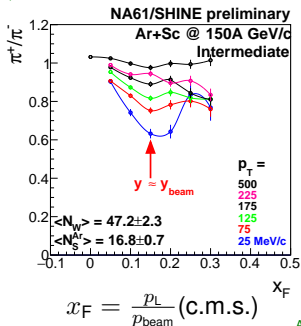
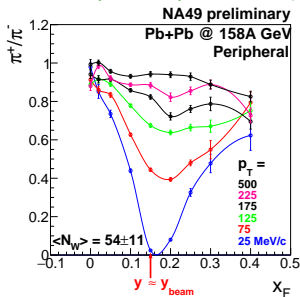
~ full forward hemisphere



- Charged spectators in non-central collisions generate EM fields, which modify trajectories of final state charged particles
- Initial asymmetry in coordinate space of the collision is transformed into momentum asymmetry; flow coefficients $v_n = \langle \cos(n(\varphi - \Psi_{RP})) \rangle$

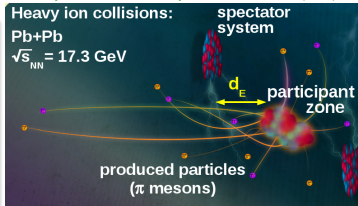
New NA61/SHINE data: 1st observation of EM effects in Ar+Sc collisions

redrawn from A. Rybicki, Acta Phys. Polon. B 42, 867 (2011)



A. Rybicki, A. Szczurek, Phys. Rev. C 75, 054903 (2007)

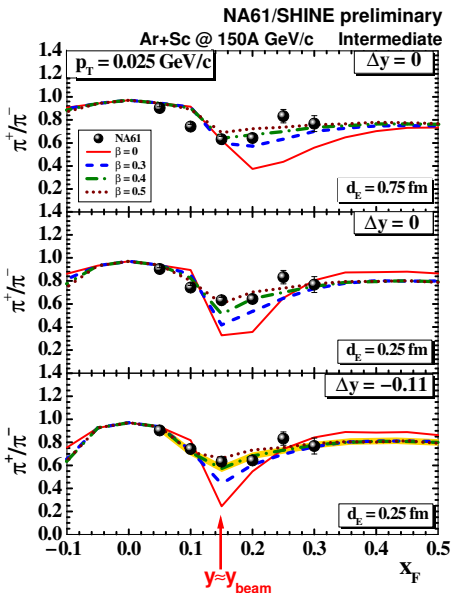
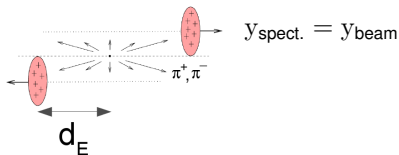
- Peripheral Pb+Pb ($Q_{spectator} \approx 70$)
→ large EM effect, $\pi^+/\pi^- \approx 0$
- Intermediate Ar+Sc ($Q_{spectator} \approx 8$)
→ visible EM effect, breaks isospin symmetry
- Central Ar+Sc ($Q_{spectator} \approx 3$)
→ still visible shadow of EM effect?



plot by I. Spatuska

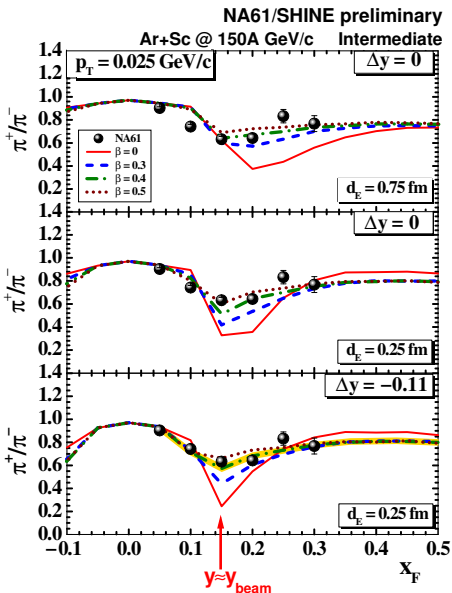
Modelling EM effects in new Ar+Sc data

A. Rybicki, A. Szczurek, Phys. Rev. C 75, 054903 (2007)

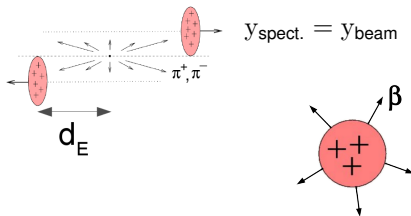


- Non-expanding spectator system cannot describe data (contrary to Pb+Pb, see A. Rybicki et al., APPB 46,737 (2015))

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A. Rybicki, A. Szczurek, Phys. Rev. C 75, 054903 (2007)



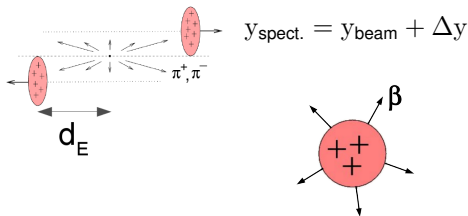
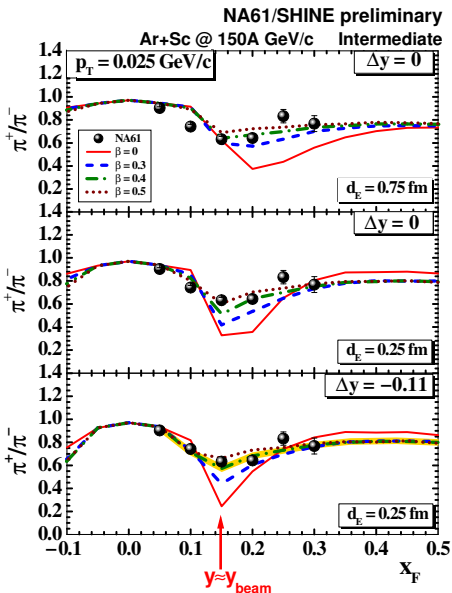
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need significant expansion velocity β of the charge cloud

Modelling EM effects in new Ar+Sc data

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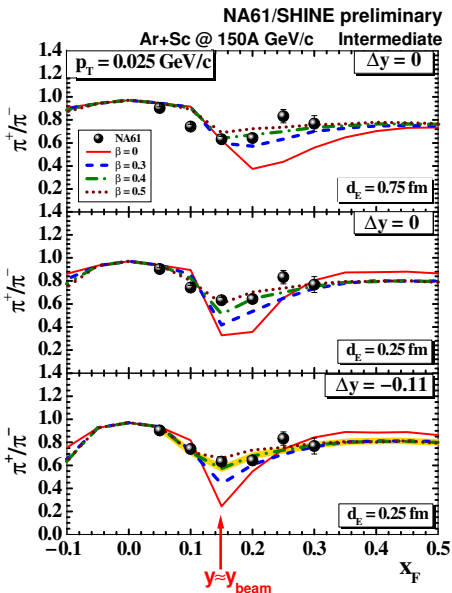
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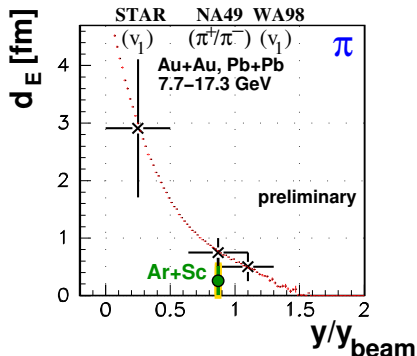
- Optimal description: charge cloud moves slower than spectator system → presence of participant charge?

Modelling EM effects in new Ar+Sc data

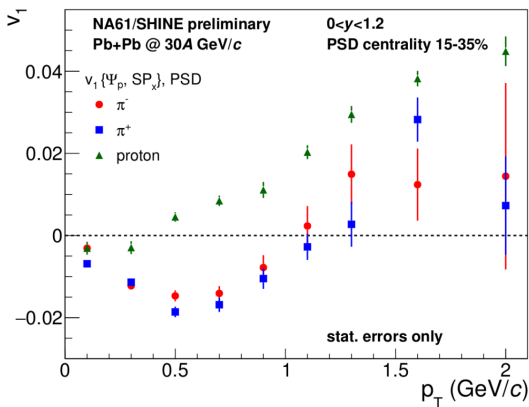


- new information on the space-time evolution of π production in Ar+Sc:

$$d_E = (0.25 \pm 0.25) \text{ fm}$$



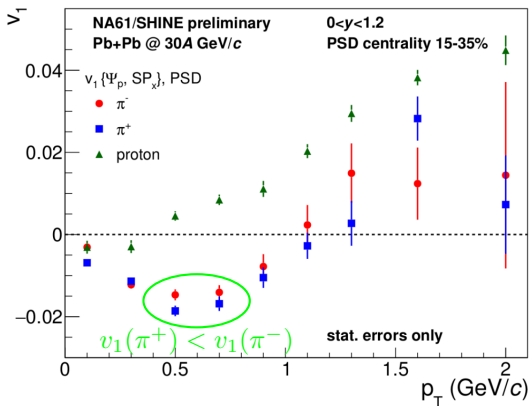
New NA61/SHINE results on directed flow in Pb+Pb



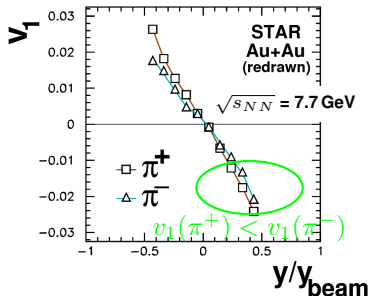
- NA61/SHINE Pb+Pb beam energy scan
 - extend existing NA49 data
 - complementary to STAR@RHIC
 - bridge to FAIR/NICA energies
- Advantage of NA61/SHINE fixed target setup:
 - tracking and particle identification over wide rapidity range
 - centrality and reaction plane via projectile spectators measurement with forward calorimeter PSD

- Significant mass dependence of v_1

New NA61/SHINE results on directed flow in Pb+Pb

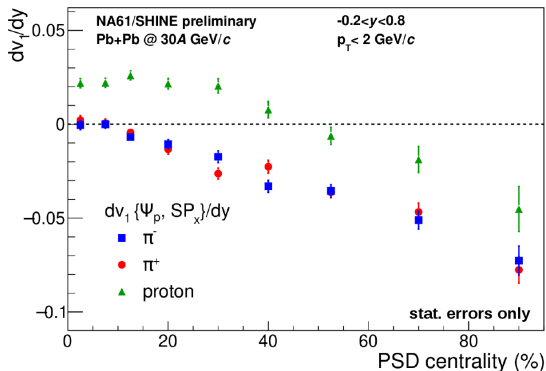


A. Rybicki et al., Acta Phys. Polon. B 46, 737 (2015)
original data: STAR, Phys. Rev. Lett. 112, 162301 (2014)



- Significant mass dependence of v_1
- Charge splitting of v_1 for pions is sensitive to spectator-induced electromagnetic effects

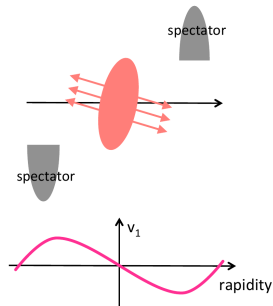
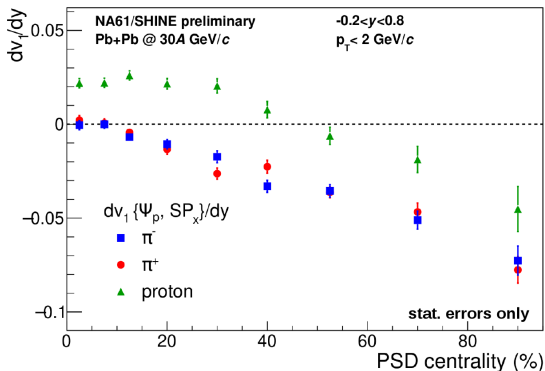
Slope of v_1 at midrapidity in Pb+Pb



- Again significant mass dependence; slope for protons changes sign at about 50% centrality

Slope of v_1 at midrapidity in Pb+Pb

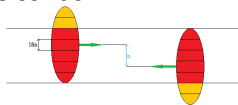
plot from M. Przybycień, Białasówka seminar 9.11.2018, Kraków
see: P. Bożek and I. Wyskiel, Phys. Rev. C **81**, 054902 (2010)



- Again significant mass dependence; slope for protons changes sign at about 50 % centrality
- In hydrodynamic models rapidity dependence of v_1 comes from 'tilted source' initial conditions

Longitudinal evolution of the system

Bricks collide ...



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

... and form **fire streaks**

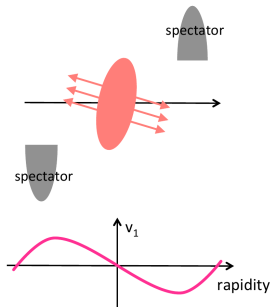


with E_s^* and y_s from **local** E - p conservation

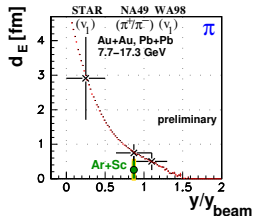
Each fire streak fragments independently into pions

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

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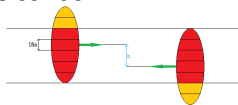


originally motivated by EM effects:



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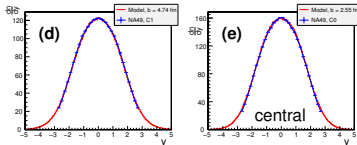
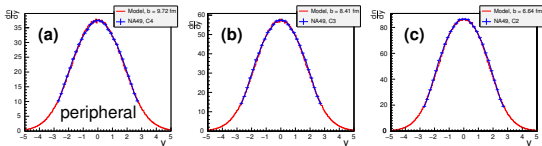


with E_s^* and y_s from **local** $E-p$ conservation

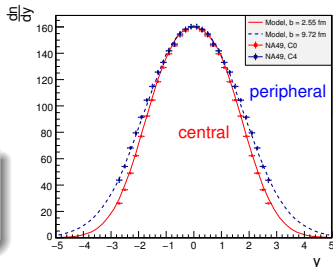
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A. Szcurek, A. Rybicki, M. Kielbowicz, Phys. Rev. C **95**, 024908 (2017); data points from: T. Anticic et al., Phys. Rev. C **86**, 054903 (2012)

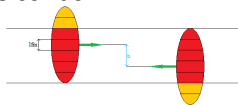


π^- in NA49 Pb+Pb@158A GeV



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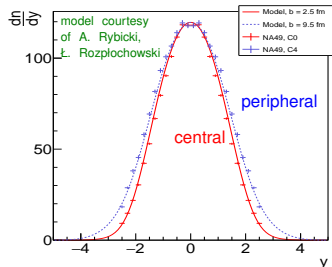
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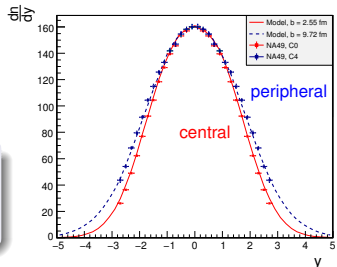
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π^- in NA49 Pb+Pb @40A GeV

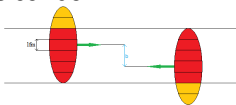


π^- in NA49 Pb+Pb @158A GeV



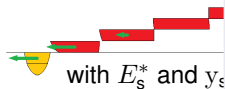
Longitudinal evolution of the system

Bricks collide ...



R. Hagedorn, C. B. Dover, W. D. Myers, Nucl. Phys. A 158 (1969) 101
(Re)invented

... and form fire stream



Each fire stream fragments independently into pions

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

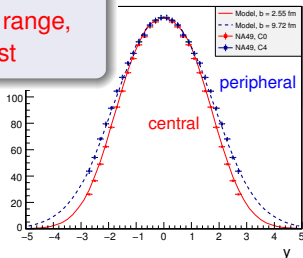
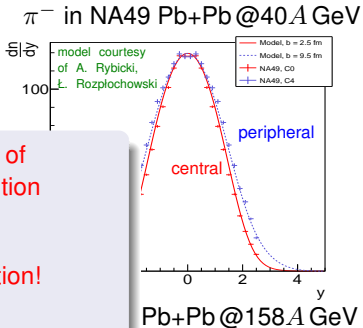
Centrality dependence of longitudinal pion distribution



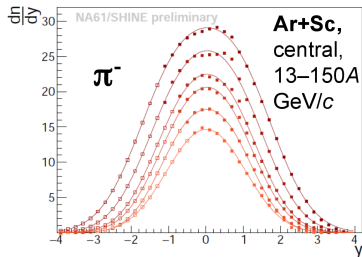
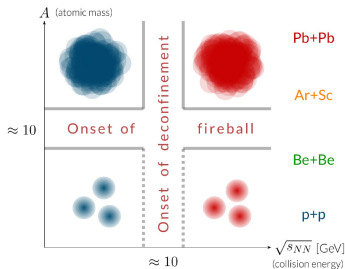
only from E - p conservation!

Valid in some extended energy range,
 $\sqrt{s_{NN}} = 9$ – 17 GeV at least

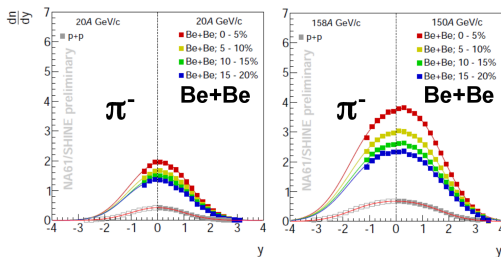
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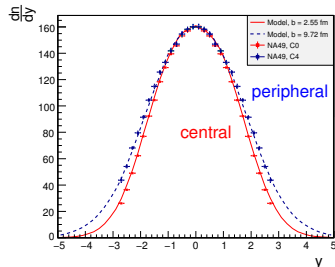
2D scan of the longitudinal evolution of the system



NA61/SHINE allows for a 2D scan of the longitudinal evolution of the system!



π^- in NA49 Pb+Pb@158A GeV



Summary

- New, preliminary results on collective effects now available from NA61/SHINE:
 - directed flow for protons and charged pions as a function of p_T and centrality in Pb+Pb collisions at $30A$ GeV/c
 - spectator-induced EM effects in charged pion emission in Ar+Sc collisions at $150A$ GeV/c
 - new, independent information on the space-time properties of the system
- Centrality dependence of pion rapidity spectra:
longitudinal evolution of the system is largely governed by energy-momentum conservation, in the tested energy range

Acknowledgements

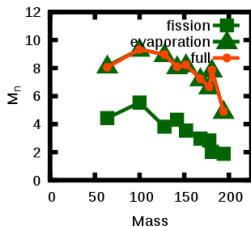
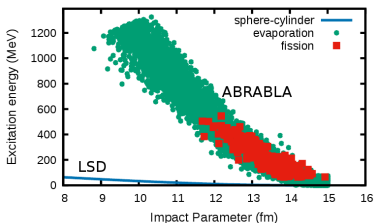
- This work was supported by the National Science Centre, Poland (grant number 2014/14/E/ST2/00018)

BACKUP

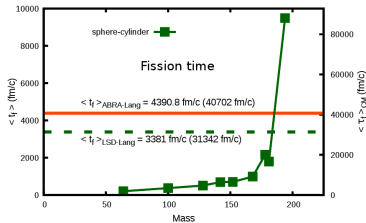
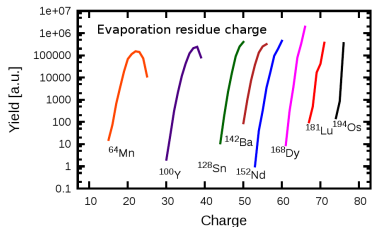
Dynamical evolution of the spectator system

- Recent theoretical work for Pb+Pb at SPS: 3 abrasion models + dynamical approach based on **4D stochastic Langevin equation**.

K. Mazurek, A. Szczurek, C. Schmitt, P.N. Nadtochy, arXiv:1708.03716 (2017)



- Excitation energy: highly model dependent
- Decay: mostly evaporation.



- Evaporation: preserves spectator charge. Fission: long time scale.
- This **agrees with EM effects** observed by NA49.

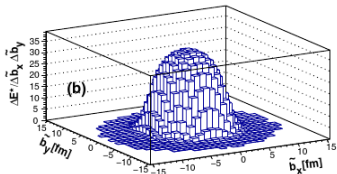
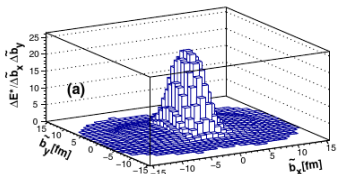
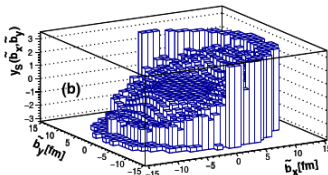
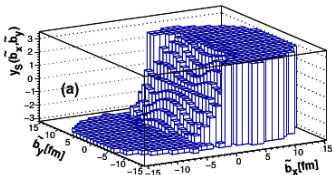
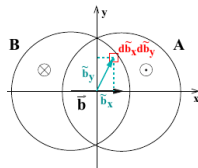
Fire streaks' parameters

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

Pb+Pb@158A GeV/c $\rightarrow \sqrt{s_{NN}} = 17.3$ GeV, $y_{beam} = 2.9$

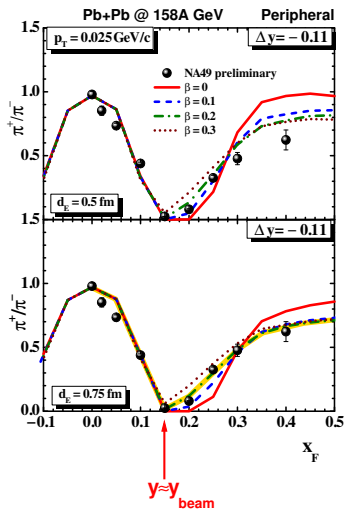
peripheral $b = 9.72$ fm

central $b = 2.55$ fm



- Very narrow (if any) 'stopped' region in non-central collisions
- ΔE^* is the streak's energy in its own c.m.s. frame
- In peripheral collisions 2 spectator regions visible (with $\Delta E^* = m$)
- Central collisions: broader 'hot' region, with higher excitation energies

Modelling EM in Pb+Pb



Energy dependence of the fragmentation function

courtesy of A. Rybicki, Ł. Rozpłochowski

