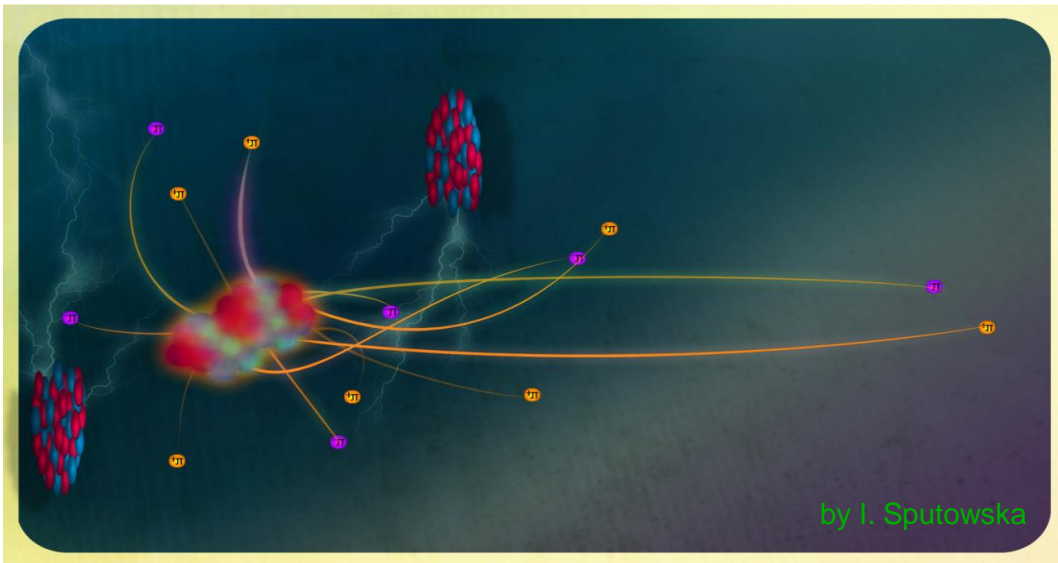


# Spectator induced electromagnetic effects in $^{40}\text{Ar}+^{45}\text{Sc}$ collisions @ 40 A GeV/c

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by I. Sputowska

## Outline

- Motivation.
- NA61/SHINE.
- Analysis.
- Results.
- Summary.

A 3D schematic of a particle detector. On the left, a particle source is shown with a red and blue rectangular component. A large number of blue lines representing particle tracks emanate from this source, passing through a series of cylindrical components. The tracks then enter a large, rectangular detector volume. Inside this volume, the tracks are shown interacting with a grid of detector elements. The detector is composed of several layers, with some elements highlighted in green and purple. The text "1) Motivation" is overlaid in the center of the detector volume.

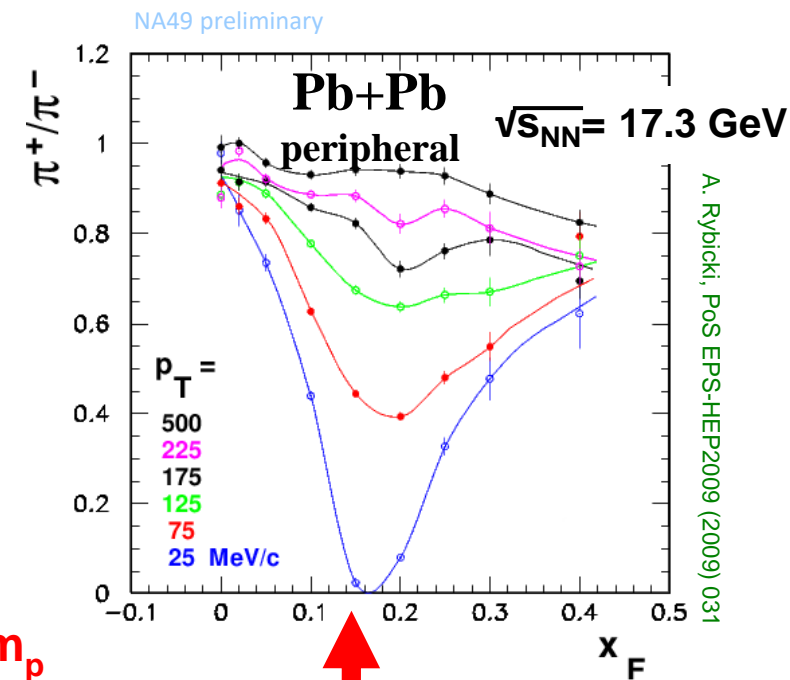
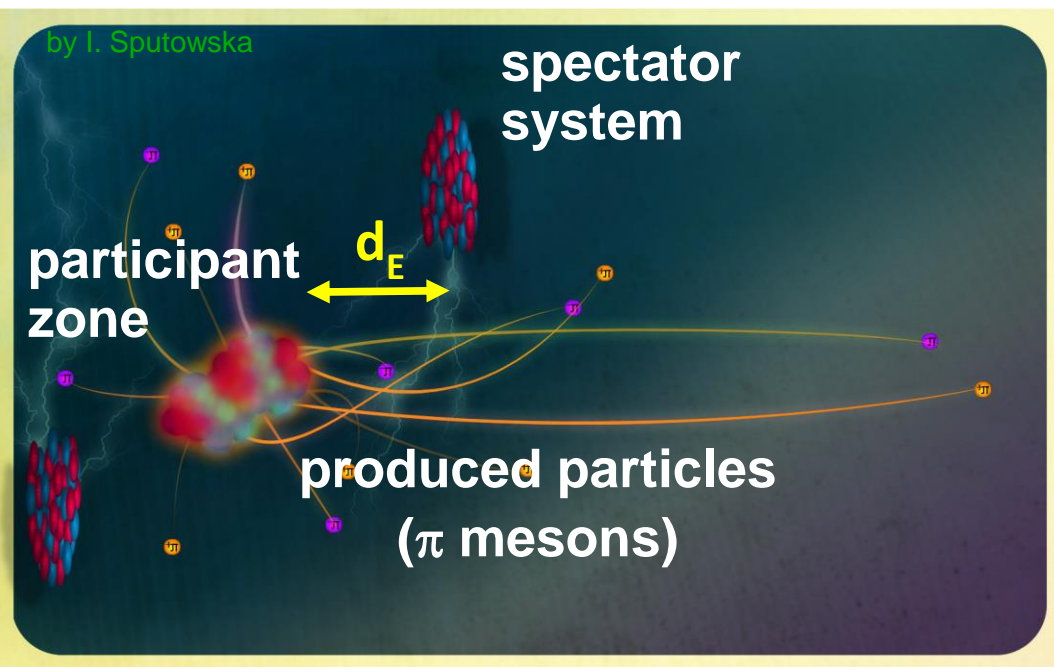
# 1) Motivation

# Spectator-induced electromagnetic (EM) effects:

- Charged spectators generate **EM fields**, which modify the trajectories of  $\pi^+$ ,  $\pi^-$  mesons.  
 → they modify the double differential  $\pi^+/\pi^-$  ratios, and result in **charge splitting of directed flow**.
- This **EM distortion** is sensitive to the distance  $d_E$  between the **pion formation zone** and the **spectator system**.  
 → new information on the **space-time evolution of the system**.

Rybicki, Szczurek,  
 PRC 75 (2007) 054903  
 PRC 87 (2013) 054903

Rybicki, MESON 2016



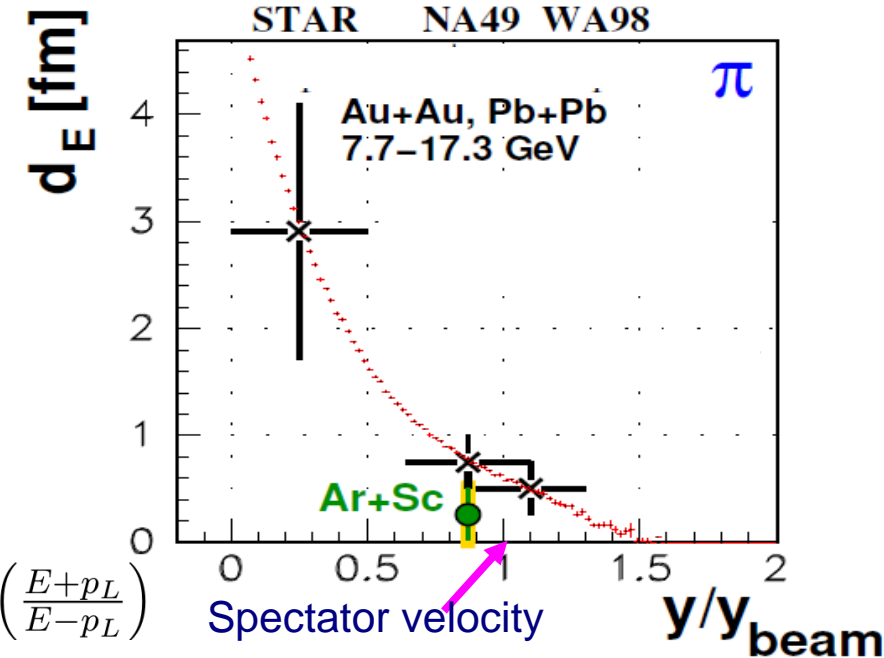
$$x_F = \frac{p_L}{p_L^{beam}}$$

(c.m.s.)

# Study of space-time evolution of the system from EM effects:

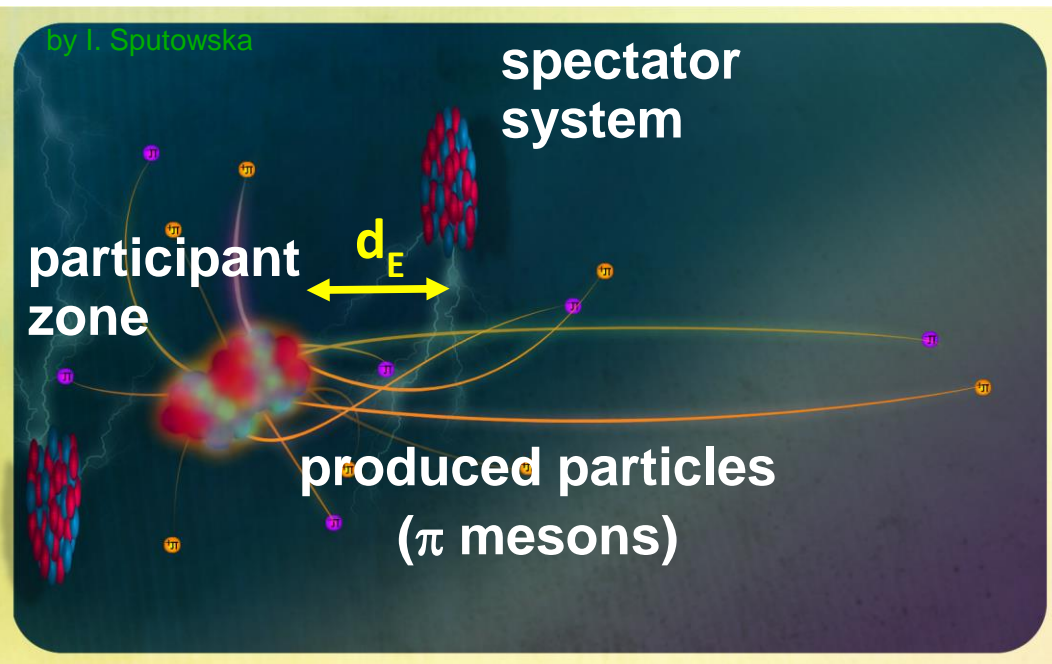
Rybicki, MESON 2016

(1) Introductory work- estimating  $d_E$  as a function of pion rapidity:  
 faster pions are produced closer to spectator system.



$$y = \frac{1}{2} \ln \left( \frac{E+p_L}{E-p_L} \right)$$

(\*) Ar+Sc@150 GeV/c, intermediate centrality, analysis M.Kiełbowicz, see also:  
 A. Marcinek for NA61/SHINE, Acta Phys. Pol. B 50, 1127 (2019)



# Study of space-time evolution of the system from EM effects:

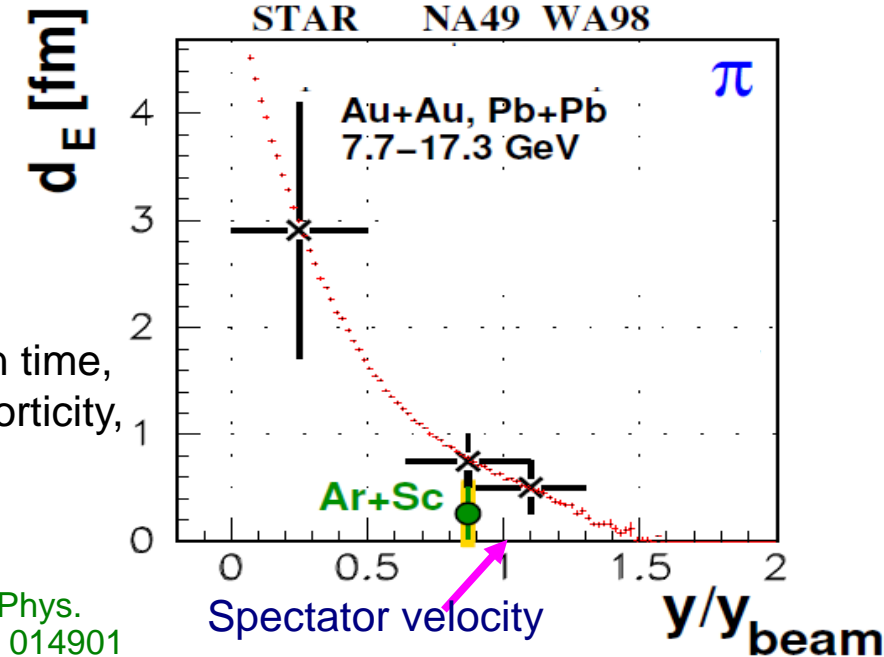
Rybicki, MESON 2016

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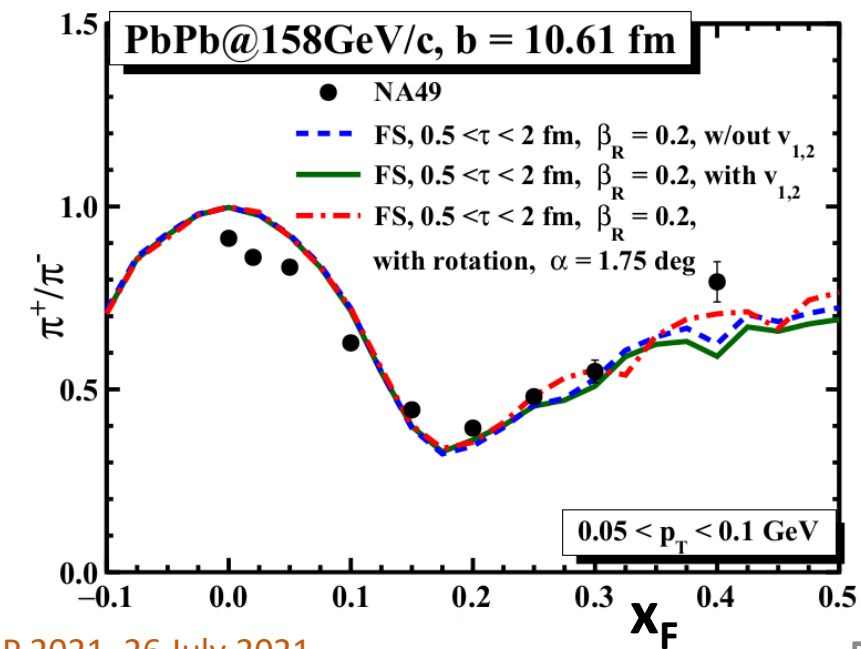
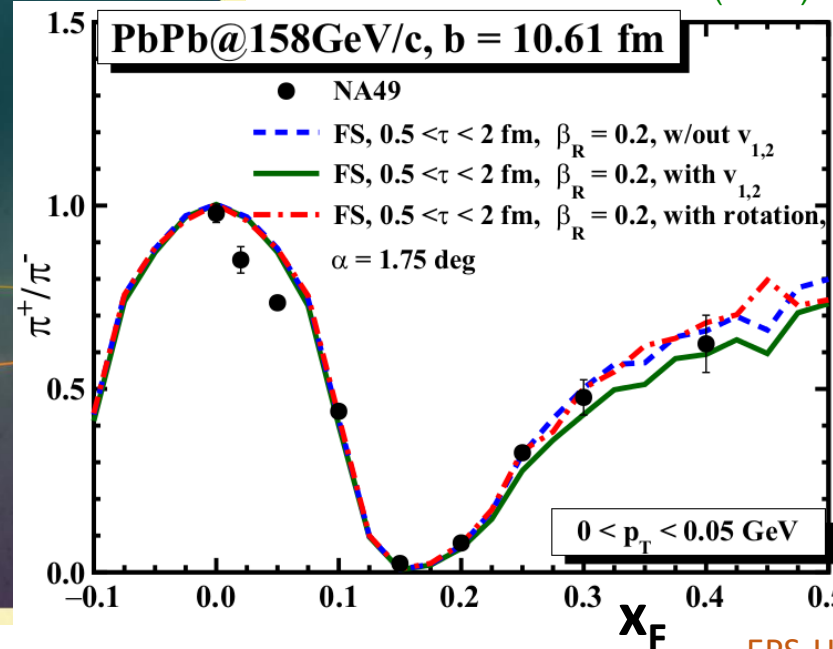
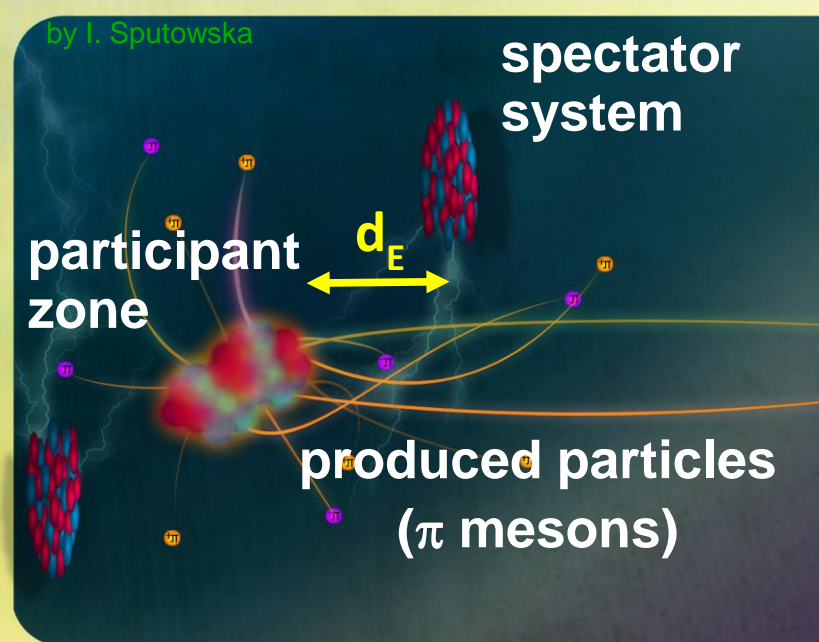
(2) First realistic description of EM distortion of  $\pi^+/\pi^-$  ratios.

- (1) collision geometry (2) longitudinal evolution, (3)  $p_T$  spectra, (4) pion creation time, (5) isospin effects, (6) directed and elliptic flow, (7) transverse expansion, (8) vorticity, (9) spectator expansion, (10) relativistic effects on EM field.

→ Information on creation time scales for fast pions.

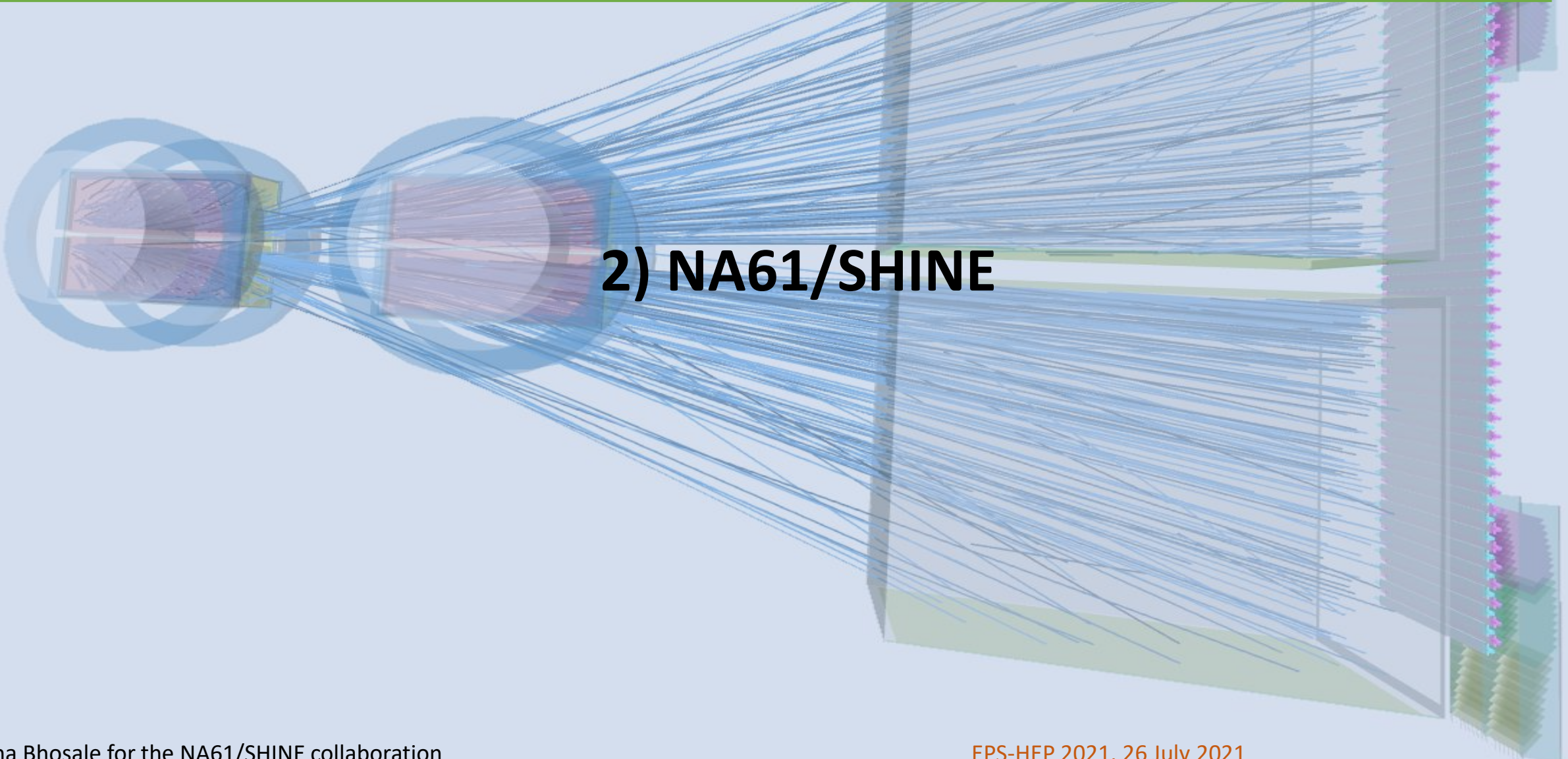


V. Ozvenchuk et al., Phys. Rev. C 102 (2020) 1, 014901

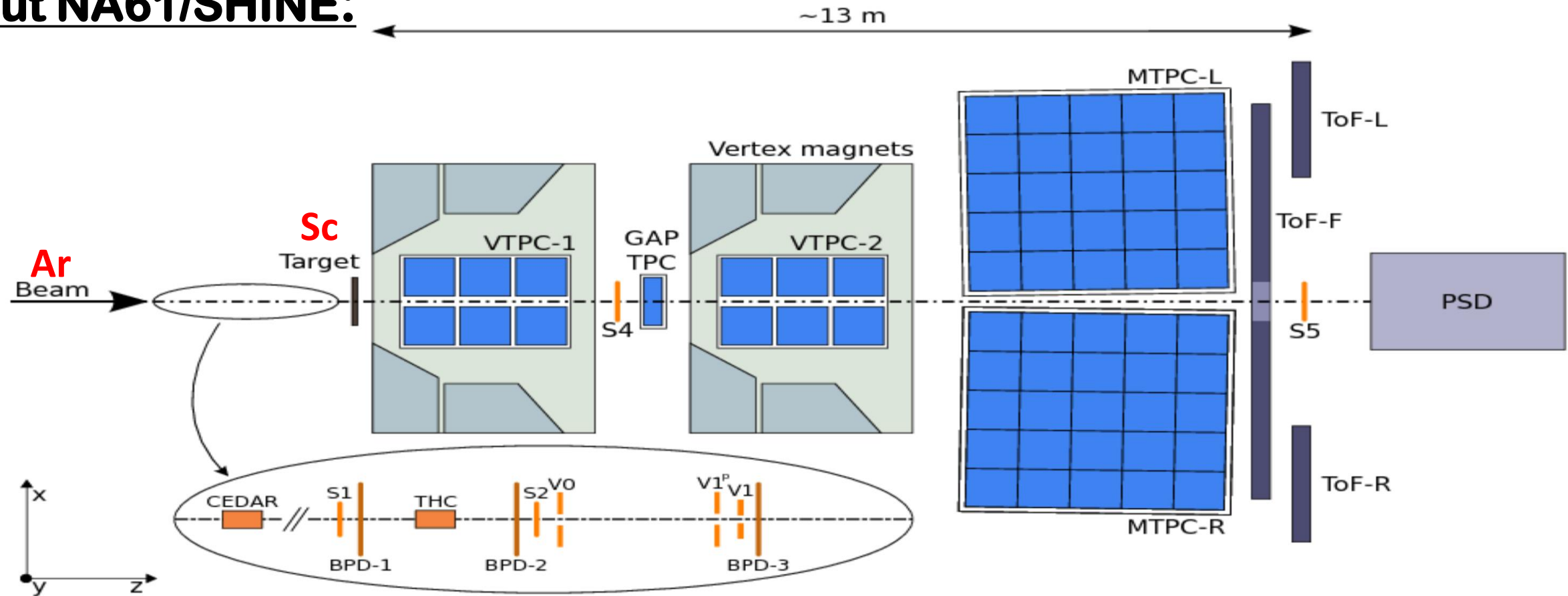


However, up to now, no corresponding information on the **full centrality** dependence of **EM effects** in a **small system** was available.  
At the CERN SPS such measurements are now **available for the first time**.

## 2) NA61/SHINE



# About NA61/SHINE:



- VTPC-1, VTPC-2 and GTPC are placed in the magnetic field.
- TPC system: track reconstruction and particle identification based on specific energy loss.
- Projectile Spectator Detector (PSD): hadronic calorimeter, measures projectile spectators energy.

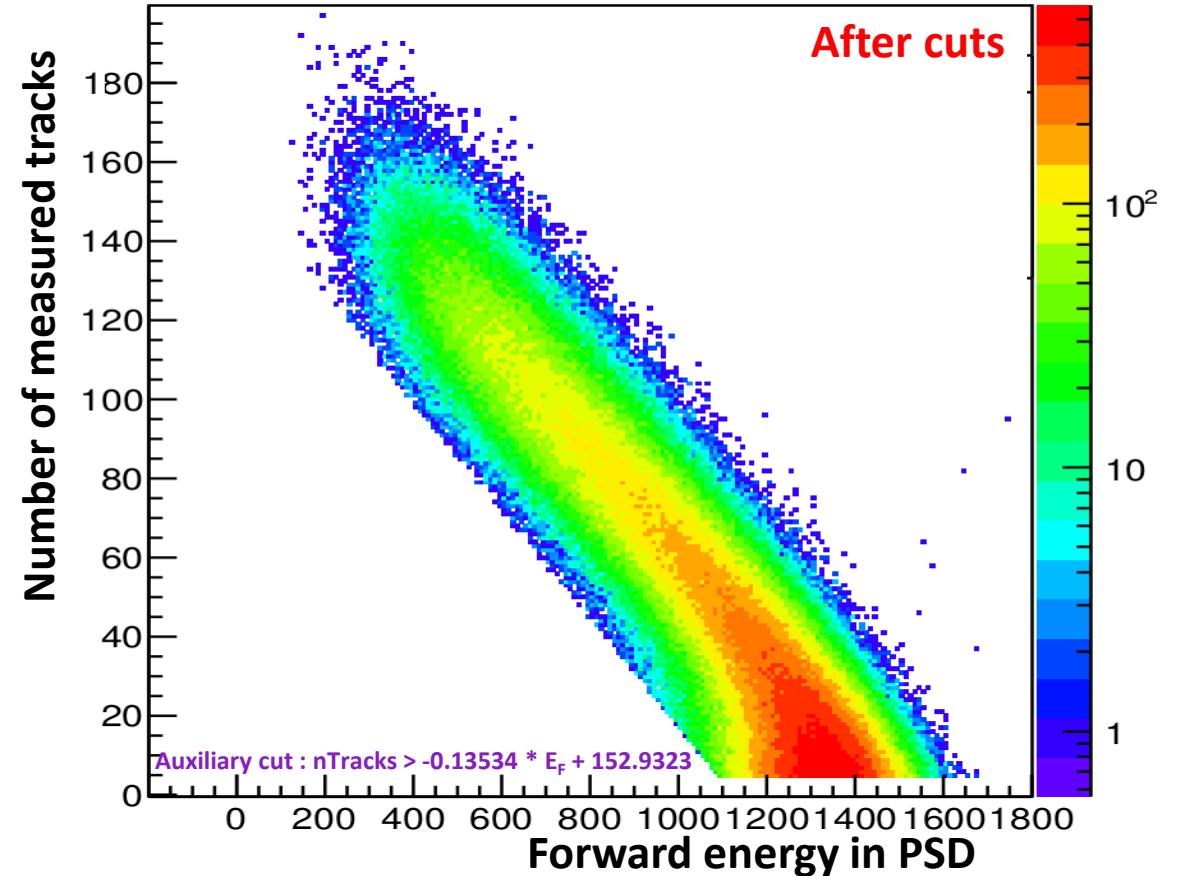
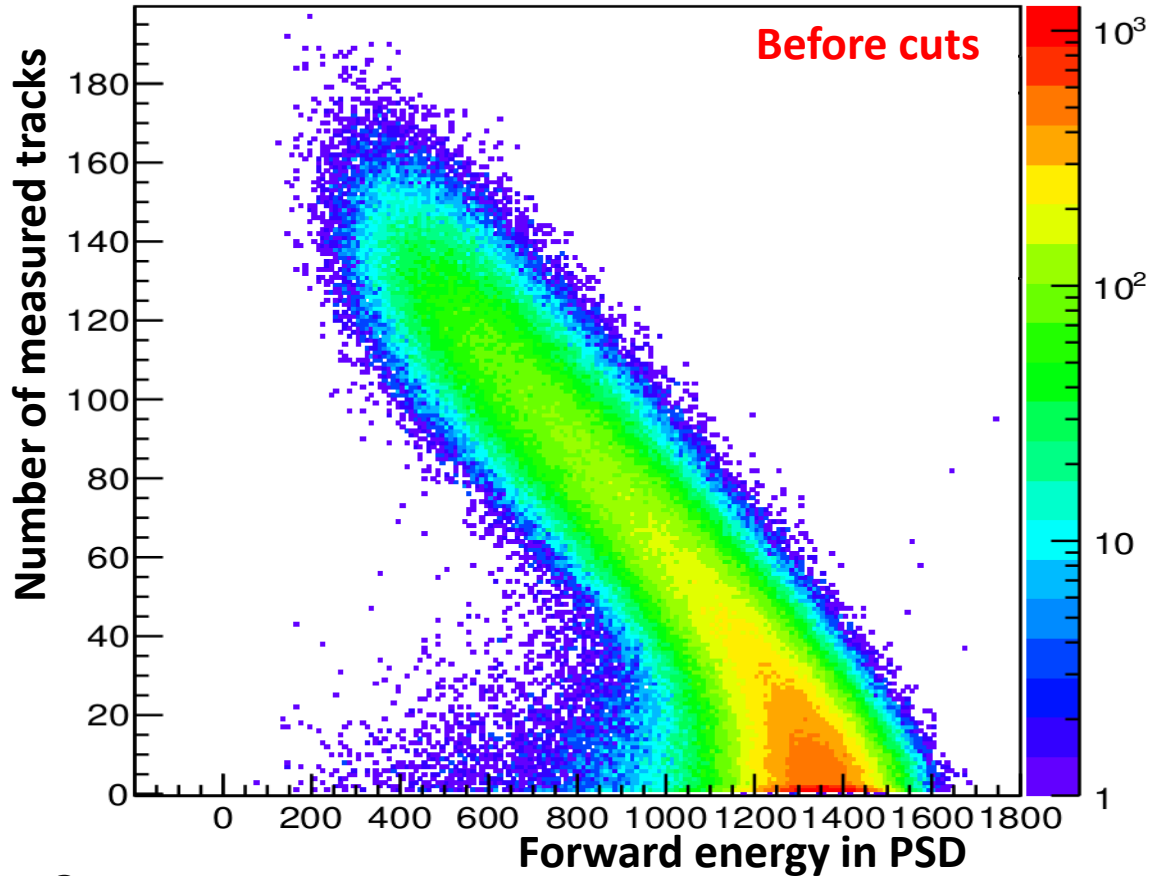


The diagram illustrates a particle detector setup. On the left, a particle source (represented by a red rectangular block) emits a beam of particles. These particles pass through a series of cylindrical components, likely beamline elements. The beam then enters a large, rectangular detector volume. Inside this volume, numerous blue lines represent the paths of particles. The detector is composed of several layers, including a central tracking region and outer calorimetric regions. The text '3) Event selection and particle identification' is overlaid on the central part of the detector.

### 3) Event selection and particle identification



# Event selection:



## Cuts:

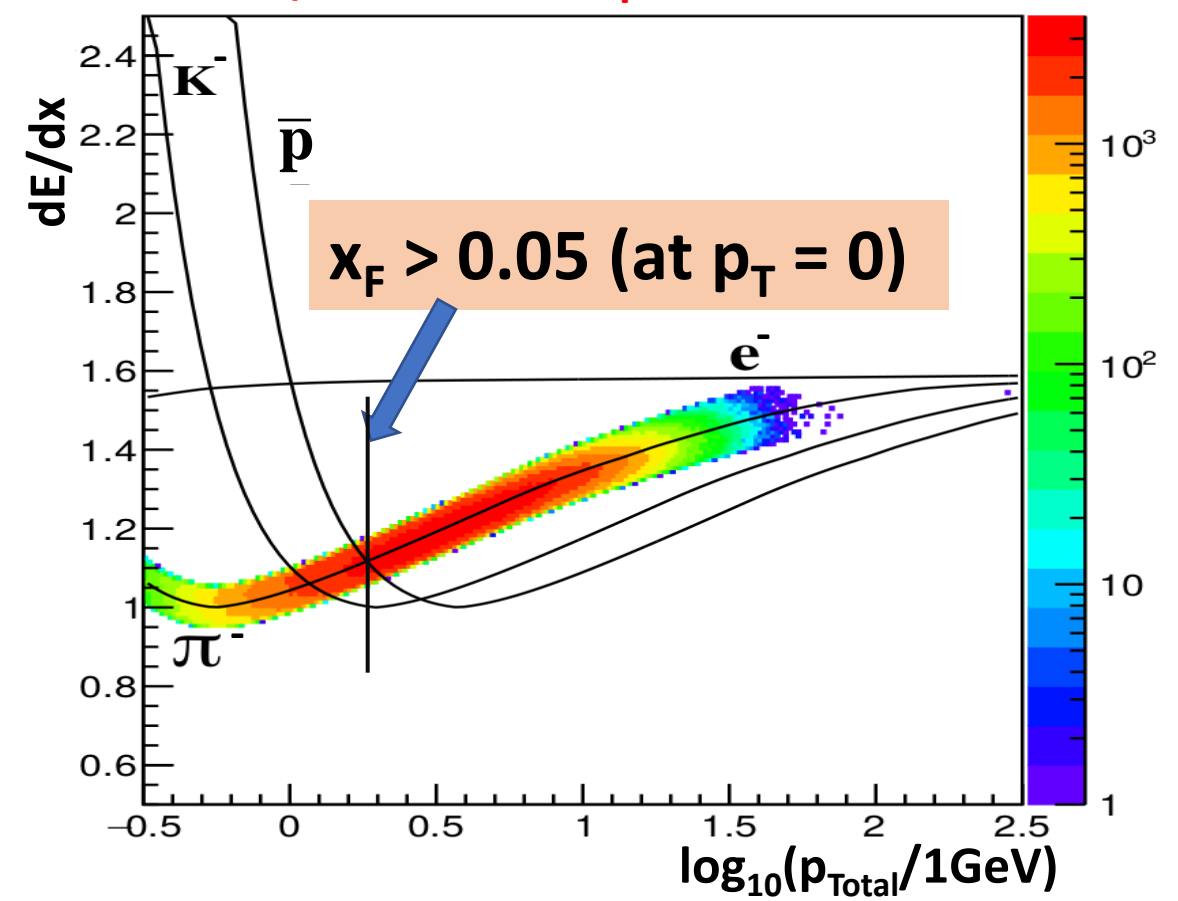
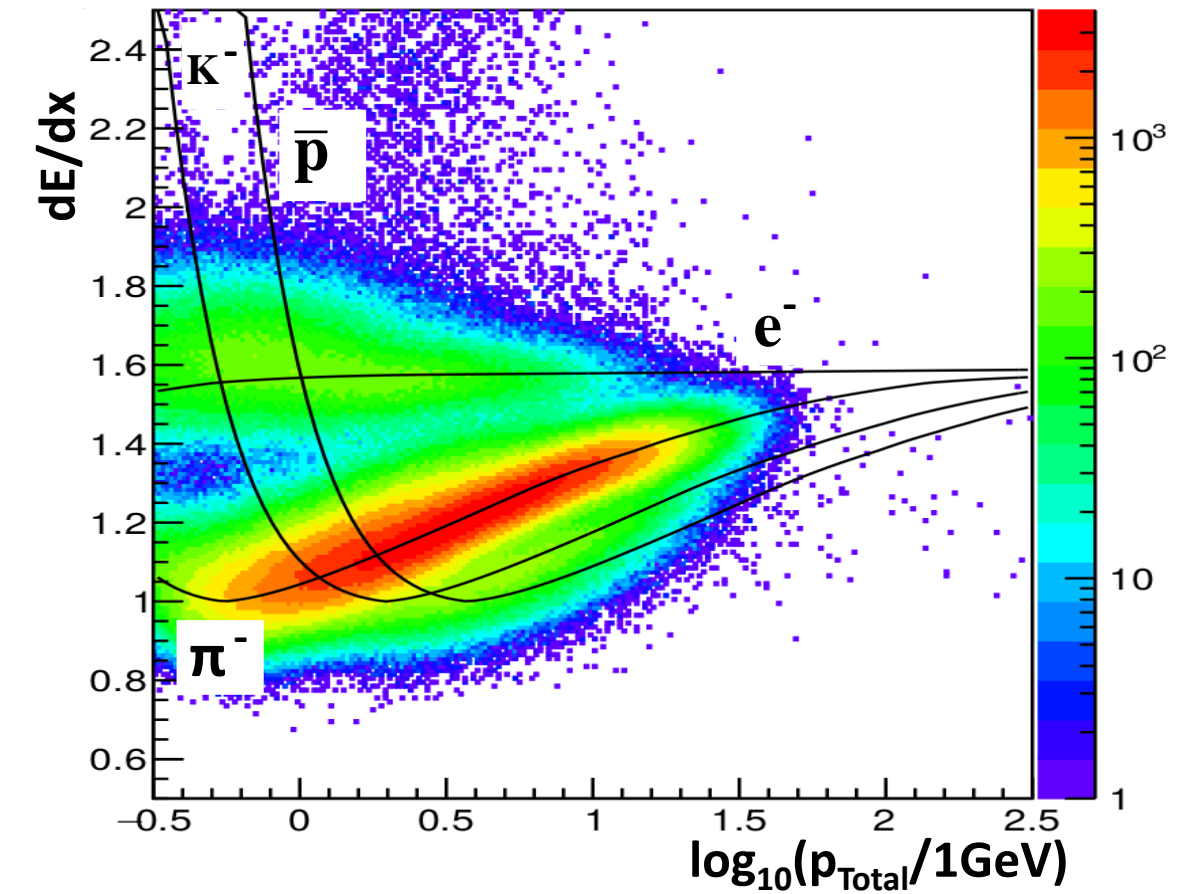
1. More than 4 tracks in the TPC system: removes the **beam peak**, introduces a **minimal bias** on low multiplicity events;
2. “**Auxiliary**” cut: removal of **background (trash) events**.  
Background from **Ar+gas** interactions remains **below 1%**.

\*\*The event selection is procedure is not the NA61/SHINE default one and is used only for this analysis.

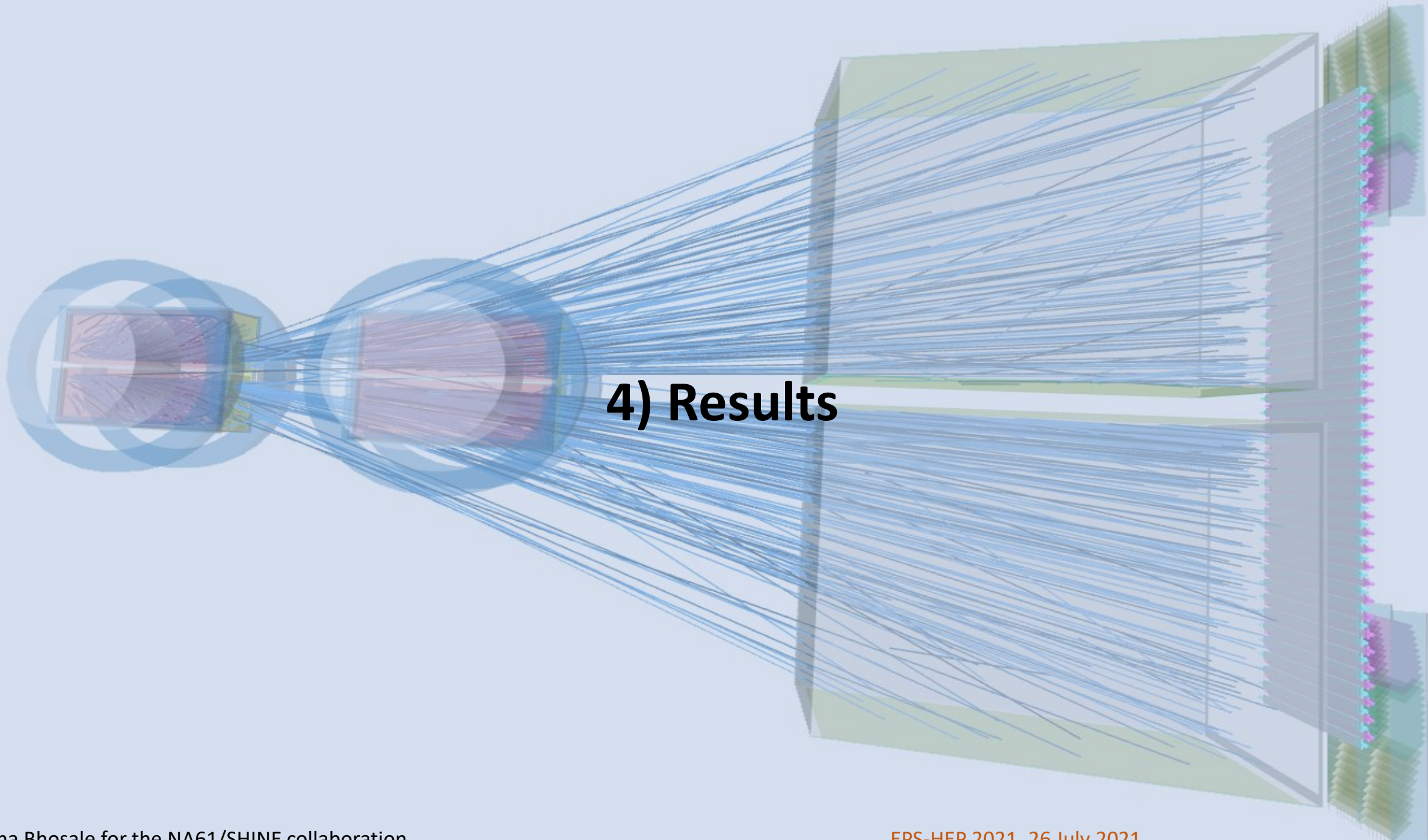
# Particle Identification:

(Note: the case of *negative* particles is shown)

$dE/dx \pm 5\%$  around pion Bethe-Bloch

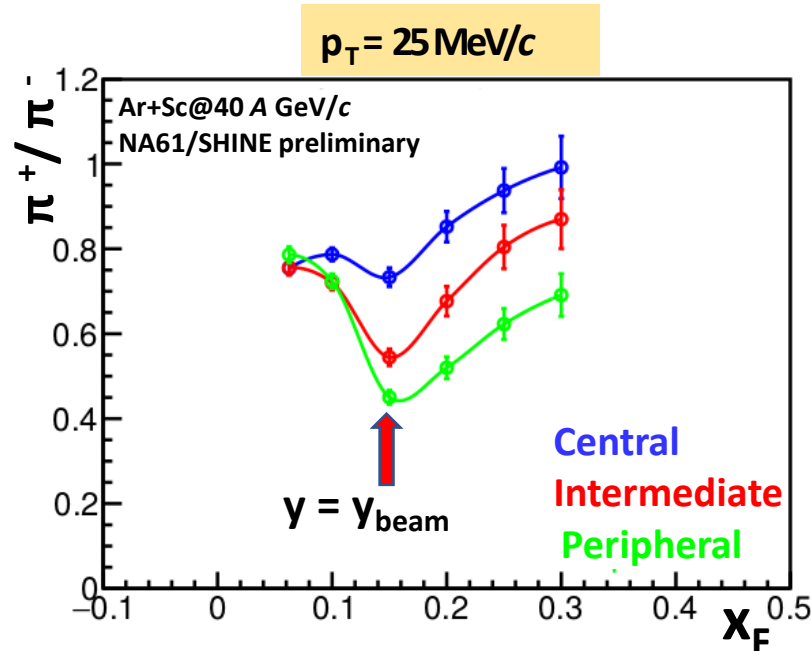
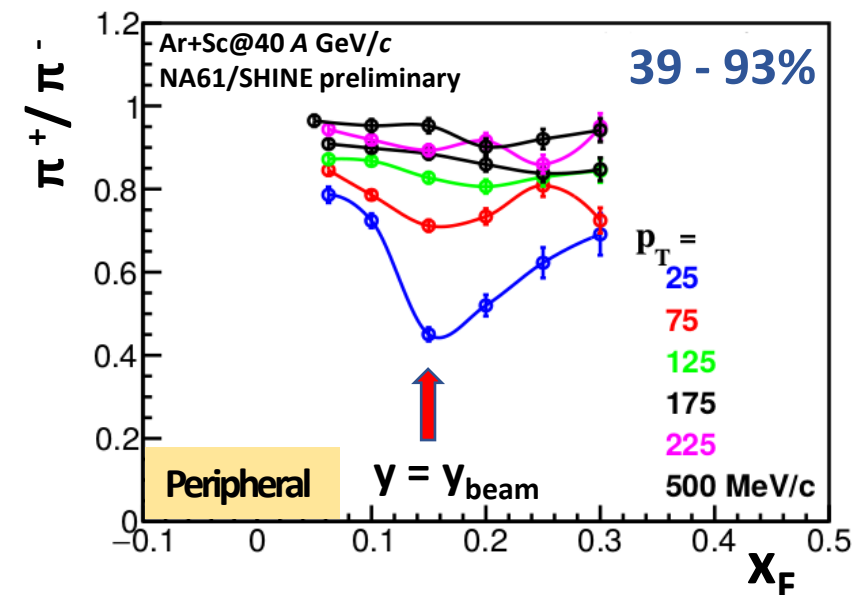
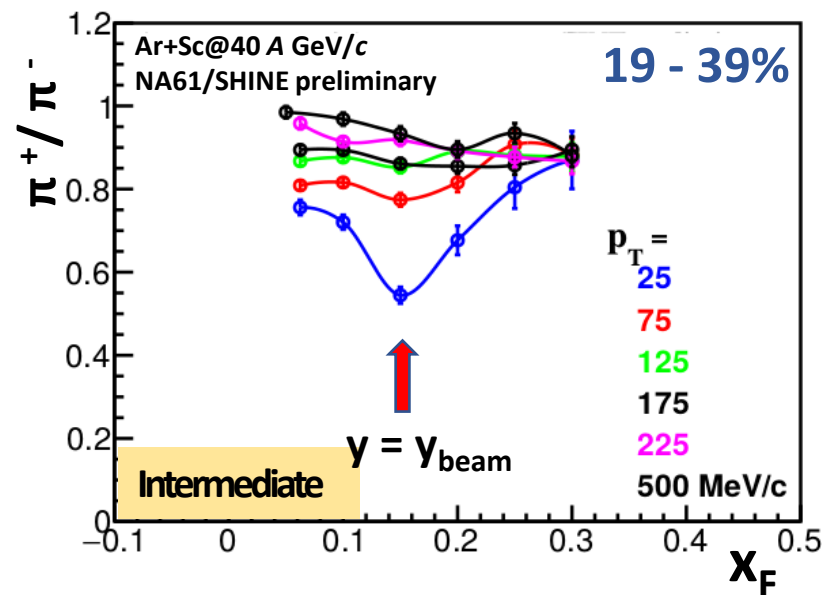
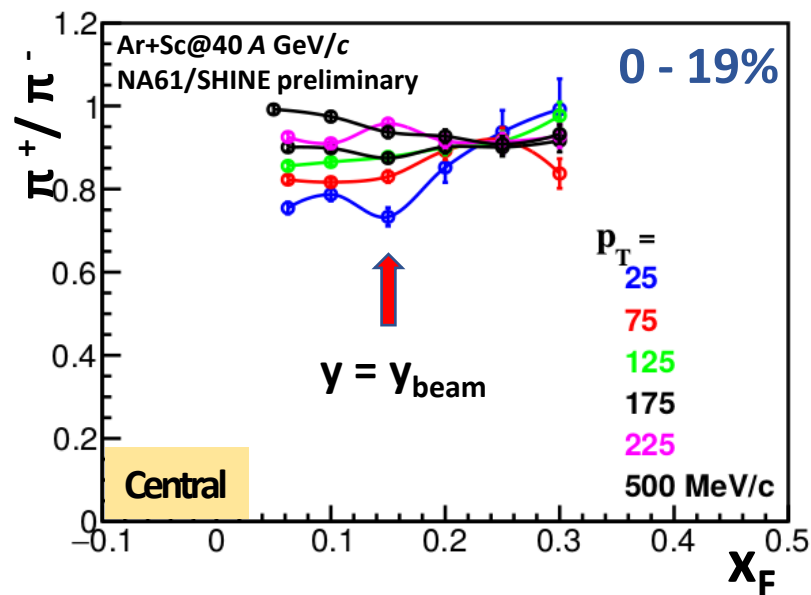


Note: this identification method can be readily used for measuring the  $\pi^+/\pi^-$  ratio (most of the imposed biases **cancel out**, the remaining can be estimated by simple methods).



# 4) Results

# $\pi^+/\pi^-$ ratio at three different centralities:

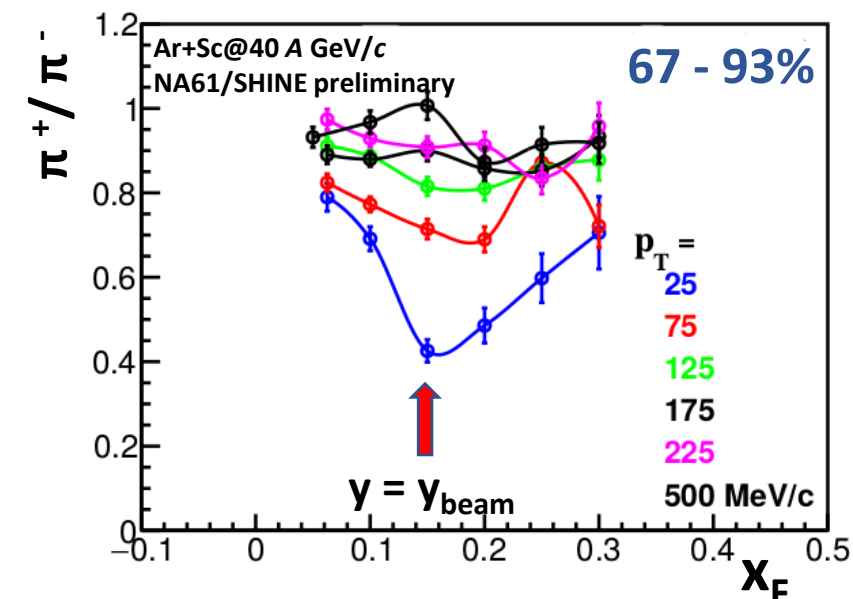
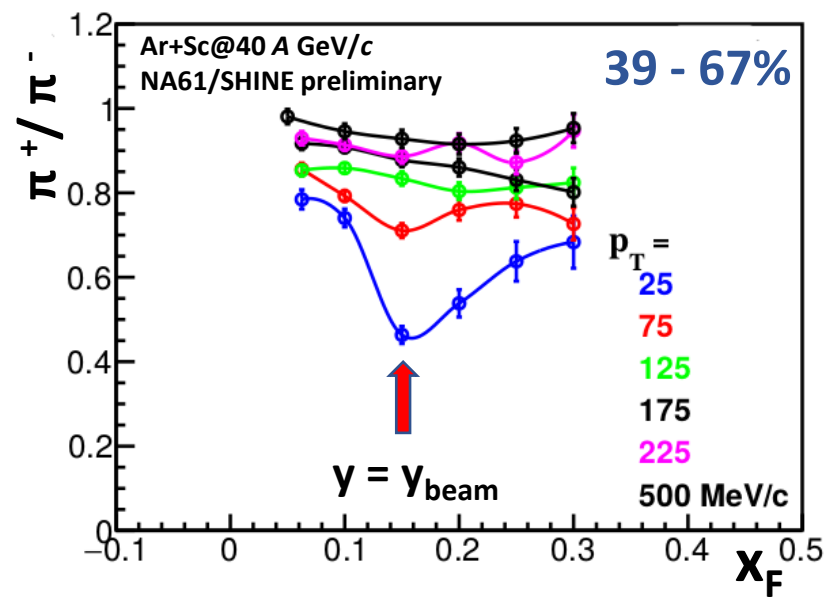
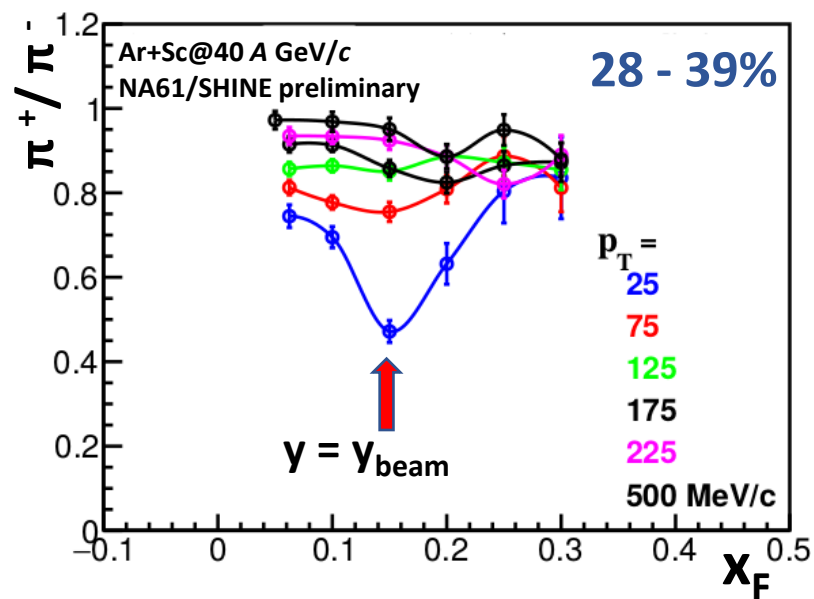
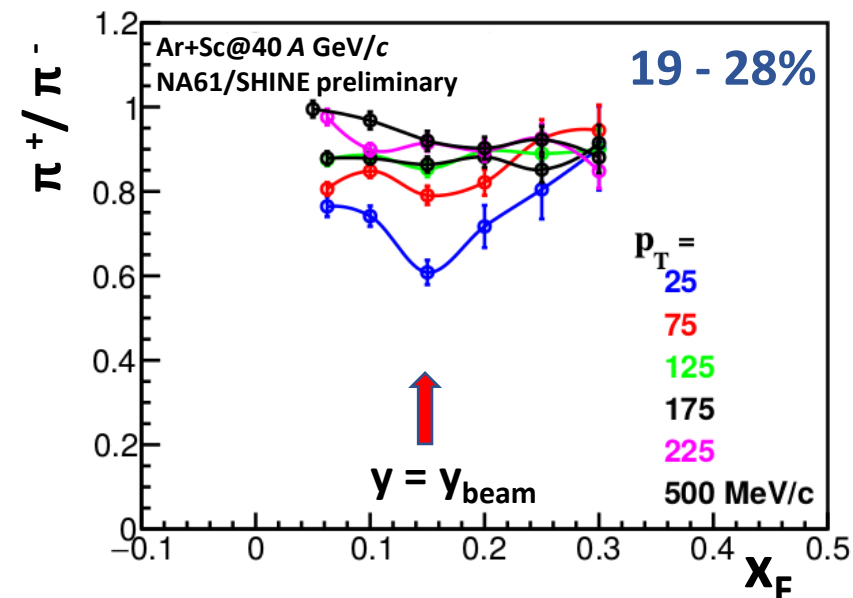
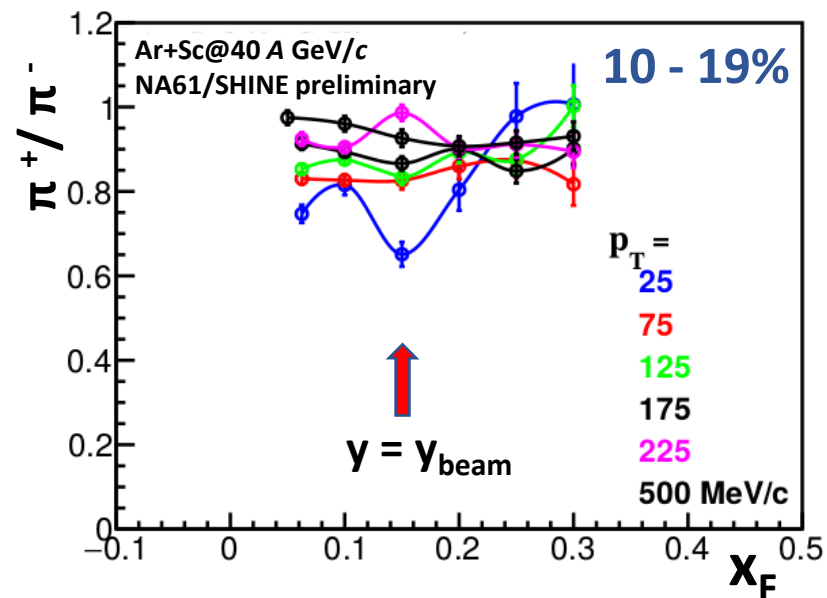
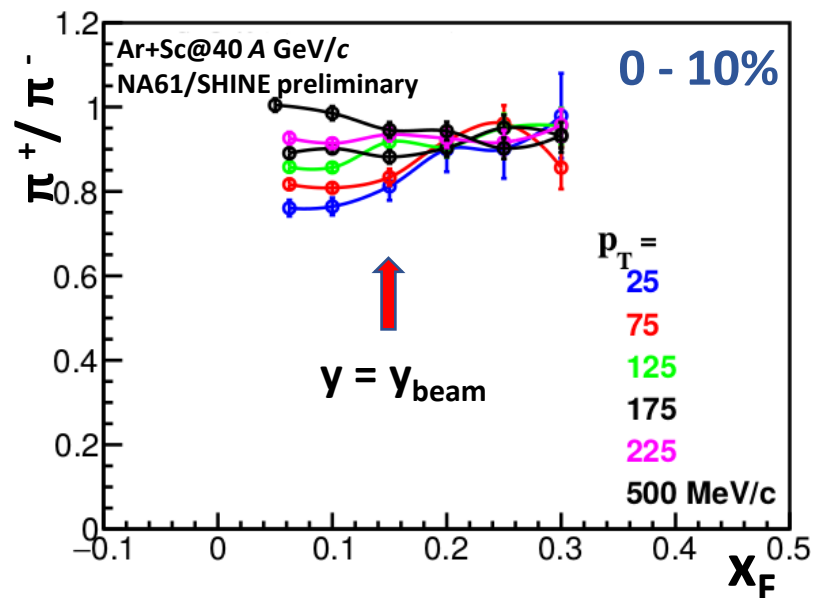


1. Spectator-induced EM effects are present in **small colliding systems**, in spite of small spectator charge (\*);

(\*) peripheral Pb+Pb:  $Q \sim 70$   
Ar+Sc:  $Q$  from 2 to over a dozen.

2. Similar shape as in **Pb+Pb** collisions ;  
3. **Slow decrease** with centrality.

# $\pi^+/\pi^-$ ratio at six different centralities:



## 5) Summary:

1. New data on spectator-induced electromagnetic effects in Ar+Sc collisions at 40 A GeV/c beam momentum ( $\sqrt{s_{NN}} = 8.76 \text{ GeV}$ ) have been presented.
2. First ever data on the full centrality dependence of these effects in small systems at the CERN SPS (and first analysis of peripheral small systems in NA61/SHINE).
3. Spectator-induced EM effects are present in small systems (in spite of the small spectator charge).
4. A very slow centrality dependence is observed (EM effects remain visible for all the studied samples apart from most central collisions).

**Thank you so much!**

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