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

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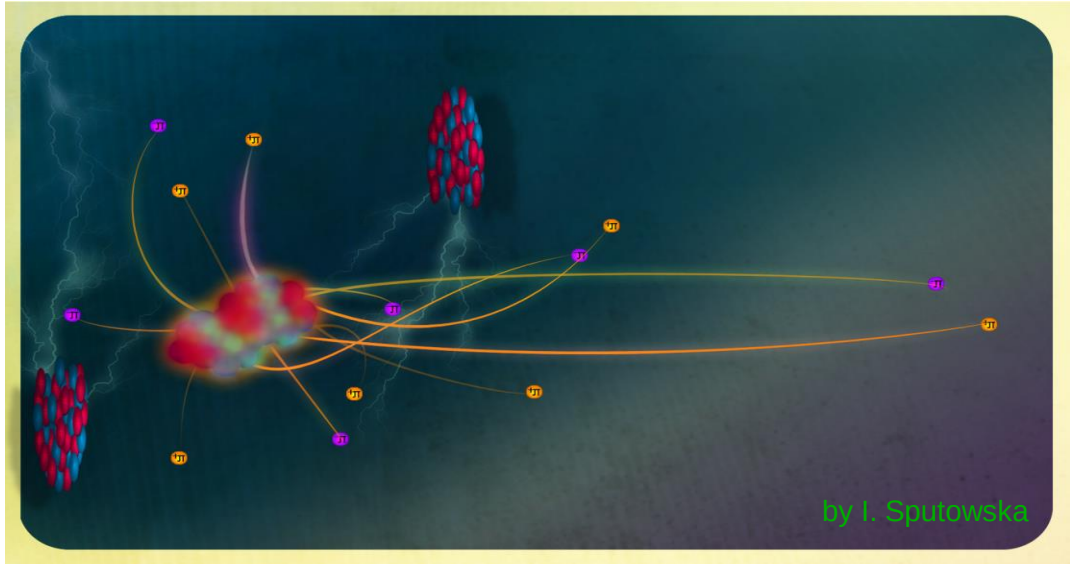
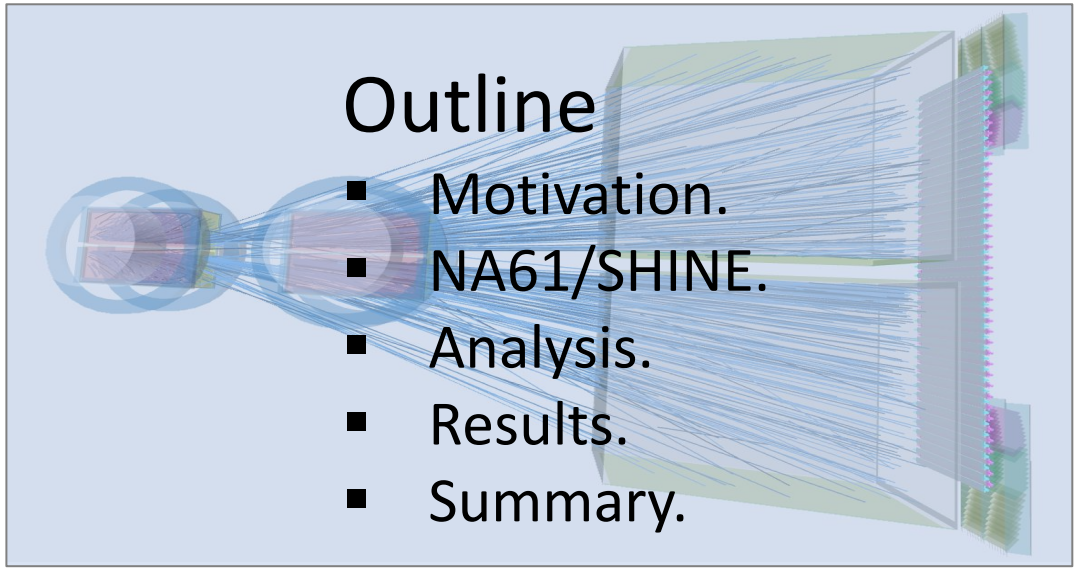
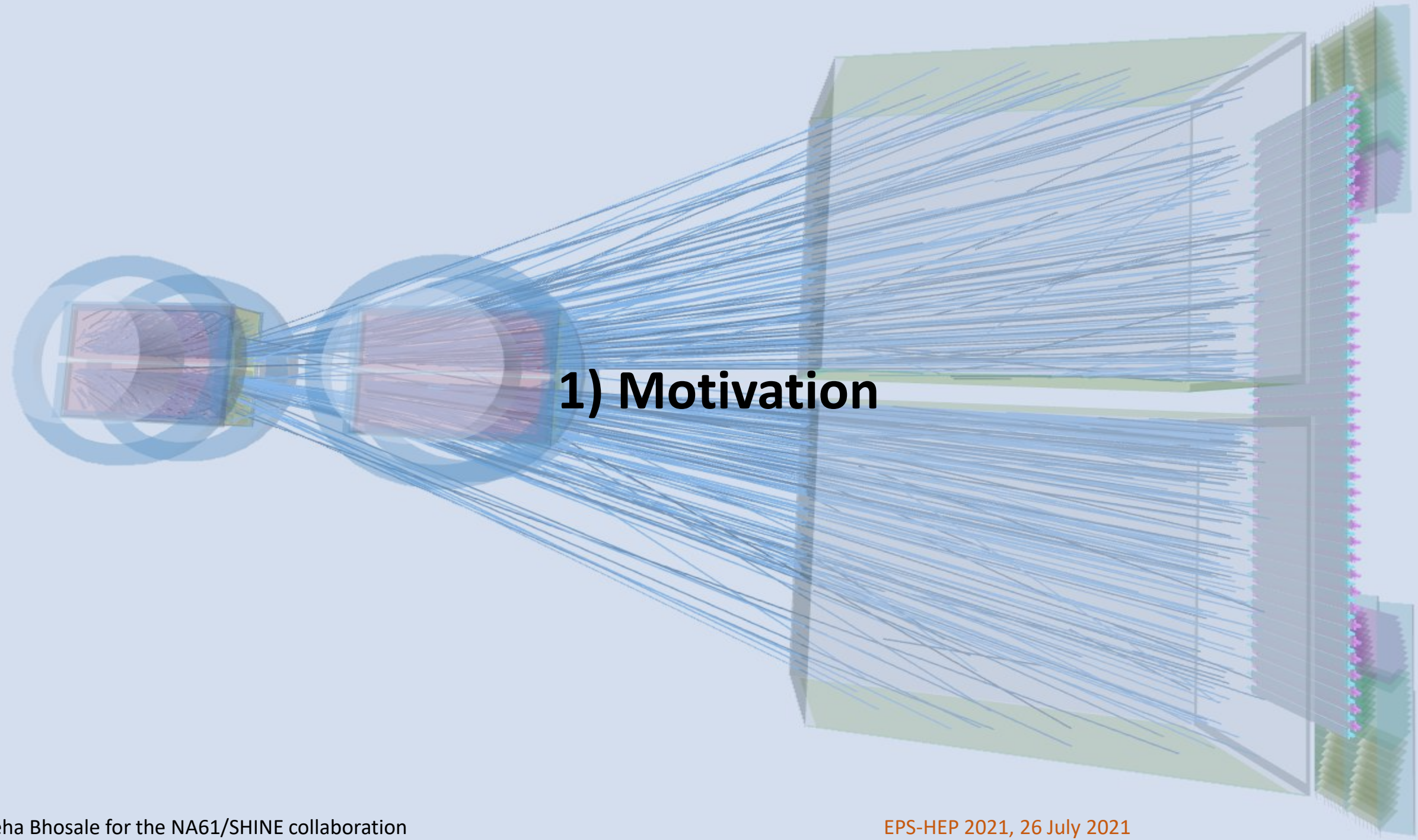




# 1) Motivation

# Spectator-induced electromagnetic (EM) effects:

- Charged spectators generate EM fields, which modify the trajectories of $\pi^+$, $\pi^-$ mesons.

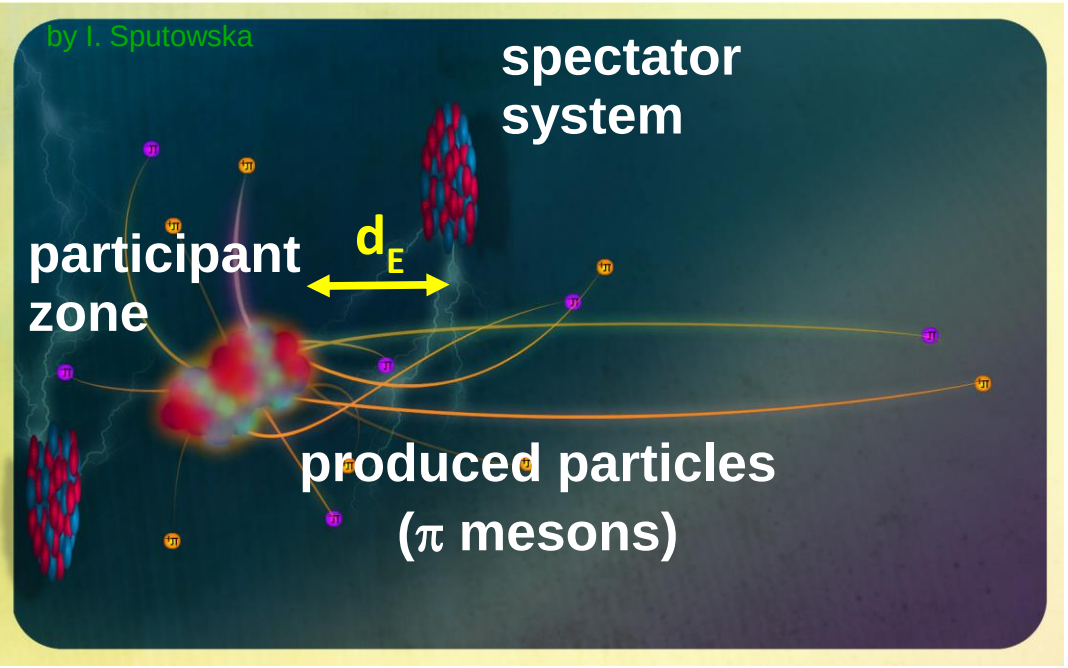
Rybicki, Szczurek,
PRC 75 (2007) 054903
PRC 87 (2013) 054909

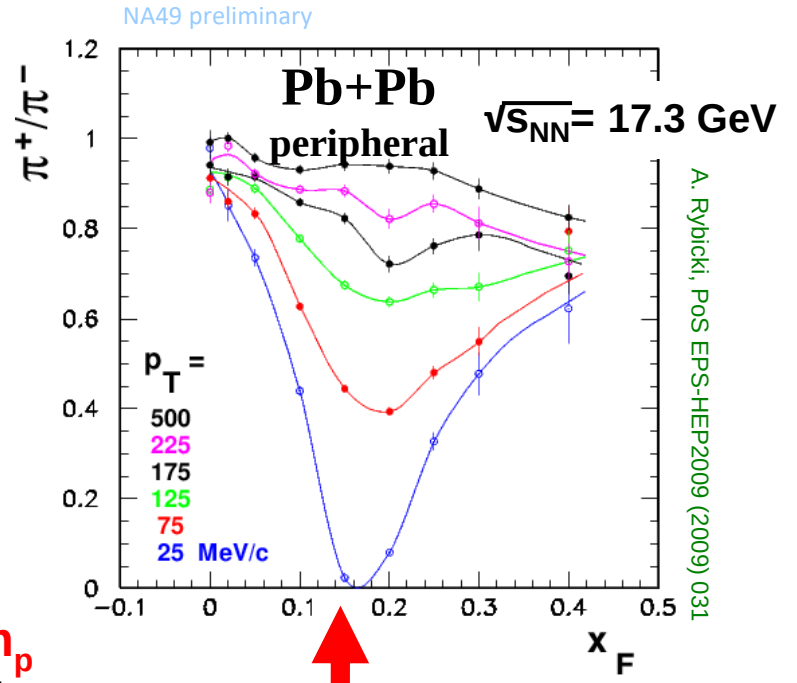
→ they modify the double differential $\pi^+/\pi^-$ ratios, and result in charge splitting of directed flow.

- 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, MESON 2016




Minimum at
$x_F = 0.15 = m_\pi/m_p$
(pions moving at spectator velocity)

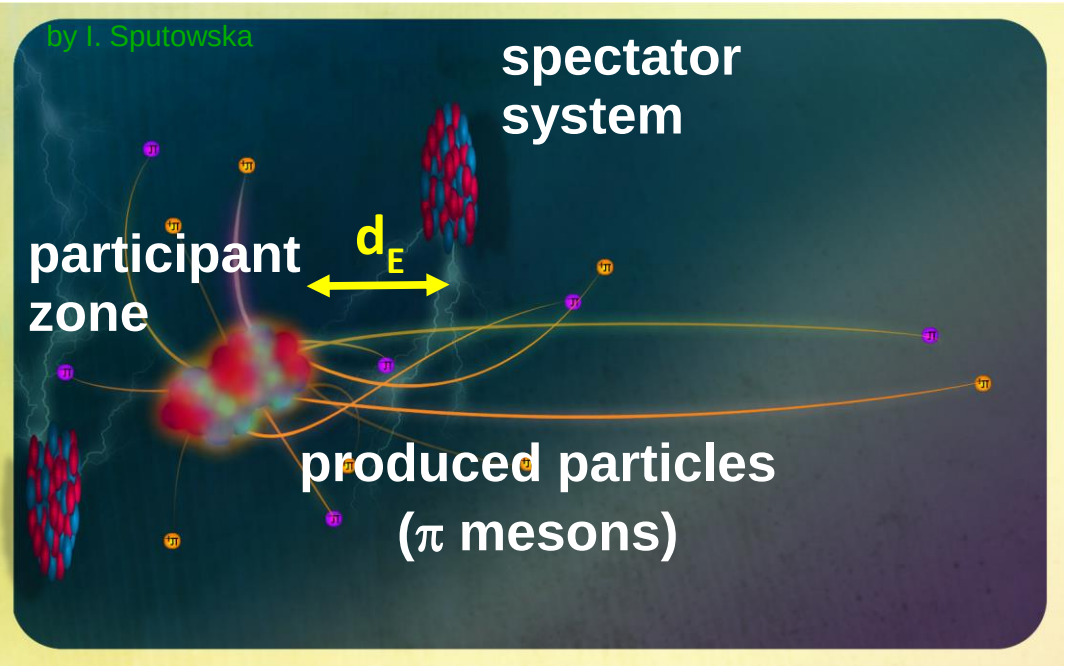
spectator velocity

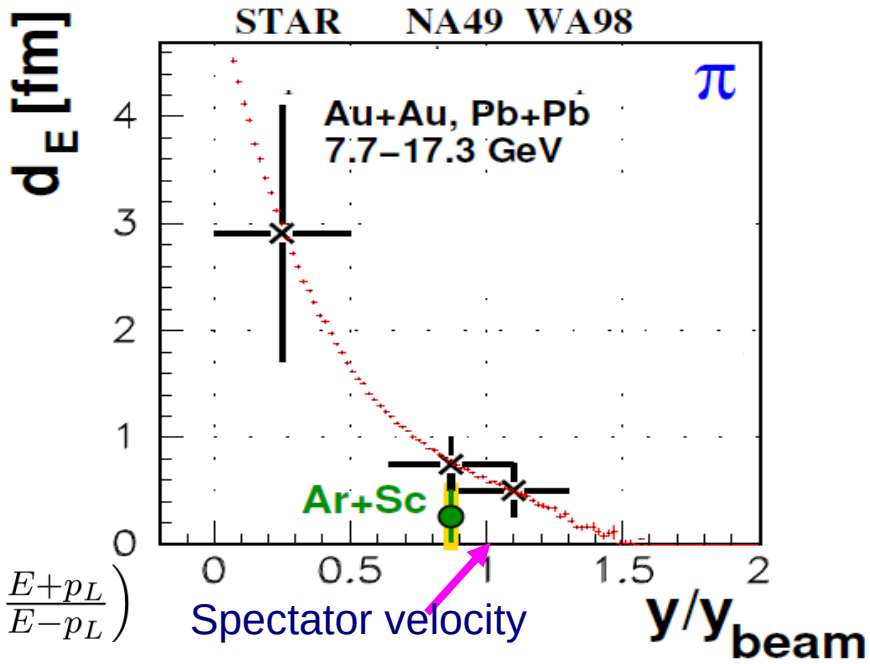
$$x_F = \frac{p_L}{p_L^{beam}}$$ (c.m.s.)

# 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:

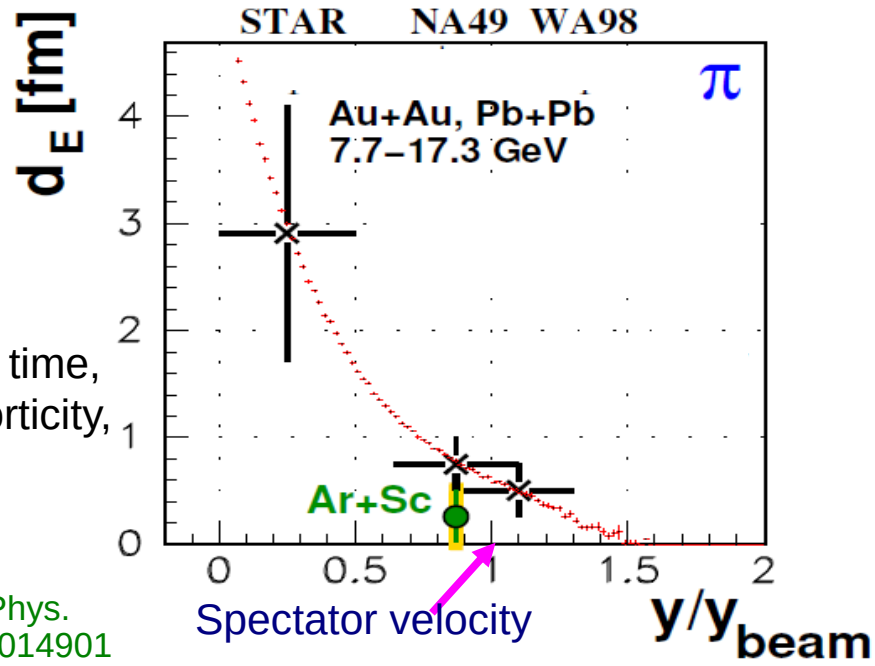
Rybicki, MESON 2016

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

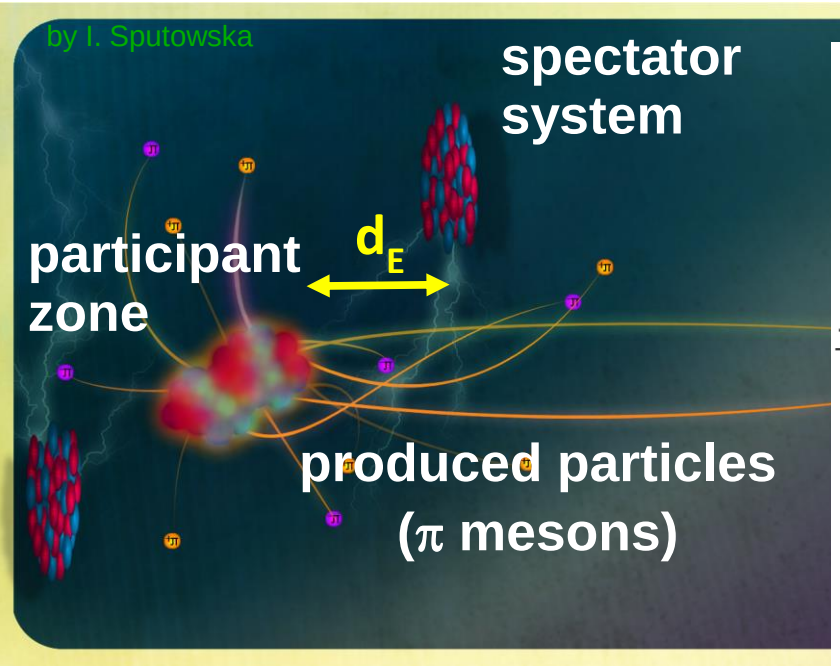
(2) First realistic description of EM distortion of $\pi^+/\pi^-$ ratios.

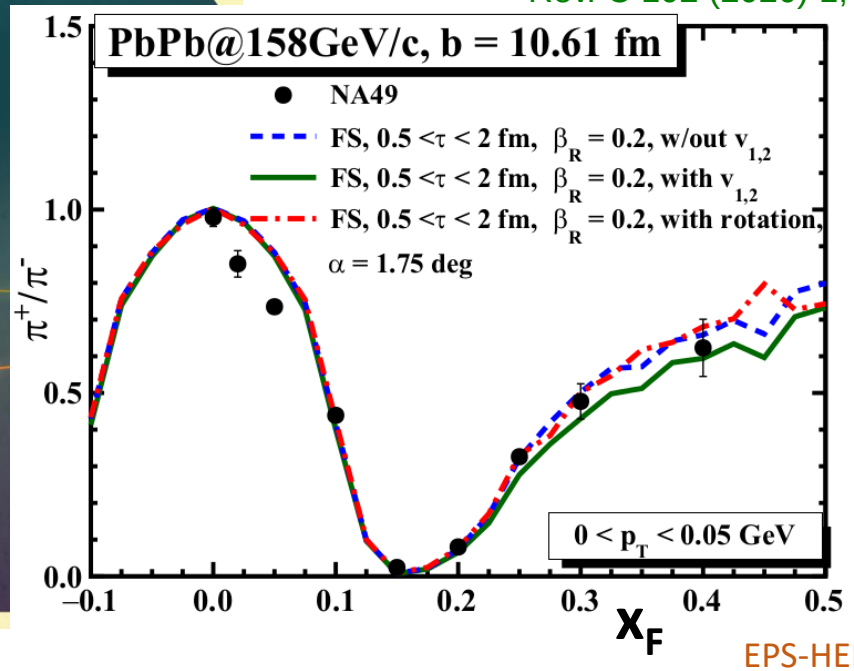
(1) collision geometry (2) longitudinal evolution, (3) $p_T$ spectra, (4) pion creation time, (5) isospin effects, (6) directed and elliptic flow, (7) transverse expansion, (8) vorticity, (9) spectator expansion, (10) relativistic effects on EM field.

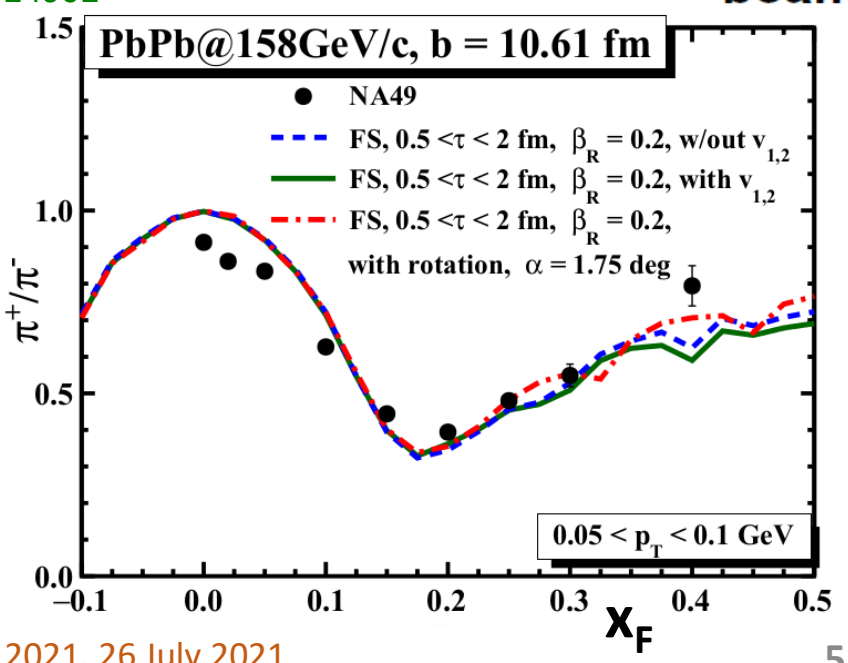
→Information on creation time scales for fast pions.



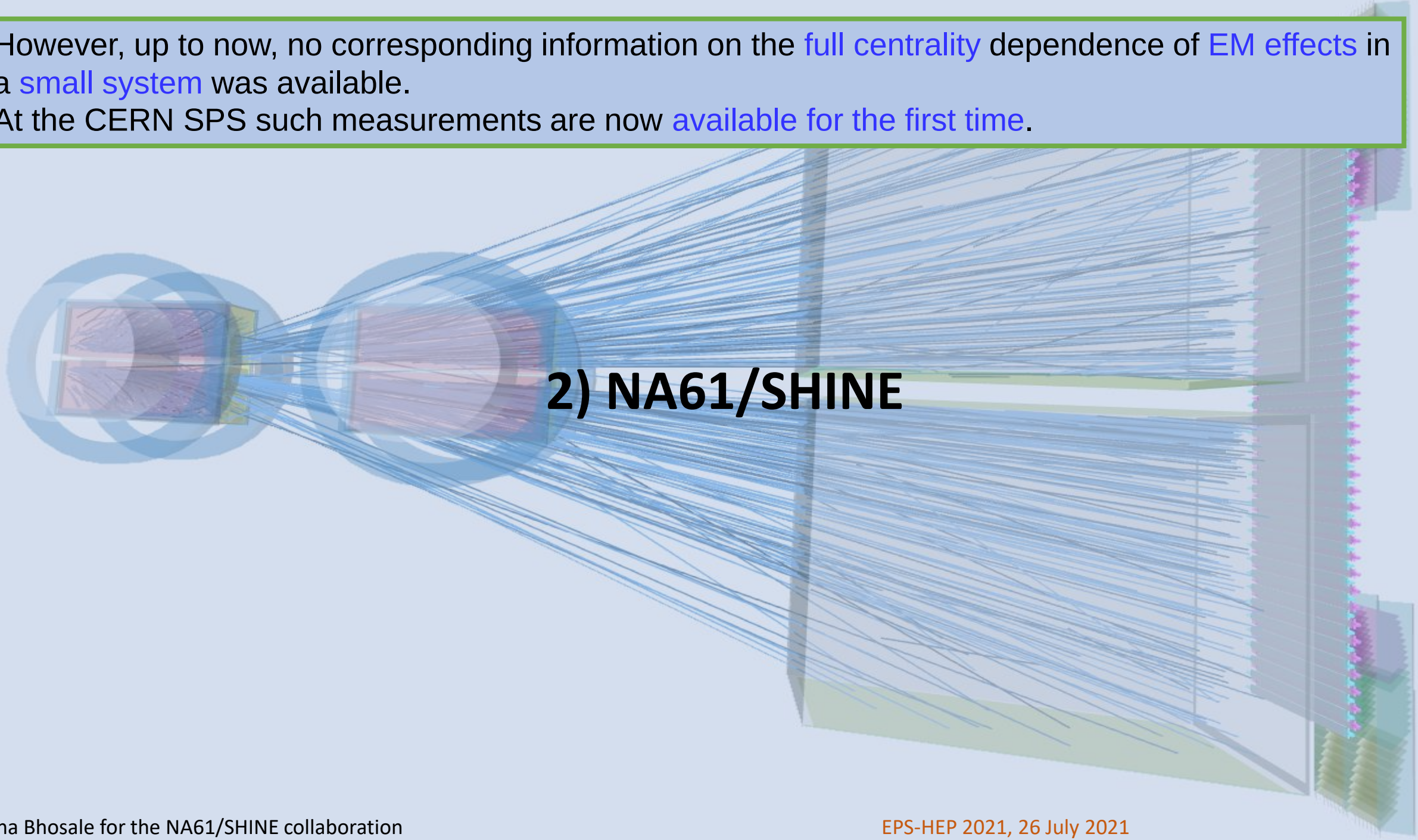

V. Ozvenchuk et al., Phys. Rev. C 102 (2020) 1, 014901



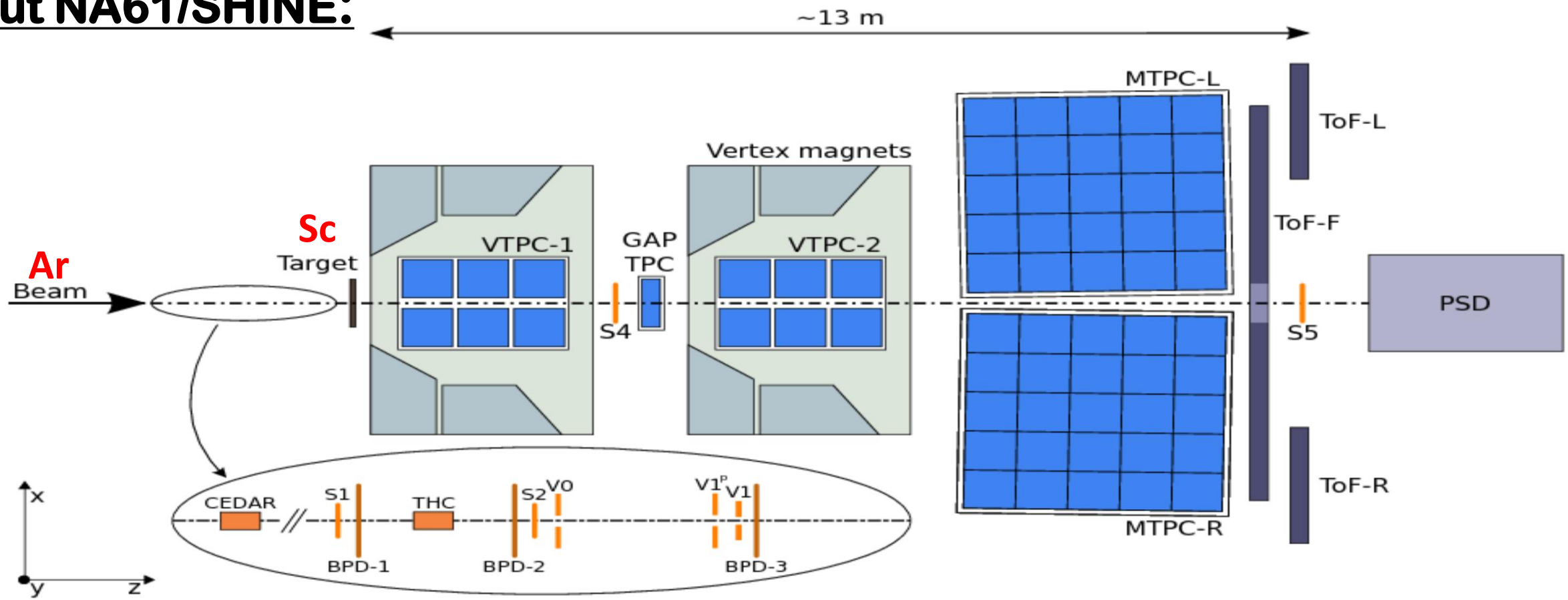



However, up to now, no corresponding information on the full centrality dependence of EM effects in a small system was available.
At the CERN SPS such measurements are now available for the first time.

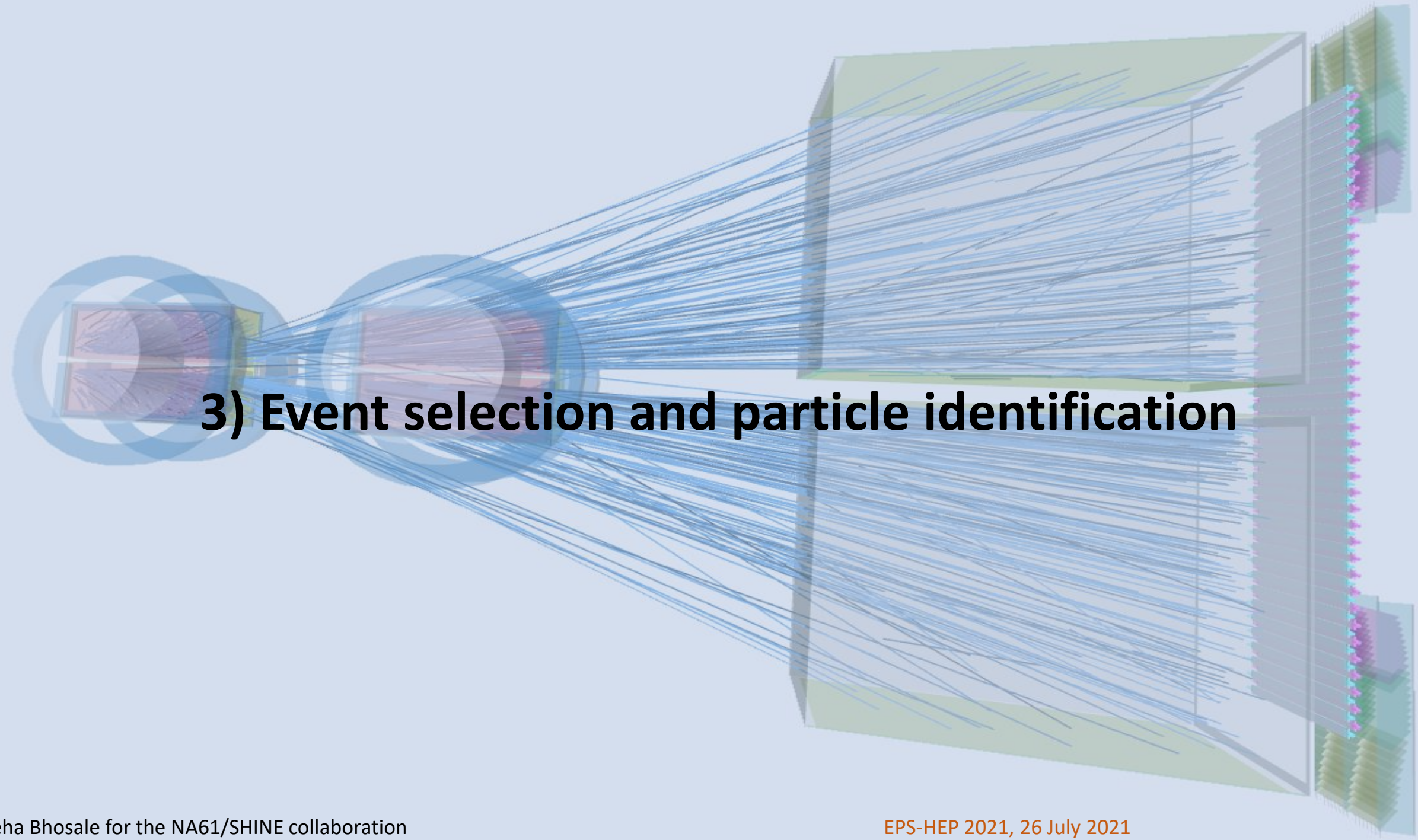


# 2) NA61/SHINE

# About NA61/SHINE:

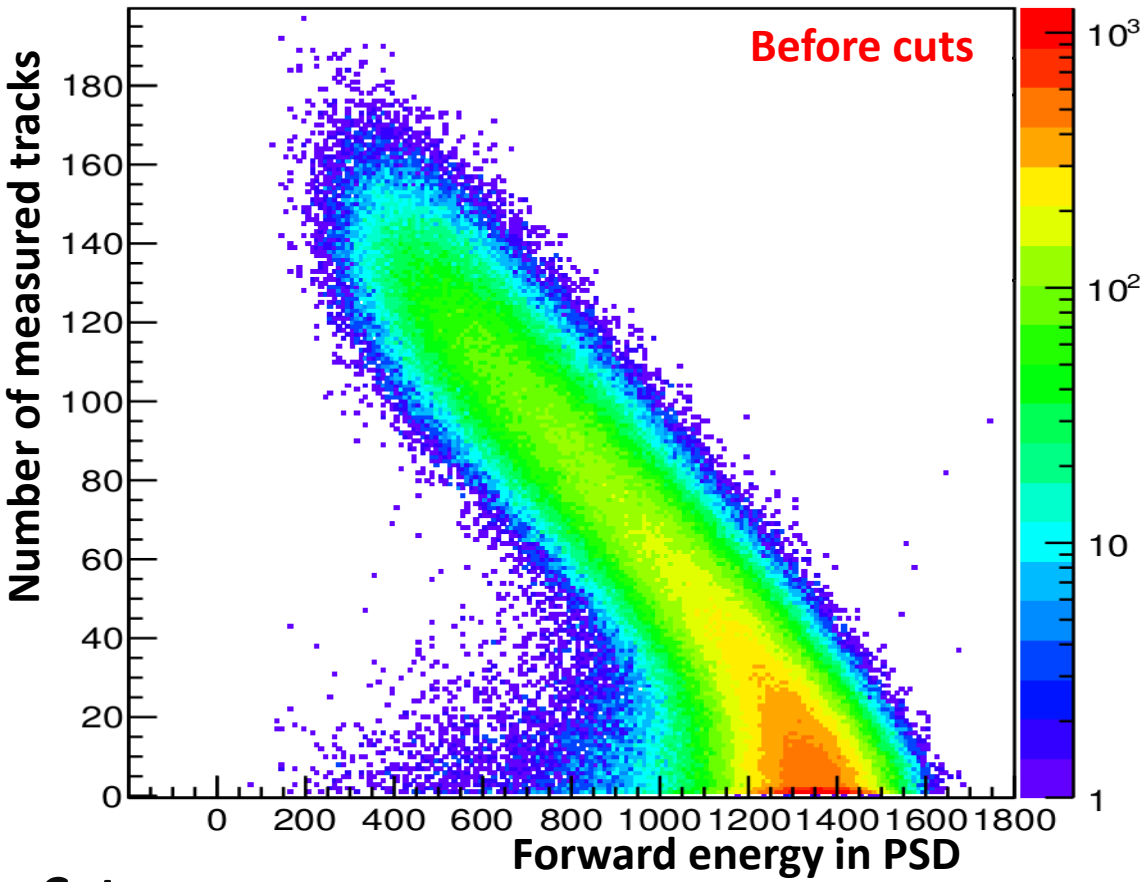


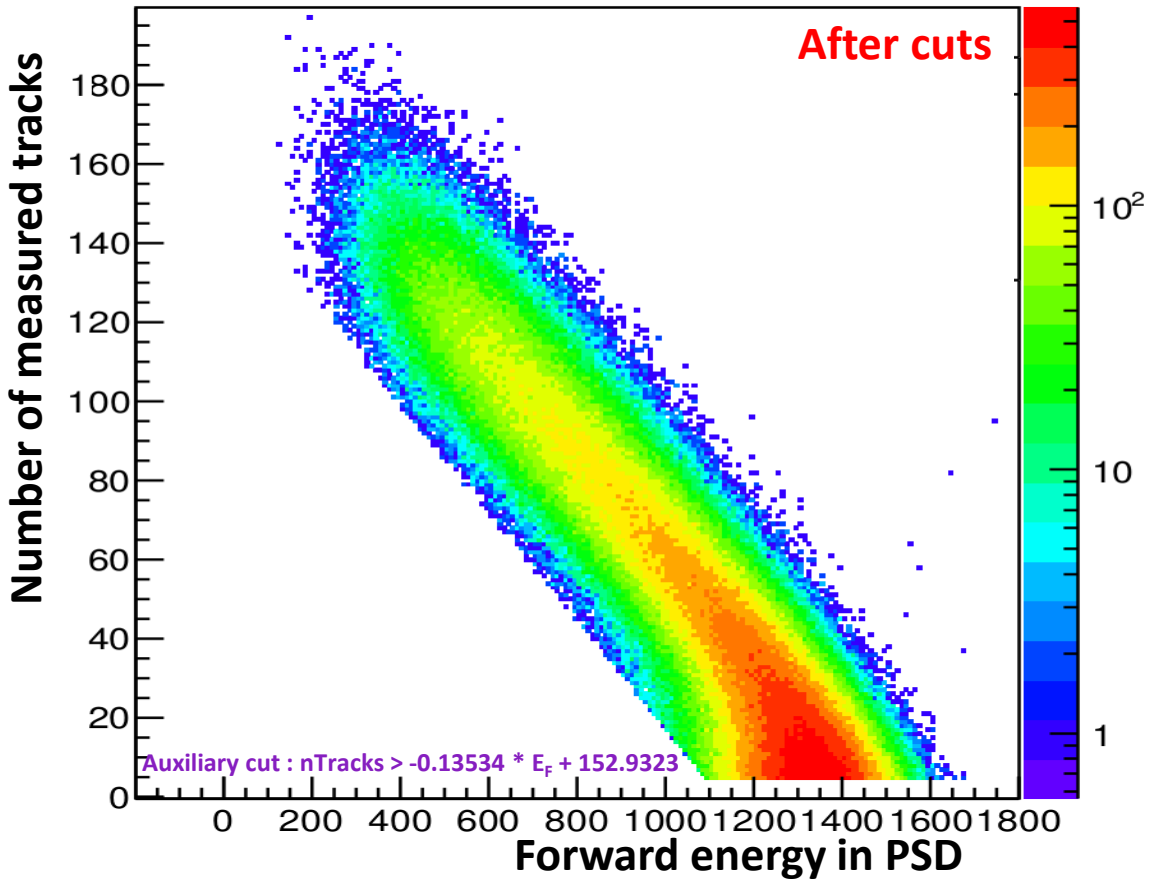

- VTPC-1, VTPC-2 and GTPC are placed in the magnetic field.
- TPC system: track reconstruction and particle identification based on specific energy loss.
- Projectile Spectator Detector (PSD): hadronic calorimeter, measures projectile spectators energy.



# 3) Event selection and particle identification

# Event selection:



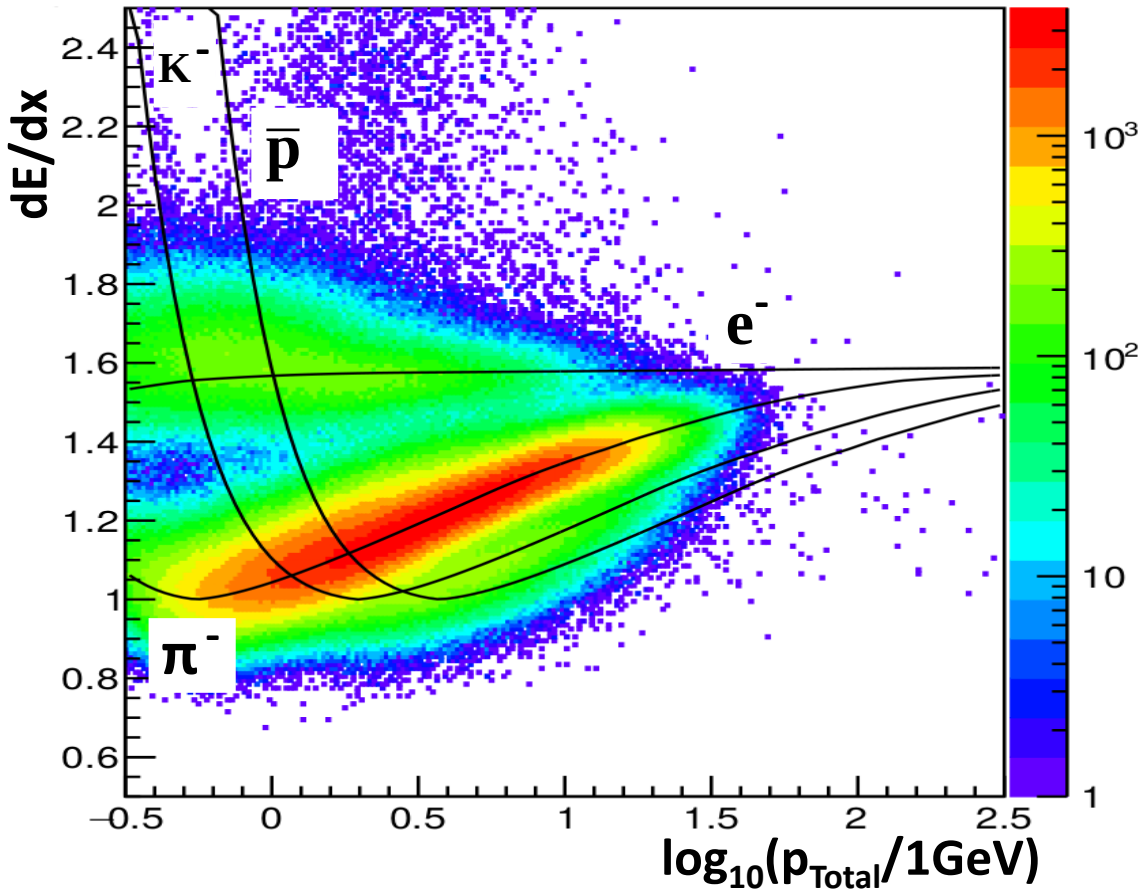

**Cuts:**

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%.

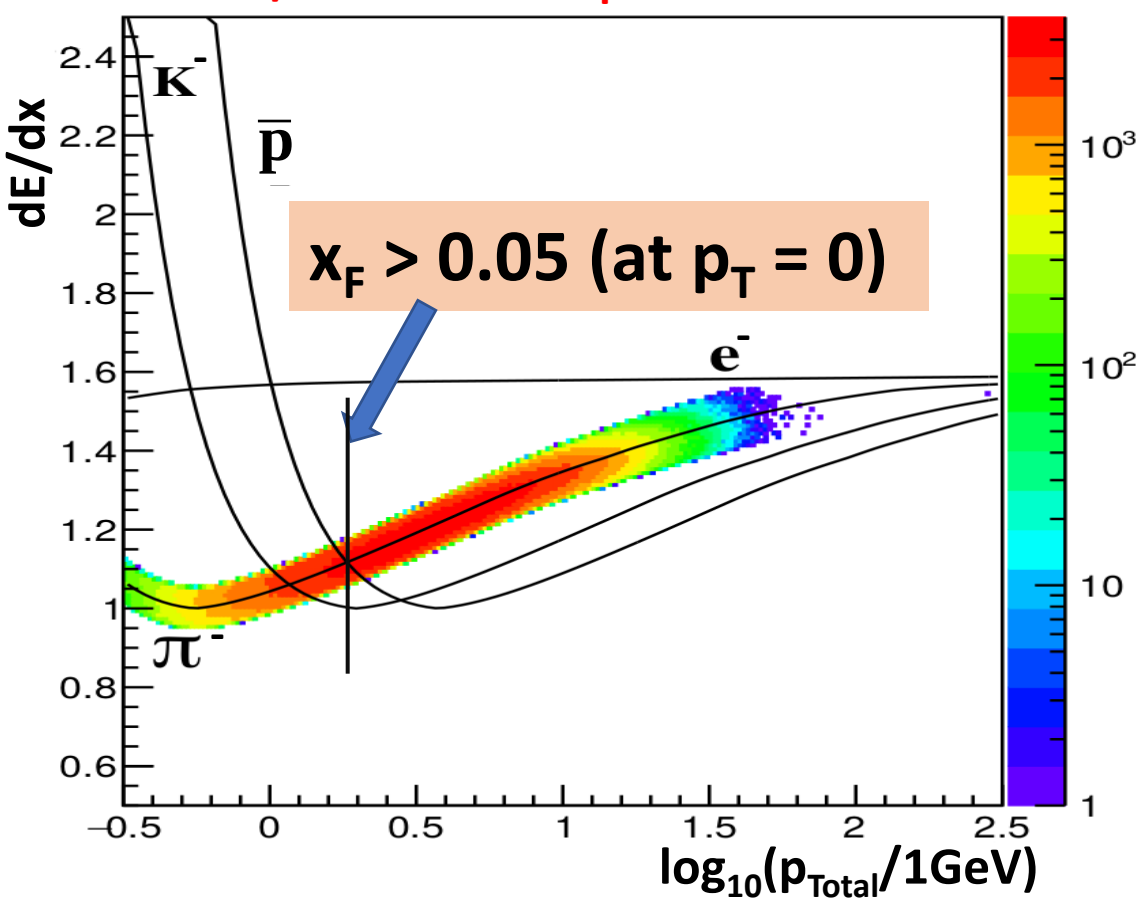
**The event selection is procedure is not the NA61/SHINE default one and is used only for this analysis.

# Particle Identification:

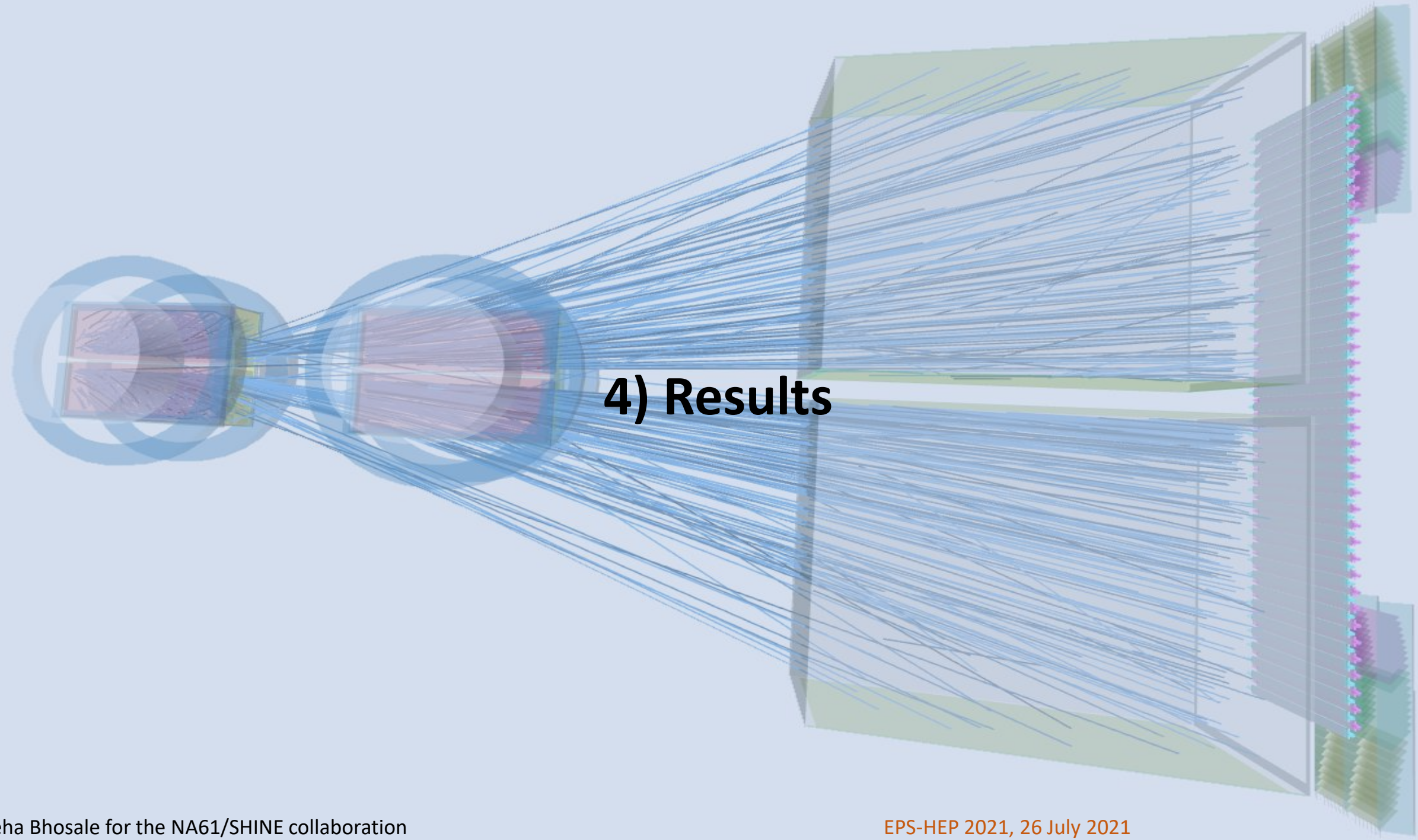
(Note: the case of *negative* particles is shown)




dE/dx ±5% around pion Bethe-Bloch

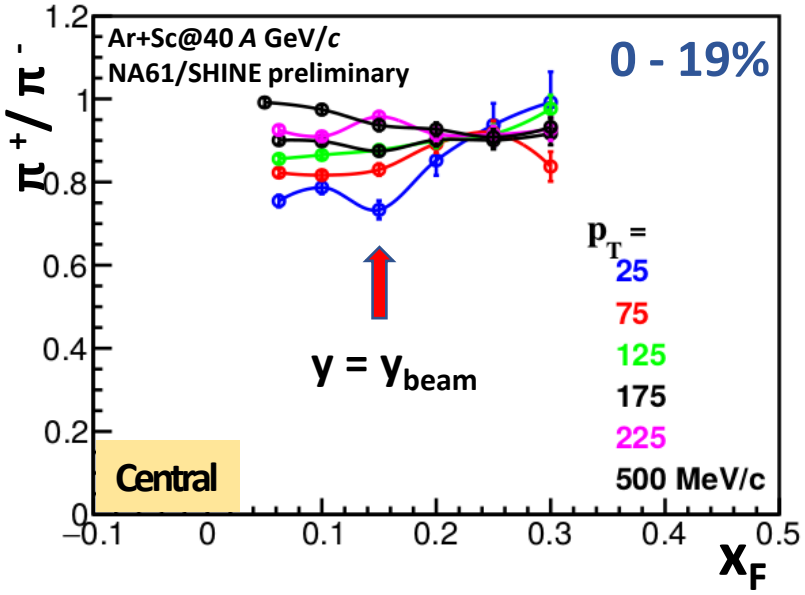


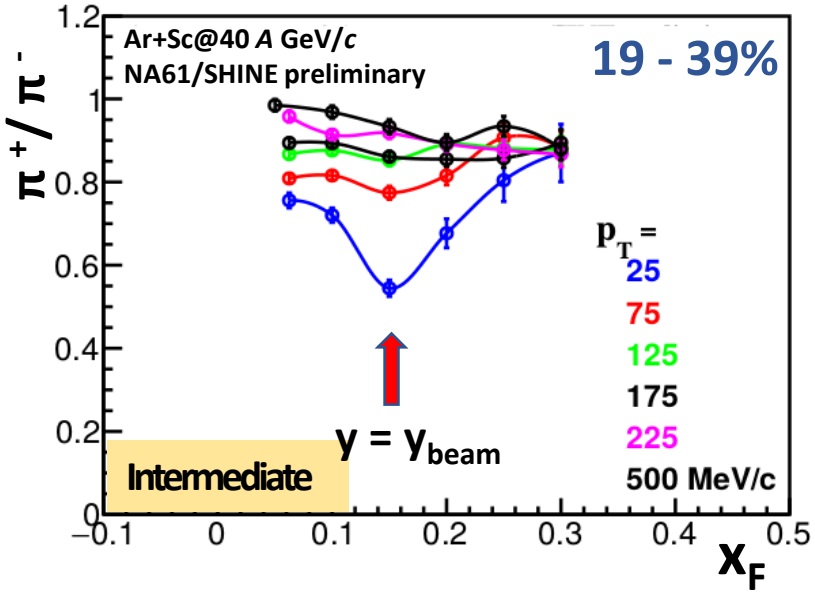

Note: this identification method can be readily used for measuring the $\pi^+/\pi^-$ ratio
(most of the imposed biases cancel out, the remaining can be estimated by simple methods).

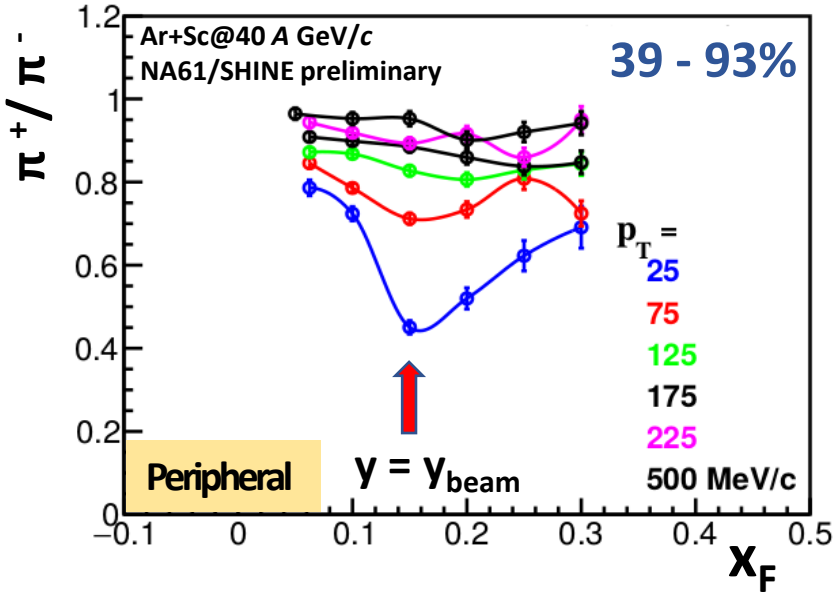


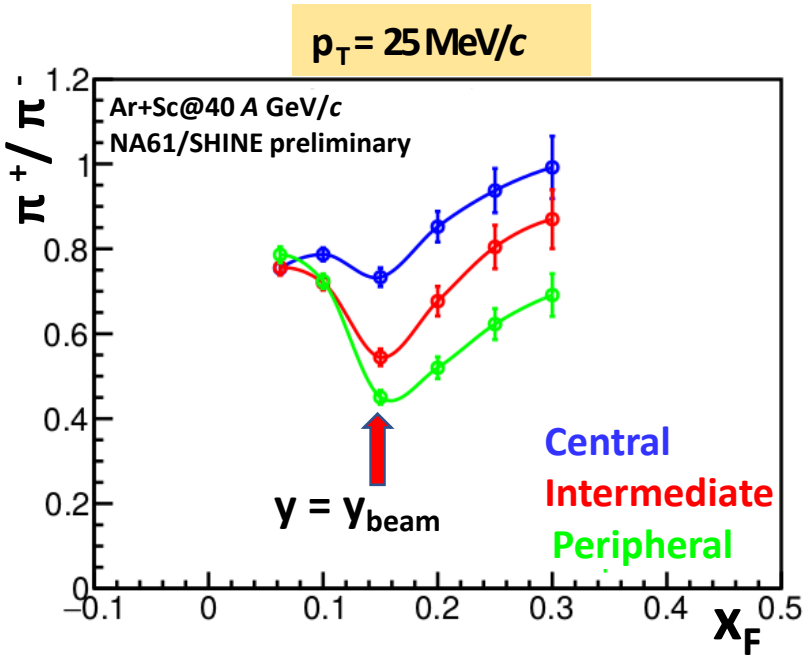
# 4) Results

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



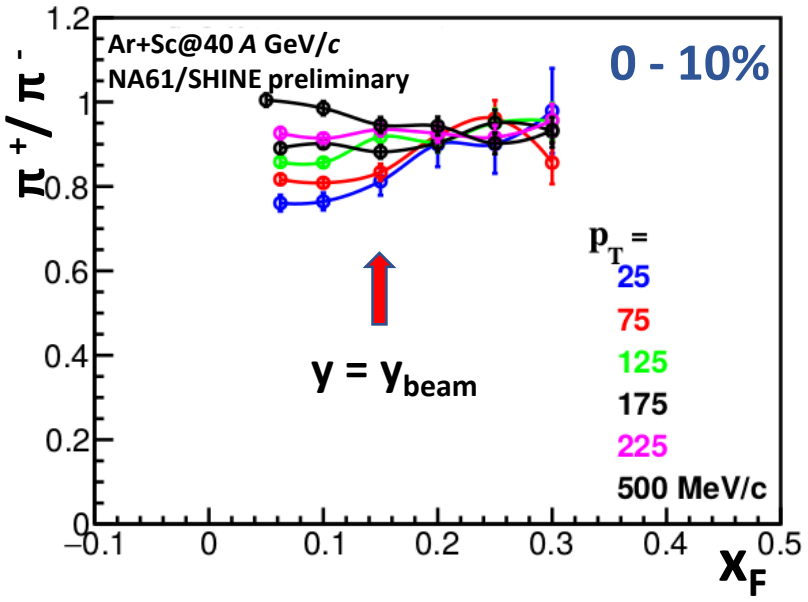



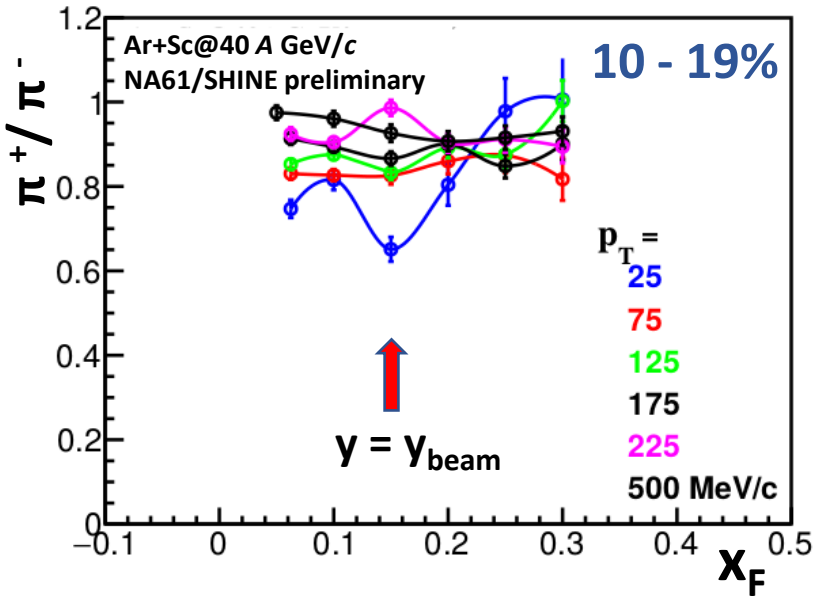

1. Spectator-induced EM effects are present in small colliding systems, in spite of small spectator charge (*) ;

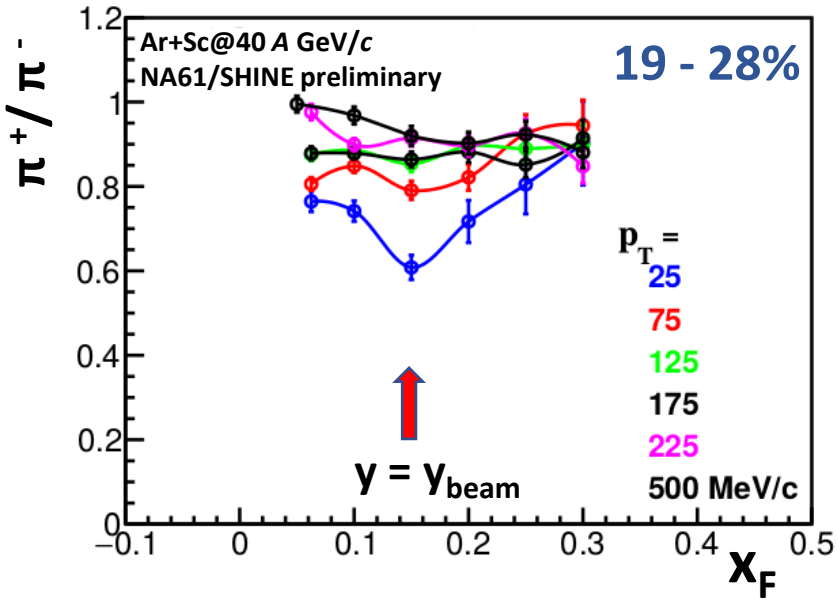
(*) peripheral Pb+Pb: Q ~70
Ar+Sc: Q from 2 to over a dozen.

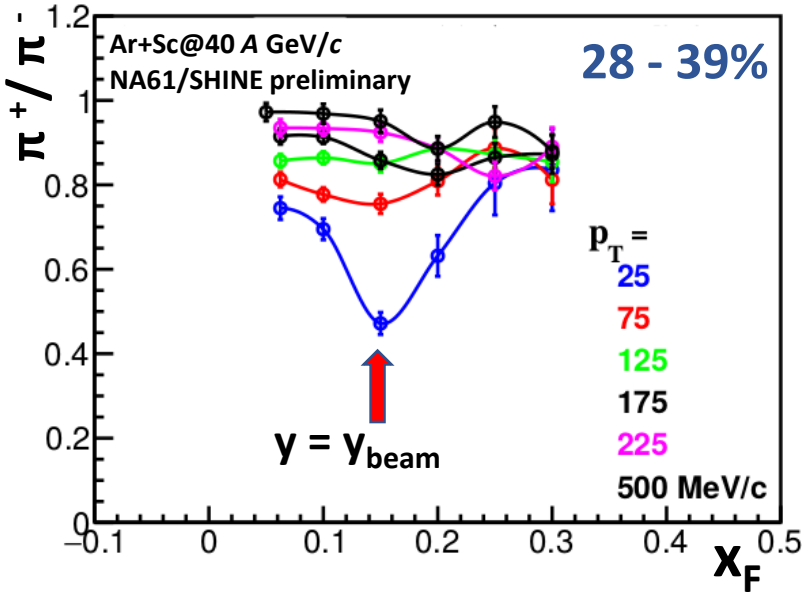
2. Similar shape as in Pb+Pb collisions ;
3. Slow decrease with centrality.

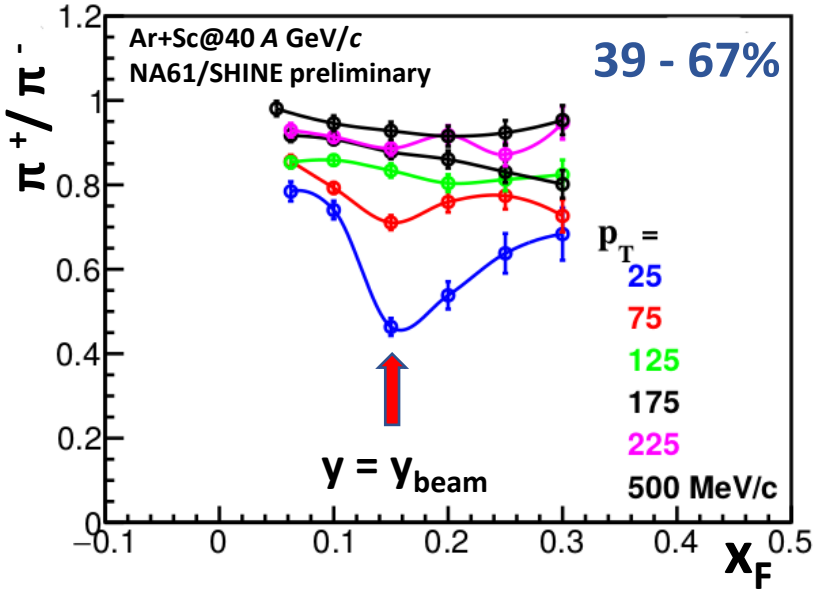
# $\pi^+/\pi^-$ ratio at six different centralities:

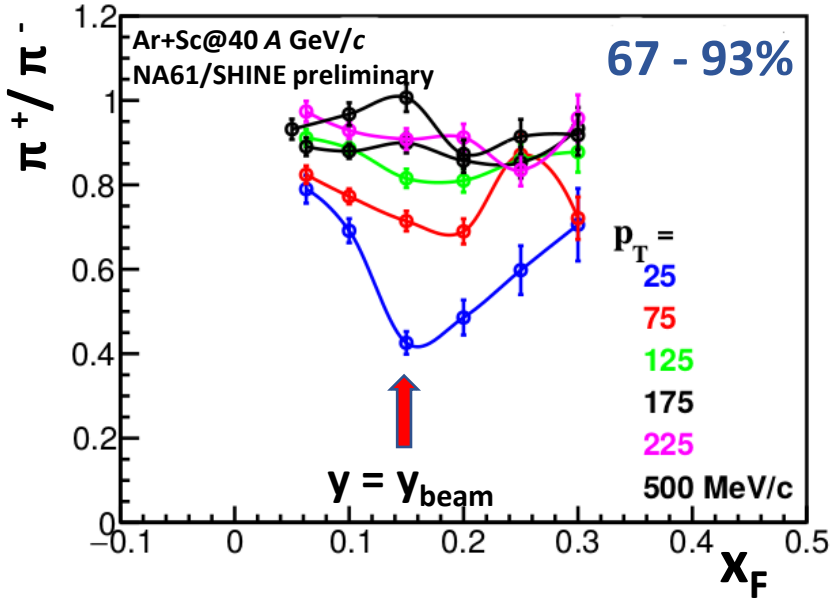


# 5) Summary:

1. New data on spectator-induced electromagnetic effects in Ar+Sc collisions at 40 A GeV/c beam momentum ( $\sqrt{s_{NN}} = 8.76$ 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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