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

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in collaboration with
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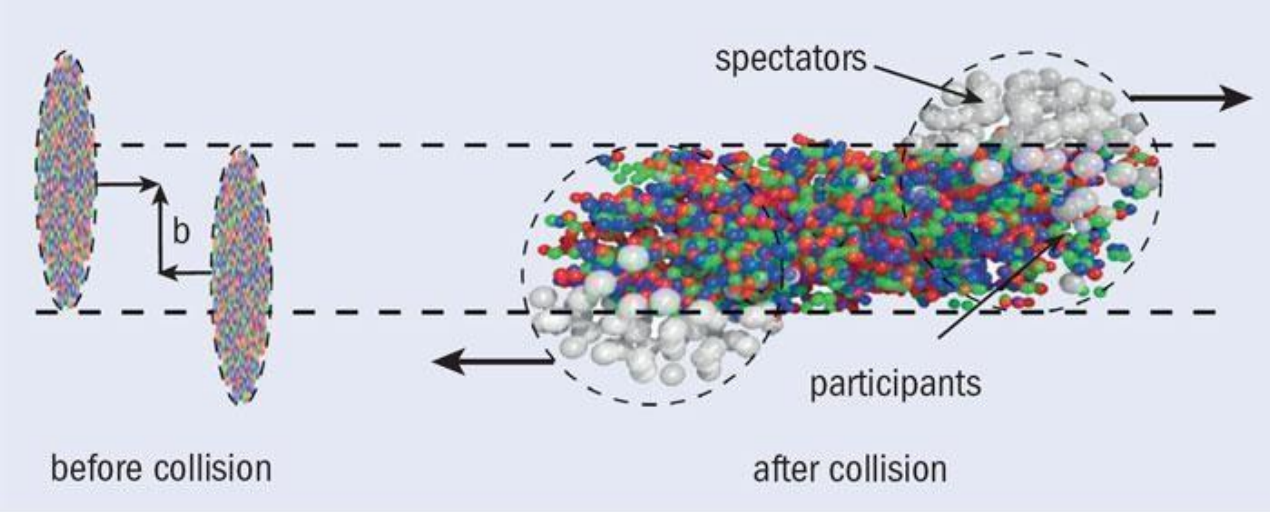


Outline

- Introduction/Motivation.
- About SHINE.
- Used data set and cuts.
- Results for π^+/π^- ratios.
- Correlations and fluctuations study.
- Summary.

1) Introduction/Motivation

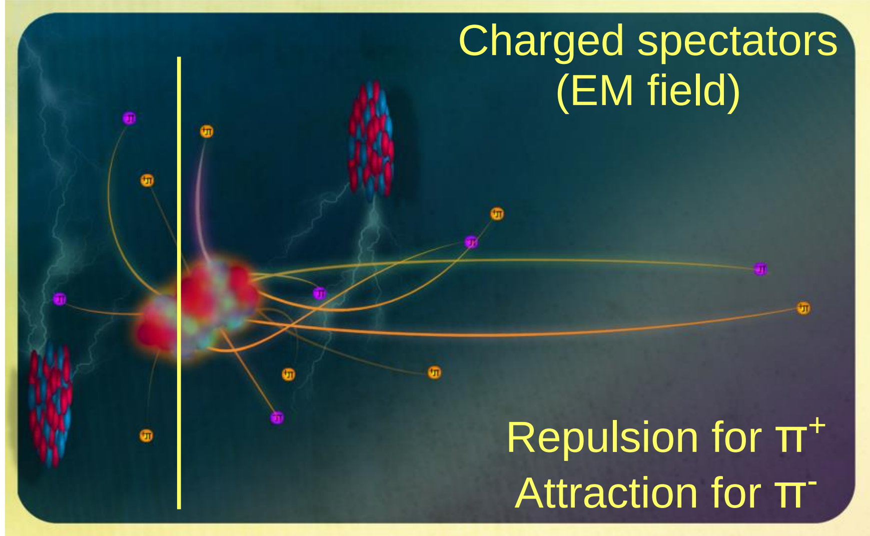
Electromagnetic effects – introduction/reminder:

- EM effects influence the emission of π mesons, namely modify the ratio of π^+/π^-.
- Dependence on p_T.
- Brings information on space-time evolution of system.

A.Rybicki and A.Szczurek Phys. Rev. C75, 054903 (2007)

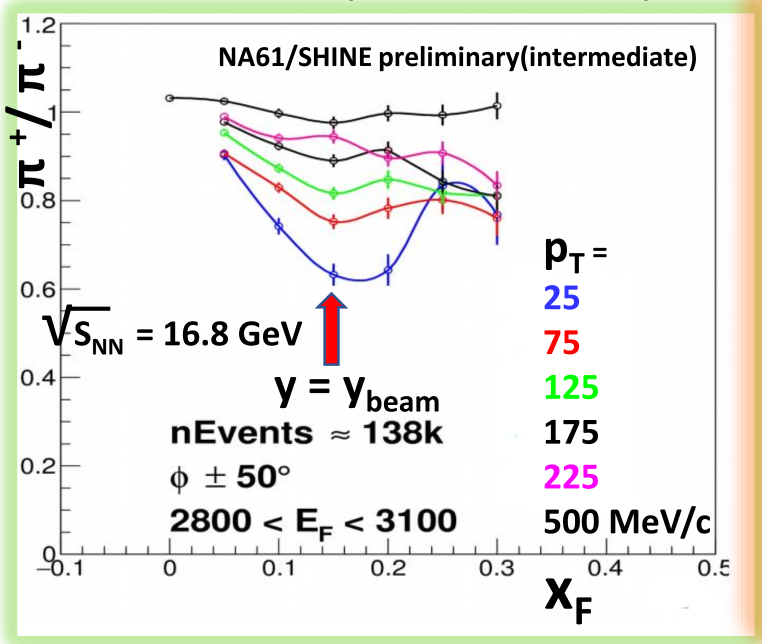
$$x_F = \frac{p_L}{p_L^{BEAM\ NUCLEON}}$$ c.m.s. frame

Plot by I. Sputowska

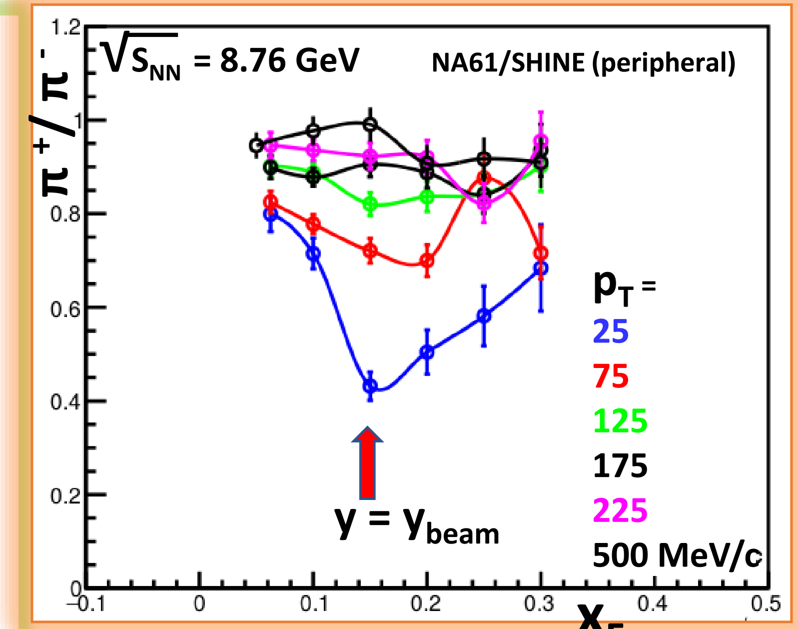


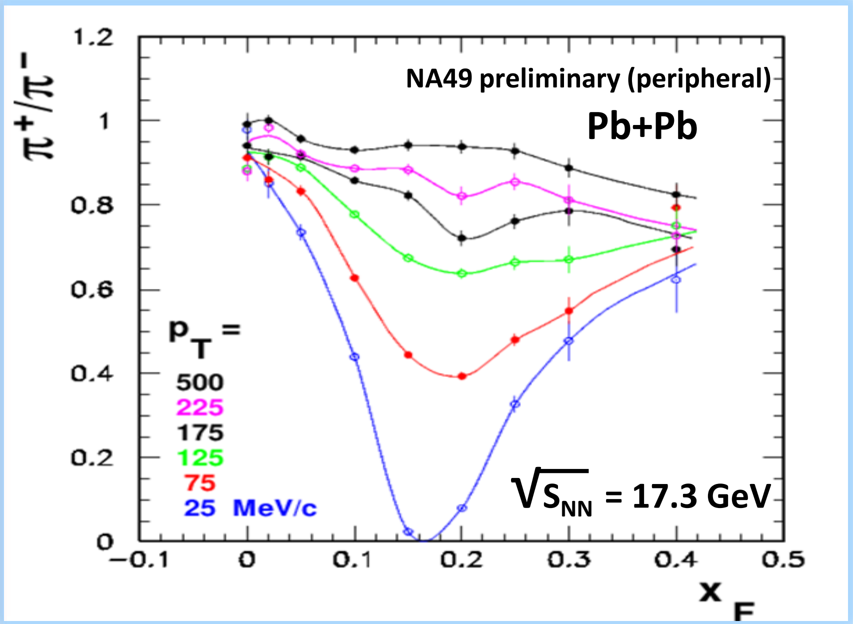
A. Rybicki, Acta Phys. Polon. B42, 867 (2011)

Ar+Sc @150 (Plot by M. Kiełbowicz)

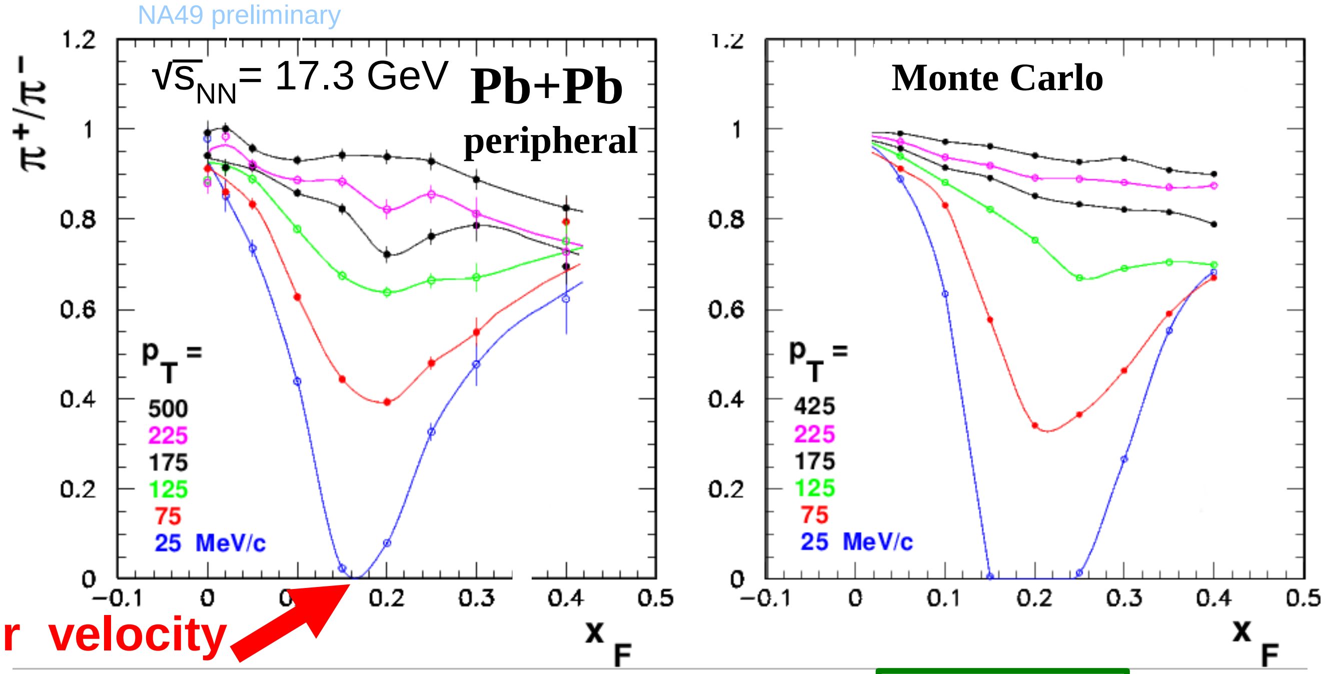


Ar+Sc @40 (my results)



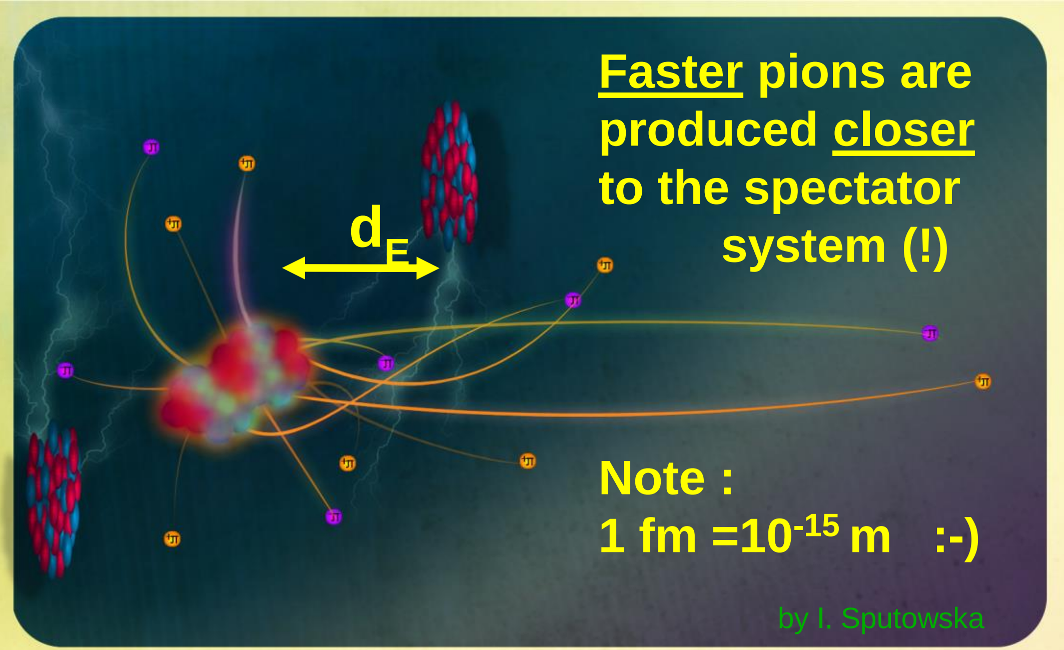


Electromagnetic effects – introduction/reminder:

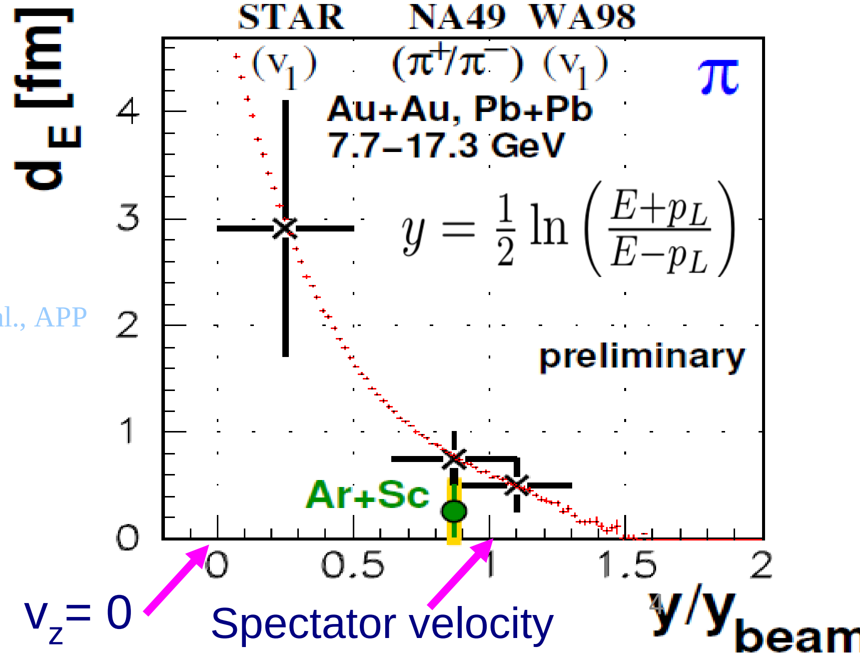


spectator velocity

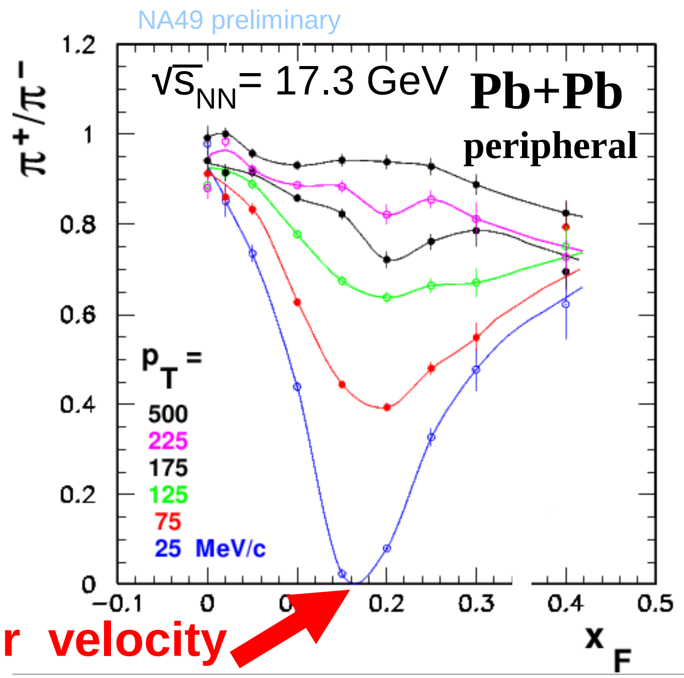
$$x_F = \frac{p_L}{p_L^{beam}}$$ (c.m.s.)

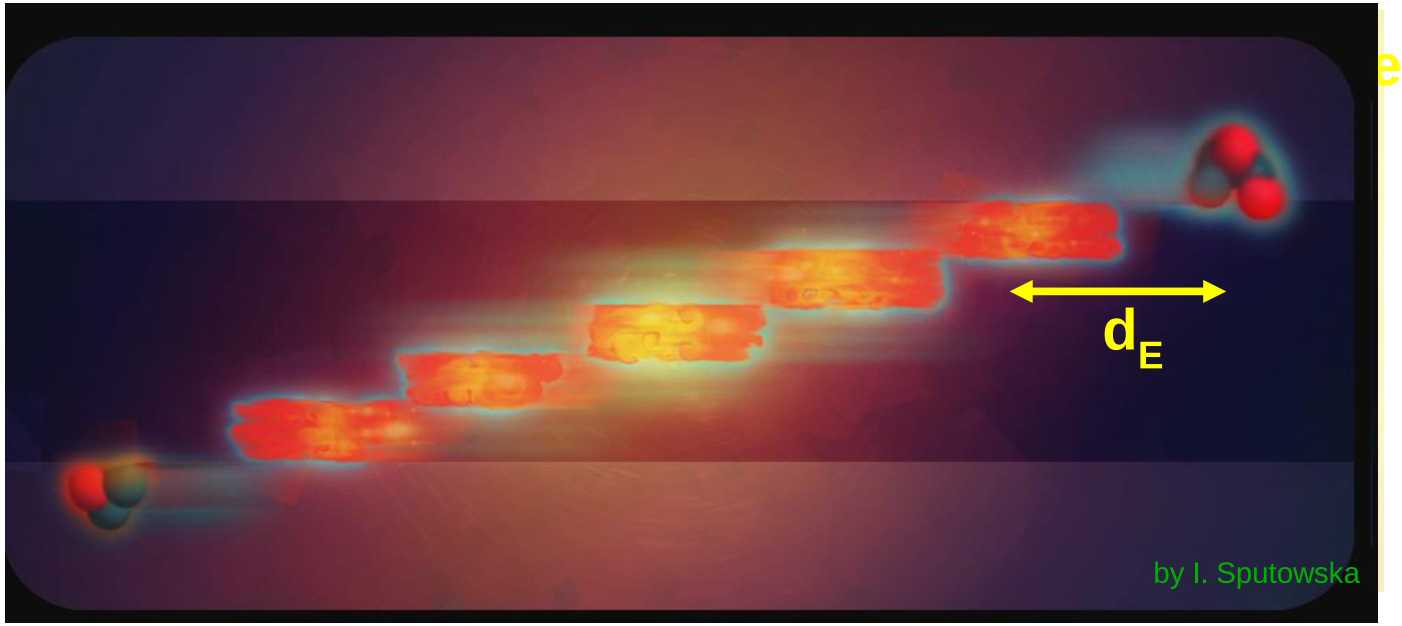


See also: A. R., A. Szczurek et al., APP Supp. 9 (2016) 303

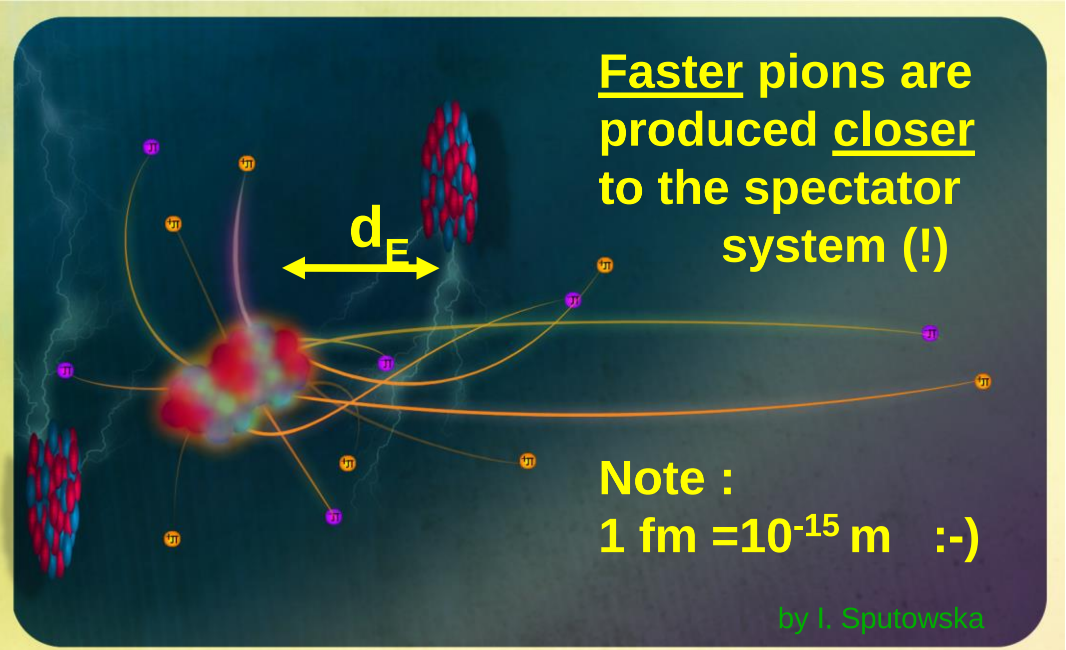


Electromagnetic effects – introduction/reminder:

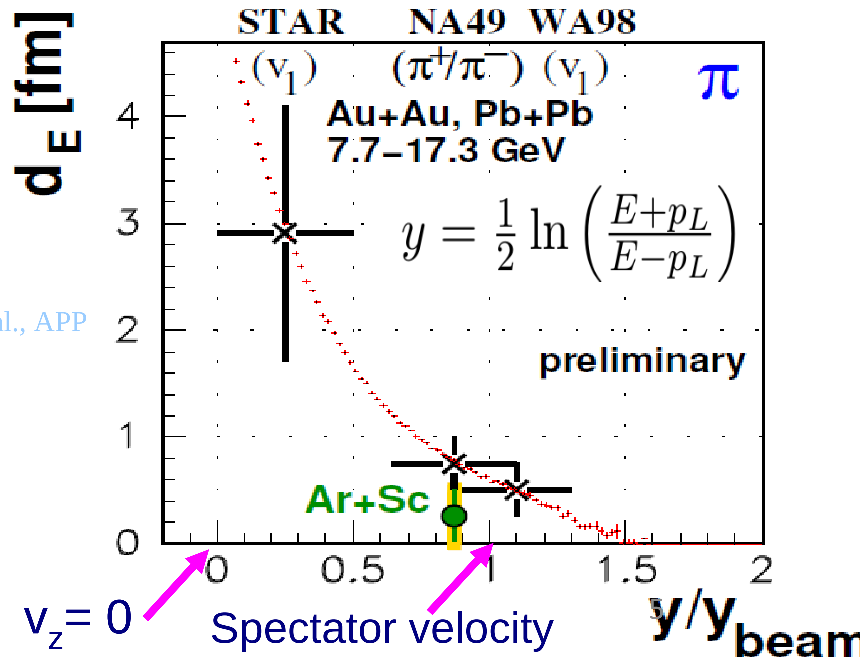




$$x_F = \frac{p_L}{p_L^{beam}}$$ (c.m.s.)

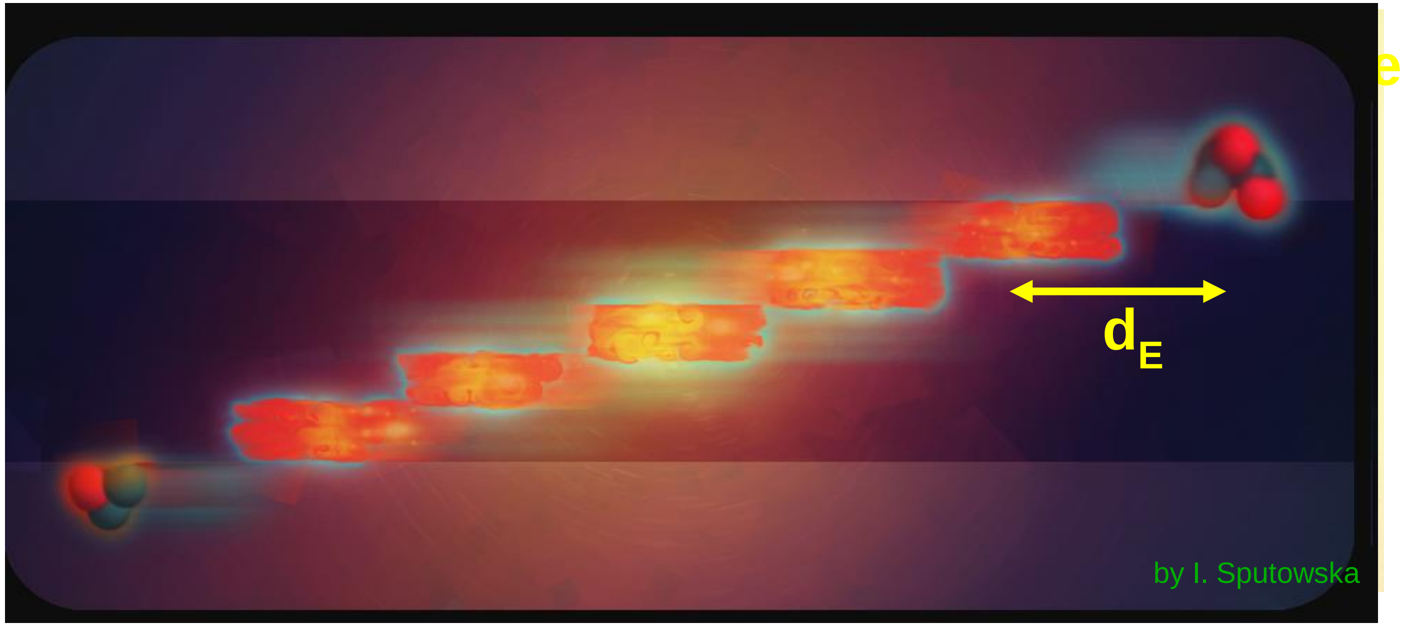


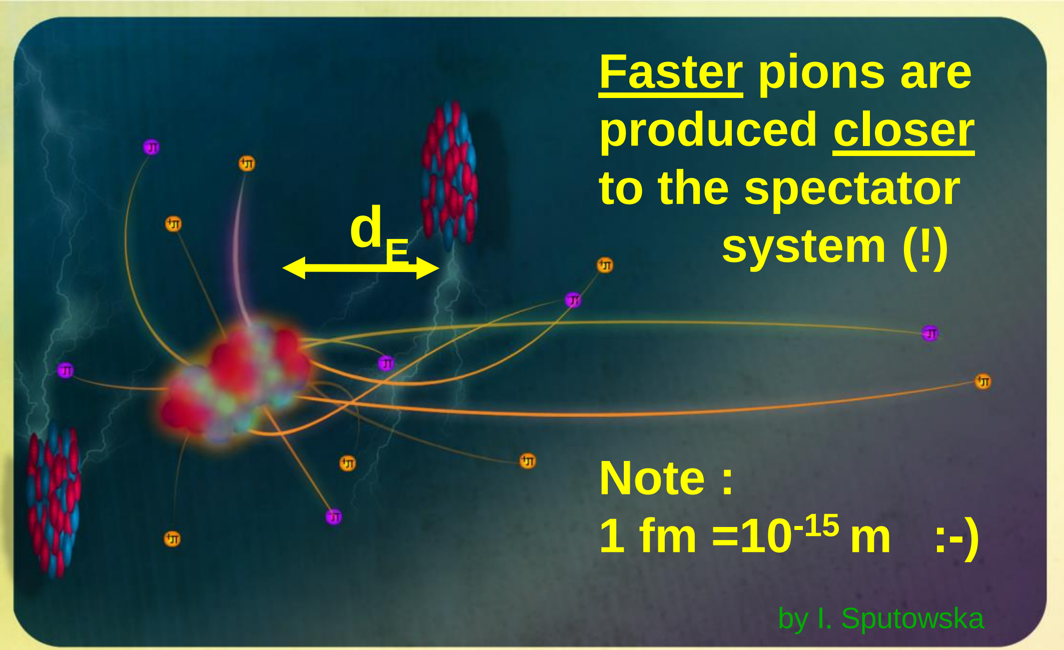
See also: A. R., A. Szczurek et al., APP Supp. 9 (2016) 303

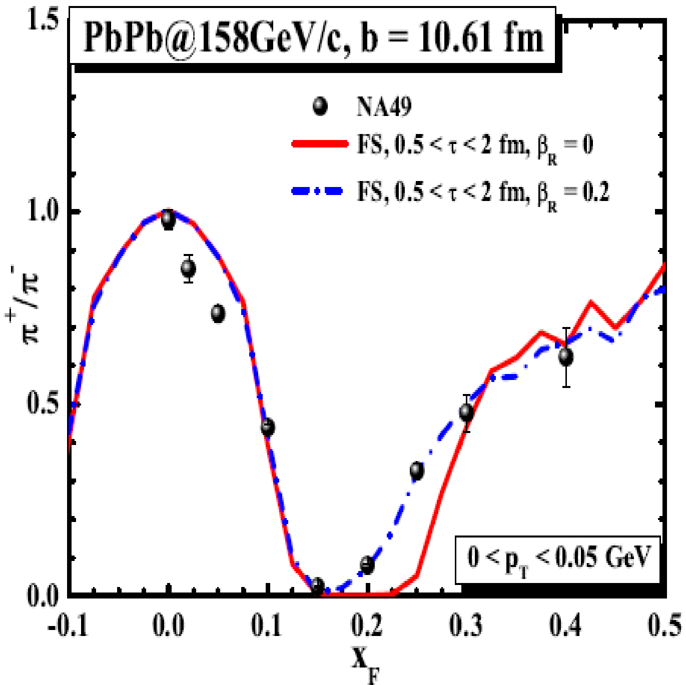


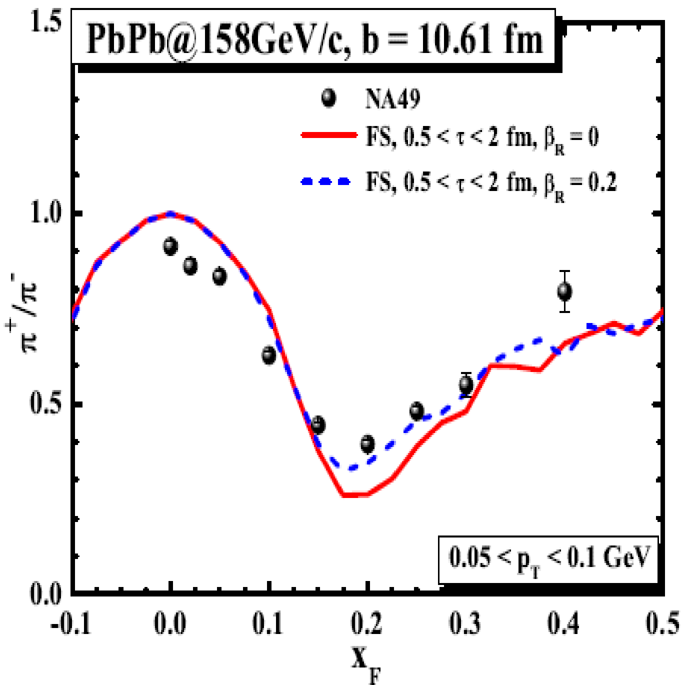
Electromagnetic effects – introduction/reminder:

Evolution from last week:
- arXiv:1910.04544 [nucl-th/hep-ph], V. Ozvenchuk et al.;
- fire-streak model merged with simulation of EM effects ;
- good description of π^+/π^- at higher x_F in Pb+Pb collisions ;
- many effects must be taken into account.
  1. longitudinal evolution of the system;
  2. pion creation time;
  3. spectator expansion.



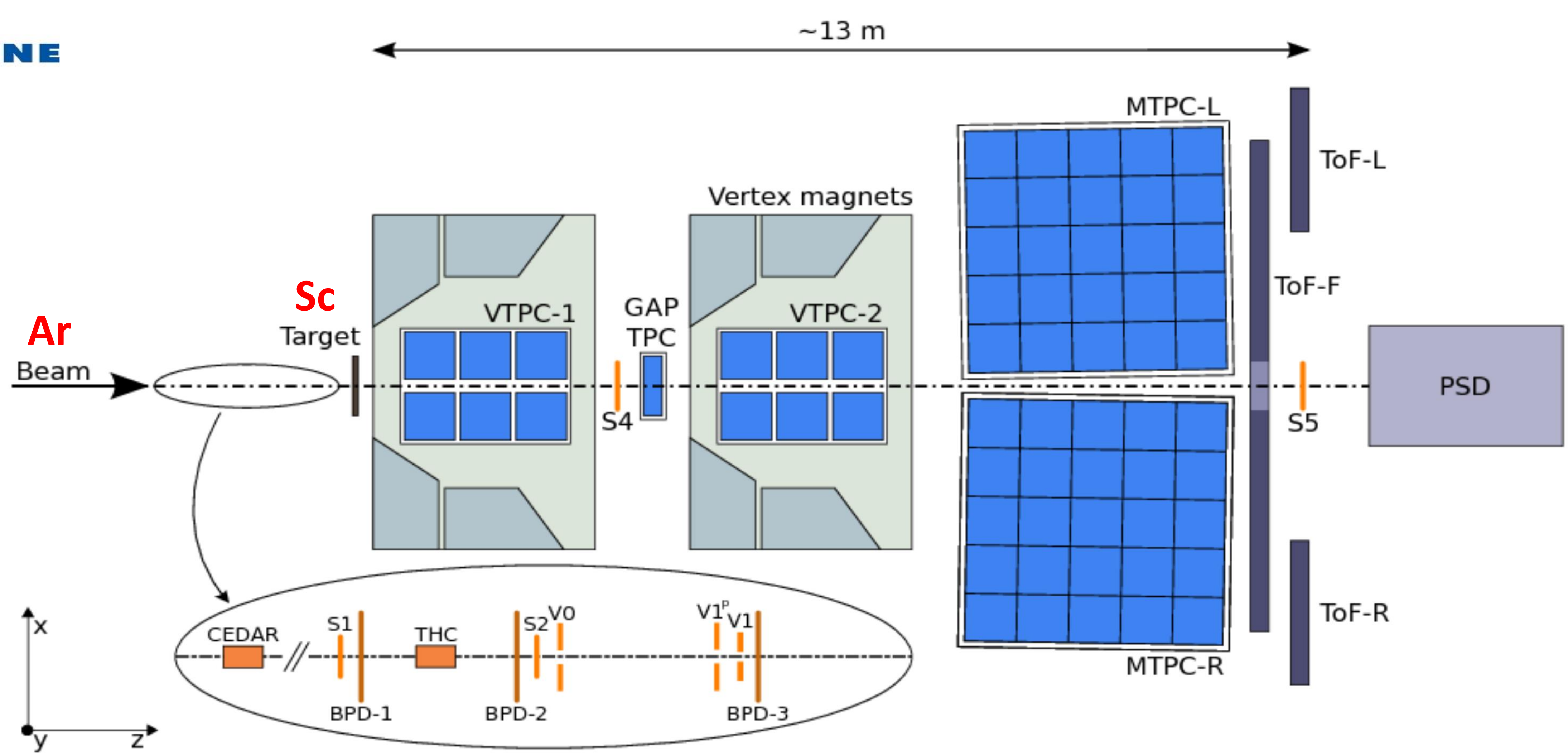






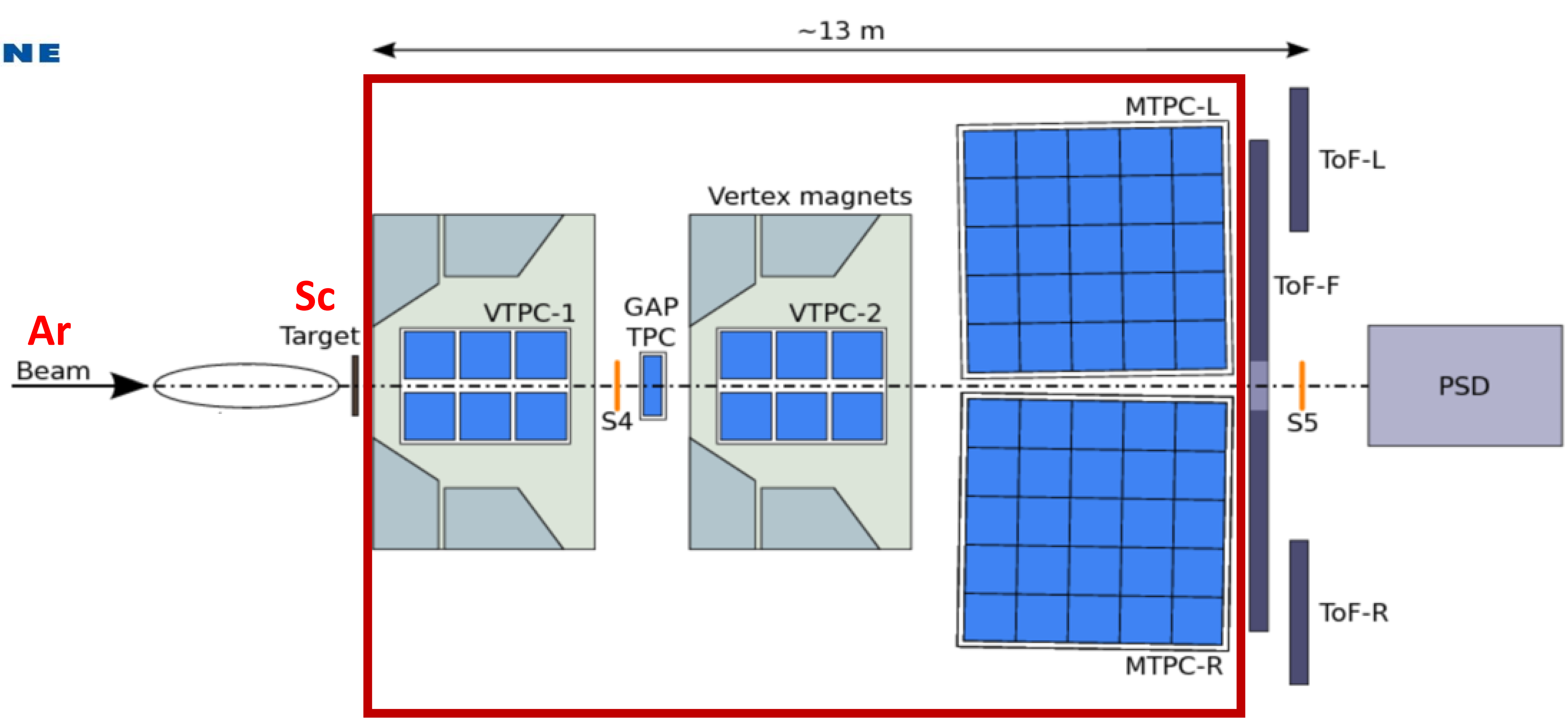
2) NA61/SHINE

About: SHINE



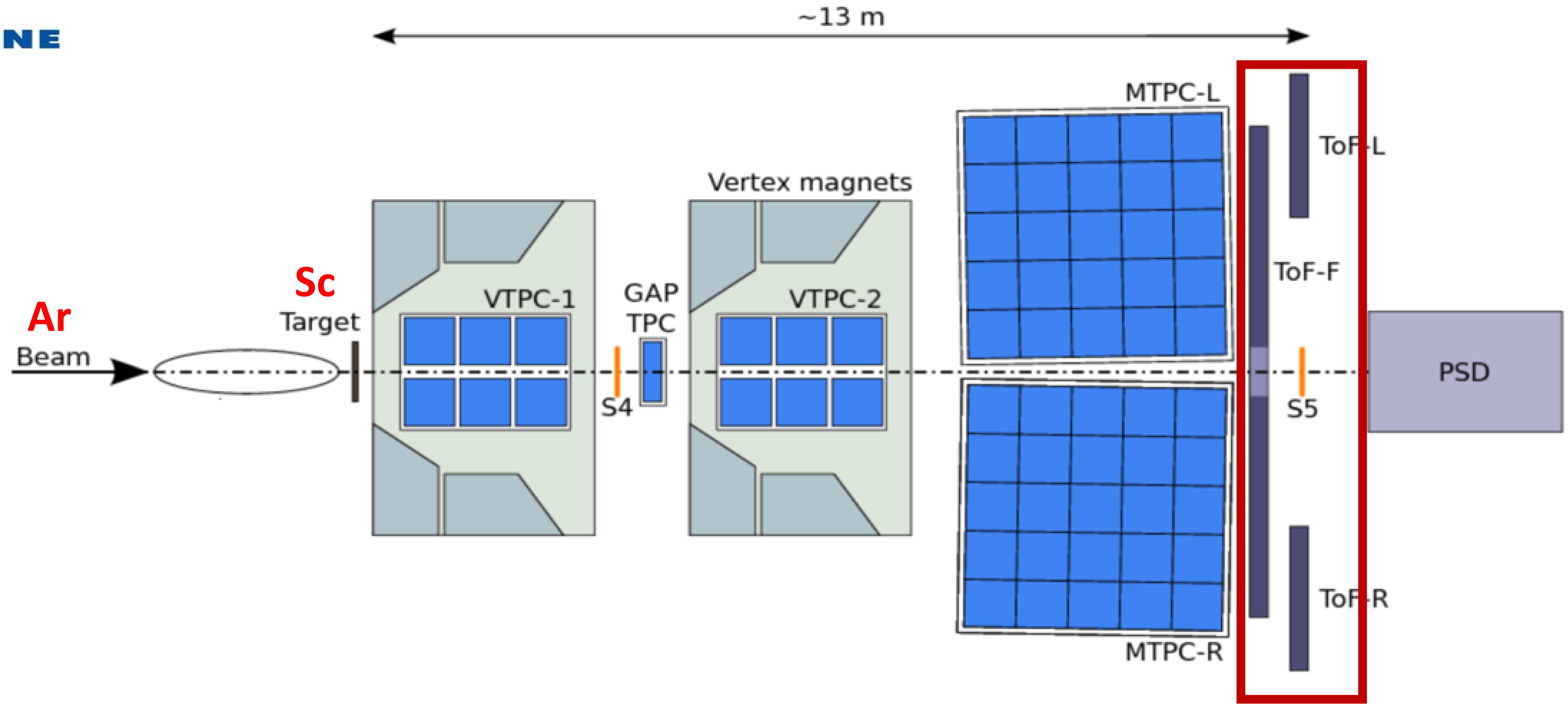
~13 m
MTPC-L
ToF-L
Vertex magnets
ToF-F
Sc
Target
VTPC-1
GAP
TPC
VTPC-2
Ar
Beam
S4
PSD
S5
CEDAR
S1
THC
S2
V0
V1^{P}
V1
BPD-1
BPD-2
BPD-3
ToF-R
MTPC-R
x
y
z

About: S··INE



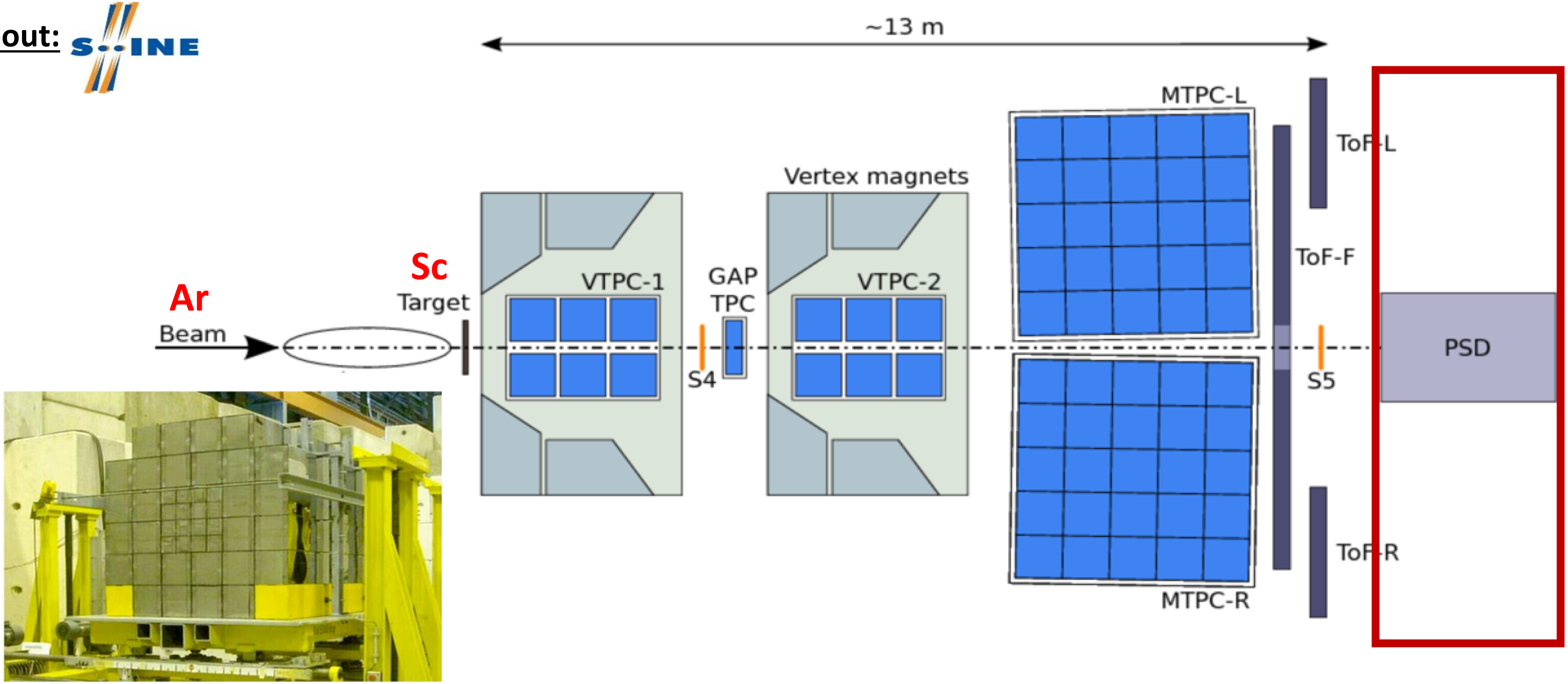
- Main detectors which detects charged particles are five TPCs.
- VTPC-1 VTPC-2 and GTPC are placed in the magnetic fields.
- TPC system allows for particle identification based on specific energy loss and vertex topology.

About: S··INE



- ToFs are the scintillator detectors measures the arrival time of the particles with precision 60ps.
- Together with TPCs, ToF improves the precision of particle identification.

About: SHINE



- Projectile spectator detector is a hadronic calorimeter intended to measure projectile spectators energy in nucleus-nucleus collisions.
- 60 pairs of alternating lead plates and scintillator tiles with 16mm and 4 mm thickness respectively.

3) Used data set and cuts

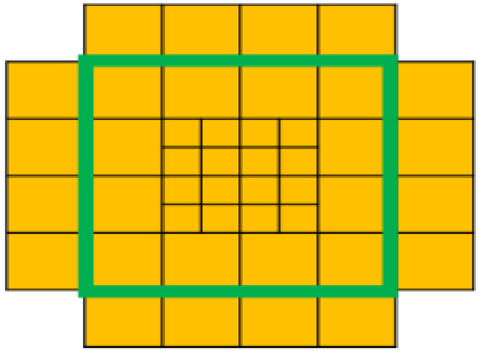
Data, event and track cuts:

● **NA61/SHINE**, ^{40}Ar + ^{45}Sc @ 40 *A* GeV/*c*.
→ **Production used**: Ar_Sc_40_15/025_17b_v1r6p0_pA_slc6_phys.
→ **Runs**: 21058-21268.

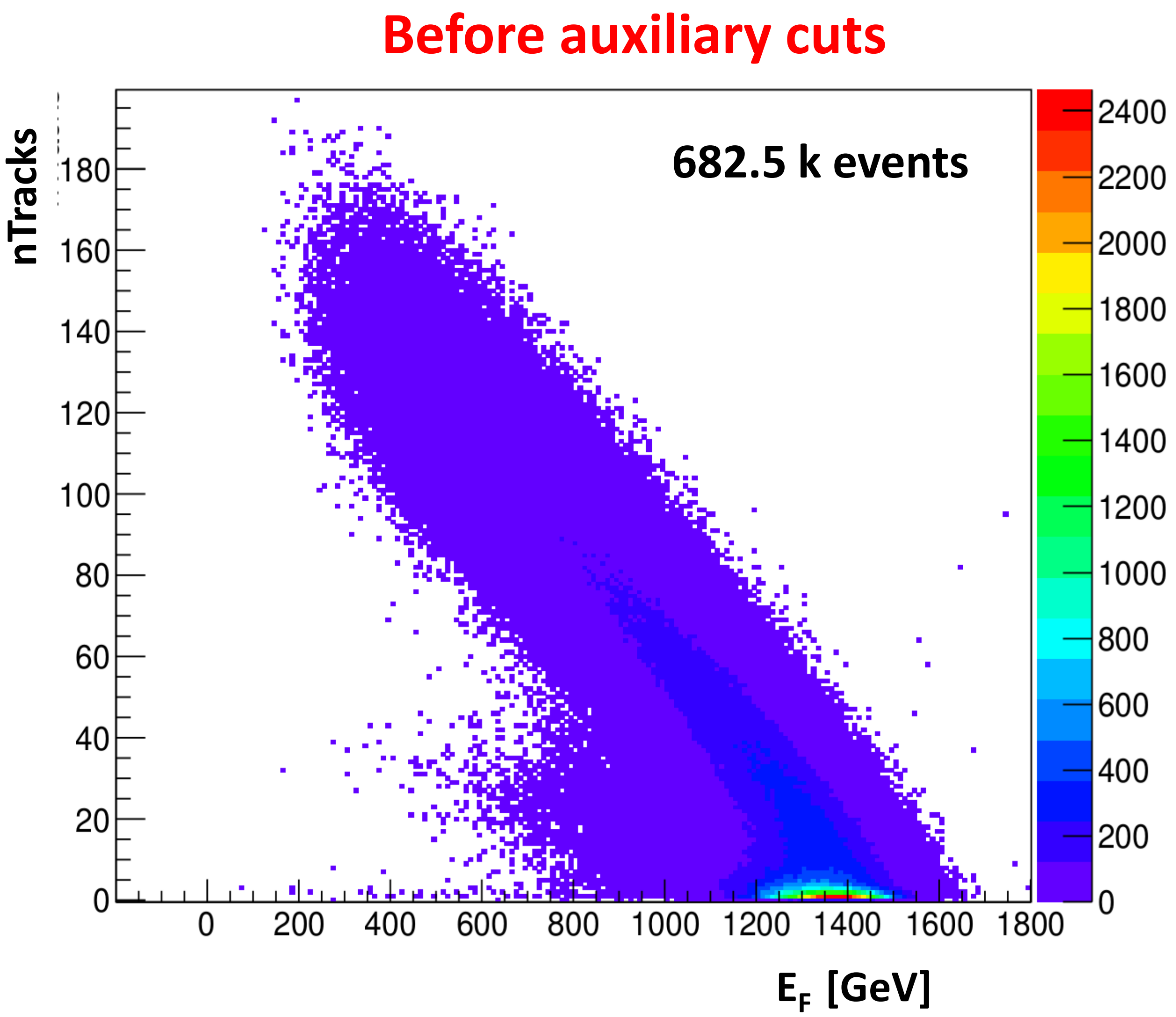
Event cuts:
- Target IN,
- BPD status,
- WFA particles (4 μs),
- WFA interaction (25 μs),
- BPD3X(Y) charge,
- S5 (0 → 170),
- **T4 trigger,**
- Vertex track fitted to the main vertex,
- Vertex fit quality = ePerfect,
- Fitted vertex position **-580 ± 3 cm,**
- **nTracks > 4,**
- **Auxiliary cuts(geometrical event cuts on nTracks vs PSD plane) will be discussed furthe**

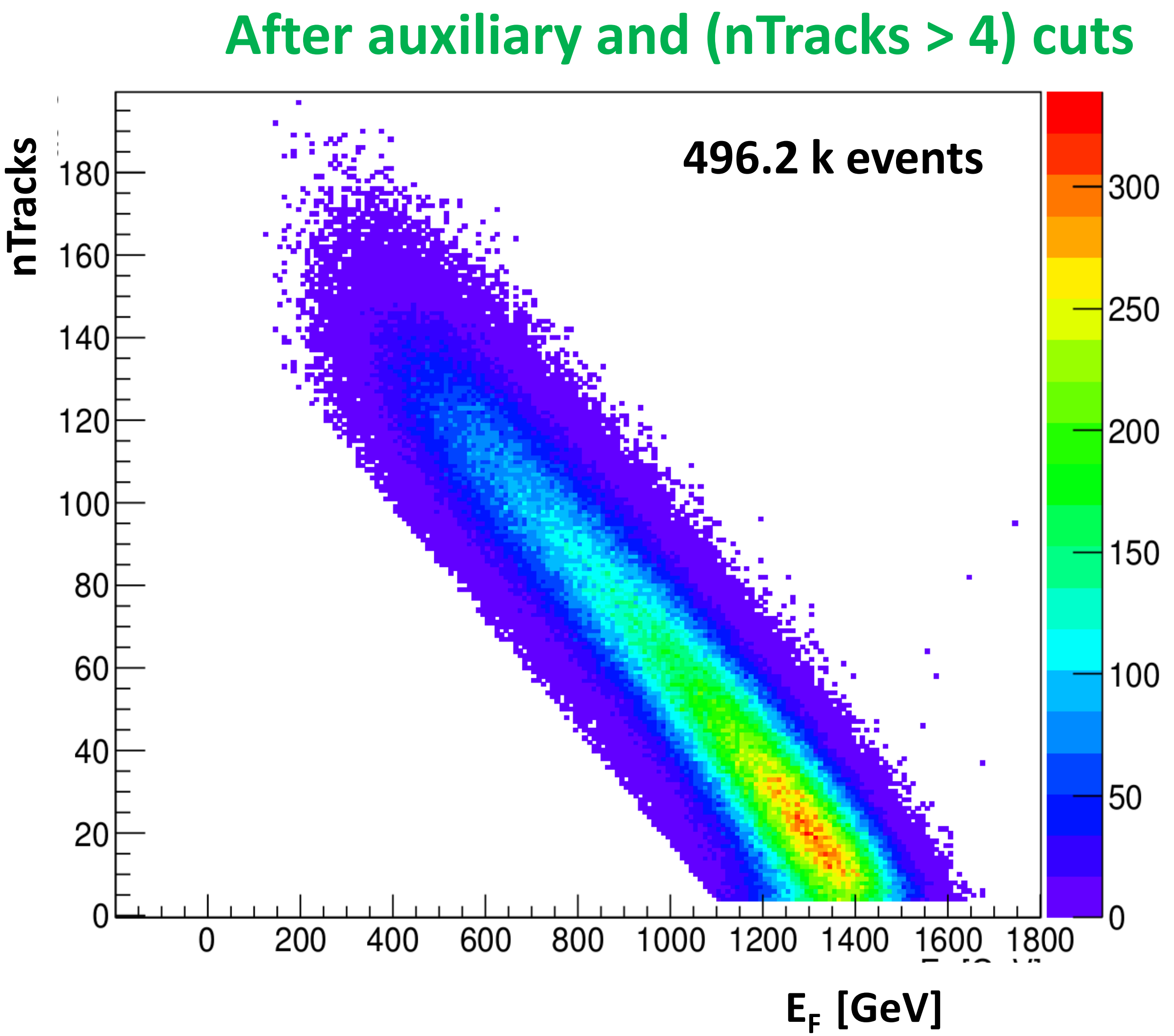
Track cuts:
- Track status,
- Charge ± 1,
- Impact point[± 4cm; ± 2cm],
- Total number of clusters ≥ 30,
- VTPCs clusters ≥ 15,
- No GTPC clusters,
- dE/dx clusters ≥ 30,
- **Φ wedge ± 75º.**

- **We have different centrality cuts based on PSD energy selection.**
- **The PSD modules 1-28 are selected.**
- **Total number of events after cuts = 496.2 k.**



Definition of “auxiliary cut”:

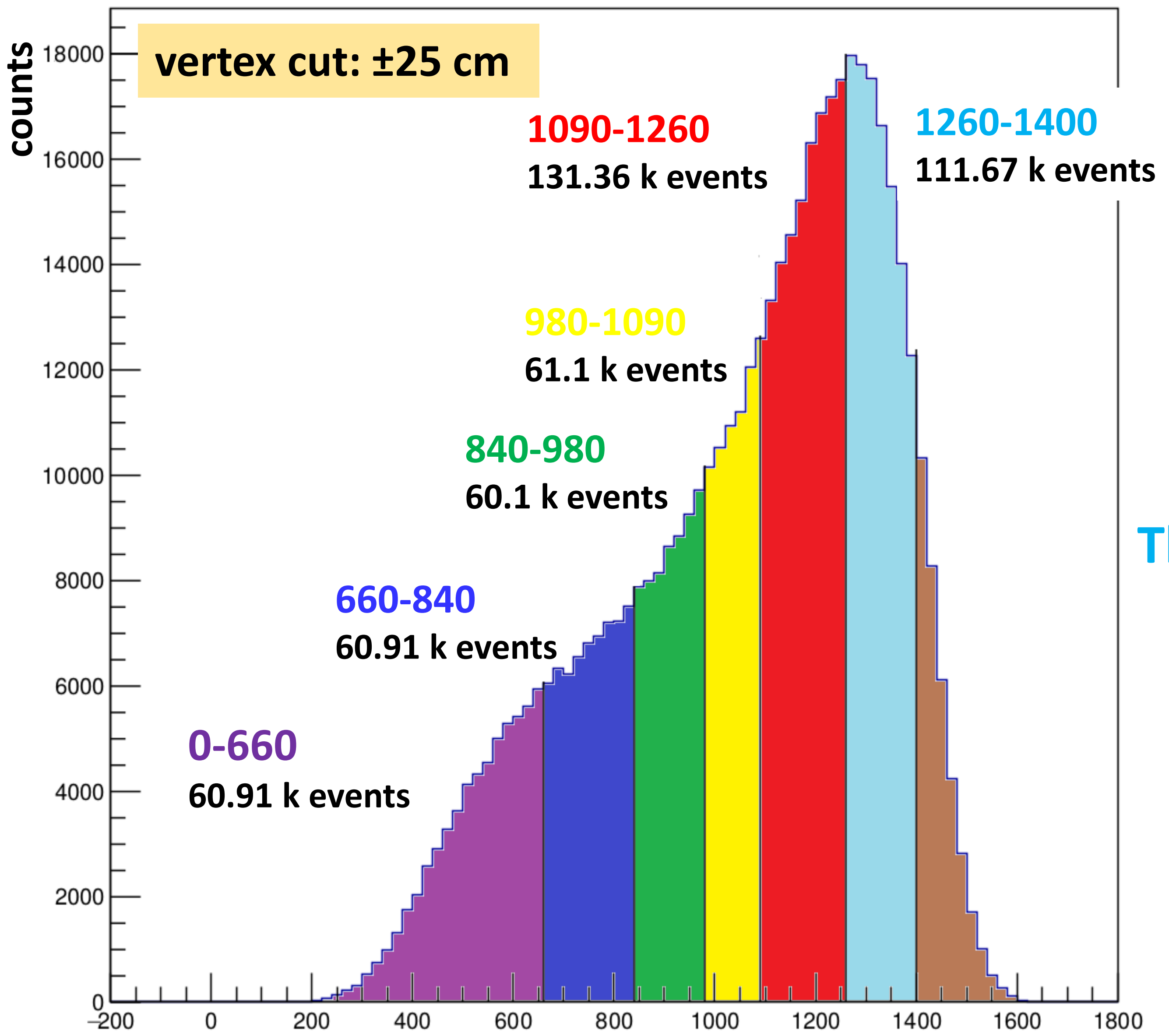




Auxiliary cut : nTracks > -0.13534 * E_F + 152.9323

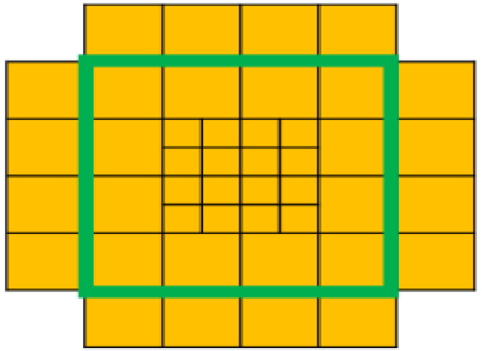
* E_F = foward energy in the PSD.

Centrality definition:

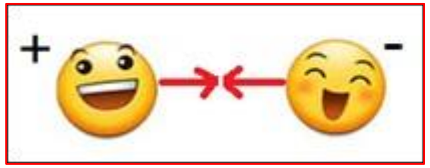


No auxiliary nor track cuts.

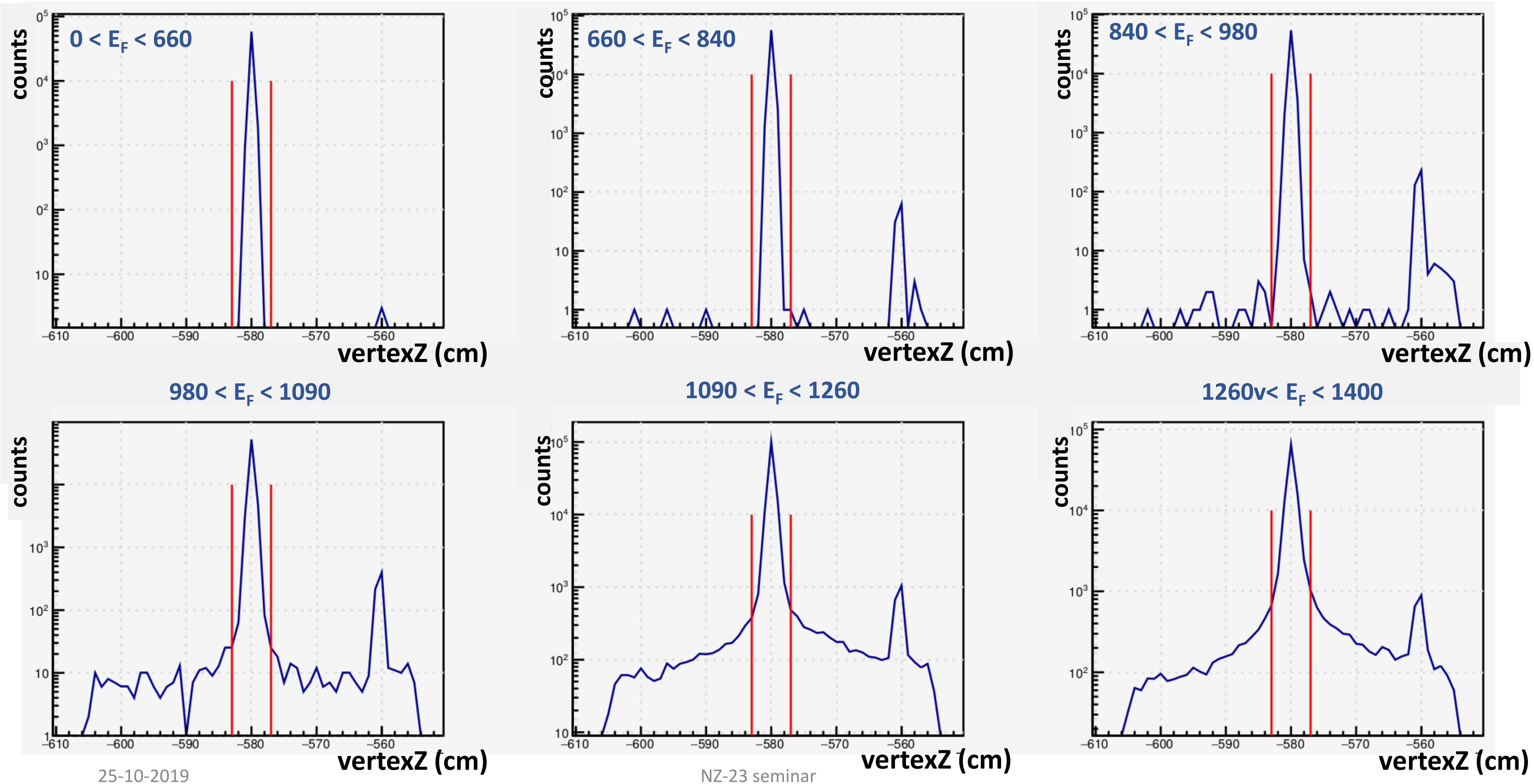
E_F = Sum of 1 to 28 PSD modules.



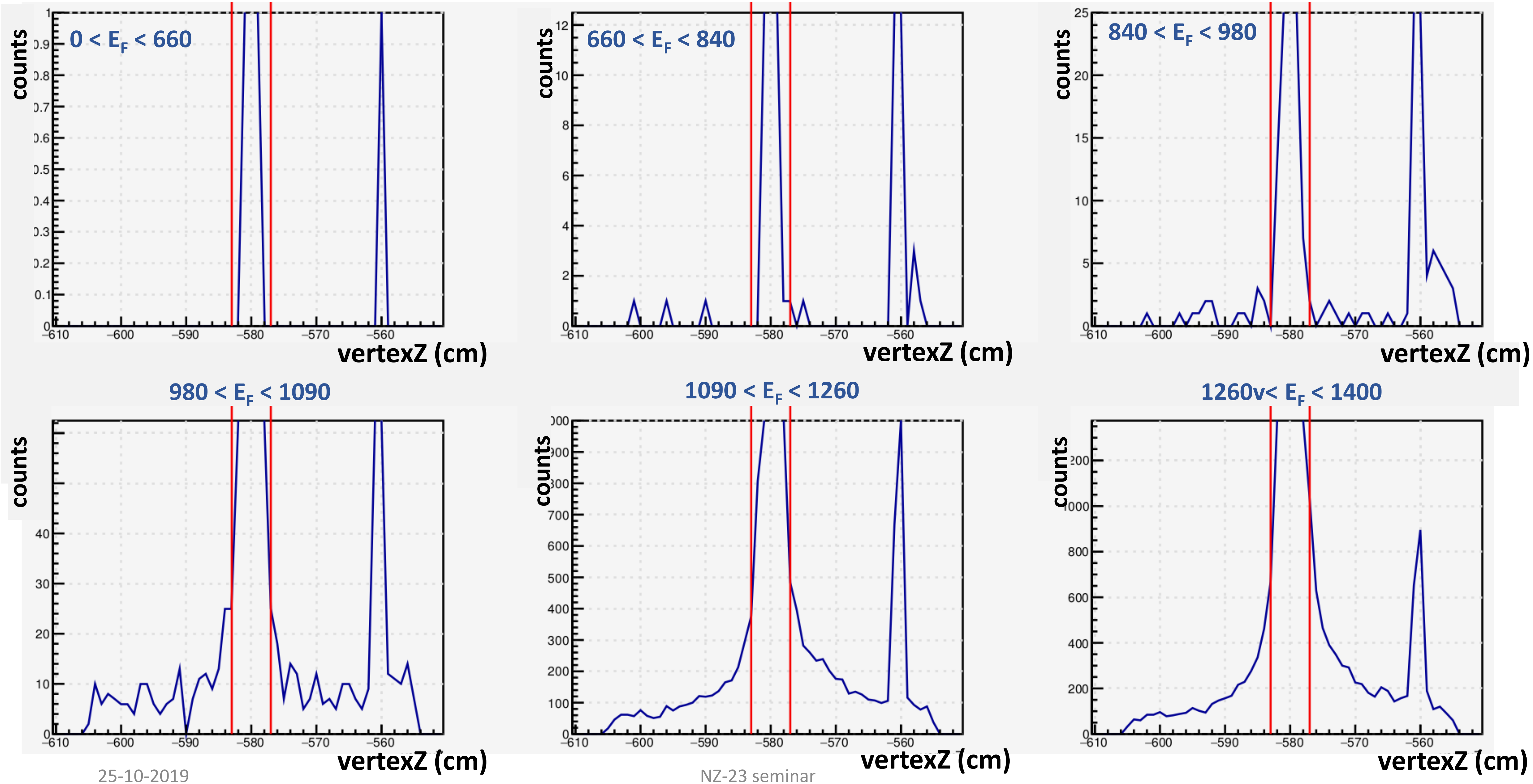
The electromagnetic effect will be most visible in more peripheral collisions!



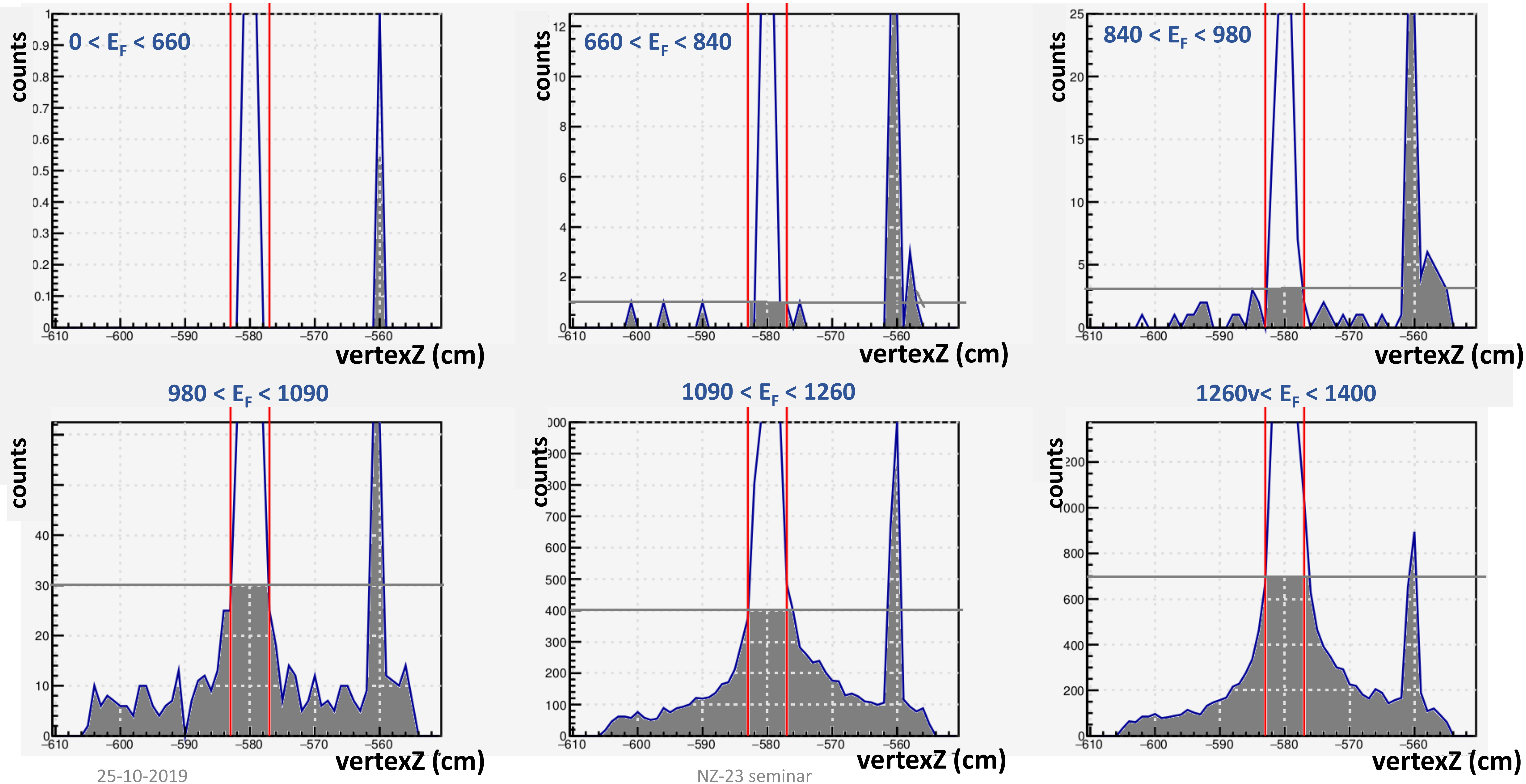
Main vertex distribution: *red lines shows vertex cut : ± 3 cm (log scale)



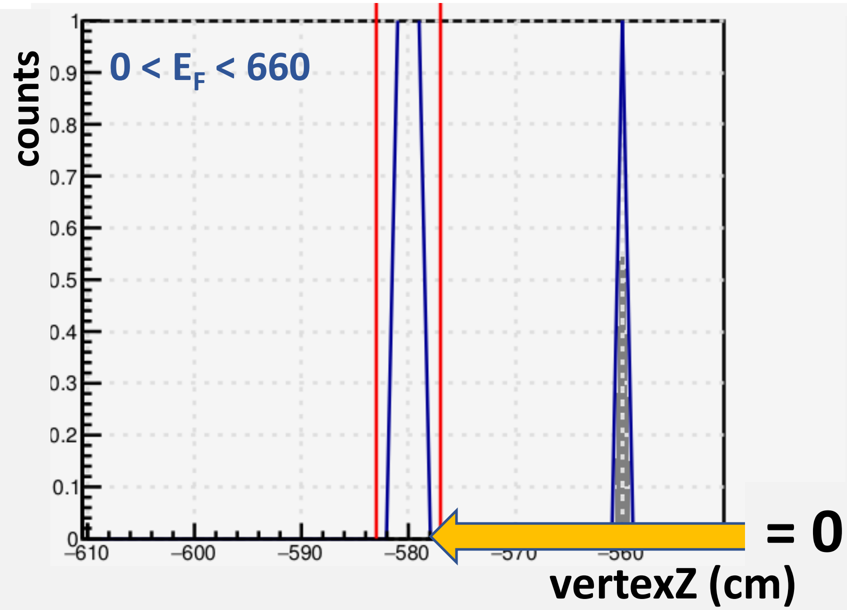
Main vertex distribution: *red lines shows vertex cut : ± 3 cm

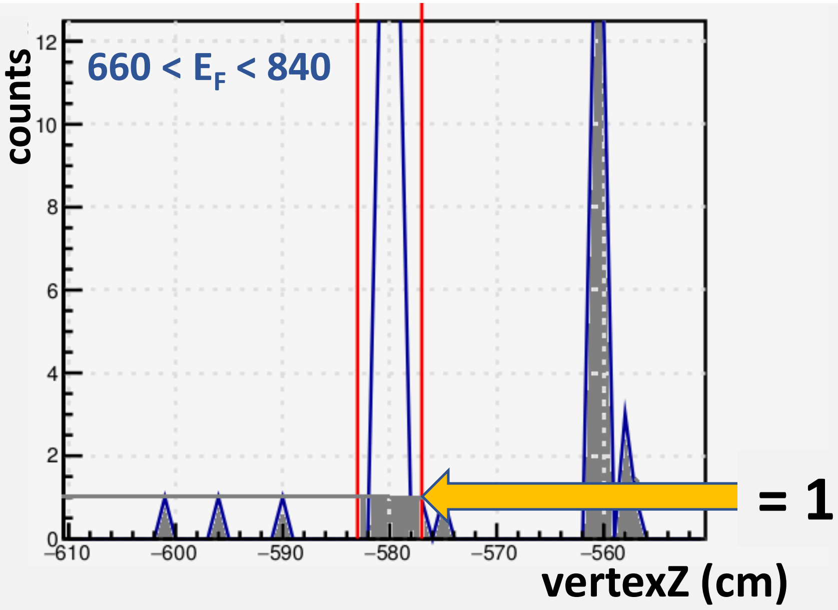


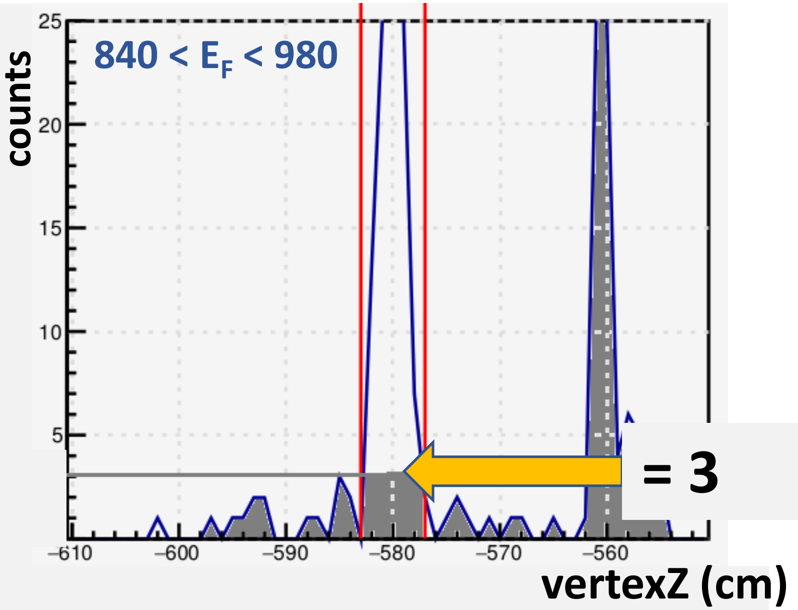
Main vertex distribution: *red lines shows vertex cut : ± 3 cm

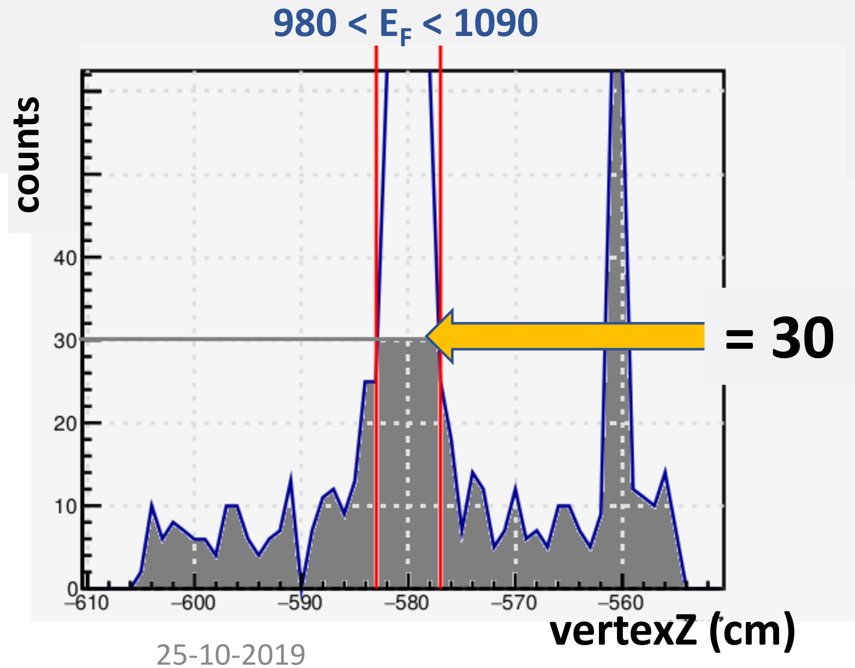


Main vertex distribution: *red lines shows vertex cut : ± 3 cm



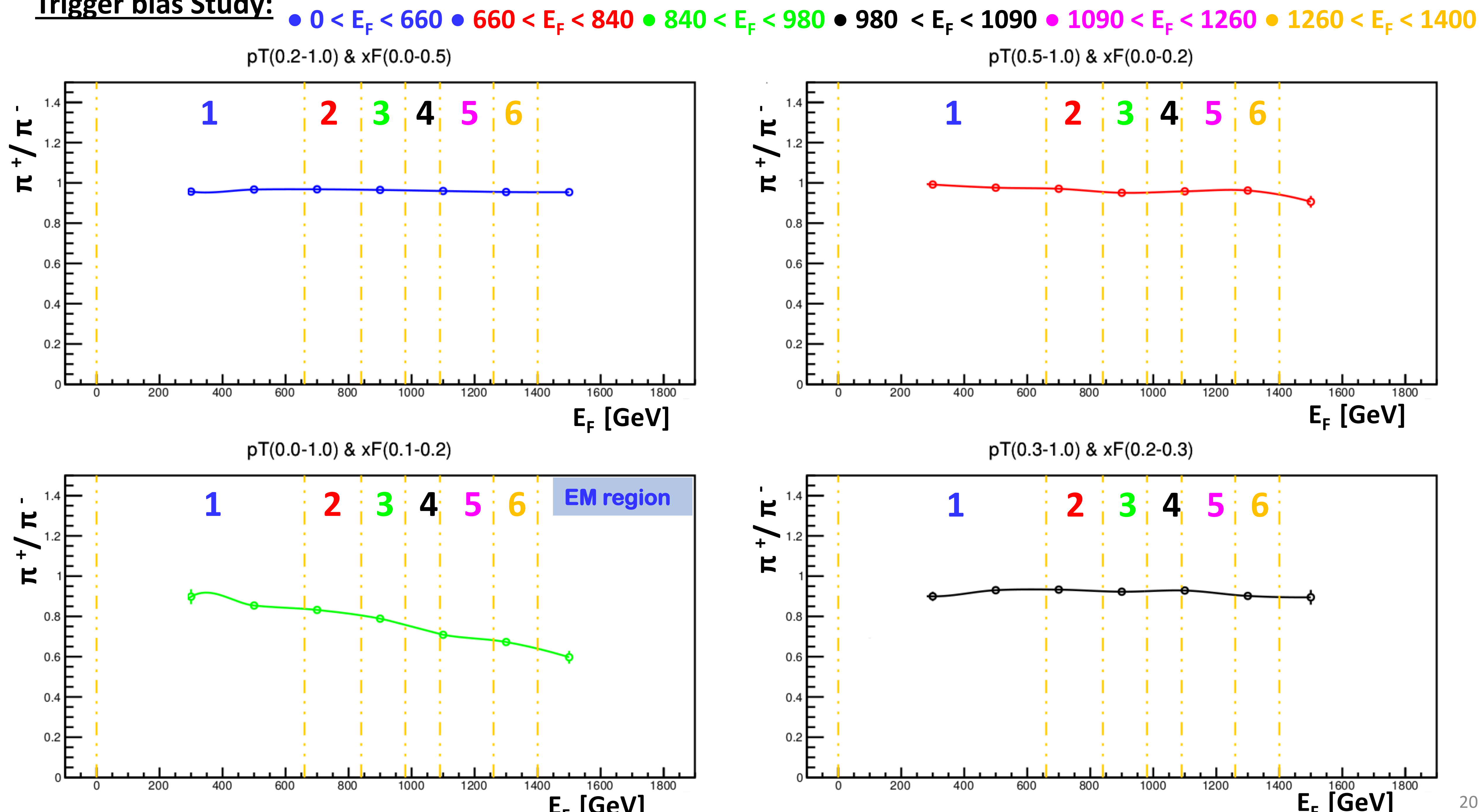






Centrality	Total Events (A)	Background
$0 < E_F < 660$	60696	0.0 %
$660 < E_F < 840$	60608	0.01 %
$840 < E_F < 980$	59957	0.03 %
$980 < E_F < 1090$	60472	0.29 %
$1090 < E_F < 1260$	127959	1.87 %
$1260 < E_F < 1400$	99157	4.23 %

Trigger bias Study:

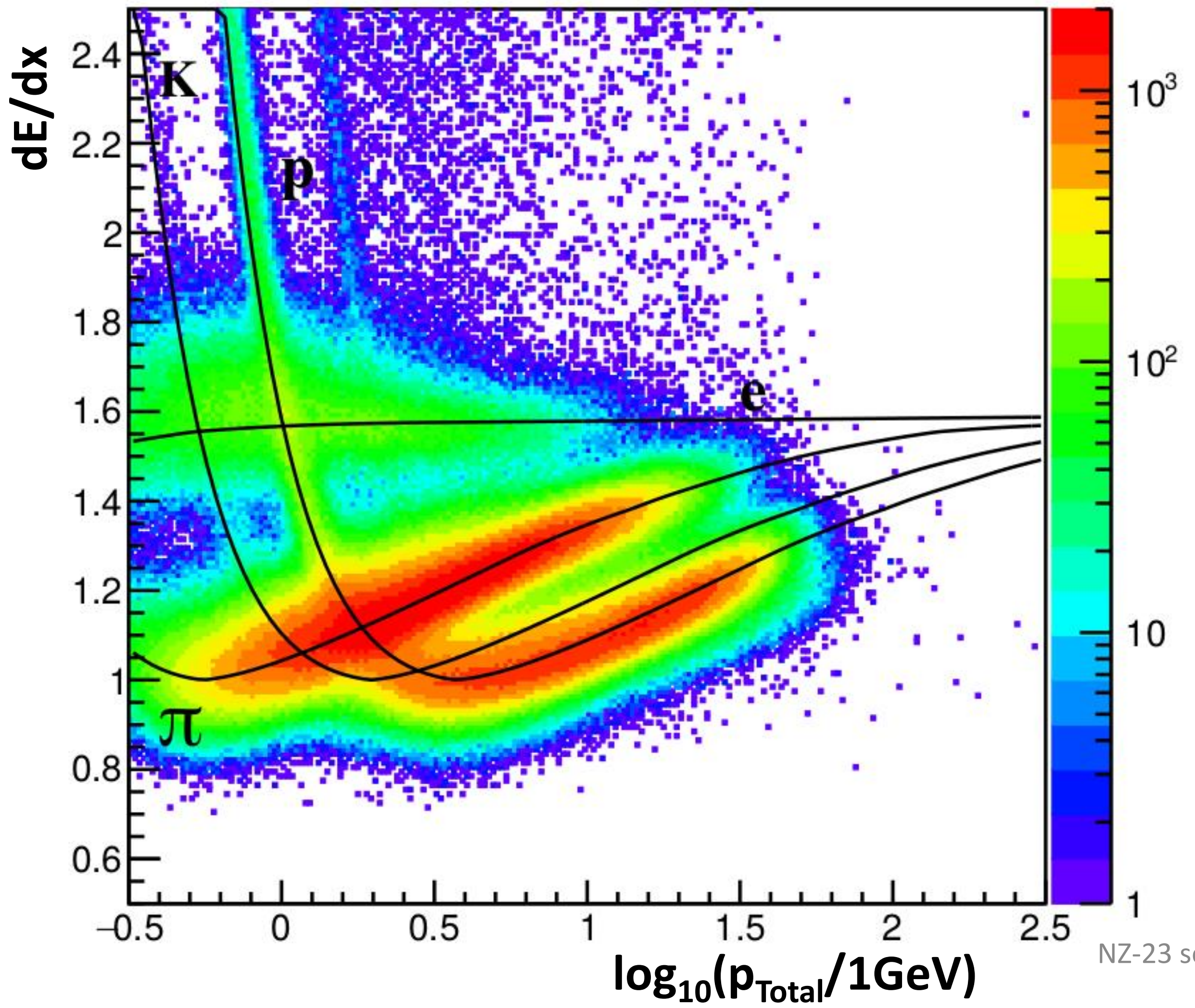


Particle identification method:

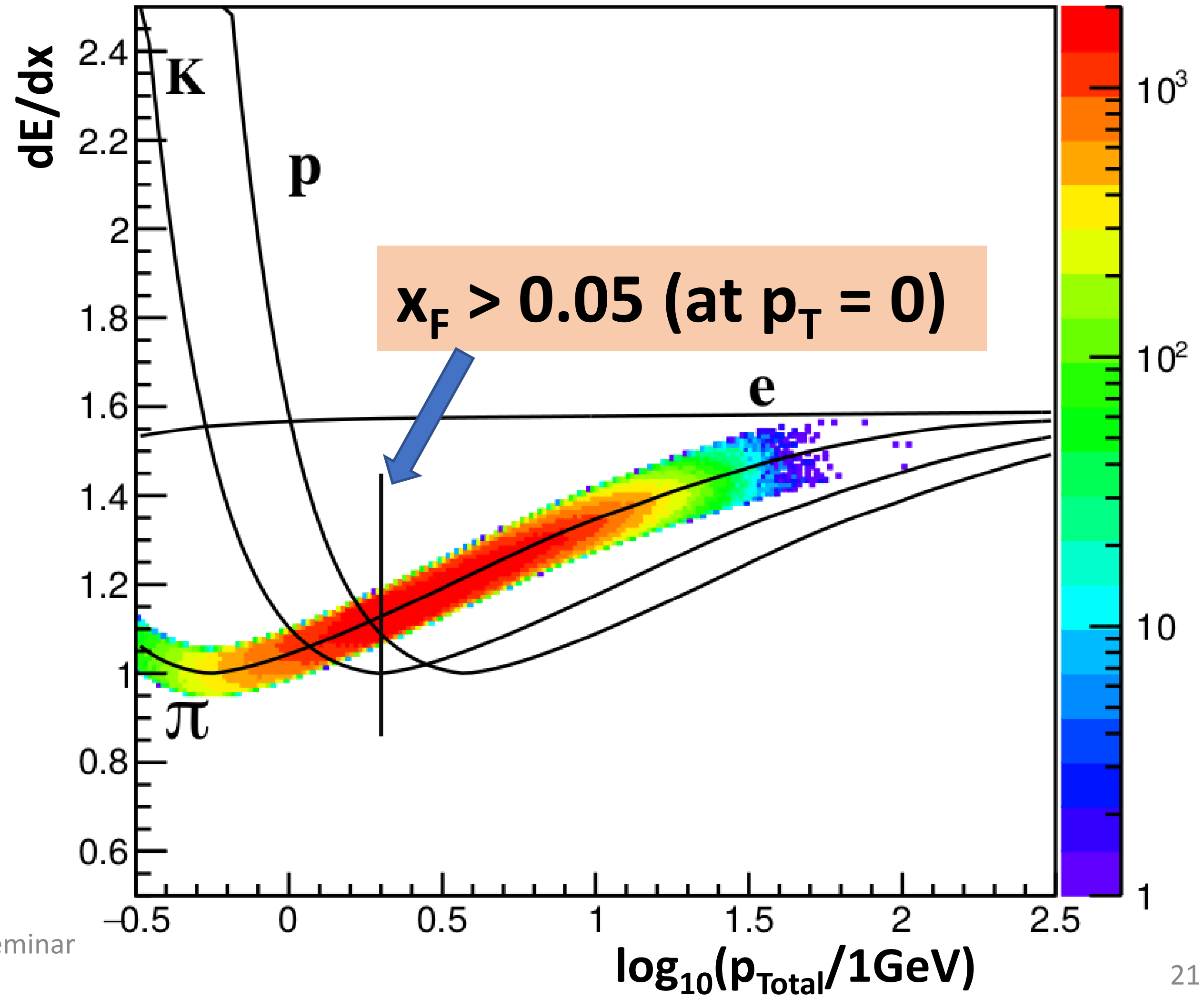
(for positive particles)

$0 < E_F < 1400$

$\Phi \pm 50^o$ cut

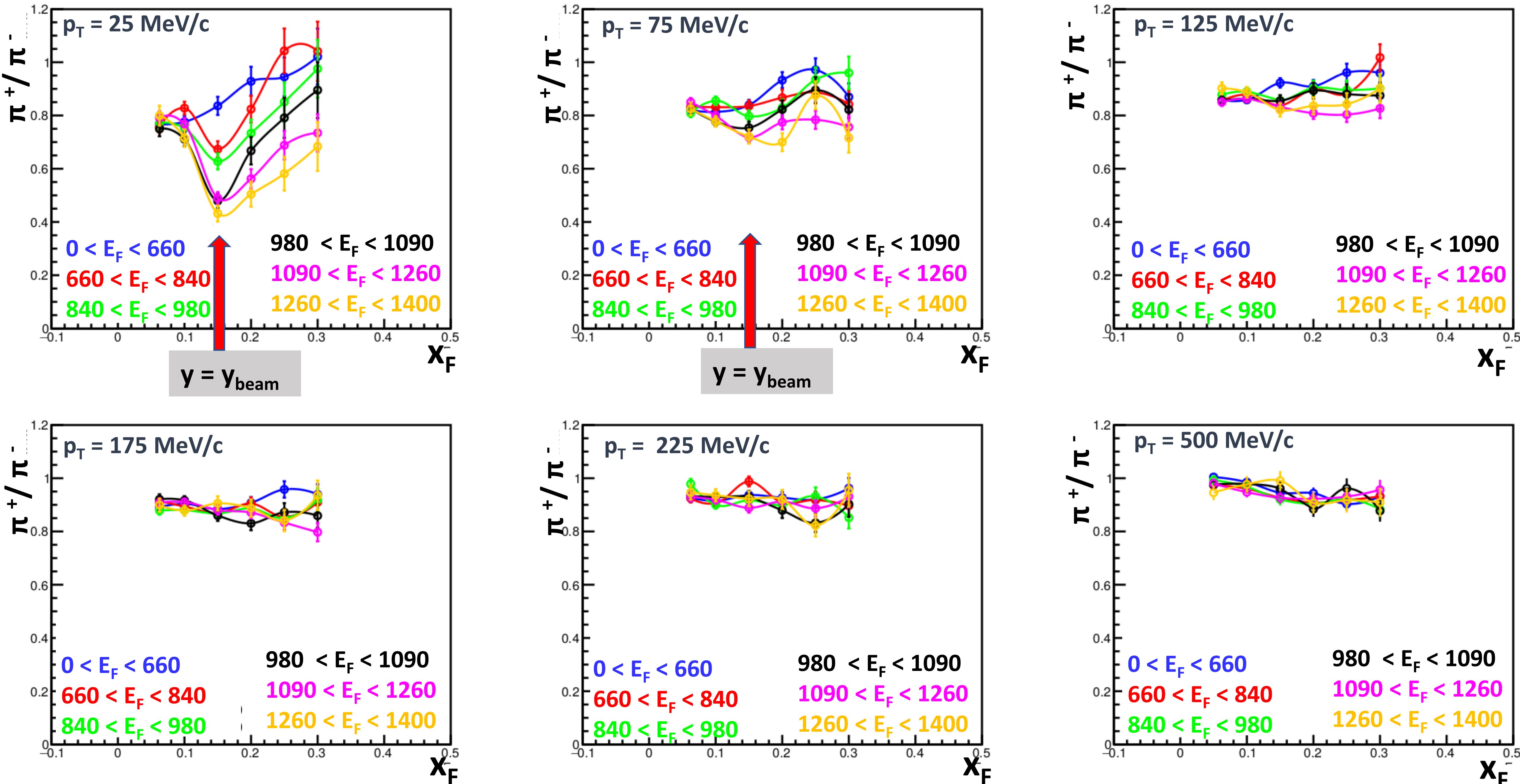


dE/dx ±5 % around pion Bethe-Bloch

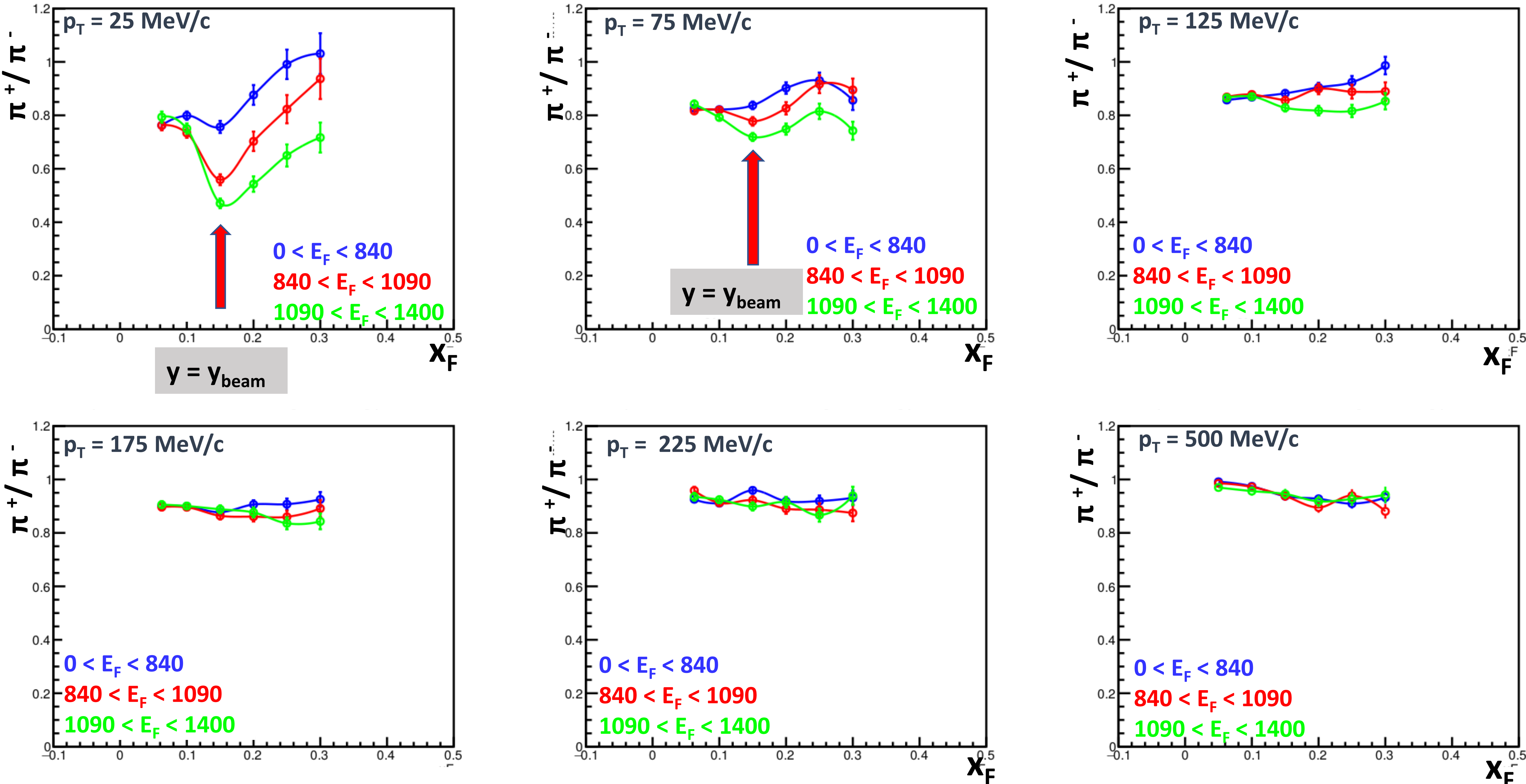


4) Results

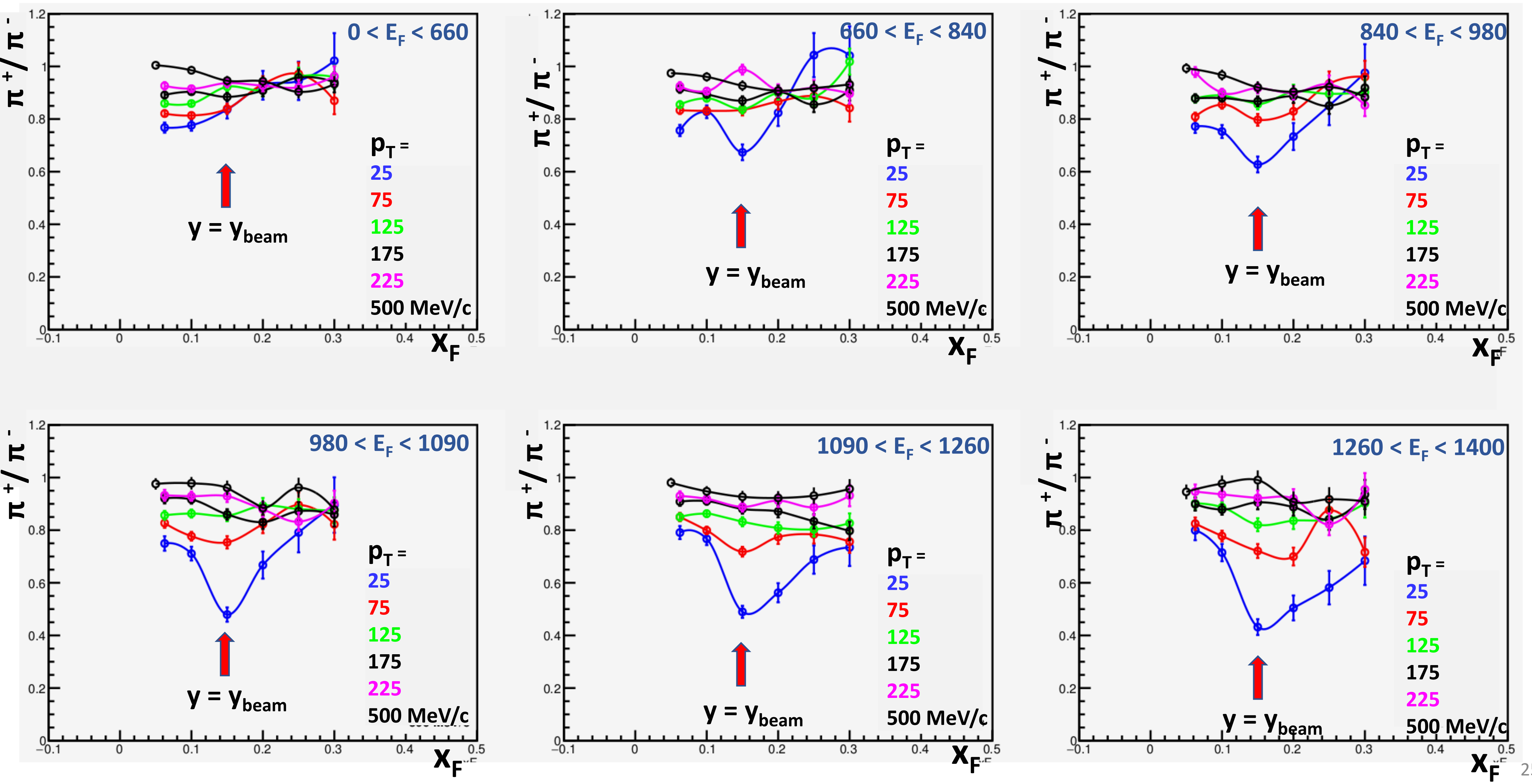
π^+/π^- ratio at six different centralities: | vertex_z = vertex_z (target) | < 3cm.



π^+/π^- ratio at three different centralities: | vertex_z = vertex_z (target) | < 3cm.

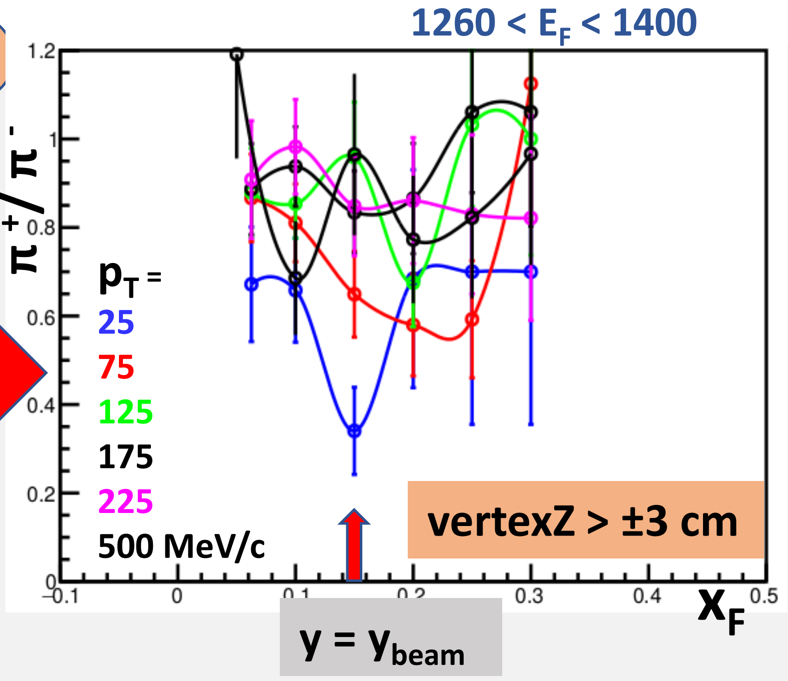


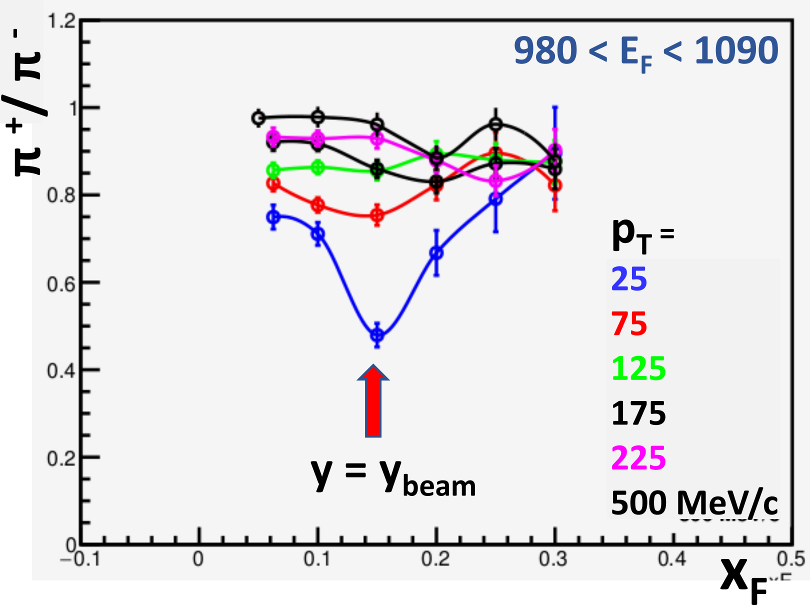
π⁺/π⁻ ratio at six different centralities: | vertex_z = vertex_z (target) | < 3cm.

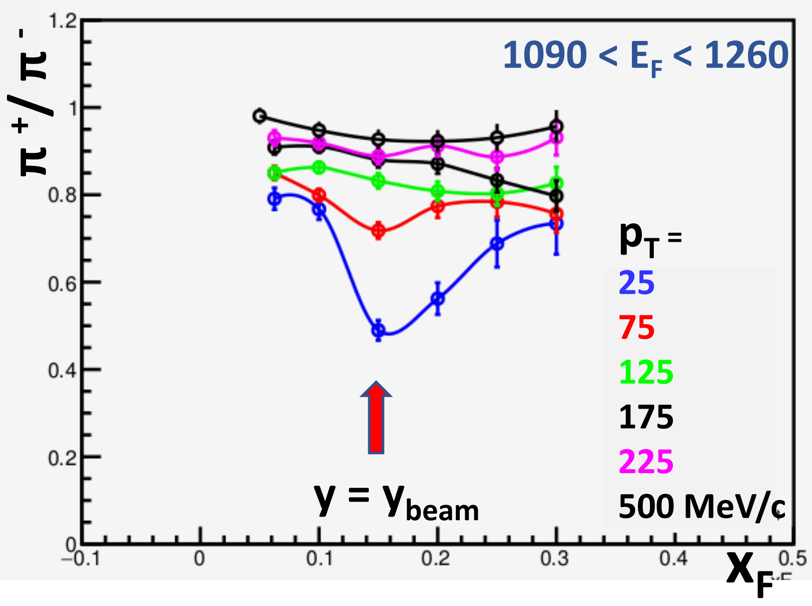


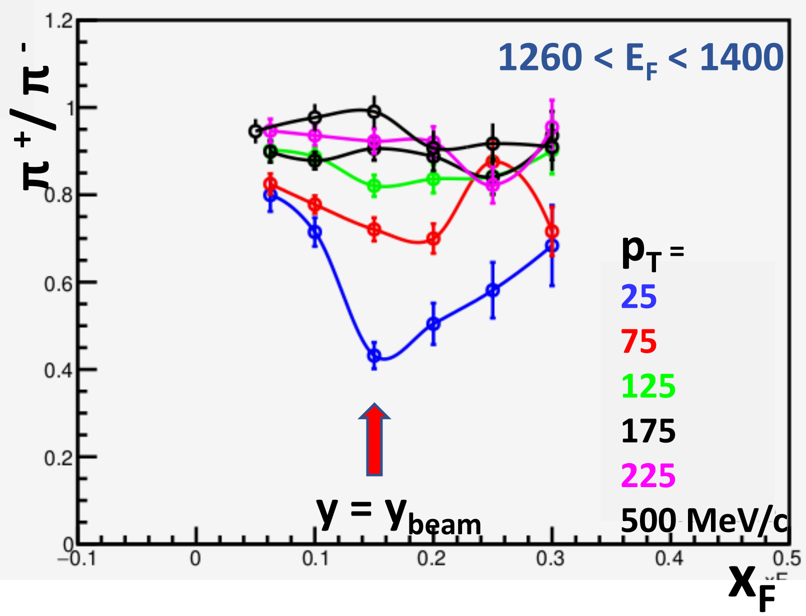
π ⁺/π⁻ ratio at six different centralities: | vertex_z = vertex_z (target) | < 3cm.

Off vertex background
- Poor statistics.
- Background has similar π ⁺/π⁻ ratios as selected Ar+Sc events (bias is small).
- EM effect is visible in peripheral background events.

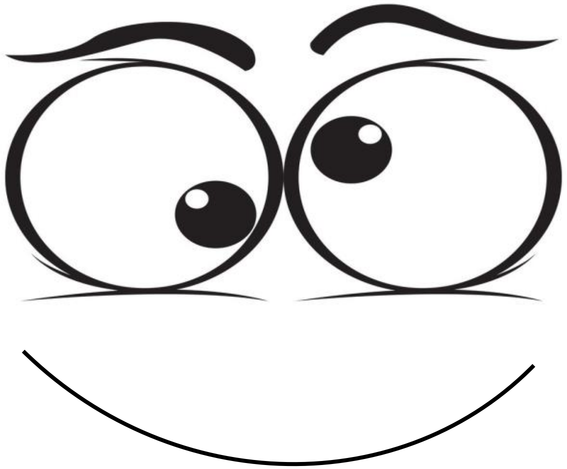




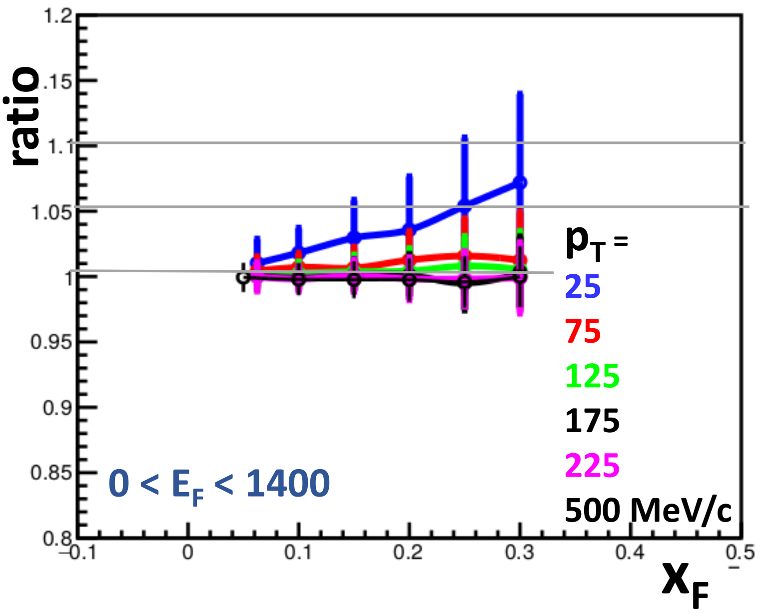


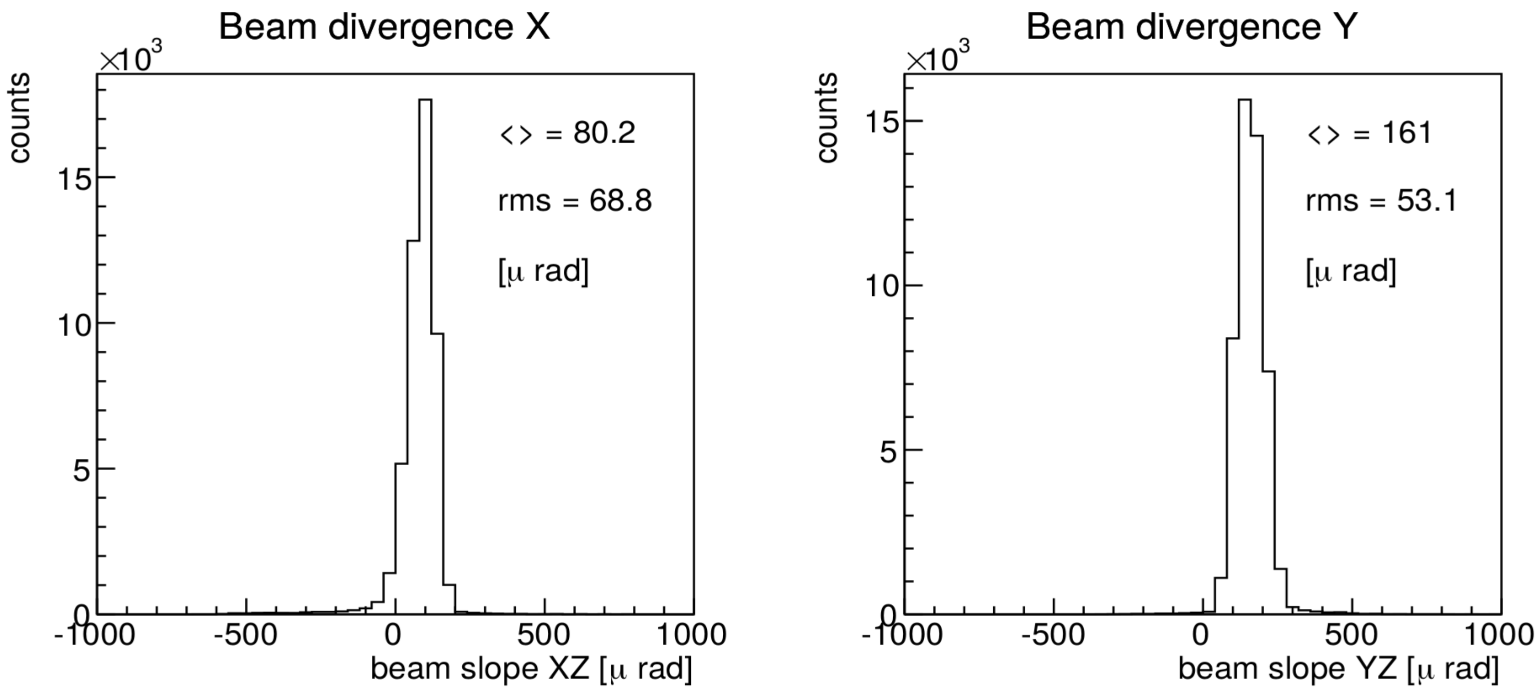


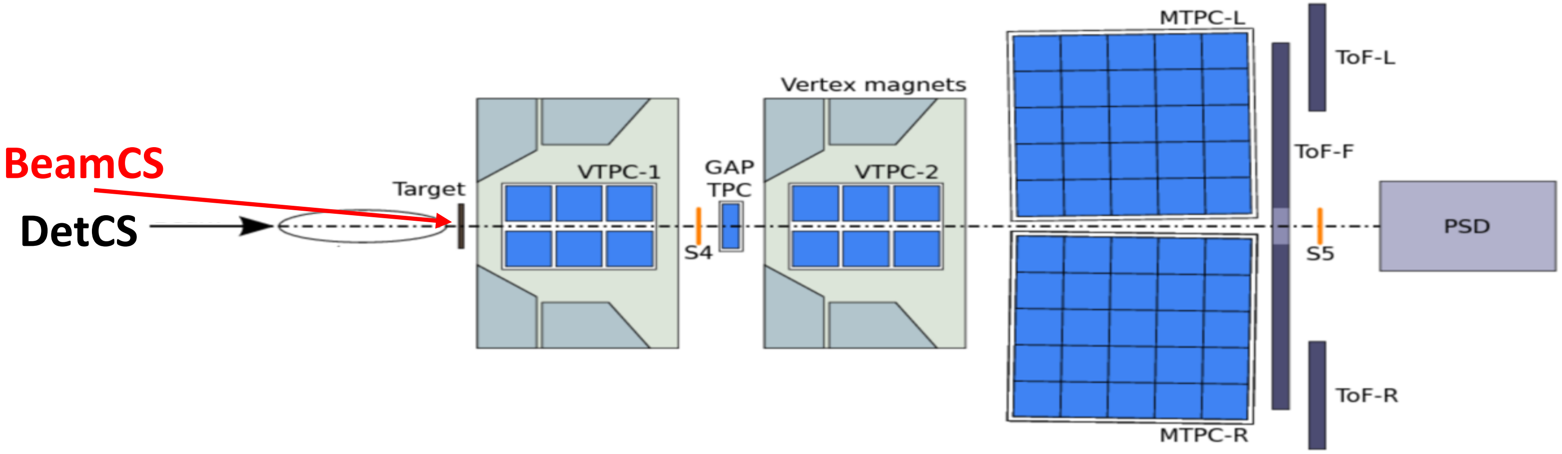
Possible biases : BeamCS over DetCS



(π^+/π^- (BeamCS)) / (π^+/π^- (DetCS)):

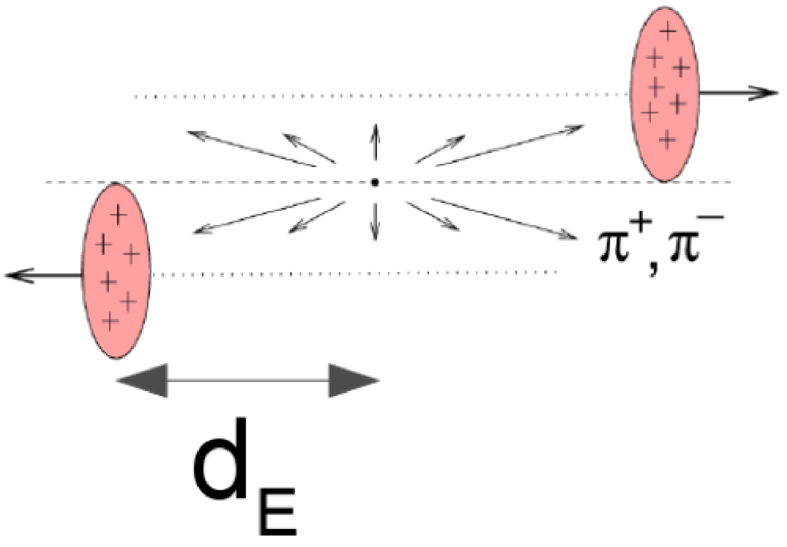


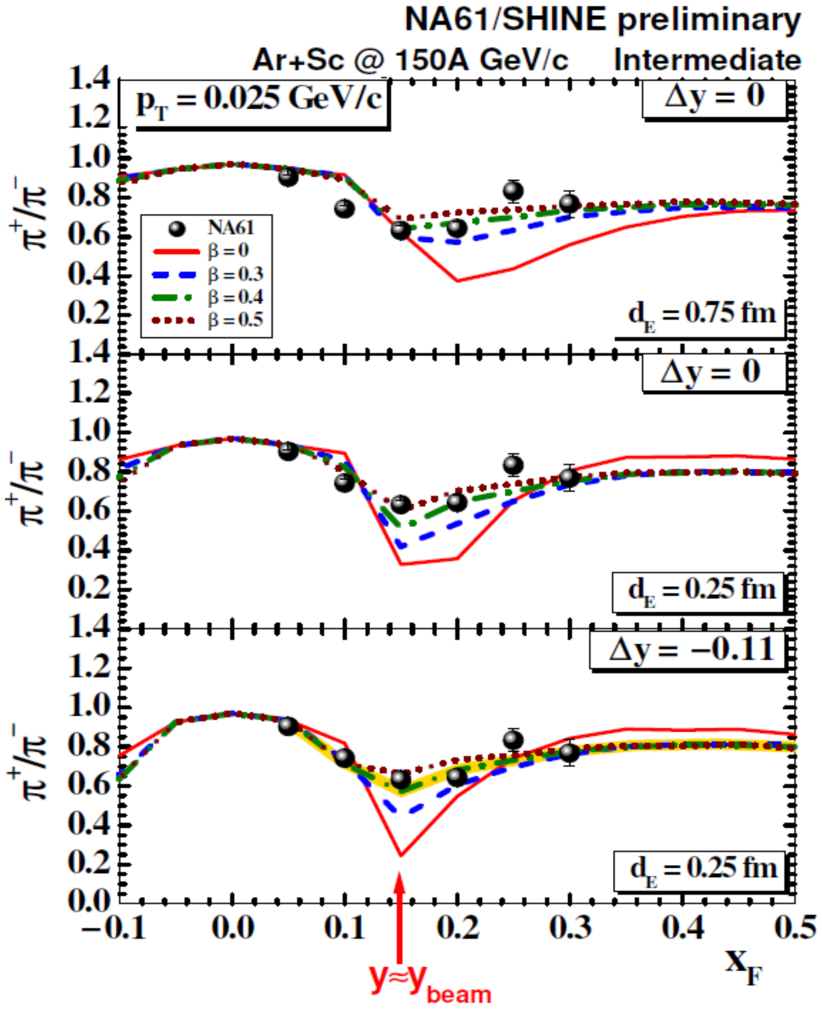


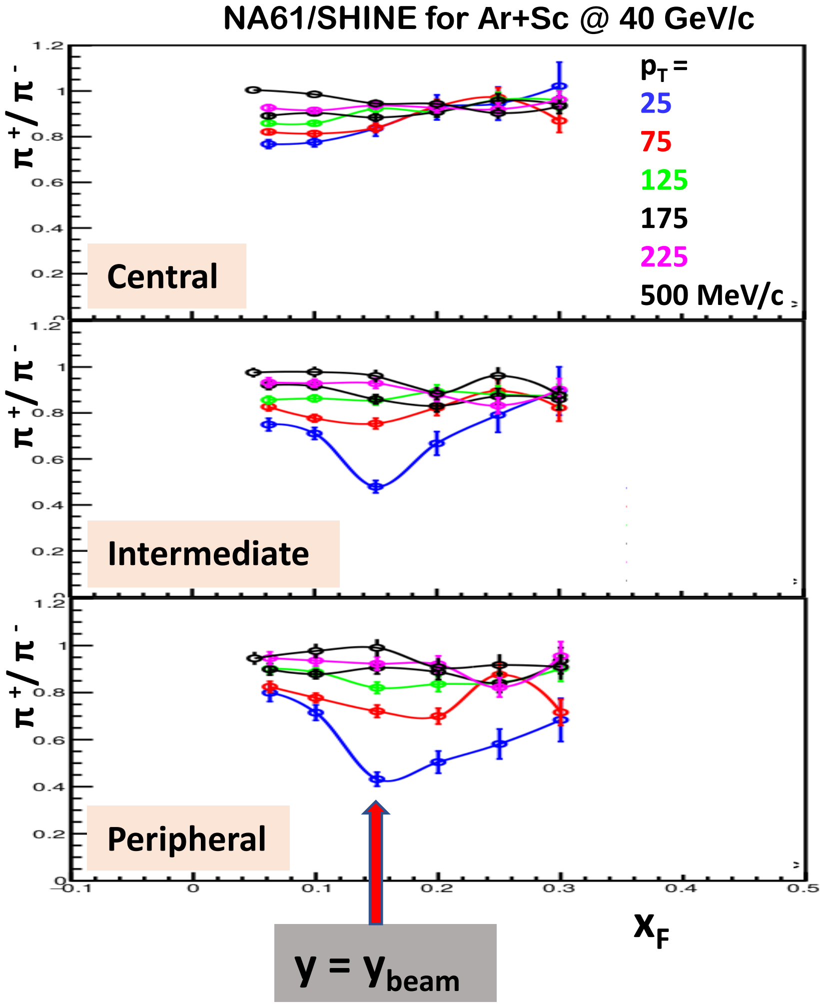


- Effect of change DetCS->BeamCS is small apart from p_T=25 MeV/c.
- At p_T=25 MeV/c, the sensitivity remains below **5%** up to x_F=0.25.
- For preliminary data, we will probably have to **drop** the point (x_F=0.3, p_T=25 MeV/c).

Outlook for π^+/π^- studies:







What do we know at the present moment about EM effects in Ar+Sc?

- simulations using a simplified model performed by Vitalii (see eg. Acta Phys.Pol. B50 (2019), 311)
- stable, non-decaying spectator does not explain the Ar+Sc data at 150*A* GeV/*c* (Mirek)
- the spectator system is higly excited (K.Mazurek, et al. Phys.Rev. C97 (2018) 024604)
- short distance d_E between the fast pion emission zone and the spectator system.

A full database on EM effects in an extended range of centrality in Ar+Sc collisions at 40*A* GeV/*c*, down to peripheral reactions, will allow for a full verification of all these statements.

5) Correlations and fluctuations study

Some definitions :

$$\omega(\pi^+) = \frac{var(n_{\pi+})}{<n_{\pi+}>} \qquad \omega(\pi^-) = \frac{var(n_{\pi-})}{<n_{\pi-}>}$$

$$b_{corr}(\pi^+, \pi^-) = \frac{cov(n_{\pi+}, n_{\pi-})}{\sqrt{var(n_{\pi+}).\, var(n_{\pi-})}}$$

$$\Sigma(\pi^+, \pi^-) = \frac{1}{n_{\pi+} + n_{\pi-}} [<n_{\pi-}>\omega(\pi^+) + \omega(\pi^-)<n_{\pi+}> - 2cov(n_{\pi+} n_{\pi-})]$$

Where $C = n_N - n_P$

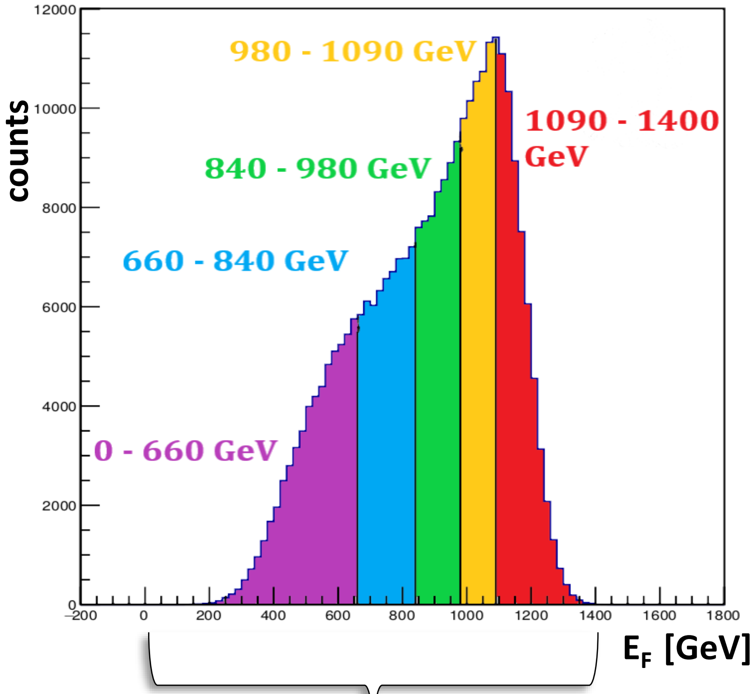
$$\Delta(\pi^+, \pi^-) = \frac{1}{C} [<n_{\pi-}>\omega(\pi^+) - \omega(\pi^-)<n_{\pi+}>]$$

- We want to investigate the **influence of EM effects;**
- Therefore we will study correlations and fluctuations for **multiplicities** of opposite charges : π^+ and π^- **;**
- We have to study them in **selected regions** of **phase space** (x_F, p_T) because the influence of EM effects changes with x_F and p_T.

*** Results from now are for Φ = ± 50°, DetCS and vertexZ = ±10 cm**

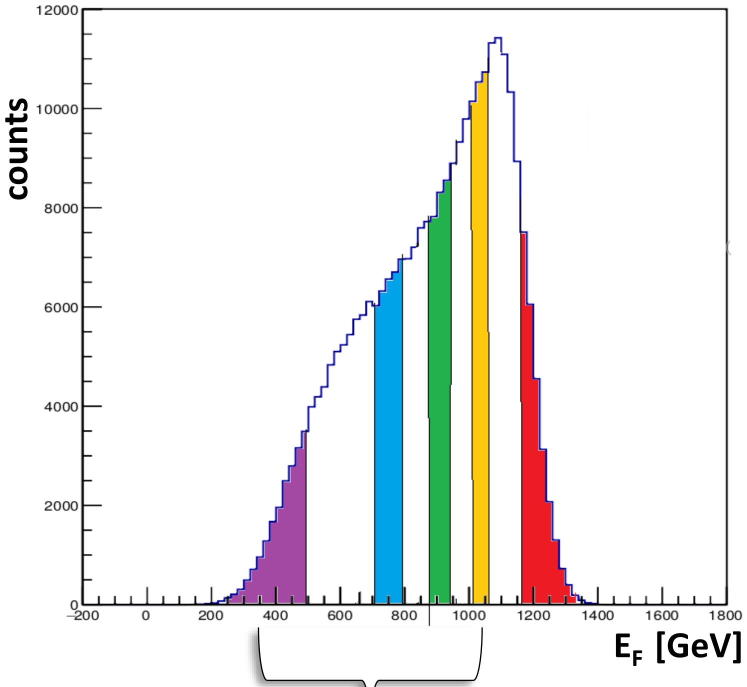
Centrality definition:

Original centrality ranges



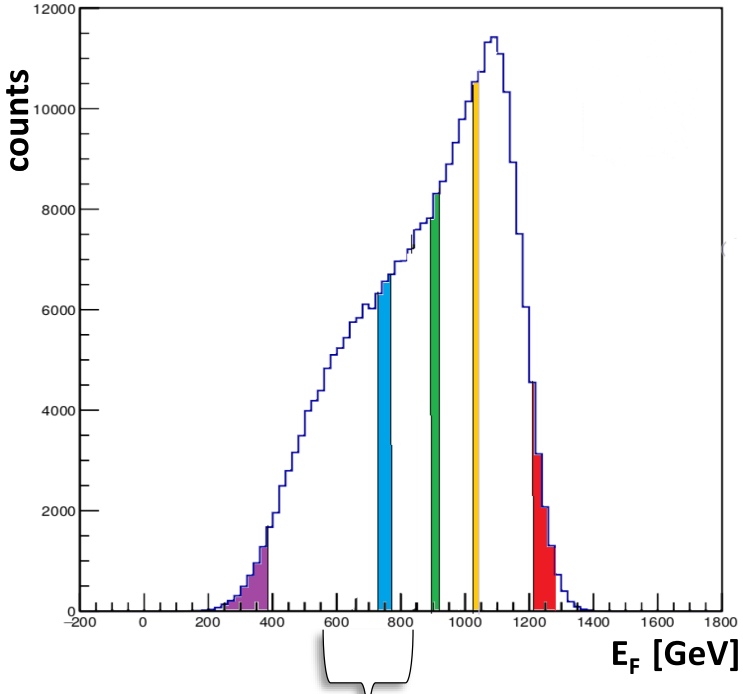
Extended range (0,1400)

2 times smaller centrality ranges



Extended range (350,1050)

5 times smaller centrality ranges



Extended range (560,840)

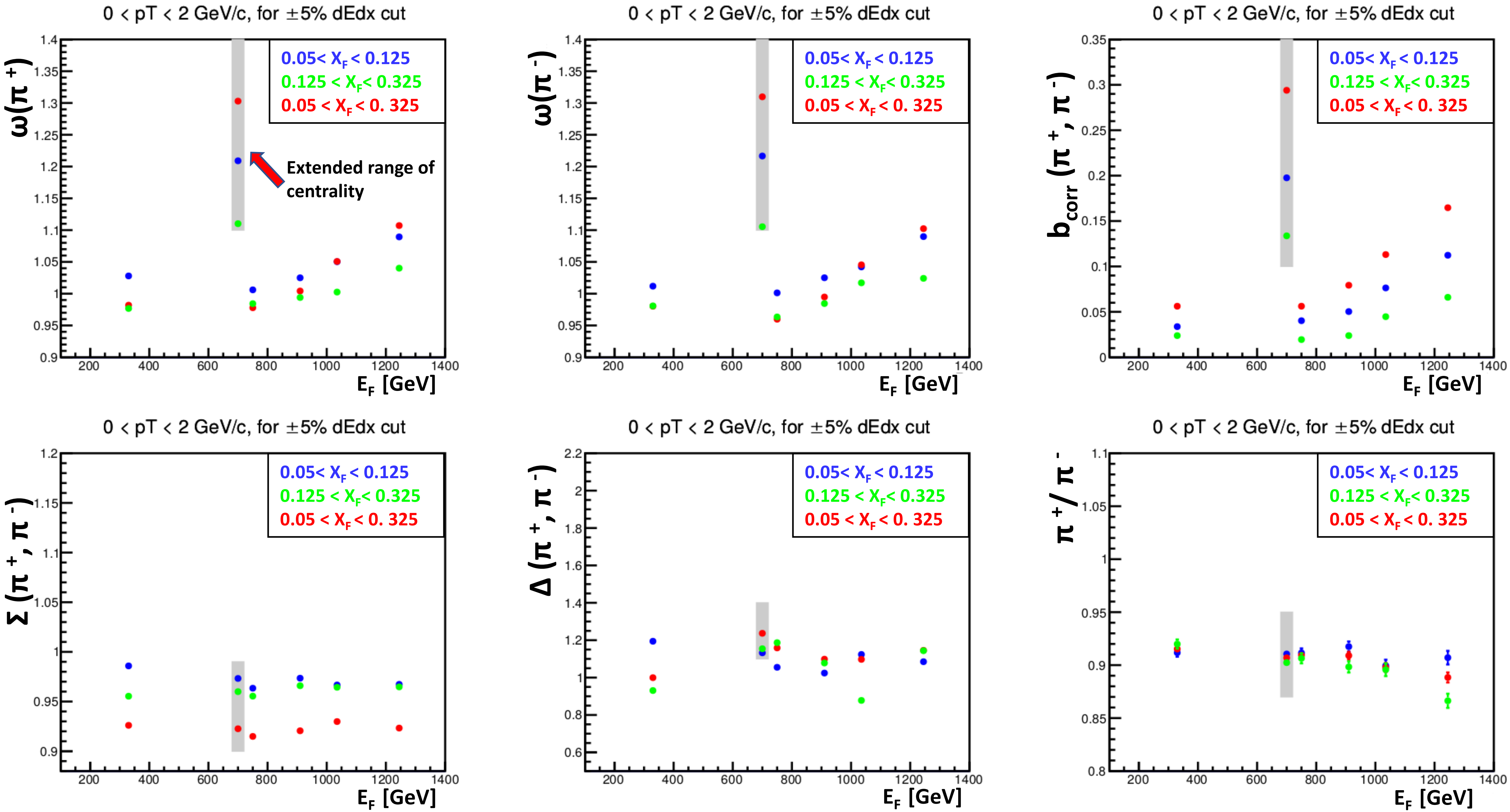
Why we do this?

As we know we have the issue of volume fluctuations so we reduce the ranges in centrality in order to reduce these fluctuations.

I. Sputowska [ALICE Collaboration], MDPI Proc.10, no. 1, 14 (2019).

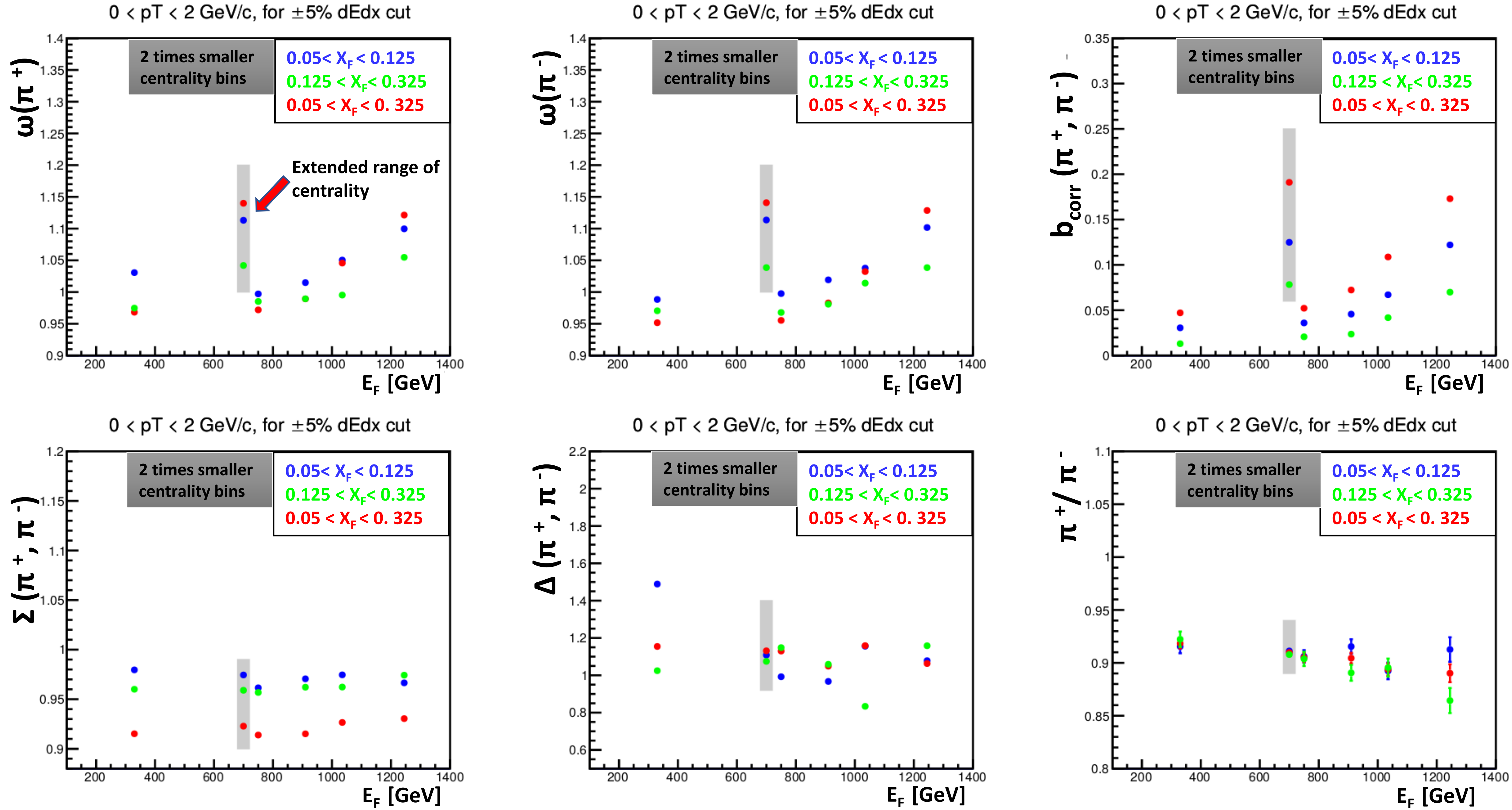
Results for Ar+Sc collisions:

* $0.05 < X_F < 0.125$: No EM region
$0.125 < X_F < 0.325$: EM region



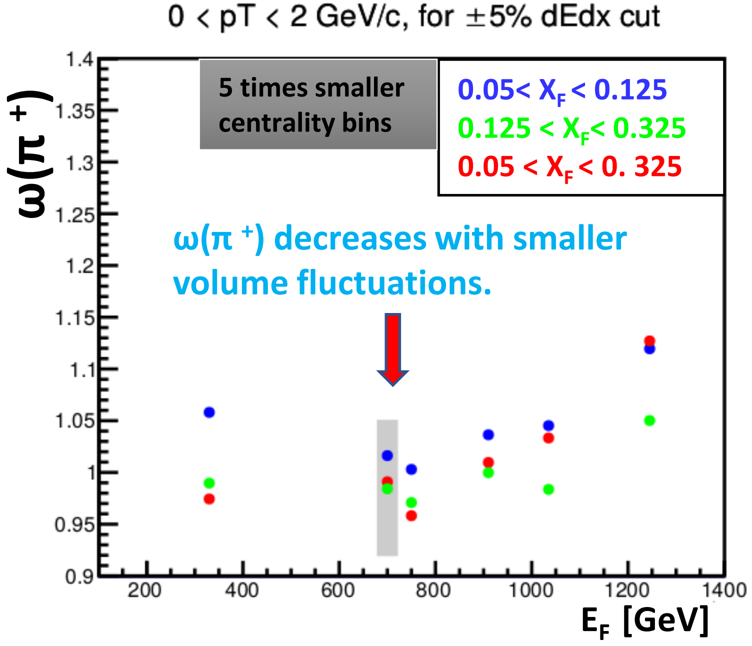
Results for Ar+Sc collisions:

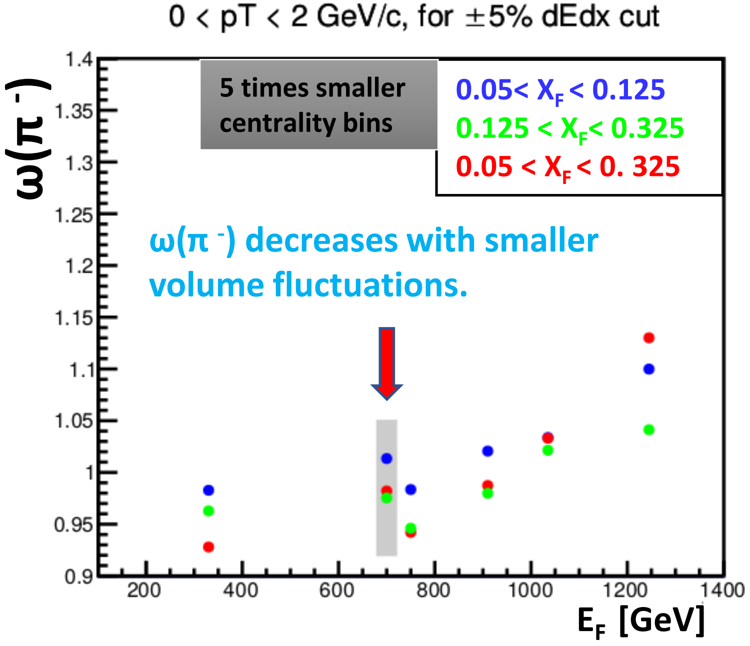
* $0.05 < X_F < 0.125$: No EM region
$0.125 < X_F < 0.325$: EM region

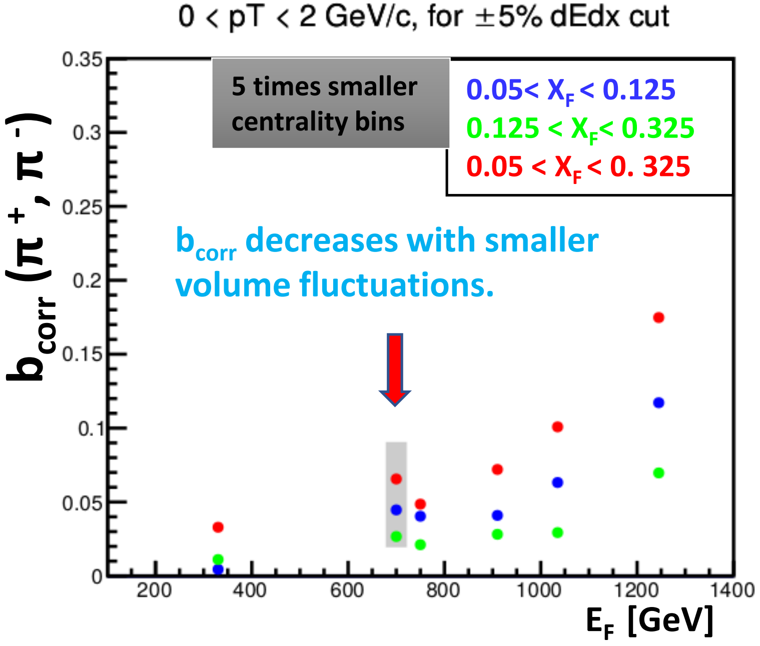


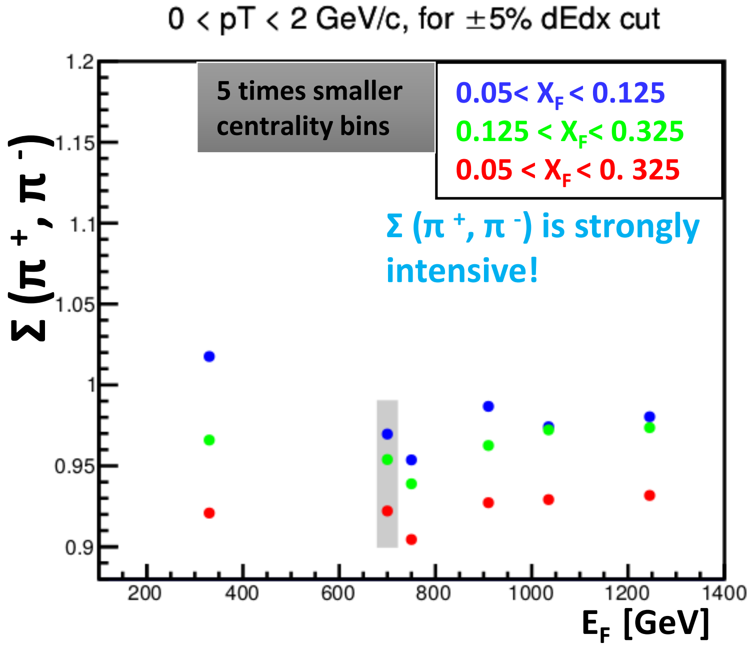
Results for Ar+Sc collisions:

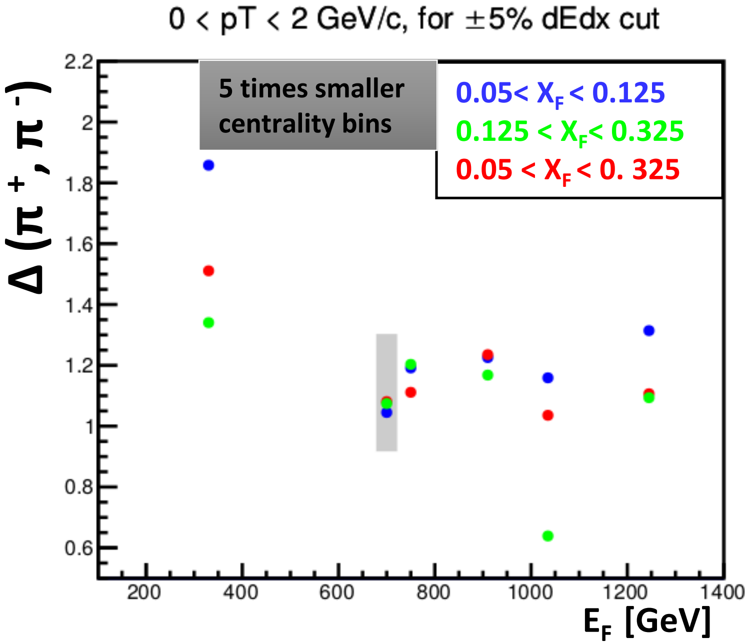
* $0.05 < X_F < 0.125$: No EM region
$0.125 < X_F < 0.325$: EM region

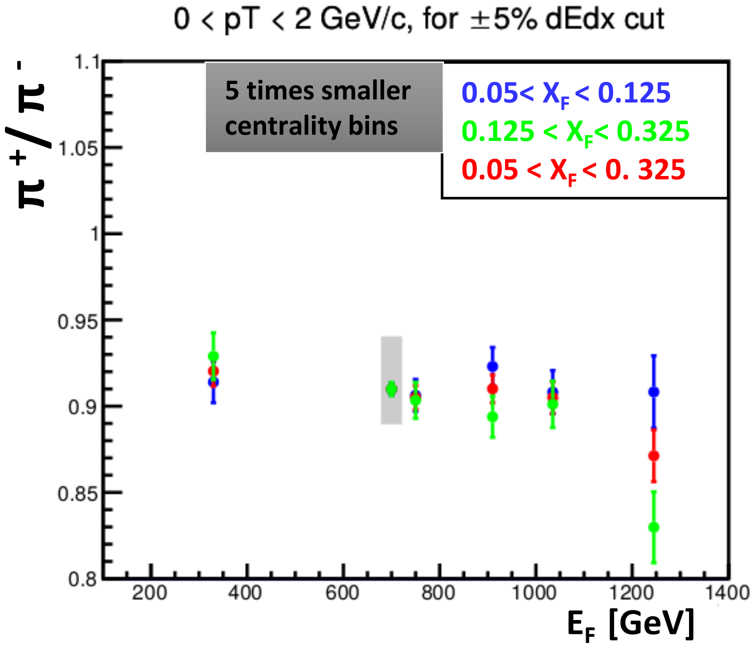




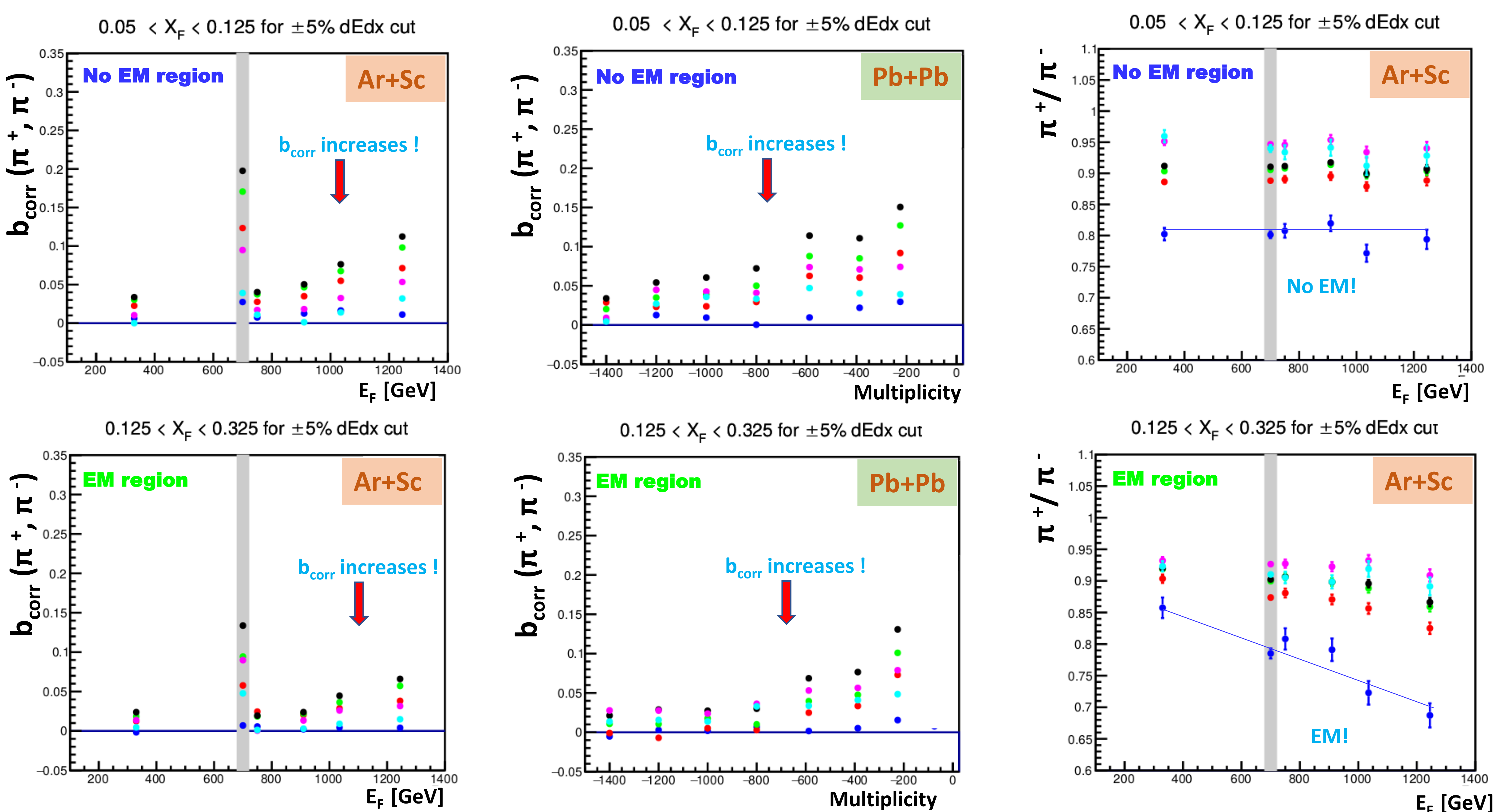






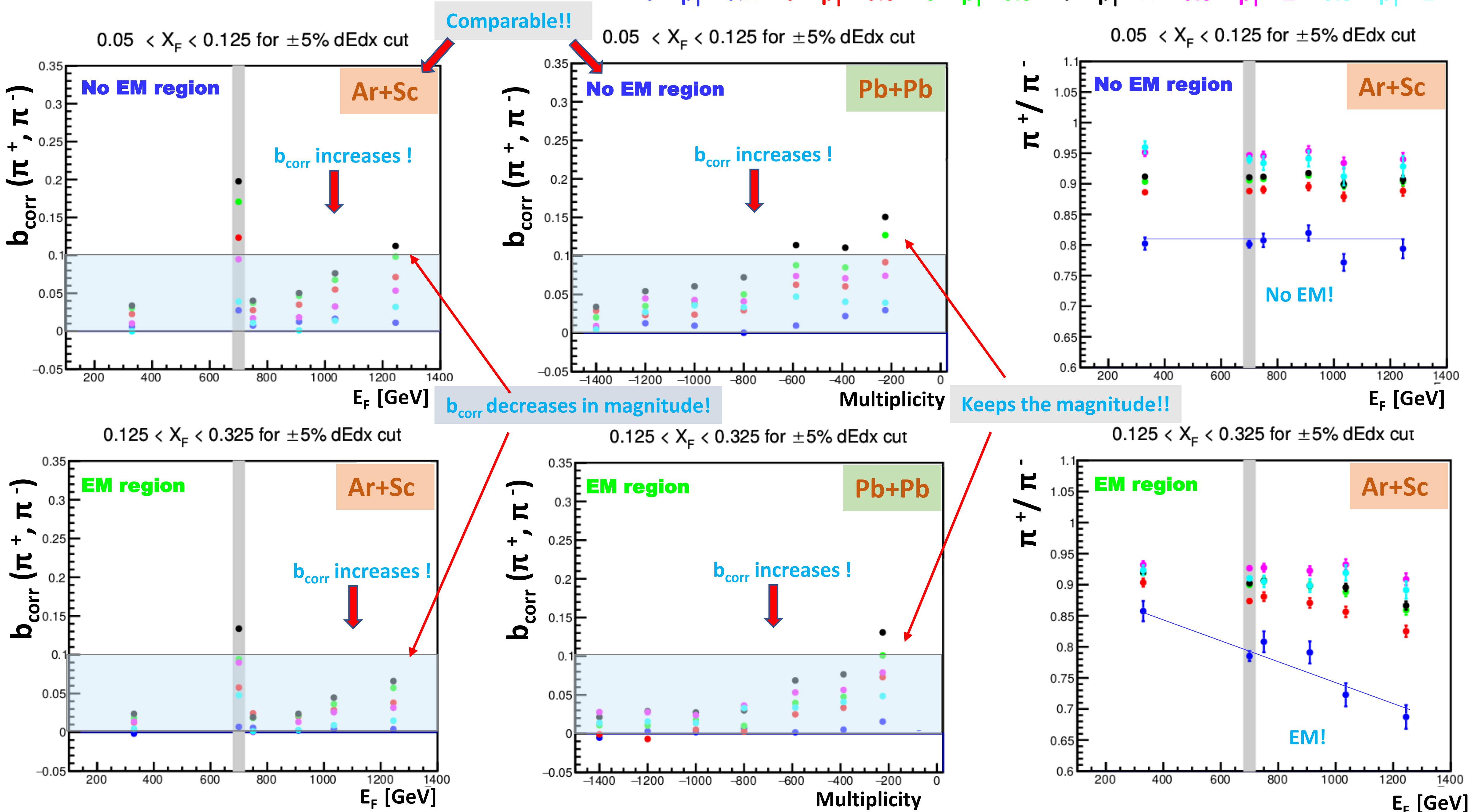


Comparison between Ar+Sc and Pb+Pb:

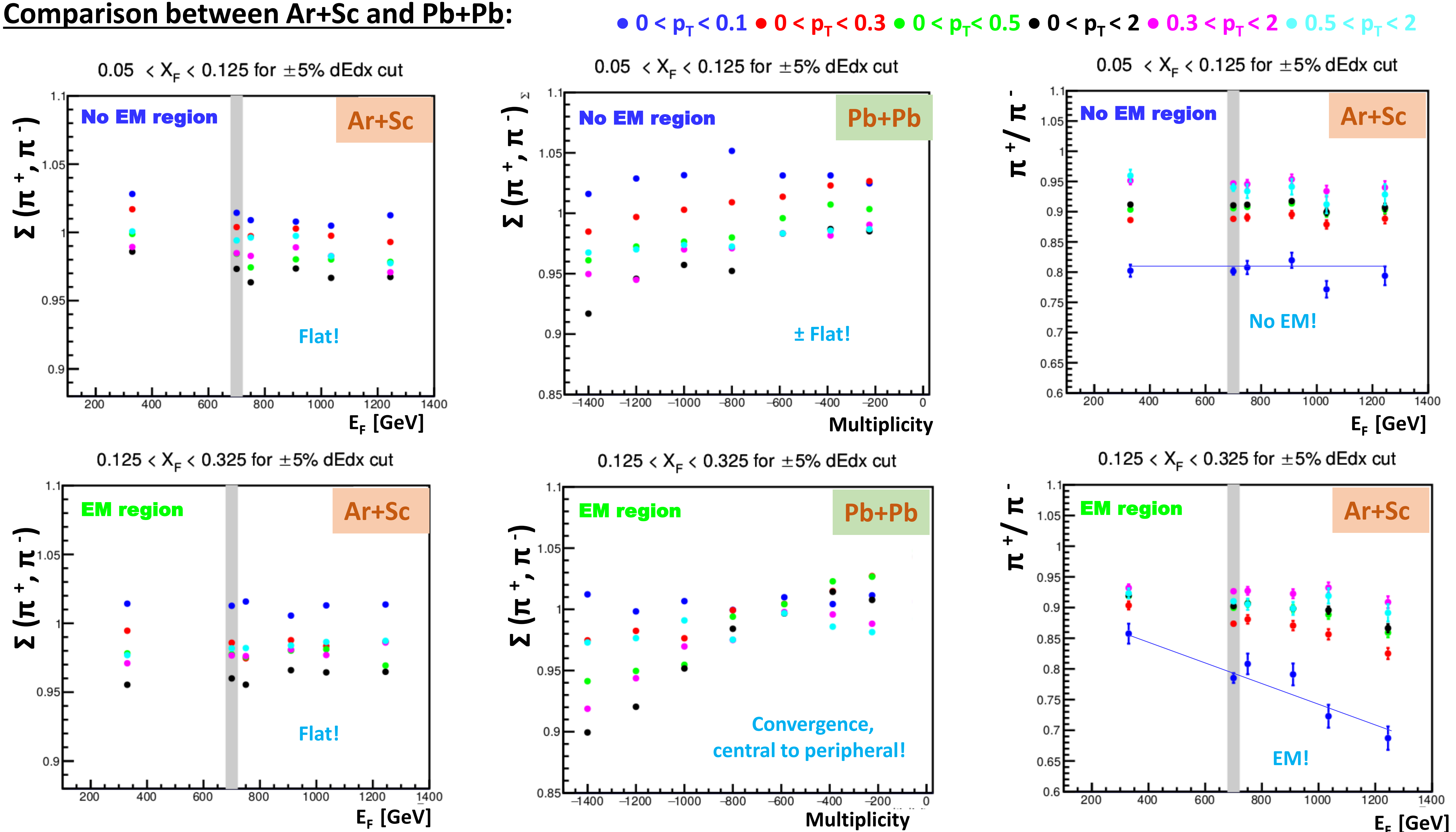


Comparison between Ar+Sc and Pb+Pb:

● $0 < p_T < 0.1$ ● $0 < p_T < 0.3$ ● $0 < p_T < 0.5$ ● $0 < p_T < 2$ ● $0.3 < p_T < 2$ ● $0.5 < p_T < 2$



Comparison between Ar+Sc and Pb+Pb:



Summary:

1. First results for π^+/π^- ratios in Ar+Sc @40 A GeV/c collisions ($\sqrt{s_{NN}}$ = 8.76 GeV).

- ➢ We see the EM effects in the full range of centrality, up to peripheral Ar+Sc reactions **(first time!).**
- ➢ As compared to Ar+Sc @ 150 A GeV/c at intermediate centrality, the effect is slightly stronger in our sample of peripheral collisions. It is weaker if compared to the data on peripheral Pb+Pb @ 158 A GeV/c .

2. A first look at correlations and fluctuations in view of our EM effect analysis.

- ➢ Dependence of $\omega(\pi^+)$, $\omega(\pi^-)$ and bcorr (π^+, π^-) on volume fluctuations as expected.
- ➢ $\Sigma(\pi^+, \pi^-)$ appears to be strongly intensive (again).

Thank you so much!

This work is supported by the National Science Centre, Poland, under grant no. 2014/14/E/ST2/00018

Extra slides

Studying EM effects, text file results!

Data, event and track cuts:

Cuts are same as for T2 trigger!!
Due to that we narrow our range in centrality!

- **NA61/SHINE**, ^{40}Ar + ^{45}Sc @ 40 *A* GeV/*c*.
  → **Production used**: Ar_Sc_40_15/025_17b_v1r6p0_pA_slc6_phys.
  → **Runs**: 21058-21268.

Event cuts:

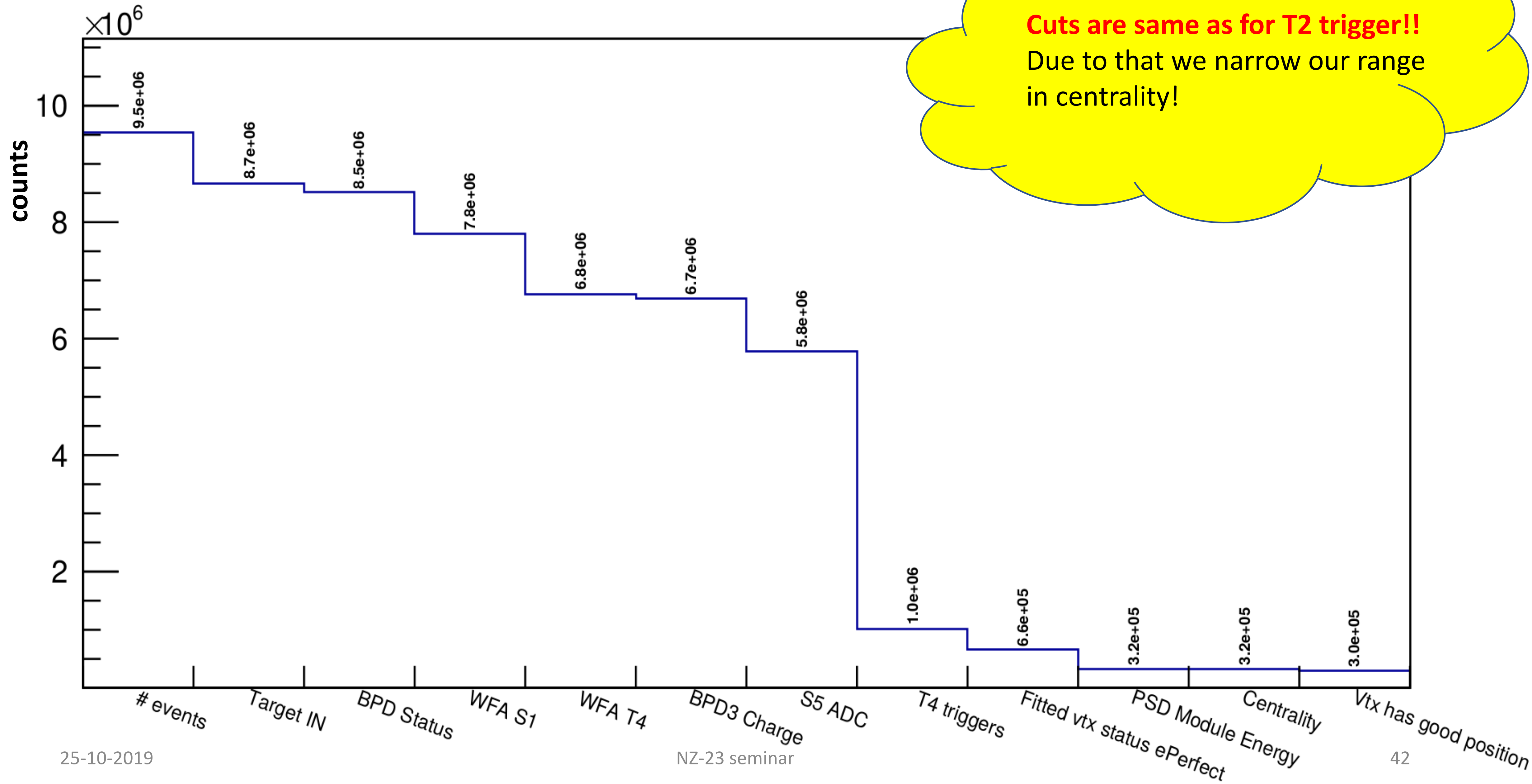
- Target IN,
- BPD status,
- WFA particles (4 μs),
- WFA interaction (25 μs),
- BPD3X(Y) charge,
- S5 (0 → 170),
- **T4 trigger,**
- Vertex track fitted to the main vertex,
- Vertex fit quality = ePerfect,
- Fitted vertex position -580 ± 10 cm.
- Inner and outer PSD module cuts.

Track cuts:

- Track status,
- Charge ± 1,
- Impact point[± 4cm; ± 2cm],
- Total number of clusters ≥ 30,
- VTPCs clusters ≥ 15,
- No GTPC clusters,
- dE/dx clusters ≥ 30,
- **Φ wedge ± 50º.**

- ❑ **We have five centrality cuts based on PSD energy selection.**
- ❑ **The PSD modules 1-28 are selected.**
- ❑ **Total number of events = 296 k.**
- ❑ **Reference NA49, Pb + Pb @ 158 A GeV/*c*, low intensity data, reconstructed with 01J (Pb+Pb chain), with dEdx calibration, centrality defined by cuts in total multiplicity of measured charged tracks.**

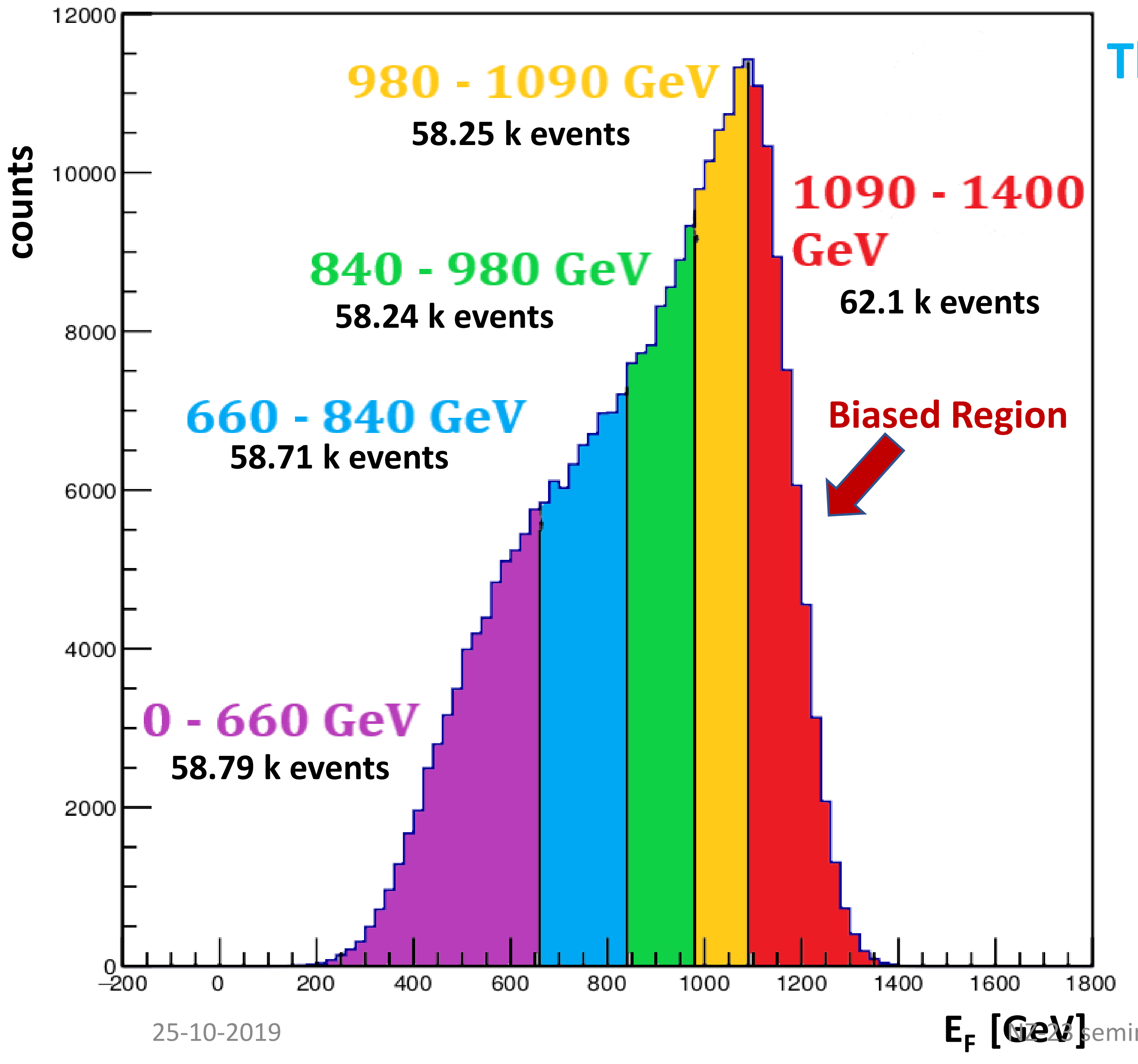
All event cut for Ar+Sc @ 40 *A* GeV/*c* T4 trigger statistics:

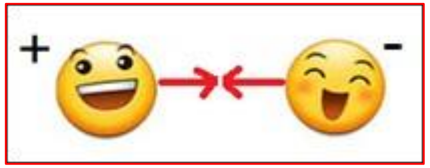


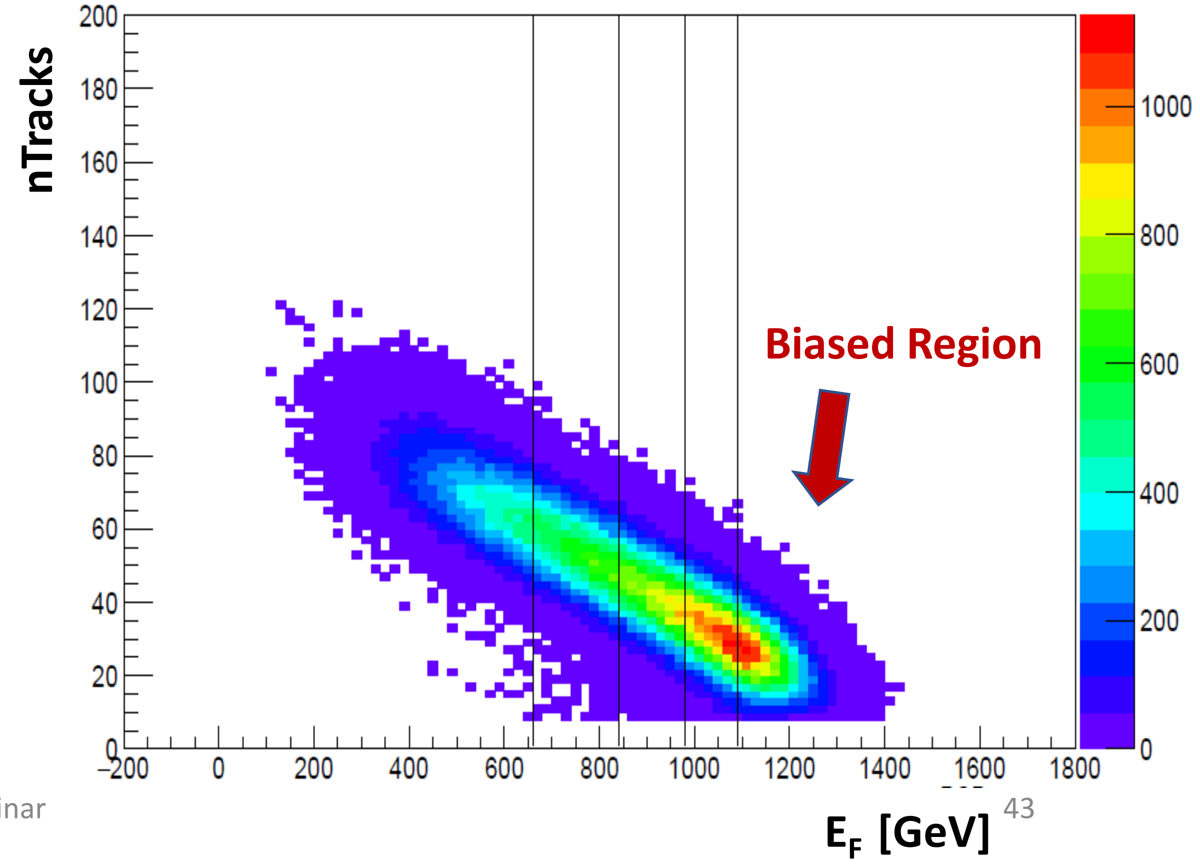
Cuts are same as for T2 trigger!!
Due to that we narrow our range in centrality!

Centrality definition:

E_F = Sum of 1 to 28 PSD modules.
Cut bias above 1090!!
The electromagnetic effect will be most visible in more peripheral collisions!

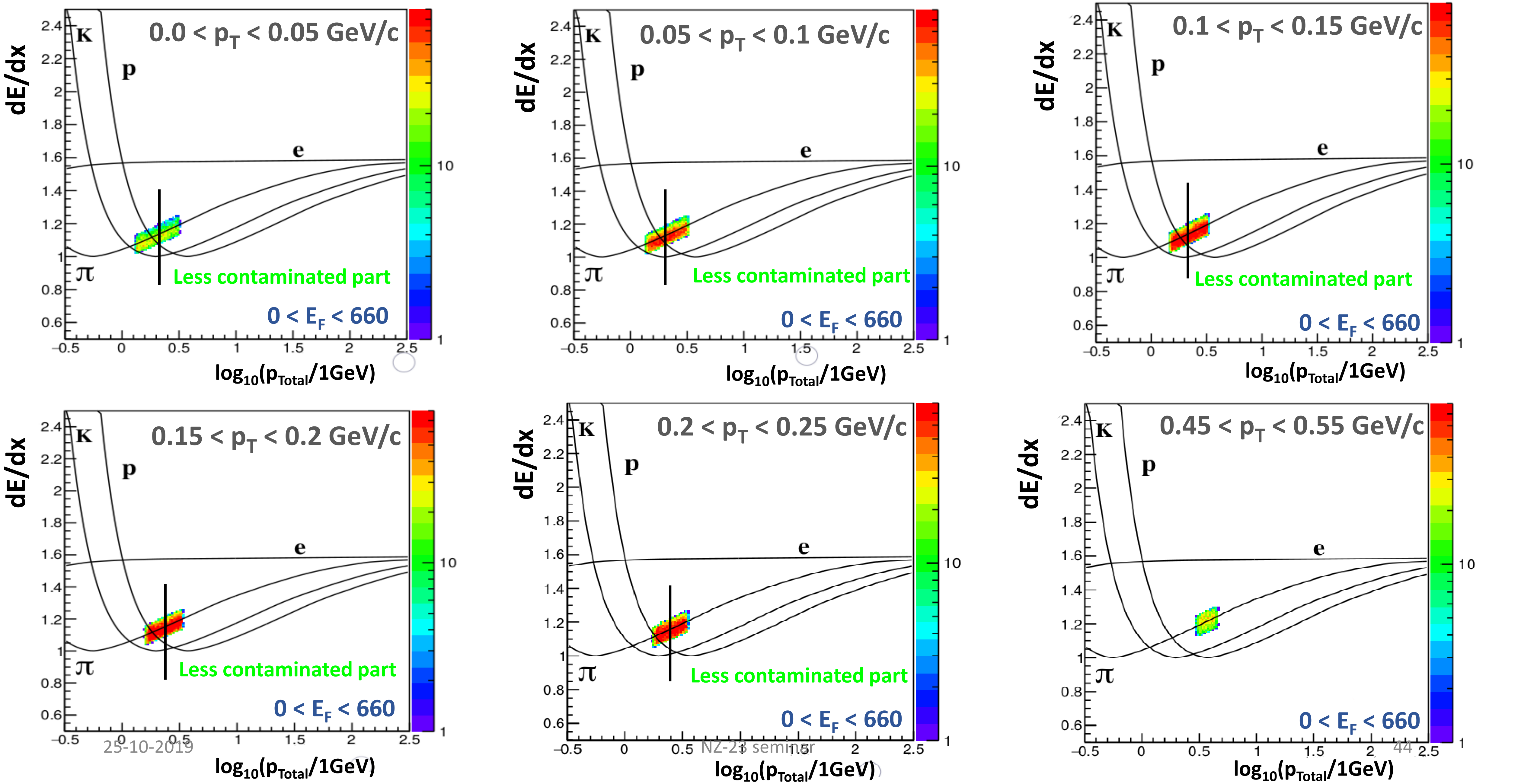




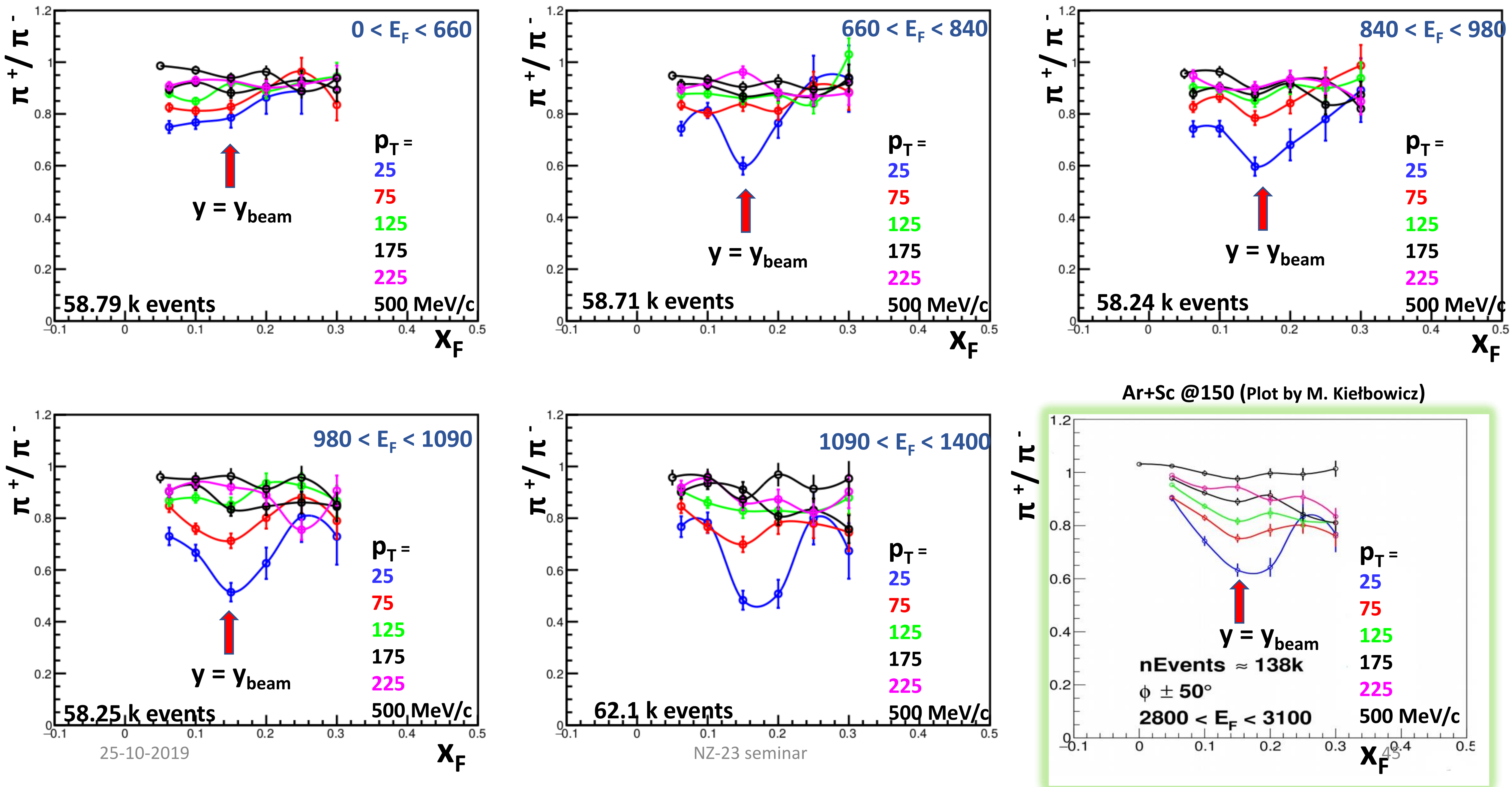


dE/dx plots for the bin $0.025 < x_F < 0.075$:

(for positive particles)



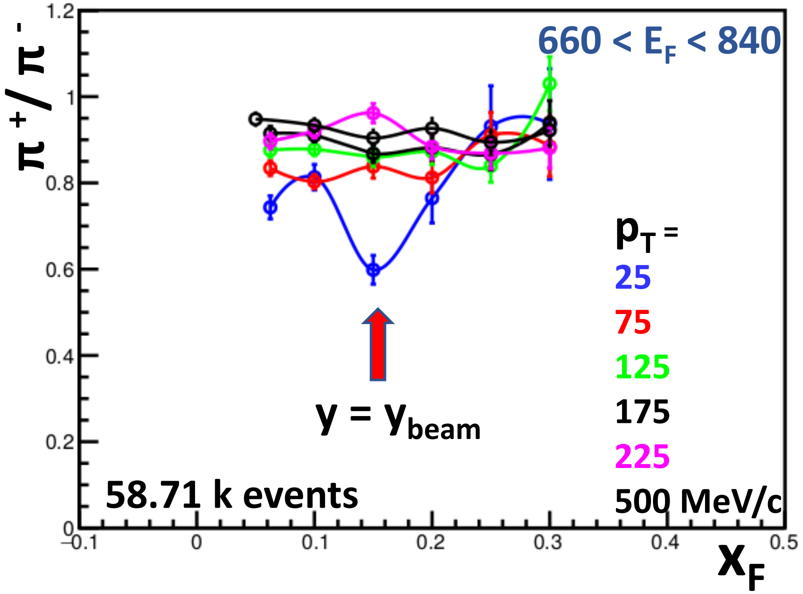
π^+/π^- ratio at five different centralities of Ar+Sc collisions @ 40 *A* GeV/*c*:



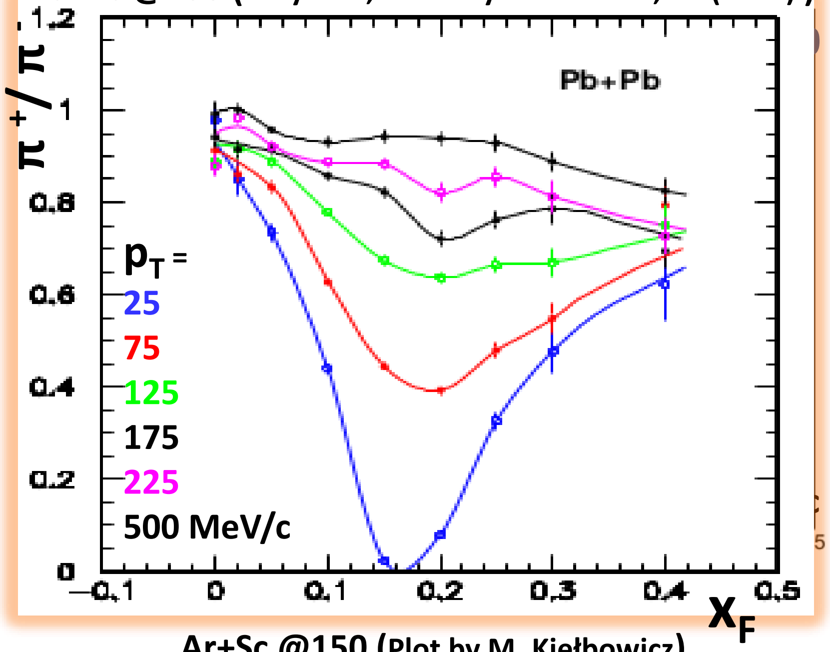
π^+/π^- ratio at five different centralities of Ar+Sc collisions @ 40 *A* GeV/*c*:

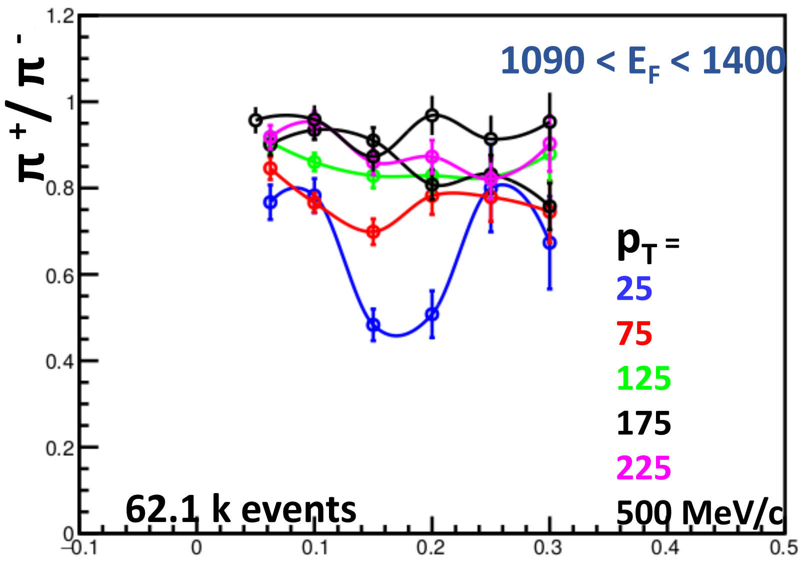
Electromagnetic effects have been seen in Ar+Sc collisions.
As compared to 150 *A* GeV/*c* effect is more strong at 40 *A* GeV/*c* but weaker than in peripheral Pb+Pb at 158 *A* GeV/*c*.

Trigger bias in most peripheral collisions needs an investigation!

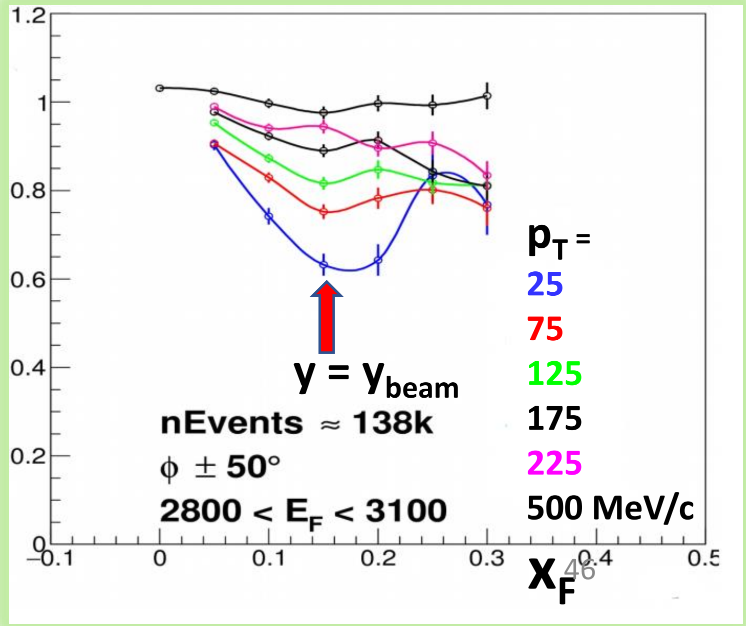


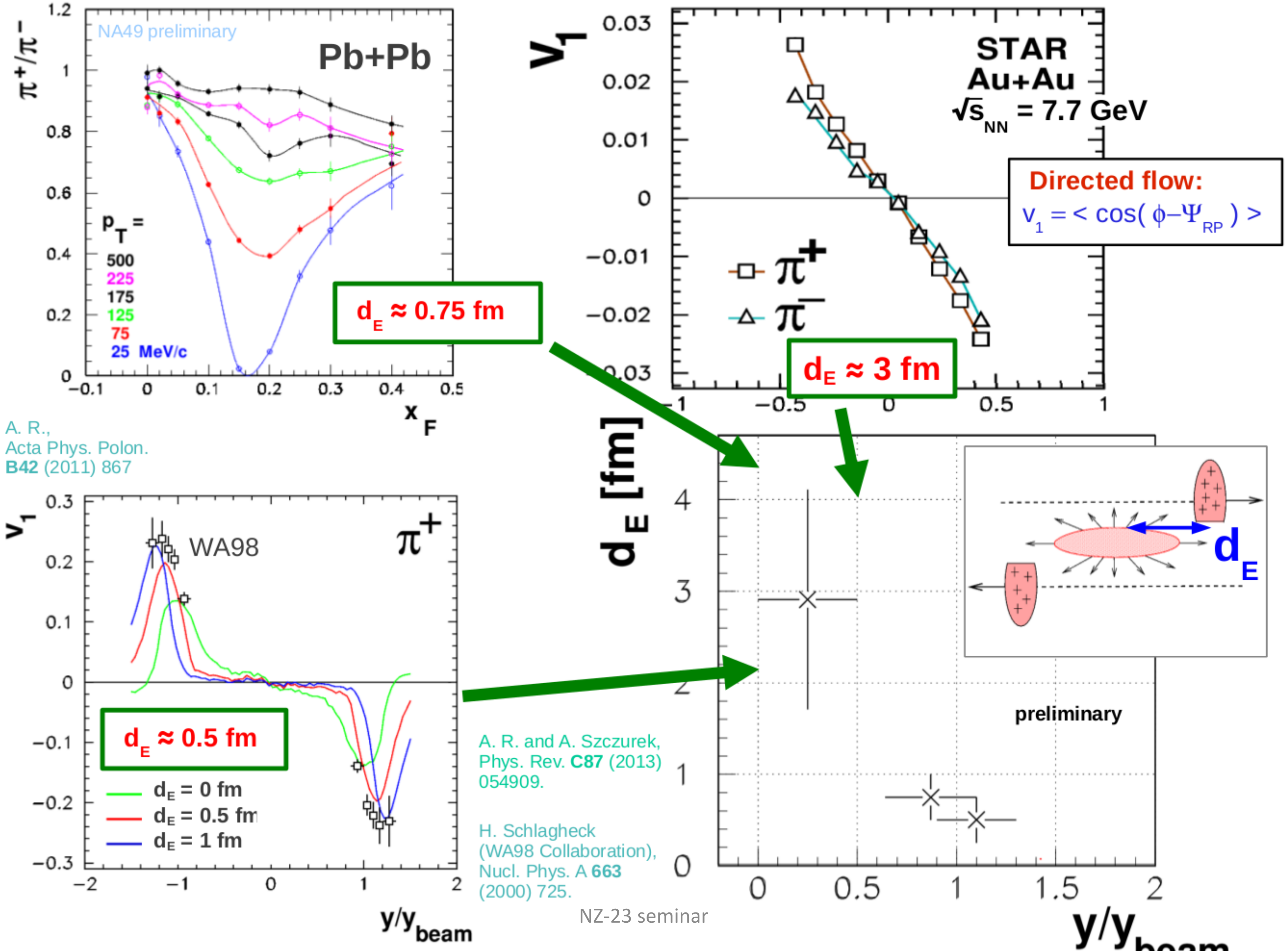
Pb+Pb @158 (A.Rybicki, Acta Phys.Polon.B42,867(2011))





Ar+Sc @150 (Plot by M. Kiełbowicz)





NA49 preliminary
Pb+Pb
π^+/π^-
p_T =
500
225
175
125
75
25 MeV/c
x_F
$d_E \approx 0.75$ fm
STAR
Au+Au
$\sqrt{s_{NN}}$ = 7.7 GeV
v_1
Directed flow:
$v_1 = < \cos(\phi - \Psi_{RP}) >$
π^+
π^-
$d_E \approx 3$ fm
A. R.,
Acta Phys. Polon.
B42 (2011) 867
d_E [fm]
d_E
preliminary
y/y_{beam}
WA98
π^+
v_1
$d_E \approx 0.5$ fm
d_E = 0 fm
d_E = 0.5 fm
d_E = 1 fm
y/y_{beam}
A. R. and A. Szczurek,
Phys. Rev. C87 (2013)
054909.
H. Schlagheck
(WA98 Collaboration),
Nucl. Phys. A 663
(2000) 725.

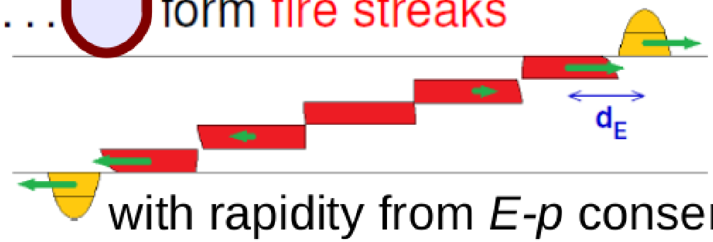
Bricks collide

1 x

Fire tubes explain the whole centrality dependence of pion dn/dy spectrum.

Valid in some extended energy range (9-17 GeV at the least)

. . . form fire streaks



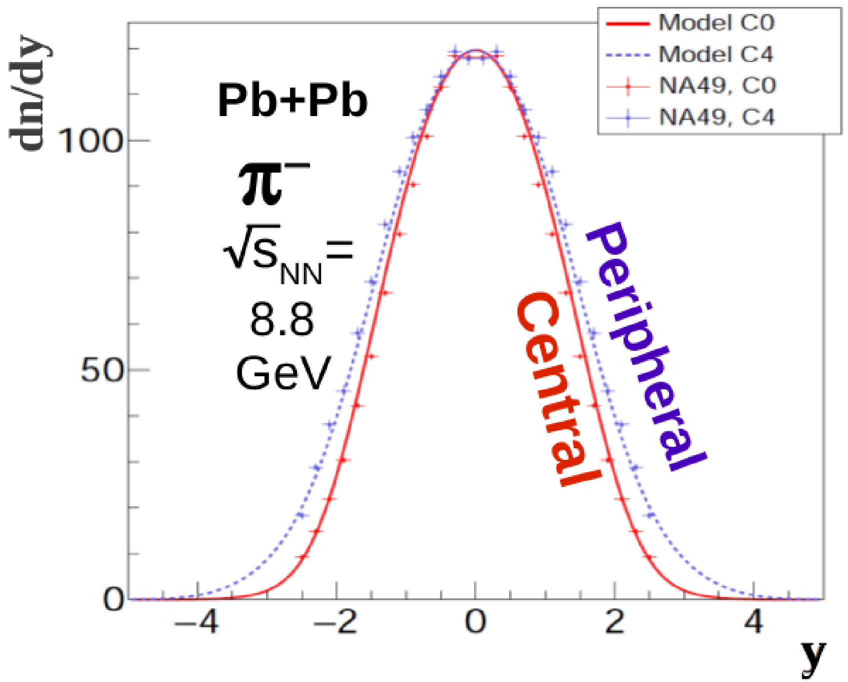
with rapidity from *E-p* conservation

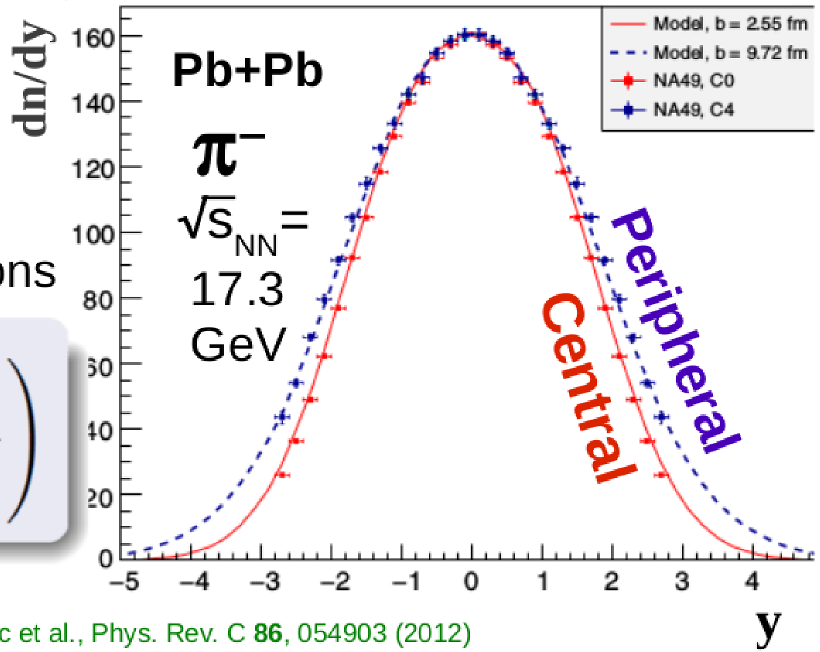
↓

Each fire streak fragments independently into pions

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

Plot at 8.8 GeV by Ł. Rozpłochowski (WFAIS UJ)





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

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