Uniwersytet Wrocławski

Pion spectra in Ar+Sc interactions

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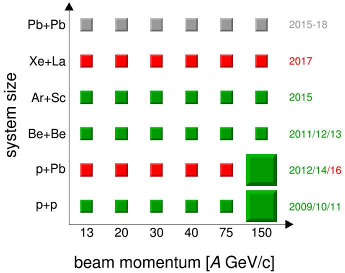
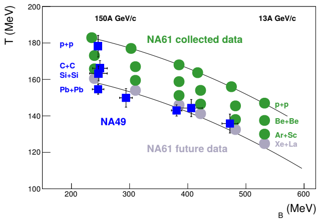
- The search for the **critical point** of the phase transistion
- The study of the **onset of deconfinement**.

Two-dimensional scan in collision energy and the system size probes the QCD phase diagram:



(CERN-SPSC-2006-034) :



This presentation focuses on the preliminary results on **Ar+Sc** collisions.

Outline

^{40}Ar+^{45}Sc energy scan: $13A$, $19A$, $30A$, $40A$, $75A$, $150A$ GeV/c:

Preliminary results on π^- produced in strong and electromagnetic processes at the primary interactions. Selected 0%-5% most central events.

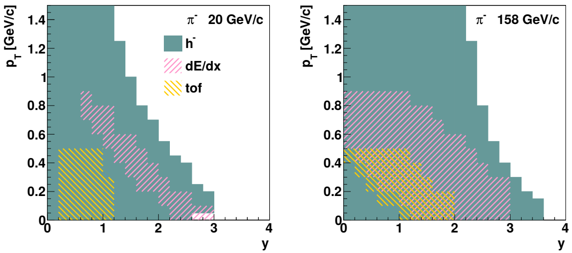
- Double differential spectra in **transverse momentum** ($p_T = \sqrt{p_x^2 + p_y^2}$) and **rapidity** ($y$).
- Rapidity spectra.
- **Asymmetry** of the rapidity distribution.
- **Width** of the rapidity distribution.
- Spectra of **transverse mass** $m_T = \sqrt{m_{\pi^-}^2 + p_T^2}$.
- **System size dependence** of π^- spectra –
  – a comparison with other systems (p+p, Be+Be, Pb+Pb).
- **Mean multiplicities** of negative pions.
- The "**kink**" plot updated with the new data.

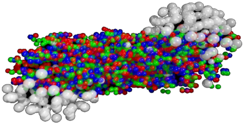
The "h^-" analysis method

Using spectra of negatively charged hadrons for pion analysis

- ≈90% of produced negatively charged hadrons are π^-.
- A small contribution of other particles (K^-, $\bar{p}$, and decays from Λ and K^0_S) is subtracted based on EPOS model.
- The dE/dx and tof identification methods cover much narrower region of the phase-space.

Example of coverage for p+p interactions:





→

- The PSD is located most downstream on the beam line and measures the projectile spectator energy E_F of the non-interacting nucleons of the beam nucleus.
- The energy measured by the PSD is used to select events classes corresponding to the collision centrality.

Note on corrections and errors

Model Corrections

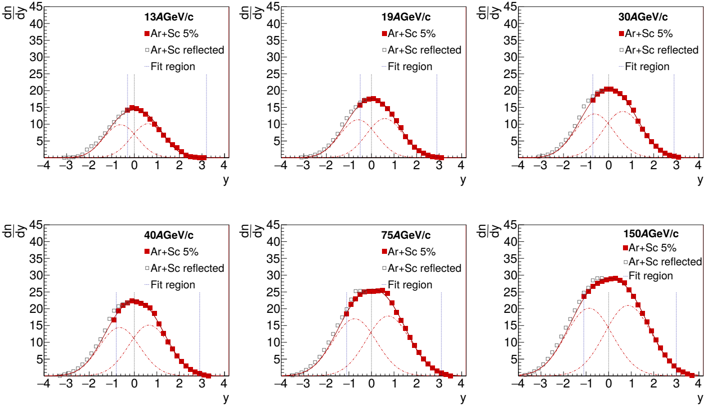
- Monte Carlo used for corrections: EPOS1.99 model (version CRMC 1.5.3), GEANT3.2.
- The centrality classes selected by the number of forward spectators.

Errors

- The spectra are drawn with statistical errors only. There are two sources:
  - Data uncertainties.
  - MC corrections uncertainties (insignificant).
- Based on a previous analysis for other systems (i.e. Be+Be, p+p) in NA61/SHINE, we estimate systematic errors on a level of 5%-10%.

π^- rapidity spectra

Preliminary results



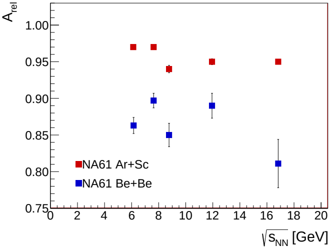
Shown spectra were extrapolated in high p_T.

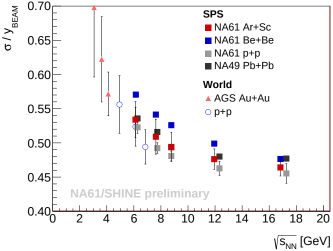
They indicate an asymmetry with respect to c.o.m. rapidity.

Preliminary results

Two symmetricaly placed gaussians, with different amplitudes, are used to construct the fitting function:

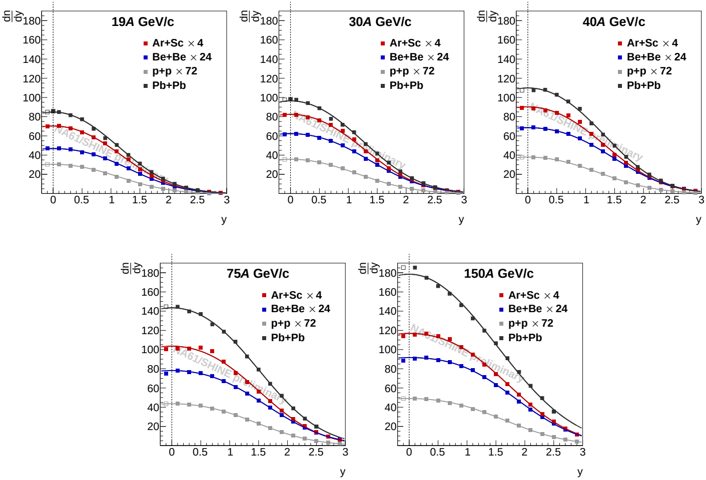
$$f(y) = \frac{A_0 A_{rel}}{\sigma_0\sqrt{2\pi}} \exp\left(-\frac{(y-y_0)^2}{2\sigma_0^2}\right) + \frac{A_0}{\sigma_0\sqrt{2\pi}} \exp\left(-\frac{(y+y_0)^2}{2\sigma_0^2}\right)$$





Shown p+p collisions are uncorrected for isospin effects.

NA61/SHINE p+p results published in Eur.Phys.J. C74 (2014) 2794

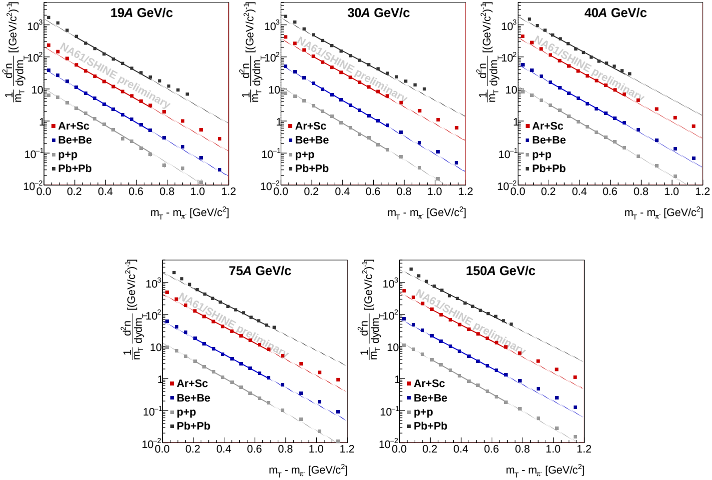


Lines to guide the eye

Preliminary results

m_T SPECTRA – SYSTEM SIZE DEPENDENCE

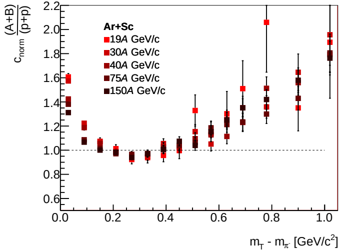
MIDRAPIDITY: $(y \in (-0.2; 0.2))$

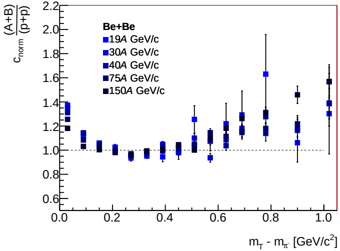


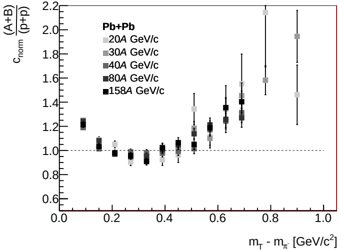
Preliminary results

m_T SPECTRA – RATIO TO $p + p$ COLLISIONS

Various collision momenta for each system.







Preliminary results

Mean Pion Multiplicity

$$\langle \pi^- \rangle = \int_{-4}^{y_{\text{min}}} g(y)dy + \sum_{y_{\text{min}}}^{y_{\text{max}}} dy \left(\frac{dn}{dy} \right) + \int_{y_{\text{max}}}^{4} g(y)dy$$

Numerical Values

Mean π^- multiplicities in the 5 % most central Ar+Sc collisions with systematic and statistical uncertainties:

Momentum [A GeV/c]	13	19	30	40	75
$\langle \pi^- \rangle$	38.46	48.03	59.72	66.28	86.12
$\sigma_{\text{stat}}(\langle \pi^- \rangle)$	$\pm$0.021	$\pm$0.021	$\pm$0.024	$\pm$0.018	$\pm$0.0079
$\sigma_{\text{sys}}(\langle \pi^- \rangle)$	$\pm$1.92	$\pm$2.40	$\pm$2.98	$\pm$3.31	$\pm$4.30

- Statistical uncertainties are propagated from the statistical uncertainties of $\frac{dn}{dydp_T}$ spectra.
- Systematic uncertainties are assumed to be 5% based on previous NA61 analysis (from p+p collisions).

Number of Wounded Nucleons

Two different models investigated:

- Glissando (Glauber Model)

  Glissando 2.73, Comp. Phys. Commu., 185(6):1759-1772, 2014

- EPOS (Parton Ladder Model)

  EPOS 1.99 (version CRMC 1.5.3), Phys. Rev. C, 74:044902, Oct 2006

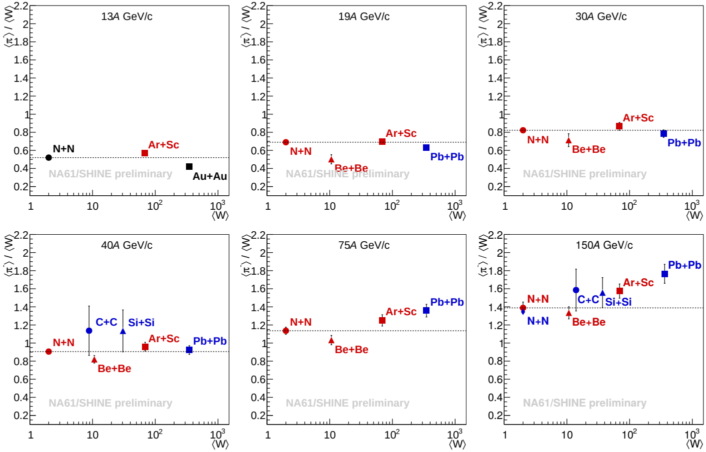
Numerical comparison

Momentum [A GeV/c]	13	19	30	40	75	150
$\langle W \rangle_{\text{EPOS}}$	50.63	54.68	58.44	59.01	61.12	63.04
$\langle W \rangle_{\text{Glissando}}$	67.44	68.85	68.98	69.01	68.87	69.18

Chosen 5 % of collisions with the smallest number of projectile spectators.

For historical consistency Glissando Model was chosen for further calculations.

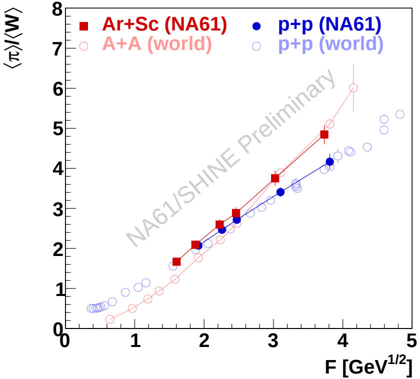
Ar+Sc and Be+Be preliminary



Comparison of the $\langle \pi^- \rangle / \langle W \rangle$ ratio from measurements in the SPS energy range.

Preliminary results

The kink



The "kink" plot with the preliminary Ar+Sc results..

- For high SPS energies Ar+Sc follows the Pb+Pb trend.
- For low SPS energies Ar+Sc follows the p+p tendency.

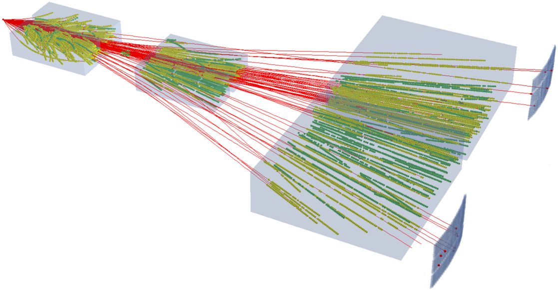
Summary

The new preliminary results on negative pion production properties in **Ar+Sc** at six beam momenta (13A-150A GeV/c) were presented.

- Rapidity spectrum is almost symmetric for **Ar+Sc** interaction (**Be+Be** data shows far higher asymmetry).
- The rapidity distribution width decreases monotonically with collision energy and falls close to the values for **Pb+Pb**
- The rapidity spectrum shape resembles the one of **Pb+Pb** interactions.
- The m_T distribution for all compared ion systems is qualitatively simillar. This suggests the presence of the radial flow.
- The number of the wounded nucleons is determined from the Glissando Model.
- Preliminary results on $\langle\pi^-\rangle/\langle W\rangle$ in Ar+Sc collisions were shown.

More analysis on this subject will follow in a near future.

Thank you for your attention!



Backup slides

PRESENTED AR+SC DATA

- **Ar+Sc** 5% most central collisions from **NA61/SHINE** at: $19A$, $30A$, $40A$, $75A$ and $150A$ GeV/c

OTHER SYSTEMS

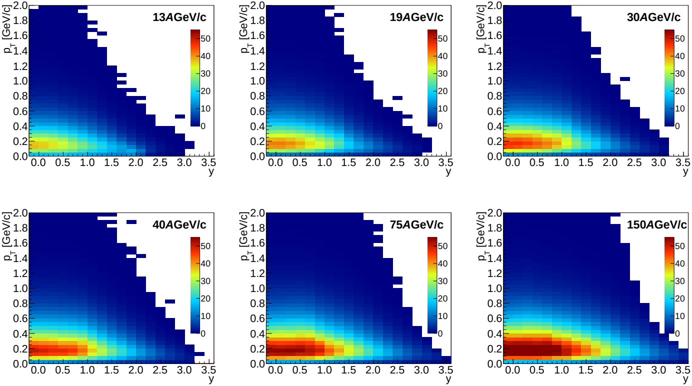
- **p+p** inelastic collisions from **NA61/SHINE** at: 20, 31, 40, 80 and 158 GeV/c
  [Eur.Phys.J. C74 (2014) 2794]
- **Be+Be** 5% most central collisions from **NA61/SHINE** at: $19A$, $30A$, $40A$, $75A$ and $150A$ GeV/c
  Preliminary results: [PoS CPOD2014 (2015) 053]
- **Pb+Pb** 5%-7% most central collisions from **NA49** at: $20A$, $31A$, $40A$, $80A$ and $158A$ GeV/c
  [Phys.Rev.C (2002) 66:054902; Phys.Rev.C (2008) 77:024903]

Double differential π^- spectra

p_T vs y in Ar+Sc collisions – preliminary

Preliminary double differential spectra:

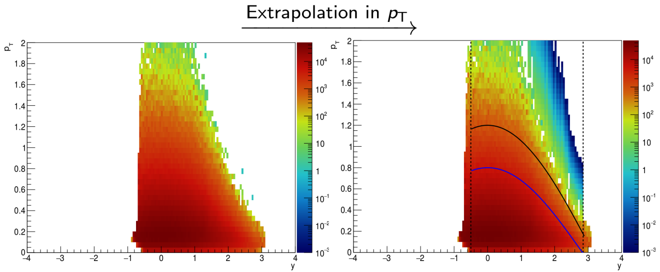
$$\frac{dn^2}{dy\ dp_T}$$



Measurements cover almost full acceptance in the forward rapidity.

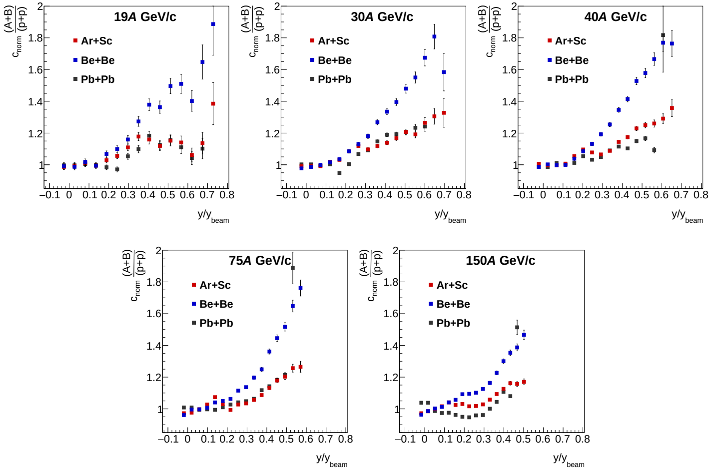
Extrapolation in p_T

- In order to increase the accuracy, the data is extrapolated beyond the detector acceptance.
- Exponential dependence in p_T is assumed.
- The extrapolation functions are fitted in the region between the blue and the black curve.
- The function integral from acceptance edge to $p_T = 3.0$ is added to the rapidity bin.



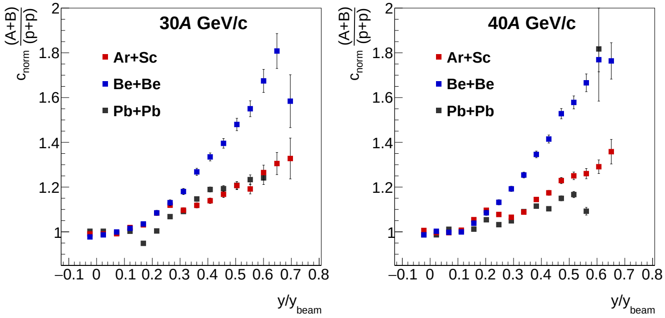
Normalized $\frac{dn}{dy}$ spectra divided by the normalized $\frac{dn}{dy}$ data on **p+p** inelastic interactions.

"Normalized" – divided by integral in $y \in (0.0, 0.5)$.



π^- rapidity spectra

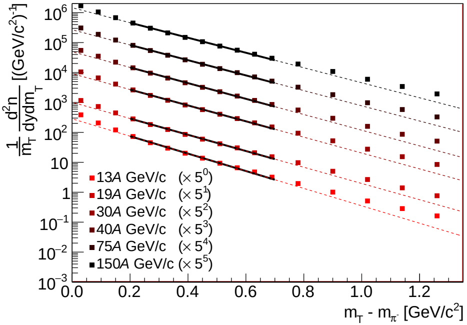
ratio to $p + p$ collisions



- The spectrum shape for **Ar+Sc** interactions is resembling very closely **Pb+Pb** spectrum.
- **Ar+Sc** spectra differ significantly from the ones for **Be+Be**.

Preliminary results

m_T distribution in midrapidity $(y \in (-0.2; 0.2))$



- The m_T spectra are scaled by an arbitrary constant for a better clarity of the plot.
- Indications of the radial flow in high m_T.

Preliminary results

Isospin correction

In order to compare results obtained for different systems, the **isospin correction** should be taken into account. To this end a phenomenological formulas are used:

$$\left\langle \pi^{-} \right\rangle_{N+N} = \left\langle \pi^{-} \right\rangle_{p+p} + \frac{1}{3}$$

$$\left\langle \pi^{-} \right\rangle^{I}_{Au+Au} = \left(\left\langle \pi^{-} \right\rangle_{Au_A u} + \left\langle \pi^{+} \right\rangle_{Au_A u} \right) /2$$

The correction is only applied to measurements where its effect is the strongest. This assumption is based on the compilation of the world data presented in

A. I. Golokhvastov; "Koba-Nielsen-Olesen scaling"; Physics of Atomic Nuclei, 64(1):84-97, 2001.

and the model presented therein.

Legitimacy of the h^- method

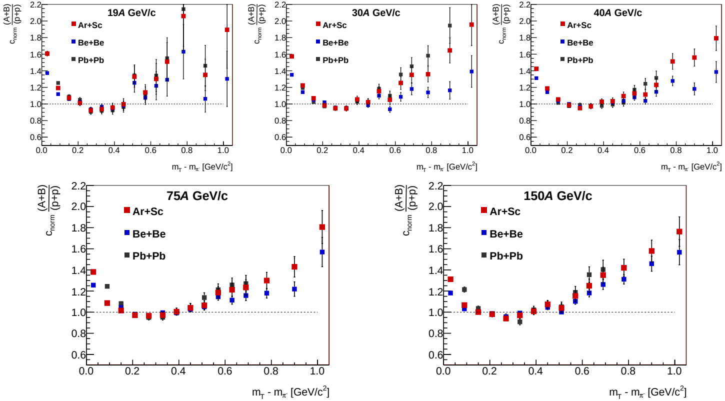
- Checked on **p+p** data:
  - The EPOS model reproduced the K^-/π^- ratio very well.
  - The EPOS model reproduced the Λ production well.
  - "h⁻" reproduced very well the results from dE/dx and dE/dx-tof analysis.
- ... and on **Be+Be** data
  - Preliminary results on dE/dx and dE/dx-tof analysis showed good agreement.

m_T SPECTRA – RATIO TO $p+p$ COLLISIONS

MIDRAPIDITY: $(y \in (-0.2; 0.2))$

Normalized ion spectra divided by the normalized **p+p** data.

"Normalized" – divided by integral in $(m_T - m_{\pi^-}) \in (0.2, 0.7)$.

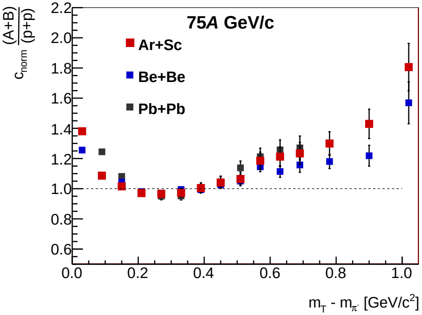


Various systems for each collision momentum.

Preliminary results

m_T SPECTRA – RATIO TO $p+p$ COLLISIONS

MIDRAPIDITY: $(y \in (-0.2; 0.2))$



- The shape of the m_T spectra for all ions' interactions is simillar.
- The deviation from the **p+p** data in high m_T is higher for heavier ions.

Preliminary results

The $\langle\pi\rangle/\langle W\rangle$ ratio has often been plotted against the Fermi energy measure

$$F = \left[\frac{(\sqrt{s_{\mathrm{NN}}} - 2m_{\mathrm{N}})^3}{\sqrt{s_{\mathrm{NN}}}}\right]^{1/4}$$

.

As for NA61/SHINE there are results only for $\langle\pi^-\rangle$ in Ar+Sc, Be+Be and p+p collisions, the multiplicities of $\langle\pi^+\rangle$ and $\langle\pi^0\rangle$ were approximated by

$$\langle\pi\rangle_{\mathrm{p+p}} = 3\langle\pi^-\rangle_{\mathrm{p+p}} + 1$$

and

$$\langle\pi\rangle_{\mathrm{Ar+Sc}} = 3\langle\pi^-\rangle_{\mathrm{Ar+Sc}}$$

.

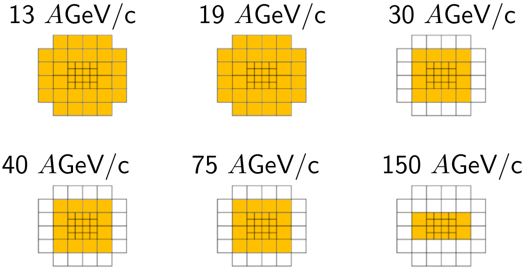
Centrality selection in Ar+Sc collisions

Projectile Spectator Detector

Due to the:

- Ratio of *Fermi motion* to the beam rapidity,
- Differences in magnetic field and
- PSD position for various energies,

different set of modules is chosen to calculate the E_F:



The module sets are chosen on the basis of corelations between energy and multiplicity for each module.

Slope parameter

The comparison of the slope T of the fitted exponenta.
(The errors are fit uncertainties)