Multiplicity fluctuations in relativistic ion collisions

Status of the h^- intermittency analysis in Xe+La at 150A GeV/c at the NA61/SHINE experiment at CERN

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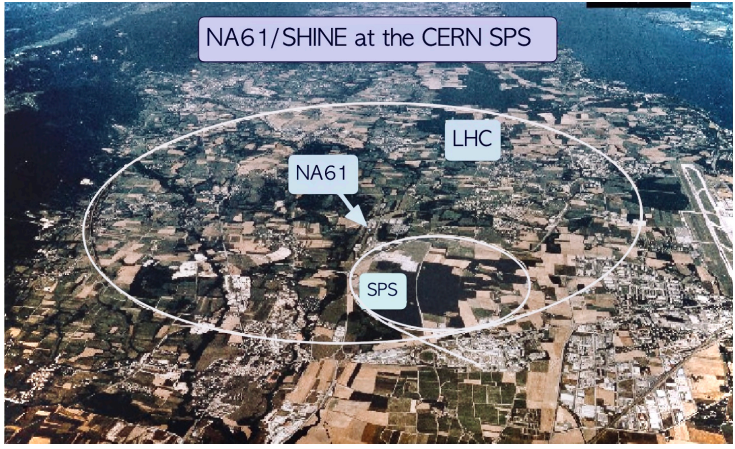
Overview

The main goal of this analysis is to locate critical point of strongly interacting matter by measuring from second to fourth scaled factorial moments (SFMs) for a selection of primarily negatively charged hadrons (from strong and electromagnetic interaction) in ^{131}Xe+^{139}La interactions at 150A GeV/c ($\sqrt{s_{NN}} \approx 17$ GeV) using statistically independent points and cumulative variables.

NA61/SHINE

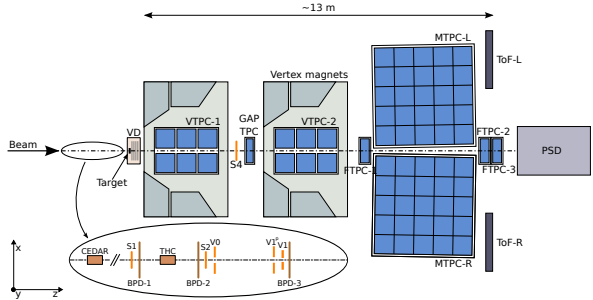
NA61/SHINE experiment at CERN/SPS

NA61/SHINE (SPS Heavy Ion and Neutrino Experiment) is a particle physics fixed-target experiment at CERN SPS. It studies the hadronic final states produced in interactions of various beam particles with a variety of fixed nuclear targets at the SPS energies.

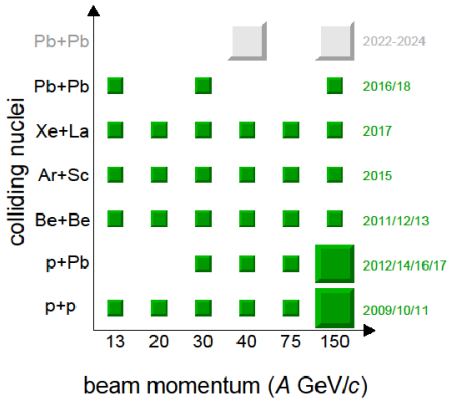


NA61/SHINE experiment at CERN/SPS

- 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



NA61/SHINE Physics program



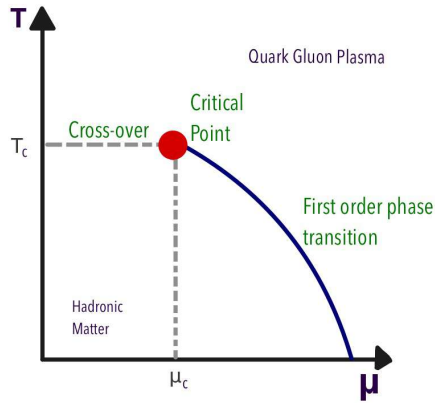
NA61/SHINE performs scan in beam momenta (13A–150A GeV/c) ($\sqrt{s_{NN}} \approx$ 5–17 GeV) and mass of colliding nuclei (p+p, p+Pb, Be+Be, Ar+Sc, Xe+La, Pb+Pb)

- Study of the properties of the onset of deconfinement
- Heavy quarks: direct measurement of open charm at SPS energies
- Measurements for the J-PARC and Fermilab neutrino programs
- Measurements of nuclear fragmentation cross sections for cosmic rays physics

Search for the Critical Point

QCD critical Point

- Critical Point (CP): a hypothetical end point of first order phase transition line (QGP-HM) that has properties of second order phase transition.
- Second order phase transition → scale invariance → power-law form of correlation function. [a]
- These expectations are for fluctuations and correlations in the configuration space.
- They are expected to be projected to the momentum space via quantum statistics and/or collective flow. [b]

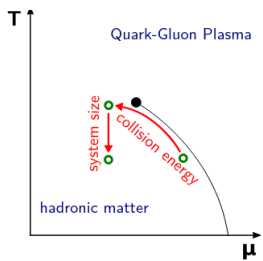


[a] Casalbuoni, De Curtis, Gatto, Pettini, PLB 231 (1989) 46

[b] Asakawa, Yazaki NPA 504 (1989) 668 Barducci

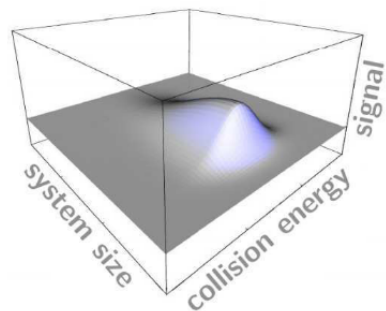
QCD critical Point

Search for the critical point in heavy-ion collisions is performed by scan in the parameters controlled in laboratory (collision energy and nuclear mass number).



By changing them, we change freeze-out parameters (T, μ_B).

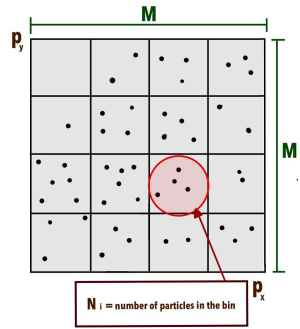
Sketch of the critical hill expected in the search for the critical point in the two dimensional plane of system size and collision energy.



Experimental measures

Scaled factorial Moments

- In NA61/SHINE at CERN SPS, intermittency analysis is performed at mid-rapidity and particle fluctuations are studied in transverse momentum plane.
- At the second order phase transition (critical point), the system becomes scale invariant.
- This phenomenon leads to enhanced multiplicity fluctuations with special properties, that can be revealed by scaled factorial moments:



$$F_r(M) = \frac{\left\langle \frac{1}{M}\sum_{i=1}^{M} N_i(N_i-1)\ldots(N_i-r+1) \right\rangle}{\left\langle \frac{1}{M}\sum_{i=1}^{M} N_i \right\rangle^r}$$

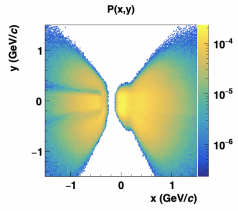
Cumulative Variables

Instead of using p_x and p_y, one can use cumulative quantitities Q_x, Q_y:

- Transform any distribution into uniform distribution (0,1)
- Remove the dependence of F_r on the shape of single particle distribution
- Intermittency index of an ideal power law correlation function remain invariant after the transformation. [a] [b]

$$Q_x = \int_{x_{min}}^{x} \rho(x)dx / \int_{y_{min}}^{x_{max}} \rho(x)dx$$

$$Q_y = \int_{y_{min}}^{y} P(x,y)dy / P(x)$$



This is just an example

[a] Bialas, Gazdzicki, PLB 252 (1990) 483

[b] Antoniou, Diakonos, https://indico.cern.ch/event/818624

Experimental results

Current progress

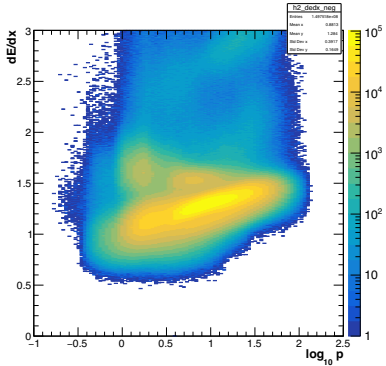
- Analysis on experimental data collisions in Xe+La at 150A GeV/c
  - Xe+La at 150A GeV/c.
  - Total number of events is: 4 737 271
  - Data obtained in 2017
- Event Selection
  - T2 trigger – 'central' events with interaction
  - Good Beam Position
  - Interaction point fit quality
  - no off-time particles
  - events with interaction point inside the target.

Current progress

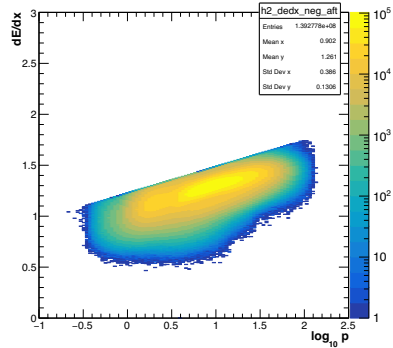
- Analysis of experimental data collisions in Xe+La at $150A$ GeV/c
- Event Selection
- Track Selection
  - Track fit status
  - number of VTPC clusters
  - number of all clusters
  - ratio of measured to potential clusters
  - Impact parameter $|b_x| < 4cm$, $|b_y| < 2cm$
  - Negative tracks (except electrons)

dE/dx Distribution: selecting h^- candidates

The analysis focuses on negatively charged hadrons, to select them, we look at the Energy Loss distribution (dE/dx) measurements done by the TPC detector, and selected the proper candidates for the analysis, by neglecting the noise and electrons using Particle Identification.



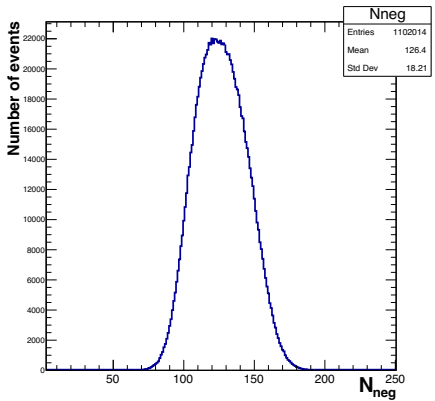
dE/dx distribution before PID cut



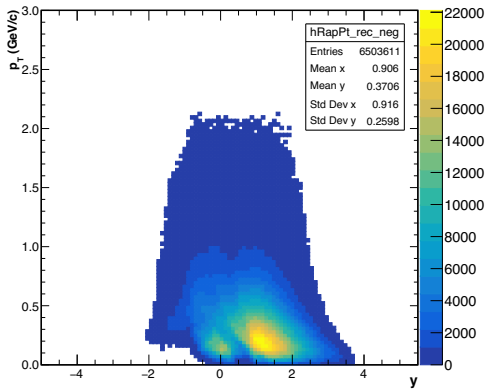
dE/dx distribution after PID cut

h^- multiplicity distribution

The current selection of candidates has the following multiplicity distribution (left) and Transverse momentum vs Rapidity (right).

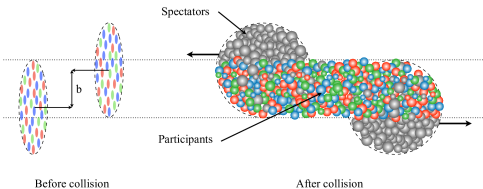


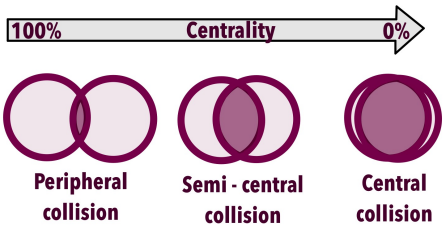
Multiplicity distribution Negative Particles



2D histogram Transverse Momentum vs Rapidity

Centrality selection for Data

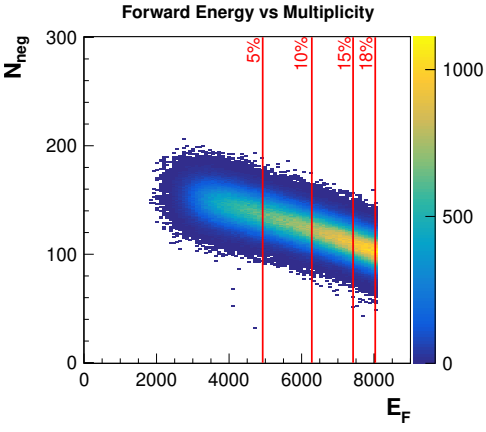


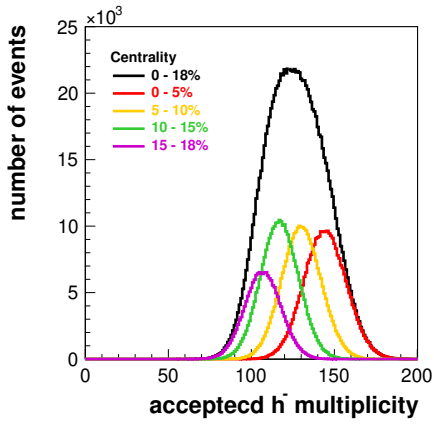


- The analysis focuses in the most central collisions
- The centrality is preliminary selected by on-line T2 trigger (0-18%). Additional selection is done based on forward energy deposited in PSD calorimeter.
- We want to reduce the effect of fluctuations in the number of participants, minimizing the variation of the number of projectile participants, therefore we use mostly central events.

Centrality selection for Data

Centrality selection based on Forward energy measured by PSD detector.





Results

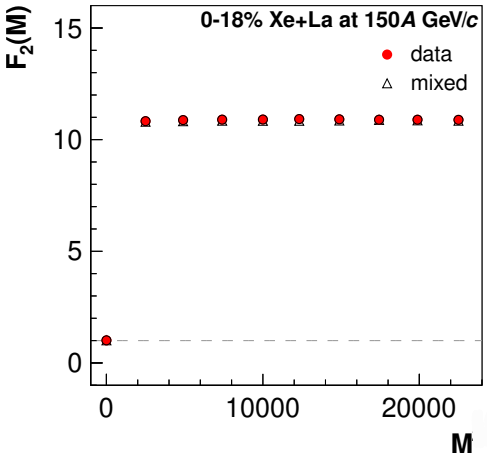
- Experimental data is noisy → a background of non critical pairs must be subtracted at the level of factorial moments. Also intermittency of Mixed events, breaks any correlation existing during the collisions that could lead to confusing results.
- In the following slides Intermittency results will be revealed at the level of subtracted moments $\Delta F_r(M)$.
- For non cumulative results: Non critical background moments can be approximated by (uncorrelated) mixed event moments; then: [1]

$$\Delta F_r(M) \approx F_r^{data}(M) - F_r^{mix}(M)$$

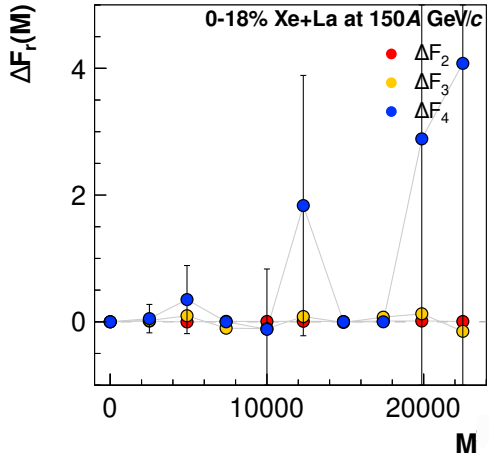
- But for Cumulative results this turns to be:

$$\Delta F_r(M) \approx F_r^{data}(M) - F_r^{data}(1)$$

Results (0–18%) centrality

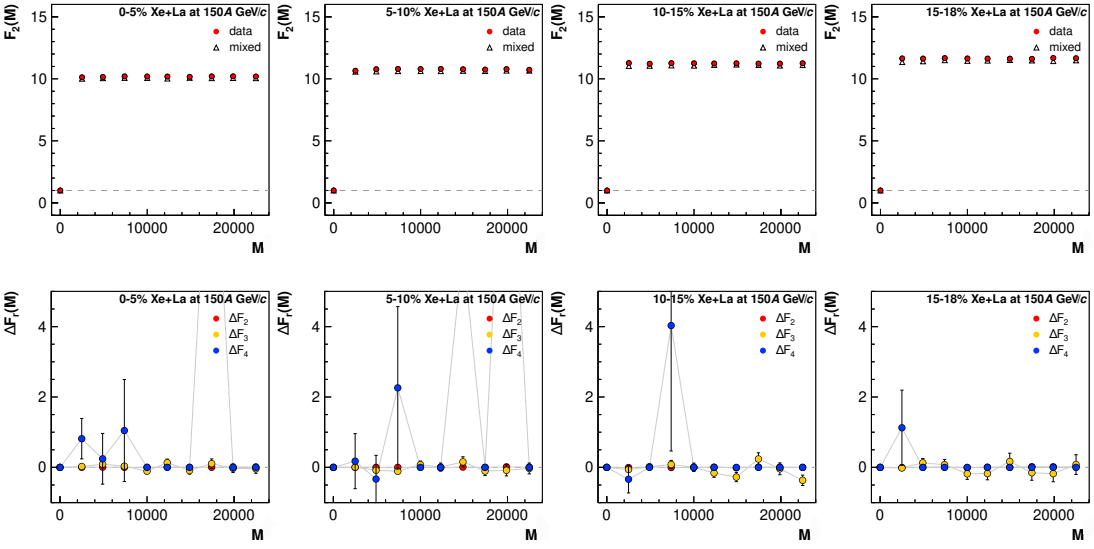


Uncorrelated points, non-cumulative



Uncorrelated points, cumulative

Results in centrality intervals



Conclusions and outlook

Summary:

- First results on Scaled Factorial Moments of primary produced negatively charged hadrons from Xe+La collisions at 150A GeV/c for non-cumulative and cumulative transverse momentum in 5 centrality intervals were presented

Current work not shown here:

- Model comparison (momentum-based Two-Track Distance, Acceptance map)
- Improvement on event and track selection

Thank you!

Backup slides

Data Description

This presentation reports the current status of h^- intermittency analysis of the following data set:

- Xe+La at 150A GeV/c.
- Total number of events is: 4 737 271
- Data obtained in 2017
- Path: `/eos/experiment/na61/data/prod/Xe_La_150_17/039_17c_v1r18p0_pA_centos7_phys/minishoe.root/`
- Global key 039, Shine Version : v1r18p0, Date: 2021-04-06

Event Cuts

The Current event selection of cuts is based on presentation of Andrey Seryakov and Oleksandra Panova [2]

Event cut List		
Cut	N.of events	Percentage
Original	4737271	
T2	3591902	100%
Good BPD	3543947	99%
Vtx Fit Quality	3541350	98%
WFA S1 and WFA T4	1853185	51%
Vertex Z	1768387	49%
BPD3 charge	1760261	48%
S1	1760131	48%
PSD status	1759801	48%
T2 biased	1102014	30%

Track cuts

Preliminary cuts from Ar+Sc:

Track cut list		
Cut	N. of tracks	Percentage
Track Status	$7.21{\cdot}10^8$	100%
VTPC cluster > 15	$3.37{\cdot}10^8$	47%
All clusters > 30	$3.37{\cdot}10^8$	47%
Measured/potential clusters > 0.5	$3.35{\cdot}10^8$	46%
$\lvert b_x\rvert < 4cm, \lvert b_y\rvert < 2cm$	$3.26{\cdot}10^8$	45%
Negative tracks	$1.50{\cdot}10^8$	21%
$dE/dx < 0.26 \cdot log(p) + 1.224$	$1.39{\cdot}10^8$	19%

Description of MC Xe+La set at 150A GeV/c

- Xe+La at 150A GeV/c.
- Total number of events is: 5M
- EPOS Production from September 2022 (thanks to Sasha)
- Path: `(EOS)/eos/experiment/na61/data/Simulation/Xe_La_150_17_v1r20p1_OP/output`

Event Cuts Applied EPOS

The Current event selection of cuts is based on presentation of Collab Meeting in Wroclaw

Event cut List		
Cut	N.of events	Percentage
Original	1745652	
HasMainVertex	1745652	100%
Vertex Z	1745652	100%

Vertex Z Position between: -603.6 and -601.6

Track Cuts Applied EPOS

The Current track selection of cuts is based on presentation of Collab Meeting in Wroclaw

Track cut List		
Cut	N.of tracks	Percentage
eGeneratorFinal	823620896	
Charged	509174477	61%
Momentum	509324543	61.5%
No Electrons	505726608	61.4%

Momentum: p_x max value is 1.5 GeV/c and p_y max value is 1.5 GeV/c

Event Cuts Applied Reconstructed

The Current event selection of cuts is based on presentation of Collab Meeting in Wroclaw

Event cut List		
Cut	N.of events	Percentage
Original	1745652	
nMainVertex	1745641	100%
hasMainVertex	1745631	99%
Vtx Fit Quality	1745614	99%
Vertex Z	1745613	99%

Vertex Z Position between: -603.6 and -601.6

Event Cuts

The Current event selection of cuts is based on presentation of Andrey Seryakov and Oleksandra Panova [3]

Event cut List		
Cut	N.of events	Percentage
Original	4737271	
T2	3591902	100%
Good BPD	3543947	99%
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WFA S1 and WFA T4	1853185	51%
Vertex Z	1768387	49%
BPD3 charge	1760261	48%
S1	1760131	48%
PSD status	1759801	48%
T2 biased	1102014	30%

Track Cuts Applied Reconstructed

Track cut List		
Cut	N.of tracks	Percentage
eGeneratorFinal	772680973	
Charged	194251640	25%
MeasuredPoints	13887094	1.7%
PotentialPoints	9025478	1.1%
ImpactParameter	8818881	1.1%
Momentum	8753478	1.06%
No electrons		%

Momentum: p_x max value is 1.5 GeV/c and p_y max value is 1.5 GeV/c Measured Points > 30 Measured Points/Potential points > 0.5 Impact Parameter should be $2 < b < 4$ cm

Track cuts Data

Preliminary cuts from Ar+Sc:

Track cut list		
Cut	N. of tracks	Percentage
Track Status	$7.21{\cdot}10^8$	100%
VTPC cluster > 15	$3.37{\cdot}10^8$	47%
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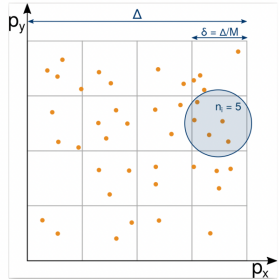
$dE/dx < 0.26 \cdot log(p) + 1.224$	$1.39{\cdot}10^8$	19%

Second Scaled Factorial moment

Second scaled factorial moments, $F_2(M)$ calculated as a average bins and events ($\langle \cdots \rangle$) .

$$F_2(M) = \frac{\left\langle \frac{1}{M^2} \sum_{m=1}^{M^2} n_m(n_m - 1) \right\rangle}{\left\langle \frac{1}{M^2} \sum_{m=1}^{M^2} n_m \right\rangle^2}$$

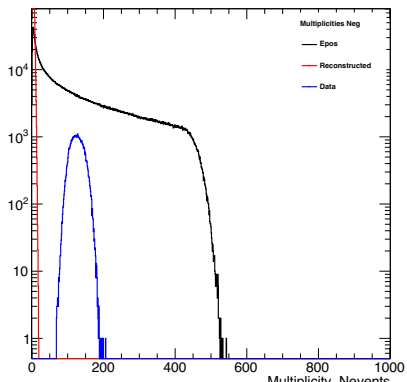


$M = \frac{\Delta}{\delta}$: number of bins in p_x and p_y
n_m : number of particles in m-th bin
The modified formula
considering pair particles is;

$$F_2(M) = \frac{2M^2}{\langle N \rangle^2} \langle N_{pp} \rangle$$

Multiplicities 1

Black is from MonteCarlo Simulations, Red is for Reconstructed MonteCarlo, and Blue is for Xe+La data.



Multiplicities 2

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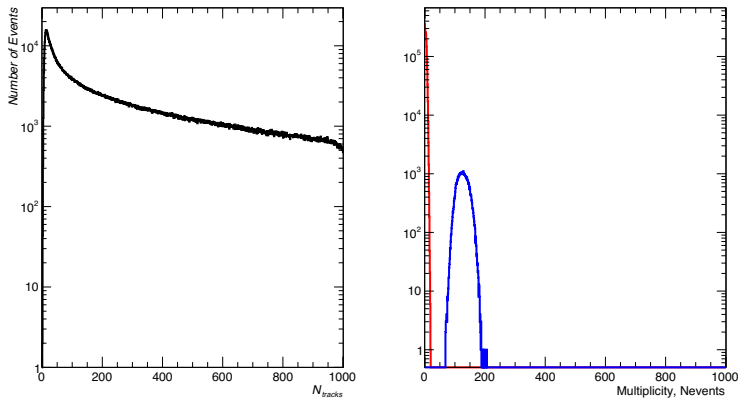

Pt 1

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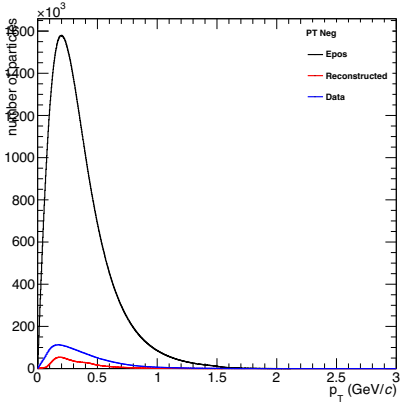
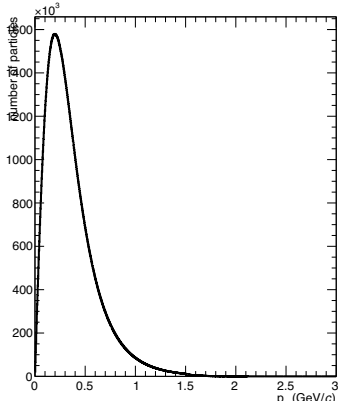
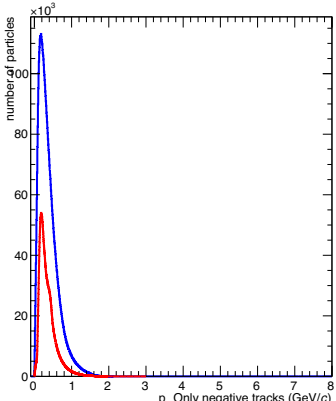


Pt 2

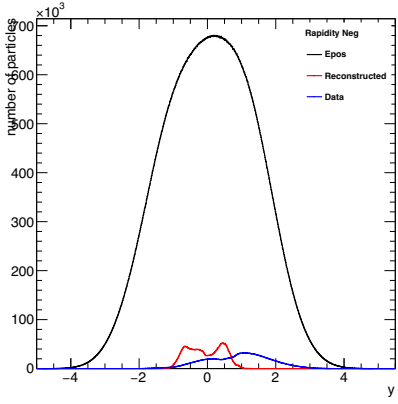
Black is from MonteCarlo Simulations, Red is for Reconstructed MonteCarlo, and Blue is for Xe+La data.





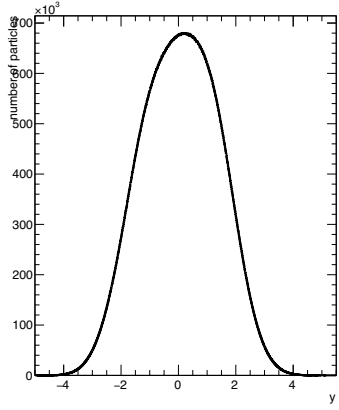
Rapidity 1

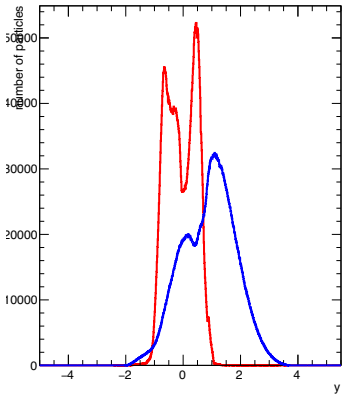
Black is from MonteCarlo Simulations, Red is for Reconstructed MonteCarlo, and Blue is for Xe+La data.



Rapidity 2

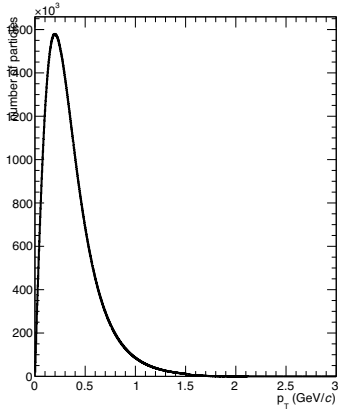
Black is from MonteCarlo Simulations, Red is for Reconstructed MonteCarlo, and Blue is for Xe+La data.

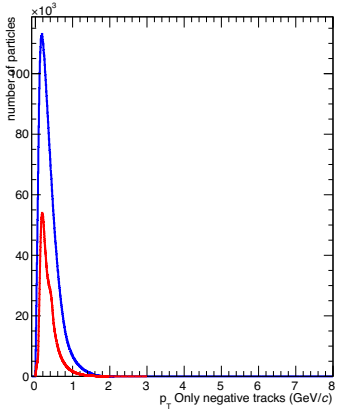




Transverse Momentum Distribution

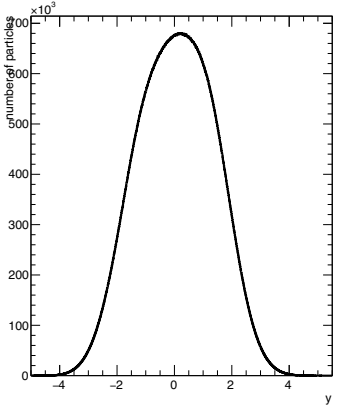
Black is from MonteCarlo Simulations, Red is for Reconstructed MonteCarlo, and Blue is for Xe+La data

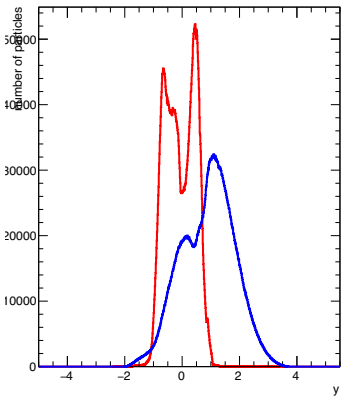




Center of Mass Rapidity Distribution

Black is from MonteCarlo Simulations, Red is for Reconstructed MonteCarlo, and Blue is for Xe+La data. Add proper legends





Transverse Momentum vs Rapidity

Left is from MonteCarlo Simulations, Center is for Reconstructed MonteCarlo, and Right is for Xe+La data. Add proper legends