Recent results from proton intermittency analysis in nucleus-nucleus collisions from NA61/SHINE at CERN SPS

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for the NA61/SHINE collaboration

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SHINE

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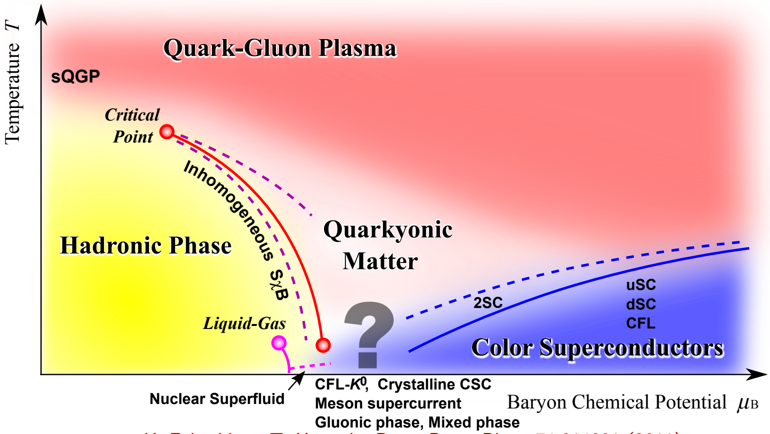
Phase diagram of QCD

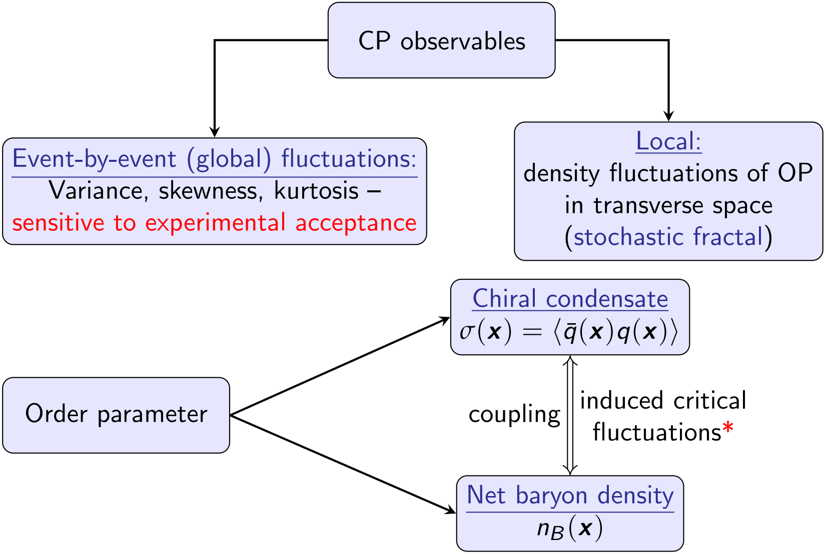
- Objective: Detection / existence of the QCD Critical Point (CP)



K. Fukushima, T. Hatsuda, Rept. Prog. Phys. 74:014001 (2011)

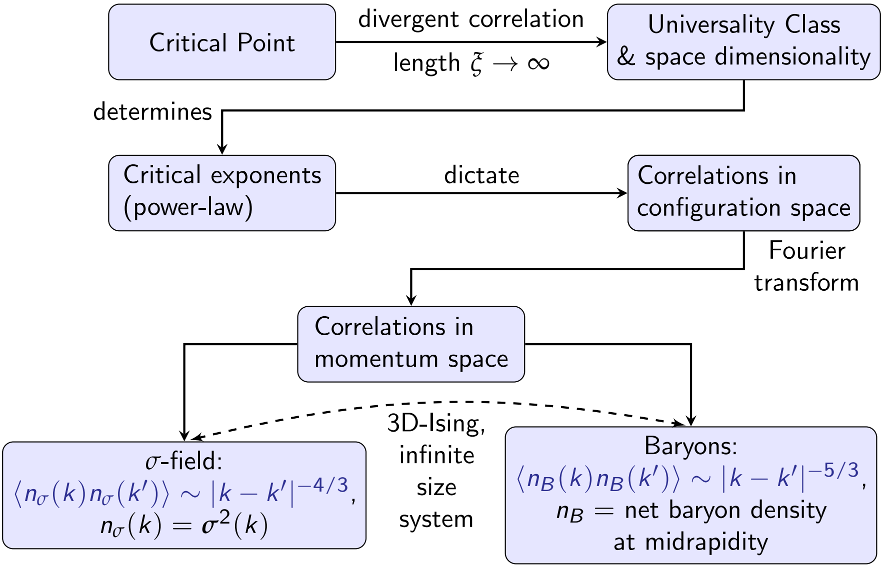
- Look for observables tailored for the CP; Scan phase diagram by varying energy and size of collision system.

Critical Observables; the Order Parameter (OP)



*[Y. Hatta and M. A. Stephanov, PRL**91**, 102003 (2003)]

Self-similar density fluctuations near the CP



Observing power-law fluctuations

Experimental observation of local, power-law distributed fluctuations

$\Downarrow$

Intermittency in transverse momentum space (net protons at mid-rapidity)

(Critical opalescence in ion collisions*)

- Net proton density carries the same critical fluctuations as the net baryon density, and can be substituted for it.

  [Y. Hatta and M. A. Stephanov, PRL**91**, 102003 (2003)]

- Furthermore, antiprotons can be dropped to the extent that their multiplicity is much lower than of protons, and proton density analyzed.

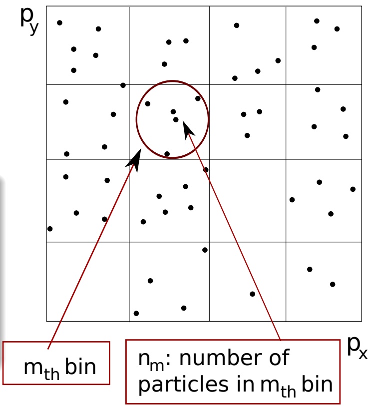
[J. Wosiek, *Acta Phys. Polon.* **B 19** (1988) 863-869]
[A. Bialas and R. Hwa, *Phys. Lett.* **B 253** (1991) 436-438]
*[F.K. Diakonos, N.G. Antoniou and G. Mavromanolakis, PoS (CPOD2006) 010, Florence]

Observing power-law fluctuations: Factorial moments

- Transverse momentum space is partitioned into M^2 cells
- Calculate second factorial moments $F_2(M)$ as a function of cell size $\Leftrightarrow$ number of cells M:

$$F_2(M) \equiv \frac{\left\langle \frac{1}{M^2} \sum_{i=1}^{M^2} n_i(n_i - 1) \right\rangle}{\left\langle \frac{1}{M^2} \sum_{i=1}^{M^2} n_i \right\rangle^2},$$

where $\langle \ldots \rangle$ denotes averaging over events.



Subtracting the background from factorial moments

- Experimental data is noisy $\Rightarrow$ a background of non-critical pairs must be subtracted at the level of factorial moments.
- Intermittency will be revealed at the level of subtracted moments $\Delta F_2(M)$.

Partitioning of pairs into critical/background

$$\langle n(n-1)\rangle = \underbrace{\langle n_c(n_c-1)\rangle}_{\text{critical}} + \underbrace{\langle n_b(n_b-1)\rangle}_{\text{background}} + \underbrace{2\langle n_b n_c\rangle}_{\text{cross term}}$$

$$\underbrace{\Delta F_2(M)}_{\text{correlator}} = \underbrace{F_2^{(d)}(M)}_{\text{data}} - \lambda(M)^2 \cdot \underbrace{F_2^{(b)}(M)}_{\text{background}} - 2 \cdot \underbrace{\lambda(M)}_{\text{ratio } \frac{<n>_b}{<n>_d}} \cdot (1-\lambda(M))\, f_{bc}$$

- The cross term can be neglected under certain conditions (non-trivial! Justified by Critical Monte Carlo* simulations)

* *[Antoniou, Diakonos, Kapoyannis and Kousouris, Phys. Rev. Lett. 97, 032002 (2006).]*

Scaling of factorial moments – Subtracting mixed events

For $\lambda \lesssim 1$ (background domination), two approximations can be applied:

1. Cross term can be neglected
2. Non-critical background moments can be approximated by (uncorrelated) mixed event moments; then,

$$\Delta F_2(M) \simeq \Delta F_2^{(e)}(M) \equiv F_2^{\text{data}}(M) - F_2^{\text{mix}}(M)$$

For a critical system, ΔF_2 scales with cell size (number of cells, M) as:

$$\Delta F_2(M) \sim \left(M^2\right)^{\varphi_2}$$

where φ_2 is the intermittency index.

Theoretical prediction for φ_2

universality class, effective actions

$$\varphi_{2,cr}^{(p)} = \frac{5}{6} \; (0.833\ldots)$$

net baryons (protons)

[N. G. Antoniou, F. K. Diakonos, A. S. Kapoyannis, K. S. Kousouris, Phys. Rev. Lett. **97**, 032002 (2006)]

Statistical uncertainties & systematic effect estimation

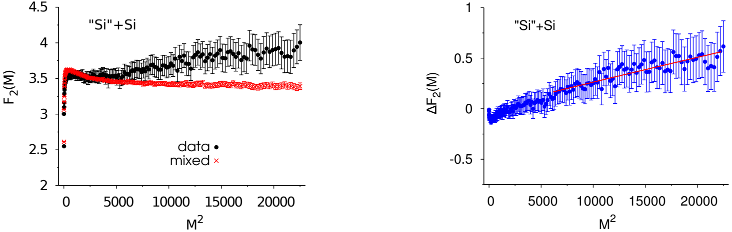
- Bootstrap method used to calculate statistical uncertainties
- Bootstrap samples of events created by sampling of events with replacement
- $\Delta F_2(M)$ calculated for each bootstrap sample; variance of sample values provides statistical error of $\Delta F_2(M)$

  [W.J. Metzger, *"Estimating the Uncertainties of Factorial Moments"*, HEN-455 (2004).]
- Distribution of φ_2 values, $P(\varphi_2)$, and confidence intervals for φ_2 obtained by fitting individual bootstrap samples

  [B. Efron, *The Annals of Statistics* **7**,1 (1979)]
- Systematic uncertainties arise from:
  - Misidentification of protons & detector effects (e.g. acceptance)
  - The fact that $F_2(M)$ are correlated for different bin sizes M
  - Selection of M-range to fit for power-law
- Bin correlations are partially handled by the bootstrap φ_2 distribution
- Other systematic uncertainties are estimated by varying proton and M-range selection

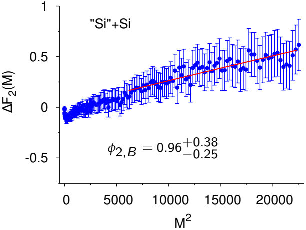
NA49: "C"+C, "Si"+Si, Pb+Pb at 158A GeV/c

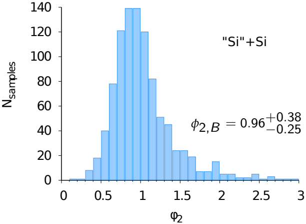
- 3 sets of NA49 collision systems were analysed, at 158A GeV/c
  [T. Anticic *et al.*, Eur. Phys. J. C 75:587 (2015), arXiv:1208.5292v5]
- Factorial moments of proton transverse momenta analyzed at mid-rapidity
- Fragmentation beams used for C and Si ("C"=C,N ; "Si"=Si,Al,P) – components were merged to enhance statistics



- Fit with $\Delta F_2^{(e)}(M\,;\,\mathcal{C},\phi_2) = e^{\mathcal{C}} \cdot \left(M^2\right)^{\phi_2}$, for $M^2 \geq 6000$
- No intermittency detected in the "C"+C, Pb+Pb datasets.

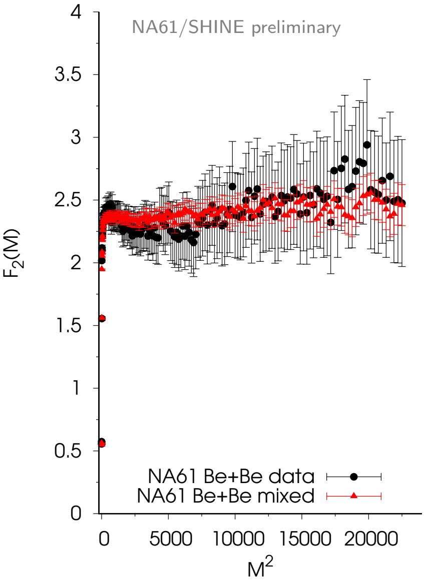
- Evidence for intermittency in "Si"+Si – but large statistical errors.





- Bootstrap distribution of ϕ_2 values is highly asymmetric due to closeness of $F_2^{(d)}(M)$ to $F_2^{(m)}(M)$.
- Based on CMC simulation, we estimate a fraction of $\sim 1\%$ critical protons are present in the sample.
- Estimated intermittency index: $\phi_{2,B} = 0.96^{+0.38}_{-0.25}(\text{stat.}) \pm 0.16(\text{syst.})$
  [T. Anticic *et al.*, Eur. Phys. J. C 75:587 (2015), arXiv:1208.5292v5]

NA61/SHINE: Be+Be at 150A GeV/c

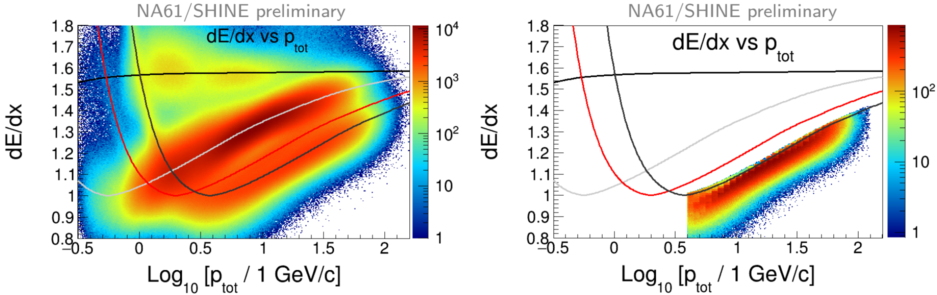


- $F_2(M)$ of data and mixed events overlap $\Rightarrow$
- Subtracted moments $\Delta F_2(M)$ fluctuate around zero $\Rightarrow$
- No intermittency effect is observed.
- Preliminary analysis with CMC simulation indicates an upper limit of $\sim$ 0.3% critical protons [PoS(CPOD2017) 054]

NA61/SHINE: $^{40}Ar + ^{45}Sc$ at 150A GeV/c

- First released results of preliminary analysis in Ar+Sc at 150A GeV/c – CPOD 2018.
- Intermittency analysis process:
  - Proton selection via particle energy loss dE/dx
  - Removal of split tracks – q_{inv} distribution & cut of proton pairs
  - Probe Δp_T distribution of proton pairs for power-law like behaviour in the limit of small p_T differences
  - Calculate factorial moments $F_2(M), \Delta F_2(M)$ for selected protons
  - Calculate intermittency index ϕ_2 (when possible) & estimate its statistical uncertainty
- Results were obtained for:
  - 0-5%, 5-10% and 10-15% centrality bins
  - 80%, 85% and 90% minimum proton purity selections

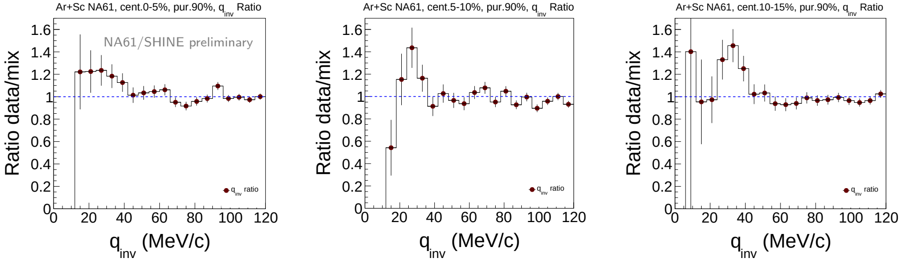
Proton selection



- Employ p_{tot} region where Bethe-Bloch bands do not overlap (3.98 GeV/c $\leq p_{tot} \leq$ 126 GeV/c)
- Fit dE/dx distribution with 4-gaussian sum for $\alpha = \pi, K, p, e$ – Bins: p_{tot}, p_T
- 30 Bins in $Log_{10}(p_{tot})$: $10^{0.6} \rightarrow 10^{2.1}$ GeV/c
- 20 Bins in p_T: 0.0 $\rightarrow$ 2.0 GeV/c
- Proton purity: probability for a track to be a proton, $\mathcal{P}_p = p/(\pi + K + p + e)$
- Additional cut along Bethe-Blochs (avoid low-reliability region between p and K curves)

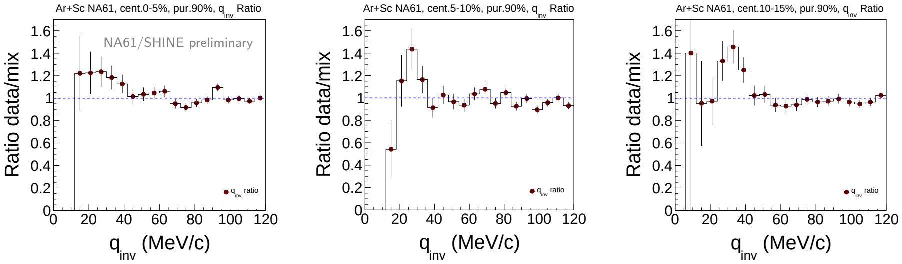
Split tracks & the q_{inv} cut

- Events may contain split tracks: sections of the same track erroneously identified as a pair of tracks that are close in momentum space.
- Three cuts to root them out:
  1. Ratio of points / potential points in a track (removes most)
  2. Minimum track distance in the detector (pair cut)
  3. q_{inv} cut (pair cut, physics-significant)
- q_{inv} distribution of track pairs probed in order to root the rest out: $q_{inv}(p_i, p_j) \equiv \frac{1}{2}\sqrt{-(p_i - p_j)^2}$, p_i : 4-momentum of i^{th} track.
- We calculate the ratio of $q_{inv}^{data} / q_{inv}^{mixed}$.



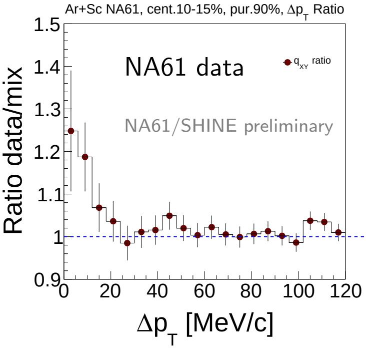
Split tracks & the q_{inv} cut

- A peak at low q_{inv} (below 20 MeV/c) indicates a possible split track contamination that must be removed.
- Anti-correlations due to F-D effects and Coulomb repulsion must be removed before intermittency analysis $\Rightarrow$ "dip" in low q_{inv}, peak predicted around 20 MeV/c [Koonin, PLB 70, 43-47 (1977)]
- Universal cutoff of $q_{inv} > 7$ MeV/c applied to all sets before analysis.

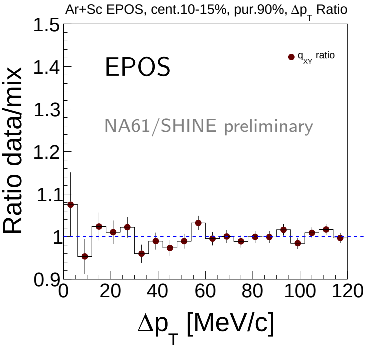


Δp_T distributions: NA61 data vs EPOS

- Ar+Sc at 150A GeV/c: $\Delta p_T = 1/2\sqrt{(p_{X_1} - p_{X_2})^2 + (p_{Y_1} - p_{Y_2})^2}$ distributions of protons selected for intermittency analysis



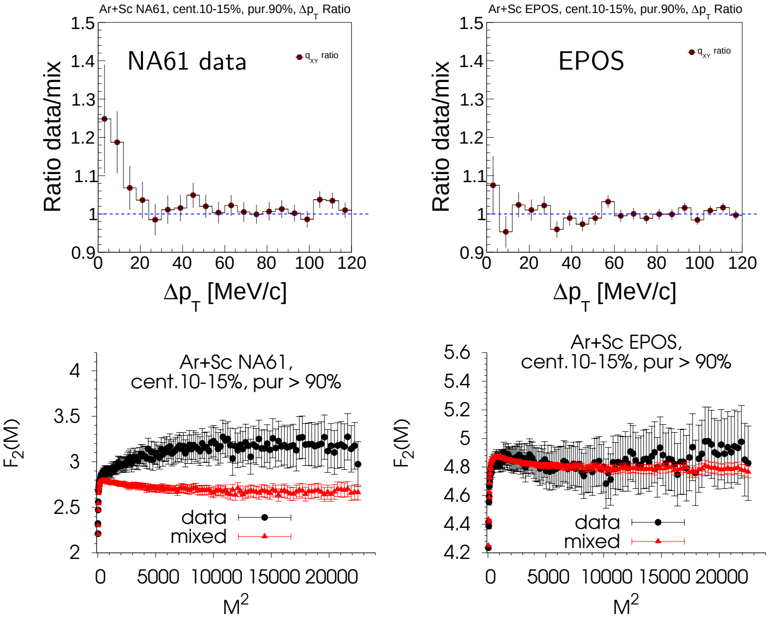
Significant peak at $\Delta p_T \to 0$



Flat distribution

- In NA61 data, we see strong correlations in $\Delta p_T \to 0 \Rightarrow$ indication of intermittent behaviour

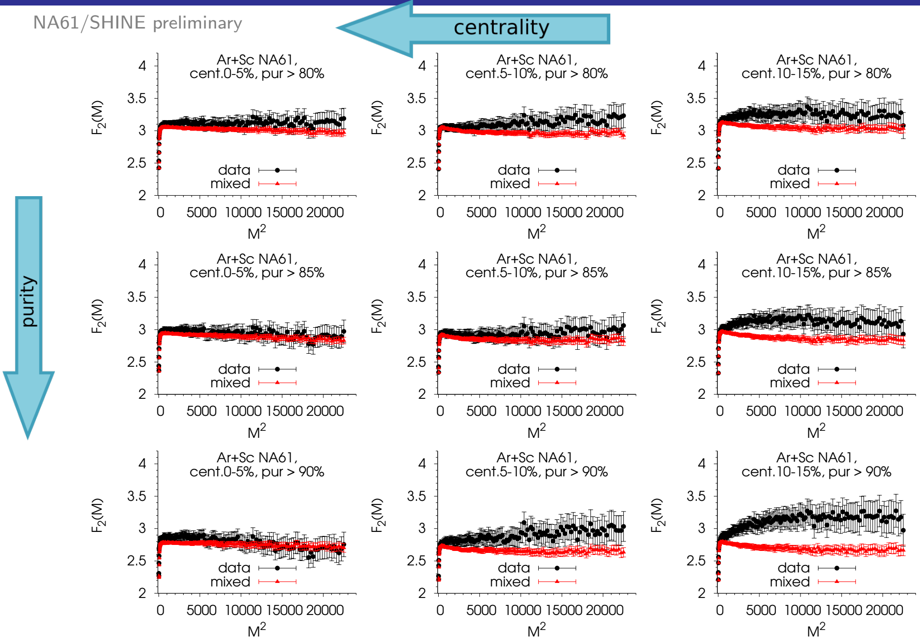
Δp_T distributions & $F_2(M)$: NA61 data vs EPOS



NA61/SHINE preliminary

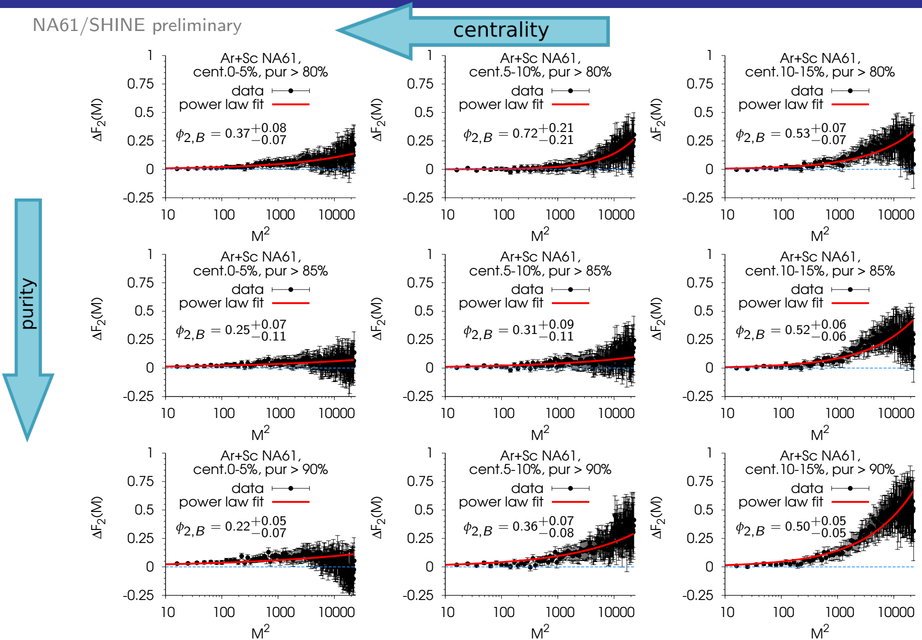
NA61/SHINE: Ar+Sc at 150A GeV/c: $F_2(M)$

NA61/SHINE preliminary



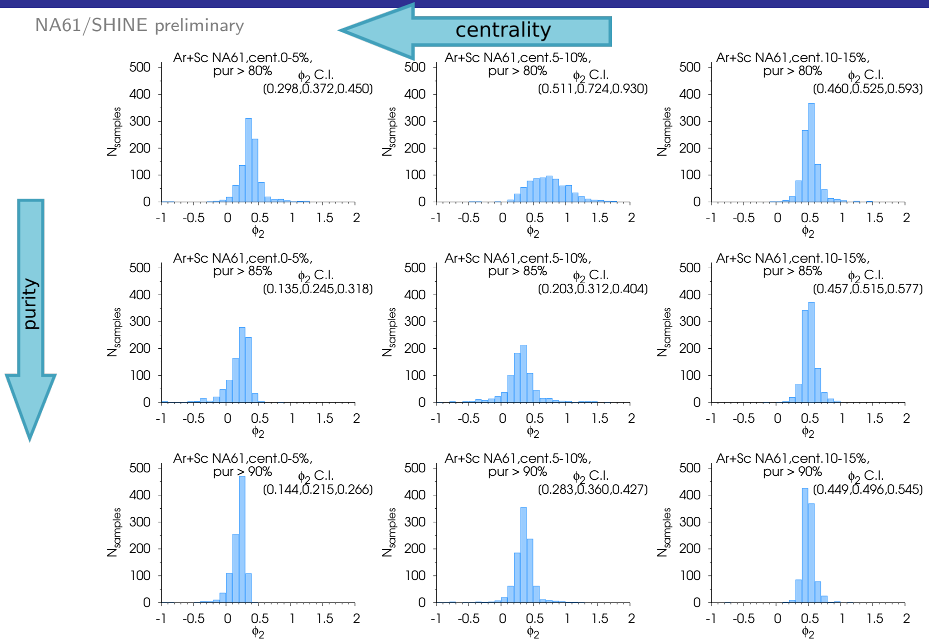
NA61/SHINE: Ar+Sc at 150A GeV/c: $\Delta F_2(M)$

NA61/SHINE preliminary

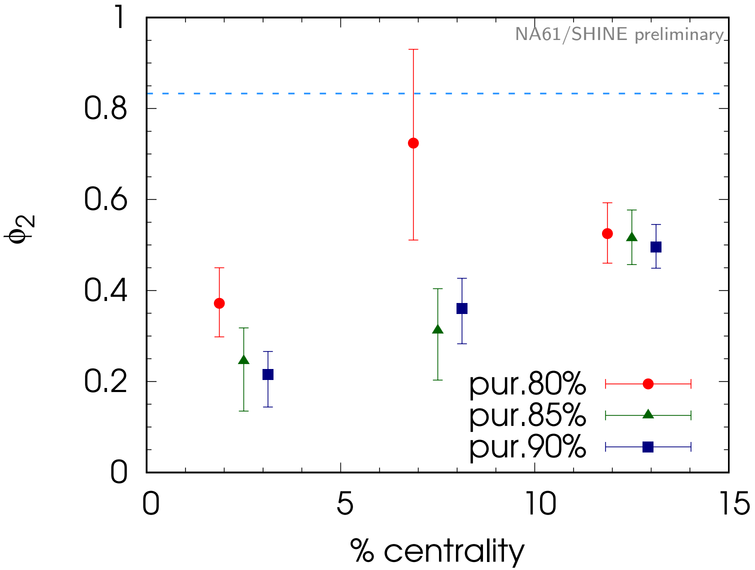


NA61/SHINE: Ar+Sc at 150A GeV/c: ϕ_2 bootstrap dist.

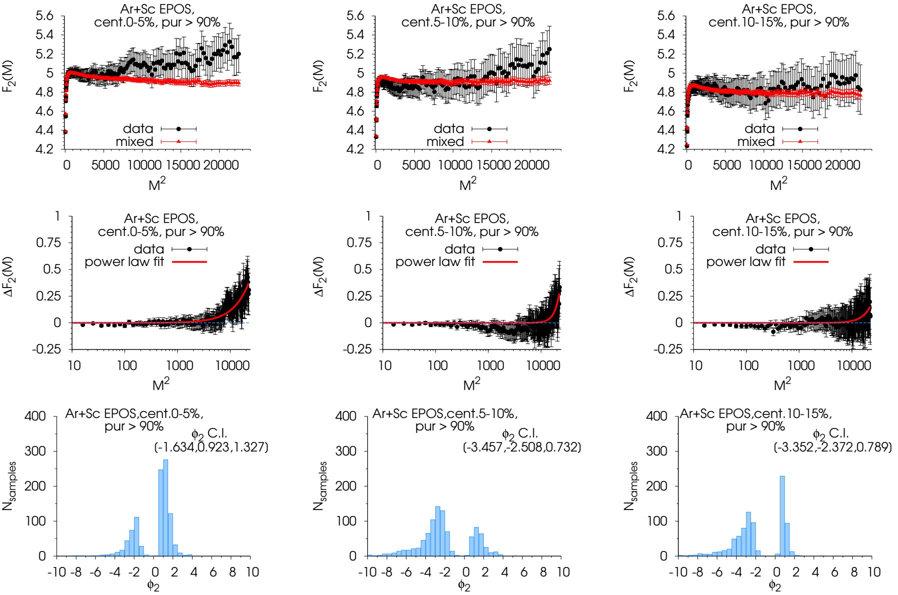
NA61/SHINE preliminary



NA61/SHINE: Ar+Sc at 150A GeV/c: Summary

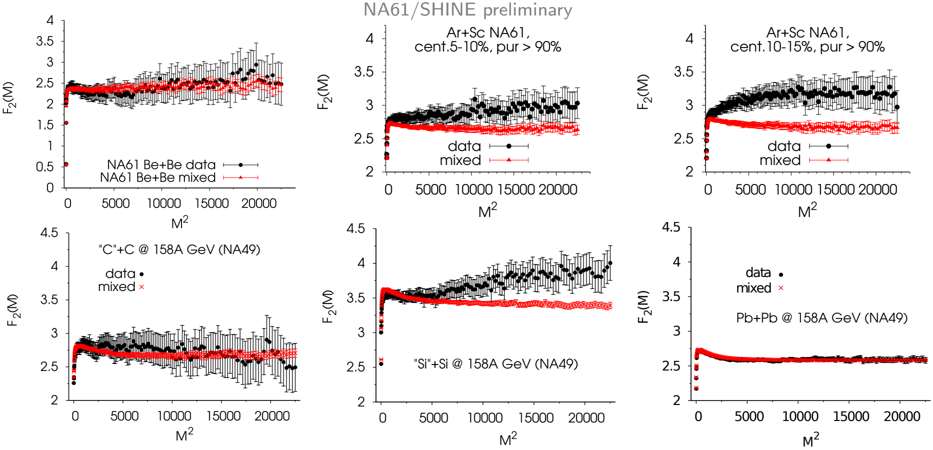


Ar+Sc EPOS: $F_2(M)$, $\Delta F_2(M)$, ϕ_2 bootstrap distribution



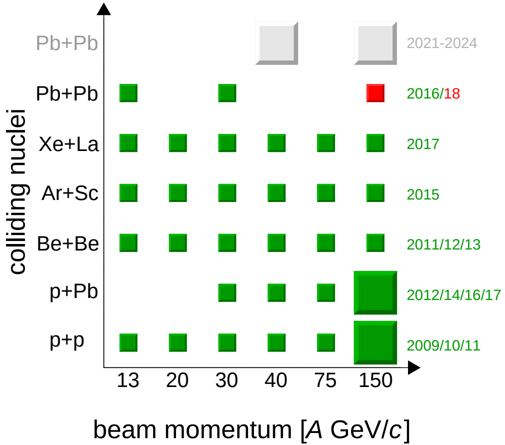
NA61/SHINE preliminary

Intermittency analysis at 150/158A GeV/c: Summary



- Indication of intermittency effect in middle-central NA61/SHINE Ar+Sc collisions
- First possible evidence of CP signal in NA61/SHINE
- Effect quality increases with increased proton purity selection, up to 90% proton purity; EPOS does not reproduce observed effect.

Outlook



- Expanding the analysis to other NA61/SHINE systems (Xe+La, Pb+Pb) and SPS energies (Ar+Sc) will hopefully lead to a **more reliable interpretation** of the observed intermittency signal in terms of the **critical point**.

Thank you!

Acknowledgements

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

Back Up Slides

Scaling of factorial moments – Subtracting mixed events

For $\lambda \lesssim 1$ (background domination), $\Delta F_2(M)$ can be approximated by:

$$\Delta F_2^{(e)}(M) = F_2^{\text{data}}(M) - F_2^{\text{mix}}(M)$$

For a critical system, ΔF_2 scales with cell size (number of cells, M) as:

$$\Delta F_2(M) \sim \left(M^2\right)^{\varphi_2}$$

where φ_2 is the intermittency index.

Theoretical predictions for φ_2

universality class, effective actions

$$\varphi_{2,cr}^{(\sigma)} = \frac{2}{3} \; (0.66\ldots)$$

sigmas (neutral isoscalar dipions)

[N. G. Antoniou **et al**, Nucl. Phys. A **693**, 799 (2001)]

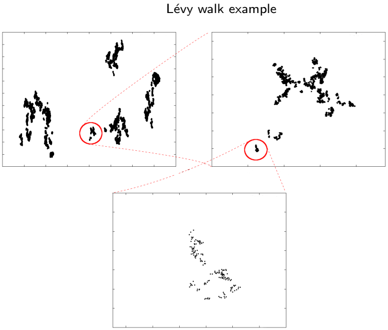
$$\varphi_{2,cr}^{(p)} = \frac{5}{6} \; (0.833\ldots)$$

net baryons (protons)

[N. G. Antoniou, F. K. Diakonos, A. S. Kapoyannis, K. S. Kousouris, Phys. Rev. Lett. **97**, 032002 (2006)]

Critical Monte Carlo (CMC) algorithm for baryons

- Simplified version of CMC* code:
  - Only protons produced
  - One cluster per event, produced by random Lévy walk: $\tilde{d}_F^{(B,2)} = 1/3 \Rightarrow \phi_2 = 5/6$
  - Lower / upper bounds of Lévy walks $p_{min,max}$ plugged in.
  - Cluster center exponential in p_T, slope adjusted by T_c parameter.
  - Poissonian proton multiplicity distribution.



Input parameters

Parameter	p_{min} (MeV)	p_{max} (MeV)	λ_{Poisson}	T_c (MeV)
Value	$0.1 \rightarrow 1$	$800 \rightarrow 1200$	$\langle p \rangle_{\text{non-empty}}$	163

* *[Antoniou, Diakonos, Kapoyannis and Kousouris, Phys. Rev. Lett. 97, 032002 (2006).]*

NA61/SHINE data analysis – $^{40}Ar + {}^{45}Sc$ at 150A GeV/c

- NA49 analysis encourages us to look for intermittency in medium-sized nuclei, in the NA61 experiment.
- Intermittency analysis requires:
  - Large event statistics $\Rightarrow \sim 100K$ events min., ideally $\sim 1M$ events.
  - Reliable particle ID $\Rightarrow$ proton purity should be $\sim 80\% - 90\%$.
  - Central collisions.
  - Adequate mean proton multiplicity in midrapidity (≥ 2)
- A preliminary analysis for Be+Be data at 150A GeV/c was previously performed [PoS(CPOD2017) 054]; no intermittency signal was observed.
- We now expand on it with our preliminary analysis in Ar+Sc at 150A GeV/c.
- Simulation through EPOS* (detector effects included) would suggest:

$$\left.\frac{dN_p}{dy}\right|_{|y_{CM}|\leq 0.75,\, p_T\leq 1.5} \sim 1.6 - 2$$

  for $\sim 0 - 15\%$ centrality; adequate for an intermittency analysis
- We perform a 2D scan in proton purity (80-90%) and centrality of collisions

*[K. Werner, F. Liu, and T. Pierog, Phys. Rev. C 74, 044902 (2006)]

$^{40}Ar + ^{45}Sc$ – data set overview

- Production used: `Ar_Sc_150_15/026_17c_v1r8p0_pA_slc6_phys_PP` (miniSHOE, unofficial)
- Runs: 20328 - 20345 , 20368 - 20380
- Bad runs rejected – almost 2/3rds of total!
- miniSHOE files with Potential Point information provided by B. Maksiak – not an official production yet
- SHINE code to select events (primary vertex charged particles)
- Event & Track cuts based on Maciej Lewicki's and Michal Naskret's h^- analysis.
- Non-bias event cuts: used Andrey Seryakov's `NonBiasEventCutsArSc` class.
- 0%-20% most central events in 5% bin intervals selected via cut in energy sum of PSD selected modules (based on Andrey Seryakov's Moscow meeting presentation on centrality determination).

Ar+Sc at 150A GeV/c: NA61 data vs EPOS

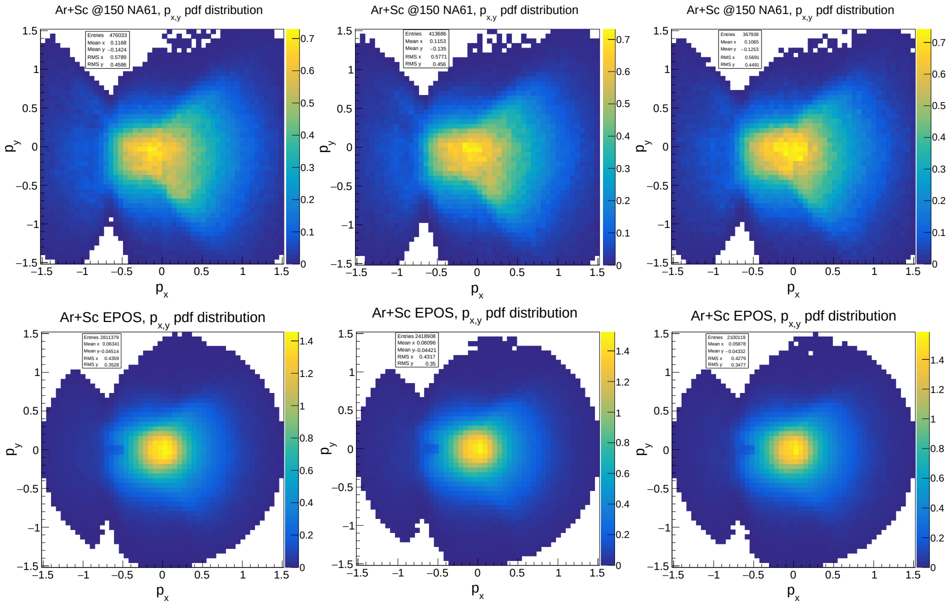
EPOS – proton p_T statistics

Centrality	#events	$\langle p \rangle_{\lvert p_T \rvert \le 1.5\ GeV,\, \lvert y_{CM} \rvert \le 0.75}$ Non-empty	With empty	$\Delta p_{x,y}$
0- 5%	293,412	3.06 ± 1.60	2.89 ± 1.70	0.35 - 0.43
5-10%	252,362	2.72 ± 1.45	2.49 ± 1.58	0.35 - 0.43
10-15%	274,072	2.45 ± 1.33	2.16 ± 1.48	0.35 - 0.43

$^{40}Ar + ^{45}Sc$ NA61 data – proton p_T statistics

Centrality	#events	$\langle p \rangle_{\lvert p_T \rvert \le 1.5\ GeV,\, \lvert y_{CM} \rvert \le 0.75}$ Non-empty	With empty	$\Delta p_{x,y}$
0- 5%	144,362	3.44 ± 1.79	3.30 ± 1.89	0.46 - 0.58
5-10%	148,199	3.00 ± 1.61	2.79 ± 1.73	0.46 - 0.58
10-15%	142,900	2.81 ± 1.53	2.58 ± 1.66	0.45 - 0.57

$p_{X,Y}$ spectra comparison – NA61 vs EPOS (0 – 15%)



Event & Track cuts

Event cuts

- Target IN/OUT,
- BPD status,
- WFA particles (4.5 μs),
- WFA interaction (25 μs),
- BPD3X(Y) charge,
- S5 $(0 \rightarrow 170)$,
- T2 trigger (eAll),
- Vertex track fitted to the main vertex,
- Vertex fit quality = ePerfect,
- Fitted vertex position -580 ± 10 cm,
- PSD Module Energy Sum cut (inner/outer),
- Centrality 0-20% (based on PSD)
- nTracksFit/nTracksAll > 0.25 if nTracksFit ≤ 50 (Andrey)

Track cuts

- Track status,
- Charge ± 1,
- Impact point $[\pm 4\text{cm}; \pm 2\text{cm}]$,
- Total number of clusters ≥ 30,
- VTPCs clusters ≥ 15,
- NO GTPC clusters,
- dE/dx clusters ≥ 30,
- $0.5 \leq \frac{\#\text{Points}}{\#\text{Potential Points}} \leq 1.0$
- TTD cut > 2 *cm*
- dE/dx ≤ 1.8 (dE/dx fit issue)
- proton selection (scan)
- 3.98 GeV/c $\leq p_{tot} \leq$ 126 GeV/c (for dE/dx proton ID – scan)

$^{40}Ar + ^{45}Sc$ – EPOS MC production overview

- Production used: `Simulation/Ar_Sc_150_15/15_011_v14e_v1r2p0_pA_slc6_phys/EPOS_with_potential_points/`
- An estimated ∼300K simulated events per 5% centrality bin.
- Potential Point information included for limited events subset.
- SHINE code to select events (primary vertex charged particles)
- Event & Track cuts (hastily) adapted to match Ar+Sc @150 data analysis (where applicable).
- No PSD simulation – centrality selection based on # of forward spectators, `nFSpec = 40 - simEvent.GetPrimaryInteraction().GetProjectileParticipants()` (see Andrey Seryakov's centrality determination information on twiki).

Event & Track cuts – EPOS

Event cuts

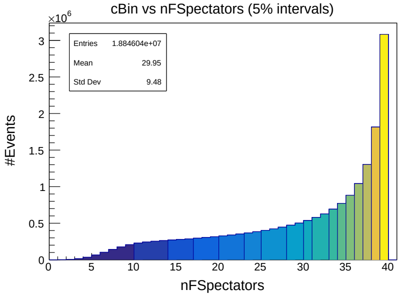
- Target IN/OUT,
- BPD status,
- Vertex track fitted to the main vertex,
- Vertex fit quality = ePerfect,
- Fitted vertex position -580 ± 10 cm,
- Centrality 10% (based on nFSpec)

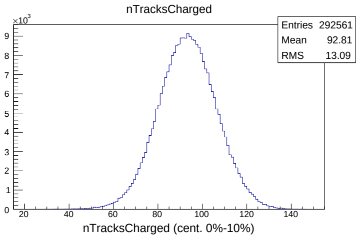
Track cuts

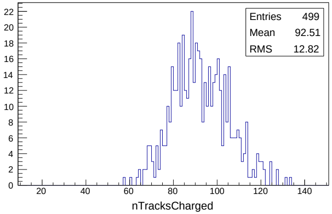
- Track status,
- Charge ± 1,
- Impact point $[\pm 4\text{cm}; \pm 2\text{cm}]$,
- Total number of clusters ≥ 30,
- VTPCs clusters ≥ 15,
- NO GTPC clusters,
- TTD cut > 2 cm,
- proton selection – matching closest simTrack,
- 3.98 GeV/c $\leq p_{tot} \leq$ 126 GeV/c (to match effect of dE/dx p_{tot} cut),
- acceptance cut

Centrality selection via # forward spectators

- A probabilistic selection based on nFSpec percentiles used to select centrality bin.

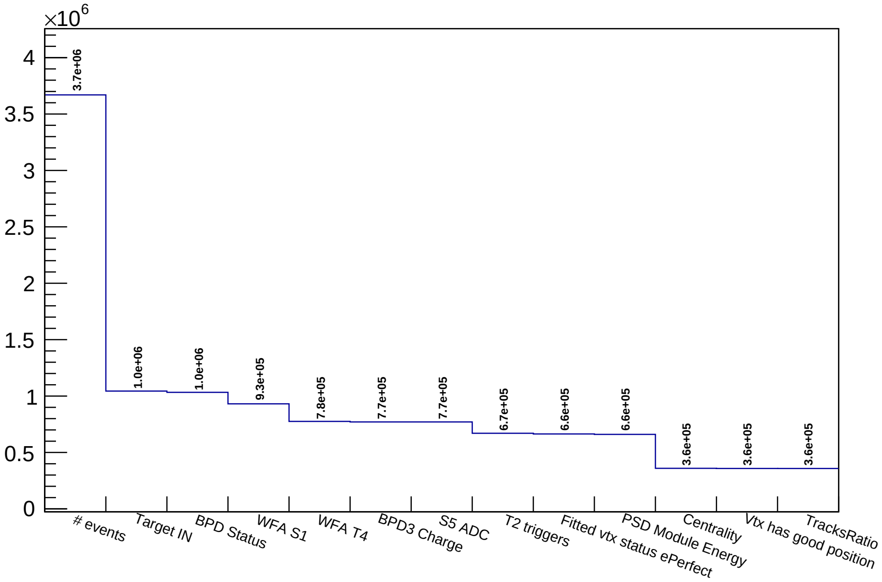




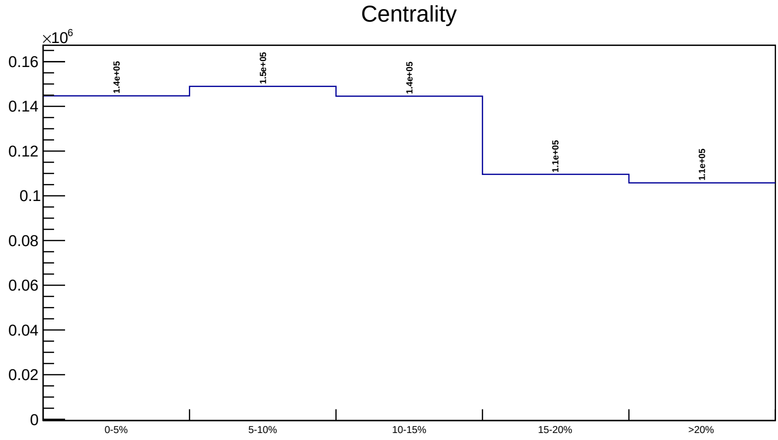


- A discrepancy observed in multiplicity distribution between data (above) & EPOS (below).
- Acceptance cut fixes the problem.

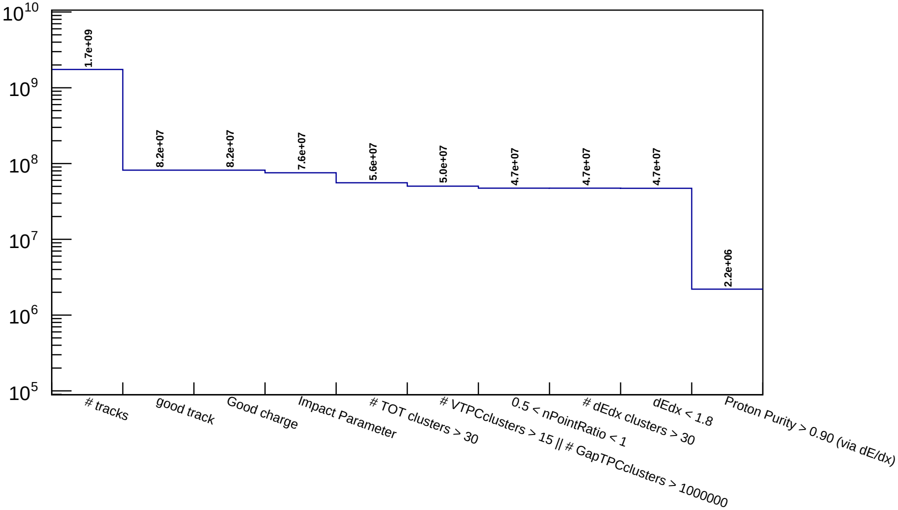
All Event cuts – statistics



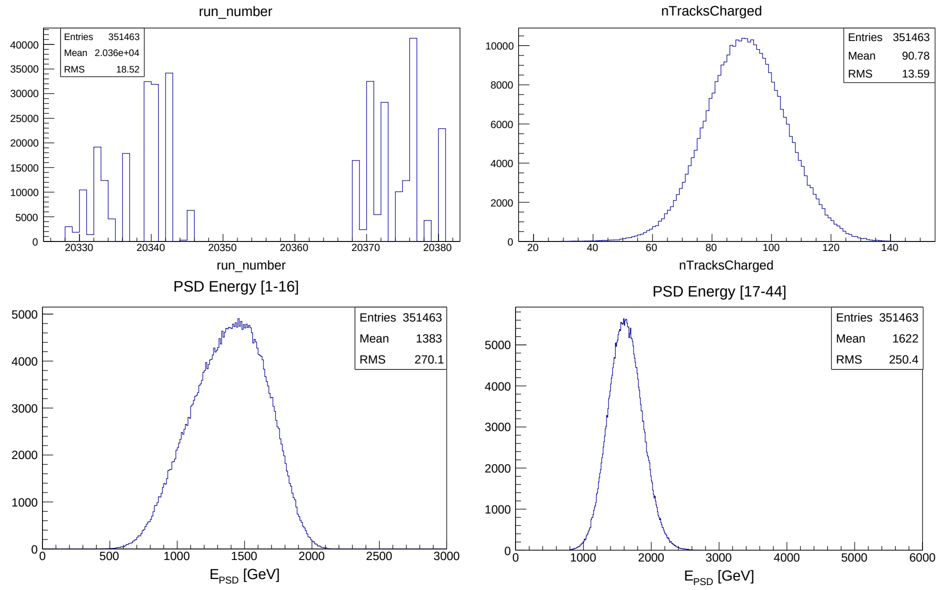
Centrality – statistics



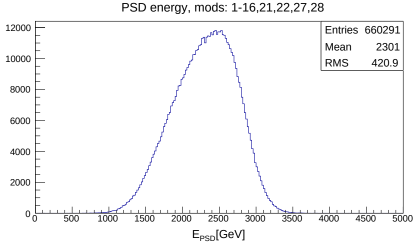
Track cuts – statistics

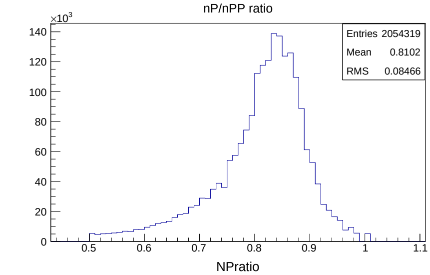


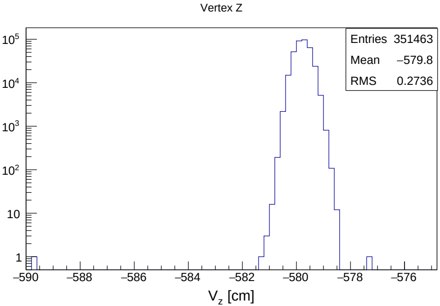
Cuts (plots)

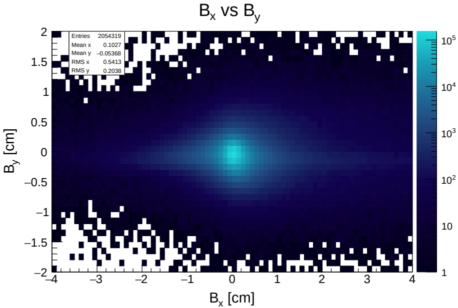

run_number
Entries 351463
Mean 2.036e+04
RMS 18.52
run_number
nTracksCharged
Entries 351463
Mean 90.78
RMS 13.59
nTracksCharged
PSD Energy [1-16]
Entries 351463
Mean 1383
RMS 270.1
E_PSD [GeV]
PSD Energy [17-44]
Entries 351463
Mean 1622
RMS 250.4
E_PSD [GeV]

Cuts (plots)

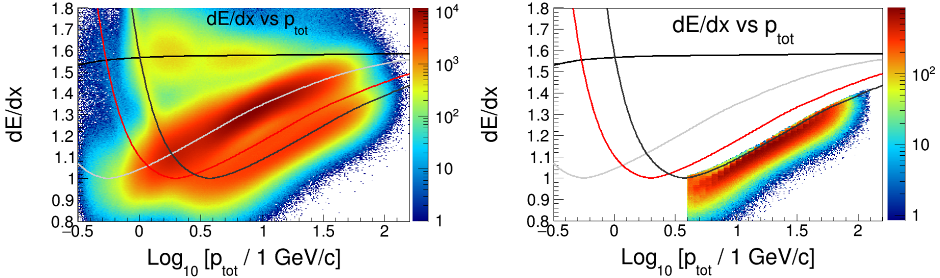

PSD energy, mods: 1-16,21,22,27,28
Entries 660291
Mean 2301
RMS 420.9
E_{PSD}[GeV]


nP/nPP ratio
Entries 2054319
Mean 0.8102
RMS 0.08466
NPratio


Vertex Z
Entries 351463
Mean −579.8
RMS 0.2736
V_z [cm]

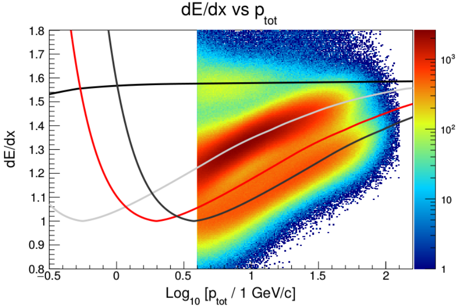

B_x vs B_y
Entries 2054319
Mean x 0.1027
Mean y −0.05368
RMS x 0.5413
RMS y 0.2038
B_y [cm]
B_x [cm]

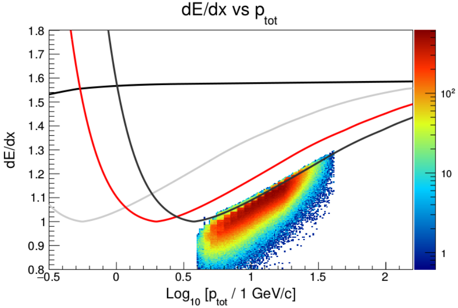
dE/dx vs p_{tot} (proton ID)



- Avoid p_{tot} region where Bethe-Bloch curves overlap (3.98 GeV/c $\leq p_{tot} \leq 126$ GeV/c)
- Using Hans Dembinski/Raul R Prado's dE/dx fitting software – Bins: p_{tot}, p_T
- Presented in Moscow meeting by Prado, Herve & Unger
- 30 Bins in $Log_{10}(p_{tot})$: $10^{0.6} \to 10^{2.1}$ GeV/c
- 20 Bins in p_T: $0.0 \to 2.0$ GeV/c
- Preliminary p selection: 90% purity removing deuterons from the model
- Cut along Bethe-Blochs: $BB_p + 0.15(BB_K - BB_p)$

dE/dx simulation & proton purity assignment in EPOS





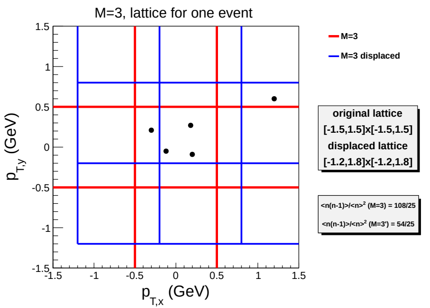
- Used *dE / dx* spectra from Ar+Sc @150 data in the 6% - 18% centrality interval
- For each track, assign a *dE / dx* value based on particle species and phase space bin
- Apply *dE / dx* & purity cuts identical to NA61/SHINE data

Improving calculation of $F_2(M)$ via lattice averaging

- Problem: With low statistics/multiplicity, lattice boundaries may split pairs of neighboring points, affecting $F_2(M)$ values (see example below).

- Solution: Calculate moments several times on different, slightly displaced lattices (see example)
- Average corresponding $F_2(M)$ over all lattices. Errors can be estimated by variance over lattice positions.
- Lattice displacement is larger than experimental resolution, yet maximum displacement must be of the order of the finer binnings, so as to stay in the correct p_T range.

Displaced lattice — a simple example



Improved confidence intervals for ϕ_2 via resampling

- In order to estimate the statistical errors of $\Delta F_2(M)$, we need to produce variations of the original event sample. This, we can achieve by using the statistical method of resampling (bootstrapping) $\Rightarrow$
  - Sample original events with replacement, producing new sets of the same statistics (# of events)
  - Calculate $\Delta F_2(M)$ for each bootstrap sample in the same manner as for the original.
  - The variance of sample values provides the statistical error of $\Delta F_2(M)$.

[W.J. Metzger, *"Estimating the Uncertainties of Factorial Moments"*, HEN-455 (2004).]

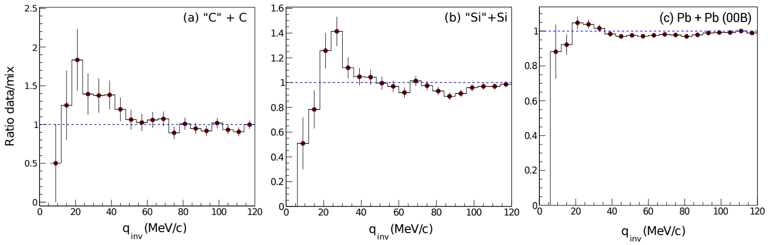
- Furthermore, we can obtain a distribution $P(\varphi_2)$ of φ_2 values. Each bootstrap sample of $\Delta F_2(M)$ is fit with a power-law:

$$\Delta F_2(M; \mathcal{C}, \varphi_2) = e^{\mathcal{C}} \cdot (M^2)^{\varphi_2}$$

and we can extract a confidence interval for φ_2 from the distribution of values. [B. Efron, *The Annals of Statistics* **7**,1 (1979)]

Split tracks; the q_{inv} cut in analysed datasets

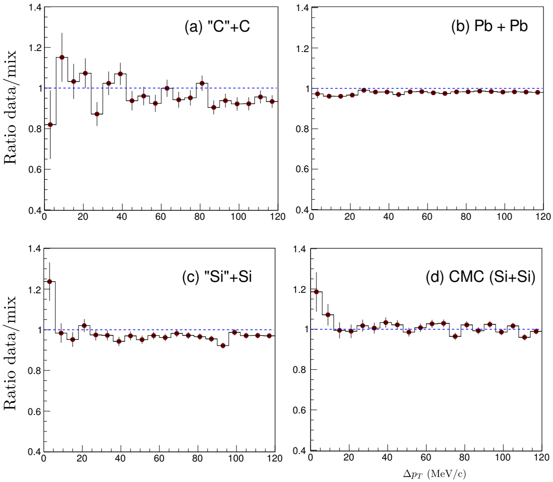
- Split tracks can create false positive for intermittency $\Rightarrow$ must be reduced or removed.
- q_{inv}-test – distribution of track pairs: $q_{inv}(p_i, p_j) \equiv \frac{1}{2}\sqrt{-(p_i - p_j)^2}$, p_i : 4-momentum of i^{th} track.
- Calculate ratio $q_{inv}^{data} / q_{inv}^{mixed} \Rightarrow$ peak at low q_{inv} (below 20 MeV/c): possible split track contamination.



- Anti-correlations due to F-D effects and Coulomb repulsion must be removed before intermittency analysis $\Rightarrow$ "dip" in low q_{inv}, peak predicted around 20 MeV/c [Koonin, PLB 70, 43-47 (1977)]
- Universal cutoff of $q_{inv} > 25$ MeV/c applied to all sets before analysis.

NA49 analysis – Δp_T distributions

- We measure correlations in relative p_T of protons via $\Delta p_T = 1/2\sqrt{(p_{X_1} - p_{X_2})^2 + (p_{Y_1} - p_{Y_2})^2}$



- Strong correlations for $\Delta p_T \to 0$ indicate power-law scaling of the density-density correlation function $\Rightarrow$ intermittency presence
- We find a strong peak in the "Si"+Si dataset
- A similar peak is seen in the Δp_T profile of simulated CMC protons with the characteristics of "Si"+Si.

Split tracks & the q_{inv} cut

- Events may contain split tracks: sections of the same track erroneously identified as a pair of tracks that are close in momentum space.
- Intermittency analysis is based on pairs distribution $\Rightarrow$ split tracks can create a false positive, and so must be reduced or removed.
- Standard cuts remove part of split tracks. In order to estimate the residual contamination, we check the q_{inv} distribution of track pairs:

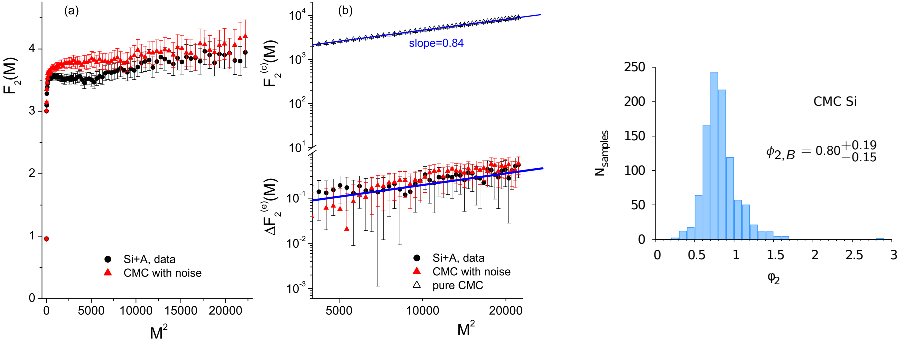
$$q_{inv}(p_i, p_j) \equiv \frac{1}{2}\sqrt{-(p_i - p_j)^2},$$

p_i : 4-momentum of i^{th} track.

- We calculate the ratio of $q_{inv}^{data}/q_{inv}^{mixed}$. A peak at low q_{inv} (below 20 MeV/c) indicates a possible split track contamination that must be removed.

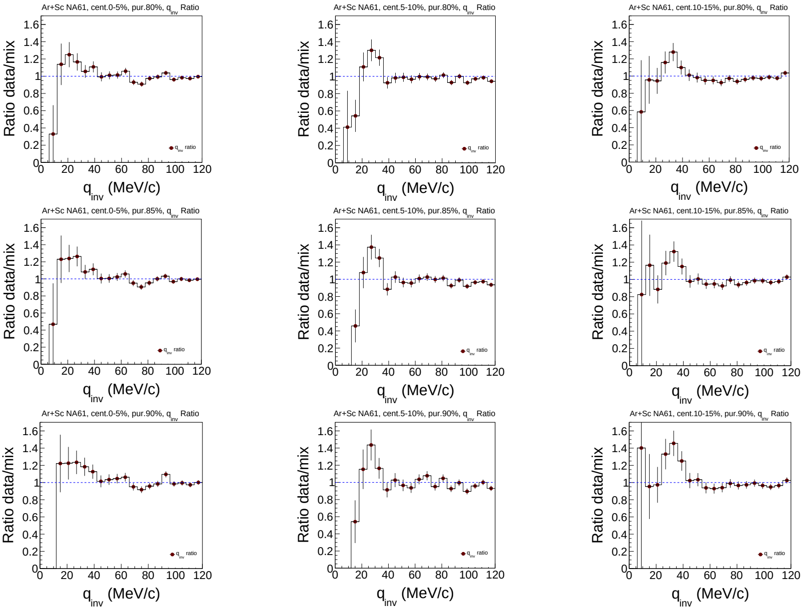
Noisy CMC (baryons) – estimating the level of background

- $F_2(M)$ of noisy CMC approximates "Si"+Si for $\lambda \approx 0.99$
- $\Delta F_2^{(e)}(M)$ reproduces critical behaviour of pure CMC, even though their moments differ by orders of magnitude!

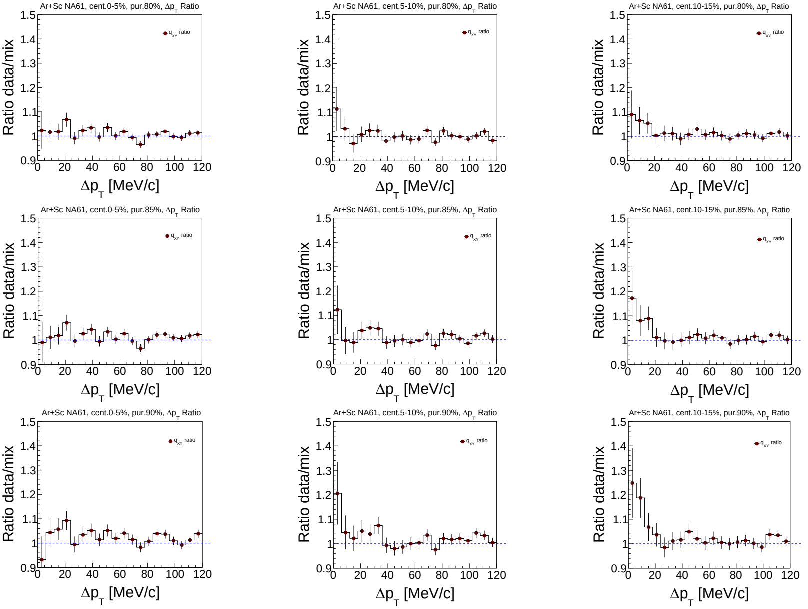


- Noisy CMC results show our approximation is reasonable for dominant background.

q_{inv} proton distributions – NA61/SHINE



Δp_T proton distributions – NA61/SHINE



q_{inv} & Δp_T distributions – EPOS