News from the NA61/SHINE experiment

Evgeny Andronov for the NA61/SHINE Collaboration

Saint Petersburg State University, LUHEP

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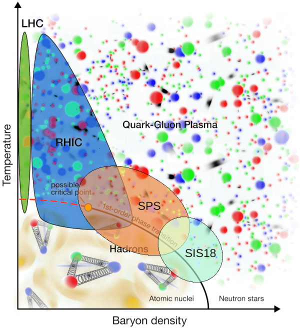
QUARKS-2018
XXth International Seminar on High Energy Physics

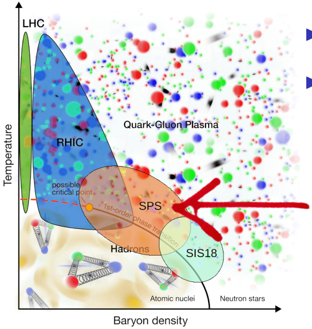
Valday, Russia

Motivation of the NA61/SHINE strong interaction programme



- Search for the critical point
- Study of properties of the onset of deconfinement

Motivation of the NA61/SHINE strong interaction programme



- Search for the critical point
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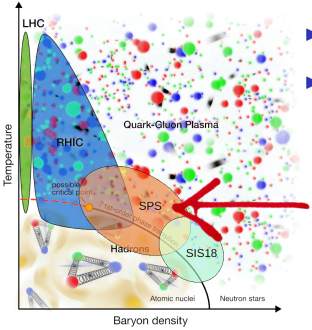
Comprehensive scan in A+A collisions with light and intermediate mass nuclei in beam momentum range 13*A*-150*A* GeV/*c*

Motivation of the NA61/SHINE strong interaction programme

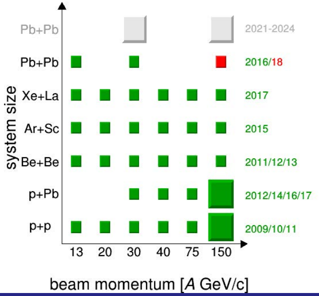


- Search for the critical point
- Study of properties of the onset of deconfinement

Comprehensive scan in A+A collisions with light and intermediate mass nuclei in beam momentum range 13*A*–150*A* GeV/*c*

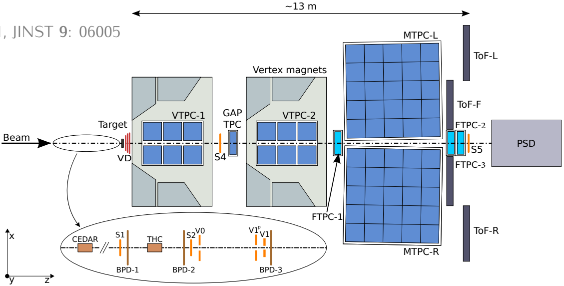
Data taking schedule:

taken data (green)
approved for 2018 (red)
proposed extension (gray)

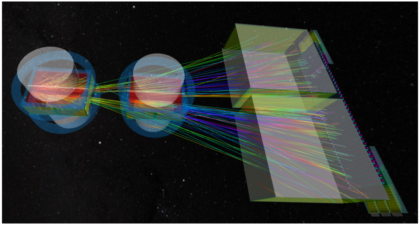


	13	20	30	40	75	150	
Pb+Pb			⬜			⬜	2021-2024
Pb+Pb	🟩		🟩			🟥	2016/18
Xe+La	🟩	🟩	🟩	🟩	🟩	🟩	2017
Ar+Sc	🟩	🟩	🟩	🟩	🟩	🟩	2015
Be+Be	🟩	🟩	🟩	🟩	🟩	🟩	2011/12/13
p+Pb			🟩	🟩	🟩	🟩	2012/14/16/17
p+p	🟩	🟩	🟩	🟩	🟩	🟩	2009/10/11

NA61/SHINE detector



NA61, JINST **9**: 06005



NA61/SHINE in virtual reality: `http://shine3d.web.cern.ch/shine3d/`

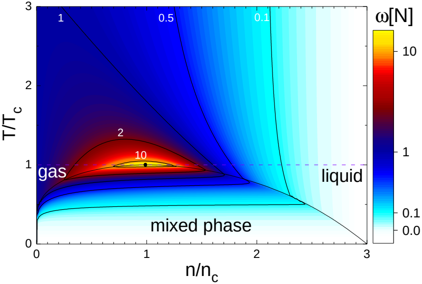
- Located at CERN SPS
- Large acceptance hadron spectrometer – coverage of the full forward hemisphere, down to $p_T = 0$ GeV/c
- Performs measurements on hadron production in h+p, h+A, A+A at 13A – 150(8)A GeV/c
- Event selection in A+A collisions by measurements of forward energy with Projectile Spectator Detector
- Recent upgrades: vertex detector (open charm measurements), FTPC-1/2/3

Intensive fluctuation measure

A ratio of two extensive quantities ($\sim W$ - number of sources (strings, wounded nucleons) or $\sim V$ - volume in statistical models) is an intensive measure.

E.g. for charged particles multiplicity N we have:

$$\omega[N] = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}$$



Vovchenko, *et al.*, JPA **48**: 305001

- Independent of W

in the Wounded Nucleon Model

Bialas, *et al.*, NPB **111**, 461

- $\omega[N] = 1$ for the Poisson distribution
- $\omega[N] = 0$ in the absence of fluctuations

- should be sensitive to critical fluctuations

(e.g. in classical van der Waals gas within GCE formulation)

- CP signal may be shadowed by volume

fluctuations $\omega[W]$

- No signs of CP observed

More details in report by A. Seryakov

Strongly intensive fluctuation measures

Baseline of search for critical behaviour: quantities with trivial properties in the reference models (e.g. WNM or IB-GCE)

$$\Delta[P_T, N] = \frac{1}{\omega[p_T]\langle N\rangle}\left(\langle N\rangle\omega[P_T] - \langle P_T\rangle\omega[N]\right)$$
$$\Sigma[P_T, N] = \frac{1}{\omega[p_T]\langle N\rangle}\left(\langle N\rangle\omega[P_T] + \langle P_T\rangle\omega[N] - 2cov(P_T, N)\right)$$

where $P_T = \sum_{i=1}^{N} p_{Ti}$

N - multiplicity of charged hadrons in an experimental acceptance

$\omega[p_T]$ - scaled variance of inclusive p_T distribution

- Independent of $\langle W\rangle$ and $\omega[W]$ in the Wounded Nucleon Model
- $\Delta[P_T, N] = \Sigma[P_T, N] = 1$ for the independent particle production model
- $\Delta[P_T, N] = \Sigma[P_T, N] = 1$ for the ideal Boltzmann gas in both Grand Canonical Ensemble and Canonical Ensemble formulations
- $\Delta[P_T, N] = \Sigma[P_T, N] = 0$ in the absence of fluctuations

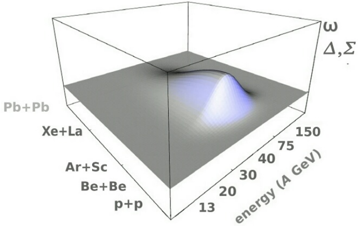
Gorenstein, Gazdzicki, PRC **84**:014904

Gorenstein, *et al.*, PRC **88** 2:024907

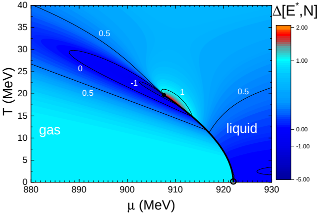
Strongly intensive fluctuation measures

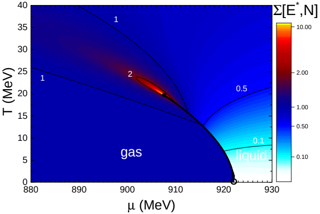
Sensitivity to critical point

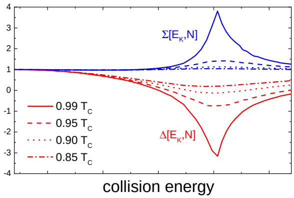
Analysis of strongly intensive fluctuation measures is expected to give more insight into the critical point location



$\Sigma[E^*, N]$ and $\Delta[E^*, N]$ for nucleon system with van der Waals EOS in GCE formulation in vicinity of critical point, E^* – excitation energy



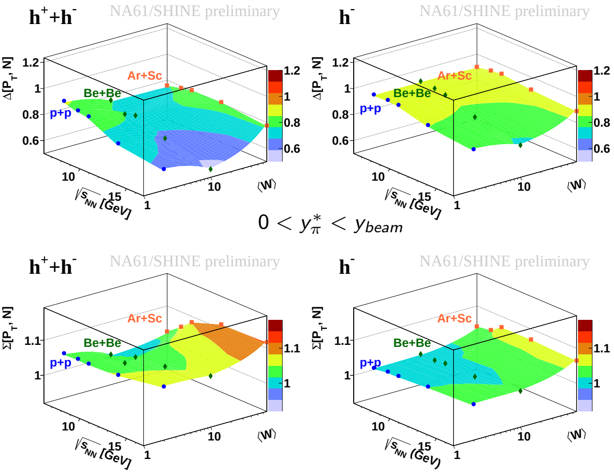




Vovchenko, Gorenstein, Stoecker, PRL **118**: 182301

$\Delta, \Sigma[P_T, N]$: energy vs. system size scan

Inelastic p+p vs. 0-5% ^{7}Be+^{9}Be vs. 0-5% ^{40}Ar+^{45}Sc



$0 < y^*_\pi < y_{beam}$

$\Delta[P_T, N] < 1$
$\Sigma[P_T, N] \geq 1$

Explanations?

- Bose-Einstein statistics of pion gas
- negative event-mean p_T vs. N correlation leads to the same inequalities.

Gorenstein, Grebieszkow, PRC **89**:034903

No prominent structures which could be related to the critical point are visible.

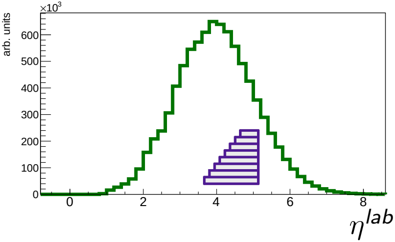
Andronov, Acta Phys. Pol. B Proc. Suppl. **10** 449

Analysis extension: choice of phase-space

^{7}Be+^{9}Be at 150A GeV/c

More details in report by D. Prokhorova

Sketch of psedorapidity (lab) spectrum of charged hadrons with proposed windows



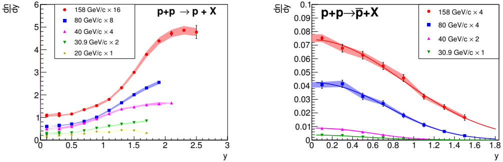
9 intervals considered:

from $\eta^{lab} \in (4.6; 5.2)$ up to $\eta^{lab} \in (3; 5.2)$

The lower cut: poor azimuthal angle acceptance and stronger electron contamination at backward rapidities. The upper cut: to reduce effects of spectators.

Rapidity width dependence studies will allow to probe different baryochemical potentials $(\frac{\overline{p}}{p} = e^{-(2\mu_B)/T})$ – extension of the phase diagram scan!

Rapidity spectra of p and $\overline{p}$ in inelastic p+p interactions at SPS energies

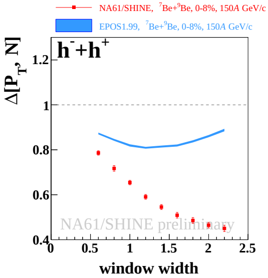


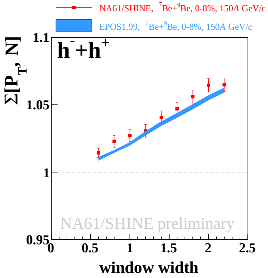
$\frac{\overline{p}}{p}$ changes significantly with rapidity

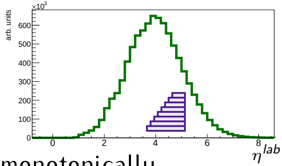
NA61, EPJC **77** 10: 671

$\Delta,\Sigma[P_T, N]$: pseudorapidity width dependence

^{7}Be+^{9}Be at 150A GeV/c







$\Delta[P_T, N] < 1$ and is monotonically decreasing with the width of the pseudorapidity interval

Disagreement with the non-trivial dependence from the EPOS1.99 model

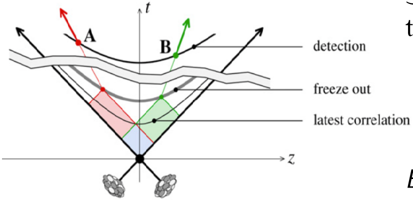
$\Sigma[P_T, N] > 1$ and is monotonically increasing with the width of the pseudorapidity interval

$\Sigma[P_T, N]$ approaches 1 for small width of the pseudorapidity interval (close to Poisson limit)

Andronov, KnE Energy and Physics 3 1:226

Forward-backward correlations

Causality requires appearance of long-range pseudorapidity correlations at early stages of evolution. Long-range correlations originate from fluctuations in the number of particle sources (many other effects like jets, flow, resonance decays, etc may affect these correlations).



Dumitru, *et al.*, NPA **810**: 91

Strength of correlations is quantified by the correlation coefficient:

$$b(B,F) = \frac{\langle BF\rangle - \langle B\rangle\langle F\rangle}{\langle F^2\rangle - \langle F\rangle^2}$$

B - an observable in "backward" η window (e.g. N_B)
F - an observable in "forward" η window (e.g. N_F)

Sensitivity to the number of sources makes correlation coefficient to be not strongly intensive, i.e. to be centrality dependent.

STAR, PRL **103**: 172301
I. Altsybeev, KnE En. Phys. **3**, 1:304

Strongly intensive fluctuation measures: two windows case

For extensive observables in two separated pseudorapidity intervals F and B one can introduce new strongly intensive quantities:

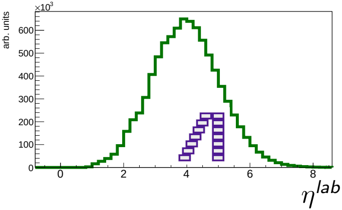
- N_F, N_B fluctuations Andronov, TMPh **185** 1: 1383

$$\Sigma\left[N_F, N_B\right] = \frac{\langle N_B\rangle\omega\left[N_F\right] + \langle N_F\rangle\omega\left[N_B\right] - 2cov\left(N_F, N_B\right)}{\langle N_B\rangle + \langle N_F\rangle}$$

Similar expressions can be given for

- N_F, P_{TB} fluctuations
- P_{TF}, P_{TB} fluctuations

Sketch of psedorapidity (lab) spectrum of charged hadrons with proposed windows



7 pairs of intervals considered:

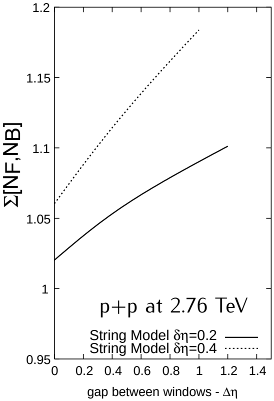
η_B^{lab} moves from (3; 3.5) up to (4.2; 4.7)
$\eta_F^{lab} \in (4.7; 5.2)$

Strongly intensive fluctuation measures: two windows case

$\Sigma[N_F, N_B]$ can be calculated in the model of independent quark gluon strings

Estimations for p+p collisions at LHC energies show growth of $\Sigma[N_F, N_B]$ with separation between windows

Predictions are based only on string decay features, no influence of volume fluctuations

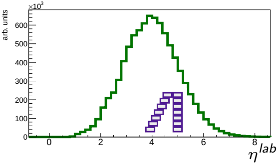


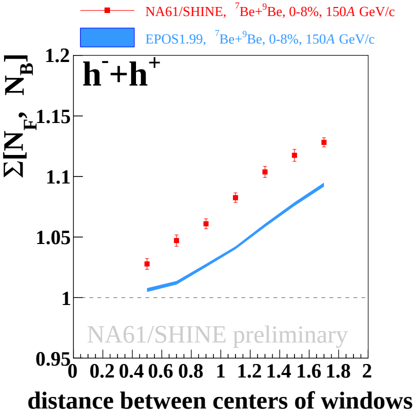
Vechernin, WPCF 2017

Vechernin, this seminar

$\Sigma[N_F, N_B]$: pseudorapidity separation dependence

^{7}Be+^{9}Be at 150A GeV/c





$\Sigma[N_F, N_B]$ is growing with separation between windows

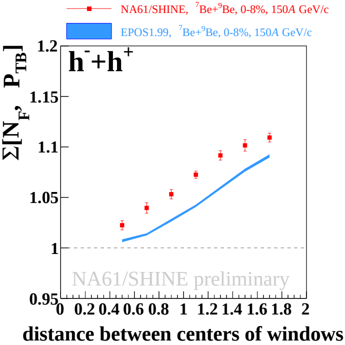
Behaviour is similar to predictions of string model for p+p collisions at LHC energies

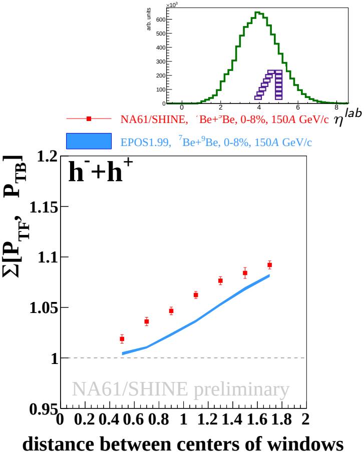
Dominating role of short-range correlations (from a single string)?

Trend is reproduced by EPOS1.99

$\Sigma[N_F, P_{TB}]$ and $\Sigma[P_{TF}, P_{TB}]$

^{7}Be+^{9}Be at 150A GeV/c



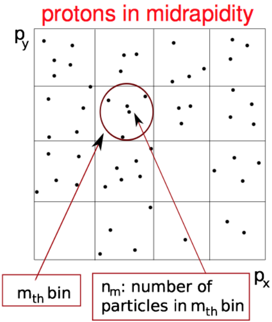


$\Sigma[N_F, P_{TB}] > 1$ and $\Sigma[P_{TF}, P_{TB}] > 1$

$\Sigma[N_F, P_{TB}]$ and $\Sigma[P_{TF}, P_{TB}]$ are growing with separation between windows

Trend is reproduced by EPOS1.99

Intermittency analysis as a CP searches tool



Second order phase transition → self-similarity → correlations in configuration space that can be observed by studying correlations in momentum space

We detect local, power-law fluctuations of baryon density by calculating the scaling of 2nd factorial moments $F_2(M)$ with cell size ⇔ cells M in transverse momentum space (intermittency) Diakonos et al., PoS (CPOD2006) 010

Second factorial moments:

$$F_2(M) \equiv \frac{\sum_m \langle n_m(n_m-1)\rangle}{\sum_m \langle n_m\rangle^2}$$

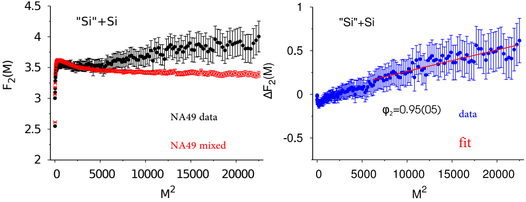
After subtracting non-critical background moments, the correlator $\Delta F_2(M) = F_2^{data}(M) - F_2^{mix}(M)$ should scale according to a power-law for $M \gg 1$

$$\Delta F_2(M) \sim (M^2)^{\phi_2},\ \phi_2 = \frac{5}{6}$$

Antoniou et al., PRL **97** 032002
Wosiek; Bialas, Peschanski; Satz ...

Intermittency analysis results

NA49 and NA61/SHINE: 150*A GeV/c*

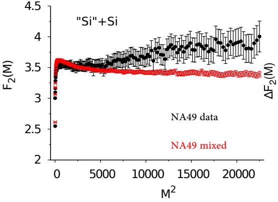


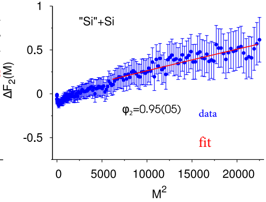
NA49: no intermittency signal in C+C and Pb+Pb collisions

Evidence for intermittency in Si+Si that is consistent with 1% of critically correlated protons in CMC model NA49, EPJC **75** 587

Intermittency analysis results

NA49 and NA61/SHINE: 150*A GeV/c*





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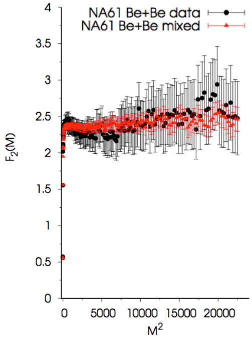
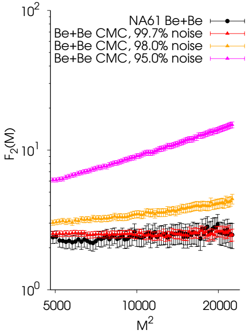




NA61: no intermittency effect in the first analysis of Be+Be collisions

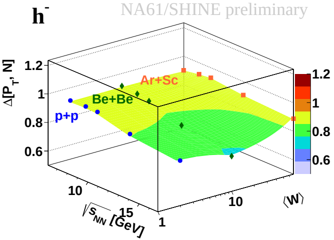
Observation is consistent with only 0.3% of critically correlated protons in MC simulations

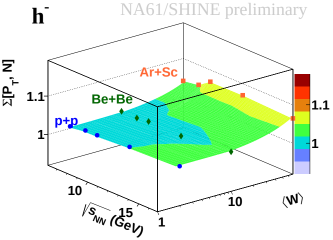
Ar+Sc, Xe+La and Pb+Pb coming soon

Conclusions

- NA61/SHINE conducts search for the critical point of strongly interacting matter by means of analysis of fluctuations, namely, multiplicity, $[P_T, N]$, intermittency and others.

- Results on system size vs. energy dependence of N and $[P_T, N]$ fluctuations for particles produced in strong and EM processes within the NA61/SHINE acceptance were reported - **no indications** of the critical point of strongly interacting matter so far





Conclusions

- Pseudorapidity dependence of $[P_T, N]$ fluctuations for forward energy selected ^{7}Be+^{9}Be collisions at 150A GeV/c - $\Delta[P_T, N]$ pseudorapidity dependence is **in disagreement** with EPOS1.99

- Intermittency analysis of self-similar (power-law) fluctuations of the net baryon density in transverse momentum spacefor forward energy selected ^{7}Be+^{9}Be collisions at 150A GeV/c indicates an upper limit of $\sim$ 0.3% critical protons.

- We are working hard to extract new results for Ar+Sc, Xe+La and Pb+Pb collisions - stay tuned!

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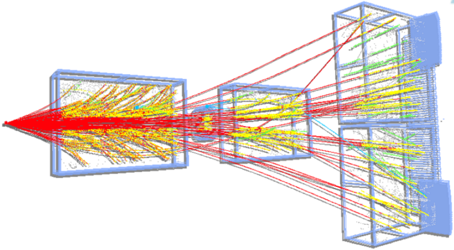
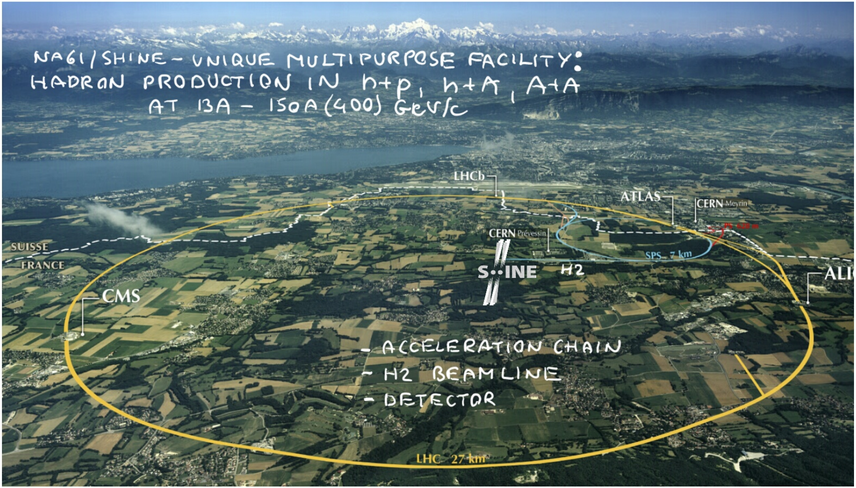
Thank You!



Back-up

DETECTOR



NA61/SHINE – UNIQUE MULTIPURPOSE FACILITY:
HADRON PRODUCTION IN h+p, h+A, A+A
AT 13A – 150A (400) GeV/c

- ACCELERATION CHAIN
- H2 BEAMLINE
- DETECTOR

NA61/SHINE Collaboration

- Azerbaijan
  - National Nuclear Research Center, Baku
- Bulgaria
  - University of Sofia, Sofia
- Croatia
  - IRB, Zagreb
- France
  - LPNHE, Paris
- Germany
  - KIT, Karlsruhe
  - Fachhochschule Frankfurt, Frankfurt
  - University of Frankfurt, Frankfurt
- Greece
  - University of Athens, Athens
- Hungary
  - Wigner RCP, Budapest
- Japan
  - KEK Tsukuba, Tsukuba
- Norway
  - University of Bergen, Bergen
- Poland
  - UJK, Kielce
  - NCBJ, Warsaw
  - University of Warsaw, Warsaw
  - WUT, Warsaw
  - Jagiellonian University, Kraków
  - IFJ PAN, Kraków
  - AGH, Kraków
  - University of Silesia, Katowice
  - University of Wrocław, Wrocław
- Russia
  - INR Moscow, Moscow
  - JINR Dubna, Dubna
  - SPBU, St.Petersburg
  - MEPhI, Moscow
- Serbia
  - University of Belgrade, Belgrade
- Switzerland
  - ETH Zürich, Zürich
  - University of Bern, Bern
  - University of Geneva, Geneva
- USA
  - University of Colorado Boulder, Boulder
  - LANL, Los Alamos
  - University of Pittsburgh, Pittsburgh
  - FNAL, Batavia
  - University of Hawaii, Manoa

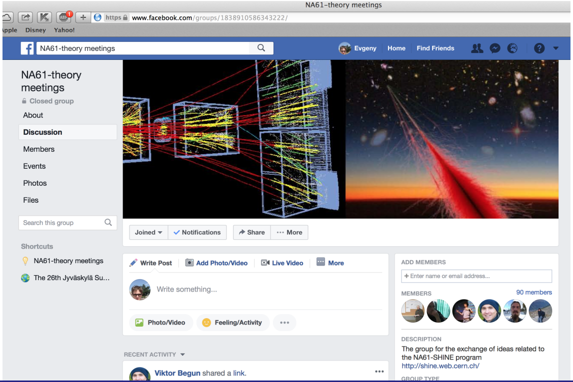
$\sim$150 physicists from $\sim$30 institutes

NA61/SHINE theory meetings

- NA61/SHINE regularly organize theory seminars with invited speakers

- Among them: K. Werner, G. Torrieri, W. Broniowski, M. Strikman and many other respected theorists

- You can find us on facebook

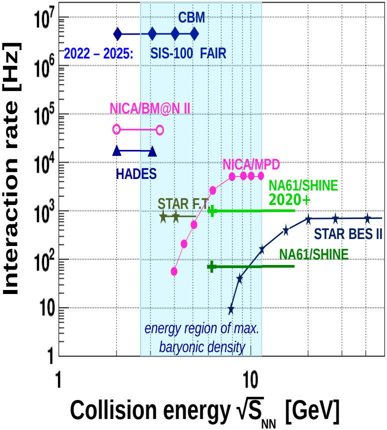


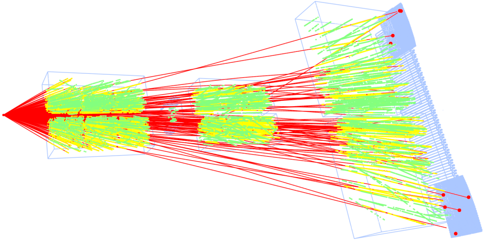
Viktor Begun shared a link.

The group for the exchange of ideas related to the NA61-SHINE program
http://shine.web.cern.ch/

NA61/SHINE in 2021-2024

- Detector upgrade: 1 kHz readout, TOF, PSD, Large Acceptance Vertex Detector during Long Shutdown in 2019-2020
- High statistics beam momentum scan with Pb+Pb collisions for precise measurements of open charm and multi-strange hyperon production
- In parallel, NA61/SHINE performs measurements for long-baseline neutrino facilities at J-PARC and Fermilab; rich neutrino program is planned to be continued after 2020





(Central Pb+Pb collision at 13*A* GeV/*c* measured in NA61/SHINE in 2016)

Higher moments of net electric charge

Relation with the correlation length

N: e-by-e net charge

Mean: $M = \langle N \rangle$

St. dev.: $\sigma = \sqrt{\langle (N - \langle N \rangle)^2 \rangle}$

Skewness: $S = \frac{\langle (N - \langle N \rangle)^3 \rangle}{\sigma^3}$

Kurtosis: $k = \frac{\langle (N - \langle N \rangle)^4 \rangle}{\sigma^4} - 3$

$$\langle (N - \langle N \rangle)^2 \rangle \approx \xi^2$$
$$\langle (N - \langle N \rangle)^3 \rangle \approx \xi^{4.5}$$
$$\langle (N - \langle N \rangle)^4 \rangle \approx \xi^7$$

Volume independent combinations of the various moments:

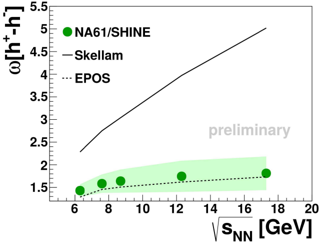
$$\omega[N] = \frac{\sigma^2}{M} = \frac{\chi^{(2)}}{\chi^{(1)}},\ S\sigma = \frac{\chi^{(3)}}{\chi^{(2)}},\ S\sigma^2 = \frac{\chi^{(4)}}{\chi^{(2)}}$$

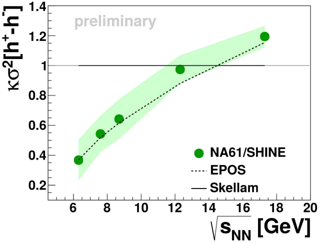
The signature of non-monotonicity of these observables is expected if there is a nearby critical point in QCD phase transition.

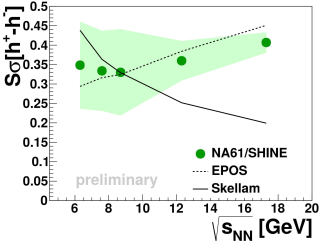
Athanasiou et al., PRD82 (2010) 074008, Stephanov, PRL 107, 052301(2011), Karsch et al., PLB 695, 136 (2011).

Fluctuations of net-charge in inelastic p+p interactions

$p_T < 1.5$ GeV/c, NA61/SHINE acceptance







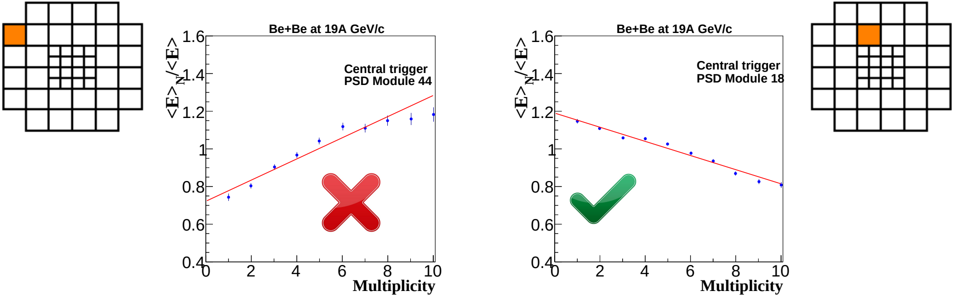
- No non-monotonic behavior suggesting CP
- EPOS model describes data on net-charge fluctuations
- Results do not agree with independent particle production (Skellam), difference may come from multi-charged particles and quantum statistics

P. Braun-Munzinger et al., Nucl.Phys. A880 48-64 (2012)

Centrality selection

One needs to choose set of modules with dominating contribution of spectators and minimal contribution from the produced particles.

The proposed selection is data-driven and is based on correlations between energy and track multiplicity in TPC acceptance - negative correlation implies dominance of spectators in specific module.

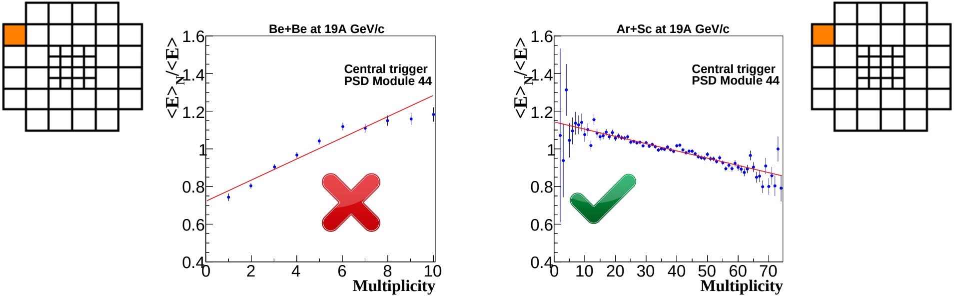


Sketch of energy in the PSD modules and multiplicity correlations for ^{7}Be+^{9}Be collisions at 19*A* GeV/*c*

Centrality selection

Due to the differences in magnetic field and PSD position for various energies, different set of modules is chosen to calculate E_F.

Unexpectedly, for the same collision energy but for different colliding systems same modules show different behaviour.

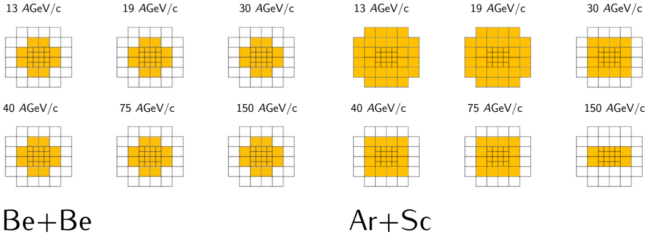


Sketch of energy in the PSD modules and multiplicity correlations for ^{7}Be+^{9}Be and ^{40}Ar+^{45}Sc collisions at 19A GeV/c

Centrality selection

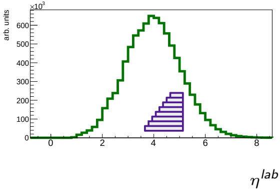
One needs to choose set of modules with dominating contribution of spectators and minimal contribution from the produced particles.

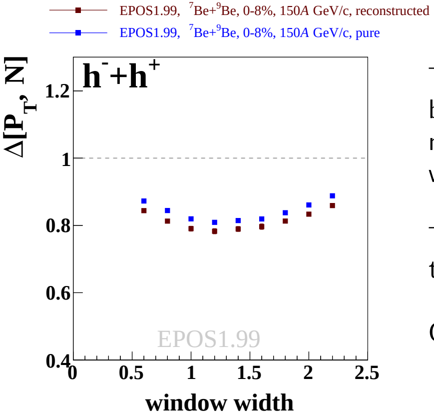
The proposed selection is data-driven and is based on correlations between energy and track multiplicity in TPC acceptance - negative correlation implies dominance of spectators in specific module.



$\Delta[P_T, N]$: pseudorapidity width dependence

^{7}Be+^{9}Be at 150A GeV/c





EPOS1.99 - Werner, *et al.*, PRC **74**:044902

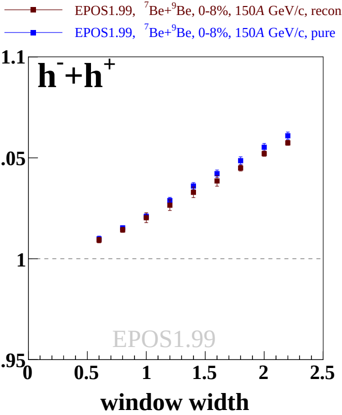
To estimate magnitude of experimental biases differences between pure and reconstructed Monte Carlo simulations were studied

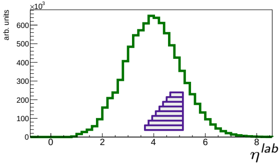
This difference was estimated to be less than 5% for all data points

Corrections are not performed

$\Sigma[P_T, N]$: pseudorapidity width dependence

^{7}Be+^{9}Be at 150A GeV/c





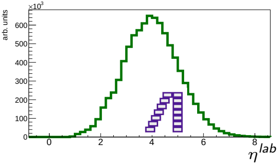
To estimate magnitude of experimental biases differences between pure and reconstructed Monte Carlo simulations were studied

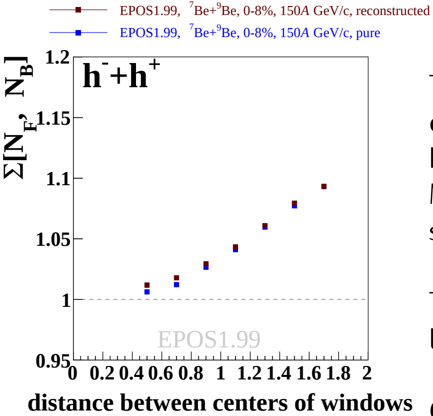
This difference was estimated to be less than 5% for all data points

Corrections are not performed

$\Sigma[N_F, N_B]$: pseudorapidity separation dependence

^{7}Be+^{9}Be at 150A GeV/c





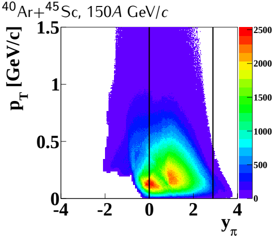
To estimate magnitude of experimental biases differences between pure and reconstructed Monte Carlo simulations were studied

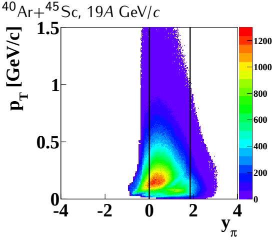
This difference was estimated to be less than 5% for all data points

Corrections are not performed

Analysis details

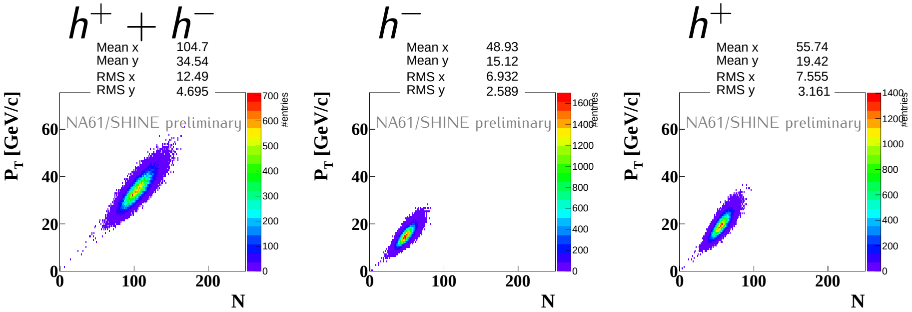
- In order to select properly measured central events one uses the following event selection criteria:
  - good beam quality
  - no off-time beam particles
  - good main vertex fit
  - centrality selected by forward energy (in simulations - selection is based on energy of all particles in the kinematic region corresponding to the selected modules)
- In order to select particles produced in strong and EM processes from the primary vertex one uses the following track selection criteria:
  - sufficient number of points inside TPCs
  - track trajectory points to interaction point
  - no electrons/positrons
  - $p_T < 1.5$ GeV/c
  - NA61/SHINE acceptance map
  - $0 < y^*_\pi < y_{beam}$ (due to poor azimuthal angle acceptance and stronger electron contamination at backward rapidities)


^{40}Ar+^{45}Sc, 150A GeV/c


^{40}Ar+^{45}Sc, 19A GeV/c

Examples of uncorrected N vs. P_T distributions

^{40}Ar+^{45}Sc at 150A GeV/c, $0-5\%$



N, P_T and $P_{T,2} = \sum_{i=1}^{N} p_{Ti}^2$ are measured for each event.

$P_{T,2}$ is needed to calculate the scaled variance of the inclusive p_T distribution $\omega[p_T] = \frac{\overline{p_T^2} - \overline{p_T}^2}{\overline{p_T}}$ using only event quantities.

Corrections

Werner, *et al.*, PRC **74**:044902

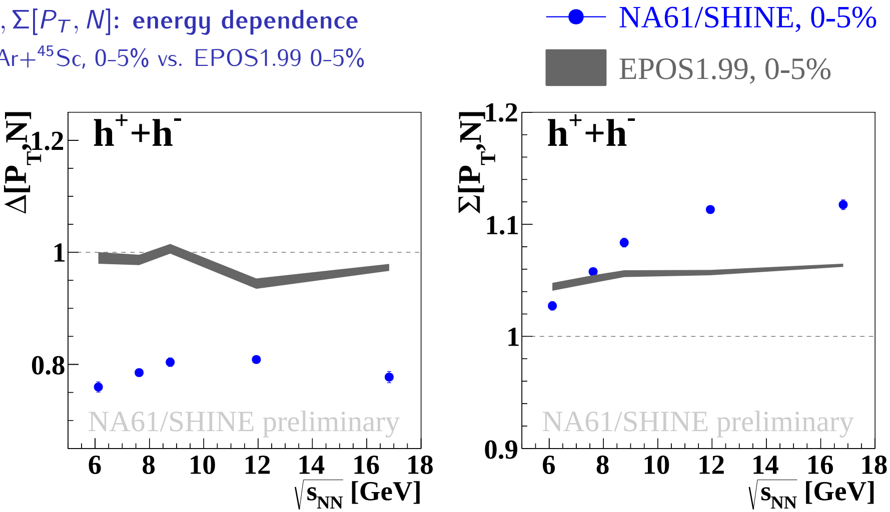
- MC used for corrections: EPOS1.99 model (version CRMC 1.5.3), GEANT3.21. The simulated data were analysed within the NA61/SHINE acceptance.
- Corrections for losses due to event and track selections, trigger biases, detector inefficiencies, secondary interactions and feed-down from weak decays for ^{40}Ar+^{45}Sc were performed on the level of the first and second moments of measured observables.
- Correction factors for $\langle N\rangle$, $\langle N^2\rangle$, $\langle P_T\rangle$, $\langle P_T^2\rangle$, $\langle N \cdot P_T\rangle$ and $\langle P_{T,2}\rangle$ were calculated as ratios of the corresponding moments for pure to reconstructed MC for positively, negatively and all charged hadrons, separately.

Note on errors

Statistical uncertainties were calculated by dividing the data sets into 30 sub-samples. The statistical error is taken as the standard ï£¡ï£¡deviation of the sub-sample results divided by $\sqrt{30}$. They are typically smaller than a marker size.

$\Delta, \Sigma[P_T, N]$: energy dependence

^{40}Ar+^{45}Sc, 0-5% vs. EPOS1.99 0-5%



The EPOS1.99 model overestimates $\Delta[P_T, N]$.

The EPOS1.99 model results are close to 1 – the independent particle production model prediction.

Comparison with PbPb results from NA49

To compare results of p_T fluctuations, NA49 cuts were applied to NA61/SHINE data.

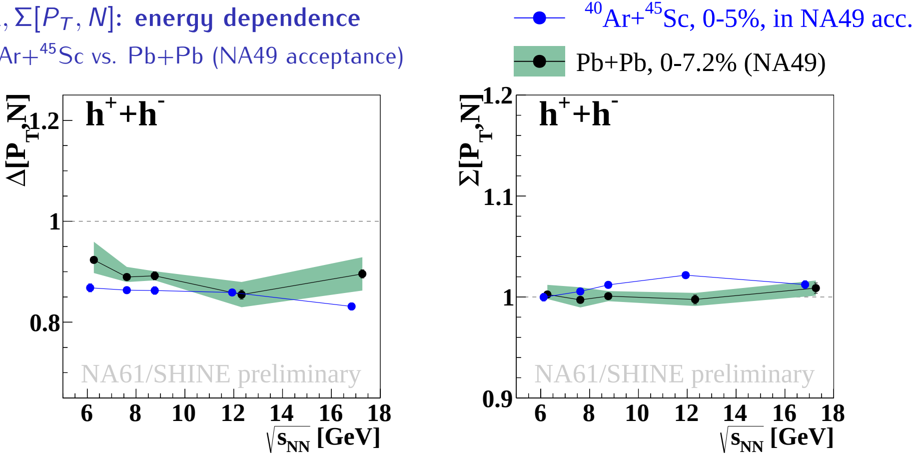
In NA49:

- because of high density of tracks, analysis was limited to forward-rapidity region $(1.1 < y_\pi < 2.6)$
- to exclude elastically scattered or diffractively produced protons, analysis was limited in proton rapidity $(y_p < y_{beam} - 0.5)$
- $0.005 < p_T < 1.5$ GeV/c
- common azimuthal acceptance for all energies

NA49, PRC **92** no.4:044905

$\Delta, \Sigma[P_T, N]$: energy dependence

^{40}Ar+^{45}Sc vs. Pb+Pb (NA49 acceptance)



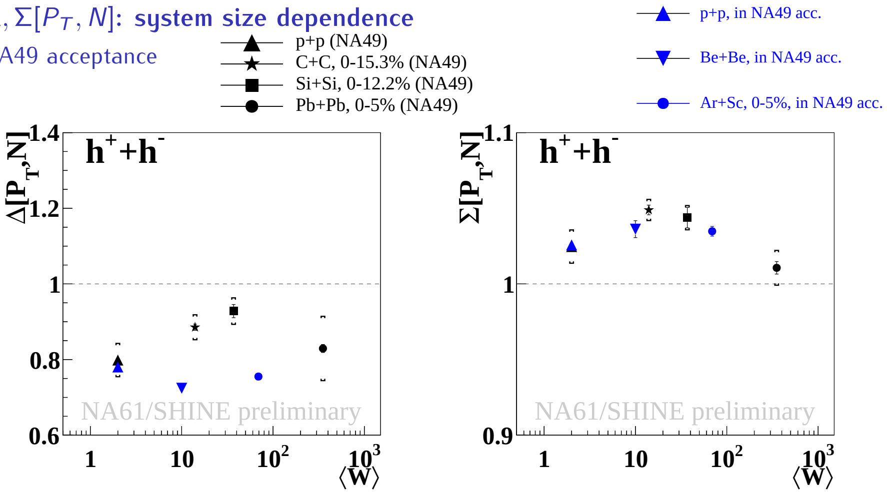
Results for ^{40}Ar+^{45}Sc collisions are very close to Pb+Pb. No prominent structures which could be related to the CP are visible.

$\Delta[P_T, N] < 1$ and $\Sigma[P_T, N] \geq 1$ for both systems.

NA49, PRC **92** no.4:044905

$\Delta, \Sigma[P_T, N]$: system size dependence

NA49 acceptance



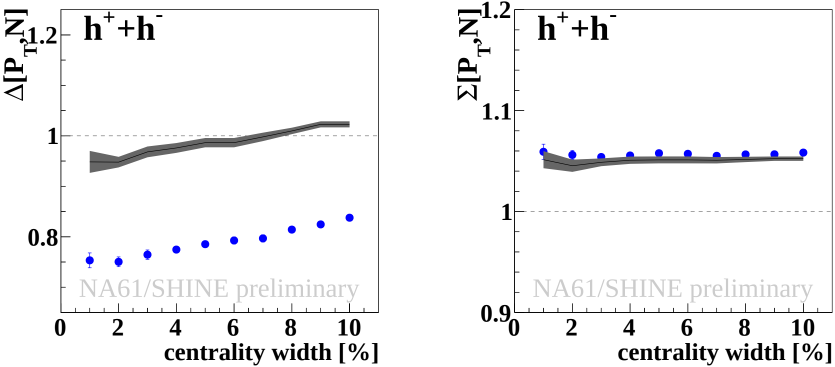
No prominent structures which could be related to the CP are visible.
$\Delta[P_T, N]$ is more sensitive to centrality selection than $\Sigma[P_T, N]$.

NA49, PRC **92** no.4:044905

$\Delta, \Sigma[P_T, N]$: centrality dependence

^{40}Ar+^{45}Sc, 30A GeV/c

Centrality classes from 0 − 1% to 0 − 10%



$\Sigma[P_T, N]$ is less centrality dependent than $\Delta[P_T, N]$ both in data and in the EPOS1.99 model.

Centrality dependence

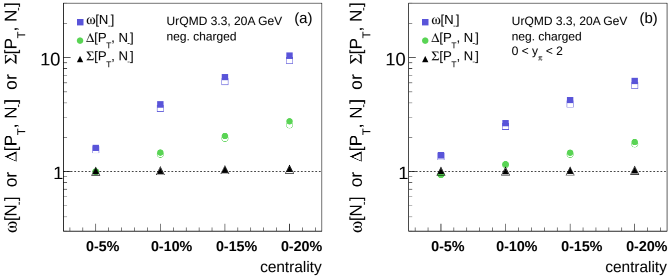
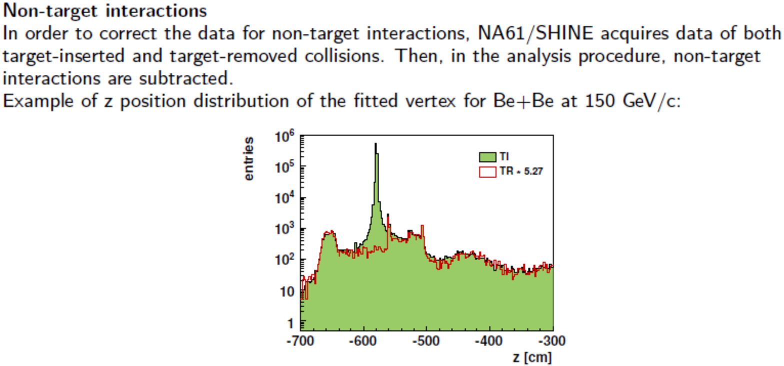


Figure 5: (Color online) The UrQMD results for the centrality dependence of $\omega[N_-]$ (*squares*), $\Delta[P_T, N_-]$ (*circles*), and $\Sigma[P_T, N_-]$ (*triangles*) in Pb+Pb collisions at $E_{lab} = 20$A GeV. A centrality selection is done with a restriction on the impact parameter b. (a): The full 4π detector acceptance. (b): Only particles with center of mass rapidity in the interval $1 < y_\pi < 2$ are accepted (pion mass was assumed for all particles). Open symbols correspond to the case when 10% of particles was randomly rejected.

Gorenstein, Grebieszkow, PRC **89**:034903

Corrections

Corrections for contamination from off-target interactions for ^{40}Ar+^{45}Sc were not applied, but with applied vertex position selection they are expected to be less than 1%.



Non-target interactions

In order to correct the data for non-target interactions, NA61/SHINE acquires data of both target-inserted and target-removed collisions. Then, in the analysis procedure, non-target interactions are subtracted.

Example of z position distribution of the fitted vertex for Be+Be at 150 GeV/c:

Multiplicity fluctuations: strongly intensive quantity

$\omega[N]$ is an intensive measure - independent of $\langle W \rangle$ in WNM
Quantities that do not depend on $\langle W \rangle$ and $\omega[W]$ are strongly intensive

For N and $E_P = E_{beam} - E_F$ one can introduce

$$\Omega[N, E_P] = \omega[N] - \frac{cov(N, E_P)}{\langle E_P \rangle}$$

In WNM:

$$\omega[N] = \omega[n] + \langle n \rangle \omega[W]$$
$$\Omega[N, E_P] = \omega[n] - \frac{cov(n, e_P)}{\langle e_P \rangle}$$

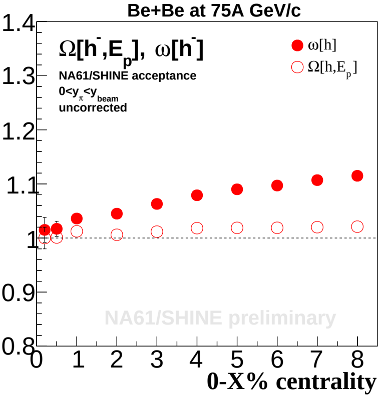
n and e_P are N and E_P for a fixed volume

For narrow centrality interval $\Omega[N, E_P] \rightarrow \omega[n]$.
If $\omega[N] \rightarrow \Omega[N, E_P]$ in data, that would mean that volume fluctuations in $\omega[N]$ are suppressed and $\omega[N] \approx \omega[n]$

Gorenstein, Gazdzicki, PRC **84**:014904
Poberezhnyuk *et al.*, Acta Phys.Polon. B **47**: 2055

$\omega[N]$ and $\Omega[N, E_P]$: centrality dependence

^{7}Be+^{9}Be collisions at 75A GeV/c

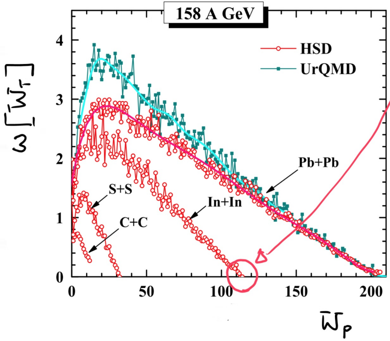


$\Omega[N, E_P]$ almost does not depend on centrality – strongly intensive!

$\Omega[N, E_P]$ and $\omega[N]$ converges to a common limit for very central events

Is this common limit $\omega[n]$?

Unwanted fluctuations



EXAMPLE FOR In+In (Xe+La);

FOR $\bar{W}_P \approx A$ (113) $\omega[\bar{W}_T] \approx 0$
AND $W_T \approx A$
⇓
$\omega[\bar{W}=\bar{W}_P+\bar{W}_T] \approx 0$

$$\omega[N] = \underline{\underline{\omega[N]_W}} + \xcancel{\langle N\rangle/\langle W\rangle \cdot \omega[W]}$$

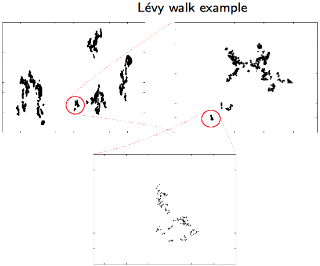
P
WANTED

UNWANTED

KANCHAKOVSKI, LUNGWITZ, GORENSTEIN BRATKOUSKAYA

Critical Monte Carlo model

- 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	$0.1 \to 1$	$800 \to 1200$	$\langle p \rangle_{\text{non-empty}}$	163

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

Critical Monte Carlo model for Be+Be collisions

- Collision parameters:
  1. ${}^{7}Be$ (beam) + ${}^{9}Be$ (target)
  2. Beam energy: $150A\ GeV$ (target rest frame) $\Leftrightarrow \sqrt{s_{NN}} = 16.8\ GeV$

${}^{7}Be + {}^{9}Be$ NA61 data – proton p_T statistics

Centrality	#events	$\langle p \rangle_{\lvert p_T \rvert \leq 1.5\ GeV,\ \lvert y_{CM} \rvert \leq 0.75}$		$\Delta p_{x,y}$
		Non-empty	With empty	
10%	166,215	1.48 ± 0.74	0.82 ± 0.92	0.38 - 0.49

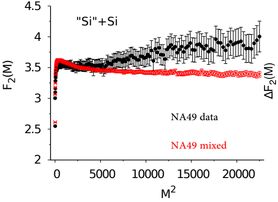
CMC simulation parameters

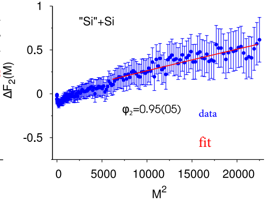
Parameter	p_{min} (MeV)	p_{max} (MeV)	λ_{Poisson}	T_c (MeV)
Value	0.85	1200	0.76	163

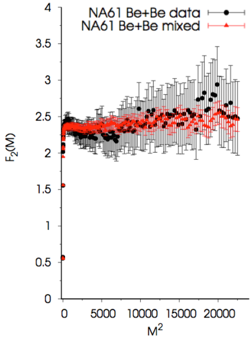
- $\langle p \rangle$ in mid-rapidity remains low, except for very central collisions

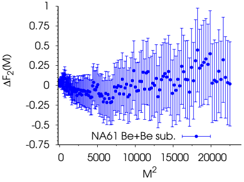
Intermittency analysis results

NA49 and NA61/SHINE: 150*A GeV/c*









NA49: no intermittency signal in C+C and Pb+Pb collisions

Evidence for intermittency in Si+Si that is consistent with 1% of critically correlated protons in CMC model NA49, EPJC **75** 587

NA61: no intermittency effect in the first analysis of Be+Be collisions

Observation is consistent with only 0.3% of critically correlated protons in MC simulations

Ar+Sc, Xe+La and Pb+Pb coming soon