Search for the critical point by the NA61/SHINE experiment

Evgeny Andronov for the NA61/SHINE Collaboration

Saint Petersburg State University, LUHEP

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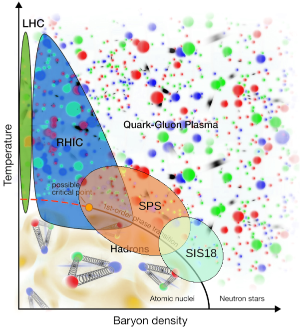
Motivation of the NA61/SHINE strong interaction programme



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

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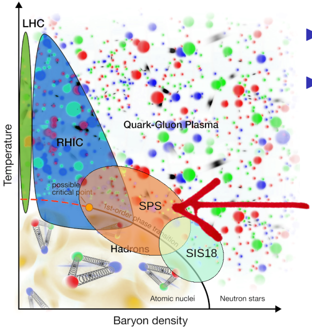

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Comprehensive scan in A+A collisions with light and intermediate mass nuclei in beam momentum range 13A-150A GeV/c

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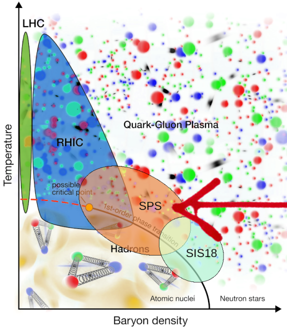

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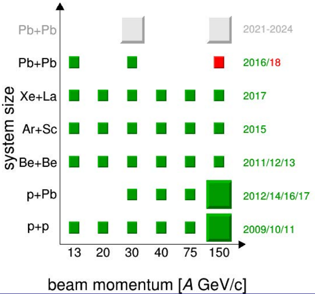
Comprehensive scan in A+A collisions with light and intermediate mass nuclei in beam momentum range 13*A*–150*A* GeV/*c*

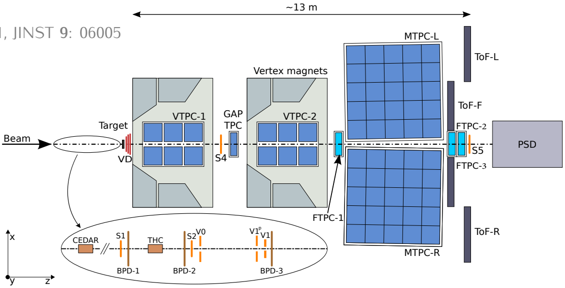
Data taking schedule:

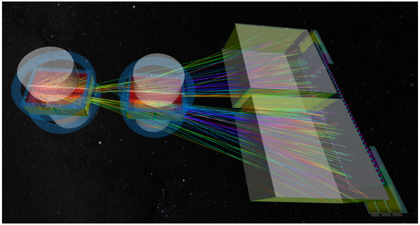
taken data (green)
approved for 2018 (red)
proposed extension (gray)



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:

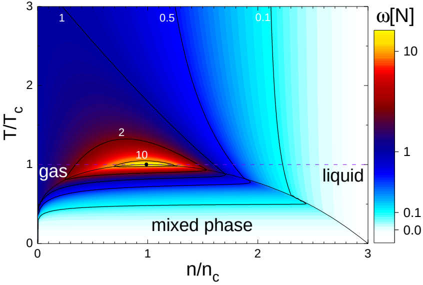
$$\omega[N] = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}$$

- Independent of W for $\omega[W] = 0$ 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

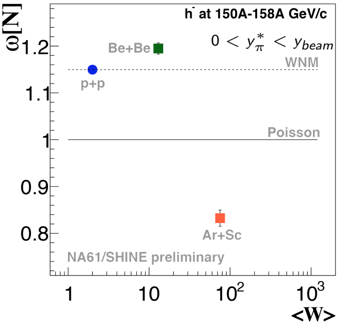
- should be sensitive to critical fluctuations (e.g. in classical van der Waals gas within GCE formulation)
- CP signal may be shadowed by volume fluctuations $\omega[W]$



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

$\omega[N]$: system size dependence

$\omega[N]$ were measured for inelastic p+p interactions and forward energy selected ^{7}Be+^{9}Be and ^{40}Ar+^{45}Sc collisions with particles produced in strong and EM processes within the NA61/SHINE acceptance. edms.cern.ch/document/1549298/1



p+p - inelastic
Be+Be - 1% most 'central' events
Ar+Sc -0.2% most 'central' events
Seryakov, KnE Energy and Physics 3 1: 170

Statistical uncertainties were calculated by the sub-sample method.

Systematic uncertainties due to experimental biases are under investigation (estimated to be smaller than 5%).

Mean number of wounded nucleons $\langle W \rangle$ estimated using the GLISSANDO model.

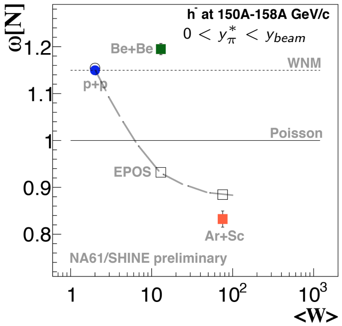
Broniowski, Rybczynski, PRC **81**: 064909

$\omega[N]$: system size dependence

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

Rapid change of $\omega[N]$ at $\langle W \rangle \approx 20$ is observed! (not described by EPOS1.99)

Tough challenge for interpretations:



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Seryakov, KnE Energy and Physics 3 1: 170

In WNM: $\omega[N] = \omega[n] + \frac{\langle N \rangle}{\langle W \rangle}\omega[W]$

n – multiplicity from a wounded nucleon

$\omega[n] = \omega[N]_{pp} \Rightarrow \omega[N]_{AA} \geq \omega[N]_{pp}$

In disagreement with data

NB: in **WQuarkM** it is possible to have $\omega[N]_{AA} \leq \omega[N]_{pp}$
if fluctuations in a number of wounded quarks are suppressed in A+A

Bialas, *et al.*, Acta Phys. Pol. B **8**, 585

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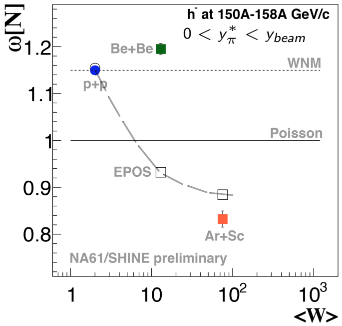

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Bialas, *et al.*, Acta Phys. Pol. B **8**, 585

In **statistical models** [IB-GCE]: $\omega[N] = 1$

In disagreement with data

Conservation laws (IB-CE) make $\omega[N] < 1$

Begun, *et al.*, PRC **76**, 024902
Begun, *et al.*, PRC **78**, 024904

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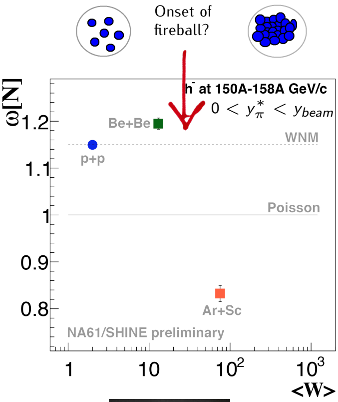


Percolation:

- collisions of light nuclei – non-overlapping particle emitting clusters
- collisions of heavy ions – large, single cluster

Baym, Physica **96A**: 131
Celik, Karsch, Satz PLB **97**: 128
Armesto, *et al.*, PRL **77**: 3736

AdS/CFT correspondence:

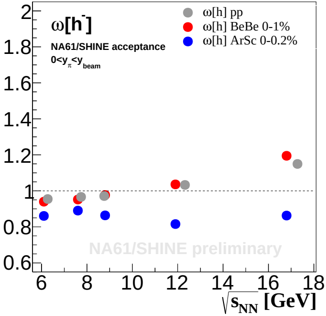
- Gravity – formation of a black hole horizon takes place when critical values of model parameters are reached
- QCD – only starting from a sufficiently large nuclear mass number the formation of the trapping surface in A+A collisions is possible

$\Rightarrow$ **Onset of Fireball**

Shuryak, Prog.Part.Nucl.Phys. **62**: 48
Lin, Shuryak, PRD **79**: 124015

$\omega[N]$: energy vs. system size dependence

Preliminary results were obtained for five collision energies.
Significant difference between small systems and Ar+Sc is present at all collision energies.



Seryakov, KnE Energy and Physics 3 1: 170

$\omega[N]$ for p+p and Be+Be are close to each other at collision energies

$\omega[N] < 1$ for Ar+Sc

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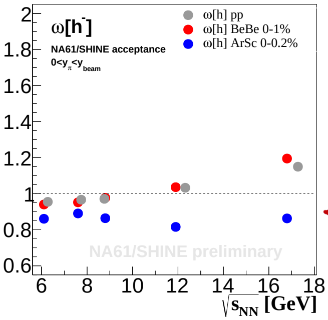


Seryakov, KnE Energy and Physics 3 1: 170

$\omega[N]$ for p+p and Be+Be are close to each other at collision energies

$\omega[N] < 1$ for Ar+Sc

$\omega[N] \approx 0.9$ for Pb+Pb measured by NA49 (in slightly smaller acceptance and wider centrality class) NA49, PRC **78** 034914

No signs that can be clearly associated with the critical point

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

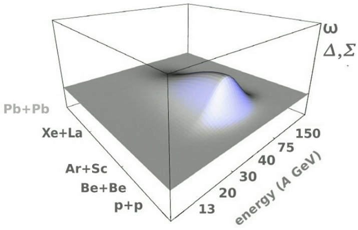
Gorenstein, Gazdzicki, PRC **84**:014904

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

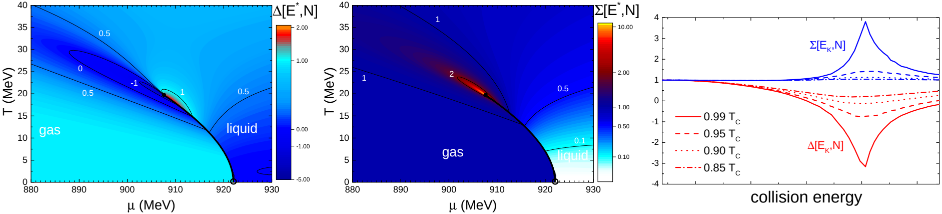
Strongly intensive fluctuation measures

Sensitivity to critical point

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



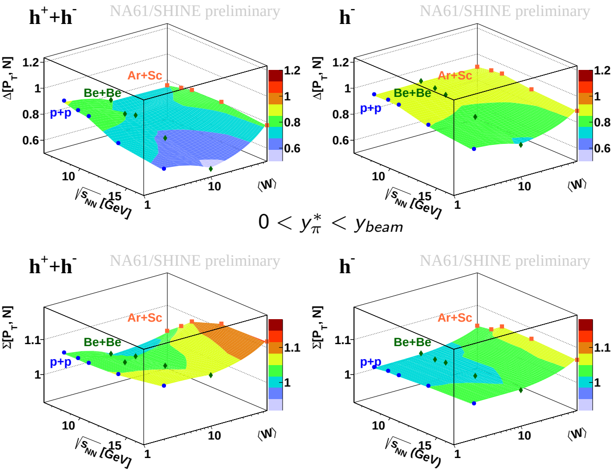
$\Sigma[E^*, N]$ and $\Delta[E^*, N]$ for nucleon system with van der Waals EOS in GCE formulation in vicinity of critical point, E^* – excitation energy



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



Data shows that
$\Delta[P_T, N] < 1$
$\Sigma[P_T, N] > 1$

Explanations?

- Bose-Einstein statistics of pion gas
- negative P_T/N vs. N correlation leads to the same inequalities.

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

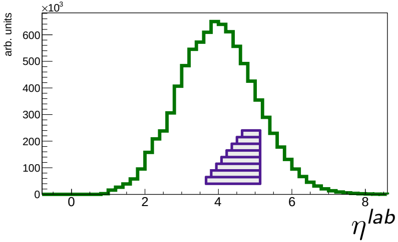
No prominent structures which could be related to the critical point are visible.

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

Analysis extension: choice of phase-space

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

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



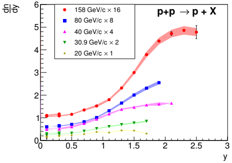
9 intervals considered:

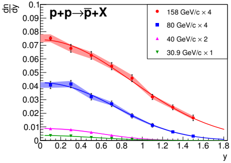
from $\eta^{lab} \in (4.6; 5.2)$ up to $\eta^{lab} \in (3; 5.2)$

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



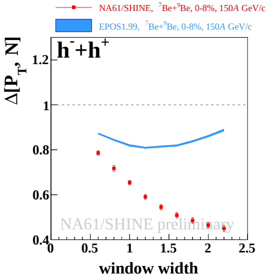


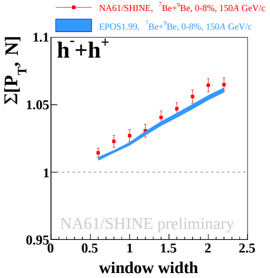
$\frac{\overline{p}}{p}$ changes significantly with rapidity

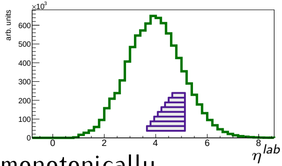
NA61, EPJC **77** 10: 671

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

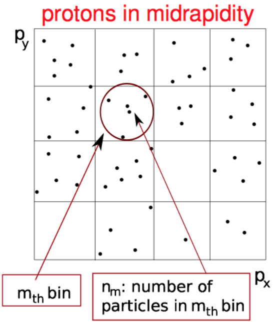
Disagreement with the non-trivial dependence from the EPOS1.99 model

$\Sigma[P_T, N] > 1$ 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

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 search for 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:

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

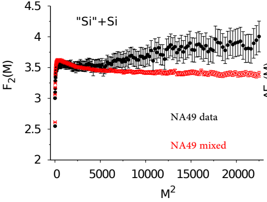
After subtracting non-critical background moments, the correlator $\Delta F_2(M) = F_2^{data}(M) - F_2^{mix}(M)$ should scale according to a power-law for $M \gg 1$

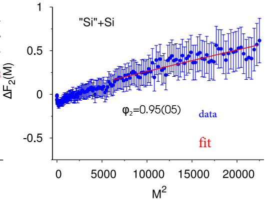
$$\Delta F_2(M) \sim (M^2)^{\phi_2},\ \phi_2 = \frac{5}{6}$$

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

More details in poster by N. Davis

Intermittency analysis results

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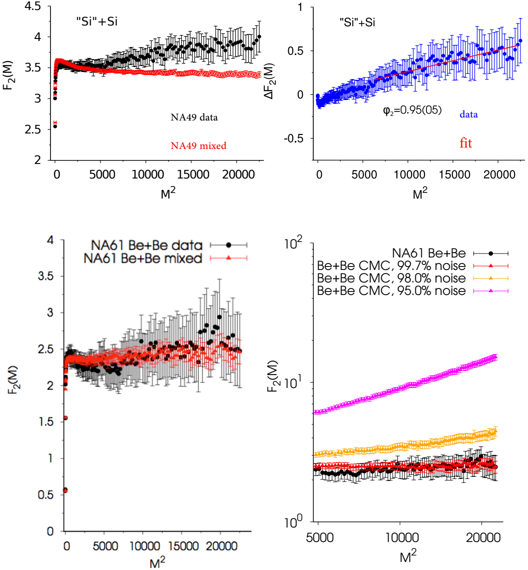

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NA61: no intermittency effect in the first analysis of Be+Be collisions

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

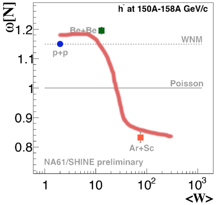
Ar+Sc, Xe+La and Pb+Pb coming soon

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

• Intriguing system size dependence of $\omega[N]$ could be interpreted as a signal of new phenomena - onset of fireball



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

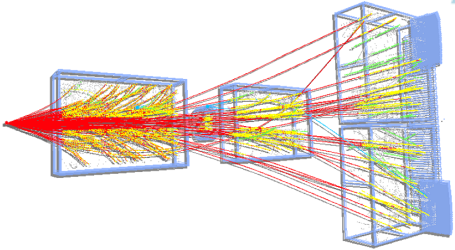
• Intermittency analysis of self-similar (power-law) fluctuations of the net baryon density in transverse momentum space for forward energy selected ^{7}Be+^{9}Be collisions at 150A GeV/c indicates an upper limit of $\sim 0.3\%$ critical protons

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

This work is supported by the Russian Science Foundation under grant 17-72-20045

evgeny.andronov@cern.ch

Thank You!



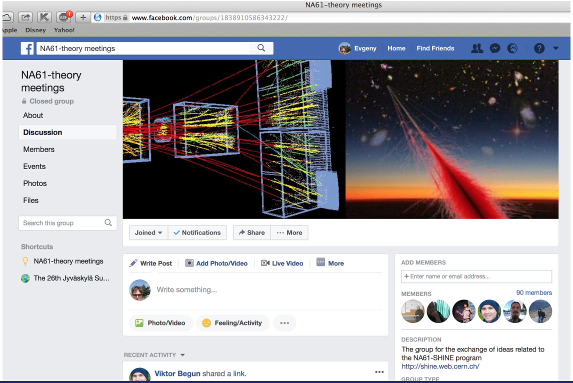
Back-up

NA61/SHINE theory meetings

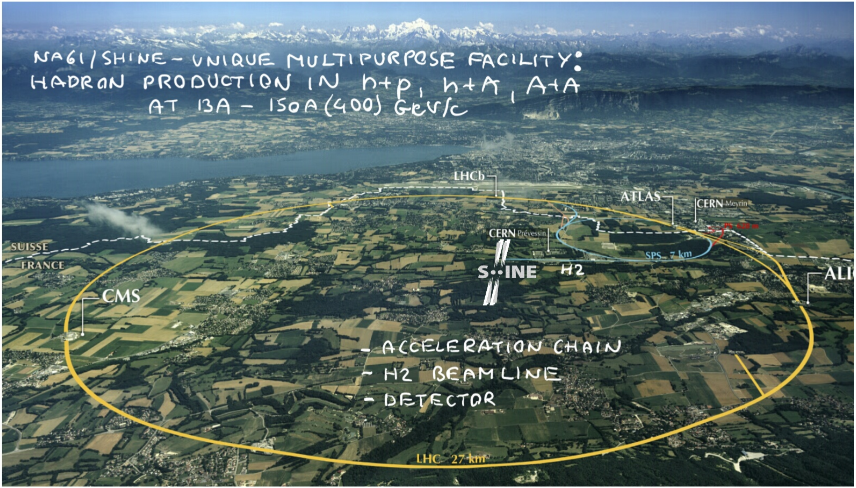
- NA61/SHINE regularly organize theory seminars with invited speakers

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

- You can find us on facebook 



DETECTOR


NA61/SHINE – UNIQUE MULTIPURPOSE FACILITY:
HADRON PRODUCTION IN h+p, h+A, A+A
AT 13A – 150A (400) GeV/c
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
SHINE
H2
CMS
ALI
– ACCELERATION CHAIN
– H2 BEAMLINE
– DETECTOR
LHC 27 km

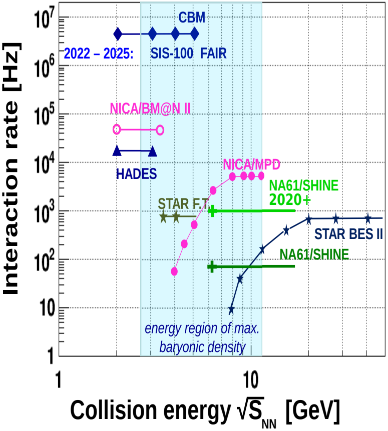
NA61/SHINE Collaboration

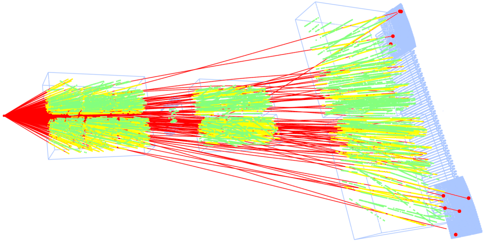
- Azerbaijan
  - National Nuclear Research Center, Baku
- Bulgaria
  - University of Sofia, Sofia
- Croatia
  - IRB, Zagreb
- France
  - LPNHE, Paris
- Germany
  - KIT, Karlsruhe
  - Fachhochschule Frankfurt, Frankfurt
  - University of Frankfurt, Frankfurt
- Greece
  - University of Athens, Athens
- 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 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 13A 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:

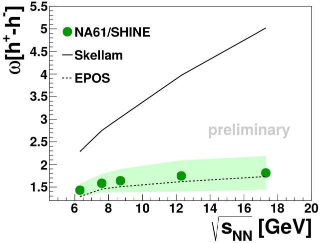
$$\omega[N] = \frac{\sigma^2}{M} = \frac{\chi^{(2)}}{\chi^{(1)}},\ S\sigma = \frac{\chi^{(3)}}{\chi^{(2)}},\ k\sigma^2 = \frac{\chi^{(4)}}{\chi^{(2)}}$$

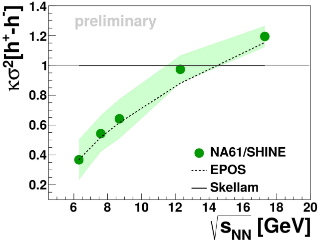
The signature of non-monotonicity of these observables is expected if there is a nearby critical point in QCD phase transition.

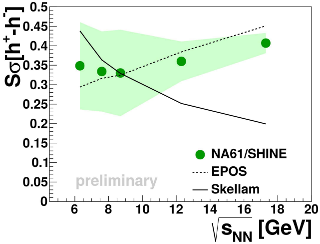
Athanasiou et al., PRD82 (2010) 074008, Stephanov, PRL 107, 052301(2011), Karsch et al., PLB 695, 136 (2011).

Fluctuations of net-charge in inelastic p+p interactions

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







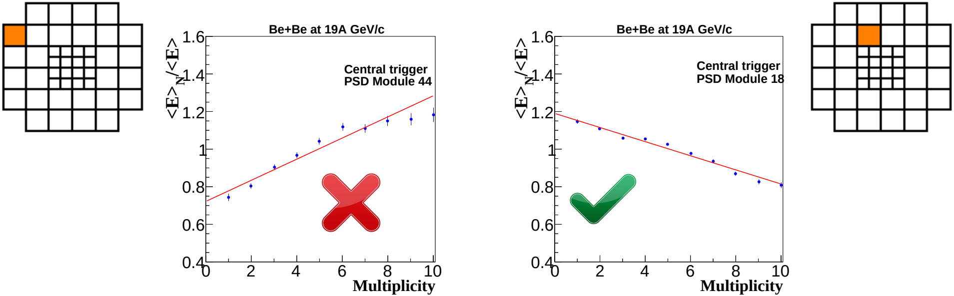
- No non-monotonic behavior suggesting CP
- EPOS model describes data on net-charge fluctuations
- Results do not agree with independent particle production (Skellam), difference may come from multi-charged particles and quantum statistics

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.

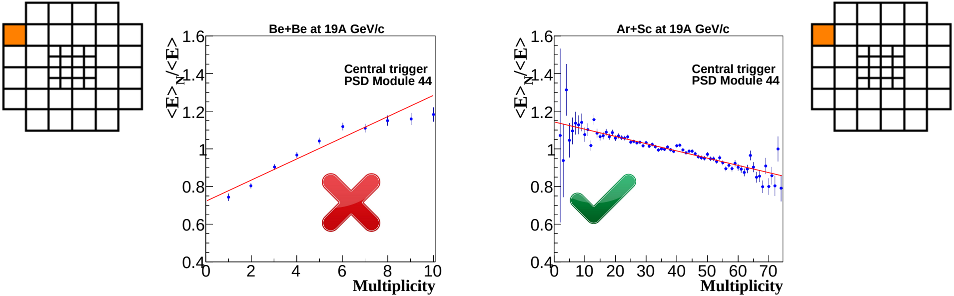


Sketch of energy in the PSD modules and multiplicity correlations for ^{7}Be+^{9}Be collisions at 19*A* GeV/*c*

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.

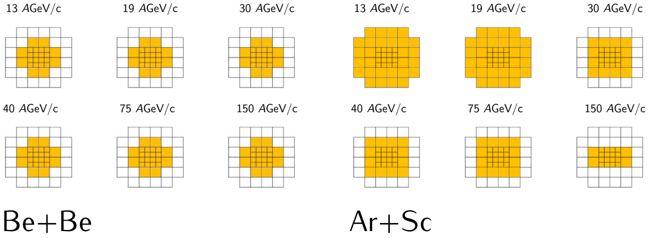


Sketch of energy in the PSD modules and multiplicity correlations for ^{7}Be+^{9}Be and ^{40}Ar+^{45}Sc collisions at 19A GeV/c

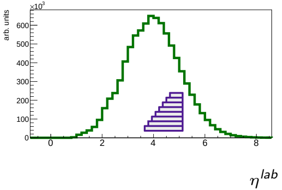
Centrality selection

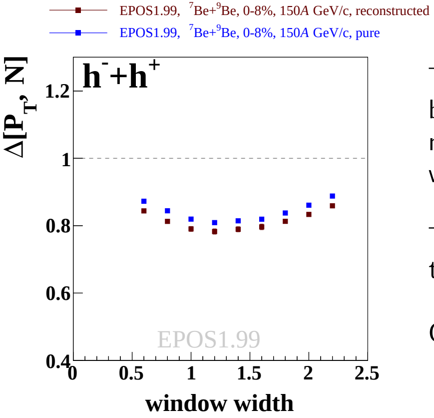
One needs to choose set of modules with dominating contribution of spectators and minimal contribution from the produced particles.

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

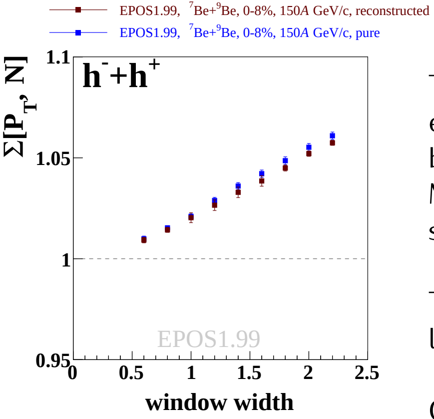
To estimate magnitude of experimental biases differences between pure and reconstructed Monte Carlo simulations were studied

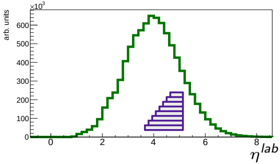
This difference was estimated to be less than 5% for all data points

Corrections are not performed

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

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



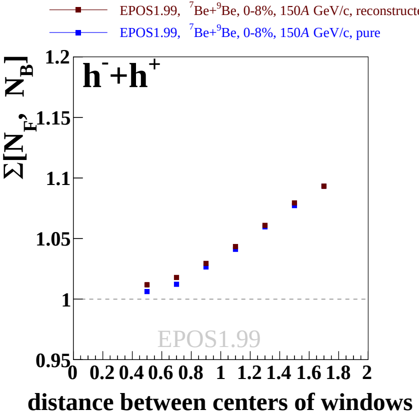


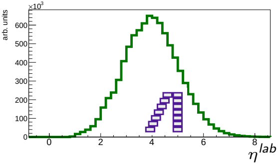
To estimate magnitude of experimental biases differences between pure and reconstructed Monte Carlo simulations were studied

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





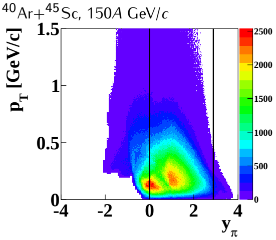
To estimate magnitude of experimental biases differences between pure and reconstructed Monte Carlo simulations were studied

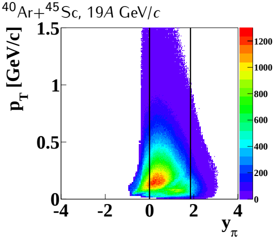
This difference was estimated to be less than 5% for all data points

Corrections are not performed

Analysis details

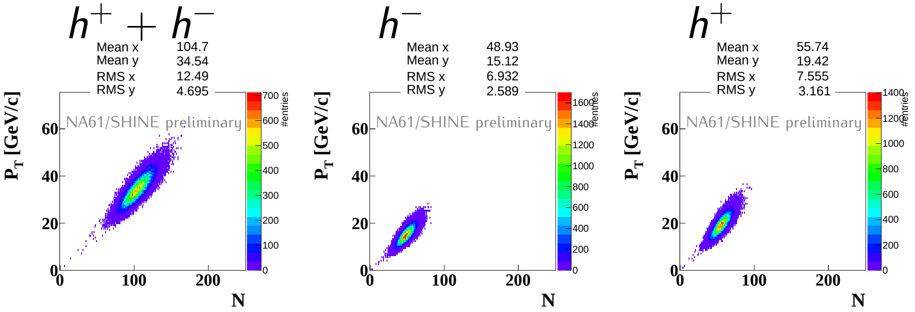
- In order to select properly measured central events one uses the following event selection criteria:
  - good beam quality
  - no off-time beam particles
  - good main vertex fit
  - centrality selected by forward energy (in simulations - selection is based on energy of all particles in the kinematic 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)





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

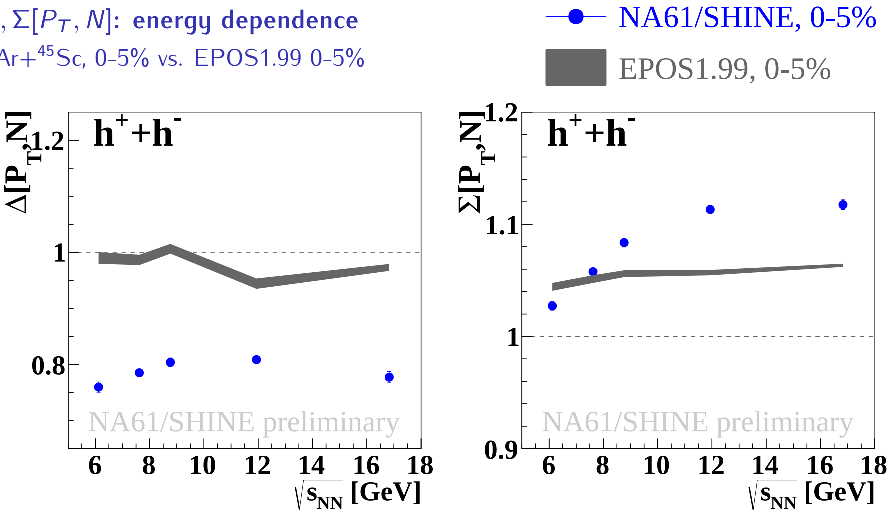
- MC used for corrections: EPOS1.99 model (version CRMC 1.5.3), GEANT3.21. The simulated data were analysed within the NA61/SHINE acceptance.
- Corrections for losses due to event and track selections, trigger biases, detector inefficiencies, secondary interactions and feed-down from weak decays for ^{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.

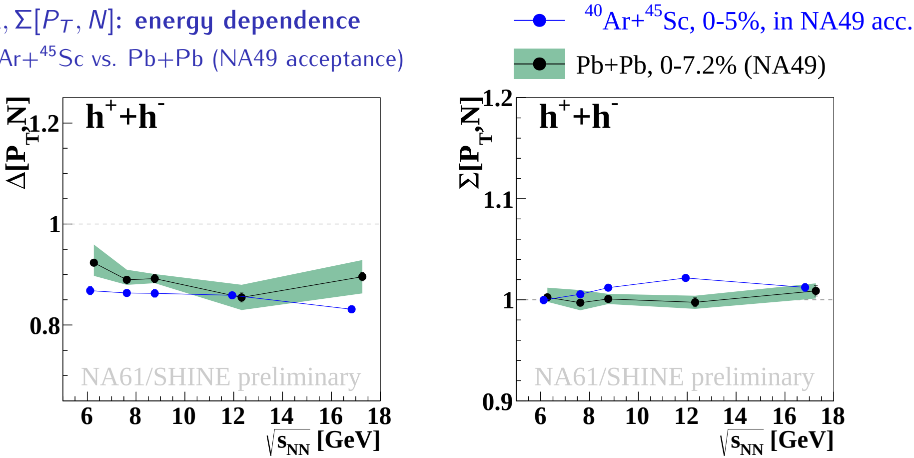
In NA49:

- 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)



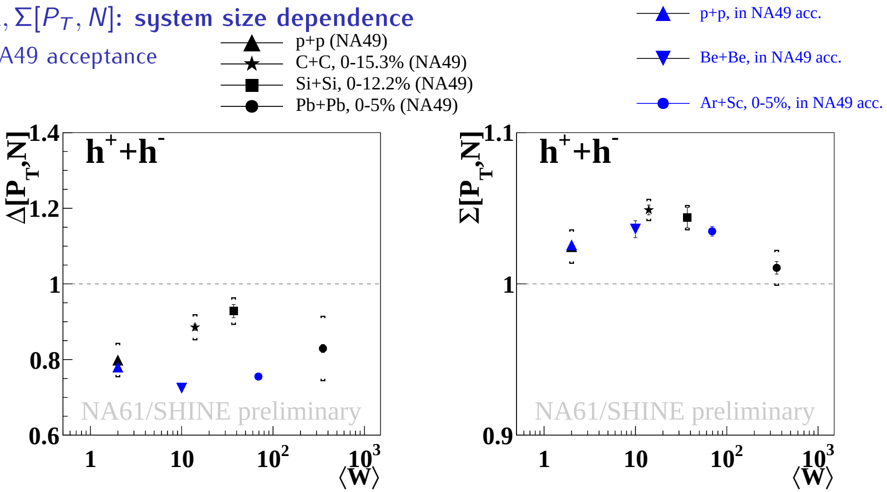
Results for ^{40}Ar+^{45}Sc collisions are very close to Pb+Pb. No prominent structures which could be related to the CP are visible.

$\Delta[P_T, N] < 1$ 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.

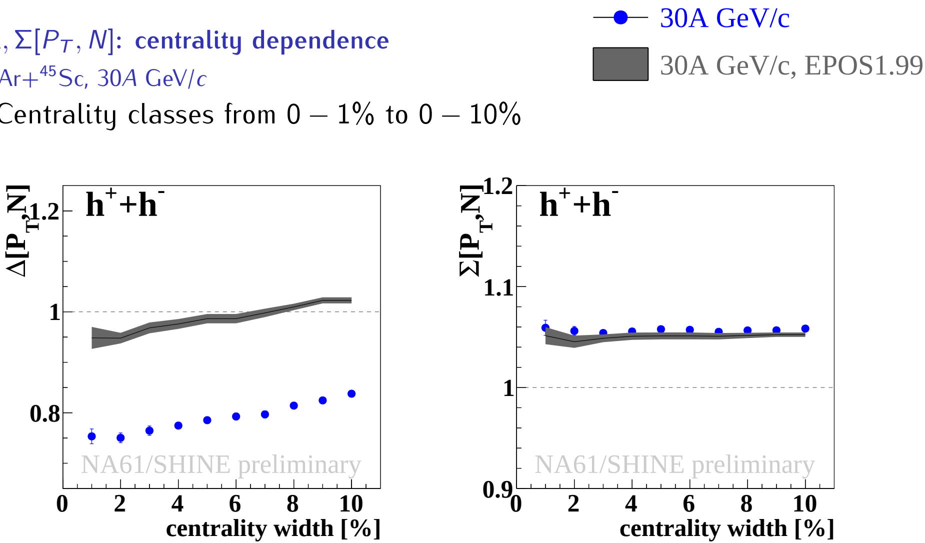
$\Delta[P_T, N]$ is more sensitive to centrality selection than $\Sigma[P_T, N]$.

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

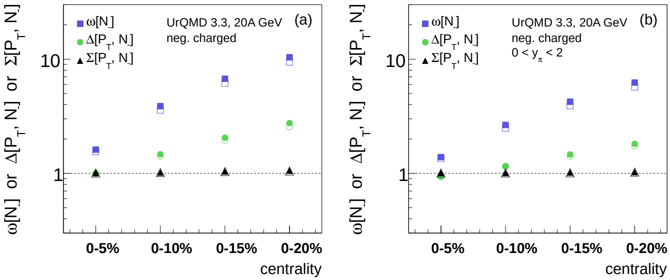


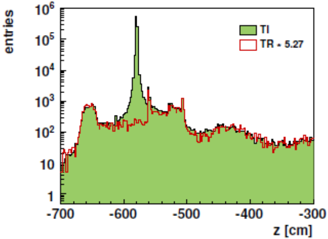
Figure 5: (Color online) The UrQMD results for the centrality dependence of $\omega[N_-]$ (*squares*), $\Delta[P_T, N_-]$ (*circles*), and $\Sigma[P_T, N_-]$ (*triangles*) in Pb+Pb collisions at $E_{lab} = 20$A GeV. A centrality selection is done with a restriction on the impact parameter b. (a): The 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:

$$\omega[N] = \omega[n] + \langle n \rangle \omega[W]$$

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

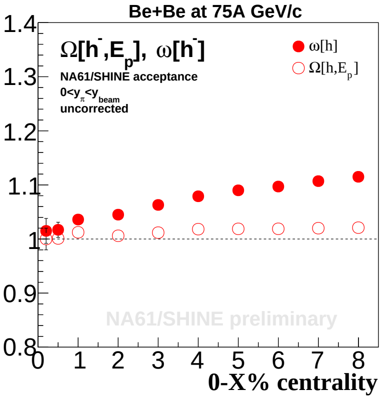
n and e_P are N and E_P for a fixed volume

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

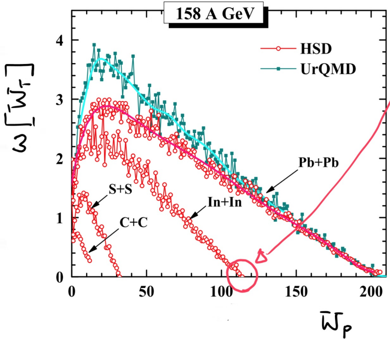


$\Omega[N, E_P]$ almost does not depend on centrality – strongly intensive!

$\Omega[N, E_P]$ 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 $W_T \approx A$

$\Downarrow$

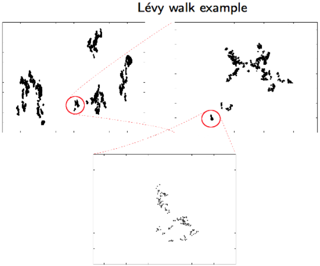
$\omega[\bar{W} = \bar{W}_P + \bar{W}_T] \approx 0$

$\omega[N] = \underbrace{\omega[N]_W}_{\text{WANTED}} + \underbrace{\langle N \rangle / \langle W \rangle \cdot \omega[W]}_{\text{UNWANTED}}$

KANCHAKOVSKI, LUNGWITZ, GORENSTEIN BRATKOVSKAYA

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	$p_{\rm min}$ (MeV)	$p_{\rm max}$ (MeV)	$\lambda_{\rm Poisson}$	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. ^7Be (beam) + ^9Be (target)
  2. Beam energy: 150A GeV (target rest frame) $\Leftrightarrow$ $\sqrt{s_{NN}} = 16.8$ GeV

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

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

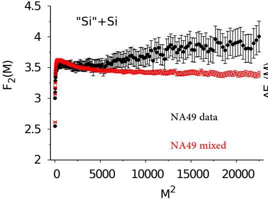
CMC simulation parameters

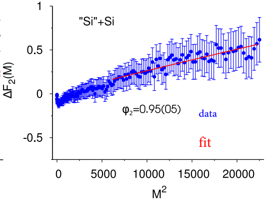
Parameter	p_{min} (MeV)	p_{max} (MeV)	$\lambda_{Poisson}$	T_c (MeV)
Value	0.85	1200	0.76	163

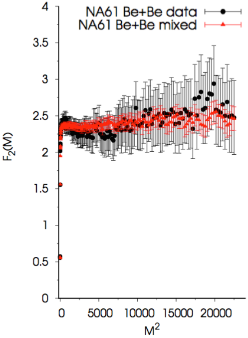
- $\langle p \rangle$ in mid-rapidity remains low, except for very central collisions

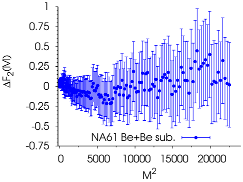
Intermittency analysis results

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