Onset of deconfinement and critical point searches in NA61/SHINE experiment at SPS.

On behalf of the **NA61/SHINE collaboration**

Damian Pszczel, National Centre of Nuclear Research, Warsaw

Outline

- NA61/SHINE detector setup and upgrade
- QCD phase diagram and definitions
- Studies of the onset of deconfinement
- Open charm production
- Search for the critical point
- Summary

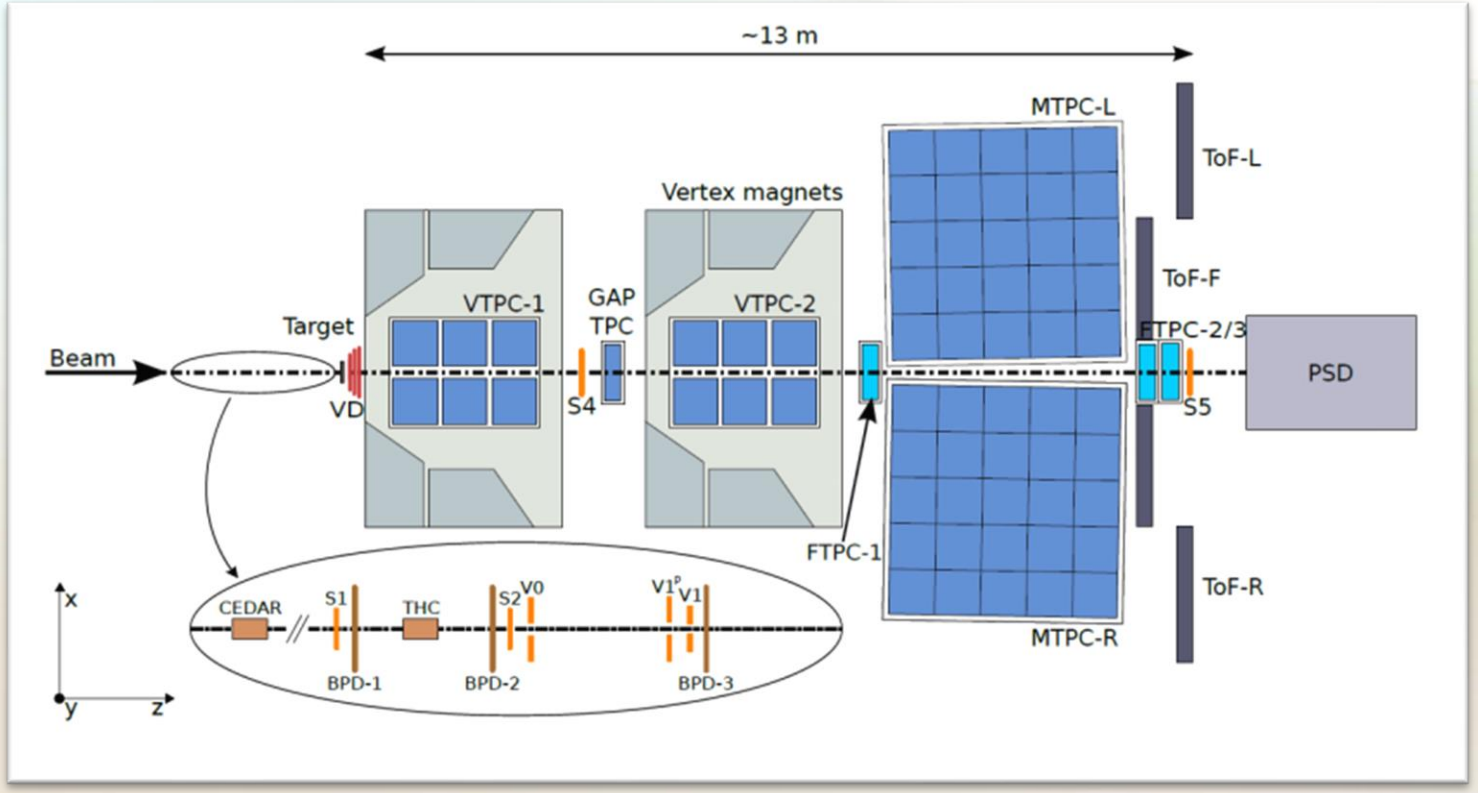
NA61/SHINE detector setup

- Large acceptance hadron spectrometer
- Fixed target experiment
- Beams:
  - Ions (Be, Ar, Xe, Pb)

    p_{beam}= 13*A*-150*A* GeV/c
  - Hadrons (pi, K, p)

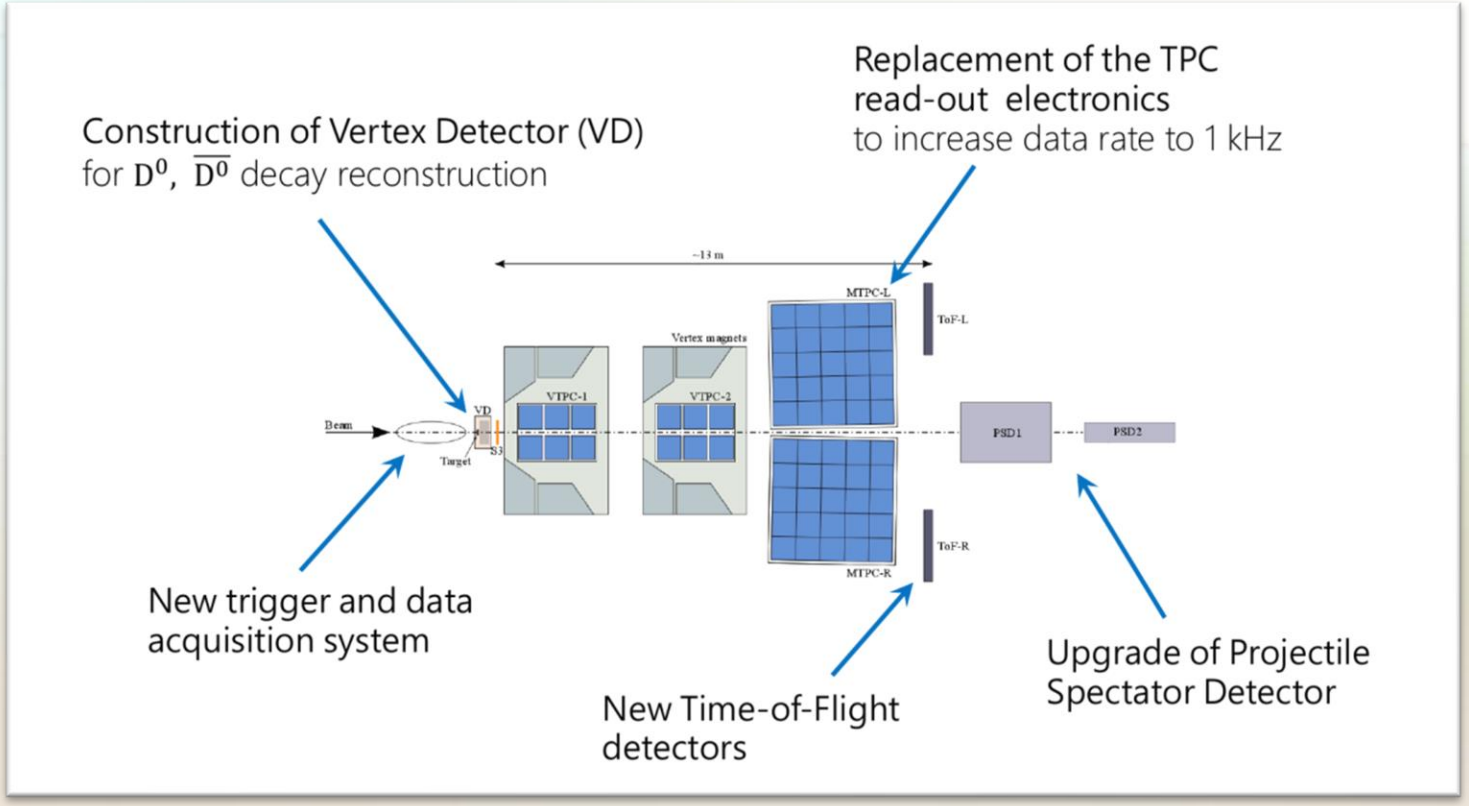
    p_{beam}= 13-400 GeV/c

$\sqrt{s_{NN}}$= 5.1-16.8 (27.4) GeV

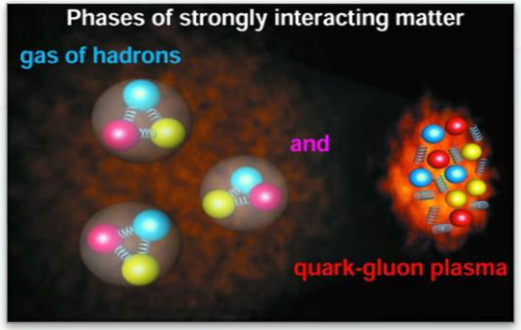


NA61/SHINE detector upgrade

- New vertex detector in order to increase the precision of secondary vertices measurements (needed for open charm production studies).
- Increase (up to 1kHz) of the data read-out frequency.
- New trigger and DAQ systems.
- New TOF detectors.
- Upgrade of the PSD detector (centrality measurements).



QCD phase diagram and definitions

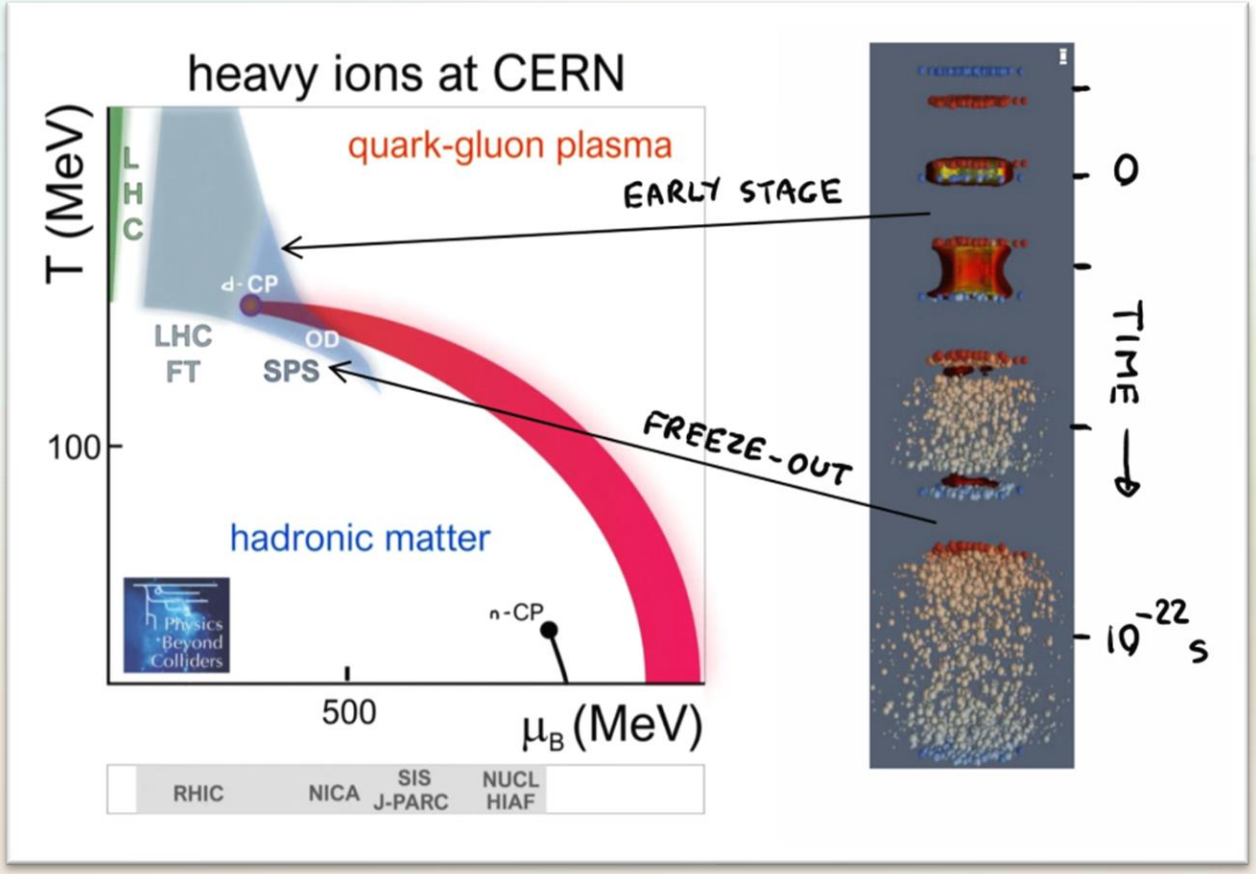


- Onset of deconfinement:

  Beginning of QGP creation with increasing collision energy.

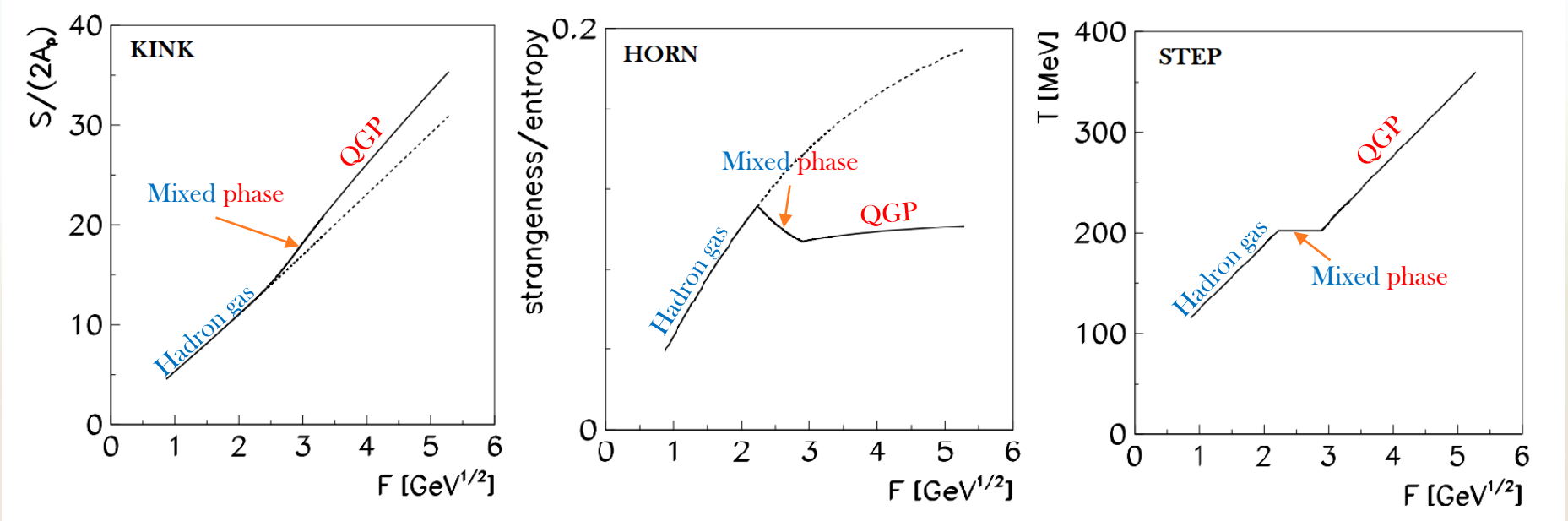
- Critical point:

  End point of 1st order transition line that has properties of a 2d order phase transition.



Studies of the onset of deconfinement: SMES model

- **S**tatistical **M**odel of the **E**arly **S**tage - Gaździcki and Gorenstein, Acta Phys. Pol. B 30, 2705 (1999)



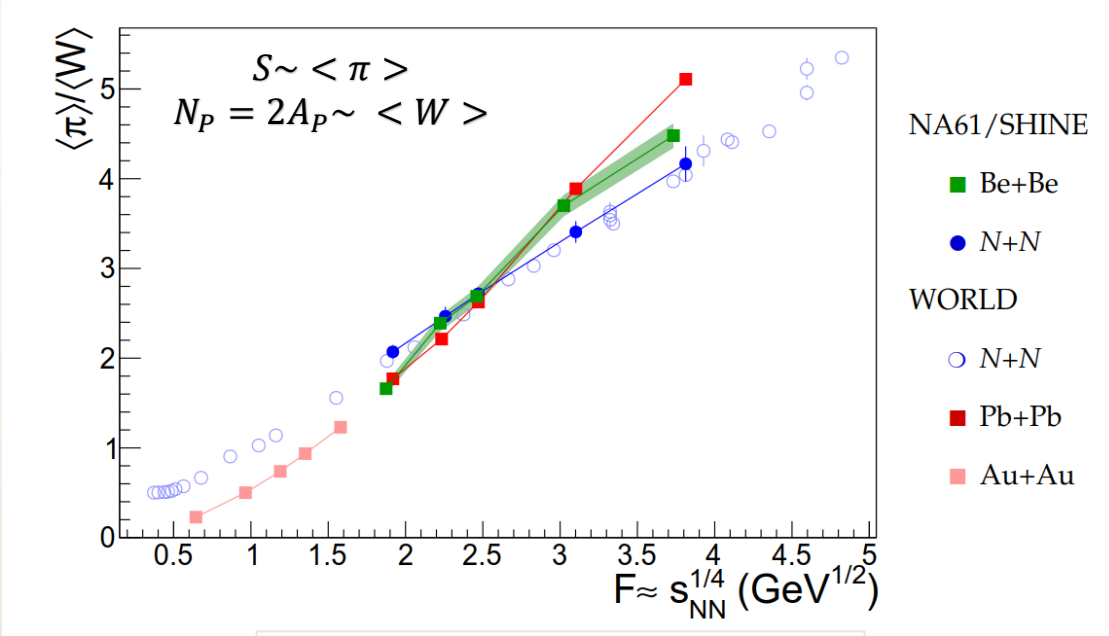
$$Fermi - Landau\ variable:\ F = \frac{\left(\sqrt{s_{NN}} - 2m_N\right)^{3/4}}{\sqrt{s_{NN}}^{1/4}} \overset{\sqrt{s_{NN}} \gg m_N}{\cong} \sqrt[4]{s_{NN}}$$

Studies of the onset of deconfinement: „KINK”

- The onset of deconfinement leads to the activation of partonic d.o.f and results in an increase of entropy.
- SMES predicts a change in the slope („**KINK**”) at the value of the collision energy corresponding to the HG-QGP transistion.

SMES:

$$\frac{<\pi>}{<N_P>} \propto g^{1/4} F \; with \; g_{QGP} > g_{HG}$$

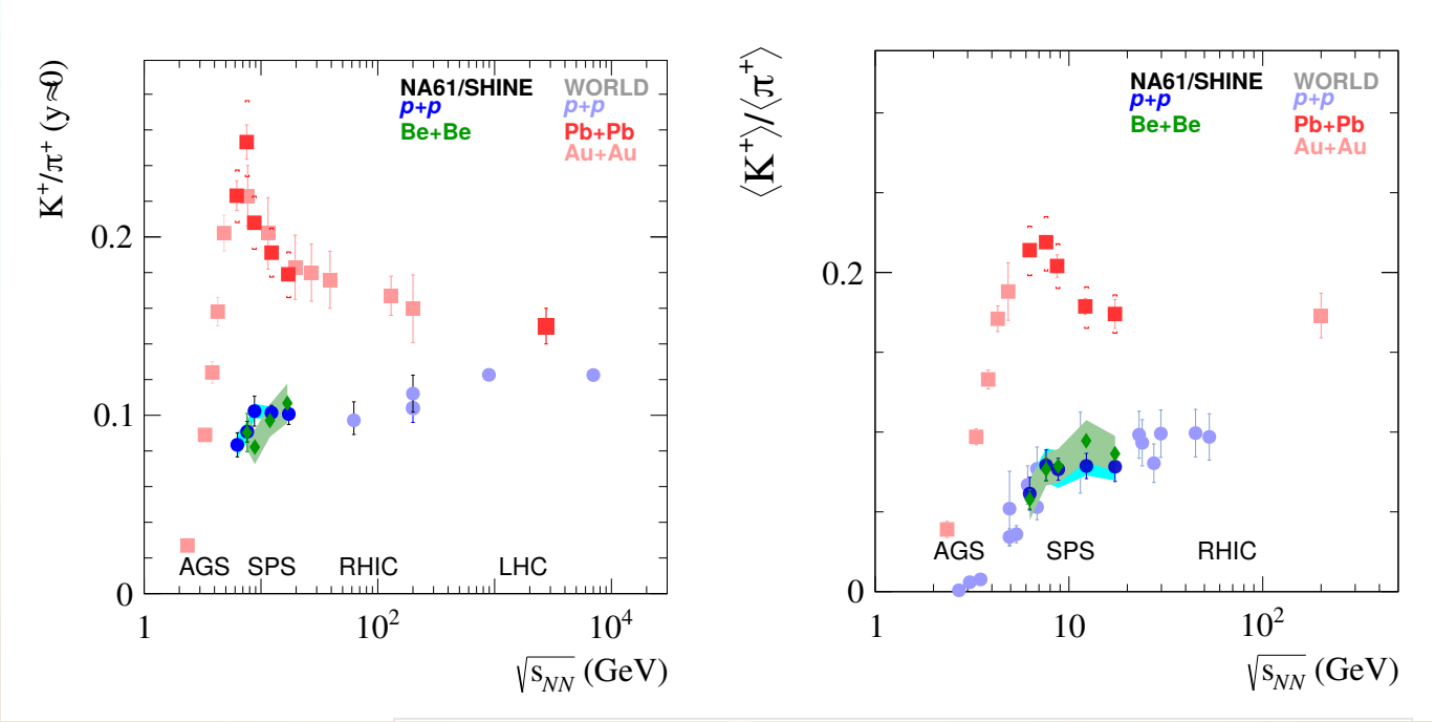


Eur. Phys. J. C (2020) 80 :961

- We observe a larger slope for Pb+Pb than for p+p.

Studies of the onset of deconfinement: „HORN”

- Sharp maximum („**HORN**”) of K^+/π^+ ratio observed in Pb+Pb collisions at SPS energies.
- Predicted by SMES as a signature of the onset of deconfinement.
- No such structure observed in p+p, Be+Be collisions.



Submitted to: Eur. Phys. J. C (recently accepted)

SMES:

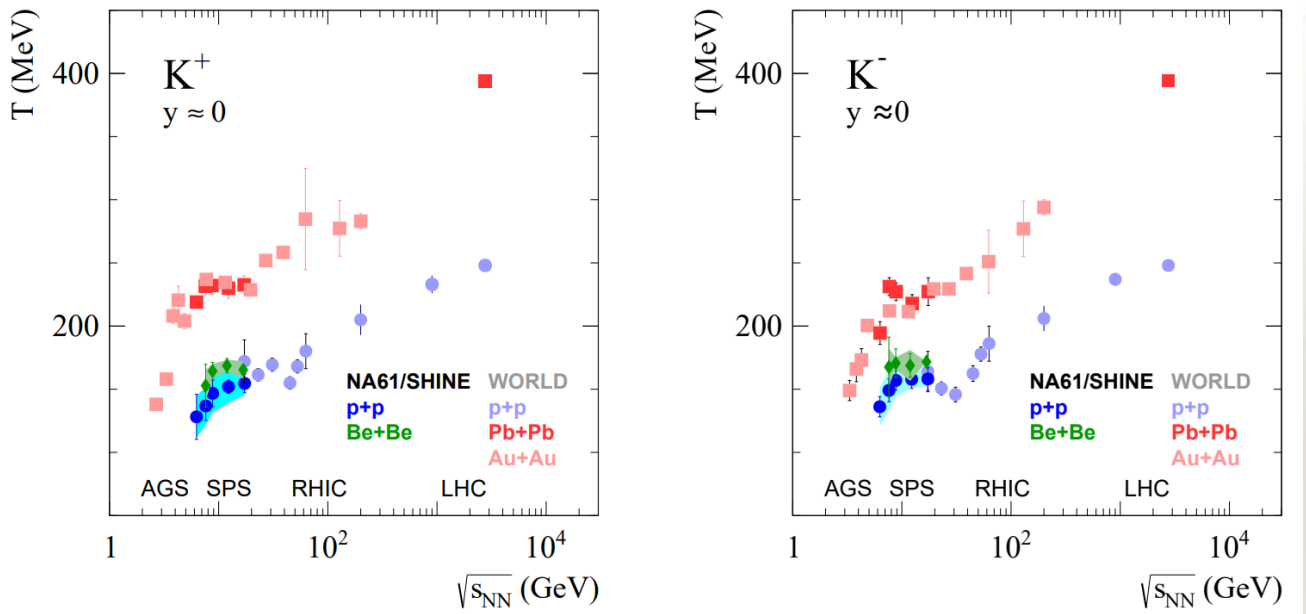
HG: $< K > \propto T^{3/2} e^{\frac{-m_K}{T}}; < \pi > \propto T^3 \rightarrow \frac{<K>}{<\pi>} \propto T^{-3/2} e^{\frac{-m_K}{T}}$

QGP: $\frac{<strangeness>}{<\pi>}$ independent of T

Studies of the onset of deconfinement: „STEP”

- Plateau („**STEP**”) in the inverse slope parameter T of m_T spectra in Pb+Pb collisions observed at SPS energies for K^+ (mid-rapidity).
- This is predicted in SMES as the signature of the appearance of the mixed phase of HG and QGP.
- Similar dependence observed in p+p, Be+Be for different T values than Pb+Pb.

$$\frac{d^2n}{dp_T dy} = \frac{S\ p_T}{T^2 + T\ m_K}\ exp\left(-\frac{\sqrt{p_T^2 + m_K^2} - m_K}{T}\right)$$



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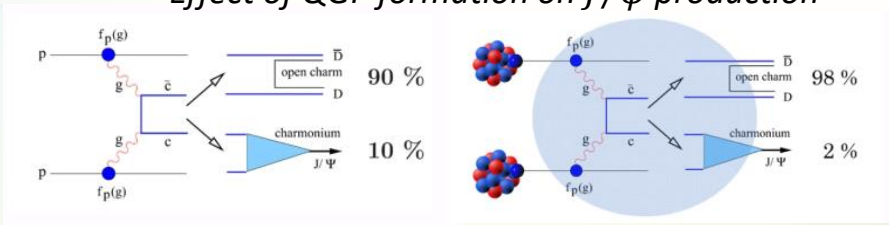
Open charm production and QGP: motivation and plans

- Impact of the QGP formation on the mechanism of J/ϕ production.
- We need to know the $< c, \bar{c} >$ production in A+A collisions.
- Precise data on $D, \overline{D}$ production needed.

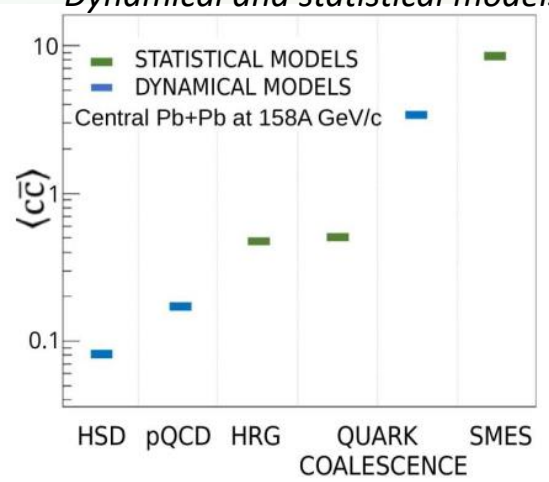
Effect of QGP formation on J/ϕ production



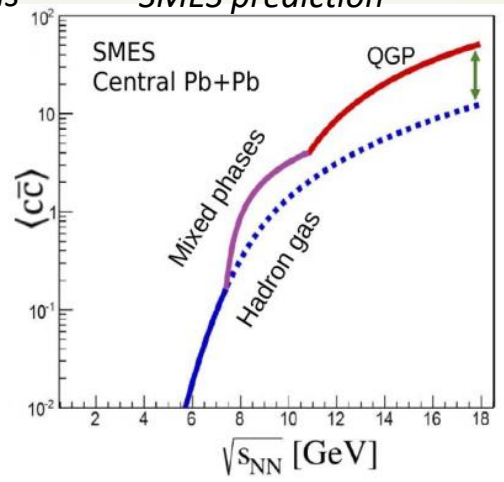
Prof. Helmut Satz, 2017

"The preliminary results on charmonium production at the SPS formed a significant basis for the CERN conclusions presented in the year 2000, claiming the observation of a new state of matter. As we have shown, such conclusions remain preliminary, as long as the corresponding open charm production data are not available. The proposed measurements of open charm in nuclear collisions at the SPS energies would allow NA61/SHINE to fill the missing gap and thus to complete an absolutely crucial part of the CERN heavy ion program"

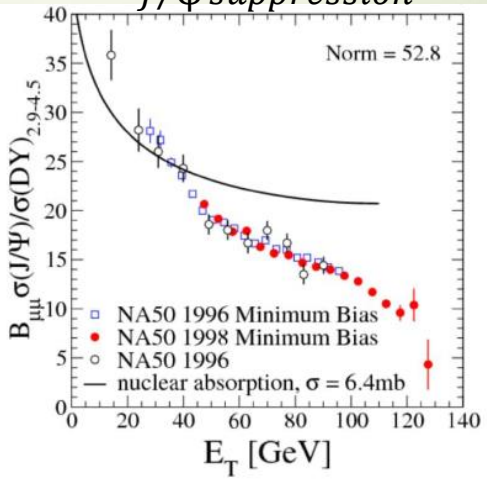
Dynamical and statistical models



SMES prediction



J/ϕ suppression

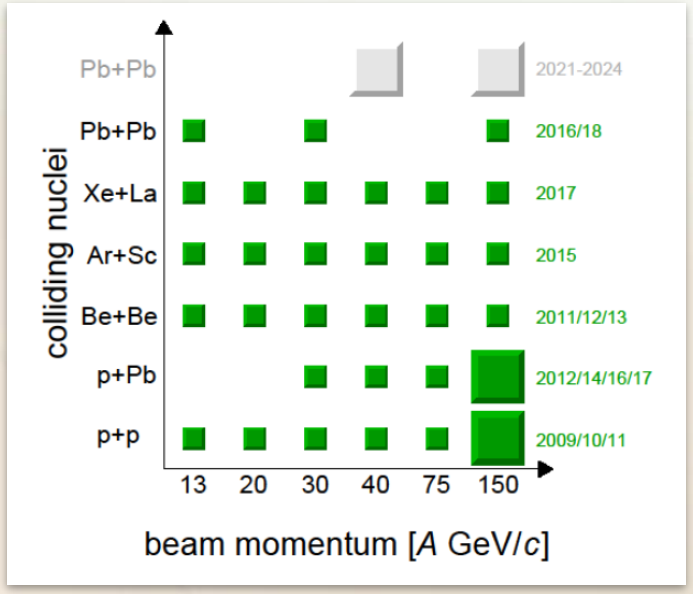


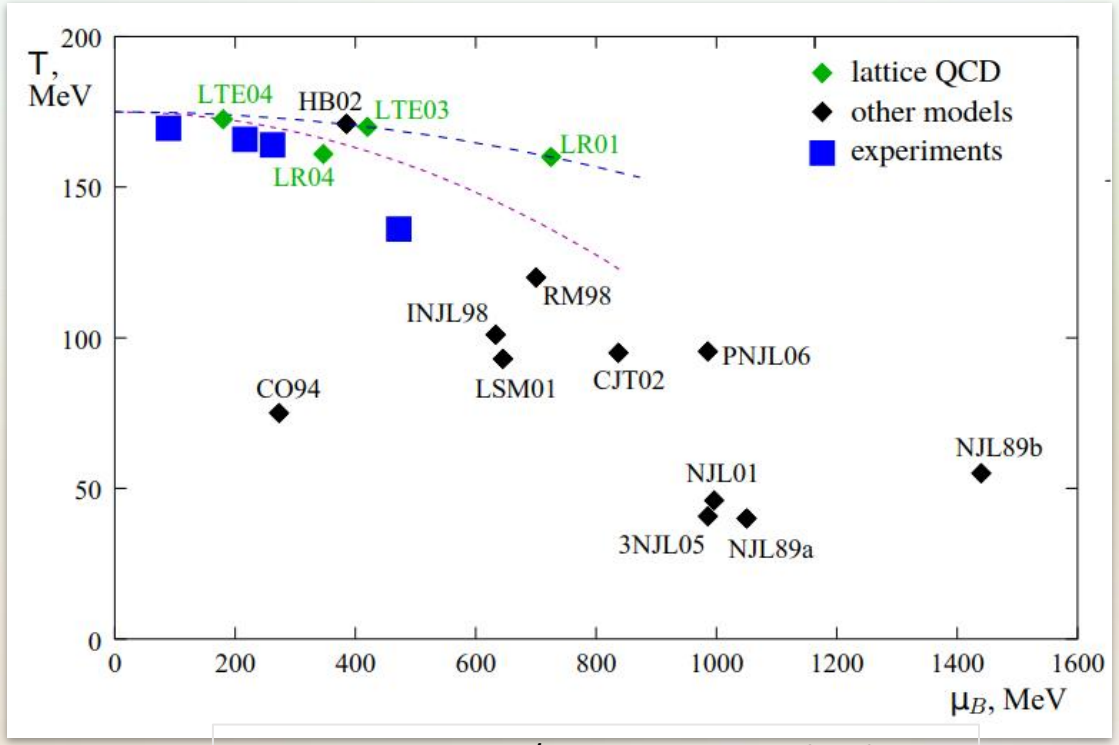
JPS Conf. Proc. , 010080 (2020)

Search for the critical point

- Observation of anomalies (enhancement, scale-invariance) in fluctuations in a narrow domain of the phase diagram could be interpreted as CP signal.
- However, predictions about the CP are model-dependent.
- Different colliding systems at various beam momenta

  → 2D scan of the phase diagram.





T. Czopowicz, NA61/SHINE Autumn School 2020

Search for the critical point: proton intermittency analysis

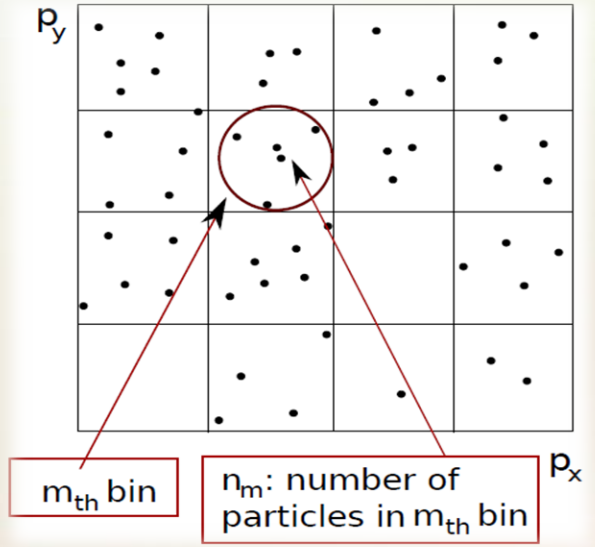
- Critical fluctuations ⟹ SSFM exhibits a **power law dependence** on the number of subdivisions M^2.
- We subtract the SSFM of mixed events in order to remove purely statistical correlations:

$$\Delta F_2(M) = F_2^{data}(M) - F_2^{mixed\ events}(M)$$

- If the freeze-out occurs at the critical point then (for protons):

$$\Delta F_2(M) \sim (M^2)^{\phi_2}, \phi_2 = \frac{5}{6} \approx 0.833$$

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



F.K. Diakonos, NA61-theory meeting, 15/11/2018

Search for the critical point: (NA49 and) NA61/SHINE

- In NA49: strong power-law scaling with M^2 observed in Si+Si.
- In NA61/SHINE: p-p intermittency analysis in Ar+Sc @ 150*A* GeV/c: ~ 800k events in 0-20% centrality range.
- A deviation of ΔF_2 from zero appears for 10-20% centrality.
- This effect is not observed for present statistics in other centrality ranges.
- New results expected soon for different energies and colliding systems.

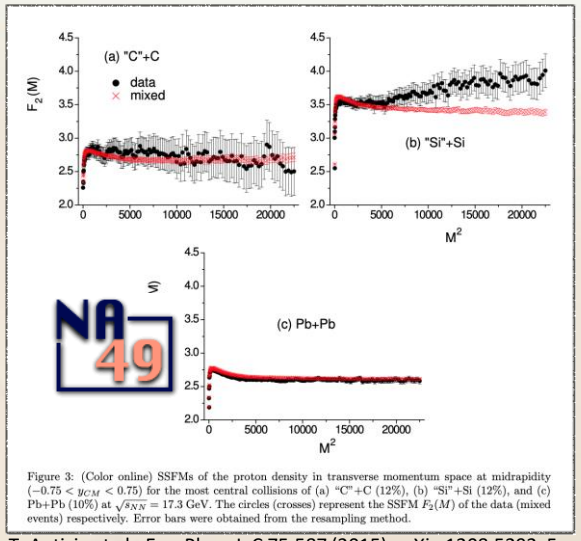
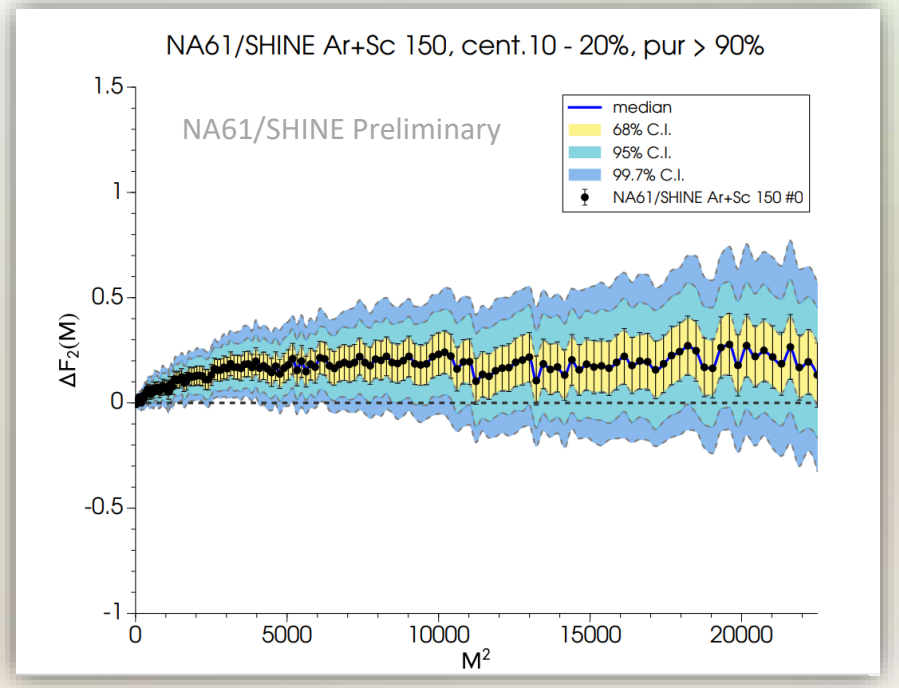


Figure 3: (Color online) SSFMs of the proton density in transverse momentum space at midrapidity ($-0.75 < y_{CM} < 0.75$) for the most central collisions of (a) "C"+C (12%), (b) "Si"+Si (12%), and (c) Pb+Pb (10%) at $\sqrt{s_{NN}} = 17.3$ GeV. The circles (crosses) represent the SSFM $F_2(M)$ of the data (mixed events) respectively. Error bars were obtained from the resampling method.

T. Anticic et al., Eur. Phys. J. C 75:587 (2015), arXiv:1208.5292v5



Summary

- NA61/SHINE continues the 2D scan of the QCD phase diagram to search for critical structures such as the onset of deconfinement and the QCD critical point.
- Differences of hadron production between light and heavy colliding systems were observed.
- We also search for QGP effects in particle correlations using different techniques (intermittent pattern in particle momenta, higher moments of multiplicity spectra, azimuthal angle versus rapidity, etc…).
- We plan to perform open charm production studies (2021-2024).

THANK YOU

BACKUP SLIDES