Recent results from NA61/SHINE

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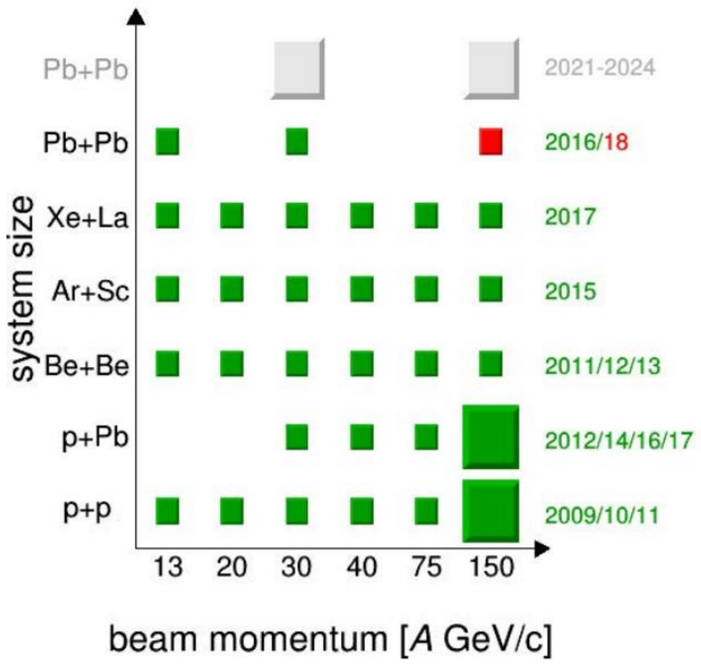
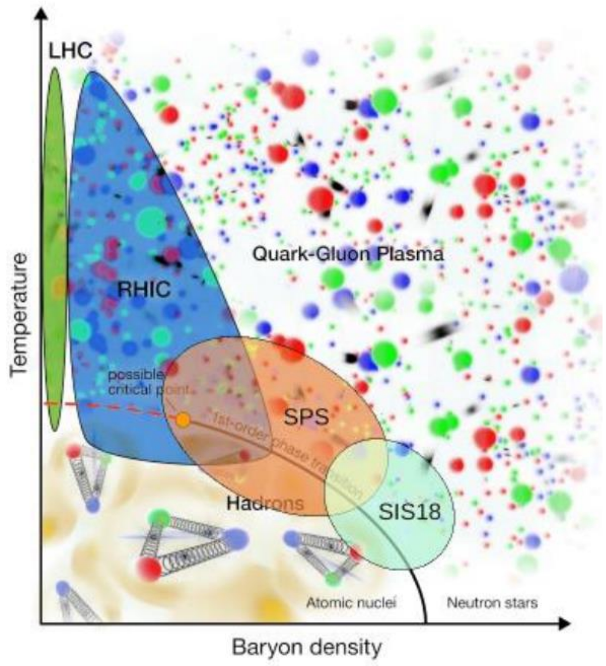
NA61/SHINE physics programmes

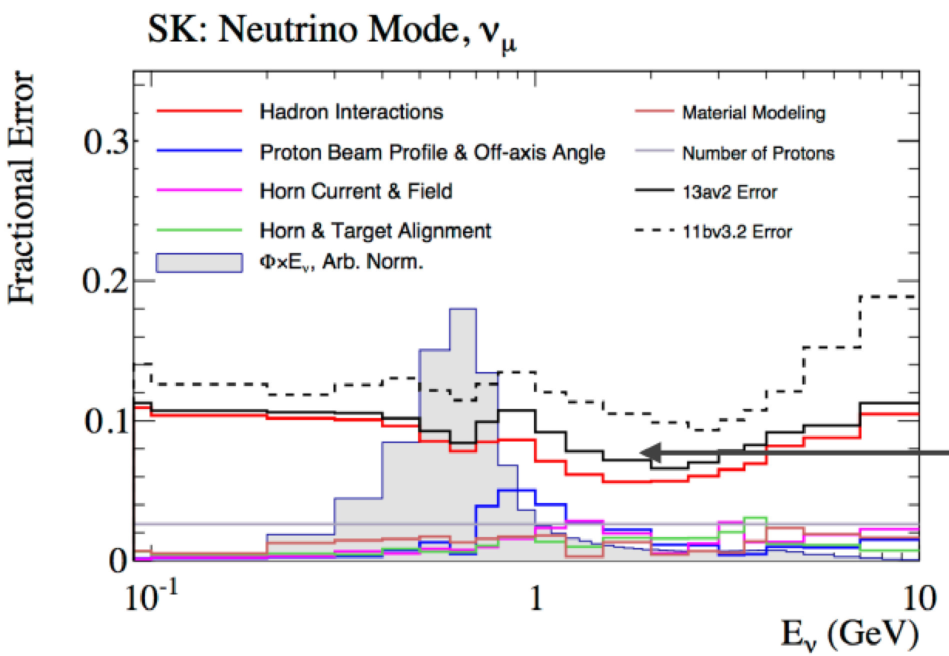
- Three main physics programmes:
  - Reference measurements for neutrino physics
  - Reference measurements for cosmic rays physics
  - Heavy ion physics – two dimensional scan in system size and beam energy



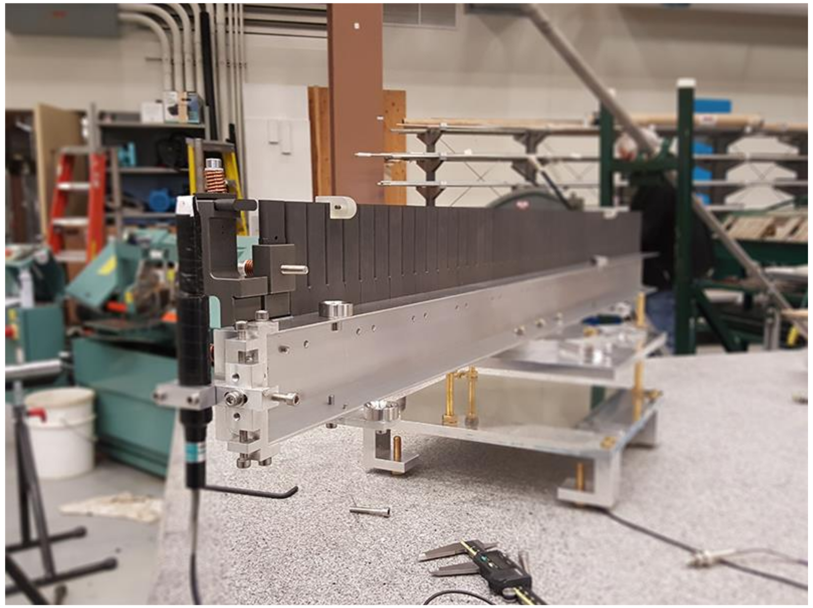


Measurements for neutrino physics

- Hadron production dominates neutrino flux uncertainty
- External measurements of hadron production help constrain uncertainty
  - Proton, pion and kaon beams on thin targets (few % of λ)
  - Measurements with replica targets of neutrino experiments (> λ)

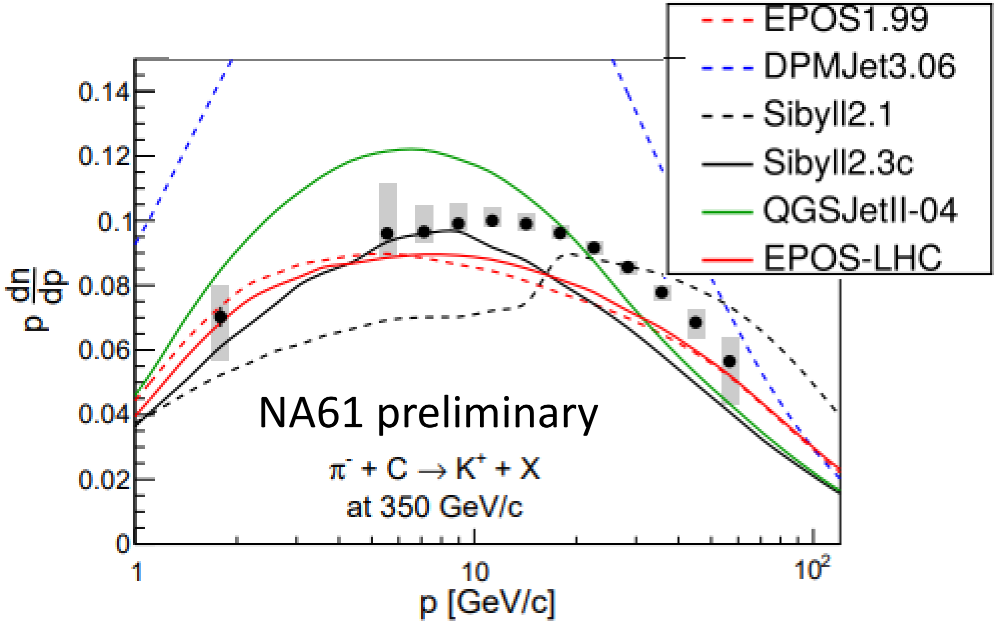


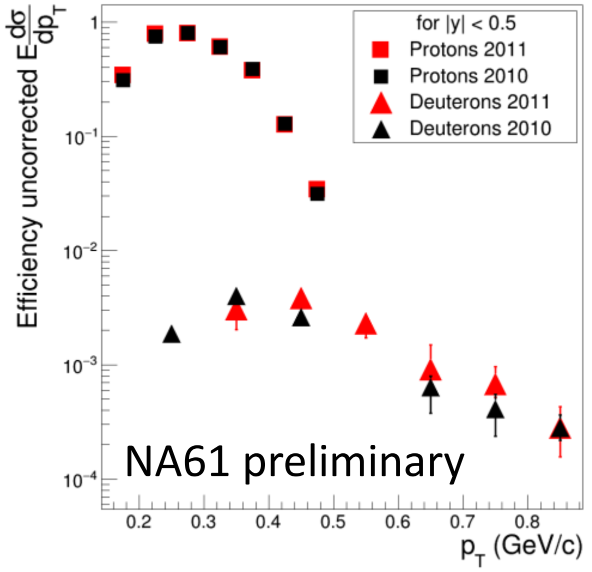
Current T2K flux uncert using thin target data

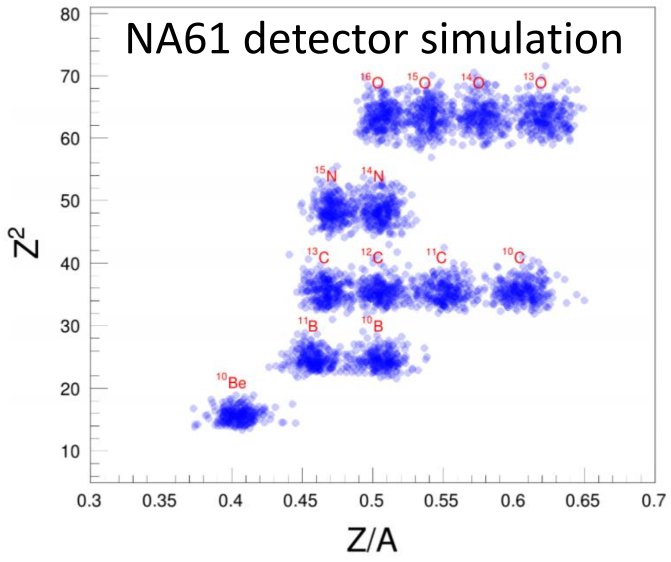


Measurement for cosmic rays physics

- Tuning MC models of cosmic rays air showers
  - Particle production in hadron + “air” interactions
- Propagation of cosmic rays in the galaxy (background for dark mater)
  - Antiproton and antideuterium production in p+p collision
  - Isotopic fragmentation cross sections



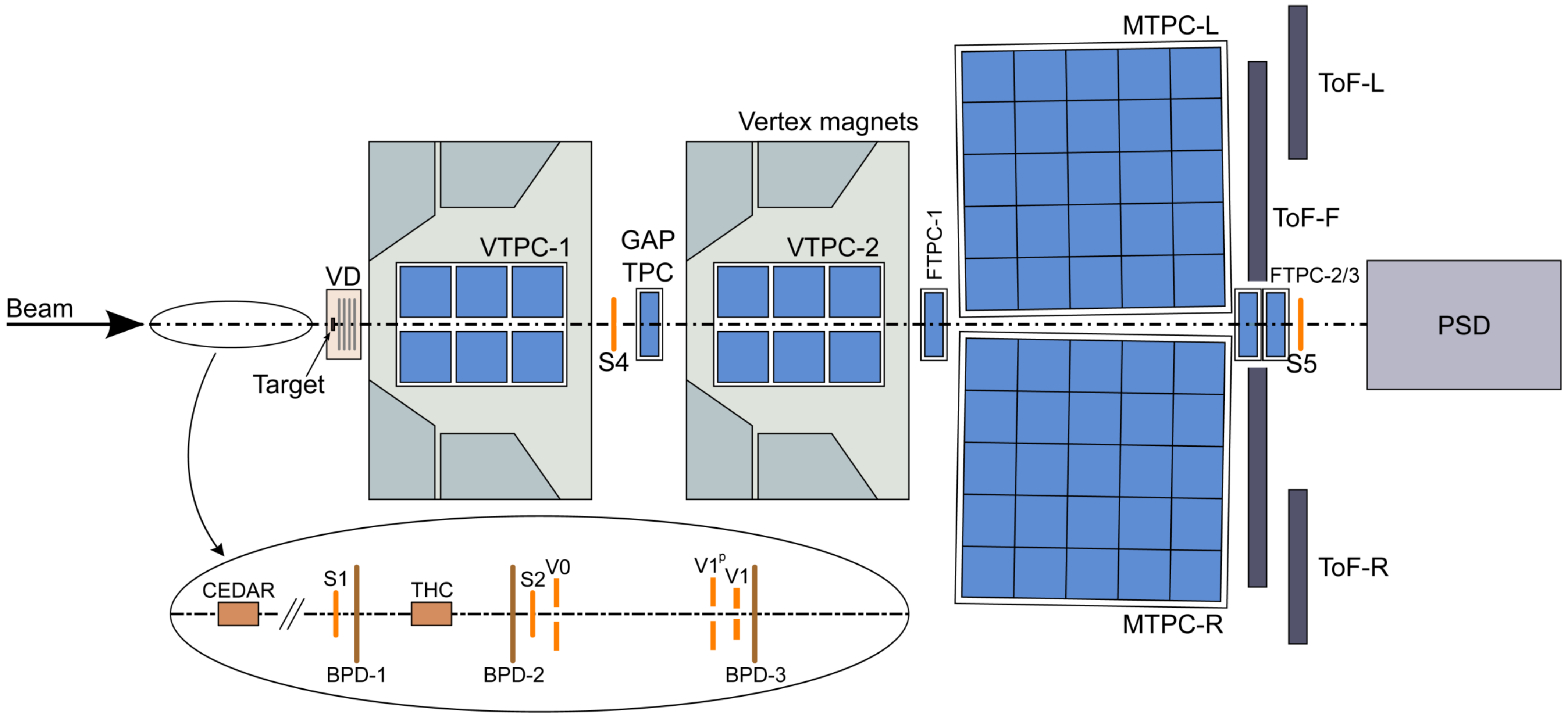




Heavy Ion physics

- Main areas of study:
  - Onset of deconfinement and onset of fireball
  - Search for critical point
  - Charm physics
- Achieved by:
  - Comprehensive scan with light and intermediate mass nuclei in beam momentum range 13*A* – 150*A* GeV/c
  - High statistics Pb+Pb at 150*A* GeV/c data taking (to be continued after LS2)

NA61/SHINE detector



Multiplicity fluctuations

- Scaled variance as a measure of multiplicity fluctuations

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

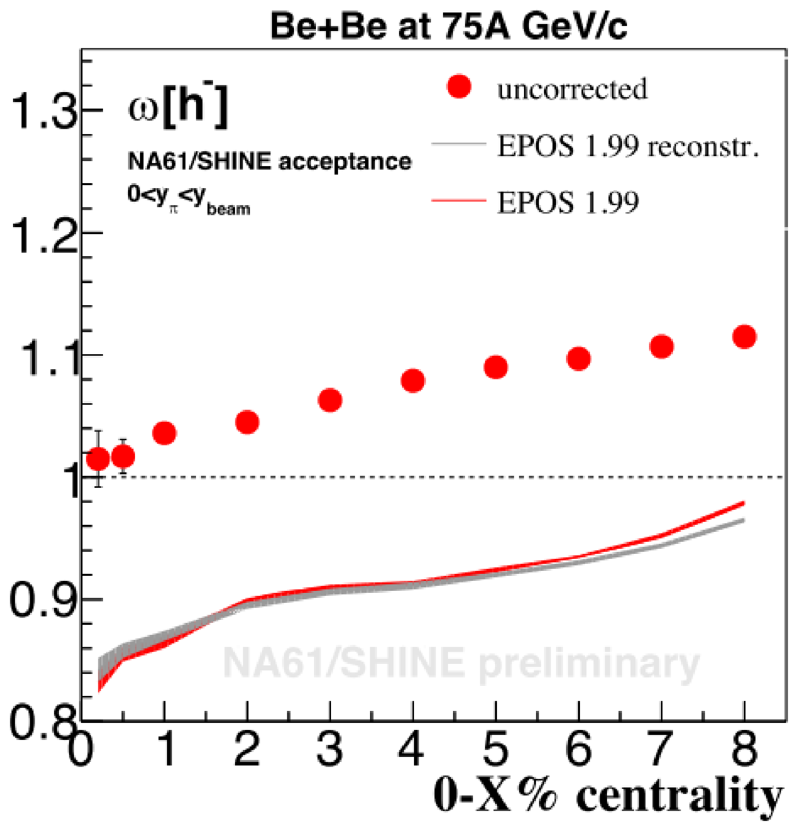
- For models with independent particle sources (Wounded Nucleon Model)

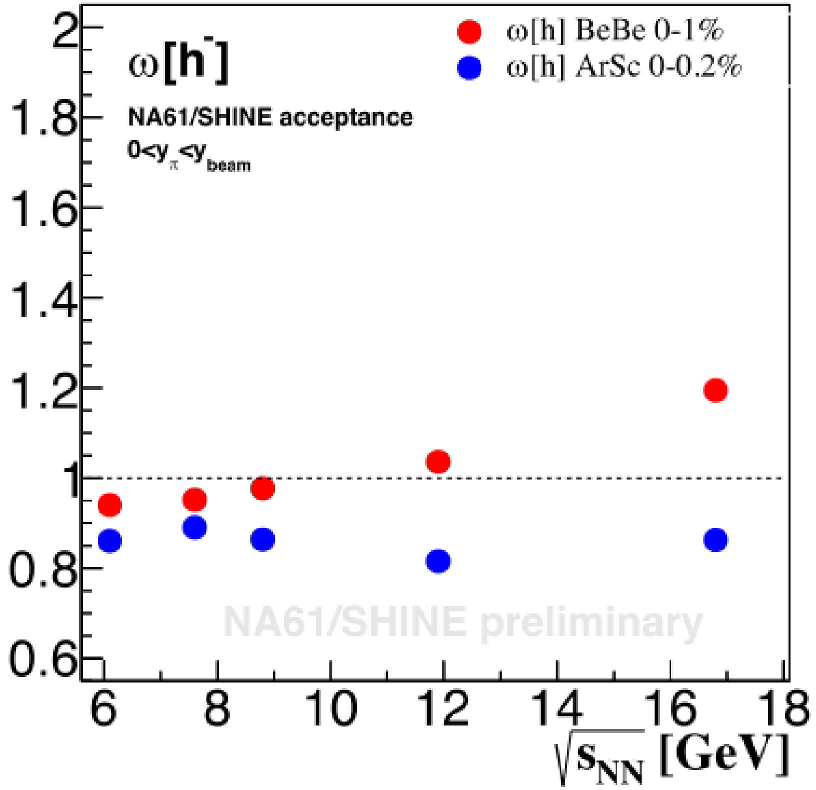
$$\omega[N] = \omega[n] + \bar{n}\omega[N_s]$$

where n is the multiplicity of the single source, $\omega[N_s]$ is the fluctuation of the number of sources.

- Dependence on the fluctuation of the number of sources can make interpretation of results difficult.

Multiplicity fluctuation, dependence on centrality





- $\omega[h^-]$ is larger for broader centrality intervals both in data and in model
- Volume fluctuations?

- Energy dependence of $\omega[h^-]$ different in Be+Be and Ar+Sc
- Volume fluctuations?

Multiplicity fluctuations, strongly intensive quantities

- We can introduce Ω[A, B] defined as:

$$\Omega[A,B] = \omega[A] - \frac{\langle AB\rangle - \langle A\rangle\langle B\rangle}{\langle B\rangle}$$

- Such quantity is independent on both volume and volume fluctuations
- If A and B are uncorrelated and originate from a single source:

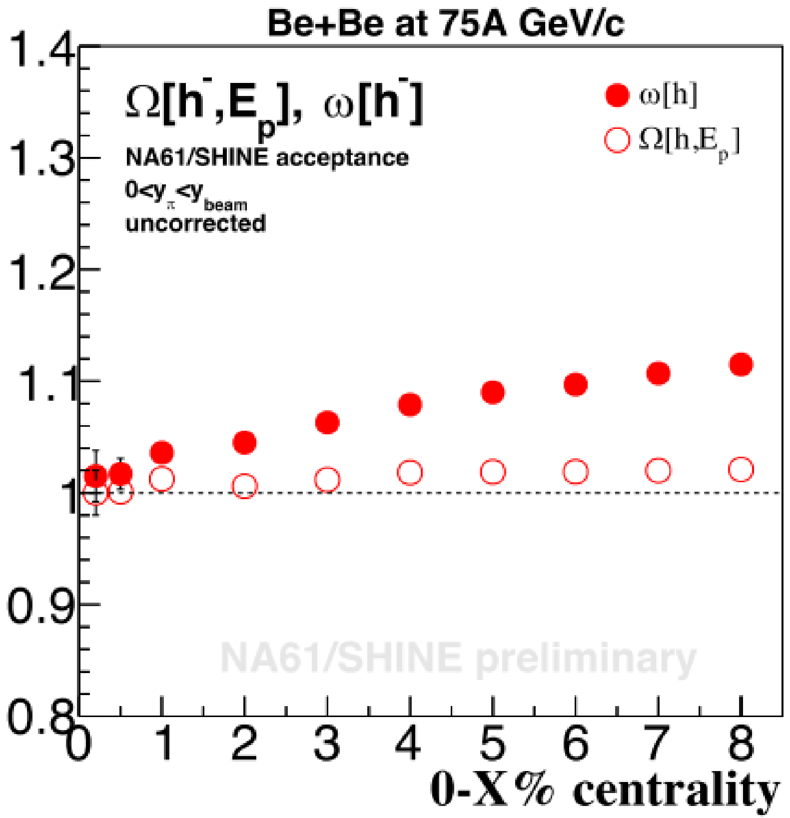
$$\Omega[A,B] = \omega[a]$$

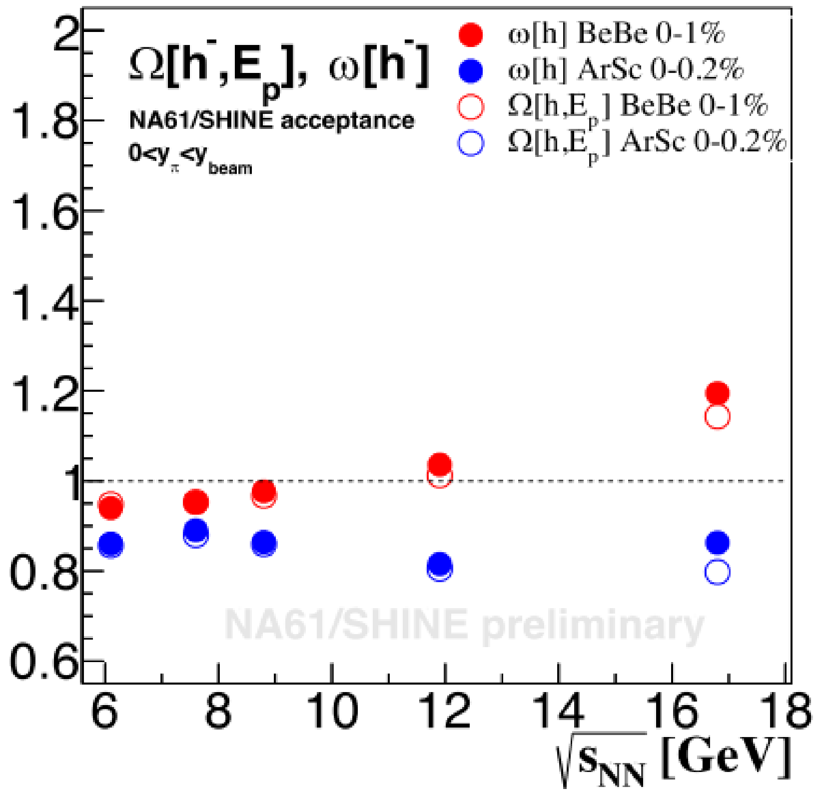
is true, where ω[a] is scaled variance of A from a single source

- We will consider $\Omega[h^-, E_p]$, where $E_p = E_{beam} - E_{forward}$
- For very central events:

$$\Omega[N, E_P] \approx \omega[N]$$

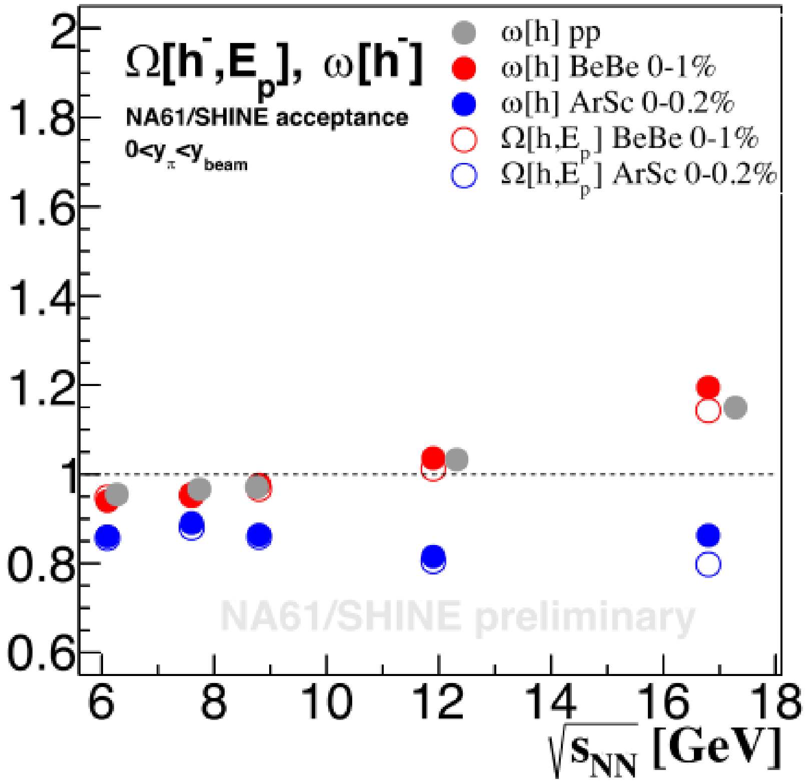
Multiplicity fluctuation, dependence on centrality

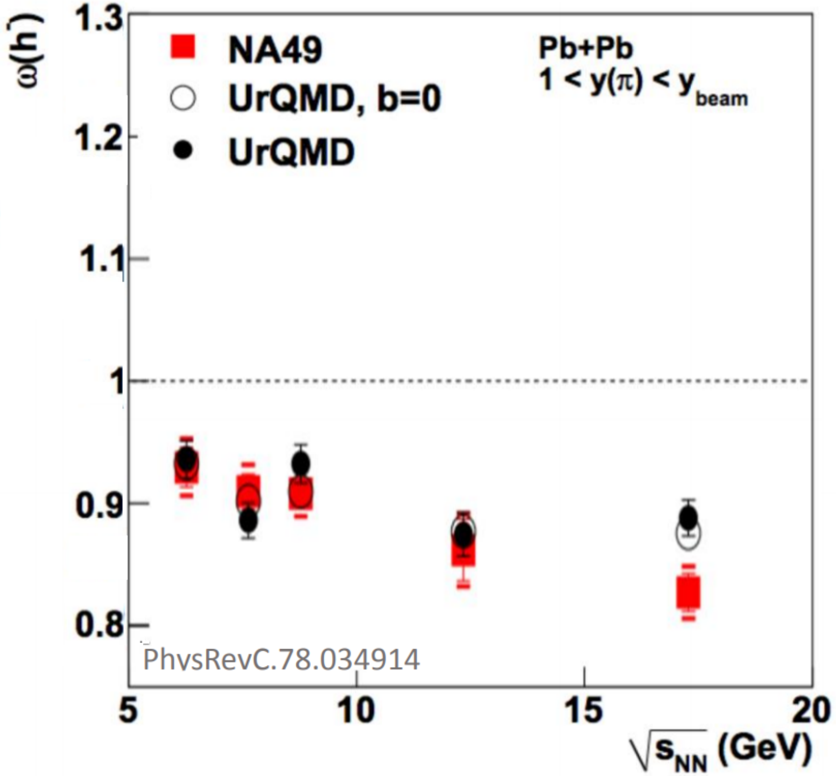




- $\Omega[h^-, E_p]$ do not depend on volume fluctuation – strongly intensive quantity
- Multiplicity fluctuation in central Be+Be collisions are significantly larger than in central Ar+Sc collsions

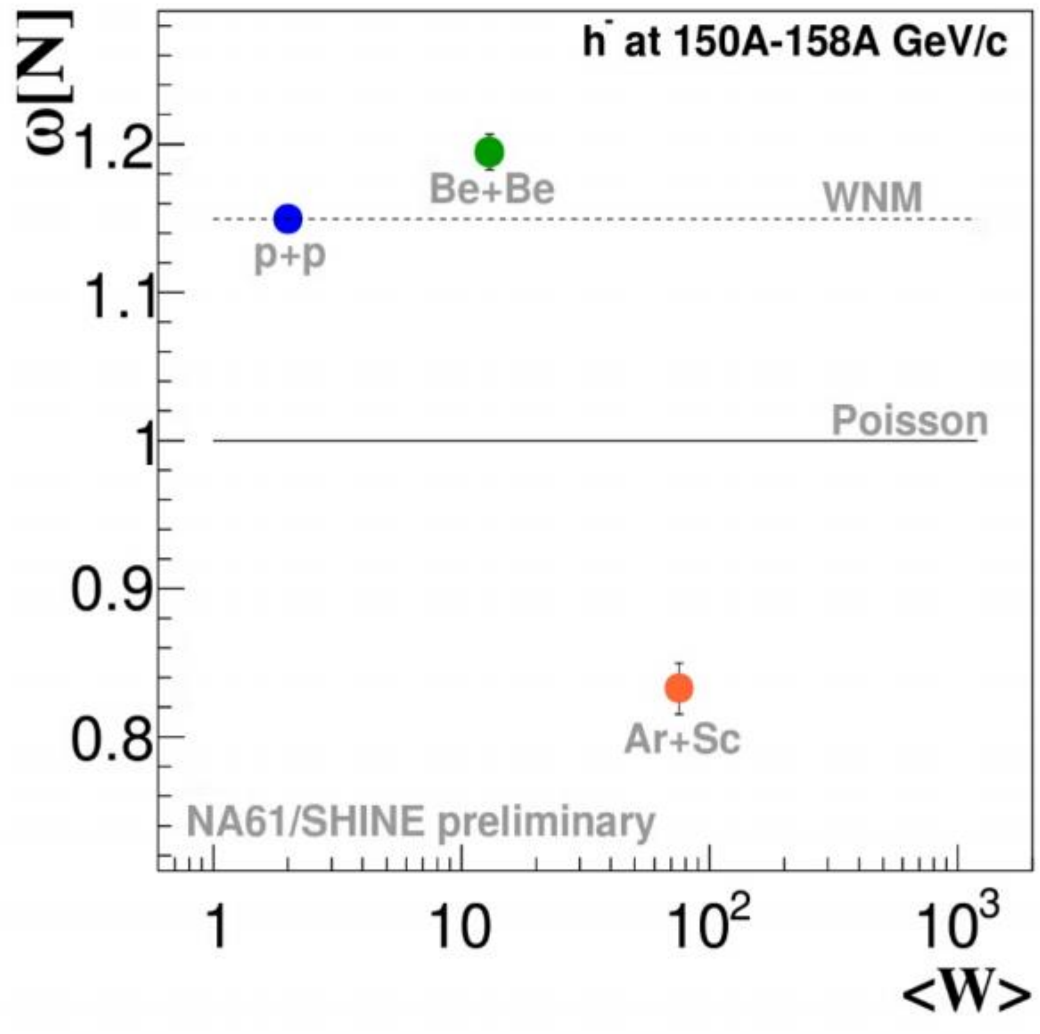
Multiplicity fluctuation, more system sizes!





- Multiplicity fluctuations in p+p and in Be+Be collisions similar
- Multiplicity fluctuation in central Pb+Pb behave similarly to fluctuations in central Ar+Sc collisions

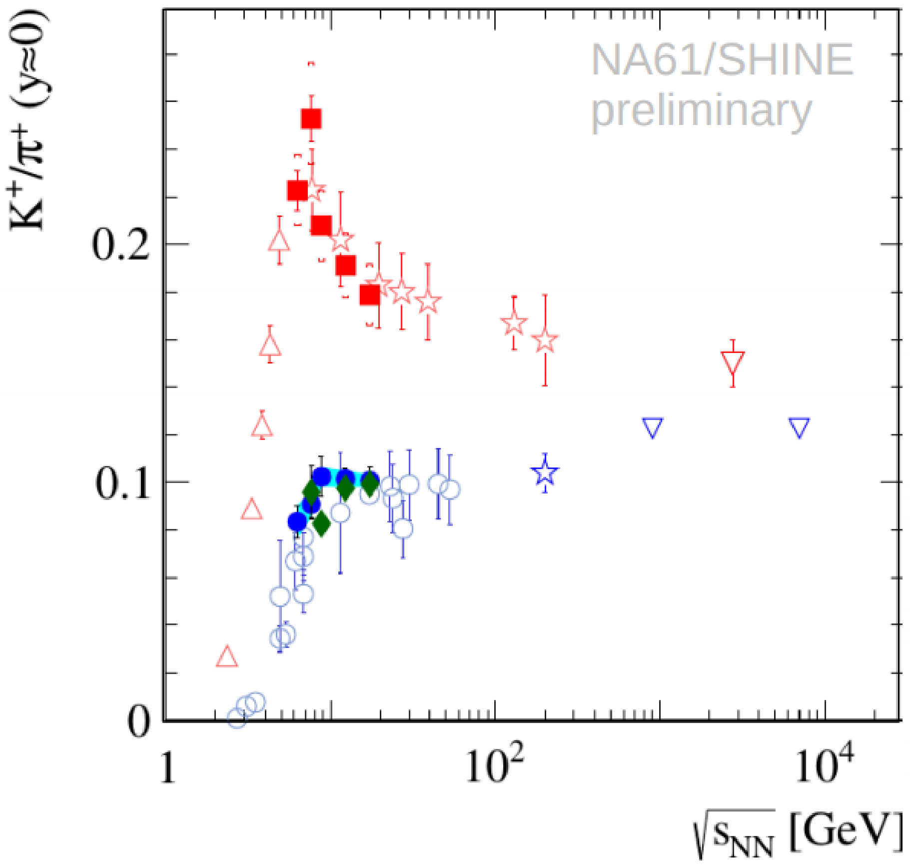
Multiplicity fluctuation, system size dependence

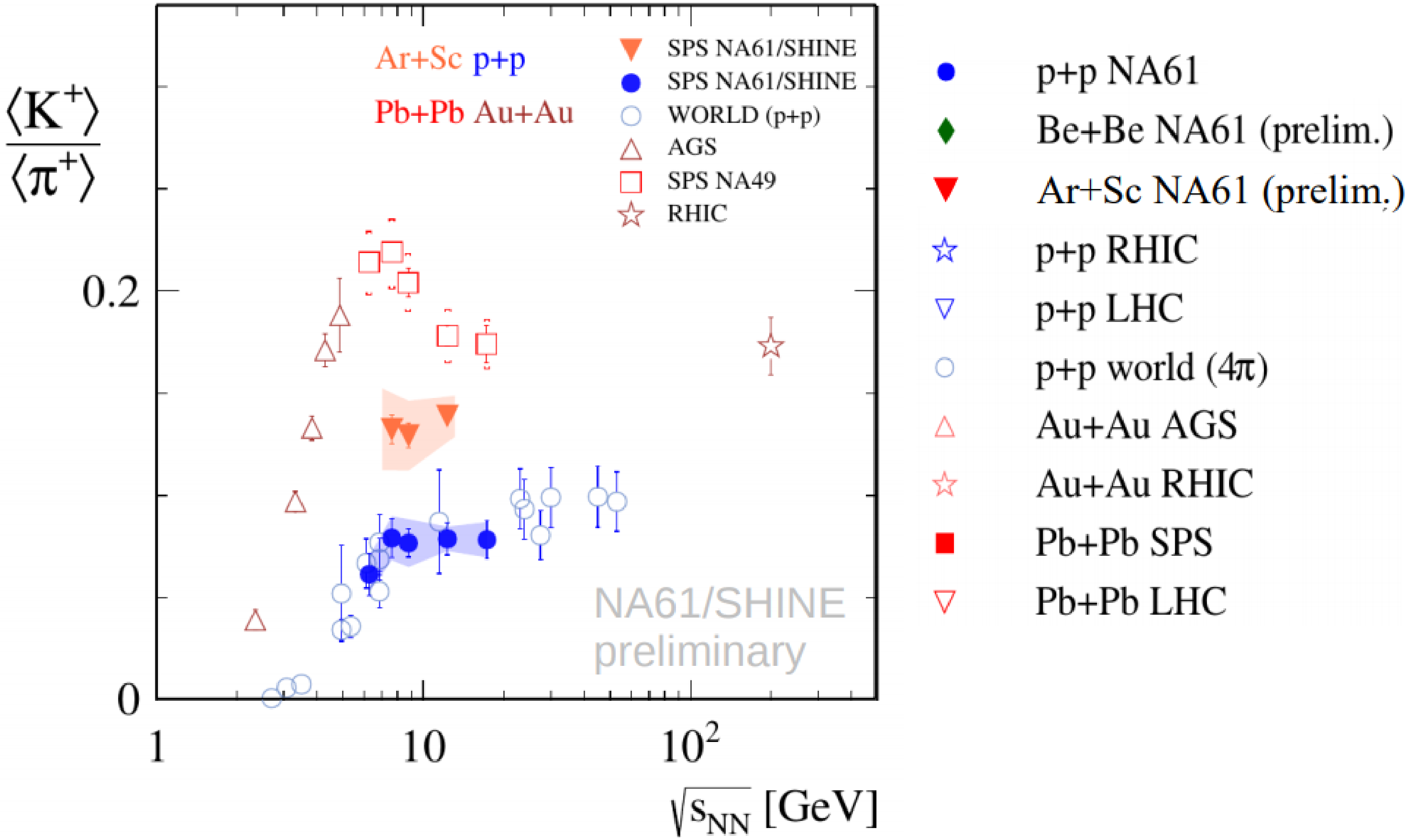


- Multiplicity fluctuations are significantly larger in light systems (p+p and Be+Be) than in heavier systems (Ar+Sc and Pb+Pb)
- Why Be+Be data is so close to p+p?
- Why fluctuations in Ar+Sc are suppressed?
- Can we see such effect for different observables?

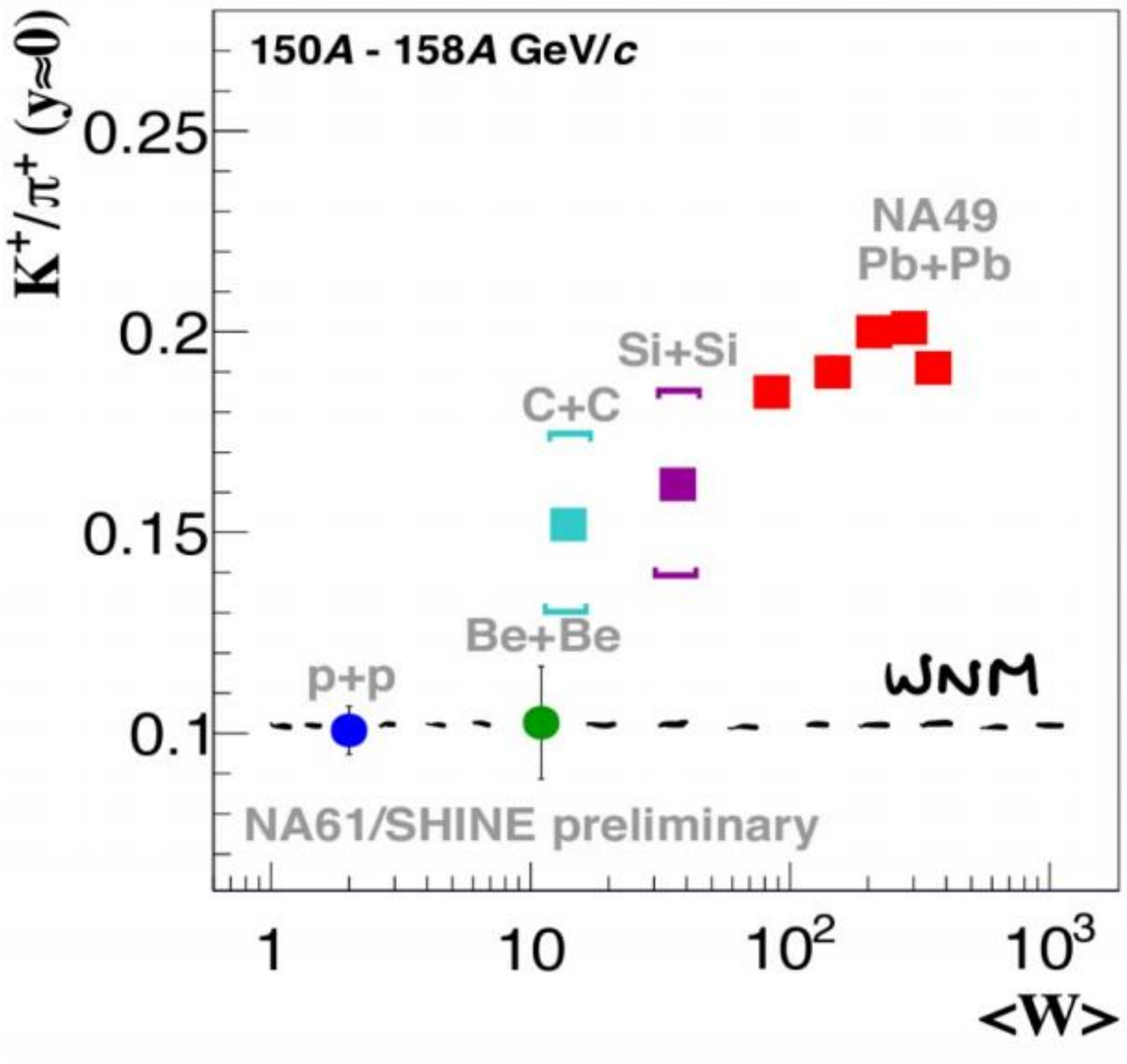
Particle ratios, energy denendence

- Rapid changes in K^+/π^+ (horn) were observed in Pb+Pb collisions.
- This was predicted within the SMES as a signature of the onset of deconfinement.



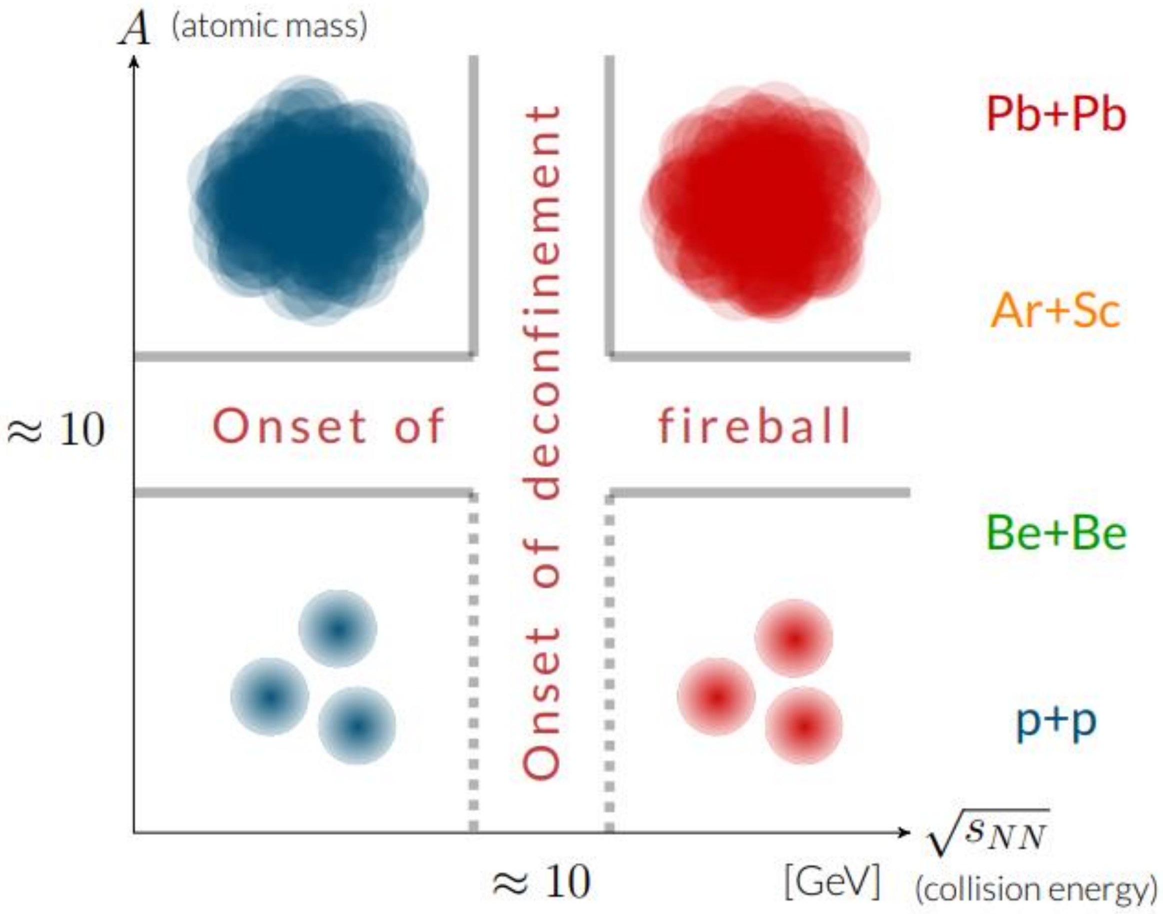


Particle ratios, system size dependence



- K^+/π^+ ratio in p+p and Be+Be is similar for at all beam momenta (here example for 150*A* GeV/c
- For heavier systems the ratio rapidly increases

Onset of deconfinement, onset of fireball



- Two different observables (K^+/π^+, $\omega[h^-]$) show rapid change between Be+Be and Ar+Sc
- Two-dimensional scan conducted by NA61/SHINE indicate four domains of particle production.
- The domains are separated by two thresholds: onset of deconfinement and onset of fireball

Interpretation of the onset of fireball

- Beginning of creation of large clusters of strongly interacting matter in nucleus-nucleus collisions with increasing mass number (A)
- Such large clusters can be described by statistical models

Percolation approach:

- With increasing A density of clusters increases
- Probability to overlap many elementary clusters may rapidly increase with A
- Percolation models

AdS/CFT correspondence:

- AdS (gravity): Formation of a black hole horizon (information trapping surface) takes place when critical values of model parameters are reached
- CFT (QCD): Formation of the trapping surface in A+A collisions is possible only from a sufficiently large mass number

Open charm measurement programme

- NA61/SHINE started open charm measurement programme in 2016
- In 2016 pilot data taking with Pb+Pb collisions were performed
- In 2017 data taking with Xe+La was performed
- In November 2018 large statistics of central Pb+Pb data at 150*A* GeV/c beam momentum will be taken for open charm studies.
- After 2020, after Long Shutdown 2, upgraded NA61/SHINE will record 100 times larger statistics of minimum bias Pb+Pb data at 150*A* GeV/c and 40*A* GeV/c beam momenta for precise open charm studies.

Motivation of NA61/SHINE charm measurements

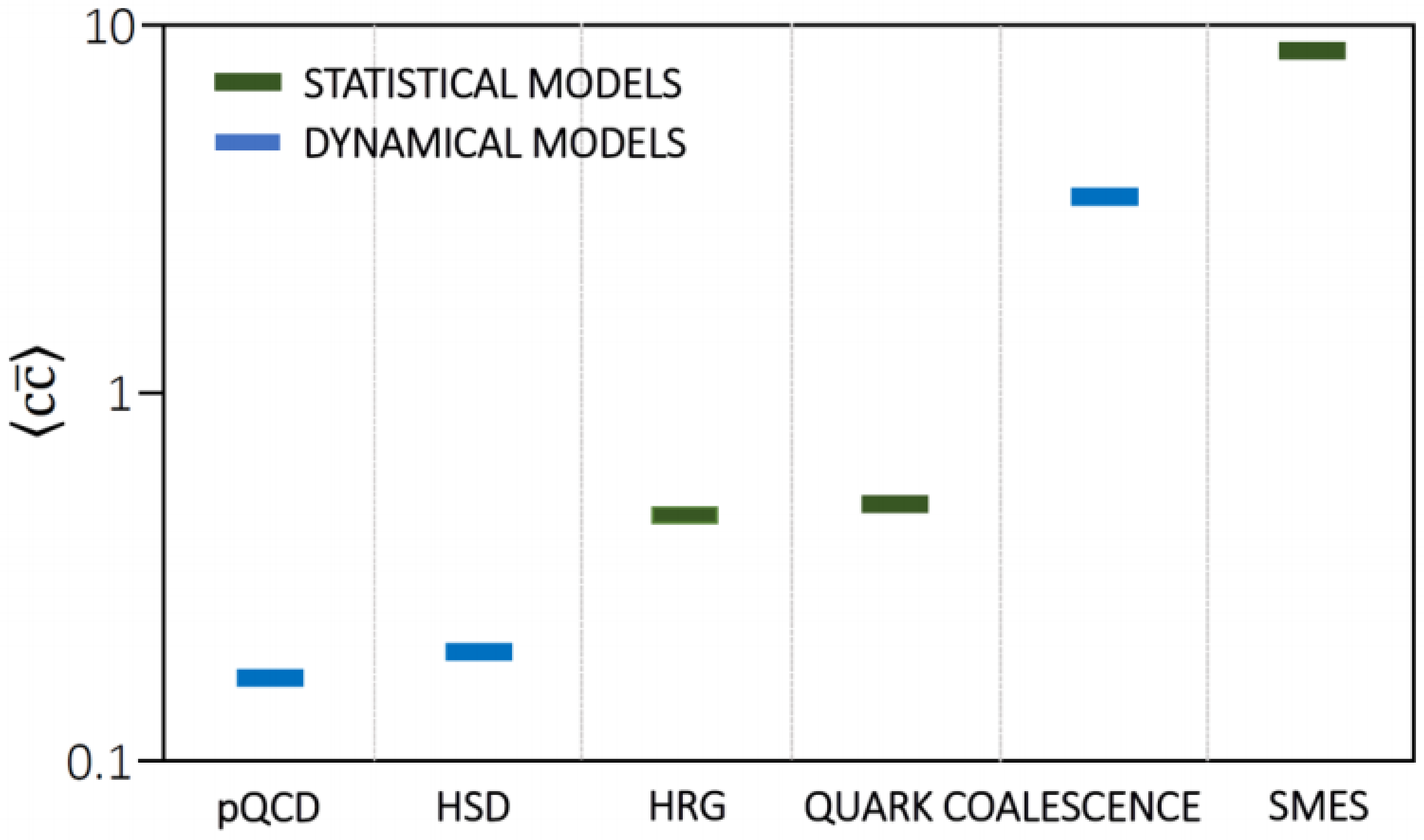
- What is the mechanism of charm production?
- How does the onset of deconfinement impact charm production?
- How does the formation of quark gluon plasma impact J/ψ production?

To answer, one needs to know:
The Mean number of charm quark pairs – $\langle c\bar{c} \rangle$,
produced in the full phase space in A+A collisions

Up to now, no corresponding experimental data is available

Models of charm production

Predictions for ⟨$c\bar{c}$⟩ in central Pb+Pb at 158A GeV/c
differ by a factor of about 50



pQCD
Gavai *et al.* IJMP A 10 2999.
Braun-Munzinger, Stachel, PL B 490, 196.

HSD
Linnyk, Bratkovskaya, Cassing, IJMP E17 1367

HRG, Quark Coalesc. Stat.
Gorenstein, Kostyuk, Stoecker, Greiner, PL B 509, 277.

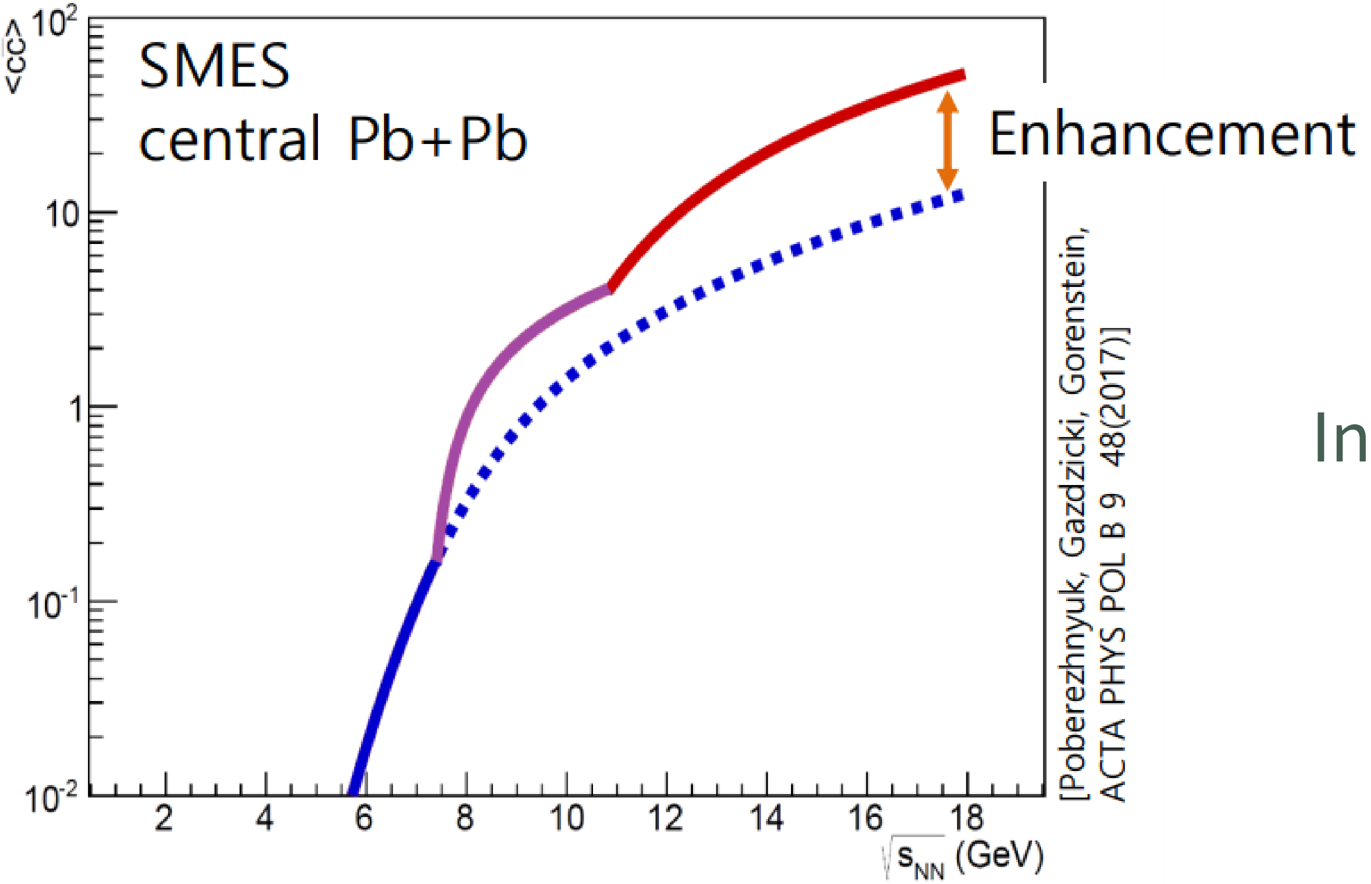
Quark Coalesc. Dyn.
Levai, Biro, Csizmadia, Csorgo, Zimanyi, JP G 27, 703

SMES
Gazdzicki, Gorenstein, APP B30, 2705.

Charm yield as the signal of deconfinement

confined matter $\xrightarrow{Tc \approx 150\text{MeV}}$ deconfined matter

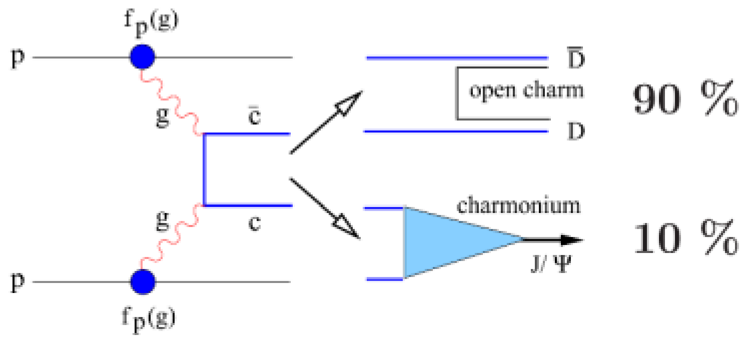
DD mesons → charm quarks

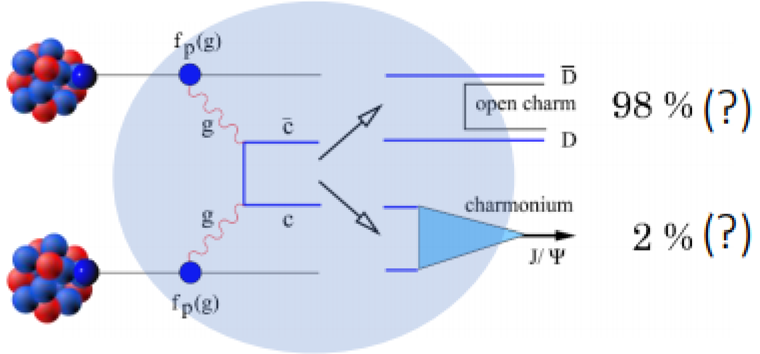


Indication of phase transition

J/ψ production as the signal of deconfinement

Open charm and J/ψ production within Matsui-Satz model
[PL B178 416]





atz, Adv. High Energy Phys. 2013 (2013) 242918]

Quark-Gluon Plasma reduces probability of J/ψ production.

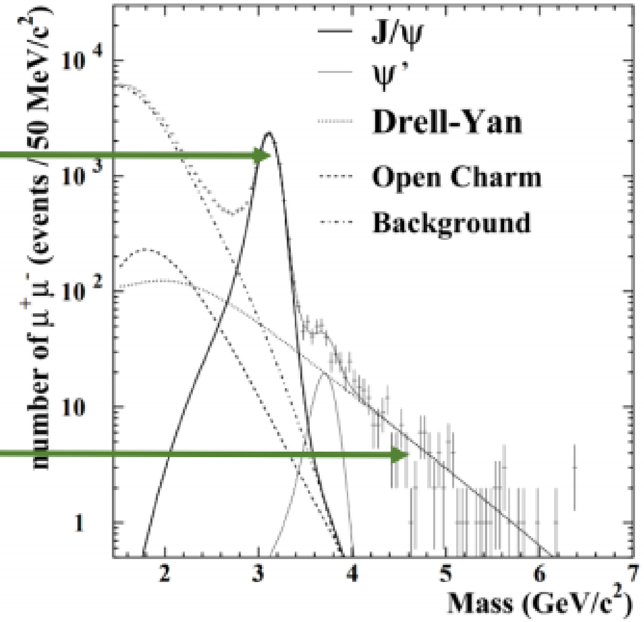
$$P(c\bar{c} \to J/\psi) \equiv \frac{\langle J/\psi \rangle}{\langle c\bar{c} \rangle} \equiv \frac{\sigma_{J/\psi}}{\sigma_{c\bar{c}}}$$

J/ψ production at the CERN SPS

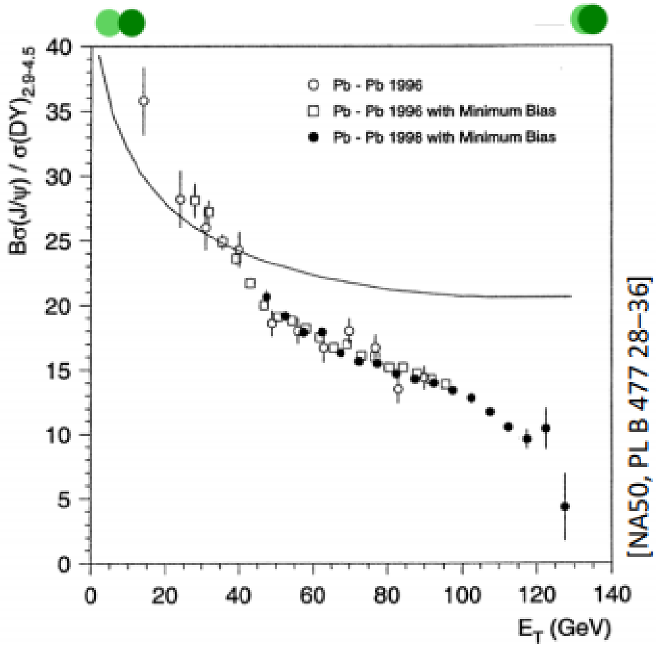
$$P(c\bar{c} \to J/\psi) \equiv \frac{\langle J/\psi \rangle}{\langle c\bar{c} \rangle} \equiv \frac{\sigma_{J/\psi}}{\sigma_{c\bar{c}}}$$

Unknown at SPS

Frequent assumption:
$\langle c\bar{c} \rangle \sim \langle DY \rangle$



[NA50, arXiv:hep-ex/0412036v1]

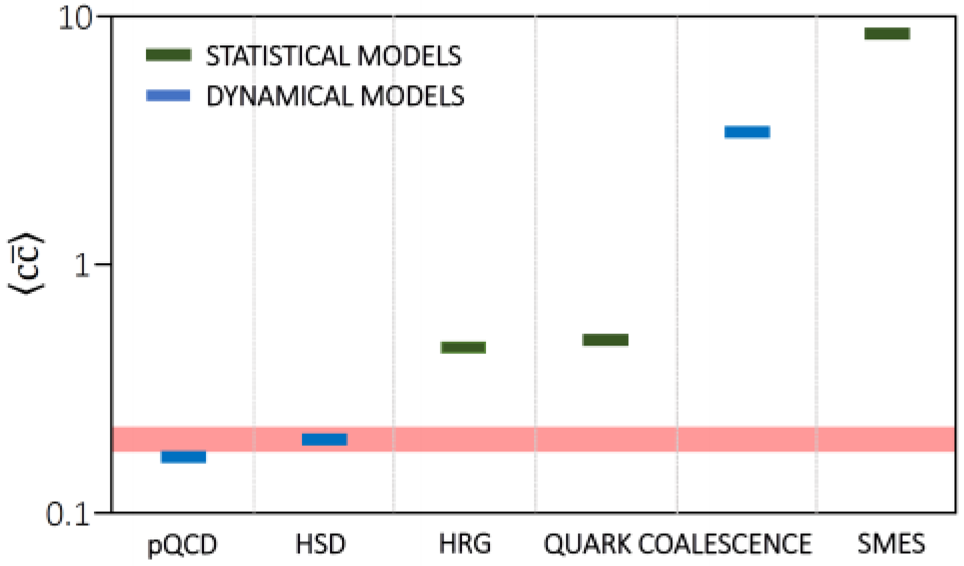


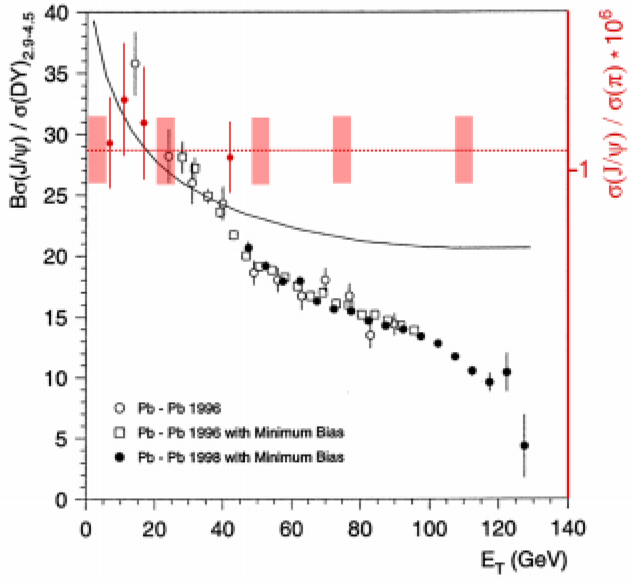
[NA50, PL B 477 28–36]

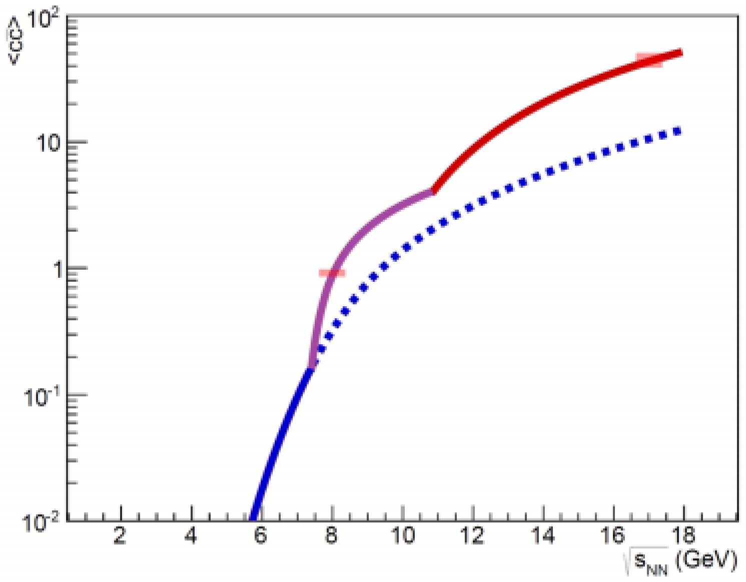
This assumptions may be incorrect due to many effects: shadowing, parton energy losses, etc.

Measuring open charm will allow to access $\langle c\bar{c} \rangle$ directly

Projected open charm resolution of NA61 after LS2

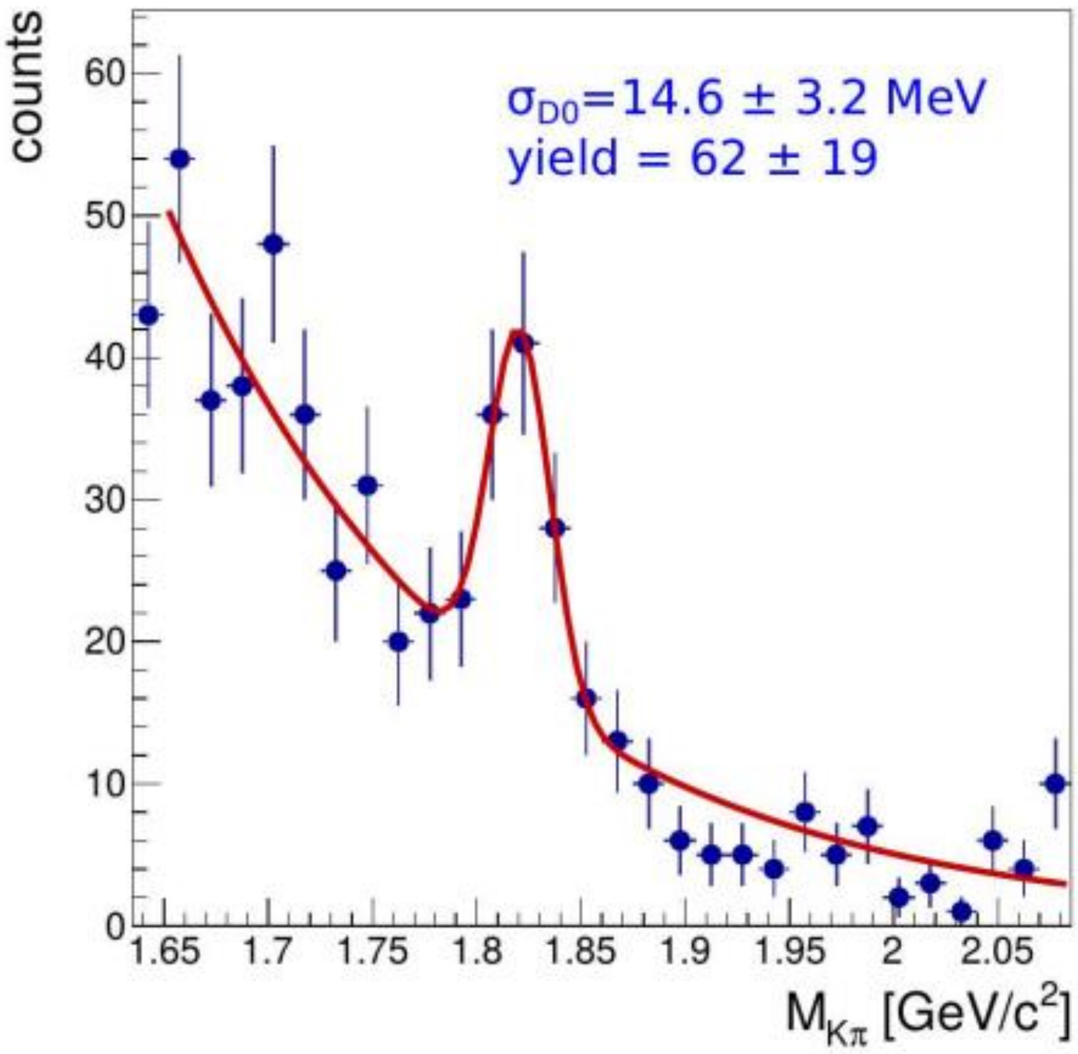






- Red bands depict uncertainty of the open charm measurements after LS2
- Increase of data taking rate by order of magnitude necessary for the measurements
- Major upgrade of the readout electronics and DAQ is underway

First direct measurement of open charm in SPS



Future of NA61/SHINE

- Improved readout rate from 80 Hz to 1000 Hz:
  - New TPC readout electronics
  - New DAQ with online data reconstruction and high level trigger
- New detectors:
  - Additional calorimeter for centrality selection
  - New mRPC Time-of-Flight walls
- Precise measurement of open charm in minimum bias Pb+Pb collisions at 40*A* and 150*A* GeV/c beam momenta
- Continuing measurements for neutrino community
- Continuing measurements for cosmic rays community

Summary

- NA61/SHINE benefits from diverse physics programme which include: neutrino, cosmic rays, and heavy ions physics
- Rapid change in multiplicity fluctuations between central Be+Be and central Ar+Sc collisions
- Rapid change in K^+/π^+ ratio in the same region
- These rapid changes interpreted as onset of fireball
- Ambitious open charm measurement programme in the near future
- Major upgrade of the detector capabilities during Long Shutdown 2.

Thank you for your attention!