

News from NA61/SHINE

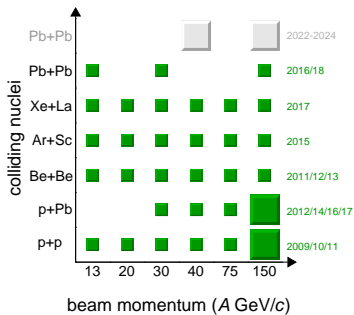


Antoni Marcinek for the NA61/SHINE Collaboration

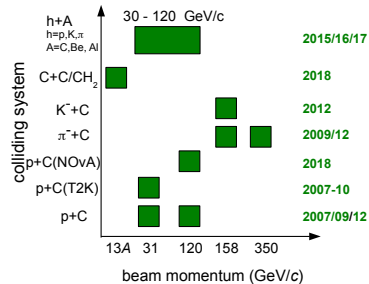
Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland

XV Polish Workshop on Relativistic Heavy-Ion Collisions
24 September 2022, Wrocław, Poland

SHINE = SPS Heavy Ion and Neutrino Experiment



$$\sqrt{s_{NN}} = 5.1-17.3(27.4) \text{ GeV}$$

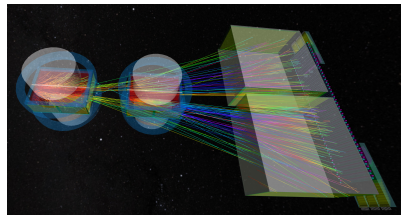
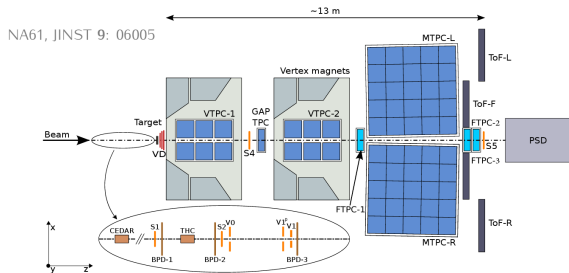


Strong interactions (this talk)

- study the onset of deconfinement
- search for the critical point

Cosmic rays and neutrinos

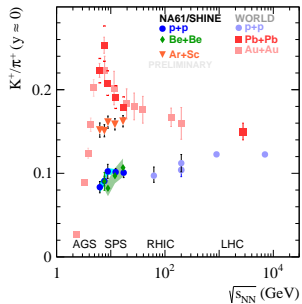
NA61/SHINE detector — unique multi-purpose facility



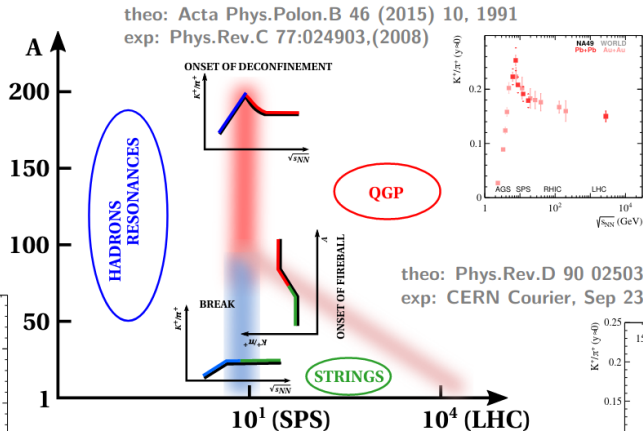
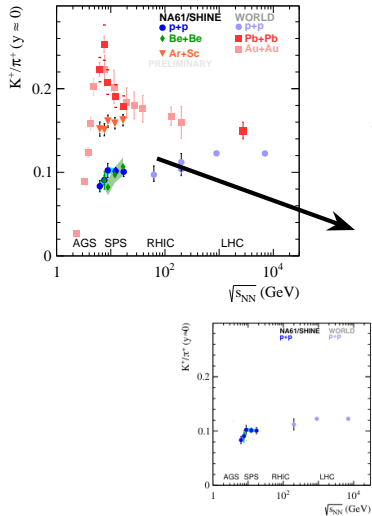
Central Ar+Sc collision at 150A GeV/c
NA61/SHINE in virtual reality: <http://shine3d.web.cern.ch/shine3d>

- large acceptance: full forward hemisphere, down to $p_T = 0$
- particle identification: dE/dx in Time Projection Chambers, Time of Flight
- ion (Be, Ar, Xe, Pb) and hadron (π , K , p) beams, various targets including liquid H_2

New results on identified hadron spectra in Be+Be and Ar+Sc collisions

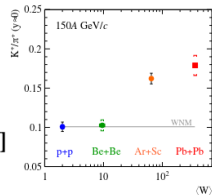


New results on identified hadron spectra in Be+Be and Ar+Sc collisions

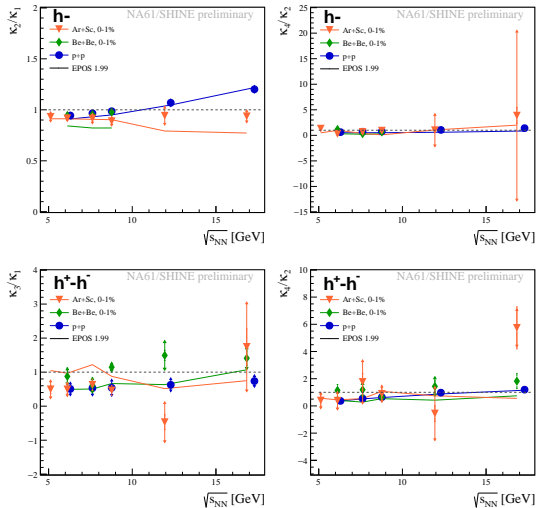


theo: Phys.Rev.D 90 025031 (2014)
 exp: CERN Courier, Sep 23rd, 2019

theo: Phys.Part.Nucl. 51 (2020) 3, 337-339
 exp: Phys.Rev.C 102 (2020) 1, 011901



Multiplicity and net-charge fluctuations in p+p, Be+Be and Ar+Sc collisions



$$\begin{aligned}\kappa_1 &= \langle N \rangle \\ \kappa_2 &= \langle (\delta N)^2 \rangle = \sigma^2 \\ \kappa_3 &= \langle (\delta N)^3 \rangle = S\sigma^3 \\ \kappa_4 &= \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2 = K\sigma^4\end{aligned}$$

where:

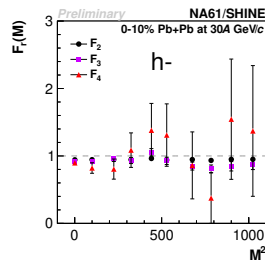
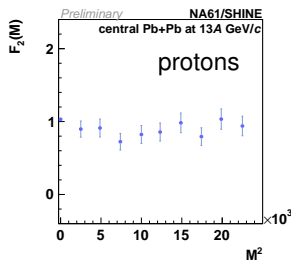
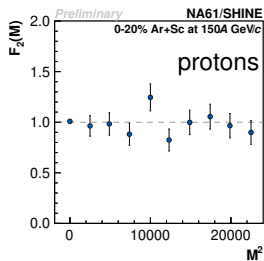
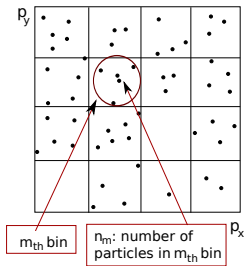
N – multiplicity; $\delta N = N - \langle N \rangle$

σ – standard deviation

S – skewness; K – kurtosis

- No structure indicating critical point
- Multiplicity κ_2/κ_1 : increasing difference between small systems (p+p and Be+Be) and a heavier system (Ar+Sc) with collision energy
- Net-charge κ_3/κ_1 : increasing difference between Be+Be and other systems (p+p and Ar+Sc) with collision energy
- κ_4/κ_2 : consistent values for all measured systems at given collision energy
- EPOS does not fully describe the data

Proton and charge hadron intermittency in Ar+Sc and Pb+Pb collisions

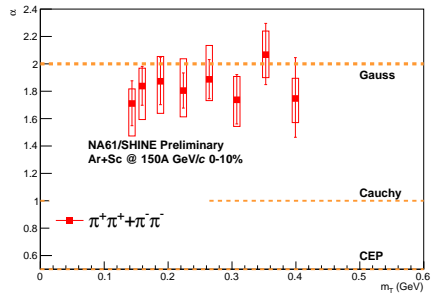
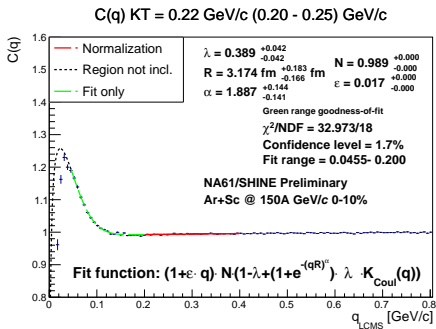


$$F_r(M) = \frac{\left\langle \frac{1}{M} \sum_{m=1}^M n_m (n_m - 1) \dots (n_m - r + 1) \right\rangle}{\left\langle \frac{1}{M} \sum_{m=1}^M n_m \right\rangle^r},$$

where $\langle \dots \rangle$ denotes averaging over events, M the number of cells

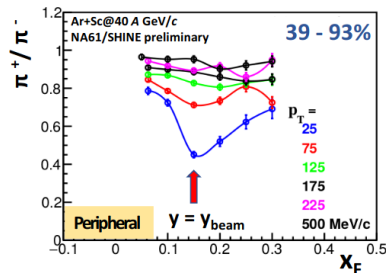
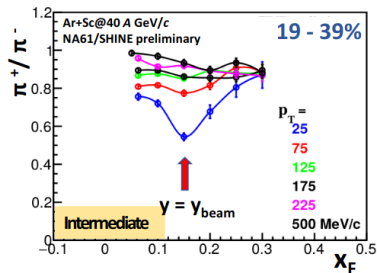
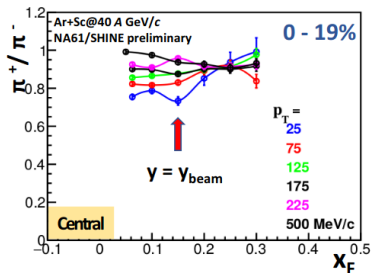
- Statistically independent points, cumulative variables
- No indication of critical point in these analyses (power-law scaling $F_r(M) \sim M^{\phi_r}$)
- Work on more advanced methodology ongoing

Symmetric Levy HBT correlations



- The Levy stability parameter α describes shape of the source
- 3D Ising model with random external field predicts $\alpha = 0.5 \pm 0.05$ at critical point

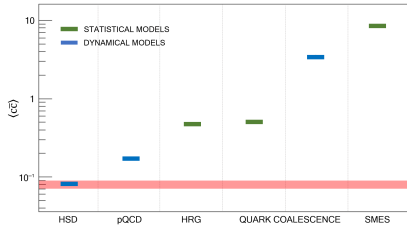
Spectator-induced electromagnetic effects in Ar+Sc collisions



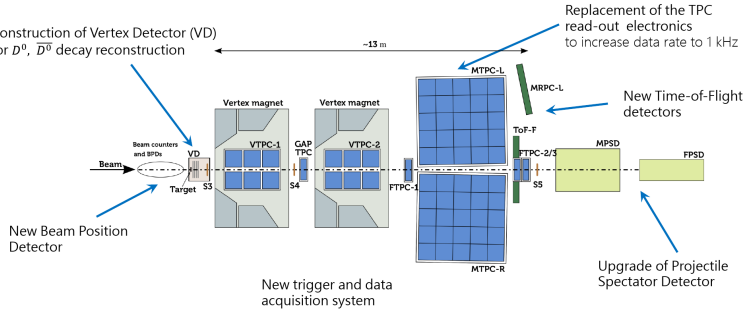
$$x_F = \frac{p_L}{p_{\text{beam}}} \text{ (c.m.s.)}$$

- First time ever observation of the spectator-induced electromagnetic effects in peripheral small systems: Ar+Sc at 40A GeV/c
- This effect provides information on the space-time evolution of the system
[Phys.Rev.C75 \(2007\) 054903](#), [Phys.Rev.C102 \(2020\) 014901](#)
- Similar effects observed in intermediate centrality Ar+Sc collisions at 150A GeV/c (NA61/SHINE) and peripheral Pb+Pb at 158A GeV/c (NA49) [Acta Phys.Polon.B 49 \(2018\) 711](#)

Main goal: first ever open charm measurements at SPS



Construction of Vertex Detector (VD) for D^0 , \bar{D}^0 decay reconstruction



This work was supported by the Norwegian Financial Mechanism 2014–2021 (grant 2019/34/H/ST2/00585)

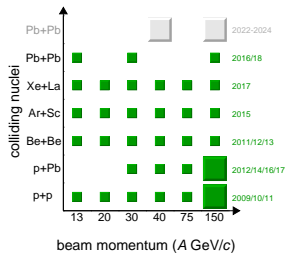
- What is the mechanism of open charm production?
- How does the onset of deconfinement impact open charm production?
- How does the formation of quark-gluon plasma impact J/ψ production?

Summary

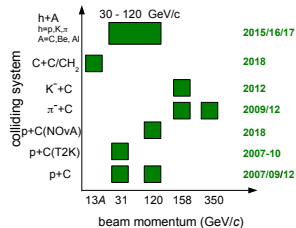
- 2D scan in system size and energy is completed revealing unexpected dependencies (onset of fireball), delivering new exciting results
- So far no convincing indication of the critical point
- Detector upgrade almost done, open charm measurements starting this year

BACKUP

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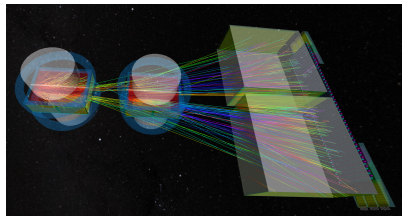
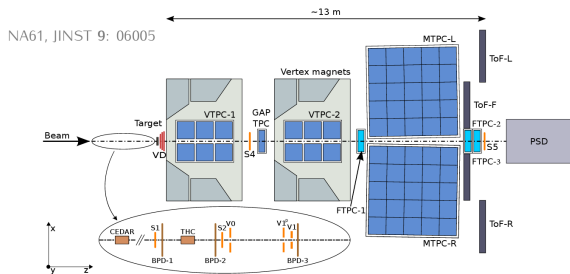
Heavy ion physics (this talk)

- 2D scan in collision energy and system size
- spectra, correlations, fluctuations
- search for the critical point
- study the onset of deconfinement

Cosmic rays and neutrinos

- precision measurements of spectra
- cosmic rays: Pierre Auger Observatory, KASCADE
- neutrinos: T2K, Minerva, MINOS, NO_νA, LBNE

NA61/SHINE detector — unique multi-purpose facility



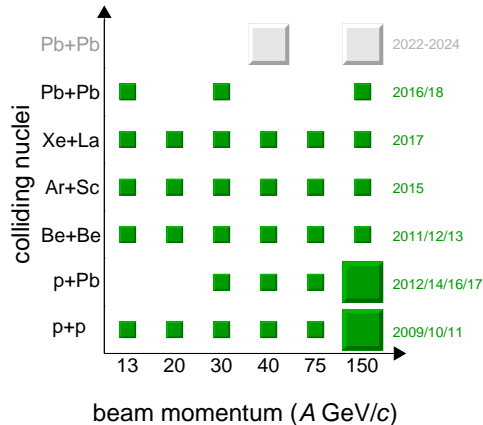
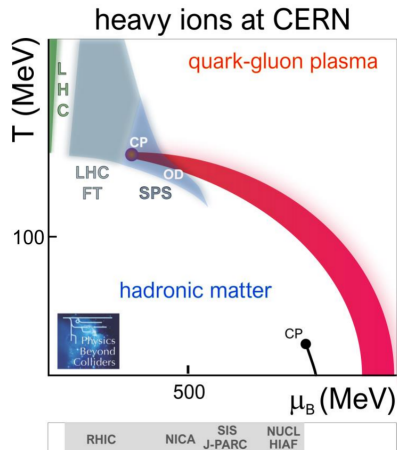
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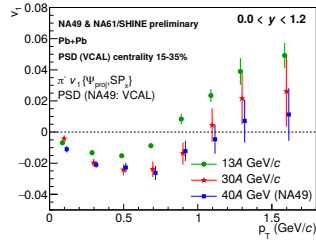
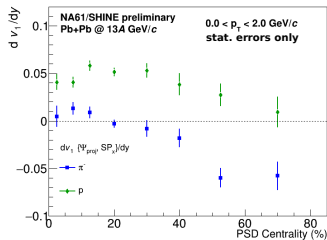
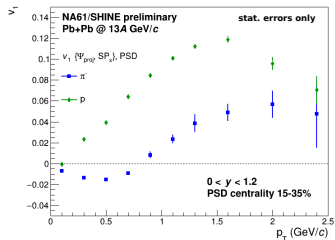
- fixed target experiment
various targets including liquid H₂
- beams:
ion (Be, Ar, Xe, Pb),
hadron (π , K , p)
- large acceptance:
full forward hemisphere,
down to $p_T = 0$
- directly only charged hadrons
- identification:
dE/dx in Time Projection Chambers,
Time of Flight
- centrality:
forward energy in Projectile Spectator
Detector

NA61/SHINE two-dimensional scan

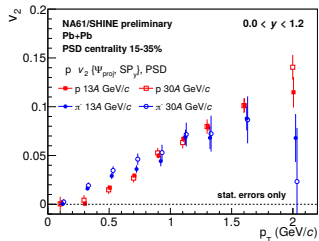
NA61/SHINE explores the phase diagram of strongly interacting matter by performing a 2D scan in collision energy and system size



Directed and elliptic flow in Pb+Pb



WPCF 2018



- Significant mass dependence of the directed flow and its midrapidity slope
- Some mass dependence also for elliptic flow
- Significant energy dependence for pion directed flow
- Insignificant energy dependence for elliptic flow