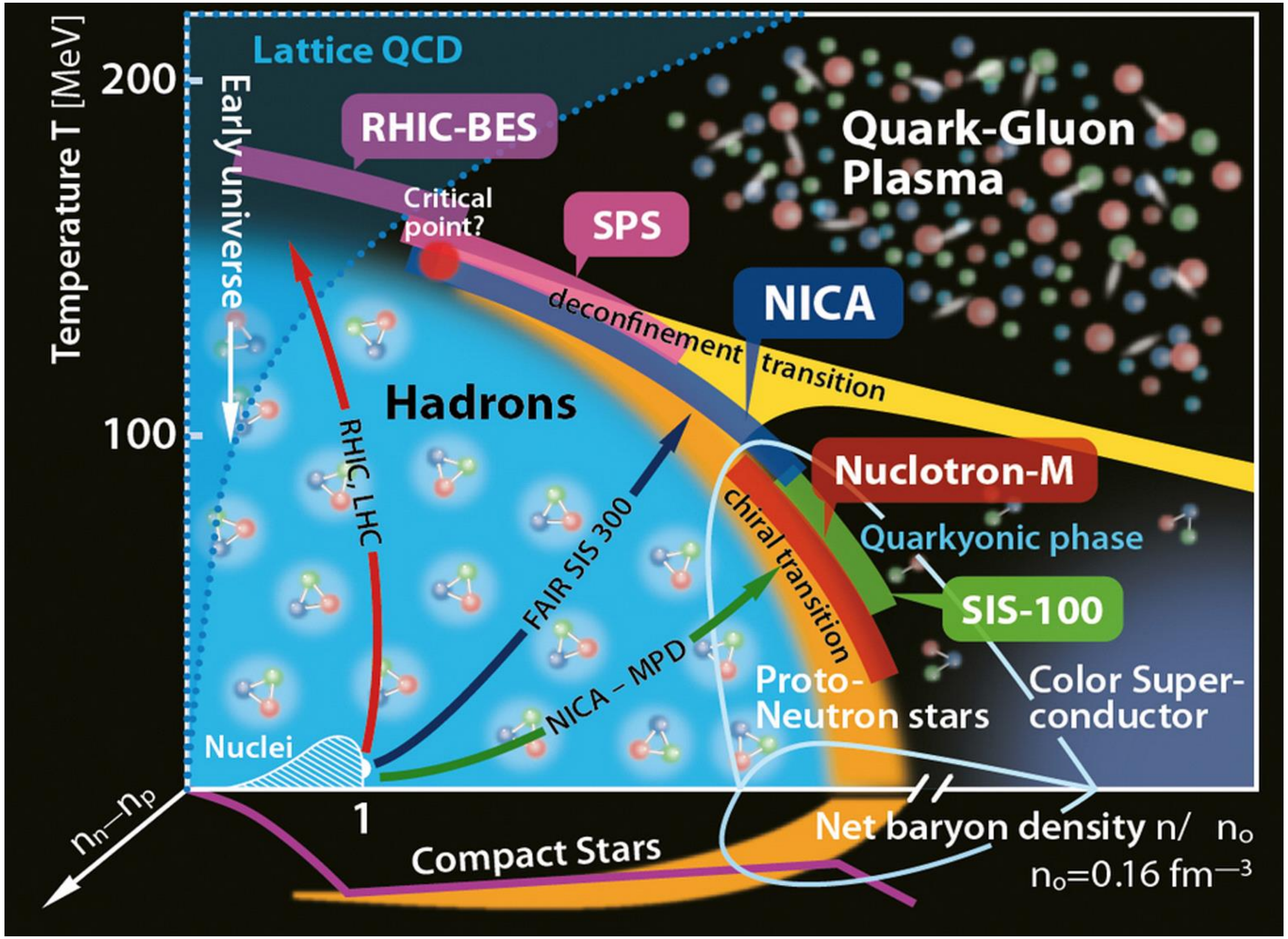
Experimental summary
Selected topics of CPOD conf.

Seweryn Kowalski

Outline

- Experimental facilities – current status
- Onsets
  - deconfiment
  - fireball
- Search for critical points
- Probe of the EOS
- Other topics
- Hardware developments and experimental measurements plans

Phase diagram

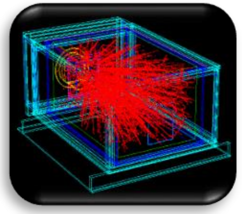


Scan of the phase diagram world status

Past measurements

Observation of the phase transition

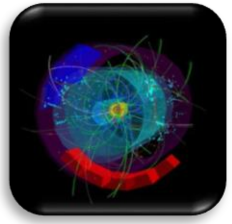
BNL AGS



CERN SPS

BNL RHIC

CERN LHC

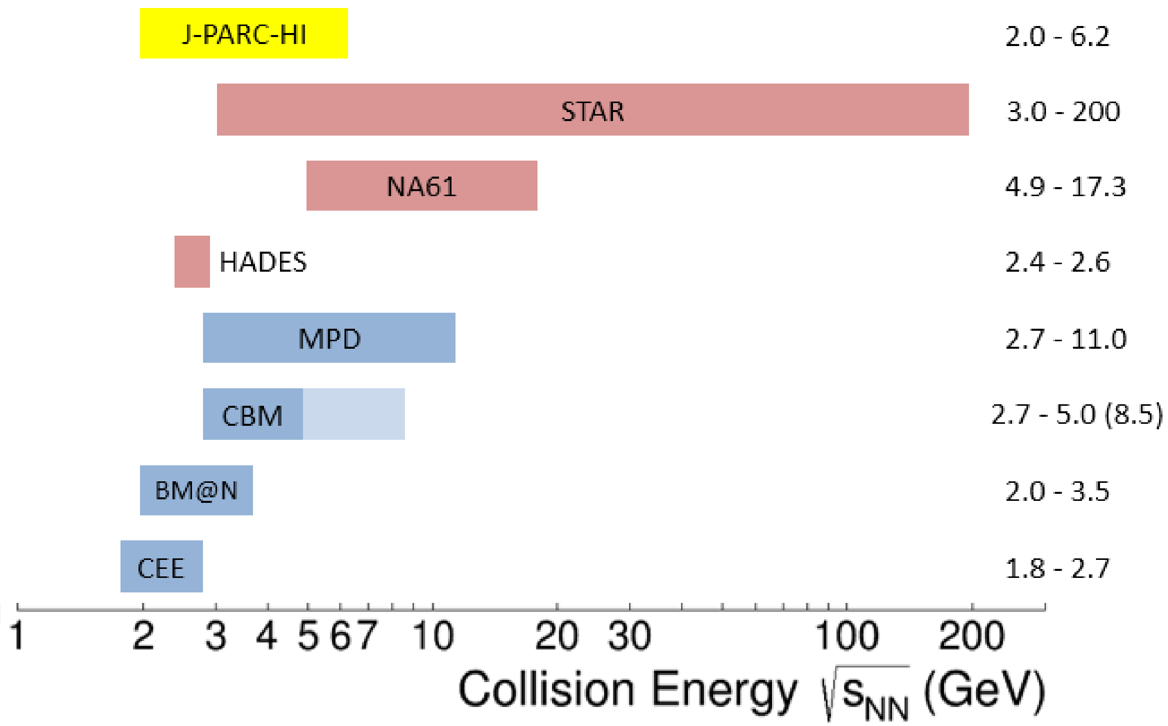


Current & future measurements

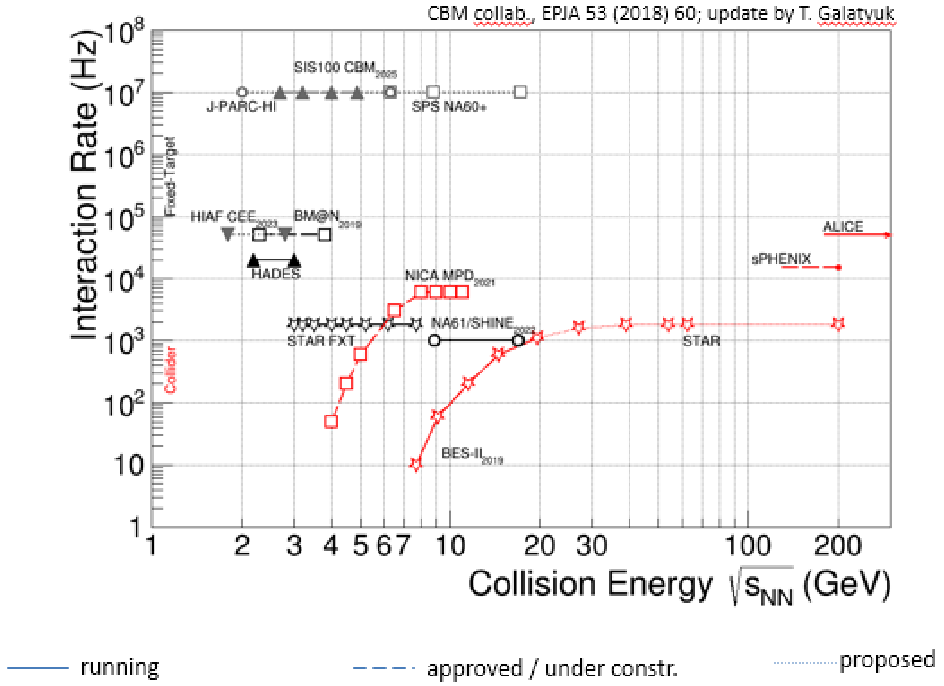
Facility	SPS	RHIC	LHC	NICA	SIS100	J-PARC-HI	HIAF
Laboratory	CERN	BNL	CERN	JINR	GSI FAIR	J-PARC	Huizhou
Experiment	NA61	STAR	ALICE, ATLAS, CMS, LHCb	BM@N MPD	HADES CBM	JHITS	CEE
Start data taking	2009	2010	2009	2018 2021	2025	2025	2024
CMS Energy [GeV/(N+N)]	5.1– 17.3	3.0 - 200	up to 5500 14000 (p+p)	2.7 - 11.0	2.3 – 4.7	1.9 – 6.2	1.8 - 2.7
Type of measurements	energy, size	energy	energy	energy	energy	energy	energy

Scan of the phase diagram world status

Collision energy



Interaction rates



Scan programs
data taking campaigns

BES I @ RHIC

Beam Energy Scan (BES I) at RHIC: $\sqrt{s_{NN}}$ ~ 7.7- 50 GeV

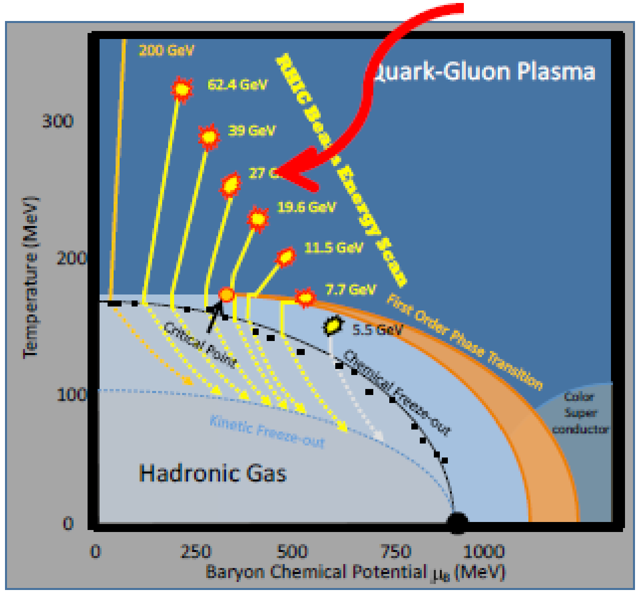
(+ 54.4, 62.4, 130, 200 GeV)

1. Search for QCD critical point
2. Search for signals of the 1st order phase transition
3. Search for turn-off of sQGP signatures

Au+Au

$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year
200	350	2010
62.4	67	2010
54.4	1300	2017
39	39	2010
27	70	2011
19.6	36	2011
14.5	20	2014
11.5	12	2010
7.7	4	2010

→ Step-by-step on the QCD Phase Diagram

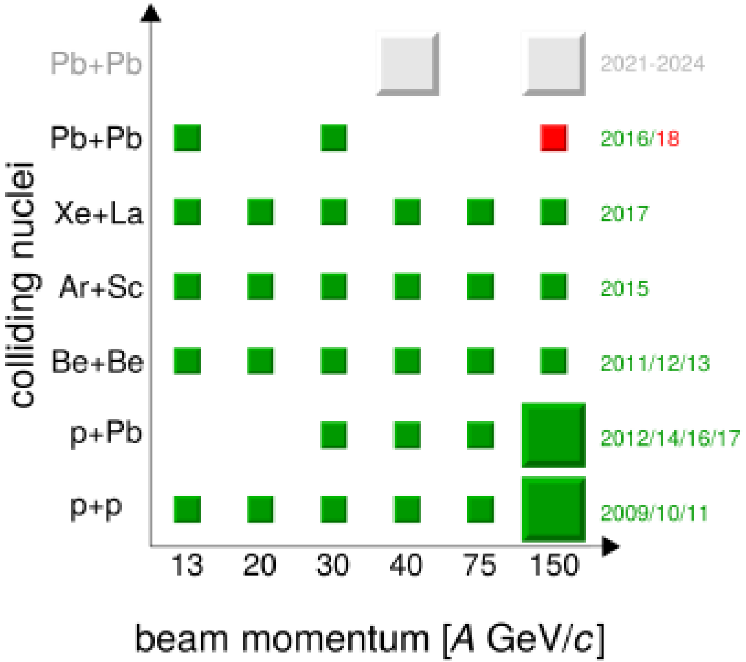


STAR

NA61/SHINE @ CERN SPS

NA61/SHINE strong interactions program

Comprehensive scan in the whole SPS energy range (beam momentum 13*A* - 150/158*A* GeV/*c* ⇔ $\sqrt{s_{NN}}$= 5.1 - 16.8/17.3 GeV) with **light and intermediate mass nuclei**



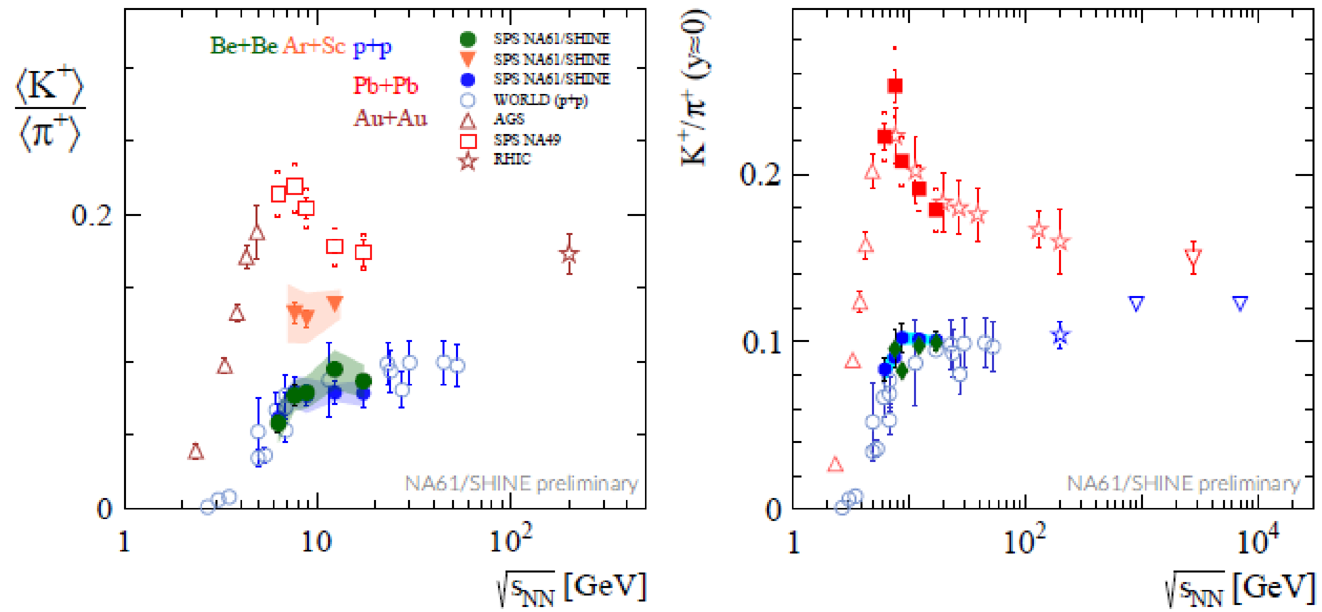
- **Search for the critical point** → search for non-monotonic behavior of CP signatures: fluctuations of N, average p_T, etc., intermittency, when system freezes out close to CP
- **Study of the properties of the onset of deconfinement** → search for the onset of the horn/kink/step/dale in collisions of light nuclei
- Study **high p_T particles** (energy dependence of nuclear modification factor)
- **Extended by Pb+Pb** → **open charm** measurements, **collective effects**, etc.

Onset of the deconfiment (phase transition)

NA61/SHINE – **horn**

Energy dependence of K^+/π^+

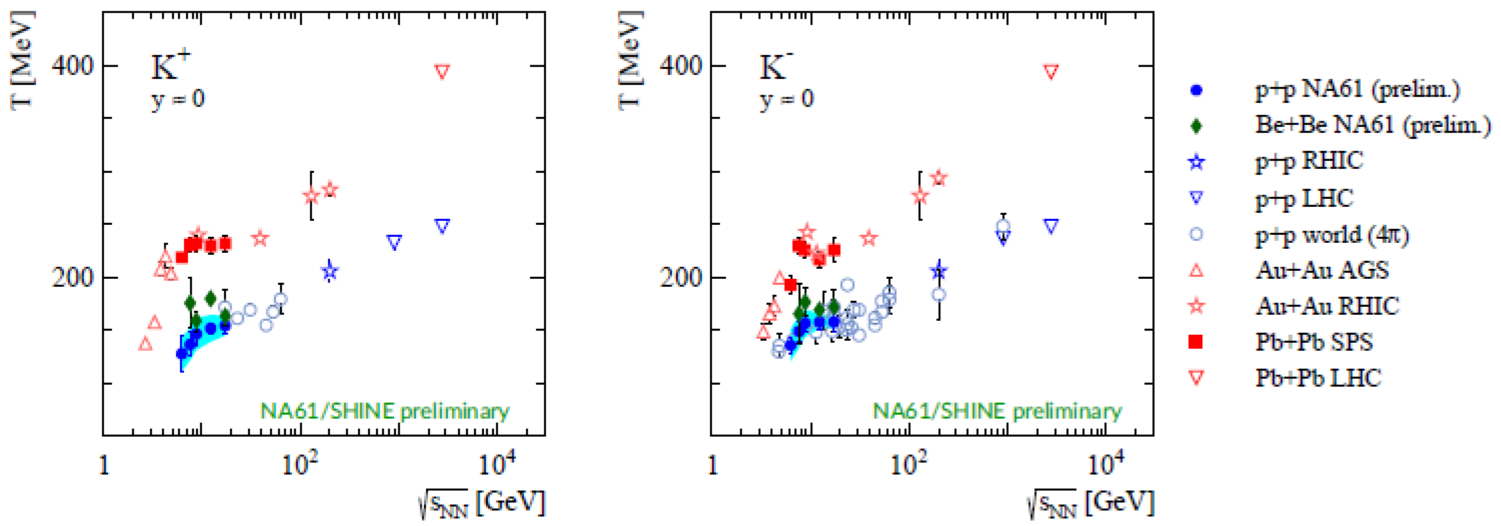
"the horn" plot



No "horn"-like structures visible in intermediate size systems: Be+Be and Ar+Sc.

NA61/SHINE – **step**

Inverse slope parameter *T*



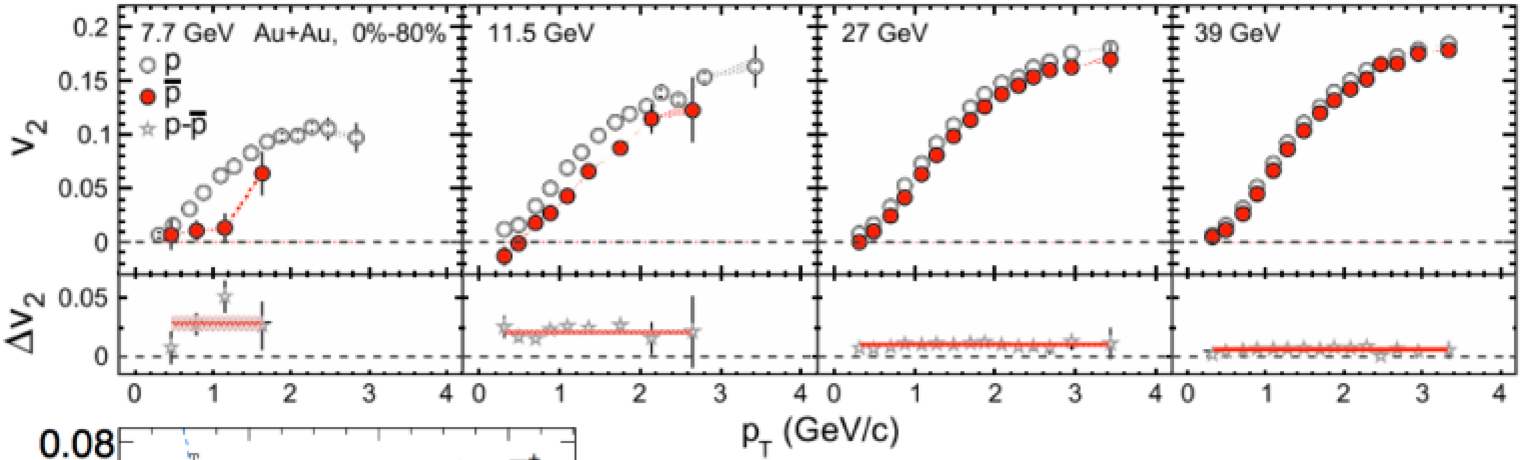
Inverse slope parameter *T* in Be+Be collisions is close to p+p measurements.

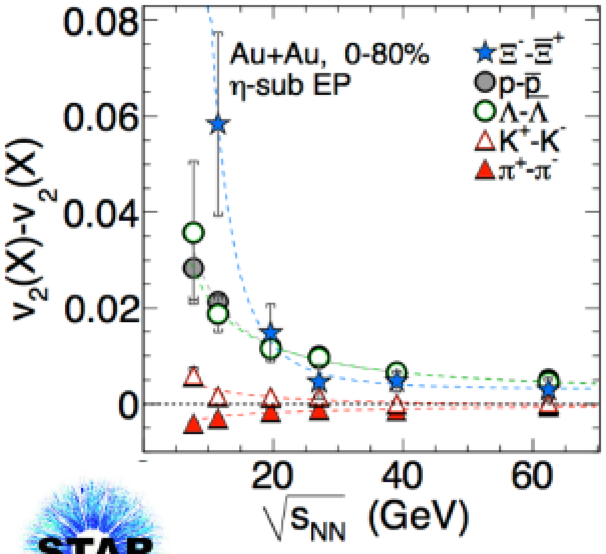
Flow @ STAR

indication that hadronic interaction become dominant at lower beam energies

BES I: v_2 difference between particle and anti-particle

STAR, PRL 110 (2013) 142301, PRC 88 (2013) 014902, PRC 93 (2016) 014907





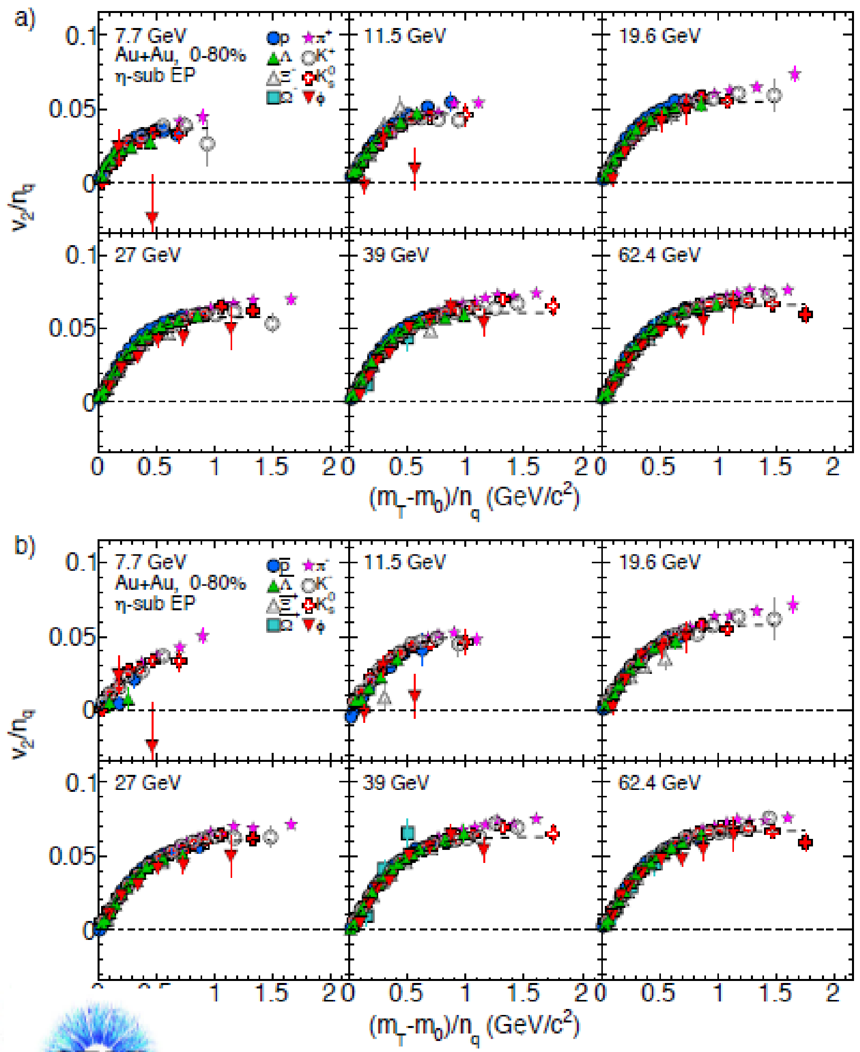
Significant difference between baryon-antibaryon v_2 at $\sqrt{s_{NN}}$<= 11.5 GeV

NCQ scaling between particles and anti-particles is broken

- ➔ consistent with hadronic interactions becoming dominant
- ➔ Indication of a phase transition ??

Flow @ STAR

indication that hadronic interaction become dominant at lower beam energies



ϕ meson v_2

STAR: PRC 88 (2013) 14902
Phys. Rev. C 93, 014907 (2016)
Phys. Rev. Lett. 116, 062301 (2016)

- ϕ meson v_2 falls off the trend from other hadrons at 11.5 GeV, but <u>very low</u> statistics

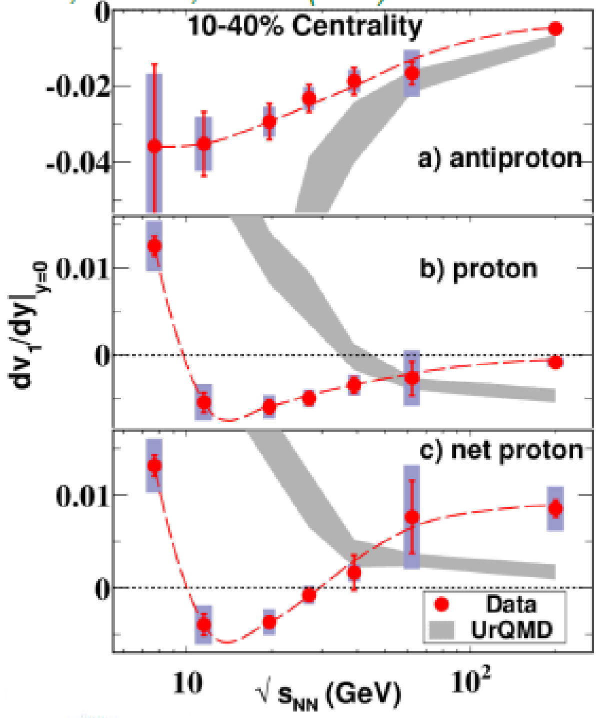
Flow @ STAR

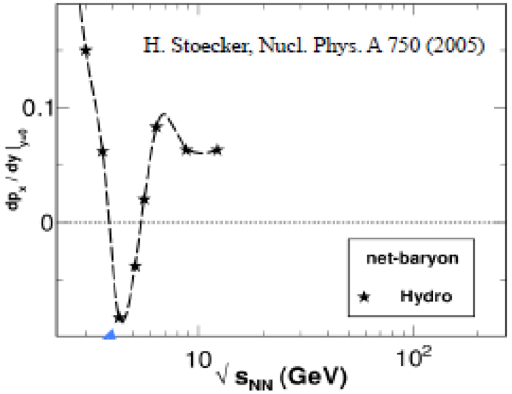
net-proton and net-Λ show double sign change in mid-rapidity dv_1/dy, as predicted for the possible 1st order phase transition, indication of a softening of EOS around 11.5-19.6 GeV

Directed flow (v_1) of identified particles

v_1 probes early stage of collision, sensitive to compression, should be sensitive to 1st order phase transition; change of sign in the slope of dv_1/dy for protons has been proposed to be a probe to the softening of EOS and/or the first-order phase transition …

STAR, PRL 112, 162301 (2014)

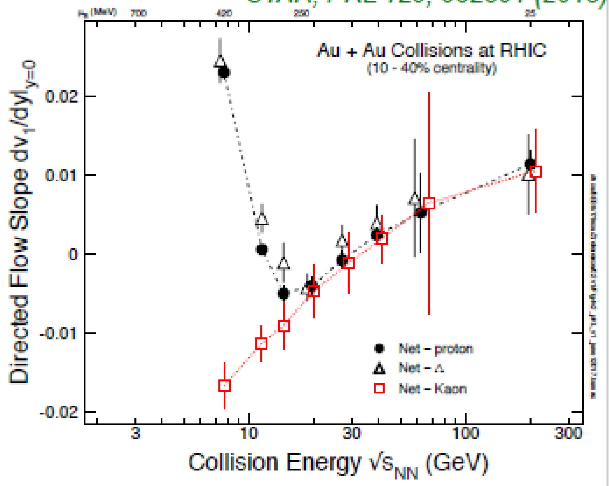




- Net-proton v_1 slope at midrapidity changes sign twice between $\sqrt{s_{NN}}$ = 7.7 - 11.5 GeV
- EOS softest point ? (1st order phase transition ?)

but: - dip at different position than model
- error bars for other particles and different centralities are large – more statistics needed and better RP resolution needed

STAR, PRL 120, 062301 (2018)



Net-protons = directed flow of transported baryons
Double sign change in dv_1/dy
Not seen in net-kaons
Results not yet reproduced by theory

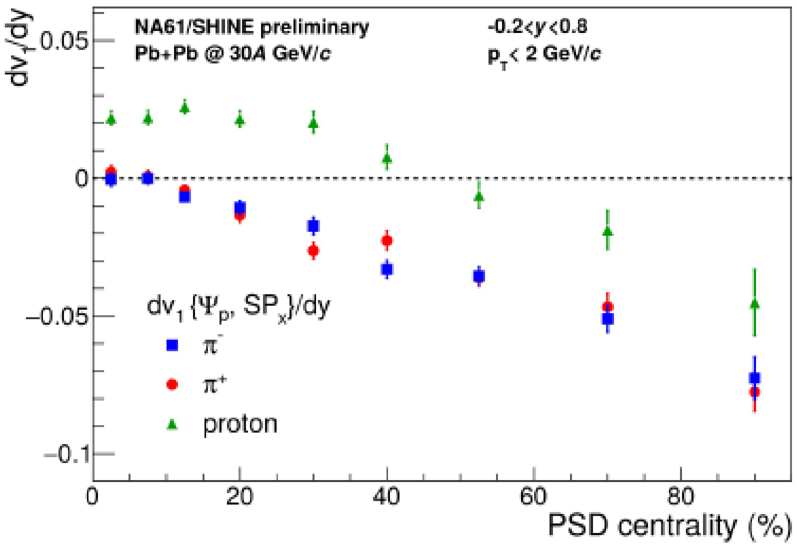
Flow @ NA61/SHINE

The first **NA61 results on anisotropic flow in Pb+Pb at 30*A* GeV/*c*** were obtained. Protons dv_1/dy change sign for centrality of about 50% → another **tool to study the properties of the onset of deconfinement**

NA61/SHINE centrality dependence of dv_1/dy in Pb+Pb at $\sqrt{s_{NN}}$ = 7.6 GeV

(30*A* GeV/*c* beam momentum; according to K^+/π^+ "horn" in Pb+Pb this is **the energy of the onset of deconfinement**)

- NA61 fixed target setup → tracking and particle identification over wide rapidity range
- Flow coefficients are measured relative to the spectator plane estimated with Projectile Spectator Detector (PSD) → unique for NA61



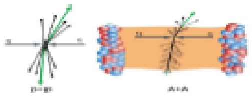
- Slope of pions v_1 is always negative
- **Slope of protons v_1 changes sign for centrality of about 50%**

Results for Pb+Pb at 13*A* and 150*A* GeV/c as well as six energies of Xe+La are coming soon

BES @ RHIC

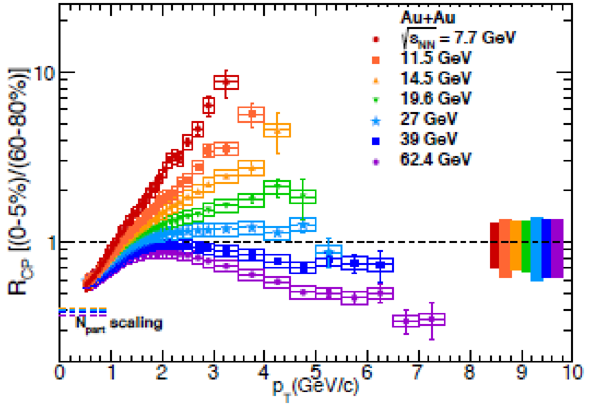
indication that hadronic interaction become dominant at lower beam energies

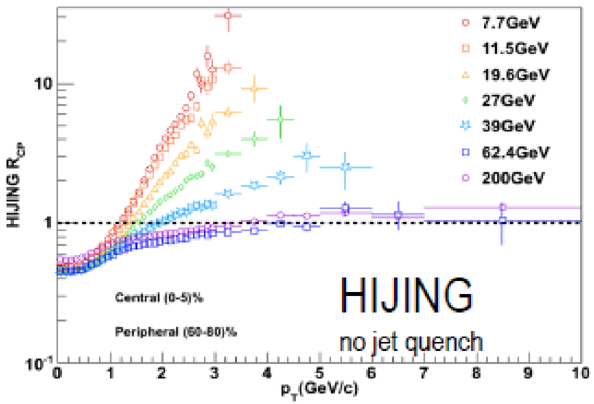
BES: R_{cp} for charged particles



$$R_{CP} = \frac{d^2Ndp_T d\eta / \langle N_{bin} \rangle (central)}{d^2Ndp_T d\eta / \langle N_{bin} \rangle (peripheral)}$$

QM 2018, PRL 121, 032301 (2018):





- R_{CP} increases from suppression at 62.4GeV to enhancement at 7.7 GeV, as expected
(energy density at low energies becomes to low to produce a sufficiently large and long-lived QGP)

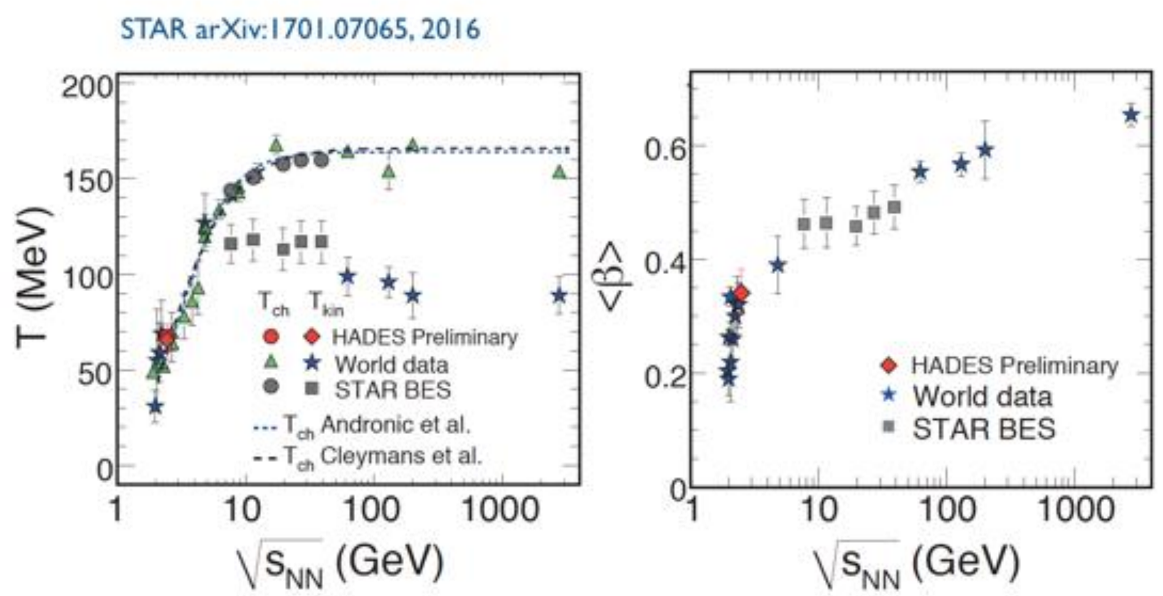
HIJING (no jet quenching, but including Cronin effect though k_T broadening) resembles $\sqrt{s_{NN}}$ dependence at low energies
(other effects can contribute e.g. radial flow, coalescence, …)

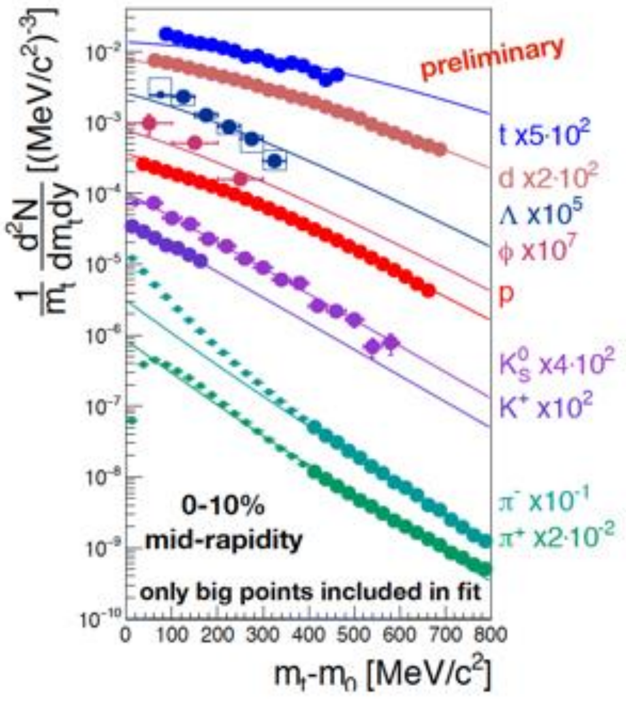
Cronin and other enhancement effects compete with jet quenching

$R_{cp} > 1$ does not automatically lead to conclusion that QGP is not formed

Flow @ HADES

Radial flow



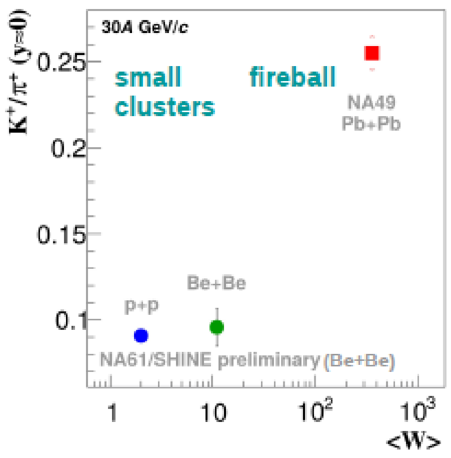


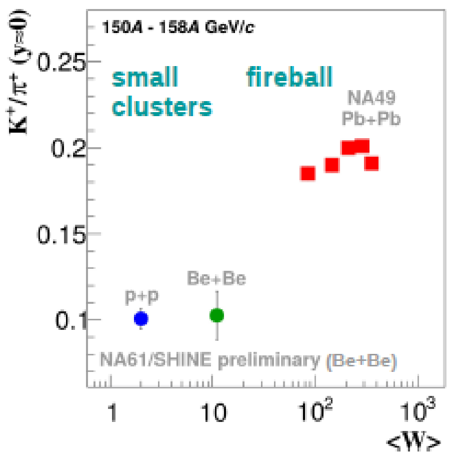
- Global freeze-out parameters fit well into trend of world data
- $T_{kin} < T_{chem}$ also at low energies
- Fit: Blast wave model with linear radial flow velocity profile
- T_{kin}=66±8 MeV, $\langle\beta_r\rangle$=0.34±0.04

Onset of the fireball (transition to equilibrium)

NA61/SHINE – **two onsets in nucleus-nucleus collisions**

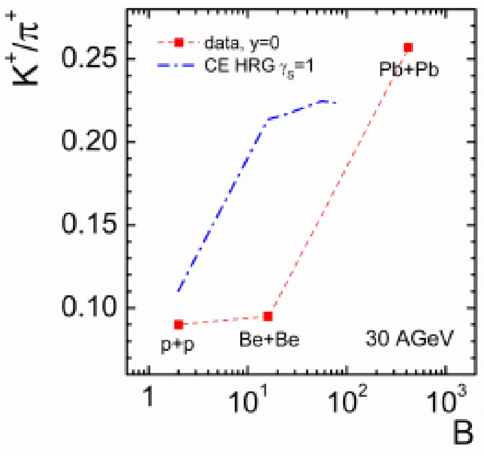
System size dependence of K^+/π^+ ratio at mid-rapidity

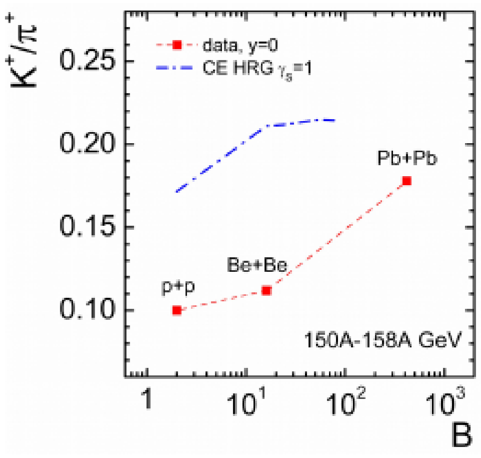




- **Be+Be** results are **close to p+p**
- **Rapid change** from p+p and Be+Be **to heavy Pb+Pb**

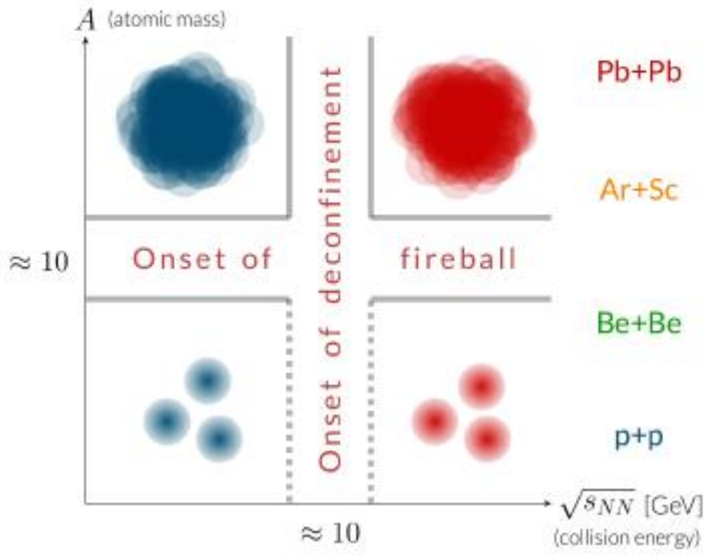
p+p: NA61, EPJC 77, 671, 2017
Pb+Pb: NA49, PR C77, 024903 2008; PR C86, 054903, 2012





- Hadron Resonance Gas model in CE formulation (γ_S=1) cannot describe NA61 data

Begun, Gorenstein, Motornenko, Vovchenko [in preparation]; see also arXiv:1805.01901, arXiv:1512.08025



Onset of deconfinement
beginning of QGP formation
Onset of fireball
beginning of formation of a large cluster which decays statistically

Search for critical point

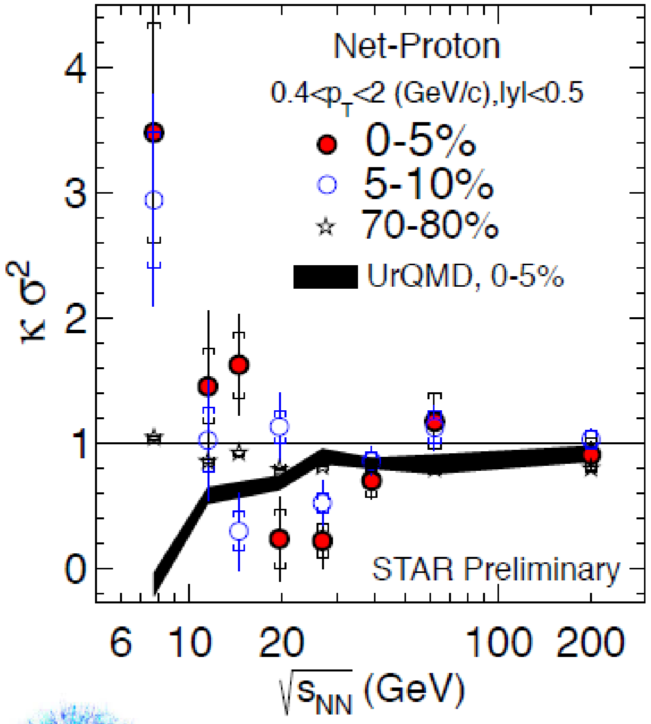
Fluctuations

Non-monotonic energy dependence of the 4th order net-proton correlation function suggestive signs of critical fluctuations

Higher moments in BES-I

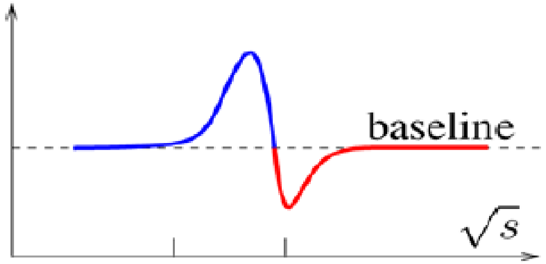
Excitation function for net-proton high moments ($\kappa\sigma^2$) in 5% most central Au+Au

STAR, PRL 112 (2014) 032302, CPOD2014, QM2015



$$\sigma^2 = \langle (N - \langle N \rangle)^2 \rangle$$
$$S = \langle (N - \langle N \rangle)^3 \rangle / \sigma^3$$
$$\kappa = \langle (N - \langle N \rangle)^4 \rangle / \sigma^4 - 3$$

- Non-monotonic behavior
- Peripheral collisions – smooth trend
- UrQMD (no CP): shows suppression at low energies which is due to baryon number conservation



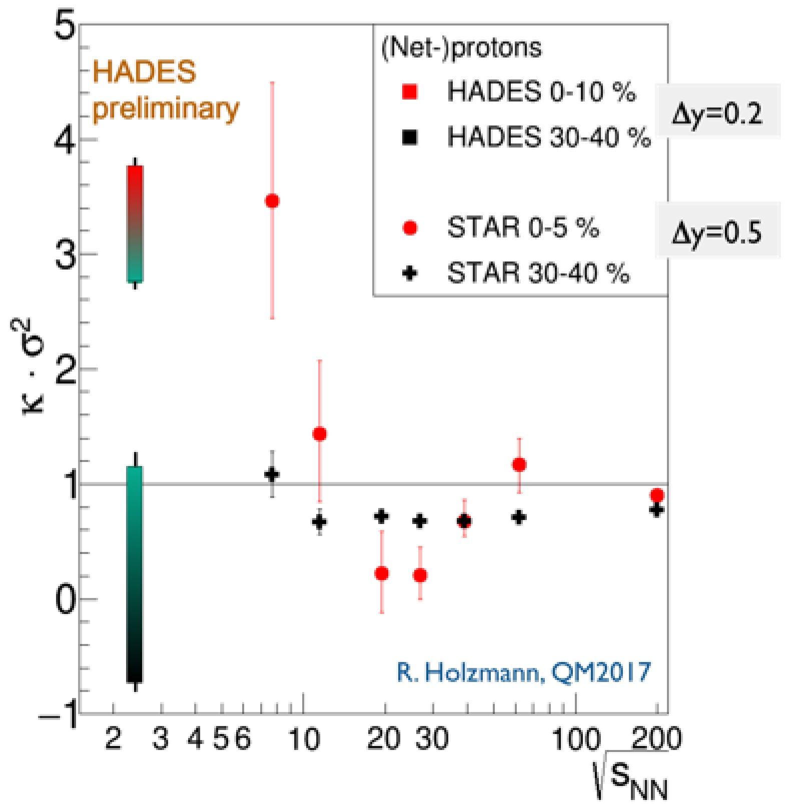
M.A.Stephanov, PRL 107, 052301 (2011)

Will the oscillation pattern emerge at lower energies ?

FXT data

Fluctuations

Proton Number Fluctuations



- Unfolding + vol. flucs. corr.
- E-b-e eff corr. of factorial moments + vol. flucs. corr.

- 1st time this kind of analysis in fixed-target experiment at $\sqrt{s_{NN}}$ = 2.42 GeV
- Detailed systematic study of experimental and instrumental effects:
  - E-b-e changes of efficiency
  - Corrections for volume fluctuations
  - Proper selection of p_t-y bite
  - Protons bound to nuclei

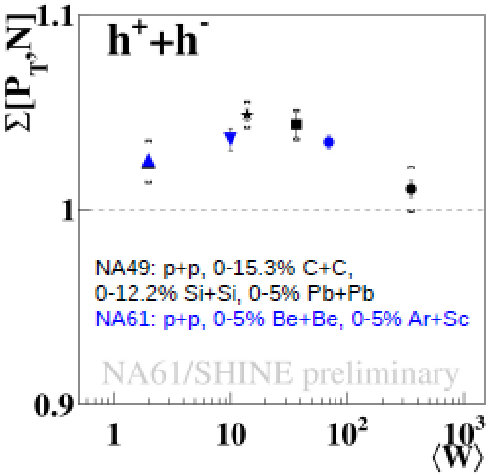
  Impact of the effects is being scrutinized

Garg et al., J. Phys. G: Nucl. Part. Phys. 40 (2013)
A. Bzdak, V. Koch, PRC 86 (2012); X. Luo, PRC 91 (2015); M. Kitasawa, PRC 93 (2016)
V. Skokov *et al.*, PRC 88 (2013) 034911; A. Rustamov *et al.*, NPA 960 (2017) 114

Fluctuations

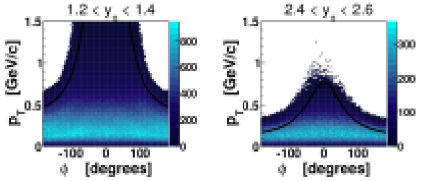
Comparison to NA49 *A*+*A* at 158*A* GeV/*c*
within NA49 two different acceptances

NA49: PR C92, 044905, 2015



$1.1 < y_\pi < 2.6$

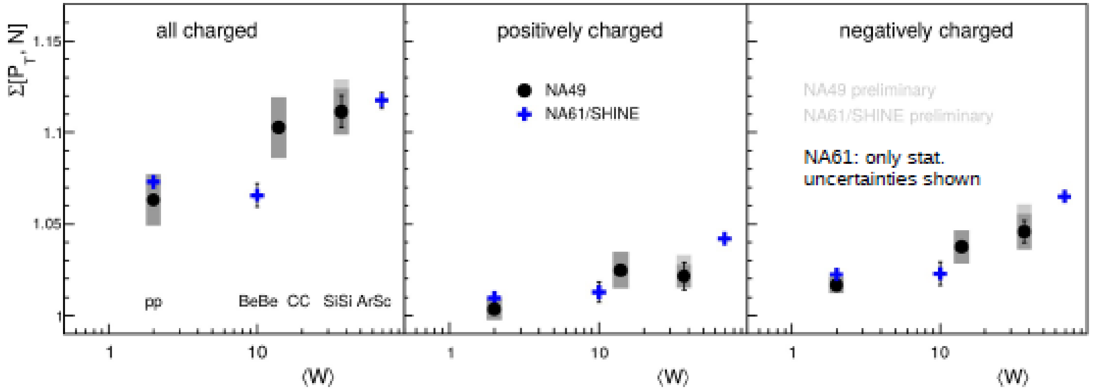
System size scan – wide azimuthal acc.
(the same for all systems)



System size dependence of $\Sigma[P_T, N]$ at 150/158*A* GeV/*c*: **NA49 and NA61 points show consistent trends**. $\Delta[P_T, N]$ (not shown here) is more centrality width sensitive (points are scattered)

NA49: preliminary (PoS EPS-HEP2017, 167, 2017)

$0 < y_\pi < y_{beam}$

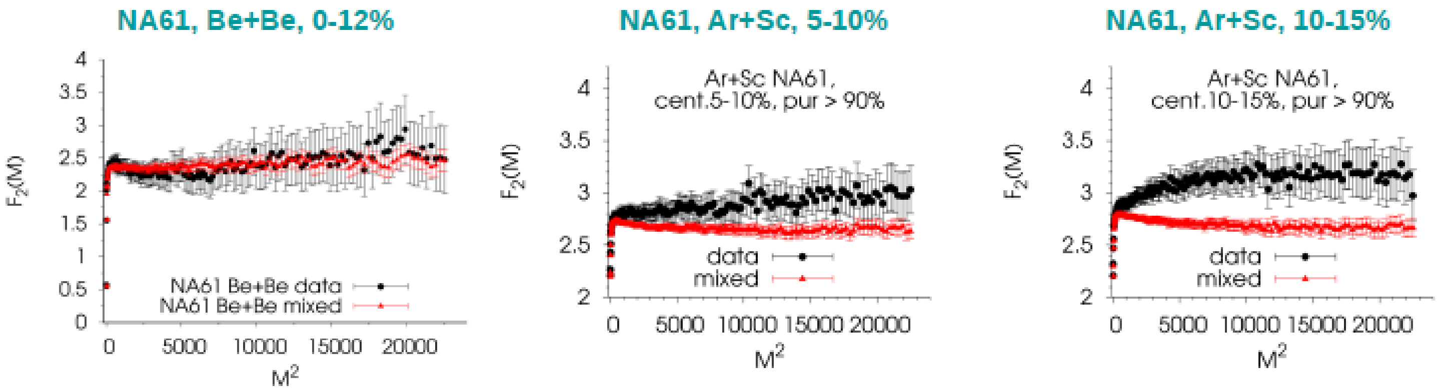


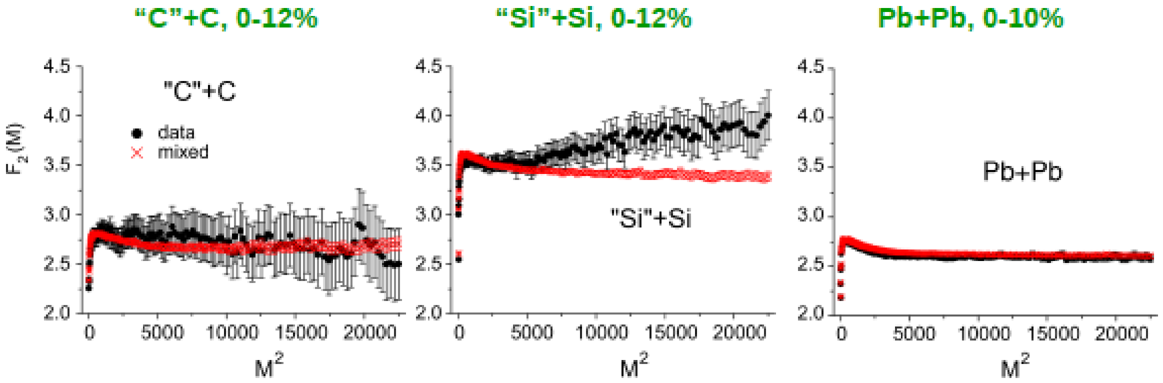
- Fluctuations are larger for larger rapidity interval
- **Increase of Σ from p+p to Ar+Sc / Si+Si**. We are waiting for Xe+La and Pb+Pb results from NA61

Intermittency

Indication of **intermittency effect in middle-central Ar+Sc at 150*A* GeV/*c*** was shown→ first possible **evidence of CP signal** in NA61/SHINE

Proton intermittency – comparison of NA61 and NA49 at 150(8)*A* GeV/*c*





NA49

EPJC 75, 587, 2015

Fragmentation "C" beam: mixture of ions with Z=6 and 7; "Si" beam: mixture of ions with Z=13, 14, 15

Older intriguing results for intermediate mass systems **at 150(8)*A* GeV/*c***

- Intermittency signal of di-pions in Si+Si → NA49, PR C81, 064907, 2010
- Increased transverse momentum and multiplicity fluctuations in Si+Si and C+C → Grebieszkow (for NA49), NP A830, 547C, 2009; NA49, PR C92, 044905, 2015

Fluctuations @ LHC

The measured second order cumulants of net-protons at ALICE are, after accounting for baryon number conservation, in agreement with the corresponding second cumulants of the Skellam distribution.

Net-protons, acceptance dependence

Contribution from global baryon number conservation

$$\frac{\kappa_2(p-\bar{p})}{\kappa_2(Skellam)} = 1-\alpha \qquad \alpha = \frac{\langle p \rangle^{measured}}{\langle B \rangle^{4\pi}}$$

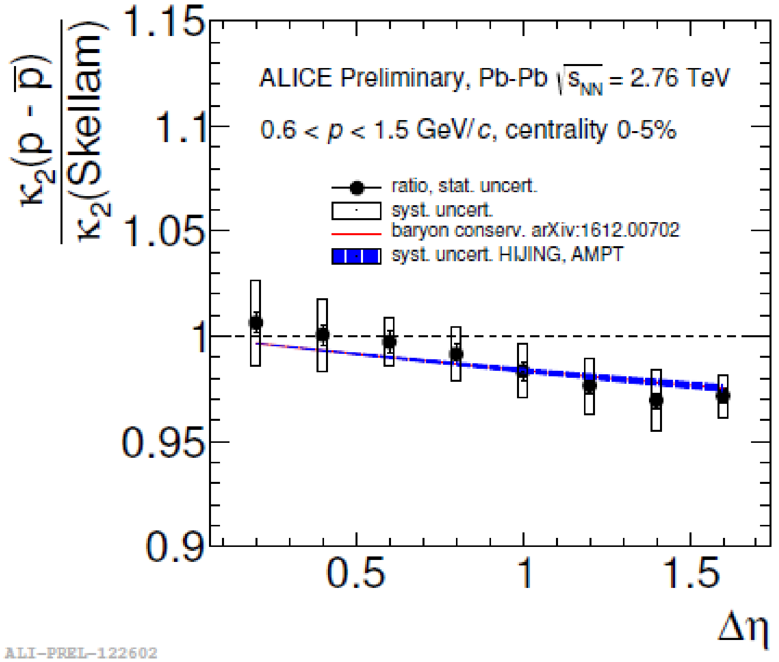
P. Braun-Munzinger, A. R., J. Stachel, arXiv:1807.08927

Inputs for $\langle B \rangle^{acc}$ from:

Phys. Lett. B 747, 292 (2015)
P. Braun-Munzinger, A. Kalweit, K. Redlich, J. Stachel

extrapolation from $\langle B \rangle^{acc}$ to $\langle B \rangle^{4\pi}$

using HIJING and AMPT models



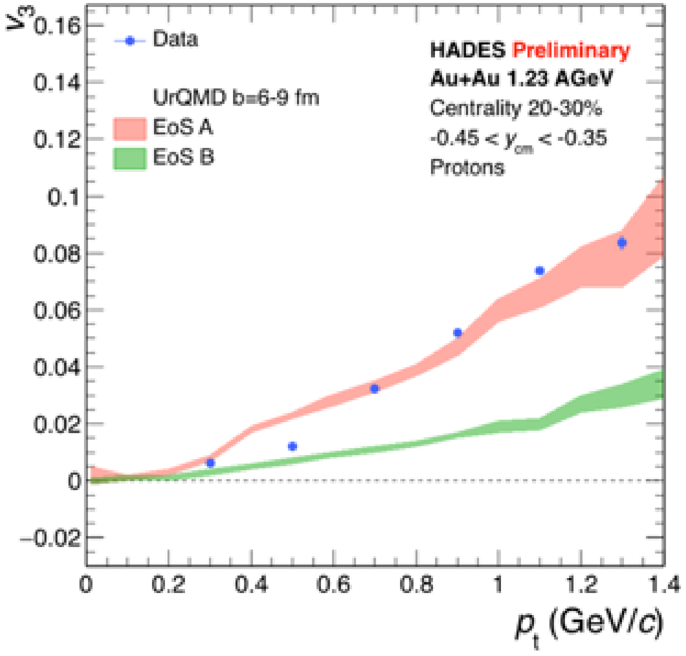
The deviation from Skellam is due to global baryon number conservation

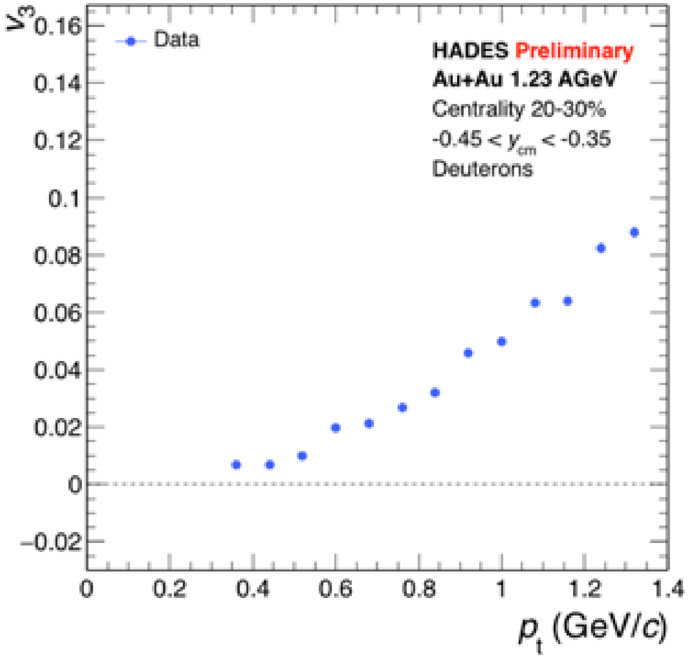
Probing of the EOS

EOS – higher Vn harmonics n>2

Triangular flow $v_3\{\psi_{RP}\}$ and EoS at SIS18 compared to UrQMD

Note: $v_3\,\{\psi_{RP}\}$ w.r.t reaction plane $v_3\{\Psi_{RP}\} = \langle\langle \cos 3(\varphi - \Psi_{RP})\rangle\rangle$





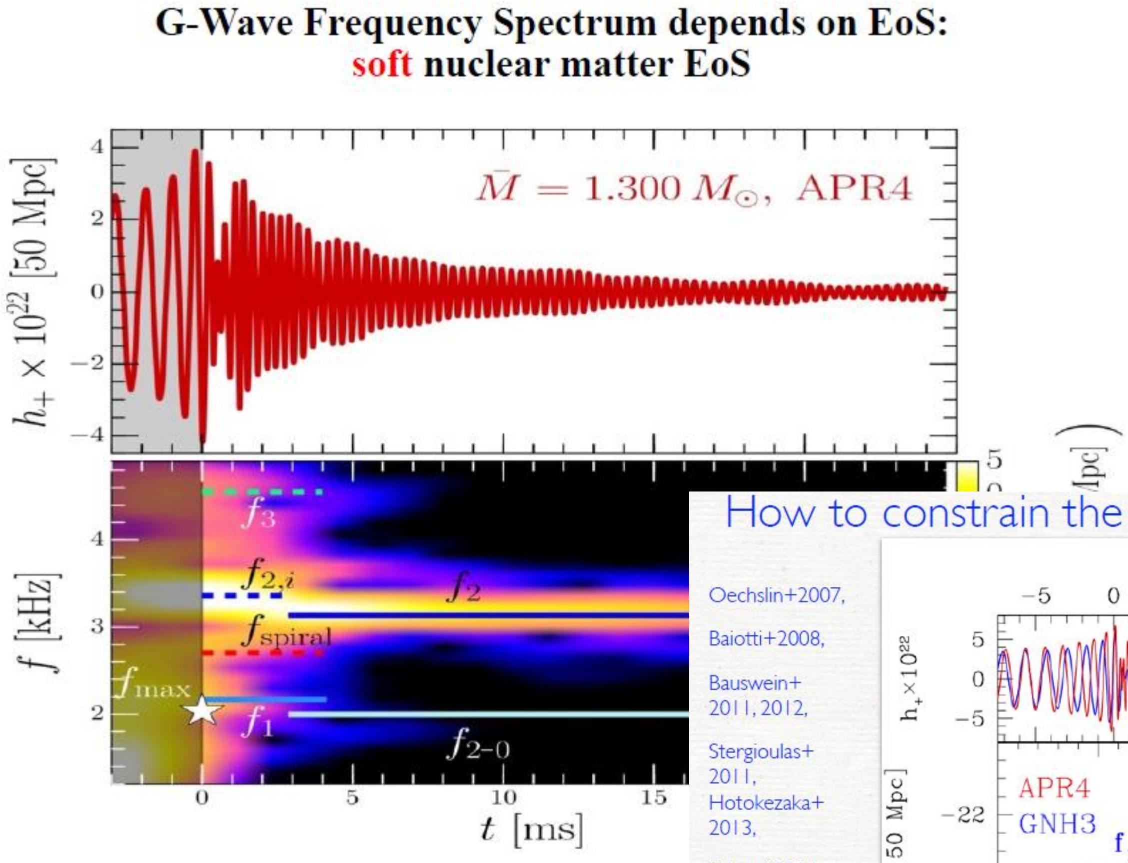
$$V_{Sk} = \alpha \cdot \left(\frac{\rho_{int}}{\rho_0}\right) + \beta \cdot \left(\frac{\rho_{int}}{\rho_0}\right)^{\gamma}$$

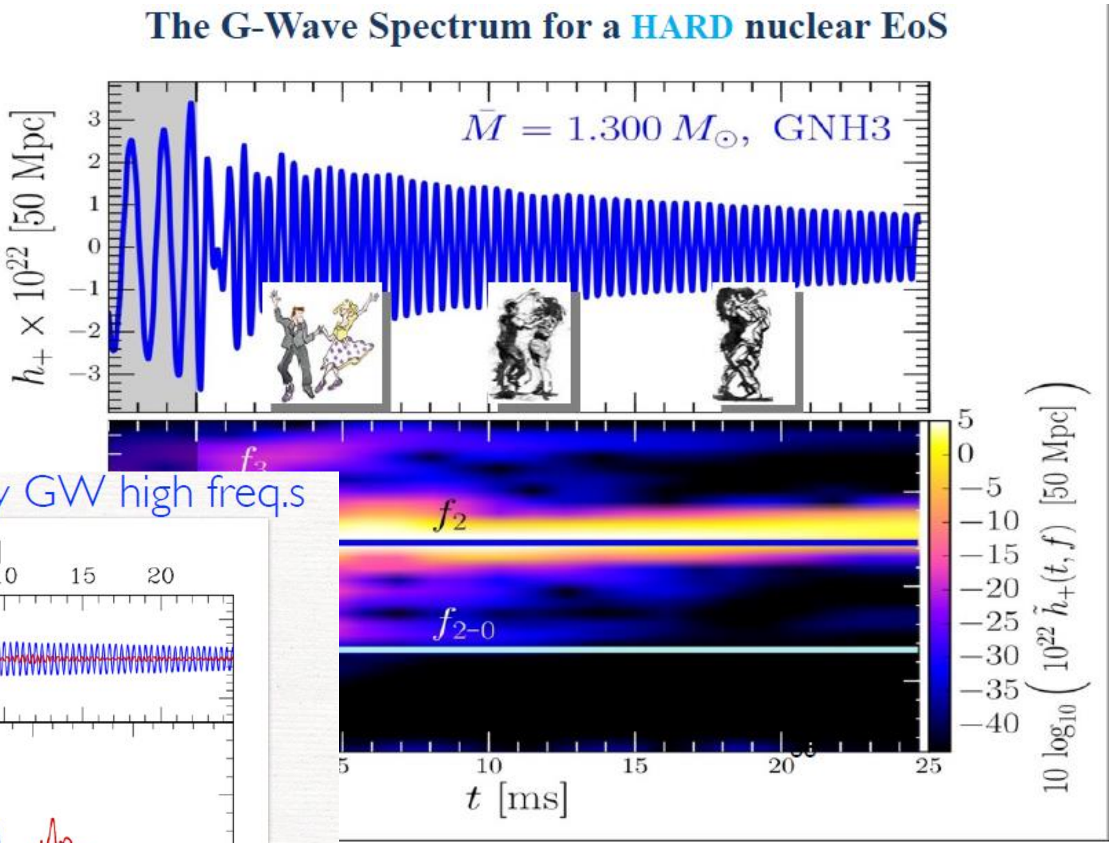
	Hard EoS	Soft EoS
α (MeV)	-124	-356
β (MeV)	71	303
γ	2	1.17

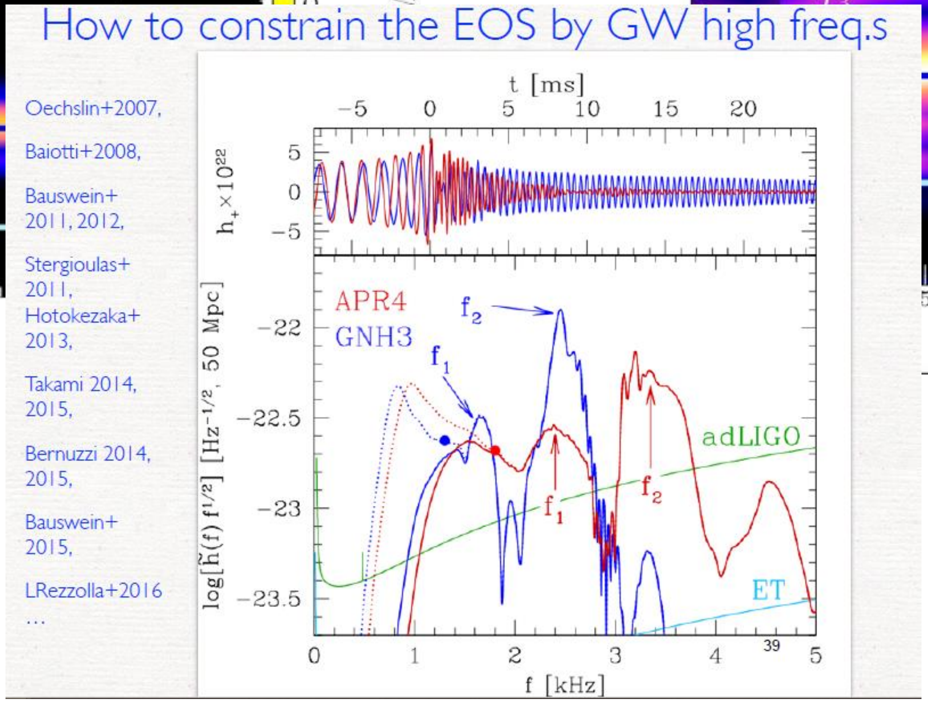
- Predicts high sensitivity of v_3 on EoS → Strong separation power

UrQMD3.4 P. Hillmann, J. Steinheimer, M. Bleicher, arXiv:1802.01951

From gravitational waves to EOS





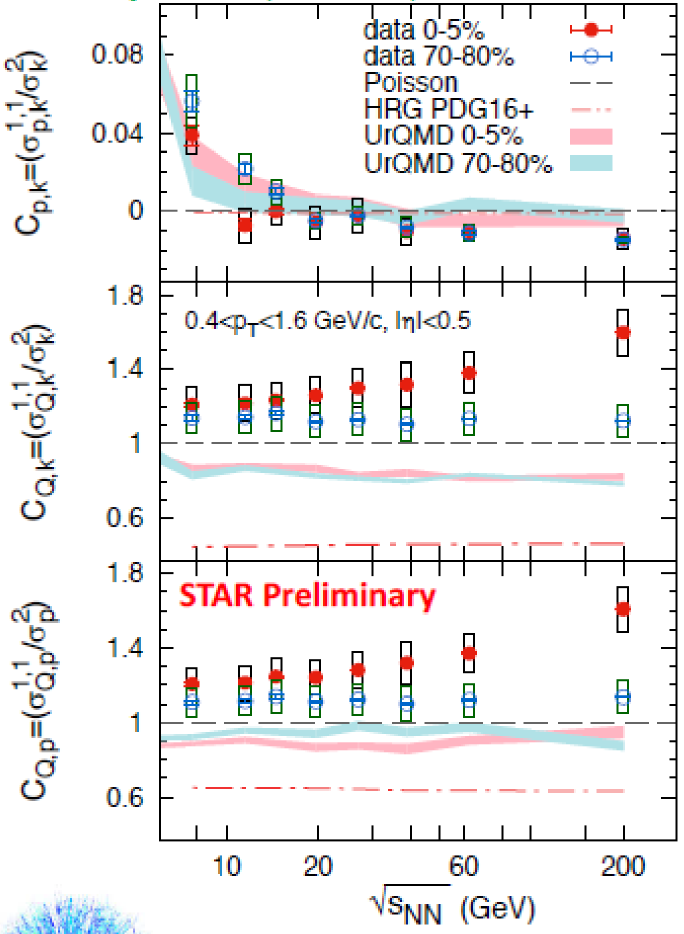


Other topics

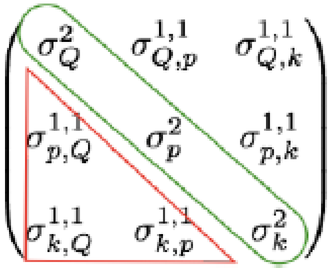
Off-diagonal cumulants

Off-diagonal cumulants of net-particle distributions

A.Chatterjee et al., (STAR coll.), QM 2018



Measurement of the off-diagonal cumulants up to the 2[nd] order between net-p, net-K, and net-Q -> additional constraints of chemical freeze-out conditions *A.Majumder et al.,, Phys. Rev. C 74 (2006) 05490*
A.Chatterjee et al., J.Phys. G43 (2016) 125103



- correlations between net-p and net-K are positive at lower energies and negative at higher
- correlations in (net-Q and net-K) and (net-Q and net-p) are above Poisson, thermal (HRG) and non-thermal (UrQMD) model calculations

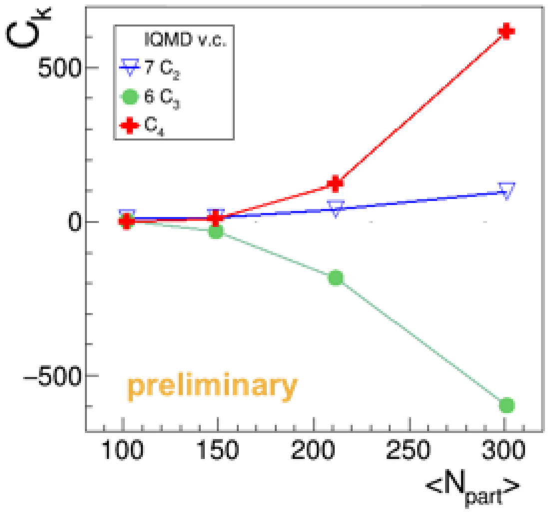
see talk by Arghya Chatterjee at this conference

STAR

Cumulants and multi-particle correlators

- The cumulants κ_k hold information on multi-particle correlators C_k Ling , Stephanov, PRC 93, 034915 (2016)
- C_k vs. N_{part} and Δy to isolate critical fluctuations Bzdak, Koch, Strodthoff, PRC 95, 054906 (2017)

HADES 2.4 GeV

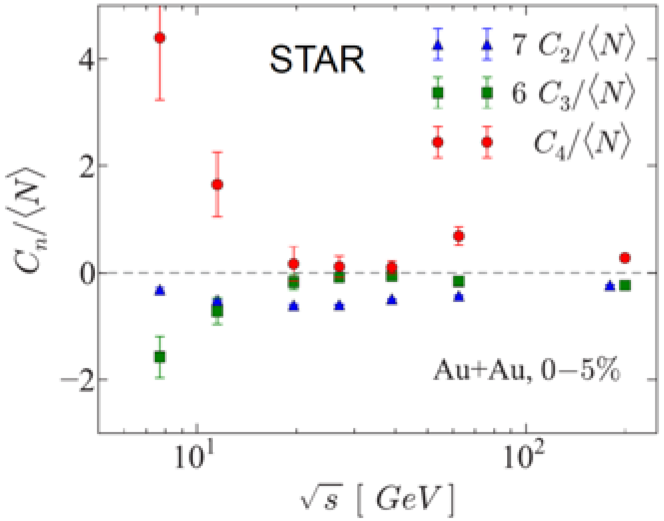


HADES 2.4 GeV

$C_4/N \simeq 36$

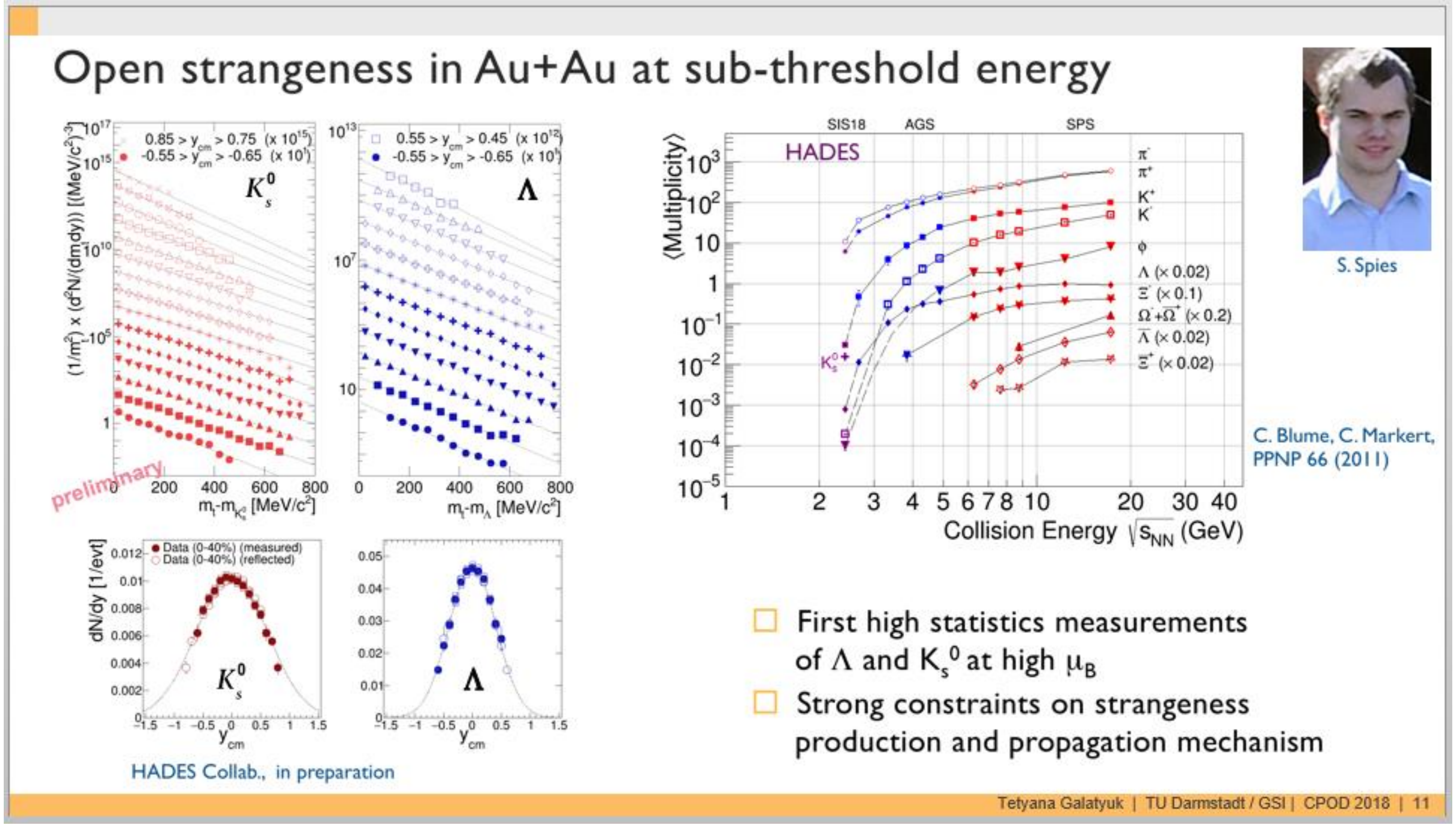
$7\, C_2/N \simeq 6$

$6\, C_3/N \simeq -35$



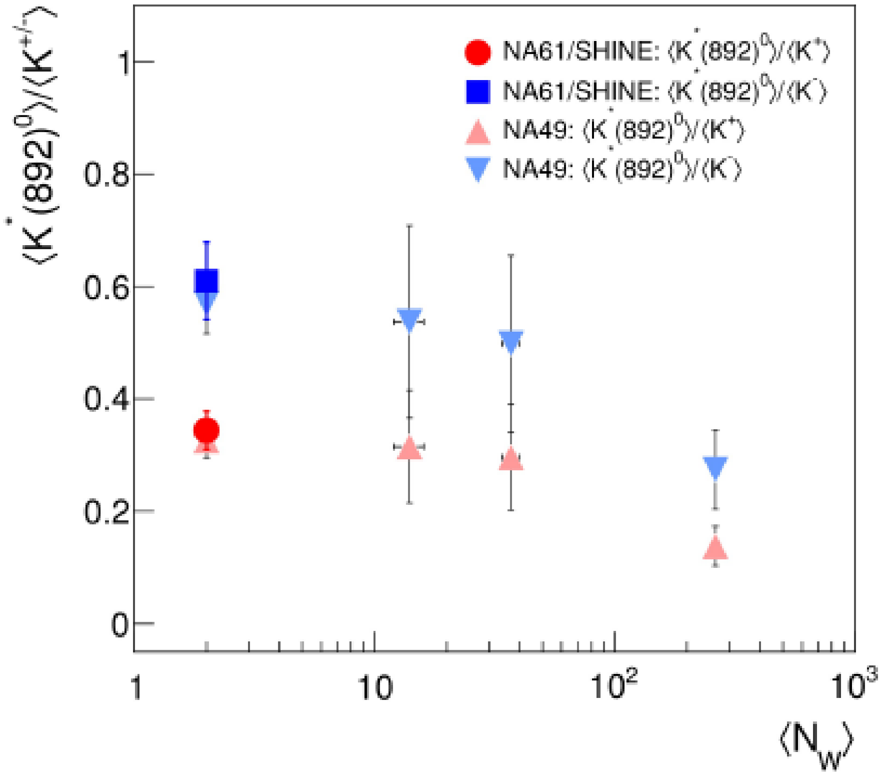
- The increase of C_n with N_{part} is even stronger at low $\sqrt{s}$?!
- Stopping of nucleons may produce multi-particle "clusters" Bzdak, Koch, Skokov, EPJC (2017) 288

Space time evolution of the particle production process



Space time evolution of the particle production process

System size dependence of $K^{*}(892)^{0}$ to charged kaon ratio at 158*A* GeV/*c*



NA61/SHINE $K^{+/-}$ (p+p): EPJC 77, 671, 2017
NA49 K^{-}: PR C84, 064909, 2011
NA49 $K^{+/-}$ (p+p): EPJC 68, 1, 2010
NA49 $K^{+/-}$ (C+C, Si+Si): PRL 94, 052301, 2005
NA49 $K^{+/-}$ (Pb+Pb): PR C66, 054902, 2002 → rescaled from 5% to 23.5% most central

Assuming:

- losses of $K^{*}(892)^{0}$ before kinetic freeze-out are due to rescattering effects
- no regeneration processes

time between chemical and kinetic freeze-outs (Δt):

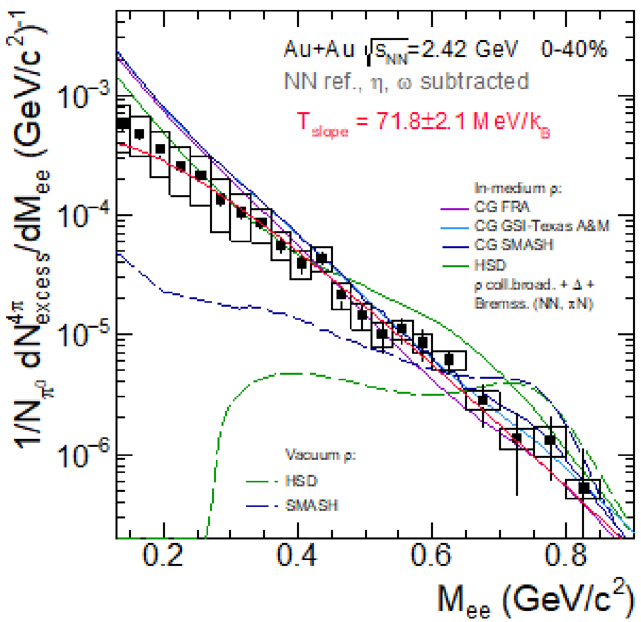
- 3.8 ± 1.1 fm/*c* for $K^{*}(892)^{0}/K^{+}$
- 3.3 ± 1.2 fm/*c* for $K^{*}(892)^{0}/K^{-}$

- **Δt at SPS > Δt at RHIC** (2 ± 1 fm/*c*, STAR, PR C71, 064902, 2005) suggesting that regeneration effects may start to play significant role for higher energies
- Regeneration may happen also at SPS → obtained **Δt is the lower limit of time between freeze-outs**

- Results from Au+Au collisions suggest a "thermalized" strongly interacting medium created at $\sqrt{s_{NN}}$=2.42 GeV:
  - Strangeness production consistent with equilibrium at SIS18
  - Thermal origin of e^+e^- excess spectrum at low energies

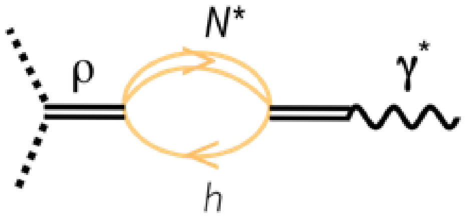
Thermal dielectrons *at $\sqrt{s_{NN}}$ = 2.42 GeV*

Excess yield fully corrected for acceptance



HADES Collab., submitted
CG FRA Endres et al.: PRC 92 (2015) 014911
CG GSI-Texas A&M TG et al.: Eur.Phys.J.A52 (2016) no.5, 131
CG SMASH: J. Staudenmaier et al., arXiv:1711.10297v1
HSD: Phys. Rev. C 87, 064907 (2013)

- Strong broadening of the in-medium ρ due to direct ρ-hadron scattering

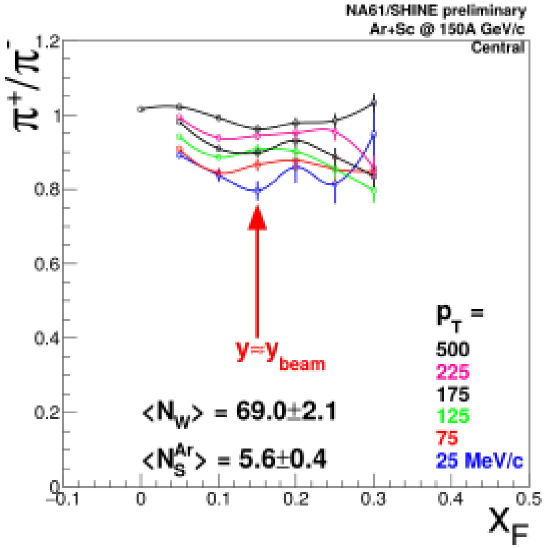


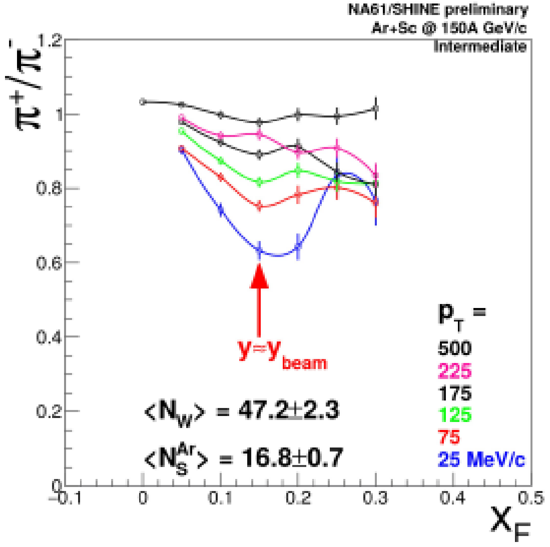
- Thermal rates folded over coarse-grained UrQMD medium evolution works at low energies
- Supports baryon-driven medium effects at SPS and RHIC (LHC)!

Space time evolution of the particle production process

π^+/π^- ratio and spectator-induced electromagnetic effects

π^+/π^- ratio in centrality selected Ar+Sc at 150*A* GeV/*c*

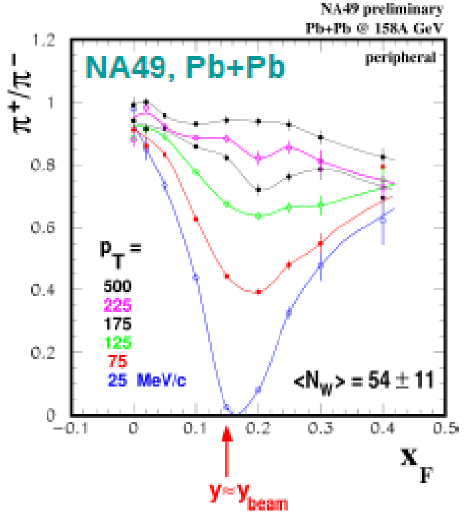




See talk by
N. Davis (Friday)
for comparison
with models

$x_F = p_L/p_L^{beam}$
(in c.m.s.)

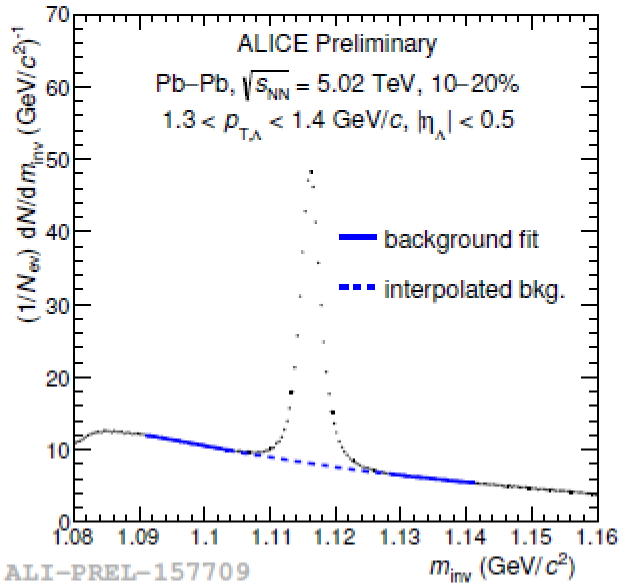
Rybicki (for NA49),
PoS EPS-HEP 2009, 031, 2009

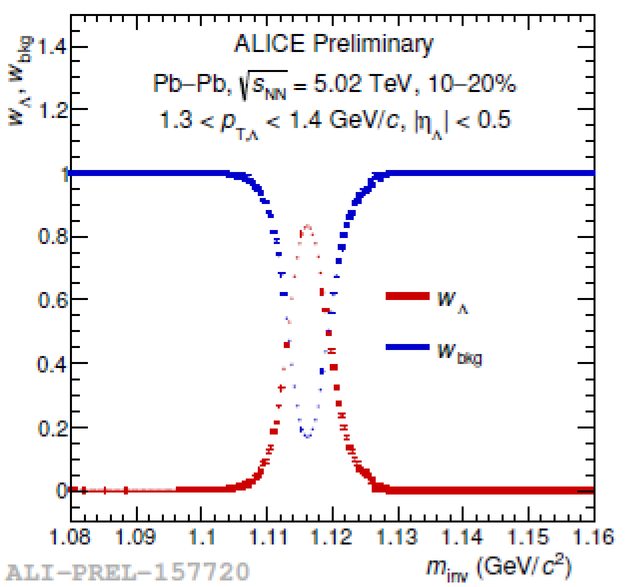


- **Repulsion of π^+** is the **strongest for pions** with rapidities **close to beam rapidity (spectators)** and with low p_T
- First observation of spectator-induced EM effects in small systems at SPS
- Similar **effect seen in intermediate centrality Ar+Sc** and (NA49) **peripheral Pb+Pb**

PID for V0

Identity Method for Λ



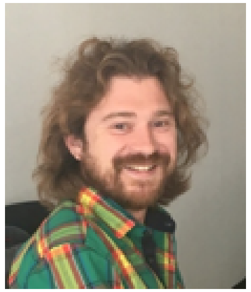


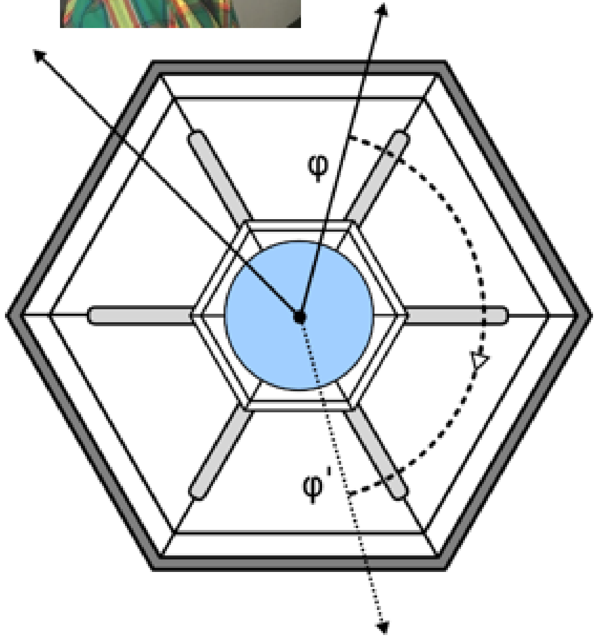
similar to the Identity method for 2 particle species (signal and background in this case)

ALICE, QM18

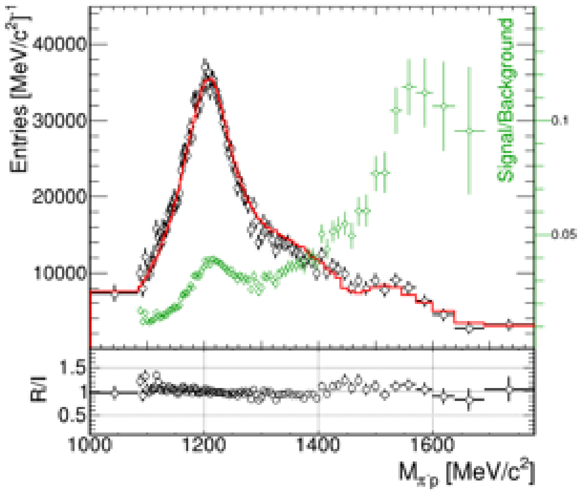
Background estimation

An iterative method for estimation of the combinatorial background





- CB is generated by random rotations of tracks around symmetry axis
- All reconstructed pair combinations are split into signal and background using an iterative procedure
- Carried out in M-p_T-y-θ space
- Kinematics of a single track contributing to the signal is accessible

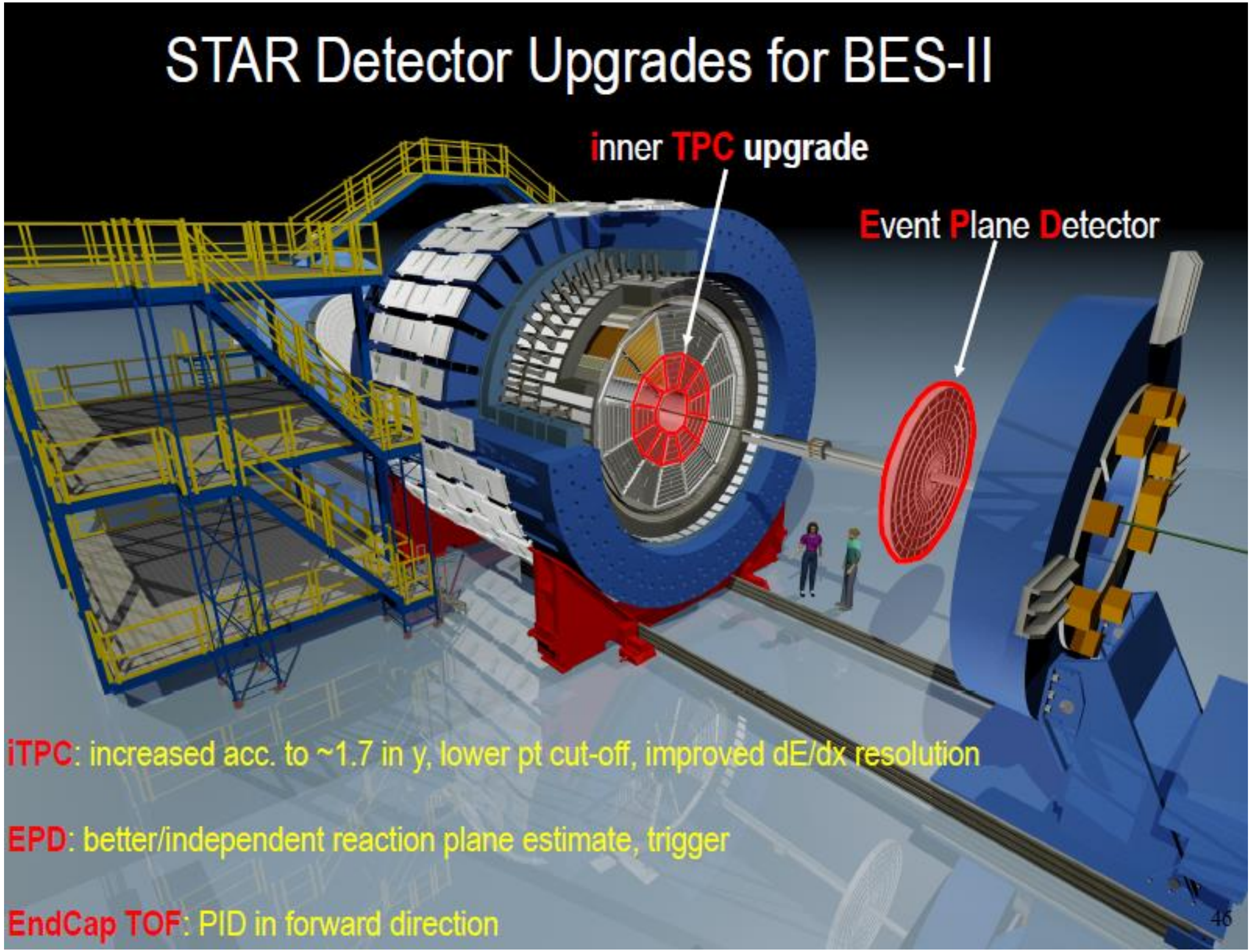


- Validation of the method:
  - with simulated data
  - with narrow states Λ, K^0_s in real data

G. Kornakov *et al.*, arXiv:1808.05466 [physics.data-an]

Hardware developments and experimental measurements plans

STAR Detector Upgrades



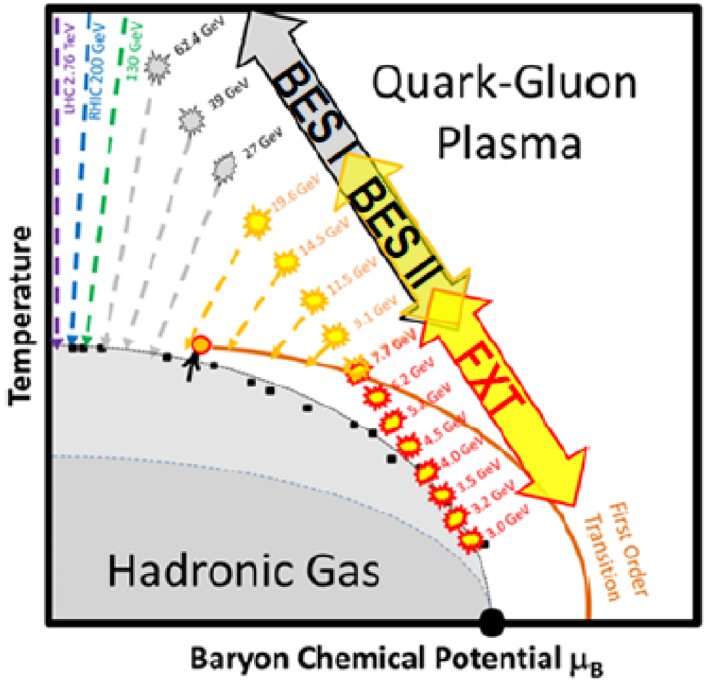
STAR Fixed Target & BES II

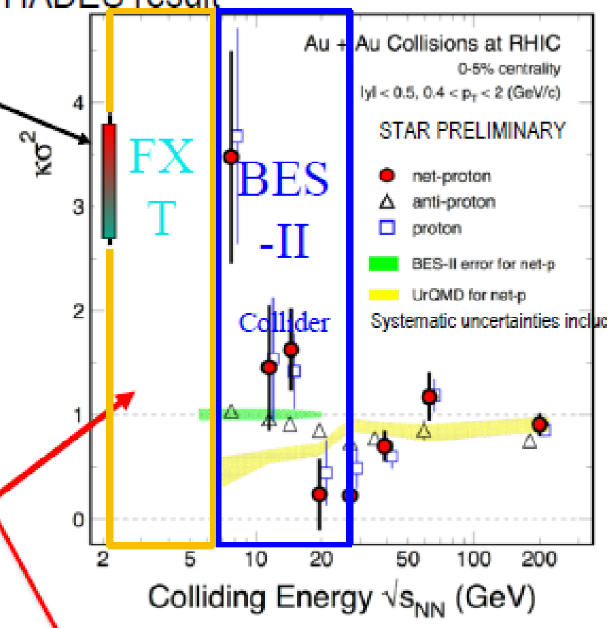
Extends energy range from √s = 7.7 down to 3 GeV (μ_B : 420 MeV → 720 MeV)

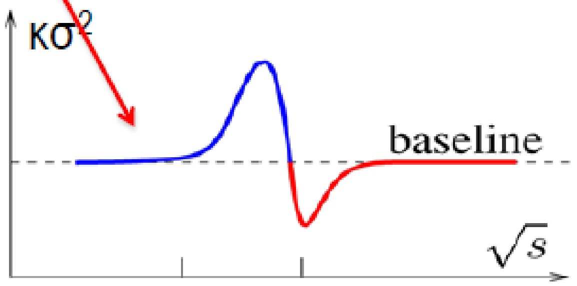
Dedicated short runs more efficient, successful test completed

Precision investigation with new techniques and the same detector

Why a Fixed-Target Program?





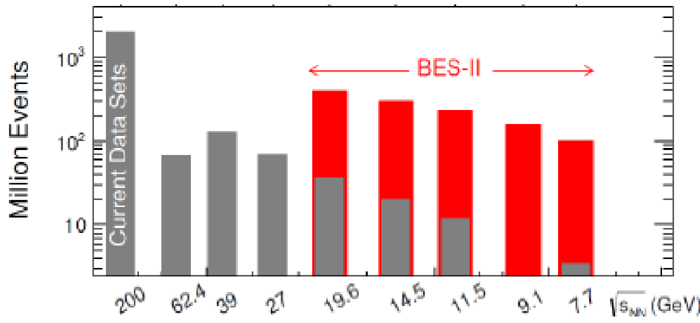


M. Stephanov. J. Physics G.: Nucl. Part. Phys. **38** (2011) 124147

- RHIC collider-mode luminosity unusable below 7.7 GeV
- FXT program extend the energy and μ_B coverage for systematic measurement of fluctuation signal:
  - kurtosis measurement is one of the future program goals

Collider Energy	Fixed-Target Energy	Single beam AGeV	Center-of-mass Rapidity	μ_B (MeV)
62.4	7.7	30.3	2.10	420
39	6.2	18.6	1.87	487
27	5.2	12.6	1.68	541
19.6	4.5	8.9	1.52	589
14.5	3.9	6.3	1.37	633
11.5	3.5	4.8	1.25	666
9.1	3.2	3.6	1.13	699
7.7	3.0	2.9	1.05	721

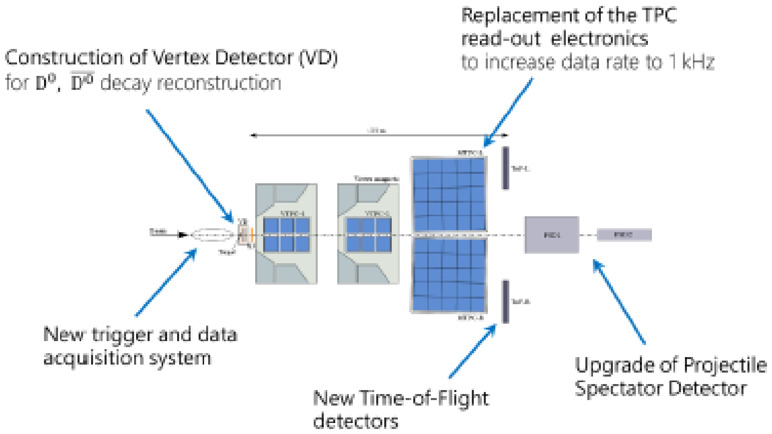
BES II Proposal

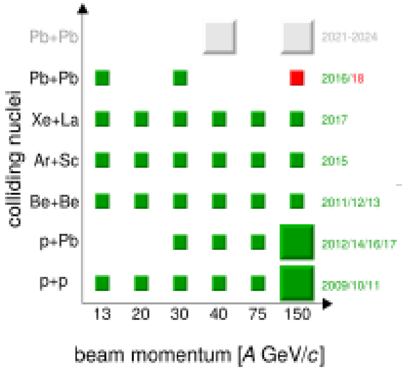


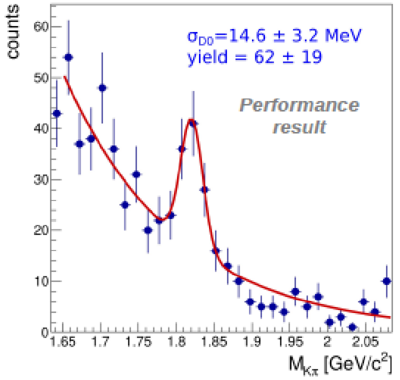
http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf

NA61/SHINE Upgrades

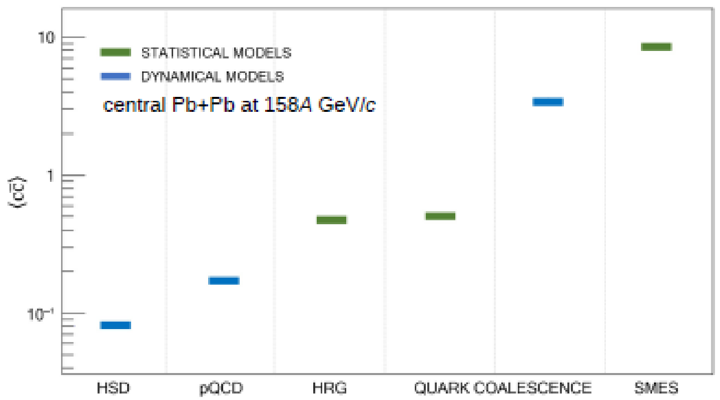
Detector upgrade foreseen during long shutdown (2019-2020)
→ motivated mainly by charm production requirements

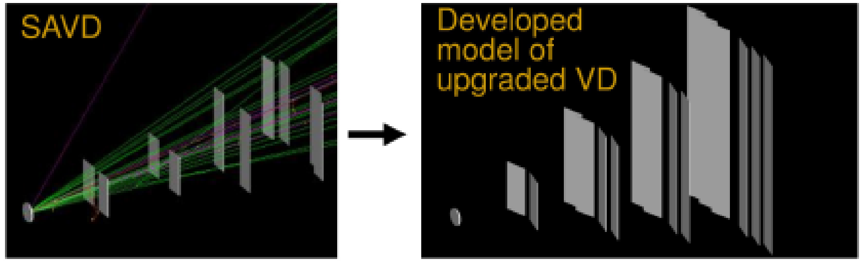






New Vertex Detector will allow for precise measurements of charm hadron production in 2021-2024



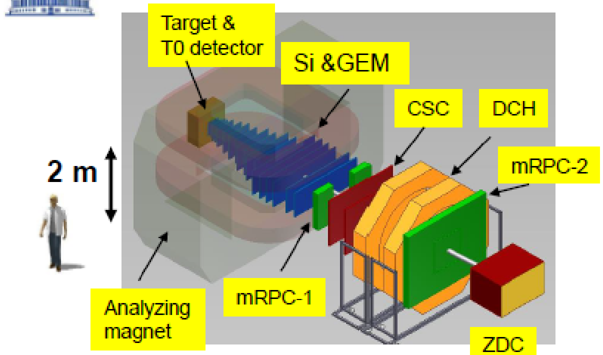


Mechanisms of charm production – validating models

- Models (implementing sequential melting + regeneration effects + initial state effects + ...) try to describe charmonium states; cross-section for charm quarks production is an important parameter, but:
- **Predictions of different models differ** by two orders of magnitude!

BM@N @ NUCLOTRON

BM@N setup



BM@N advantage: large aperture magnet (~1 m gap between poles)

→ fill aperture with coordinate detectors which sustain high multiplicities of particles

→ divide detectors for particle identification to "near to magnet" and "far from magnet" to measure particles with low as well as high momentum (p > 1-2 GeV/c)

→ fill distance between magnet and "far" detectors with coordinate detectors

- Central tracker (Si + GEM) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (CSC, DCH) behind magnet to link central tracks to ToF detectors
- ToF system based on mRPC and T0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions and form trigger
- Detectors to form T0, L1 centrality trigger and beam monitors
- Electromagnetic calorimeter for γ,e+e-

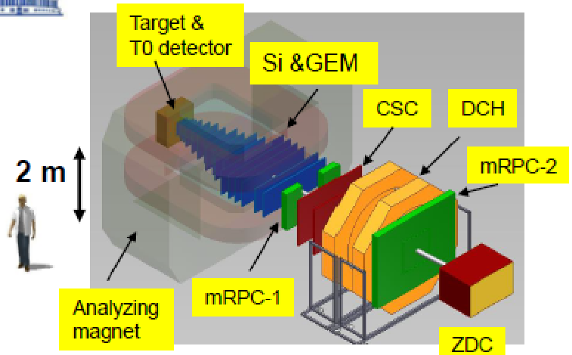
Beam parameters and setup at different stages of BM@N experiment

Year	2016	2017 spring	2018 spring	2020	2021 and later
Beam	d(↑)	C	Ar,Kr, C(SRC)	Au	Au,p
Max.intensity, Hz	0.5M	0.5M	0.5M	1M	2-5M
Trigger rate, Hz	5k	5k	10k	10k	20k→50k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 small Si planes	7 GEM full planes + small + large Si planes	7 GEM full planes + small + large Si planes
Experimental status	technical run	technical run	technical run+physics	stage1 physics	stage2 physics

BM@N @ NUCLOTRON

BM@N setup

BM@N



• Central tracker (Si + GEM) inside analyzing magnet to reconstruct AA interac

• Oute magne detect

• ToF detect nucleu

• ZDC of AA

• Dete trigger

• Elec

BM@N advantage: large aperture magnet (~1 m gap between poles)

→ fill aperture with coordinate detectors which sustain high multiplicities of particles

→ divide detectors for particle identification to “near to magnet” and “far from magnet” to measure particles with low as well as high momentum (p > 1-2 GeV/c)

→ fill distance between magnet and “far” detectors with coordinate detectors

M.Kapishin BM@N / MPD experiments

Beam parameters and setup at different stages of BM@N experiment

BM@N

Year 2016 2017 2018 2020 2021

d later

p

M

→50k

EM full

nes +

all +

ge Si

nes

ge2

sics

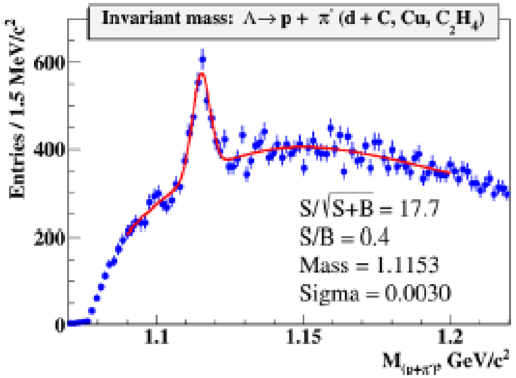
Λ in deuteron and carbon beams

BM@N

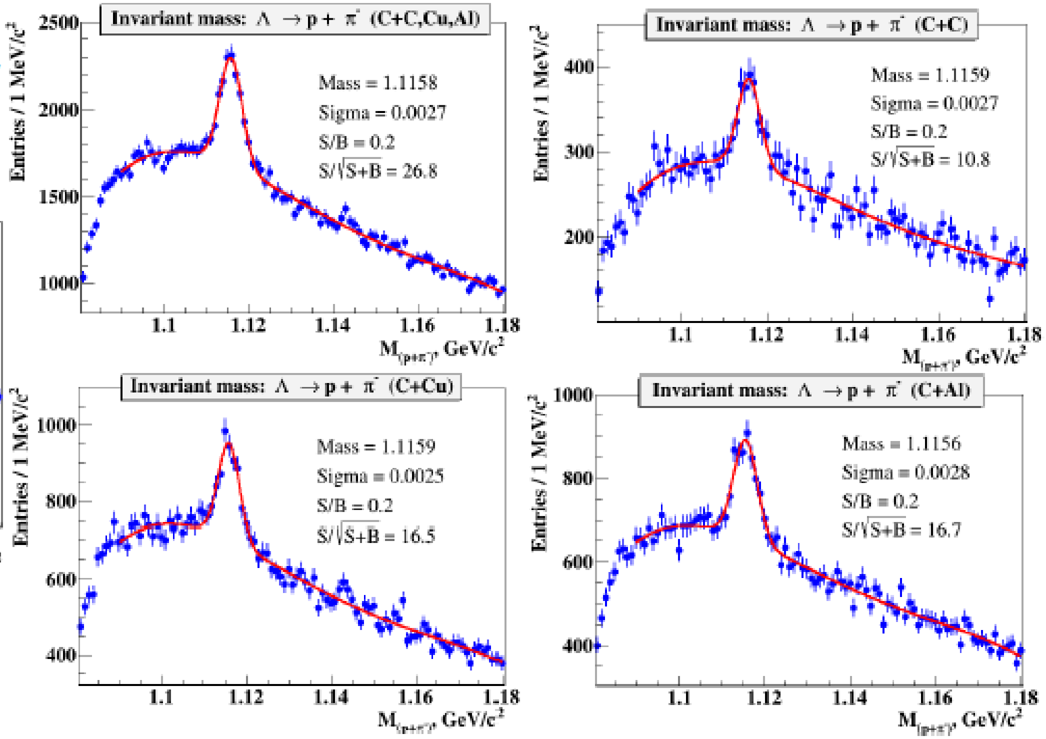
d (C) + target → X

Λ signal width ~ 2.5-3 MeV

Deuteron Data



Carbon beam run, 4 AGeV

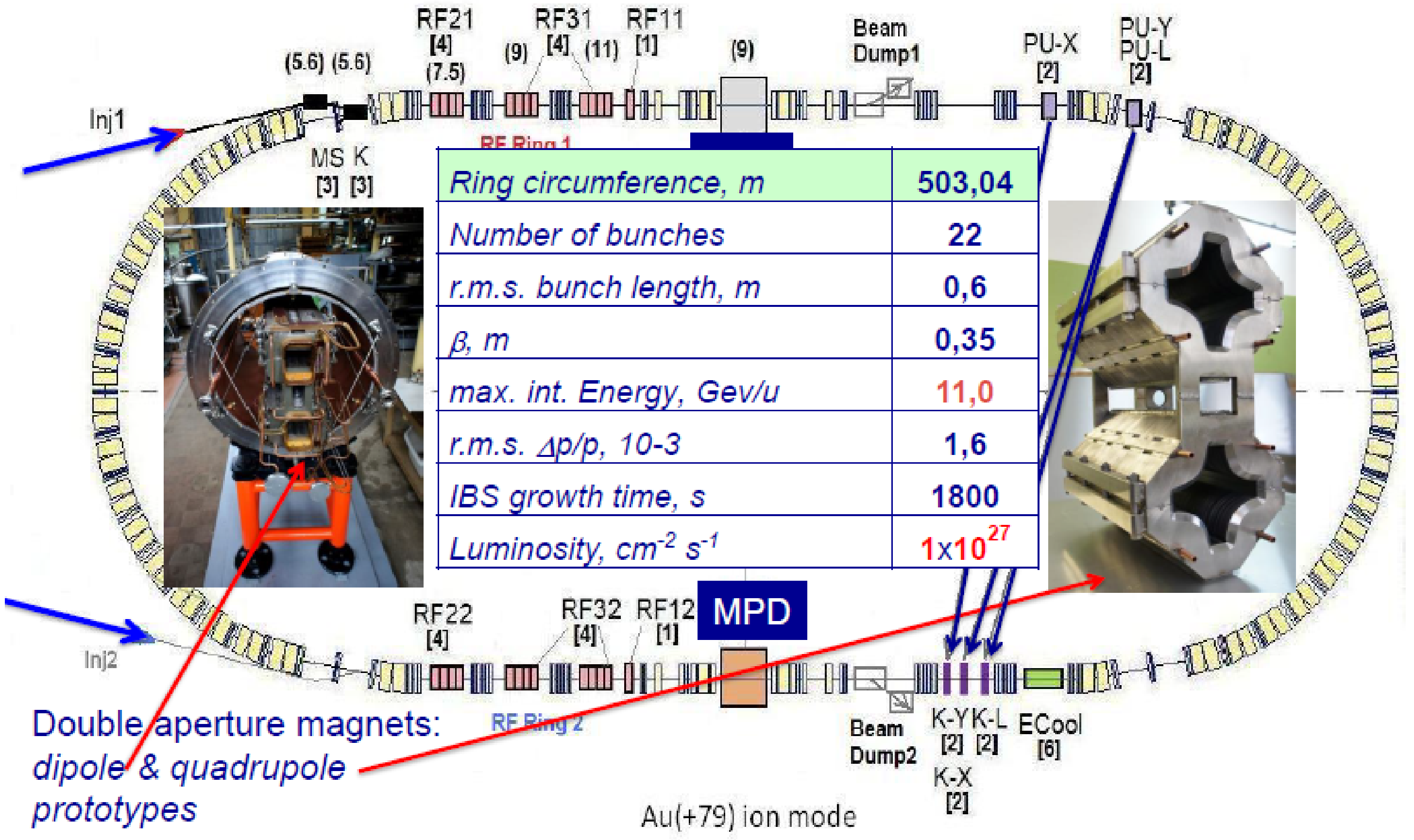


Algorithms for event reconstruction and analysis are being developed, signals of Λ hyperon decays are reconstructed

NICA

NICA Collider

45 T*m, *4.5 GeV/u for* ***Au^{79+}***



Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. Δp/p, 10-3	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**$1x10^{27}$**

Double aperture magnets:
dipole & quadrupole prototypes

NICA

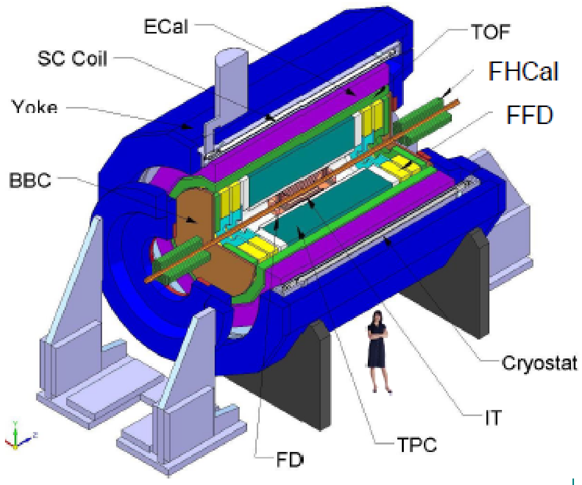
NICA complex with two experiments BM@N and MPD has a potential for competitive research *in the field of baryon rich matter*

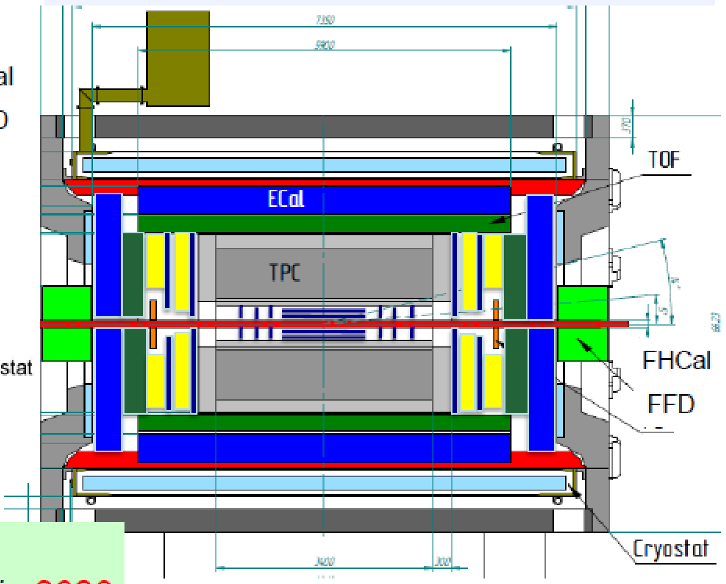
Multi-Purpose Detector (MPD)

tracking: *up to |η|<1.8* (**TPC**)
PID: *had., e, γ* (**TOF**, **TPC**, **ECAL**)
Reaction: *centrality & plane determination* (**FHCal**)

Stage 1 (2020): TPC, TOF(barrel), ECAL(barrel), FHCAL, FFD

Stage 2 (2023): ITS + EndCap (tracker, TOF, ECAL)

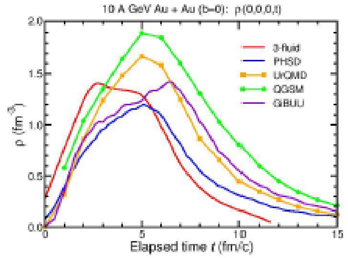


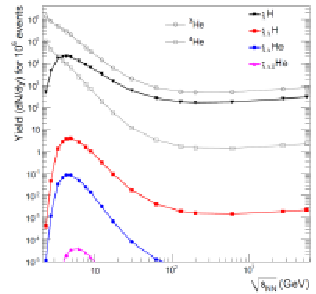


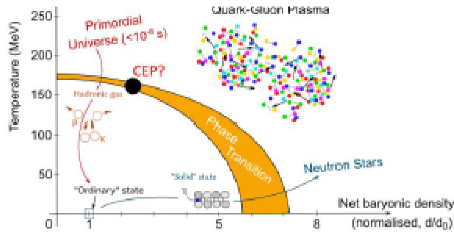
Plan: *overall commissioning starts in 2020*

QCD matter at MPD / NICA energies

- *maximum of net baryon density – **density frontier***
- *maximum of K^+/π^+ ratio*
- *maximum of Λ/π ratio*
- *maximum yield of hyper-nuclei*
- *transition from Baryon to Meson dominated system*
- *maximum of Λ polarization*
- *1-st order transition & mixed phase creation*
- *Critical Endpoint ?*

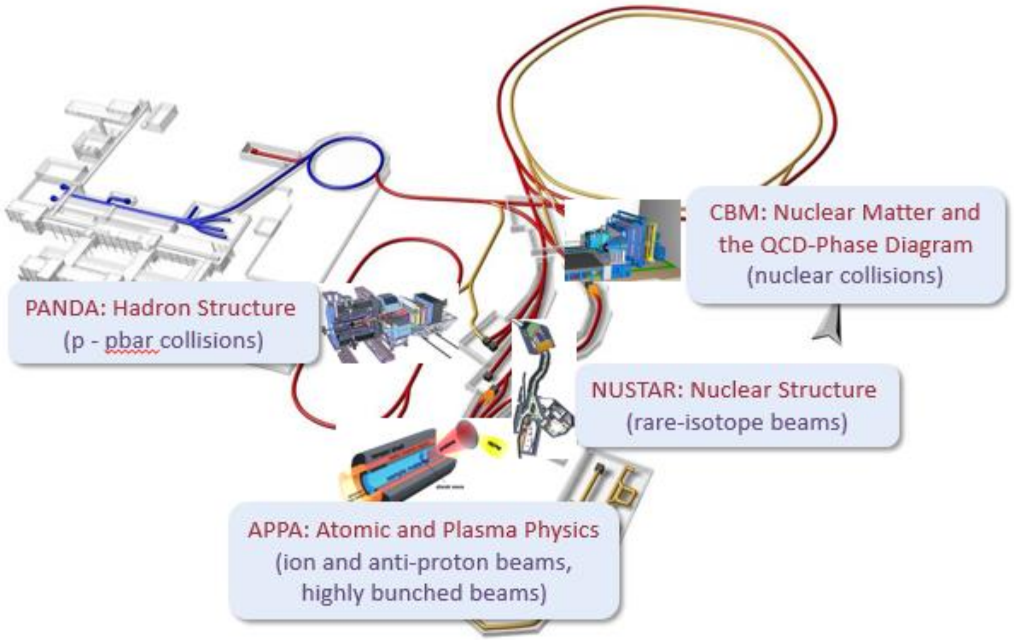




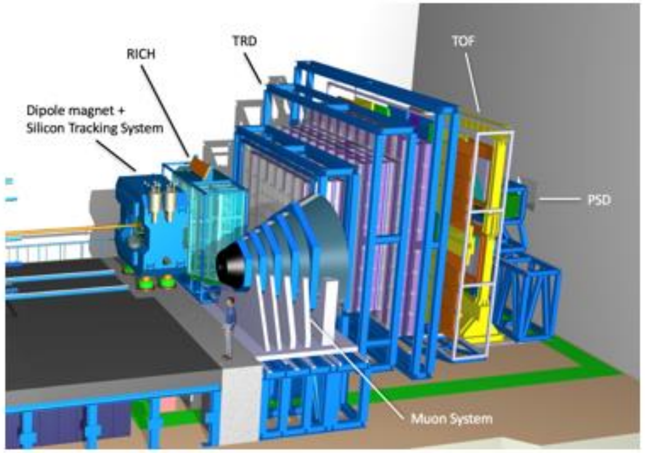


FAIR

FAIR: Research Programmes



The CBM experiment at FAIR



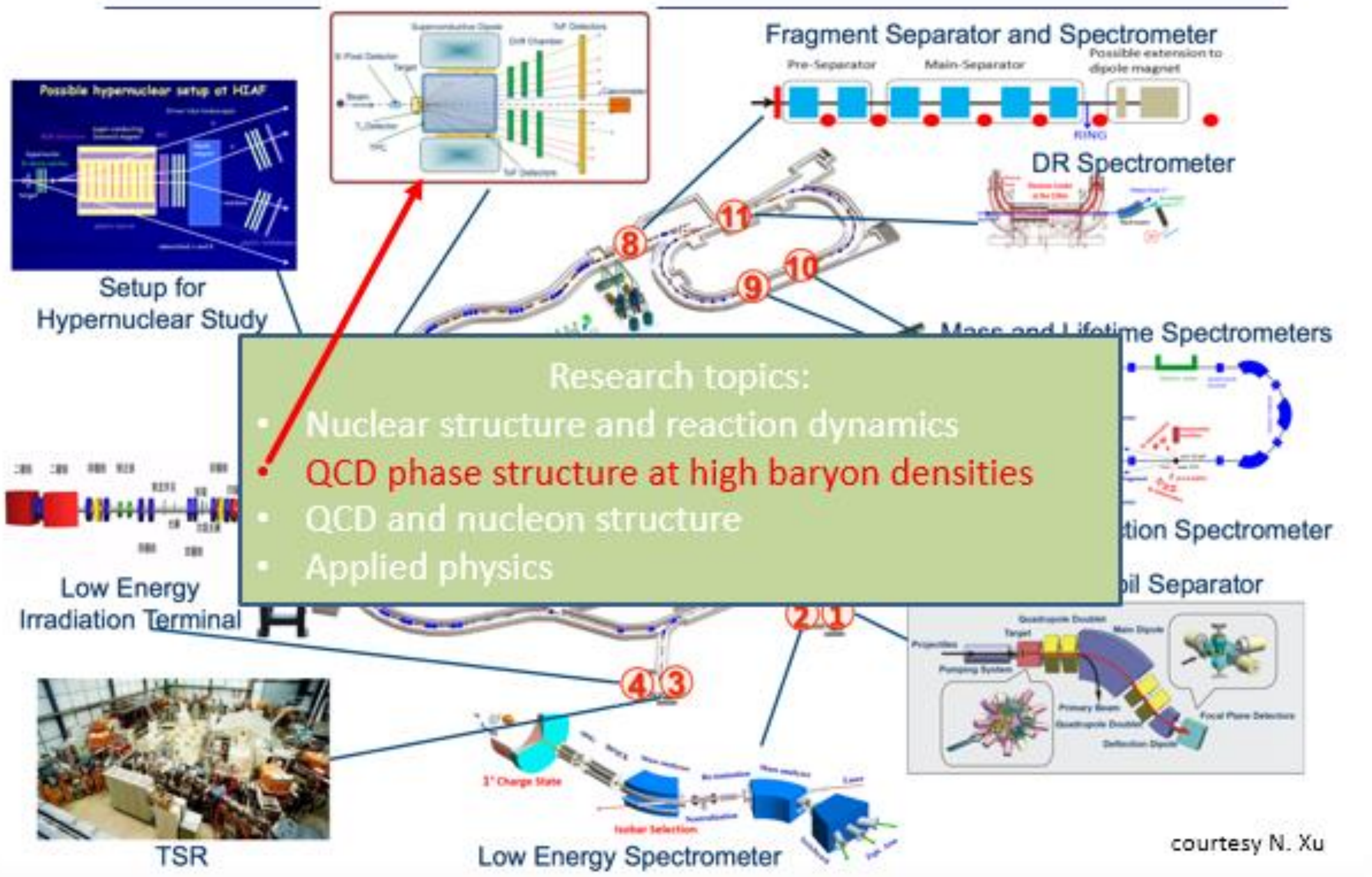
- Fixed-target spectrometer
- Hadron, electron and muon ID
- Large (central to forward) acceptance
- Tracking in dipole field
- Electron ID after tracking
- Extreme rate capability: up to 10^7 / s
- Trigger-less readout
- Event building and selection on CPU in real-time

Now under construction;
Full-system test (mCBM) February 2019

2024 commissioning with SIS-100 beam

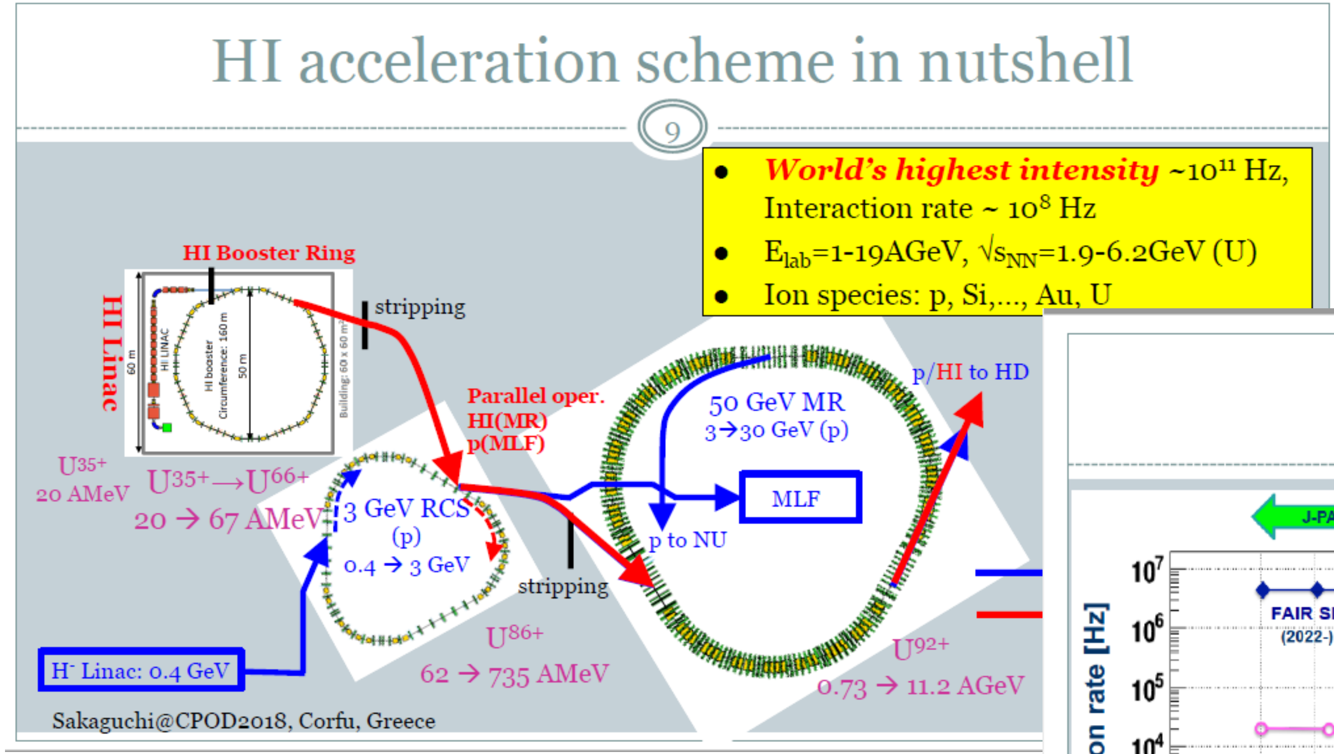
HIAF

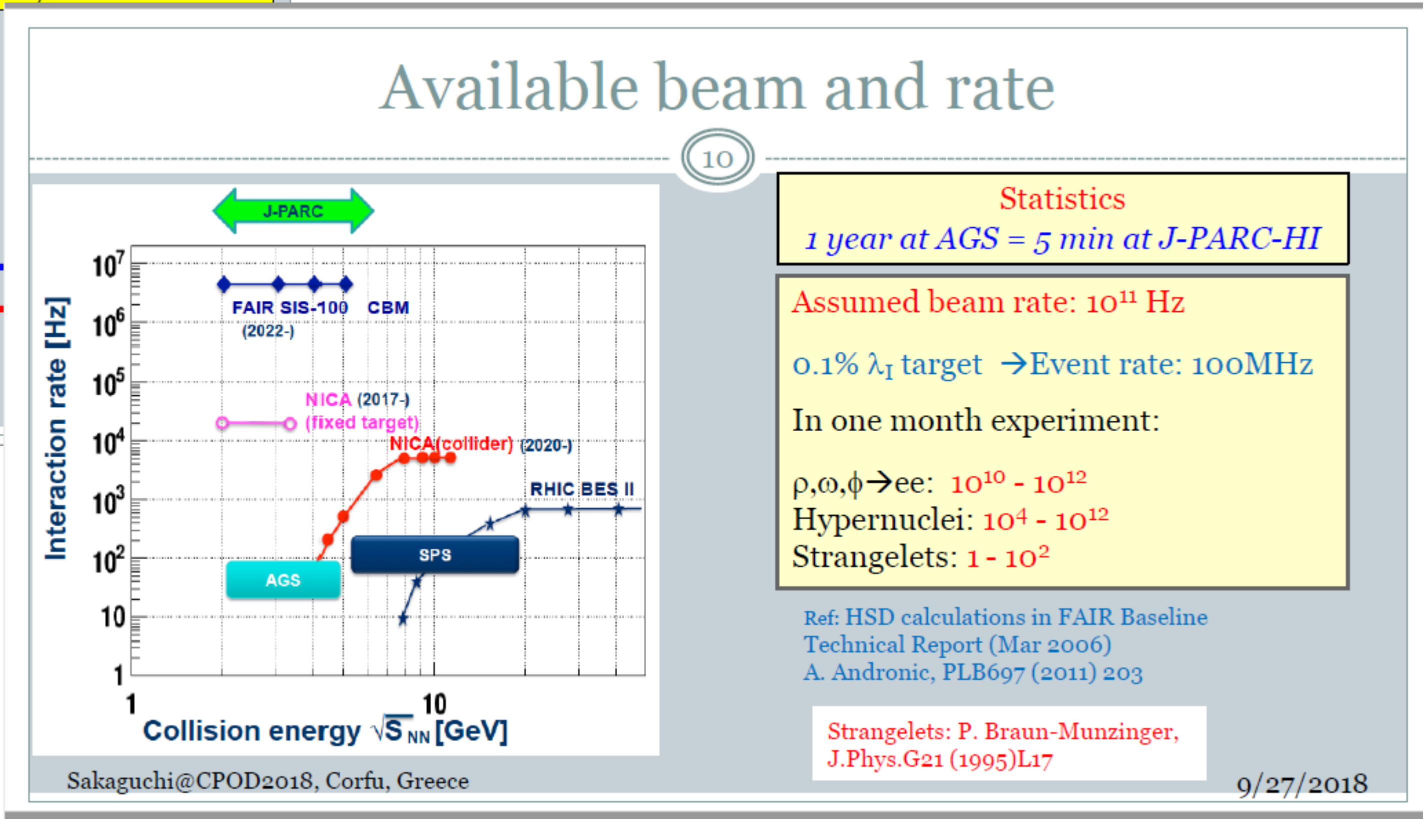
HIAF



courtesy N. Xu

J-PARC-HI


HI acceleration scheme in nutshell
9
World's highest intensity ~10¹¹ Hz,
Interaction rate ~ 10⁸ Hz
Elab=1-19AGeV, √sNN=1.9-6.2GeV (U)
Ion species: p, Si,..., Au, U
HI Booster Ring
HI Linac
stripping
Parallel oper.
HI(MR)
p(MLF)
50 GeV MR
3→30 GeV (p)
p/HI to HD
MLF
p to NU
U35+
20 AMeV
U35+→U66+
20 → 67 AMeV
3 GeV RCS
(p)
0.4 → 3 GeV
stripping
U86+
62 → 735 AMeV
U92+
0.73 → 11.2 AGeV
H- Linac: 0.4 GeV
Sakaguchi@CPOD2018, Corfu, Greece


Available beam and rate
10
J-PARC
FAIR SIS-100 CBM
(2022-)
NICA (2017-)
(fixed target)
NICA(collider) (2020-)
RHIC BES II
AGS
SPS
Interaction rate [Hz]
Collision energy √S NN [GeV]
Statistics
1 year at AGS = 5 min at J-PARC-HI
Assumed beam rate: 10¹¹ Hz
0.1% λI target →Event rate: 100MHz
In one month experiment:
ρ,ω,ϕ→ee: 10¹⁰ - 10¹²
Hypernuclei: 10⁴ - 10¹²
Strangelets: 1 - 10²
Ref: HSD calculations in FAIR Baseline
Technical Report (Mar 2006)
A. Andronic, PLB697 (2011) 203
Strangelets: P. Braun-Munzinger,
J.Phys.G21 (1995)L17
Sakaguchi@CPOD2018, Corfu, Greece
9/27/2018

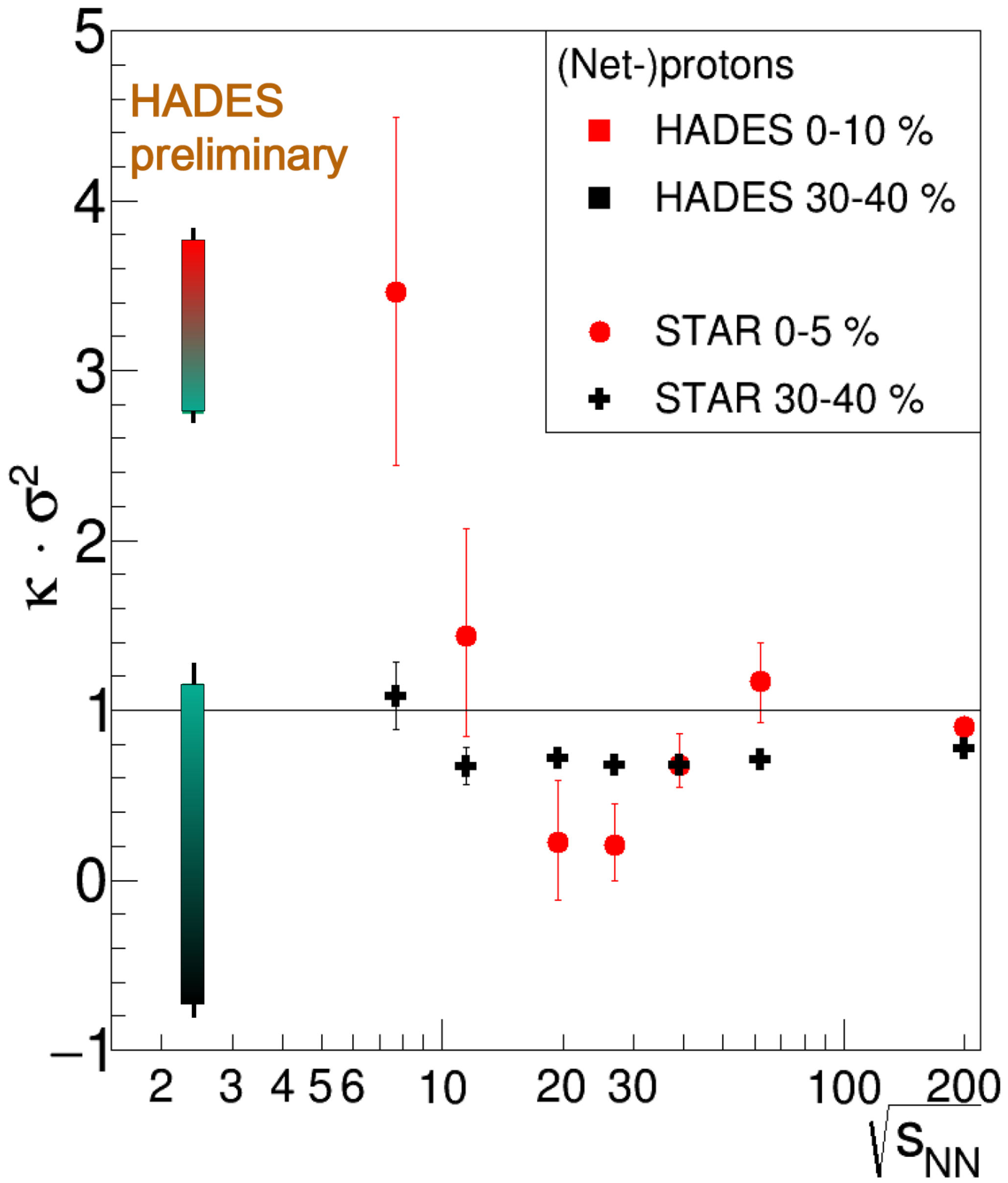
Summary

- System size and energy scans
- Onset of the deconfiment - observation of the changes in many observables
- Onset of the fireball
- Search for critical point
- New techniques for EOS constrain
- New facilities running at the end of the first quarter of the twenty-first century
- Look for better quality data

Thank you

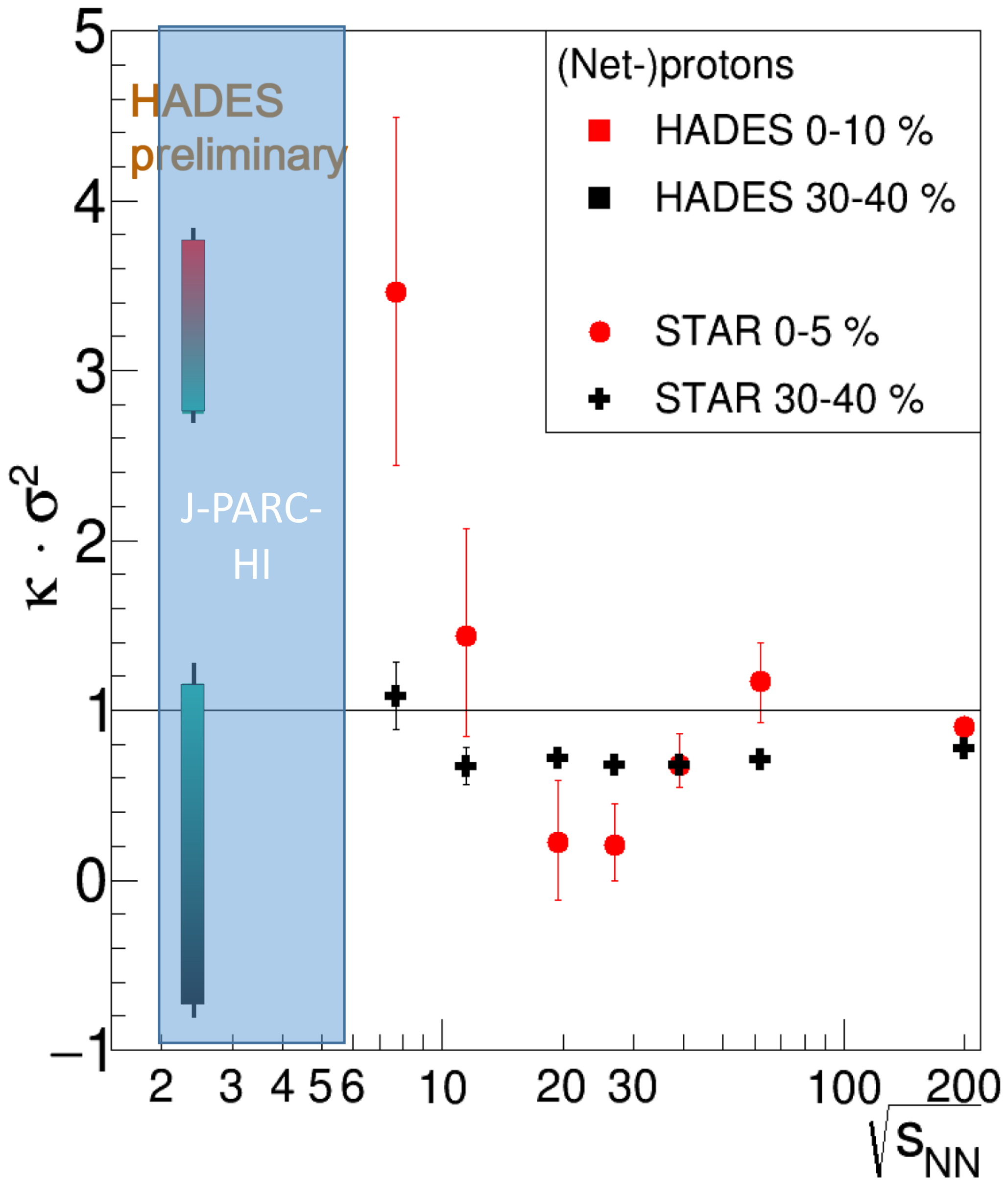
Fluctuation

HADES
STAR



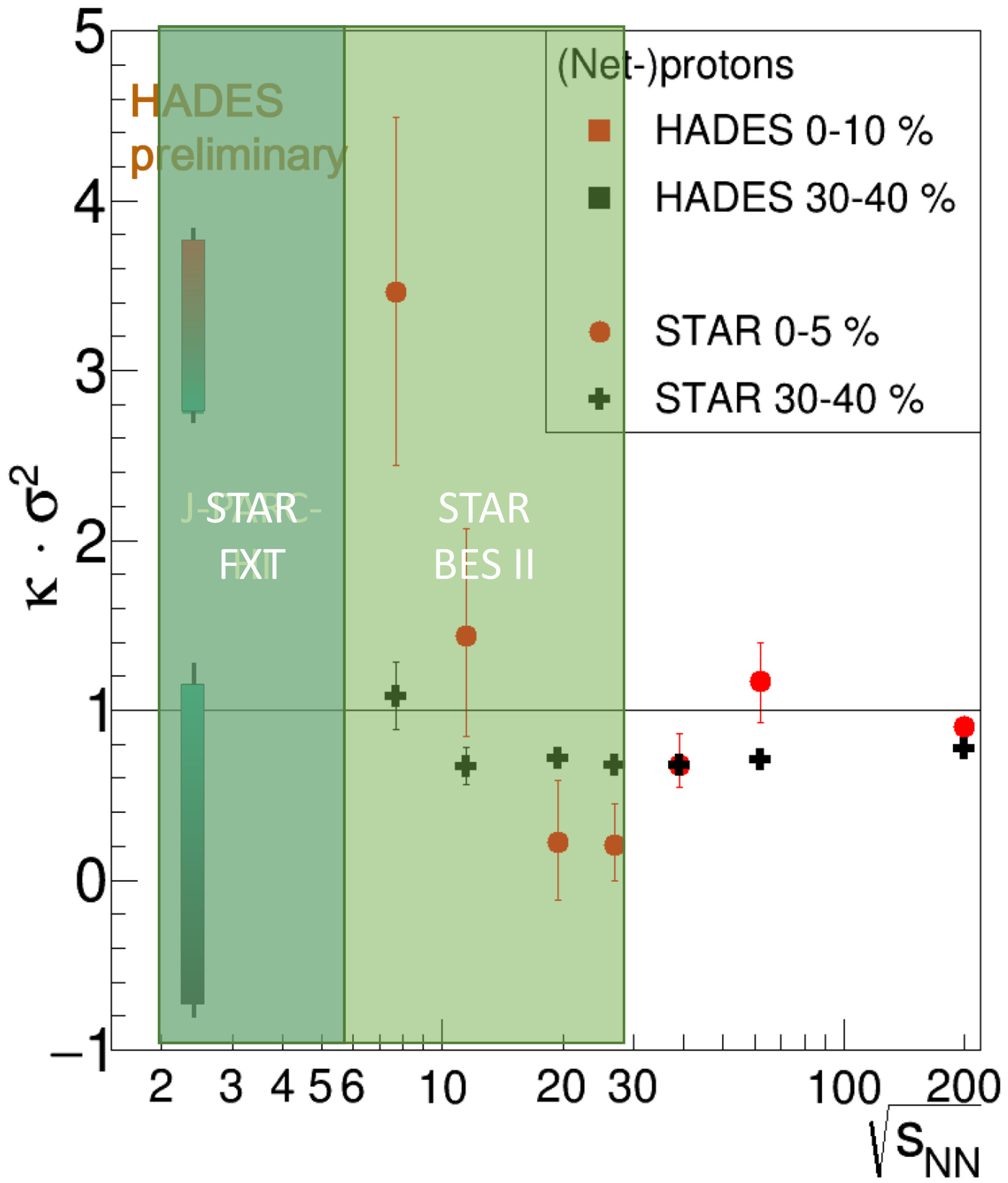
Fluctuation

HADES
STAR
J-PARC-HI



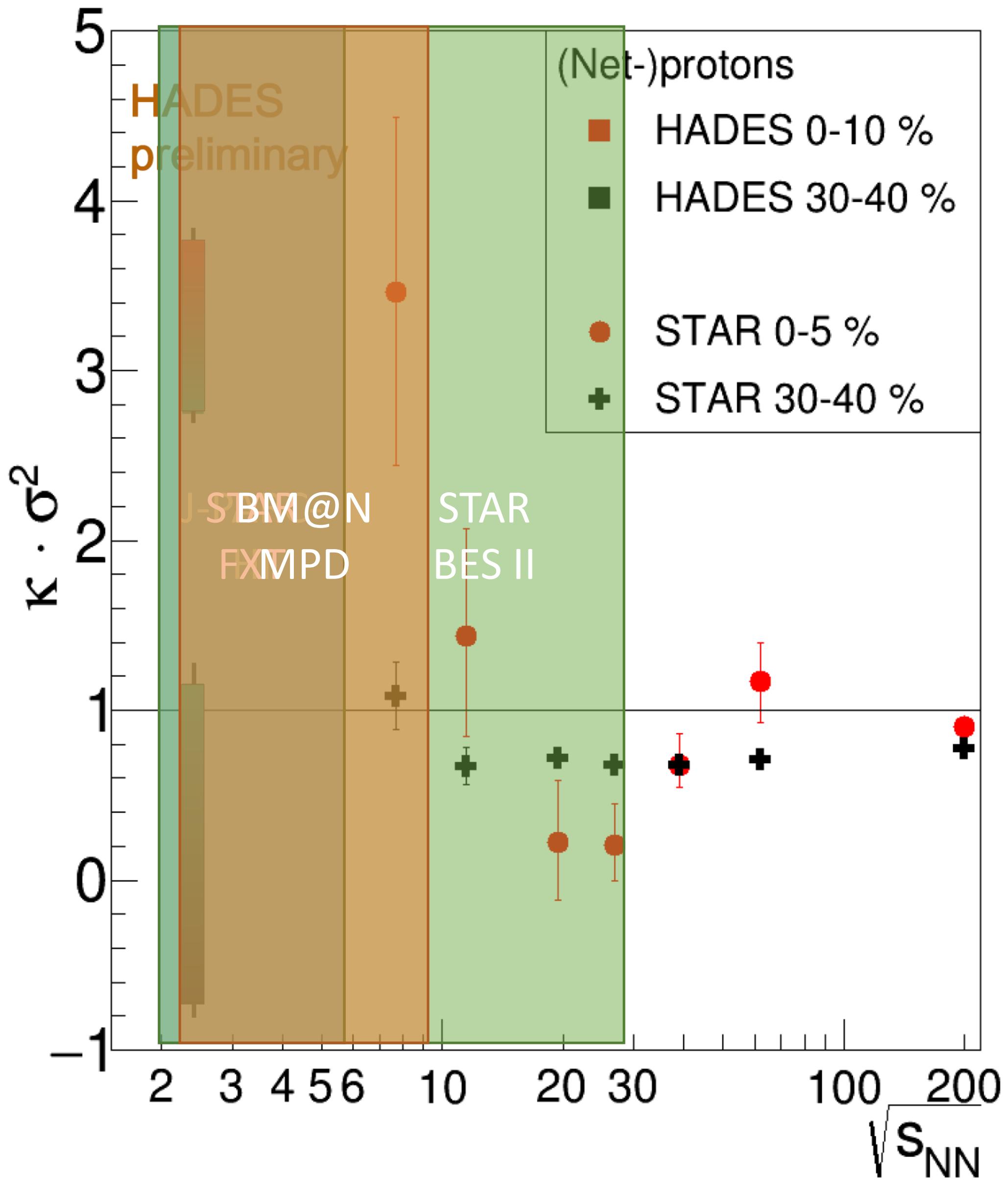
Fluctuation

HADES
STAR
J-PARC-HI
STAR FXT
STAR BES II



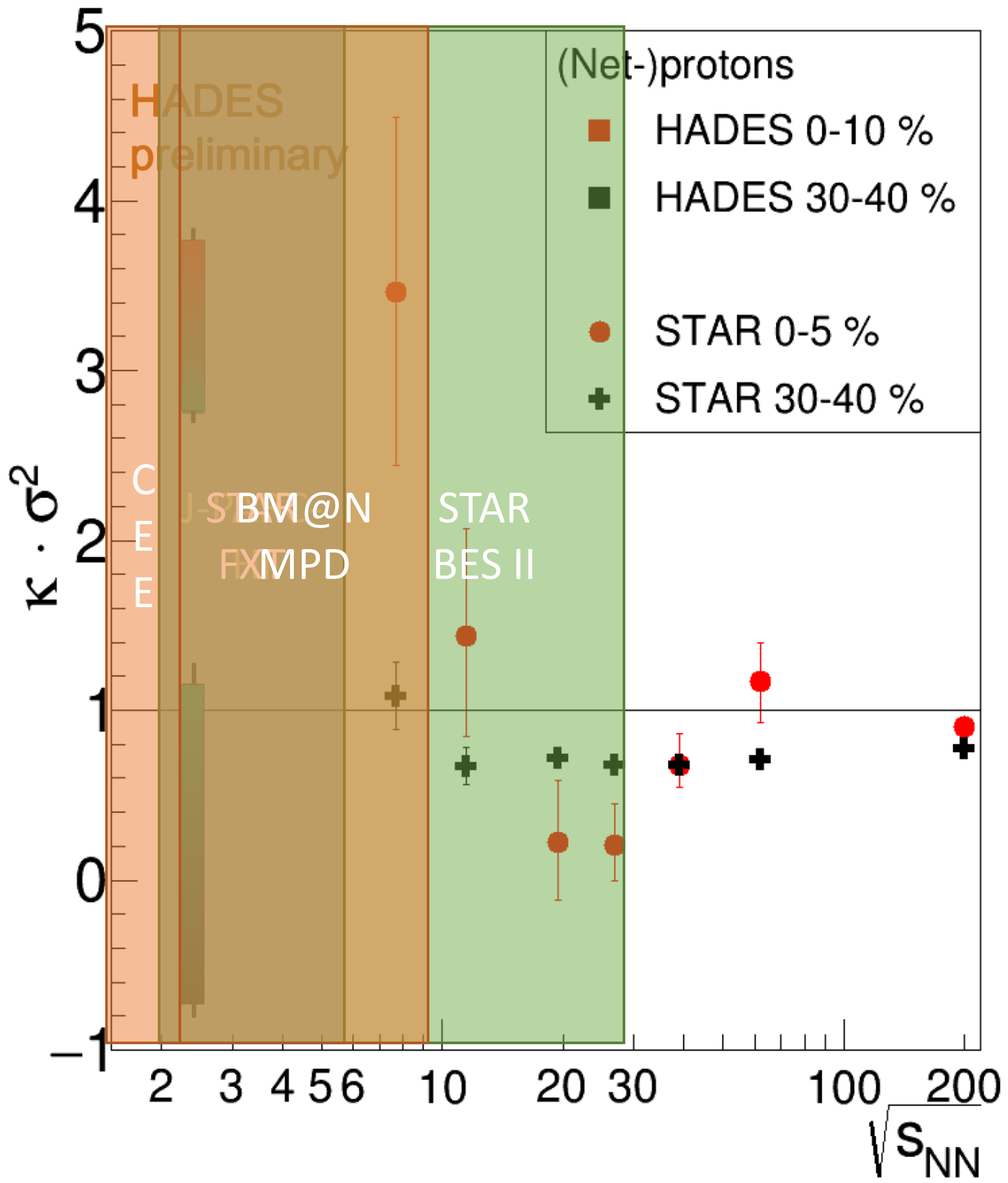
Fluctuation

HADES
STAR
J-PARC-HI
STAR FXT
STAR BES II
BM@N
MPD



Fluctuation

HADES
STAR
J-PARC-HI
STAR FXT
STAR BES II
BM@N
MPD
CEE



Fluctuation

HADES
STAR
J-PARC-HI
STAR FXT
STAR BES II
BM@N
MPD
CEE
CBM