Beam Energy Scan Program at RHIC (BES I & BES II)

Probing QCD Phase Diagram with Heavy-Ion Collisions

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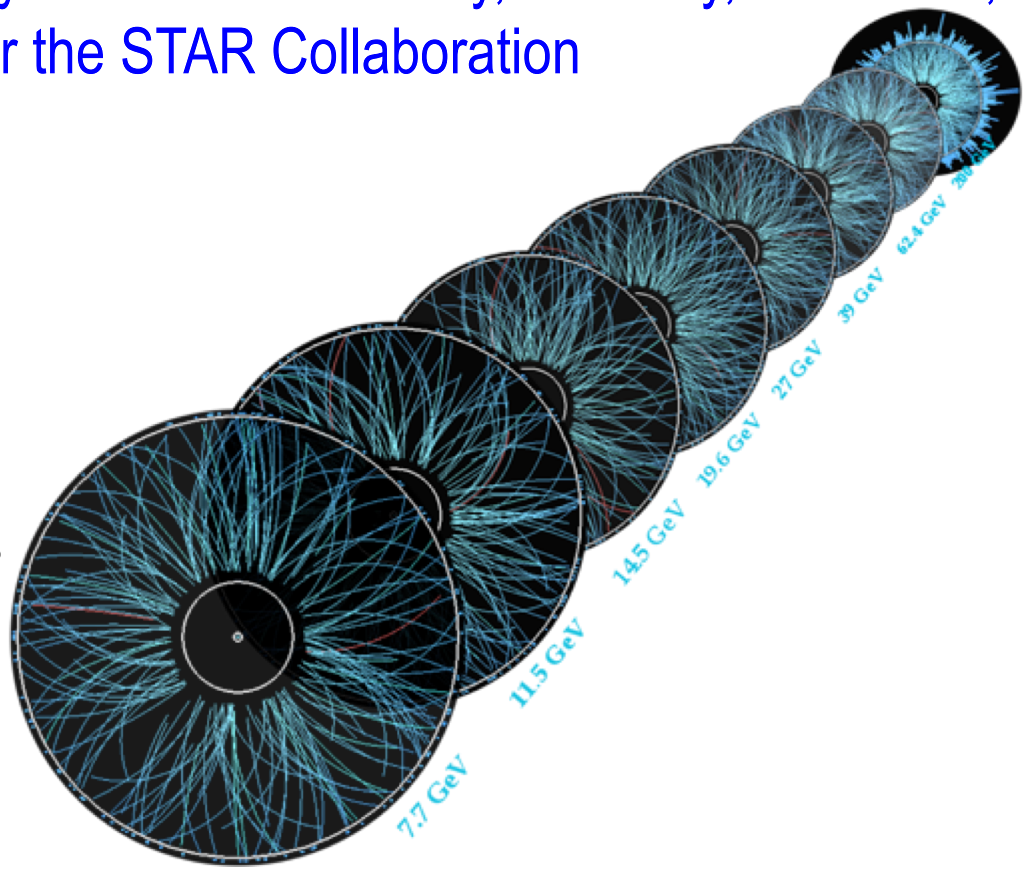
for the STAR Collaboration

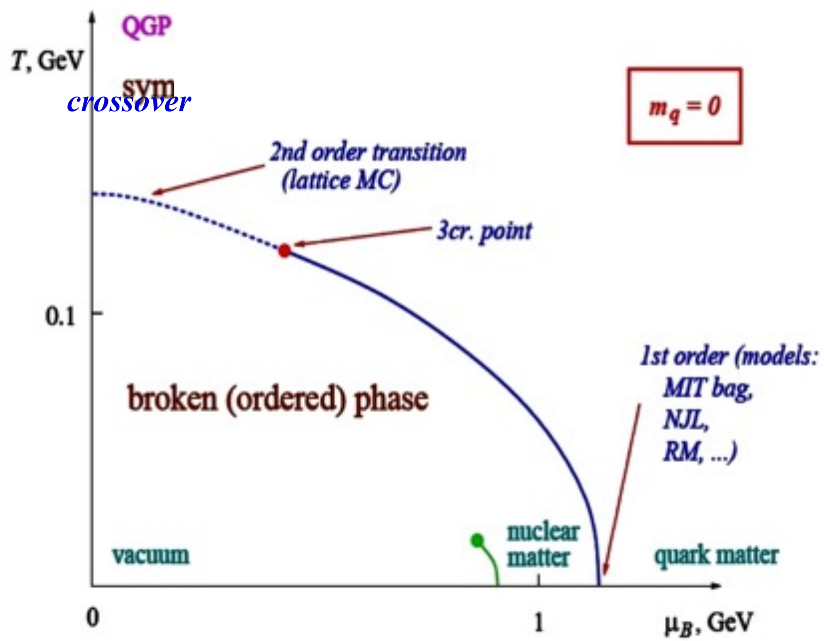
Outline:

- Introduction and motivations
- BES-I - selected results
    - what have we learned ?
- BES-II (starting now !)



QCD phase diagram - Theory

M.Stephanov, hep-ph/0402115v1 (March 2006)



Theory at the “edges” is believed to be well understood:

1. Lattice QCD finds a smooth crossover at large T and μ_B~0
2. Various models find a strong 1-st order transition at large μ_B

So, there must be a critical point, <u>but where?</u>

<u>Strategy</u>: by changing energy map the phase diagram (μ_B ,T)

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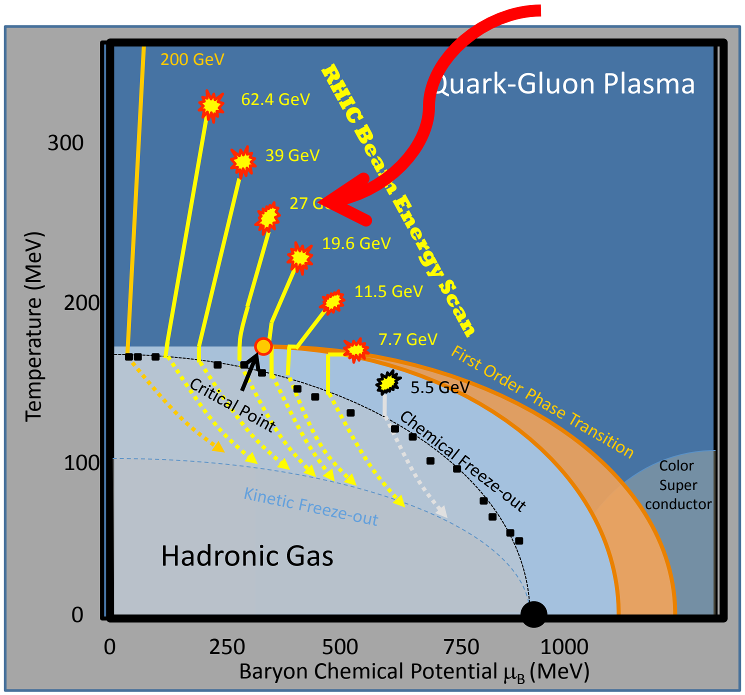
Beam Energy Scan (BES I) at RHIC: $\sqrt{s_{NN}}$ ~ 7.7- 50 GeV

(+ 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

$\sqrt{s_{NN}}$ (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



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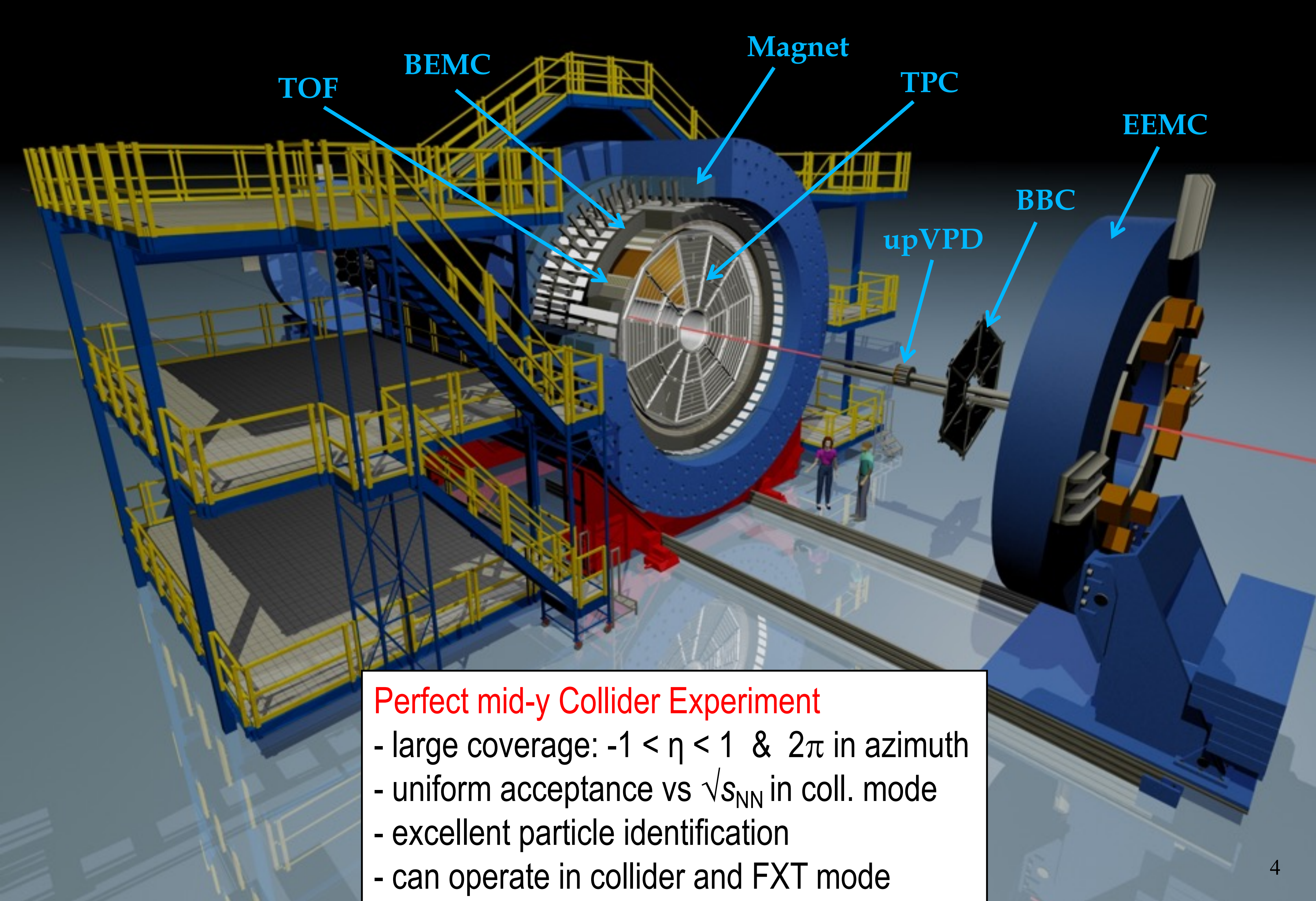
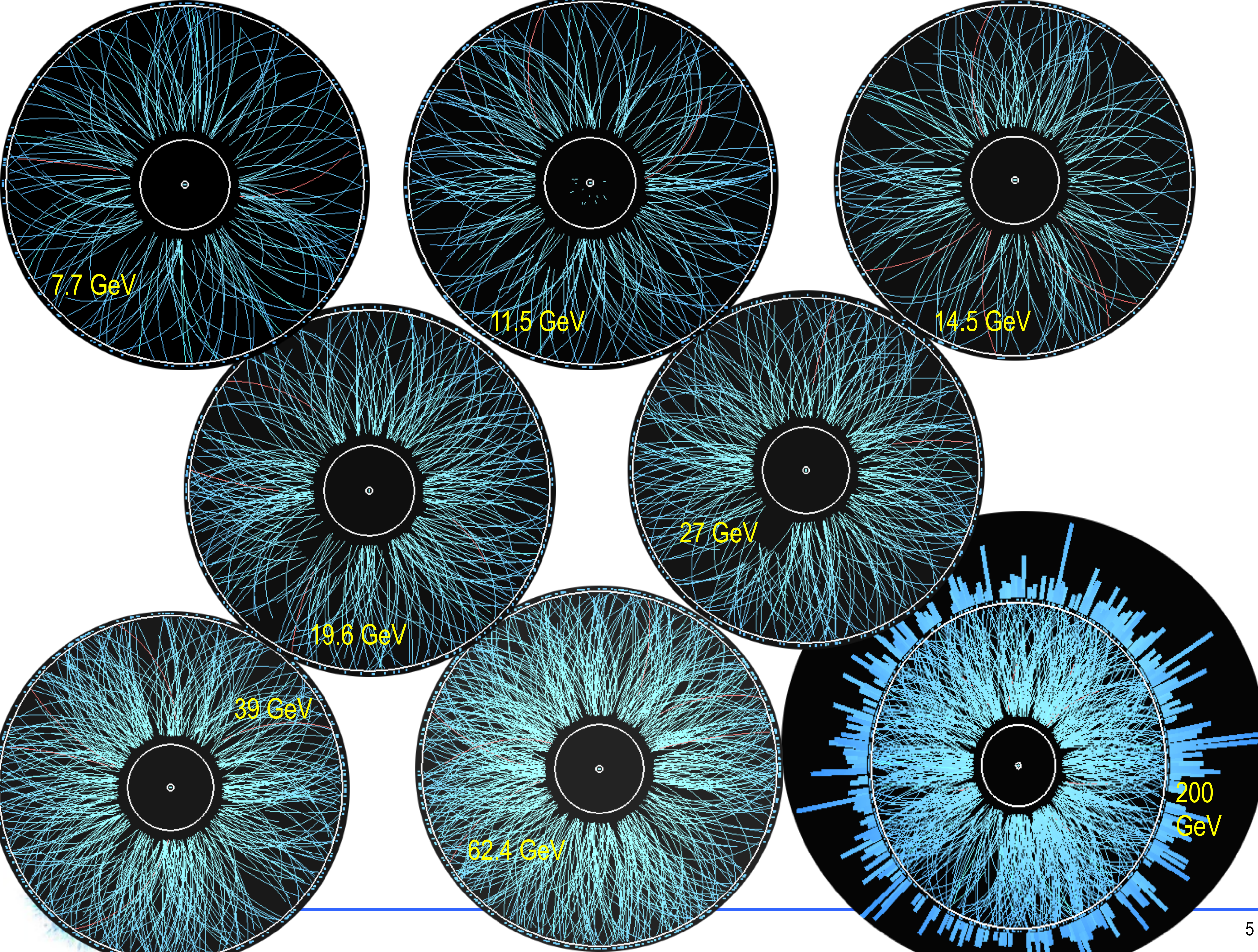
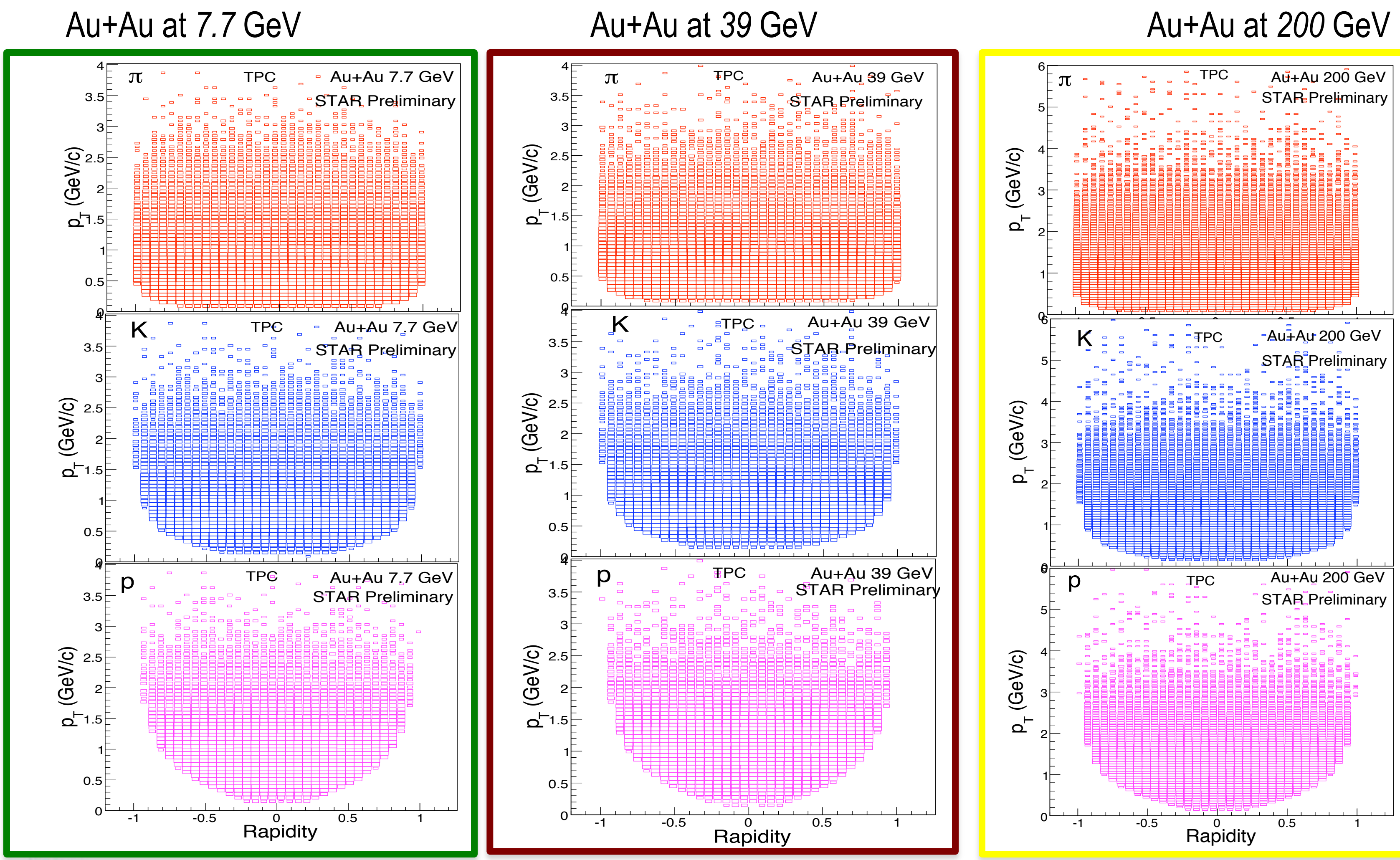
The Solenoid Tracker At RHIC (STAR)



Perfect mid-y Collider Experiment
- large coverage: $-1 < \eta < 1$ & 2π in azimuth
- uniform acceptance vs $\sqrt{s_{NN}}$ in coll. mode
- excellent particle identification
- can operate in collider and FXT mode


7.7 GeV
11.5 GeV
14.5 GeV
19.6 GeV
27 GeV
39 GeV
62.4 GeV
200 GeV

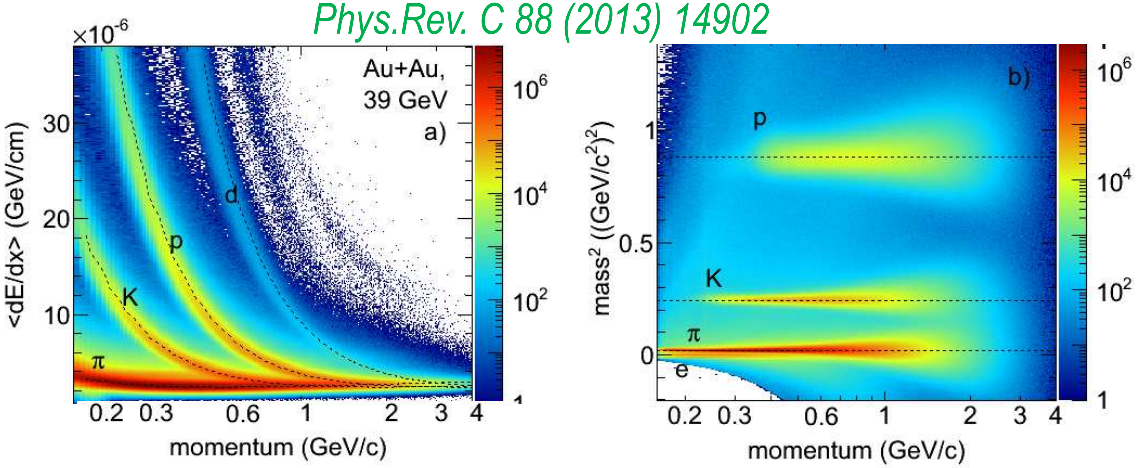
Identified Particle Acceptance at STAR



At collider geometry - similar acceptance for all particles and energies

Particle Identification

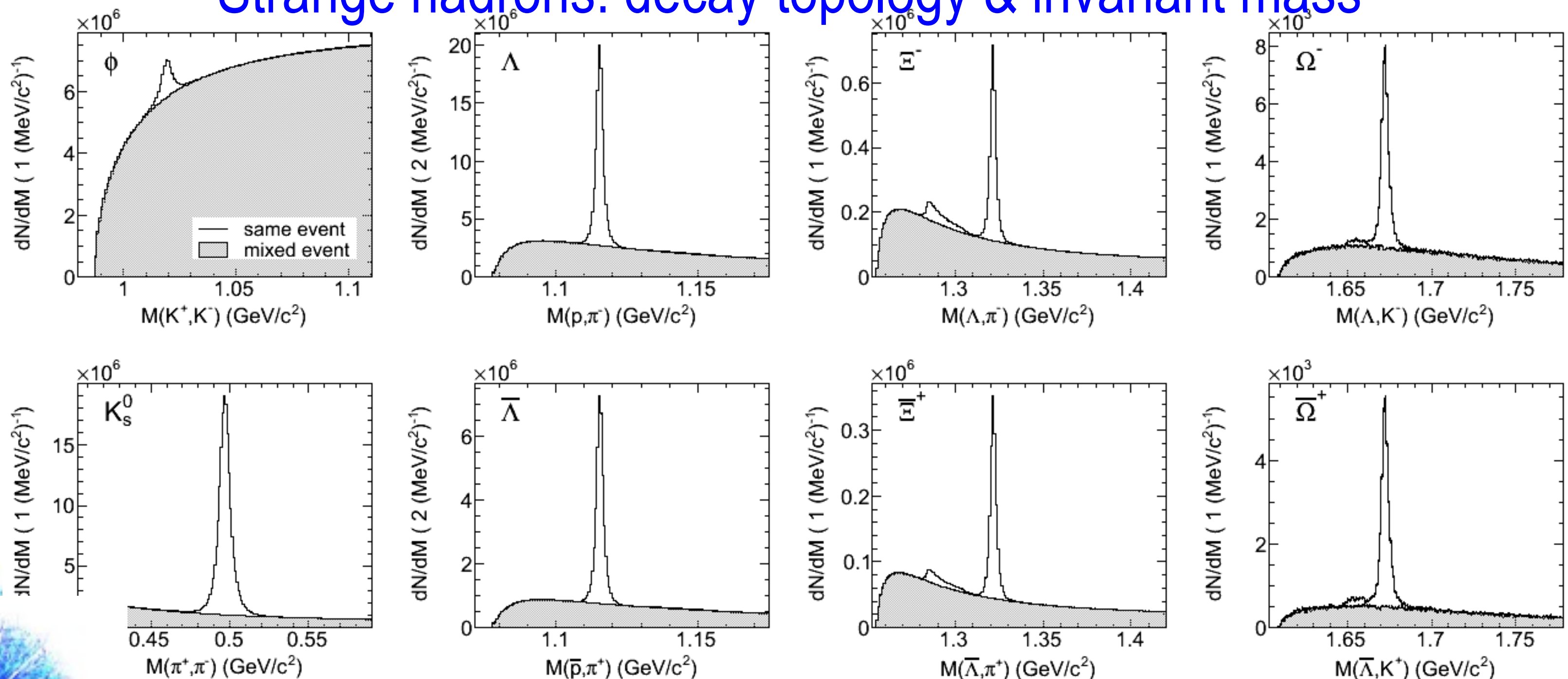
Phys.Rev. C 88 (2013) 14902



Au+Au 39 GeV

PID (TPC+TOF):
pion/kaon: p_T~1.6 GeV/c
proton p_T~3.0 GeV/c

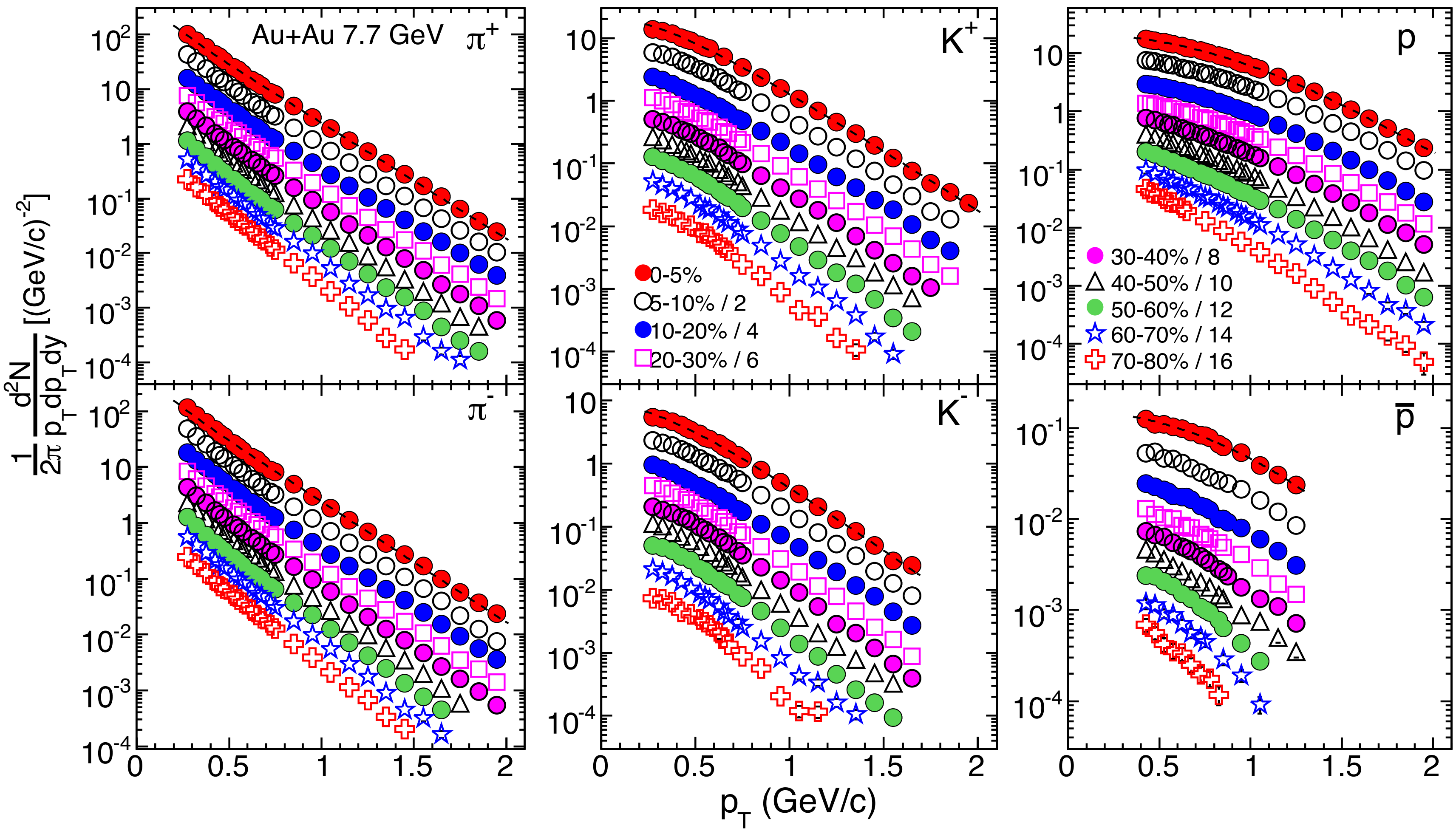
Strange hadrons: decay topology & invariant mass



Landscape

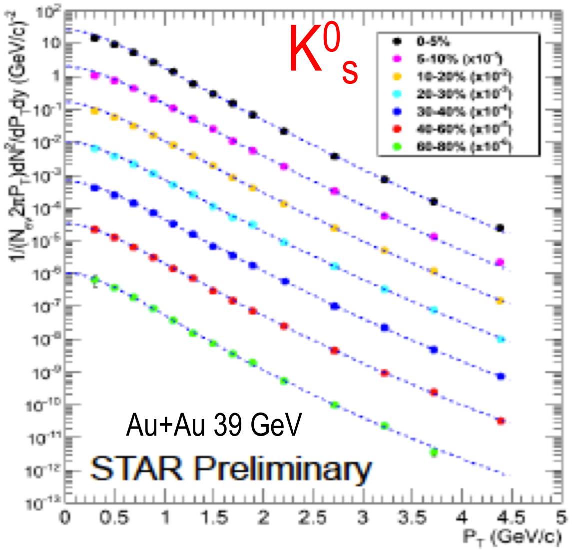
π, K, p spectra at mid-rapidity (|y|<0.1) at $\sqrt{s_{NN}}$=7.7 GeV

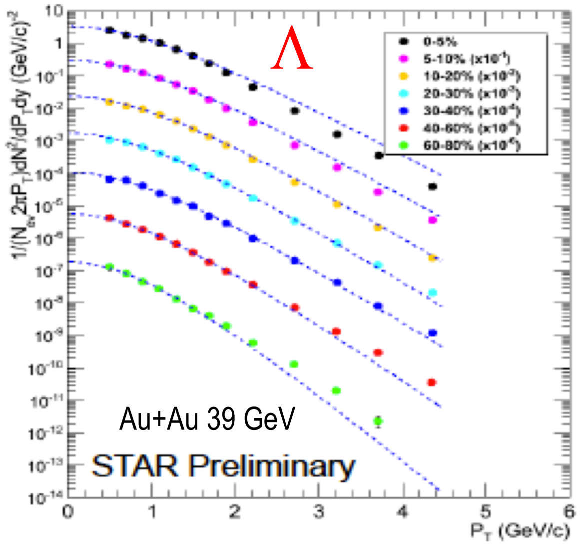
STAR: PRC 96 (2017) 44904

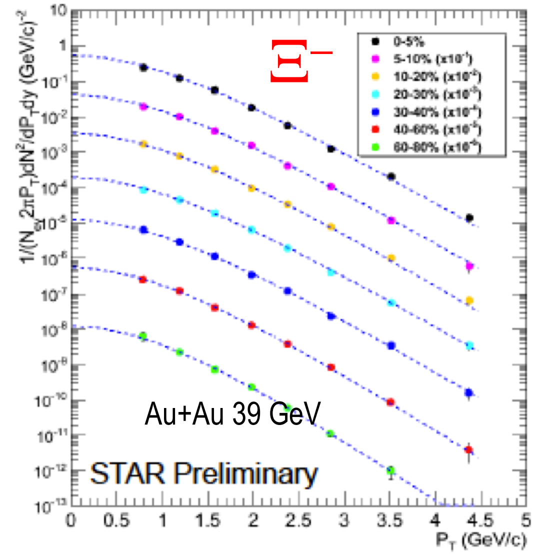


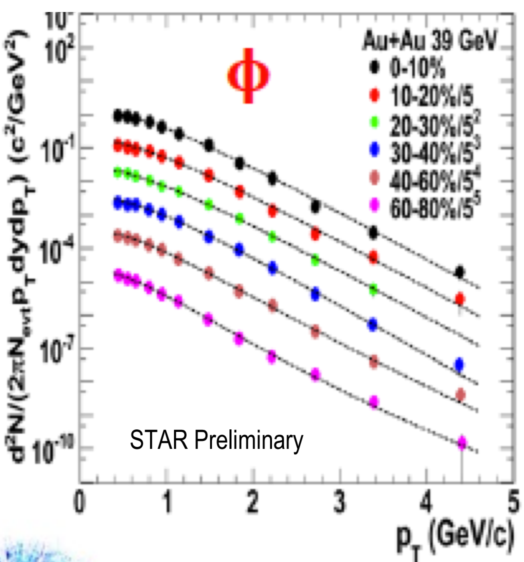
Inverse slopes of the identified hadron spectra follow the order π < K < p

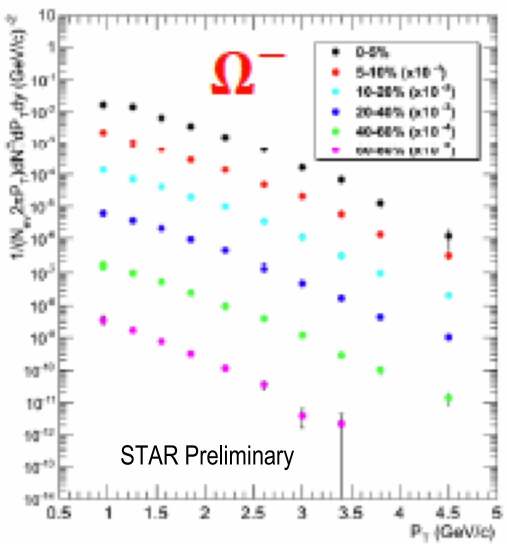
Spectra : strange hadrons











ϕ, K^0_s: Levy function fit

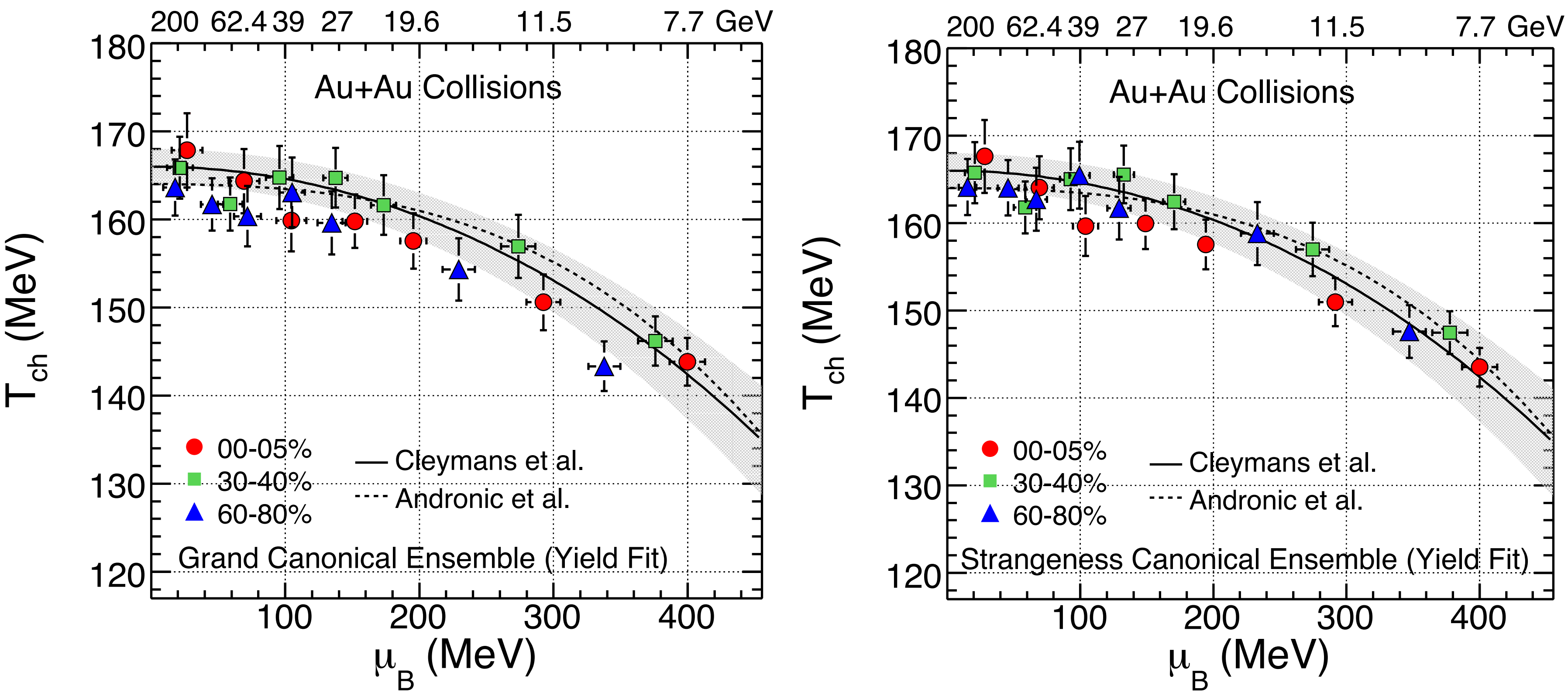
Λ, Ξ : Boltzmann fit

Λ: feed-down corrected

Chemical freeze-out parameters (T vs. μ_B) extracted from measured particle yields with THERMUS model fits

(Wheaton and Cleymans, Comput. Phys. Commun. 180, 84 (2009))

STAR: PRC 96 (2017) 44904



(μ_B,T): J.Cleymans et al.,PRC 73, 034905 (2006)

BES data (Phase I) extends relevant region of the QCD Phase Diagram from μ_B= 20 MeV to ~ 400 MeV ($\sqrt{s_{NN}}$ =7.7 GeV)

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BES: Experimental Program

STAR: *http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493, arXiv:1007.2613*

STAR: *http://drupal.star.bnl.gov/STAR/starnotes/public/sn0598, BES WP*

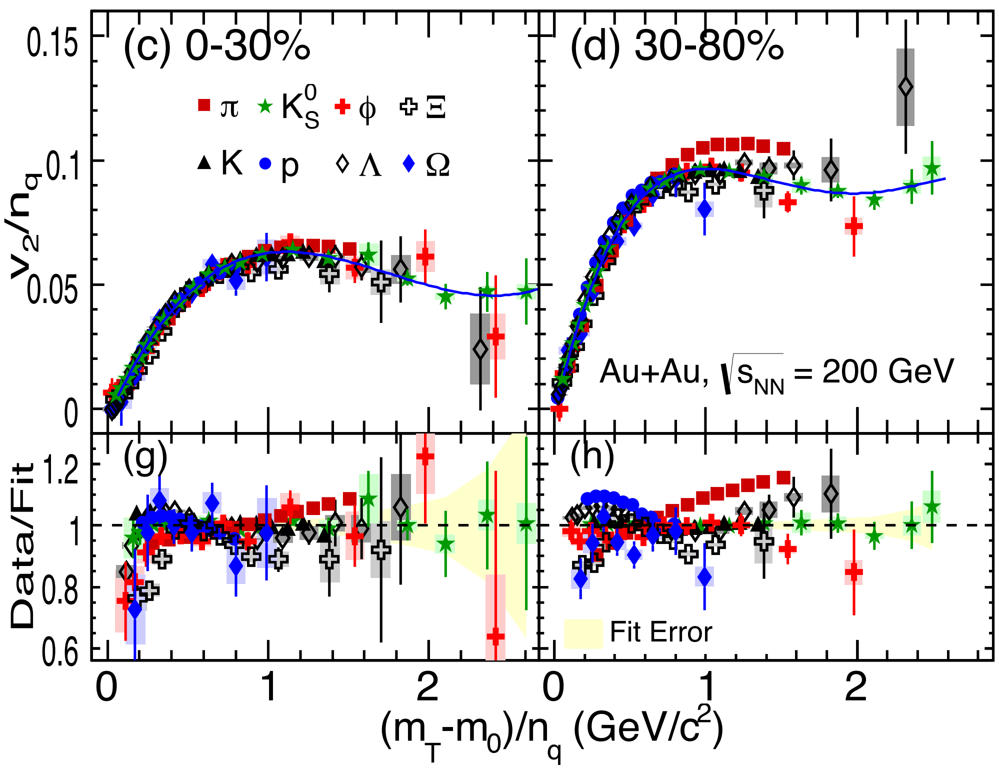
- Study onset of QGP (disappearance of signals of partonic degrees of freedom seen at 200 GeV)
  - nuclear modification factor R_{cp}
  - NCQ scaling of elliptic flow
  - charge separation w.r.t. EP (if induced by chiral magnetic effect)
- Indication of the existence of Critical Point (CP)
  - fluctuations analyses
- Observation of phase transition (softening of EOS as we lower the beam energy, what type of phase transition ?
  - directed flow v_1
- Chiral symmetry restoration ?
  - low-mass vector mesons, dielectrons
  - CME

On set of QGP

disappearance of signals of partonic degrees of freedom seen at 200 GeV - “turn off signatures of QGP” one of the main finding at RHIC:

partonic degrees of freedom in Au+Au at 200 GeV

PRL 116 (2016) 62301



Scaling elliptic flow, v_2, by quark content n_q (baryons=3, mesons=2) resolves meson-baryon separation of final state hadrons (all points collapsed to one curve)

flow developed in pre-hadronic stage
DECONFINEMENT at RHIC

With lowering energy, disappearance of n_q scaling would suggest that we <u>exit partonic dof world</u>

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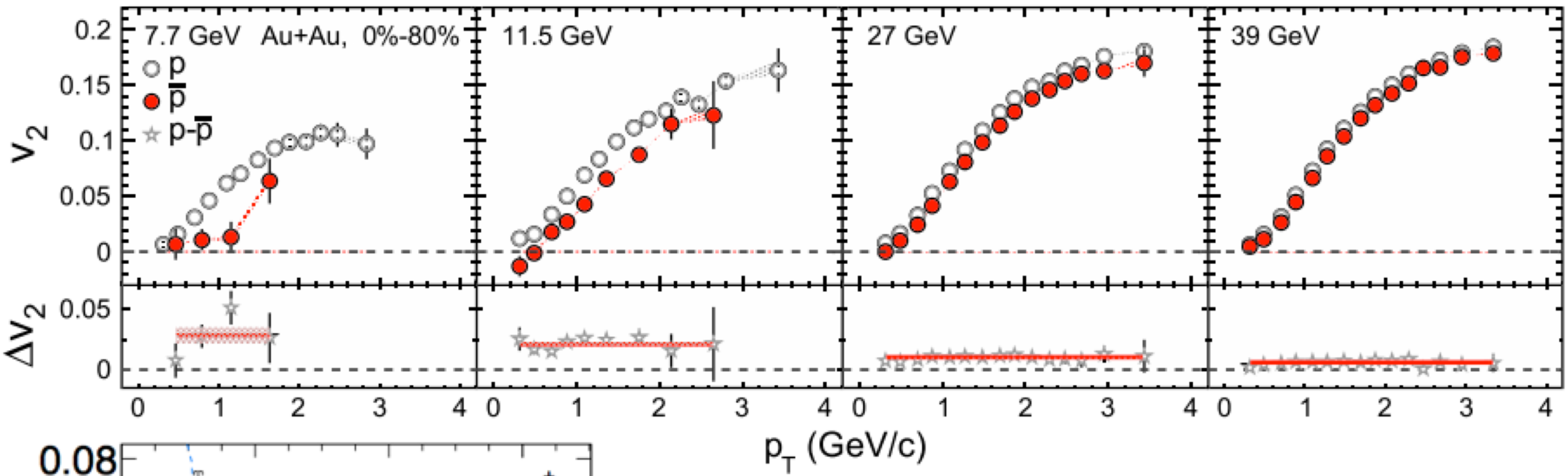
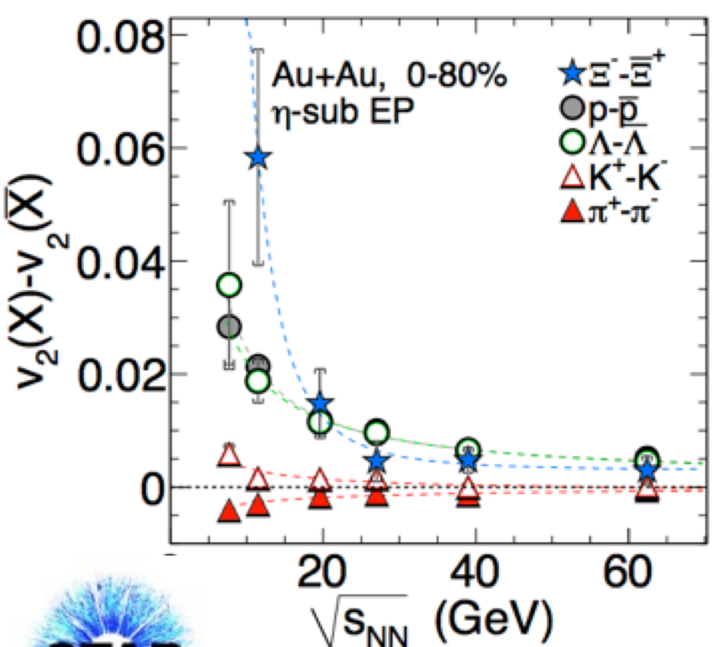
BES I: v_2 difference between particle and anti-particle

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

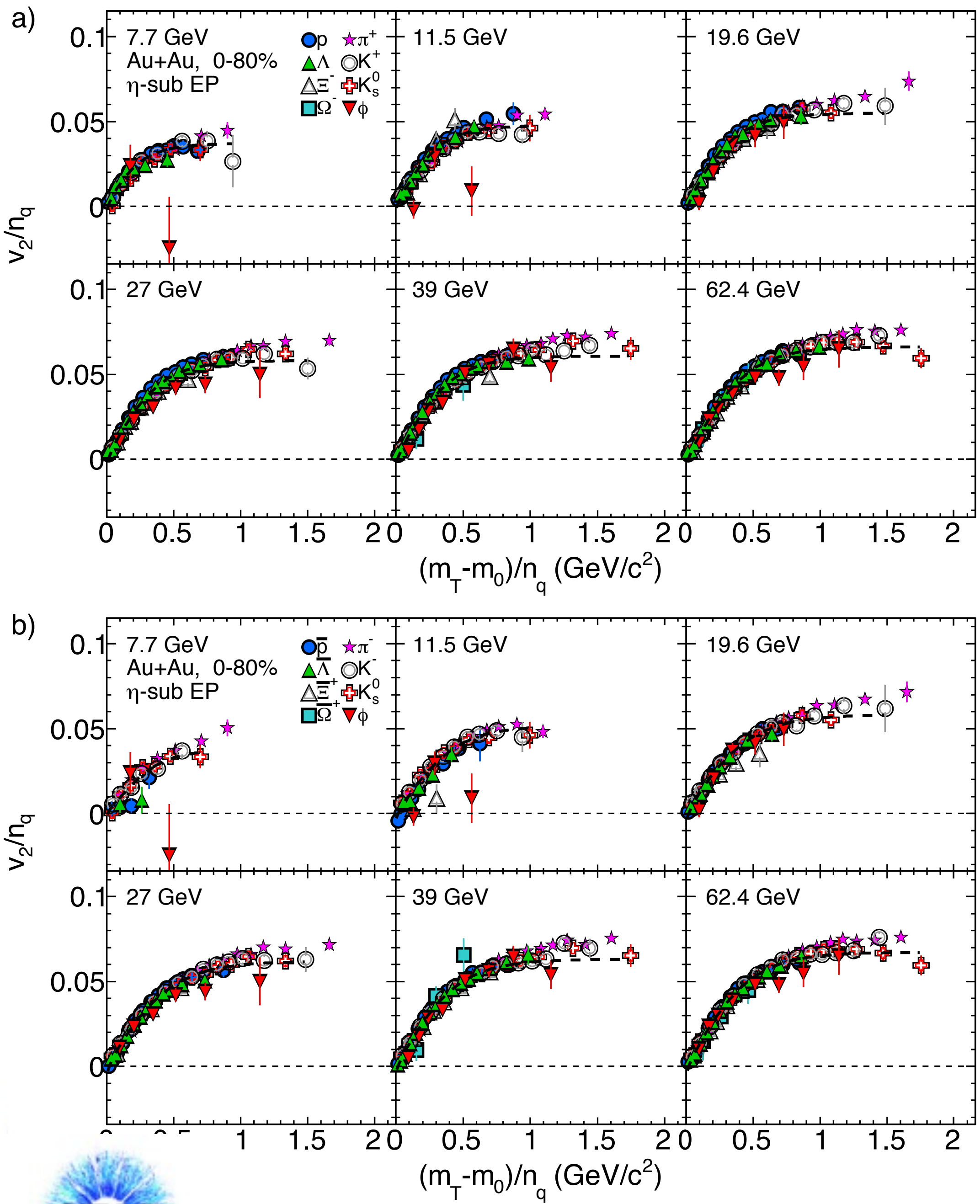




Significant difference between baryon-antibaryon v_2 at $\sqrt{s_{NN}}$<= 11.5 GeV

NCQ scaling between particles and anti-particles is broken

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

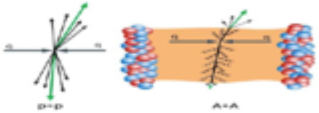


ϕ meson v_2

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

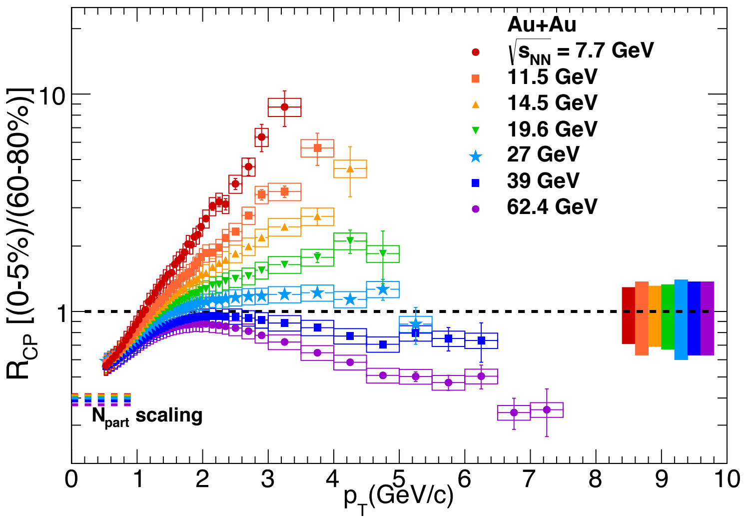
- ϕ meson v_2 falls off the trend from other hadrons at 11.5 GeV, but very low statistics

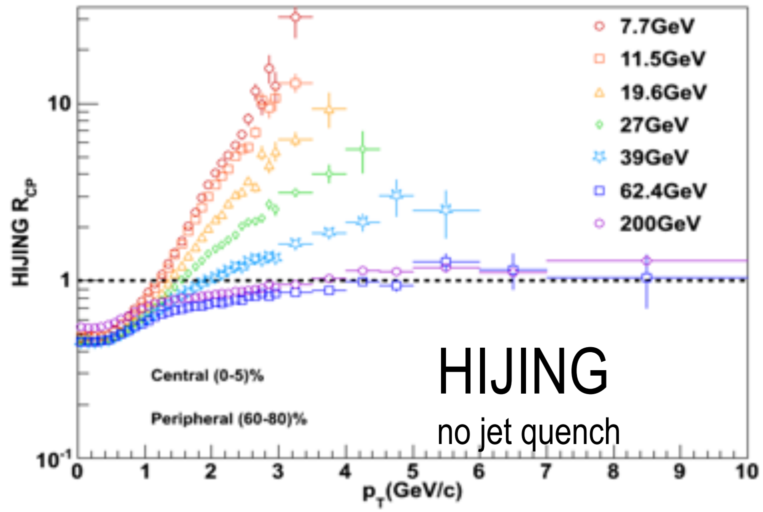
BES: R_{cp} for charged particles



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

QM 2018, PRL 121, 032301 (2018):

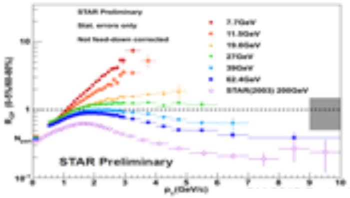




- R_{CP} increases from suppression at 62.4GeV to enhancement at 7.7 GeV, as expected
(energy density at low energies becomes to low to produce a sufficiently large and long-lived QGP)

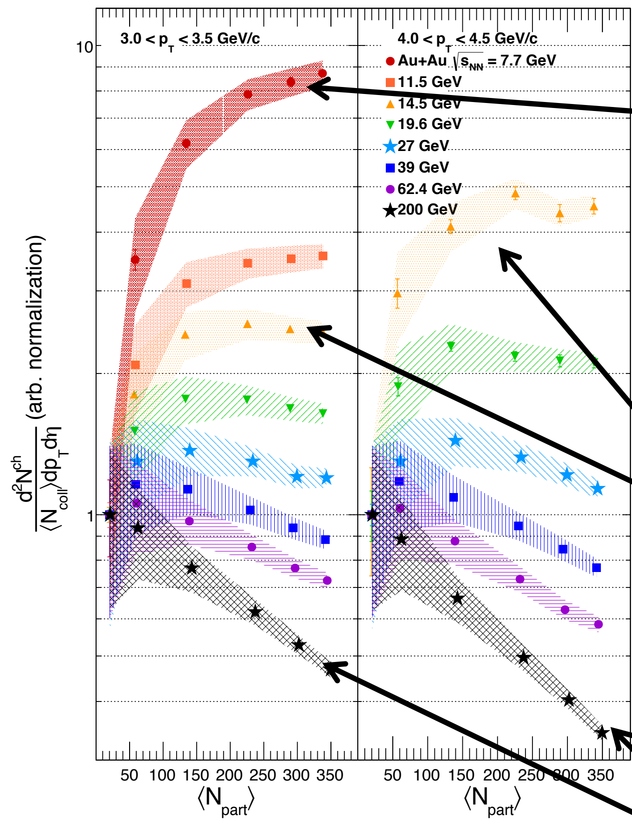
HIJING (no jet quenching, but including Cronin effect though k_T broadening) resembles $\sqrt{s_{NN}}$ dependence at low energies
(other effects can contribute e.g. radial flow, coalescence, …)

Cronin and other enhancement effects compete with jet quenching
R_{cp} > 1 does not automatically lead to conclusion that QGP is not formed



Charged hadrons yield per binary collision vs N_{part}

PRL 121, 032301 (2018)



Left: highest p_t bin in 7.7 GeV,
Right: highest p_t bin in 14.5 GeV

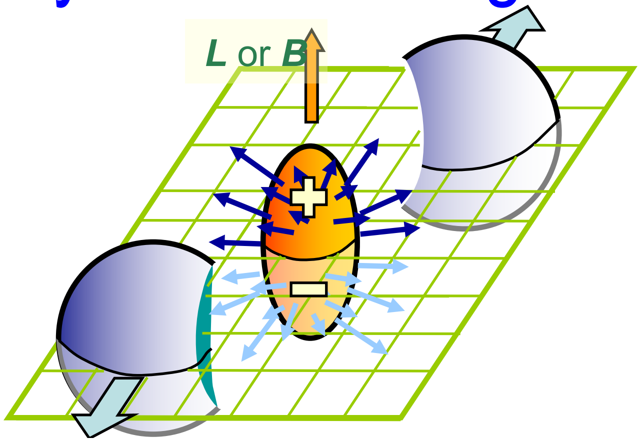
Disentangling processes ?

At 7.7 GeV:
increases monotonically with increase of N_{part}

At 14.5 GeV:
peak at N_{part} ~230 -> enhancement effects increase faster than suppression for N_{part}<250. For N_{part} >250 , suppression effects increase at the same rate (or slightly faster) than enhancement effects.

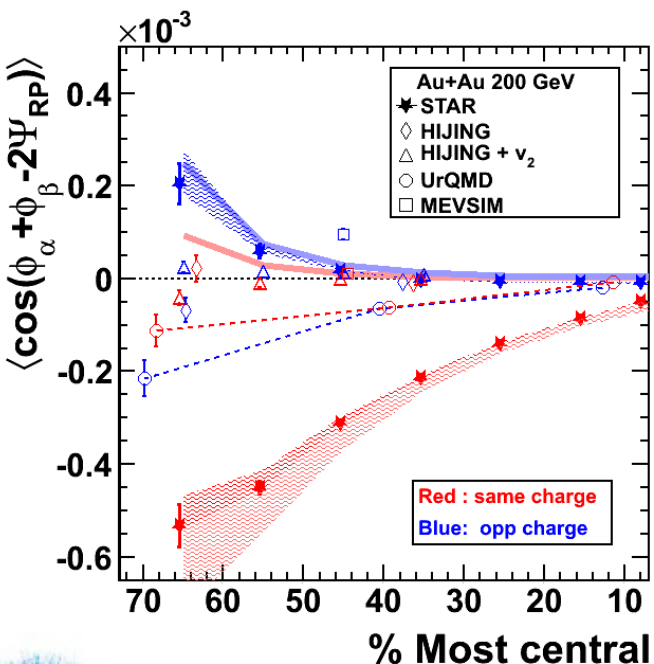
At 200 GeV :
decreases monotonically with increasing N_{part} → increase in jet quenching from peripheral to central coll. stronger than the increase of enhancement effects

Dynamical charge correlations (Chiral Magnetic Effect)



- under strong magnetic field, when the system is in the state of deconfinement and chiral symmetry restoration is reached, local fluctuation may lead to local parity violation.

D.Kharzeev et al, Nucl.Phys. A 803, 227 (2008); Phys.Lett. B 633, 260 (2006); Annals Phys.325,205 (2010)
K.Fukushima et al., Phys.Rev. D78, 074033 (2008)
R.Gatto et al., Phys.Rev. D 85, 054013 (2012)



PRL 103 (2009) 251601

- experimentally: separation of the charges along the magnetic field axis in high-energy nuclear collisions (CME)

- AuAu, UU and CuCu at top RHIC energies show charge separation

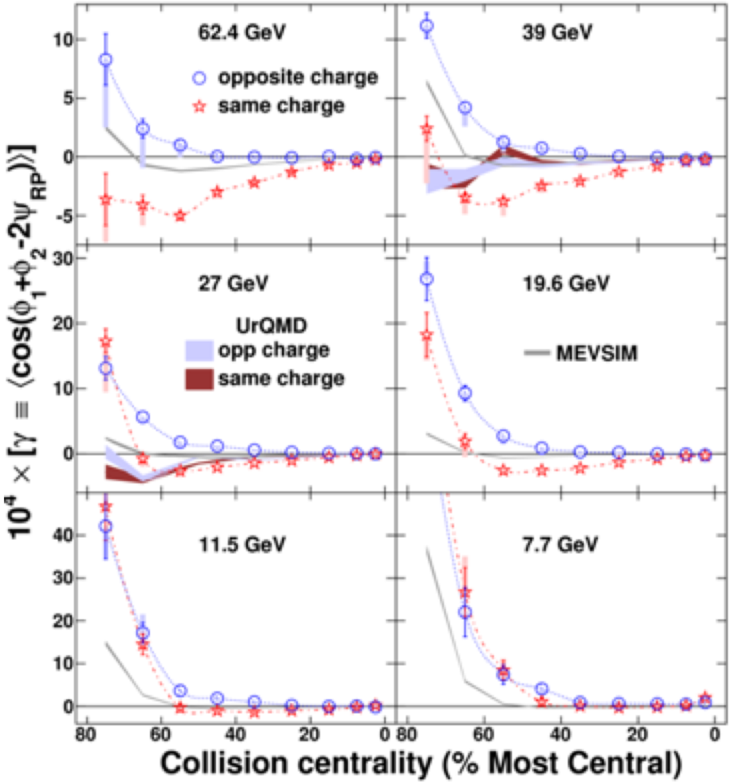
If interpretation is correct:

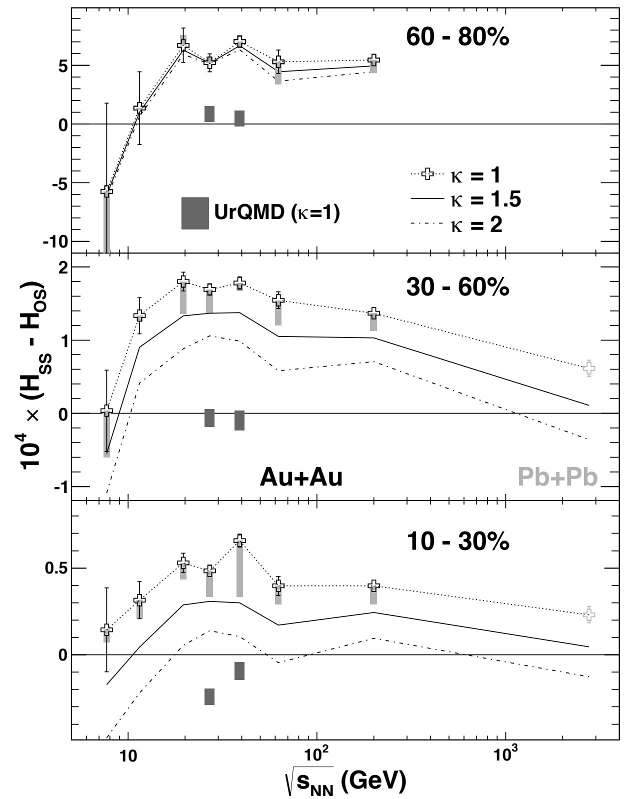
gradual reduction of signal with decreasing energy

→ turn-off of deconfinement (?)

Dynamical charge correlation signal vs. $\sqrt{s_{NN}}$

PRL 113 (2014) 52302





Splitting between same and opposite-sign charges decreases with decreasing $\sqrt{s_{NN}}$ and disappears below $\sqrt{s_{NN}}$ = 11.5 GeV

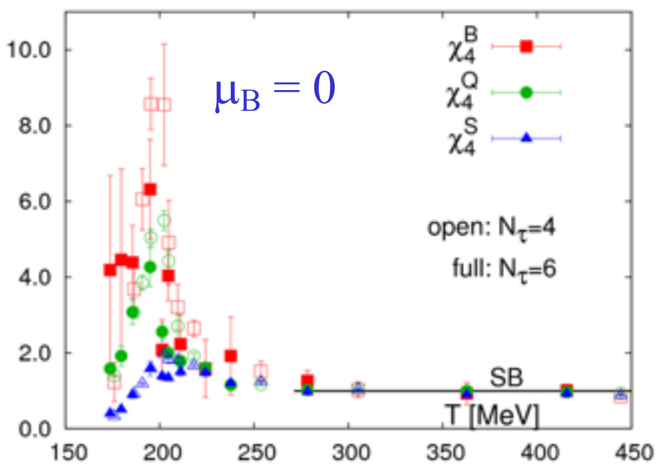
H_{ss} - H_{os} - correlator (with bck ~removed):
- non-zero charge separation above 19 GeV,
- rapidly decreases to zero in the interval between 19.6 and 7.7 GeV

→ dominance of hadronic interactions over partonic ones at lower collision energies

In 2018 Isobaric run Zr+Zr & Ru+Ru to entangle CME signal from background the most exciting …

Critical Point

CP: Why fluctuations and correlations ?



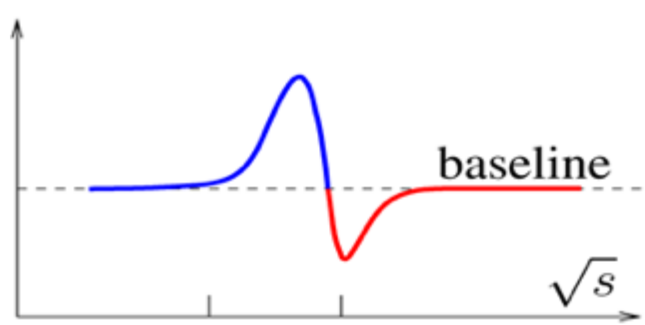
M.Cheng et al., arXiv:0811.1006

Divergence of the correlation length is expected near the QCD critical point
-> observation of non-monotonic behavior of correlations and fluctuations related to conserved quantities (B, Q, S) could be indicative of the QCD critical point

Higher moments of conserved quantities (B,Q,S) measure non-Gaussian nature of fluctuations and are more sensitive (than e.g. variance σ^2) to CP induced fluctuations (-> to correlation length)

$$<(\delta N)^2> \approx \xi^2, <(\delta N)^3> \approx \xi^{4.5}, <(\delta N)^4> -3<(\delta N)^2>^2 \approx \xi^7$$

Theory predicts an oscillation pattern in the energy dependence of the higher order moments

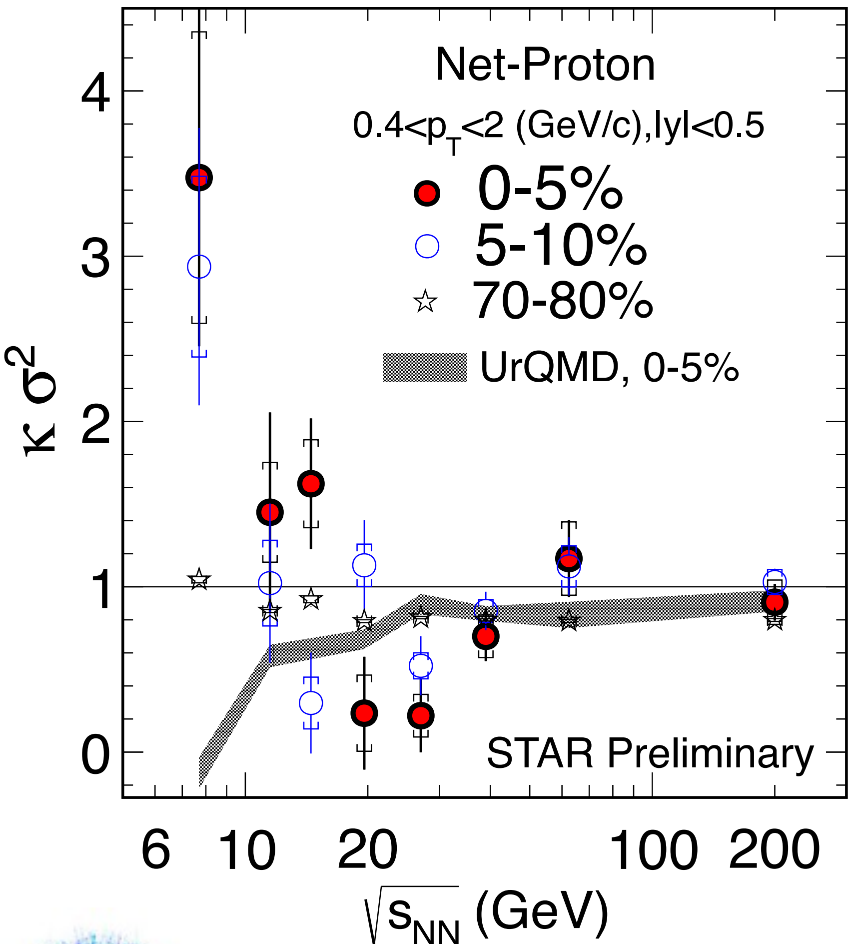


M.A.Stephanov, PRL 107, 052301 (2011), Schaefer&Wanger, PRD 85, 034027 (2012)

Higher moments in BES-I

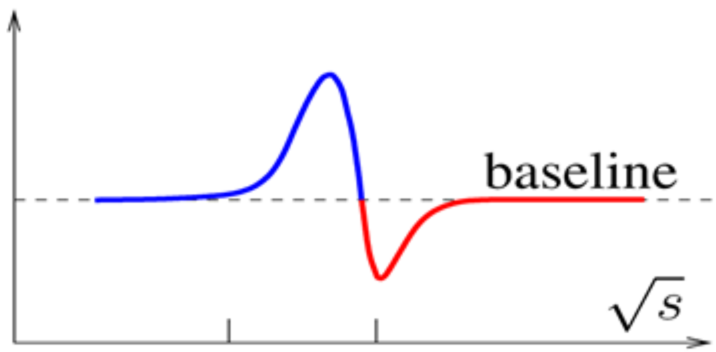
Excitation function for net-proton high moments ($\kappa\sigma^2$) in 5% most central Au+Au

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



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

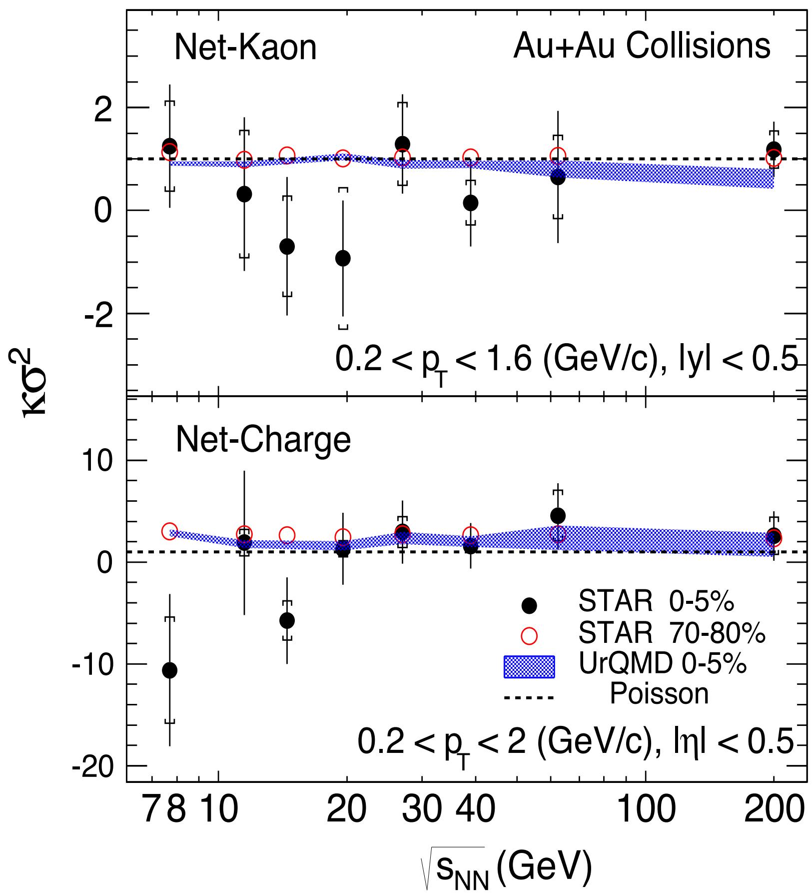
- Non-monotonic behavior
- Peripheral collisions – smooth trend
- UrQMD (no CP): shows suppression at low energies which is due to baryon number conservation



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

Will the oscillation pattern emerge at lower energies ?
FXT data

Moments of net-charge and net-kaon distributions



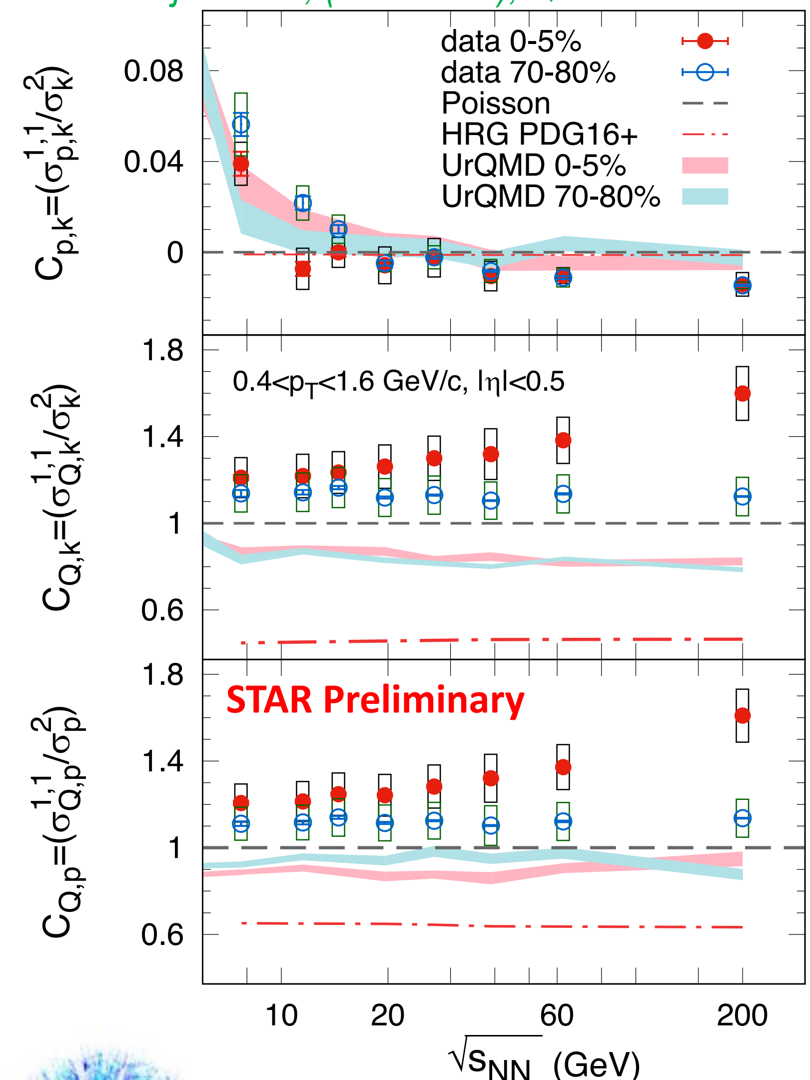
$\kappa\sigma^2$ for net-kaon and net-charge are consistent with unity

UrQMD (no CP) show no energy dependence

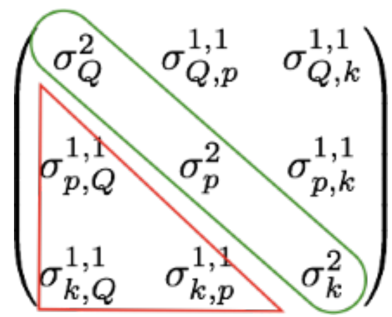
PRL 113 (2014) 92301
Phys. Lett. B 785 (2018) 551

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) 054901* *A.Chatterjee et al., J.Phys. G43 (2016) 125103*

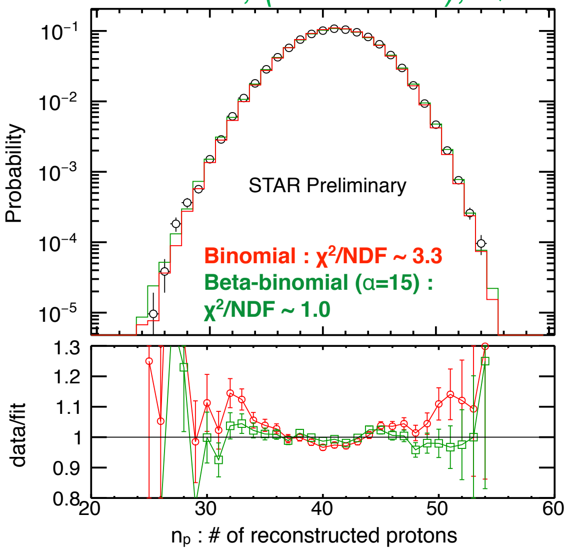


- correlations between net-p and net-K are positive at lower energies and negative at higher
- correlations in (net-Q and net-K) and (net-Q and net-p) are above Poisson, thermal (HRG) and non-thermal (UrQMD) model calculations

see talk by Arghya Chatterjee at this conference

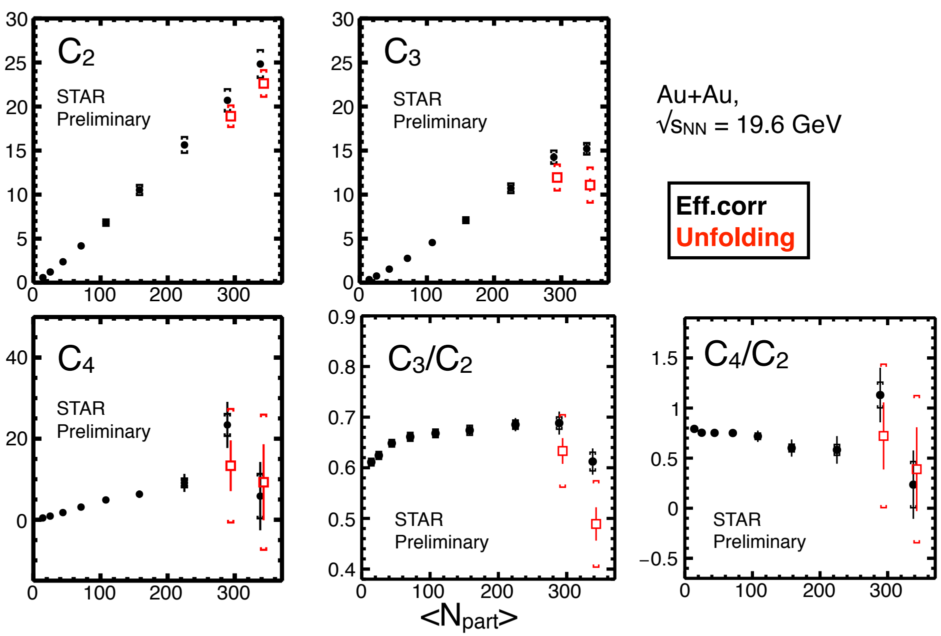
Progress towards understanding of efficiency corrections Non-binomial efficiencies – results of MC test

T. Nonaka at al., (STAR coll.), QM 2018



- detector efficiency <u>may not</u> be exactly binomial due to experimental effects track splitting, track merging, particle mis-identification, etc and due to residual multiplicity dependence of efficiency

- MC simulations with embedding protons and anti-protons into 19.6 GeV data showed that the response matrix is close to the beta-binomial distribution which is wider than binomial:



Systematic suppression of C_1 and C_3 with respect to results of efficiency correction assuming binominal efficiencies

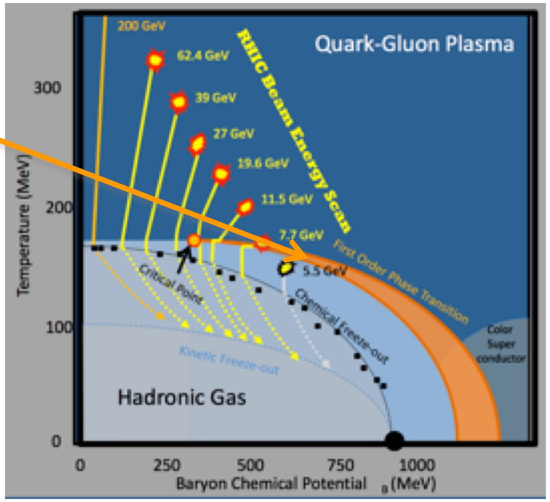
C_4, C_3/C_2 and C_4/C_2 are consistent with large systematic uncertainties (limited by embedding samples)

work in progress

the equivalent of CP … (!)

Phase transition

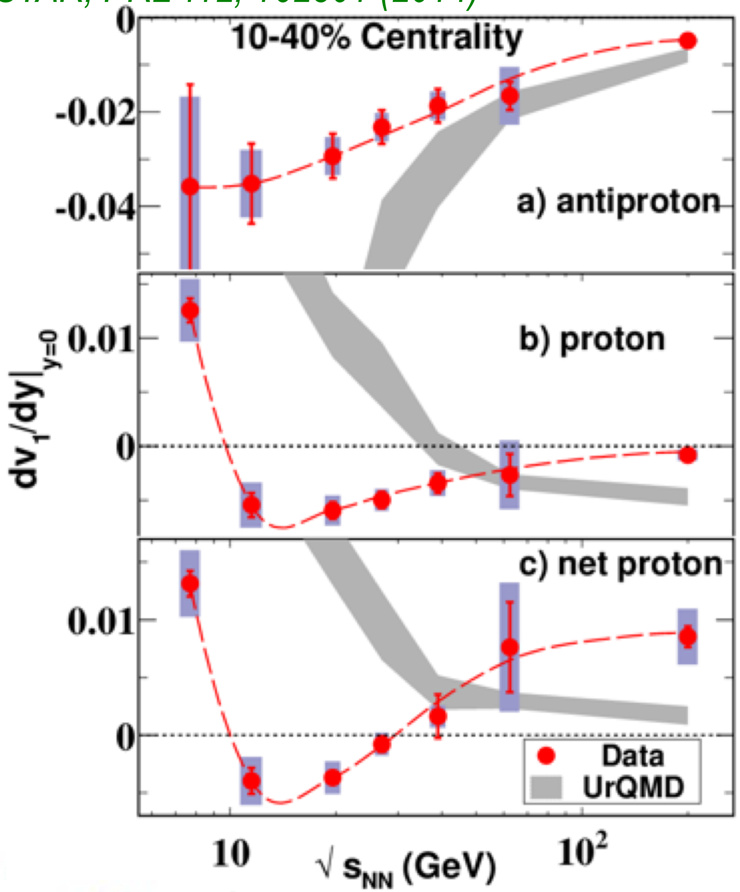
can we demonstrate the softening of EOS ?

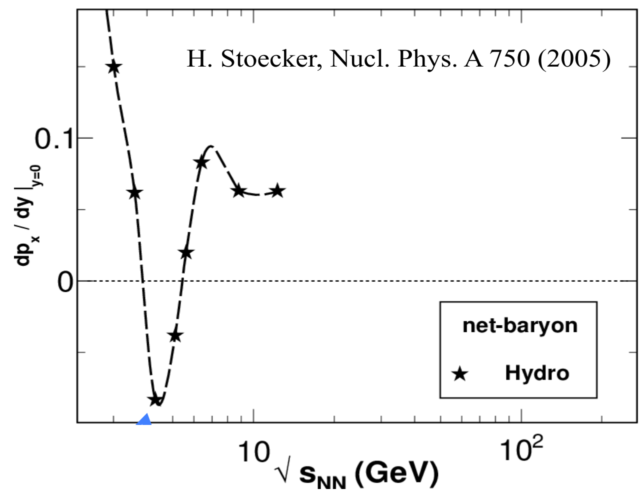


Directed flow (v_1) of identified particles

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 …

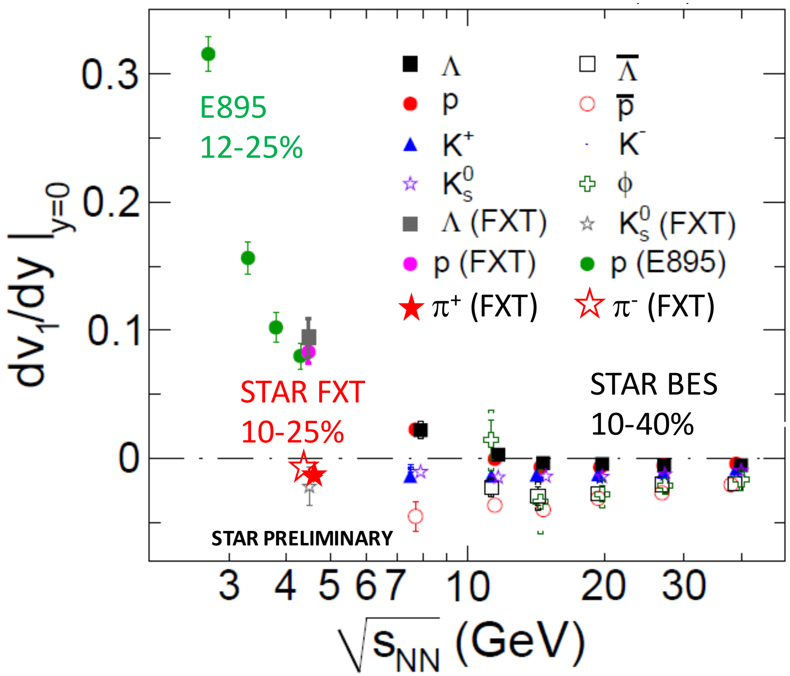
STAR, PRL 112, 162301 (2014)





- 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



low √ s:

slope v_1 (baryons) – positive

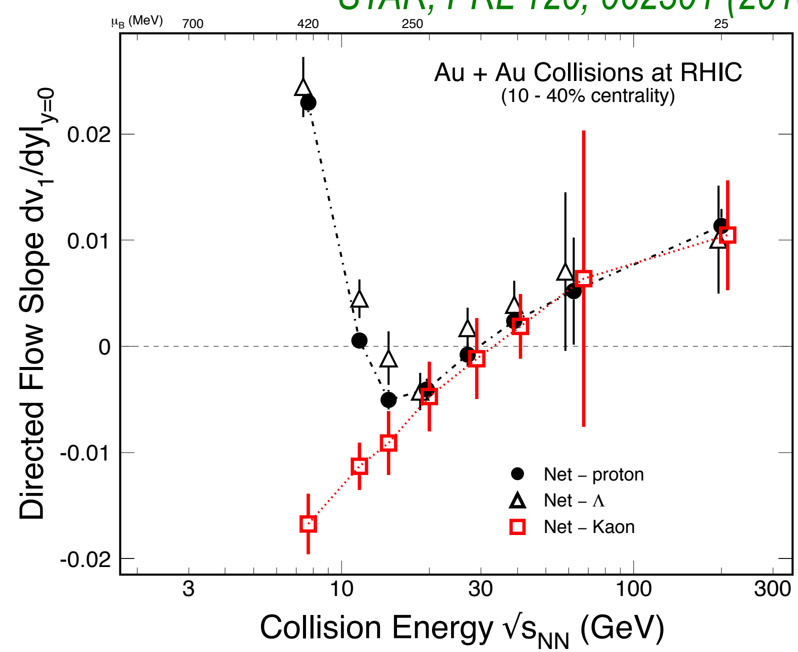
slope v_1 (mesons) –negative

Baryon dv_1/dy trend vs. $\sqrt{s_{NN}}$ - complex interplay of:

-v_1 baryons transported from beam

-v_1 from pair production

STAR, PRL 120, 062301 (2018)



Net-protons = directed flow of transported baryons

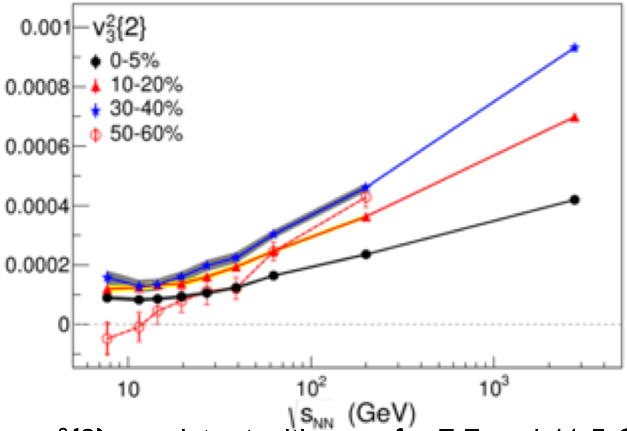
Double sign change in dv_1/dy

Not seen in net-kaons

Results not yet reproduced by theory

Softening of EoS ?

STAR

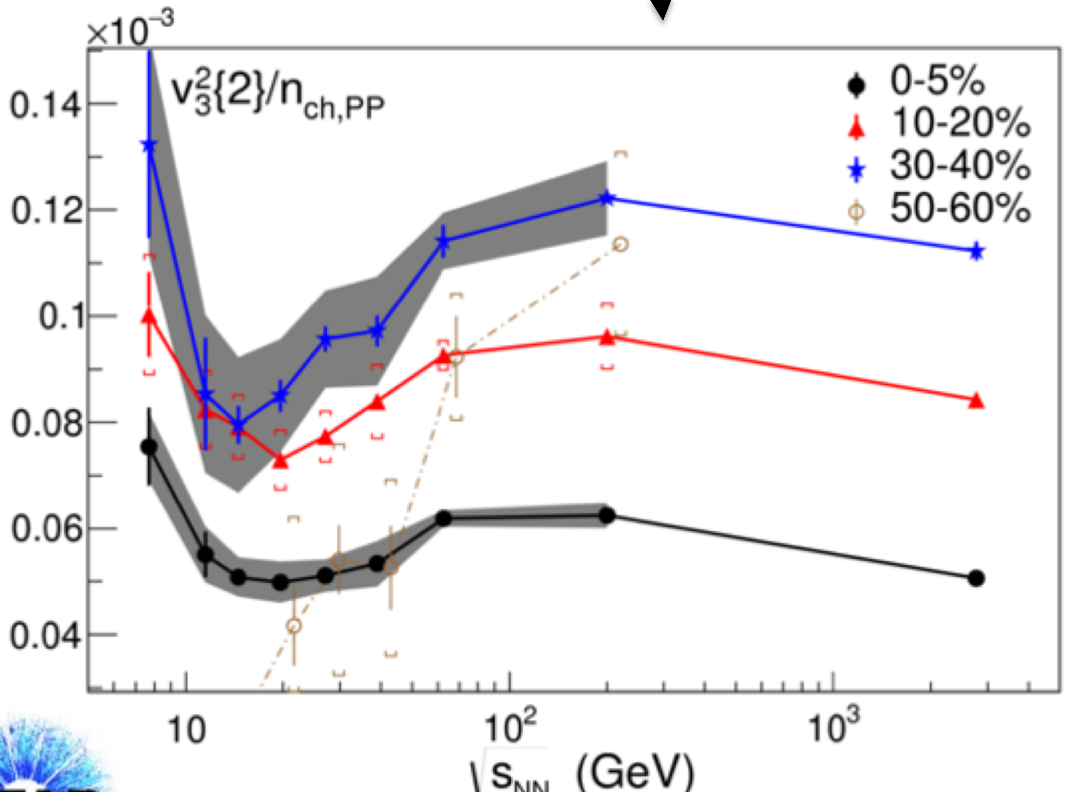


$V_3^2(2)=\langle\cos3(\phi_1-\phi_2)\rangle$

particularly sensitive to the existence of a low viscosity QGP phase early in the collision

J.Auvinen and H.Petersen, PRC 88, no.6, 064908 (2013)
D.Slanki et al., Phys. Lett. B 720, 352 (2013)

$v_3^2\{2\}$ consistent with zero for 7.7 and 11.5 GeV peripheral collisions -> absence of low viscosity QGP phase in low energy peripheral collisions



$v_3^2(2)$ scaled by pseudorapidity density of charged particles multiplicity per participating nucleon pair in Au+Au and Pb+Pb (2.76 TeV) collisions

local minimum near $\sqrt{s_{NN}}$ = 15-20 GeV for central collisions

Summary: what have we learned from BES Phase-I

STAR and RHIC - excellent performance down to 7.7 GeV

Several signatures demonstrate the dominance of parton regime at the BES high energies, these signatures either disappear, lose significance, or lose sufficient reach in the low energy region of the scan (NCQ scaling, ϕ v_2 , high-p_t suppression, charge separation, …)

→ indication that hadronic interaction become dominant at lower beam energies

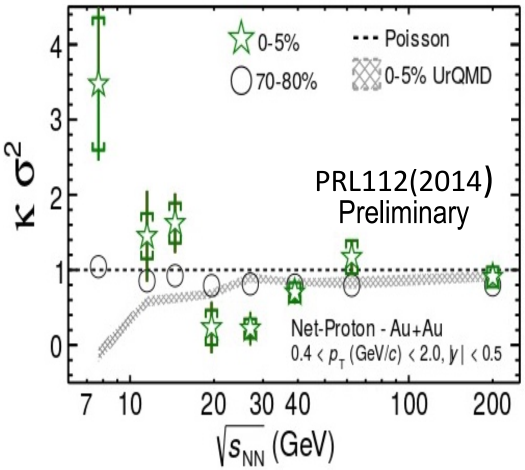
Both net-proton and net-Λ show double sign change in mid-rapidity dv_1/dy, as predicted for the possible 1st order phase transition, indication of a softening of EOS around 11.5-19.6 GeV

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

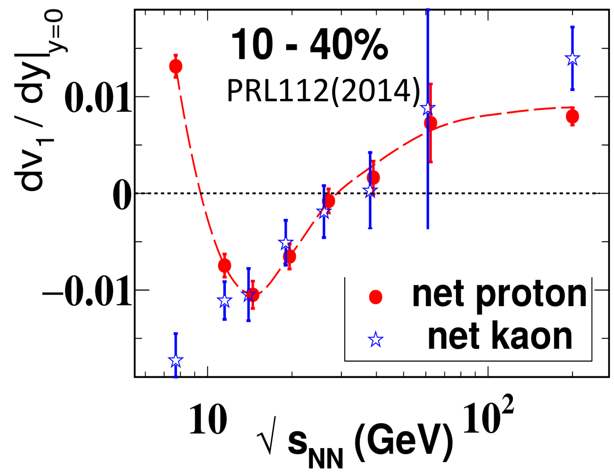
→ Future: high statistics data and extension to higher baryon density region with fixed target program

all interesting things are happening around $\sqrt{s_{NN}}$ ~ 20 GeV !

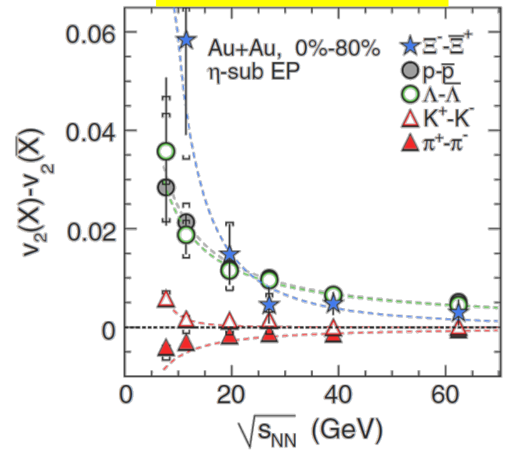
Critical Point



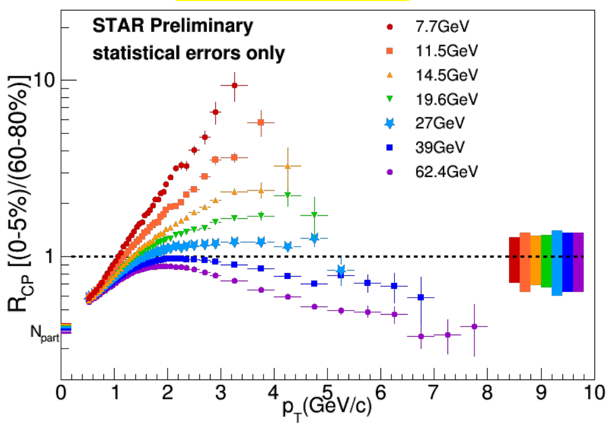
Phase Transition



Bulk Behavior



Energy Loss



RHIC BES explored QCD phase structure in an interesting region

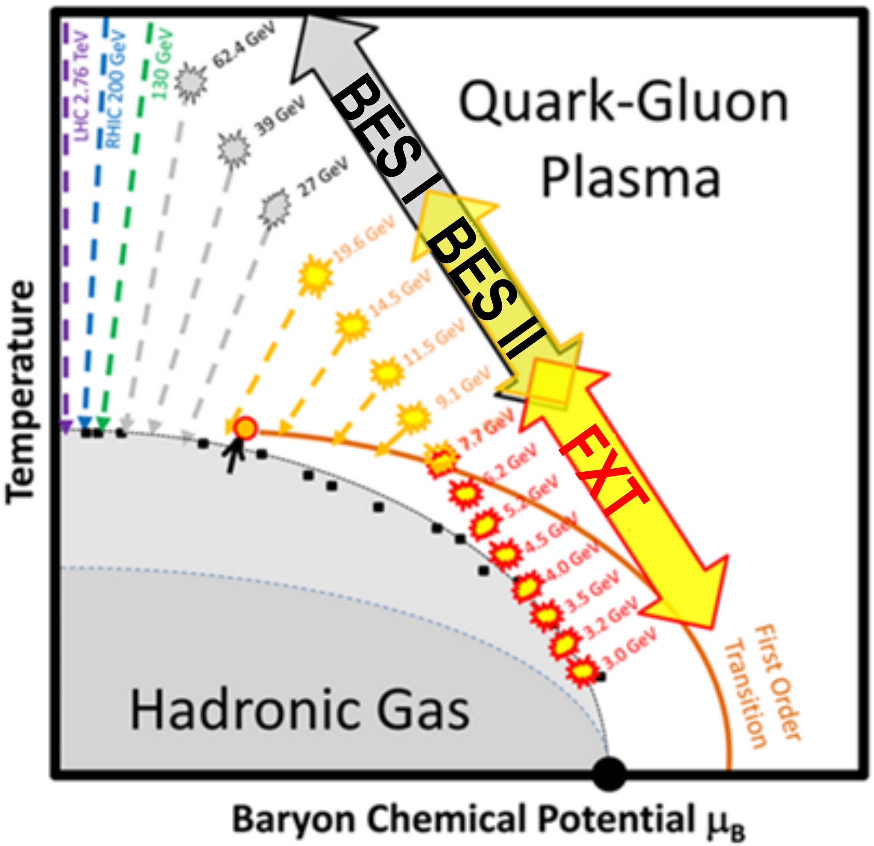
Interesting behaviors seen on many fronts …

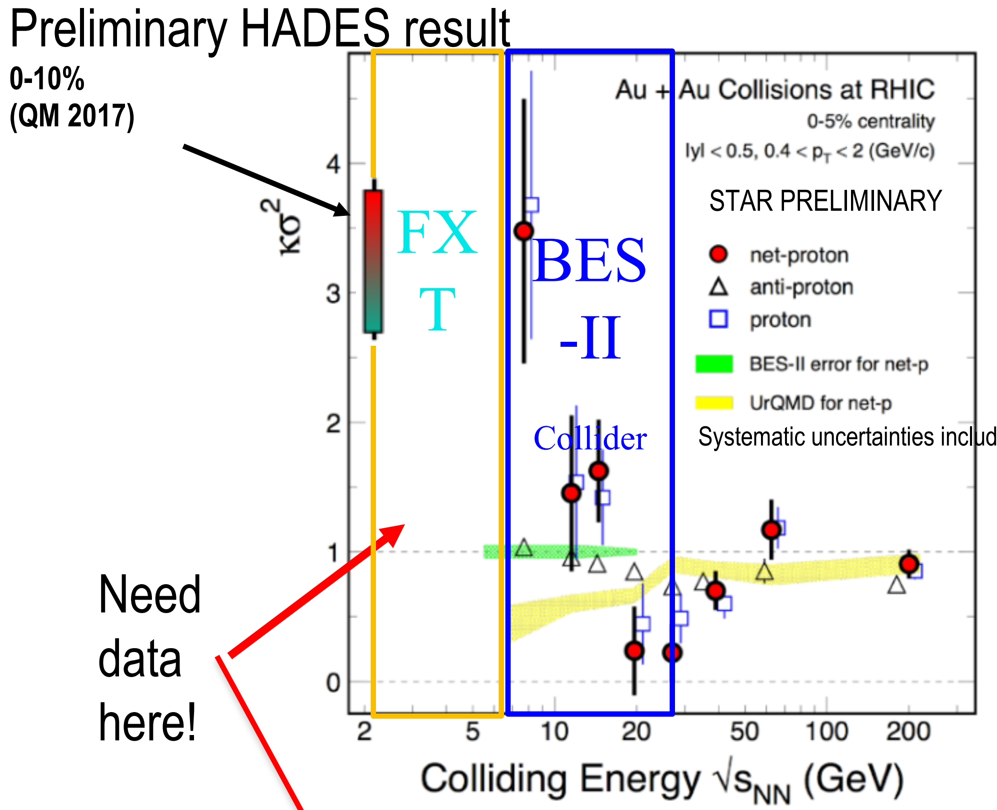
but a compelling picture requires

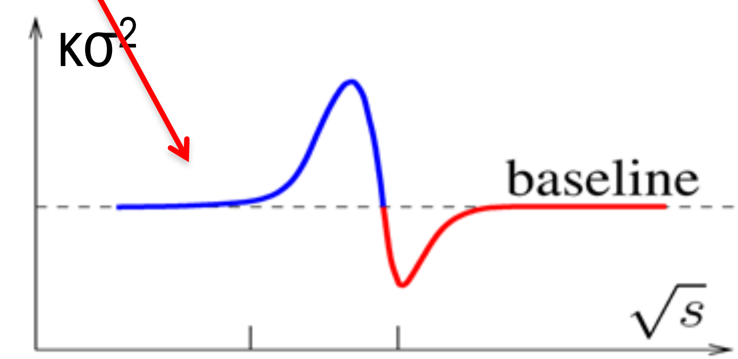
- better statistics, especially at lower energies
- finer energy scan 7~20 GeV region
- ideally, reach to lower energies (⟶ FTX)

Fixed target program in STAR

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

Fixed Target program in STAR

FXT@STAR: Au target inside beam pipe at z = 201 cm (at the entry to STAR TPC)

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

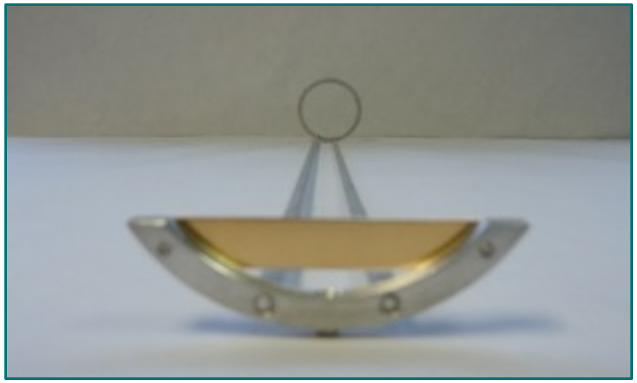
Extends energy range from $\sqrt{s}$ = 7.7 down to 3 GeV (μ_B : 420 MeV → 720 MeV)

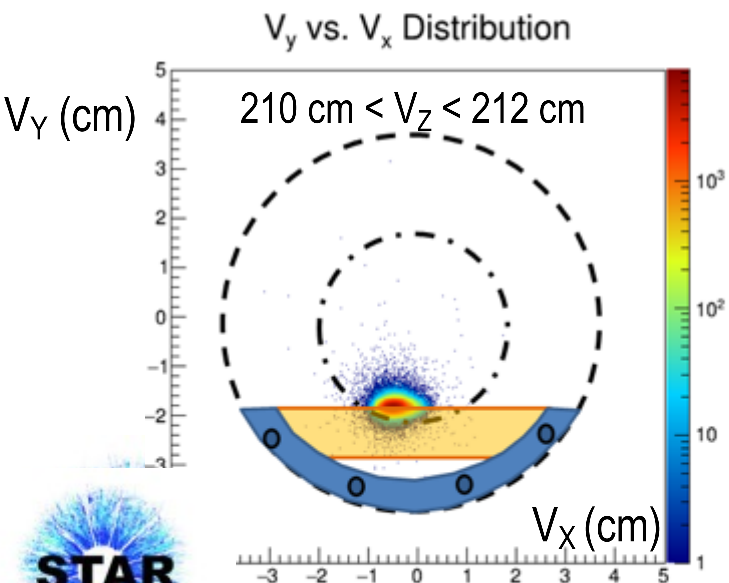
Dedicated short runs more efficient, successful test completed

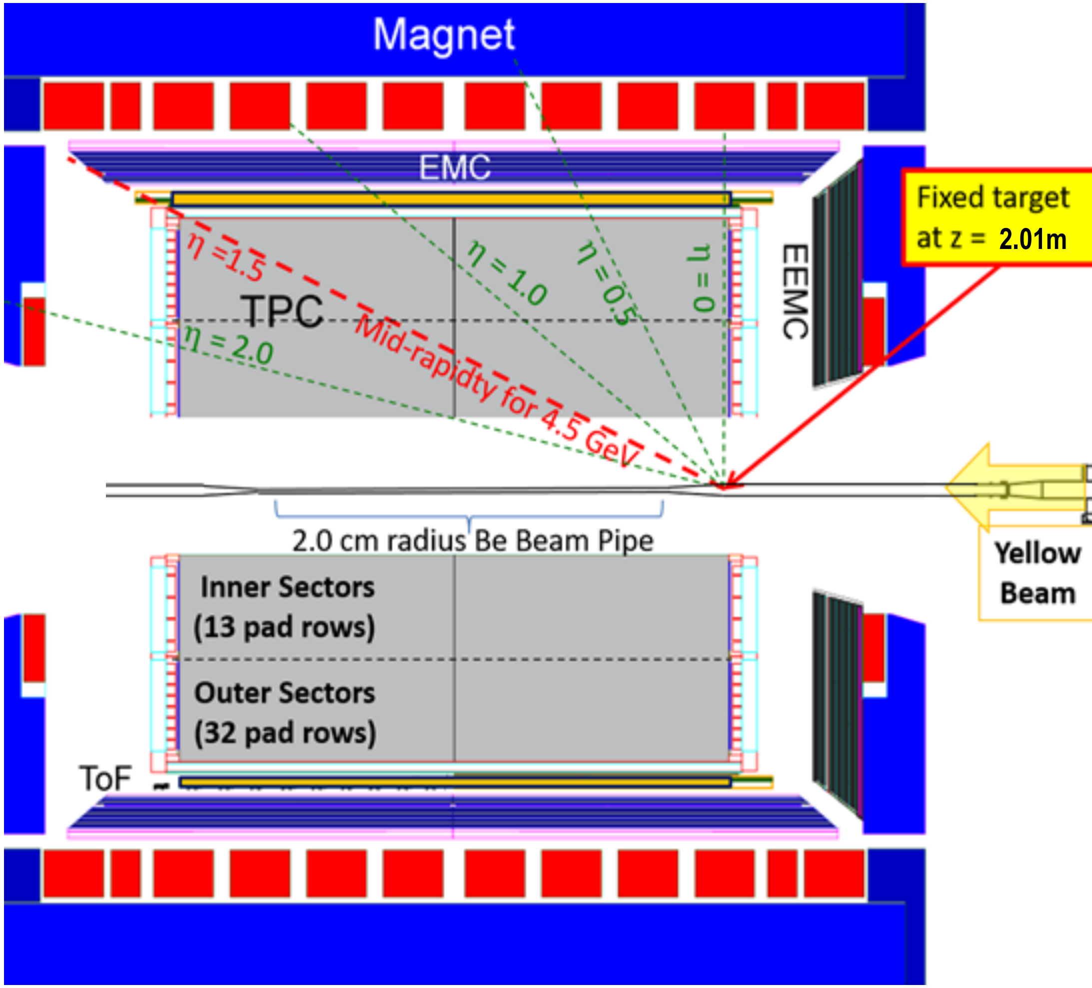
Precision investigation with new techniques and the same detector

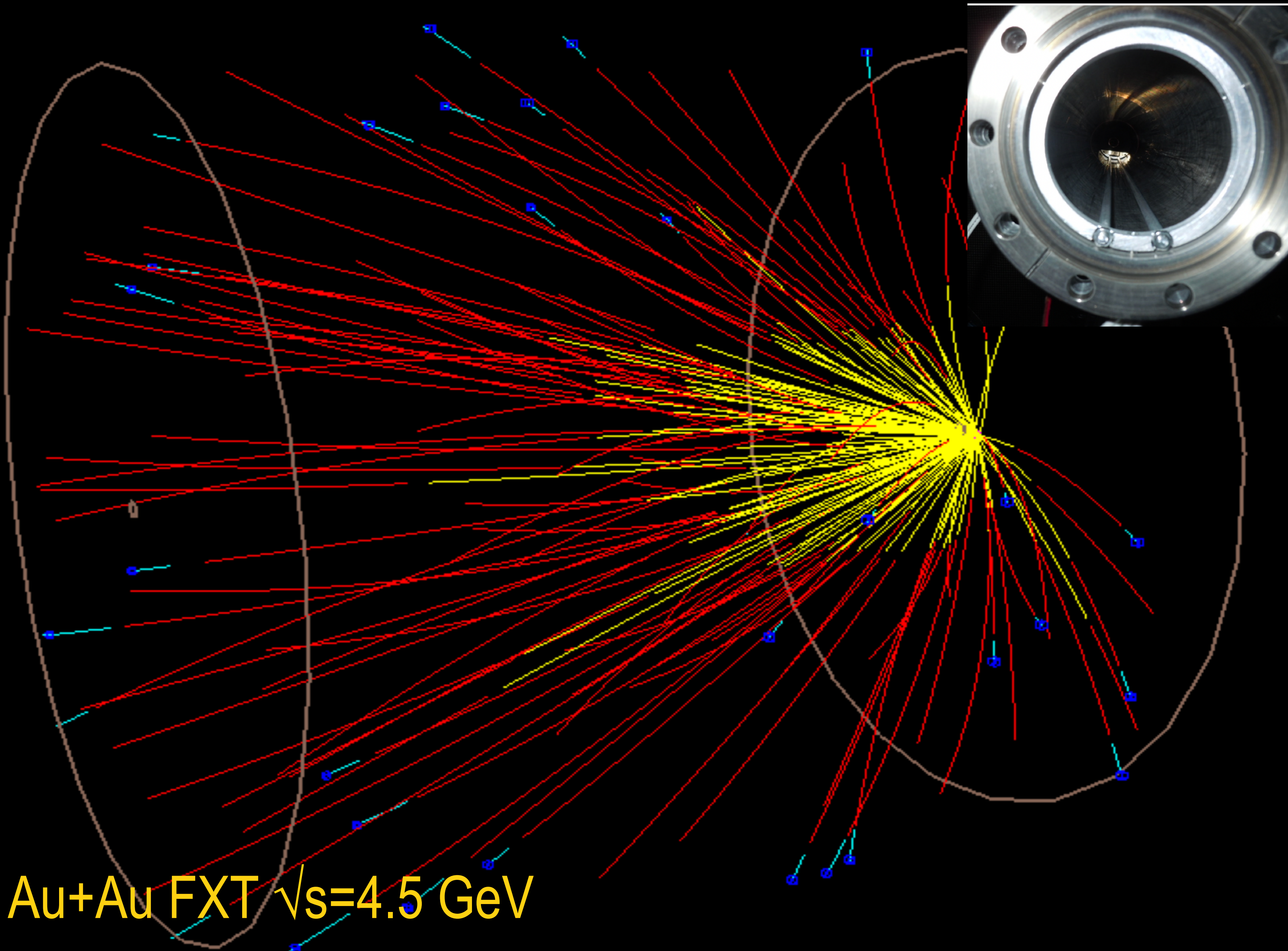
First dedicated FTX Au+Au run at $\sqrt{s_{NN}}$ = 4.5 GeV in 2015

- 1.3 million events, top 30% central trigger, Au+Au $\sqrt{s_{NN}}$ = 4.5 GeV
- 1 mm thick (4% interaction probability) gold foil target

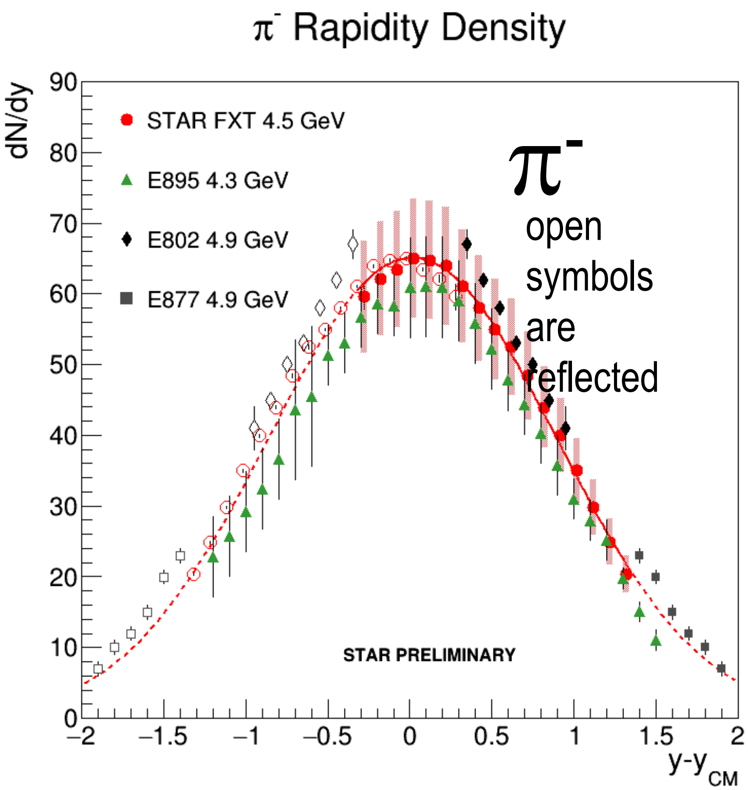


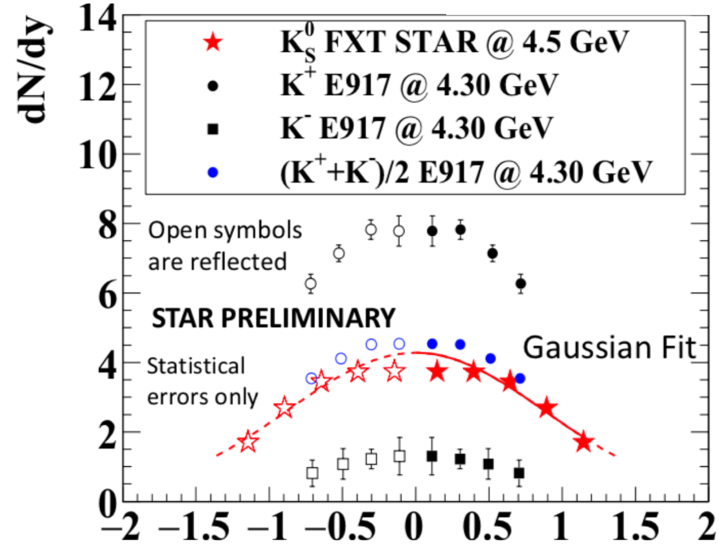


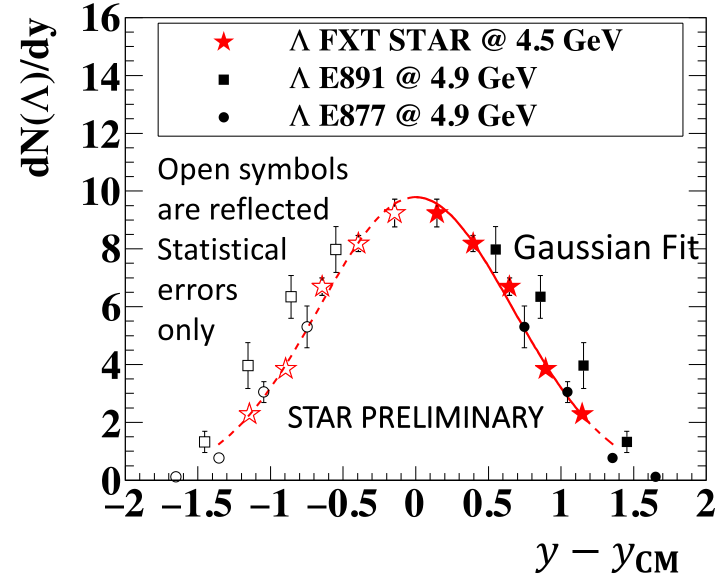



Au+Au FXT √s=4.5 GeV

dN/dy from pilot run at $\sqrt{s_{NN}}$ =4.5 GeV





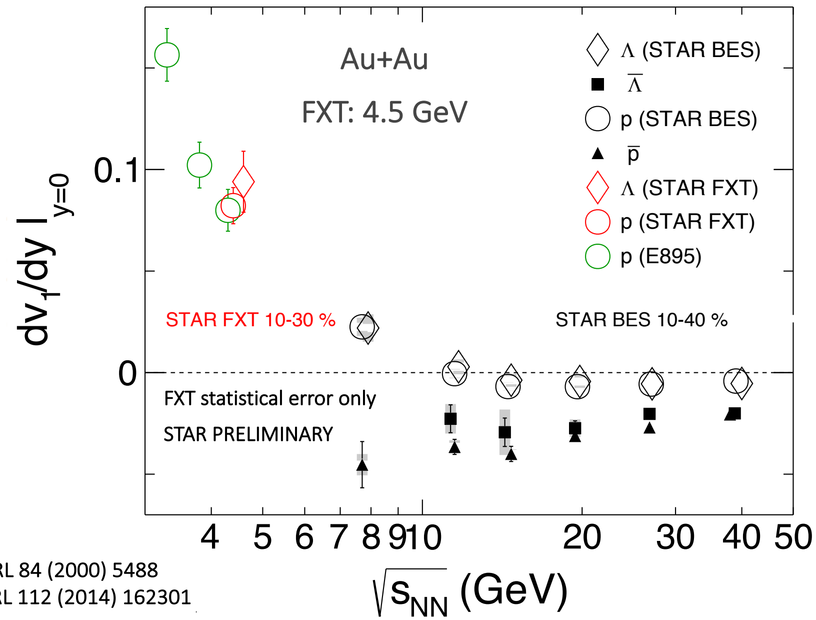


Systematic error shown for STAR and E895

E877_PRC62(2000)024901
E802_PRC57(1998)R466
E895_PRC68(2003)054905

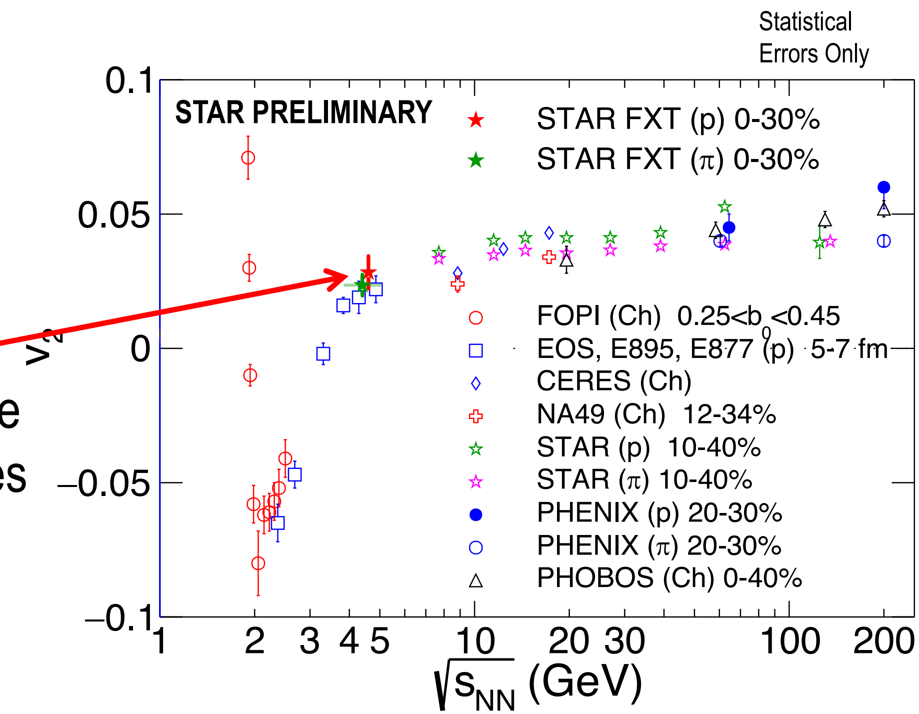
- Amplitudes and widths of the rapidity densities are consistent with AGS data
- $m_T - m_0$ and y range will be extended by eTOF and iTPC upgrades

Directed and elliptic flow at $\sqrt{s_{NN}}$ = 4.5 GeV



E895 PRL 84 (2000) 5488
STAR PRL 112 (2014) 162301

Baryon v_1 slope is consistent with E895 at 4.3 GeV



Good agreement with the world data in the region where energy dependence changes

STAR FXT test at 4.5 GeV shows :

Validation of FXT mode of operation - STAR operates successfully in FXT mode despite being optimized as a collider experiment

Spectra and yields comparable with AGS data

Directed and elliptic flow measured first time at this energy range (as well as HBT, fluctuations, strange particles etc).
Mass ordering seen as at higher energies.

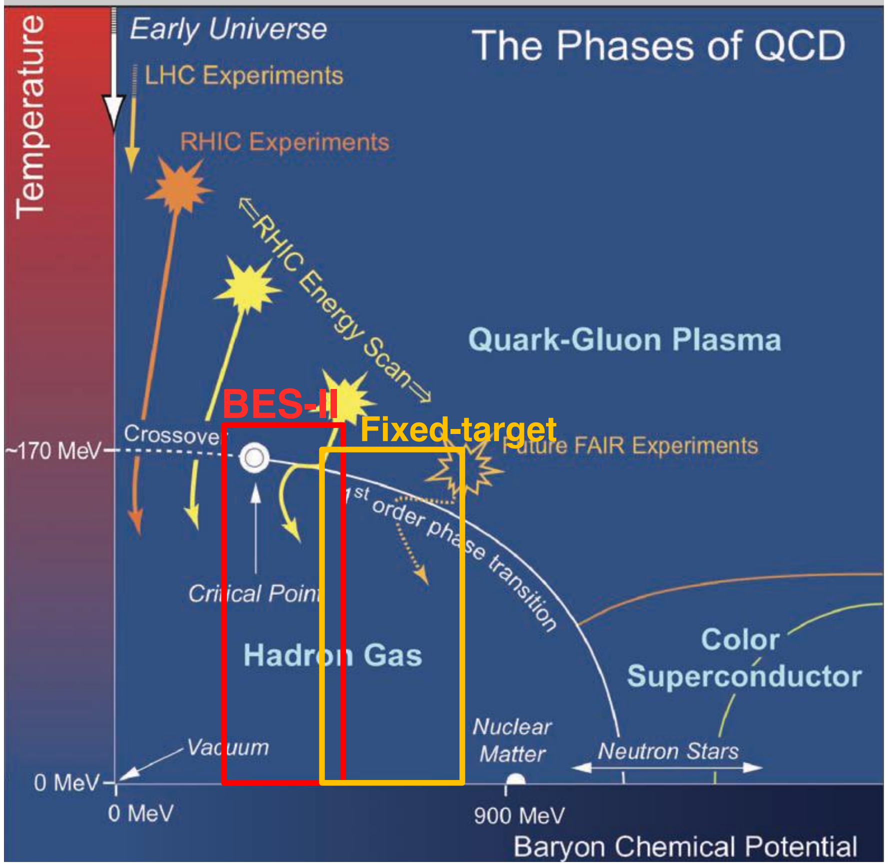
FXT energy scan approved and ongoing. Will extend the BES-II reach down to $\sqrt{s}$ = 3 GeV (μ_B = 720 MeV) to include high baryon density region of phase diagram

FXT Run 18:
200 M events at 7.2 GeV
300 M events at 3.0 GeV
EPD operational

STAR Note 0696, BUR Request for Run19+

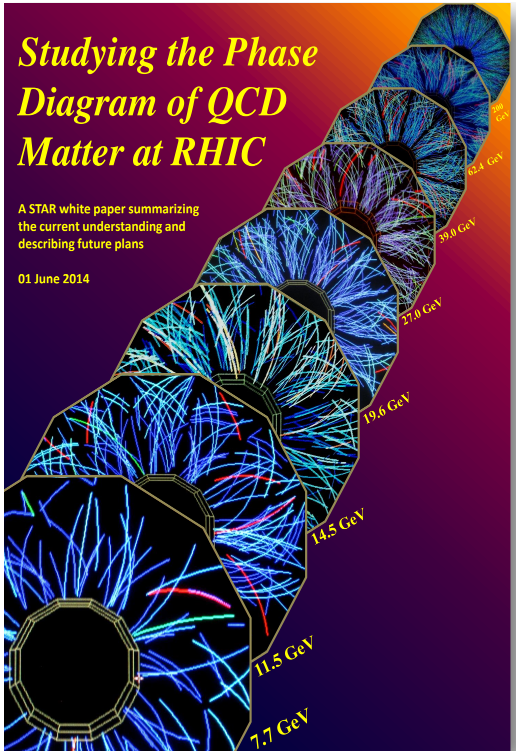
Single Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	Run Year	Run Time	Species	Min-Bias Events Number
5.75	3.5 (FXT)	2020	2 days	Au+Au	100M
7.3	3.9 (FXT)	2019	2 days	Au+Au	100M
9.8	4.5 (FXT)	2019	2 days	Au+Au	100M
13.5	5.2 (FXT)	2020	2 days	Au+Au	100M
19.5	6.2 (FXT)	2020	2 days	Au+Au	100M
31.2	7.7 (FXT)	2019	2 days	Au+Au	100M

+ added recently for run19:
3.0 GeV and 3.2 GeV



BES II

dedicated second phase proposed in 2014 (STAR note 598):



precision measurements in range √s = 7.7 – 19.6 GeV
smaller errors, maximize fraction particles measured
extension of energy range to √s = 3GeV (Fixed Target mode)
taking data in 2019, 2020 and 2021
detector + machine upgrades (higher luminosity)

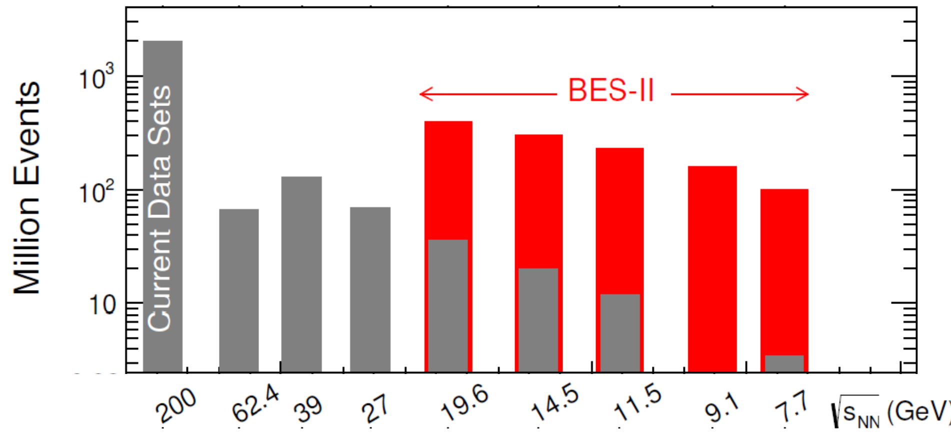
goal: turn trends and features into definite conclusions

BES II Proposal

Long Range Plan 2015

Strong endorsement by NSAC:

"Trends and features in BES-I data provide compelling motivation for […] experimental measurements with higher statistical precision from BES-II"



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

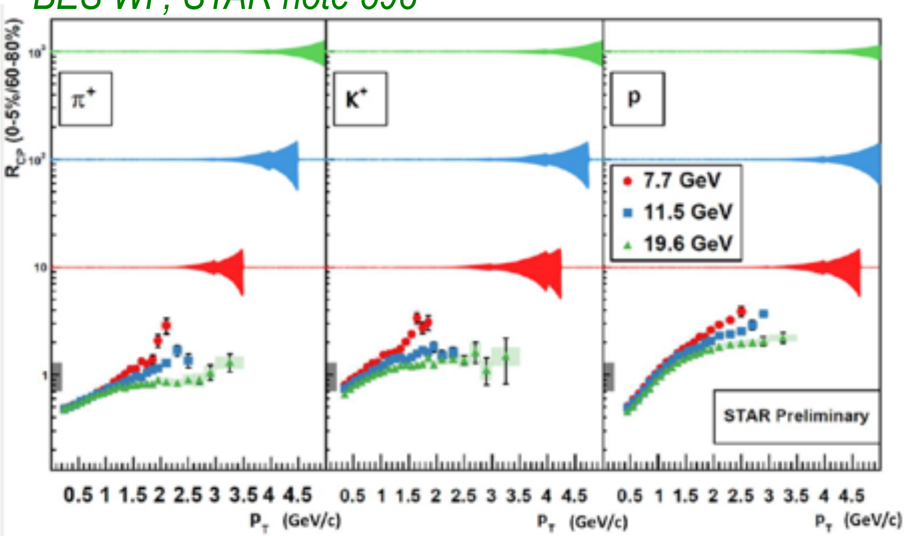
Table 2. Event statistics (in millions) needed for Beam Energy Scan Phase-II for various observables.

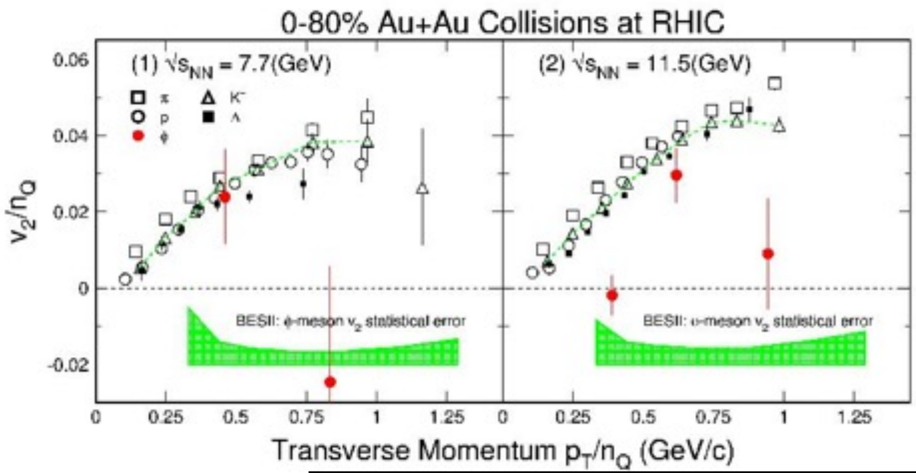
Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Observables					
R_{CP} up to $p_T = 5$ GeV/c	–		160	125	92
Elliptic Flow (ϕ mesons)	100	150	200	200	400
Chiral Magnetic Effect	50	50	50	50	50
Directed Flow (protons)	50	75	100	100	200
Azimuthal Femtoscopy (protons)	35	40	50	65	80
Net-Proton Kurtosis	80	100	120	200	400
Dileptons	100	160	230	300	400
Required Number of Events	**100**	**160**	**230**	**300**	**400**

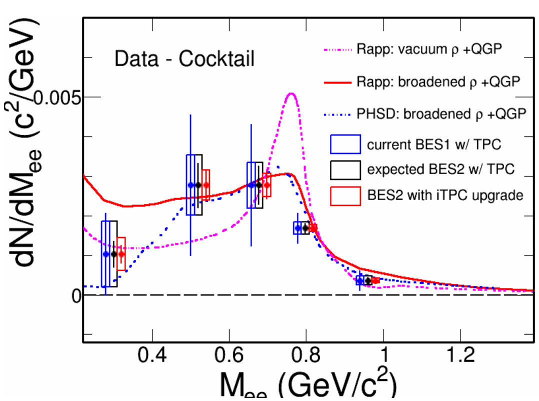
STAR Note 598

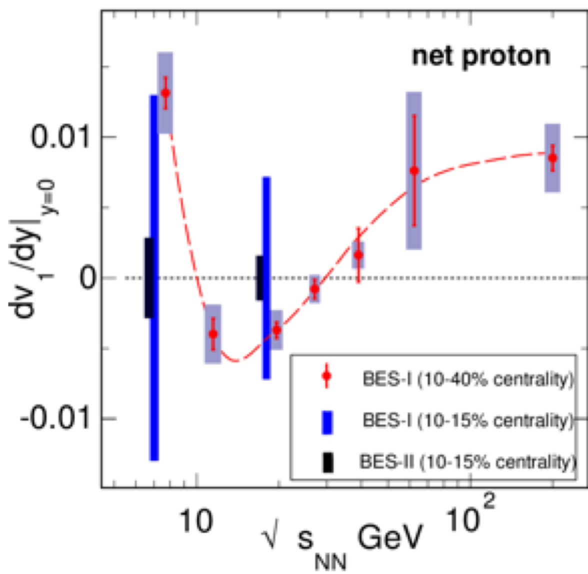
BES-II measurement uncertainties will be **SMALL**

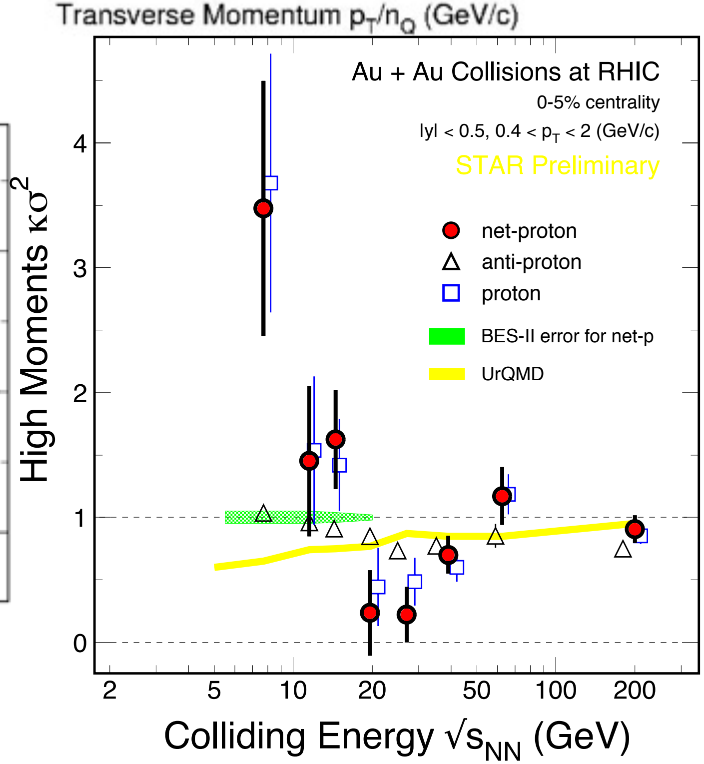
BES WP, STAR note 598









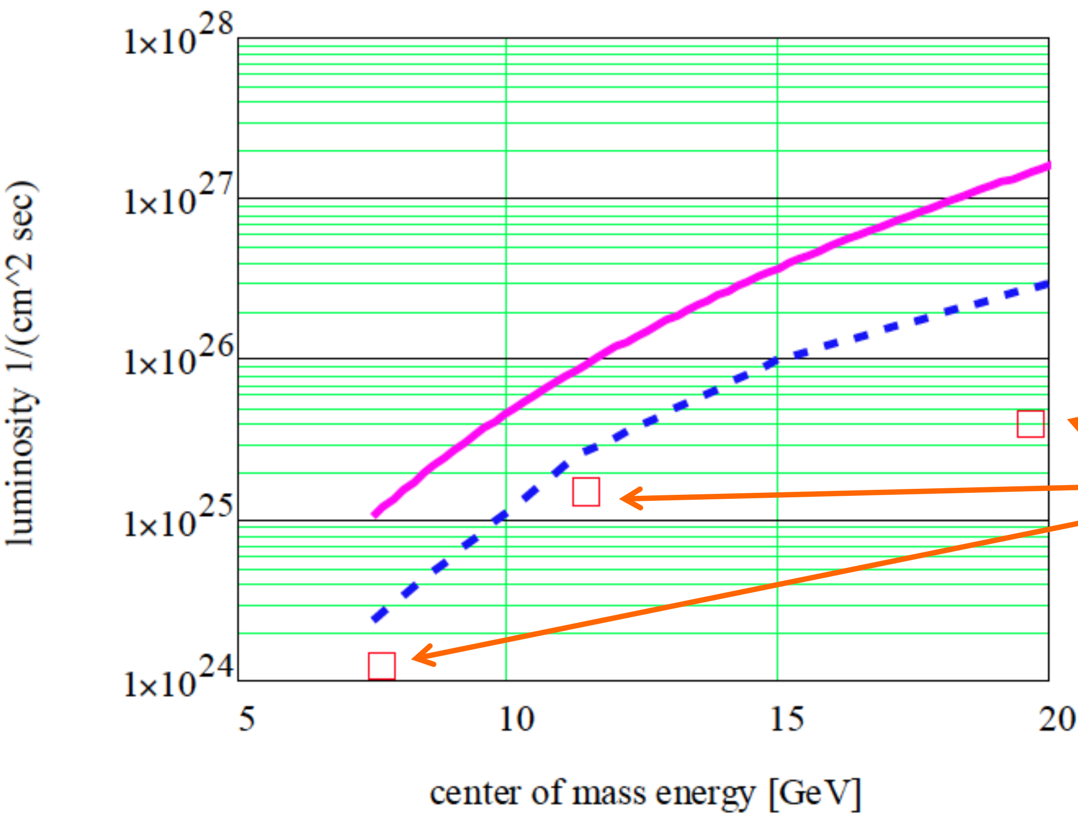


Improvements prepared for BES-II

- Accelerator improvements:
  - Luminosity
  - Electron cooling

- STAR detector upgrades
  - iTPC
  - eTOF
  - EPD

Luminosity improvements for BES-II



RHIC with e-cooling and long bunches (v_z = ± 1m)

Minimum projection (e-cooling only)

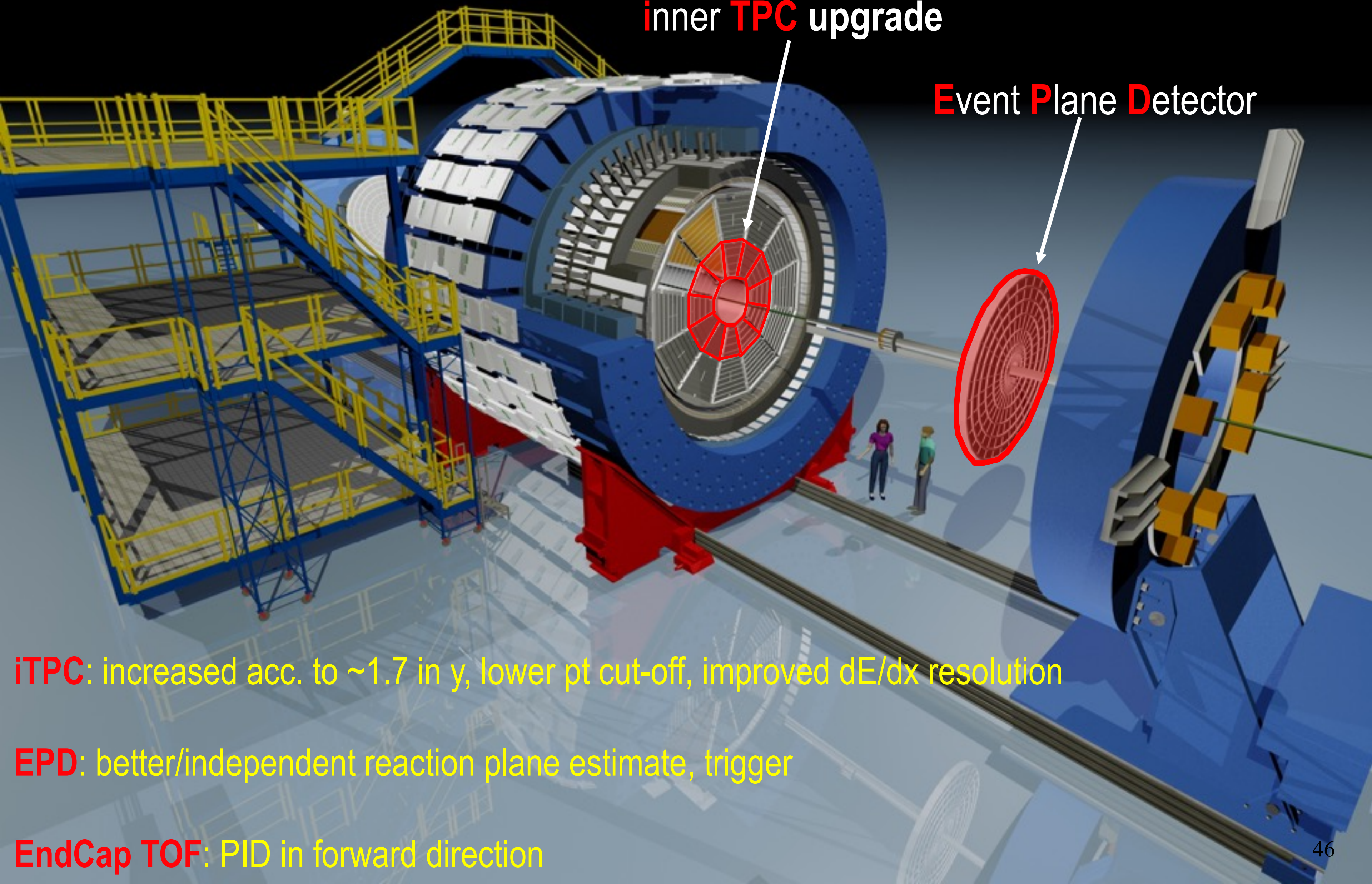
BES-I performance

Implementation:
2019 - $\sqrt{s_{NN}}$: 15 - 20 GeV
2020 - $\sqrt{s_{NN}}$: 7.7-11.5 GeV
2021 -

Electron cooling + longer beam bunches for BES-II provide factor 4-15 improvement in luminosity compared to BES-I

Every energy available with electron cooling

STAR Detector Upgrades for BES-II



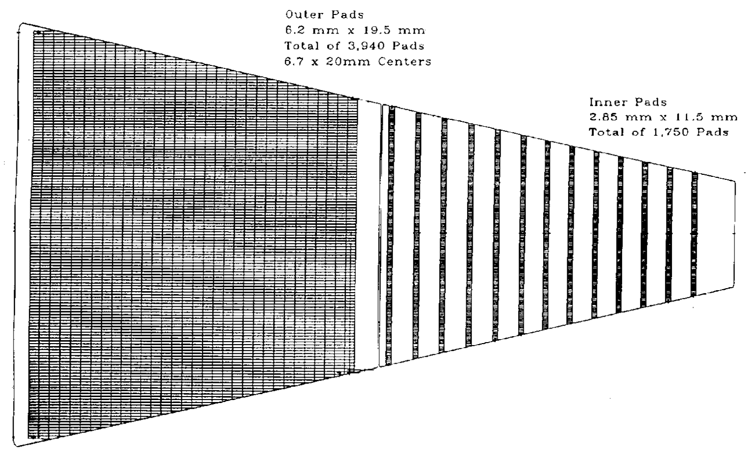
iTPC: increased acc. to ~1.7 in y, lower pt cut-off, improved dE/dx resolution

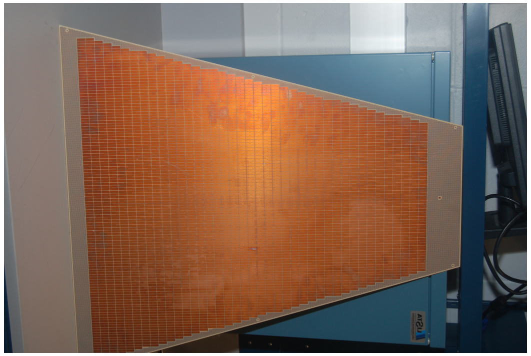
EPD: better/independent reaction plane estimate, trigger

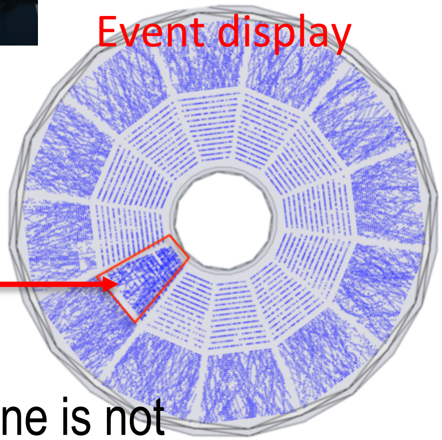
EndCap TOF: PID in forward direction

iTPC

Inner sectors upgrade







one sector has been installed in October 2017
data collected in 2018

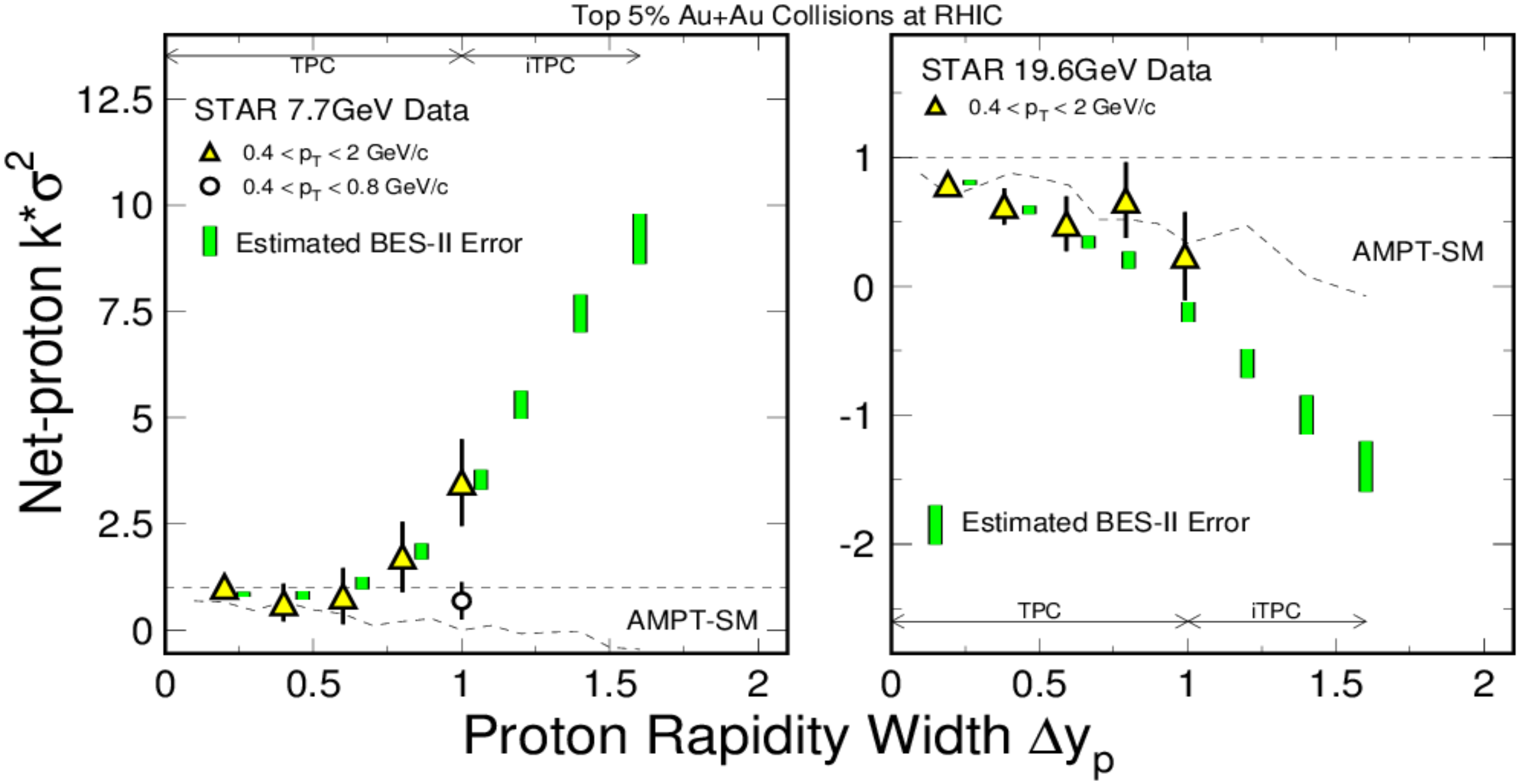
The outer pad plane have continuous tracking… while the inner pad plane is not

- Increase the segmentation on the inner pad plane, new electronics for inner sectors
- Renew the inner sector wires which are showing signs of aging

Better momentum resolution, better dE/dx resolution, and improved acceptance at high η
Old: $-1 < \eta < 1$ New: $-1.5\ (-1.7) < \eta < 1.5\ (1.7)$

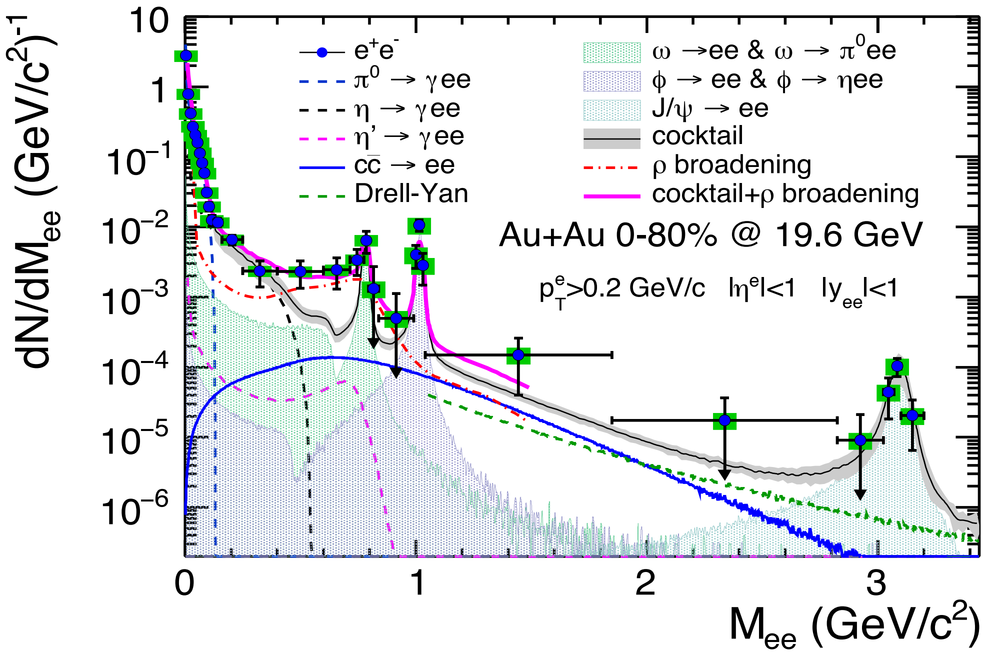
CP search – Kurtosis measurement

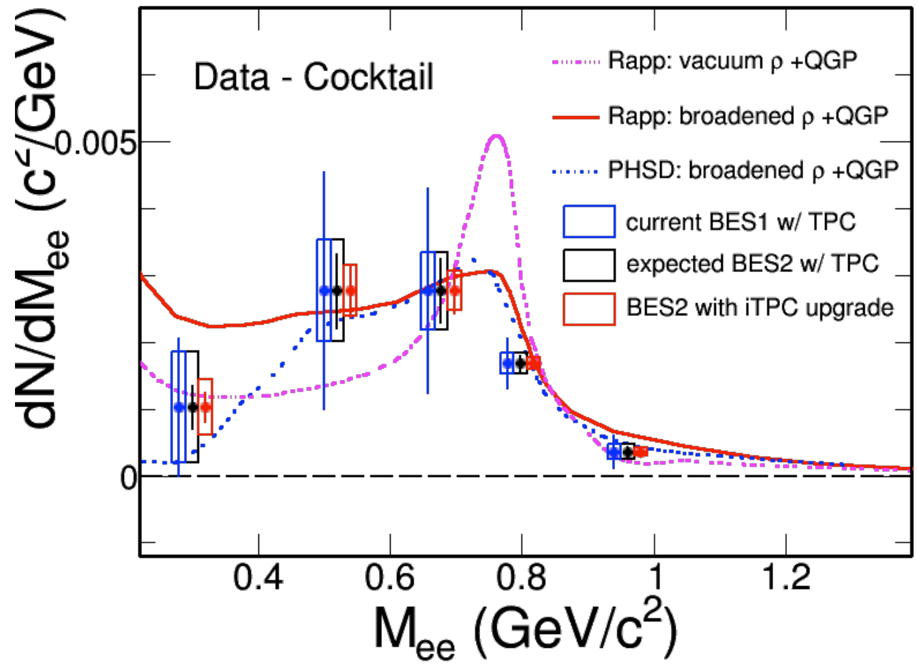
STAR note 619 : A proposal for iTPC upgrade



- Non-trivial energy dependence from BES-I
- Rapidity length of correlation is important
- Enlarged rapidity window enables high significance measurement of net-proton high moments (enhanced sensitivity of iTPC with increase of rapidity window)

Di-electron measurements





Systematic study of di-electron continuum from $\sqrt{s_{NN}}$ 7.7 to 19.6 GeV

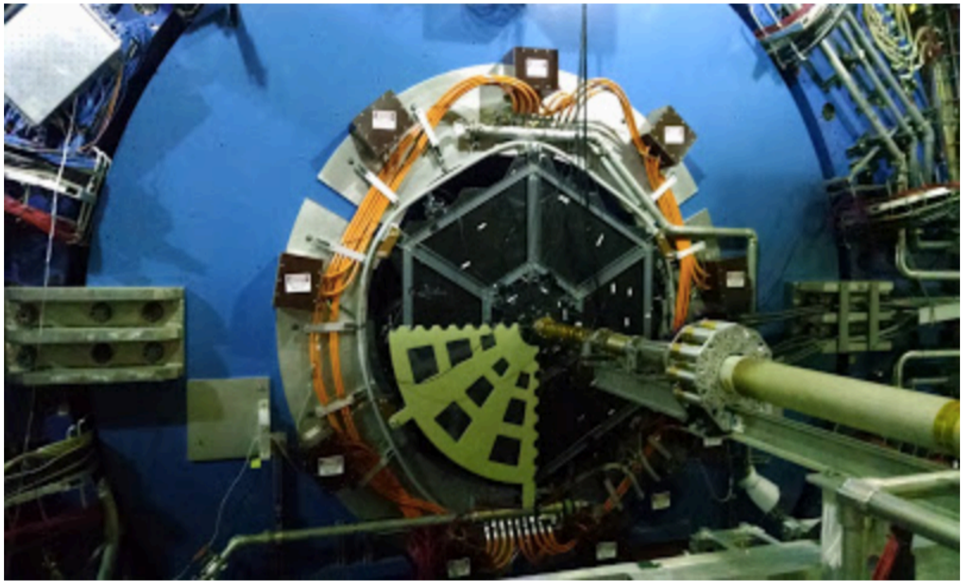
Low Invariant Mass Range (LMR) excess

iTPC upgrade : reduced systematic (improved PID) and statistical uncertainties

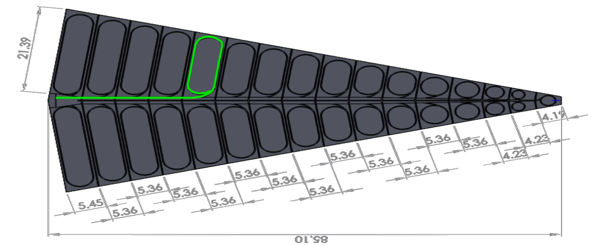
- study baryon density effect on LMR excess yield
- distinguish models with different ρ-meson broadening mechanism
- study low-p_t enhancement

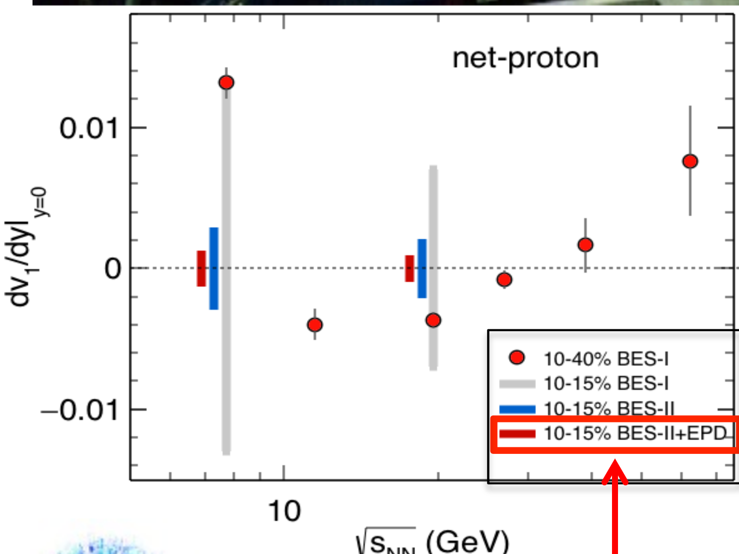
EPD

Event Plane Detector (EPD)



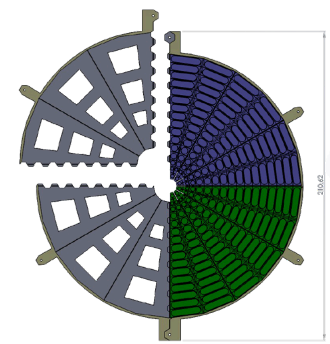
Trapezoidal tiles : 2 wheels, 12 super sectors
2 x 372 channels
Coverage: 2.1 <|η|<5
SiPM readout <1nsec timing resolution





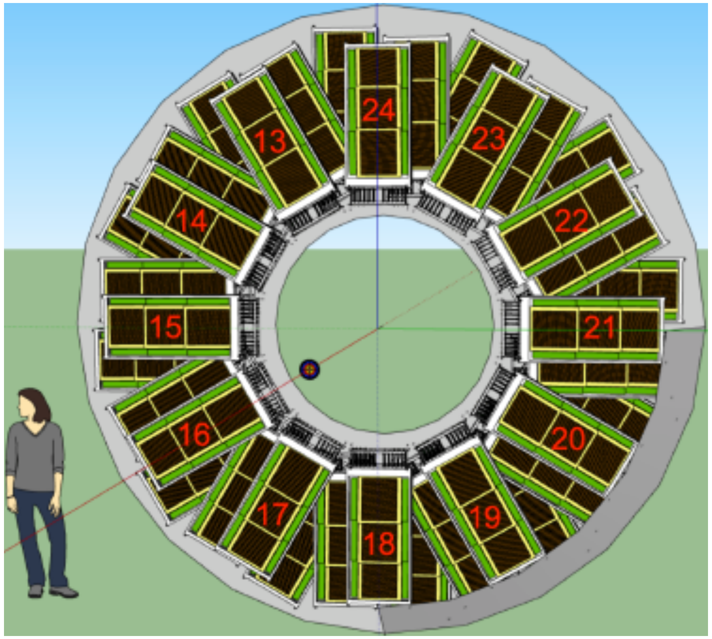
directed flow expected improvement

Improves:
Event plane determination
Centrality definition
Triggering



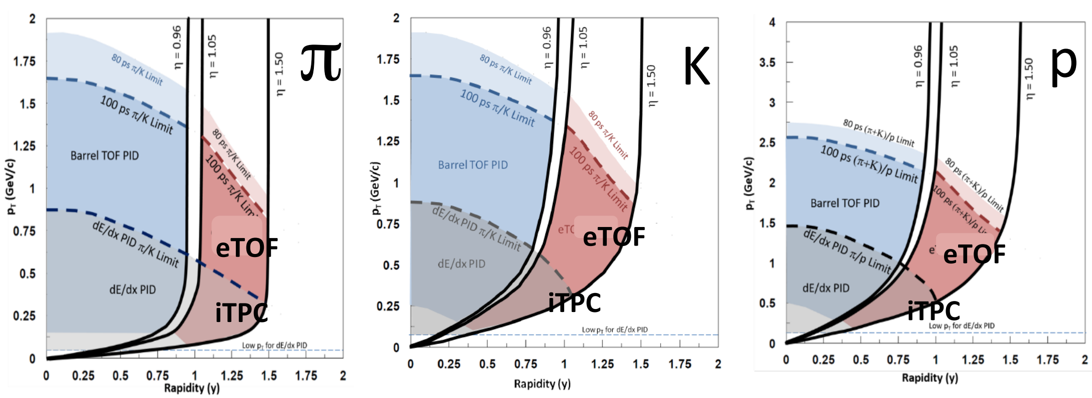
Installed in STAR in 2017
and took successfully data in 2018

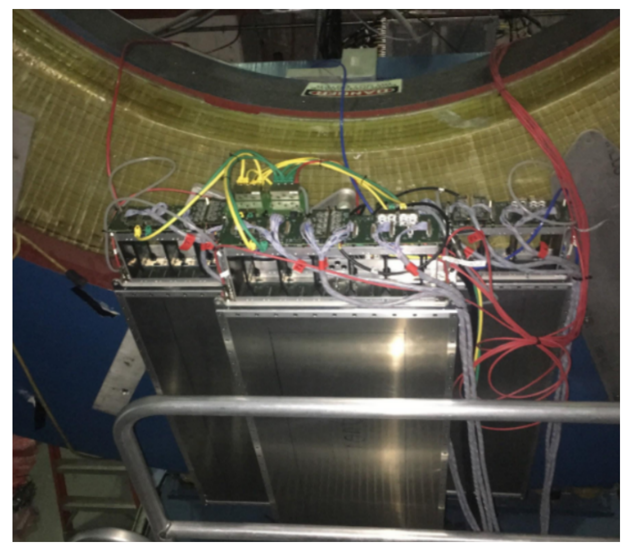
Endcap Time-Of-Flight (eTOF)



Installed on one side of STAR; part of FAIR Phase-0
36 modules in 3 layers matched to 12 TPC sectors
Long strip MRPC readout
Multiple hit probability <7.4 %
Provide TOF PID in $1.1<\eta<1.6$
Operation experience for CBM effort

One sector with 3 modules have been installed for run in 2017 and took successfully data
Full installation in November 2018





Significant extension of PID due to eTOF

Readiness of BES-II

3 year BES-II program 2019-2021 just starting

First BES-II run in 2019

run19: 19 and 14.5 GeV - will start from higher energies

run 20: 11.5, 9.1, 7.7 (part of) GeV - electron cooling available from 2020

run21: 7.7 GeV (finish)

STAR and STAR upgrades will be ready to take data on time

iTPC and eTOF installation will be completed before March 2019

EPD already installed and commissioned in 2018 run

Summary

Data exists over wide range of $\sqrt{s}$ for heavy & light ions, p(d), and pp

High statistics exploration of QCD phase diagram and its key features is about to begin

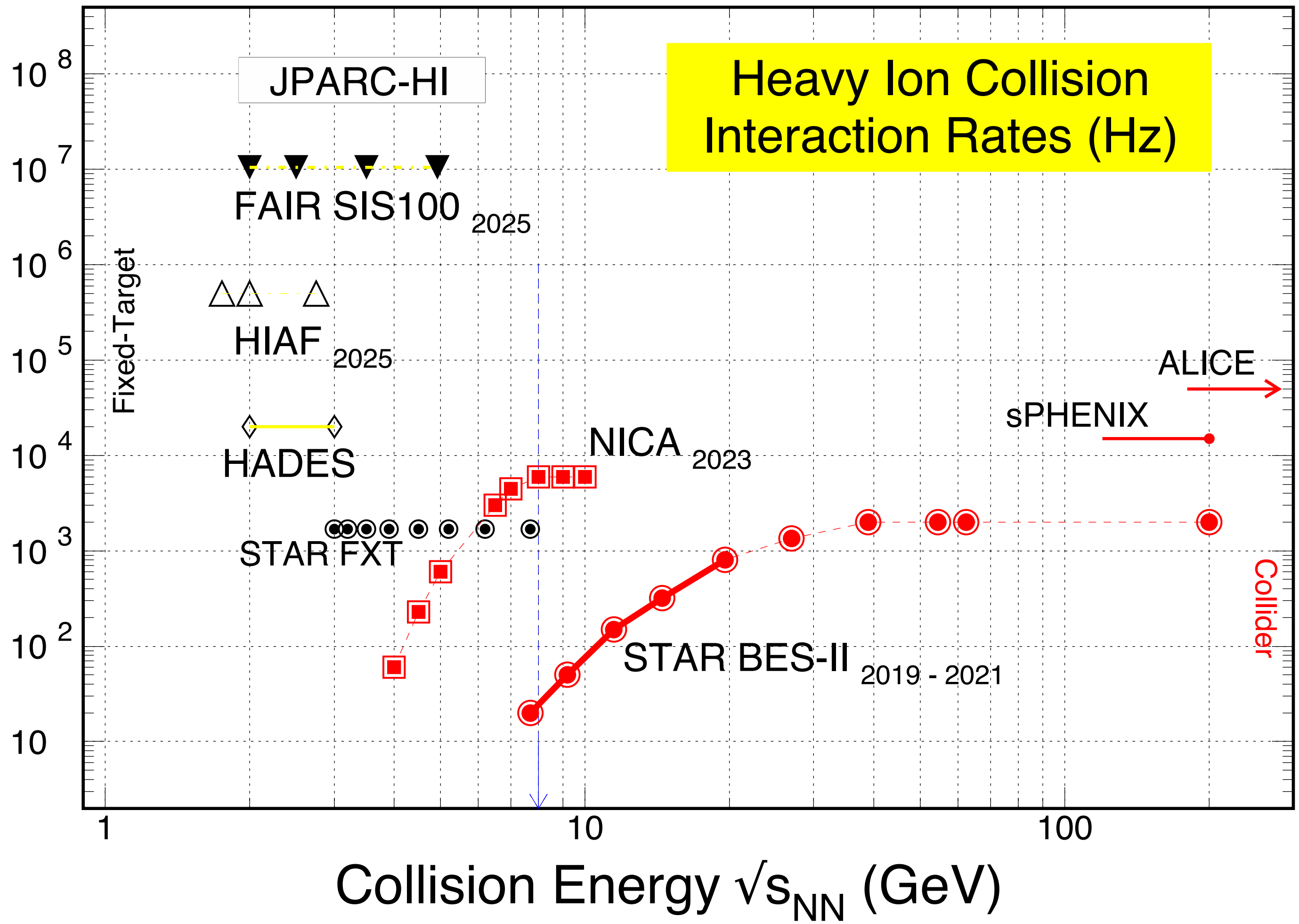
Wealth of data in hand and more coming soon (RHIC, SPS, NICA, FAIR)

Significant upgrades to detection capabilities compare to existing data

Strong theoretical interest focused in BEST and HICforFAIR

Turn trends and features into definite conclusions

present / future :



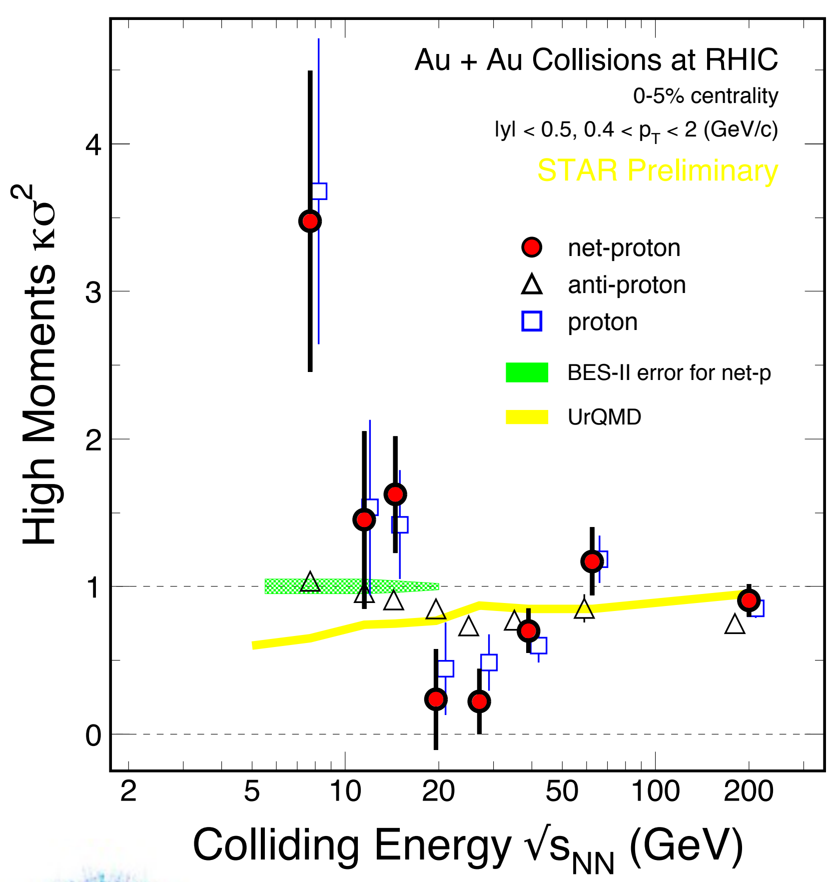
Thank you !

Higher moments in BES I

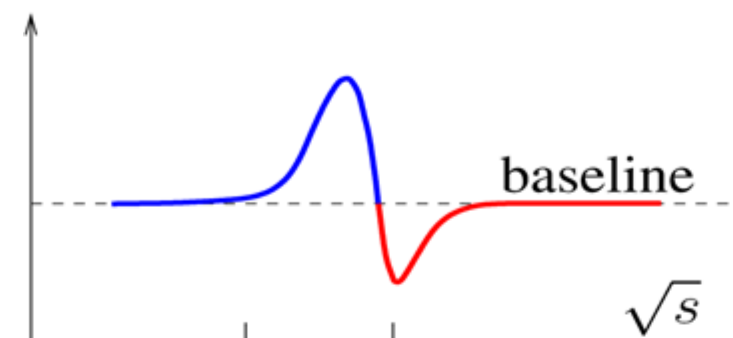
Excitation function for net-proton high moments ($\kappa\sigma^2$) in 5% most central Au+Au

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