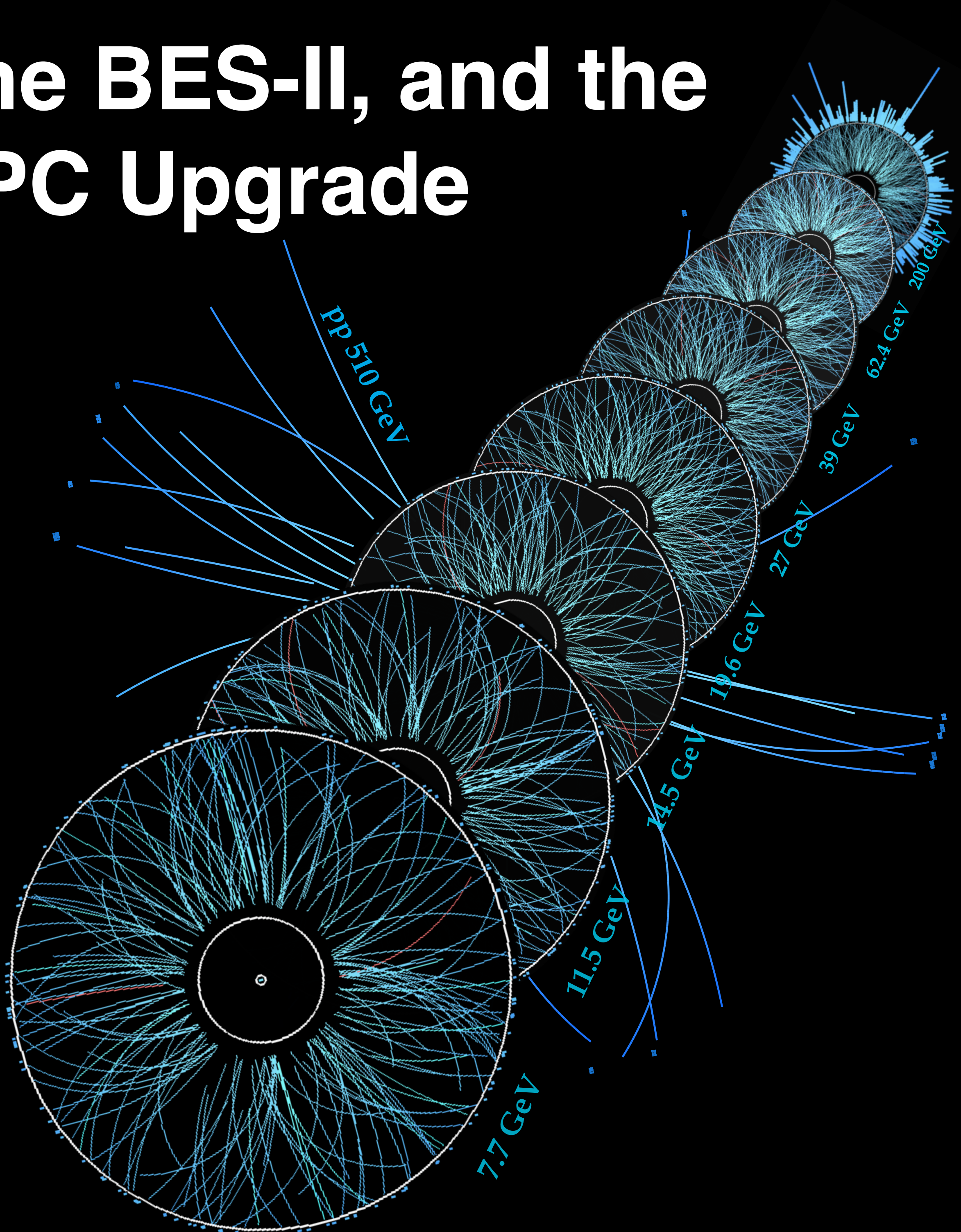
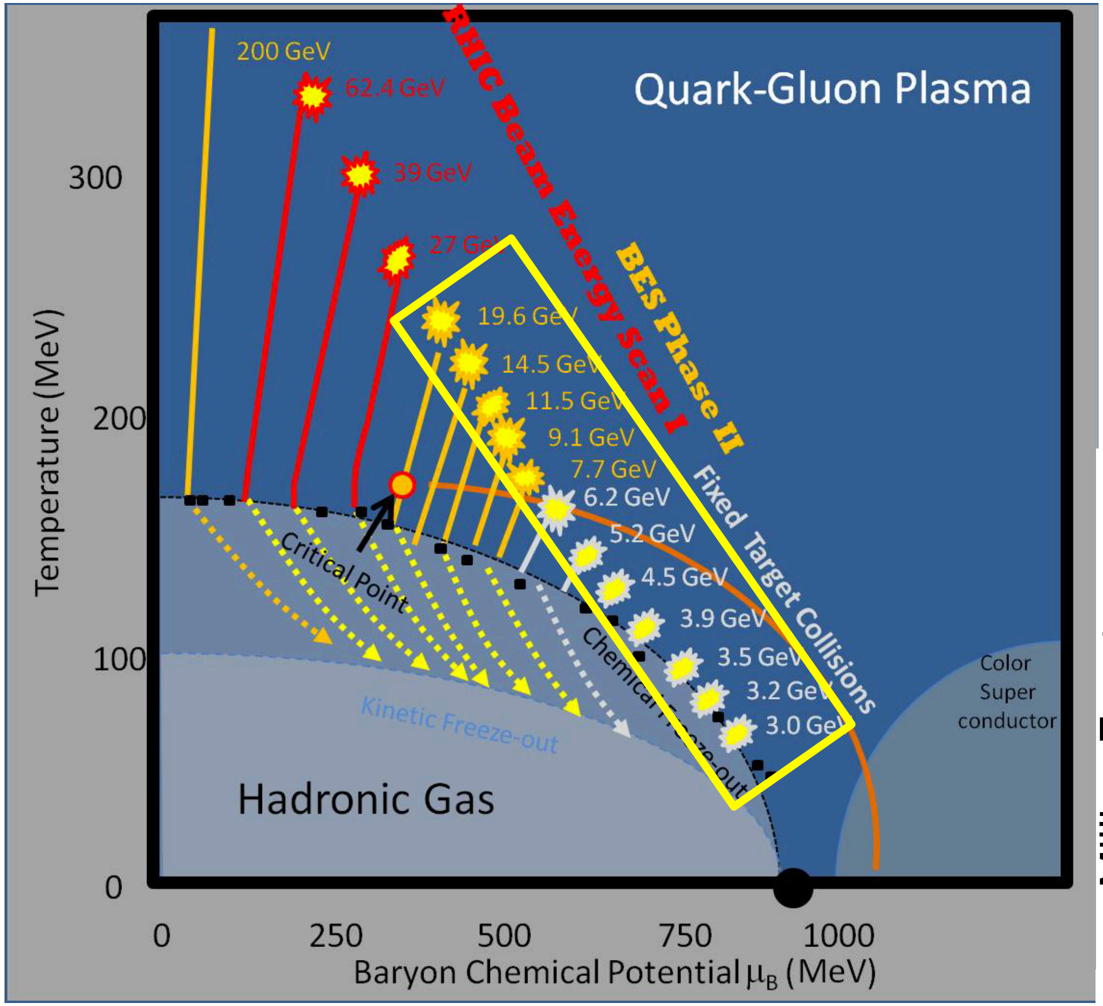
STAR, the BES-II, and the iTPC Upgrade



Helen Caines
Yale

BNL-PAC
June 2016

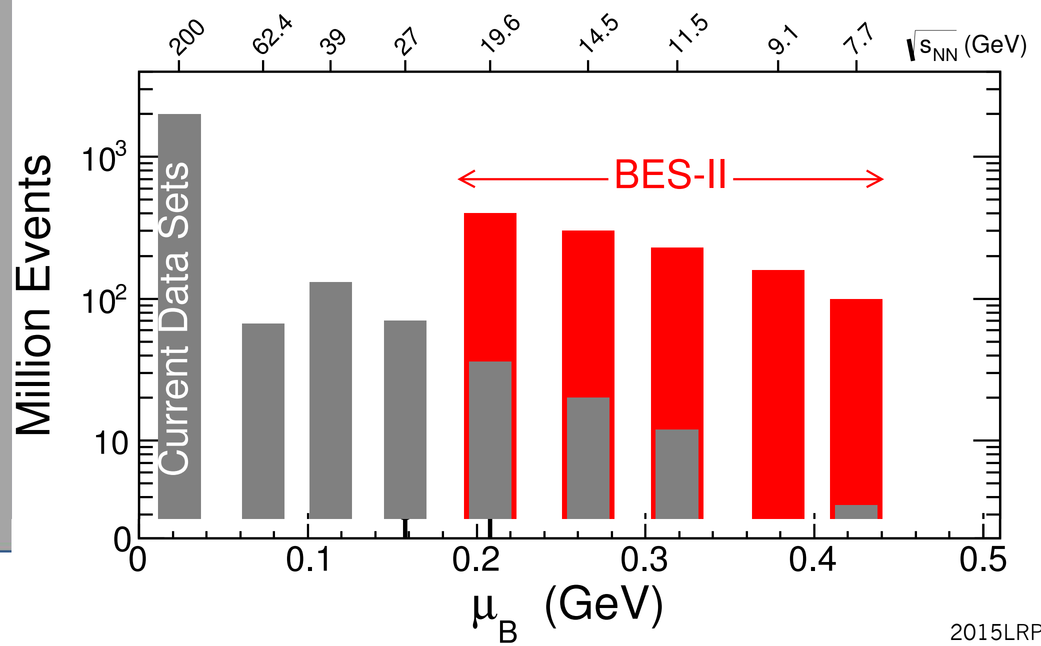
BES-I → BES-II



BES-I:

Hints that at low √s

- QGP turns off
- 1^{st} order phase transition
- Critical Point
- Chiral symmetry restoration

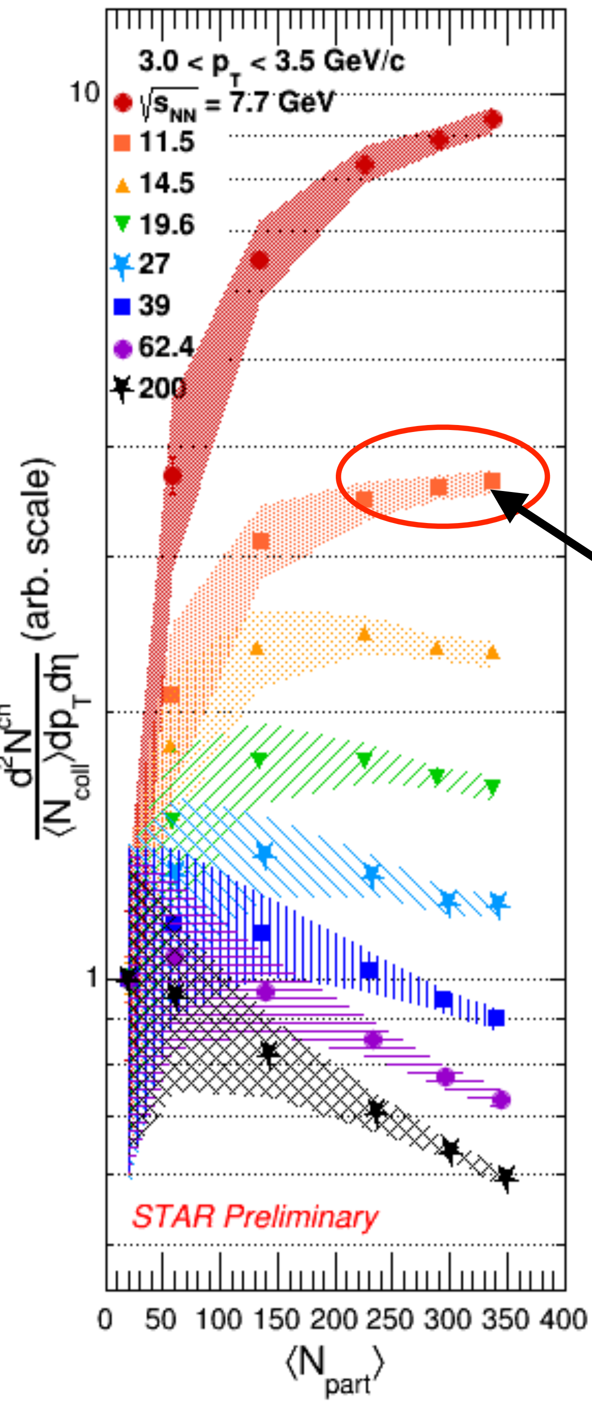


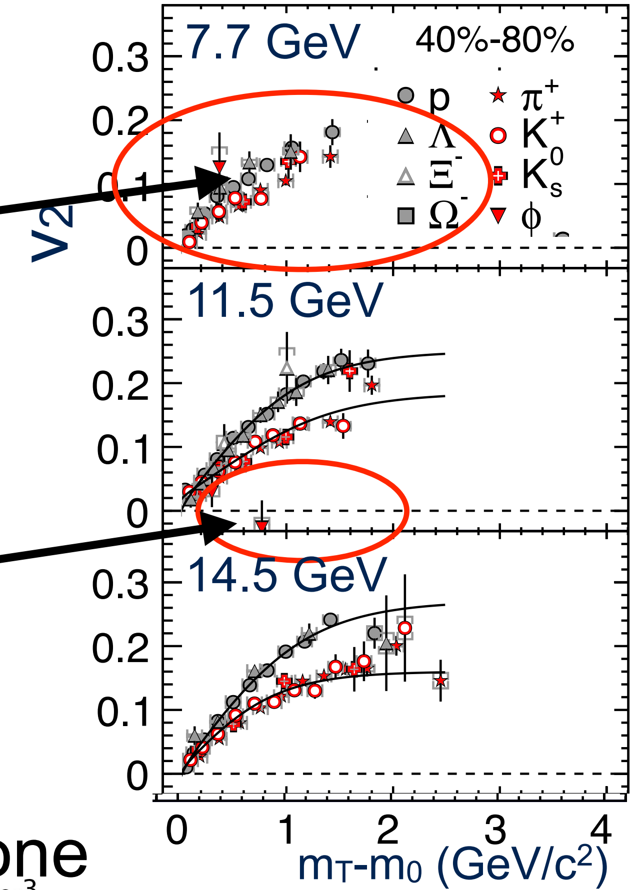
BES-II:

- Examine regions of interest
- Maximizing fraction particles measured
- Probe lower √s - (e Cooling/fixed target)

Turn trends and features into definitive conclusions

Disappearance of QGP?



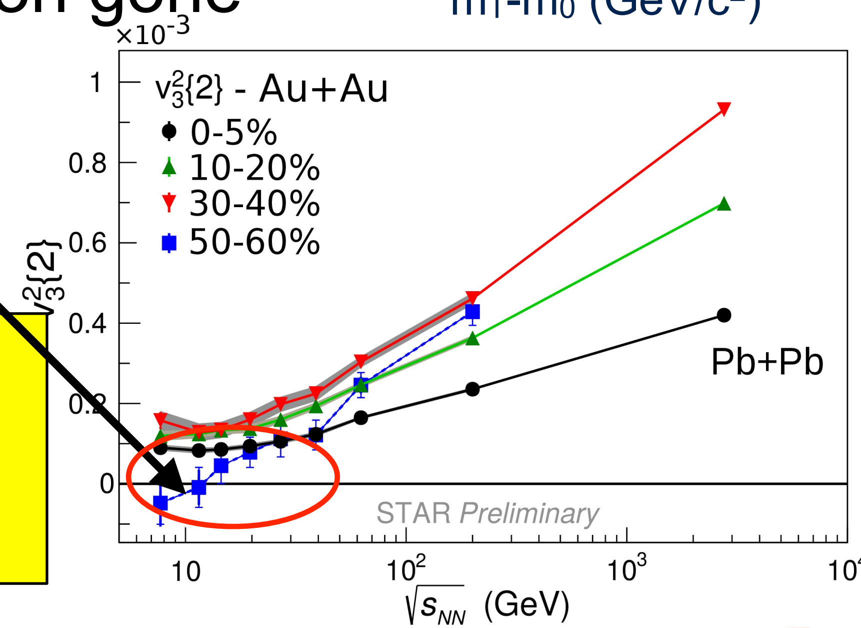


B-M v_2 separation gone

φ v_2 ~ 0

High p_T suppression gone

v_3 ~ 0



Several standard signals disappear at √s ~ 15 GeV

First Order Phase Transition?

Beam energy baryon dv_1/dy trend complex interplay of:

v_1 baryons transported from beam

v_1 from pair production

Net-Proton isolates directed flow of transported:

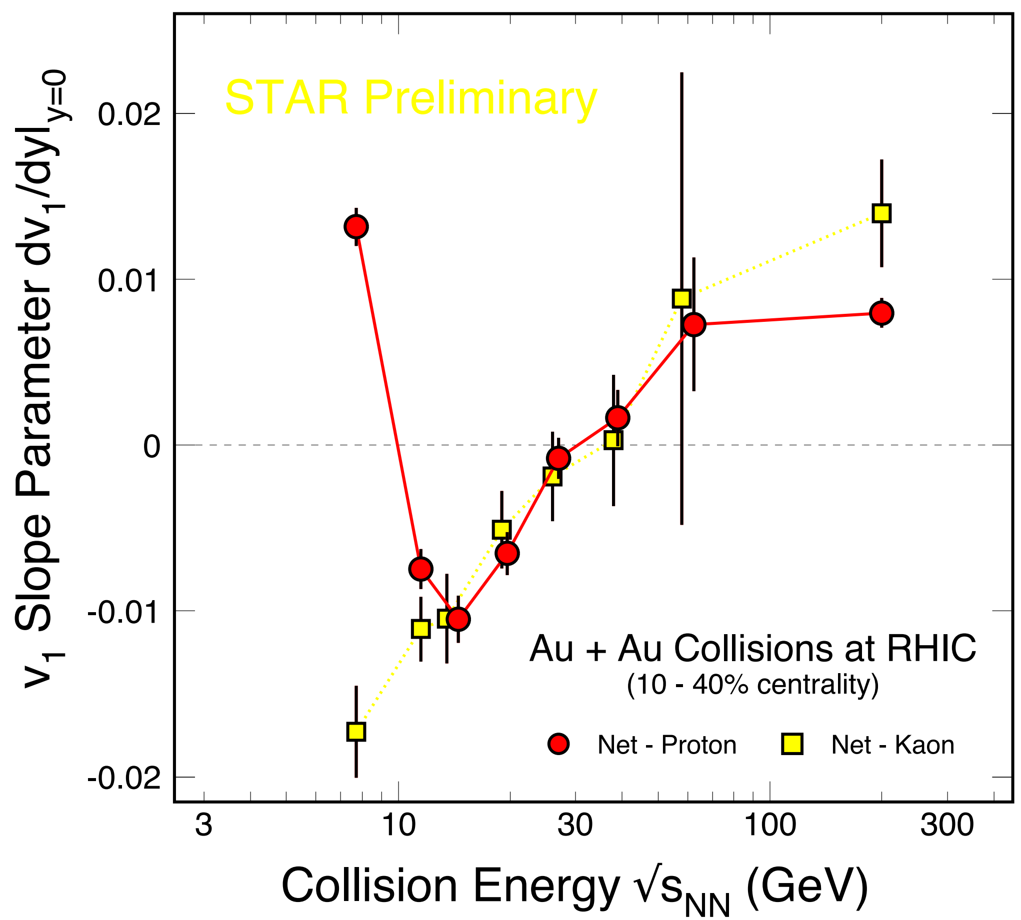
Double sign change in dv_1/dy

14.5 GeV in published trend

Not seen in kaons

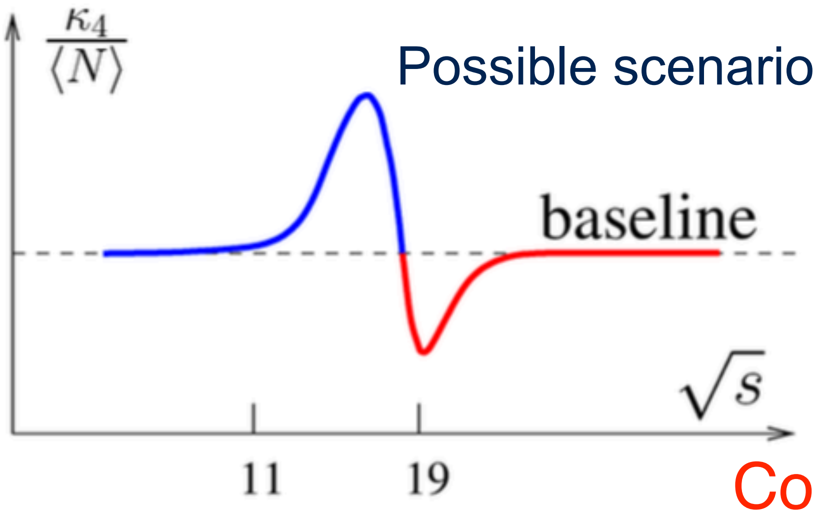
Many transport models have monotonic trend

PRL 112,162301 (2014)



Softening of EoS ?

Presence of Critical Point?



Critical Points:

divergence of susceptibilities

e.g. magnetism transitions

divergence of correlation lengths

e.g. critical opalescence

Correlation lengths diverge → Net-p $\kappa\sigma^2$ diverge

Top 5% central collisions:

Non-monotonic behavior

Enhanced p_T range → enhanced signal

Peripheral collisions:

smooth trend

5-10% central collisions:

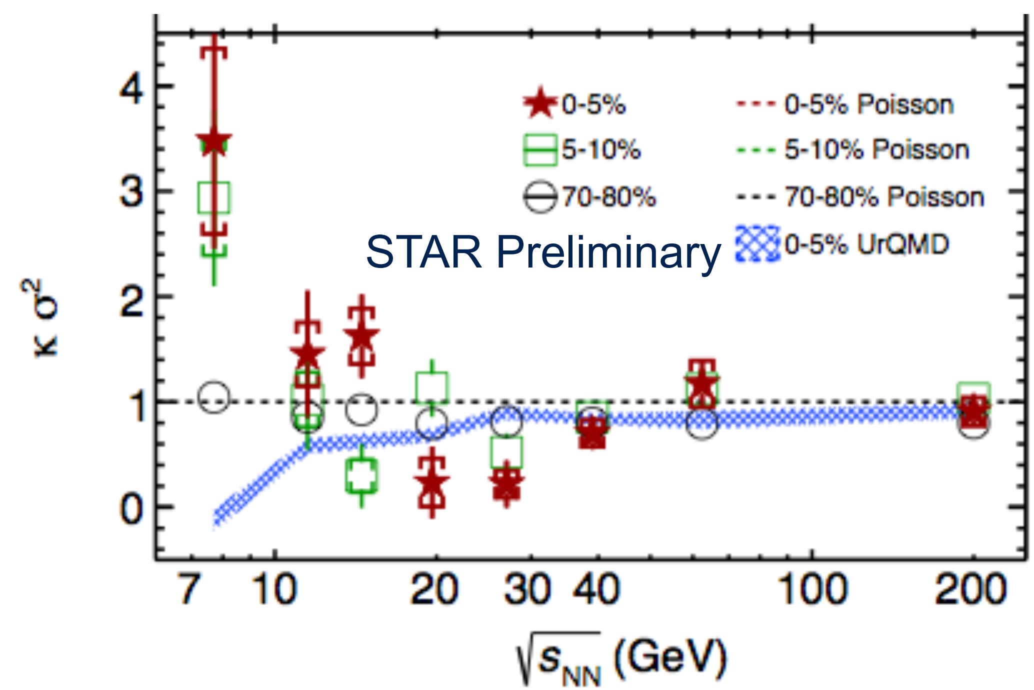
in between

UrQMD (no Critical Point):

shows suppression at lower energies

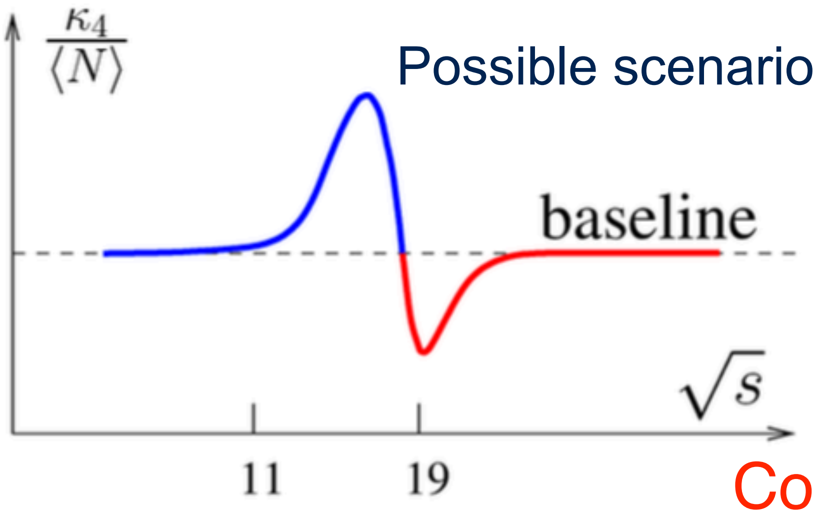
- due to baryon number conservation

Hints of Critical fluctuations



STAR PRL 112 (2014) 32302

Presence of Critical Point?



Critical Points:

divergence of susceptibilities

e.g. magnetism transitions

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e.g. critical opalescence

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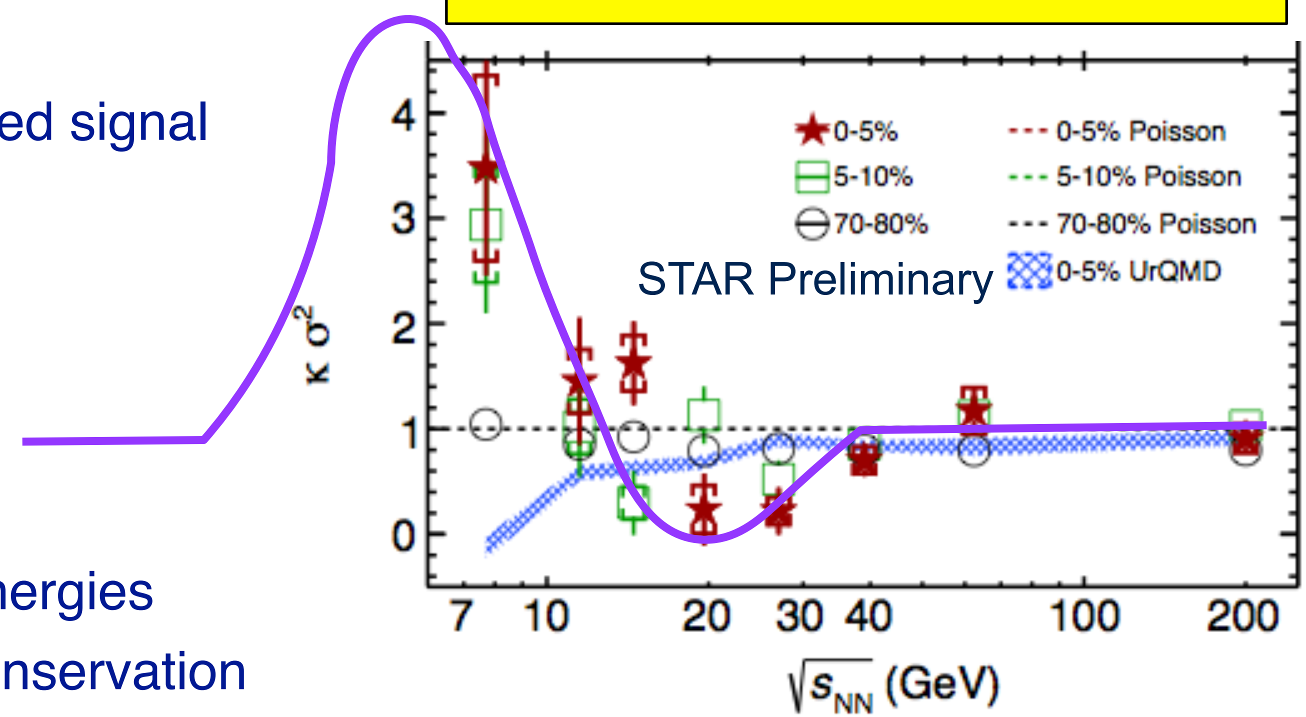
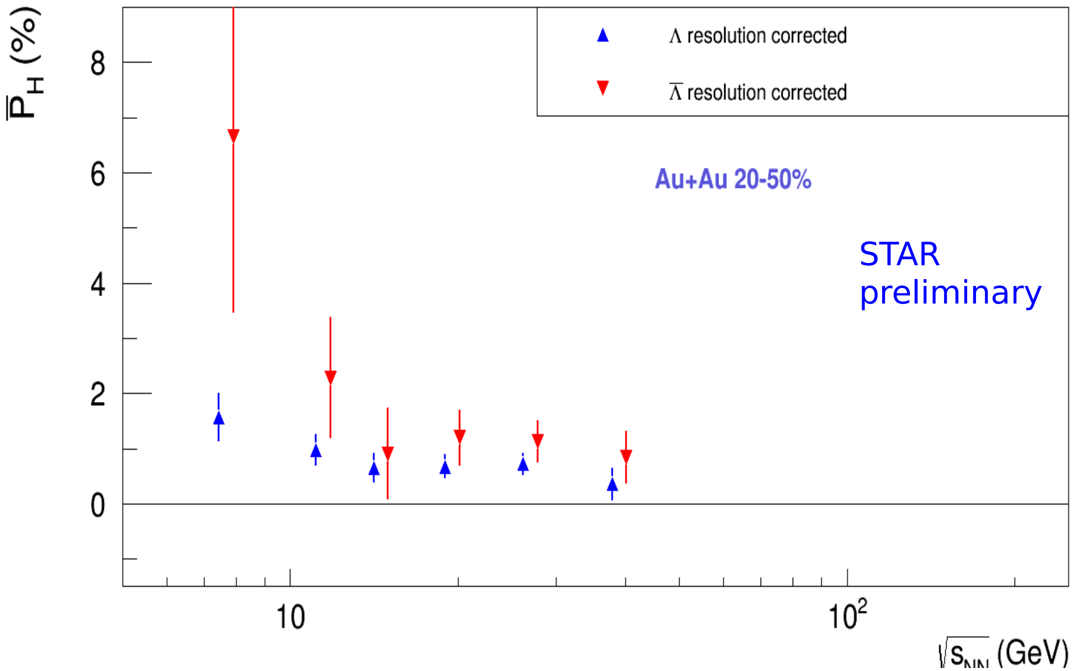
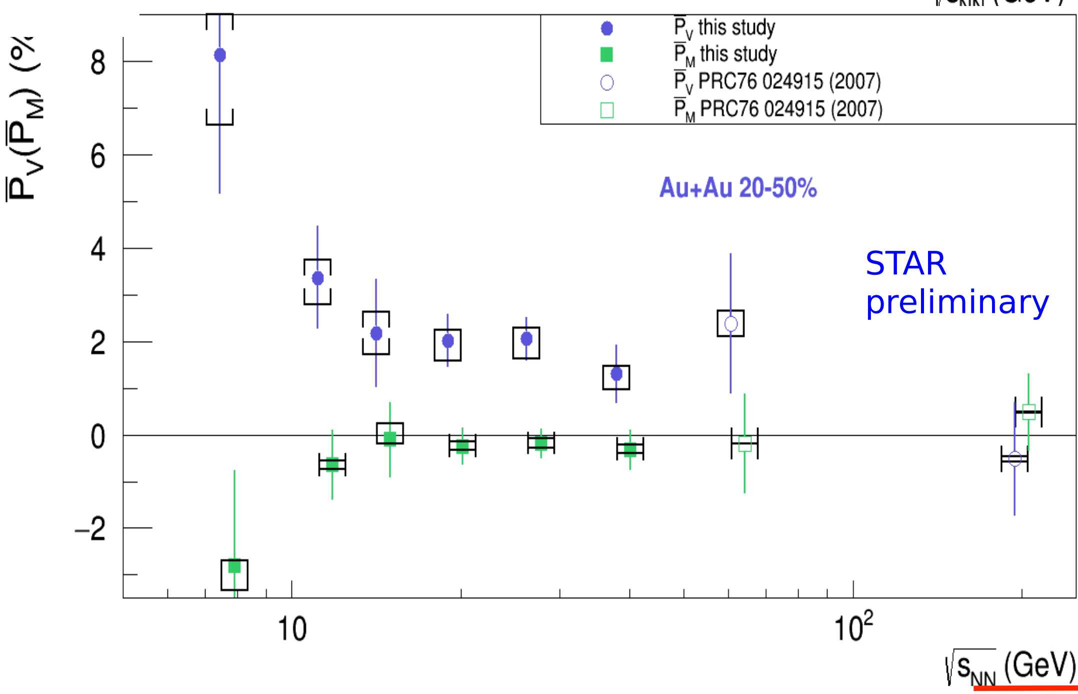


STAR PRL 112 (2014) 32302

The spinning QGP





Marginal significance for each energy

Ensemble and trend add confidence

anti-Λ > Λ

Both EM and vorticity

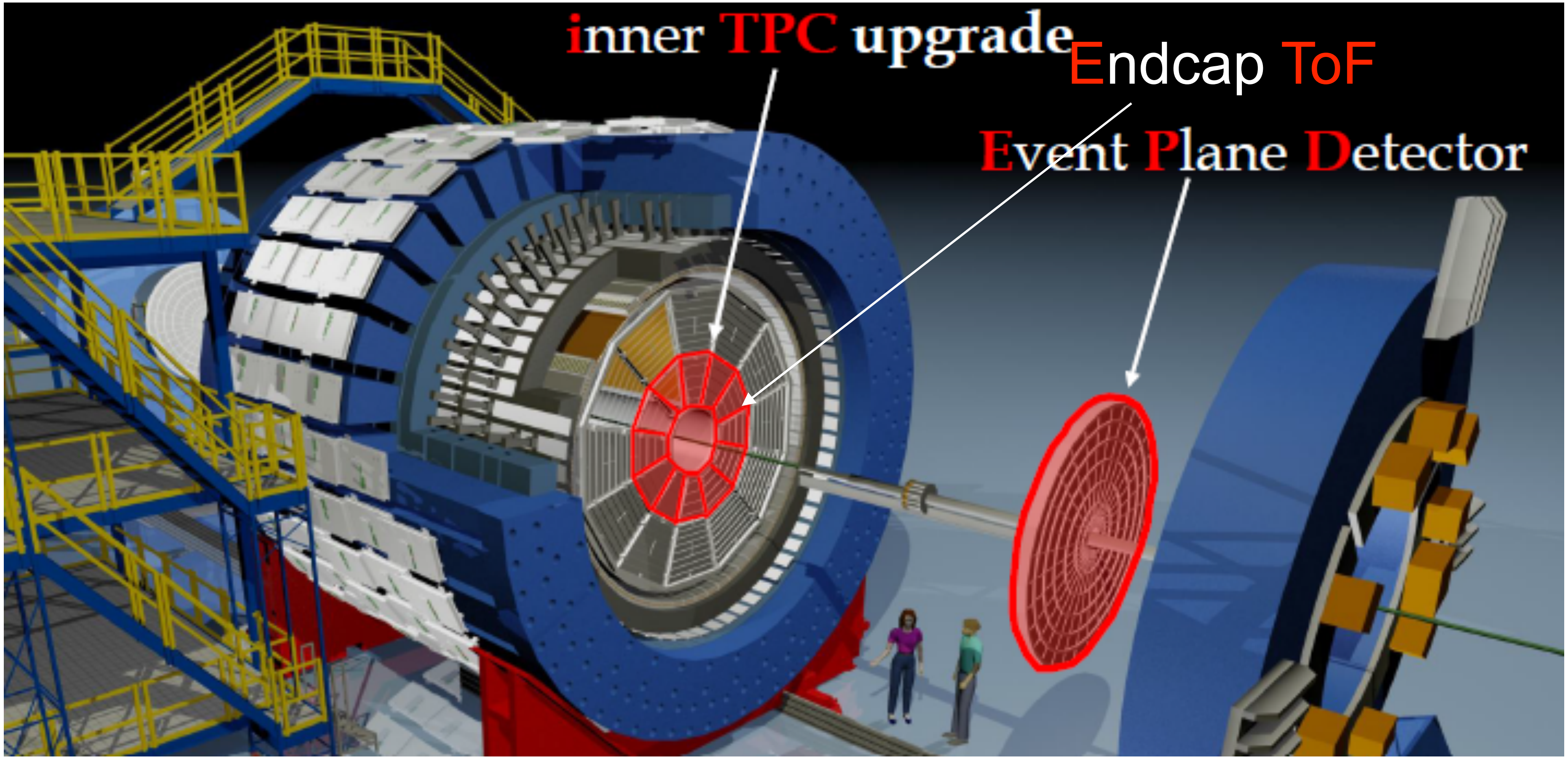
$$P_{vortical} = \frac{1}{2}(P_\Lambda + P_{\bar{\Lambda}})$$

$$P_{EM} = \frac{1}{2}(P_\Lambda - P_{\bar{\Lambda}})$$

First observation of global hyperon polarization

Feeddown corrected

STAR upgrades for BES-II



Enhanced Acceptance
Enhanced PID
Enhanced Event Plane Resolution
Enhanced Centrality Definition

⟺ iTPC, EPD, eTOF

iTPC: Approved Project

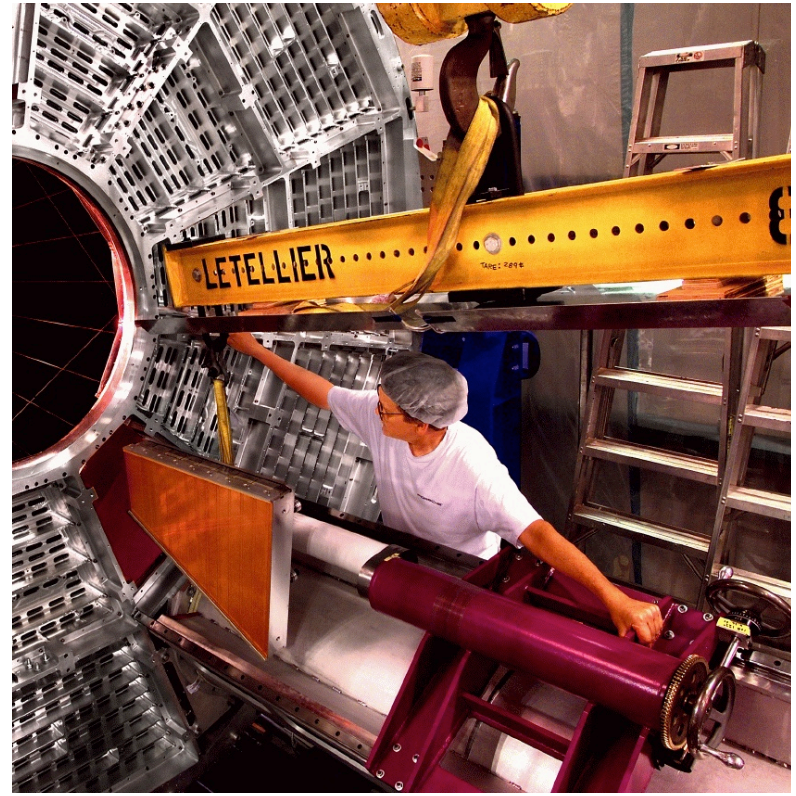
Increase in #channels in 24 inner sectors by ~factor 2

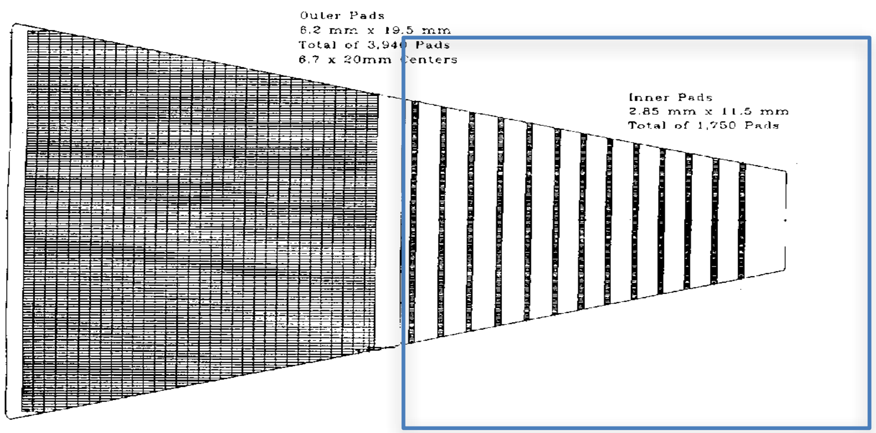
Provides near complete coverage

New electronics for inner sectors

Enhanced rapidity coverage

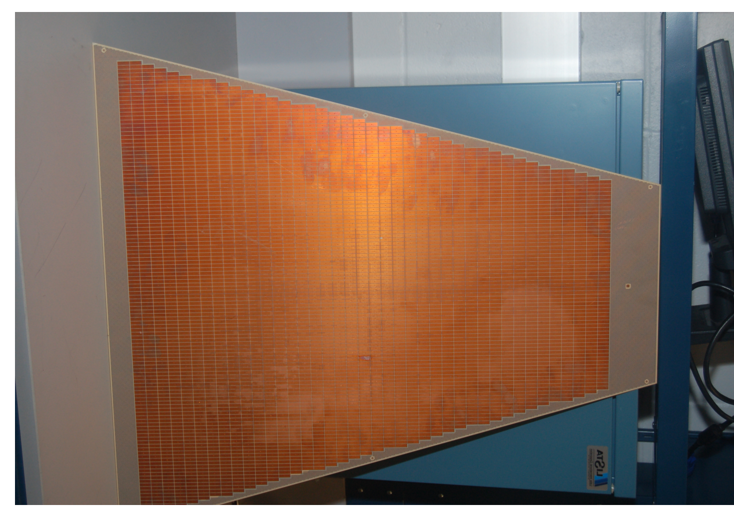
Old	New
	better *dE/dx*;
$-1 < \eta < 1$	$-1.5 < \eta < 1.5$;
p_T >125 MeV/c	p_T > 60 MeV/c.





Outer

Inner

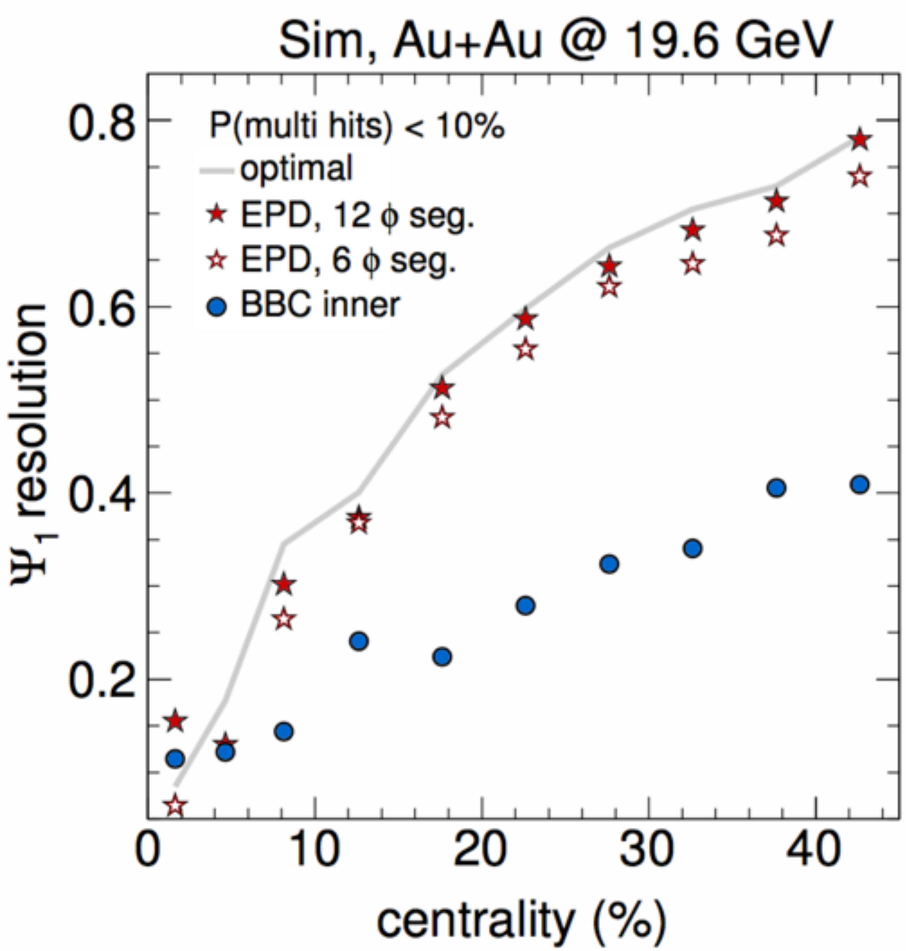


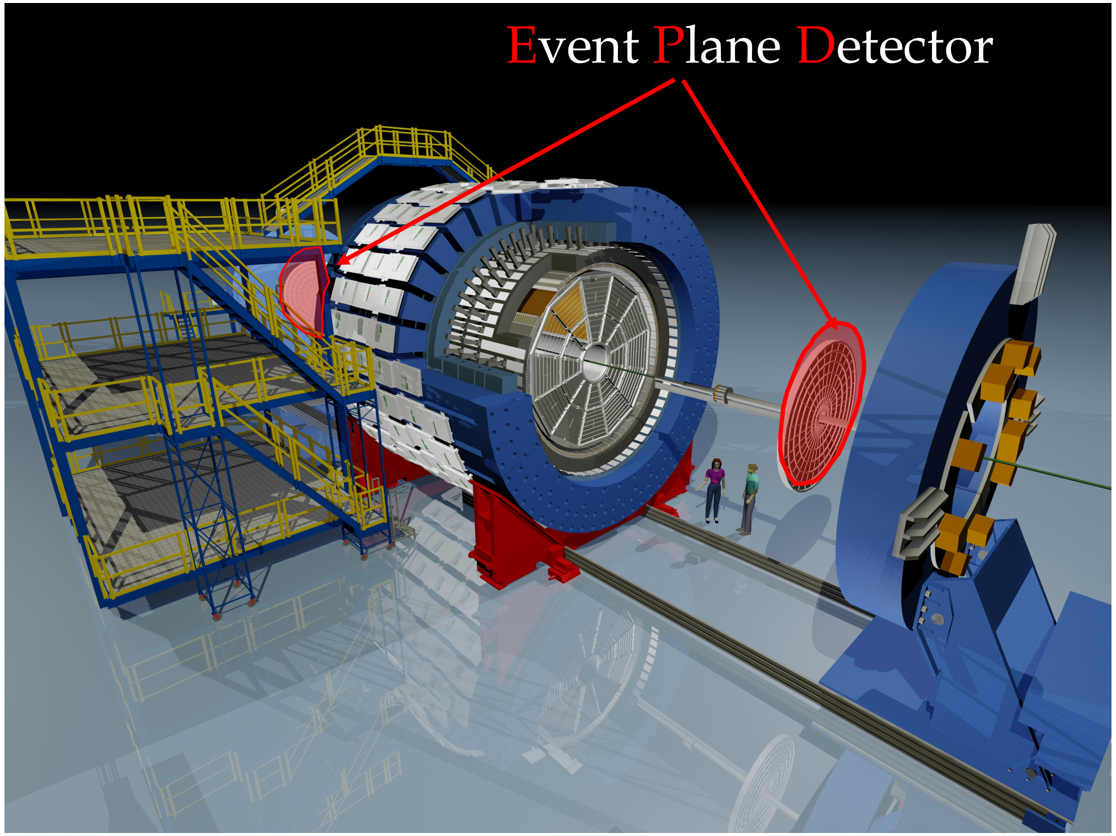
Event Plane Detector: EPD

2.1 < |η| < 5.0

Replacing BBCs

Proposal approved by STAR





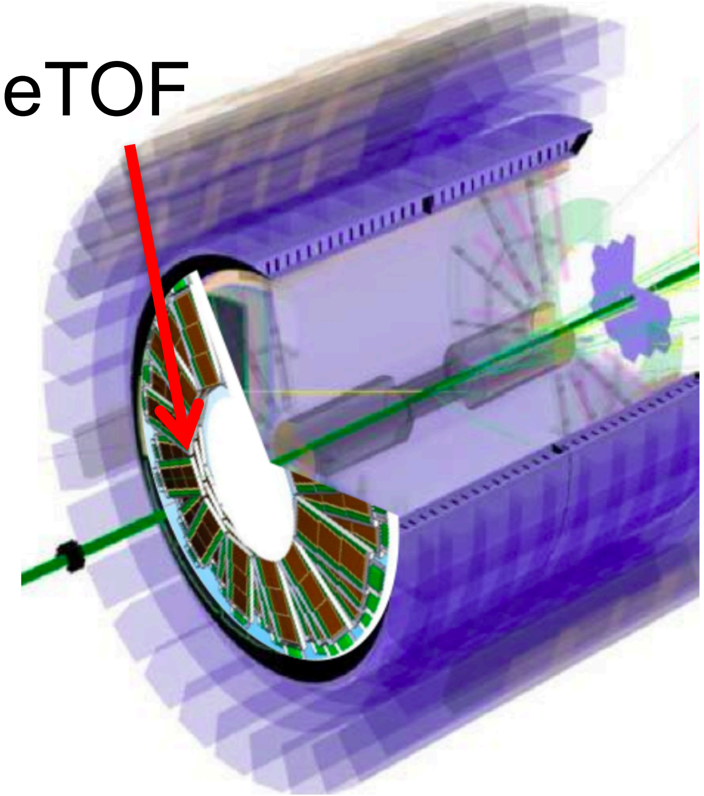
Greatly improved Event Plane Resolution

especially 1st-order EP

Determine Centrality away from mid-rapidity

Better trigger & background reduction

Endcap Time-Of-Flight: eTOF



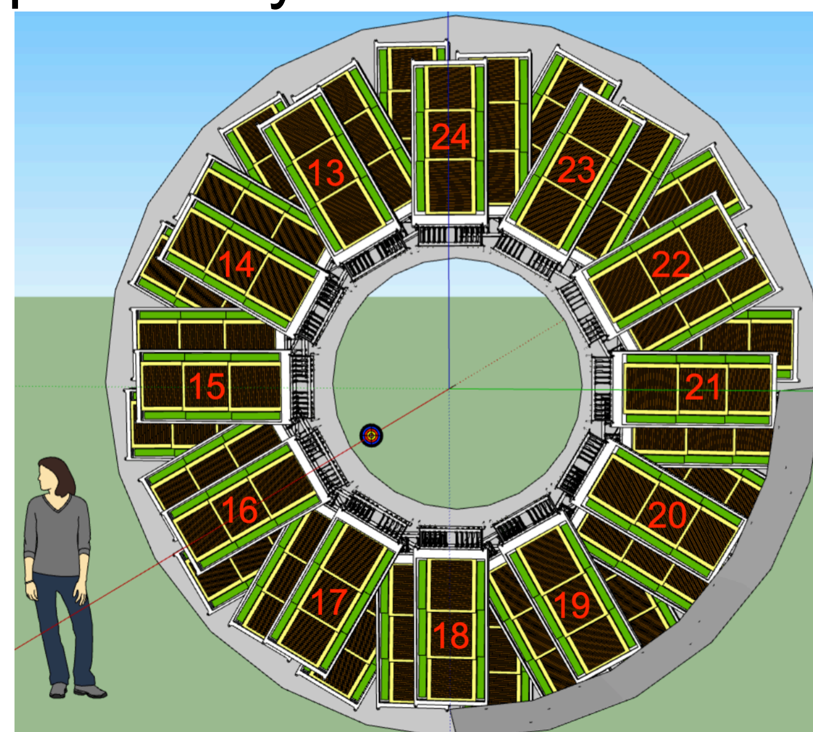
Forward PID over iTPC η range

$-1.6 < \eta < -1.1$

TPC dE/dx effic. drops rapidly in this range due to p_Z boost

LOI prepared between institution

Proposal approved by STAR



Compressed Baryonic Matter Experiment (CBM)

- 1/10th TOF modules installed inside East pole-tip

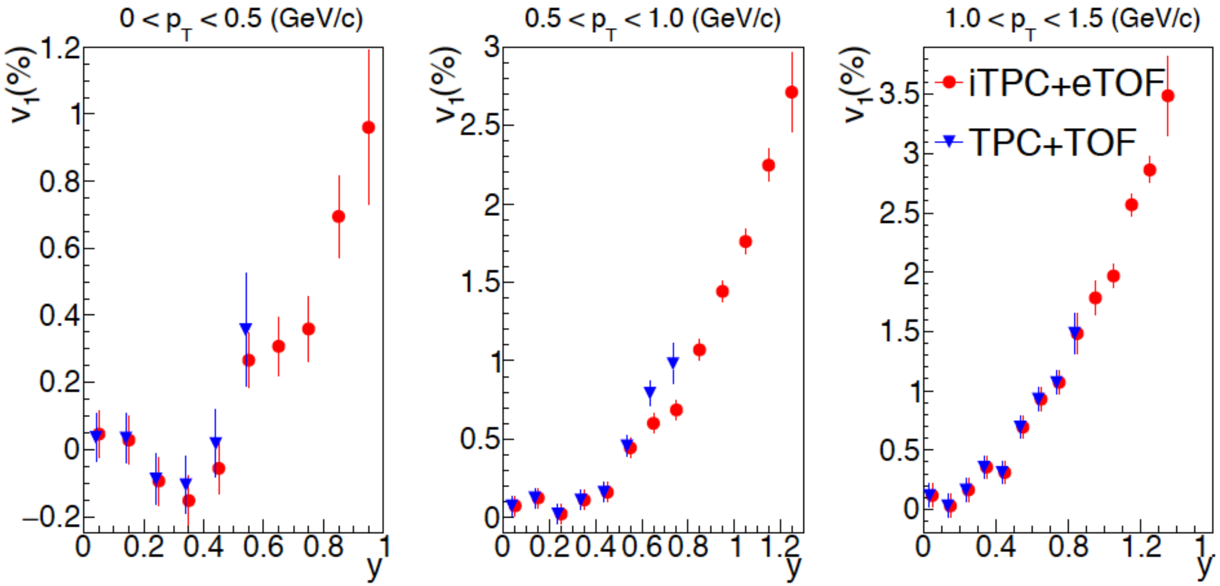
- Large-scale integration test of system for CBM

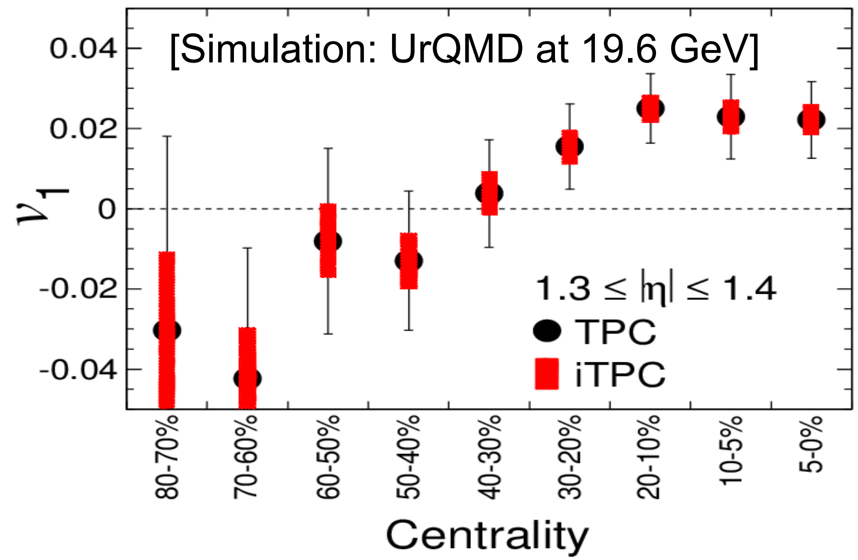
Single TOF module for Run-17
- integration test

BES-II: Softening of EoS

BES-I: Double sign change of v_1

Precision measurement of dv_1/dy as function of centrality





iTPC+ eTOF:

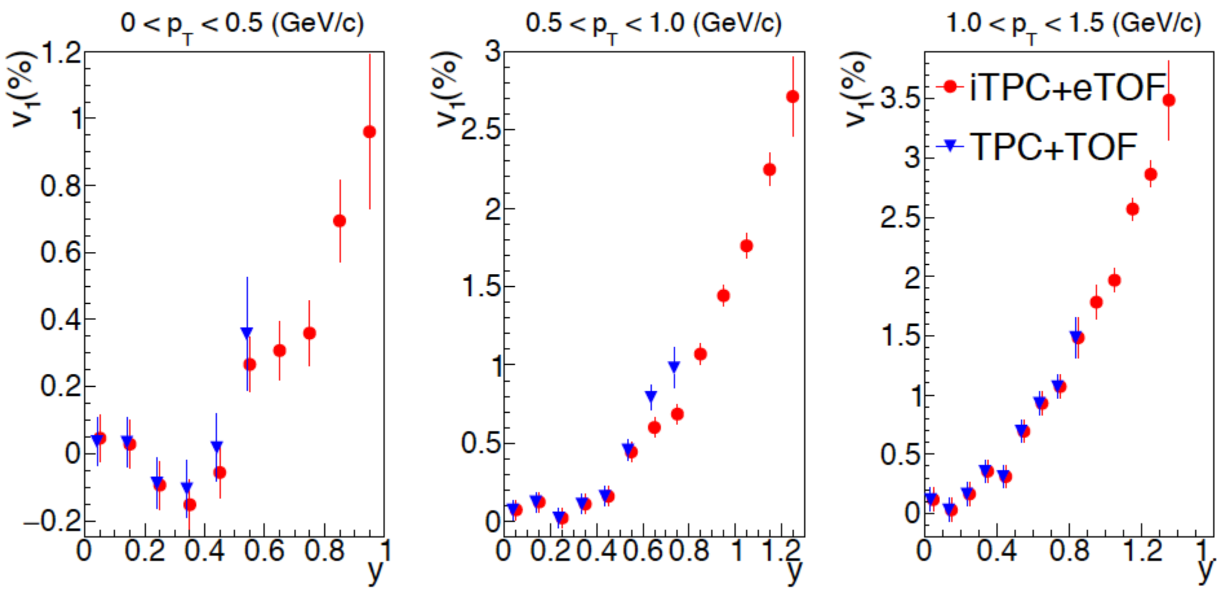
Enhanced coverage at forward y

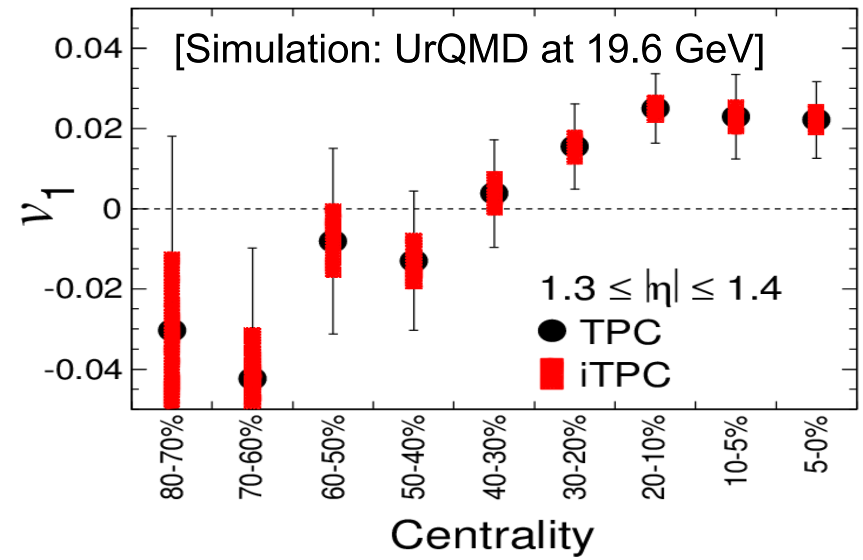
Signal larger - role of baryon stopping

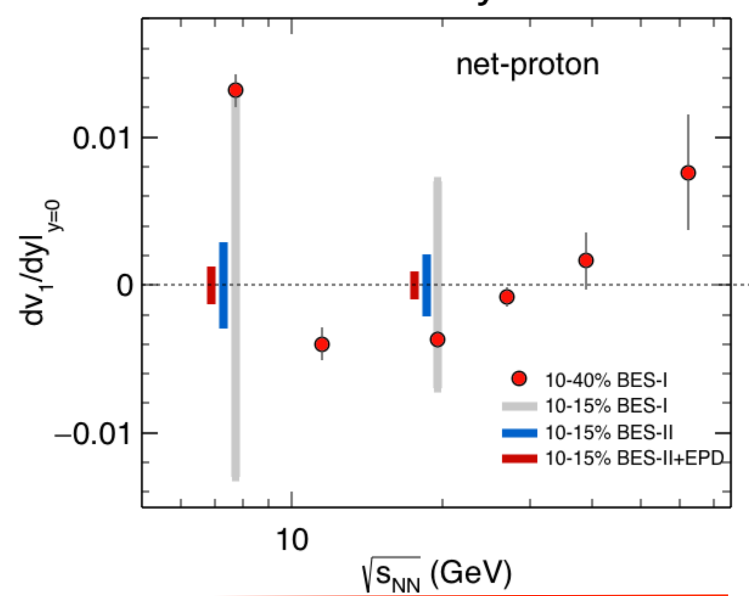
BES-II: Softening of EoS

BES-I: Double sign change of v_1

Precision measurement of dv_1/dy as function of centrality







iTPC+ eTOF:

Enhanced coverage at forward y

Signal larger - role of baryon stopping

EPD:

Enhanced 1st order EP resolution

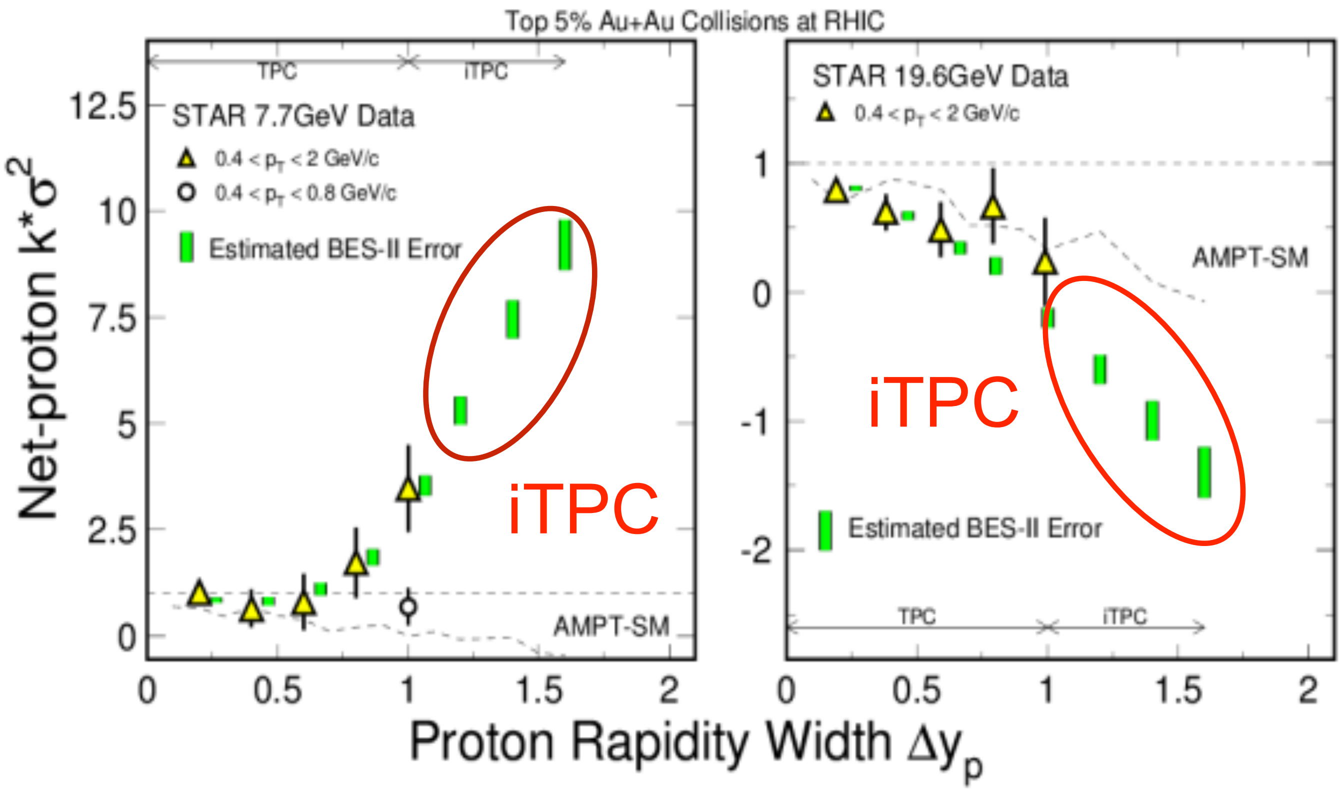
Reduced systematics

BES-II: Critical Fluctuations

BES-I: Suggestive of non-trivial √s dependence of net proton cumulant ratios

iTPC:
Increase Δy_p acceptance
$\Delta y_p > \Delta y$ correlation

EPD:
Improved centrality selection
Use all TPC for measurement

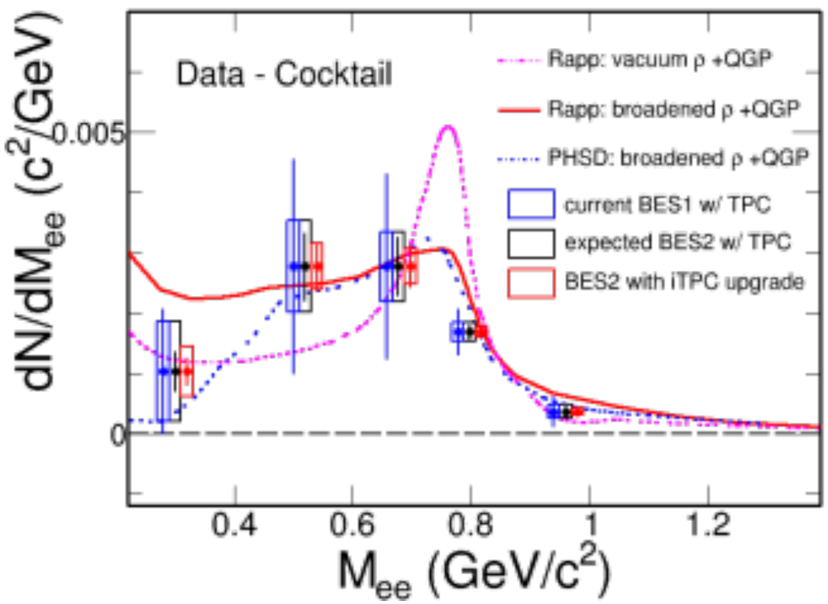


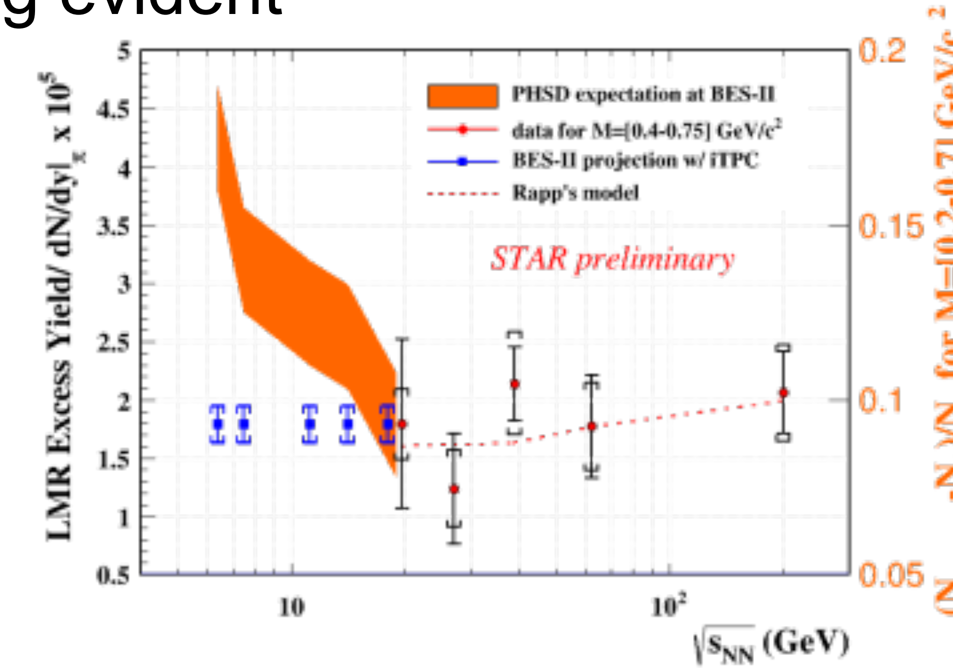
Establish true nature of correlation

Subject actively pursued theoretically

BES-II: Chirality Restoration

BES-I: Dilepton mass broadening evident





ρ-meson broadening:

different predictions for di-electron continuum (Rapp vs PHSD)

iTPC: Significant reduction in sys. and stat. uncertainties

Enables to distinguish between models for √s =7.7-19.6 GeV

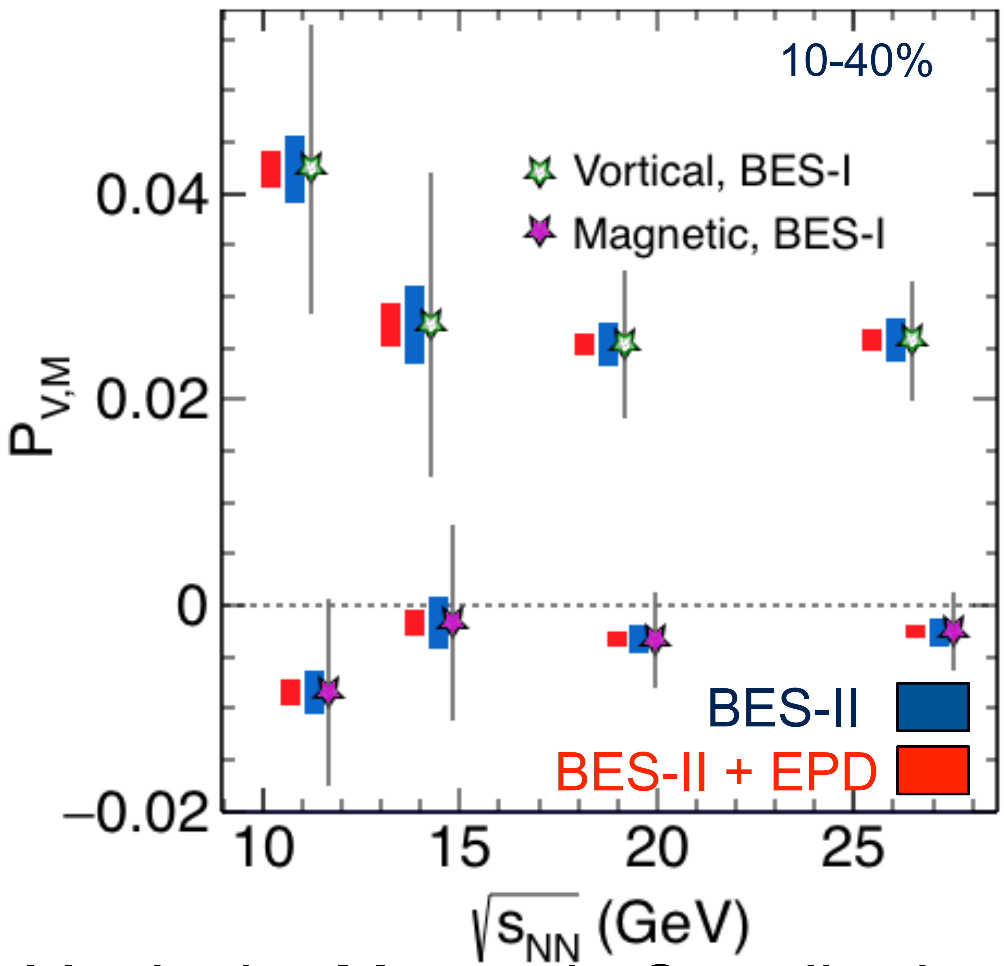
Low Mass Region:

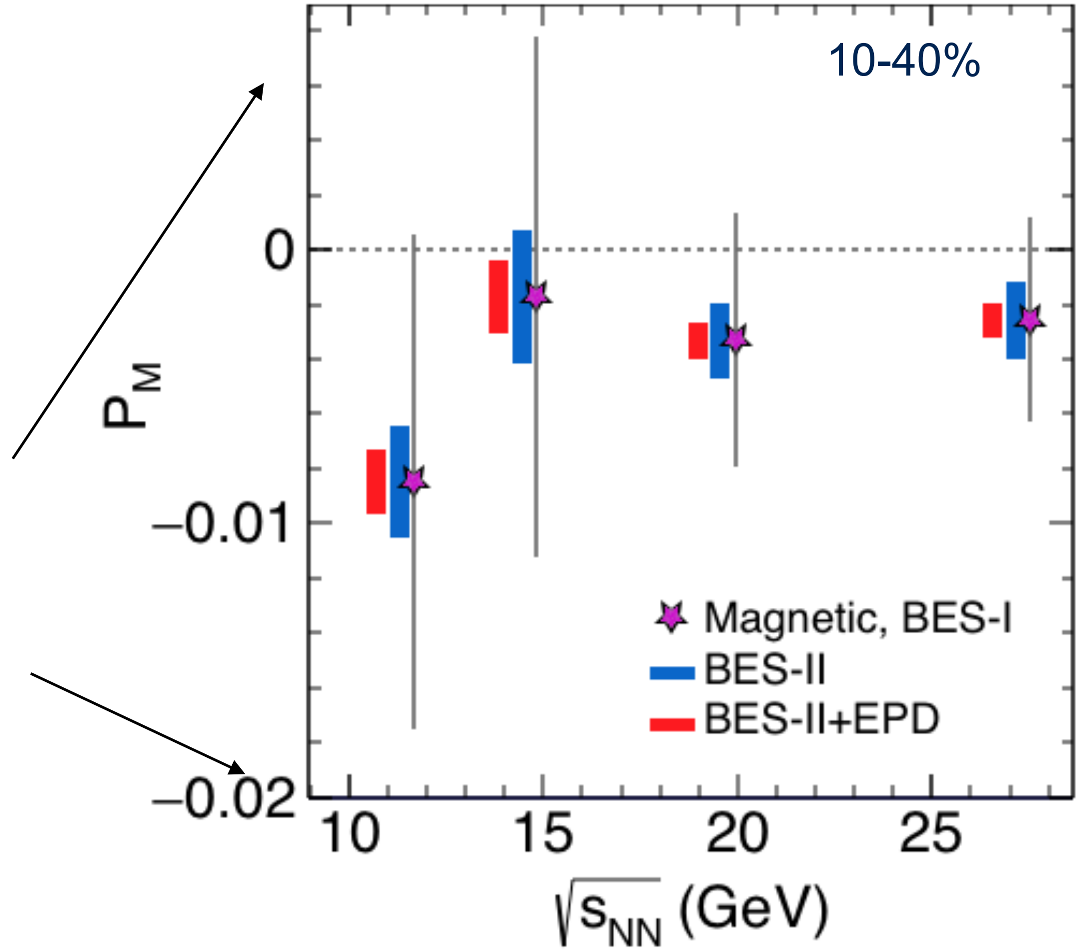
iTPC: Significant reduction in sys. and stat. uncertainties

Disentangle total baryon density effects

BES-II: Vorticity and Initial B-field

BES-I: First measurement of Λ **Global** Polarization





Vortical + Magnetic Contributions:

Current data barely stat. significant

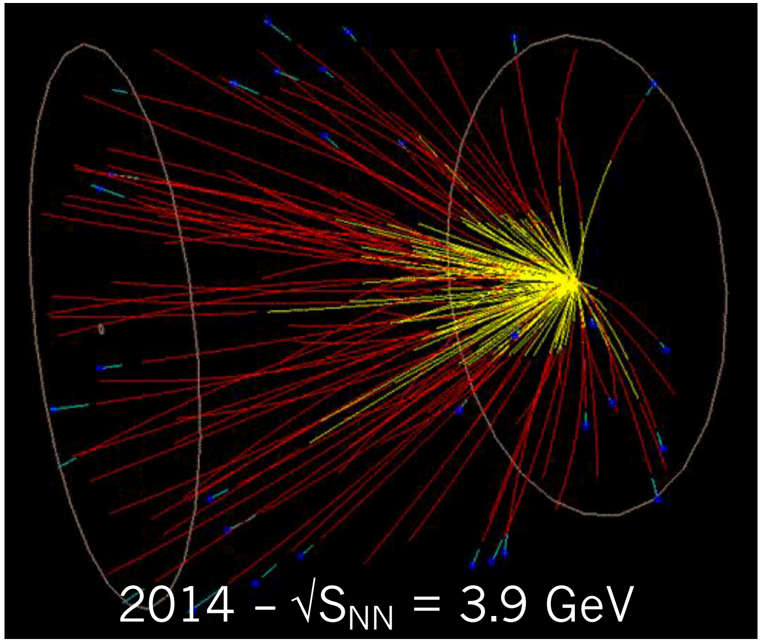
EPD:

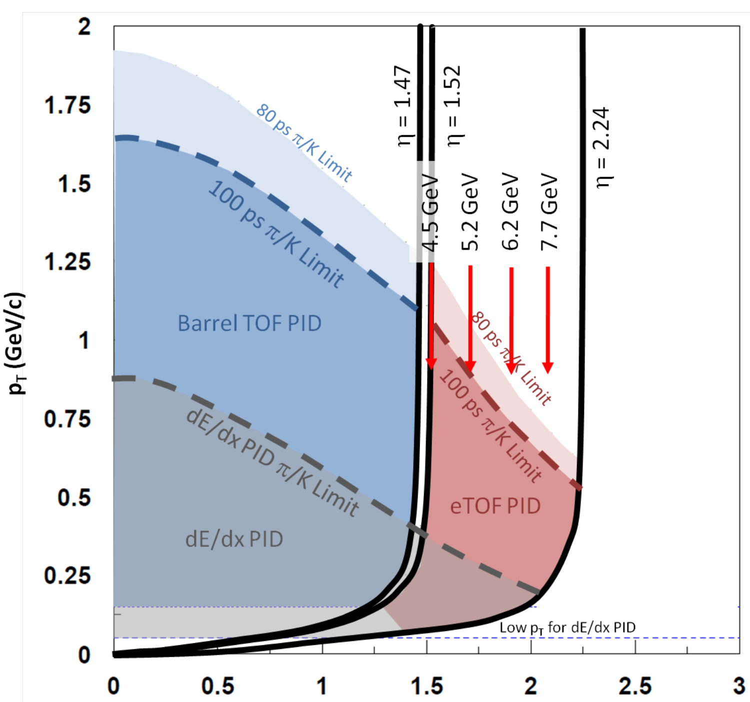
Improved EP resolution

BES-II: 3σ effect

Unique measurement of B
Significant input to CME/CVE interpretations

BES-II: Onset of Deconfinement





NA49 - onset of deconfinement at $\sqrt{s}$ = 7.7 GeV

Fixed target program
- Collider can't run below 7.7GeV
- Target in beam pipe at z=210cm

Will perform dedicated short runs
- More efficient
- Successful tests completed

eTOF+iTPC:
- Forward acceptance in fixed target mid-rapidity range
  - Reach 7.7 GeV for fixed target too

Precision investigation with new techniques

BES-II: Detailed Run Plan

Run in 2019 & 2020 will have significant physics impact

Group	Collision Energies (GeV):	7.7	9.1	11.5	14.5	19.6
	Chemical Potential (MeV):	**420**	**370**	**315**	**260**	**205**
	Observables	Millions of Events Needed				
QGP	R_{CP} up to p_T 4.5 GeV	NA	NA	160	92	22
QGP	Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400
1st P.T.	Local Parity Violation (CME)	50	50	50	50	50
1st P.T.	Directed Flow studies (v_1)	50	75	100	100	200
1st P.T.	asHBT (proton-proton)	35	40	50	65	80
C.P.	net-proton kurtosis ($\kappa\sigma^2$)	80	100	120	200	400
EM Probes	Dileptons	100	160	230	300	400
	Proposed Number of Events:	**100**	**160**	**230**	**300**	**400**
	BES-I stats.	4	N/A	12	20	36

Fixed target running enables data from $\sqrt{s}$ = 3-7.7 GeV

eCooling - Enables the significant statistics enhancement

BES-II: Executive Summary

High statistics exploration of QCD phase diagram and its key features

Significantly extended detection capabilities

iTPC → enhanced y- p_T acceptance - Project en route to success

EPD → crucially improved EP resolution - Hopeful support will be found

eTOF → significant improvement to PID - Hopeful support will be found

eCooling → higher beam luminosities, better statistics

In conjunction: Turn trends and features into definitive conclusions

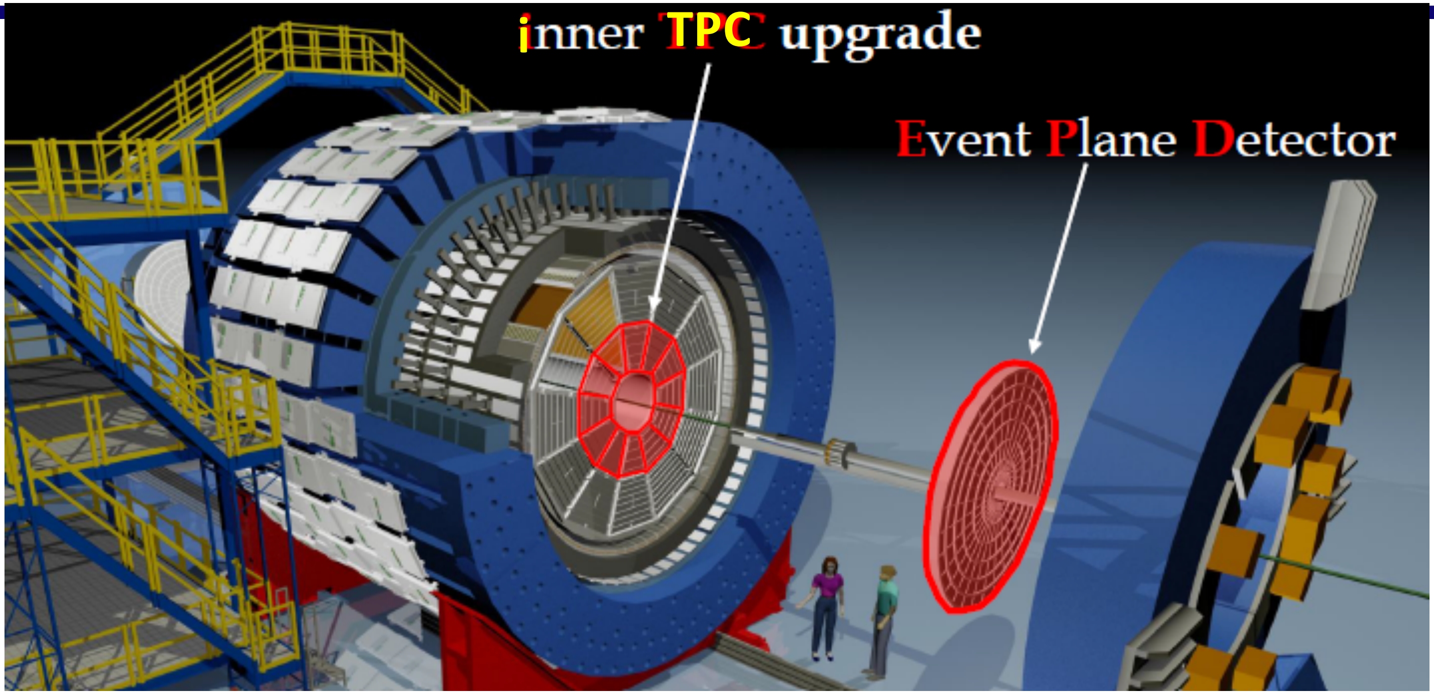
Strong theoretical interest: BEST Collaboration & 2016 INT Workshop

STAR looks forward to using these new capabilities for top-energy studies

iTPC status

Flemming Videbæk
STAR collaboration

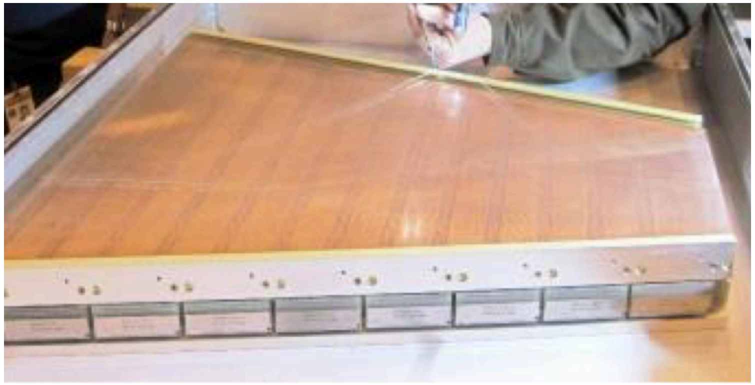
iTPC



TPC	iTPC
Sparse Pads	Cover Full area
	Better dE/dx
$-1 < \eta < 1$	$-1.5 < \eta < 1.5$
$p_T > 125$ MeV/c	$p_T > 60$ MeV/c

iTPC Upgrade

- 24 Inner sector modules
  - Al Strongbacks
  - Pad planes
  - Padplane Joining
  - Multi Wire Proportional Chamber (MWPC) assembly
- Readout Electronics
  - iFEE
  - iRDO
- Installation and Insertion Tooling



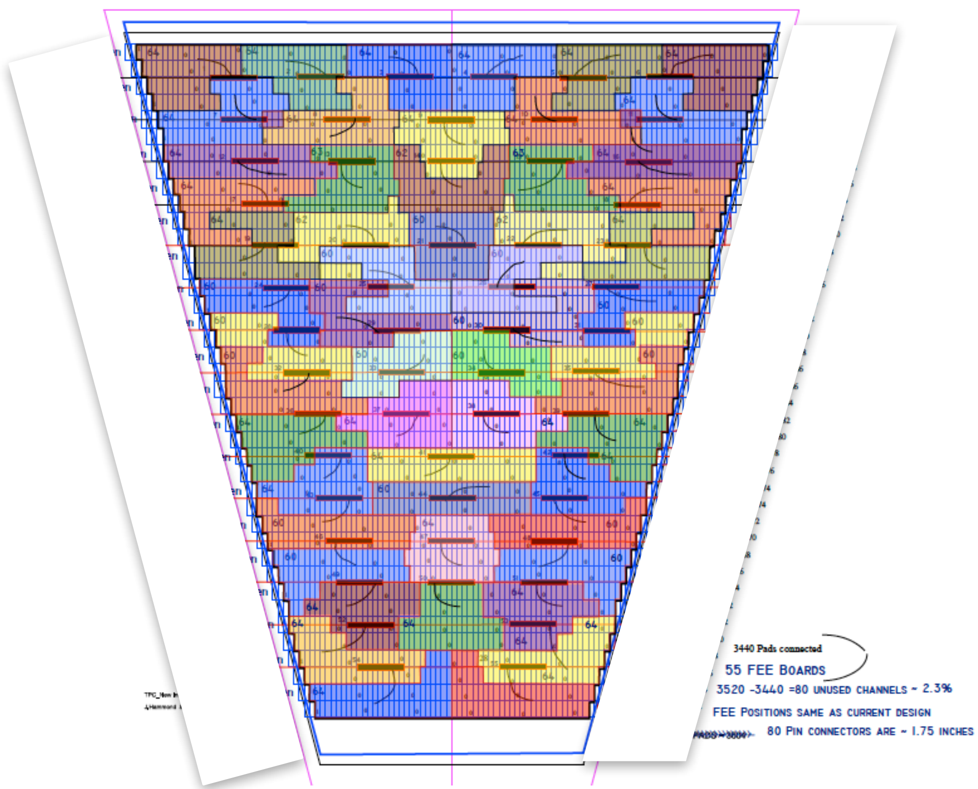
Recent Developments

- Technical Design Report Completed (Dec 2015)
- Risk assessment requested by ALD for TPC and iTPC submitted early December
- Directors review Jan 22 2016
  - External Reviewers, DOE attending
  - Favorable Report, with follow up response from STAR
- Meeting with DOE NP February 18, 2016
  - Approved to proceed with Project
- Management Plan iterated with DOE NP
- The addition of the short Run-18 has led to review of installation schedule and implication for Run-19
- Final prototyping for production moving ahead

Pad plane layout

Pad plane connector Layout

- Minimize trace length (noise)
- Same #even/odd pads per connector
- Allows testing of new sectors with old electronics (Shandong)



TPC strong backs

2 Prototype (old design) fabricated by UT Austin.
One used to setup and practice techniques at Shandong
3D CAD design – (lower fabrication and inspection cost)

- Production on-going
- First 2 articles completed;
- Inspection report delivered;
- Once accepted full production completed in 6-8 wks

MWPC production and assembly

- Joining of padplane (LBNL)
  - Contract being setup
- Work in China – Shandong, USTC, SINAP
  - Prototype of iTPC (ongoing)
  - Wire plane production 24+spares and assembly– Start December 2016
  - Sector test (uniformity, efficiency and linearity)
  - Shipping sector to BNL (last shipment July 2018)
- Work at BNL
  - Testing of all module at BNL before installation

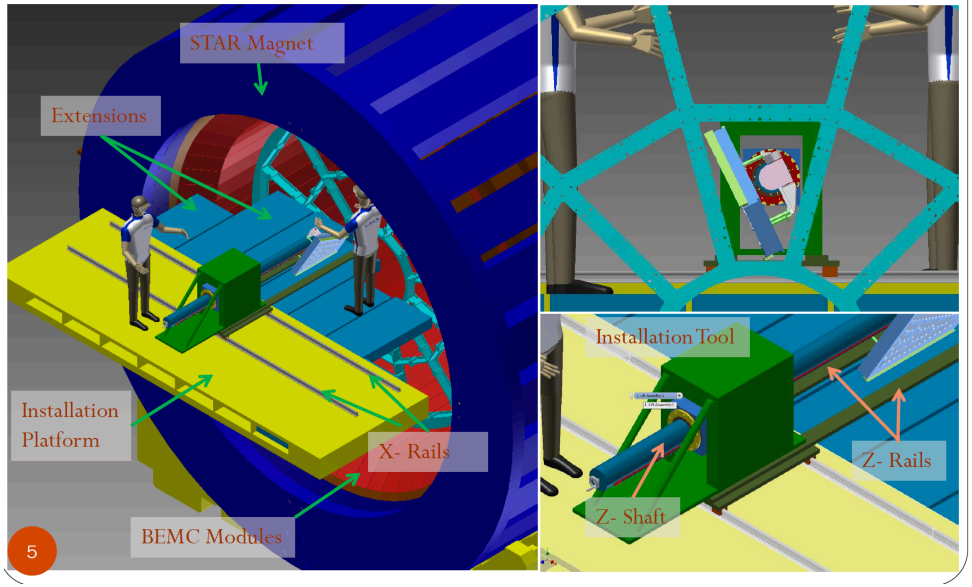
iTPC Electronics

- STAR iFEE
  - In the PCB layout phase (finished ~June 20)
  - Plan to make ~10 PCBs at first
  - PCB delivery expected mid July -- matches the SAMPA BGA schedule
- STAR iRDO
  - Design changed to make it simpler and better integrated with other STAR Electronics Projects
  - Based upon a commercial daughtercard which houses the FPGA, PROM, SDRAM, clocks etc

- Data Receiver
  - Based upon a similar commercial daughtercard as the iRDO which saves us a lot of effort and makes it simple to do
  - 4 fibers, PCIe x4 readout interface
  - For FY17 tests we plan to use a commercial Xilinx development board (1 optical fiber, PCIe interface)
- A prototype for a 2 iFEE readout expected Sept and will be installed on one existing sector for the pp500 run in 2017
- Mitigating risks by early prototyping and testing in collision environment

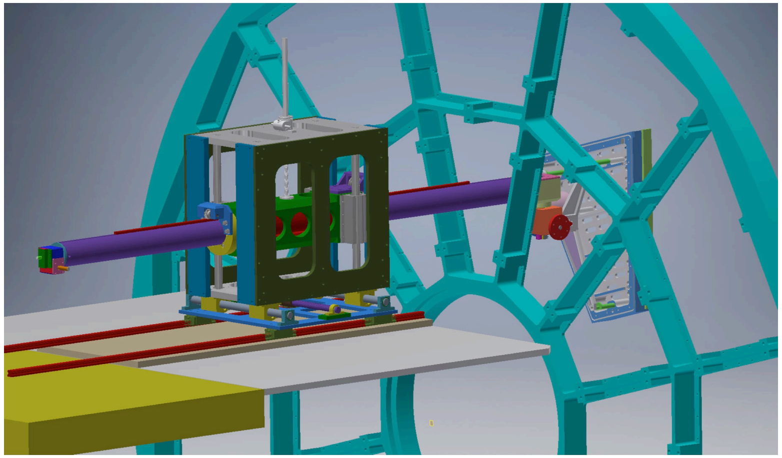
Insertion Tooling

Cartesian Installation Tool Design



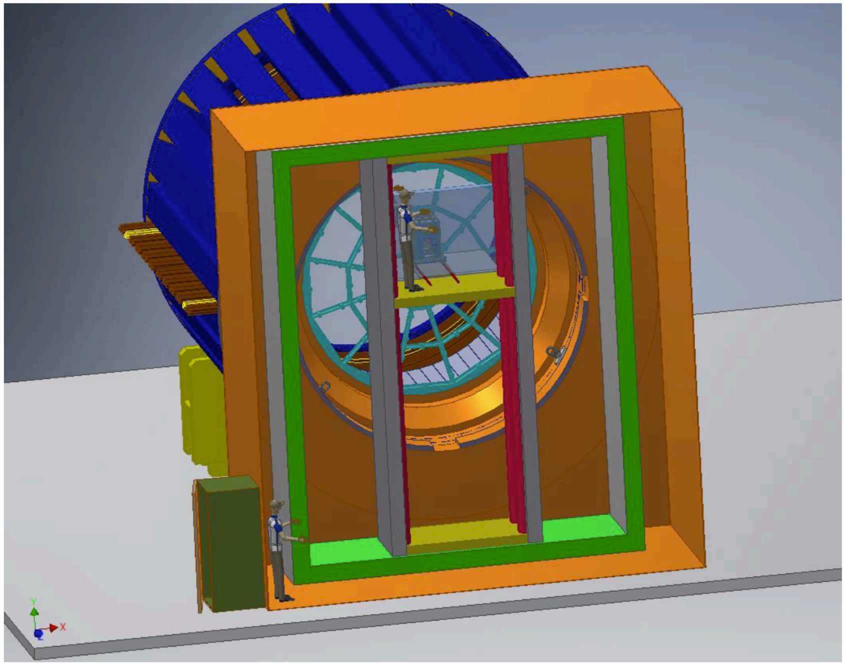
Insertion tooling needed for installation and for replacement of two outer bad sectors

Designed by Rahul Sharma, Ralph Brown and much input from LBNL, CERN

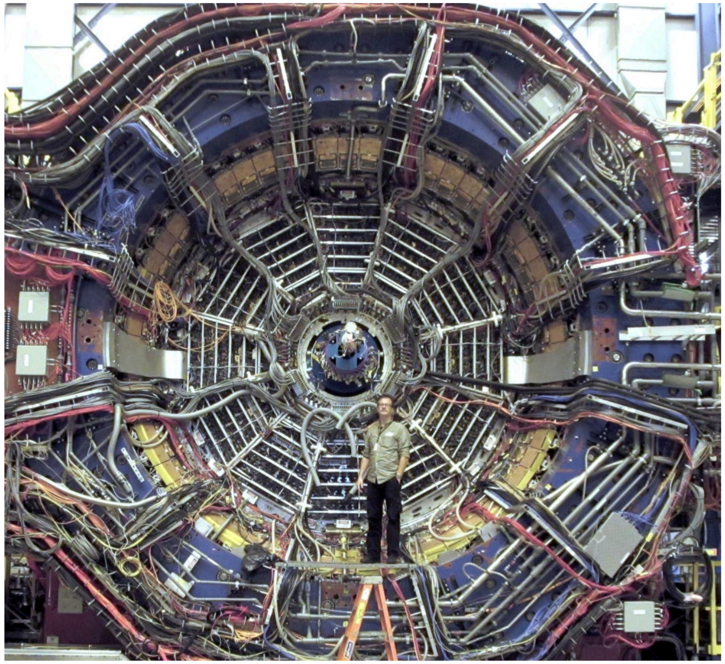


Installation

Conceptual clean environment
Essential to keep dust from getting into TPC



Reality - messy



Installation schedule

- End Run-17 (6/1/2017)
  - 8 month installation period
  - Roll-in/out of STAR 3 mo.
  - Verify & test installation tooling
  - Exchange one outer sector, and possibly one new inner sector module with electronics (risk mitigation)
- Run 18 Start 2/1/2018 End 4/30/2018 (13 weeks)
  - Long installation (shutdown) period needed
  - Not much float and time full commissioning
  - Aim for start of Run-19 in March 2019
  - Need to be kept in mind and discussed with RHIC as project moves forward

Summary

- iTPC important upgrade for BES-II
- US-China collaboration for production
- Production of inner sectors has started
- Installation Schedule between Run-18 and Run-19 is very tight
- Yearly Review with DOE NP being scheduled for September.

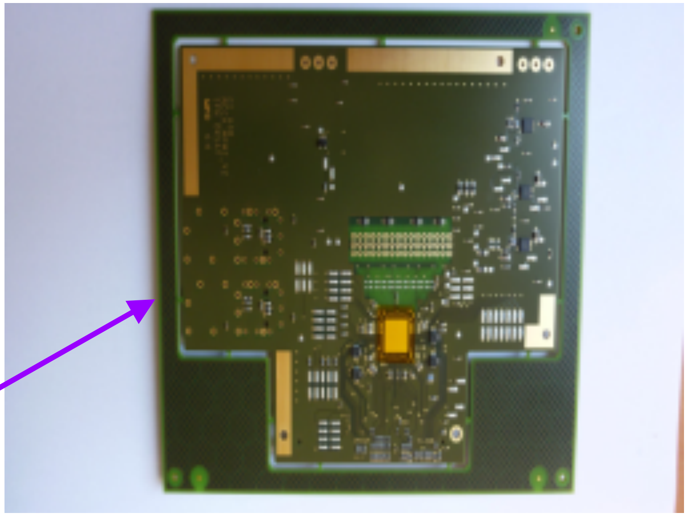
BACKUP

Report main points

- Are the costs of the project sufficiently well understood, and are all the resources required to complete the project fully identified?
  - Answer: Yes.
- Is the schedule of the project sufficiently well understood and matched to the plan for full operation in the FY19 RHIC Run?
  - Answer: Yes.
- Are the risks introduced by the project into the successful operation of the STAR detector in the Beam Energy Scan Phase 2 run fully understood and are sufficient plans to mitigate these risks in place?
  - Answer: Yes
- Full report available as aux material

iTPC Electronics Status

- SAMPA chip prototype 2 ("MWP2")
  - Wafers arrived in Orsay (France)
  - They were unpacked, checked and sent for further processing
    - Thinning (started June 8, expected ~1 week)
    - Dicing (another week)
    - Bonding to a CERN developed "NCCA" test board expected
      to start June 22 ⇒ available early/mid July
  - Similar process for the BGA started
    - 340 packaged BGAs expected mid July
- Test Boards
  - CERN group (Orsay) developed 2 passive test boards
    - For the raw die (bonded chip), so-called "NCCA"
    - For the packaged BGA ("PCCA")
  - STAR gets 1 of each for early SAMPA tests and firmware development
  - The FPGA "intelligence" interface board is a commercial Altera-based board which we purchased already



iTPC Electronics Near-term Schedule

SAMPA basic tests with CERN-developed NCCA & PCCA boards	Jul-Aug 2016
iFEE SAMPA tests & firmware development continue...	Aug-... 2016
iFEE⇔ iRDO ⇔ Receiver Card basic readout integration	Sep-Dec 2016
Final iRDO design (based upon what we learn from prototype)	~ Nov 2016 - Mar 2017
Install 2 iFEEs (128 ch total) + 1 iRDO prototype + 1 Receiver Card prototype into TPC	Dec/Jan
SAMPA evaluation with real collisions in RHIC	Jan-... 2017
Readout chain firmware & software development continues...	Jan-... 2017
Final Receiver Board design	~ Jan-May 2017

- *if* MWP2 works for STAR , we assume we can get enough of them for 1 sector for FY18
- This plan to (re)discuss in early Fall with the SAMPA team.
- The general SAMPA schedule also assumes MWP3 to be available roughly 1 year (or less) from now so there might actually make a sector's worth of our electronics with that (potentially improved, close-to-final) version.
- At this early point two options for Run-18: MWP2 or MWP3. The point is that we have options

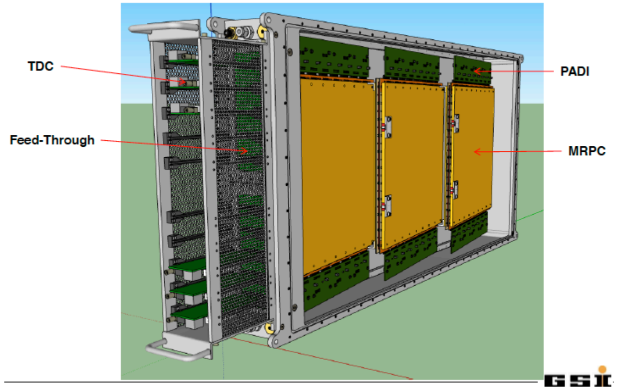
EPD timeline

- Install 1/8 EPD installation for Run 17
- Finalize design after Run-17
- Produce and install the remaining 7/8 for Run-18 (19)

- Total cost: 240-330 k$

eTOF

- Schedule
  - June 2016: submit the plan and schedule for the prototype installation to STAR operations
  - Install and operate 1 prototype module for Run-17
  - June 2017: submit the plan and schedule for the endcap TOF installation to STAR operations.
  - October 2018: Complete the installation of the endcap TOF system. Begin commissioning.
  - July 2020: Decommission the endcap TOF system and prepare the CBM TOF equipment for return to CBM.
- Cost to STAR
  - 114k$ + manpower for installation.



Prototype eTOF module

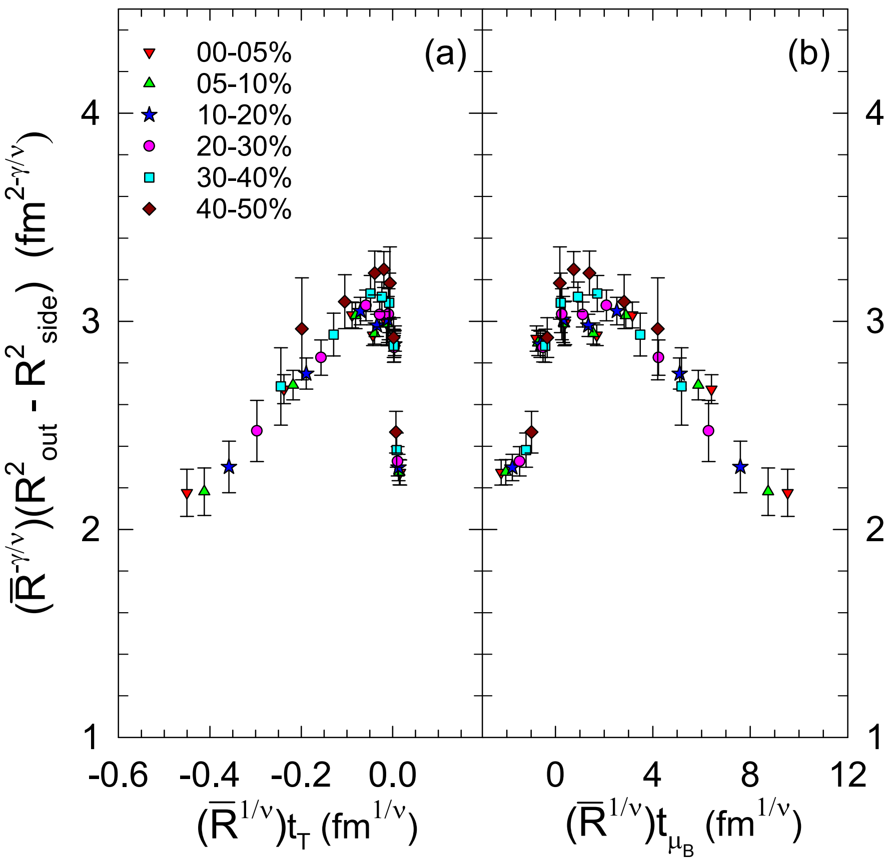
BACK UP

Evidence for a Critical Point?

HBT radii:

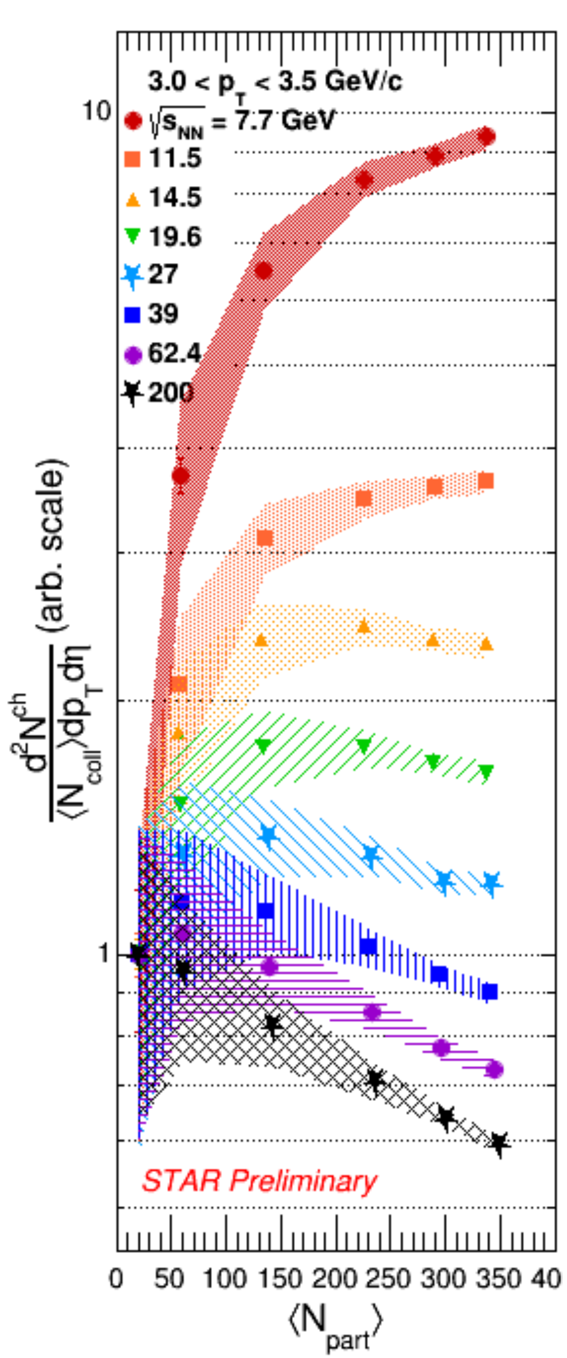
Non-monotonic behavior

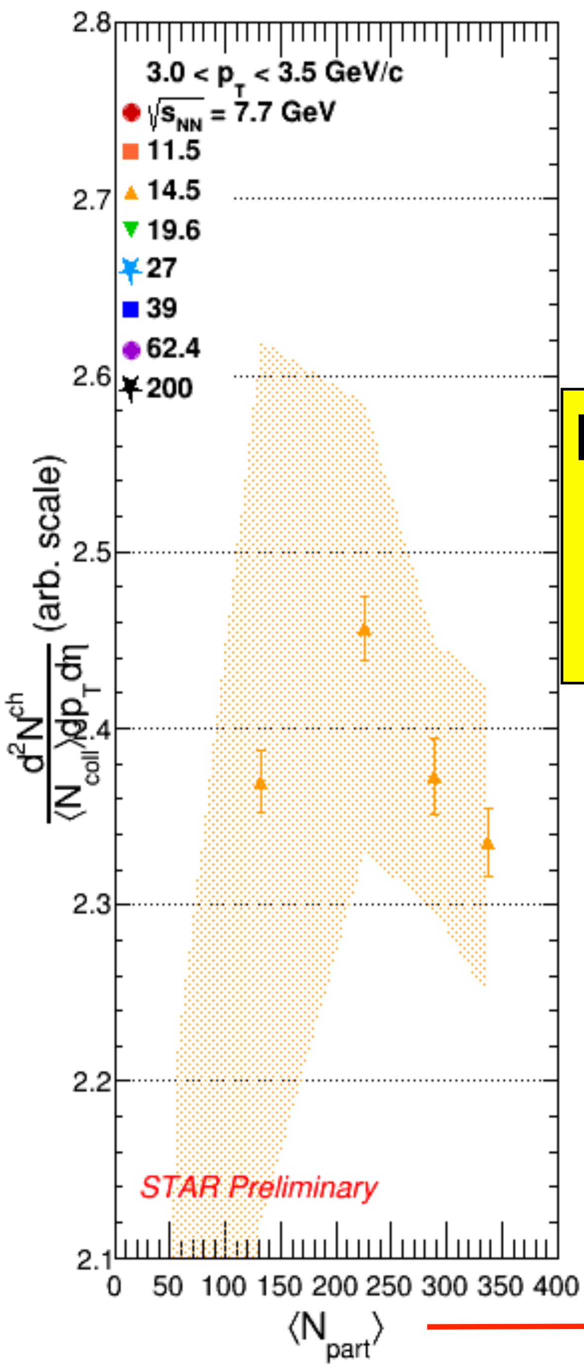
“softening” of speed of sound?

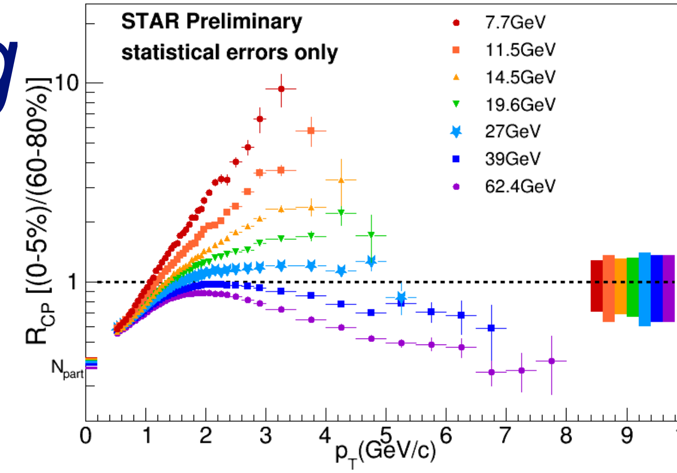


R. Lacey, PRL **114**, 142301

QGP Creation: Jet Quenching







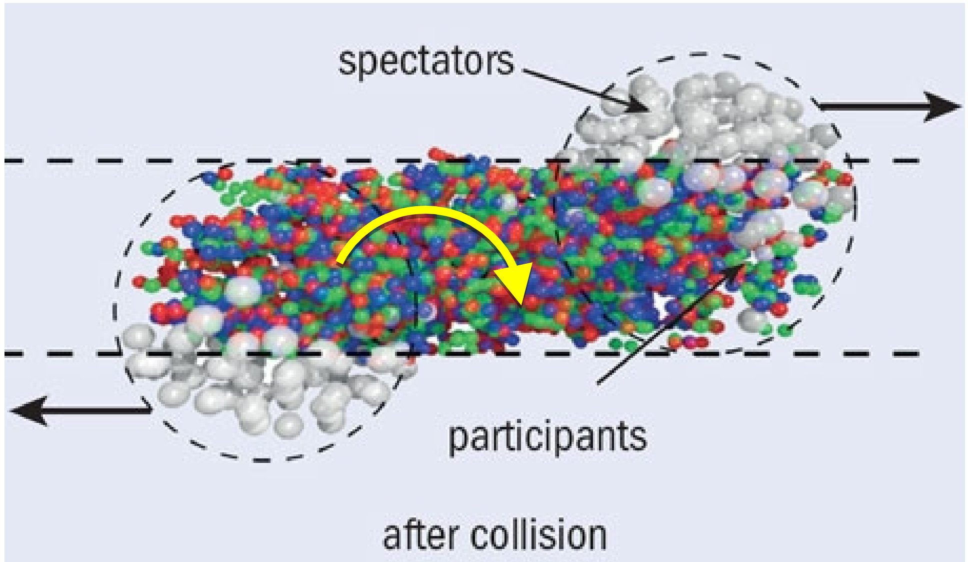
Cronin may be hiding E_{loss}

For $\sqrt{s_{NN}}$ ≥ 14.5 GeV central events show suppression compared to next peripheral bin

7.7 and 11.5 GeV results increase monotonically

200 GeV results decrease monotonically

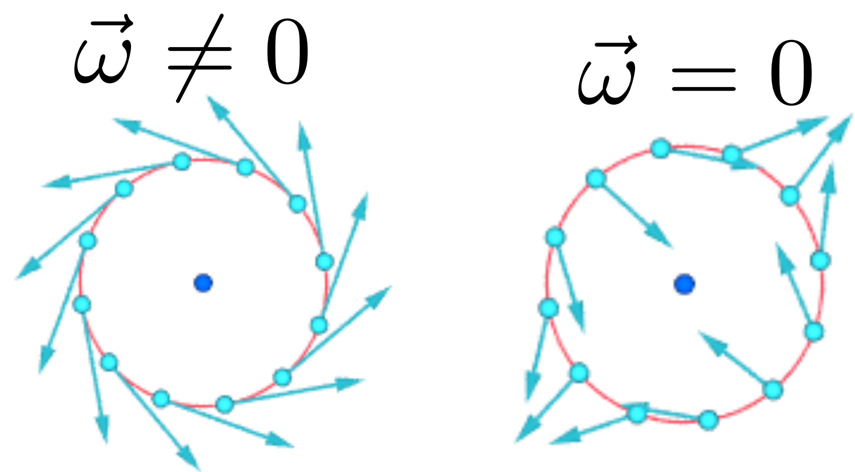
The Spinning QGP



|L| ~ 10^5 in peripheral collisions

Do we generate a "spinning" QGP?

Does this angular mom get distributed thermally?



How does that affect fluid/transport?
Vorticity - local spinning motion

$$\vec{\omega} = \vec{\nabla} \times \vec{v}$$

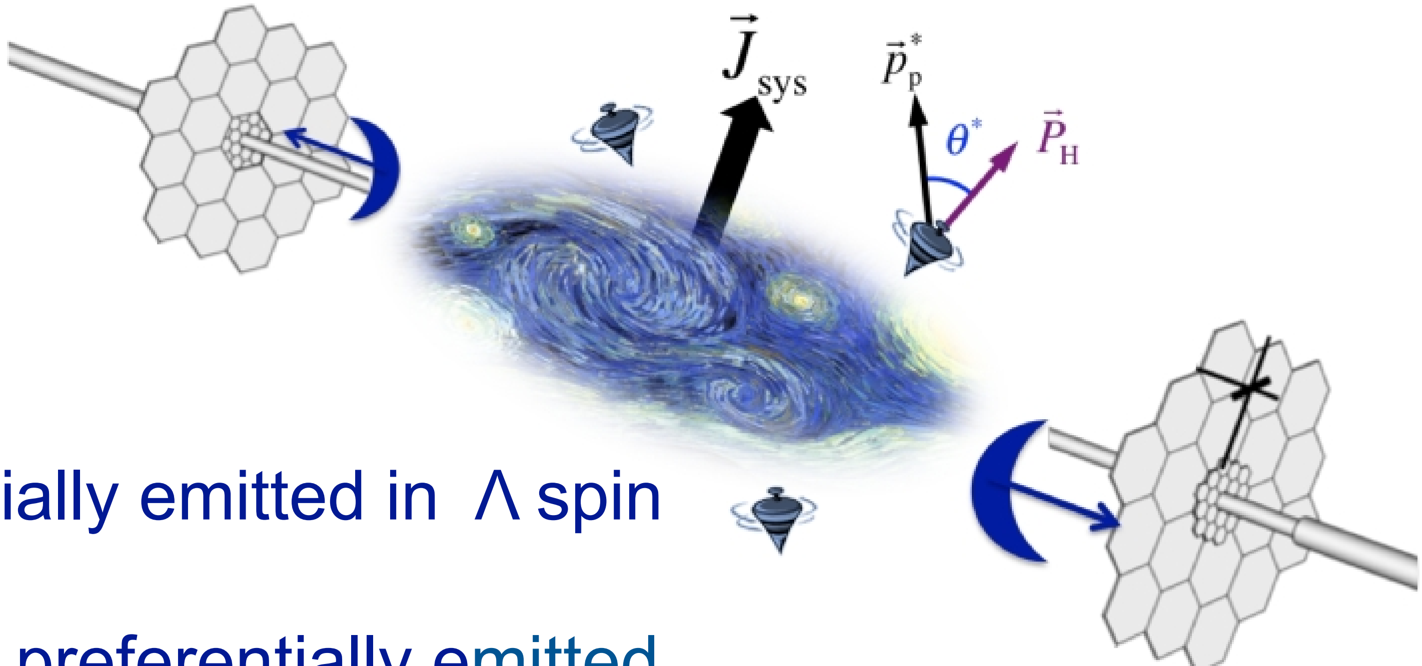
Viscosity dissipates vorticity to fluid at larger scales

Can we see any manifestation of this spinning in the data?

Measuring Λ **Global** Polarization

Direction of L:

Estimate from 1st order reaction plane from BBC



Λ Polarization

Self analyzing

Decay p preferentially emitted in Λ spin direction

Decay anti-proton preferentially emitted against Anti-Λ spin direction

Λ and anti-Λ spins aligned with L → Vortical or QCD spin-orbit

- Sigma feed-down tends to dampen the effect

Λ anti-aligned, anti-Λ aligned with L → μ_H - B coupling

- Sigma feed-down goes with the primaries

Vorticity → Global Polarization

Alignment of spin with |L|

Global polarization of emitted particles

- Betz, Gyulassy, Torrieri PRC76 044901 (2007)
- Becattini et al., PRC88 034905 (2013)
- Becattini et al., JPhys 509 012055-5 (2014) (SQM2013)
- Csernai et al., JPhys 012054-5 (2014) (SQM2013)
- Grossi JPhys 527 012015-5 (2014) (XIV Conf. Th. Physics)
- Becattini et al. arxiv:1501.04468

QCD spin-orbit coupling (non- hydro picture)

Similar conclusions

- Voloshin arxiv:nucl-th/0410089
- Liang and Wang, PRL94 102301 (2005); PRL96 039901(E) (2006)
- Liang and Wang, PLB629 20 (2005)

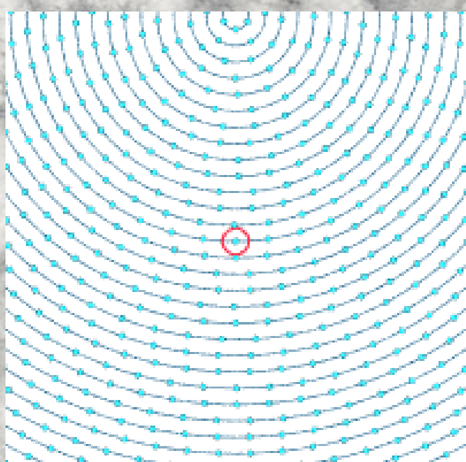
Baryon stopping generates localized vortices

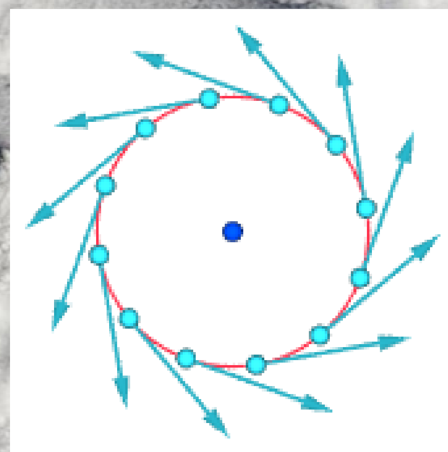
Rotational & Irrotational Vortices

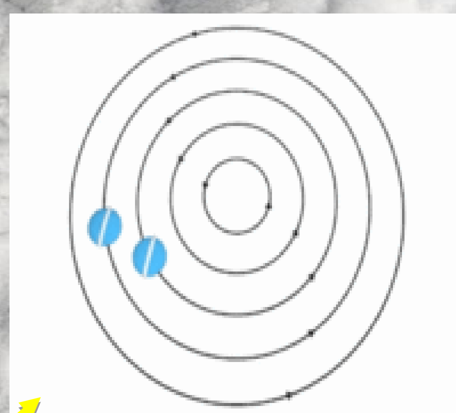
Simplest vorticity: $\vec{\omega} = \vec{\nabla} \times \vec{v}$

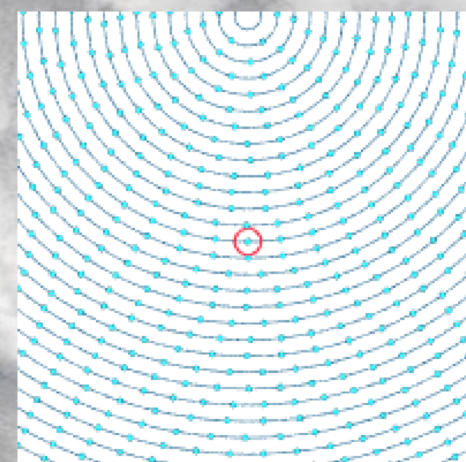
Rigid-body-like vortex
$v \propto r$

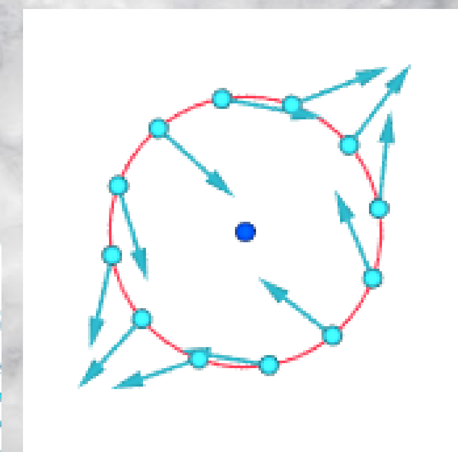
Irrotational vortex
$v \propto 1/r$











Like the moon, always the same side toward Earth

Notice the rotation, or lack thereof, in the fluid elements