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WAYNE STATE

STAR Highlights

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For the STAR Collaboration

Brookhaven National Laboratory

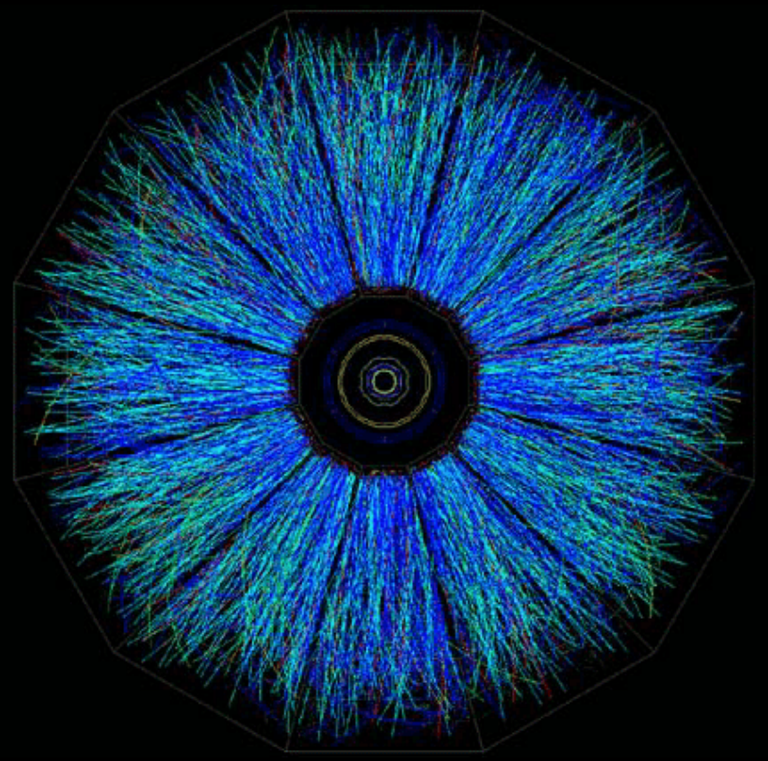
20 years of RHIC

October 22-23, 2020 | Virtual RHIC/AGS Annual Users' Meeting

Topical workshops: October 22 | Plenary sessions: October 23

Spin and Cold QCD

Light Flavor Spectra



Ultra Peripheral Collisions

Flow, Chirality & Vorticity

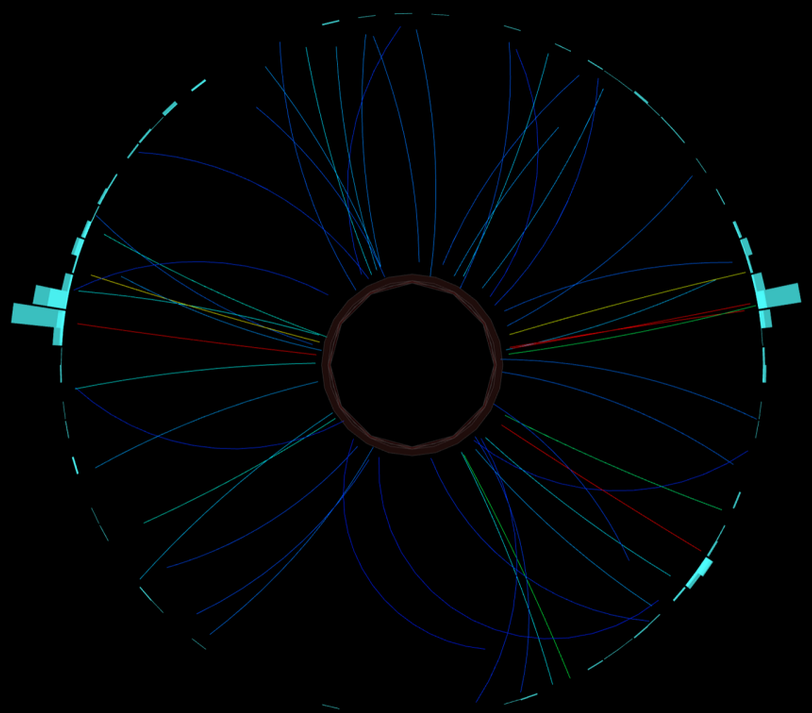
Correlations & Fluctuations

Jets & High p_T Correlations

Heavy Flavor

Spin and Cold QCD

Light Flavor Spectra



Ultra Peripheral Collisions

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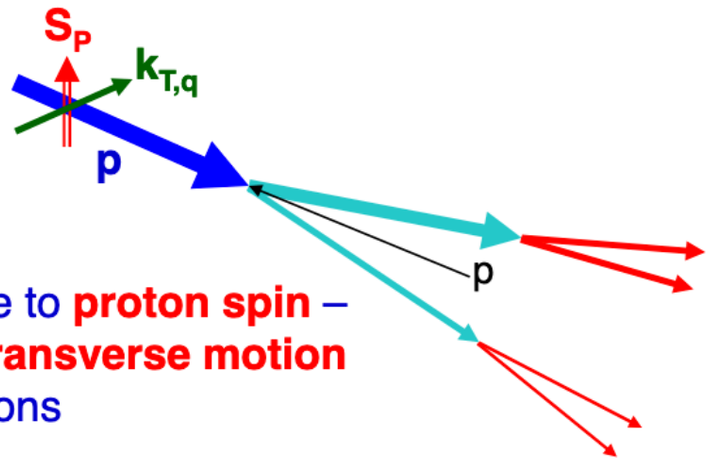
Observing the Sivers effect

pp polarized

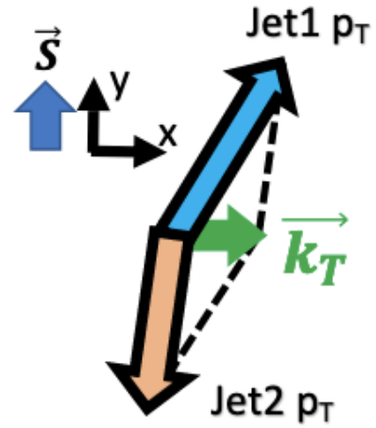
Sivers or twist-3 mechanisms:



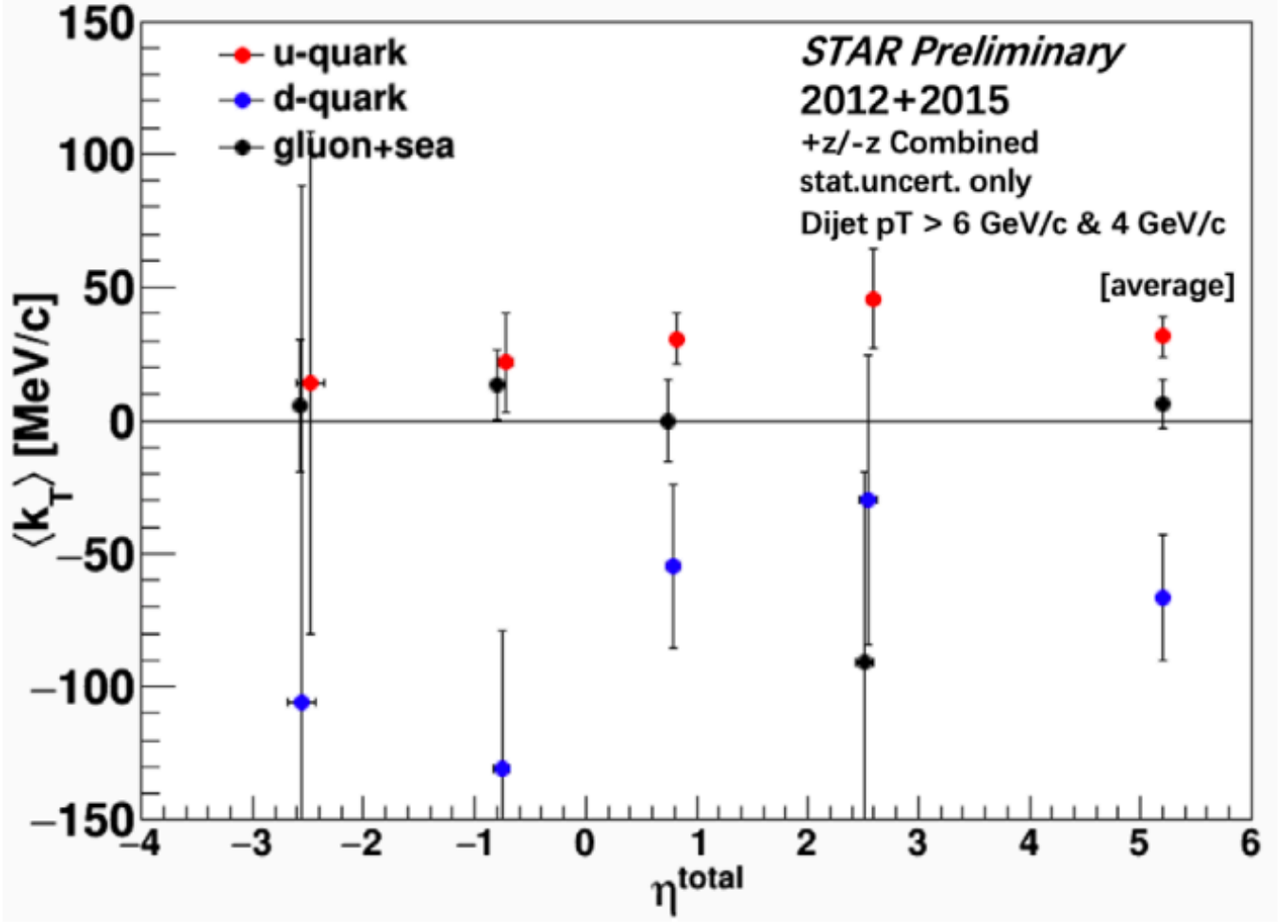
Sensitive to **proton spin** – parton **transverse motion** correlations

$$\langle \vec{S}_{proton} \cdot (\vec{P}_{proton} \times \vec{k}_T) \rangle \neq 0$$

Parton k_T preference leads to spin-dependent tilt of dijet opening angle



- Sivers effect measures spin-dependent parton k_T
- Measurement looks for spin-dependent kinks of the di-jet opening angle
- First non-zero Sivers asymmetries in dijet production in polarized *pp* collisions



Spin Asymmetries

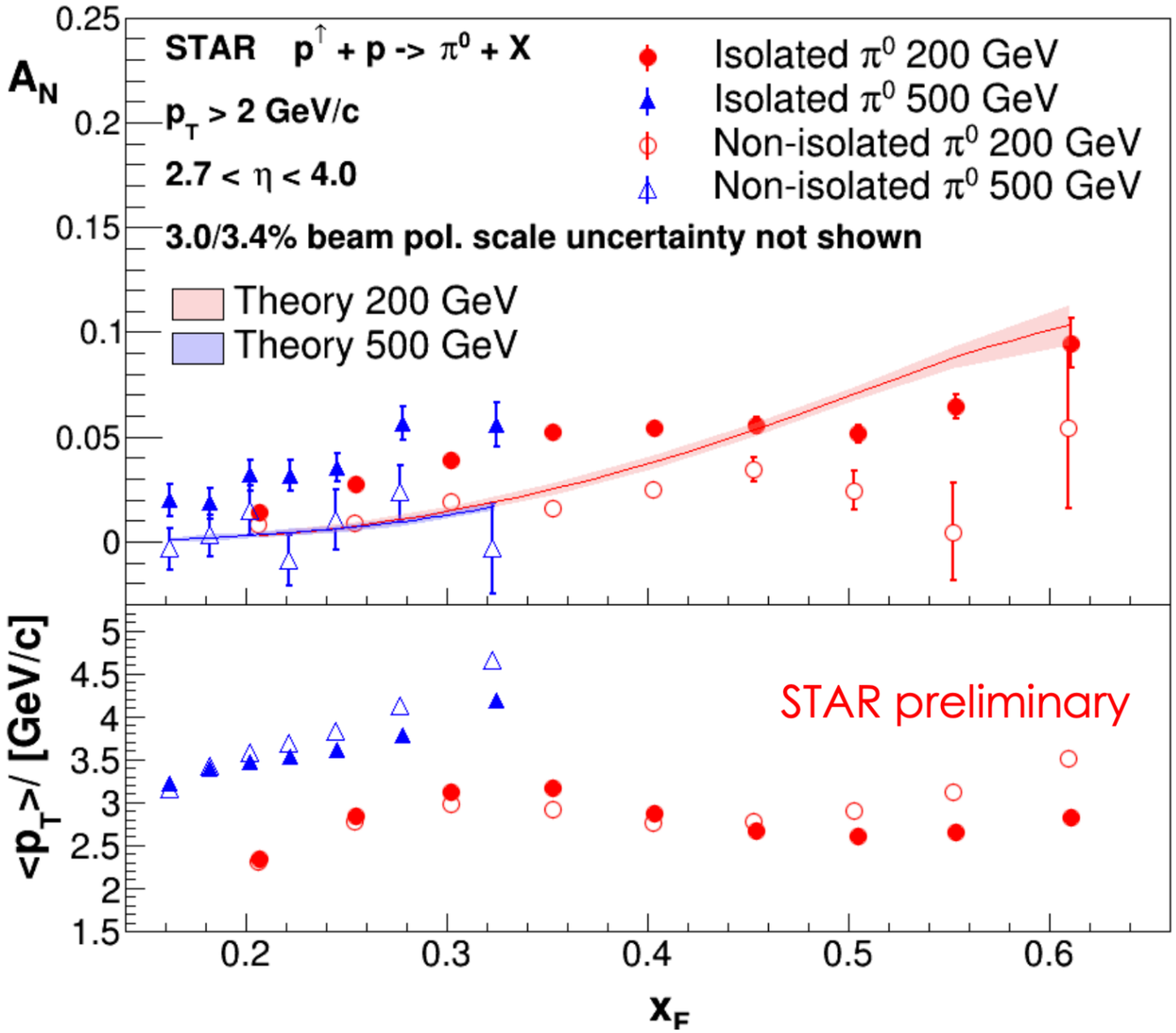
pp polarized

Transverse Single Spin Asymmetries

- 2011 $\sqrt{s} = 500$ GeV
  2015 $\sqrt{s} = 200$ GeV

- A_N for π^0s from the FMS shows a weak $\sqrt{s}$ dependence

- Significant difference for isolated π^0 vs non-isolated π^0
  - pointing to novel mechanisms (other than Collins or Sivers) for generation of $A_N > 0$



see talk by Nick Lukow

Spin Asymmetries

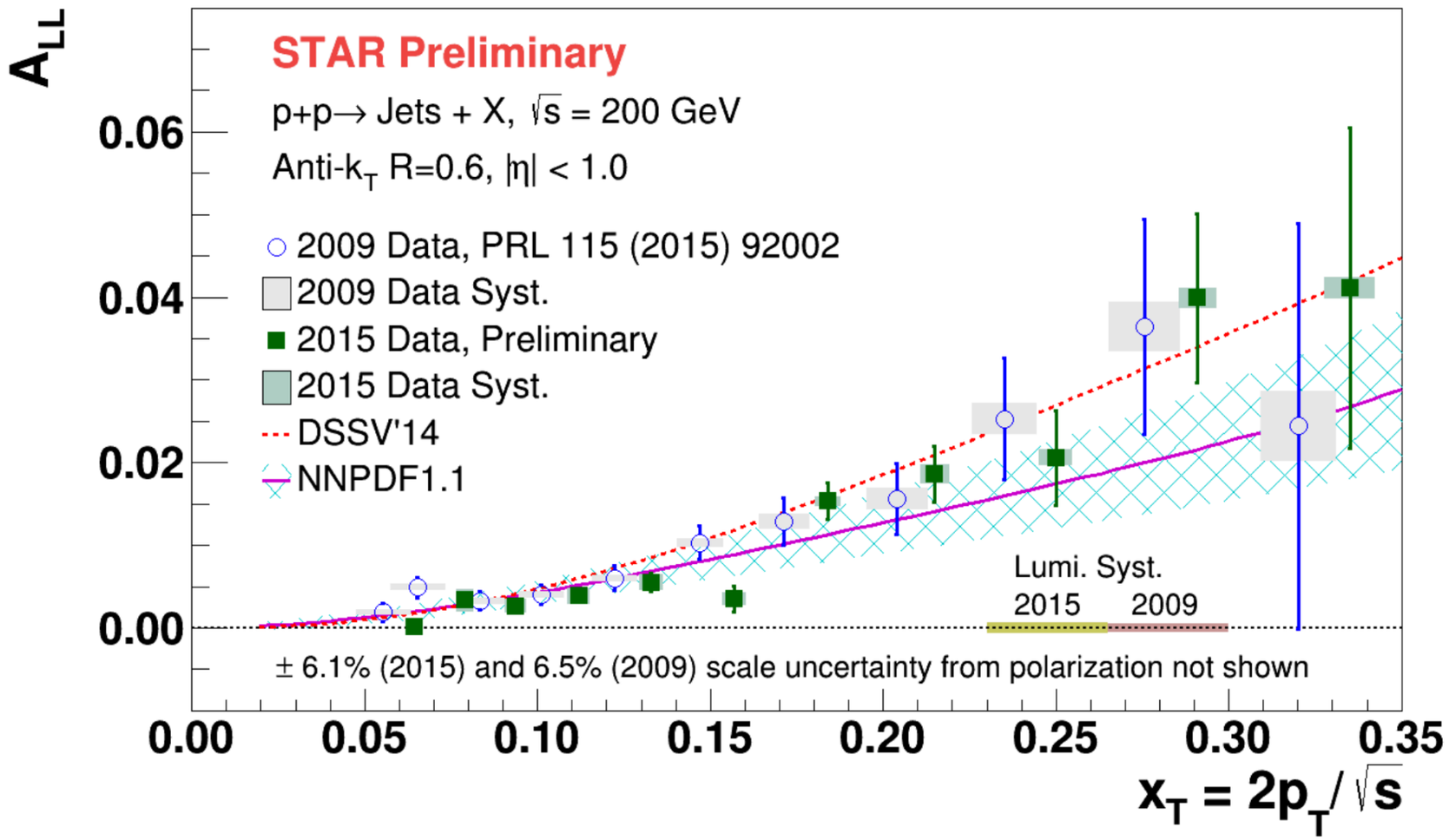
pp polarized

Longitudinal Double spin A_{LL}

- 2015 $\sqrt{s} = 200$ GeV dataset is factor of 2 greater in statistics than 2009

- $\Delta G(x, Q^2)$ is positive for $x > 0.05$

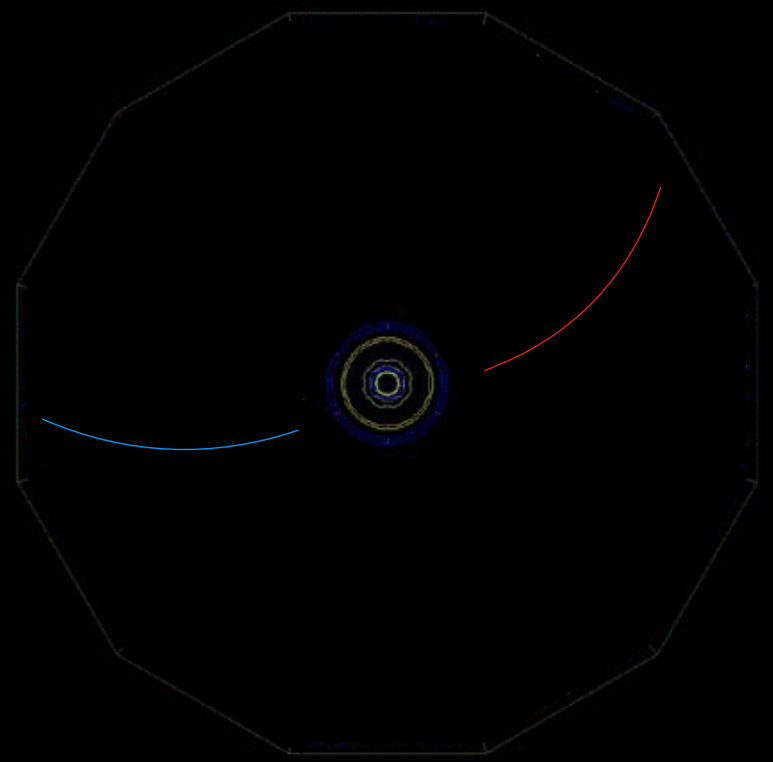
- The most stringent constraints for $x > 0.1$ until the EIC



see talk by Nick Lukow

Spin and Cold QCD

Light Flavor Spectra



Ultra Peripheral Collisions

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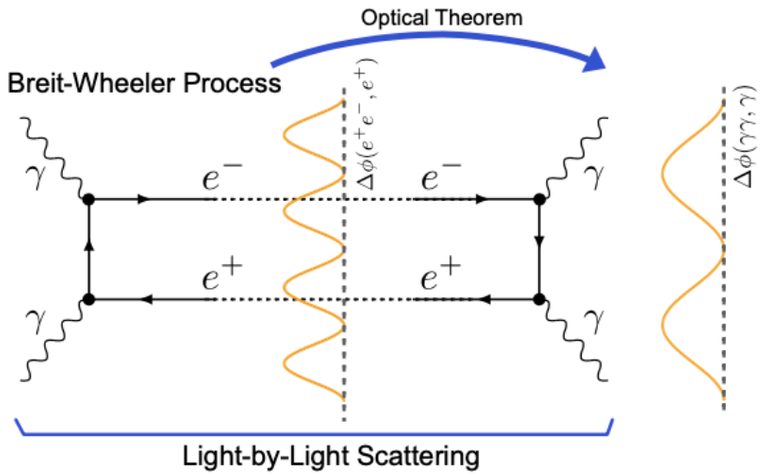
Heavy Flavor

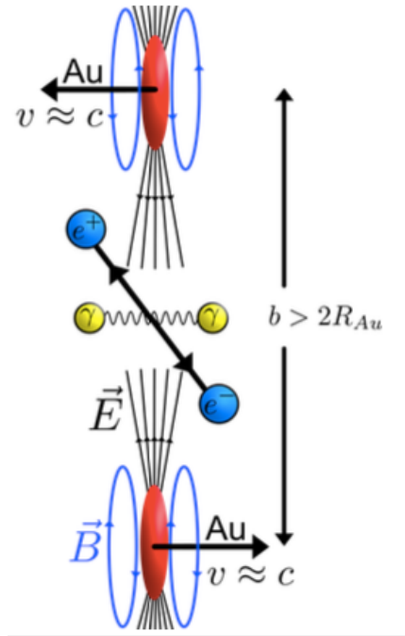
Light by light scattering leading to particle production



- Observation of exclusive Breit-Wheeler process with all possible kinematic distributions (yields, M_{ee}, p_T, angle)

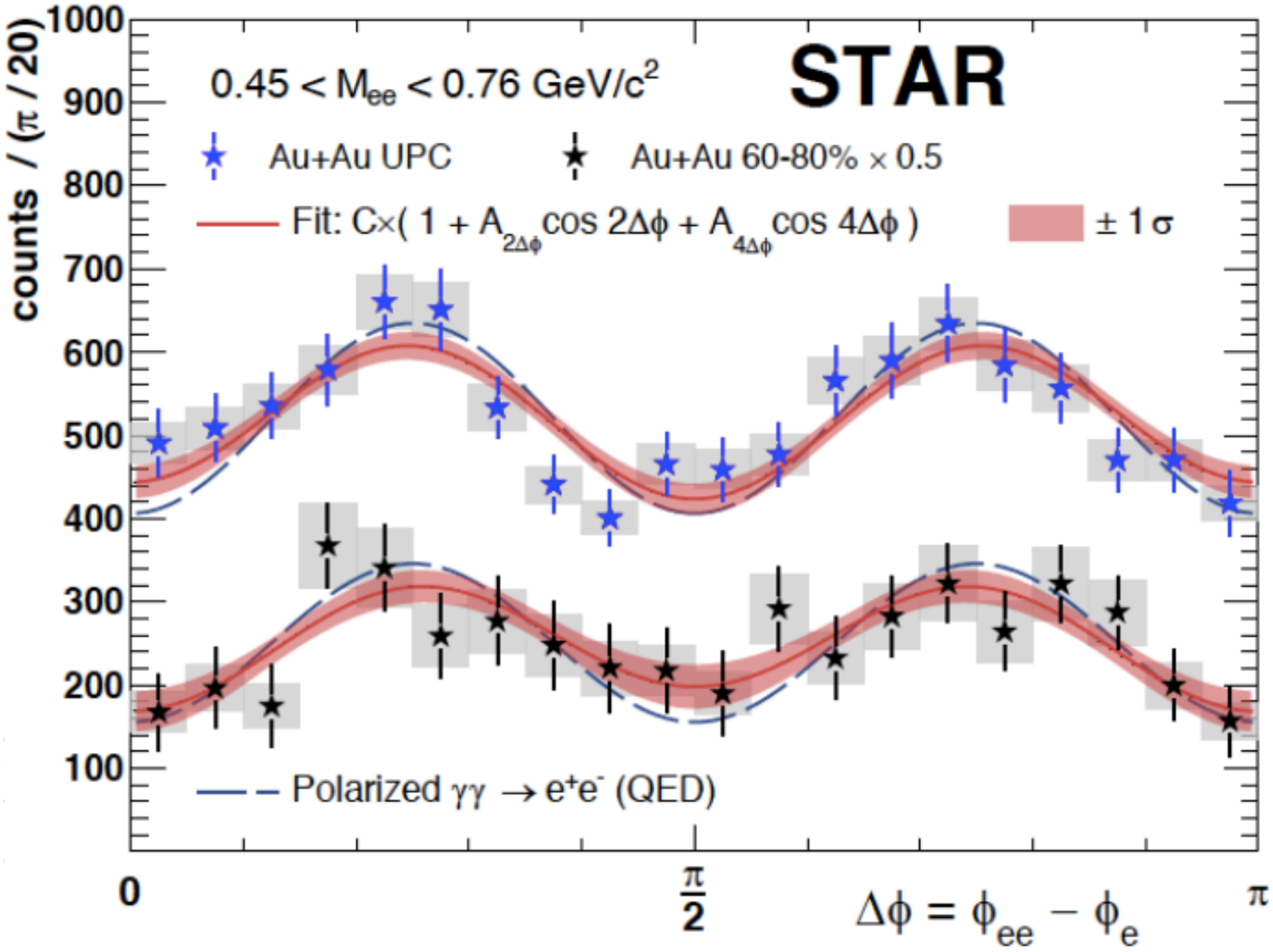
- Observation of Vacuum Birefringence at 6.7σ in UPC

1934, Breit and Wheeler, Collision of two light Quanta to create matter and antimatter (e+e-)



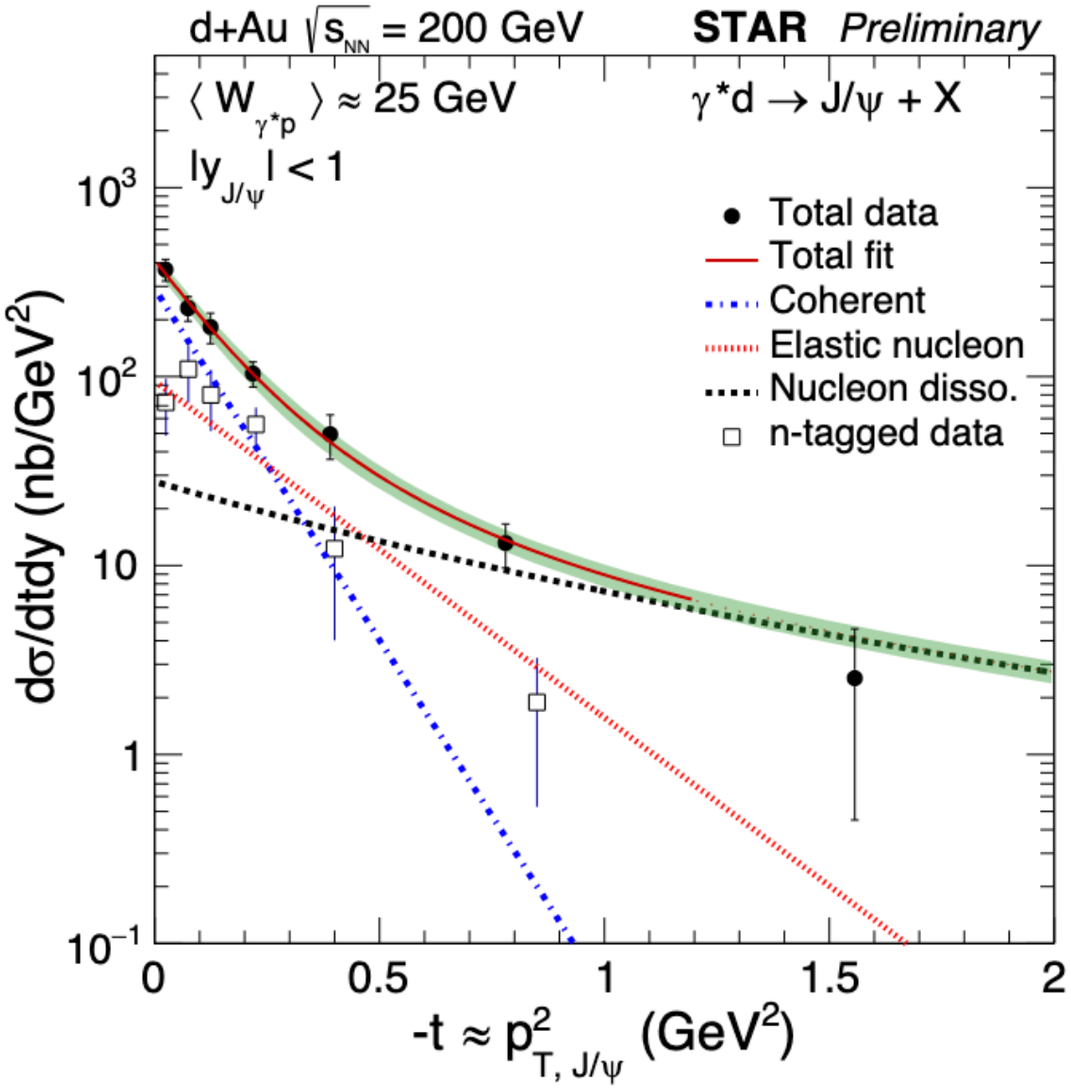
Au+Au

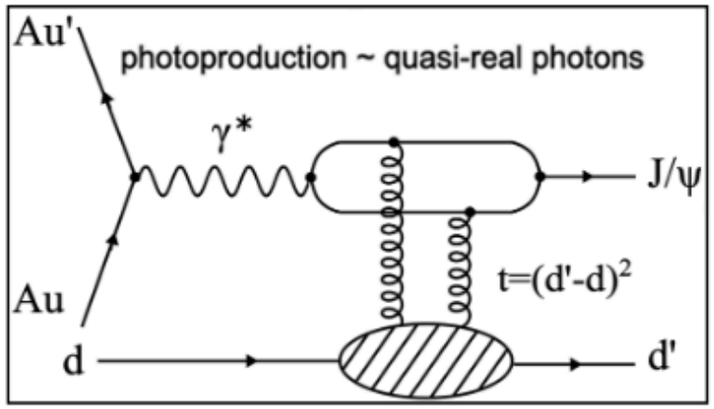
STAR arXiv: 1910.12400

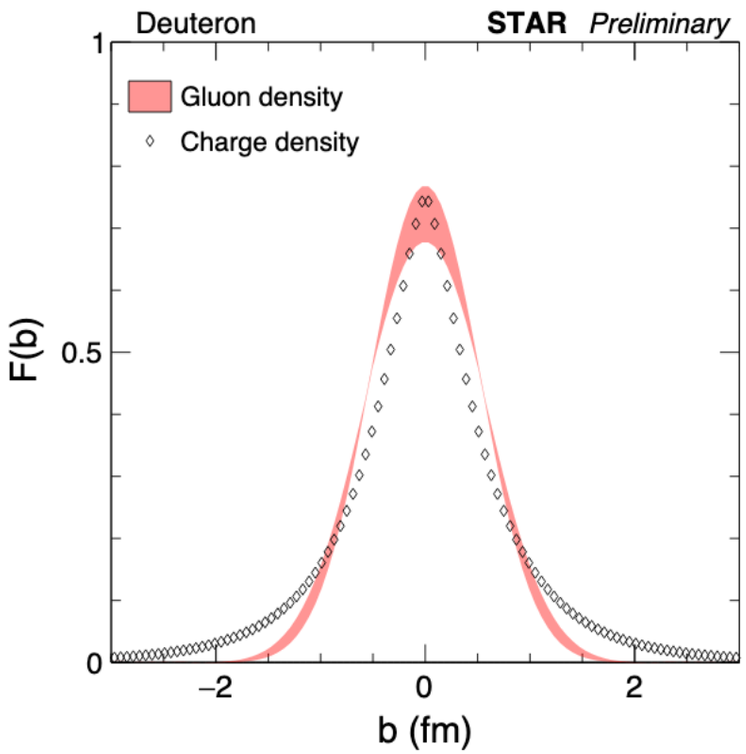


J/ψ photo-production

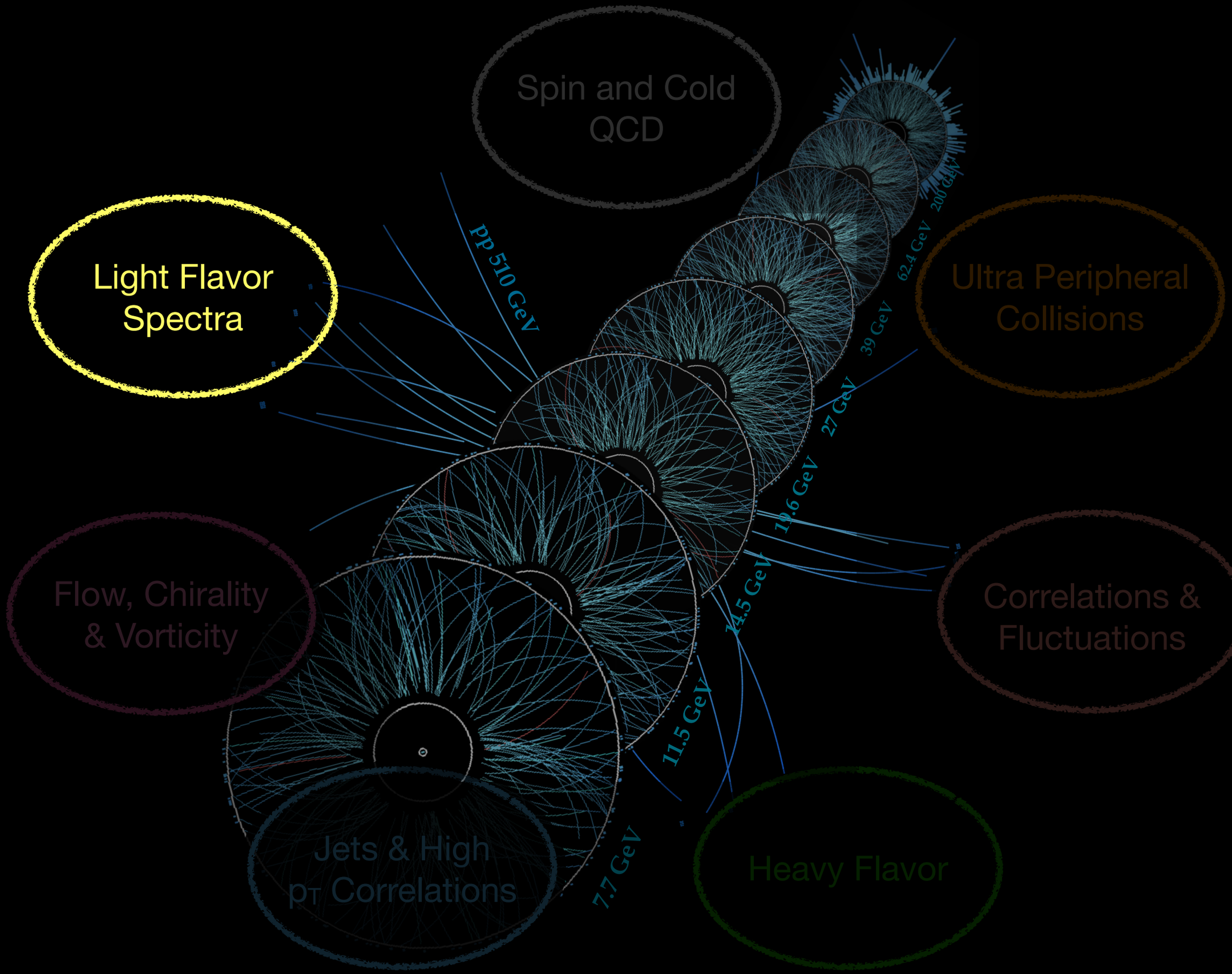
Ultra-peripheral triggers were used during 2016 data taking d-Au @ $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, with J/ψ vector meson targeted (i.e., topological requirement)







- Gluon distributions are wider
- Sensitive to the deuteron wave function


Spin and Cold QCD
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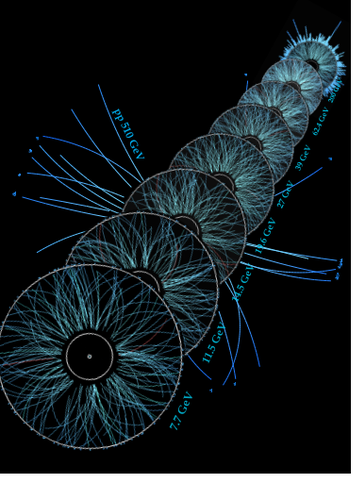
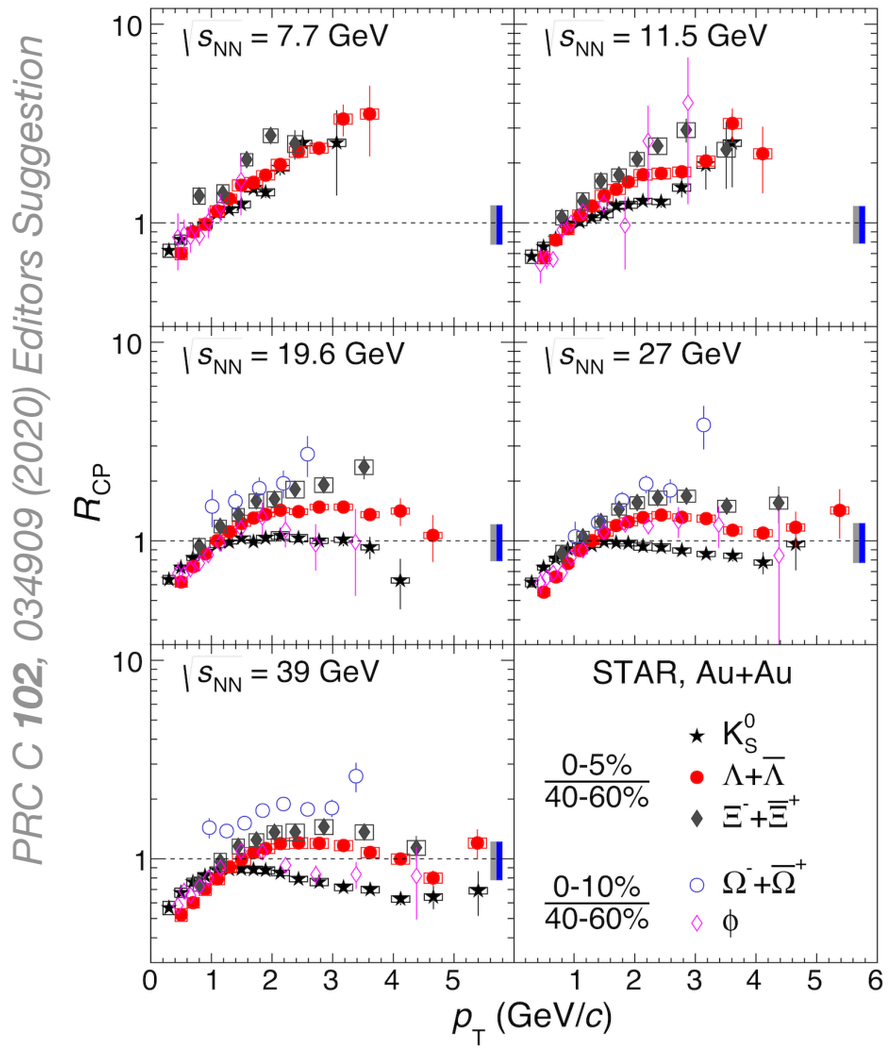
Heavy Flavor
pp 510 GeV
200 GeV
62.4 GeV
39 GeV
27 GeV
19.6 GeV
14.5 GeV
11.5 GeV
7.7 GeV

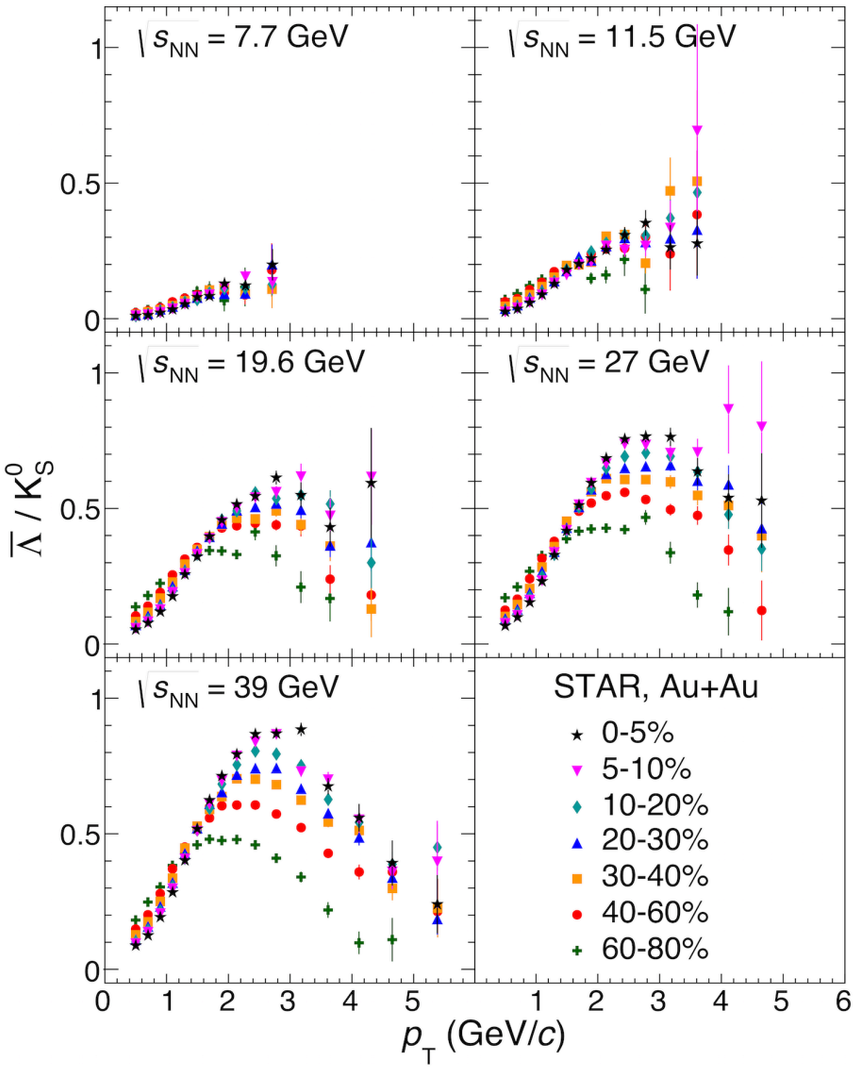


Strange hadron production

Au+Au

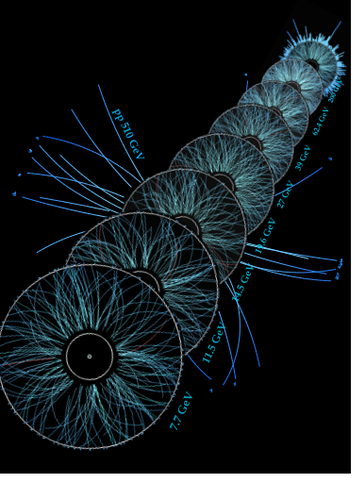
- Strangeness production well documented in BES
- R_{CP} starts to turn over around $\sqrt{s_{NN}} \approx 20$ GeV





To be improved by BES-II

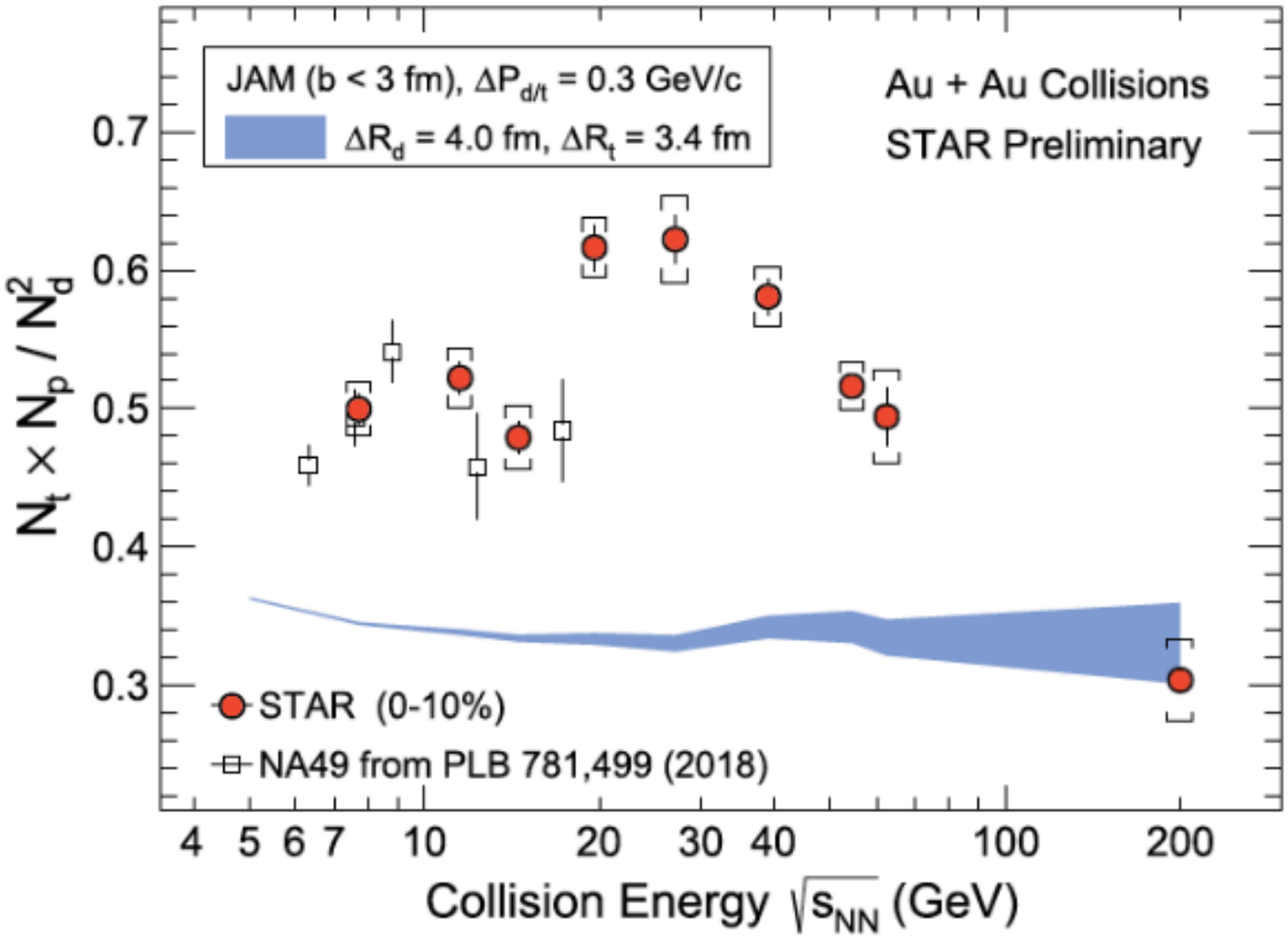
- Baryon-to-meson enhancement at intermediate p_T (≈ 2.5 GeV/c) in central collisions at energies above 19.6 GeV
- Both suggest that there is likely a change of the underlying strange quark dynamics at collision energies below 19.6 GeV



Light nuclei production

Au+Au

Snowballs in hell!



The yield ratio is related to neutron density fluctuations.

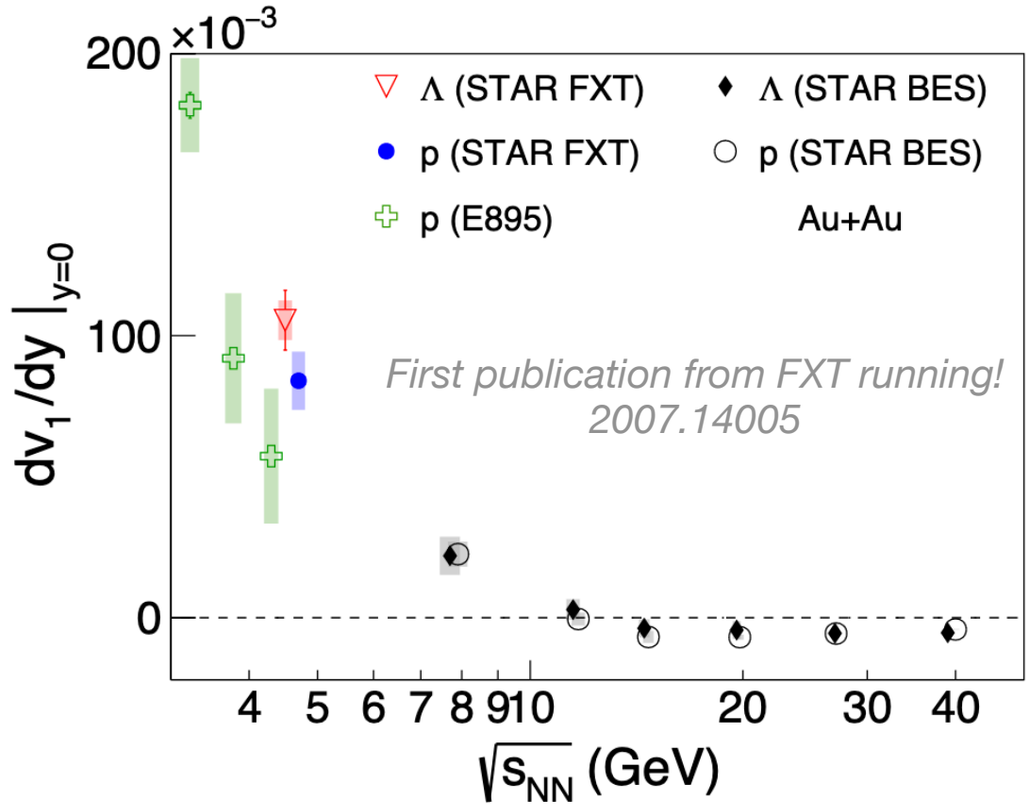
$$N_t \cdot N_p/N_d^2 = g(1+\Delta n),$$
$$\text{with } g = 0.29$$

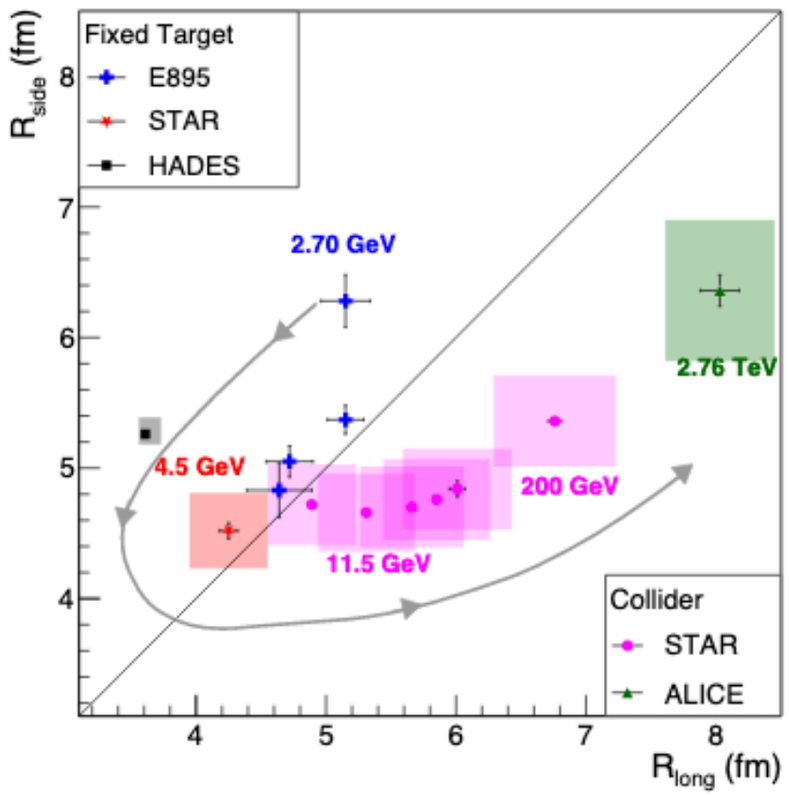
Note the trends at $\sqrt{s_{\mathrm{NN}}}$ ~ 10-20 GeV

- Measurements from STAR and NA49 are Consistent
- Trends in data not captured by theoretical calculation

Flow and HBT in FXT

- Directed flow(v_1) of protons and Λ baryons is in line with measurements at higher and lower energies within systematic uncertainties



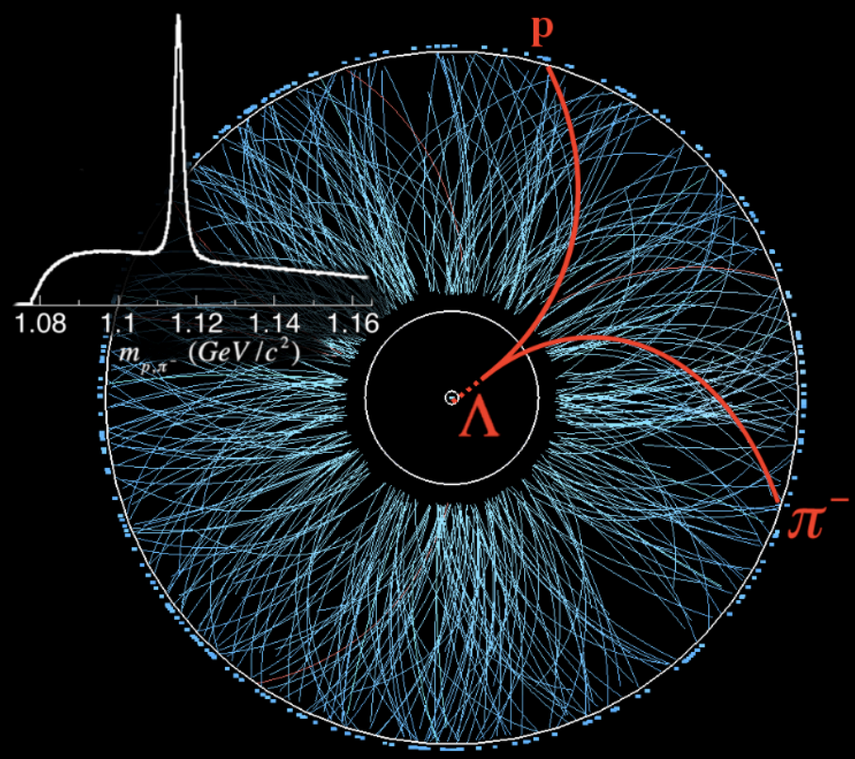


- HBT femtoscopy points to a transition region between oblate and prolate spatial sources!

- Pion source radii agree quantitatively with previous measurements at the AGS, and with the broader systematic trends established at higher beam energies.

Spin and Cold QCD

Light Flavor Spectra



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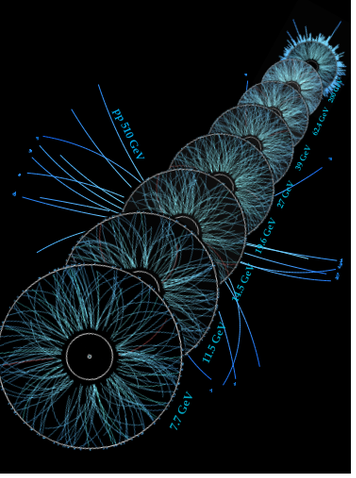
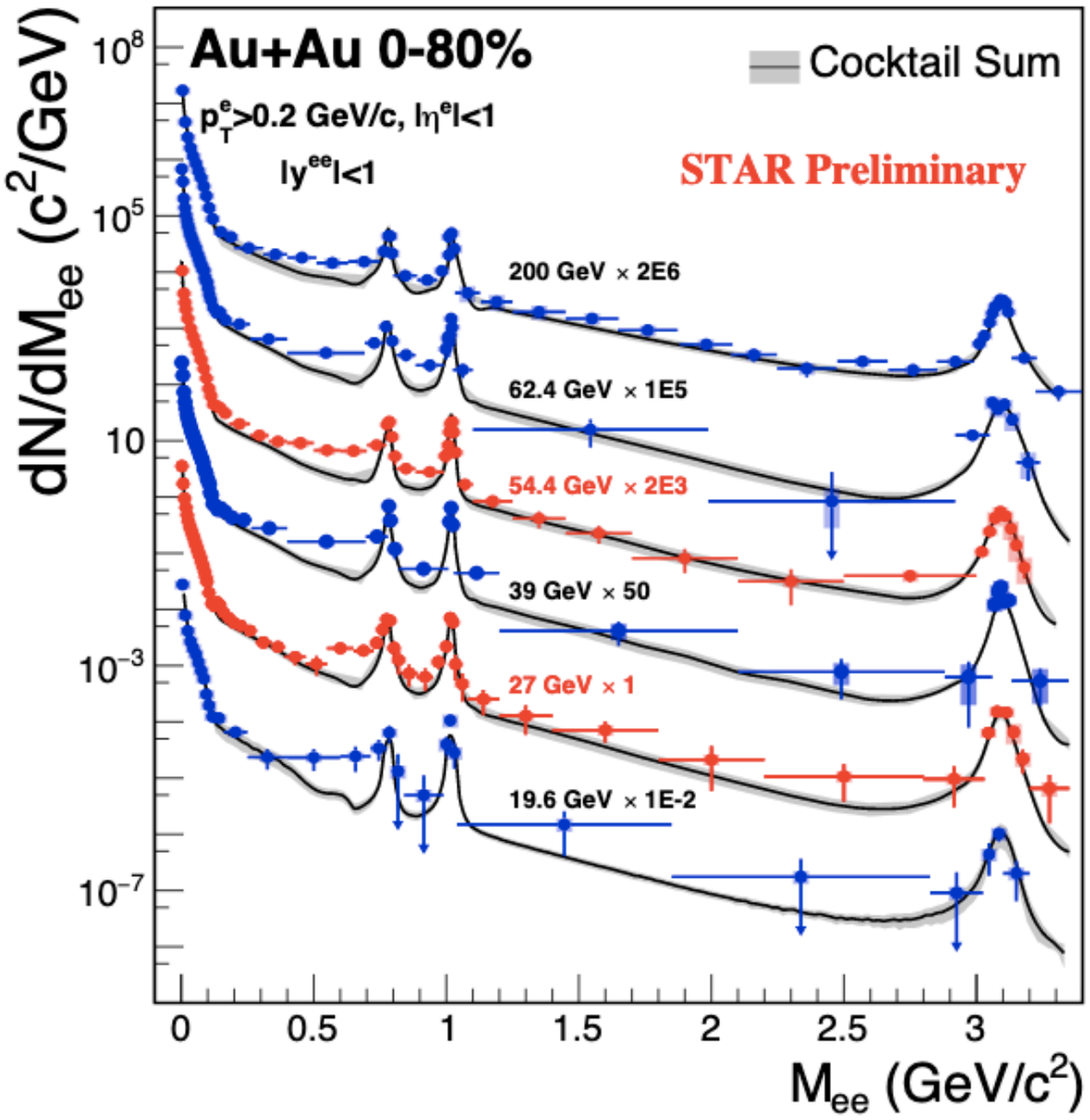


Search for chiral symmetry restoration

Au+Au

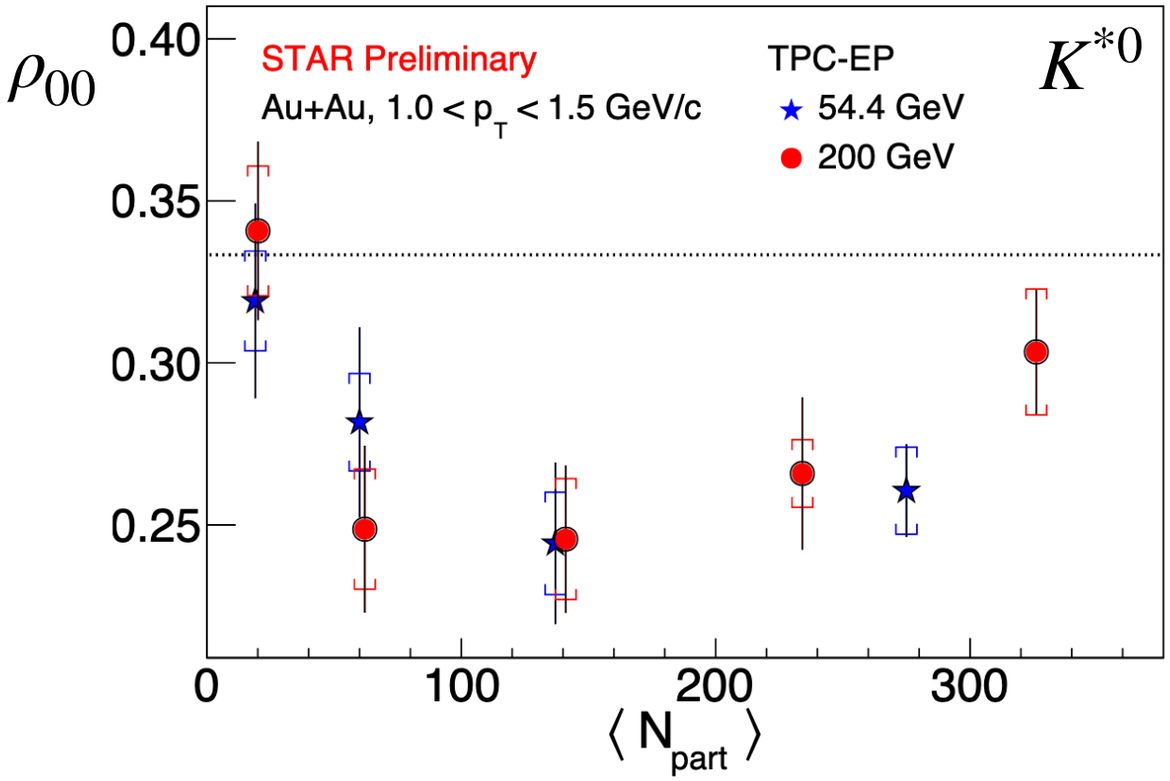
To be improved by BES-II



Search for broadening of resonances (ρ) - symmetry restoration

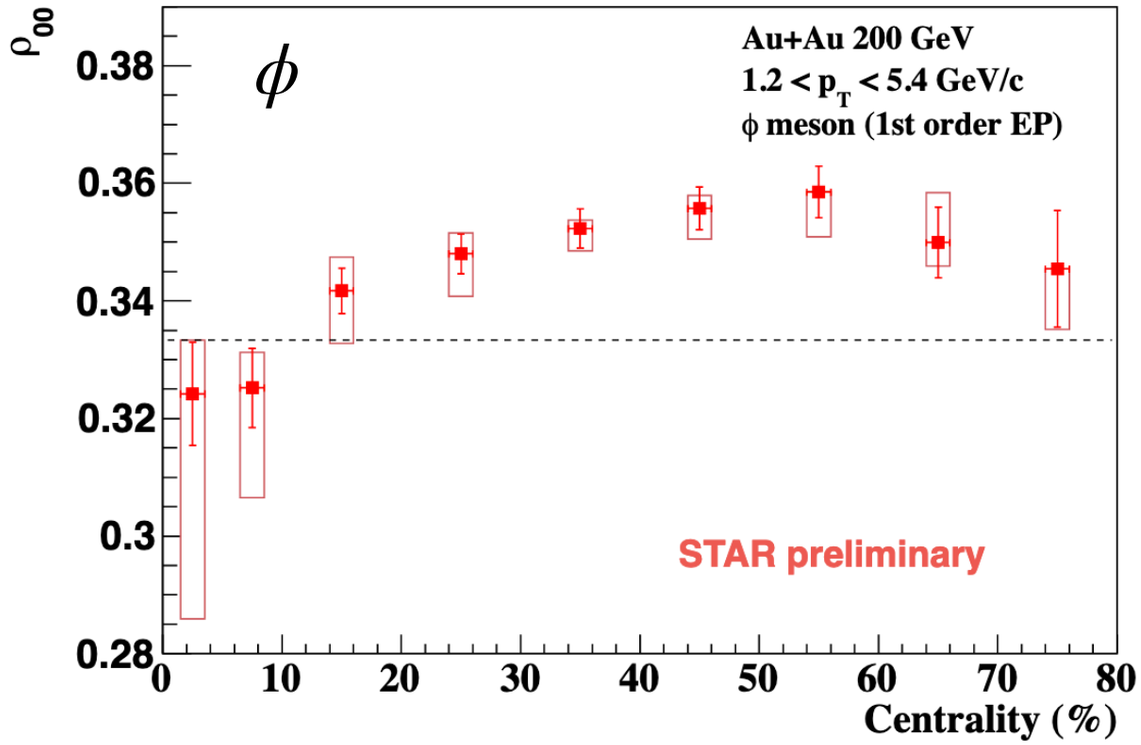
- Yield in intermediate mass range can also point to thermal contribution used to extract medium temperature -
  - Hints of excess in 27 GeV data!
- Increased statistics allow us to measure differentially

Vector meson spin-alignment

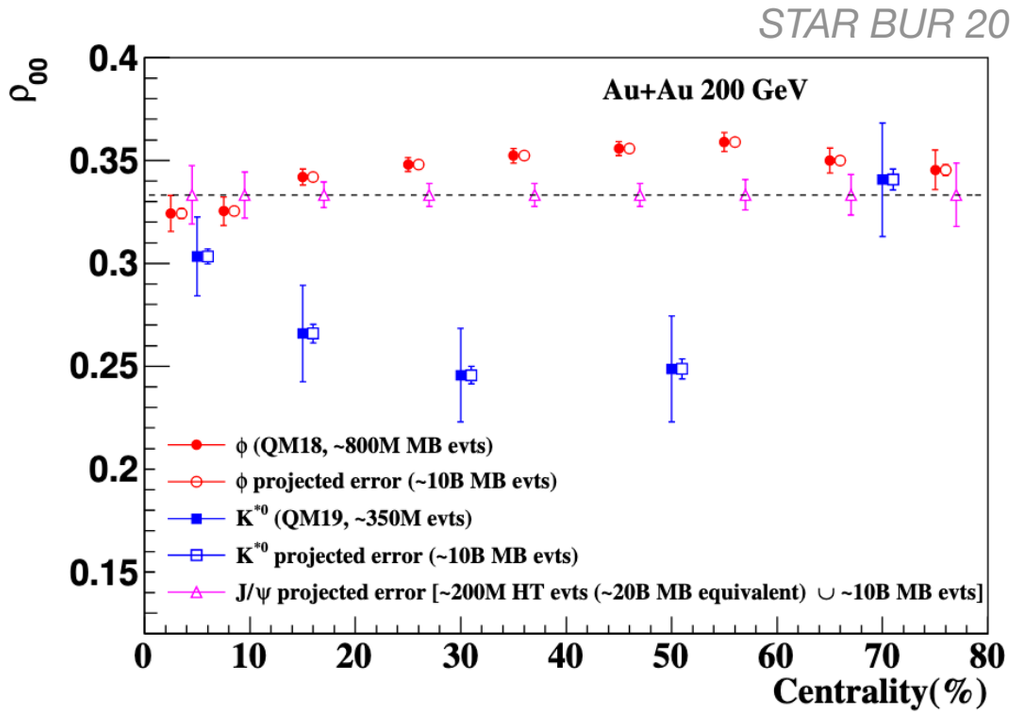


- Large deviation from 1/3 - needs a novel explanation

- Exciting deviation in trends for ϕ meson between RHIC and the LHC - more theory input is needed



STAR BUR 20



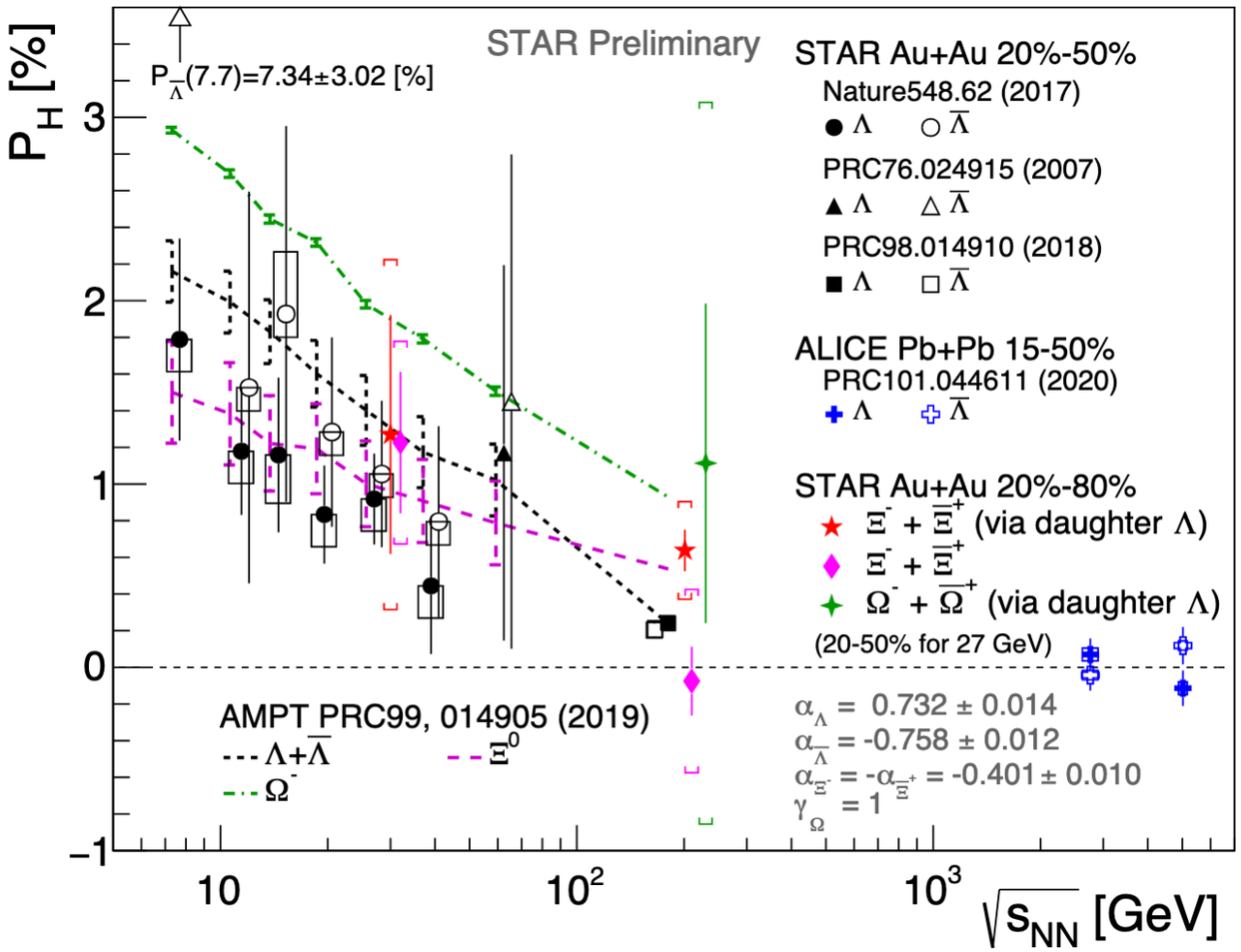
To be improved by larger statistics in Runs 23

Differential measurements of global polarization

Au+Au

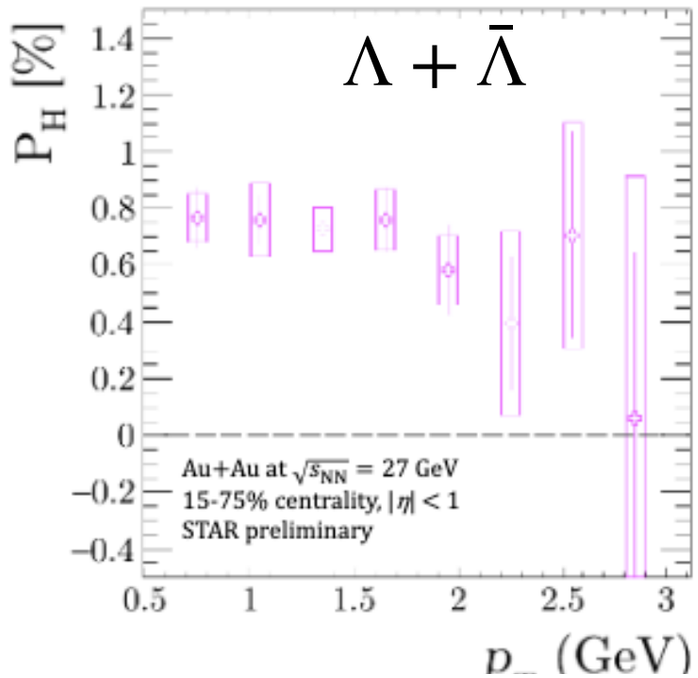
$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha_H \mathrm{P_H} \cos\theta^*$$

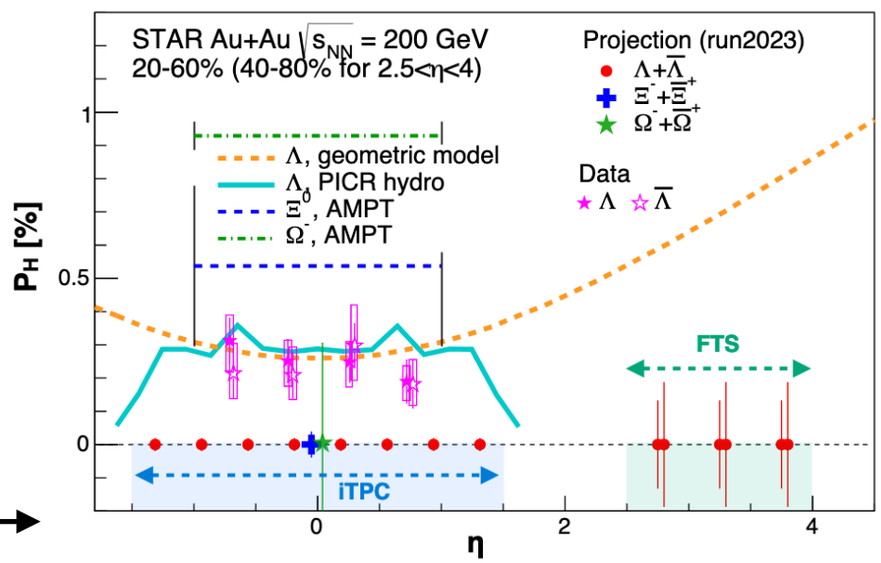
see talk by Takafumi Niida



* published results are rescaled by $\alpha_{old}/\alpha_{new}$~0.87

- P_H(%) as a function of momentum, rapidity, centrality, particle mass and spin (Ξ and Ω), azimuthal angle, charge…
- Different predictions from theory for rapidity dependence →



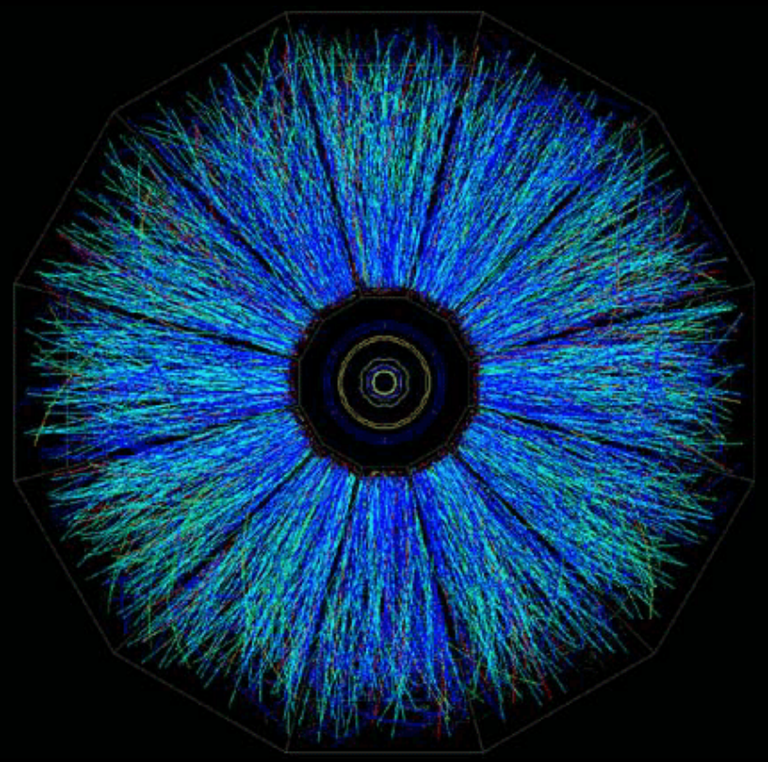


To be improved by larger statistics in Runs 23

Spin and Cold QCD

Light Flavor Spectra

Ultra Peripheral Collisions



Flow, Chirality & Vorticity

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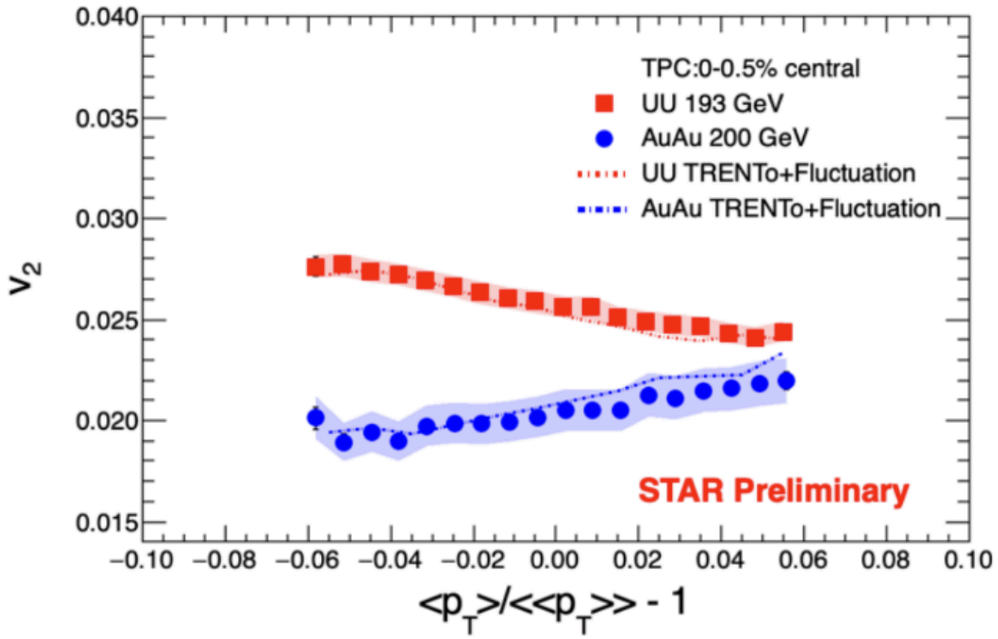
Jets & High p_T Correlations

Heavy Flavor

Flow and mean p_T correlation

Sensitive to deformations



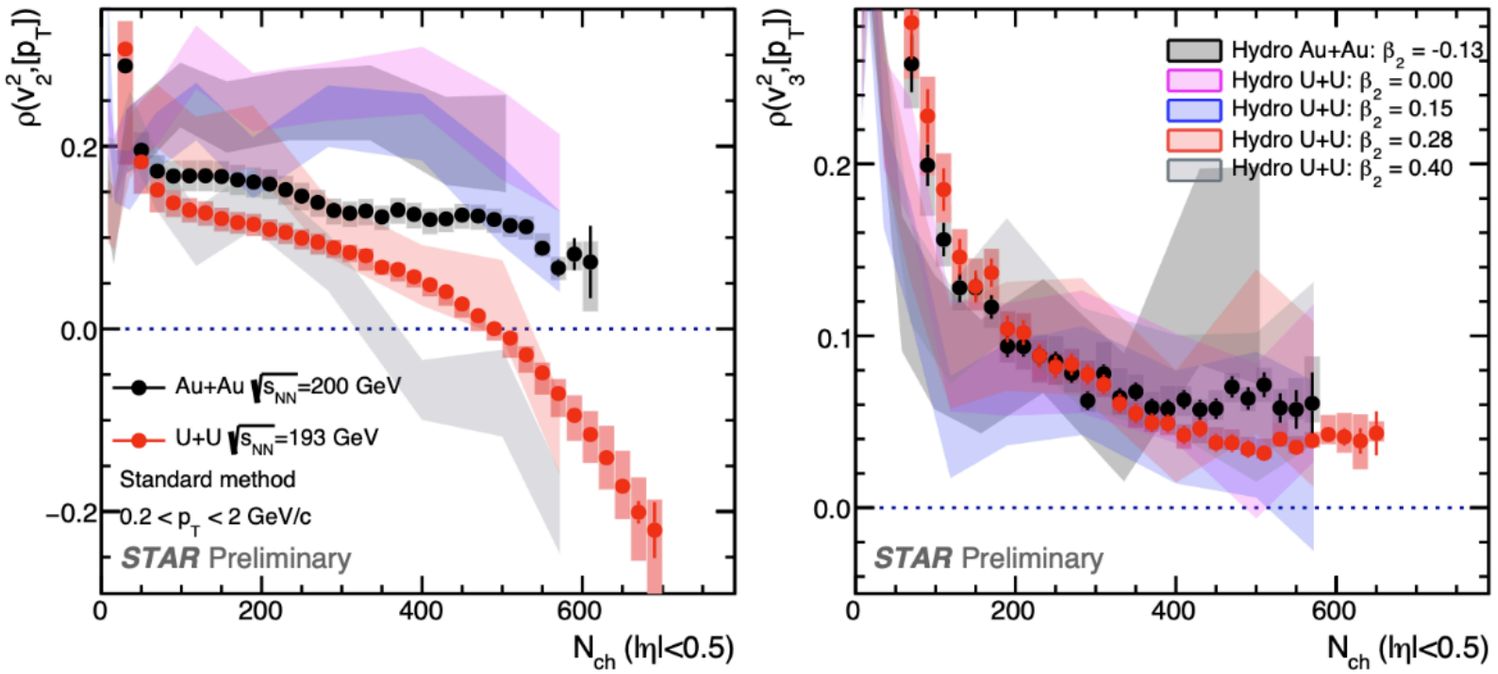
- An anti-correlation is observed between v_2 and $\langle p_T \rangle$ for top 0.5% U+U collisions while a positive correlation in Au+Au
  - v_3 and $\langle p_T \rangle$ correlations are positive and similar

- Considering the effect of finite multiplicity in an event, TRENTO can quantitatively describe data!

Pearson Coefficients

- $\rho(v_2^2, [p_T])$ has clear difference: negative in U+U central, positive in Au+Au central while $\rho(v_3^2, [p_T])$ is always positive in Au+Au and U+U

- IP-Glasma-Hydro describes $\rho(v_3^2, [p_T])$ but not the $\rho(v_2^2, [p_T])$ quantitatively.
  - Nevertheless it does predict negative $\rho(v_2^2, [p_T])$ in central U+U for some β_2 values



see poster by Chunjian Zhang

Non-linear mode coupling and EP correlations

Au+Au

Nonlinear mode-coupling coefficient:

$$\chi_{n+2,2n} = \frac{\langle v_{n+2}\cos((n+2)\Psi_{n+2} - 2\Psi_2 - n\Psi_n)\rangle}{\sqrt{\langle v_2^2 v_n^2\rangle}}$$

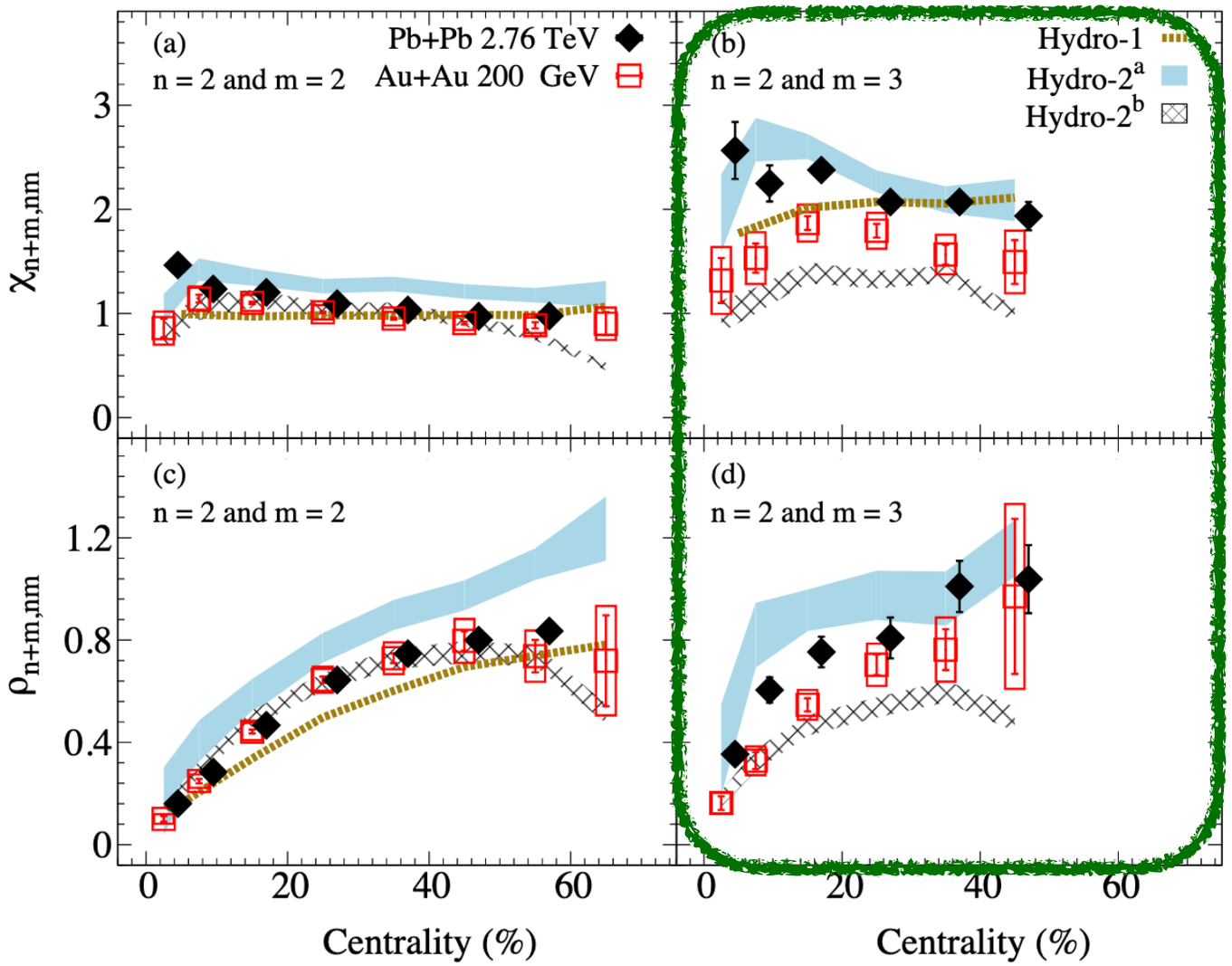
Event-Plane Angular Correlation:

$$\rho_{n+2,2n} \sim \langle\cos((n+2)\Psi_{n+2} - 2\Psi_2 - n\Psi_n)\rangle$$

	Hydro−1 [63]	Hydro−$2^{a/b}$ [64]
η/s	0.05	0.12
Initial conditions	TRENTO Initial conditions	IP-Glasma Initial conditions
Contributions	Hydro + Direct decays	(a) Hydro + Hadronic cascade (b) Hydro only

	Strong	Weak
centrality	$\rho_{4,22}$, $\rho_{5,23}$	$\chi_{5,23}$
$\sqrt{s_{NN}}$		$\chi_{5,23}$, $\rho_{5,23}$

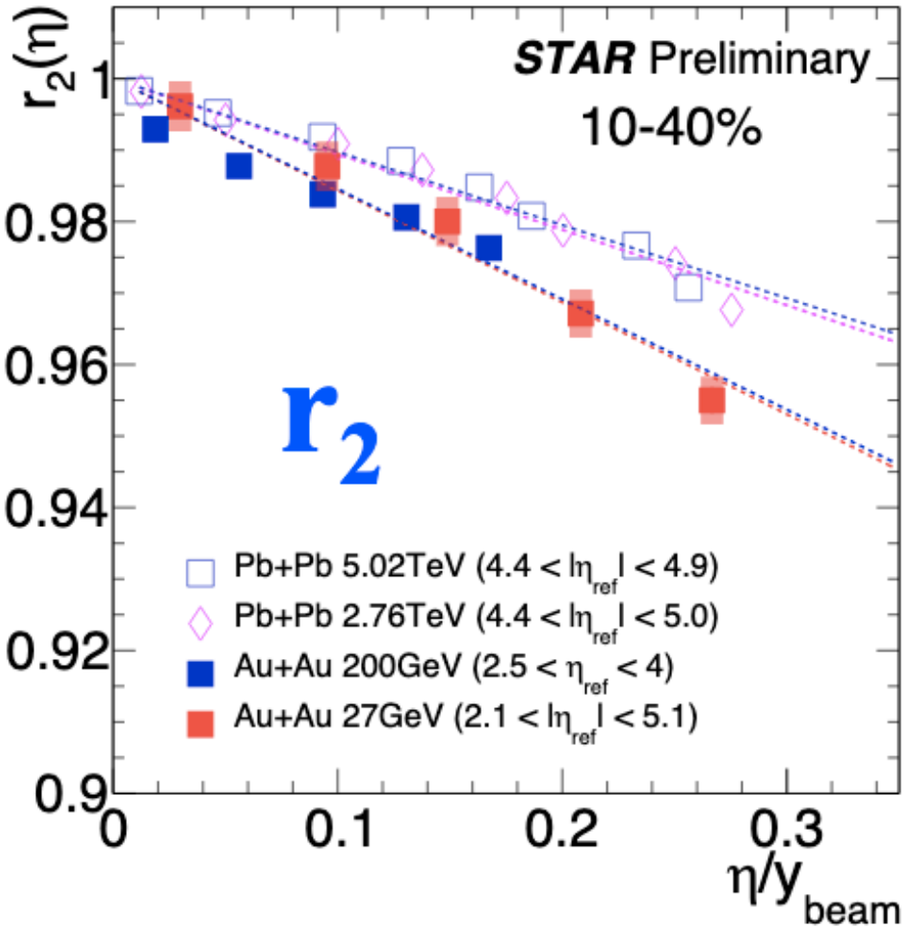
2006.13537



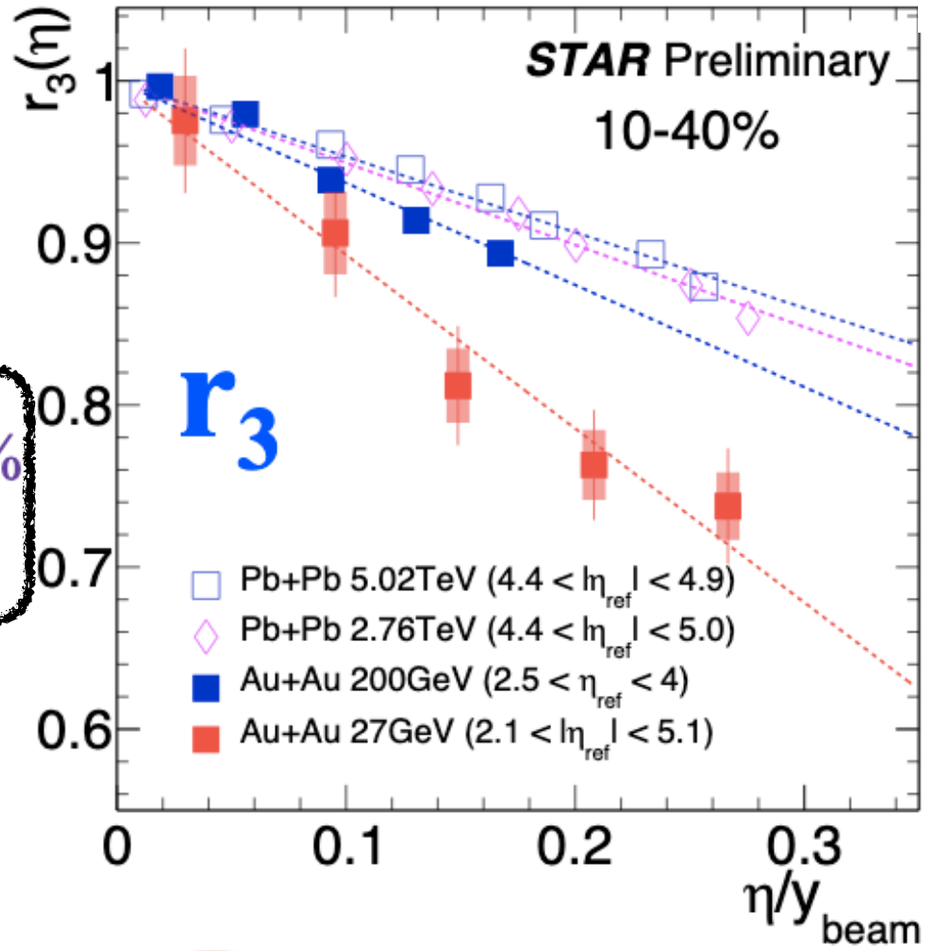
Both coefficients can be used to distinguish hydrodynamic models

Longitudinal flow decorrelation

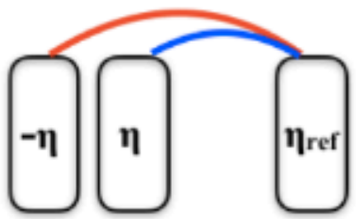
Au+Au



r_3 shows up to 30% decorrelation



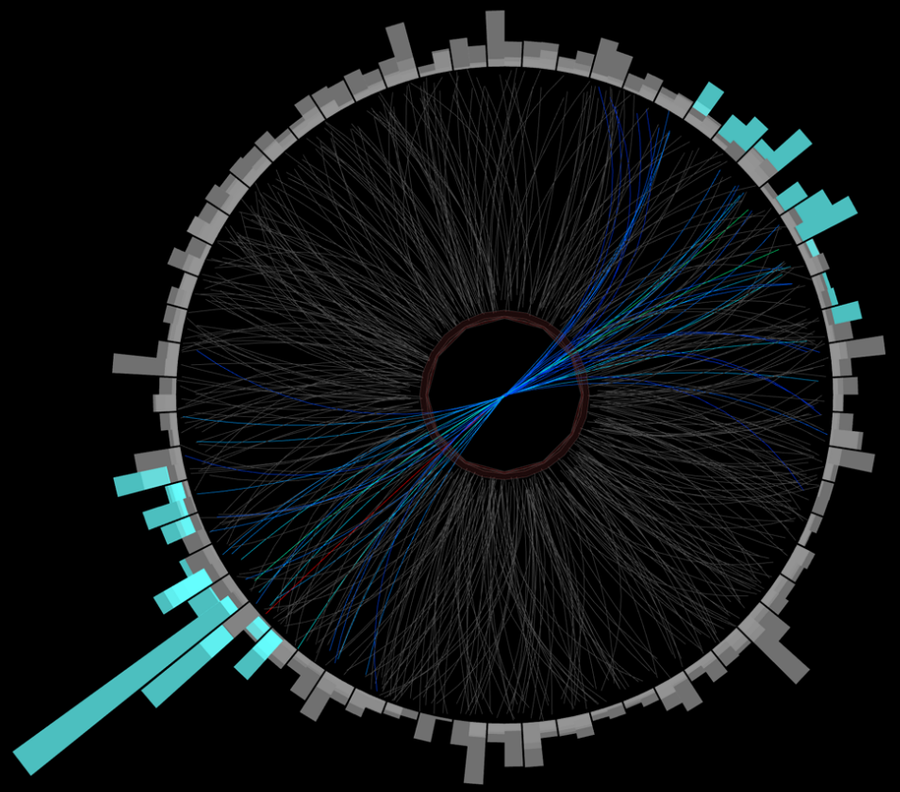
$$r_n(\eta) = \frac{\langle V_n(-\eta) V_n^*(\eta_{\rm ref})\rangle}{\langle V_n(\ \eta) V_n^*(\eta_{\rm ref})\rangle}$$



- No energy dependence of r_2 at RHIC energies
- Clear energy dependence of r_3 at RHIC energies

Spin and Cold QCD

Light Flavor Spectra



Ultra Peripheral Collisions

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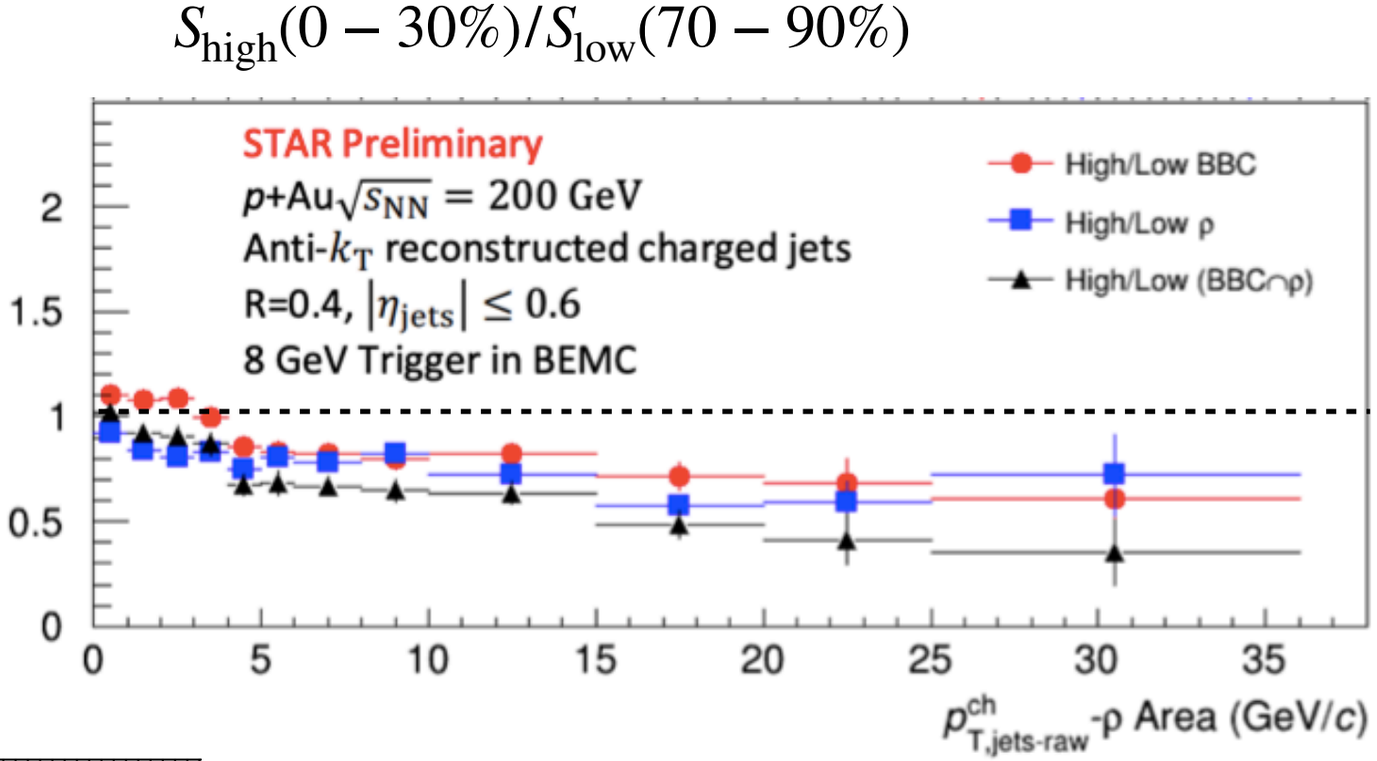
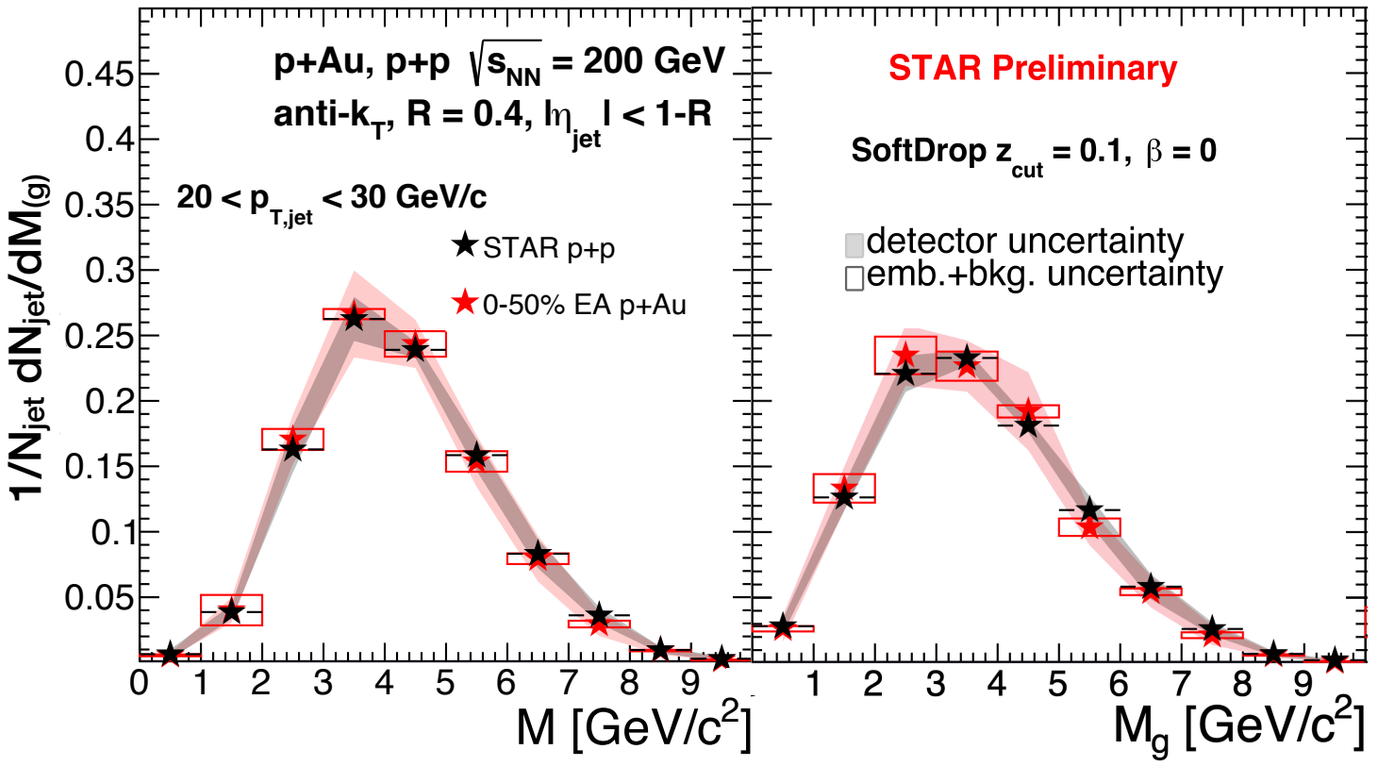
Heavy Flavor

Jets and small systems

High activity events (based on Au-going BBC selection) in p+Au show suppression in jet spectra …



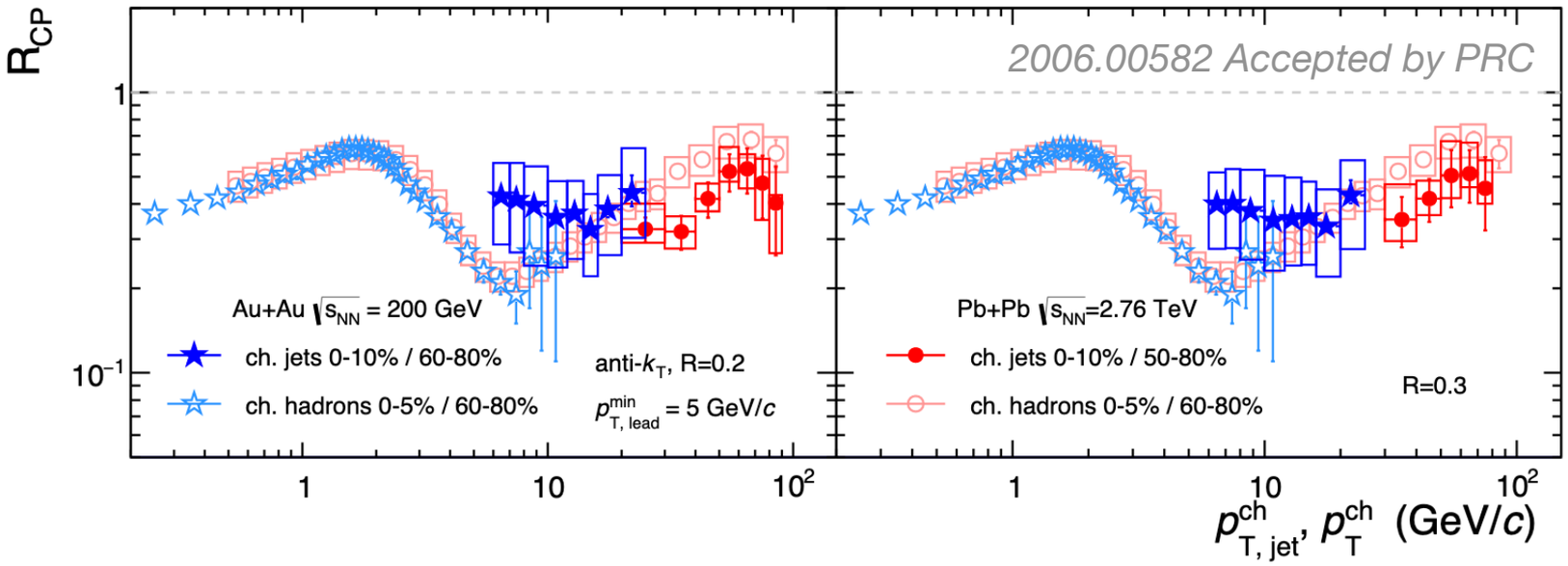


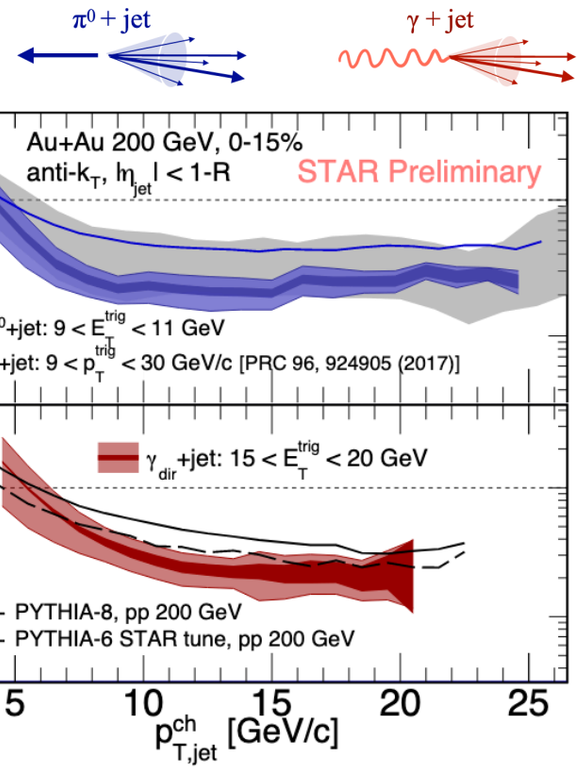
… jet substructure is not modified!

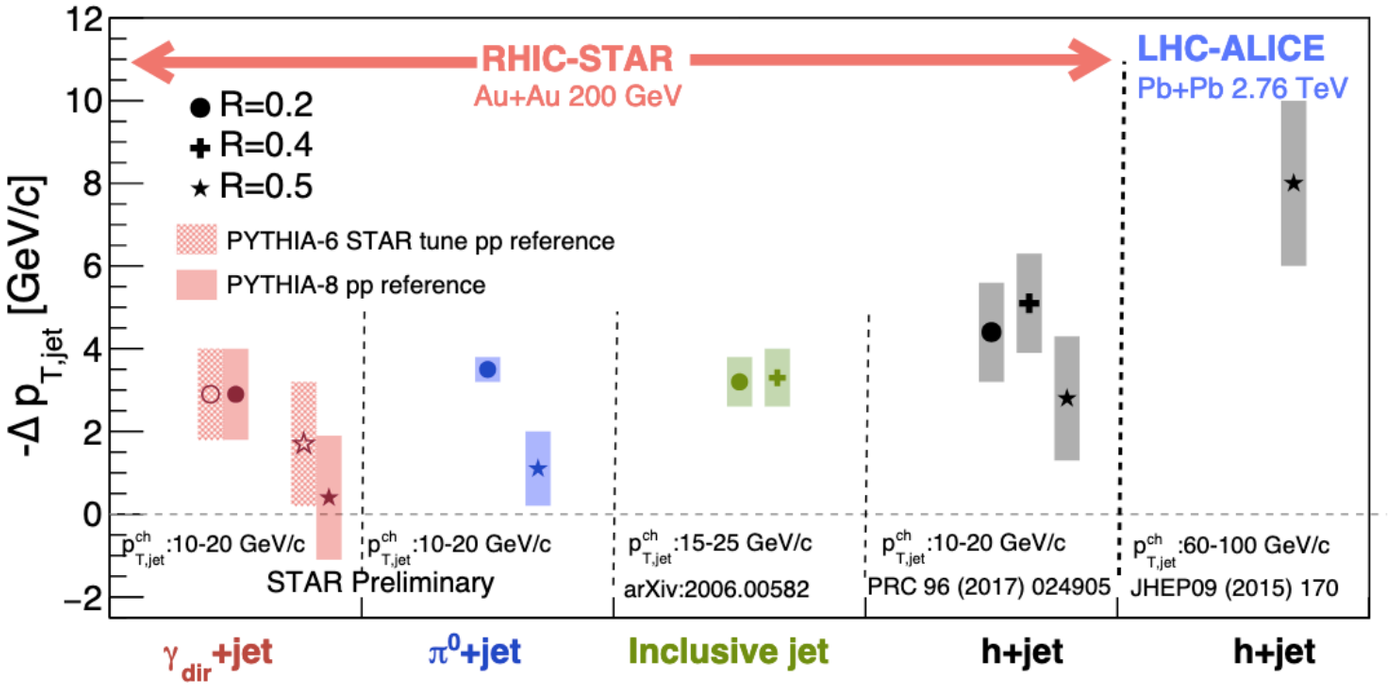
This points to that suppression in jet-like activity at mid-rapidity is likely caused by event classification based on backward (Au-going) rapidity activities

- Early time effect!

Parton energy loss at RHIC

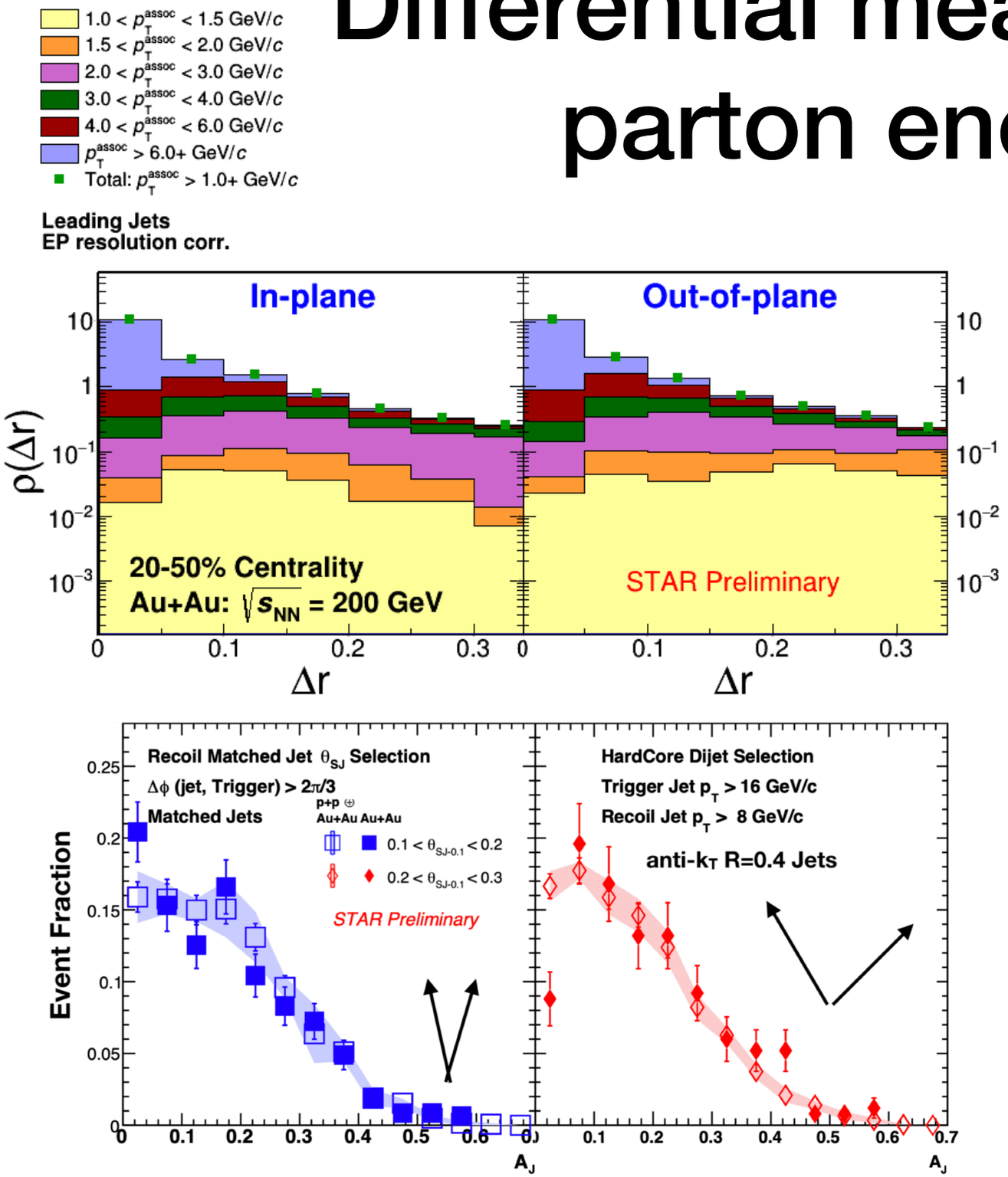






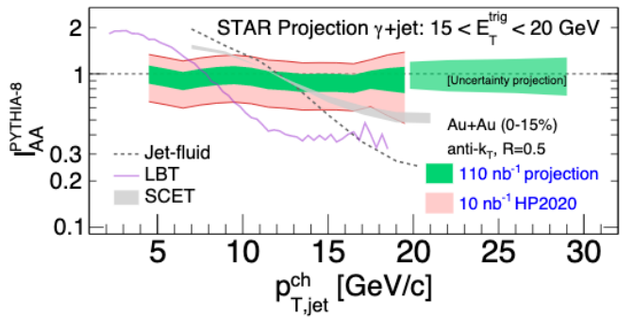
- Extracting energy loss from inclusive and semi-inclusive jet measurements at RHIC points to roughly 2-4 GeV/c p_T shift (re: energy loss) due to medium induced radiation
- Indication of smaller absolute energy loss at RHIC than at the LHC

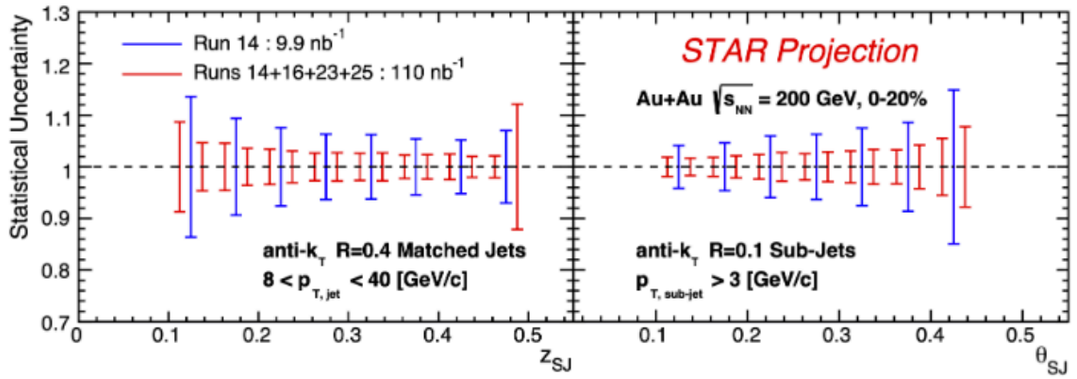
Differential measurements of parton energy loss



- Measure energy loss in momentum and angular scales differentially
- Jet shapes - show hints of path length dependent modification with increased soft particle yield in out-of-plane jets
- Isolate populations of jets with large/small opening angles - measure soft gluon emission via LPM effect!

To be improved by larger statistics in Runs 23



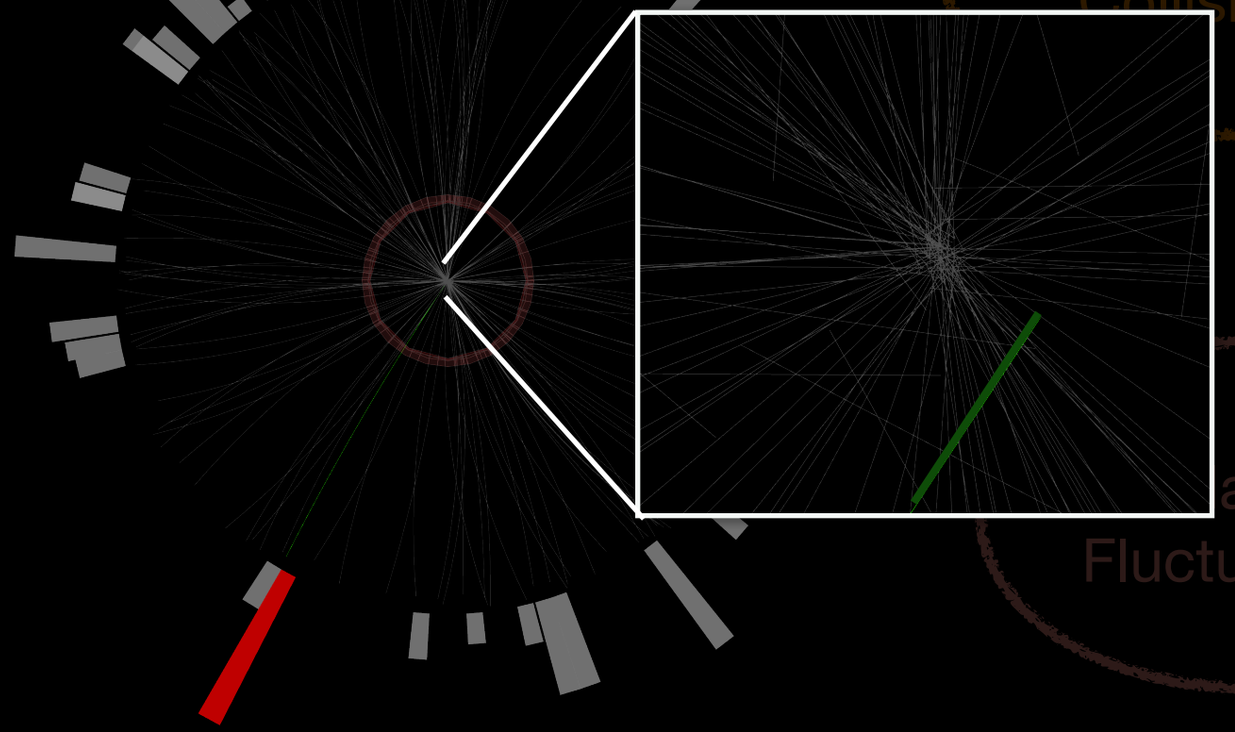


see talk by Isaac Mooney

Spin and Cold QCD

Light Flavor Spectra

Ultra Peripheral Collisions



Flow, Chirality & Vorticity

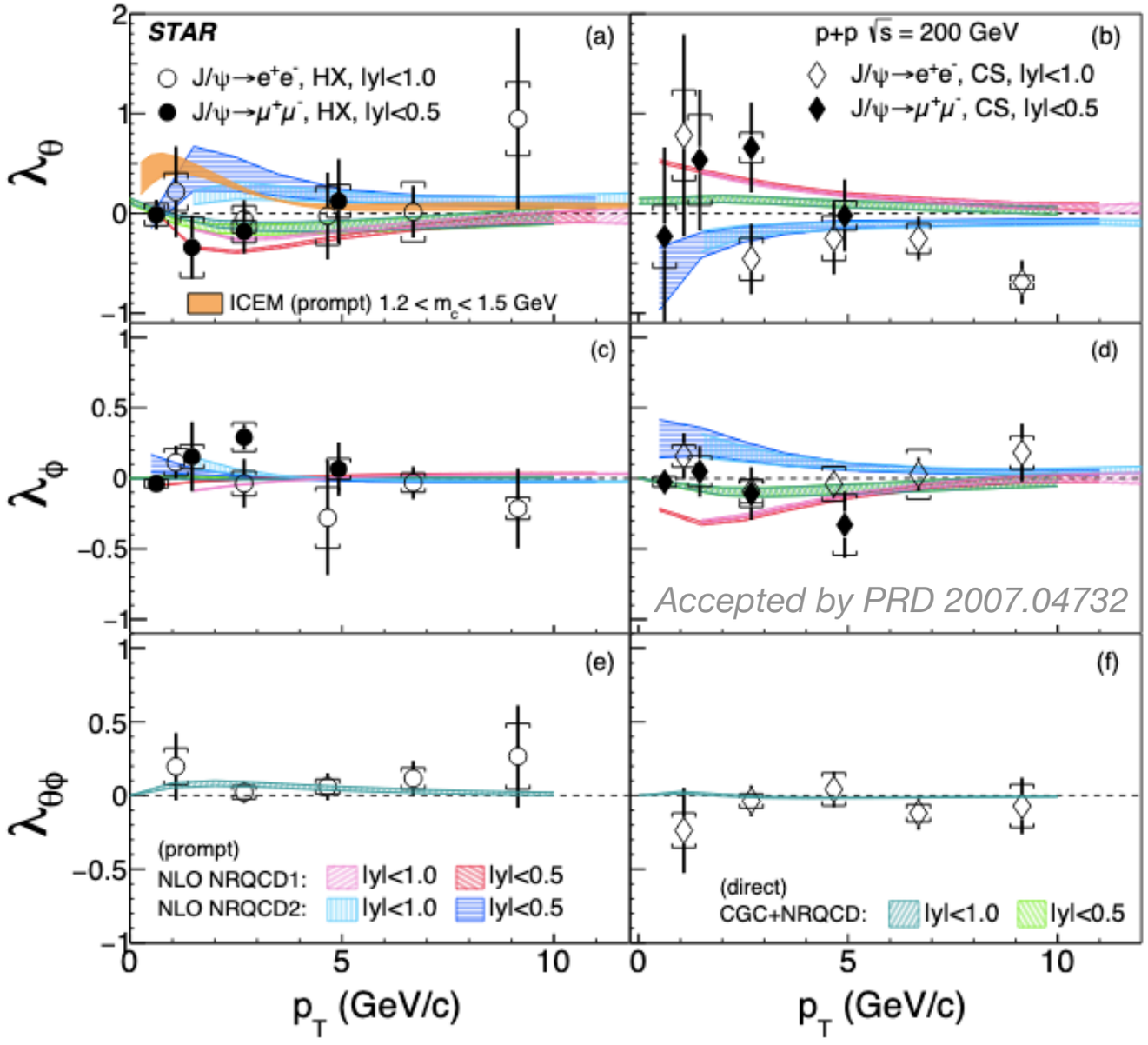
ations & Fluctuations

Jets & High p_T Correlations

Heavy Flavor

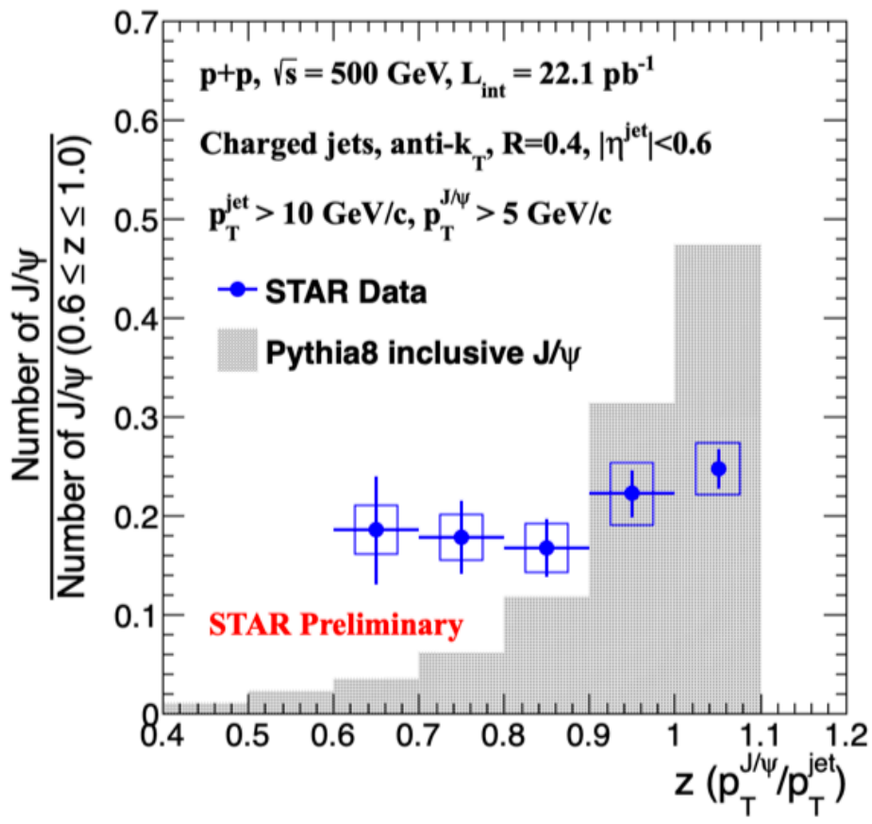
J/ψ production and polarization

pp



Accepted by PRD 2007.04732

- Polarization measurements are consistent with zero for most of the reference frames and kinematics, except λ_θ in CS frame at high p_T

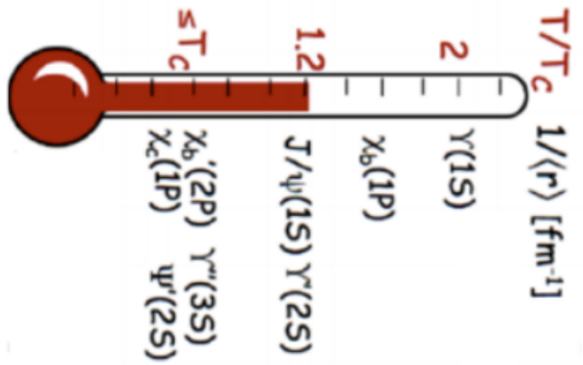


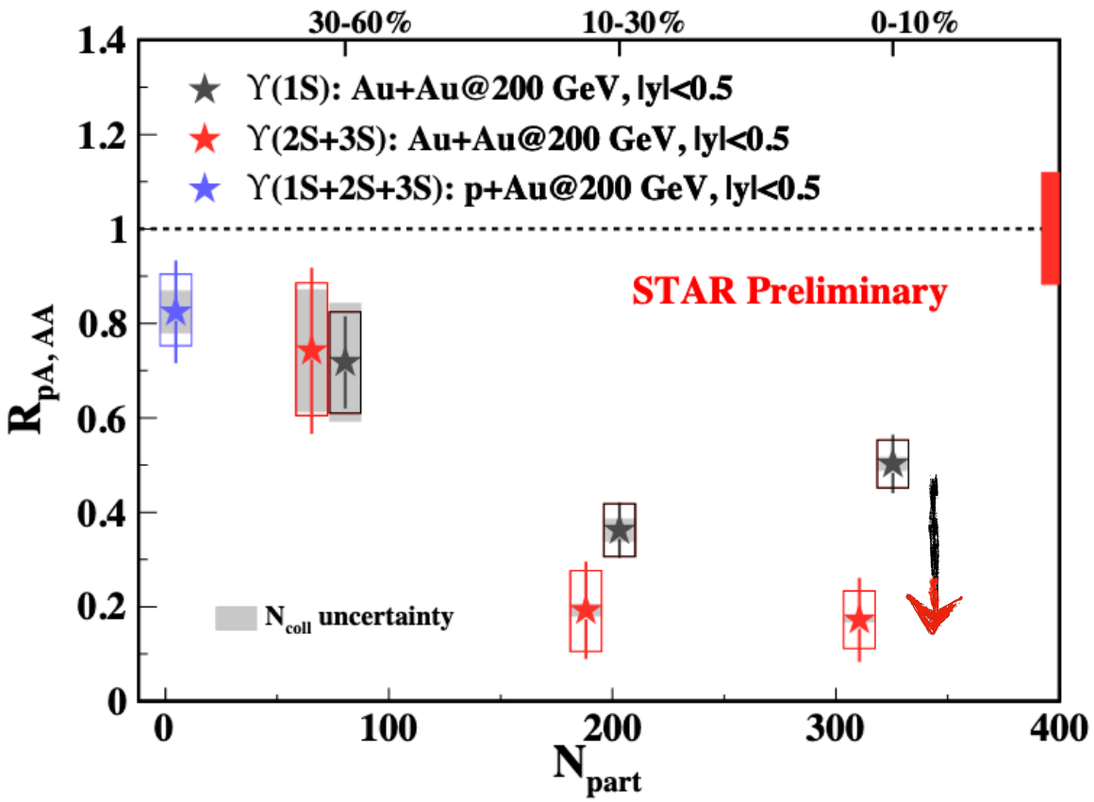
- First measurement of J/ψ production for jet p_T > 10 GeV/*c*
- MC models (PYTHIA 8) are not able to reproduce the data

see talk by Qian Yang

Υ and J/ψ suppression

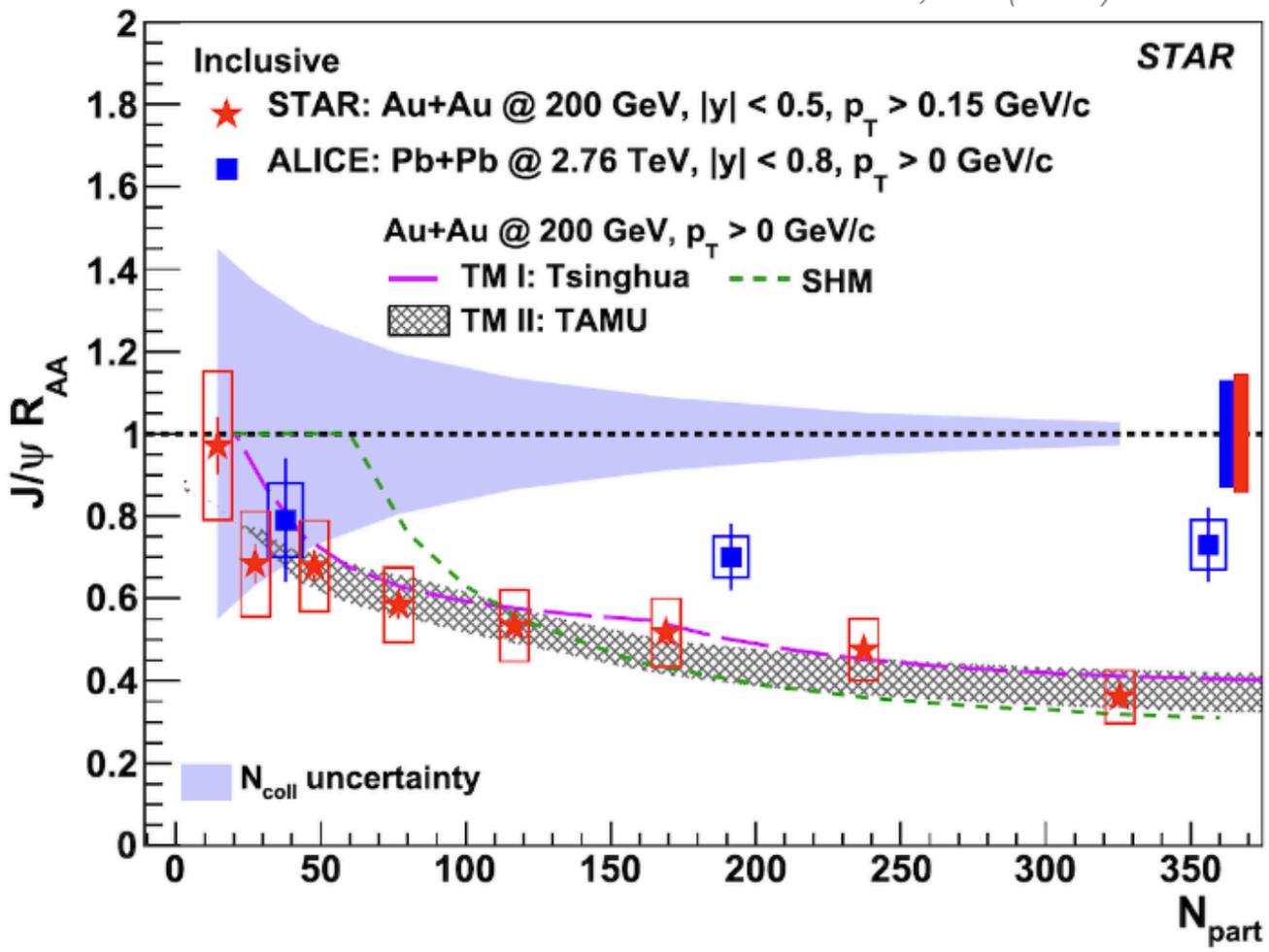
Au+Au *p*+Au





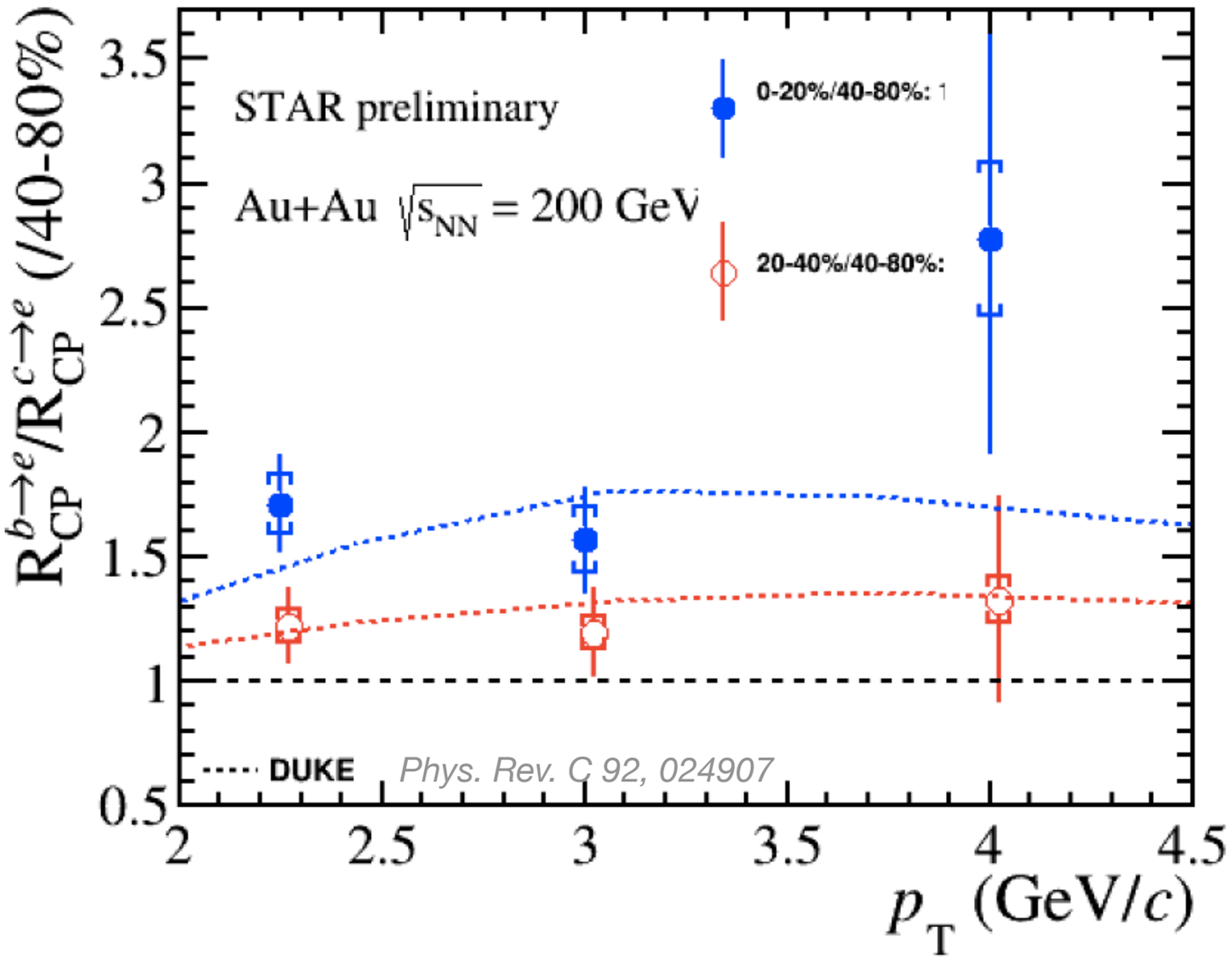
- CNM effects are not negligible in pAu
- Significantly smaller R_{AA} for higher mass Υ states - sequential suppression

PLB,797 (2019) 134917



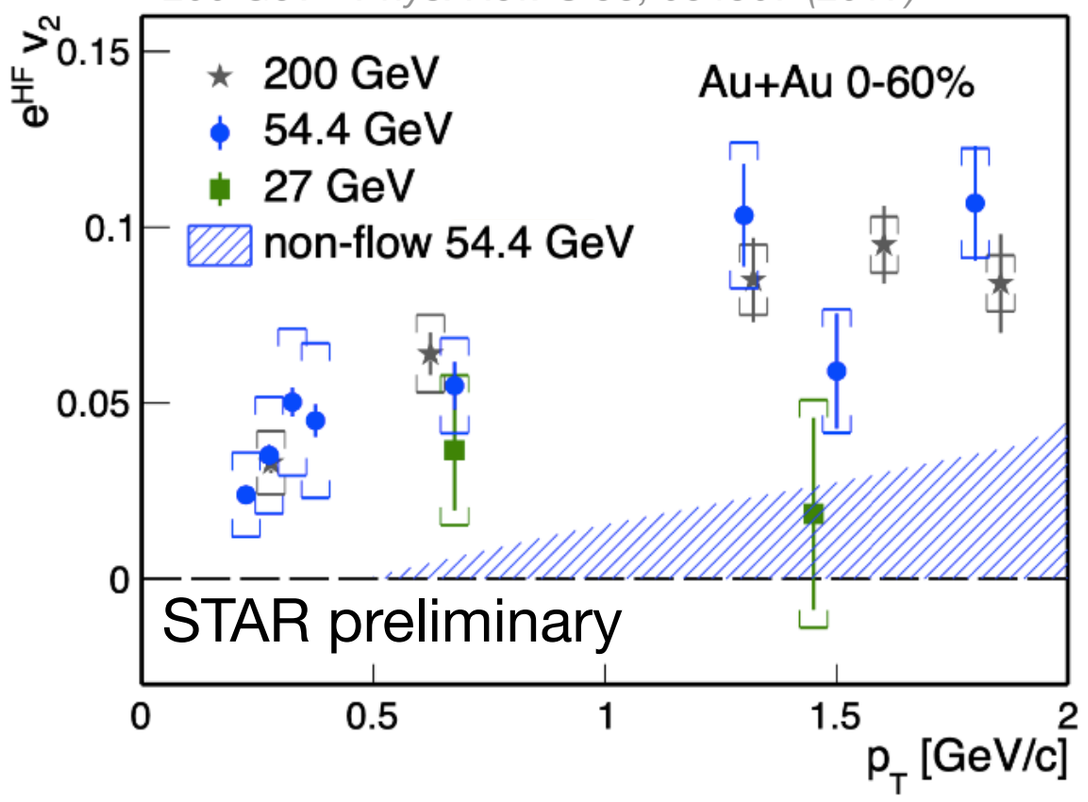
- Low-p_T: more suppressed at RHIC than at LHC in central collisions → smaller charm production cross-section at RHIC and also smaller regeneration…
- high-p_T : color screening in the medium

Heavy flavor quark flow and suppression



- RCP[0-20%/40-80%] double ratio (b->e/c->e) deviates from unity by 4.4σ
- Data consistent with Duke Langevin model predictions

200 GeV - Phys. Rev. C 95, 034907 (2017)

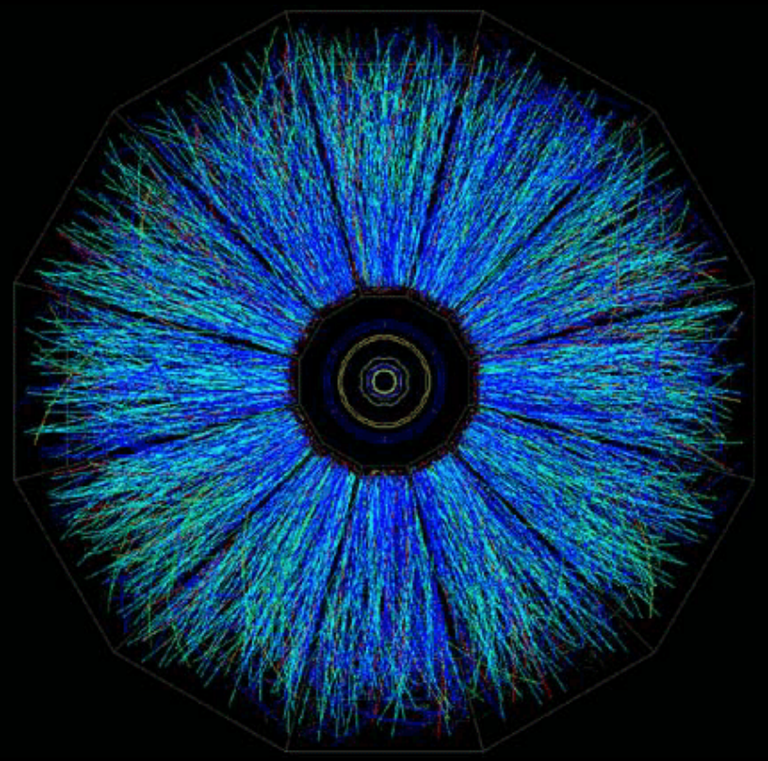


- Significant flow for non-photonic electrons at $\sqrt{s_{NN}}$ = 200 and 54.4 GeV
- 27 GeV preliminary data consistent with zero at high p_T
- model predictions deviate for p_T < 1 GeV/*c*!

see talk by Matt Kelsey

Spin and Cold QCD

Light Flavor Spectra



Ultra Peripheral Collisions

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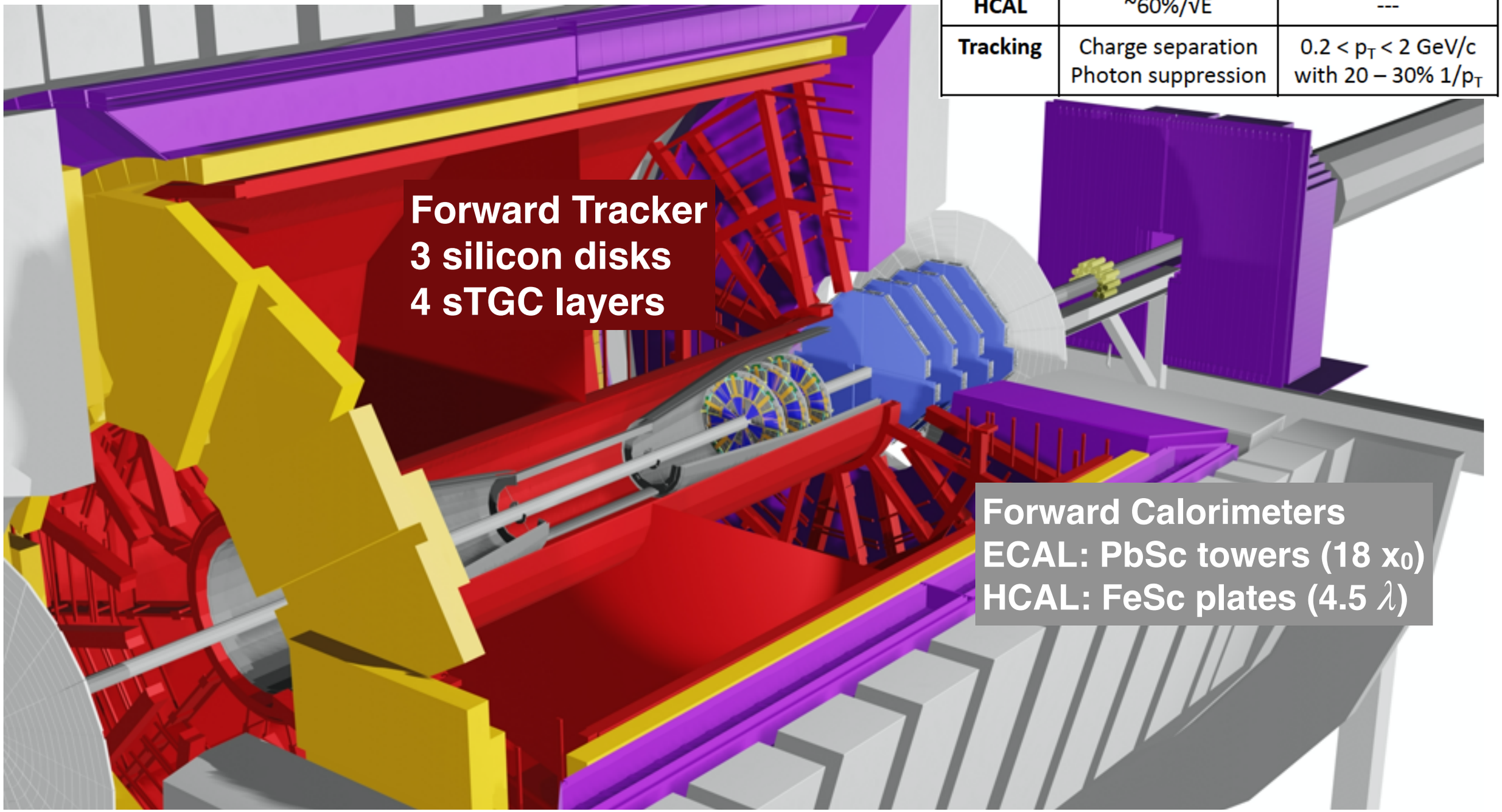
Heavy Flavor

STAR Forward

see talk by Scott Wissink

Preparing for data-taking from 2022+

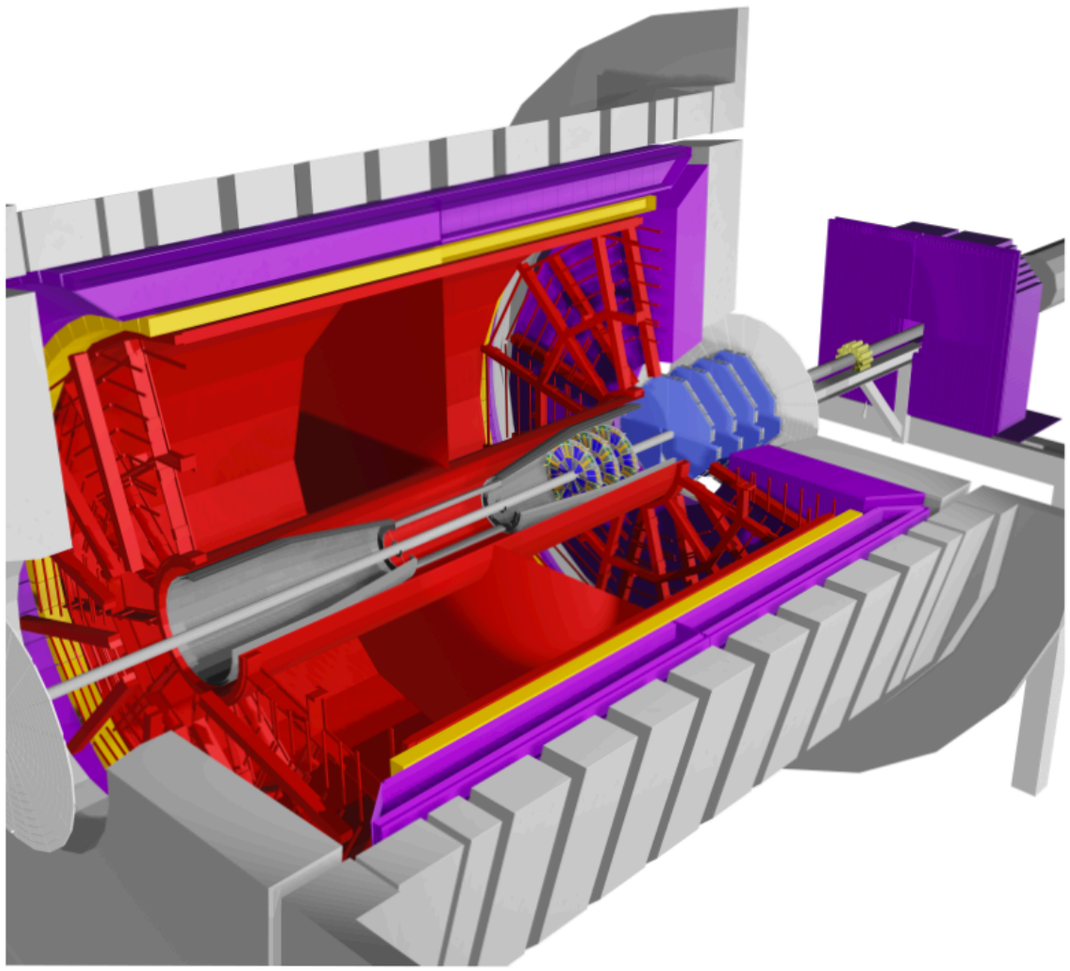
Detector	pp and pA	AA
ECAL	~10%/√E	~20%/√E
HCAL	~60%/√E	---
Tracking	Charge separation Photon suppression	$0.2 < p_T < 2$ GeV/c with 20 – 30% $1/p_T$



STAR BUR 2020

The STAR Beam Use Request for Run-21, Run-22 and data taking in 2023-25

The STAR Collaboration



Thank you very much!

Backup

Polarized pp beams @ RHIC

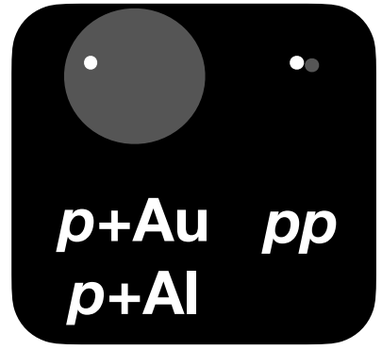
Year	System	$\sqrt{s}$ (GeV)	Recorded Lumi. (pb^{-1})	Polarization	B/Y $\langle P \rangle$ (%)
2009	p+p	200	25	Longitudinal	55/55
2009	p+p	500	10	Longitudinal	39/39
2011	p+p	500	12	Longitudinal	48/48
2011	p+p	500	25	Transverse	48/48
2012	p+p	200	22	Transverse	61/56
2012	p+p	510	82	Longitudinal	50/53
2013	p+p	510	300	Longitudinal	51/52
2015	p+p	200	52	Transverse	53/57
2015	p+p	200	52	Longitudinal	53/57
2015	p+Au	200	0.45	Transverse	60/–
2015	p+Al	200	1	Transverse	54/–
2017	p+p	510	320	Transverse	55/55

Recently approved by PAC for Run 22

$\sqrt{s}$ (GeV)	Species	Polarization	Run Time	Sampled Luminosity	Priority
510	p+p	Transverse	16 weeks	400 pb^{-1}	1

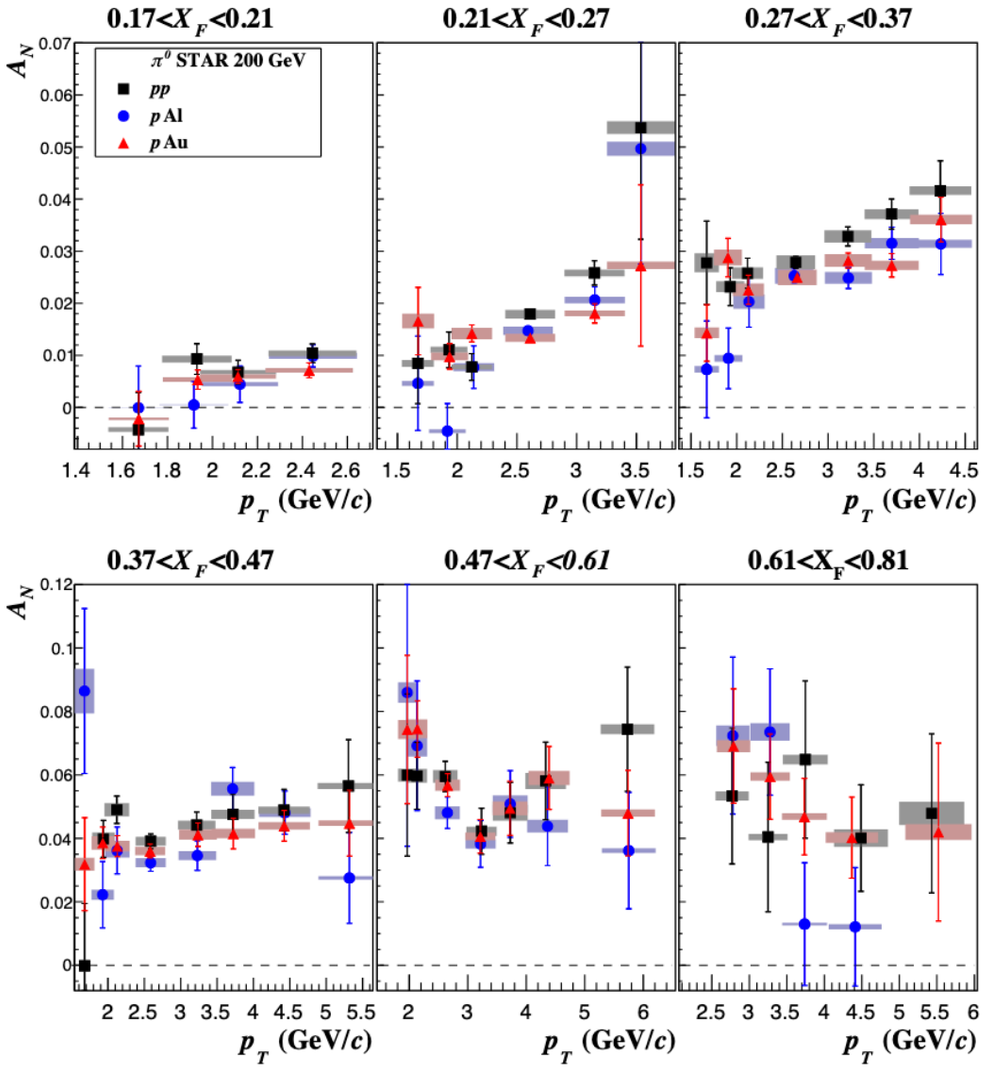
Cold QCD

Search for nuclear effects



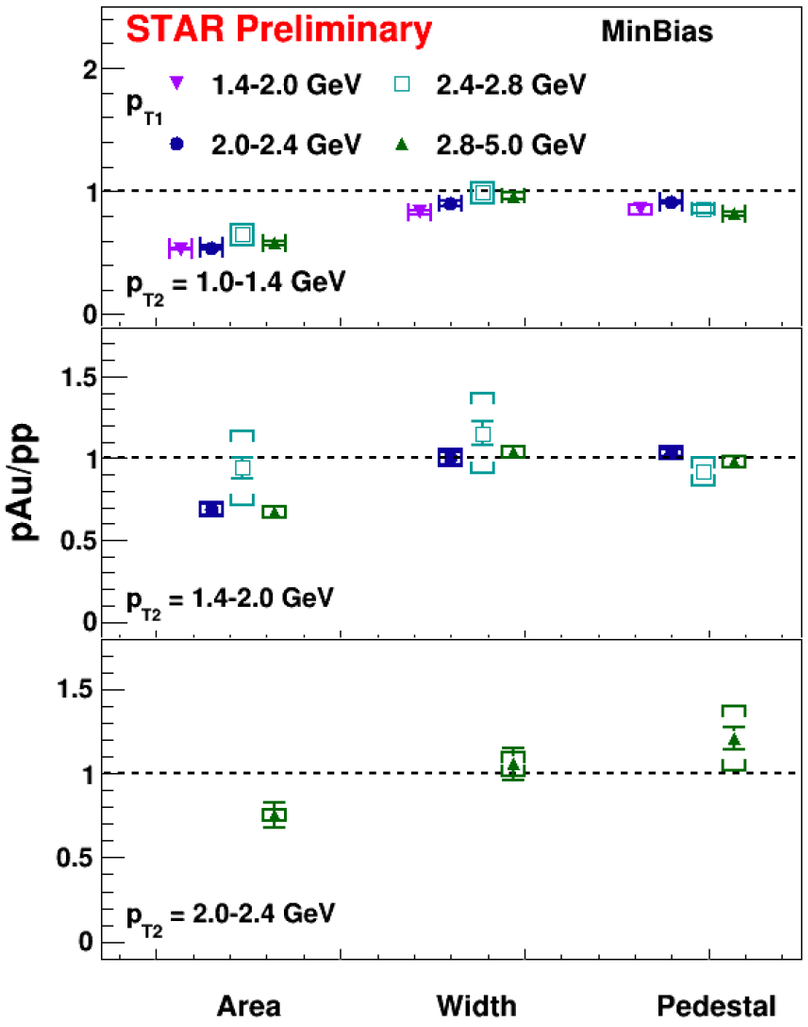
- Detailed measurements of forward π^0 as functions of x_F and p_T in $\sqrt{s_{NN}} = 200$ GeV pp, p+Al, and p+Au

- Weak nuclear dependence is observed for inclusive $\pi^0 A_N$, within measured p_T range.



- Angular correlation of back-to-back forward di-π^0 is sensitive to non-linear low-x gluon dynamics

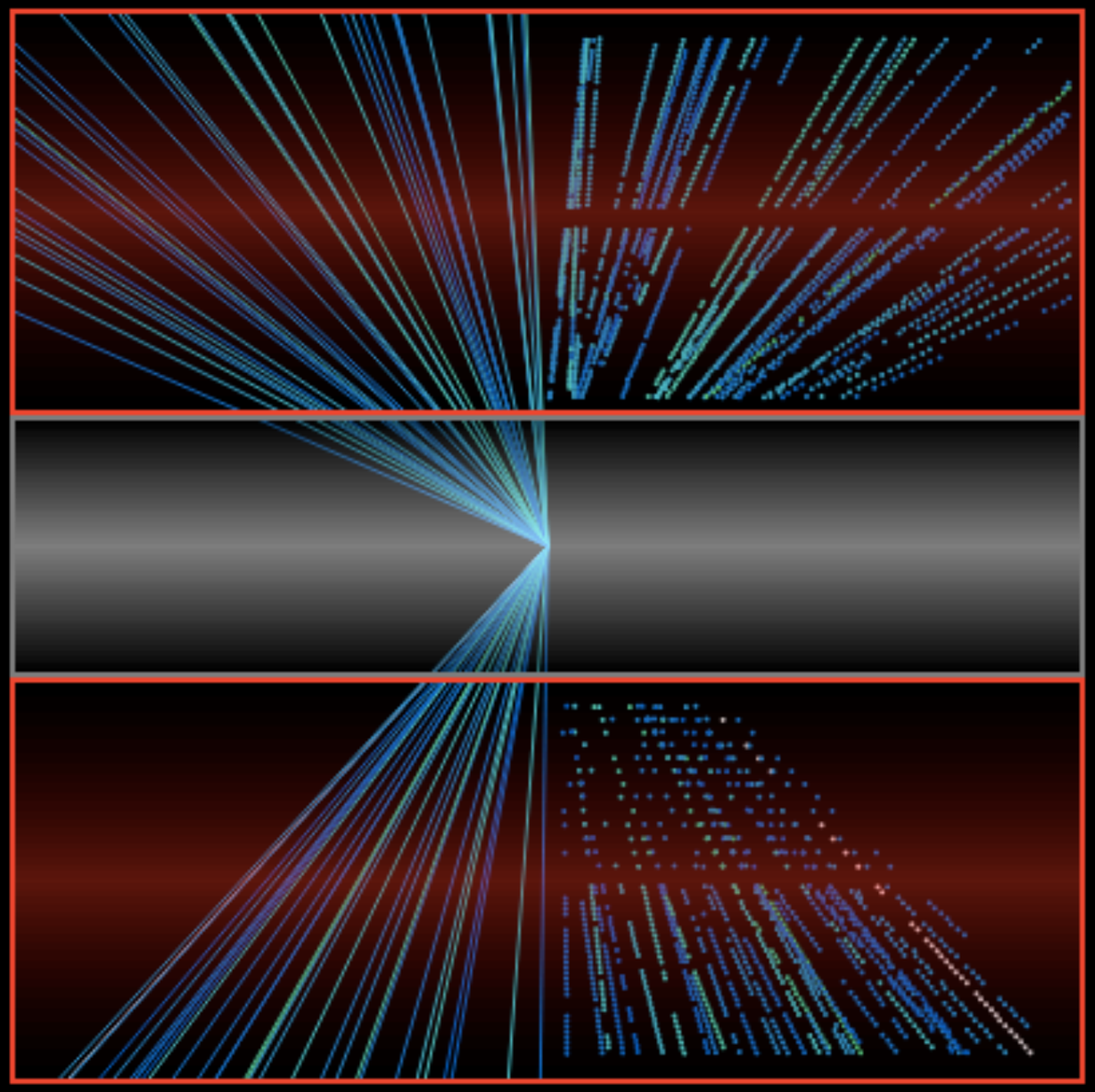
- Back-to-back yield (area) is suppressed in p+Au while the underlying pedestal and the back-to-back width are almost unchanged

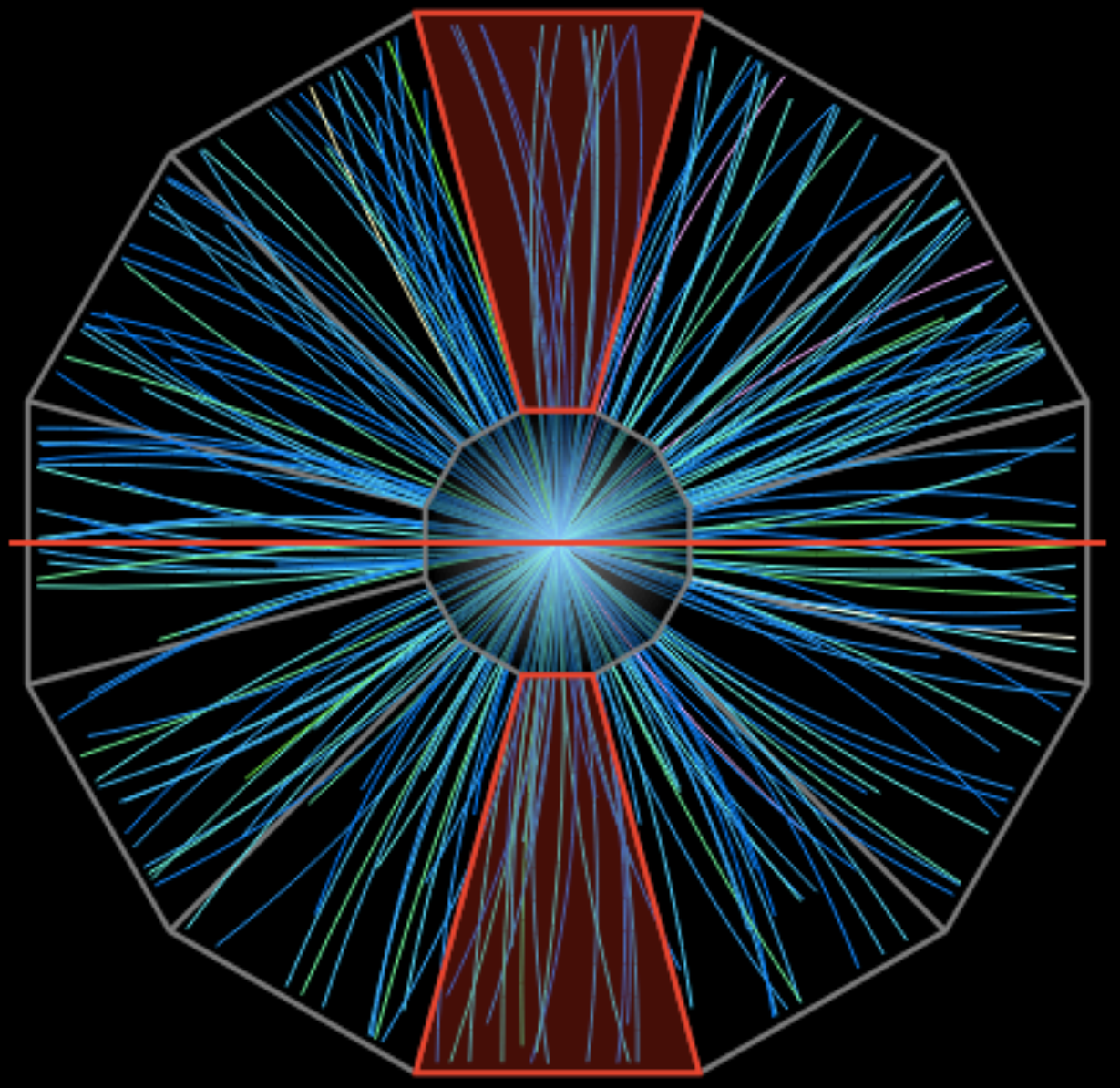


To be improved by STAR forward

To be submitted to PRD soon - arXiv:XXXX

Inner TPC





Isobar and Blind Analysis status