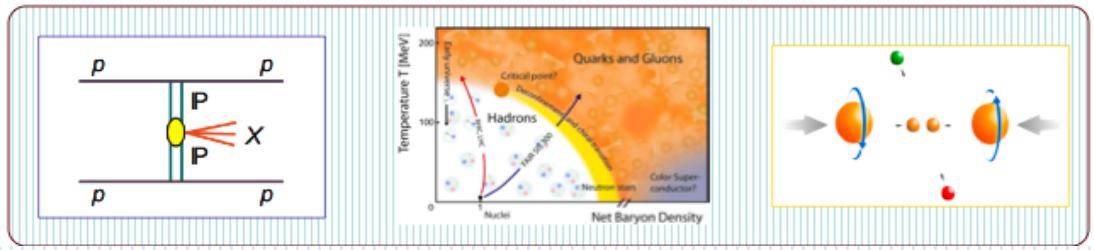
STAR Physics Program

STAR Beam Use Request for Runs 13, 14

Nu Xu
for the STAR Collaboration



Outline

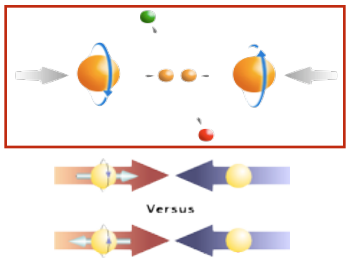
1) Introduction

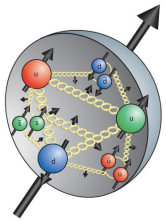
2) Run 12 Status

3) Selected Recent Results
   - Spin Physics Results
   - Results from 200 GeV Au+Au Collisions
   - Results from BES Phase I (BES-I)

4) BUR for Run 13 and 14

STAR Physics Focus

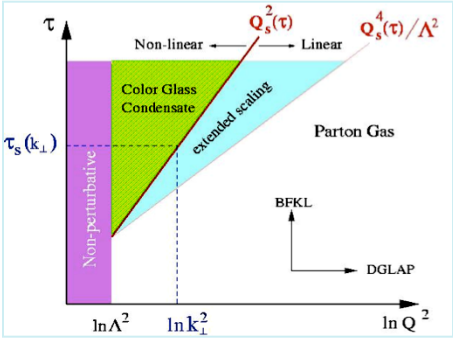




Polarized *p+p* Program

- Study ***proton intrinsic properties***

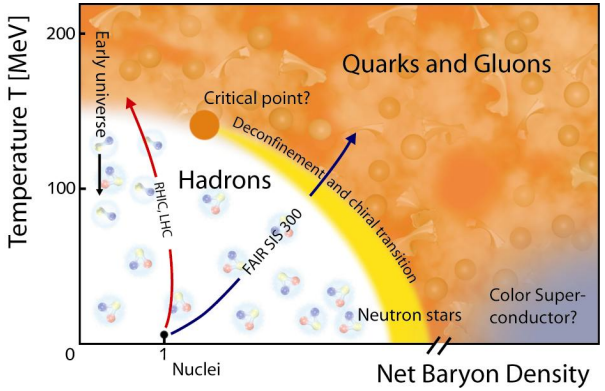
Carl's Talk



Small-x Physics Program

- Study low-x properties, initial condition, search for ***CGC***
- Study elastic and inelastic processes in pp2pp

STAR ***Decadal Plan*** + *2020 -* **eRHIC** (eSTAR)



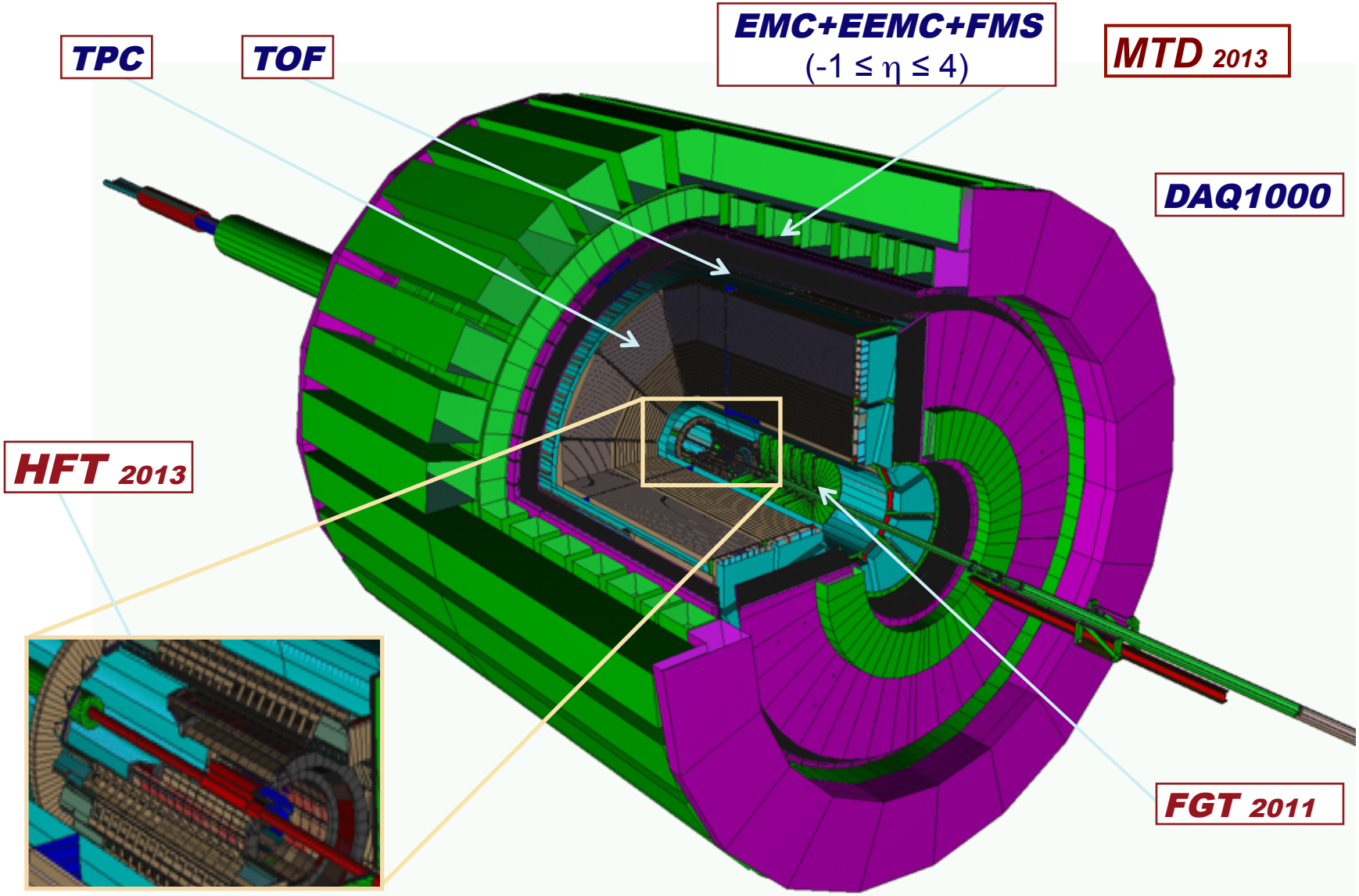
1) At 200 GeV at RHIC

- Study ***medium properties, EoS***
- pQCD in hot and dense medium

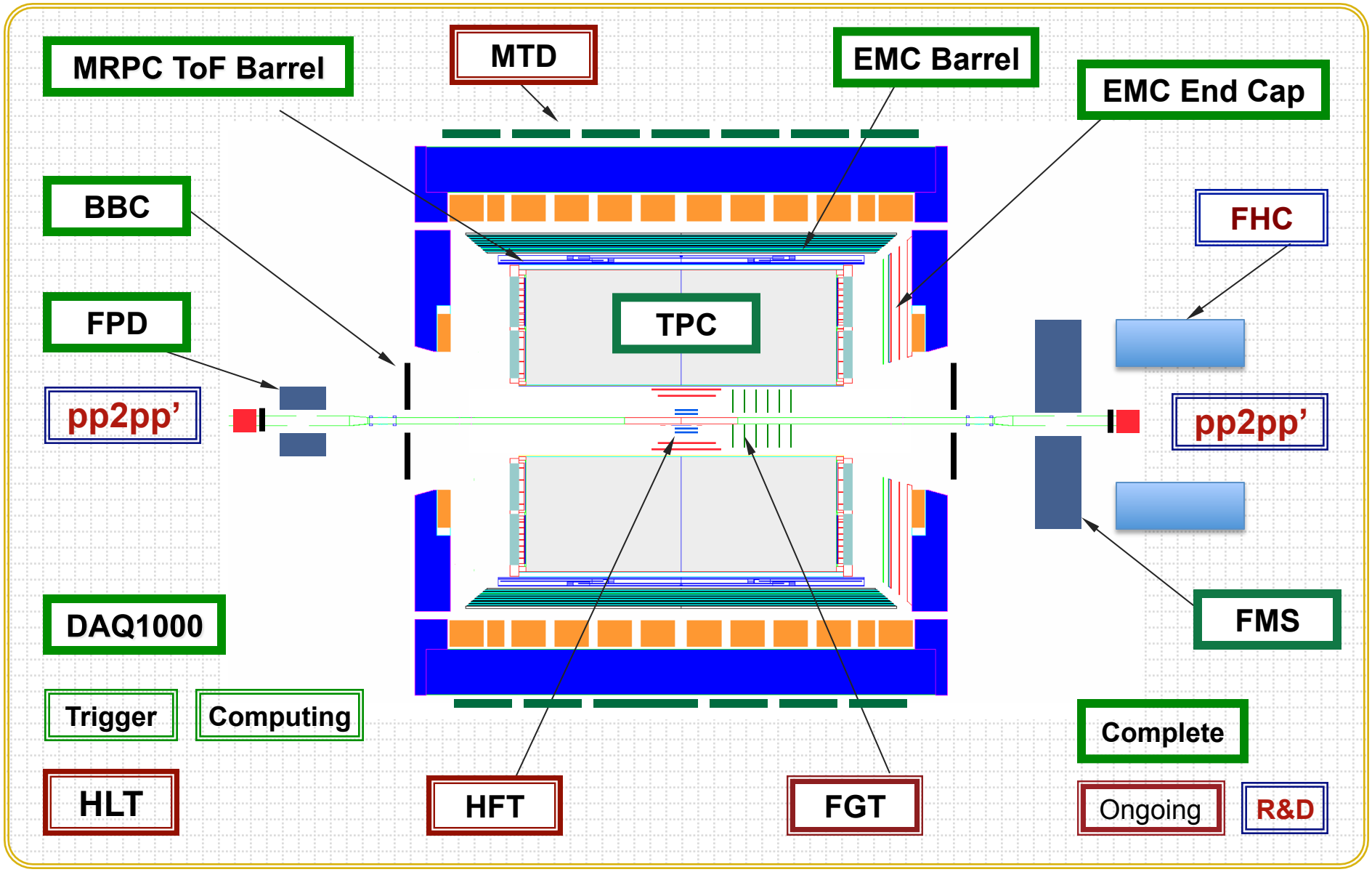
2) RHIC Beam Energy Scan (BES)

- Search for the ***QCD critical point***
- Chiral symmetry restoration

STAR Detectors *Fast and Full azimuthal particle identification*



STAR Experiment



STAR Upgrade Timeline

Upgrade	Completion	Key Physics Measurements
FMS	Completed 2008	(a) Trans. Asymmetry at forward-y (b) CGC
TPC DAQ1000	Completed 2009	Minimal dead time, large data set
MRPC TOF	Completed 2010	Excellent PID in full azimuthal acceptance
FGT	14/24 Quadrants Run 12 Complete Run 13	Forward-y $W^{\pm}$ for flavor separated quark polarization
HFT	Engineering Run 13 Complete Run 14	(a) Precision hadronic ID for charm and Bottom hadrons (b) Charm and Bottom hadron energy loss and flow
MTD	Summer 2013 Ready for Run 14	(a) High p_T muon trigger (b) Quarkonia states
pp2pp'	Summer 2014 Ready for Run 15	

STAR Detector Configurations

	Period	Detectors	Physics
	2001-2010	TPC	*u, d, s*
	2010	TPC + TOF	*u, d, s + dilepton*
	2013	TPC + TOF + **MTD***	*u, d, s, c + dilepton*
	2014	TPC + TOF + **MTD+HFT**	

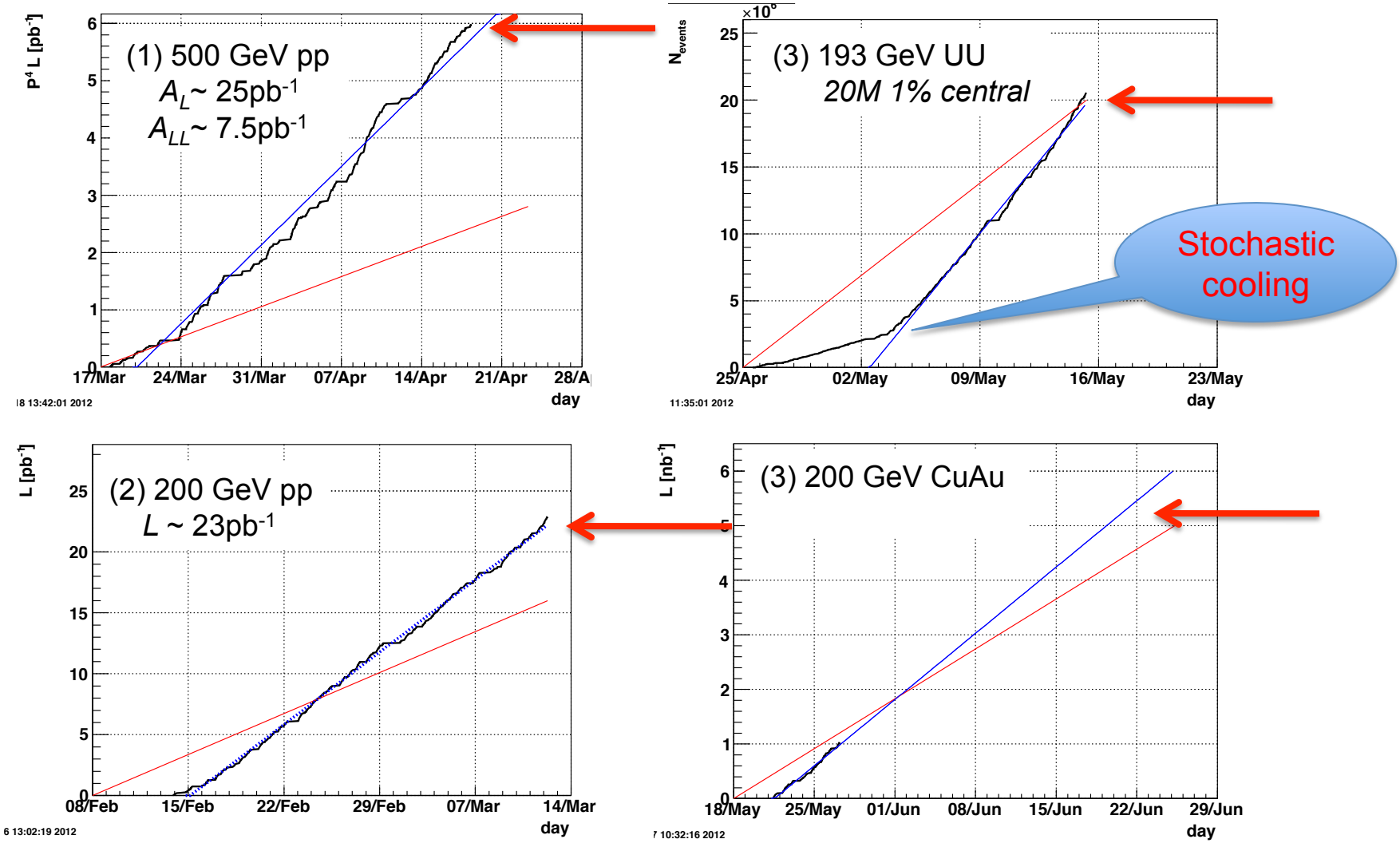
➔ **Large coverage, excellent particle ID, fast DAQ**

- detects all particles produced at RHIC, except neutrinos
- multiple fold correlation measurements
- **Probes:** bulk, penetrating, and *bulk-penetrating*

➔ **STAR: Perfect mid-y Collider Experiment**

2) Run 12 Status

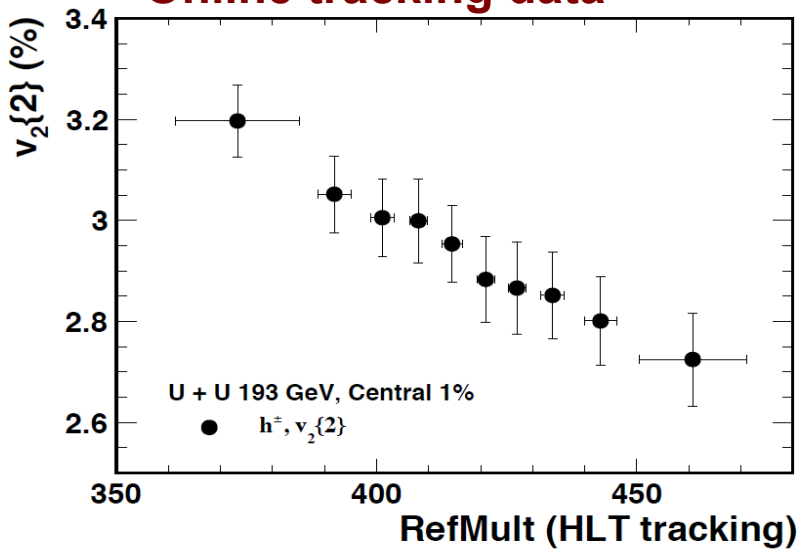
Run12: Integrated Luminosities



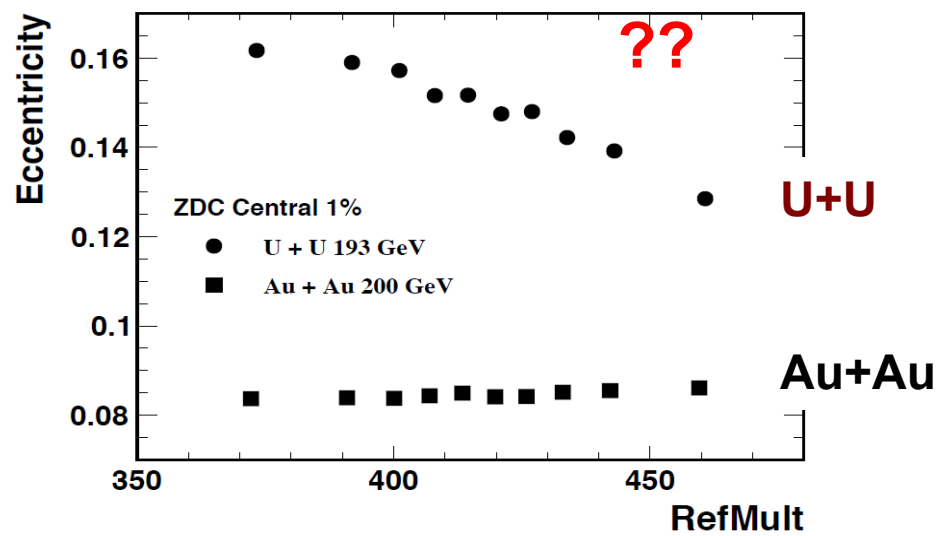
STAR's goals in Run 12

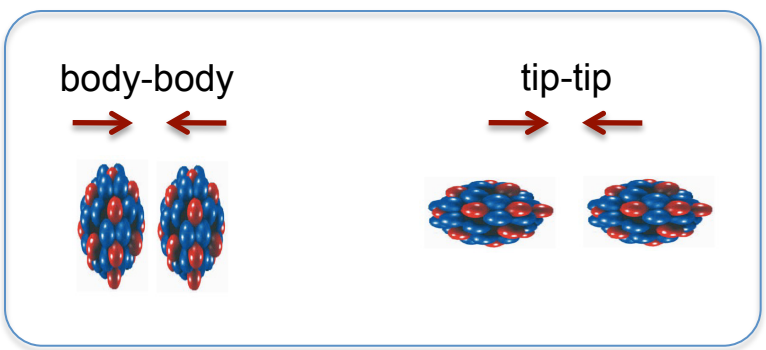
$\sqrt{s_{NN}}$ = 193GeV U+U Collisions

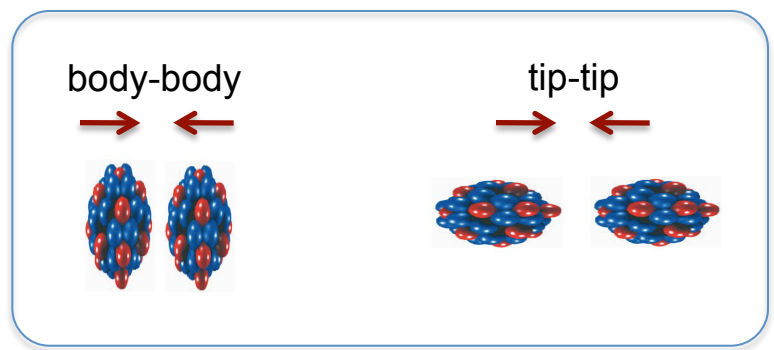
Online tracking data



Simulations



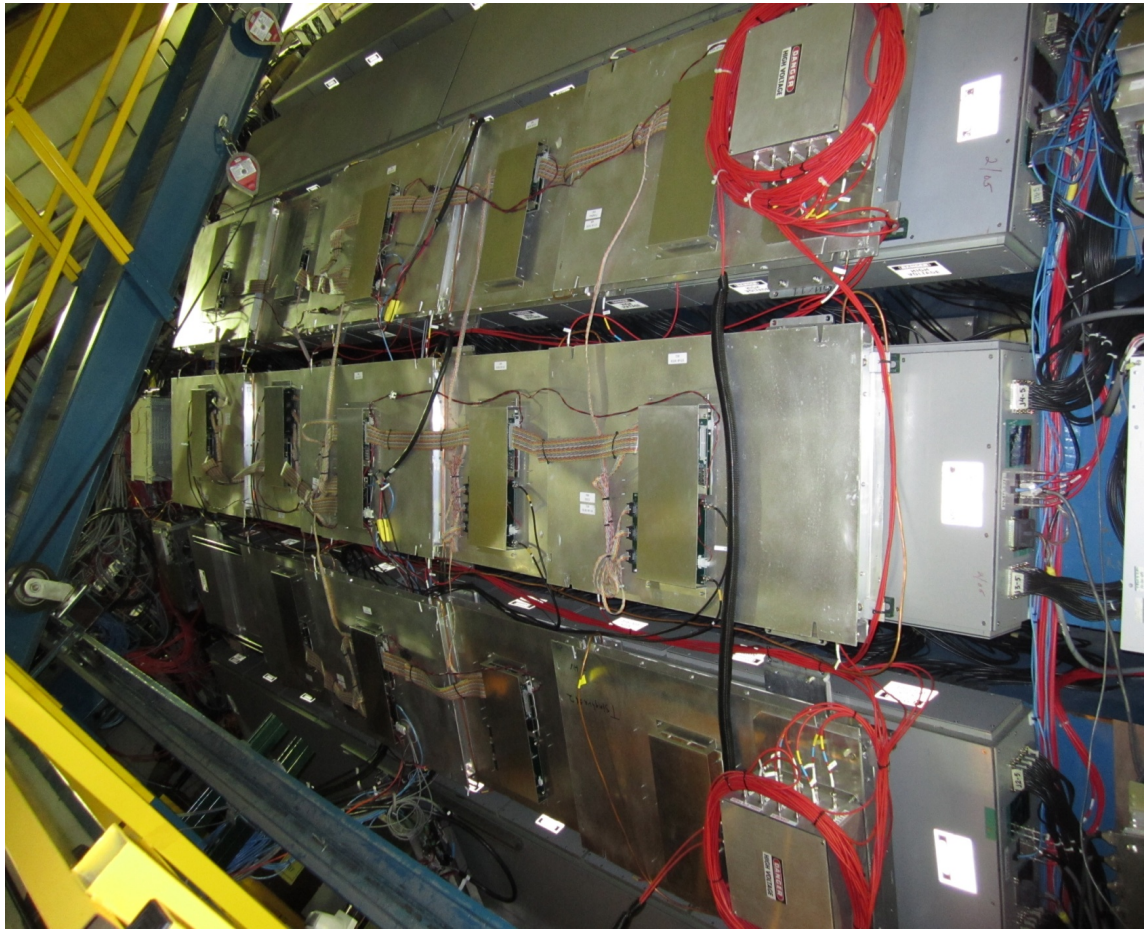




U+U Collisions: (1) test CME with small external B-field
(2) test v_2 at 30% higher density
(3) test path-length dependence of R_{AA}

STAR Performance slide

STAR-MTD

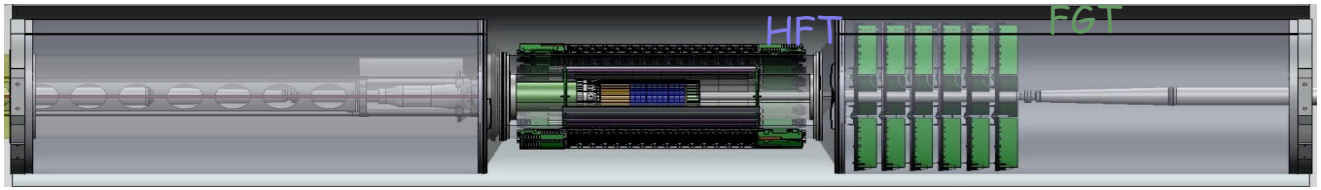


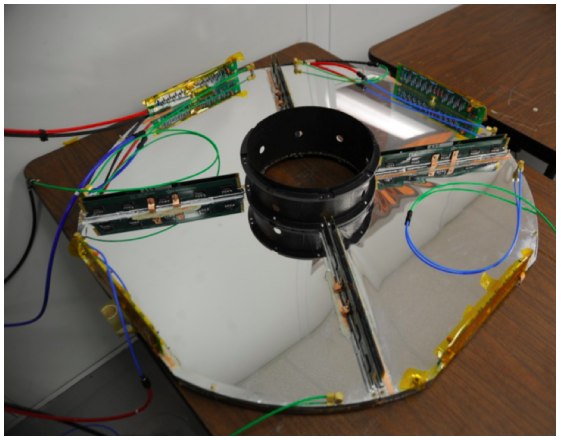
1) MTD timing resolution: Δt ~ 100 ps
   consistent with proposal

2) Run 13: 43%

3) Run 14: complete

STAR: Forward GEM Tracker



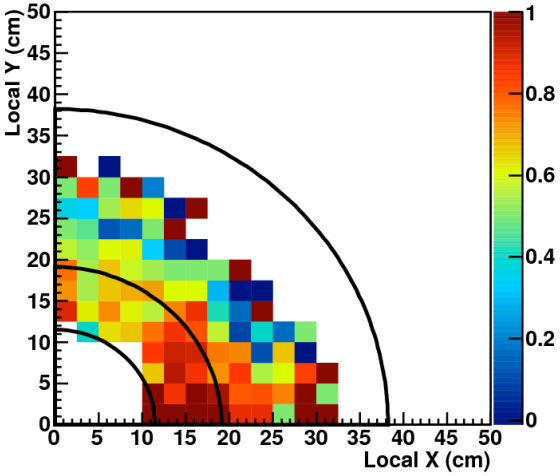


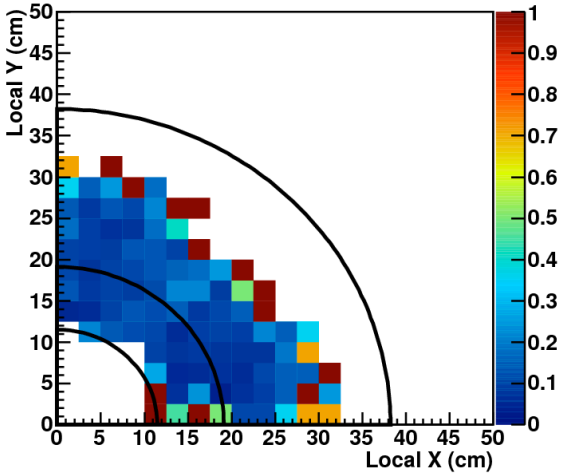
1) FGT works

2) Fine tune on HV, gas mixture are ongoing

3) Tracking software

4) **Run 13**: completed FGT





STAR BUR for Runs 13 and 14

Run	Beam Energy	Time	System	Goal
13	$\sqrt{s}$ = 510 GeV	4 days	$p_{\uparrow}\, p_{\uparrow}$	σ_{TOT}, A_N, A_{NN}, A_{SS}, Exclusive Central Production
		10 weeks	$p_{\rightarrow}\, p_{\rightarrow}$	i) $W^{\pm}$ A_L: P^2*L= 50 pb^{-1} ii) di-jets A_{LL}: P^4*L= 15 pb^{-1}
	$\sqrt{s_{NN}}$ = 200 GeV	4 weeks	Au + Au	i) MTD e-μ correlation, 2 nb^{-1} (280M central events) ii) HFT engineering run
14	$\sqrt{s_{NN}}$ = 200 GeV	10 weeks	Au + Au	i) HFT & MTD heavy flavor, 10 nb^{-1}(500M M.B.) ii) Fixed-target data taking(3)
	$\sqrt{s}$ = 200 GeV	5 weeks	$p_{\uparrow}\, p_{\uparrow}$	i) Heavy ion reference data L= 40 pb^{-1} (500M M.B.) ii) Δg, L= 40 pb^{-1}

Run 13: 20 cryo-week. 510pp: 65% polarization

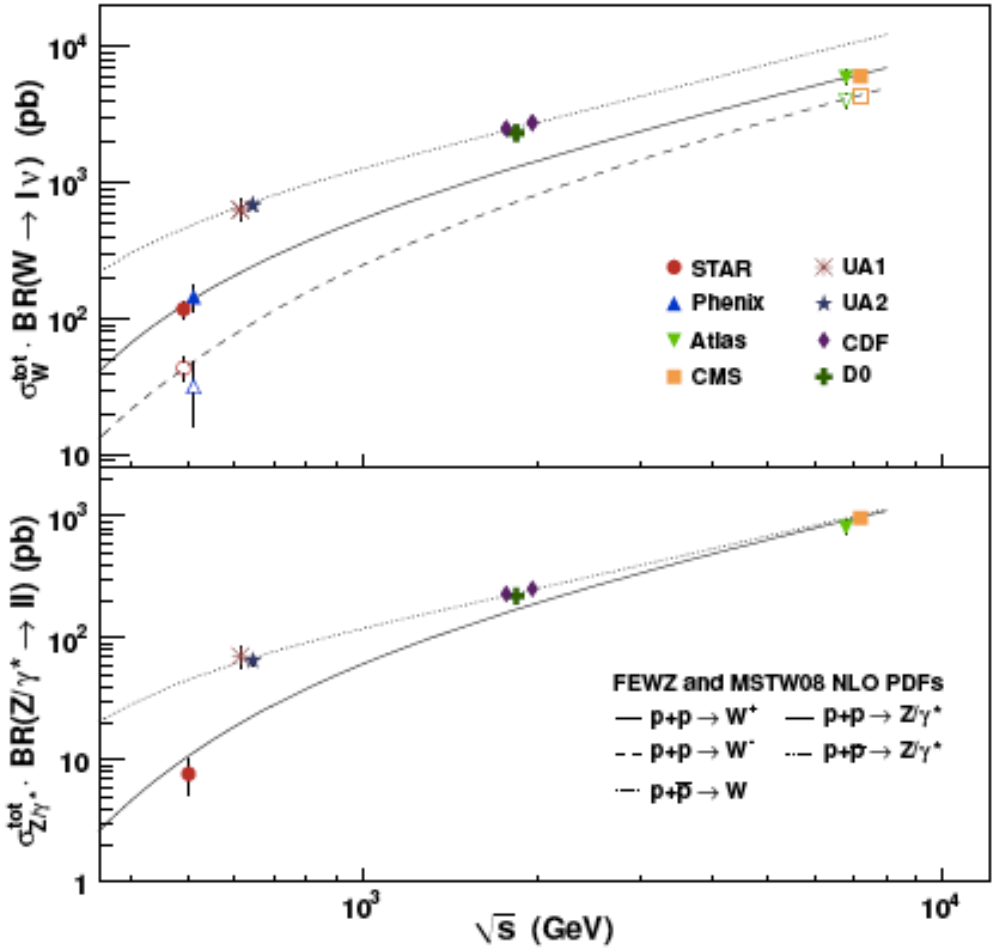
Run 14: 20 cryo-week. 200pp: 65% polarization

3) Selected Results:

(1) Spin Physics Results

W and Z/γ* Production at √s = 500 GeV

STAR Run 9: PRD**85,** 92010 (2012)

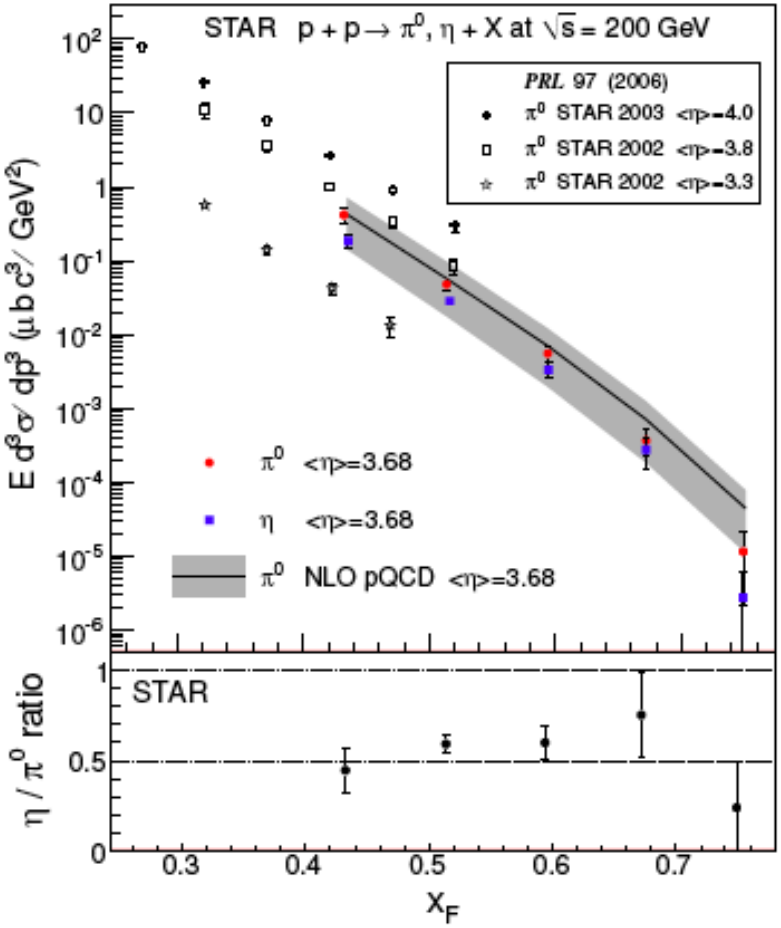


p+p collisions at √s = 500 GeV

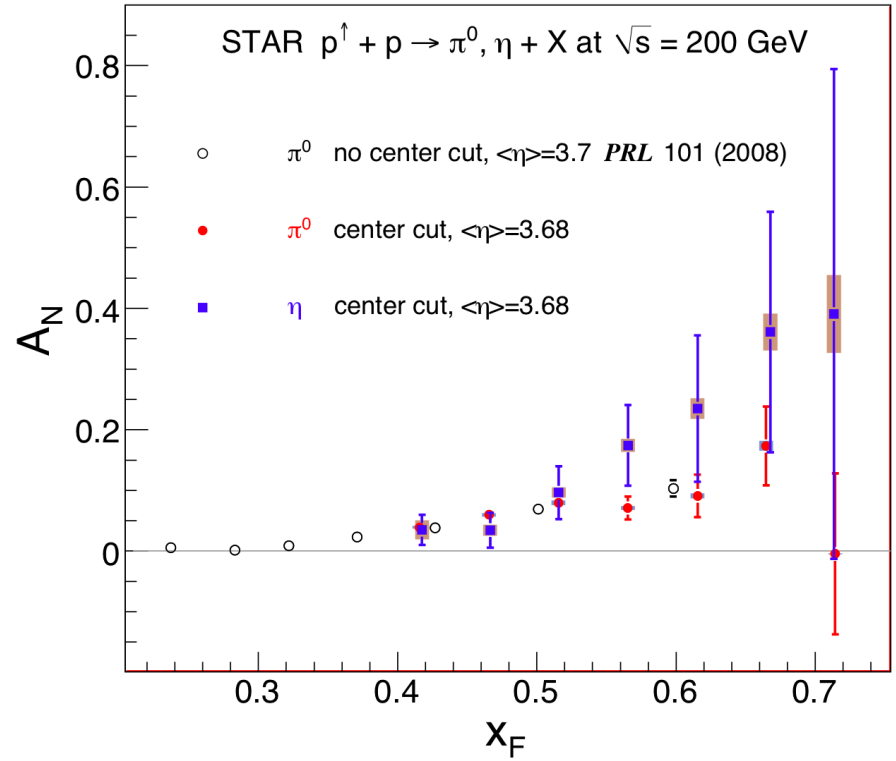
1) Results from NLO QCD models are consistent with STAR new data

2) Future high statistics W data important for flavor asymmetry of the sea quark study

Forward Meson Productions



	A_N	
π^0	0.081 ± 0.016	$0.55 < x_F < 0.75$
η	0.210 ± 0.056	$0.55 < x_F < 0.75$

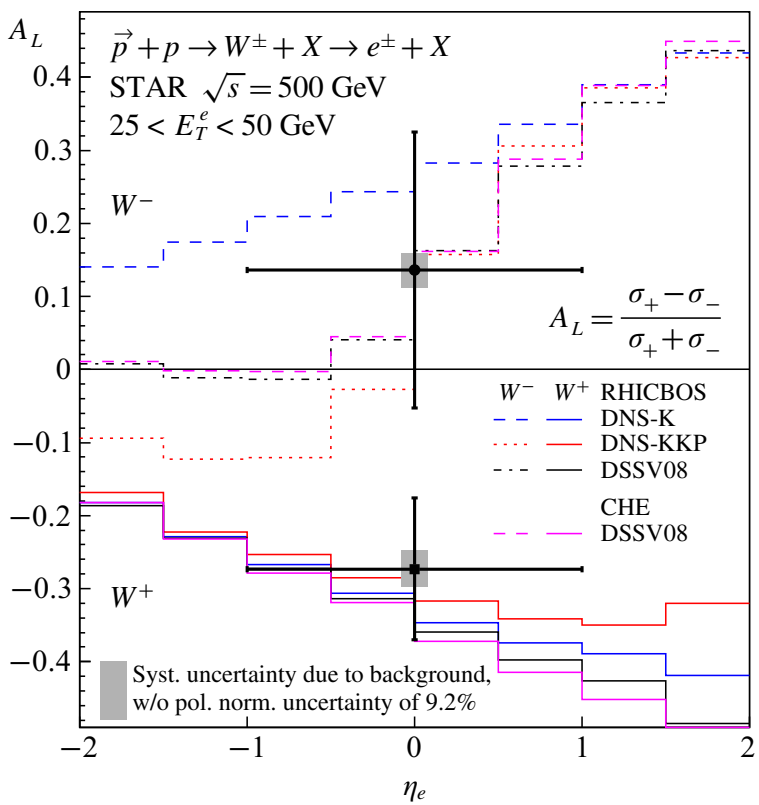


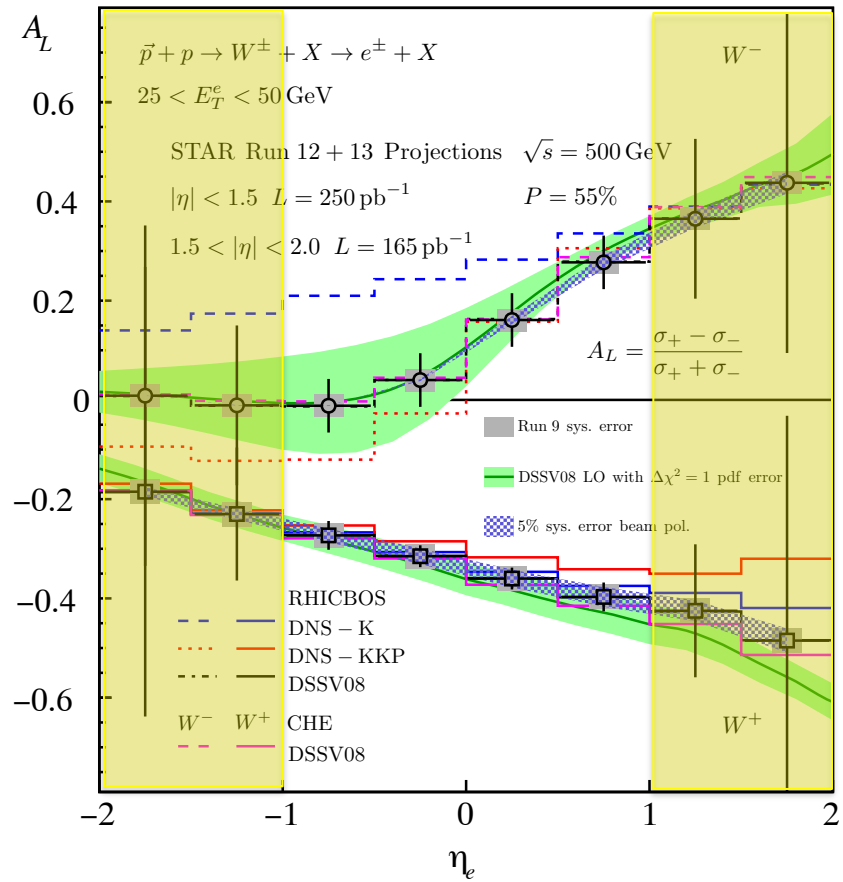
1) 200 GeV p+p collisions: $\sigma(\pi^0) \sim \sigma(\eta)$; $\mathbf{A_N(\eta) > A_N(\pi^0)}$*
2) pQCD model generated large A_N for η-meson due to twists-3 effect of the s-quark

STAR: submitted to PRD

Quark Flavor Measurements: W±

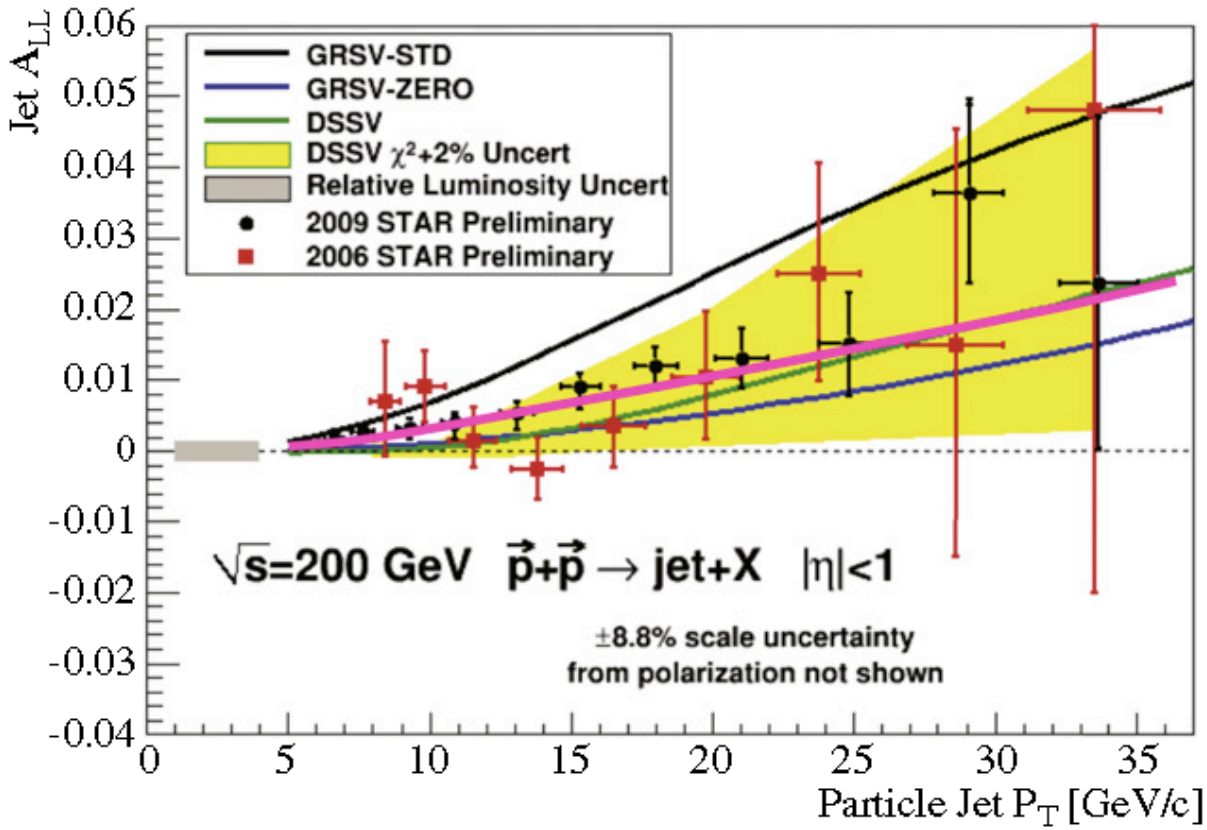
* STAR Run 9: PRL 106, 62002(2010)





1) STAR first results* consistent with models: Universality of the helicity functions!
2) Precision measurements require **large luminosity** and **high polarization** at RHIC!
3) Projections: (a) |η| ≤ 1.0, Run 12 + 13; (b) 1.0 ≤|η| ≤ 1.5, FGT, Run 13

STAR A_{LL} from 2006 to 2009

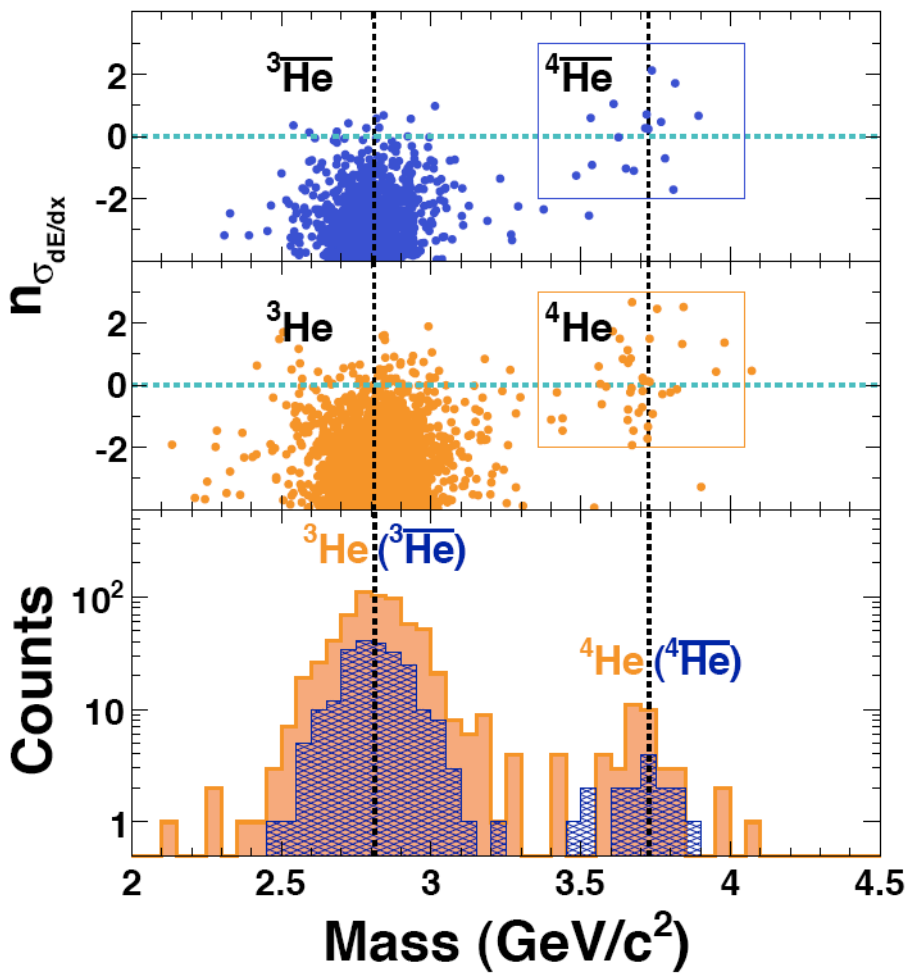


- 2009 **STAR** A_{LL} measurements:
- **Results fall between predictions from DSSV and GRSV-STD**
- Magenta line: new fit with STAR run 9 results

3) Selected Results:

(2) Results from $\sqrt{s_{NN}}$ = 200 GeV

Particle Identification at STAR (TPC + TOF + HLT)



- Clean Identification: TPC and ToF

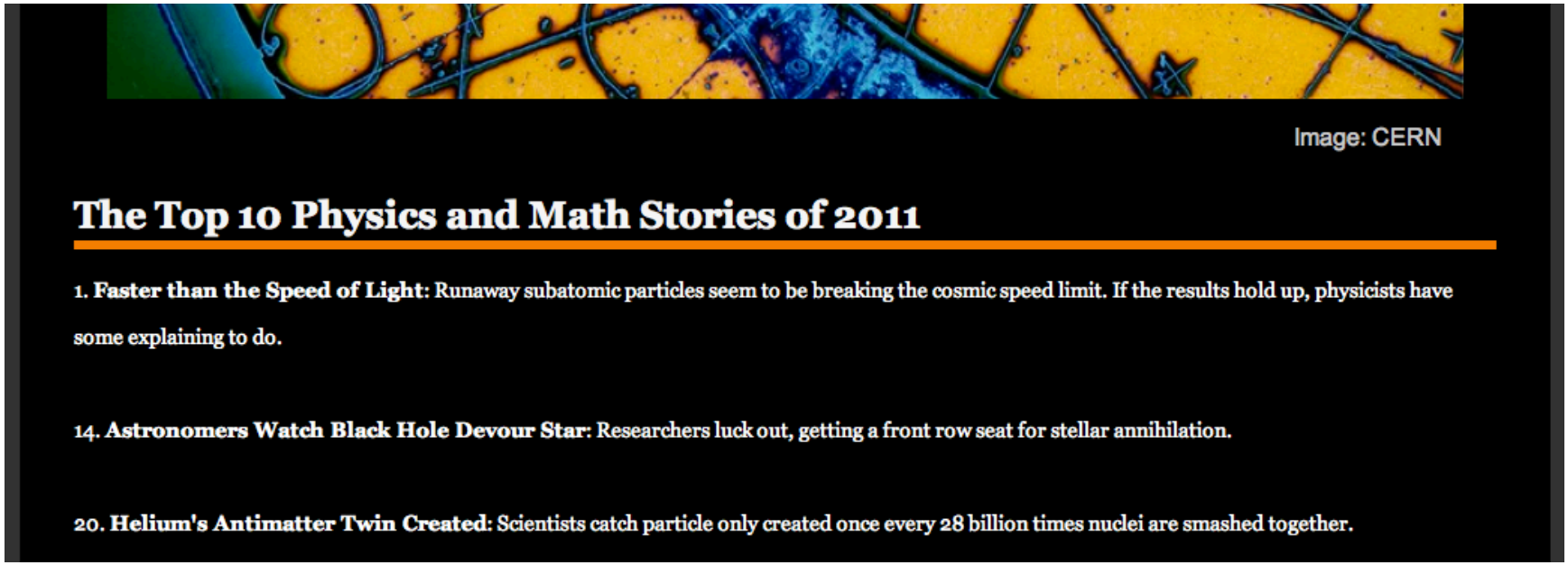
$$m^2 = p^2\left(1/\beta^2 - 1\right)$$

- China-US: Time of Flight (ToF) Detector

- High Level Trigger

Nature (2011) DOI: doi:10.1038/nature10079 || **STAR Experiment**
Received 14 March 2011 | Accepted 04 April 2011 | Published online 24 April 2011

$\bar{\alpha}$: Top-100 Physics and Math Science in 2011

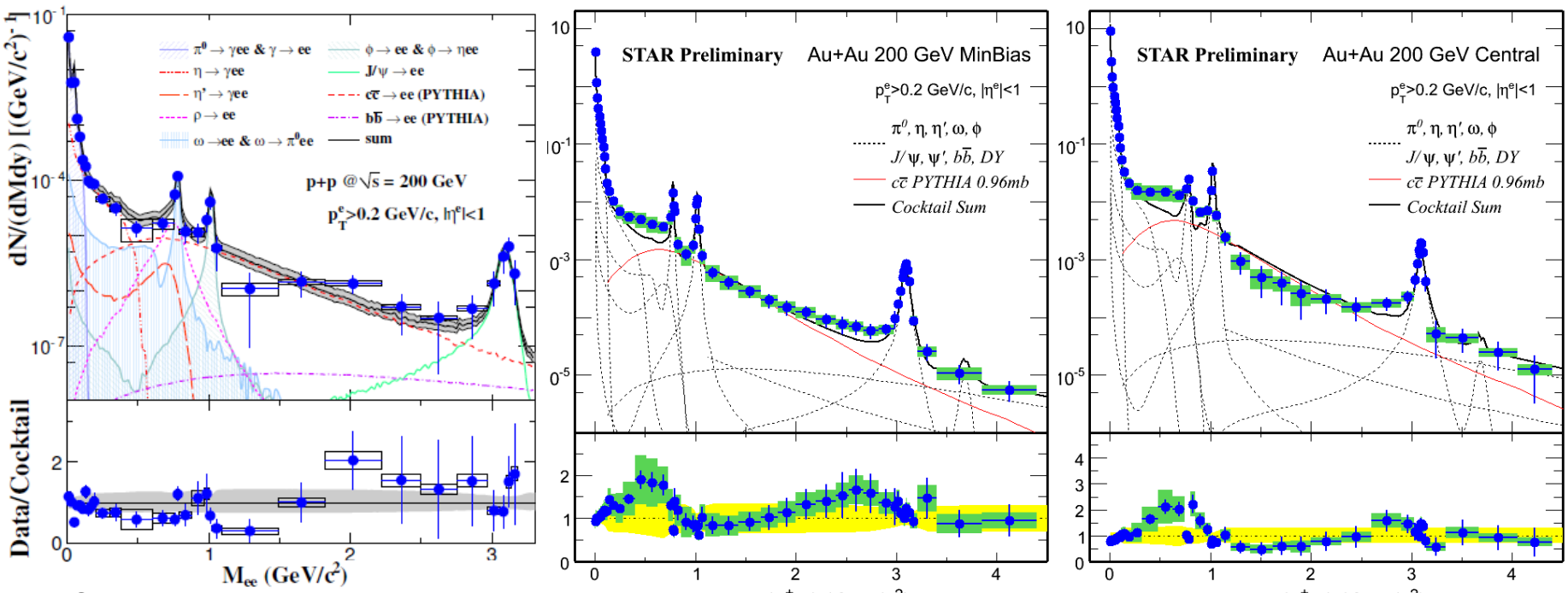


Discovery Magazine:http://discovermagazine.com/photos/19-top-100-stories-of-2011

Since last PAC meeting we have published: 3 PRL; 2 PRD; 5 PRC papers including high-p_T PID, D/D*, strangeness enhancement in HI, W production cross sections

STAR Di-electron Program

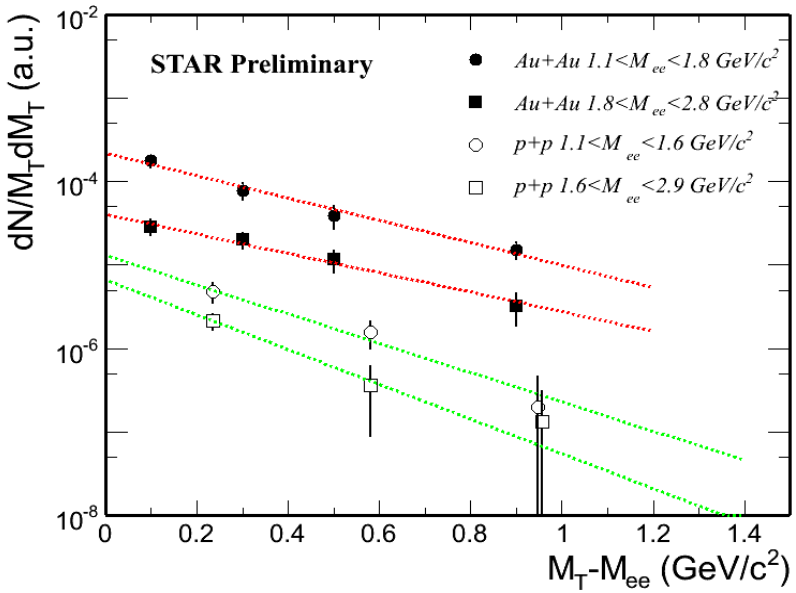
$\sqrt{s}$ = *200 GeV* **p+p** **Au+Au MinBias** **Au+Au Central**



STAR: arXiv:1204.1890

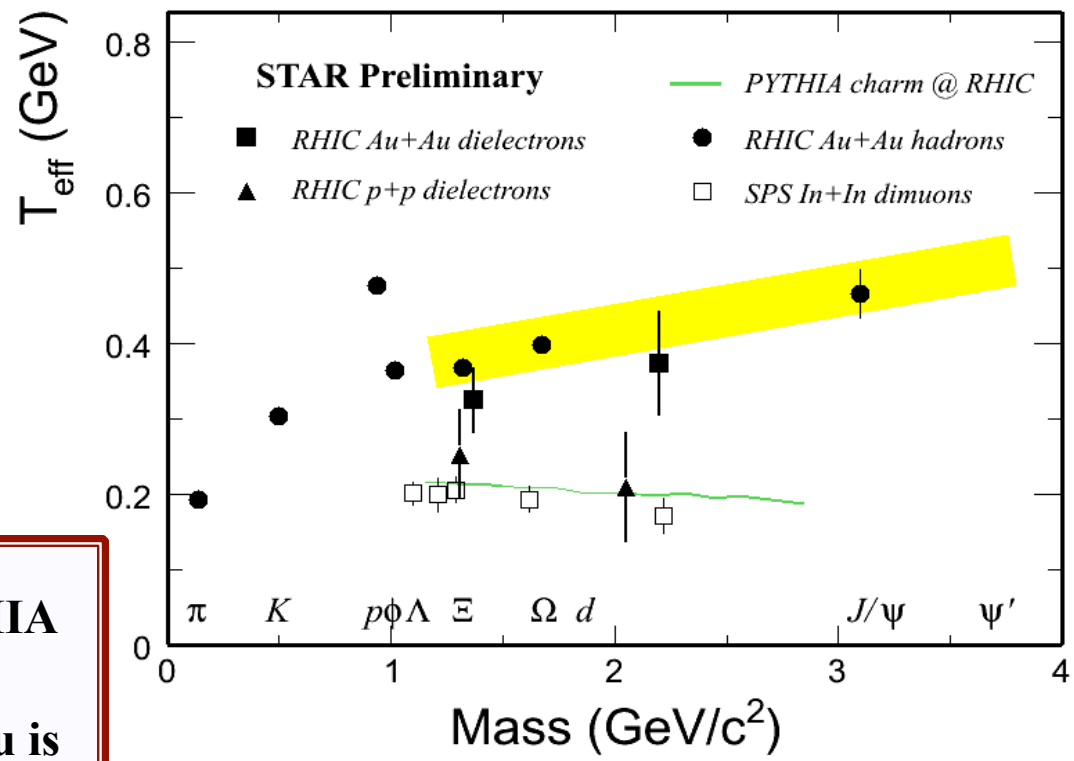
1) Direct radiation, penetrating-bulk probe, **new to STAR**!
2) Beam energy, p_T, centrality, mass dependence (8-10x more events): **R_{AA}, v_2, radial expansion, HBT, polarization, …**
3) HFT/MTD upgrades: key for the correlated charm contributions.

Transverse Mass Spectra



A + A: Minbias collisions

RHIC Au + Au 200 GeV / SPS In + In 17.2 GeV

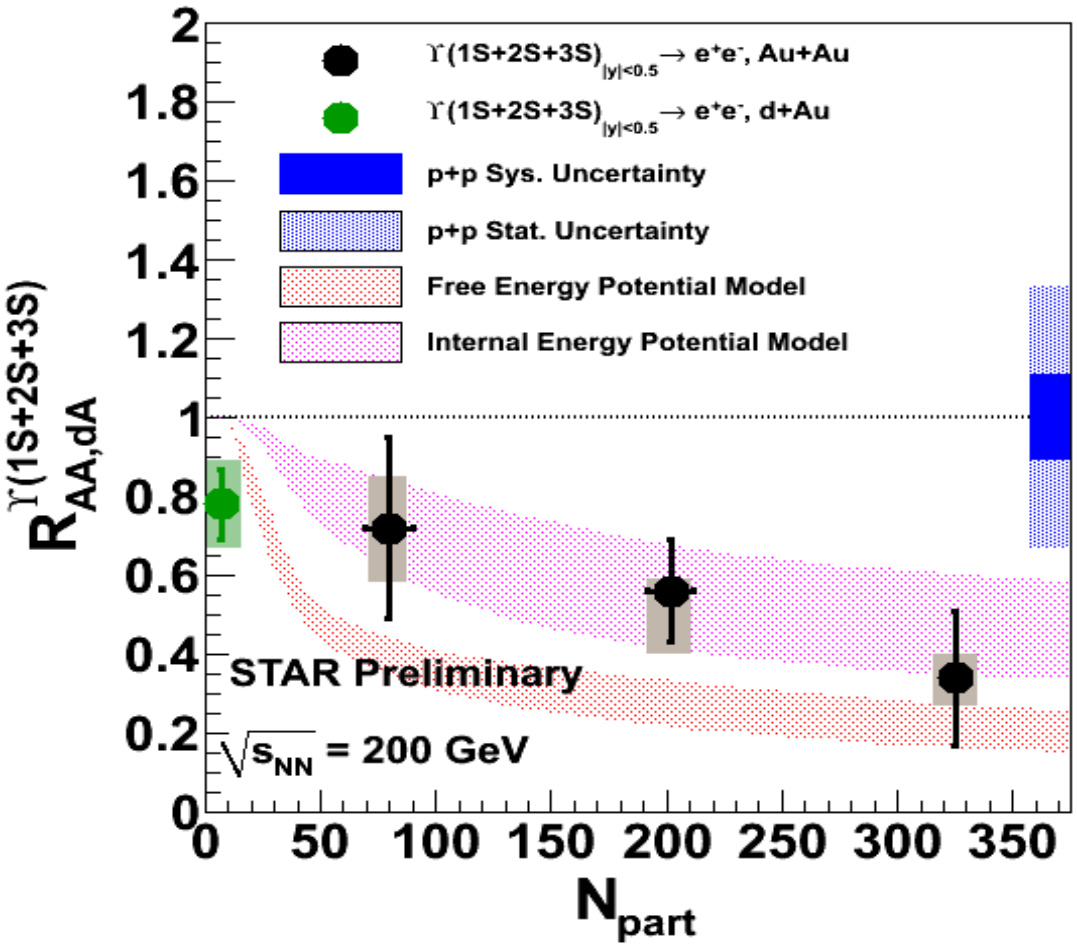


SPS data: charm/DY subtracted - PRL 100, 022302 (2008)
STAR data: inclusive di-electron, statistical error only

- **p + p result consistent with PYTHIA charm contributions**
- **The m_T slope parameter in Au+Au is higher than that in p + p**
- **Inclusive di-lepton slope in Au+Au at RHIC is also higher than that at SPS**

Υ(1S+2S+3S) R_{AA}

$\sqrt{s_{NN}}$ = *200* GeV Au+Au collisions



1) STAR: Triggered events

2) In central collisions, Υ(1S+2S+3S) is suppressed, 3σ away from R_{AA} = 1!

3) R_{AA} (0-60%)= 0.56±0.11 (stat)+0.02-0.14(sys)

   R_{AA} (0-10%)= 0.34±0.17 (stat)+0.06/-0.07(sys)

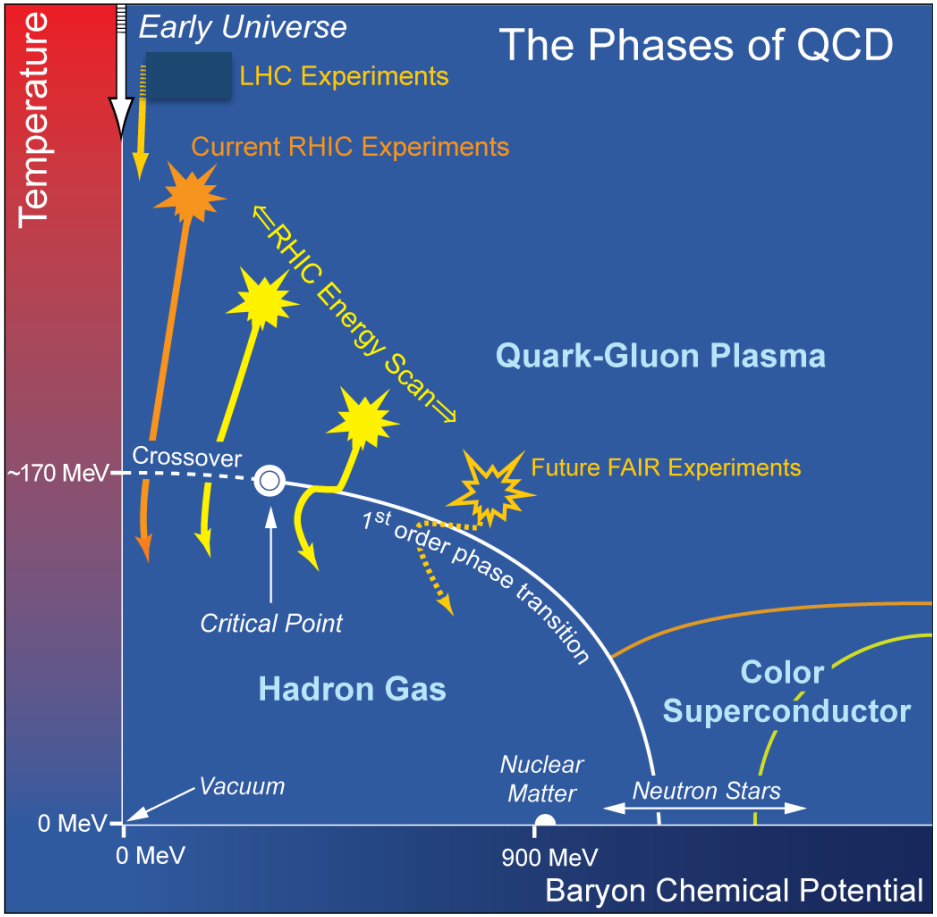
3) Selected Results:

(3) RHIC Beam Energy Scan (BES-I)

Beam Energy Scan at RHIC

Study QCD Phase Structure

- Signals of phase boundary
- Signals for critical point



Observations:

(1) Azimuthally HBT
1st order phase transition

(2) Directed flow v_1
1st order phase transition

(3) Dynamical correlations
partonic vs. hadronic dof

(4) v_2 - NCQ scaling
partonic vs. hadronic dof

(5) Fluctuations
Critical point, correl. length

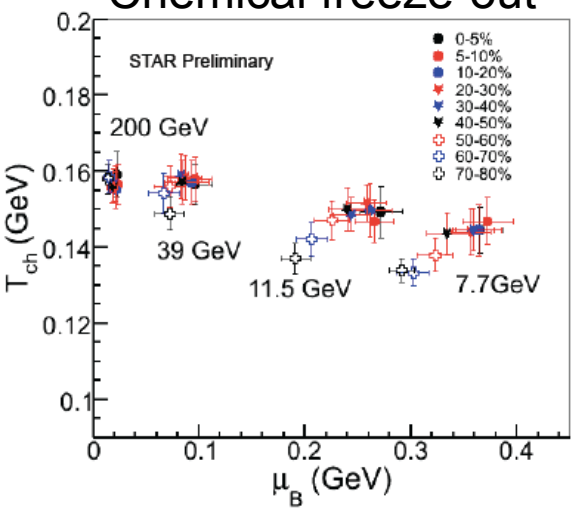
- http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493

- arXiv:1007.2613

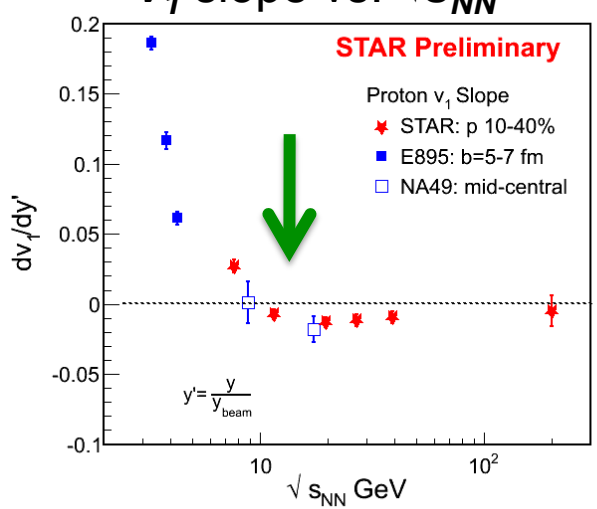
RHIC BES-I Au+Au Dataset

	Runs	Events(10^6)	$\sqrt{s_{NN}}$ (GeV)	μ_{B^*} (MeV)
1	10	130	39	112
2	11	70	27	156
3	11	36	19.6	206
4	10	12	11.5	316
5	10	5	7.7	420
6	**12***	--	**5**	550

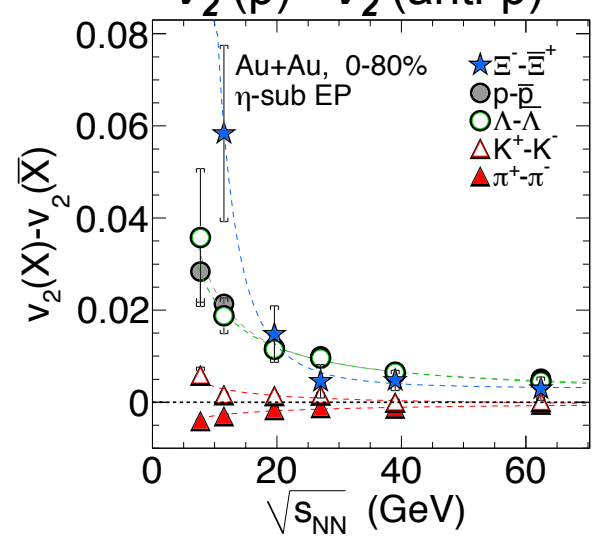
Chemical freeze-out



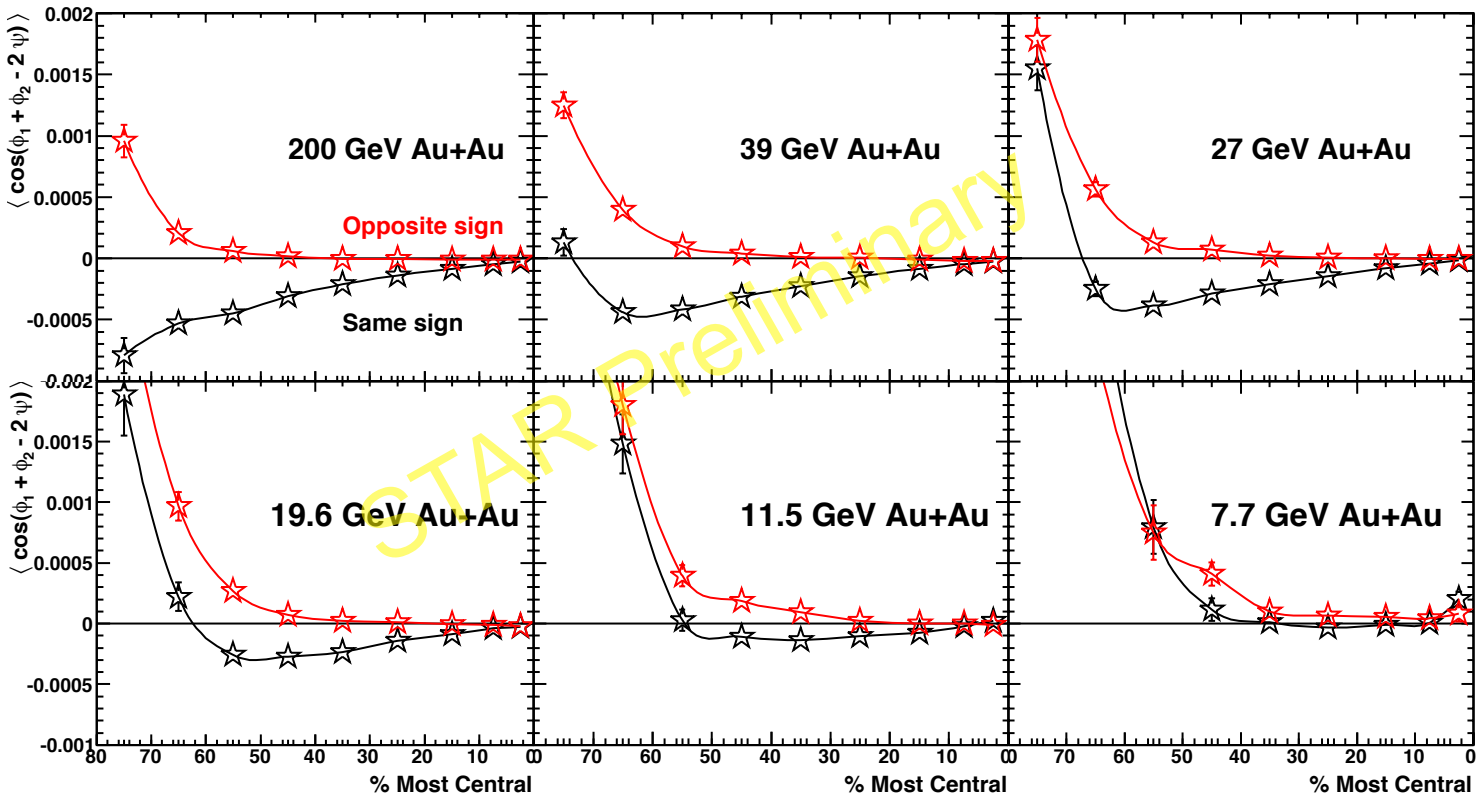
v_1 slope vs. $\sqrt{s_{NN}}$



v_2 (p) - v_2 (anti-p)



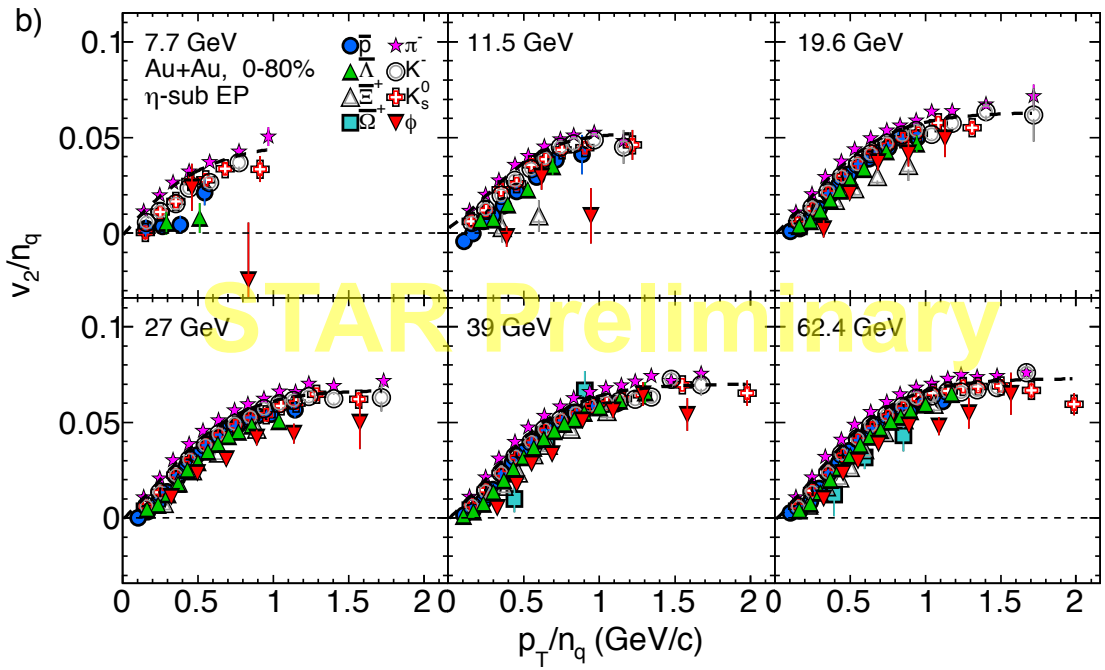
Dynamical Correlations (LPV)



(1) Below $\sqrt{s_{NN}}$ = 11.5 GeV, the splitting between the same- and opposite-sign charge pairs disappeared

(2) If QGP is the source for the observed splitting at high-energy nuclear collisions ➔ hadronic interactions become dominant at $\sqrt{s_{NN}} \leq$ 11.5 GeV

Systematic Collectivity Measurements

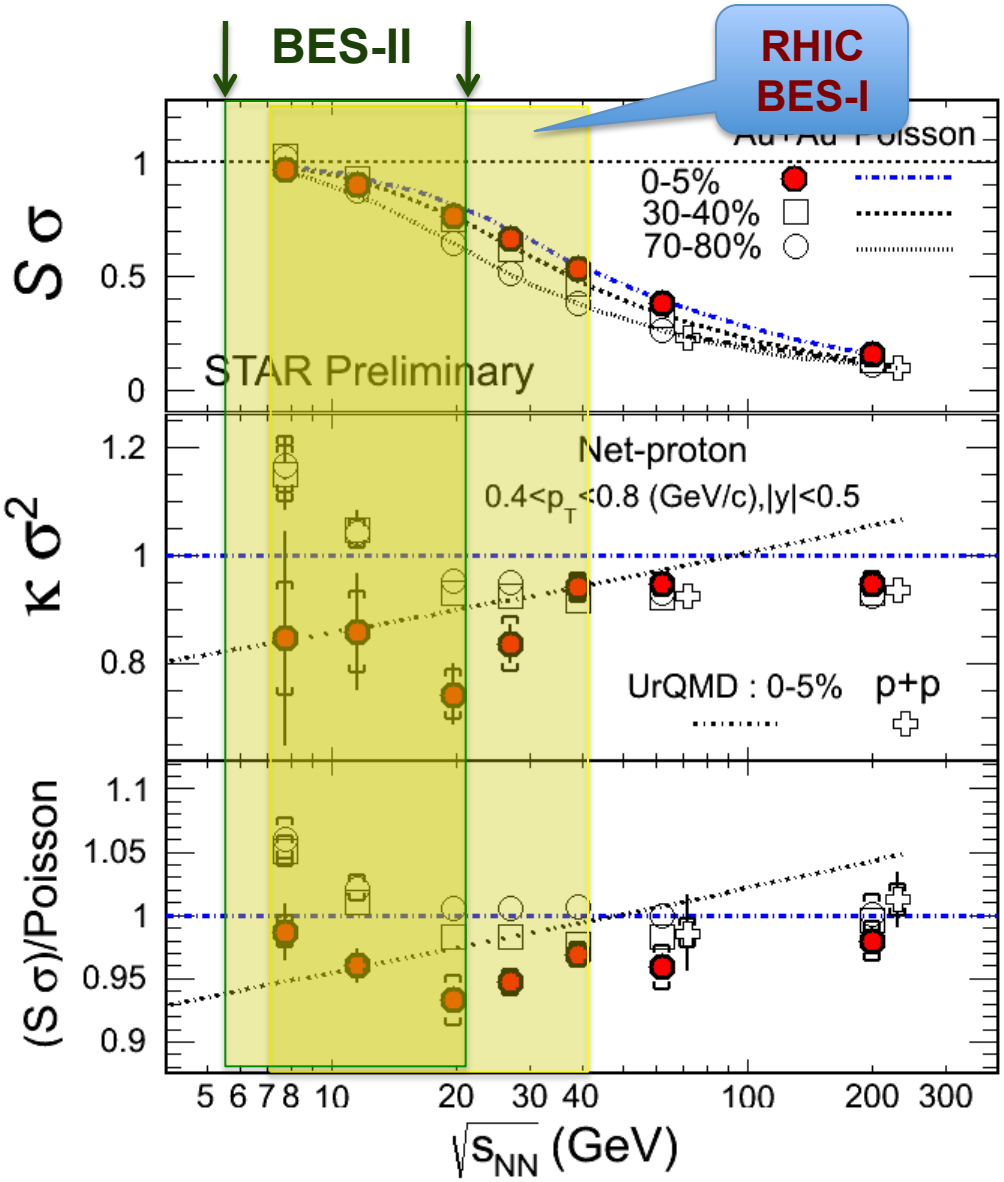


1) STAR has made systematic measurements of collectivity.

2) Number of quark scaling is broken and hadronic interaction become dominant, especially for $\sqrt{s_{NN}} < 11.5$ GeV

3) To understand ϕ-meson $v_2$behavior, need higher statistics for collisions $\sqrt{s_{NN}} < 20$ GeV

Net-proton Higher Moment



RHIC BES-I key findings:

1) Changes around $\sqrt{s_{NN}}$ **=** 20 GeV Au+Au collisions
- high moments
- LPV
- v_2 ϕ-meson drops
- …

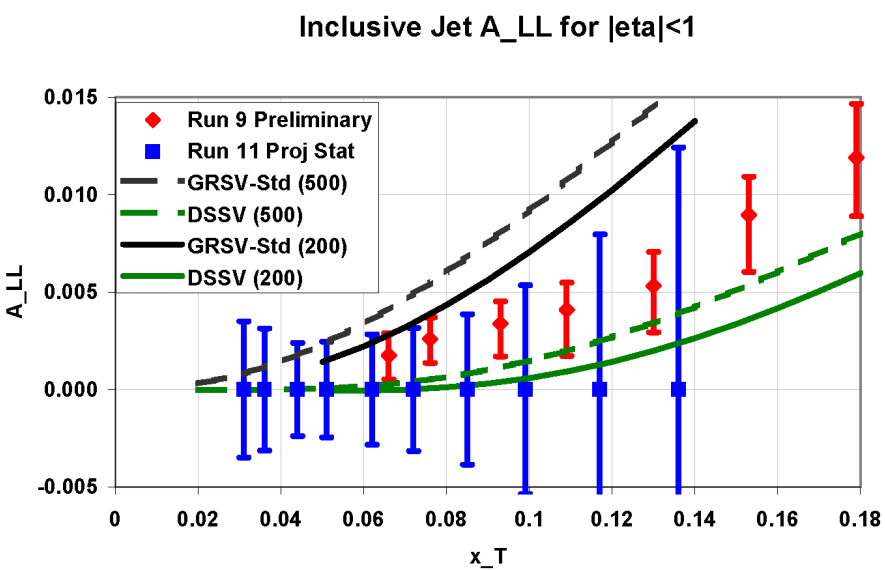
2) Need higher statistics for collisions $\sqrt{s_{NN}}$ < *20 GeV*

BES-II: focus $\sqrt{s_{NN}}$ = 5-20 GeV

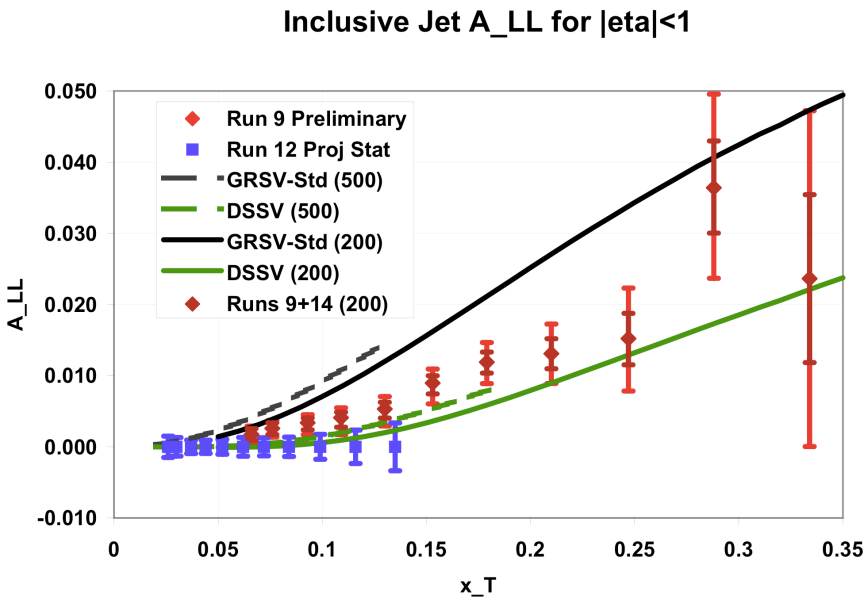
3) Beam Use Request for Run 13, Run 14 and Beam Energy Scan-II

Expected inclusive jet A_{LL} precision

Run 11



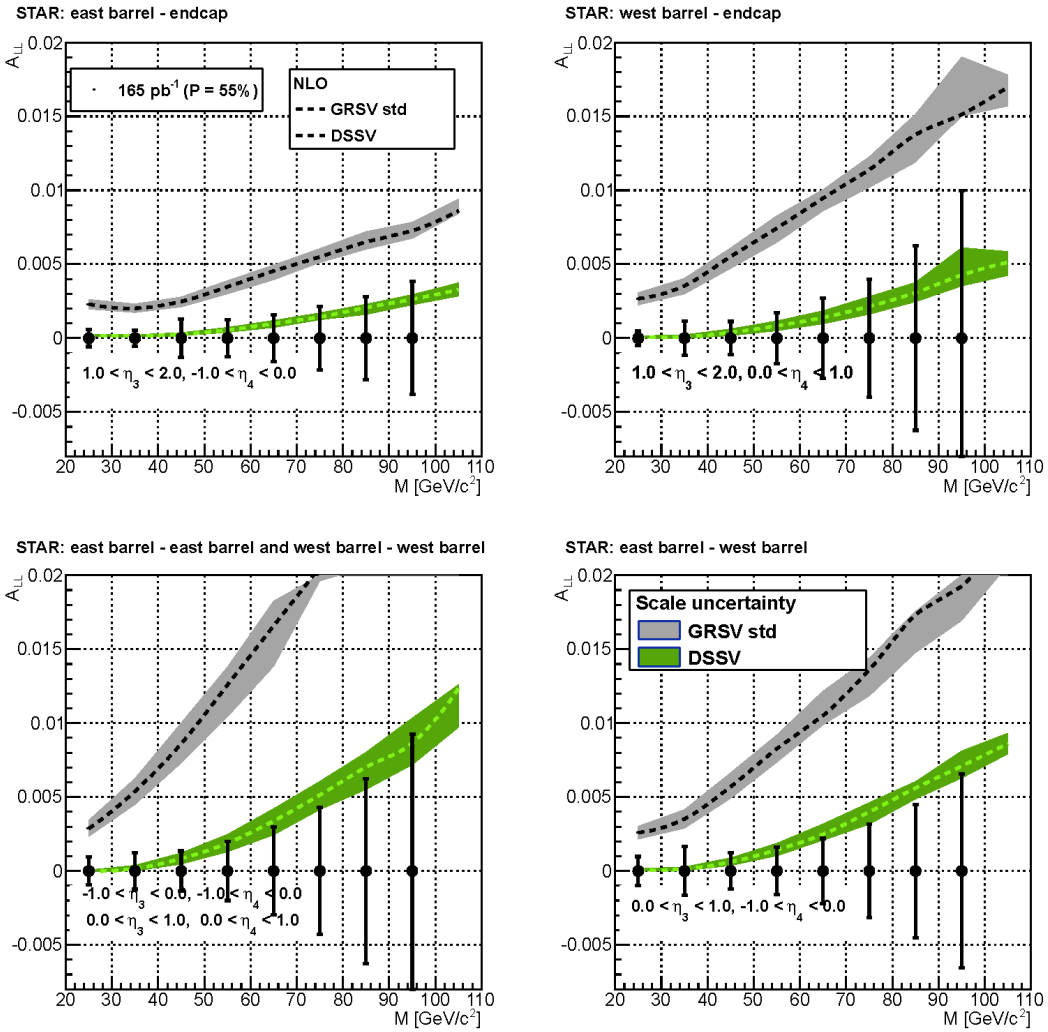
Run 14



- Run 14 will provide a very useful complement to Run 9
- During Run 13, further reduce the 200 GeV uncertainties compared to Run 9 by:
  - A factor of ~2 for jet p_T >~ 12 GeV
  - A factor of ~sqrt(2) for jet p_T <~ 12 GeV

Projected Sensitivity at 500 GeV

Run 13: Assumes 165 pb^{-1} delivered @ P = 55%



$$x_1, x_2 = \frac{M}{\sqrt{s}} \exp\left(\pm \frac{\eta_3 + \eta_4}{2} \right)$$

- Higher energy accesses lower x_g
- Expect smaller A_{LL}
- Projections include information on trigger rates, etc., from 2009
- Uncertainties shown are purely statistical

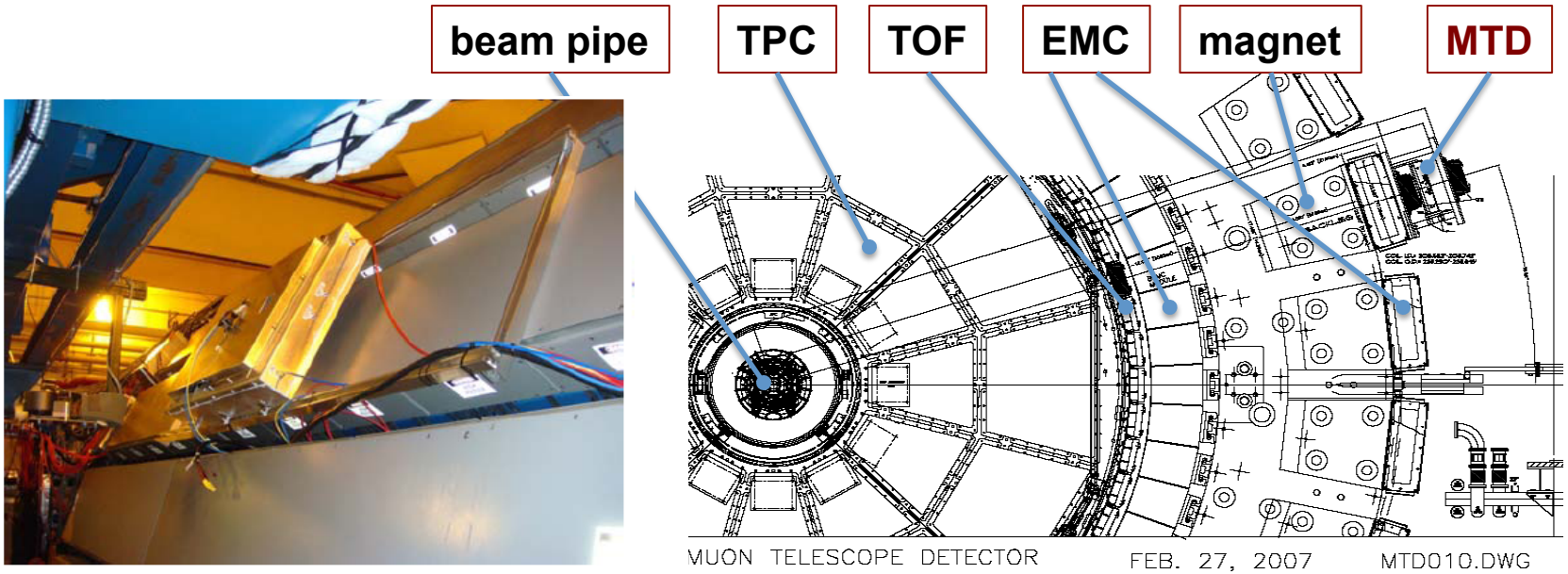
Run 13: pp2pp

1) Four-day pp2pp data taking at the beginning of Run 13. Minimized effects on other physics programs at RHIC

2) First data $\boldsymbol{\sigma_{TOT}}$, for example, at $\sqrt{s}$ = 510 GeV with the Roman Pots and a large dataset of Exclusive Central Production

3) Last chance for the measurement?

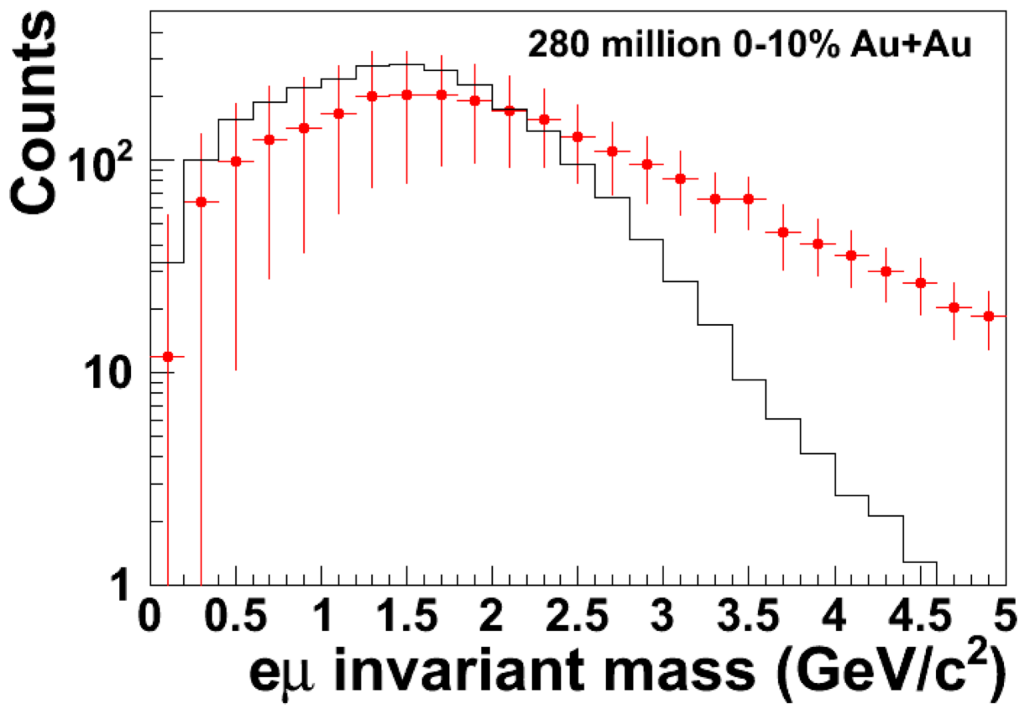
STAR: Muon Telescope Detector



Muon Telescope Detector (MTD) at STAR:

1) MRPC technology; μ_ε ~ 36%; cover ~45% azimuthally and |y| < 0.5
2) TPC+TOF+MTD: muon/hadron enhancement factor ~ $10^{2\text{-}3}$
3) For high p_T muon trigger, heavy quarkonia, light vector mesons, B→J/Ψ+X
4) China-India-STAR collaboration: approved by DOE and China + India
5) **Run 13**: 43% MTD will be ready

Run 13 MTD: e-μ Correlations

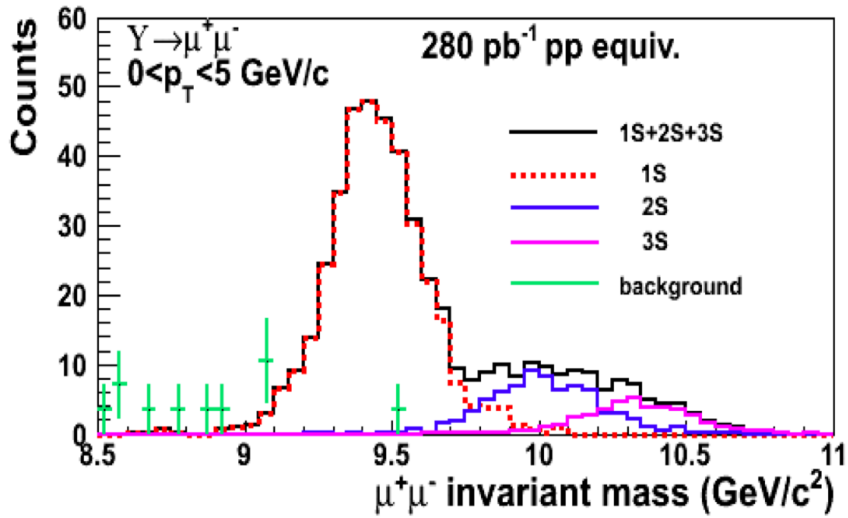


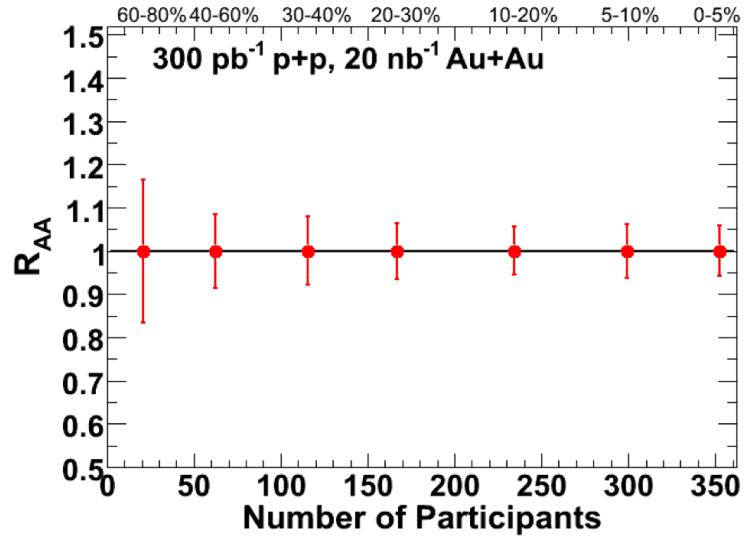
1) The e-μ invariant mass from 280M 0-10% central Au+Au events and MTD coverage as in Run 13.
2) Red points assume full correlation from PYTHIA
3) Black curve assumes full de-correlation and softening of the charm momentum distribution to match non-photonic electron R_{AA}

Run 13: Five-week Au+Au collisions allow us:

- Commissioning HFT in real HI environment, assure the success in Run 14
- Utilizing the partially installed MTD measure the e-μ

MTD: Run 13 + 14 …





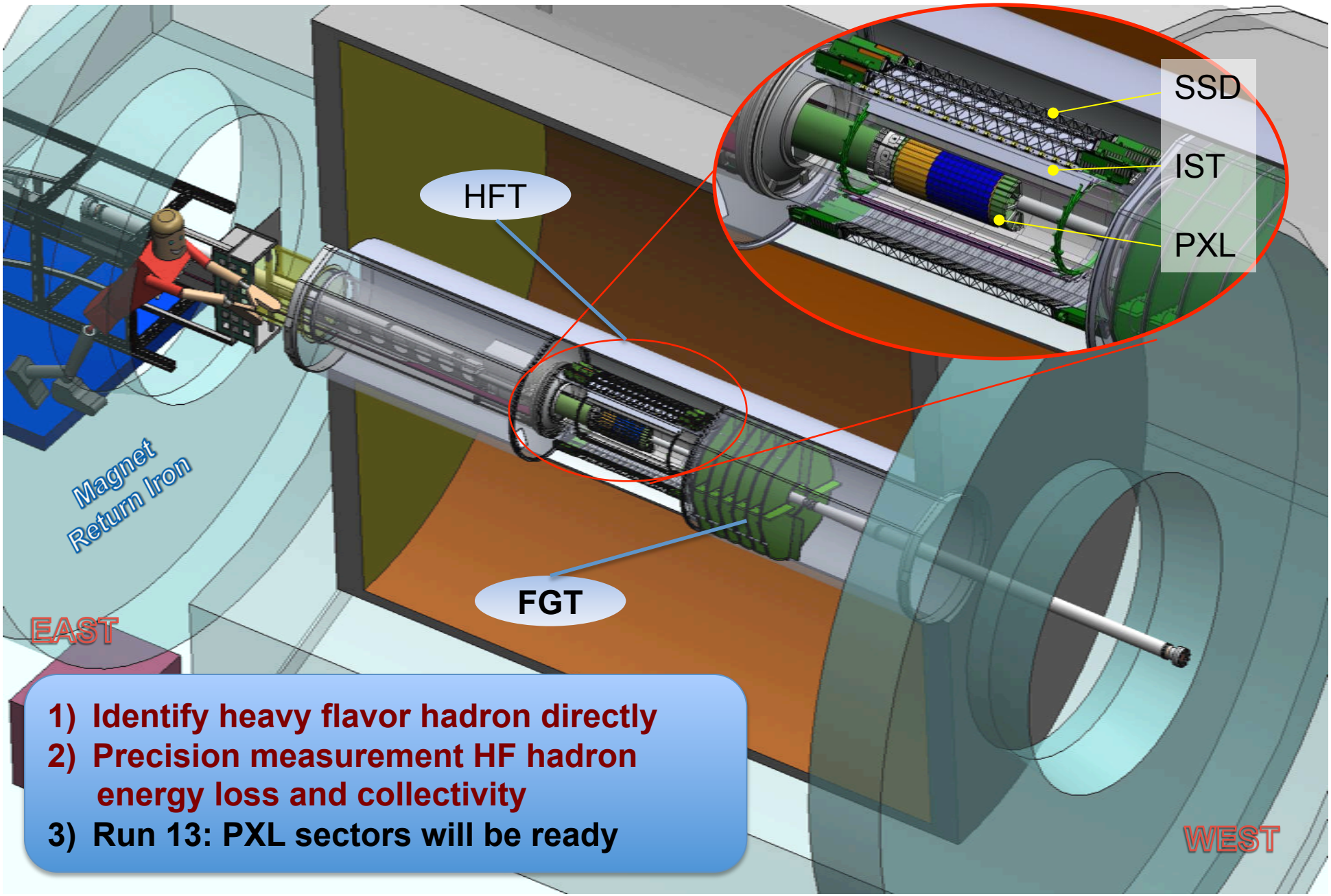
Runs	System	Upsilon (3S)	Upsilon(2S+3S)
14	200 GeV p+p	420 pb^{-1}	150 pb^{-1}
13	500 GeV p+p	140 pb^{-1}	50 pb^{-1}
14	200 GeV Au+Au	10 nb^{-1}	3.8 nb^{-1}

1) **Upsilon at RHIC:** unique, no regeneration, only initial production

2) **MTD at STAR:** $\Upsilon \Rightarrow \mu\mu$, unique, no Bremsstrahlung tails, clean separation of the excited states

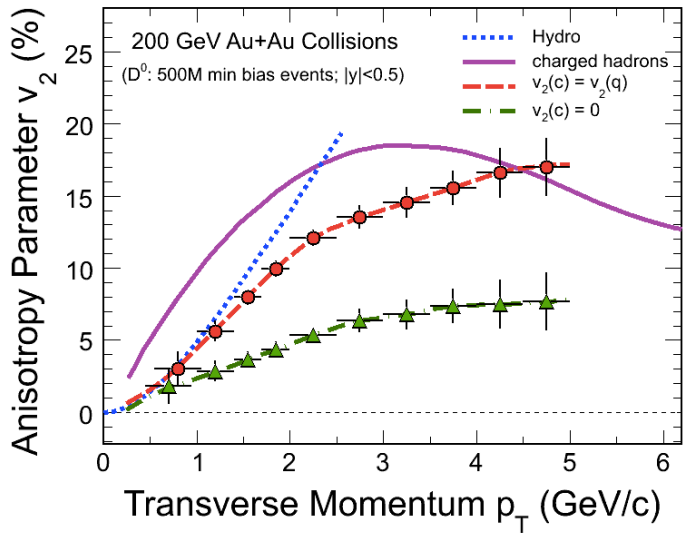
STAR multi-year program to accumulate sufficient luminosity

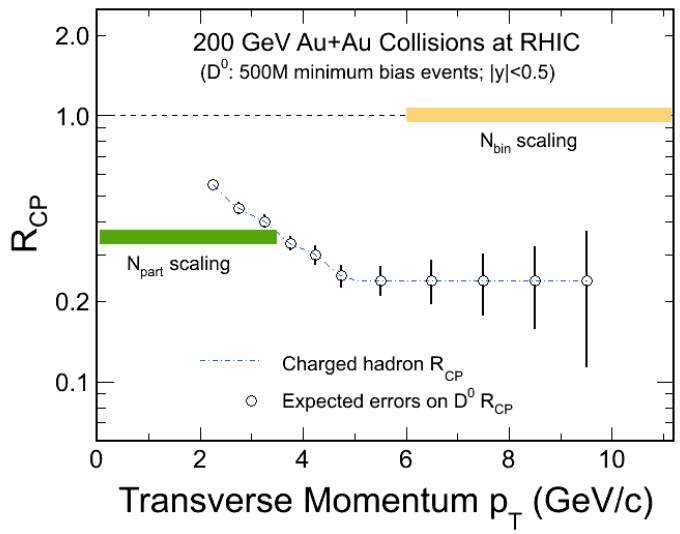
Heavy Flavor Tracker at STAR

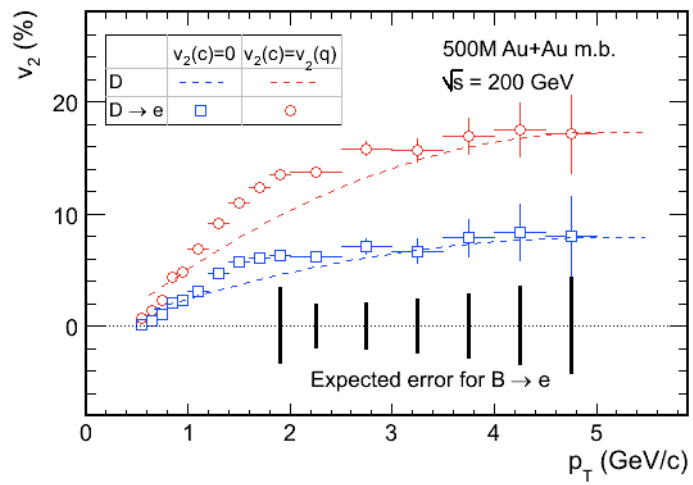


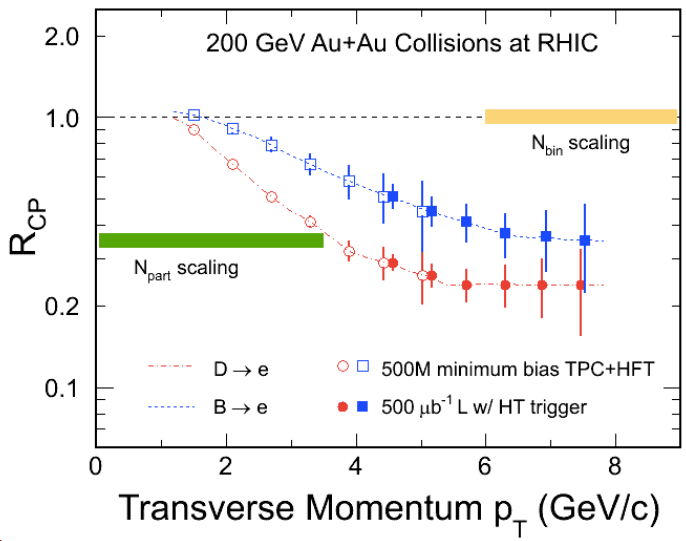
1) Identify heavy flavor hadron directly
2) Precision measurement HF hadron energy loss and collectivity
3) Run 13: PXL sectors will be ready

Run14: Physics Goals for HFT

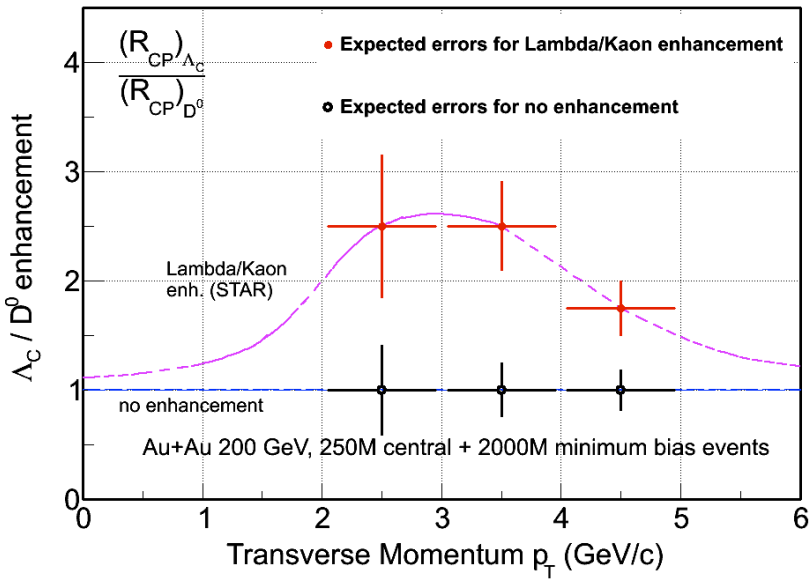






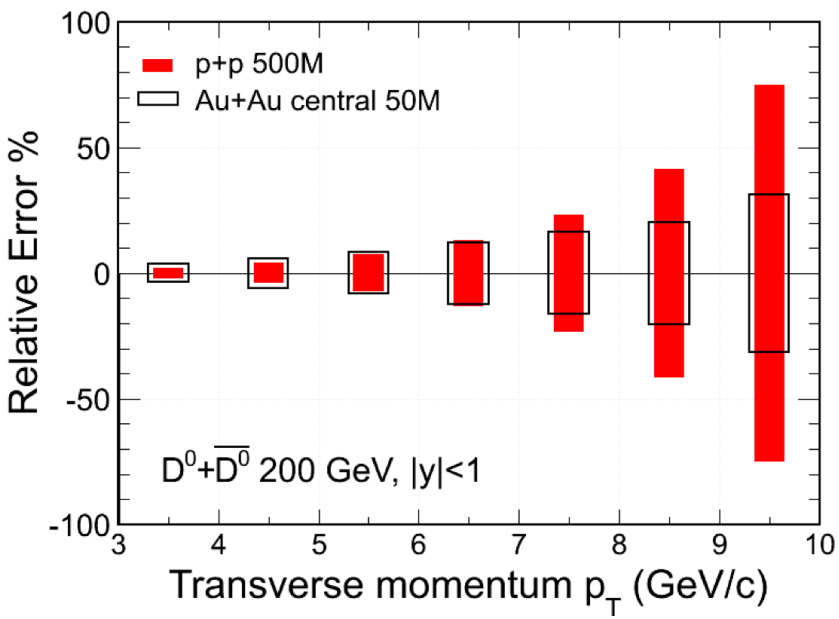


HF Physics: Run 14 and beyond



Λ_C: lowest charm baryon state, cτ ~ 60μm

- Hadro-chemistry with charm
-Heavy flavor energy loss, meson vs. baryon effect

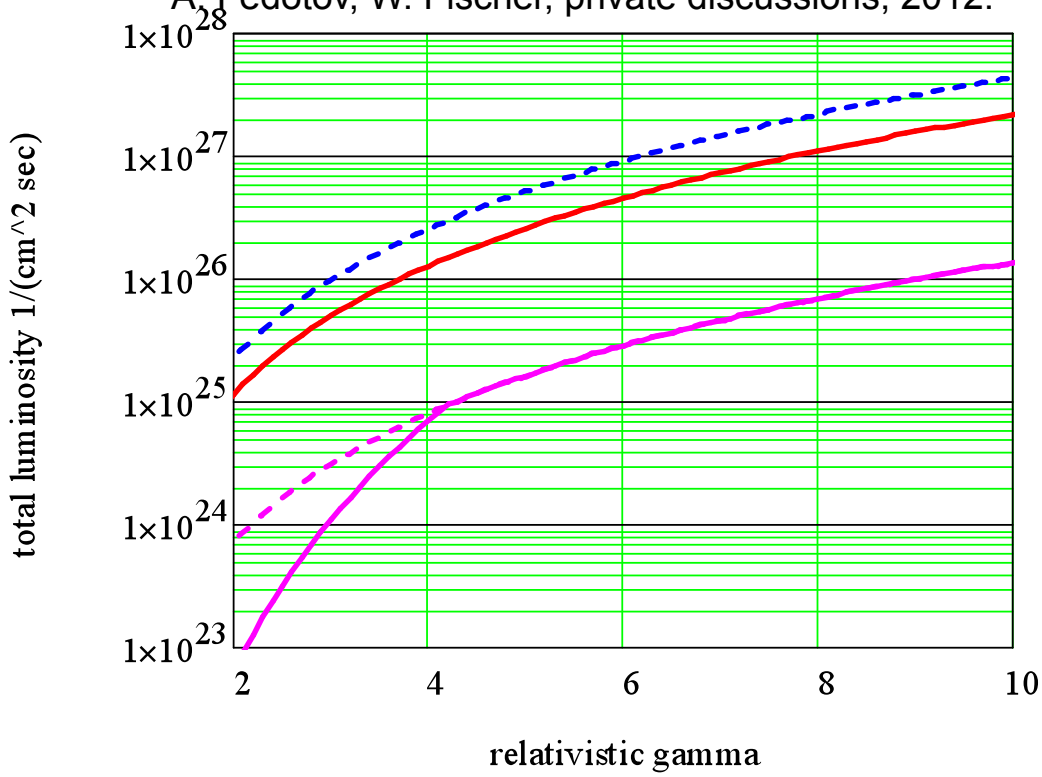


STAR multi-year physics program with the heavy flavor measurements requires high statistics data from both p+p and heavy ion collisions

e-cooling at RHIC for BES-II

Fermi Lab Pelletron

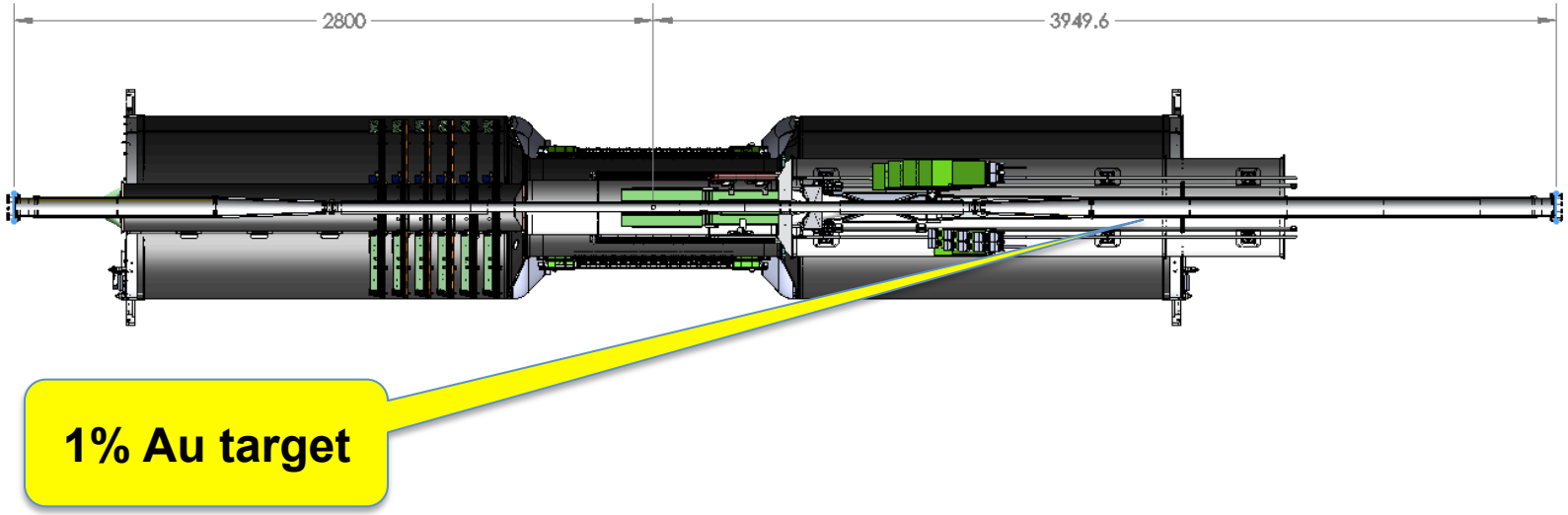
A. Fedotov, W. Fischer, private discussions, 2012.



$\sqrt{s_{NN}}$ (GeV)	~ 5	~ 20
Increasing factor*	3-5	10

STAR request install the e-cooling device
BES-II takes data in 2015 - 2017

Fixed-Target Mode



Collider mode $\sqrt{s_{NN}}$ (GeV)	Fixed-target mode $\sqrt{s_{NN}}$ (GeV)	Fixed-target mode μ_B (MeV)
19.6	**4.5**	585
15	**4.0**	625
11.5	**3.5**	670
7.7	**3.0**	720
5	**2.5**	775
	$v_{0,1,2}$, *asHBT*	

Summary

STAR has been very effective and productive:

1) TOF, HLT, DAQ1k upgrades successfully completed. FGT, **MTD** and **HFT** upgrades are on track.

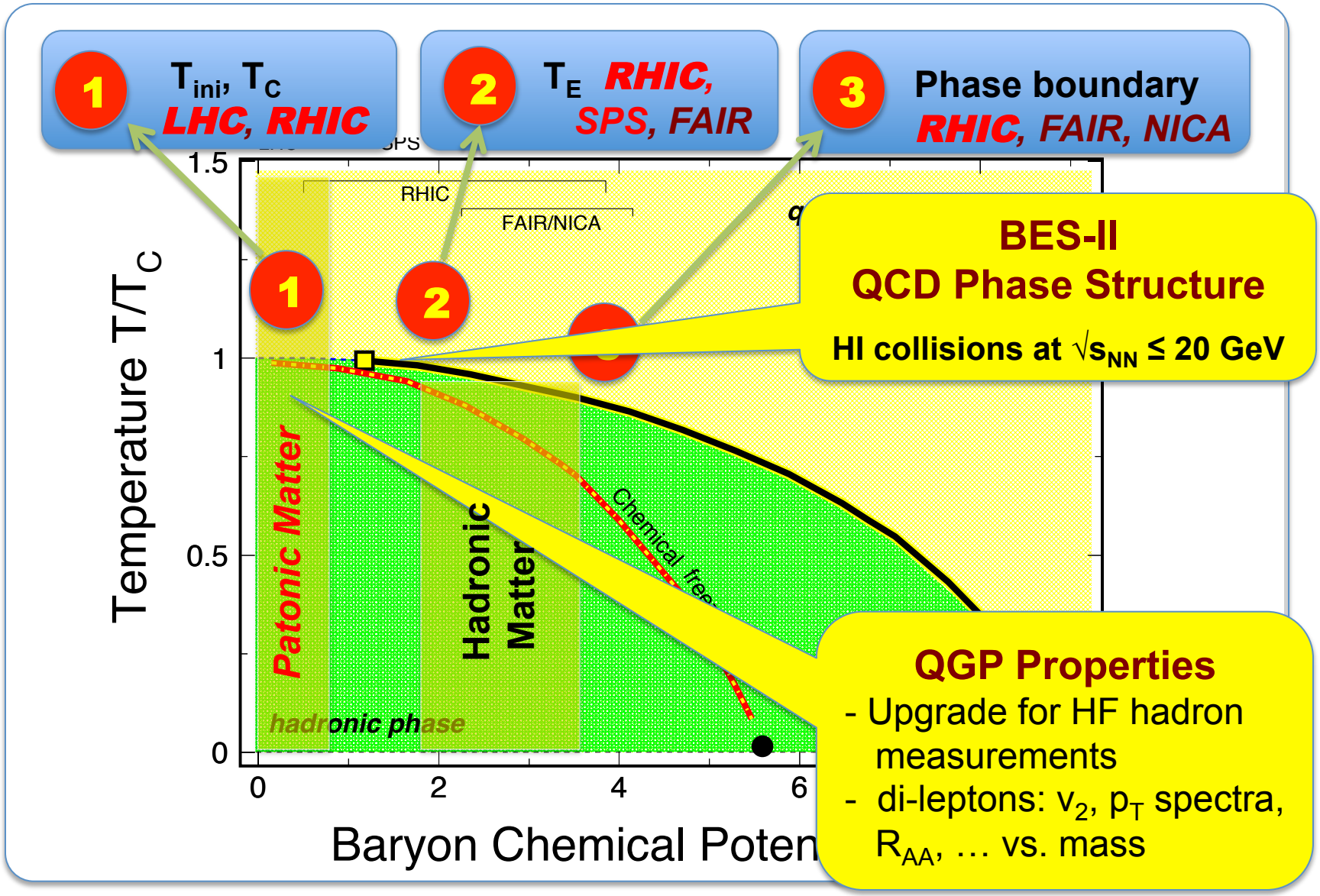
2) 200 GeV Au+Au collisions:
   - Large acceptance di-electron program started
   - Upsilon suppression vs. centrality and high statistics J/ψ v_2

3) Beam Energy Scan Phase-I (BES-I)
   - Systematic analysis of Au+Au collisions at 7.7/11.5/27/19.6/39/62.4:
   $\sqrt{s_{NN}} \geq 39$ GeV: partonic // **$\sqrt{s_{NN}} \leq 11.5$ GeV: hadronic**

4) Spin Physics
   - First $W^{\pm}$ A_L and cross section results published
   - di-jet A_{LL} analysis

5) High statistics, high quality data have been collected:
   - pp 200, 500 GeV; UU 193 GeV; Cu+Au 200 GeV

BES-I,II: (5, 7.7, 11.5, 15.5, 19.6, 27, 39, 62.4, 200 GeV)



For Runs 13 & 14: We Request

1) **Spin Physics (polarized p+p collisions)**
   - $W^{\pm}$ A_L at both mid-y and forward-y (2013)
   - σ_{TOT} and DPE at 500 GeV (2013)
   - Δg measurements at 200 GeV* (2014)

     * Reference data for heavy ion programs

2) **Heavy Ion Physics (Au+Au collisions)**
   - Physics with partial MTD and HFT engineering run (2013)
   - Physics run for HFT+MTD (2014)

3) **Late start of Run13: January 1, 2012**

4) **BES-II: $\sqrt{s_{NN}} \leq 20$ GeV and install e-cooling**

STAR BUR for Runs 13 and 14

Run	Beam Energy	Time	System	Goal
13	$\sqrt{s}$ = 510 GeV	4 days	$p_{\uparrow}\, p_{\uparrow}$	σ_{TOT}, A_N, A_{NN}, A_{SS}, Exclusive Central Production
		10 weeks	$p_{\rightarrow}\, p_{\rightarrow}$	i) $W^{\pm}$ A_L: P^2*L= 50 pb^{-1} ii) di-jets A_{LL}: P^4*L= 15 pb^{-1}
	$\sqrt{s_{NN}}$ = 200 GeV	4 weeks	Au + Au	i) MTD e-μ correlation, 2 nb^{-1} (280M central events) ii) HFT engineering run
14	$\sqrt{s_{NN}}$ = 200 GeV	10 weeks	Au + Au	i) HFT & MTD heavy flavor, 10 nb^{-1}(500M M.B.) ii) Fixed-target data taking(3)
	$\sqrt{s}$ = 200 GeV	5 weeks	$p_{\uparrow}\, p_{\uparrow}$	i) Heavy ion reference data L= 40 pb^{-1} (500M M.B.) ii) Δg, L= 40 pb^{-1}

Run 13: 20 cryo-week. 510pp: 65% polarization

Run 14: 20 cryo-week. 200pp: 65% polarization