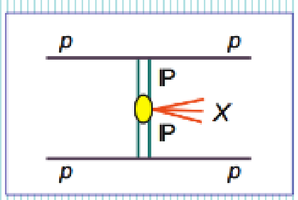
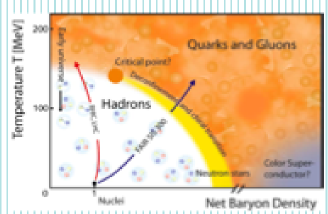
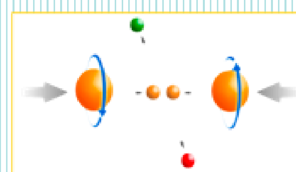
STAR Physics Program

STAR Beam Use Request for Runs 12, 13

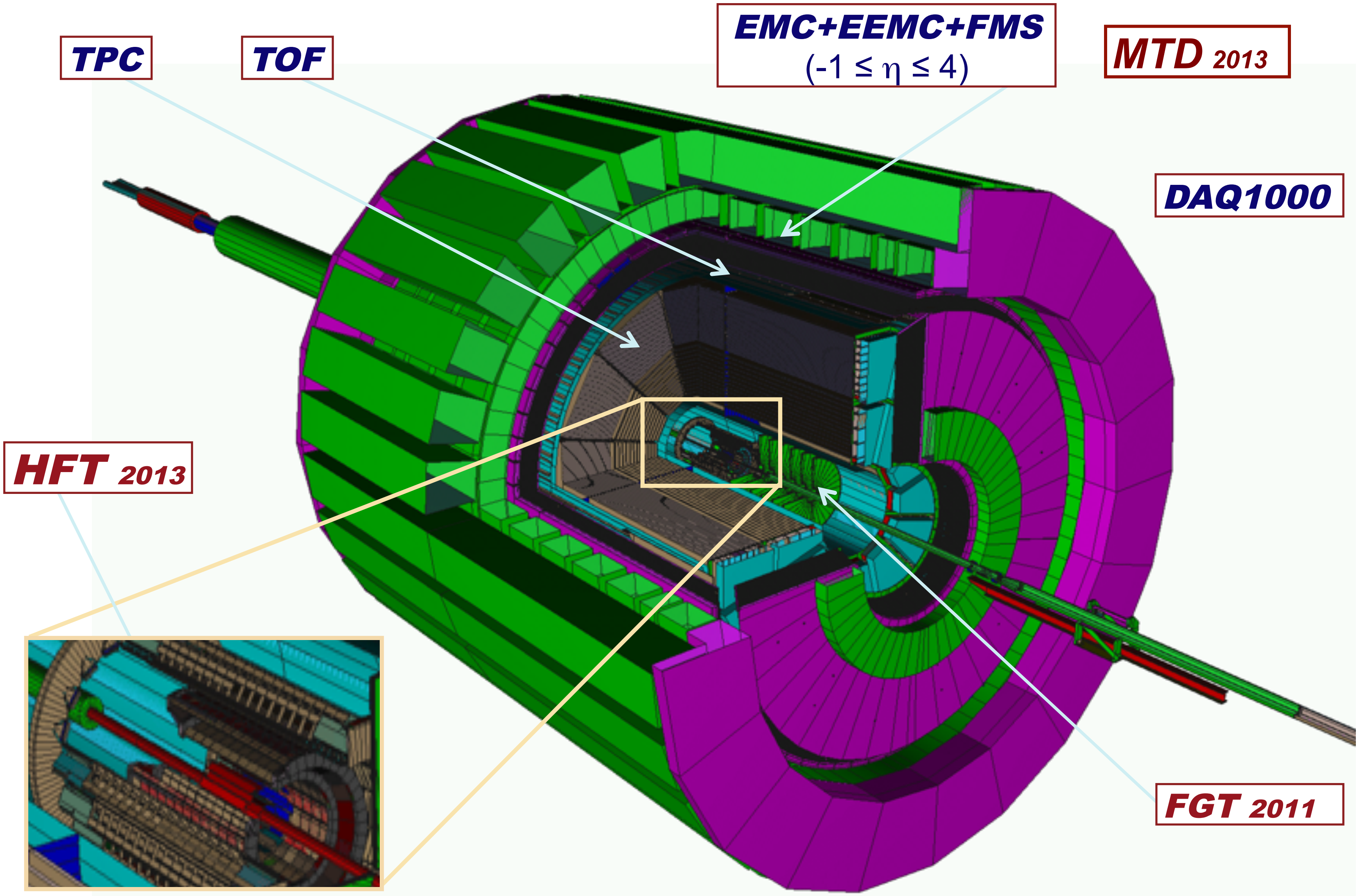
Nu Xu
for the STAR Collaboration



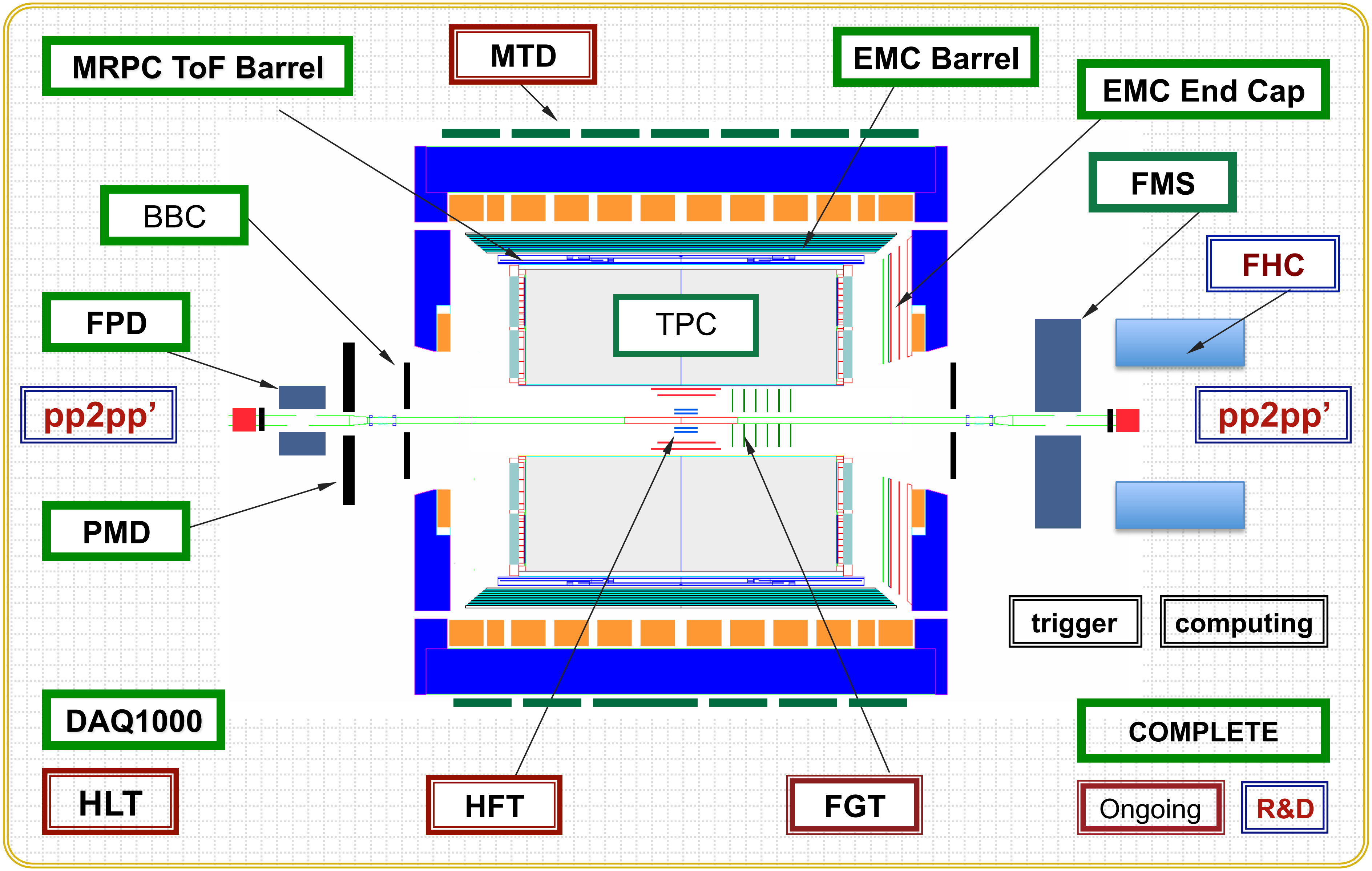




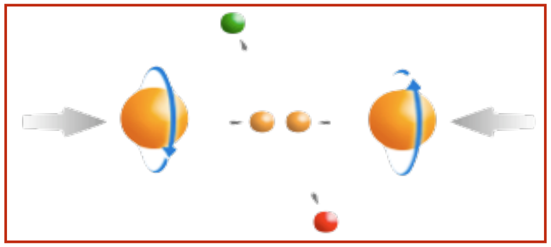
STAR Detectors ***Fast*** *and* ***Full*** *azimuthal particle identification*



STAR Experiment

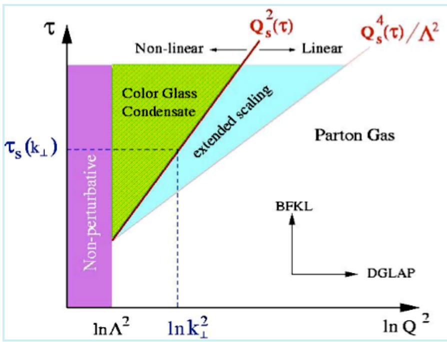


STAR Physics Focus



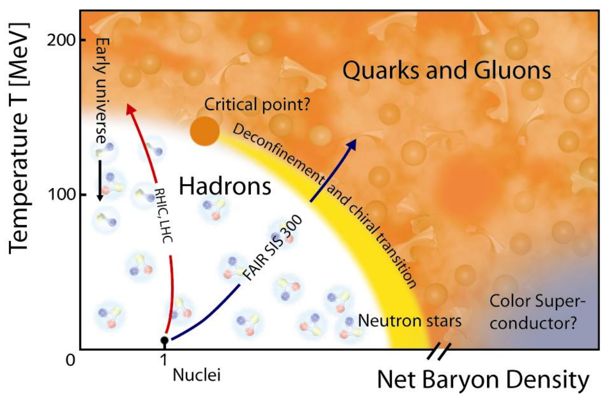
Polarized *p+p* program

- Study ***proton intrinsic properties***



Forward program

- Study low-x properties, search for ***CGC***
- Study elastic (inelastic) processes (pp2pp)
- Investigate ***gluonic exchanges***



1) At 200 GeV top energy

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

2) RHIC beam energy scan

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

STAR BUR for Runs 12 and 13

Run	Beam Energy	Time	System	Goal
12	$\sqrt{s_{NN}}$ = 27 GeV	1 week	Au + Au	150M minbias
	$\sqrt{s}$ = 500 GeV	3 weeks	p + p	FGT commissioning
		9 weeks	$p_{\rightarrow}\ p_{\rightarrow}$	P^2*L= 42 pb^{-1} P^4*L= 12 pb^{-1}
		1 week	$p_{\uparrow}\ p_{\uparrow}$	pp2pp at high β^* = 7.5m
	$\sqrt{s_{NN}}$ = 193 GeV	6 weeks	U + U	200 M minbias 200 M central
13	$\sqrt{s}$ = 500 GeV	8 weeks	$p_{\rightarrow}\ p_{\rightarrow}$	long. P^2*L= 50 pb^{-1}
	$\sqrt{s}$ = 200 GeV	10 weeks	$p_{\uparrow}\ p_{\uparrow}$ $p_{\rightarrow}\ p_{\rightarrow}$	trans. P^2*L= 7.2 pb^{-1} long. P^4*L= 7.1 pb^{-1} L = 60 pb^{-1}
	$\sqrt{s_{NN}}$ = 200 GeV	6 weeks	Au + Au (Pb + Pb)	HFT & MTD engineering

Run 12: 26 cryo-week. 500pp: 50% polarization

Run 13: 30 cryo-week. 500pp: 50% polarization // 200pp: 60-65% polarization

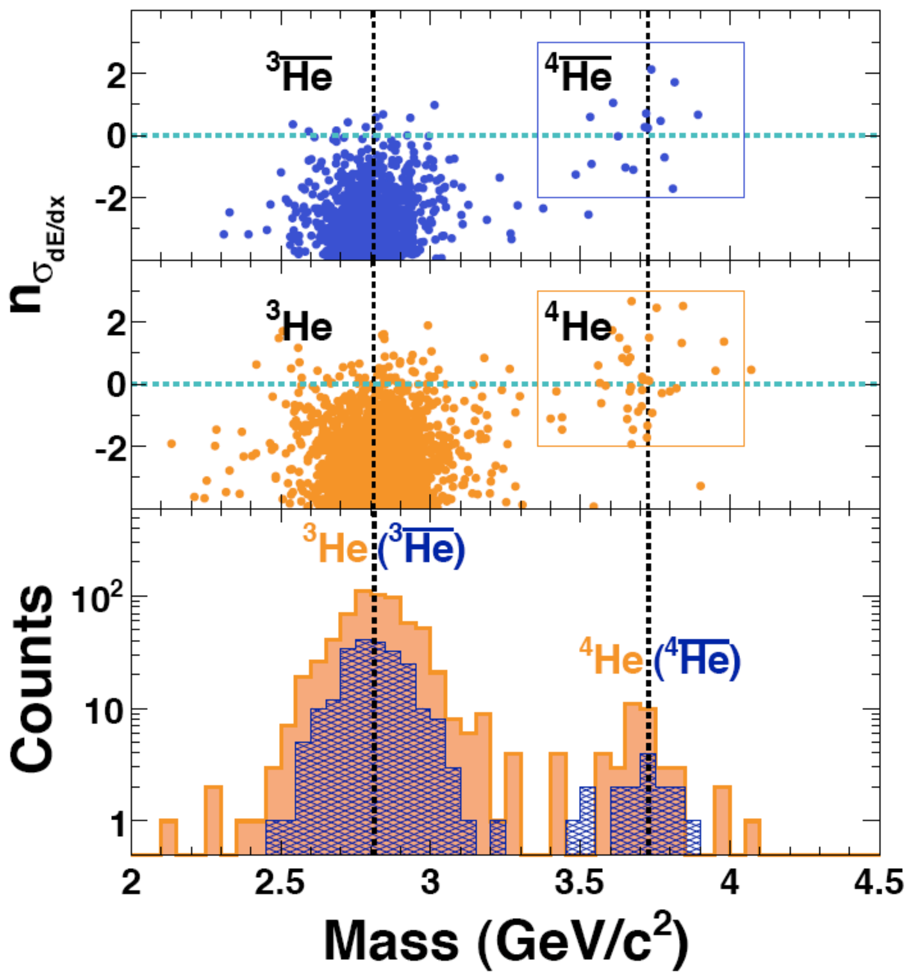
Selected Results

1) 200 GeV results

2) Beam Energy Scan results

3) Spin Physics results

Particle Identification at STAR (TPC + TOF + HLT)



- Clean Identification: TPC and ToF

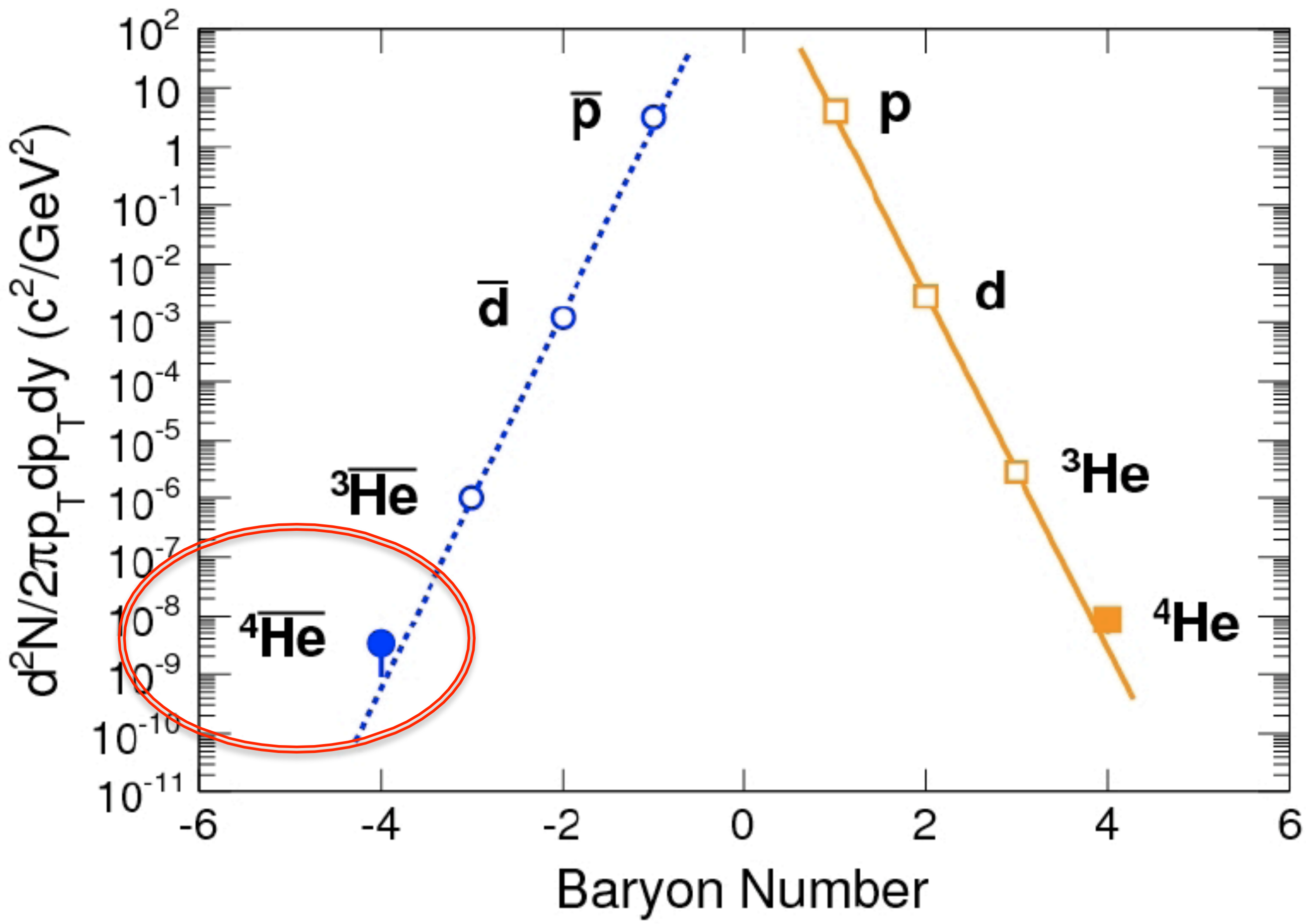
$$m^2 = p^2\left(1/\beta^2 - 1\right)$$

- 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

Light Nuclei Production at RHIC



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

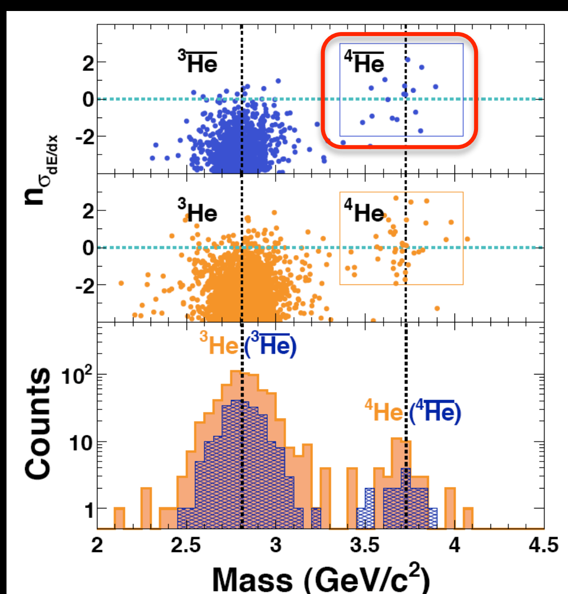
Antimatter Discoveries by STAR at RHIC

nature April, 2011

"Observation of the Antimatter Helium-4 Nucleus"

by ***STAR Collaboration***

Nature*, 473, 353(2011).*

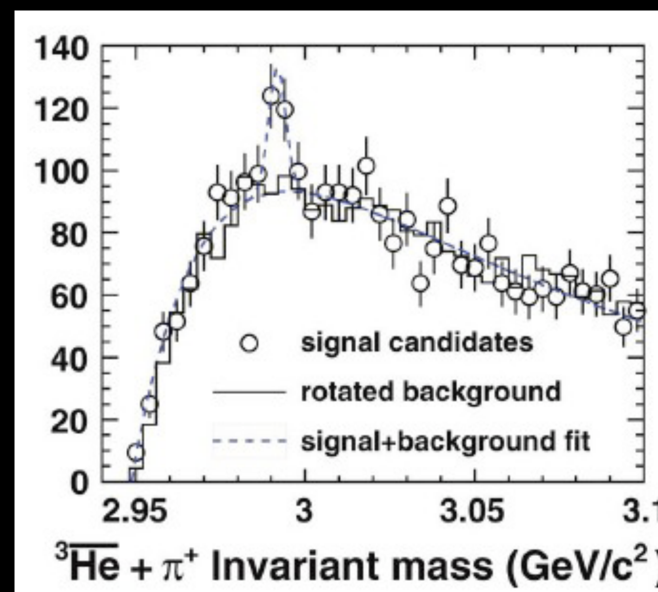


Science March, 2010

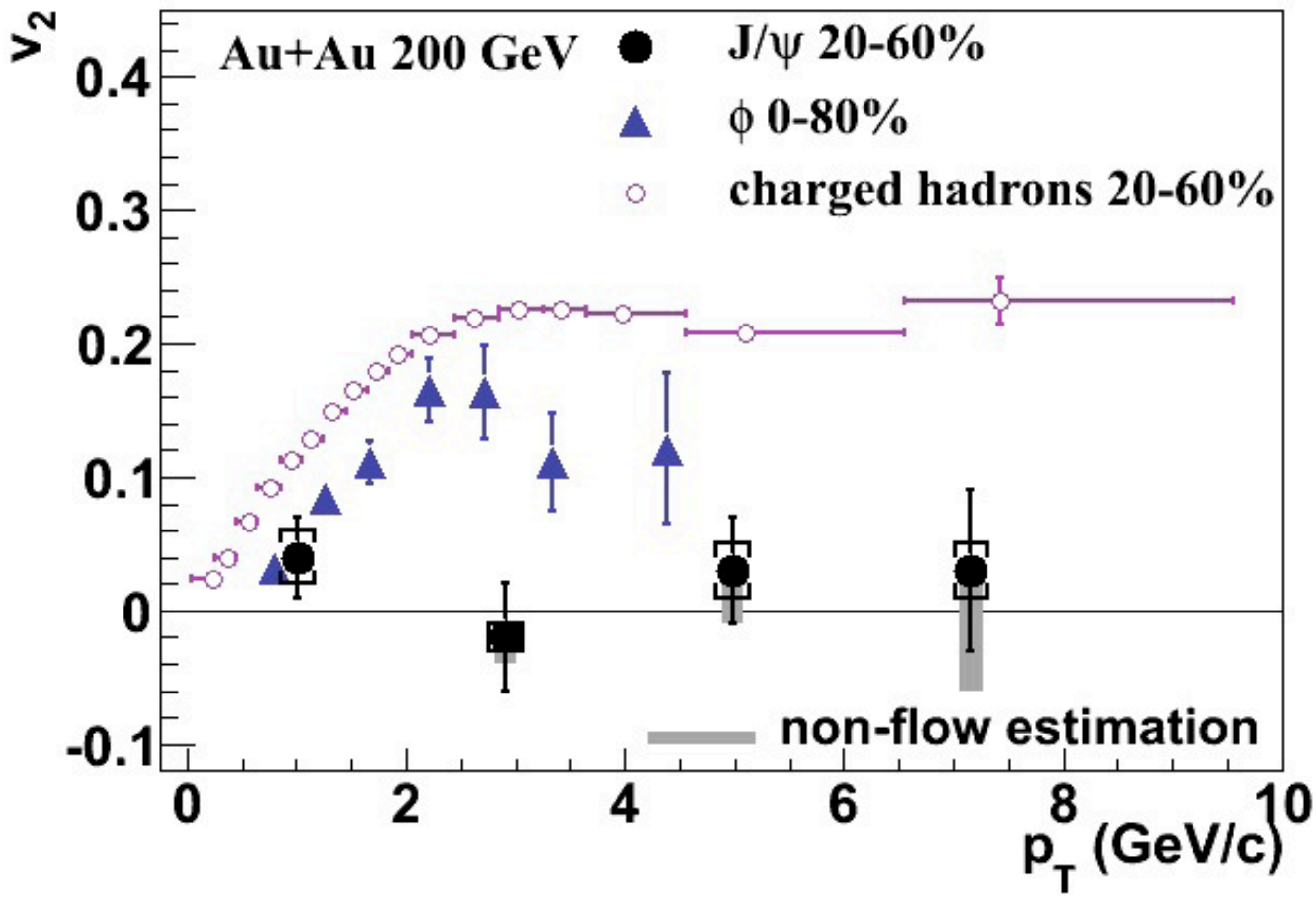
"Observation of an Antimatter Hypernucleus"

by ***STAR Collaboration***

Science*, 328, 58(2010).*



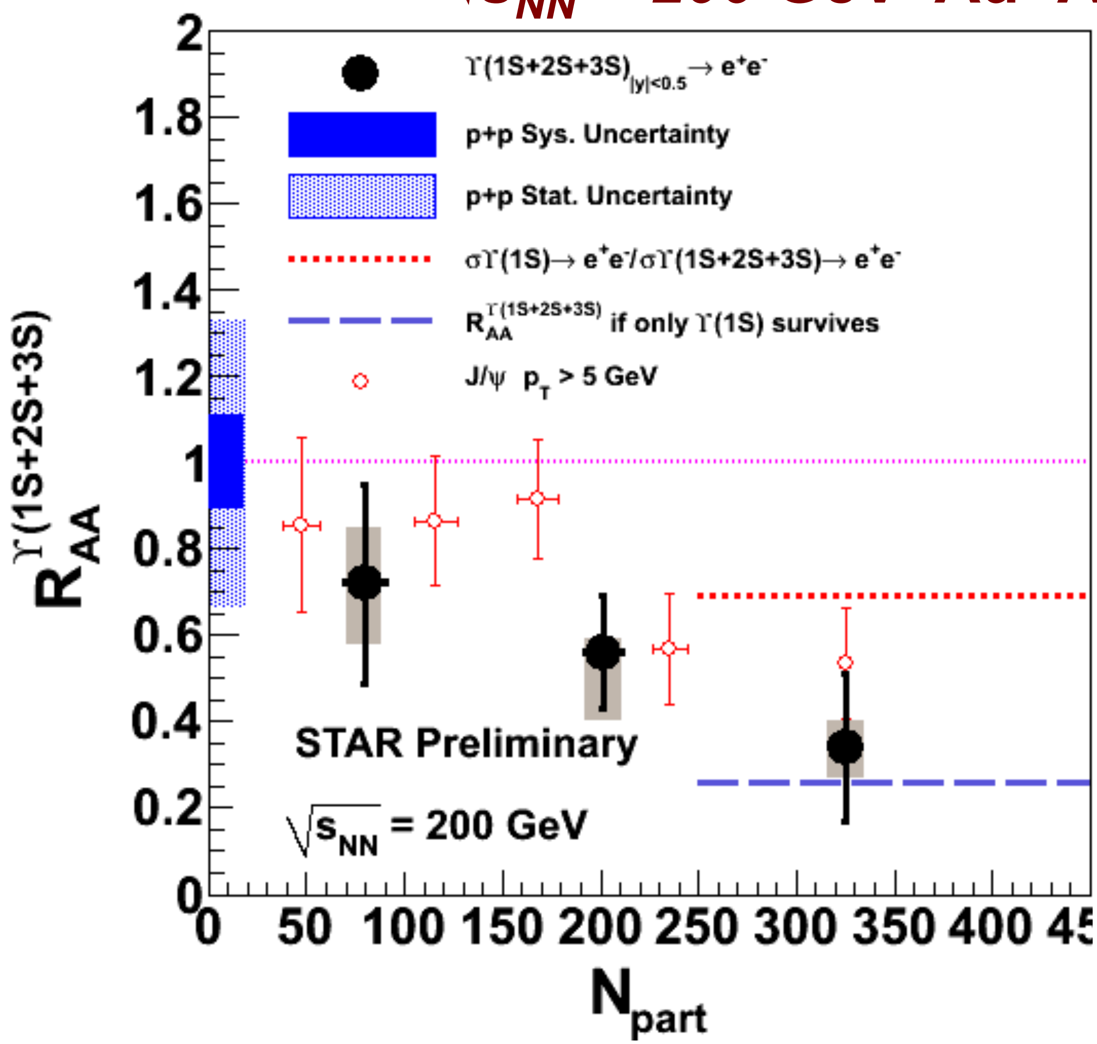
v_2 of J/ψ vs. p_T



1) STAR: **TPC + TOF + HLT**
2) $v_2^{J/\psi}(p_T)$ ~ 0 up to p_T = 8 GeV/c in 200 GeV Au+Au collisions
3) Either ***c*-quarks do not flow** or **coalescence is not the dominant process for J/ψ production at RHIC.**

Υ(1S+2S+3S) R_{AA}

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



1) STAR Triggered

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

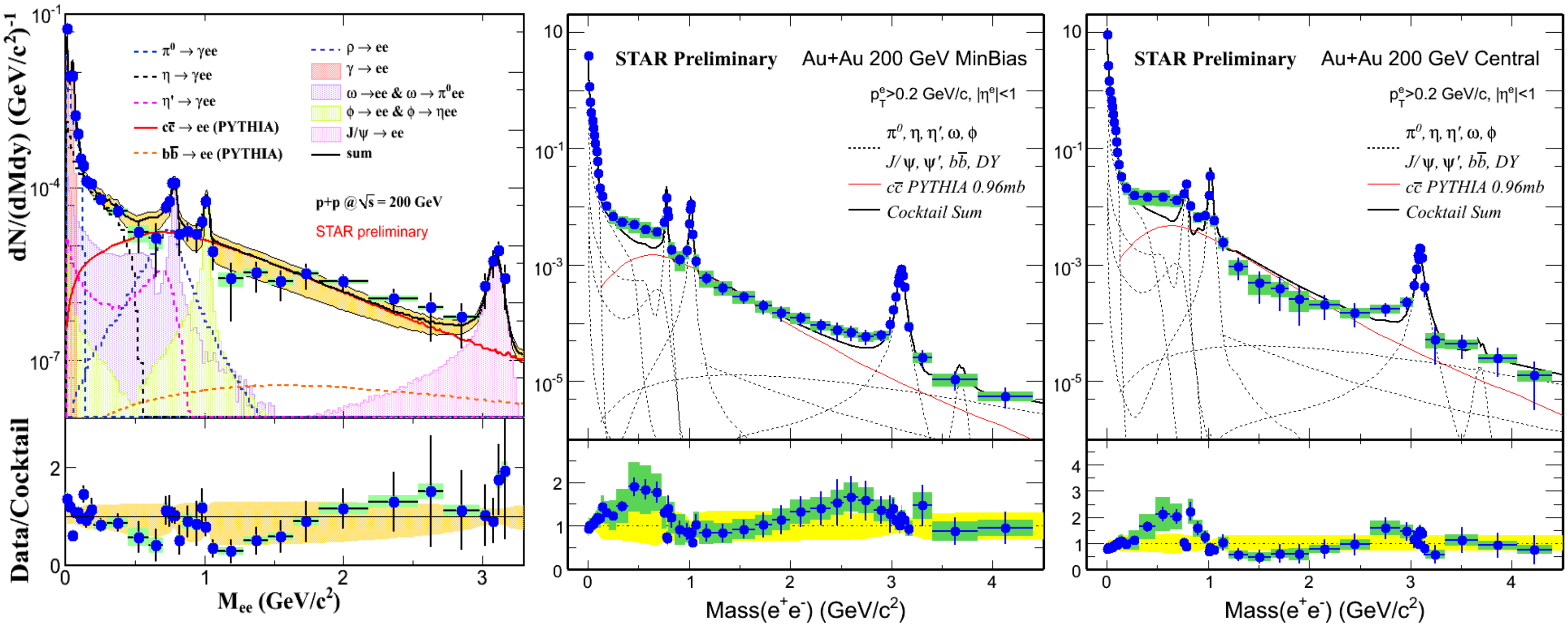
3) R_{AA} (0-60%)= 0.56±0.11 (stat)+0.02-0.14(sys)

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

*QM2011 flash talk

STAR Di-electron Program

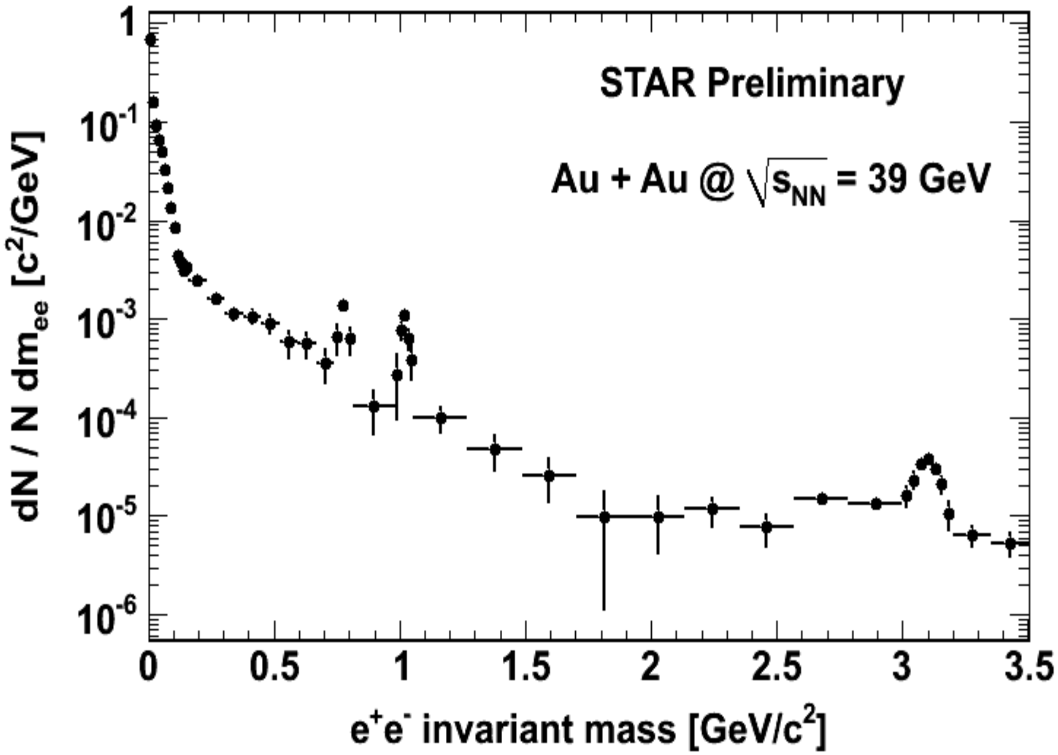
$\sqrt{s}$ = *200 GeV* **p+p** **Au+Au MinBias** **Au+Au Central**



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.

STAR Di-electron Program

$\sqrt{s_{NN}}$ = *39 GeV* **Au+Au MinBias**



With the large acceptance and low material, STAR beam energy scan program:

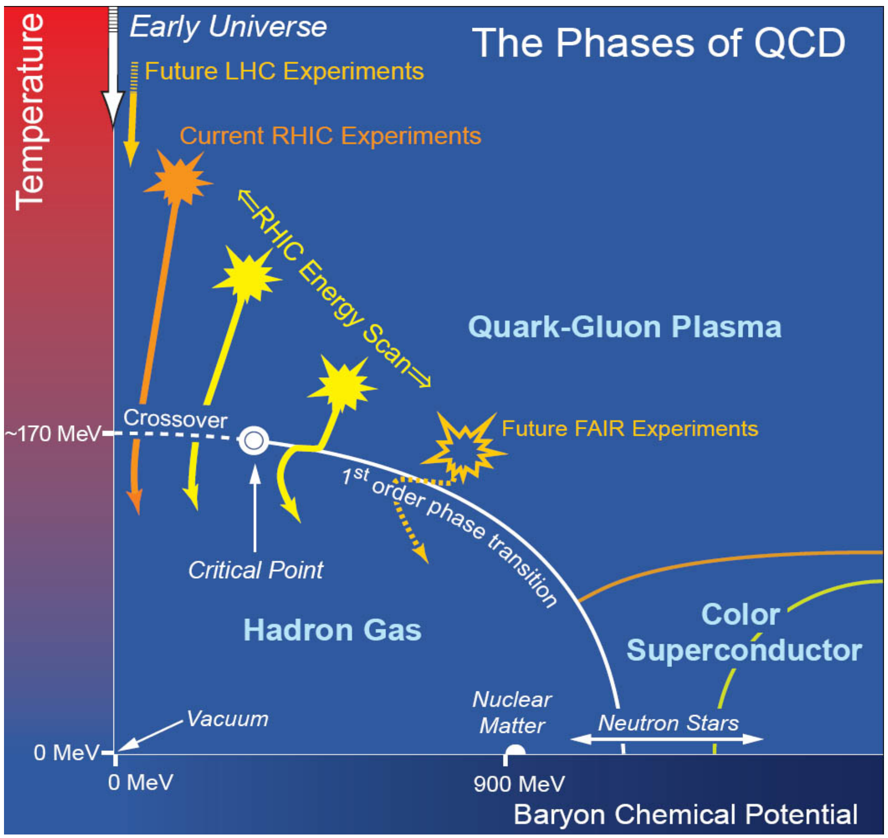
$\sqrt{s_{NN}}$ = ***27, 39, 62.4, 200 GeV*** **Au+Au Collisions**

RHIC Beam Energy Scan

(Phase-I)

Beam Energy Scan at RHIC

Motivations:
Signals of phase boundary
Signals for critical point



Observations:

(1) v_2 - NCQ scaling:
partonic vs. hadronic dof

(2) Dynamical correlations:
partonic vs. hadronic dof

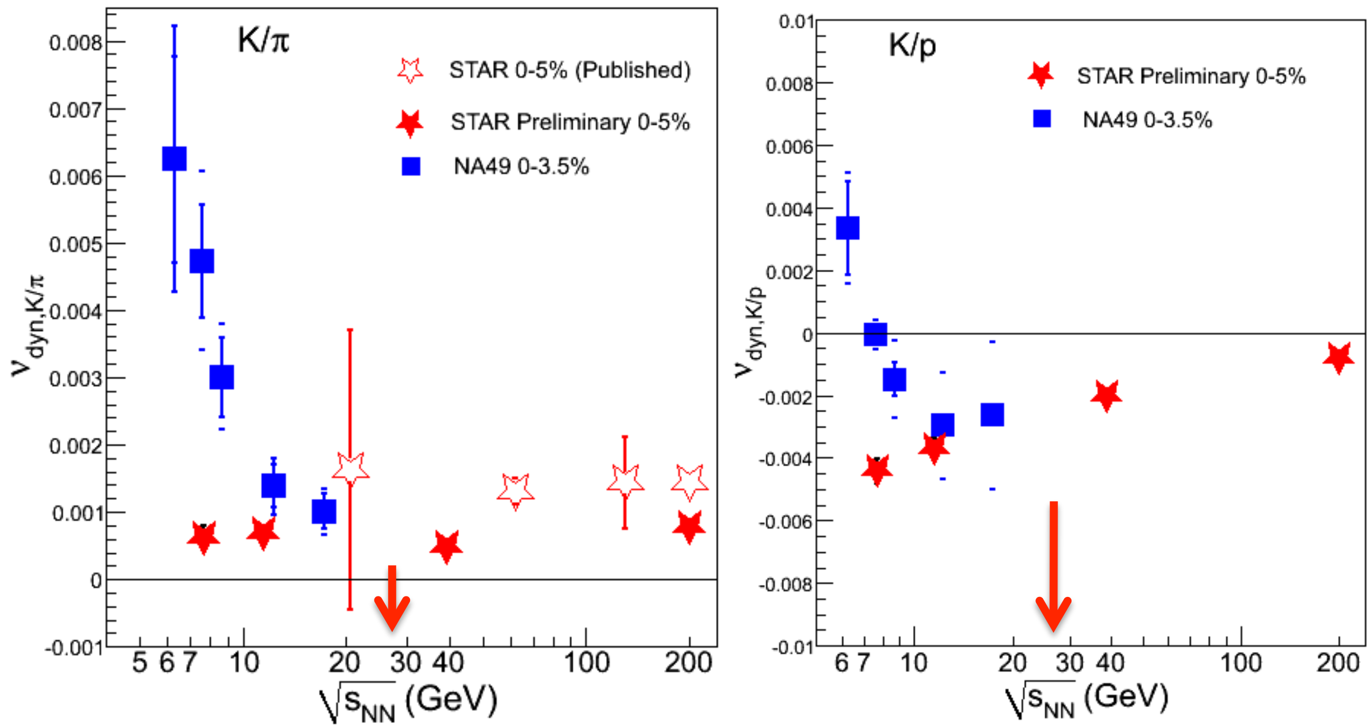
(3) Azimuthally HBT:
1^{st} order phase transition

(4) Fluctuations:
Critical points

(5) Directed flow v_1
1^{st} order phase transition

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

E-by-E Particle Ratio Fluctuations

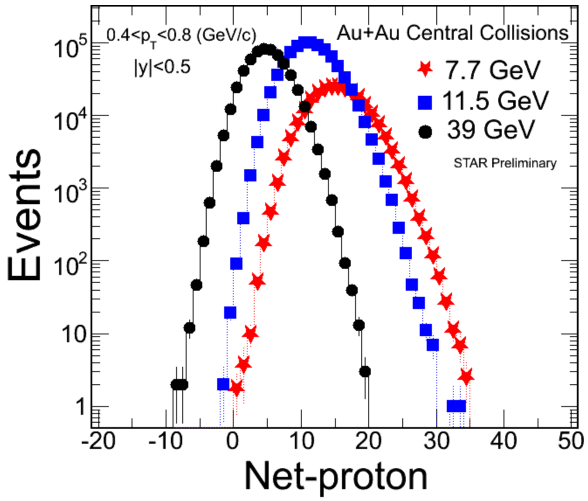


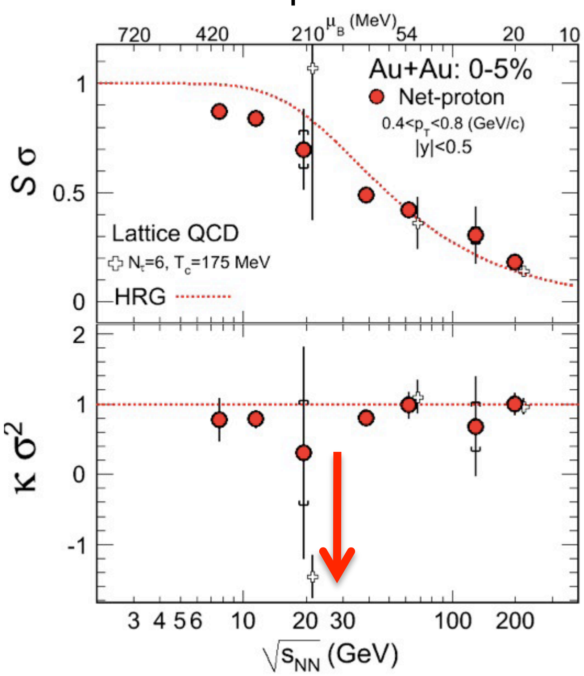
1) Fluctuations in particle ratios are sensitive to particle numbers at chemical FO not kinetic FO; the volume effects may cancel.

S. Jeon, V. Koch, PRL 83, 5435 (1999)

2) Apparent differences (results with Kaons) with SPS when $\sqrt{s_{NN}}$ < 12 GeV.

Higher Moments of Net-protons





1) STAR results* on net-proton high moments for Au+Au collisions at $\sqrt{s_{NN}}$ = 200, 62.4 and 19.6 GeV.

2) Sensitive to critical point**:

$$\left\langle (\delta N)^2 \right\rangle \approx \xi^2, \ \left\langle (\delta N)^3 \right\rangle \approx \xi^{4.5}, \ \left\langle (\delta N)^4 \right\rangle \approx \xi^7$$

3) Direct comparison with Lattice results**:

$$S*\sigma \approx \frac{\chi_B^3}{\chi_B^2}, \qquad \kappa*\sigma^2 \approx \frac{\chi_B^4}{\chi_B^2}$$

4) Extract susceptibilities and freeze-out temperature. An independent test on thermal equilibrium in HI collisions.

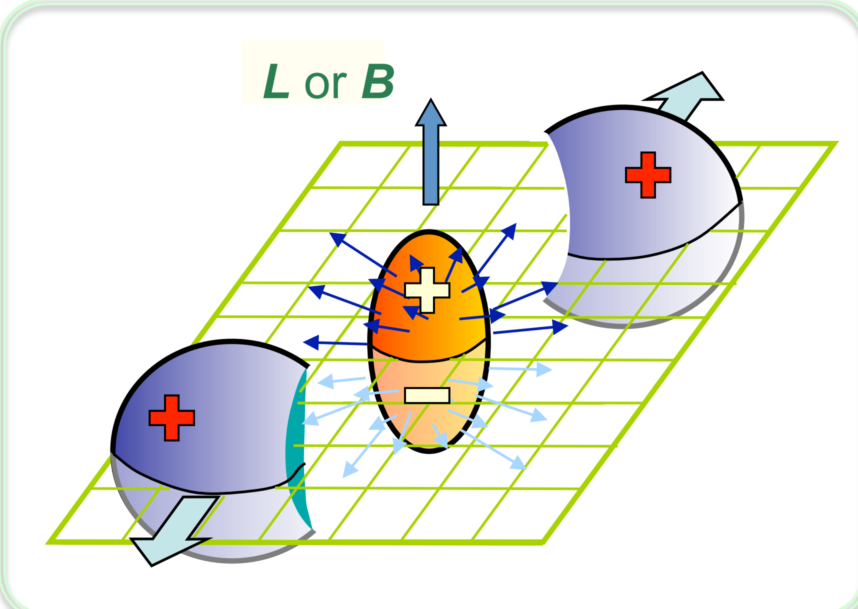
5) 17M good events at 19.6GeV collected in Run 11.

6) Run12 request: 27 GeV Au+Au collisions!

* STAR: 1004.4959, PRL 105, 22303(2010).
** M. Stephanov: PRL,102, 032301(09).
*** R.V. Gavai and S. Gupta: 1001.2796.

Search for Local Parity Violation

in High Energy Nuclear Collisions

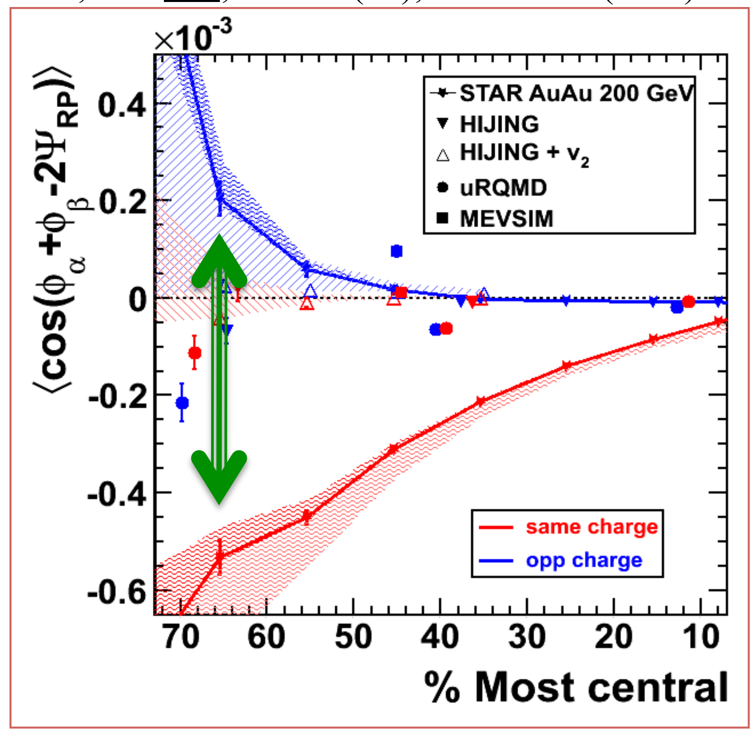


$$\left\langle \cos\left(\phi_\alpha + \phi_\beta - 2\Psi_{RP}\right)\right\rangle$$

Parity even observable

Voloshin, PR C62, 044901(00).

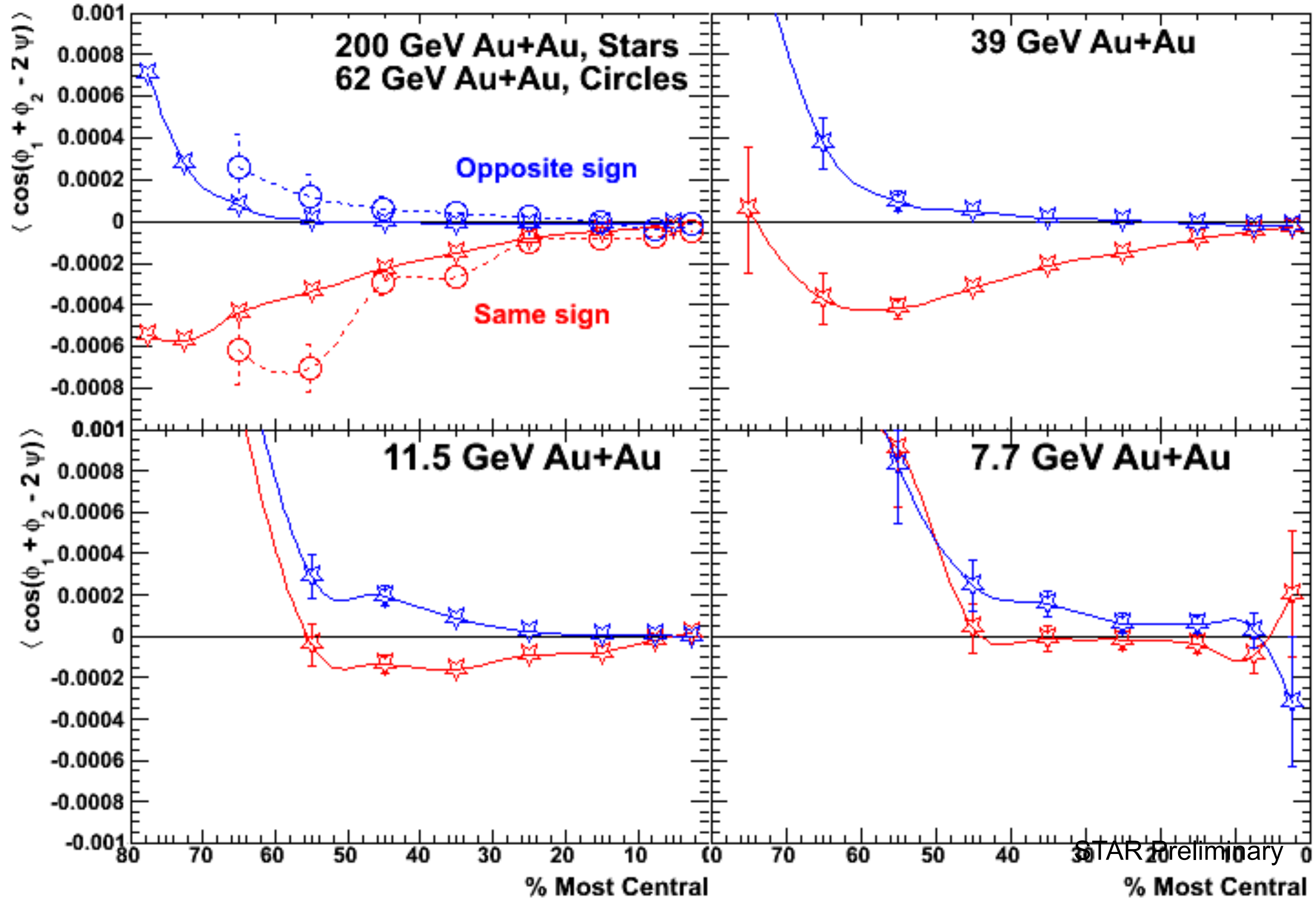
STAR; PRL**103**, 251601(09); 0909.1717 (PRC).



The separation between the same-charge and opposite-charge correlations.

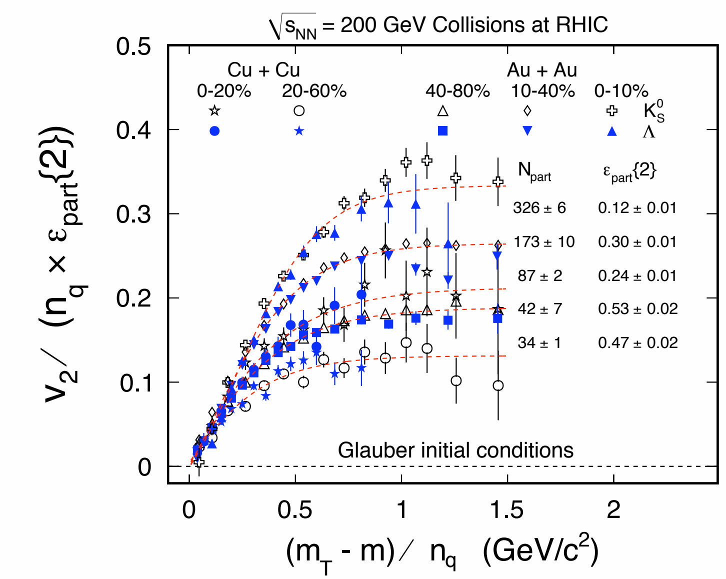
- **Strong external EM field**
- ***De-confinement* and *Chiral symmetry restoration***

LPV vs. Beam Energy

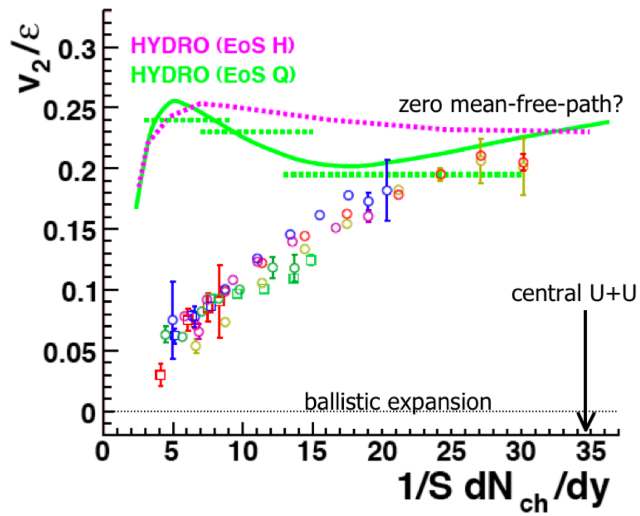


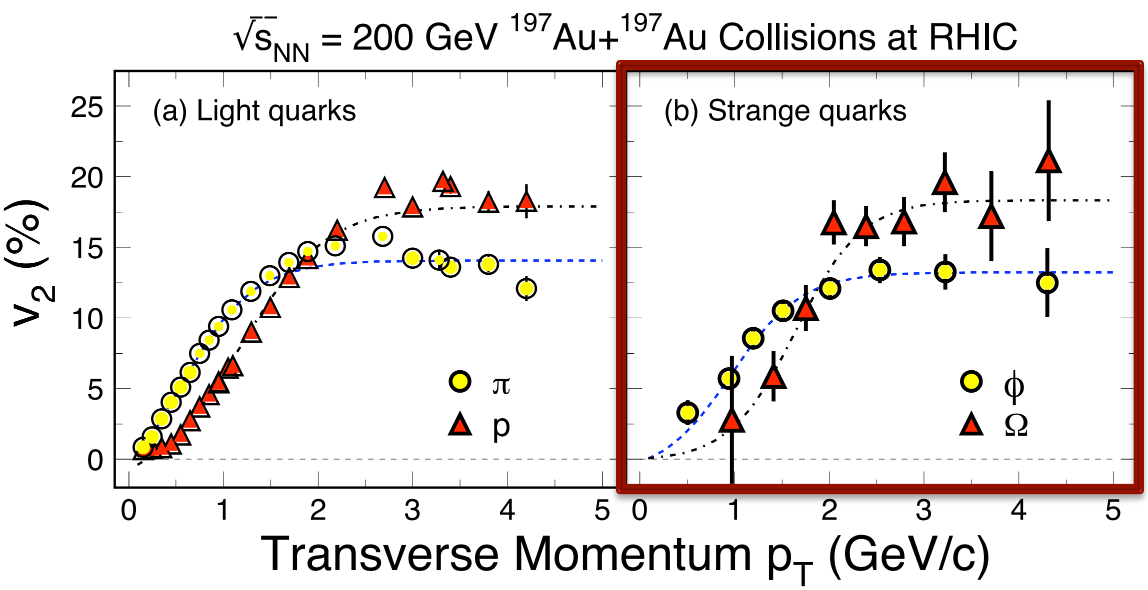
1) Difference between same- and opposite-sign correlations decreases as beam energy decreases
2) Same sign charge correlations become positive at 7.7 GeV
3) Several different approaches in the collaboration

Systematic Results on Collectivity



***STAR*:**
PRL **92**, 052302(04)
PRL **95**, 122301(05)
PRC ***77***, 54901(08)
PRC ***81***, 44902(10)



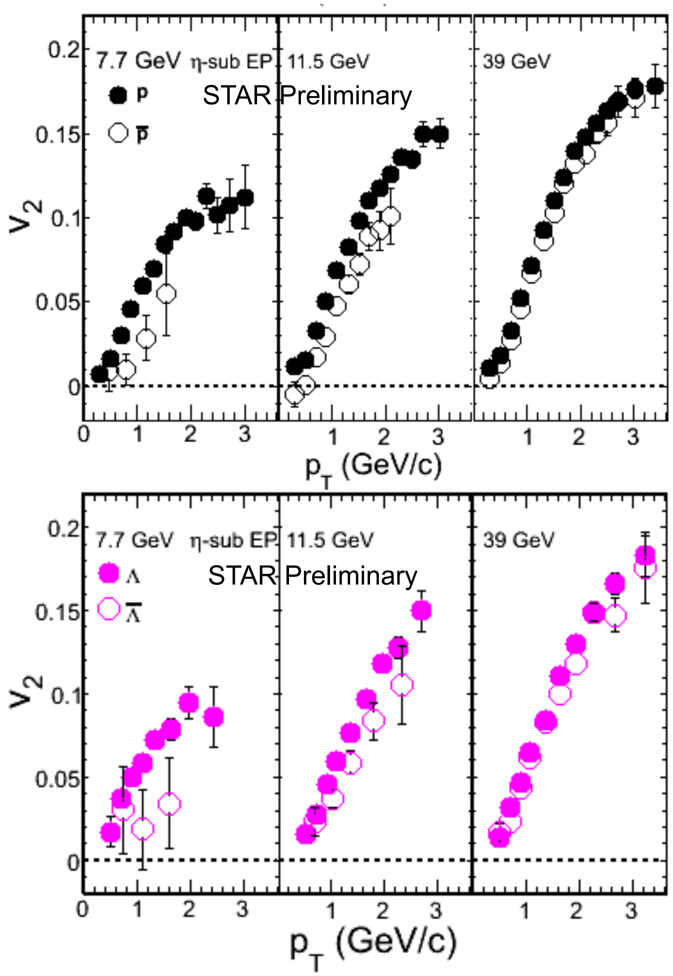


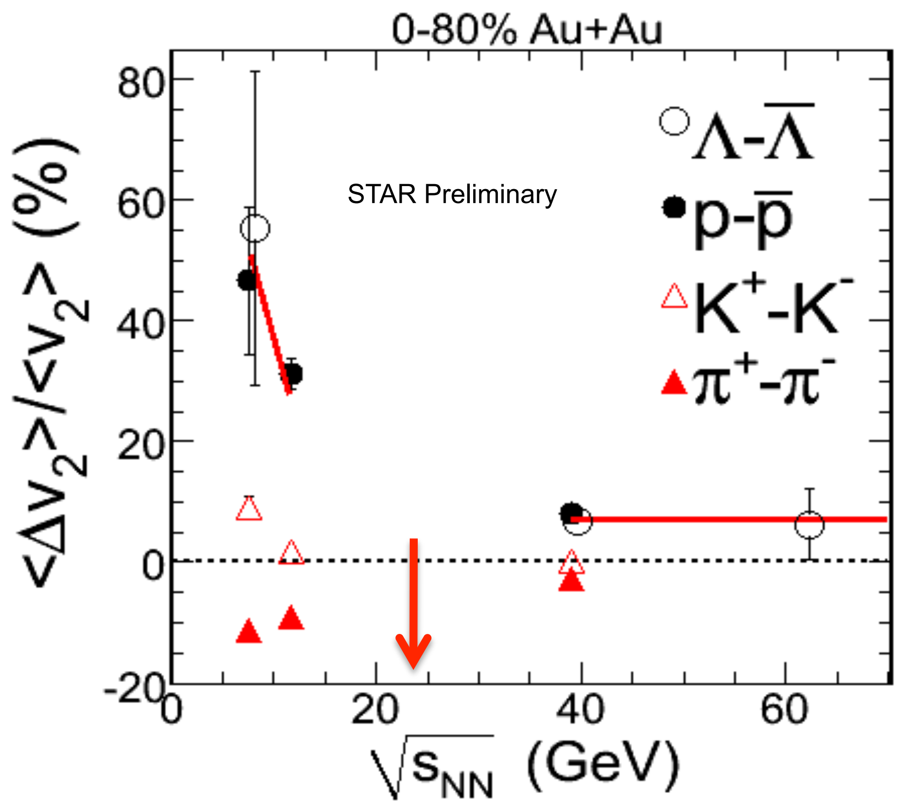
Results:

1) Partonic collectivity at RHIC
2) Number of constituent quark scaling – partonic degrees of freedom at play

➔ **Run 12 request**: UU collisions test the hydro limit, LPV, …

Particle and Anti-Particle v_2 vs. $\sqrt{s_{NN}}$

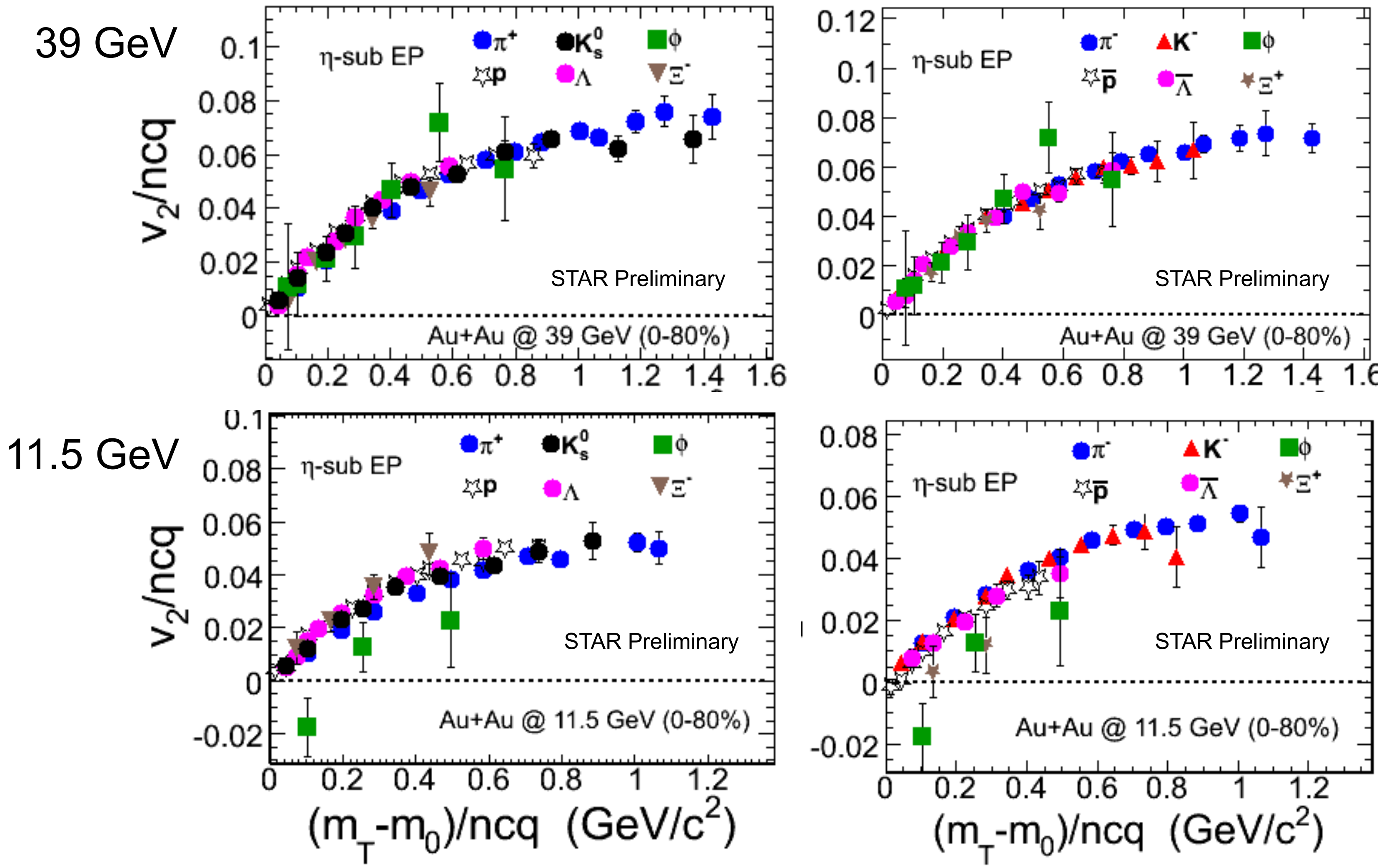




1) v_2(baryon) > v_2 (anti-baryon); $v_2(\pi^+) < v_2(\pi^-)$ at 7.7 GeV

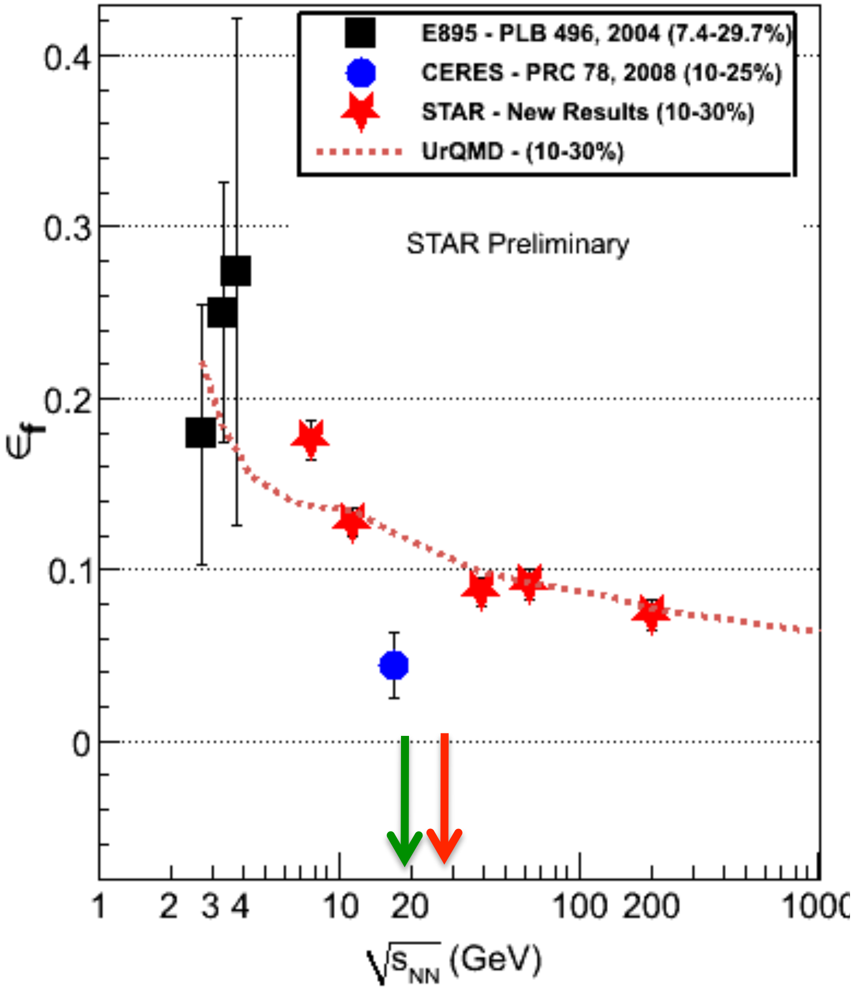
2) Run 12 request: 27 GeV Au+Au collisions

v_2 Scaling vs. Beam Energy



φ meson v_2 falls off the scaling trend from other hadrons at 11.5 GeV

Azimuthally Sensitive HBT vs. $\sqrt{s_{NN}}$



Freeze-out eccentricity w.r.t react plane:
$(R^2_y - R^2_x) / (R^2_y + R^2_x) = 2 R^2_{s,2} / R^2_{s,0}$

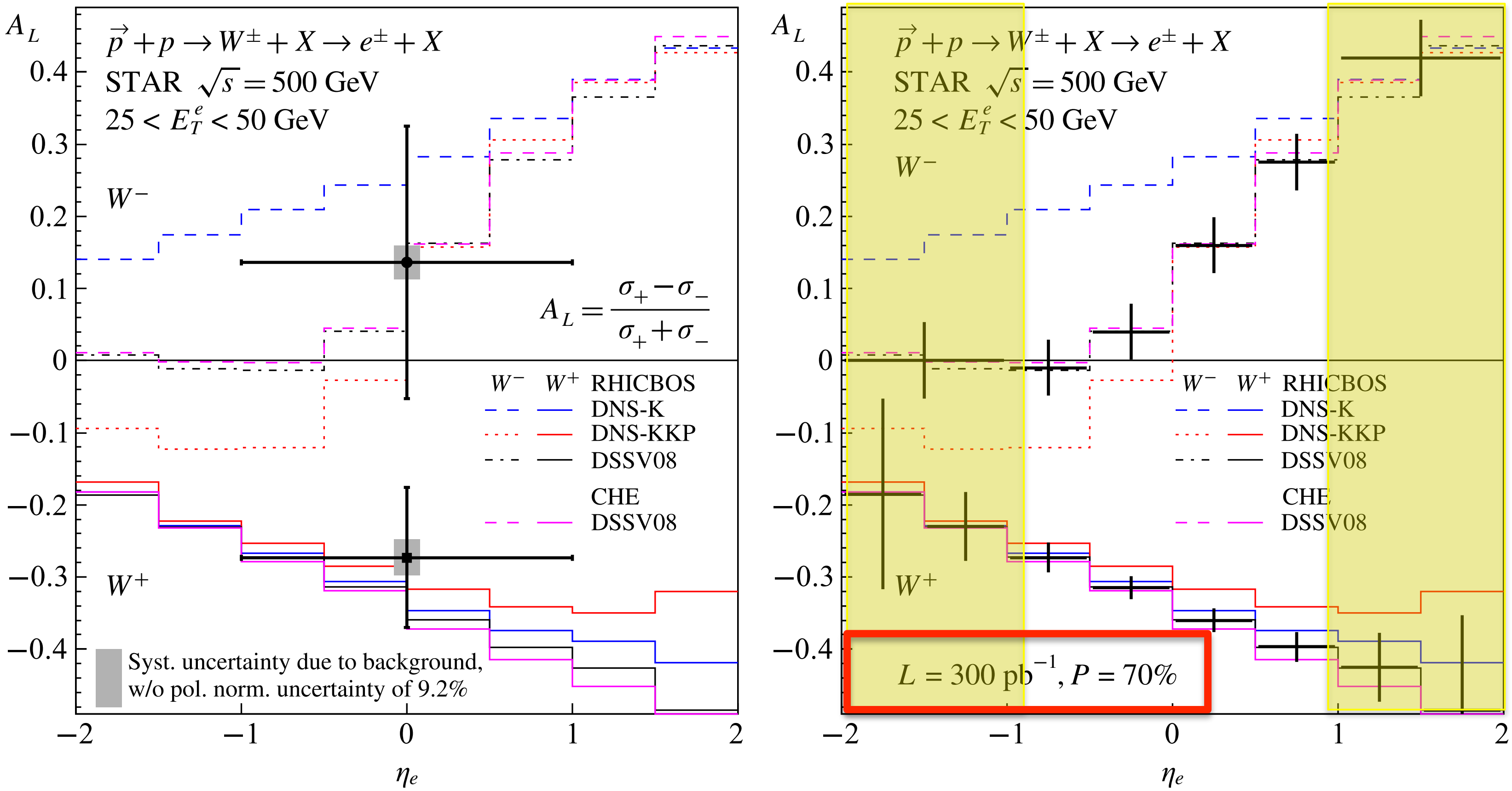
E895: PLB 496 (2000) 1
CERES: PRC 78 (2008) 064901
STAR: PRL 93 (2004) 012301

Expt	$\sqrt{s_{NN}}$ (GeV)	Centrality	η	Event Plane
AGS/ E895	2.35,3.0, 3.6	7.4 - 29.7	+/- 0.6	1st order
SPS/ CERES	17.3	7.5 - 25	-1.0 - 0.5	2nd order
RHIC/ STAR	**7.7, 11.5, 39,** 62.4 200	5 - 30	+/- 0.5	2nd order

1) Non-monotonic variation in freeze-out eccentricity vs. beam energy
2) UrQMD (and hydro) model ***does not*** reproduce the dip by CERES.

Spin Physics Results

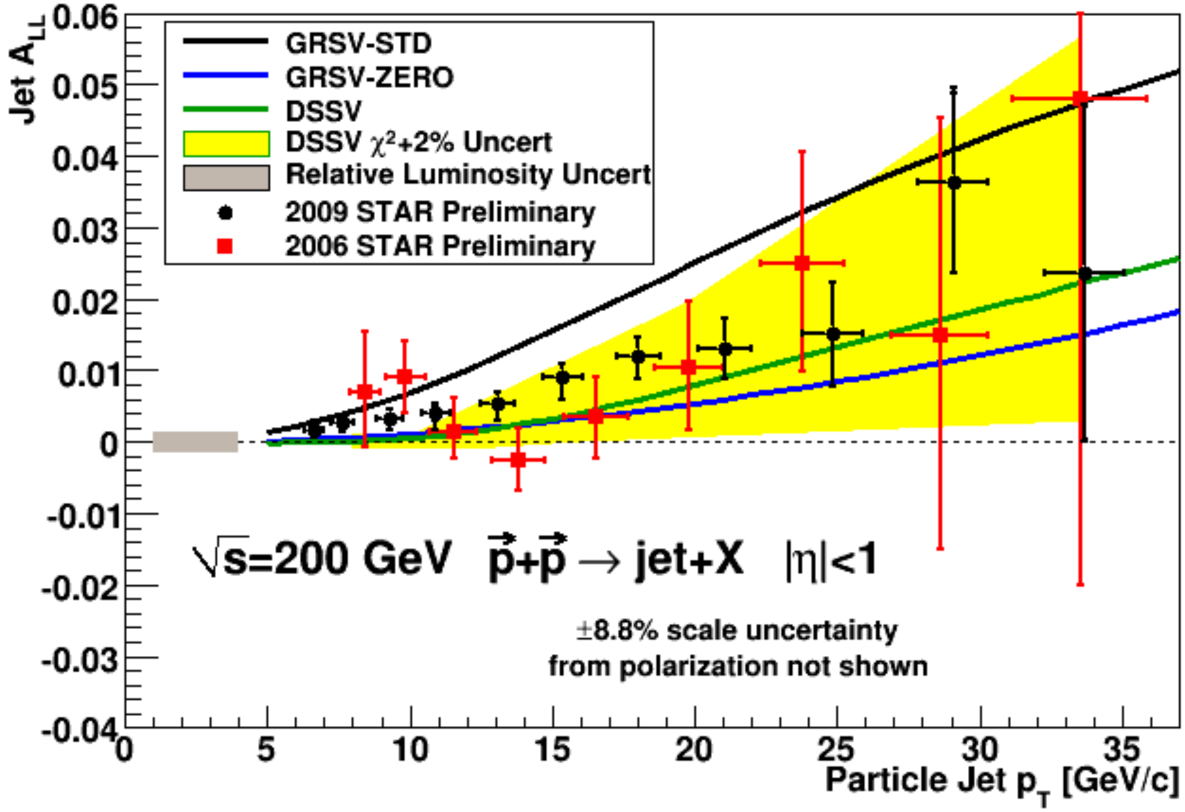
Quark Flavor Measurements: W±



1) STAR first results* consistent with models: Universality of the helicity distribution functions!
2) Precision measurements require **large luminosity** and **high polarization** at RHIC!

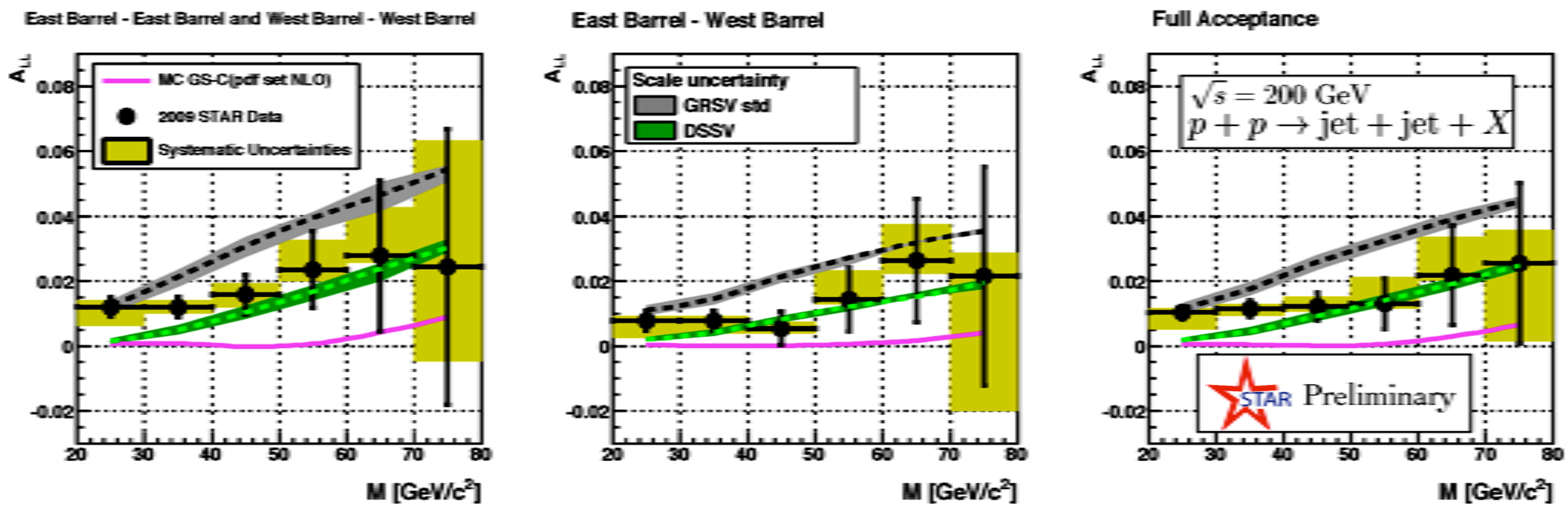
* STAR: PRL 106, 62002(2010).

STAR A_{LL} from 2006 to 2009



- 2009 **STAR** A_{LL} measurements:
- **Results fall between predictions from DSSV and GRSV-STD**
- Precision sufficient to merit finer binning in pseudorapidity

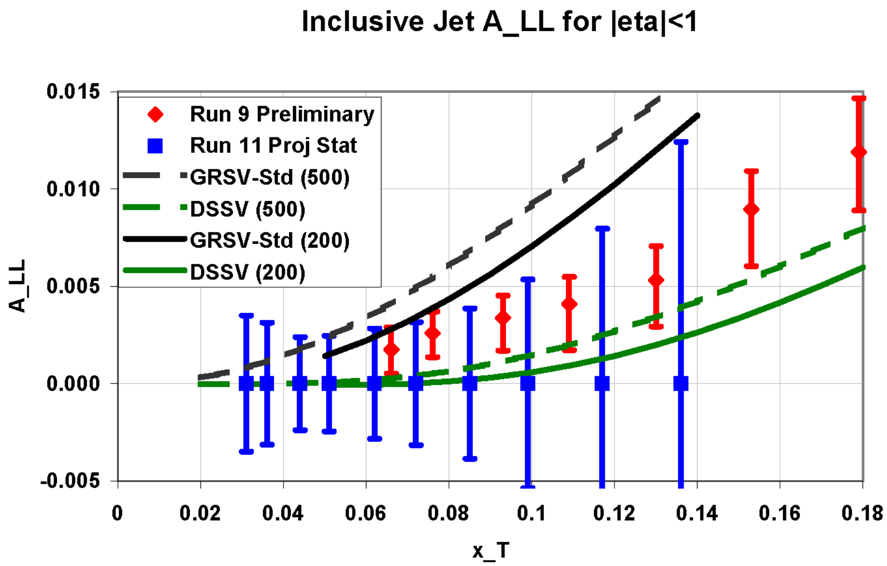
STAR di-jet A_{LL} (2009)



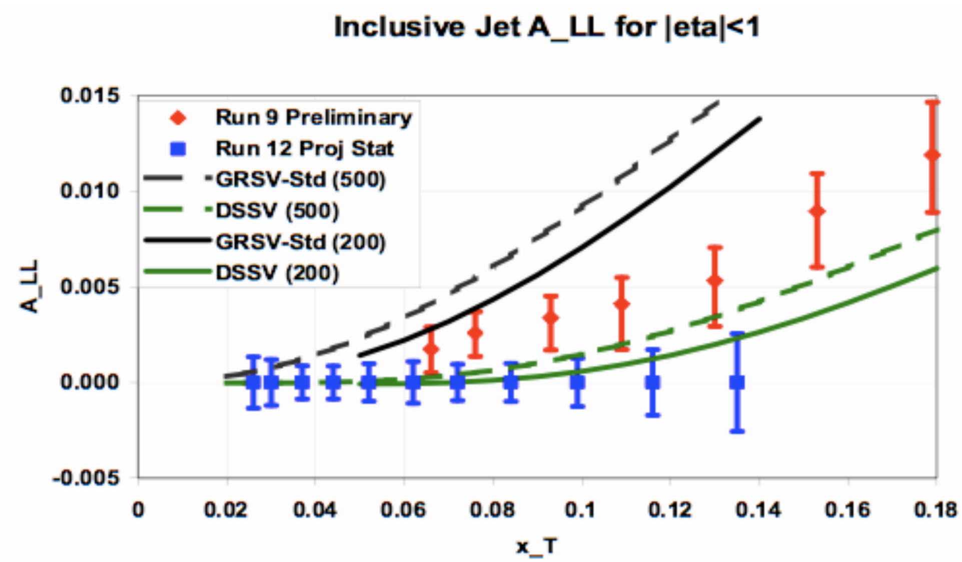
- For fixed M, different kinematic regions sample different *x* ranges
  - East-east and west-west sample higher x_1, lower x_2, and smaller $|\cos(\theta^*)|$
  - East-west samples lower x_1, higher x_2, and larger $|\cos(\theta^*)|$
- **A_{LL} falls between DSSV and GRSV-STD**

Expected inclusive jet A_{LL} precision

Run 11



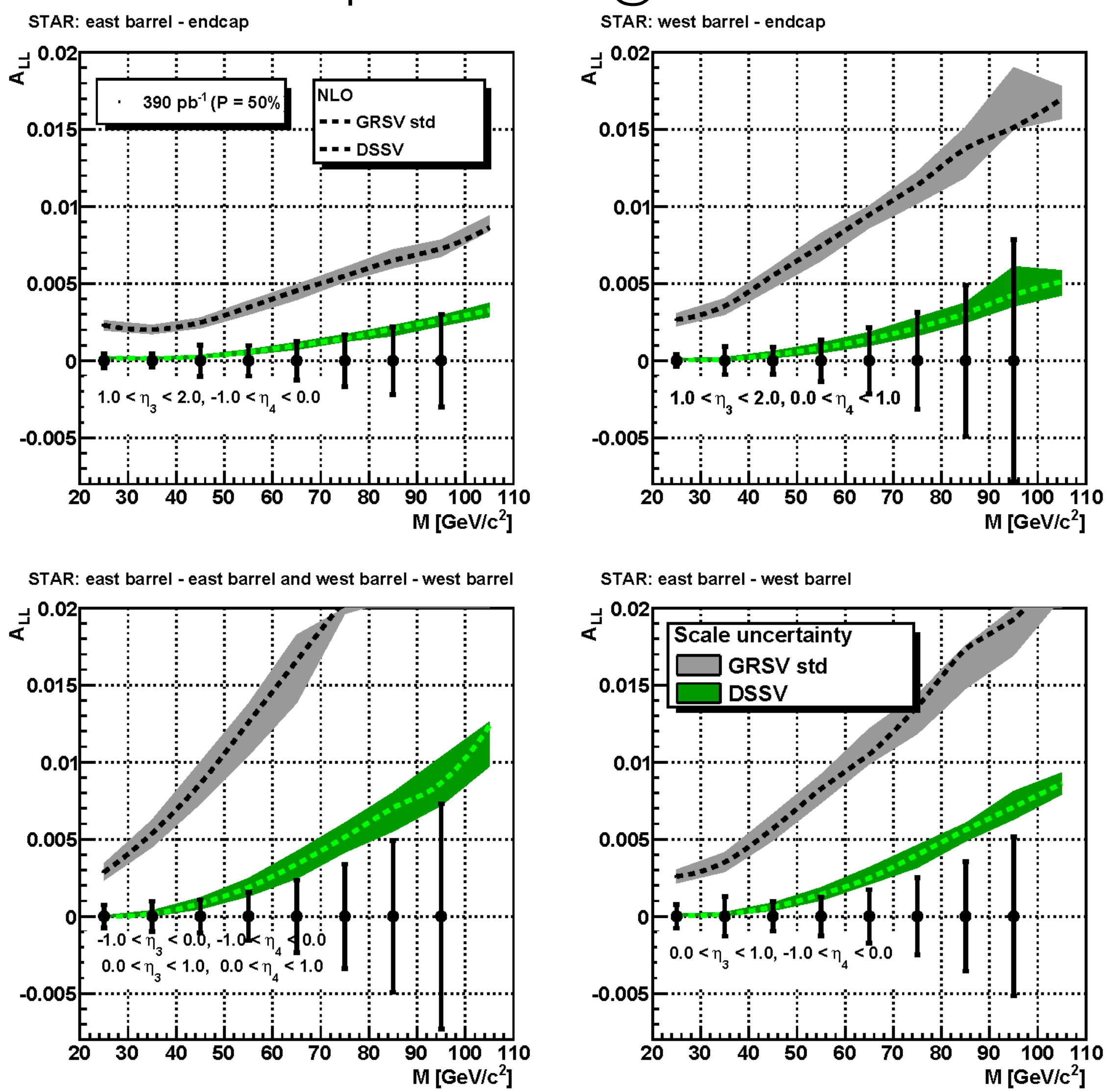
Run 12



- Run 12 will provide a very useful complement to Run 9
- During Run 13, we can 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

Assumes 600 pb^{-1} delivered @ P = 50%



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

- Higher energy accesses lower x_g
- Expect smaller A_{LL}

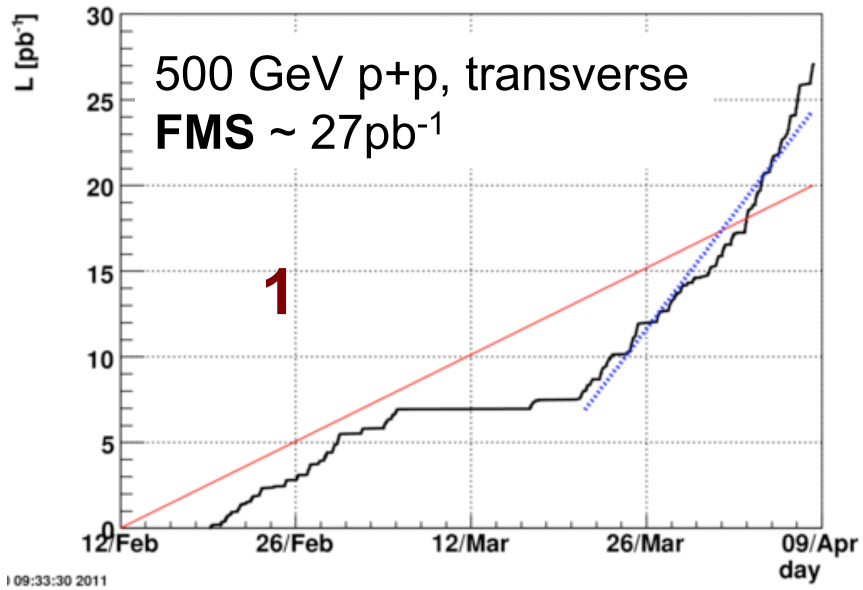
- Projections include information on trigger rates, etc., from 2009
- Uncertainties shown are purely statistical

- Maybe add EEMC-EEMC di-jets to reach lowest *x* values once FGT is installed (?)

Run 11 Status

U+U Collisions

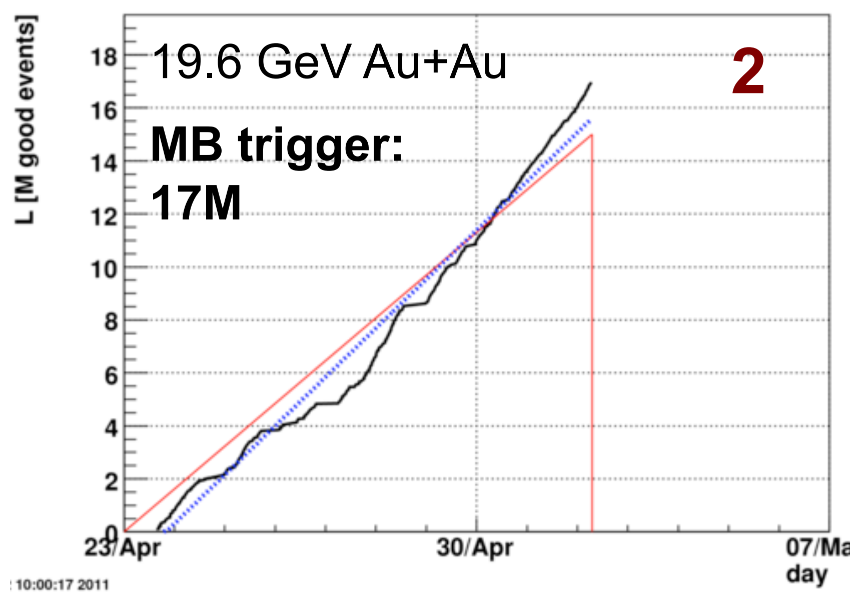
Run11: Integrated Luminosities

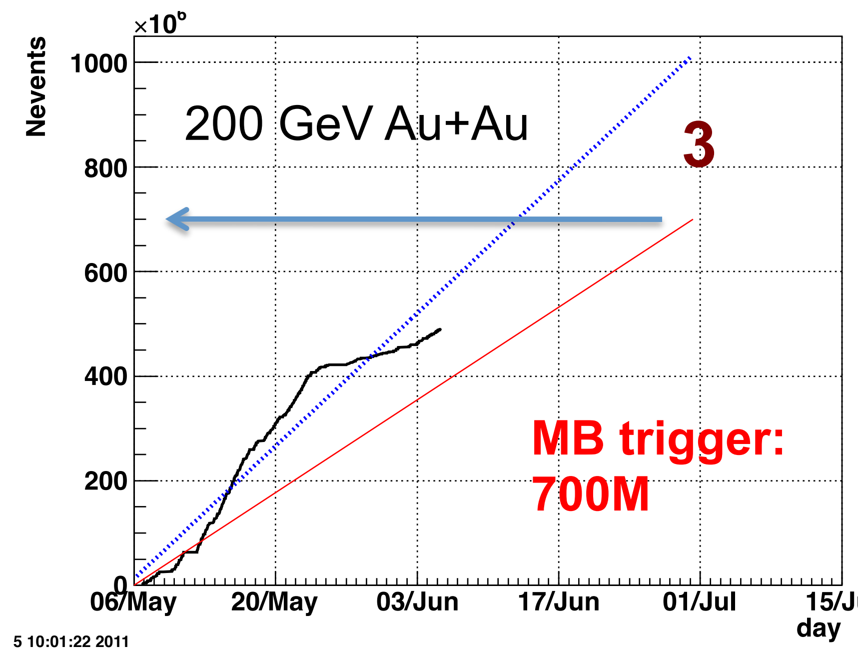


1) 500 GeV transverse p+p collisions
   - FMS, small-x

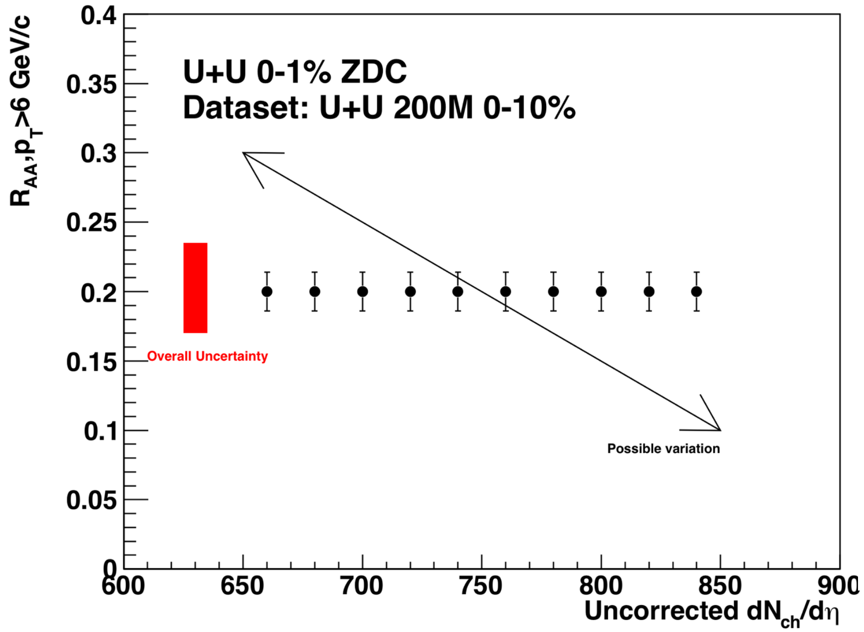
2) 19.6 GeV Au+Au collisions
   - critical point search

3) 200 GeV Au+Au collisions
   - di-electron and Upsilon

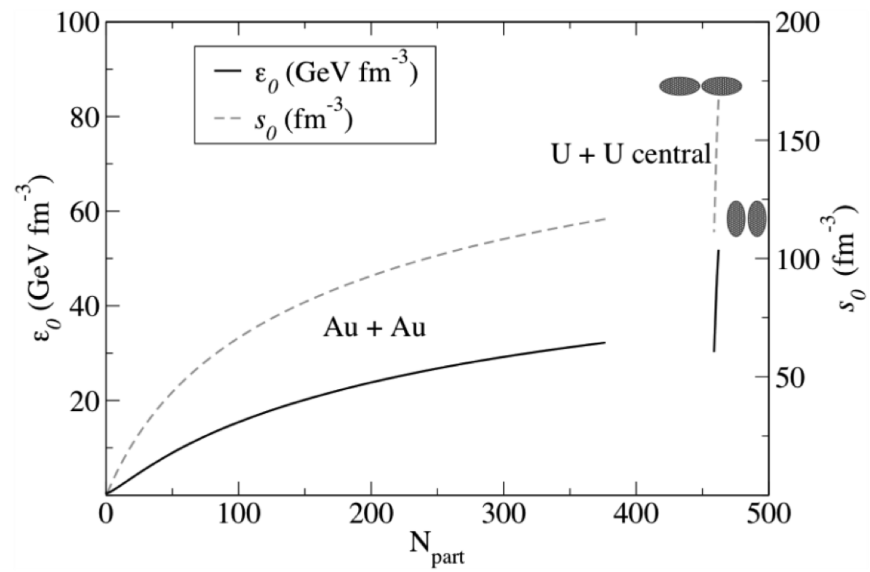




Run 12 Request U+U Collisions

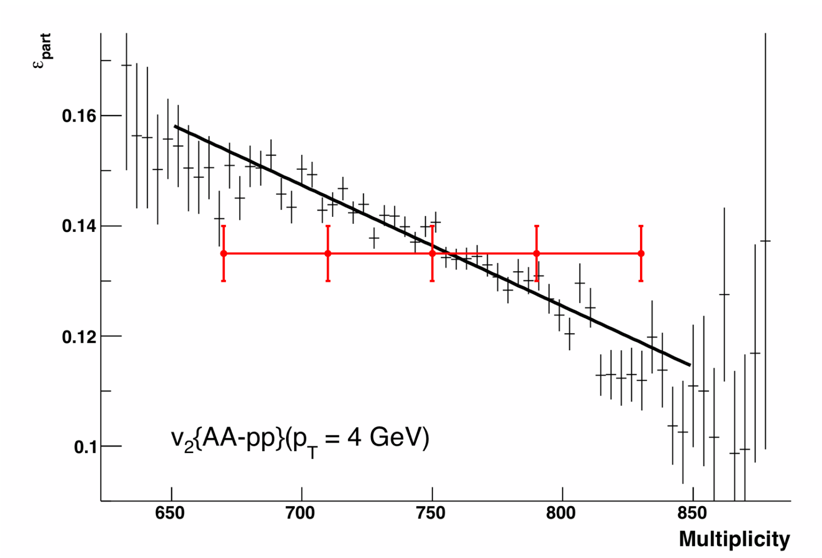


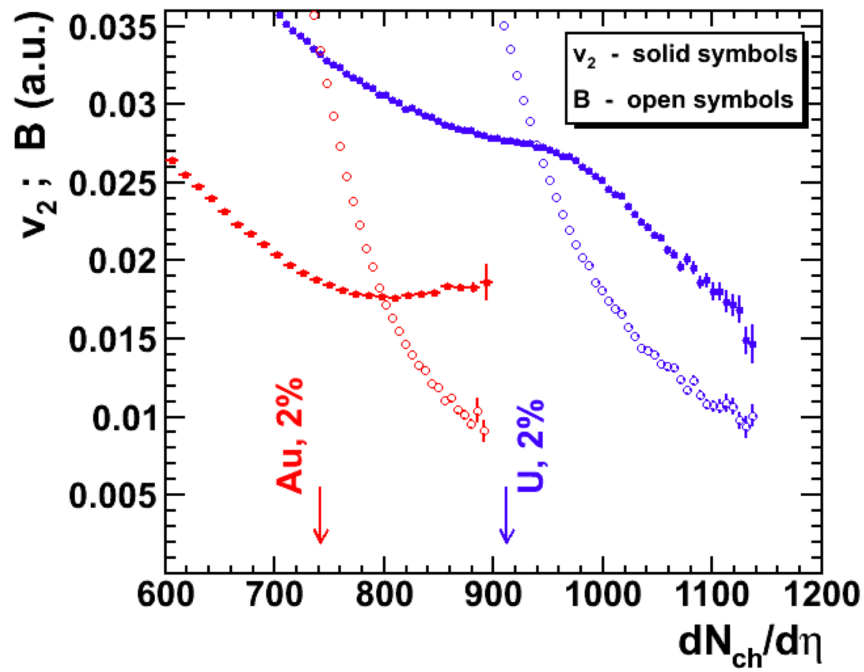
U. Heinz et al, PRL **94**, 132301(05)



1) Significant increase in energy density for hydrodynamic studies
2) Prolate shape: path-length dependence of E_{loss} at much higher density

Run 12 request: 200M MB and 200M central U+U collisions.





<u>Left plot</u>: **Black**: <ε_{part}> as a function of measured mid-rapidity multiplicity in the most 1% central U+U collisions, as selected by the number of participants. **Red**: estimated uncertainties on v_2\{AA-pp\} for p_T=4 GeV/c for such events, as selected with the ZDCs.

<u>Right plot*</u>: v_2 and external B-field vs. mid-y multiplicity. Greater sensitivity seen in U+U central collisions for $dN_{ch}/d\eta$ > 1000.

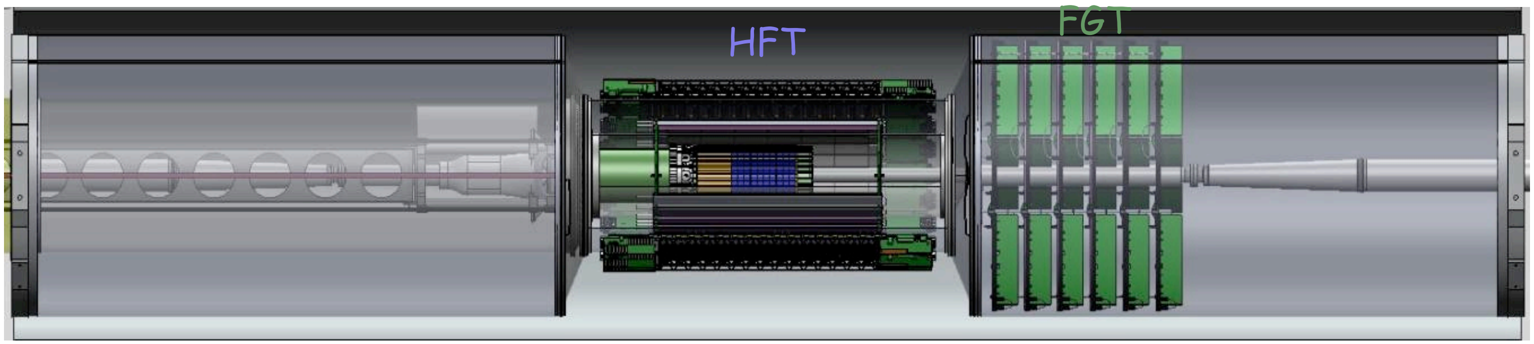
* S. Voloshin, PRL105, 172301(2010).

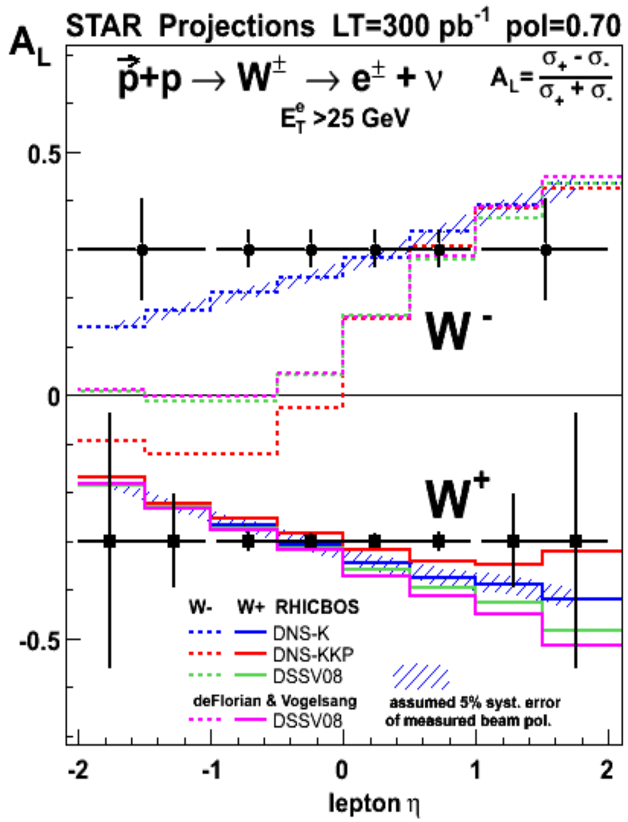
FGT Status

STAR Future Upgrades

eSTAR Task Force

Forward GEM Tracker





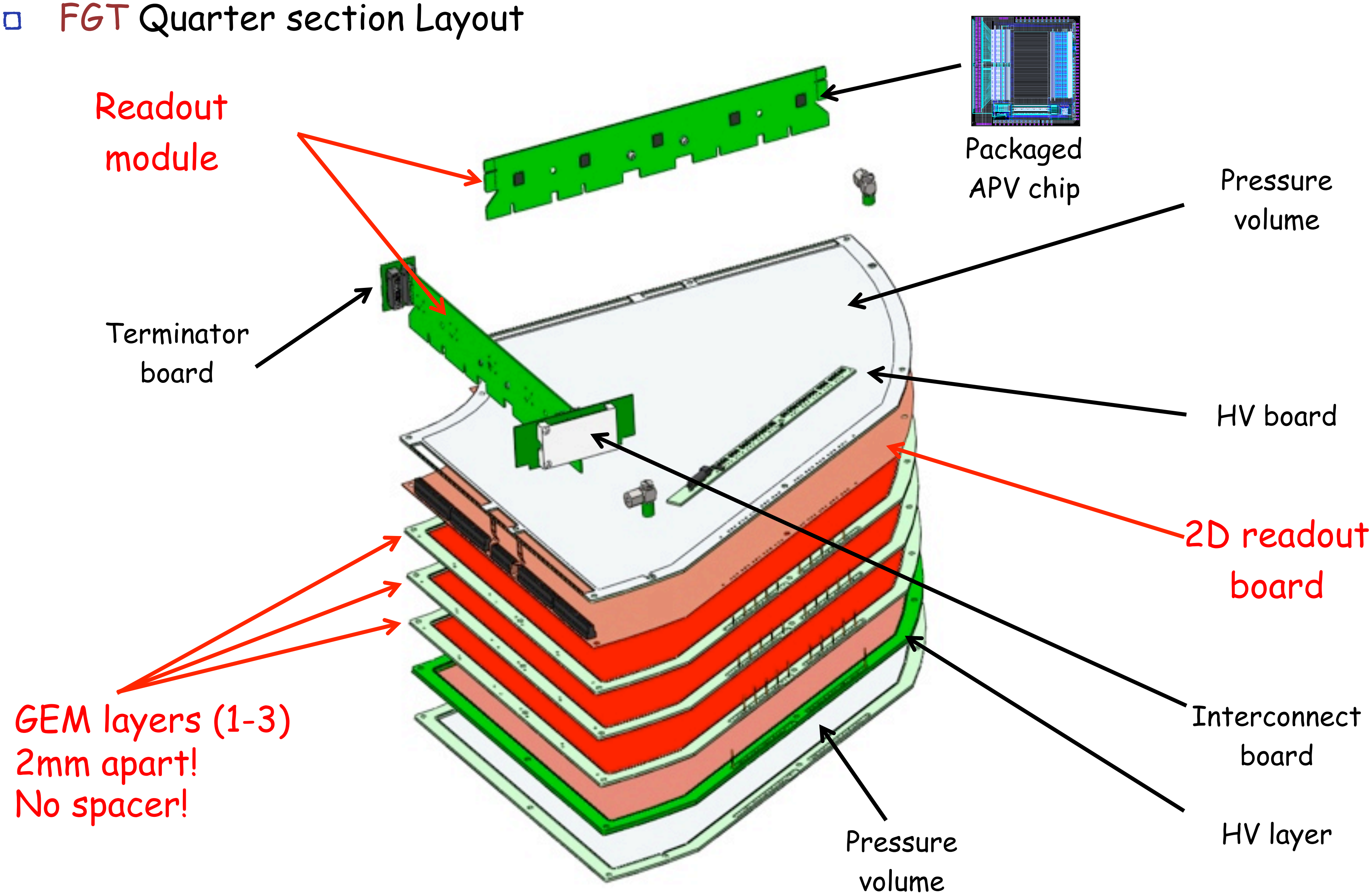
1) FGT: RHIC CP project
2) Six light-weight triple-GEM disks
3) New mechanical support structure
4) Planned installation: Summer 2011

1) Full charge-sign discrimination at high-p_T
2) Design polarization performance of **70% or better** to collect at least 300pb^{-1}
3) **Ready* for Run 12!**

*** minimal configuration**

FGT Quadrant

- FGT Quarter section Layout

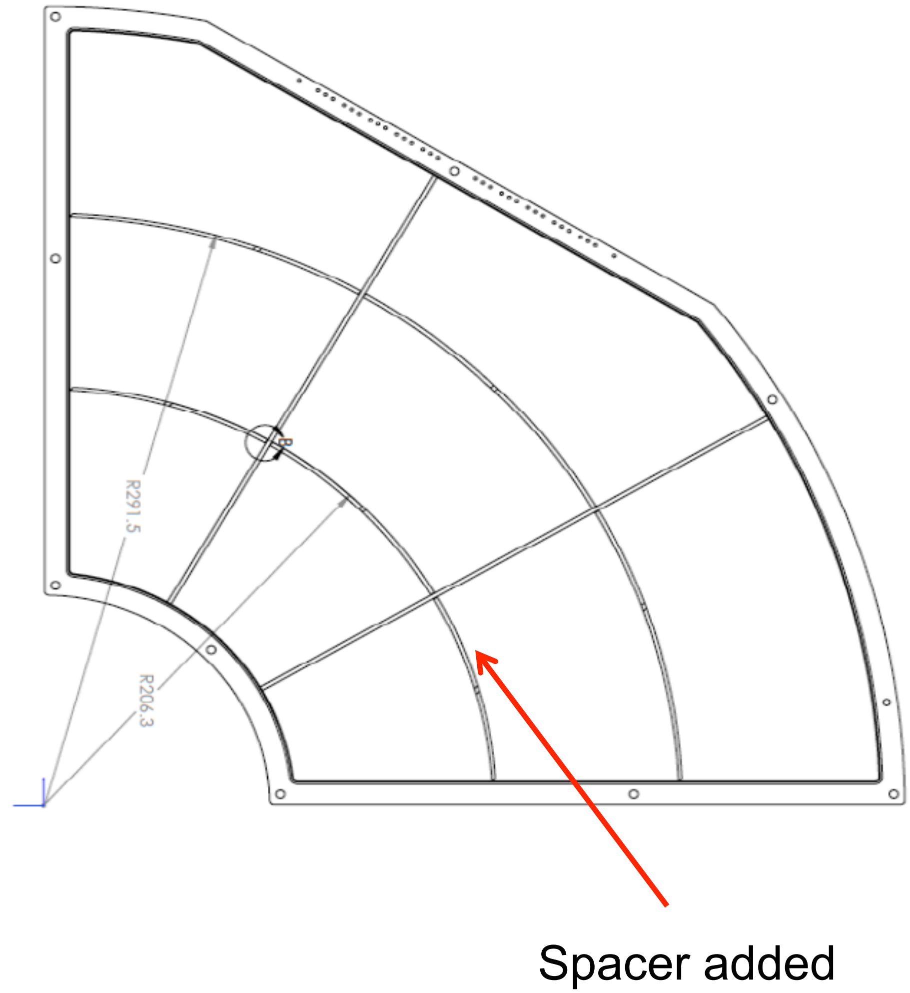


FGT Quadrant Problems and Solutions

- Quarter section fully assembled and operational (Cosmic-ray signal / 55Fe signal) without spacer grid:

P1: GEM foils cannot be stretched sufficiently to guarantee that GEM foils separated by 2mm. Original design to avoid efficiency loss.
➡ Solution: Need for a spacer grid. Order has been placed and expect full quarter section assembly including spacer grid by mid of June.

P2: GEM foil frames are part of HV distribution. The distance between HV lines and metallic pins are ~1mm / Difficulty in holding full HV (~4kV).
➡ Solution: Need for non-metallic pins providing sufficient strength / Likely G10 in addition to stretching bars



FGT Schedule

I. Minimal configuration

1) Full FGT: 24 quarter sections / 6 disks (4 quarter sections per disk)
2) Minimal configuration: 4 disks with 3 quarter sections each, i.e. 50% of full FGT system (24 quarter sections)
3) 4 disks, i.e. 4 space points are required for proper charge-sign discrimination

II. Schedule (draft)

1) July-September 2011: Quarter section assembly and testing
2) September 2011: Disk assembly and WSC integration
3) October 2011: Integration of ESC / WSC / Beam pipe
4) November 2011: Installation in STAR

Request RHIC cool down: January 1, 2012

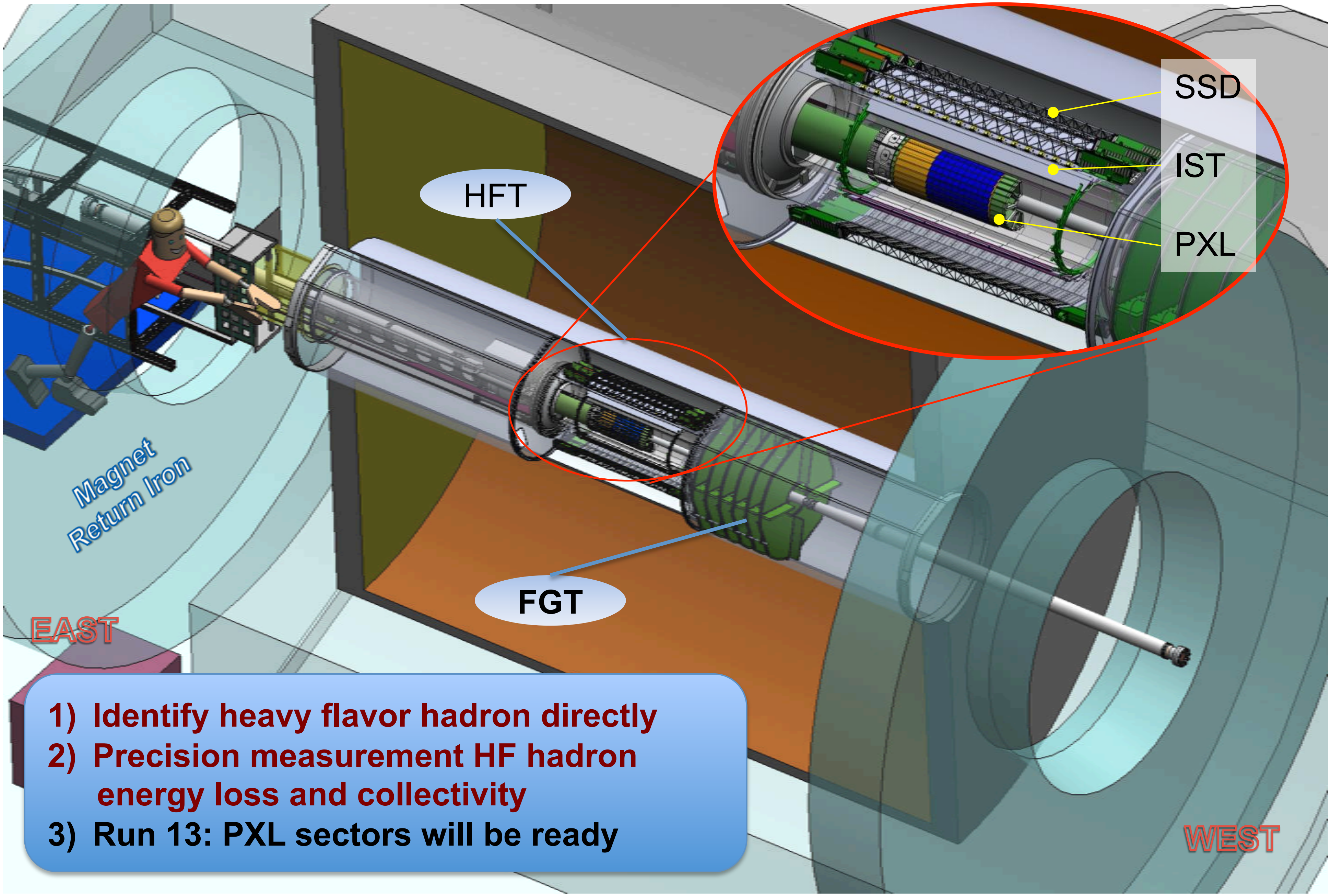
in order to install as many FGT disks as possible

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	Fast PID in full azimuthal acceptance
FGT	Summer 2011 Ready* for Run 12	Forward-y $W^{\pm}$ for flavor separated quark polarization
HFT	Summer 2013 Ready for 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	

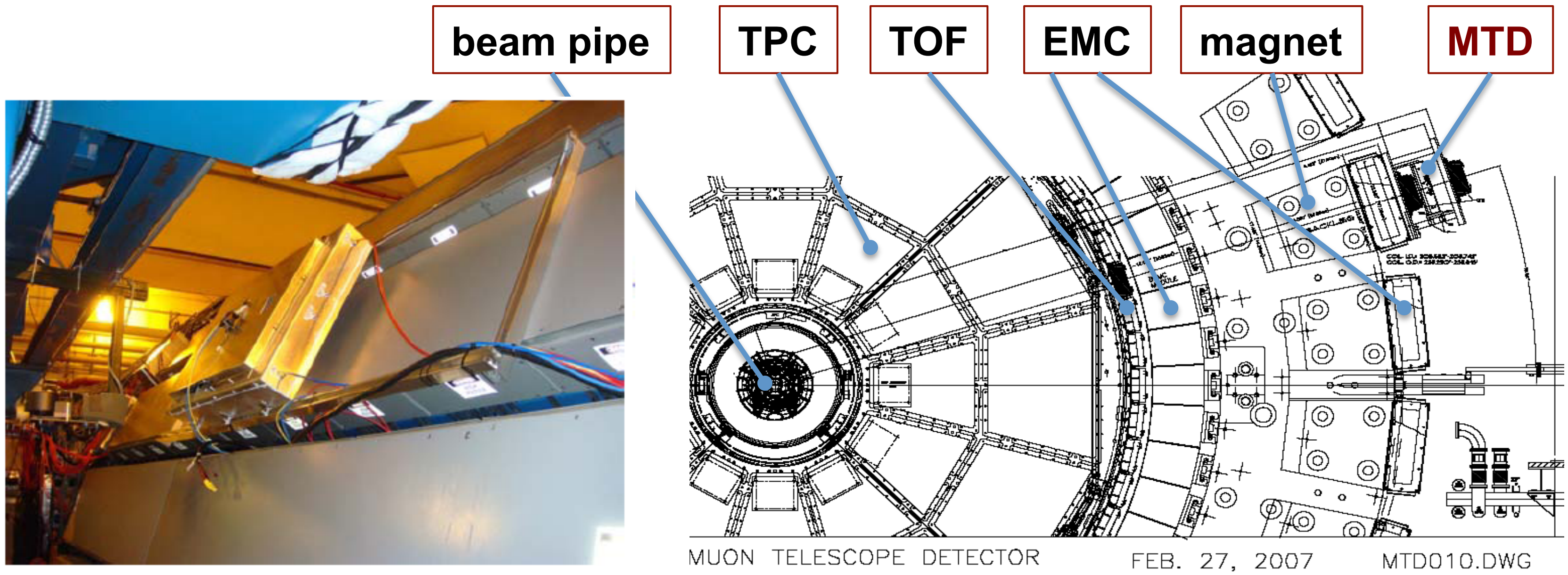
* Minimal configuration

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

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**: 50% MTD will be ready

eSTAR Task Force

<u>Membership:</u> Subhasis Chattopadhyay, Hank Crawford, Renee Fatemi, Carl Gargliardi*, Jeong-Hun Lee, Bill Llope, ***Ernst Sichtermann***, Huan Huang, Thomas Ullrich, Flemming Videbaek, Anselm Vossen, Wei Xie, Qinghua Xu, ***Zhangbu Xu***

Ex-officio: B. Christie, J. Dunlop, O. Evdokimov, B. Mohanty, B. Surrow, N. Xu

<u>Charges:</u> In order to prepare the experiment to complement the ongoing physics programs related to *AA, pA and pp collisions with a strong ep and eA program by an* additional electron beam and prepare the collaboration to participate in the US Nuclear Physics Long Range Planning exercises during 2012-2013, we establish the eSTAR Task Force. This task force will be in function during the next three years. The main charges for the task force are:

(1) Identify important physics measurements and assess their science impact during the eSTAR era (2017-2020). Prepare a white paper or an updated decadal plan including physics sensitivities and detailed R&D projects.
(2) With (1) in mind as well as the eRHIC interaction region design(s) and other constraints, identify and advise STAR Management on priorities for detector R&D projects within the collaboration.
(3) Engage the collaboration by organizing special *ep/eA* workshops, document the progress and report annually to the collaboration.
(4) Work with the STAR management and the EIC task force (setup by the BNL management) to strengthen the physics case(s) for eSTAR and a future EIC

Summary

STAR has been very effective and productive:

1) **TOF, HLT, DAQ1k upgrades successfully completed**

2) **200 GeV Au+Au collisions**
   - Large acceptance di-electron program started
   - Upsilon suppression vs. centrality and high statistics J/ψ v_2
   - Full jets reconstruction program presses on
   - … anti-^{4}He, …

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

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

5) **High statistics, high quality data have been collected**
   - pp 500 GeV FMS and low material Au+Au 200 GeV

For Runs 12 & 13: We Request

1) Spin Physics (polarized p+p collisions)

- $W^{\pm}$ A_L at both mid-y and forward-y (2012/2013)
- DPE and hadronic spin-flip amplitude (2012)
- Δg measurements at 500 GeV (2012) and 200 GeV* (2013)

  * Reference data for heavy ion programs

2) Heavy Ion Physics (A+A collisions)

- Complete the Phase-I RHIC BES at 27 GeV (2012)
- U+U collisions: hydro limit, LPV, path length dep. (2012)
- Engineering run for HFT & MTD in Au+Au(Pb+Pb) (2013)

3) Start of Run12: January 1, 2012

STAR BUR for Runs 12 and 13

Run	Beam Energy	Time	System	Goal
12	$\sqrt{s_{NN}}$ = 27 GeV	1 week	Au + Au	150M minbias
	$\sqrt{s}$ = 500 GeV	3 weeks	p + p	FGT commissioning
		9 weeks	$p_{\rightarrow}\, p_{\rightarrow}$	P^2*L= 42 pb^{-1} P^4*L= 12 pb^{-1}
		1 week	$p_{\uparrow}\, p_{\uparrow}$	pp2pp at high β^* = 7.5m
	$\sqrt{s_{NN}}$ = 193 GeV	6 weeks	U + U	200 M minbias 200 M central
13	$\sqrt{s}$ = 500 GeV	8 weeks	$p_{\rightarrow}\, p_{\rightarrow}$	long. P^2*L= 50 pb^{-1}
	$\sqrt{s}$ = 200 GeV	10 weeks	$p_{\uparrow}\, p_{\uparrow}$ $p_{\rightarrow}\, p_{\rightarrow}$	trans. P^2*L= 7.2 pb^{-1} long. P^4*L= 7.1 pb^{-1} L = 60 pb^{-1}
	$\sqrt{s_{NN}}$ = 200 GeV	6 weeks	Au + Au (Pb + Pb)	HFT & MTD engineering

Run 12: 26 cryo-week. 500pp: 50% polarization

Run 13: 30 cryo-week. 500pp: 50% polarization // 200pp: 60-65% polarization