

New Observables in Quarkonium Production (Quarkonium2016)

Feb. 2 – Mar. 4, 2016, ECT*, Trento, Italy

Prospects for Quarkonium Studies at RHIC

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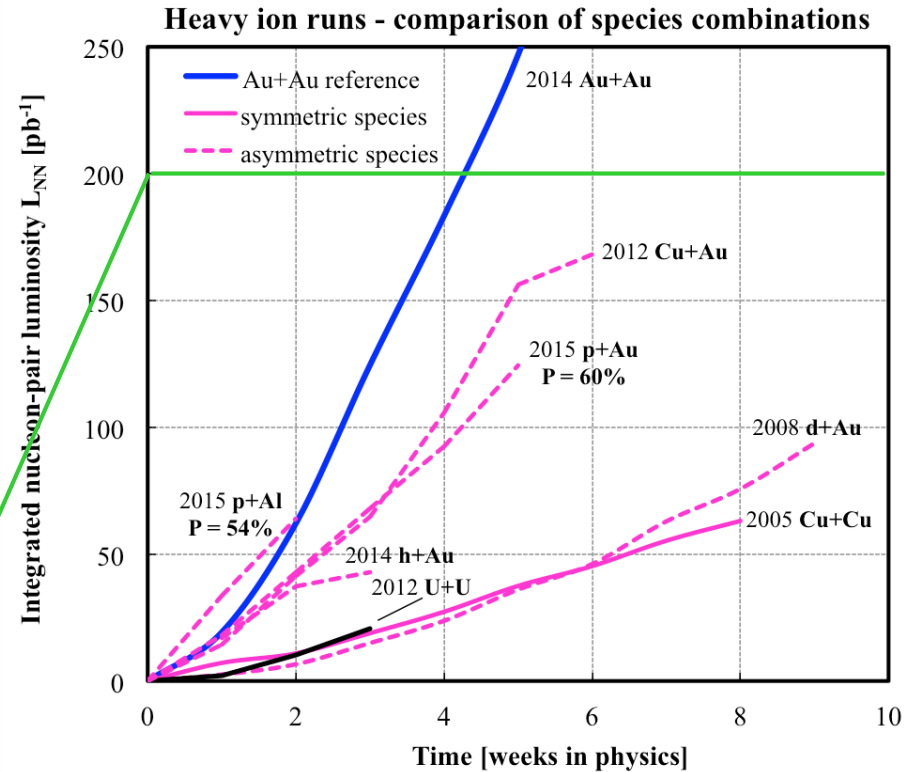
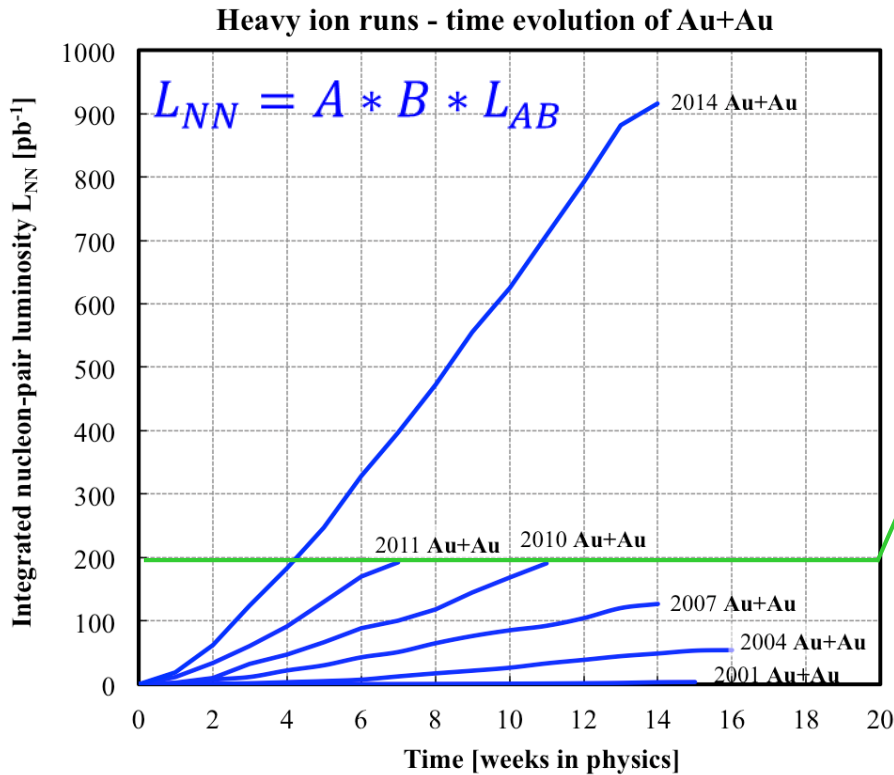
Recent RHIC runs

Year	Species	Energy (GeV)	Delivered Luminosity*	Unit
2010	Au+Au	200, 62, 39, 11, 7	10, 0.5, 0.2, 0.04, 0.08	nb ⁻¹
2011	p+p	500	160	pb ⁻¹
	Au+Au	200, 27, 20	10, 0.06, 0.03	nb ⁻¹
2012	p+p	200, 500	74, 283	pb ⁻¹
	U+U	193	0.7	nb ⁻¹
	Cu+Au	200	27	nb ⁻¹
2013	p+p	500	1000	pb ⁻¹
2014	Au+Au	200, 15	44, 0.04	nb ⁻¹
	³ He+Au	200	0.1	pb ⁻¹
2015	p+Au	200	1	pb ⁻¹
	p+Al	200	4	pb ⁻¹
	p+p	200	382	pb ⁻¹

*Shared by STAR and PHENIX

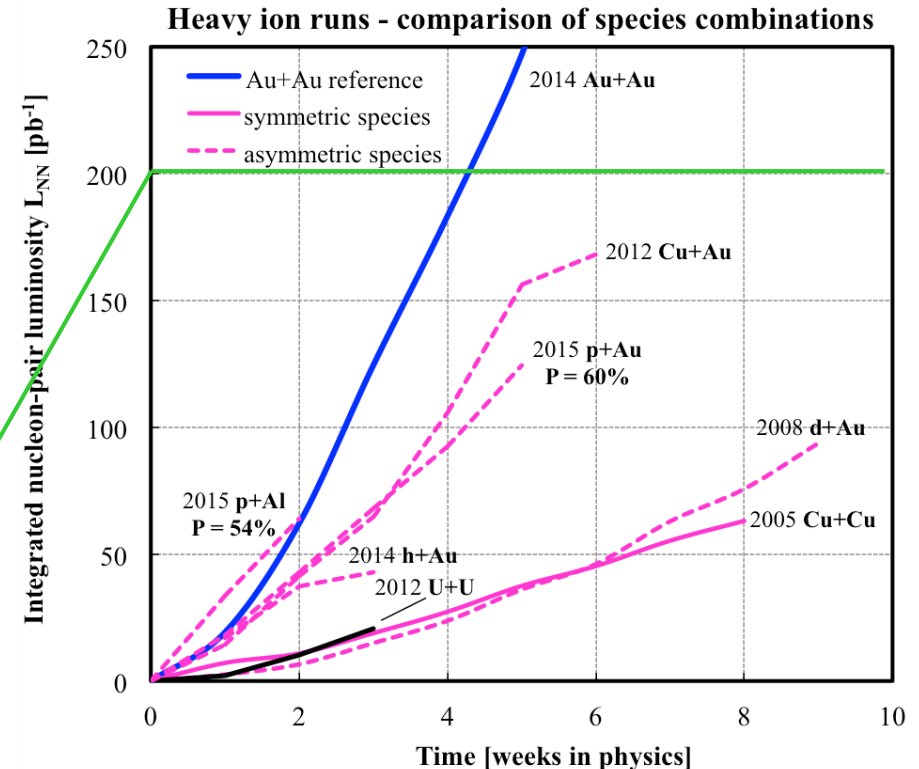
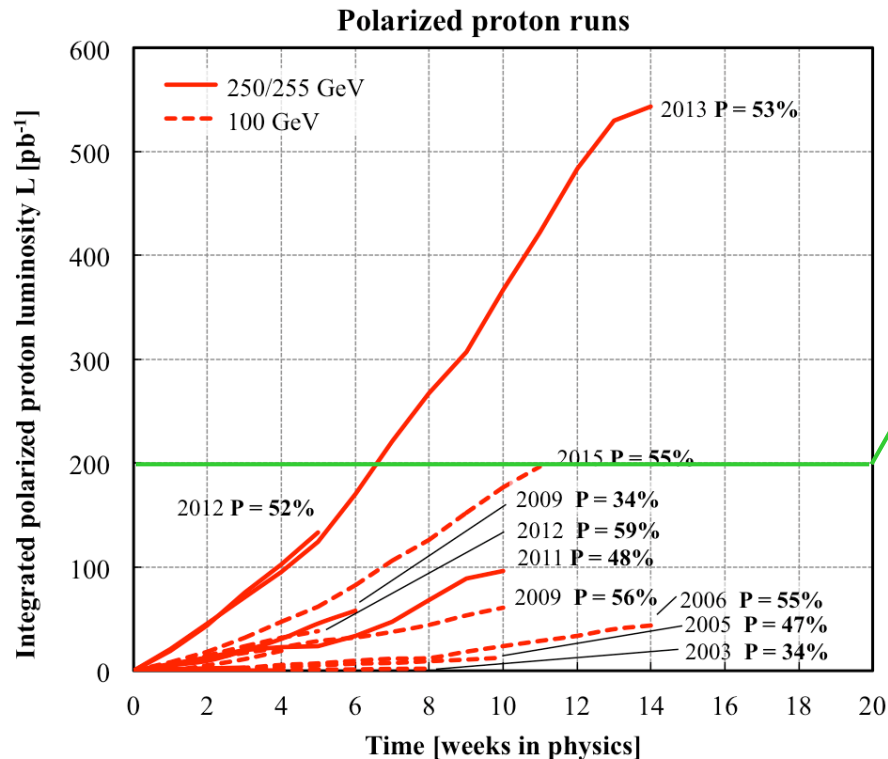
<http://www.rhichome.bnl.gov/RHIC/Runs/>

Integrated luminosity in heavy-ion runs



- Slope improves significantly year to year.
- The largest heavy-ion datasets are 2010-2011 and 2014 Au+Au.
- The statistics of 2012 Cu+Au and 2015 p+Au
 ~ 2007 Au+Au, but with much higher S/B ratio.

Integrated luminosity with polarized proton



- High statistics reference data taken in 2015 (**5x** 2009)
- p+Au ~ 2015 p+p > p+Al ~ 2008 d+Au ~ 2009 p+p
- 500 GeV p+p (2013) statistics improved by **5x** compared to 2011

RHIC run plan

Year	Species	Energy	Status	STAR
2016	Au+Au	200	Running 10 weeks	STAR and PHENIX
	d+Au	200, 62, 39, 20	CAD preparing 5 weeks	
2017	p+p	510	Likely	STAR only
	p+p	Match d+Au BES		
	${}_{44}^{96}\text{Ru}+{}_{44}^{96}\text{Ru}$	200		
	${}_{40}^{96}\text{Zr}+{}_{40}^{96}\text{Zr}$	200		
2018	No runs			
2019-20	Au+Au	5-20 (BES-II)		
2021-22	Long Au+Au run with STAR forward upgrades and sPHENIX?			
2023-	No Runs! Transition to eRHIC? http://www.rhichome.bnl.gov/RHIC/Runs/			

Data availability

PHENIX reported physics results from almost all dataset taken before 2016

STAR dataset awaiting for full production/reconstruction:

- 2012 Cu+Au
- 2014 Au+Au
- 2014 $^3\text{He}+\text{Au}$
- 2015 p+Au
- 2015 p+Al
- 2013 p+p (500 GeV)
- 2015 p+p

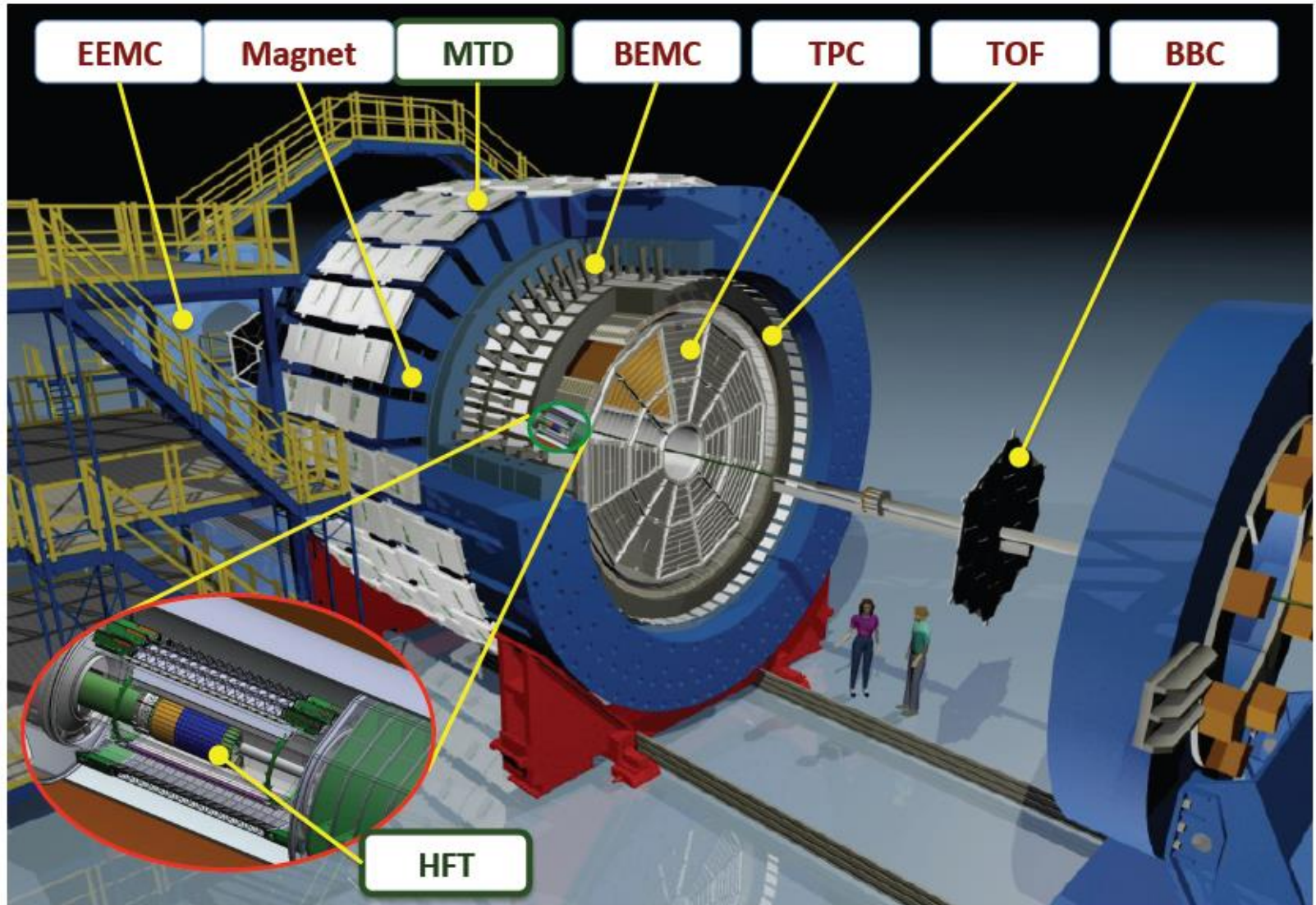
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	<u>p+p</u>	200	382	pb ⁻¹

2014 data 100% by spring of 2016

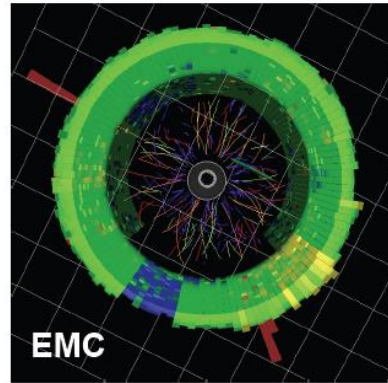
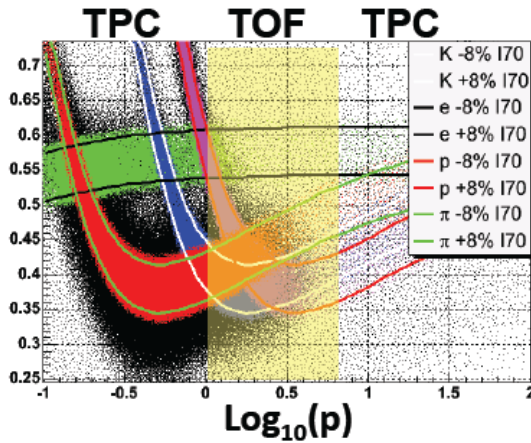
2015 data 50% by end of 2016

Frank Geurts, BNL PAC meeting

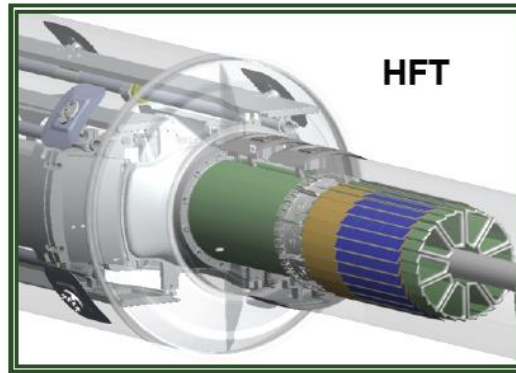
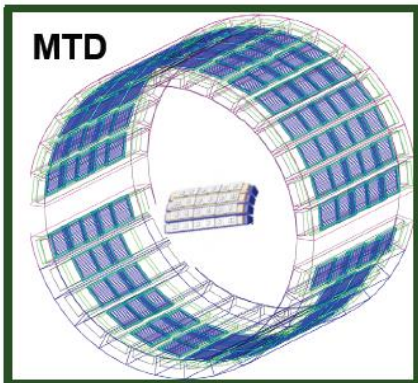
STAR Detector System



STAR Detector System



Period	Detectors at mid-y
2001-2005	TPC
2005-2009	TPC+EMC
2009	DAQ1k (TPC→TPX)
2010	TPX+EMC+TOF
2013	TPX+EMC+TOF+MTD
2014-2016	TPX+EMC+TOF+MTD+HFT
2016-	... + Forward Upgrades

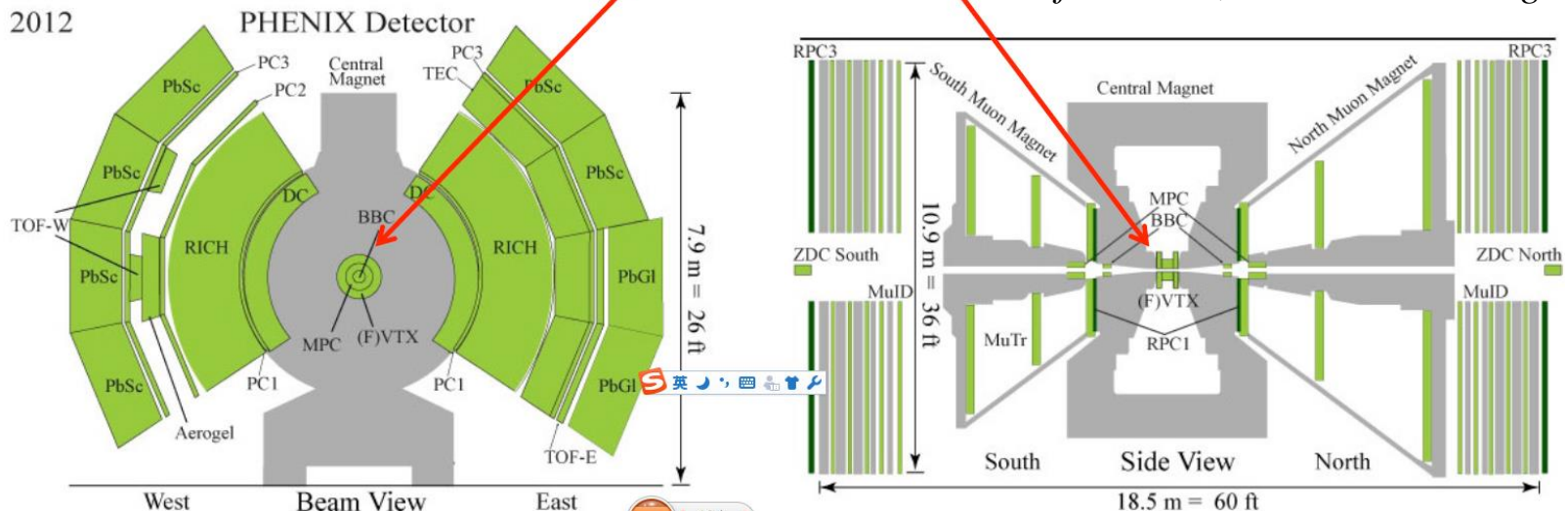


STAR:

- Large acceptance, excellent PID
- Perfect **mid-rapidity** experiment
- Expanding into forward rapidity region

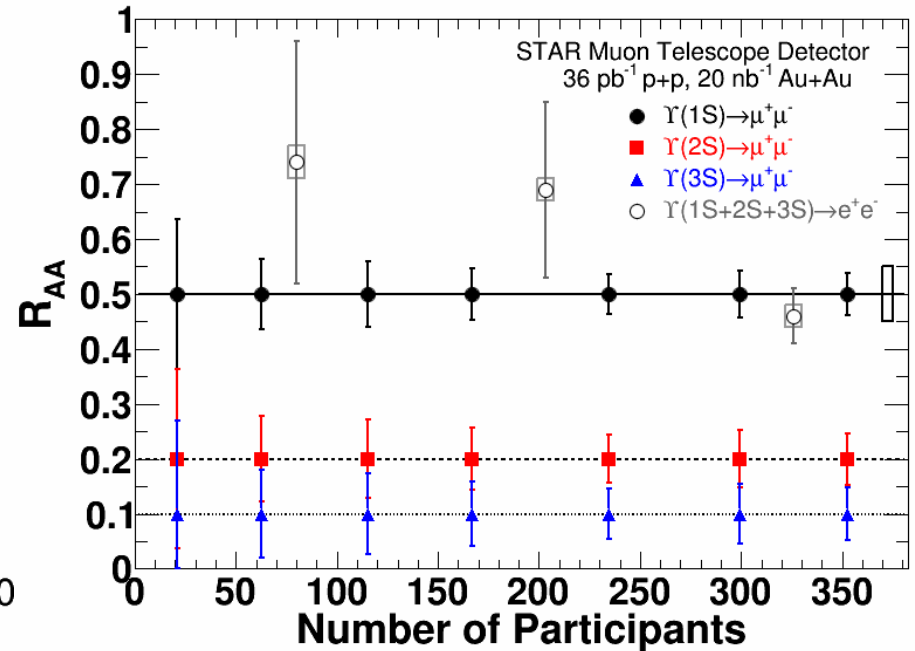
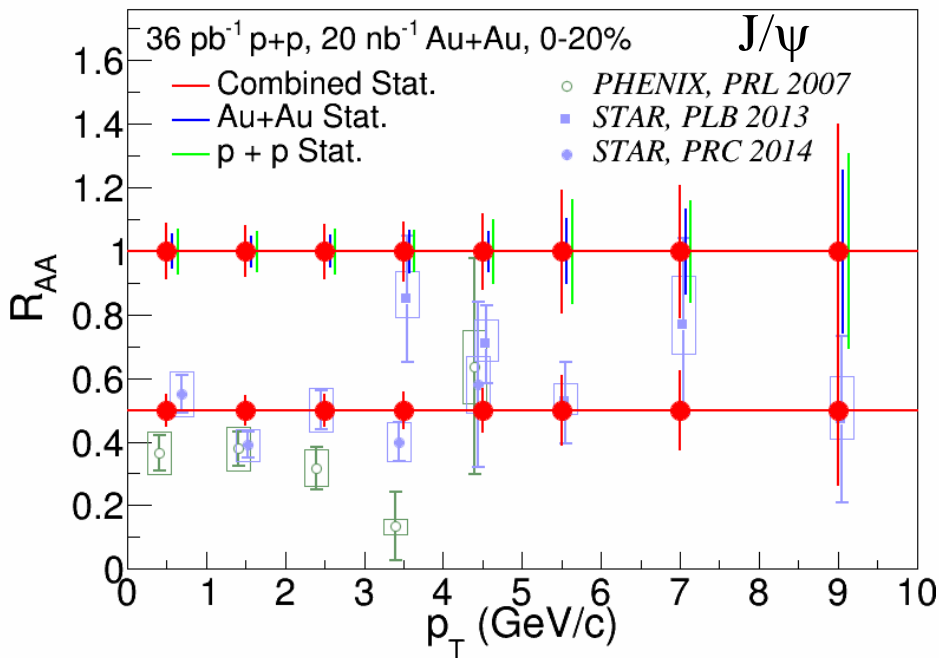
PHENIX Detector System

- 2009--2010: Hadron Blind Detector (HBD)
- 2011--present: Silicon Vertex Detector (VTX)
- 2012--present: - Forward Silicon Vertex Detector (FVTX)



- Excellent quarkonium capability at **forward rapidity**
- **Switching to large acceptance Υ measurements at mid-rapidity with sPHENIX**

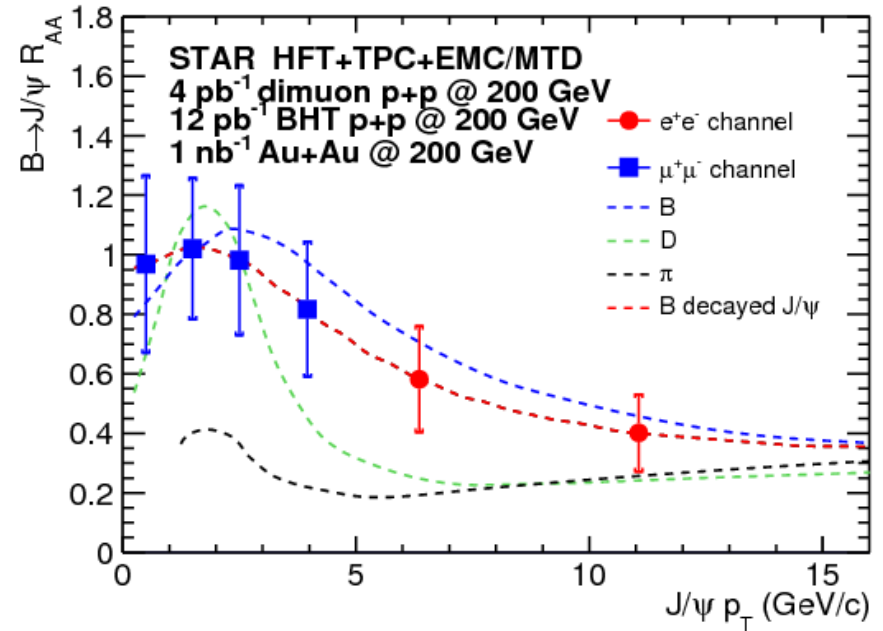
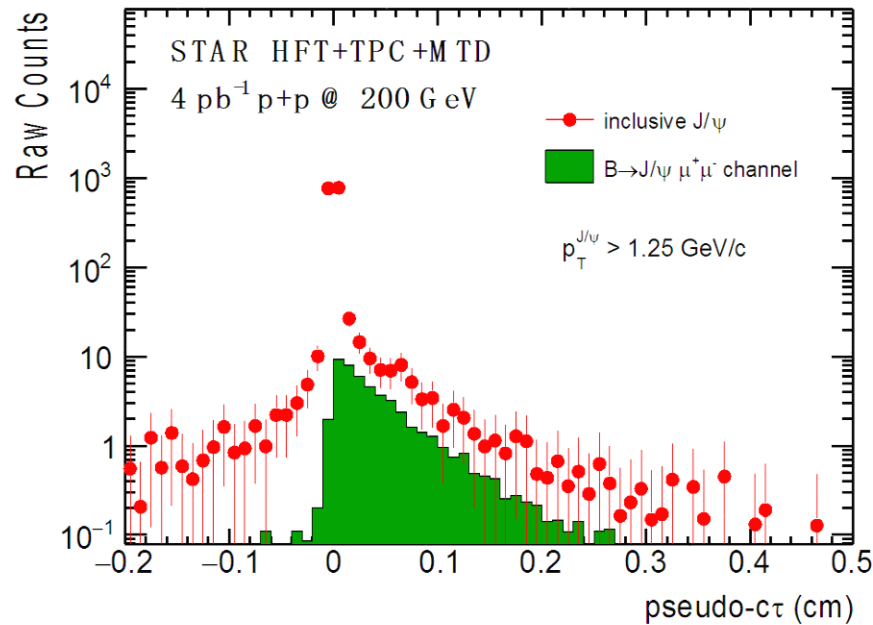
Quarkonia yield in Au+Au with MTD



- Improves statistical uncertainty
- As well as systematic uncertainty

- Improve statistics
- Be able to separate different states

Opportunity with Silicon Detector HFT



MTD + HFT:

$B \rightarrow J/\psi \rightarrow \mu^+\mu^-$

Separate prompt and non-prompt J/ψ

J/ψ / D Ratio

Primordial J/ψ ~ N_{cc}

Regenerated J/ψ ~ N_{cc}^2

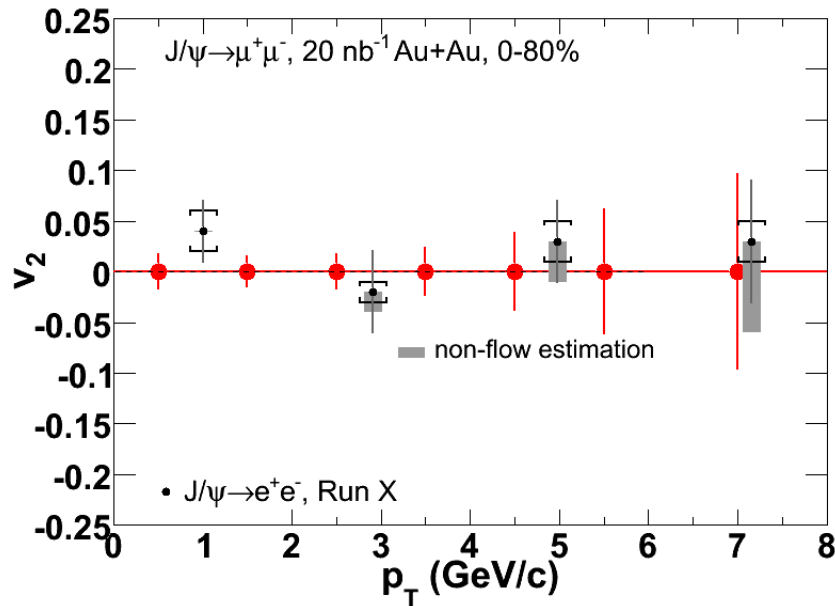
D ~ N_{cc}

v_2 and polarization in Au+Au

J/ψ v_2 in heavy-ion collisions

- Melting vs. Regeneration
- Magnetic effect?

Phys. Lett. B751 (2015) 215-219



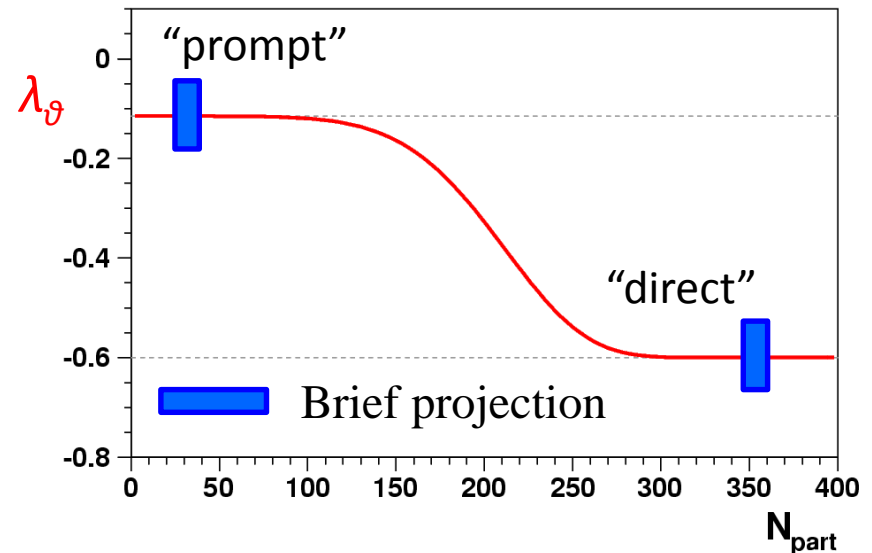
- Projection for v_2 with MTD
- High- p_T can be improved with EMC

J/ψ polarization in heavy-ion collisions

- Screening of non-perturbative physics?

PRC 68, 061902 (2003)

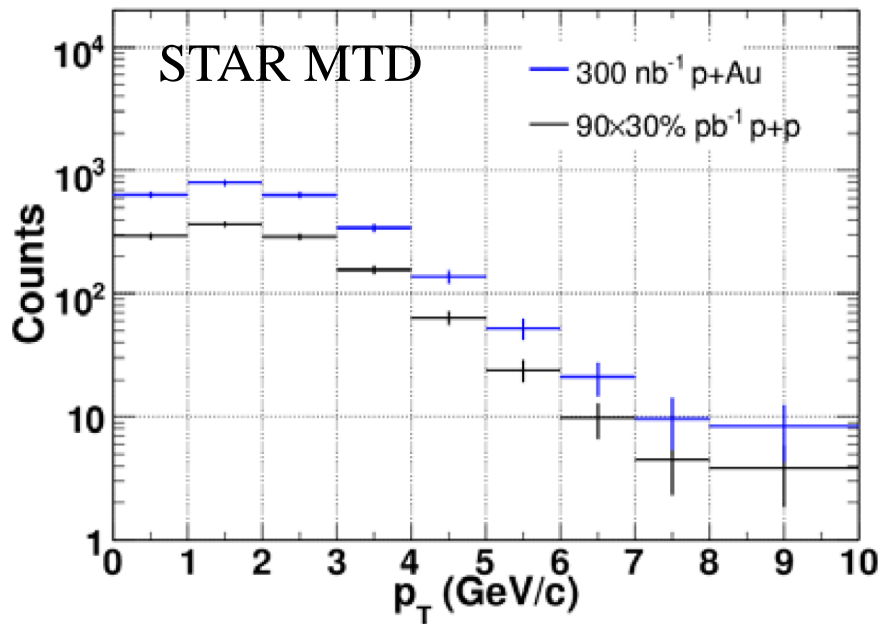
- Magnetic effect?
- Sequential suppression?



Curve from Joao Seixas, workshop AFTER@ECT

Cold Nuclear Matter Effect

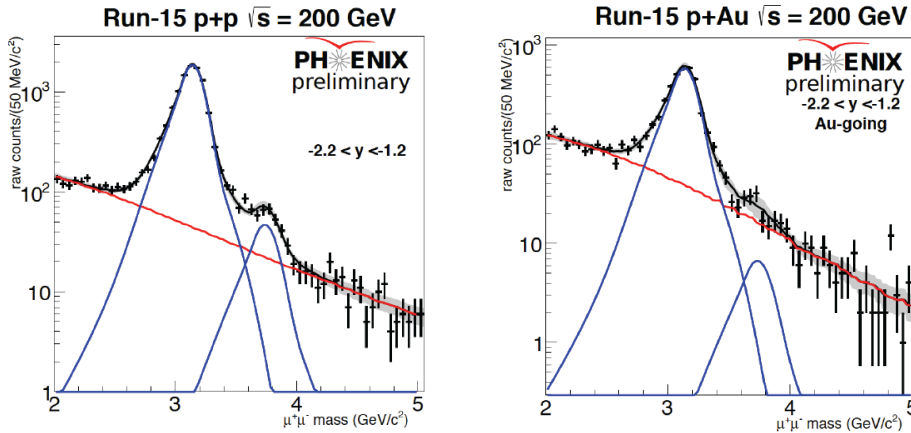
- Reference for heavy-ion collisions
- CNM itself is important



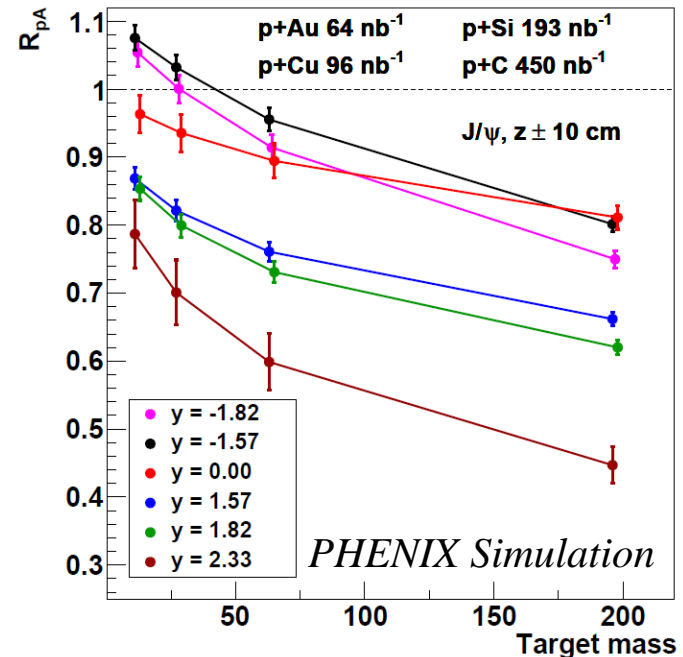
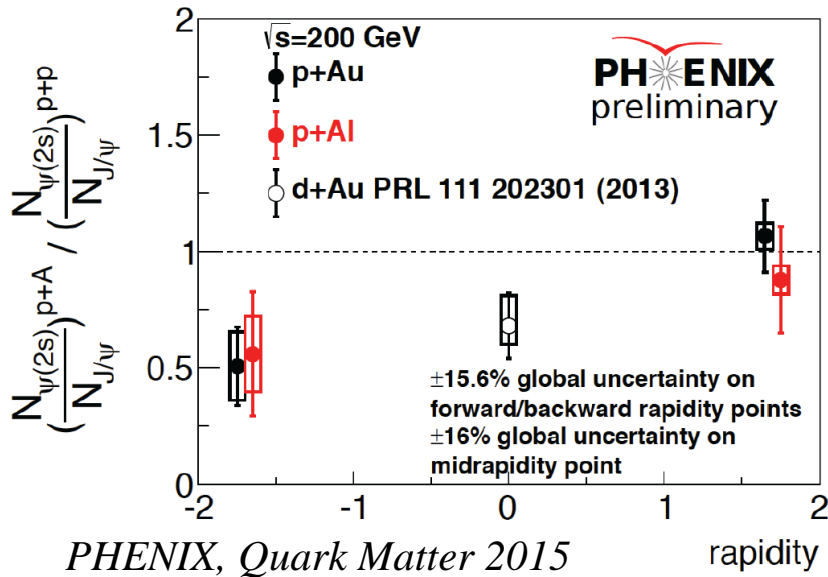
R_{pA} statistical uncertainty (STAR mid-y)

- $0 < p_T < 4$ GeV/c
10% with MTD with 300 nb⁻¹
- $4 < p_T < 8$ GeV/c
5% with EMC with 50 nb⁻¹
- $8 < p_T < 10$ GeV/c
15% with EMC with 300 nb⁻¹

PHENIX Forward Rapidity



- Preliminary double ratio at **forward** rapidity is available
- Fully corrected J/ψ results are yet to come
- Non-prompt J/ψ ?



Quarkonia in p+p collisions

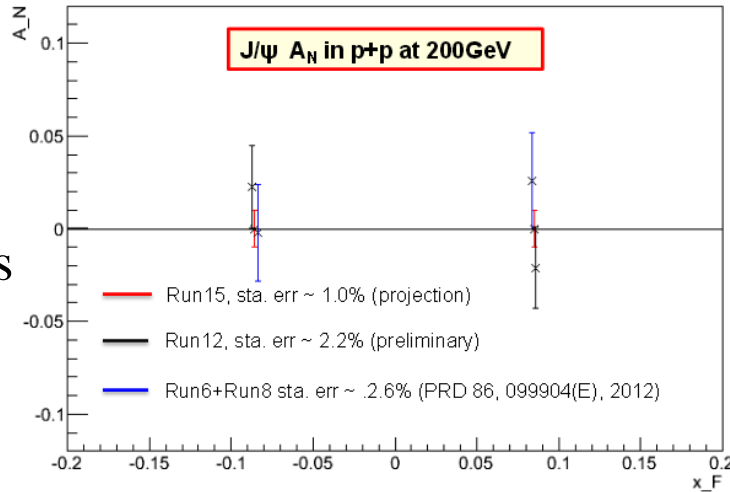
High statistics p+p runs at 200 GeV and 500 GeV with upgraded detectors

- Improve the precision of **spectra** and **polarization**
Constraint production mechanism
- Measurement of $\psi(2S)$ and $B \rightarrow J/\psi$
- Associated production:
J/ ψ -hadron: Associated hadron yield and composition (Theory input?)
J/ ψ -D?

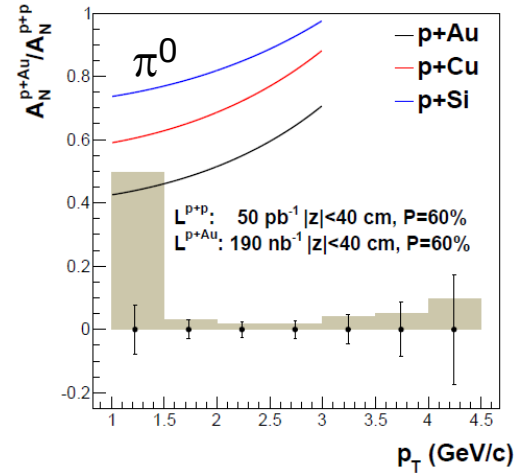
Single Spin Asymmetry

PHENIX
J/ψ results

Chen Xu,
DNP 2015



Extend to polarized p+A collisions?



PHENIX
projection
for π⁰ with
MPC-EX

Year	√s	<P>	L _{STAR}	L _{PHENIX}
2006	200	55	8.5 pb ⁻¹	1.8 pb ⁻¹
2008	200	45	7.8 pb ⁻¹	4.5 pb ⁻¹
2011	500	55	25 pb ⁻¹	-
2012	200	60	22 pb ⁻¹	9.2 pb ⁻¹
2015	200	60	53 pb ⁻¹	50 pb ⁻¹
2017	500		400/900?	-

Statistics are (will be) significantly improved!

Upgrade detectors

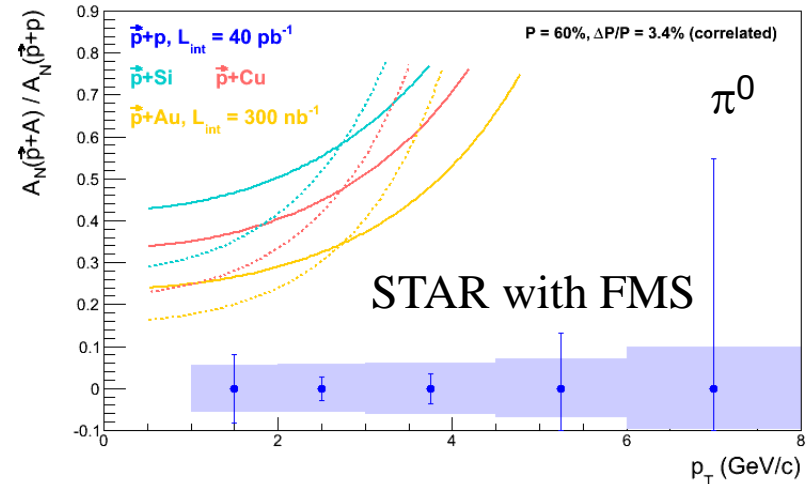
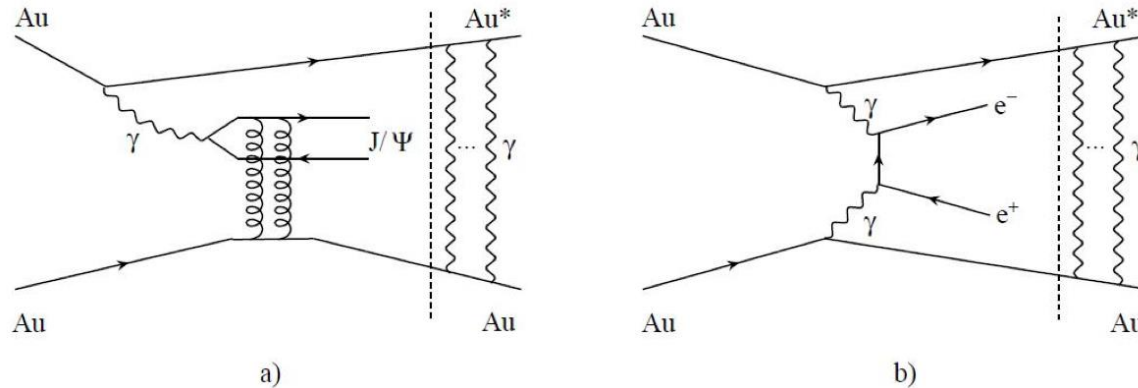


Photo-induced production

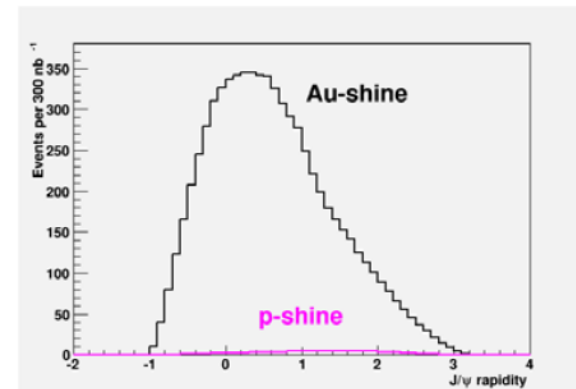
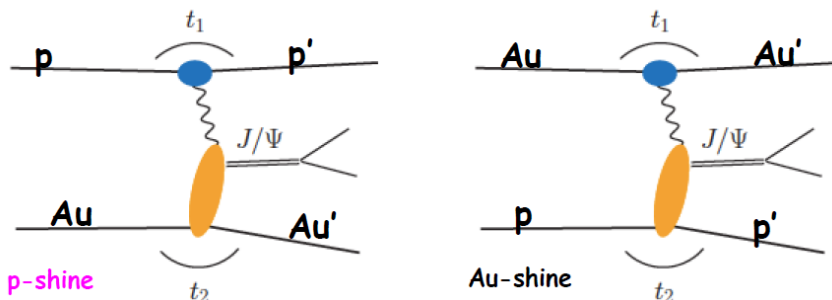
- Photo-production in Ultra-Peripheral heavy-ion collisions



- Very low- p_T J/ψ in peripheral and semi-central heavy-ion collisions

Measurement at mid-rapidity in Au+Au at 200 GeV is [in progress](#)

- p+A collisions



STAR Forward Upgrades

Incremental upgrades/improvements, big impacts

Run15,16,17, 19, 20 (Year2015—2020)

Trigger/DAQ x2 throughput

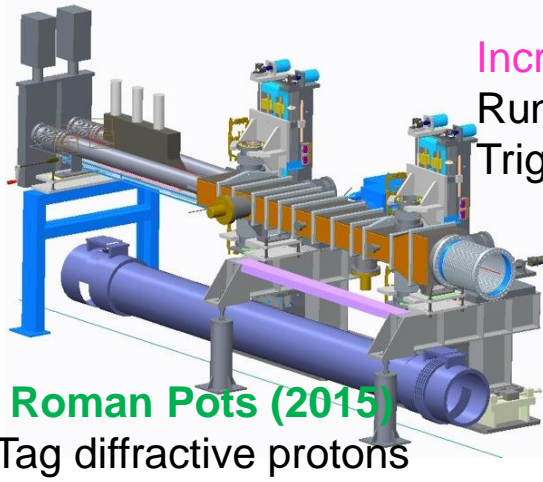
iTPC upgrade (2018)

Replace inner TPC Sectors

Extend rapidity coverage

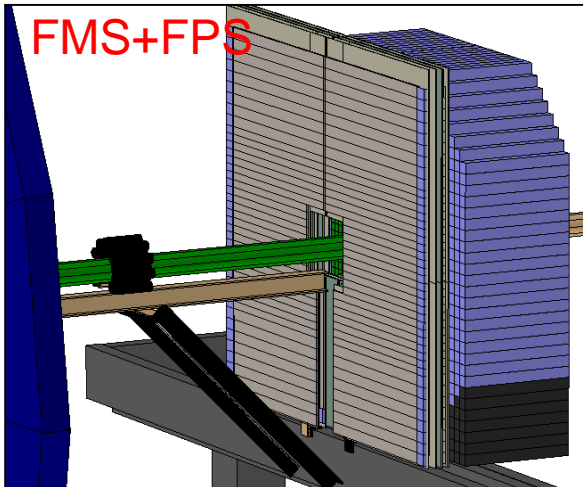
Better particle ID; Low p_T coverage

Proposal: public STAR Note 0619



Roman Pots (2015)

Tag diffractive protons



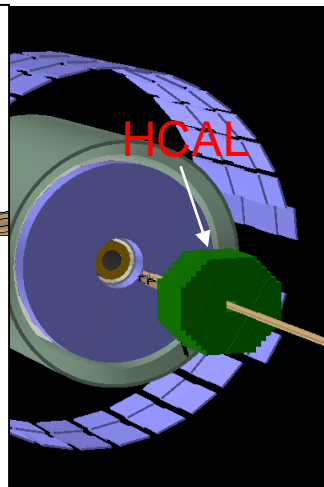
FMS+FPS

Forward calorimeter instrumentation (2015—2020)

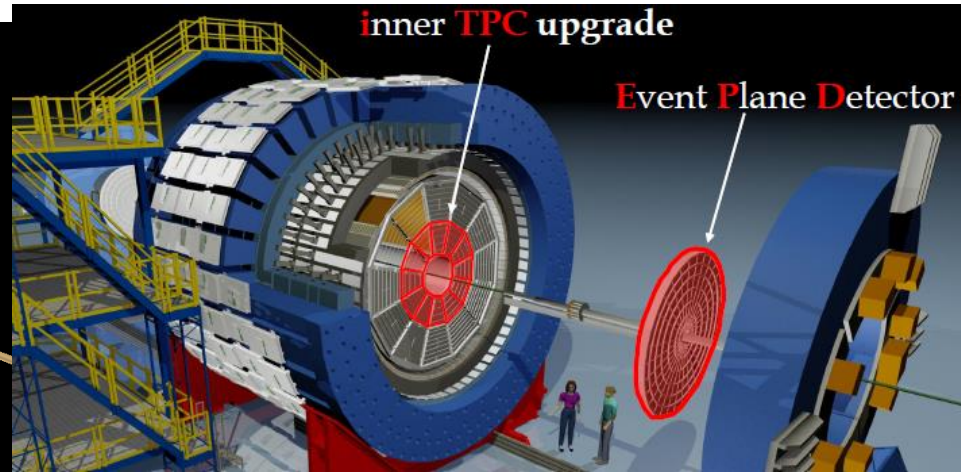
FMS + pre-shower (2015), +post-shower (2017)

A_N photon, jets, Drell-Yan; ridge, fluctuation, spectators

Refurbished HCAL (--2020, forward spectator)



HCAL



inner TPC upgrade

Event Plane Detector

Event Plane Detector (2018):

Greatly improved Event Plane Info

Centrality definition

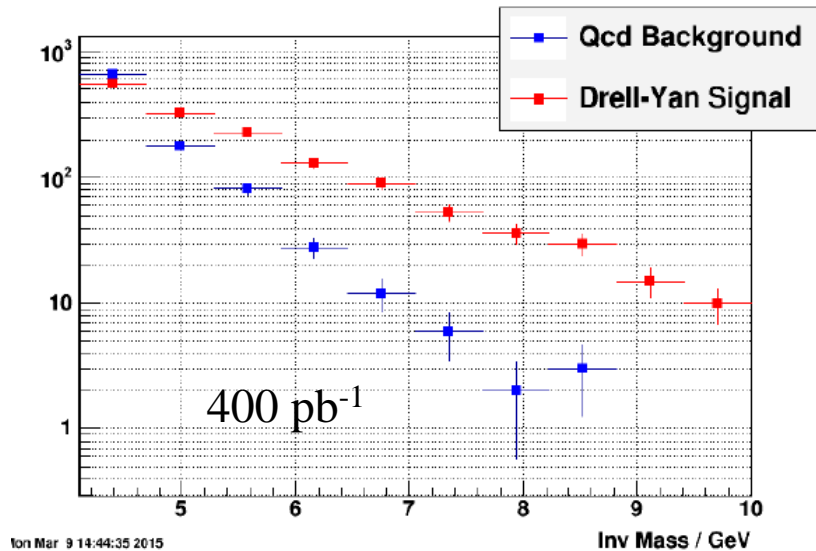
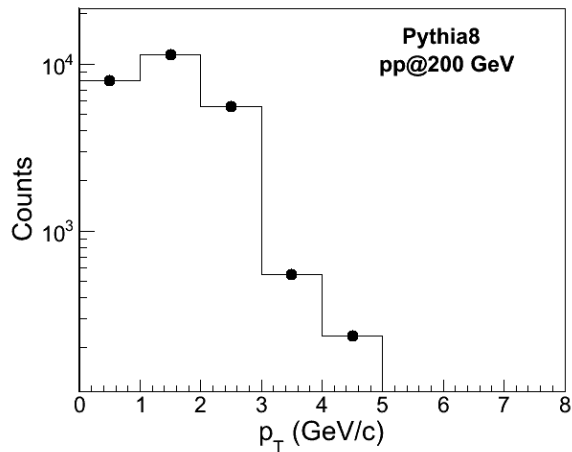
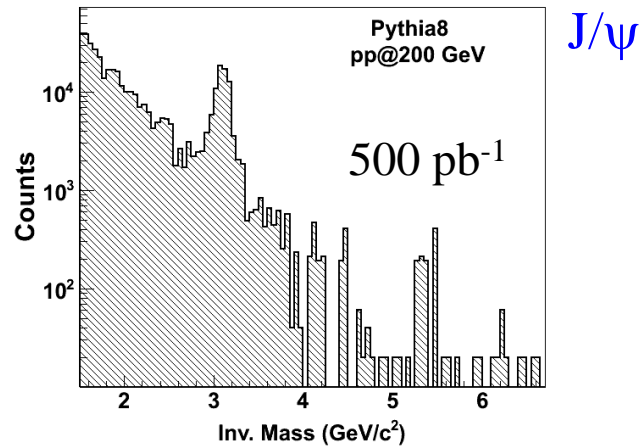
Better trigger

Background rejection

**CBM TOF for
STAR Endcap**

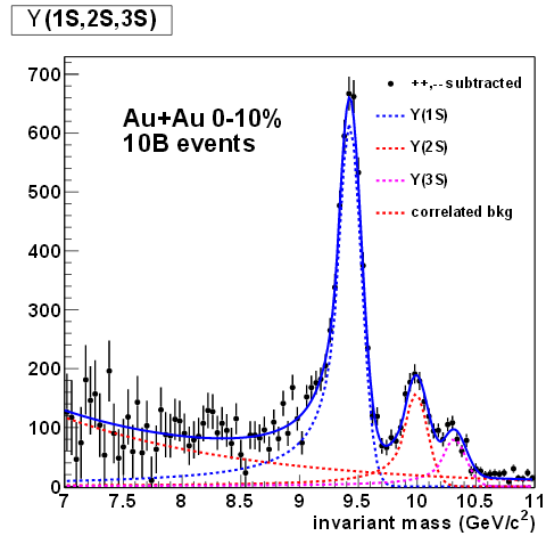
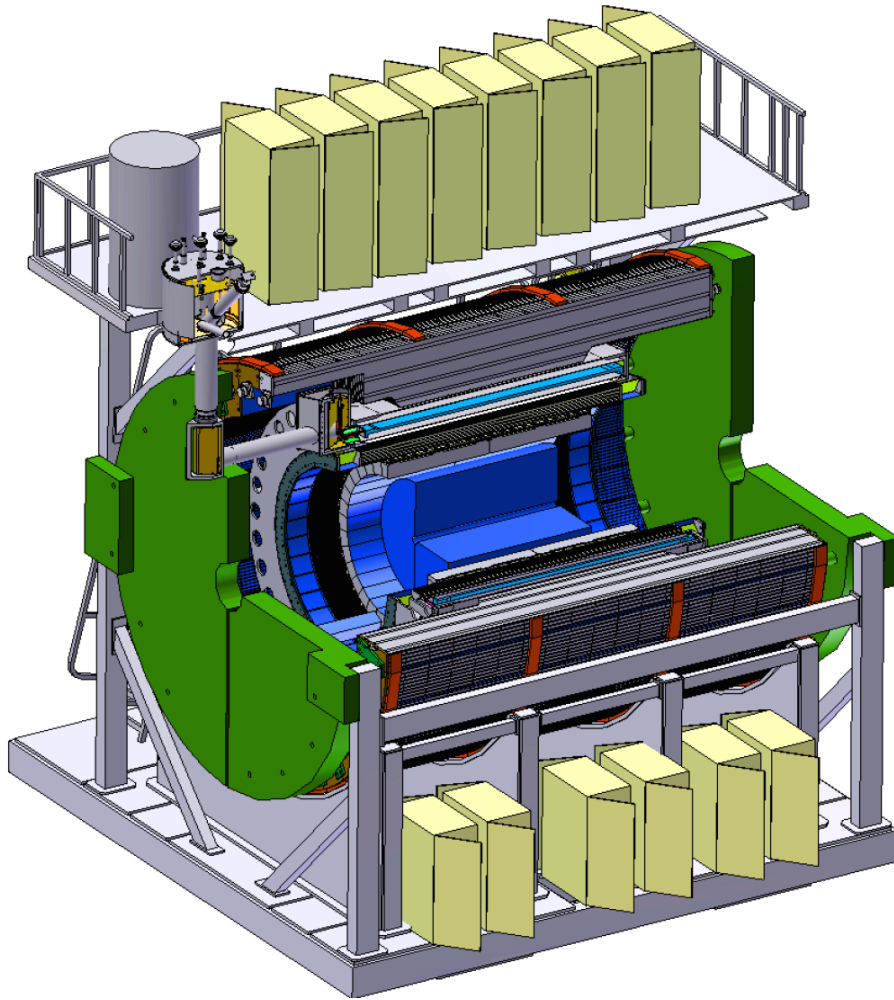
Quarkonia at STAR Forward

Expand measurements to $2.5 < \eta < 4.0$



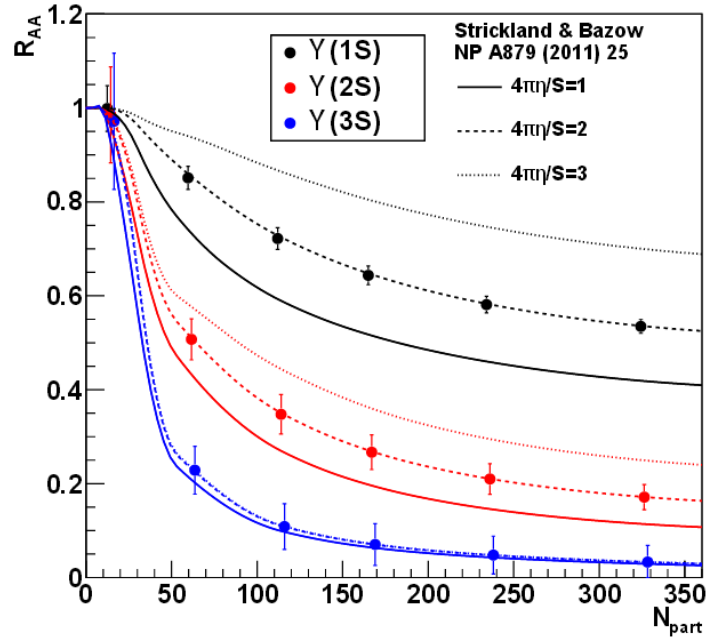
Upsilon?

sPHENIX

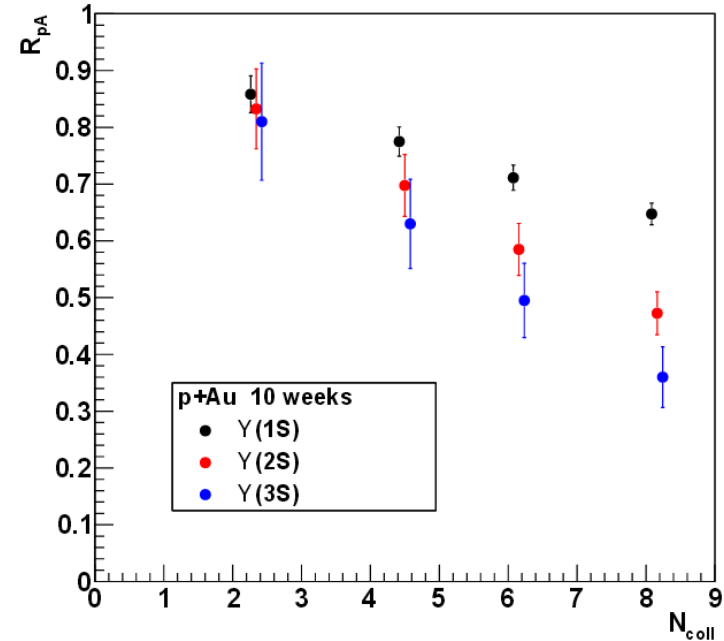


Upsilon at mid-y with sPHENIX

100 billion Au+Au events



10 weeks p+Au run



Summary

- STAR have lots of data taken in various collision systems with state-of-the-art detectors awaiting for fully production/reconstruction
- PHENIX data are not fully analyzed
- PHENIX will be decommissioned after this Run
STAR will continue for a few more years
- STAR forward upgrades and sPHENIX will extend the quarkonia capability at RHIC