STAR
Experimental Overview
Runs 14 & 15

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Office of Science
U.S. DEPARTMENT OF ENERGY

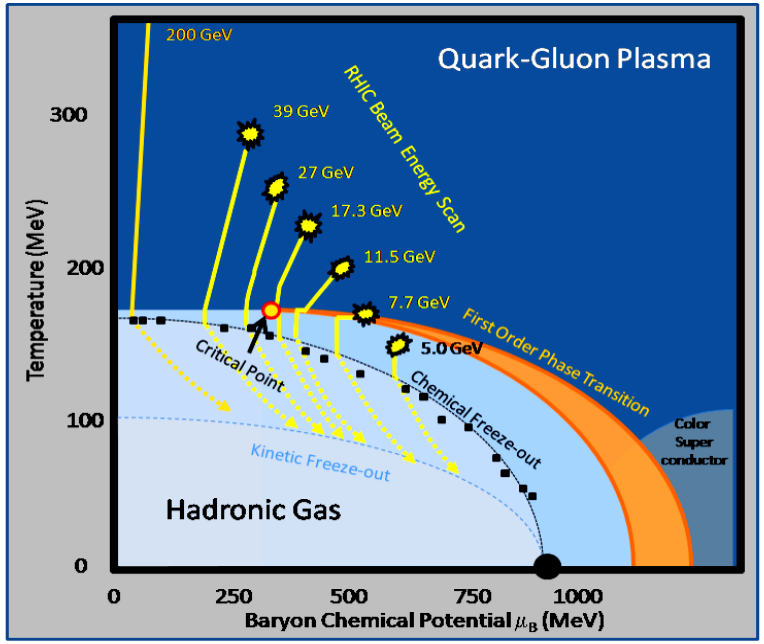
RICE

Outline

- STAR Physics & Detector
- Publications 2015/2016
- Offline Physics Production
  - run 14 & 15 production status
- Run 14 & 15 Analysis Highlights

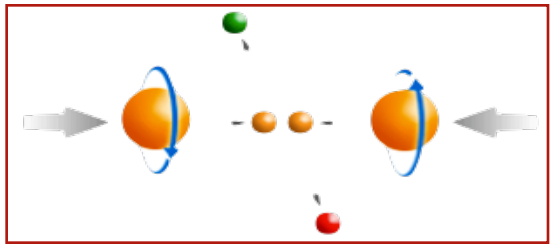
eight key unanswered questions

Hot QCD Matter

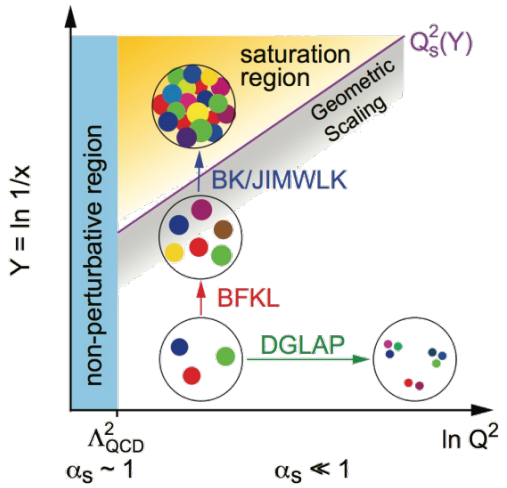


1: Properties of the sQGP
2: Mechanism of energy loss:
weak or strong coupling?
3: Is there a critical point, and if so, where?
4: Novel symmetry properties
5: Exotic particles

Partonic structure



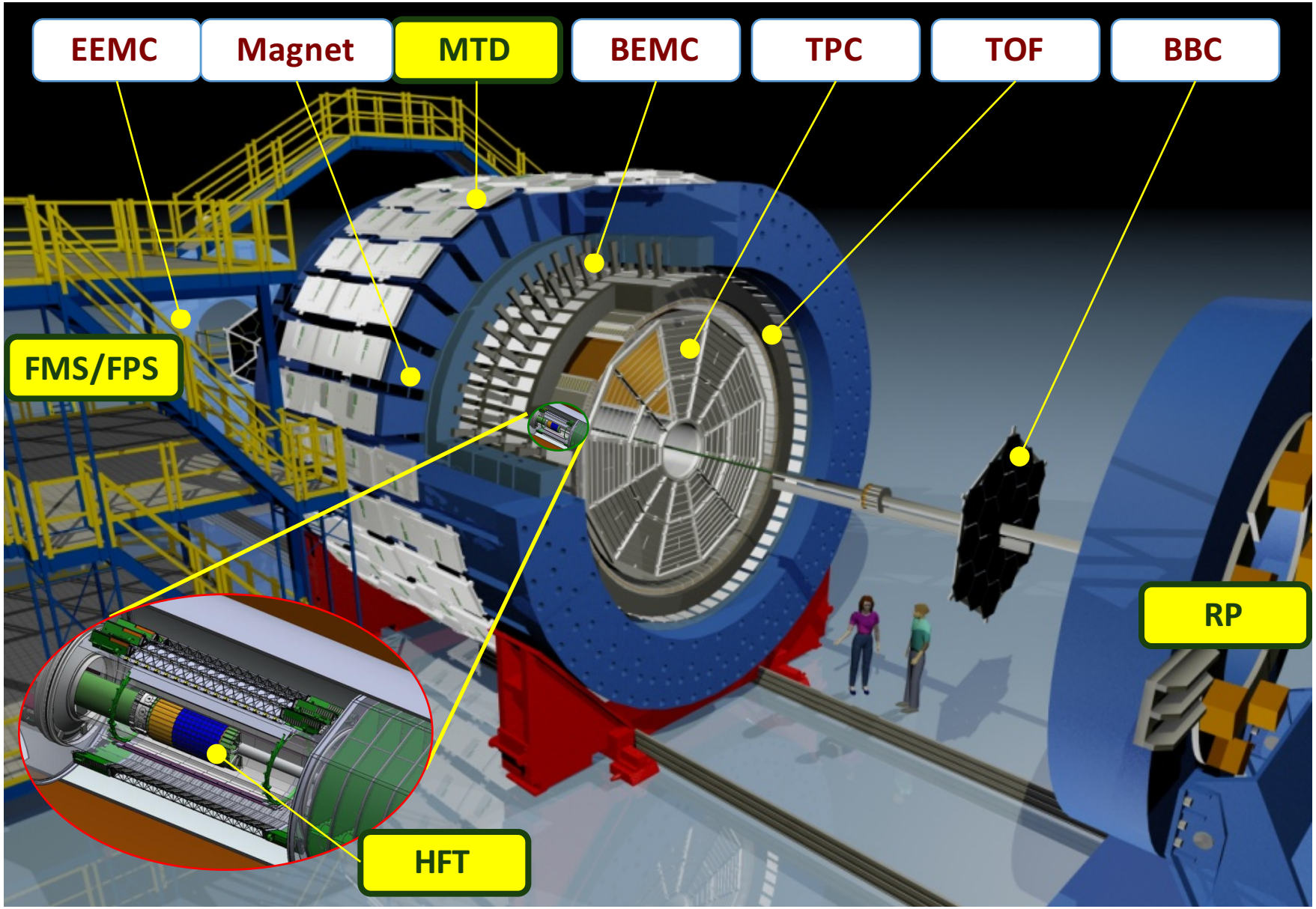
6: Spin structure of the nucleon
7: Image proton in momentum and coordinate space



8: What are the properties of cold nuclear matter?

STAR Decadal Plan
http://www.bnl.gov/npp/docs/STAR_Decadal_Plan_Final%5b1%5d.pdf

STAR Detector System



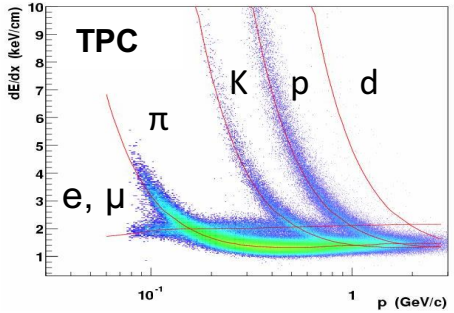
Run-14/15 key upgrades:

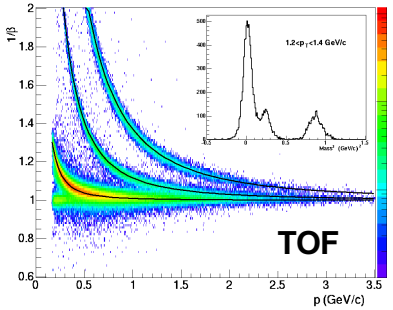
- Heavy Flavor Tracker
- Muon Telescope Detector

- Roman Pot upgrade

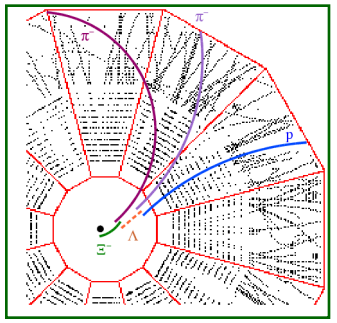
- Forward Meson Spectrometer
  - restacked
- FMS Preshower
  - first use of SiPMs

Particle Identification at STAR

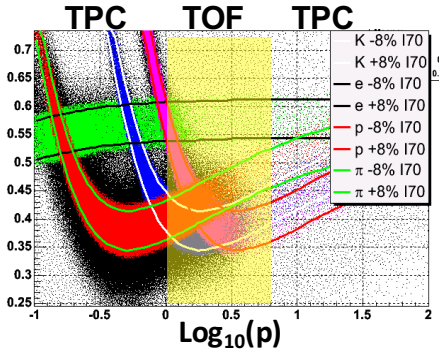


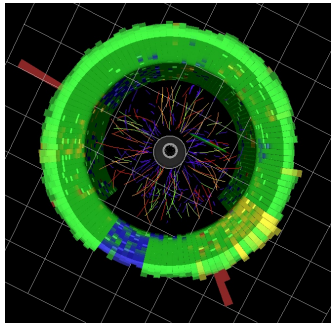


Charged hadrons

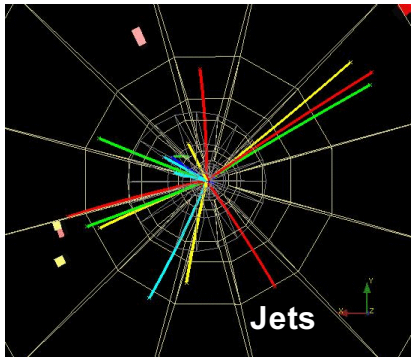


Hyperons & Hyper-nuclei

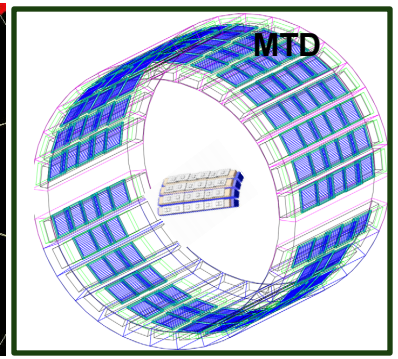




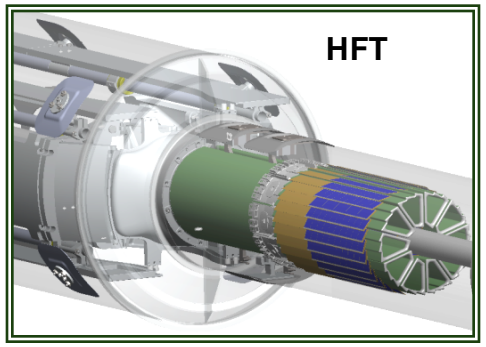
EM particles



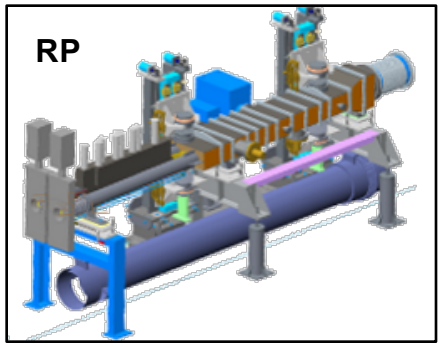
Jets & Correlations



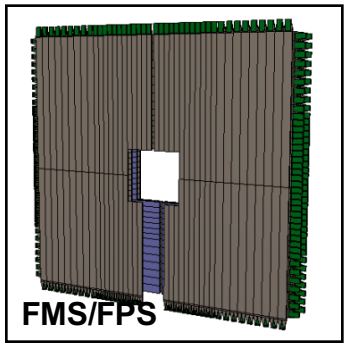
High p_T muons



Heavy-flavor hadrons



Forward protons



Forward photons

Multiple-fold correlations for identified particles!

STAR Detector Systems

	Period	Detectors	Physics
	2001-2010	**TPC**	*u, d, s*
	2009	DAQ1000	
	2010	TPC + TOF	*u, d, s + dilepton*
	2013	TPC + TOF + MTD	*u, d, s, c, b + dilepton*
	2014	TPC + TOF + MTD **+ HFT**	
	2015	TPC + TOF + MTD+HFT+**FPS/FMS+RP**	

- STAR: large coverage, excellent PID, fast DAQ
  - detects nearly all particles produced at RHIC
  - multiple fold correlation measurements
  - probes: bulk, penetrating, and *bulk-penetrating*
- STAR: perfect mid-rapidity collider experiment
- STAR: expanding into forward rapidity regions

STAR Publications: Citation Summary

Generated on 2016-06-06

188 papers found, 188 of them citeable (published or arXiv)

Citation summary results	Citeable papers	Published only
Total number of papers analyzed:	188	188
Total number of citations:	22,828	22,828
Average citations per paper:	121.4	121.4
Breakdown of papers by citations:		
Renowned papers (500+)	11	11
Famous papers (250-499)	11	11
Very well-known papers (100-249)	40	40
Well-known papers (50-99)	38	38
Known papers (10-49)	68	68
Less known papers (1-9)	20	20
Unknown papers (0)	0	0
h_{HEP} index [?]	73	73

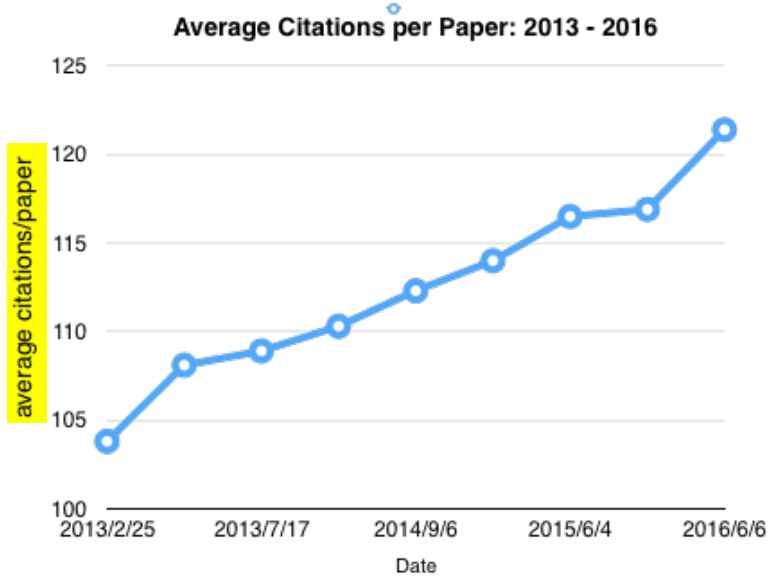
Source: inspire.net

Citations (as per June 6)

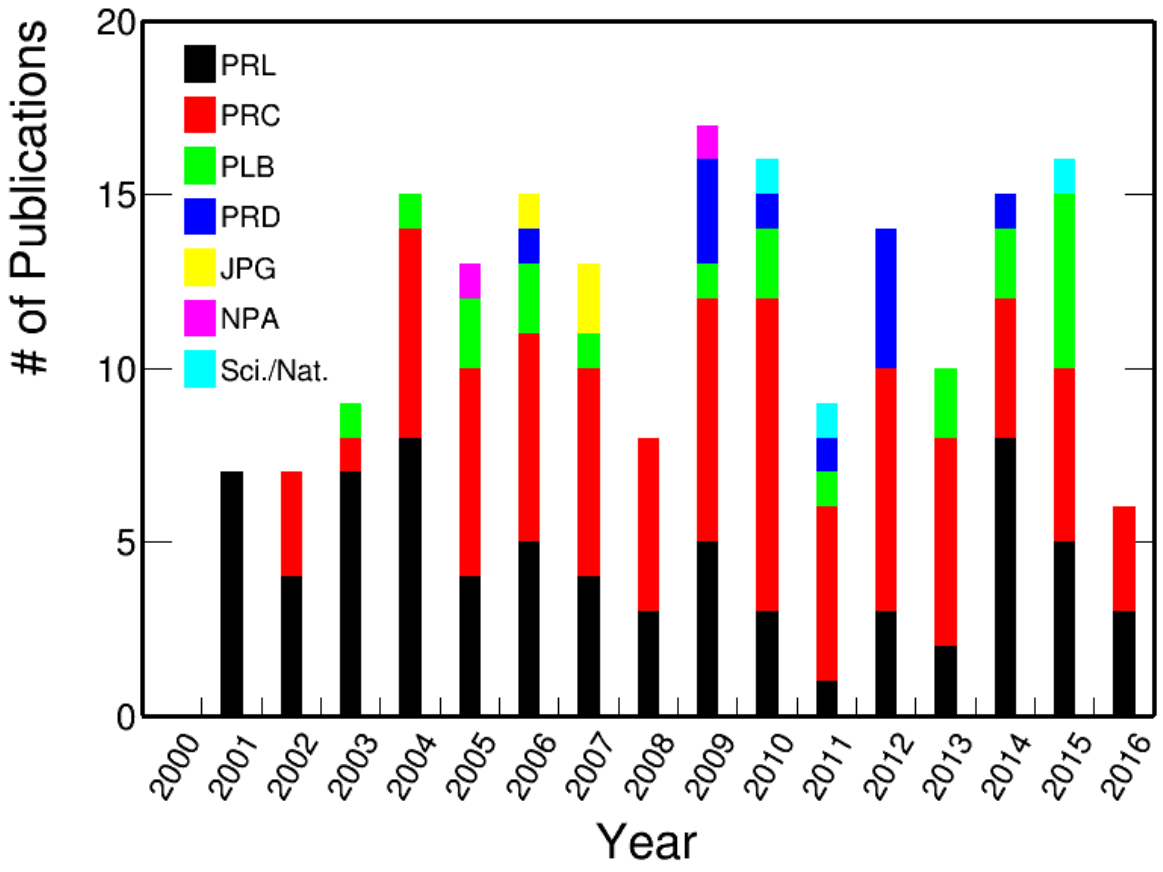
- 22,828 citations
- 188 peer-reviewed scientific papers
- 2005 white paper: 2334
- average citations/paper: 121.4

Renowned and Famous Papers: 11 + 11

2015: 9+10; 2014: 6+9



STAR Publication History



June 2015 – 2016

- 17 published papers (incl. 1 accepted)
  - 7 PRLs, 6 PRCs, 3 PLB, 1 Nature
    - ➢ 3 *PRL Editor's Suggestion*
- 5 in journal review
- 13 in collaboration (GPC) review process
- 9 paper proposals readied for GPC
- 14 PhD graduations

Published Papers :: June 2015 – now (1)

Long-range Correlations in d+Au at 200GeV

- Di-Hadron correlations with identified leading hadrons in 200 GeV Au+Au and d+Au collisions at STAR
  - Phys. Lett. B **751** (2015) 233
- Long-range pseudorapidity dihadron correlations in d+Au collisions at $\sqrt{s_{NN}}$ =200 GeV
  - Phys. Lett. B **747** (2015) 265

Au+Au at 200GeV

- Measurement of interaction between antiprotons
  - Nature **527** (2015) 345
- Azimuthal anisotropy in U+U and Au+Au collisions at RHIC
  - Phys. Rev. Lett. **115** (2015) 222301
- Centrality and transverse momentum dependence of elliptic flow of multi-strange hadrons and ϕ meson in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
  - Phys. Rev. Lett. 116 (2016) 62301

Polarized p+p at 200/500GeV

- Precision measurement of the longitudinal double-spin asymmetry for inclusive jet production in polarized proton collisions at $\sqrt{s}$ = 200GeV
  - Phys. Rev. Lett. **115** (2015) 92002 {**PRL Editor's Suggestion**}
- Observation of transverse spin-dependent azimuthal correlations of charged pion pairs in p+p at $\sqrt{s}$ =200 GeV
  - Phys. Rev. Lett. **115** (2015) 242501
- Measurement of the transverse single-spin asymmetry in $p+p \rightarrow W^{\pm}/Z$ at RHIC
  - Phys. Rev. Lett. 116 (2016) 132301 {**PRL Editor's Suggestion**}

Published Papers :: June 2015 – now (2)

Dielectron Measurements

- Measurements of dielectron production in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV from the STAR Experiment
  - Phys. Rev. C **92** (2015) 024912
- Energy dependence of acceptance-corrected dielectron excess mass spectrum at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 and 200GeV
  - Phys. Lett. B **750** (2015) 64

CNM (p+p and d+Au at 200GeV)

- J/ψ Production at low transverse momentum in p+p and d+Au collisions at $\sqrt{s_{NN}}$=200 GeV
  - Accepted by PRC

16 papers published
1 accepted

Beam Energy Scan (➢ incl. Run-14 14.6GeV)

- Beam energy dependent two-pion interferometry and the freeze-out eccentricity of pions in heavy ion collisions at STAR
  - Phys. Rev. C **92** (2015) 014904
- Kπ, pπ, and Kp fluctuations in Au+Au collisions from $\sqrt{s_{NN}}$ = 7.7 to 200GeV
  - Phys. Rev. C **92** (2015) 021901(R)
- Observation of charge asymmetry dependence of pion elliptic flow and the possible chiral magnetic wave in heavy-ion collisions
  - Phys. Rev. Lett. **114** (2015) 252302 {**PRL Editor's Suggestion**}
- Probing parton dynamics of QCD matter with Ω and ϕ production
  - Phys. Rev. C 93 (2016) 21903

➢ Centrality dependence of identified particle elliptic flow in relativistic heavy ion collisions at $\sqrt{s_{NN}}$ = 7.7-62.4 GeV
  - Phys. Rev. C **93** (2016) 014907

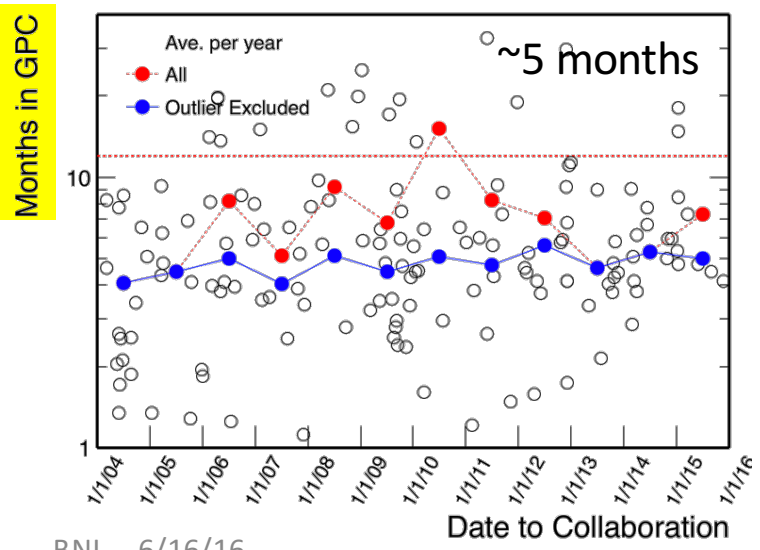
➢ Beam energy dependence of the 3rd harmonic of azimuthal correlations in Au+Au collisions at RHIC
  - Phys. Rev. Lett. 116 (2016) 112302

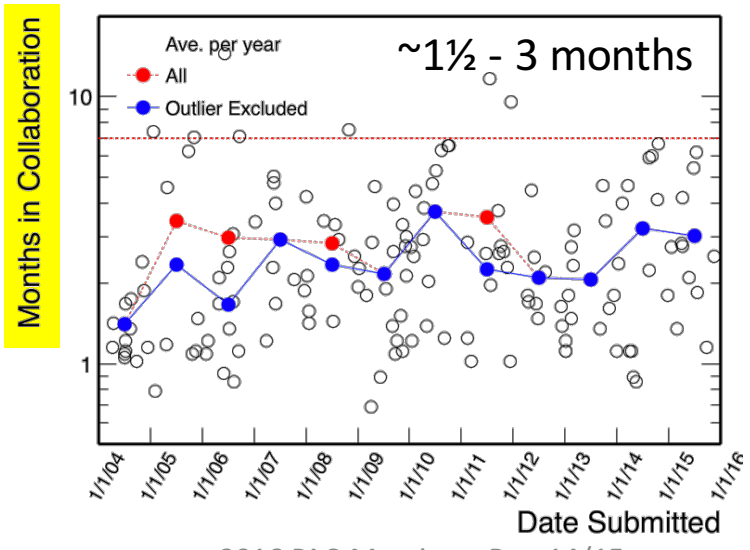
STAR Formal Paper Process

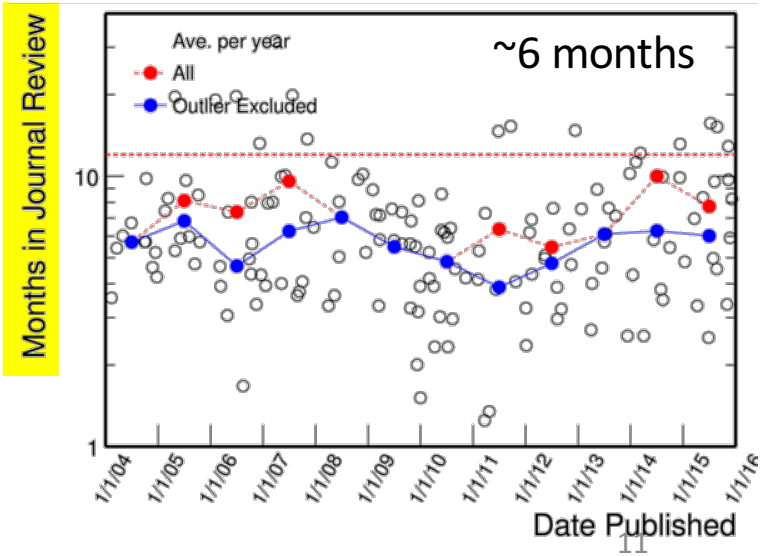
tracked by PWGs — *tracked by Editorial Board*

PWGC "early" preview	PWG review	GPC	Collaboration Review	Journal Submission /Referee Report
introduction outline of data and physics draft plots	review physics analysis review draft technical note (incl. analysis code)	review paper ensure persuasive physics message technical accuracy correctness of analysis	open for comments from all of STAR + 5 institutional readers	distribute report to the collaboration work with GPC on response

Monitor Progress and Minimize Outliers …







Paper Plans in PWGs :: PWGC previews

Paper proposals prepared across all 6 PWGs

14 pwgc previews

date	pwg	title/url
June 23, 2015	Spin	inclusive jet cross-section in p+p@200GeV
July 7, 2015	BulkCorr	➢ BES v3 ***published***
July 7, 2015	BulkCorr	➢ BES PID v2 ***published***
Oct. 6, 2015	UPC	Coherent Diffraction of rho mesons ***in GPC***
Oct.27, 2015	Heavy	D^0 and D* Production in p+p@500GeV ***ready for GPC***
Nov. 3, 2015	Spin	2011 IFF in pp@500GeV
Nov. 3, 2015	JetCorr	Di-jet imbalance measurements in Au+Au@200GeV ***in GPC***
Dec. 8, 2015	Heavy	➢ D^0 v2 in Au+Au@200GeV (HFT) ***in GPC***
Dec. 15, 2015	JetCorr	Away-side jet correlations in Au+Au@200GeV ***submitted***
Jan.5, 2016	BulkCorr	➢ Three-particle harmonic decomposition ***in GPC***
Jan.12, 2016	LFS	BES Dielectron ***ready for GPC***
Feb. 2, 2016	BulkCorr	Charge-dependent directed flow in Cu+Au ***ready for GPC***
Feb. 23, 2016	BulkCorr	➢ Global polarization of Lambdas in BES ***ready for GPC***
March 22, 2016	JetCorr	Hadron-Triggered Charged Jets in Au+Au@200GeV

➢ Includes Run-14/15 data

Offline Physics Production

- Physics production priorities regularly reviewed and set by the joint PWGs
  with input from Software & Computing leadership

Priorities from PWGs (Fall 2015)

Top priority

- Run14 Au+Au@200GeV
  - main physics stream (HFT)

Immediate priorities (in parallel)

- Run14 Au+Au@200GeV :: MTD stream
- Run15 p+p and p+A :: FMS stream

Next priorities (no order)

- Run15 RP stream
- Run15 p+Al
- Run15 p+p and p+A heavy-ion/spin physics
- FXT for Au+Au @4.5GeV and Au+Al @4.9GeV

Modification (early 2016)

- Reproduction Run-14 Au+Au HFT stream
  - following a fix in the HFT decoding software

Prioritization 2015/16 – considerations:

Run 14 Au+Au

1. Fast-track Run-14 Au+Au at 200GeV to enable HFT publications
2. Understand MTD performance ahead of Run-16 Au+Au
3. J/ψ and Y from MTD
   – Estimate backgrounds

Run 15 p+p

4. Input from Run-15 FMS data in p+p and p+A (FMS stream)
5. Roman Pot data sets from Run-15 p+p and p+Au (RP stream)
6. Run-15 p+p and p+Au heavy-ion/spin physics

Run 14 and 15 Production Status

Run 14:

✓Au+Au @ 14.6GeV
- production finished Jan. '15

✓Au+Au @ 200GeV
- started: March '15
- completed: April '16
- includes HFT and MTD

✓^{3}He+Au @ 200GeV
- preview production

- Au+Au @ 200GeV
  - ➢ reproduction of HFT stream
    (ongoing, currently at 30%)

Run 15:

✓Fixed Target production
- Au+Au @ 4.5GeV
- Au+Al @ 4.9GeV

- $p+p_{trans}$ and $p+p_{long}$
  - ✓FMS, RP streams
  - physics stream (ongoing, currently at 39%)
  - MTD stream (ongoing, currently at 71%)

✓p+Au @ 200GeV
- FMS stream
  (calibrations done)

- p+Al @ 200GeV
  - not started
    (calibrations done)

Run 16: calibrations being prepared

Production Projections

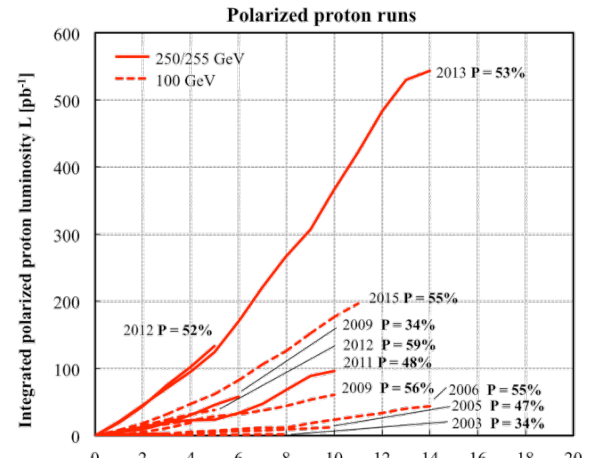
status	Dataset	Projection	Farm Occupancy
ongoing	2014 Au+Au reproduction	80 days (September 2016)	50%
	2015 pp production	50 days (August 2016)	50%
queued	2015 p+Au/p+Al	5.5 months	50%
preparing calibrations	2016 Au+Au	8 months	100% (all streams)

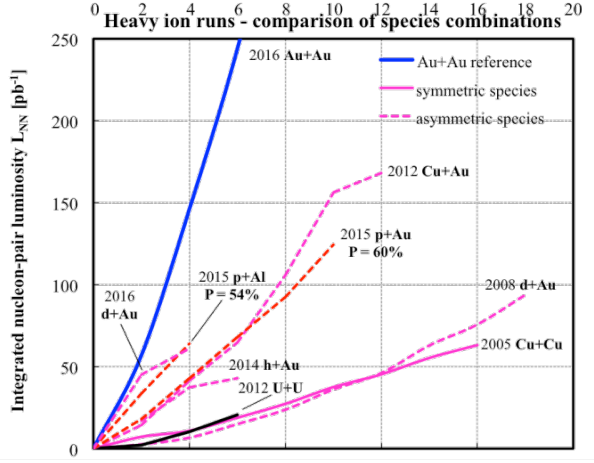
Enable parallel productions

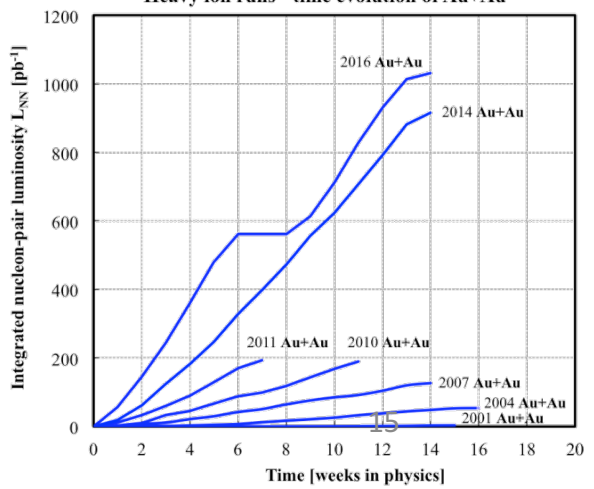
- maximimize involvement of all PWGs
- optimal usage of RHIC farm
  - (100% = 13k nodes)

Continued concern about lack of scaling of available computing resources

➢ Effort to involve other facilities (Dubna/NERSC) up to 20% impact on current projections







Postproduction Resources :: Storage

Context:

- Large and very active analysis community
- Wide variety of data sets
  - species, energies, data streams
- Significant increase in size of individual data sets
  - per run: RAW ~10PB; DST ~6PB
- No proportional growth in active storage availability at BNL
  - total distributed storage 8PB

Mitigation:

- Data Carousel: rotate datasets (staging)
- Data format: evolve from DST to MuDST
  - still reaching 6 PB/year
- PWGs move to picoDST further expand use case
  - expect reduction by ~5-10

➢ **Impact**

- timelines of physics analyses and paper prospects
- local storage at "Tier2" institutes and availability of data sets to the collaboration

	Current Usage
Data written & read per run	RAW 10PB
	DST 6 PB
I/O Bandwidth (max)	RAW 1.6 GB/sec
	DST 15 TB/day
	User 15 GB/sec
Permanent online storage (projected ~2020)	DST 8 PB (DST 20 PB)

Source: STAR Note PSN0658 – *Exascale Requirements Review for Nuclear Physics – STAR, from data taking to analysis*

Run14/15 at Major Conferences in 2015/16

ISMD XLV (2015)

- Central exclusion production in p+p

DIS 2016

- accepted: 5
- J/ψ production in UPC
- A_N in p+p and p+A

SQM 2016 (coming up)

- accepted: 14
- Global Lambda polarization
- BES v_2, v_3
- FXT strangeness
- Quarkonium in p+p and Au+Au (MTD)
- BES net-Kaon moments
- Ds production
- D^0 v_2, v_3

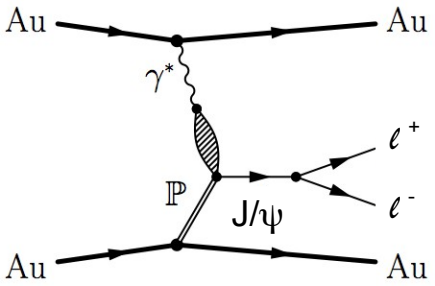
Quark Matter 2015

- 21 oral presentations (incl. teaser, plenary, flash)
- 21 posters

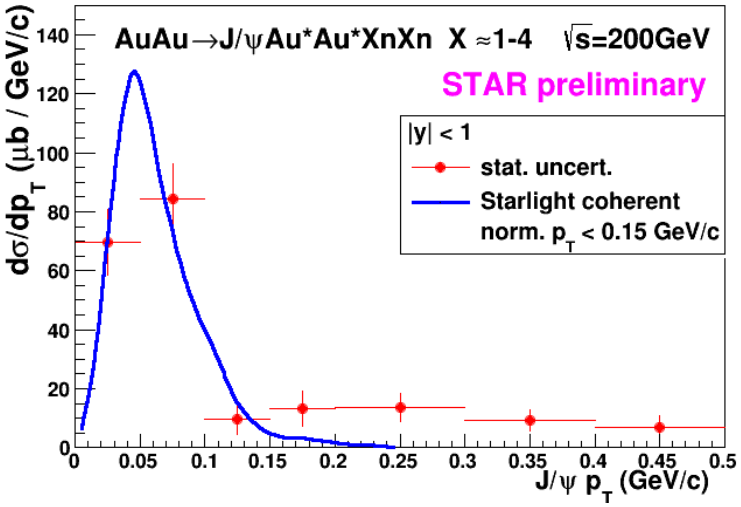
- BES v_1 of identified hadrons
- BES di-hadron correlations
- Higher moments in net-p and net-Q at 14.5GeV
- Jet-quenching and charged-particle R_{CP} in 14.5GeV
- Identified particle spectra in 14.5GeV
- BES rapidity density distributions
- Fixed target results
- Nuclear modification factors of D mesons
- D-meson v_2
- D_S measurements
- Quarkonium measurements
- STAR HFT and upgrade plans

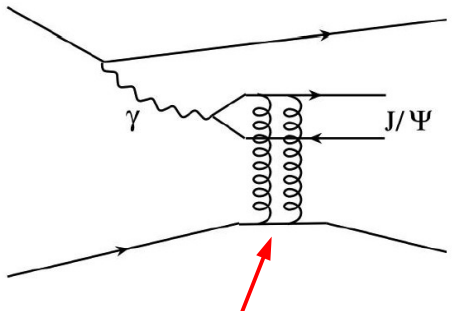
Ultra-Peripheral Collisions Highlight: J/ψ

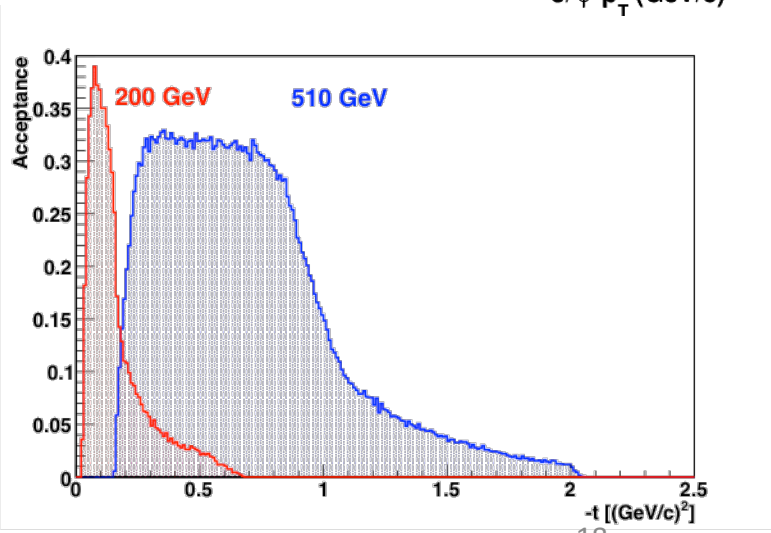
- VM production from UPC photoproduction on other nucleus
- J/ψ production sensitive to Au gluon content
  - clear signal in Run 10/11
  - run14: large sample with new EM trigger
- GPDs in polarized p
  - run15: RPs tag/measure scattered p
  - phase-II*: RPs closer than Run9
  - larger |t| range, increased acc.



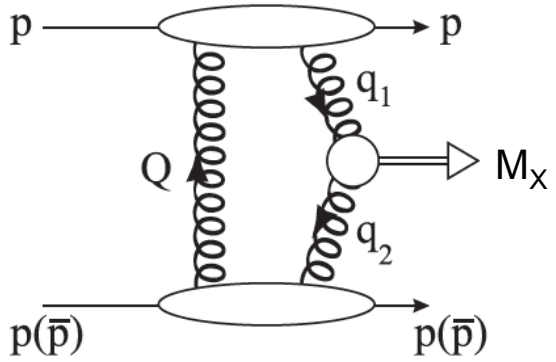
DIS 2016





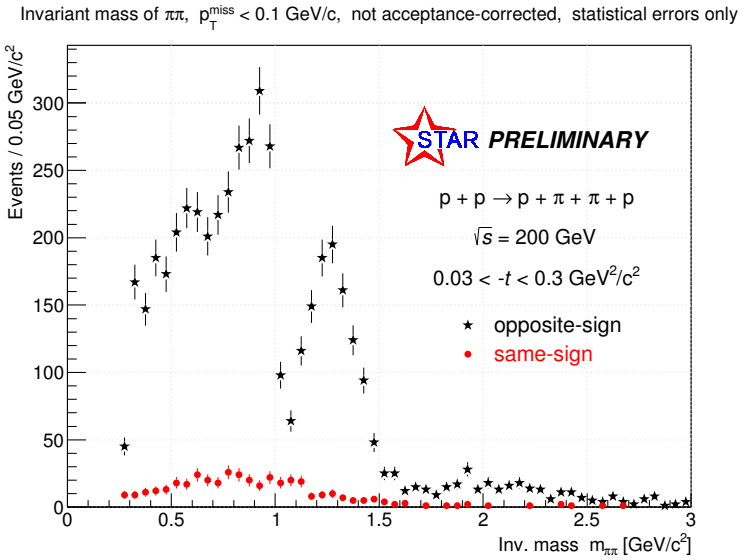


UPC Highlight: Central Exclusive Production

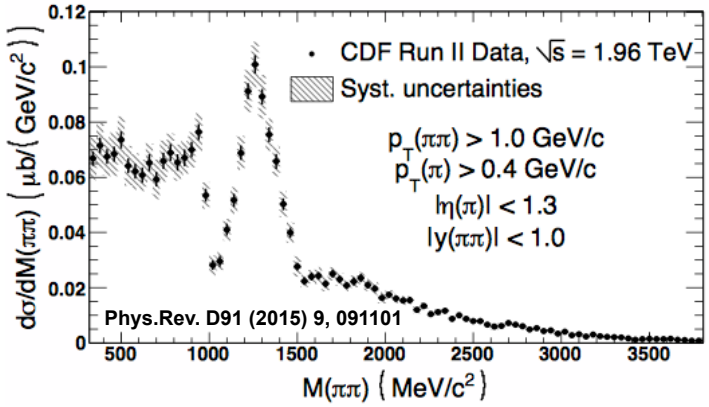


- Colliding protons interact via color-singlet exchange
- Expect system of mass M_X to be produced
  - decay products present in the central detector region
- Tag on forward protons with RPs

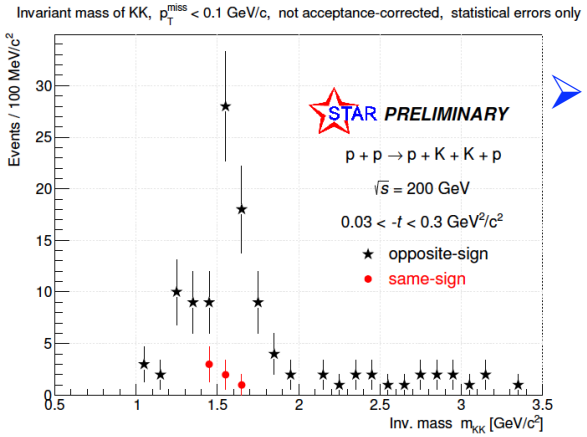
➢ First results (based on 2.5% of the full 2015 data sample of 600M CEP triggers, ~18 pb^{-1})



ISMD XLV (2015)

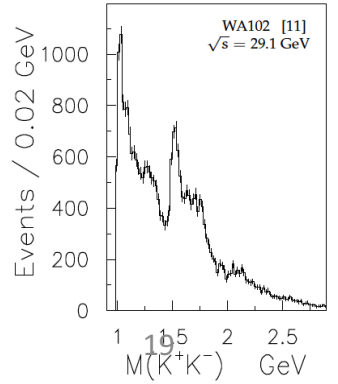


➢ $M_X(ππ)$ similar resonance-like features as seen by CDF and AFS (at ISR)



➢ $M_X(KK)$ similar peak structure 1.5-1.6 GeV/c^2, similar as seen by WA102

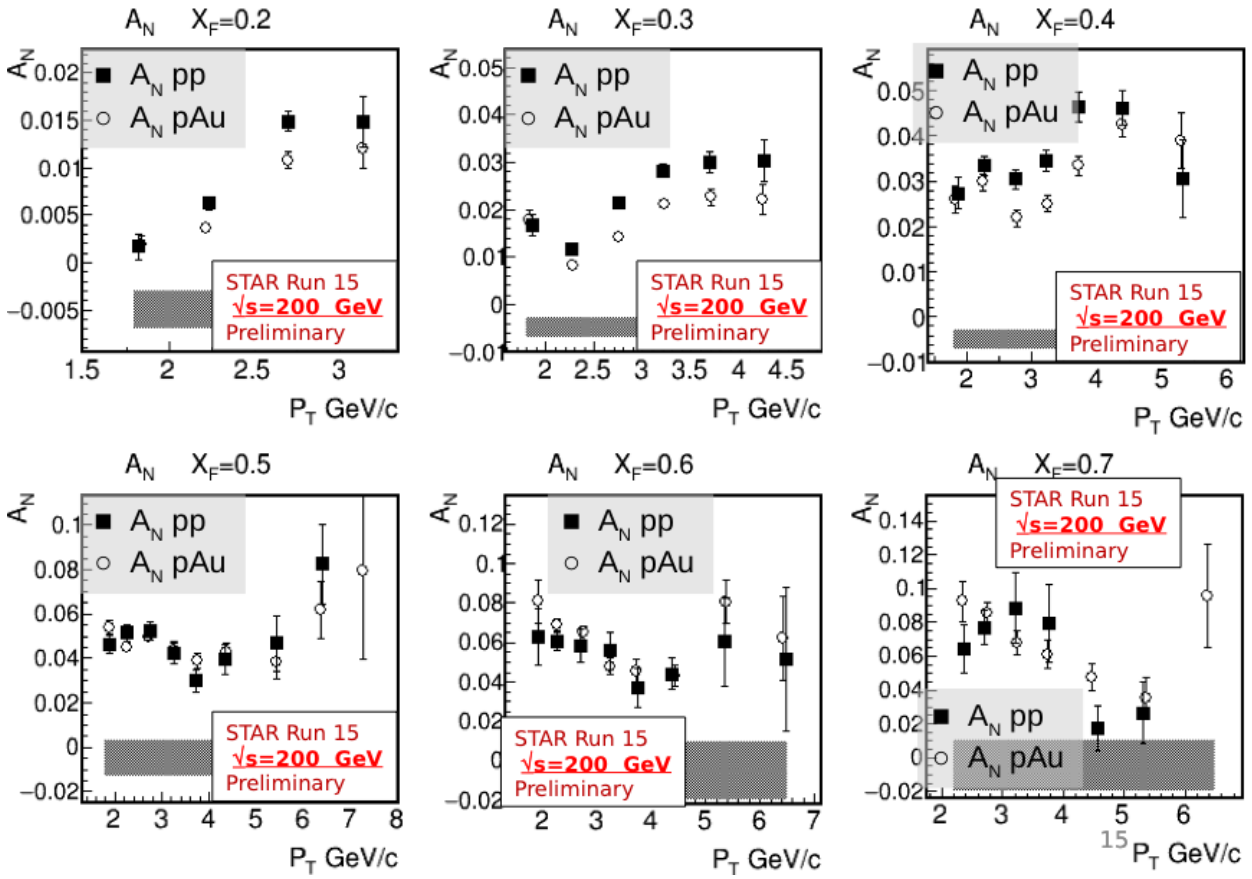
- absence of $f^0(980)$ due to limited STAR acceptance



Spin Highlight: Transverse Single-Spin A_N

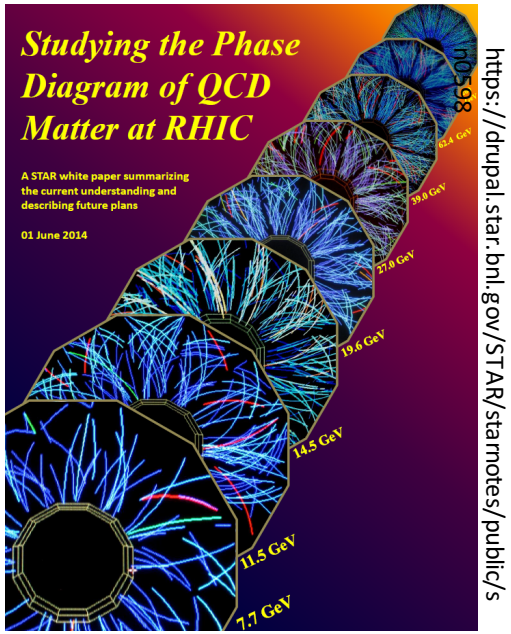
- Spin asymmetries are a unique way to probe the gluon nuclear wave function and confront CGC and pQCD models.
- Forward Meson Spectrometer
  - EM calorimeter for detecting forward π^0s
- Run 15 pp
  - large A_N, rising with x_F, p_T
- Run 15: first data for polarized p+A
  - compare AN in p+A to p+p
  - similar dependence on π^0 topology
  - study centrality and nuclear modification factors
- Use RPs to investigate whether A_N depends on diffraction
  - tag outgoing proton(s)

MPI2015/DIS 2016

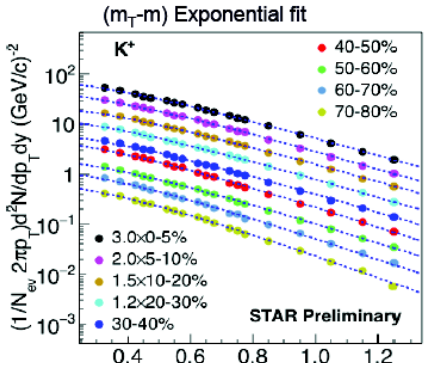


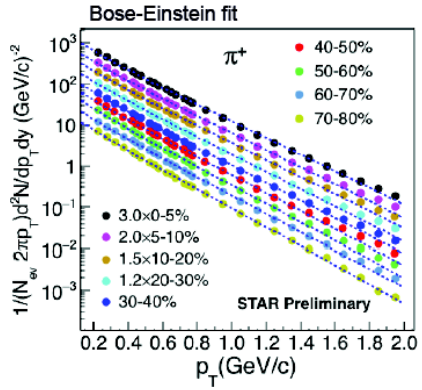
Heavy-Ion Highlights: 14.5 GeV Au+Au

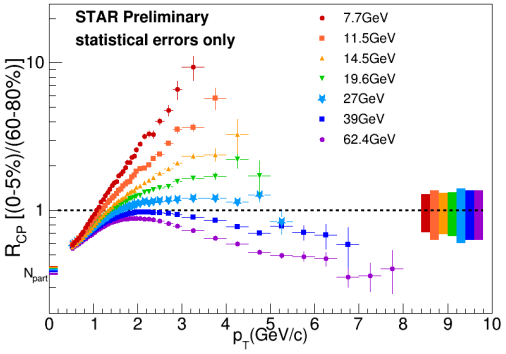
- All 14.5 GeV analyses are in their final stages - 24M events (BES-2 : ~300M)
- Concludes Beam Energy Scan – Phase 1
  - many BES papers have been submitted/accepted in the past years
- **QM 2015:**
  - 11 presentations that involve new measurements with 14.5 GeV data
  - preliminary results available for all key BES analyses
  - *cf.* STAR plenary presentation for a concise overview
    https://drupal.star.bnl.gov/STAR/files/2015-10-01-QM15-STAR-Overview-v5.pdf

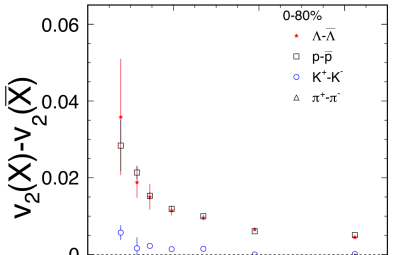


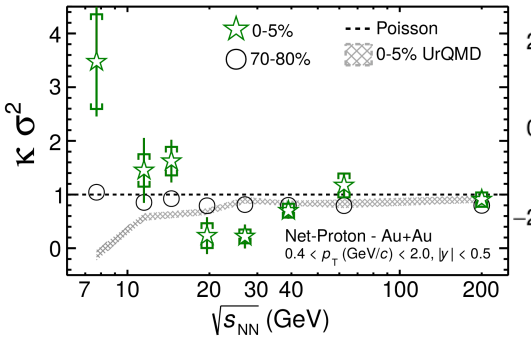
https://drupal.star.bnl.gov/STAR/starnotes/public/s0598

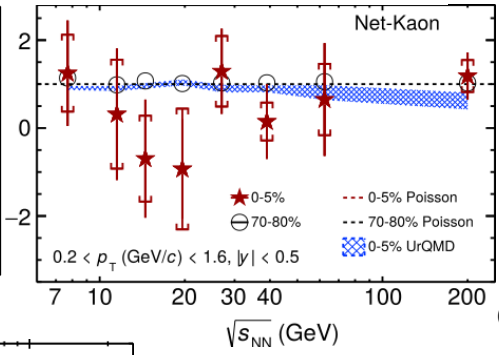


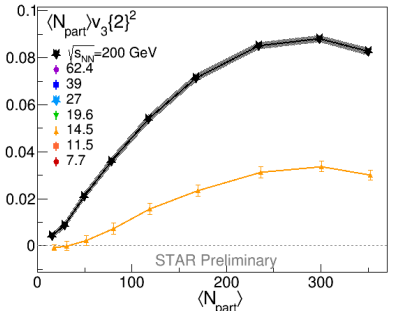


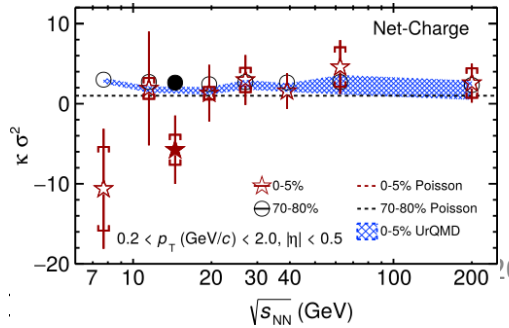


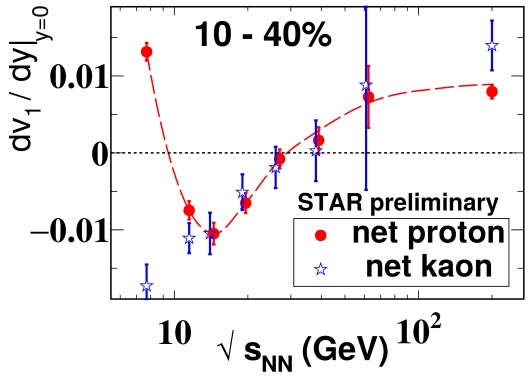










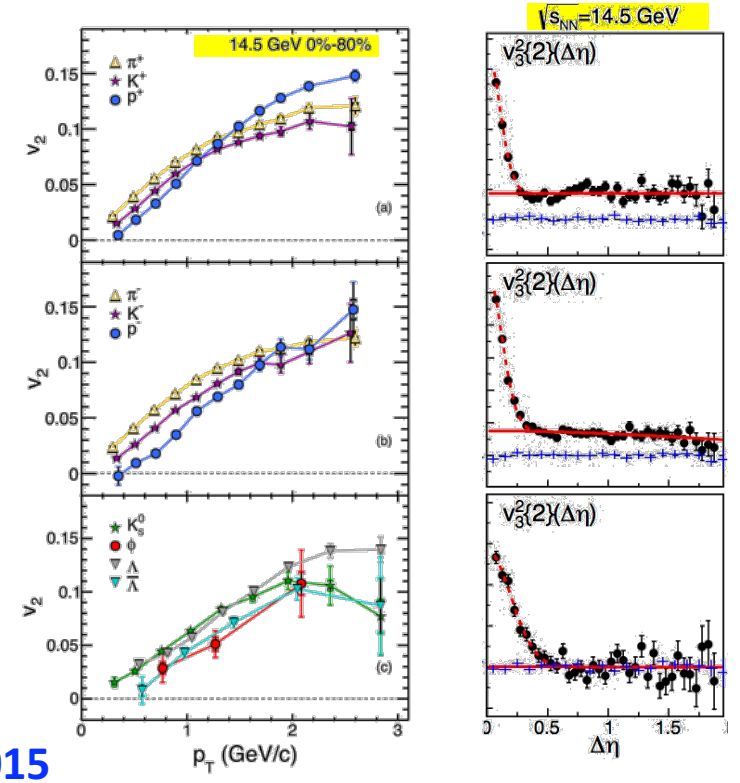


Au+Au 14.5 GeV results

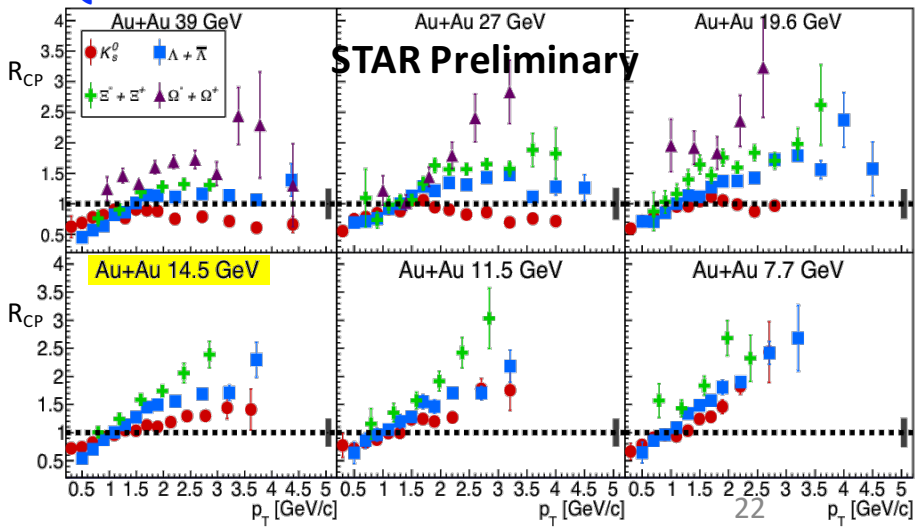
Publication Strategy:

- Results are or will be integrated with several (BES) paper proposals that are already in an advanced state:
  - BES identified particle v_2 (published)
  - BES v_3 (published)
  - Kaon v_1 measurements (preparing for GPC)
  - R_{CP} of charged and identified hadrons (preparing for GPC)
  - Rapidity density (pending PWGC preview)
- In addition, key results shown at QM2015
  - strangeness: Ω, ϕ, Ks, Λ, and Ξ results (preparing for GPC)
  - Light nuclei B_2 (pending PWGC preview)
  - 3.9 GeV fixed target analysis using 14.5 GeV data

PRC 93 (2016) 14907 PRL 116 (2016) 112303



QM2015



Heavy-Ion Highlights: CME and CMW in Au+Au 14.5 GeV

➢ See Paul Sorensen's talk on behalf of CME Taskforce

Charge Separation in BES

- different γ_{os} and γ_{ss} consistent with CME expectations
- charge separation diminishes at lower energies
  - ➢ 14.5 GeV follows the trend

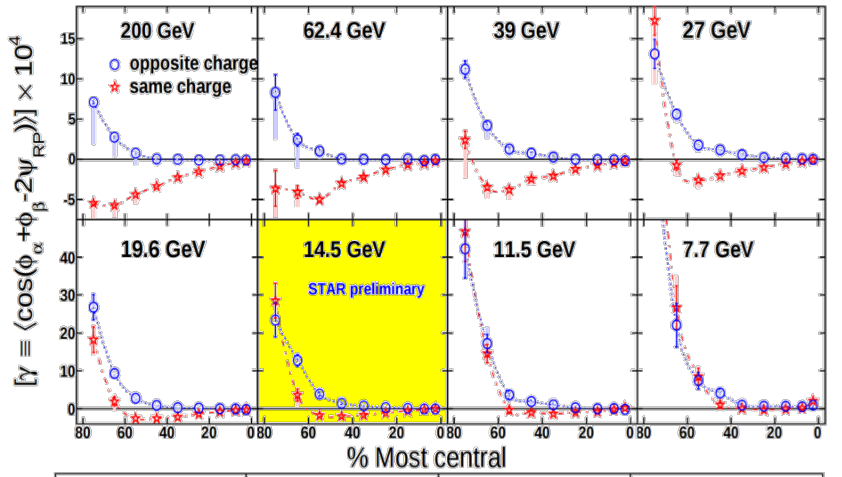
v_2 of (anti-)particles as a function of charge asymmetry A_{ch}

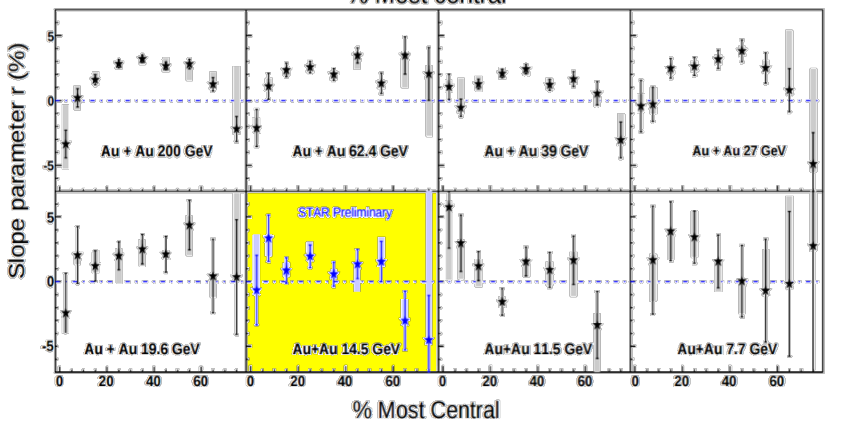
slope parameter in $v_2^{\pm} = v_2^{base} \pm (q_e/\rho_e) A_{ch}$

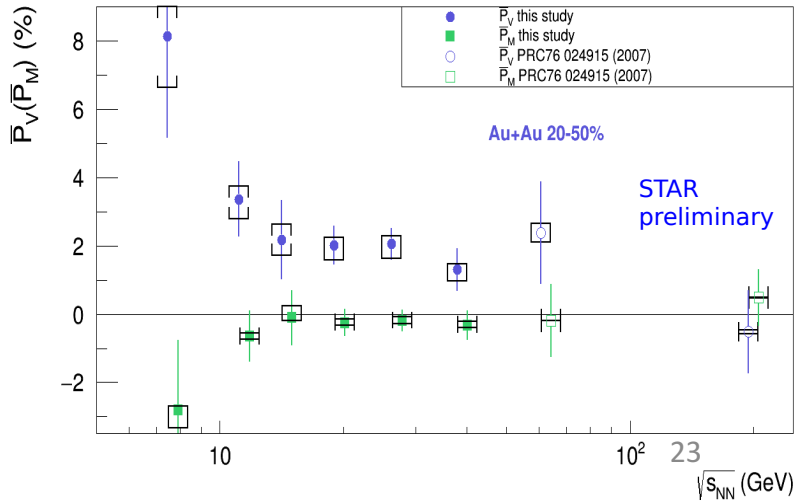
- chiral separation effect + CME → Chiral Magnetic Wave
  - collective excitation
  - signature of chiral symmetry restoration
- STAR measurements at 200GeV consistent with CMW theoretical calculations
  - ➢ similar trend pattern down to 19.6 GeV

➢ Study global hyperon polarization to probe vorticity and B field

- first observation of global Λ polarization
- decompose into magnetic (B) and vortical (V)



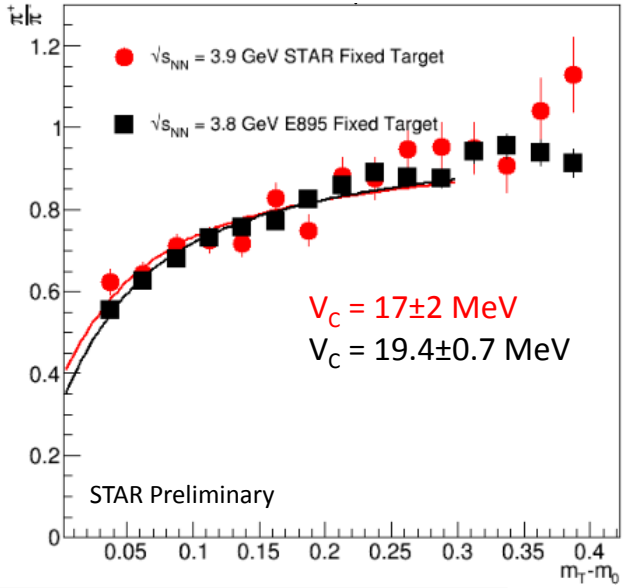


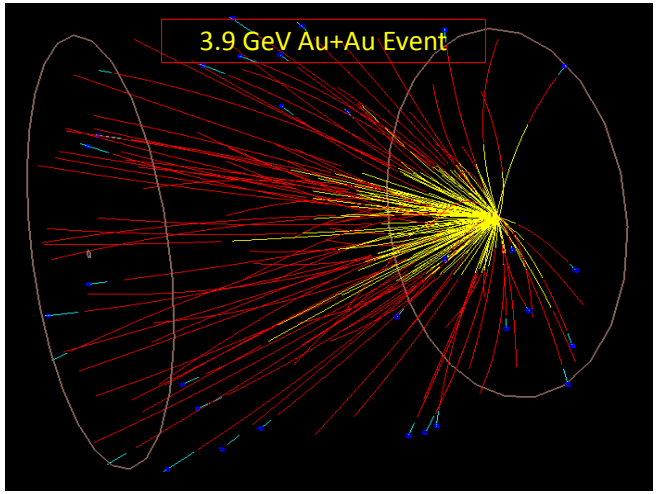


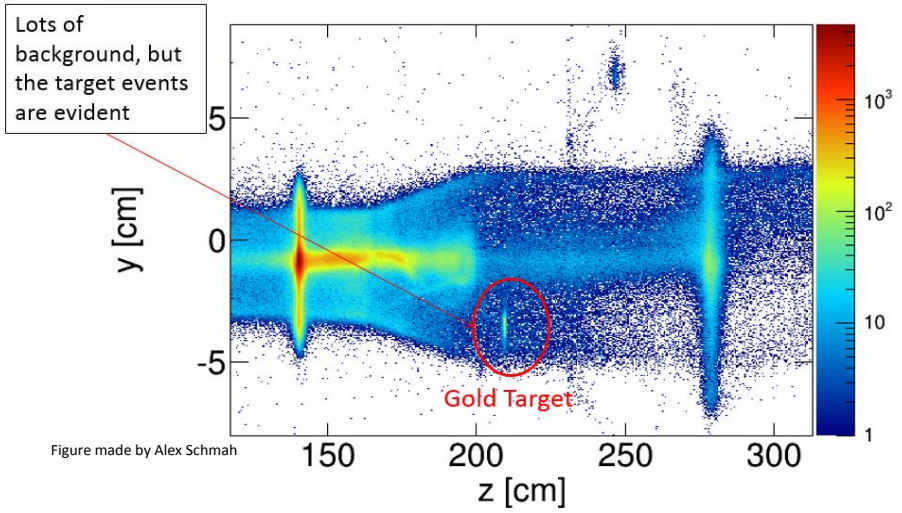
Heavy-Ion Highlights: Fixed Target

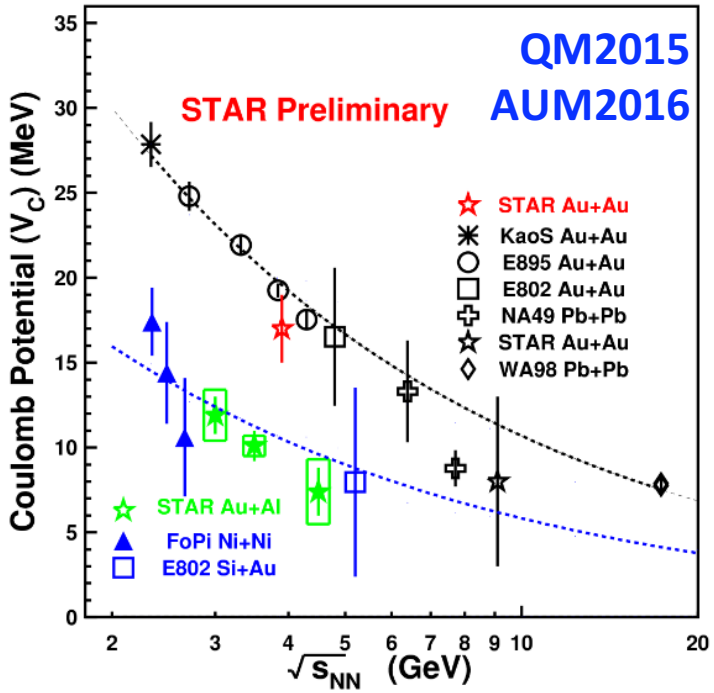
- Gold target inserted in 14.5 GeV run
  - $\sqrt{s_{NN}}$ = 3.9 GeV
  - 2015: test run with beam lowered for direct collisions with target ($\sqrt{s_{NN}}$=4.5 GeV)

➢Fixed target preliminary results consistent with published data



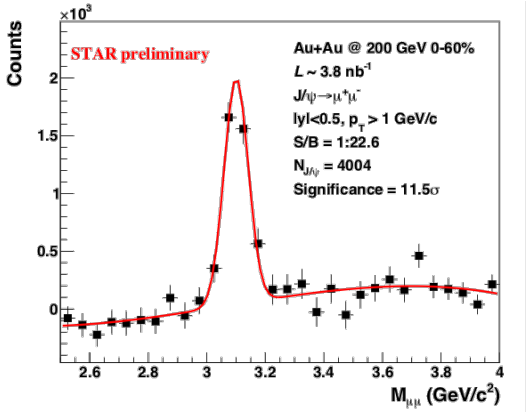


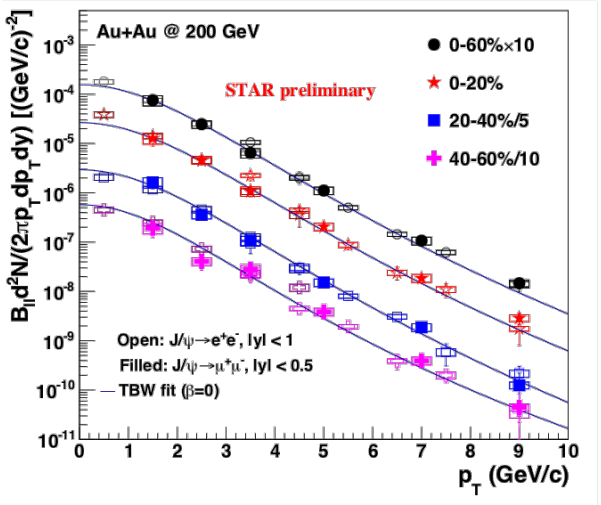




QM 2015 – Flash Talk

Heavy-Ion Highlights: Quarkonia

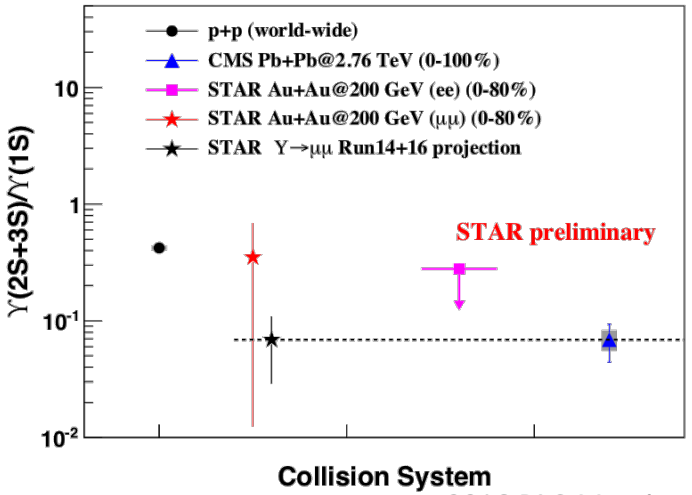


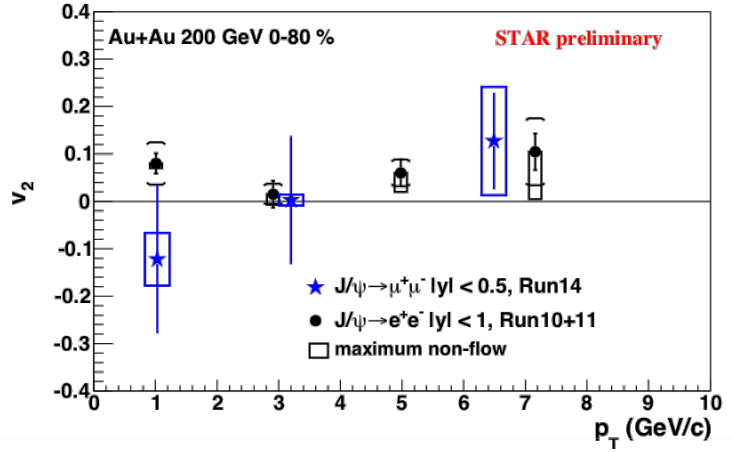


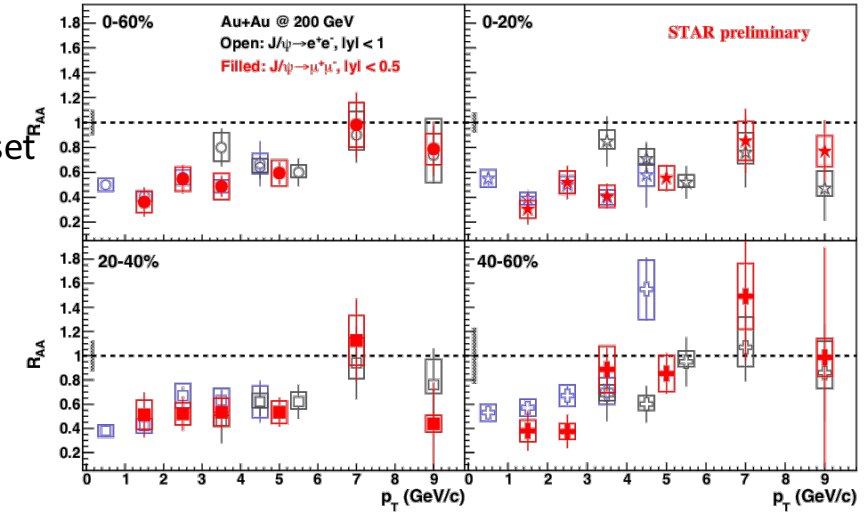
$J/\psi \rightarrow \mu^+\mu^-$(BR~6%) and $\Upsilon \rightarrow \mu^+\mu^-$(BR~2.5%)

- no γ conversion
- less Bremsstrahlung → better resolution
- less contribution from Dalitz decays
- trigger capability for J/ψ in central A+A

- Run 14 data with full MTD
  - analyses ongoing – results based on 30% of 2014 data set
  - ➢ J/ψ R_{AA}, v_2, and dN/dp_T
    - All confirm published dielectron results
  - ➢ Υ(2S+3S)/Υ(1S) ratio consistent with dielectron channel
    - Large error bars





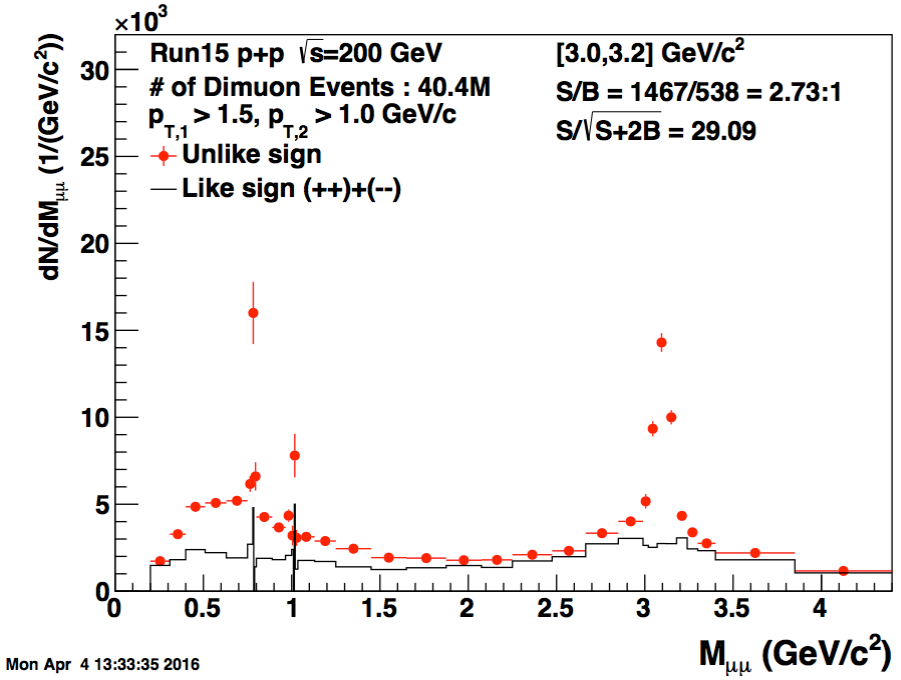


- Expect 7x statistics for Run14+16
- Use mixed-event background to further reduce v2

QM2015

Heavy-Ion Highlights: Run-15 dimuons

- Run 15 p+p data with full MTD
  - dimuon $M_{\mu\mu}$ invariant mass distribution
  - ➢ clear ω, ϕ, and J/ψ signals
  - analyses ongoing – results based on 13% of 2015 MTD-triggered data set

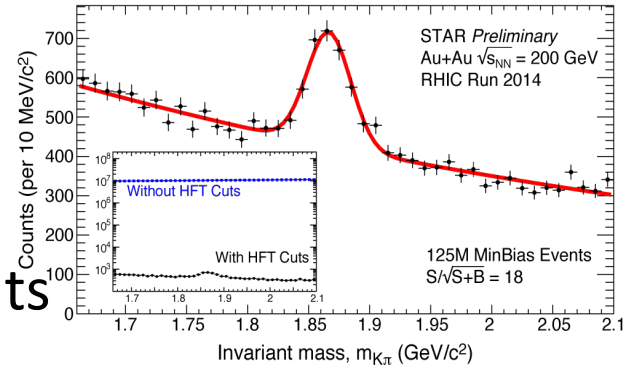


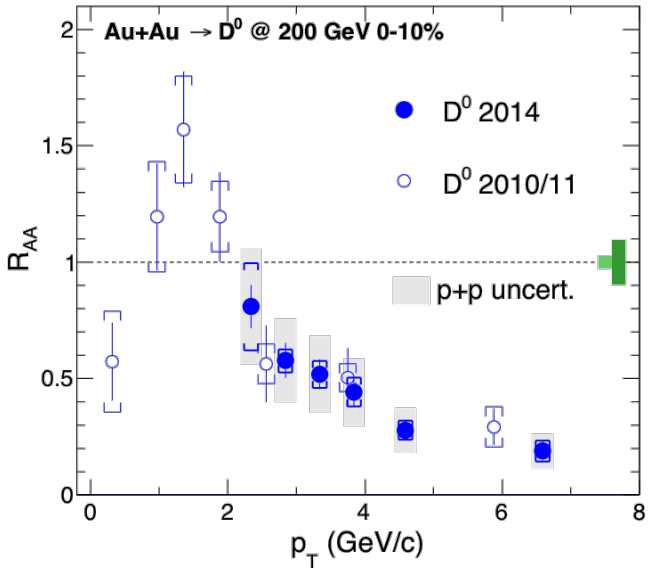
Heavy-Ion Highlights: Open Charm

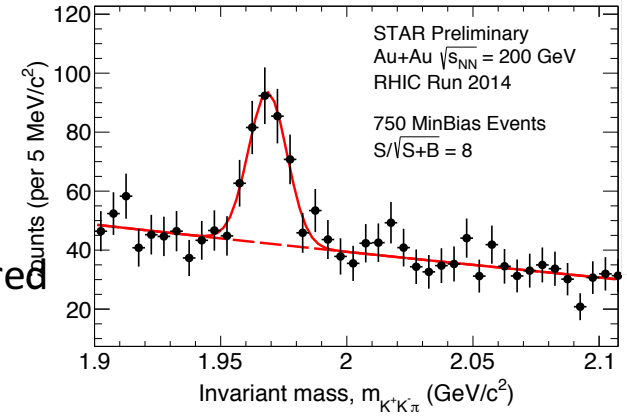
- HFT will enable high-precision open-charm measurements
  - thermalization and modification of charm?
  - ➢ charm v_2 and R_{AA}

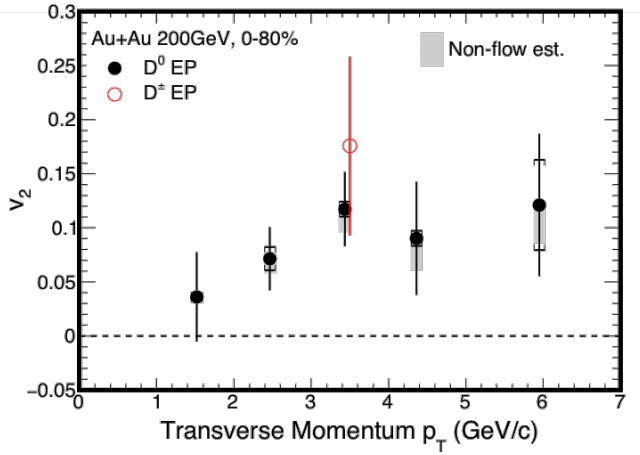
➢ clear D^0 signal with HFT
  - when compared without

- QM2015: 780M out of 1.2B minbias events
  - D^0 R_{AA} and $D^{0/\pm}$ v_2
    - Charm is produced early … will experience the full evolution
    - At LHC v_2 is compatible with light flavors … thermalized?
    - Seek simultaneous constrains to models
      - At low p_T : sensitive to partonic medium
      - At high p_T: test energy loss mechanisms
  - D_S measurements
    - ➢ Strangeness enhancement reflected in RAA (compared to other D)?
    - ➢ Effects of expected early freeze-out in a reduced elliptic flow?







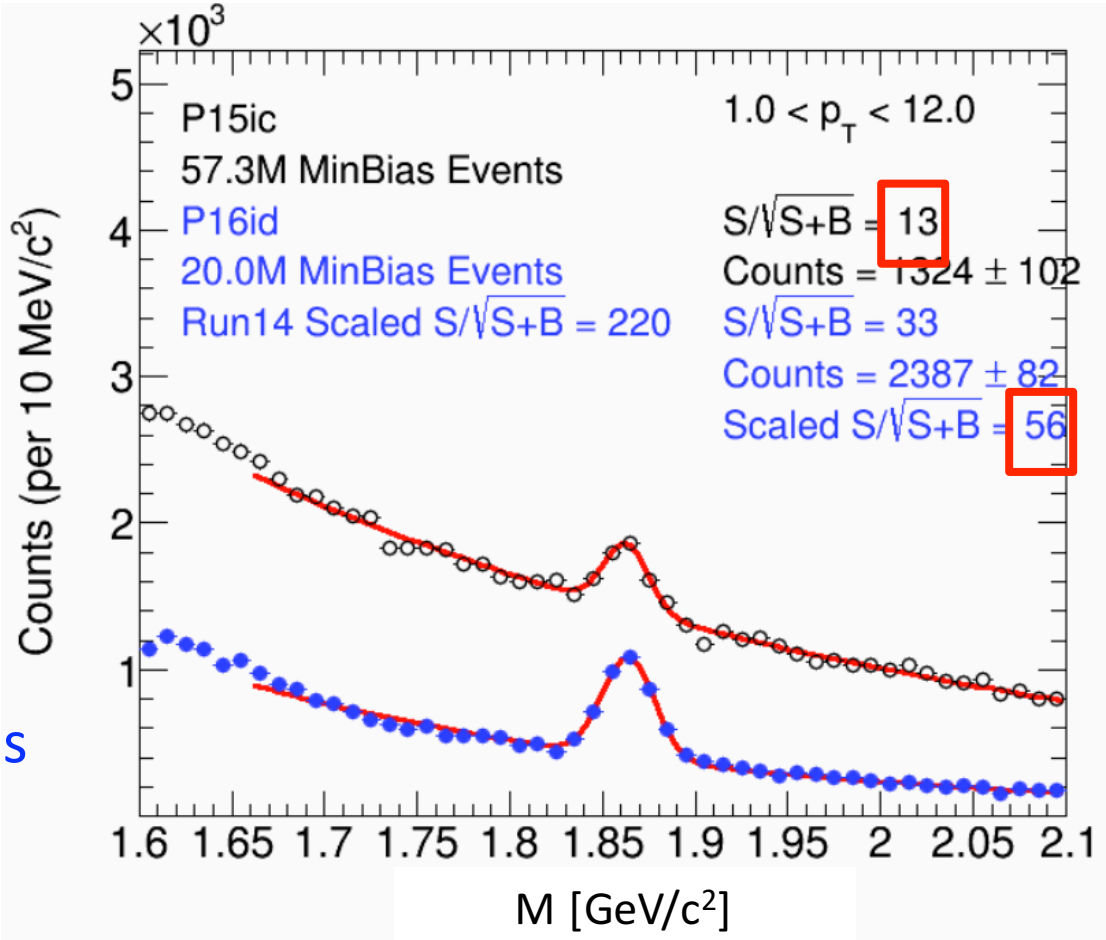


QM2015

Heavy Ion Highlights: Open Charm (2)

Current Status

- STAR initiated reproduction of Run-14 Au+Au
  - solved HFT decoding issue in the production software
  - significant improvement in single-track efficiencies
  - reproduction of HFT physics stream only



Improvement factor in D^0 significance is about 4 at low p_T, and 2-2.5 at high p_T

Summary

- STAR is fully engaged in the Runs 14 and 15 physics analyses
  - 14.5GeV data set concludes BES Phase-1
  - new HFT & MTD with improved DAQ and high luminosities
  - STAR has fully entered its high-precision Heavy-Flavor era
- Run 14 Au+Au production has finished; reproduction ongoing
  - significant improvement in HFT reconstruction
  - expect to see Λ_C in Run-14 data set!
- Run 15 productions are underway
  - FMS and RP streams have been done
  - p+p physics stream ongoing
- BES results and papers made available to heavy-ion community
  - include 14.5GeV results where possible

➢ Concerns remain on limited production and post-production resources
  - production: production times are (very) long
  - post-production: unable to sustain multiple large active data sets (run 14+15+16 …)

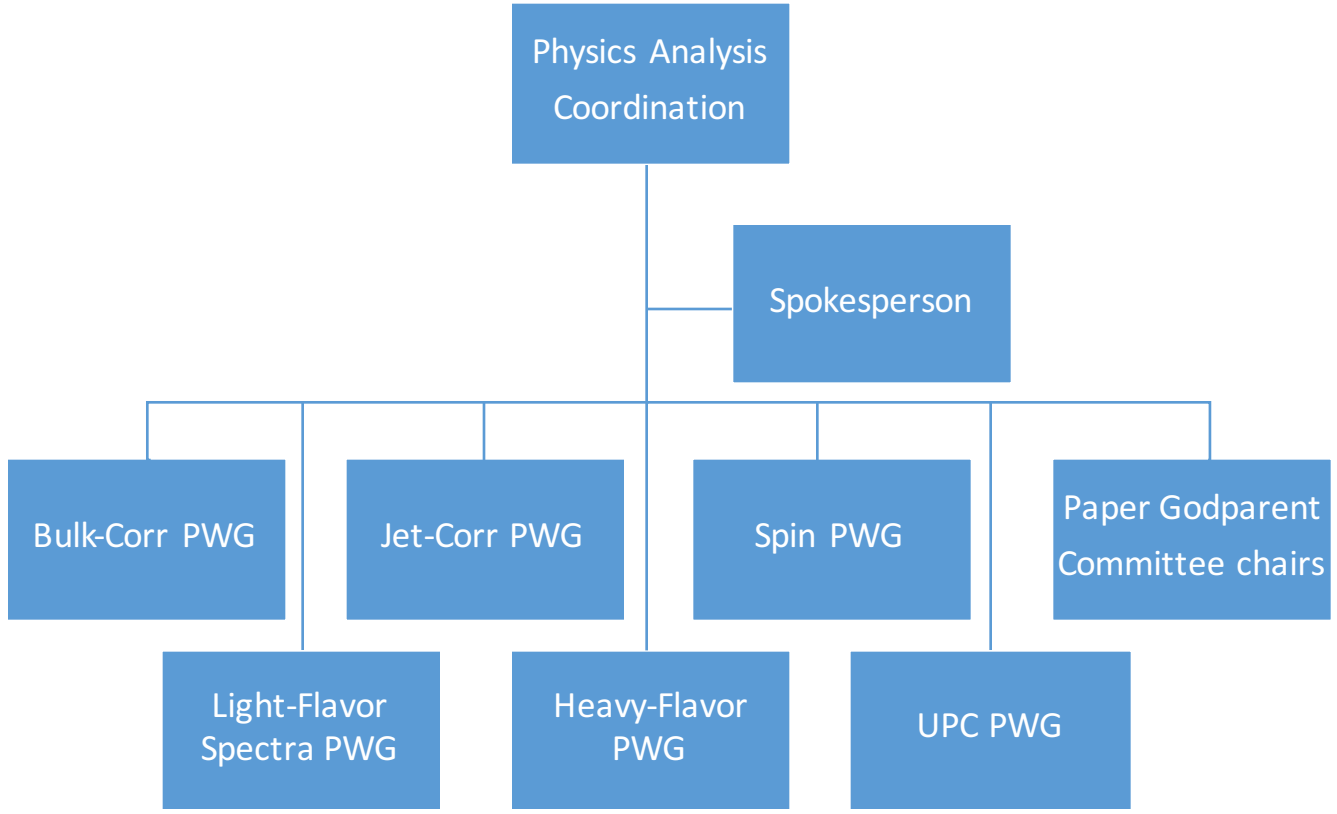
Backup

Physics Organization: PWGs & Editorial Board

New entity in STAR's editorial process

- GPC chairs and PWG conveners
- Track progress in GPC
- Quickly recognize issues that can benefit from direct PAC/convener involvement
- not a new layer

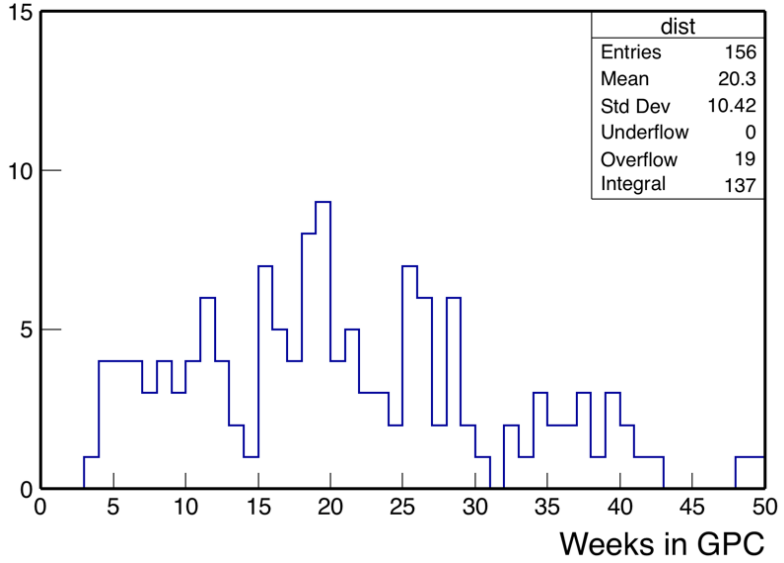
➢ Physics production priorities regularly reviewed and set by the joint PWGs

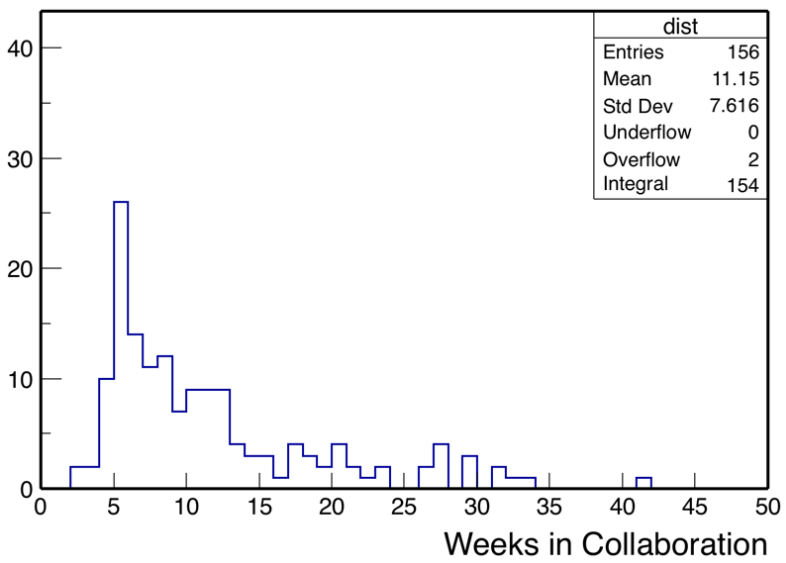


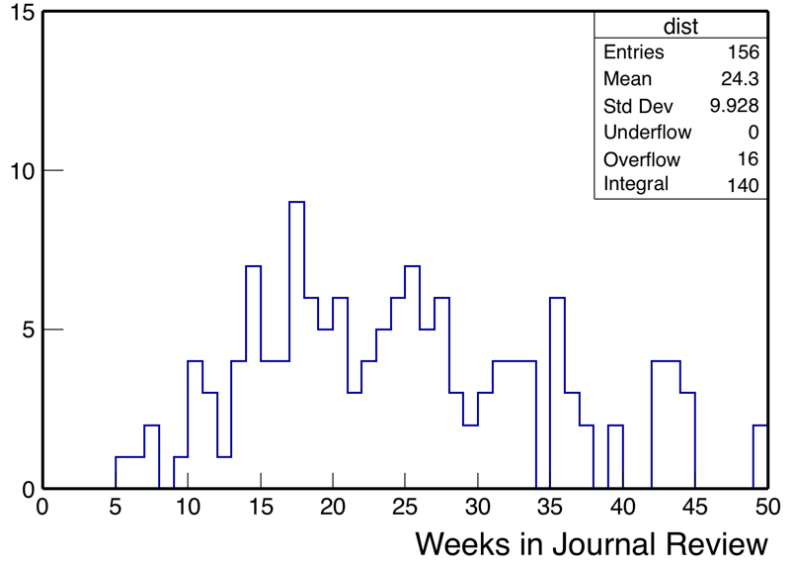
STAR Paper Proposal Tracking

Notes:

1. input to each plot involves published papers only
2. mean/std.dev based on truncation at 50 wks







Citation History :: Details

➢Two papers crossed from “famous” to “renowned” earlier this year

- Transverse momentum and centrality dependence of high-pT non-photonic electron suppression in Au+Au @200GeV
  - PRL 98 (2007) 192301, PRL 106 (2011) 159902

- Systematic Measurements of Identified Particle Spectra in pp,d+Au and Au+Au
  - Phys.Rev. C79 (2009) 034909