J/ψ Production and J/ψ-Hadron Correlations in p+p Collisions at √s=200 and 500 GeV with STAR

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Zhenyu Ye[1,2] (for the STAR collaboration)

1. University of Illinois at Chicago
2. Central China Normal University

UIC The University of Illinois at Chicago

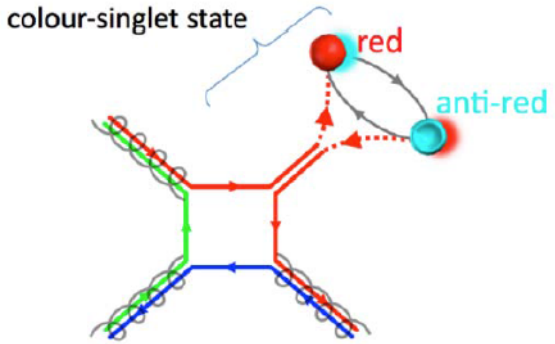
Office of Science U.S. DEPARTMENT OF ENERGY

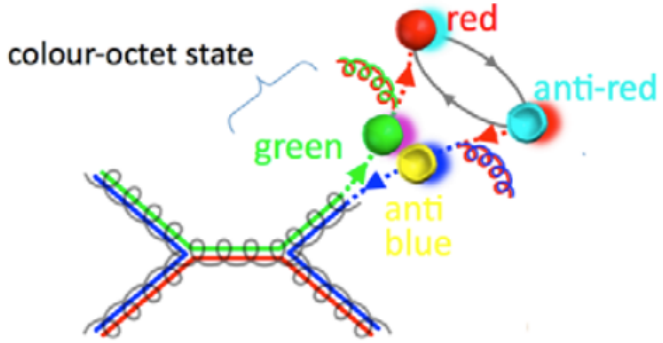
華中師範大學 HuaZhong Normal University

Motivation

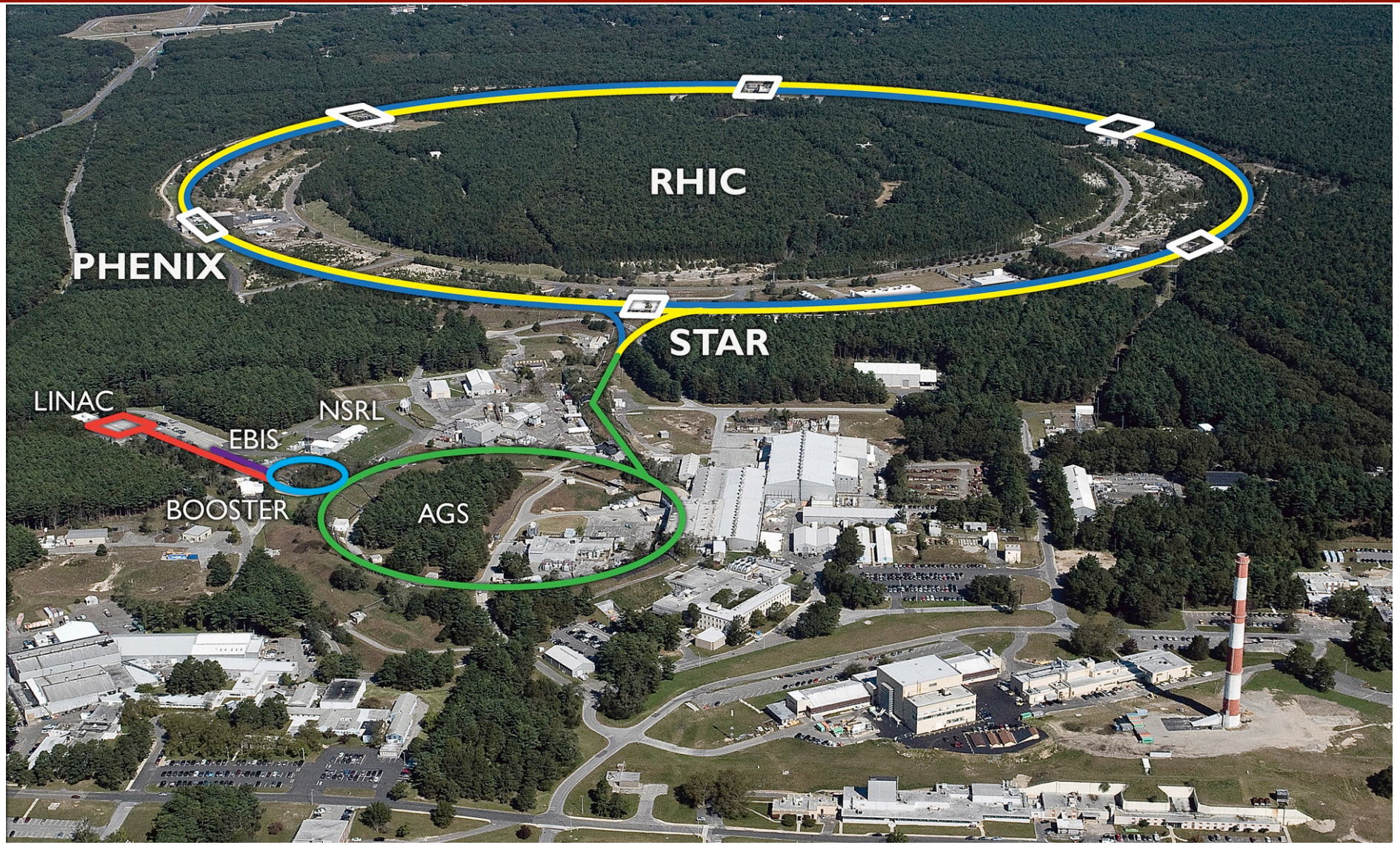
- Quarkonium production mechanisms in p+p collisions are not fully understood
  - Hard processes for heavy quark pair production - pQCD
  - Non-perturbative soft processes for hadronization – CEM, CSM, NRQCD

- More differential and comprehensive studies at different energies may shed new lights on quarkonium production and thus QCD
  - **J/ψ production cross-section**
  - **J/ψ yield vs event activity (N_{ch})**
  - **J/ψ-hadron azimuthal correlations**
  - **J/ψ polarization (S. Luo)**
  - …



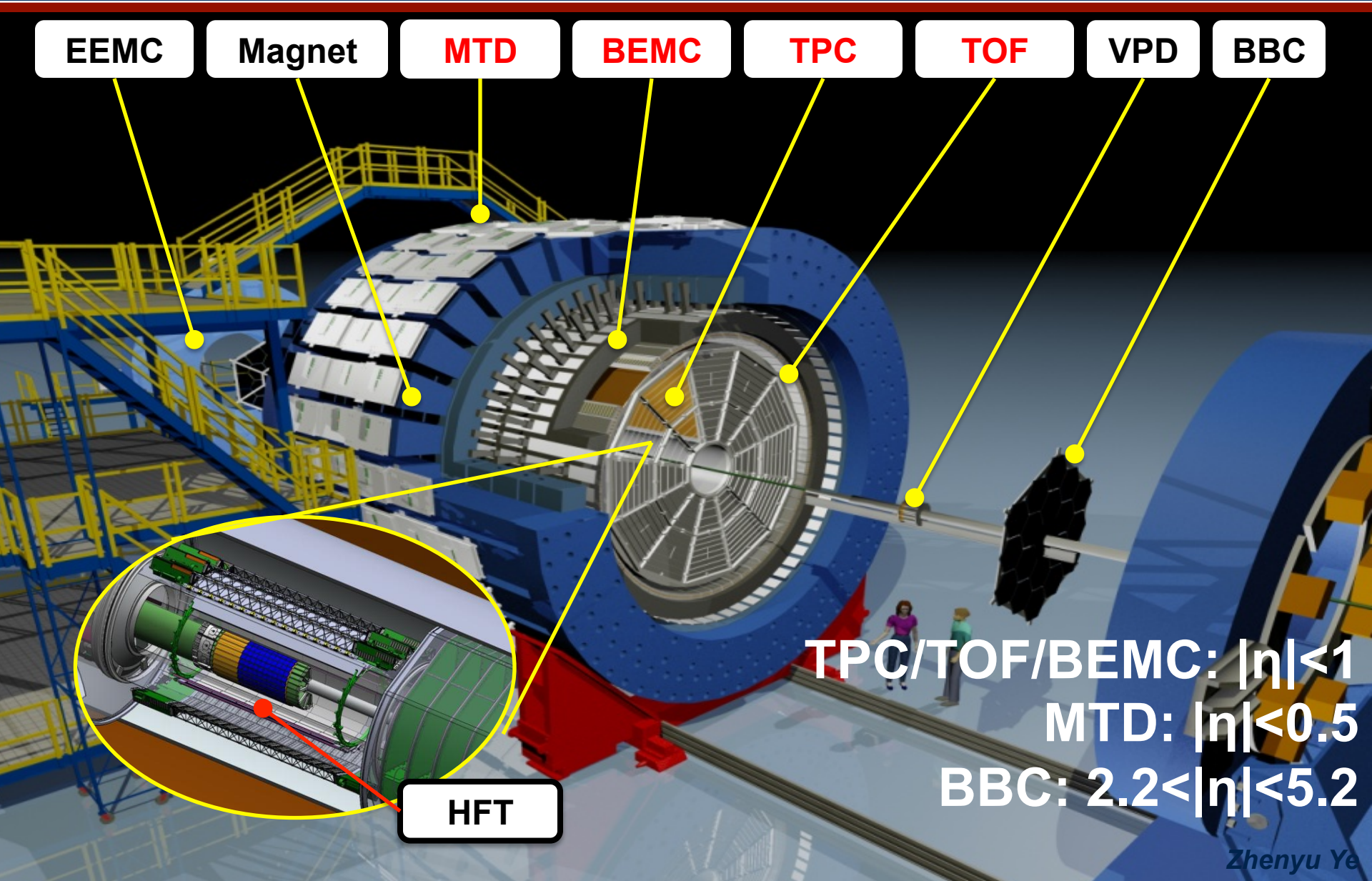


Relativistic Heavy Ion Collider



p+p (this talk), p+Au, d+Au, **Au+Au (T. Todoroki),** U+U, **…**

STAR Experiment at RHIC



Data in p+p Collisions by STAR

Year	√s (GeV)	Min. Bias	HT0 (pb^{-1})	HT1 (pb^{-1})	HT2 (pb^{-1})	HT3 (pb^{-1})	dimuon (pb^{-1})	Measurement Status
2005	200			2.8				PRC**80** (2009) 041902
2006	200				11.3			
2009	200	77M	1.9			23		PLB**722** (2013) 55 PRC (arXiv1602.02212)
2011	**500**			**22**				**This Talk**
2012	**200**	400M	**1.4**		**24**			**This Talk**
2013	**500**						**28**	**This Talk**
2015	200	1.1B		38	120		120	Study underway
2017	500				300		300	Data to-be-taken

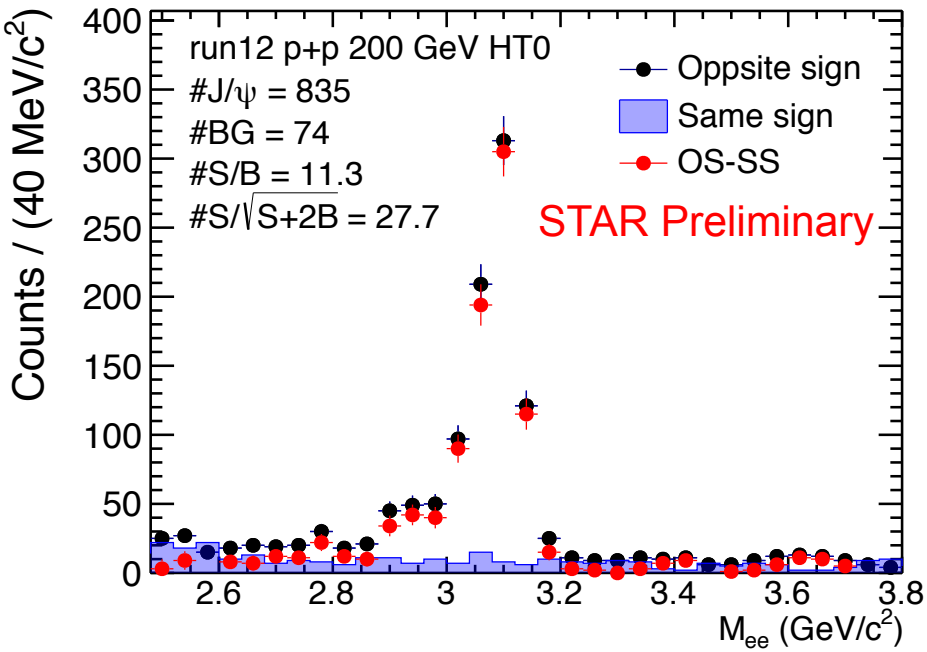
Electron trigger threshold (electron E_T):

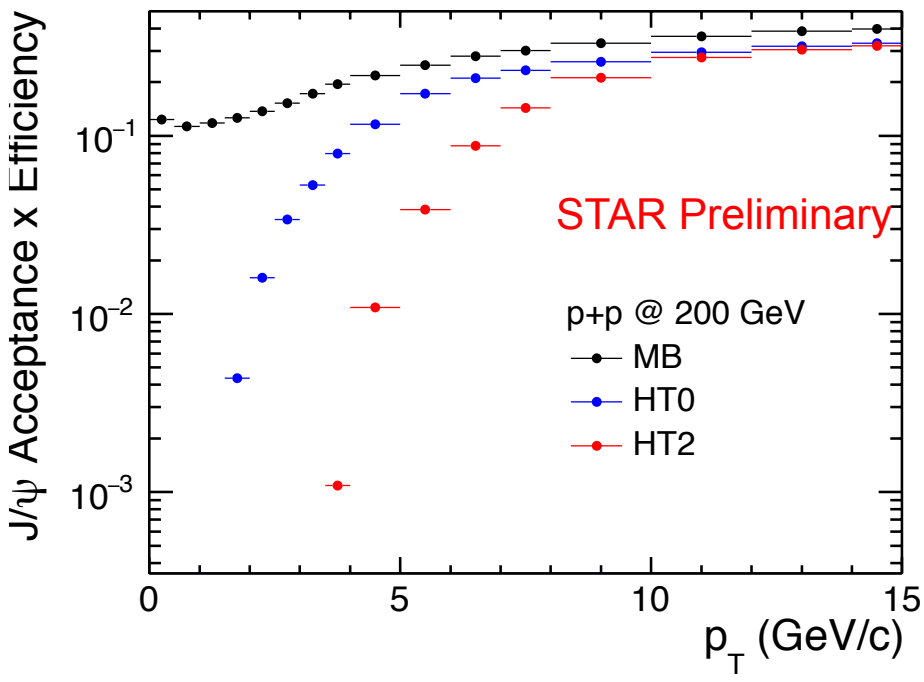
200GeV: HT0~2.6 GeV, HT1~3.5 GeV, HT2~4.3 GeV, HT3~6.0 GeV

500GeV: HT1~4.3 GeV, HT2~6.0 GeV

Dimuon trigger threshold (muon p_T): ~1.2 GeV/c

J/ψ Reconstruction





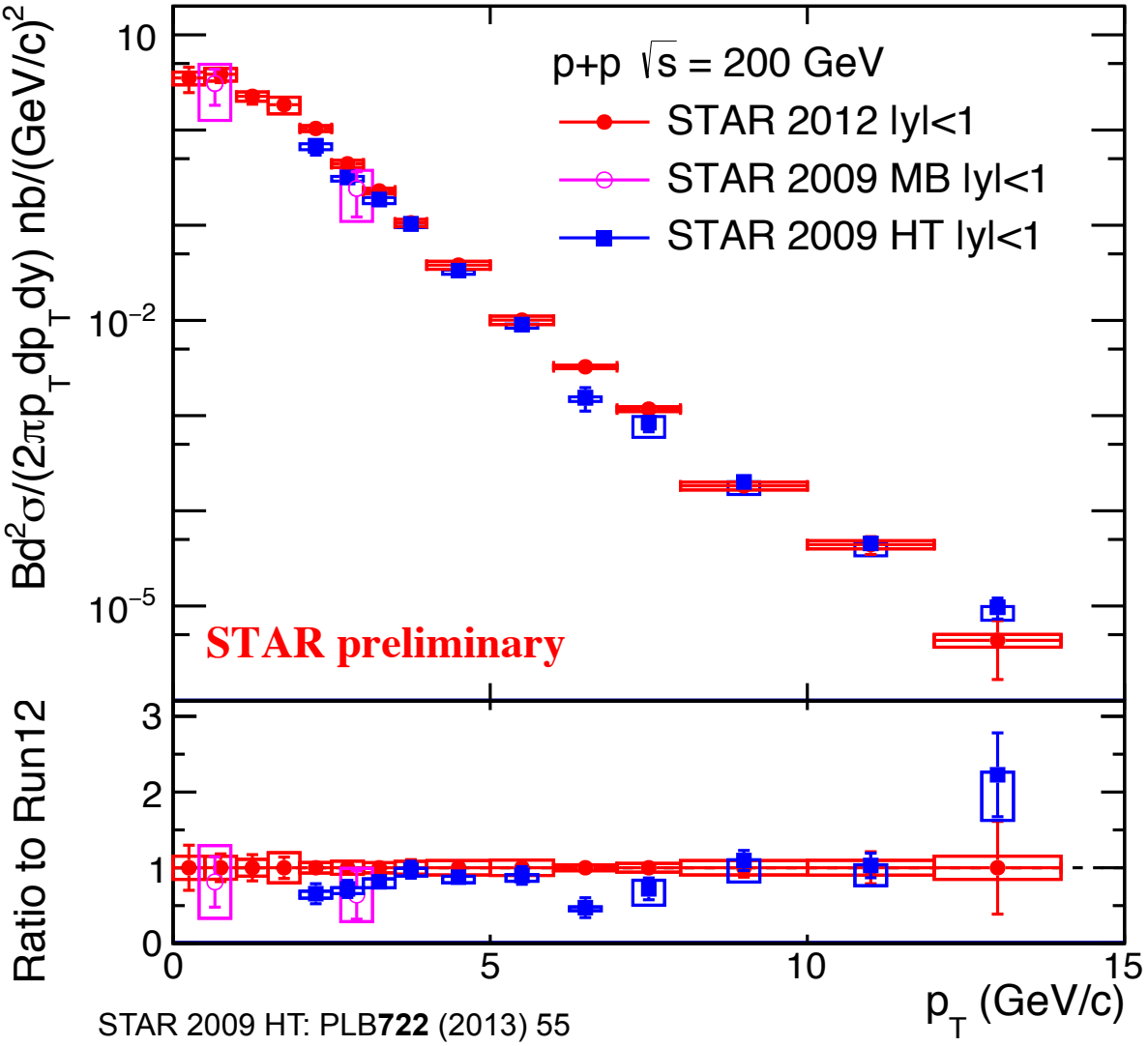
dielectron channel:

- triggered electron p_T>2.5/3.6/4.3 GeV/c
  partner electron p_T>0.2 GeV/c
- $|\eta_e|<1$
- $2.9<m_{ee}<3.2$ GeV/c^2
- $|y_{J/\psi}|<1$

dimuon channel:

- p_{T1} >1.5 GeV/c
  p_{T2}>1.2 GeV/c
- $|\eta_\mu|<0.8$
- $2.9<m_{ee}<3.2$ GeV/c^2
- $|y_{J/\psi}|<0.5$

J/ψ Cross-Section at 200 GeV



STAR 2012 data preliminary

$$B_{ee}\frac{d\sigma_{J/\psi}}{dy} = 47.3 \pm 2.9 \pm 6.1 \pm 3.8\ nb$$

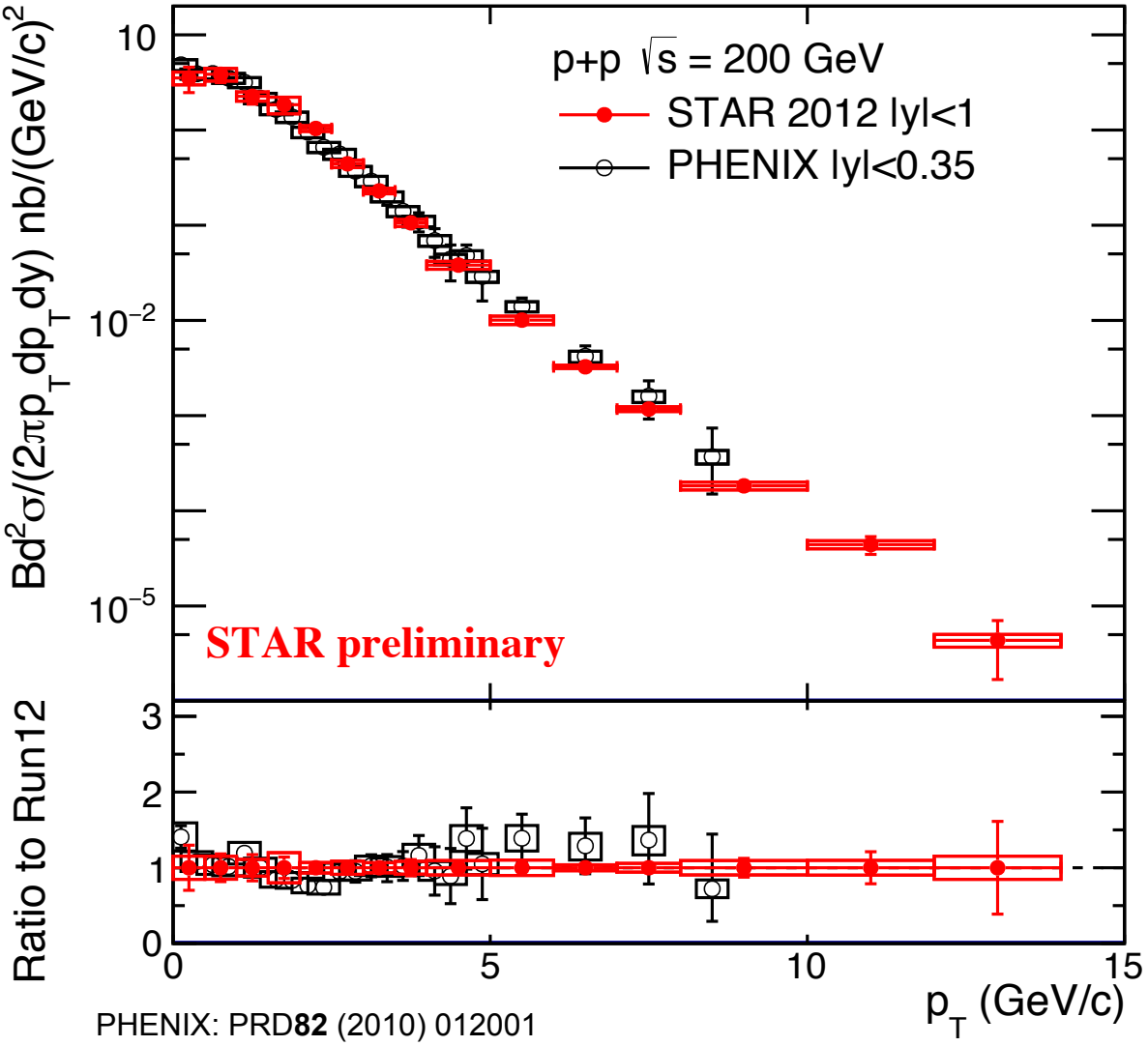
STAR 2009 data published

$$B_{ee}\frac{d\sigma_{J/\psi}}{dy} = 38 \pm 11 \pm 16\ nb$$

- Significant improvement at p_T<2 GeV/c and >6 GeV/c from 2012 MB and HT2 data

STAR 2009 HT: PLB**722** (2013) 55
STAR 2009 MB: PRC (arXiv1602.02212)

J/ψ Cross-Section at 200 GeV



PHENIX: PRD**82** (2010) 012001

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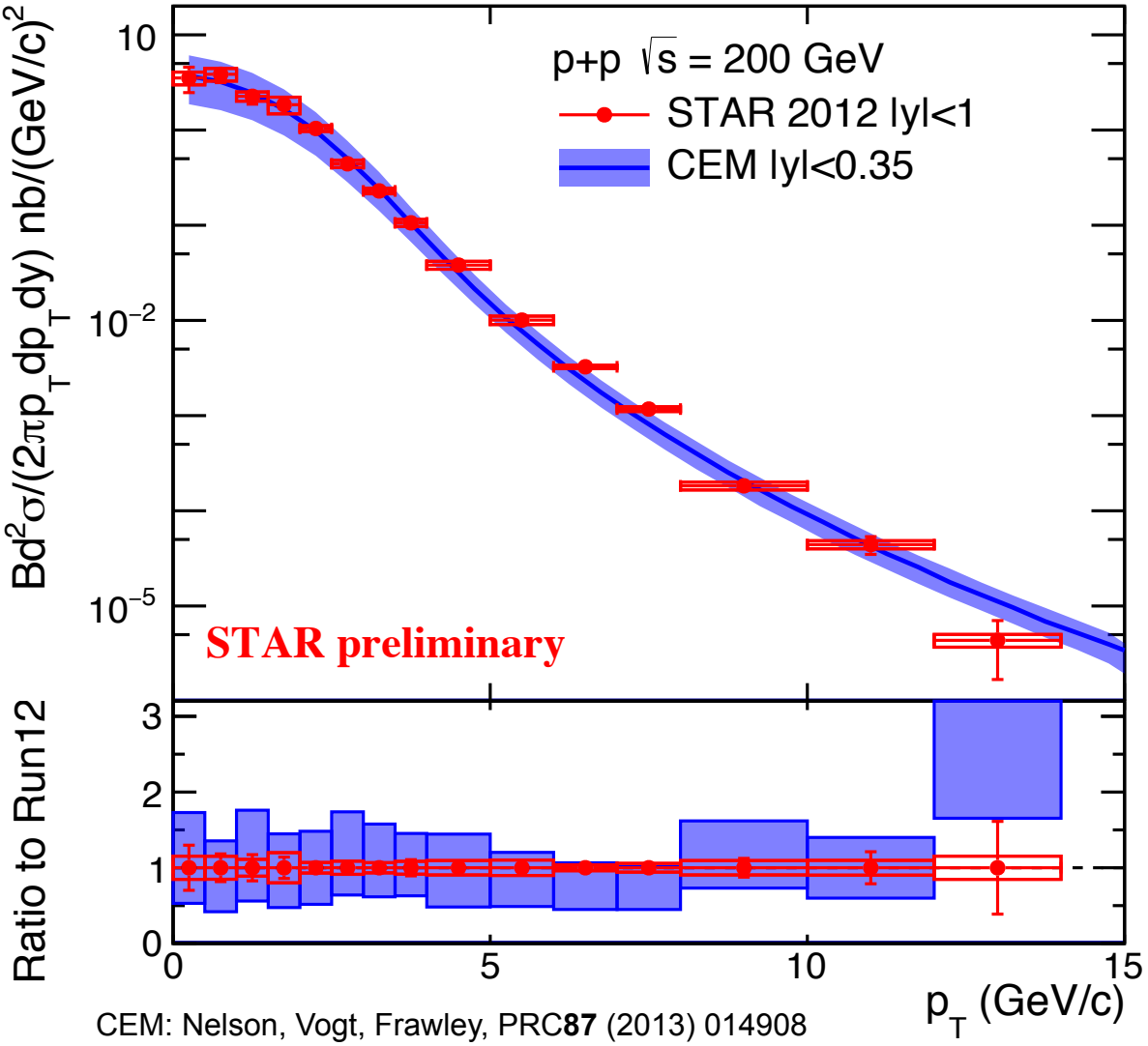
PHENIX

$$B_{ee}\frac{d\sigma_{J/\psi}}{dy} = 42.5 \pm 1.4 \pm 4.8 \pm 3.1\ nb$$

- Significant improvement at p_T<2 GeV/c and >6 GeV/c from 2012 MB and HT2 data
- Consistency with PHENIX result; Better precision at p_T>2 GeV/c

J/ψ Cross-Section at 200 GeV



CEM: Nelson, Vogt, Frawley, PRC**87** (2013) 014908

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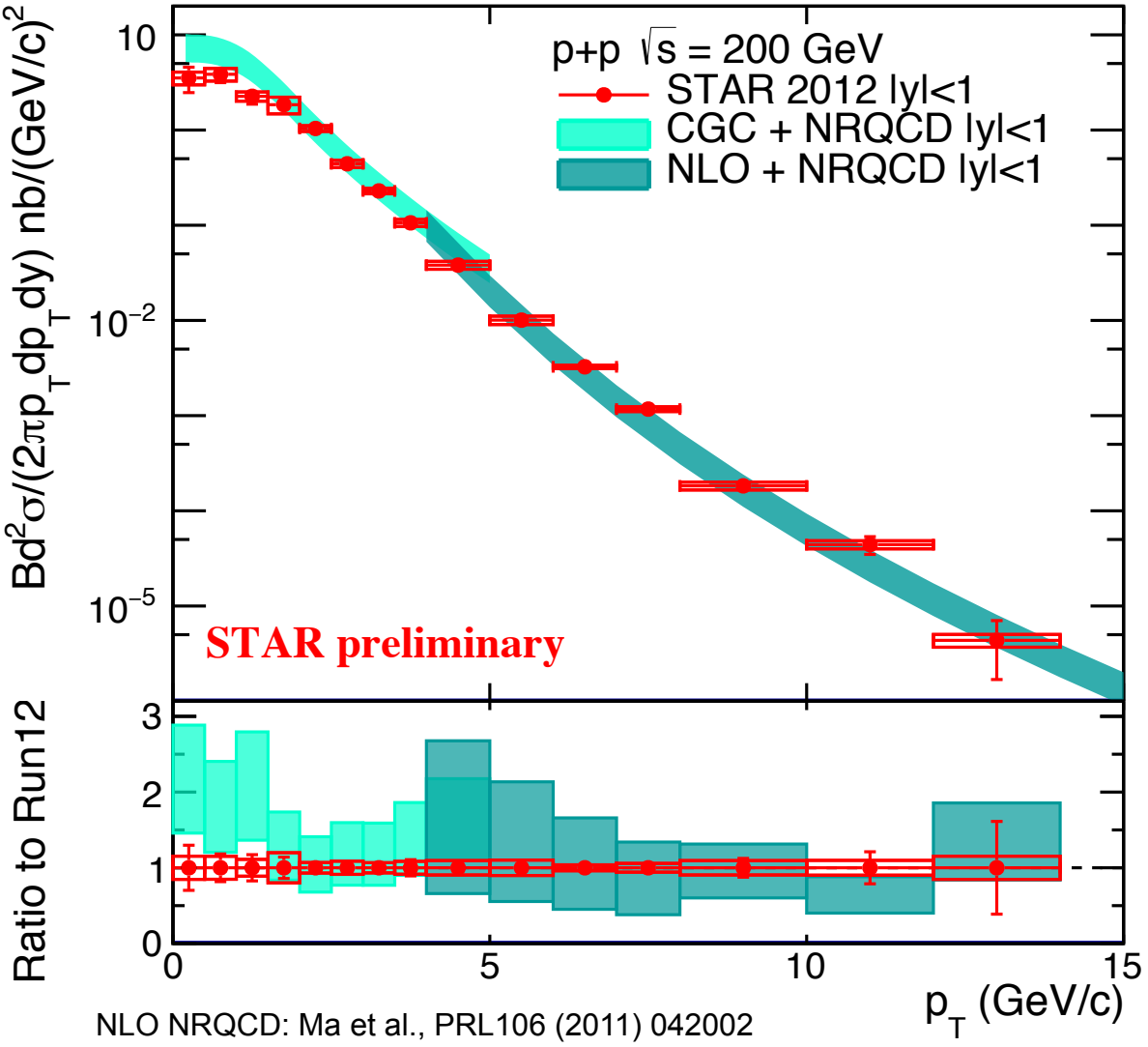
- Significant improvement at p_T<2 GeV/c and >6 GeV/c from 2012 MB and HT2 data
- Consistency with PHENIX result; Better precision at p_T>2 GeV/c
- CEM describes data very well

J/ψ Cross-Section at 200 GeV



NLO NRQCD: Ma et al., PRL106 (2011) 042002
CGC+NRQCD: Ma, Venugopalan, PRL**113** (2014) 192301

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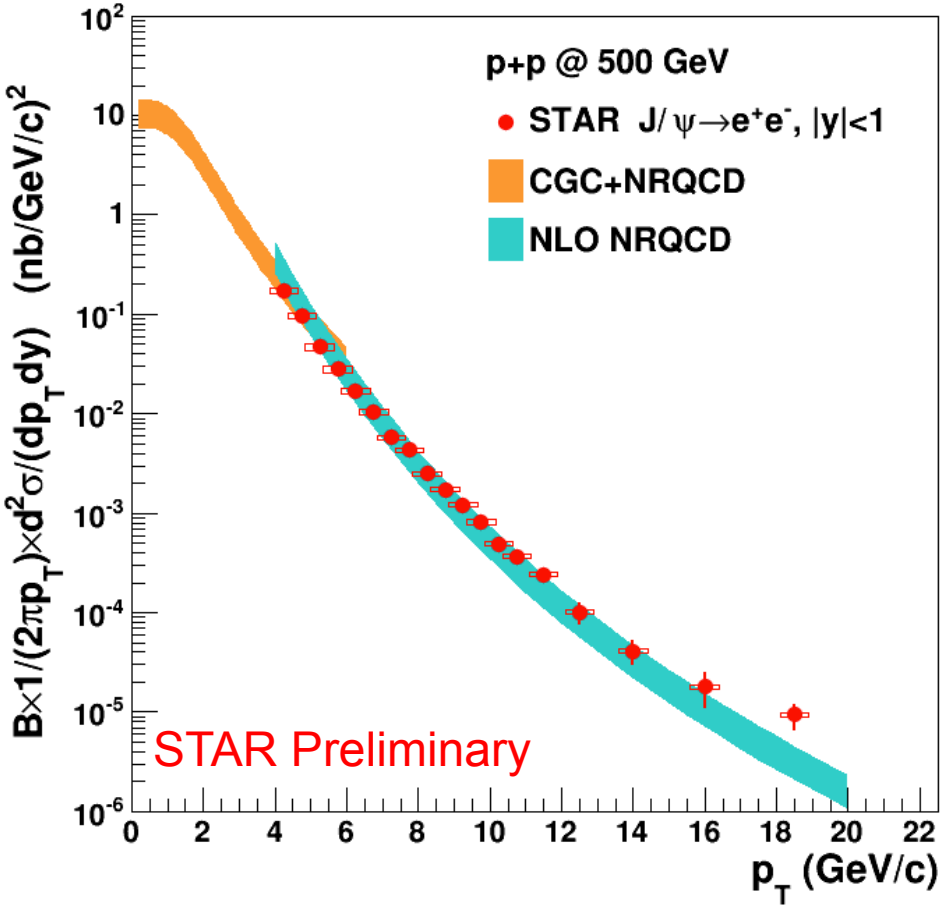
PHENIX

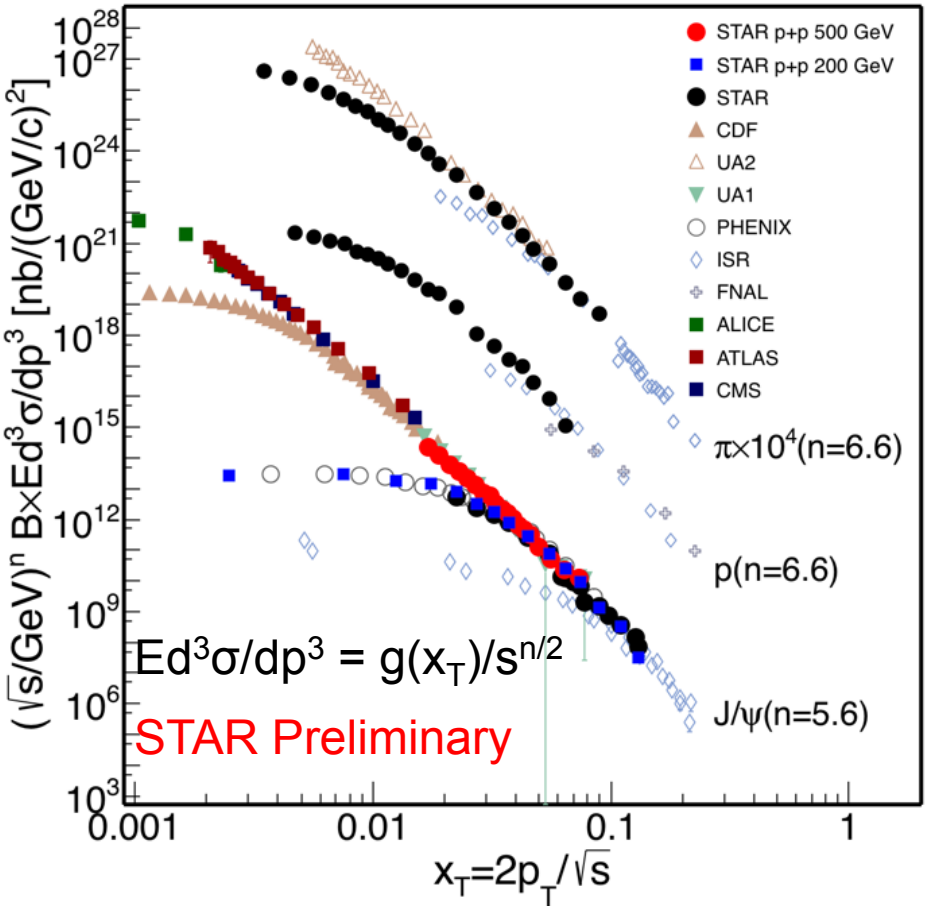
$$B_{ee}\frac{d\sigma_{J/\psi}}{dy} = 42.5 \pm 1.4 \pm 4.8 \pm 3.1\ nb$$

- Significant improvement at p_T<2 GeV/c and >6 GeV/c from 2012 MB and HT2 data
- Consistency with PHENIX result; Better precision at p_T>2 GeV/c
- CEM describes data very well
- NRQCD describes data fairly well; Small tension at p_T<1.5 GeV/c with CGC+NRQCD

J/ψ Cross-Section at 500 GeV



PRC**80** (2009) 041902



- Precise measurement at 500 GeV for high p_T (4-19 GeV/c) J/ψ production
- CGC+NRQCD and NLO NRQCD describes data quite well
- x_T scaling broken below certain x_T ➔ transition from hard to soft process

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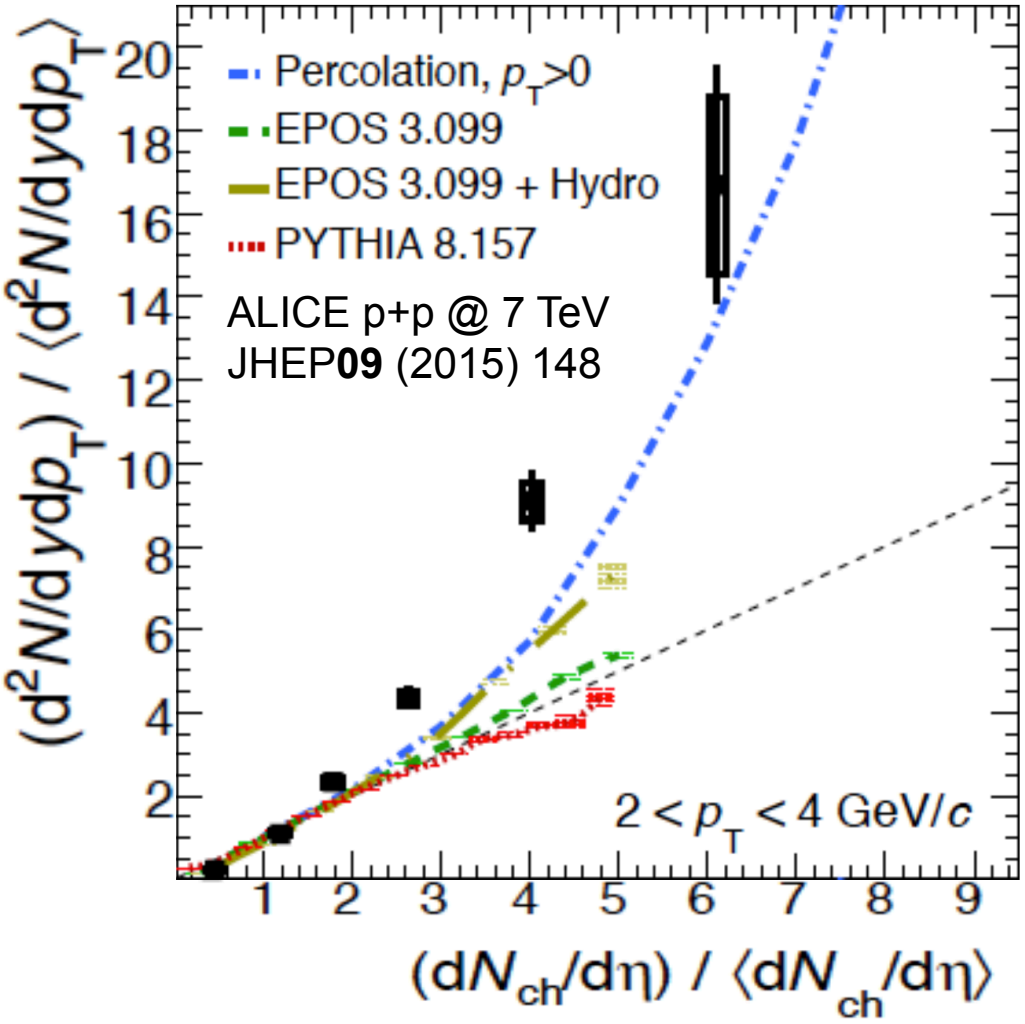
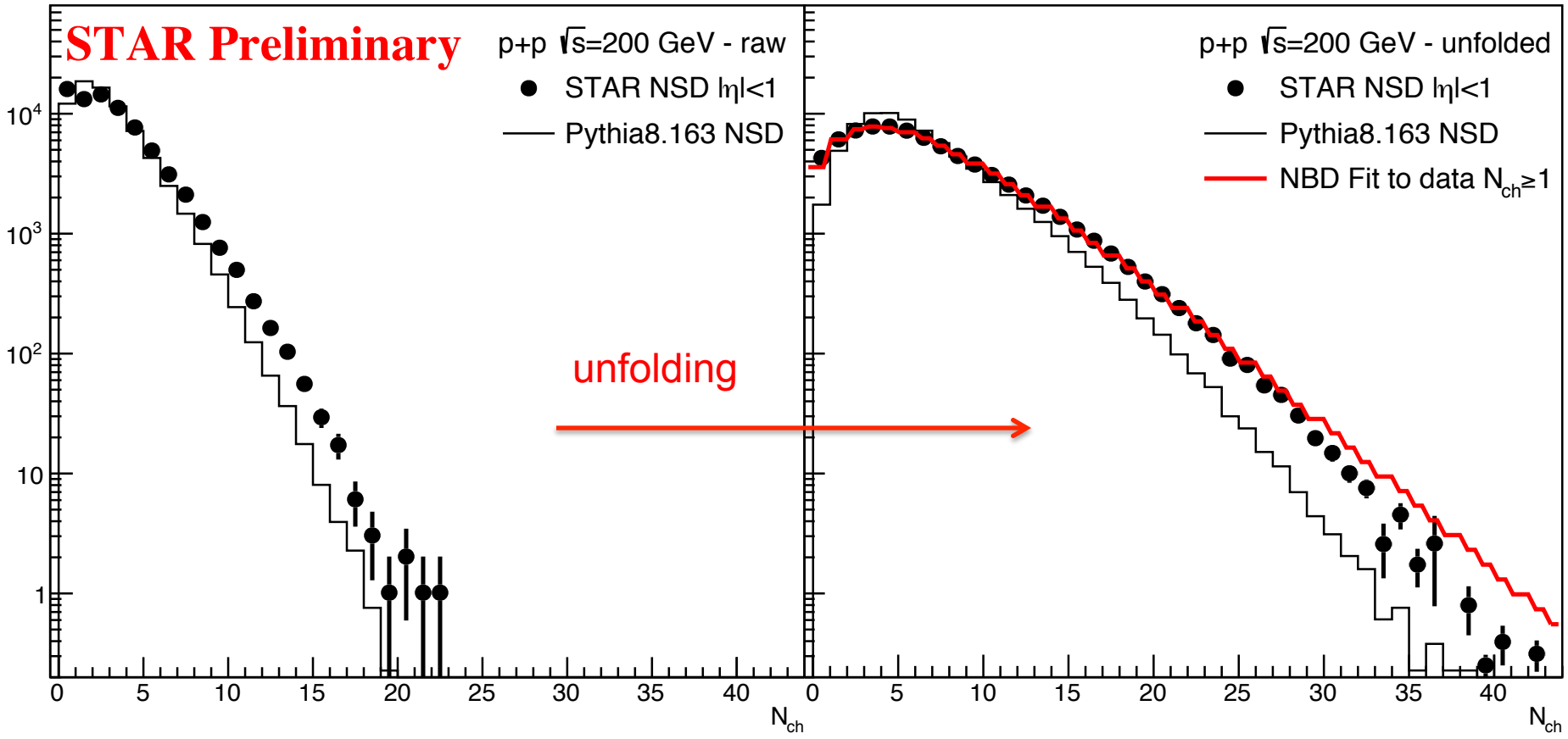
J/ψ Yield vs Event Activity (N_{ch})



Faster-than-linear rise of open charm production vs N_{ch} in p+p @ 7 TeV

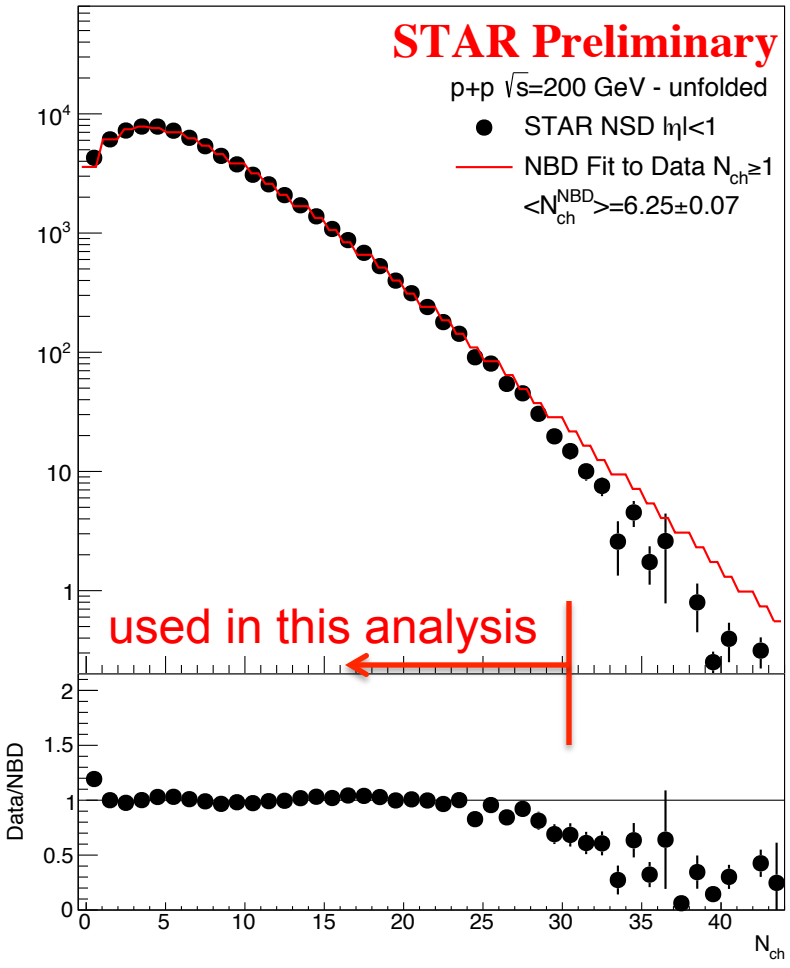
- **Percolation model**: exchange color sources in collisions. High energy density suppresses soft process more than hard process
  N_{hard} rises faster than N_{ch}
- **EPOS3**: Gribov-Regge multiple parton scattering for initial conditions,
  $N_{hard} \propto N_{ch} \propto N_{MPI}$
- **EPOS3+Hydro**: energy density in 7 TeV p+p is high enough to apply hydrodynamic evolution to the core of the collisions.
  N_{hard} rises faster than N_{ch}
- **PYTHIA8**: including Multiple-Parton-Interaction
  $N_{hard} \propto N_{ch} \propto N_{MPI}$

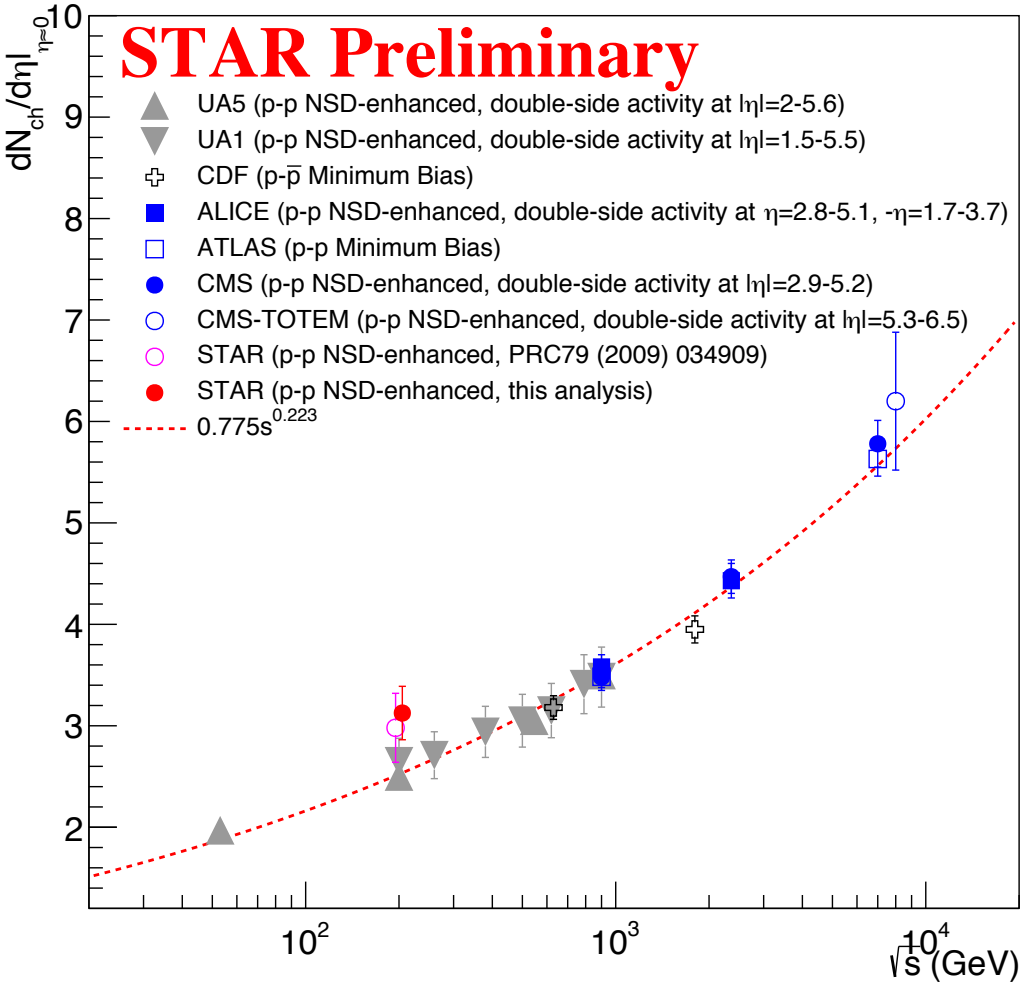
Measure N_{ch} at STAR



- Charged particles with p_T>0.2 GeV/c and |η|<1 are reconstructed by TPC and matched with TOF hits in NSD-enhanced (BBC 2.2<|η|<5.2) events.
- Raw N_{ch} distributions are unfolded to p_T>0 GeV/c and |η|<1 (corrected for detector efficiency and strange particle decays)

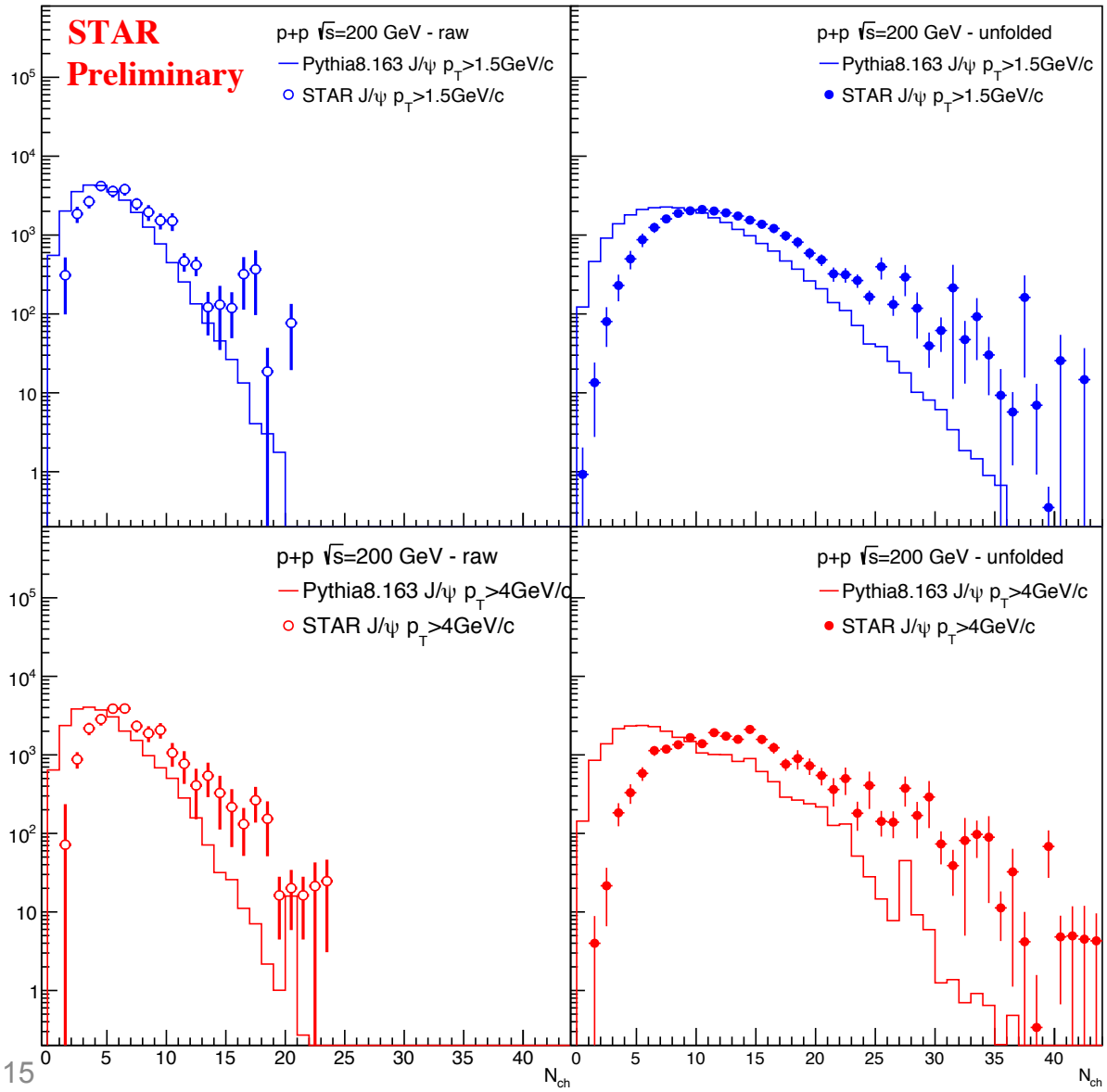
N_{ch} in p+p Collisions at 200 GeV





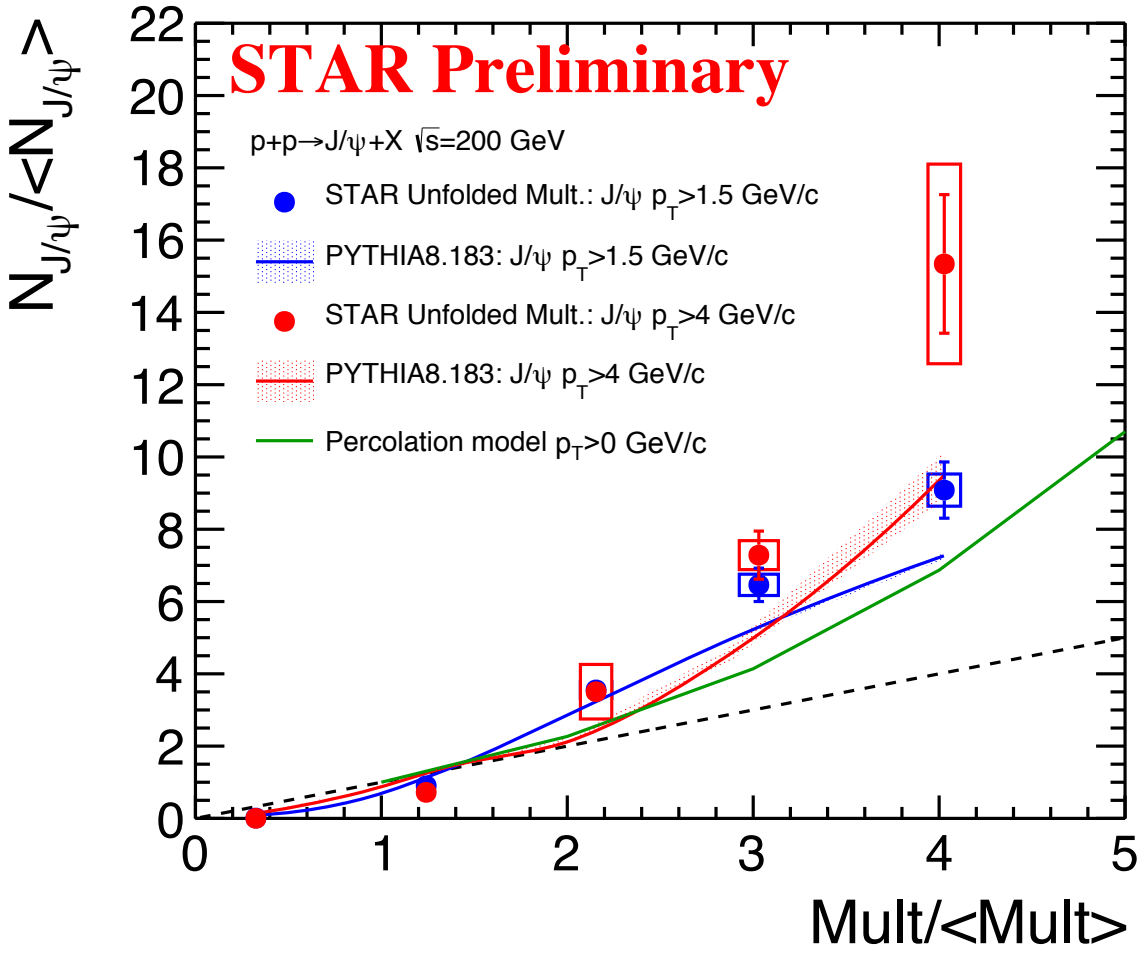
- Unfolded N_{ch} distribution can be described by negative binomial distribution.
- $dN_{ch}/d\eta$=3.13±0.27 consistent with previous STAR result 2.98±0.34

J/ψ Yield vs N_{ch} – 200 GeV



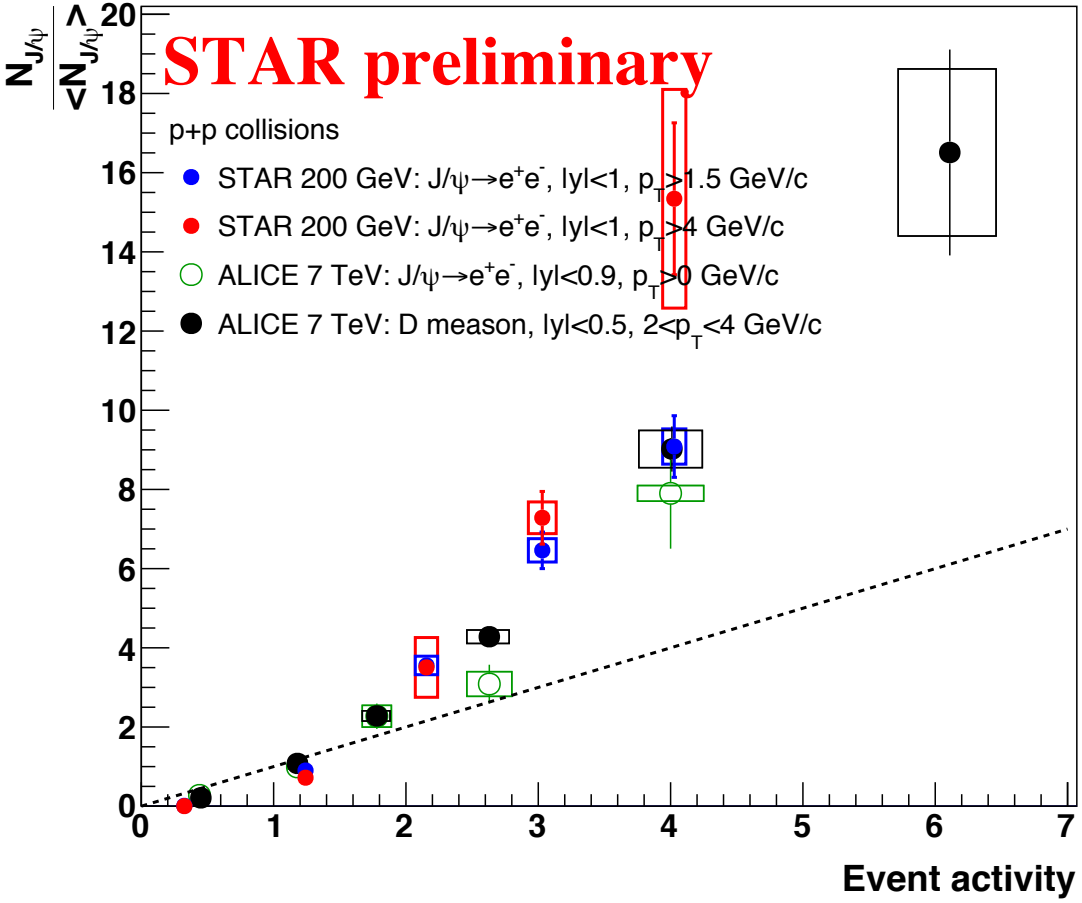
- Unfolded N_{ch} distribution for J/ψ events can not be described by PYTHIA8. $\langle N_{ch} \rangle$ in data higher than that in PYTHIA8 for J/ψ production.

J/ψ Yield vs N_{ch} – 200 GeV



- Unfolded N_{ch} distribution for J/ψ events can not be described by PYTHIA8. $<N_{ch}>$ in data higher than that in PYTHIA8 for J/ψ production.
- Relative J/ψ yield vs N_{ch} increases faster than linear. Such an increase is also seen by PYTHIA8 and Percolation model but underestimated.

J/ψ Yield vs N_{ch} – RHIC vs LHC

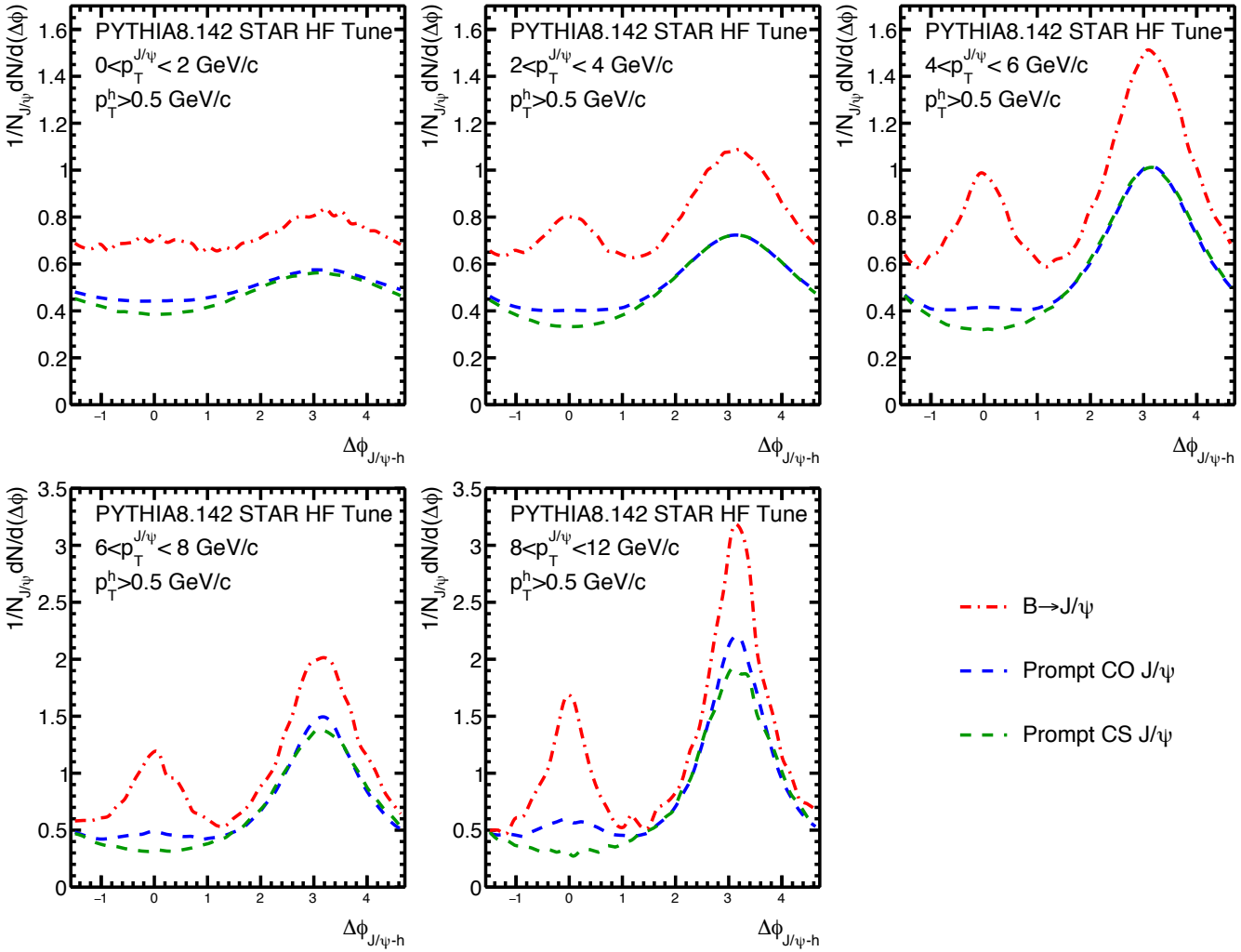


The results at 200 GeV and 7 TeV seem to follow a global trend:

- **Percolation model**: very small collision energy dependence **N_{hard} rises faster than N_{ch} at both RHIC and LHC**
- **EPOS3+Hydro**: Expect strong collision energy dependence, and thus smaller difference to EPOS3 w/o Hydro at lower collision energy **$N_{hard} \propto N_{ch} \propto N_{MPI}$ at 200 GeV?**
- **PYTHIA8**: underestimate data in both 200 GeV and 7 TeV

It will be interesting to see EPOS3 with and without Hydro calculations for 200 and 500 GeV (results underway) to compare with STAR J/ψ data

J/ψ-Hadron Azimuthal Correlations



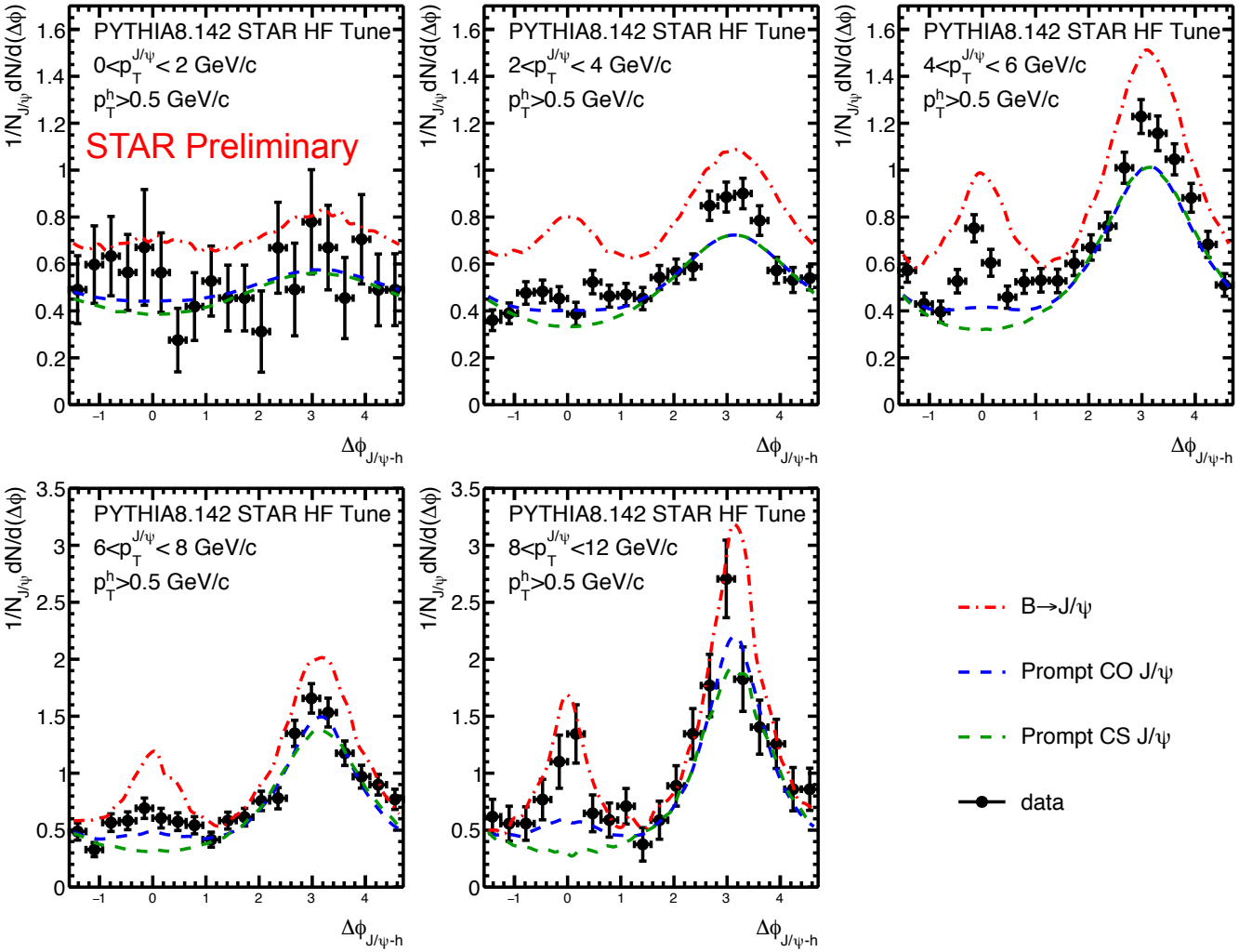
J/ψ-hadron azimuthal correlations sensitive to production mechanisms:

- Non-prompt J/ψ from B hadron decays have significantly higher near and away side peaks than prompt J/ψ.
- Prompt J/ψ produced from intermediate CS and CO states have similar away-side peaks, but different near-side peaks

Can be used to extract different contributions?

Templates coming directly from PYTHIA8

J/ψ-Hadron Azimuthal Correlations



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- Prompt J/ψ produced from intermediate CS and CO states have similar away-side peaks, but different near-side peaks

Can be used to extract different contributions?

- data analysis in progress

Data not fully corrected for acceptance and efficiency

Zhenyu Ye

Summary and Outlook

- J/ψ production in p+p collisions at 200 and 500 GeV has been studied in great details at STAR
  - **differential production cross-section vs J/ψ p_T**

  CEM and NRQCD describe data with small tension at low p_T by CGC+NRQCD
  - **yield vs event activity (N_{ch})**

  Stronger-than-linear rise following the same trend at 200 GeV and 7 TeV, probably not a hot medium effect but something more fundamental
  - **J/ψ-h azimuthal correlations**

  Potential to separate different contributions? work in progress
  - J/ψ polarization (S.Luo)

- More precise results with significantly increased (5-10) data size and upgraded STAR detectors can be expected.
  - Heavy Flavor Track for non-prompt J/ψ
  - Muon Telescope Dector for low p_T J/ψ