J/ψ Production and J/ψ-Hadron Correlations in p+p Collisions at $\sqrt{s}$=200 and 500 GeV with STAR

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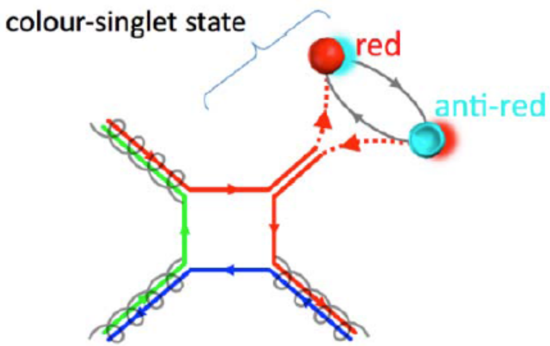
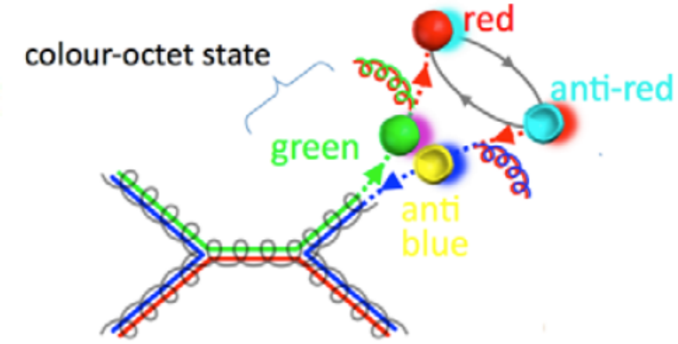
Motivation

- 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)**
  - …





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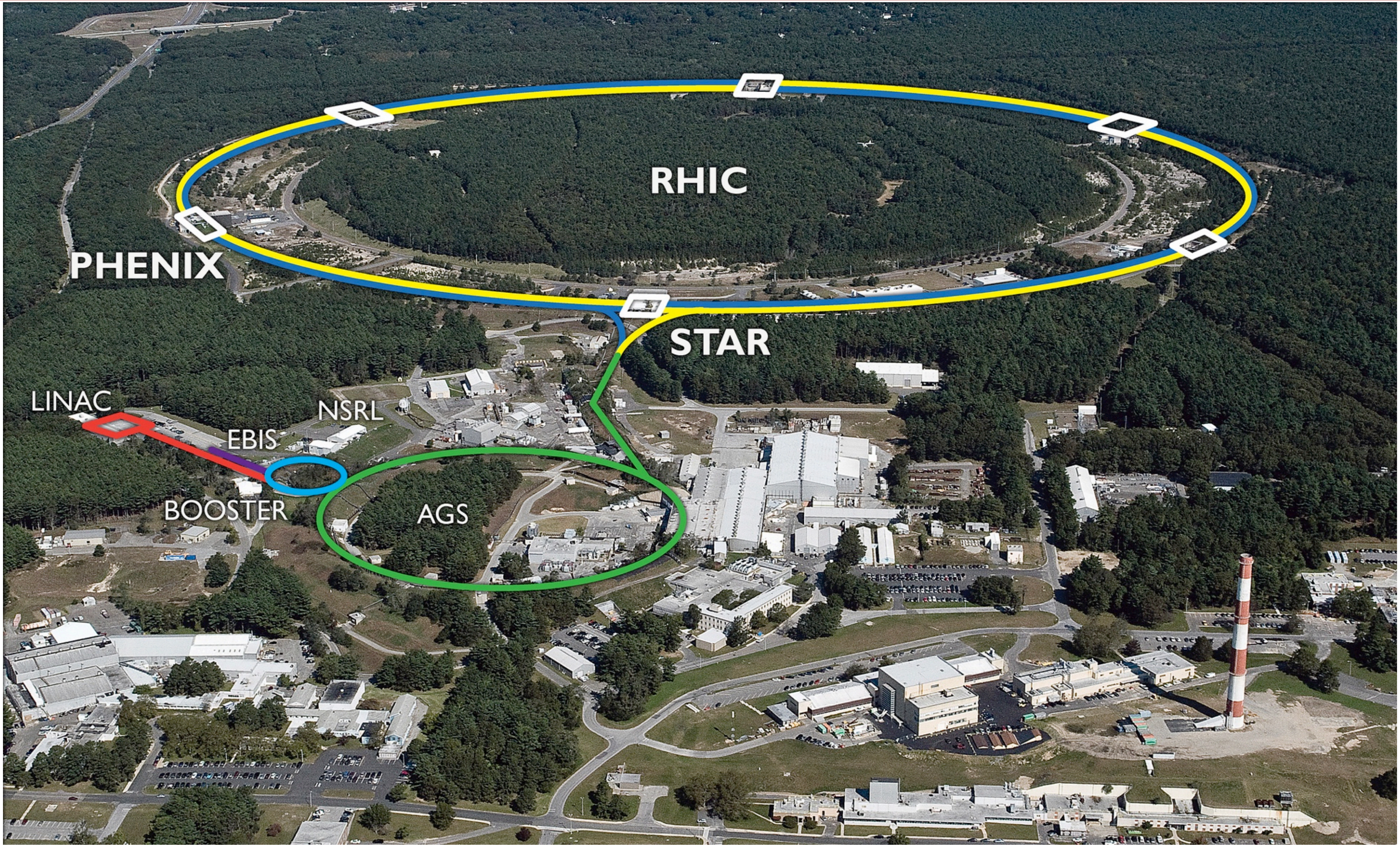
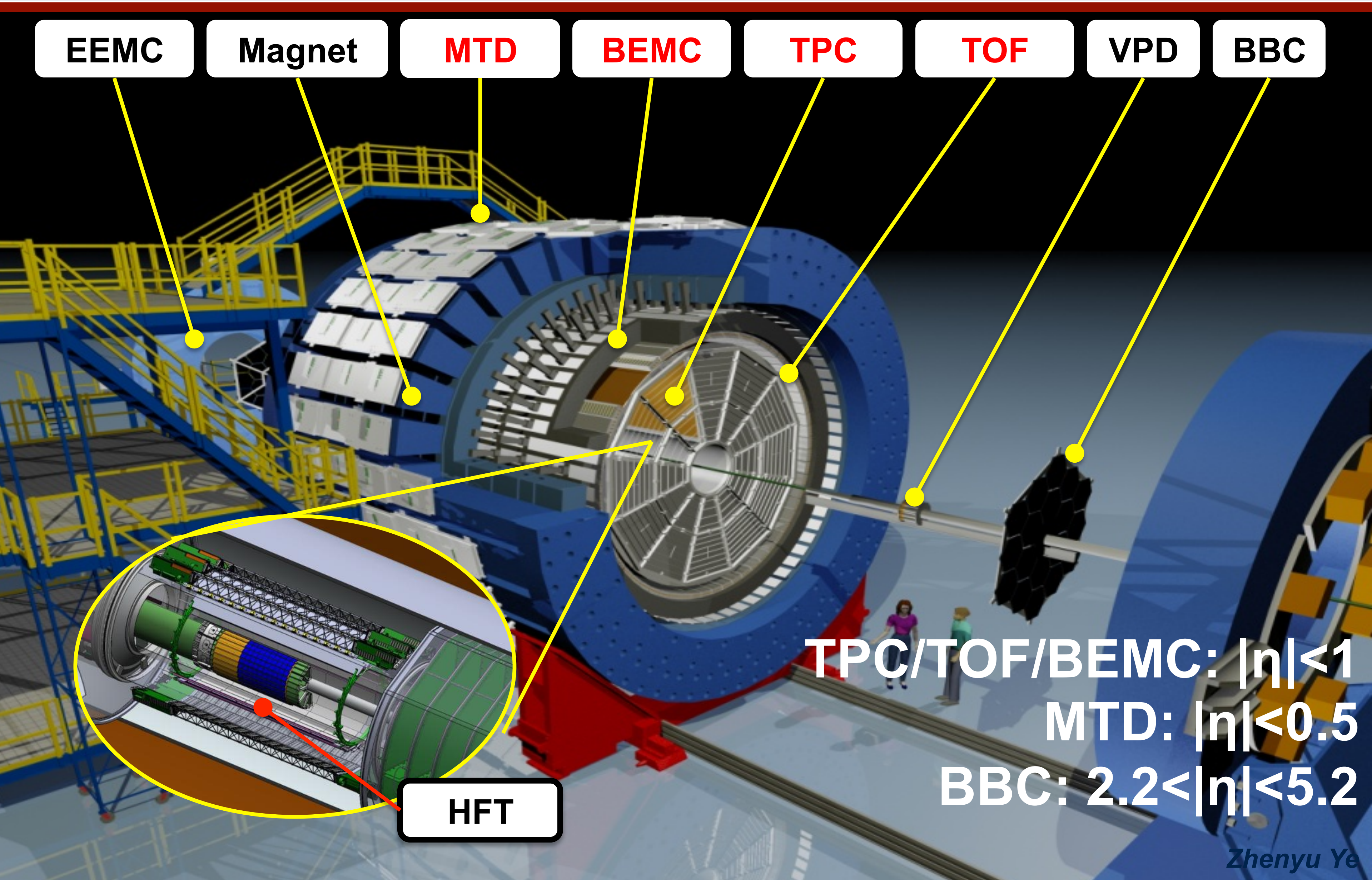
Relativistic Heavy Ion Collider



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

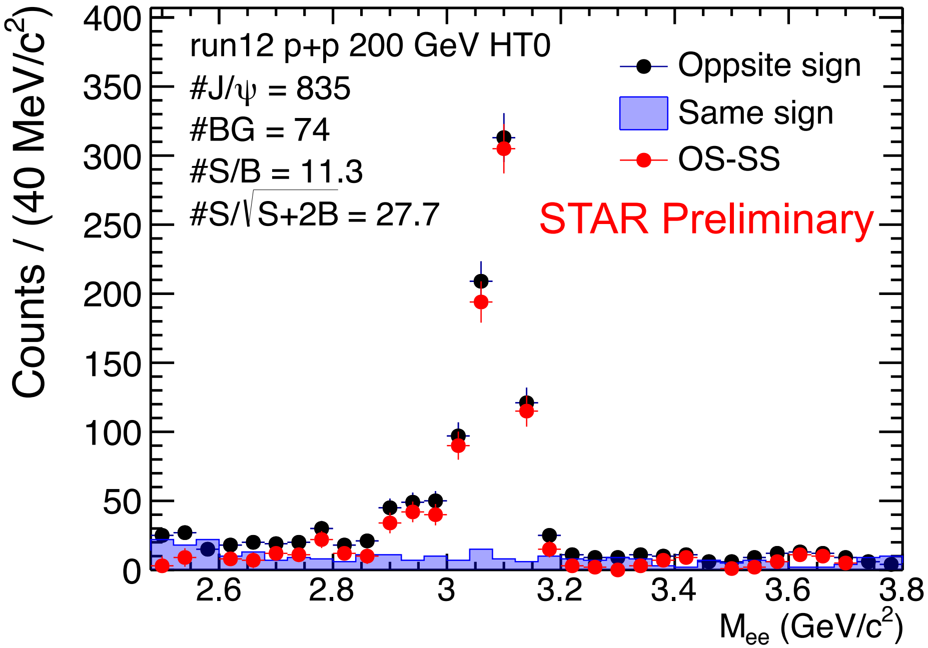
Electron trigger threshold (electron E_T):

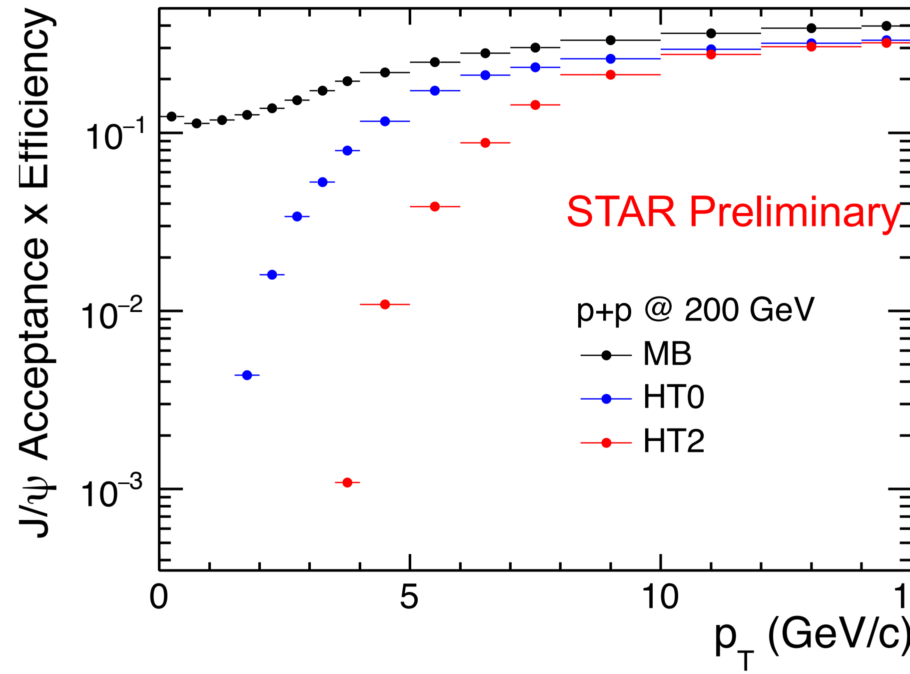
200GeV: HT0~2.6 GeV, HT1~3.5 GeV, HT2~4.3 GeV, HT3~6.0 GeV

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

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

J/ψ Reconstruction





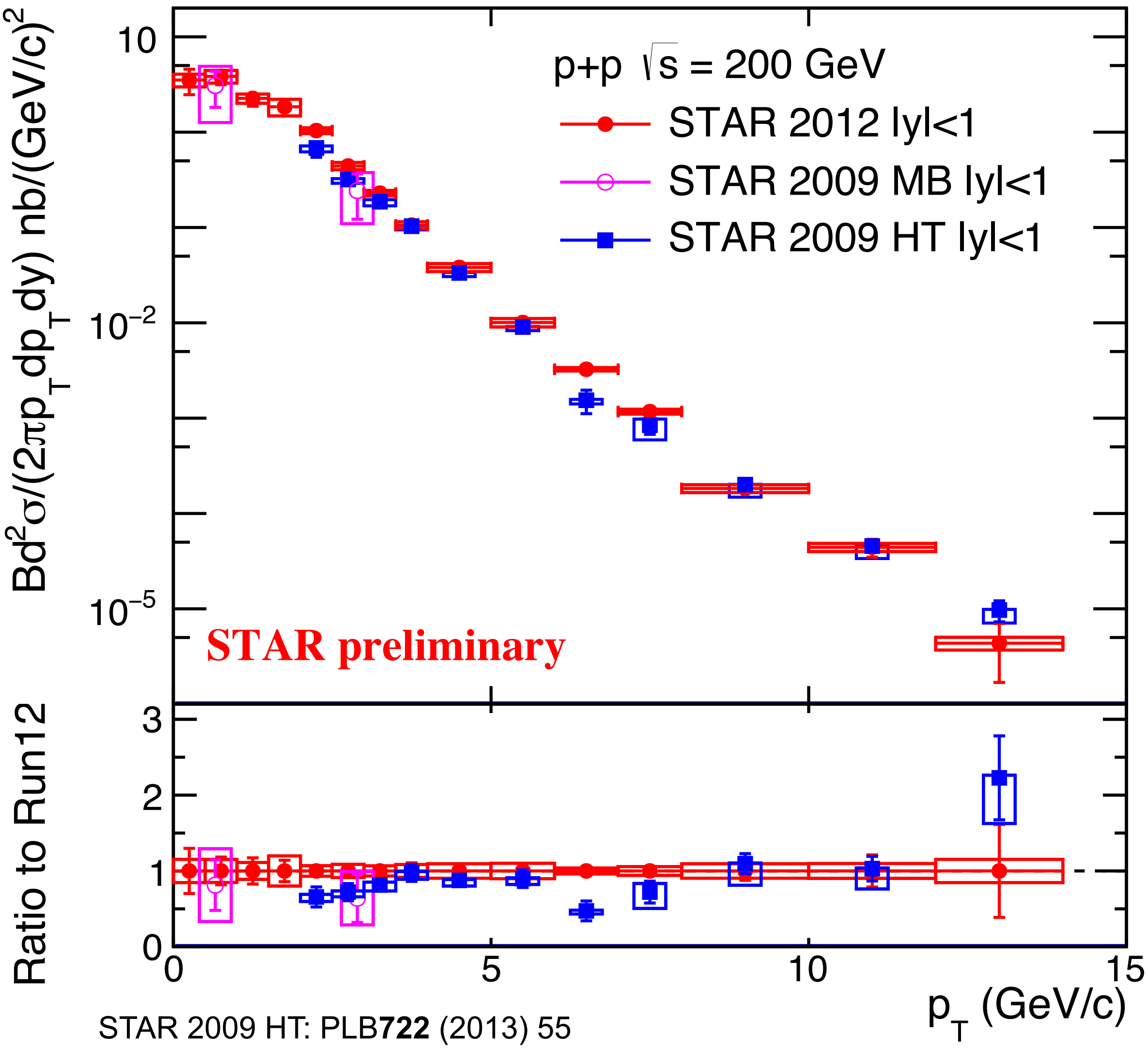
dielectron channel:

- 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

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

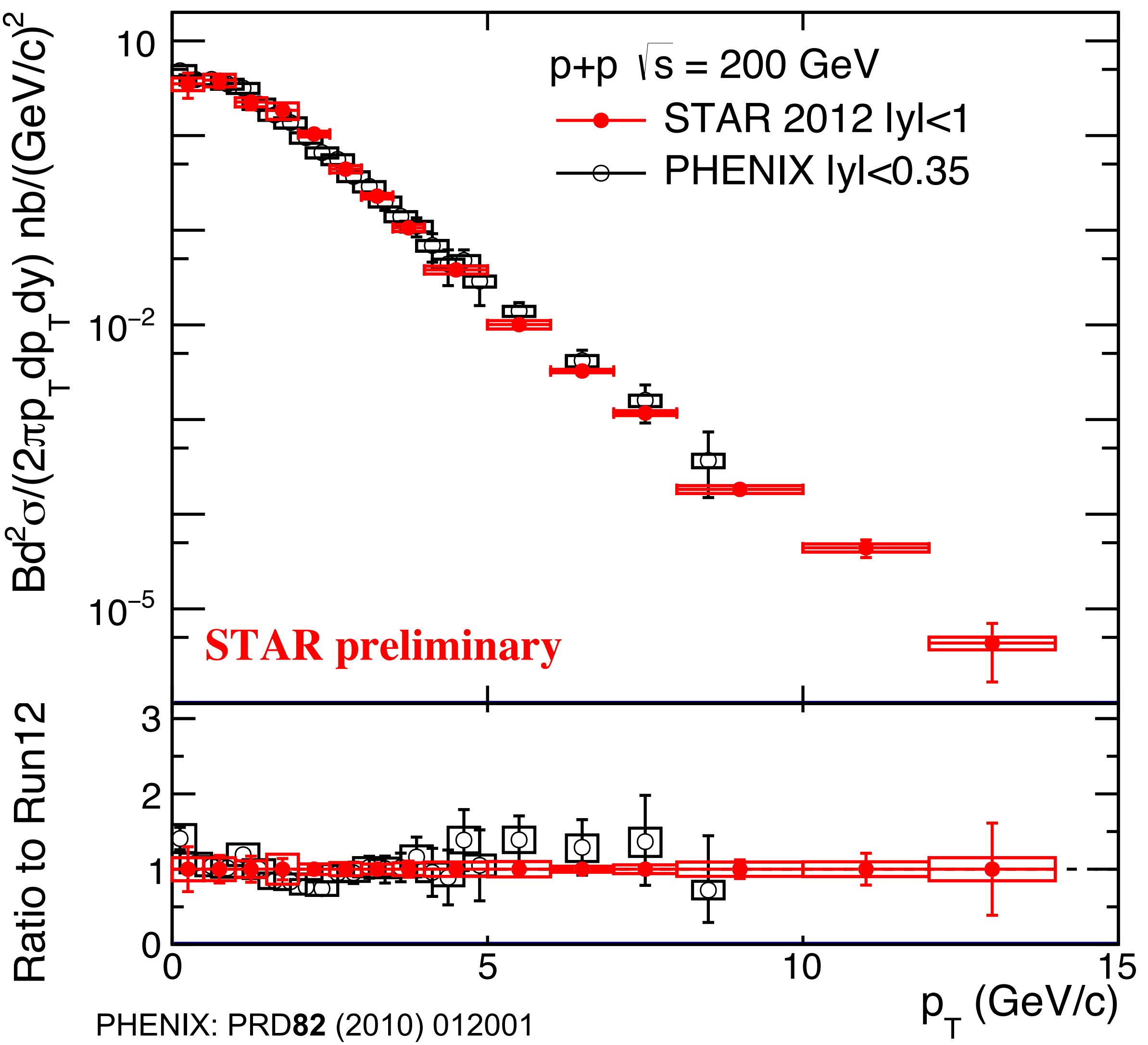
STAR 2009 data published

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

- 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

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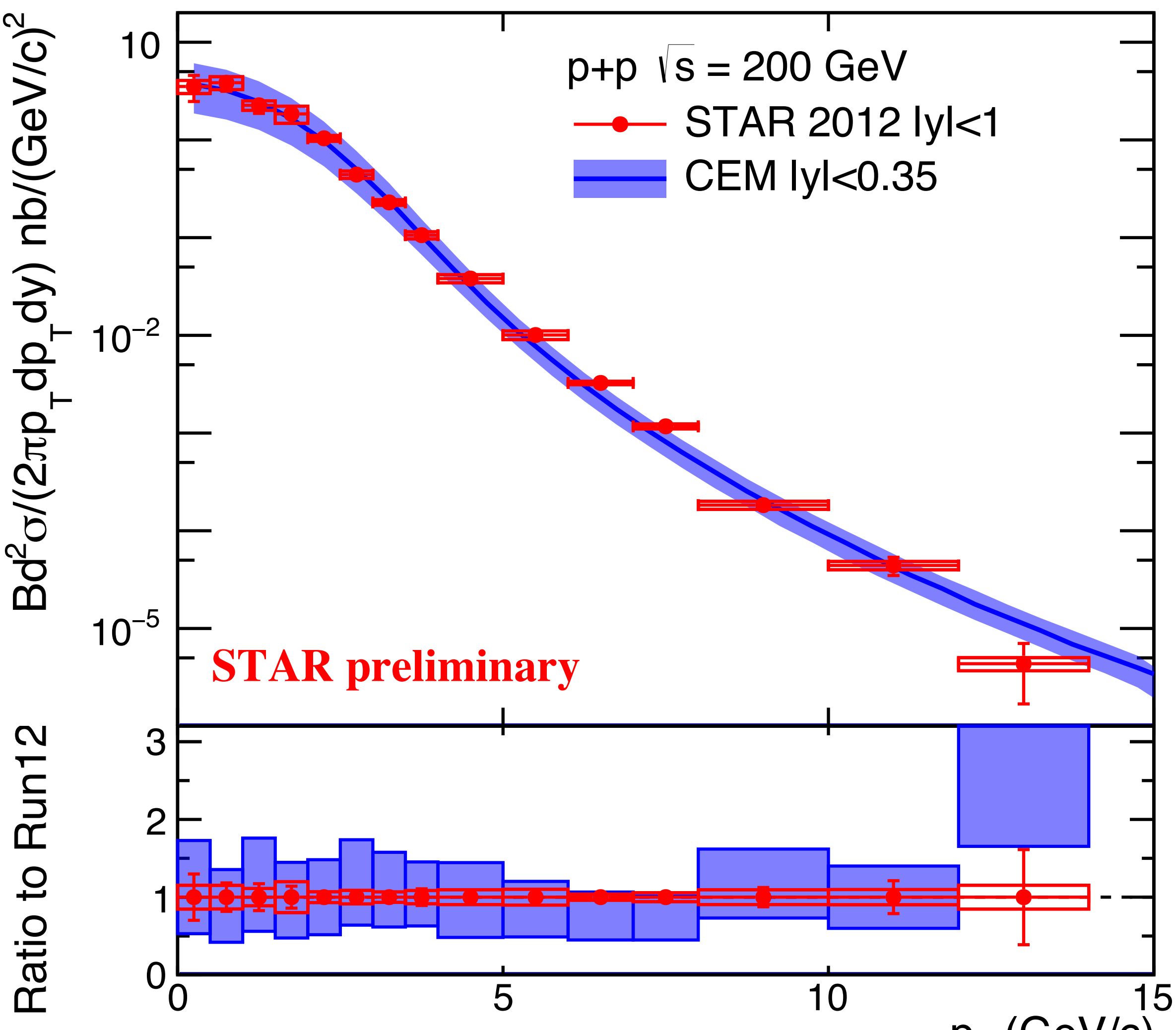
J/ψ Cross-Section at 200 GeV



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

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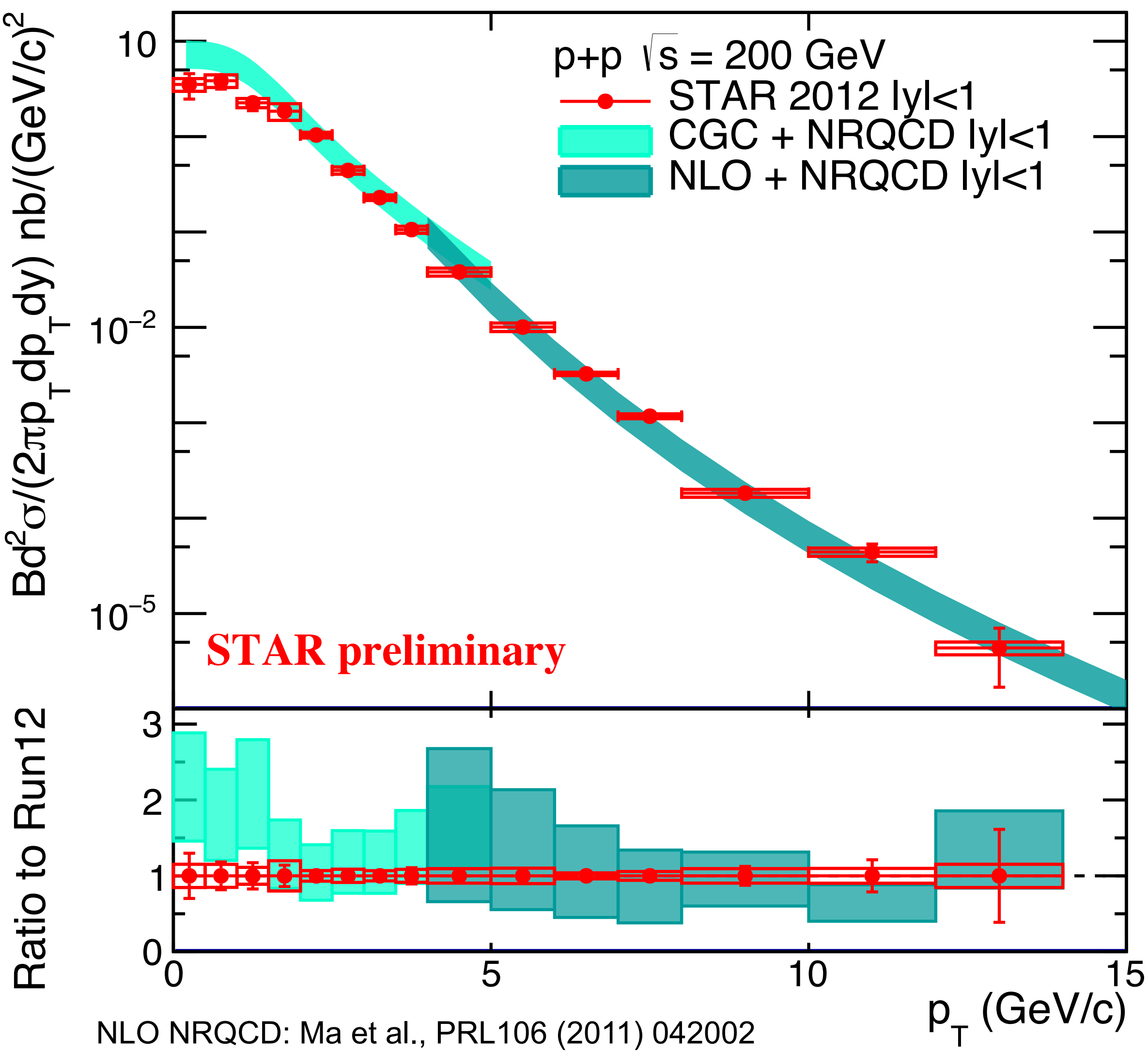
J/ψ Cross-Section at 200 GeV



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

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

- 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

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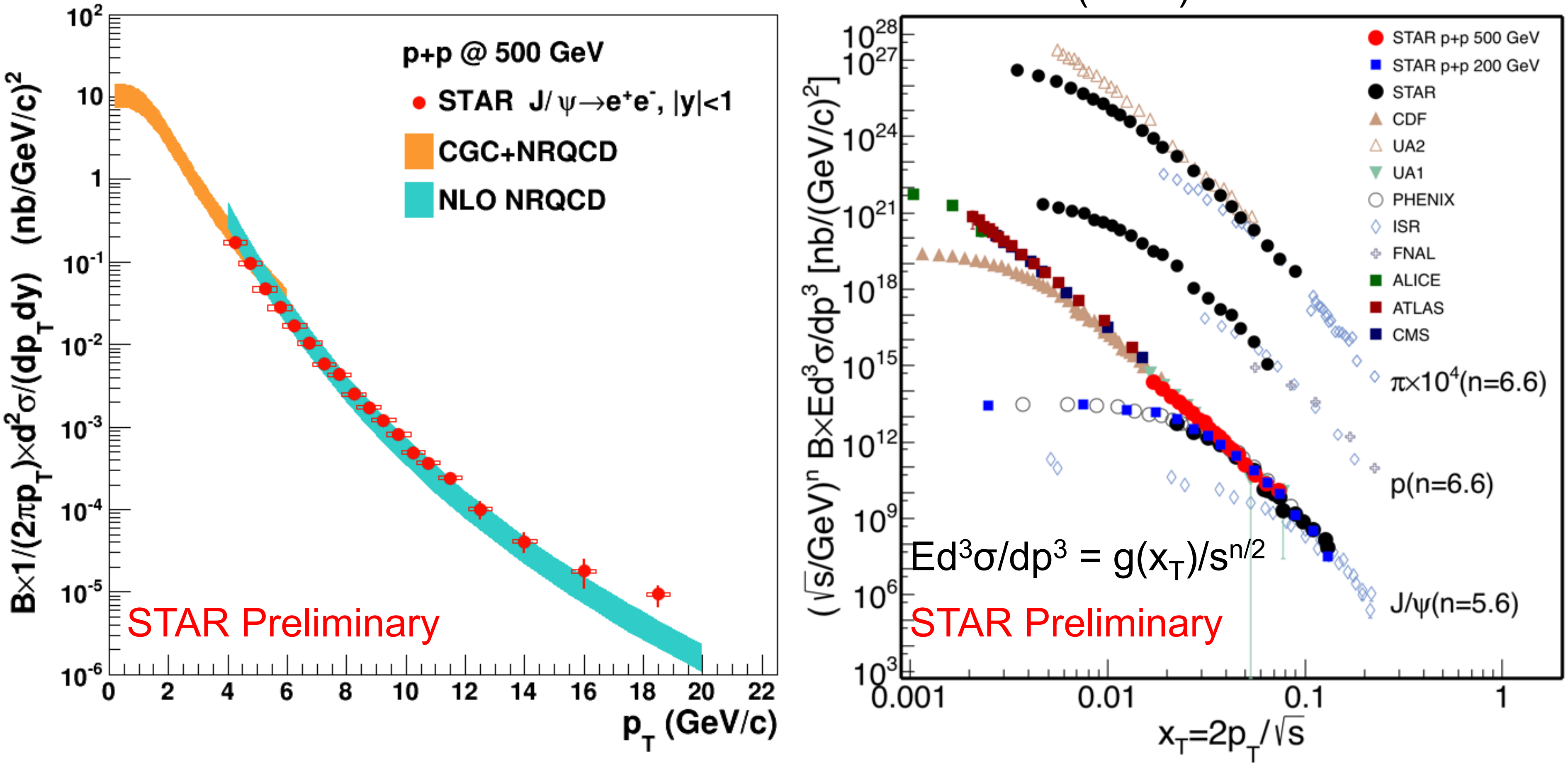
J/ψ Cross-Section at 500 GeV

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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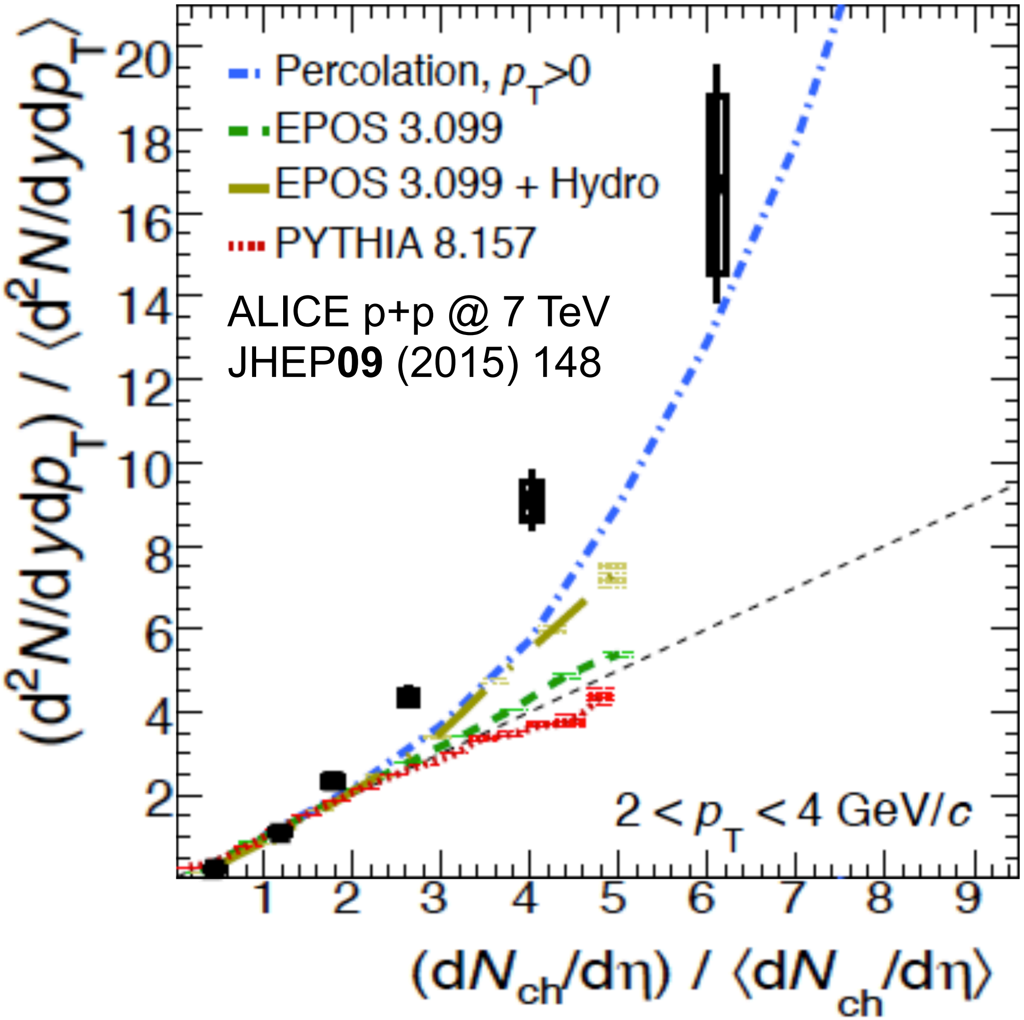
J/ψ Yield vs Event Activity (N_{ch})



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
  $N_{hard} \propto N_{ch} \propto N_{MPI}$

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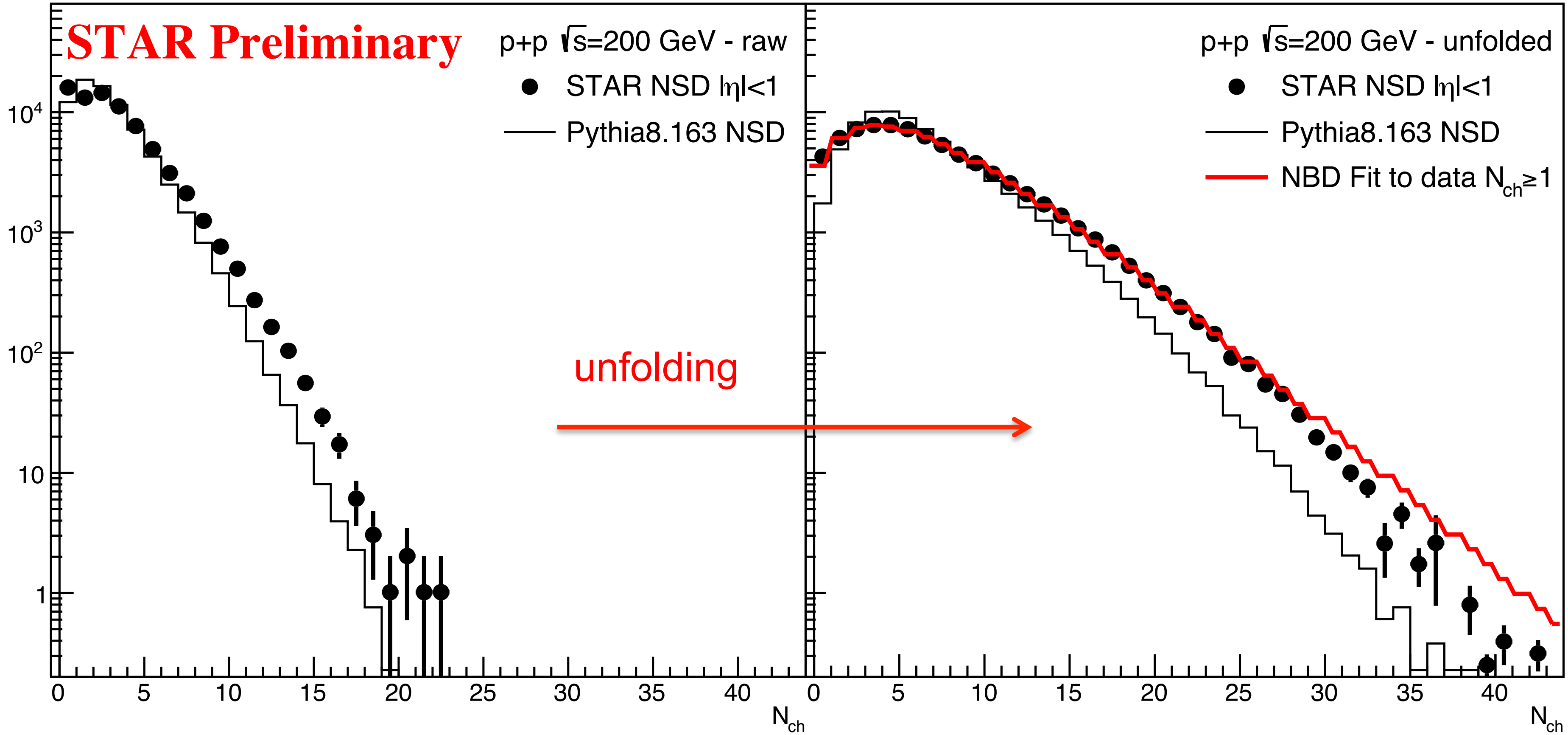
Measure N_{ch} at STAR



- 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)

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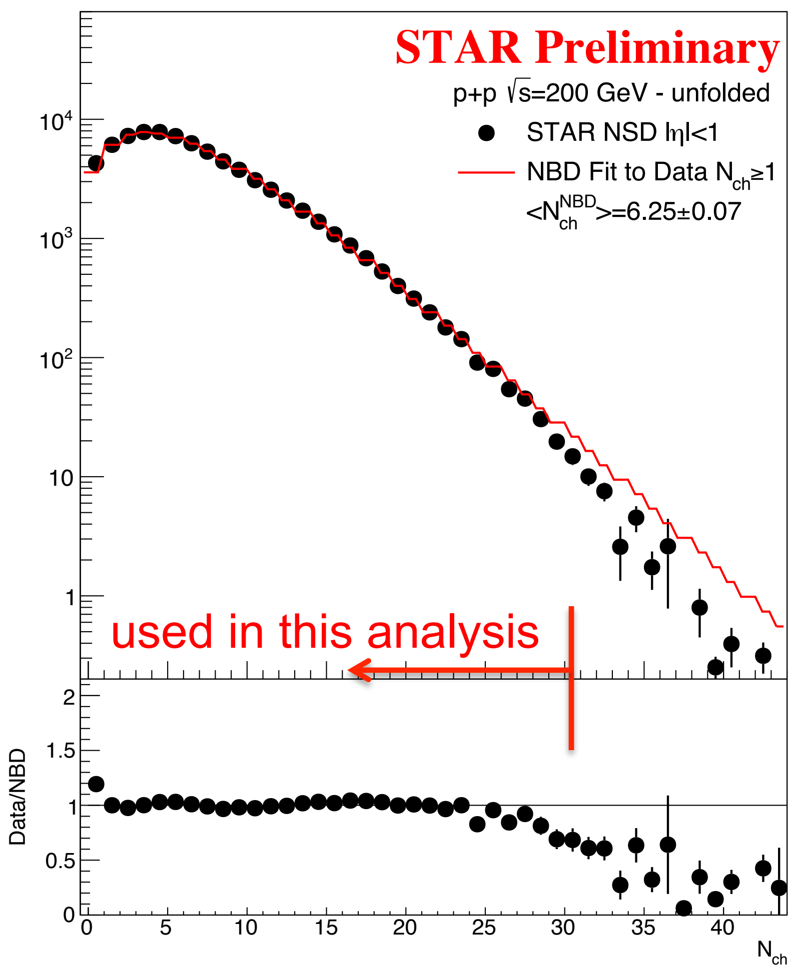
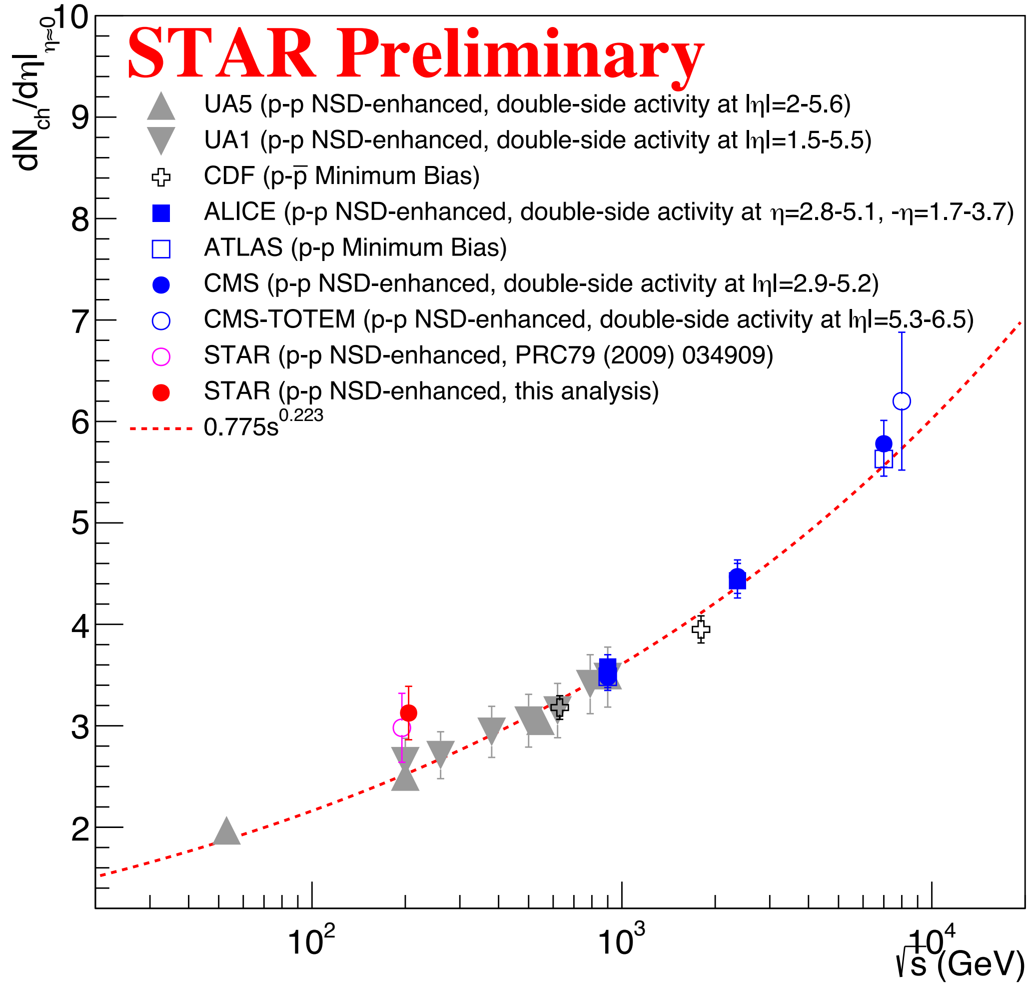
N_{ch} in p+p Collisions at 200 GeV





- Unfolded N_{ch} distribution can be described by negative binomial distribution.
- $dN_{ch}/d\eta=3.13\pm0.27$ consistent with previous STAR result 2.98 ± 0.34

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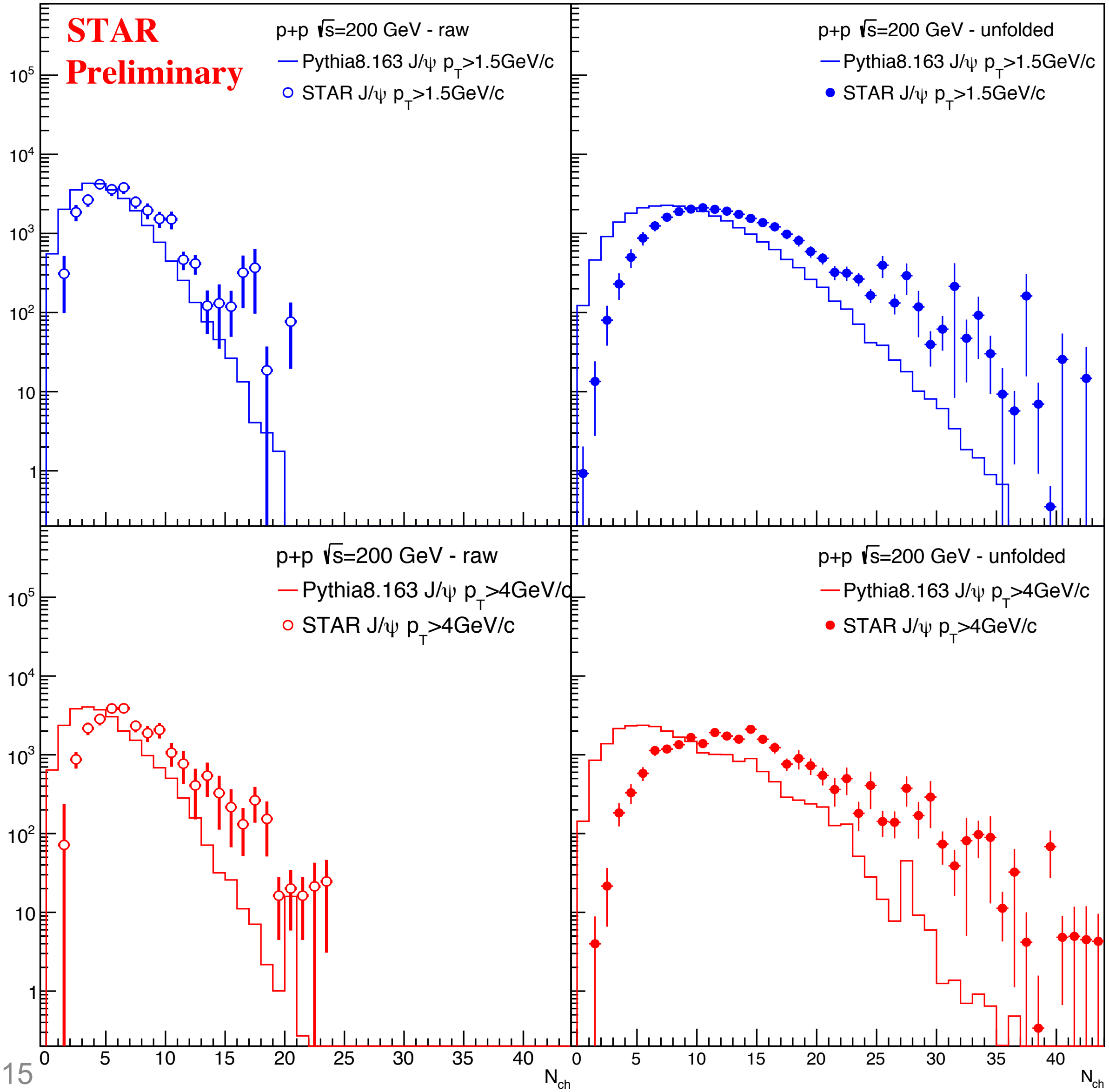
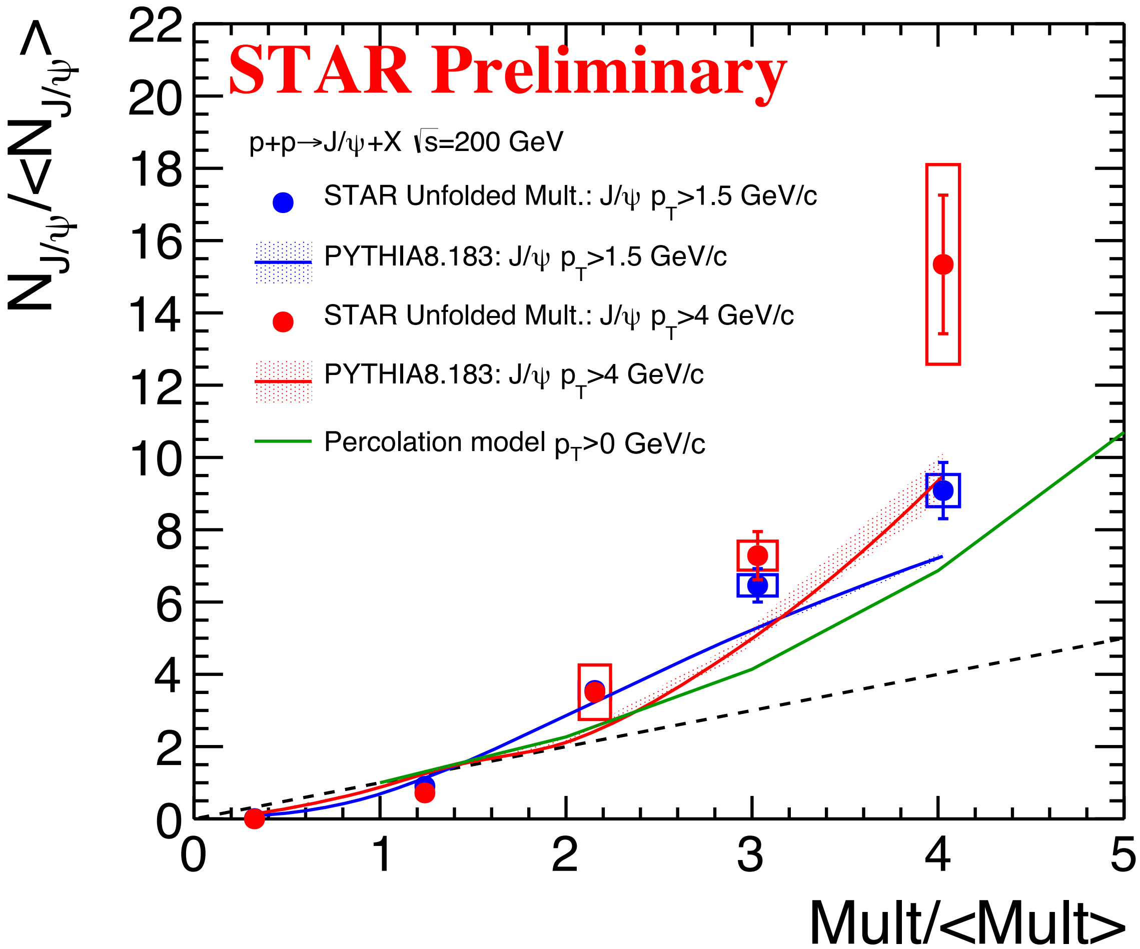
J/ψ Yield vs N_{ch} – 200 GeV



- 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.

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.

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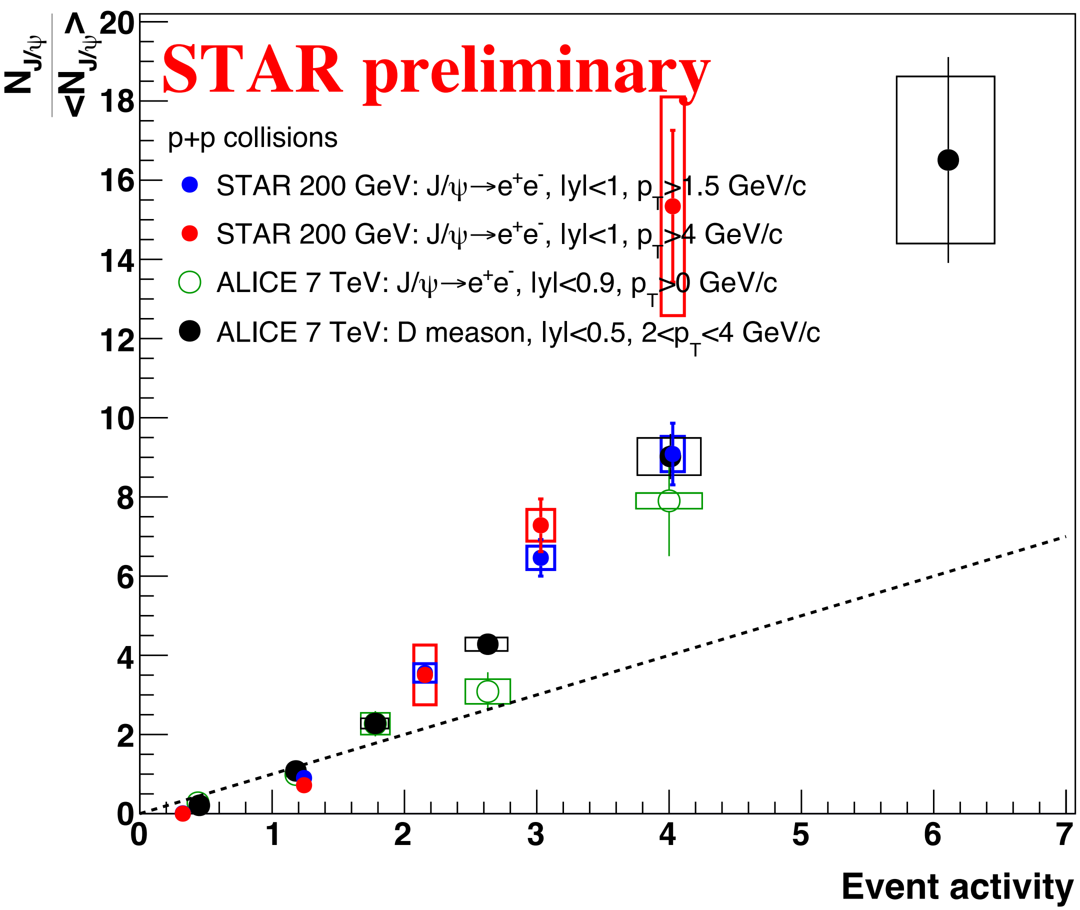
J/ψ Yield vs N_{ch} – RHIC vs LHC

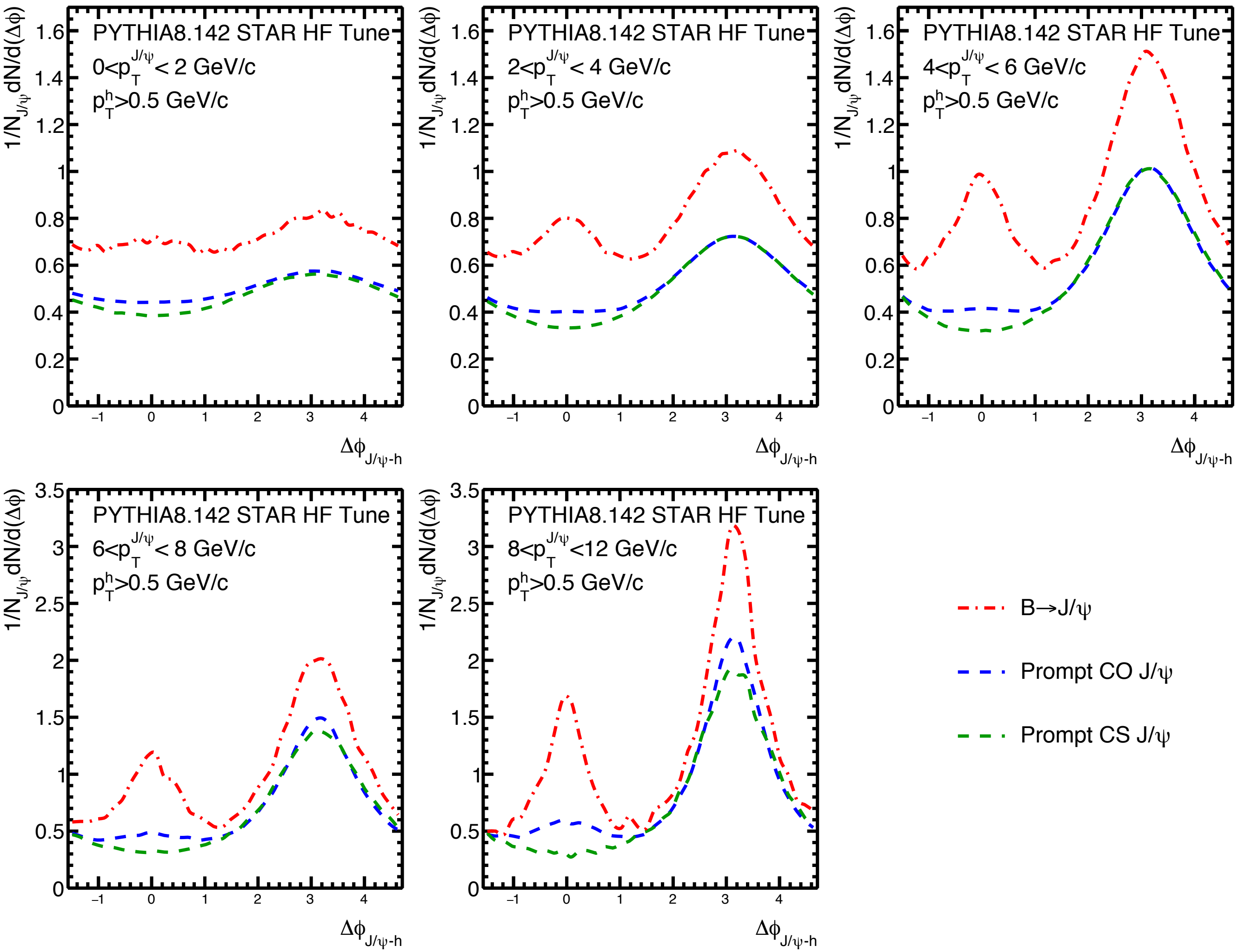


The results at 200 GeV and 7 TeV seem to follow a global trend:

- **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

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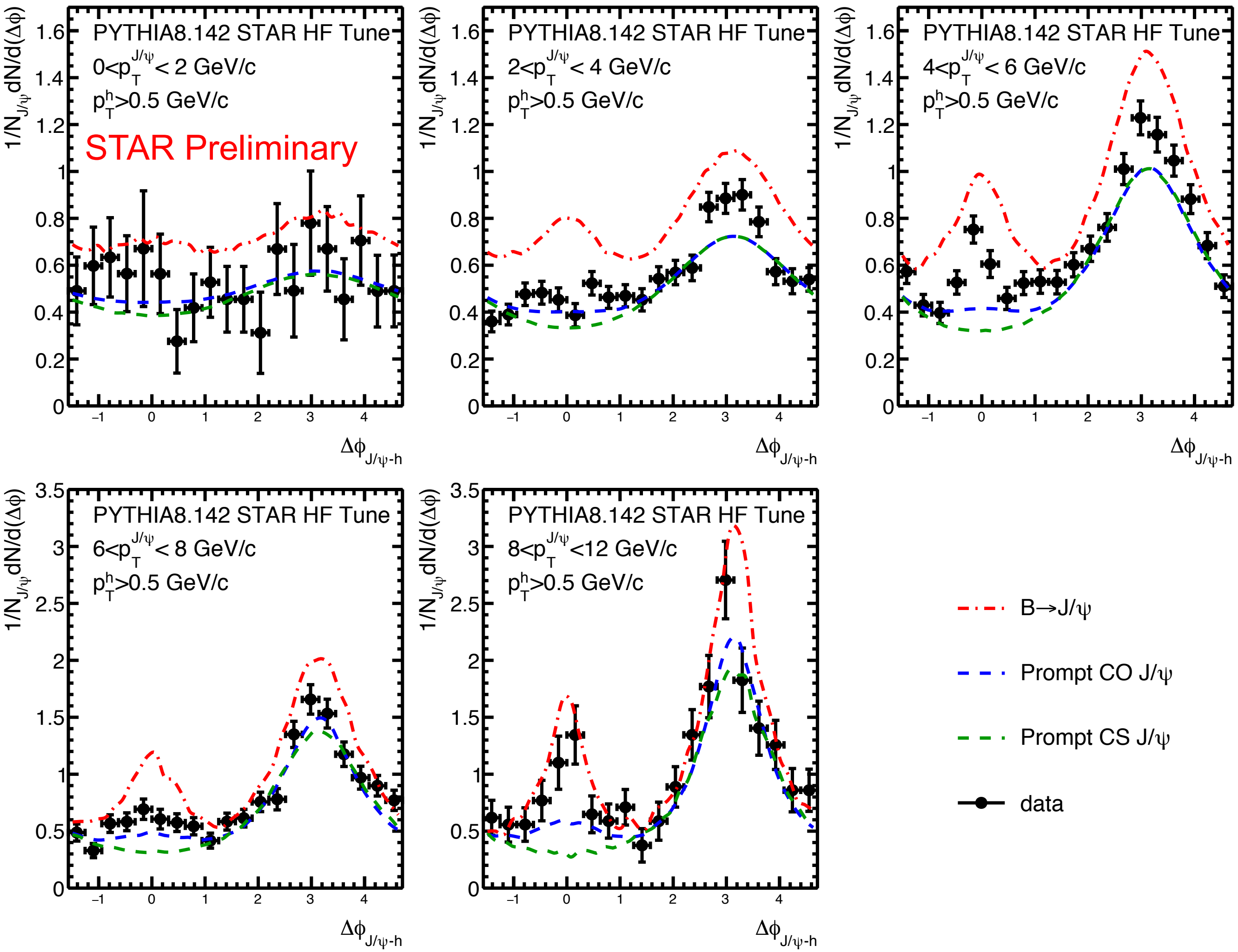
J/ψ-Hadron Azimuthal Correlations



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Can be used to extract different contributions?

- data analysis in progress

Data not fully corrected for acceptance and efficiency

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