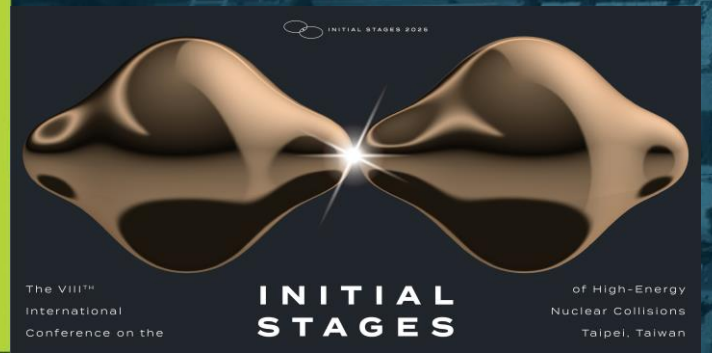
Fraction of B-meson Decays in J/ψ yields in p+p Collisions at $\sqrt{s} = 200$ GeV Measured by the PHENIX Detector at RHIC



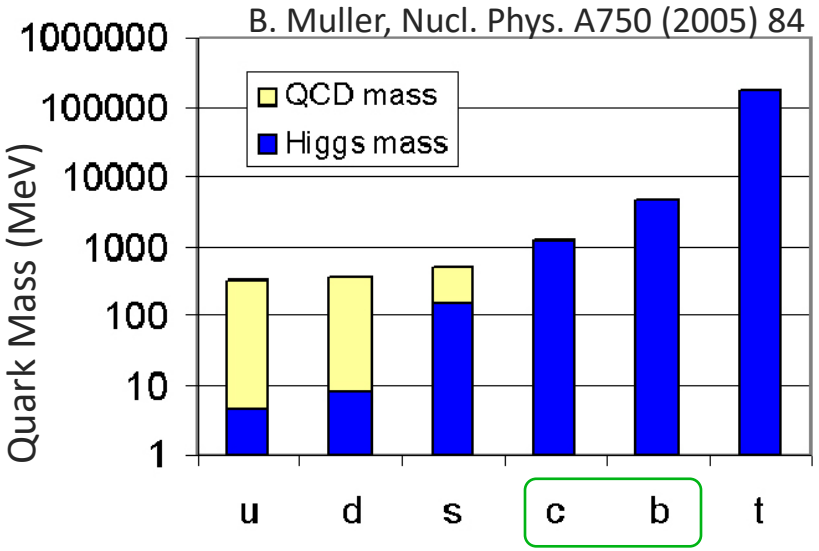
Rachid Nouicer, for the PHENIX Collaboration

Brookhaven National Laboratory

Heavy Flavor: Ideal Probe of QCD Matter

Theoretical motivation

- Symmetry breaking
  - **Higgs mass:** electroweak symmetry breaking
    → **current quark mass**
  - **QCD mass:** chiral symmetry breaking
    → **constituent quark mass**
- Charm and beauty quark masses are not affected by QCD vacuum
  → **ideal probes to study QGP**



State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.36	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
Radius (fm)	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

- Heavy quarks ($c\bar{c}$, $b\bar{b}$)
  - Bound states (J/ψ, Υ)
- Due to their mass ($m_Q >> T_{cri}$, Λ_{QCD})
  → **higher penetrating power**
- Gluon fusion dominates
  → **sensitive to initial state gluon distribution**

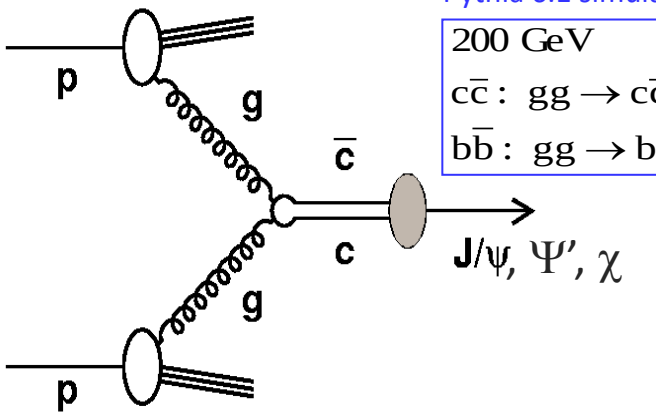
M. Gyulassy and Z. Lin, Phys. Rev. C51 (1995) 2177

Pythia 6.1 simulation (LO)

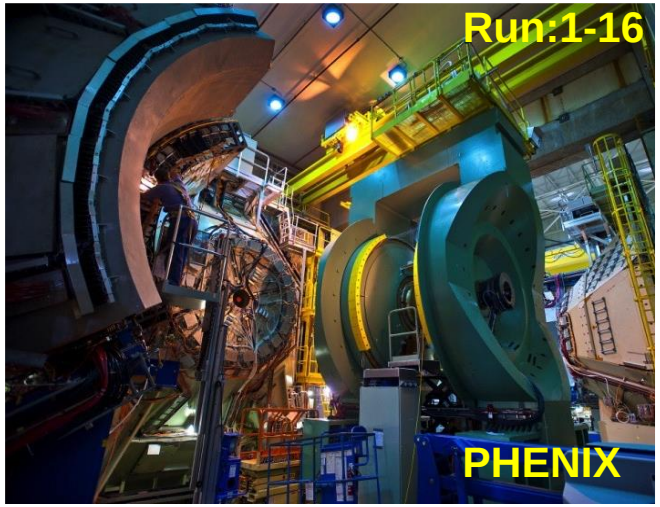
200 GeV

$c\bar{c}$: $gg \rightarrow c\bar{c}$ 95%

$b\bar{b}$: $gg \rightarrow b\bar{b}$ 85%



PHENIX Collected and Analyzing a Golden Data from RHIC



❖ 2012 to 2016: data were taken with Central Silicon Vertex Tracker for Heavy Flavor Physics

Run	Species	Total particle energy [GeV/nucleon]	total delivered Luminosity [mb^{-1}]
I (2000)	Au+Au Au+Au	56 130	< 0.001 20
II (2001/2002)	Au+Au Au+Au p+p	200 19.6 200	25.8 0.4 1.4×10^{-6}
III (2003)	d+Au p+p	200 200	73×10^{-3} 5.5×10^{-6}
IV(2004)	Au+Au Au+Au p+p	200 62.4 200	3.53×10^{-3} 67 7.1×10^{-6}
V (2005)	Cu+Cu Cu+Cu Cu+Cu p+p p+p	200 62.4 22.4 200 410	42.1×10^{-3} 1.5×10^{-3} 0.02×10^{-3} 29.5×10^{-6} 0.1×10^{-6}
VI (2006)	p+p p+p	200 62.4	88.6×10^{-6} 1.05×10^{-6}
VII (2007)	Au+Au Au+Au	200 9.2	7.25×10^{-3} Small
VIII (2008)	d+Au p+p Au+Au	200 200 9.6	437×10^{-3} 38.4×10^{-6} Small

Run	Species	Total particle energy [GeV/nucleon]	Total delivered luminosity [mb^{-1}]
IX (2009)	p+p +p	500 200	110×10^{-6} 114×10^{-6}
X (2010)	Au+Au Au+Au Au+Au Au+Au Au+Au	200 62.4 39 7.7 11.5	10.3×10^{-3} 544 206 4.23 7.8
XI (2011)	p+p Au+Au Au+Au Au+Au	500 19.6 200 27	166×10^{-6} 33.2 9.79×10^{-3} 63.1
XII (2012)	p+p p+p U+U Cu+Au	200 510 193 200	74×10^{-6} 283×10^{-6} 736 27×10^{-3}
XIII (2013)	p+p	510	1.04×10^{-9}
XIV (2014)	Au+Au Au+Au ^{3}He+Au	14.6 200 200	44.2 43.9×10^{-3} 134×10^{-3}
XV (2015)	p+p p+Au p+Al	200 200 200	282×10^{-6} 1.27×10^{-6} 3.97×10^{-6}
XVI (2016)	Au+Au d+Au d+Au d+Au d+Au	200 200 62.4 19.6 39	52.2×10^{-3} 46.1×10^{-3} 44.0×10^{-3} 7.2×10^{-3} 19.5×10^{-3}

Heavy Flavor Physics Program in PHENIX

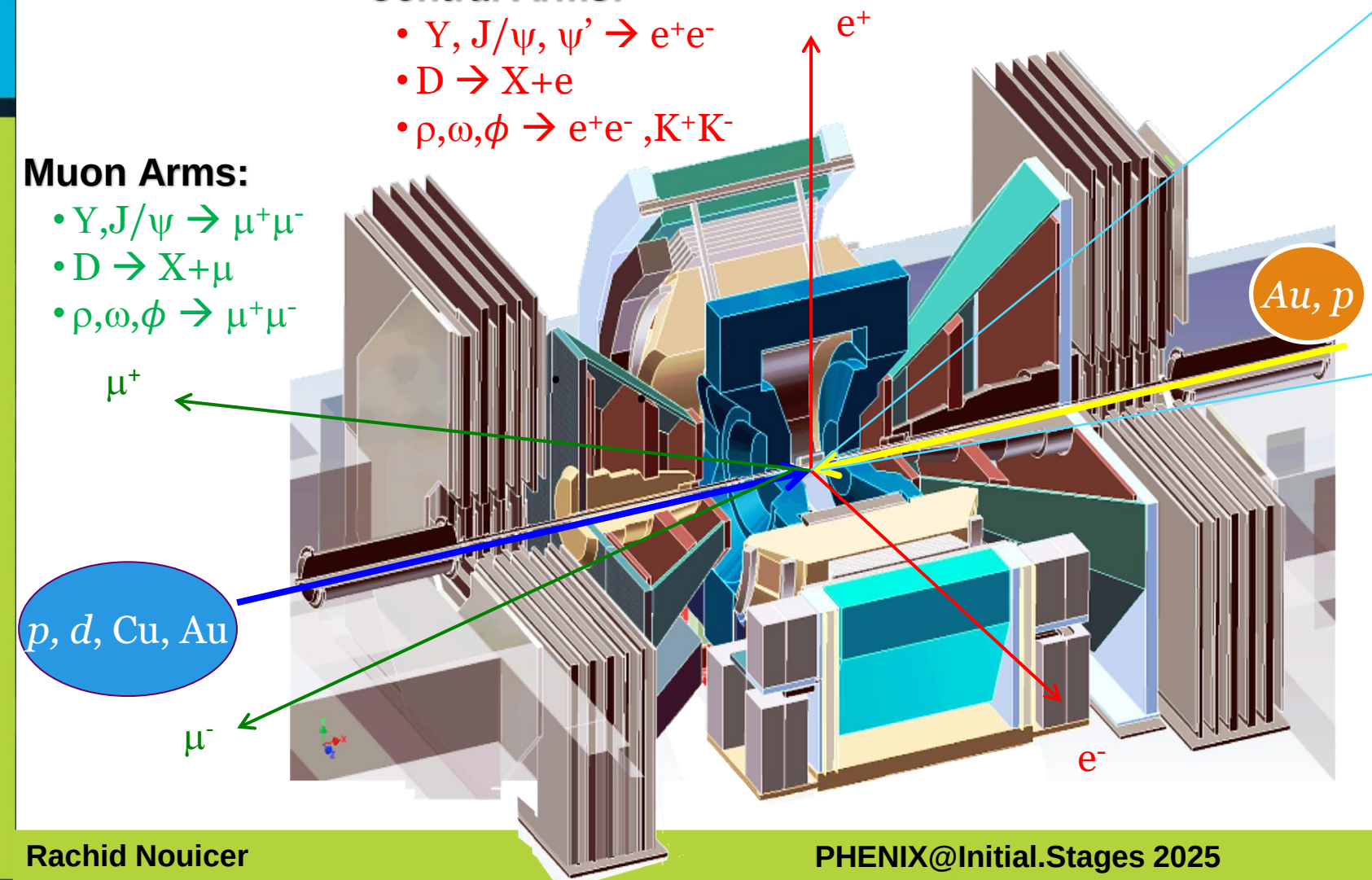
- PHENIX optimized to measure leptons: rapidity coverage: 1.2<|y|<2.2 and |y|<0.35

Central Arms:

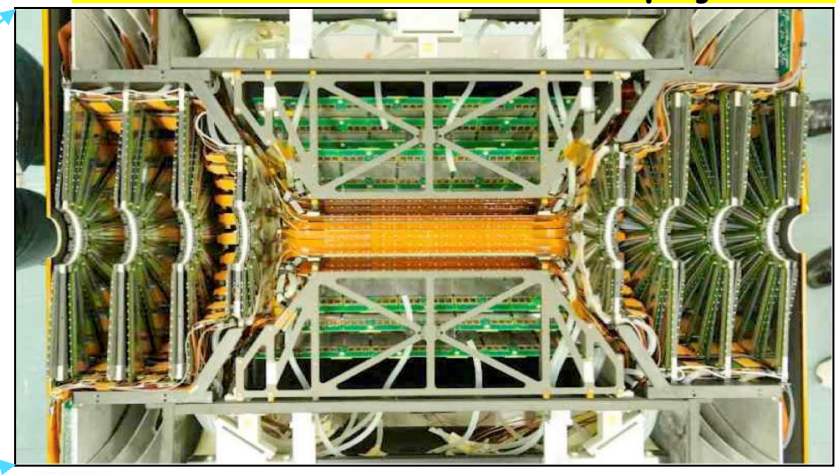
- Υ, J/ψ, ψ' → e^+e^-
- D → X+e
- ρ,ω,ϕ → e^+e^- ,K^+K^-

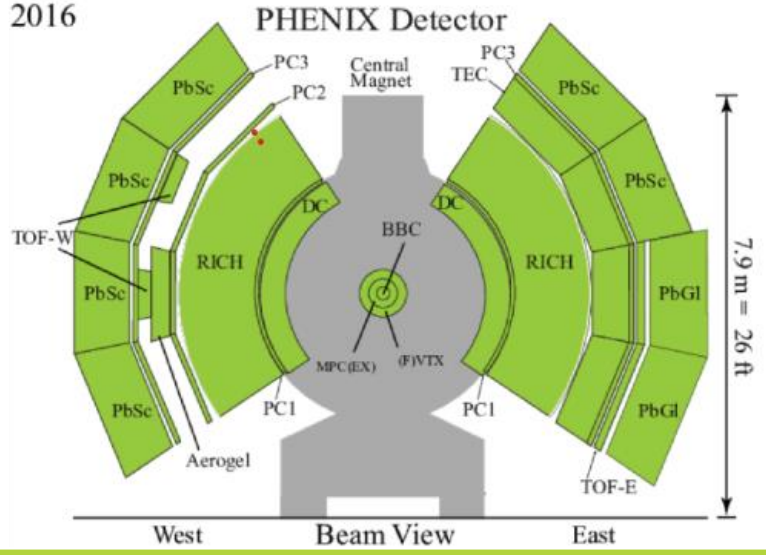
Muon Arms:

- Υ,J/ψ → $\mu^+\mu^-$
- D → X+μ
- ρ,ω,ϕ → $\mu^+\mu^-$

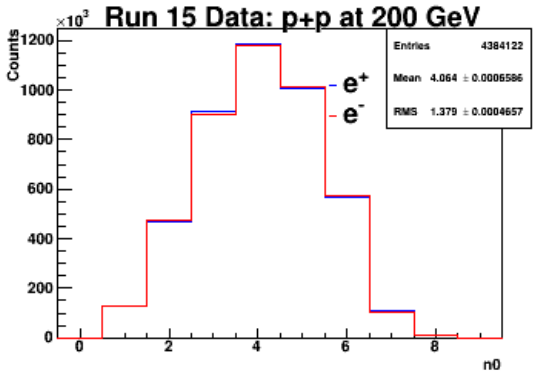


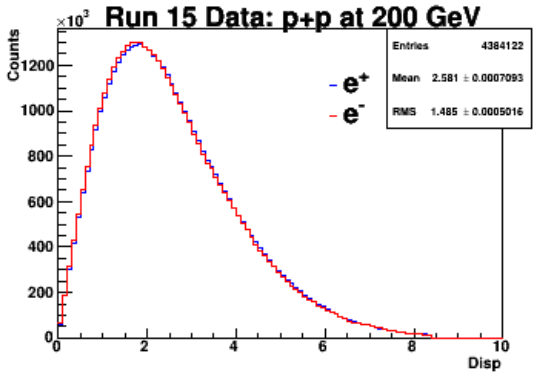
2012: upgraded with Silicon detector VTX/FVTX for HF physics

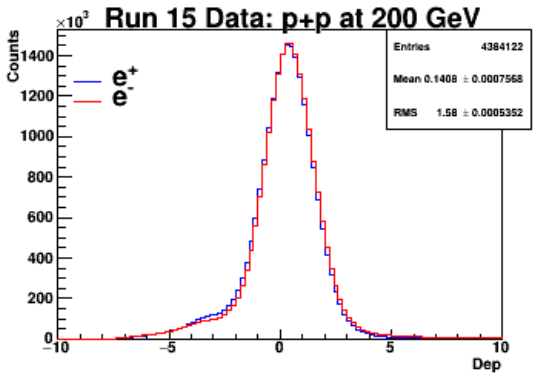


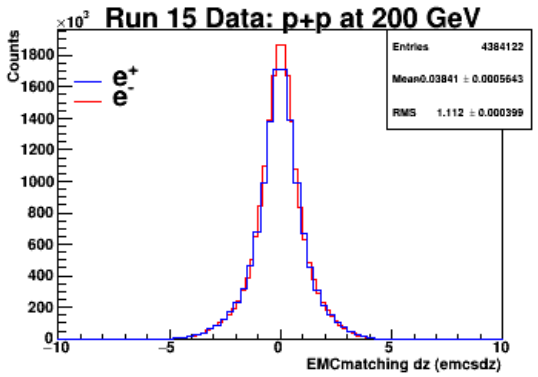


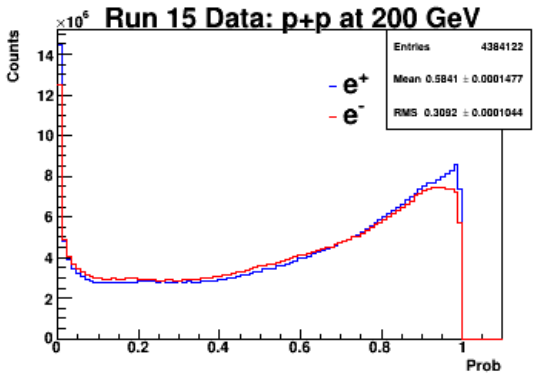
Detector Signals and Analysis Cuts

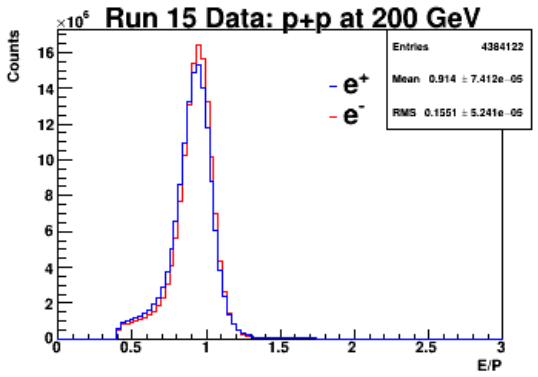










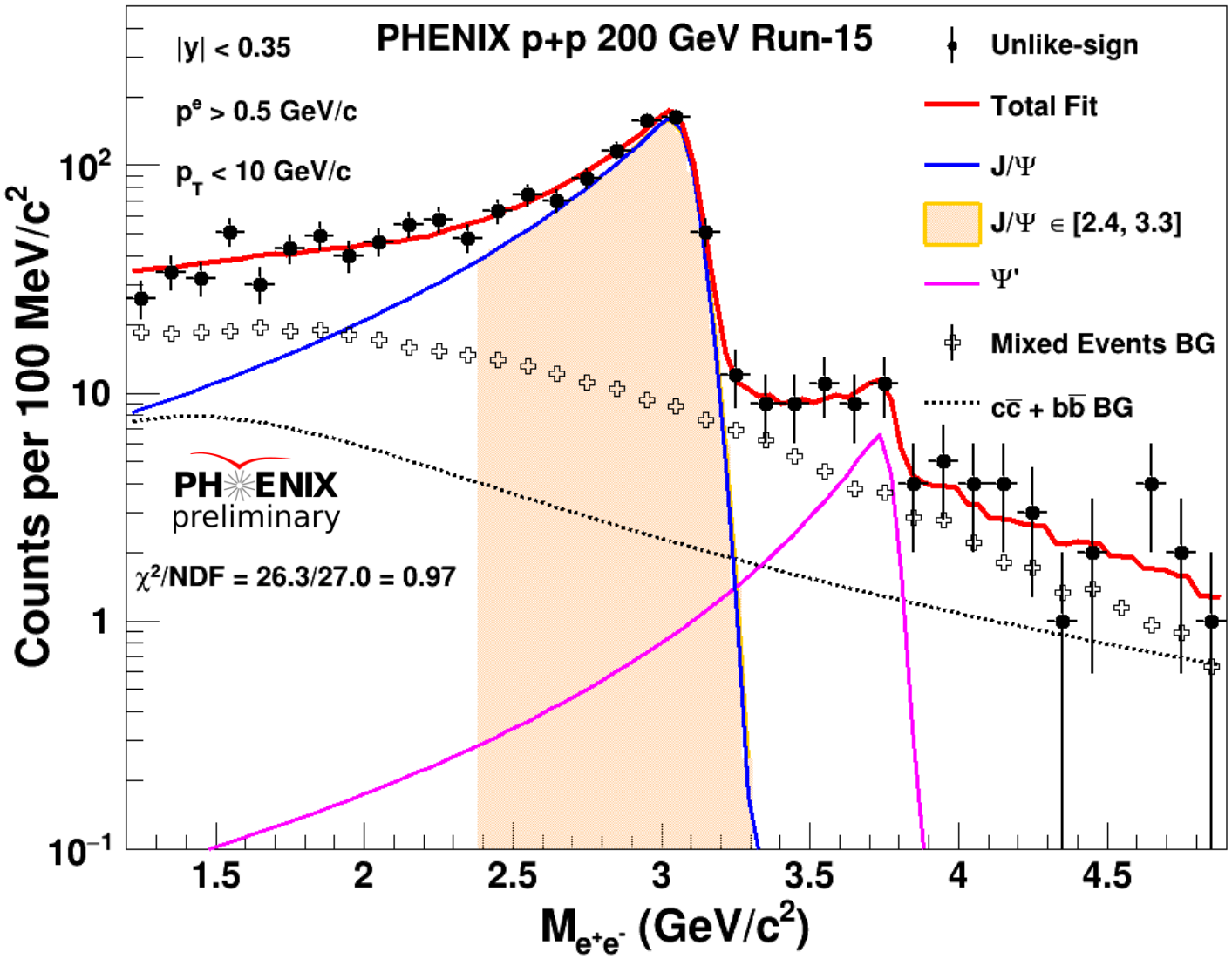


Few plots on sub-detectors signal responses for e^+ and e^-:
VTX, DC, Rich, and EmCal
- plots shown are for data
- similar plots are obtained with Pythia simulation

Event Selections

Analysis Cuts $p + p$ at 200 GeV Run 15, ERT Data Production 108		
Track Quality cuts	Electron/Positron ID cuts (RICH and EMCal)	Silicon Vertex Tracker (VTX)
DC quality = 31 || 63 |DC Zed| < 75	n0 ≥ 2 prob > 0.01 $E/p > 0.7$ | dep | > -2 | emcsdphi_e | < 5 | emcsdz_e | < 5	Vertex: beam center (seed vertex) | zvtx | ≤ 10 cm χ^2/ndf < 8 Conversion Veto all layers

Analysis Method: Dielectron Invariant Mass Distribution



Using Crystall Ball Function for J/ψ and ψ (2S)

The Crystal Ball function is given by:

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

where

$$A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

$$B = \frac{n}{|\alpha|} - |\alpha|,$$

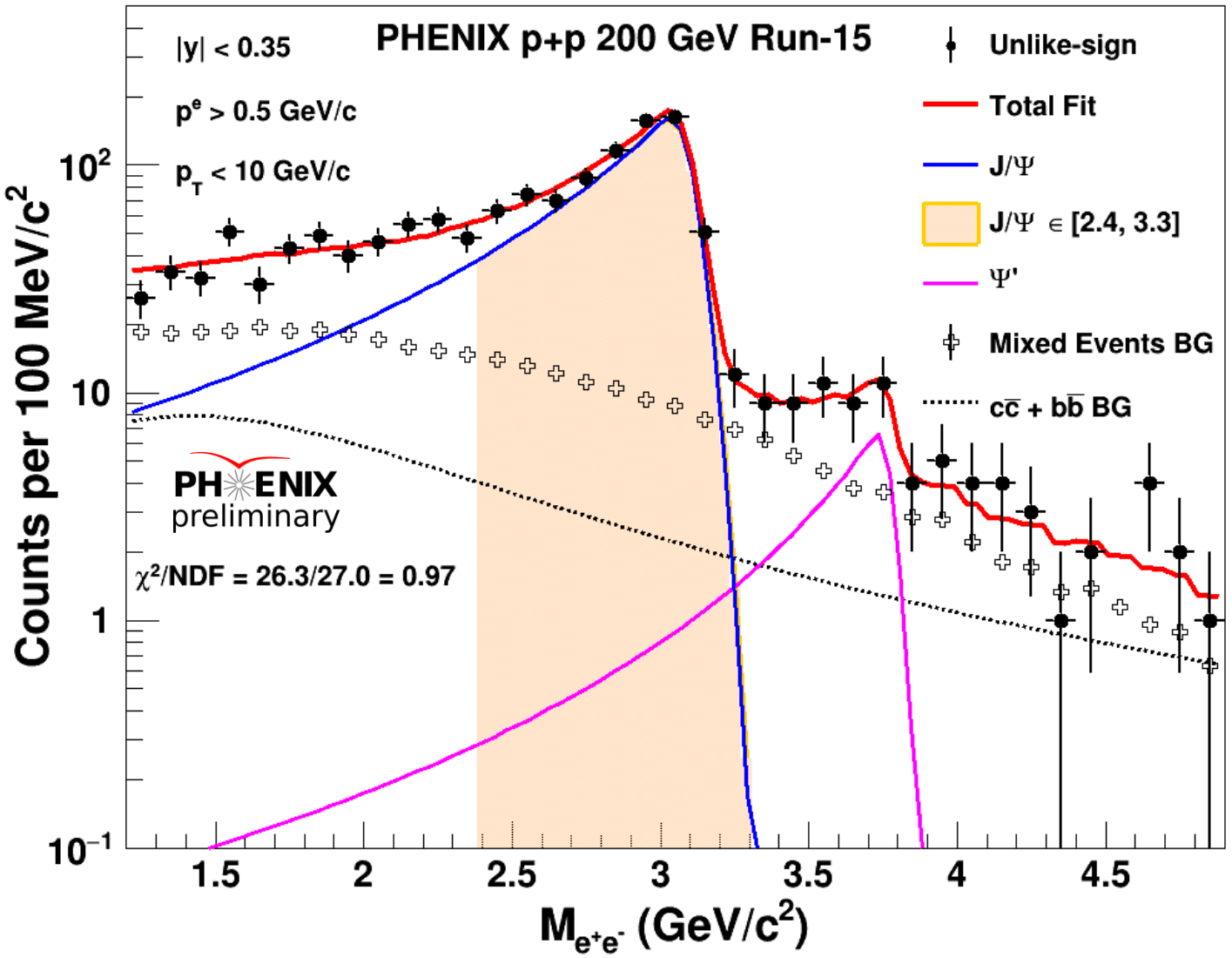
$$N = \frac{1}{\sigma(C+D)},$$

$$C = \frac{n}{|\alpha|} \cdot \frac{1}{n-1} \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

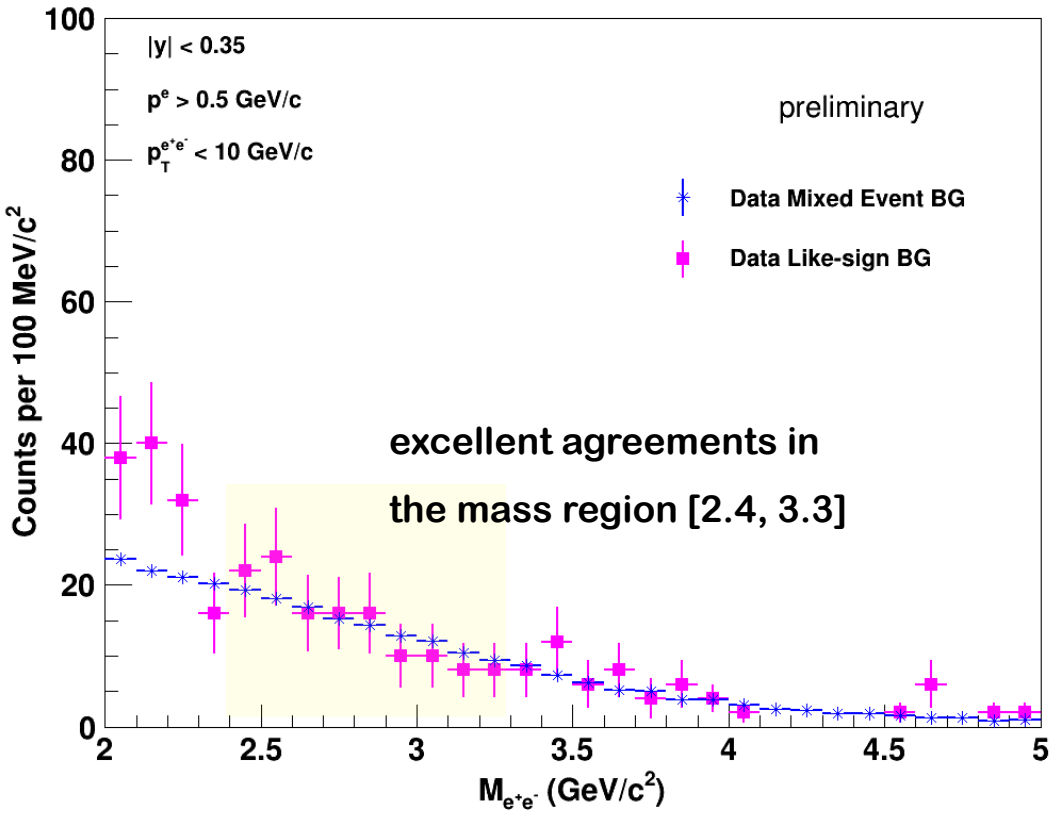
$$D = \sqrt{\frac{\pi}{2}}\left(1 + \operatorname{erf}\left(\frac{|\alpha|}{\sqrt{2}}\right)\right).$$

Measures the dielectron invariant mass distribution, selects inclusive J/ψ peak, and determines the raw yields of J/ψ and heavy flavor ($c\bar{c}$ + $b\bar{b}$) background in the mass region of $M_{e^+e^-}$= [2.4, 3.3] GeV/c^2

Analysis Method: Dielectron Invariant Mass Distribution

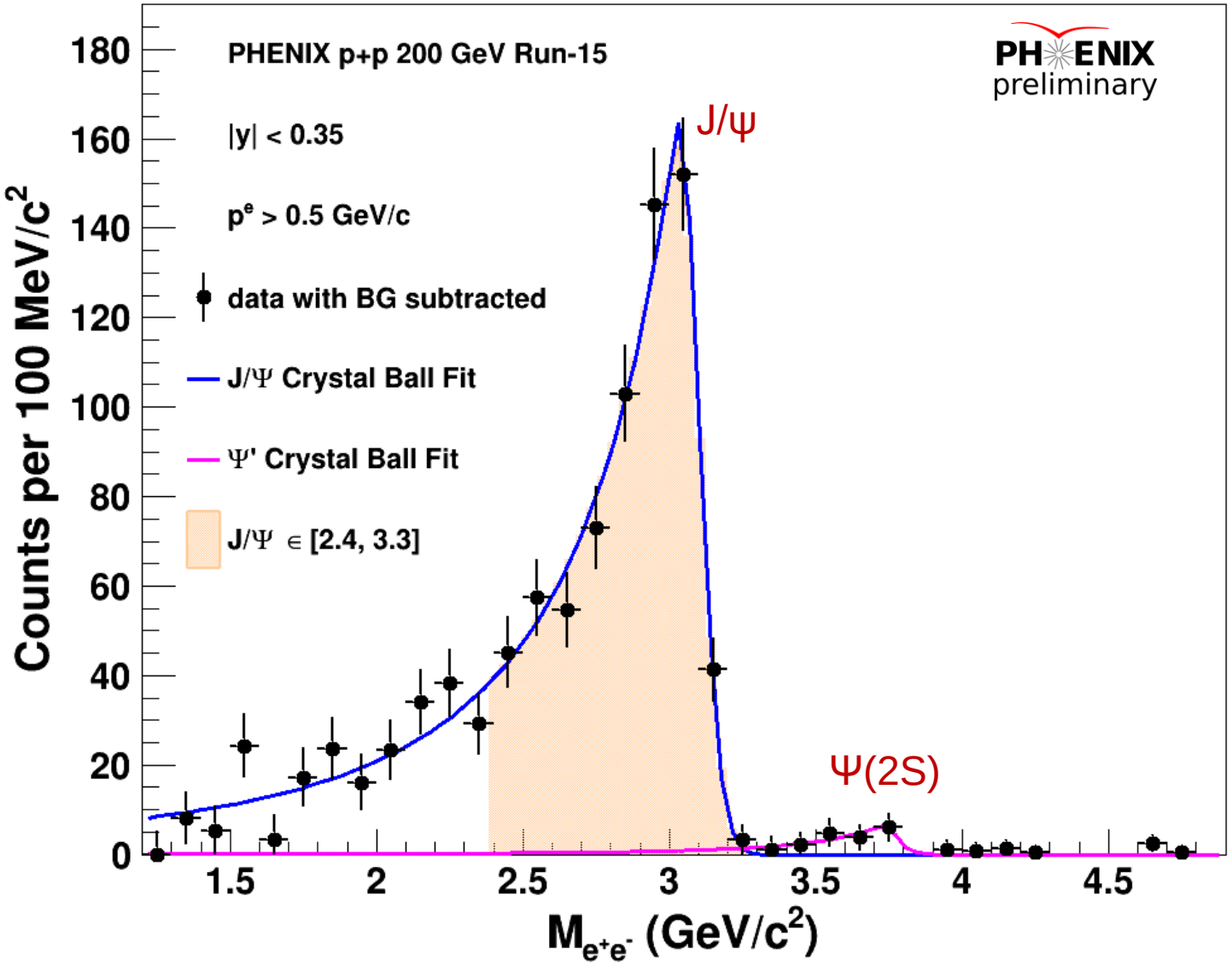


Comparison of Mixed Events and like-sign Backgrounds

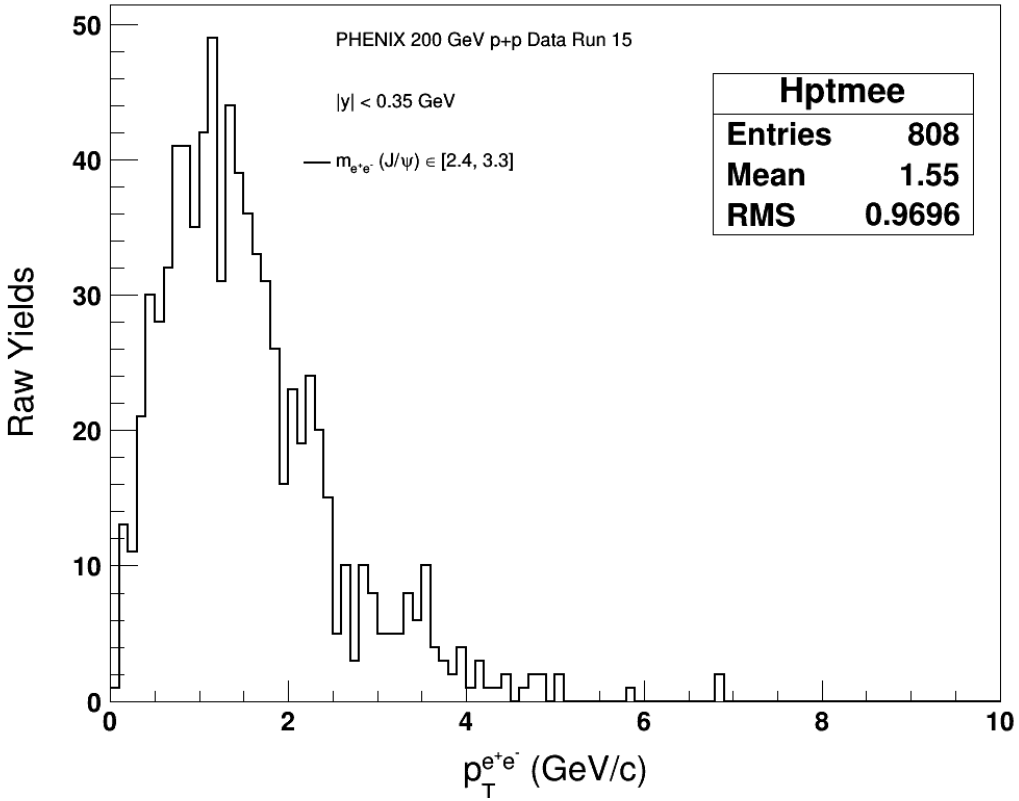


Measures the dielectron invariant mass distribution, selects inclusive J/ψ peak,
and determines the raw yields of J/ψ and heavy flavor ($c\bar{c}$ + $b\bar{b}$) background in the mass region of $M_{e^+e^-}$= [2.4, 3.3] GeV/c^2

Analysis Method: Dielectron Invariant Mass Distribution BKG Subtracted

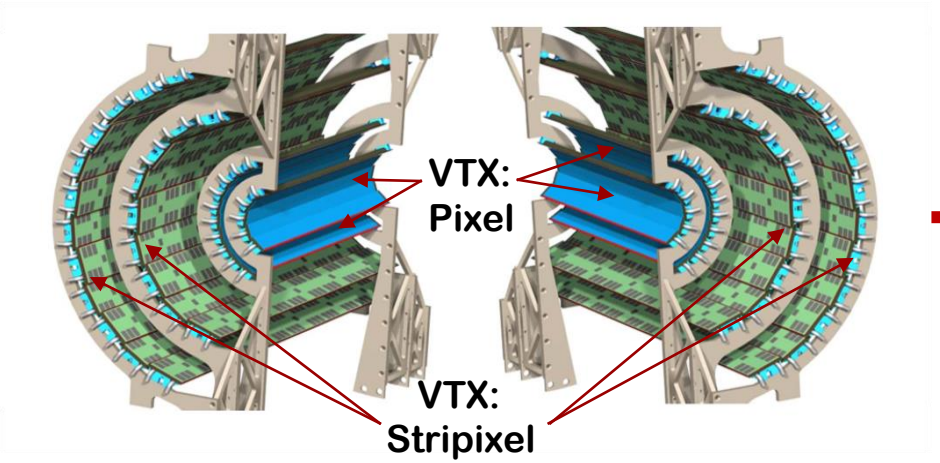


J/ψ momentum-p_T momentum distribution in the mass region [2.4,3.3]

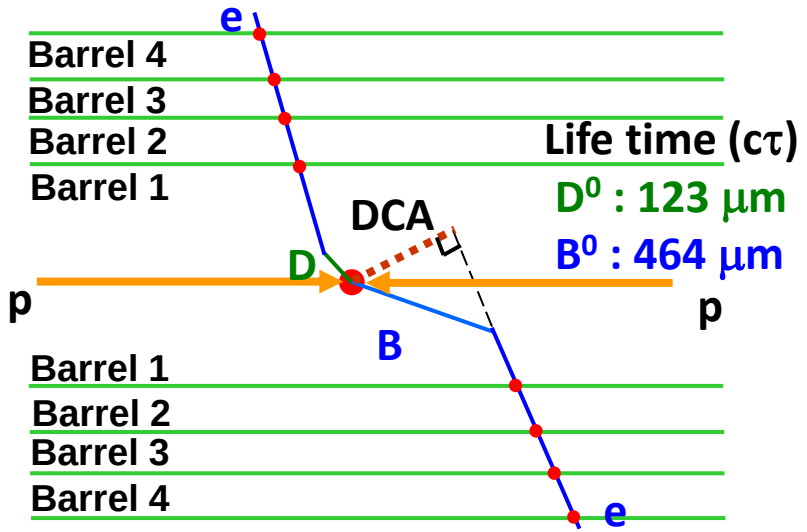


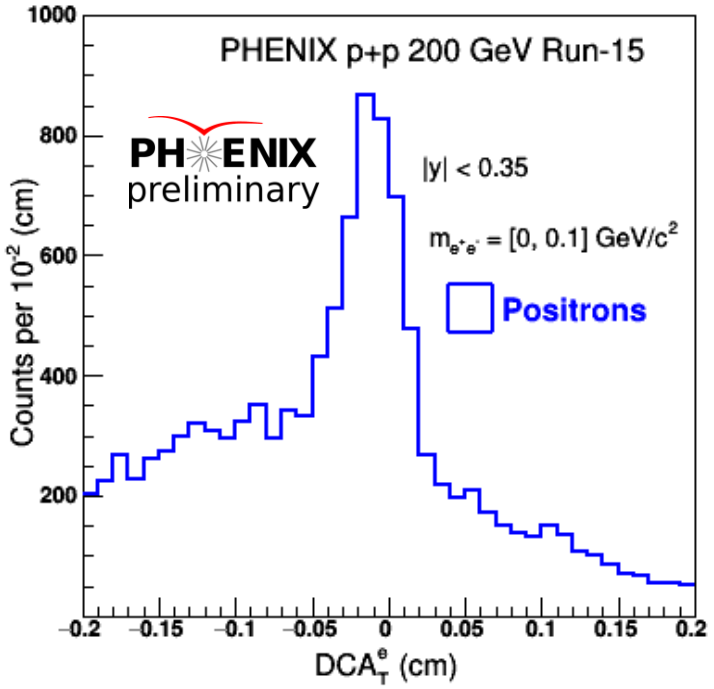
DCA_T Distributions of e+/e- from Dalitz Decay and Photon Conversion $M_{e^+e^-} < 0.1\ GeV/c^2$

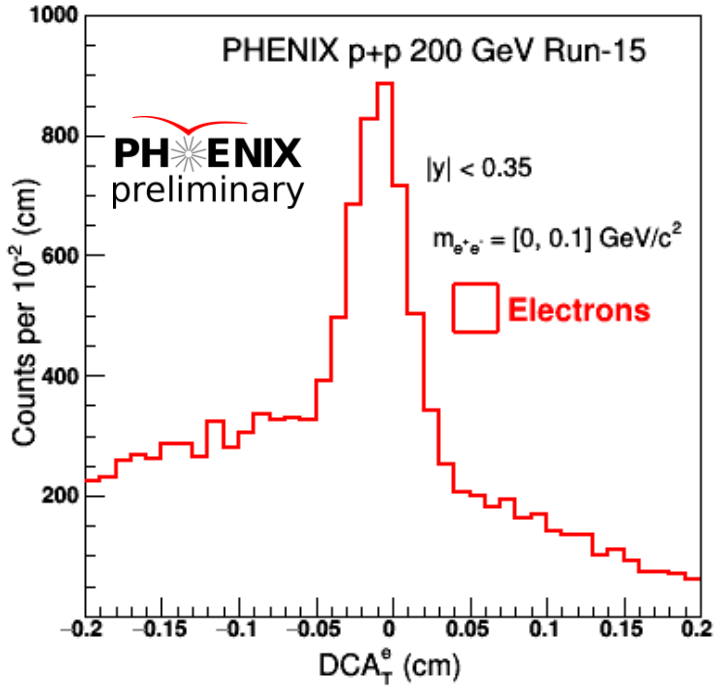
VTX: silicon VerTeX barrel tracker

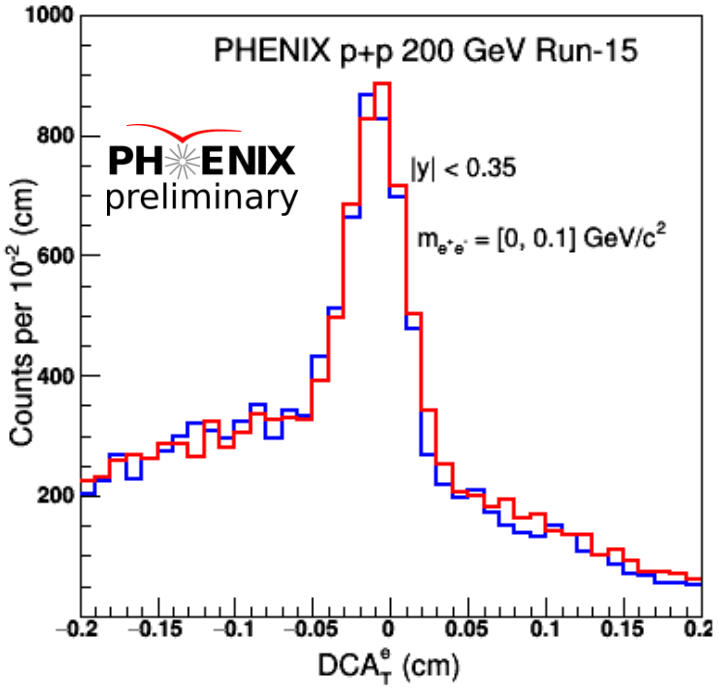


DCA









Analysis Method: Extract the Fraction of B-meson Decays to J/ψ $F_{B\to J/\psi}$

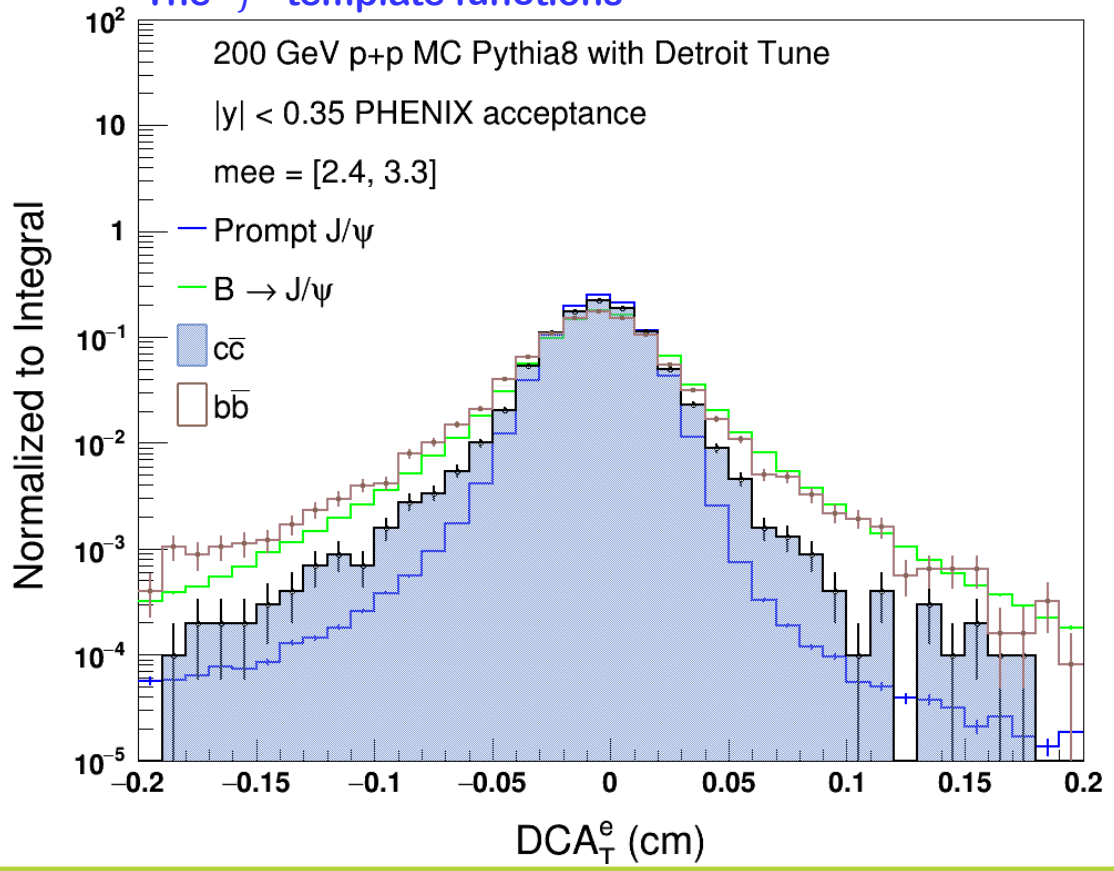
DCA Fit function

In p+p collisions at 200 GeV, $R_b = 0.3 \pm 0.1$

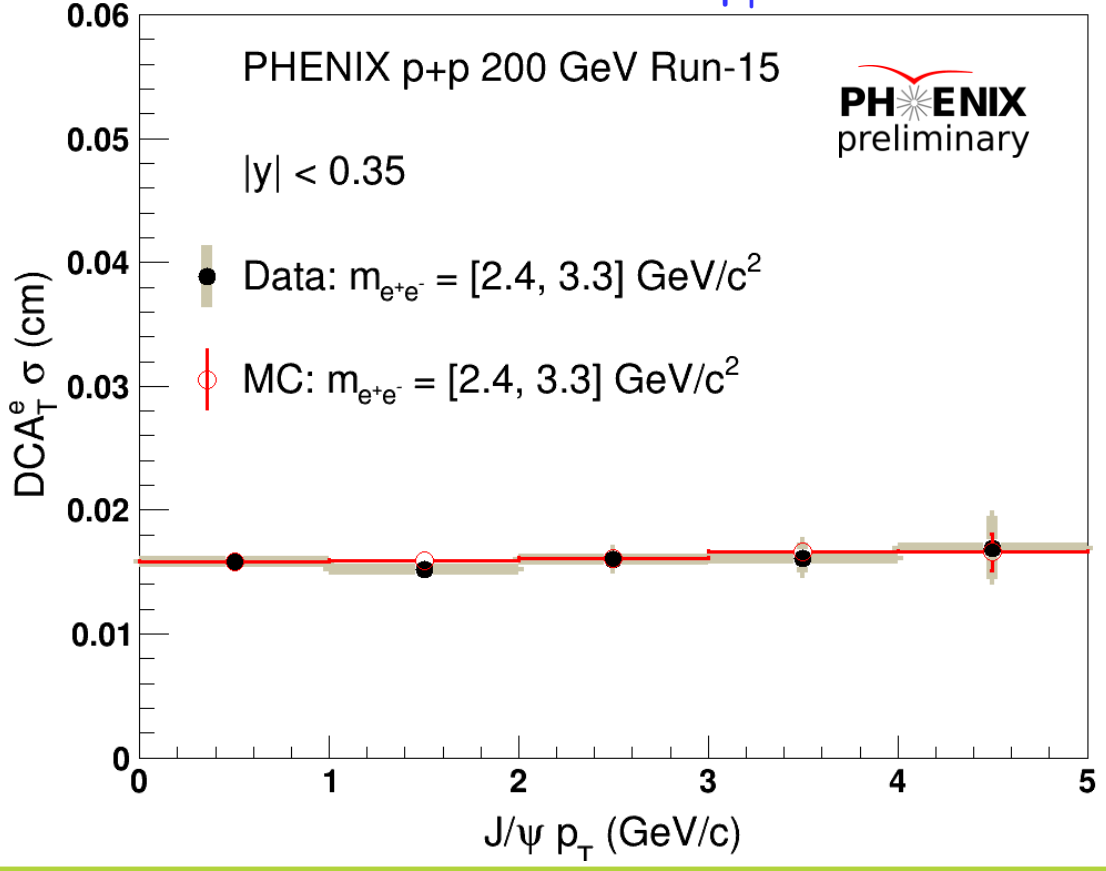
$$f_{\text{total}}(\text{DCA}_T) - f_{\text{combinatorial}}(\text{DCA}_T) = \text{Yield}_{\text{incl. } J/\psi} \times [F_{B\to J/\psi} \times f_{B\to J/\psi}(\text{DCA}_T) + (1 - F_{B\to J/\psi}) \times f_{\text{prompt } J/\psi}(\text{DCA}_T)]$$

$$+ \text{Yield}_{c\bar{c}+b\bar{b}} \times [(1 - R_b) \times f_{c\bar{c}}(\text{DCA}_T) + R_b \times f_{b\bar{b}}(\text{DCA}_T)]$$

The "f" template functions

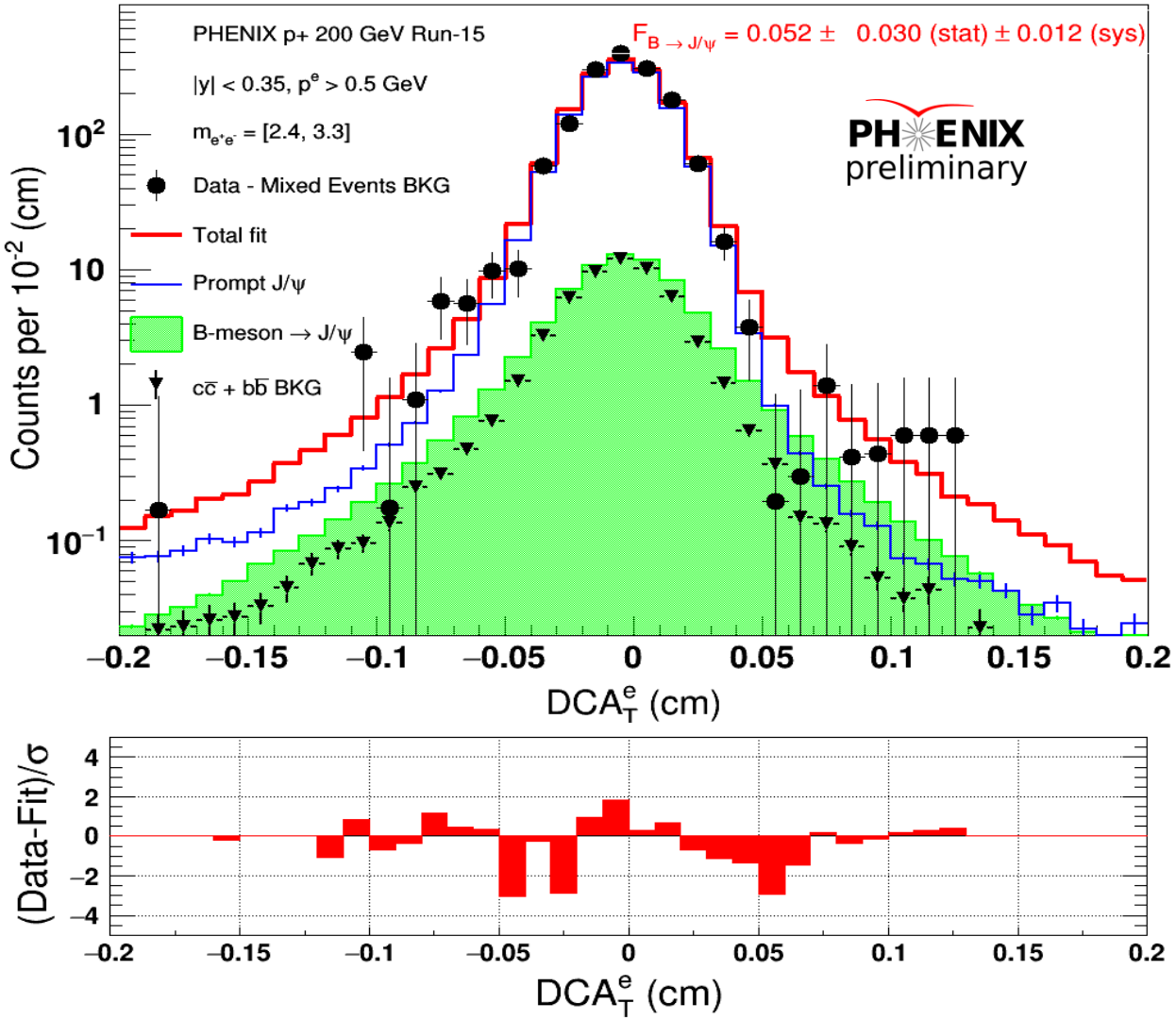


DCA resolution Data and MC vs p_T



Results: B→ J/ψ using DCA Technique

Extraction of fraction B-meson decays to J/ψ ($F_{B\to J/\psi}$)



$F_{B\to J/\psi}$ distribution for 200k fit iterations

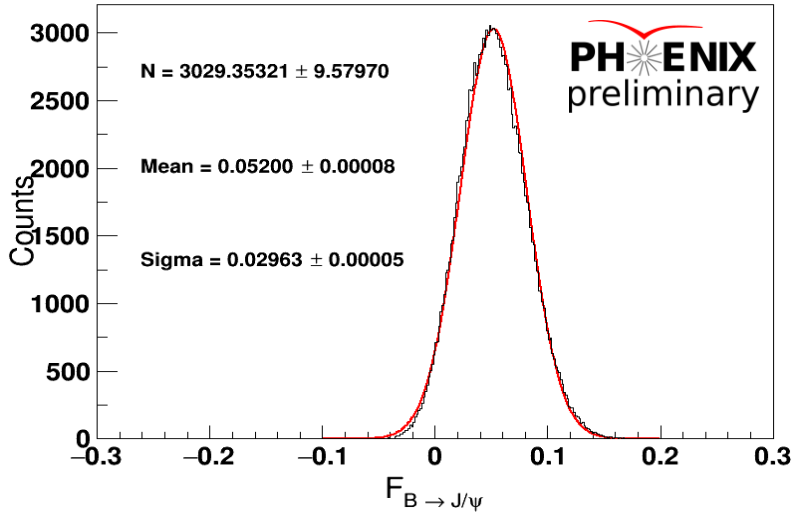


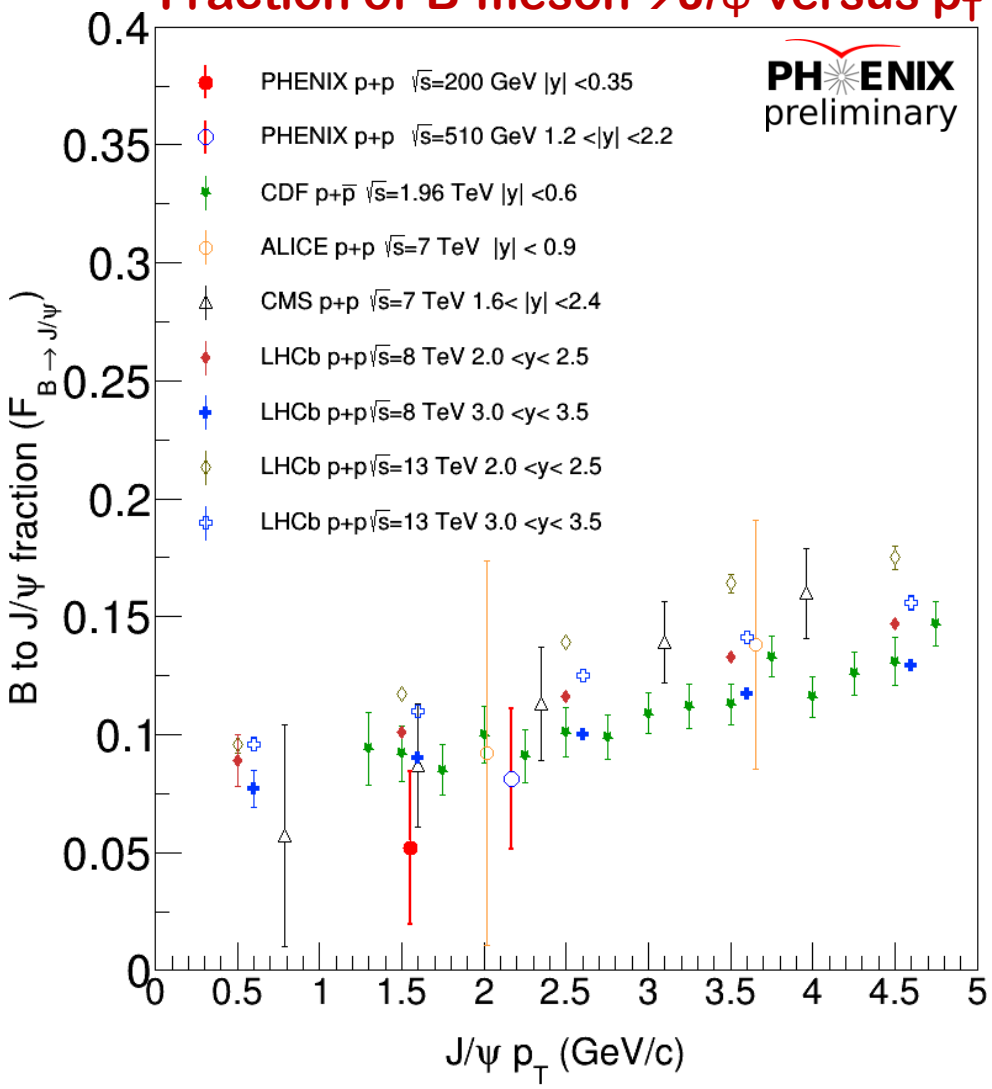
Table 2: Systematic uncertainty summary for the fraction of J/ψ from B-meson decay in the $-0.35 < y < 0.35$ rapidity regions. Values are in absolute scale.

Source	$-0.35 < y < 0.35$	Specific meaning
a	< 1%	Fit method variation
b	6.0%	Fraction of charm and bottom (R_b) variation
c	6.3%	J/ψ yield variation
d	6.7%	Collision vertex variation
e	4.6%	Mixed events background variation
Total syst uncertainty	**23.6%**	

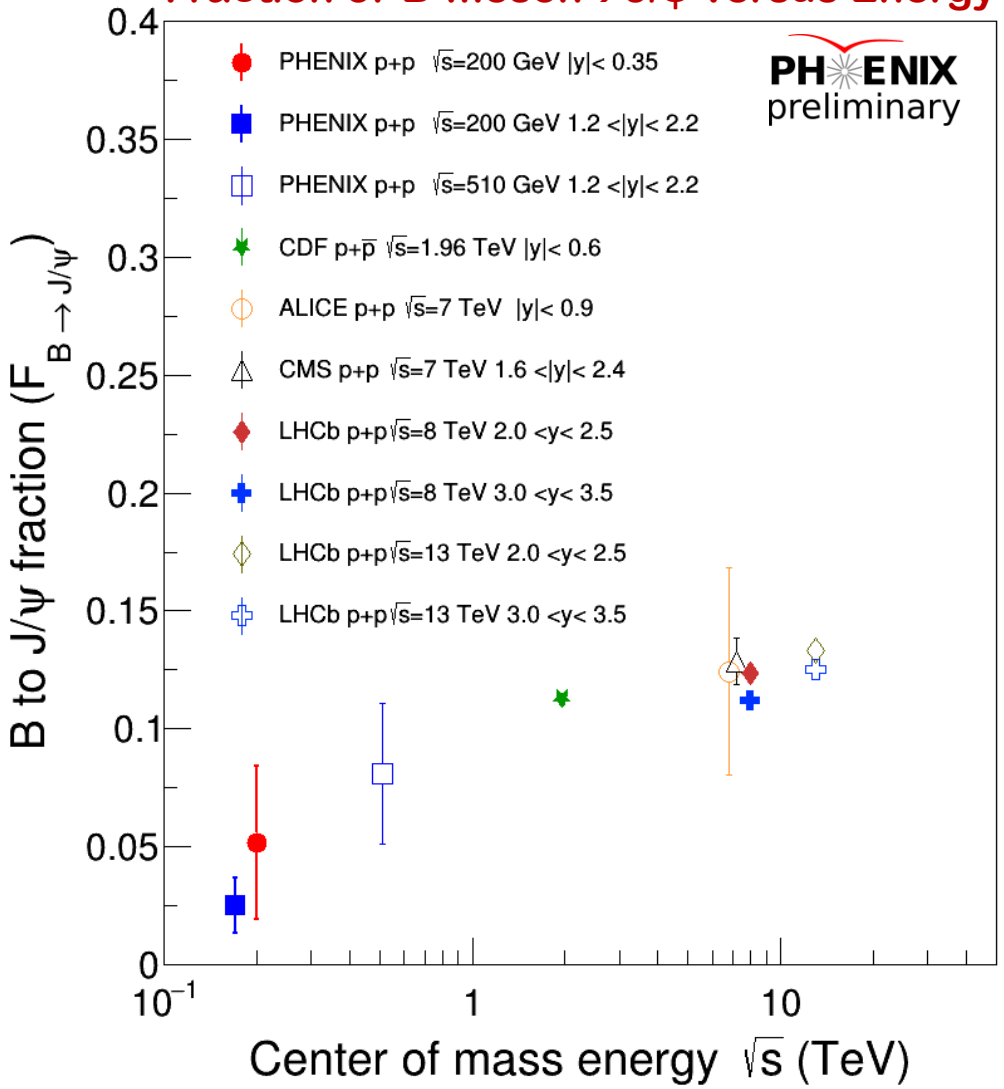
$$F_{B\to J/\psi} = 0.052 \pm 0.030\ (\text{stat}) \pm 0.012\ (\text{sys})$$

Results: Energy and Transverse Momentum Dependence

Fraction of B-meson→J/ψ versus p_T



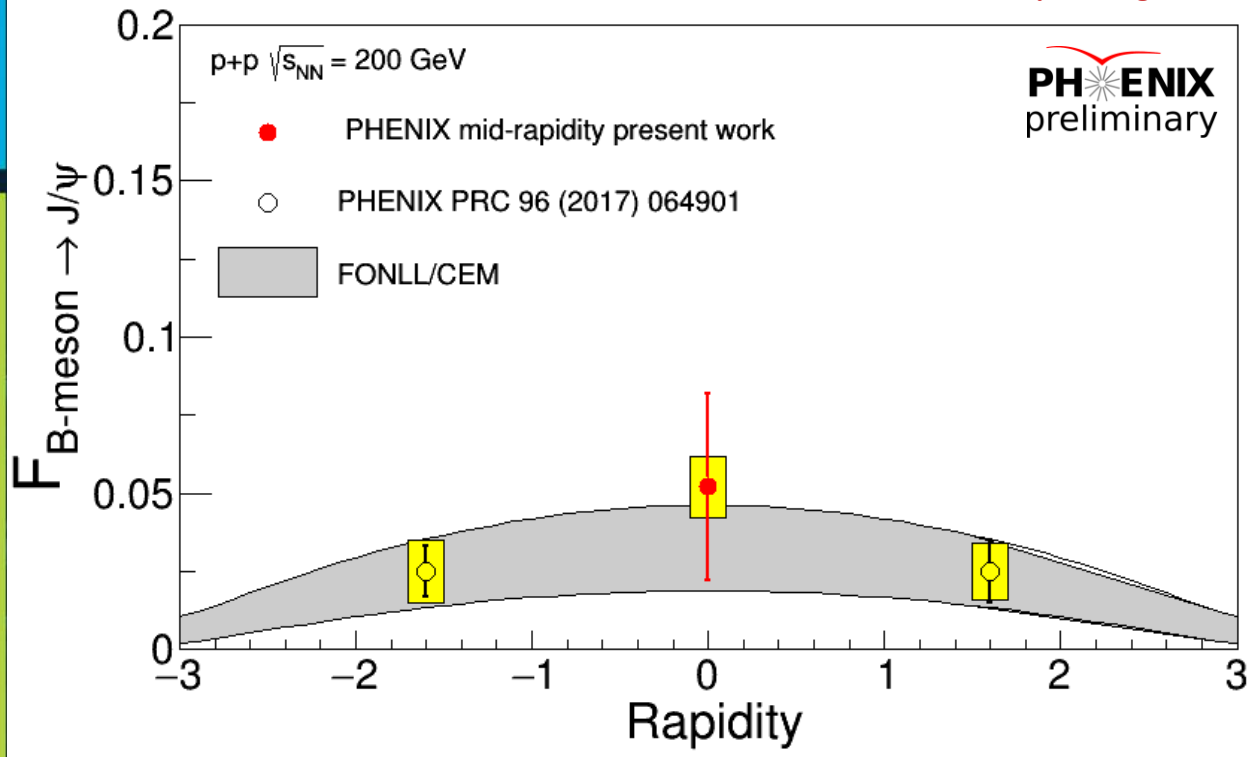
Fraction of B-meson→J/ψ versus Energy



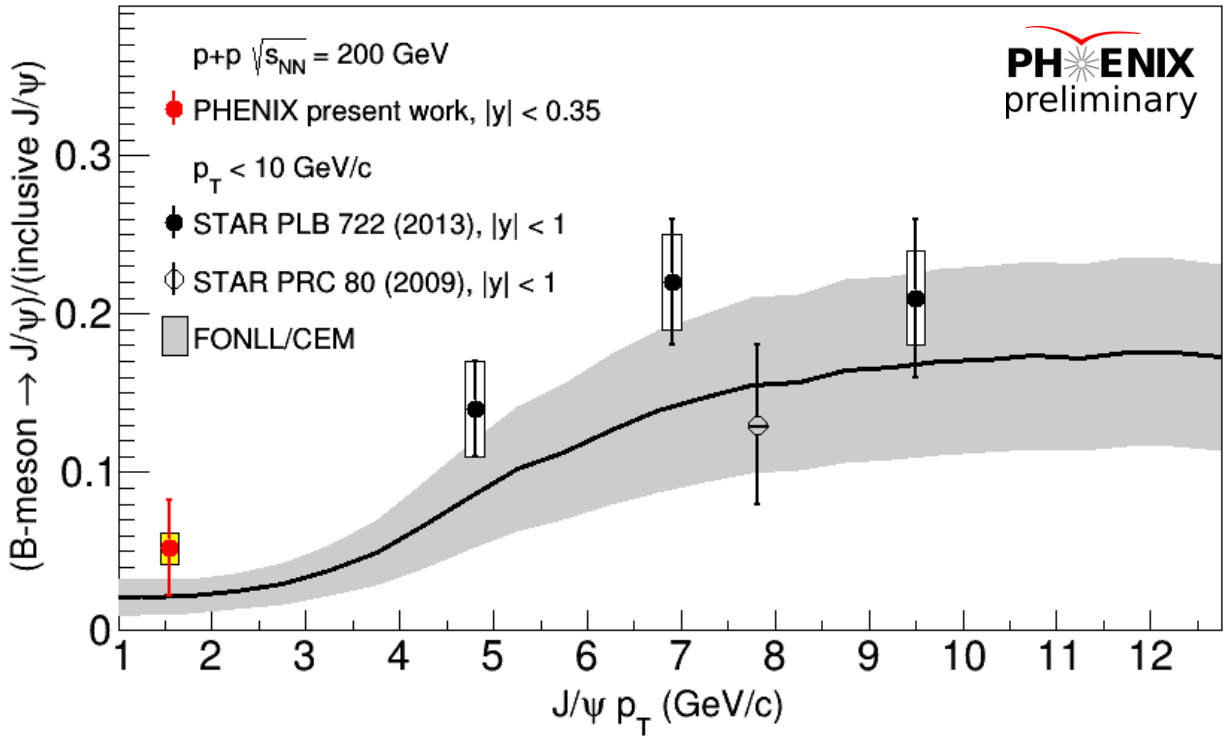
Excellent agreement with CDF/ALICE/CMS/LHCb measurements

Results: Rapidity Dependence and PHENIX/STAR Comparison

Fraction of B-meson→J/ψ versus rapidity



PHENIX and STAR results versus p_T



Note: STAR results used correlation method (not DCA technic)

Excellent agreement with Fixed-Order-Next-to-Leading-Logarithm plus Color-Evaporation-Model (FONLL+CEM) predictions across large rapidity range.

Summary & Outlook

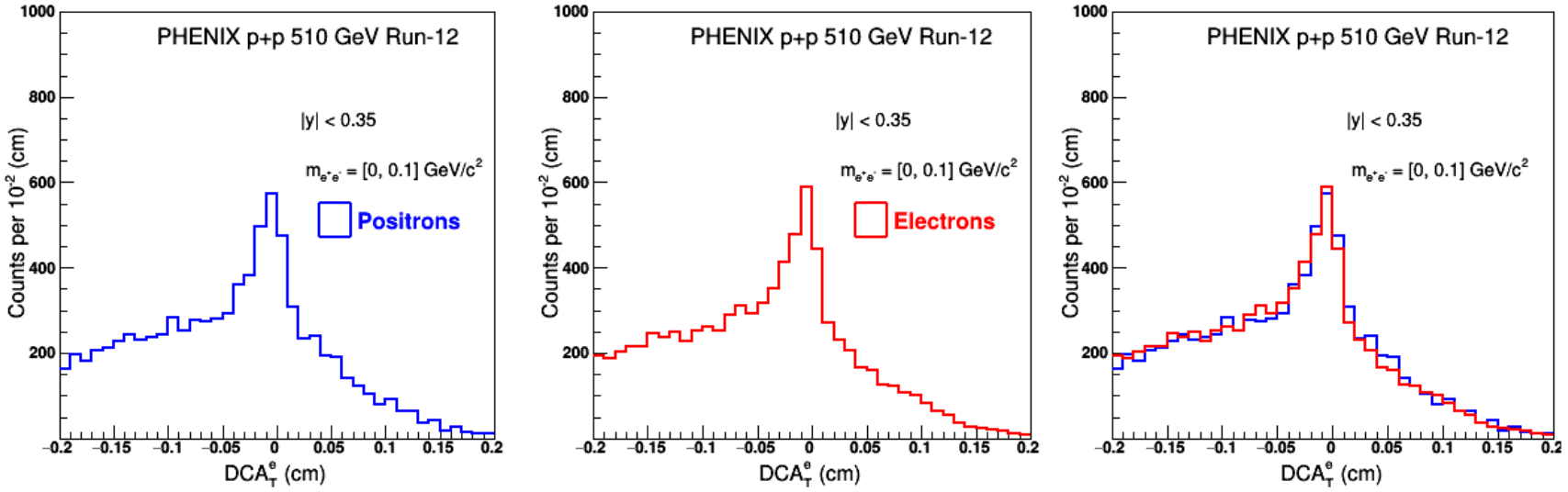
Few bullets to remember

1) **pp@200 GeV:** fraction of B-meson decays in J/ψ yields over large rapidity range has been measured, and excellent agreement with FONLL+CEM predictions

   - **next step:** measure B-meson→J/ψ for different p_T bins

2) **pp@510 GeV:** recently, excellent progress was made on data calibration; we will measure the fraction of B-meson decays in J/ψ yields soon

Performance plot for pp@510 GeV



Performance plot for pp@510 GeV: DCA_T Distributions of e+/e- from Dalitz Decay and Photon Conversion

$M_{e^+e^-} < 0.1\ GeV/c^2$

Summary & Outlook

Few bullets to remember

1) pp@200 GeV: fraction of B-meson decays in J/ψ yields over large rapidity range has been measured, and excellent agreement with FONLL+CEM predictions
   - next step: measure B-meson→J/ψ for different p_T bins

2) pp@510 GeV: recently, excellent progress was made on data calibration; we will measure the fraction of B-meson decays in J/ψ yields soon

3) The present results in p+p collisions serve as a crucial baseline for the future measurements of B-meson→J/ψ in more complex environments like in small-collision systems p+Al, p+Au, d+Au, He+Au, and in the large collision system Au+Au at RHIC.