Measurement of $J/\psi \rightarrow \mu^+\mu^-$ in p+p collisions at $\sqrt{s}$ = 200 GeV with the PHENIX experiment at RHIC

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for the PHENIX collaboration

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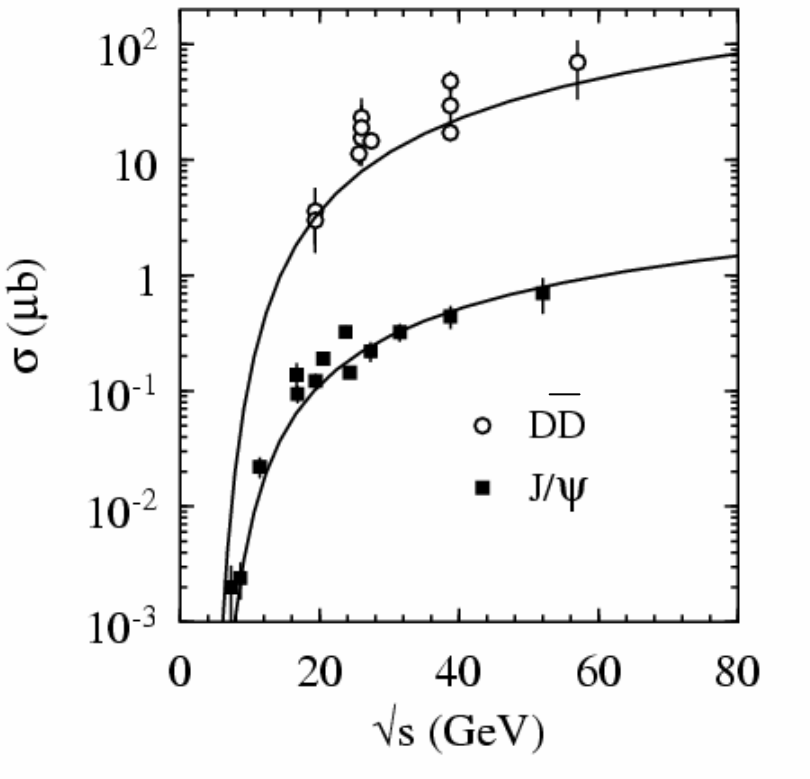
Physics Motivations

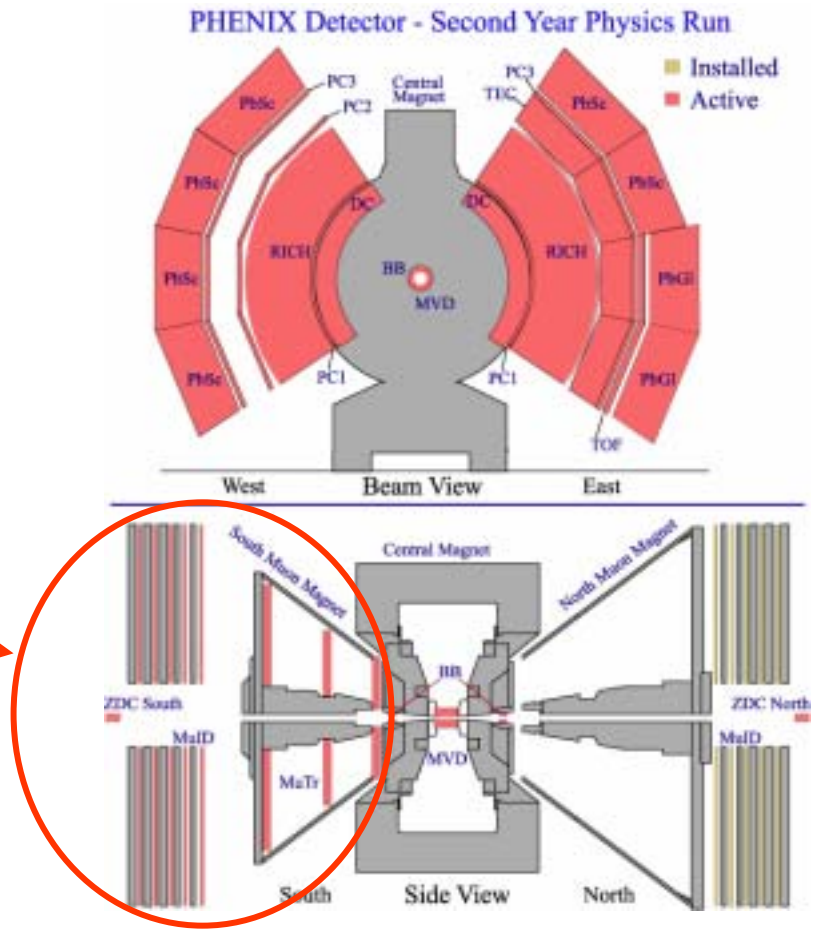
- J/ψ production cross-section in p+p collisions at √s = 200 GeV
  - First measurement of the total cross section of J/ψ at unexplored energy region
  - Discriminate theoretical predictions for the production mechanism
  - Reference point for the search of the anomalous suppression in Au+Au collisions
- Polarization of J/ψ → challenging with the limited statistics of Run-2
- Double-longitudinal spin asymmetries for J/ ψ production in polarized p+p collisions (polarized gluon densities) → Run 3 and later



√s dependence of the J/ψ total cross section with previous experiments

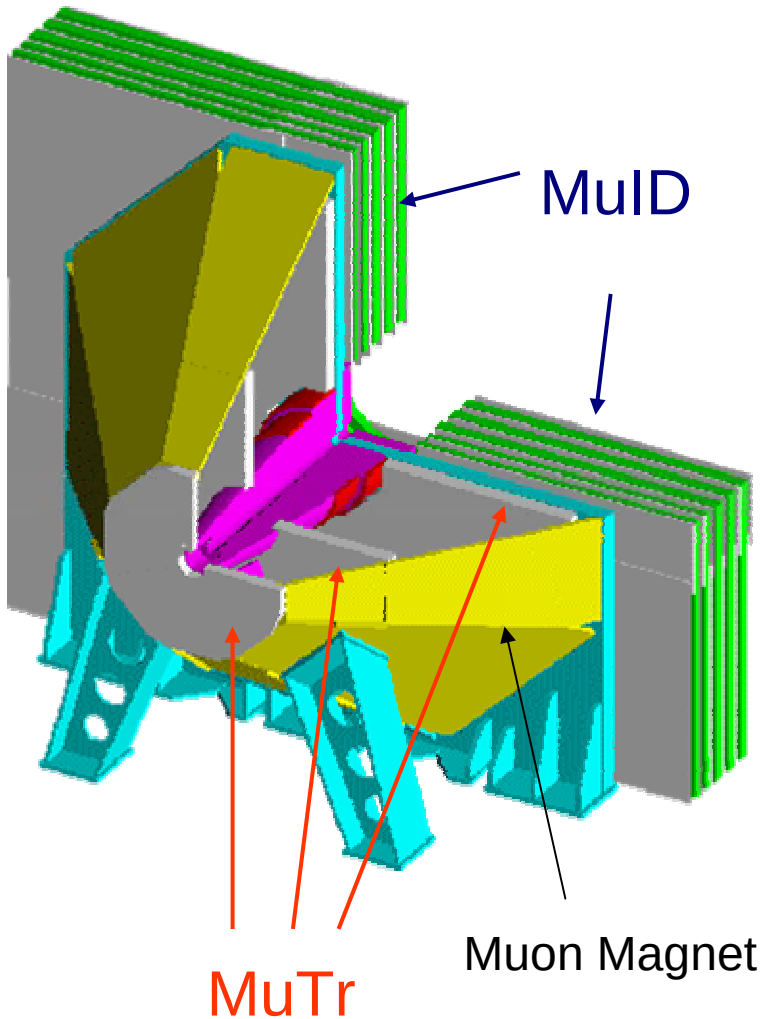
PHENIX Run-2 configuration

- Central Arms to detect hadrons, electrons and photons
  - $|\eta| < 0.35$
  - $p_T > 0.2\text{GeV}/c$
- South Muon Arm for detect muons in the forward region
  - $1.2 < \eta < 2.2$
  - $p_{tot} > 2\text{GeV}/c$



PHENIX Muon Arm

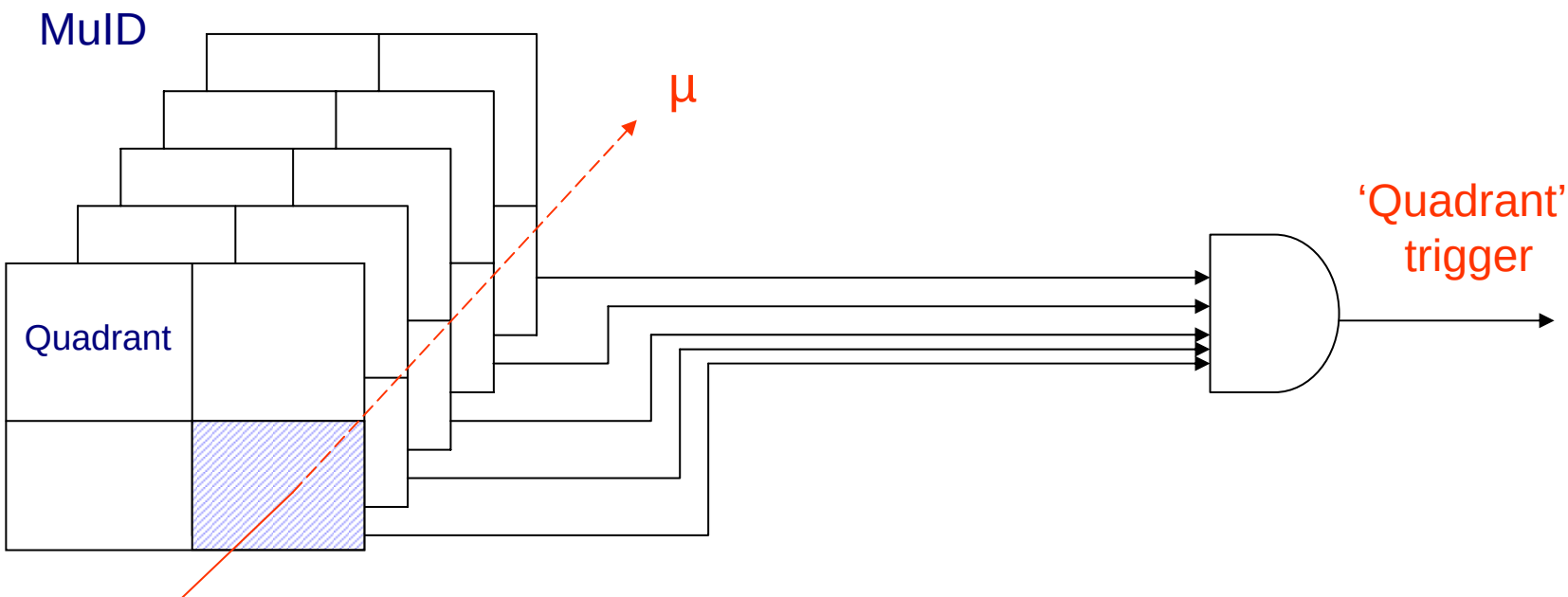
- Detect muons with p_{tot} >2GeV/c, 1.2<η <2.2 (South Arm)
- Pre-hadron-rejection with Central Magnet steel (λ_{int} ~5)
- Muon Tracking Chamber (MuTr)
  - Measure momentum of muons with cathode-readout strip chambers at 3 stations inside Muon Magnet
- Muon Identifier (MuID)
  - π/μ separation with 5-layer sandwich of chambers (Iarocci tubes) and steel
  - Trigger counter
- Successfully operated first time during Run-2



See Ken Read's poster for details

Muon Trigger in Run-2 p+p

- Coincidence of fired planes of each "quadrant"
- One quadrant for "single-muon trigger" and more than one quadrant for "dimuon trigger"
- Inefficiencies from hardware dead time is 1~2%
- Trigger rate was dominated by non-collision beam related background → survived with Run-2 luminosity



p+p Muon Event sample in Run-2

- After final muon-trigger setup has done

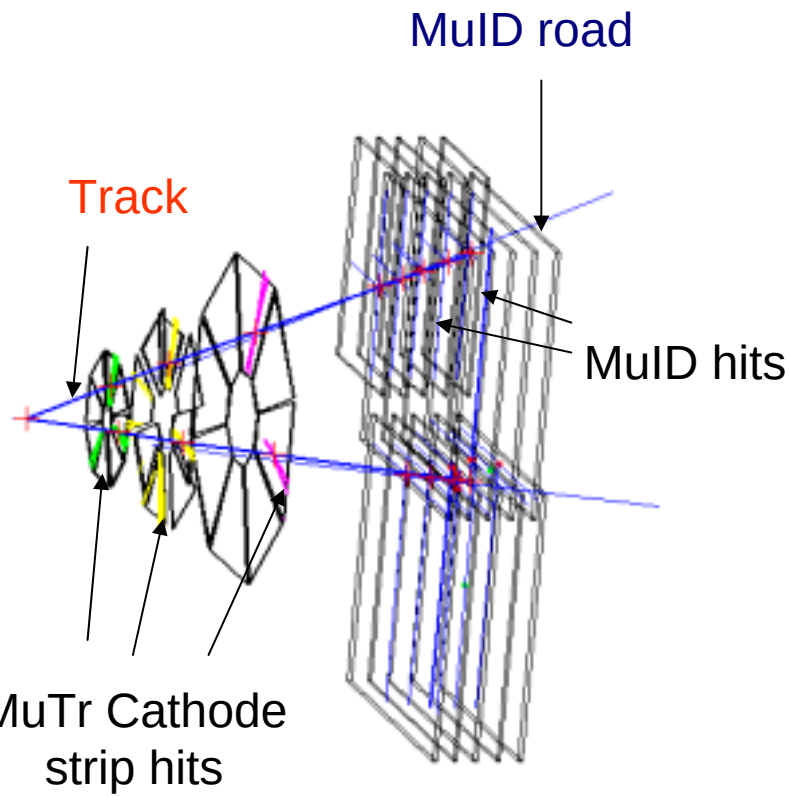
Number of p+p minimum-bias triggered events	196M
Number of single muon triggered events	34M
Number of dimuon triggered events	4.8M

Contains most of J/ψ statistics

Finding muon tracks

- Find roads (tracks in MuID)
- Find tracks in MuTr using roads as seeds
- Fit tracks including an event-vertex point

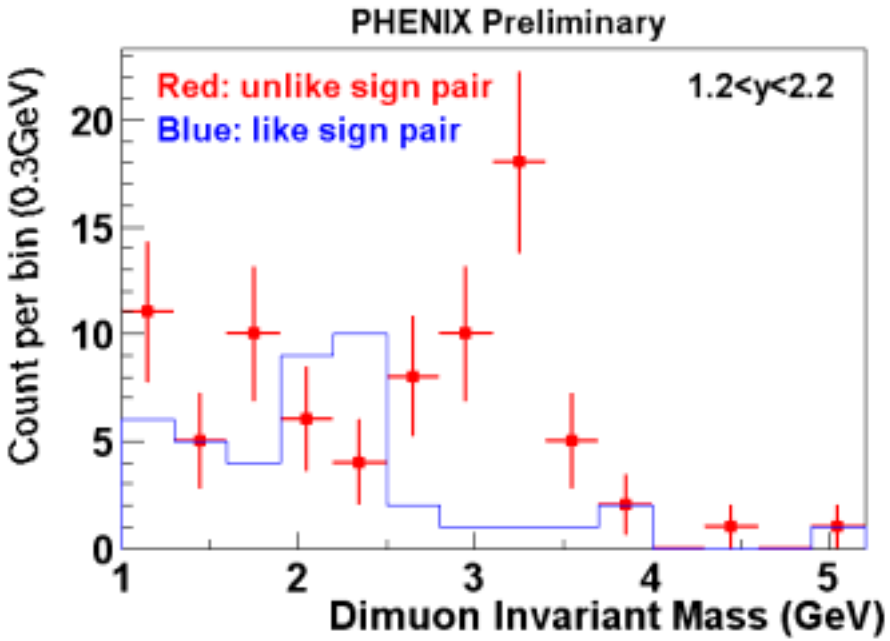
See Jason Newby's poster for details

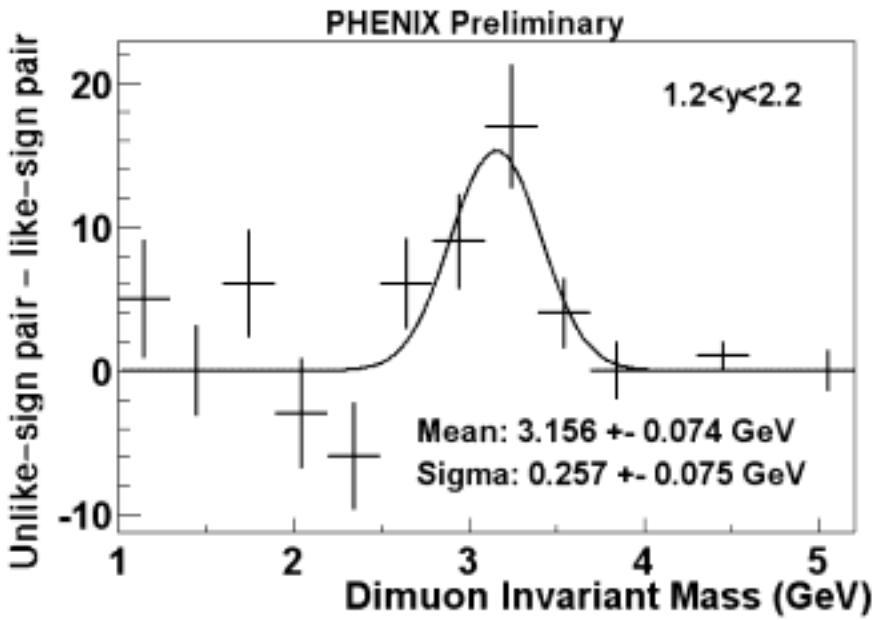


"J/ψ candidate" event

Dimuon mass

|Collision z-vertex| < 38cm
Track z-vertex matching <30cm





- Significant enhancement of unlike-sign pair in the J/ψ mass region
  - Peak (3156 ± 74 MeV/c^2) is consistent with J/ψ mass
  - Mass width (257 ± 75 MeV/c^2) is consistent with expectation → further improvement is expected
- 36 counts in 2.5<mass<3.7GeV/c assuming same count of unlike and like-sign pairs from background (confirmed with simulation)
- Systematic error on the count ~10 % by changing mass cut

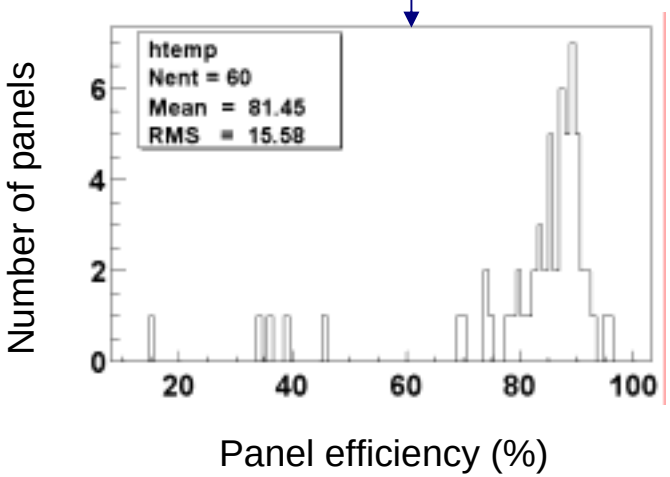
Normalizations

$$B_r \frac{d\sigma_{J/\psi}}{dy} = \frac{N_{J/\psi}}{A_{cc}\varepsilon_{MuID}\varepsilon_{MuTr}\varepsilon_{int\_J/\psi}L}$$

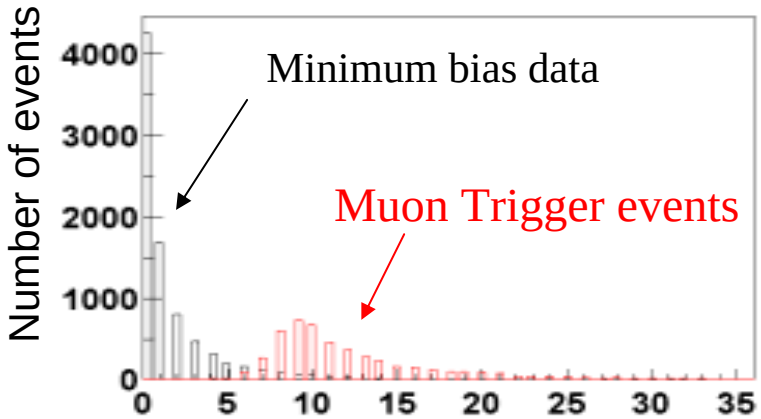
- $N_{J/\psi}$: Number of measured J/ψ in 1.2<y<2.2
- A_{cc}: South Muon Arm Acceptance ✕reconstruction efficiency for J/ψ (1.2<y<2.2) → $\mu^+\mu^-$ with the ideal detector
- ε_{MuID}: Real MuID trigger and road efficiency
- ε_{MuTr}: Real MuTr track efficiency
- $\varepsilon_{int\_J/\psi}$: Interaction trigger efficiency for J/ψ events
- L: Luminosity with good vertex cut (|z-vertex|<38cm)

MuID trigger and road efficiencies

- Realistic panel-by-panel efficiencies are used in simulation (obtained from minimum bias real data)
- Single muon trigger✕road efficiency ~ 0.80
- Dimuon trigger✕road efficiency ~ 0.62
- Systematic uncertainty (run dependence) ~ 11%
- Ratio (road efficiency)/(trigger ✕road efficiency) is consistent with real data (~0.9)
- Efficiency doesn't lose when mixed with real data since occupancy is low enough (underneath)

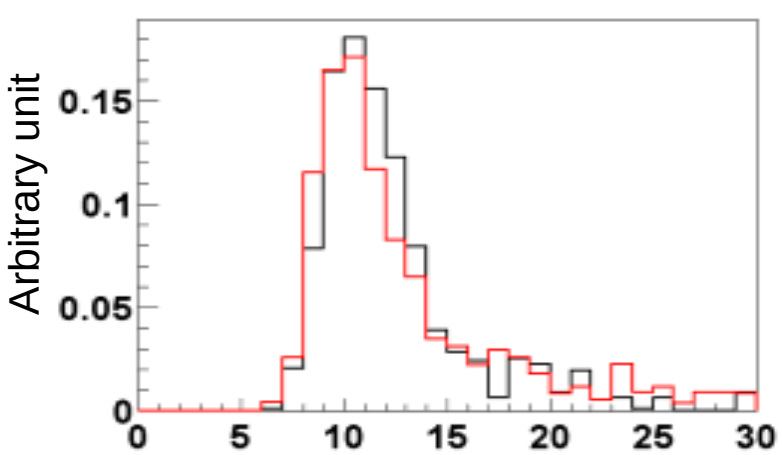


MuID hit rate in p+p

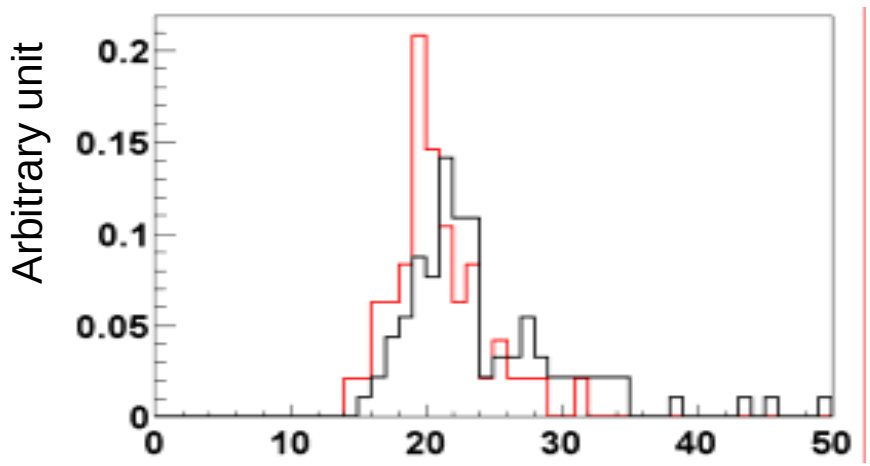


If a single muon passes through the MuID, it produces ~10 hits nominally

→ Background is small in p+p



Total number of MuID hits when a road found



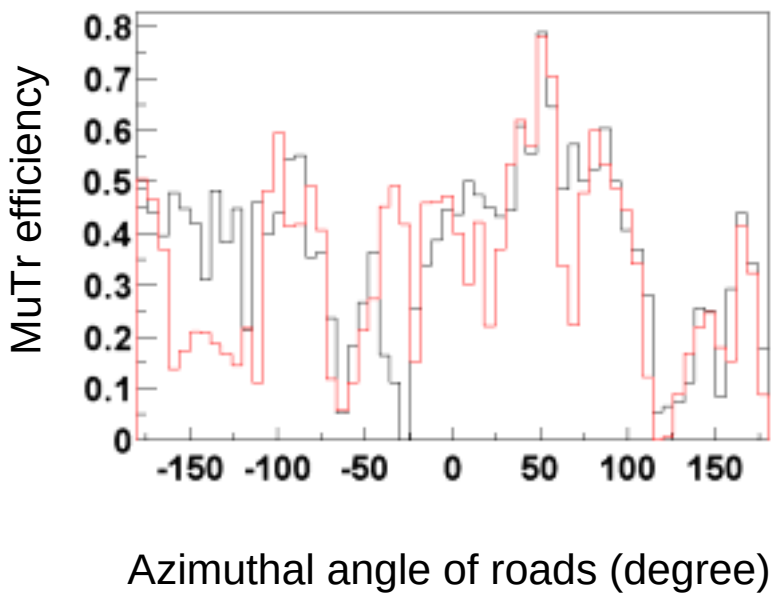
Total number of MuID hits for dimuons events in the J/ψ mass region

MuID Background hits in p+p data is small and consistent with expectation.

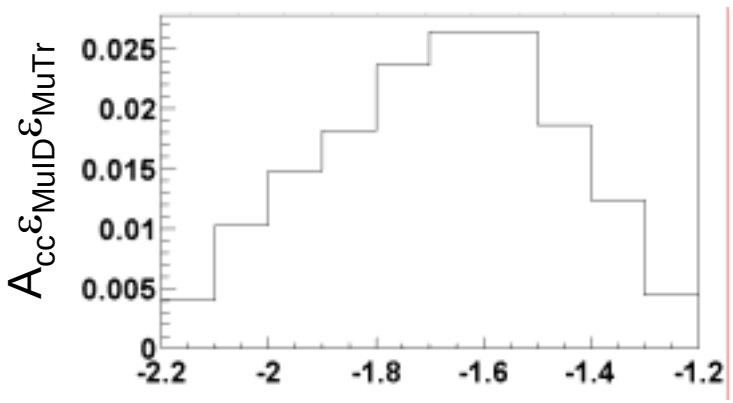
MuTr Track efficiency

- MuTr inefficiency is caused mainly due to dead HV and dead FEM during the run
- Efficiency for dimuons ~ 0.23
- MuTr efficiency obtained using MuID roads is consistent with simulation except Octant-5 and Octant-7
- 10% systematic error is assigned from this inconsistency
- Run dependence will be small <10% since only high “Duty Fraction” runs(>0.89) were selected.

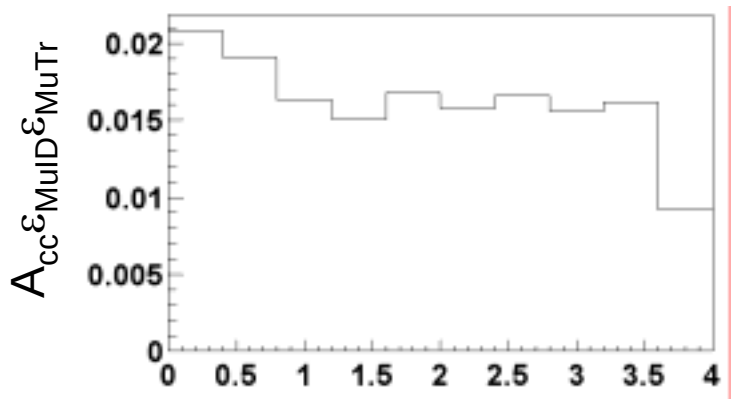
MuTr efficiency ≡ (number of roads with a track) / (number of roads)



J/ψ Acceptance × reconstruction efficiency with real chamber efficiencies



J/ψ rapidity



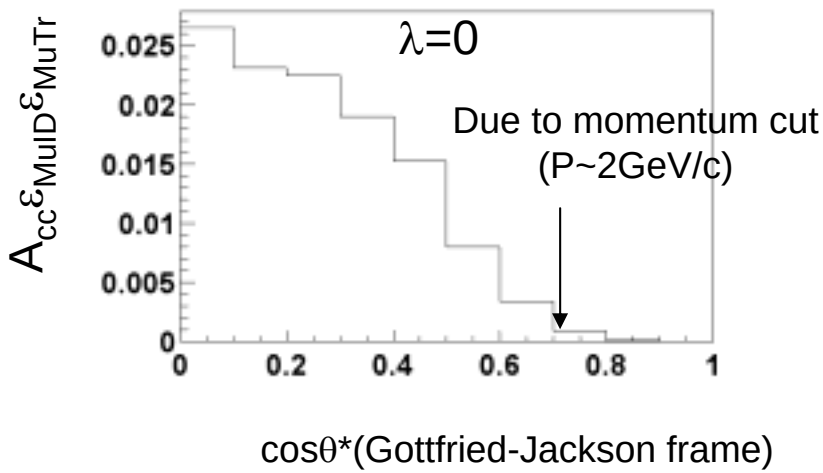
J/ψ p_T (GeV/c)

$$\langle A_{cc}\varepsilon_{MuID}\varepsilon_{MuTr}\rangle_{1.2<y<2.2} = 0.0163$$

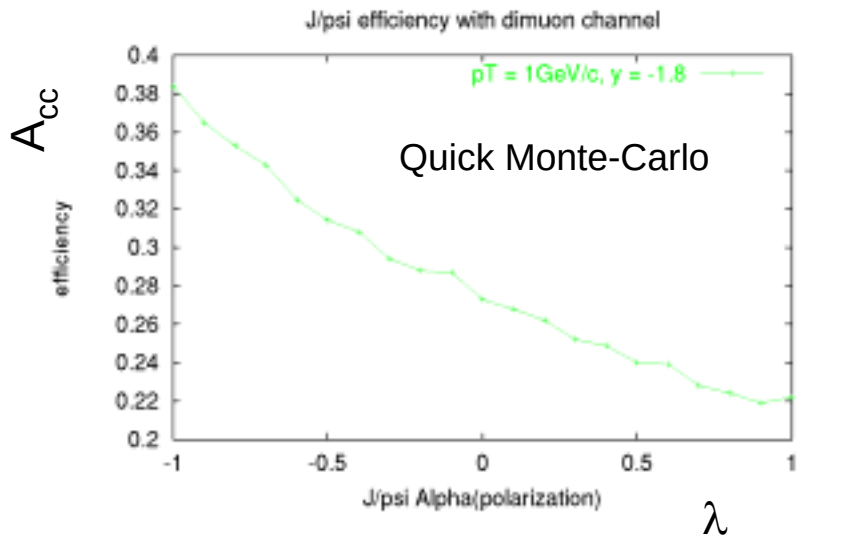
- dσ/dy in 1.2<y<2.2 can be measured with the South Muon Arm
- p_T dependence is small
- Uncertainty from unknown J/ψ polarization ~ 10% (underneath)

J/ψ polarization dependence of acceptance

cosθ* dependence of J/ψ acceptance
(with real chamber efficiencies)



λ(J/ψ polarization) dependence of J/ψ acceptance



- There is J/ψ polarization dependence of acceptance because of intrinsic momentum cut (~2GeV/c) of the Muon Arm
- But there is no indication from previous experiment (both Fixed target energy and Tevatron) |λ| is larger than 0.3.
- Assign 10% systematic error assuming |λ| < 0.3.

Interaction counter efficiency and luminosity

$$\varepsilon_{int\_J/\psi} L = \frac{\varepsilon_{int\_J/\psi}}{\varepsilon_{int\_inela}} \frac{N_{int}}{\sigma_{inela}}$$

$$= \frac{0.74}{0.51} \frac{1.73 \times 10^{9}}{42mb}$$

$$= 60nb^{-1}$$

- σ_{inela}: p+p inelastic cross section = 42mb (PYTHIA, $\sqrt{s}$ fit)
- $\varepsilon_{int\_J/\psi}$: interaction trigger efficiency for p+p $\rightarrow$ J/ψ X$\rightarrow$ $\mu^+\mu^-$ events
  p_T(J/ψ) dependence is small
- ε_{int_inela}: interaction trigger efficiency for p+p inelastic events

simulation

- N_{int}: Number of interaction triggers with vertex cut (|z|<38cm)

Real data

- Machine value of $\varepsilon_{int\_inela}\sigma_{inela}$= 18.5mb $\rightarrow$ 15% discrepancy
- Discrepancy with STAR value (analysis in progress)

↓

Assign 20% error on $\varepsilon_{int\_inela}\sigma_{inela}$

Br $d\sigma/dy|_{1.2<y<2.2}$ and its uncertainties

	Center value	Uncertainty
$N_{J/psi}$	36 ($2.5<mass<3.7 GeV/c^2$)	19% (statistical) 10% (cut dependence)
$A_{cc}\varepsilon_{MuID}\varepsilon_{MuTr}$	0.0163 ($1.2<y<2.2$)	10% (J/ψ pol. dep., $\lvert\alpha\rvert<0.3$) 11% (MuID efficiency) 10% (MuTr efficiency)
$\varepsilon_{int\_J/\psi}L$	$60 nb^{-1}$	20% (consistency with machine value) <5% (Trigger counter efficiency)

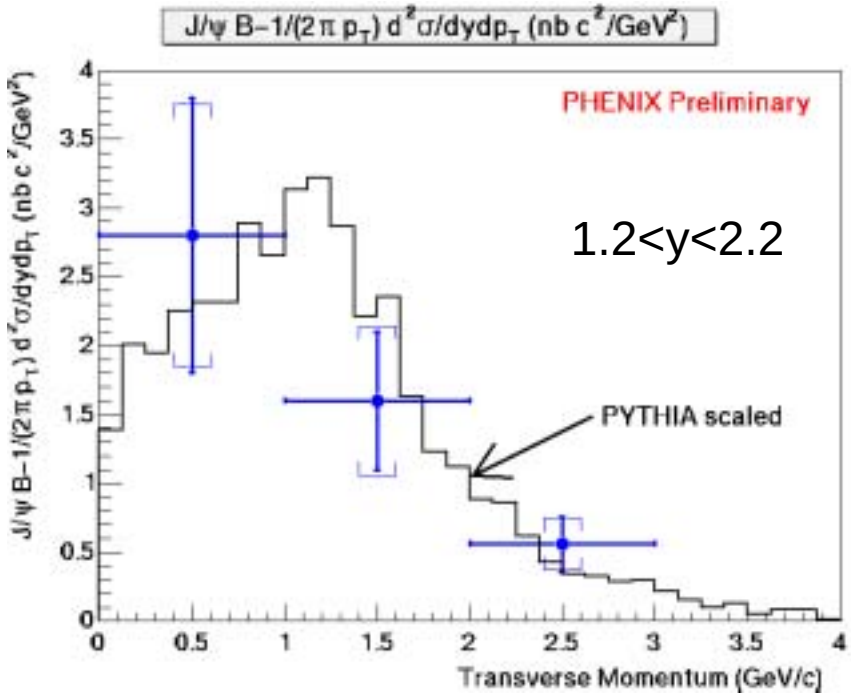
PHENIX Preliminary

Br $d\sigma_{J/\psi}/dy|_{1.2<y<2.2}$ = 37 ± 7(stat.) ±11(syst.) nb

J/ψ p_T distribution

PHENIX Preliminary

P_T bin	$N_{J/\psi}$	Br $(1/2\pi p_T)$ $d\sigma/dydp_T$ $[nb/(GeV/c)^2]$
0-1	10 ± 4	2.8 ± 1.4
1-2	15 ± 5	1.6 ± 0.7
2-3	8 ± 3	0.6 ± 0.3

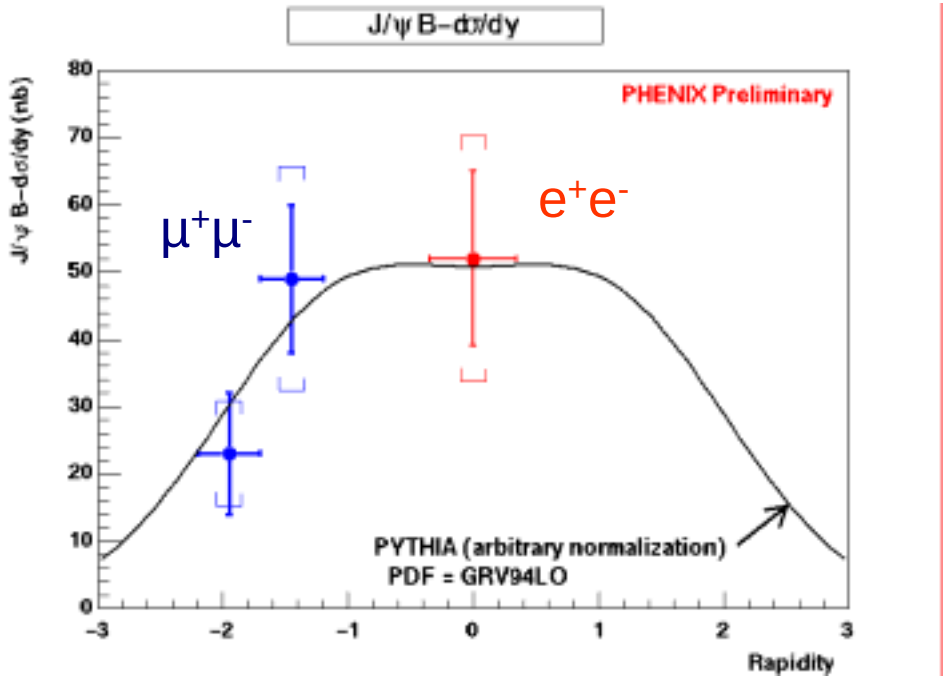


- p_T distribution (shape) is consistent with PYTHIA (color-singlet model) prediction

J/ψ Rapidity distribution and Total cross section

rapidity	$N_{J/\psi}$	Br dσ/dy(nb)
1.2<y<1.7	26 ± 6	49 ± 18
1.7<y<2.2	10 ± 4	23 ± 11

PHENIX Preliminary

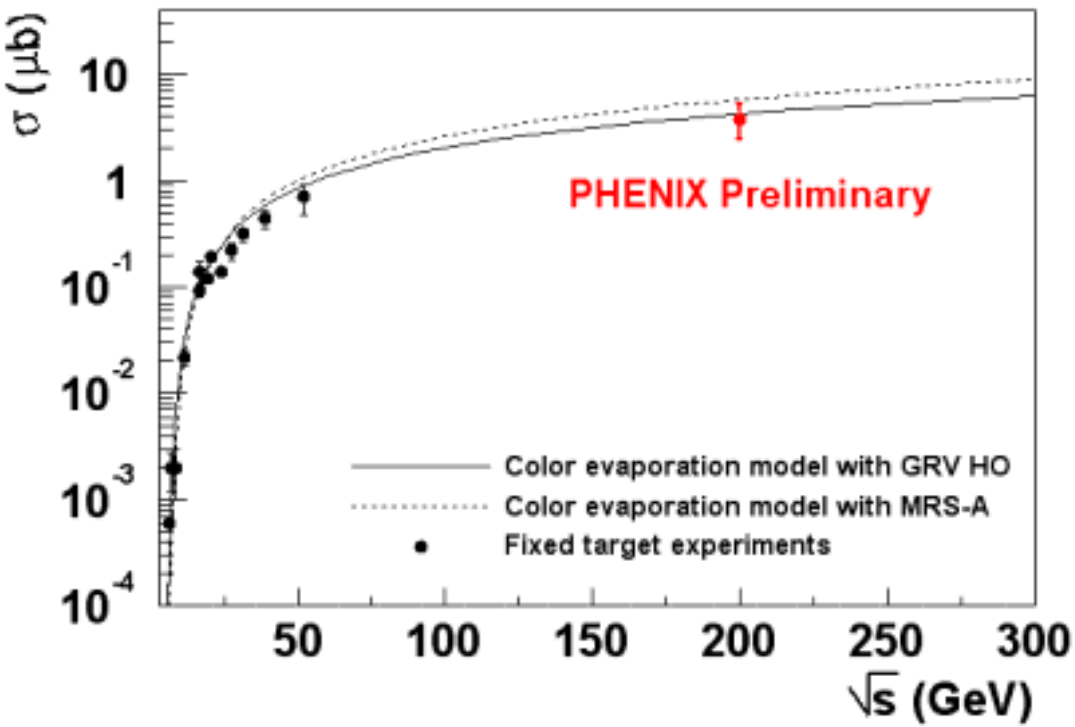


- Rapidity distribution is consistent with PYTHIA
- Global fit including $J/\psi \rightarrow e^+e^-$ (y=0) data gives

Br σ(total) = 226 ± 36 (stat.) ± 79 (syst.) nb
σ(total) = 3.8 ± 0.6 (stat.) ± 1.3 (syst.) μb

PHENIX Preliminary

Total Cross section compared with the Color-Evaporation Model prediction



- Agree with the Color Evaporation Model prediction

Summary

- PHENIX South Muon Arm was successfully operated first time in p+p collisions at $\sqrt{s}$ = 200GeV
- J/ψ is clearly identified with unlike-sign dimuon pairs in its mass region. Width is consistent with expectation (200~300MeV)
- Br $d\sigma_{J/\psi}/dy|_{1.2<y<2.2}$ = 37 $\pm$ 7(stat.) $\pm$ 11(syst.) nb is obtained
- p_T and rapidity distributions are shown
- Rapidity fit including electron data gives
  $\sigma_{J/\psi}$(total) = 3.8 $\pm$ 0.6(stat.) $\pm$ 1.3(syst.) μb
  $\rightarrow$ agree with the Color-Evaporation model prediction

Other Muon related posters

- Kenneth F. Read

  “The Performance of the PHENIX South Muon Arm”

- Jason Newby

  "Reconstruction Performance of the PHENIX South Muon Arm"

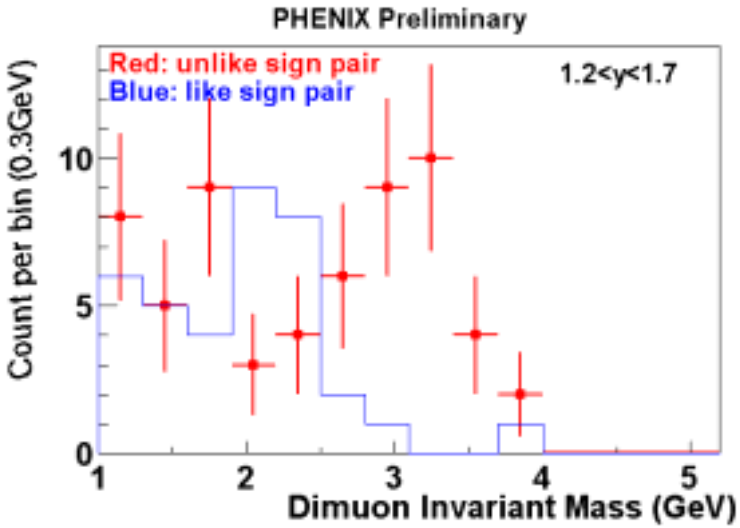
- DongJo Kim

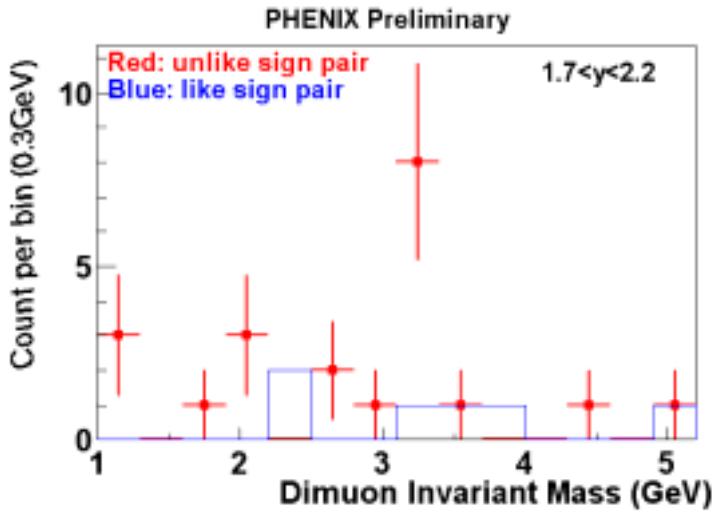
  "Cluster fitting algorithm for the PHENIX muon tracker"

- Ming Xiong Liu

  ”Dimuon Production from Au-Au Collisions at $\sqrt{s}$=200 AGeV”

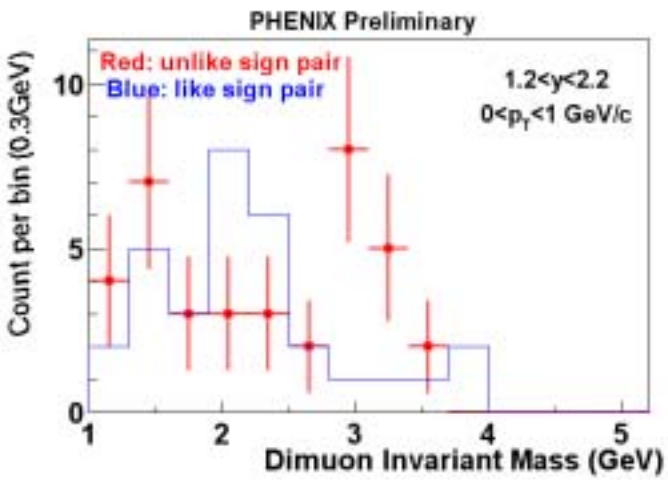
Additional J/psi mass…

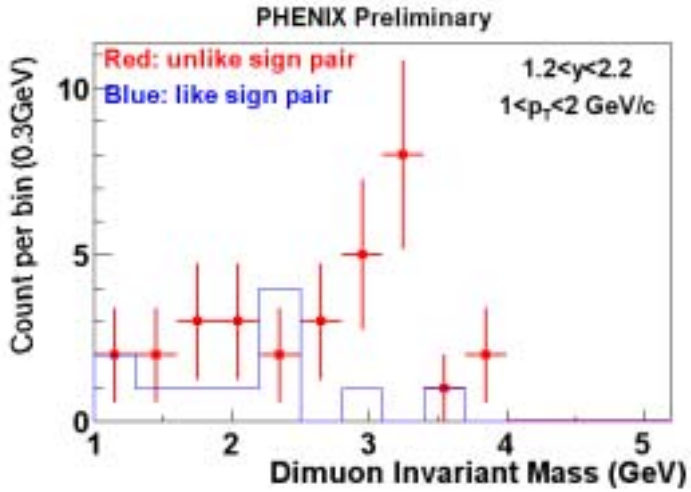


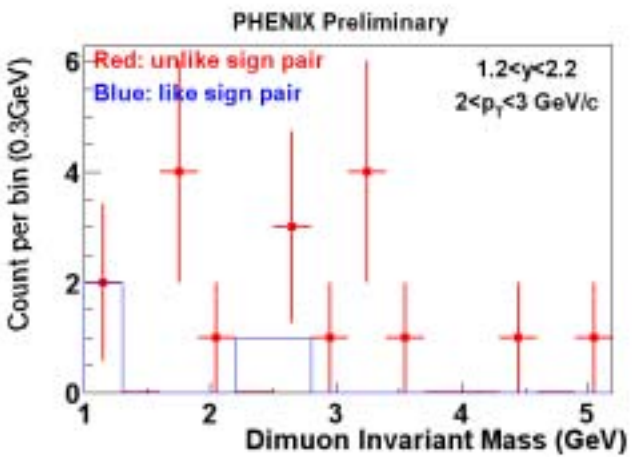


- 2 Rapidity bins

Additional J/psi mass…



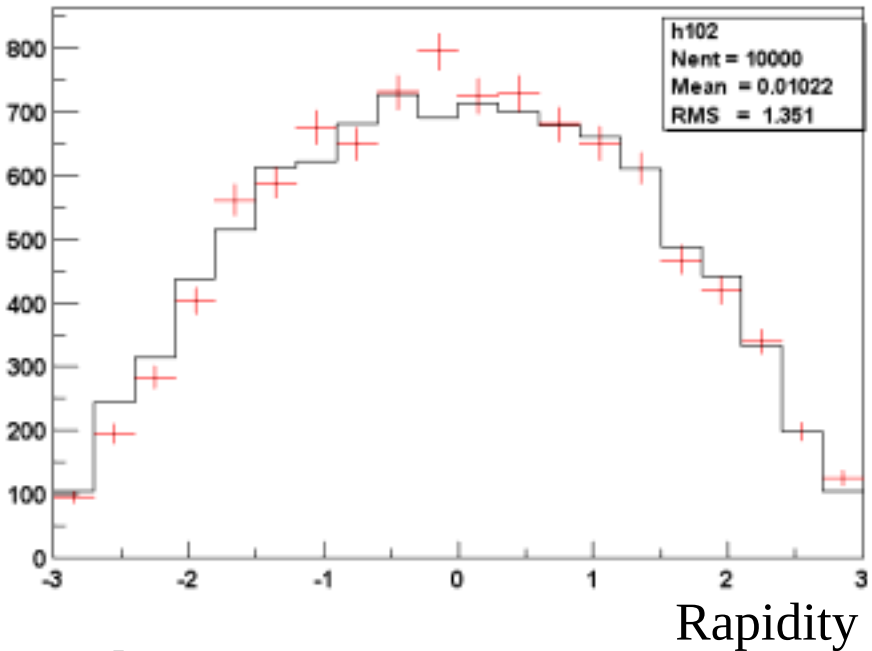


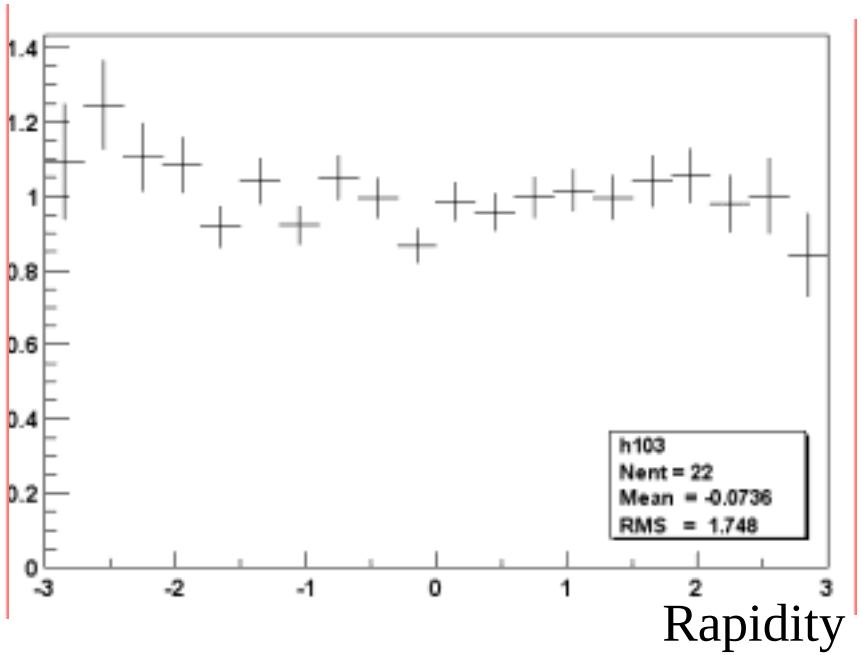


3 pT bins

GRV94LO vs CTEQ4M(NLO)

p+p -> J/psi at sqrt(s) = 200GeV





Red: CTEQ4M

Black; GRV94LO

GRV94LO/CTEQ4M