Low Mass Vector Mesons Nuclear Modification Factors in d+Au Collisions @ 200GeV

Lei Guo

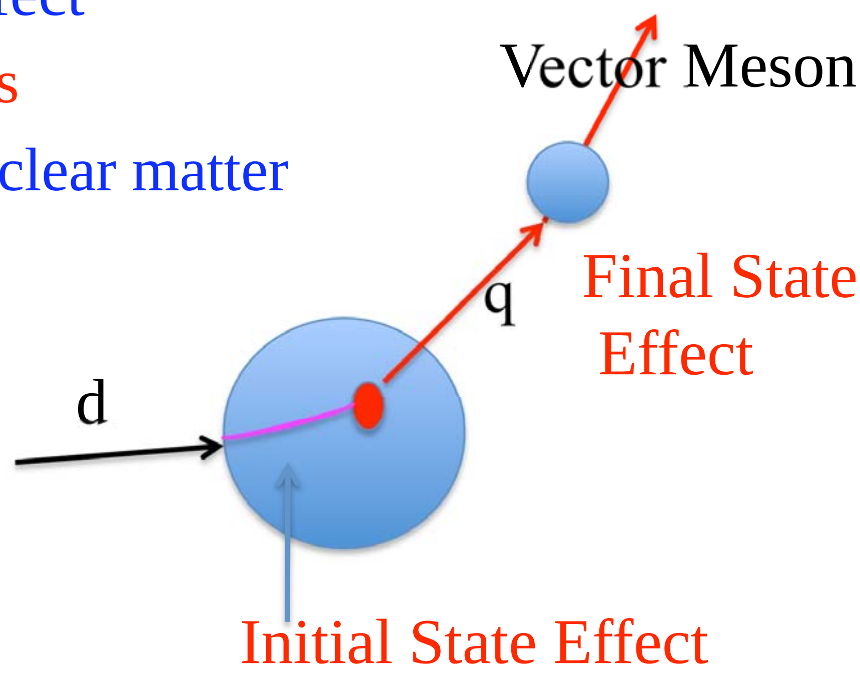
Los Alamos National Laboratory

PHENIX Collaboration

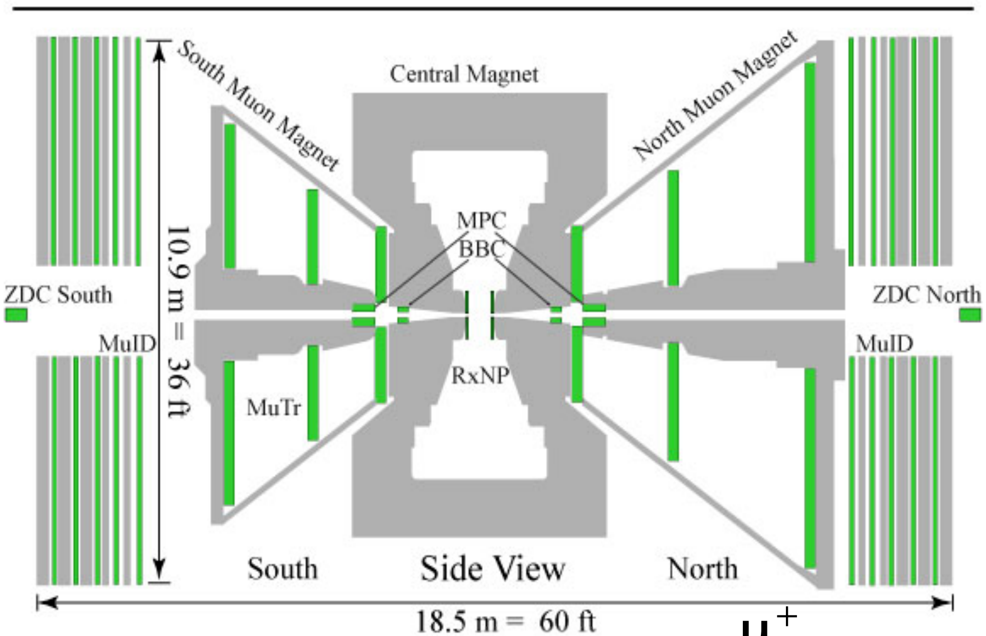
(Presented by Ming Liu)

Motivation

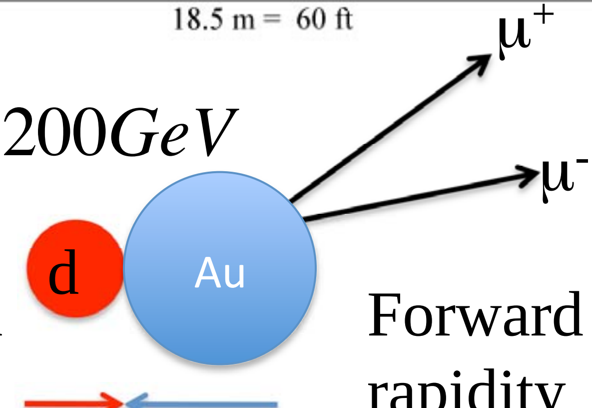
- Cold Nuclear Matter Effect on Low Mass Vector Meson production
  - Nuclear suppression at forward rapidity has been observed for J/Ψ, and other hadrons.
  - Low mass vector mesons only studied in Mid-Rapidity
- Intial State Effect vs Final State Effect
  - partonic scatterings with nucleons
  - hadronic interaction with cold nuclear matter
- Cronin Effect
  - Enhancement at moderate p_T
- First measurement of R_{CP} for $\phi, \rho+\omega$ at forward rapidity



Experimental Setup and Raw Mass Spectrum

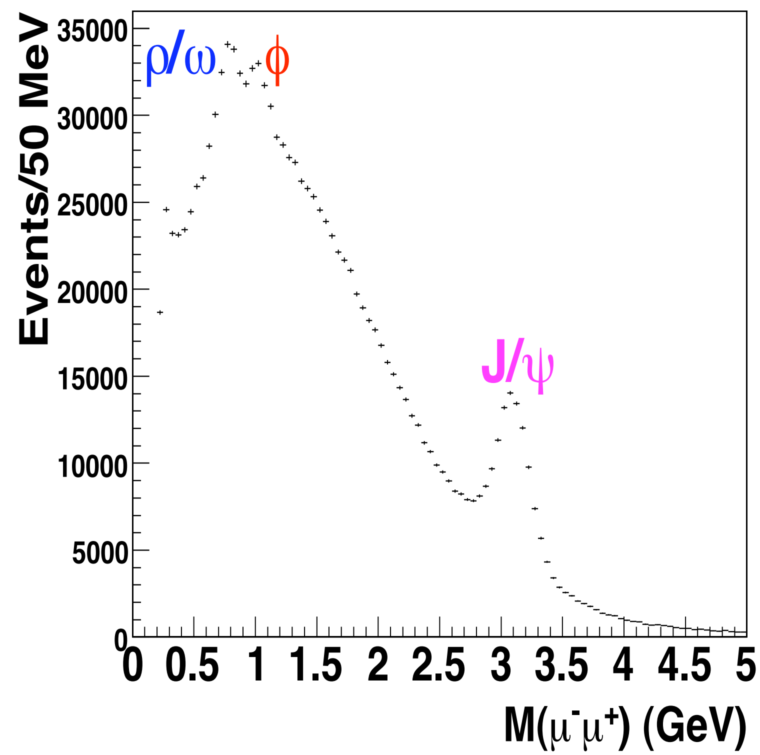


$$\sqrt{S^{NN}} = 200GeV$$



Backward rapidity

Forward rapidity



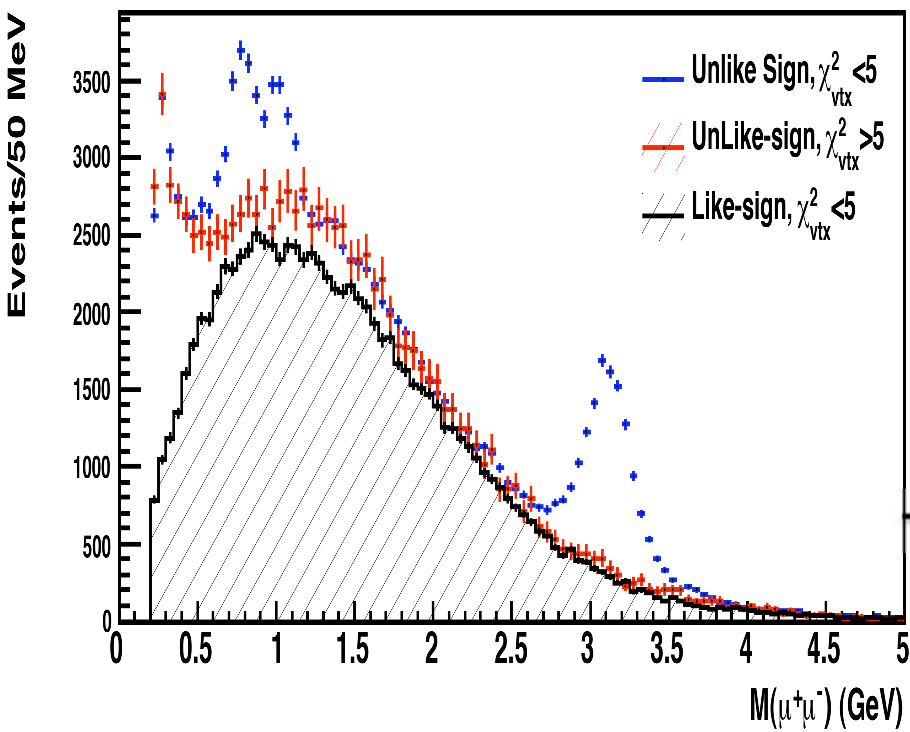
Background at low mass range challenging to describe

Basic Data and Analysis Information

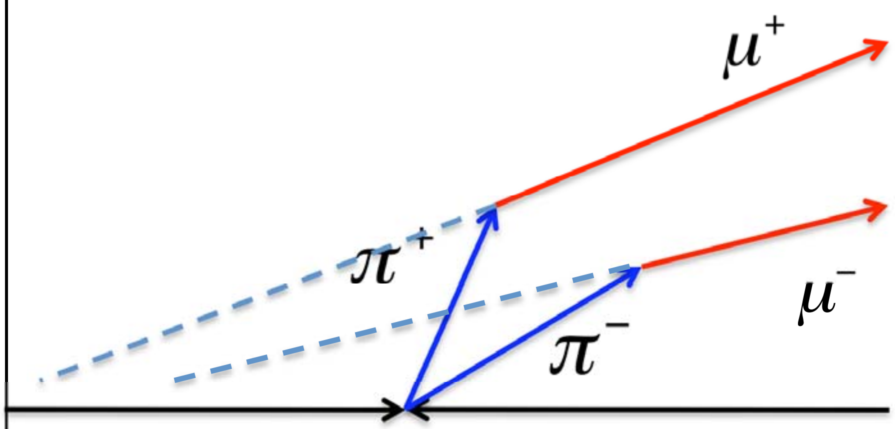
- Data set:
  - Run 8 d+Au @ 200 GeV, 2008 @ PHENIX, RHIC
  - Detecting two muons
  - Luminosity = 81nb^{-1}
  - 160 Billion Collisions Sampled, 437TB
- Basic Analysis Cuts used:
  - $|V_z| < 30$ cm (Determined by BBC)
  - di-muon $p_T > 0.9$ GeV
  - Rapidity range: $1.2 < |y| < 2.4$
  - Require two muons come from event vertex

Background Estimation Challenge

y<0, Centrality: 20-40

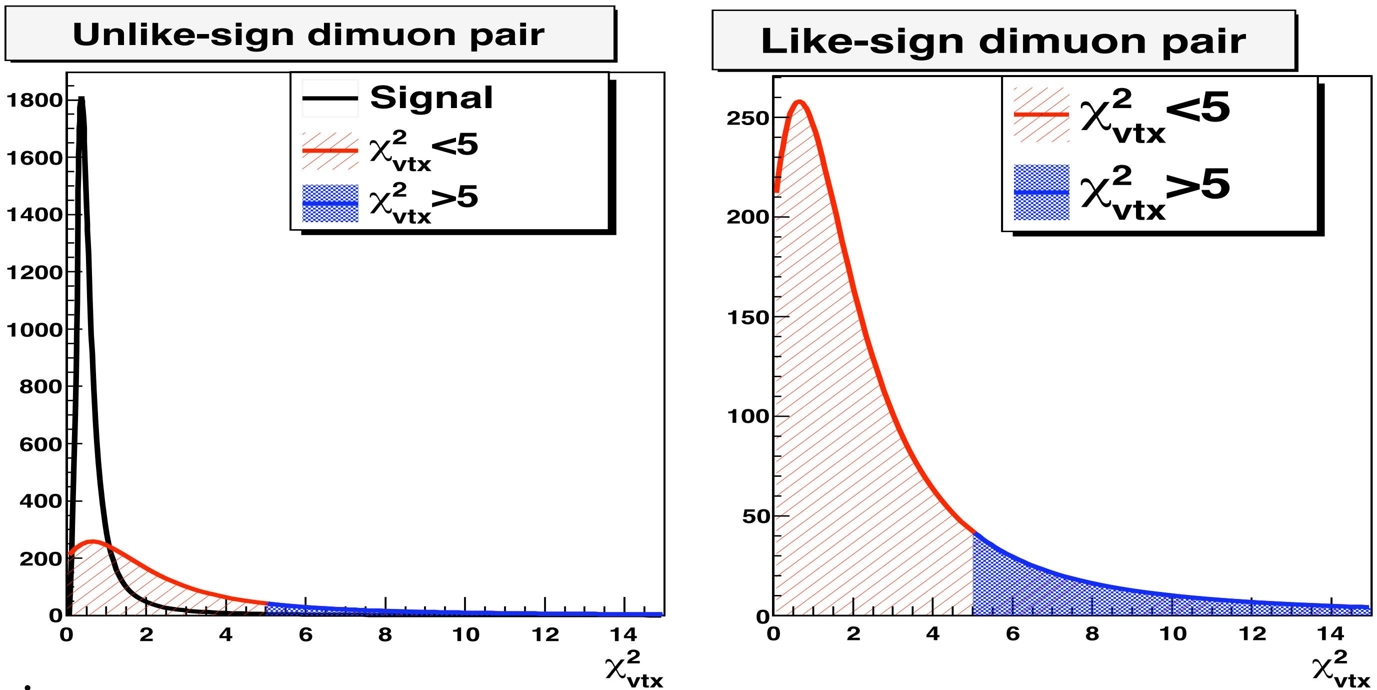


Correlated background



- A new data-driven background estimation method developed
- Use di-muon pairs with large $\chi2_{vtx}$ to estimate the background
    - Addresses the issue of correlated hadrons that decays to $\mu^{+/-}$
- Achieved good background description at all mass range

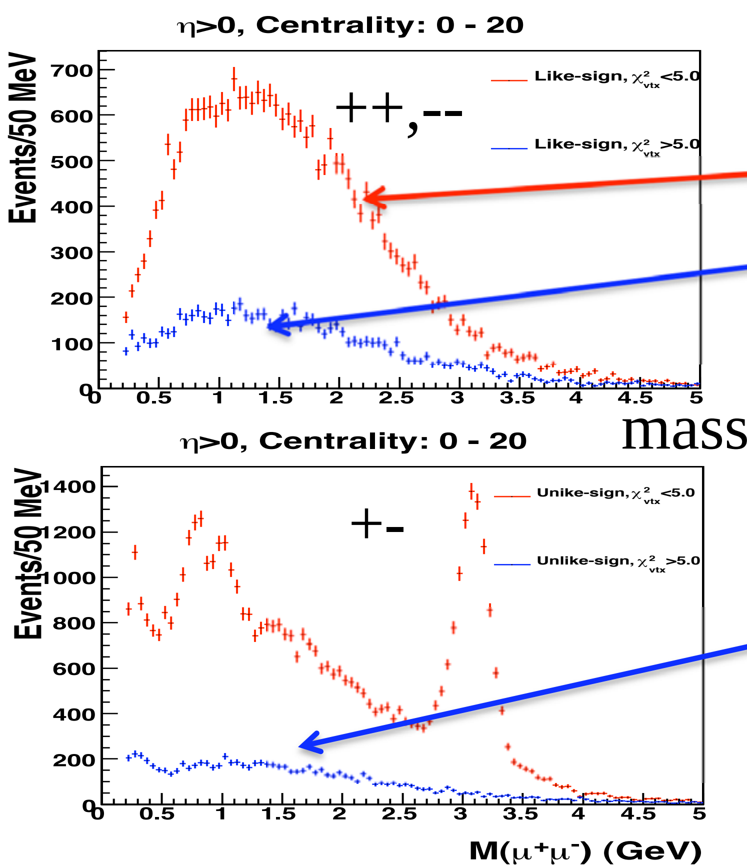
Concept of a new method of data-driven background estimation: decomposition of χ^2_{vtx} distributions



Assumptions:

- Background dominated by muons from pion/Kaon decay, and have wider χ^2_{vtx} distribution than vector meson signals
- Events outside χ^2_{vtx} cut can be used to predict background under the signal
- Like-sign events can be used to derive the normalization factor

Background estimation example



$$N^{Like}(m) = 2\sqrt{N^{++}(m)N^{--}(m)}$$

Procedure:

•Divide the normalized like sign events distribution with $\chi^2 < 5$ by that with $\chi^2 > 5$

•Resulting ratio is fitted with a second order polynomial function from 0.5-2.5 GeV

•This normalization function is multiplied to the unlike-sign events distribution with $\chi^2 > 5$, giving the background

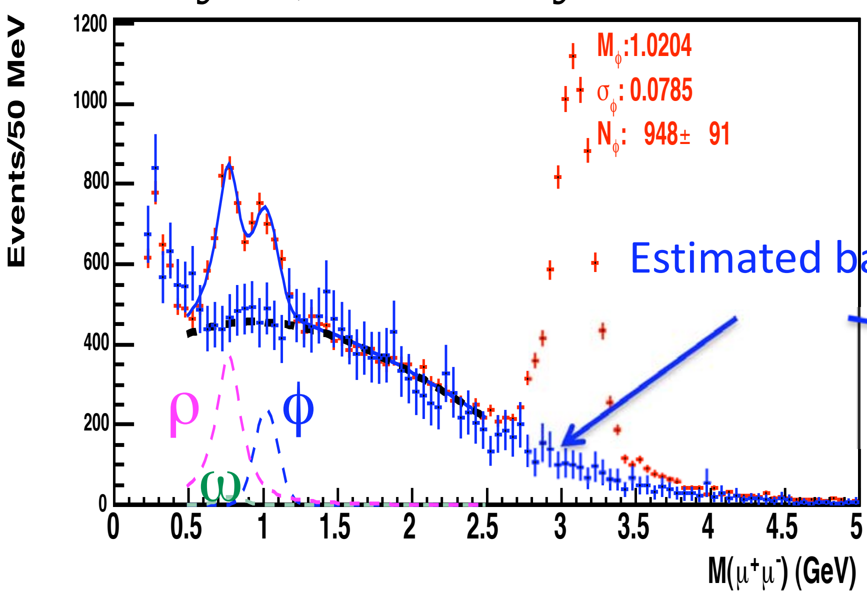
$$N'_{bg}(m) = CN^{+-}_{\chi^2>5}(m)\frac{N^{Like}_{\chi^2<5}(m)}{N^{Like}_{\chi^2>5}(m)}$$

$$C = \frac{\int_{1.5GeV}^{2.5GeV} N^{+-}_{\chi^2<5}(m)}{\int_{1.5GeV}^{2.5GeV} N_{bg}(m)}$$

Yield Extraction Examples

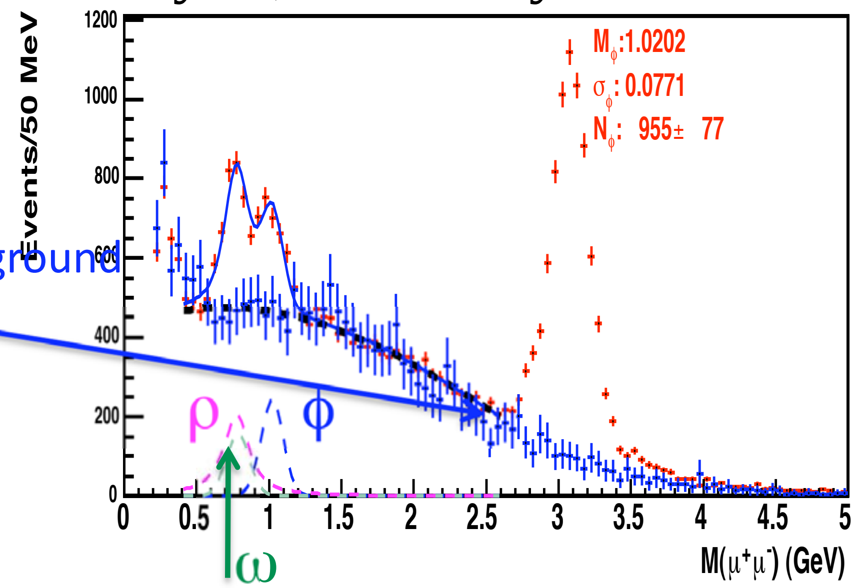
- Fitting function: Two Gaussian (ϕ/ω) + One Relativistc BW (ρ) +Background (Defined by estimated shape)
  - ϕ yields stable when fitting procedure changes
  - ρ+ω yields using background subtraction (large uncertainty)

y>0, Centrality: 40-60



Smaller fitting range:0.5-2.5 GeV
Larger parameter range

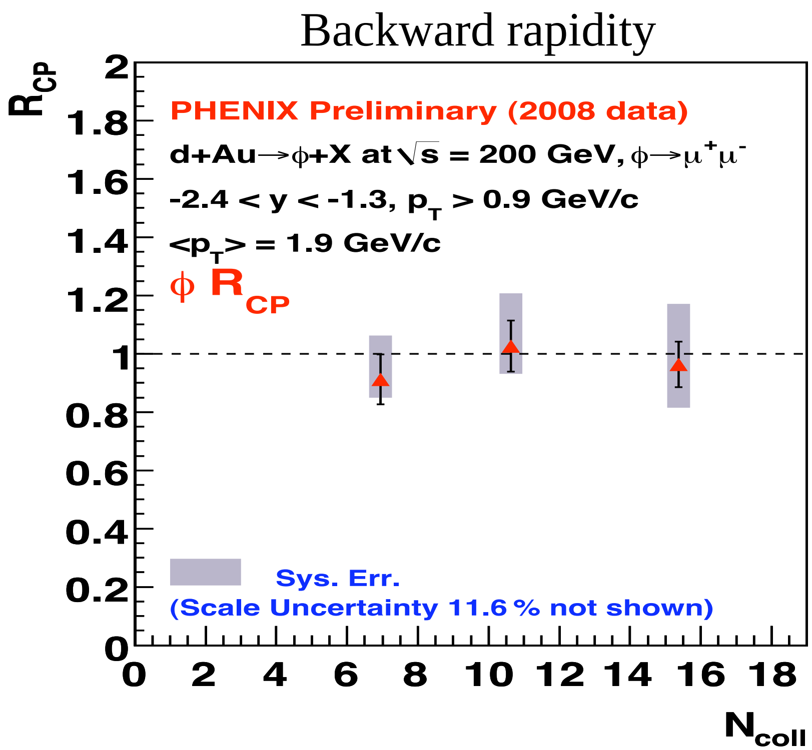
y>0, Centrality: 40-60

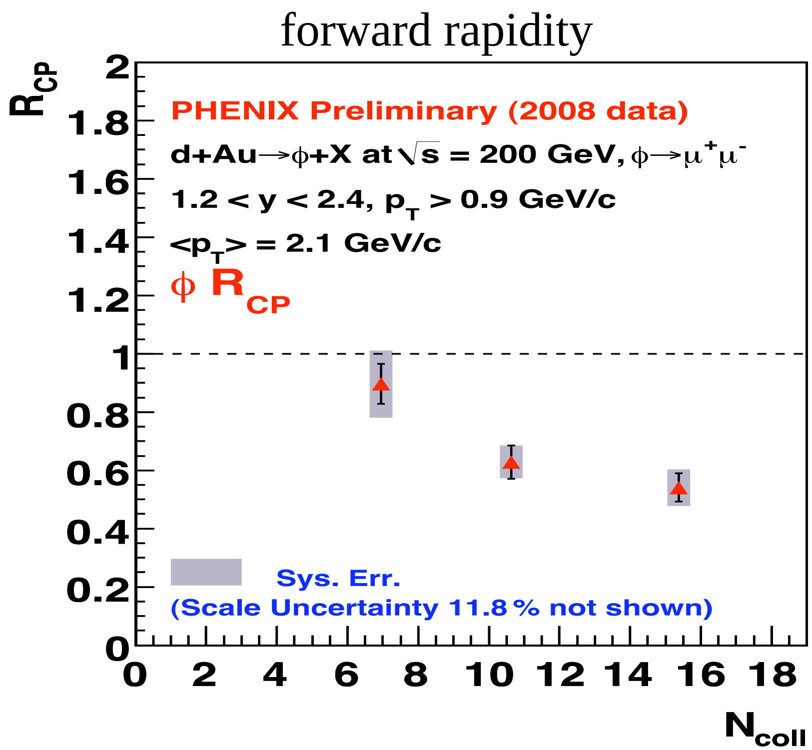


Larger fitting range:0.4-2.6GeV
Smaller parameter range

Results of Nuclear Modification Factor R_{CP}: ϕ

Nuclear Modification Factor R_{CP} for ϕ





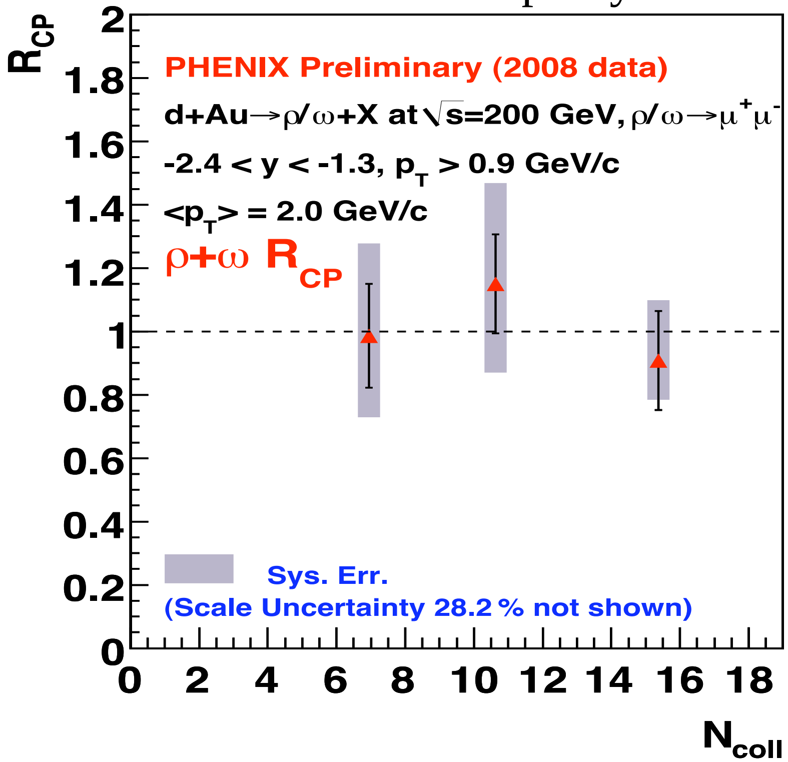
$$R_{CP} = \frac{N(\phi)/N_{coll}}{N^0(\phi)/N^0_{coll}}$$

Yield Ratio normalized by N_{coll} (average number of binary collisions)

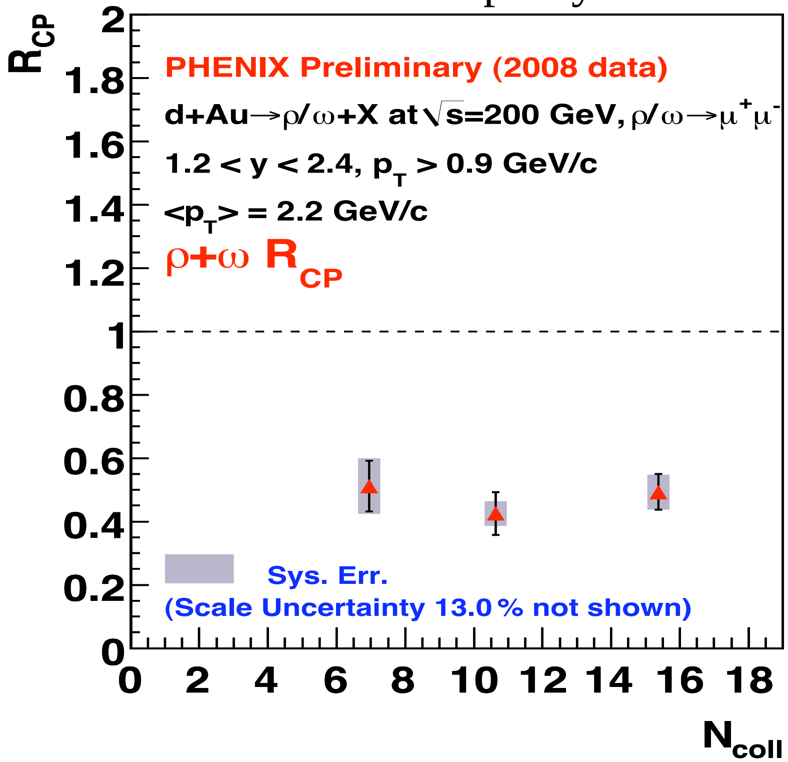
Results of Nuclear Modification Factor R_{CP}: $\rho+\omega$

Nuclear modification factor R_{CP} for $\rho+\omega$

Backward rapidity



forward rapidity

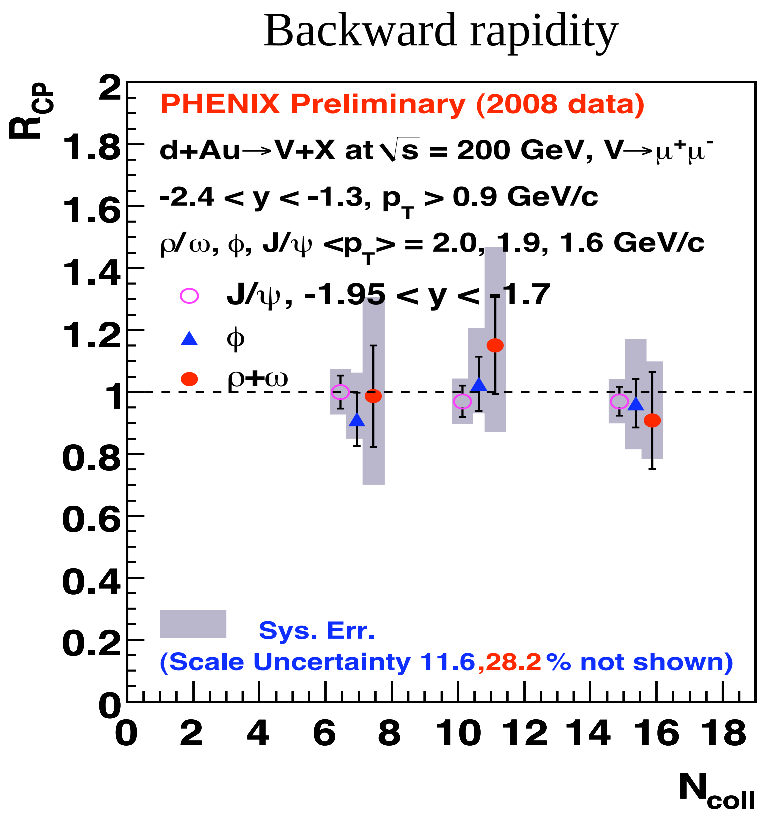


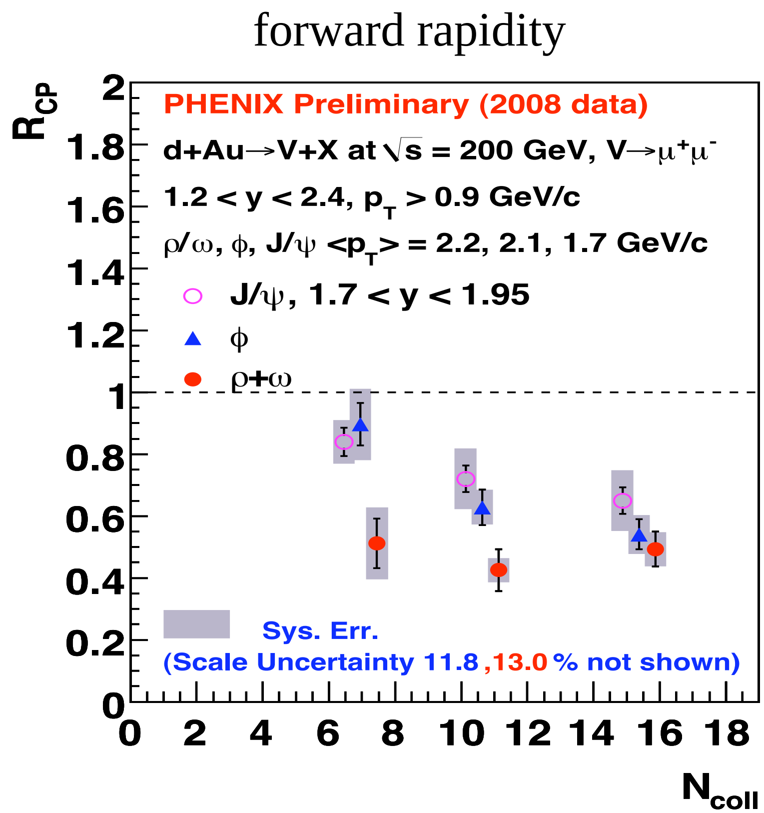
Large uncertainty due to background subtraction:

$$N_{\rho+\omega}=N_{Total}-N_{bg}-N_{\phi},\ d^2N_{\rho+\omega}=d^2N_{Total}+d^2N_{bg}+d^2N_{\phi}$$

Comparison of Vector Meson R_{CP}

Comparing Nuclear Modification Factor R_{CP} for $\rho+\omega$, ϕ, and J/Ψ

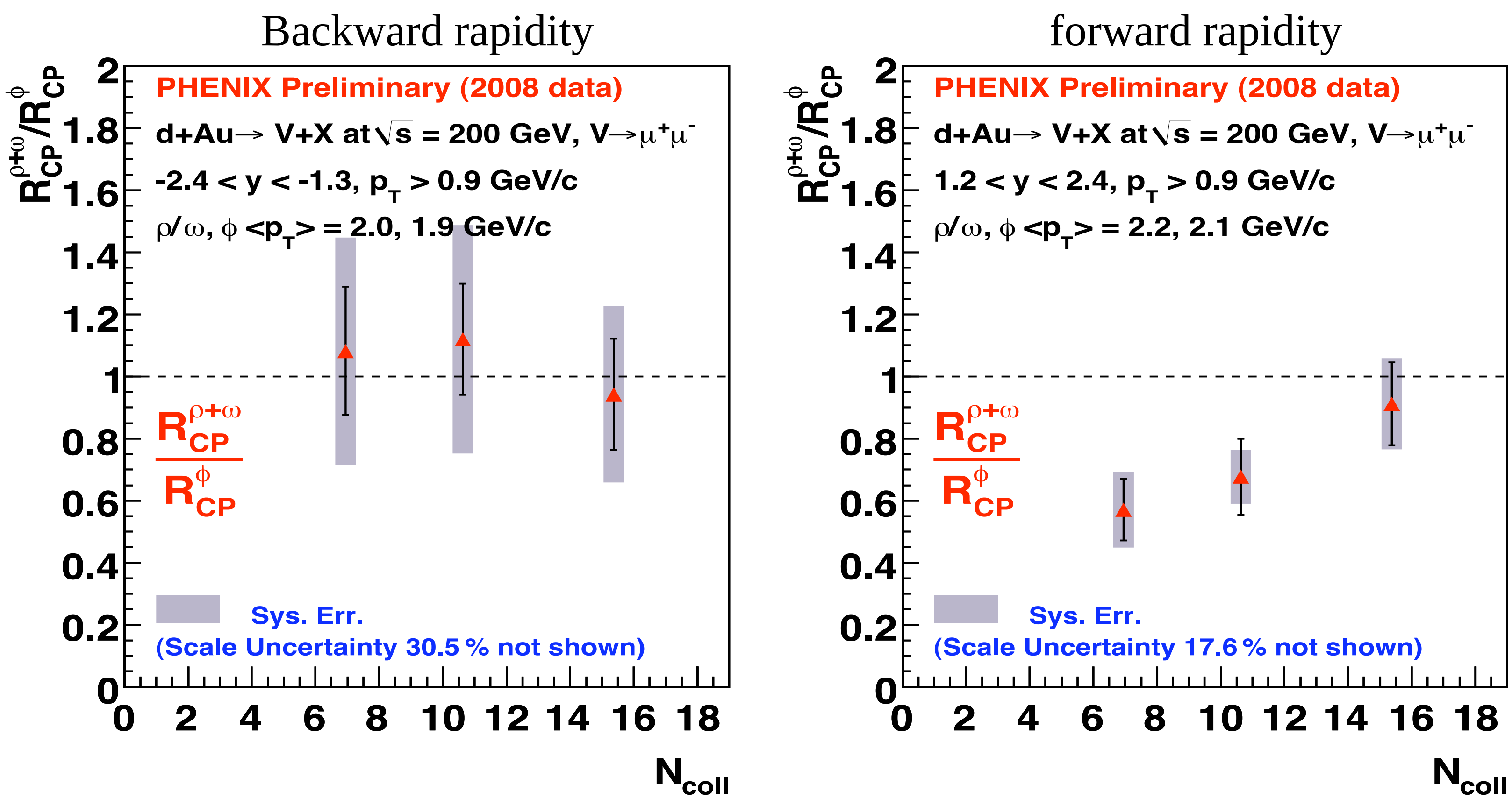




Caution is needed when interpreting the difference, due to different p_T coverage, mass and production-mechanism dependent

R_{CP} Ratio: $(\rho+\omega)$ to ϕ

Ratios: R_{CP} of $(\rho+\omega)$ to R_{CP} of ϕ



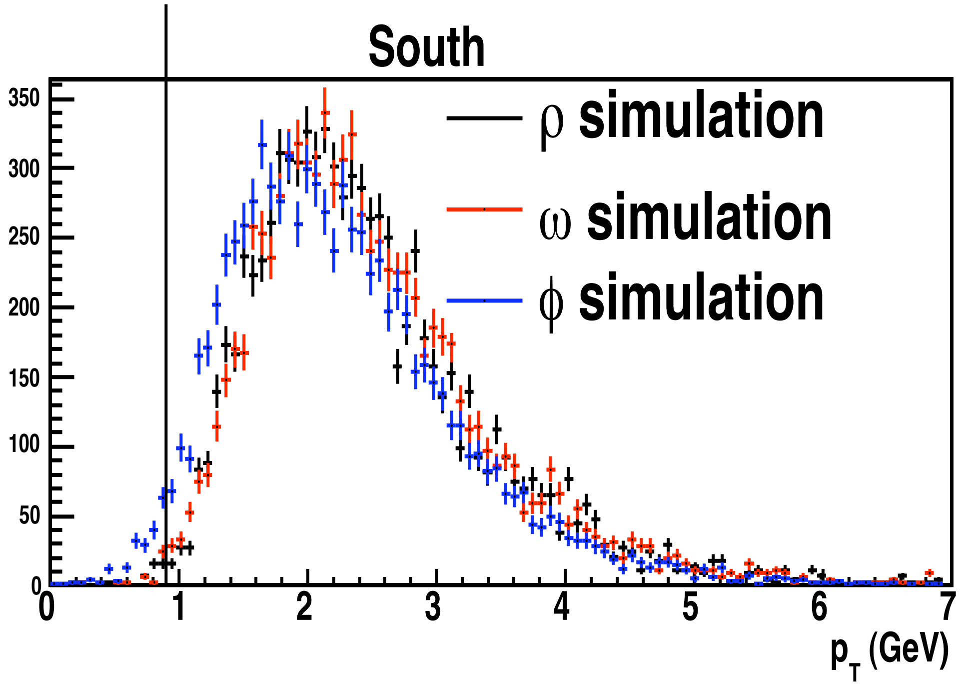
Systematic uncertainties due to N_{coll}, trigger efficiency correction, and reconstruction efficiency correction, are cancelled

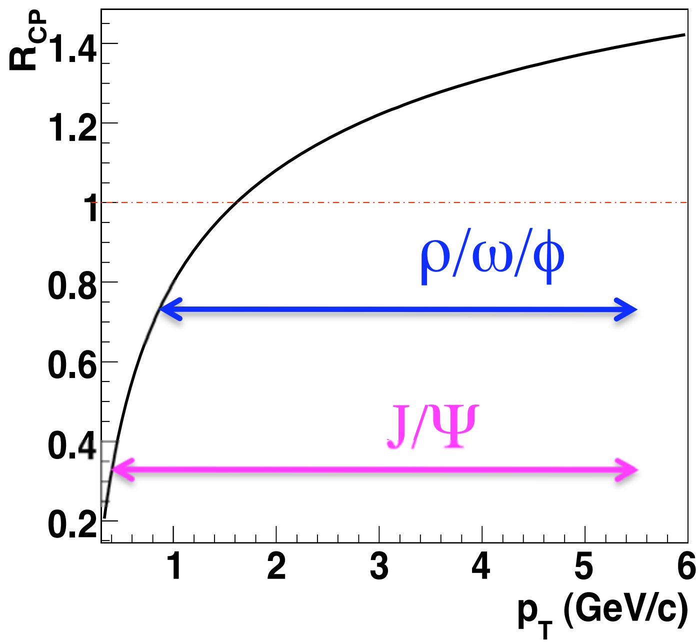
Summary and discussion

- Significant suppression in forward rapidity
- Stronger suppression for ρ/ω than ϕ and J/Ψ
  - Due to lighter quark content, and/or different production mechanisms?
- ϕ suppression consistent J/Ψ within uncertainties
- Future plan:
  - R_{dA} results
  - Rapidity and p_T bins

Backup Slides

p_T coverage bias when comparing R_{CP}





- Cronin effect: enhancement at high p_T

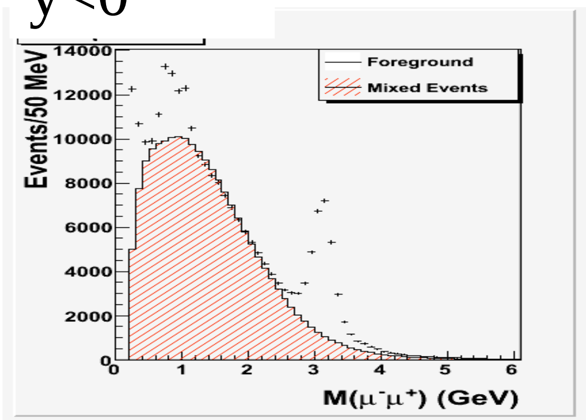
- Muon arm p_T coverage in the lower range: $J/\Psi > \phi > \rho/\omega$
- Actual difference between R_{CP} of $\phi(J/\Psi)$ and ρ/ω could be higher

Mixed-Events technique for BG estimation

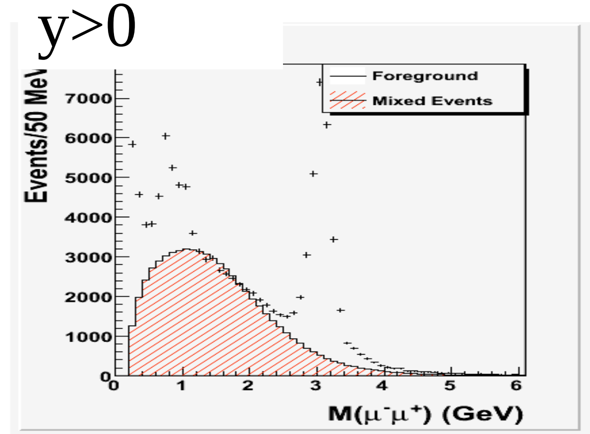
- What were the main issues in the analysis

Background estimation below 1.5 GeV

y<0



y>0

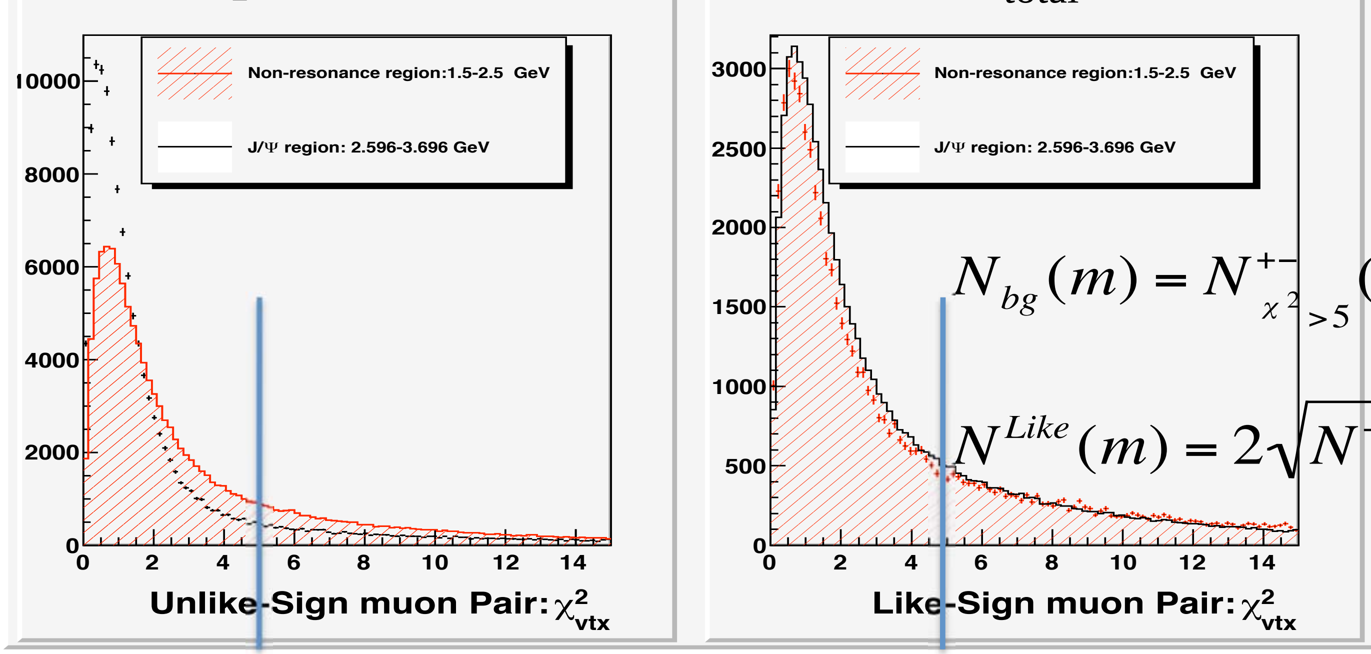


$$Normalization = \frac{\int_{1.3GeV}^{5.0GeV} \sqrt{Fg^{++}Fg^{--}}}{\int_{1.3GeV}^{5.0GeV} \sqrt{Mixed^{++}Mixed^{--}}}$$

- Low mass dimuon pairs could have contamination of correlated pion pairs
- Neither mixed events or like-sign-pair method describes low mass region

Data χ^2_{vtx} distrubtions

Spectra shown normalized to N_{total}



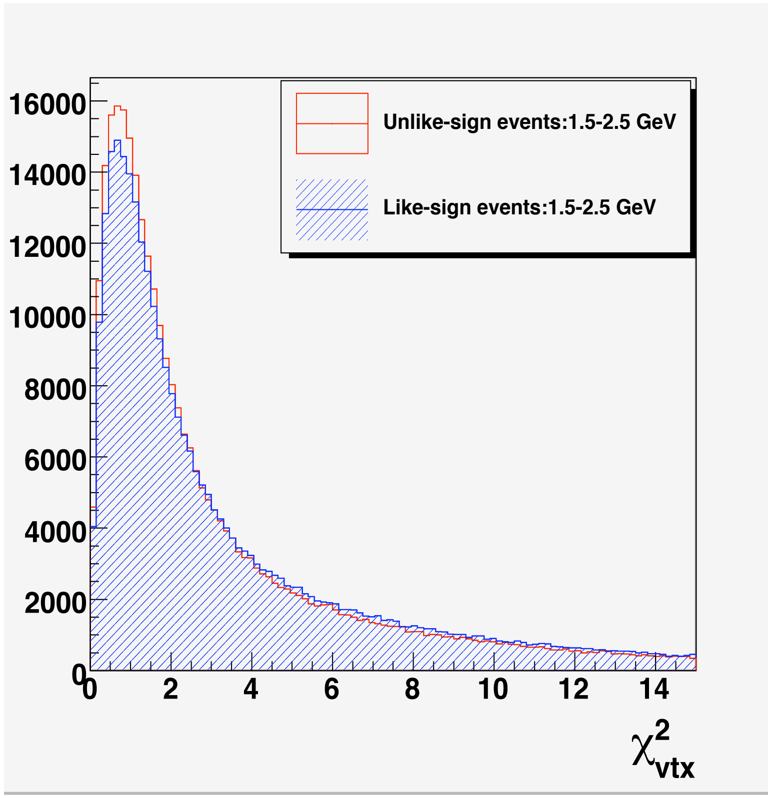
$$N_{bg}(m) = N^{+-}_{\chi^2>5}(m) * \frac{N^{Like}_{\chi^2<5}(m)}{N^{Like}_{\chi^2>5}(m)}$$

$$N^{Like}(m) = 2\sqrt{N^{++}(m)N^{--}(m)}$$

- In unlike-sign signal region, χ^2_{vtx} distribution is narrower
- Tail in the signal region is due to background contamination
- In like-sign events, χ^2_{vtx} is slightly mass-dependent

  Normalization function for background is mass-dependent

Non-resonant region
χ^2_{vtx} distributions and background formula



- Non-resonant region: 1.5-2.5 GeV
- Like-sign events matches well the unlike-sign events
- The small mis-match would lead to an overall normalization factor
- Background formula:

$$N'_{bg}(m) = C * N^{+-}_{\chi^2>5}(m) * \frac{N^{Like}_{\chi^2<5}(m)}{N^{Like}_{\chi^2>5}(m)}$$

$$C = \frac{\int_{1.5GeV}^{2.5GeV} N^{+-}_{\chi^2<5}(m)}{\int_{1.5GeV}^{2.5GeV} N_{bg}(m)}$$

- Overall normalization factor C (close to 1) is only necessary if using like-sign events to derive the normalization function
- Unlike-sign events can also be used to derive the normalization function, then there is no need for the factor C.

Procedure of yield extraction

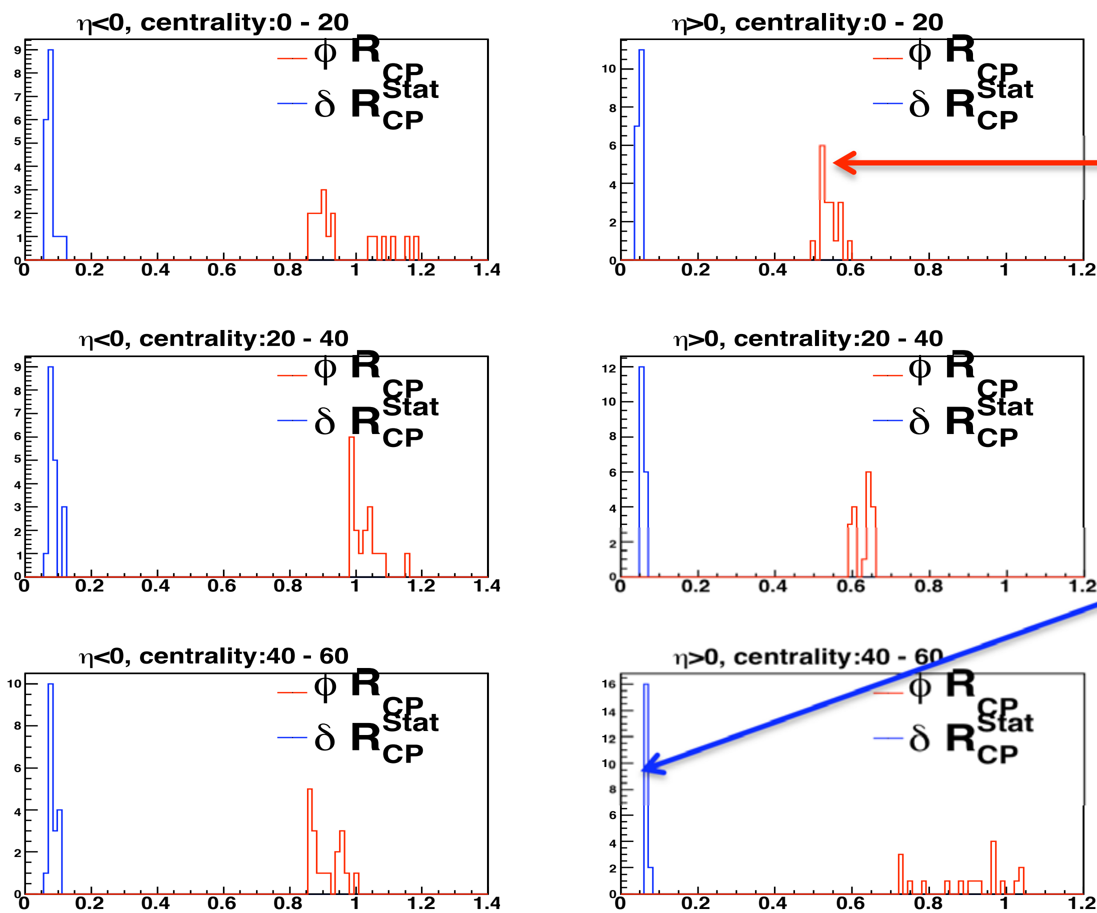
- Fitting function: polynomial background (defined by estimated shape)+ two gaussian (ϕ,ω) and one relativistic BW (ρ)
- Fitting parameters:
  - Free within predefined errors:
    - Within 2(4)σ: M(ϕ), σ(ϕ), M(ω), σ(ω), M(ρ), Γ(ρ) (Total:6, from simulation)
    - Within 1(3)σ: Polynomials: up to 7 (6/5) parameters (6^{th} /4^{th}/3^{rd}, order)
  - Free parameter:
    - N(ϕ), N(ω), N(ρ)/N(ω) (Total: 3)
    - N(ρ)/N(ω): 0.25-4 (Model-dependent, but has small effect on ϕ yield)
  - Fixed without change
    - L: Orbital Angular momentum quantum number for ρ Breit-Wigner shape
    - R: Interaction Radius for ρ Breit-Wigner shape
- Total number of parameters: 18 (6^{th} polynomial)
- Variation of fits: two fitting ranges (0.4-2.6, 0.5-2.5 GeV)

  two sets of fitting parameters ranges
- 18 values for each bin, systematic error due to yield extraction extracted from RMS

Systematics Study

- Three main systematics Errors are included
- Uncertainty in N_{coll} and centrality-dependent trigger efficiency correction factor (~10%)
- Uncertainty in yield extraction (18 fits for each bin, 4-10%)
  - Three sets of fits
    - Nominal fitting procedure
    - Wider range of variation for fitting parameters (4/3 σ instead of 2/1 σ)
    - Wider fitting range (0.4-2.6 GeV, instead of 0.5-2.6 GeV)
  - Three different orders of polynomial for background parameterization
  - Two types of normalization
  - Uncertainty extracted from the RMS of 18 values for each bin
- Uncertainty in south arm reconstruction efficiency
  - Using global uncertainty of 15%
  - Will be determined later from embedded simulation

Obtaining final ϕ R_{CP} values



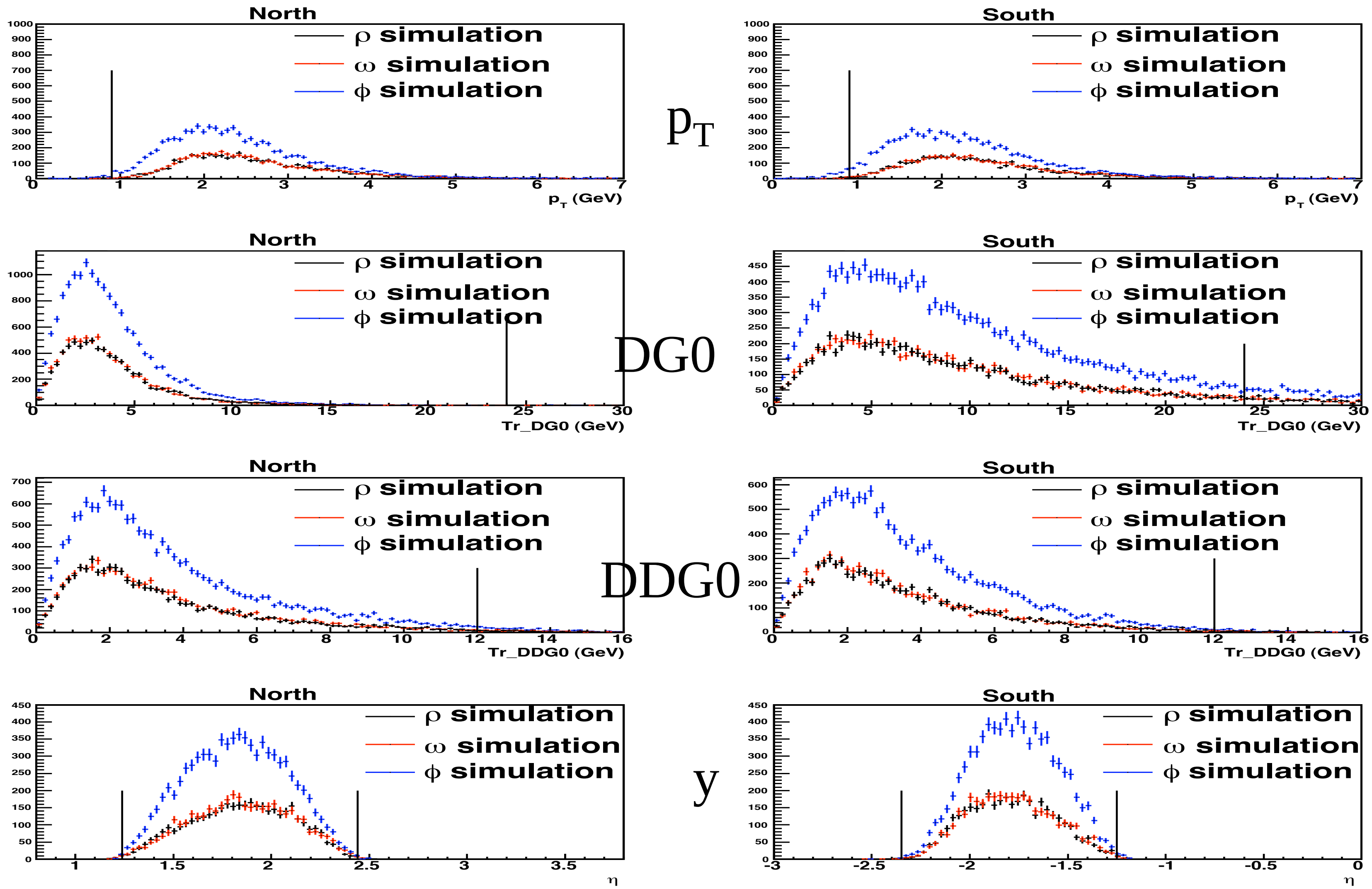
Final values R_{cp} :Mean

Systematic error due to yield extraction: RMS

Final statistical error:

Mean

Cuts defined by simulation



x coverage from simulation