Photoproduction at Hadron Colliders

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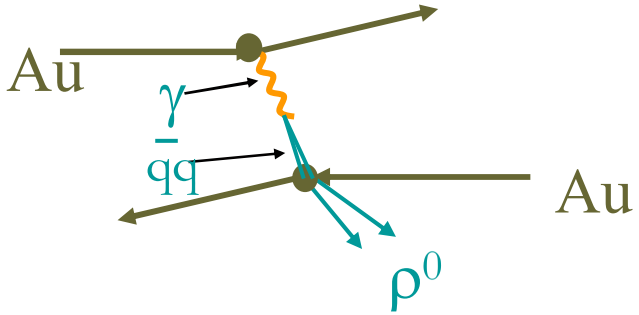
Photoproduction at Hadron Colliders

Results from STAR at RHIC

Photoproduction at Ion Colliders

- Heavy Ions have strong electromagnetic fields
  - Equivalent to high intensity photon beam
    - Weizsacker-Williams
    - Photons are almost-real
- Here: focus on γA reactions
- At the LHC
  - $W_{\gamma p}$ ~ 10 TeV ~ 50x HERA
  - $W_{\gamma A/n}$ ~ 1 TeV ~ 10x fixed target
  - Measure structure functions in protons and nuclei at low-x
- With ions, the high photon flux is allows multiple interactions between a single ion pair

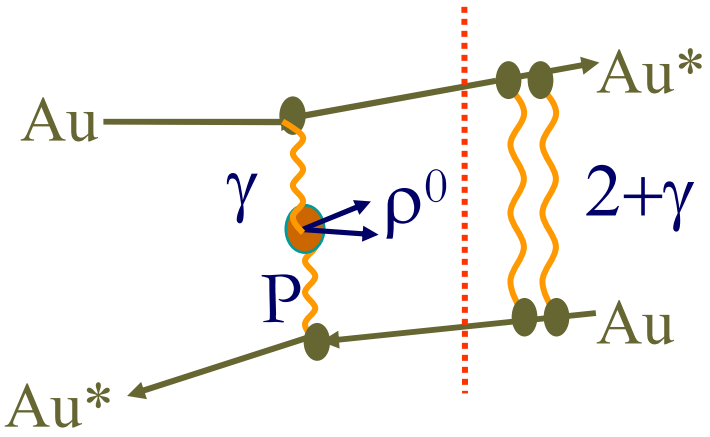


Photon tagging

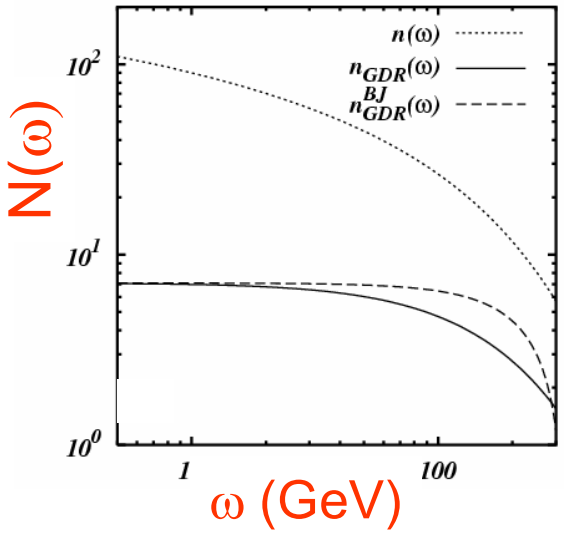
- Nuclear excitation ‘tag’s small b
- Multiple Interactions are independent

$$\sigma = \int d^2 b P_{2EXC}(b) P_{\rho^0}(b)$$

- Au* decay via neutron emission
  - simple, unbiased trigger
- Multiphoton events have:
  - smaller <b>
  - Harder photon spectrum
    - Production at smaller |y|
  - Photon polarizations follow E field
    - Polarizations are collinear



RHIC – Au γ-spectra with and w/o nuclear excitation



G. Baur et al. 2003

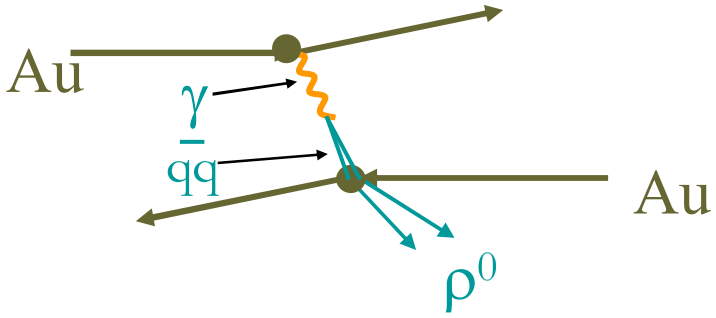
Photoproduction at proton colliders

- Z=1 --> lower photon flux
- Luminosities much higher than in AA
  - More than compensates for lower flux
- Backgrounds may be higher than in AA
- $\sigma(p(\gamma)p \rightarrow pJ/\psi p) \sim 0.1\%$ of $\sigma(pp \rightarrow J/\psi X)$
  - An exclusive J/ψ final state with 2 rapidity gaps should give a clean photoproduction sample
    - Caveat – background from double-diffractive production e.g. $\chi_c \rightarrow \gamma J/\psi$
  - Sensitive to gluon density

Klein & Nystrand, 2004

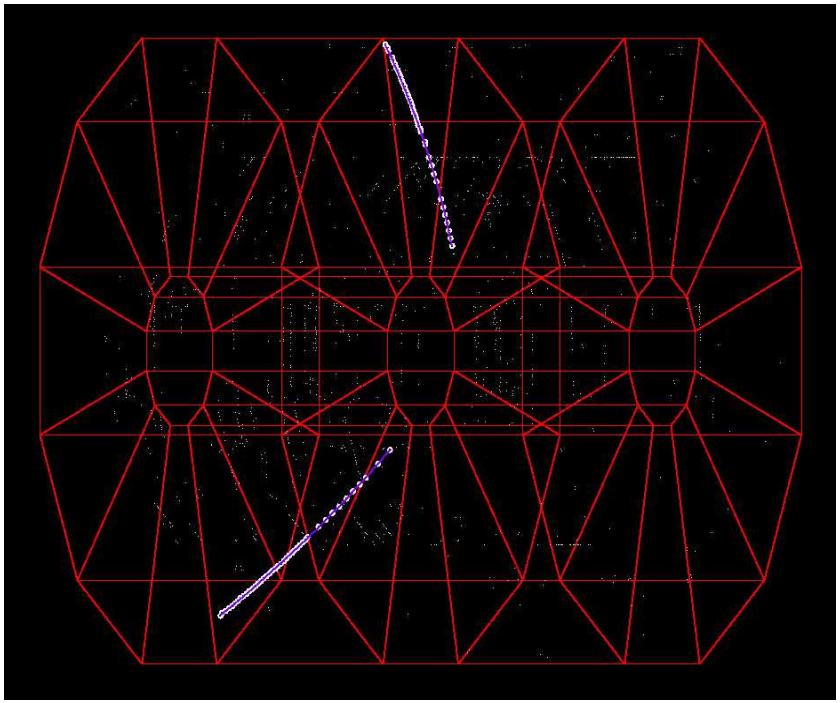
Exclusive Vector meson Production at RHIC

- A virtual photon from one nucleus fluctuates to a qq pair which scatters elastically from the other nucleus and emerges as a vector meson
  - For heavy mesons (J/ψ), the scattering is sensitive to nuclear shadowing
- Coherent photon emission and scattering
  - $\sigma(\rho)$ ~ 8 % of σ(had.) for gold at 200 GeV/nucleon
    - 120 /sec at RHIC design luminosity
  - Other vector mesons are copiously produced
    - LHC is a vector meson factory
      - up to 230,000 ρ^0 & 780 J/Ψ/sec (with Ca beams)



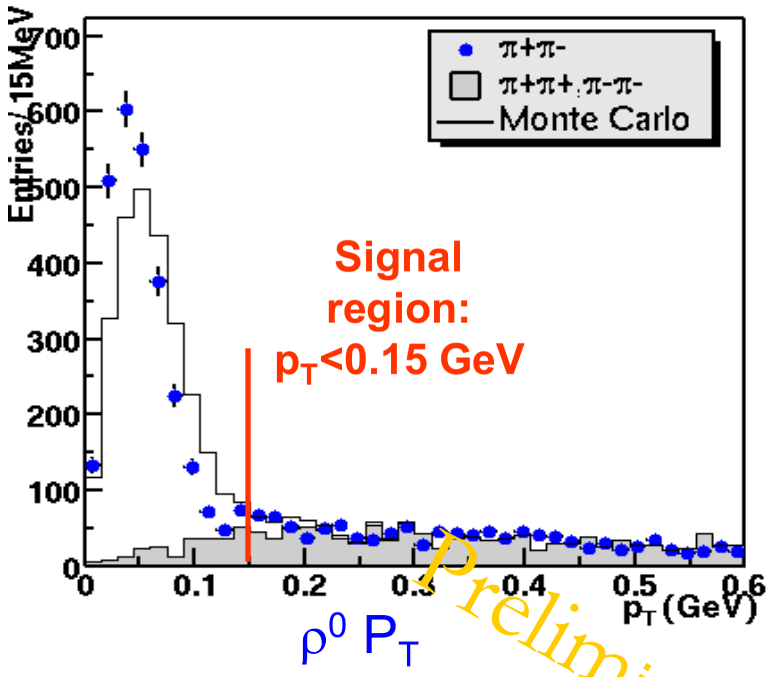
Triggering on ρ^0 in STAR

- Exclusive ρ^0
  - ρ^0 and nothing else in TPC
  - Trigger on 2 charged particles in central trigger barrel
- ρ^0 + mutual Coulomb excitation
  - ρ^0 in TPC + signals in forward (zero degree) calorimeters
  - Trigger on neutron signals in calorimeters

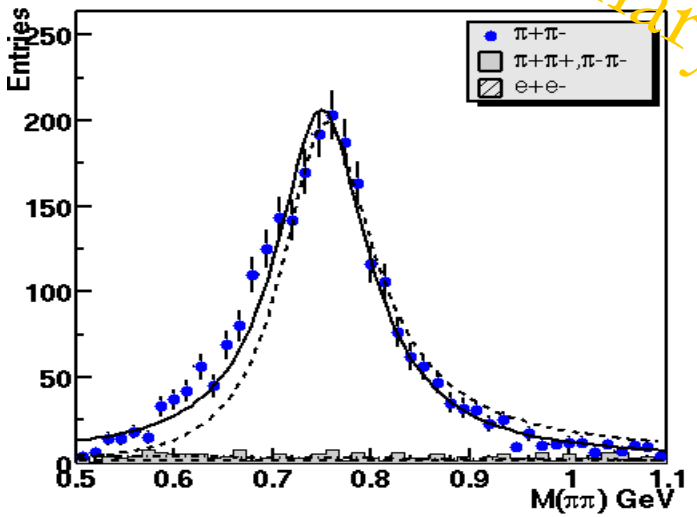


200 GeV Exclusive ρ^0

- 1.5 Million triggers in 2002
- 2 track vertex
  - non-coplanar; $\theta < 3$ rad to reject cosmic rays
- Backgrounds from $\pi^+\pi^+$ and $\pi^-\pi^-$
  - scaled up by ~2
  - Incoherent ρ^0 (w/ p_T>150 MeV/c) are defined as background here
- asymmetric $M_{\pi\pi}$ peak from interference with direct $\pi^+\pi^-$ production
  - Ratio comparable to that seen at HERA



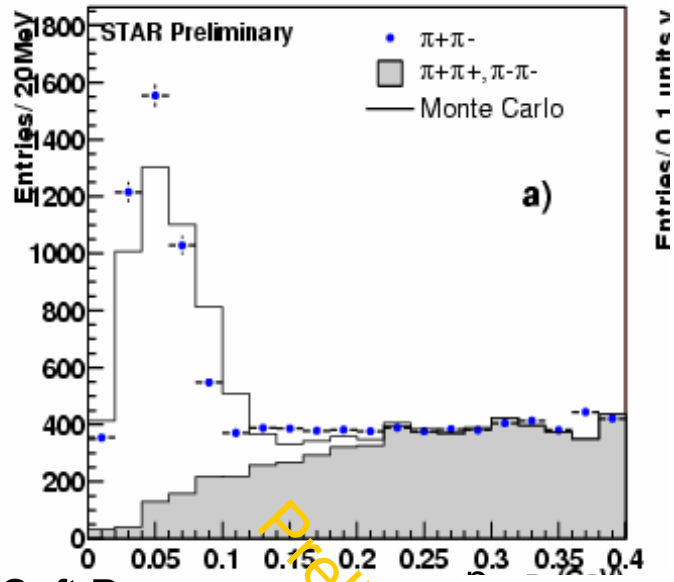
ρ^0 P_T



$M(\pi^+\pi^-)$

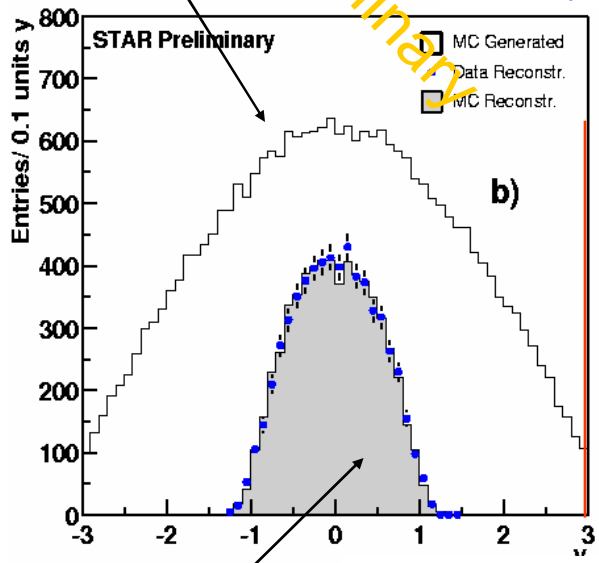
200 GeV XnXn data

- 1.7 million ZDC coincidence triggers in 2002
- Require a 2 track vertex
- $\pi^+\pi^+$ and $\pi^-\pi^-$ model background
- single (1n) and multiple (Xn) neutron production
  - 1n mostly from Giant Dipole Resonance
- Cross section and rapidity distribution match soft Pomeron model



Soft Pomeron

ρ^0 P_T



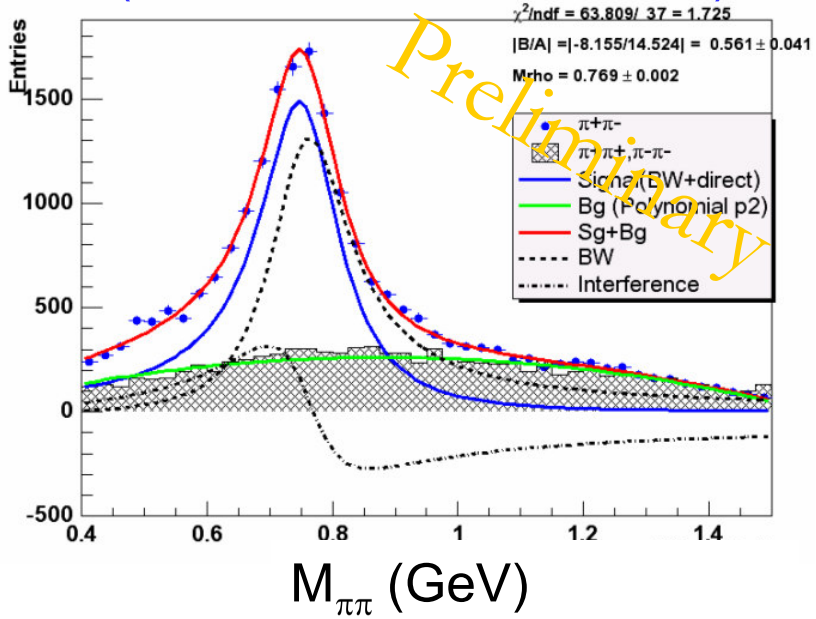
After detector simulation

ρ^0 Rapidity

ρ^0 production in dAu

- Photons usually come from Au
  - Small contribution due to photons from deuteron
- $\gamma d \rightarrow \rho^0 d$
  - Coherent coupling to entire deuteron
    - A=2, so coherence is modest
- $\gamma d \rightarrow \rho^0 pn$
  - Coupling to individual nucleons
- $R_d \sim 2$ fm and $R_p \sim 0.7$ fm
  - ρ^0 p_T can be large

$\gamma d \rightarrow \rho^0 pn$
(neutron detected in ZDC)



$M_{\pi\pi}$ fit to ρ^0 + direct $\pi\pi$

ρ^0 mass, width consistent with particle data book

ρ^0:direct $\pi\pi$ ratio slightly lower than AuAu data

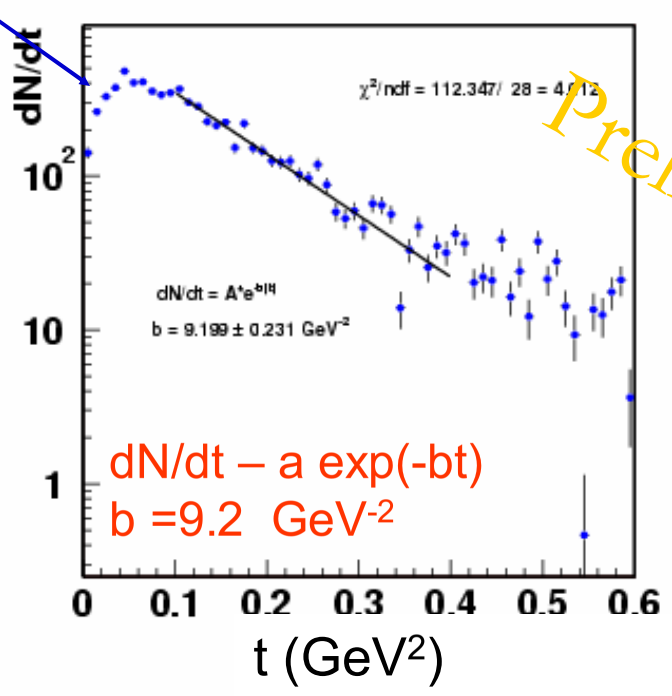
$t_\perp = p_T^2$ spectra

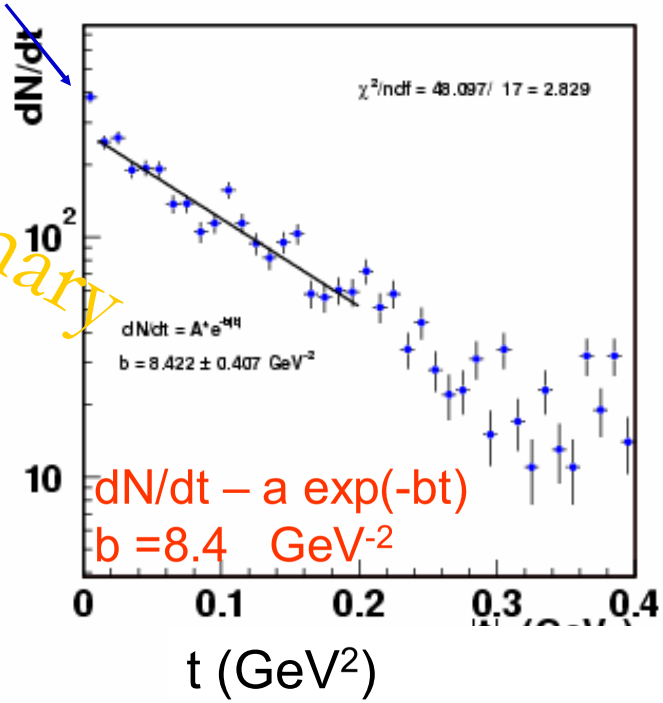
Not enough energy for dissociation

γ d --> pn ρ^0
Deuteron dissociates

γ from Au

γ d --> d ρ^0
Deuteron stays intact



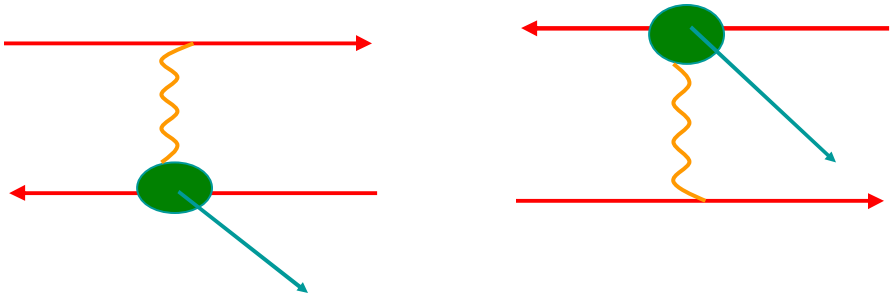


Preliminary

- Slopes are similar
  - Deuteron coherence not a large effect here
- HERA finds b=11 GeV^{-2} for γp --> ρp
  - Not exactly comparable measurements

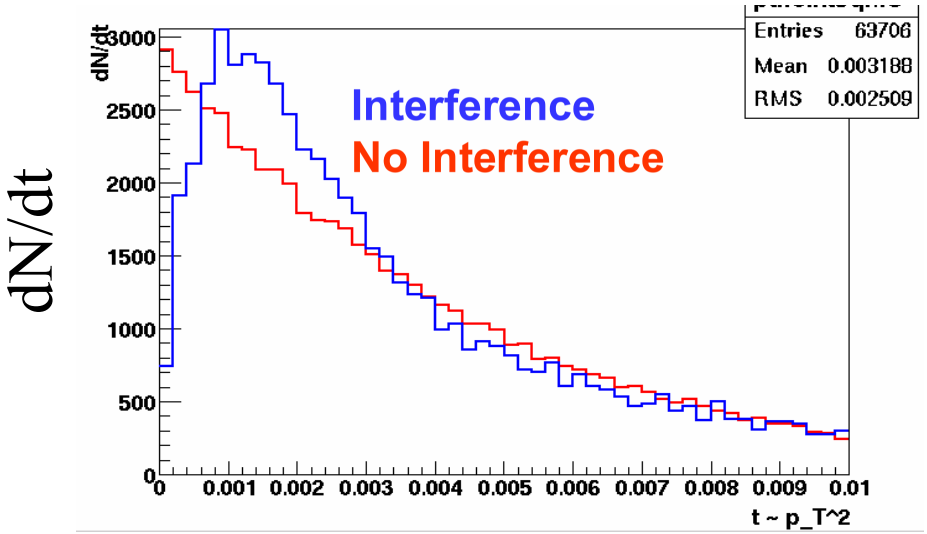
Interference & t-spectra in AuAu

- 2 indistinguishable possibilities
  - Interference!!
- 2-source interferometer with separation b
- ρ is negative parity
- For pp, AA parity transform -->
  - $\sigma \sim |A_1 - A_2 e^{ip\cdot b}|^2$
  - At y=0 $\sigma=\sigma_0[1 - \cos(p\cdot b)]$
- For pbar p: CP transform ->
  - $\sigma \sim |A_1 + A_2 e^{ip\cdot b}|^2$
- b is unknown
  - Reduction for p_T <<1/<b>



ρ^0 w/ mutual Coulomb dissoc.

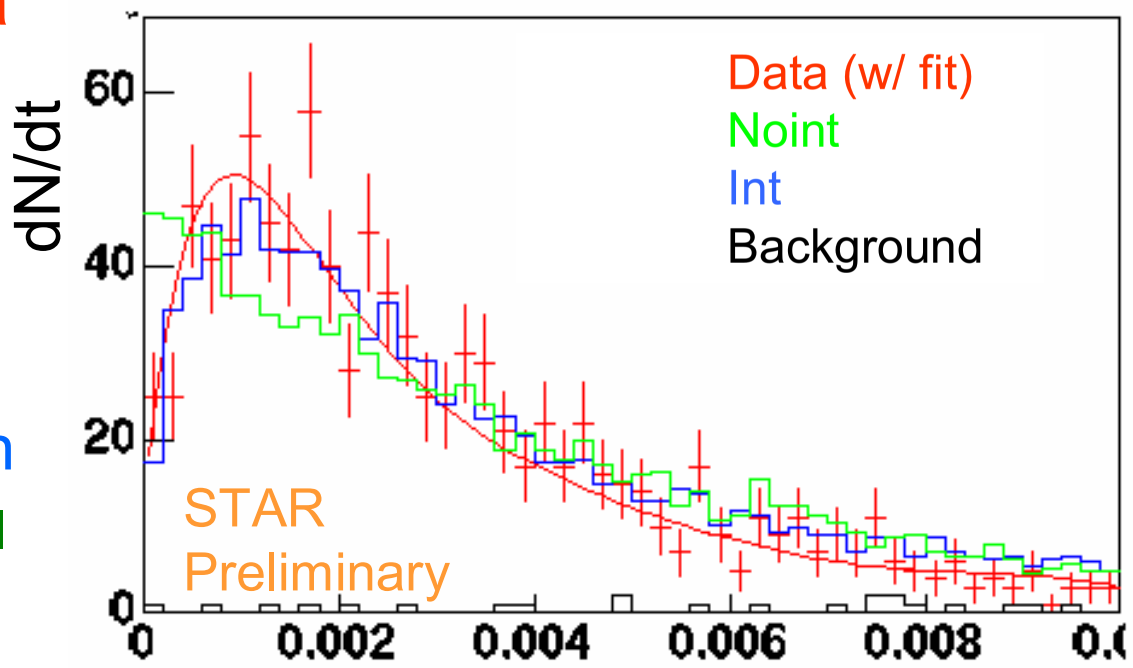
0.1< |y| < 0.6



t $(GeV/c)^2$

t for 0.1 < |y| < 0.5 (XnXn)

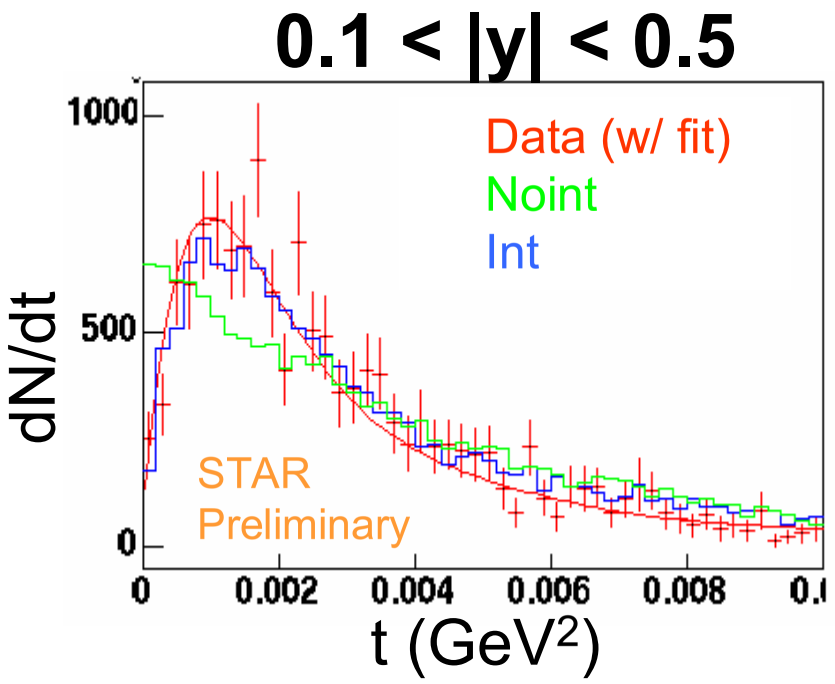
- Use tight cuts to select a clean ρ^0 sample
- 2 Monte Carlo samples:
  - Interference
  - No interference
  - w/ detector simulation
    - Detector Effects Small
- Drop at low t matches interference calculation
- 973 events

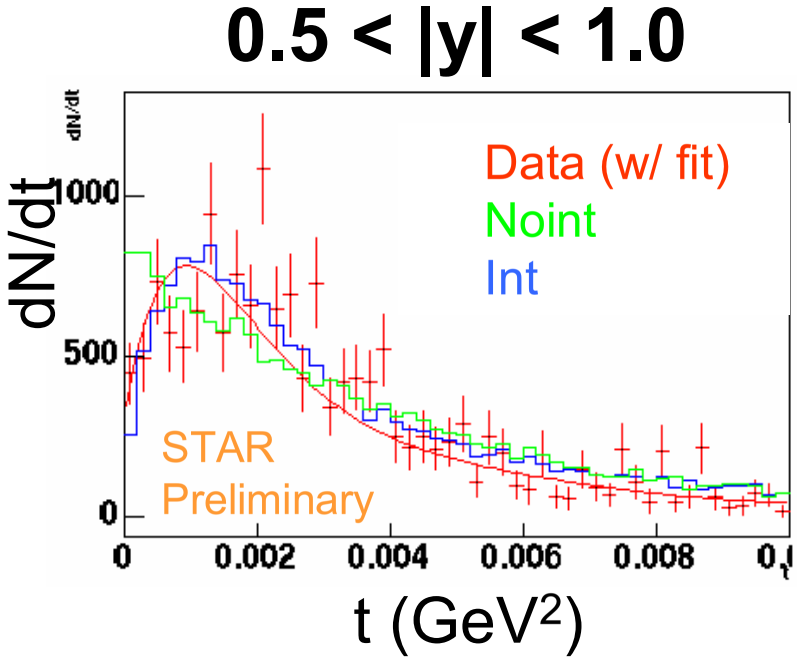


$t\ (GeV^2) = p_T^2$

Fitting the Interference

- Efficiency corrected t
- 1764 events total
- R(t) = Int(t)/Noint(t)
  - Fit with polynomial
- dN/dt =A*exp(-bt)[1+c(R(t)-1)]
  - A is overall normalization
  - b is slope of nuclear form factor
    - b = 301 +/- 14 GeV^{-2}
      304 +/- 15 GeV^{-2}
  - c=0 -- > no interference
  - c=1 -- > “full” interference
    - c = 1.01 +/- 0.08
      0.78 +/- 0.13
- Data and interference model match



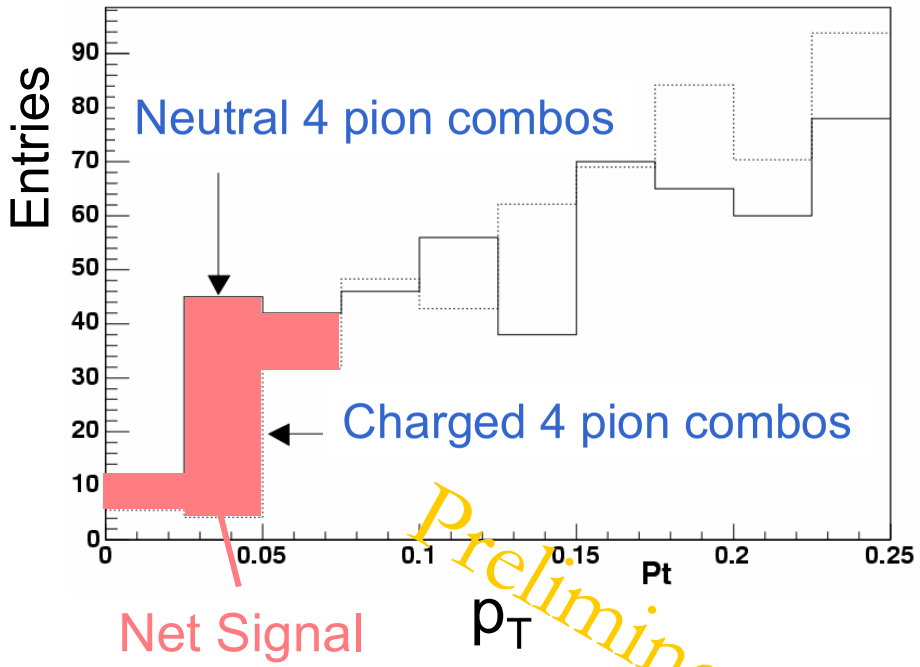


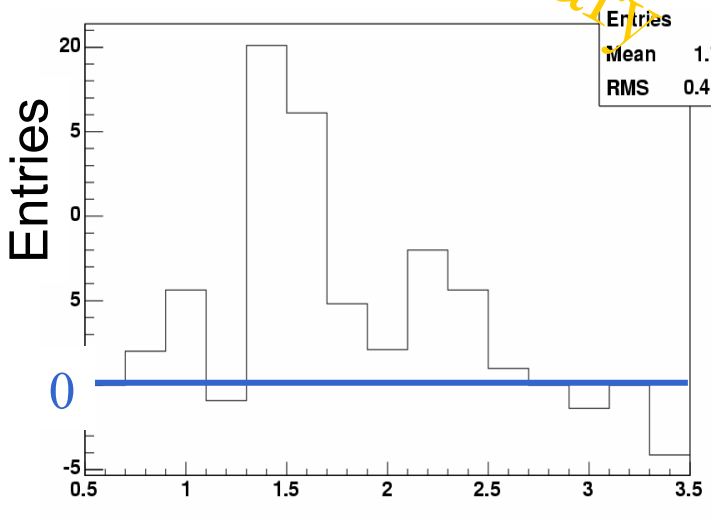
Exclusive ρ^0 & results

- Similar results for exclusive ρ^0 production
  - Larger <b> so interference only visible for smaller p_T
  - Somewhat less statistical significance
- The results are consistent -- > take weighted mean
  - c= 0.93 +/- 0.06 (statistical)
- The b's for the exclusive ρ^0 and breakup data differ by 20%
  - Exclusive ρ^0 : 364 +/- 7 GeV^{-2}
  - Coulomb breakup: 303 +/- 10 GeV^{-2}
  - Photon flux ~ $1/b^2$ (here b ~ impact parameter)
    - More ρ^0 production on 'near' side of target
      - Smaller apparent size
- Preliminary systematic errors
  - Experimental 8% (detector simulation…)
  - Theoretical 15% (functional form of interference)

4-prong analysis

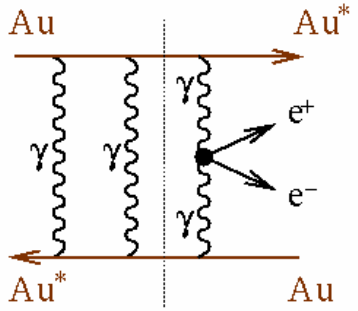
- Very preliminary
- 'Model' reaction
  - $\gamma A \rightarrow \rho^{0}*(1450/1700) \rightarrow \pi^{+}\pi^{-}\pi^{+}\pi^{-}$
  - Expect ~ 100 events
- Follows 2-prong analysis
  - p_T < 100 MeV/c
  - Excess for $\pi^{+}\pi^{-}\pi^{+}\pi^{-}$
    - Over $\pi^{+}\pi^{+}\pi^{+}\pi^{-}$
    - Only at low p_T
- Analysis on a fraction of data
- Background subtracted mass spectrum peaks at ~1.5 GeV



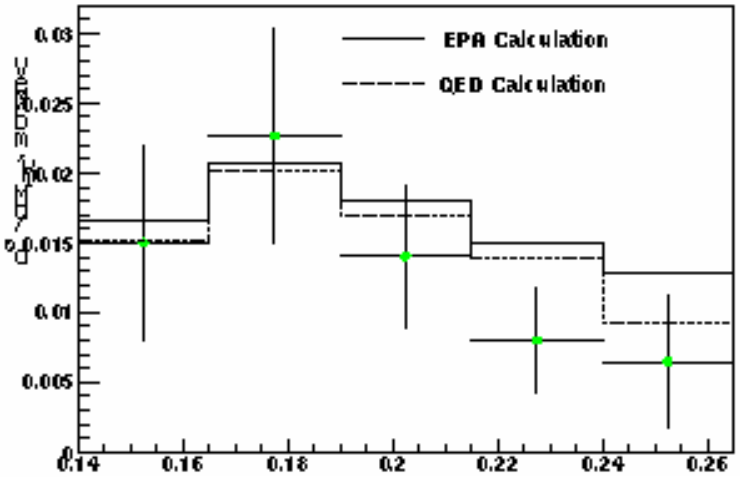


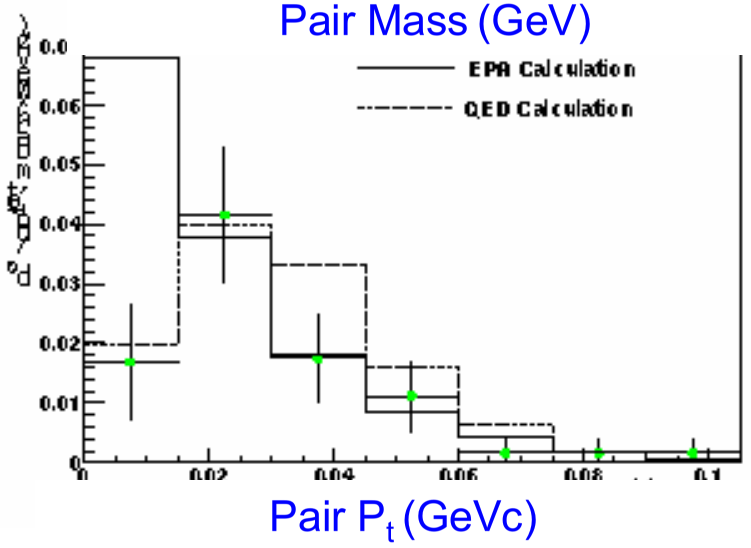
$\pi\pi\pi\pi$ mass (GeV)

Au Au $\gamma\gamma$ --> e^+e^- Au* Au*



- e^+e^- pairs accompanied by nuclear breakup
- $Z\alpha_{EM} \sim 0.6$
  - Higher order corrections?
- Cross section matches lowest order quantum electrodynamics calculation
  - No large higher order corrections
- p_T peaked at ~ 25 MeV
  - Matches QED calculation
  - 4σ disagreement with equivalent photon (massless photon) calculation
- V. Morozov PhD dissertation





Conclusions & Outlook

- Photoproduction can be profitably studied at hadron colliders.
  - The LHC will reach γp energies 10 times higher than HERA.
- STAR has observed coherent photonuclear ρ^0 and $\pi^+\pi^-\pi^+\pi^-$ (likely the ρ^{*0}) production.
  - The ρ^0 cross sections and kinematic distributions agree with theoretical models.
- We observe 2-source interference in ρ^0 production.
  - The interference occurs even though the ρ^0 decay before the wave functions of the two sources can overlap.
- The cross section for e^+e^- pair production is consistent with lowest order quantum electrodynamics.
- In 2004, we multiplied our data sample, and hope to observe photoproduction of the J/ψ.