Photoproduction at the Relativistic Heavy Ion Collider with STAR

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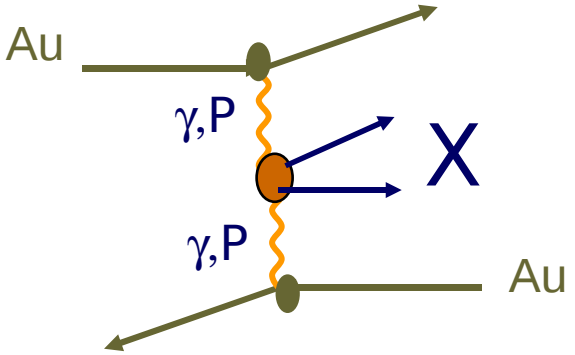
Ultra Peripheral Collisions

- Ultra Peripheral Collisions – nuclei miss each other and interact via long range electromagnetic fields
  - Weizsacker-Williams: a field of almost-real photons
    - Virtuality $Q^2 < (h/R_A)^2$
- Photon $E_{max} \sim \gamma h/R_A$
  - 3 GeV with gold at RHIC
- Photon flux ~ Z^2
  - Higher intensity with heavy ions, higher probability of multi-photon interactions



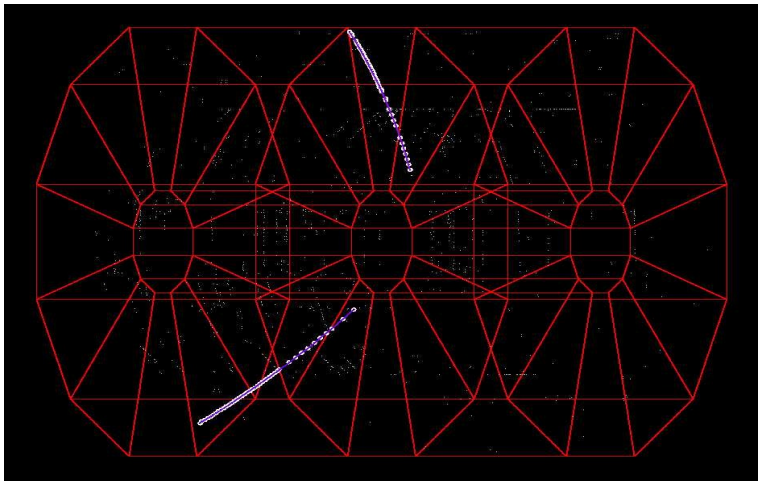
- Photonuclear vector meson production is the dominant
- Both processes can be exclusive and coherent
  - Exclusive : nuclei stay in tact no other particles in the event
  - Coherent: fields couple to the entire nucleus with momentum transfer at the order of $\hbar/R_A$
    - At RHIC : $\sigma(\text{AuAu} \rightarrow \text{AuAu}+\rho^0)$ = 530 mb

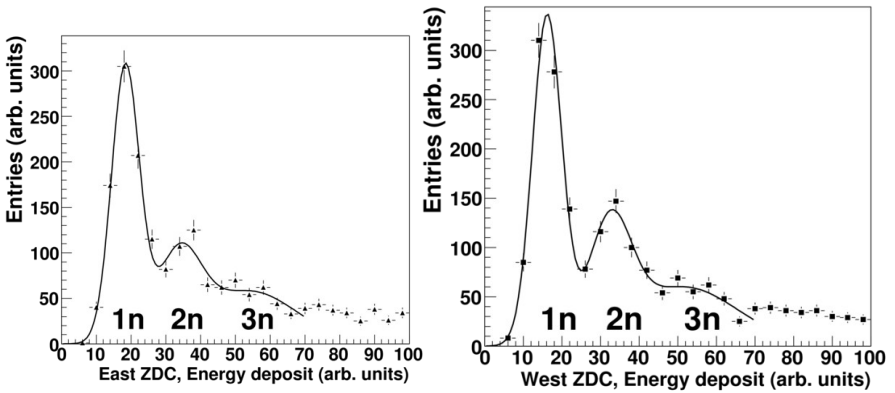
Photoproduction Physics

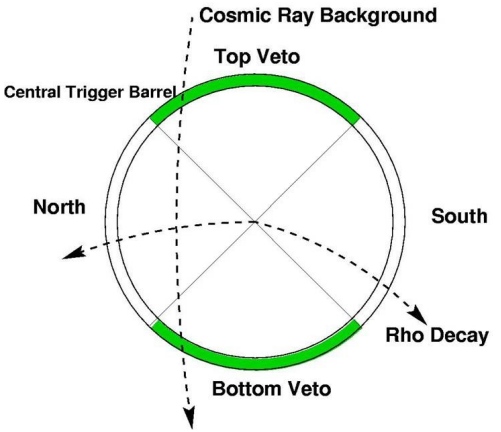
- Gluon structure function
  - gA -> J/Ψ, cc(bar), dijets, etc
    - $\sigma_{J/\Psi} \sim g^2(x)$
    - $\sigma_{QQ,\ dijets} \sim g(x)$
- Meson spectroscopy
  - ρ,ω,φ, excited states, etc
    - ρ' state which believed to consist of r(1450) and r(1700)
    - $\sigma(\gamma p \rightarrow \rho p)$ and $\sigma(\gamma A \rightarrow \rho A)$ of the two components should scale differently with A due to shadowing
- Transition from soft physics (ρ,ω,φ) to pQCD (J/Ψ, Y)
- Fundamental tests of Quantum Mechanics
  - Interference between non overlapping particles
- Multiple production
  - Unitarization of the strong electromagnetic fields leads to production of multiple VM in a single event

Signature and Triggering

- Signatures:
  - Coherent production dominates
  - $p_T \leq 2h/RA \approx 60$ MeV/c
  - Low multiplicity events with vertex
  - Events with nuclear breakup accompanied by forward neutrons
- Triggers:
  - “Minimum bias”
    - Low multiplicity
    - Neutrons in both ZDCs
  - “Topology”
    - Low multiplicity events
    - Coincidence of North and South
    - Top and Bottom veto cosmics





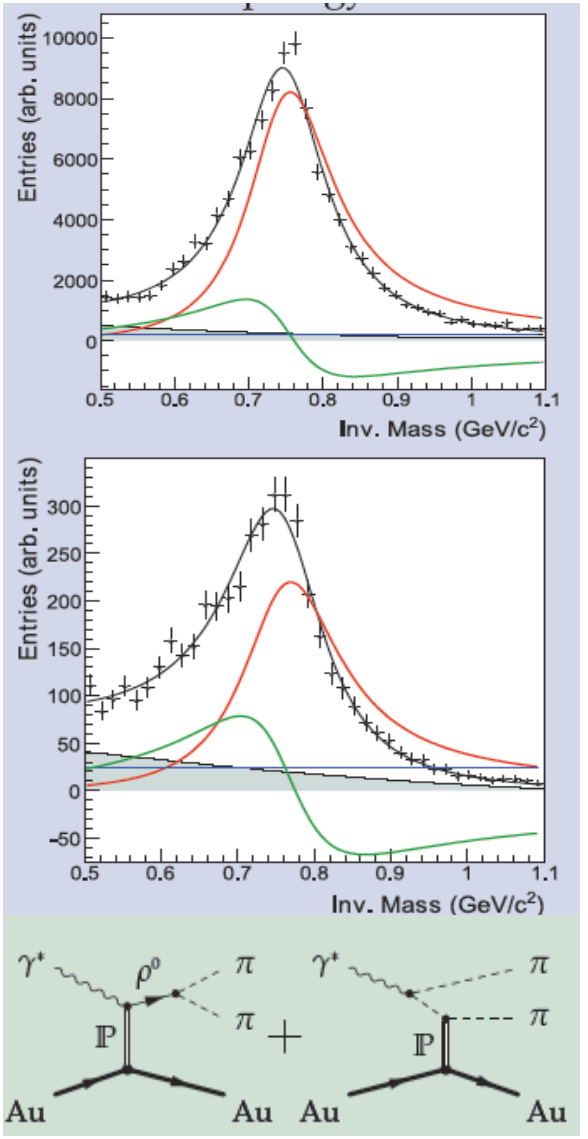


ρ^0 Photoproduction at STAR

- Coherently produced events
  - Exclusive ρ^0 accompanied by mutual Coulomb excitation
  - p_T < 150 MeV/c
  - Acceptance corrected
- Fit function:
  - Relativistic Breit-Wigner for ρ^0 signal
  - Mass independent direct $\pi^+\pi^-$ production amplitude
  - Söding term for the interference of the two

$$\frac{d\sigma}{dM_{\pi\pi}} = \left| A \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + i M_\rho \Gamma_\rho} + B \right|^2 .$$

- Background
  - Beam Gas Interactions
  - Peripheral hadronic interactions
  - Pile up events
  - Cosmic Rays



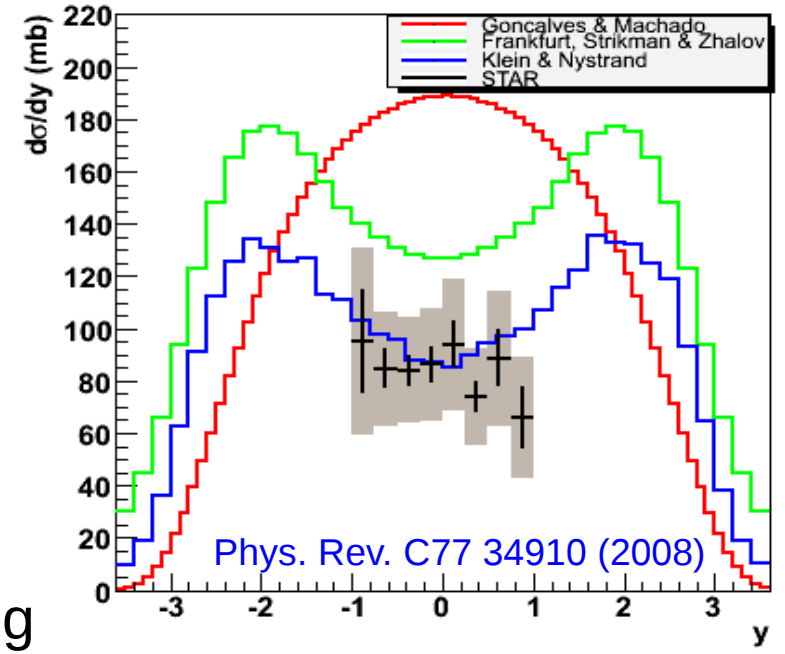
Phys. Rev. C77 34910 (2008)

ρ^0 Photoproduction Cross Section

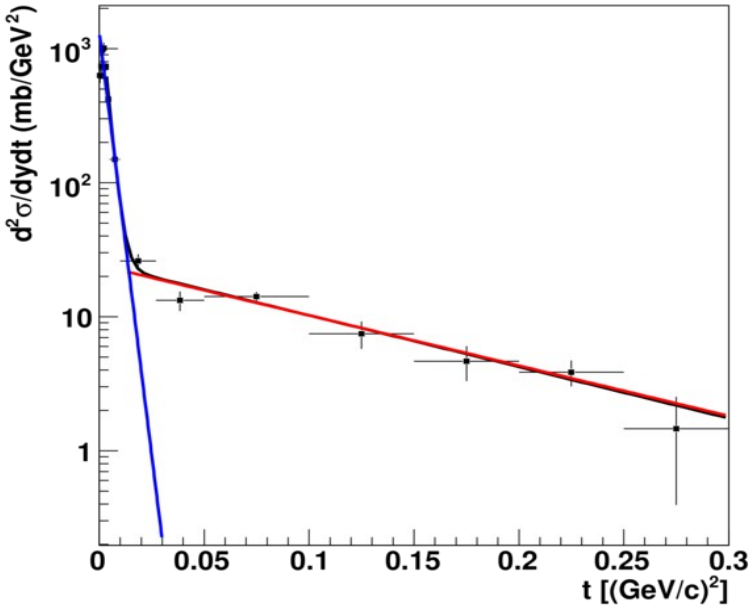
Goncalves & Machado (EPJ C29,2003)
- QCD color dipole approach
- Nuclear effects and parton saturation phenomena

Frankfurt, Strikman & Zhalov (PRC67 034901 2003)
- Generalized vector dominance (VDM)
- QCD – Gribov-Glauber approach

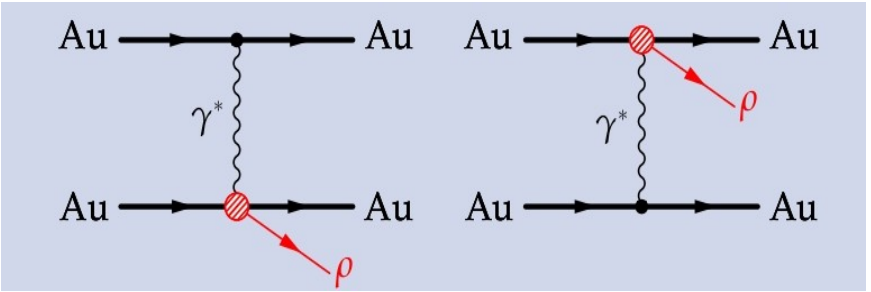
Klein & Nystrand (PR C60 014903, 1999)
- VDM
- Classical mechanical approach for scattering



- Coherent and incoherent form factors
  - Double exponential fit function
- Incoherent production – nucleon form factor
  - $b_N = 8.8 \pm 1.0$ GeV^{-2}
- Coherent production
  - $b_{Au} = 388.4 \pm 24.8$ GeV^{-2}
    - Data sensitive to hadronic radius of gold
      - $b_{Au} \sim R_A^2$
- $\sigma(\text{incoh})/\sigma(\text{coh}) \sim 0.29 \pm 0.03$



Interference in ρ Production



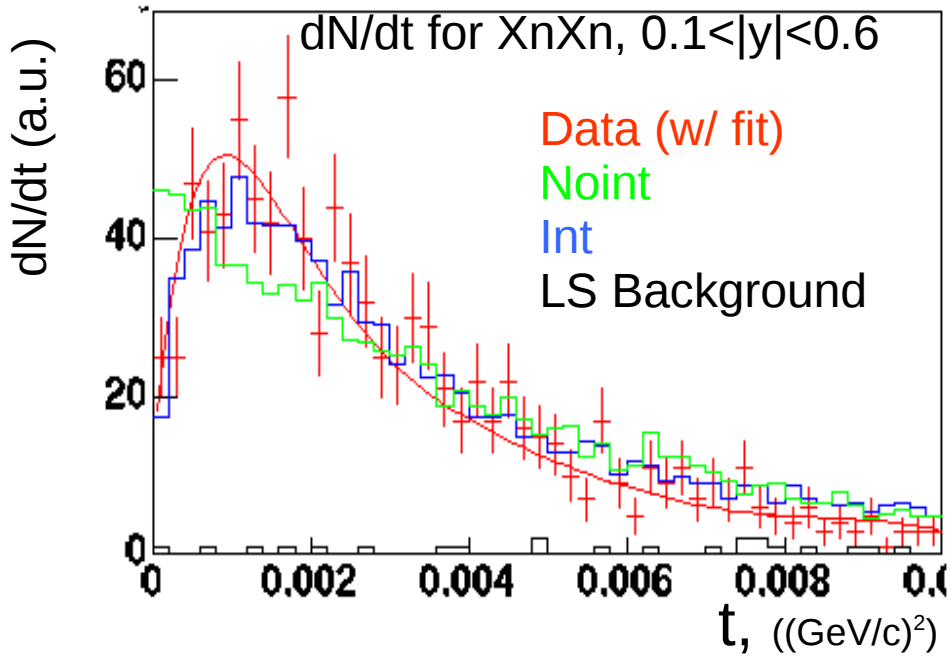
PRL 102, 112301 (2009)

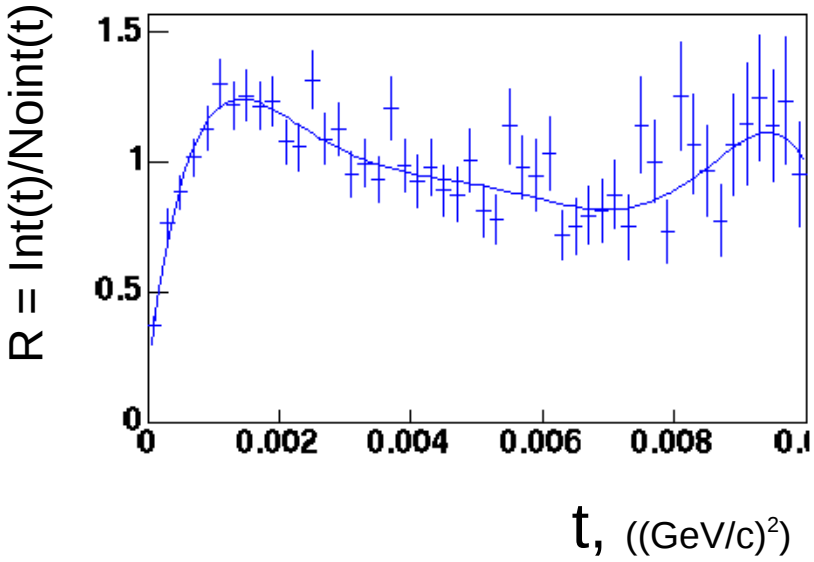
- Impossible to distinguish source of γ and target
  - VM are short lived
  - Decay points are separated in space-time
    - No interference

    OR
    - The wave function retains amplitudes for all possible decays, long after decay occurs
  - Non-local wave function
    - Non factorizable $\Psi_{\pi+\pi-} = \Psi_{\pi+}\Psi_{\pi-}$
  - Example of the EPR paradox
- ρ,ω, ϕ, J/ψ are $J^{PC} = 1^{--}$
  - $\sigma \sim |A_{1(b,y)} - A_{2(b,-y)}e^{ip\cdot b}|^2$ where b is impact parameter
    - Suppression at low $p_T \leq h/\langle b \rangle$
- Different triggers provide access to different median impact parameter
  - Topology data : median b ≈ 46 fm
  - Minimum bias : median b ≈ 18 fm (extends interference effects to larger p_T)
- Photon energy dependence of the ρ production amplitudes leads to the decrease of the interference at large rapidities

Analysis Technique

- Tight cuts
  - Exactly 2 tracks
  - 1 vertex with net charge =0
  - $0.52 < M\pi\pi < 0.92$ GeV
- 2 Monte Carlo samples
  - Interference
  - No interference
  - Including detector effects
    - Momentum smearing
- Data matches int
- Inconsistent with noint
- Fit to dN/dt = A exp(-kt)* [1+c(R(t)-1)]
  - Exponential for nuclear form factor
  - R = Int(t)/NoInt(t) where t ~p_T^2
  - Separates nuclear form factor (exponential) & interference

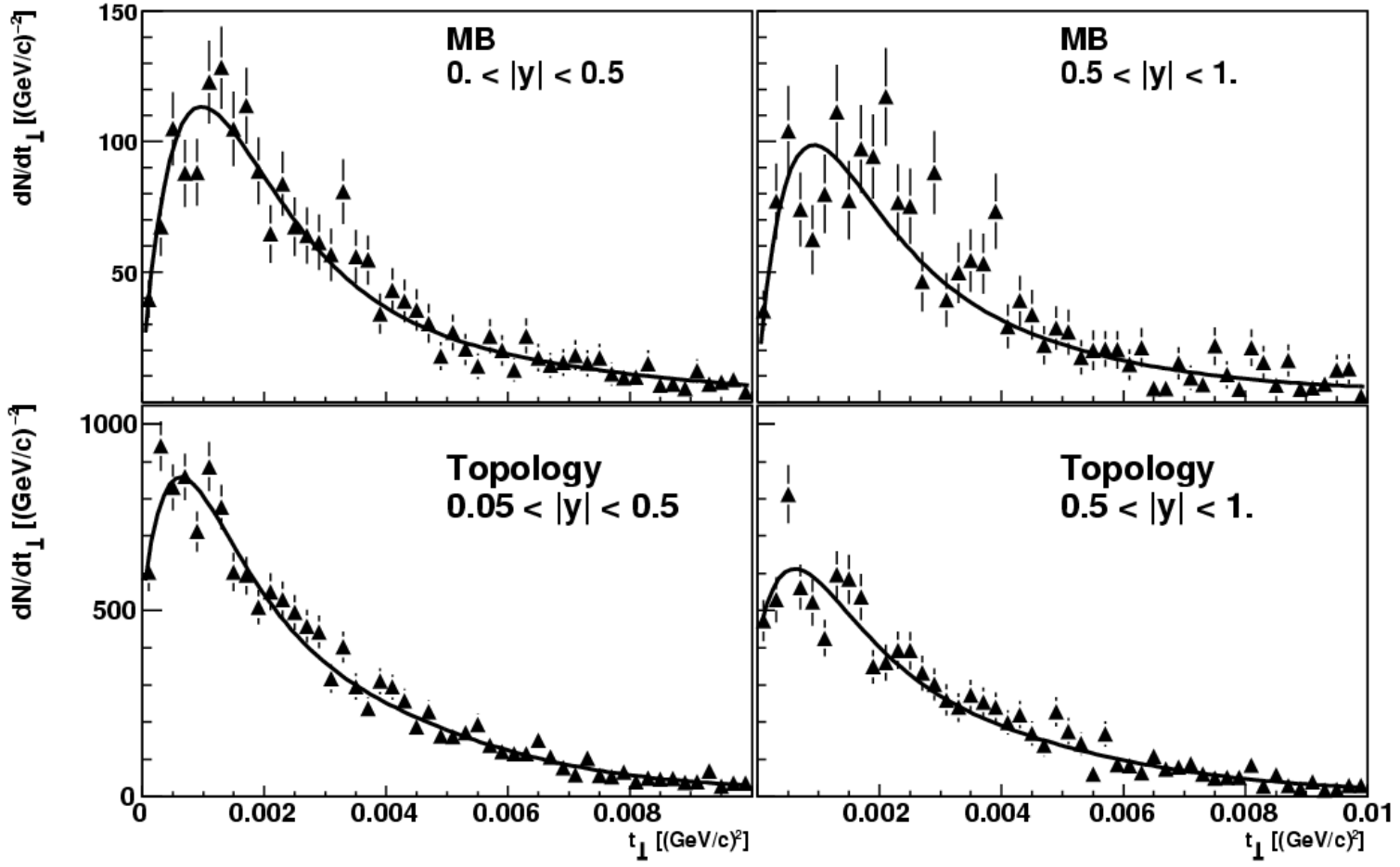




PRL 102, 112301 (2009)

Interference Effects in ρ^0 production

PRL 102, 112301 (2009)



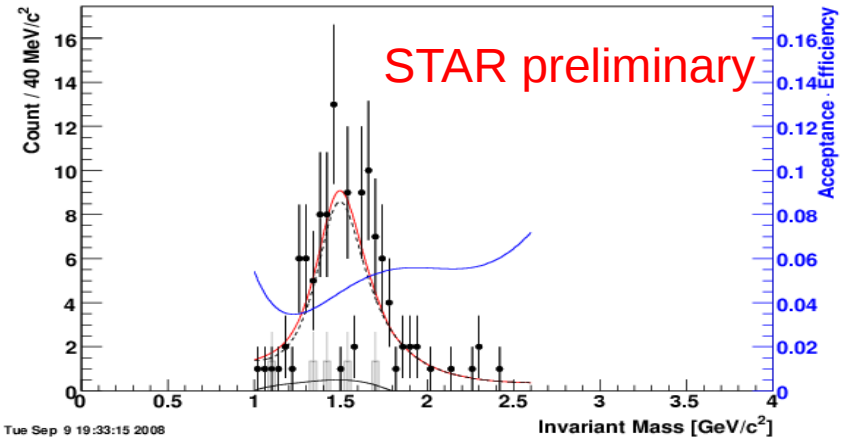
Systematic errors due to trigger (10% for topology), other detector effects (4%), background (1%), fitting & nuclear radius(4%), theoretical uncertanties (5%)

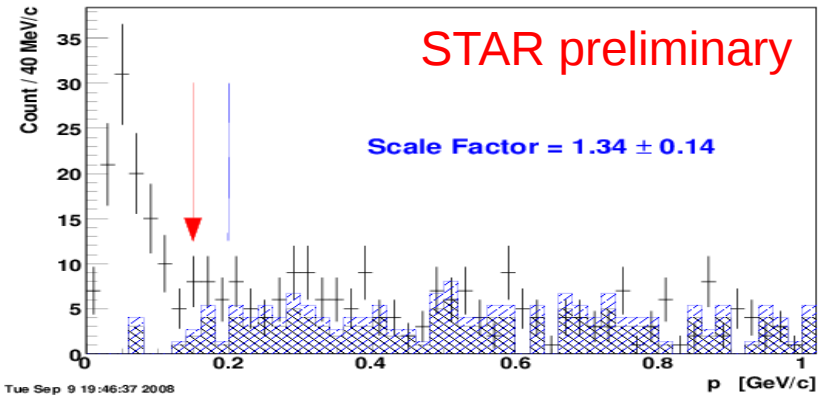
Combined measured interference

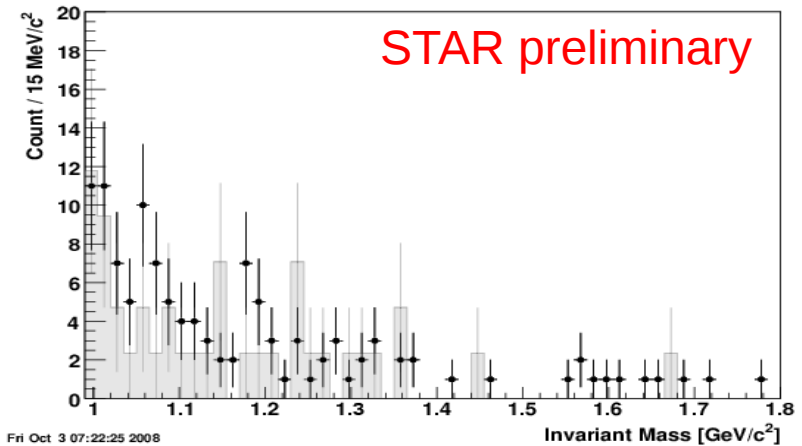
$c = 0.87 \pm 0.05$ (stat.) $\pm$ 0.08 (syst.)%

Photoproduction of $\pi^+\pi^-\pi^+\pi^-$

- Expected to be largely through a radially excited ρ
  - Could be ρ(1450) and/or ρ(1700)
- Peaks at low p_T due to the coherent production
- Mass spectra similar to γp collisions
- Studies of the substructure showed low mass pion pairs accompanied by ρ(770)







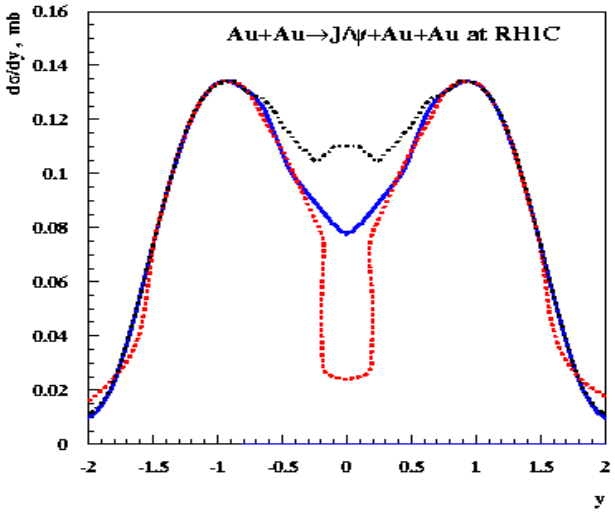
Zoom into higher mass region show no signal for $\rho' \rightarrow \pi^+\pi^-$ channel

Summary and Outlook

- Hadron collider is the unique tool to study photoproduction
  - At RHIC, STAR & PHENIX have studied several topics
    - Published new measurement of ρ^0 production cross section at $\sqrt{s}$=200 GeV
      - Good agreement with theoretical predictions
      - Paper about interference effect has been published - PRL 102, 112301 (2009)
    - Several ongoing analysis
      - ρ^0 production dAu at 200 GeV and AuAu at 62 GeV
      - Resonant production of $\pi\pi\pi\pi$ at $\sqrt{s}$ = 200 GeV in AuAu collisions
  - New subsystems are being commissioned right now
    - Central Trigger Barrel is replaced by Time of Flight
      - Improved triggering performance
    - New Data Acquisition system
      - Readout rate at the level of 1 kHz

Physics Outlook

- New DAQ 1000 system should increase available statistic by factor 10
  - Studies of J/Ψ, etc
    - Gluon shadowing
      - $\sigma \sim g(x,Q^2)^2$ with x ~ few 10^{-2} for J/ψ at RHIC
  - Substructure in 4 pion state
  - Meson spectroscopy : $\rho^*, \rho^0\rho^0, \omega, \varphi$, etc



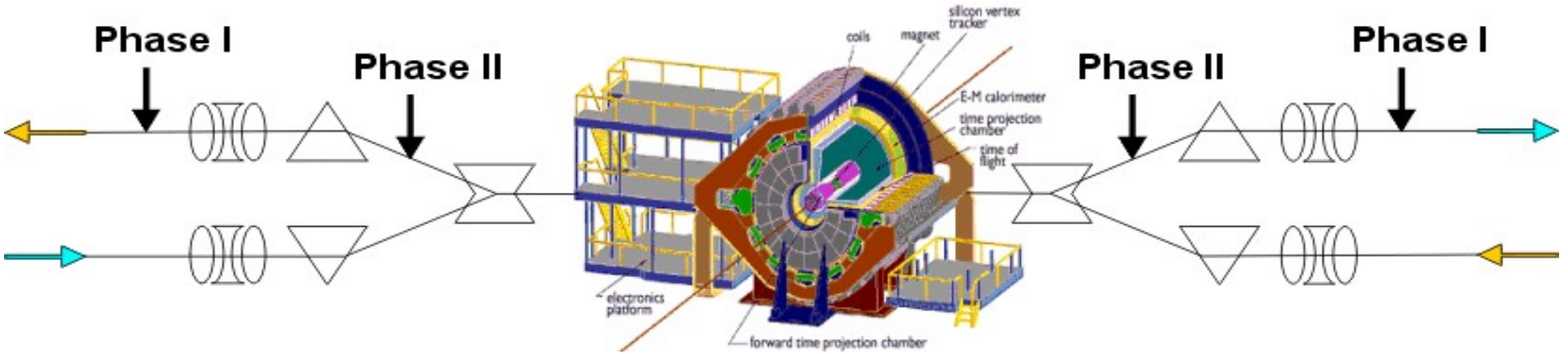
- Roman pots system
  - Elastic and inelastic diffractive processes and spin dependence
  - Exotics

RHIC is a great place to study diffractive and electromagnetic processes in heavy ion collisions

BACKUP

BACKUP SLIDES

Backup slide



Roman pots system has been installed

Dedicated three day run this year

Phase I – elastic scattering and particle production in Double Pomeron Exchange (DPE)

Phase II - increased data set for elastic scattering and particle production in DPE