Photo-production at Relativistic Heavy Ion Collider with STAR

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For the STAR collaboration

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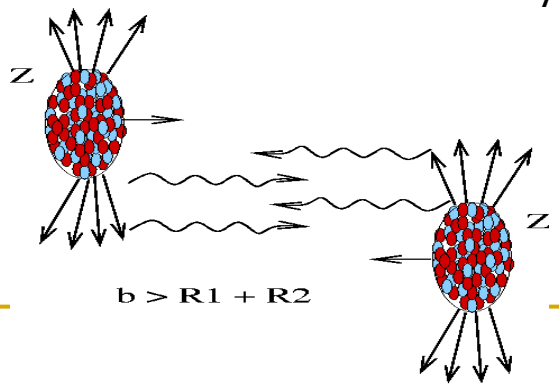
Ultra Peripheral Collisions

- Ultra peripheral collisions (UPC)
  - Nuclei miss each other (b > 2R)
    - Electromagnetic field of an ultra-relativistic particle ~ photon flux with continuous energy
      - Weizsacker-Williams Approach
    - Photon induced interactions
      - $\sigma(\gamma X) \sim Z^2$ and $\sigma(\gamma\gamma) \sim Z^4$
        - Higher intensity with heavy ions , higher probability on multi photon interactions
        - 10x times higher photon flux compare to HERA
    - Coherent fields couple to the entire nucleus with momentum transfer at the order of $\hbar/R_A$

Klein & Nystrand, PRC60 014903
Baltz et al PRL89 012301(2002)
Bauer et al NP A729 787 2003



Physics of Photon Induced Interactions

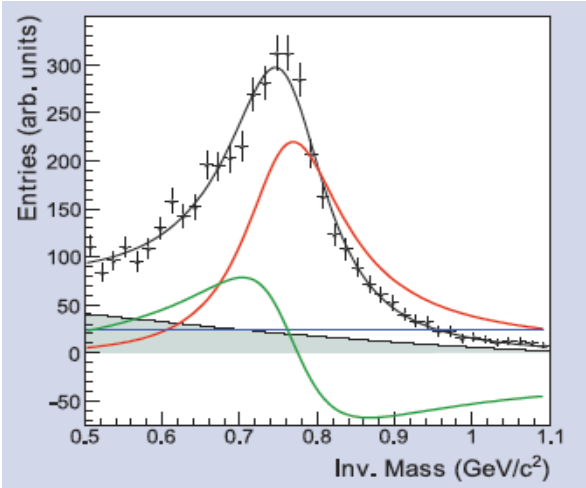
- Vector meson production
  - Light vector mesons ($\rho,\omega,\phi,\rho^*\ldots$)
  - Heavy vector mesons (J/ψ, ψ', $\Upsilon\ldots$)
    - Scattering may be described via 2-gluon exchange
      - Sensitive to gluon distribution
      - Understand initial state for central collisions
      - Directly probe 'new phases of matter' like color glass condensate
  - Transition from soft physics (ρ,ω,φ) to pQCD (J/Ψ, Υ)
  - Fundamental tests of quantum mechanics

Signals and Backgrounds

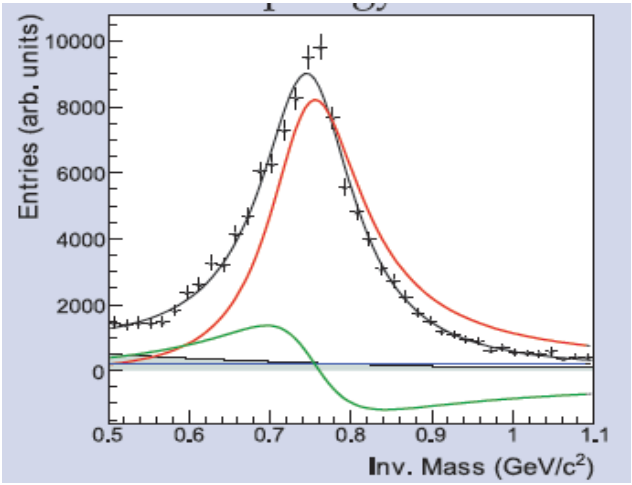
- Non physical (rejected by trigger)
  - Cosmic rays
    - No vertex no signal from nuclei breakup
  - Beam gas interactions
    - No vertex and large number of particles produced in an event
- Physical (rejected by analysis cuts)
  - Peripheral AA collisions
    - Large multiplicities and large transverse momentum
  - Hadronic diffractive
- Signal
  - Incoherent UPC
    - $\gamma+n \rightarrow n+X$
  - Coherent UPC
    - $\gamma+\gamma \rightarrow X$; $\gamma+A \rightarrow X$

ρ^0 Photoproduction Mass Spectra

Minimum bias trigger
With neutron tag



Topology trigger
Exclusive

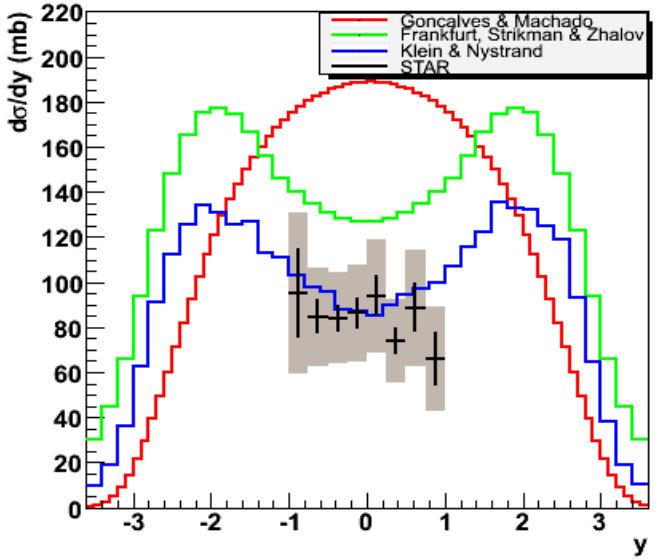


Phys. Rev. C77 34910 (2008)

- Coherent produced events
  - p_T < 150 MeV/c
- Fit function:
  - Relativistic Breit-Wigner for ρ^0 signal
  - Mass independent direct $\pi^+\pi^-$ production amplitude
  - Söding term for the interference of the two
- ρ^0 to $\pi^+\pi^-$ ratio is same as in γp reactions at HERA

Coherent ρ^0 production

- 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

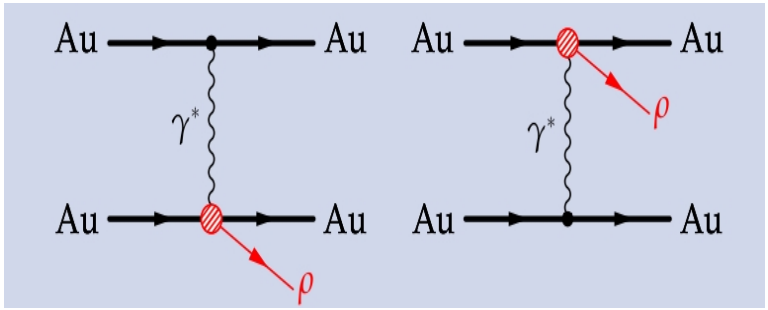


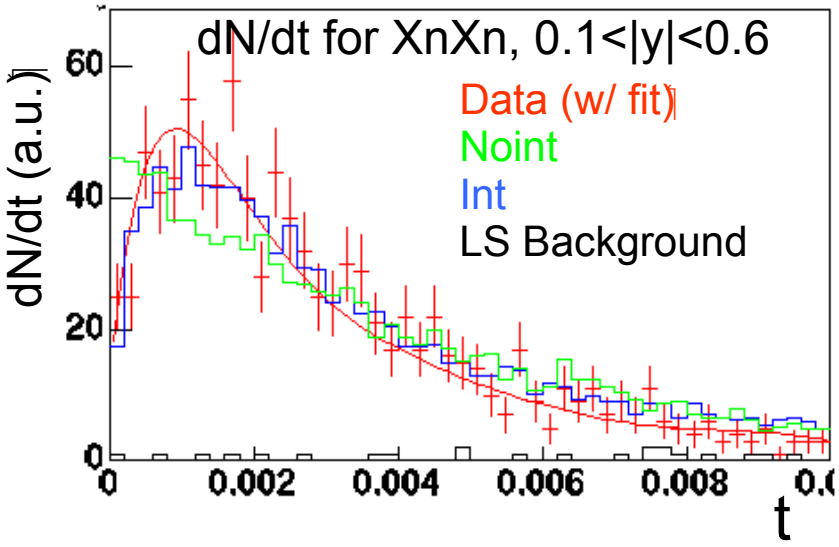
Phys. Rev. C77 34910 (2008)

Limited *y* range does not allow to discriminate shapes
Klein and Nystrand model agrees well with the data

Interference effects in ρ^0 Photoproduction

- Impossible to distinguish source of γ and target
  - Interference
  - Entangled final state $\pi\pi$ wave function
- $\rho,\omega,\phi,J/\psi$ 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 $p_T \leq h/<$





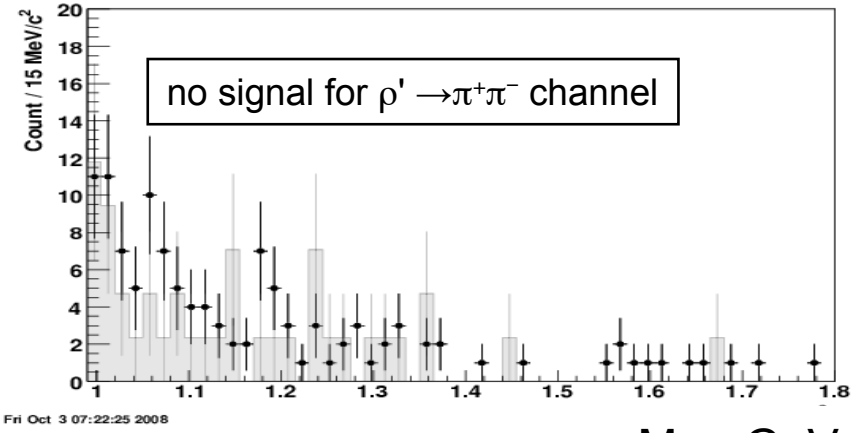
PRL **102**, 112301 (2009)

- Two data sets with different impact parameters
  - median b ~ 46 fm
  - median b ~ 18 fm
    - Extends interference to higher pT
  - Maximum interference at |y| =0 and decreases as |y| rises
    - Due to Photon energy dependence of the r production amplitudes
  - Measured interference:
  - c=0.87 ± 0.05 (stat.) ± 8 (syst.)%

Photo production of $\pi^+\pi^-\pi^+\pi^-$

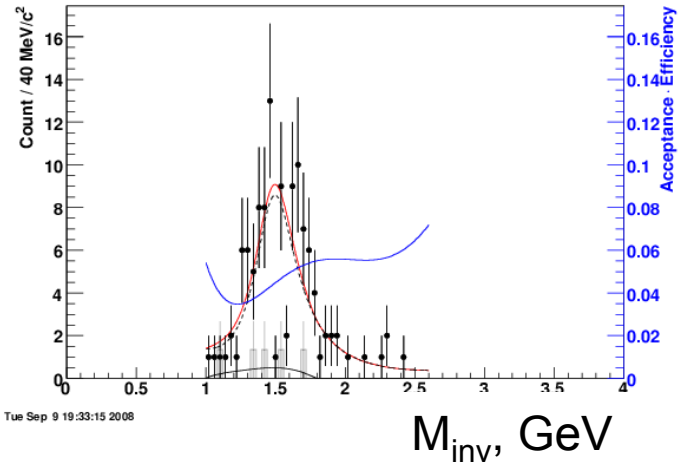
- Expected to be largely through a radially excited
  - Could be $\rho(1450)$ and/or $\rho(1700)$
    - m_0 = 1540 ±40 MeV/c2, Γ_0 = 570 60MeV
- Studies of the substructure showed low mass pion pairs accompanied by $\rho(770)$

$\sigma_{coh}(\pi^+\pi^-\pi^+\pi^-)/\sigma_{coh}(\rho[770])=13.4 \pm 0.8$ %



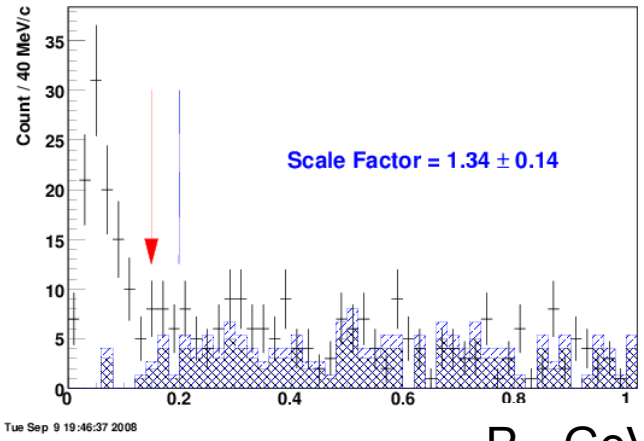
M_{inv}, GeV

Phys. Rev. C **81** (2010) 44901



M_{inv}, GeV

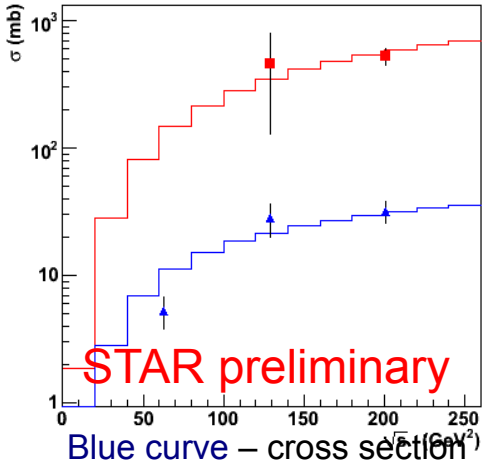
Peak at low p_T is due to the coherent production

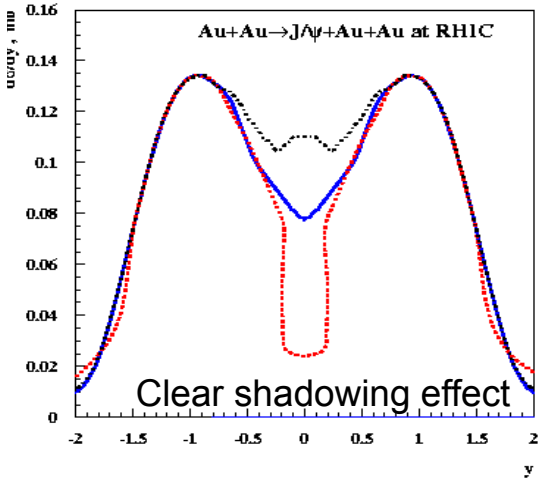


P_T, GeV

Plans

- With current data set
  - Meson spectroscopy
    - $\rho^*, \rho^0\rho^0, \omega, \varphi, \ldots$
    - Energy dependence
  - Studies of J/Ψ
    - Gluon shadowing
- During upcoming run 11
  - 2-3 x increase in the available statistics
  - Revitalize di-lepton trigger and focus on heavier states
- Working towards release of STARlight UPC MC generator
  - Simulates two-photon and photon-Pomeron interactions between relativistic nuclei and protons
    - Final states include : lepton pairs and variety of mesons





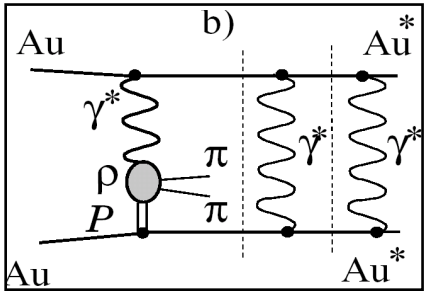
M. Strikman, F. Strikman and M. Zhalov, PL B540, 220 (2002)

Summary

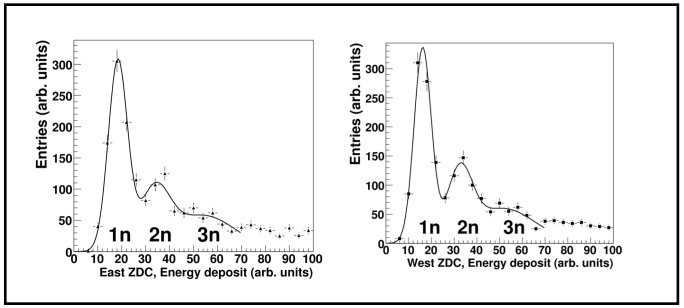
- New enhanced capabilities of STAR
  - Time of Flight in L0 trigger for low multiplicity events selection
  - Upgrade of the data acquisition system
    - 10x higher triggering rate
- STAR measured photonuclear ρ production in Ultra Peripheral Collisions
  - Measured cross section agrees well with theoretical model
  - Studied effects of interference in ρ production
- Ongoing/Planned
  - Energy dependence of ρ production cross section at $\sqrt{s}$=39 , 62, 130 and 200 GeV
  - Study of resonant production $\pi^+\pi^-\pi^+\pi^-$ with enhanced statistics
    - 10 times statistics compare to the previous publication
  - J/Ψ production
- New home for UPC MC generator STARLIGHT at http://projects.hepforge.org/starlight/

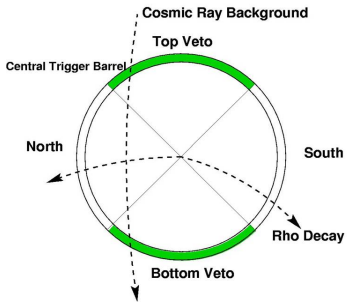
Backup

How to Trigger?



- Signatures:
  - Low multiplicity events
  - Events characterized by the rapidity gaps
  - Large probability of multiple photon exchange
  - Nuclei excitation , likely via GDR, decays via neutron emission
- Solution:
  - Minimum bias
    - Low multiplicity (TOF)
    - Neutrons in both ZDC
  - Topology
    - Low multiplicity
    - Coincidences of North and South
    - Top and bottom used as veto





STAR

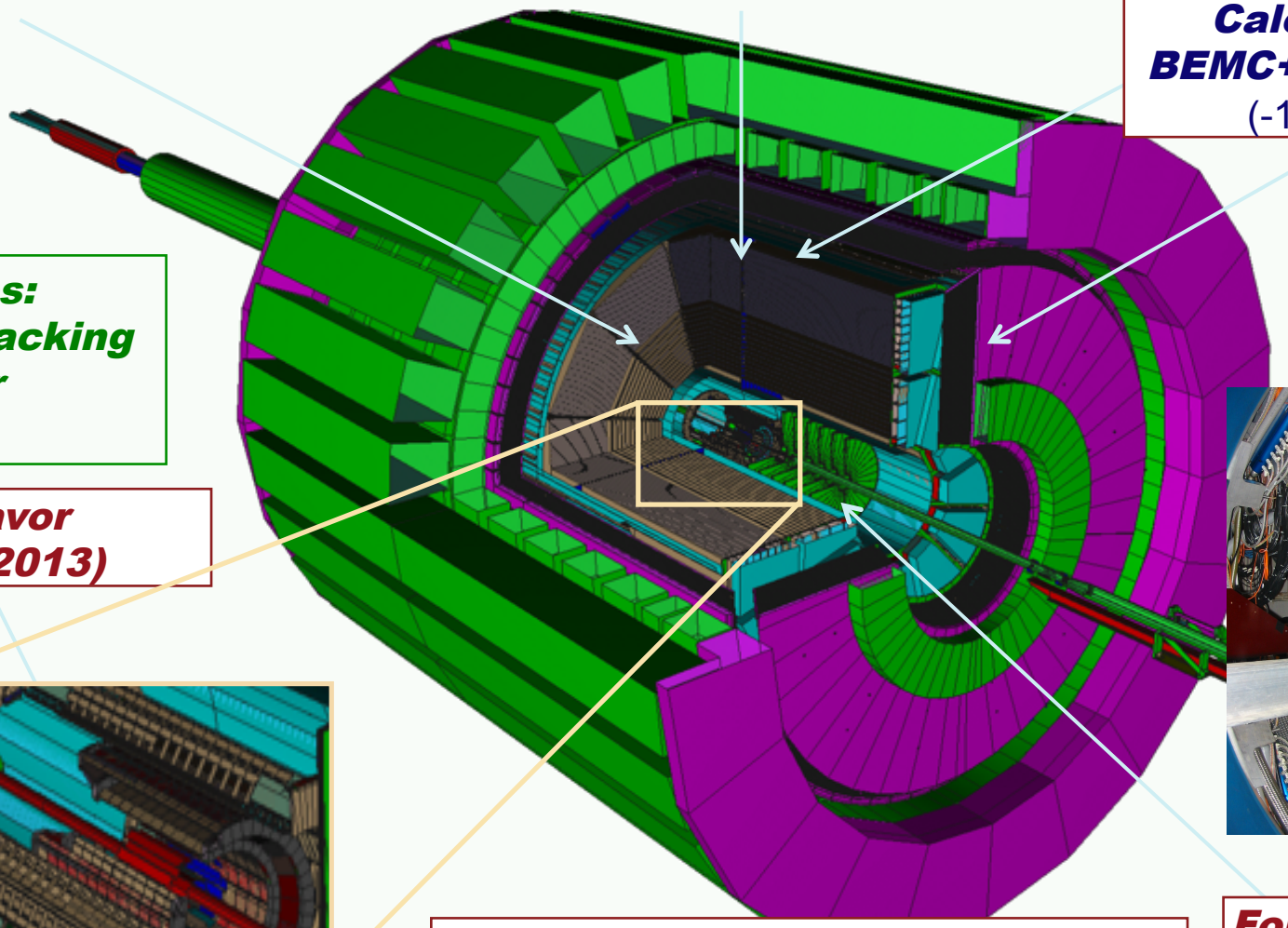
Tracking: TPC

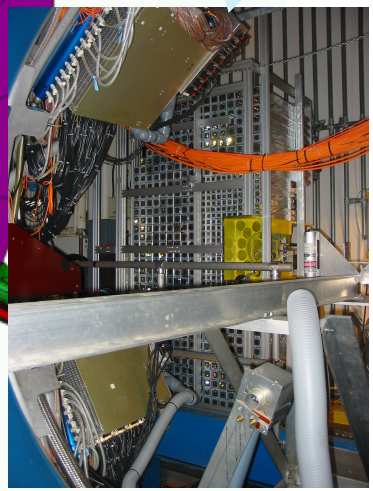
Particle ID: TOF

Electromagnetic Calorimetry: BEMC+EEMC+FMS
$(-1 \leq \eta \leq 4)$

Upgrades:
Muon Tracking Detector
HLT

Heavy Flavor Tracker (2013)



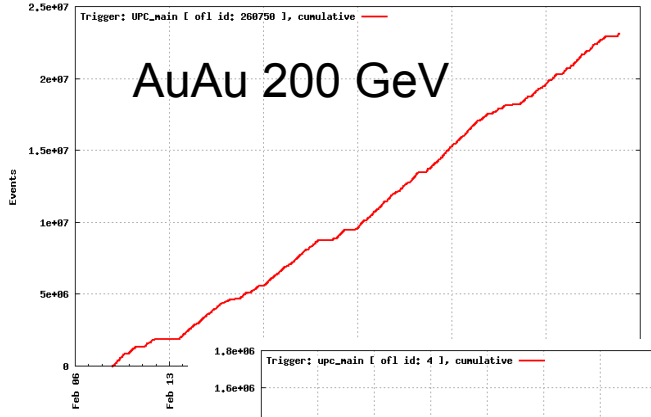


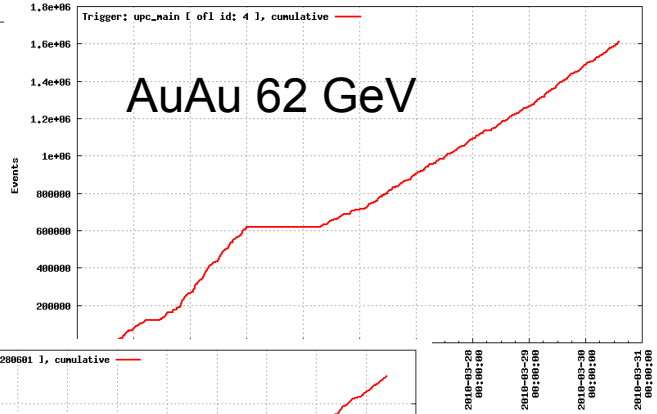
Full azimuthal particle identification over a broad range in pseudorapidity

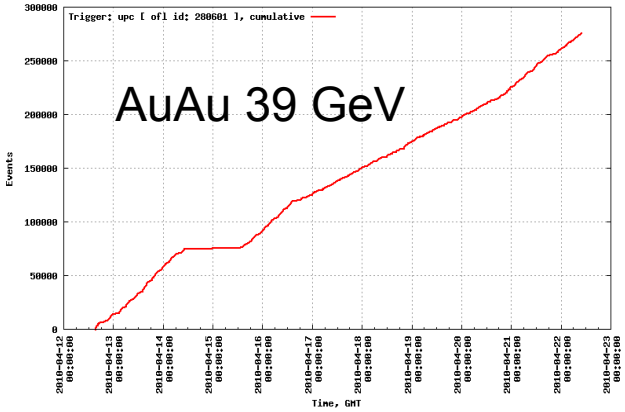
Forward Gem Tracker (2011)

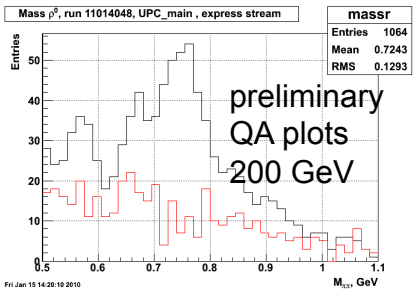
Latest Run 2010

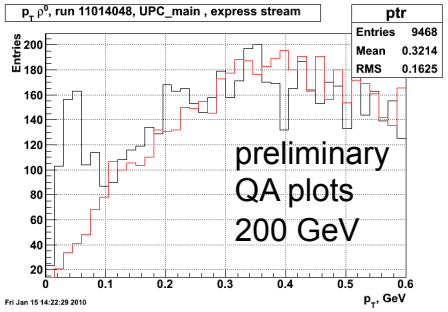
- Ten times increase in the available statistics
  - AuAu 200 GeV
    - Min bias ~ 38 M evt
    - Topology 1.34 M evt
  - AuAu 62 GeV
    - Min bias ~ 2.01 M evt
    - Topology ~ 1.26 M evt
  - AuAu 39 GeV
    - Min bias ~ 390 K evt





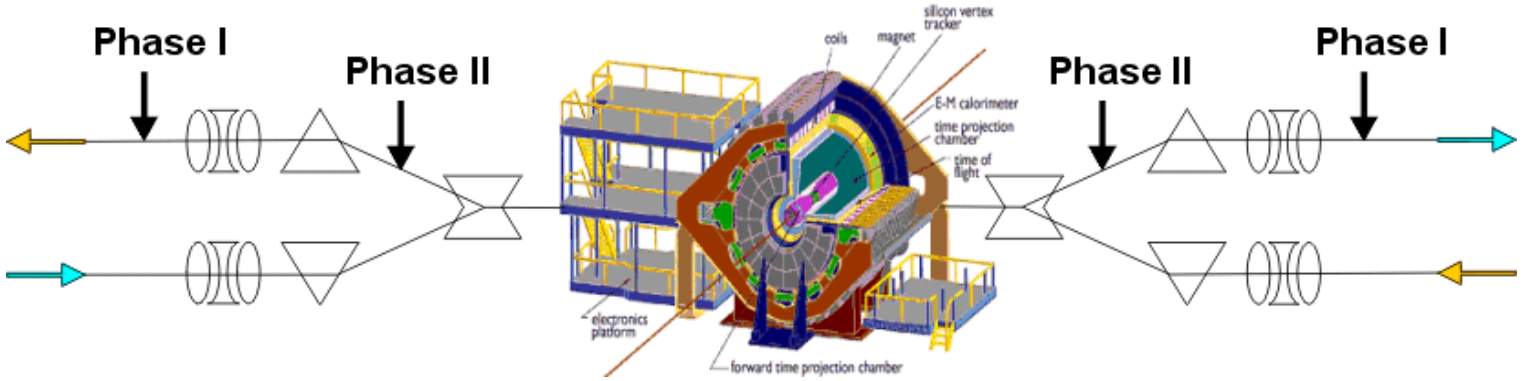






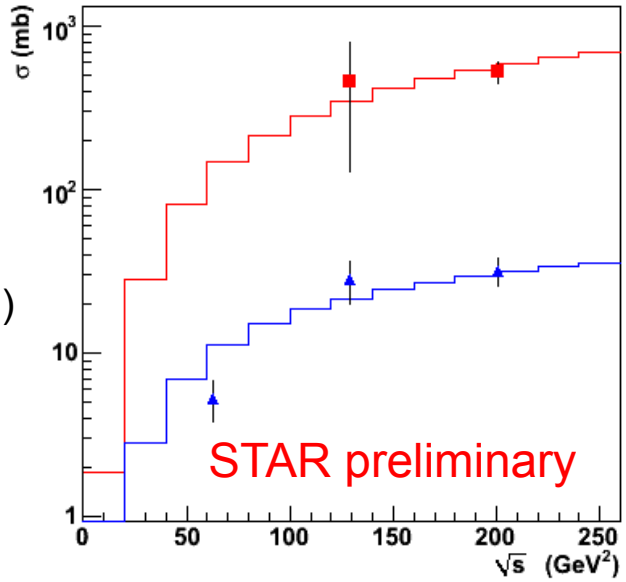
pp Diffraction

- Diffractive system at STAR
  - Reach pp diffraction program
    - Phase I optimized for elastic scattering
      - Requires special low-β beam optics
    - Phase II has larger acceptance



ρ^0 Production energy dependence

- Data sets:
  - Cross section energy dependence
    - AuAu $\sqrt{s}$=39 GeV — In progress
    - AuAu $\sqrt{s}$=62 GeV — In progress
    - AuAu $\sqrt{s}$=130 GeV — PRL89 272302 (2002)
    - AuAu $\sqrt{s}$=200 GeV — PRC77 34910 (2008)
    - dAu $\sqrt{s}$=200 GeV — In progress



Blue curve – cross section with mutual excitation

Red curve – total cross section