Photoproduction in Ultra Peripheral Relativistic Heavy Ion Collisions with STAR

Yury Gorbunov
Creighton University
for the STAR collaboration

6th SMALL X AND DIFFRACTION WORKSHOP
FERMILAB, March 28 - 31 2007

- ρ^0 photoproduction in AuAu and dAu collisions
- ρ^0 interferometry
- 4-prong ($\rho^{0'}$)
- Conclusion

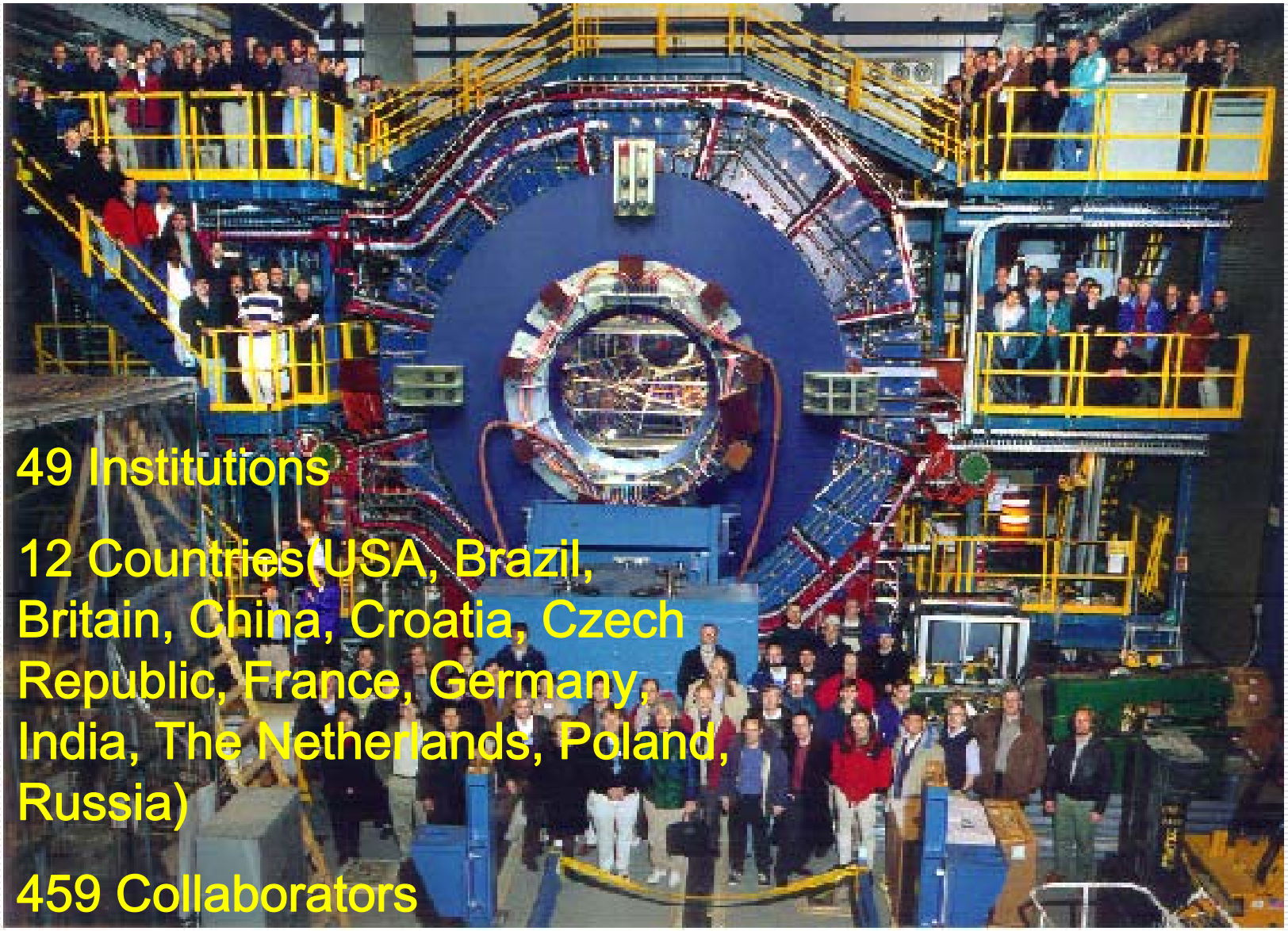
Physics Topics

- γA->VA cross section
  - σ(γA->VA) is related (through optical theorem) to the total VM-nucleon cross section.
  - J/Ψ, ϒ sensitive to the gluon distribution in nuclei
  - Coherent and incoherent production

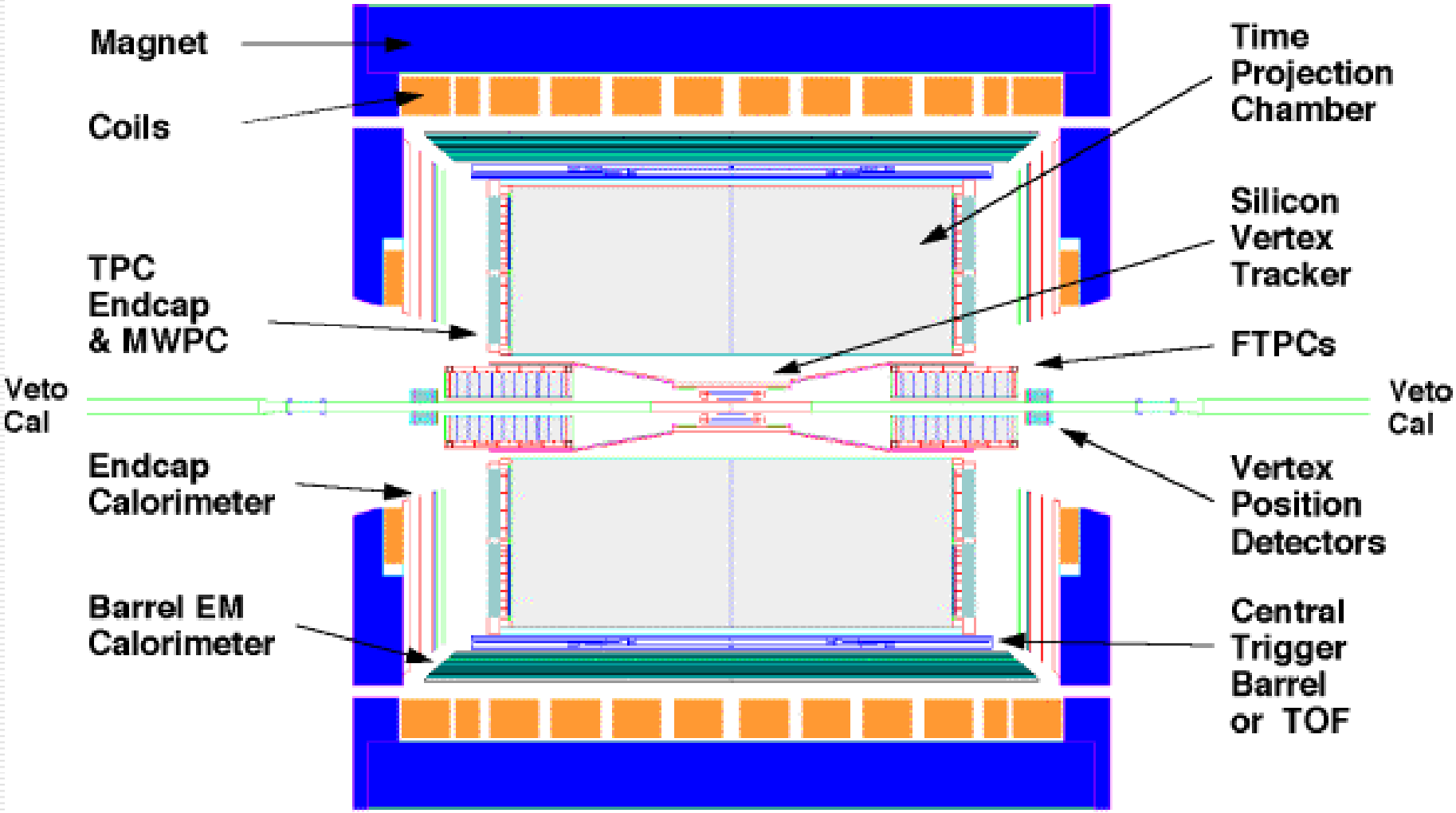
- Vector meson spectroscopy
  - ρ(1600) proposed to be composed of ρ(1470) and ρ(1700)
  - Cross section in γp and γA has to scale differently with A due to the shadowing

- Interferometry
  - The nuclei act as a two-source interferometer for short-lived particle - example of the Einstein-Podolsky-Rosen paradox.

STAR & RHIC

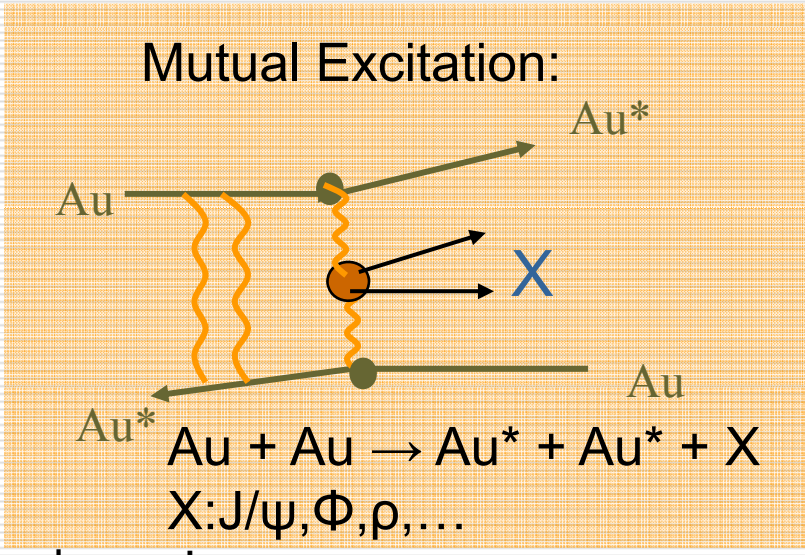

49 Institutions
12 Countries(USA, Brazil, Britain, China, Croatia, Czech Republic, France, Germany, India, The Netherlands, Poland, Russia)
459 Collaborators

RHIC & STAR


Magnet
Coils
TPC
Endcap
& MWPC
Veto
Cal
Endcap
Calorimeter
Barrel EM
Calorimeter
Time
Projection
Chamber
Silicon
Vertex
Tracker
FTPCs
Veto
Cal
Vertex
Position
Detectors
Central
Trigger
Barrel
or TOF

Production

- High energy heavy-ions produce strong E.M. fields due to coherent action
- Equivalent flux of photons in EM
  - b_{min} ~$2R_A$~20fm in AA collisions

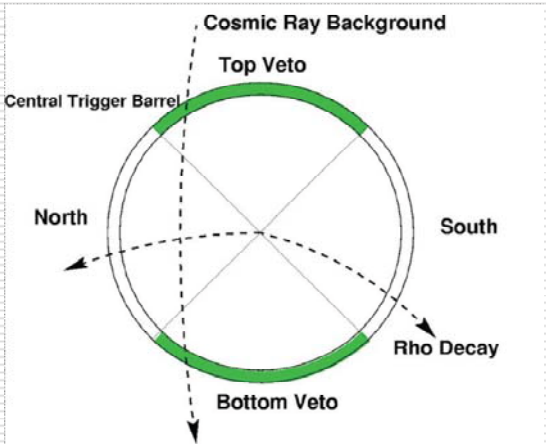


- Photon beams.
  - Flux ~ Z^2, $\sigma(\gamma\gamma)\sim Z^4$
  - Coherent conditions: γ wavelength > nucleus size
  - Final state has $\Sigma p_T < 2h/R_A$ ~0.100 GeV/c; $P_L \sim \gamma h/R_A$~6 GeV

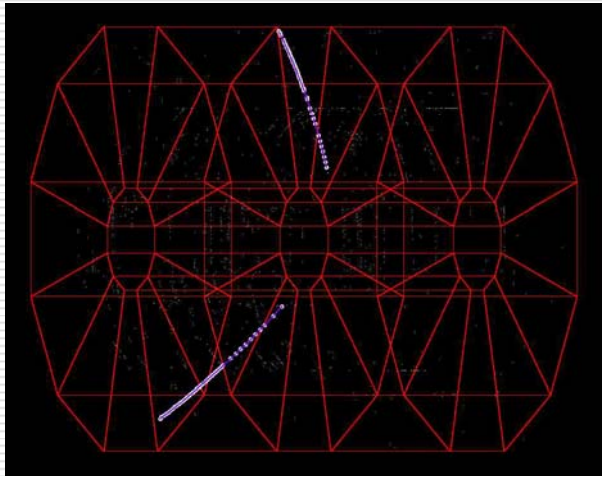
- The coherent process dominates mid rapidity vector meson production, incoherent process also can be studied
  - Clear signature
    - Au* decay via neutron emission - simple, unbiased trigger
  - Enhanced rates for heavy ions

Trigger

- Topology
  - Central trigger Barrel divided into 4 quadrants
  - ρ candidates with hits in North and South quadrants
  - Events with hits Top/Bottom are vetoed



- Minimum Bias
  - Events with low multiplicity selected with Central Trigger Barrel detector
  - At least one neutron in each of the Zero Degree Calorimeter
    - distinctive signature for nuclear breakup
    - Nuclear excitation 'tag's small b

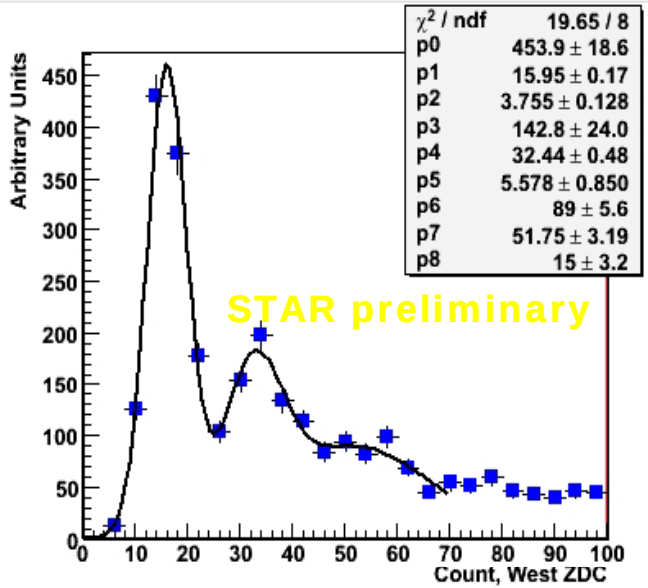


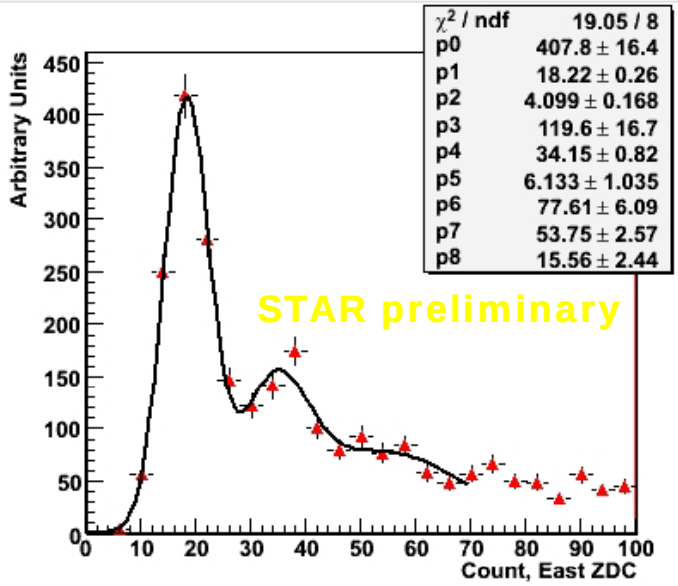
- Background
  - Beam gas
  - Peripheral hadronic interactions
  - Cosmics

Data Samples

- Run 2000 130 GeV AuAu
  - Topology
  - Minimum bias
- Run 2001 200 GeV AuAu
  - Topology
  - Minimum bias
- Run 2004 AuAu
  - 200 GeV 4 prong
  - 200 GeV J/Ψ
  - 200, 62 GeV Minimum bias
- Run 2005 CuCu
  - 200 GeV J/Ψ
  - 200, 62 GeV Minimum bias

Zero Degree Calorimeter

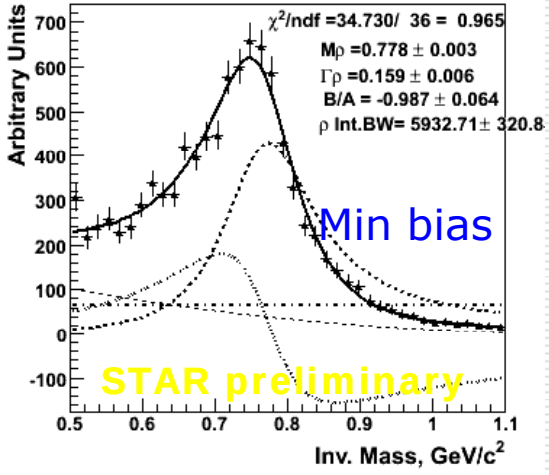


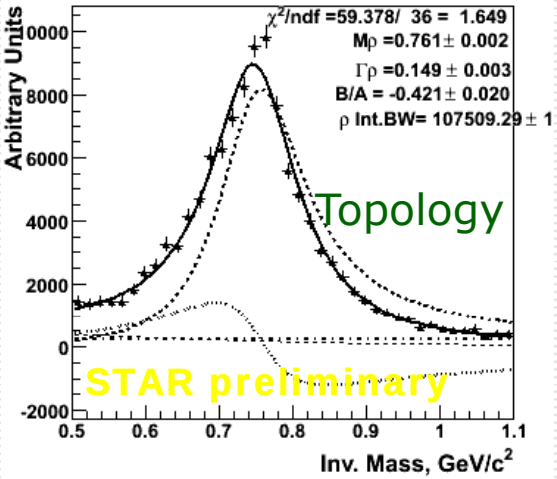


- ZDC spectra obtained with the minimum bias sample
- Allows to distinguish between different excited states of produced vector mesons (1n,2n,3n,... - 2.37:1.15:1)
- Acceptance ~ 100%

Available Statistics

- Approximately 16 000 candidates in two samples 2001 (minimum bias and topology sample)





- M_{pp} spectra includes ρ^0 and direct $\pi^+\pi^-$ production
- $\pi^+\pi^+$ and $\pi^-\pi^-$ model background
- Fitted with
  - Breit-Wigner function for the signal
  - Soding's interference term: direct $\pi^+\pi^-$ production
  - Background estimated with like sign pairs
    - described by the second order polynomial

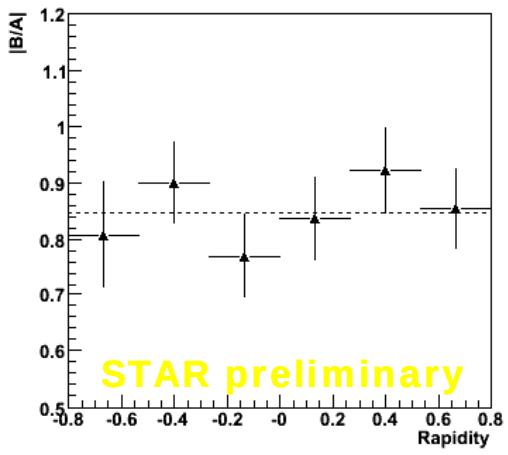
$$\frac{d\sigma}{dM_{\pi\pi}} = \left| A\frac{\sqrt{M_{\pi\pi}M_\rho\Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + iM_\rho\Gamma_\rho} + B \right|^2 + f_{PS}$$

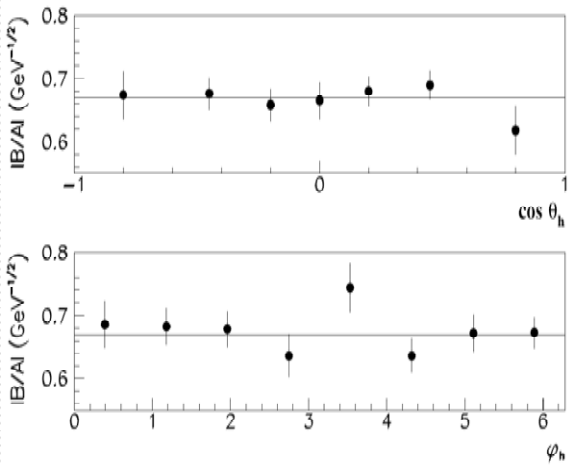
A - amplitude for ρ^0

B - amplitude for direct $\pi^+\pi^-$

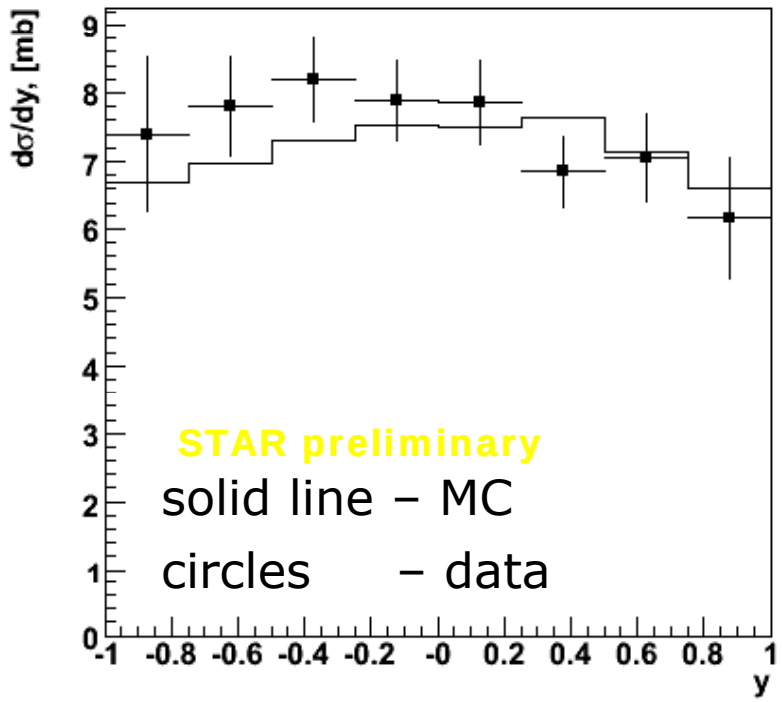
Direct Pion Production

- |B/A| - measure of non-resonant to resonant production
  - The model predicts decrease of the |B/A| with |t| and no angular dependence (hep-ph 9701407)
  - Fit function of the invariant mass gives access to the direct pion production
  - |B/A| = 0.84 ± 0.11 GeV $^{-1/2}$ in agreement with previous STAR results |B/A| = 0.81 ± 0.28 GeV $^{-1/2}$
  - No angular dependence -> in agreement with ZEUS measurements and model
  - Flat as the function of rapidity => photon energy $y = 1/2 \ln(2E_\gamma / M_\rho)$

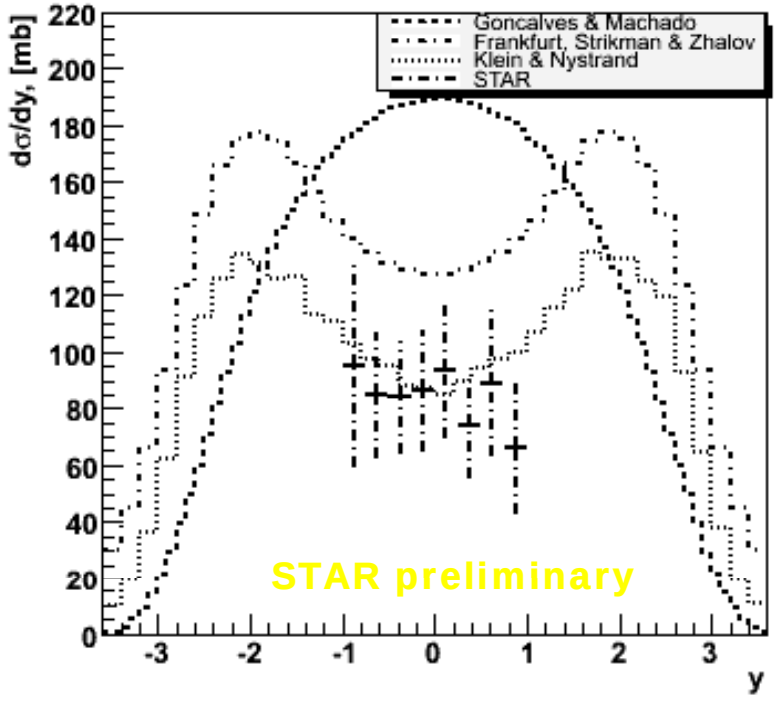




Cross Section



ρ⁰ production cross section for events with mutual excitation (X_nX_n) in AuAu collisions at 200 GeV/c



- ρ⁰ total production cross section (AuAu, 200 GeV) along with 3 theoretical models
- ρ⁰ scaled from XnXn
  - X_0X_0/X_nX_n from toplogy sample
  - extrapolation to 4π based on MC

Models

- Nystrand, Klein: vector dominance model (VDM) & classical mechanical approach for scattering, based on γp→ρp experiments results
  - Vector dominance model – effects of the nuclear shadowing for γA interactions
  - PRC 60(1999)014903
- Frankfurt, Strikman, Zhalov : generalized vector dominance model + Gribov-Glauber approach
  - Gribov–Glauber approach – total cross section of photoproduction off heavy nuclei
  - Phys. Rev. C 67, 034901 (2003)
- Goncalves, Machado: QCD dipole approach (nuclear effects and parton saturation phenomenon)
  - Eur.Phys.J. C29 (2003) 271-275

Cross Section Comparison

- ρ^0 production cross was measured by STAR at 200 GeV and 130 GeV (PRL 89, 027302 (2002))
- Normalized to 7.2 b hadronic cross section

	STAR $\sqrt{s}$=200GeV, mb	STAR $\sqrt{s}$=130GeV, mb
σ_{xnxn}	30.26±1.1±6.35	26.2±1.8±5.8
σ_{total}	509.2±34.5±106.9	410±190±100

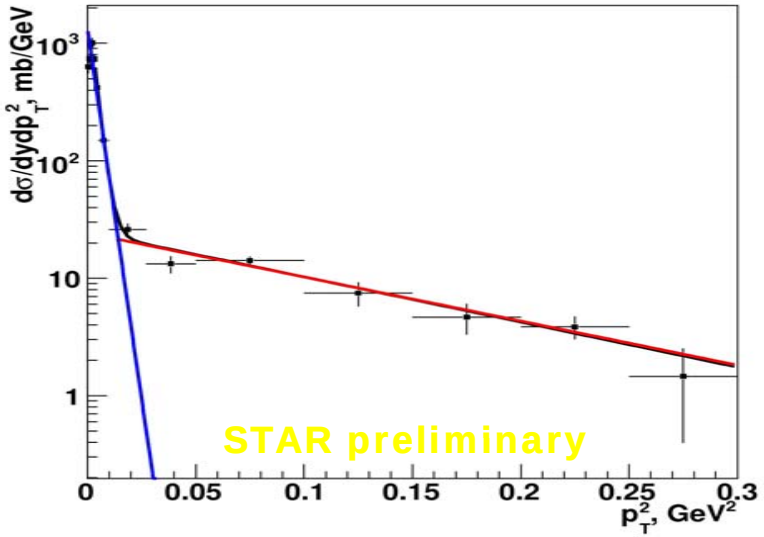
Nystrand & Klein σ_{total}	Goncalves, Machado σ_{total}	Frankfurt, et al. σ_{total}
590 mb	876 mb	934 mb

Cross Section

- Measured ρ^0 coherent plus incoherent production cross section
- Fit function:

$$\frac{d\sigma}{dt} = a * \exp(b * t) + c * \exp(d * t)$$

To the p_T^2 range: (0.002,0.3) Cev^2



- Incoherent production
  - d = 8.8 ±1.0 GeV^{-2}– access to the nucleon form factor;
  - $R_{AU}=\sqrt{4b}$ ~ 1.2±0.4 fm
  - In agreement with b from incoherent production in dAu collisions shown earlier
- Coherent production
  - b = 388.4 ±24.8 GeV^{-2} – nuclear form factor
  - $R_{AU}=\sqrt{4b}$ ~ 7.9±1.8 fm
    - In agreement with previous measurement
- σ incoh/coh ~ 0.29 ±0.03

Spin Density Matrix

- 2-dimensional correlation of Φ_h vs $\cos(\Theta_h)$ allows to determine the ρ0 spin density matrix elements
  - allows measurement of 3 of the 15 spin density matrix elements (SDME)
  - Θ – polar angle between ion and direction of $\pi+$
  - Φ – azimuthal angle between decay plane and production plane
- s-channel helicity conservation (SCHC)
  - vector meson retains helicity of photon - all 3 SDMEs are predicted to be about zero
  - Based on QCD model of the Pomeron as two gluon exchange

- Fit function: K. Schilling and G. Wolf, Nucl. Phys. B61, 381 (1973)

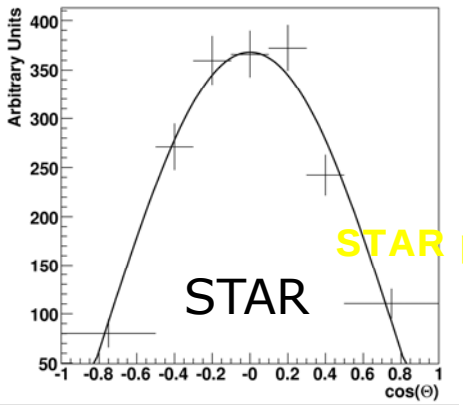
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\Theta_h d\Phi_h} = \frac{3}{4\pi}\left[\frac{1}{2}(1-r^{04}_{00})+\frac{1}{2}(3r^{04}_{00}-1)\cos^2\Theta_h-\sqrt{2}\Re e[r^{04}_{10}]\sin 2\Theta_h\cos\Phi_h-r^{04}_{1-1}\sin^2\Theta_h\cos 2\Phi_h\right] \quad (1)$$

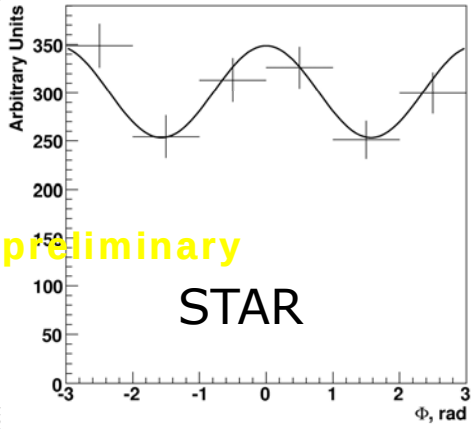
  - r^{04}_{00} represents probability ρ0 having a helicity
  - r^{04}_{1-1} related to the level of interference helicity non flip & double flip
  - $\Re e[r^{04}_{10}]$ related to the level of interference helicity non flip & single flip
  - In case of s-channel helicity conservation r^{04}_{1-1} $\Re e[r^{04}_{10}]$ equal 0 and small r^{04}_{00}

Matrix Elements

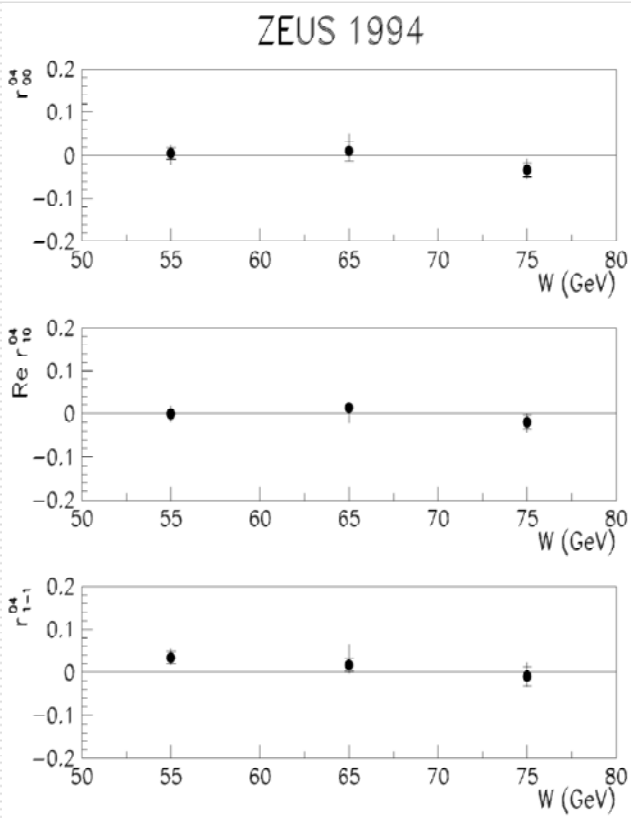
- Fit results are consistent with S-channel helicity conservation
- In agreement with ZEUS experiment measurements

Parameter	STAR	ZEUS
r_{00}^{04}	-0.03±0.03±0.06	0.01±0.03
$\Re e[r_{10}^{04}]$	0.04±0.02±0.03	0.01±0.02
r_{1-1}^{04}	-0.01±0.03 ±0.05	-0.01±0.02



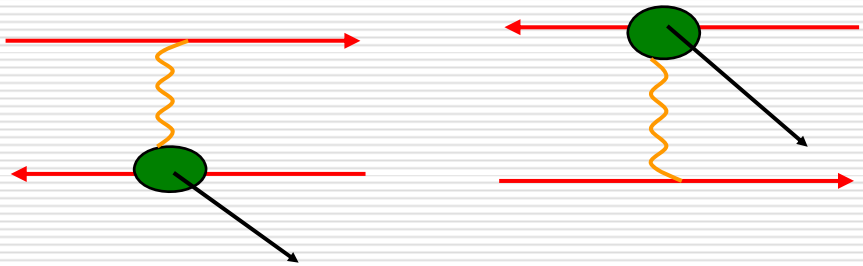


STAR preliminary



Interference

- Two possible scenarios:
  - Photon emitted by nucleus 1 and scattered from nucleus 2
  - Photon emitted by nucleus 2 and scattered from nucleus 1



- Cross section:
  - Due to ρ negative parity amplitudes subtracted
  1. $A(p,r,t) = \int A(p,r,t;x,t')\,dx\,dt' \propto \int E(x,t')\,\rho(x,t')\,dx\,dt'$
  2. E-field: $E(x,t) = -E(-x,t)$ anti symmetric
  3. Density: $\rho(x,t) = \rho(-x,t)$ symmetric
  - At mid rapidity (p_z=0)
    - Contribution equal from both sources
    - σ depends on the transverse momentum and impact parameter

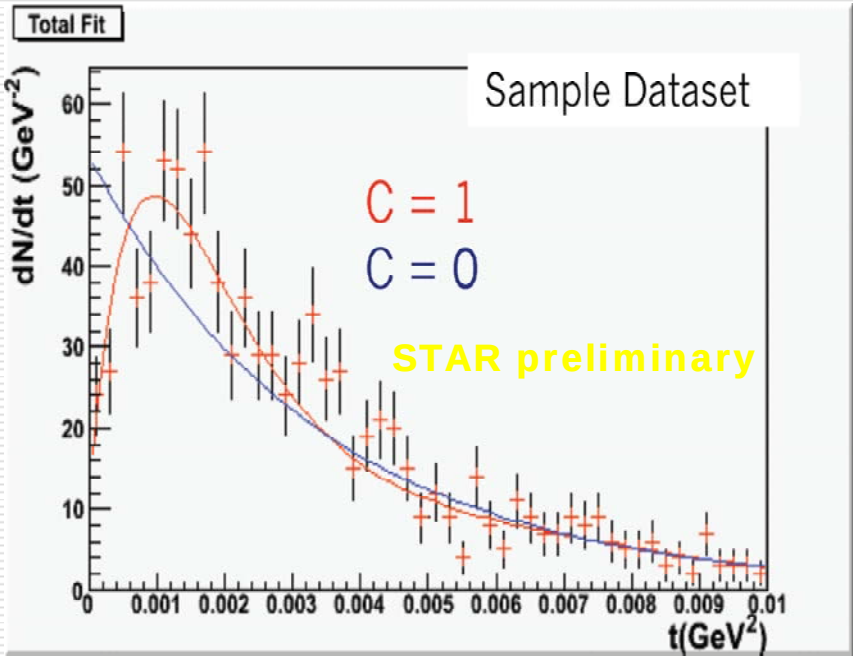
      $d\sigma/dy\,dpT = \int |A1 + A2|^2\,db^2$

      $|A1 + A2|^2 = 2\,|A1|^2\,[1 - \cos(\mathbf{p}\cdot\mathbf{b})]$
  - P_T spectra suppressed for $P_T < h/\langle b \rangle$

Measuring the Interference

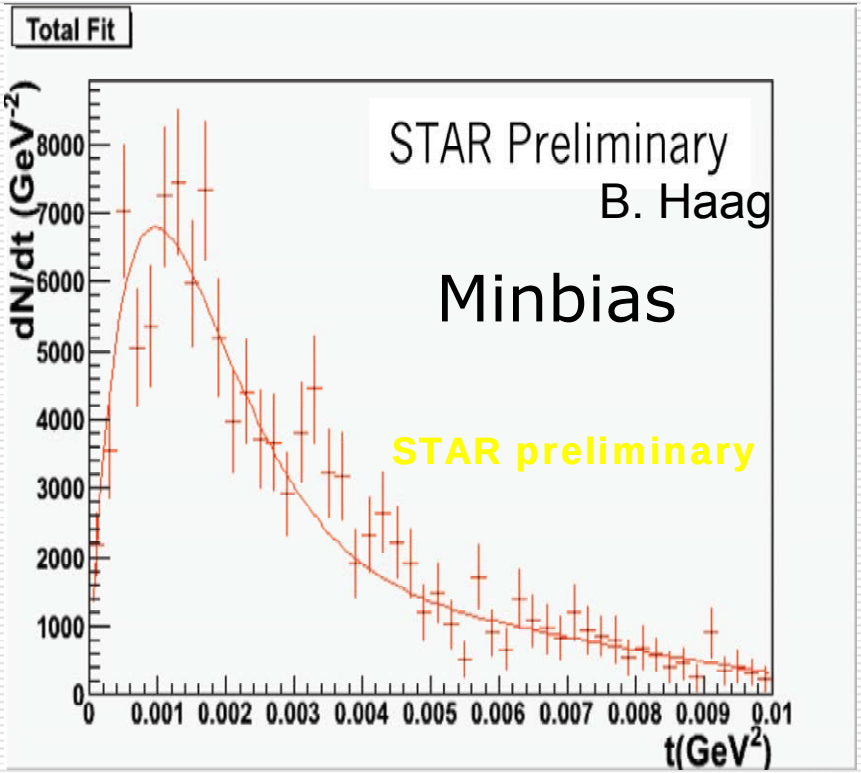
- Two samples topology and minimum bias
  - Differ in median impact parameter
  - Larger interference for events with Coulomb excitation
    - topology ~ 46 fm
    - minimum bias ~ 16 fm
- Fit function: $\frac{dN}{dt} = Ae^{-kt}(1 + c[R(t) - 1])$
- c – degree of interference
  - c = 1 – interference
  - c = 0 – no interference
- R(t) – correction factor
  - $R(t) = MC_{int}(t) / MC_{no\ int}(t)$

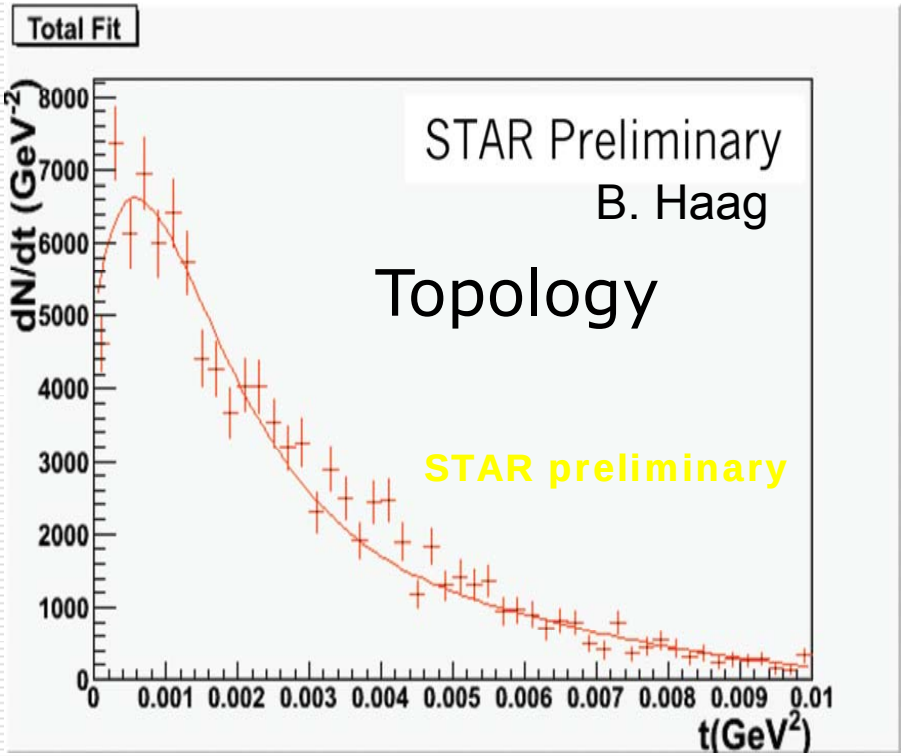
$$R(t) = a + \frac{b}{(t+0.012)} + \frac{c}{(t+0.012)^2} + \frac{d}{(t+0.012)^3} + \frac{e}{(t+0.012)^4}$$



Based on B. Haag presentation

Measuring the Interference





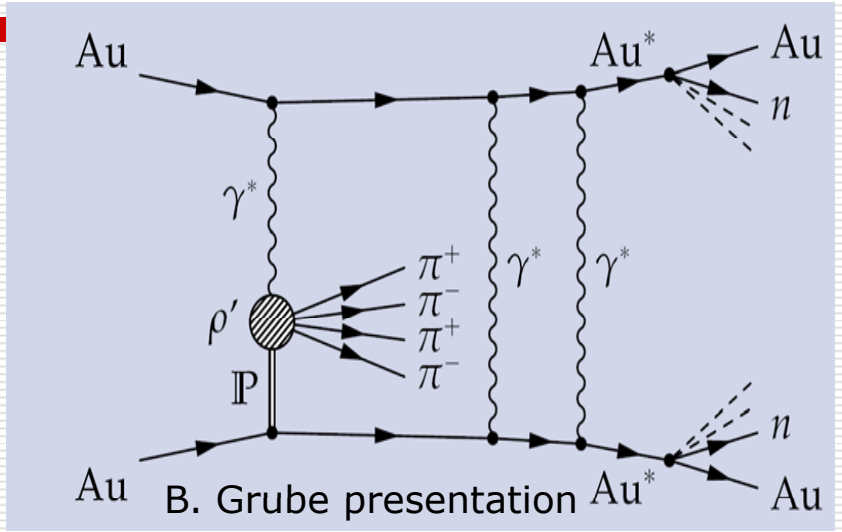
- Interference is largest at y ~ 0
  - Decrease as |y| rises
  - |y| <0.1 contains a lot of cosmics

Rapidity	c	X2/ndf
0.1<y<0.5	1.01±0.08	51/47

c	X2/ndf
0.93±0.11	80/47

ρ′ production

- γAu -> ρ(1450/1700) -> $\pi^+\pi^+\pi^-\pi^-$
  - Overlapping resonances ρ′(1600) consist of two states ρ(1450) & ρ(1700)
    http://pdg.lbl.gov/reviews/rppref/mini/2006/rho1700_m065-web.pdf
  - Amplitude for the vector meson production of the Glauber scattering includes non diagonal elements (GVDM)
    - γ→V′
    - γ→V→V′→V – change of meson in multiple rescattering



B. Grube presentation

➢Signature

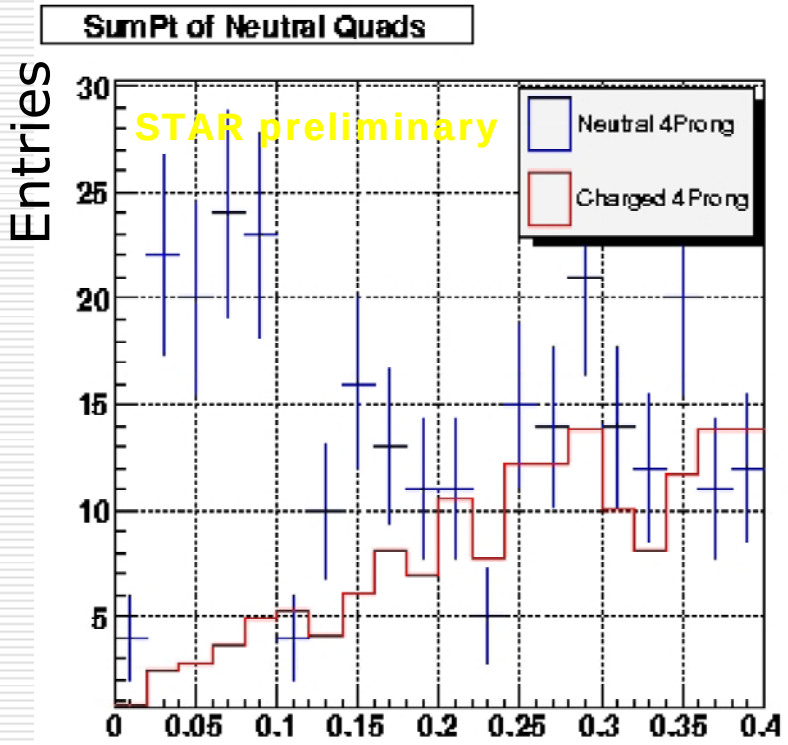
4 charged tracks with ΣQ = 0
Low PT
Hits in ZDC

➢Trigger

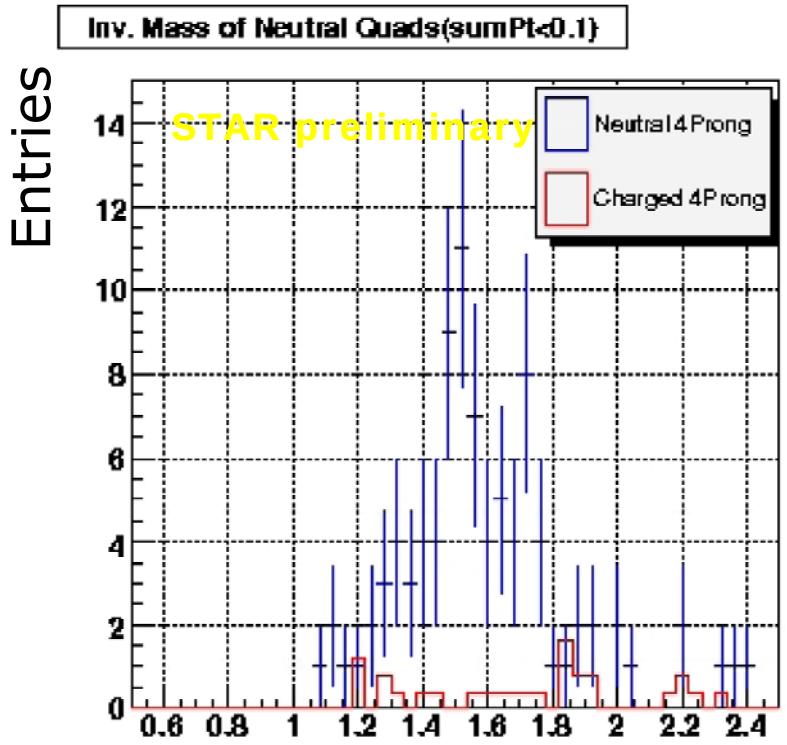
Neutrons detected in ZDC
Cut on multiplicity

ρ’ in 2004 Data

- Analyzed:3.9 *10^6 events
- ~123 ρ’ candidates
- Signal $\pi^+\pi^-\pi^+\pi^-$ Background $\pi^+\pi^+\pi^+\pi^-$ plus low p_T



P_T, GeV

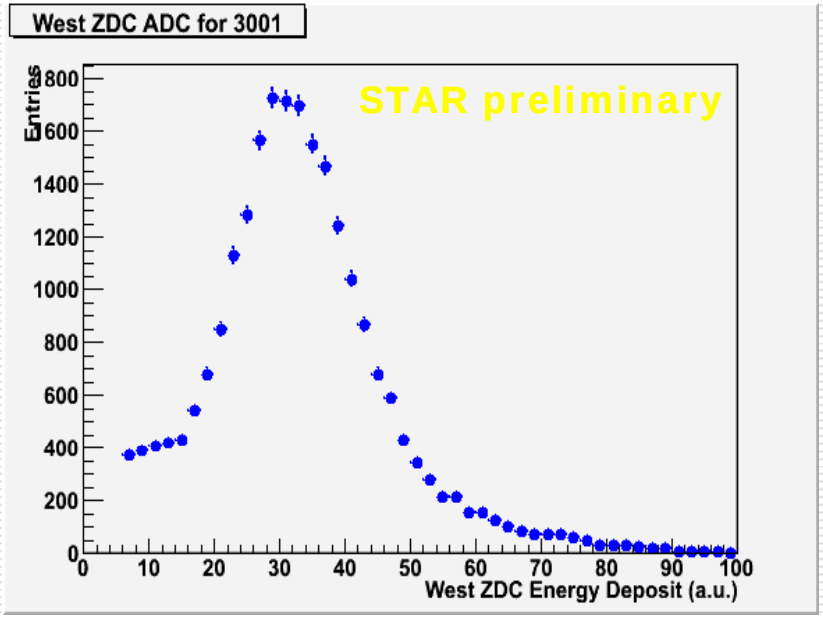


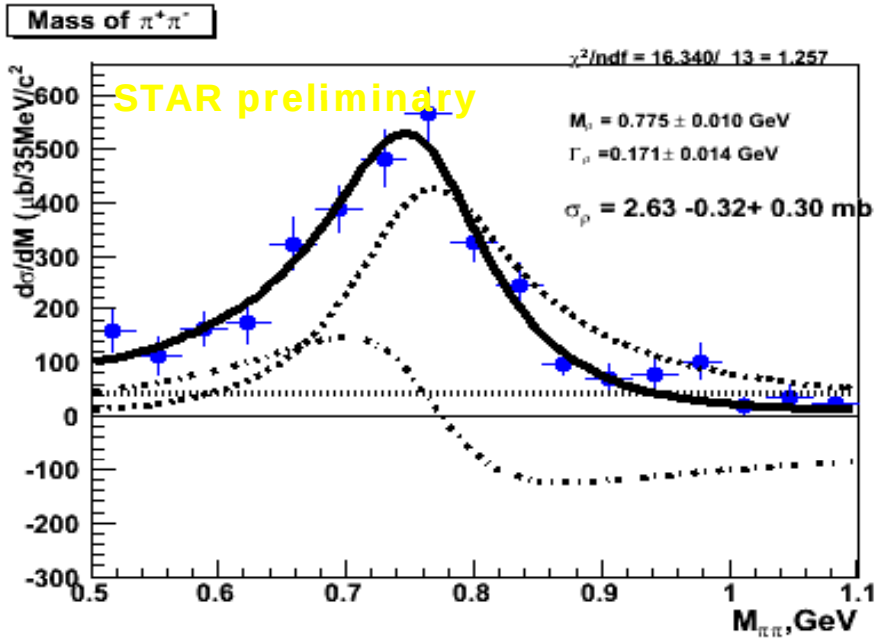
Inv. Mass, GeV

Based on B.C Kim presentation

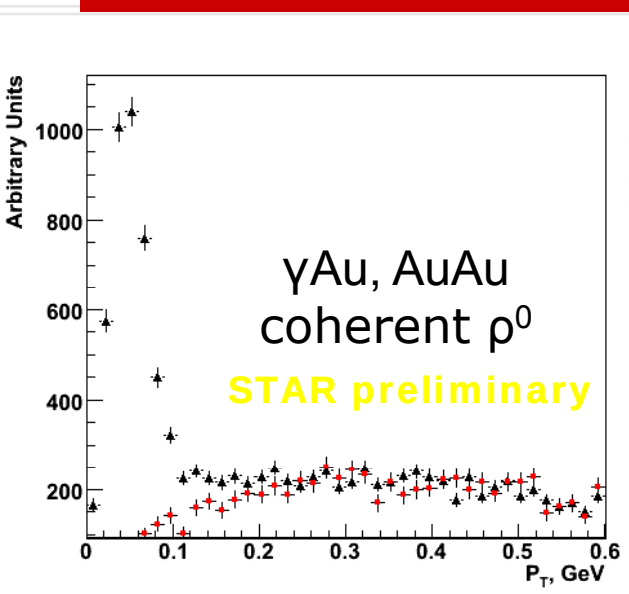
dAu->d(np)Auρ Cross Section

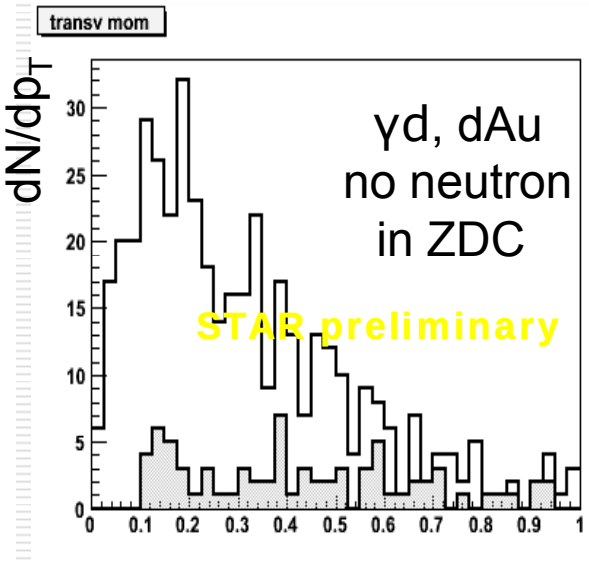
- Triggered with topology trigger + neutron registered in West ZDC
- Sample of 13400 events
- Fitted by BW + direct pions + BG
  - σ = 2.63±0.32±0.73 mb
  - mass width in agreement with PDG

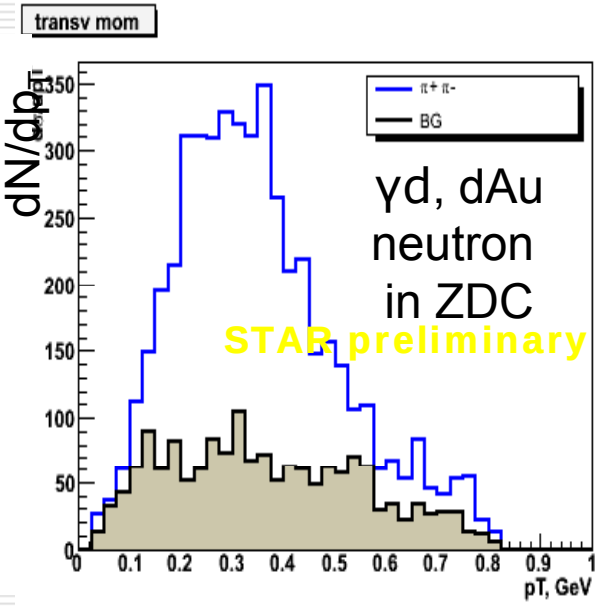




P_T in *dAu->d(np)Aup*







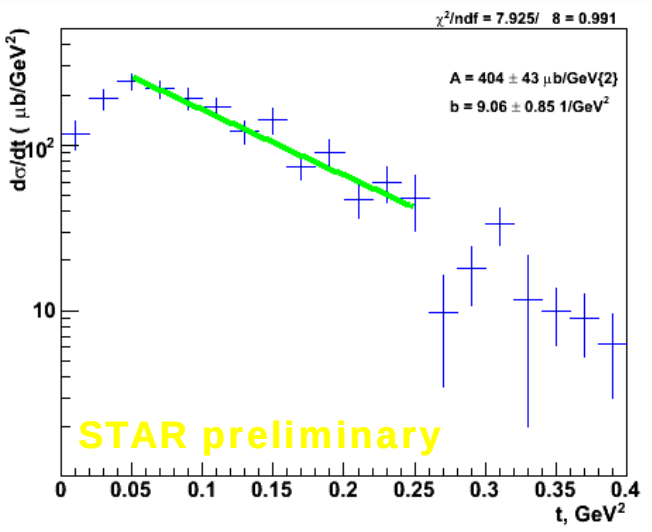
- P_T spectra reflects γd and no γAu interactions in dAu sample
- Coherent (deuteron stays intact) and incoherently (deuteron dissociation) produced ρ^0 are accessible in dAu sample

dAu->d(np)Aup t Spectra

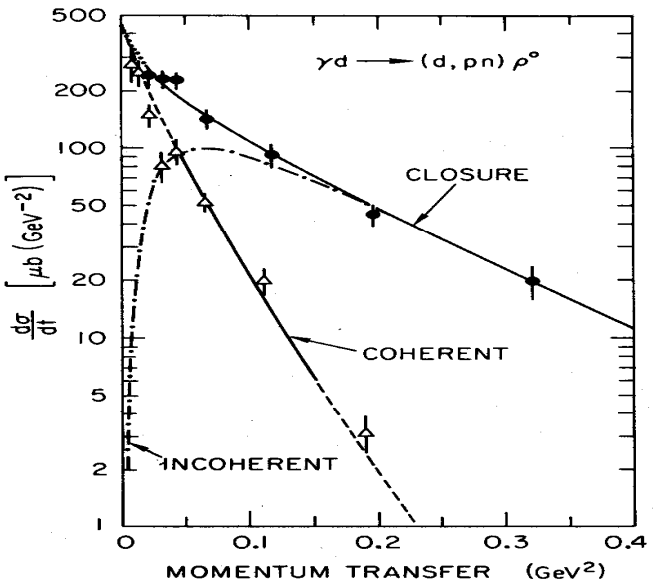
- Fit to the *t* spectra
- Fit function:

$F(t)=e^{-bt}$ – access to the nucleon form factor

  - b = 9.06±0.85 GeV^{-2}
    - In agreement with STAR results
    - Same as ZEUS



- Turndown at small t
  - The same behavior seen by γd experiment (SLAC 4.3 GeV)
  - Y.Eisenberg et al Nucl Phys B 104 61 1976



Plans

- Improved trigger for the run 2007
  - Improved cluster finder for J/Ψ trigger
  - Monitoring of CTB
- TOF will replace CTB in the near future
  - Trigger simulation is underway
    - Triggering on multiplicity
    - Topology trigger
    - Possible PID

Conclusion

- STAR has measured photonuclear ρ^0 production in AuAu and dAu at $\sqrt{s}$= 130 and 200 GeV
  - measured coherent and incoherent ρ^0 production cross section
  - measured ρ^0 production cross section agrees with theoretical prediction
  - consistent with S-channel helicity conservation
  - interference in ρ^0 production
- $\rho' \rightarrow \pi^+\pi^+\pi^-\pi^-$ events observed

Luminosity (backup)

- The luminosity is determined from the hadronic cross section
  - 14 reference tracks
    - PT<0.1 GeV
    - |η|<0.5
    - 80% of the total hadronic production cross section 7.2 b
  - SVT detector was read out not in all event → different dead time to events
  - $L_{(2002,\ minimum\ bias)} = 461.3 \pm 45.5 mb^{-1}$