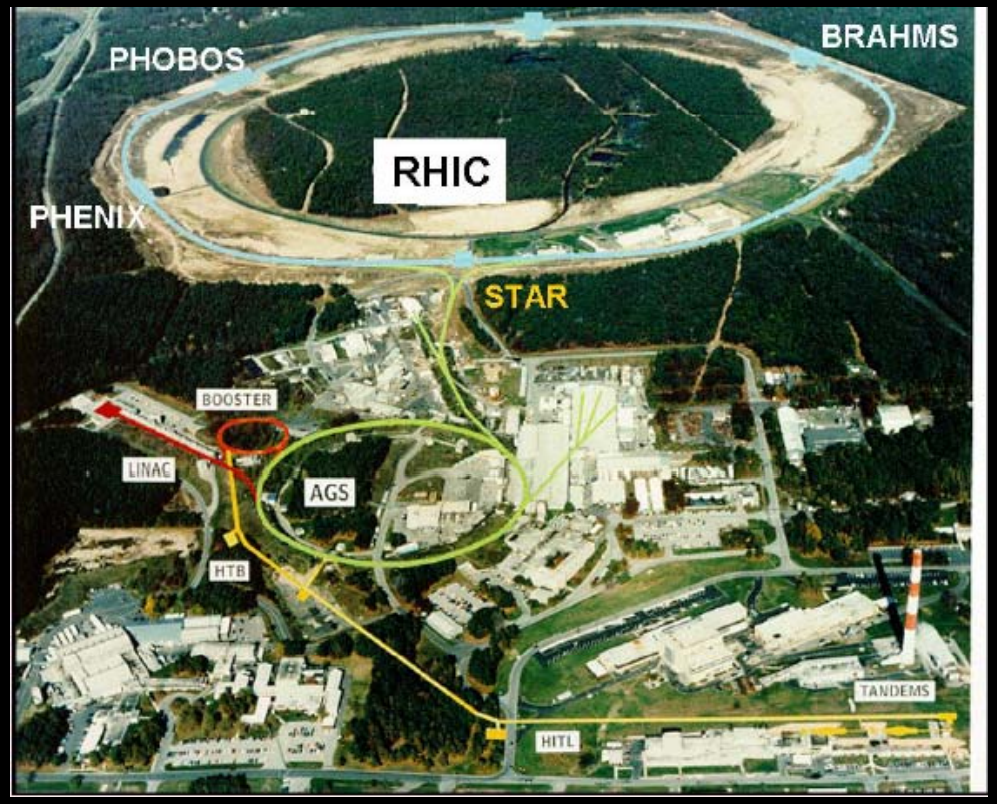
Photoproduction in Ultra-Peripheral Relativistic Heavy Ion Collisions with STAR

Janet Seger (for the STAR Collaboration)

Creighton UNIVERSITY

RHIC

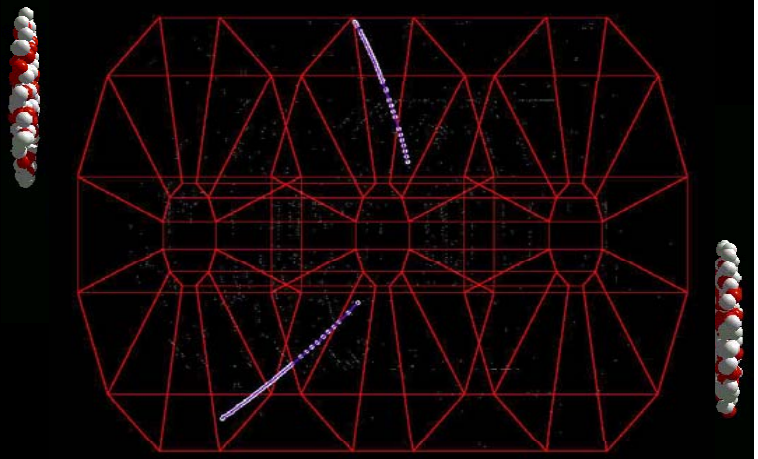


- AuAu
  - $\sqrt{s_{NN}}$ = 19.6, 62.4, 130, 200 GeV
- CuCu
  - $\sqrt{s_{NN}}$ = 62.4, 200 GeV
- dAu
  - $\sqrt{s_{NN}}$ = 200 GeV
- polarized pp
  - $\sqrt{s_{NN}}$ = 200, 410 GeV

STAR

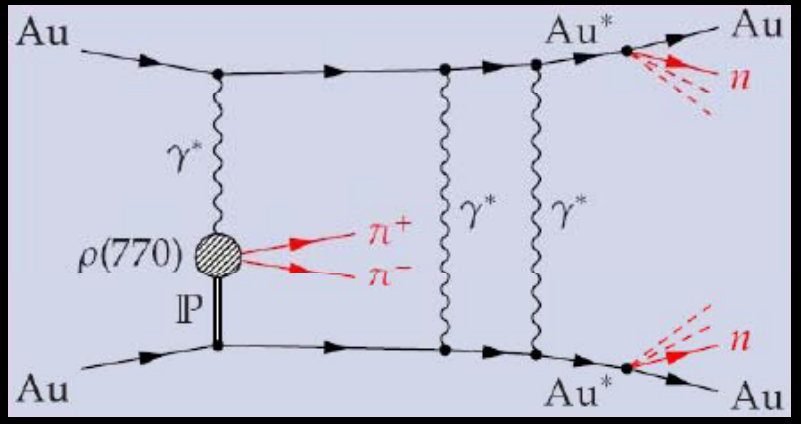
48 Institutions,
13 countries,
~ 562 Scientists
and Engineers

Ultraperipheral Collisions



- Nuclei miss each other geometrically
  - $b > R_1 + R_2$
  - No nucleon-nucleon collisions
- Strong electromagnetic fields (~ Z^2) act for very short time
- Photon(s) exchanged
  - Nuclear Coulomb excitation
  - e^+e^- pair or meson pair production
  - vector meson production

Photoproduction of vector mesons



- Photon flux ~ Z^2
- Photon emitted by nucleus fluctuates to virtual $q\bar{q}$ pair
- $q\bar{q}$ pair scatters from nucleus
- real vector meson produced
  - coherence condition requires $p_T < h/2R_A$ ~150 MeV
- Additional (independent) photons may excite nuclei→ neutron emission

$$\sigma = \int d^2b \left(P(b)_{\substack{\rho \\ \text{production}}} \; P(b)_{\substack{\text{nuclear} \\ \text{excitation}}} \; P(b)_{\substack{\text{no hadronic} \\ \text{interaction}}} \right)$$

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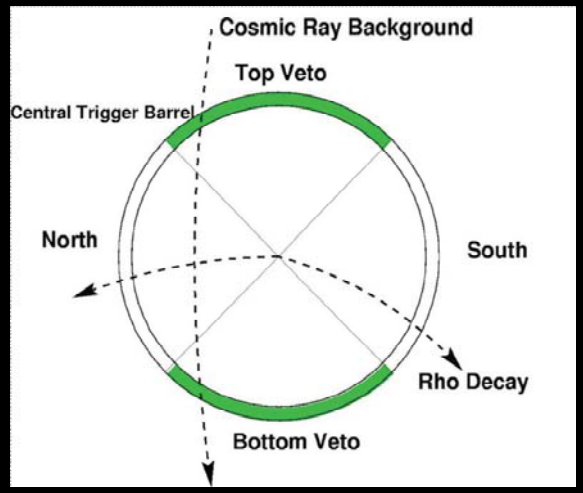
STAR Triggers

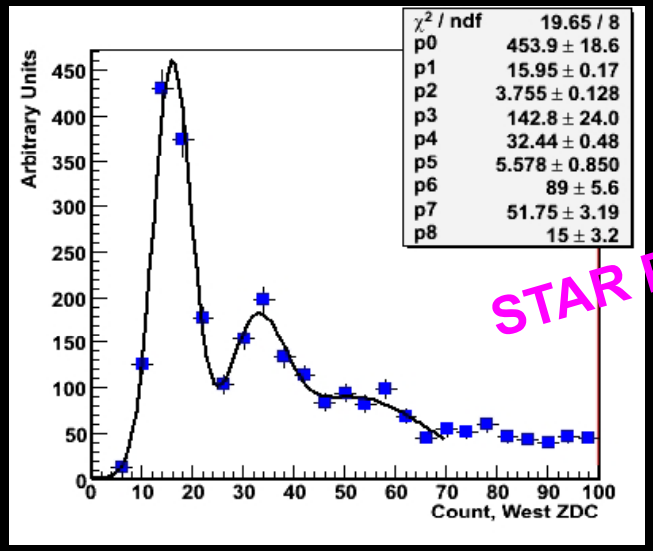
- Topology (2-prong)
  - coincidence in North/South CTB quadrants
  - Events with hits Top/Bottom are vetoed
  - Low multiplicity
- Minimum Bias
  - Coincident neutrons in ZDCs
  - Low multiplicity
- Multi-prong
  - Coincident neutrons in ZDCs
  - Low multiplicity
  - BBC veto
- J/psi
  - Coincident neutrons in ZDCs
  - Low multiplicity
  - High towers in non-neighboring BEMC sectors

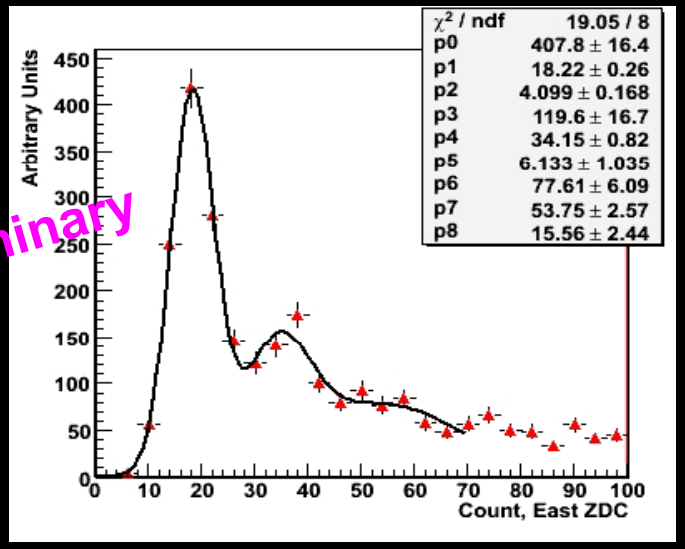


Sensitive only to events with nuclear excitation

Zero Degree Calorimeters

Run II Au-Au minimum bias sample

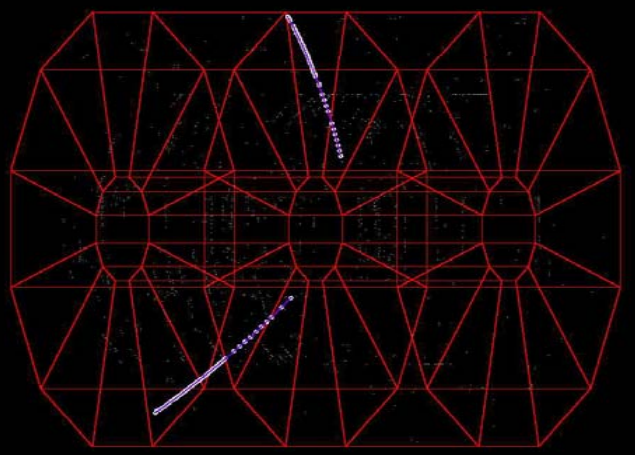




STAR Preliminary

- Acceptance ~ 100%, sensitive to single neutrons
- Can experimentally select different excited states of produced vector mesons (1n, 2n,...)

Data Selection



Tracks in TPC for typical UPC event

- 2 tracks
  - Opposite charge
  - common vertex
  - back-to-back in transverse plane
  - Low total p_T
- Backgrounds
  - Cosmic rays
  - Beam-gas interactions
  - Hadronic interactions

Can be reduced with ZDC requirement, cut around y = 0

Can be reduced with multiplicity, vertex cuts

Can be reduced with multiplicity, p_T cuts

Rho Yield from Run II (200 GeV Au-Au)

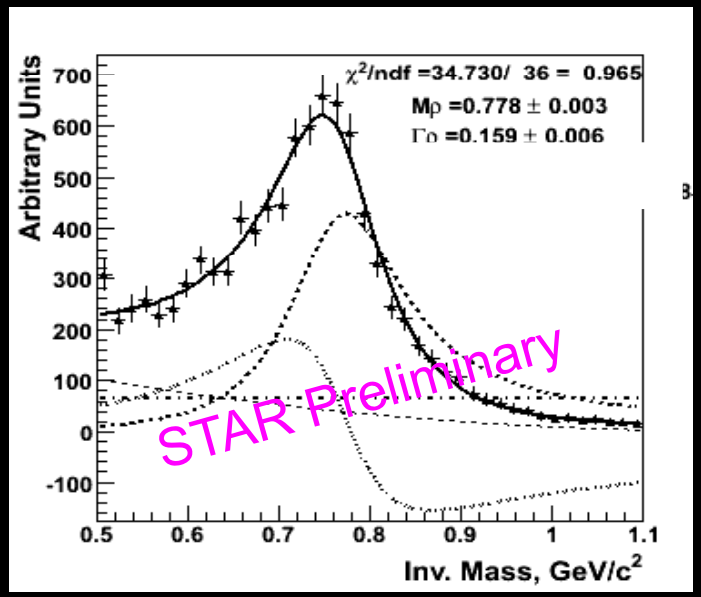
- Mass distribution fit with
  - Breit-Wigner function for the signal
  - Söding interference term for direct $\pi^+\pi^-$ production
  - Second order polynomial to describe background
    - Background estimated with like sign pairs

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

A: amplitude for ρ^0

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

Min Bias dataset



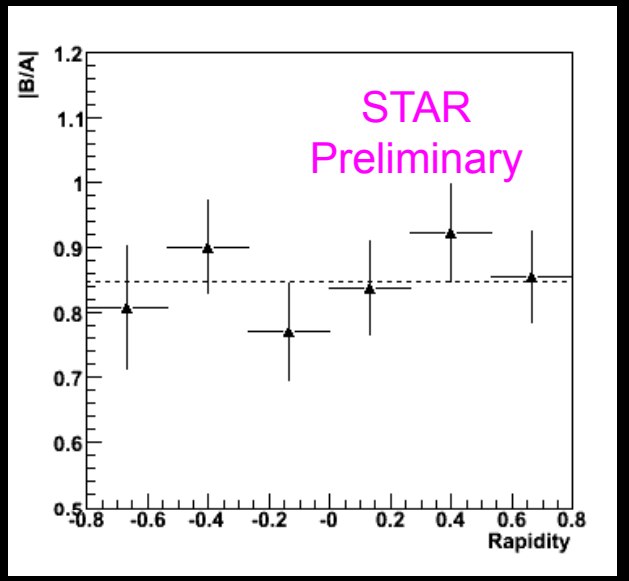
- Approximately 16,000 candidates in topology and min-bias samples combined

Direct Pion Production

- Fit to invariant mass

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

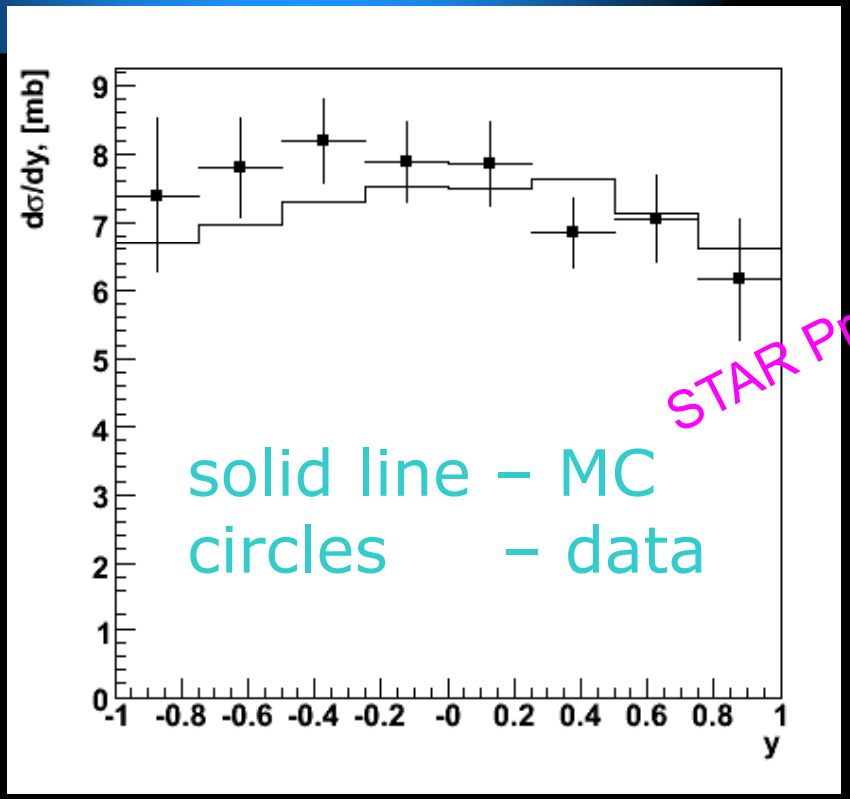
- Ratio of B/A is varied in fit → provides measure of non-resonant to resonant production
  - 200 GeV AuAu: $|B/A| = 0.84 \pm 0.11$ GeV $^{-1/2}$
    - in agreement with STAR results at 130 GeV: $|B/A| = 0.81 \pm 0.28$ GeV $^{-1/2}$
  - No angular dependence or rapidity dependence → in agreement with ZEUS measurements



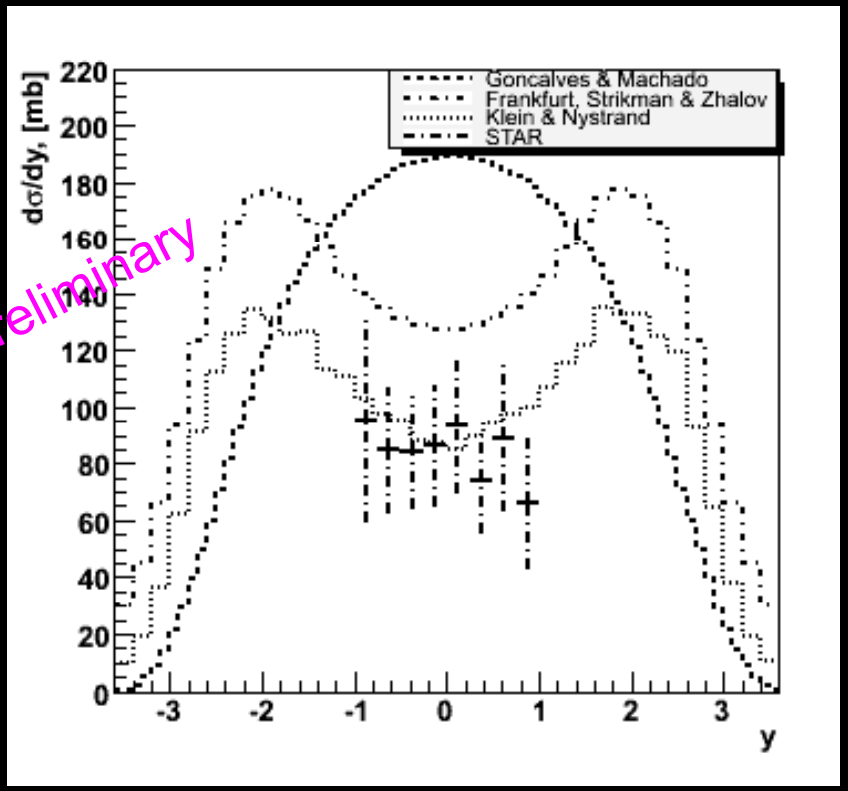
Model predictions for ρ cross section

- Klein, Nystrand: vector dominance model (VDM) & classical mechanical approach for scattering, based on $\gamma p \rightarrow \rho p$ experiments results
  - PRC 60 (1999) 014903
- Frankfurt, Strikman, Zhalov: generalized vector dominance model + Gribov-Glauber approach
  - PRC 67 (2003) 034901
- Goncalves, Machado: QCD dipole approach (nuclear effects and parton saturation phenomenon)
  - Eur.Phys.J. C29 (2003) 271-275

ρ^0 production cross section (200 GeV AuAu)



Events with mutual excitation



Total production cross section

Scaled using σ(0n,0n)/σ(xn,xn) from topology sample

Total Cross Section Comparison for Coherent Interactions

- Normalized to 7.2 b hadronic cross section

	STAR $\sqrt{s}$=130GeV (PRL 89, 027302 (2002))	STAR $\sqrt{s}$=200GeV	Nystrand & Klein 200 GeV	Goncalves, Machado 200 GeV	Frankfurt, et al 200 GeV
σ_{xnxn} (mb)	**26.2 ± 1.8 ± 5.8**	**30.26 ± 1.1 ± 6.35**			
σ_{total} (mb)	**410 ± 190 ± 100**	**509.2 ± 34.5 ± 106.9**	**590**	**876**	**934**

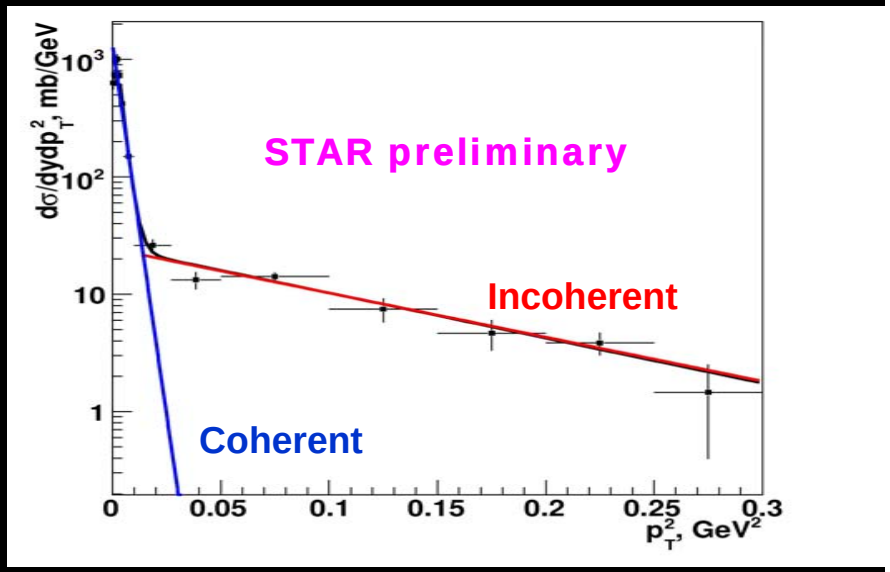
Extrapolated to full rapidity using distribution of KS, FSZ

Compare Coherent and Incoherent Production

- Extend p_T range for measurement of ρ^0 production
- Fit function:

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

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



- Incoherent production
  - d = 8.8 ±1.0 GeV^{-2}– access to the nucleon form factor
- Coherent production
  - b = 388.4 ±24.8 GeV^{-2} – access to nuclear form factor
- σ(incoh)/σ(coh) ~ 0.29 ±0.03

Spin Density Matrix Elements

- Measure decay angular distribution in rest frame of ρ^0
  - determine 3 of the 15 spin density matrix elements (SDME)
- Fit function: K. Schilling and G. Wolf, Nucl. Phys. B61, 381 (1973)

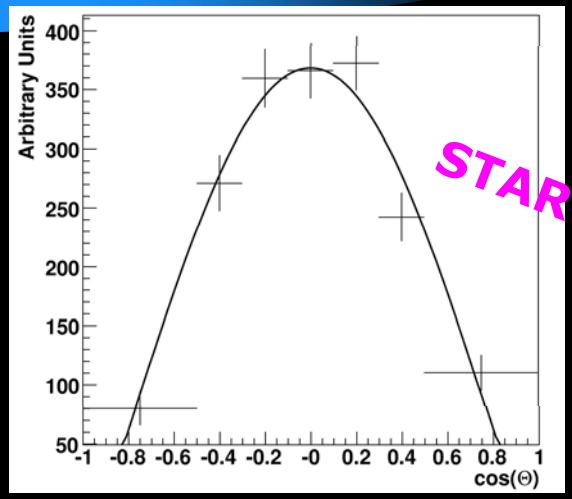
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\Theta_h d\Phi_h} = \frac{3}{4\pi}\left[\frac{1}{2}(1-r^{04}_{00})+\frac{1}{2}(3r^{04}_{00}-1)\cos^2\Theta_h-\sqrt{2}\Re e[r^{04}_{10}]\sin 2\Theta_h\cos\Phi_h-r^{04}_{1-1}\sin^2\Theta_h\cos 2\Phi_h\right] \quad (1)$$

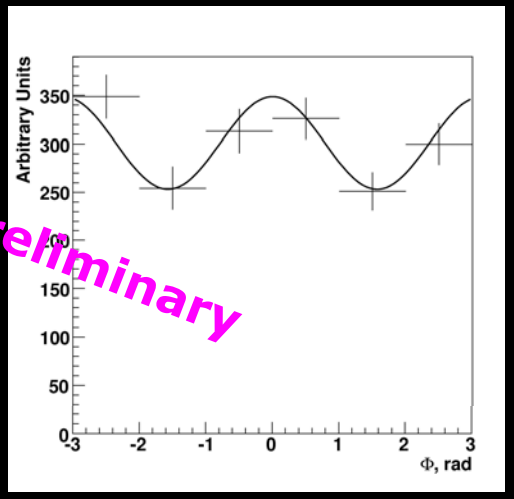
  - Θ: polar angle between ion and direction of π+
  - Φ : azimuthal angle between decay plane and production plane
  - r^{04}_{00} represents probability ρ has helicity 0
  - r^{04}_{1-1} related to the level of interference helicity non flip & double flip
  - $\Re e[r^{04}_{10}]$ related to the level of interference helicity non flip & single flip

Follows HERA analysis

- s-channel helicity conservation (SCHC)
  - vector meson retains helicity of photon
  - all 3 SDMEs are predicted to be ~ zero

Measured Matrix Elements





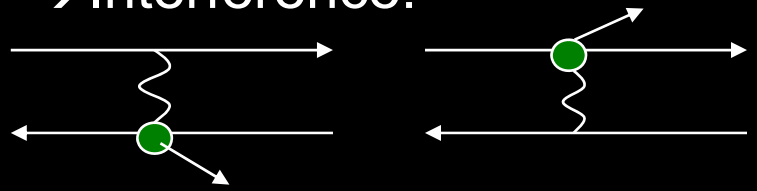
STAR preliminary

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

consistent with s-channel helicity conservation

Interference

- Can't distinguish between emitter and target
  - →Interference!

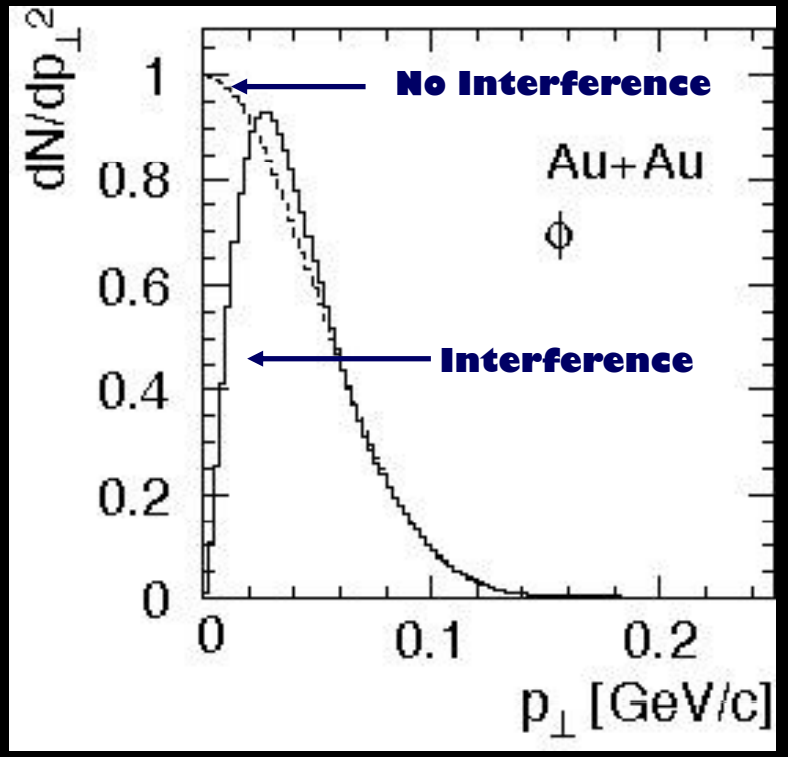


- ρ has negative parity
  - →amplitudes subtract
- At mid-rapidity

$$|A_1 + A_2|^2 = 2|A_1|^2 [1 - \cos(\mathbf{p}\cdot\mathbf{b})]$$

  - Expect reduction in cross section for $p_T <$ h/<b>

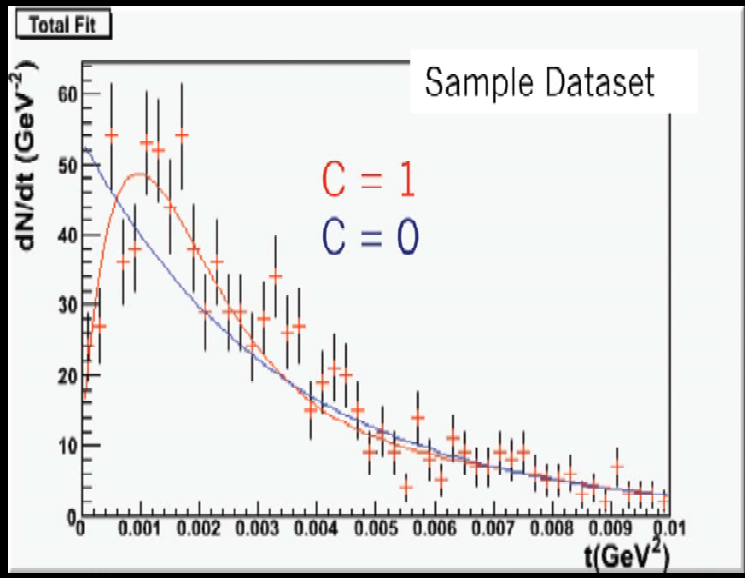
Expected signal



S. Klein and J. Nystrand, Phys. Rev. Lett. 84(2000)2330

Measuring the Interference

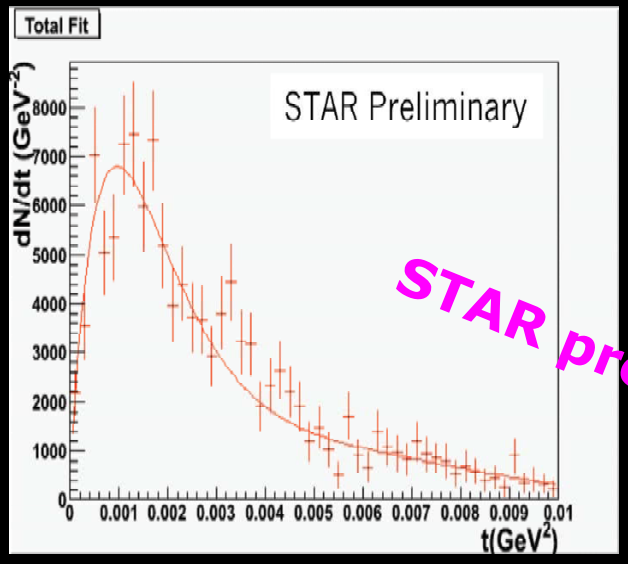
- Fit function: $\frac{dN}{dt} = Ae^{-kt}(1 + c[R(t) - 1])$
- R parametrizes effect of interference
  - Based on Monte Carlo
  - R = (MC including interference)/(MC w/o interference)
- Fit parameter c measures extent of interference
  - c = 1 → expected interference
  - c = 0 → no interference
- Two samples: topology and minbias
  - Differ in median impact parameter
    - topology ~ 46 fm
    - minbias ~ 16 fm



Measuring the Interference

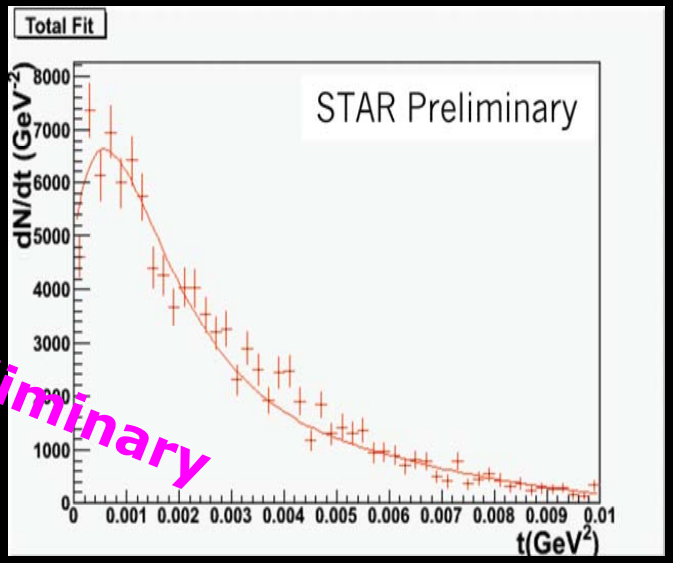
B. Haag, UC-Davis

Minbias 0.1<y<0.5



c	X^2/ndf
1.01 ± 0.08	51/47

Topology 0.1<y<0.5



c	X^2/ndf
0.93 ± 0.11	80/47

STAR preliminary

Systematic errors still being finalized

- Interference is largest at y ~ 0
  - Decreases as |y| rises
  - |y| <0.1 removed because of contamination with cosmic rays

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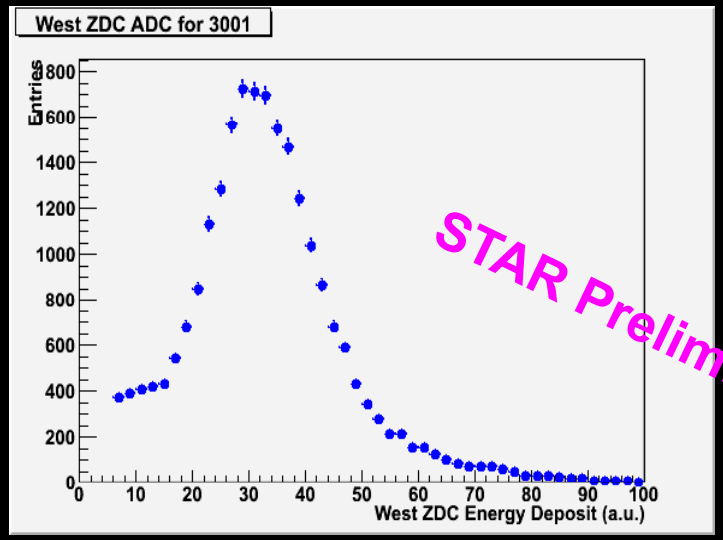
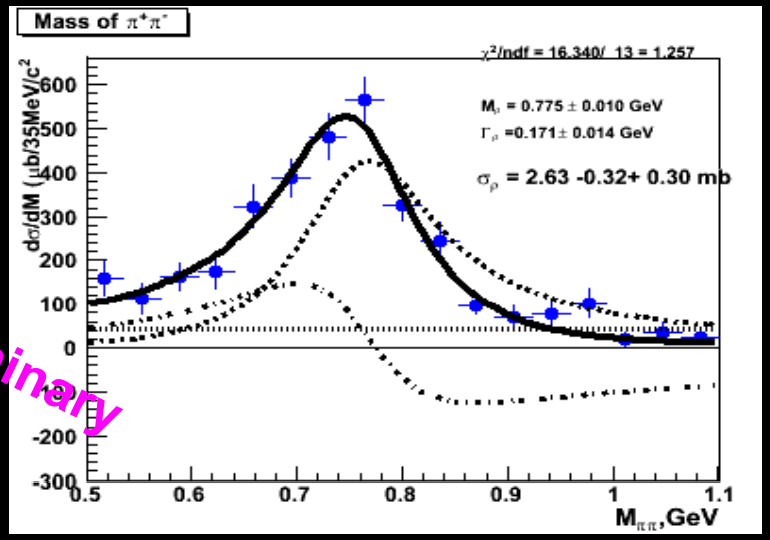
dAu → d(np)Aup Cross Section

Sergei Timoshenko, MePHI

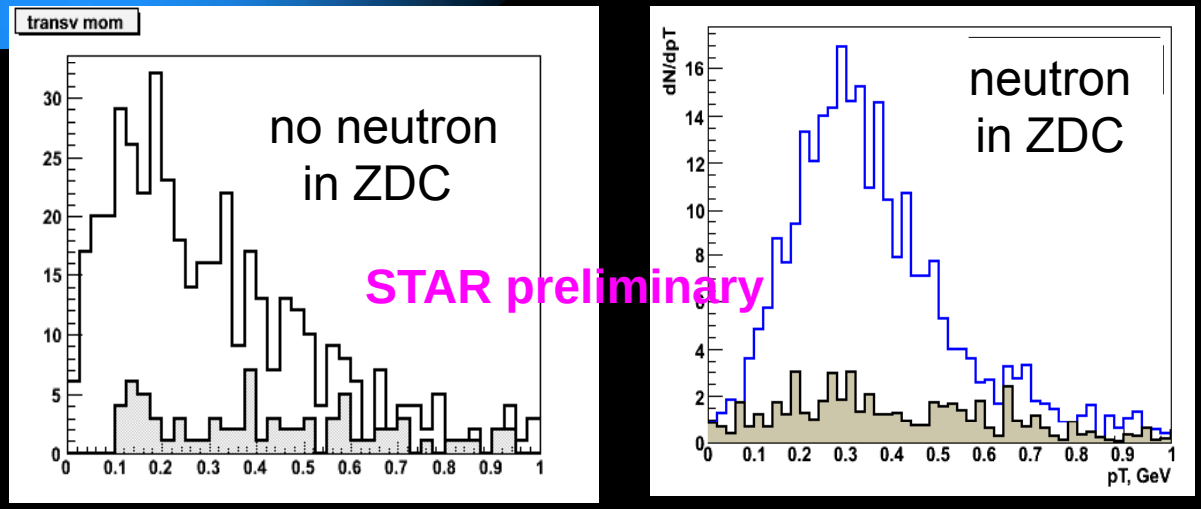
- Trigger: topology requirement + neutron from deuteron break-up
- Sample of 13,400 events
- Fitted with Breit-Wigner + direct pions + background
  - σ = 2.63±0.32±0.73 mb
  - mass and width in agreement with PDG





p_T in dAu → d(np)Auρ

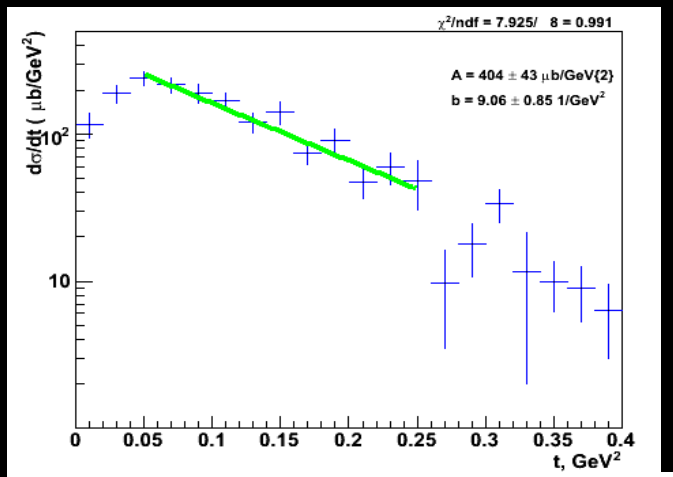
Sergei Timoshenko, MePHI



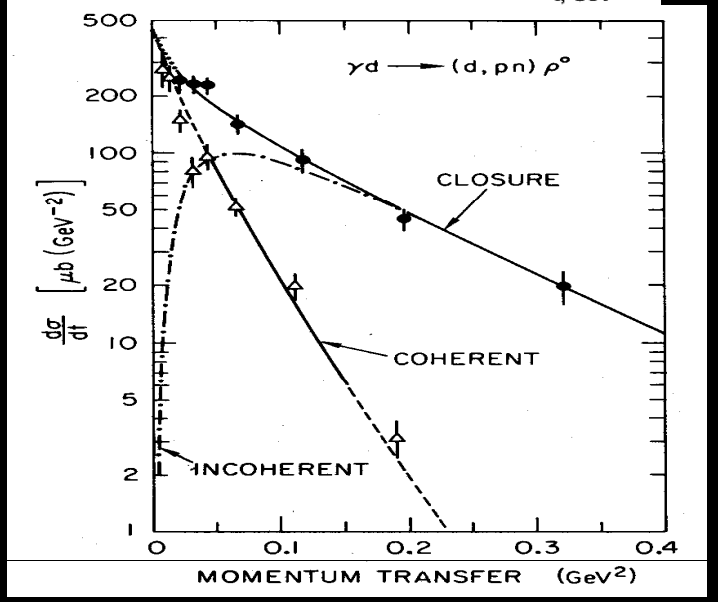
- Photons primarily emitted by Au nucleus
- Coherently (deuteron stays intact) and incoherently (deuteron dissociation) produced ρ^0 are accessible in dAu sample

t spectrum in dAu → d(np)Auρ

- Fit function: $F(t) = e^{-bt}$
  - access to the nucleon form factor
  - $b = 9.06 \pm 0.85$ GeV^{-2}
  - Same as ZEUS
- Turndown at small t
  - No deuteron dissociation
  - Similar behavior seen by fixed target experiments



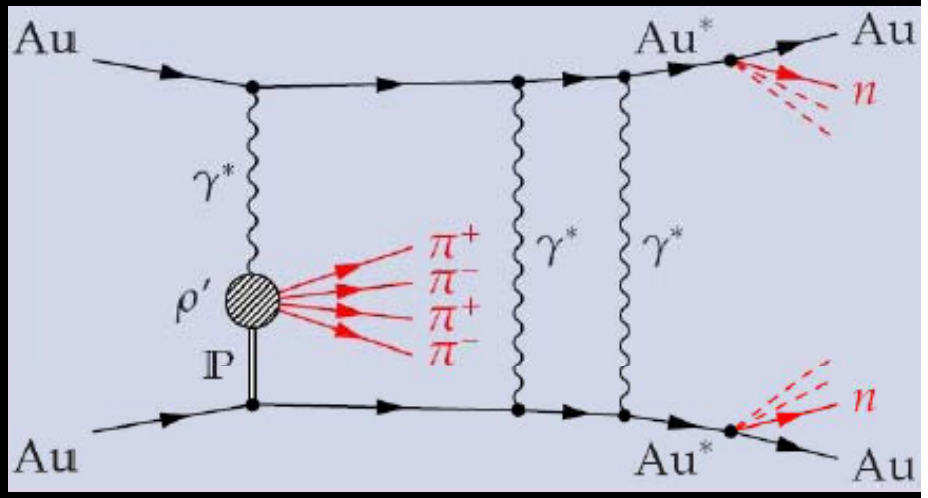
Sergei Timoshenko, MePHI



Y.Eisenberg et al Nucl Phys B 104 61 1976

Excited ρ' state(s)

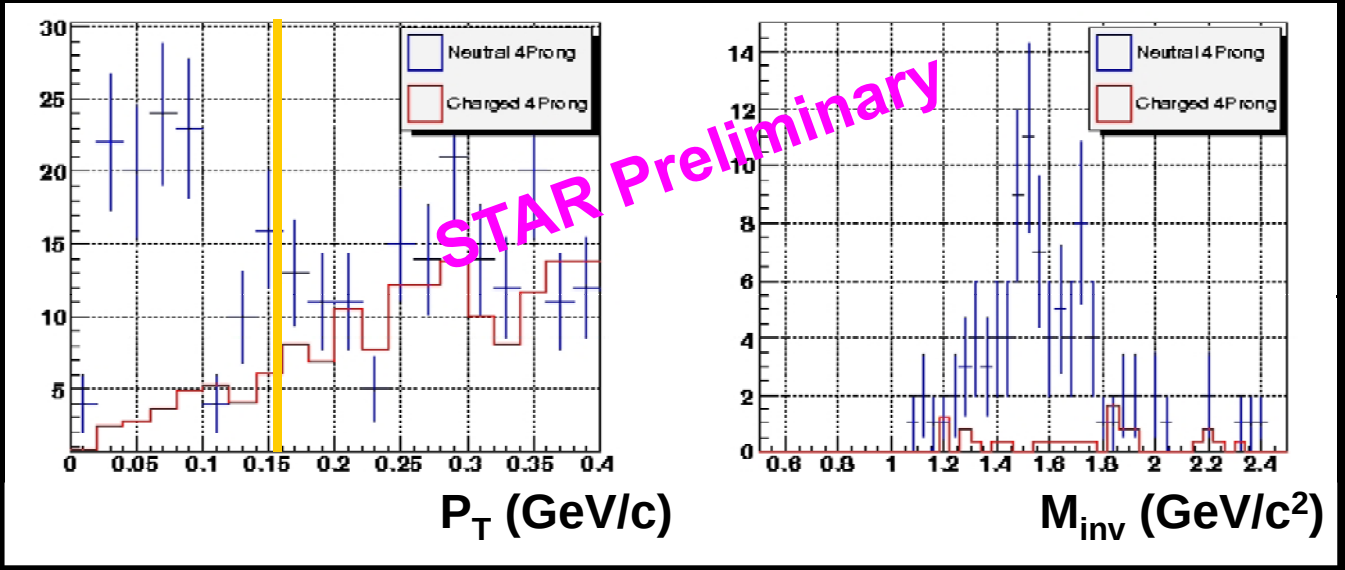
- STAR can observe the process $\gamma Au \rightarrow \rho' \rightarrow \pi^+ \pi^- \pi^+ \pi^-$
- Trigger
  - Neutron coincidence in ZDCs
  - Low multiplicity
  - BBC veto
- Signature
  - 4 charged tracks with
    - $\Sigma_{tracks} Q = 0$
    - $\Sigma_{tracks} P_T < 150$ MeV/c



ρ´in 200 GeV Au-Au: first results

B. C. Kim, Pusan National University

- Preliminary results from pilot run (Run IV)
  - Analyzed: 3.9 *10^6 events
  - ~123 ρ′ candidates

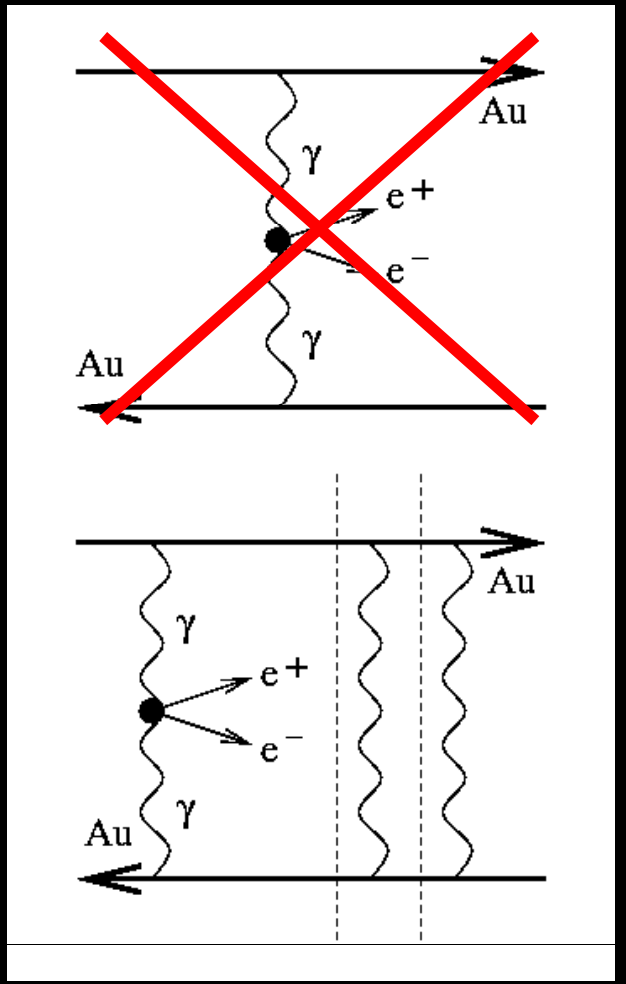


- Hope to at least double the statistics in Run VII

e^+e^- Pair Production

V. Morozov

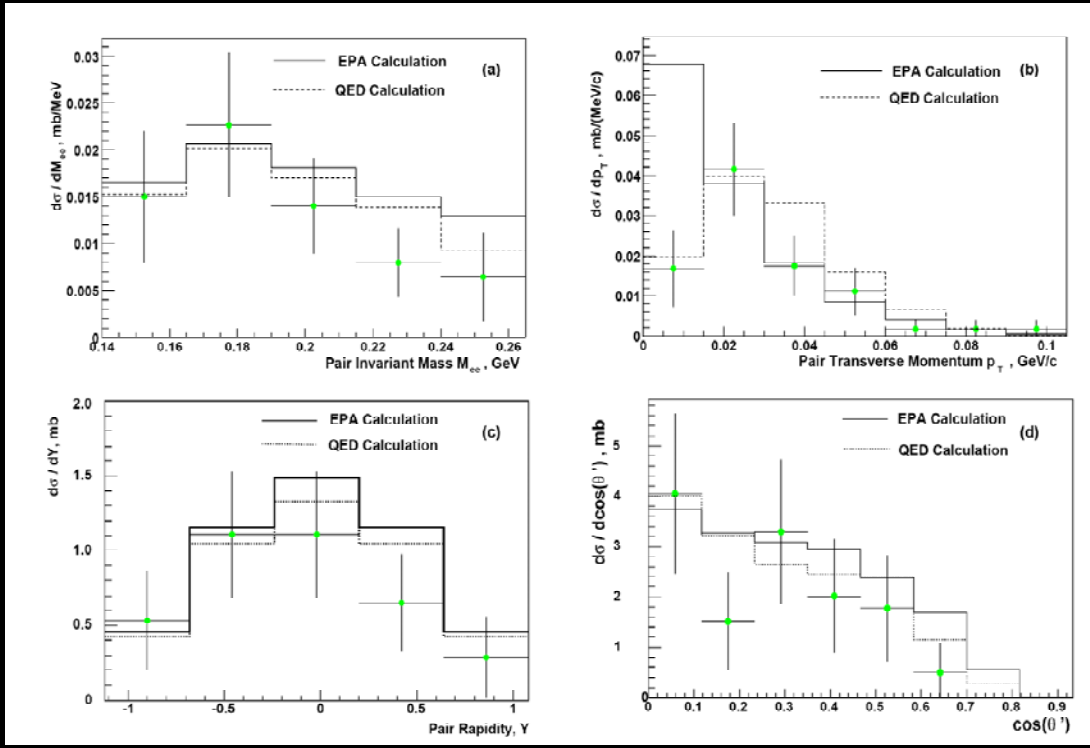
- Very low p_T electrons
- Only studied in half-field environment
  - Minimum bias trigger only, since electrons do not reach CTB



e^+e^- Pairs Cross Section

V. Morozov

- Event selection based on dE/dx
- Background from mis-identified $\pi^+\pi^-$ pairs and incoherent hadronic events
- Differential cross sections compared with two models
  - equivalent photons (photon virtuality ignored) Klein, Nystrand
  - lowest order QED Hencken, Baur, Trautman
- Photon virtuality required to describe p_T distribution



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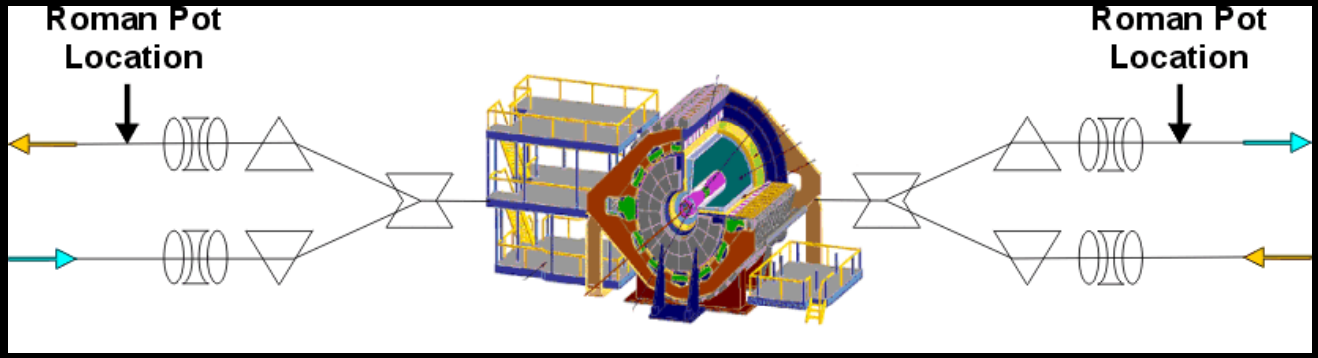
Run VII

- Just finished collecting ~2 M Triggers, 200 GeV Au-Au
  - Will be analyzed this fall
  - Expect ~ 50,000 ρ
    - Various trigger issues may reduce yield
  - Possibility to study rarer processes (e.g., J/Ψ)

Future: Experimental Diffraction

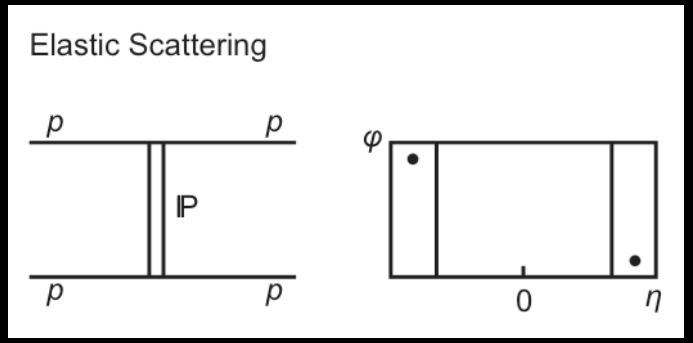
Wlodek Guryn, BNL

- Move Roman pots from pp2pp to STAR
- Installation planned after Run 7
  - Plan to take data in Run VIII
- Detect protons scattered at small angles
  - Pots will be ~50 m downstream of STAR
  - Can fully reconstruct events
- Expect ~ 40,000 DPE events

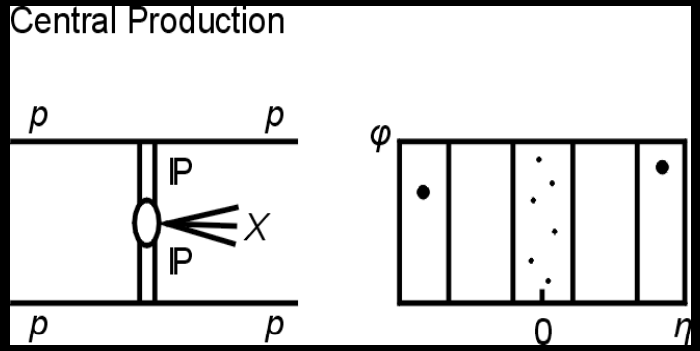


Diffraction in pp collisions

- Pomeron dominated
- pp elastic scattering



- pp diffraction & Dual Pomeron Exchange (DPE)
  - pp → pp X
  - Search for glueballs & other exotica
  - Meson spectroscopy
  - Pomeron physics
    - Odderon (3-gluon counterpart of 2-gluon Pomeron)



- Polarized Pomeron studies unique to RHIC

STAR upgrades for 2009

- Time of Flight
  - Replaces central trigger barrel
  - Trigger simulation is underway
    - Triggering on multiplicity
    - Topology trigger
    - Possible PID
- Upgrade of data acquisition (DAQ)
  - New TPC front-end electronics based on ALICE's ALTRO chip
  - Will permit trigger rates of ~ 1 kHz

Summary

- STAR has measured
  - coherent and incoherent photoproduction of ρ^0 in AuAu at 200 GeV
    - *dN/dy* compared to theoretical models
    - spin density matrix elements consistent with S-channel helicity conservation
  - interference in ρ^0 production
  - $\rho' \rightarrow \pi^+\pi^+\pi^-\pi^-$ production in AuAu at 200 GeV
  - incoherent ρ^0 photoproduction in dAu
- Run VII and beyond should bring additional interesting physics!