Photon-Pomeron and Photon-Photon Interactions in Ultra-Peripheral Heavy Ion Collisions at RHIC

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For the STAR Collaboration

Photon 2001,
Ascona, Switzerland
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- **Ultra-Peripheral Collisions**
- **Exclusive Meson Production**
- **Meson Production with Nuclear Breakup**
- **Interference with Direct $\pi\pi$ Production**
- **Photon-Photon Interactions**
- **Summary**

Ultra-Peripheral Collisions

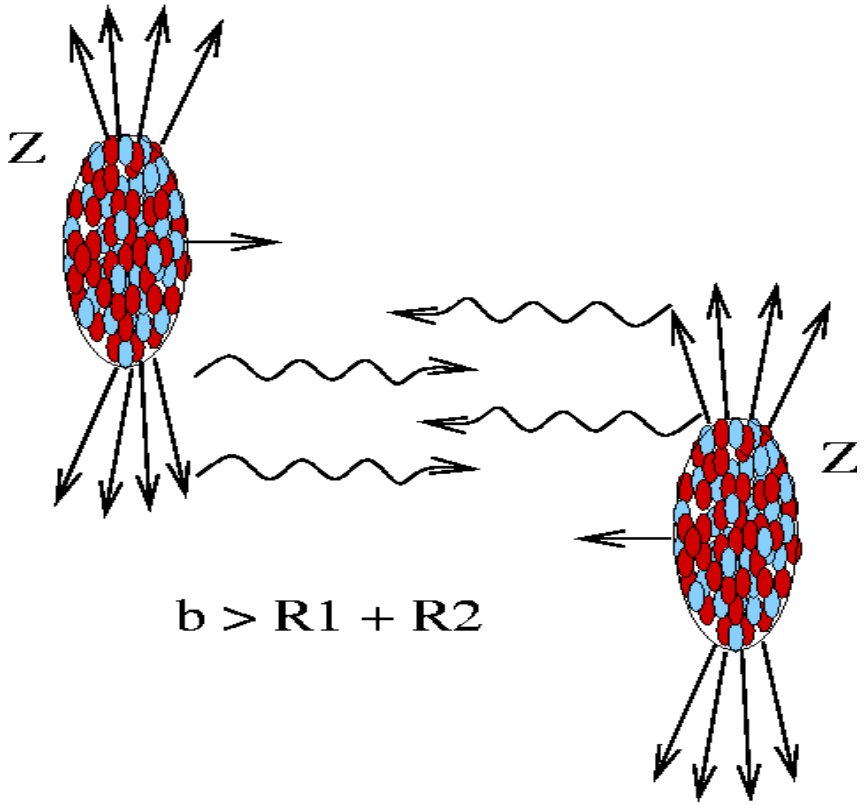
Two nuclei 'miss' each other and interact via their photon fields at impact parameters $b > 2R_A$

Equivalent Photon Approximation

(Weizsaecker-Williams, Fermi)

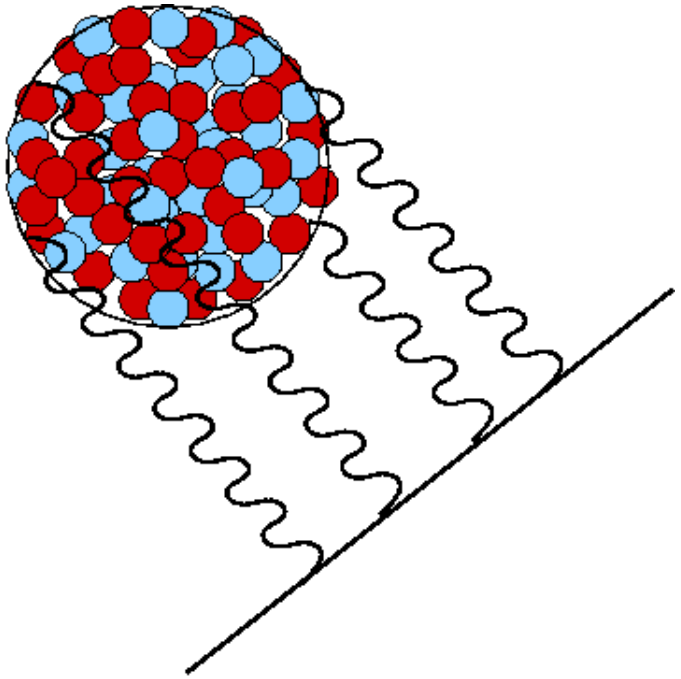
$$P(b) = \frac{1}{4\pi}\int |\mathbf{E}\times\mathbf{B}|\,\sigma_\gamma(\omega)d\omega$$

$$= \int \frac{n(\omega,b)}{\omega}\sigma_\gamma(\omega)d\omega$$



- **Interaction via long range fields**
- **Large cross section**
- **Coherent coupling to both nuclei**
- **Small transverse momentum**
- **Nuclei may be mutually excited**

Coherent Coupling to Extended Charge



Photon(Pomeron) = plane wave

Can't distinguish between different points of origin

Coherence condition from uncertainty principle:

- Small transverse momentum:

$$p_T < 2h/R_A \sim 60 \text{ MeV}$$

- Longitudinal component

$$P_L < 2\gamma h/R_A \sim 6 \text{ GeV/c} << P_{\text{nuclei}}$$

Coupling Strength

- Photon $\propto Z^2$ (Au: $Z^2 = 6241$)
- Pomeron $\propto A^{4/3}$ to A^2 ($A^{4/3} \propto$ surface, in the limit $\sigma^{\rho N} \rightarrow \infty$; $A^2 \propto$ volume, in the weak limit)

$\sigma \sim 5600$

Exclusive Vector Meson Production $\gamma A \rightarrow VA$

Large cross section:

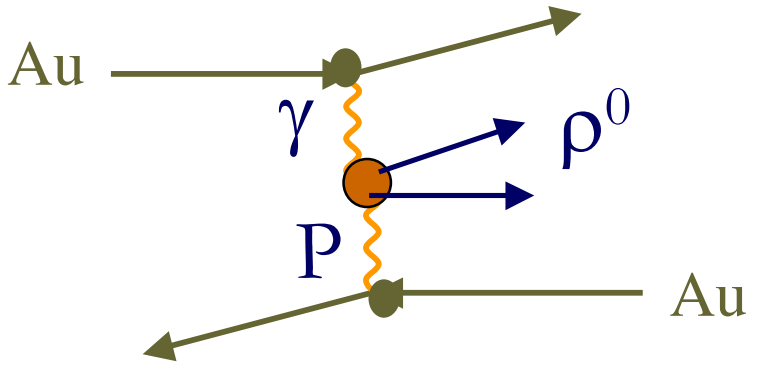
380 mb for Au at $s^{1/2}$=130 GeV/nuc.

~5% of hadronic cross section

~ 10^{7-9}/year at RHIC

~600 mb at 200 GeV/nuc.

Au+Au --> Au+Au + ρ^0



Cross sections $\sigma^{\rho N}$ well understood

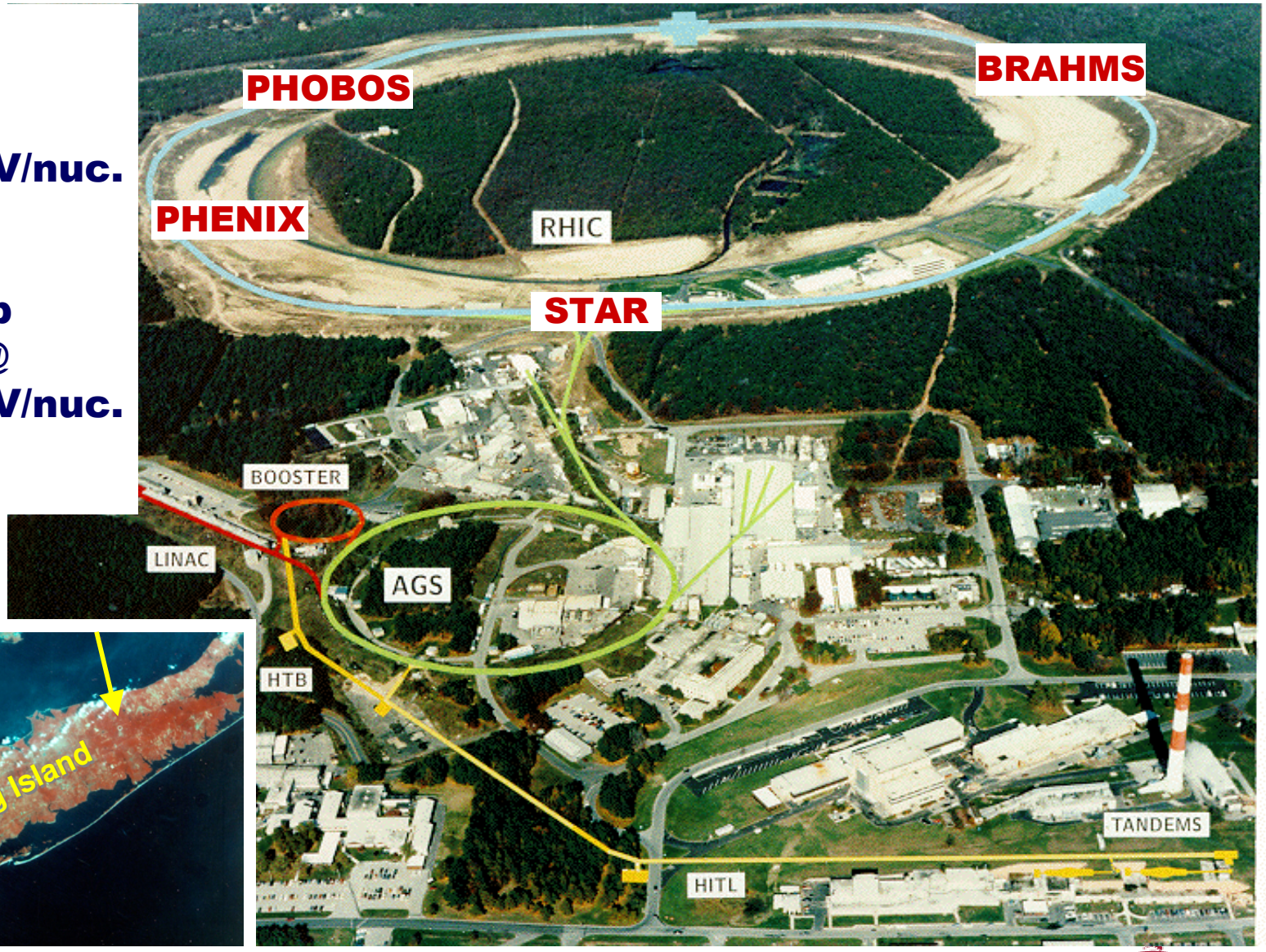
- **Photon flux from Weizsäcker-Williams:**
- **Photon-nucleon cross sections γp --> Vp from HERA and fixed target data**
- **extrapolate to γA --> VA with Glauber calculation**

Large cross section allows for multiple production of identical Vector mesons, following Bose-Statistics

RHIC at BNL

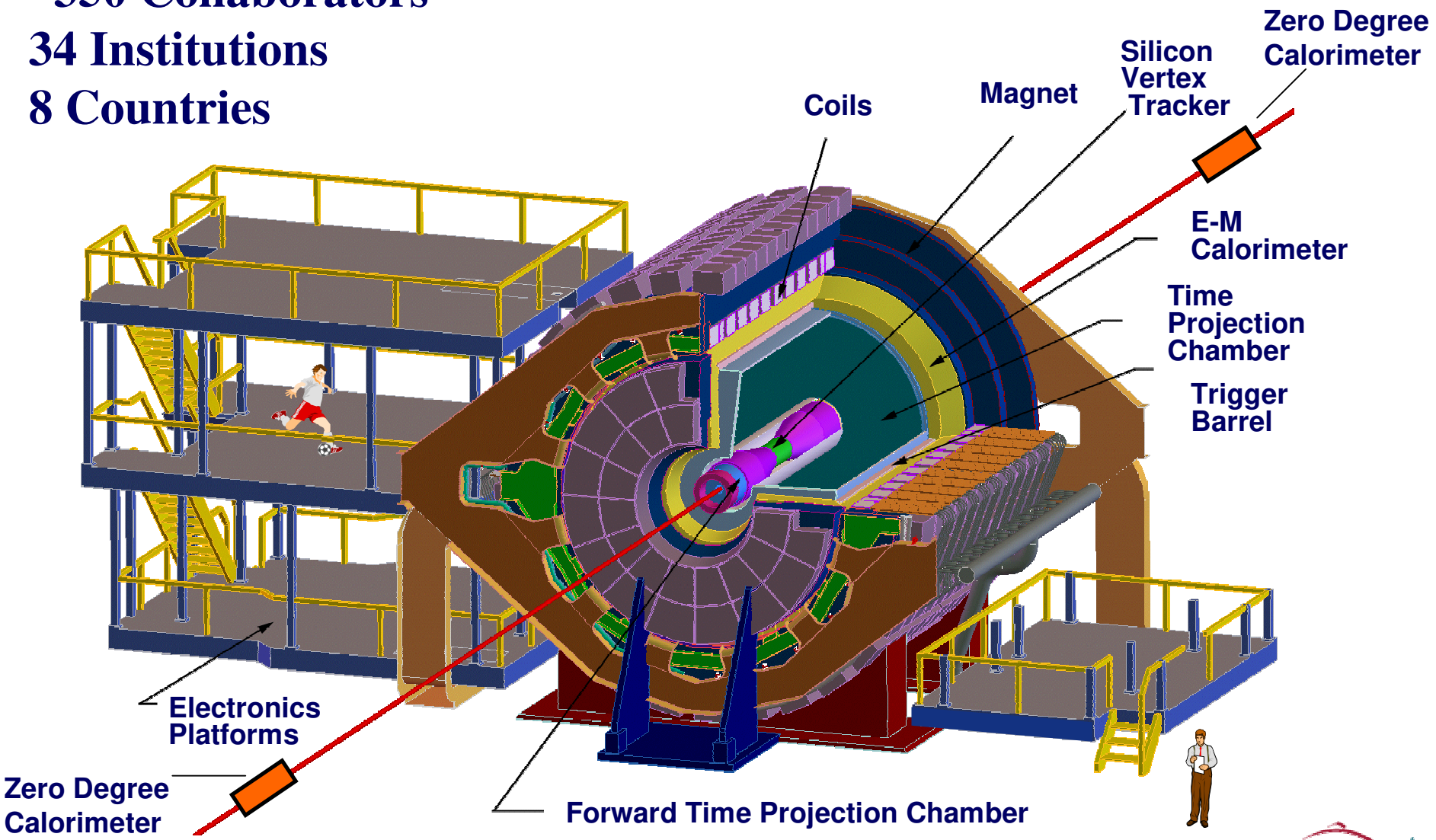
2000:
AuAu@
$s^{1/2}$=130 GeV/nuc.

2001:
polarised pp
and Au Au @
$s^{1/2}$=200 GeV/nuc.

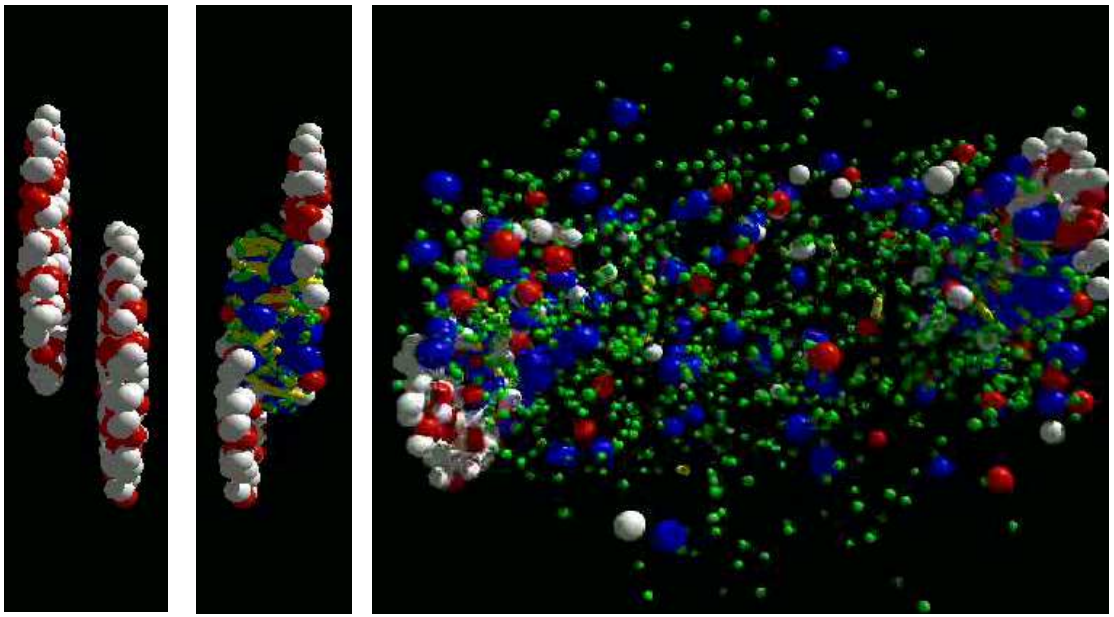


STAR at RHIC

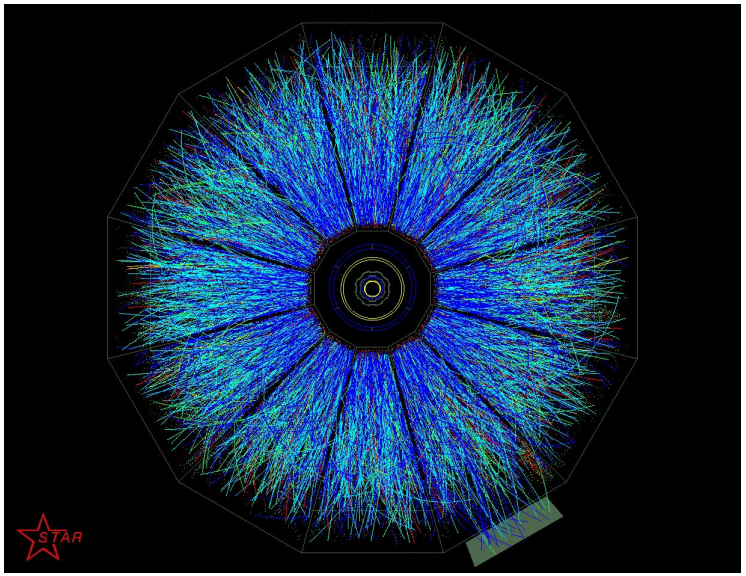
~350 Collaborators
34 Institutions
8 Countries

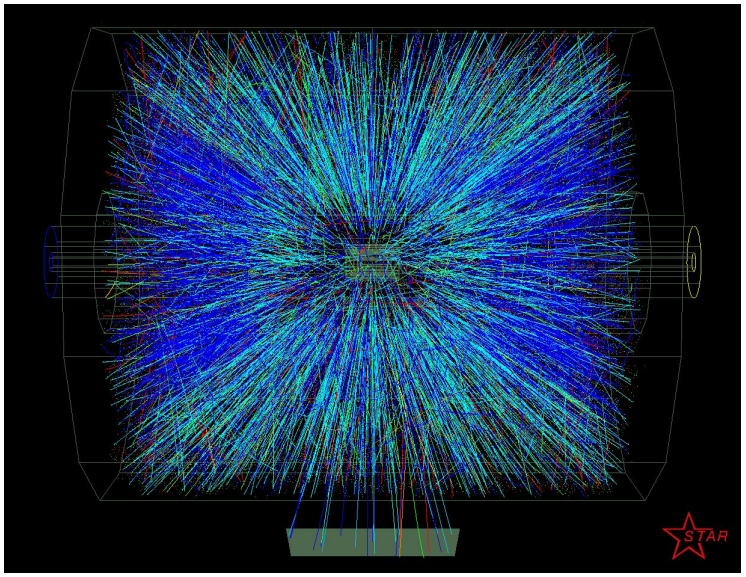


Heavy Ion Collision



(Au Au, 200GeV/nucleon, University of Frankfurt)





RHIC 2000 run: $s^{1/2}$=130 GeV/nucleon
(2001 run: $s^{1/2}$= 200 GeV/nucleon)

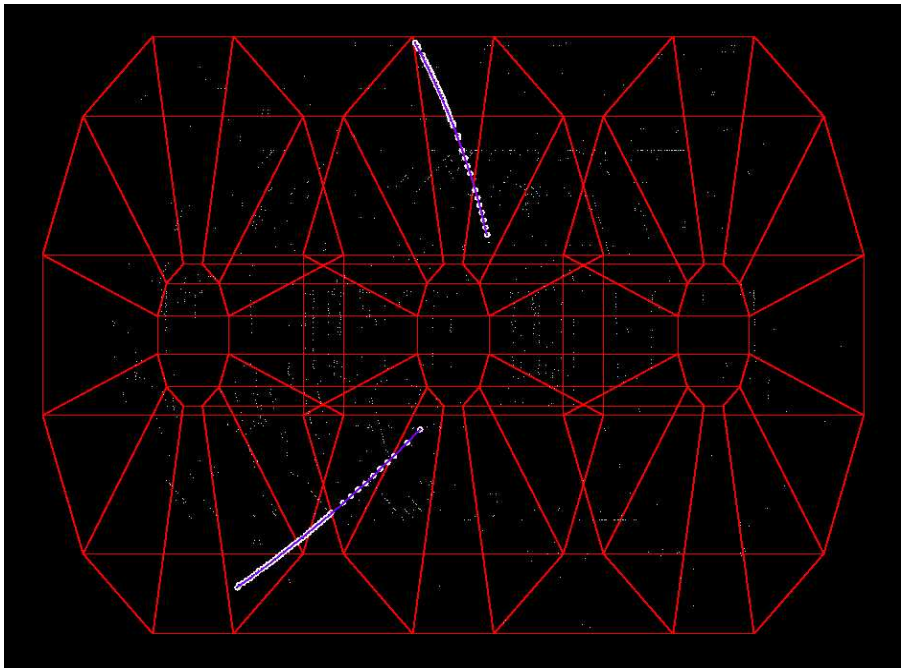
Up to ~2000 tracks per event

Triggers

- **Multiplicity in Central Trigger Barrel**
- **Neutron Deposit in Zero Degree Calorimeter**

Experimental Signature

- Only two oppositely charged tracks
- Low total p_T
- Back-to-back transverse plane
- Challenge: Trigger
- Topology requirements in central trigger barrel



Major Backgrounds

Non-Physics/Trigger:

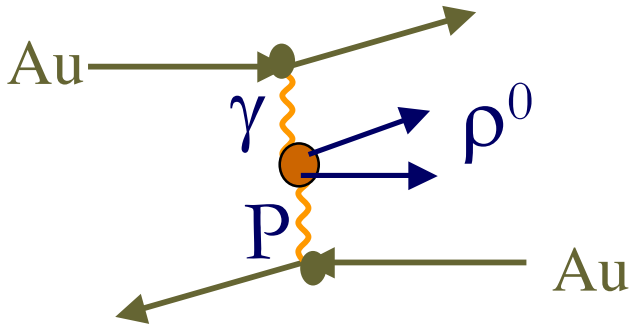
Overlap, Cosmics, Beam Gas

Incoherent:

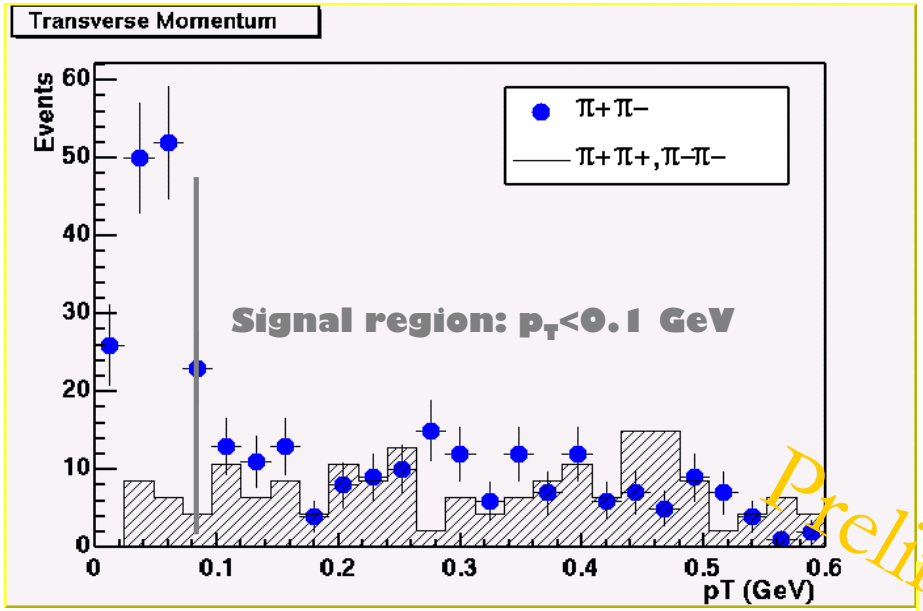
peripheral hadronic events,
incoherent photo-nuclear interactions

Coherent:

e^+e^- pairs, direct $\pi^+\pi^-$ pair production

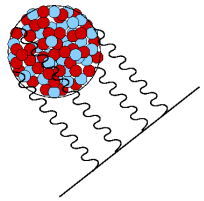


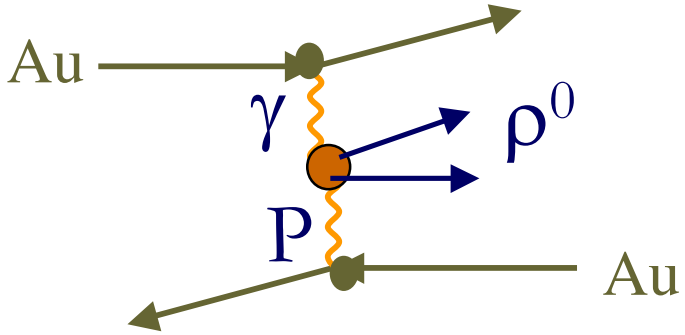
Transverse Momentum & Invariant Mass Spectra



Peak at low p_T => coherent interaction

Au+Au -> Au +Au +ρ^0

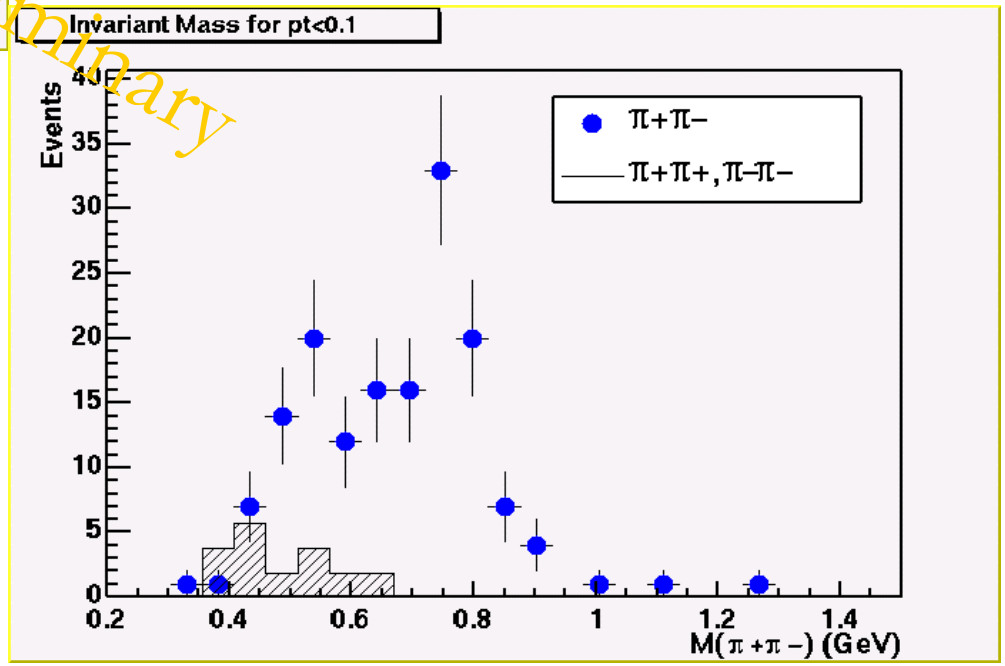




Background model from wrong sign pairs normalized to data

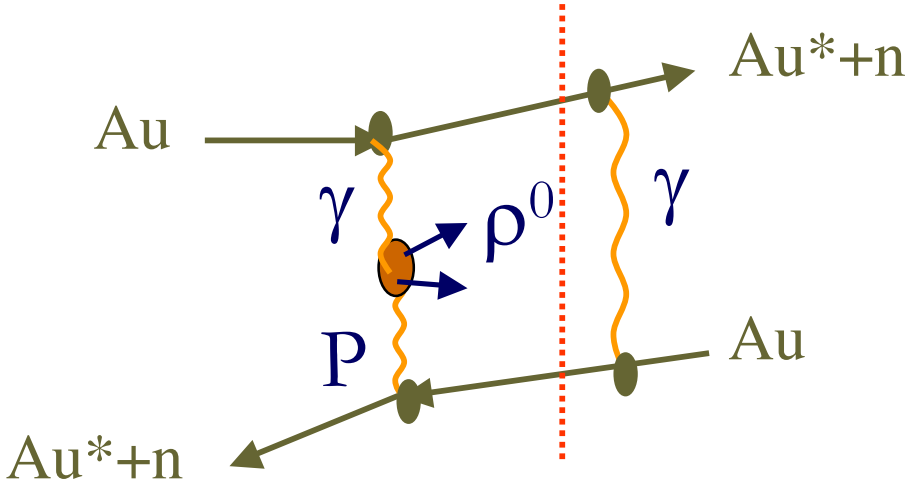
Topology trigger 2000: 7 hrs of data, 30k events

No neutron signal in ZDC



Nuclear Excitation

In addition to ρ^0 production, nuclei can exchange one or more separate photons and become mutually excited.



Au+Au -> Au*+Au* + ρ^0

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

Believed to factorize as function of impact parameter

Gold decay by single (1n,1n) (2.5mb) and multiple (xn,xn) (50mb) neutron emission

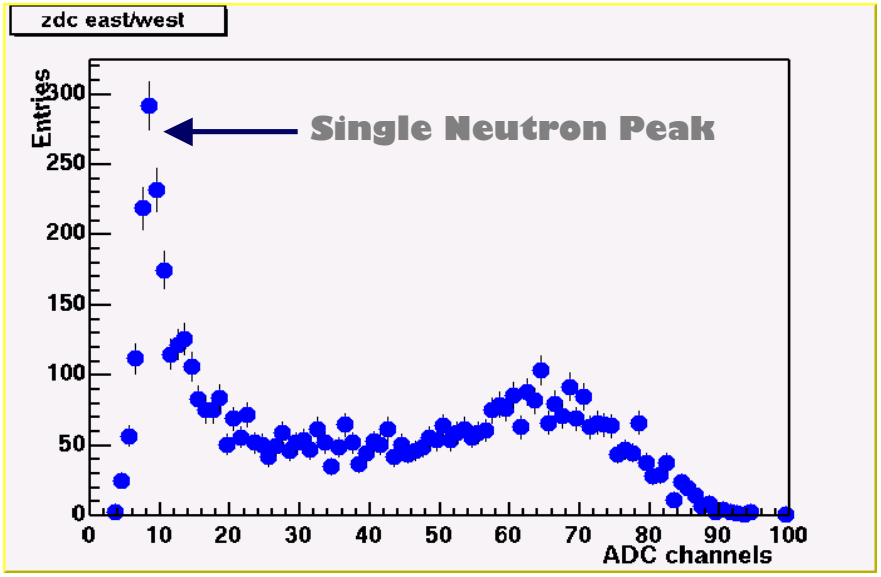
Selection of single/multiple neutron emission selects different ranges of impact parameter and different kinematics

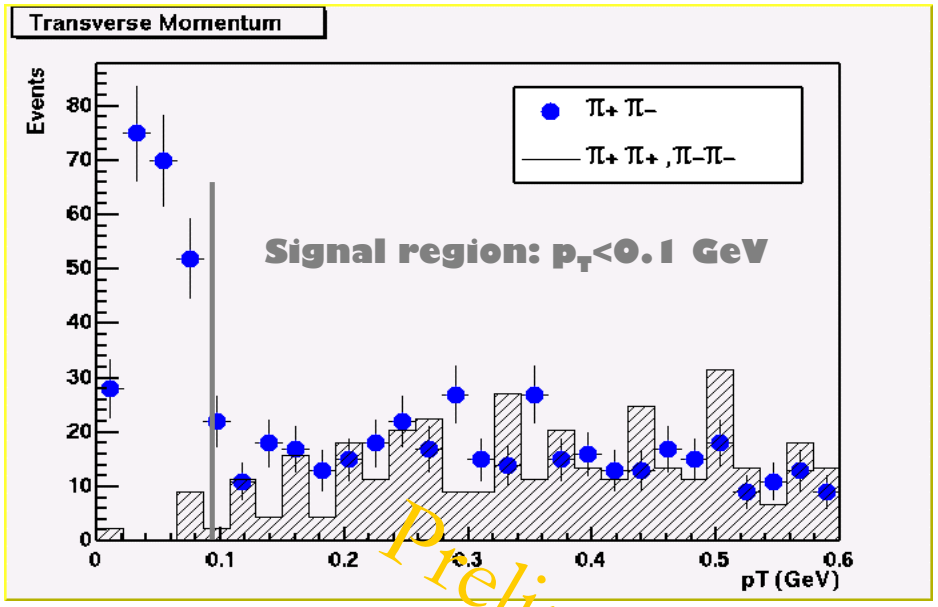
Meson Production with Nuclear Break-up

Au+Au -> Au*+Au* + ρ^0

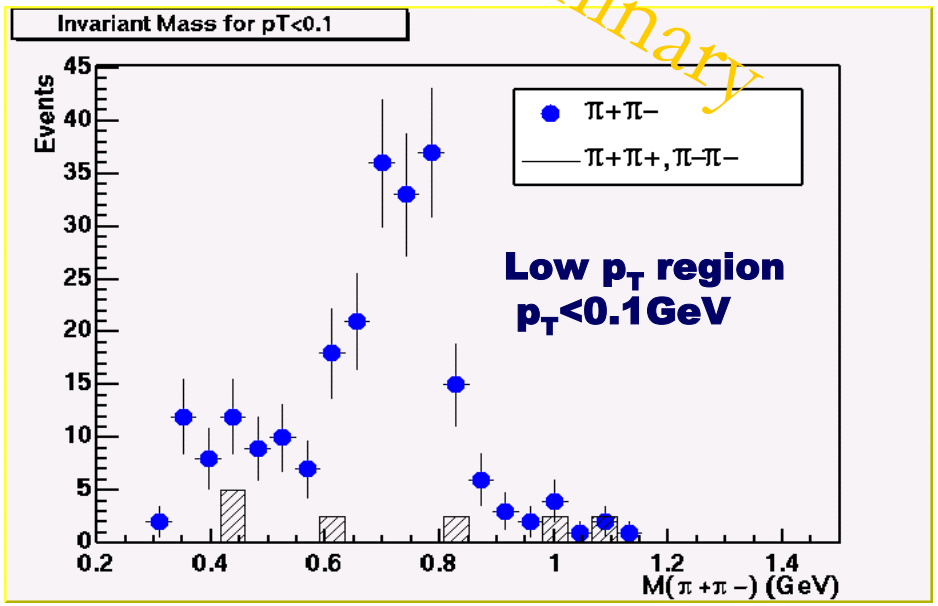
Minimum Bias Trigger
Require coincident neutron signal in ZDC

2000: 400k events



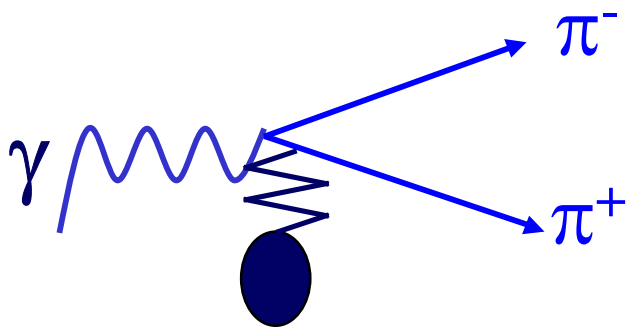


Preliminary

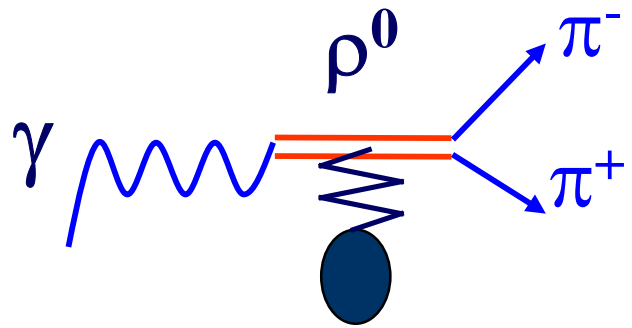


Photon 2001, Ascona

Direct $\pi^+\pi^-$ Production



$\gamma A \Rightarrow \pi^+ \pi^- A$



$\gamma A \Rightarrow \rho^0 A \Rightarrow \pi^+ \pi^- A$

- **The two processes interfere**

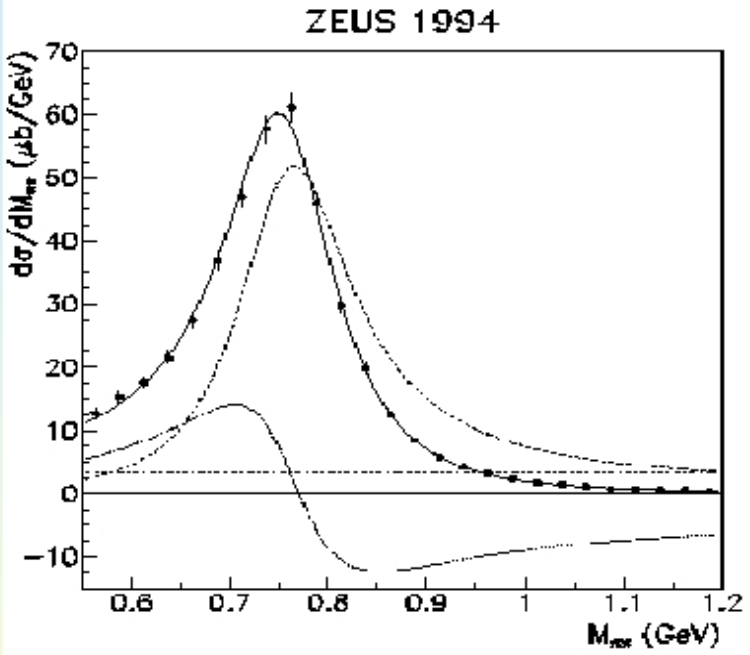
=> 180^0 phase shift at M(ρ^0) changes $\pi^+ \pi^-$ lineshape

- **good data with γp**
- **$\pi^+ \pi^-$ fraction expected to decrease as A rises**
- **Comparison of $\gamma A \Rightarrow \rho^0 A$ to $\gamma p \Rightarrow \rho^0 A$**

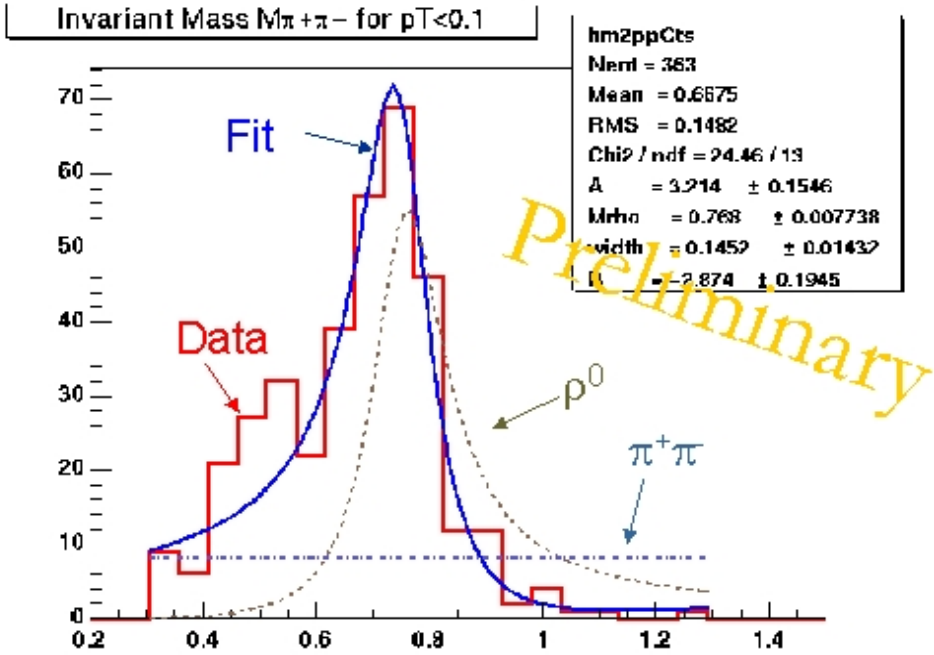
  photon-nucleon to photon-nuclei scattering allows to study hadronic diffractive interactions i.e. the Pomeron

ρ^0 lineshape

ZEUS $\gamma p \rightarrow (\rho^0 + \pi^+\pi^-)p$



STAR $\gamma Au \rightarrow (\rho^0 + \pi^+\pi^-)Au$



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

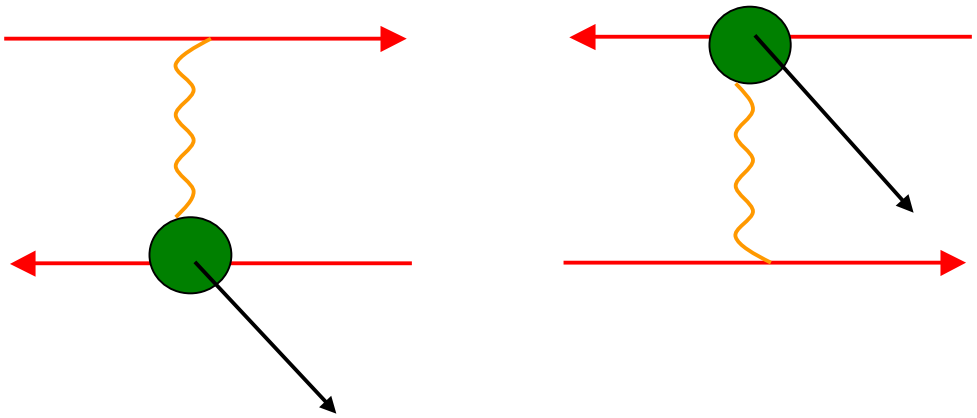
Set =0 for STAR

$\rho/\pi\pi$ ratio similar as in γp

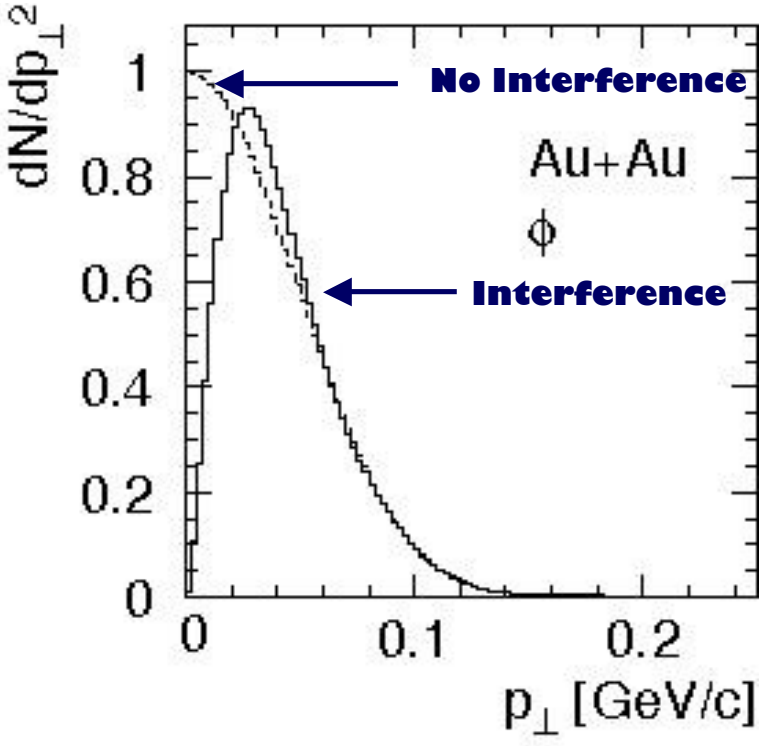
A-dependence of $\rho/\pi\pi$ **?**

Interference

Can't differentiate between projectile and target



Expected Signal



2-slit interferometer with separation of impact paramter b!

<b> ~ 40 fermi >>R_A ~ 7 fm

$\rho, \omega, \phi, J/\psi$ have negative parity $J^{PC} = 1^{--}$

Amplitudes have opposite signs

$$\sigma \sim |A_1 - A_2 e^{ip\cdot b}|^2$$

destructive interference at p_T=0 (maximal at y=0 when A_1=A_2)

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

Entangled Nonlocal Wavefunctions

- VM are short lived (~10^{-23} s)
  decay before traveling distance b
- Decay products interfere

- J/Ψs many decays: $e^+ e^-$, $\mu^+\mu^- \tau^+\tau^-$, hadrons
- At the decay time(s) neither amplitude can know about the other (no overlap)

Either

independent decays --> little/no interference

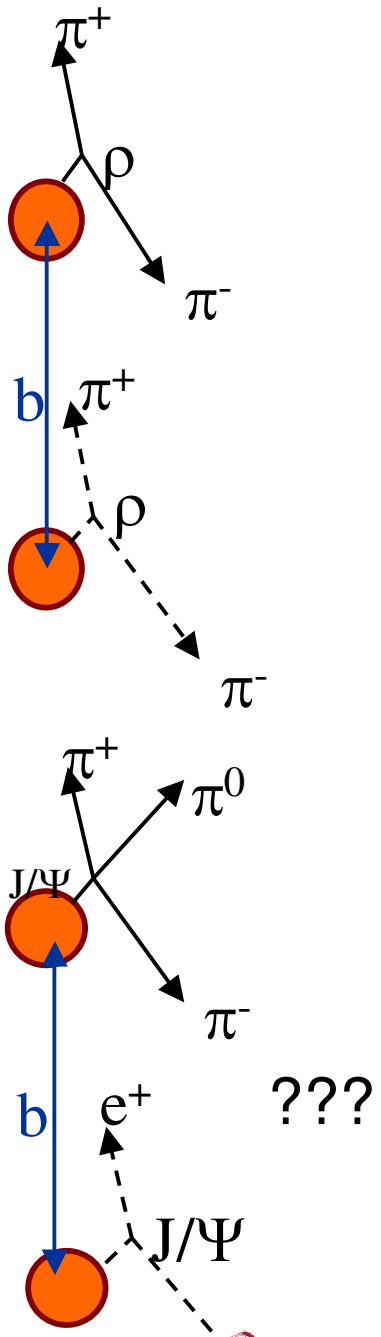
OR

The wave function retains amplitudes for all possible decays, long after the decay occurs

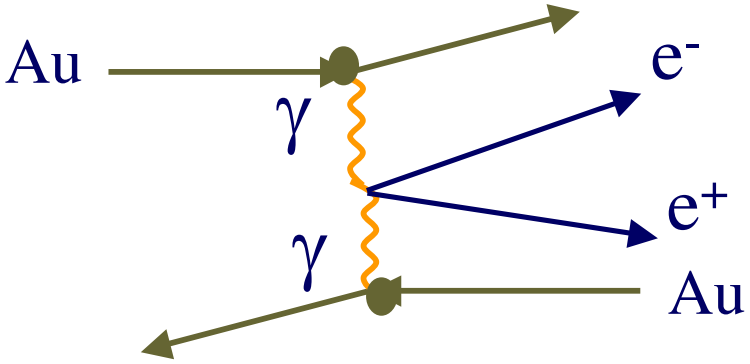
The wave function only collapses when it interacts with the detector

Quantum mechanics predicts choice 2

Example of the Einstein-Podolsky-Rosen paradox

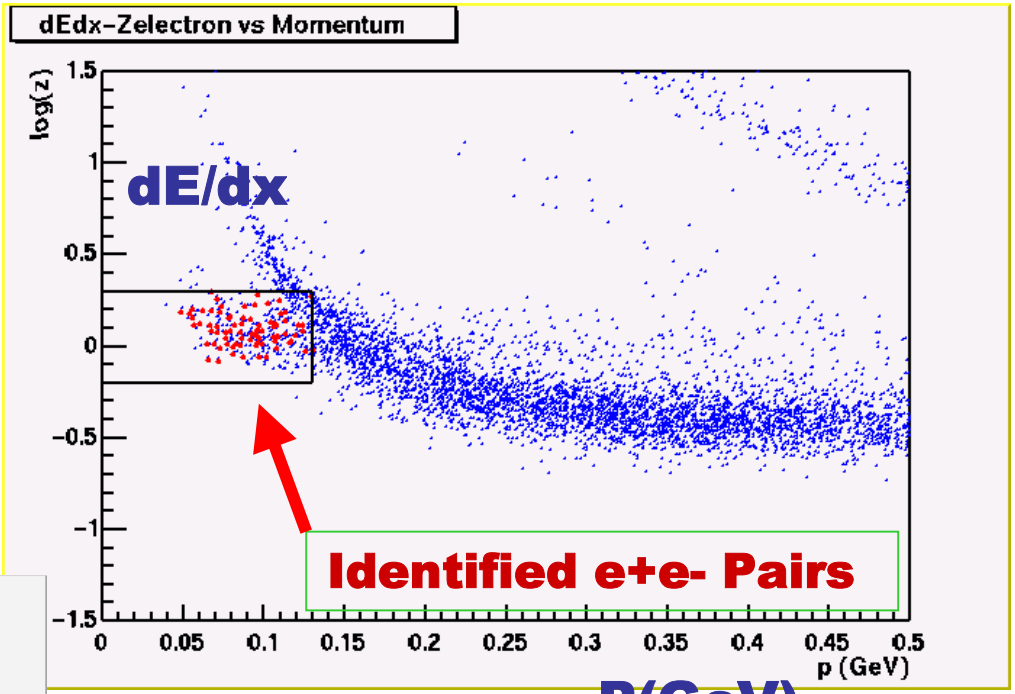


Electromagnetic Interaction $\gamma\gamma$->e^+e^-

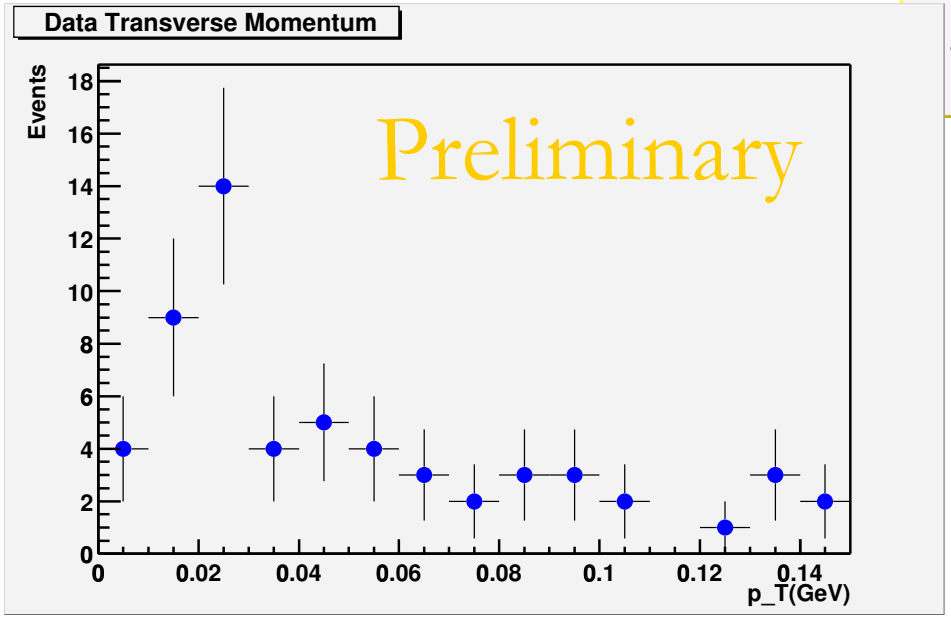


Strong field QED $Z\alpha \sim 0.6$

Large cross section $\propto Z^4\alpha^4$ (RHIC 33 kb)



P(GeV)



e^+e^- Pairs are all at low p_T

$\Rightarrow$ Signature for coherent process Au Au-> Au*Au* e^+e^-

Falk Meissner, LBNL

Summary

First observation of exclusive meson production in ultra-peripheral heavy ion collisions. Two processes observed for the first time: **Au + Au -> Au + Au + ρ^0 and Au + Au -> Au* + Au* + ρ^0 .**

Ultra-peripheral heavy ion collisions form a 2-source interferometer for short-lived particles

2001 Data is rolling in, more interesting physics to do

- **Interference of decaying particles**
- **Excited vector mesons (ρ^*)**
- **J/ψ**
- **e+e- strong field QED**
- **Glue ball search (8mb)**

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