Central Exclusive Production with STAR detector at RHIC

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On behalf of STAR Collaboration

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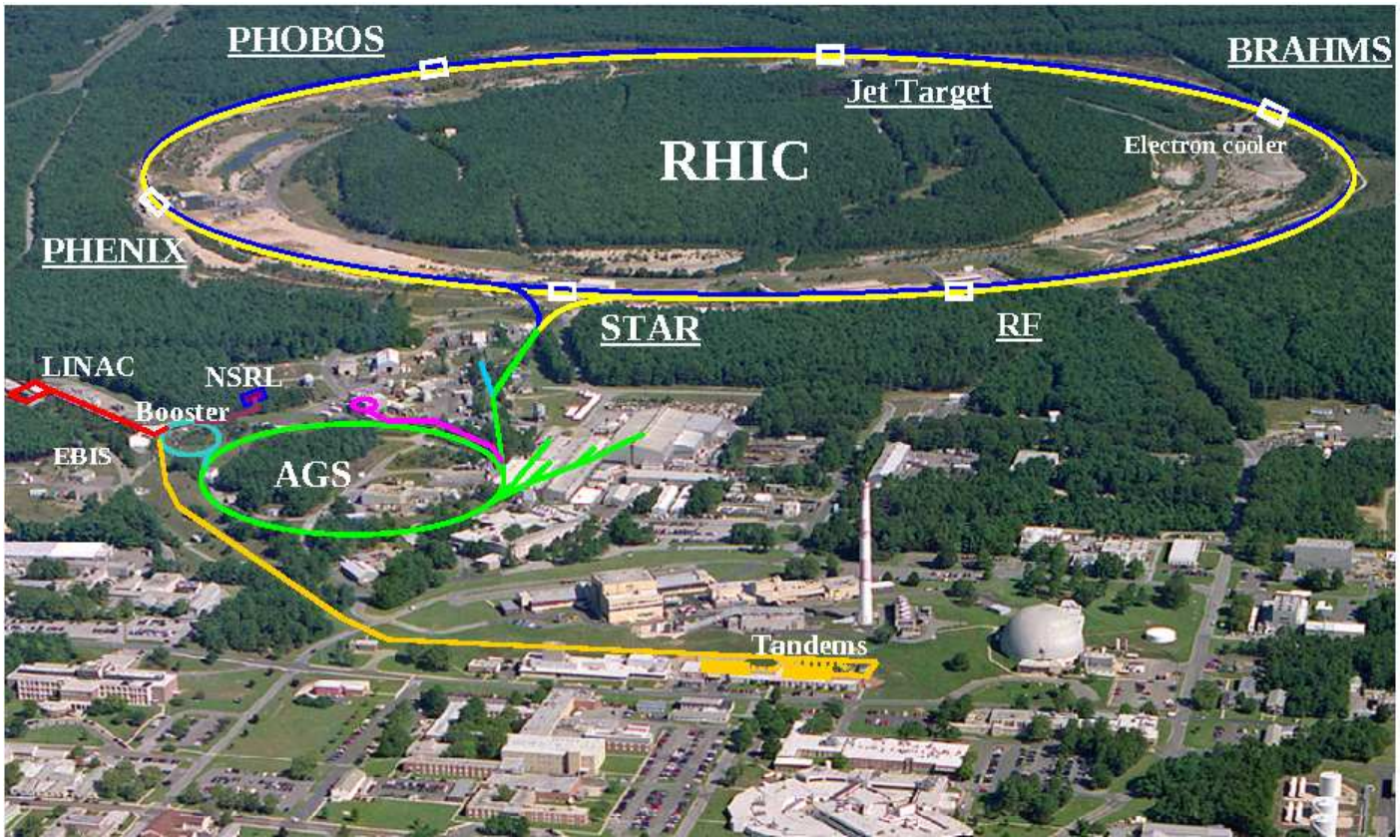
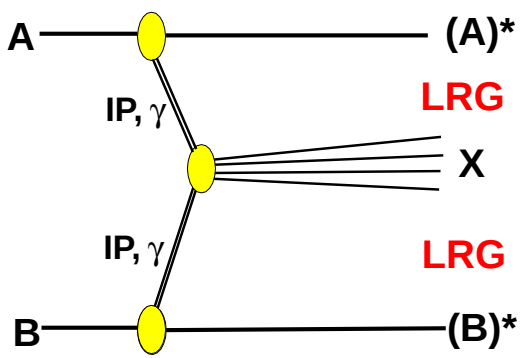
RHIC

AA: Au-Au, Cu-Cu, Cu-Au, d-Au, U-U up to $\sqrt{s_{NN}} = 200$ GeV
this talk: $\mathrm{Au} + \mathrm{Au} \rightarrow (\mathrm{Au})^{\star} + (\mathrm{Au})^{\star} + X$; $X : \rho^0, J/\Psi$



polarized proton-proton: up to $\sqrt{s} = 510$ GeV
this talk: $p + p \rightarrow p + p + X$; $X : \pi^+ + \pi^-$

Central Exclusive Production in Colliders



Central Exclusive Production (CEP):

$$A + B \to (A)^{\star} \;\; gap \;\; X \;\; gap \;\; (B)^{\star}$$

where X is a simple centrally produced system.

e^+e^- from LEP to ILC: $\gamma\gamma \to l^+l^-$

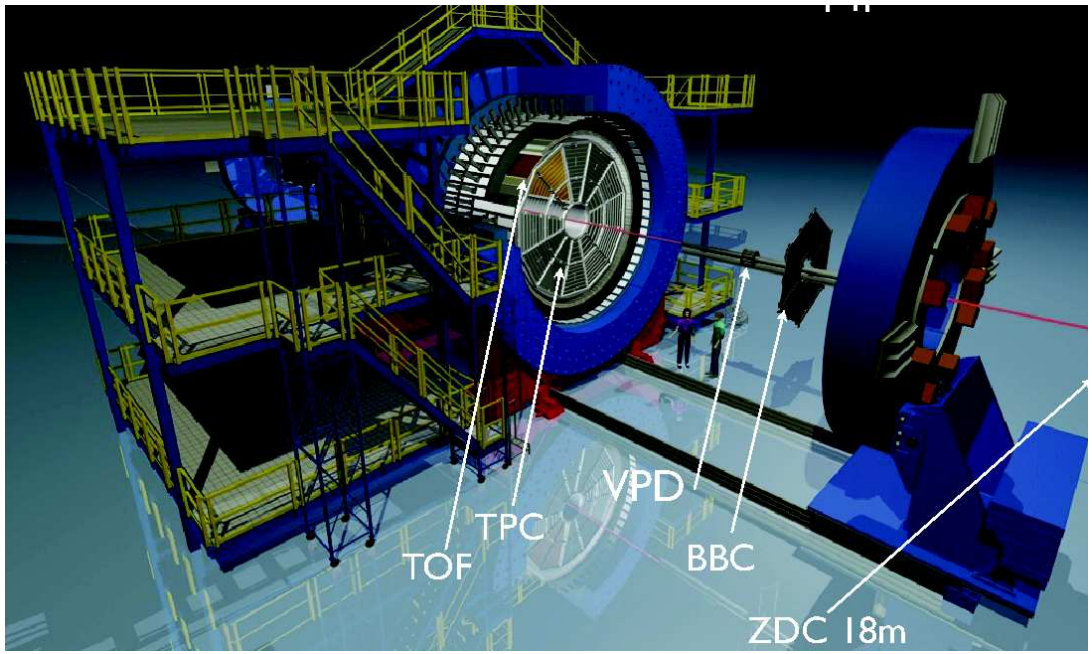
ep HERA: $\gamma\gamma \to l^+l^-$; $\gamma I\!P \to$ vector mesons

$pp(p\bar{p})$ ISR, TEVATRON, RHIC, LHC:
$\gamma\gamma \to l^+l^-$; $\gamma I\!P \to$ vector mesons; $I\!P I\!P \to$ hadrons
this talk: $I\!P I\!P \to \pi^+\pi^-$

AA RHIC, LHC:
$\gamma\gamma \to l^+l^-$; $\gamma I\!P \to$ vector mesons; $I\!P I\!P \to$ hadrons
this talk: $\gamma I\!P \to \rho^0, J\psi$

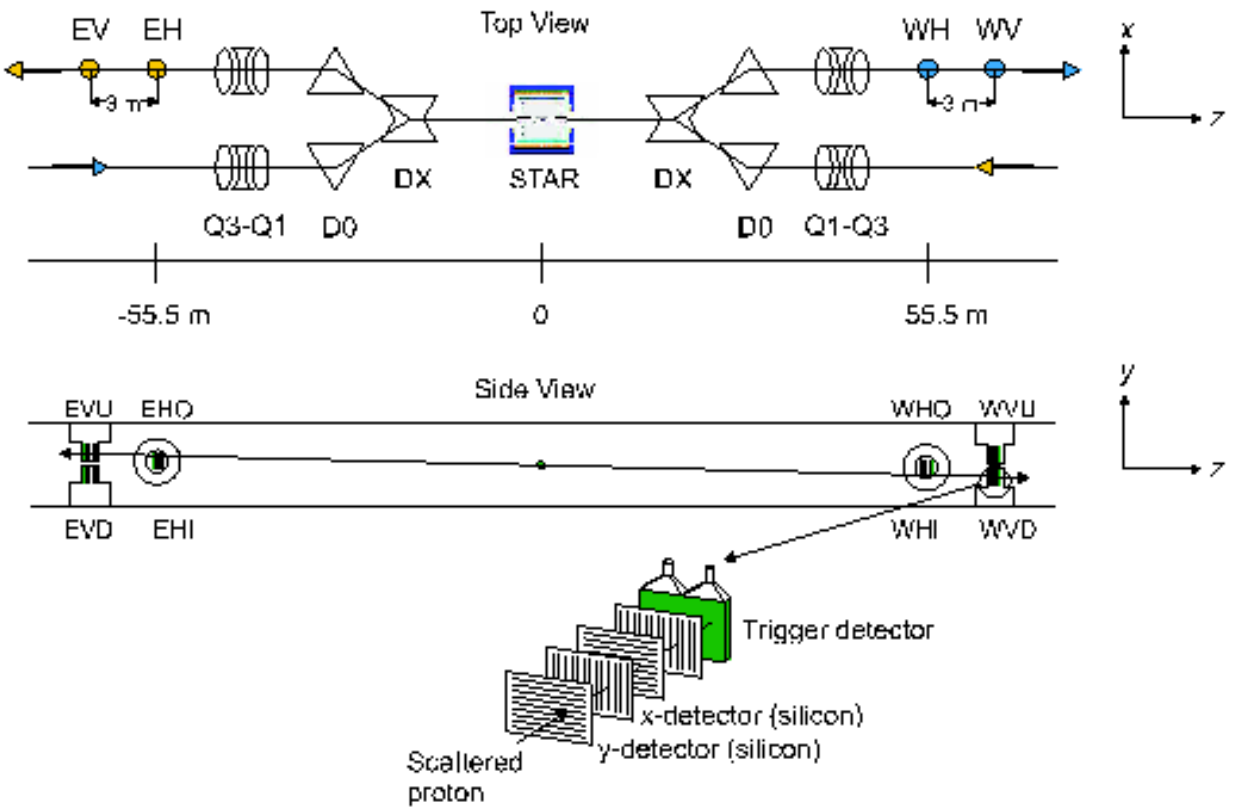
CEP with STAR detector

$pp \to ppX, \quad X = \pi^+\pi^-$
$\mathrm{AuAu} \to (\mathrm{Au})^\star(\mathrm{Au})^\star X, \quad X = \rho^0, J/\Psi.$



- high resolution tracking with TPC: $-1 < \eta < 1$
- particle identification: TPC dE/dx, ToF+VPD counters
- possible rapidity gap: BBC veto, $2.1 < \eta < 5.2$
- tagging nucleon excitation: neutrons in ZDC

Forward proton tagging at STAR



- 8 Roman Pot stations with 4 silicon strip layers
- full ϕ coverage
- current data
  at $\sqrt{s} = 200$ GeV; $0.003 < -t < 0.03$ GeV^2
- possible upgrade
  at $\sqrt{s} = 500$ GeV; $0.1 < -t < 1.5$ GeV^2

CEP in pp collisions 2009 data, $\sqrt{s} = 200$ GeV

$$pp \to ppX, \quad X = \pi^+\pi^-$$

- both scattered protons detected with Roman Pots
- produced state X fully measured with TPC
- acceptance limits kinematics:

$$0.003 < -t_1, -t_2 < 0.03 \text{ GeV}^2$$

$$0.5 < M_{\pi\pi} < 2.3 \text{ GeV}$$

- in principle both $I\!P I\!P$ and $\gamma I\!P$ contribute but:

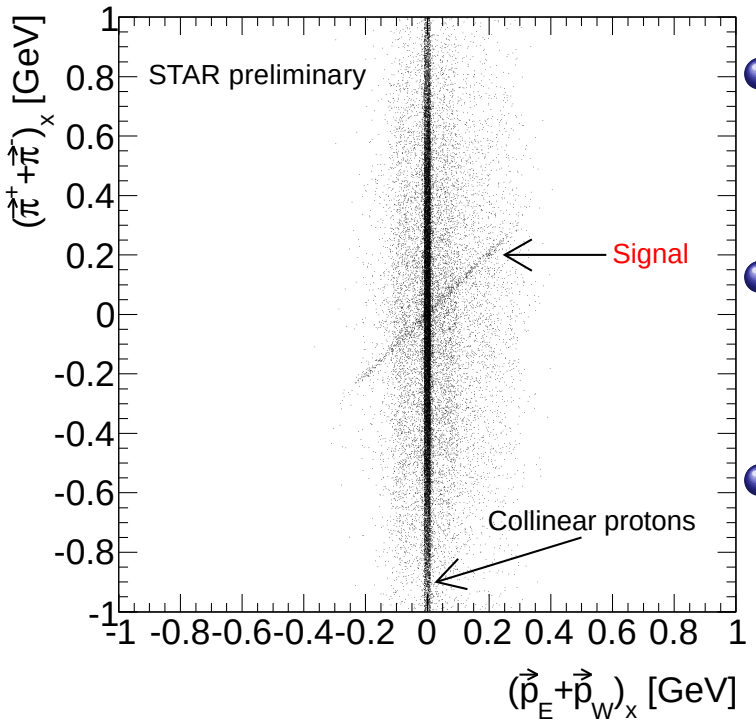
$$-t(\gamma) \ll -t(I\!P)$$

  - $\gamma I\!P \to \rho$ significantly suppressed
  - data dominated by low mass production via Double Pomeron Exchange

CEP in pp collisions 2009 data, $\sqrt{s} = 200$ GeV

Data selection:

- trigger based on Roman Pots only
- two protons (one on each side of STAR)
- two TPC tracks from primary vertex:
  - $p_T > 150$ MeV
  - $|\eta| < 1.0$

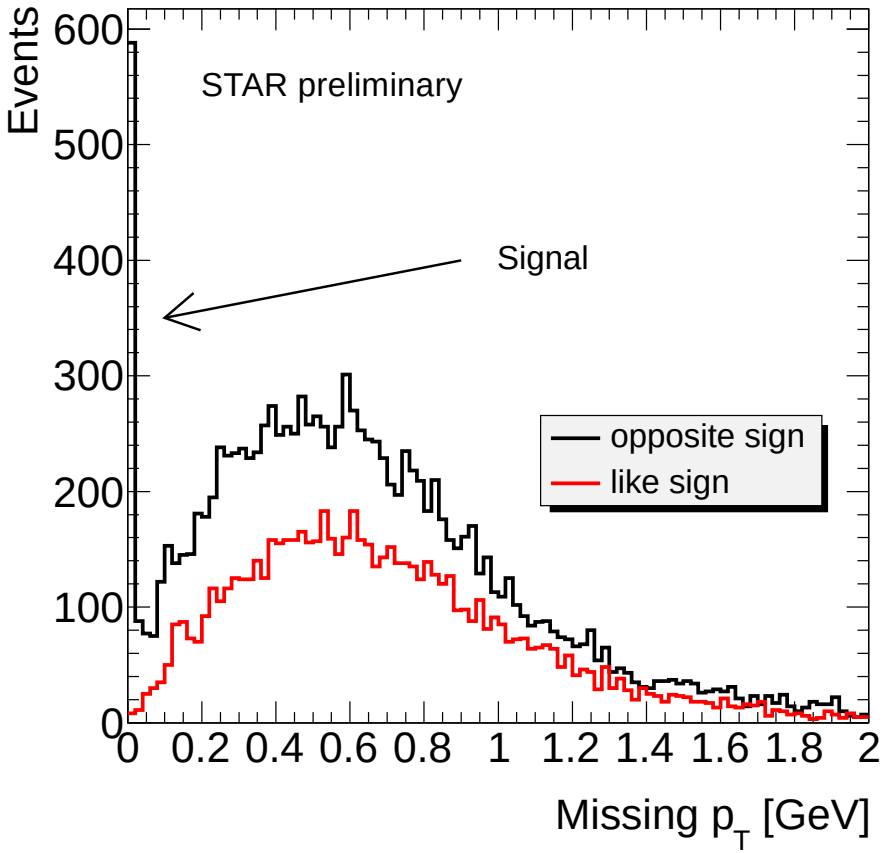


- data contains elastic $pp \rightarrow pp$ events with overlap with TPC tracks not belonging to the same interaction vertex (collinear line)
- this overlap events can not be removed by momentum balance in the back-to-back pion pairs configuration (cosmics)
- remove collinear proton tracks with $\Delta\Theta > 0.15$ mrad cut to remove cosmics

$$\Delta\Theta = \sqrt{(\Theta_E^X - \Theta_W^X)^2 + (\Theta_E^Y - \Theta_W^Y)^2}$$

CEP in pp collisions 2009 data, $\sqrt{s} = 200$ GeV

Data selection:

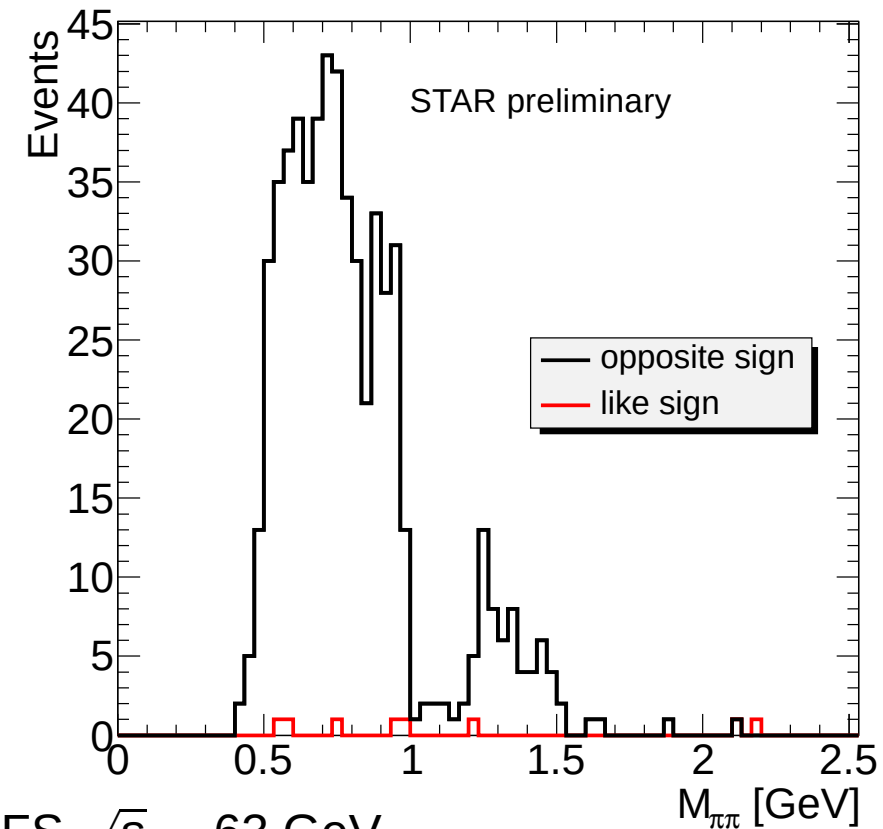


- transverse momentum balance

$$p_T^{miss} = |(\vec{p}_E + \vec{p}_W + \vec{\pi^+} + \vec{\pi^-})_T|$$

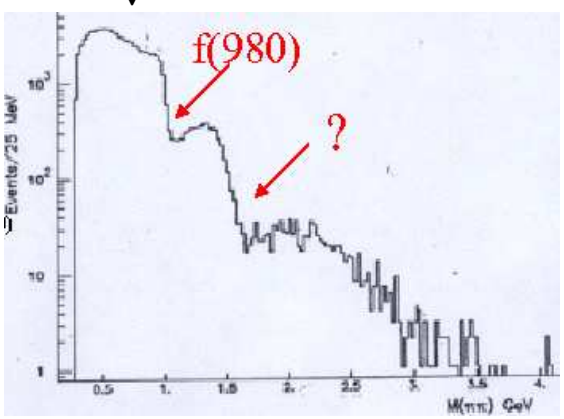
- requirement of $p_T^{miss} < 0.02$ GeV very efficient in reduction of the non-exclusive background, characterized by large fraction of like-sign tracks
- almost no like-sign background in the signal region

CEP in pp collisions 2009 data, $\sqrt{s} = 200$ GeV



- two TPC tracks from primary vertex:
  - $p_T > 150$ MeV
  - $|\eta| < 1.0$
- $p_T^{miss} < 0.02$ GeV
- $\Delta\Theta > 0.15$ mrad
- $|dE/dx - (dE/dx)_\pi| < 3\sigma$

AFS $\sqrt{s} = 63$ GeV

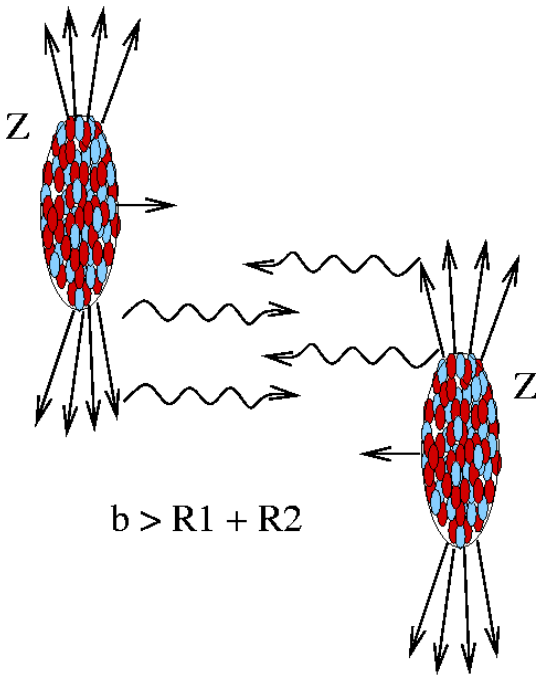


- spectrum similar to the one published by Axial Feld Spectrometer at ISR
- dominated by low mass pairs <1 GeV
- characteristic cross section drop at 1 GeV due to $f_0(980)$ in final state

CEP in Ultra-peripheral collisions of heavy ions

$AuAu \to (Au)^{\star}(Au)^{\star}X, \quad X = \rho^0, J/\Psi.$

- Relativistic heavy ions is an intense source of photon fluxes
- virtuality $Q^2 < (\hbar/R_A)^2 < 10^{-3}\text{GeV}^2$
- $7,6\ GeV < \sqrt{s_{\gamma N}} < 20,6$ GeV for Au Au with $\sqrt{s_{NN}} = 200$ GeV
- large impact parameter $\to$ separation of electromagnetic and hadron interactions

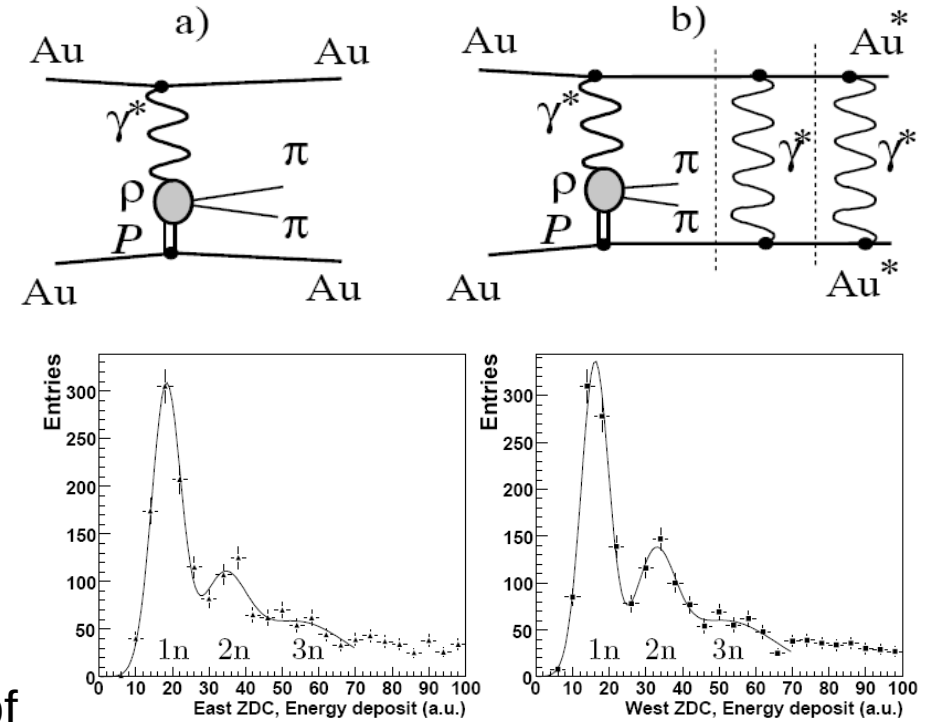


$$\vec{p}_T = p_T^{\vec{\gamma}} + p_T^{\vec{I\!P}}; \quad \frac{\hbar}{b} \approx p_T^{\gamma} < \frac{\hbar}{R_A}; \quad \langle p_T^{I\!P} \rangle \approx \frac{\hbar}{R_A}$$

for gold ($R_A = 7$ fermi) and UPC ($b > 2R_A$) $\to p_T < \dfrac{2\hbar}{R_A} = 0.06$ GeV

CEP in Ultra-peripheral collisions of heavy ions

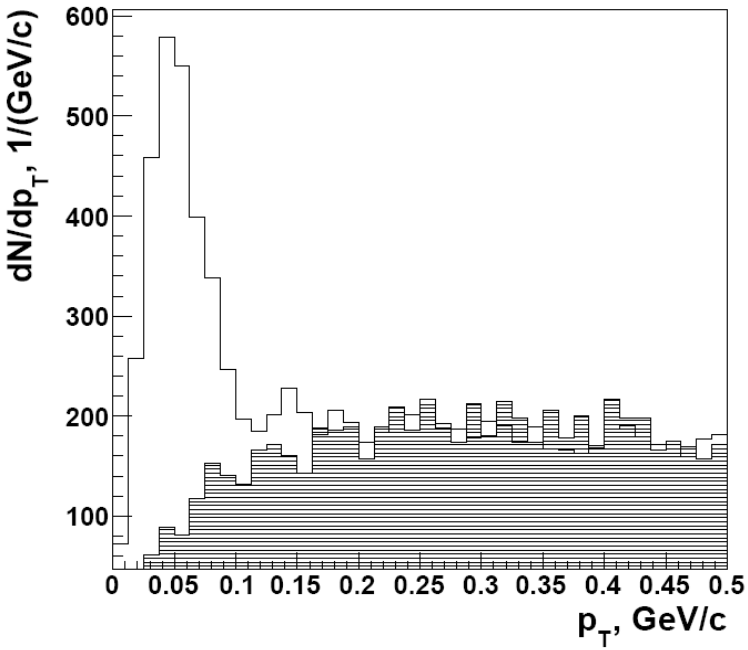
- Photon emitted by one ion fluctuates into a $q\bar{q}$ state which then interacts with other ion by the Pomeron exchange
- coherent exclusive production (a) triggered by back-to-back tracks in TPC with veto for up-down tracks (cosmics)
- coherent with nuclear excitation (b) triggered by tagging fast forward neutrons coming from de-excitation of $(Au)^{\star}$



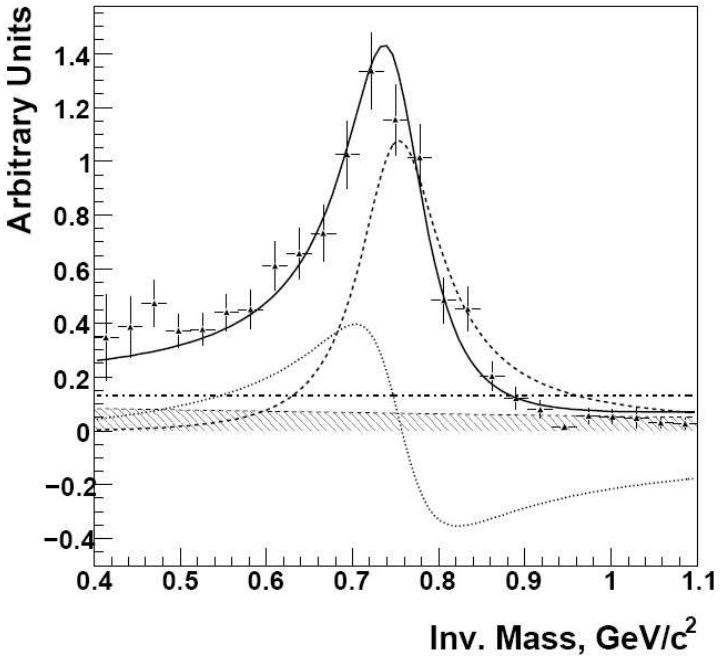
$\sqrt{s_{NN}} = 200$ GeV (2001)

CEP in Ultra-peripheral collisions of heavy ions

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}\rho^0$; $\sqrt{s_{NN}} = 62.4$ GeV (2004)
Phys. Rev. C 85 (2012) 14910



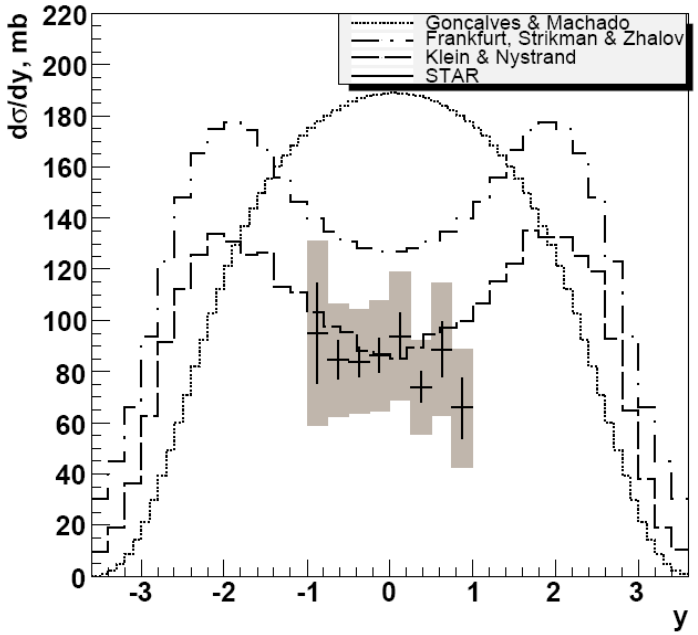
- open histogram - ρ^0 candidates
- hatched histogram - like-sign pairs

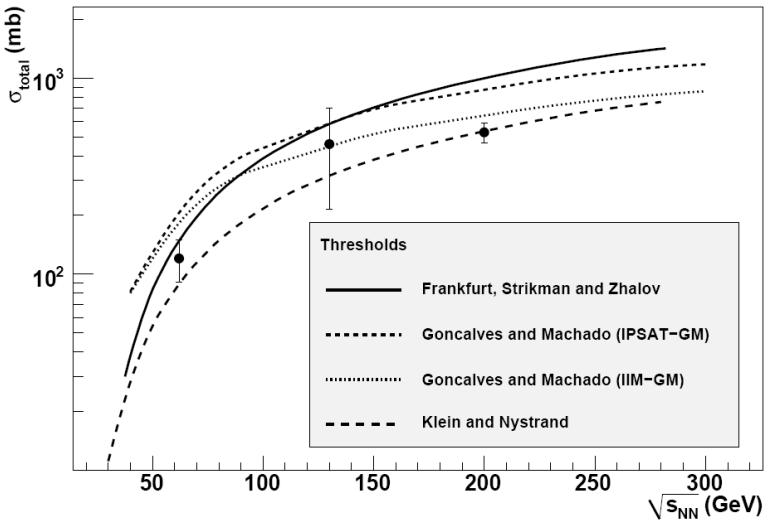


- dashed line - ρ^0 Breit-Wigner shape
- dash-dotted line - non-resonant $\pi^+\pi^-$
- dotted line - interference term

CEP in Ultra-peripheral collisions of heavy ions

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}\rho^{0}; \quad \sqrt{s_{NN}} = 62.4; 130; 200$ GeV $(2001 - 2007)$



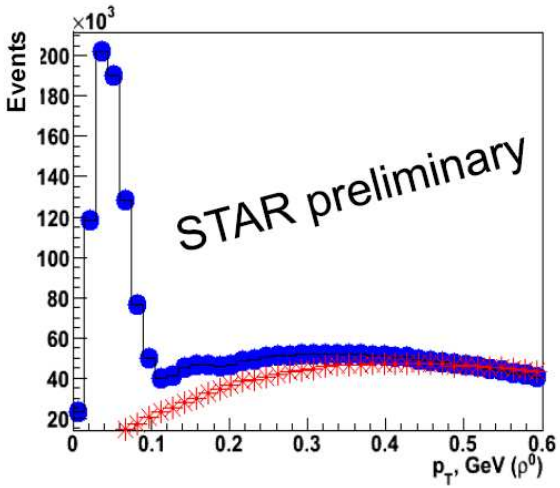


- $\sqrt{s_{NN}} = 200$ GeV (2001)
- assumptions for $d\sigma/dy$ needed to calculate cross sections in full rapidity range

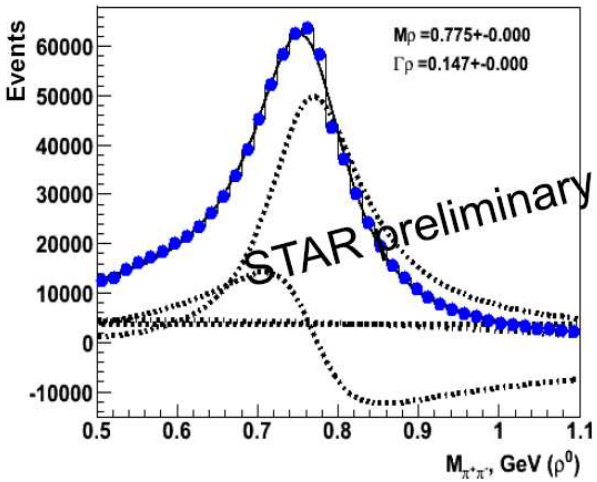
- the rise in cross sections is closer to the models with the saturation of gluon density in nuclear targets

CEP in Ultra-peripheral collisions of heavy ions

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}\rho^0; \quad \sqrt{s_{NN}} = 200$ GeV (2010)



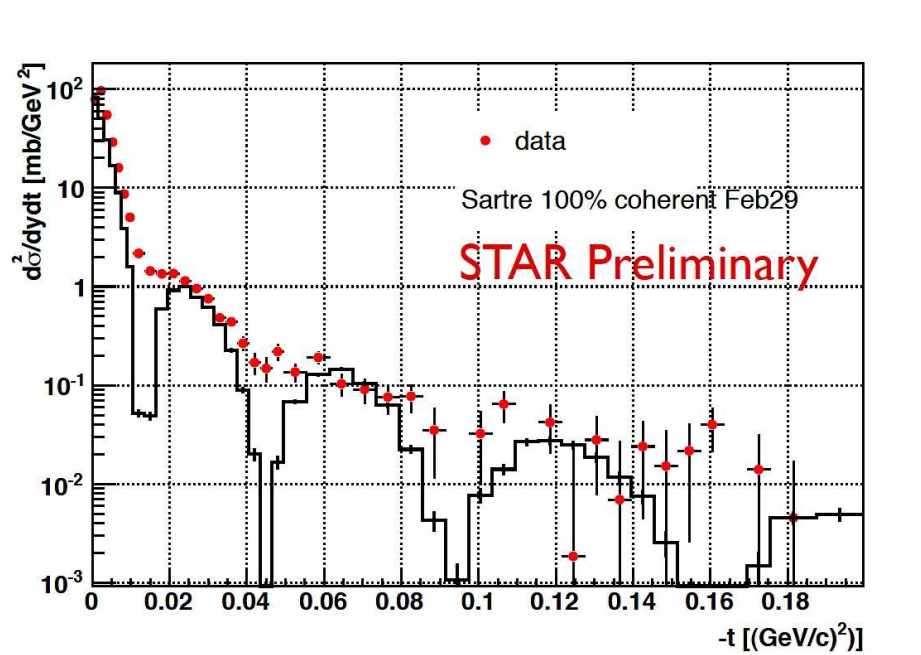
- large statistics 2010 data
- 650 000 ρ^0



- exactly two tracks from the vertex
- pair transverse momentum < 0.15 GeV
- pair rapidity $0.05 < |y| < 1$

CEP in Ultra-peripheral collisions of heavy ions

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}\rho^{0}; \quad \sqrt{s_{NN}} = 200$ GeV(2010)



- each $(Au)^{\star}$ emits 1 neutron
- pair rapidity $|y| < 1$
- no pair p_T cut
- instead dN/dt background subtracted based on the shape and magnitude of the like-sign events
- incoherent component fit to a power law function
- efficiency corrected

- the diffraction pattern is evident up to its third peak
- the slope of the first peak as well as the location of the peaks is consistent with the coherent interaction with an object with dimensions comparable to the Au nucleus
- Sartre is an event generator based on an impact parameter dependent dipole model T.Ulrich and T.Toll
- the diffraction pattern will constrain the models dipole cross section

CEP in Ultra-peripheral collisions of heavy ions

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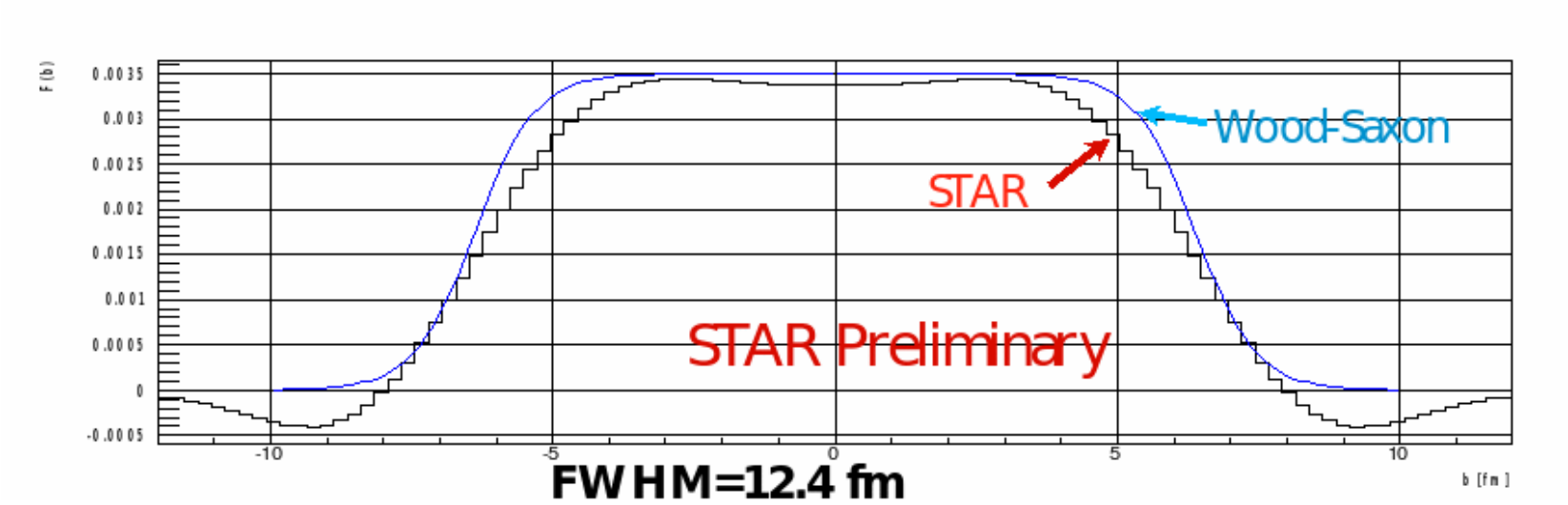
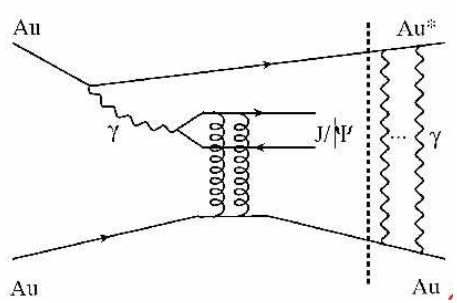


- Fourier transform of the $d^2\sigma/dydt$ relates to the partonic form factor of the Au nucleus
- measurement agrees with the Wood-Saxon distribution

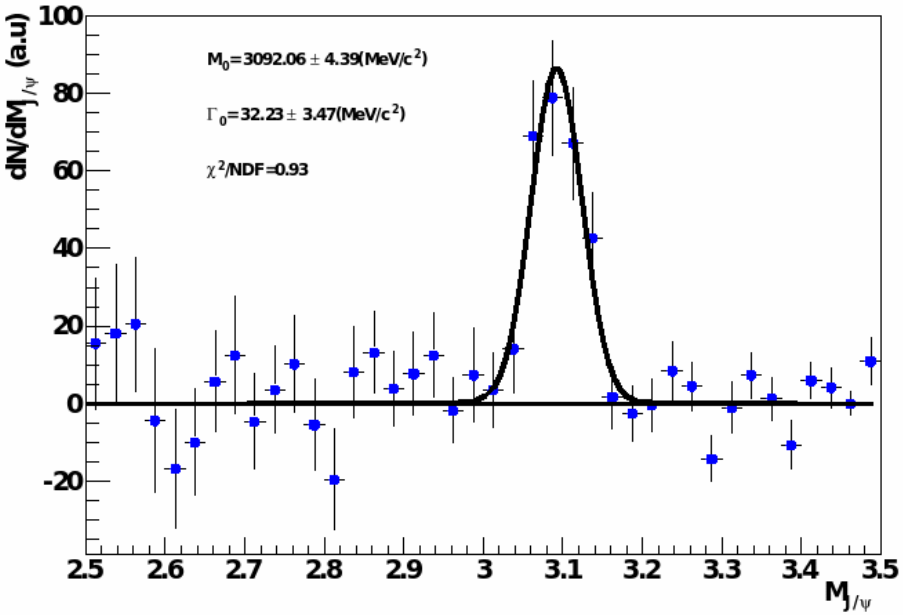
CEP in Ultra-peripheral collisions of heavy ions

$AuAu \rightarrow (Au)^{\star}(Au)^{\star}J/\Psi; \quad \sqrt{s_{NN}} = 200\ \text{GeV}(2010)$



- heavy vector meson production probe short distance scales
- scattering may be described via 2-gluon exchange
- sensitive to gluon distribution at $x \approx 0.01$ and $Q^2 \approx M^2_{J/\Psi}$
- directly probe new type of matter like color glass condensate

STAR Preliminary



- exactly two tracks from the vertex
- pair transverse momentum < 0.15 GeV
- pair rapidity $0.05 < |y| < 1$
- like-sign Background subtracted
- efficiency corrected

Summary and outlook

$pp \to ppX, \quad X = \pi^+\pi^-$

- measurement of the CEP of $\pi^+\pi^-$ pairs in pp collisions at $\sqrt{s} = 200$ GeV using Roman Pot tagging of the diffractively scattered protons has been shown
- very small non-exclusive background, estimated by like-sign content of the two-pion sample, has been demonstrated
- further studies of the 200 GeV sample (cross section, interpretation of the measured spectrum, angular distributions, spin dependence, comparison with models) in progress
- preparation for the analogous measurement at 500 GeV in 2013 in progress (30-40 times larger statistics, PWA possible)
- possible trigger based on Rapidity Gap method instead of proton tagging gives access to the very small $-t$ ($\gamma I\!P$ and $\gamma\gamma$ CEP)

$AuAu \to (Au)^\star(Au)^\star X, \quad X = \rho, J/\Psi$

- measurement of the central exclusive production of ρ^0 and J/Ψ vector mesons in the ultra-peripheral collisions of Au-Au at $\sqrt{s_{NN}}$ range 64-200 GeV has been shown
- analysis of the large set of data (2010) in progress
- we will soon complement this data set with a similar size set collected in run 2011