STAR results on Central Exclusive Production in proton-proton collisions

Mariusz Przybycień
AGH University of Science and Technology, Krakow, Poland

(on behalf of the STAR Collaboration)

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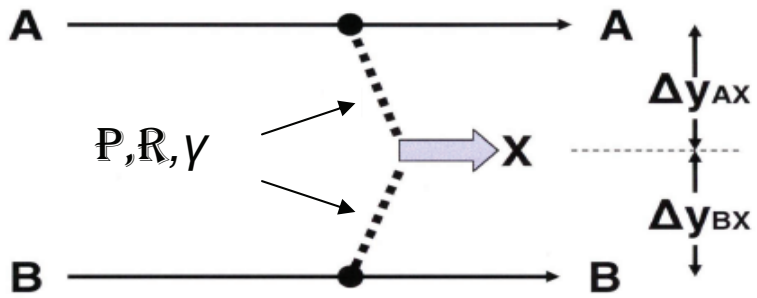
Central Exclusive Production and DPE

Central Exclusive Production

- $A + B \to A + X + B$
- colliding particles emerge intact,
- produced state X is fully measured,
- X couples to colour neutral objects: Regge trajectories, photons



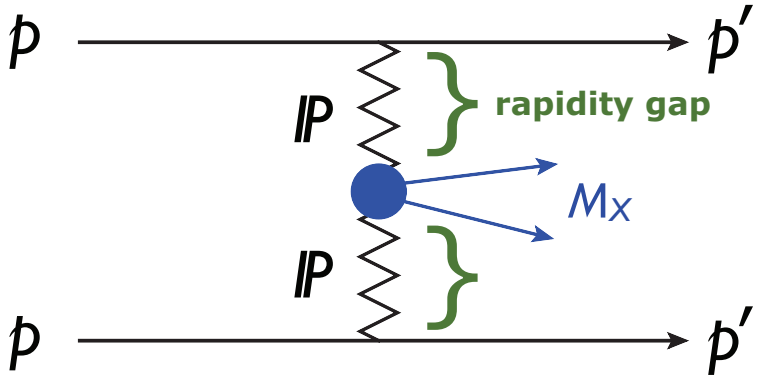
For hadronic processes at high energies CEP is dominated by Double Pomeron Exchange (DPE), photon-Pomeron or photon-photon fusion.

In DPE process each proton 'emits' a Pomeron and the two Pomerons interact producing a final masive state M_X.

Kinematics:

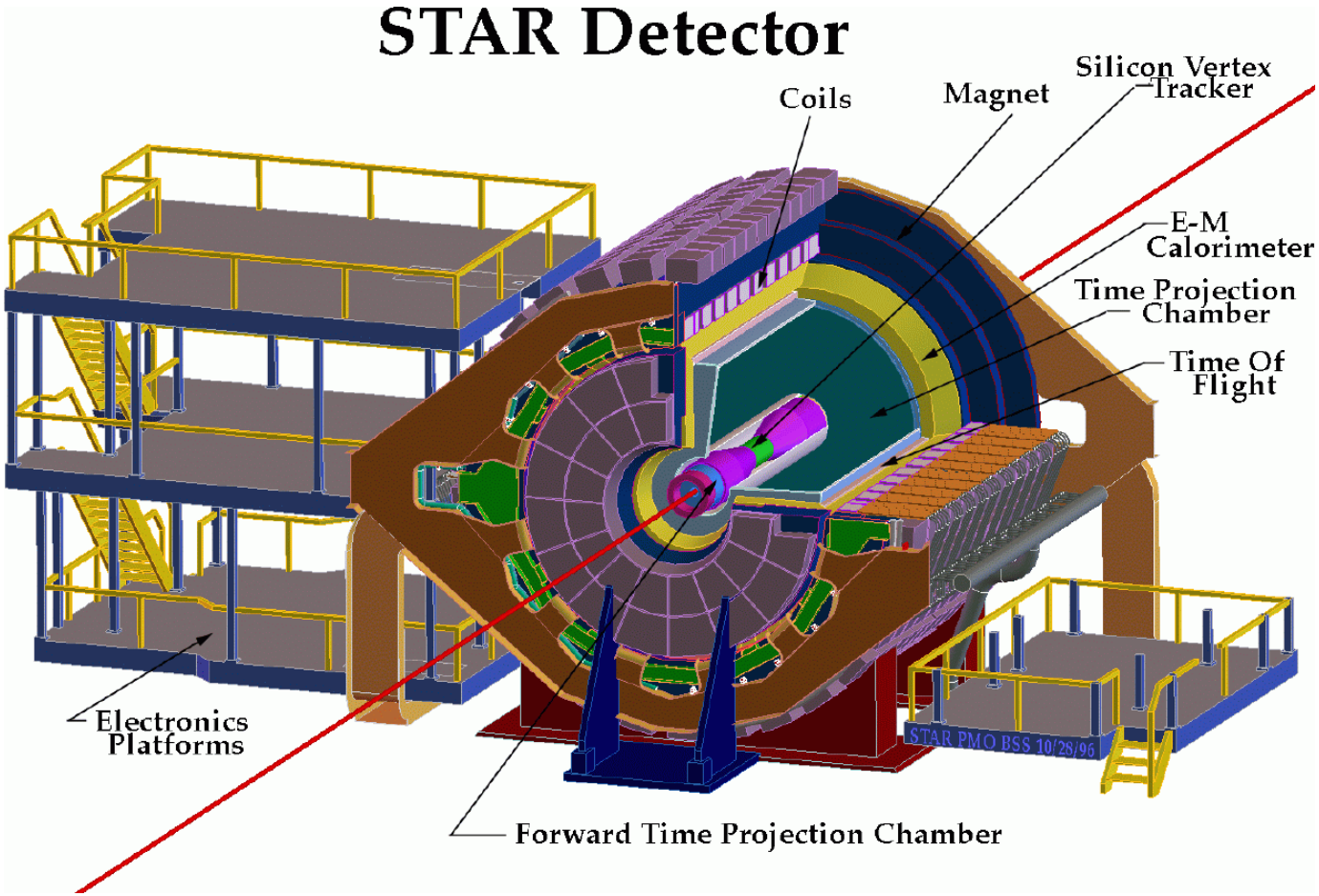
- t – four momentum transfer
- $\xi = \Delta p/p$ - momentum loss of the proton
- Invariant mass: $M_X = \sqrt{\xi_1 \xi_2 s}$

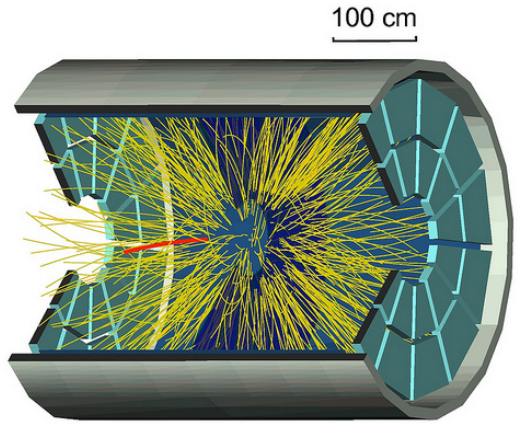
$M_X = \pi^+\pi^-, \chi_c(\chi_b), qq(\text{jets}), gg(\text{gluballs}), ...$

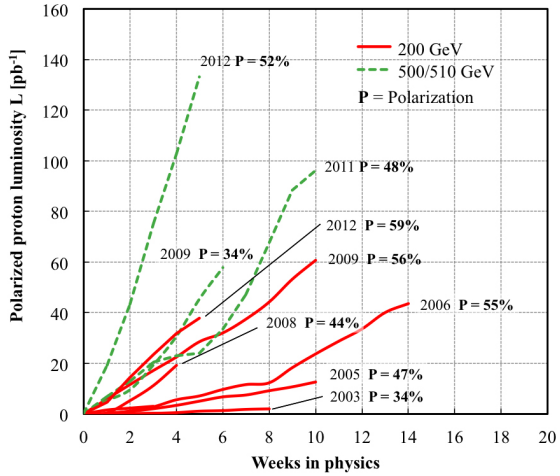


DPE is a spin-parity-isospin filter $I^G J^{PC}$ for system X: 0^+0^{++}, 0^+2^{++}
Diffractive photoproduction (γ+Pomeron) of vector particles ($J/\Psi, \rho, ...$)

STAR - Solenoidal Tracker At RHIC





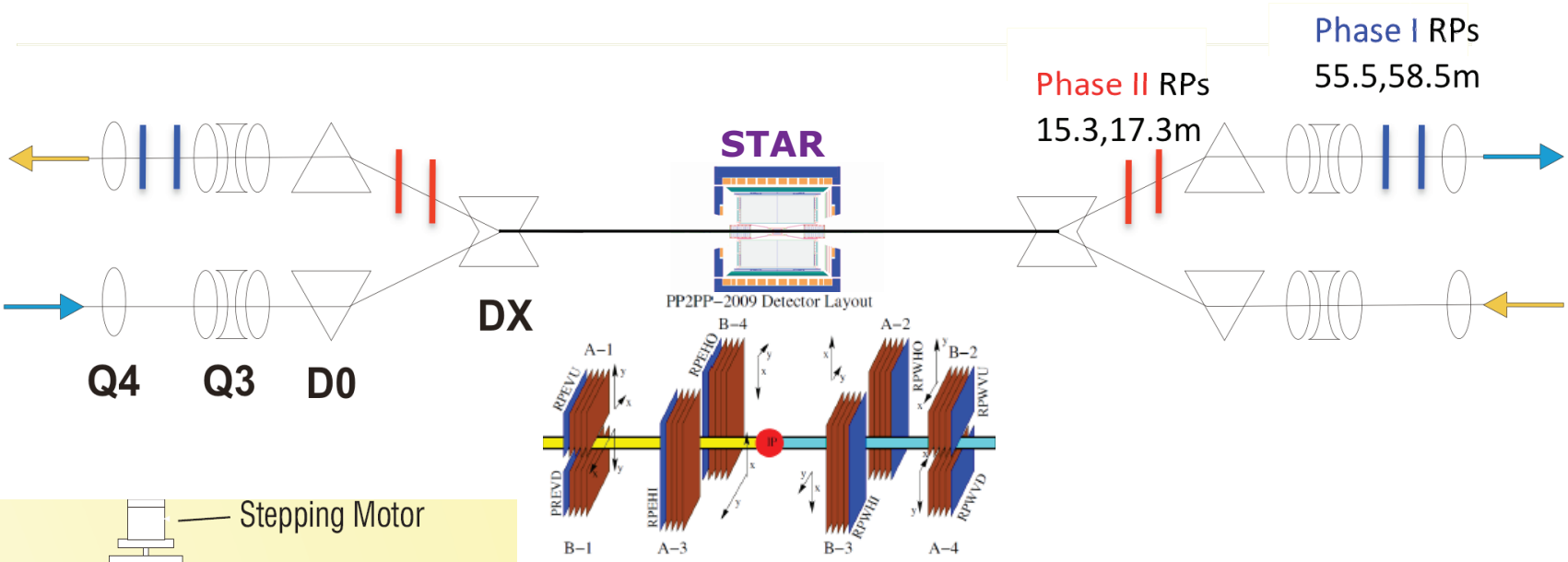


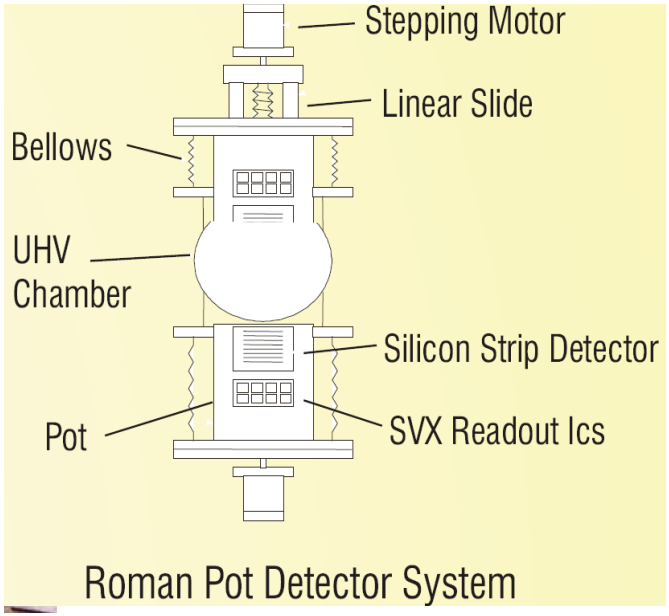
STAR - large acceptance detector running since 2000

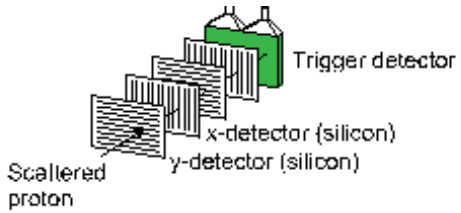
- high resolution tracking device: TPC in $-1 < \eta < 1, \quad -\pi < \phi < \pi$
- forward rapidity gap veto: FTPC: $2.5 < |\eta| < 4.2$, BBC: $3.8 < |\eta| < 5.2$
- excellent particle identification capability: TPC dE/dx, ToF
- this analysis is based on data collected in 2009 during 5 day period of running with special optics $\beta^* = 20$ m.

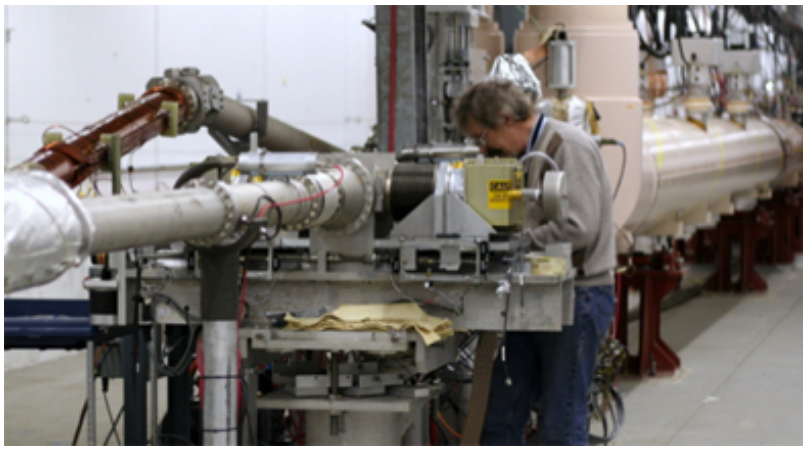
Forward Proton Taggers

Need detectors (Roman Pots) to measure forward protons:
small t (four momentum transfer) and ξ (fraction of proton momentum loss).









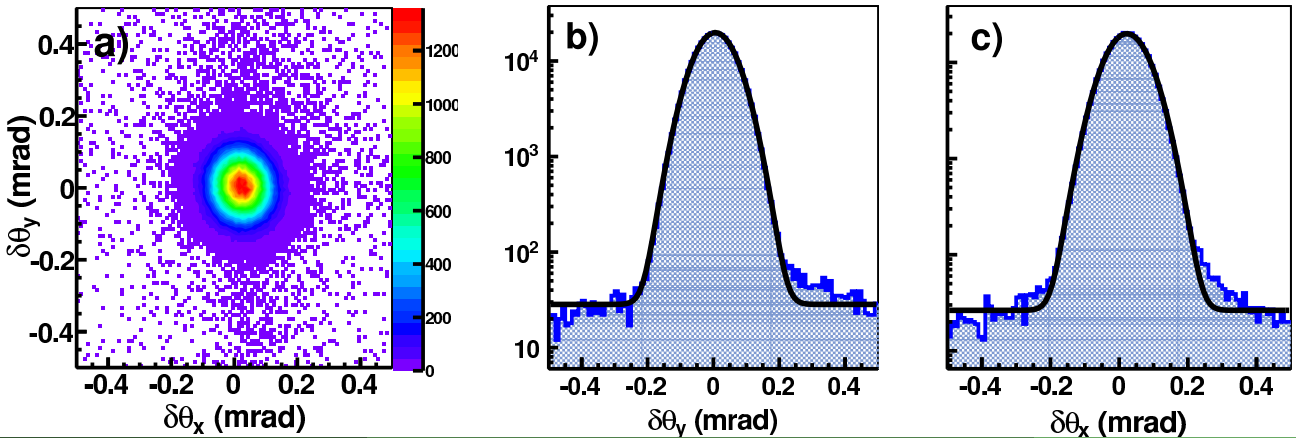
Principle of the measurement of forward protons

Beam transport equations relate measured position to scattering angle at IP:

$$\begin{pmatrix} x_D \\ \theta^x_D \\ y_D \\ \theta^y_D \end{pmatrix} = \begin{pmatrix} a_{11} & L^x_{eff} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L^y_{eff} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \theta^\star_x \\ y_0 \\ \theta^\star_y \end{pmatrix}$$

x_0, y_0 - position at the IP
$\theta^\star_x$, $\theta^\star_y$ - scattering angle at IP
x_D, y_D - position at detector
θ^x_D, θ^y_D - angle at detector

- run 2009: both beams transversely polarized with 60% polarization,
- excellent detector performance - nearly 100% efficiency and only 5 dead/noisy strips per aprox. 14000 active strips,
- full ϕ coverage,
- ideal optics $\beta^\star = 21$ m - terms other than L_{eff} were very small,
- single beam divergence 40 μrad (typical scattering angle 1 mrad),



Central Exclusive Production of $\pi^+\pi^-$ pairs

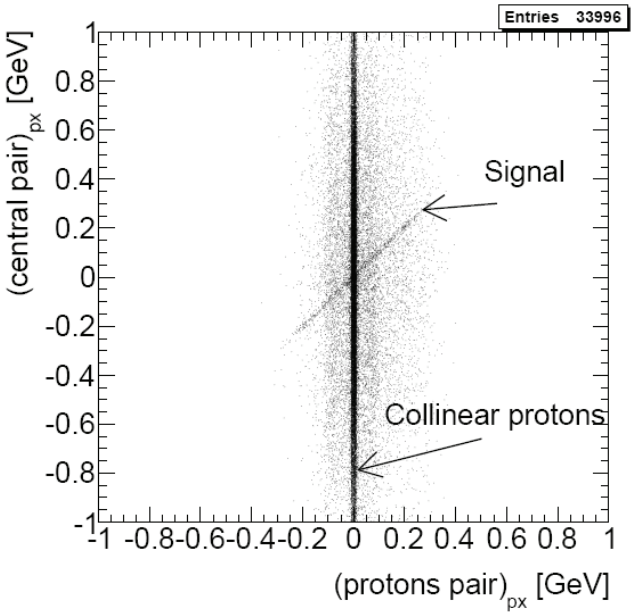
Use of polarized $p+p$ data collected at $\sqrt{s} = 200$ GeV in 2009 (Run 9)

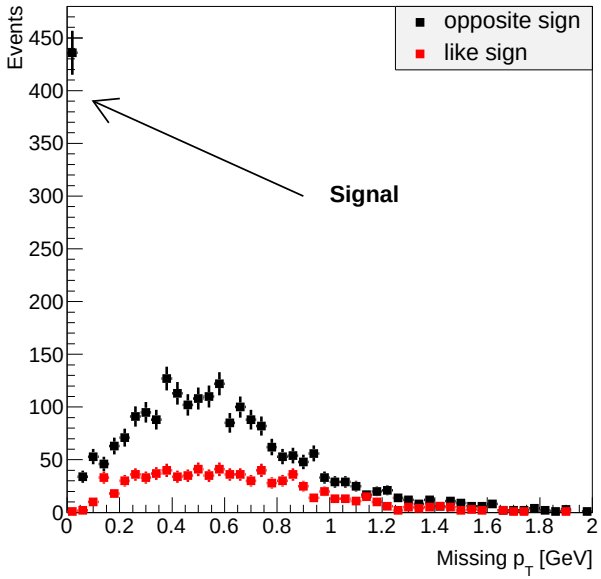
Kinematical limits:

- $0.003 < |t| < 0.035$ GeV^2
- $0.5 < M_{\pi\pi} < 2.3$ GeV

Data selection:

- RP trigger - two forward protons
  $0.005 < t_1, t_2 < 0.03$ GeV^2 ($p_{1,2} \approx 100$ GeV)
- two opposite charge tracks in TPC,
  ($|\eta| < 1$, $p_T > 0.15$ GeV, > 15 hits, from PV)
- at least one track matched with ToF hit
  - this cut removes elastic events with overlaping TPC tracks not belonging to the same interaction vertex or cosmic,
- transverse momentum balance
  $p_T^{miss} = |(\vec{p}_1 + \vec{p}_2 + \vec{\pi}_1 + \vec{\pi}_2)_T| < 0.02$ GeV
  (removes overlaping ev. and the non-exclusive background.)





Detector efficiency and acceptance

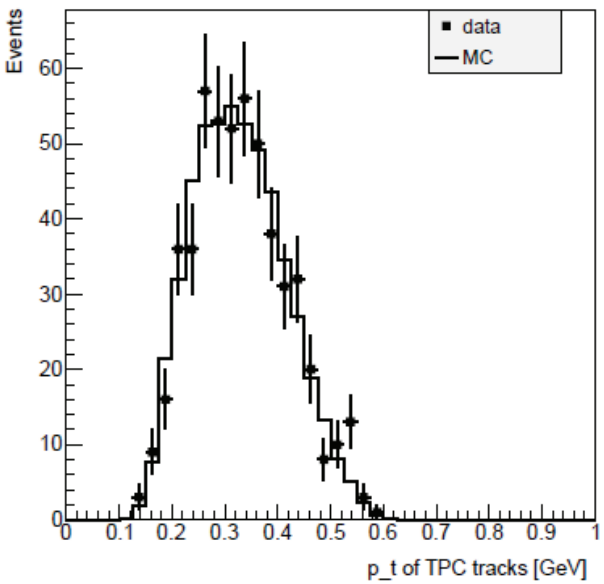
Data were corrected for geometrical acceptance, trigger and detector efficiency using simple generator ansatz for $pp \to ppX$ process:

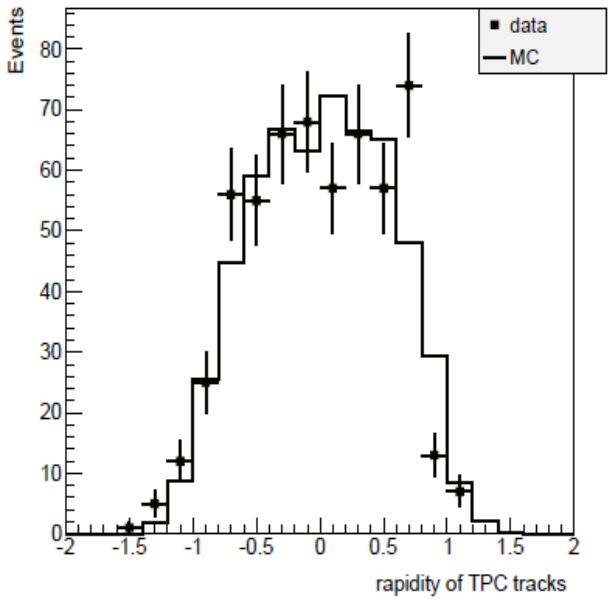
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t_1 \mathrm{d}t_2 \mathrm{d}M_X^2 \mathrm{d}y} \propto \mathrm{e}^{bt_1} \mathrm{e}^{bt_2} \frac{1}{M_X^2}$$

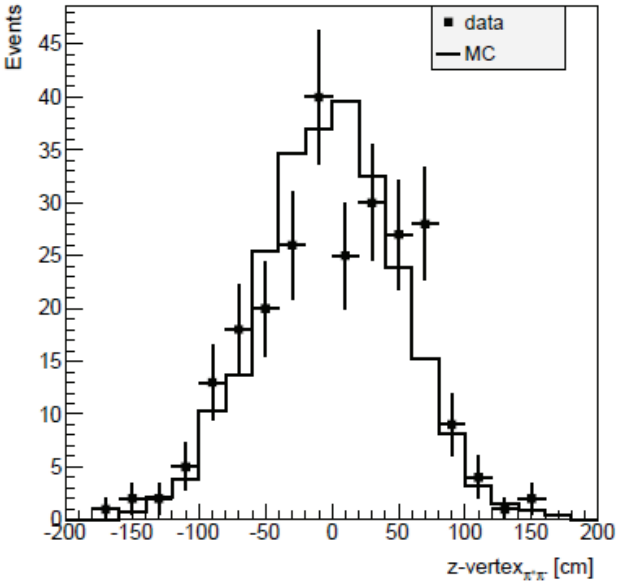
with isotropic decay of $X \to \pi^+\pi^-$ in X rest frame.

Generated events were passed through full STAR detector simulation of TPC and ToF and Geant4 simulation of beam line and RP trigger and acceptance.

Data distributions are very good described by the simulation (Monte Carlo predictions are normalized to data).







Total cross section in visible kinematic range

Definition of visible kinematic range:

- momentum transfered to protons: $0.005 < -t_1, -t_2 < 0.03\ \mathrm{GeV}^2$
- pseudorapidity of pions measured in TPC: $|\eta_\pi| < 1.0$
- pseudorapidity of $\pi\pi$ system: $|\eta_{\pi\pi}| < 2.0$

Data are normalized using elastic pp scattering events measured in the same experiment and $\sigma_{\mathrm{tot}} = 51.6$ mb (from fit to world data). As the RP trigger and detector are common for elastic stattering and central production, many systematic uncertainties cancel out in cross section calculation.

Preliminary cross section for Central Exclusive Production of $\pi^+\pi^-$ pairs in pp collisions at $\sqrt{s} = 200$ GeV in visible kinematic range:

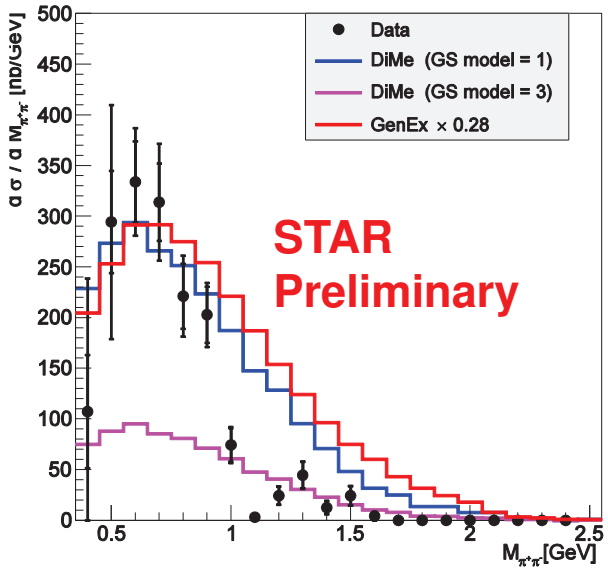
$$\sigma_{\mathrm{CEP}}(200) = 133 \pm 8\,(\mathrm{stat}) \pm 12\,(\mathrm{syst})\ \mathrm{nb}$$

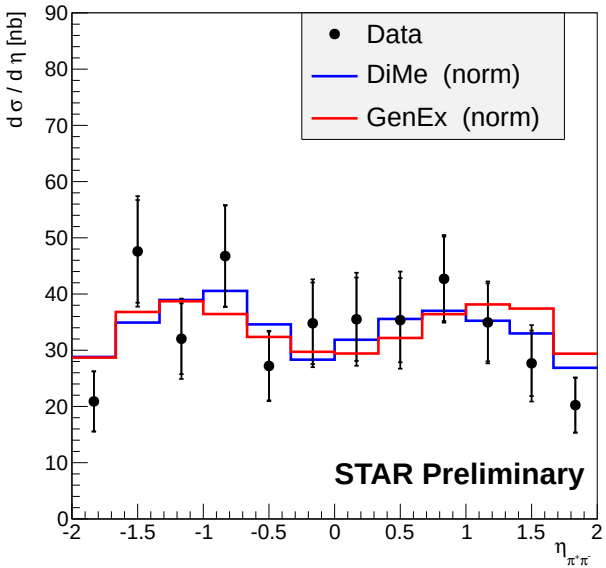
Main sources of systematic uncertainty:

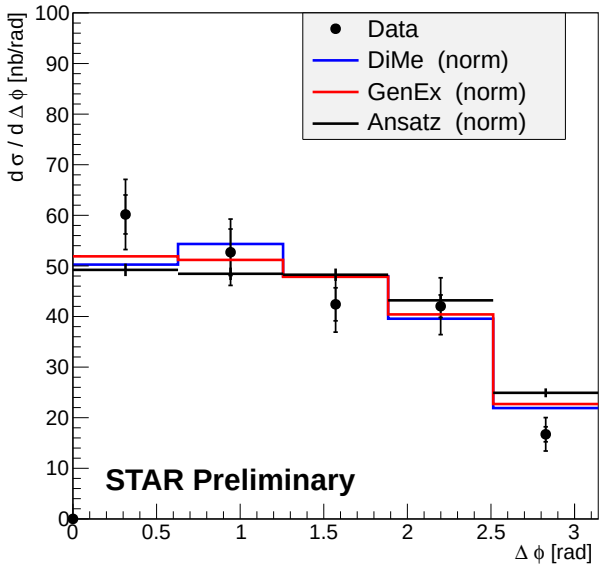
- sensitivity to variation of TPC track selection cuts - 6%
- uncertainty of absolute normalization using elastic sample - 5%
- uncertainty of ToF trigger efficiency - 5% (estimated from ToF independent trigger)

Differential cross sections measurements

- Dime model (Eur. Phys. J. C (2014) 74:2848, http://dimemc.hepforge.org) for non-resonant background with model 1 gap survival is consistent with the measured cross section.
- GenEx model (based on Phys. Rev. D81 (2010) 036003) is also consistent with measured cross section assuming survival factor ≈ 0.28.
- Cross sections in function of $\eta_{\pi\pi}$ and $\Delta\phi$ (difference in azimuthal angle of the scattered protons) in the mass range $0.5 < M_{\pi\pi} < 1$ GeV are also well described by both models (predictions of the models are normalized to measured cross section in this mass range).

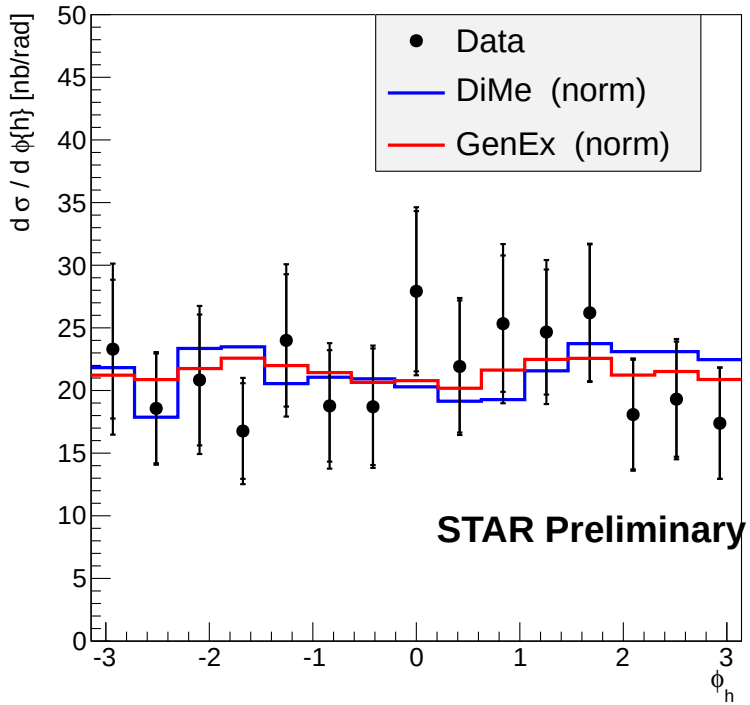


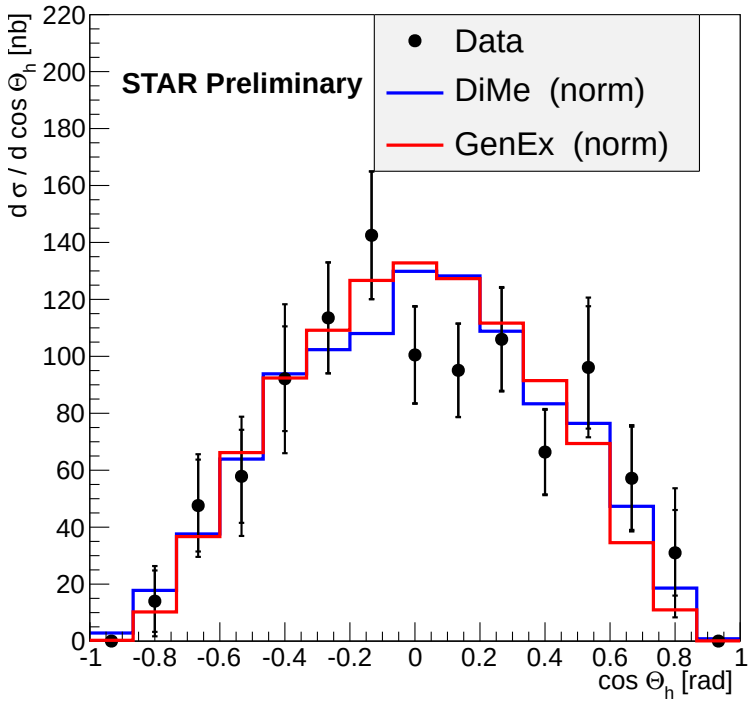




Helicity angles of π^+ in the rest frame of $\pi\pi$ system

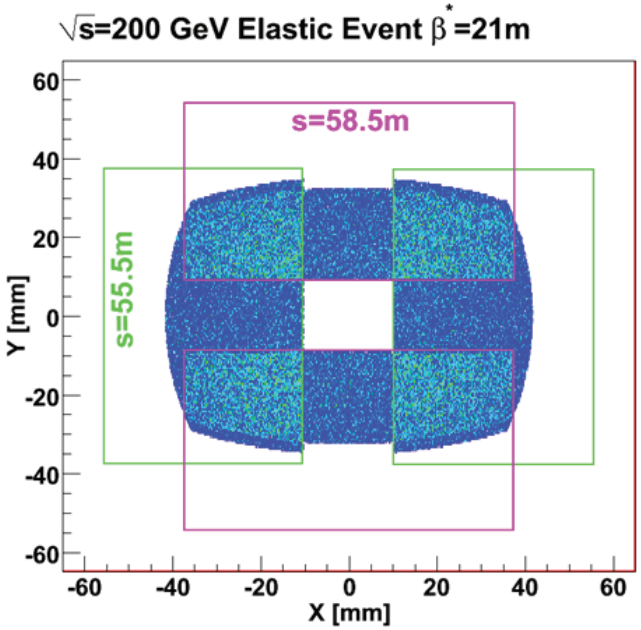
- Angular distributions in the rest frame of the $\pi\pi$ system are well described.

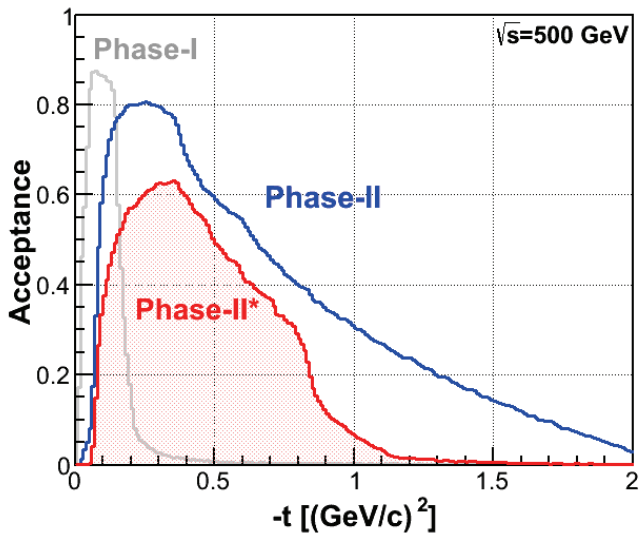


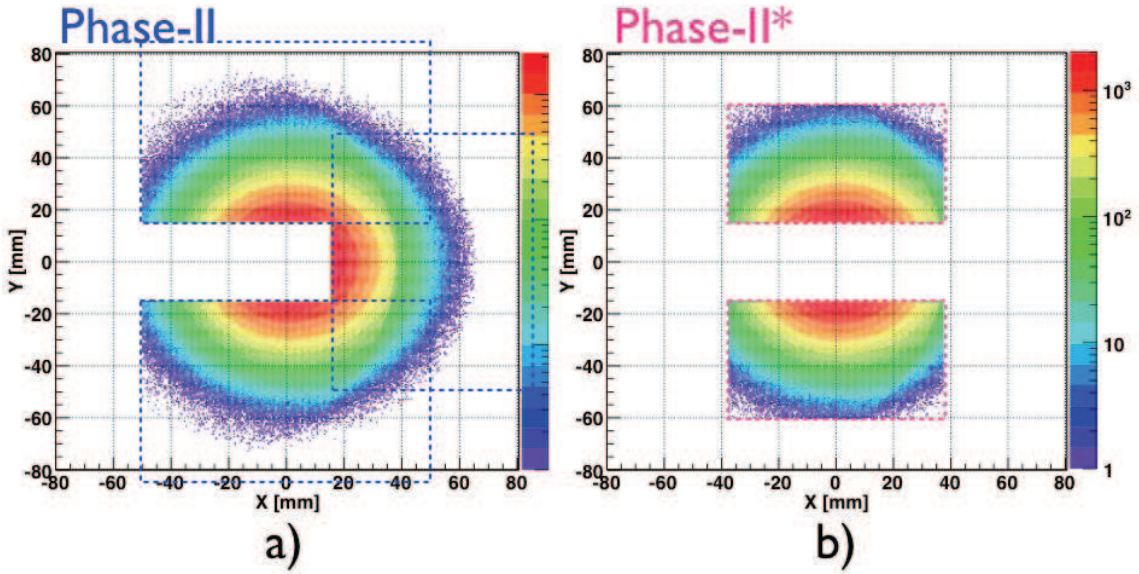


Acceptance in phase 1 vs. pahse 2

- Phase I (2009): $\sqrt{s} = 200$ GeV
  - $0.003 < t < 0.035$ GeV^2
  - invariant mass reach, $M_X^{max} = 10$ GeV
- Phase II*, II (2015 $\rightarrow$): $\sqrt{s} = 200,\ 500$ GeV
  - $0.003 < t < 2.3$ GeV^2
  - wide rapidity gaps, beam rapidity $y \sim 6.3$ for $M_X < 3$ GeV, rapidity gap > 4 units
  - higher reach in inv. mass, $M_X^{max} = 25$ GeV
  - no special beam optics required, high lumi







Summary and outlook

- STAR has provided preliminary results on Central Exclusive Production of $\pi^+\pi^-$ pairs in DPE in proton-proton collisions at $\sqrt{s} = 200$ GeV,
- the Roman Pot technique has been used for tagging of the diffractively scattered protons at very small momentum transfers ($0.005 < t < 0.03$ GeV^2),
- the non-exclusive background, estimated with like-sign content of selected two pion sample, has been demonstrated to be negligible,
- preliminary cross section for CEP of $\pi^+\pi^-$ pairs in visible kinematic range: $\sigma_{\mathrm{CEP}}(200) = 133 \pm 8(\mathrm{stat}) \pm 12(\mathrm{syst})$ nb,
- predictions of cross section for non-resonant background (DIME and GenEx generators) based on Regge model tuned to ISR measurement of CEP at $\sqrt{s} = 62$ GeV are consistent with the present measurement, taking into account uncertainty of the survival factor calculation,
- shapes of the measured distributions are well described by both models,
- preparations for the CEP measurements with the STAR detector at $\sqrt{s} = 200$ and 510 GeV in broader t-range and with significantly larger statistics are ongoing.

Thank you for your attention!