Recent results on central exclusive production with the STAR detector at RHIC

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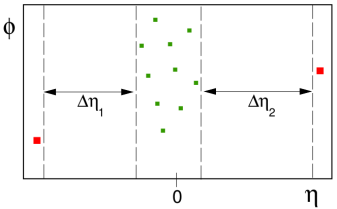
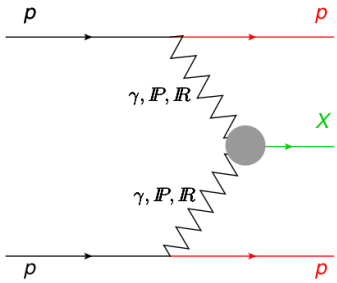
- Colliding protons stay intact and are measured in the Roman Pots (RP)
- Produced **central** system X is well separated by rapidity gaps $\Delta\eta_{1,2}$ from the outgoing protons p
- **Central** system X is fully measured in the Time Projection Chamber (TPC) and in the Time-of-Flight (TOF) systems

$$p + p \to p \overset{\Delta\eta_1}{\oplus} X \overset{\Delta\eta_2}{\oplus} p$$



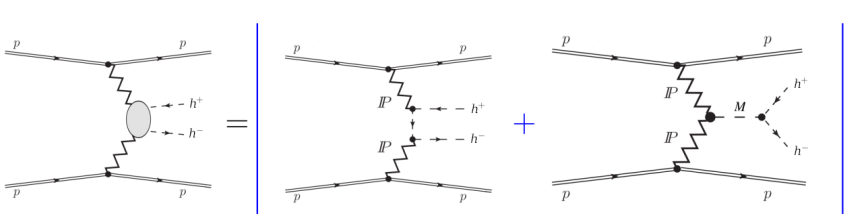
Possible mechanisms of CEP:

- Double Photon Exchange
  $\gamma + \gamma \to \gamma\gamma, l^+l^-, W^+W^-$
- Photon − IPomeron/ IRegeon fusion (photoproduction)
  $\gamma + \mathbb{P}/\mathbb{R} \to$ (pseudo)vector mesons, continuum
- Double IPomeron Exchange
  $\mathbb{P} + \mathbb{P} \to$ continuum, scalar/tensor mesons, glueballs



DIPE is expected to be dominant at the RHIC energies

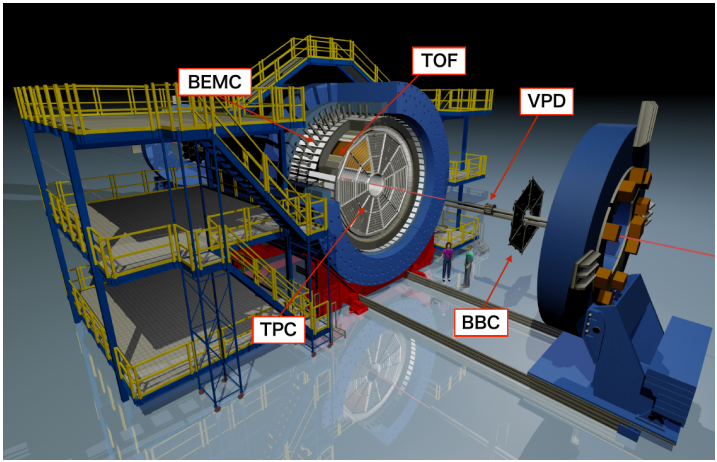
- CEP of h^+h^- is the simplest four(three) body QCD process: $p + p \to p + M(h^+h^-) + p$
- Topologically simple, theoretically complex and rich in phenomena
- Pomeron in QCD at lowest order is represnted by a pair of gluons
  $\Rightarrow$ DIPE is suitable for glueball production
- Dominantly low masses produced ($\lesssim 2$ GeV), lack of hard scale and pQCD not applicable
- Significant rescattering (absorption) effects via additional interaction between the protons
- Significant interference effects between resonance and continuum production



- Two phenomenological models based on Regge theory implemented in the form of MC generator:
  - **DiMe**: L.A. Harland-Lang et al., Eur. Phys. J. C72 (2012) 2110
    The phenomenology of CEP at hadron collider (dynamical treatment of absorption effects)
  - **GenEx**: P. Lebiedowicz and A. Szczurek, Phys. Rev. D81(2010)036003
    Exclusive $pp \to pp\pi\pi$ from the threshold to LHC (without absorptive corrections)
- Models can generate **only continuum** production
- Continuum also generated in Pythia8, with MBR model - R. Ciesielski, K. Goulianos, arXiv:1205.1446

- **GRANIITTI**, a MC generator for high energy diffraction - M. Mieskolainen, arXiv:1910.06300
- GRANIITTI calculates inv. mass spectra assuming continuum and resonances contributions
  $M = f_0(500),\ \rho(770),\ f_0(980),\ \phi(1020),\ f_2(1270),\ f_0(1500),\ f_2(1525),\ f_0(1710)$
- Added CEP resonance couplings also tuned to STAR results at $\sqrt{s} = 200$ GeV

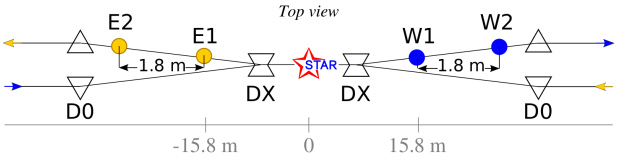
- Tracking of charged particles in the TPC covering $|\eta| < 1$ and full azimuthal angle
- Precise particle identification through the measurement of dE/dx and TOF
- Forward rapidity Beam-Beam Counters ($2.1 < |\eta| < 5.0$) used to ensure rapidity gaps
- Silicon Strip Detectors (SSD) in RP allow full reconstruction of the forward proton momentum and verification of interaction's exclusivity

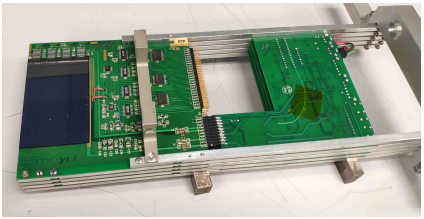


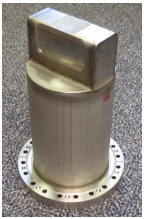
- Roman Pot Phase II* setup has been used since 2015

  S. Bültmann et al., Nucl. Instr. Meth. A535, 415 (2004)

- Detectors are mounted in 4 stations, 2 stations on each side of STAR
- Each station holds one RP above and one RP below the beamline
- Each RP vessel contains a SSD package with active area of $\sim 8 \times 5$ cm^2
- Each package consists of a scintillation trigger counter and 4 SSDs with spatial resolution of $\approx$ 30 μm

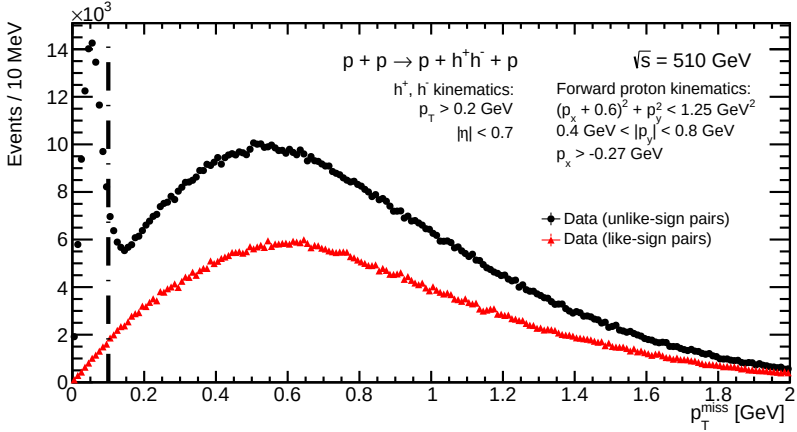






- Outgoing protons pp and cental system h^+h^- are fully measured
- The momentum conservation is used to verify **exclusivity** of the process

$$p_{\mathrm{T}}^{miss} := \left(\vec{p}_1 + \vec{p}_2 + \vec{h}_+ + \vec{h}_-\right)_{\mathrm{T}} = 0$$

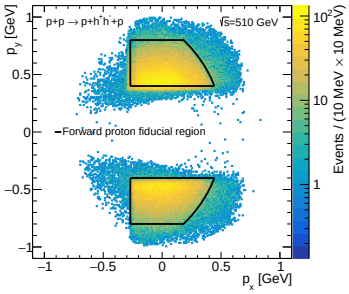


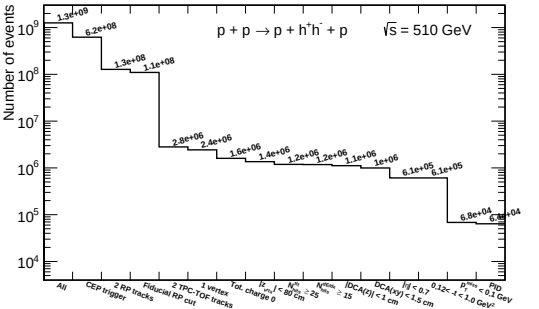
Data sample:

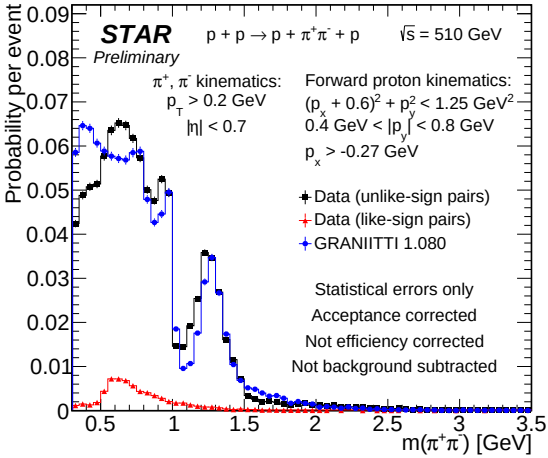
- Data from proton-proton collisions at $\sqrt{s} = 510$ GeV
- 622M events with CEP triggers were analyzed

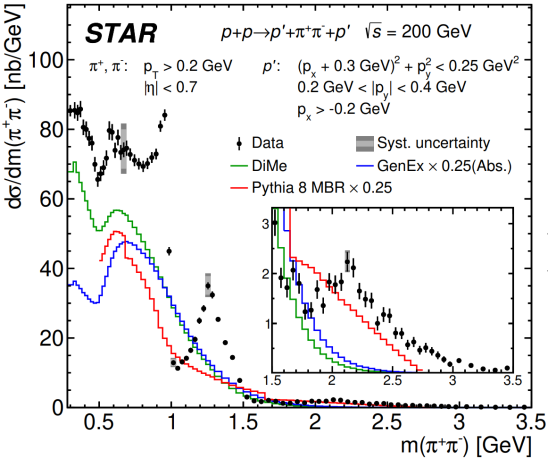
Events selection:

- Exactly two tracks in Roman Pots inside the p_x, p_y fiducial region with all eight silicon planes used in reconstruction
- Exactly two primary TPC tracks matched with two TOF hits and originating from the same vertex
- Total charge of those tracks equals 0 (looking for h^+h^-)
- $|z\text{-position of vertex}| < 80$ cm
- Good TPC track quality cuts and $|\eta| < 0.7$
- Exclusivity cut: $p_{\mathrm{T}}^{miss} < 100$ MeV
- Particles were identified using the dE/dx and TOF
- After all the above selection criteria:
  62077 $\pi^+\pi^-$, 1697 K^+K^- and 125 $p\bar{p}$



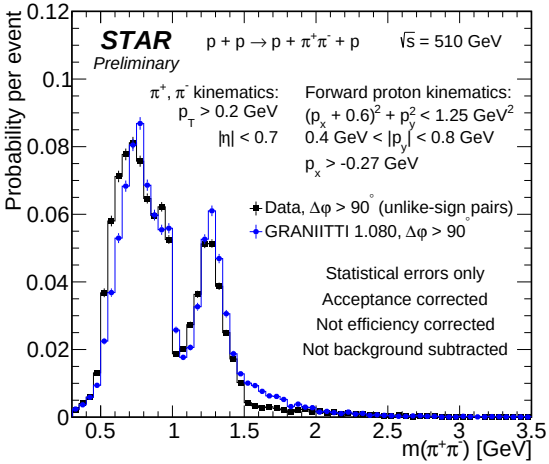


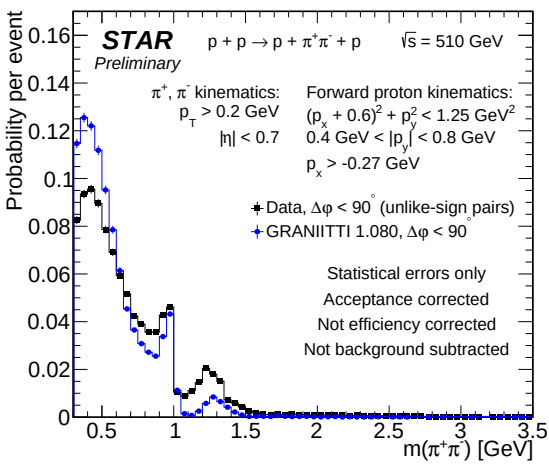


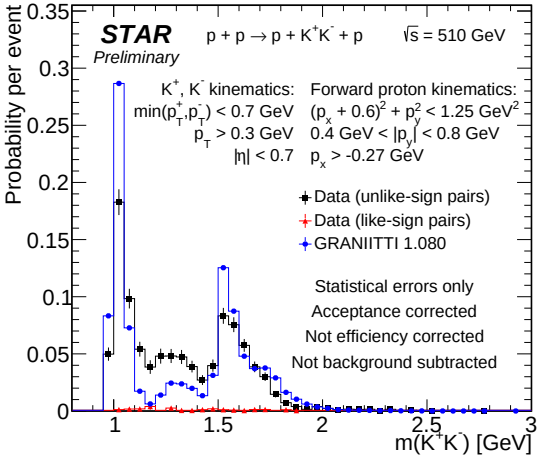


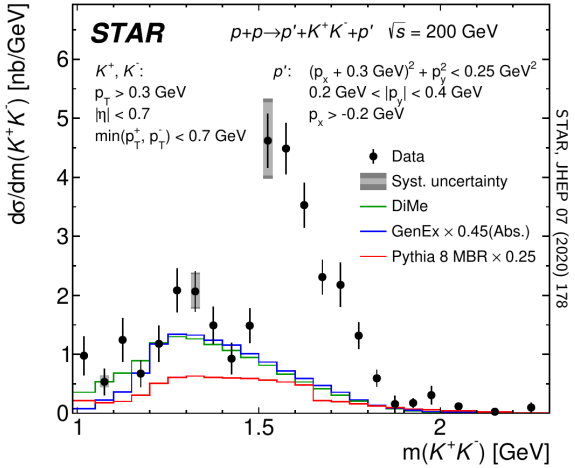
- Four times better precision of the cross section compared to previous DIPE measurement with forward proton tagging

- Spectra were divided into two $\Delta\varphi$ regions, the difference of azimuthal angles of the forward protons $\Rightarrow$ different Pomeron dynamics



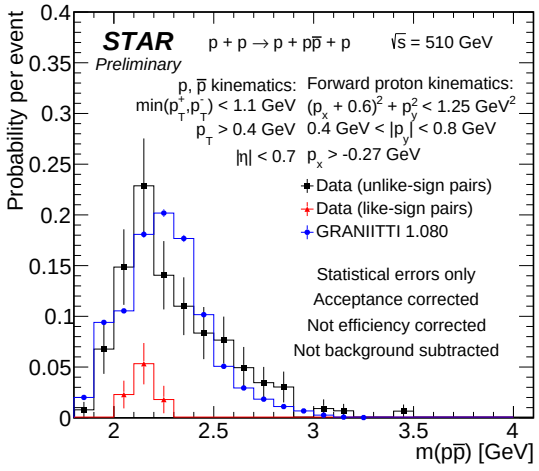


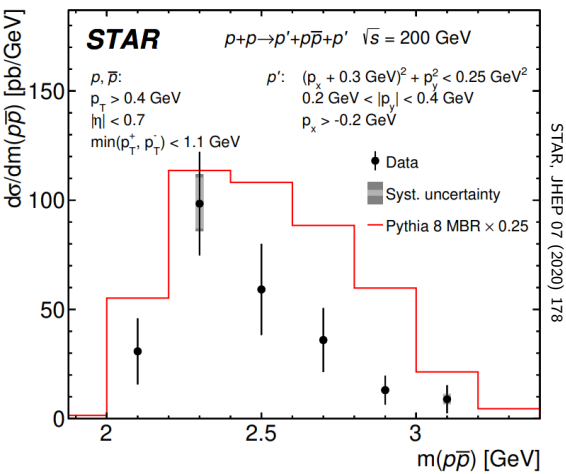




- A peak at 1 GeV (possible $\phi(1020)$ or $f_0(980)$) is close to the K^+K^- mass threshold
  $\Rightarrow$ more studies have to be done

Invariant mass of exclusively produced $p\bar{p}$





- The invariant mass spectrum of $p\bar{p}$ pairs does not show any resonances

- Results on the CEP of $\pi^+\pi^-$, K^+K^- and $p\bar{p}$ pairs in pp collisions at $\sqrt{s} = 200$ and 510 GeV measured by the STAR experiment at RHIC have been presented
- These are currently the highest center-of-mass energies at which the Double IPomeron Exchange has been measured with the detection of the forward-scattered protons
- Measurement of the diffractively scattered protons allowed full control of the interaction's kinematics and verification of its exclusivity
- High precision of this measurement, should help to constrain free parameters of the models
- The new MC generator, GRANIITTI, was compared to the data at $\sqrt{s} = 510$ GeV giving promising results
- The invariant mass spectra of $\pi^+\pi^-$, K^+K^- and $p\bar{p}$ pairs confirmed features seen in previous measurements
- Interesting features are seen, like the peak at about 1 GeV in K^+K^- at $\sqrt{s} = 510$ GeV

Thank you!

Backup

- Particles were identified using combined information from the TPC ($\chi^2_{dE/dx}$) and TOF (m^2_{TOF})

$$\chi^2_{dE/dx}(h^+h^-) = (n\sigma_{h^+})^2 + (n\sigma_{h^-})^2 \tag{1}$$

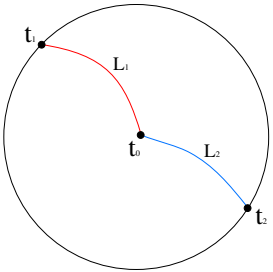
- m^2_{TOF} is derived from the assumption that both particles are of the same type ($m_1^2 = m_2^2 = m^2_{\mathrm{TOF}}$)

$$t_1 - t_0 = L_1\sqrt{1 + \frac{m_1^2}{p_1^2}} \tag{2}$$

$$t_2 - t_0 = L_2\sqrt{1 + \frac{m_2^2}{p_2^2}} \tag{3}$$

$$t_1 - t_2 = L_1\sqrt{1 + \frac{m_1^2}{p_1^2}} - L_2\sqrt{1 + \frac{m_2^2}{p_2^2}} \tag{4}$$

$$A \cdot (m^2_{\mathrm{TOF}})^2 + B \cdot m^2_{\mathrm{TOF}} + C = 0, \tag{5}$$



- $\pi^+\pi^-$ pairs production is dominant, as expected in DPE process at RHIC energies
- Kaons and protons can be seen in dE/dx plot
- Peaks of pions, kaons and protons about their real mass squared can be seen
- Pions misidentified as kaons, using only the dE/dx information, can be seen as well