

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

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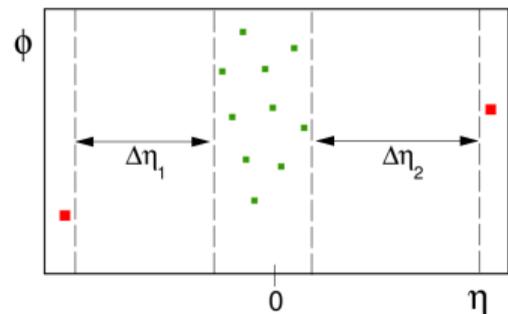


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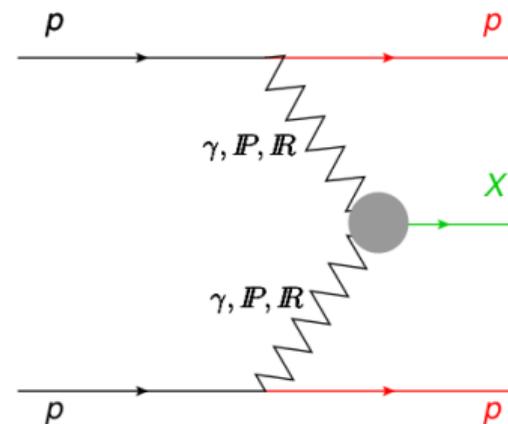
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- Colliding protons stay intact and are measured in the Roman Pots (RP)
- Produced **central** system X is well separated by rapidity gaps $\Delta\eta_{1,2}$ from the outgoing protons p
- **Central** system X is fully measured using the Time Projection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



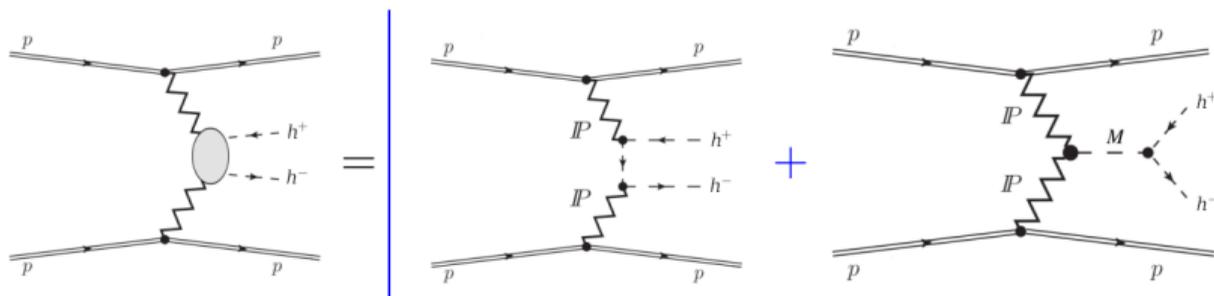
Possible mechanisms of CEP:

- Double Photon Exchange
 $\gamma + \gamma \rightarrow \gamma + \gamma / I^+ + I^- / W^+ + W^-$
- Photon – IPomeron / IReggeon fusion (photoproduction)
 $\gamma + \mathbb{P}/\mathbb{R} \rightarrow (\text{pseudo})\text{vector mesons} / \text{continuum}$
- Double IPomeron Exchange (DIPE)
 $\mathbb{P} + \mathbb{P} \rightarrow \text{continuum} / \text{scalar or tensor mesons} / \text{glueballs}$



DIPE is expected to be dominant at the RHIC energies

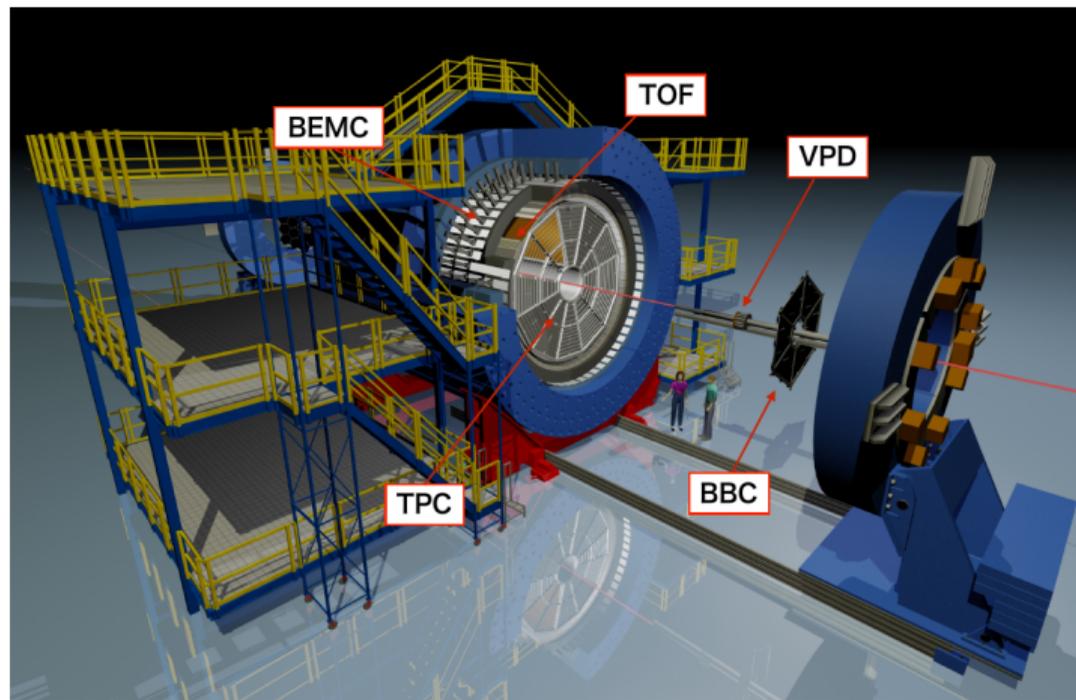
- CEP of h^+h^- is the simplest four(three) body QCD process: $p + p \rightarrow p + M(h^+h^-) + p$
- Topologically simple, theoretically complex and rich in phenomena
- Pomeron in QCD at lowest order is represented by a pair of gluons
 \Rightarrow DIPE is suitable for glueball production
- Pairs with low invariant mass ($\lesssim 2$ GeV) dominantly produced
 \Rightarrow 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



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- 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 $pp \rightarrow pp\pi\pi$ 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

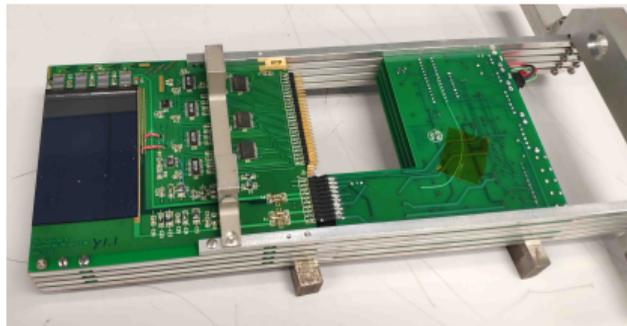
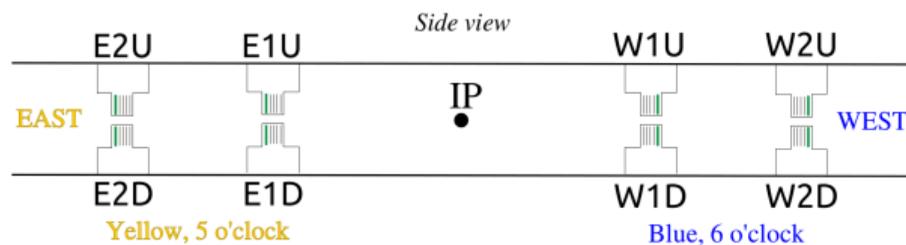
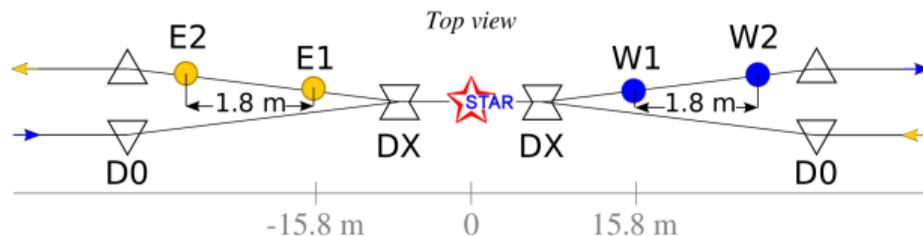
- Tracking of charged particles in the TPC covering $|\eta| < 1$ and full azimuthal angle
- Precise particle identification through the measurement of dE/dx and TOF
- Forward rapidity Beam-Beam Counters ($2.1 < |\eta| < 5.0$) used to ensure rapidity gaps
- Silicon Strip Detectors (SSD) in RP allow full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



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

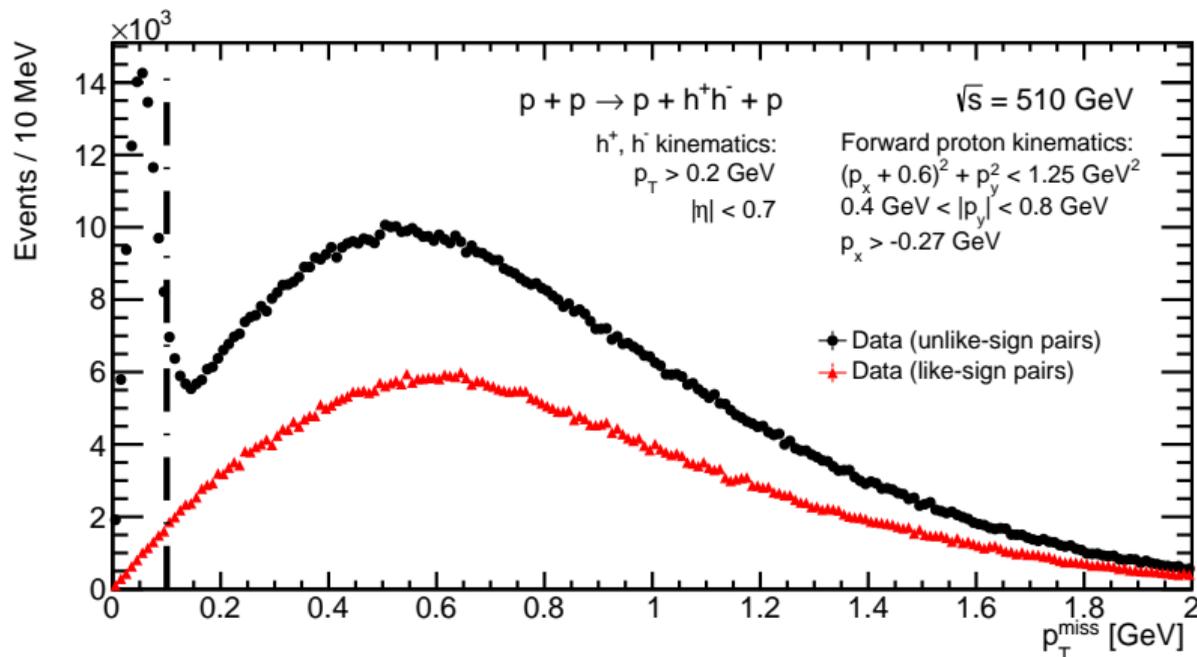
S. Bültmann et al., Nucl. Instr. Meth. A535, 415 (2004)

- 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 $\sim 8 \times 5 \text{ cm}^2$
- Each package consists of a scintillation trigger counter and 4 SSDs with spatial resolution of $\approx 30 \mu\text{m}$



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

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

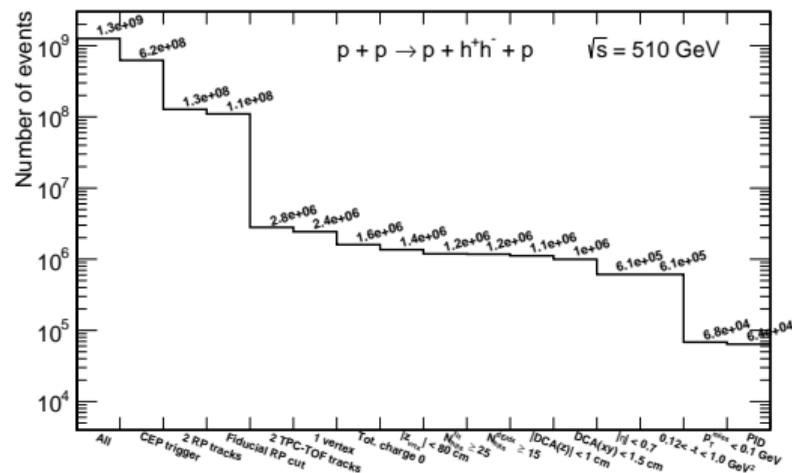
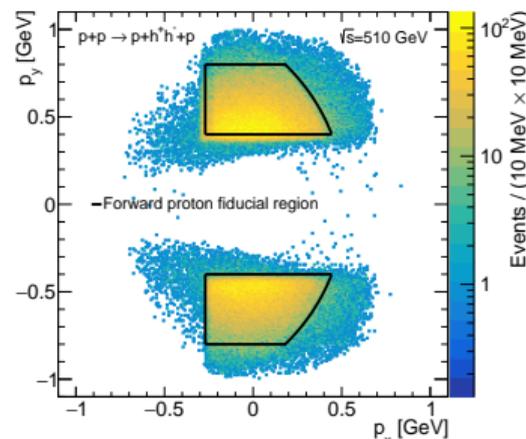


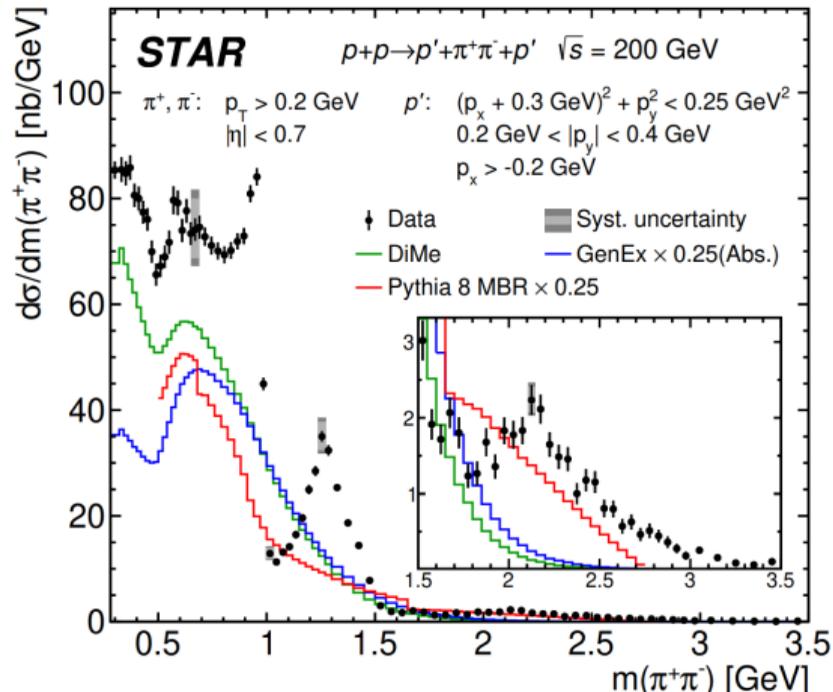
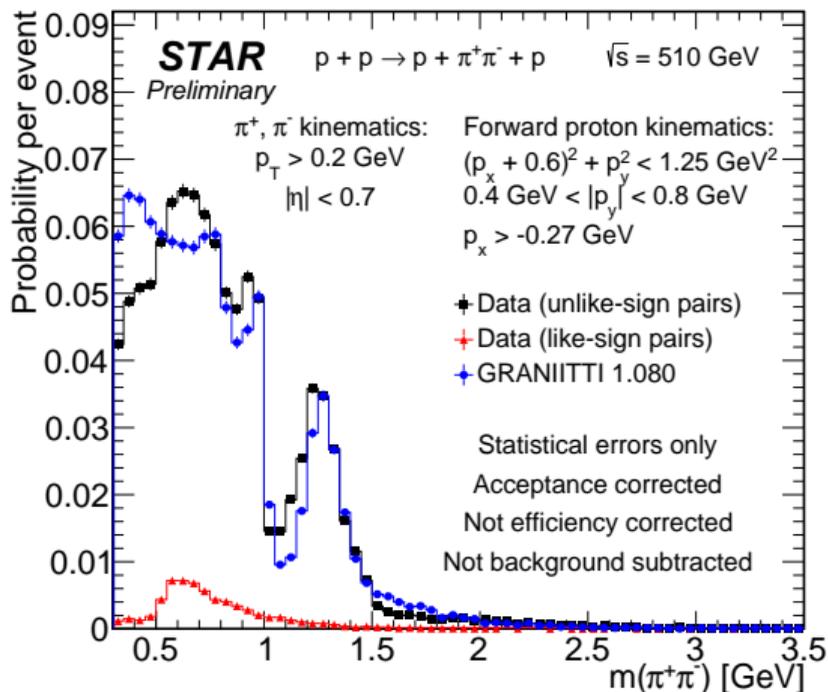
Data sample:

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

Events selection:

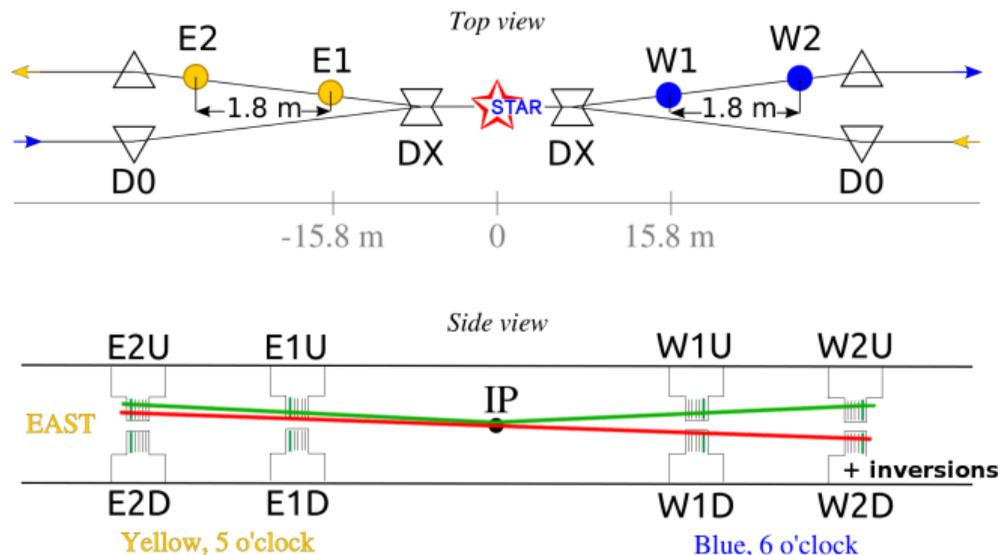
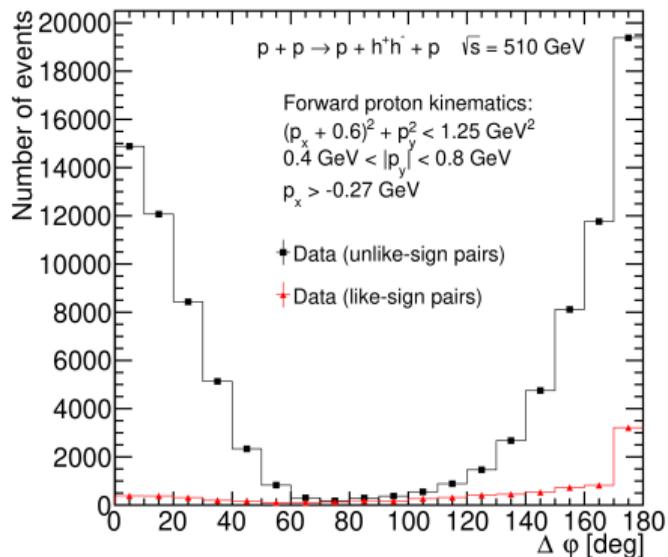
- Exactly two tracks in Roman Pots inside the p_x, p_y fiducial region with all eight silicon planes used in reconstruction
- Exactly two primary TPC tracks matched with two TOF hits and originating from the same vertex
- Total charge of those tracks equals 0 (looking for h^+h^-)
- $|z\text{-position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

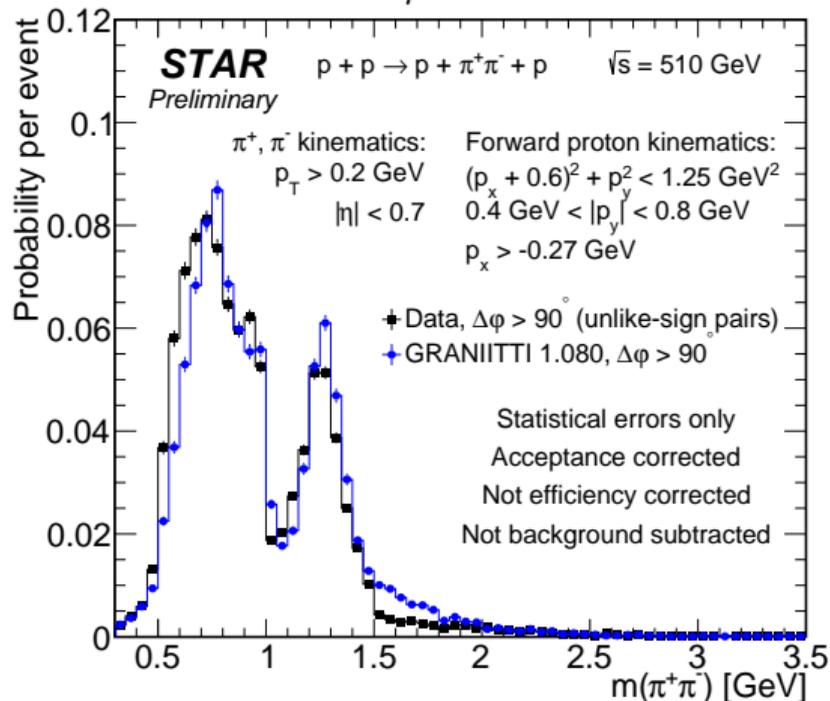
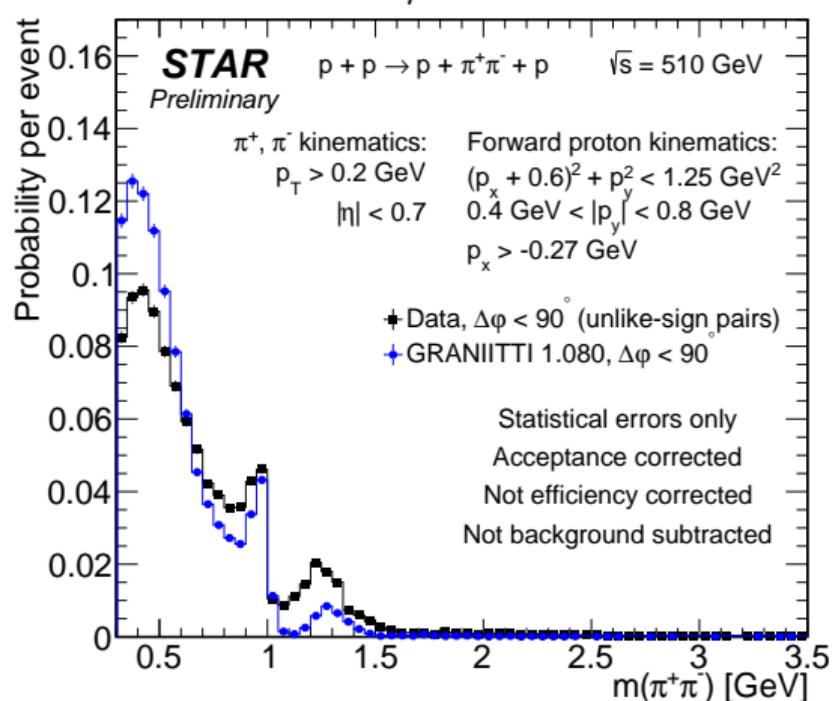


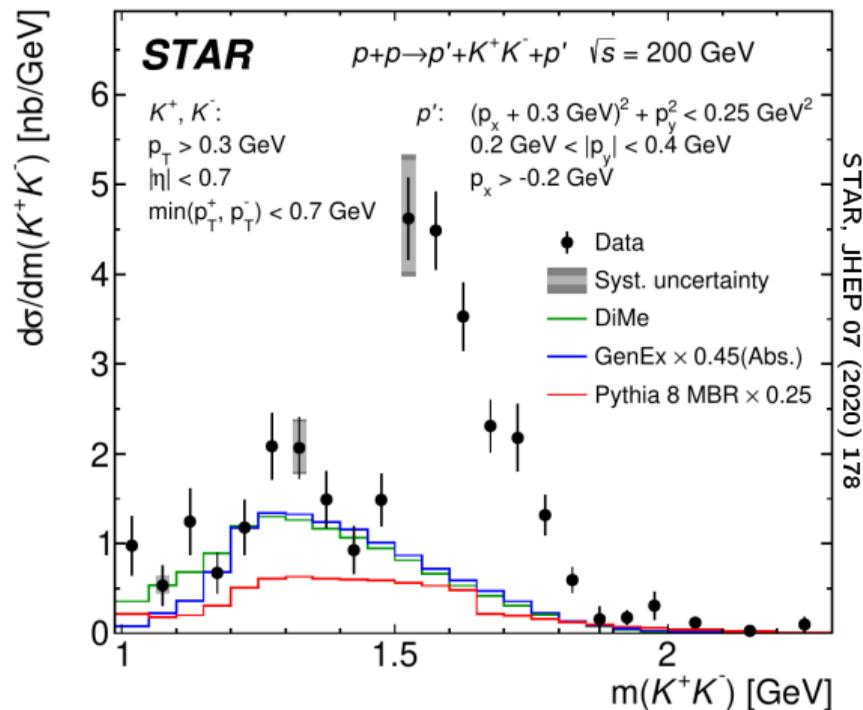
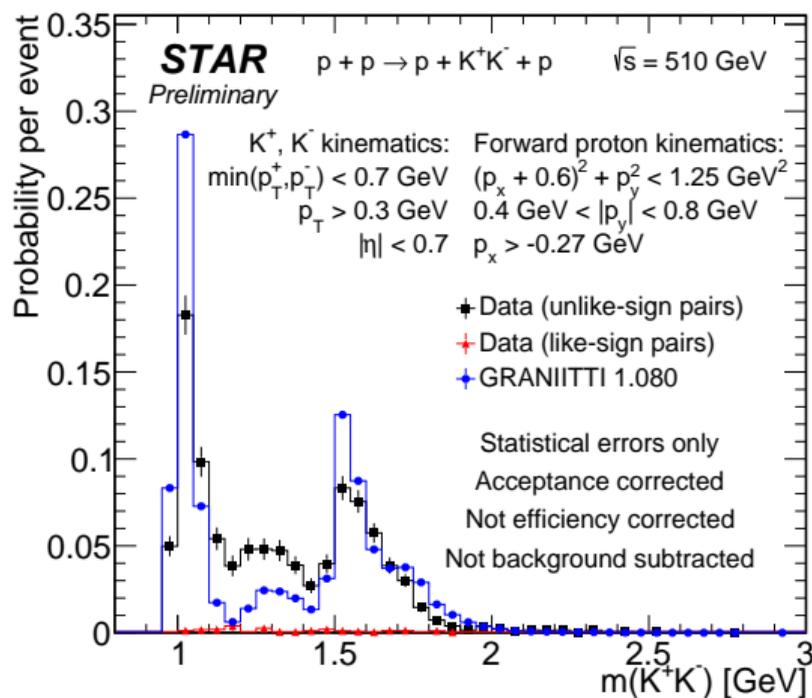


- Four times better precision of the cross section compared to previous DIPE measurement with forward proton tagging
- Systematic uncertainties for 200 GeV results are shown only for a few data points as they are almost fully correlated between neighboring bins

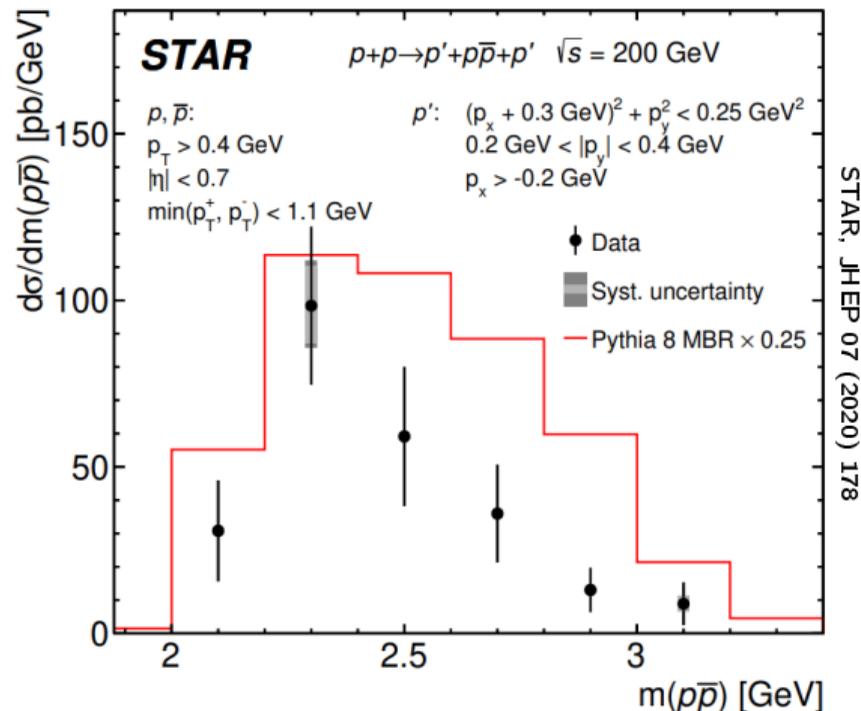
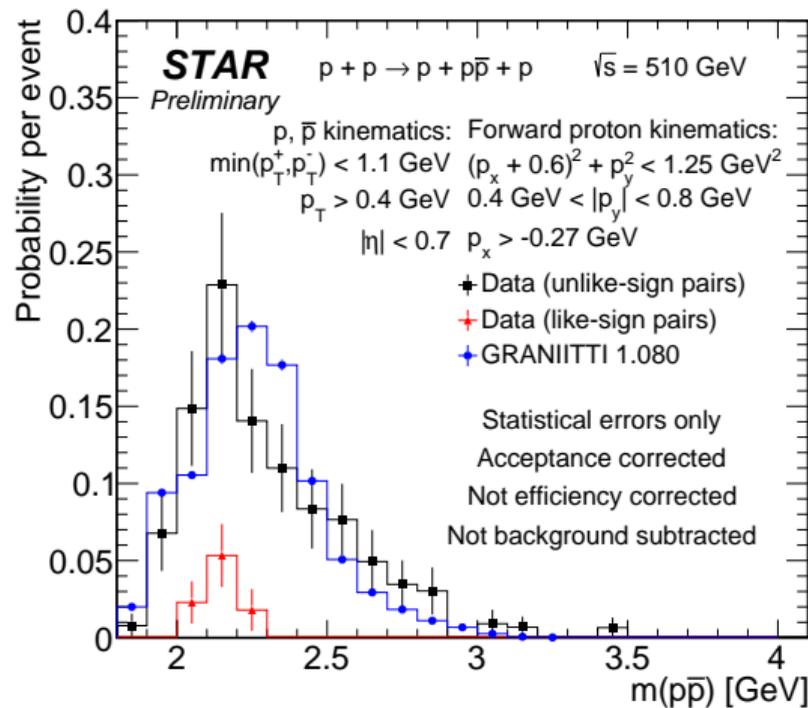
- Spectra were divided into two $\Delta\phi$ regions, the difference of azimuthal angles of the forward protons
- Different dynamics and different absorption effects are expected



$\Delta\varphi > 90^\circ$  $\Delta\varphi < 90^\circ$ 



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



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

- 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 MC generator, GRANITTI, 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 ($\chi_{dE/dx}^2$) and TOF (m_{TOF}^2)

$$\chi_{dE/dx}^2(h^+h^-) = (n\sigma_{h^+})^2 + (n\sigma_{h^-})^2 \quad (1)$$

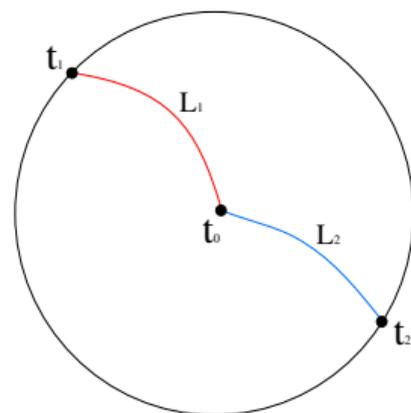
- m_{TOF}^2 is derived from the assumption that both particles are of the same type ($m_1^2 = m_2^2 = m_{\text{TOF}}^2$)

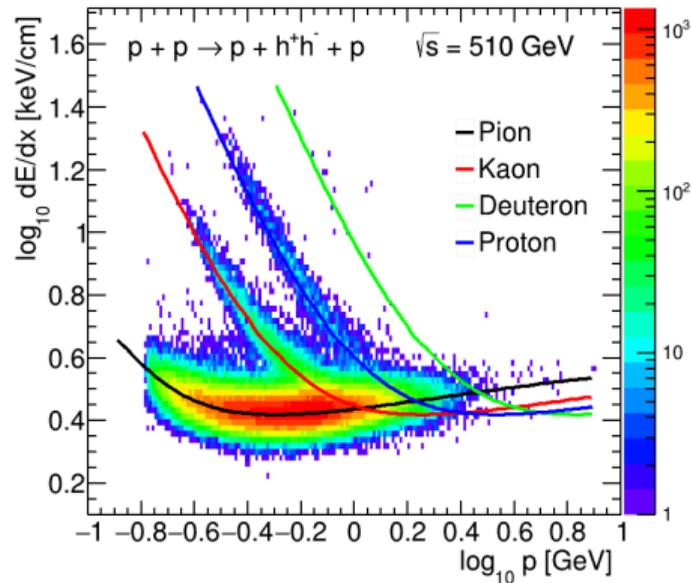
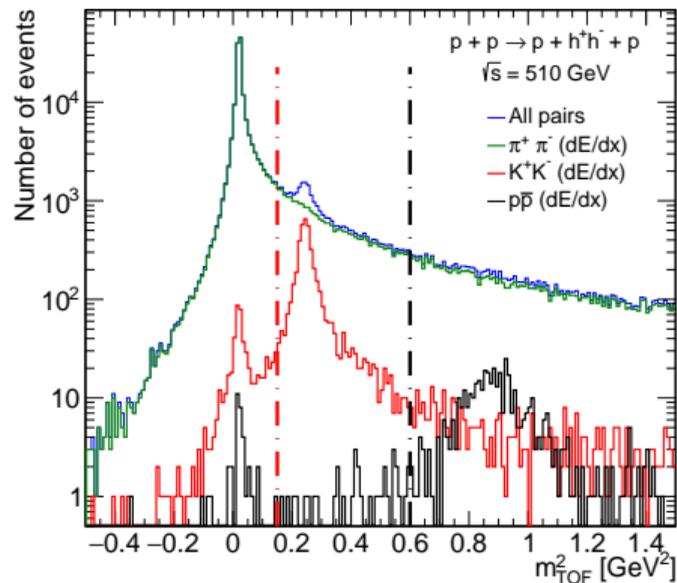
$$t_1 - t_0 = L_1 \sqrt{1 + \frac{m_1^2}{p_1^2}} \quad (2)$$

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

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

$$A \cdot (m_{\text{TOF}}^2)^2 + B \cdot m_{\text{TOF}}^2 + C = 0, \quad (5)$$





- $\pi^+ \pi^-$ pairs production is dominant, as expected in DIPE 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