Study of central exclusive production in proton-proton collisions at $\sqrt{s} = 510$ GeV with STAR detector at RHIC

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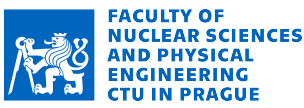
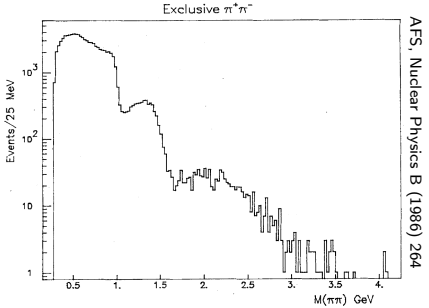
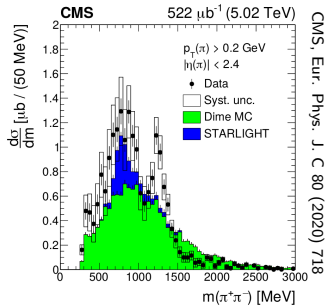


Supported in part by

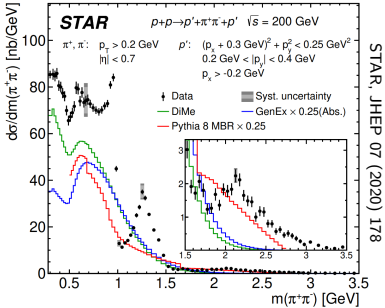
- Central Exclusive Production (CEP) through Double Pomeron Exchange (DPE) provides a gluon-rich environment for particle production
- CEP is considered to be a potential source of glueballs
- Glueballs are bound states consisting of only gluons and are predicted by the QCD theory
- Despite its theoretical predictions, the existence of a glueball has not been confirmed yet
- The first CEP through DPE was measured at Intersecting Storage Rings and since then it has been studied at numerous experiments (AFS, WA76, NA22, CDF, UA8, STAR, CMS, ATLAS...)



AFS, Nuclear Physics B (1986) 264



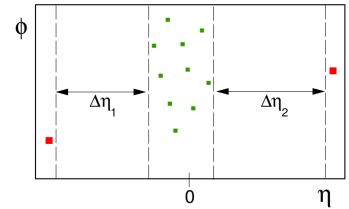
CMS, Eur. Phys. J. C 80 (2020) 718



STAR, JHEP 07 (2020) 178

- 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

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

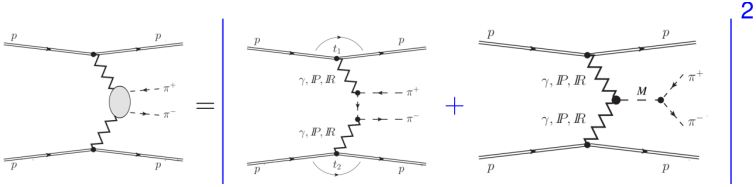


- Each proton "emits" a IPomeron
- The IPomerons fuse and produce neutral system X
- Double IPomeron Exchange (DIPE) is expected to be dominant at the RHIC energies
- I focus on $p + p \to p\ h^+h^-\ p$, h^+h^- stands for $\pi^+\pi^-$, K^+K^- and $p\bar{p}$
- To verify **exclusivity** of the process we used

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

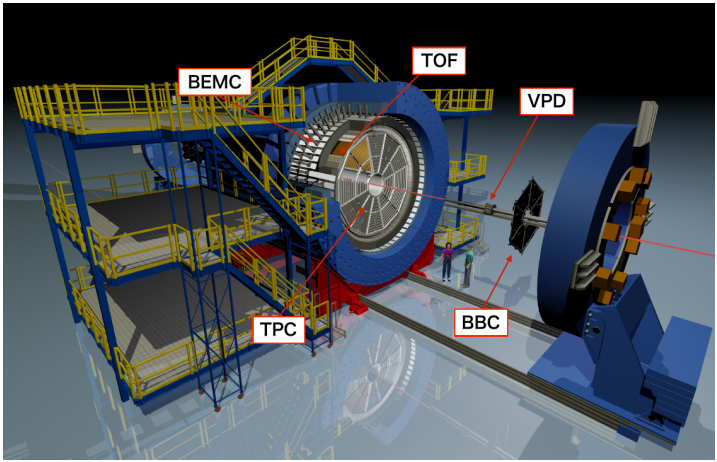
$\Rightarrow$ events with small p_{T}^{miss} are **Exclusive**

- CEP of h^+h^- is the simplest four(three) body QCD process: $p + p \rightarrow p + M(h^+h^-) + p$
- Experimentally simple, theoretically complex
- Significant interference effects between resonance and continuum production
- Significant rescattering effects via additional interaction between the protons

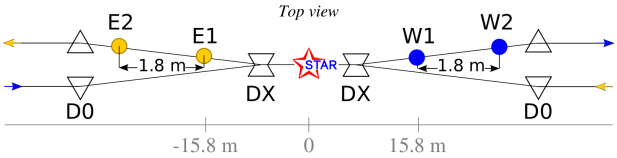


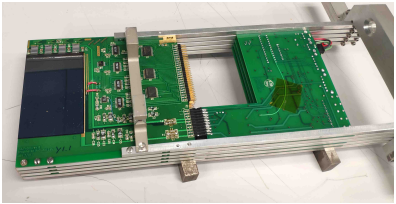
- GRANIITTI, a Monte Carlo event generator for high energy diffraction
  - M. Mieskolainen, arXiv:1910.06300
- GRANIITTI calculates inv. mass spectra assuming continuum and resonances contributions
  $M = f_0(500),\ \rho(770),\ f_0(980),\ \phi(1020),\ f_2(1270),\ f_0(1500),\ f_2(1525),\ f_0(1710)$
- GRANIITTI v. 1.080 with added CEP resonance couplings also tuned to STAR 200 GeV results

- 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
- 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 vessels contains a SSD package with active area of roughly 79×49 mm^2
- Each package consists of a scintillation trigger counter and 4 SSDs with spatial resolution of $\approx$ 30 μm



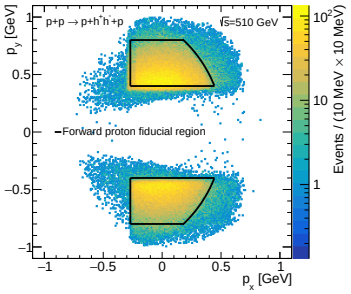


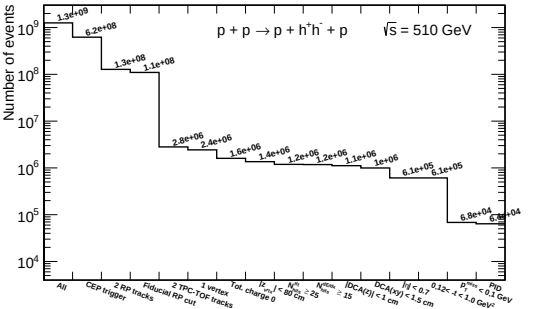
Data sample:

- 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 $p\bar{p}$





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

$$\chi^2_{dE/dx}(XX) = \left(n\sigma_X^{trk1}\right)^2 + \left(n\sigma_X^{trk2}\right)^2 \tag{1}$$

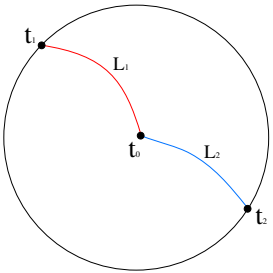
- m^2_{TOF} is derived from the assumption that both particles are of the same type ($m_1^2 = m_2^2 = m^2_{\mathrm{TOF}}$)

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

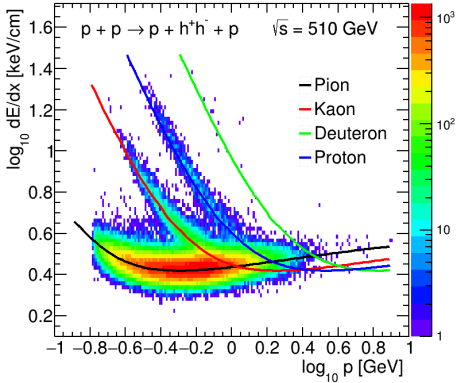
$$t_2 - t_0 = L_2\sqrt{1 + \frac{m_2^2}{p_2^2}} \tag{3}$$

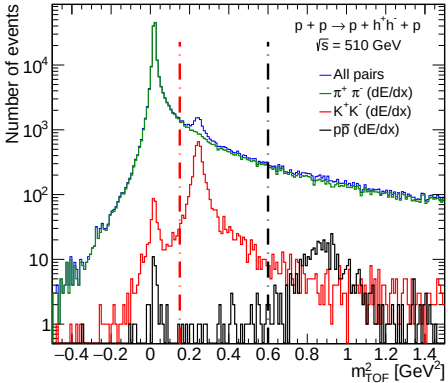
$$t_1 - t_2 = L_1\sqrt{1 + \frac{m_1^2}{p_1^2}} - L_2\sqrt{1 + \frac{m_2^2}{p_2^2}} \tag{4}$$

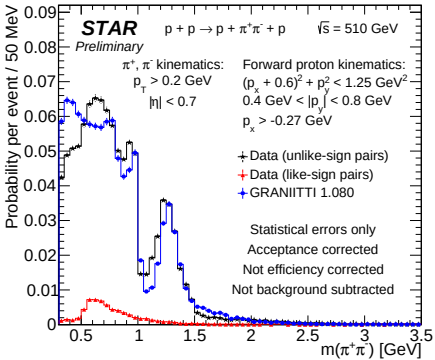
$$A \cdot (m^2_{\mathrm{TOF}})^2 + B \cdot m^2_{\mathrm{TOF}} + C = 0, \tag{5}$$

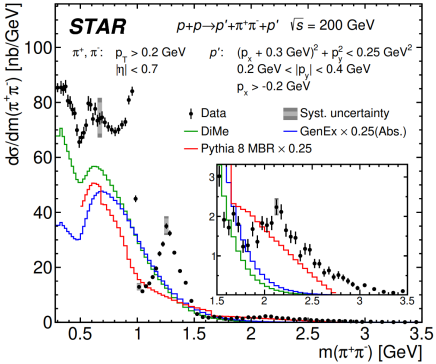


- $\pi^+\pi^-$ pairs production is dominant, as expected in DPE process at RHIC energies
- Kaons and protons can be seen in dE/dx plot
- Peaks of pions, kaons and protons about their real mass squared can be seen
- Pions misidentified as kaons, using only the dE/dx information, can be seen as well



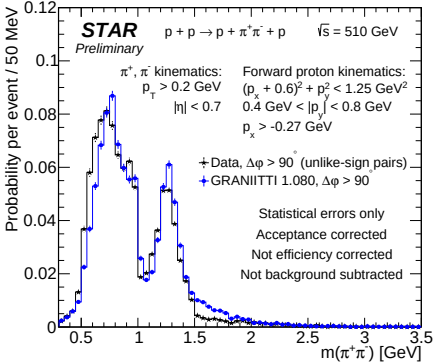


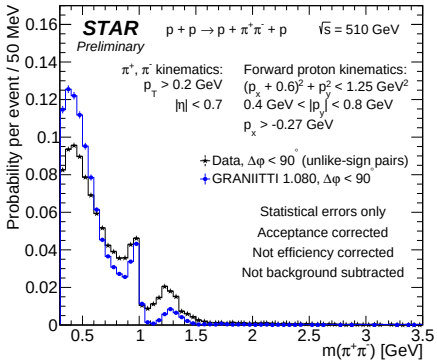


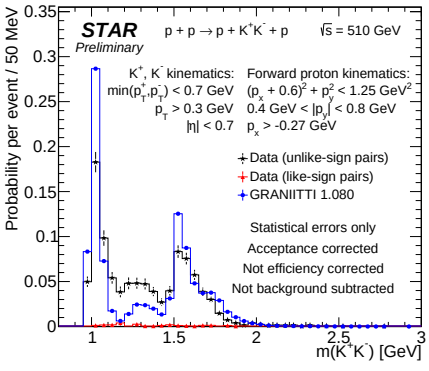


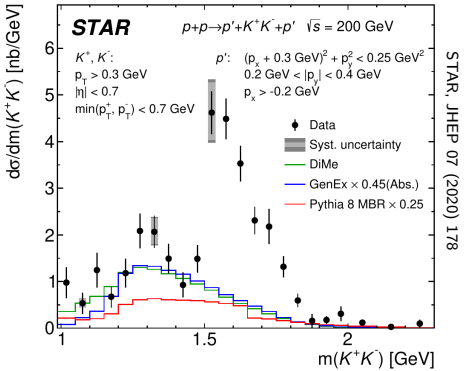
- The expected features in the invariant mass distribution are seen:
  - a drop at about 1 GeV, negative interference of $f_0(980)$ with continuum
  - a peak at about 1270 MeV, consistent with $f_2(1270)$
- The structure below 0.6 GeV is caused by the fiducial cuts (acceptance)
- Features similar to those at $\sqrt{s} = 200$ GeV are observed

- Spectra were divided into two $\Delta\varphi$ regions, the difference of azimuthal angles of the forward protons $\Rightarrow$ different Pomeron dynamics
- A suppression of $f_2(1270)$ in $\Delta\varphi < 90^\circ$ can be seen
- An enhancement at low invariant mass in $\Delta\varphi < 90^\circ$ is observed



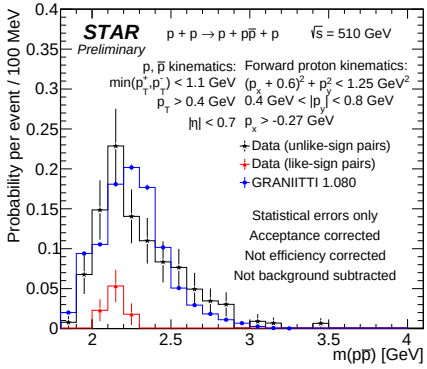


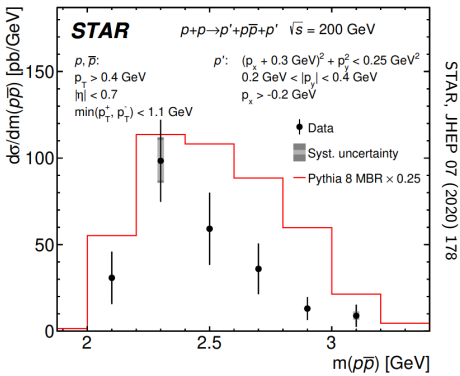




- A peak at 1 GeV (possible $\phi(1020)$) is close to the K^+K^- mass threshold, more studies have to be made: determination of non-exclusive background ($p + \phi + X + p$)
- GRANIITTI shows the enhancement around 1 GeV at 510 GeV while it does not at 200 GeV
- Peaks at 1.3 and 1.5 GeV are consistent with $f_2(1270)$ and $f_2(1525)$, respectively
- Differentiation into two $\Delta\varphi$ regions needs to be done and studied

Invariant mass of $p\bar{p}$ compared $\sqrt{s} = 200$ GeV results





- The invariant mass spectrum of $p\bar{p}$ pairs does not show any resonances
- Consistent with the measurement at $\sqrt{s} = 200$ GeV
- Data has large statistical errors and more studies need to be done to make any conclusions

Summary:

- The first results on the CEP of $\pi^+\pi^-$, K^+K^- and $p\bar{p}$ pairs in pp collisions at $\sqrt{s} = 510$ GeV measured by the STAR experiment at RHIC have been presented
- Measurement of the diffractively scattered protons allowed full control of the interaction's kinematics and verification of its exclusivity
- The invariant mass spectra of $\pi^+\pi^-$, K^+K^- and $p\overline{p}$ pairs confirmed features seen in previous measurements
- Interesting features are seen, like the peak at about 1 GeV in K^+K^-
- The new MC event generator, GRANIITTI, was compared to the data giving promising results

Outlook:

- There are ongoing studies of $\pi^+\pi^-$, K^+K^-, $p\bar{p}$ and also $\pi^+\pi^-\pi^+\pi^-$ channels
- An analysis involving the partial wave analysis in the $\pi^+\pi^-$ channel is planned

Thank you!