Central Exclusive Production at the STAR experiment

- **Physics motivation: Central Exclusive Production in Double Pomeron Exchange process**
- **Experimental setup: RHIC complex, STAR detector, Roman Pots**
- **Data sample**
- **Preliminary results from Run 2015 @ $\sqrt{s}$ = 200 GeV :**
  - **Mass spectrum of exclusive $\pi^+\pi^-$ production**
  - **Mass spectrum of exclusive K^+K^- production**
- **Summary and outlook**

Kin Yip for STAR Collaboration

3rd Elba Workshop on Forward Physics

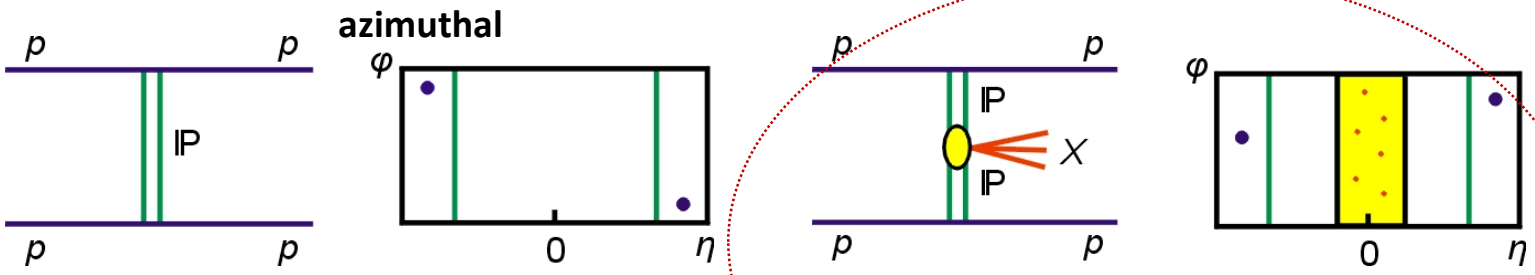
La Biodola, Isola d'Elba, Italy

May 30, 2016

Physics with Tagged Forward Protons in RHIC

QCD color singlet exchange: C=+1 (Pomeron), C=–1

This talk



p + p → p + p

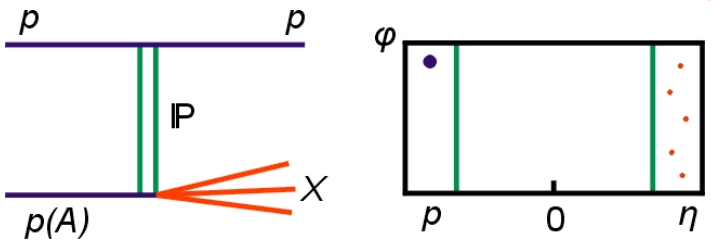
Elastic

p + p → p + X + p

Double Pomeron Exchange (DPE)

diffractive X= particles, glueballs

Discovery Physics



Single Diffraction Dissociation (SDD)

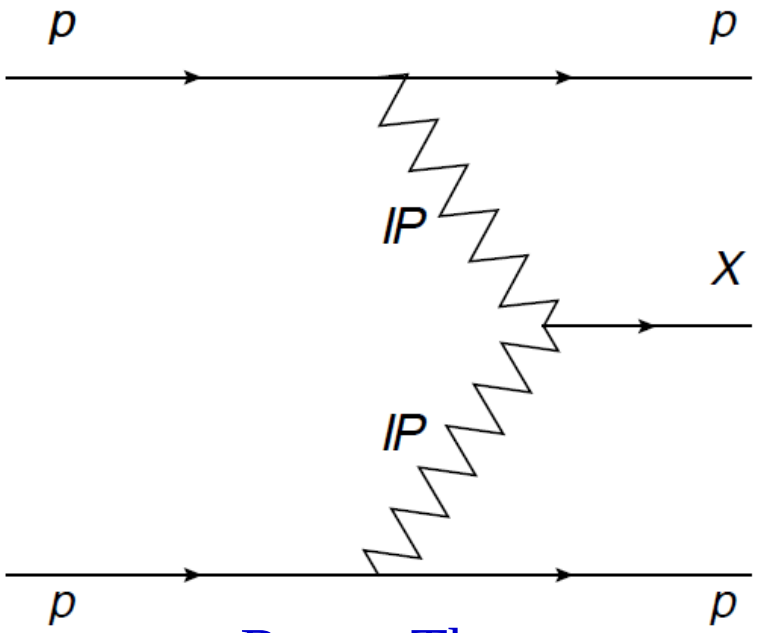
Central Production at High Energies

As predicted by Regge Theory, the diffractive cross section at high energy, including RHIC is dominated by the Pomeron (**gluonic**) exchange:

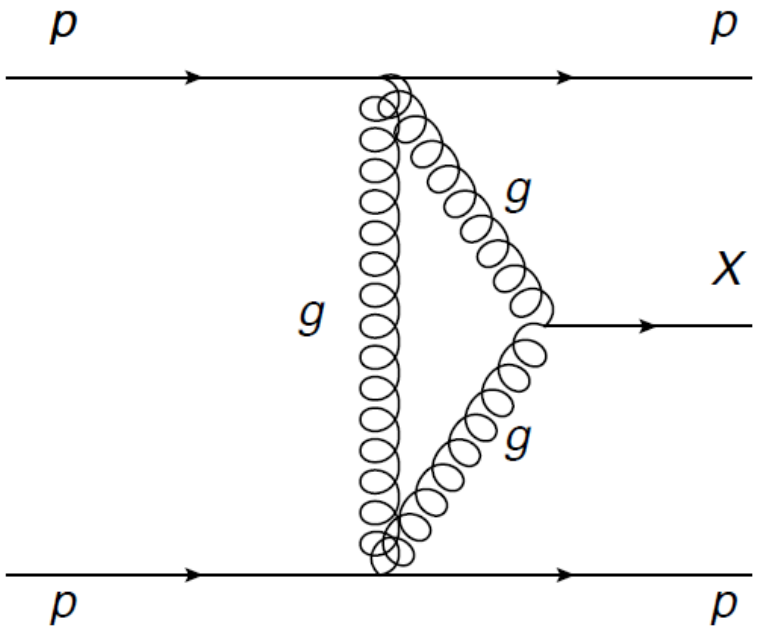
$\sigma_{RR} \sim s^{-1}$

$\sigma_{RP} \sim s^{-0.5}$

$\sigma_{PP} \sim$ const. or s^{α} where $\alpha \sim O(0.1)$

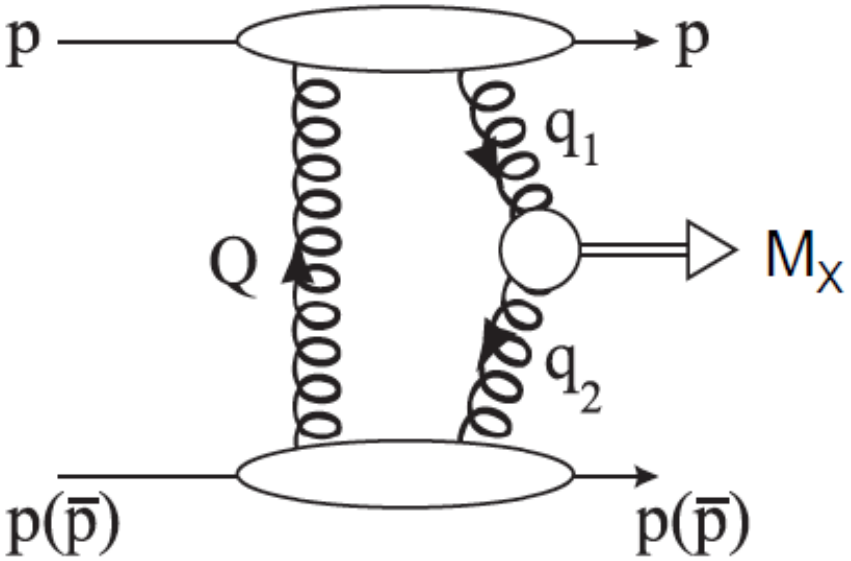


Regge Theory



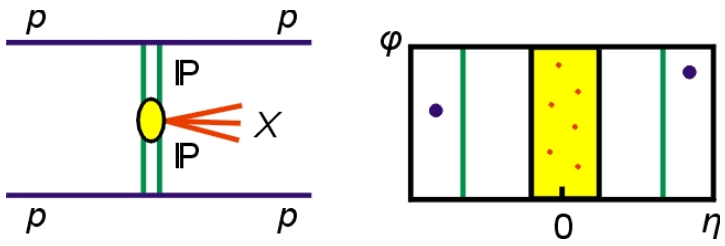
QCD

Central Production at High Energies



- Colliding protons interact via a color singlet (0^{++}) exchange as constrained by the Pomeron vertex.
- In the collider experiment, those protons follow magnetic field of the accelerator and remain in the beam pipe.
- A system of mass M_X is produced, whose decay products are present in the central detector region.
- Tagging on forward protons assures rapidity gap + soft rescattering processes $\Rightarrow$ protons in the beam pipe to be detected by roman-pot.

Central Production in DPE



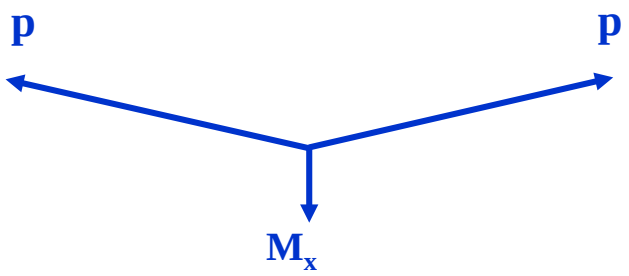
For each proton vertex one has

t four-momentum transfer

$\xi = \Delta p/p$

$M_X = \sqrt{\xi_1 \xi_2 \, s}$ invariant mass

In the double Pomeron exchange process, each proton "emits" a Pomeron and the two Pomerons interact producing a massive system M_X



RHIC

where $M_X = \pi^+ \pi^-$, gg(glueballs)?, χ_c(χ_b),

qq(jets), H(Higgs boson),

The massive system could form resonances. We expect that, due to the constraints provided by the double Pomeron interaction, glueballs, hybrids, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes.

Glueball spectrum

Sparse spectrum!

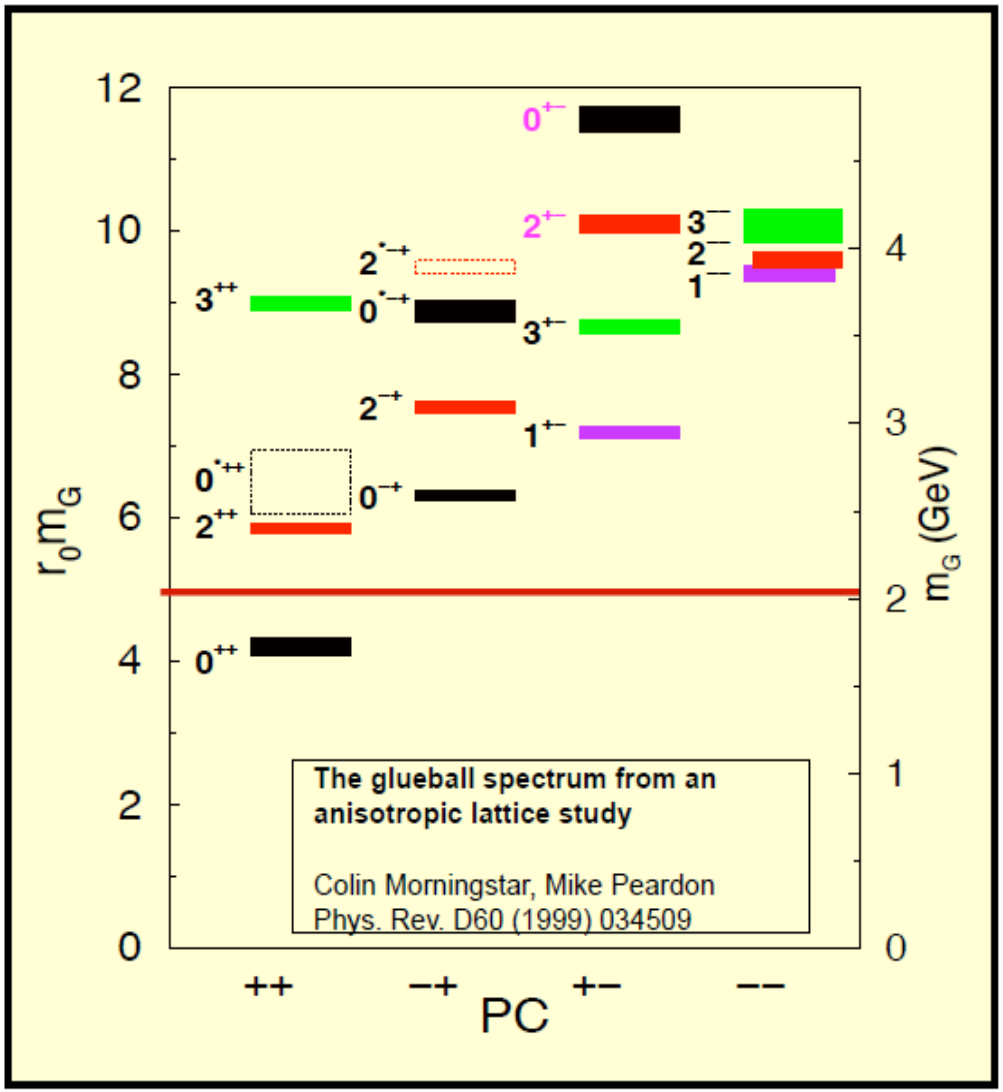
New I=0 mesons starting with

0^{++} 1.6 GeV

0^{-+} , 2^{++} 2.3 - 2.5 GeV

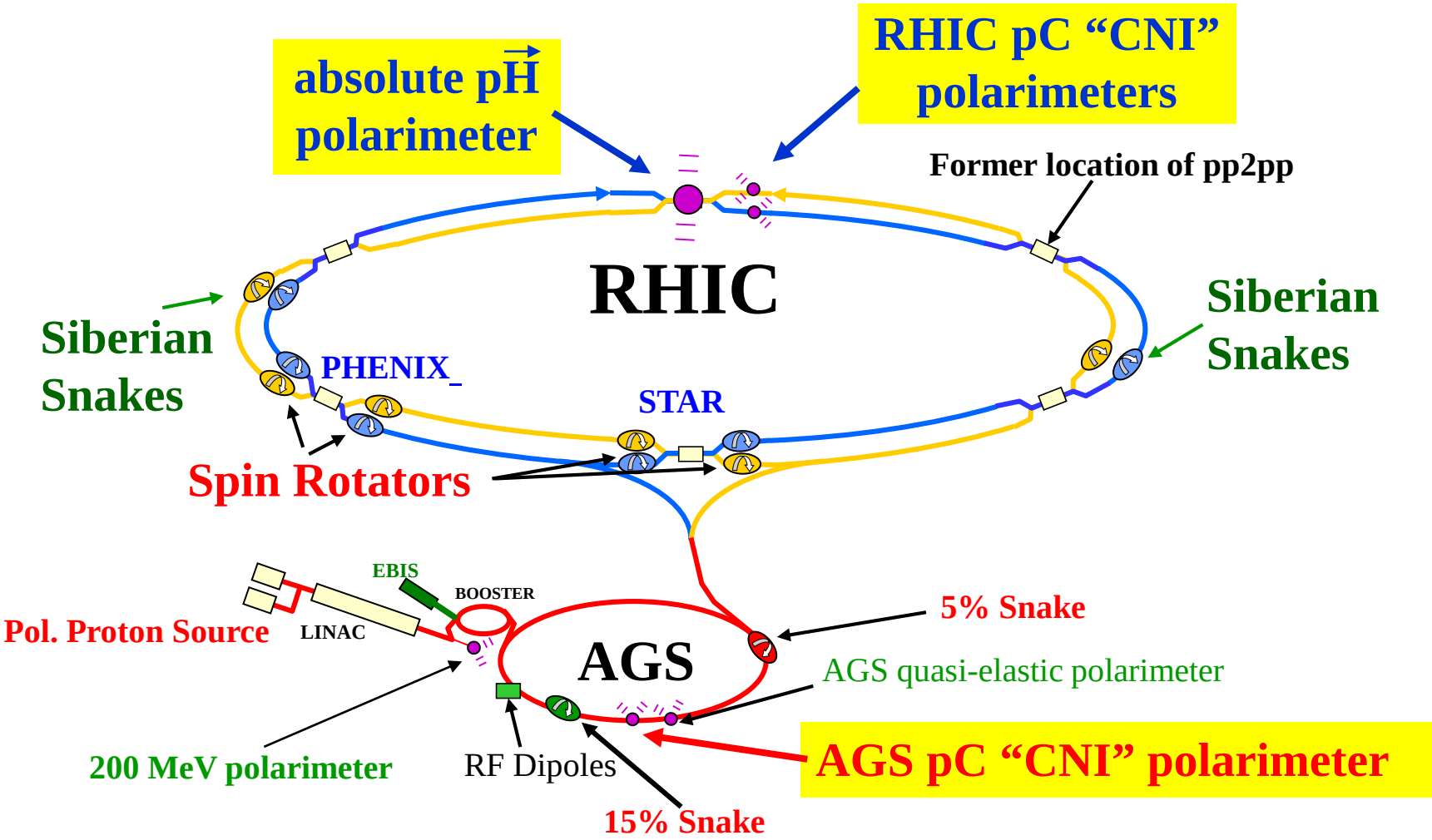
No J^{PC}-exotic glueballs until

2^{+-} at 4 GeV



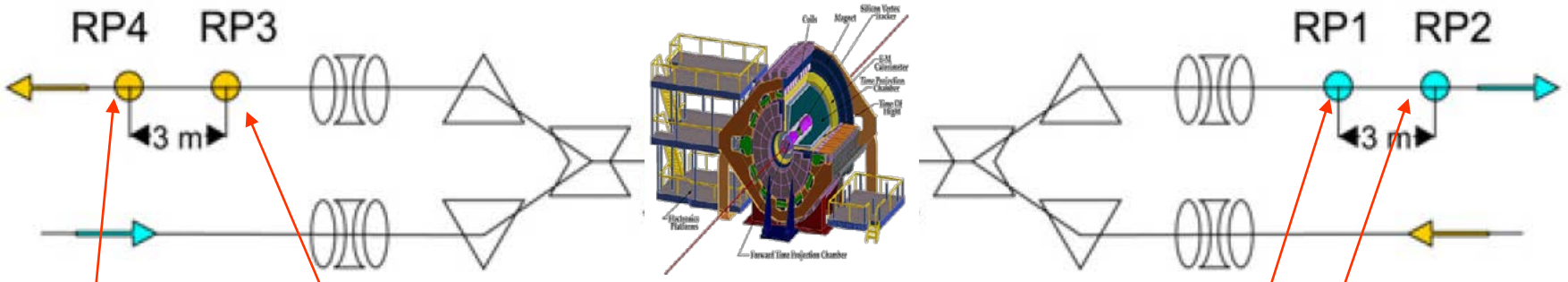
dashed line ↔ tentative glueball interpretation

RHIC-Spin Accelerator Complex



RHIC is a versatile QCD Laboratory:
Nucleus- Nucleus collisions (AuAu, CuCu, UU…); Asym. Nucl. (dAu, pAu, CuAu …);
Polarized proton-proton; eRHIC - Future

Implementation at RHIC in 2009 (Phase I)
— optimized for low-t coverage (large β^*)



How to measure ?

- Need detectors to measure forward protons: t, $\xi = \Delta p/p$, M_X
  - ⇒ **Roman-Pots of PP2PP (~2003)**
- Need detectors with good acceptance and particle ID to measure the central system
  - ⇒ **STAR** (TPC + Time-of-Flight for particle ID)
- Setup of the PP2PP experiment, used to measure pp elastic scattering at RHIC was moved to STAR to advance a physics program with tagged forward protons

PP2PP Setup at STAR

Roman Pot Station PP2PP and 2009

4 planes of detectors

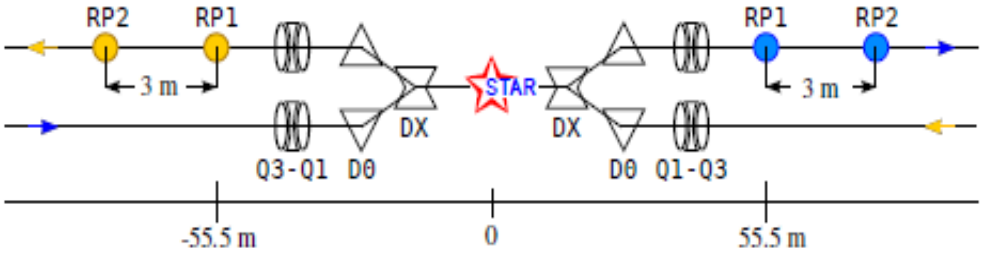
Phase I preliminary results in CEP

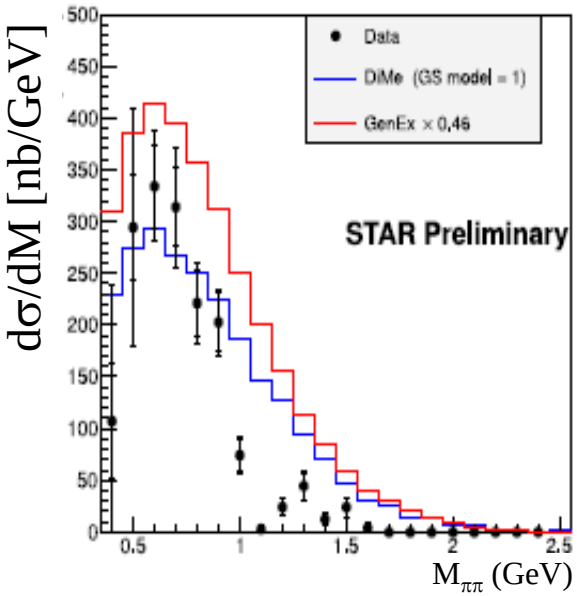
Kinematic coverage:

$0.005 < -t < 0.03\ \mathrm{GeV}^2/c^2$

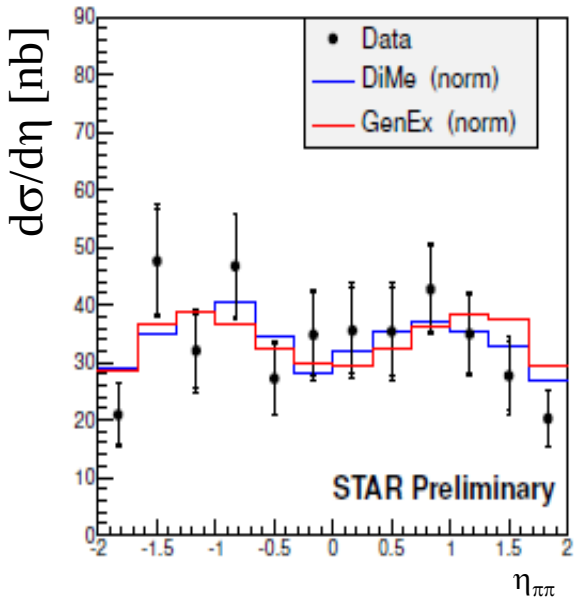
$0 < \phi < 2\pi \quad |\eta_\pi| < 1 \quad |\eta_{\pi\pi}| < 2$

Detector layout description: [9]



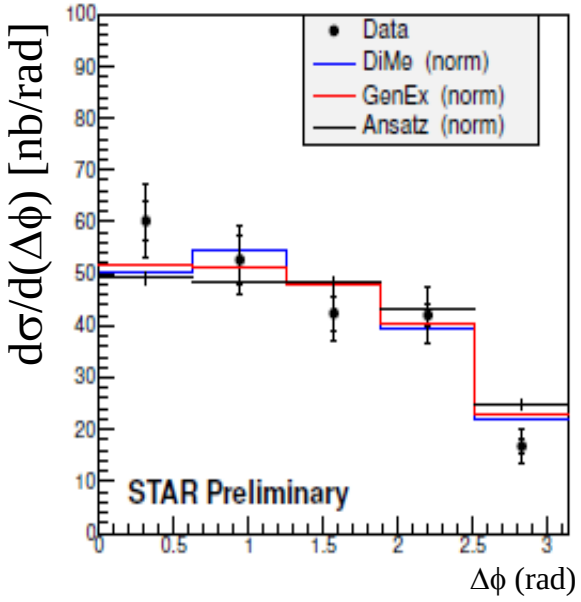


Models of non-resonant $\pi^+\pi^-$ production [2, 3] agree with STAR data up to $\approx 1\ \mathrm{GeV}/c^2$



Preliminary cross section in given kinematic range at $\sqrt{s} = 200\ \mathrm{GeV}$

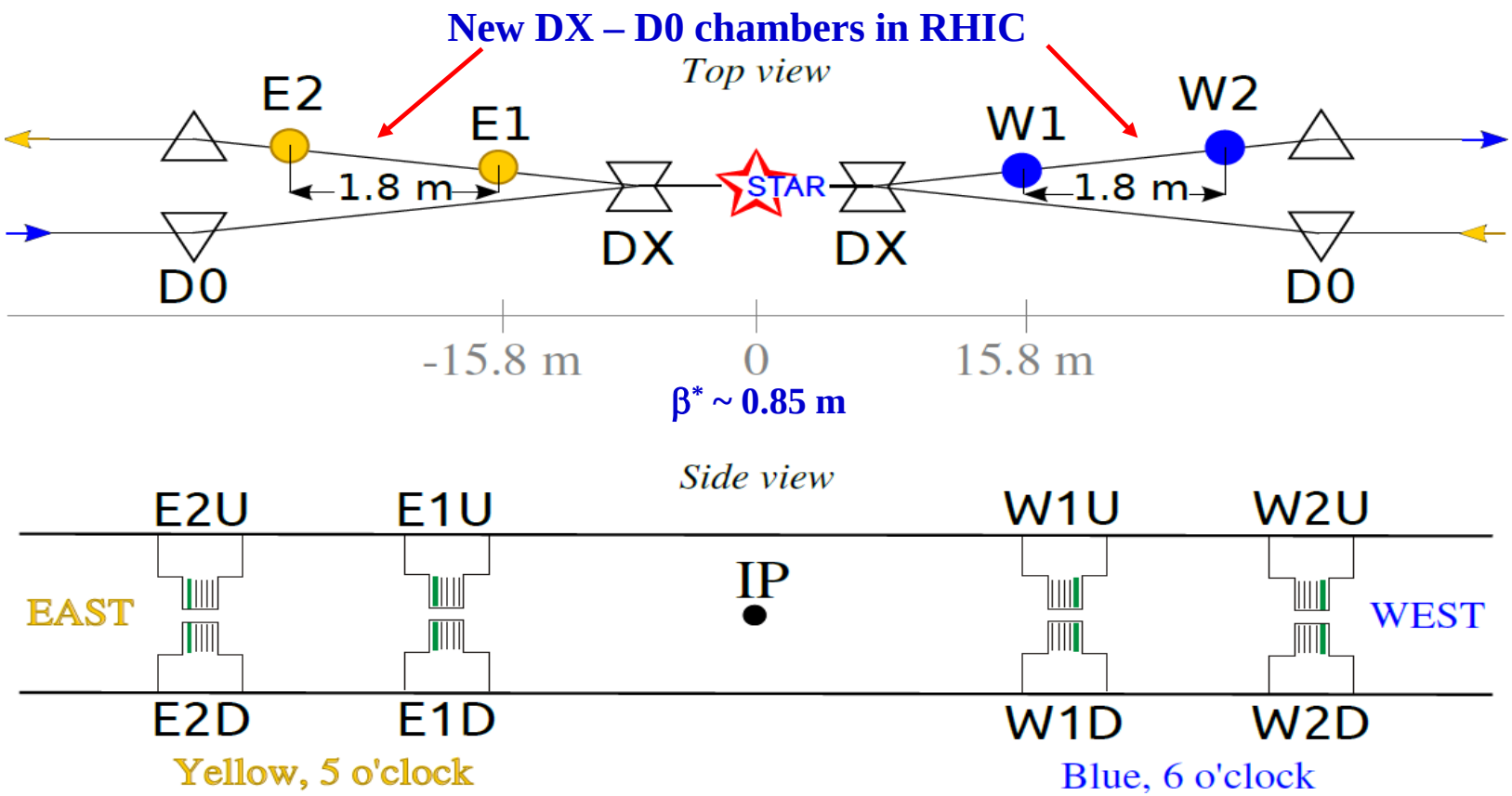
$\sigma^{\pi\pi}_{\mathrm{CEP}} = 133 \pm 8(\mathrm{stat}) \pm 12(\mathrm{sys})\ \mathrm{nb}$



No significant (unexpected) correlation between scattered protons has been found

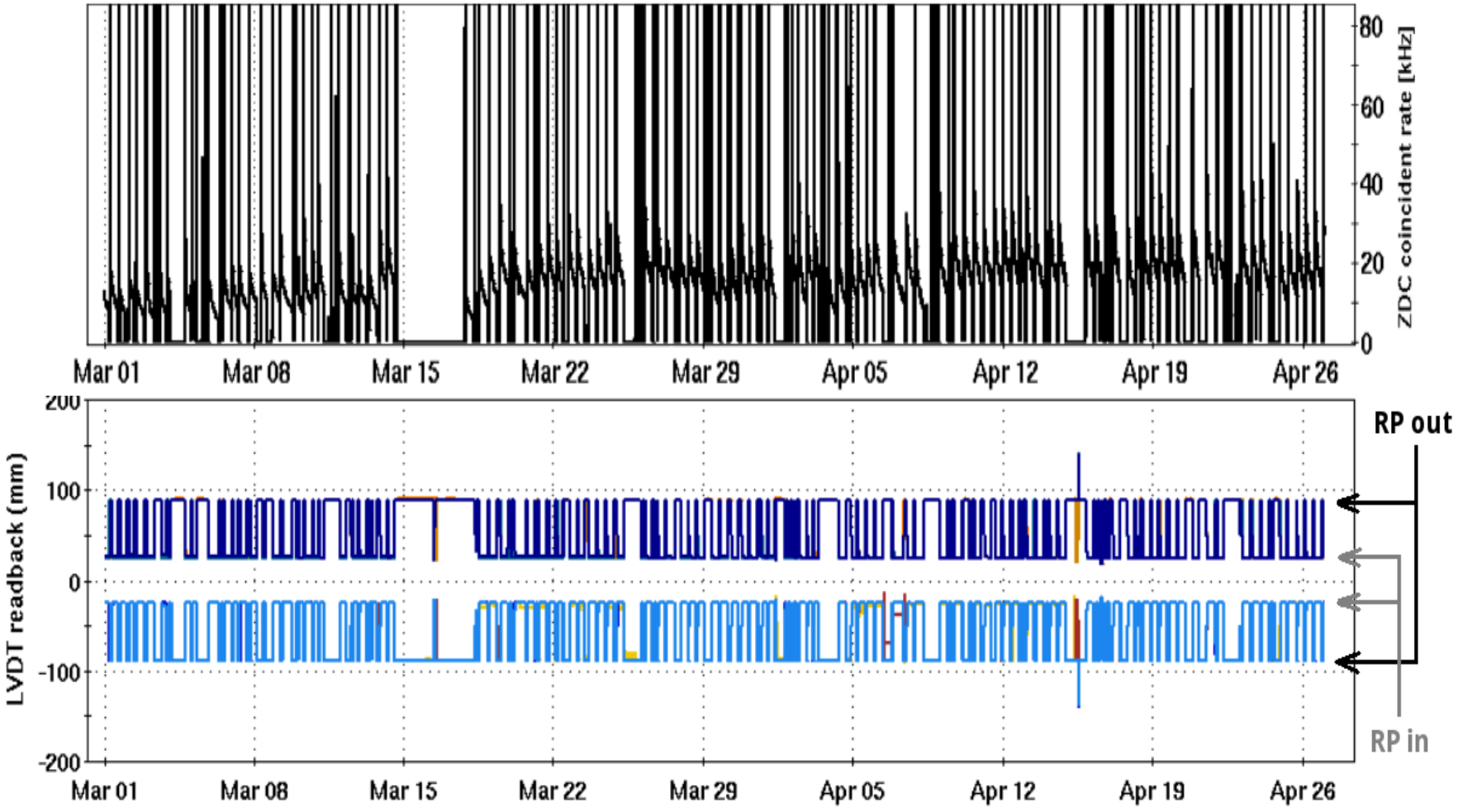
Details can be found in Int. J. Mod. Phys. A29 (2014) no. 28, 1446010

Implementation at RHIC in 2015 & beyond (Phase II*)



In this configuration, CEP program is able to acquire large data samples without special conditions (ie. the roman-pot detector can take data along with other STAR detectors).

Roman Pot Operation in the 2015 RHIC run



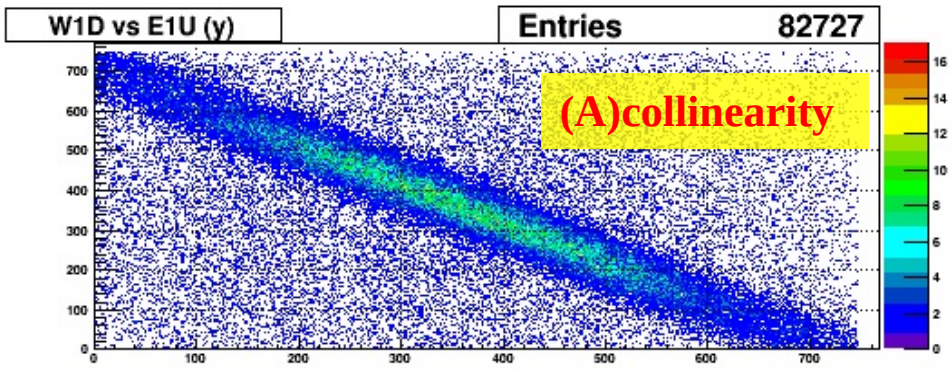
Routine operation of Roman Pots at ≈ $8\sigma_y$ of the beam

Data sample (Roman-pot detectors) in Run 2015

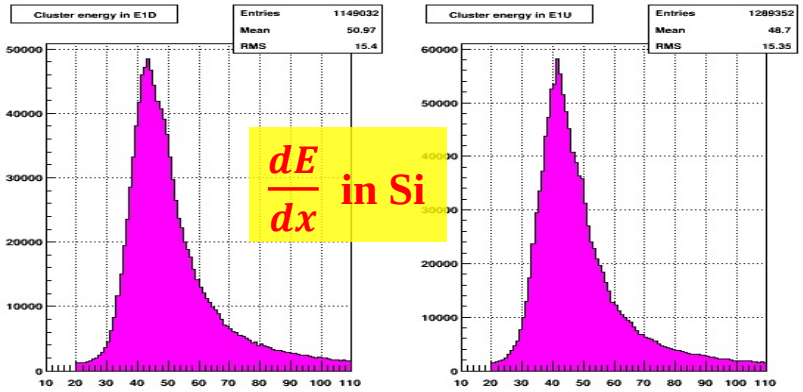
- Collected 6×10^{8} CEP triggers in polarized proton-proton collisions with transverse and longitudinal proton polarizations
- Integrated luminosity: $\approx 18\ pb^{-1}$
- Trigger conditions for CEP events:
  - At least 2 hits in Time-of-Flight detector (to ensure presence of charged tracks in TPC)
  - Signal in trigger counters in at least 1 Roman Pot at both STAR sides (detecting diffractive protons)
  - Veto on signal in small tiles of Beam Beam Counters covering $3.3 < |\eta| < 5.0$ (rapidity gap)

- The preliminary results presented here are obtained with 2.5% of whole collected data sample using fast offline processing.
- Full offline reconstruction for proton-proton collisions has been done and analyses are ongoing.

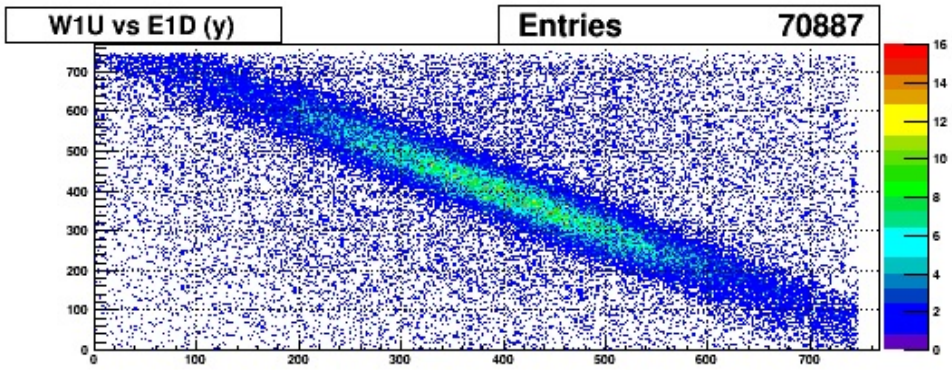
Si Detector Performance in Elastic Scattering

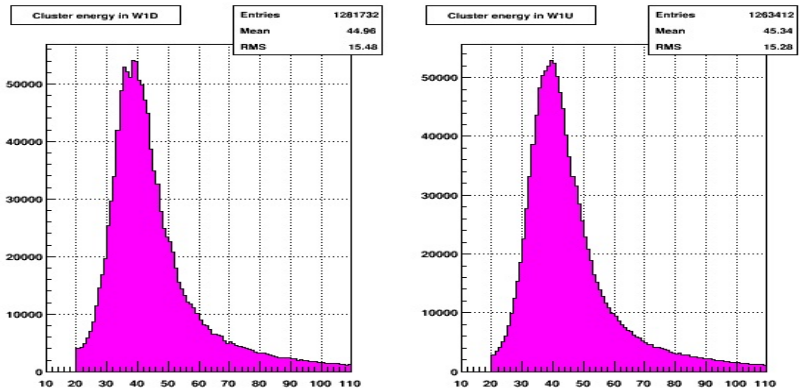


(A)collinearity



$\frac{dE}{dx}$ in Si





- Very good performance of the Silicon detectors
  - Low noise
  - High (>20) signal to noise ratio
  - High single plane efficiency
  - High proton track reconstruction efficiency

CEP Event Selection — two mesons

- Exactly 2 opposite-sign tracks in TPC matched with hits in Time-of-Flight detector
- Consistence between z-component of vertex measured in TPC and the vertex reconstructed from ToF of protons detected in Roman Pots (to remove overlap of elastic scattering with minimum-bias events)

$$\left| z_{VTX}^{TPC} - z_{VTX}^{RP} \right| < 3\sigma$$

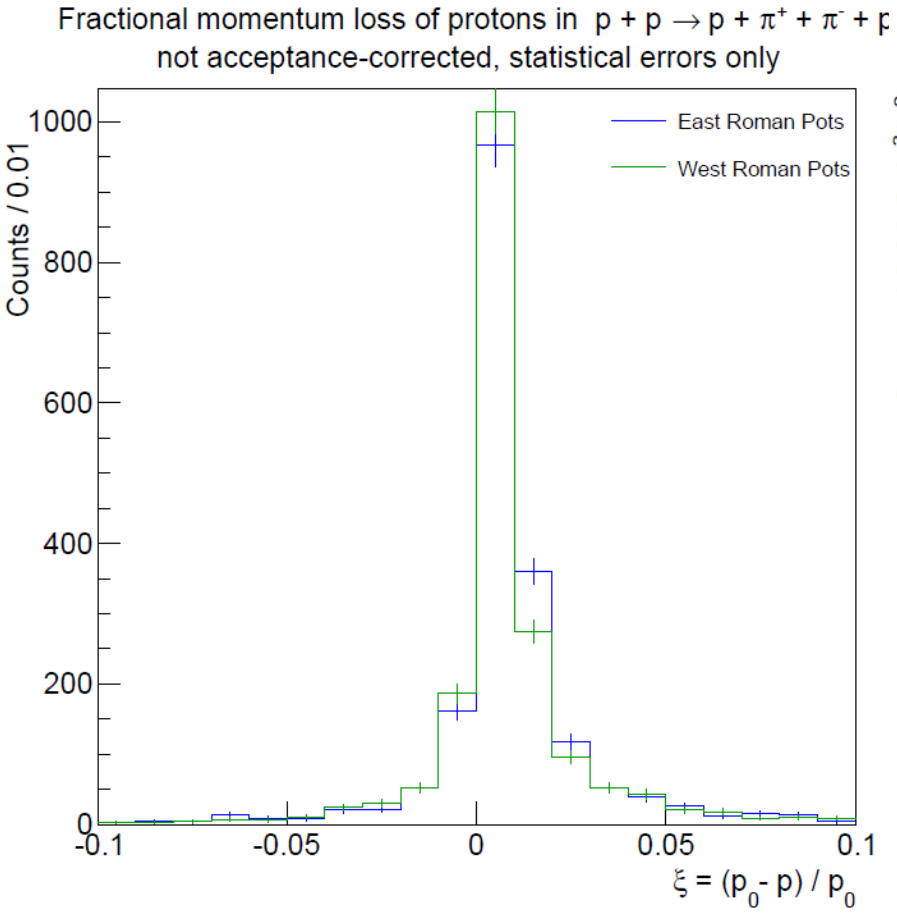
- Protons (consistent with $\xi = 0$) not collinear (to remove elastic events as described above)

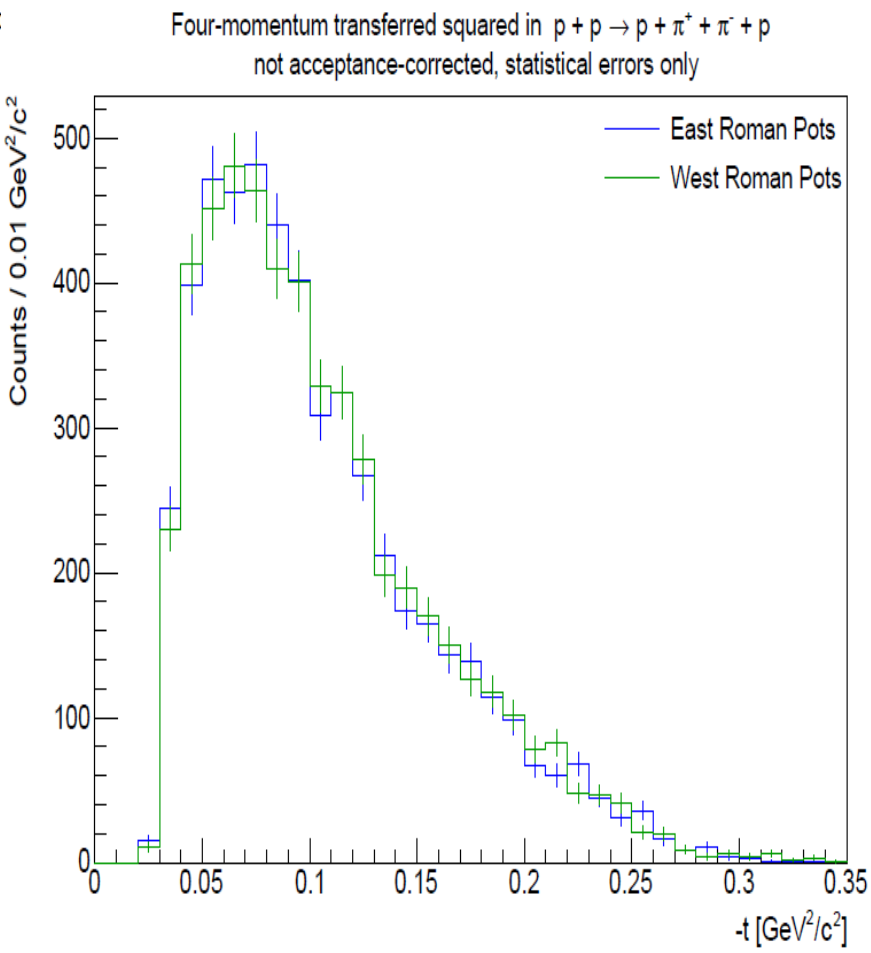
$$\left| \overrightarrow{p_1} + \overrightarrow{p_2} \right|_T > 60 \frac{MeV}{c}$$

- Veto in large Beam Beam Counter tiles ($2.1 < |\eta| < 3.3$) to confirm rapidity gap
- Particle ID determined by $\left| \frac{dE}{dx} - \frac{dE}{dx}_{\pi, K} \right| < 3\sigma$
- Momentum balance between central system M_X and protons measured in the Roman Pots

Proton kinematics of the exclusive $\pi^+\pi^-$ production

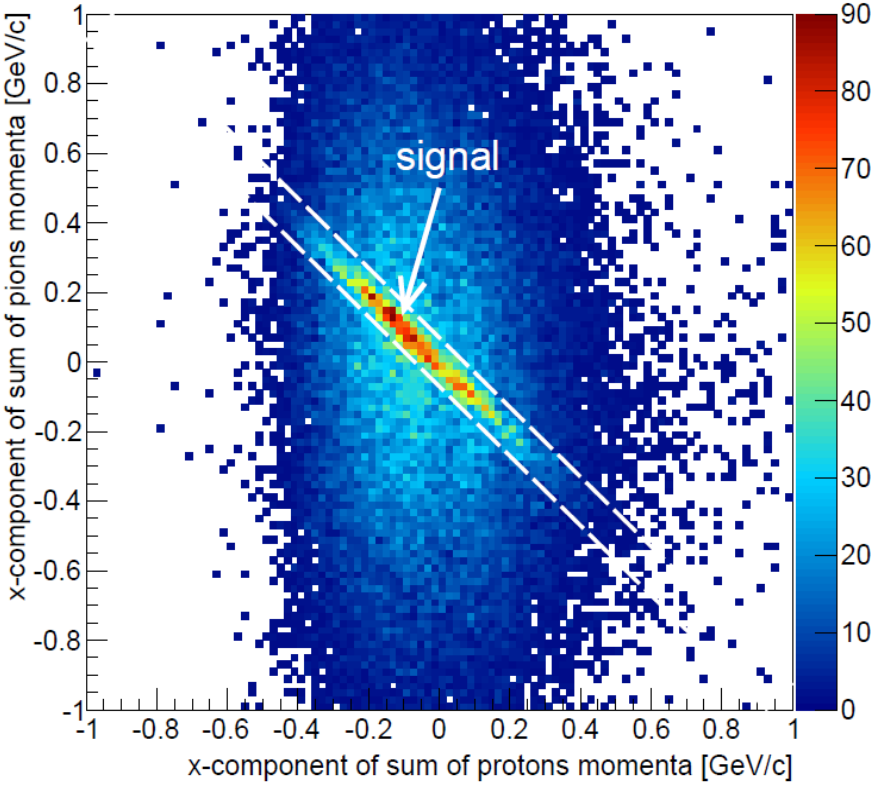
- **Majority of protons in exclusive $\pi^+\pi^-$ production have very low momentum loss $\xi < 0.05$**
- **Acceptance in -t range [0.03, 0.3] $(\frac{GeV}{c})^2$**

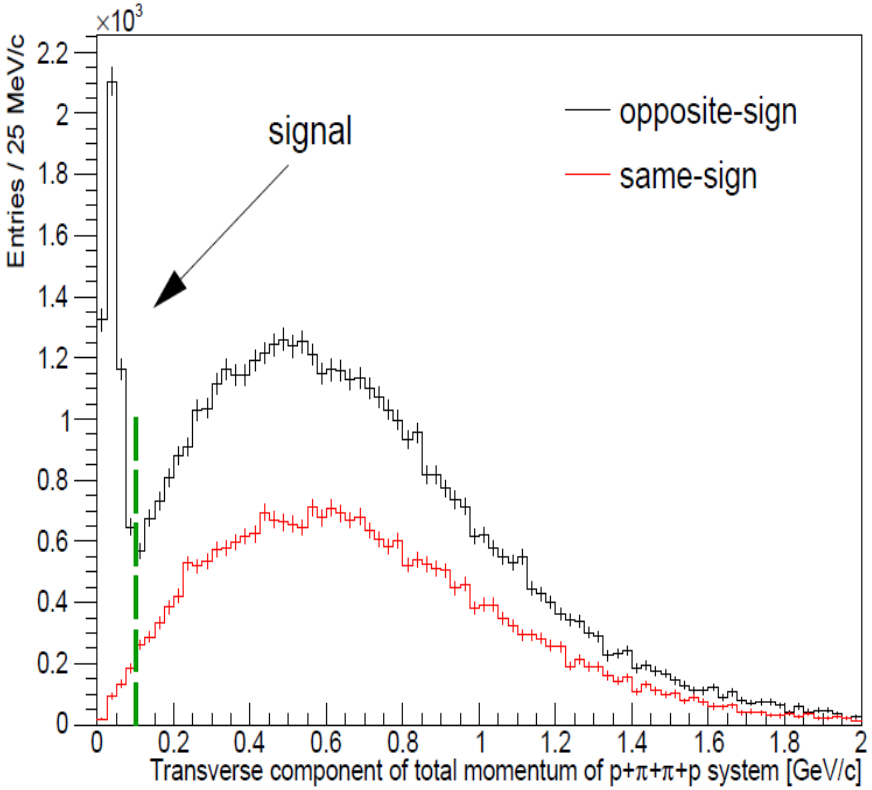




CEP $\pi^+\pi^-$ sample : Missing momemtum

Detection and momentum reconstruction of all final state particles provides the ability to ensure exclusivity of the system via momentum balance check

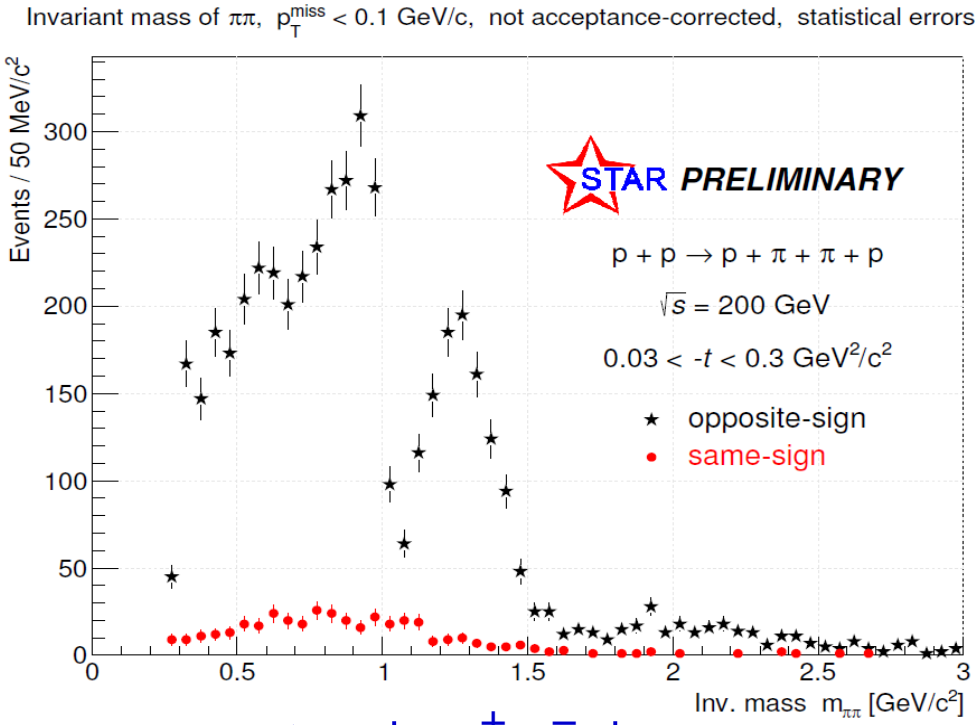




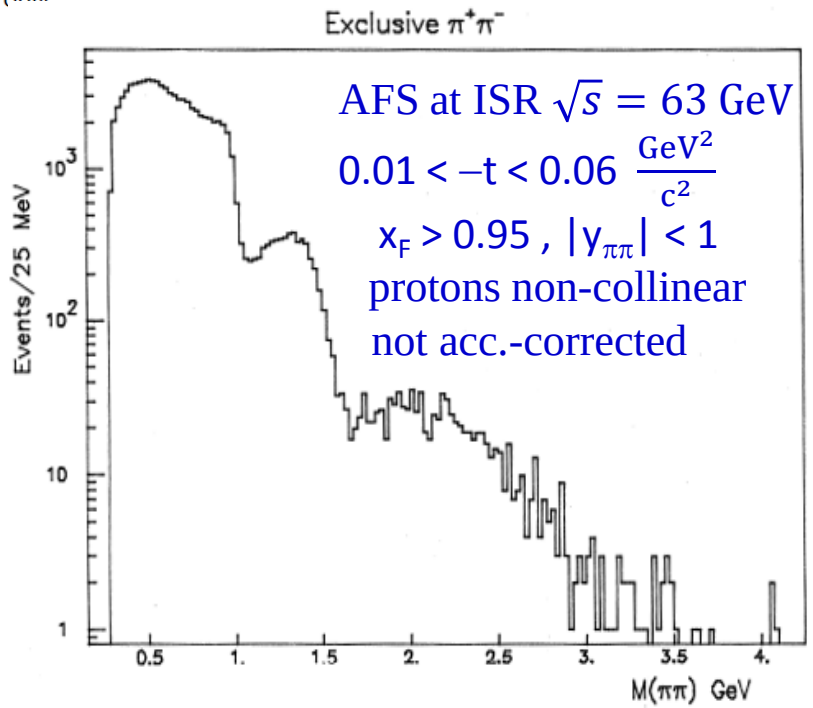
Signal visible as strong anti-correction of proton momentum and central track momentum

Small total (missing) momentum of full reconstructed p + X + p system ⇒ excellent exclusivity determinant ($p_T^{miss} < 0.1 \frac{\text{GeV}}{\text{c}}$)

Invariant Mass Distribution $M_X(\pi\pi)$



$$pp \Rightarrow p + \pi^+\pi^- + p$$



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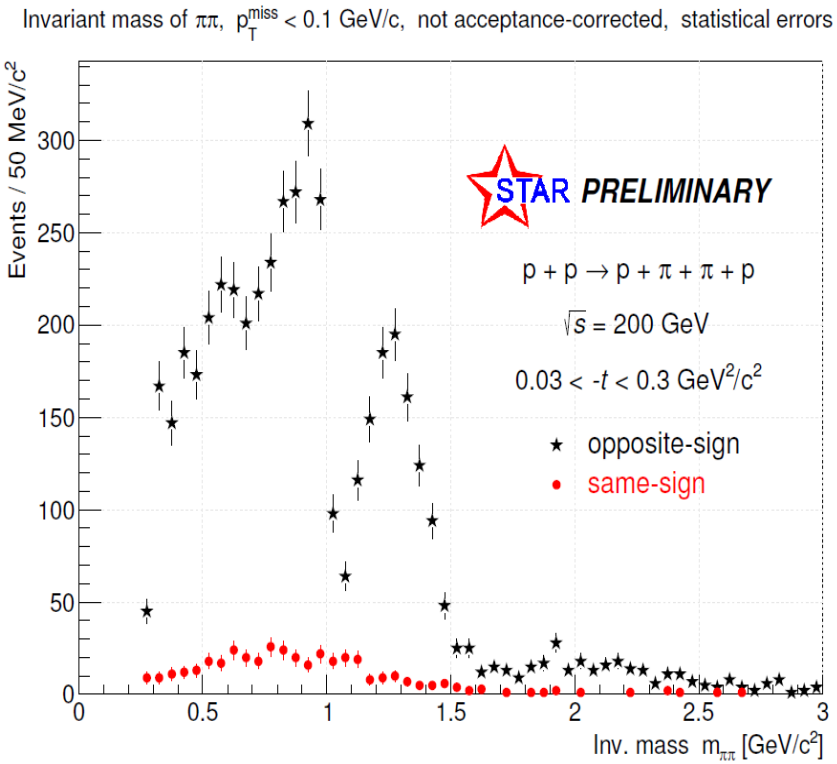
Small Background after momentum balance cut!

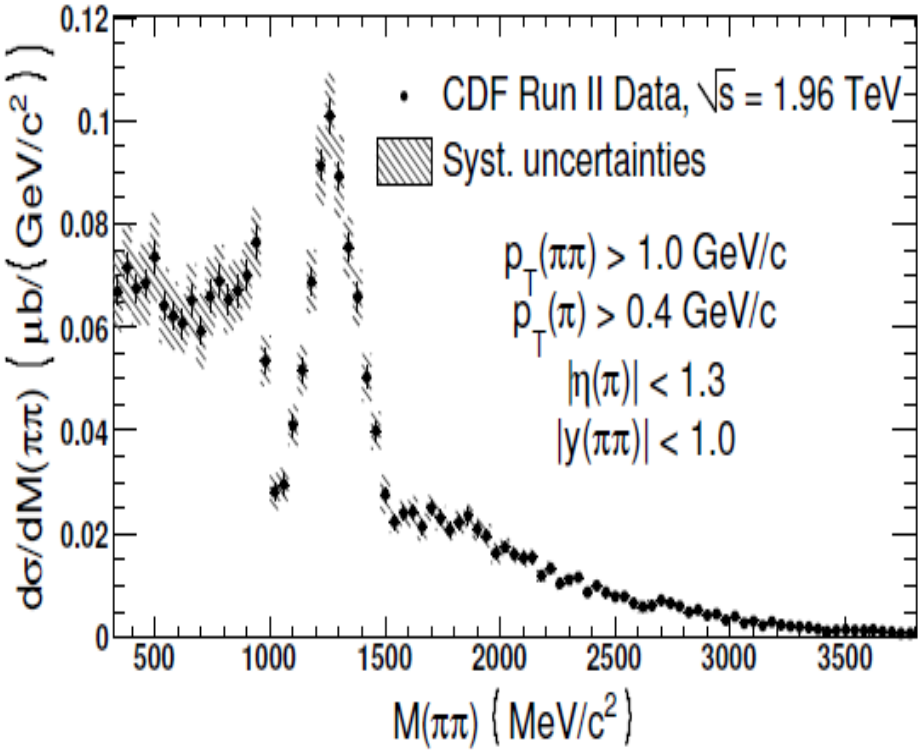
- **broad structure extending from $\pi^+\pi^-$ threshold to approximately 1 $\frac{GeV}{c^2}$**
- **sharp drop at about 1 $\frac{GeV}{c^2}$**
- **resonance-like structure between 1-1.5 $\frac{GeV}{c^2}$**

$\Rightarrow$ Expect ~75K events expected for $M_X(\pi^+\pi^-) > 1 \frac{GeV}{c^2}$

Compare with CDF Result on $\pi^+\pi^-$ Central Production



Phys. Rev. D91 (2015) 9, 091101

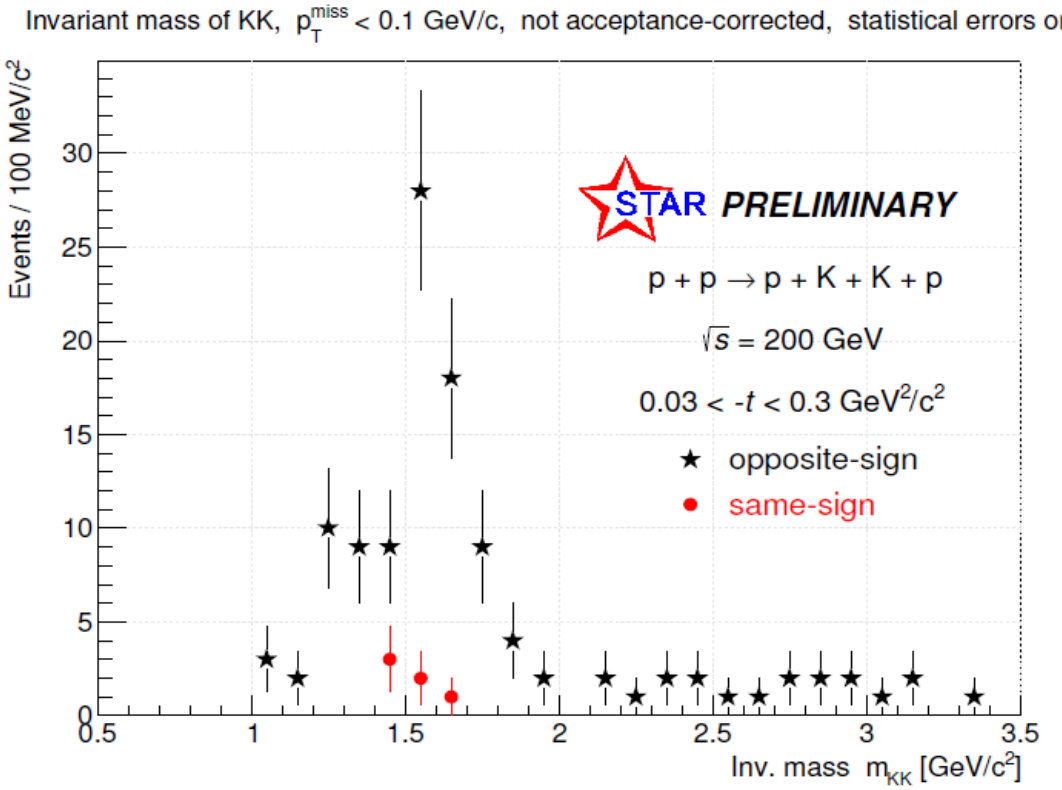


$pp \Rightarrow p + \pi^+\pi^- + p$

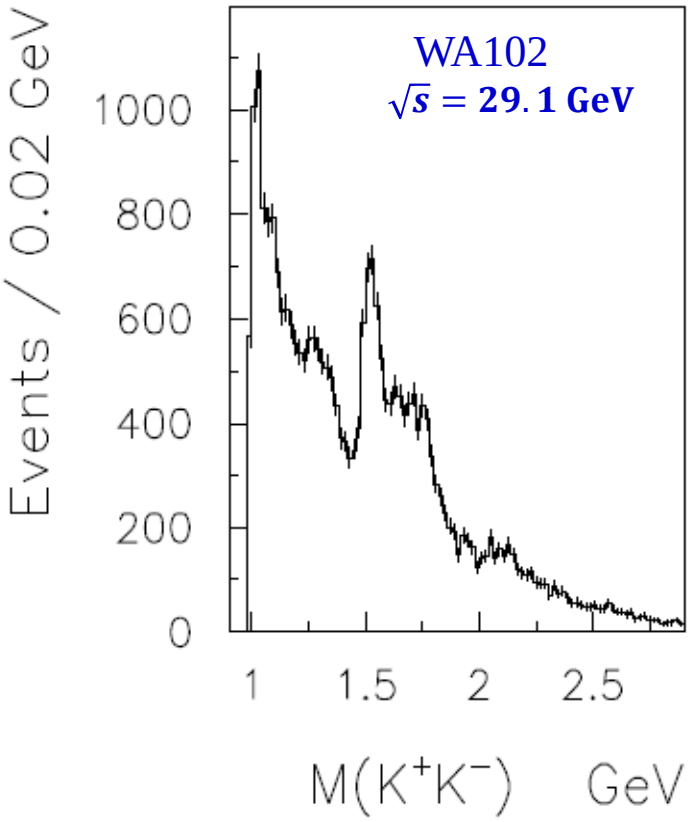
$p\bar{p} \Rightarrow \text{gap} \oplus \pi^+\pi^- \oplus \text{gap}$

- The essential features of the STAR result are the same as those at other colliders
- Similar spectrum to those found by AFS at ISR(pp) and CDF ($p\bar{p}$, with no $p/\bar{p}$ tagging but by rapidity gap method)

Invariant Mass Distribution $M_X(KK)$



Phys. Lett. B Vol. 453(1999) 305



- prominent peak around 1.5–1.6 $\frac{\mathbf{GeV}}{\boldsymbol{c^2}}$
- some enhancement at $f_2(1270)/f_0(1370)$ region
- In spectrum measured by WA102 (fixed target), there is significant contribution from $f_0(980)$ not seen by STAR (most probably an effect of limited acceptance at low masses (low K p_T))

⇒ Expect ~ 10^4 exclusive K^+K^- events at full statistics allowing measurement of cross-section and Partial Waves Analysis.

Summary and Outlook

- **STAR experiment at RHIC has suitable conditions to study diffractive physics, which has been demonstrated by CEP measurement with Roman Pot Phase I.**
- **We had a very successful data taking run in 2015 @ $\sqrt{s}$ = 200 GeV for both pp and pA (Phase II*).**
- **Routine operation of Roman Pots at ≈ $8\sigma_y$ of the beam was achieved.**
- **In 2015, STAR collected large sample of high quality CEP-dedicated data, whose 2.5% sub-sample was used to prepare presented preliminary mass distributions of exclusively produced pion and kaon pairs.**
- **We are analyzing *the full data sample* to search for scalar particles (0^{++}) as well as higher J^{PC} states including 4π states.**
- **We are looking forward to proton-proton data run in 2017 @ $\sqrt{s}$ = 510 GeV. Data will be collected in larger kinematic region and will allow comparison of results from two energies.**