

Central Exclusive Production of $\pi^+\pi^-$ pairs in pp collisions at $\sqrt{s} = 200$ GeV

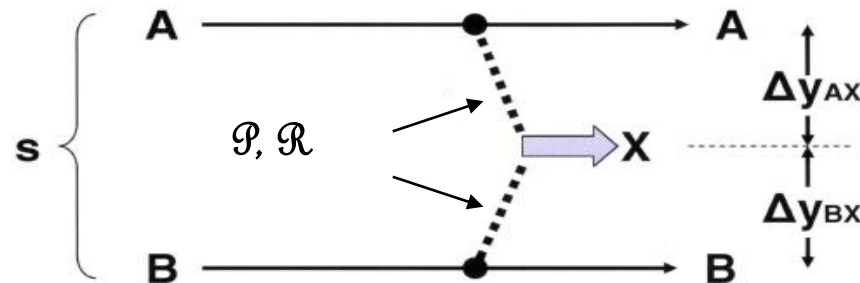
Jacek Turnau for the STAR Collaboration

Outline:

- Central Exclusive Production studies : physics motivation
- STAR detector at RHIC and forward proton tagging at STAR
- selection of Central Exclusive Production events
- results
- summary and outlook



Central Exclusive Production (CEP)



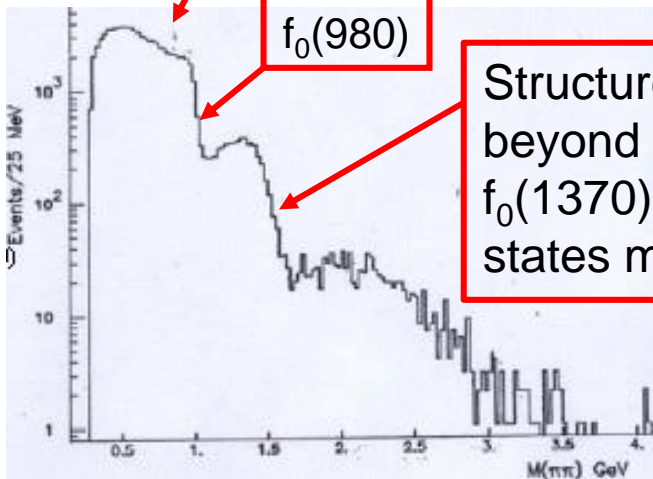
- ❑ colliding particles emerge intact
- ❑ produced state X is fully measured
- ❑ rapidity gaps A-X and B-X (subenergies s_{AX} , s_{BX}) large enough to justify regge description
- ❑ our measurement : $p + p \rightarrow p + X + p$ $X : \pi^+ \pi^-$
- ❑ at sufficiently large collision energy Double Pomeron Exchange (DPE) becomes dominant

Physics motivation for studies of low mass central exclusive production

Axial Field Spectrometer at ISR : NP B264(1987)154 : **A search for Glueballs and a Study of double Pomeron exchange at CERN ISR**

Heuristic hypothesis : glueballs, hadronic states built from valence gluons, are preferentially produced in processes having high gluonic contents \rightarrow DPE

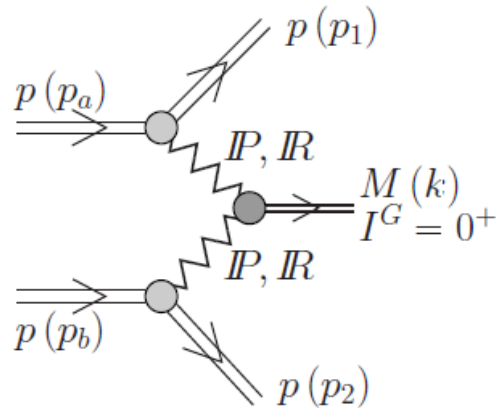
No $\rho(770)$, $\sigma(500)$?



$f_0(980)$

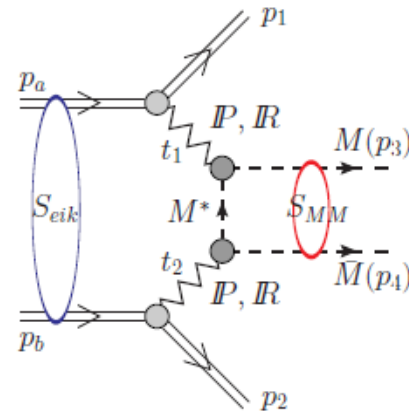
Structures still not well understood beyond $f_0(980)$:
 $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ scalar $q\bar{q}$ states mixed with pure gluon field ?

Physics motivation for studies of low mass central exclusive production



resonance production

+



non-resonant background

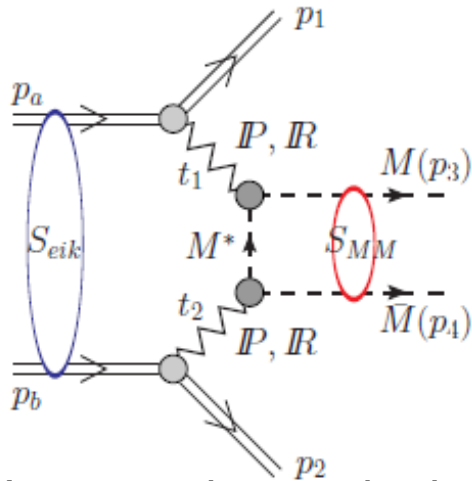
P.Lebiedowicz, A. Szczurek

L.A. Harland-Lang et al.

- Complication from secondary Regge trajectories \rightarrow go to higher energies
- Ensure exclusivity of the studied process \rightarrow tag

Tag scattered protons in pp collisions at RHIC

Non-resonant background of CEP MM spectrum



MODEL

P.Lebiedowicz, A. Szczurek
Phys.Rev.D81(2010)036003

L.A. Harland-Lang et al.
arXiv:1312.4553

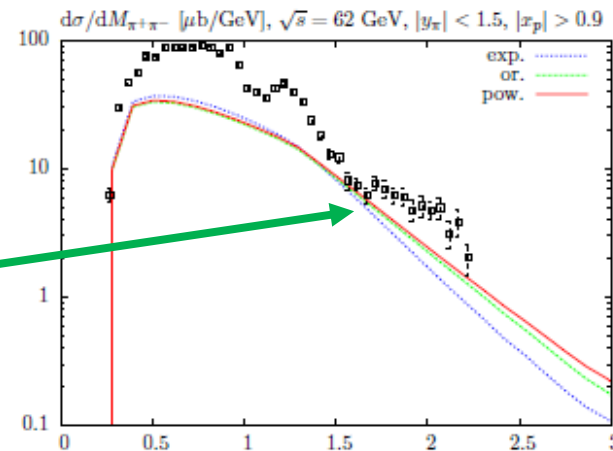
MC GENERATOR

GenEx

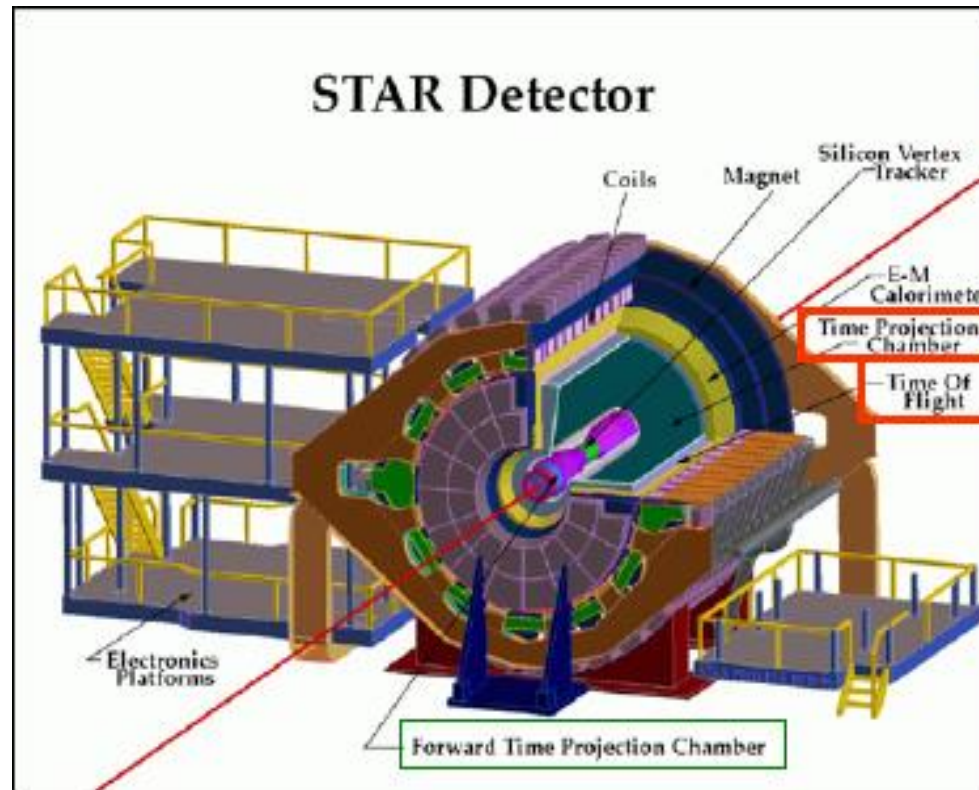
DiMe

In general terms both models represent convolution of Regge parametrisation of pM elastic off-shell scattering and appropriate exchanged meson propagator. In addition DiMe includes pp rescattering

Only uncertainty of the model, off shell formfactor, is tuned to ISR mass spectrum so that non-resonant background nowhere exceeds the data (Figure reproduced from L.A. Harland-Lang *et al.* arXiv1312.4553)



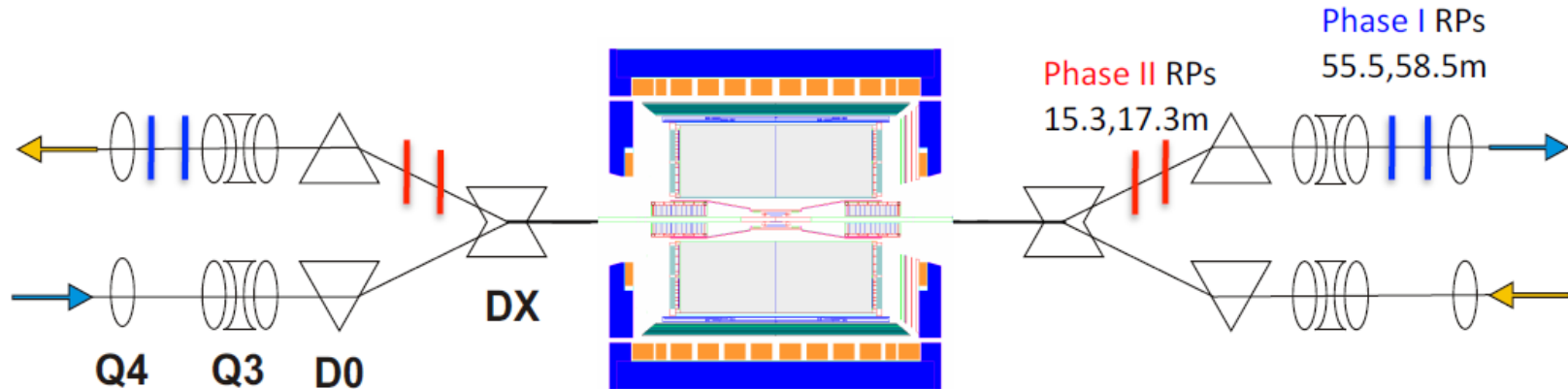
The STAR experiment at RHIC



Large acceptance detector running since 2000

- High resolution tracking device : TPC $-1 < |\eta| < 1$
- Particle identification capability : TPC dE/dx ; TOF

Forward proton tagging



- Roman pots with silicon strip detector for forward proton tagging
- Staged implementation to cover wide kinematic range:
 - Phase I (present data, low momentum transfer $t < 0.035 \text{ GeV}^2$)
 - Phase II (2015, large t coverage, large data sample)

Event selection, polarized pp 100 + 100 GeV, 2009 data

➤ **Trigger**

- Signal in one RP both on East and West sides
- Low multiplicity Time Of Flight (TOF) signal

➤ **Tracks in STAR TPC**

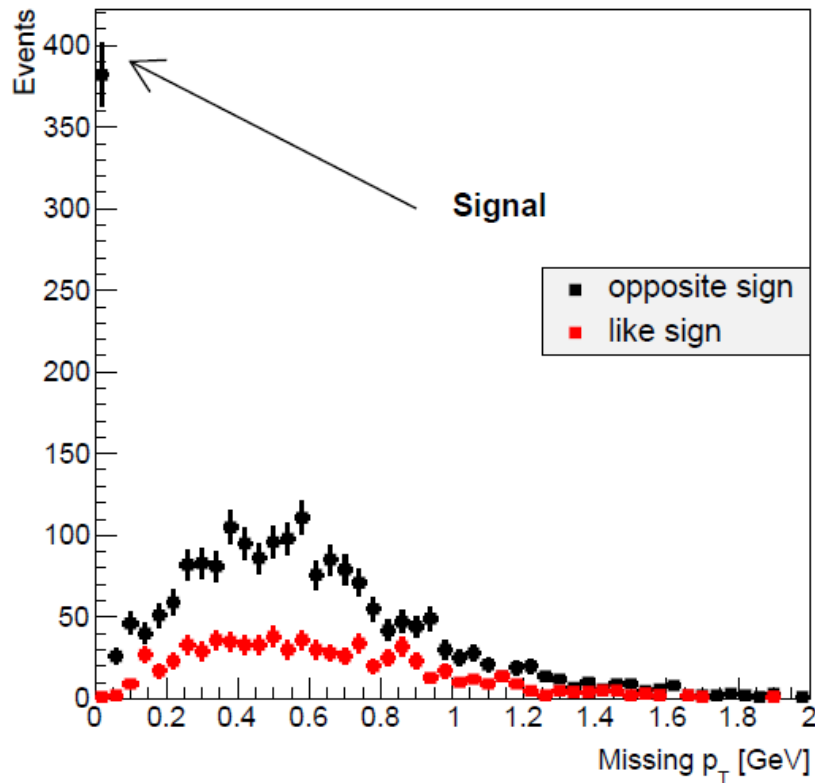
- Two opposite charge tracks from Primary Vertex**
- At least one matched with TOF hit
- $|\eta| < 1$
- > 15 hits/track
- $p_T > 150$ MeV

➤ **Tracks in Roman Pot detector**

- Exactly one track in RP on East and West
- $0.005 < t_1, t_2 < 0.03$ GeV² (assuming $E_p=100$ GeV)
- Transverse momentum balance**

$$p_T^{miss} = \left| (\vec{p}_E + \vec{p}_W + \vec{\pi}^+ + \vec{\pi}^-)_T \right| < 0.02 \text{ GeV}$$

Event selection: exclusivity



- transverse momentum balance

$$p_T^{miss} = |(\vec{p}_E + \vec{p}_W + \vec{\pi}^+ + \vec{\pi}^-)_T|$$

- requirement of $p_T^{miss} < 0.02$ GeV
very efficient in reduction of the non-exclusive background, characterized by large fraction of like-sign tracks
- almost no like-sign background in the signal region
- 380 clean events

Determination of cross section

Data were corrected for geometrical acceptance, trigger and detector efficiency using simple generator ansatz for $pp \rightarrow ppX$ proces, STAR simulation of TPC and TOF and Geant4 simulation of the RP trigger, beam line and Roman Pot detector geometry.

Data were corrected to visible kinematic range :

- $0.005 < -t_1, -t_2 < 0.03 \text{ GeV}^2$ (momentum transfer to protons)
- $|\eta_{\pi}| < 1.0$ (pseudorapidity of pions measured in STAR TPC)
- $|\eta_{\pi\pi}| < 2.0$ (pseudorapidity of $\pi\pi$ system)

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

Cross section in visible kinematic range

Visible kinematic range :

- $0.005 < -t_1, -t_2 < 0.03 \text{ GeV}^2$ (momentum transfer to protons)
- $|\eta_\pi| < 1.0$ (pseudorapidity of pions measured in STAR TPC)
- $|\eta_{\pi\pi}| < 2.0$ (pseudorapidity of $\pi\pi$ system)

STAR preliminary cross section for Central Exclusive Production of $\pi^+\pi^-$ pairs at $\sqrt{s}=200 \text{ GeV}$ in visible kinematic range

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

Systematic uncertainty includes:

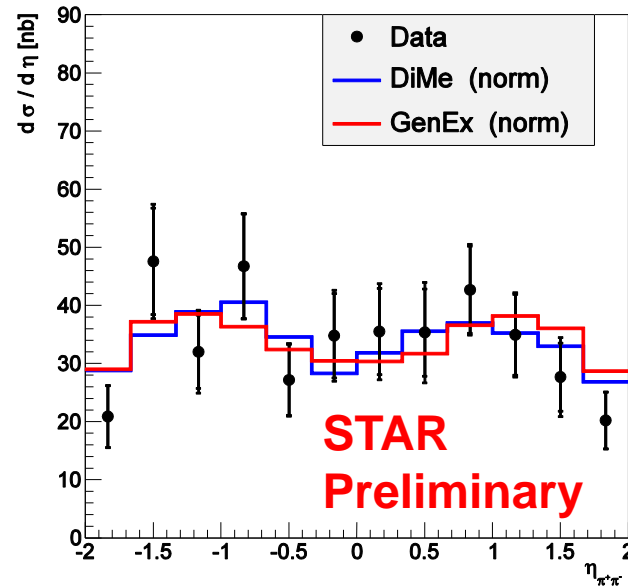
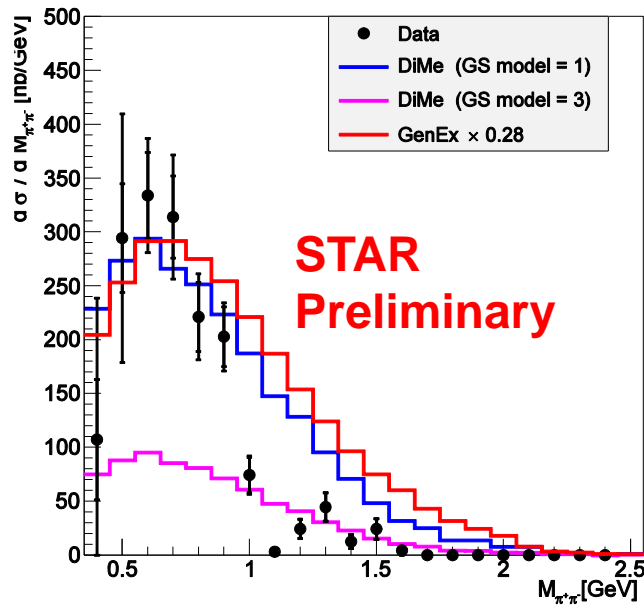
6% - sensitivity to variation of TPC track selection cuts

5% - uncertainty of absolute normalization using elastic sample

5% - uncertainty of TOF trigger efficiency (estimated from TOF independent trigger)

Total systematic uncertainty was obtained by adding in quadrature above numbers.

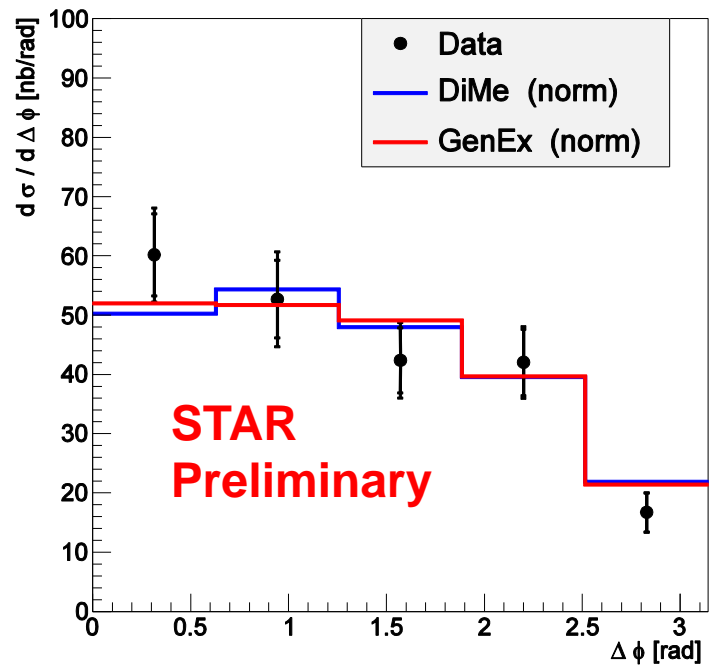
Cross section $d\sigma/dM_{\pi\pi}$; $d\sigma/dy_{\pi\pi}$



- DIME model for non-resonant background with *Model 1 Gap Survival* (see arXiv:1312.4552) is consistent with the measured cross section
- GenEx consistent with measured cross section assuming survival factor ~ 0.28
- Models do not describe cross section above 1 GeV \rightarrow other distributions calculated in the range $M_{\pi\pi} < 1$ GeV, predictions of the models normalized to cross section measured in this range (GS model = 1 assumed)

Cross section $d\sigma/d\Delta\phi$; $\Delta\phi = |\varphi_E - \varphi_W|$

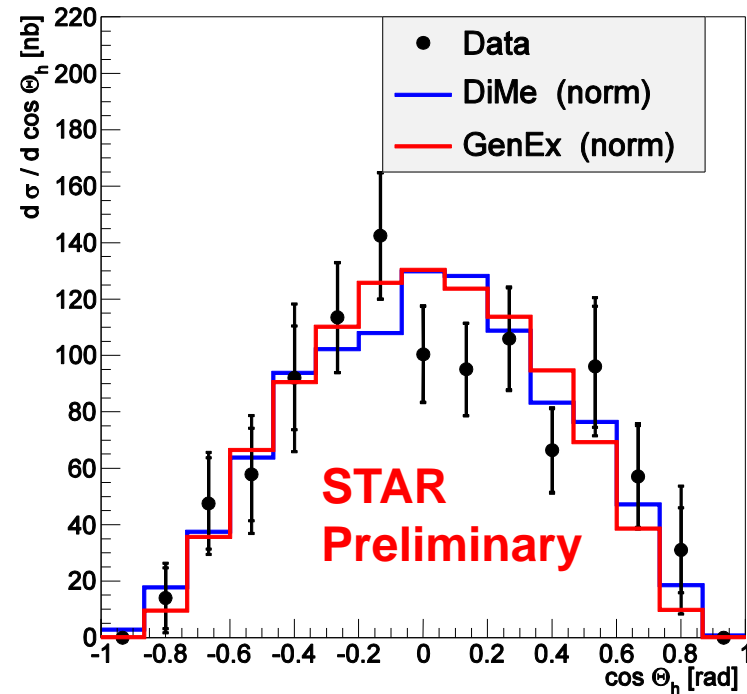
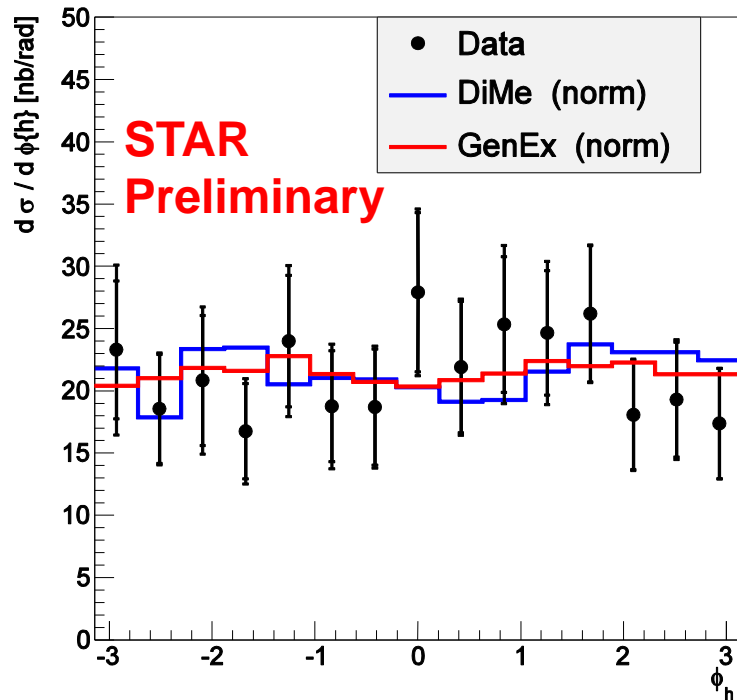
$0.5 < M_{\pi\pi} < 1.0 \text{ GeV}$



Models describe azimuthal correlation between scattered protons

$0.5 < M_{\pi\pi} < 1.0 \text{ GeV}$

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



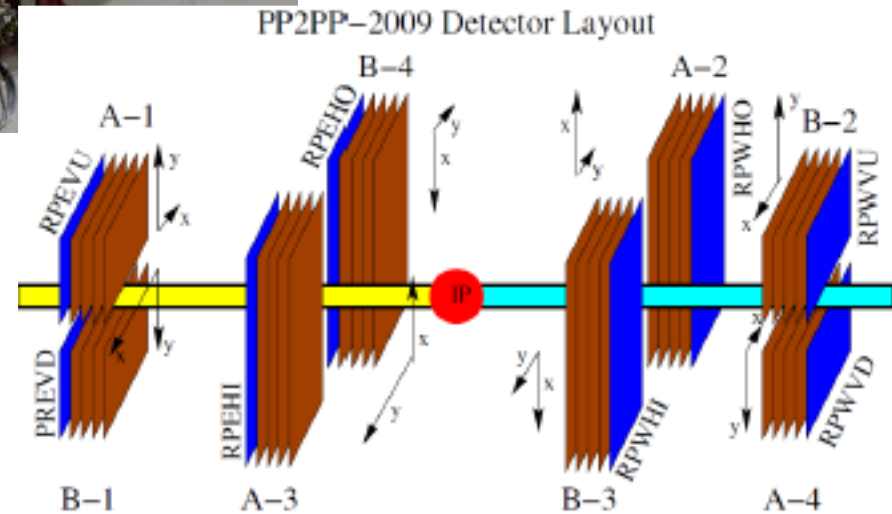
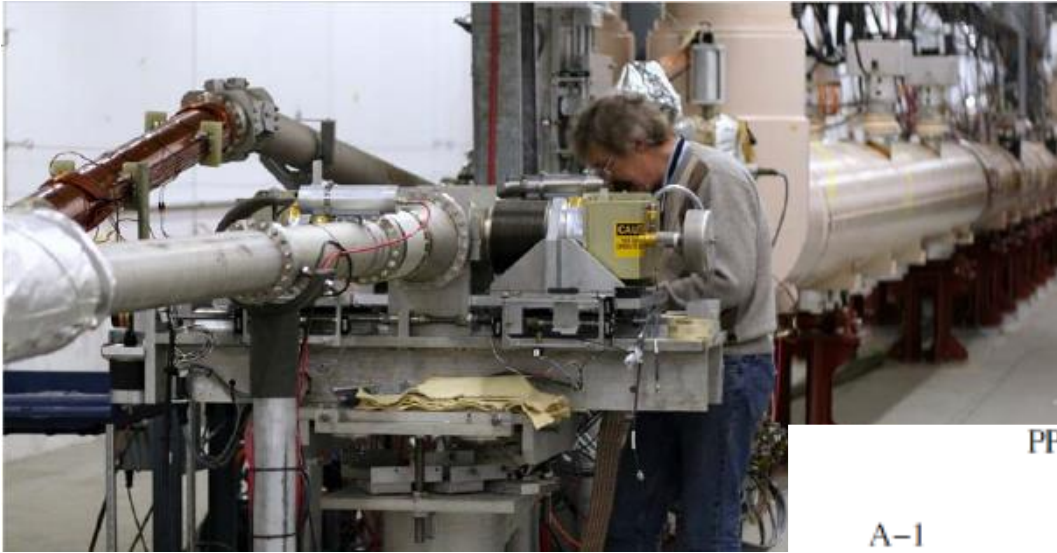
Models describe angular distributions in $\pi\pi$ rest frame system

Summary and outlook

- ❑ **measurement of the central exclusive production of $\pi^+\pi^-$ pairs** in proton-proton collisions at 200 GeV using Roman Pot tagging of the diffractively scattered protons at very small momentum transfers has been shown
- ❑ **very small non-exclusive background**, estimated by like-sign content of the two-pion sample, has been demonstrated
- ❑ Taking into account uncertainty of the survival factor calculation **predictions of cross section for non-resonant background** (DIME and GenEx generators) based on regge model tuned to ISR measurement of central exclusive production at 62 GeV **are broadly consistent with the present data at 200 GeV**
- ❑ shape of the measured distributions is well described by models
- ❑ **preparation for the analogous measurement at 200 GeV in 2015** in progress (30-40 times larger statistics, Partial Wave Analysis possible)

Backup slides

RP Phase I (2009) at STAR detector



Horizontal and vertical RP for full ϕ coverage

Detector efficiency and acceptance corrections

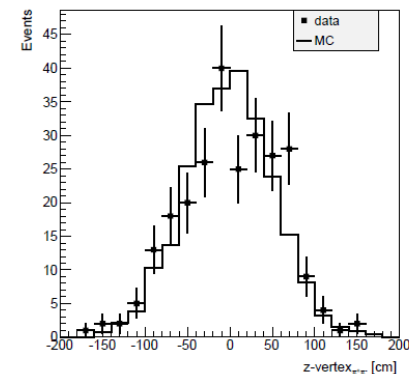
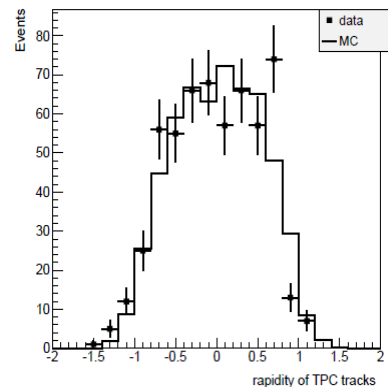
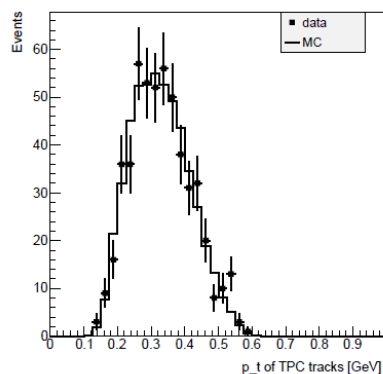
Data were corrected for geometrical acceptance, trigger and detector efficiency using simple ansatz for $pp \rightarrow ppX$ process

$$\frac{d\sigma}{dt_1 dt_2 dM_X^2 dy} \propto e^{bt_1} e^{bt_2} \frac{1}{M_X^2}$$

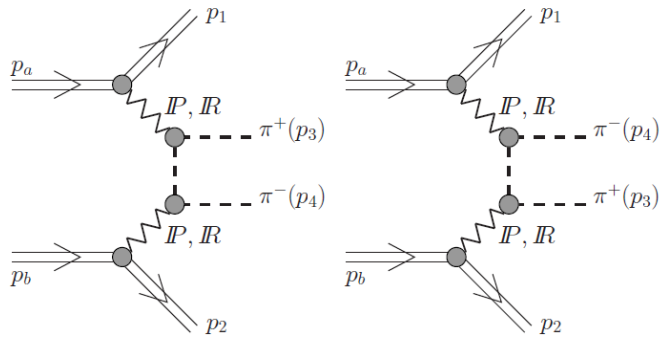
$$M_X \rightarrow \pi^+ \pi^-$$

Isotropic decay in M_X r.s.

Generated event were passed through full detector simulation (TCP+TOF+RP), resulting in fairly good description of the raw data

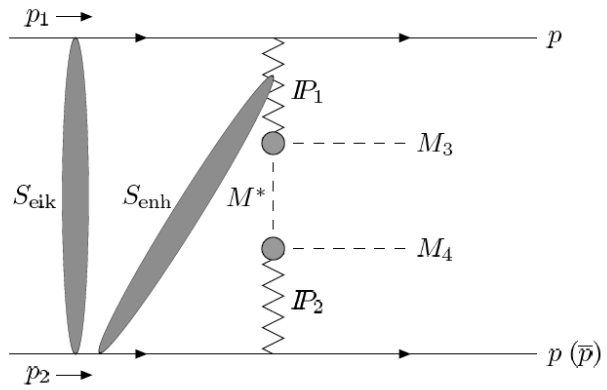


Model for non-resonant background and Gap Survival factor



$$\mathcal{M}^{pp \rightarrow pp\pi\pi} = M_{13}(t_1, s_{13}) F(t_a) \frac{1}{t_a - m_\pi^2} F(t_a) M_{24}(t_2, s_{24}) + M_{14}(t_1, s_{14}) F(t_b) \frac{1}{t_b - m_\pi^2} F(t_b) M_{23}(t_2, s_{23}),$$

$$M_{ik}(t_i, s_{ik}) = i s_{ik} C_P \left(\frac{s_{ik}}{s_0}\right)^{\alpha_P(t_i)-1} \exp\left(\frac{B_P}{2} t_i\right) + (a_f + i) s_{ik} C_f \left(\frac{s_{ik}}{s_0}\right)^{\alpha_R(t_i)-1} \exp\left(\frac{B_R}{2} t_i\right) \pm (a_\rho - i) s_{ik} C_\rho \left(\frac{s_{ik}}{s_0}\right)^{\alpha_R(t_i)-1} \exp\left(\frac{B_R}{2} t_i\right)$$

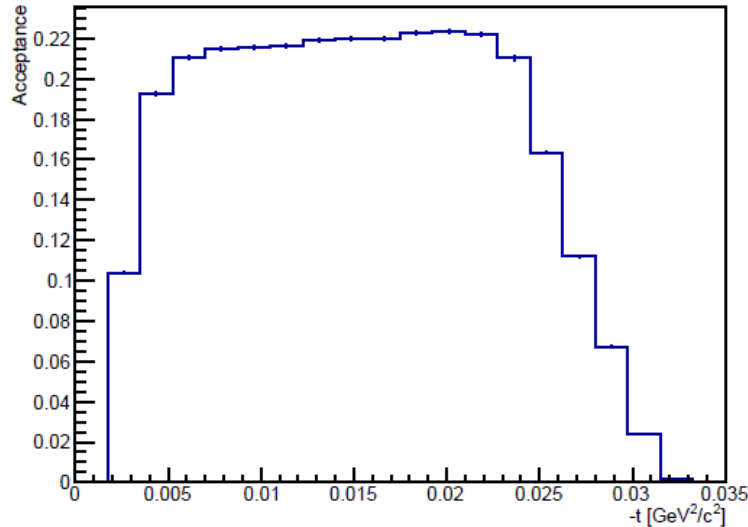


$$\langle S_{eik}^2 \rangle = \frac{\int d^2 \mathbf{b}_{1t} d^2 \mathbf{b}_{2t} |\mathcal{M}(s, \mathbf{b}_{1t}, \mathbf{b}_{2t})|^2 \exp(-\Omega(s, b_t))}{\int d^2 \mathbf{b}_{1t} d^2 \mathbf{b}_{2t} |\mathcal{M}(s, \mathbf{b}_{1t}, \mathbf{b}_{2t})|^2}$$

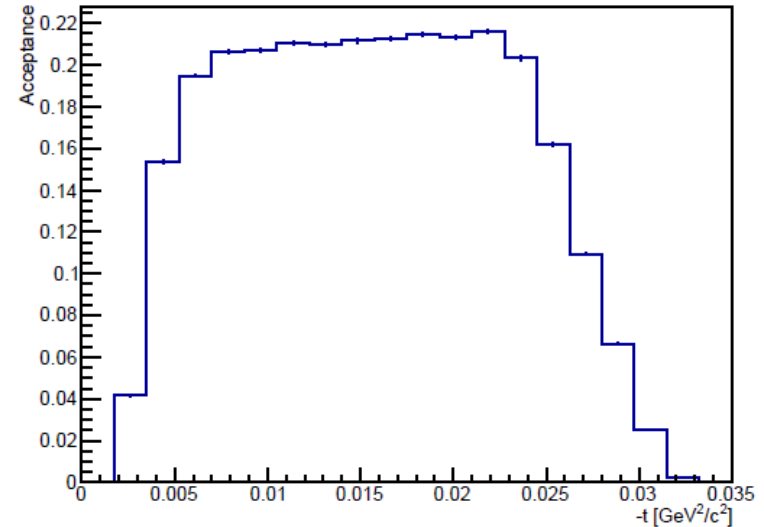
GS models 1-4 correspond to different parametrizations of proton opacity $\Omega(\dots)$

Acceptance

Acceptance of EHI-WHO, φ range width: 1.8 rad,



Acceptance of EHO-WHI, φ range width: 1.8 rad,



- obtained with full Geant4 simulation (protons generated with TM, full reconstruction, trigger veto and TAC cut-off introduced)
- calculated as $\frac{\text{reconstructed } dN/dt_{reco} \text{ histogram in } \pm 0.9 \text{ range in } \varphi}{\text{generated } dN/dt_{true} \text{ in full } \varphi}$
- Δt bin width = 0.00175, which is about 2.5x t resolution (calculated with Geant4)