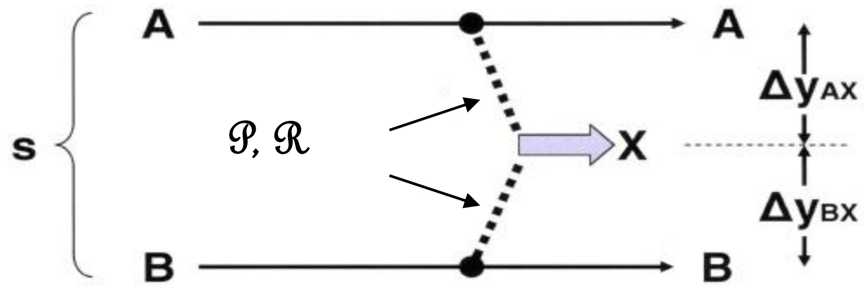
# Central Exclusive Production of $\pi^+\pi^-$ pairs in pp collisions at $\sqrt{s} = 200$ GeV

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

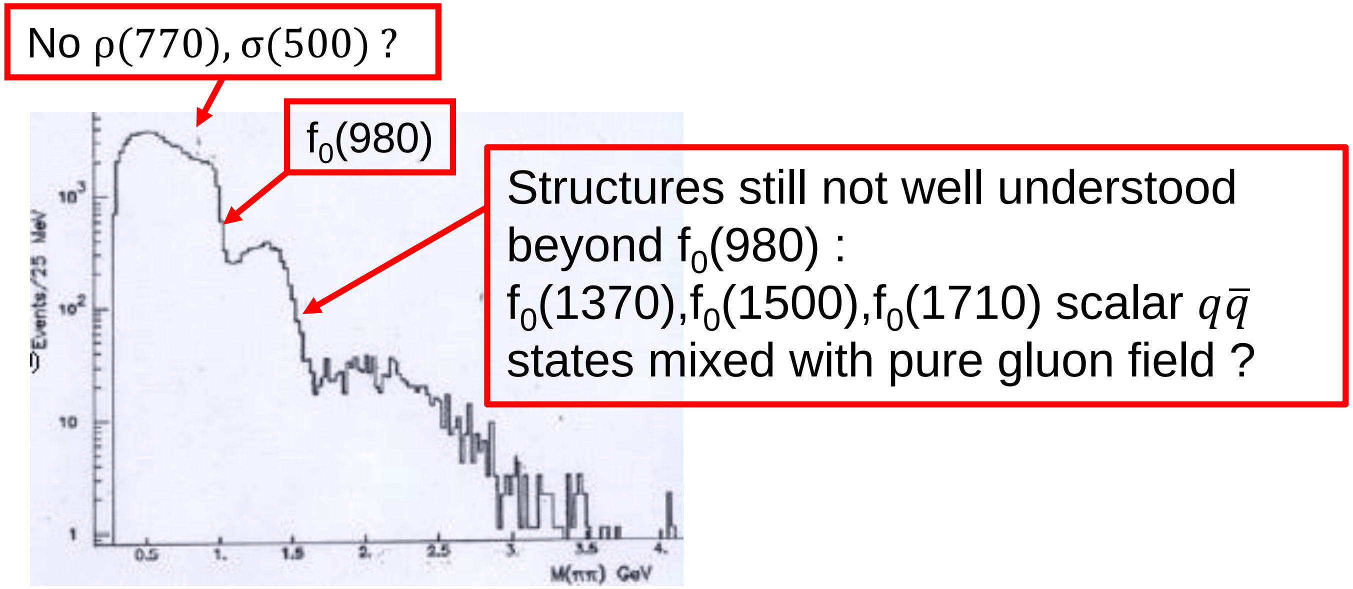
# Central Exclusive Production (CEP)



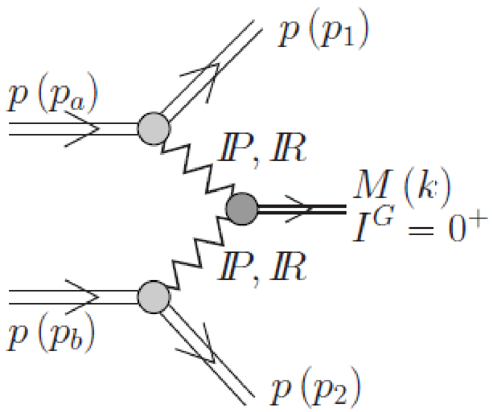

- colliding particles emerge intact
- produced state X is fully measured
- rapidity gaps A-X and B-X (subenergies $s_{AX}$, $s_{BX}$) large enough to justify regge description
- our measurement : p + p → p + X + p   X : $\pi^+ \pi^-$
- at sufficiently large collision energy Double Pomeron Exchange (DPE)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

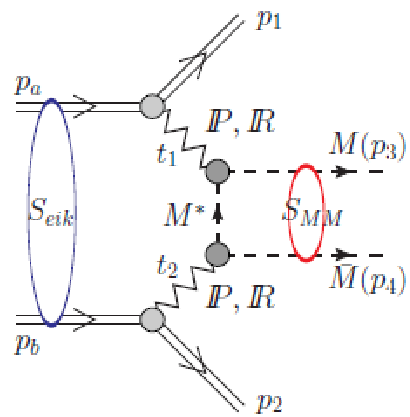
# Physics motivation for studies of low mass central exclusive production

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 → DPE



# Physics motivation for studies of low mass central exclusive production




P.Lebiedowicz, A. Szczurek

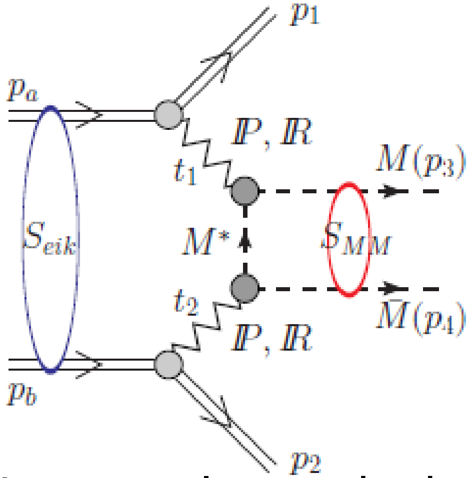
L.A. Harland-Lang et al.

**resonance production** + **non-resonant background**

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

Tag scattered protons in pp collisions at RHIC

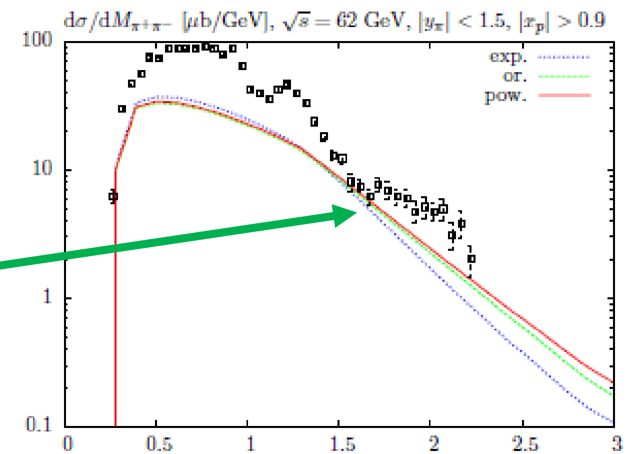
# Non-resonant background of CEP MM spectrum



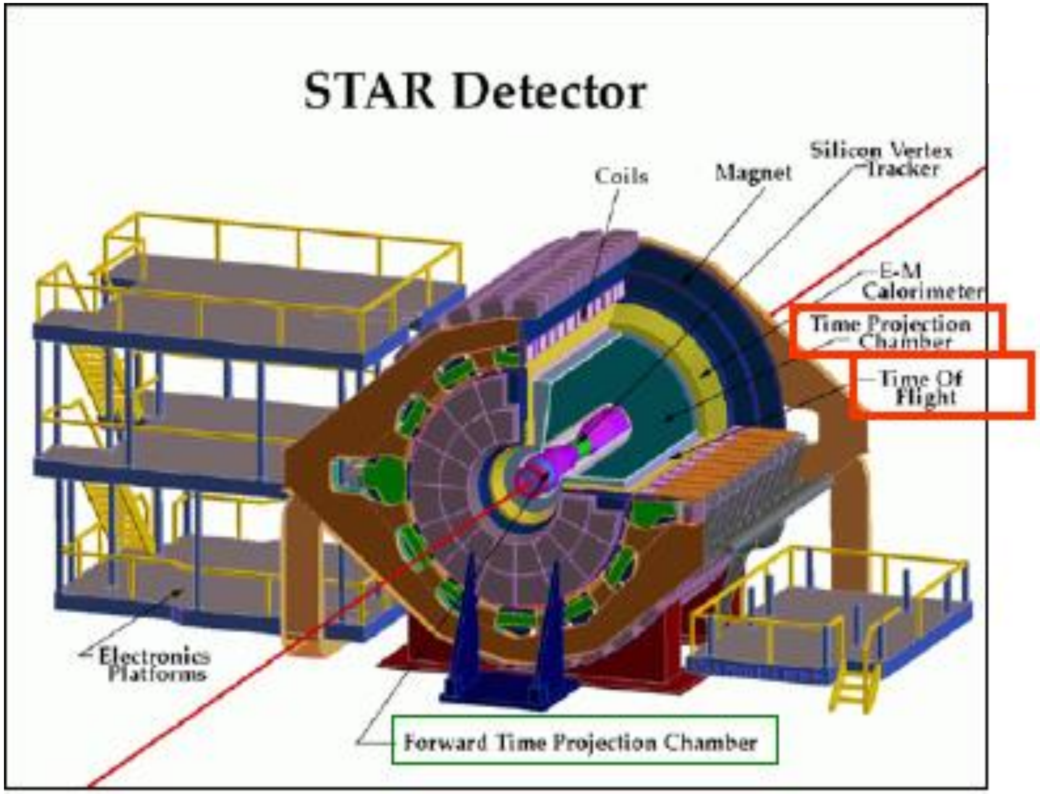

| MODEL | MC GENERATOR |
|---|---|
| **P.Lebiedowicz, A. Szczurek**<br>Phys.Rev.D81(2010)036003 | GenEx |
| **L.A. Harland-Lang et al.**<br>arXiv:1312.4553 | DiMe |

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*



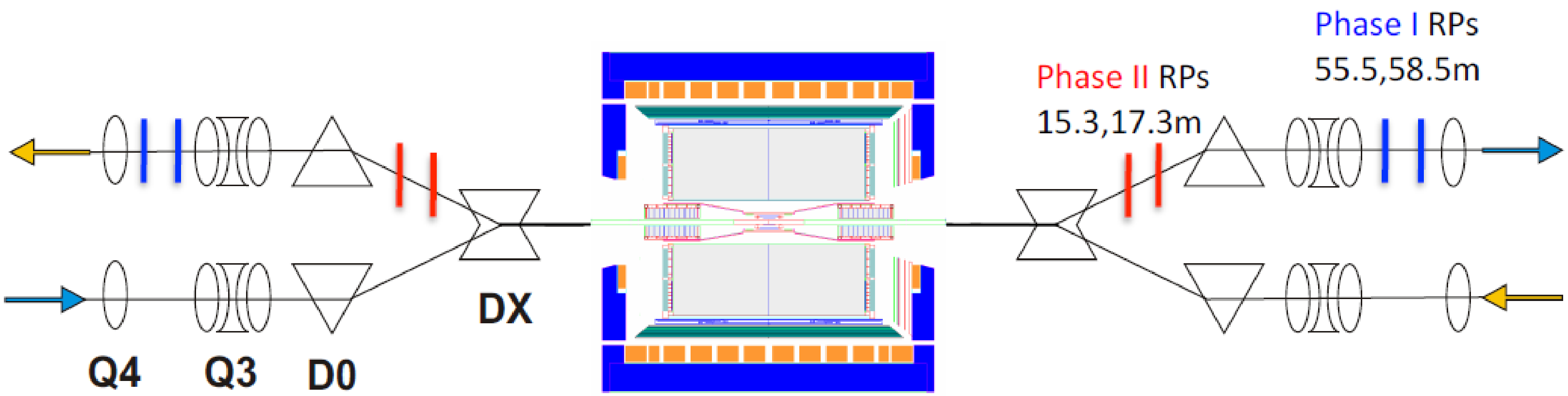
# The STAR experiment at RHIC




Large acceptance detector running since 2000

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

# Forward proton tagging



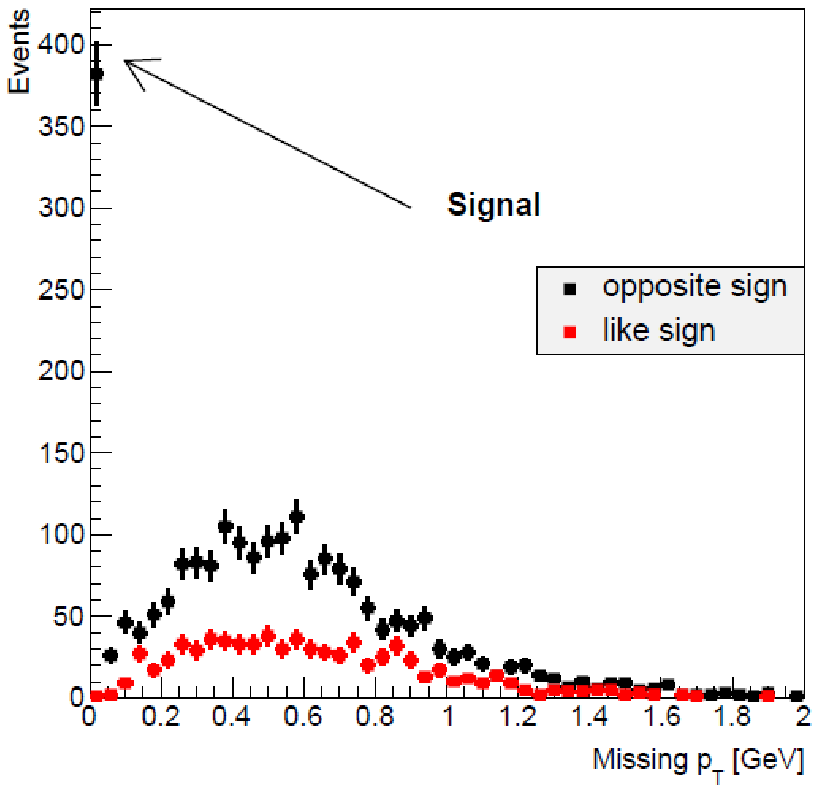

- Roman pots with silicon strip detector for forward proton tagging
- Staged implementation to cover wide kinematic range:
  - Phase I (present data, low momentum transfer $t < 0.1$ GeV$^2$)
  - Phase II ( 2015, large t coverage, large data sample)

# 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
  - **$0.005 < t_1, t_2 < 0.03$ GeV$^2$ (assuming $E_p$=100 GeV)**
  - Transverse momentum balance

$$p_T^{miss} = \left|(\overrightarrow{p_E} + \overrightarrow{p_W} + \overrightarrow{\pi^+} + \overrightarrow{\pi^-})_T\right| < 0.02 \text{ GeV}$$

# 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 anzatz for pp→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 :

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

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

# Cross section in visible kinematic range

Visible kinematic range :

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

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

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

Systematic uncertainty includes:

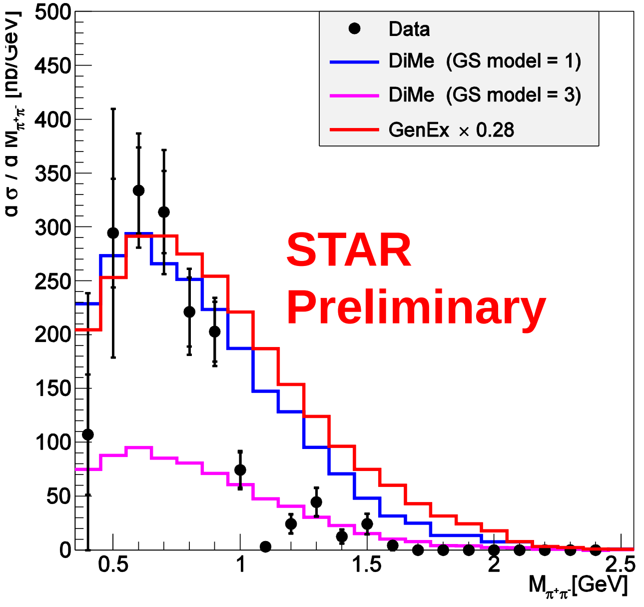
6% - sensitivity to variation of TPC track selection cuts

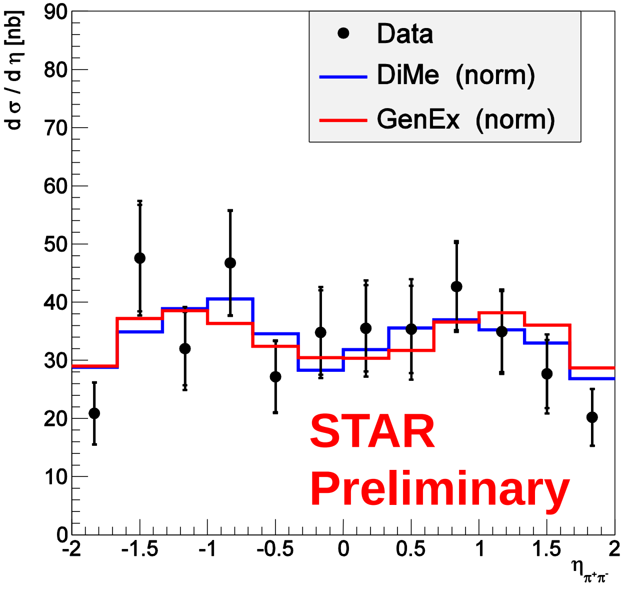
5% - uncertainty of absolute normalization using elastic sample

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

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

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

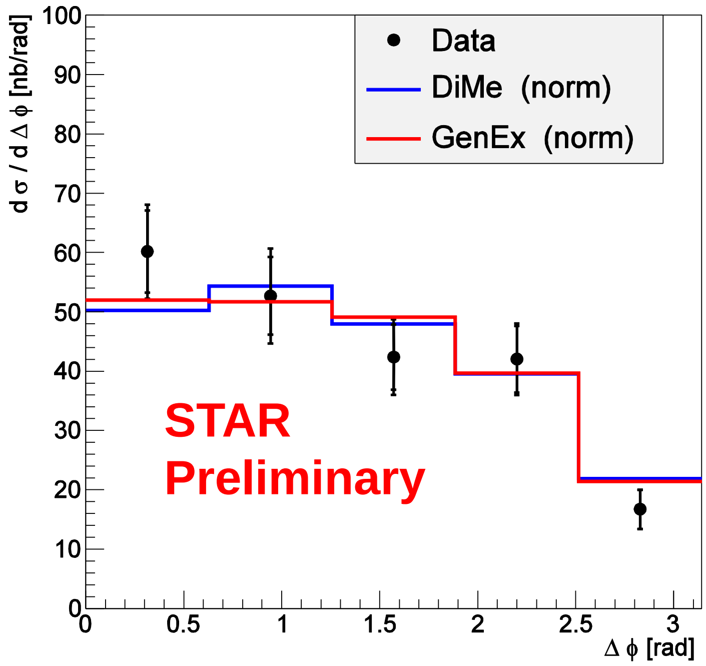



- DIME model for non-resonant background with *Model 1 Gap Survival* (see arXiv:1312.4552) is consitent with the measured cross section
- GenEx consitent with measured cross section assuming survival factor ~0.28
- Models do not describe cross section above 1 GeV → other distributions calculated in the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

# Cross section $^{d\sigma}/_{d\Delta\varphi}$; $\Delta\varphi = |\varphi_E - \varphi_W|$

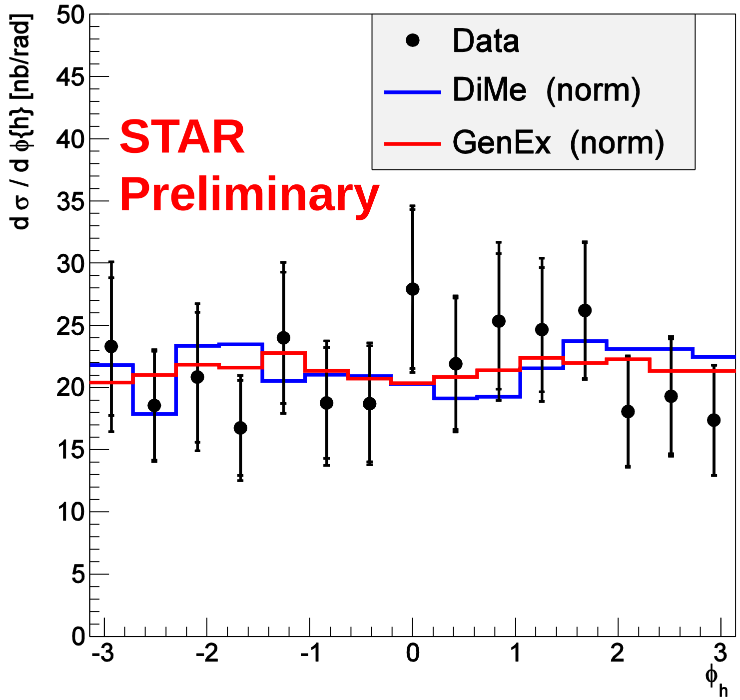
# $0.5 < M_{\pi\pi} < 1.0$ GeV

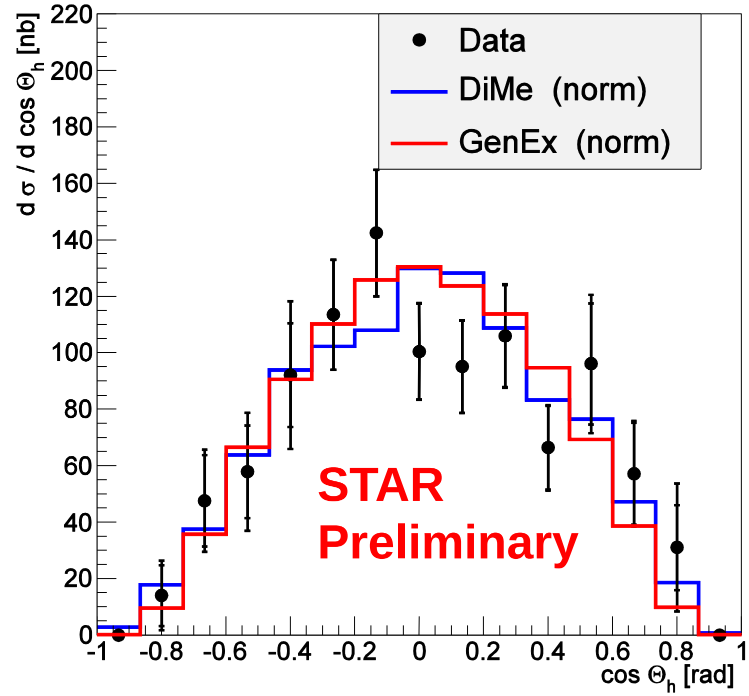



Models describe azimutal correlation between scattered protons

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

Helicity angles of $\pi^+$ 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

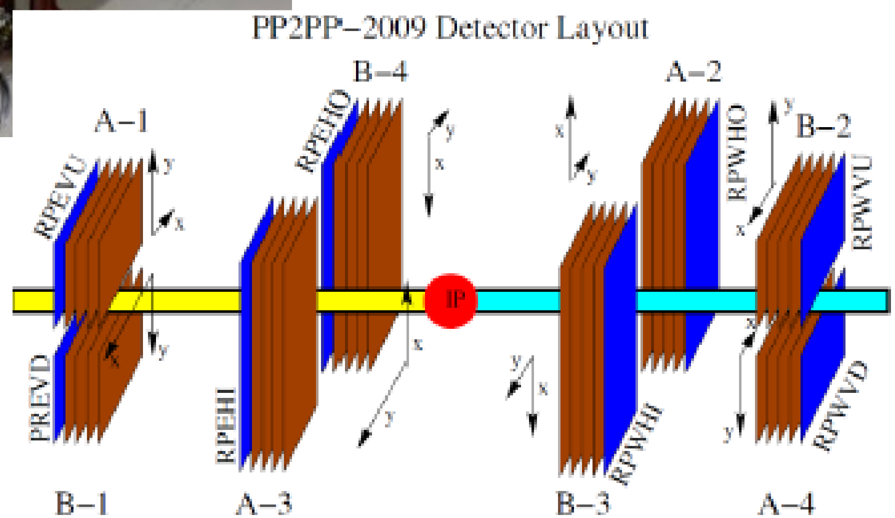
❑ Taking into account uncertainty of the survival factor calculation **predictions of cross section for non-resonant background** (DIME and GenEx generators) based on regge model tuned to ISR measurement of central exclusive production at 62 GeV **are broadly consistent with the present data at 200 GeV**

❑ 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, PWA possible)

# Backup slides

# RP Phase I (2009) at STAR detector




Horizontal and vertical RP for full φ coverage

# Detector efficiency and acceptance corrections

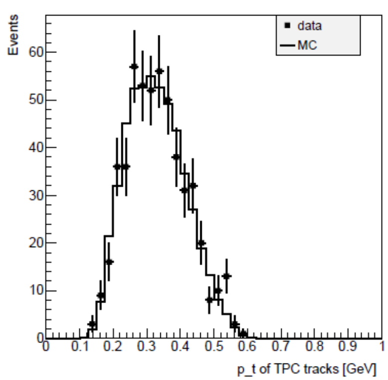
Data were corrected for geometrical acceptance, trigger and detector efficiency using simple anzatz for pp→ppX process

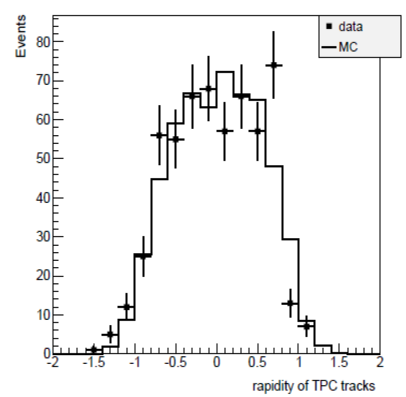
$$\frac{d\sigma}{dt_1\ dt_2\ dM_X^2\ dy} \propto e^{bt_1} e^{bt_2} \frac{1}{M_X^2}$$

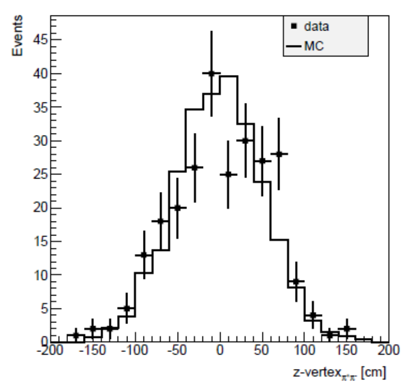
$$M_X \rightarrow \pi^+\pi^-$$

Isotropic decay in $M_X$ r.s.

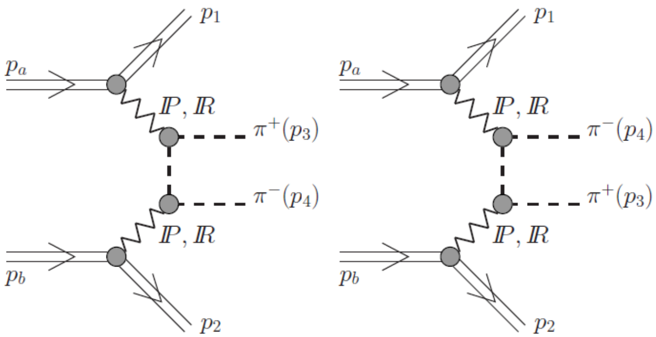
Generated event were passed through full detector simulation (TCP+TOF+RP ), resulting in fairly good decription of the raw data



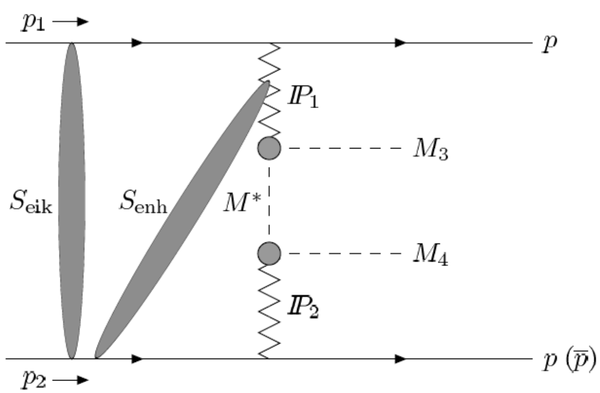



# Model for non-resonant background and Gap Survival factor




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

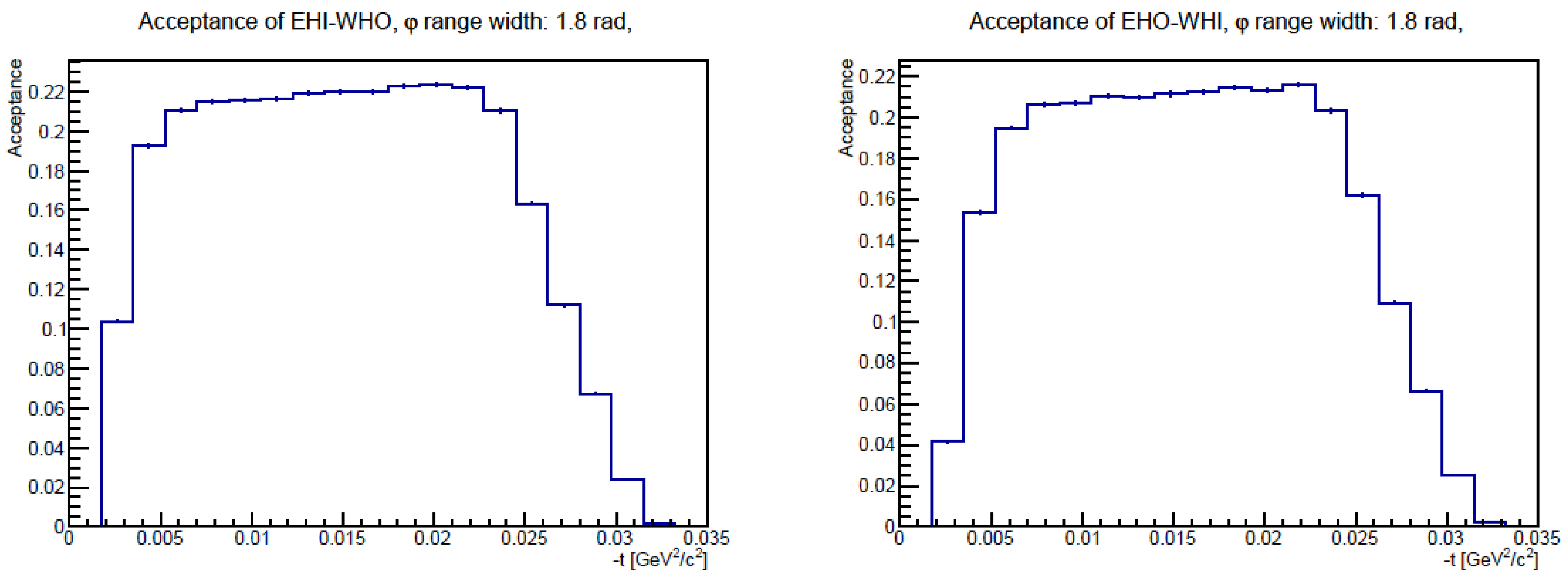
$$M_{ik}(t_i, s_{ik}) = \mathrm{i}\; s_{ik}\, C_{I\!P} \left(\frac{s_{ik}}{s_0}\right)^{\alpha_{I\!P}(t_i)-1} \exp\left(\frac{B_{I\!P}}{2}\, t_i\right) + (a_f + \mathrm{i})\; s_{ik}\, C_f \left(\frac{s_{ik}}{s_0}\right)^{\alpha_{I\!R}(t_i)-1} \exp\left(\frac{B_{I\!R}}{2}\, t_i\right) \pm (a_\rho - \mathrm{i})\; s_{ik}\, C_\rho \left(\frac{s_{ik}}{s_0}\right)^{\alpha_{I\!R}(t_i)-1} \exp\left(\frac{B_{I\!R}}{2}\, t_i\right)$$




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

GS models 1-4 correspond to different parametrizations of proton opacity Ω(...)

# Acceptance




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