Diffraction with STAR
(a selection)

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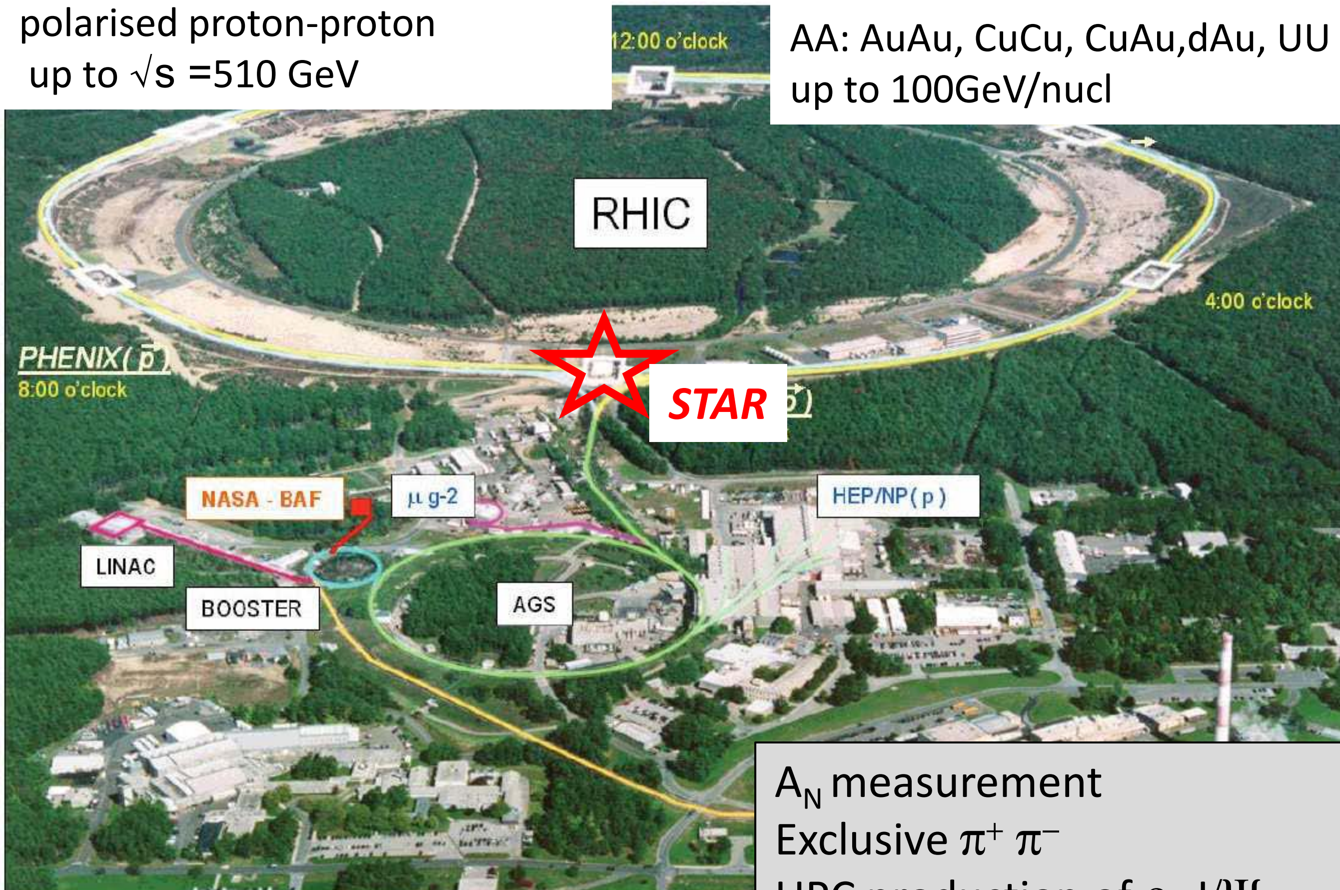
On behalf of the STAR Collaboration

polarised proton-proton
up to $\sqrt{s}$ =510 GeV

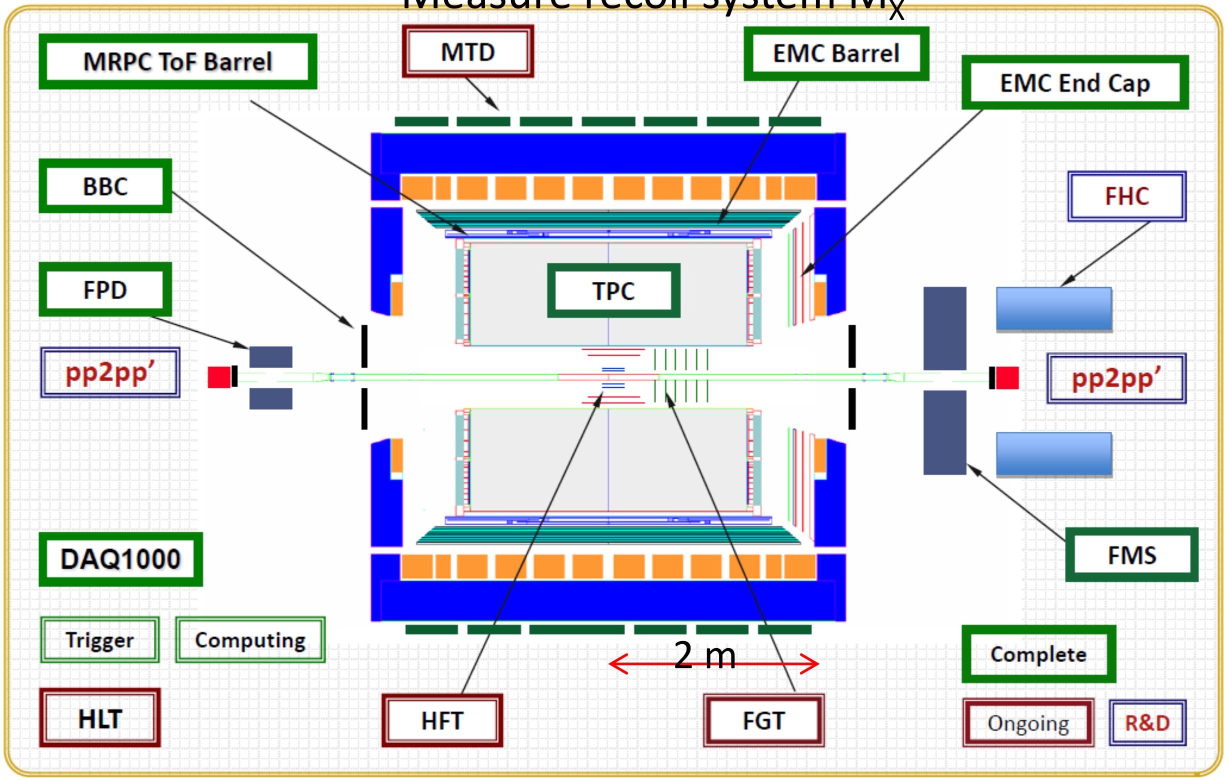
AA: AuAu, CuCu, CuAu,dAu, UU
up to 100GeV/nucl



A_N measurement
Exclusive $\pi^+ \pi^-$
UPC production of ρ, J/Ψ

STAR@RHIC

Measure recoil system M_X



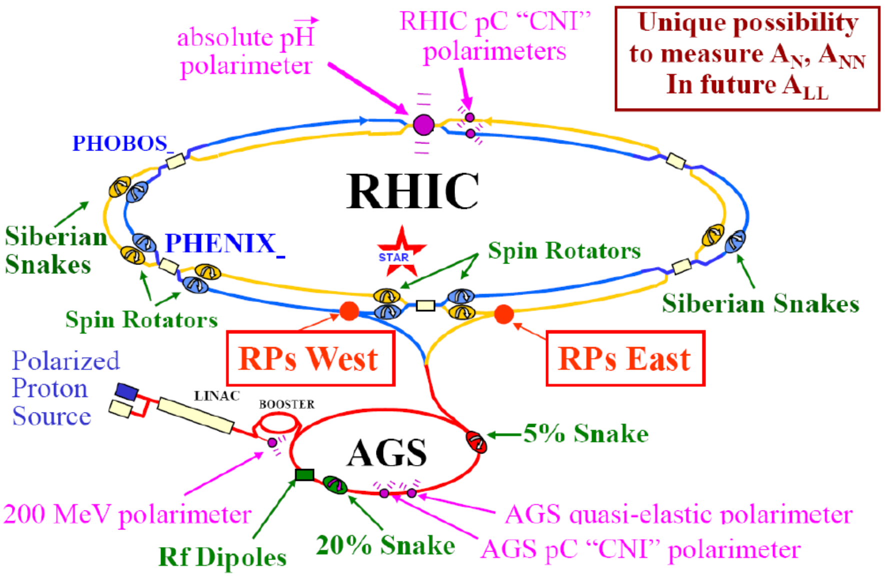
Relatively large acceptance detector – runs since 2000

High resolution tracking with TPC: $-1 < \eta < 1$

Excellent particle id: TPC dE/dx, ToF counters

Possible forward rapidity gap veto BBC: $3.8 < |\eta| < 5.2$

RHIC polarised proton-proton collider



$$\langle P_Y + P_B \rangle = 1.224 \pm 0.038$$
$$\langle P_Y - P_B \rangle = -0.016 \pm 0.054$$

CNI Polarimeter Group@RHIC 2009

elastic scattering

non – flip: $\varphi_1(s,t) = \langle ++ | M | ++ \rangle$

double flip: $\varphi_2(s,t) = \langle ++ | M | -- \rangle$

non – flip: $\varphi_3(s,t) = \langle +- | M | +- \rangle$

double flip: $\varphi_4(s,t) = \langle +- | M | -+ \rangle$

single flip: $\varphi_5(s,t) = \langle ++ | M | +- \rangle$

A_N comes from interference of: spin flip and non-flip amplitudes

$$A_N \frac{d\sigma}{dt} = -\frac{4\pi}{s^2} \mathrm{Im}\, \{\phi_5^*(\phi_1 + \phi_2 + \phi_3 - \phi_4)\}$$

$$A_N \frac{d\sigma}{dt} = -\frac{8\pi}{s^2} \mathrm{Im}\, (\phi_5^{em*}\phi_+^{had} + \phi_5^{had*}\phi_+^{em})$$

$$\sigma_{tot} = \frac{4\pi}{s} \mathrm{Im}\{\phi_1 + \phi_3\}_{t=0}$$

$$\Delta\sigma_T = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow} = -\frac{8\pi}{s} \mathrm{Im}\{\phi_2\}_{t=0}$$

$$\Delta\sigma_L = \sigma^{\overset{\rightarrow}{\leftarrow}} - \sigma^{\overset{\rightarrow}{\rightarrow}} = \frac{8\pi}{s} \mathrm{Im}\{\phi_1 - \phi_3\}_{t=0}$$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}\{|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2\}$$

$$A_N = \frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}} \qquad A_{NN} = \frac{\sigma^{\uparrow\uparrow+\downarrow\downarrow} - \sigma^{\uparrow\downarrow+\downarrow\uparrow}}{\sigma^{\uparrow\uparrow+\downarrow\downarrow} + \sigma^{\uparrow\downarrow+\downarrow\uparrow}}$$

N – protons fully polarised along normal to the scatt. plane

S – protons fully polarised along a vector in the scatt. plane and perp. to the beam

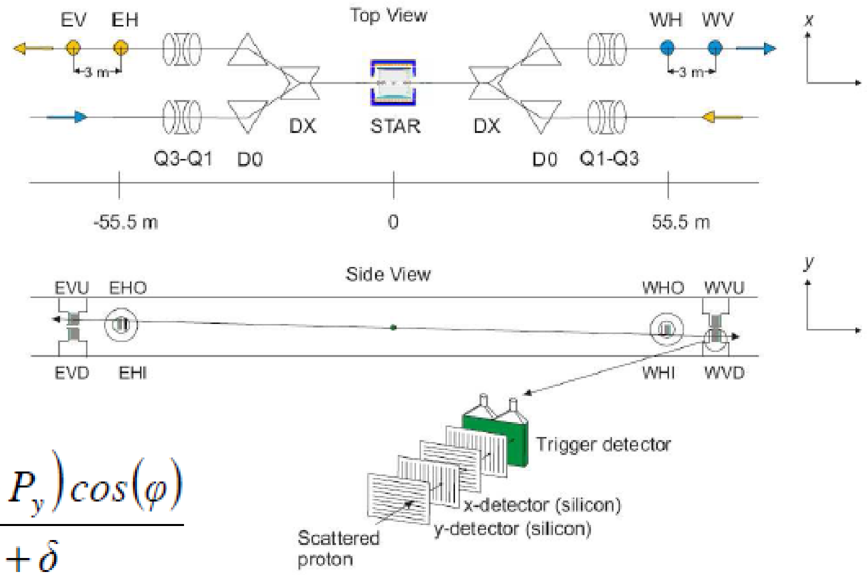
Also possible:

A_{NN} (s,t), A_{SS} (s,t), A_{SL} (s,t), A_{LL} (s,t)

Elastic pp - pp2pp@STAR

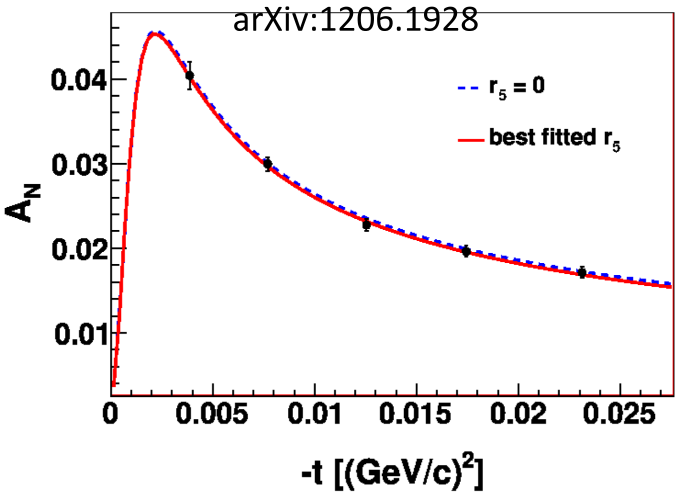
Silicon strip detectors (4 layers) in RP
t range 0.003 – 0.035 GeV^2/c^2
Parallel-to-point focusing

Select elastic:
two collinear track events
$-t = p^2(1-\cos\Theta)$ p = 100.22 GeV/c
~21 million events
non-collinear bckgrnd <1%



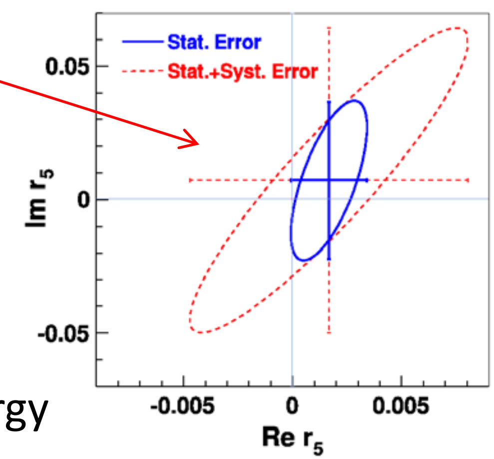
$$\varepsilon_N = \frac{\sqrt{N^{\uparrow\uparrow}(\varphi)N^{\downarrow\downarrow}(\pi-\varphi)} - \sqrt{N^{\uparrow\uparrow}(\pi-\varphi)N^{\downarrow\downarrow}(\varphi)}}{\sqrt{N^{\uparrow\uparrow}(\varphi)N^{\downarrow\downarrow}(\pi-\varphi)} + \sqrt{N^{\uparrow\uparrow}(\pi-\varphi)N^{\downarrow\downarrow}(\varphi)}} = \frac{A_N(P_b + P_y)\cos(\varphi)}{1+\delta}$$

Submitted to Phys. Lett. B
arXiv:1206.1928



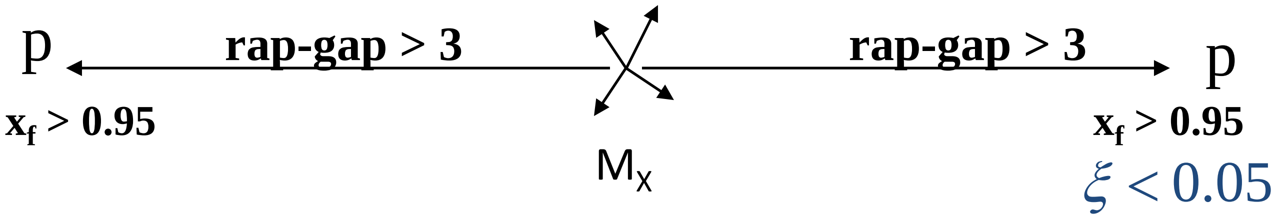
$$A_N(t) \sim f(\mathrm{Re}\, r_5, \mathrm{Im}\, r_5)$$

$$r_5 = \frac{2m}{\sqrt{-t}} \frac{\varphi_5^{had}}{\mathrm{Im}(\varphi_1^{had} + \varphi_3^{had})}$$



Final result consistent with
no hadronic spin-flip at this energy

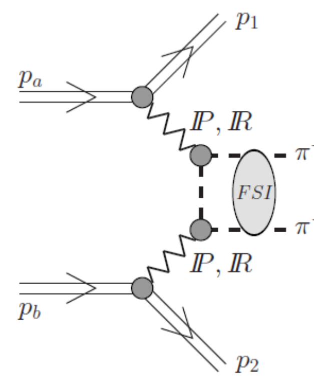
Central exclusive production - run 2009 data



Colliders : ISR, TEVATRON, RHIC,LHC,

$$M_X = \sqrt{s \cdot \xi_1 \cdot \xi_2}$$

- ISR, RHIC : low mass region :
- spectroscopy, glueball search
- non-perturbative aspects of meson production

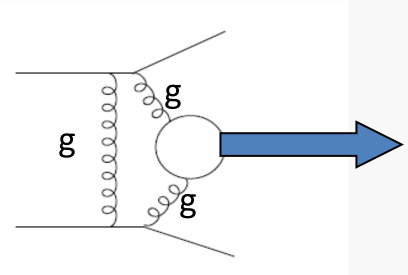


- LHC (> 2015) H, WW, …
- TEVATRON: high mass region < 100 GeV : heavy mesons production, perturbative QCD

Central exclusive production - run 2009 data

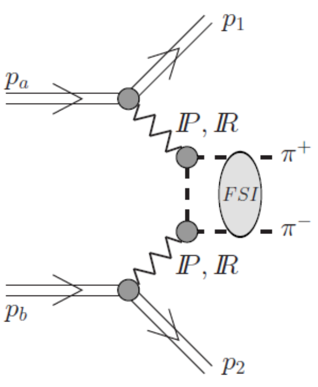
Spectroscopy :

- understanding of scalar meson spectrum. CEP advantage: spin and isospin filter simplifies PWA
- general agreement that lightest glueball should be a scalar with mass in the range 1 – 2 GeV. In DPE its formation might be enhanced



Non-perturbative aspects of meson production:

- L. A. Harland-Lang et al., The phenomenology of CEP at hadron colliders arXiv:1204.4803
- P. Lebiedowicz et al., Exclusive $pp \rightarrow pp\pi^{+}\pi^{-}$ reaction: From the threshold to LHC, Phys. Rev. D81(2010)036003
- R. Staszewski et al. Exclusive $\pi^{+}\pi^{-}$ Production at the LHC with



Central exclusive production - run 2009 data

Data selection:

1. Pots:
   RP trigger on each side (East, West) – two protons (~100 GeV)
   Non-collinear tracks (difference of scattering angles)

$$\Delta\theta = \sqrt{(\theta_x^W - \theta_x^E)^2 + (\theta_y^W - \theta_y^E)^2} > 0.15\,\mathrm{mrad}$$

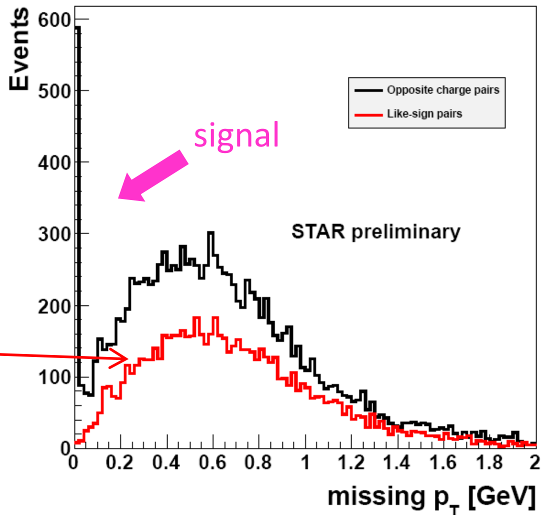
2. STAR central detector:
   two unlike sign charge tracks in the TPC - $|\eta|<1$,
   primary vertex,
   more than 14 hits/track
   track p_T > 150 MeV/c

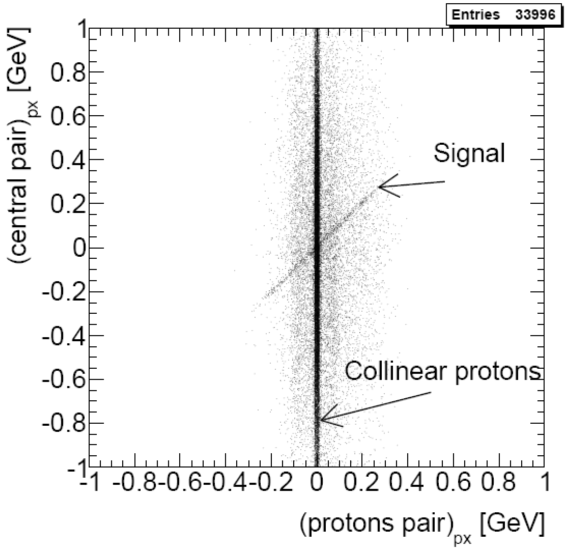
3. Transverse momentum balance for an event:

$$p_T^{miss} = \left|(\overrightarrow{p_E} + \overrightarrow{p_W} + \overrightarrow{\pi^+} + \overrightarrow{\pi^-})_T\right| < 0.02\,\mathrm{GeV/c} \quad \text{with } |p_E|,|p_W| \approx 100 GeV/c$$

Central exclusive production - run 2009 data

- partially selected sample: pp + two charged tracks (no Δθ > 0.15 mrad cut)
- contains elastic pp→pp events with TPC track not belonging to the same interaction vertex, characterized by large fraction of like-sign tracks (red curve)
- these ``overlap'' events can be removed by requirement of TOF signal within a bunch for central tracks at the cost of statistics
- transverse momentum balance cut very efficient in reduction of the ``overlap'' events as well as the non-exclusive background
- Δθ > 0.15 mrad cut still needed to remove cosmics





Central exclusive production - run 2009 data

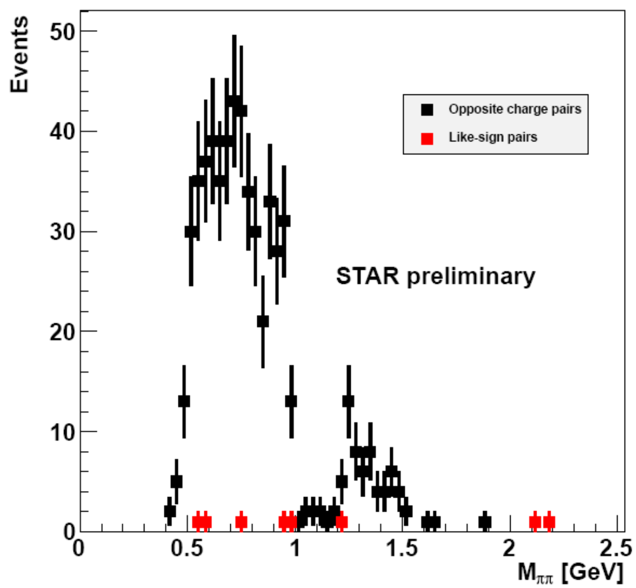
Exclusive non-back-to-back pion pairs

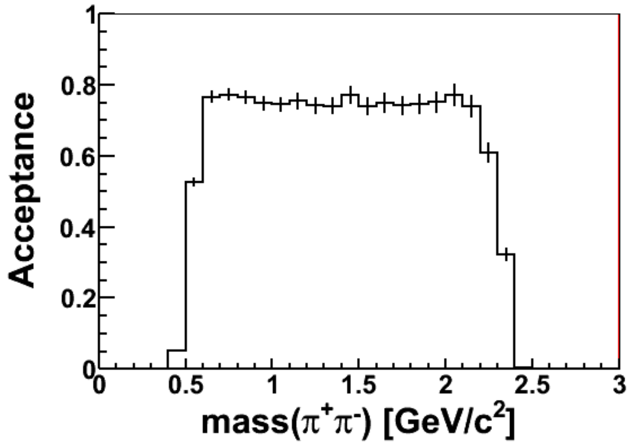
- $p_T^{miss} < 0.02$ GeV
- $\Delta\theta > 0.15$ mrad
- $|dE/dx - (dE/dx)_\pi| < 3\sigma$

Spectrum similar to the one published by AFS at ISR (1985):

- almost no like-sign background
- dominated by
  low invariant mass pairs < 1 GeV
- characteristic cross section drop ~1 GeV due to $f_0(980)$ in final state interaction

$\pi^+ \pi^-$ invariant mass spectrum





Heavy Ion Ultraperipheral Collisions

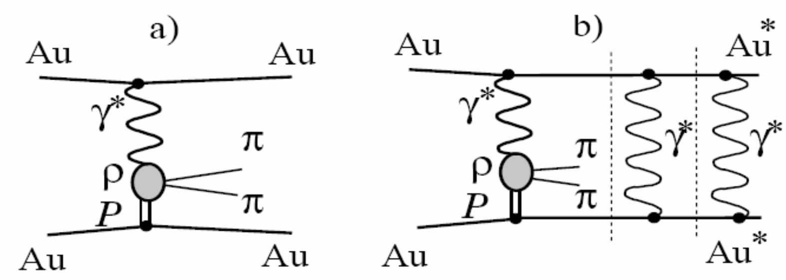
- Physics processes:

$$\gamma\gamma \to \rho^0\rho^0, \pi^+\pi^-, l^+l^-, Q\bar{Q}$$

$$\gamma I\!P \to \rho^0, \pi^+\pi^-, \pi^+\pi^-\pi^+\pi^-, J/\Psi$$

- Large impact parameter (coherence)– separation of electromagnetic and hadron interactions

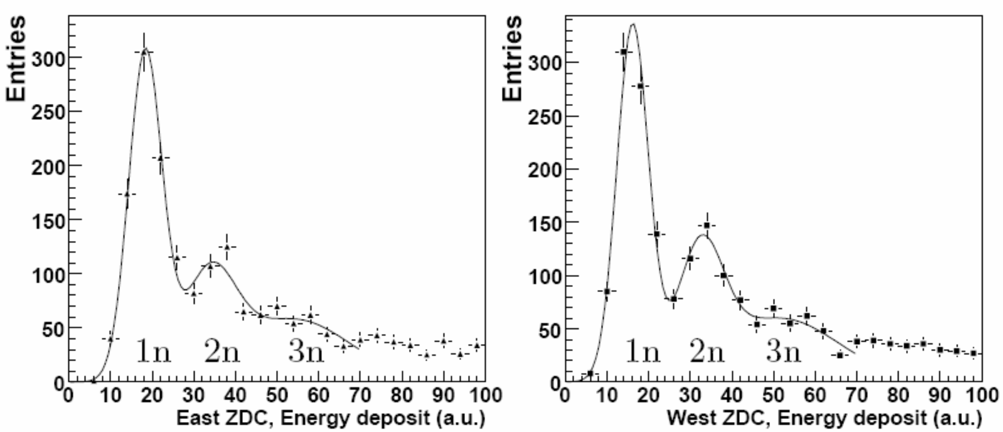
$$b > 2R_A \to p_T < \frac{h}{2R_A} \Rightarrow R_{Au} \approx 7\ fermi \to p_T < 90 MeV/c$$



Coherent

Coherent+ GDR excitations

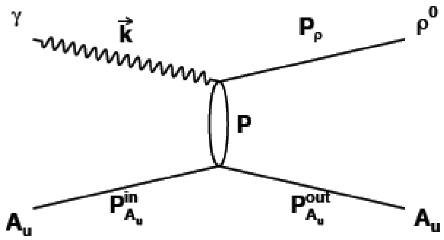
ZDC energy spectra



de-excitation via forward n emission

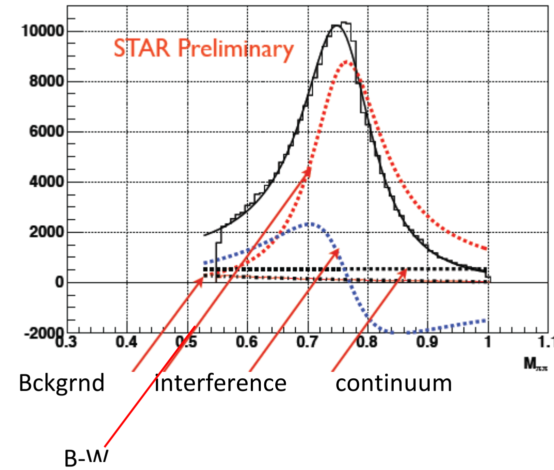
simple experimental signature:
neutron registered in the ZDCs
at b = $2R_A$ σ(both A) = 3.5b, p = 0.35

Coherent ρ^0, J/Ψ photoproduction in AuAu UPC – 2010 run

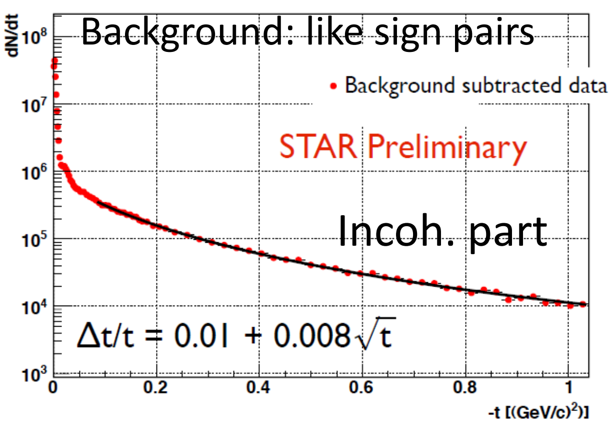


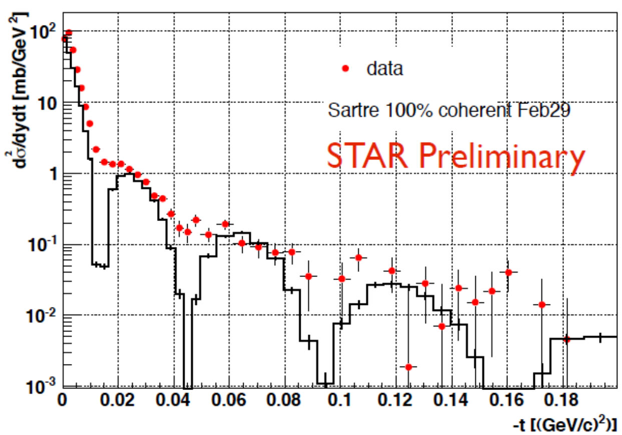
Data selection:
Each ZDC – 1n
Vertex connected to ToF trig.
Particles with TPC dE/dx
2 tracks from the vertex

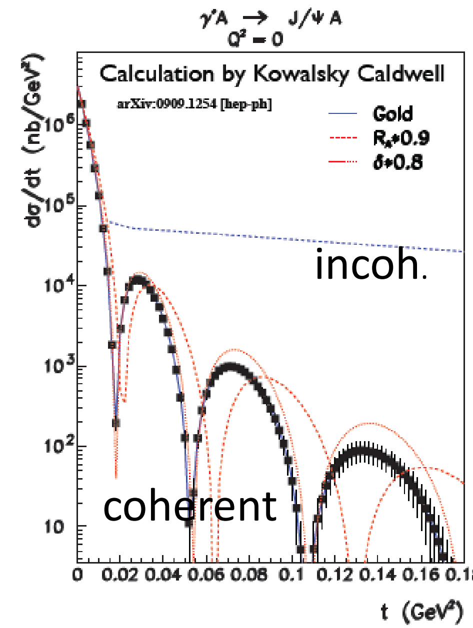
2.8 million ρ candidates



Diffraction pattern

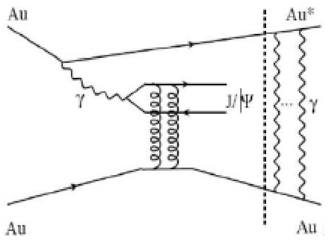




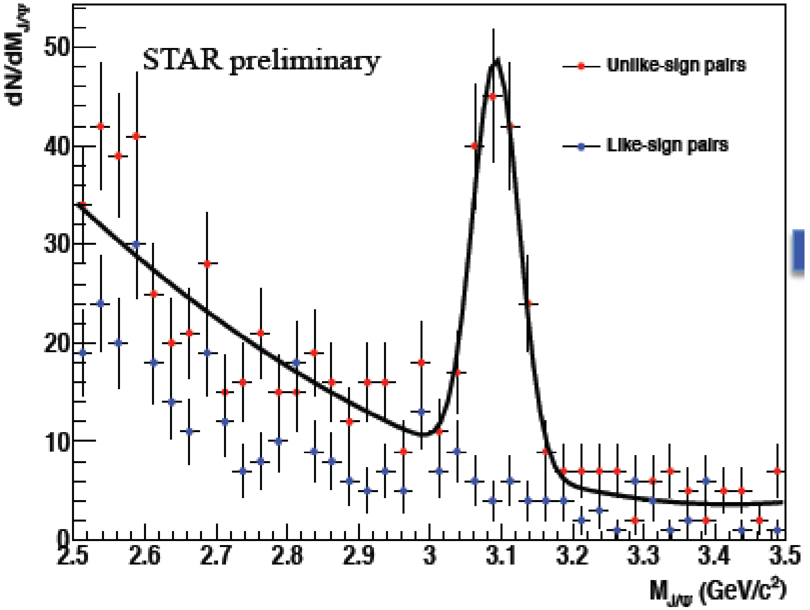


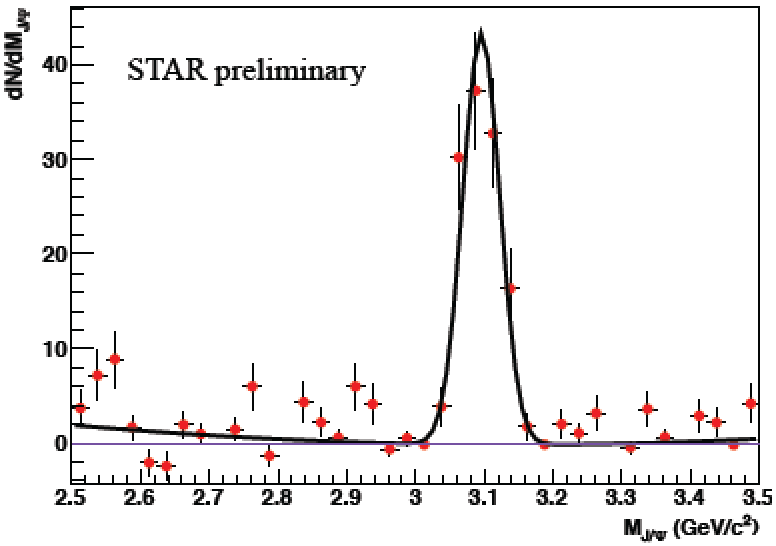
Sartre: T. Ullrich&T.Toll:
Impact parameter dependent dipole model

Coherent ρ^0, J/Ψ photoproduction in AuAu UPC – 2010 run



Gluon distribution
($x \approx 0.015$, $Q^2 = m^2_{J/\Psi}$)
Probing short distance scales





Gaussian J/Ψ signal
Polynomial background

About 113 events
in the peak area

Summary

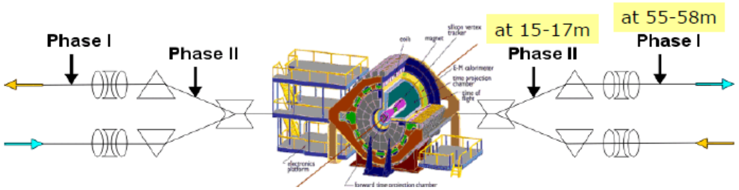
RHIC demonstrates a wide diffraction programme in the AA and pp modes.

Roman Pots + Central detector:

Unique opportunity to measure spin dependent quantities in polarised pp scattering
A_N consistent with no hadronic spin-flip models

Central exclusive production of $\pi^+\pi^-$ pairs in pp collisions at 200 GeV:

- feasible measurement,
- very low non-exclusive background estimated with like sign combinations,
- work in progress.



Possible extension of the program to Phase-II:

$\sqrt{s}$ = 510 GeV $1 < -t < 1.5$ GeV^2/c^2 with standard beam optics, very large statistics, RPs@15-17m

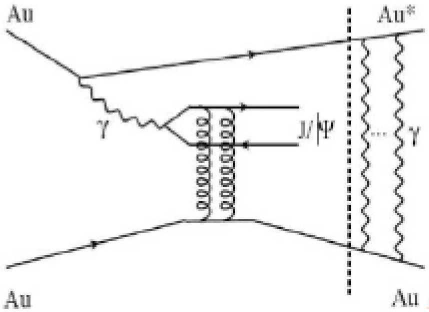
various studies of non-perturbative QCD e.g. instanton and glueball searches, J/Ψ, χ_C

Central detector+ZDCs:

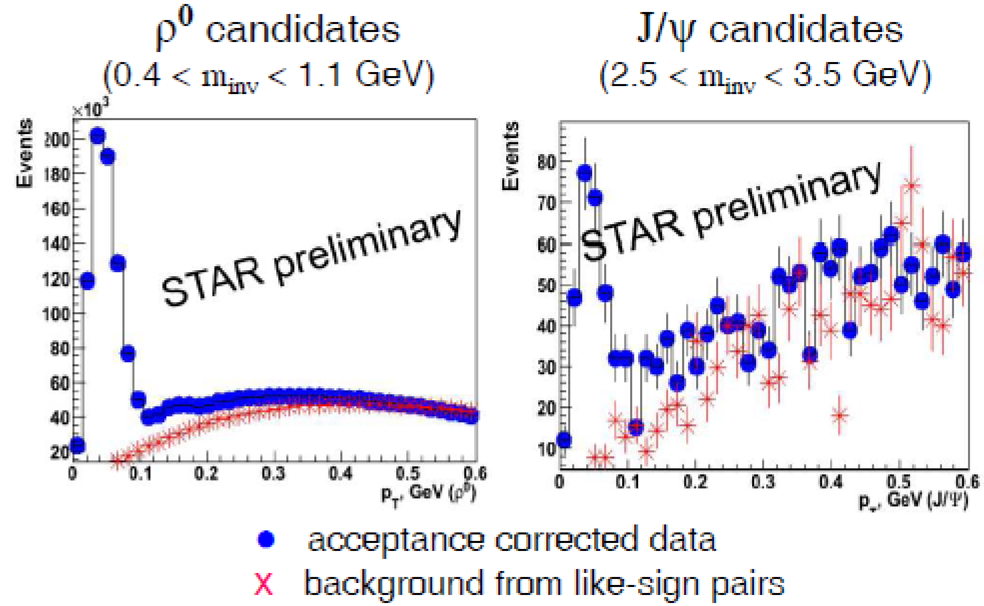
Photoproduction signals in UPC of heavy ions:
coherent and incoherent ρ signals – diffractive pattern
clear J/Ψ signal

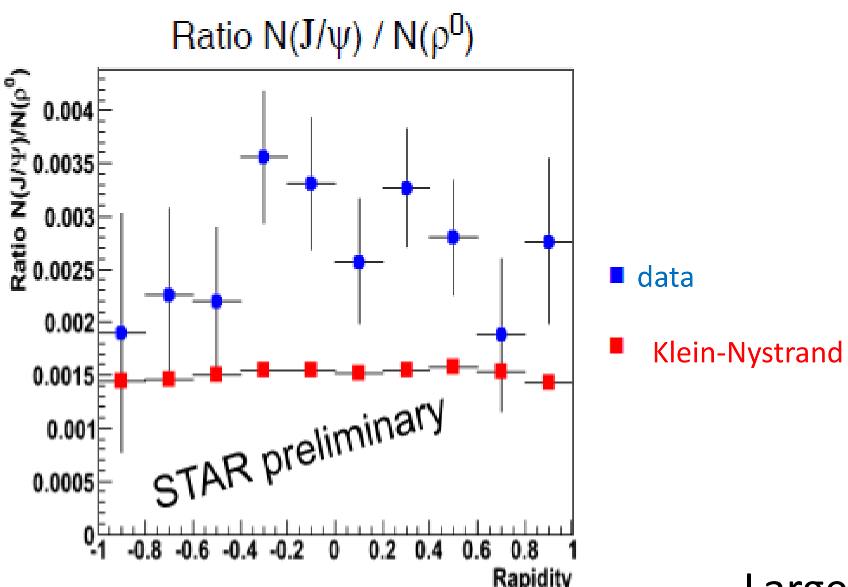
Backup transparencies

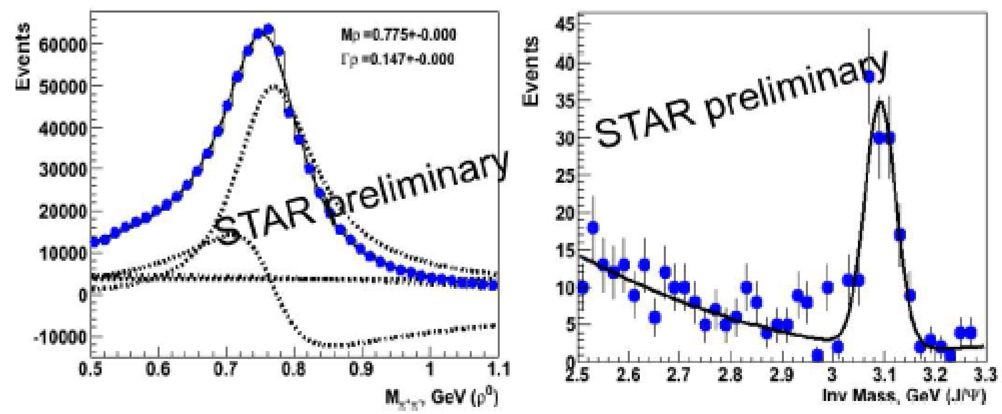
Coherent ρ^0, J/Ψ photopproduction in AuAu UPC



Gluon distribution ($x \approx 0.015$, $Q^2 = m^2_{J/\Psi}$)
Probing short distance scales



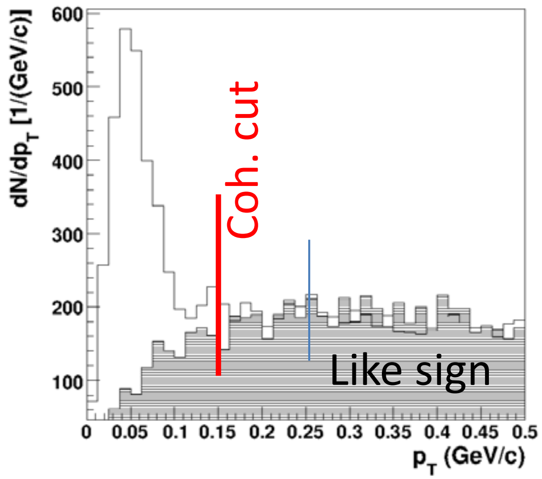




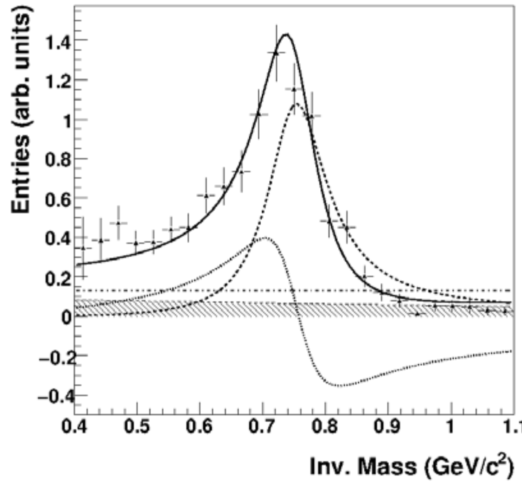
Large ρ sample (~650 000) – it was also earlier analysed
125 J/Ψ events

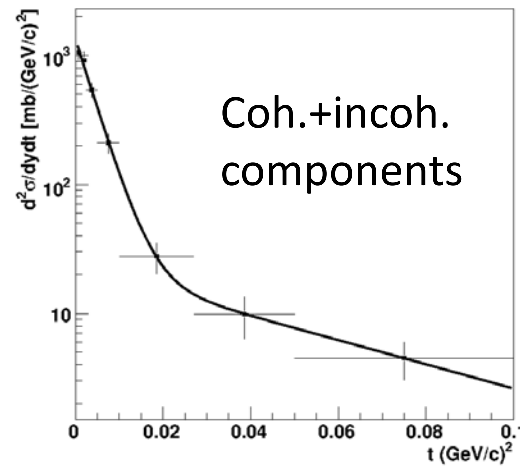
Coherent ρ^0 production in AuAu UPC $\sqrt{s_{NN}}$ = 62.4 GeV

ρ^0 candidates

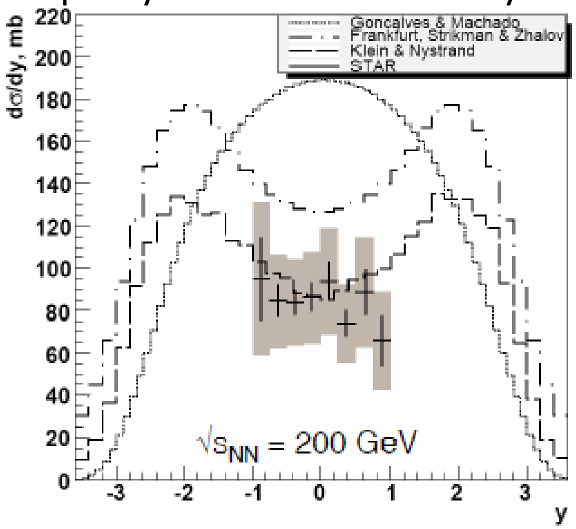


- - - - - - ρ^0 BW   -·-·-·-· direct $\pi\pi$
·········· interference (Söding)

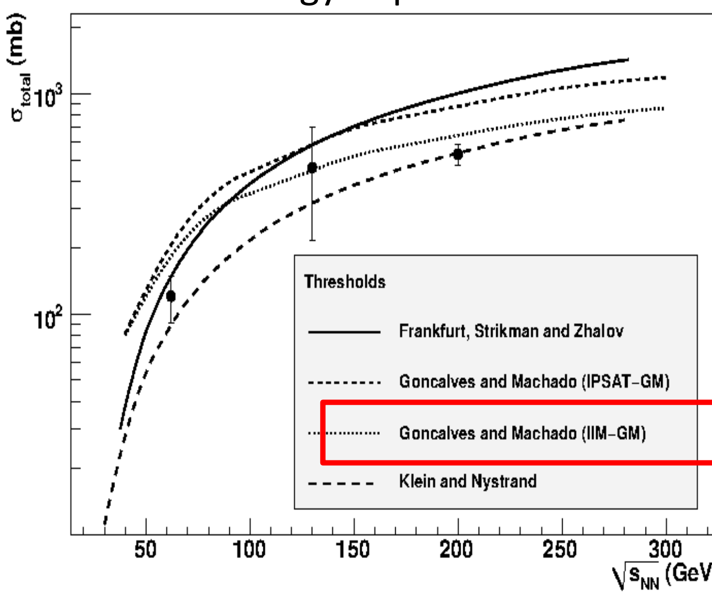




Rapidity distr. – best Klein-Nystrand



Energy dependence



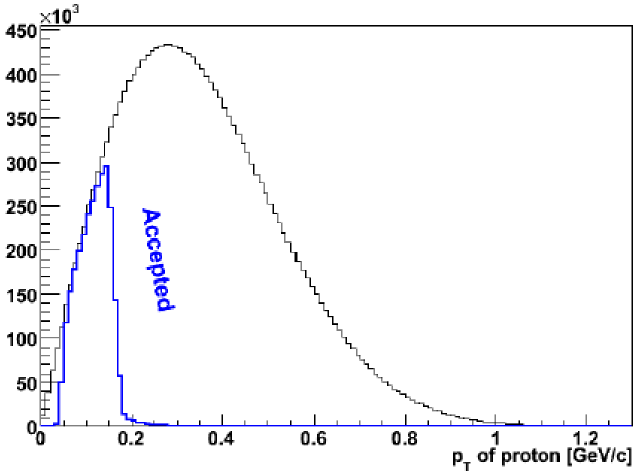
GVDM+QCD GG

CD+nucl.eff.+part.ssaturation

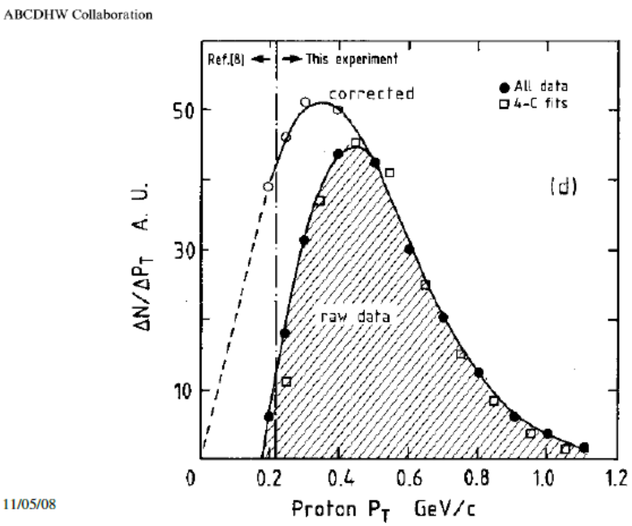
Above+DGLAP+σ_{CD} (b)

VDM+Glauber for nucl.scatt.

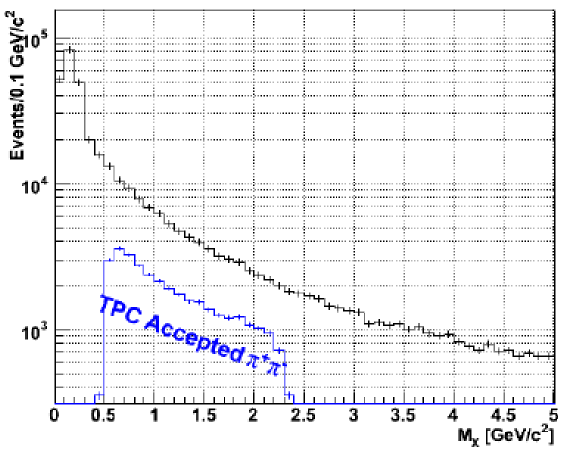
Acceptance for pp→ppπ⁺π⁻



STAR

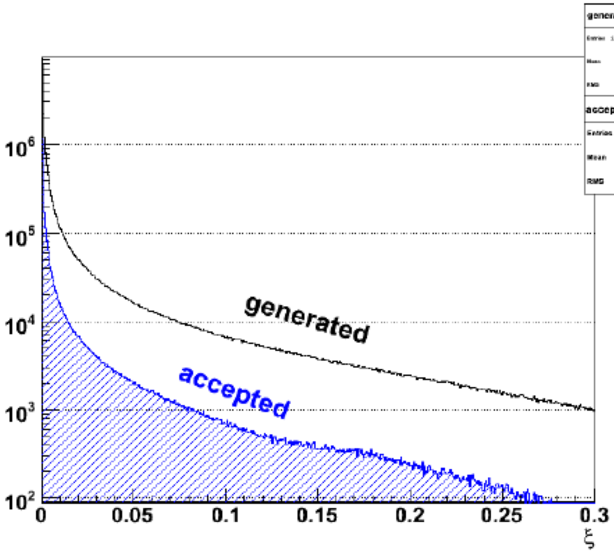


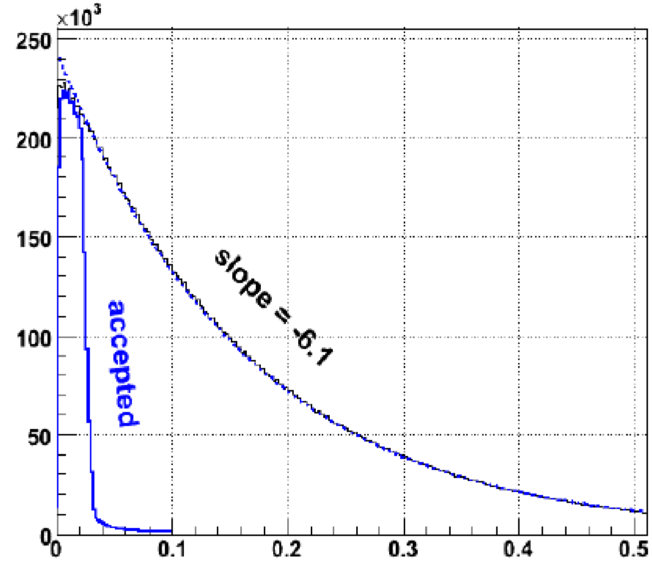
ISR

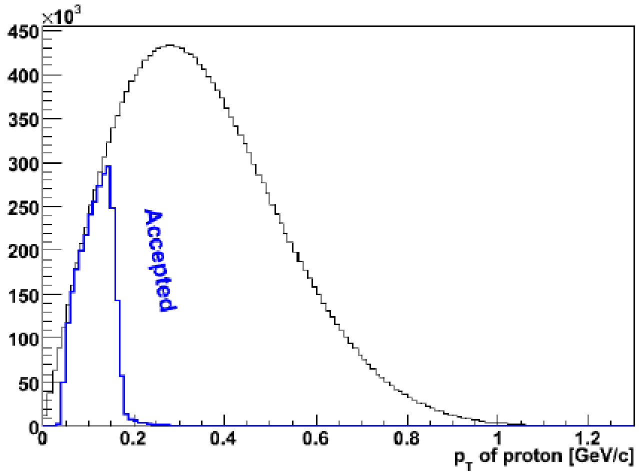


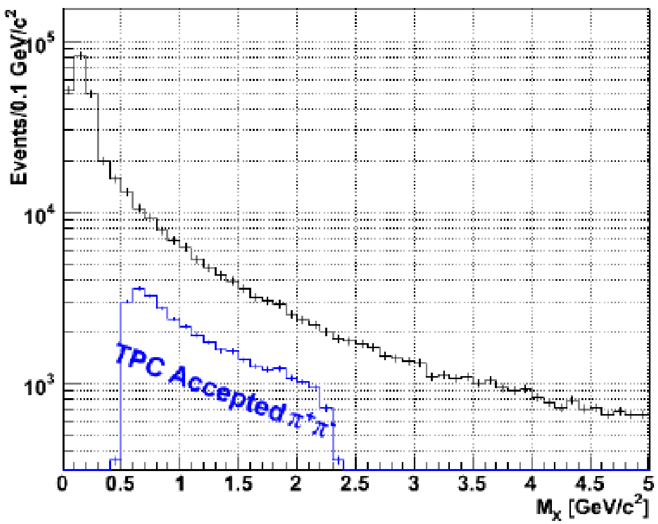
- acceptance for small p_T diffractive protons (unlike ISR AFM experiment)
- acceptance (TPC+protton tagger) is ~flat in two-pion invariant mass

Acceptance studies for pp→ppππ

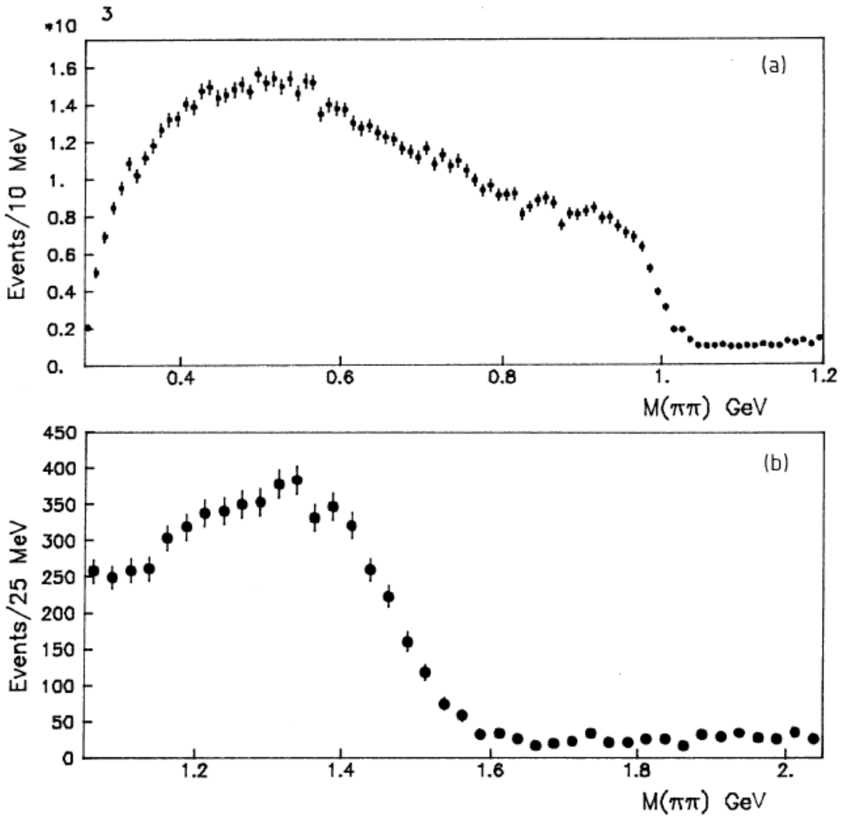


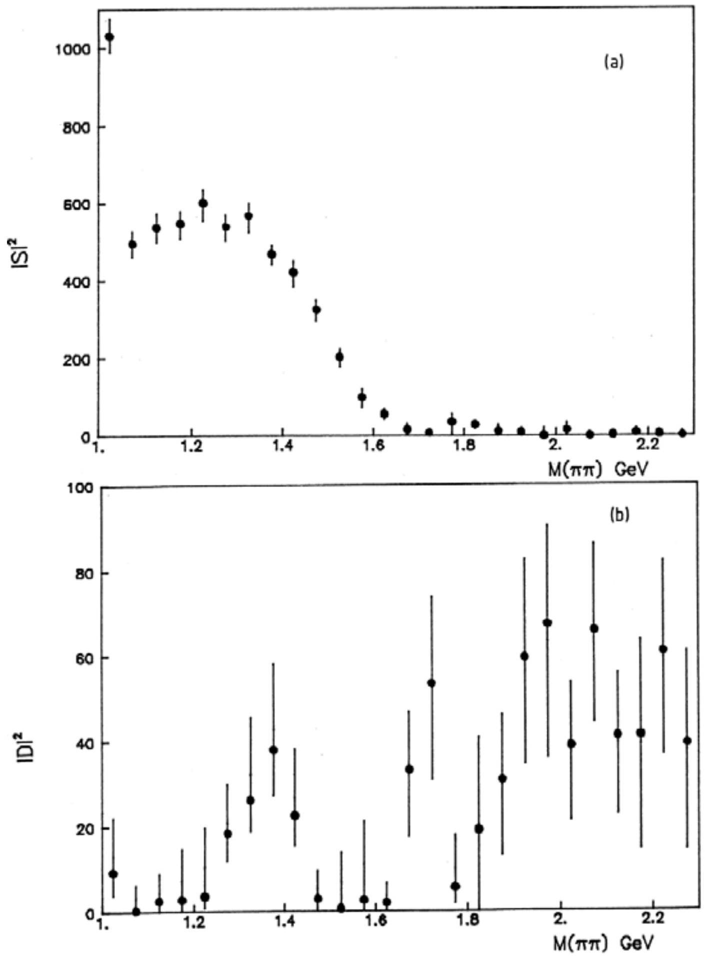




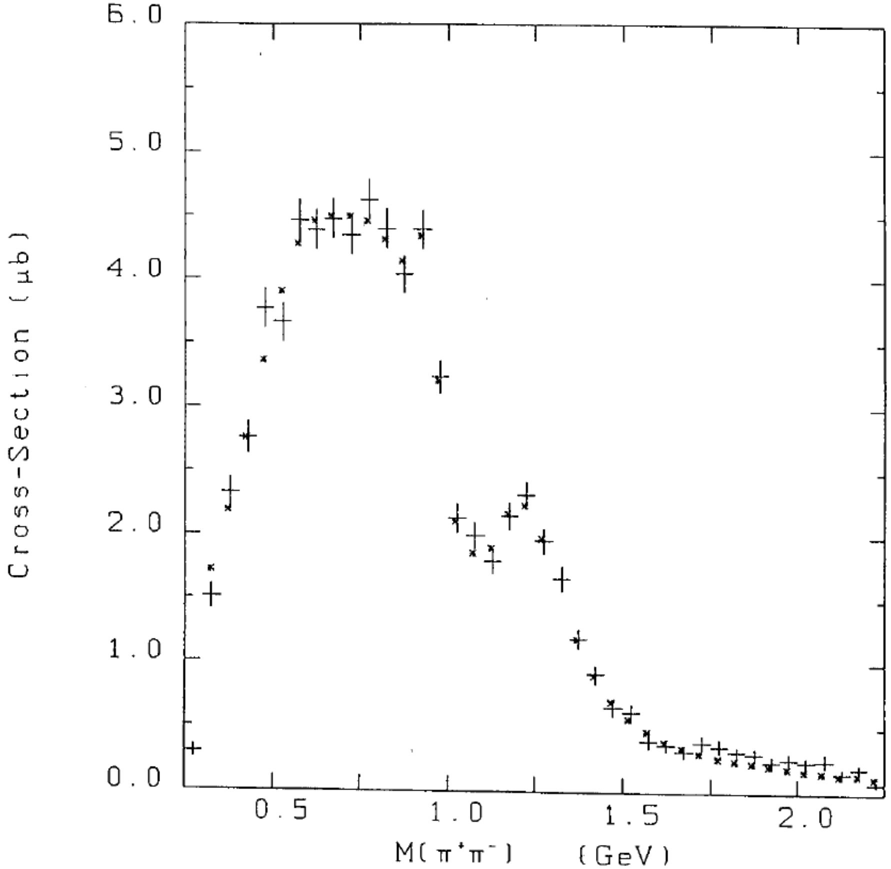


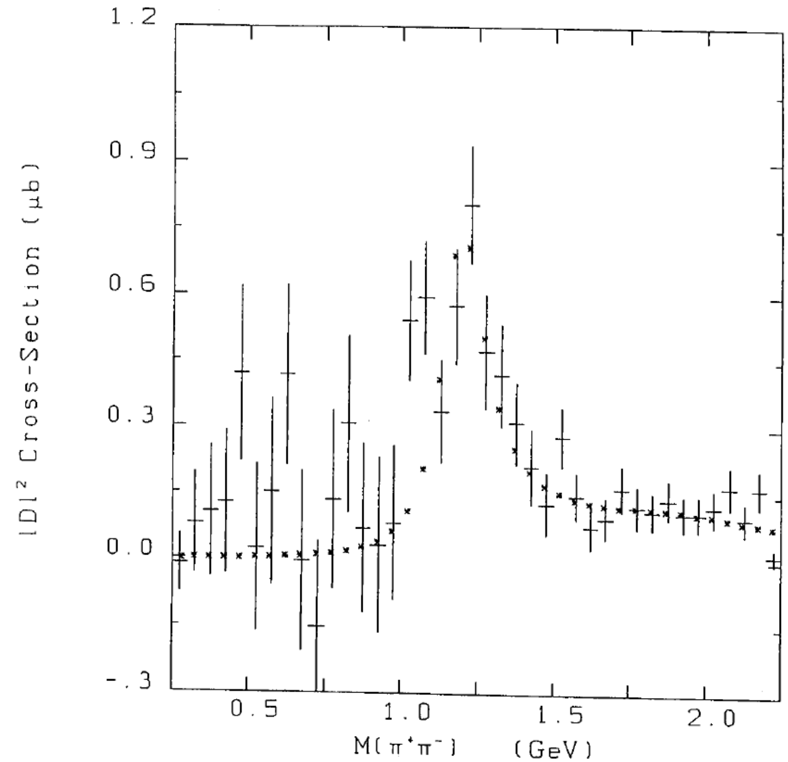
AFS ISR 62 GeV CEP $\pi^+\pi^-$ inv. mass



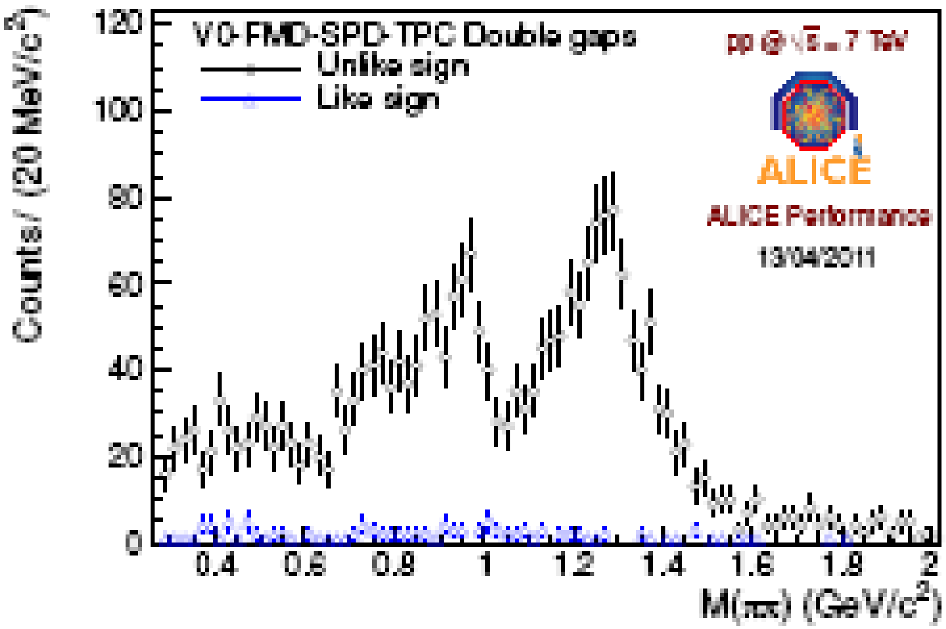


AABCDHW ISR 62 GeV CEP $\pi^+\pi^-$ inv. mass





ALICE LHC 7.0 TeV CEP $\pi^+\pi^-$ inv. mass



Scalar pion formfactor in B→πππ decays

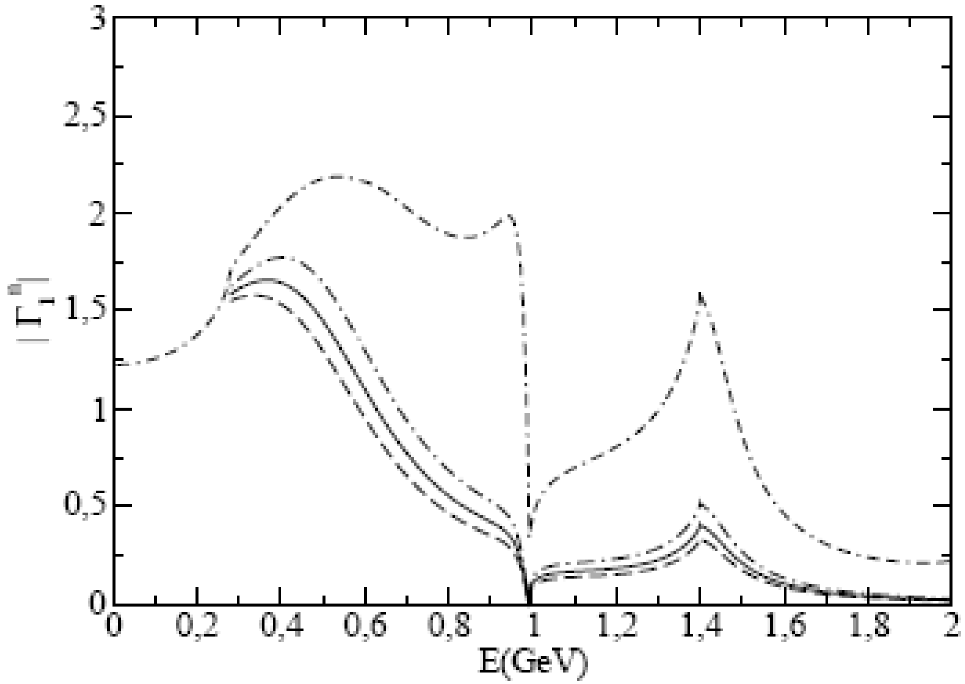
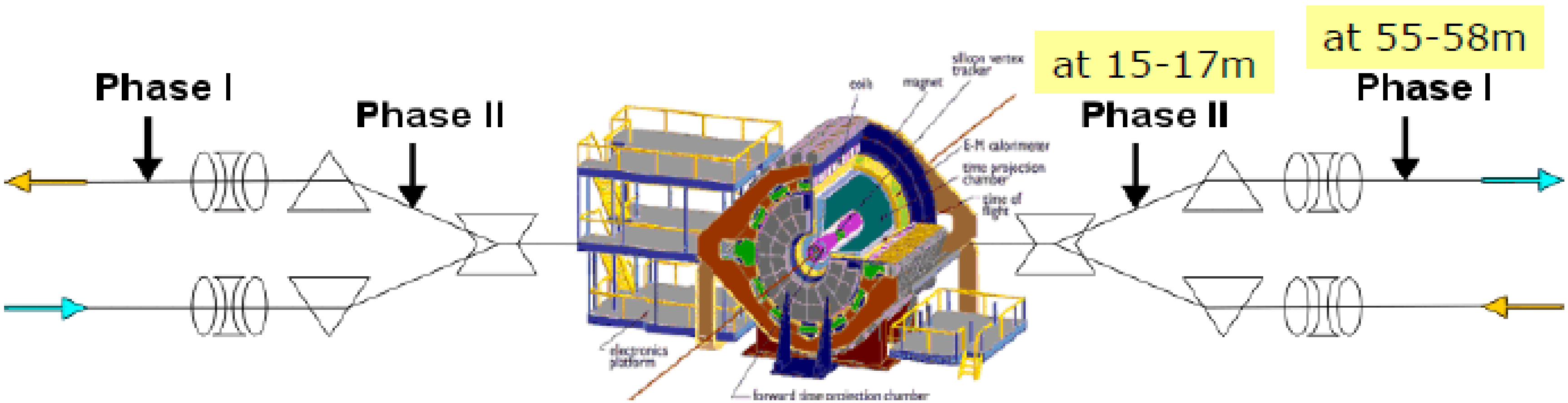


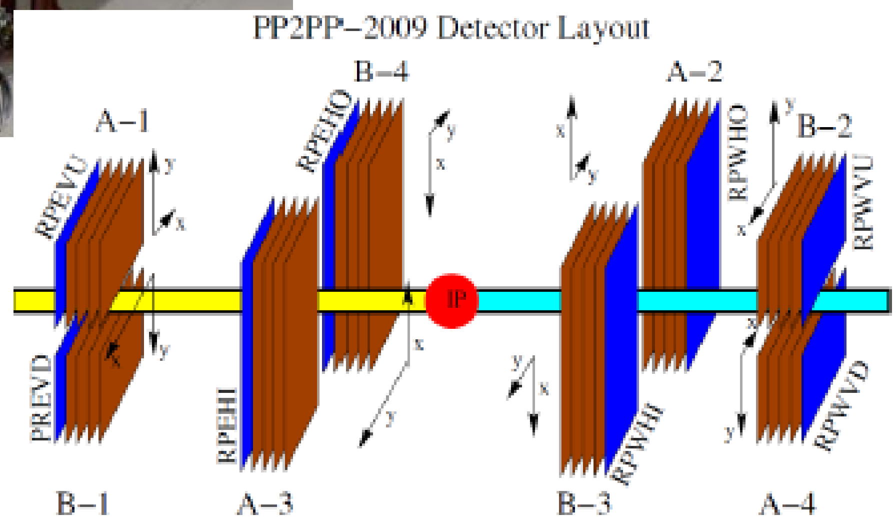
Fig. 1. Modulus of the pion scalar form factor Γ_1^n (solid line), obtained in our fit using the NLO a_1^p with $\kappa = 2$ GeV and for which the fitted parameter $c = (19.5 \pm 4.2)$ GeV^{-4}, compared to that calculated in Ref. [37] using the Muskhelishvili-Omnès equations (double-dash dot line). The dash-dot line (for $c = 15.3$ GeV^{-4}) and the dashed one (for $c = 23.7$ GeV^{-4}) represent the variation of the Γ_1^n modulus when c varies within its error band.

Roman Pots at STAR



- roman pots with silicon strip detector for forward proton tagging
- staged implementation to cover wide kinematic range:
  - ➢ phase I (present data, 200 GeV, low momentum transfer ~0.003 < -t < ~0.03)
  - ➢ phase II (500 GeV, larger t coverage ~0.1 < -t < ~1.5, standard optics, large data samples)

RP Phase I (2009) at STAR detector



Horizontal and vertical RP for full ϕ coverage