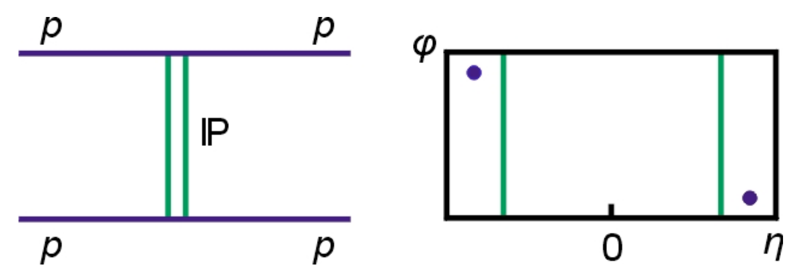
Present and Future of Central Production with STAR Detector at RHIC

Włodek Guryn BNL (for the STAR Collaboration)

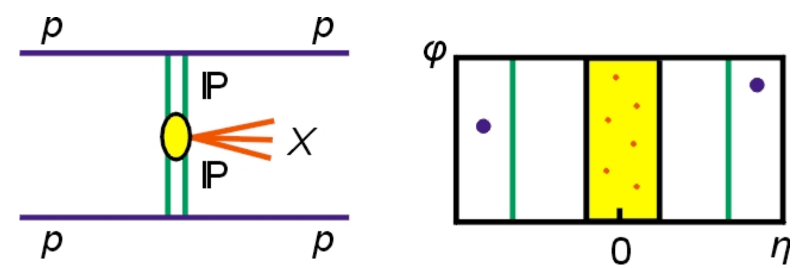
- Process of central production - physics program at STAR with forward protons
- The present 2009 run preliminary results of Phase I program
- The near future Phase I program continued
- The future – Phase II program, large data samples for Central Production
- Summary

Processes with Tagged Forward Protons

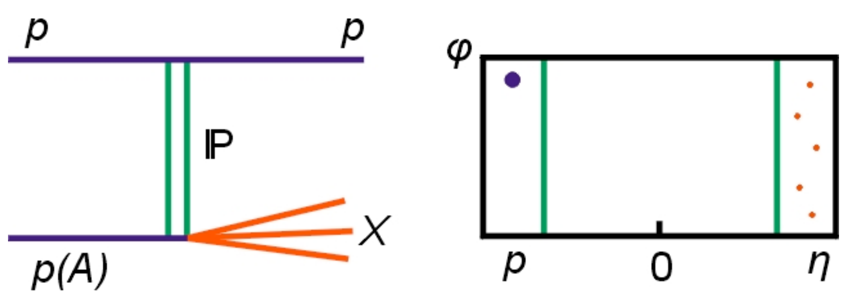
QCD color singlet exchange: C=+1(Pomeron), C=−1(Odderon)



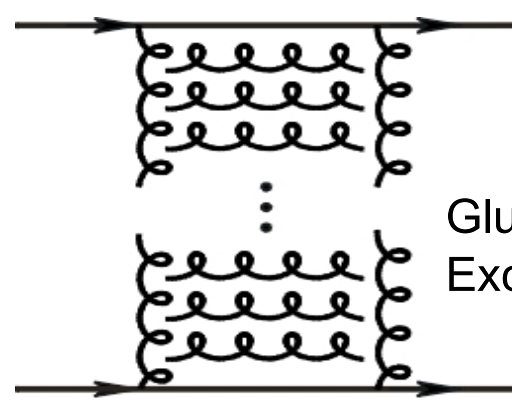
p + p → p + p elastic



p + p → p + X + p
diffractive X= particles, glueballs

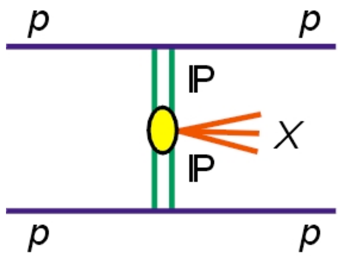


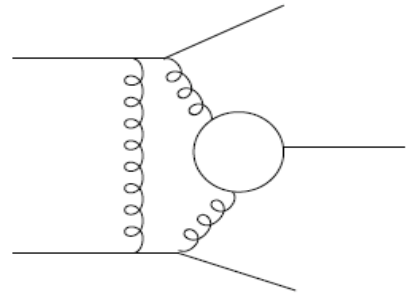
p + p → p + X SDD



Gluon
Exchanges

Central Exclusive Production in Double Pomeron Exchange (DPE)



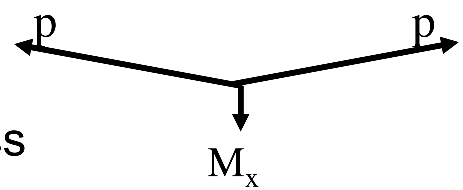


Method is complementary to:

- **GLUEX experiment (2015)**
- **PANDA experiment (>2015)**
- **COMPASS experiment (taking data)**
- **BESIII**

In the Double Pomeron Exchange (DPE) process each proton "emits" a Pomeron and the two Pomerons interact producing a massive system M_X

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



For each proton vertex one has

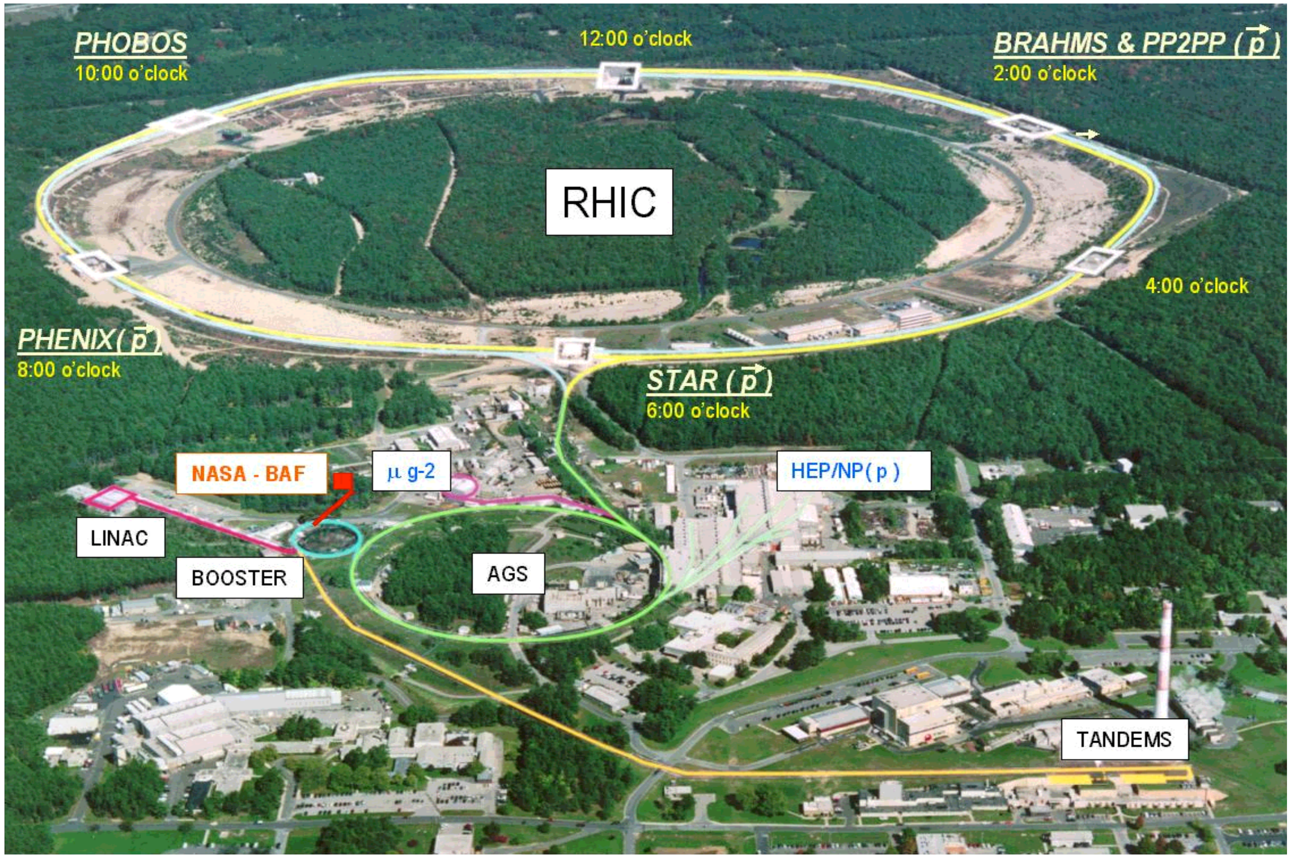
t four-momentum transfer

$\xi = \Delta p/p$

where $M_X = \pi^+ \pi^-$, χ_c(χ_b), qq(jets), H(Higgs boson), gg(glueballs)

The massive system could form resonances. We expect that because of 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.

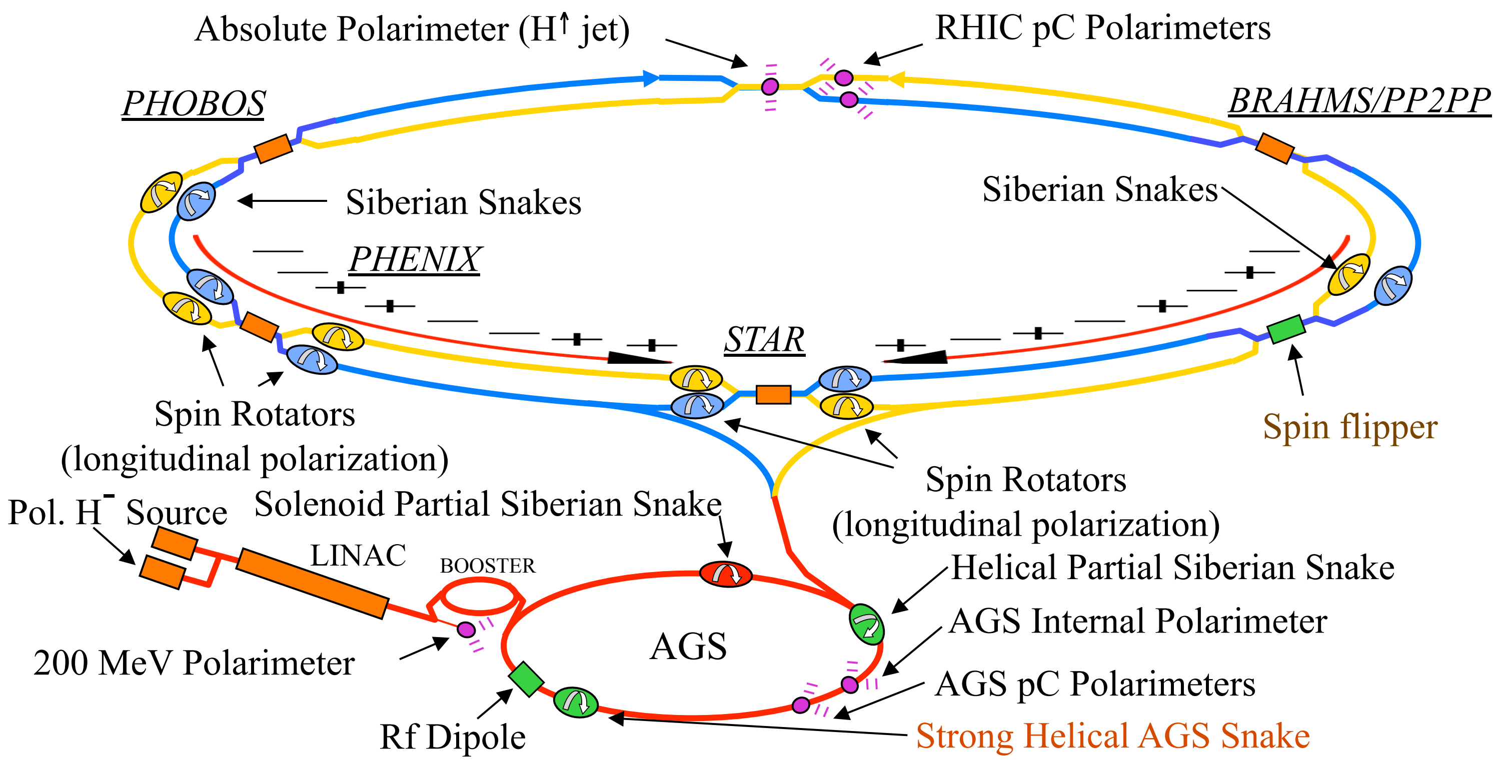
The Relativistic Heavy Ion Collider



RHIC is a QCD Laboratory:

Nucleus- Nucleus collisions (AuAu, CuCu…); Asym. Nucl. (dAu); Polarized proton-proton; eRHIC - Future

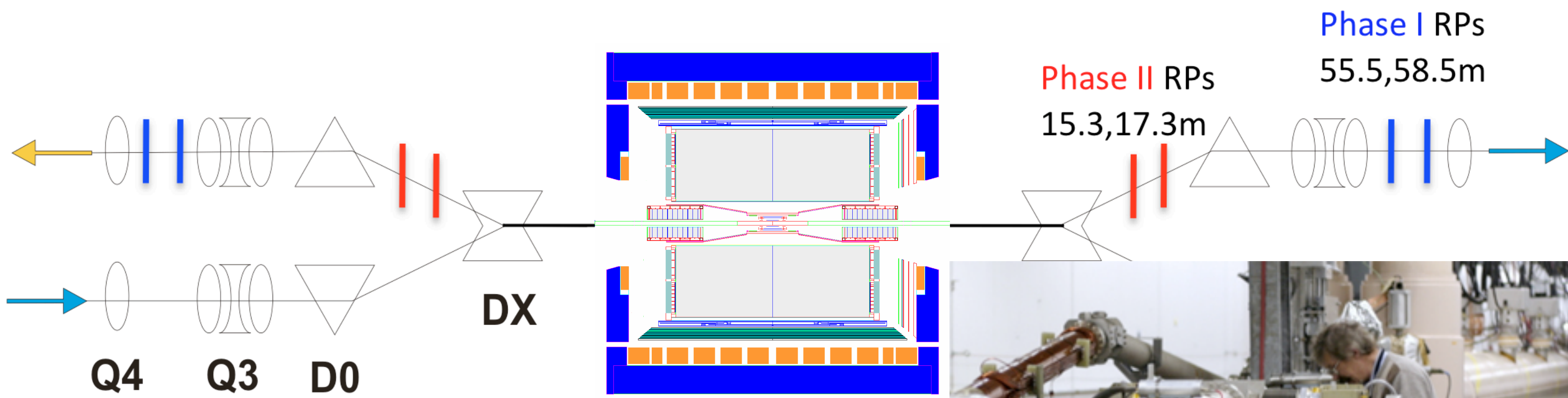
RHIC: the world's first polarized pp collider



- Spin varies bunch by bunch
- Spin pattern changes from fill to fill
- Spin rotators provide choice of spin orientation
- "Billions" of spin reversals during a fill with little if any depolarization

Implementation at STAR + pp2ppp

1. Need detectors to measure forward protons: **t** - four-momentum transfer, **$\xi = \Delta p/p$, M_X** invariant mass and;
2. Detector with good acceptance and particle ID to measure central system

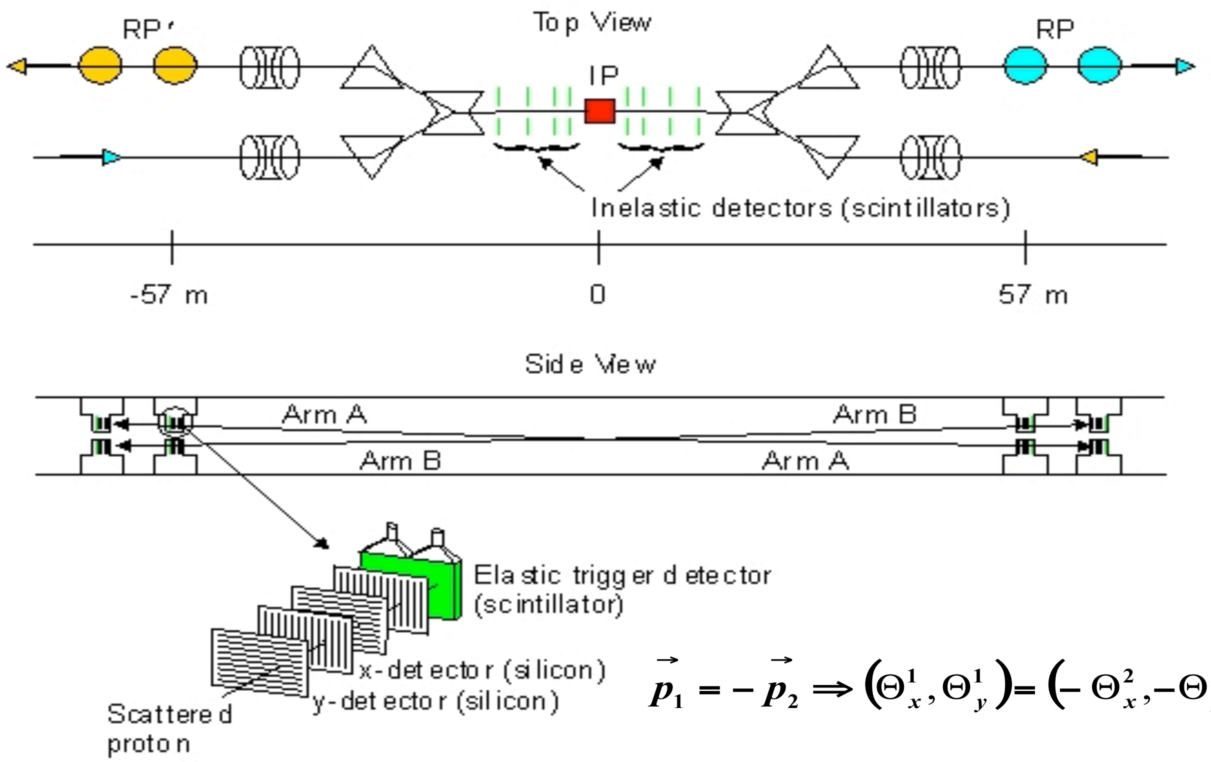


1. Roman Pot (RP) detectors - forward protons
2. Staged implementation:
   - Phase I, present: low-t coverage - use existing equipment
   - Phase II, future: higher-t coverage, large data samples – requires new construction

Implementation at RHIC - tag forward protons

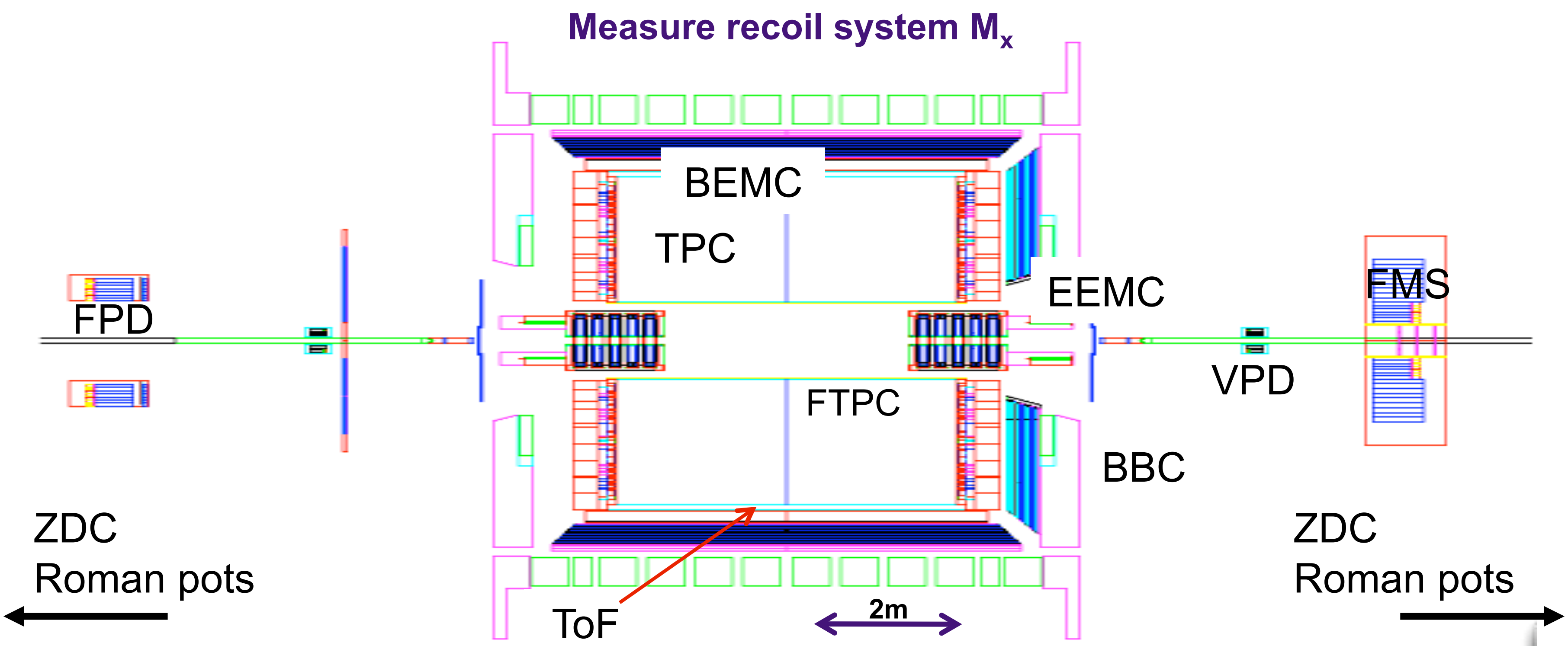
PP2PP Setup

Phys. Lett. B 579 (2004) 245-250, Phys. Lett. B 632 (2006) 167-172, Phys. Lett. B 647 (2007) 98-103
(Polish coauthors Chwastowski, Pawlik, Sandacz)



$$\vec{p}_1 = -\vec{p}_2 \Rightarrow \left(\Theta_x^1, \Theta_y^1\right) = \left(-\Theta_x^2, -\Theta_y^2\right)$$

Current ***STAR*** detector in cross section



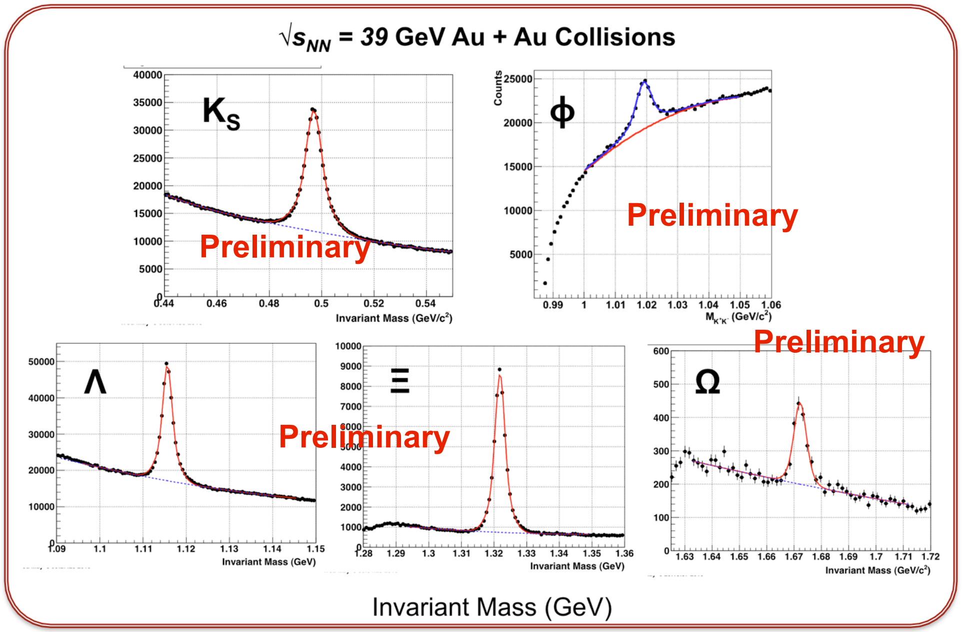
Large acceptance detector running since 2000

- High resolution tracking device: TPC in $-1<\eta<1$, $-\pi<\varphi<\pi$
- Forward rapidity gap veto
- FTPC: $2.5<|\eta|<4.2$, BBC: $3.8<|\eta|<5.2$

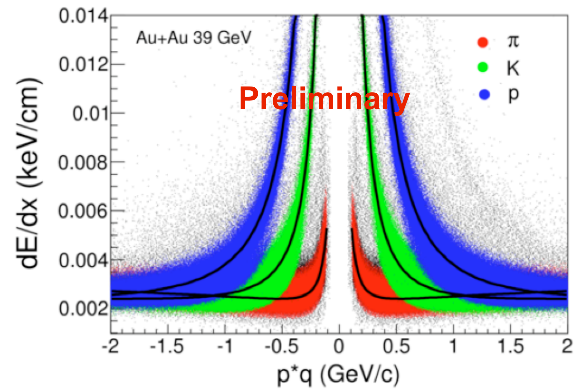
Great Charged Particle ID in the STAR TPC

- High resolution tracking device: TPC in $-1<\eta<1$, $-\pi<\varphi<\pi$
- Excellent particle identification capability: TPC dE/dx, ToF

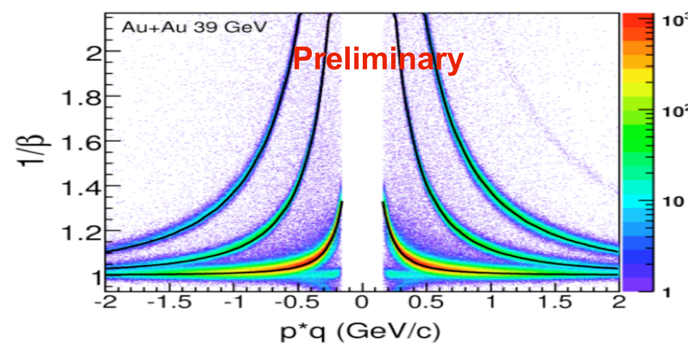
Particle Identification at STAR



Reconstructed hadrons: K_S, ϕ, Λ, Ξ, and Ω in Au+Au collisions at $\sqrt{s_{NN}}$ = 39 GeV



dE/dx vs. rigidity compared with theoretical expectations



Particle identification with new barrel Time-of-Flight system.

Glueball Spectrum from Lattice QCD

Sparse spectrum!

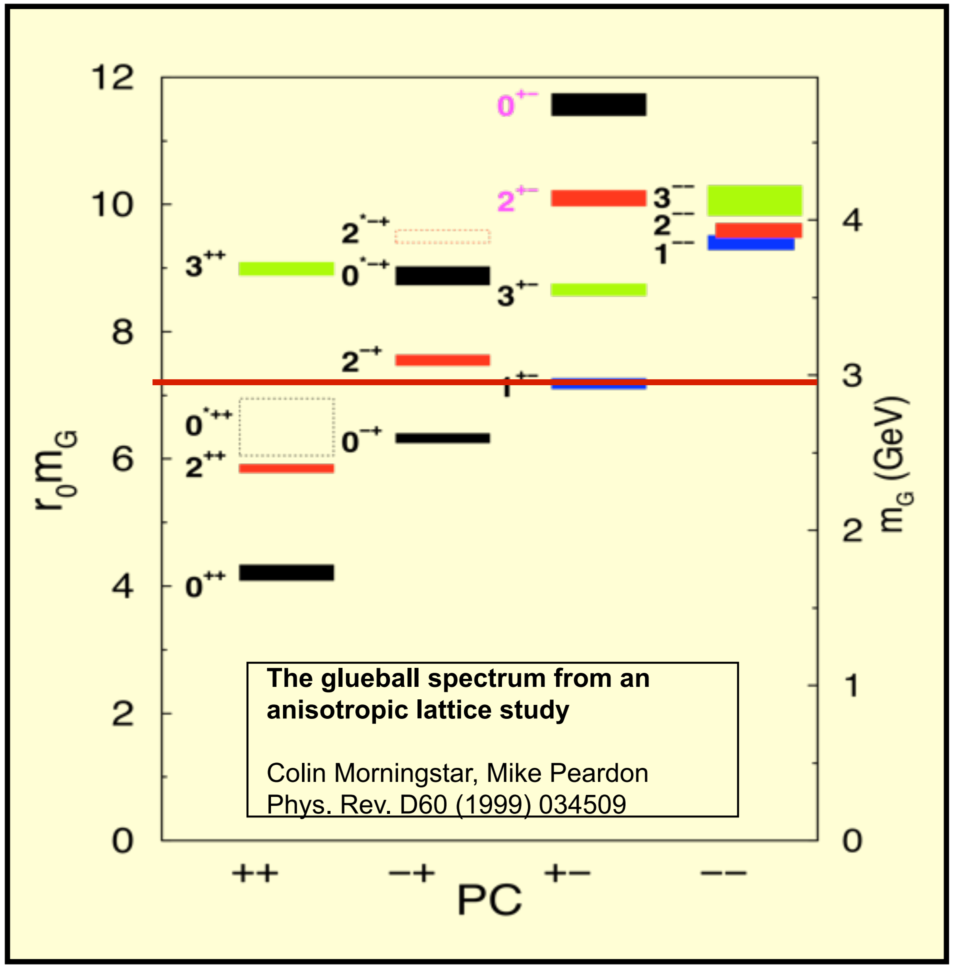
New I=0 mesons starting with

0^{++} 1.6 GeV

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

No **J^{PC}-exotic** glueballs until

2^{+-} at 4 GeV



Kinematic "filter" (dp_T) for "gg"

(F. Close et al./WA102)

- Coupling of the exchange particles to the final state mesons for gluon exchange (small dp_T) and quark exchange (large dp_T)
- Spin-dependence of the coupling can be studied at RHIC

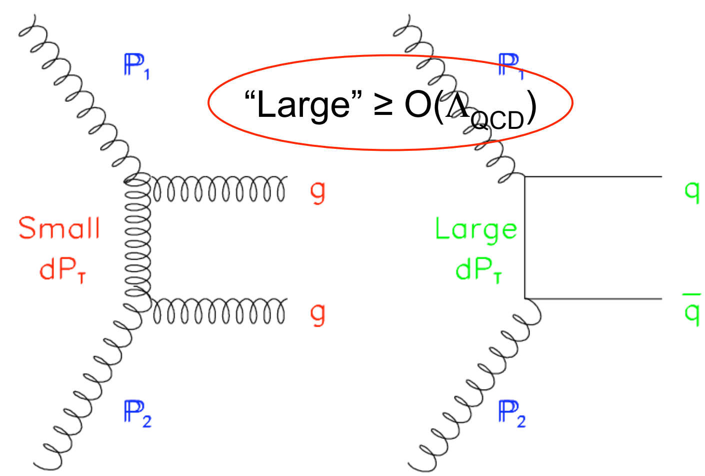
PLB 397 339 (1997)

As predicted by Regge theory the diffractive cross section at RHIC is dominated by the Pomeron (gluonic) exchange, :

$\sigma_{RR} \sim s^{-2}$

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

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



WA102 $f_0(1500)$ $\pi^+\pi^-\pi^+\pi^-$

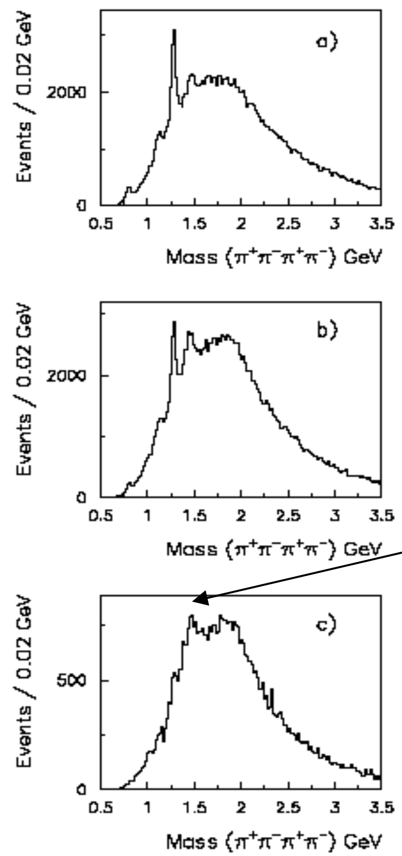
$\sigma(f_1)$= 7 μbarn

We are sensitive to this level of cross section

$\sigma(f_0)$= 3 μbarn

$f_1(1285)$

F.E.Close and A.Kirk, PLB397, 333 (1997).



dP_T > 0.5 GeV/c

0.2 GeV < dP_T < 0.5 GeV/c

$f_0(1500)$

dP_T < 0.2 GeV/c

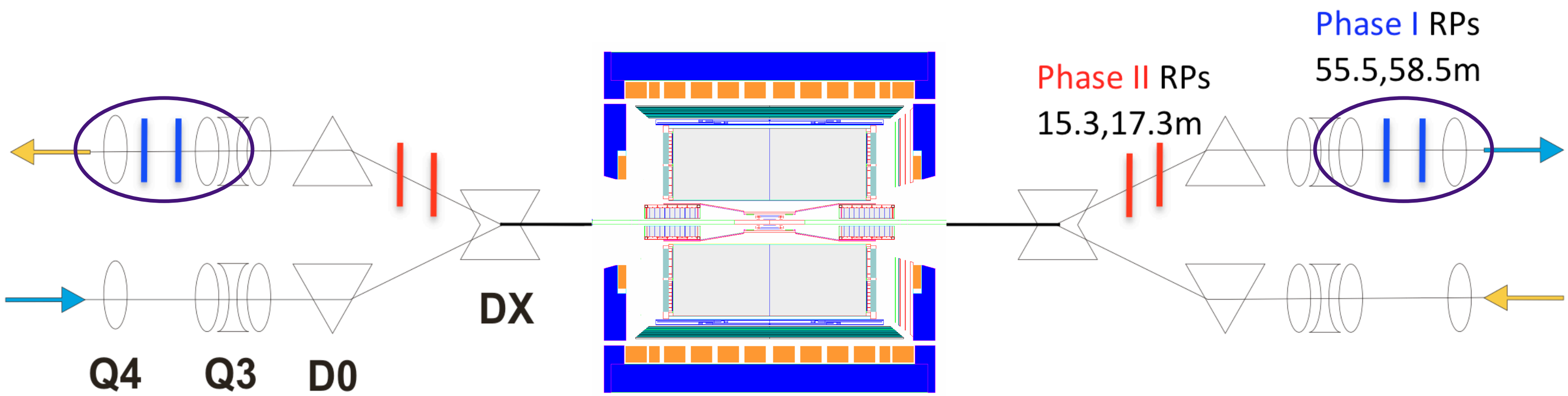
Figure 3: The 4π mass spectra (i) With $dP_T > 0.5$ GeV exhibiting a clear $f_1(1285)$; (ii) $0.2 < dP_T < 0.5$ GeV (iii) $dP_T < 0.2$ GeV where the $f_1(1285)$ has disappeared while the $f_0(1500)$ is seen more clearly.

Central Exclusive Production Process in DPE

$p_1 p_2 \rightarrow p_{1'} M_X p_{2'}$

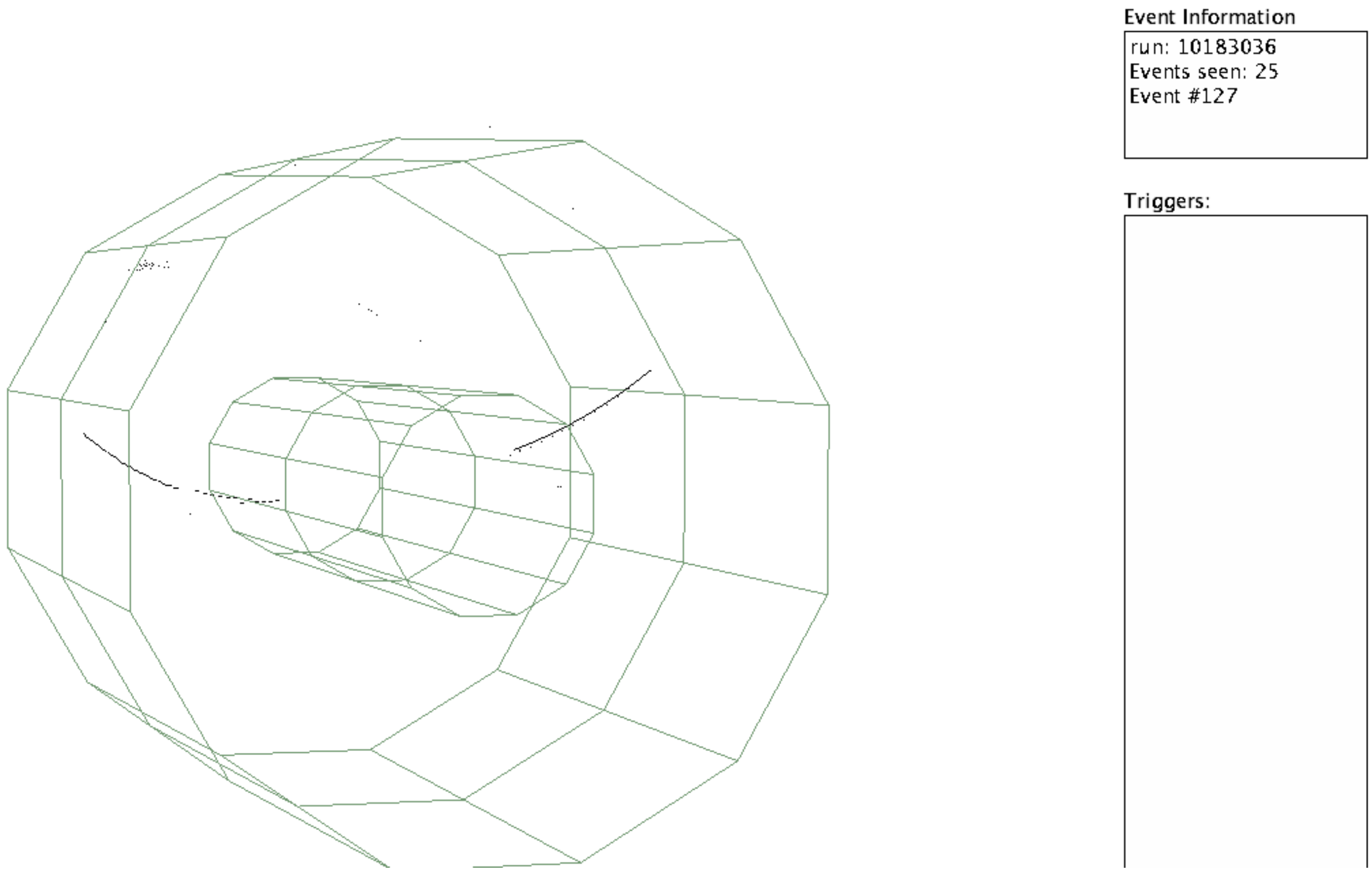
- Exclusive process with "small" momentum transfer: $-t_1(p_1 \rightarrow p_1')$ and $-t_2(p_2 \rightarrow p_2')$
- M_X is centrally produced, nearly at rest, through DPE process
- In pQCD, Pomeron is considered to be made of two gluons: natural place to look for gluon bound state
- $M_X(\sim 1 - 3\ \mathrm{GeV}/c^2) \rightarrow \pi^+\pi^-, \pi^+\pi^-\pi^+\pi^-, K^+K^-, \ldots$
- Lattice cal.: Lightest glueball $M(0^{++}) = 1.5\text{-}1.7\ \mathrm{GeV}/c^2$ (PRD73 2006)
- Search for glueball (gg) candidates in M_x
- Candidates with conventional quantum numbers: need to be studied in a wide kinematical range

Phase I: First Look at DPE Data



- Data taken with RP and ToF multiplicity triggers for the central process
- About 700k Central Production triggers collected during a special one week run at RHIC in 2009
- Data analysis is in progress

Run 9 Candidate Central Production Event

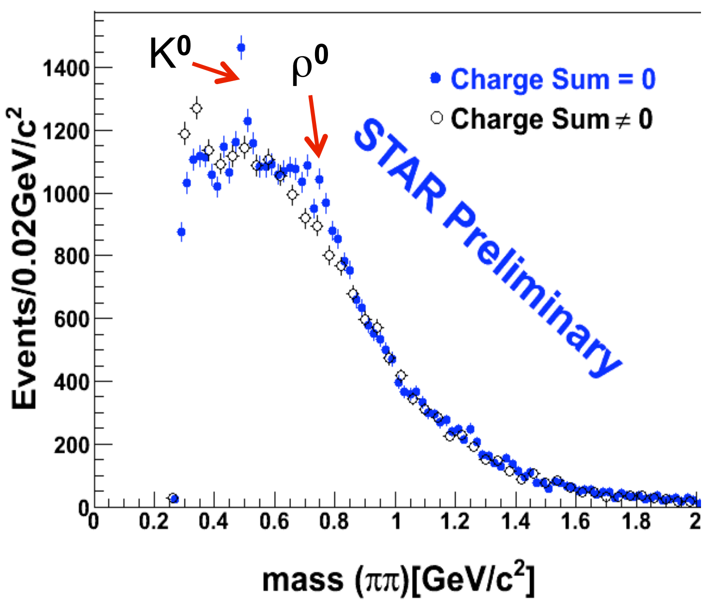


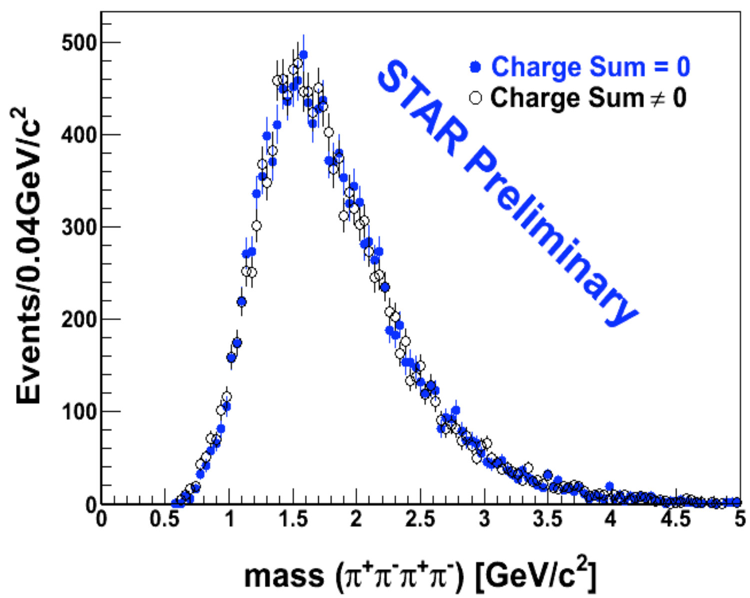
Phase I: First Look at DPE Data

(non exclusive channels)

- Tracks reconstructed in the STAR TPC
- Require two reconstructed tracks in opposite direction in the RPs
- Work in progress for identifying exclusive DPE events:

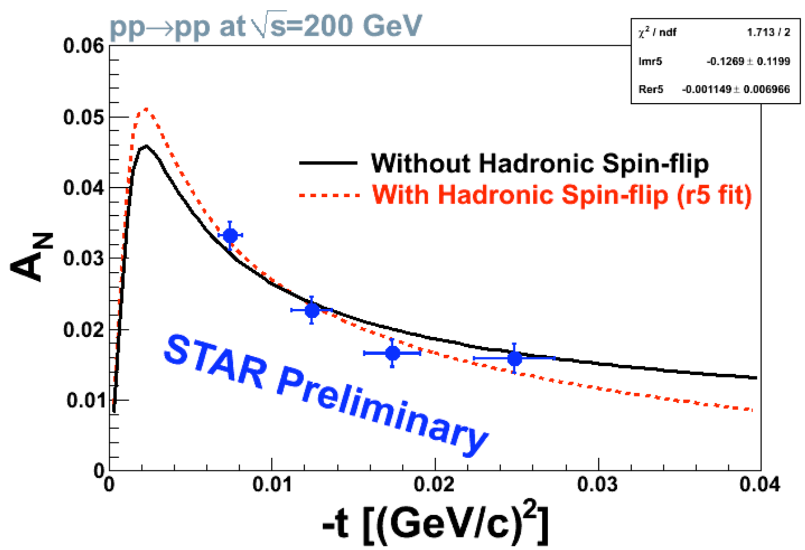
rapidity gaps, PID, p_T-balance, missing-mass





Phase I Elastic Scattering: high-statistics measurement of A_N at $\sqrt{s}$=200 GeV

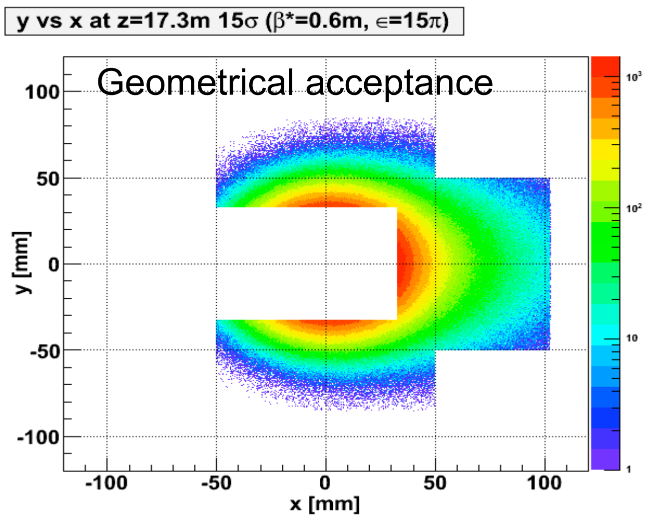
$$A_N(t) = \frac{\sigma^{\uparrow}(t) - \sigma^{\downarrow}(t)}{\sigma^{\uparrow}(t) + \sigma^{\downarrow}(t)} = C_1 \phi_{flip}^{em*} \phi_{non-flip}^{had} + C_2 \phi_{flip}^{had*} \phi_{non-flip}^{em}$$

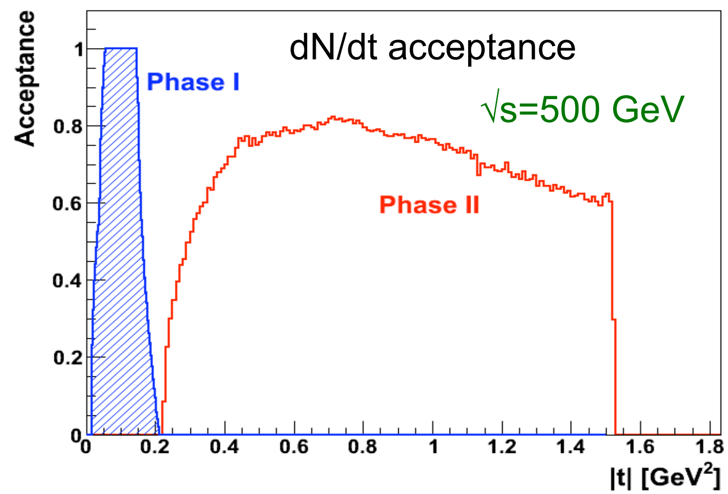


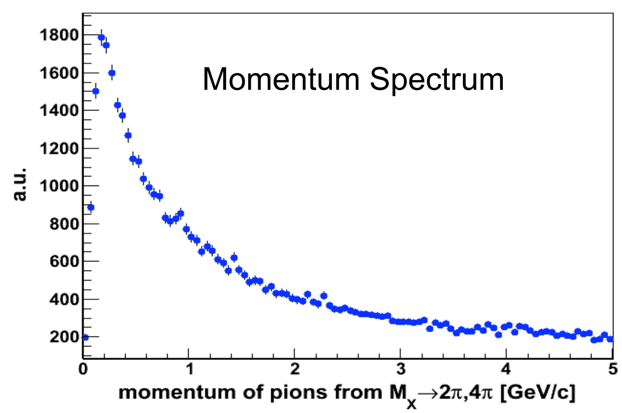
- Statistical errors + systematic *t*-scale uncertainty (10%) in the fit
- Higher-*t* reach planned from the upcoming $\sqrt{s}$=500 GeV (and with Phase II set-up) at RHIC

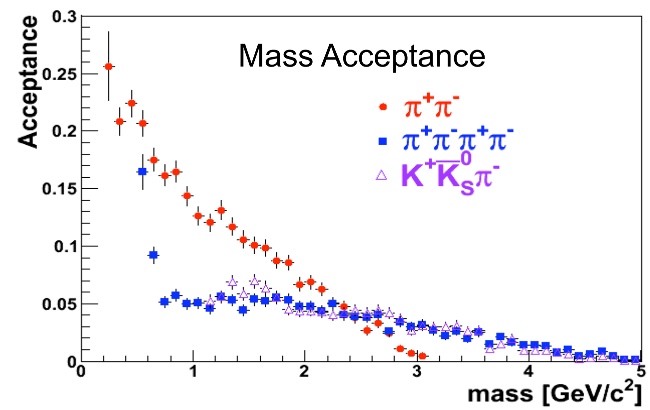
Phase II – The future

Simulation of proton transport done using HECTOR simulator, $\sqrt{s}$=500 GeV









Acceptance and expected yields in M_X

- We assume the DPE cross section 140 μbarn, and branching ratios as measured at the ISR (A. Breakstone *et al.*, Z. Phys. **C42**, (1989) 387)
- Mass M_X calculated from the proton kinematics
- Use phase space to determine the decay of mass M_X in a particular channel
- Use STAR TPC acceptance to make sure that all decay products are seen.
- High-M_x reconstruction is limited by PID (π/K separation up to ~ 1.6 GeV/c)

Event yields for 20 week run at 500 GeV

$\pi^+\pi^-\pi^+\pi^-$ - 2.7×10^6 events
$\pi^+\pi^-$ - 10.4×10^6 events
K^+K^- - 0.8×10^6 events

See P. Lebiedowicz, A. Szczurek at this conference
PL B680 (2009) 459, PRD 81 (2010) 036003

Summary

1. A new rich diffractive physics program with tagged forward protons in polarized proton-proton scattering at RHIC, has been launched and its significant expansion has been proposed.

2. It will search for new physics, including glueballs, Odderon and sphalerons.

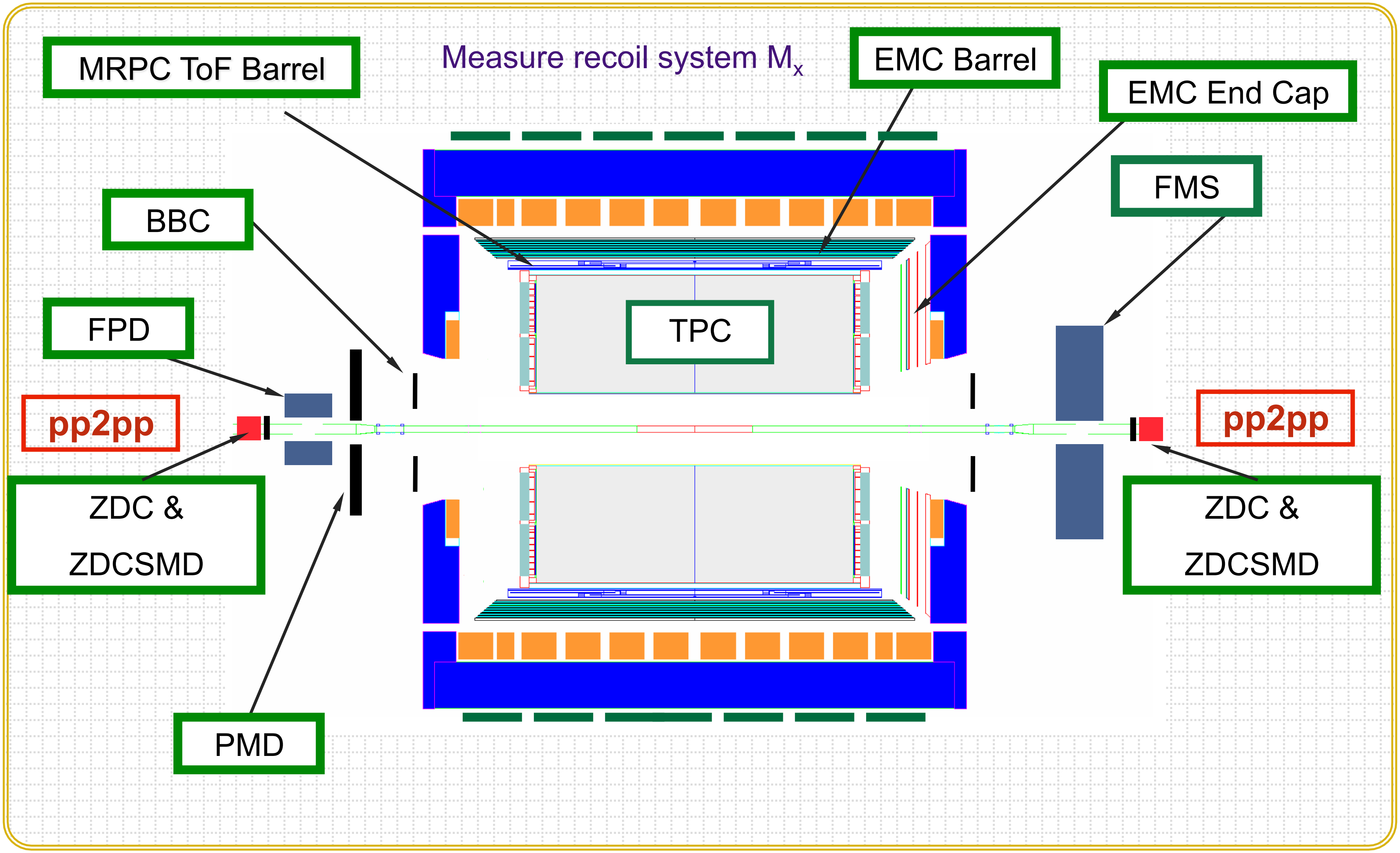
3. It will search for diffractive production of light and massive systems in double Pomeron exchange process. Possible Pomeron - Odderon interaction => J/ψ production, C−odd glueball.

4. Not discussed here - systematic study of the spin dependence of elastic scattering, of the shape of the differential elastic cross section $d\sigma/dt$ in unexplored ranges of t and $\sqrt{s}$.

RHIC is an exciting, and complementary to other hadron colliders, place to do diffractive physics both in pp and HI

New collaborators are welcome!

Implementation at RHIC - STAR Detector



Great Charged Particle ID in the STAR TPC

- High resolution tracking device: TPC in -1<η<1, -π<φ<π
- Excellent particle identification capability: TPC dE/dx, ToF