Spectroscopy in DPE processes in polarized p+p collisions at STAR/RHIC

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for STAR Collaboration

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Dec 1, Hadron09, Tallahassee

Outline

- New opportunity for spectroscopy with Relativistic Heavy-Ion Collider and STAR
- Glueball search in Double Pomeron Exchange
- Some experimental details and rate estimates
- Outlook

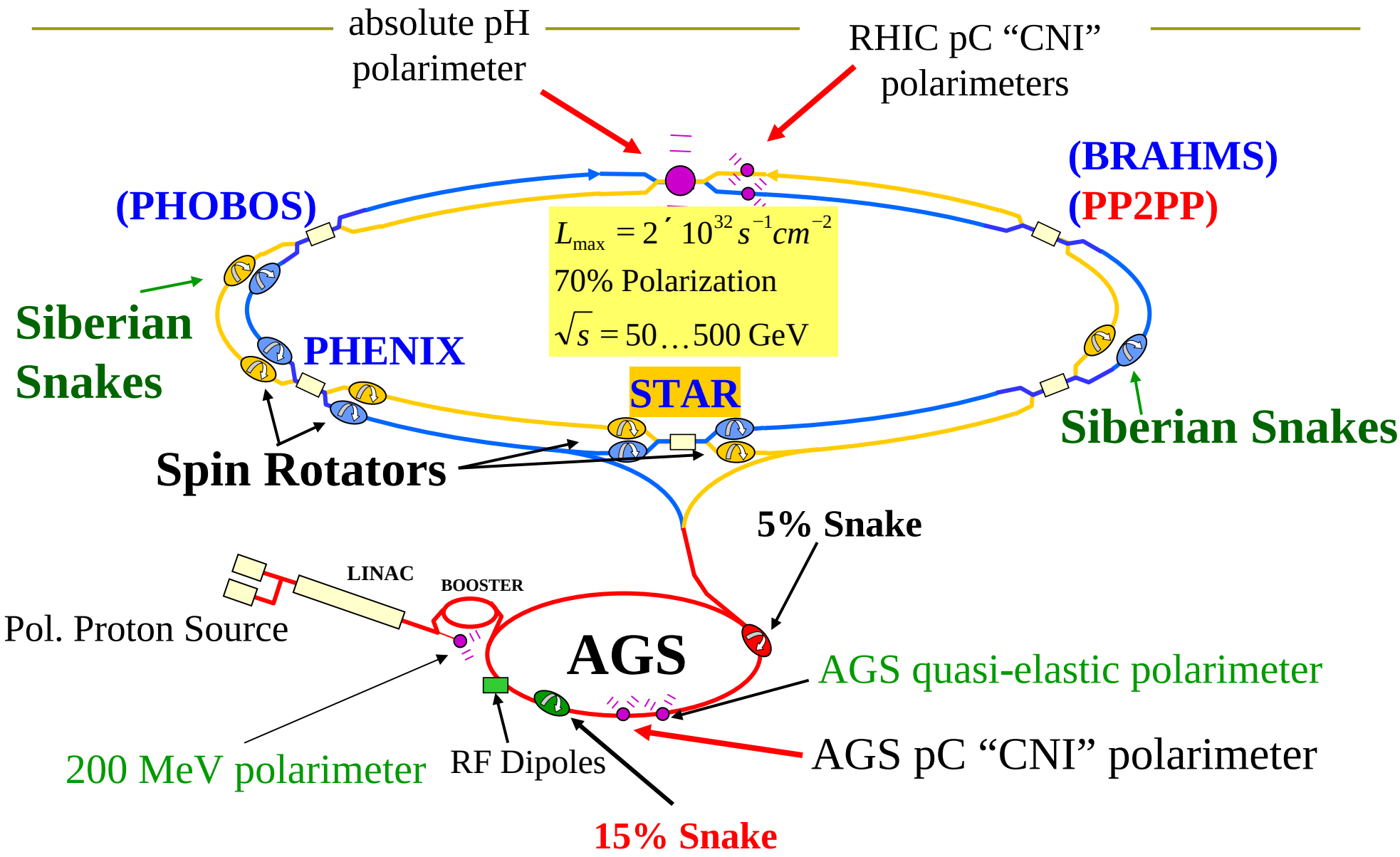
Relativistic Heavy Ion Collider (RHIC): THE QCD Factory

QCD is the theory of strong interaction:
"Theoretical evidences" vs. current and future Experimental QCD measurements at RHIC

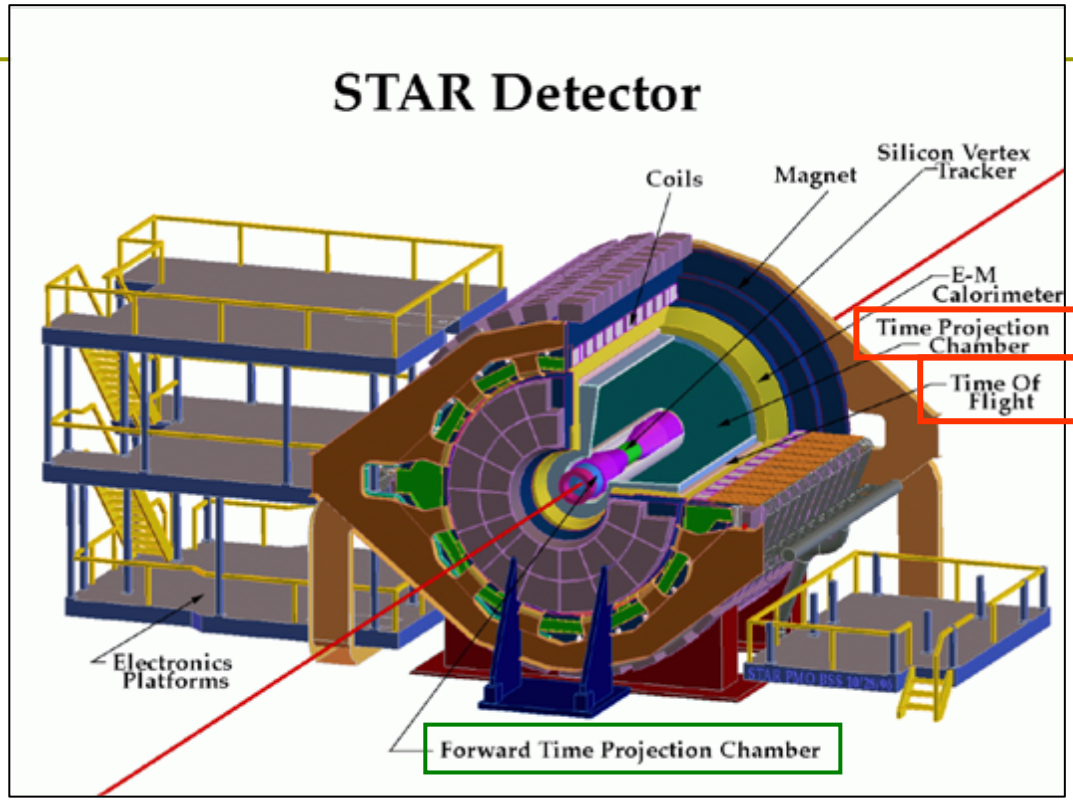
- Deconfinement/phase of QCD - QGP
- Distribution of spin in the nucleon - Spin sum rule
- Parton splitting limit - Saturated gluon state (Color Glass Condensate…)
- Gluonic degree of freedom in Hadrons – Exotica (glueballs…)
- Nature of diffractive processes – structure of Pomeron, Odderon…

Further investigation at eRHIC

RHIC as $p^{\uparrow}p^{\uparrow}$ Collider



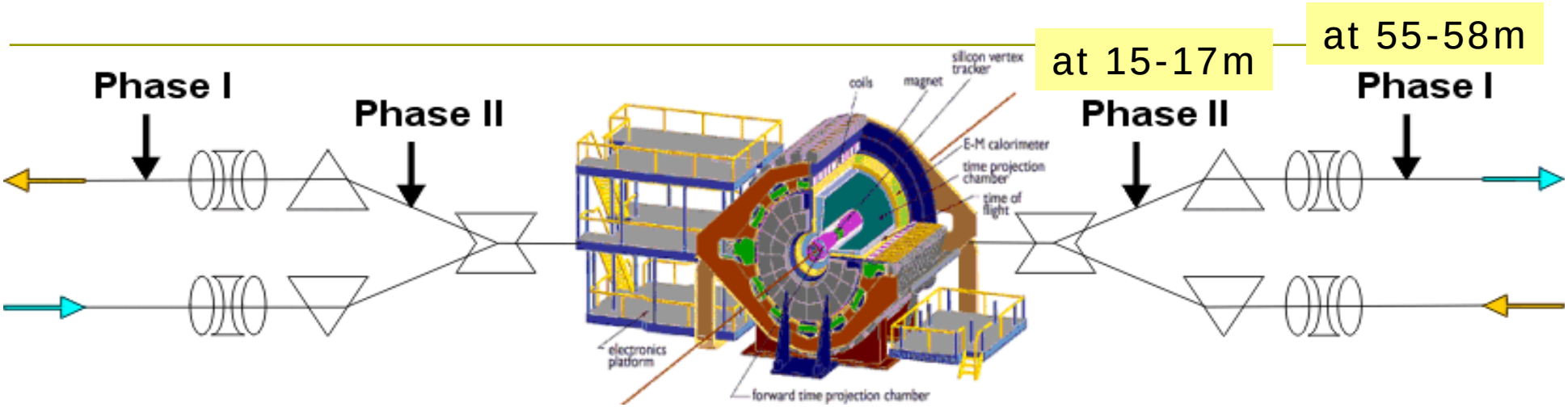
The **STAR** experiment at RHIC



Large Acceptance Detector running since 2000

- High resolution tracking device: TPC in $-1<\eta<1$, $-\pi<\phi<\pi$
- Forward rapidity gap veto
  - FTPC: $2.5<|\eta|<4.2$, BBC: $3.8<|\eta|<5.2$
- Excellent particle identification capability: TPC *dE/dx*, ToF

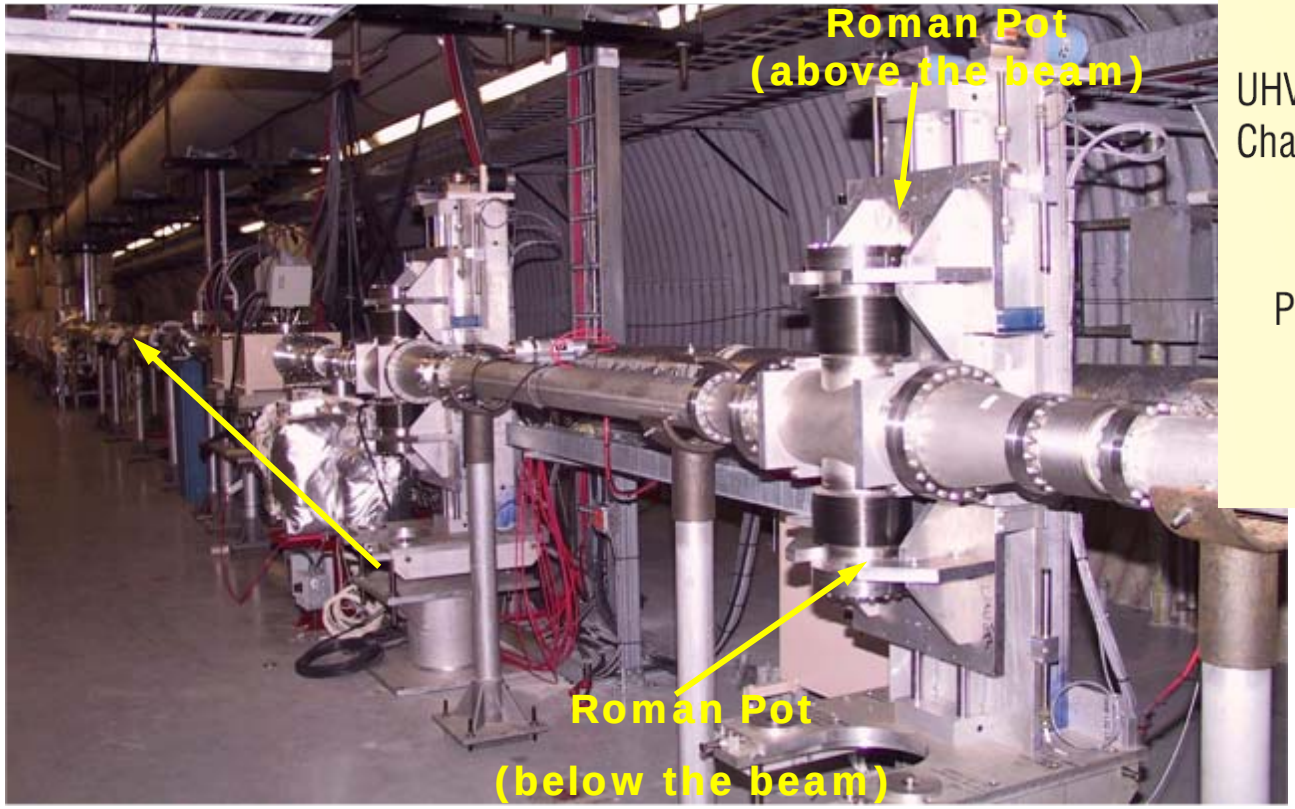
Forward Proton Tagging

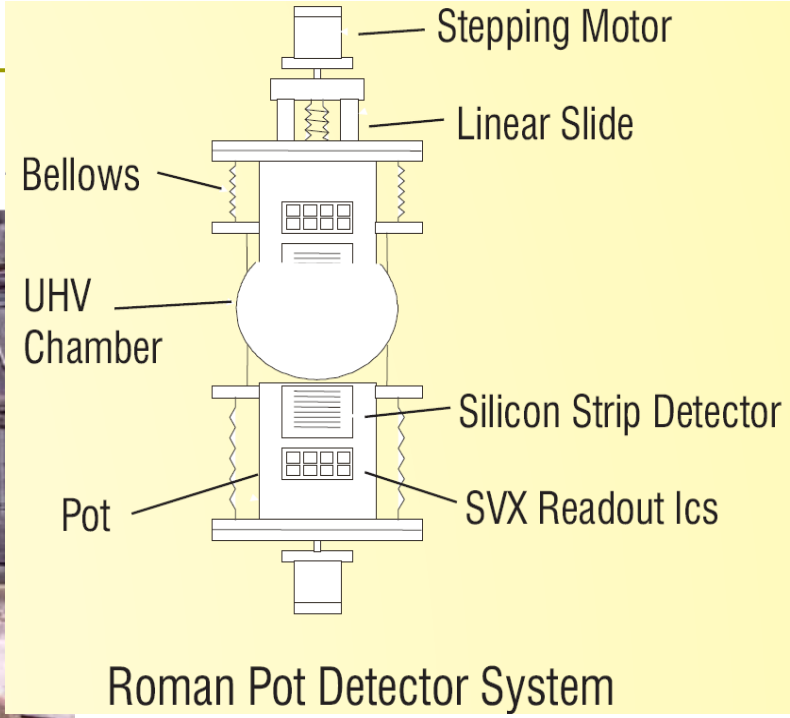


- **Roman Pot** detectors to measure forward scattered protons in diffractive processes
  - **Staged implementation** to cover wide kinematic coverage
    - Phase I (Installed): for low-t coverage
    - Phase II (planned) : for higher-t coverage

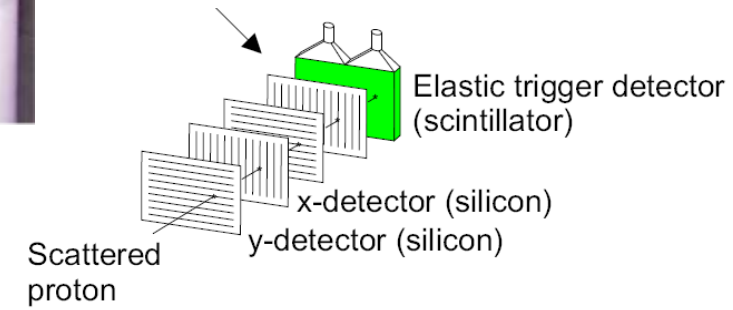
Roman Pots used (2002-2003) for pp2pp experiment at RHIC

pp2pp set-up





Roman Pot Detector System



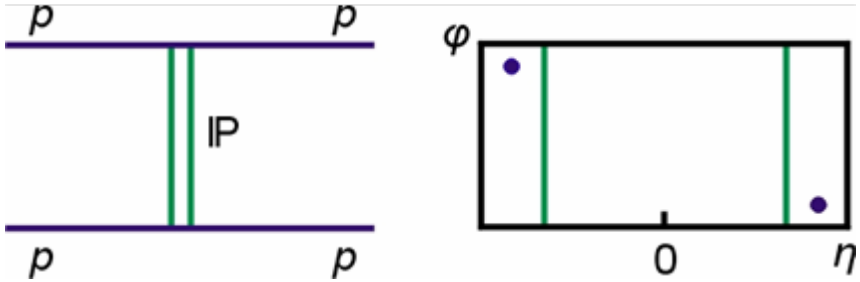
Phys. Lett. B 579 (2004) 245-250,
Phys. Lett. B 632 (2006) 167-172,
Phys. Lett. B 647 (2007) 98-103

Roman Pots in STAR (Phase I)

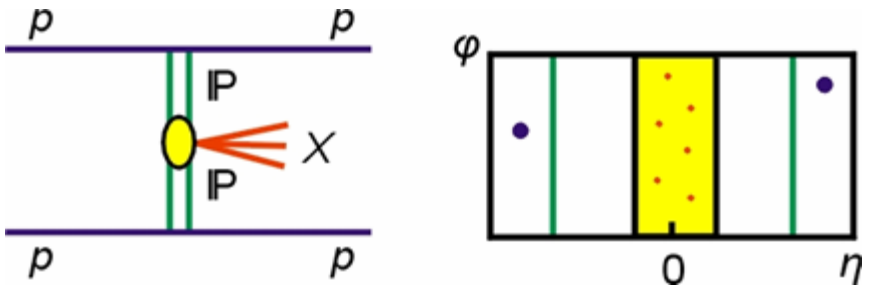
- Vertical AND Horizontal RP setup for a complete ϕ coverage

Program with tagged forward protons at RHIC studying:

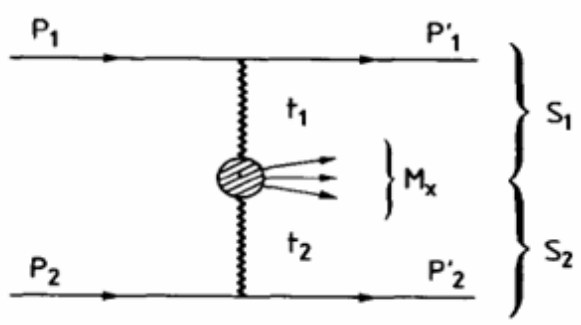
- Elastic scattering for understanding structure of Pomeron and Odderon (+single diffraction)



- Central production for searching for glueballs in Double Pomeron Exchange (DPE) processes



Inelastic Process: DPE $p_1p_2 \rightarrow p_1', M_X p_2'$



- 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 (nearly at rest) produced via a Double Pomeron Exchange/Fusion
- In pQCD, Pomeron is considered to be made of two gluons: natural place to look for gluon bound state
- $M_X(\sim 1 - 3\ \mathrm{GeV}/c^2) \rightarrow \pi^+\pi^-,\ \pi^+\pi^-\pi^+\pi^-,\ K^+K^-$
- Lattice cal.: Lightest glueball $M(0^{++}) = 1.5\text{-}1.7\ \mathrm{GeV}/c^2$
- Search for glueball (gg) candidates in M_x
- Candidates with conventional quantum numbers: need (kinematic) "filtering"

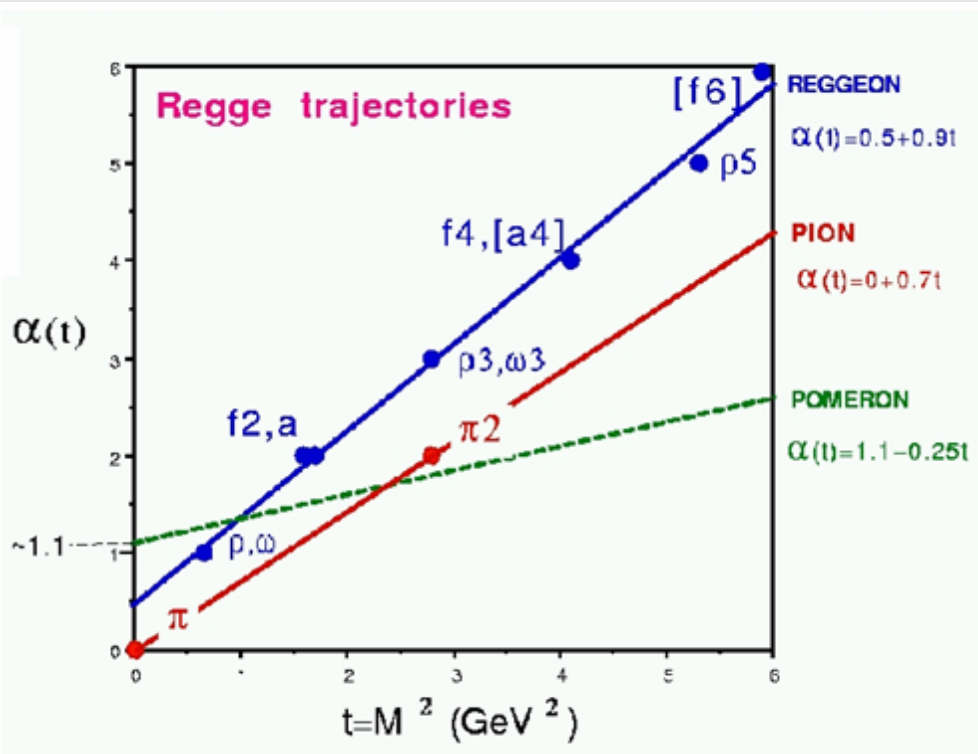
DPE Central Production at RHIC

- Pomeron-Pomeron dominant
  - $\sigma_{RR} \sim s^{-2}$, $\sigma_{RP} \sim s^{-1}$, $\sigma_{PP} \sim$ const. (or s^x where x $\sim O(0.1)$)
- Wide rapidity gap
  - Beam rapidity at $\sqrt{s}$ = 500 GeV : $y_{beam} \sim 6.3$
  - $M_X < 3$ GeV/c^2 will have a rapidity gap > 4 units
- Higher reach in M_x
  - 200 GeV: $M_{x\ max} \sim 10$ GeV/c^2,
  - 500 GeV: $M_{x\ max} \sim 25$ GeV/c^2
- Polarization dependence of DPE: provide extra constraint for theoretical interpretation

Central Production Spectroscopy experiments/publications

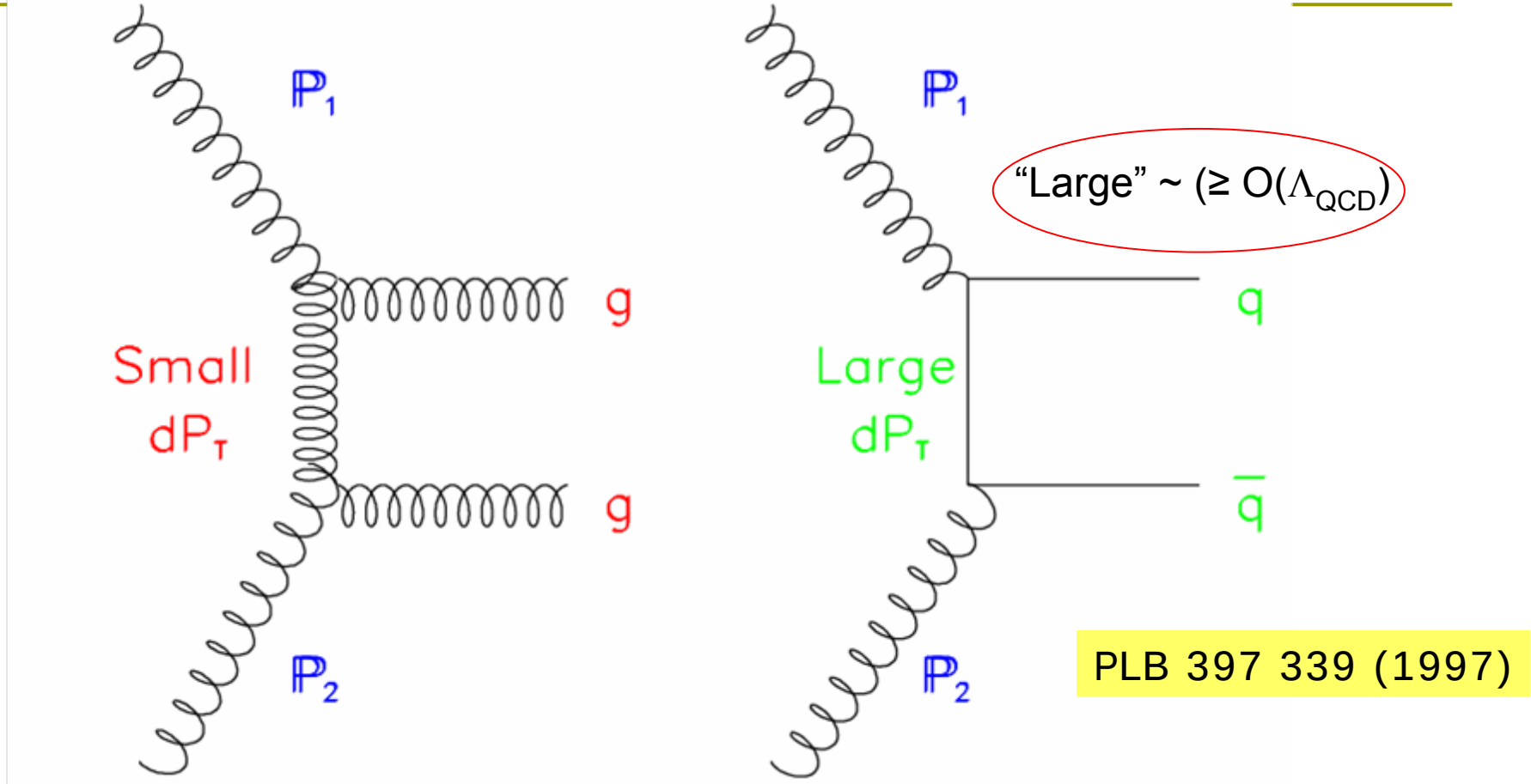
- Many measurements in $\sqrt{s}$ ~10-60 GeV
  - Fixed Target
    - CERN Ω (~1990)
      - WA76 ($\sqrt{s}$ =12.6 GeV), WA91(23.7), WA102(29.1)
    - CERN GAMS ($\sqrt{s}$ = 29.1) (~1990)
    - FNAL E690 ($\sqrt{s}$=38.8) (~1990)
  - Collider
    - ISR AFS R807 ($\sqrt{s}$ = 62) (~1980)
- In this energy range, likely significant Reggeon-Reggeon contribution: difficulties in interpretations

Quantum number "filter" for Pomeron-Pomeron (PP)



- Pomeron has vacuum Quantum number (P=C=+1, colorless)
- DPE cannot produce I=1 state such as ρ(770) (Isospin conservation)
  - B=Q=S=0, $I^G J^{PC}$ = $0^+ even^{++}$
  - $f_J(1710)$ $0^+ even^{++}$
  - …

Kinematic "filter" (dp_T) for "gg" (F. Close et al./W102)



PLB 397 339 (1997)

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

dp_T "filter": WA102 ($\sqrt{s}$=29 GeV)

dp_T < 0.2 GeV/c | 0.2< dp_T< 0.5 | dp_T > 0.5 GeV/c

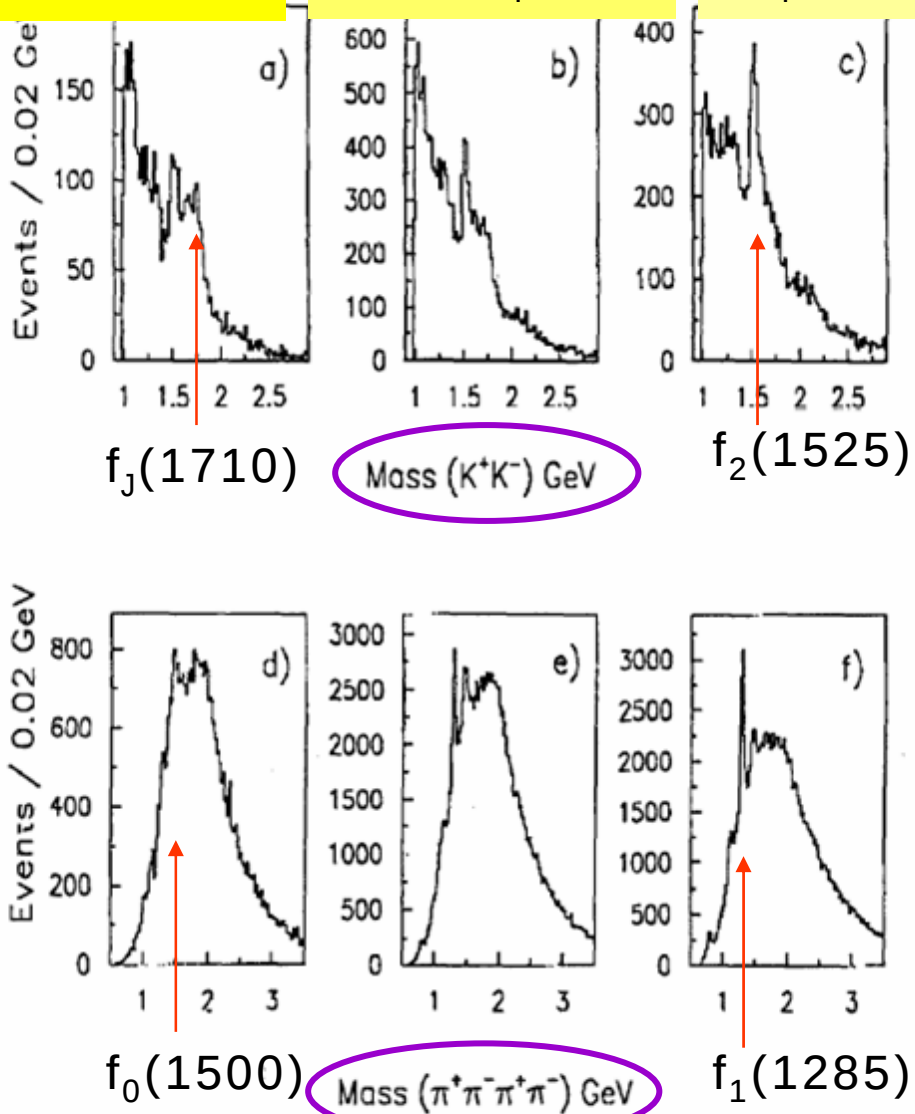
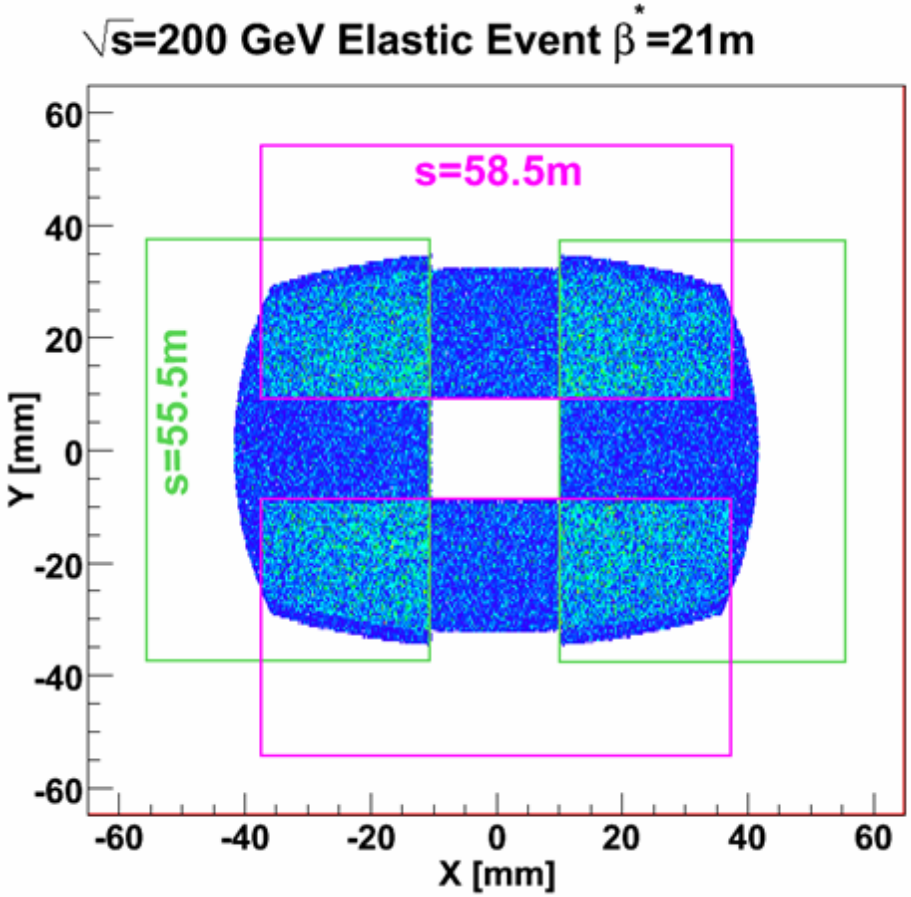


Fig. 3. K^+K^- mass spectrum for a) $dP_T < 0.2$ GeV, b) $0.2 < dP_T < 0.5$ GeV and c) $dP_T > 0.5$ GeV and the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum for d) $dP_T < 0.2$ GeV, e) $0.2 < dP_T < 0.5$ GeV and f) $dP_T > 0.5$ GeV.

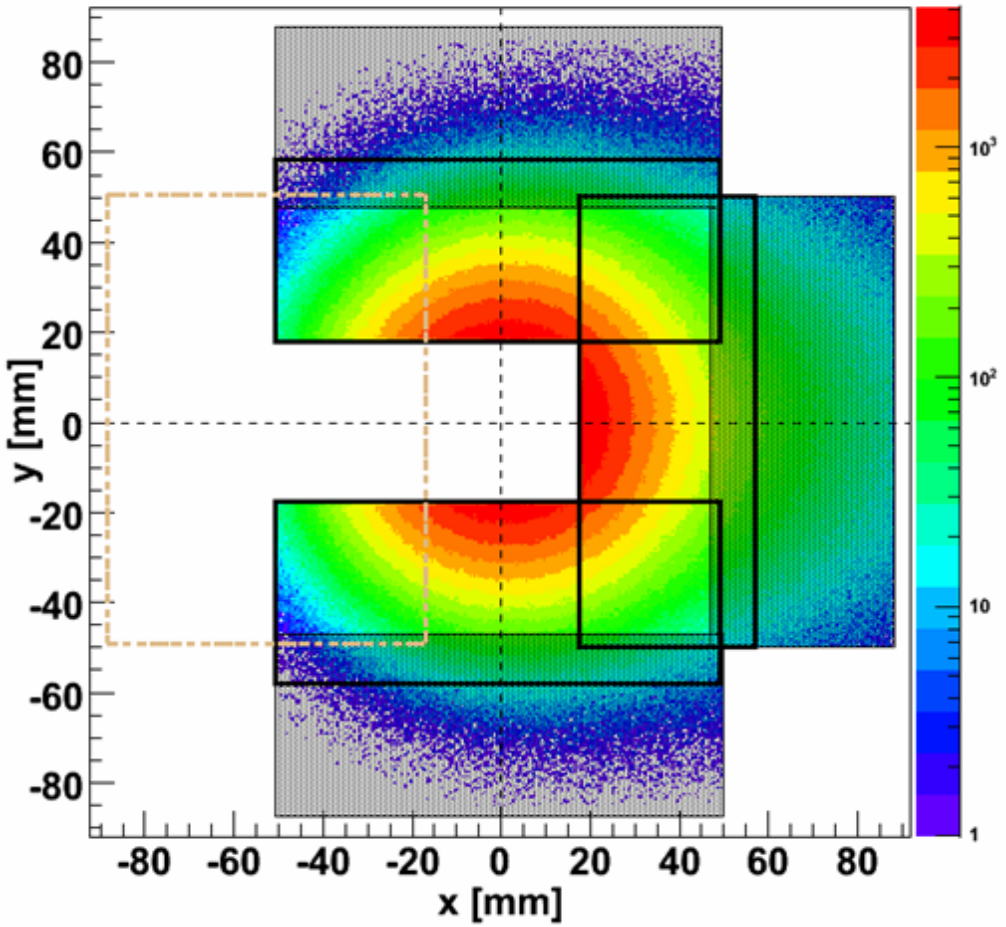
Roman Pots at STAR (Phase I)



Beam transport simulation using Hector

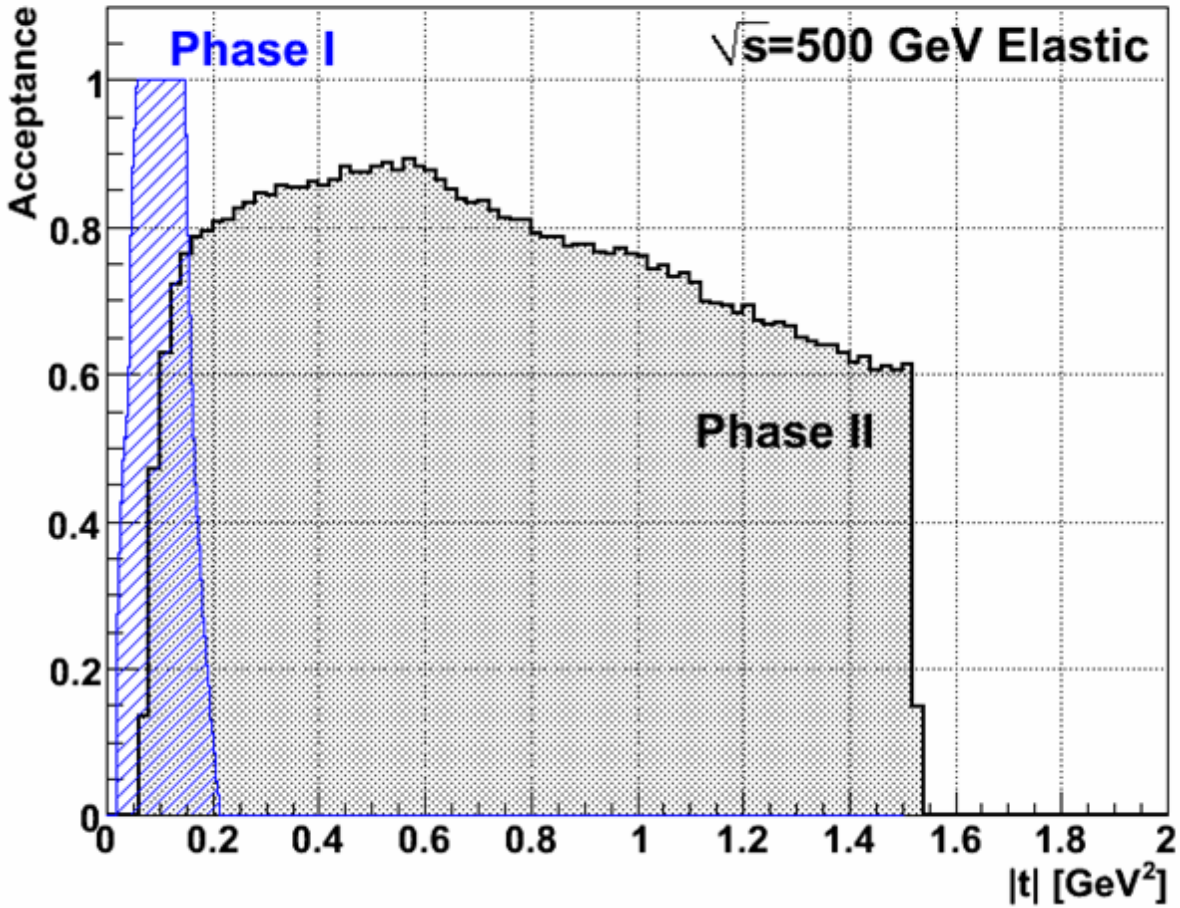
- Phase I: 8 Roman pots at ±55.5, ±58.5m from the IP
- Require special beam tune :large β* (21m for √s=200 GeV) for minimal angular divergence
- Successful run in 2009: Analysis in progress focusing on small-t processes ($0.002<|t|<0.03$ GeV^2)

Roman Pots (Phase II)



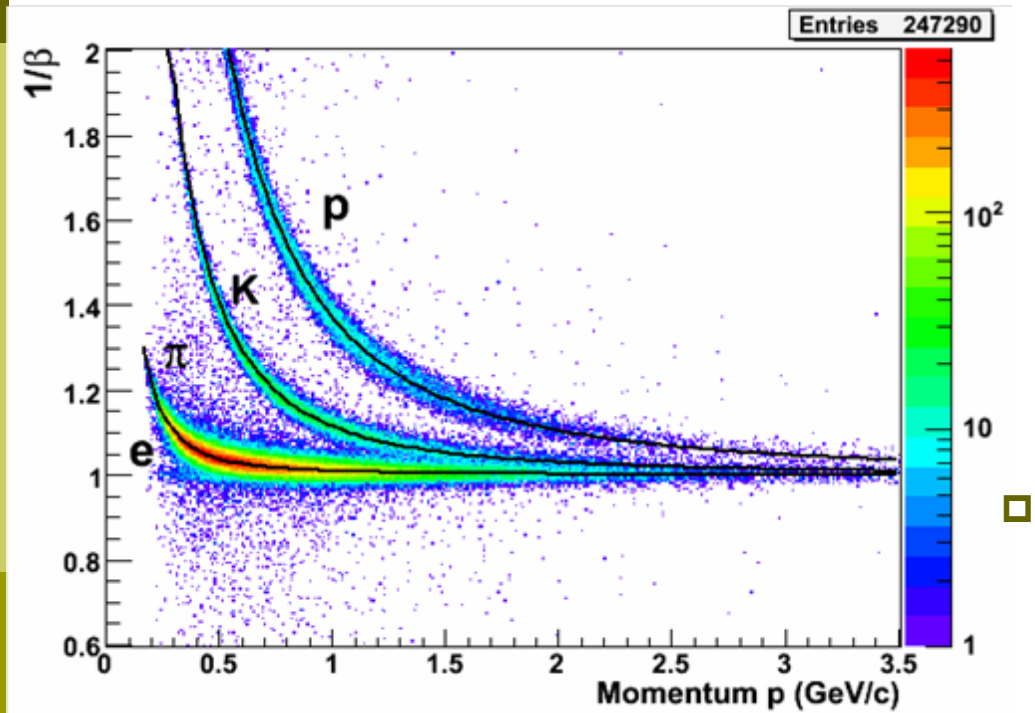
- Phase II: 8(12) Roman Pots at ±15 and ±17m
- Planed to be implemented in 2011-2012
- Doesn't require special beam optics: main set-up for central DPE processes requiring wide-t coverage and high-luminosity
- 2π coverage in ϕ will be limited due to machine constraint (incoming beam)

t-Acceptance of Roman Pots



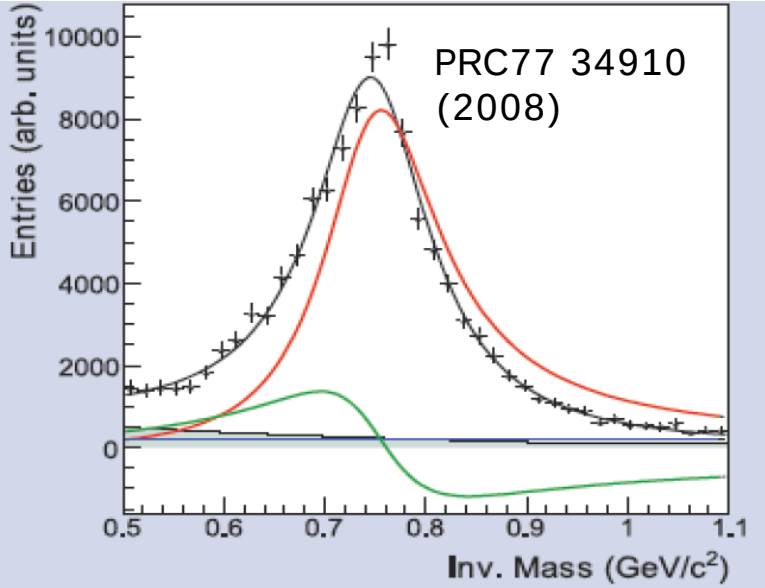
- Phase I set-up focuses on low-t (installed)
- Phase II covers higher-t range (planned)

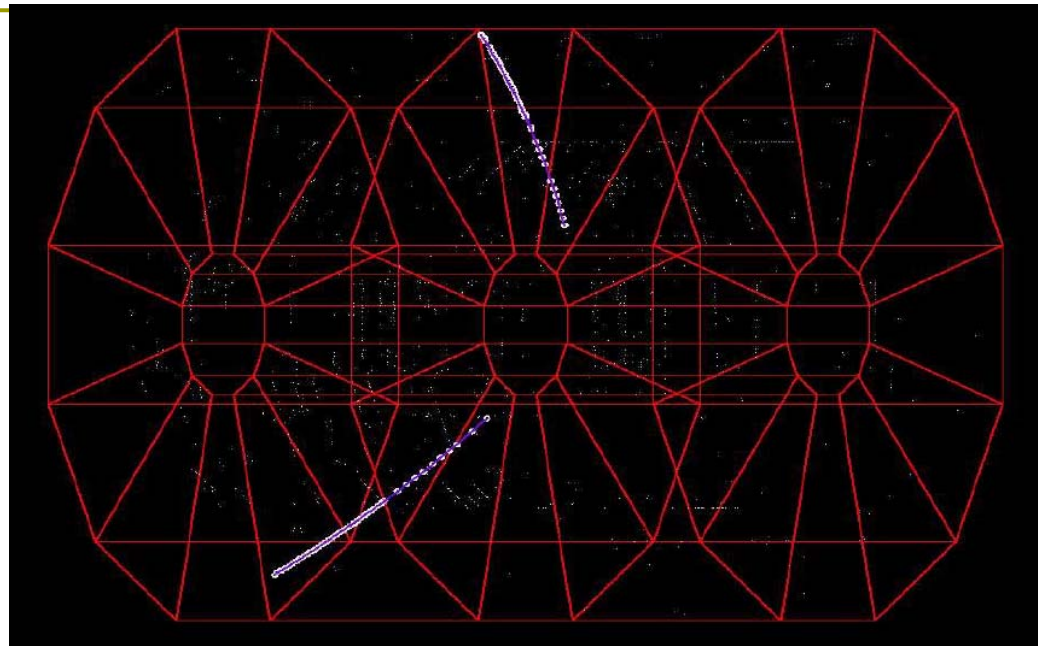
Trigger and Data Reconstruction

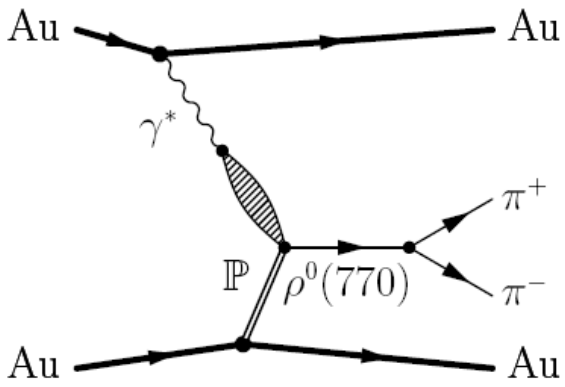


- Trigger
  - Elastic (collinear) and inelastic trigger
  - Multiplicity trigger using TOF barrel for selecting low multiplicity ($0<N<6$) central events as used in STAR UPC Trigger
  - Rapidity gap trigger using Beam-Beam counters
- Reconstruction
  - Scattered proton momentum momentum reconstruction using RPs and beam transport
  - STAR TPC tracking in $|y|<1$ with TOF barrel and TPC PID (π/K separation up to ~1.6 GeV/c)

Ultra-Peripheral Collision (UPC) program with AuAu in STAR

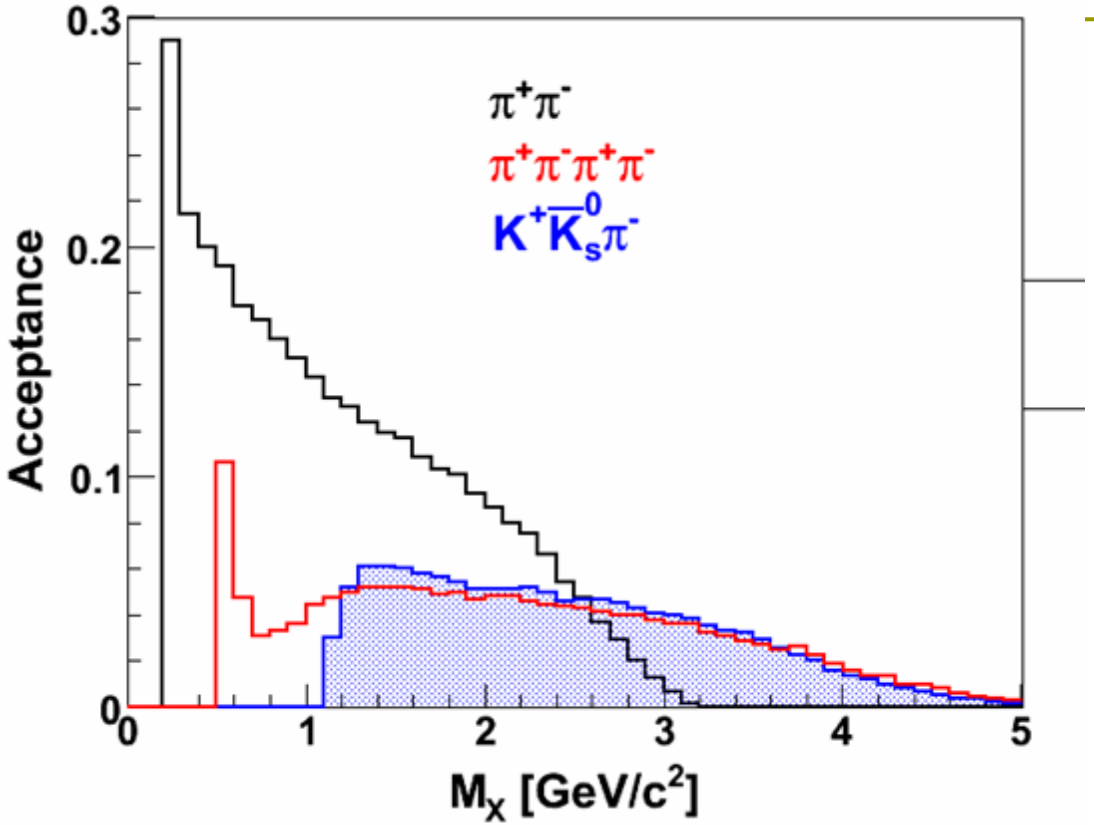






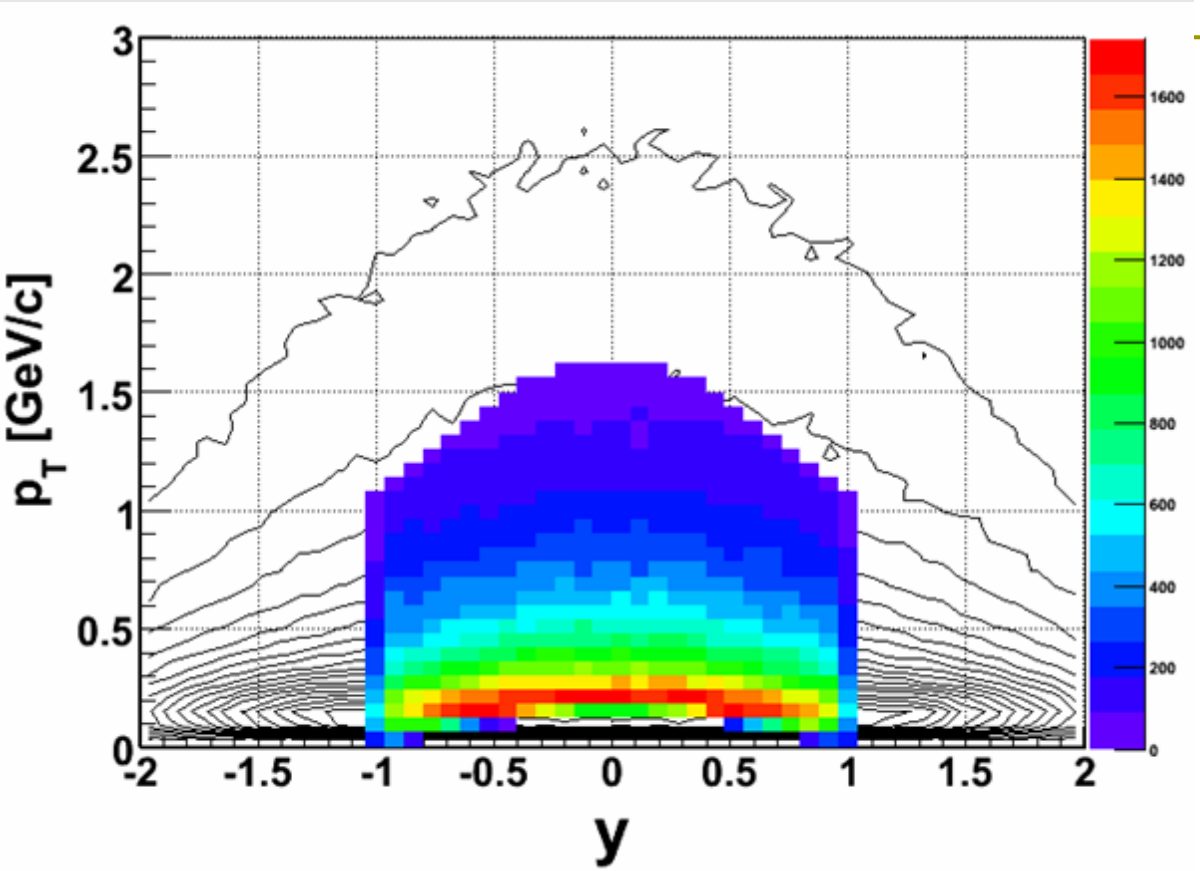
- Complementary program with central production in p+p
  - Spectroscopy in photoproduction
  - Common machinery: trigger, data reconstruction…

Mass dependent acceptance



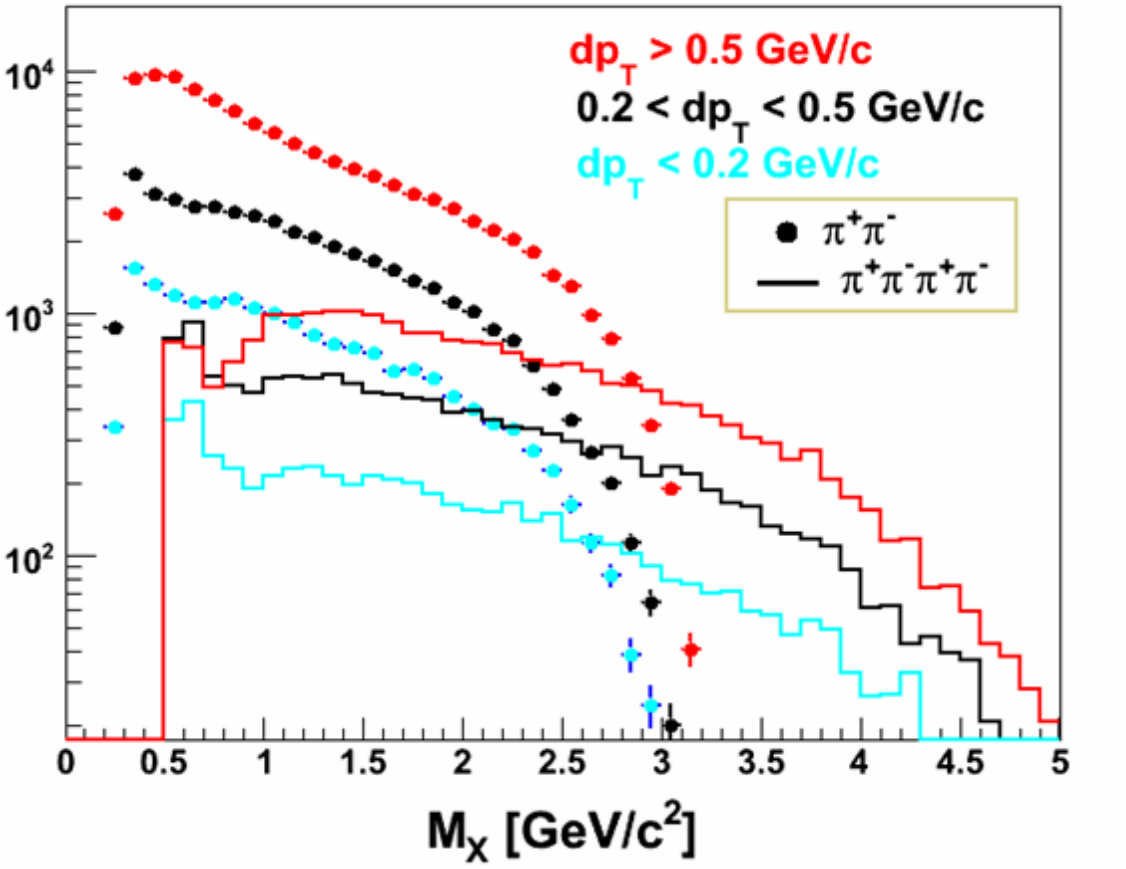
- ~5-10% in ~1<M_x<2
- High mass range limited by ToF PID
- Lower mass range limited by track reconstruction at low momentum

Acceptance and PID for decaying particles



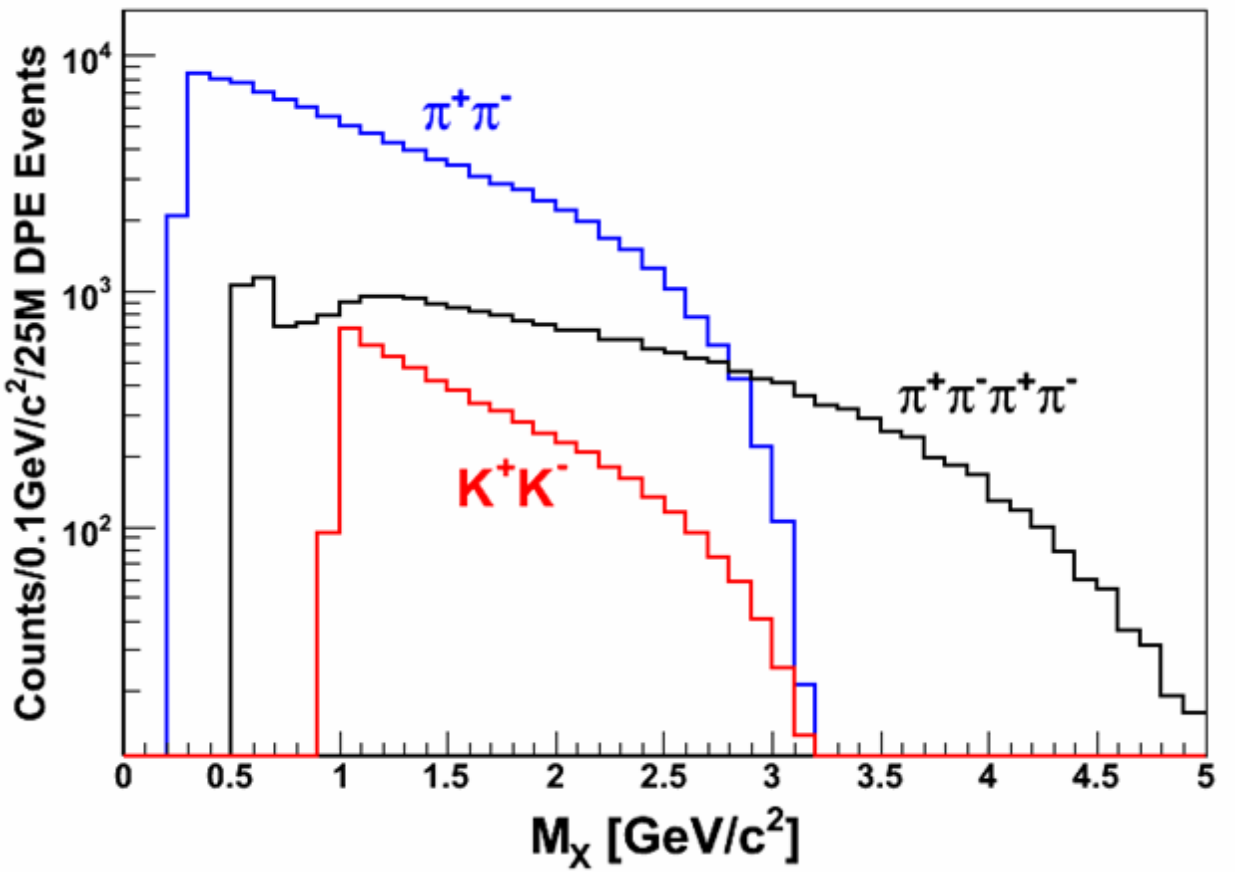
- Accepted phase-space in y-p_T for π from M_X decaying to $\pi^+\pi^-\pi^+\pi^-$ (No isobar assumed)

dp_T-dependent accepted yield



- $dp_T = |p_{T1} - p_{T2}|$ for the "kinematic filter"
- No significant dp_T-dependence in shape of the acceptance in $M_X > 1$ GeV/c^2

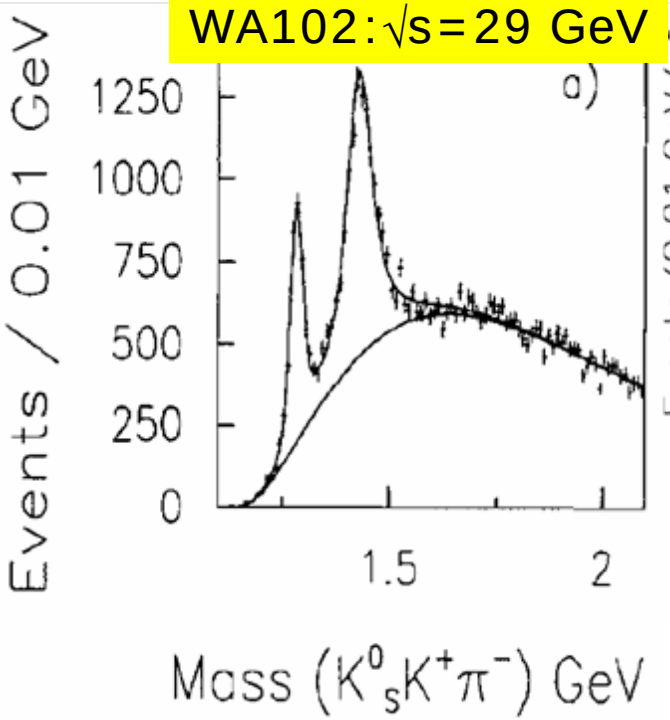
Expected yields as function of M_X



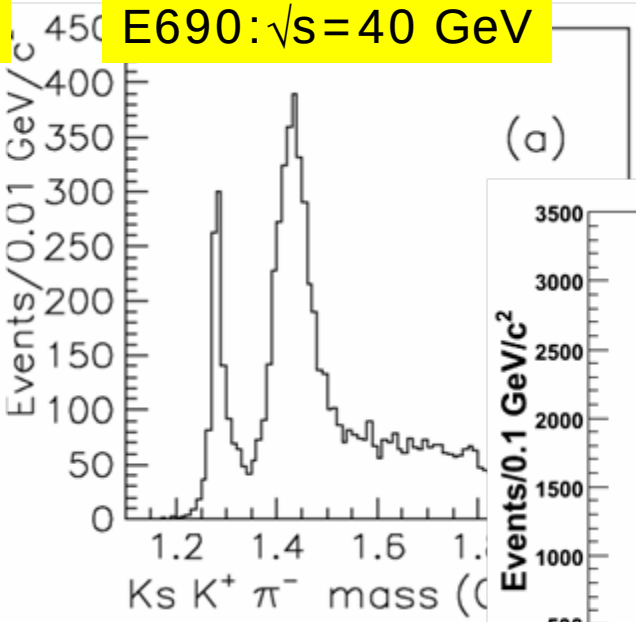
- Expected reconstructed phase-space including 140 μbarn DPE Cross-section and branching ratios measured at ISR per 25M DPE events
- M_x=1-3 GeV/c^2 is kinematically well accessible in pion and Kaon decay channels
- Expected Trigger rate for DPE: ~100 Hz at $\mathcal{L}=1\times10^{31}cm^{-2}s^{-1}$
- 20 Week RHIC running: ~2M K^+K^- ~6M $\pi^+\pi^-\pi^+\pi^-$ sample
- Phase I setup is expected to produce an exploratory data sample of ~100K $\pi^+\pi^-$ with 5 days of running with special beam tune (β^*=21m) in July of 2009

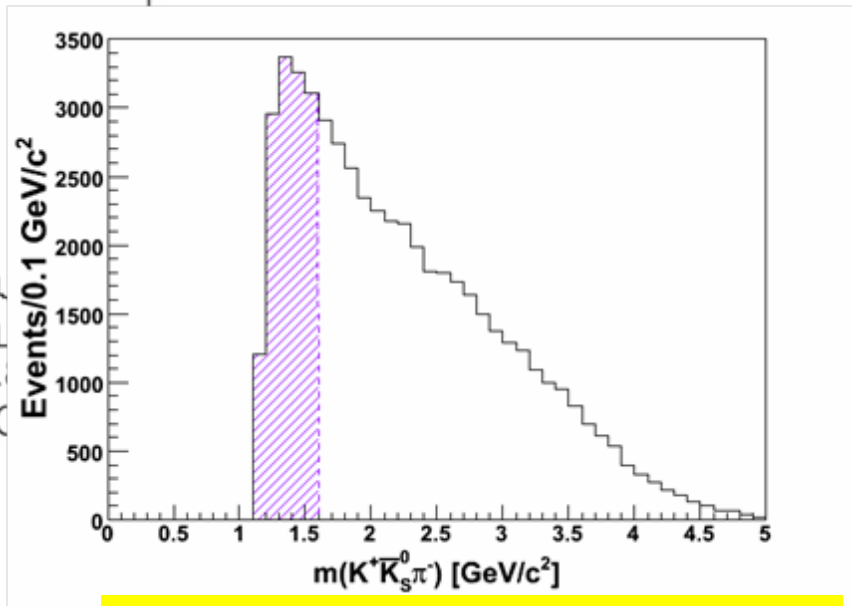
$f_1 \rightarrow K^{\pm}K^0\pi$ in DPE

WA102: $\sqrt{s}$ = 29 GeV



E690: $\sqrt{s}$ = 40 GeV





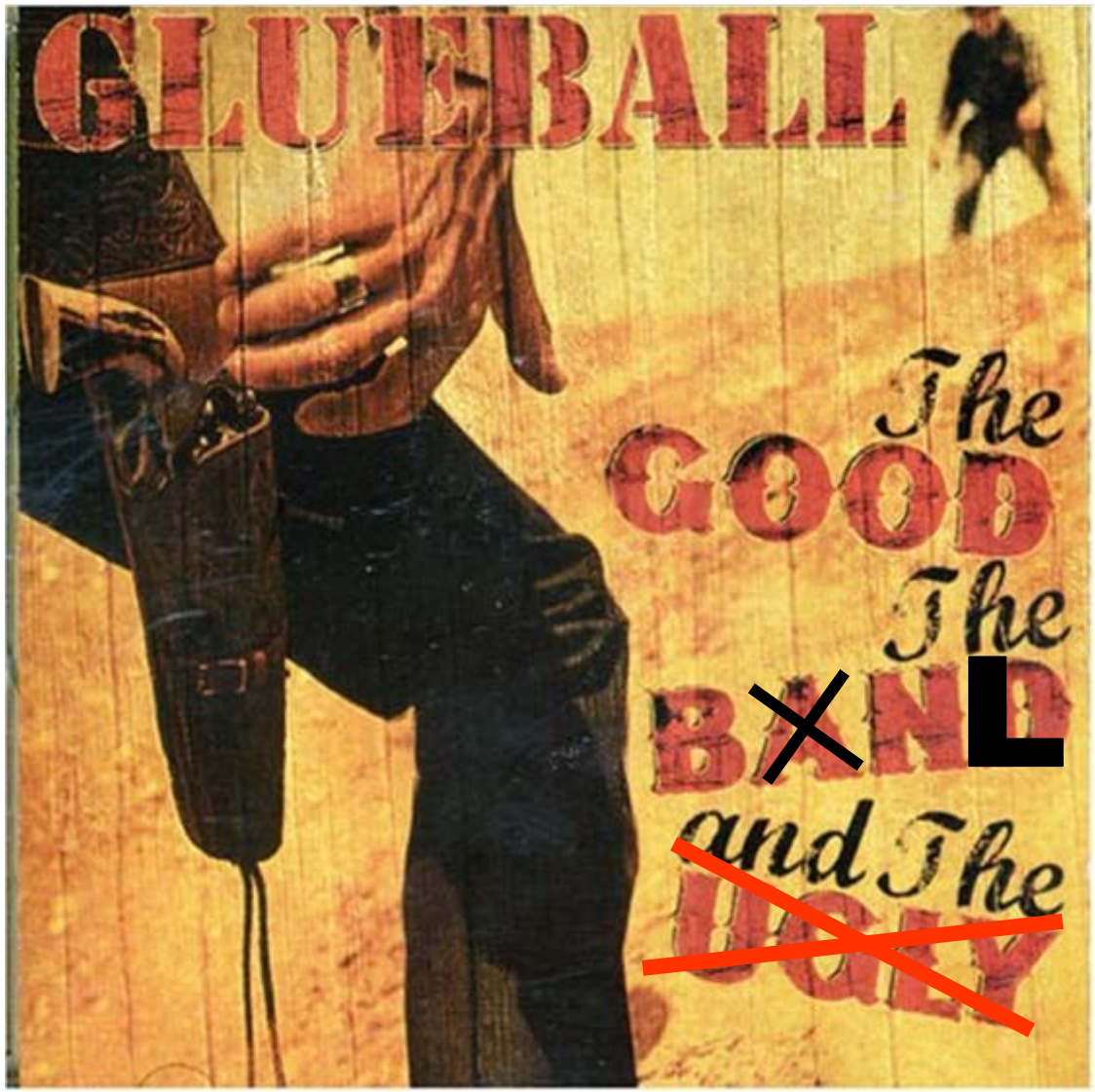
STAR Accepted phase-space: $M_x \rightarrow K^{\pm}K^0\pi$

- Is $f_1(1420)$ a non q-qbar candidate?
- Expect ~0.5M $KK\pi$ sample expected in $1.2 < M(KK\pi) < 1.6$ GeV/c^2 assuming cross-section of ~5μbarn (PLB 489 (2000))

Summary

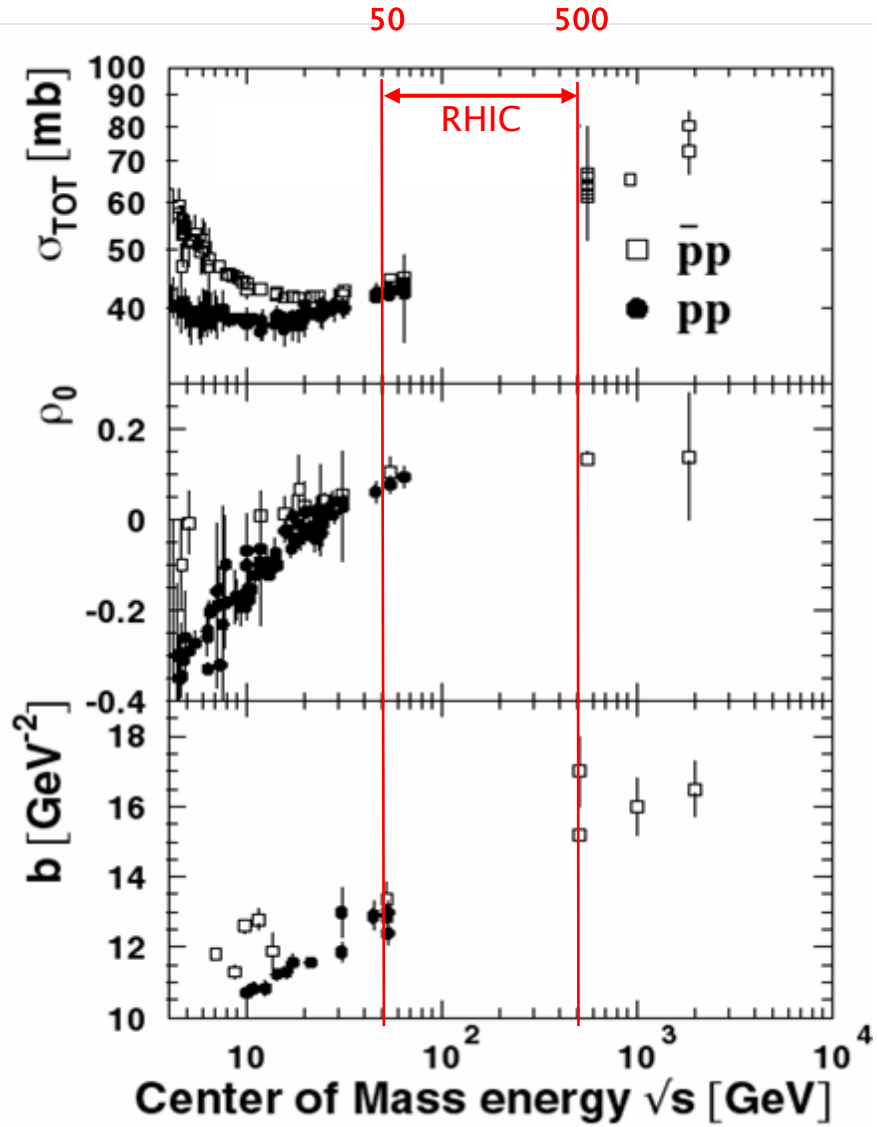
- New program to **search for glueball with the STAR detector at RHIC**
  - At **high energy** where Pomeron-Pomeron interaction is expected to be dominant with clean rapidity gap with DPE
  - Using **large acceptance** and high resolution detector
  - With **polarized high luminosity** beam
- Looking forward to rich spectroscopy and diffractive programs with staged Roman Pot implementation at STAR

New collaborators are WELCOME!



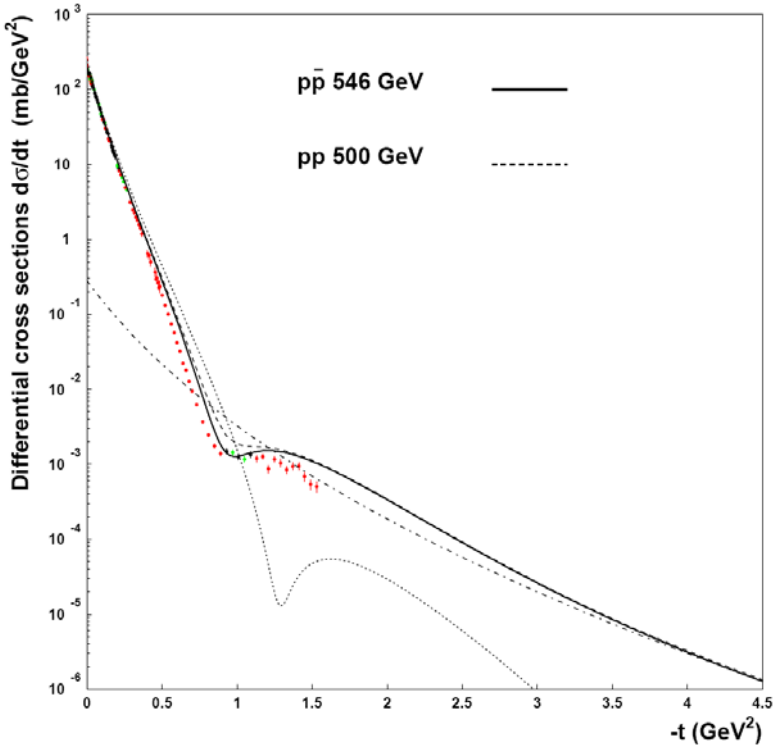
Backup Slides

Summary of the Existing Elastic Data (unpolarized)



- Highest energy so far:
  - pp: 62 GeV (ISR)
  - $\bar{p}p$: 1.8 Tev (Tevatron)
- RHIC energy range:
  - 50 GeV ≤ √s ≤ 500 GeV
- Elastic measurements: Details on the nature of elastic scattering at the energy are NOT well understood in the energy range: Unique measurements in **wide t-range** with **polarized** beams

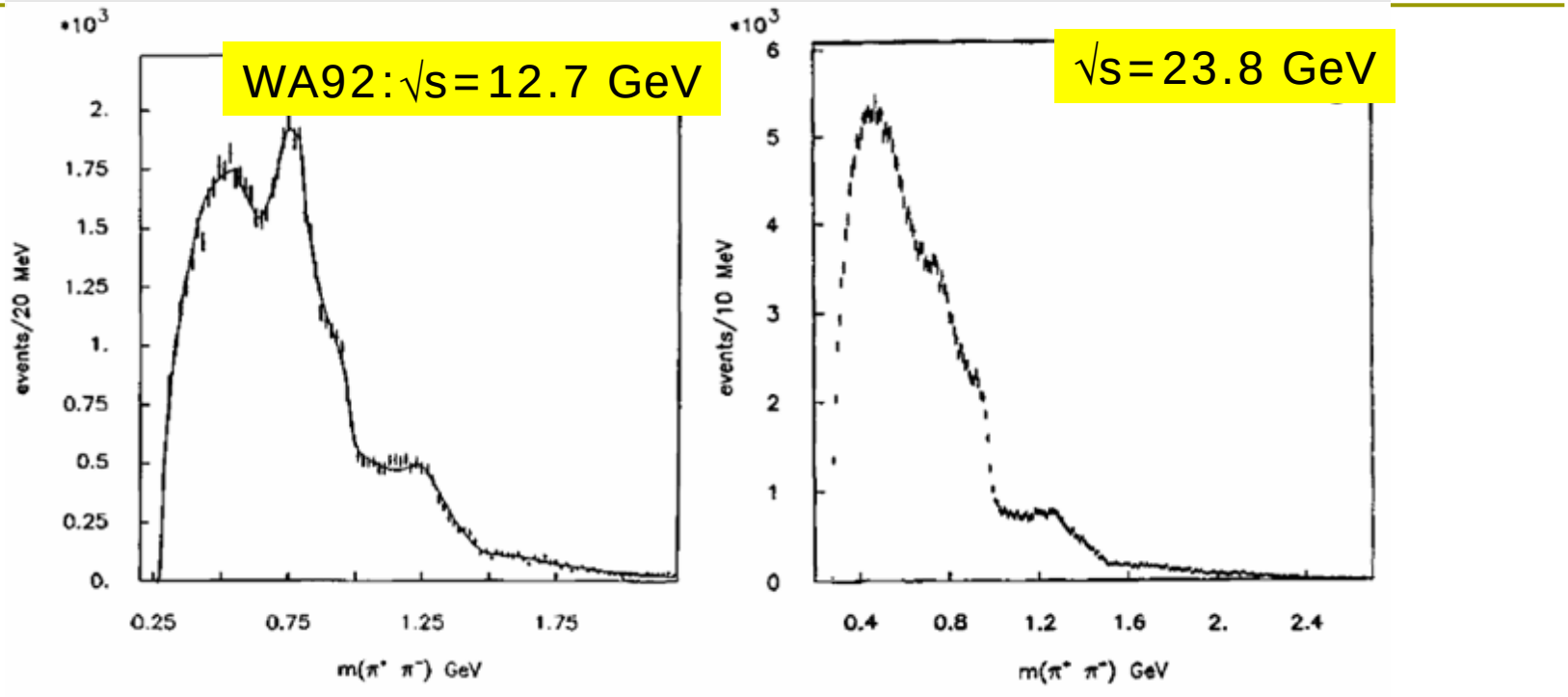
Can Odderon be identified at RHIC?



hep-ph/0210437 M. Islam et al.

- Odderon is a counterpart of Pomeron (C=1) with C=-1: "RHIC is the machine to find it" (E. Leader, Odderon Workshop (2005)) by measuring
  - $\Delta\sigma_{pp} - \Delta\sigma_{pbarp} \neq 0$ (~3mb)
  - $d\sigma/dt_{pp} \neq d\sigma/dt_{pbarp}$
  - Shape of Asymmetries: A_{NN}
  - Centrally produced C=-1 particle

Diffraction at RHIC: pomeron dominant?



- RHIC energy Pomeron-Pomeron dominant (small Reggion contribution)

Inclusive Double Pomeron interaction at ISR

Z. Phys. C – Particles and Fields 42, 387–395 (1989)

Table 1. Cross-Sections for exclusive reactions. The quoted errors do not include a global systematic error (estimated as a *factor of 1.5*) which results from an overall uncertainty in the acceptance and the liminosity calibration

Reaction	Number of events	Cross section [μb]
(1) $pp \to pp(\pi^+\pi^-)$	16400	79.0 ± 13.0
(2) $pp \to pp(2\pi^+ 2\pi^-)$	5800	46.0 ± 10.0
(3) $pp \to pp(3\pi^+ 3\pi^-)$	1900	32.0 ± 9.0
(4) $pp \to pp(K^+K^-)$	560	6.5 ± 1.7
(5) $pp \to pp(K^+K^-\pi^+\pi^-)$	150	10.0 ± 3.3
(6) $pp \to pp(p\bar{p})$	120	0.8 ± 0.17
(7) $pp \to pp(p\bar{p}\pi^+\pi^-)$	65	1.3 ± 0.36

$\sqrt{s} = 62$ GeV

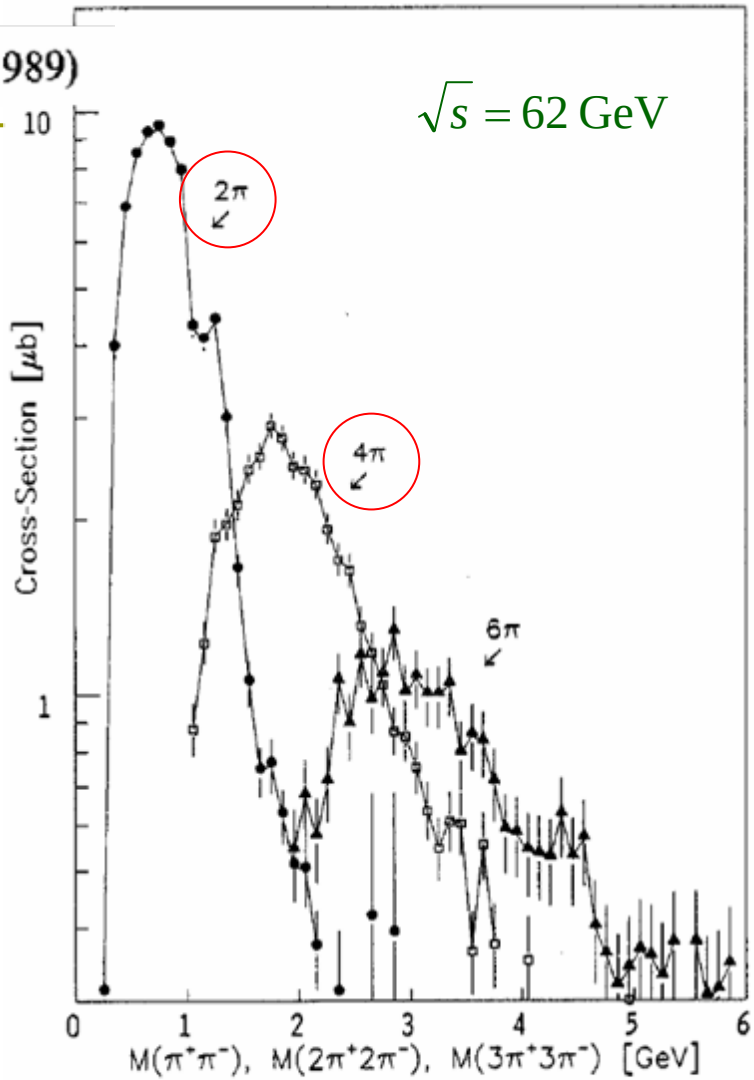


Fig. 3. Invariant mass distributions for the central $\pi^+\pi^-$, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$ systems from reactions (1–3) respectively (in μb per 100 MeV bin). This figure, and all subsequent figures, show data which have been acceptance corrected