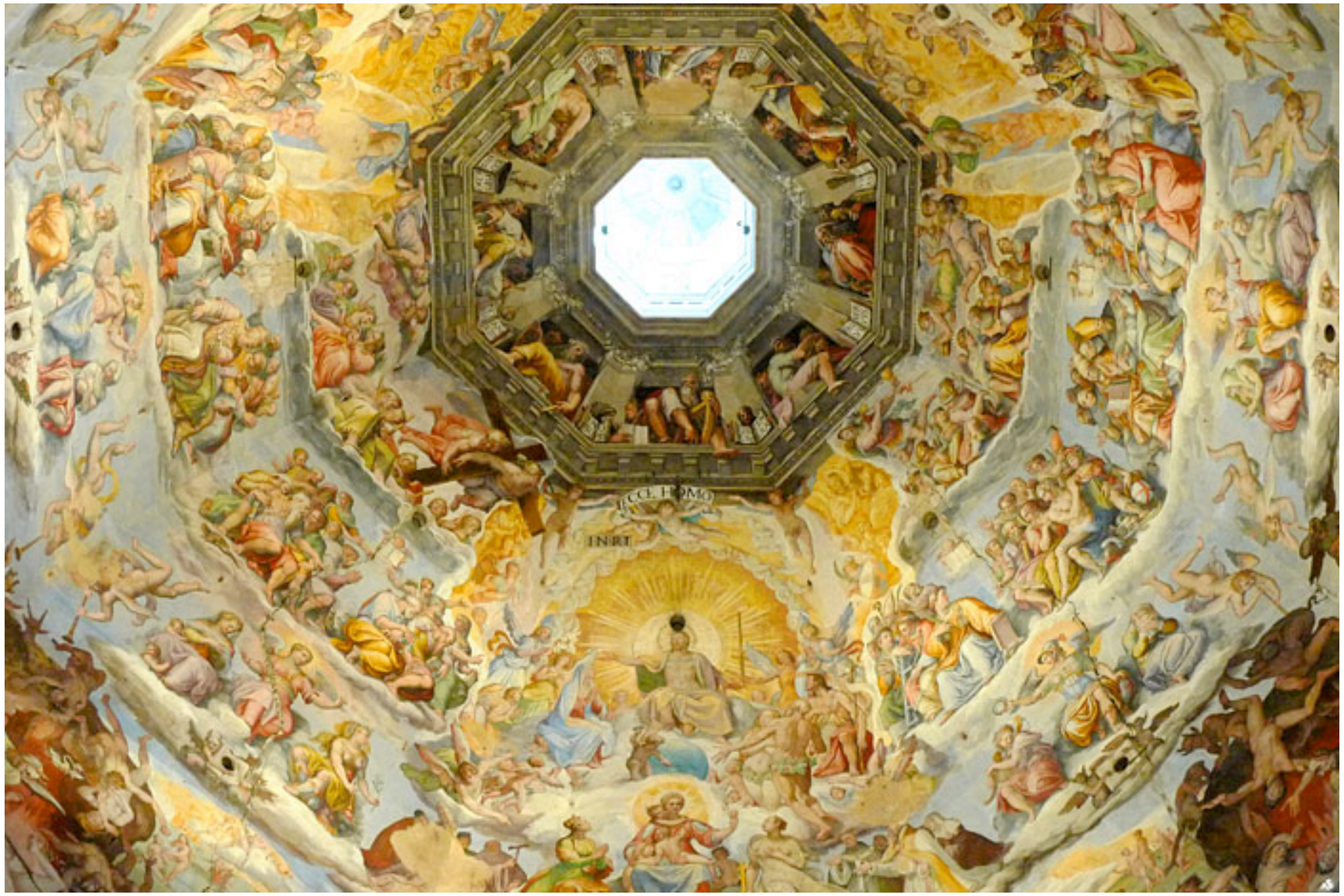
Diffractive Physics Program with Tagged Forward Protons at STAR/RHIC



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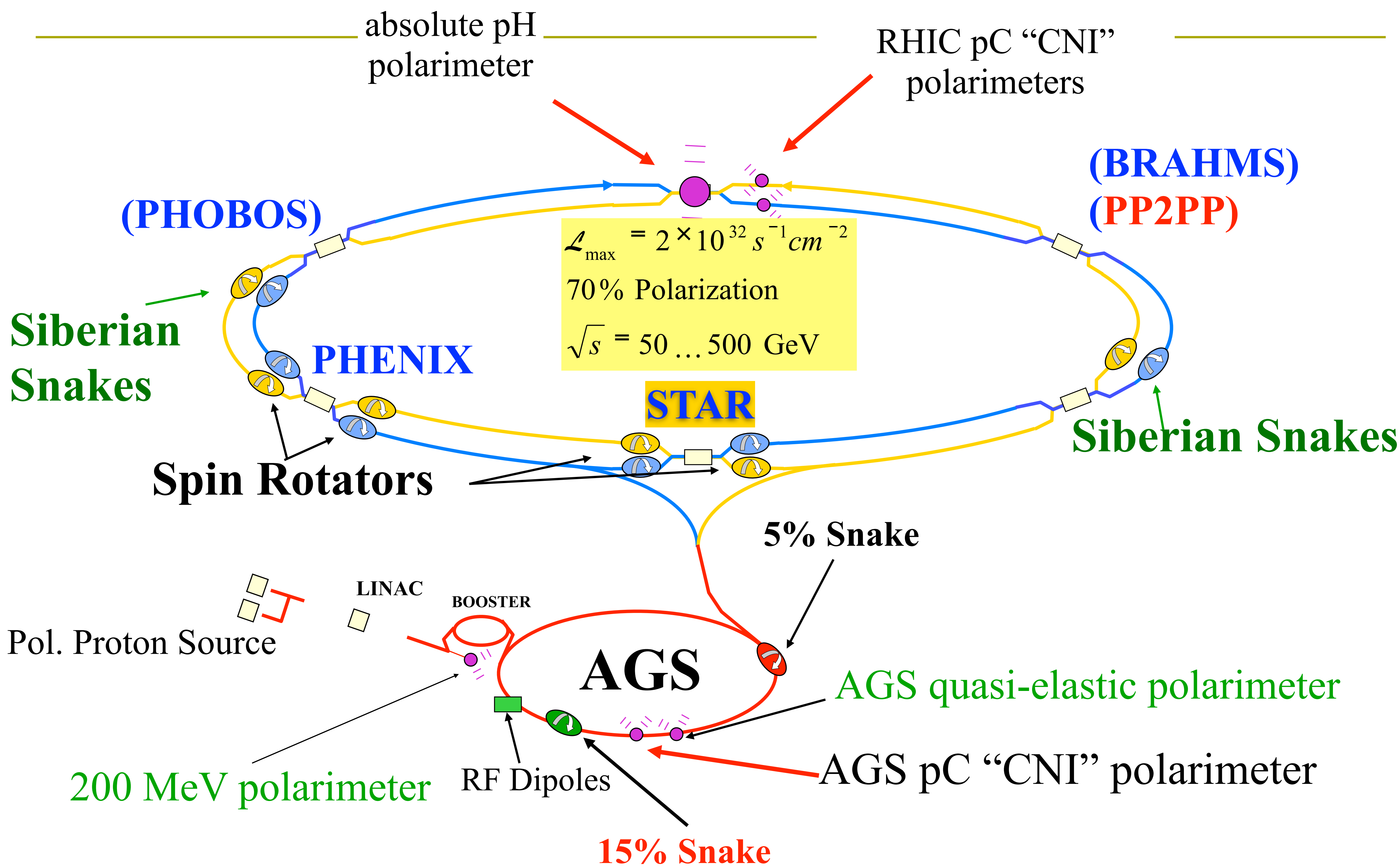
Outline

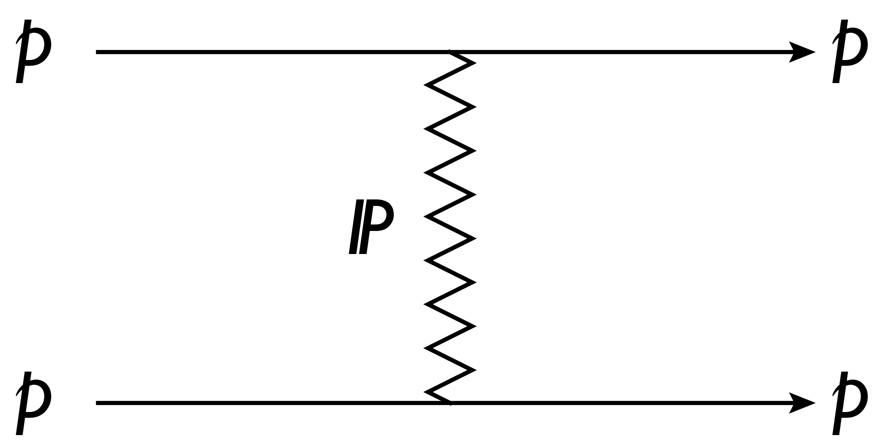
- Diffraction measurements with Roman Pots in STAR at RHIC (Phase I, Phase II)
- Polarized elastic diffraction
  - Motivation
  - Preliminary results on Single Spin Asymmetries at CNI region
- Inelastic diffraction: central production
  - Motivation
  - First look at the data
- Outlook

RHIC as p↑p↑ Collider

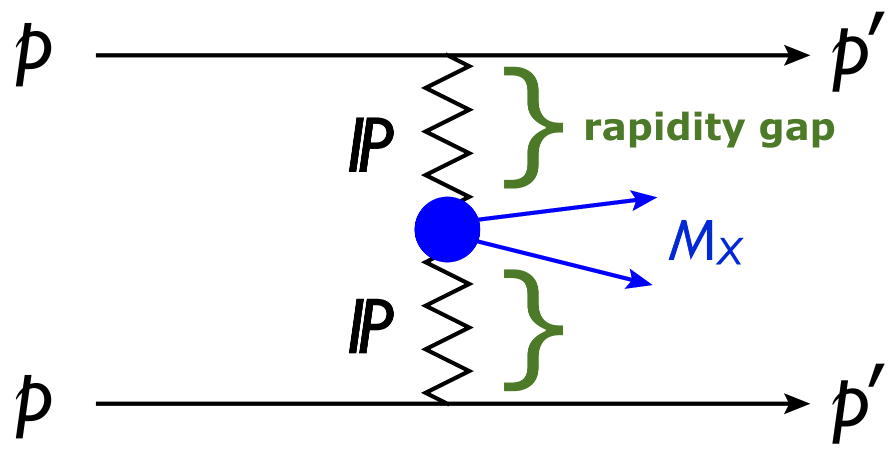


Diffractive Physics Program with tagged forward protons at RHIC studying mainly:

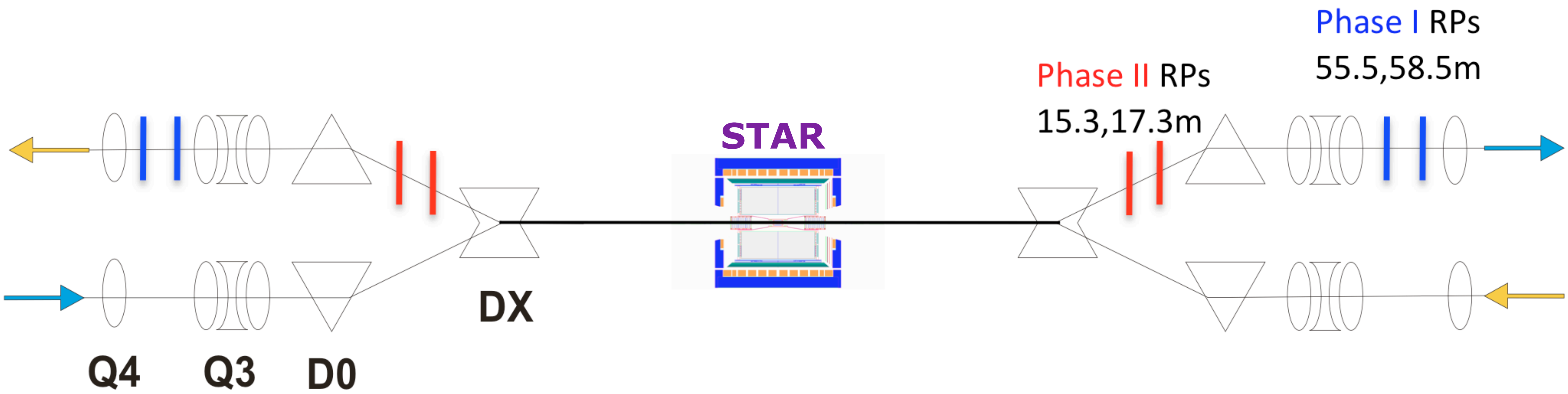
- Polarized elastic scattering for understanding structure of Pomeron (and Odderon)



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

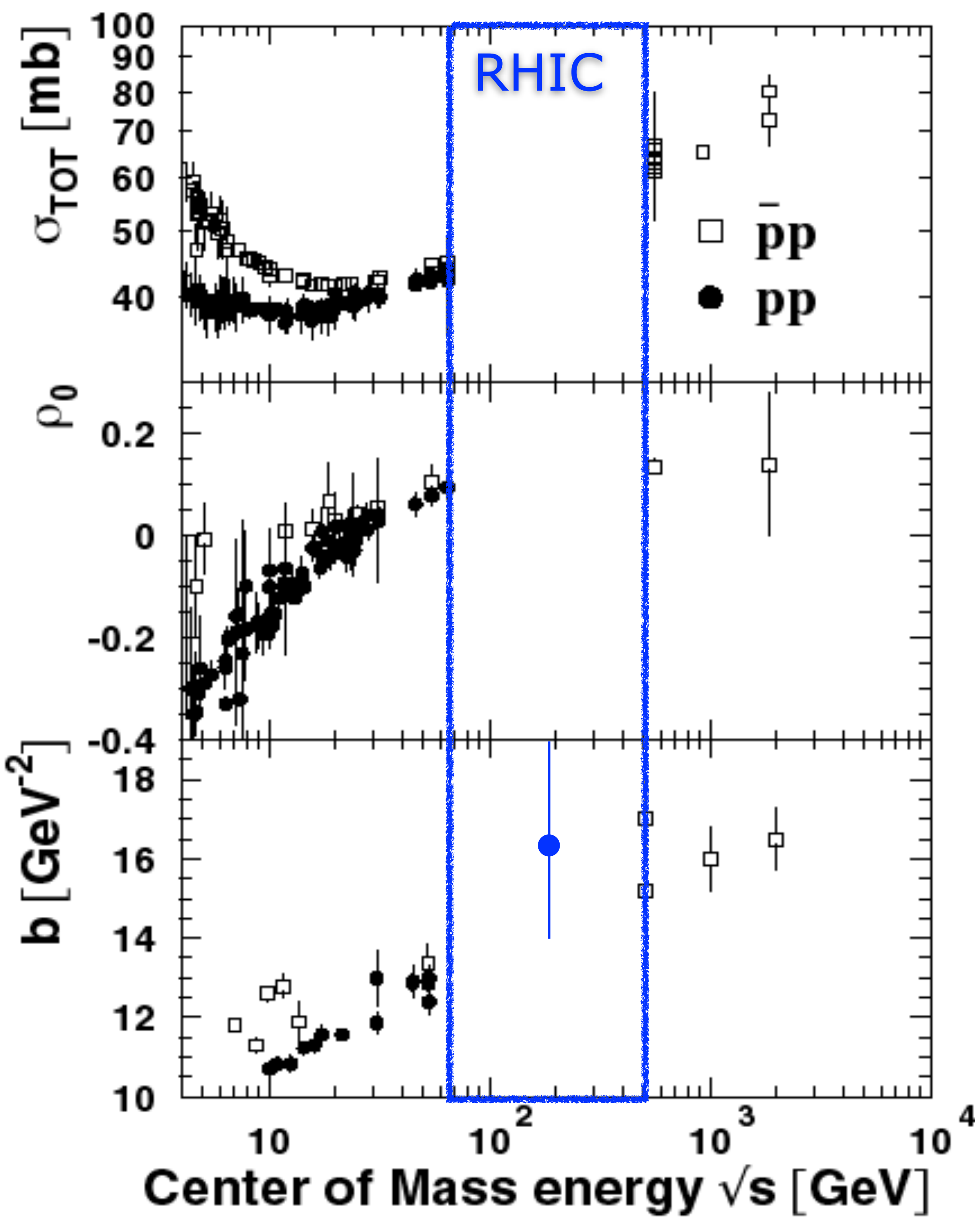


Forward Proton Tagging



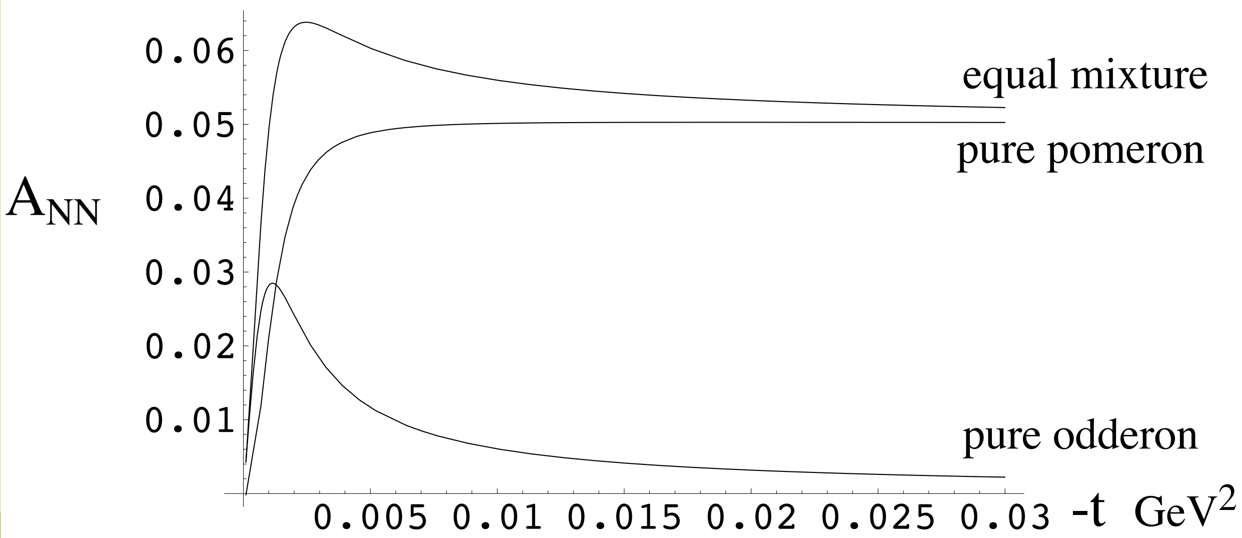
- Roman Pot (RP) detectors to measure forward scattered protons in diffractive processes
  - Staged implementation to cover wide kinematic coverage
    - Phase I (Installed): for low-t coverage
    - Phase II (planned) : for higher-t coverage

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 $\leq \sqrt{s} \leq$ 500 GeV
- Elastic measurements: Details on the nature of elastic scattering at high energy (Pomeron) are NOT well understood: Unique measurements in **wide *t*-range** with **polarized** beams

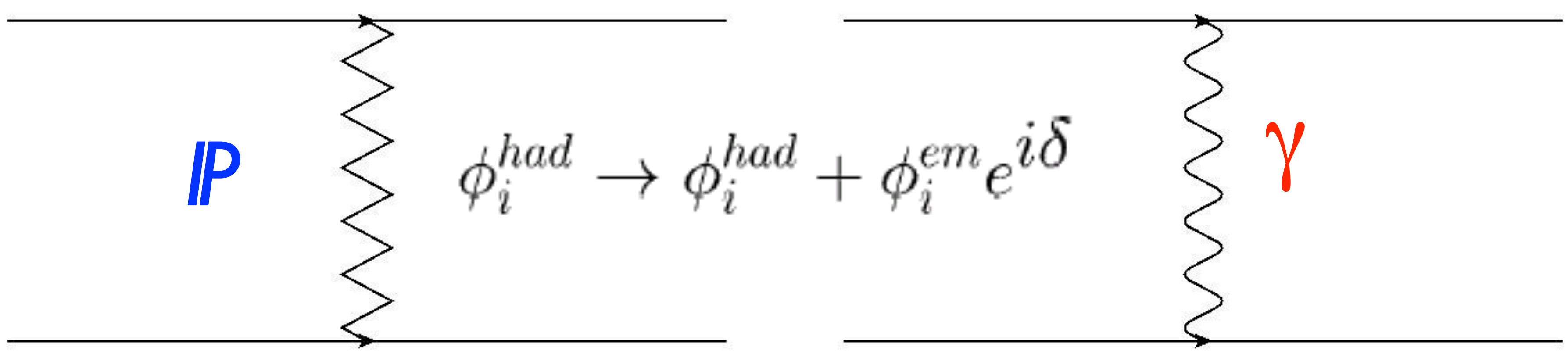
Can Odderon be identified at RHIC?



Leader, Trueman PRD 61 (2000), hep-ph/0604153

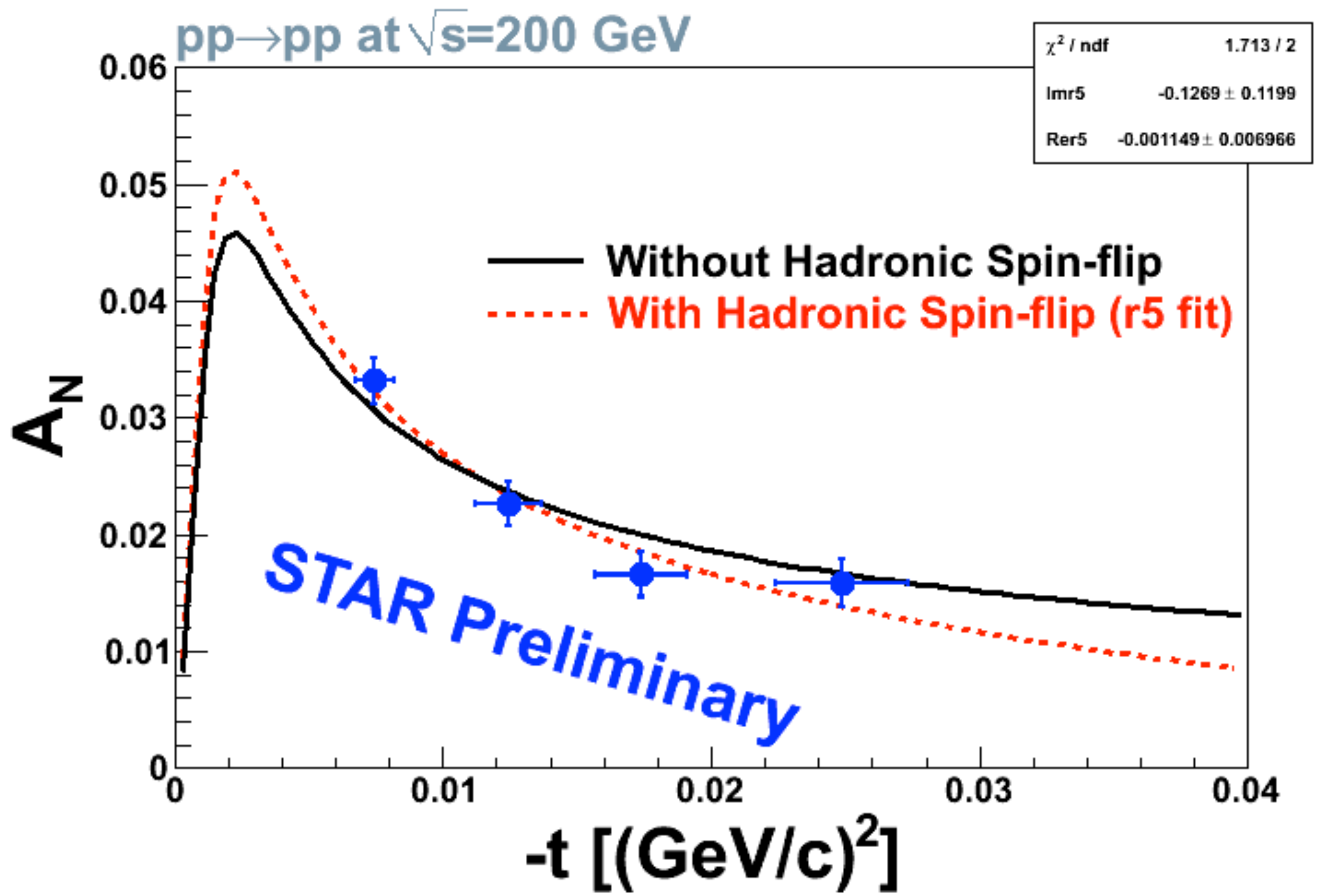
- Odderon is a counterpart of Pomeron (C=1) with C=-1 and not yet experimentally established: "RHIC is the machine to find it" (E. Leader, Odderon Workshop (2005)) by measuring
  - $\Delta\sigma_{pp} - \Delta\sigma_{pbarp} \neq 0$ (~3mb)
  - $d\sigma/dt_{pp} \neq d\sigma/dt_{pbarp}$
  - Shape of Asymmetries: A_{NN}
  - Centrally produced C=-1 particle

Probing the Spin-Structure of Pomeron: Single Spin Asymmetries (A_N) at the Coulomb-Nuclear Interference (CNI) Region



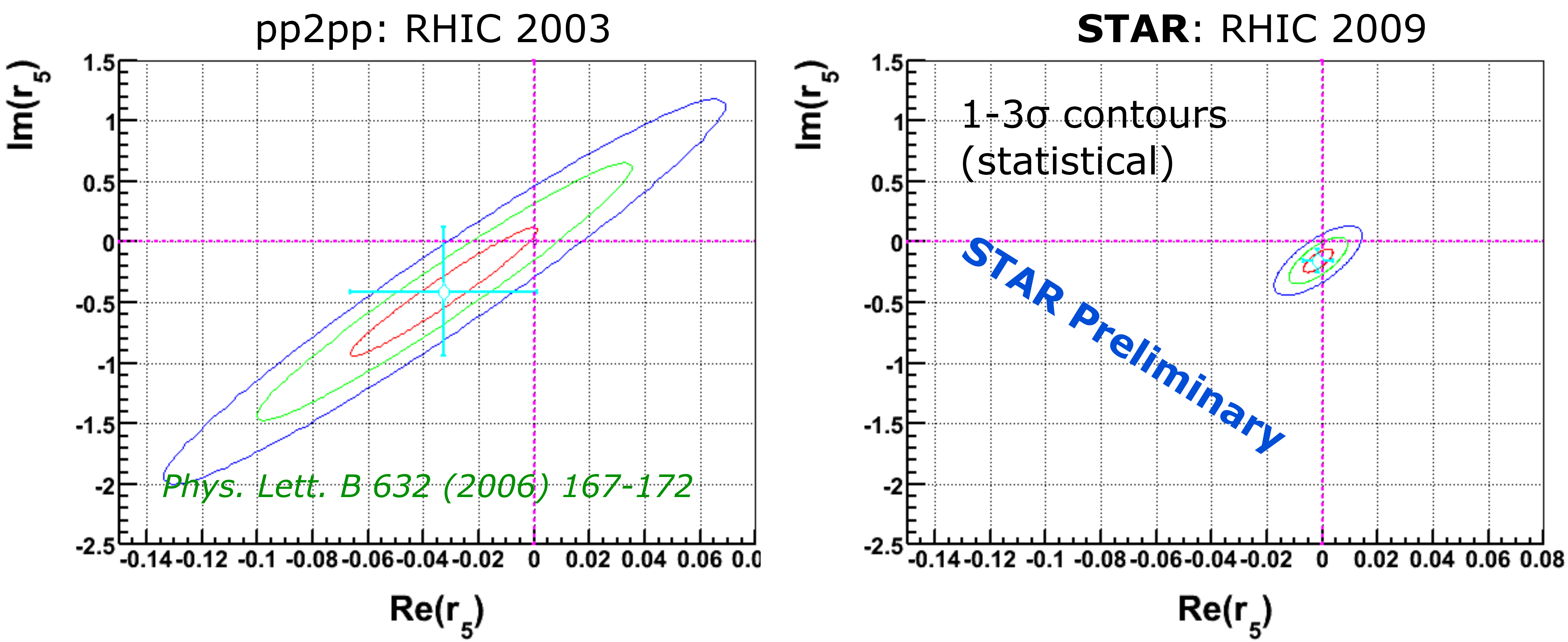
- Hadronic spin-flip (QCD) part can be measured as a modification of A_N from the CN interference (QED) at small-*t* region (Kopeliovich, Lapidus 1974)
- A_N data at CNI region available at lower energies (√s<20 GeV). At the RHIC energies, hadronic diffractive processes are expected to be dominated by the Pomeron

First high-statistics measurement of CNI at high-energy ($\sqrt{s}$=200 GeV)



- 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

Hadronic Spin-Flip amplitude



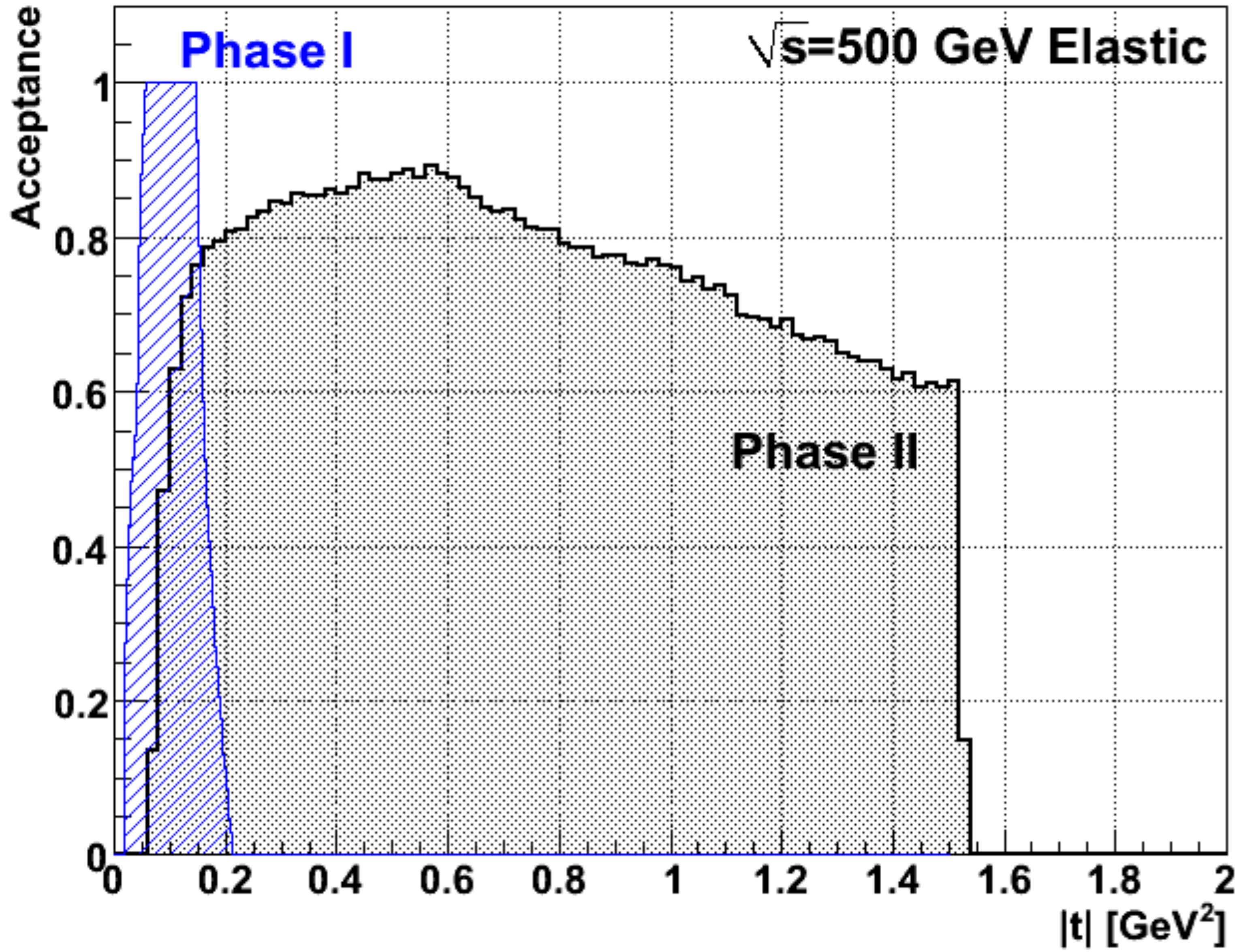
- Fit to the data with hadronic spin-flip (r_5-fit)

$$r_5 = \mathrm{Re}\, r_5 + i\, \mathrm{Im}\, r_5 = \frac{m\phi_5}{\sqrt{-t}\, \mathrm{Im}\, \phi_+}$$

relative amplitude between hadronic spin-flip (Φ_5) and non-flip (Φ_+) helicity amplitudes

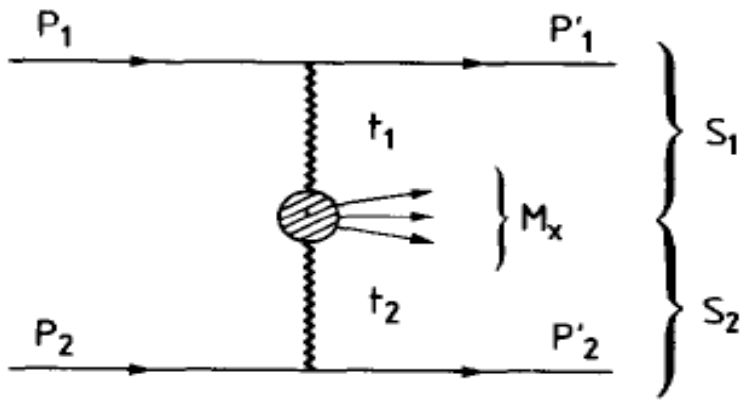
- No significant Hadronic spin-flip required in the fit

t-Acceptance of Roman Pots



- Phase I set-up focuses on low-*t* (installed)
- Phase II covers higher-*t* range (planned to be installed in 2013)

Inelastic Process: DPE $p_1p_2 \rightarrow p_1{'}M_Xp_2{'}$

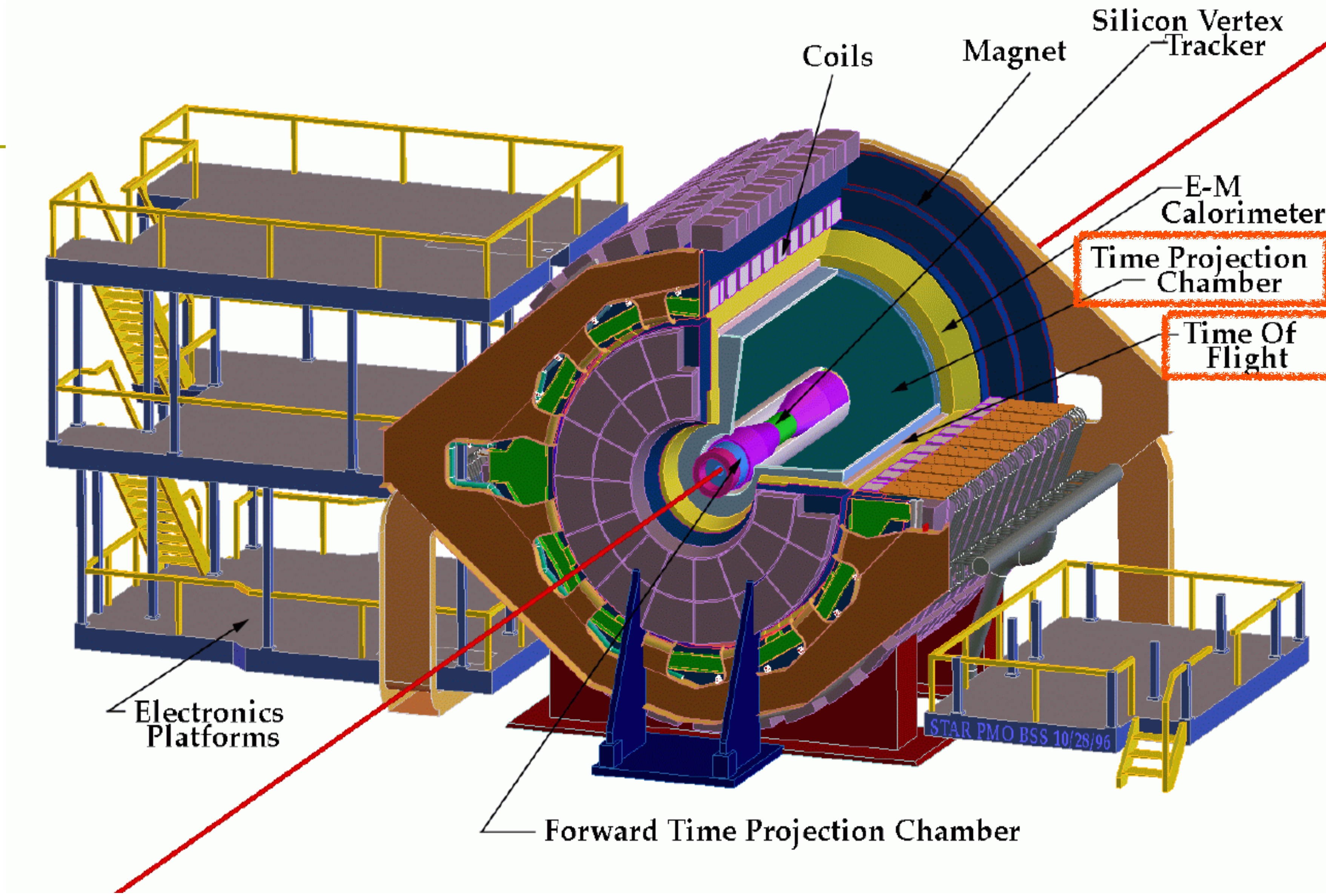


- Exclusive process with "small" momentum transfer: $-t_1(p_1 \rightarrow p_1{'})$ and $-t_2(p_2 \rightarrow p_2{'})$
- M_X is centrally (nearly at rest) produced via a Double Pomeron Exchange/Fusion
- In pQCD, Pomeron is considered to be made of two gluons: natural place to look for gluon bound state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

DPE Central Production at RHIC

- Pomeron ($\mathbb{P}$) dominant over Reggeon (R) exchanges
  - $\sigma_{RR} \sim s^{-2}$, $\sigma_{R\mathbb{P}} \sim s^{-1}$, $\sigma_{\mathbb{P}\mathbb{P}} \sim$ const. (or s^x where $x \sim \mathcal{O}(0.1)$)
- 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 and DPE filtering

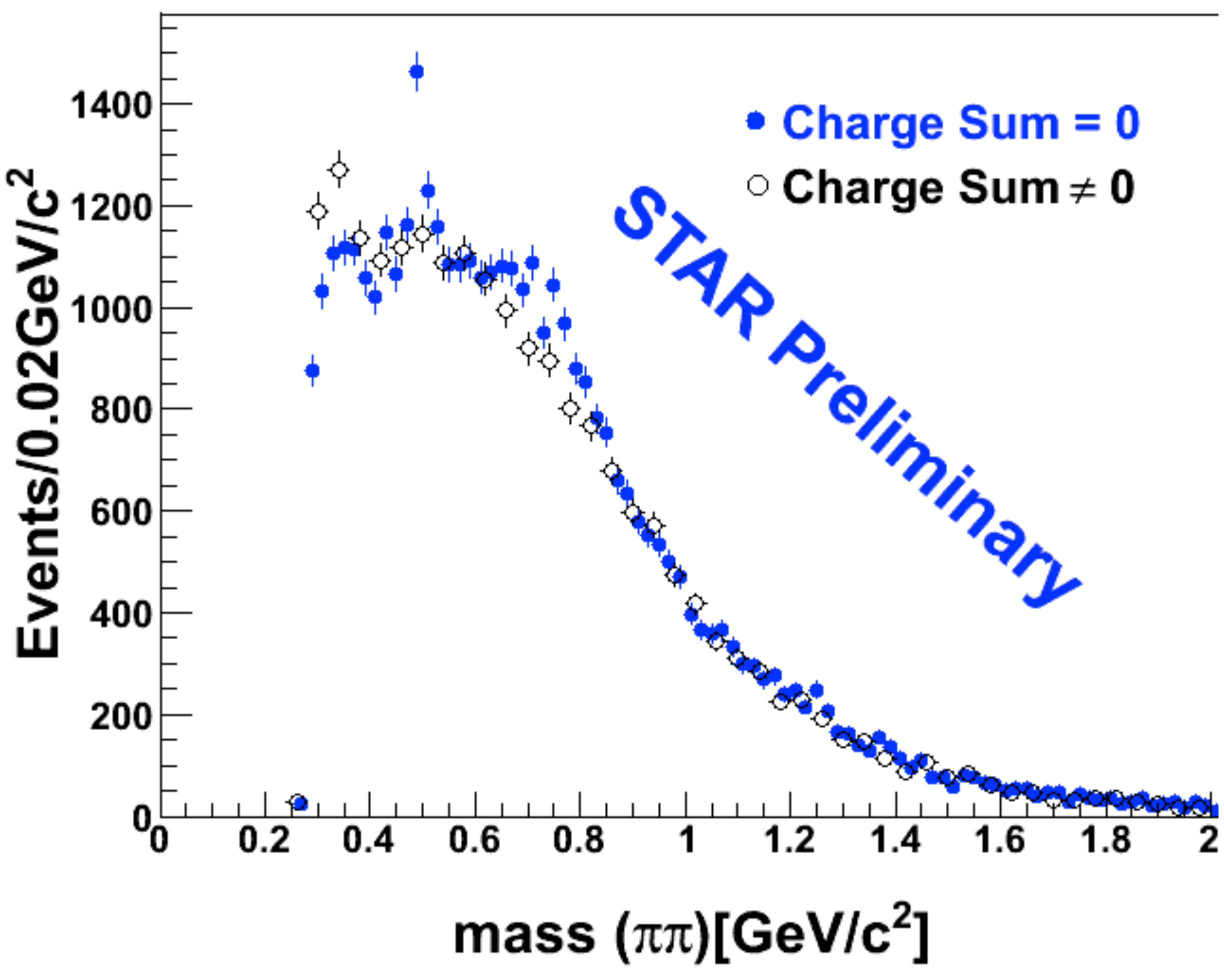
Reconstructing centrally produced system in the STAR detector

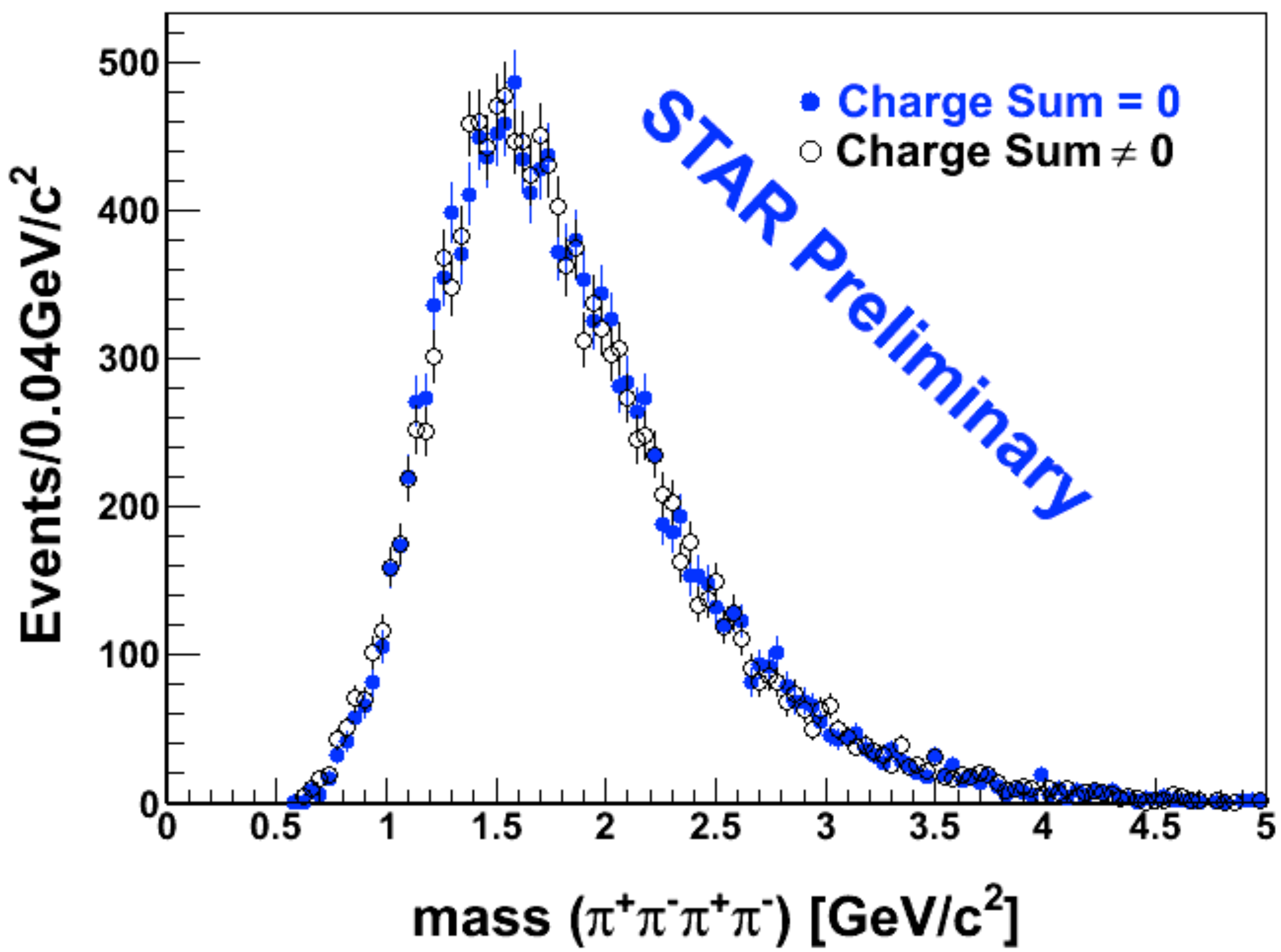


STAR: Large Acceptance Detector running since 2000

- 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

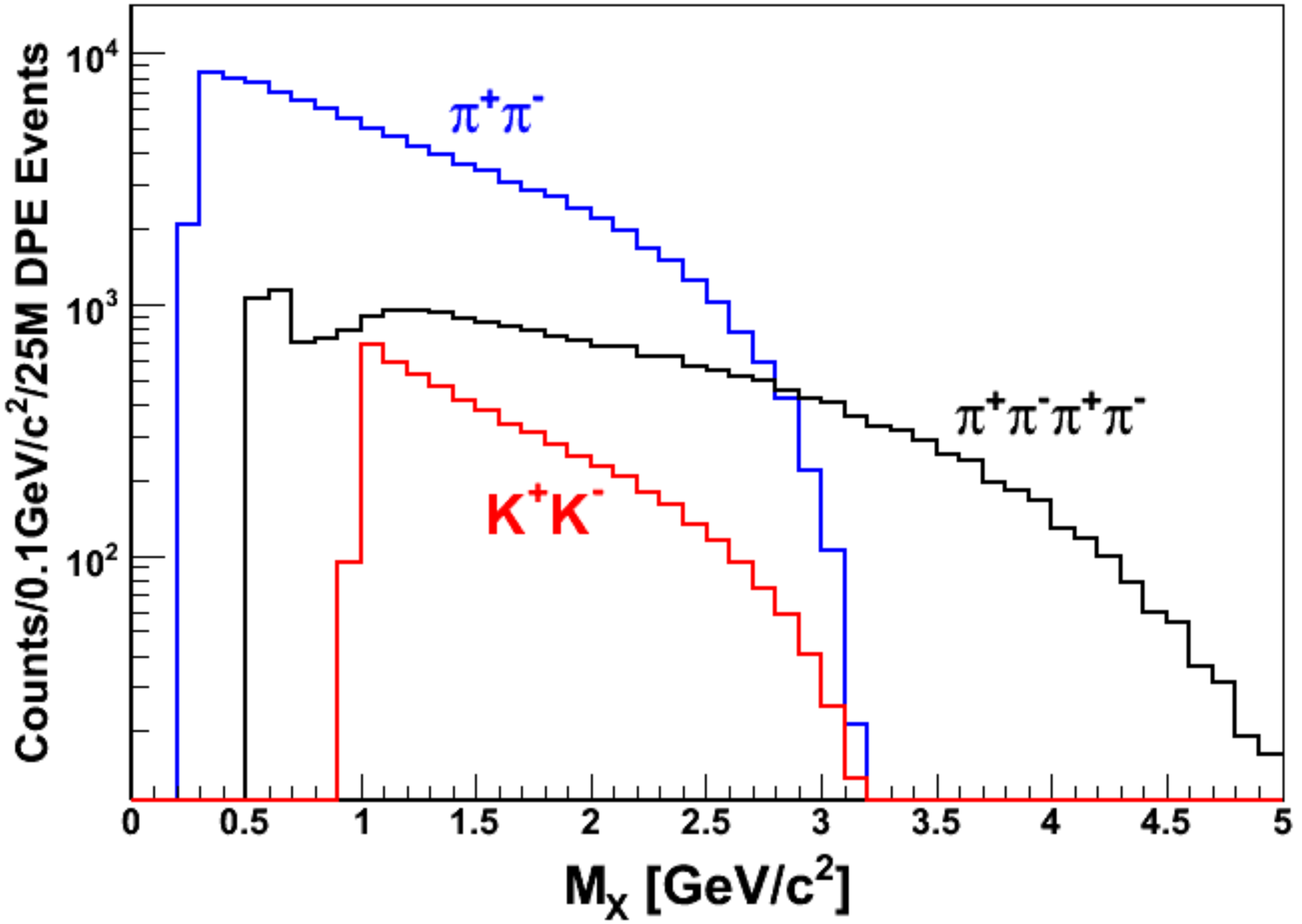
First Look at DPE data from Phase I set-up





- Taken with RP and ToF multiplicity triggers for the central process
- Track reconstruction in TPC
- 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…
- Main data taking will be with Phase II set-up at $\sqrt{s}$=500 GeV

Expected yields as function of M_X at $\sqrt{s}$=500 GeV



- **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 $\mathcal{L}$=1x10^{31}cm^{-2}s^{-1}
- 20 Week RHIC running: ~2M K^+K^- ~6M $\pi^+\pi^-\pi^+\pi^-$ sample

Summary

- New diffractive physics program with the STAR detector at RHIC to **study properties of the Pomeron and search for the Odderon and the Glueball**
  - At **high energies** where the Pomeron interaction is expected to be dominating
  - Using **large acceptance** and high resolution detector
  - With **polarized high luminosity** beam
- First high statistics data of spin asymmetries at CNI region and more to come
- Looking forward to rich diffractive and spectroscopy programs with staged Roman Pot implementation at STAR

Back-Up

Spin Dependence in Elastic Scattering

Five independent helicity amplitudes describe proton-proton elastic scattering

$$\phi_1(s,t) \propto \langle ++ | M | ++ \rangle \leftarrow \text{non-flip}$$
$$\phi_2(s,t) \propto \langle ++ | M | -- \rangle \leftarrow \text{double-flip}$$
$$\phi_3(s,t) \propto \langle +- | M | +- \rangle \leftarrow \text{non-flip}$$
$$\phi_4(s,t) \propto \langle +- | M | -+ \rangle \leftarrow \text{double-flip}$$
$$\boxed{\phi_5(s,t) \propto \langle ++ | M | +- \rangle \leftarrow \text{single-flip}}$$

$$\phi_i(s,t) = \phi_i^{em}(s,t) + \phi_i^{had}(s,t)$$
$$\phi_+ = \tfrac{1}{2}(\phi_1 + \phi_3)$$
$$\phi_- = \tfrac{1}{2}(\phi_1 - \phi_3)$$
$$\phi_i^{had} = \phi_i^{R} + \phi_i^{Asympt.}$$

Some of the measured quantities are

$$\sigma_{tot}(s) = \frac{4\pi}{s} \mathrm{Im}\left[\phi_+(s,t)\right]_{t=0}$$

$\sigma_{\mathbf{tot}}$ of gives ***s*** dependence of ϕ_+

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

Contributes to the shape of $A_{\mathbf{N}}$

Experimental Determination of A_N

Use *Square-Root-Formula* to calculate

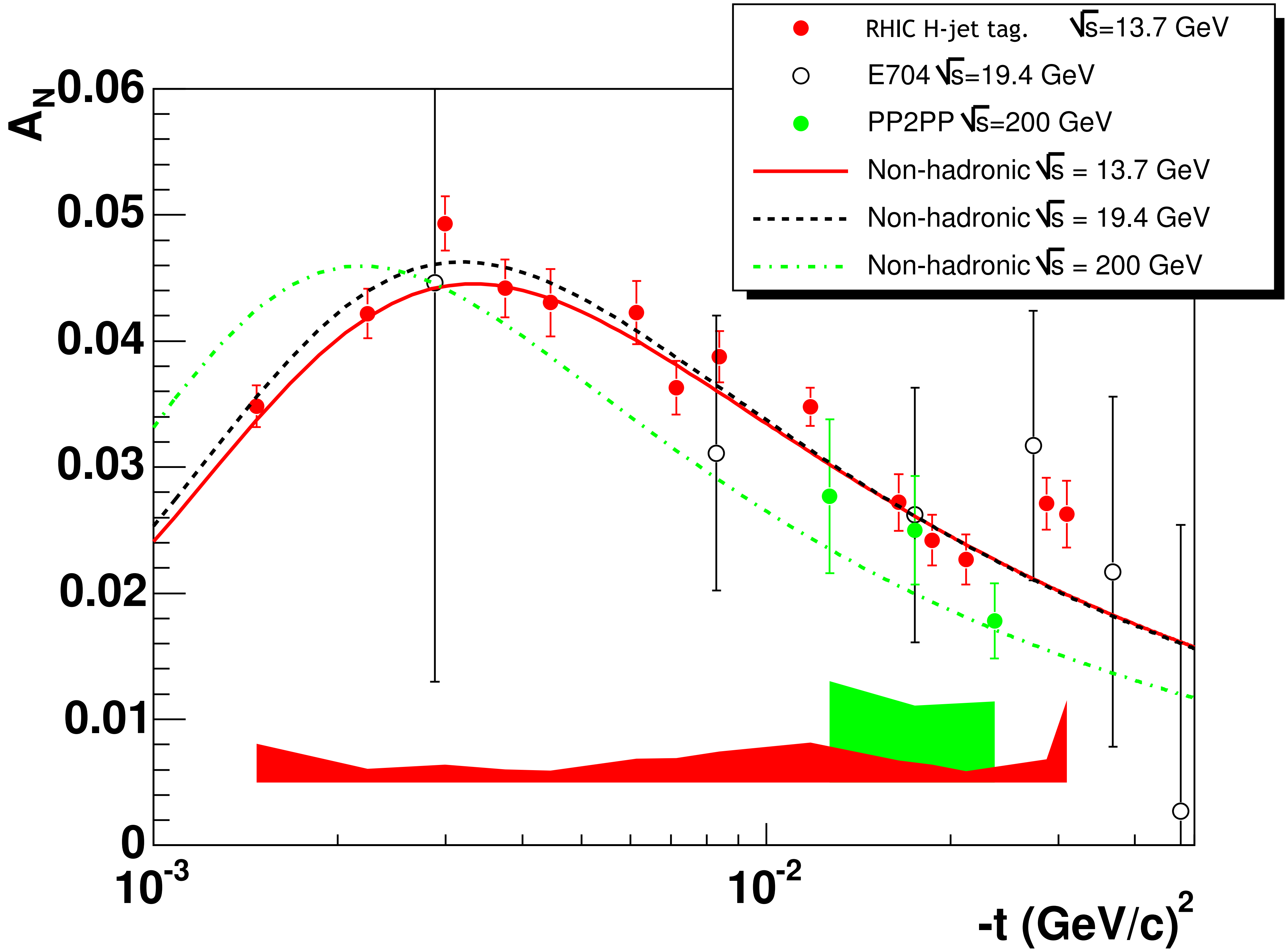
spin (↑↑, ↓↓) and false asymmetries (↑↓, ↓↑)

$$A_N(\varphi) = \frac{1}{(P_1 + P_2)\cos\varphi} \frac{\sqrt{N_L^{\uparrow\uparrow} N_R^{\downarrow\downarrow}} - \sqrt{N_R^{\uparrow\uparrow} N_L^{\downarrow\downarrow}}}{\sqrt{N_L^{\uparrow\uparrow} N_R^{\downarrow\downarrow}} + \sqrt{N_R^{\uparrow\uparrow} N_L^{\downarrow\downarrow}}}$$

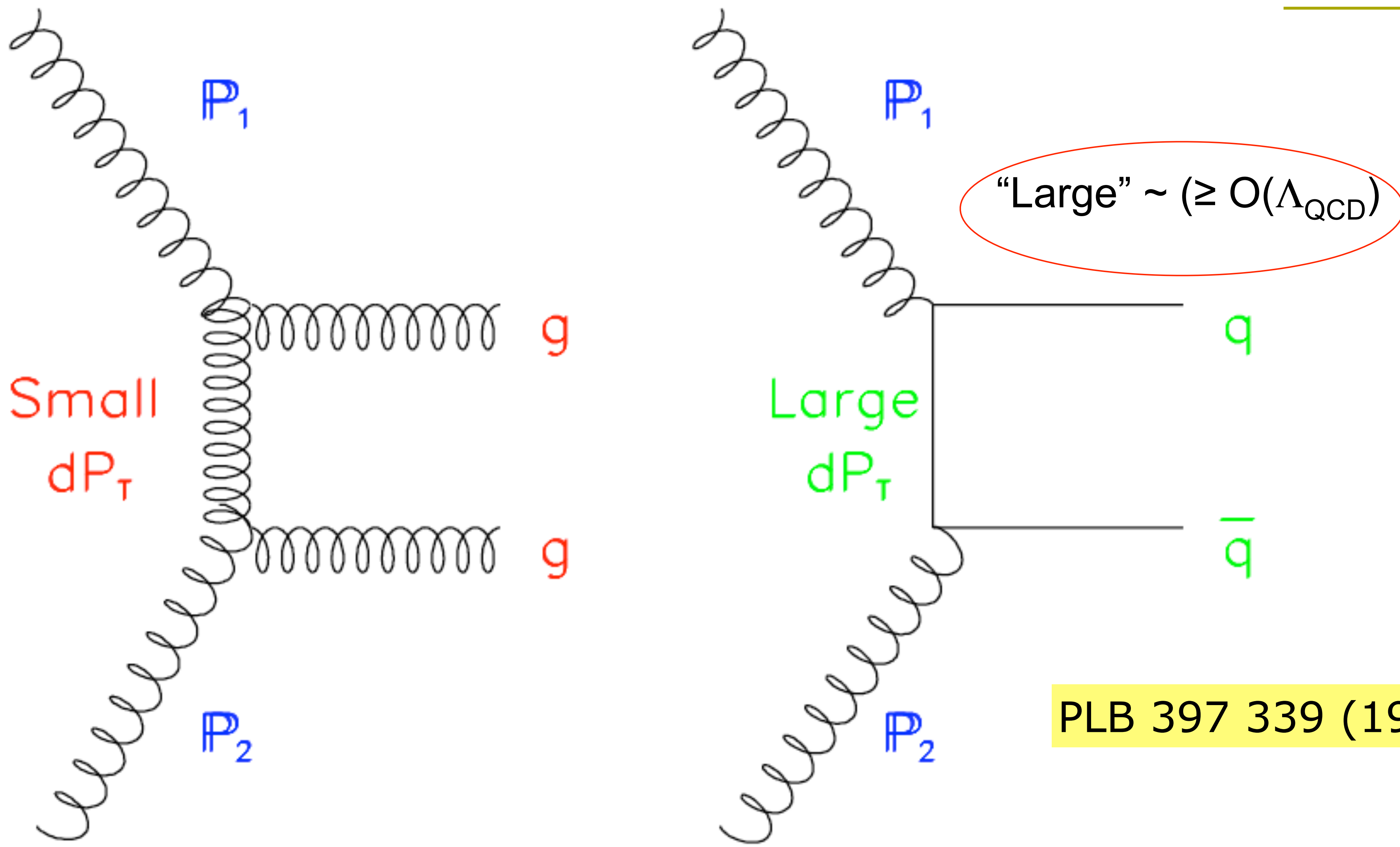
$$A_N^F(\varphi) = \frac{1}{(P_1 + P_2)\cos\varphi} \frac{\sqrt{N_L^{\uparrow\downarrow} N_R^{\downarrow\uparrow}} - \sqrt{N_R^{\uparrow\downarrow} N_L^{\downarrow\uparrow}}}{\sqrt{N_L^{\uparrow\downarrow} N_R^{\downarrow\uparrow}} + \sqrt{N_R^{\uparrow\downarrow} N_L^{\downarrow\uparrow}}}$$

Since A_N is a relative measurement the efficiencies $\varepsilon(t, \phi)$ cancel

Measurements of A_N as a function of $\sqrt{s}$ and t



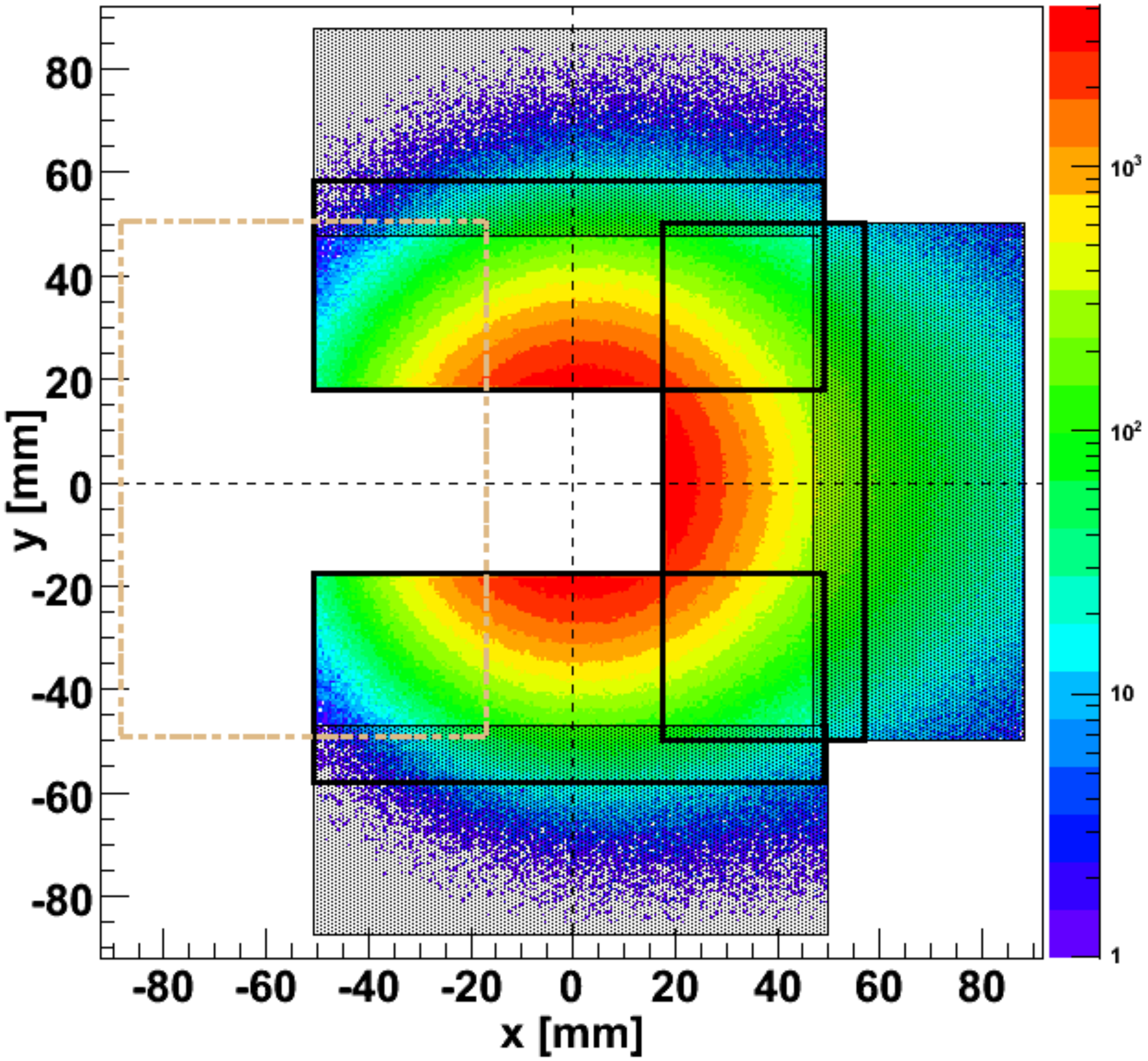
Kinematic "filter" (dp_T) for "gg" (F. Close et al./W102)



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

Roman Pots (Phase II)



- Phase II: 8(12) Roman Pots at ±15 and ±17m
- Planed to be implemented in ~2013
- 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)

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

342 WA102 Collaboration / Physics Letters B 397 (1997) 339–344

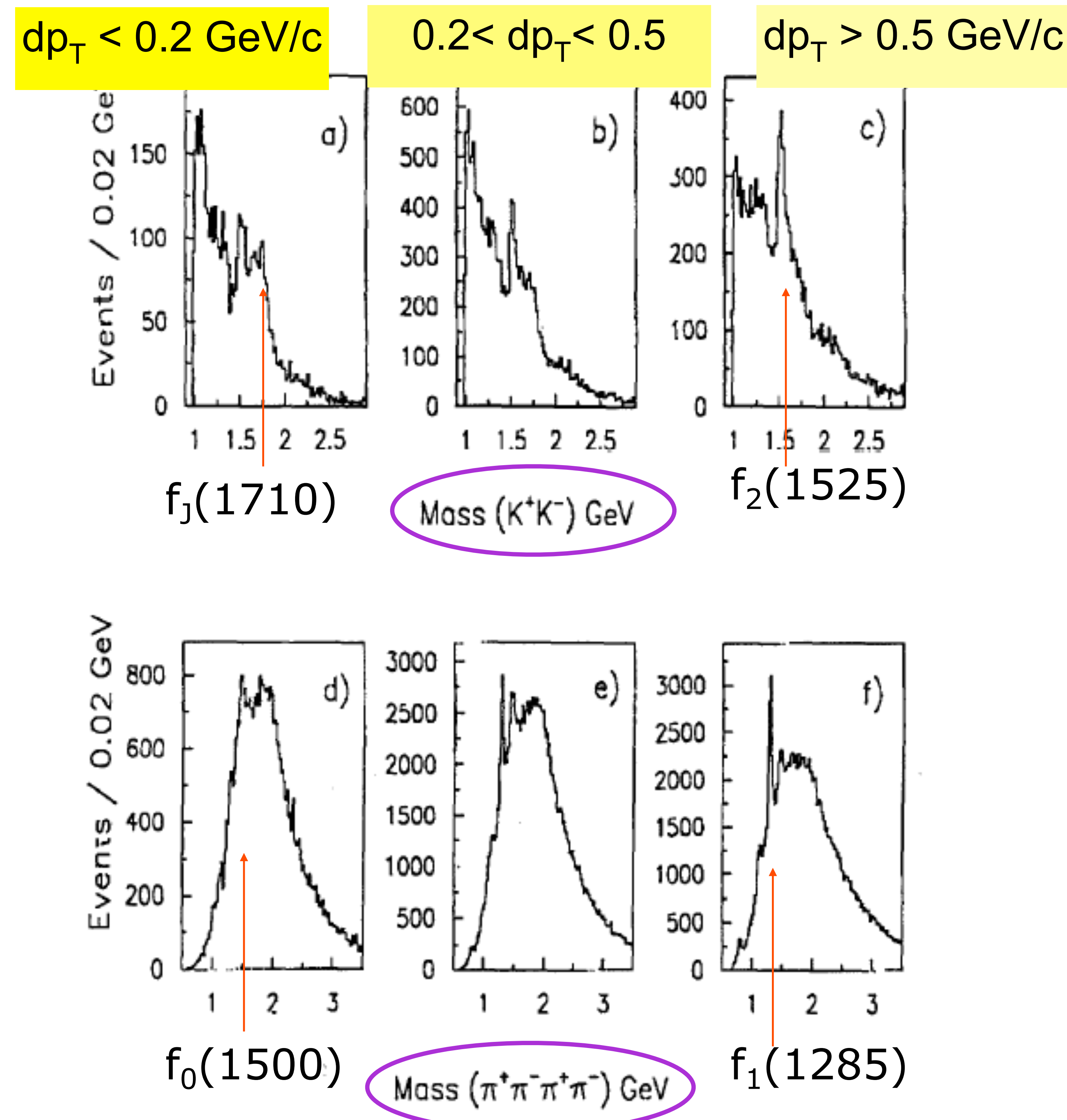
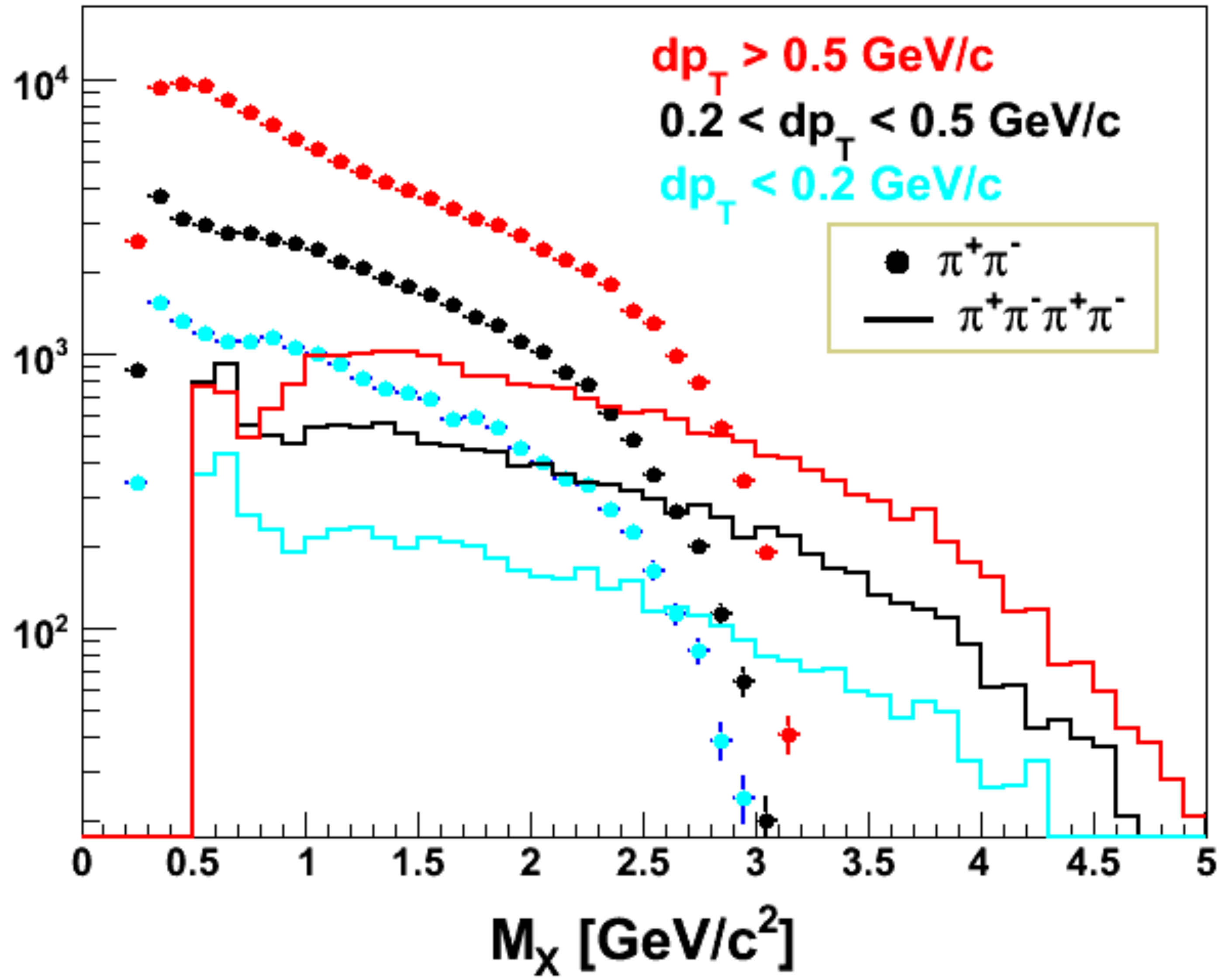


Fig. 3. K^+K^- mass spectrum for a) $dP_T < 0.2$ GeV, b) $0.2 < dP_T < 0.5$ GeV and c) $dP_T > 0.5$ GeV and the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum for d) $dP_T < 0.2$ GeV, e) $0.2 < dP_T < 0.5$ GeV and f) $dP_T > 0.5$ GeV.

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

dp_T-dependent accepted yield (Simulation for Phase II)



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