A Program of Hadron Spectroscopy with STAR

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http://www.phy.bnl.gov/~e852/reviews.html

Plan of Talk

- Introduction:
  A brief overview of exotic mesons($J^{PC} = 1^{-+}$)
- Current Status of the Photon-Pomeron Fusion Process
  $\mathrm{Au} + \mathrm{Au} \to \mathrm{Au}^{(*)} + \mathrm{Au}^{(*)} + \rho^0, \quad \rho^0 \to \pi^+\pi^-$
  "4-prong" trigger $X(J^{PC} = 0^{+-},\ 2^{+-}) \to \pi^+\pi^-\pi^+\pi^-$
  Future Plans
- Roman Pots for Double-Pomeron Fusion Process
  $p + p \to p + p + X, \quad X(J^{PC} = 1^{-+},\ 3^{-+}) \to \pi^+\pi^-\pi^+\pi^-$
  A Preliminary Conceptual Design
- Conclusions and Future Prospects

Definition: Exotic Mesons

- Conventional $q\bar{q}$ mesons
  $\vec{J} = \vec{L} + \vec{S}$, $P = (-)^{L+1}$, $C = (-)^{L+S}$;
  Forbidden J^{PC}=0^{--}, 0^{+-},1^{-+}, 2^{+-}, 3^{-+}, etc.

- Exotic mesons:
  $n\bar{n} + g$, $n = \{u, d\}$, mass ~ 1.9 GeV with $J^{PC} = 1^{-+}$ as the lightest meson
  $n\bar{n} + n\bar{n}$; 4-quark exotics

- Notation for Exotic Mesons: The key determinant is $\{PC\}$, e.g.

$I^G(J^{PC})$	$1^-(0^{-+})$	$0^+(0^{-+})$	$1^-(1^{-+})$	$0^+(1^{-+})$
Name	π	η	$\pi_1(1400)$	$\eta_1(1400?)$

$I^G(J^{PC})$	$1^+(1^{+-})$	$0^-(1^{+-})$	$1^+(2^{+-})$	$0^-(2^{+-})$
Name	$b_1(1235)$	$h_1(1170)$	$b_2(1900?)$	$h_2(1900?)$

Exotic Meson (BNL E-852):

Reaction: $\pi^- p \to \eta\pi^- p$ at 18 GeV/c, $\eta \to \gamma\gamma$, $\sigma(\eta \to \gamma\gamma) \sim 30$ MeV

$\sim 47\,200$ events

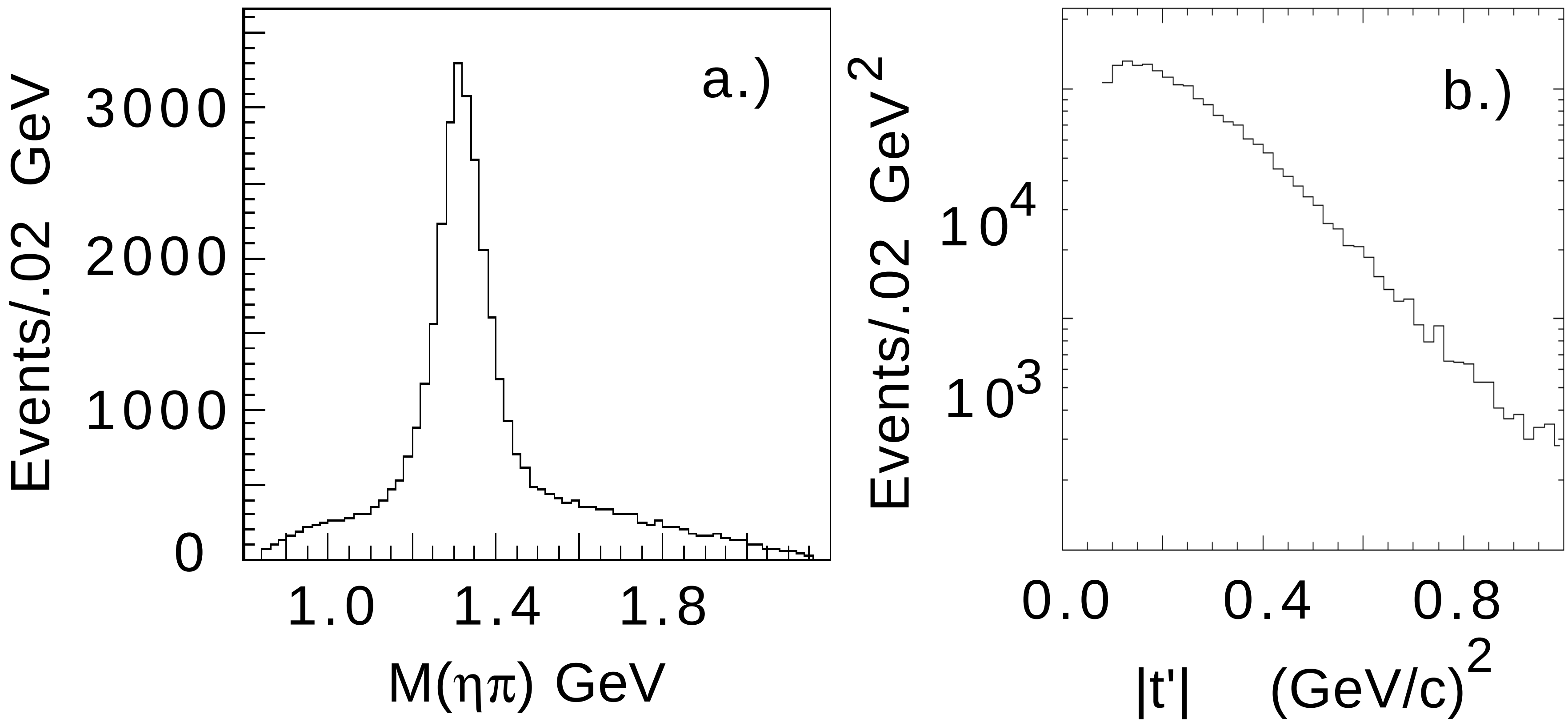


Figure 1

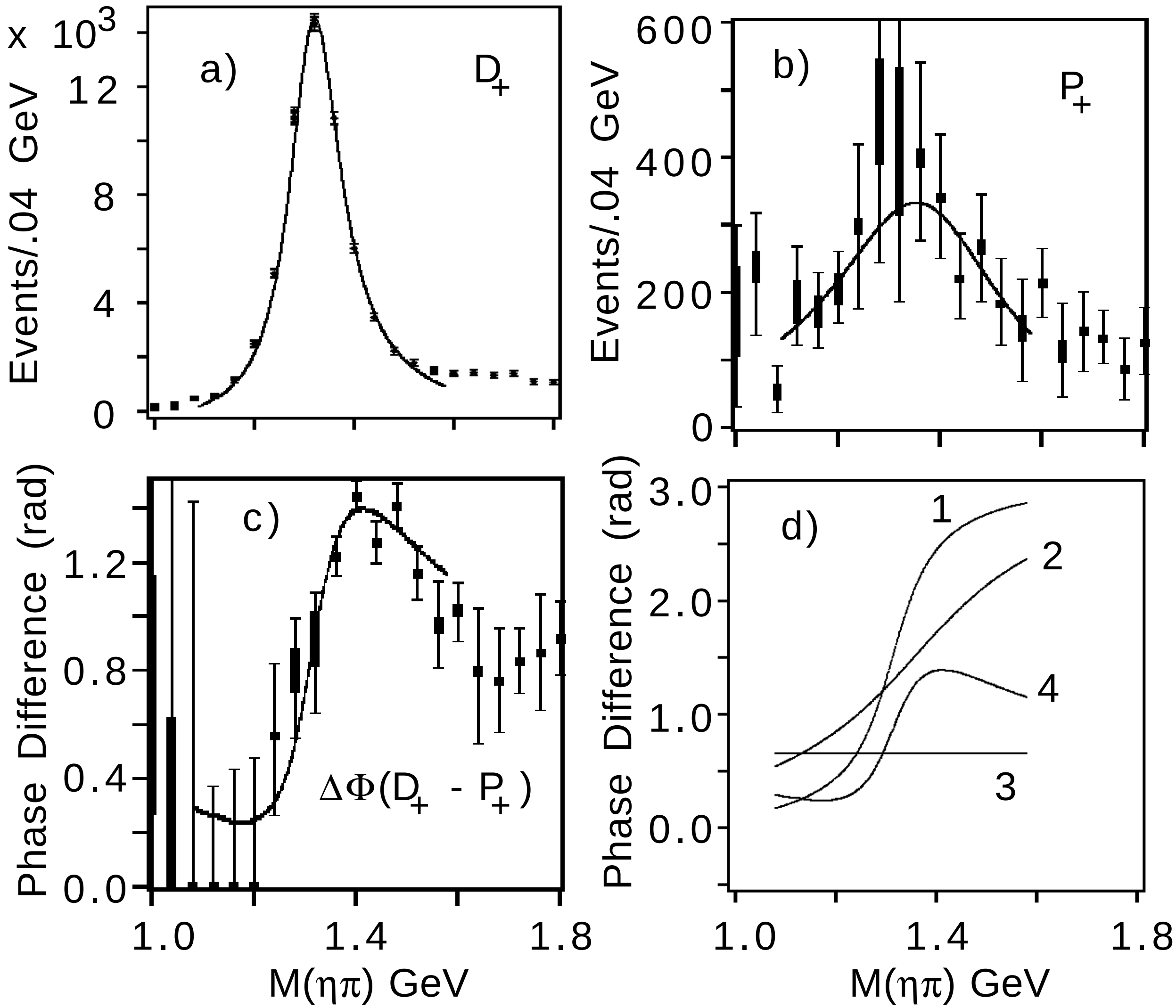
Exotic Meson (BNL E-852): $\pi_1^-(1400) \to \eta\pi^-$

Reaction: $\pi^- p \to \eta\pi^- p$ at 18 GeV/c, $\eta \to \gamma\gamma$

$\sim 47\,200$ events

$1^{-+}1^+\, \eta \left[{P \atop 0}\right] \pi \to P_+$

$2^{++}1^+\, \eta \left[{D \atop 0}\right] \pi \to D_+$



$$\begin{cases} M(P_+) = 1370 \pm 16\, {}^{+50}_{-30} \\ \Gamma(P_+) = 385 \pm 40\, {}^{+\ 65}_{-105} \end{cases}$$

PRL 79, 1630 (1997)

PRD 60, 092001 (1999)

Figure 3

Exotic Meson (BNL E-852): $\pi_1^-(1600) \to \rho^0(770)\pi^-$, $\rho^0(770) \to \pi^+\pi^-$

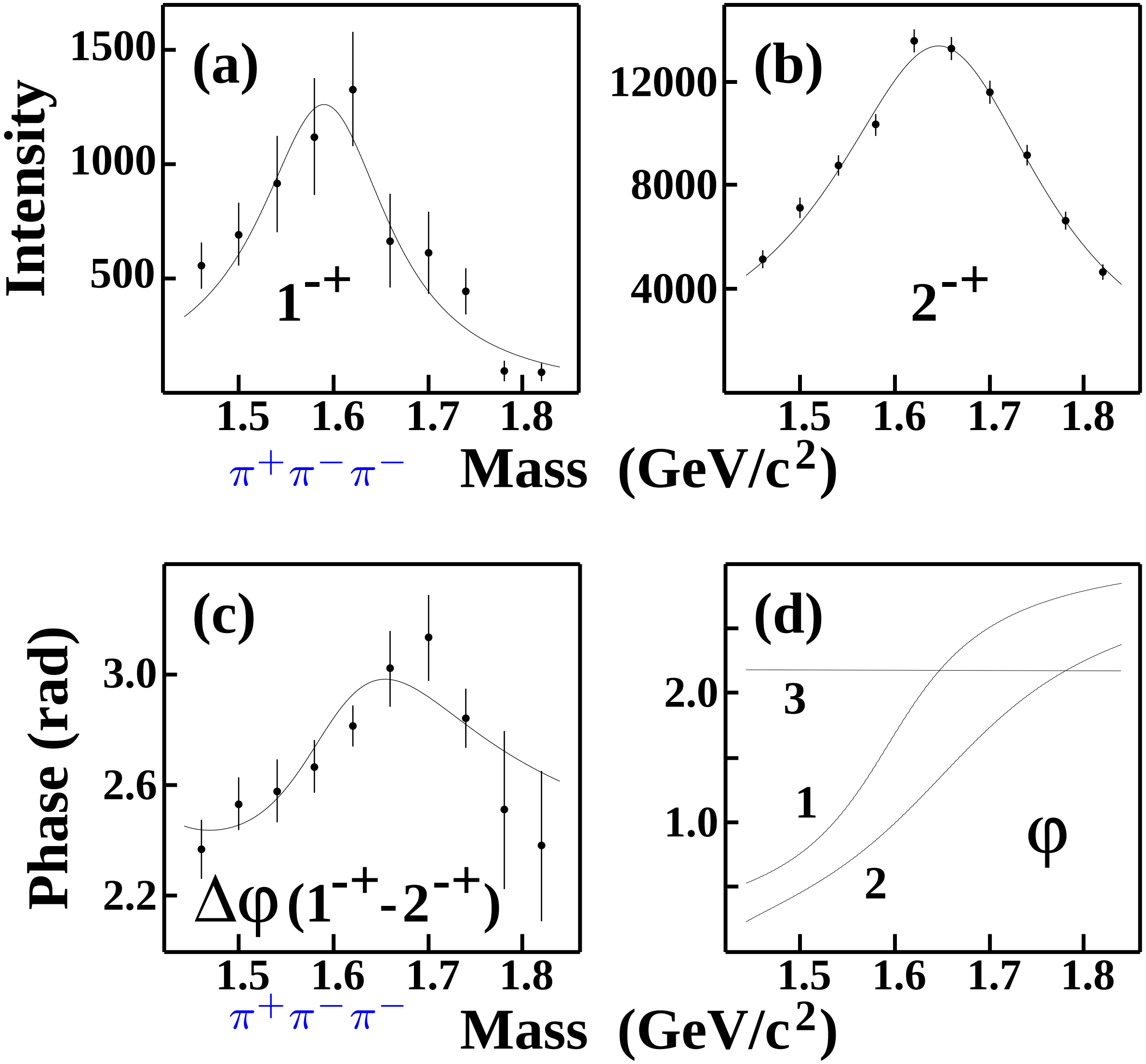
Reaction: $\pi^- p \to \pi^+\pi^-\pi^- p$ at 18 GeV/c

$\sim$ 250 000 events

Partial waves: $1^{-+}1^+\rho(770)[P]\pi$, $2^{-+}0^+ f_2(1270)[S]\pi$

$1^{-+}1^+\ \rho\left[{P \atop 1}\right]\pi$

$2^{++}0^+\ f_2\left[{S \atop 2}\right]\pi$



$$\begin{cases} M = 1593 \pm 8 \, {+\ 29 \atop -\ 47} \\ \Gamma = 168 \pm 20 \, {+150 \atop -\ 12} \end{cases}$$

PRL 81, 5760 (1998)

PRD 65, 072001 (2002)

Exotic Mesons

Three Exotic Mesons from **BNL-E852**: $I^G(J^{PC}) = 1^-(1^{-+})$

1. $\pi_1(1400)$: $M \sim 1370$ MeV, $\Gamma \sim 400$ MeV

   $\rightarrow \eta\pi$

   $\not\rightarrow \eta'\pi,\ \rho\pi?,\ f_1(1285)\pi,\ b_1(1235)\pi$

   $\Rightarrow$ If $10 \oplus \overline{10}$, then predict no $\eta_1(1400)$ partner but $\rho(1400)$

   S. U. Chung, E. Klempt and J. G. Körner, Eur. Phys. J. A 15, 539 (2002)

2. $\pi_1(1600)$: $M \sim 1590$ MeV, $\Gamma \sim 300$ MeV

   $\not\rightarrow \eta\pi$

   $\rightarrow \eta'\pi,\ \rho\pi,\ f_1(1285)\pi,\ b_1(1235)\pi$

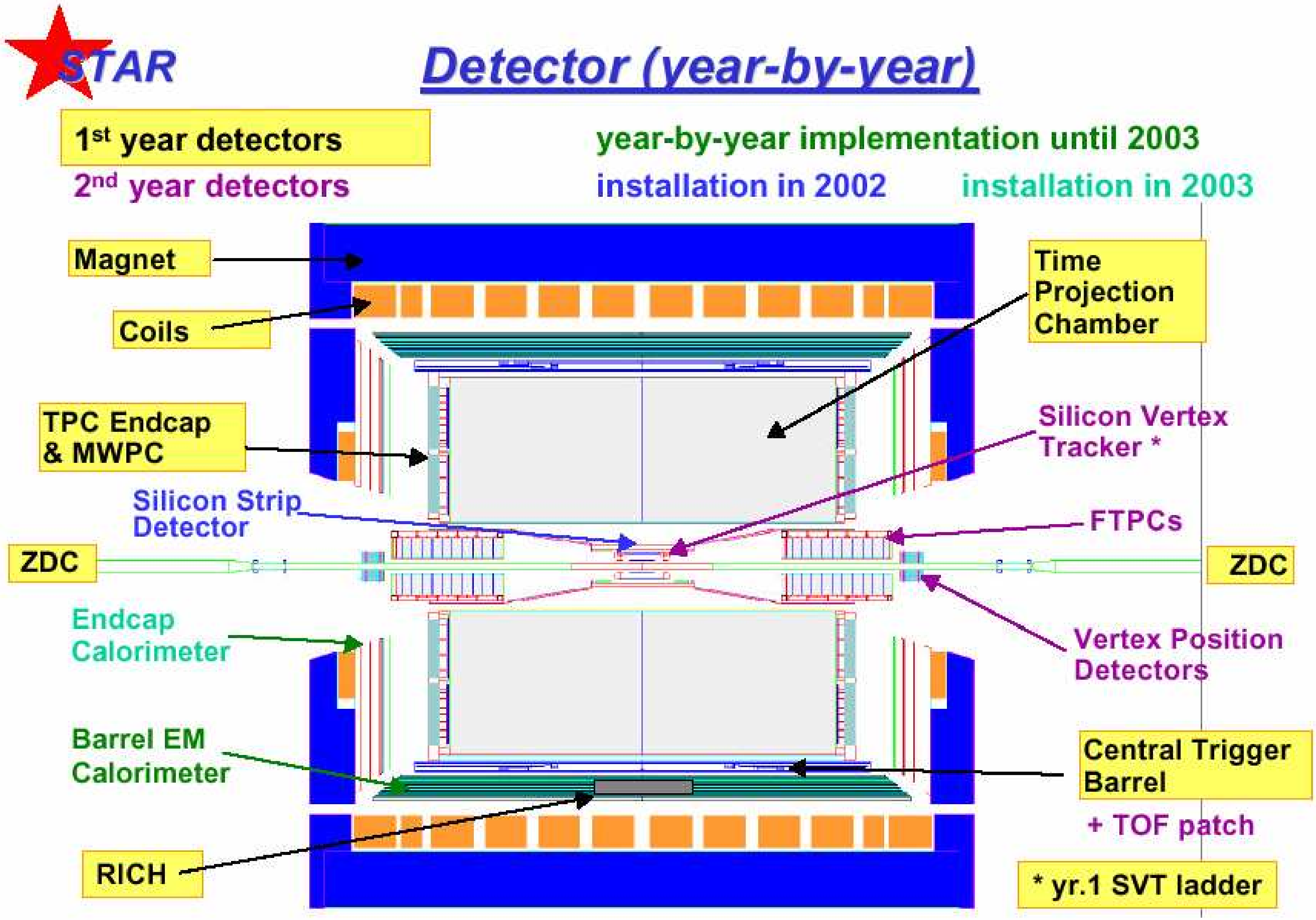
   PRL 86, 3977 (2001)
   hep-ex/0401004
   hep-ex/0405044

3. $\pi_1(2000)$: $M \sim 2000$ MeV, $\Gamma \sim 300$ MeV (Preliminary)

   $\rightarrow f_1(1285)\pi,\ b_1(1235)\pi$ (Preliminary)

   hep-ex/0401004
   hep-ex/0405044

STAR Detector



Some References of Interest

"RHIC and its Detectors," Nucl. Instr. and Meth. A 499, 235 (2003)

A partial list of recent work by the STAR Working Group on ultra-peripheral collisions (the UPC group):

- "Coherent ρ^0 Production in Ultra-Peripheral Heavy-Ion Collisions,"
  nucl-ex/0206004 (2002)
  PRL 89, 272302 (2002)
- "Coherent Vector Meson Production in Ultra-Peripheral Heavy-Ion Collisions at STAR,"
  nucl-ex/0210028 (2002)
- "Quantum Interferometry in ρ^0 Production in Ultra-Peripheral Heavy Ion Collisions,"
  nucl-ex/0402007 (2004)
- "Production e^+e^- Pairs Accompanied by Nuclear Dissociation in Ultra-Peripheral Heavy Ion Collisions,"
  nucl-ex/0404012 (2004)

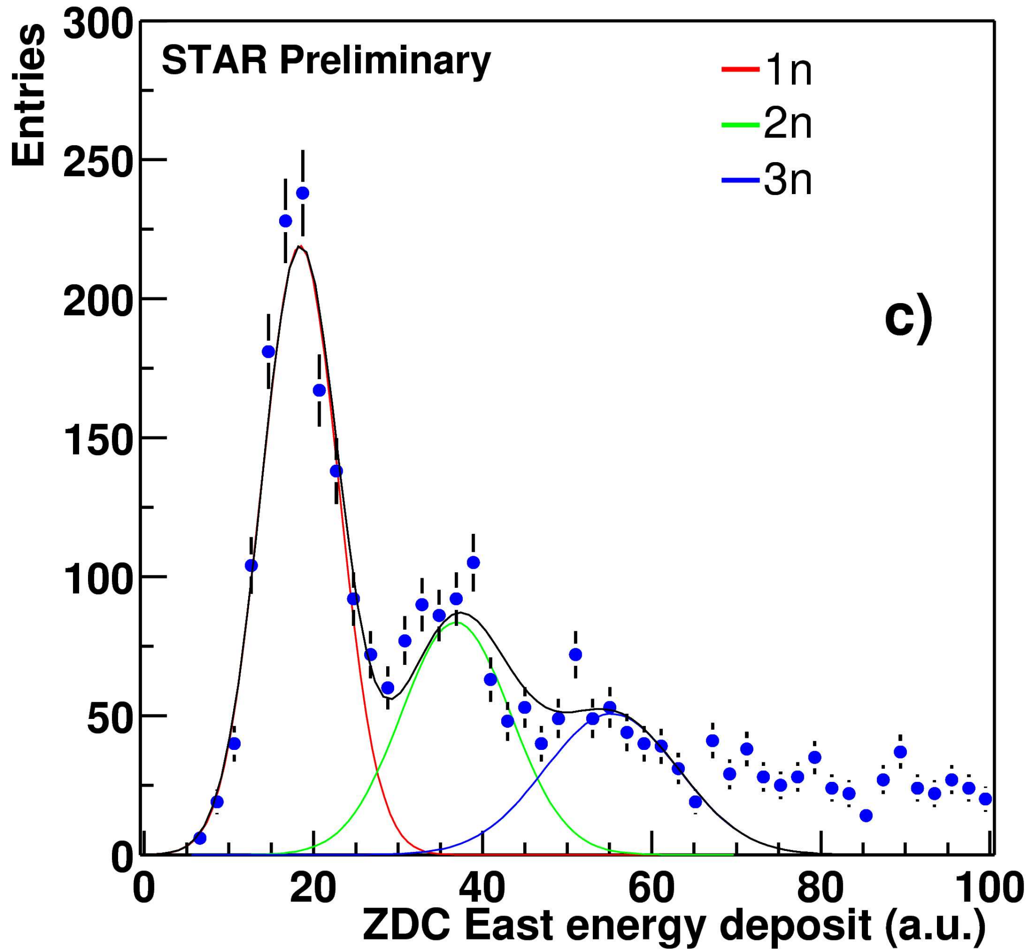
All the figures shown from the STAR data
have been lifted from the preprints cited above.

The RHIC zero-degree Calorimeters (ZDCs)

Nucl. Instr. and Meth. A **470**, 488 (2001)

Two calorimeters for each intersection point,
18 m away from the point,
to detect neutrons emitted
in the beam direction.

Each ZDC: $10\,\text{cm} \times 13.5\,\text{cm}$
Tungsten plates+Optical fibers

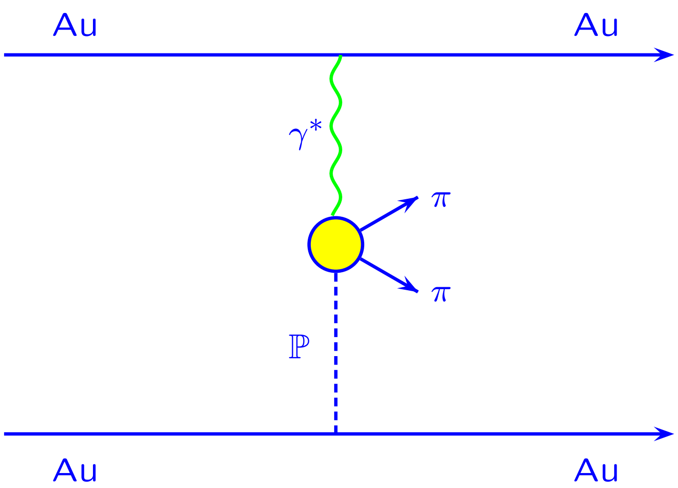


Photon+Pomeron→ ρ^0

Pioneering Work by S. Klein, *et al.* (UPC group): RHIC run in 2000 at $\sqrt{s_{NN}} = 130$ GeV

Central Trigger Barrel (CTB) in quadrants

2-prong trigger⟹30 000 events



$$\mathrm{Au} + \mathrm{Au} \to \mathrm{Au} + \mathrm{Au} + \rho^0, \qquad \rho^0 \to \pi^+\pi^-$$

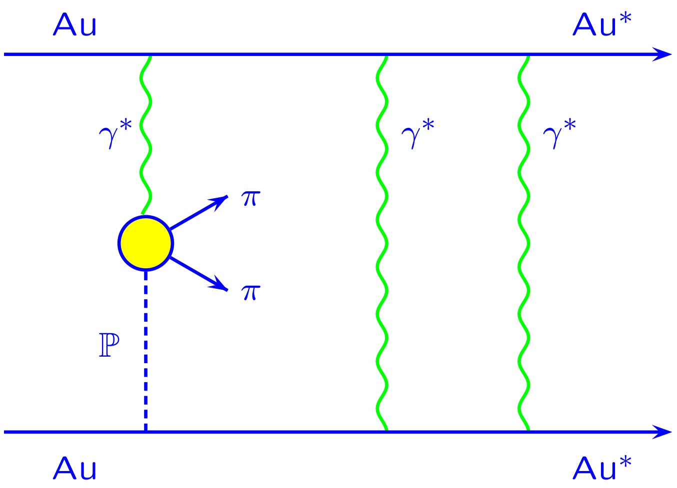
$\sigma = 370 \pm 170 \pm 80$ mb

S. Klein, *et al.* (UPC group):

Minimum-Bias Data at $\sqrt{s_{NN}} = 130$ GeV

Zero-degree Calorimeter (ZDC) in coincidence

800 000 events



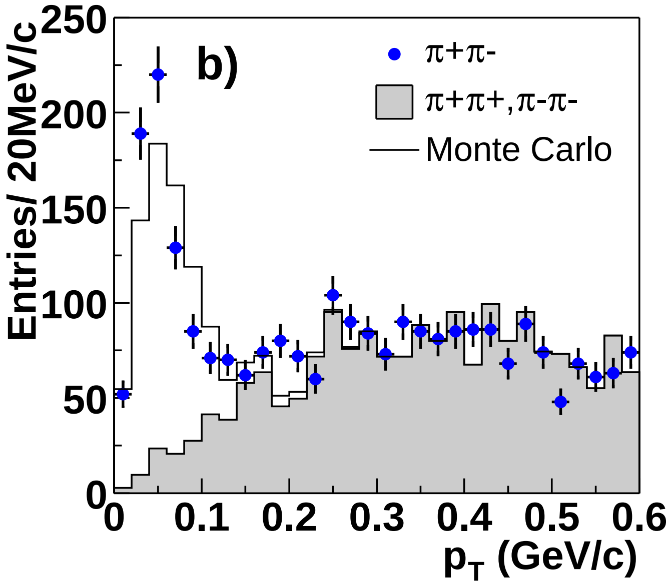
$$\mathrm{Au} + \mathrm{Au} \to \mathrm{Au}^* + \mathrm{Au}^* + \rho^0, \qquad \rho^0 \to \pi^+\pi^-$$

$\sigma = 39.7 \pm 2.8 \pm 9.7$ mb

PRL 89, 272302 (2002)

Photon+Pomeron$\rightarrow \rho^0$

S. Klein, *et al.* (UPC group):



ρ^0 candidates for $|y_\rho| < 1$

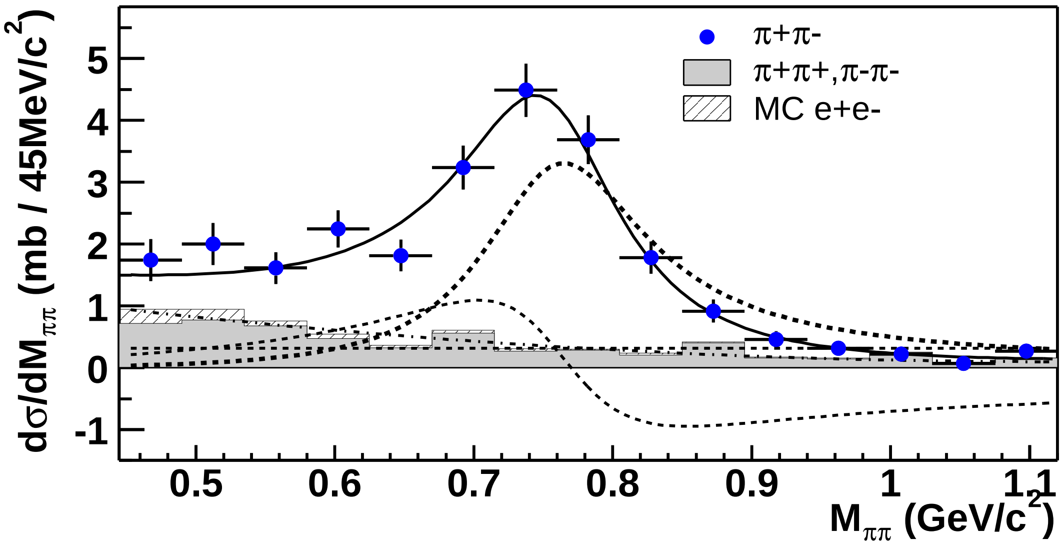
Minimum-Bias Data—(ZDC) Trigger

2-prong trigger similar—not shown

p_T peaked at 50 MeV/c

Like-sign background normalized for $p_T > 200$ MeV/c

MC p_T normalized to ρ^0 for $p_T < 150$ MeV/c



ρ^0 candidates for $|y_\rho| < 1$

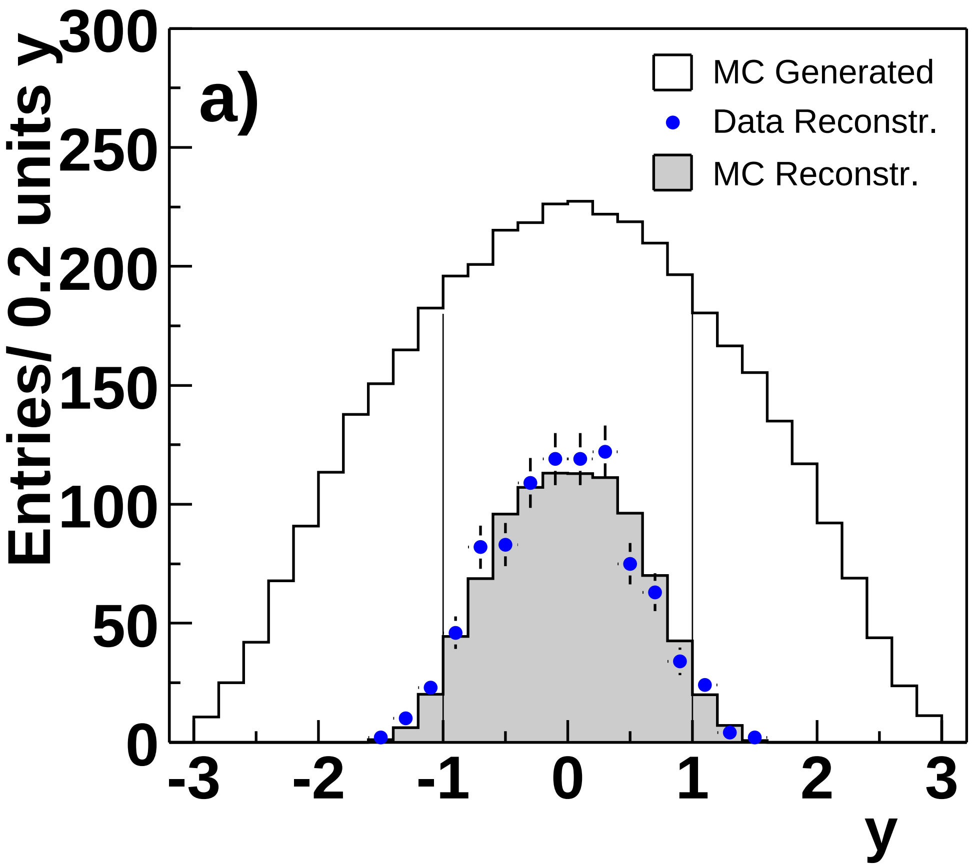
Minimum-Bias Data—(ZDC) Trigger

2-prong trigger similar—not shown

$p_T < 150$ MeV/c

M (MeV)	Γ (MeV)
778 ± 7	148 ± 14
777 ± 7	139 ± 13
773 ± 7	127 ± 13

ρ^0 Rapidity Distribution



Minimum-Bias Data—(ZDC) Trigger

2-prong trigger similar—not shown

Photon+Pomeron$\rightarrow X \rightarrow \pi^+\pi^-\pi^+\pi^-$

$$\mathrm{Au} + \mathrm{Au} \rightarrow \mathrm{Au}^* + \mathrm{Au}^* + X, \qquad X \rightarrow \pi^+\pi^-\pi^+\pi^-$$

"4-prong" trigger:

1. Low-multiplicity neutrons in the beam line (ZDCs in coincidence)
2. Reject high-multiplicity events (with CTB adc)

Total number of triggers (2004) = 5×10^6

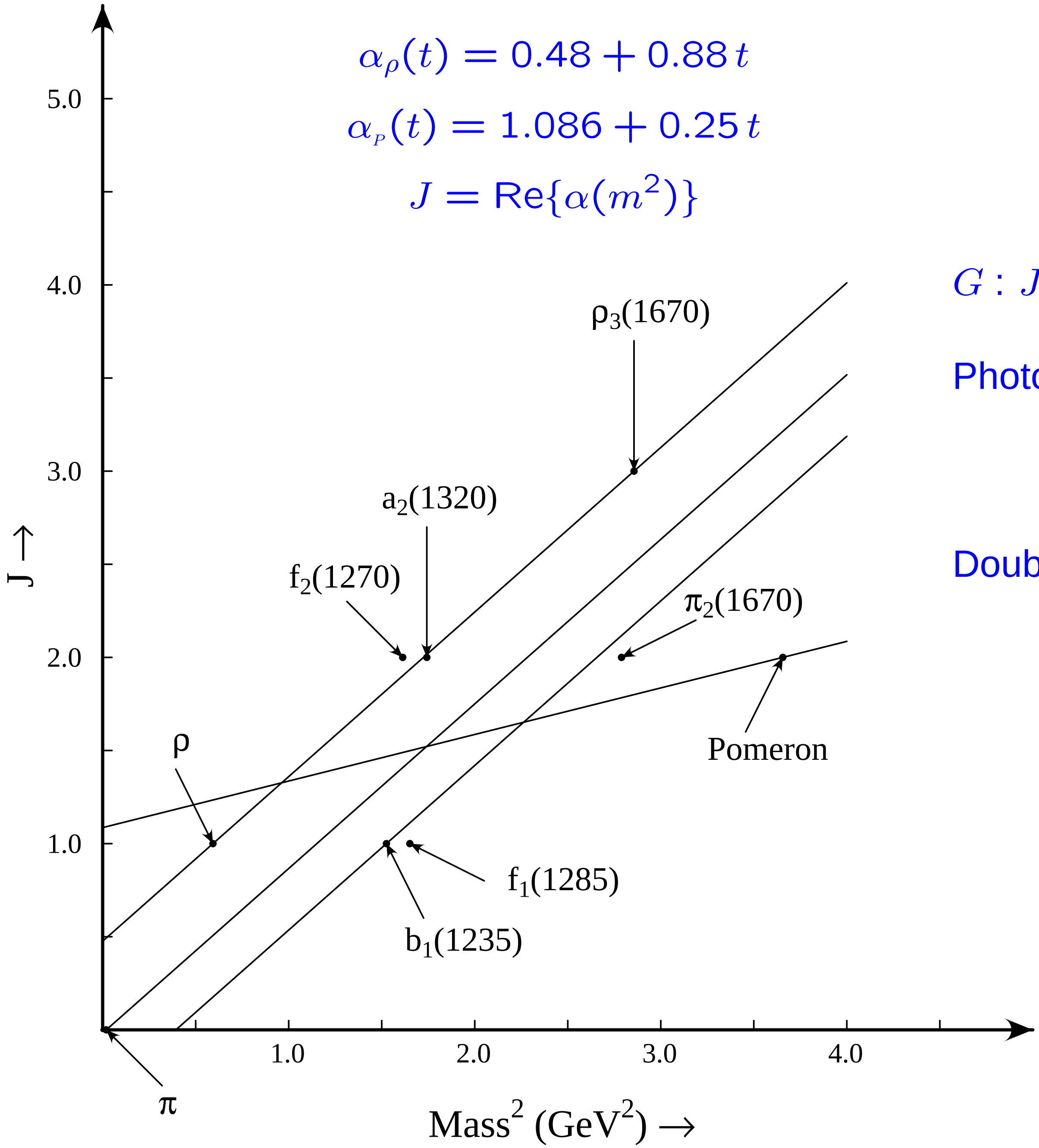
Future: TOF Pads for more efficient trigger ?
DAQ upgrade for more efficient data-taking ?

Regge Trajectories

$$\alpha_\rho(t) = 0.48 + 0.88\,t$$

$$\alpha_{_P}(t) = 1.086 + 0.25\,t$$

$$J = \mathrm{Re}\{\alpha(m^2)\}$$



$G:\,J^{PC} = 2^{++}$ glueball

Photon-Pomeron Fusion Process:

$$\gamma + G \to X$$

Double-Pomeron Fusion Process:

$$G + G \to X$$

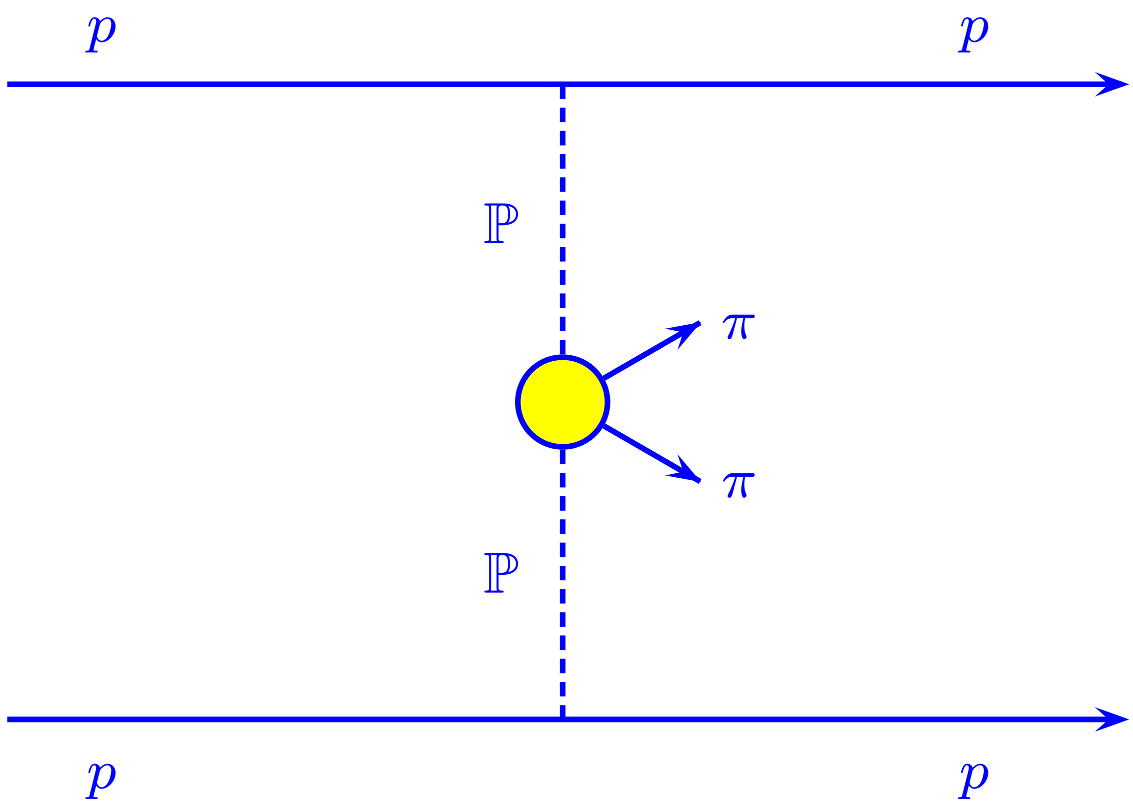
Allowed Decay Modes of a Meson with $I^G(J^{PC})$

Why Photon+Pomeron $\rightarrow \pi^+\pi^-\pi^+\pi^-$?

Decay Modes	$I^G(J^{PC})$
$\pi^+\pi^-$	$0^+(0^{++}), 1^+(1^{--}), 0^+(2^{++}), 1^+(3^{--})$
K^+K^-	$0^+(0^{++}), 1^-(0^{++}), 0^-(1^{--}), 1^+(1^{--}), 0^+(2^{++}), 1^-(2$
$\eta\ \pi,\ \eta'\ \pi$	$\boxed{1^-(1^{-+})}, 1^-(3^{-+}), \cdots$
$(\rho\ \pi)^0 \rightarrow \pi^+\pi^-\pi^0$	$0^-(0^{--}), \boxed{1^-(1^{-+})}, 0^-(2^{+-}), \cdots$
$\rho^0\ \rho^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$	$0^+(1^{-+}), \cdots$
$\boxed{\rho^0\ f_0(600) \rightarrow \pi^+\pi^-(\pi\pi)^0}$	$\boxed{1^+(0^{+-}), 1^+(2^{+-}), \cdots}$
$f_0(600)\ f_0(600) \rightarrow (\pi\pi)^0\ (\pi\pi)^0$	$0^+(0^{++}), 0^+(2^{++}), \cdots$

Pomeron+Pomeron$\rightarrow X \rightarrow \pi^+\pi^-\pi^+\pi^-$

$$
\begin{aligned}
p + p &\rightarrow p + p + X, & X &\rightarrow \pi^+\pi^- \\
p + p &\rightarrow p + p + X, & X &\rightarrow \pi^+\pi^-\pi^+\pi^-
\end{aligned}
\tag{1}
$$



Double-Pomeron Fusion Process

If the effective mass of the central system is limited to 1–10 GeV and its rapidity to $-1 < y < +1$, then the cross section is estimated to be

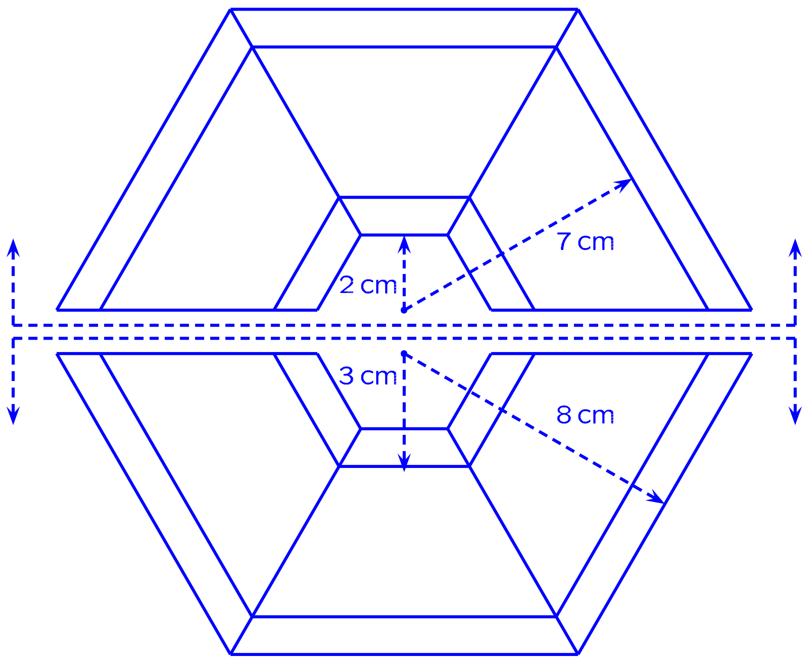
$$\sigma(\mathbb{P} + \mathbb{P}) = 109\,\mu\mathrm{b} \tag{2}$$

The counting rate is, assuming the following parameters for a $p \times p$ run at $\sqrt{s} = 200$ GeV,

$$\begin{aligned} &[\mathcal{L} = 10^{31}\,\mathrm{cm}^{-1}\,s^{-1}] \;\otimes\; [\sigma(\mathbb{P} + \mathbb{P}) = 109\,\mu\mathrm{b}] \otimes \\ &\otimes\; [\text{overall acceptance} \sim 0.1\%] \quad\Longrightarrow\quad IR \simeq 1\,\mathrm{Hz} \end{aligned} \tag{3}$$

where the overall acceptance is our rough guess; and the interaction rate (IR) does not include the background trigger rate. In a $p \times p$ run lasting one month (10^6 s), we should accumulate $\sim 1 \times 10^6$ events.

Roman Pots



Resolutions:

0.2mm (radial)

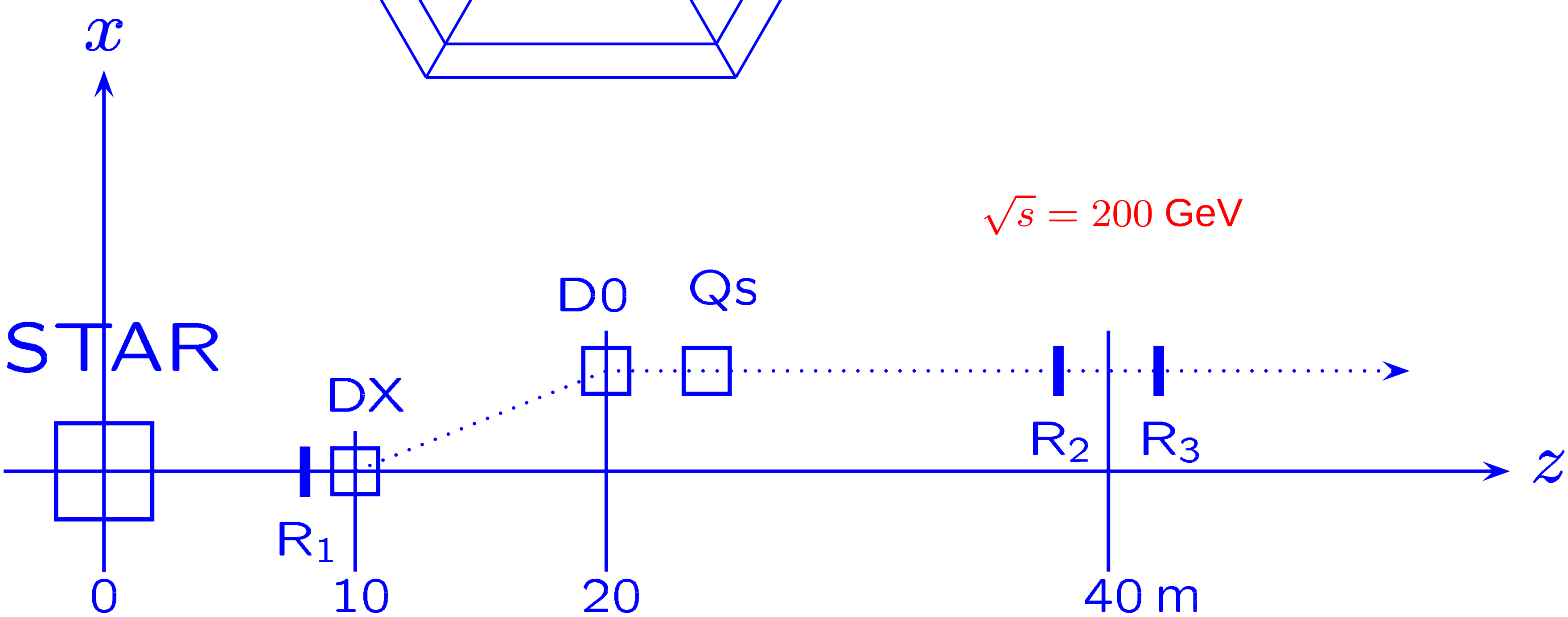
0.4mm (tangential)

Six Roman Pot Stations:

R_2 and R_3 in front of D0 (A. Bravar)

Total Cost=$1.0–1.5M ?

$\sqrt{s} = 200$ GeV



Conclusions and Future Prospects

- Hadron Spectroscopy with STAR:
  An important sector of QCD at RHIC
- Photon-Pomeron Fusion Process:
  5×10^6 triggers on hand
  MC Work on $X \to \rho'(1450, 1700) \to \pi^+\pi^-\pi^+\pi^-$ and acceptance studies
  Data processing to start soon
- A more efficient trigger and data-taking for "4-prong events"
  with TOF pads and DAQ upgrade in the future ?

Characteristics of a $J^{PC} = 0^{+-},\ 2^{+-}$ State:

I^G	Intermediate States	Final States
1^+	$\rho^0\,(770)\,f_0\,(600)$, $a_2^{\pm}(1320)\,\pi^{\mp}$	$\pi^+\pi^-\pi^+\pi^-$
1^+	$f_0(980)\,\rho^0(770)$, $f_2'(1525)\,\rho^0(770)$	$K^+K^-\pi^+\pi^-$
1^+	$K^*(890)\,\bar{K}$, $K_2^*(1420)\,\bar{K}$, $a_2^{\pm}(1320)\,\pi^{\mp}$	$K_S\,K^{\pm}\pi^{\mp}$
0^-	$K^*(890)\,\bar{K}$, $K_2^*(1420)\,\bar{K}$	$K_S\,K^{\pm}\pi^{\mp}$
0^-	$a_0^0(980)\,\rho^0(770)$, $a_2^0(1320)\,\rho^0(770)$	$K^+K^-\pi^+\pi^-$

Conclusions and Future Prospects

- Double-Pomeron Fusion Process:
  Construct Roman pots in two to three years ?
- Search for $J^{PC} = 1^{-+},\ 3^{-+}$ States:
  Possible Decay Modes: $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$, $K_S K^\pm\pi^\mp$

Current and Future Complementary Venue for Hadron Spectroscopy:

- STAR/RHIC/BNL
- COMPASS, IHEP/Protvino, J-PARC (Japan Hadron Facility)
- IHEP/Beijing, BaBar, Belle, CLEO-C, GlueX (Hall D)/JLab
- CDF/Fermilab and D0/Fermilab
- Panda (GSI)/Darmstadt, LHC/CERN