Glueball, Odderon, Exotics Search

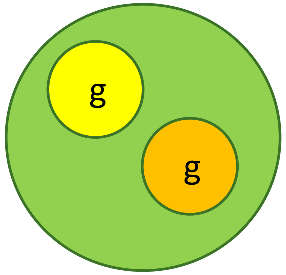
Selected Topics

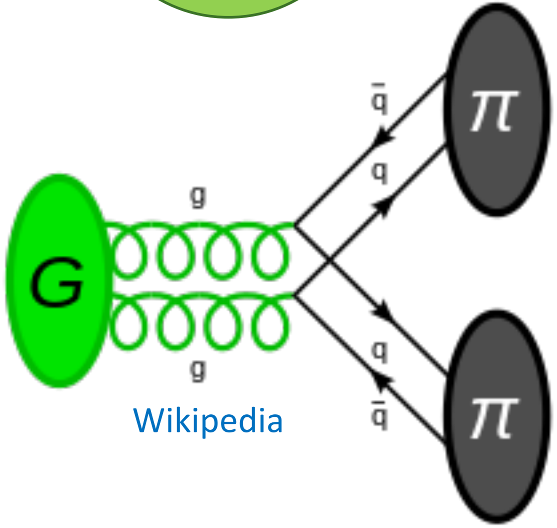
Włodek Guryn, BNL

1. Program at RHIC with STAR detector
   - Glueball
   - Odderon
2. Possibilities at the EIC – examples from HERA

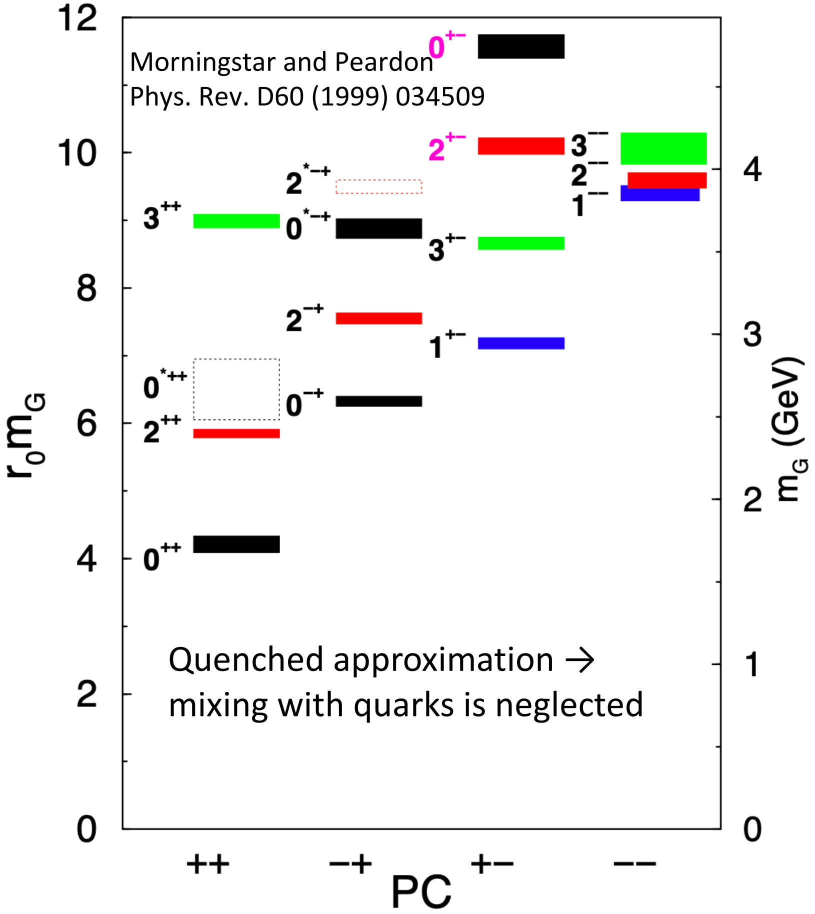
Glueballs

Glueball gg





Wikipedia



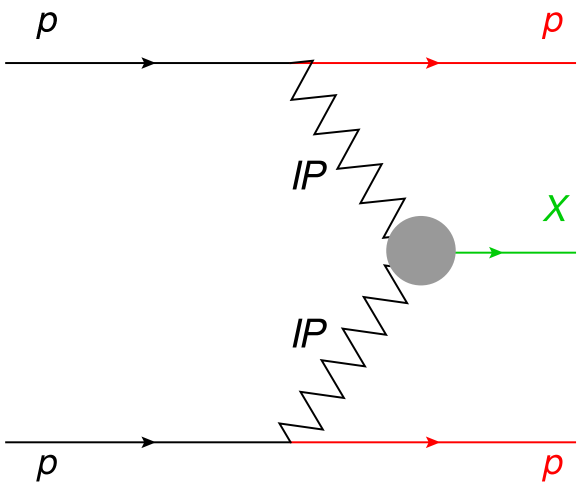
Closely linked to the Pomeron: J = 0.25M 2 + 1.08
Mixing between glueball 0++ and light mesons
Scalar Candidates: f0(1370) f0(1500)
Pseudoscalar Candidates: η(1295) η(1405)
0++ and 0−+ glueballs shared between those states
f0(1710) η(1475)

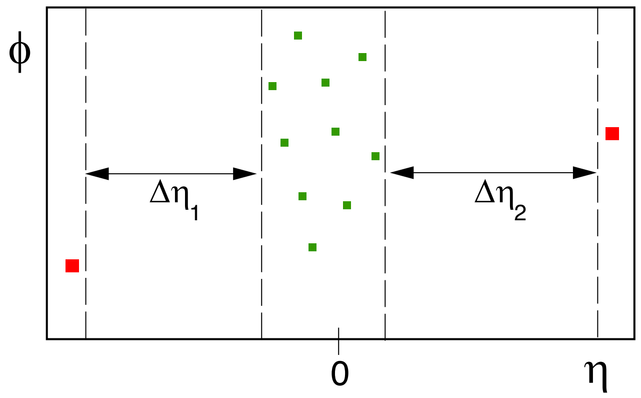
Possible candidates
M(0++) = 1.730 ± 0.130 GeV
M(0−+) = 2.590 ± 0.170 GeV
M(2++) = 2.400 ± 0.145 GeV

Central Exclusive Production (CEP)

Exclusive means that all particles in the final state are measured

pp => p X p





For each proton vertex one has

t four-momentum transfer

$\xi = \Delta p/p$

M_X invariant mass

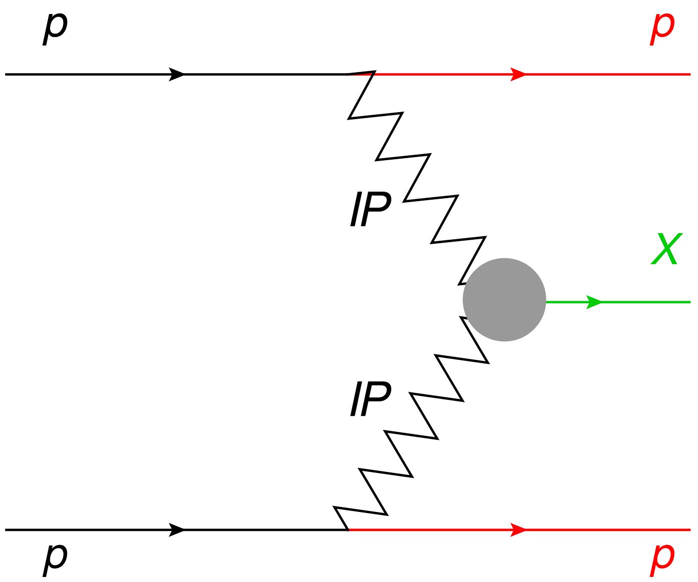
In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons. Hence, triggering on forward protons at high (RHIC) energies predominantly selects exchanges mediated by gluonic matter.

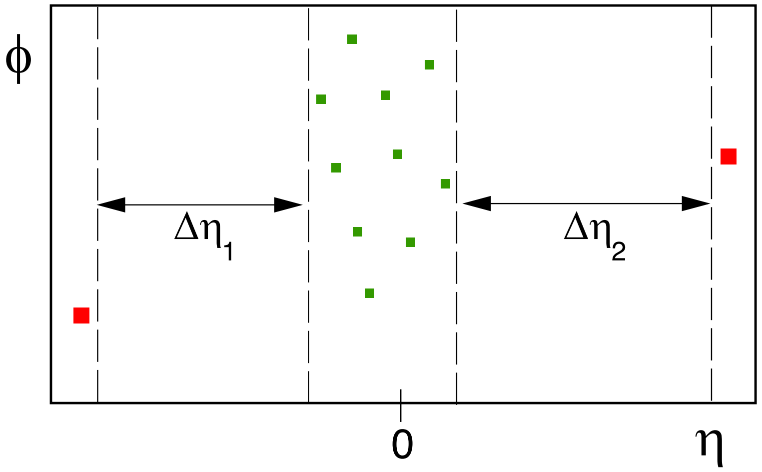
Program at RHIC with the STAR detector

Exclusive Processes in Search for Glueballs

Exclusive means that all particles in the final state are measured

pp => p X p $\quad$ **X = $\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-$, K^+K^-** or $p\bar{p}$ production in CEP



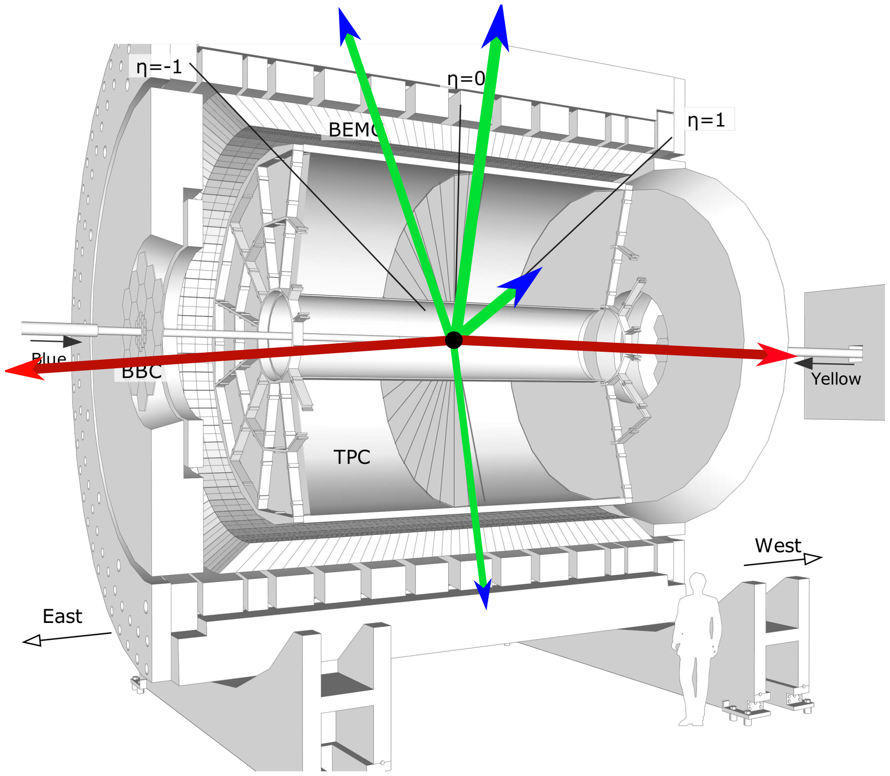


At sufficiently high center-of-mass energies the process is expected to be dominated by double- Pomeron exchange. The Pomeron carries neither electric nor color charges and is expected to have positive parity and charge conjugation. Thus, Double-Pomeron Exchange (DPE) should favor production of isoscalar particles in a glue-rich environment of the DPE process.

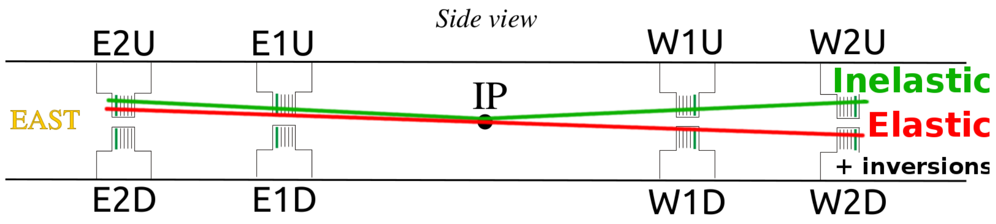
CEP at STAR: Combine Excellent PID of STAR with Forward Proton Measurement in Roman Pots

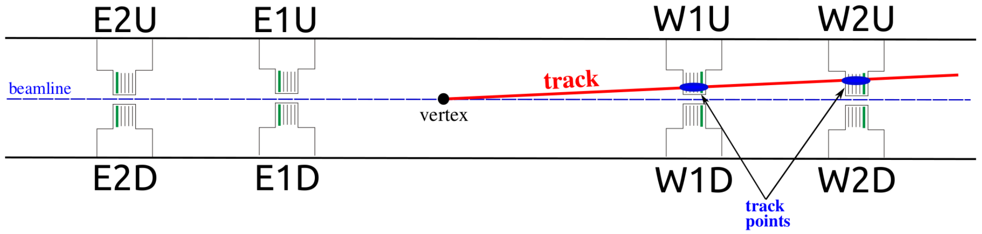
pp => p X p

Forward protons are measured in Roman Pots and the recoil system **X** is measured in the STAR TPC



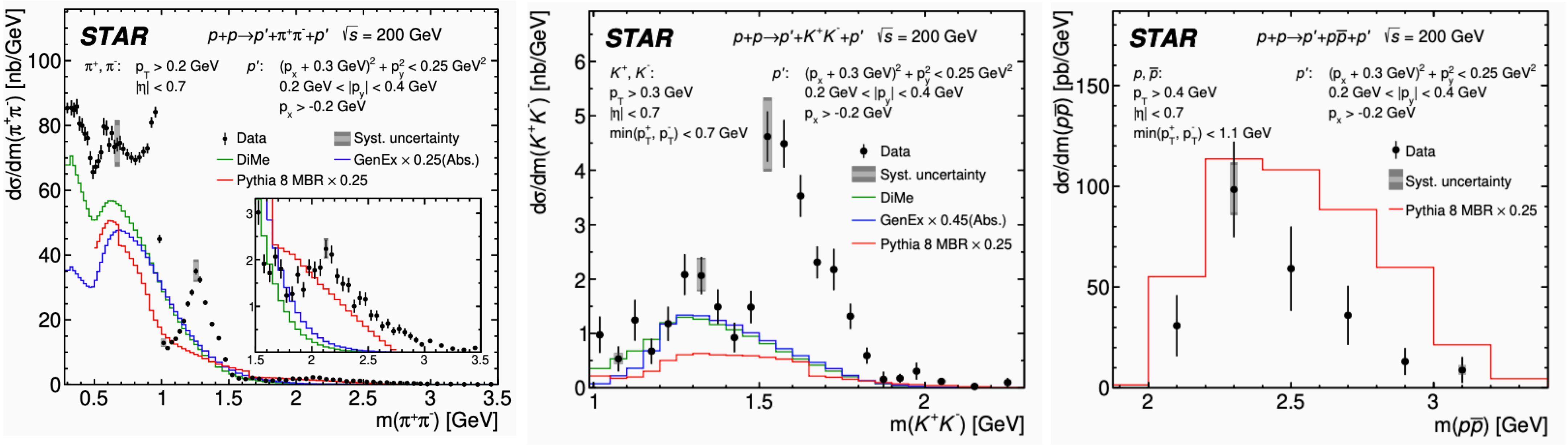
Roman Pots





STAR Results on CEP: $\pi^+\pi^-$, K^+K^-, $p\bar{p}$ production at $\sqrt{s}$ = 200 GeV

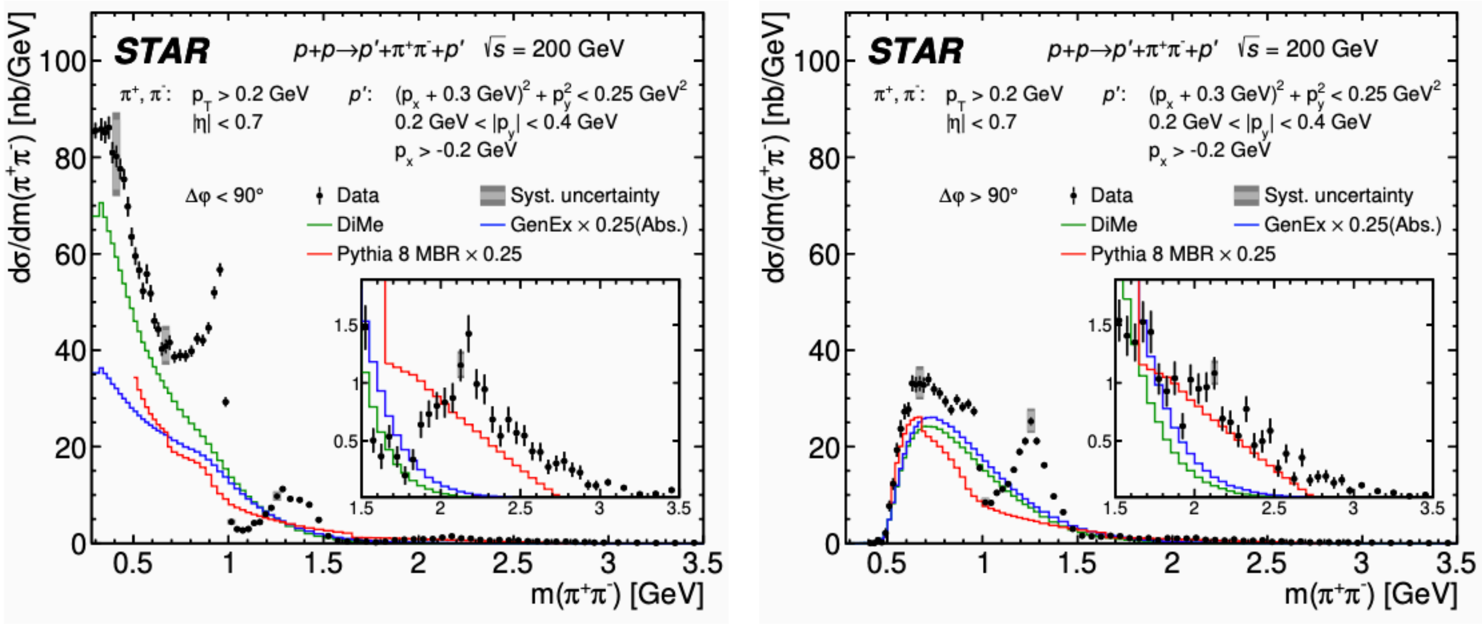
J. High Energy Phys. **2020,** 178 (2020)



1. In $\pi^+\pi^-$ spectrum drop at f0(980), a peak at f2(1270) MeV and structure at about 2200 MeV , are observed.
2. No clear indication a glueball candidate. Need more data, especially in K^+K^- channel.

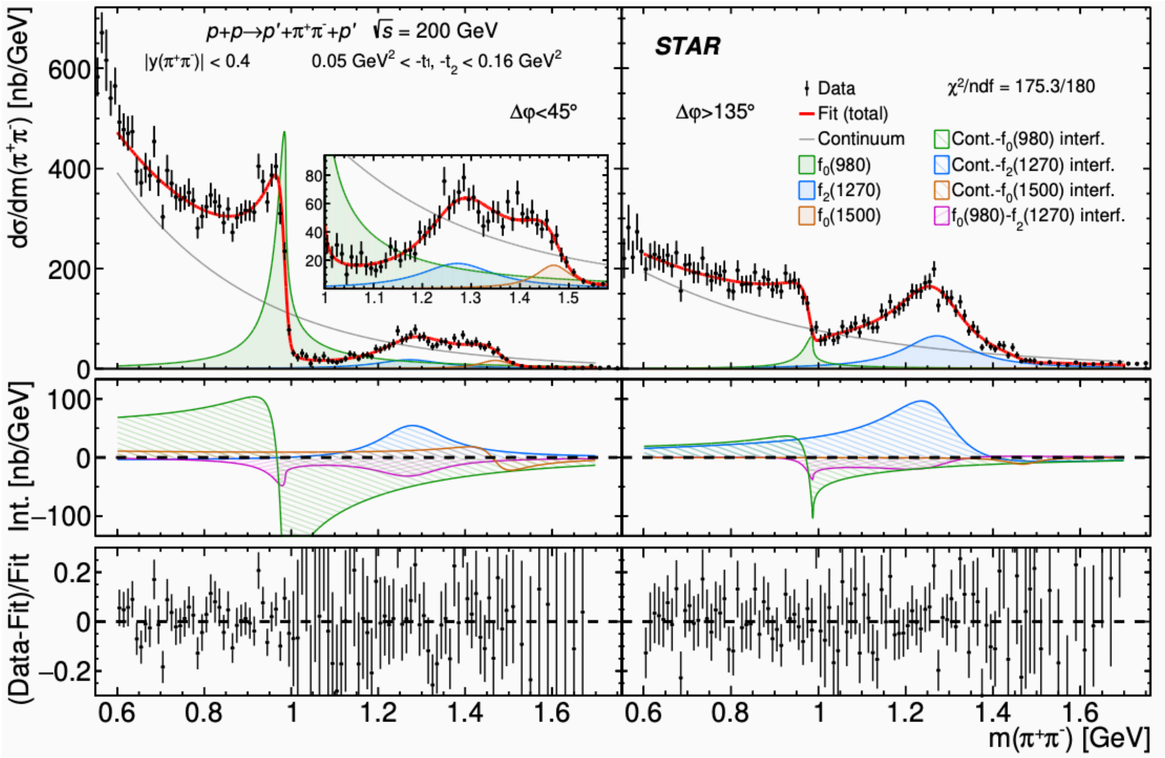
Results on CEP: $\pi^+\pi^-$ at $\sqrt{s}$ = 200 GeV in more detail $\Delta\phi$ dependence – simple glueball filter

J. High Energy Phys. **2020,** 178 (2020)



1. in the $\Delta\phi < 90^\circ$ range, the peak around the f2(1270) resonance in data is significantly suppressed.
2. peak at f0(980) as well as possible resonances in the mass ranges 1.3 − 1.5 GeV and 2.2 − 2.3 GeV, are enhanced compared to the $\Delta\phi > 90^\circ$ range.

Results on CEP: $\pi^+\pi^-$ in more detail mass spectrum interpretation

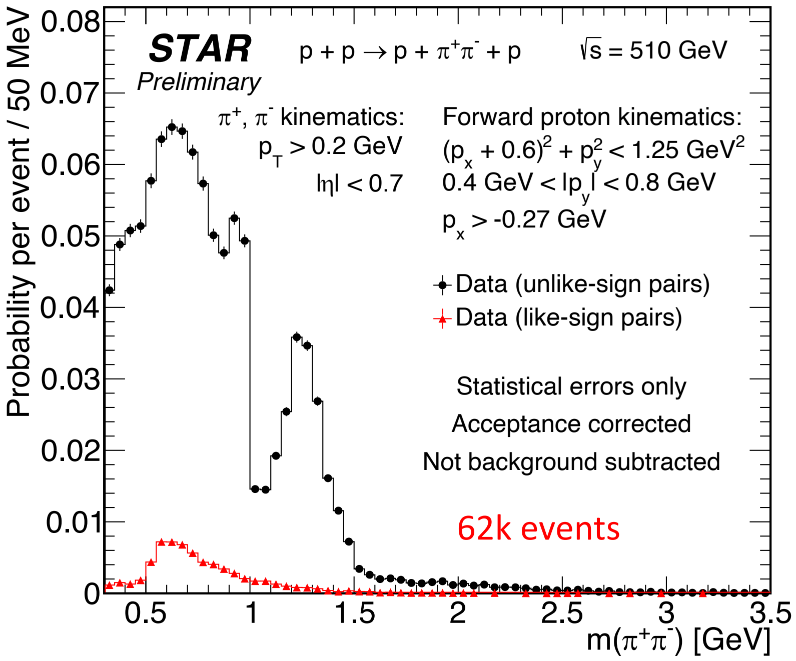


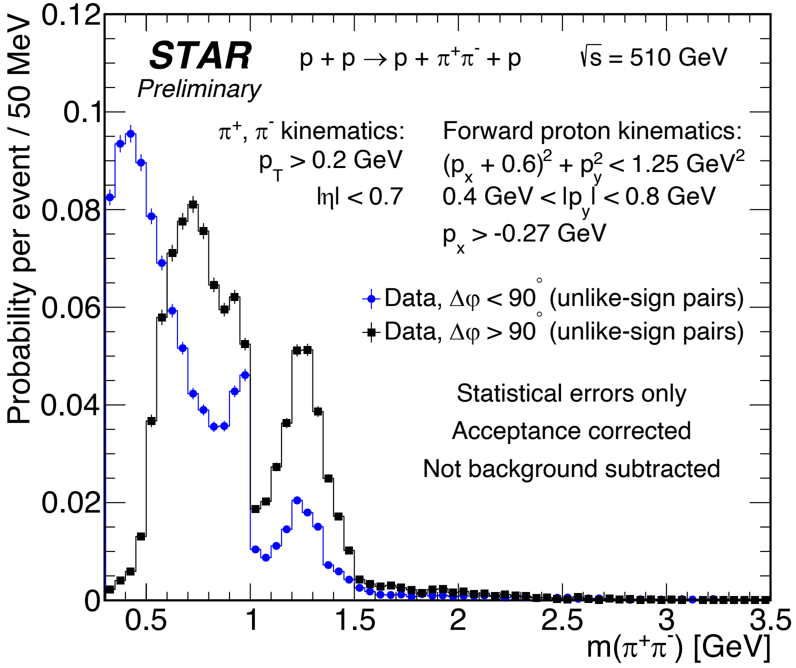
J. High Energy Phys. **2020,** 178 (2020)

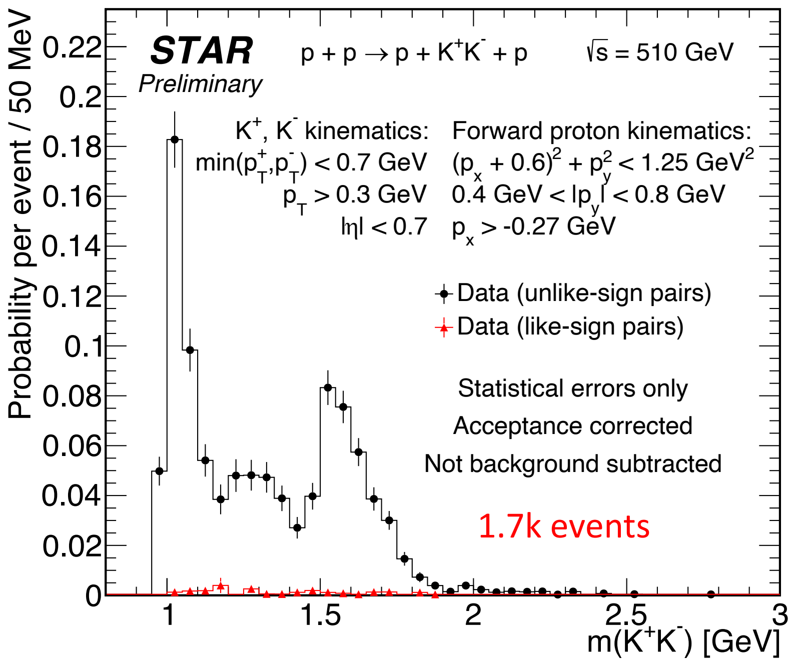
1. Two $\Delta\phi$ regions are examined.
2. The result of the fit is drawn with a solid red line. The squared amplitudes for the continuum and resonance production are drawn with lines of different colors.
3. The most significant interference terms are plotted in the middle panels, while the relative differences between each data point and the fitted model is shown in the bottom panels.

Results on CEP at $\sqrt{s} = 510$ GeV

PoS ICHEP2020 (2021) 530







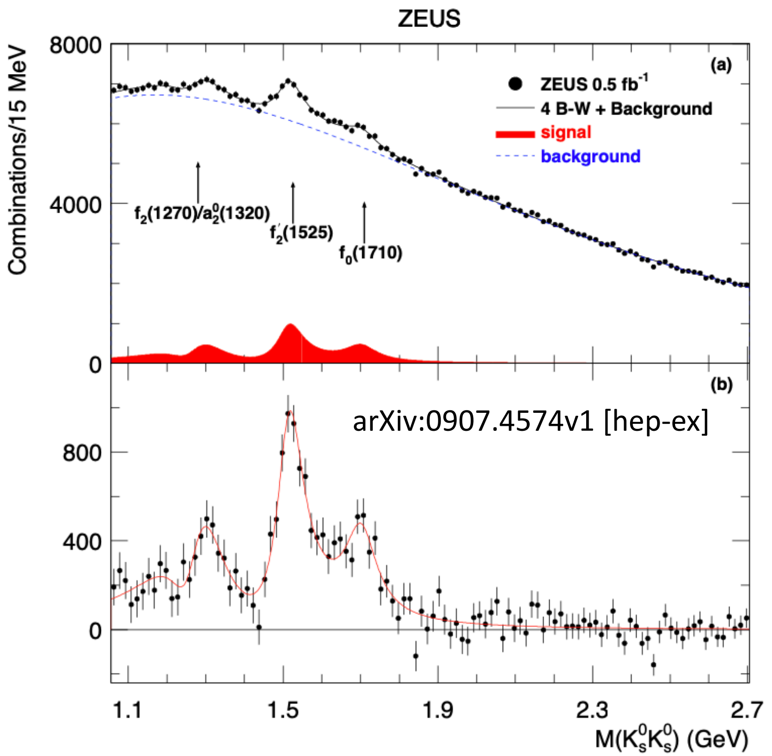
Features similar to those at $\sqrt{s}$ = 200 GeV are observed.

The hunt continues.

Exotic Mesons and Glueballs at the EIC

- Excellent review in V. Crede and C. A. Meyer arXiv:0812.0600v3
- There are many resonances in the range 1 – 2 GeV, hence it is not easy to untangle the glueball resonance(s)
- One needs to perform PWA analysis to untangle them
- The searches at RHIC were limited by statistics and mass range
- There is more hope at $\sqrt{s}$ = 510 GeV at RHIC
- At the EIC photon, whose JPC = 1-- couples through Vector Meson Dominance mechanism with the Pomeron (two gluons) from the proton vertex
- It allows production of wide range of JPC of the mesons
- High luminosity, excellent PID and very good acceptance gives an opportunity to continue those searches at the EIC

Glueball Search: Example from HERA $ep \rightarrow eK_S^0\, K_S^0 + \mathrm{X}$



$$ep \rightarrow eK_S^0\, K_S^0 + \mathrm{X} \rightarrow e\, 4\pi^+\, \pi^-\, \pi^+\, \pi^- X$$

Fit	No interference		Interference		PDG 2007 Values	
χ^2/ndf	96/95		86/97			
in MeV	Mass	Width	Mass	Width	Mass	Width
$f_2(1270)$	1304 ± 6	61 ± 11	1268 ± 10	176 ± 17	1275.4 ± 1.1	$185.2^{+3.1}_{-2.5}$
$a_2^0(1320)$			1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1523 \pm 3^{+2}_{-8}$	$71 \pm 5^{+17}_{-2}$	$1512 \pm 3^{+2}_{-0.6}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1692 \pm 6^{+9}_{-3}$	$125 \pm 12^{+19}_{-32}$	$1701 \pm 5^{+5}_{-3}$	$100 \pm 24^{+8}_{-19}$	1724 ± 7	137 ± 8

Table 1: *Fitted masses and widths for $f_2(1270)$, $a_2^0(1320)$, $f_2'(1525)$ and $f_0(1710)$ from the incoherent and coherent fits compared to PDG. The first error is statistical. For $f_2'(1525)$, $f_0(1710)$ the second errors are systematic uncertainties.*

- Significant production of $J^{PC} = 2^{++}$ tensor mesons and of the 0^{++} glueball candidate $f_0(1710)$ was seen.
- More statistics are needed to perform PWA analysis to determine QM of contributing resonances
- EIC will be a great place to pursue this glueball search

Odderon

Odderon Amplitude in Elastic Scattering

PRL Vol 54 No 20, 2180 (1985)

$$A = A(s,t) \ \text{ scattering amplitude is function of (s,t)}$$

$$A_+(s,t) = \frac{1}{2}(A_{pp}(s,t) + A_{p\bar{p}}) \ \text{ symmetric under crossing}$$

$$A_-(s,t) = \frac{1}{2}(A_{pp}(s,t) - A_{p\bar{p}}) \ \text{ asymmetric under crossing}$$

$$A_{pp}(s,t) = A_+(s,t) + A_-(s,t)$$

$$A_{p\bar{p}}(s,t) = A_+(s,t) - A_-(s,t)$$

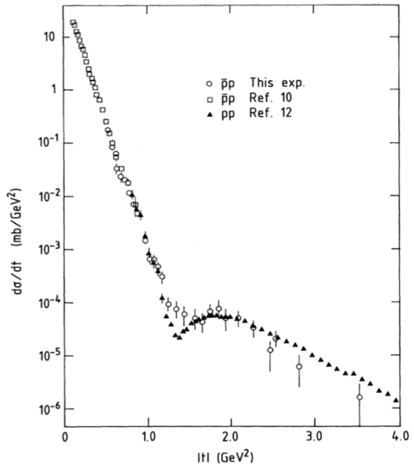


FIG. 2. Elastic differential $\bar{p}p$ cross section at $\sqrt{s} = 53$ GeV. Only t-dependent errors are shown. The systematic scale error is estimated at $\pm 30\%$. Included are the low-t data from our previous experiment (Ref. 10) and the pp data of Ref. 12.

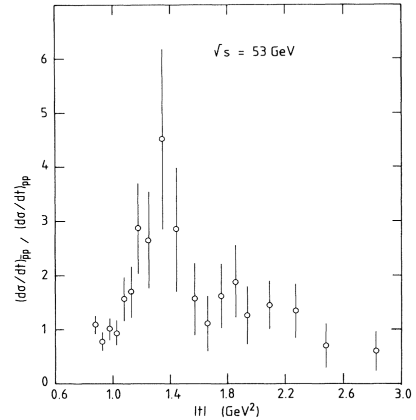


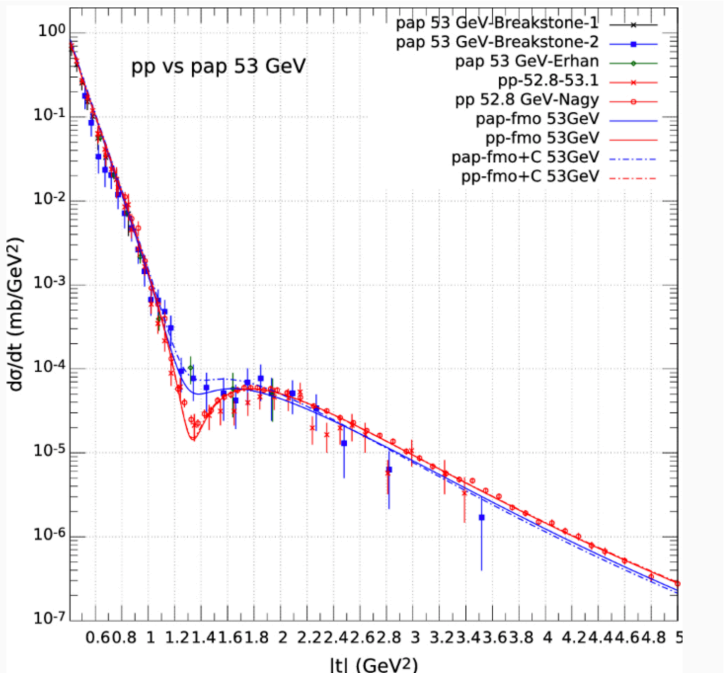
FIG. 3. The ratio of the $\bar{p}p$ differential cross section from this experiment to the pp differential cross section of Ref. 12 in the range $0.7 < |t| < 3.0$ $(\mathrm{GeV}/c)^2$. The pp data of Ref. 12 have been multiplied by the factor 0.71 to take into account the normalization differences of the two experiments. Only t-dependent errors are shown. The ratio has an overall uncertainty of $\pm 30\%$ due to these normalization uncertainties.

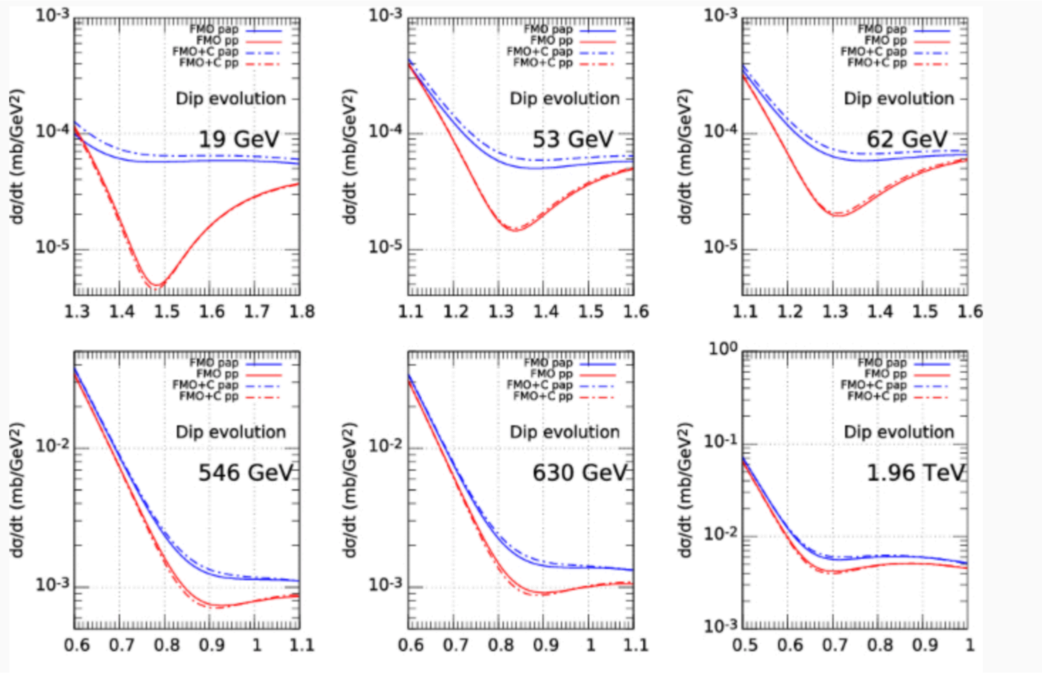
- In the dip region $p\bar{p}$ is flat while pp has a dip.
- The first evidence of the Odderon amplitude in pp and $p\bar{p}$ scattering was observed at CERN's ISR.
- One needs to compare pp and $p\bar{p}$ in the dip region at the same energy.

Diffractive minimum (dip) evolution in pp and ppbar for a model that has Odderon amplitude.

Odderon is a C=-1 partner of the Pomeron and is a solid part of QCD – three gluon exchange

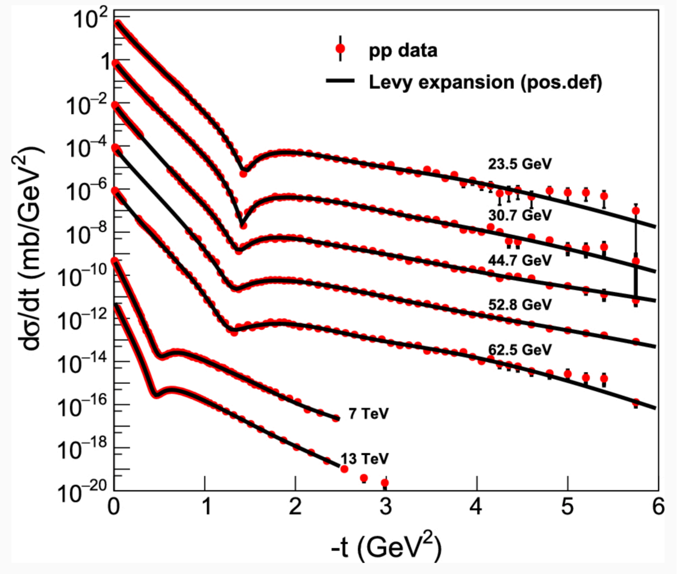
Eur.Phys.J.C16:499-511,2000

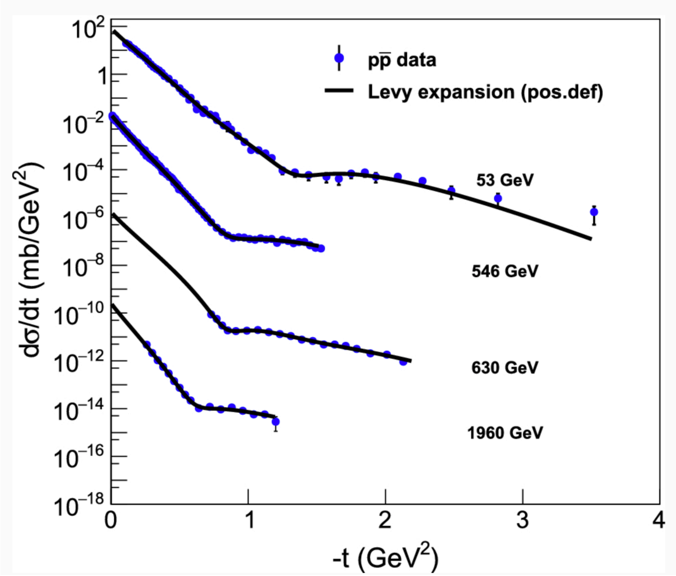




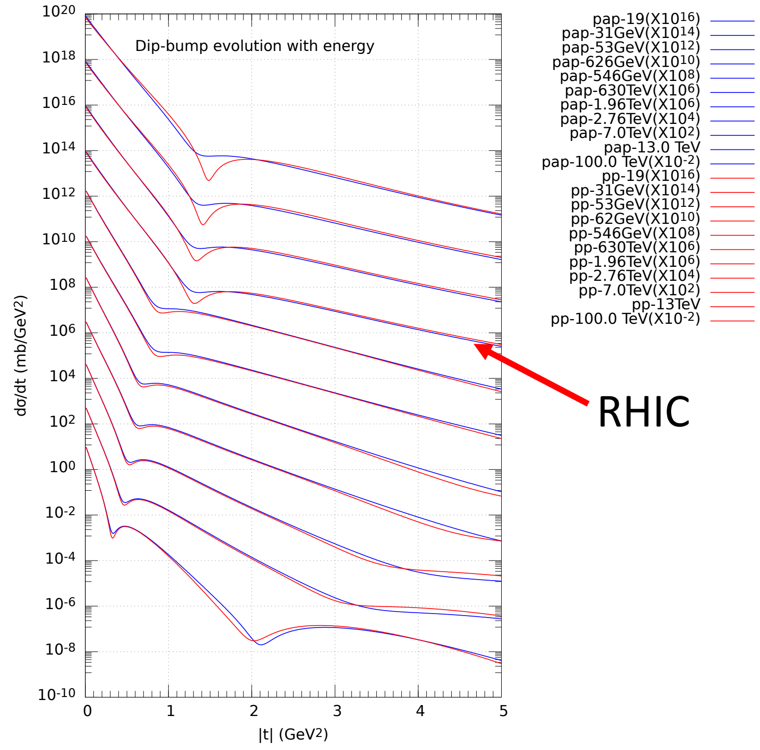
A shallow dip in $p\bar{p}$ is expected and seen in at $\sqrt{s}$ = 53 GeV at the ISR and higher $\sqrt{s}$

Odderon - Current Status





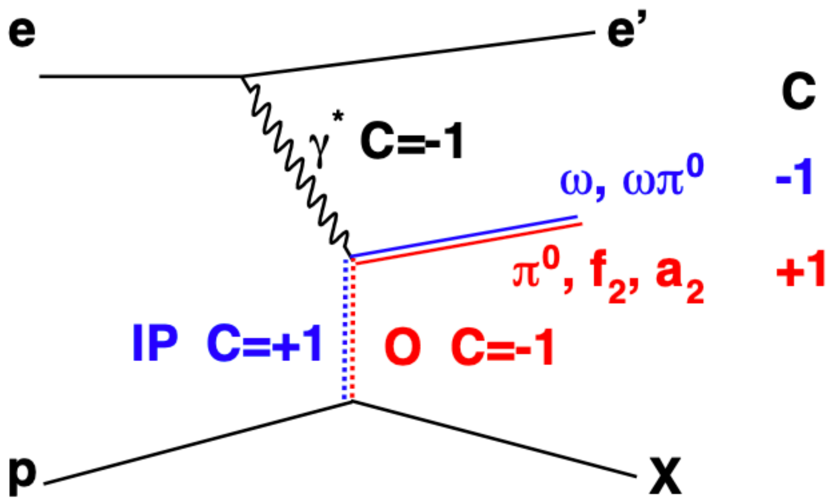
FMO = Froissart Maximal Odderon



- Clearly there are dips in pp and no dips in $p\bar{p}$ at high energy.
- The only direct comparison that could be done is 546 GeV $p\bar{p}$ and 510 GeV in pp at RHIC (STAR).

Most recent model with the fit to world data on elastic scattering within the framework of Regge theory shows dips in pp and no dips in $p\bar{p}$ up to TEV range.

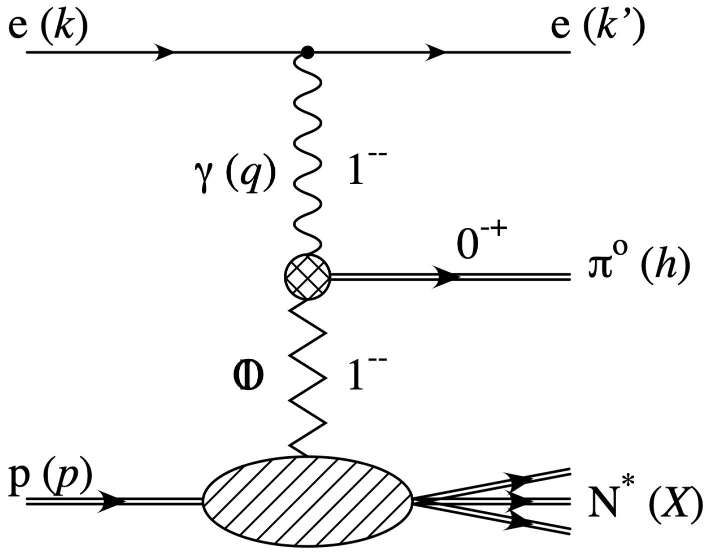
Odderon in ep Scattering – Inspiration for EIC

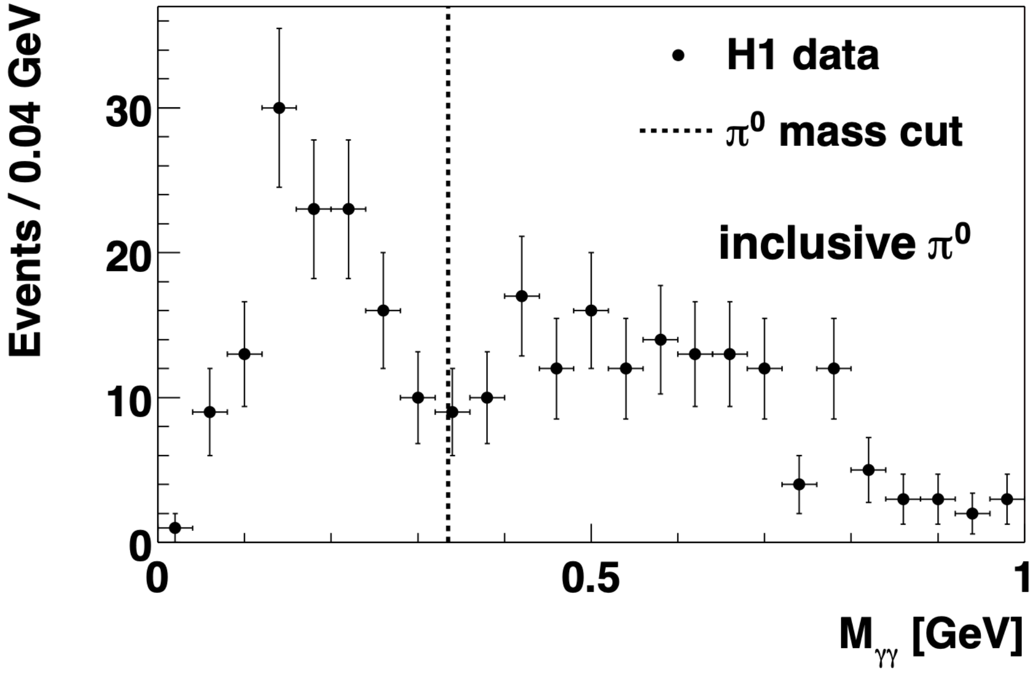


$$ep \rightarrow e\pi^0 N^* \rightarrow e\pi^0 \text{nX}$$

1. The proton is excited into an (I=1/2)-isobar while a high energy single π^0 is produced by photon-Odderon fusion.
2. $N^* \rightarrow$ nX has 48% branching ratio
3. Large cross section predicted but not observed at H1 at HERA

H1 Result





e – detected in small angle electron tagger

n – detected in FNC

π^0 – detected in EM calorimeter in e direction (VLQ and/or SPACAL)

Status of Odderon Searches

- One of the best channels in Odderon search is comparison of the elastic scattering of $p\bar{p}$ and pp
- There is a positive claim from the LHC of such comparison at 1.96 TeV, where the TOTEM data at the LHC were extrapolated to D0 energy, *arXiv:2012.0398v1 [hep-ex]*
- There is also a positive claim using scaling functions to do the same as above, *Eur. Phys. J. C (2021) 81: 180*
- But there is no direct comparison of $p\bar{p}$ and pp elastic scattering in the dip region at the same energy
- There is an opportunity at RHIC to compare pp at $\sqrt{s}$ = 510 GeV with $p\bar{p}$ at $\sqrt{s}$ = 546 GeV of the UA4 experiment - this work is ongoing
- There is a negative result from H1 at HERA in $ep \rightarrow e\pi^0 N^*$ channel, but the same search at the EIC with better detectors could prove more successful

Case for Odderon Searches at the EIC

- The relevant detectors for the event identification are well defined for the EIC.
- Those can be used to study the performance for this physics.
- My guess is that they are already suitable enough and probably better than those at HERA.
- The advantage of the EIC is that it will have higher luminosity and the cross section for Odderon induced reactions does not change significantly with with $\sqrt{s}$.
- One issue is that the predicted cross section was high 200 nb, so this should have been seen at HERA, but…
- This would be a great day one physics topic.

Summary

- RHIC program in proton-proton scattering certainly inspires physics topics for the EIC in the exotic sector
- Given the quantum numbers of ep collisions, C = -1 of the photon, complementary channels for glueballs and exotic particles searches can be explored
- Odderon search in $ep \rightarrow e\pi^0 N^*$channel is a great candidate for the day one topic since it does not require high luminosity
- Glueball Search $ep \rightarrow eK_S^0\ K_S^0 + \mathrm{X}$ is also a channel of interest
- EIC with its high luminosity and detectors with excellent PID will have opportunity to address (answer) questions which eluded answers at *pp* colliders