Study of central exclusive production at 13 TeV

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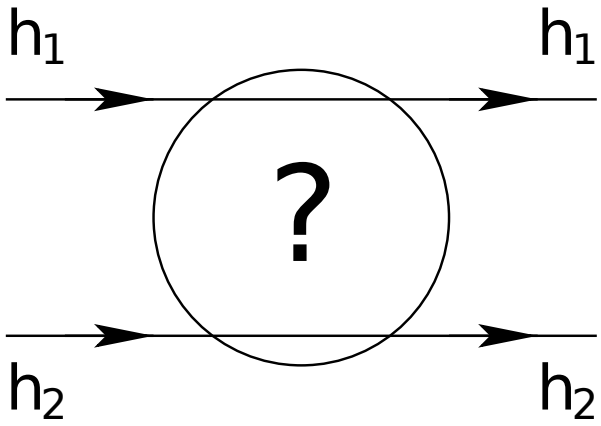
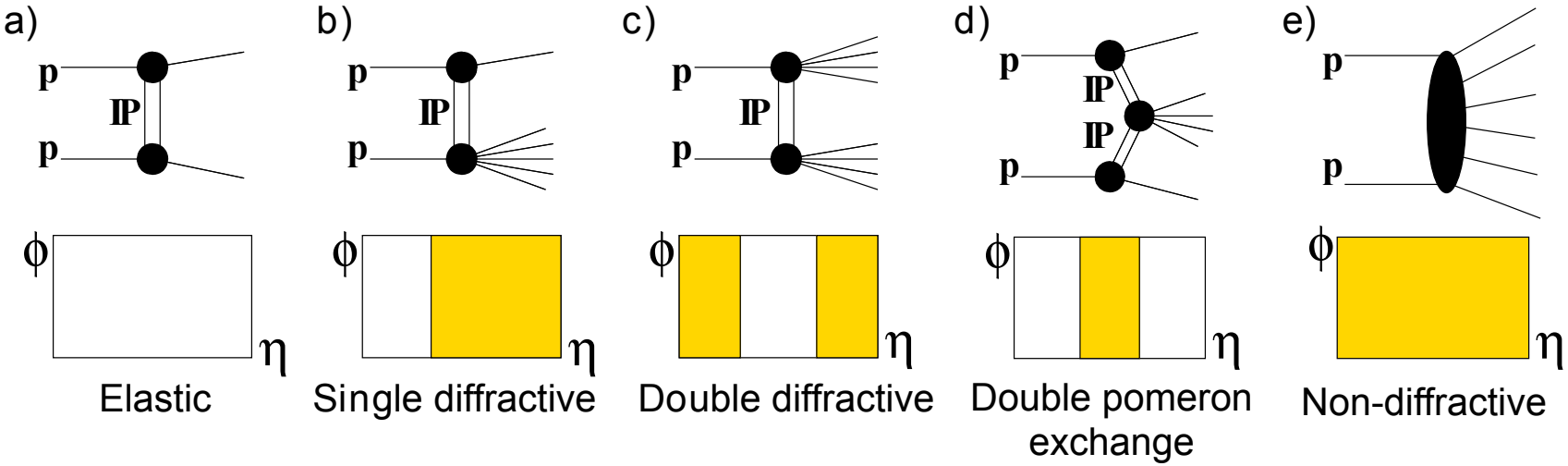
Types of proton-proton collisions

- Elastic scattering
- Inelastic scattering
  - Single diffraction
  - Double diffraction
  - Double pomeron exchange or central diffraction
  - Non-diffractive scaterring





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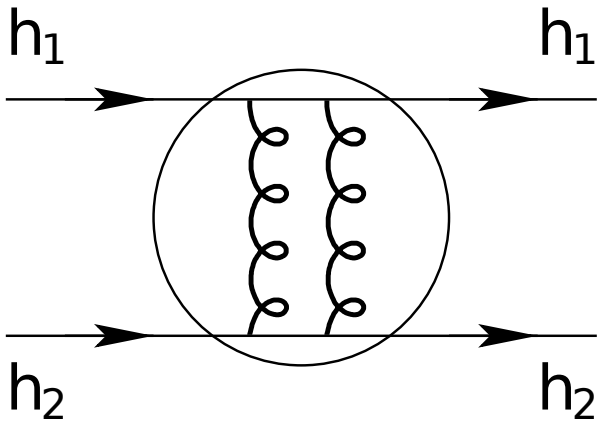
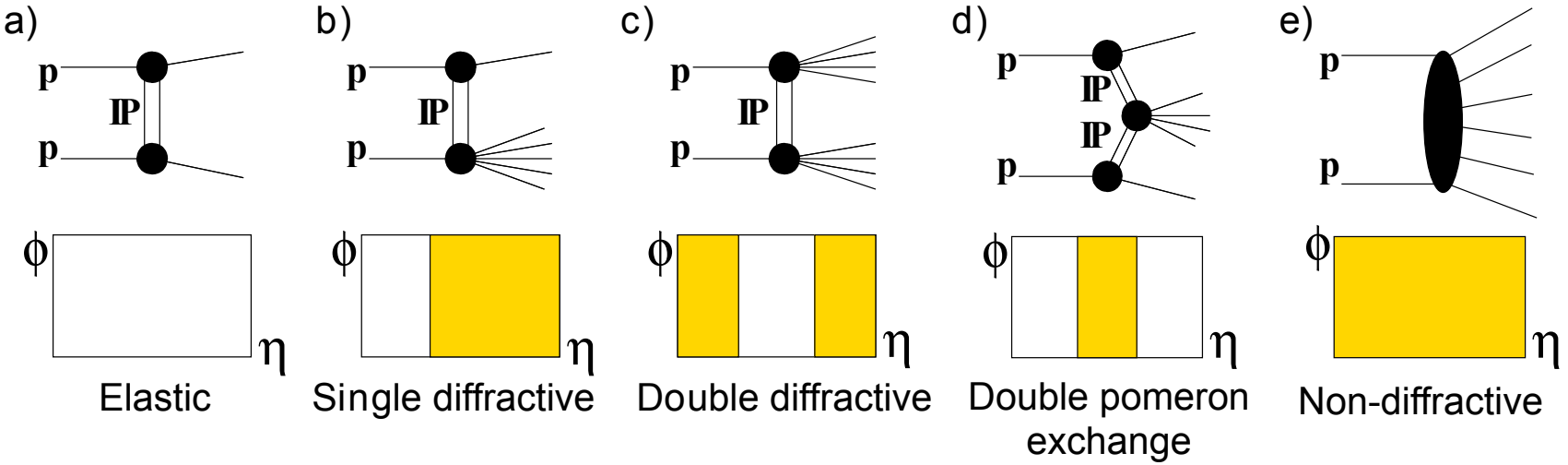
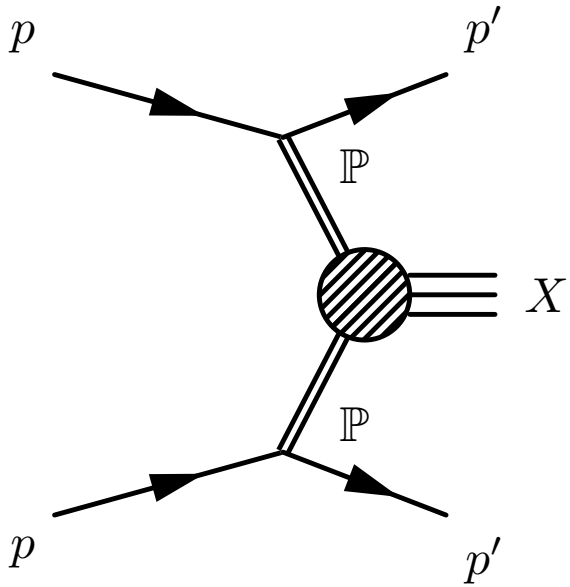




Central exclusive production (CEP)

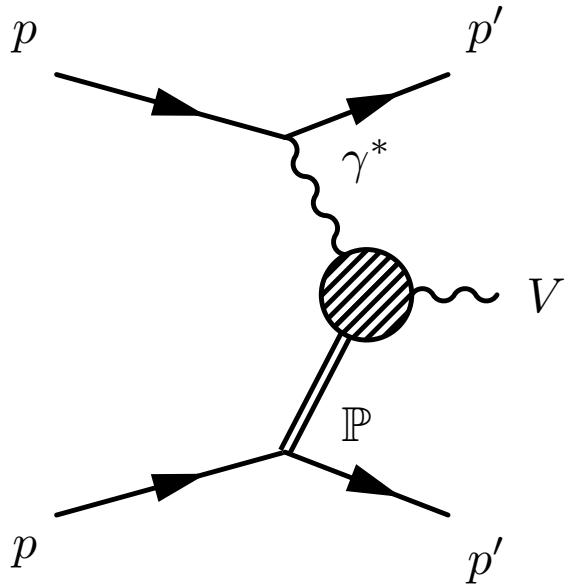
Double pomeron exchange (DPE)
$I^G(J^{PC}) = 0^+(J^{++})$, J is even

For example: $f_0(980)$, $f_2(1270)$, $f_0(1500)$, $f_0(1710)$

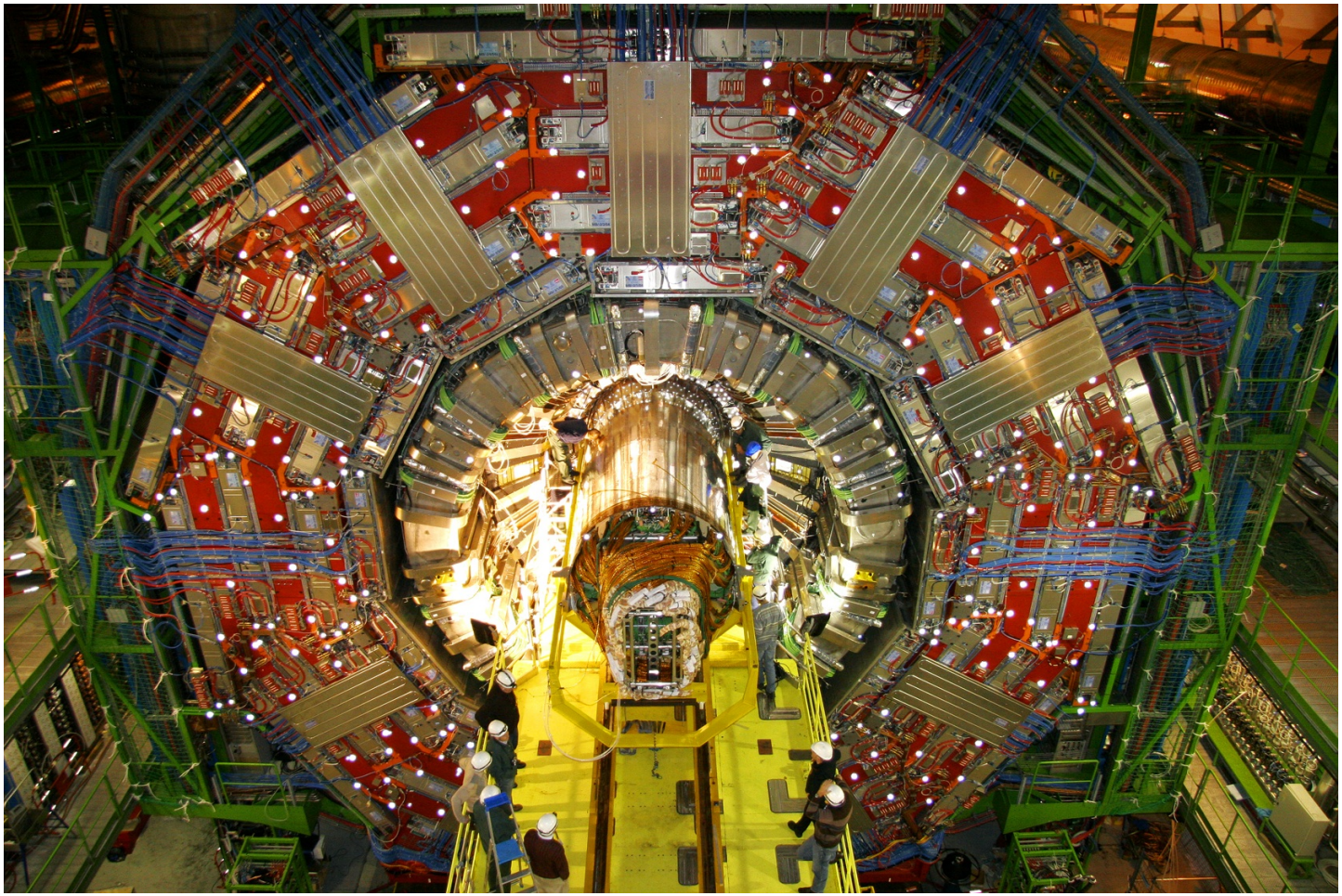


Vector meson photoproduction (VMP)
$I(J^{PC}) = 0, 1(1^{--})$

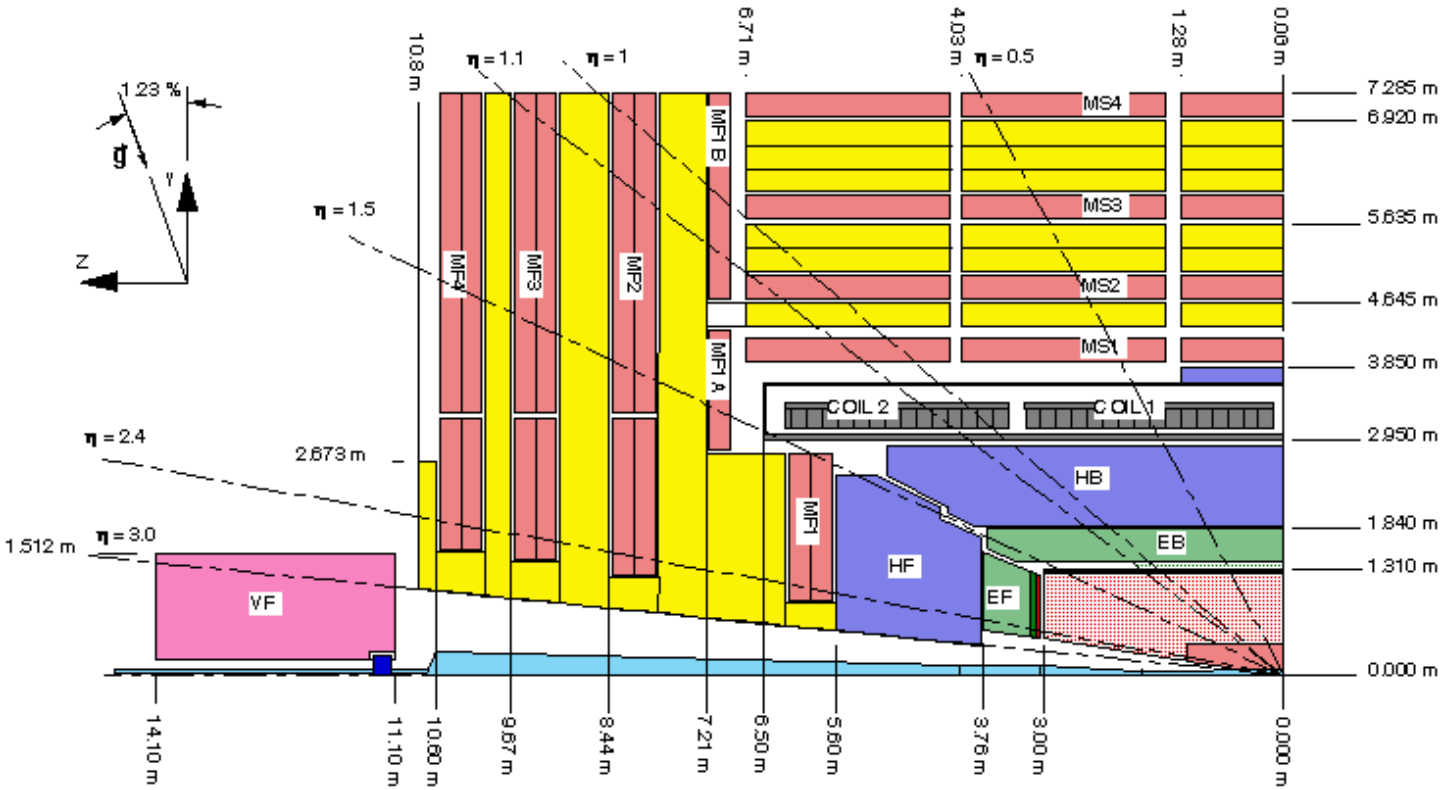
For example: $\rho(770)$, $\omega(782)$, $\phi(1020)$



The CMS detector



The CMS detector



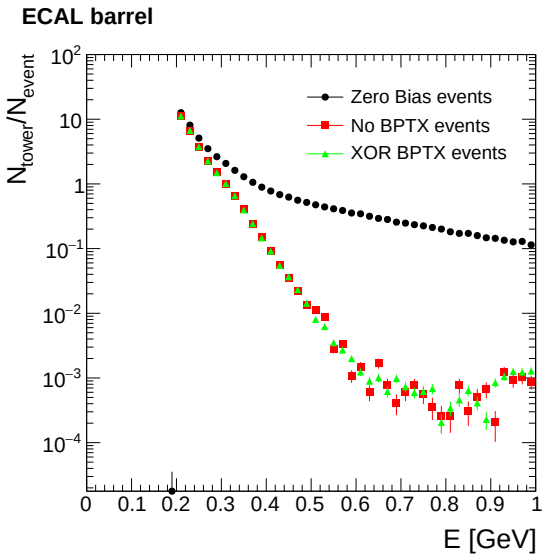
The analysis

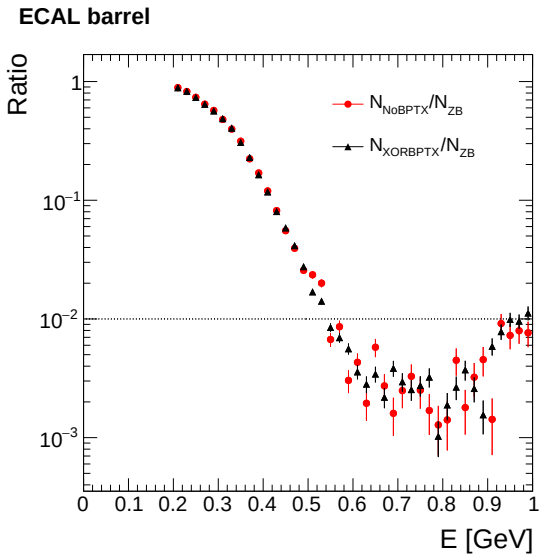
Aims: observation of particles produced in CEP

- Selection of CEP events
- Construction of invariant mass spectra
- Identifying resonances in spectra
- Estimation of resonance parameters
- Comparison with PDG results and other experiments
- (Attemp to observe $f_0(1710) \to \rho\rho$ – most probable glueball candidate)

Data: $\sim$41 million events, 13 TeV pp collisions

Calorimeter thresholds





Task: determine noise thresholds for calorimeter segments

Definition:
Noise must be below 1% of signal.

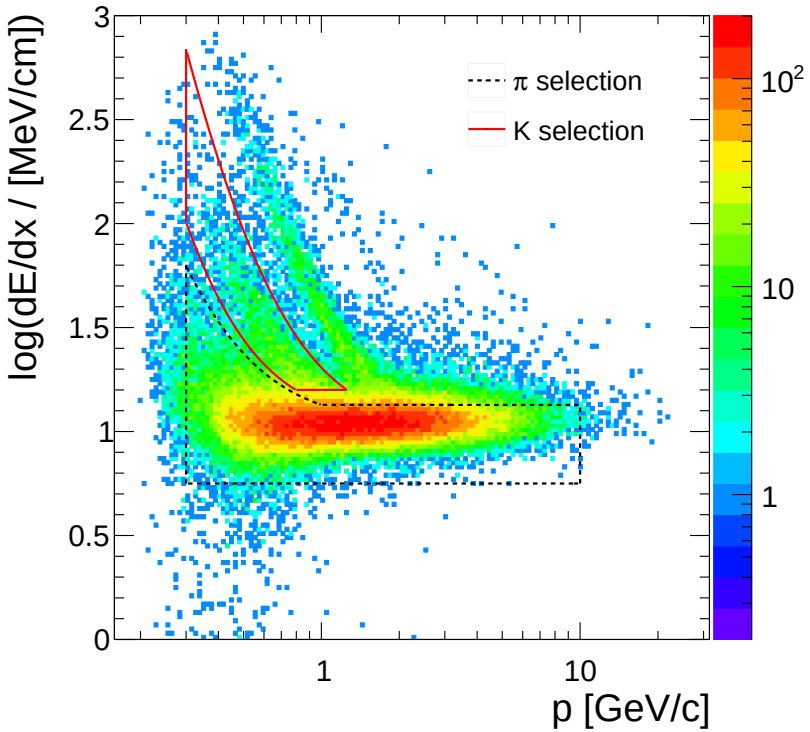
Calorimeter constituent	Threshold [GeV]
ECAL barrel	0.55
ECAL endcap	3.3
HCAL barrel	1.9
HCAL endcap	2.8
HF	6.2

Selection type	Selected events	
	Two tracks	Four tracks
All events	362431	432309
No EB	303752	329341
No EE	344299	401591
No HB	357353	423702
No HE	321659	365703
No HF	56350	34076
All criteria	45656	24245

Particle identification

Bethe-Bloch formula

$$-\left\langle \frac{dE}{dx} \right\rangle = Kq^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \left(\frac{2m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} \right) - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



Measure of mean energy-loss in tracking detector elements

- Two tracks: 57717
  - π pairs: 22192
  - K pairs: 65
- Four tracks: 68697
  - Four π: 9007

Event selection

- Track selections
  - One interaction vertex.
  - Two/four tracks, at least 5 five hits in the tracker.
- Calorimeter selections.
  - No ECAL hit over threshold.
  - No HCAL hit over threshold, except in the ring belonging to examined tracks.
  - No HF hit over threshold.
- Particle identification

Selection type	Two tracks Number of events	Four tracks Number of events
No selections	362431	432309
Only track selections	140529	149950
All track and calorimeter selections	18348	8546
All tracks are π	15082	2964
All tracks are K	66	0

Data-driven background estimation

- Non-zero total charge (NZC): non-exclusive background (due to charge conservation)
- Zero total charge (ZC): signal + non-exclusive background

Idea: estimate the background contribution to ZC sample using the NZC events. $\Rightarrow$ Simple combinatorial reasoning: number of possible combinations of different total charge events

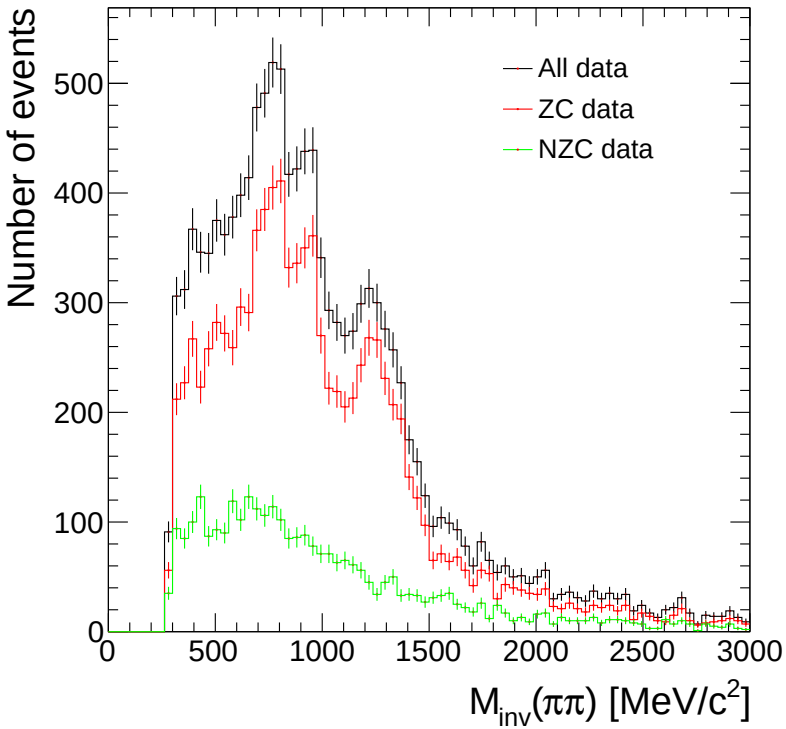
- Two-track events: CEP $=$ ZC $- 1 \cdot$ NZC

$\sum Q$	-2	0	$+2$
CEP events		$+-, -+$	
Diffractive background	$--$	$+-, -+$	$++$

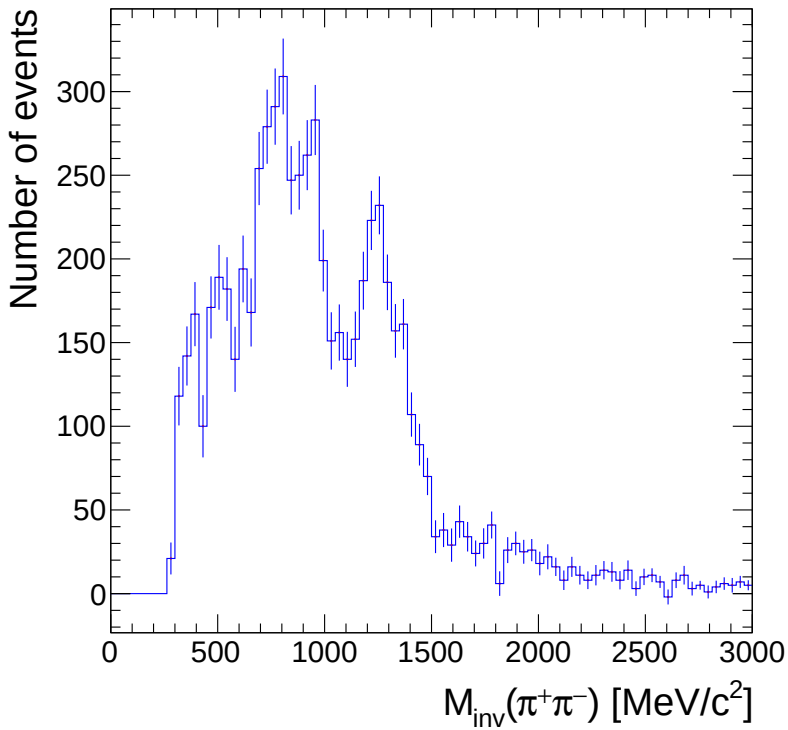
- Four-track events: CEP $=$ ZC $- 6/10 \cdot$ NZC (similarly)

$\pi\pi$ invariant mass spectrum

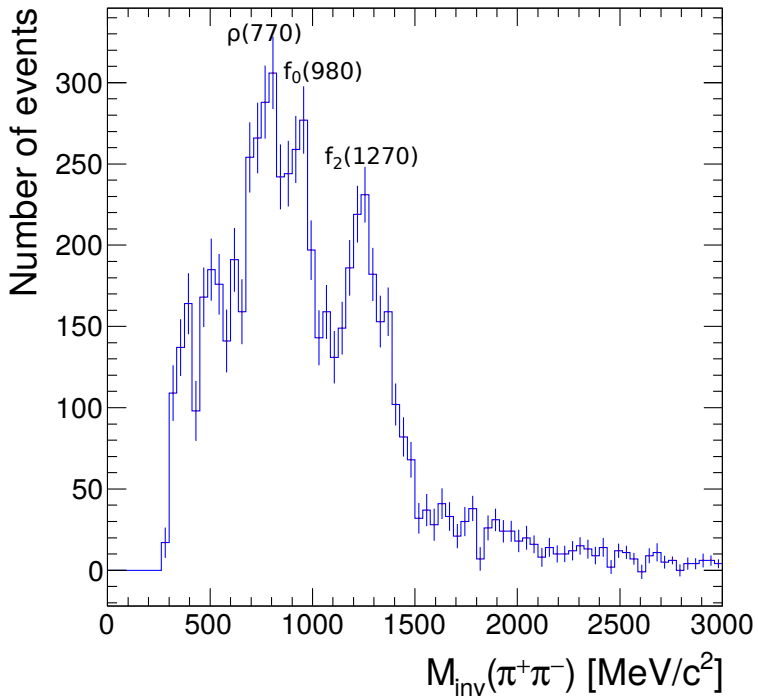
Mass spectrum



After background subtraction



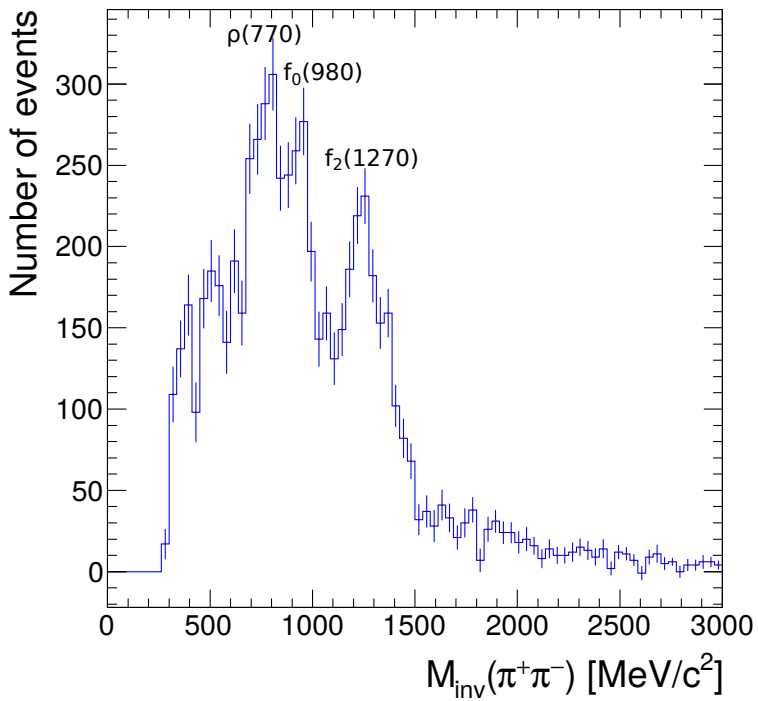
$\pi\pi$ invariant mass spectrum



Main features:

- Resonance-like structures between 250 and 600 MeV/c^2. Only compatible: $f_0(500)$, but much wider: $\Gamma = 400 - 700$ MeV/c^2. $\Rightarrow$ Particles from non-exclusive events.
- Peak at $\approx$ 800 MeV/c^2, probably $\rho(770)$. (VMP)
- Likely resonance at $\approx$ 950 MeV/c^2, probably $f_0(980)$. (DPE)

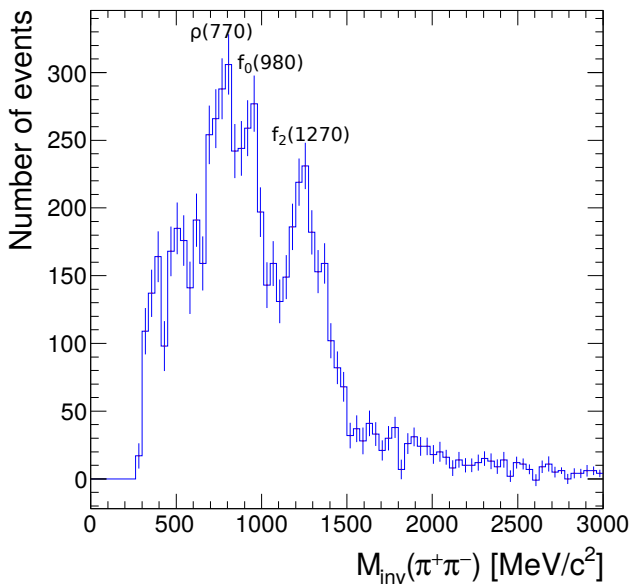
$\pi\pi$ invariant mass spectrum

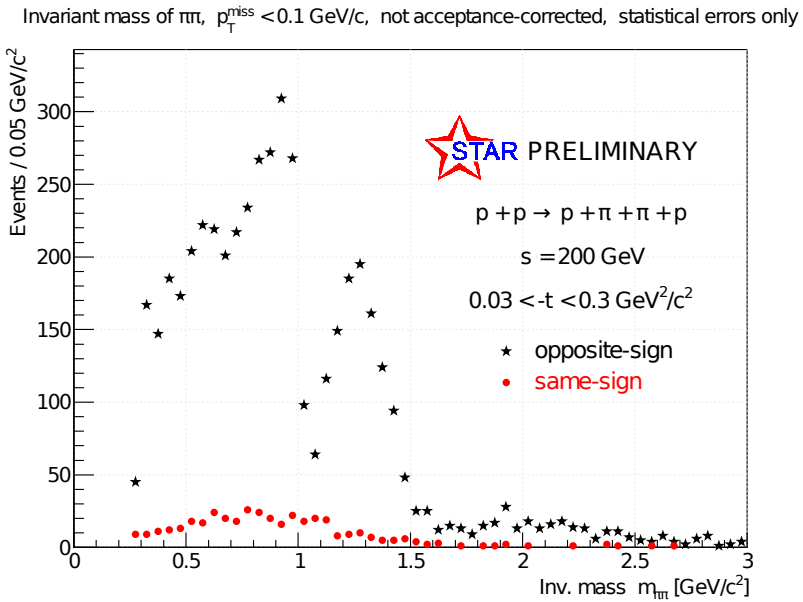


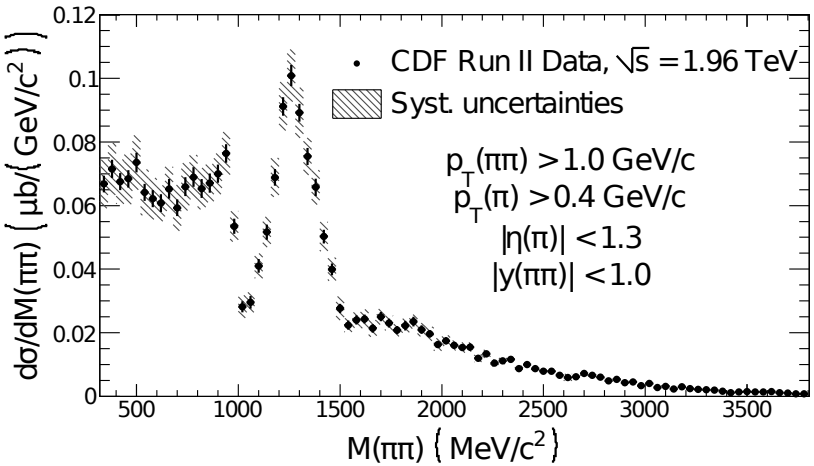
Main features:

- Sharp drop at $\approx$ 1000 MeV/c^2. Possible explanations:
  - K^+K^- threshold.
  - Destructive interference of $f_0(980)$ with some other resonance.
  - Can be fit with resonances and smooth background.
- Prominent peak at $\approx$ 1200-1300 MeV/c^2, identified as $f_2(1270)$. (DPE)

Comparison to other experiments



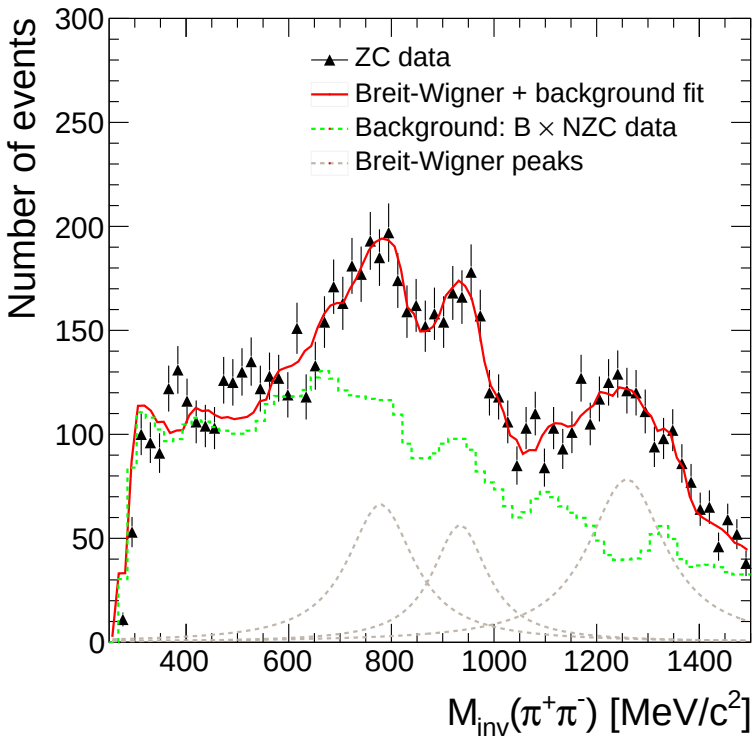




Common features:

- $\rho(770)$ at STAR
- Sharp drop at 1000 MeV/c^2
- $f_2(1270)$ resonance

$\pi\pi$ invariant mass spectrum – fit with Breit-Wigner



Fit function:

$$f(x) = B(x) + \sum_{i=1}^{3} \frac{A_i}{2\pi} \frac{\Gamma_i}{(x - M_i)^2 + \Gamma_i^2/4}$$

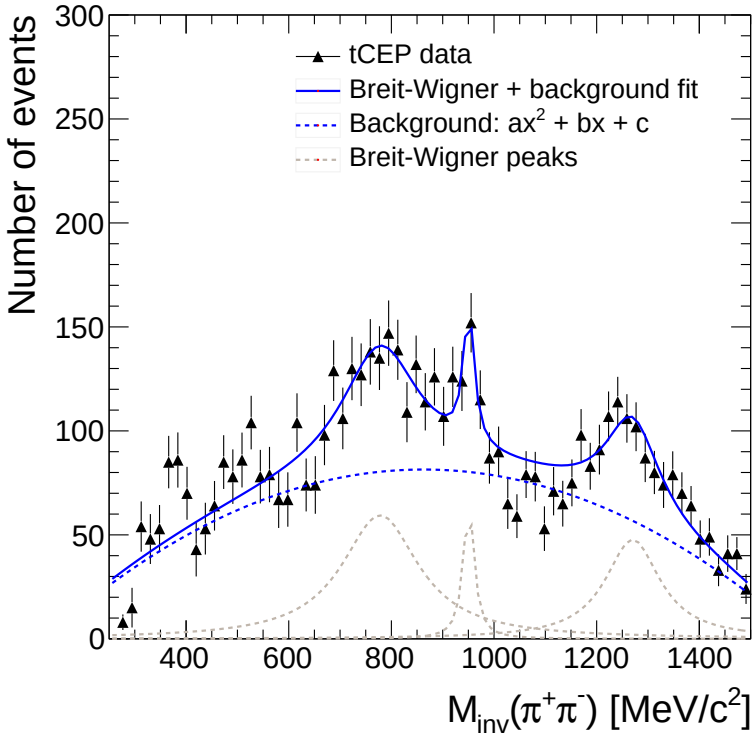
ZC data is used for the fit

Background:

$$B(x) = B \cdot \mathrm{NZC}(x).$$

Non-resonant CEP events assumed to have same distribution as NZC.

$\pi\pi$ invariant mass spectrum – fit with Breit-Wigner



Fit function:

$$f(x) = B(x) + \sum_{i=1}^{3} \frac{A_i}{2\pi} \frac{\Gamma_i}{(x - M_i)^2 + \Gamma_i^2/4}$$

CEP data is used for the fit

Background:

$$B(x) = ax^2 + bx + c$$

Comparison with PDG results

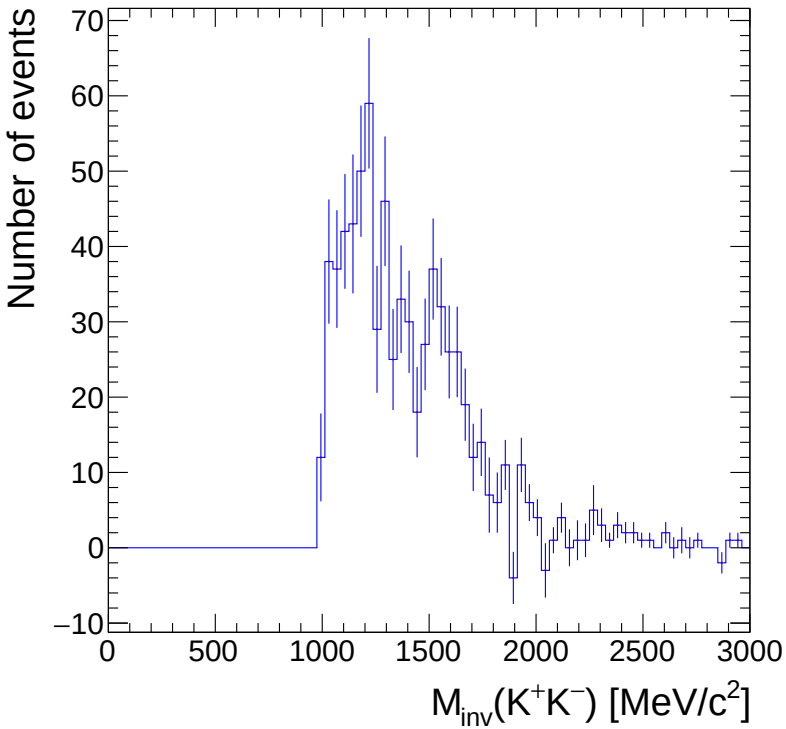
The results of the two fitting are averaged.
The differences of the two values are used to estimate systematic uncertainties.

	M_{PDG} [MeV/c^2]	M_{avg} [MeV/c^2]
$\rho(770)$	775.26 ± 0.25	779 ± 9.3 (stat) ± 1 (syst)
$f_0(980)$	990 ± 20	942 ± 8.3 (stat) ± 9 (syst)
$f_2(1270)$	1275.5 ± 0.8	1264 ± 6.4 (stat) ± 6 (syst)

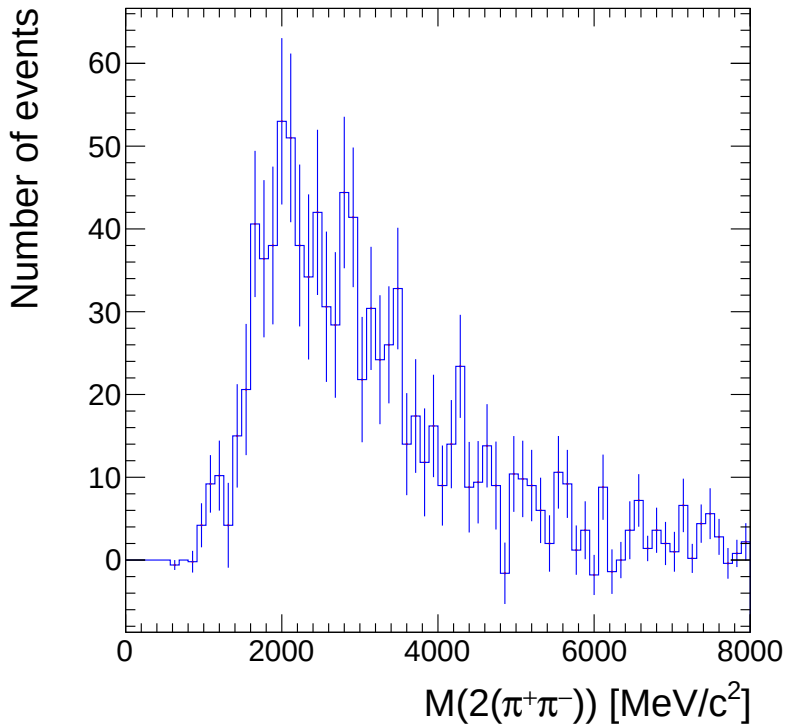
	Γ_{PDG} [MeV/c^2]	Γ_{avg} [MeV/c^2]
$\rho(770)$	149.1 ± 0.8	170 ± 29 (stat) ± 10 (syst)
$f_0(980)$	40 to 100	78 ± 23 (stat) ± 55 (syst)
$f_2(1270)$	$186.7^{+2.2}_{-2.5}$	155 ± 19 (stat) ± 25 (syst)

KK and 4π invariant mass spectrum

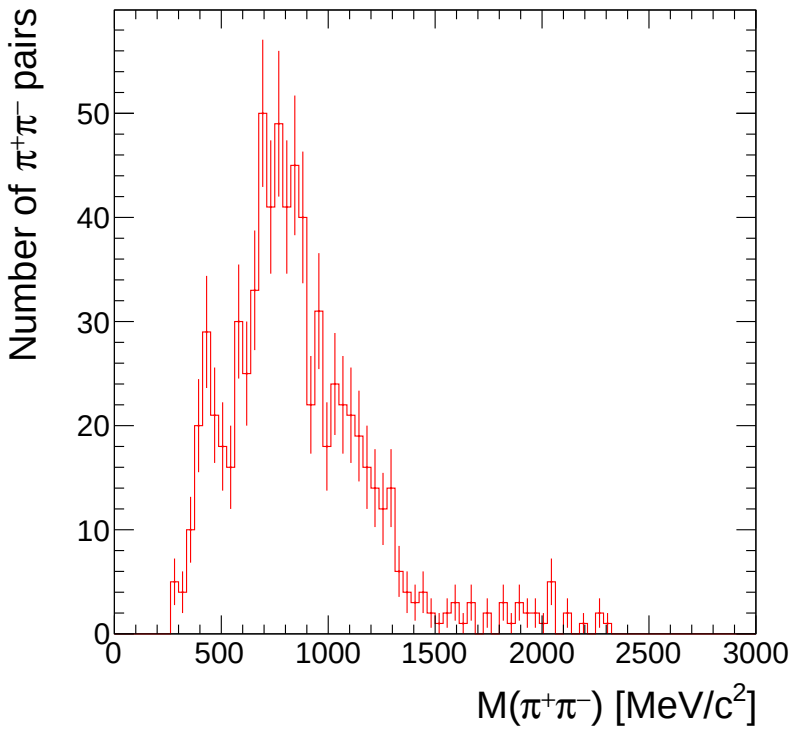
At least one is K



Four tracks are π



4π invariant mass spectrum – spectrum of π pairs

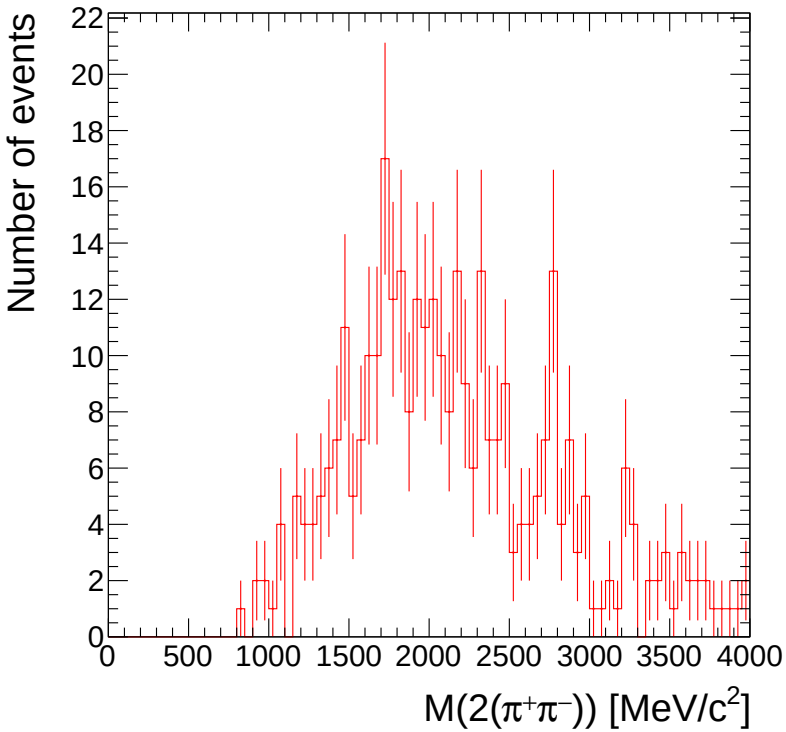


Attempt to observe
$X \to CC \to 2(\pi^+\pi^-)$ decays.
Criterion:
$|M_{\pi_1^+\pi_2^-} - M_{\pi_3^+\pi_4^-}| < 0.15$ GeV/c^2.

Results:

- $C = K_S^0$
- $C = \rho(770)$

4π invariant mass spectrum – spectrum of π pairs



Not enough events to identify peaks.
$f_0(1710) \to \rho\rho$ is expected, which is a glueball candidate.
More data is needed to reconstruct $f_0(1710)$.
Expected width:
$\Gamma \approx 139$ MeV/c^2.

Conclusions

Main results:

- Mesons are identified in $\pi\pi$ spectrum.
  - Scalar resonances: $f_0(980)$ and $f_2(1270)$
  - Vector resonances: $\rho(770)$
- The resonance parameters are calculated and compared to PDG values.
- Decays in 4π events:
  - $K_S^0 K_S^0$
  - $\rho\rho$

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Future plans:

- Improved particle identification method: maximum likelihood estimation.
- Comparison of results with MC $\rightarrow$ corrections
- Calculation of cross sections
- When more data is available: further study of KK and 4π spectra
- Other energies: for example recent 5 TeV pp runs.

Thank you for your attention!