Central exclusive $\pi^+\pi^-$ production in pp collisions at $\sqrt{s} = 5.02$ and 13 TeV in the CMS experiment

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5th December 2019

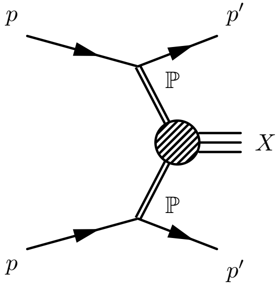
Central exclusive production

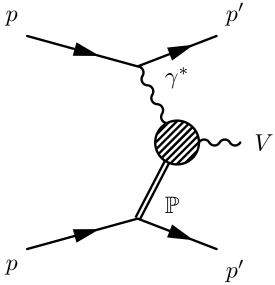
Double pomeron exchange (DPE)
$I^G(J^{PC}) = 0^+(J^{++})$, J is even

For example: $f_0(500)$, $f_0(980)$, $f_2(1270)$, $f_0(1710)$

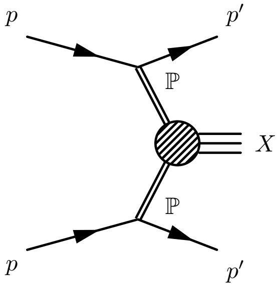
Vector meson photoproduction (VMP)
$I(J^{PC}) = 0, 1(1^{--})$

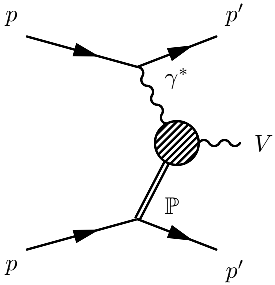
For example: $\rho(770)$, $\phi(1020)$





Central exclusive production

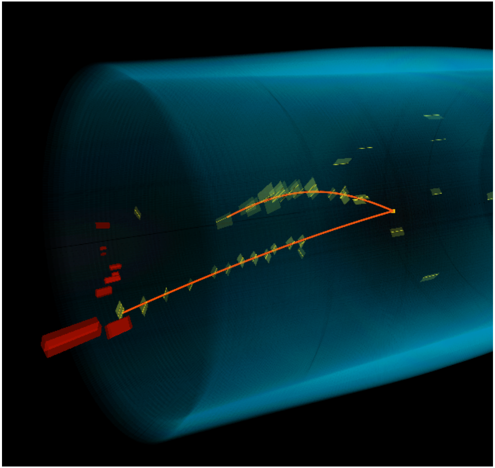




Motivations:

- Restricted quantum numbers
- Filter certain low mass resonances
- Gluon-rich environment in DPE $\rightarrow$ glueball search

Central exclusive dipion production at CMS



Measurement of total and differential cross sections of central exclusive $\pi^+\pi^-$ production in proton-proton collisions at 5.02 and 13 TeV

CMS-PAS-FSQ-16-006 – http://cds.cern.ch/record/2679648

Dataset, trigger, event selections

Dataset: low-pileup data in 2015 at

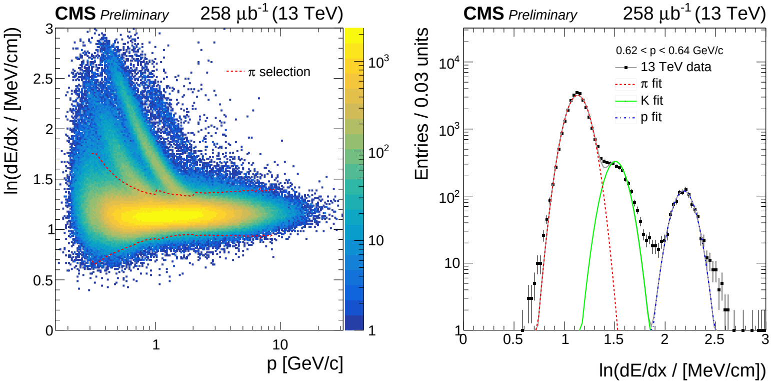
- $\sqrt{s} = 5.02$ TeV, 522 μb^{-1}
- $\sqrt{s} = 13$ TeV, 258 μb^{-1}

Trigger: random bunch-crossings (zero bias)

Event selection:

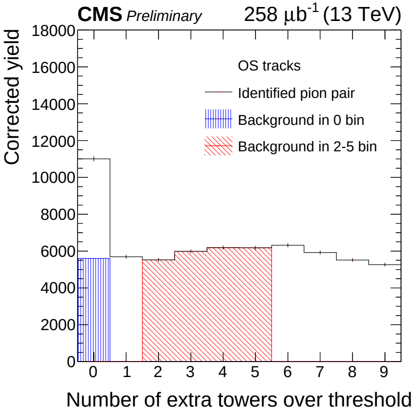
- Exactly two, oppositly charged tracks tracks
- No activity in calorimeters,
  except 3σ cone around extrapolated track hit in η and ϕ
- π identification via dE/dx
- $p_T(\pi) > 0.2$ GeV, $|\eta(\pi)| < 2.4$

Particle identification



- dE/dx measured from charge in the silicon tracker
- p-slices fitted with Gaussians
- High π identification efficiency $\rightarrow$ large K contamination, treated in the analysis

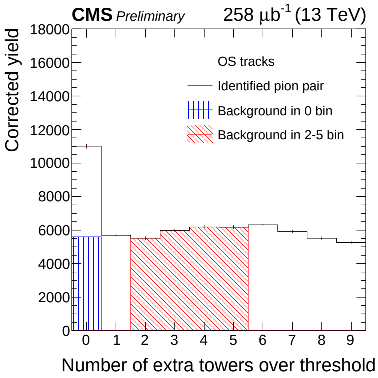
Multihadron background estimation

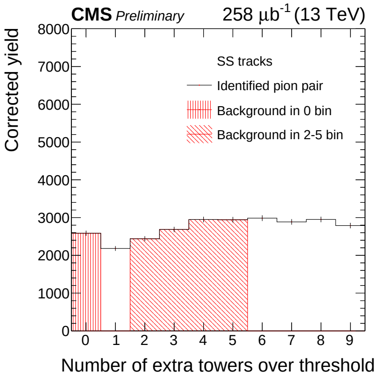


- Using a sample with extra calorimeter hits
- Background distribution from events with 2 – 5 extra calorimeter hits
- Normalization based on same sign distribution
- Systematic uncertainties from varying control region

Calorimeter	Threshold [GeV]	η coverage
ECAL barrel	0.6	$\lvert\eta\rvert < 1.5$
ECAL endcap	3.3	$1.5 < \lvert\eta\rvert < 3.0$
HCAL barrel	2.0	$\lvert\eta\rvert < 1.3$
HCAL endcap	3.8	$1.3 < \lvert\eta\rvert < 3.0$
HF	4.0	$3.15 < \lvert\eta\rvert < 5.2$

Background estimation

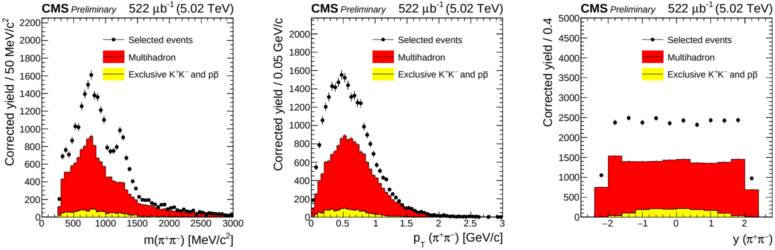




Normalization calculated from SS events using the assumption:

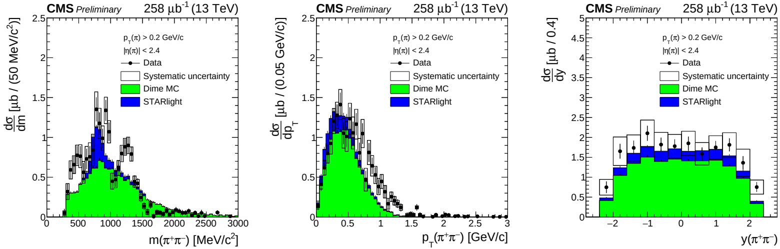
$$\frac{\text{\# OS BKG, 0 towers}}{\text{\# OS, 2-5 towers}} = \frac{\text{\# SS, 0 towers}}{\text{\# SS, 2-5 towers}}$$

Background distributions



- Multihadron background: events with 2 – 5 extra calorimeter hits
- Exclusive KK background: exclusive pairs with at least one identified kaon
  - Normalization: calculated from dE/dx fits
- Subtracting background distribution from the measured results

Results

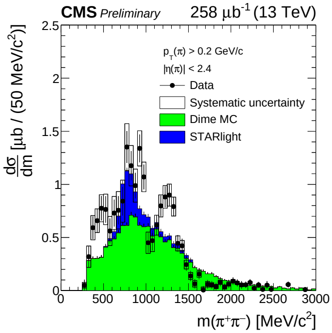


- Monte Carlo simulations:
  - STARLIGHT: exclusive $\rho(770)$ photoproduction.
  - DIME MC: DPE continuum contribution.
- No simulation describes certain low mass resonances (f_0 and f_2).
- Total exclusive $\pi^+\pi^-$ cross section in $p_T(\pi) > 0.2$ GeV, $|\eta| < 2.4$ region:

$$\sigma(\sqrt{s} = 5.02 \text{ TeV}) = 19.6 \pm 0.4\,(\text{stat.}) \pm 3.3\,(\text{syst.}) \pm 0.01\,(\text{lumi.})\ \mu\text{b}$$

$$\sigma(\sqrt{s} = 13 \text{ TeV}) = 19.0 \pm 0.6\,(\text{stat.}) \pm 3.2\,(\text{syst.}) \pm 0.01\,(\text{lumi.})\ \mu\text{b}$$

Results – invariant mass distribution



- Enhancement in $\rho(770)$ region
- Sharp drop at around 1 GeV
  - Indication of $f_0(980)$ resonance
  - Interference between resonance and continuum
- Significant peak at $f_2(1270)$
- Dime MC overestimates 1500 MeV region

Describing the mass spectrum

- QM amplitude of CEP processes:

$$A_{\text{CEP}} = A^{\pi\pi-\text{continuum}} + \sum_i A_i^{\text{resonant}}$$

- Interference appears in $\sigma \propto |A_{\text{CEP}}|^2$
- Theory results: $< 1\%$ interference between VMP and DPE
- Fit function:

$$f(x) = |A^{\rho}(x)|^2 + \left| \sum_i A_i^{\text{DPE}}(x) e^{i\phi_i} + \sqrt{b \cdot B^{\text{DIME}}(x)} \right|^2$$

$A_i(x)$: relativistic Breit-Wigner amplitude
ϕ_i: phase angle to describe interference

Describing the mass spectrum

- Fit function:

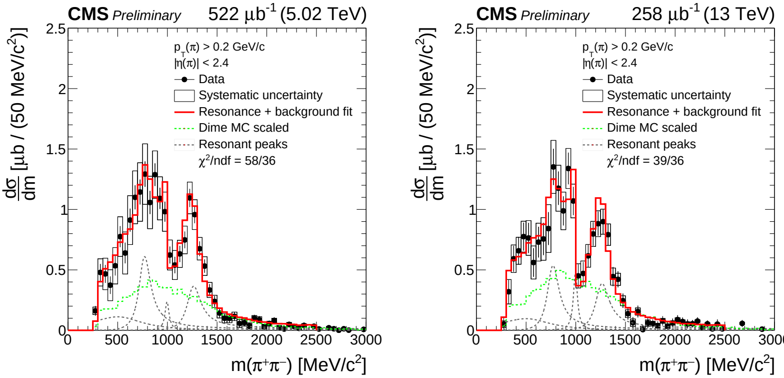
$$f(x) = |A^{\rho}(x)|^2 + \left| \sum_i A_i^{\mathrm{DPE}}(x) e^{i\phi_i} + \sqrt{b \cdot B^{\mathrm{DIME}}(x)} \right|^2$$

- Relativistic Breit-Wigner amplitudes for spin J resonance

$$A(x;J) = A_0 \frac{\sqrt{xM\Gamma(x;J)}}{x^2 - M^2 + iM\Gamma(x;J)},$$

$$\Gamma(x;J) = \Gamma_0 \frac{M}{x} \left[\frac{x^2 - 4m_\pi^2}{M^2 - 4m_\pi^2} \right]^{\frac{2J+1}{2}}$$

Results – mass fits



- $f_0(500)$, $\rho(770)$, $f_0(980)$ and $f_2(1270)$ resonances used in the fit
- Resonance yields extracted

Summary

- Exclusive dipion production at 5.02 and 13 TeV in CMS: http://cds.cern.ch/record/2679648
- Pions identified via their dE/dx
- Mass spectrum is described by four interfering Breit-Wigner resonances + continuum distribution
- Total and resonant cross sections measured

Thank you for your attention!