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

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Central exclusive production

Double pomeron exchange (DPE) 
\[ l^G(J^{PC}) = 0^+ (J^{++}), \ J \text{ is even} \]
For example: \( f_0(500), f_0(980), f_2(1270), f_0(1710) \)

Vector meson photoproduction (VMP) 
\[ l(J^{PC}) = 0, 1(1^{--}) \]
For example: \( \rho(770), \phi(1020) \)
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, $522 \mu b^{-1}$
- $\sqrt{s} = 13$ TeV, $258 \mu b^{-1}$

**Trigger:** random bunch-crossings (zero bias)

**Event selection:**
- Exactly two, oppositely charged tracks
- No activity in calorimeters, except $3\sigma$ cone around extrapolated track hit in $\eta$ and $\phi$
- $\pi$ 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 $\pi$ 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
Normalisation based on same sign distribution
Systematic uncertainties from varying control region

<table>
<thead>
<tr>
<th>Calorimeter</th>
<th>Threshold [GeV]</th>
<th>$\eta$ coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL barrel</td>
<td>0.6</td>
<td>$</td>
</tr>
<tr>
<td>ECAL endcap</td>
<td>3.3</td>
<td>$1.5 &lt;</td>
</tr>
<tr>
<td>HCAL barrel</td>
<td>2.0</td>
<td>$</td>
</tr>
<tr>
<td>HCAL endcap</td>
<td>3.8</td>
<td>$1.3 &lt;</td>
</tr>
<tr>
<td>HF</td>
<td>4.0</td>
<td>$3.15 &lt;</td>
</tr>
</tbody>
</table>
**Background estimation**

**CMS Preliminary** 258 µb⁻¹ (13 TeV)

- **OS tracks**
  - Identified pion pair
  - Background in 0 bin
  - Background in 2-5 bin

- **SS tracks**
  - Identified pion pair
  - Background in 0 bin
  - Background in 2-5 bin

**Normalization calculated from SS events using the assumption:**

\[
\frac{\# \text{ OS BKG, 0 towers}}{\# \text{ OS, 2-5 towers}} = \frac{\# \text{ SS, 0 towers}}{\# \text{ SS, 2-5 towers}}
\]
• **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
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  
  \( \phi_i \): phase angle to describe interference
Describing the mass spectrum

- Fit function:

\[
f(x) = |A^0(x)|^2 + \left| \sum_i A_i^{\text{DPE}}(x)e^{i\phi_i} + \sqrt{b \cdot B^{\text{DIME}}(x)} \right|^2
\]

- Relativistic Breit-Wigner amplitudes for spin \( J \) resonance

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

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