Partial Wave Analysis of $\pi^+\pi^-$ system produced in Double Gap collisions at $\sqrt{s} = 7$ TeV energy (with ALICE)

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## Introduction

- What do we study?
  - *Diffraction*

- What is that?
  - Appearance of *light* maxima and minima in space after *its* interaction with other objects.

- What is that in particle physics?
  - Appearance of *particle* maxima and minima in space after *some* interaction.
  - In case of pp-collisions:

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Typical diffraction picture in pp-collisions
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ISSP 2018, Erice
Classification

- Non-diffractive
  \[ \frac{dN}{dy}(\sqrt{s} = 7 \text{ TeV}) \sim 6 \Rightarrow \Delta y \sim 0.2 \]

- Single diffraction

- Double diffraction

- Central diffraction

\[ dN \]

= vacuum quantum numbers exchange

\[ \Delta y \sim \text{several units} \]
Pomeron

- **Pomeron**: colour singlet object with vacuum quantum numbers.
- The Pomeron was introduced as a Regge trajectory responsible for the growth of the total cross-section with collision energy.
- Events in which a pomeron is exchanged: diffraction.
- Thereby the study of diffraction helps in understanding nature of the Pomeron and its connection the soft QCD processes and vice versa.

\[
\sigma_{\text{tot}}(S) \sim \left(\frac{S}{S_0}\right)^{\alpha(0)-1}
\]

Regge trajectories of ordinary particles

E. Levin. An Introduction to Pomerons. TAUP 2522/98, DESY 98-120.

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)
Why study diffraction?

- Because it's there!
  - pp-collisions @ 7 TeV CME*: >30% of total Xsection is coming from diffractive processes.
    - $\sigma_{\text{tot}} \sim 100 \text{ mb}$, $\sigma_{\text{diff}} \sim 30 \text{ mb}$, only small part of it can be explained by pQCD.
  - Diffraction is dominated by soft processes → can lead a light on what's happening in non-perturbative QCD sector.

Detectors which can be used in diffractive studies:

- tracking detectors (with PID)
- forward “gap” detectors
Excellent PID for low momentum particles: opportunity to study central production in various channels ($\pi\pi$, KK, ...)

**ITS**

**TPC**

**TRD**

**TOF**
ALICE PSEUDORAPIDITY COVERAGE

- VZERO-C: -3.7 to -1.7
- FMD-C: -3.4 to -1.7
- Barrel: -0.9 to 0.9
- SPD outer layer: -1.5 to 1.5
- SPD inner layer: -2 to 2
- VZERO-A: 2.8 to 5.1
- FMD-A: 1.7 to 5.0

Gap C: -3.7 < η < -0.9
Tracks: -0.9 < η < 0.9
Gap A: 0.9 < η < 5.1

Total pseudorapidity coverage is almost 9 units!
According to Regge theory, all contributions to CP die out with increasing energy, except pomeron-pomeron fusion.

Enhancement of $0^{++}, 2^{++}, ...$ resonances production and suppression of other resonances production is expected in double-pomeron exchange.
Partial Wave Analysis?

Mass of 2track double gap events, all tracks assumed to be pions

Not corrected for efficiency and acceptance

\begin{itemize}
  \item Partial Wave Analysis is needed to proof observation of:
    \begin{itemize}
      \item \( f_0(980) \) spin 0 particle, should appear as S-wave (L=0);
      \item \( f_2(1270) \) spin 2 particle, should appear as D-wave (L=2);
    \end{itemize}
\end{itemize}
$f_2(1270)$

Mass of 2track double gap events, all tracks assumed to be pions

- $f_2(1270)$ signal expected to be very clean as:
  - Left: all the low-mass background goes to S an P waves as there are no expected spin 2 states lighter than $f_2(1270)$ in DPE;
  - Right: background seems to be negligible.
Resonance shape

- It's common to use Breit-Wigner distribution to fit resonance peak;
- However the shape of resonance strongly depends on its production mechanism.

Most simple parametrisation of differential cross section for DPE can be expressed as:

\[
d\sigma_{p_1p_2 \rightarrow p_1Xp_2} = e^{bt_1} (1 - x_1)^{1-2\alpha_F(t_1)} e^{bt_2} (1 - x_2)^{1-2\alpha_F(t_2)} \sigma_{\text{PPPP} \rightarrow X} dx_1 d^2q_1 dx_2 d^2q_2
\]

- Continuum mass production:

\[
\sigma_{\text{PPPP} \rightarrow X \rightarrow \pi^+\pi^-} \propto \frac{p_{\pi}}{M_X} e^{-2p_{\pi}^2}
\]

- Resonance production: Breit-Wigner convoluted with Pomeron-Pomeron flux.
Simple MC modelling

- Simple MC generator is developed to simulate continuum mass and resonance production in DPE process.

### Convolution of dropping continuum mass and Breit-Wigner distribution leads to change of resonance shape!

<table>
<thead>
<tr>
<th>Mass, MeV</th>
<th>Width, MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1275.5</td>
<td>185.9</td>
</tr>
<tr>
<td>1255±1</td>
<td>167±1</td>
</tr>
</tbody>
</table>

Mass, MeV | Width, MeV |
-----------|------------|
PDG        | 1275.5     | 185.9      |
Fit results| 1255±1     | 167±1      |
Theoretical predictions

- Anthony Szczurek, Otto Nachtmann and Piotr Lebiedowicz developed a model for DPE: continuum production + $f_0(980) + f_2(1270)$ where several PPf2 couplings are considered.

\[ M_{\lambda_a\lambda_b \rightarrow \lambda_1\lambda_2 \pi^+\pi^-} \simeq -3\beta_{\mathbb{P}NN}2(p_1 + p_a)^{\mu_1}(p_1 + p_a)^{\nu_1}\delta_{\lambda_1\lambda_2}F_1(t_1) \frac{1}{4s_1}(-is_1\alpha'_{\mathbb{P}})^{\alpha_{\mathbb{P}}(t_1)-1} \]

\[ \times \Gamma^{(\mathbb{P}f_2)}_{\mu_1\nu_1,\mu_2\nu_2,\rho\sigma}(q_1, q_2)\Delta^{(f_2)\rho\sigma,\alpha\beta}(p_{34}) \frac{g_{f_2\pi\pi}}{2M_0}(p_3 - p_4)_\alpha(p_3 - p_4)_\beta F^{(f_2\pi\pi)}(s_{34}) \]

\[ \times \frac{1}{4s_2}(-is_2\alpha'_{\mathbb{P}})^{\alpha_{\mathbb{P}}(t_2)-1}3\beta_{\mathbb{P}NN}2(p_2 + p_b)^{\mu_2}(p_2 + p_b)^{\nu_2}\delta_{\lambda_2\lambda_b}F_1(t_2). \]

\[ i\Gamma^{(\mathbb{P}f_2)}_{\mu_\nu,\kappa\lambda,\rho\sigma}(q_1, q_2) = \left( i\Gamma^{(\mathbb{P}f_2)}_{\mu_\nu,\kappa\lambda,\rho\sigma}(1) \right|_{\text{bare}} + \sum_{j=2}^{7} i\Gamma^{(\mathbb{P}f_2)}_{\mu_\nu,\kappa\lambda,\rho\sigma}(j, q_1, q_2) \right|_{\text{bare}} \right) \tilde{F}^{(\mathbb{P}f_2)}(q_1^2, q_2^2, p_{34}^2). \]

\[ f_2(1270) \text{ propagator} \quad i\Delta^{(f_2)}_{\mu_\nu,\kappa\lambda}(p_{34}) = \frac{i}{p_{34}^2 - m_{f_2}^2 + im_{f_2}\Gamma_{f_2}} \]

\[ \times \left[ \frac{1}{2} (\hat{g}_{\mu\kappa}\hat{g}_{\nu\lambda} + \hat{g}_{\mu\lambda}\hat{g}_{\nu\kappa}) - \frac{1}{3} \hat{g}_{\mu\nu}\hat{g}_{\kappa\lambda} \right], \]
Theoretical predictions

- Anthony Szczurek, Otto Nachtmann and Piotr Lebiedowicz developed a model for DPE: continuum production + $f_0(980) + f_2(1270)$ where several PPf2 couplings are considered.

Contributions from different couplings. Note mass shift and change of the shape in general.

Experimental data needed to estimate PP-resonance coupling constants.

Background-free peak of $f_2(1270)$ in D-waves will provide extremely helpful constraints on PPf2 coupling constants.

Phys. Rev. 93, 054015 (2016)
Instead of conclusion...

- ALICE will provide a very interesting result on resonance production in DG pp-collisions:
  - First full-scale PWA at LHC experiments;
  - The result will help in tuning theoretical models.

Now the results are being discussed internally in the ALICE collaboration.

Thank you!