Diffractive physics in ALICE

- ALICE detector
- Diffractive trigger in ALICE
- Signatures of soft/hard Pomeron
- Signatures of Odderon
- Photoproduction of heavy quarks
- Conclusions, outlook
The ALICE experiment

Acceptance
central barrel

\(-0.9 < \eta < 0.9\)

Acceptance
muon spectr.

\(2.5 < \eta < 4.\)
ALICE diffractive gap trigger

→ additional forward detectors (no particle identification)
  \[ 1 < \eta < 5 \]
  \[ -4 < \eta < -1 \]

→ definition of gaps \( \eta_+ \), \( \eta_- \)

Luminosity \( L = 5 \times 10^{30} \text{ cm}^{-2} \text{s}^{-1} \):

→ one interaction/ 80 bunches
diffractive L0 trigger (hardware):
gap \( \eta_+ \): \( 3 < \eta < 5 \) \( \Delta \eta \sim 0.5 \)
gap \( \eta_- \): \( -2 < \eta < -4 \) \( \Delta \eta \sim 0.5 \)

high level trigger (software):
  \( -3.7 < \eta < 5 \)
ALICE forward calorimeter

- neutron calorimeter on each side
  - Placed at 116 m from interaction region
  - Measures neutral energy at 0°
- Diffractive events:
  - $pp \rightarrow ppX$ : no energy in zero degree calorimeter
  - $pp \rightarrow pN*X$ : energy in one calorimeter
  - $pp \rightarrow N*N*X$ : energy in both calorimeters

(no Roman pots for proton tagging)
Acceptance LHC experiments

- **ALICE:**
  - trigger central barrel tracks $p_T > 500$ MeV/c (+ *gap trigger*)
  - Electron identification in TPC, TRD
  - tracking inner detectors $> 50$ MeV/c

- **CMS:**
  - calorimeter trigger $> 4$ GeV
  - muon trigger $> 3.5$ GeV/c
  - Tracking inner detector $> 0.3$ GeV/c

→*good ALICE acceptance for $\phi$, J/Psi, $\Psi$ by electron decays*
ALICE pseudorapidity acceptance

- ALICE acceptance matched to diffractive central exclusive production

\[ \Delta \eta \sim 3 \quad \Delta \eta \sim 4 \]

\[ \phi \quad \text{gap} \quad \text{had} \quad \text{gap} \]

\[ \eta \]
Signatures soft/hard pomeron

Pomeron intercept controls the energy dependence of cross section at high energy

\[ \sigma_{pp} = X s^{\varepsilon_1} + Y s^{\varepsilon_2} \]

→ Fits to data (Donnachie, Landshoff 1992): \( \varepsilon_1 \sim 0.08, \varepsilon_2 \sim -0.5 \)

well supported by HERA measurement of \( \gamma p \) total cross section

→ expect \( F_2 \) at small \( x \) (HERA): \( F_2(x,Q^2) \sim A_1(Q^2) x^{-\varepsilon_1} + A_2(Q^2) x^{-\varepsilon_2} \)

→ \( F_2 \) data need additional term \( \sim A_0(Q^2) x^{-\varepsilon_0} \) with \( \varepsilon_0 \sim 0.4 \)

→ hard pomeron: \textit{Is it needed in} \( \sigma_{pp} \) ?

\textit{P.V. Landshoff, Blois Conf. 2005:} \( \sigma_{pp} = 125 \pm 25 \) mb
Observables soft/hard pomeron

- Diffractive events with soft/hard scale: $P_T \lesssim P_{\text{Thresh}}$
  - Diffractive central system: $P_T$ distr, multiplicity, mass
  - Correlations $P_T$ – multiplicity – mass
- Look at these observables as function of gap width
- Mass distribution: $\frac{d\sigma}{dM^2} \sim \frac{1}{M^2}$, look at $\lambda = \lambda(P_{\text{Thresh}})$
- Correlate with zero degree calorimeter information
The Odderon

- Consider processes: $a + b \rightarrow a + b$, amplitude $A^{ab}(s,t)$
  $a + b \rightarrow a + b$, amplitude $A^{a\overline{b}}(s,t)$

- Define: $A_\pm(s,t) = \frac{1}{2} (A^{ab}(s,t) \pm A^{a\overline{b}}(s,t))$
  
  $A^{ab}(s,t) = A_+(s,t) + A_-(s,t)$
  $A^{a\overline{b}}(s,t) = A_+(s,t) - A_-(s,t)$

  $A_+$ identical for both processes, *positive C-parity*: Pomeron

  $A_-$ changes sign, *negative C-parity*: Odderon, (Photon)

  $\rightarrow$ *mesonic reggeon contributes to $A_-$*

  $\rightarrow$ *Odderon is part of $A_-$ which doesn`t vanish rapidly with $s$*
Signature Odderon cross section

Look at exclusive processes with rapidity gaps

Examples:

**diffractive pseudo scalar and tensor meson production:**
- $C = +1$ states

**diffractive vector meson production:**
- $C = -1$ states

→ **measure cross sections**
The hunt for the Odderon

- Production cross sections in pp at LHC energies
  - diffractive production: $\pi^0, \eta, \eta_c(J^{PC}=0^{-+}), f_0(0^{++}), a_2(2^{++})$
  - contributions from Photon-Photon, Photon-Odderon, Odderon-Odderon

- Look for diffractive $J/\Psi$ production: $J^{PC}=1^{--}$
  - Photon-Pomeron, Odderon-Pomeron contributions

→ such an experimental effort is a continuation of physics programs carried out at LEP ($\gamma\gamma$) and HERA ($\gamma$-Odderon)
Odderon experimental status

- Odderon searches at HERA:
  - $\gamma p \rightarrow p\pi^0$ *published, no signal found*
  - $\gamma p \rightarrow p\eta_c$ *analysis ongoing?*
- Weak evidence for Odderon by comparing pp and $p\bar{p}$ scattering data at CERN-ISR at $\sqrt{s} = 53$ GeV in the dip region at $|t| \sim 1.5$ GeV$^2$

  → *LHC: How large are cross sections? Interference effect*

  → Donnachie, Dosch, Landshoff, Nachtmann: ‘Pomeron physics and QCD‘
  "The continuing non-observation of the Odderon would have a major impact on our understanding of diffractive phenomena"
Diffractive $J/\Psi$ production in pp at LHC

- First estimates by Schäfer, Mankiewicz, Nachtmann 1991
- pQCD estimate by Bzdak, Motyka, Szymanowski, Cudell
  - Photon: t-integrated $\frac{d\sigma}{dy}\bigg|_{y=0} \sim 15$ nb (2.4 - 27 nb)
  - Odderon: t-integrated $\frac{d\sigma}{dy}\bigg|_{y=0} \sim 0.9$ nb (0.3 - 4 nb)

At $L = 5 \times 10^{30}$ cm$^{-2}$s$^{-1}$:

$\rightarrow$ 0.15 $J/\Psi$ in ALICE central barrel in 1 s, 150k in $10^6$ s

$\rightarrow$ 9000 in $e^+e^-$ channel in $10^6$ s

$\rightarrow$ identify Photon and Odderon contribution by analysing $p_T$ distribution (Odderon harder $p_T$ spectrum)
Signature Odderon interference

- Cross sections contain squared Odderon amplitudes

→ Odderon-Pomeron interference!

\[ d\sigma \sim |A_\gamma(A_P + A_O)|^2 \, d^Nq \]
\[ \sim |A_P|^2 + 2\text{Re}(A_PA_O^*) + |A_O|^2 \]

→ look at final states which can be produced by Odderon or Pomeron exchange

→ find signatures for interference of C-odd and C-even amplitude
Interference signal

- Interference effects (relative contribution \( C = -1 \))
  - Asymmetries in \( \pi^+\pi^- \) and \( K^+K^- \) pairs (\( C = \pm 1 \)) in continuum
  - Charge asymmetry relative to polar angle of \( \pi^+ \) in dipion rest frame

\[ C\text{-even: } \vec{P}_{\text{sum}}: \text{sum of transverse momenta of } \pi^+, \pi^- \]
\[ C\text{-odd : } \vec{P}_{\text{diff}}: \text{difference of transverse momenta of } \pi^+, \pi^- \]

\( \rightarrow \) look at distribution of angle \( \alpha \) (\( \vec{P}_{\text{diff}} \) relative to \( \vec{P}_{\text{sum}} \))

\( C\)-transformation: \( \alpha \rightarrow \alpha + \pi \)

\( \rightarrow \) signature in coefficients of Fourier series \( e^{i\alpha} \)
Incl. heavy quark photoproduction in pp @ LHC

- Photoproduction of $Q\bar{Q}$
  - Photon fluctuates into $Q\bar{Q}$,
  - Interacts as color dipole
- $\sigma_{\text{dip}}(x,r) = 2 \int d^2b \{1 - S(x,r,b)\}$
- S matrix element $S(x,r,b) = \exp(-r^2 \frac{Q_s^2(x,b)}{4})$
- $Q\bar{Q}$-production cross section in pp-collisions
- $\sigma(pp \rightarrow Q\bar{Q} pp) = 2 \int d\omega \frac{\text{d}n_p^{pp} (\omega)}{\text{d}\omega} \sigma_{\gamma p \rightarrow Q\bar{Q}(W\gamma_h)} d\omega$

<table>
<thead>
<tr>
<th>$Q\bar{Q}$ (LHC)</th>
<th>Collinear pQCD</th>
<th>CGC model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$cc$</td>
<td>16 $\mu$b</td>
<td>5 $\mu$b</td>
</tr>
<tr>
<td>$bb$</td>
<td>230 nb</td>
<td>110 nb</td>
</tr>
</tbody>
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Goncalves, Machado
Diffractive Photoproduction of heavy quarks

- Advantage of diffractive photoproduction
  - Clear final state defined by two rapidity gaps

Goncalves, Machado

<table>
<thead>
<tr>
<th></th>
<th>pp</th>
<th>pPb</th>
<th>PbPb</th>
</tr>
</thead>
<tbody>
<tr>
<td>c\bar{c}</td>
<td>92 nb</td>
<td>54 \mu{b}</td>
<td>59 mb</td>
</tr>
<tr>
<td>b\bar{b}</td>
<td>0.2 nb</td>
<td>0.09 \mu{b}</td>
<td>0.01 mb</td>
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</table>

pPb mode: \( L = 10^{29} \text{ cm}^{-2}\text{s}^{-1} \rightarrow R(\text{c\bar{c}}) \sim 5 \text{ Hz} \)
Acceptance \( \sim 10 \% \), Efficiency \( \sim 50 \% \) \( \rightarrow R(\text{c\bar{c}}) \sim 20k \text{ per day} \)

Heavy quarks can also be produced by central exclusive diffraction, ie two pomeron fusion \( \rightarrow \) harder spectrum of quarks, hence could be disentangled in p_{T} spectrum
Conclusions, outlook

- ALICE has unique opportunity to do diffractive physics
- Diffractive trigger defined by two rapidity gaps
- Neutron tagging at zero degree
- Phenomenology of Pomeron/Odderon
- Photon-Photon physics
Photoproduction of heavy quarks in pA/AA

- $\gamma p$ cross section is input to pA/AA coherent process.

$$\sigma(pA \rightarrow Q\bar{Q} pA) = \int \frac{d n_{\gamma p}(\omega)}{d \omega} \sigma_{\gamma p \rightarrow Q\bar{Q}(\omega)} d \omega$$

<table>
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<tr>
<th>$Q\bar{Q}$</th>
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<tbody>
<tr>
<td>$cc$</td>
<td>8 mb</td>
<td>5 mb</td>
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<tr>
<td>$bb$</td>
<td>40 $\mu$b</td>
<td>80 $\mu$b</td>
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</table>

**pA @ LHC**

Goncalves, Machado

**PbPb @ LHC**

Goncalves, Machado
EPJC 31 (2003)

<table>
<thead>
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<th>$Q\bar{Q}$</th>
<th>Collinear pQCD</th>
<th>CGC model</th>
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<tbody>
<tr>
<td>$cc$</td>
<td>1200 mb</td>
<td>633 mb</td>
</tr>
<tr>
<td>$bb$</td>
<td>5 mb</td>
<td>8 mb</td>
</tr>
</tbody>
</table>
Trigger rates

- pp @ 14 TeV: $L = 5 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$

\[ \text{TOF} = \text{TOF MULT}, \text{NV0} = V0A \text{ mult} = V0C \text{ mult} \]

<table>
<thead>
<tr>
<th>NV0=0</th>
<th>NV0&lt;3</th>
<th>NV0&lt;5</th>
<th>NV0&lt;7</th>
<th>NV0=0 + topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOF ≥ 2</td>
<td>TOF ≥ 2</td>
<td>TOF ≥ 2</td>
<td>TOF ≥ 2</td>
<td>~ 5 Hz</td>
</tr>
<tr>
<td>100 Hz</td>
<td>1.7 kHz</td>
<td>6.5 kHz</td>
<td>15 kHz</td>
<td>~ 5 Hz/µb</td>
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<tr>
<td>1.1 kHz</td>
<td>7.0 kHz</td>
<td>20 kHz</td>
<td>36 kHz</td>
<td>~ 1 /µb</td>
</tr>
</tbody>
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PYTHIA

→ different downscaling for NV0=0, NV0=0 + topology
→ need additional TRD L0 inputs to CTP

Rainer Schicker, Uni Heidelberg  
EDS07 conference, May 21-25, 2007, DESY