Diffractive production of mesons

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may 29, 2014
Introduction to Diffraction

Diffraction in Regge phenomenology - QCD

Interest in Central Diffraction

Experimental results from COMPASS

Experimental results from RHIC

Experimental results from TEVATRON

Experimental results from LHC
**Diffraction**

- Diffraction in optics

  diffraction pattern of a red laser after passing through a small circular hole (→ *Huygens principle*)

- Diffraction in nuclear physics: Landau-Pomeranchuk, 1953

  Good and Walker, 1960: A phenomenon is predicted in which a high-energy particle beam undergoing diffractive scattering from a nucleus will acquire components corresponding to various products of the virtual dissociations of the incident particle. These diffractively produced systems would have a characteristic narrow distribution in transverse momentum and would have the same quantum numbers as the initial state.
Diffraction in hadronic physics

- In a diffractive reaction, no quantum numbers are exchanged between the particles colliding at high energies.
- A diffractive reaction is characterized by a large rapidity gap in the final state (Bjorken, 1993).
  - non-diffractive events: \( \frac{dN}{d\Delta \eta} \sim e^{-\Delta \eta} \)
  - diffractive events: \( \frac{dN}{d\Delta \eta} \sim \text{constant} \)

- Experimental signatures of diffractive events:
  - events with very forward beam particles, or beam fragments
  - events with large rapidity gaps

- Traditional framework for hadronic diffraction is Regge theory.
  - Hadronic interaction is described by an exchange of objects (→ Reggeons), and characterized by their Regge trajectory
  - At high energy, the Pomeron trajectory dominates
  - Regge language: Diffractive reactions are Pomeron induced
Hadron-hadron cross section

Donnachie-Landshoff fits: $\sigma_{tot} = X \cdot s^{0.08} + Y \cdot s^{-0.45}$
Event topologies

- elast. scattering
- single diff. diss.
- double diff. diss.
- central prod.
- central prod./single diss.
- central prod./double diss.

- Pomerons and Reggeons contribute to these topologies
- Rapidity gaps can also be due to photon and $W^\pm$-exchange
- Are there reactions to which only Reggeons contribute? 
  \(\rightarrow\ \text{yes, charge exchange reactions}\)
- Pomerons and photons contribute differently in pp, pA and AA
Modeling of high-energy soft reactions

- physics of exchanges, Regge regime $\sqrt{s} \to \infty$, $\sqrt{|t|} \leq 1 \text{GeV}$

- exchanges: Pomeron $\mathcal{P}$, Reggeons $f_2, a_2, \omega, \rho$
  
  - elastic scattering: $p + p(\bar{p}) \to p + p(\bar{p})$
  - photoproduction: $\gamma + p \to \rho^0 + p$
  - central production: $p + p \to p + \text{meson} + p$
  
  - $\pi + p \to \pi + p$
  - $\gamma + \gamma \to \rho^0 + \rho^0$

- O. Nachtmann et al., Trento workshop march 2012:
  Marriage between Regge theory and QFT, based on effective propagators and vertices, Pomeron exchange emerges as an effective rank-two tensor exchange
  "A Model for Soft High-Energy Scattering: Tensor Pomeron and Vector Odderon", Annals Phys. 342 (2014) 31

- P. Lebiedowicz et al., "Exclusive central diffractive production of scalar and pseudoscalar mesons tensorial vs. vectorial pomeron", Annals Phys. 344 (2014) 301

→ talk P. Lebiedowicz, monday 18:10 h
The study of the strong interaction is now a mature subject - we have a theory of the fundamentals* (QCD) that is correct* and complete*.

Regge phenomenology is strikingly successful, both in scattering and spectroscopy, but its QCD foundations are weak.

Experimentalists understanding:

In QCD, the Pomeron is a (reggeized) multi-gluon exchange in colour singlet state.
**Interest in Central Diffraction**

- The environment of two Pomerons fusing and hadronizing is a gluon rich environment, hence an interesting place to look for glueballs and hybrids.

- The mother of all central measurements done with the Axial Field spectrometer at CERN ISR (pp @ $\sqrt{s} = 63$ GeV).

A Search for Glueballs and a Study of Double Pomeron Exchange at the CERN Intersecting Storage Rings, Nucl. Phys. B264 (1986) 154

![Axial Field Spectrometer](image)

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The COMPASS experiment at SPS

Beams from CERN SPS
- 190 GeV/c $\pi^-, K^-$
- 190 GeV/c $\rho, \pi^+, K^+$

Targets
- liquid $H_2$
- nuclear targets (Pb, Ni, W)

Two-stage magnetic spectrometer
- Large angular acceptance
- Broad kinematic range
- Tracking, calorimetry, particle ID

Accessible final states:
- Charged ($\pi^\pm, p, ..$)
- Neutral ($\pi^0, \eta, ..$)
- Kaonic ($K^\pm, K_s, ..$)

A. Austregesilo
SaporeGravis Workshop, dec 2-5, 2013
Experimental results from COMPASS

\[ \sqrt{s} = 12.7 \text{ GeV}/c^2 \]
\[ \sqrt{s} = 18.9 \text{ GeV}/c^2 \]
\[ \sqrt{s} = 23.7 \text{ GeV}/c^2 \]

- Production of \( \rho(770) \) disappears rapidly with increasing \( \sqrt{s} \)
- Low-mass enhancement and \( h_0(980) \) remain practically unchanged → characteristic for \( s \)-independent Pomeron-Pomeron scattering
- Kinematic selection cannot single out pure DPE sample

A. Austregesilo
SaporeGravis Workshop, dec 2-5, 2013

→ Partial Wave Analysis of two-track final state needed
The STAR experiment at RHIC

Large acceptance detector running since 2000

- High resolution tracking device: TPC, $-1 < |\eta| < 1$
- Particle identification capability: TPC dE/dx; TOF

J. Turnau, CEP at STAR, DIS2014, april 28 - may 2
Experimental results from STAR

- Roman pots with silicon strip detector for forward proton tagging
- Staged implementation to cover wide kinematic range:
  - Phase I (present data, low momentum transfer $t < 0.035 \text{ GeV}^2$)
  - Phase II (2015, large $t$ coverage, large data sample)

J. Turnau, CEP at STAR, DIS2014, april 28 - may 2
Experimental results from STAR

- transverse momentum balance
  \[ p_T^{\text{miss}} = |(\vec{p}_E + \vec{p}_W + \pi^+ + \pi^-)_T| \]
- requirement of \( p_T^{\text{miss}} < 0.02 \text{ GeV} \)
  - very efficient in reduction of the non-exclusive background, characterized by large fraction of like-sign tracks
- almost no like-sign background in the signal region
- 380 clean events

J. Turnau, CEP at STAR, DIS2014, april 28 - may 2
Experimental results from STAR

- DIME model for non-resonant background with Model 1 Gap Survival (see arXiv:1312.4552) is consistent with the measured cross section
- GenEx consistent with measured cross section assuming survival factor \( \sim 0.28 \)
- Models do not describe cross section above 1 GeV \( \rightarrow \) other distributions calculated in the range \( M_{\pi\pi} < 1 \) GeV, predictions of the models normalized to cross section measured in this range (GS model = 1 assumed)

- shape of the measured distributions well described by models
- preparation run 200 GeV in 2015, 30-40 times larger data sample

J. Turnau, CEP at STAR, DIS2014, april 28 - may 2
The CDF experiment at the TEVATRON

- Superconducting storage ring
- 1 km radius, 1 beam-pipe
- Collisions 1985-2011
  - Runs 0 and 1 - vs=546, 630 GeV, 1800 GeV
  - Run II: Mar 2001-Sept 2011
  - Produced ppbar collisions at 1.96 TeV
    - 36x36 bunches
    - ~E10-E11 particles per bunch

Ch. Mesropian, WE-Heraeus-School Heidelberg, sep 2 - 6, 2013
**Experimental results from CDF**

**Tevatron energy scan - data**

September 8 – 16, 2011
- 3x3 bunches
- Special trigger
- 1 interaction per crossing (no pile-up)

Total data taking time:
- 10 h at 300 GeV and 39 h at 900 GeV

| √s  | 0-bias | Minbias | Gap-X-Gap | Jets   | e,μ,γ | Total # events |
|-----|--------|---------|-----------|--------|-------|----------------|
| 300 | 1.89 M | 12.1 M  | 9.2 M     | 8.3 K  | 352   | 23.2 M         |
| 900 | 8.0 M  | 54.3 M  | 21.8 M    | 550 K  | 16 K  | 84.7 M         |

Ch. Mesropian, WE-Heraeus-School Heidelberg, sep 2 - 6, 2013

→ talk M. Zurek, monday 17:50 h
ALICE has taken data:

- pp at \( \sqrt{s} = 900 \) GeV, 7 TeV, 8 TeV
- p-Pb at \( \sqrt{s_{NN}} = 5.02 \) TeV
- Pb-Pb at \( \sqrt{s_{NN}} = 2.76 \) TeV
Experimental results from ALICE

- Invariant mass distribution of pion pairs

\[ \text{Counts} / (20 \text{ MeV}/c^2) \]

\[ M(\pi\pi) \text{ (GeV}/c^2) \]

\begin{itemize}
  \item distribution for double gap events
  \item unlike and like-sign pairs
  \item like-sign corrected distribution for double and no-gap events
  \item \( \rightarrow \) enhanced \( f_0, f_2 \) production in double gap events
\end{itemize}

R. Schicker, EDS Blois workshop, Quy Nhon, dec 15-21, 2011

- preparations ongoing for Run II at \( \sqrt{s} = 13 \) TeV, improved statistics, additional detector rapidity coverage
- ALICE results on coherent photoproduction of \( \rho^0 \) in Pb-Pb

\( \rightarrow \) talk Ch. Mayer, thursday 17:10 h
The LHCb experiment at the LHC

The LHCb detector

Interaction point

Vertex detector

Tracking

Calo

Muon

300 mrad

Fully instrumented from $2 < \eta < 5$

R. McNulty, Central exclusive quarkonium production at LHCb

CERN-LHC seminar, feb 4, 2013
Photo-production cross-section

\[
\frac{d\sigma}{dt}(\gamma^* p \to J/\psi p) \bigg|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha} \left[ \frac{\alpha_s(Q^2)}{Q^4} x g(x, Q^2) \right]^2 \left( 1 + \frac{Q^2}{M_{J/\psi}^2} \right)
\]

\[Q^2 = (Q^2 + M_{J/\psi}^2)/4, \quad x = (Q^2 + M_{J/\psi}^2)/(W^2 + M_{J/\psi}^2)\]

Cross-section proportional to gluon² \( \sigma \sim (xg)^2 \)
and so \( \sigma \sim x^\lambda \)

[1] Martin A D, Nockles C, Ryskin M and Teubner T 2008 Small x gluon from exclusive J/\psi production Phys. Lett. B 662 252 (arXiv:0709.4406)
[2] Ryskin M G 1993 J/\psi electroproduction in LLA QCD Z. Phys. C 57 89
[3] Ryskin M G, Roberts R G, Martin A D and Levin E M 1997 Diffractive J/\psi photoproduction as a probe of the gluon density Z. Phys. C 76 231 (arXiv:hep-ph/9511228)
[4] S. Jones, A. Martin, M. Ryskin, and T. Teubner, Probes of the small x gluon via exclusive J/\psi and \( \Upsilon \) production at HERA and the LHC, JHEP 1311 (2013) 085,

R. McNulty, Central exclusive quarkonium production at LHCb
CERN-LHC seminar, feb 4, 2013
Non-resonant background very small

Distributions not background-subtracted. 55985 $J/\psi$ and 1565 $\psi(2s)$

R. McNulty, Central exclusive quarkonium production at LHCb

CERN-LHC seminar, feb 4, 2013
Exclusive J/Ψ production from LHCb

Selected $\chi_{c0,1,2}$ candidates

R. McNulty, Central exclusive quarkonium production at LHCb
CERN-LHC seminar, Feb 4, 2013
Parallel talks at Meson2014

- Exclusive photoproduction of J/ψ and Ψ(2S) mesons in proton-proton collisions
  → talk A. Cisek, friday 15:20 h

- Exclusive production in CMS
  → talk G. Gil da Silveira, monday 15:50 h
Conclusions

- A wealth of data exists on central exclusive production at hadron colliders
- Partial wave analysis needed for extraction of resonance parameters
- Search for glueballs, hybrids and exotica in central exclusive production ongoing
- Sensitivity to gluon pdf at low-x in photoproduction of J/Psi
- LHC community is preparing for Run II at $\sqrt{s} = 13,14$ TeV
Outlook

- LHC Run II at $\sqrt{s} = 13,14$ TeV starting in spring 2015
- forward physics working group discussing common strategy across the LHC experiments for optimum beam conditions for data taking
  - special high-$\beta^*$ runs, all LHC experiments participating
- upgrade programmes ongoing in all LHC experiments for improved detector coverage
- Future Circular Collider FCC kick-off meeting in Feb 2014
  - an IP with special optics parameters for forward physics measurements?