ALICE status and perspectives diffraction

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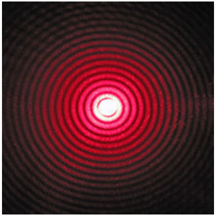
Dec 10, 2014

Diffraction

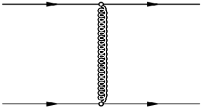
- Diffraction in optics



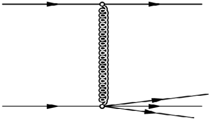
diffraction pattern of a red laser after passing through a small circular hole (→ *Huygens principle*)

- Diffraction in nuclear physics: Feinberg-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.

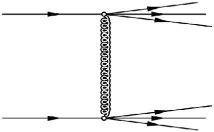
Event topologies



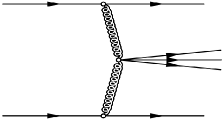
elast. scattering



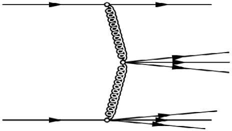
single diff. diss.



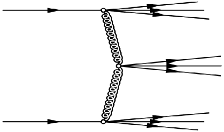
double diff. diss.



central prod.



central prod./single diss.



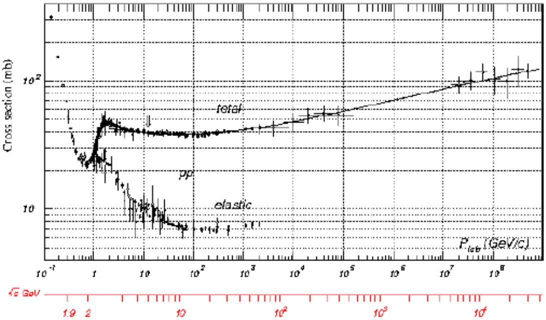
central prod./double diss.

- Identify these topologies by measuring forward scattered protons or fragments, or by detecting the rapidity gap
- Events defined by colour singlet exchange, Pomeron/Reggeons
- Rapidity gaps can also be due to photon and $W^{\pm}$-exchange
- Pomerons and photons contribute differently in pp, pA and AA

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: $\frac{dN}{d\Delta\eta} \sim constant$
- 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



pp total and elastic cross section

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

- 2 terms: Pomeron and degenerate Reggeons f_2, a_2, ρ, ω: A. Donnachie, P.V. Landshoff, Phys. Lett. B296 (1992) 227.
- 3 terms: Pomeron and degenerate Reggeons f_2, a_2 and ρ, ω: A. Donnachie, P.V. Landshoff, Phys. Lett. B727 (2013) 500.

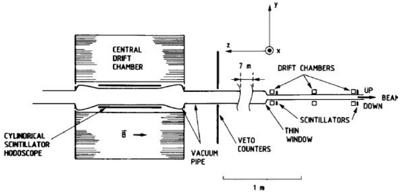
Regge Phenomenology and QCD

- Frank Wilczek, Opening Talk Quark Matter Conference 2014
  "Quarks (and Glue) at Frontiers of Knowledge"
  - Challenges, Opportunities
  - 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.

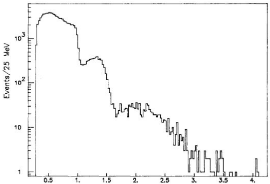
Central Production Measurement at the ISR

- 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

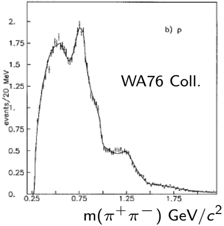


inv. mass $\pi^+\pi^-$

Central Production Measurements I

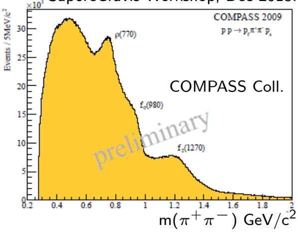
- The $\rho(770)$ ($J^{PC} = 1^{--}$) can not be produced by double Pomeron exchange
- ρ-signal is indicator for Reggeon/photon exchanges

T.A. Armstrong et al.,
Z.Phys.C 51 (1991) 351.



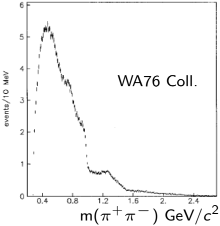
$\sqrt{s} = 12.7$ GeV

A. Austregesilo
SaporeGravis Workshop, Dec 2013.



$\sqrt{s} = 18.9$ GeV

T.A. Armstrong et al.,
Z.Phys.C 51 (1991) 351.

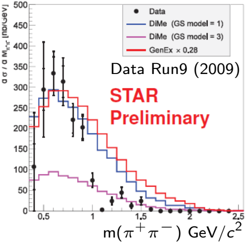


$\sqrt{s} = 23.7$ GeV

Central Production Measurements II

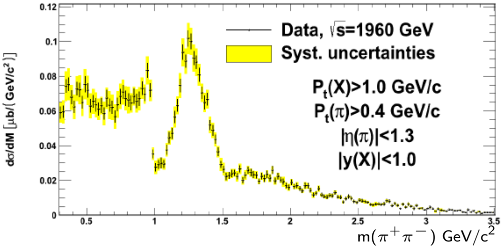
- Analysis of non-LHC central production data ongoing at COMPASS, CDF and STAR

M. Przybycien for STAR Coll.,
Diffraction Conf., Sept. 2014.



$\sqrt{s} = 200$ GeV

M. Zurek for CDF Coll.,
Diffraction Conf., Sept. 2014.

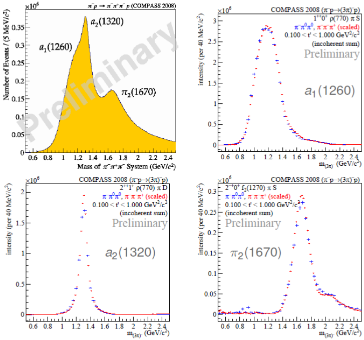


$\sqrt{s} = 1960$ GeV

Analysis of Invariant Mass Spectra

- Partial Wave Analysis of invariant $\pi^+\pi^-$, K^+K^- mass spectra
- Decomposition of measured final state into intermediate resonances including the background

A. Austregesilo
SaporeGravis Workshop,
Dec 2013.

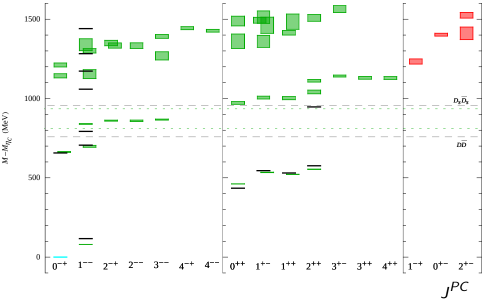


- Stephan Paul, CERN seminar, Dec 13, 2013:

  The virtue of precision spectroscopy: A new axial-vector meson and the structure of the $(\pi\pi)$ S-wave isobar. $\rightarrow \left[a_1(1420), I^G(J^{PC}) = 1^-(1^{++})\right]$.

Interest in Central Production at LHC Energies

- Larger cross section for higher mass states
- Spectroscopy of Strangeonia and Charmonia states
  - Cross section of exclusive Strangeonia/Charmonia production?
- Dynamical lattice QCD calculations done for the charmonium system with resulting multiplets and supermultiplets:
  - L. Liu et al., "Excited and exotic charmonium spectroscopy from lattice QCD", JHEP 1207 (2012), 126.



known states (listed in PDG) in black

non-exotic states in green

exotic states in red

Exclusive Charmonia Production at LHC Energies

- J/ψ, $\psi(2S)$ and χ_c-family serve as references
- The LHCb collaboration has analyzed exclusive J/ψ and $\psi(2S)$ production at $\sqrt{s} = 7$ TeV in the range $2 < \eta < 4.4$
- The LHCb Collaboration, J.Phys.G 40 (2013), 045001.
  - $\sigma_{pp\rightarrow J/\psi(\rightarrow\mu+\mu)}(2.0 < \eta_{\mu\pm} < 4.5) = (307 \pm 21 \pm 36)$ pb (cross section x decay branching)
  - $\sigma_{pp\rightarrow \psi(2S)(\rightarrow\mu+\mu)}(2.0 < \eta_{\mu\pm} < 4.5) = (7.8 \pm 1.3 \pm 1.0)$ pb (cross section x decay branch.)

    (cross section value with statistical and systematic uncertainties)
  - Cross sections per unit rapidity (flat rapidity dependence)
    - $\frac{d\sigma(J/\psi)}{dy}|_{y=0} = (2.2 \pm 0.5 \pm 0.8)$ nb
    - $\frac{d\sigma(\psi(2S))}{dy}|_{y=0} = (0.40 \pm 0.07 \pm 0.05)$ nb
  - similar analysis for χ_0, χ_1, χ_2
    - $\frac{d\sigma(\chi_0)}{dy}|_{y=0} = (5.2 \pm 1.2 \pm 1.9 \pm 1.0)$ nb
    - $\frac{d\sigma(\chi_1)}{dy}|_{y=0} = (0.32 \pm 0.1 \pm 0.1 \pm 0.06)$ nb
    - $\frac{d\sigma(\chi_2)}{dy}|_{y=0} = (0.94 \pm 0.2 \pm 0.3 \pm 0.2)$ nb

    (cross section value with statistical and systematic error and luminosity uncertainty)

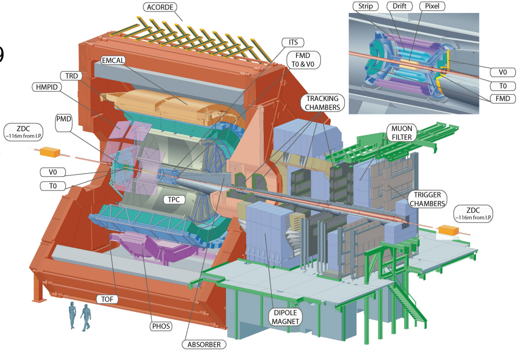
ALICE data taking Run I

- Is a rapidity gap analysis a useful concept ?
- Hardware L0 double-gap trigger ?
  - activity in Inner Tracking System (ITS), no signals in V0A,V0C

Central Barrel $|\eta| < 0.9$

Detectors rapidity gap:
V0A: $2.8 < \eta < 5.1$
V0C: $-3.7 < \eta < -1.7$

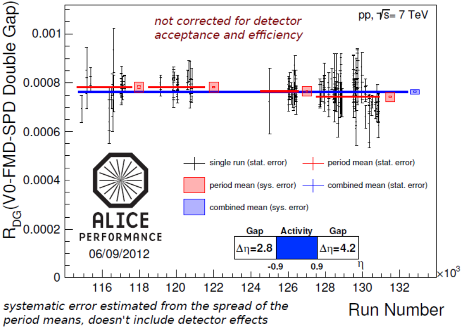
trigger MB_{OR}:
(ITS or V0A or V0C)
trigger MB_{AND}:
(V0A and V0C)



- Data taking in Run I at $\sqrt{s} = 7$ GeV with zero-bias (bunch crossings) and min-bias triggers MB_{OR} and MB_{AND}.

Results from Run I

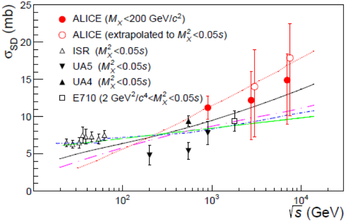
- Analysis of double gap events in pp-collisions at $\sqrt{s} = 7$ TeV with the ALICE experiment, master thesis F. Reidt, 2012.



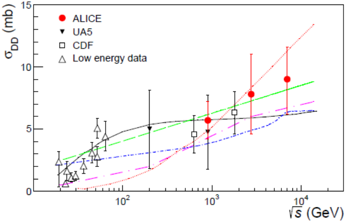
- AIP Conf.Proc. 1523 (2012) 17.
  - $R_{DG} = \frac{N_{DG}}{N_{MBand}} = (7.63 \pm 0.02 \pm 0.87) \times 10^{-4}$ (not corrected for detector effects)
  - yes, rapidity gap condition is a useful concept at LHC energies

Results from Run I

- At TEVATRON energy of $\sqrt{s} = 1.8$ TeV, diffractive processes (single and double diffractive combined) constitute about 25% of the inelastic collisions.
- Single and double diffractive cross section at LHC energies $\sqrt{s} = 0.9$, 2.76 and 7 TeV analyzed by ALICE collaboration, and published Eur.Phys.J. C(2013) 73:2456.



(single diffr. cross section)

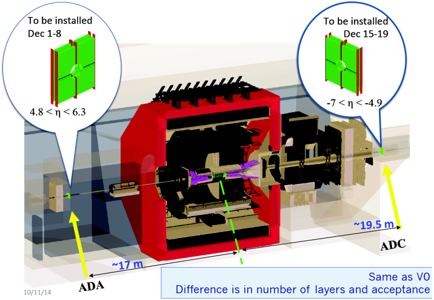


(double diffr. cross section)

Expectations for Run II

- Improve the rapidity coverage by installing new detectors:
  - ADA detector (scintillator paddles), $4.8 < \eta < 6.3$
  - ADC detector (scintillator paddles), $-7.0 < \eta < -4.9$

ALICE Diffractive Detector



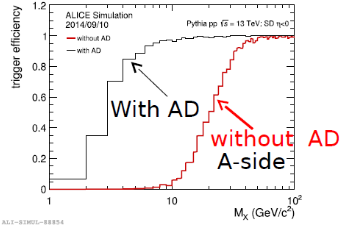
Same as V0
Difference is in number of layers and acceptance

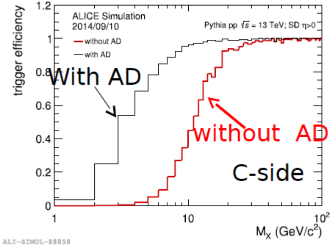
- Analyze single and double diffractive dissociation, central diffraction at $\sqrt{s} = 13{,}14$ TeV, reference data at $\sqrt{s} = 5$ TeV.

New detectors ADA, ADC

- Improve the rapidity coverage by installing new detectors:
  - ADA detector (scintillator paddles), $4.8 < \eta < 6.3$
  - ADC detector (scintillator paddles), $-7.0 < \eta < -4.9$

- Acceptance for diffractive masses





Summary

- Diffractive event topologies can be singled out by identifying rapidity gaps within an event
- Analysis of single and double diffractive cross sections
- Analysis of central diffractive events of interest for hadron spectroscopy
- Partial Wave Analysis framework necessary to extract the parameters of centrally produced resonances
- ALICE diffractive physics analysis group is looking forward to Run II with data taking at $\sqrt{s} = 5$, 13 and 14 TeV

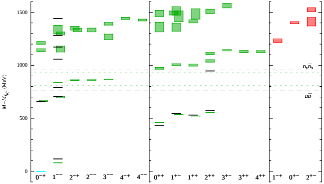
Backup slides

The Strangeonia system

- Strangeonium sector not well known
- Strange quarkonia consist of mesons (u,d,s) with at least one strange quark in the dominant $q\overline{q}$-component
- Kaonia and anti-kaonia consist of $n\overline{s}$- and $s\overline{n}$-configurations (n=u,d)
- Strangeonia is composed of the $s\overline{s}$-configuration
- Up to mass of 2.2 MeV/c^2, 22 strangeonia states are expected, only 7 are known
- The 7 known states are $\eta - \eta'$ (maximally mixed), ϕ(1019), h_1(1386), f_1(1426), f_2'(1525), ϕ(1680), ϕ_3(1854)
  - ϕ(1680), ϕ_3(1854) are controversial
- T. Barnes, N. Black, P.R. Page, Strong Decays of Strange Quarkonia, Phys. Rev. D68 (2003) 054014.

The Charmonia system

- Search for exotic and non-exotic hybrids
  - Hybrid states: $q\overline{q}$-states with large admixture of a gluon component
  - States with quantum numbers allowed in quark model are non-exotic
  - States with quantum numbers not allowed in quark model are exotic



L. Liu et al., JHEP 1207 (2012) 126.

known states (listed in PDG) in black

non-exotic states in green

exotic states in red

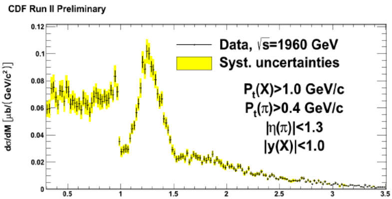
- Many of the non-exotic states follow the $n^{2S+1}L_J$ pattern as predicted by quark potential models
- States grouped in multiplets and supermultiplets

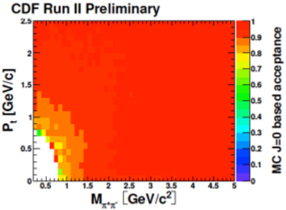
L	0 (S)		1 (P)		2 (D)		3 (F)		4 (G)	
S	0	1	0	1	0	1	0	1	0	1
J^{PC}	0^{-+}	1^{--}	1^{+-}	$(0,1,2)^{++}$	2^{-+}	$(1,2,3)^{--}$	3^{+-}	$(2,3,4)^{++}$	4^{-+}	$(3,4,5)^{--}$

supermultiplets of quark-antiquark pairs

Central Production at CDF

- 2D acceptance of CDF detector at TEVATRON:





2-D acceptance

- KK-theshold opening at 1 GeV/c^2, destructive interference bwtween f$_0$(980) and f$_0$(600)/sigma ?