Diffractive production of mesons

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Introduction to Diffraction

Diffraction in Regge phenomenology - QCD

Interest in Central Diffraction

Experimental results from COMPASS

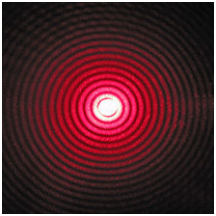
Experimental results from RHIC

Experimental results from TEVATRON

Experimental results from LHC

Diffraction

- Diffraction in optics



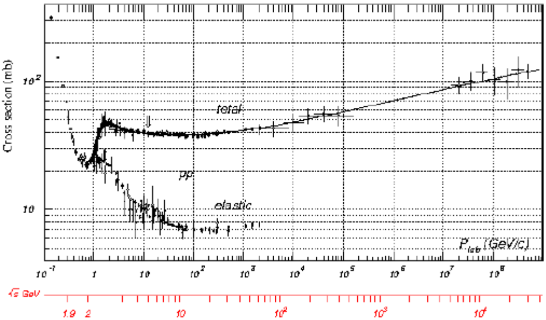
diffraction pattern of a red laser after passing through a small circular hole ($\rightarrow$ *Huygens principle*)

- 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: $\frac{dN}{d\Delta\eta} \sim constant$
- 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 ($\rightarrow$ Reggeons), and characterized by their Regge trajectory
  - At high energy, the Pomeron trajectory dominates
  - Regge language: Diffractive reactions are Pomeron induced

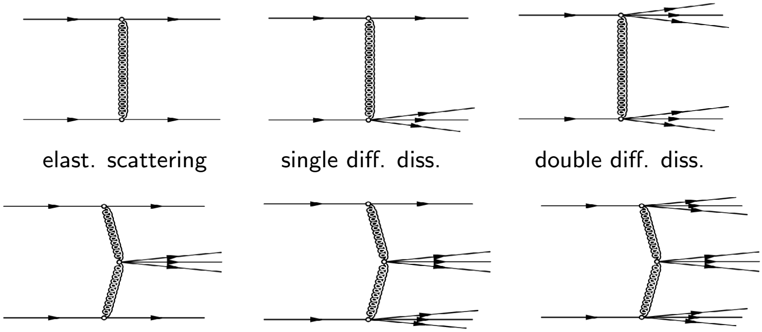
Hadron-hadron cross section



pp total and elastic cross section

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

Event topologies



elast. scattering | single diff. diss. | double diff. diss.

central prod. | central prod./single diss. | central prod./double diss.

- Pomeron 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 ?
  $\rightarrow$ *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 $\sqrt{s} \to \infty$, $\sqrt{|t|} \leq 1 GeV$
- exchanges: Pomeron $\mathcal{P}$, Reggeons f_2, a_2, ω, ρ

elastic scattering:	photoproduction:	central production:
$p + p(\overline{p}) \to p + p(\overline{p})$	$\gamma + p \to \rho^0 + p$	$p + p \to p + meson + p$
$\pi + p \to \pi + p$	$\gamma + \gamma \to \rho^0 + \rho^0$	

- 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

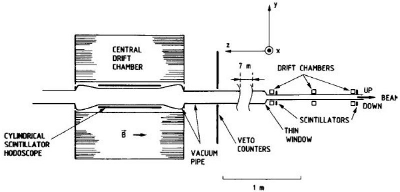
Regge Phenomenology and QCD

- 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.

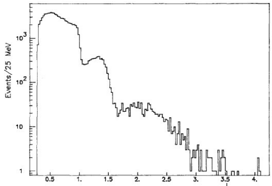
Interest in Central Diffraction

- 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

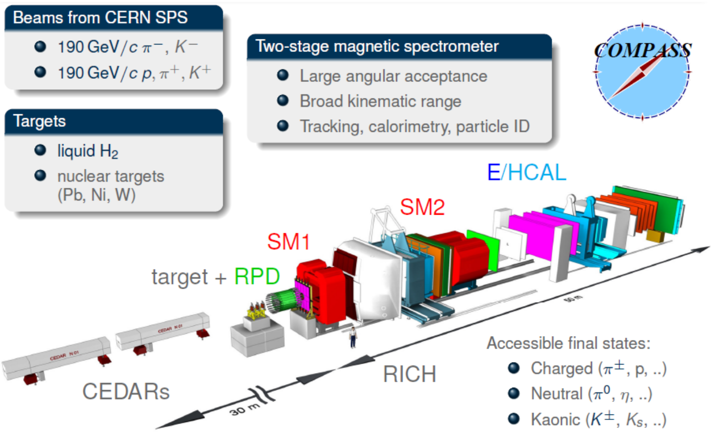


Axial Field Spectrometer



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

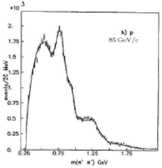
The COMPASS experiment at SPS



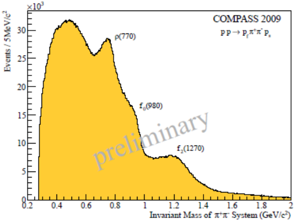
A. Austregesilo
SaporeGravis Workshop, dec 2-5, 2013

Experimental results from COMPASS

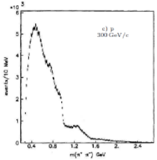
T.A. Armstrong et al. [Z. Phys. C51 (1991)]



$\sqrt{s} = 12.7\,\mathrm{GeV}/c^2$



$\sqrt{s} = 18.9\,\mathrm{GeV}/c^2$



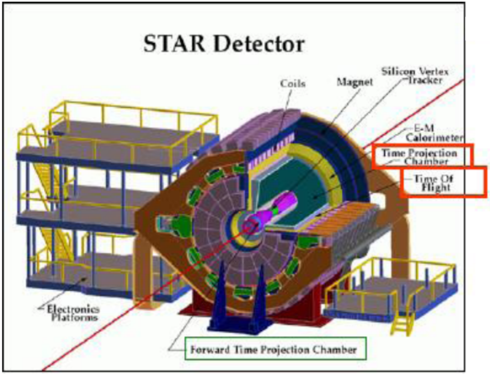
$\sqrt{s} = 23.7\,\mathrm{GeV}/c^2$

- Production of $\rho(770)$ disappears rapidly with increasing $\sqrt{s}$
- Low-mass enhancement and $f_0(980)$ remain practically unchanged
  $\rightarrow$ characteristic for s-independent Pomeron-Pomeron scattering
- Kinematic selection cannot single out pure DPE sample

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

$\rightarrow$ *Partial Wave Analysis of two-track final state needed*

The STAR experiment at RHIC

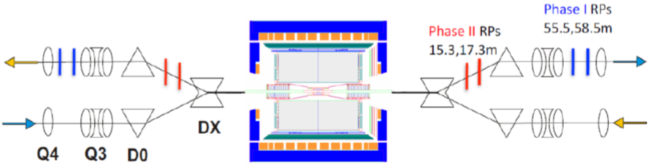


Large acceptance detector running since 2000

- 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

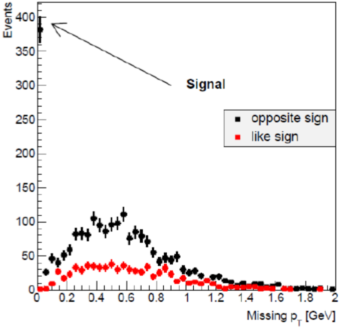
Experimental results from STAR



- 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 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



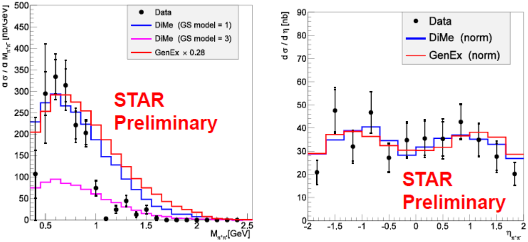
- transverse momentum balance

$$p_T^{miss} = |(\vec{p}_E + \vec{p}_W + \vec{\pi^+} + \vec{\pi^-})_T|$$

- requirement of $p_T^{miss} < 0.02$ 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

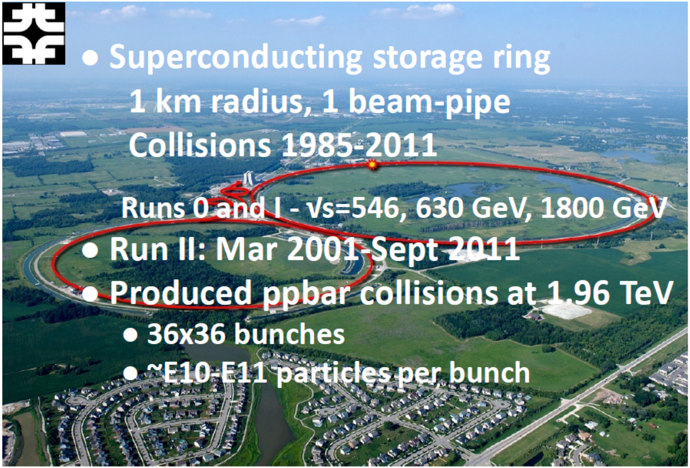


- DIME model for non-resonant background with *Model 1 Gap Survival* (see arXiv:1312.4552) is consitent with the measured cross section
- GenEx consitent with measured cross section assuming survival factor ~0.28
- Models do not describe cross section above 1 GeV → other distributions calculated in the 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



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 :

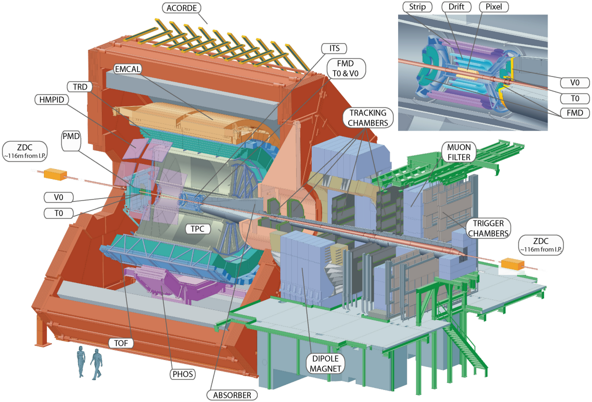
10 h at 300 GeV and 39 h at 900 GeV

√s	0-bias	Minbias	Gap-X-Gap	Jets	e,μ,ν	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

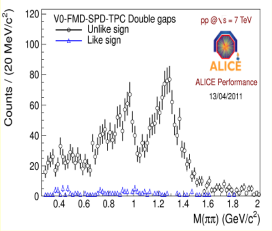
The ALICE experiment at the LHC



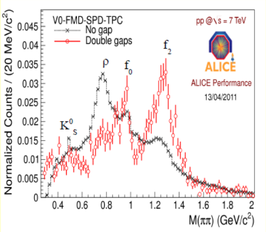
ALICE has taken data: pp at $\sqrt{s}$ = 900 GeV, 7 TeV, 8 TeV
p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

Experimental results from ALICE

- Invariant mass distribution of pion pairs



distribution for double gap events unlike and like-sign pairs



like-sign corrected distribution for double and no-gap events

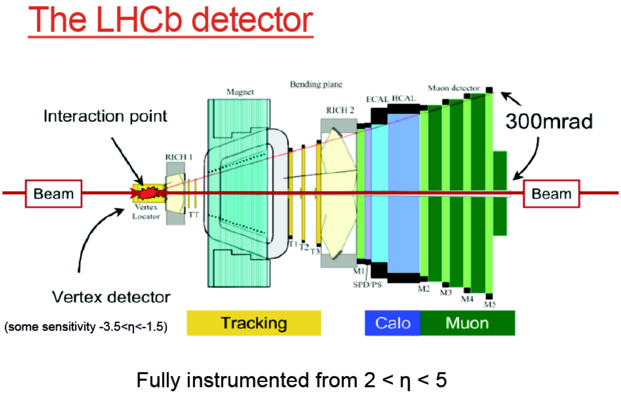
→ *enhanced f_0, f_2 production in double gap events*

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 ρ^0 in Pb-Pb

→ *talk Ch. Mayer, thursday 17:10 h*

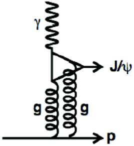
The LHCb experiment at the LHC



R. McNulty, Central exclusive quarkonium production at LHCb
CERN-LHC seminar, feb 4, 2013

Exclusive J/Psi production from LHCb

Photo-production cross-section

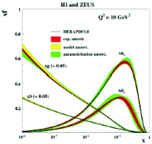


$$\frac{d\sigma}{dt}(\gamma^* p \to J/\psi\ p)\Big|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} xg(x,\bar{Q}^2)\right]^2 \left(1 + \frac{Q^2}{M_{J/\psi}^2}\right)$$

$$\bar{Q}^2 = (Q^2 + M_{J/\psi}^2)/4, \qquad x = (Q^2 + M_{J/\psi}^2)/(W^2 + M_{J/\psi}^2).$$

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/ψ production *Phys. Lett.* B **662** 252 (arXiv:0709.4406)

[2] Ryskin M G 1993 J/ψ 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/ψ photoproduction as a probe of the gluon density *Z. Phys.* C **76** 231 (arXiv:hep-ph/9511228)

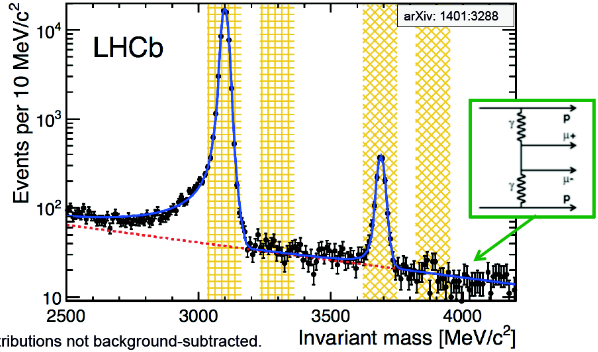
[4] S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and Υ production at HERA and the LHC*, JHEP **1311** (2013) 085,

R. McNulty, Central exclusive quarkonium production at LHCb

CERN-LHC seminar, feb 4, 2013

Exclusive J/Psi production from LHCb

Non-resonant background very small

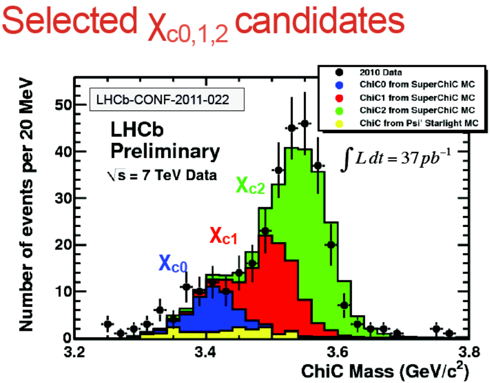


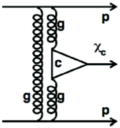
Distributions not background-subtracted.
55985 J/ψ and 1565 ψ(2s)

R. McNulty, Central exclusive quarkonium production at LHCb

CERN-LHC seminar, feb 4, 2013

Exclusive J/Psi production from LHCb





R. McNulty, Central exclusive quarkonium production at LHCb

CERN-LHC seminar, feb 4, 2013

Parallel talks at Meson2014

- Exclusive photoproduction of J/Ψ and $\Psi(2S)$ mesons in proton-proton collisions

  $\rightarrow$ *talk A. Cisek, friday 15:20 h*

- Exclusive production in CMS

  $\rightarrow$ *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-β^* 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 ?