Central exclusive meson production in proton-proton collisions in ALICE at the LHC

Rainer Schicker

Phys. Inst., Heidelberg

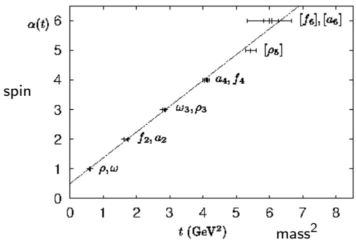
for the ALICE Collaboration

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

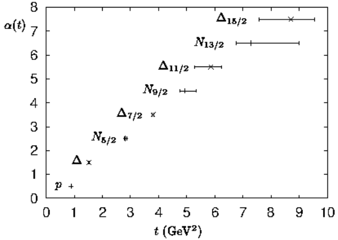
ALICE

Regge theory

- Hadronic interaction due to exchange of objects (Reggeons), and characterized by the associated Regge trajectory:



ρ, ω, a, f trajectories (degenerate)



N, Δ trajectories

figures from:

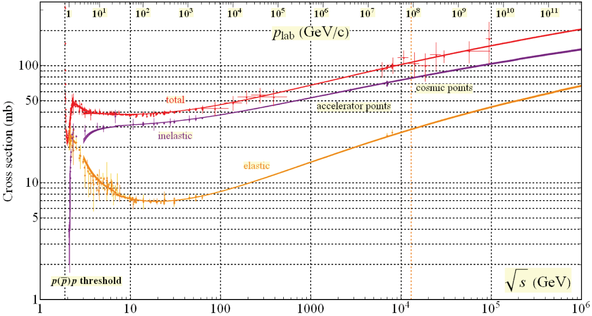
S.Donnachie, G.Dosch, P.Landshoff, O.Nachtmann,

Pomeron Physics and QCD, Cambridge University Press, 2002.

- $\alpha(t) = 1+\varepsilon+\alpha' t$, with intercept $1+\varepsilon$ ($\varepsilon < 0$) and slope α'. For meson trajectories $\varepsilon \sim$ -0.5, $\alpha' \sim 0.9$ GeV^{-2}.

Hadron-hadron cross section

- Cross section contr. of traj. $\alpha(t) = 1+\varepsilon+\alpha' t$ is $\sigma_{tot} \propto s^{\varepsilon}$
  $\rightarrow$ Reggeon contributions decrease with increasing energy
- Hadron-hadron cross section



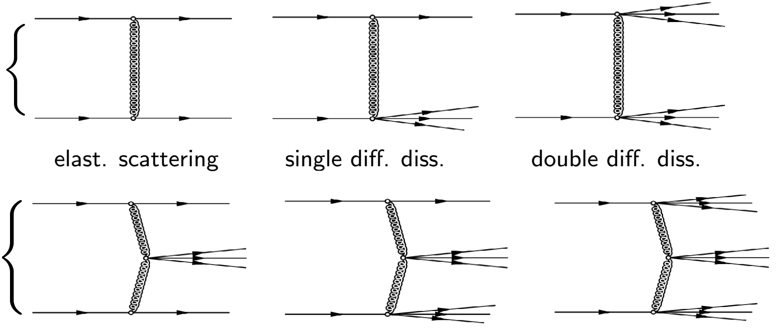
pp total, elastic and inelastic cross section (Fig. 51.6, pdg.lbl.gov)

- Donnachie-Landshoff fits: $\sigma_{tot} = X \cdot s^{0.08} + Y \cdot s^{-0.45}$
- At high energy, the Pomeron trajectory dominates
- Regge language: Diffractive reactions are Pomeron induced
- Soft Pomeron: $\alpha(t) = 1+\varepsilon+\alpha' t$, $\varepsilon \sim 0.08$, $\alpha' \sim 0.25\,\text{GeV}^{-2}$.

Event topologies

elastic/ inelastic scatter.

central prod.



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 $W^{\pm}$,Z-exchange
- Are there reactions to which only Reggeons contribute ?
  $\rightarrow$ *yes, charge exchange reactions*
- Pomerons and photons contribute differently in pp, pA and AA

The spin structure of the soft Pomeron

- Properties of the Pomeron (trajectory):
  charge Q=0, colour charge Q_c=0, isospin I=0, charge conj. C=1
- Spin structure: $\rightarrow$ scalar, vector, tensor exchange?
- Spin structure can be tested in exclusive reactions

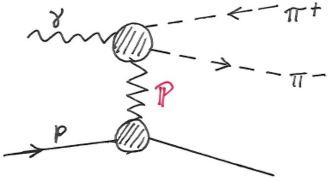
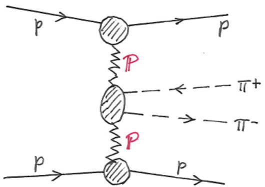


photo prod. $\pi^+\pi^-$-pairs



central diffr. prod.

- Calculate amplitude for scalar, vector and tensor exchange
  - Ewerz,Maniatis,Nachtmann, Ann. Phys. 342 (2014) 31.
  - Lebiedowicz,Nachtmann,Szczurek, Ann. Phys. 344 (2014) 301.
  - Lebiedowicz,Nachtmann,Szczurek, Phys.Rev. D91(2015)074023.
  - Ewerz,Lebiedowicz,Nachtmann,Szczurek, PL B763 (2016)382.

Helicity amplitudes in pp elastic scattering

- 16 helicity amplitudes, 5 independent:

$$\begin{aligned}
\phi_1(s,t) &=< ++|\ \mathrm{T}\ |++ > \\
\phi_2(s,t) &=< ++|\ \mathrm{T}\ |-- > \\
\phi_3(s,t) &=< +-|\ \mathrm{T}\ |+- > \\
\phi_4(s,t) &=< +-|\ \mathrm{T}\ |-+ > \\
\phi_5(s,t) &=< ++|\ \mathrm{T}\ |+- >
\end{aligned}$$

Goldberger et al., PR 120 (1960) 2250
Buttimore et al., PR D18 (1978) 694;
PR D59 (1999) 114010.

	helicity	tensor	vector	scalar
$\phi_1(s,t)$	non-flip	$8s^2$	$8s^2$	$8s^2$
$\phi_2(s,t)$	double-flip	$10m_p^2t$	$16m_p^2t$	$2s^2t/m_p^2$
$\phi_3(s,t)$	non-flip	$8s^2$	$8s^2$	$8s^2$
$\phi_4(s,t)$	double-flip	$-10m_p^2t$	$-16m_p^2t$	$-2s^2t/m_p^2$
$\phi_5(s,t)$	single-flip	$-8sm_p\sqrt{-t}$	$-8sm_p\sqrt{-t}$	$-4s^2\sqrt{-t}/m_p$

Table: $s \gg m_p^2, |t|$

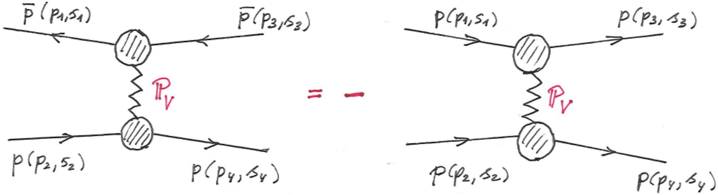
- $\sigma_{tot}(p,p) = \frac{1}{4\sqrt{s(s-4m_p^2)}} \sum_{s_1,s_2} \mathcal{I}m < 2s_1, 2s_2|\,T\,|2s_1, 2s_2 > |_{t=0}$
$$= \frac{1}{2\sqrt{s(s-4m_p^2)}} \mathcal{I}m[\phi_1(s,0) + \phi_3(s,0)]$$

(Ewerz,Lebiedowicz,Nachtmann,Szczurek, PL B763 (2016)382.)

- *σ_{tot} has no predictive power on scalar/vector/tensor nature of Pomeron*

The vector Pomeron

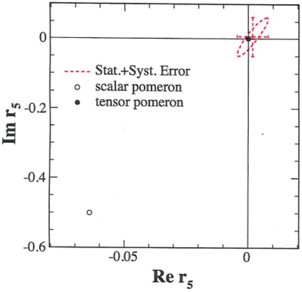
- Problem with the vector Pomeron:

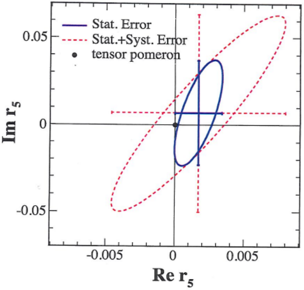


- The minus sign for amplitude $\bar{p}p$ versus pp is of same origin as in the case of e^+e^- versus e^-e^- scattering in the one photon exchange approximation (vector exchange has C=-1).
- Opt. theorem: $\sigma_t = \Im m\, A(t=0)$, $\rightarrow$ $\sigma_t(\bar{p}, p)^{P_V} = -\sigma_t(p, p)^{P_V}$
- Vector Pomeron not a viable option, we are left with scalar and tensor Pomeron, both corresponding to C=+1 exchanges.
- Vector Pomeron doesn't contribute to real Compton scattering amplitude
  $\rightarrow$ doesn't contribute to total photoabsorption cross section

Spin structure of soft Pomeron vs STAR measurement

- Measurement of single spin asym. A_N by the STAR coll. in elast. pp scattering, $\sqrt{s}$=200 GeV, Phys.Lett.B719 (2013) 62.

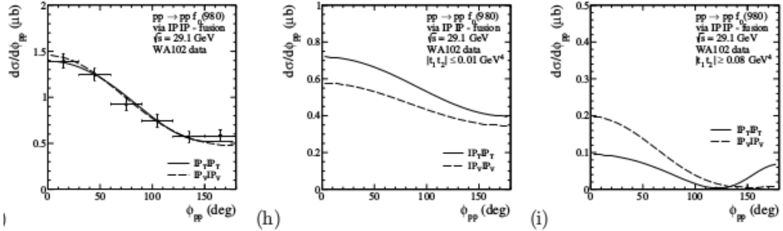




- $r_5(s,t) = \frac{2m_p\phi_5(s,t)}{\sqrt{-t}\ \mathcal{I}m[\phi_1(s,t)+\phi_3(s,t)]}$
- STAR data point
- calc. by C.Ewerz, P.Lebiedowicz, O.Nachtmann, A.Szczurek

Universal nature of Pomeron

- *Are there observables in central diffractive production sensitive to scalar/vector/tensor nature of Pomeron?*
- Lebiedowicz,Nachtmann,Szczurek, Ann. Phys. 344 (2014)301. "Exclusive central diffractive production of scalar and pseudoscalar mesons; tensorial vs. vectorial pomeron"

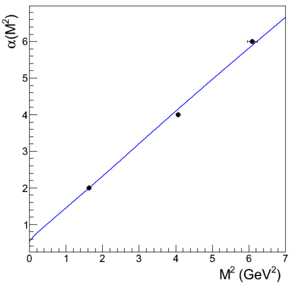


DAMA model of central production

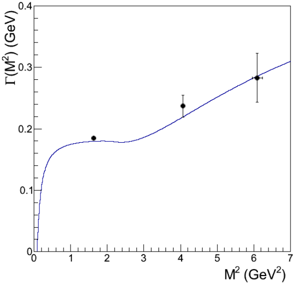
- DAMA model (Dual Amplitude with Mandelstam Analyticity) requires complex non-linear trajectories, complex part of trajectory derived from the width of the resonances.
  (A.I. Bugrij et al., Fortschr. Phys. 21, 427 (1973))
- In DAMA model, the direct channel pole decomposition of the dual amplitude $A(M_x^2, t)$ is relevant, with contributions from different non-linear, complex trajectories $\alpha_i(M_x^2)$, with $A(M_X^2, t) = a \sum_{i=f,P} \sum_J \frac{[f_i(t)]^{J+2}}{J-\alpha_i(M_X^2)}$.
- The cross section Pomeron-Pomeron $\rightarrow$ resonance is defined by the optical theorem: $\sigma_t^{PP}(M_X^2) = \Im m\, A(M_X^2, t=0)$.
- Cross section proton-proton $\rightarrow$ resonance is defined by convoluting the Pomeron distribution in the proton with cross section at Pomeron level.
  (R.Fiore, L.Jenkovszky, R.Schicker, Eur. Phys. J. C78 (2018) no.6, 468)

Non-linear Regge trajectories

- Real and imaginary part of trajectory obey dispersion relation.
- Imag. part related to width of resonance: $\Gamma(M_R) = \frac{\Im m\ \alpha(M_R^2)}{\alpha' M_R}$



real part f_2 traj.



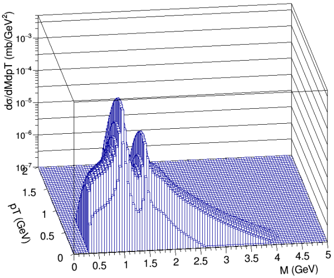
imaginary part f_2 traj.

figures from:

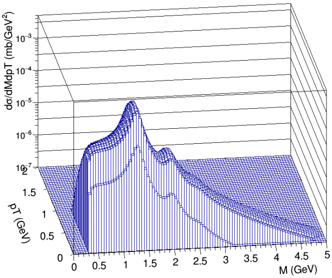
R.Fiore, L.Jenkovszky, R.Schicker, Eur.Phys.J. C76 (2016) no.1,38.

DAMA model of central production

- FJS-model based on Dual Amplitude with Mandelstam Analyticity predicts double differential cross section $d\sigma/dMdp_T$ for resonances on trajectories.



$f_0(980)$ traj.

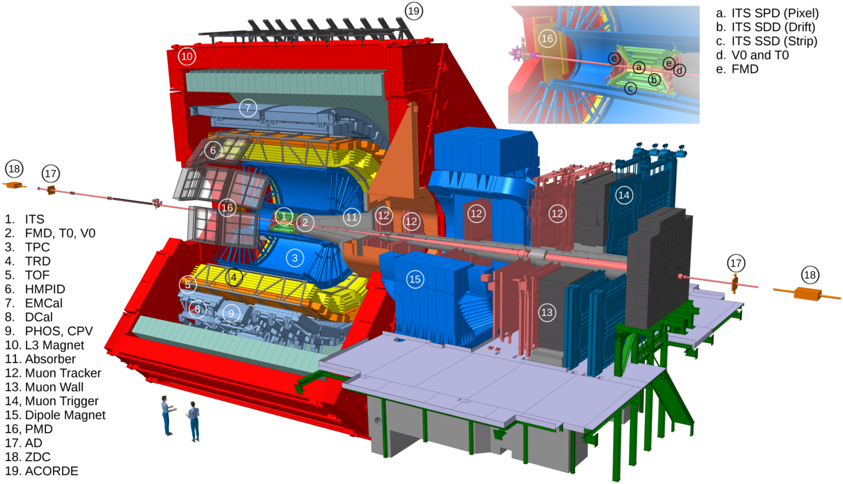


$f_2(1270)$ traj.

figures from:

R.Fiore, L.Jenkovszky, R.Schicker, Eur.Phys.J. C78 (2018) no.6,468.

The ALICE Detector

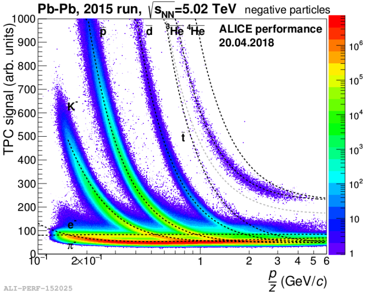


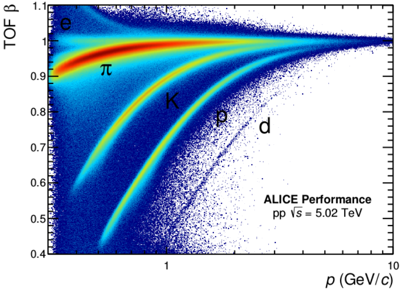
a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE

ALICE particle identification capability

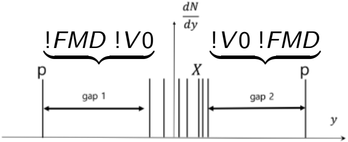
- Particle identification by specific ionisation loss dE/dx in TPC, and by TOF detector





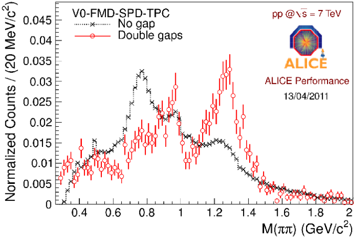
ALICE data on central production

- Double Pomeron events in ALICE are characterized by forward beam particles, or their remnants, and a hadronic system at mid-rapidity

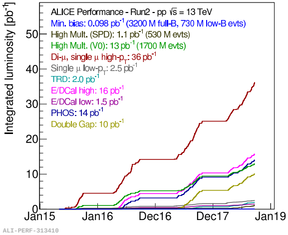


central barrel

- Analyze double Pomeron events from min-bias data, or from double-gap triggered events



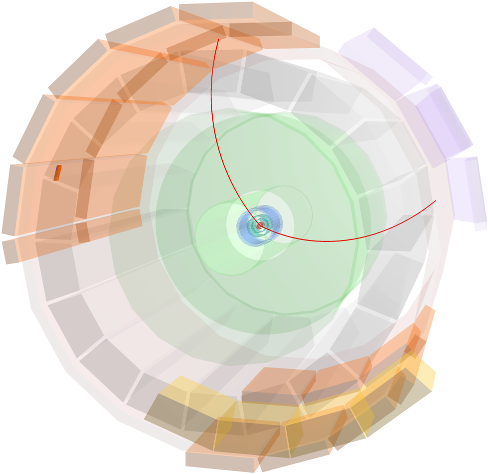
double gap events from min-bias events Run 1 (2010) $\sim$ .0054 pb^{-1}



Int. luminosity for various triggers in pp-collisions at $\sqrt{s}$ = 13 TeV during Run 2 (2015-2018)

double gap trigger 2017-2018 $\sim$ 10 pb^{-1}

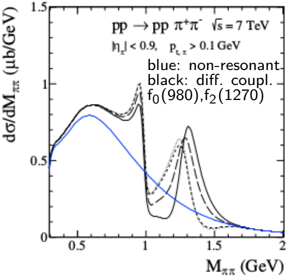
Double gap triggered event in ALICE

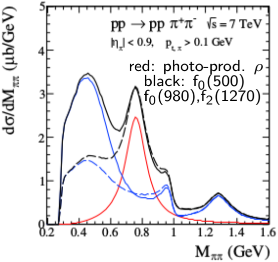


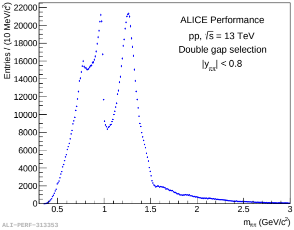
Run:288640
Timestamp:2018-06-26 07:20:29(UTC)
System: pp
Energy: 13 TeV
Double-gap triggered event

ALICE data diffractive pion-pair production

- P.Lebiedowicz, O.Nachtmann, A.Szczurek, Phys.Rev.D93 (2016),054015.



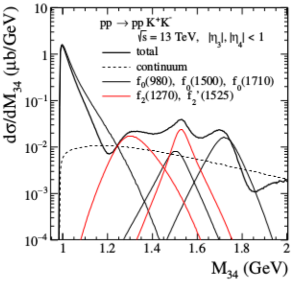


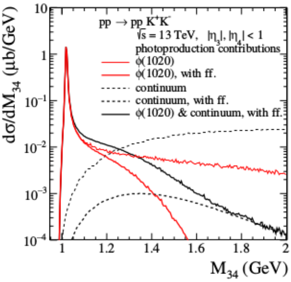


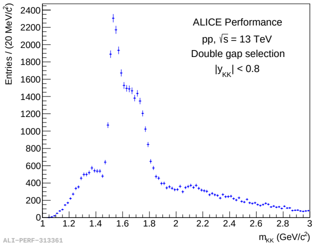
- ALICE data pp at 13 TeV:
  $\pi^+\pi^-$ invariant mass spectrum
  in double gap events (veto in V0
  and AD det.)

ALICE data diffractive kaon-pair production

- P.Lebiedowicz, O.Nachtmann, A.Szczurek, Phys.Rev.D98 (2018),014001.







- ALICE data pp at 13 TeV: K^+K^- invariant mass spectrum in double gap events (veto in V0 and AD det.)

ALICE analyses of double gap events

- Study double Pomeron events in min-bias data, or from DG trig. events
- Partial Wave Analysis of resonances in search of glueballs, hybrids and exotica
- Possible mixing schemes of scalar glueballs with f_0 resonances depend on the existence of the $f_0(1370)$, see
  W.Ochs, The Status of Glueballs, J.Phys.G40 (2013) 043001.
- Strangeonium sector so far not well known. Up to a mass of 2.2 GeV/c^2, 22 states are expected, however only 7 are known: maximally mixed $\eta - \eta^{'}$, $\phi(1019)$, $h_1(1386)$, $f_1(1426)$, $f_2^{'}(1525)$, $\phi(1680)$, $\phi_3(1853)$.
  T.Barnes, N.Black, P.R.Page, Strong decays of strange quarkonia, Phys.Rev.D 68, (2003) 054014.

Summary, Outlook

- Summary analyses ALICE double gap events
  - Study of centrally produced resonances
    - diffractive production
    - photo production
  - Spin structure of the soft Pomeron
  - DAMA model for resonances on trajectories
- Outlook
  - expect 200 pb^{-1} in pp at $\sqrt{s}$=14 TeV by end of Run3, stat. x 40.

BACKUP

The Tensor Pomeron and Low-x Deep Inelastic Scattering

- D.Britzger, C.Ewerz, S.Glazov, O.Nachtmann, St.Schmitt, arXiv: 1901.08524 "The Tensor Pomeron and Low-x Deep Inelastic Scattering"
- Study of structure functions in DIS, which are given by the absorptive part of the forward virtual Compton amplitude
- Soft and hard Pomeron, plus f_2 Reggeon exchange
- Vector Pom. doesn't contribute to real Compton scatt. ampl., hence doesn't contribute to total photoabsorpt. cross section

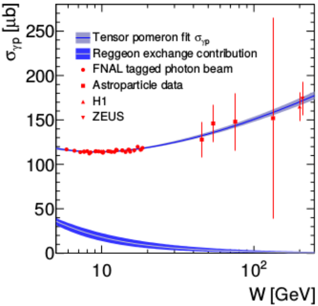


Figure 5, Britzger et al.:
Figure: Comparison of the global fit to the photoproduction cross sections. The Reggeon contribution is indicated. The experimental uncertainties of the fit are indicated as shaded bands.

→ The Tensor Pomeron gives excellent description of the real photoabsorption cross section.

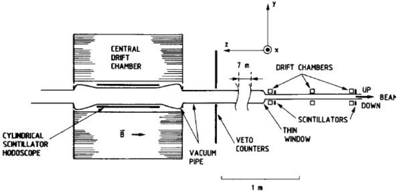
Regge Phenomenology and QCD

- 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.

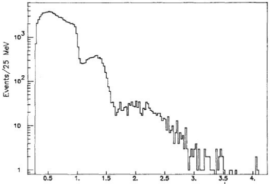
Interest in Central Diffraction

- 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

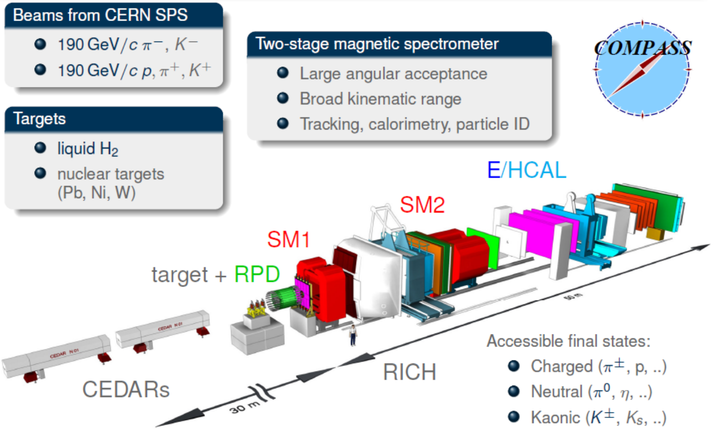


Axial Field Spectrometer



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

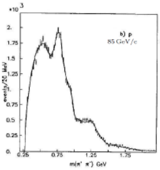
The COMPASS experiment at SPS



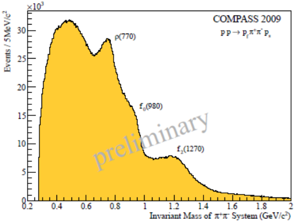
A. Austregesilo
SaporeGravis Workshop, dec 2-5, 2013

Experimental results from COMPASS

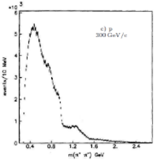
T.A. Armstrong et al. [Z. Phys. C51 (1991)]



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



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



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

- Production of $\rho(770)$ disappears rapidly with increasing $\sqrt{s}$
- Low-mass enhancement and $f_0(980)$ 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*