ALICE diffraction and forward physics

- ALICE detector
- Diffractive gap trigger in ALICE
- Pomeron/Odderon signatures in p-p
- Pomeron signatures in Pb-Pb
- Central diffractive production of χ_c in p-p
- Signature of gluon saturation in diffraction
- Conclusions, outlook

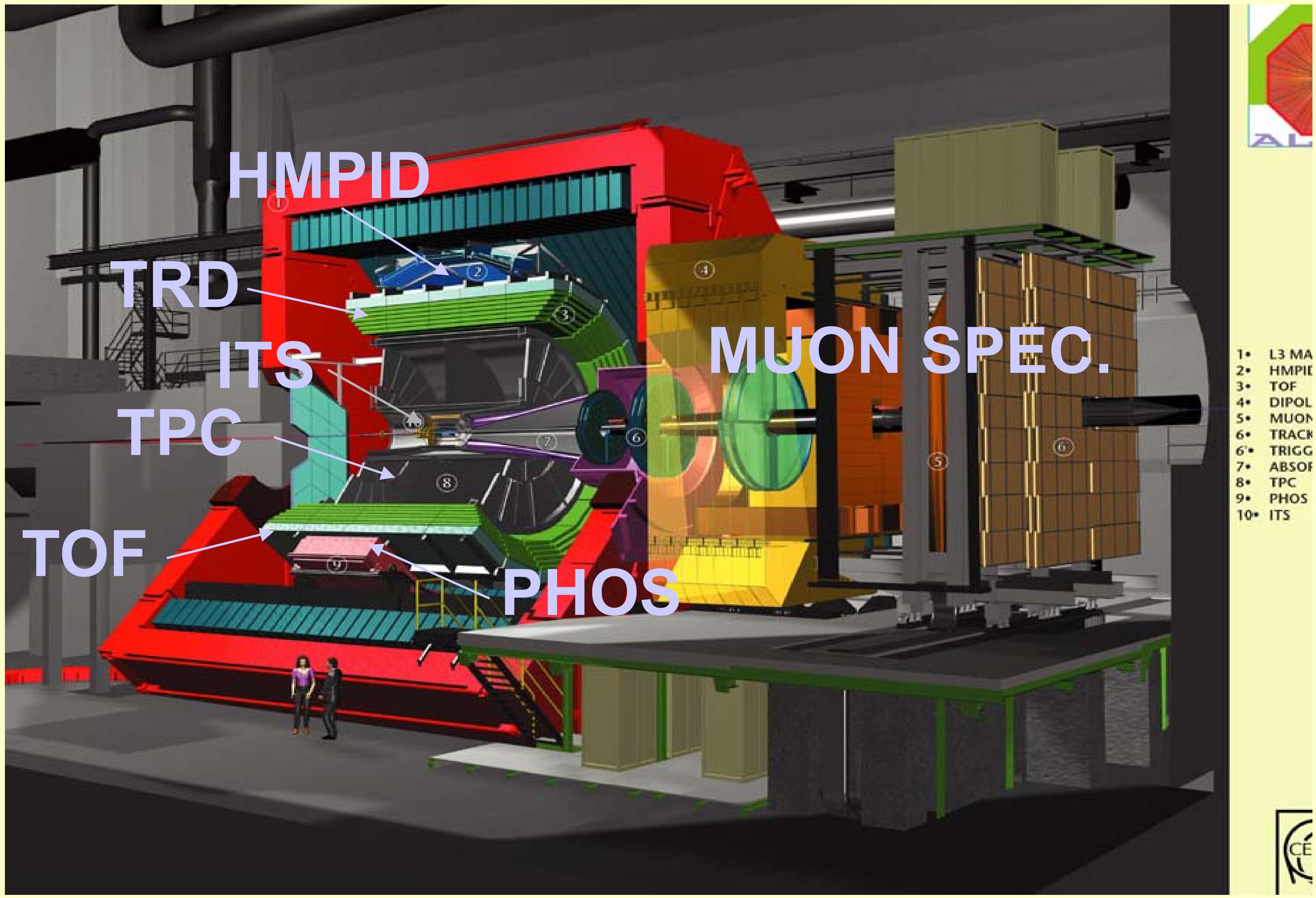
The ALICE experiment

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 η_+ , η_-

p-p luminosity L = 5x10^{30}cm^{-2}s^{-1} :

→ one interaction/ 80 bunches

diffractive L0 trigger (hardware):

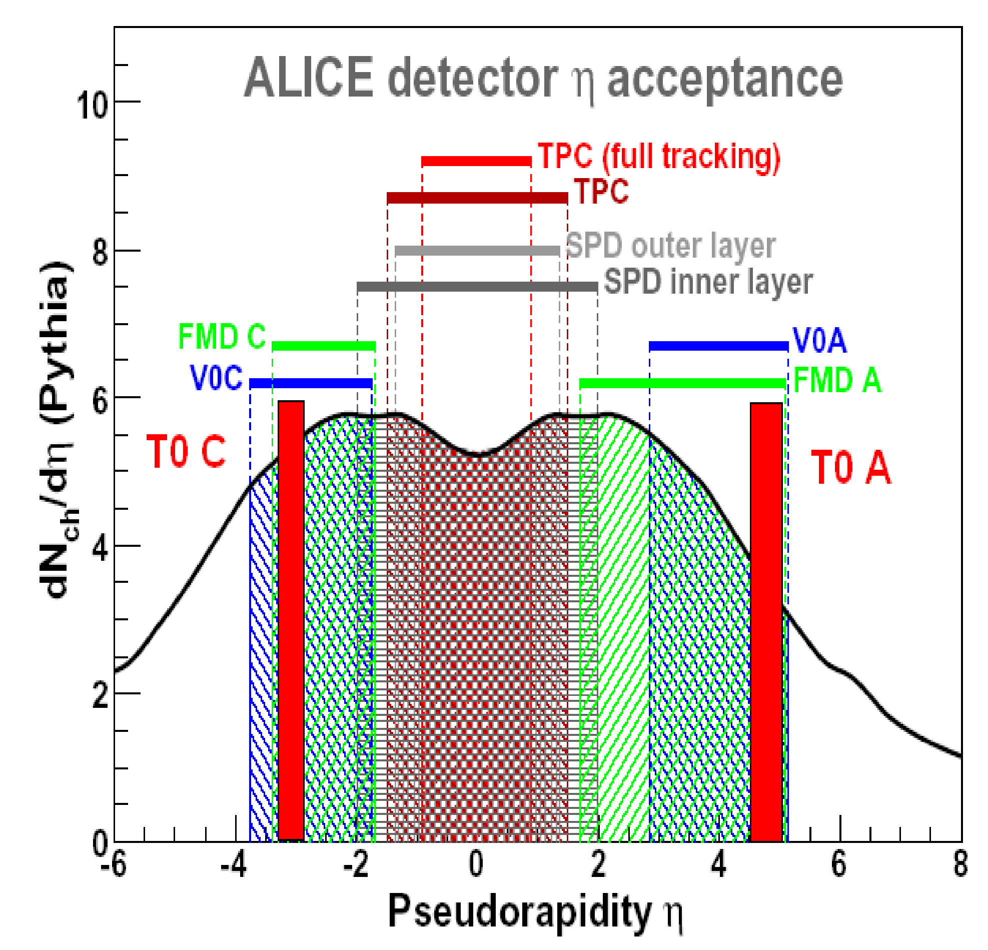
Pixel or TOF mult (central barrel)

gap η_+: $3 < \eta < 5 \rightarrow \Delta\eta \sim 0.5$

gap η_-: $-2 < \eta < -4 \rightarrow \Delta\eta \sim 0.5$

high level trigger (software):

$$-3.7 < \eta < 5$$

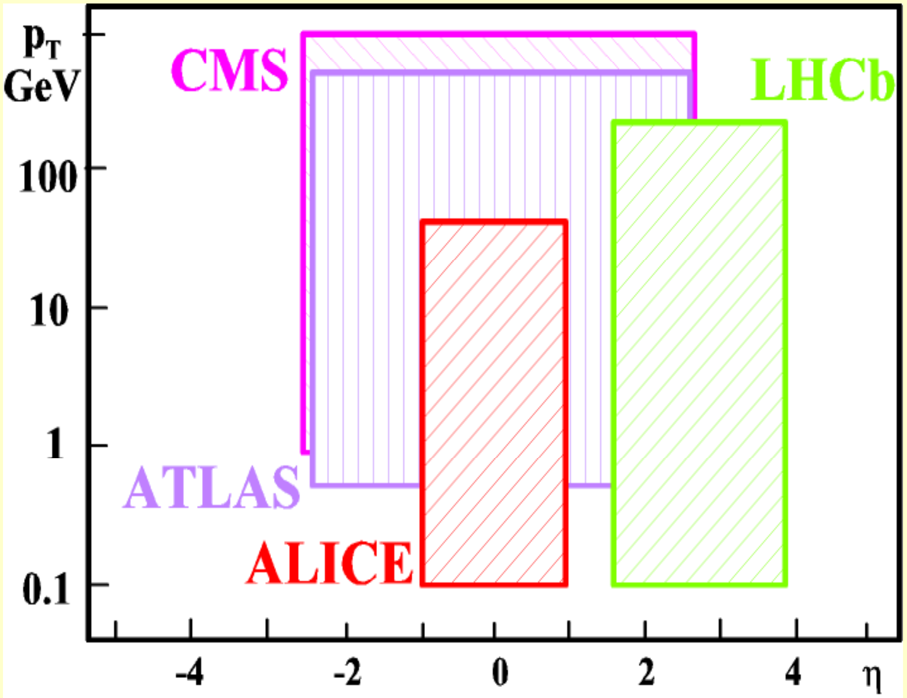


ALICE central barrel comparison to other LHC detectors

low magnetic field

	Magn. field (T)	P_T cutoff GeV/c	Material x/x0 (%)
ALICE	**0.2-0.5**	**0.1-0.25**	**7**
ATLAS	**2.0**	**0.5 (0.08)**	**20**
CMS	**4.0**	**0.75 (0.2)**	**30**
LHCb	**4Tm**	**0.1**	**3.2**

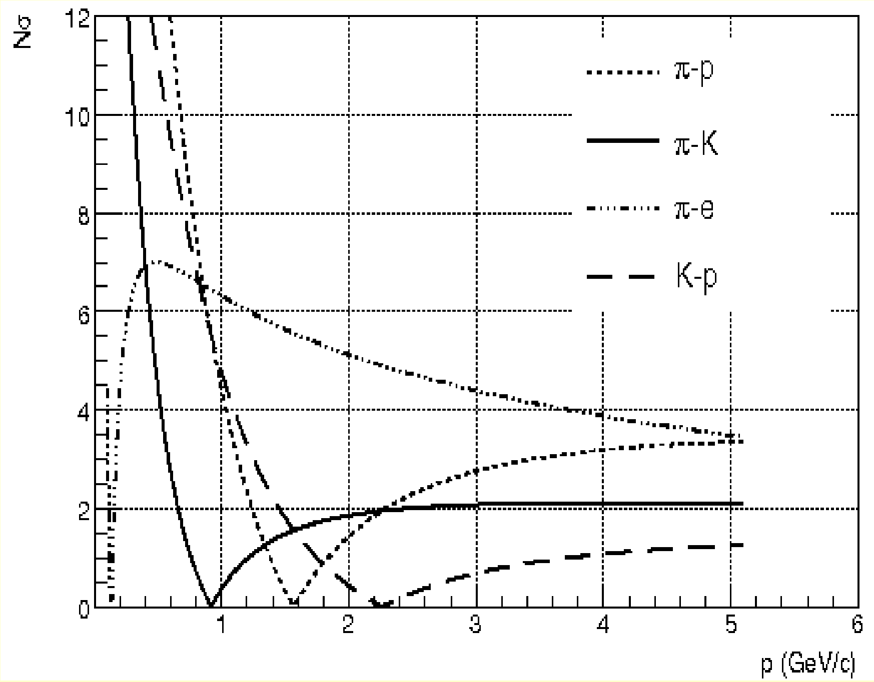
η–pt acceptance

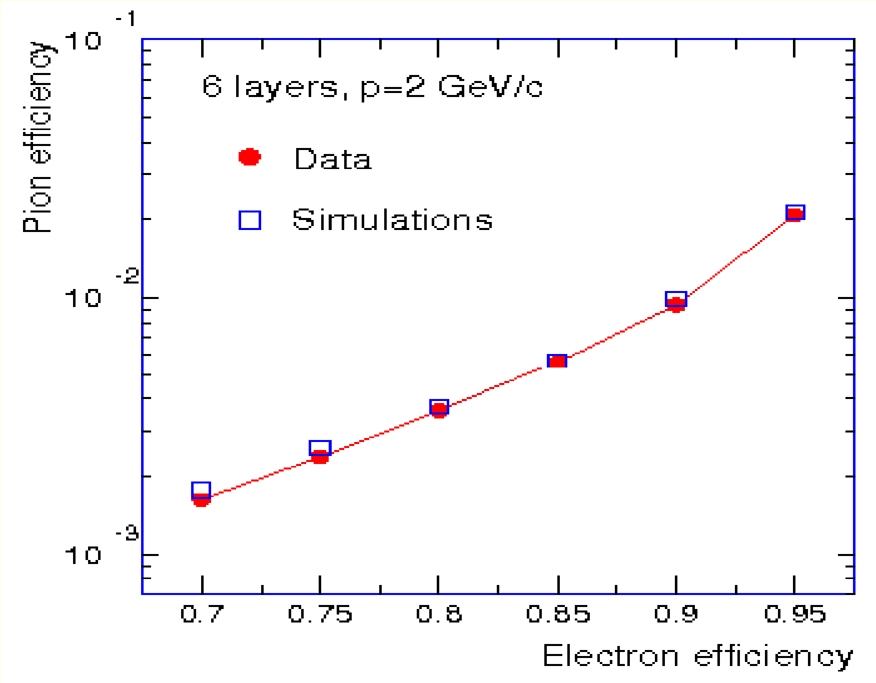


→ low p_T trigger ?

→good ALICE acceptance for ϕ, J/Psi, Ψ by electron decays ($p_T > 0$ MeV/c)

ALICE central barrel particle identification





Particle identification by dE/dx in central barrel as function of momentum

In addition time of flight information for non-relativistic momenta

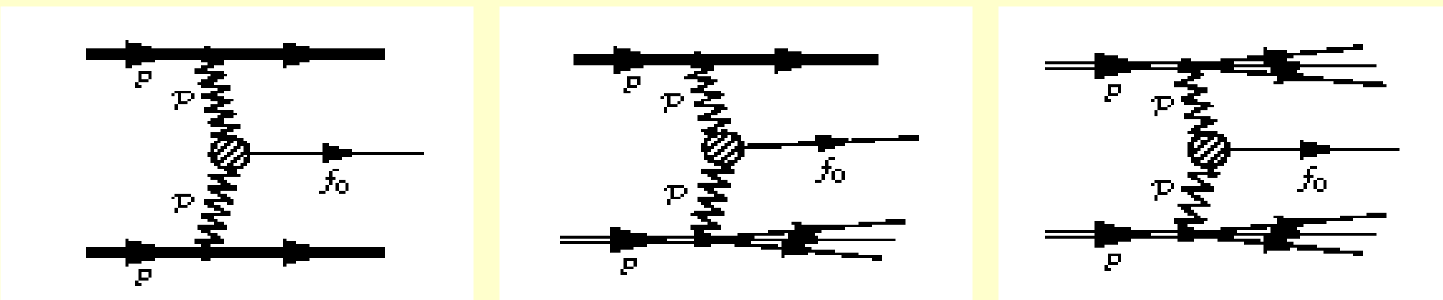
Electron-pion separation in TRD as function of momentum

→identify vector mesons by e^+e^- decay

ALICE forward calorimeter

- **neutron calorimeter on each side**
  - **Placed at 116 m from interaction region**
  - **Measures neutral energy at 0°**
- **Diffractive events with and without proton breakup:**
  - **pp → ppX : no energy in zero degree calorimeters**
  - **pp → pN*X, N*N*X : energy in one or in both calorimeters**

Identify the three topologies:



A B C

$$\frac{\sigma_A}{\sigma_B} \equiv f(x_1, x_2, ..)\frac{\sigma_{elast}}{\sigma_{SD}}$$

$$\frac{\sigma_B}{\sigma_C} \equiv g(x_1, x_2, ..)\frac{\sigma_{SD}}{\sigma_{DD}}$$

$$\frac{\sigma_A}{\sigma_C} \equiv h(x_1, x_2, ..)\frac{\sigma_{elast}}{\sigma_{DD}}$$

A → elast scattering

B → single diffractive dissociation

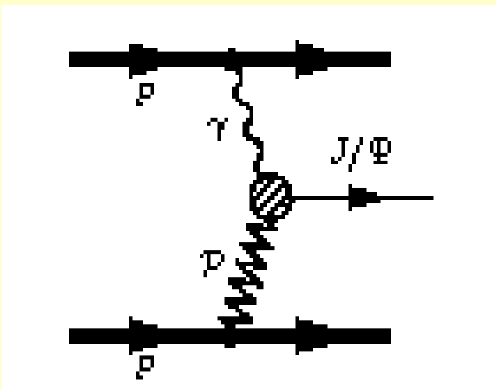
C → double diffractive dissociation

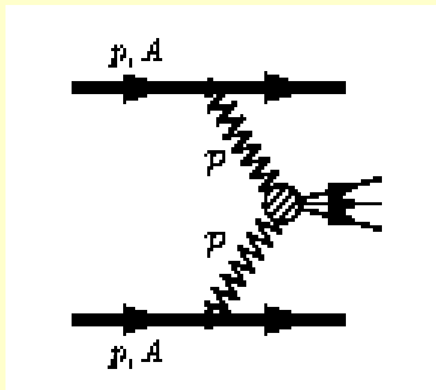
→ what are $f(x_i)$, $g(x_i)$, $h(x_i)$?

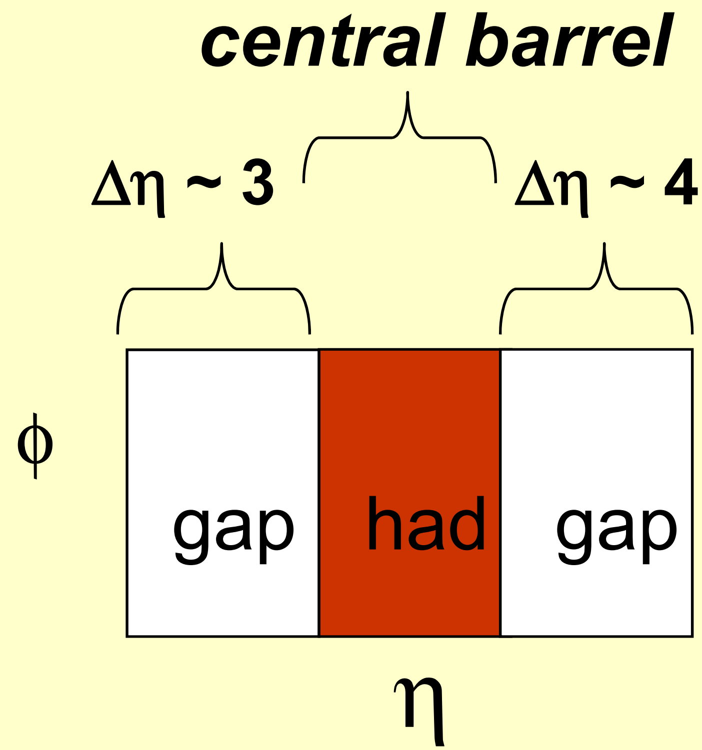
ALICE diffractive physics

- ALICE acceptance matched to diffractive central production:

γ-pomeron, double pomeron, odderon-pomeron







Data taking:
pp @ L = $5x10^{30}$ $cm^{-2}s^{-1}$ $(\rightarrow \frac{d\sigma}{dy}\Big|_{y=0} \sim nb)$
pPb @ L = 10^{29} $cm^{-2}s^{-1}$
PbPb @ L = 10^{27} $cm^{-2}s^{-1}$

Pomeron signatures

POMERON: C = +1 part of gluon color singlet exchange amplitude

Compare pomeron-pomeron fusion events to min bias inelastic events

1) Enhanced production cross section of glueball states: *study resonances in central region when two rapidity gaps are required*

2) Slope pomeron traj. $\alpha' \sim 0.25 GeV^{-2}$ in DL fit, $\alpha' \sim 0.1 GeV^{-2}$ in vector meson production at HERA, t-slope triple pom-vertex < $1 GeV^{-2}$

→ mean k_t in pomeron wave function $\alpha' \sim 1/k_t^2$ probably $k_t > 1$ GeV

→ *$<p_T>$ secondaries in double pomeron > $<p_T>$ secondaries min bias*

3) $k_t > 1$ GeV implies large effective temperature

→ *K/π, η/π, η'/π ratios enhanced*

Central exclusive $\pi^+\pi^-$ production at $\sqrt{s}$ = 63 GeV

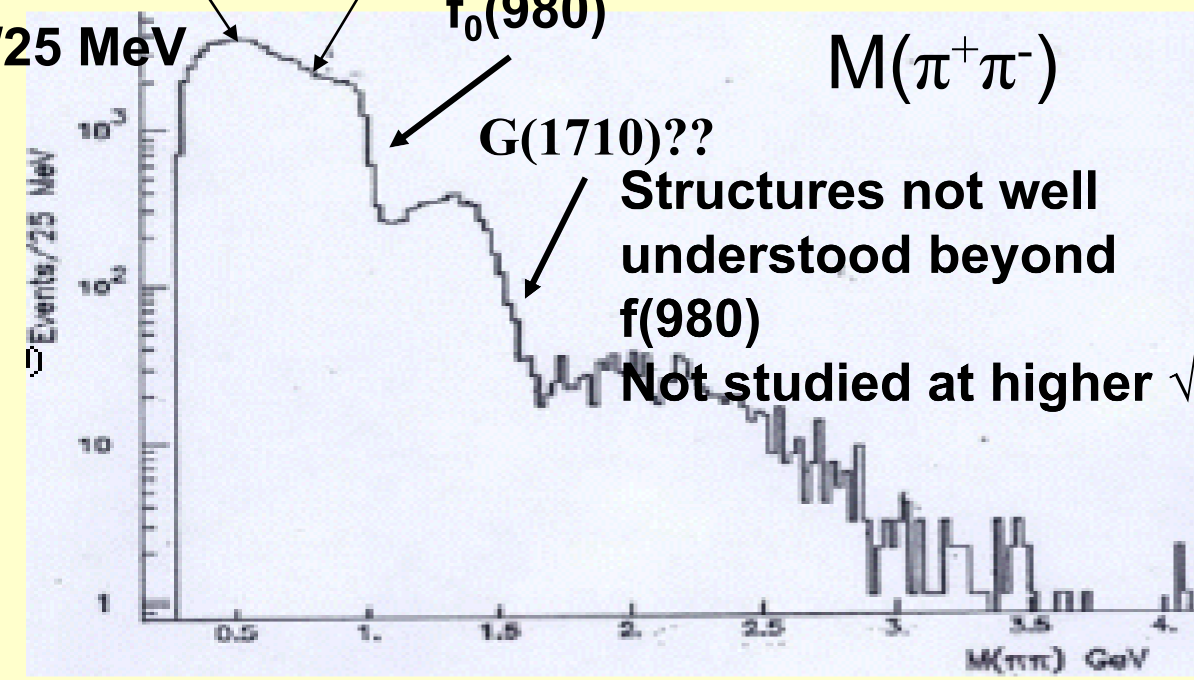
Data taken by Axial Field Spectrometer at ISR $\sqrt{s}$ = 63 GeV (R807)
very forward drift chambers added for proton detection

p ⟵ $\pi^+\pi^-$ ⟶ *p*

f_0(600)=σ   no ρ

f_0(980)

3500 events/25 MeV



Structures not well understood beyond f(980)

Not studied at higher $\sqrt{s}$

T.Akesson et al 1986:

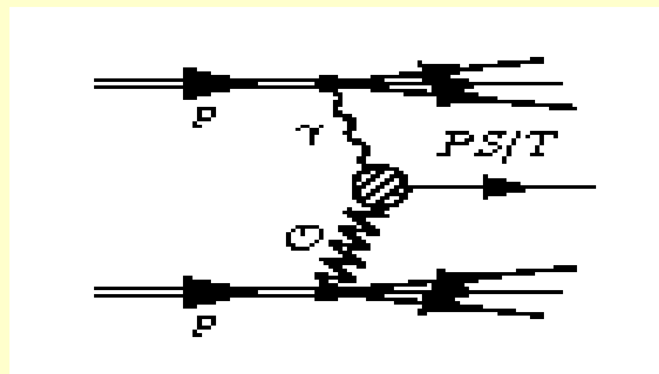
Flavour independence: equal numbers of $\pi^+\pi^-$ and K^+K^- pairs for masses larger than 1 GeV

Signature Odderon cross section

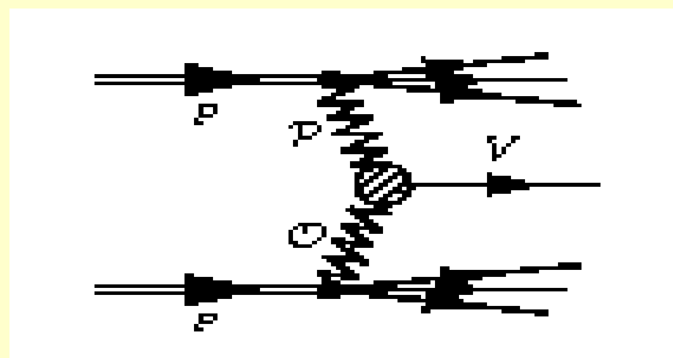
ODDERON: C = -1 part of gluon color singlet exchange amplitude

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: $\pi_0, \eta, \eta_c (J^{PC} = 0^{-+}), \; a_2(2^{++})$

    → contributions from Photon-Photon, Photon-Odderon, Odderon-Odderon
  - Look for diffractive J/Ψ production: $J^{PC} = 1^{--}$

    → Photon-Pomeron, Odderon-Pomeron contributions

→ such an experimental effort is a continuation of physics programs carried out at LEP (γγ) and HERA (γ-Odderon)

Diffractive J/Ψ production in pp at LHC

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

At L = 5×10^{30} $cm^{-2}s^{-1}$:

→ ***0.15 J/Ψ in ALICE central barrel in 1 s, 150k in 10^6 s***

→ ***9000 in e^+e^- channel in 10^6 s***

→ identify Photon and Odderon contribution by analysing p_T distribution (Odderon harder p_T spectrum)

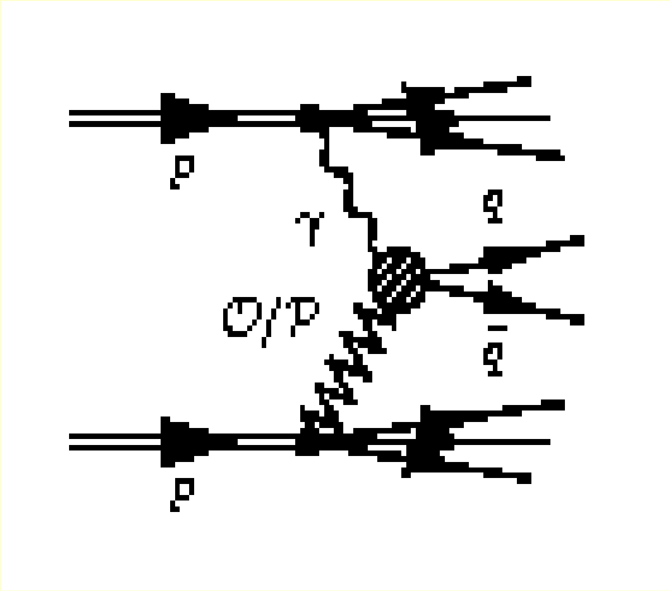
Signature Odderon interference

- Cross sections contain squared Odderon amplitudes

→ *Odderon-Pomeron interference !*

$$d\sigma \sim |A\gamma(A_P + A_O)|^2 \, d^N q$$

$$\sim |A_P|^2 + 2Re(A_P A_O^*) + |A_O|^2$$



→ 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

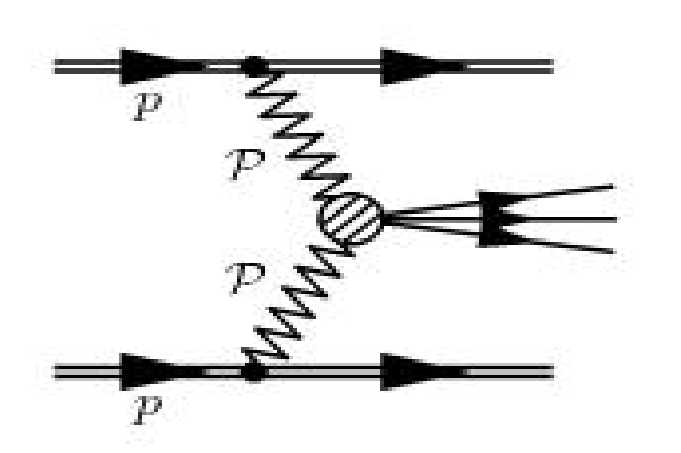
  → charge asymmetry relative to polar angle of π^+ in dipion rest frame

  → fractional energy asymmetry in open charm diffractive photoproduction

  → *asymmetries in HERA kinematics estimated 10 % - 15 %*

Signatures of Pomeron in lead-lead collisions

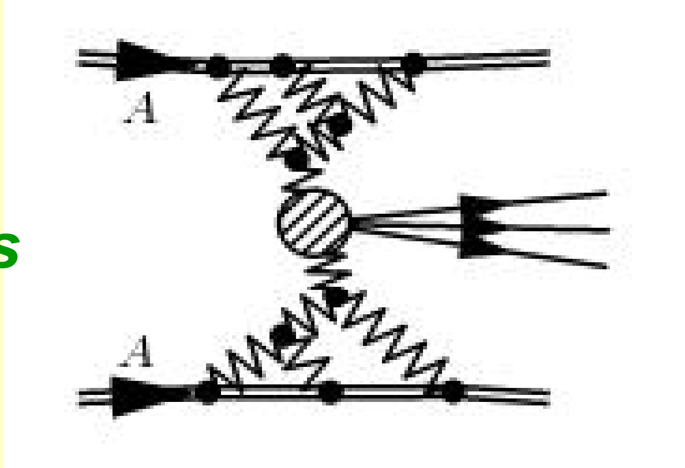
pomeron exchange in p-p



pomeron exchange in Pb-Pb:

absorption, shadowing

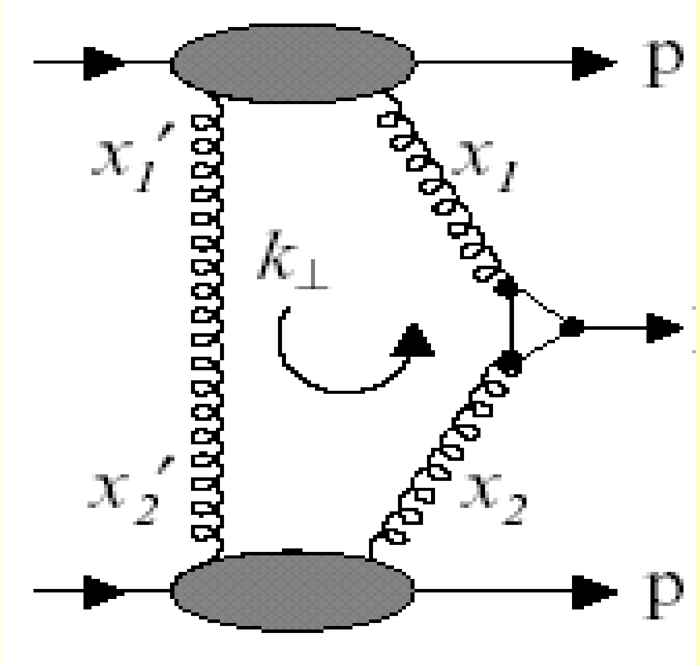
→ ***A-dependence reflects effects of triple pomeron couplings***



Central exclusive production

Diffractive Higgs production has small cross section with large
uncertainties (gap survival factor, Sudakov factor)
Same formalism can be used to predict $\gamma\gamma$, dijet and χ_c,χ_b

→ check uncertainties by measuring systems with larger cross section (smaller mass)



. → measure dijets and χ_c,χ_b with rapidity gap on either side

ALICE measurement of χ_c

- Khoze, Martin, Ryskin, Stirling 2004:

χ_c at LHC $\sqrt{s}$ = 14 TeV: $\left.\frac{d\sigma_{excl}}{dy}\right|_{y=0}$ = 340 nb $\rightarrow 3.5 \cdot 10^6$ χ_c in 10^6 s

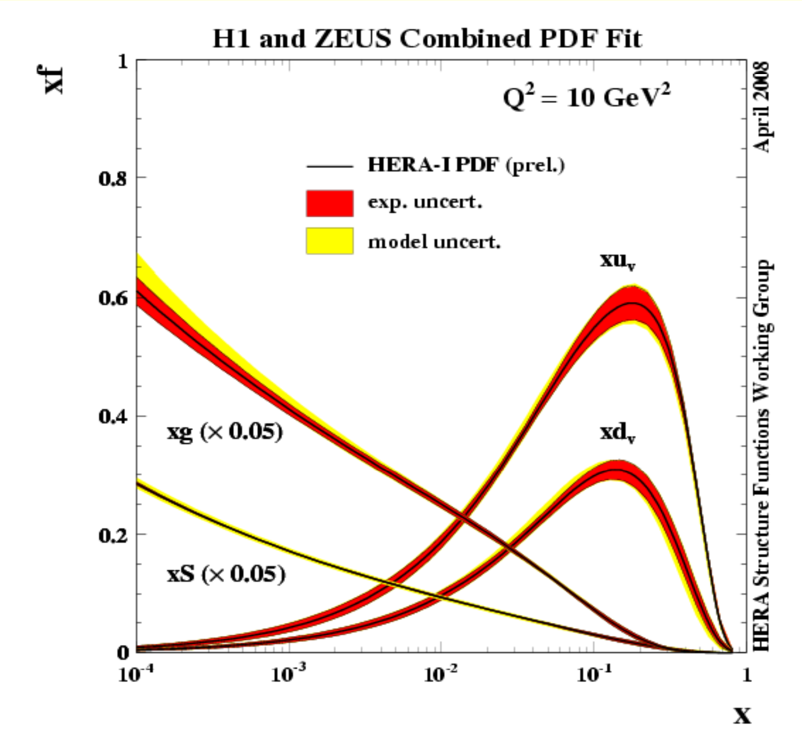
decay mode	BR	signal	backgnd
$\chi_c \rightarrow \pi\pi$	$7 \cdot 10^{-3}$	$2.4 \cdot 10^4$	??
$\chi_c \rightarrow K^+K^-$	$6 \cdot 10^{-3}$	$2.1 \cdot 10^4$	??
$\chi_c \rightarrow J/\psi\ \gamma$	$1 \cdot 10^{-2}$	$3.5 \cdot 10^4$	??
$\chi_c \rightarrow p\bar{p}$	$2 \cdot 10^{-4}$	700	??

} *χ_c measurement seems feasible*

feasibility study $\chi_c \rightarrow J/\psi\ \gamma$, BR $J/\psi \rightarrow e^+e^-$, acceptance γ, reconstruction eff, signal ~35

Gluon saturation

- Fits of parton densities xu_v, xd_v, xg, xS to HERA data



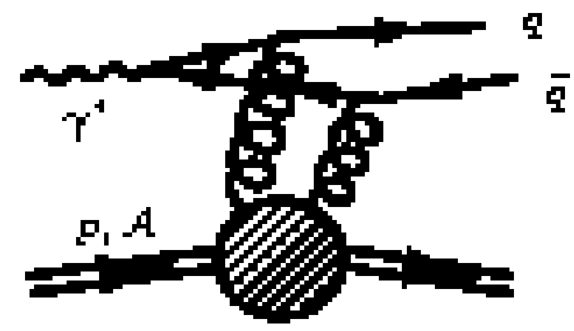
- How does gluon density behave at low x ?

- Where does gluon saturation set in ?

- Are there observables which are sensitive to gluon saturation ?

Heavy quark photoproduction in pp @ LHC

- Photoproduction of $Q\bar{Q}$
  - photon fluctuates into $Q\bar{Q}$,
  - Interacts as color dipole



$$\sigma_{dip}(x,r^2) = \sigma_0\{1-\exp(-\frac{r^2}{4R_0^{\,2}(x)})\}$$

Golec-Biernat, Wuesthoff 1999

$$R_0(x) = \frac{1}{GeV}\,(\frac{x}{x_0})^{\lambda/2}$$

σ_0, λ from fits of F_2 with $x < 0.01$

⟶ σ_{dip} saturates when $r \sim 2R_0$

$Q\bar{Q}$ -production cross section in pp-collisions

$$\sigma(pp \to Q\bar{Q}pp) = 2\int \frac{dN_\gamma^p(\omega)}{d\omega}\,\sigma_{\gamma p \to Q\bar{Q}(W_{\gamma h})}\,d\omega$$

$Q\bar{Q}$ (LHC)	Collinear pQCD	CGC model
$c\bar{c}$	16 μb	5 μb
$b\bar{b}$	230 nb	110 nb

Goncalves, Machado Phys. Rev. D71 (2005)

Diffractive Photoproduction of heavy quarks

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

Goncalves, Machado Phys. Rev. D75 (2007)

	pp	pPb	PbPb
$c\,\bar{c}$	92 nb	54 μb	59 mb
$b\,\bar{b}$	0.2 nb	0.09 μb	0.01 mb

pPb mode: L = 10^{29} $cm^{-2}s^{-1}$ → R (cc) ~ 5 Hz
Acceptance ~ 10 %, Efficiency ~ 50 % → R(cc)~20k per day

Heavy quarks can also be produced by central exclusive diffraction, ie two pomeron fusion → harder spectrum of quarks, hence could be disentangled in p_T spectrum

Conclusions, outlook

- ALICE has unique opportunity to do soft diffractive physics @LHC
- Diffractive trigger defined by two rapidity gaps
- Neutral energy measurement at 0^0
- Phenomenology of Pomeron/Odderon
- Multipomeron couplings in comparison pp - AA data
- Measurement of diffractive χ_c feasible
- Gluon saturation in heavy quark photoproduction
- Photon-Photon physics