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

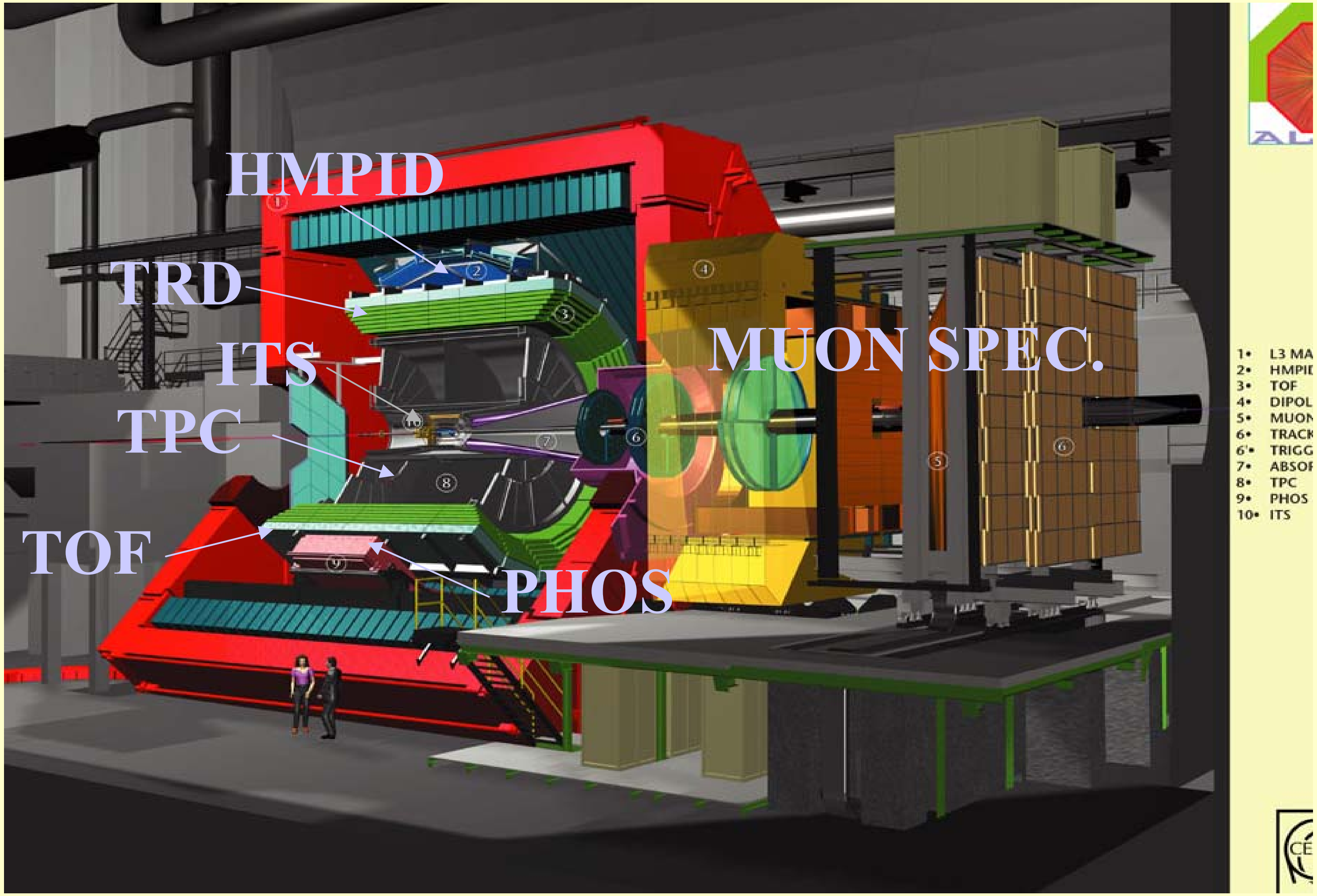
The ALICE experiment

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):

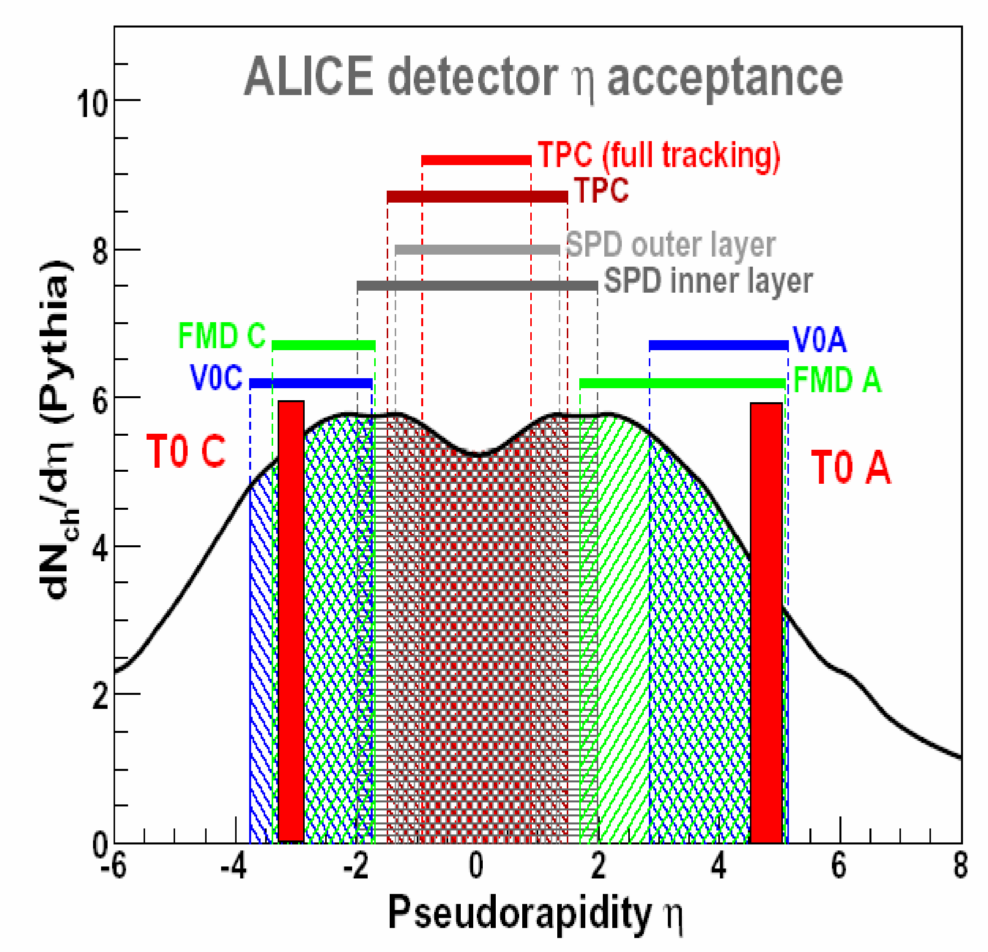
Pixel or TOF mult (central barrel)

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

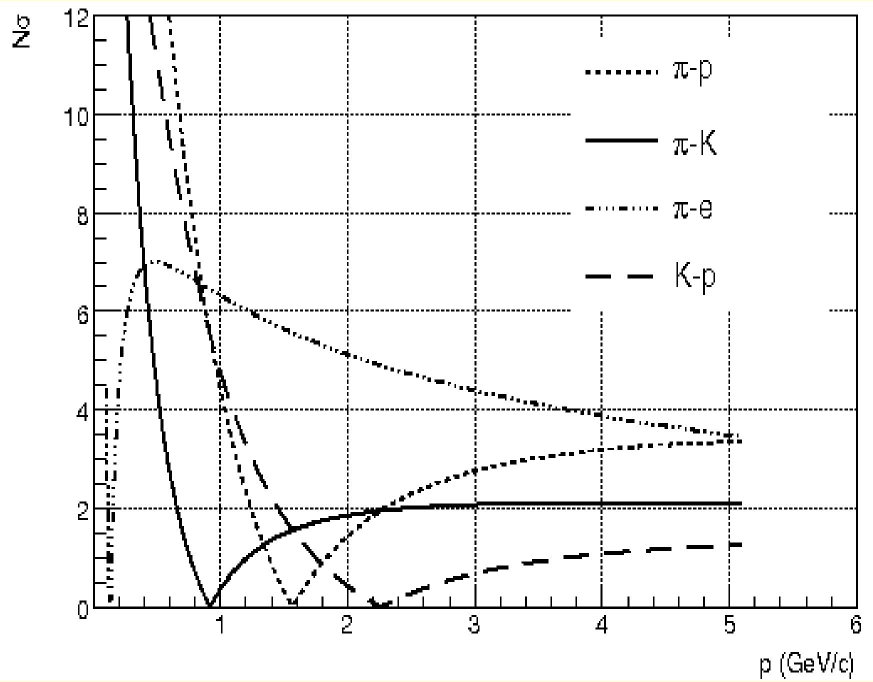
gap η_-: $-2 < \eta < -4 \rightarrow \Delta\eta \sim 0.5$

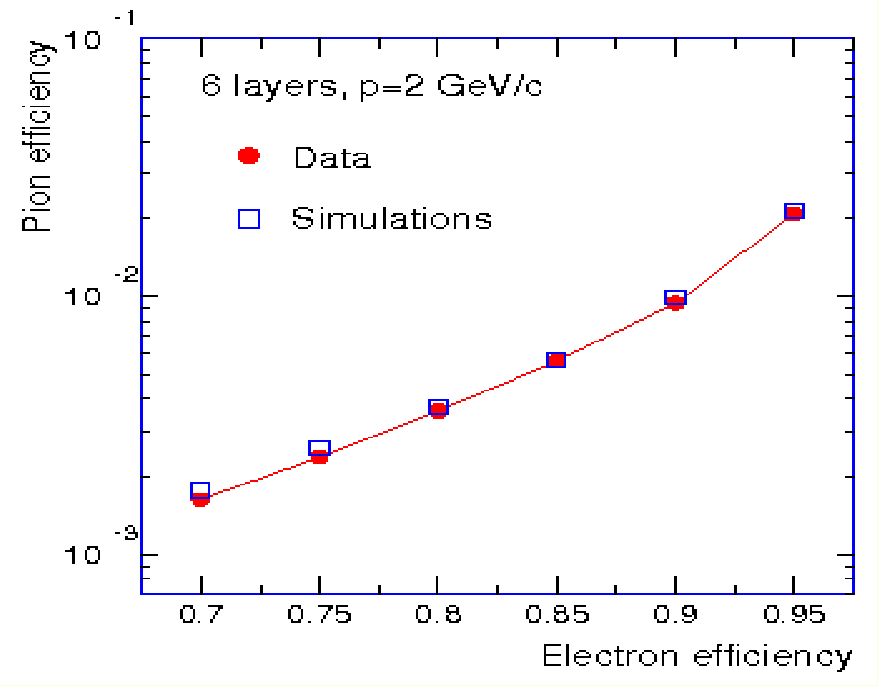
high level trigger (software):

$-3.7 < \eta < 5$



ALICE central barrel 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

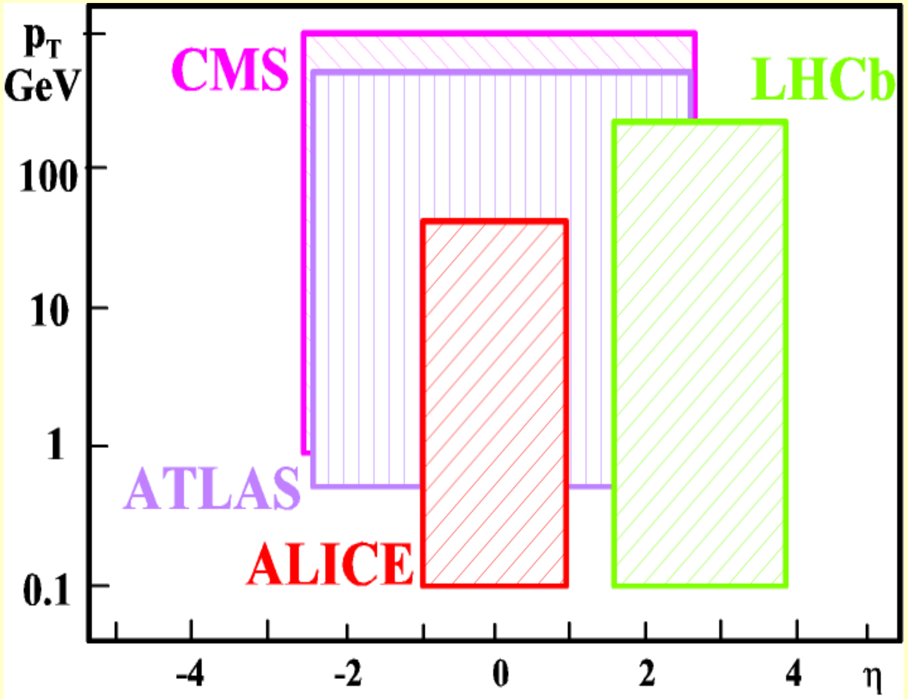
→identify vector mesons by e^+e^- decay

ALICE 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



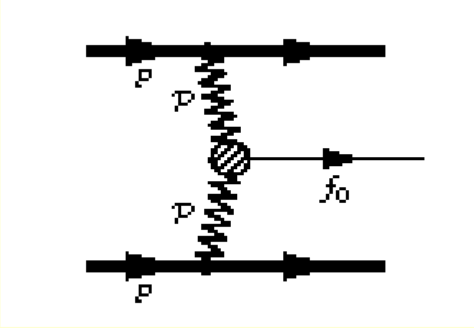
→ low p_T trigger ?

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

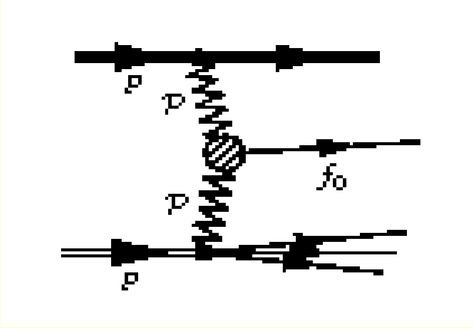
ALICE forward calorimeter

- **neutron calorimeter on each side**
  - **Placed at 116 m from interaction region**
  - **Measures neutral energy at 0^o**
- **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**

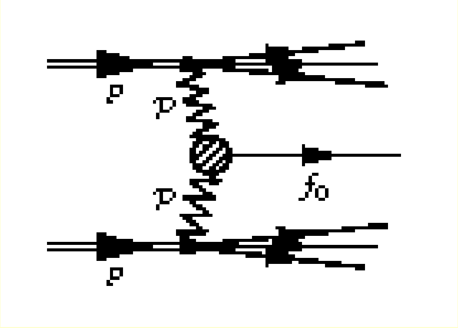
Identify the three topologies:



A



B



C

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

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

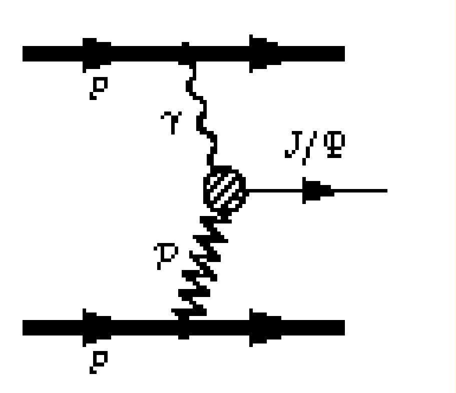
$$\frac{\sigma_A}{\sigma_C} \equiv h\,(x_1, x_2, ..)\frac{\sigma_{elast}}{\sigma_{DD}}$$

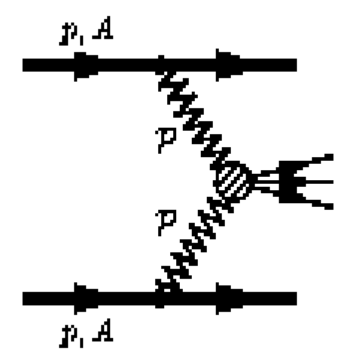
→ *what are* $f(x_i)$, $g(x_i)$, $h(x_i)$ *?*

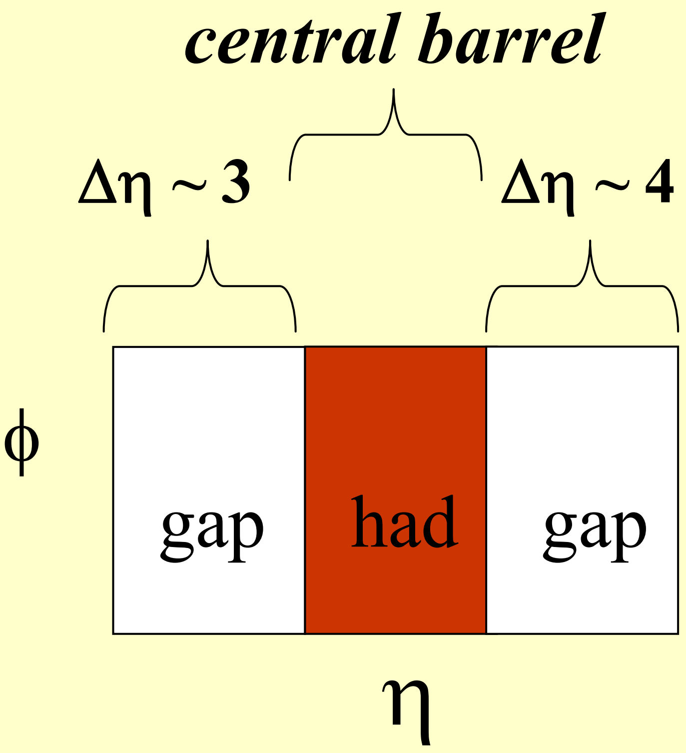
ALICE diffractive physics

- ALICE acceptance matched to diffractive central production:

  γ-pomeron, double pomeron, odderon-pomeron







central barrel

Δη ~ 3

Δη ~ 4

ϕ

gap

had

gap

η

Data taking:
pp @ L = $5\text{x}10^{30}$ cm^{-2}s^{-1} $\quad (\rightarrow \frac{d\sigma}{dy}\Big|_{y=0} \sim nb)$
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. $\alpha' \sim 0.25\text{GeV}^{-2}$ in DL fit, $\alpha' \sim 0.1\text{GeV}^{-2}$ in vector meson production at HERA, t-slope triple pom-vertex $< 1\text{GeV}^{-2}$

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

→ *$\langle p_T \rangle$ secondaries in double pomeron > $\langle p_T \rangle$ secondaries min bias*

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

→ *K/π, η/π, η'/π ratios enhanced*

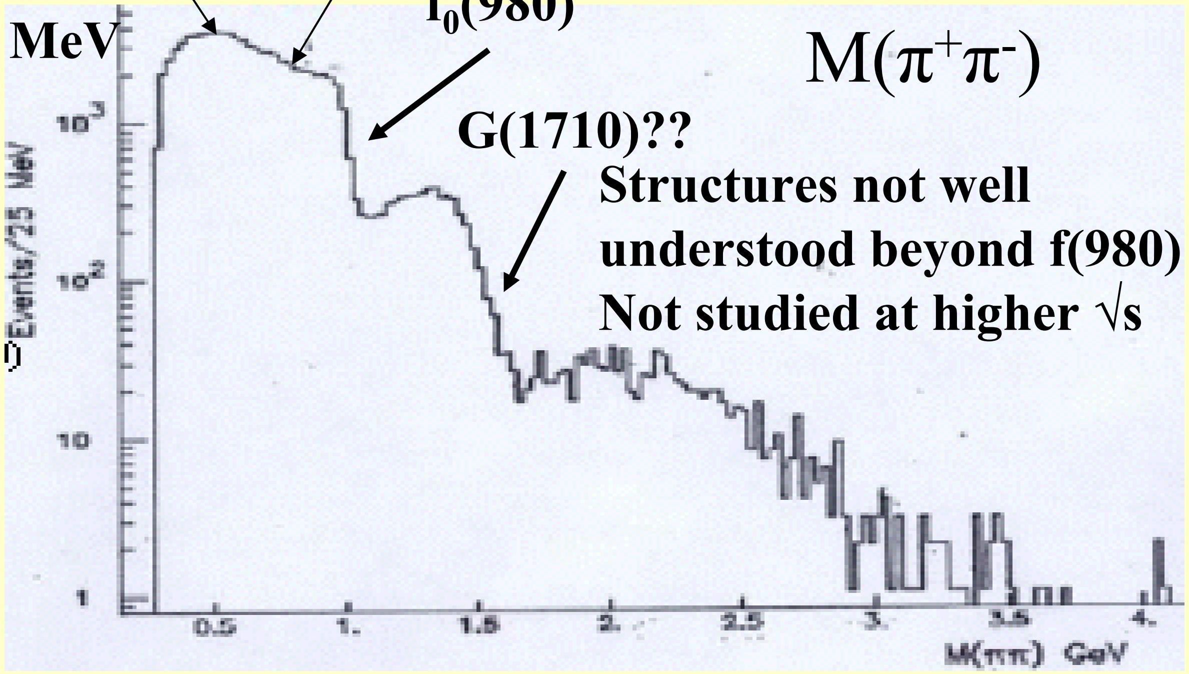
Central exclusive $\pi^+\pi^-$ production at $\sqrt{s}$ = 63 GeV

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

$$p \longleftarrow \boldsymbol{\pi^+\pi^-} \longrightarrow p$$

T.Akesson et al 1986:

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



$f_0(600)=\sigma$ **no ρ**

$f_0(980)$

3500 events/25 MeV

$M(\pi^+\pi^-)$

G(1710)??

Structures not well understood beyond f(980)
Not studied at higher $\sqrt{s}$

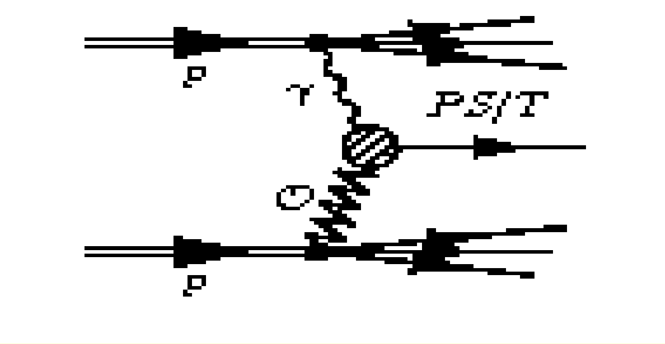
Signature Odderon cross section

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

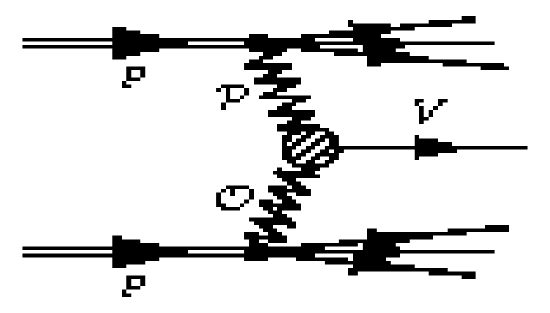
Look at exclusive processes with rapidity gaps

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 $\left.\frac{d\sigma}{dy}\right|_{y=0} \sim$ 15 nb (2.4 - 27 nb)
  - Odderon: t-integrated $\left.\frac{d\sigma}{dy}\right|_{y=0} \sim$ 0.9 nb (0.3 - 4 nb)

At $L = 5 \times 10^{30}$ $cm^{-2}s^{-1}$:

→ *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)

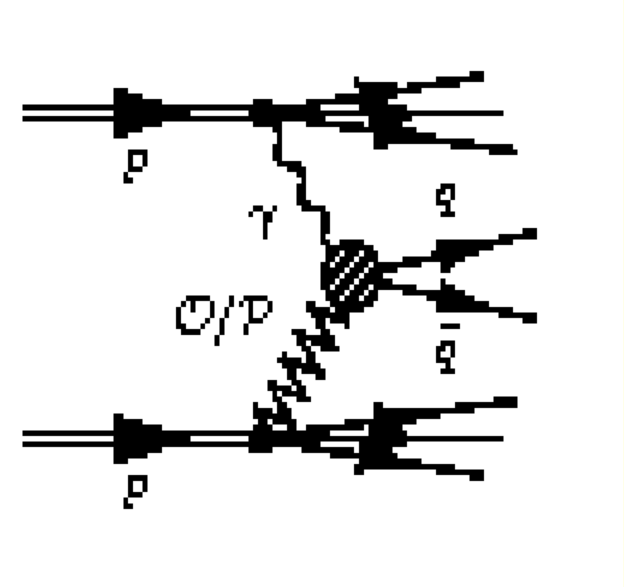
Signature Odderon interference

- Cross sections contain squared Odderon amplitudes

→ ***Odderon-Pomeron interference !***

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

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



→ ***look at final states which can be produced by Odderon or Pomeron exchange***

→ ***find signatures for interference of C-odd and C-even amplitude***

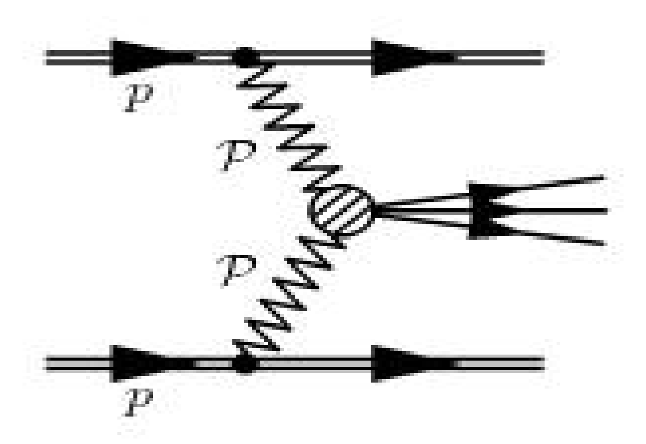
Interference signal

- 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 %

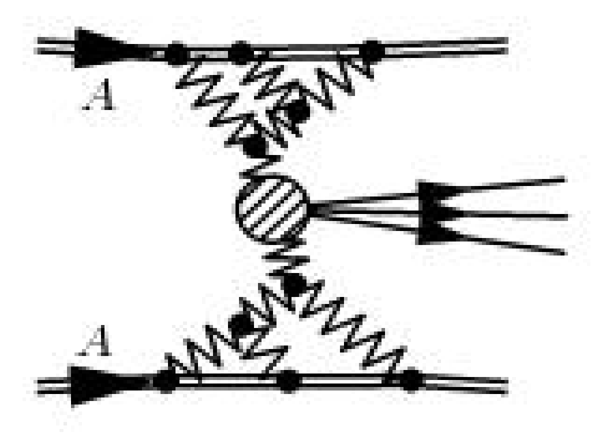
Signatures of Pomeron in lead-lead collisions

pomeron exchange in p-p



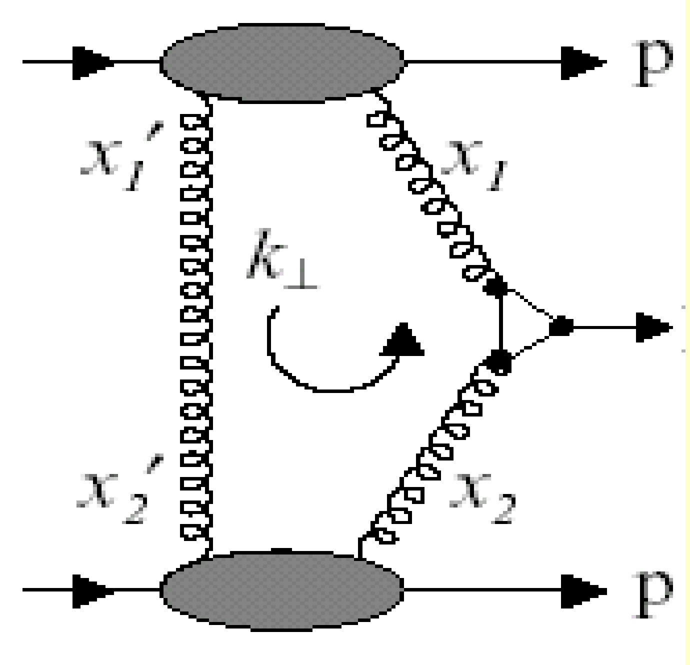
pomeron exchange in Pb-Pb: absorption, shadowing

→ 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 γγ, dijet and χ_c,χ_b



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

. → *measure dijets and χ_c 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 $\rightarrow 3.5\cdot 10^6\ \chi_c$ in 10^6 s

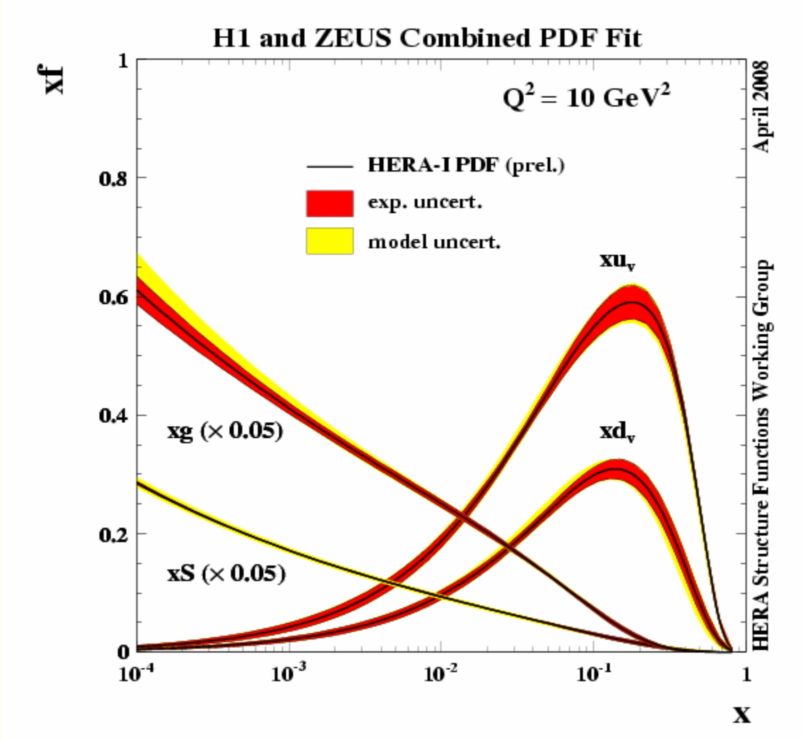
decay mode	BR	signal	backgnd
$\chi_c \rightarrow \pi\pi$	$7\cdot 10^{-3}$	$2.4\cdot 10^4$	??
$\chi_c \rightarrow K^+K^-$	$6\cdot 10^{-3}$	$2.1\cdot 10^4$	??
$\chi_c \rightarrow J/\psi\ \gamma$	$1\cdot 10^{-2}$	$3.5\cdot 10^4$	??
$\chi_c \rightarrow p\bar{p}$	$2\cdot 10^{-4}$	700	??

} *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

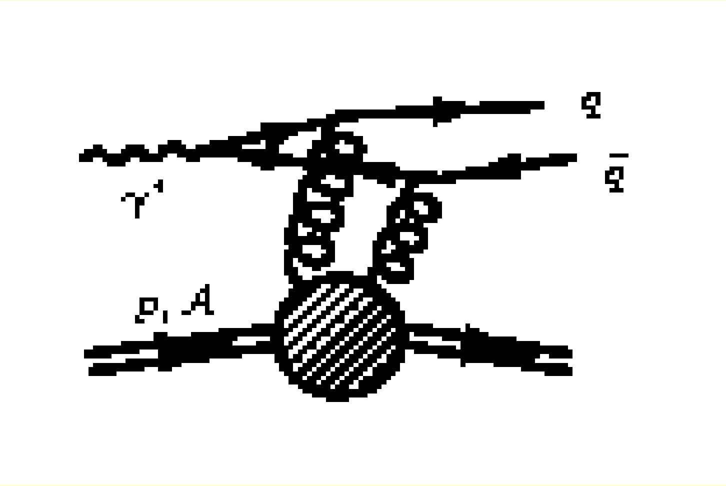


- How does gluon density behave at low x ?

- 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

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

$Q\bar{Q}$ (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 ($\bar{c}c$) ~ 5 Hz
Acceptance ~ 10 %, Efficiency ~ 50 % → R($\bar{c}c$)~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