# Hard Diffraction at Colliders

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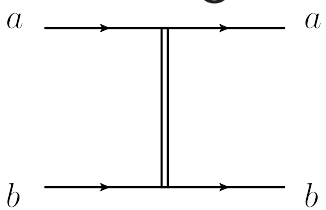
# Contents

# Diffraction

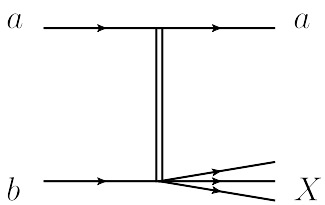


- Diffractive topologies

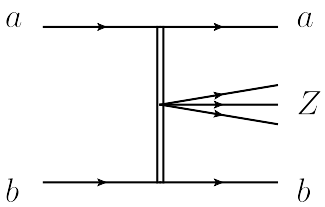
elastic scattering



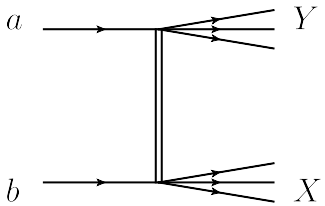

single diffraction




central diffraction




double diffraction



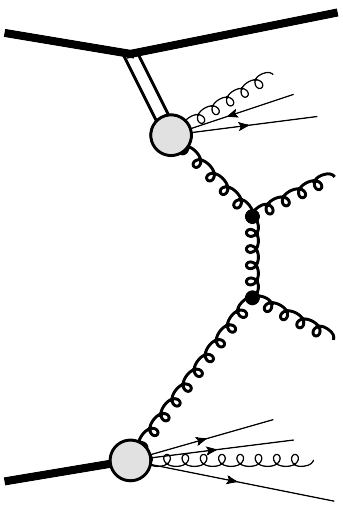

- Diffractive signatures
  - large rapidity gap
  - forward (anti-)proton
- Hard diffraction: diffraction + hard scale
- Hard diffractive topologies
  - single diffraction
  - central diffraction (double pomeron exchange)
  - central exclusive production
  - jet–gap–jet

# Mechanism of hard diffraction



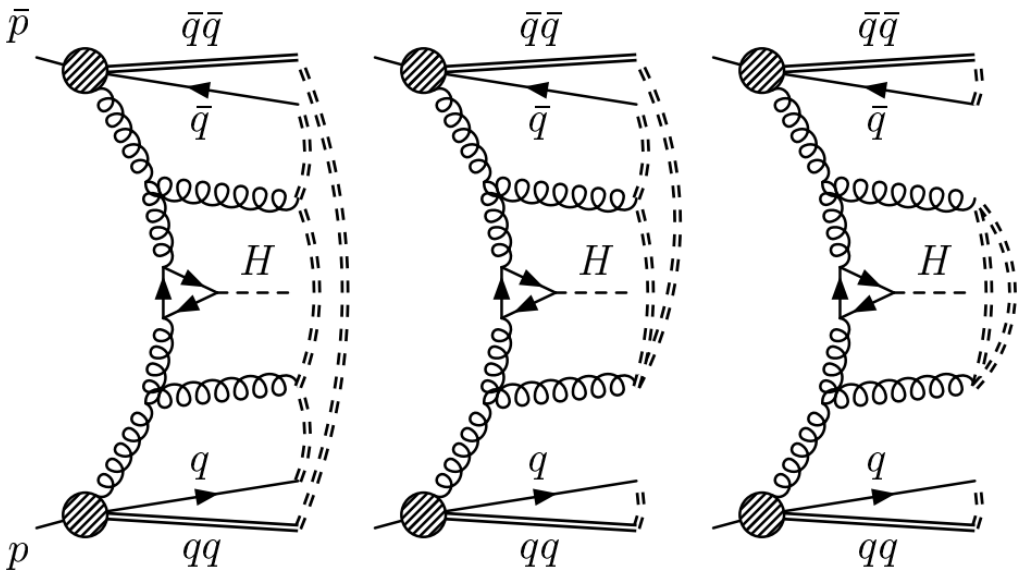
## Resolved pomeron

- Ingelman-Schlein model
- pomeron has partonic structure



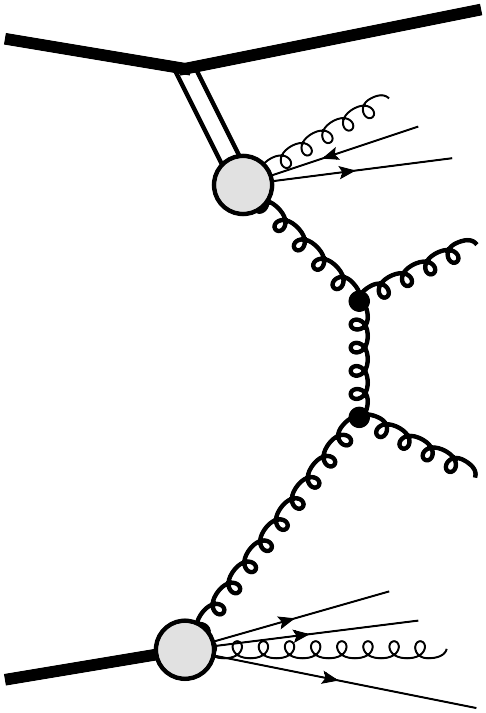
## Soft colour interactions

- QCD-inspired model
- additional gluon exchanges screen the color flow

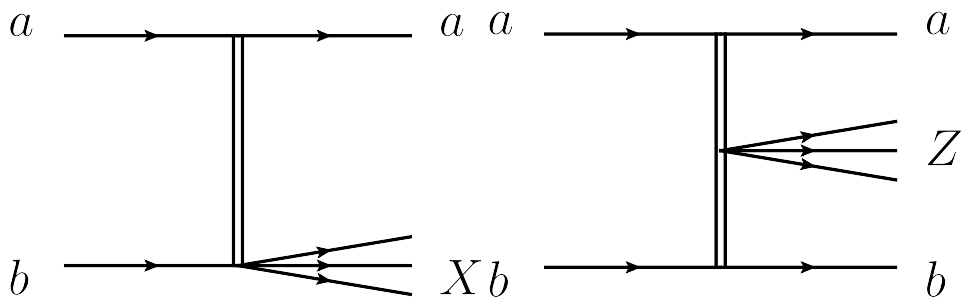


# Kinematics





- $\xi$ – momentum fraction of the proton carried by the pomeron
- $t$ – squared four-momentum transferred from the proton
- $\beta$ – momentum fraction of the pomeron carried by the interacting parton
- $M_X$ – diffractive mass




$M_X^2 = s\xi$ $\qquad$ $M_X^2 = s\xi_1\xi_2$

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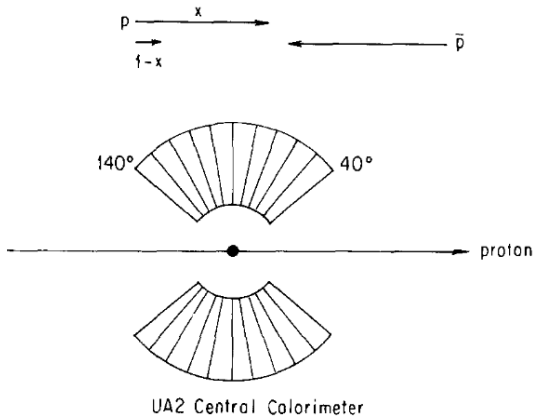
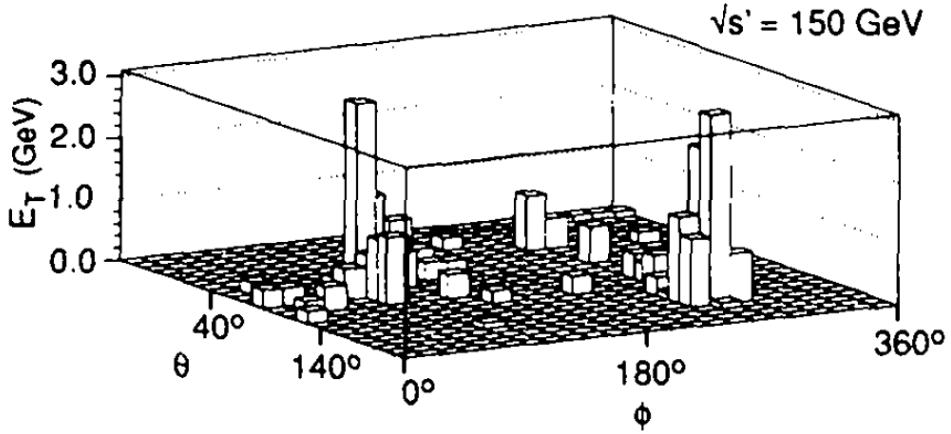
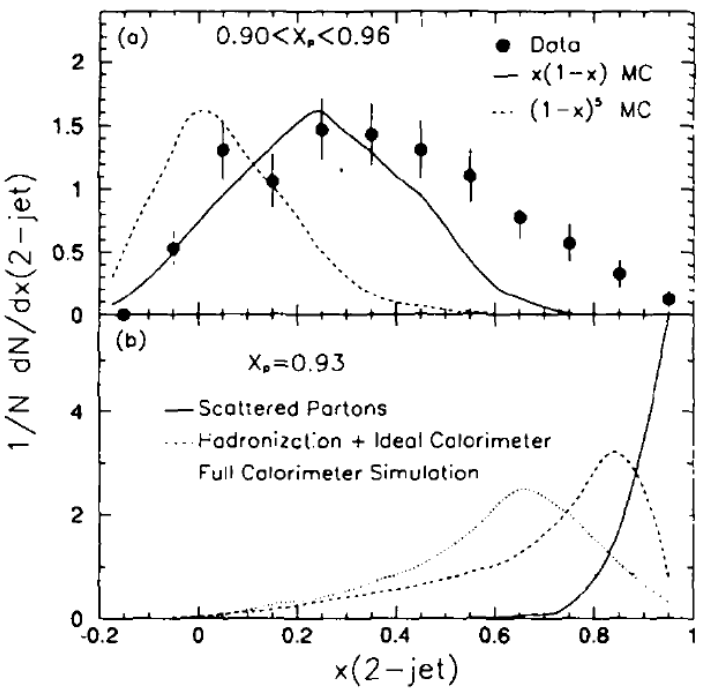
# SPS: diffractive jets





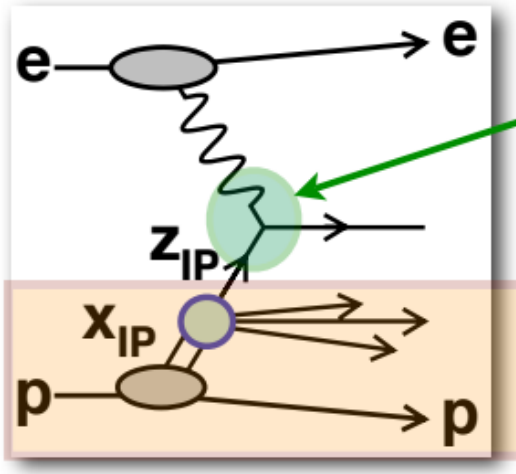




- UA8 experiment
- SPS: $p\bar{p}$ collisions
- $\sqrt{s} = 630$ GeV
- First observation of hard diffraction
- Studies of pomeron structure

# HERA: Diffractive PDFs

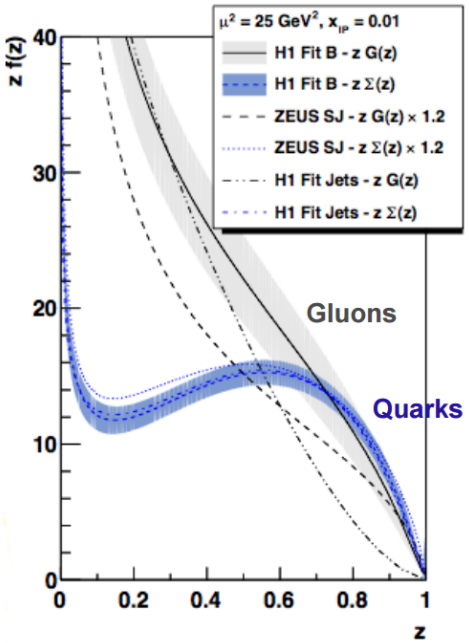


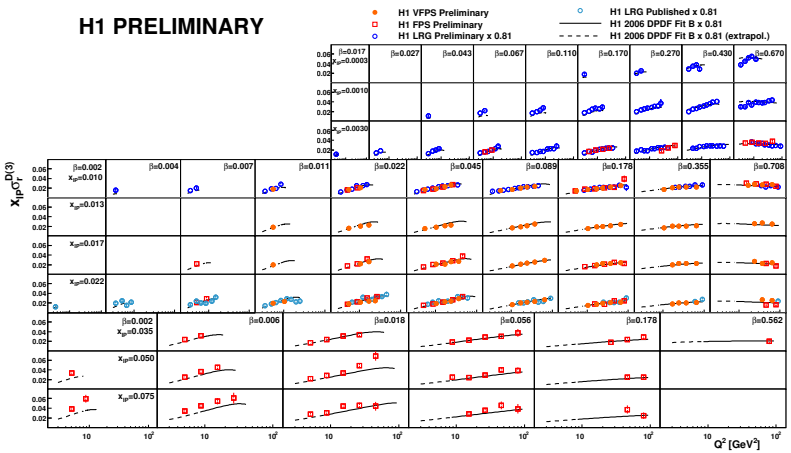



- hard scattering matrix element
- process dependent

Universal parton densities in diffractive exchange

Proved by J. Collins PRD 57,3051(1998)

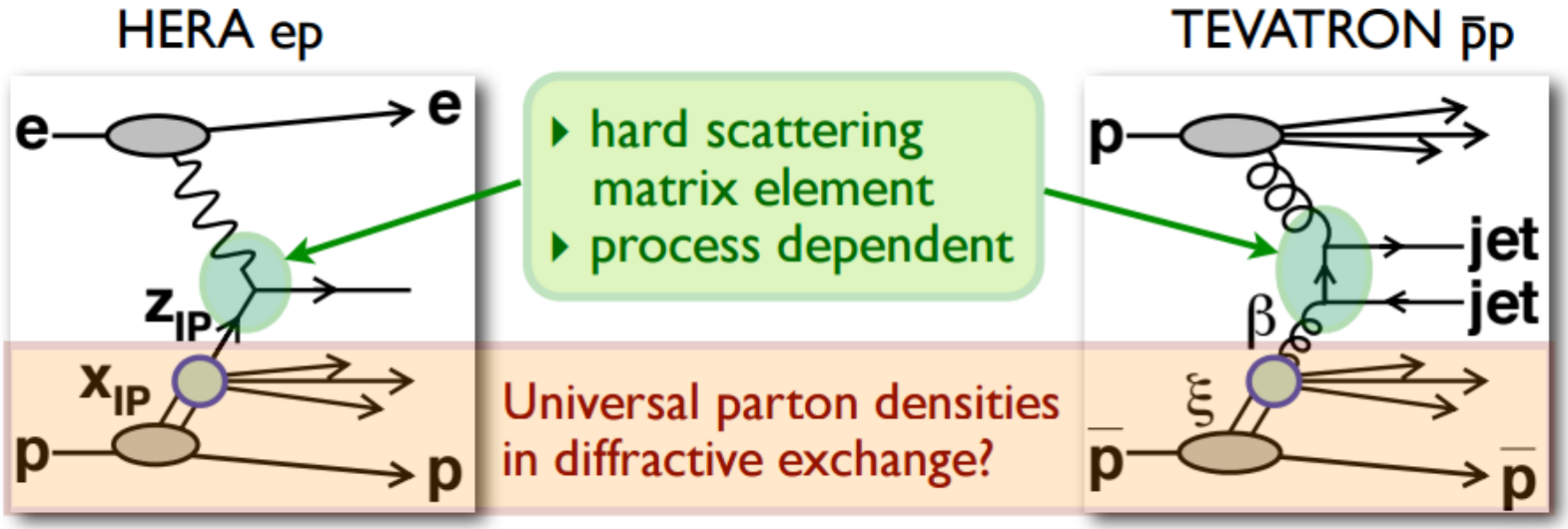


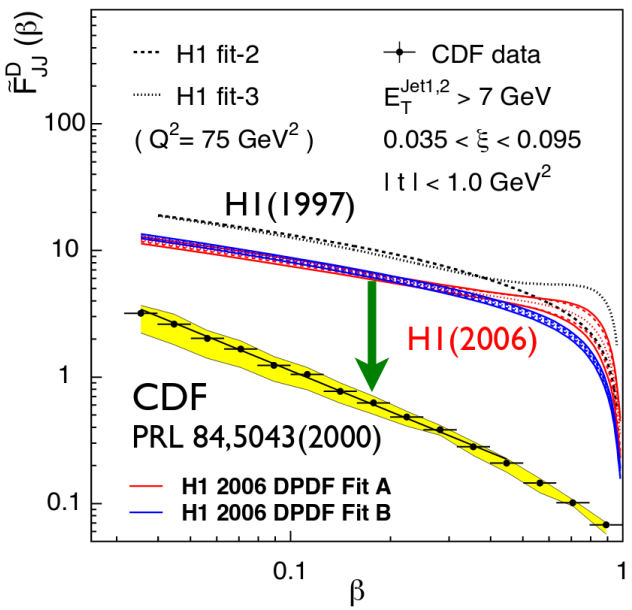




- QCD fits
- dominated by gluons
- jet production
- charm production
- measurements with proton tagging and LRG method

# Factorisation breaking





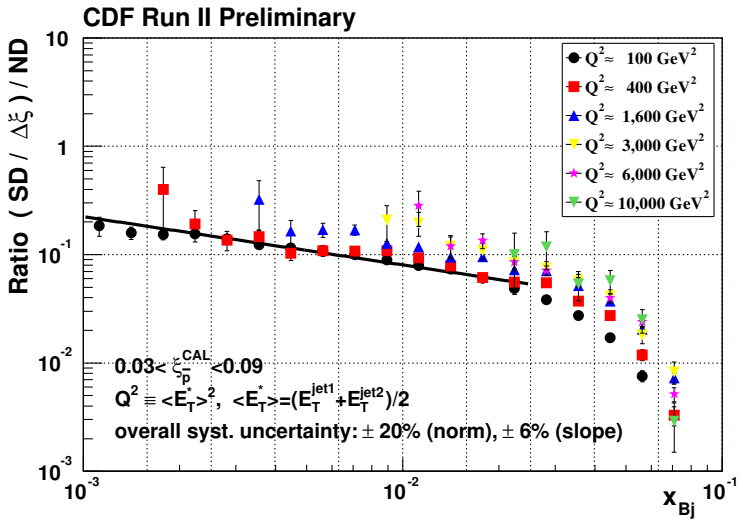




- Hard diffractive events rarer than naive extrapolations from HERA
- Suppression factor: gap survival probability
- Origin: additional interactions
- Confirmed in many processes, including photoproduction at HERA

# Tevatron: diffractive processes



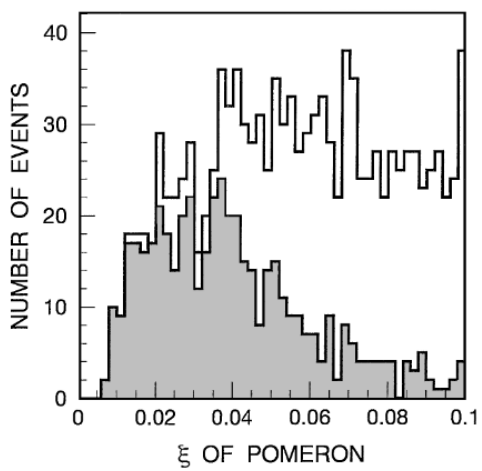
## Dijets



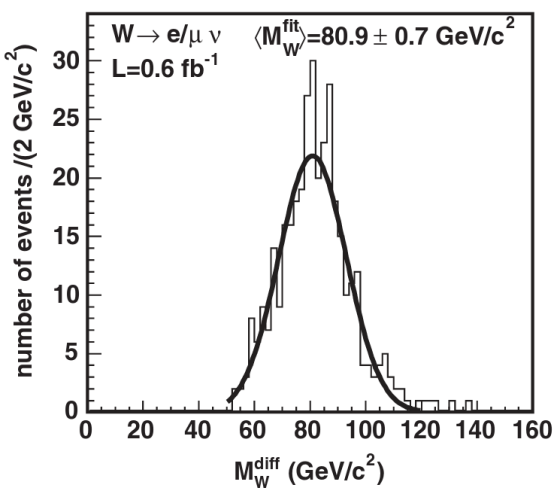

## Diffractive fraction [%]

| | | | |
|---|---|---|---|
| $W$ | 1.00 | ± | 0.10 |
| $Z$ | 0.88 | ± | 0.22 |
| jets | 0.75 | ± | 0.10 |
| $b$-quarks | 0.62 | ± | 0.25 |
| $J/psi$ | 1.45 | ± | 0.25 |

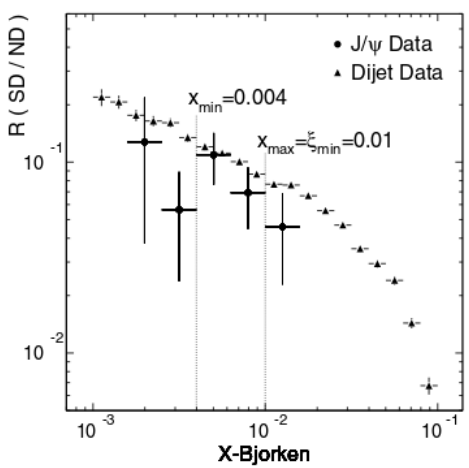
## b-quarks




## W and Z

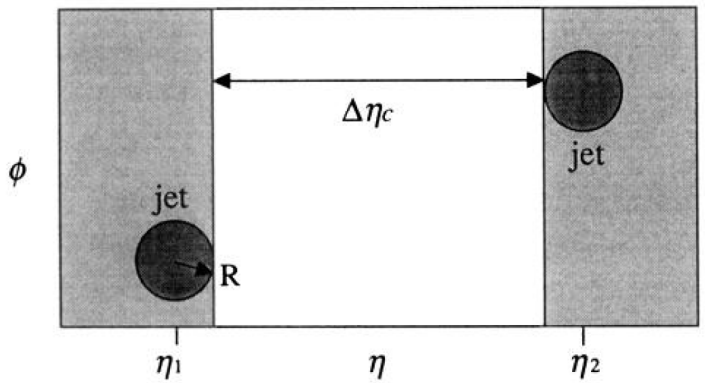


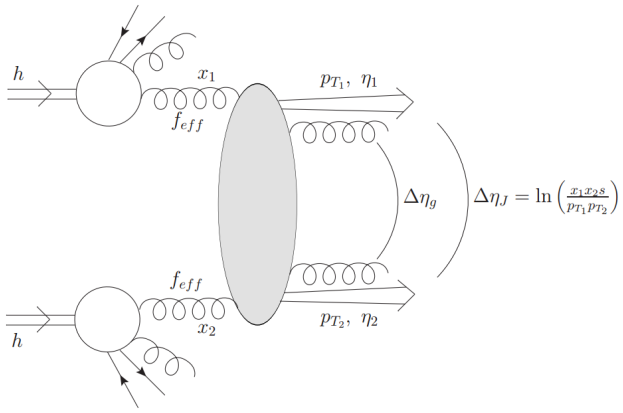

## J/ψ

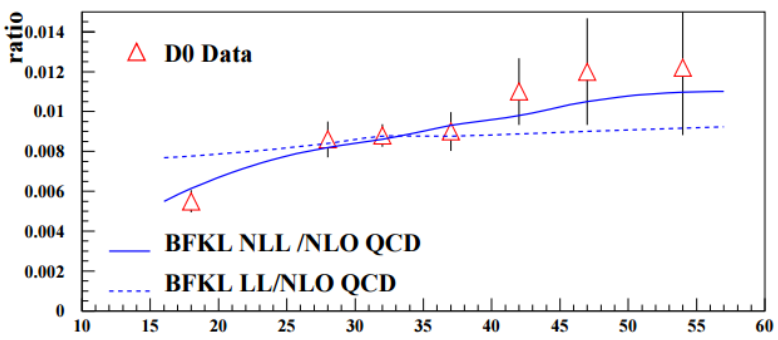


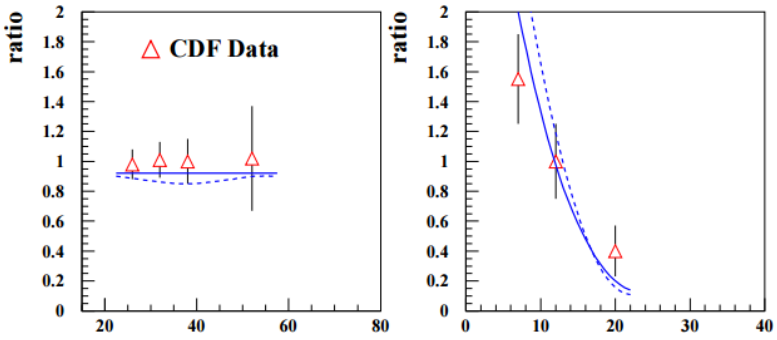
# Tevatron: Jet–gap–jet

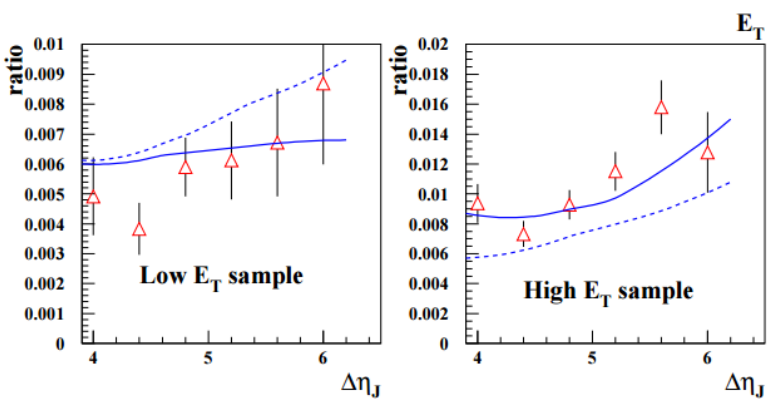


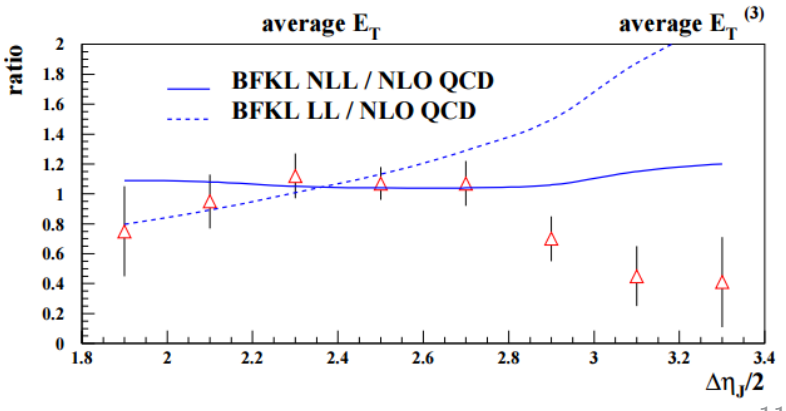


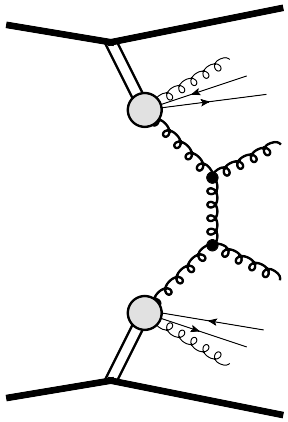



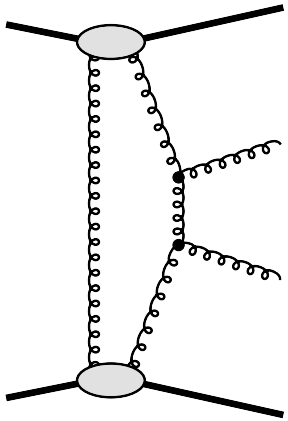
# Tevatron: central and exclusive hard diffraction



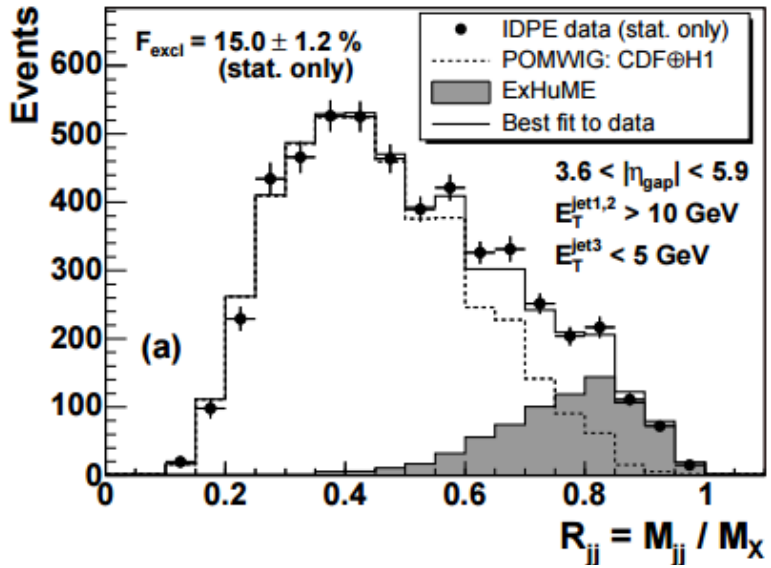
**central diffraction**

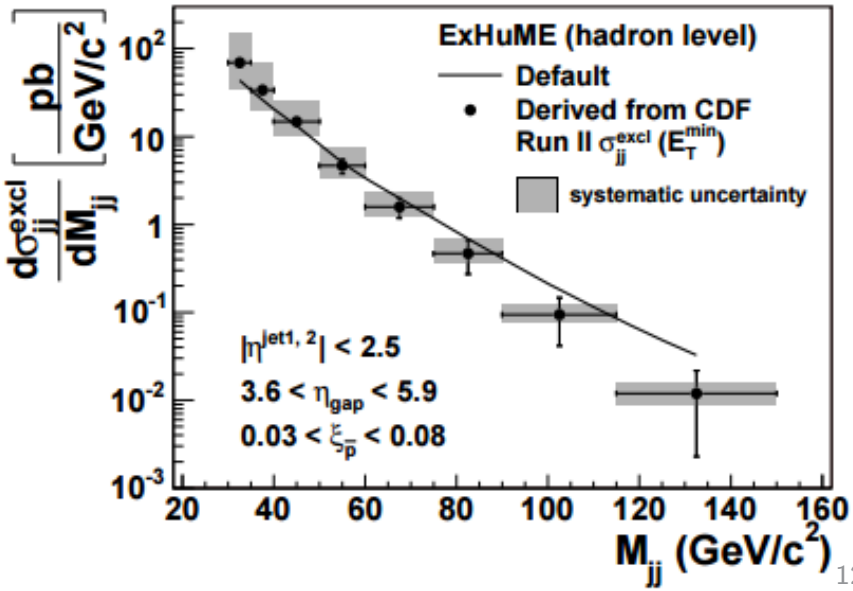


**exclusive production**



**Durham/KMR model**



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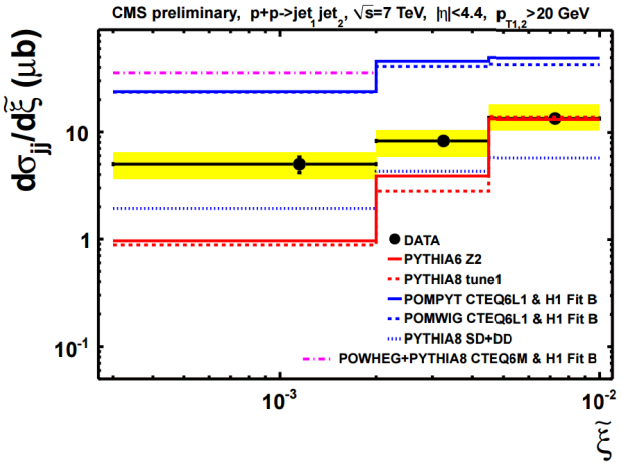
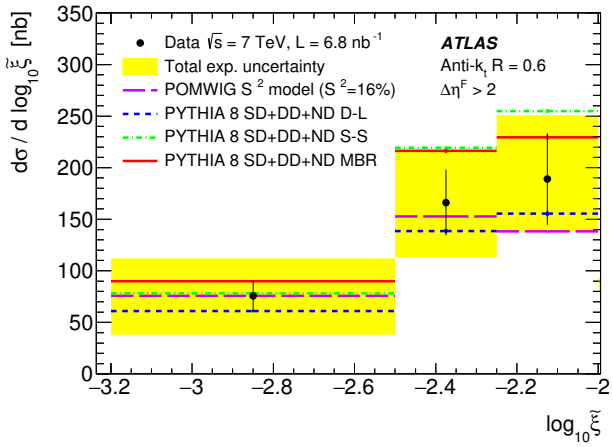
# Hard diffraction at LHC

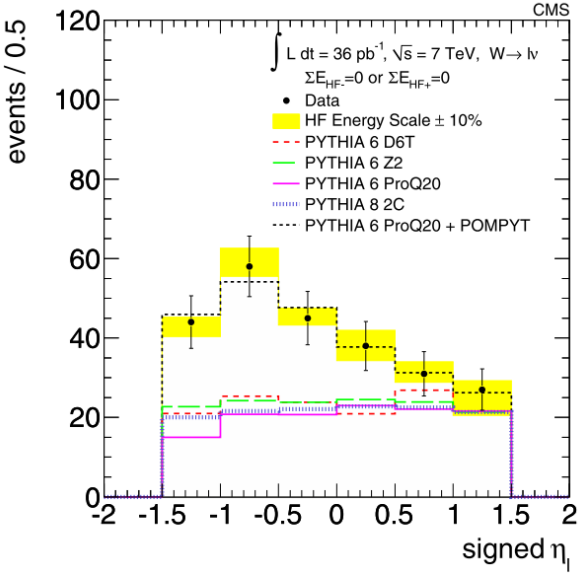


## Diffractive jets

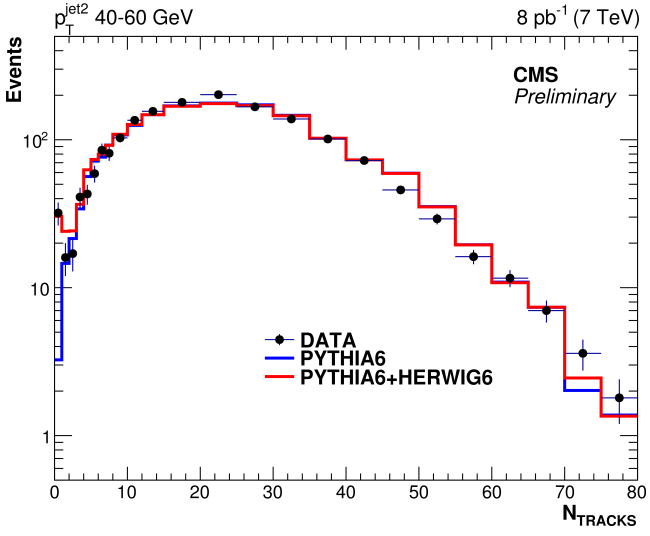



## Diffractive W and Z



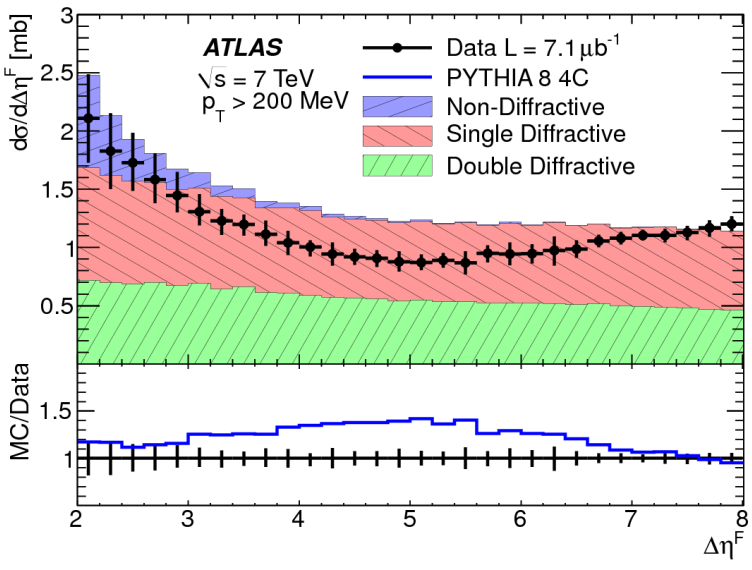

## Jet–gap–jet



# Rapidity gap at the LHC



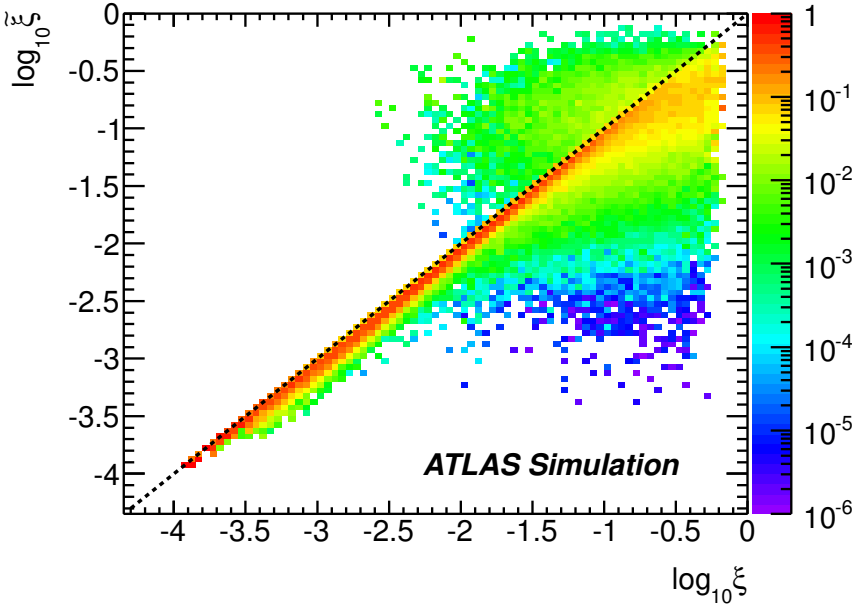
## Gap too large




low-mass dissociation indistinguishable from no dissociation

detector noise

## Gap too small



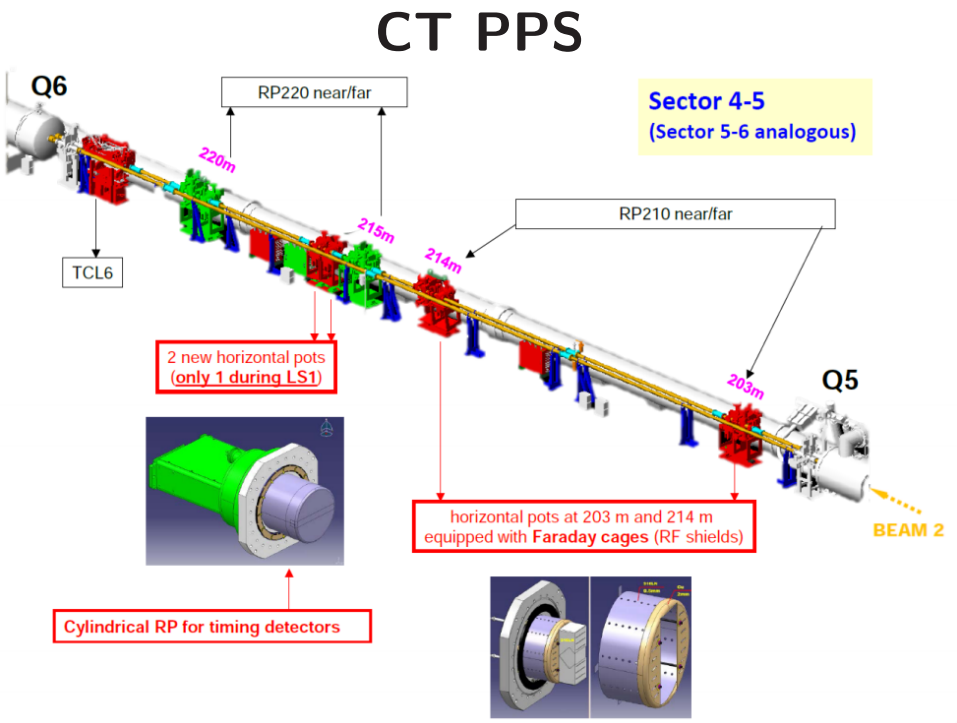

in high-mass events the gap is outside the calorimeter

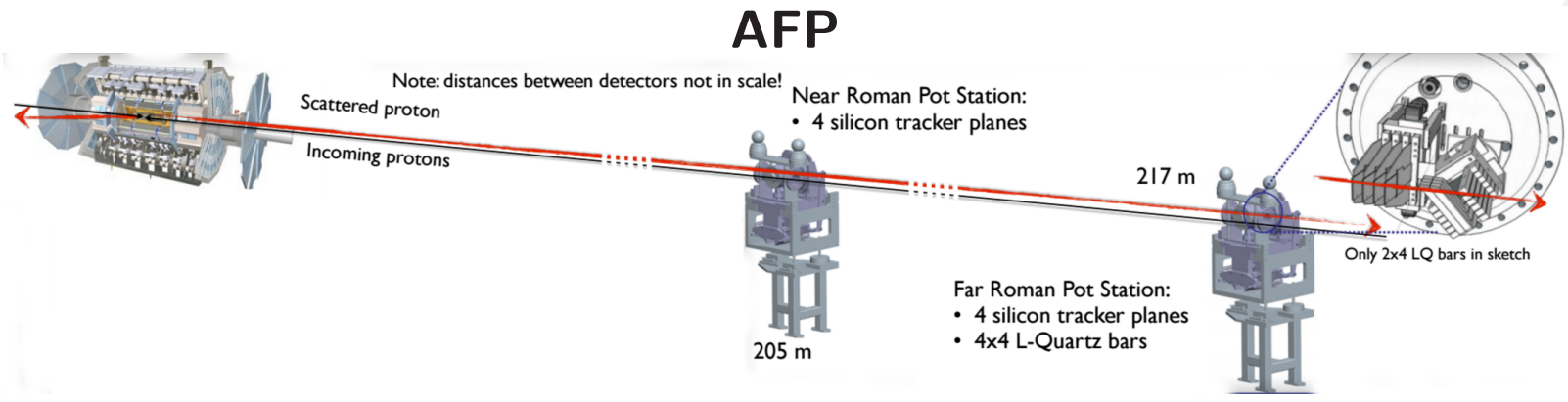
particle density fluctuation in non-diffractive events

# LHC Forward Proton Tagging



- Dedicated for elastic scattering and soft diffraction:
  - TOTEM
  - ALFA
- Dedicated for hard processes
  - CT PPS
  - AFP

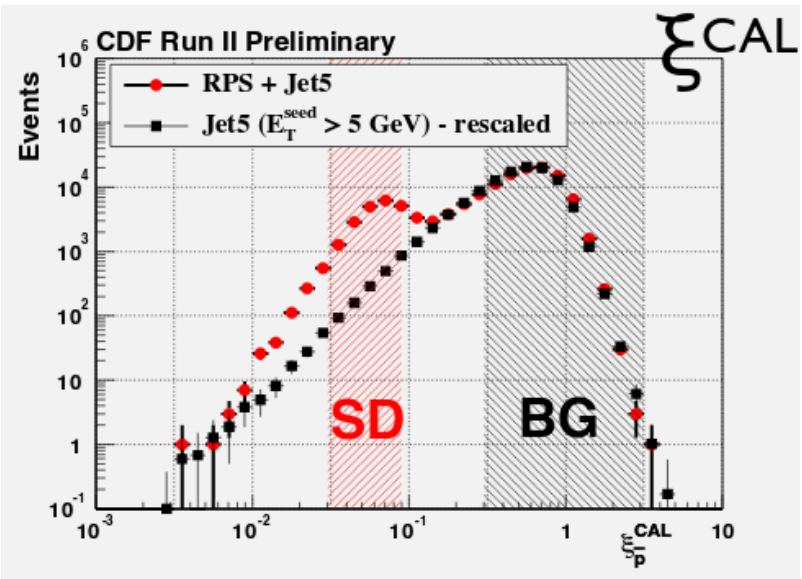


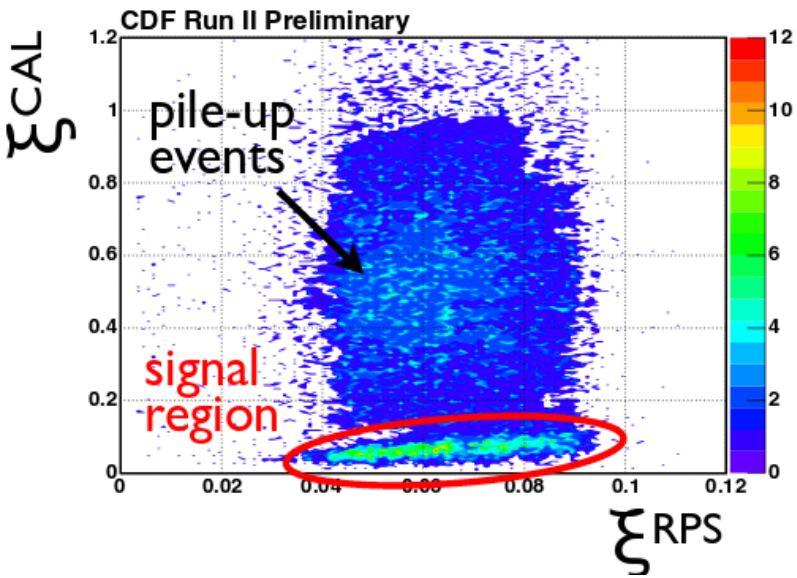



# Pile-up



- pile-up: several independent $pp$ interaction in an event
- twofold effect
  - rapidity gap can be filled with particles from other interactions
  - the observed forward (anti-)protons may originate from different interaction than the hard object
- its importance observed already at the Tevatron



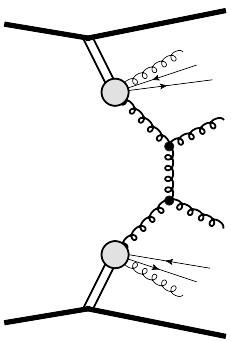

- full luminosity of LHC cannot be exploited in vast majority of diffractive measurements (especially for single diffraction)
- dedicated runs needed (but limited time)

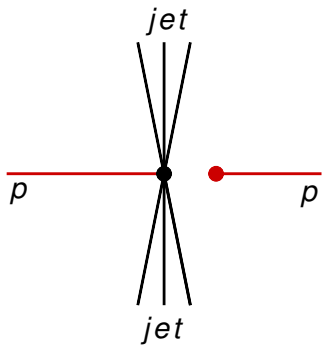
# Pile-up rejection

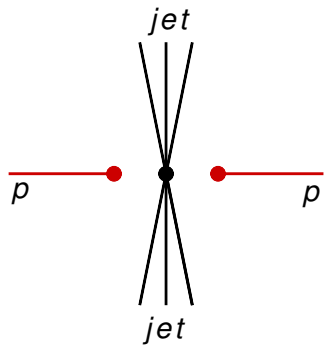


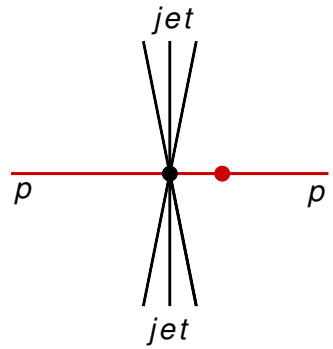
- Timing detectors: measurement of longitudinal vertex position

**signal** **backgrounds**

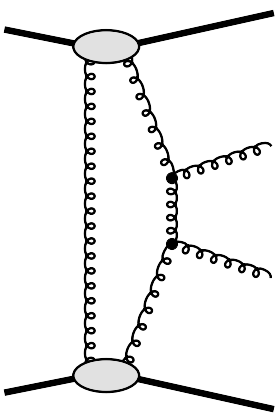


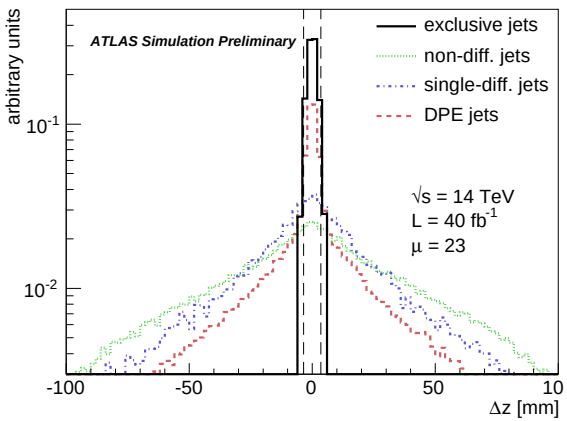


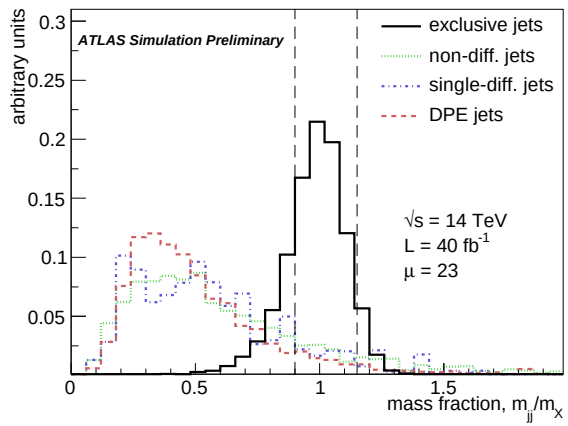




- Exclusivity selection



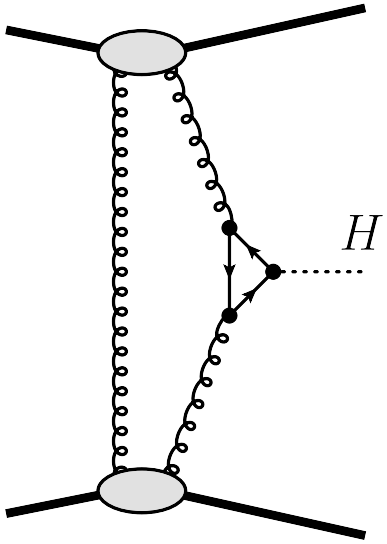


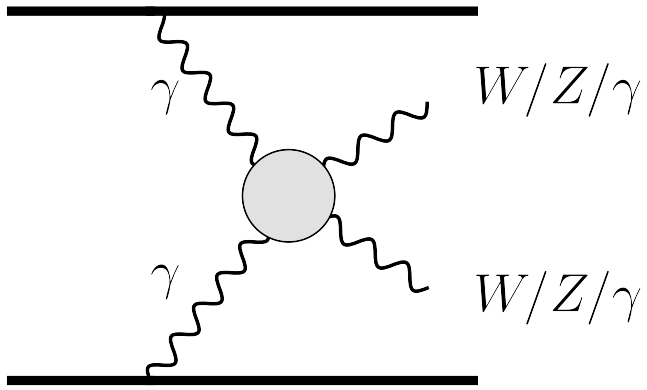




- Exclusive measurements should be possible at high luminosity

# Exclusive Higgs & new physics






- Measurement of exclusive Higgs would require detectors installed in cold LHC region
- The attempts were not successful

- The existing detectors allow measurements of higher masses
- Possibility of new physics searches in two-photon events

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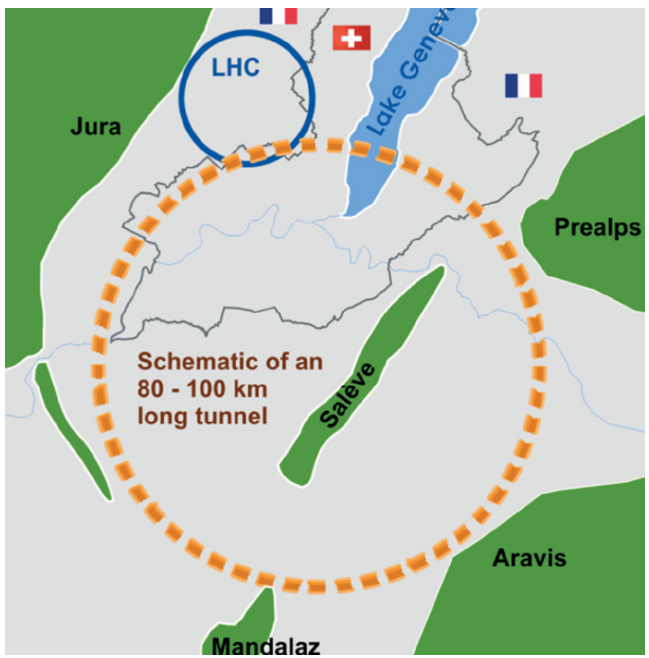
# Future Colliders



It is important that the forward proton detectors are foreseen and installed as soon as possible




- possible optimisation of the accelerator design
- participation in the development of the safety procedures
- data-taking always starts with low luminosity

# Summary and conclusions



- Hard diffraction is a well established phenomenon
- Many hard diffractive processes measured at different energies
- Diffractive PDFs known from DDIS at HERA
- QCD factorisation in DDIS
- Factorisation breaking in hadron-hadron interactions
- Details not fully understood
- Jet-gap-jet process described with NLL BFKL
- New measurements with proton tag expected at LHC