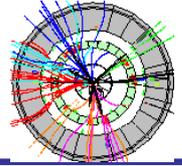


Physics at hadron colliders

- ◆ **Hadron-hadron interactions**
- ◆ **QCD & electroweak**
- ◆ **Top physics**
- ◆ **Higgs**
- ◆ **Future colliders**



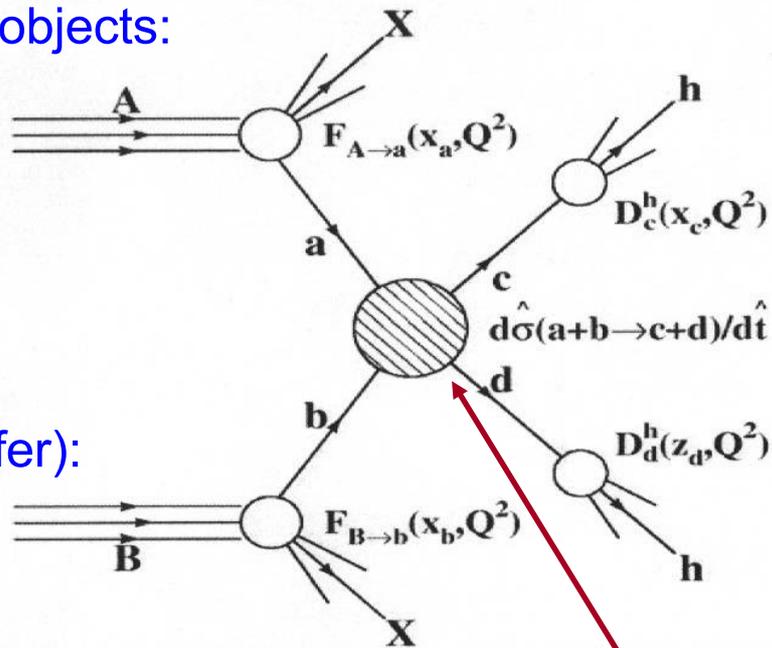
Hadron-hadron interactions

protons complex objects:
partonic
substructure:
quarks & gluons

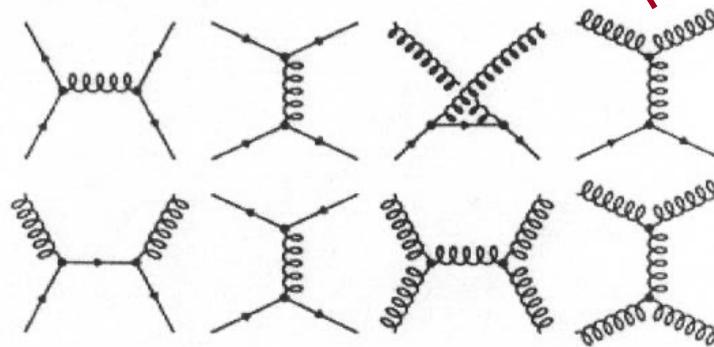
hard scattering
processes (large
momentum transfer):

quark-quark
quark-gluon
gluon-gluon

at parton level

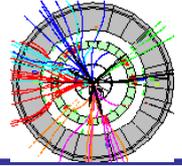


scattering or annihilation



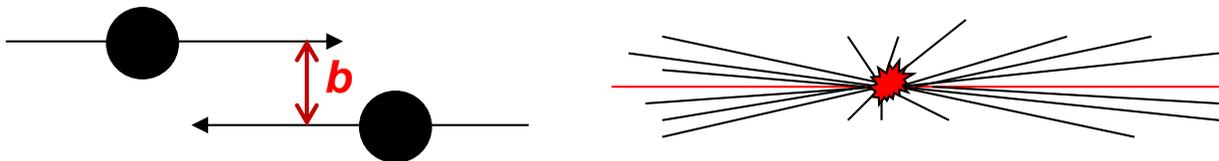
however: **hard scattering** (high p_T processes) represent only a tiny fraction of the total inelastic pp cross section. e.g. total inelastic cross section ~ 80 mb at $\sqrt{s} = 13$ TeV.

Dominated by events with small momentum transfer, in particular by two event types: **diffractive** (colourless exchange with the quantum numbers of vacuum between the two protons) & **minimum-bias** (exchange of colour).



Inelastic low p_T hadron-hadron collisions

Most interactions due to interactions at large distance between incoming protons where protons interact as “a whole” → **small momentum transfer** ($\Delta p \approx \hbar / \Delta x$) / **large impact parameter b** → particles in final state have large (small) longitudinal (transverse) momentum.



$\langle p_T \rangle \approx 500 \text{ MeV}$ (of charged particles in final state)

$$\frac{dN}{d\eta} \approx 6$$

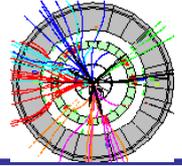
~6 charged particles per pseudorapidity unit in central region of experiment (uniform distribution in azimuthal angle) (LHC numbers)

most energy escapes down the beam pipe.

Called **minimum-bias events** (“soft” events) & constitute a large fraction of the total cross section e.g. $\sim 60 \text{ mb}$ of $\sim 110 \text{ mb}$ at $\sqrt{s} = 13 \text{ TeV}$. Perhaps not very interesting in themselves but needs to be understood. Cross section large that they occur multiple times per bunch crossing (e.g. 2024-26: ~ 60 times) \Rightarrow overlap interesting collisions (“pile-up”) & change measured event quantities.



Diffraction



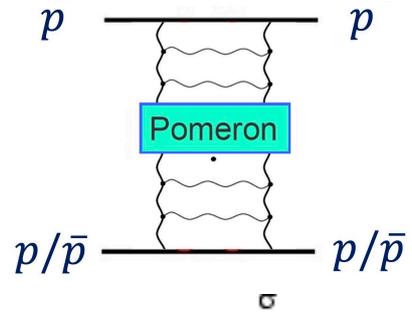
Diffractive processes

another large part of the total cross section are diffractive processes, where non-colored object(s) are exchanged referred to as "Pomeron(s)". Pomeron is described by a system of two (or even number) of gluons or gluon ladder

diffractive events characterized by "rapidity gaps"
(= regions of pseudorapidity without primary particle production)

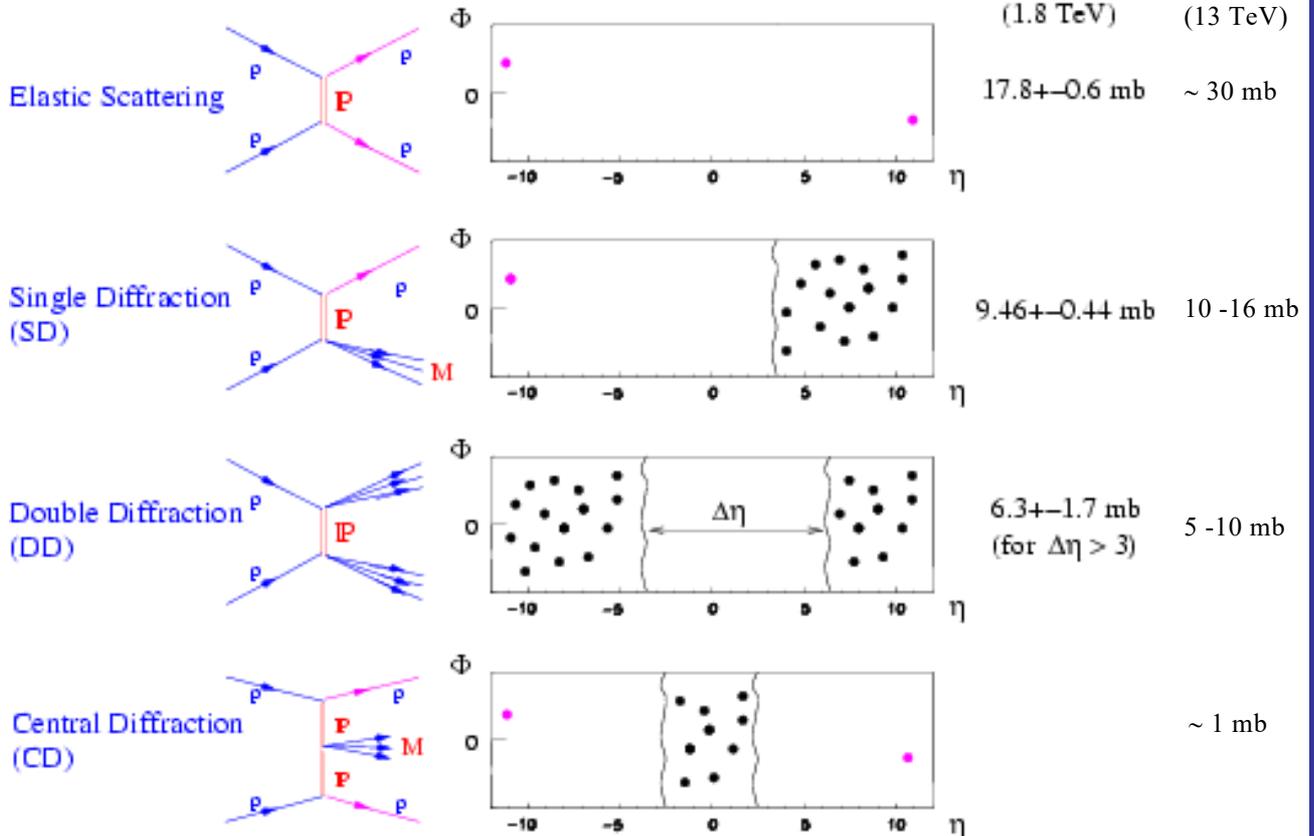
- elastic scattering ~ 30 mb
 - single diffraction 10 – 16 mb
 - double diffraction 5 – 10 mb
 - central diffraction ~ 1 mb
- in total ~ 50 mb @ $\sqrt{s} = 13$ TeV.

e.g. elastic scattering



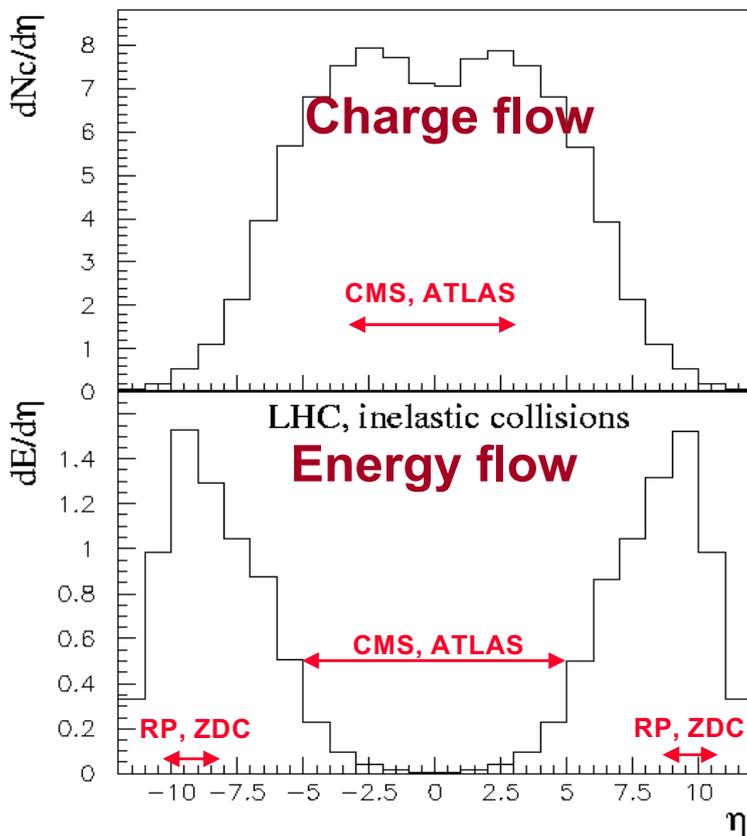
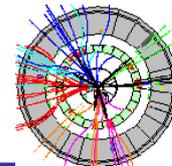
(1.8 TeV) (13 TeV)

17.8 ± 0.6 mb ~ 30 mb





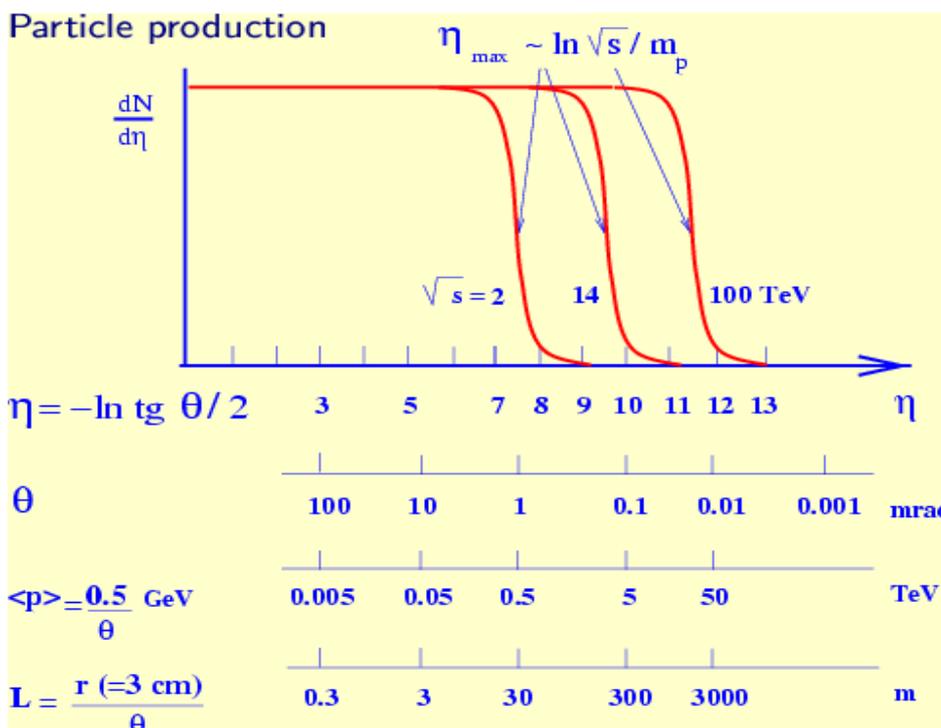
Hadron-hadron interactions



charged particle & energy flow in an average proton-proton collision at LHC.

The acceptancies of baseline ATLAS & CMS experiments are also indicated

RP = Roman Pots (detect protons)
ZDC = Zero Degree Calorimeters (detect neutral particles)



pseudorapidity

$$\eta = -\ln \tan \frac{\theta}{2}$$

polar angle

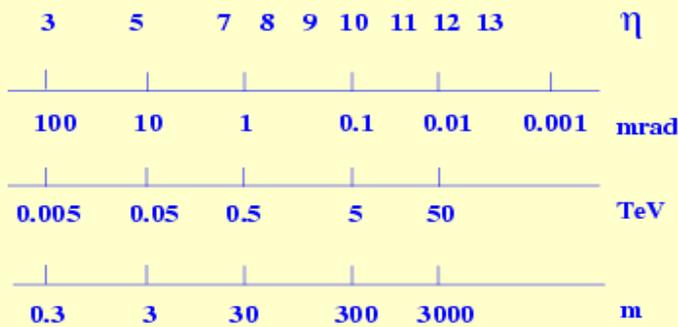
θ

average particle momentum

$$\langle p \rangle = \frac{0.5 \text{ GeV}}{\theta}$$

distance to IP @ LHC vacuum chamber radius

$$L = \frac{r (=3 \text{ cm})}{\theta}$$



IP = interaction point