Diffractive and forward Physics at LHC

- What is forward physics?
- The Yellow Report on "LHC Forward Physics"
- Experimental signature
- The tools
- Central Exclusive production
- New Physics

Nicolo Cartiglia, INFN, Torino, 23 May, Pollenzo

What is "Forward Physics" at LHC

Forward physics includes a wide range of topics, and different experimental techniques.
It goes **from total cross section to extra dimension.**

The common link is that the signature comprises activity at high rapidity

The most obvious measurement is the **total cross section** and it's components.

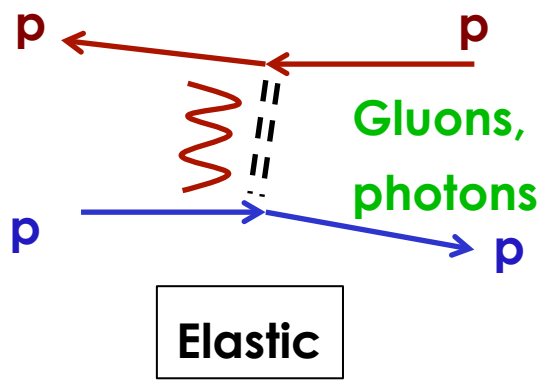
However Particle Multiplicity, dN/dη, Particle correlations are performed using detectors that covers rapidity < 3

Soft diffraction, Hard Diffraction, and Exclusive production use higher rapidity detectors, and possibly proton tagging.

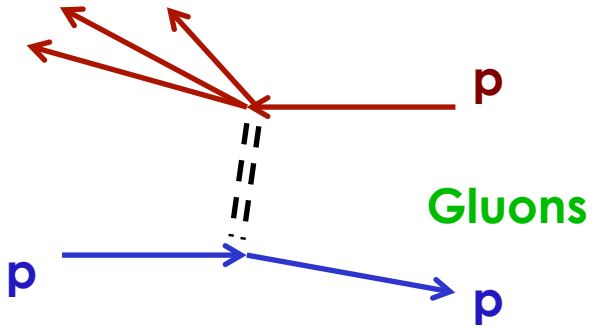
Is LHC the right place for forward physics? No

QCD or QED origin…

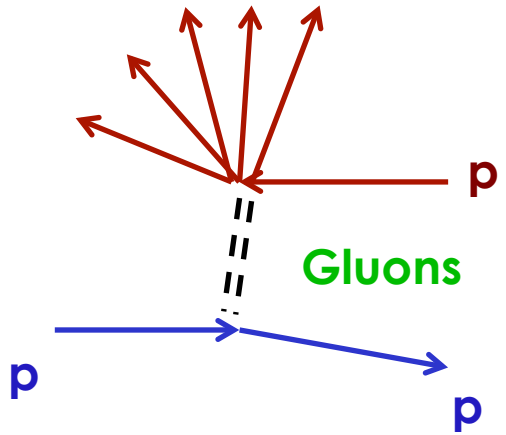
The **Elastic, Soft diffraction, Hard Diffraction, and Central Exclusive production** have in common the **exchange of a color neutral object** between the incoming particles:



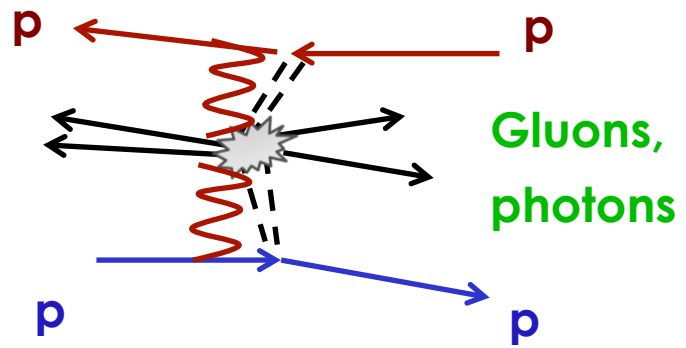
Elastic



Soft Diffraction



Hard Diffraction



Central Exclusive Production

The Yellow Report: need for coordination

- Large community (>100), dispersed on several experiments.
- Lack of a "Nobel prize" measurement to be used as PR weapon
- Very small weight in the LHC decision process

Two distinct needs:

- Identify the most important physics challenges
- Have weight in the experiment-LHC decision

Main problem: data collected at high luminosity (~ 50 interactions per bunch crossing) cannot be used for forward physics, there are too many overlapping events

Basic request to LHC: enough time at reduced beam intensity to collect enough luminosity for forward physics studies.

The yellow report

"…which hopefully represents the unanimous views of the broad forward-physics community…"

CERN-PH-LPCC-2015-001
SLAC-PUB-16364
DESY 15-167

September 3 2015

LHC Forward Physics

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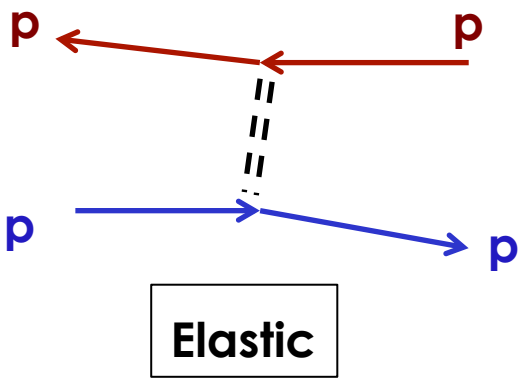
The logic of the YR

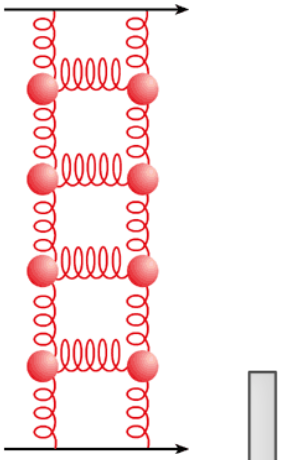
The goal of this report is to give a comprehensive overview of the rich field of forward physics, with a special attention to the topics that can be studied at the LHC.

- **Monte Carlo simulation tools**
- **Phenomenology of QCD at low and high momentum transfer**,
- **Central exclusive production**
- **Cosmic Ray**
- **Heavy Ion physics**
- **The BFKL dynamics, multiparton interactions, and saturation.**
- **Detectors**

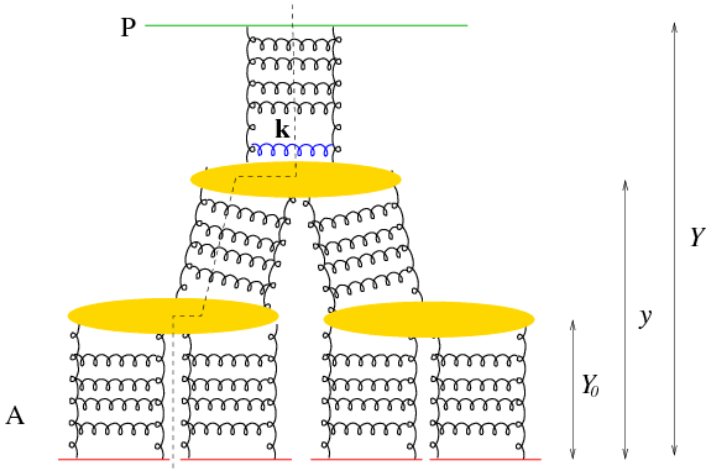
QCD: what is exchanged?

The most obvious configuration is the exchange of a 2-gluon state, but it can get very complicated…





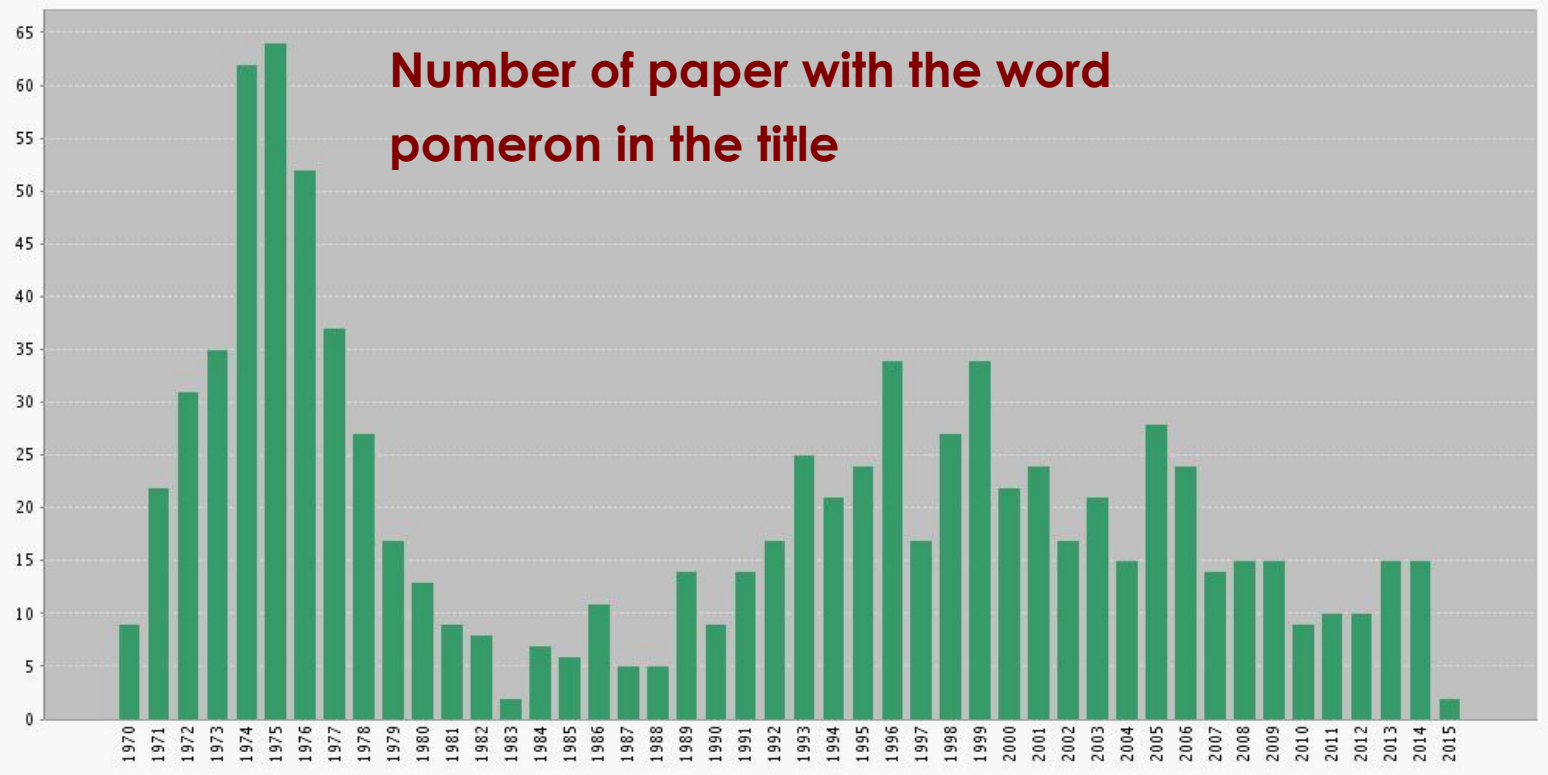
As these gluons are soft, calculations use various parameterizations as pQCD cannot be used.
The exchanged colorless object takes the generic name of **Pomeron**



The return of the Pomeron

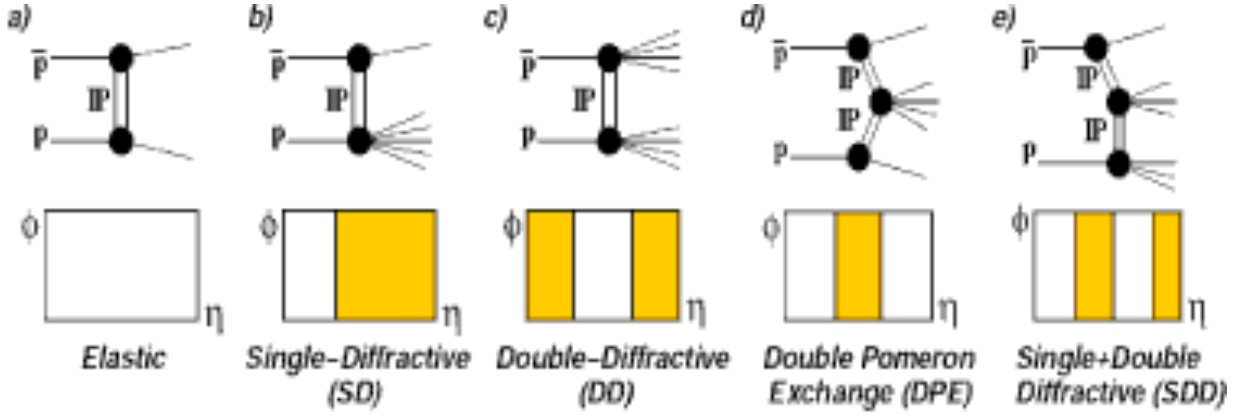
The word "pomeron" was very fashionable in the seventies, then it almost disappeared due to the lack of people able to do the appropriate calculations.

It had a revival with the HERA data, and it's still going pretty well



Experimental signatures: rapidity gaps

If somebody says "**pomeron**" you should think "**rapidity gap**"



In QCD fragmentation, rapidity gaps between two adjacent particles are exponentially suppressed:

$$p(\Delta\eta) \propto e^{-\Delta\eta}$$

In pomeron exchange, rapidity gaps between two adjacent particles are not exponentially suppressed:

$$p(\Delta\eta) \propto const$$

Where is the rapidity gap at LHC?

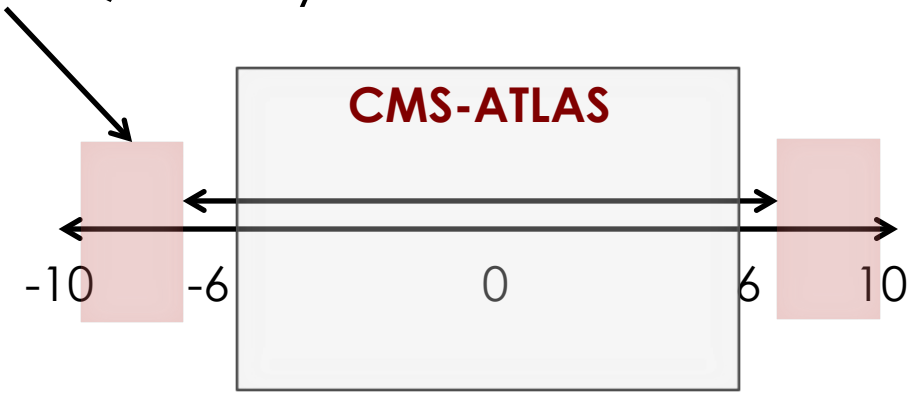
Total LHC pseudorapidity interval:

$$\Delta\eta \sim \ln (s/m_p^2) \sim 20$$

Assume a diffractive mass Mx ~ 500 GeV

$$\Delta\eta \sim \ln (M_x^2/m_p^2) \sim 12$$

The rapidity gap, $\Delta\eta \sim$ **3-4**, is very forward, outside the CMS-ATLAS acceptance $\Delta\eta \sim 10$



Rapidity gap at LHC: survival probability

Use parton densities measured at HERA to predict diffractive cross section at the LHC: would it be a good prediction?

- Factorisation is not expected to hold: soft gluon exchanges in initial/final states

- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept

- Value of survival probability assumed in these studies: 0.1 at Tevatron (measured), 0.03 at LHC (extrapolated)

Why are we here?

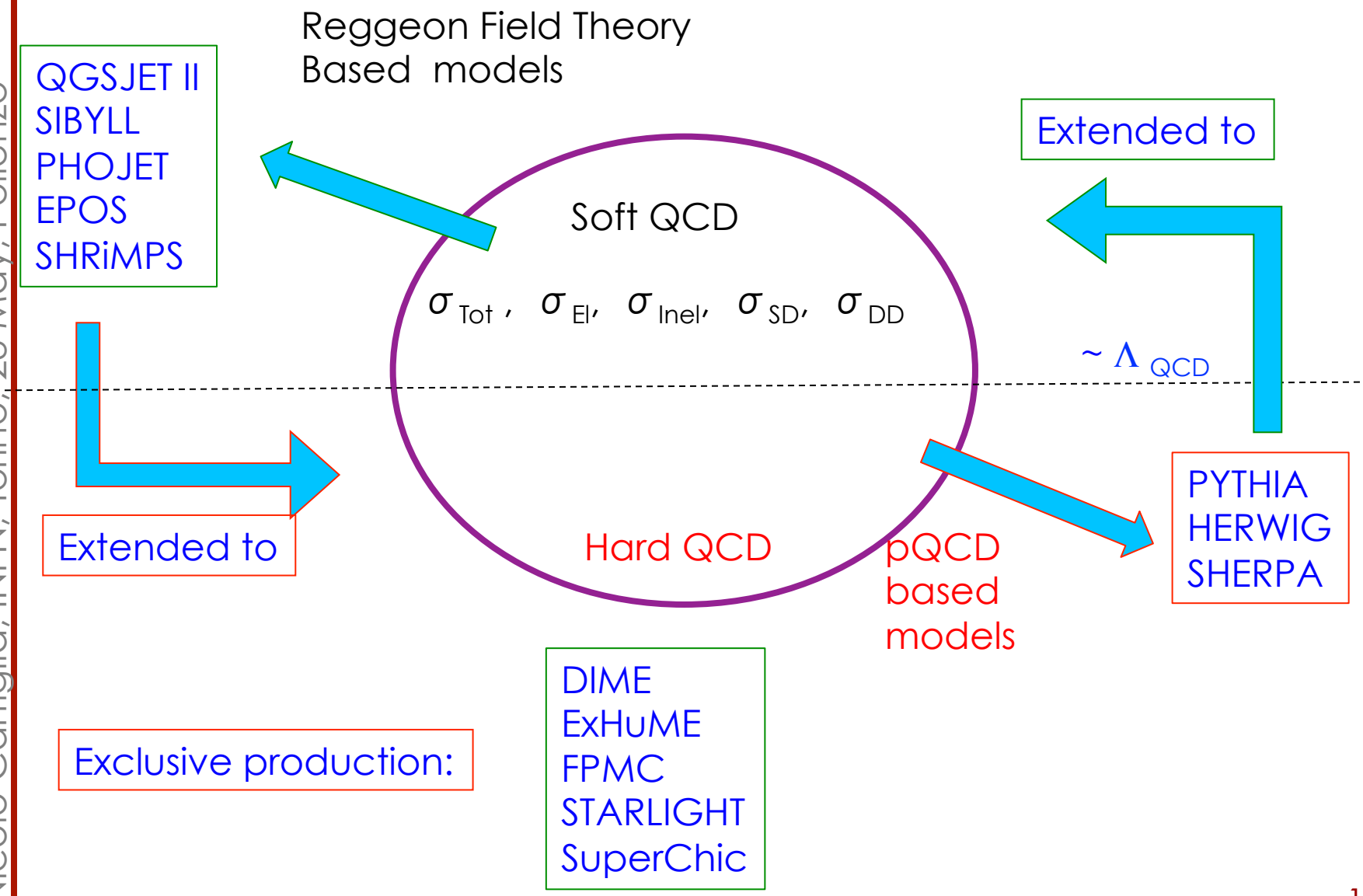
To summarize the status of your key experimental signature:

- The gap is most likely outside the detectors

- If it is inside, it is most likely filled by extra soft particles

- Or it is most likely filled by overlapping events

Montecarlo Models



Montecarlo Issues

Montecarlo is a very complicated topic in forward physics. The task is very complex (physics with many scales), and the manpower is not much.

"High precision LHC MCs" do not include forward physics accurately

"Forward MC"s tend to be specialized (inclusive diffraction, central exclusive production), they do not include standard LHC physics, and often they predictions are limited to a specific process.

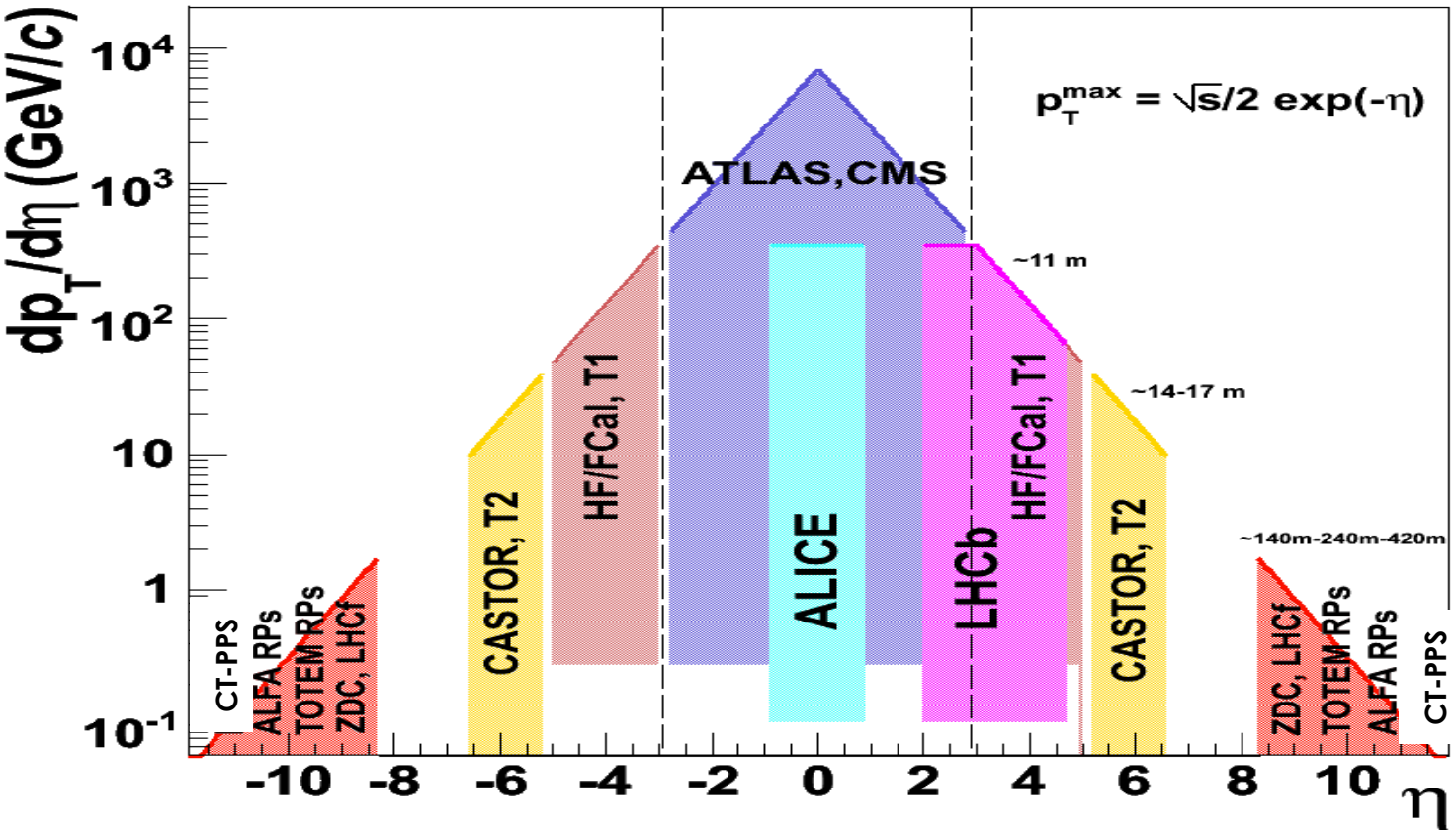
Data-MC agreement in forward physics is often less accurate than what we require for High Pt physics.

Many analyses on forward physics are not completed due to this issue.

Physicists' ingenuity

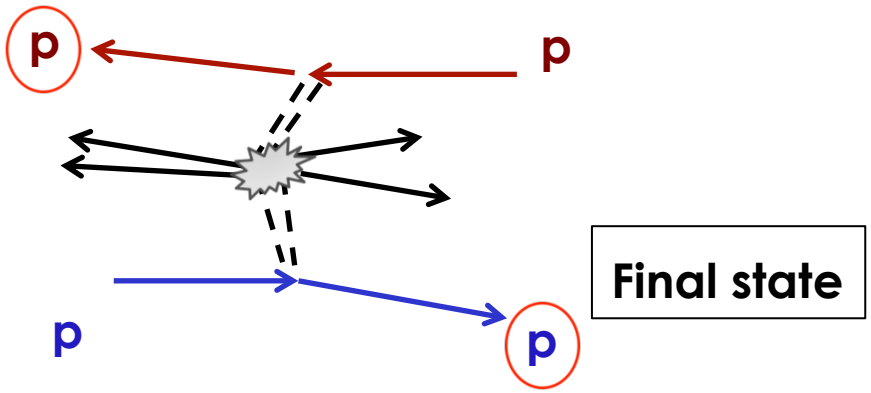
The goal of detector coverage is therefore to detect:

- **Leading protons**
- **Rapidity gaps**
- **Particle production**
- **Identification of specific final state**



Game changers: forward protons taggers

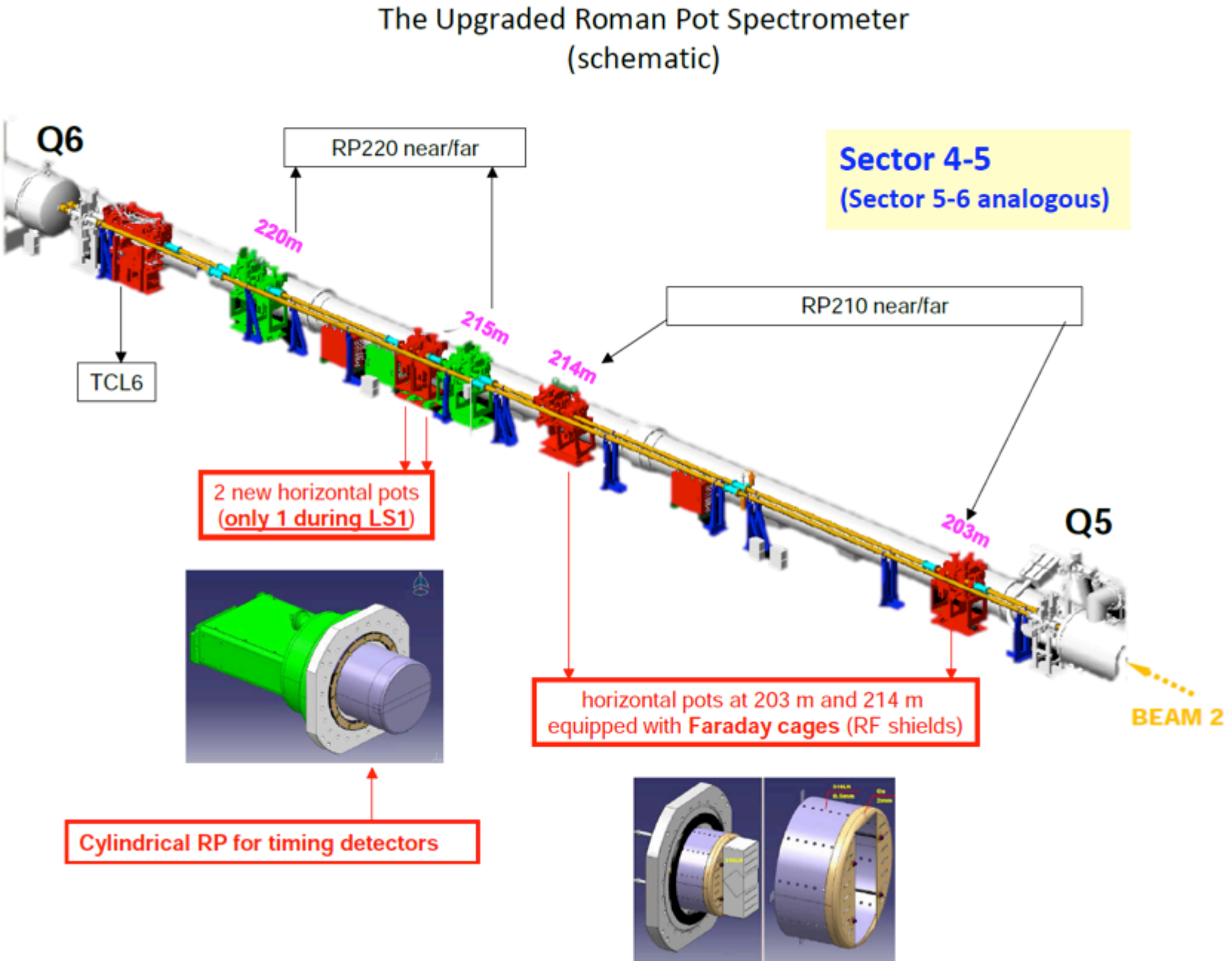
The secret weapon is to tag the forward protons



As the proton does not fragment, it retains a large fraction of the initial energy.

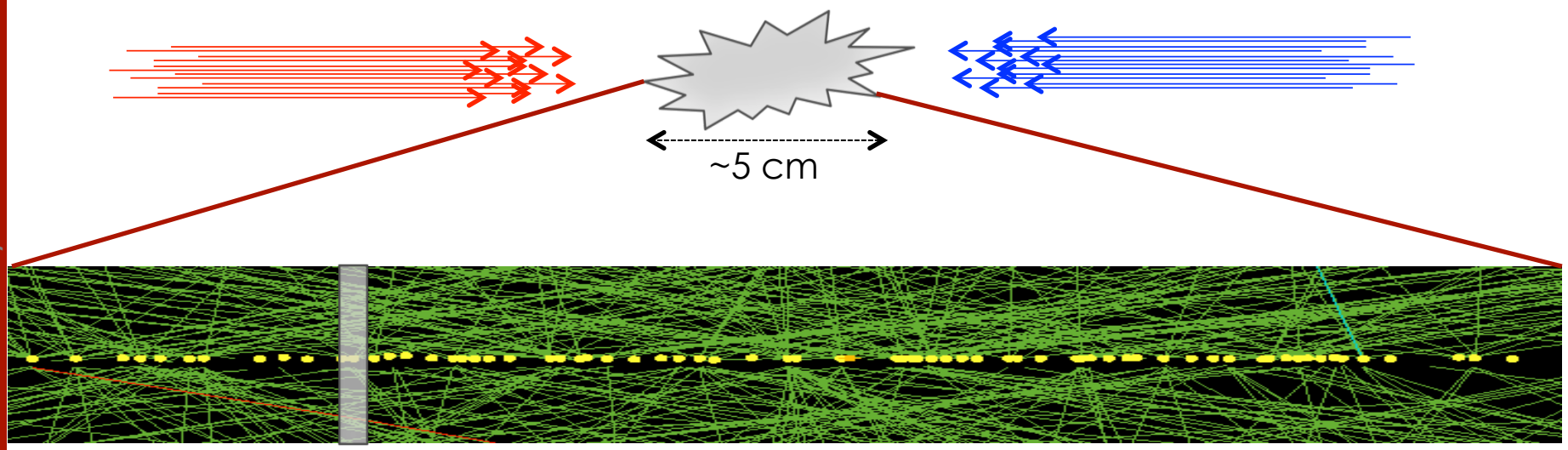
It has high momentum and low pt, so it travels along side of the accelerator beam.

CT-PPS (CMS) AFP (ATLAS): High tech detectors

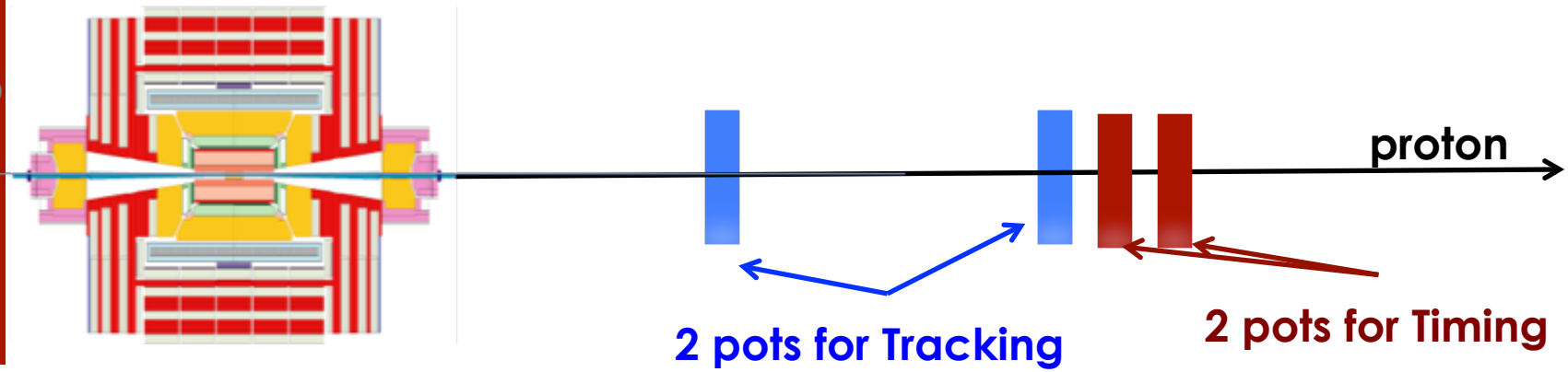


Why do we need timing?

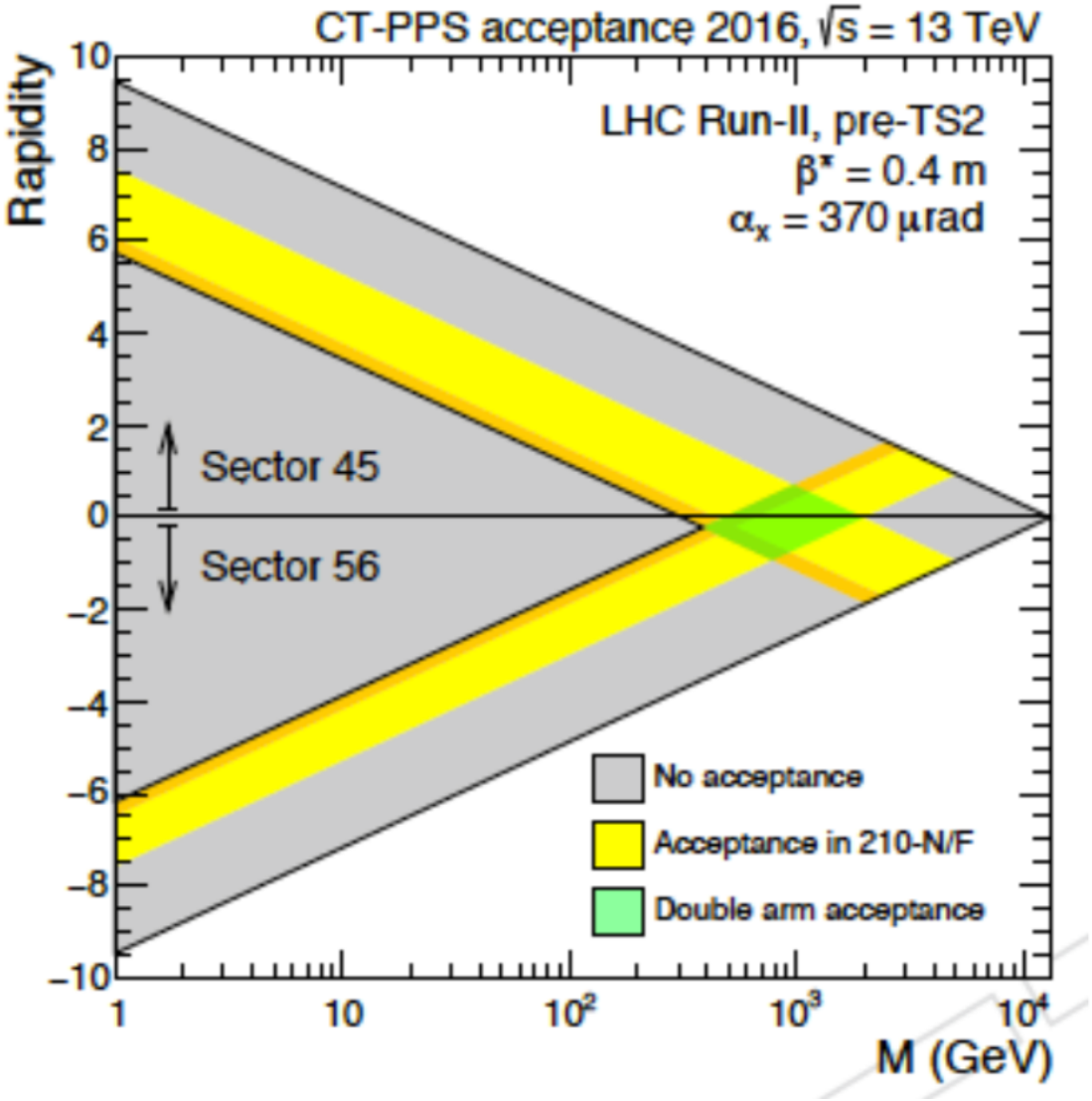
Pileup! At each bunch crossing, there are many interactions (~ 50)



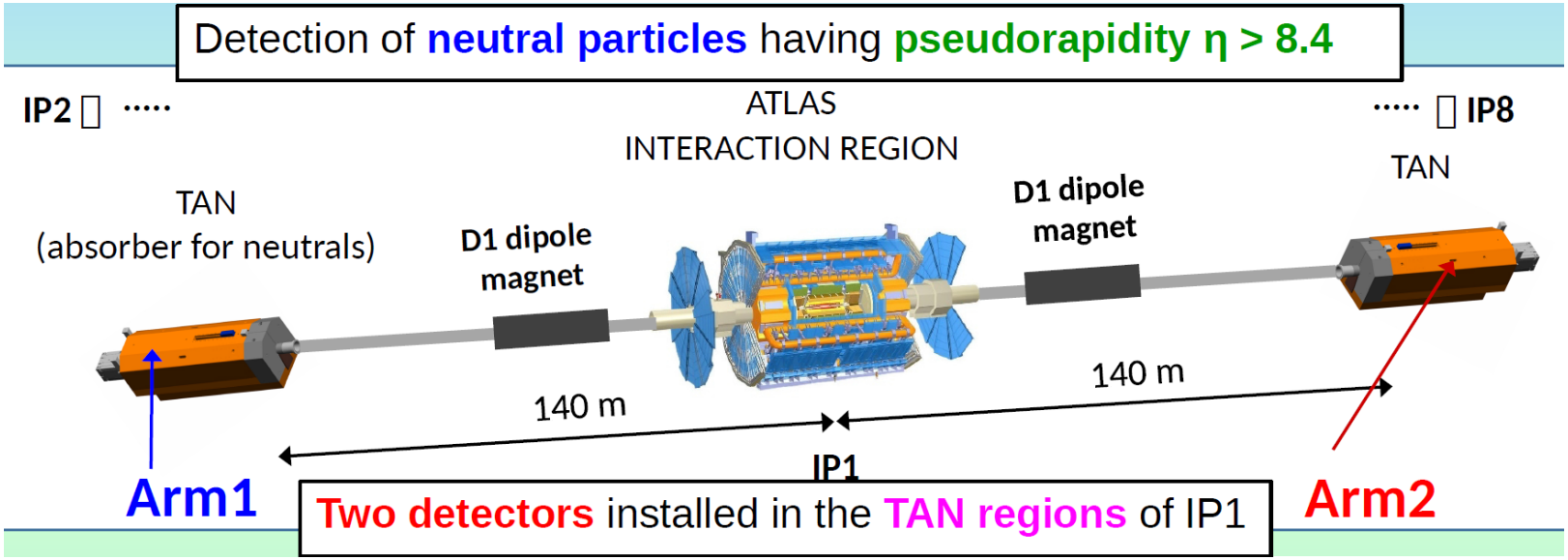
A precision of ~ 10 ps is needed in the detection of the leading **proton to associate the proton to the correct vertex** using "z-by-timing"



What is the mass coverage of the CT-PPS/AFP?

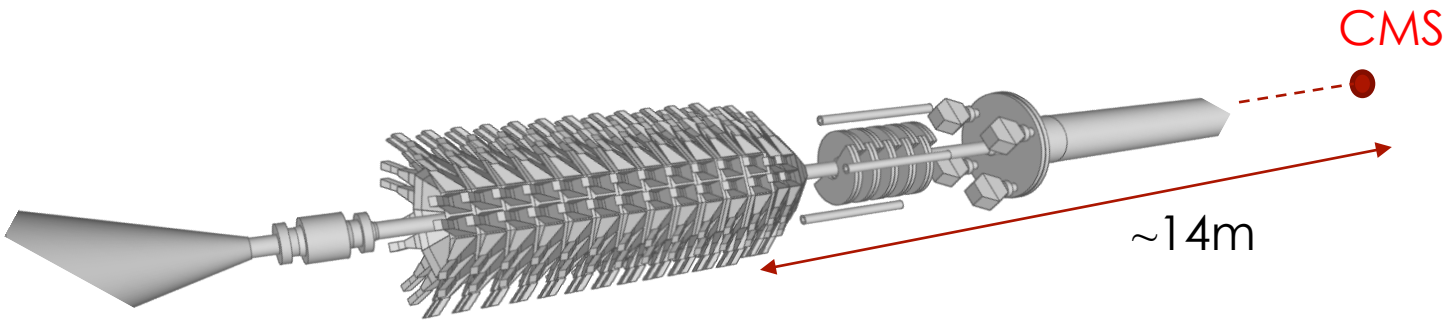


Very high rapidity neutral detector: LHCf and CMS Castor



CASTOR:

Forward CMS detector: $-6.6 < \eta < -5.2$,



LHC running conditions

If the rapidity gaps is used as tag, it might be a problem:
Rapidity gaps are filled by pile-up events at LHC

If you want to measure a process that has a rapidity gap signature, then you need special runs with low luminosity, which are short in time:

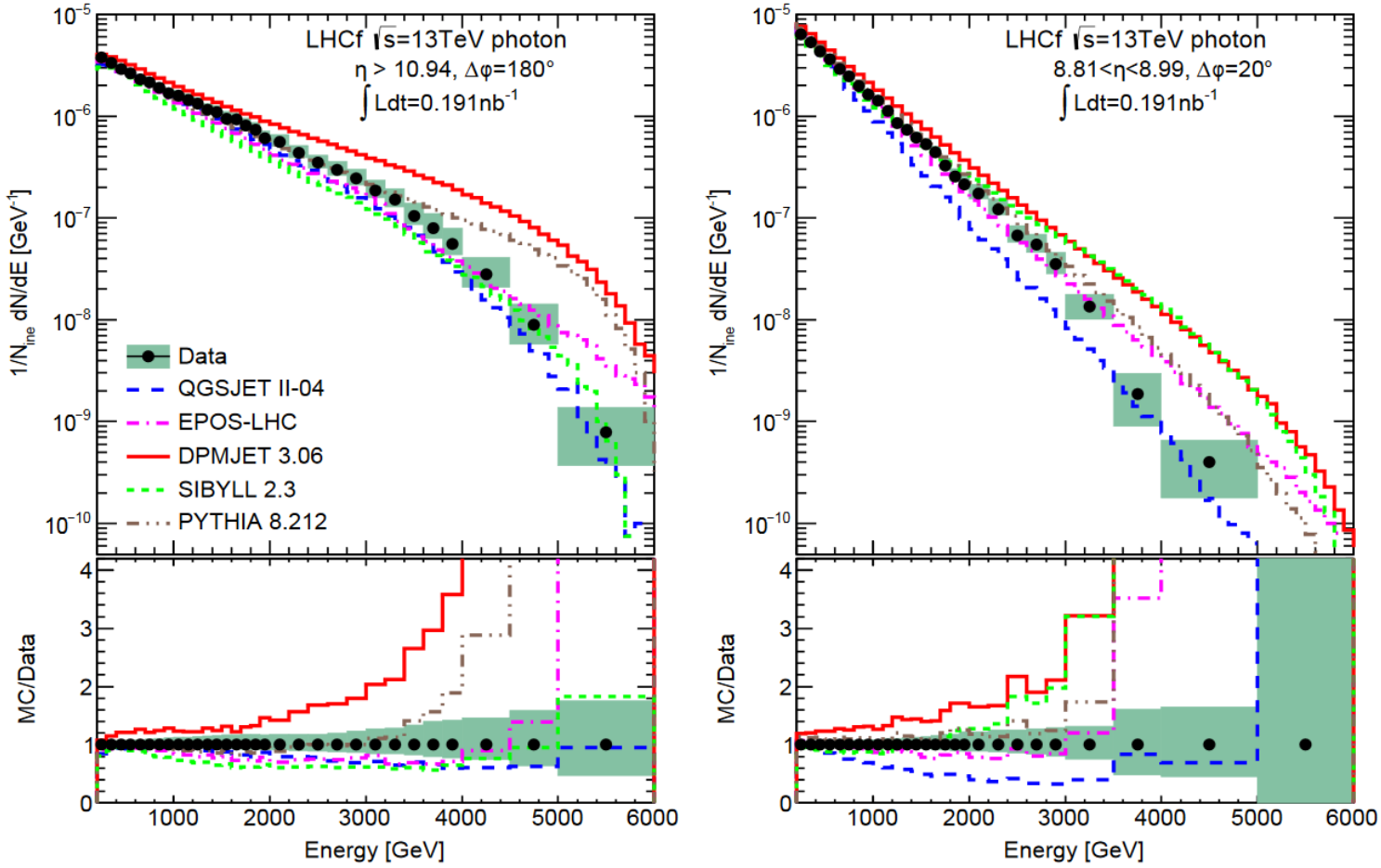
➔ **Only large cross section process can be measured**

In the YR we divided the processes in 4 categories:

- Extremely low pileup and luminosity (few nb-1) **Rapidity gap**
- low pileup and luminosity (few 10 pb−1) **Proton tagging**
- medium luminosity (few 100 pb−1) **Proton tagging**
- high luminosity (100 fb−1) **Proton tagging**

Extremely low pileup and luminosity - I

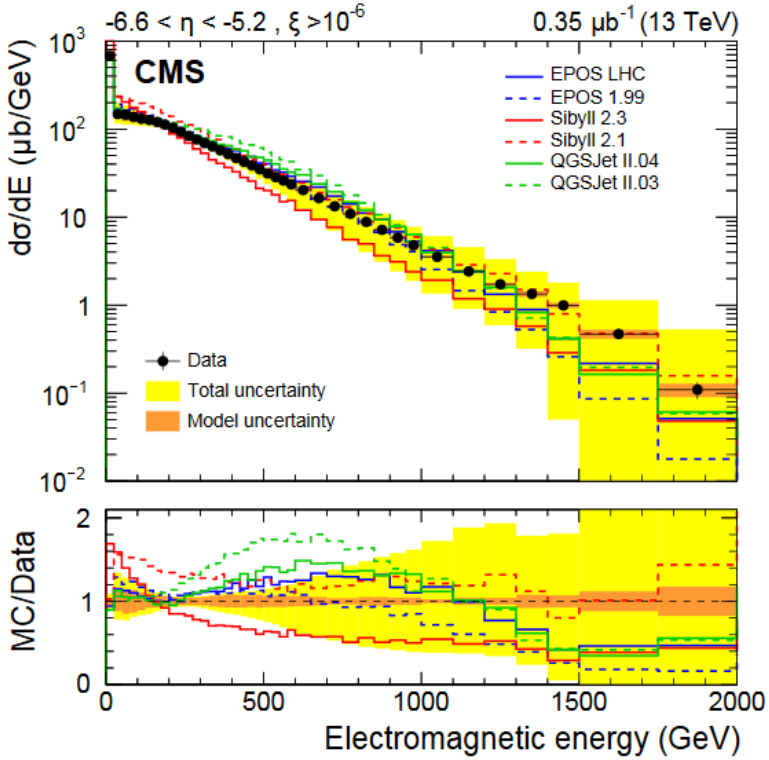
LHCf: forward photon spectrum

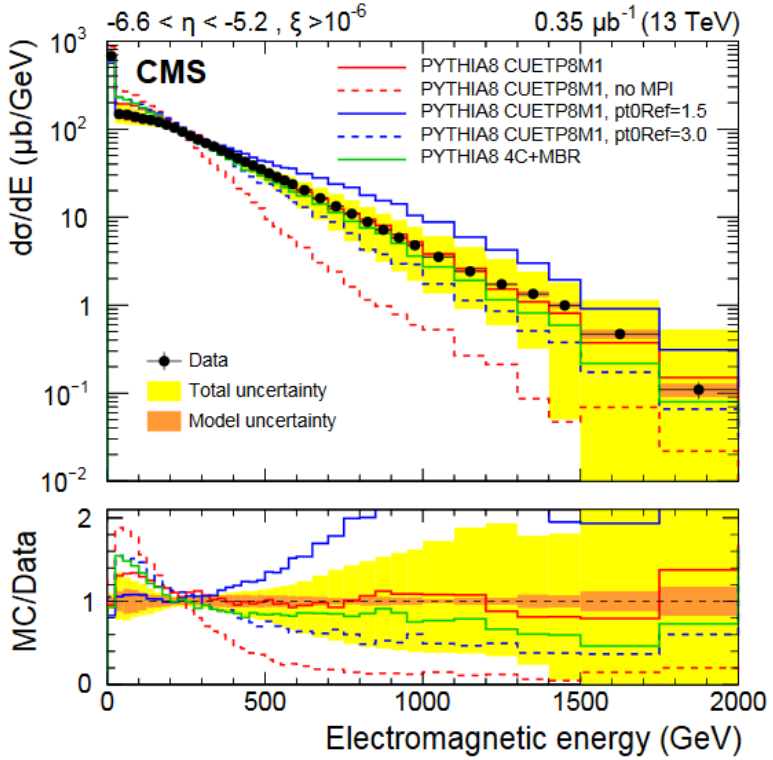


Important for interaction models for HECR Physics.

Extremely low pileup and luminosity - II

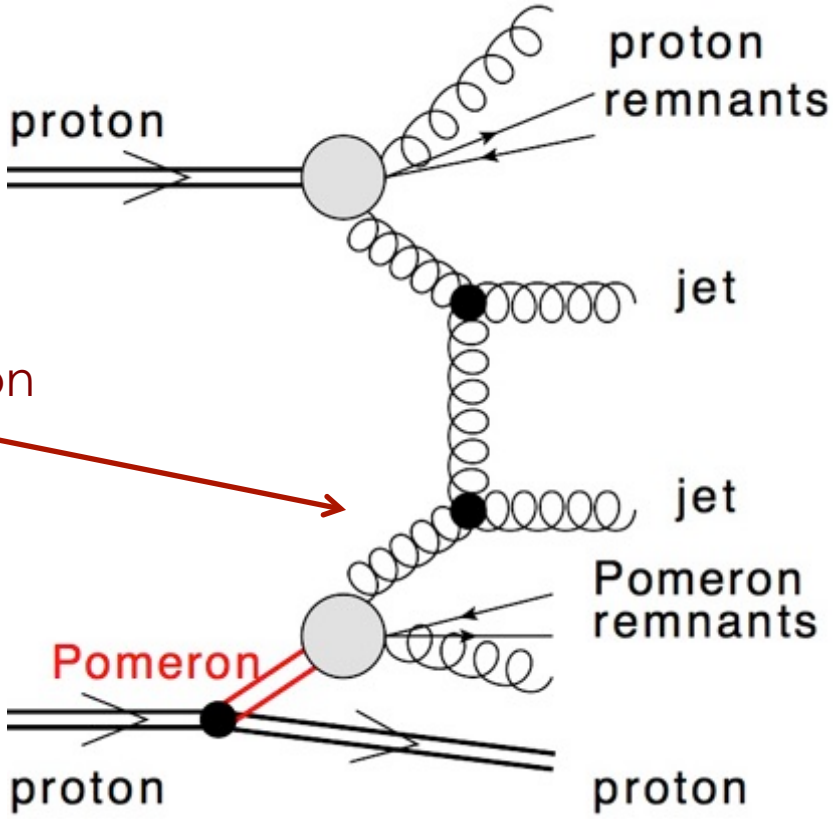
Inclusive energy spectrum in the very forward direction





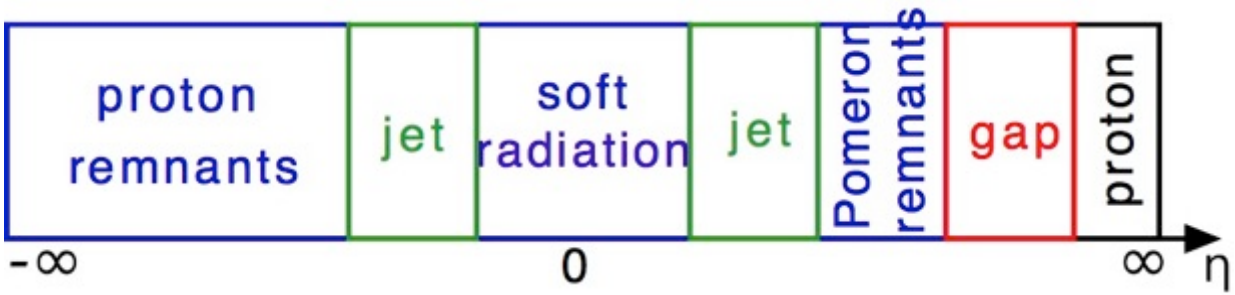
Spectrum harder that expected, most MC below

Diffraction Case Study: Single Pomeron with Jets, Z, W



Main Goal:

Gluon structure function

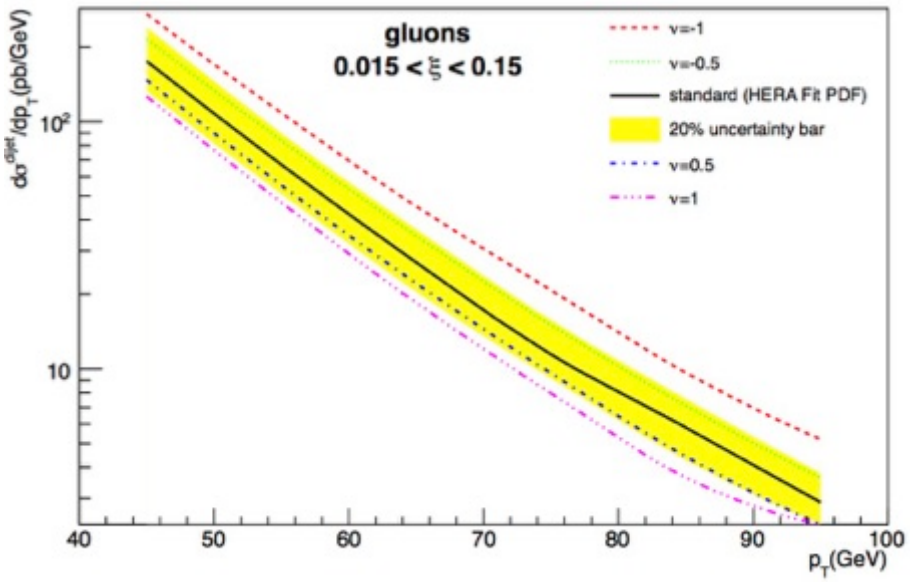


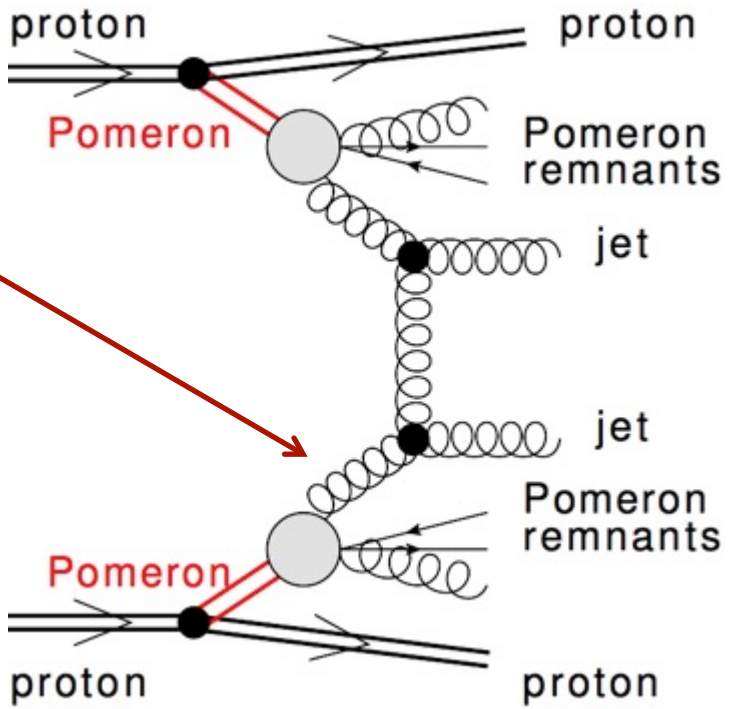
Tagging technique: gap + proton

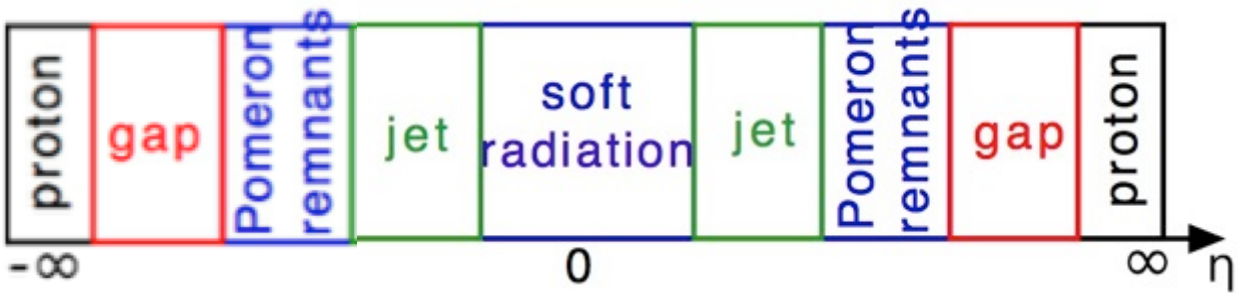
Diffraction Case Study: Double Pomeron Exchange (DPE)

Main Goal:

Gluon structure function



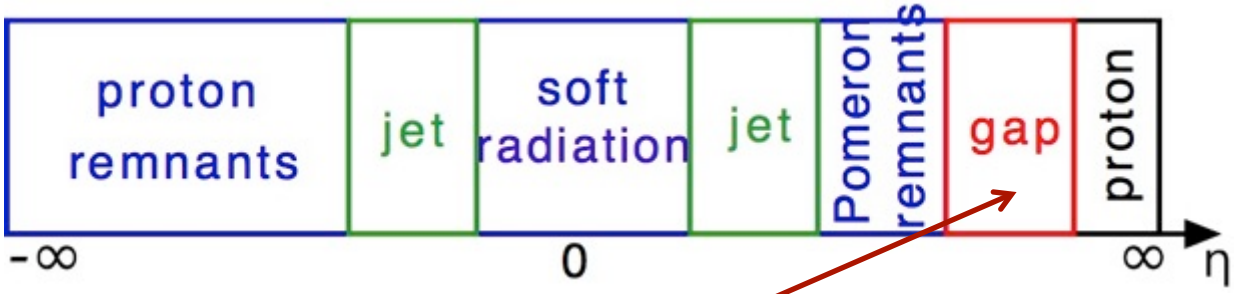




Tagging technique: proton + proton

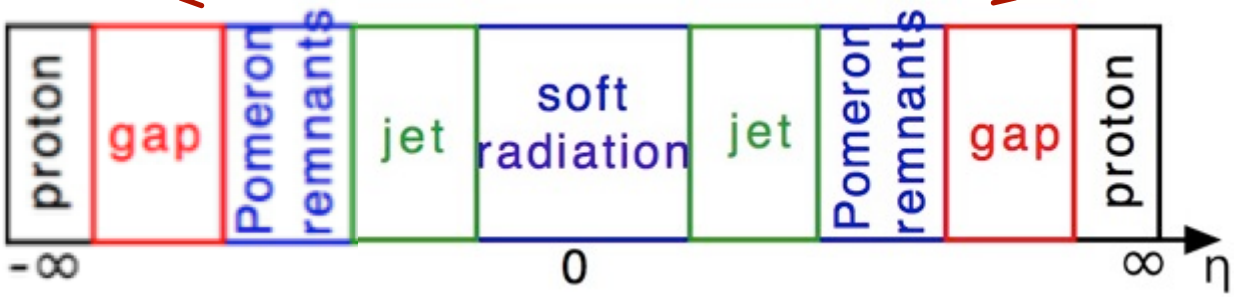
Are we going to see these events?

Single pomeron



Double pomeron

Most likely not visible



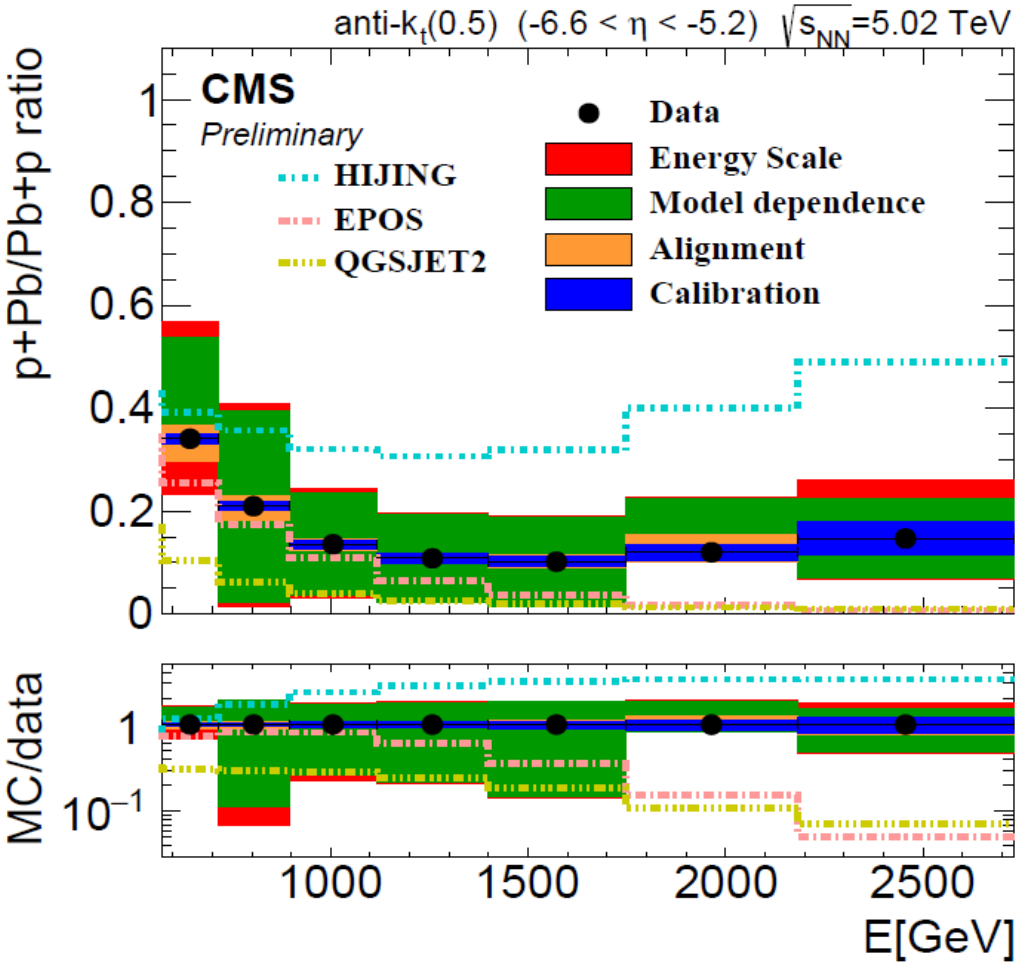
Almost impossible without the proton taggers

Very forward inclusive jet cross sections in p+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV

Very interesting question: how does the multi-nucleon dynamic influence energy flow? In heavy ion collision, gluon small-x and high density can show the onset of non DGLAP evolution.

The ratio of the energy deposition in CASTOR for p-Pb /Pb-p is experimentally well defined.

Montecarlo do not reproduce it very well



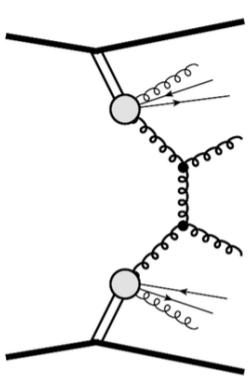
Central Exclusive Production (CPE)

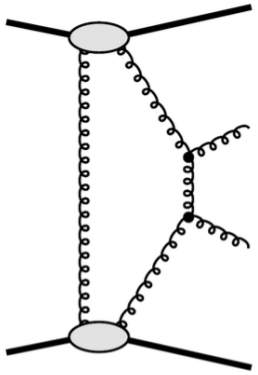
CPE is a particularly interesting reaction as its kinematics are over constrained.

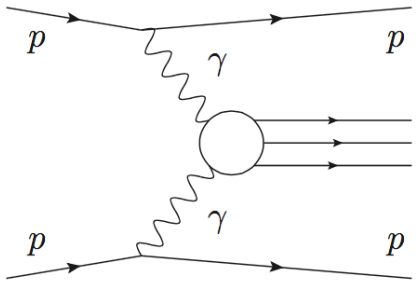
Mx can be determined either by:

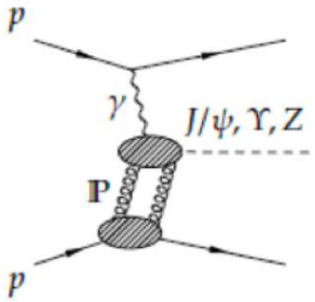
- The central detectors
- The momentum of the two scattered protons

Many processes contribute to CEP:







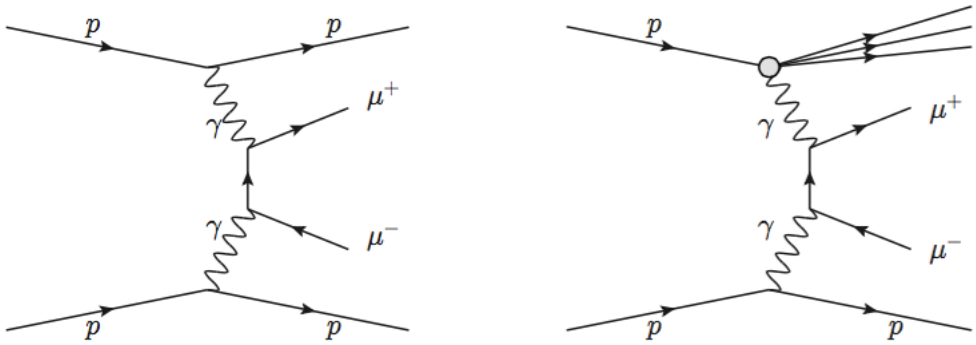


Mx

Very rich physics program: Jets, glue ball, charmonium,

One example: γγ ➔ μμ

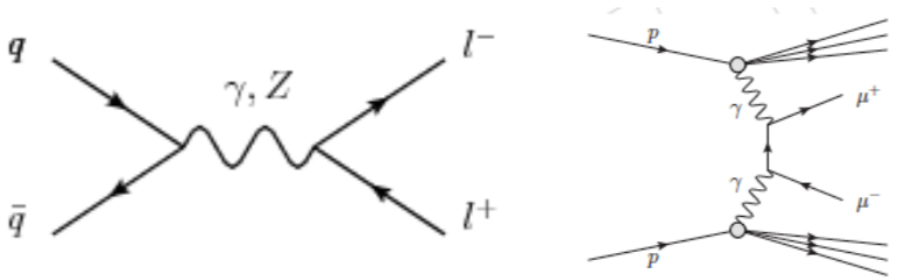
Signal, pure QED process:



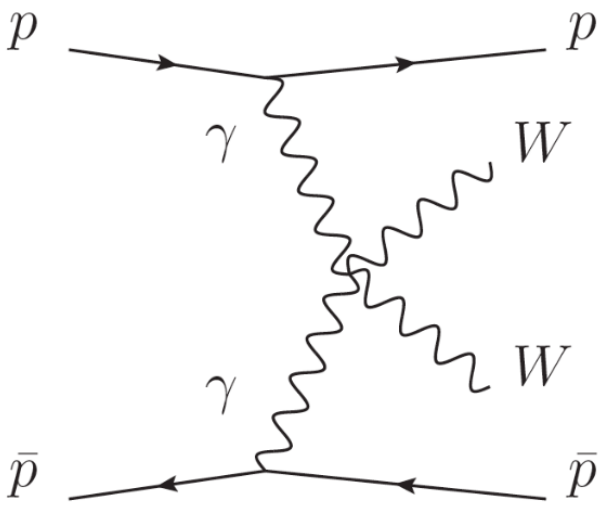
Problem: events with two protons in the CT-PPS acceptance have high mass, while this process has a small M(μμ) mass

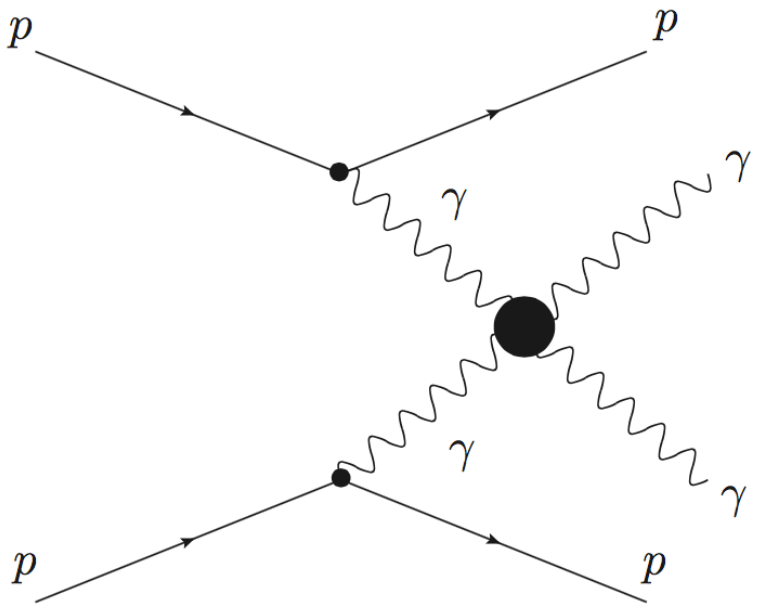
➔ Use single dissociation events, and catch only one proton

Background:



Anomalous coupling:γγγγ and γγWW





Forward physics is a window on new physics:
SM prediction: σ(pp➔ pp WW) = 96 fb

However: anomalous quartic coupling changes this value. This coupling is set = 0 in the SM.

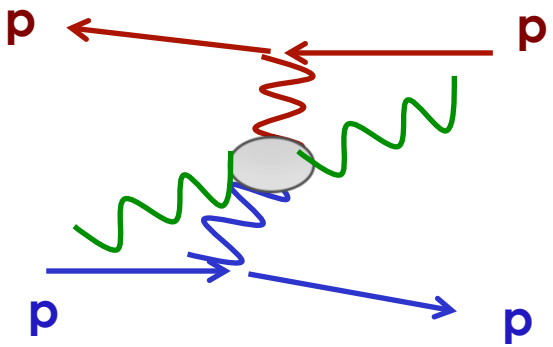
Need 300 fb-1 with the proton taggers (CT-PPS, Alpha) working

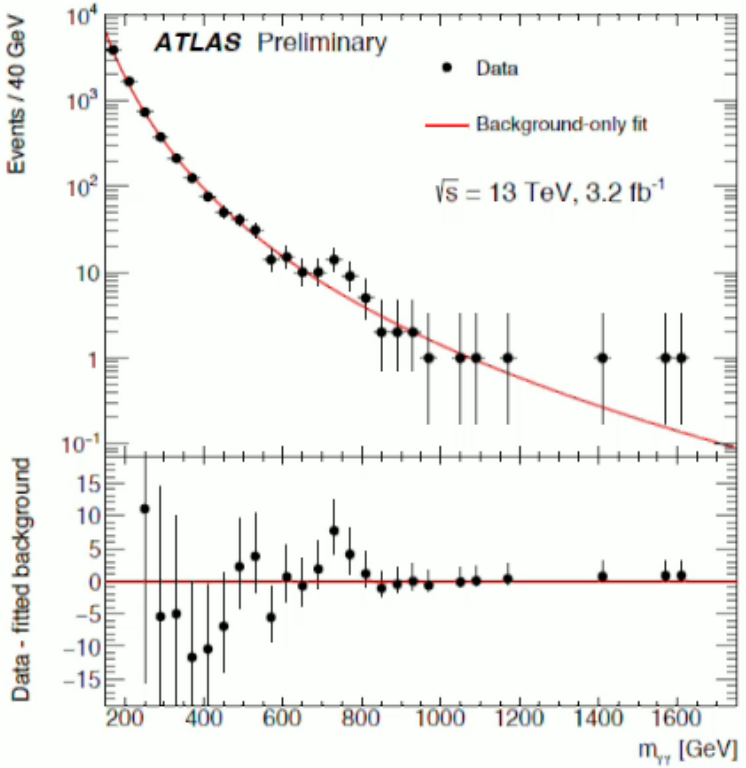
Our 5 minutes of fame

In the 2015 CMS-ATLAS data there was an indication of a resonant state at 650 GeV decaying in $\gamma\gamma$

If it decays in $\gamma\gamma$, it can also be produce by $\gamma\gamma$…

We had a crash program to take data with the CT-PPS detector to measure it in CEP processes, as a way to define its quantum numbers.





It graciously disappeared with the 2016 data

Conclusions

LHC is not quite the appropriate place to study forward physics, however Forward physics at LHC stubbornly refused to go away.

Very difficult to collect data in good conditions, however the game changers are the forward proton taggers.

CT-PPS and Alpha will allow a rich physics program, starting in 2017.

So, maybe, LHC is the right place to be, let you know in 2019