Summary of LHC working group on Forward Physics

Run II (2015-2017) LHC Forward Physics program

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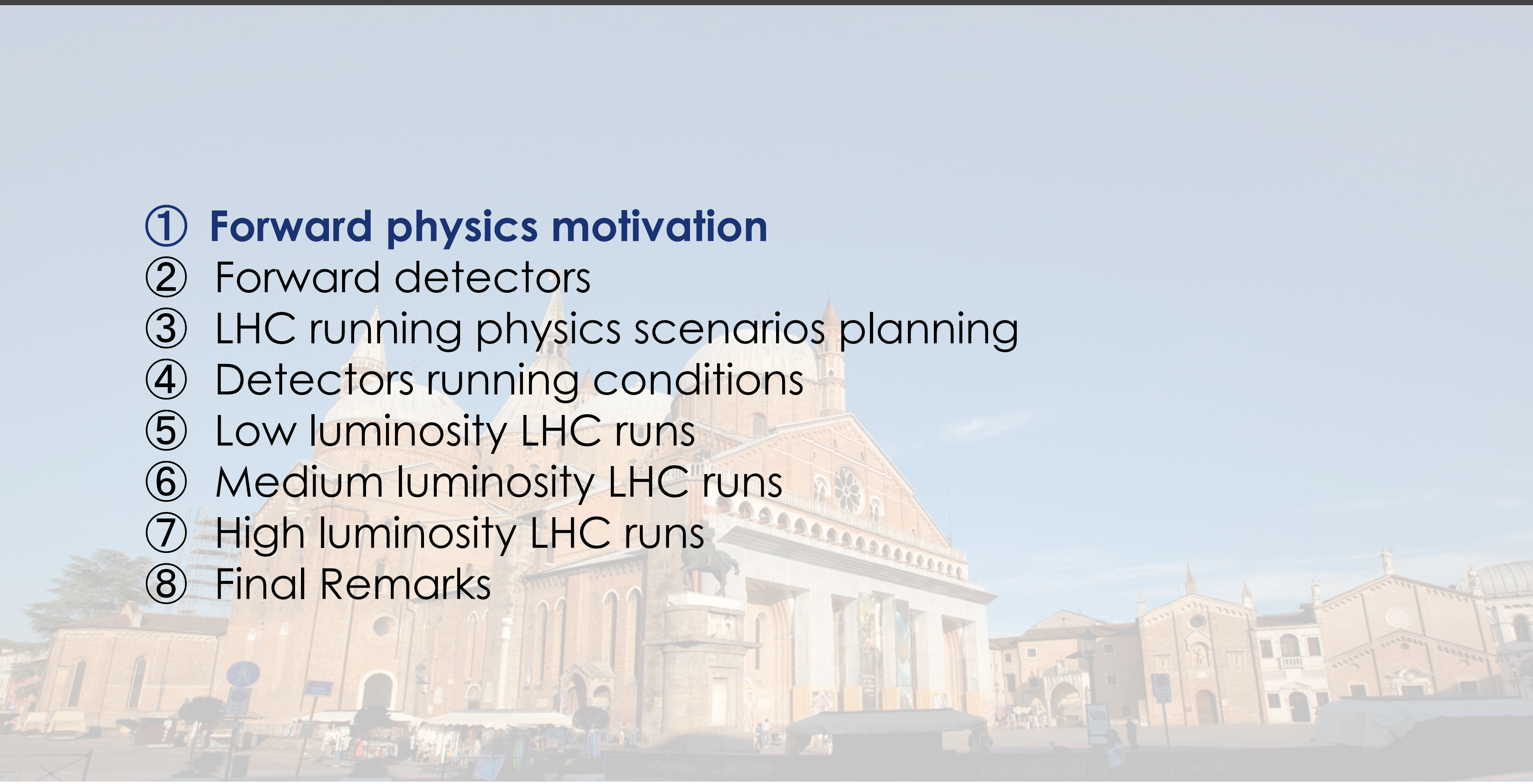
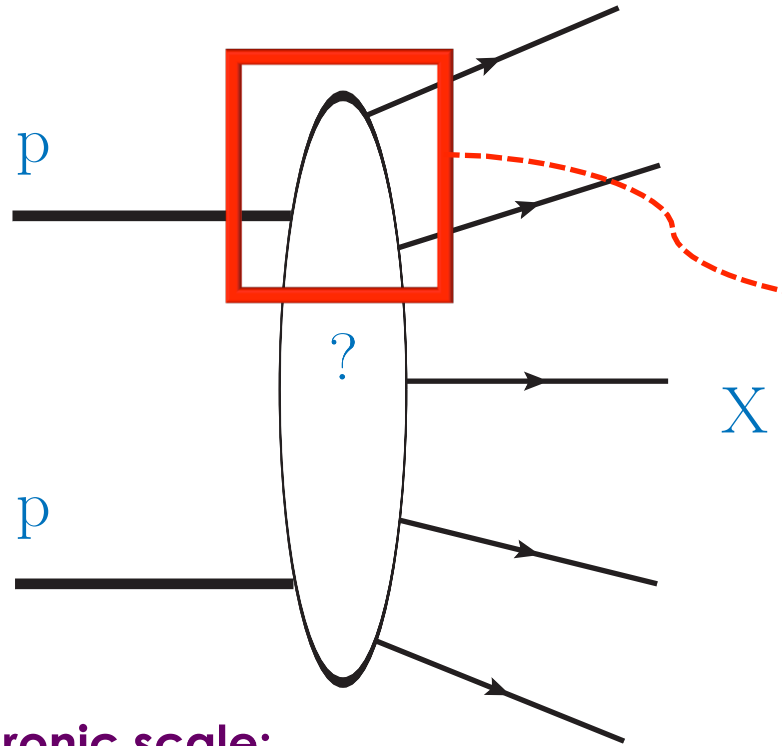
Outline



1. **Forward physics motivation**
2. Forward detectors
3. LHC running physics scenarios planning
4. Detectors running conditions
5. Low luminosity LHC runs
6. Medium luminosity LHC runs
7. High luminosity LHC runs
8. Final Remarks

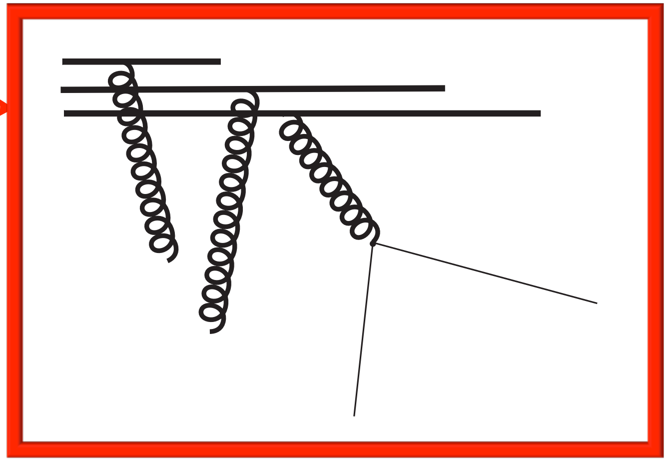
Forward physics motivation: a general view

Inelastic processes… Probing of *partonic processes* at high energies.



Hadronic scale:

Phenomenology of pions exchange,
Classical particles scattering…



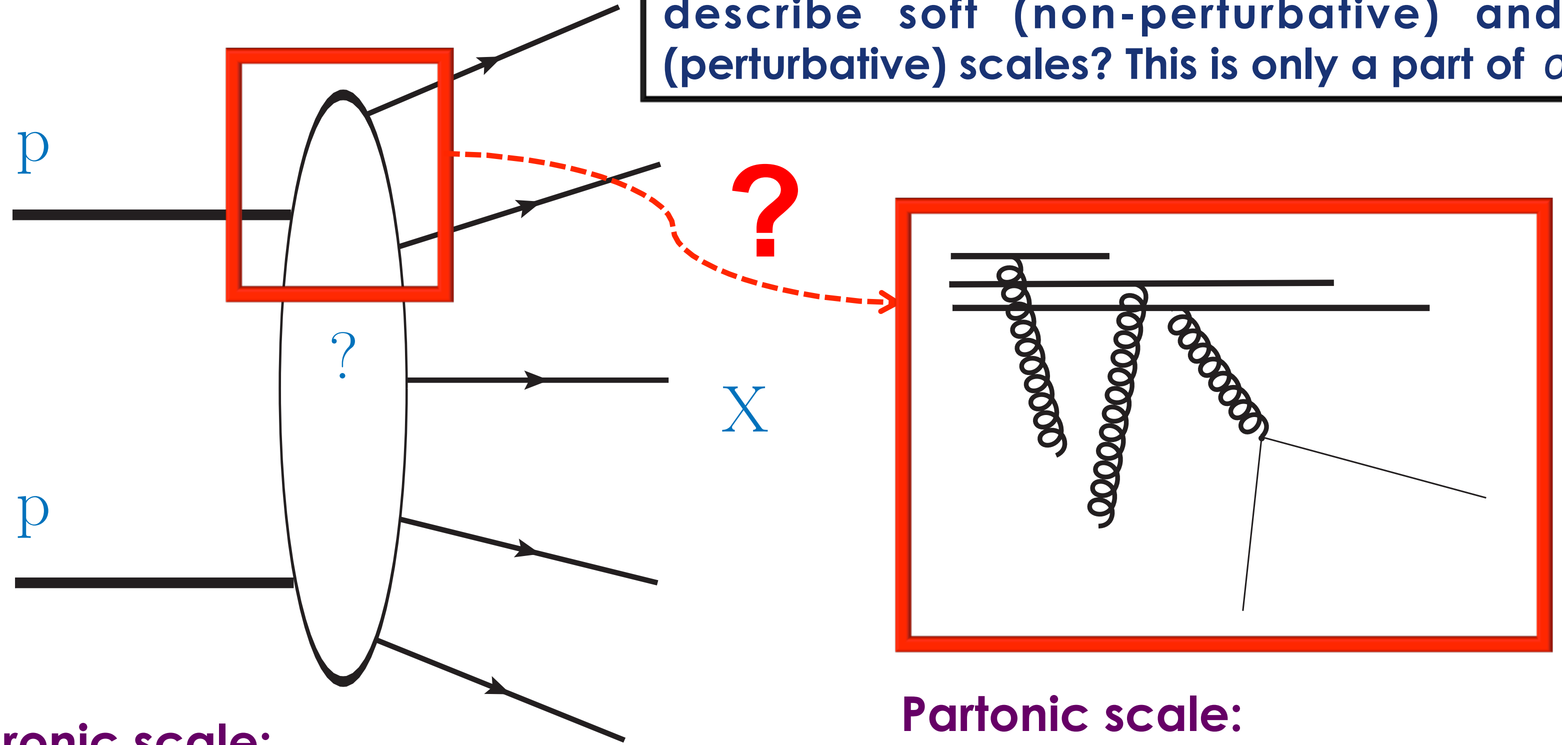
Partonic scale:

QCD, a field theory, synthesis of many classical scattering models and phenomenology.

Forward physics motivation: a general view

Inelastic processes… Probing of *partonic processes* at high energies.

How a single strong interaction theory can describe soft (non-perturbative) and hard (perturbative) scales? This is only a part of $\sigma_{total,pp}$.



Hadronic scale:

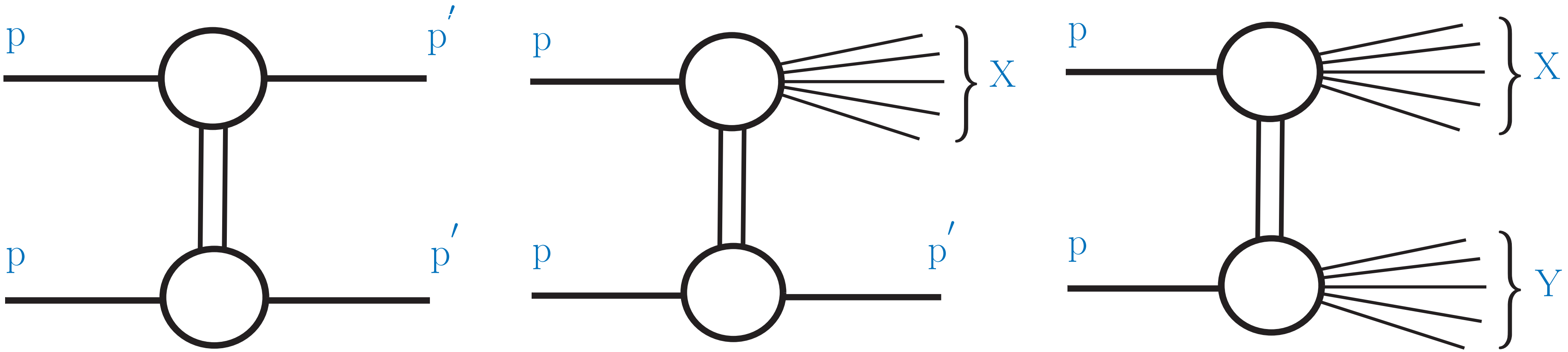
Phenomenology of pions exchange,
Classical particles scattering…

Partonic scale:

QCD, a field theory, synthesis of many classical scattering models and phenomenology.

Forward physics motivation: diffractive physics

Diffractive Physics is an **phenomenon experimentally measured**.



Elastic *pp* scattering — Single dissociative (SD) — double dissociative (DD)

$$\sigma_{\mathrm{total,pp}} = \sigma_{\mathrm{el}} + \sigma_{\mathrm{SD}} + \sigma_{\mathrm{DD}} + \sigma_{\mathrm{ND}}$$

Dissociative component **X** (and **Y**), can be in ***soft scale*** (~1 fm and non-pertubative) or ***hard scale*** (probing *parton* scale from pQCD) final states. **Pomeron is dominant in elastic and diffractive processes.**

Forward physics motivation: what can we explore?

Forward Physics addresses QCD dynamics at the interface between *hard* and *soft* physics.

- ✓ Total pp cross section probes long transverse distances;
- ✓ BFKL (*Balitsky-Fadin-Kuraev-Lipatov*) *Pomeron* is valid at short distances: *high order* calculation and *new degrees of freedom*;
- ✓ Long distance: hadron-hadron (*Pomeron* trajectory);
- ✓ Probing "structure" of *Pomeron*.

Event topology experimentally well defined.

- ✓ Search for large rapidity gaps (LRGs) and/or tagging the proton(s);
- ✓ Useful to search Physics beyond standard model (central exclusive production).

Important to understanding underlying events, soft QCD.

- ✓ MC tuning to describe soft QCD.

Cosmic Ray Physics

- ✓ Understanding the sources and the propagation of cosmic rays are central questions of Astroparticle physics. LHC can help with measurements of forward region for MC tuning.

Forward physics motivation: technology

New actors in the LHC forward physics scene…

① Front-end optoelectronics, high memory buffering and very fast transceivers for triggering proton tagging detectors to main detector (far away from interaction point): construct dedicated diffractive triggers with rates reduced due to the coincidences between forward and central detectors;

② New radiation hard active cells and readouts technology to survive more time close to the beam: Roman pots technology allows detector movement;

③ Timing Resolution of **picoseconds**: combine central detector and forward detector information;

④ TeV energy scale and pb^{-1}.

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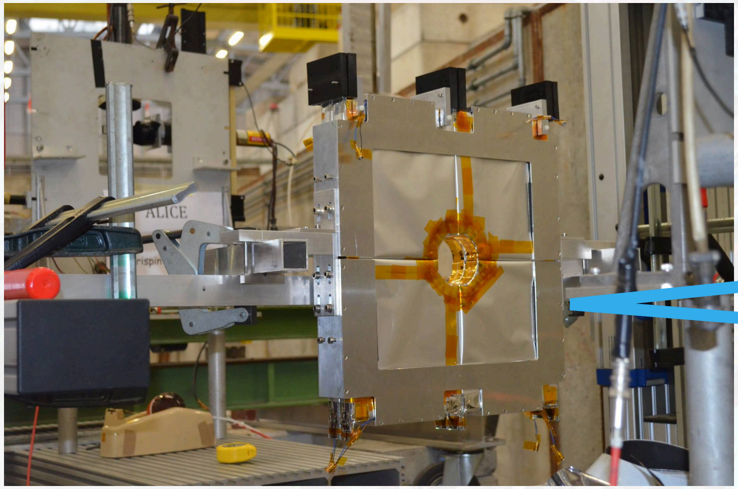
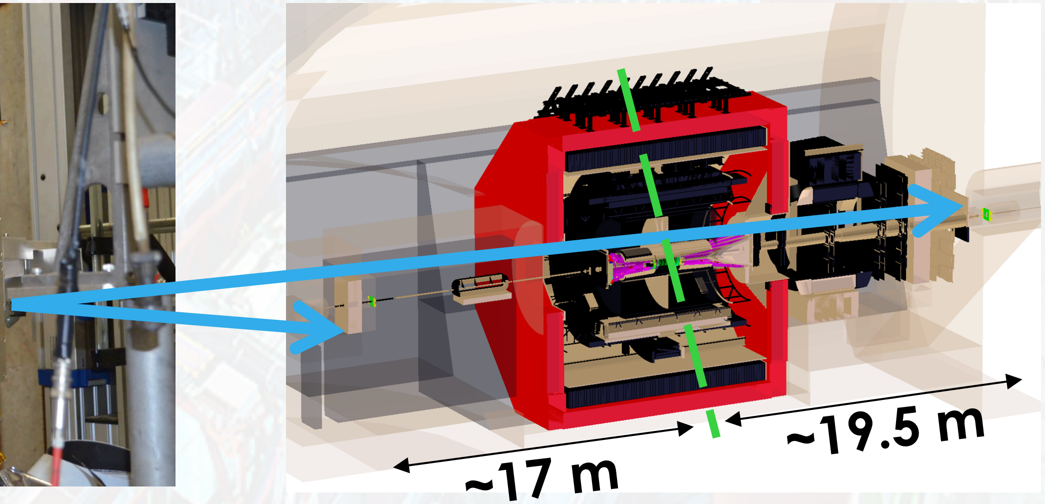
Forward Detectors: ALICE

ALICE Diffractive (AD) Detector

- ✓ Two new **scintillator** *hodoscopes* placed respectively at **Z = -1958 cm and 1700 cm** on each side of the interaction point, covering $-7.0 < \eta < -4.9$ and $4.8 < \eta < 6.3$ and **included in trigger (hardware level)**;
- ✓ Improvement in trigger efficiency of single diffractive events in proton-proton collisions at 13 TeV, when using AD detectors;
- ✓ **It will be installed in December 2014.**

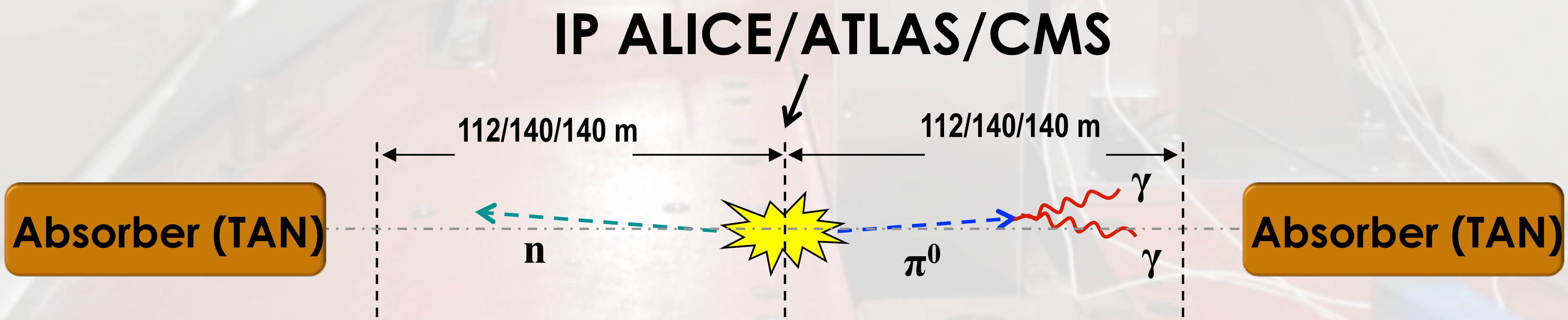




Target Absorber Neutral (TAN) Forward Detectors: ALICE/ATLAS/CMS

The Large Hadron Collider forward (LHCf/ATLAS), Zero Degree Calorimeter (ZDC/ALICE, ZDC/ATLAS and ZDC/CMS):

- ✓ It has been designed to use the LHC benchmark the **hadronic models used in cosmic-ray physics**;
- ✓ **Compare measurements** with interaction models used in **cosmic-ray physics**. It measures neutral (**photons, π^0, and neutrons**) particles emitted in the **very forward** region of the LHC *pp*, *pA*, *AA* collisions: energy and multiplicity spectrum;
- ✓ Installed in the same TAN area slot. Each side of interaction points (IP) 1, 2 and 5;
- ✓ Electromagnetic (**EM**) + hadronic (**HAD**) calorimeter sections cover $|\eta| > 8$ acceptance for ZDC/ATLAS and ZDC/CMS and for ZDC/ALICE (**EM**) $4.8 < |\eta| < 5.7$ and (**HAD**) $|\eta| > 8$;
- ✓ They can be used for beam calibration.

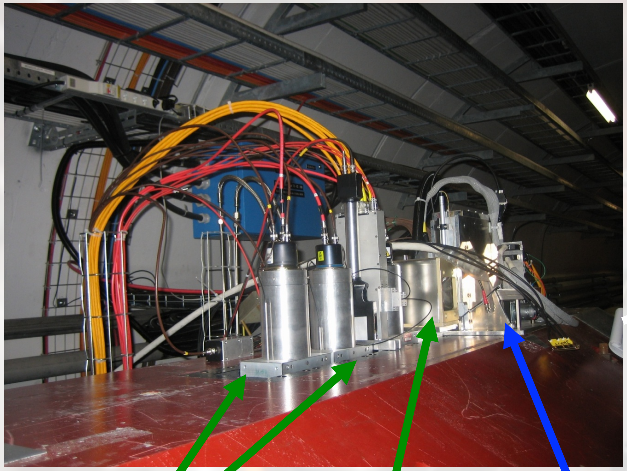


Target Absorber Neutral (TAN) Forward Detectors: ALICE/ATLAS/CMS

ZDC/ALICE

Neutral (ZN) and Proton (ZP) calorimeter

ZDC/ATLAS

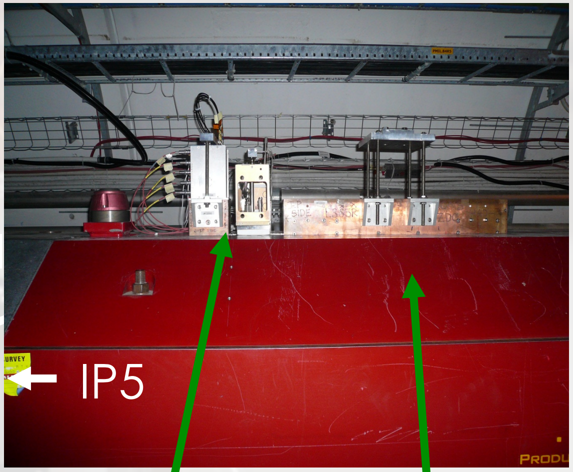


ATLAS ZDC ECAL

ATLAS ZDC HCAL

LHCf

ZDC/CMS



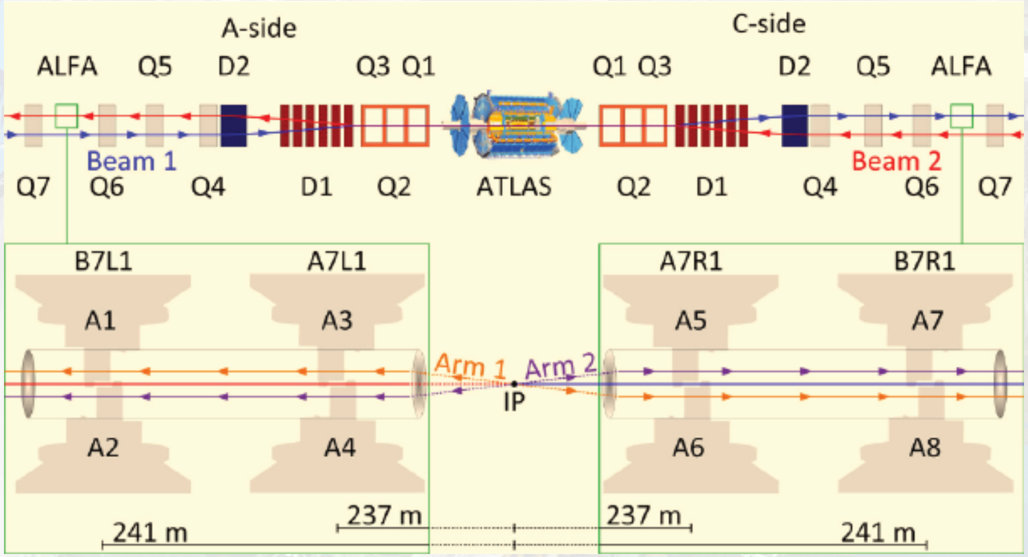
CMS ZDC HCAL

CMS ZDC ECAL

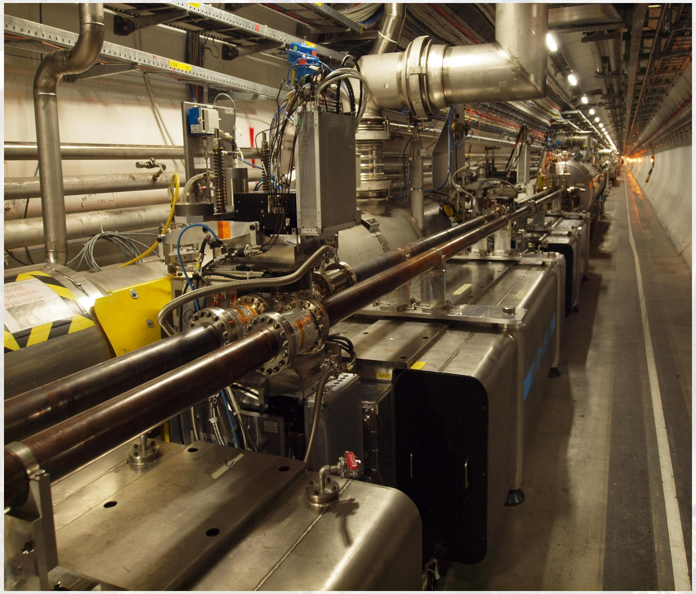
Detector	Material	Description
LHCf (Atlas)	scintillators (Arm#1) and Silicon (Arm#2) with tungsten	Two arms. EM calorimeter with position layers. **Planning common diffractive trigger with ATLAS.**
ZDC Atlas	tungsten/quartz-fibers layers	1 EM module + 3 HAD modules (both sides)
ZDC CMS	tungsten plate/quartz fiber ribbon sandwich	1 EM module + 4 HAD modules (both sides)
ZDC ALICE	stack of heavy metal plates/matrix of quartz fibers	1 EM module (±7.5 m IP2) + 2 HAD (±112.5 m IP2)

Forward Detectors: ATLAS

ALFA (Absolute Luminosity For ATLAS):



Roman Pot Station



- ✓ Designed **for dedicated low pileup runs**;
- ✓ The set-up consists of four Roman Pot (RP) stations, two on both sides of the interaction point (**with 8 detectors**) each housing two vertically movable detectors;
- ✓ With 1500 **scintillating fibers** arranged in 20 U/V detection planes, providing a spatial resolution of **30 μ m**;
- ✓ 237 and 245 m from IP.

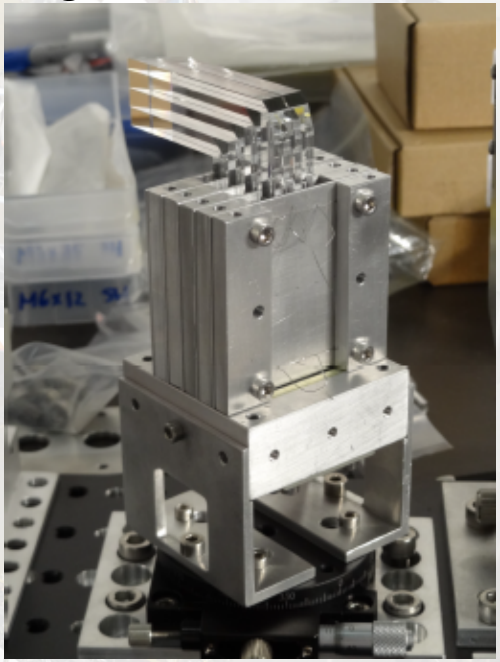
R. Staszewski **@ LHCC meeting, 2014**

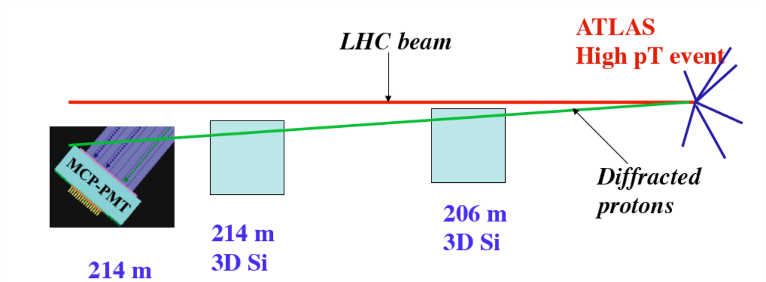
Forward Detectors: ATLAS

AFP (ATLAS Forward Protons):

- ✓ **Tracking, Timing and Roman pots;**
- ✓ 4 RPs: stations at 206 and 214 m from IP, on both outgoing beams;
- ✓ Two stations on each side: trajectory position and direction;
- ✓ Tracking detectors (stations 204 and 212m): **silicon detectors with resolution ~10 μ m**, 1 μ rad;
- ✓ **Timing detectors** in stations at 212 m: precise timing for reconstructing longitudinal vertex position (needed for high pileup scenarios, **up to ~10 ps** resolution for overlap background rejection).

Timing detector test beam

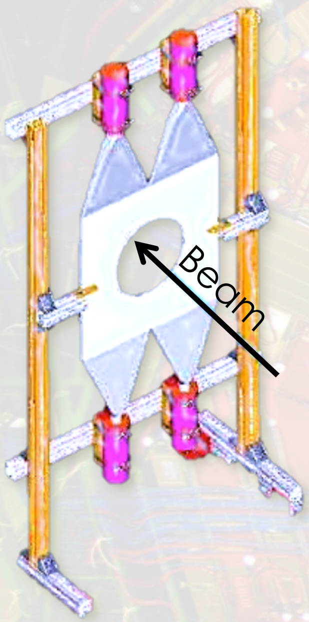




M. Taševský @ **Diffraction 2014**

Forward Detectors: CMS

Centauro And STrange Object Research (CASTOR), Forward Shower Counters (FSC) and T1 and T2 (TOTEM telescopes)

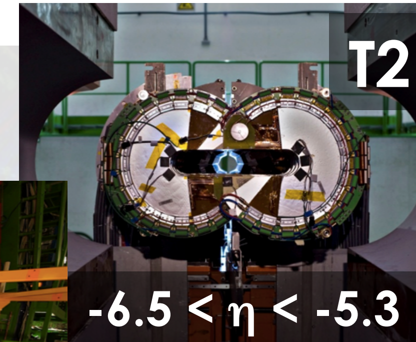


FSC Station

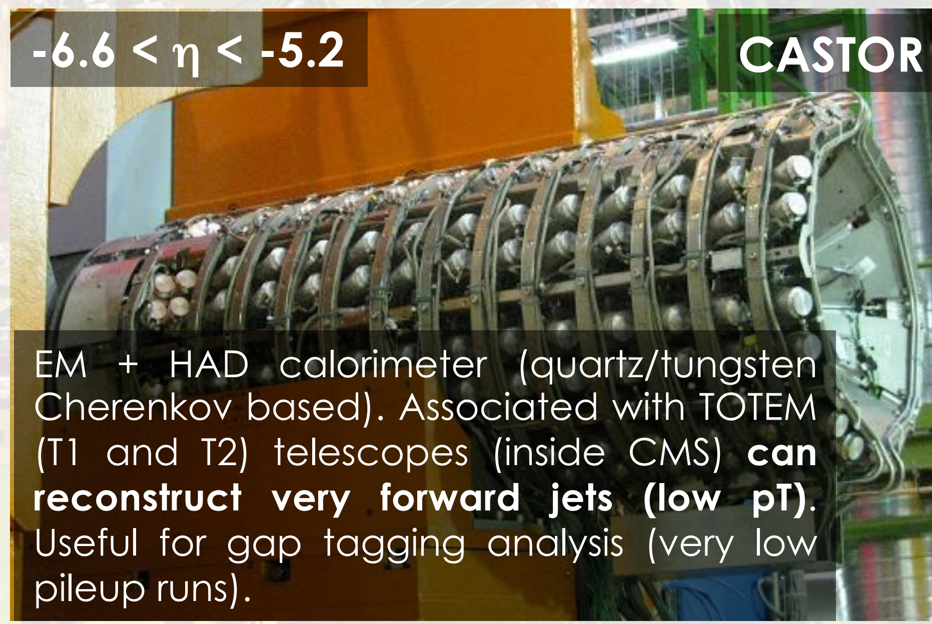
$$6 < |\eta| < 8$$

FSC Stations installed at ± 59, ± 85, ± 114m at IP5 (CMS)

Scintillator paddles (25 x 25)cm with one photomultiplier (PMT) each. **Detect showers** from high rapidity particles interacting with beam pipe elements. Symmetric at IP5 (CMS). 3 and 4 stations for each side. Very useful for CEP searches, dissociation measurements and beam monitor.



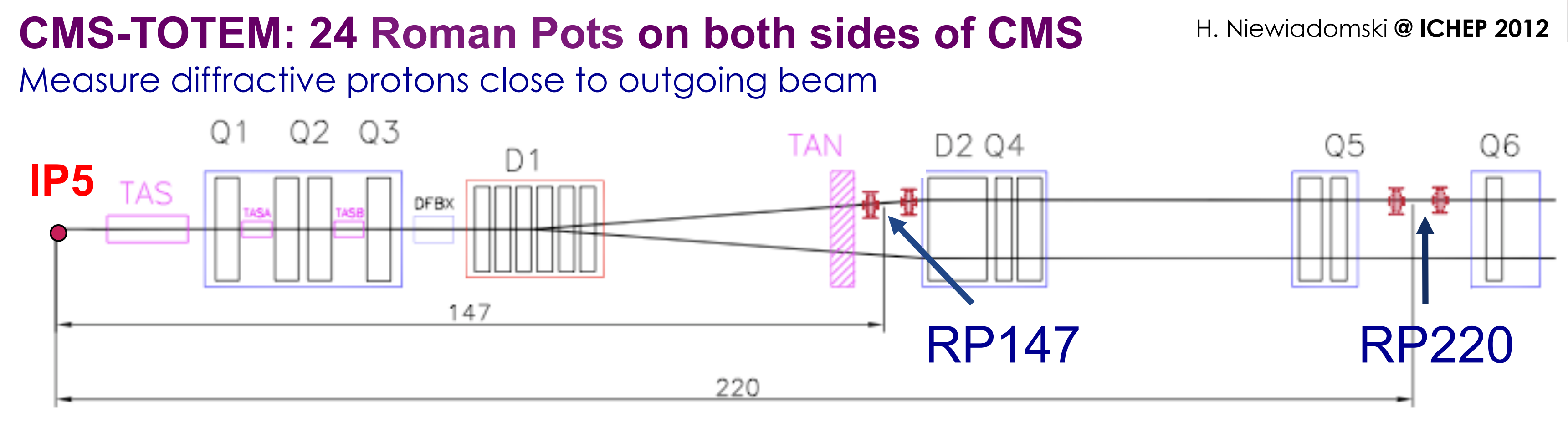
T1 and T2: charged particle & vertex reconstruction.



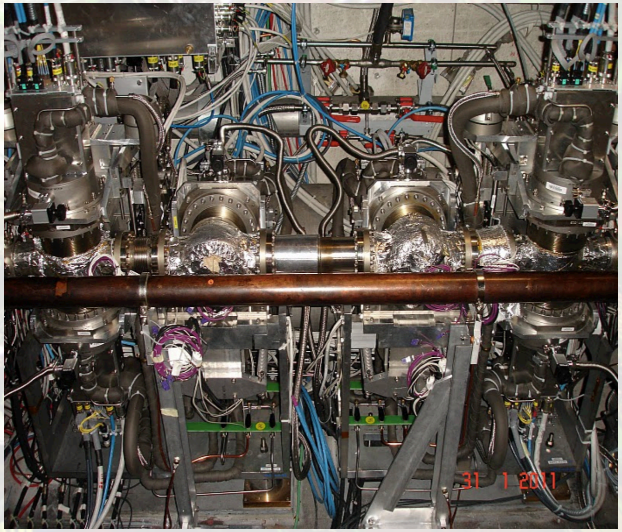
EM + HAD calorimeter (quartz/tungsten Cherenkov based). Associated with TOTEM (T1 and T2) telescopes (inside CMS) **can reconstruct very forward jets (low pT)**. Useful for gap tagging analysis (very low pileup runs).

Forward Detectors: CMS

CMS-TOTEM Roman Pots (High β^* = 90 m, low pileup runs):



- ✓ Detect protons scattered at IP5 (CMS);
- ✓ **Near-beam movable devices**;
- ✓ Equipped with edgeless **silicon microstrip** detectors;
- ✓ Resolution of **~16μm**;
- ✓ Trigger capability with FPGA processing.



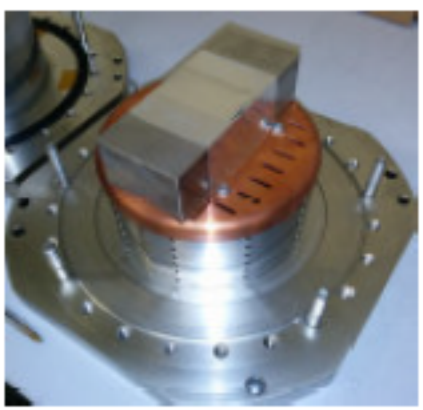
Forward Detectors: CMS

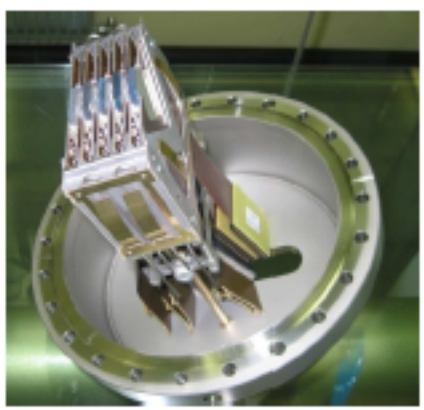
CERN-LHCC-2014-021
CMS-TDR-13, TOTEM-TDR-003

CMS-TOTEM Precision Proton Spectrometer CT-PPS (Low β^* = 0.55 m, high pileup):

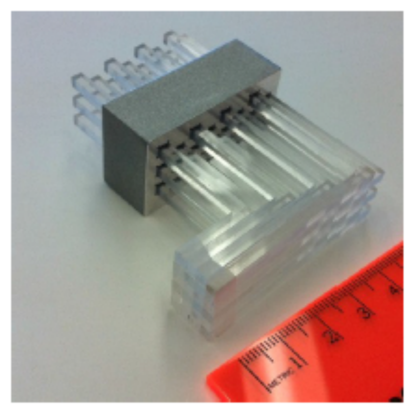
- ✓ Measurements in the very forward regions on both sides of CMS during standard LHC running;
- ✓ Two new stations for **tracking detectors (pixel ~10 μm)** and two new stations for **timing detectors** installed at ~210 m from the common CMS-TOTEM interaction point (IP5) on both sides of CMS;
- ✓ LHC magnets between IP5 and the detector stations used to bend out of the beam envelope protons;
- ✓ **Fractional longitudinal momentum loss (ξ) between 2% and 10%;**
- ✓ Ability to **reject the background** expected in the high pile-up (μ =50) environment of normal LHC running, mainly inelastic events overlapping with SD protons from the same bunch crossing.

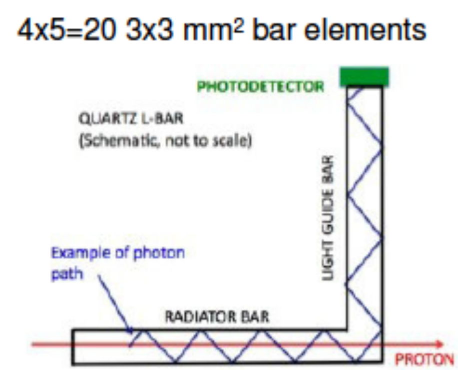
2 new horizontal rectangular RPs equipped with tracking detectors





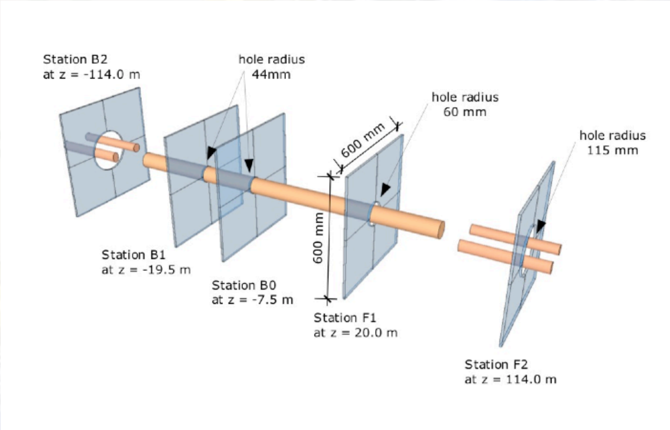
2 new horizontal cylindrical RPs equipped with timing detectors (~30 ps)





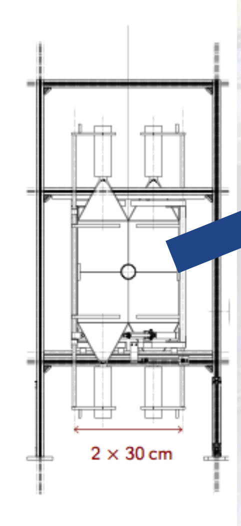
Ada Solano @ Diffraction 2014: https://agenda.infn.it/getFile.py/access?contribId=120&sessionId=14&resId=0&materialId=slides&confId=7520

Forward Detectors: LHCb



New Herschel Scintillators:

- ✓ No pile up (μ << 1, very low luminosity runs);
- ✓ Idea of Herschel is to install scintillation counters in the tunnel where the beam pipe is accessible;
- ✓ Stations installed at **Z = 20, 114 m and Z = -7.5, -19, -114 m;**
- ✓ **Extend LHCb coverage with very forward scintillators** in LHC tunnel upstream and downstream of experiment;
- ✓ **Improve selection of and triggering on events with large rapidity gaps** and interpretation of central exclusive and single diffractive analyses.



P. Collins @ 2nd Workshop on FWD Detectors LHC: https://indico.cern.ch/event/295567/session/4/contribution/19/material/slides/1.pdf

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LHC running physics scenarios: nomenclature

Low luminosity runs:

- ✓ No pile up (μ << 1) (very low luminosity) - dedicated to LHCf measurements (together will all other LHC experiments);
- ✓ No pile up high β^* (90 m), ALFA and TOTEM;
- ✓ Very low pile up with proton tagged or not: 0.1 to 1 pb^{-1}, a few days are needed.

Medium luminosity runs:

- ✓ LHCb runs with little pile up, a few fb^{-1} accumulated;
- ✓ ALICE, ATLAS, CMS runs at low pile up, rapidity gap measurements;
- ✓ CMS-TOTEM and ALFA/AFP special runs at high β^* (90 m), μ~1, a few days needed to accumulate 1 to 10 pb^{-1};
- ✓ AFP and CMS-TOTEM running at low pile up (μ = 2, ..., 5), between one and two weeks of data taking, 10 to 100 pb^{-1}.

High luminosity runs:

- ✓ High pile up (μ = 20, ...,100), low β^* (0.55 m, LHC nominal) and high luminosity runs with proton tagging;
- ✓ Possibility to collect data with high pile up (50 and above) and also at μ~25 by restricting to end of store data taking and tails of the vertex distribution: 40% of total luminosity can be collected.

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Detectors running conditions

Low instantaneous luminosity, very low and low pileup:

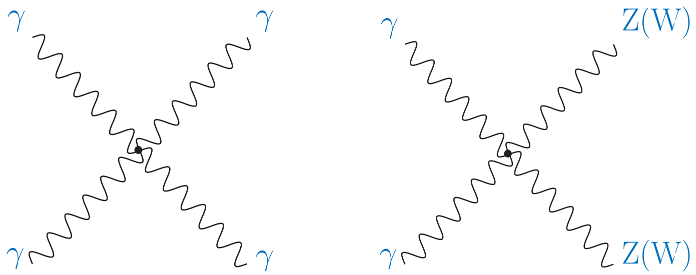
- ✓ Forward energy and multiplicity measurements: LHCf, ALICE;
- ✓ Total cross section measurement: ALFA/TOTEM;
- ✓ Low mass resonances and exotic states: CMS-TOTEM, AFP, LHCb;
- ✓ Soft QCD with proton tagging: CMS-TOTEM, AFP;
- ✓ Single diffractive measurements: CMS-TOTEM, AFP, ALICE.

Medium inst. luminosity, low pileup:

- ✓ Exclusive diffractive measurements: vector mesons, jets. LHCb, CMS-TOTEM, AFP, ALICE;
- ✓ DPE/QCD measurements, understanding the structure of diffraction: jets. CMS-TOTEM, AFP;
- ✓ Jet-gap-jet in diffraction: AFP, CMS-TOTEM;
- ✓ Preparing for high luminosity measurements: AFP, CT-PPS.

High inst. Luminosity, high pileup: AFP, CT-PPS

- ✓ QCD physics: Exclusive dijet, high mass state;
- ✓ Exploratory physics: anomalous couplings.



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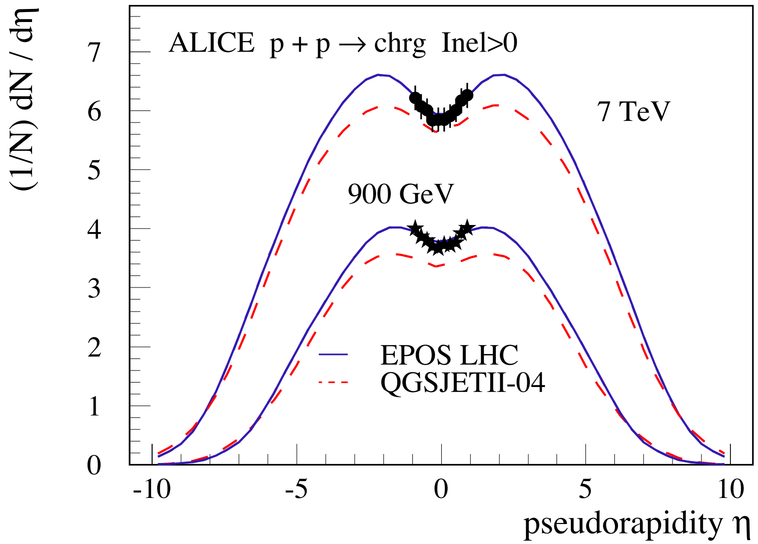
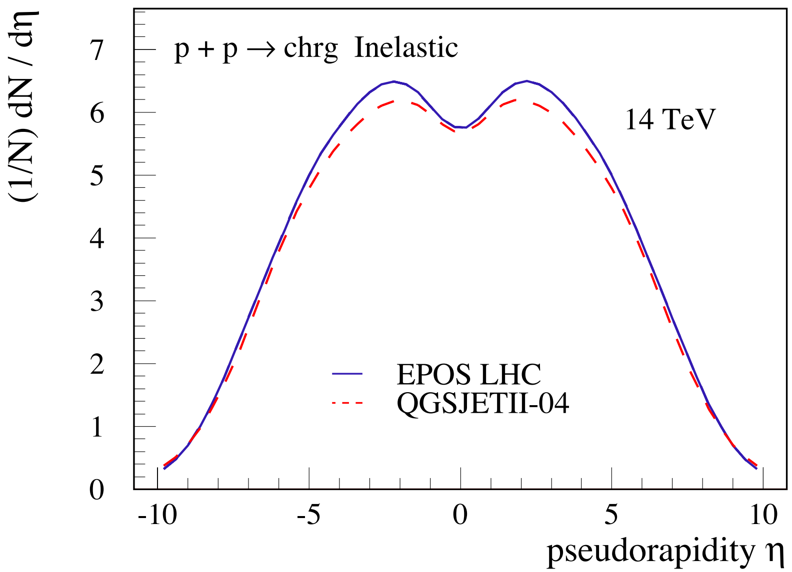
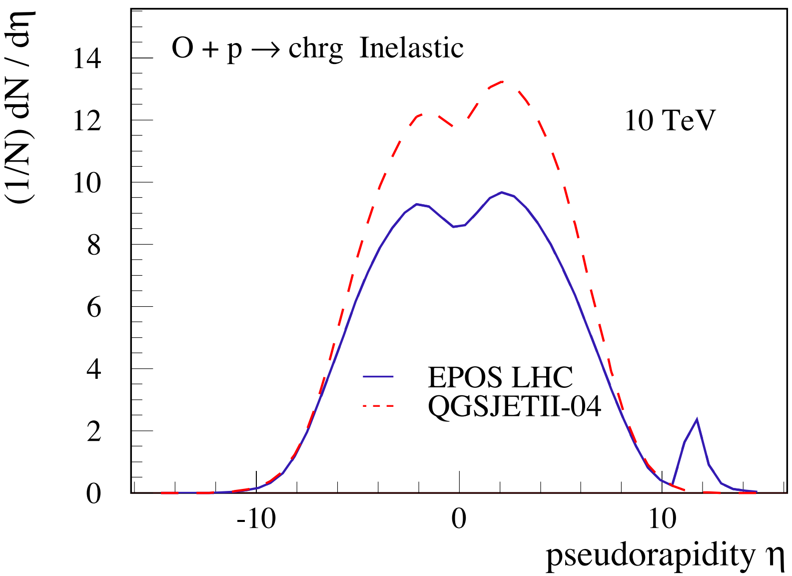
Low luminosity LHC Runs

Soft Interactions:

- ✓ These studies exploit detectors with forward acceptance to better constrain phenomenological models of soft diffractive proton dissociation;
- ✓ Measure particles multiplicity, energy distribution, and rapidity gaps to compare different MC models (underlying events, ISR and FSR radiation) with data;
- ✓ Measurement of soft diffraction, total cross section: high β^* measurement in TOTEM, ATLAS-ALFA;
- ✓ Constrain cosmic-ray models: importance of measuring p-Oxygen (useful to tune air shower models).







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Medium luminosity LHC Runs

Hard diffraction at the LHC:

- ✓ Intact protons assumed to be tagged in CMS-TOTEM (CT-PPS) or ALFA (AFP);
- ✓ Constrain the structure of the colorless exchanged object, the **Pomeron**: single diffractive (SD) topology can explore quark-fusion processes (W and Z boson);
- ✓ Probe evolution equation of QCD (BFKL): Jet gap jet in diffraction;
- ✓ Inclusive double Pomeron exchange (DPE): tests on gluon content of the Pomeron;
- ✓ CEP dijet production: dominated by *gg* exchanges (J_z= 0, quark contribution is suppressed, "*Durham Model*").

Three important opened questions:

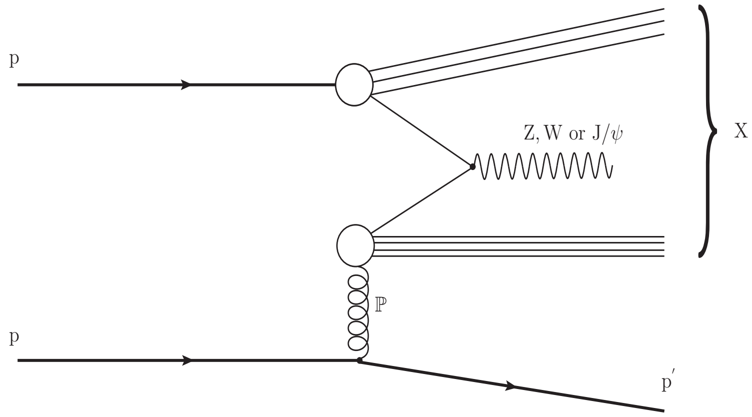
- ✓ Is it the same object which explains diffraction in *pp* (Tevatron, LHC) and *ep (HERA)*? **Universality of the model.**
- ✓ Further constraints on the structure of the ***Pomeron*** as was determined at HERA: measure dPDFs (diffractive PDFs);
- ✓ Survival probability: **difficult to compute theoretically**, needs to be measured, inclusive diffraction is optimal place for measurement.

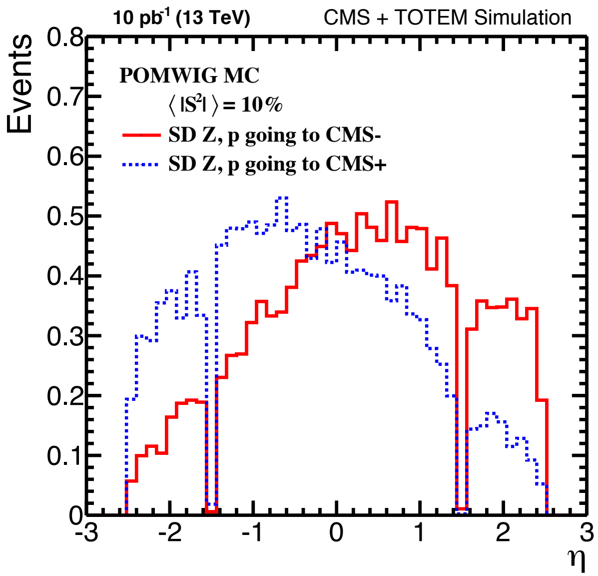
Medium luminosity LHC Runs

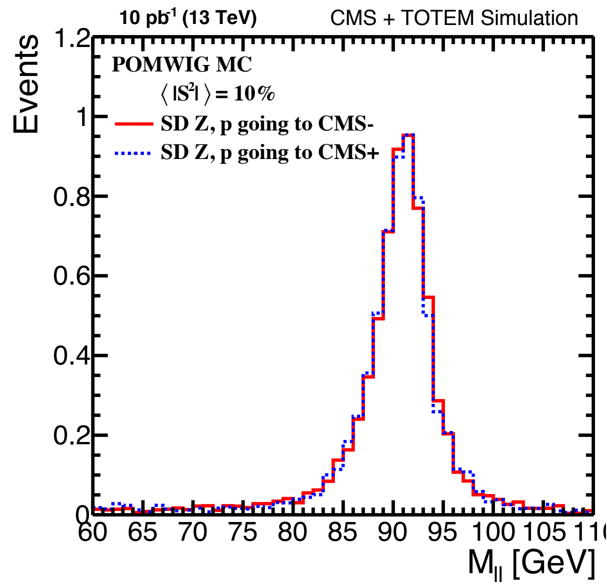
CMS PAS FSQ-14-001
TOTEM-NOTE-2014-002

Single Diffraction (SD) with Proton Tagging at High β^*

- ✓ Run at high β^*: study different single diffractive processes with low pile up and measure their cross-sections. J/Ψ, Z (or W) Boson;
- ✓ Measurement gap survival probability for different SD hard process.



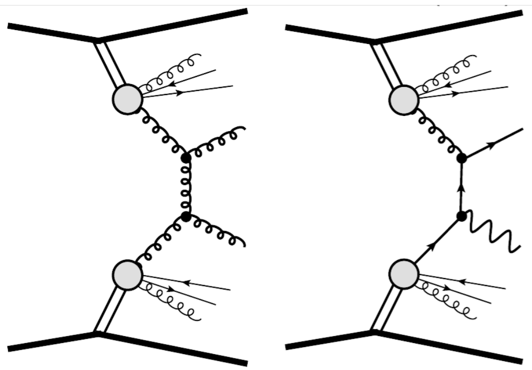


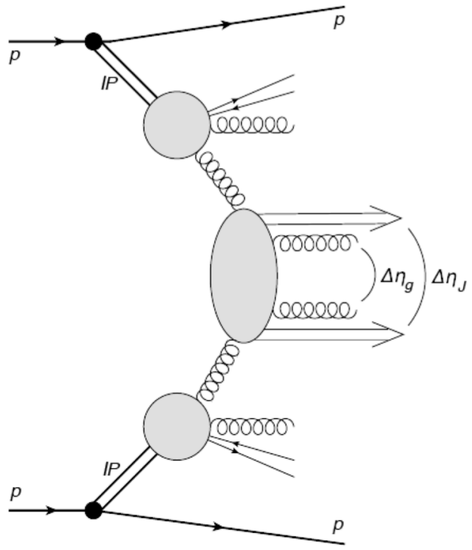


Medium luminosity LHC Runs

Inclusive Double Pomeron Exchange (DPE) with Proton Tagging

- ✓ Dijet cross section at the LHC in AFP/CMS-TOTEM acceptance;
- ✓ Test sensitivity to gluon density of the *Pomeron*;
- ✓ Possibility to constrain the quark content in the *Pomeron* using γ + jet final state events;
- ✓ Moderate pile-up for DPE jet measurements (μ = 2-3).





Jet gap Jet events with proton tagging

- ✓ BFKL (Balitsky-Fadin-Kuraev-Lipatov) allows for QCD prediction (valid at short distances, hard perturbative region) for final states with rapidity gaps;
- ✓ Signals: jets of similar pT (opposite hemispheres) that are widely separated in large rapidity (Mueller-Navelet);
- ✓ Background: incluse DPE. It can be separated requiring a LRG between jets.
- ✓ Study BFKL dynamics using jet gap jet events.

Medium luminosity LHC Runs

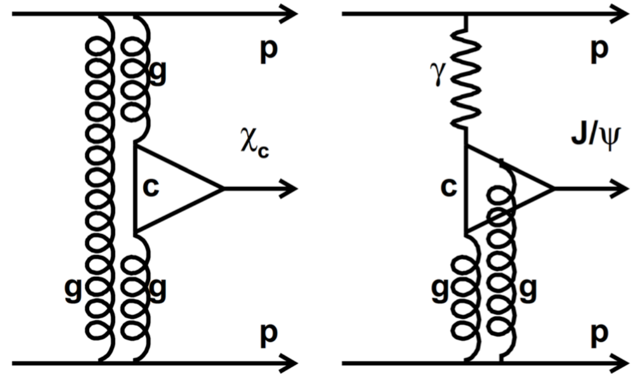
Exclusive State Measurements

- ✓ Many exclusive states can be measured in high β^* runs in CMS-TOTEM, and in standard runs in LHCb;
- ✓ CMS-TOTEM: detect both protons, information from central detector, particle Id (pions, kaons with tracker) and timing detectors;
- ✓ Search for *glueball* candidates state in CEP (theorical framework is sensitive on the gluon PDF in the low-x and Q^2 regions);
- ✓ With 1 pb^{-1}: confirmation of unobserved possible $f_0(1710)$ and $f_0(1500)$ decay modes (glueball candidates from lattice QCD) and first cross-section × branching ratio estimates for f-states;
- ✓ With 5-10 pb^{-1}: unambiguous determination of spin and precise measurement of cross-section × branching ratio for f-states (*needed for glueball analysis*) and cross-section × branching ratio estimates for all three χ_C (0,1,2 states), comparison with perturbative QCD. Spin analysis to reject events.
- ✓ Low mass exclusive dijet production: $M_X > 60$ GeV, cross section of ~ 100 pb.

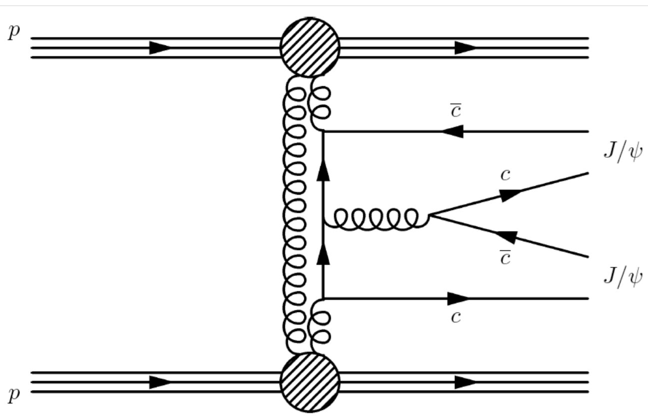
Medium luminosity LHC Runs

Exclusive single meson production

- ✓ Many exclusive channels can be studied at medium luminosity: jets, χ_C (J/Ψ γ), J/Ψ, $\pi^+\pi^-$ and others;
- ✓ Possibility to reconstruct the properties of the object produced exclusively (via photon and gluon exchanges) from the tagged proton: system completely constrained;
- ✓ Possibility of constraining the background by asking the matching between the information of the two protons and the produced object.



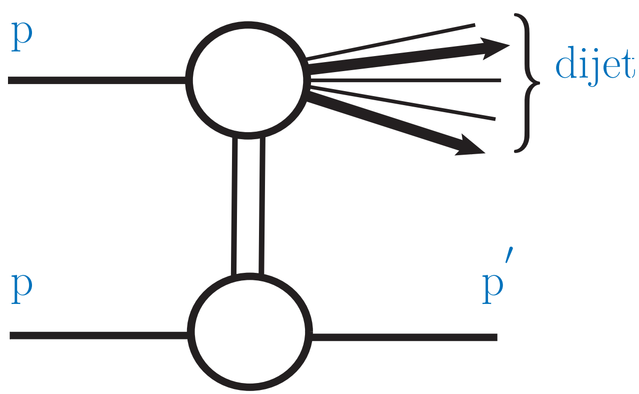
Exclusive double mesons production



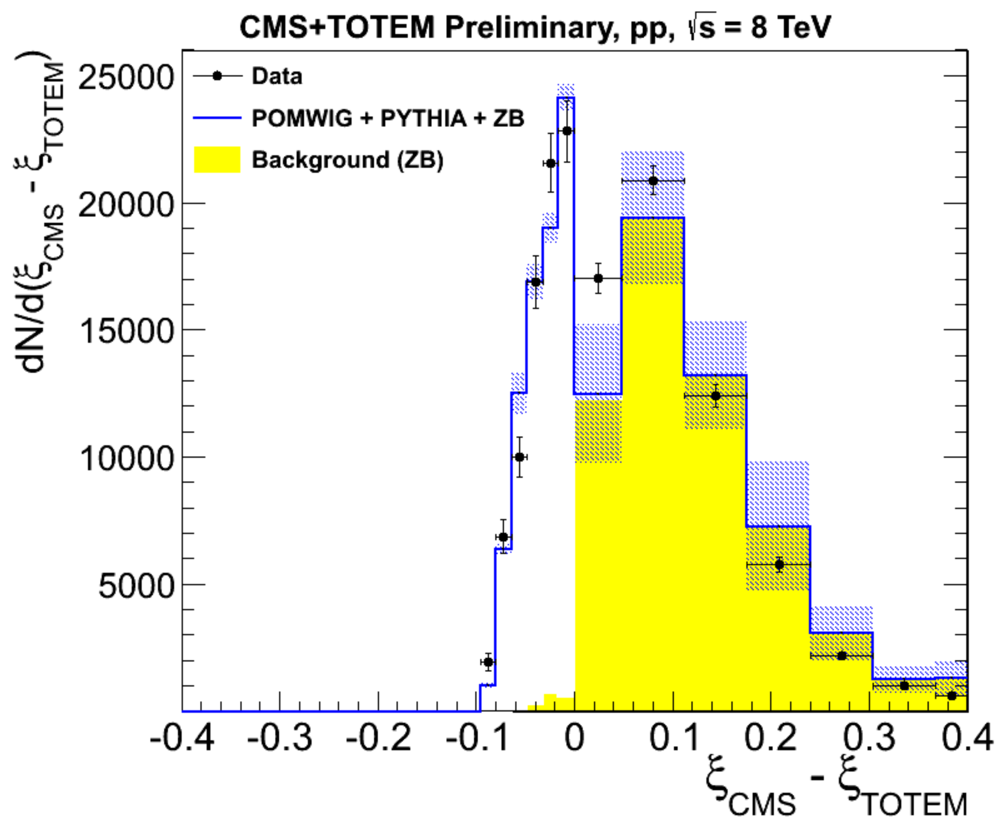
- ✓ LHCb measurement of double meson: very clean sample, example of LHCb, no proton tagging (charmonium with 3 fb^{-1}). It constitutes a background process for the observation of X_C decays;
- ✓ Measurement performed in parallel with theory developments;
- ✓ Such channels are sensitive to new physics: searches for *glueballs* or *tetraquarks* states.

Medium luminosity LHC Runs

Background Substraction



$$\xi^{\pm}_{\rm CMS} = \frac{1}{\sqrt{\rm s}} \sum_{\rm i}^{\rm N} E_{T,i} e^{\pm\eta_{\rm i}}$$



- ✓ Proton tagging analysis with 2012 CMS-TOTEM data, high β^* run (similar with Run II) and 50 nb^{-1};
- ✓ Pileup and beam halo events are estimated about 4%. Background events can be rejected. **Confirmed method for pileup rejection**.

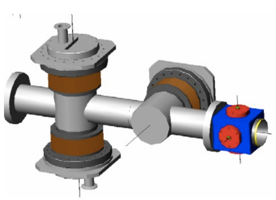
Outline

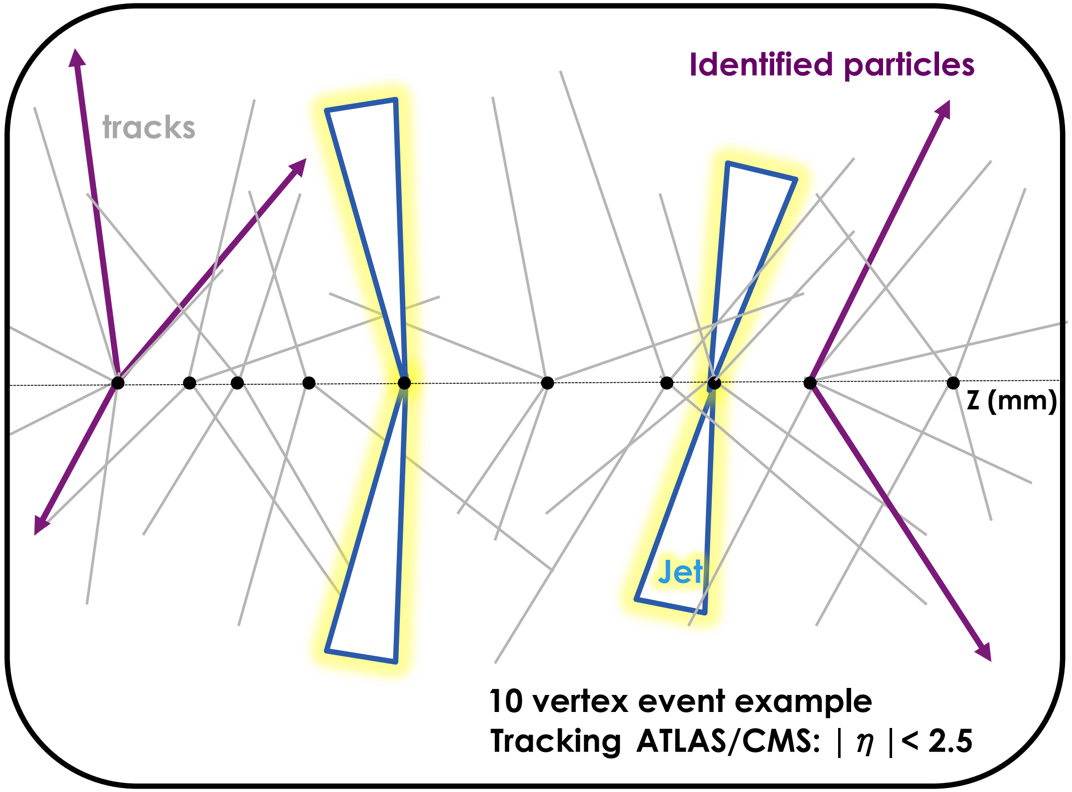
① Forward physics motivation
② Forward detectors
③ LHC running physics scenarios planning
④ Detectors running conditions
⑤ Low luminosity LHC runs
⑥ Medium luminosity LHC runs
⑦ **High luminosity LHC runs**
⑧ Final Remarks

High luminosity LHC Runs

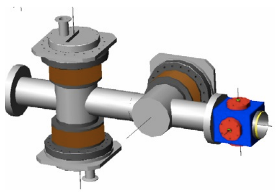
- ✓ Low β^* runs: high pileup scenario (> 50 extra vertex events). Forward detectors should have time **resolution in few picoseconds to identify the interested event vertex**;
- ✓ Vertex matching (z position measurement): main detector (ATLAS/CMS) and forward detectors stations (based on the diference of the proton arrival time in negative and positive pots);
- ✓ Search new phenomena taking advantage of CEP clean signature.

Stations along the –Z direction





Stations along the +Z direction



High luminosity LHC Runs

- ✓ Low β^* runs: high pileup scenario (> 50 extra vertex events). Forward detectors should have time **resolution in few picoseconds to identify the interested event vertex**;
- ✓ Vertex matching (z position measurement): main detector (ATLAS/CMS) and forward detectors stations (**based on the diference of the proton arrival time in negative and positive pots**);
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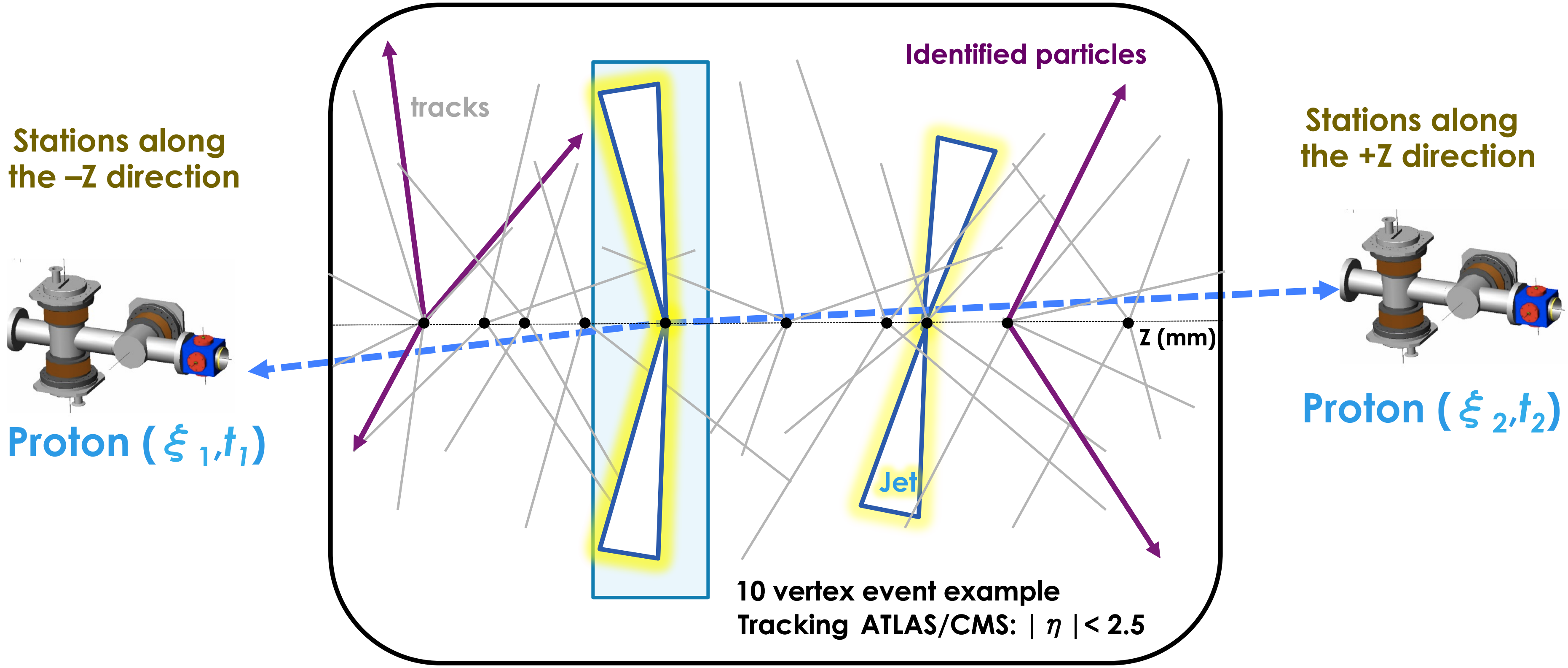
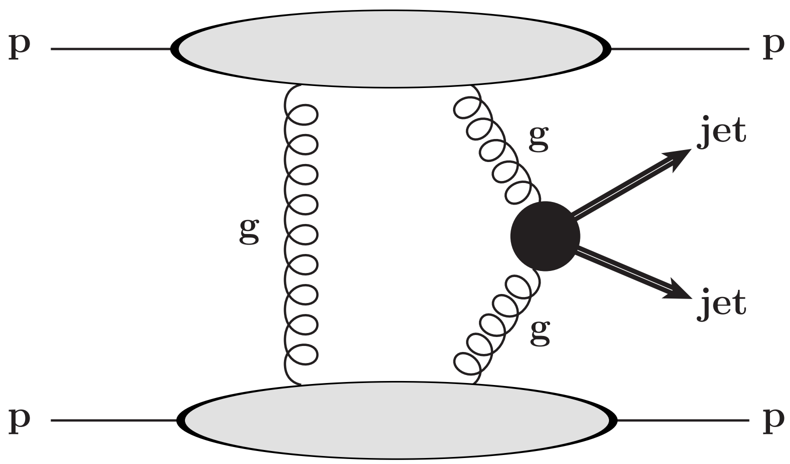
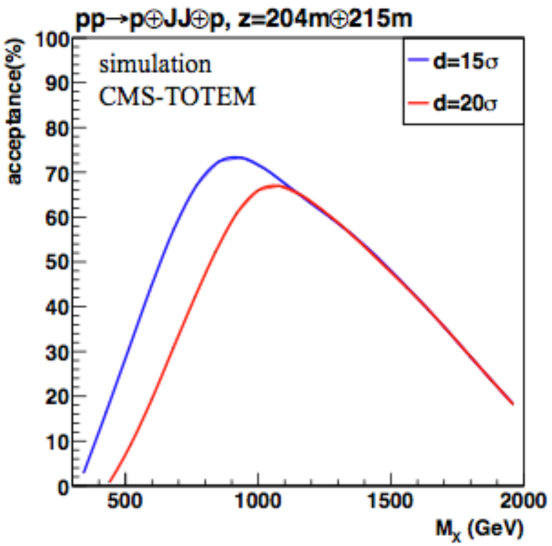


High luminosity LHC Runs

CERN-LHCC-2014-021

Central Exclusive Dijet Production (CEP)



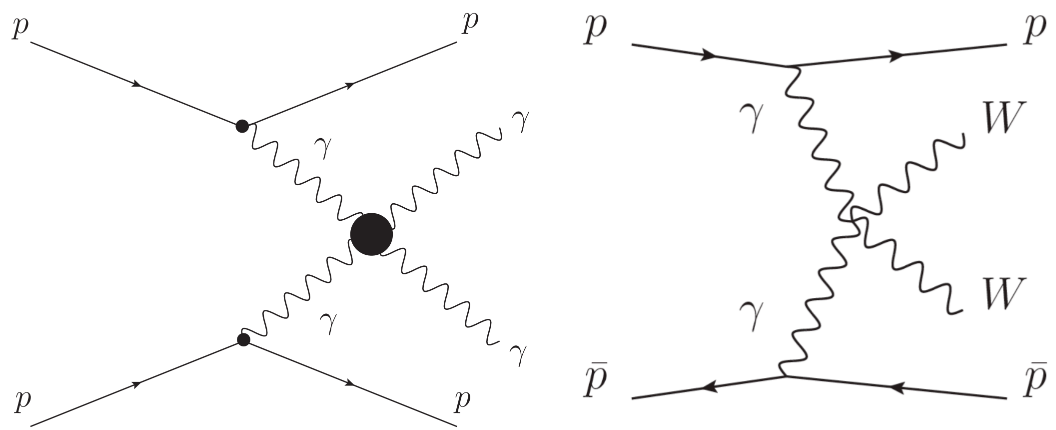


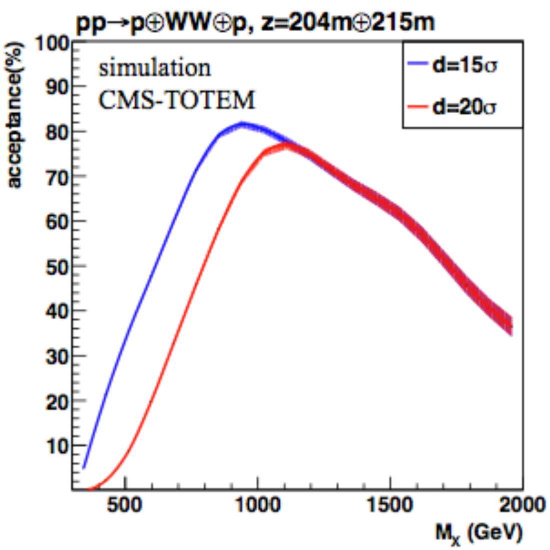
- ✓ Search new phenomena taking advantage of CEP clean signature;
- ✓ Unique topology to explore gluon jet physics at LHC: test of pQCD mechanism of exclusive production;
- ✓ High jet p_T events (M_{jj} > 400-500 GeV);
- ✓ Event yields based on MC simulations: for 1 fb^{-1} of data, Signal/Background ~ 1/3 (pileup=25) and ~1/8 (pileup=50);
- ✓ Central exclusive production is a potential channel for Beyond Standard Model (BSM) physics: sensitivity to high masses up to 1.8 TeV (masses above 400 GeV, depending how close one can go to the beam).

CERN-LHCC-2014-021

High luminosity LHC Runs

Search for anomalous quartic gauge coupling: Exclusive WW (ZZ or $\gamma\gamma$)





Selection (WW): leptons pT > 160 GeV, E_{miss} > 20 GeV (for W) and $M_{T,W}$ > 800 GeV, proton both sides. Similar for ZZ.

- ✓ Study of the processes: pp → ppWW, pp → ppZZ and pp → pp$\gamma\gamma$. Standard Model predicts diphoton via gluon/photon box diagrams. **For anomalous coupling, the signal appears only for high masses final states. Test of gaugle couplings exclusion limits.**
- ✓ Sensitivity to anomalous couplings: studying in detail electroweak symmetry breaking, topology predicted by extra-dimensional models (and composite Higgs models);
- ✓ Based on MC simulations: exclusivity cuts suppresses all pile-up backgrounds.

Outline

1. Forward physics motivation
2. Forward detectors
3. LHC running physics scenarios planning
4. Detectors running conditions
5. Low luminosity LHC runs
6. Medium luminosity LHC runs
7. High luminosity LHC runs
8. **Final Remarks**

Final Remarks

Future Plans

2015

- ✓ No pile up, multiplicity and energy flow measurement in the very forward region: LHCf data in spring;
- ✓ High $\beta*$, no pile up: total cross section (TOTEM, ATLAS/ALFA);
- ✓ High $\beta*$, very low pile up ($\mu \sim 0.1$): ~**5-7 pb^{-1}** (ATLAS/ALFA, CMS-TOTEM): low mass diffraction. ~1 week of data taking;
- ✓ **Physics aim**: study nature of f_0(1710), measure exclusive J/ψ and χ_C, measure several hard single and double diffractive processes, inclusive DPE jets, energy and multiplicity particle flow in forward region, jet-gap-jet events…

2016

- ✓ High $\beta*$, no pile up: total cross section.(TOTEM, ATLAS/ALFA);
- ✓ High $\beta*$, low pile up (μ = 0.5 - 1), 10 - 100 pb^{-1} (ATLAS/ALFA, CMS-TOTEM). ~1 week of data taking;
- ✓ Test of timing detector with moderate resolution (50 ps or so).
- ✓ **Physics aim**: study missing mass signals, exclusive dijet production (low mass), quark content of the *Pomeron, jet-gap-jet, inclusive DPE jets...*

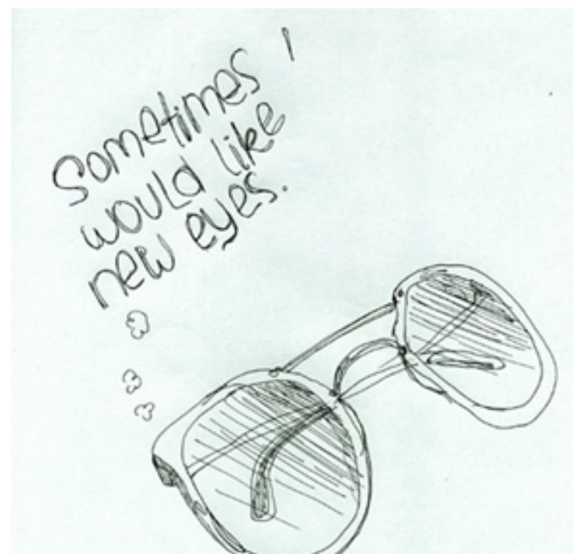
2017 and beyond

- ✓ Low $\beta*$ and low pile up (CT-PPS, ATLAS/AFP), understanding for high luminosity running: high mass diffraction and exploratory physics;
- ✓ LHCb and ALICE interested in taking data during those runs (low luminosity, calibration);
- ✓ CT-PPS and AFP aim at accumulating 100 fb^{-1} of data before LHC LS2 (2018).
- ✓ **Physics aim**: anomalous couplings, exclusive dijet production (high mass).

Final Remarks

Yellow Report document (editors by chapters): detailed discussion about LHC Forward Physics.

- **Introduction:** N. Cartiglia, C. Royon, J. Bartels
- **Monte Carlo:** L. Harland-Lang
- **Soft Diffraction:** V. Avati, T. Martin
- **Hard Diffraction:** M. Ruspa, M. Trzebinski
- **Central Exclusive Production:** M. Saimpert, P. Collins, O. Kepka, L. Harland-Lang
- **Forward Physics:** C. Marquet, J. Bartels
- **Cosmic ray:** T. Pierog
- **Heavy ions:** D. Tapia Takaki
- **Detectors:** J. Baechler, M. Rijssenbeek



by Andrew Coulter Enright

LHC is gluon-gluon or $\gamma\gamma$ collider!

Backup

DGLAP and BFKL equations

DGLAP and BFKL equations, which are synonymous with calculations of high-energy, strong interactions scattering process, together form the basis of current understanding of high energy scattering in QCD.

DGLAP

- ✓ QCD evolution equations are widely used in global determinations of *parton* distributions;
- ✓ They are valid in strong theory and determine the rate of change of *parton* densities (probability densities to find a *parton* in a proton) when the energy scale chosen for their definition is varied;
- ✓ Are the basis of all the phenomenological approaches that are used to describe **hadron interactions at short distances**.

BFKL

- ✓ Lipatov *at al* show that the gauge vector boson in Yang-Mills theory is "reggeized" with radiative corrections, the vector boson becomes a moving pole in the complex angular momentum plane near J=1. **BFKL describes the evolution of gluon ladder**.
- ✓ In QCD, this pole is not directly observable itself because it corresponds to a colour exchange. More meaningful is an exchange of two or more "reggeized" gluons, which lead to "colourless" exchange in t-channel, either with vacuum quantum numbers (Pomeron). Construction of bare Pomeron in QCD. **DGLAP does not take into account Pomeron contributions**;
- ✓ The gluon ladder in colour-singlet configuration contributes directly to the QCD Pomeron.

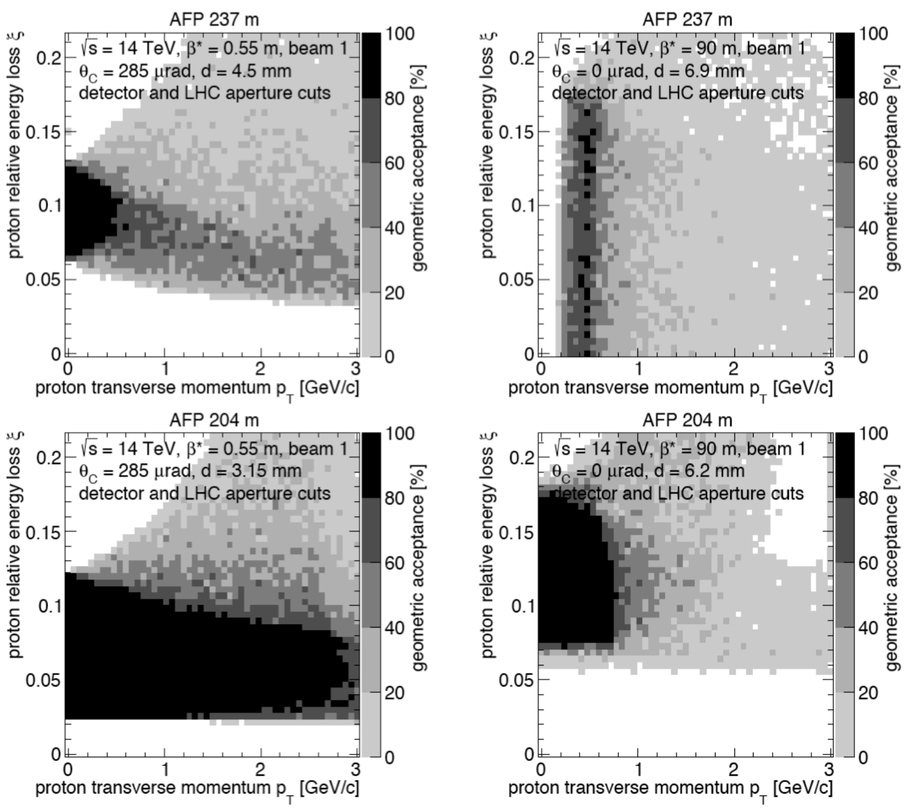
Detectors running conditions

Proton Tagging Detector:

- ✓ Possibility to tag intact protons in the final state in CMS and in ATLAS;
- ✓ High and low β^* running: complementarity in kinematical domain.

$\beta^* = 0.55$ m
nominal (*collision*)

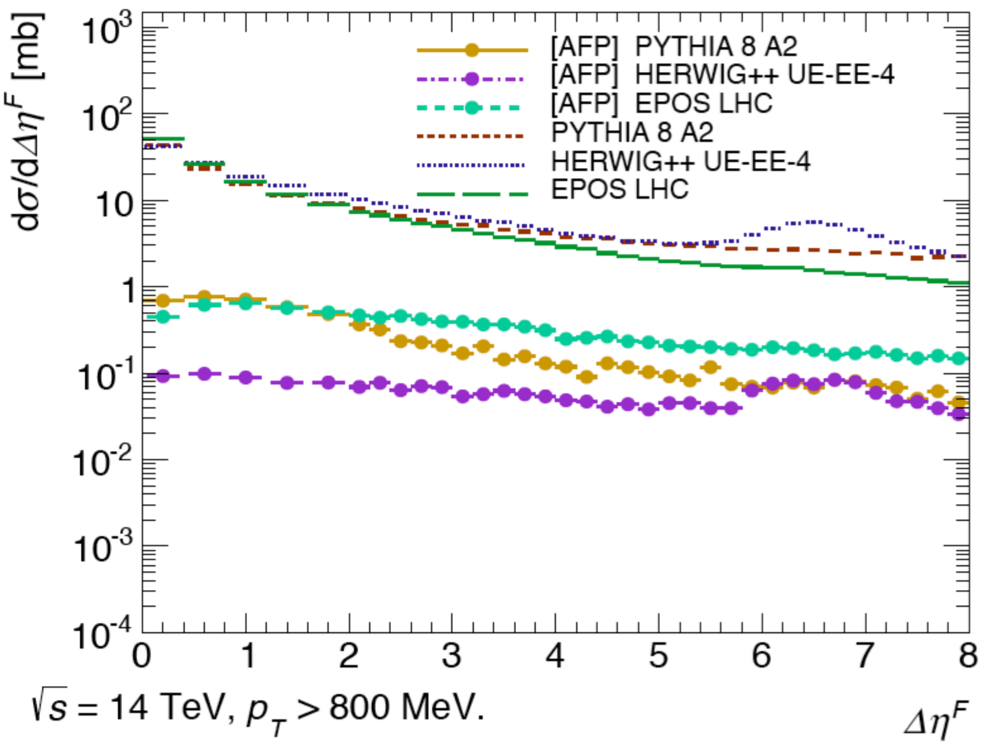
$\beta^* = 90$ m
special (*high-β^**)



Low luminosity LHC Runs

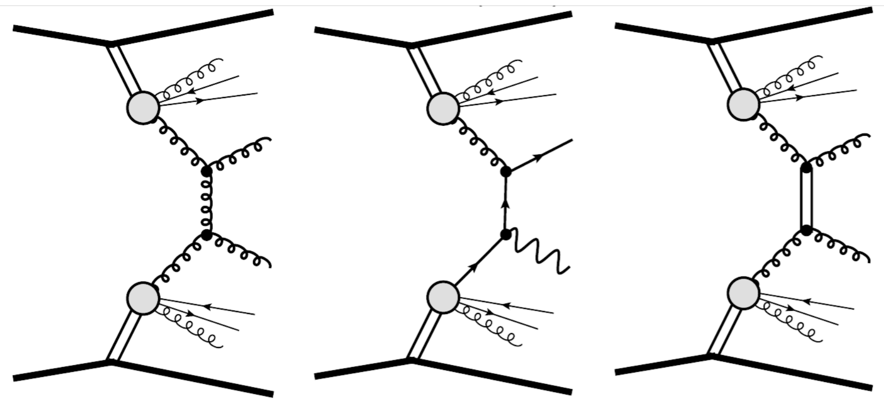
Forward gap in soft diffraction:

- ✓ Measure size of forward gap in diffractive events (signature of diffractive processes);
- ✓ Measurement important to tune models (hadronisation);
- ✓ Larger differences between models when proton is tagged in AFP or CMS-TOTEM (for different thresholds up to 200 MeV).



Medium luminosity LHC Runs

Inclusive Double Pomeron Exchange (DPE) with Proton Tagging



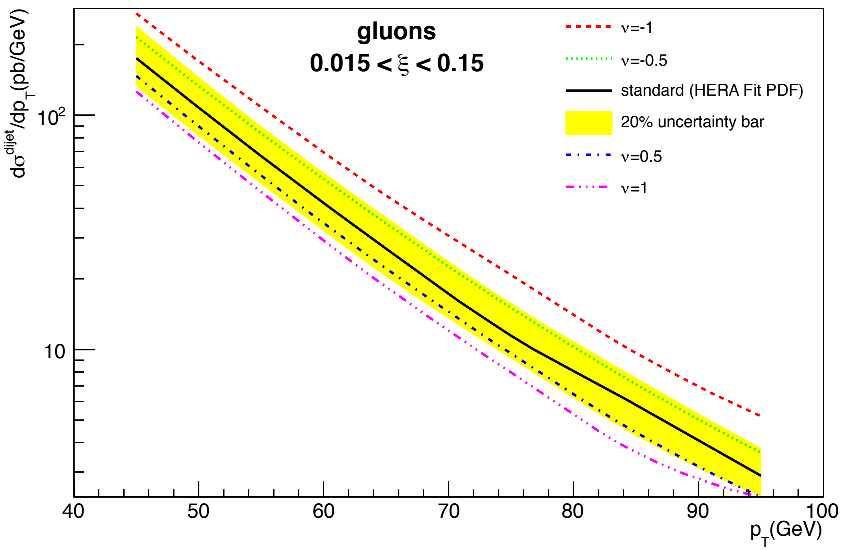
- ✓ Dijet cross section at the LHC in AFP/CMS-TOTEM acceptance;
- ✓ Test sensitivity to gluon density of the *Pomeron* and the **universality of the model**;
- ✓ Possibility to constrain the quark content in the *Pomeron* using γ + jet events;
- ✓ Moderate pile-up for DPE jet measurements (μ = 2-3).

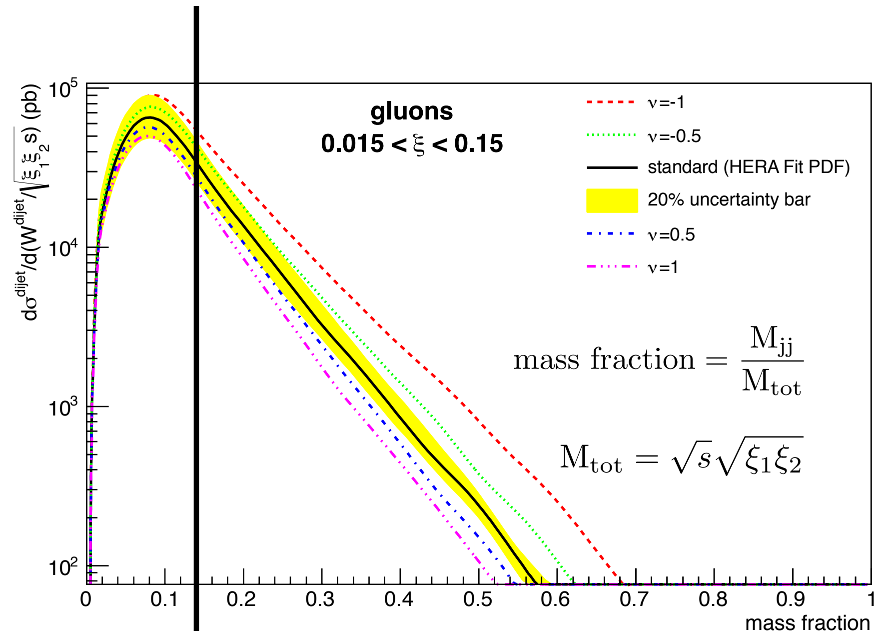
Single hard diffraction

- ✓ Study by ATLAS including pile up (CMS-TOTEM at 8 TeV on data);
- ✓ Low Pile up runs (μ = 0.1) to get a sample of high purity for SD events;
- ✓ Dominant background: non-diffractive hard interaction overlaid with soft pile-up process(es) giving a forward proton(s).

DPE Dijet and Gluon density

Dashed curves correspond to different modification of the Pomeron gluon density extracted from HERA.

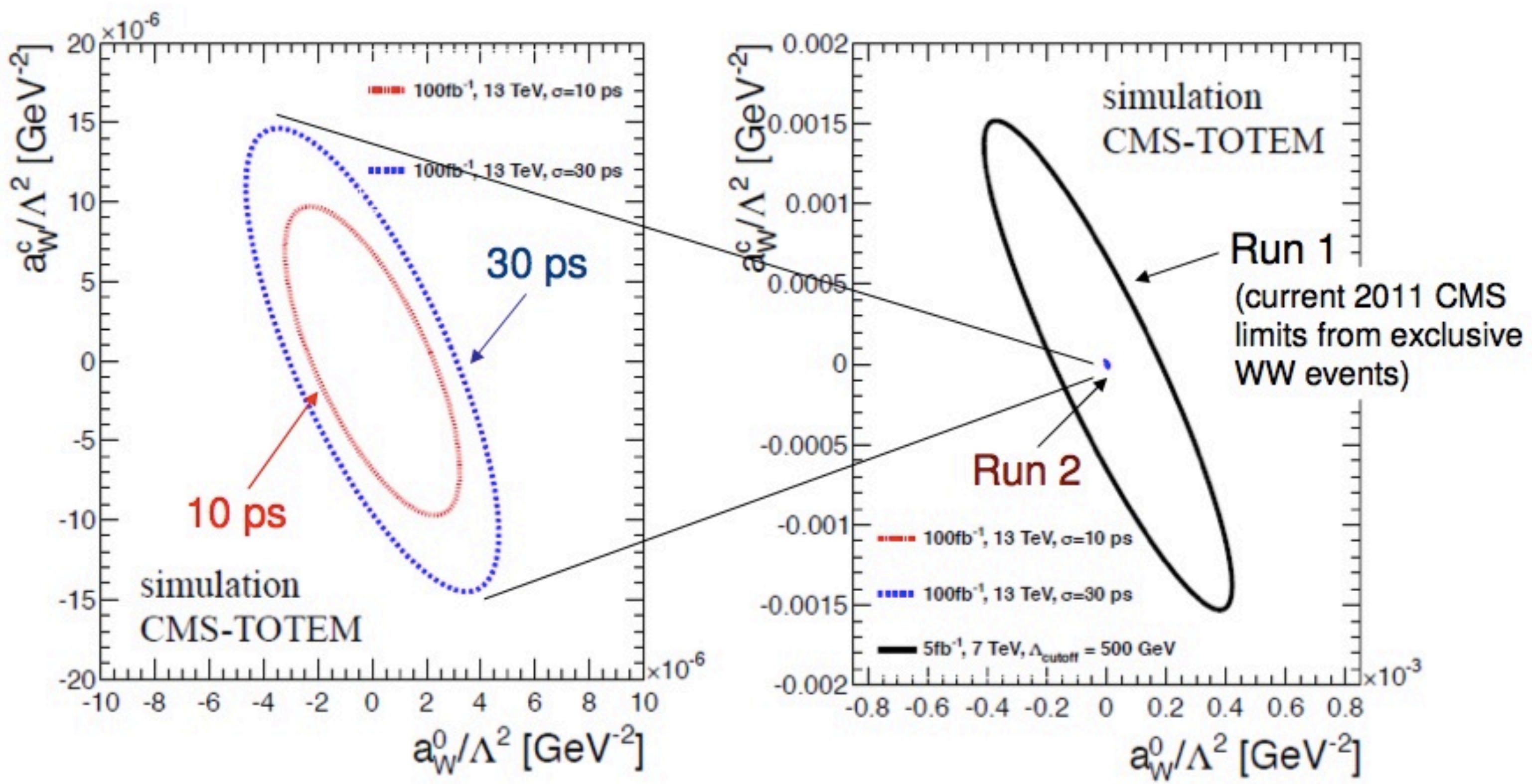




- ✓ The central black line displays the cross section value for the gluon density in the Pomeron measured at HERA including an additional gap survival probability of 3%. The yellow band shows the effect of the 20% uncertainty on the gluon density taking into account normalisation uncertainties;
- ✓ Dashed curves display how the cross section at the LHC is sensitive to gluon density distribution especially at high β (means Pomeron momentum fraction carried by the parton inside the Pomeron which interacts). The gluon density in the Pomeron from HERA by $(16\beta)^{\nu}$;
- ✓ Right plot shows mass fraction (another observable) for different values of ν. The gluon densities are much more spaced, meaning that this observable is indeed sensitive to gluon density.

Anomalous Coupling: AQGC

Expected limits @95%CL:
(areas outside the contours are excluded)



Ada Solano @ Diffraction 2014: https://agenda.infn.it/getFile.py/access?contribId=120&sessionId=14&resId=0&materialId=slides&confId=7520

Final Remarks: CT-PPS

The CT-PPS project includes an exploratory phase in 2015-2016 and a production phase until LHC LS2 (2018)

Exploratory phase (2015-16)

- ✓ Prove the ability to operate detectors close to the beamline at high luminosity;
- ✓ Show that CT-PPS does not prevent the stable operation of the LHC beams and does not affect significantly the luminosity performance of the machine.

– In 2015

- ✓ Evaluate RPs in the 204-215 m region;
- ✓ Demonstrate the timing performance of the Quartic baseline;
- ✓ Use TOTEM silicon strip detectors at sustainable radiation intensity;
- ✓ Integrate the CT-PPS detectors into the CMS trigger/DAQ system.

– In 2016

- ✓ Upgrade the tracking to pixel detectors;
- ✓ Upgrade the timing detectors if required/possible;
- ✓ Data Production phase.

Aim at accumulating 100 fb^{-1} of data before LHC LS2.

Some References

Forward Detectors and Status:

2nd Workshop on Detectors for Forward Physics at LHC

https://indico.cern.ch/event/295567/other-view?view=standard

Diffraction 2014

https://agenda.infn.it/conferenceDisplay.py?confId=7520

Based on C. Royon @LHC Working Group on Forward Physics and Diffraction

https://indico.cern.ch/event/325664/other-view?view=standard