Forward Physics plans for 2015-2016 and beyond at the LHC

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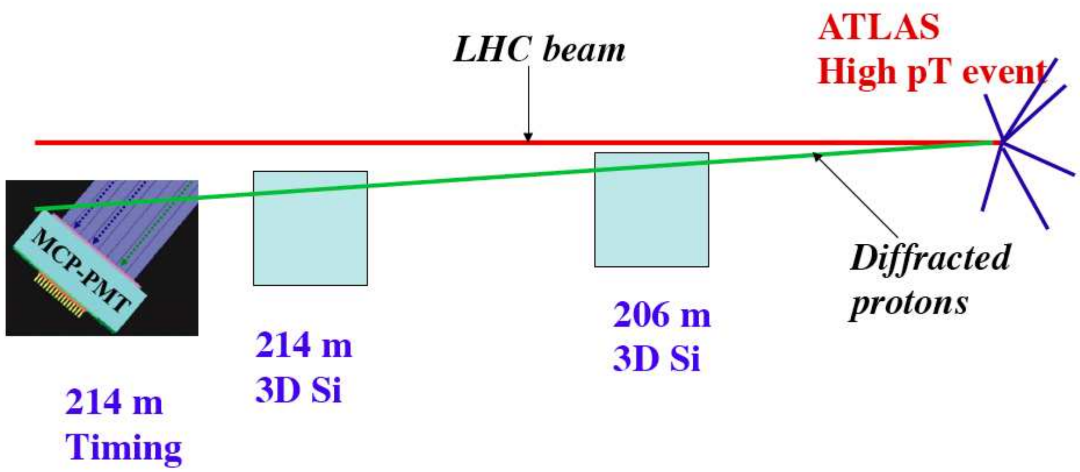
Contents: Forward Physics (QCD and exploratory physics)

- Low luminosity, high β^* (90 m) - no pile up - 2015
- Medium luminosity, high β^* (90 m) - very low and low pile up - 2015-2016
- High luminosity, low β^* (0.6 m) - beyond 2017, see the talk at the previous LHCC meeting

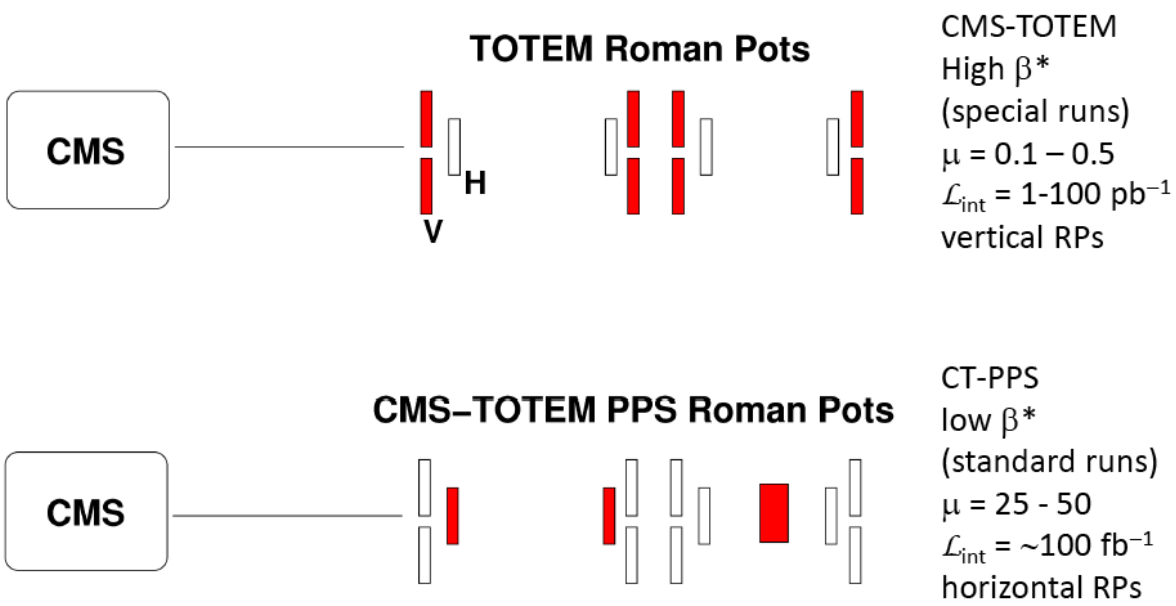


LHC running conditions vs experiments

- Low luminosity runs
  - No pile up ($\mu << 1$) (very low luminosity) - dedicated to LHCf measurements (together will all other LHC experiments)
  - No pile up high β^*, ALFA and TOTEM
  - Very low pile up (μ ~0,1) with proton tagged or not: 5 to 10 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^*, μ ~1, a few days needed to accumulate 10 to 100 pb^{-1}
  - AFP and CMS/TOTEM running at low β^*, low pile up ($\mu = 2, ..., 5$), one week of data taking, few 100 pb^{-1}
- High pile up (μ =20,...,100) (high luminosity) 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

Forward detectors

- LHCf close to ATLAS in the very forward region
- New Herschel scintillators in LHCb
- New forward scintillators in Alice
- CASTOR, ZDC in CMS, ZDC, LUCID, ALFA in ATLAS....
- CMS-TOTEM and CT-PPS (Precison Proton Spectrometer)



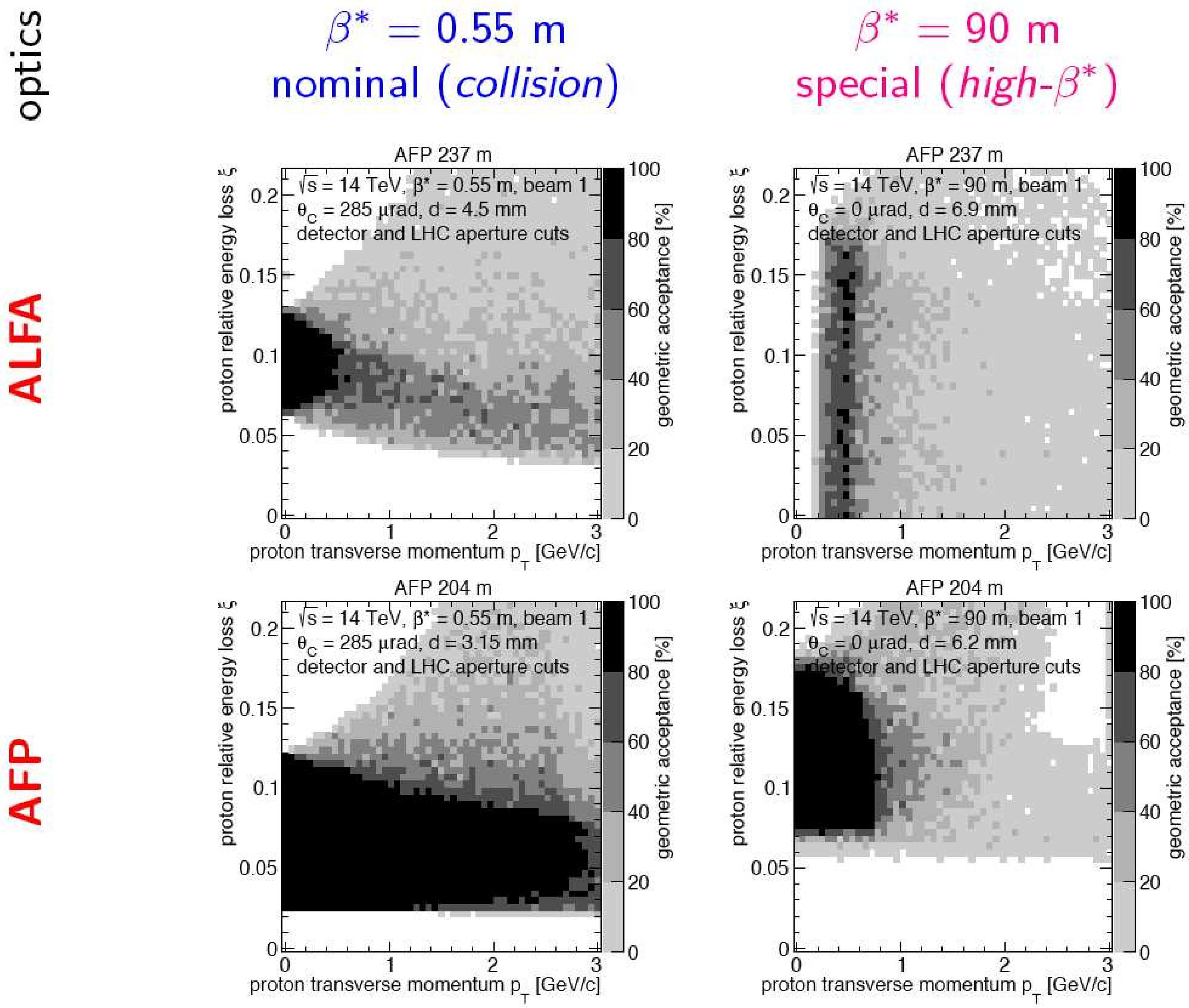
- AFP: Additional horizontal roman pots in ATLAS at 220 m with respect to ALFA vertical pots

Running conditions

- Low instantaneous luminosity, very low and low pile up
  - Forward energy and multiplicity measurements: LHCf
  - Total cross section measurement: ALFA/TOTEM
  - Low mass resonances and glueballs: CMS/TOTEM, AFP/ALFA. LHCb
  - Soft QCD with proton tagging: CMS/TOTEM, AFP/ALFA
  - Single diffractive measurements: TOTEM/CMS, AFP/ALFA, Alice
- Medium instantaneous luminosity, low pile up
  - Exclusive diffractive measurements: vector mesons, $c\bar{c}$, jets...: LHCb, CMS-TOTEM, AFP/ALFA
  - DPE/QCD measurements, understanding the structure of diffraction: jets, γ+jet,.CMS/TOTEM, AFP/ALFA
  - Jet gap jet in diffraction: AFP, CMS/TOTEM
  - Preparing for high lumi measurements: AFP/CT-PPS
- High luminosity: AFP, CT-PPS
  - QCD physics: Exclusive jets....
  - Exploratory physics: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$ anomalous couplings

Running conditions: proton tagging

- Possibility to tag intact protons in the final state in CMS-TOTEM and in ATLAS
- High and low β^* runnings: complementarity in kinematical domain, see ξ versus t plots



Running conditions 2015-2016 and beyond

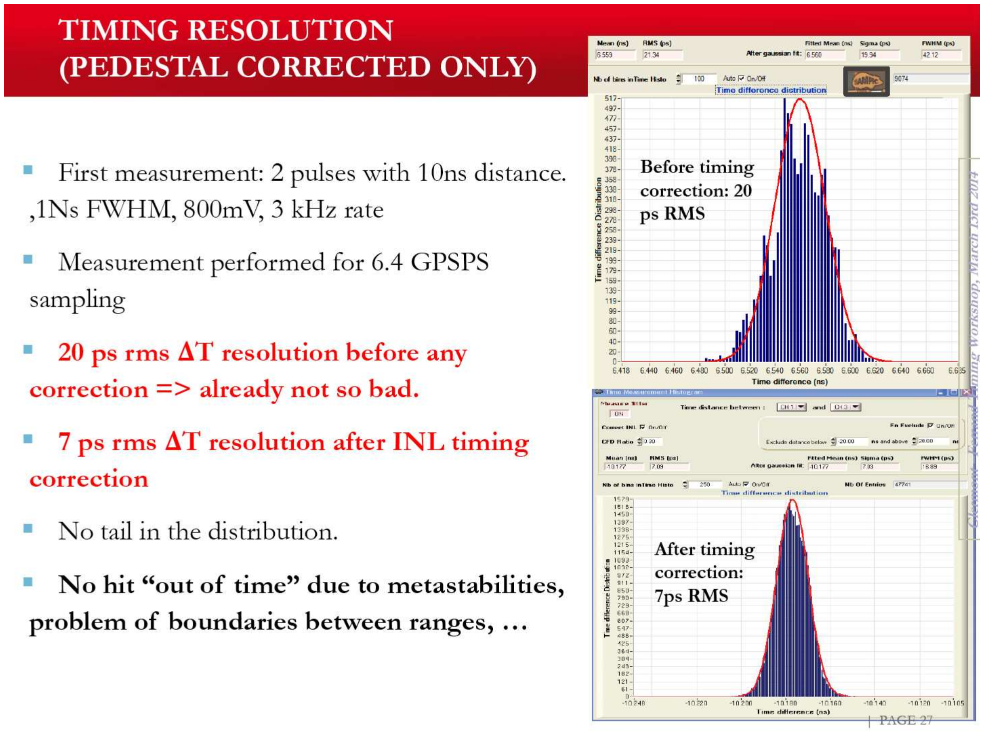
- 2015:
  - No pile up, multiplicity and energy flow measurement in the very forward region: LHCf data in spring
  - High β^*, no pile up: total cross section, elastic... (TOTEM, ATLAS/ALFA)
  - High β^*, very low pile up (μ=0.1): 5 to 10 pb^{-1} (ATLAS/ALFA, CMS-TOTEM): low mass diffraction
- 2016:
  - High β^*, no pile up: total cross section.(TOTEM, ATLAS/ALFA)
  - High β^*, low pile up (μ =1), 10 to 100 pb^{-1} (ATLAS/ALFA, CMS-TOTEM), requires timing detector with moderate resolution, not possible for ALFA, (50 ps or so): low mass diffraction
- 2017 and beyond: Low β^* and low pile up (CT-PPS, ATLAS/AFP), understanding for high luminosity running: high mass diffraction and exploratory physics, : to be rediscussed when more experience with forward detectors obtained, background constraints
- LHCb and ALICE interested in taking data in injection β^* during those runs (low luminosity, calibration...)
- ATLAS (like CMS-TOTEM) is now investigating the physics reach of one week of data taking at β^* ~90 m in 2015 with 5 to 10 pb^{-1} of data

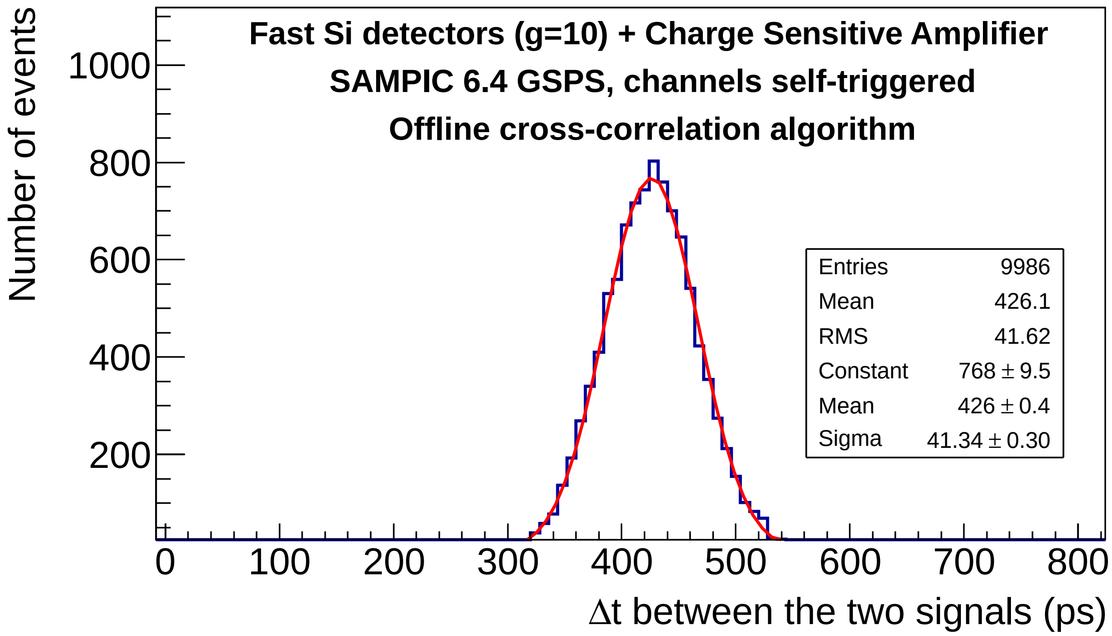
Timing detectors for 2017

- Timing detectors: quartz bars (QUARTIC), Su or diamond detectors
- Development of a fast timing chip, SAMPIC (Saclay):
  - Uses waveform sampling method
  - Sub 10 ps timing, 1GHz input bandwidth, low dead time for targeted data taking; Serial readout at 2 Gbit/s
  - 10 bit Wilkinson on chip for analog to digital conversion; Wilkinson diitisation at 2 Gsamples/s
  - Low cost: 10 $ per channel
- Chip being tested in stand-alone mode, with laser (Si detectors), beam tests

ΔT measurements, only pedestal corrected

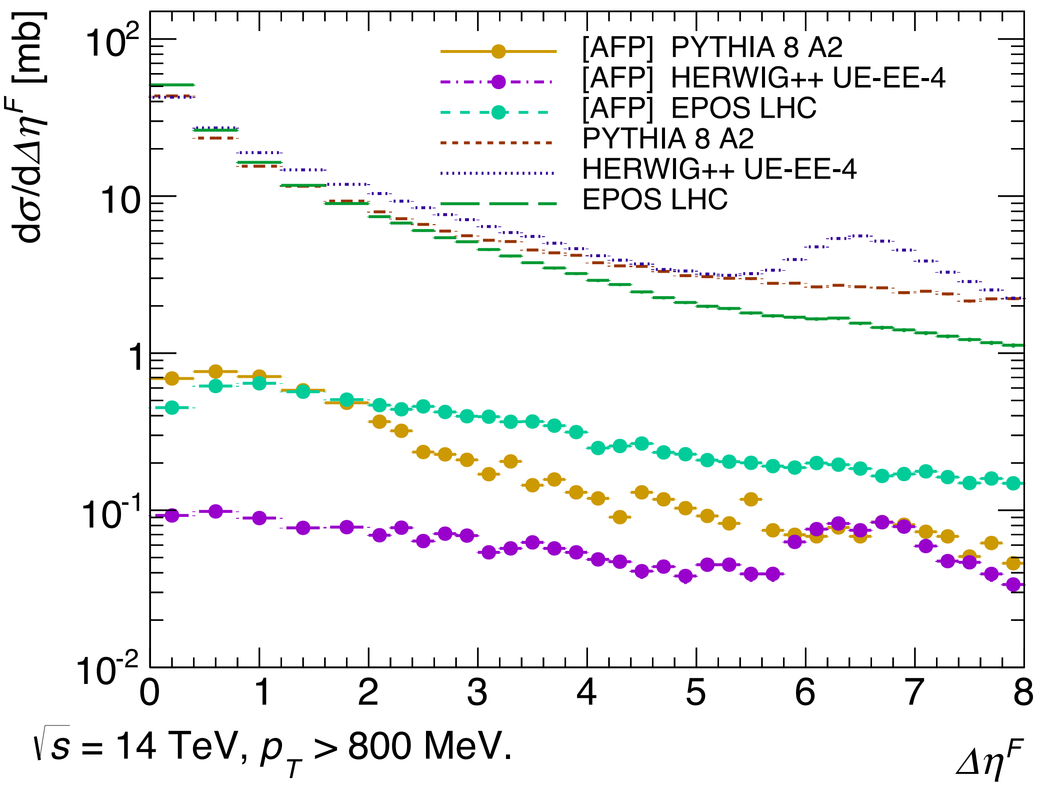
- SAMPIC intrinsic resolution: ∼3-4 ps
- Tests with Si detector and laser: ∼ ∼30 ps
- Common R&D and tests between CMS/TOTEM and ATLAS/AFP



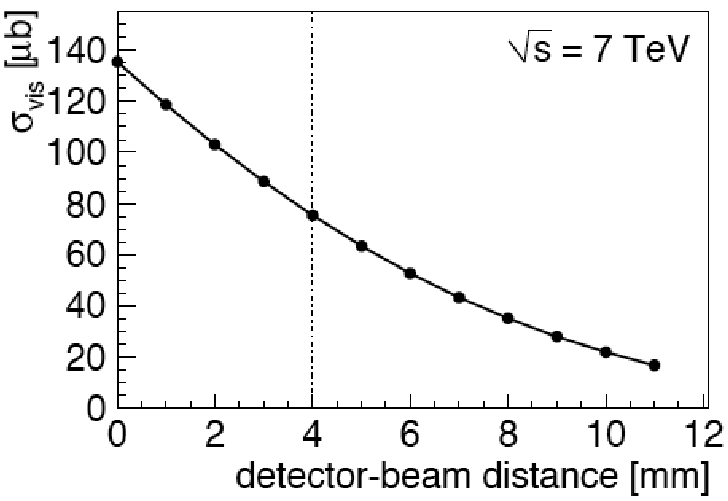


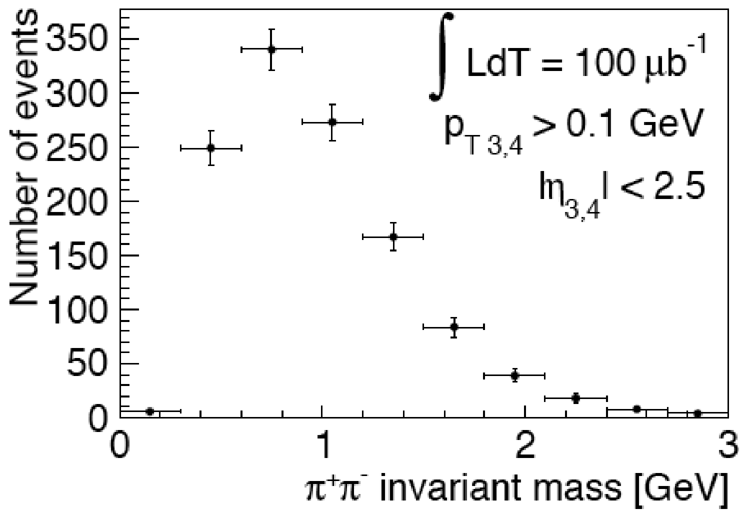
Very low lumi I: Forward gap in soft diffraction

- Important for understanding underlying events, soft QCD: MC tuning, almost all MC designed for hard processes and new physics have difficulties with incorporating diffraction, and need improvement. Measurements of diffraction (rapidity gaps) are vital for testing MC
- Measure size of forward gap in diffractive events
- Measurement important to tune models (hadronisation...) and for cosmic ray physics
- Larger differences between models when proton is tagged in AFP/ALFA or CMS/TOTEM
- Measurement can be performed in ∼1 day without pile up



Very low lumi II: $\pi\pi$ exclusive production

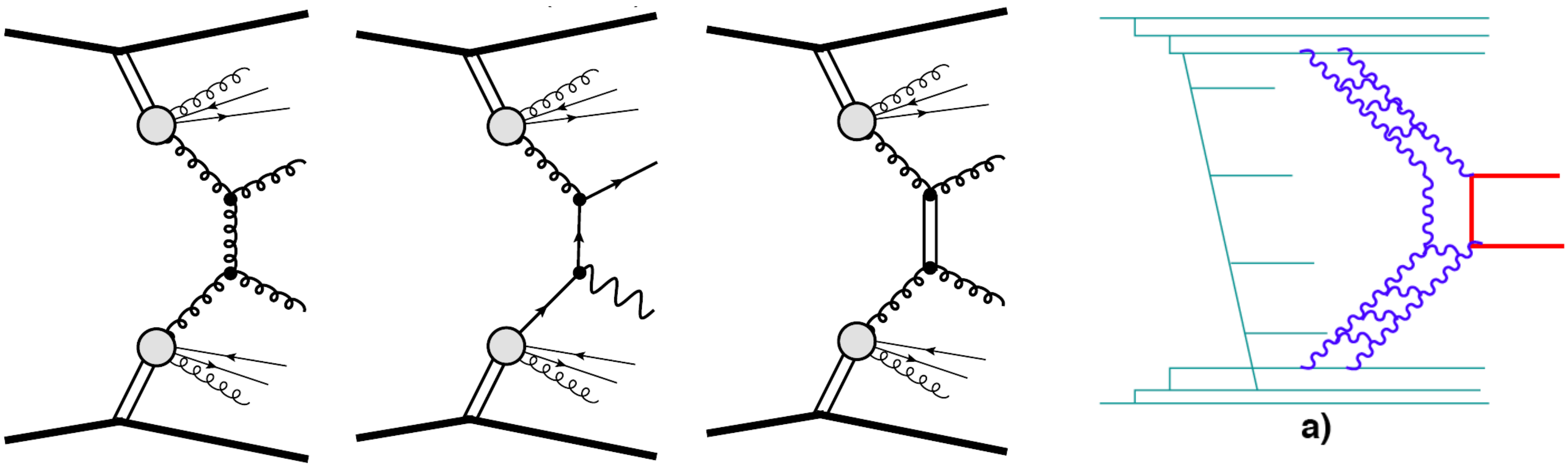




- Measurement of the exclusive $pp \rightarrow p\pi\pi p$ cross section at the LHC at high β^*; protons tagged in CMS-TOTEM or ATLAS-ALFA
- Interesting measurement to compare with QCD low mass models, and it is also a background for f_2, charmonium, glueball production
- Measurement being performed in ALFA at 8 TeV but would benefit from higher collected luminosity in 2015 at high β^*: couple of days at very low pile up

low-Medium Luminosity I: Hard diffraction at the LHC

- Intact protons assumed to be tagged in CMS/TOTEM or AFP/ALFA
- Constrain the structure of the colorless exchanged object, the Pomeron, and probe evolution equation of QCD
- Dijet production: dominated by gg exchanges
- γ+jet production: dominated by qg exchanges
- Jet gap jet in diffraction: Probe BFKL
- Three aims
  - Is it the same object which explains diffraction in pp and ep?
  - Further constraints on the structure of the Pomeron as was determined at HERA
  - Survival probability: difficult to compute theoretically, needs to be measured, inclusive diffraction is optimal place for measurement



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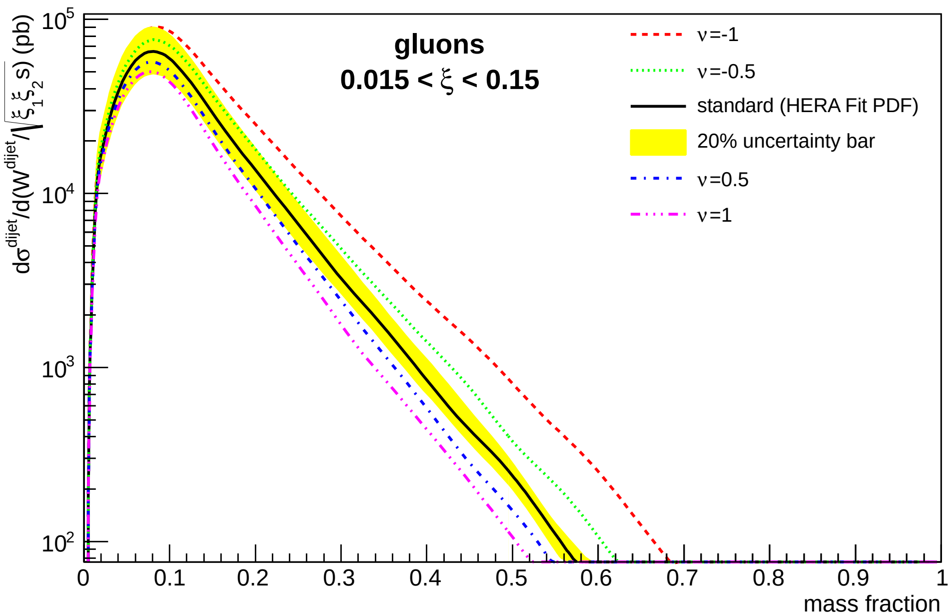
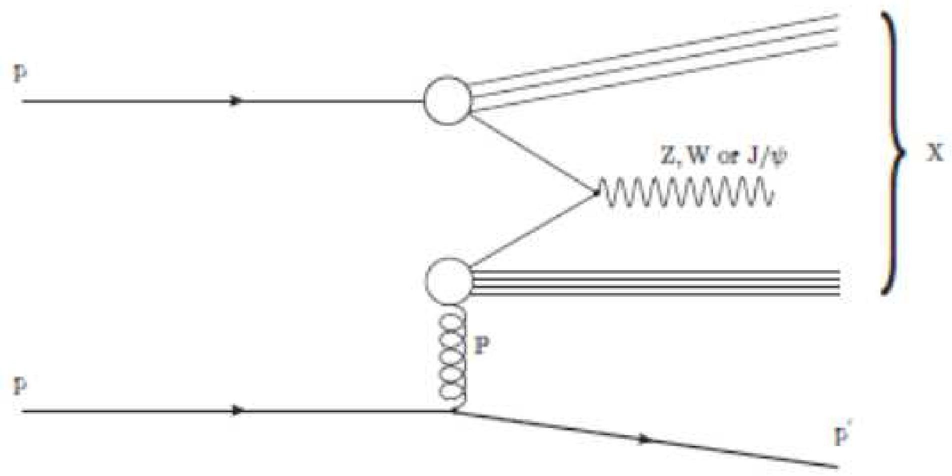
Low-Medium Luminosity II: Hard diffraction at the LHC with proton tagging: sensitivity to gluon density

- DPE dijet cross section at the LHC in ALFA-AFP/CMS-TOTEM
- Sensitivity to gluon density in Pomeron: in order to illustrate this and show the sensitivity on high β gluon density, multiply the gluon density by $(1-\beta)^{\nu}$ with $\nu = -1, ..., 1$
- Measurements possible at low and high β^*, allows to test if gluon density is similar between HERA and LHC (universality of Pomeron)
- Measurement of dijet mass fraction specially interesting M_{JJ}/M_{tot} where $M_{tot} = \sqrt{S \xi_1 \xi_2}$, $\xi_{1,2}$ being the proton momentum carried out by the Pomeron, measured by AFP-ALFA/CMS-TOTEM ($\sim$5 pb^{-1} needed)
- Possibility to constrain the quark content in the Pomeron using $\gamma+$ jet events



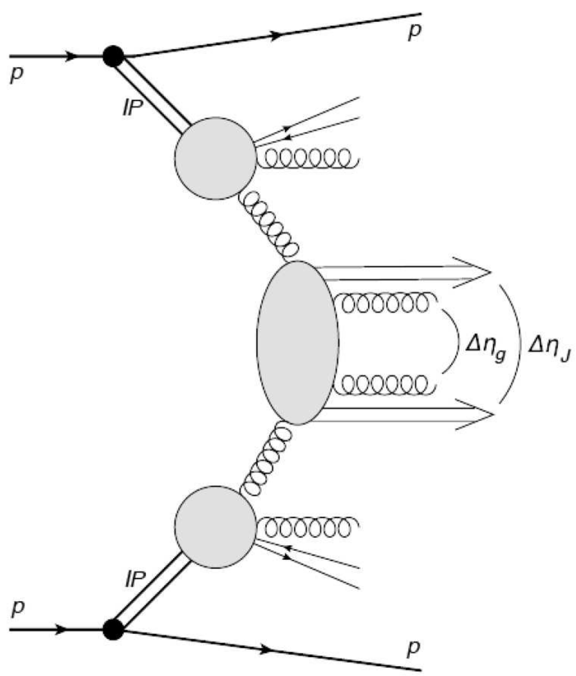
Low-Medium Luminosity III: Single diffraction with proton tagging at high β^*

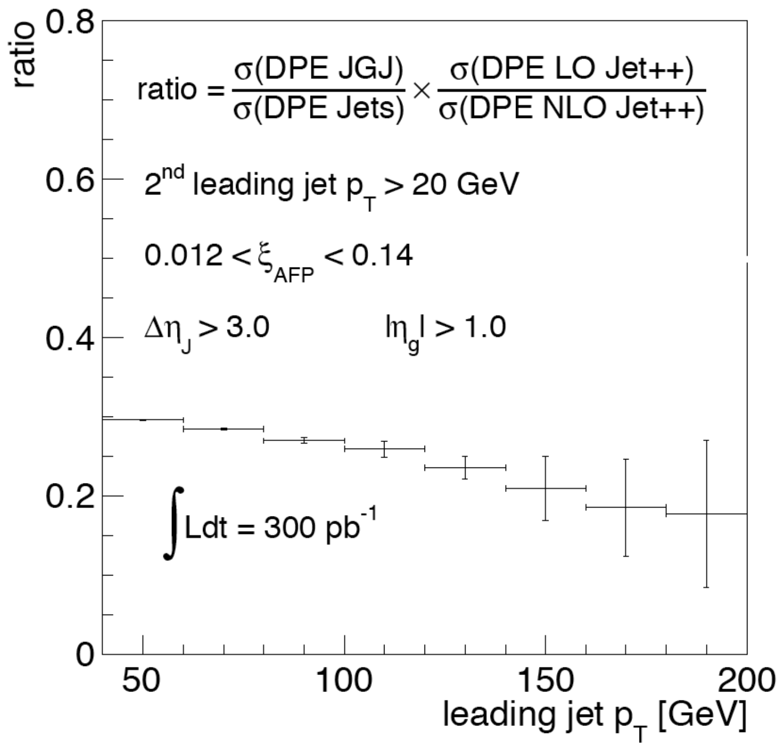
- Run at high β^* (no ξ cut) in CMS-TOTEM/ATLAS-ALFA
- Study different single diffractive processes with low pile up
  - J/Ψ production: Two muons with opposite charge, $3.05 < M_{\mu\mu} < 3.15$ GeV, 3080$\pm$90 for 10 pb^{-1}
  - W production: leading lepton p_T >20 GeV, $60 < M_T < 110$, about 340$\pm$10 events for 10 pb^{-1}
  - Z production: same cuts, 30$\pm$1 events for 10 pb^{-1}
- SD jet production...
- Needs both proton tagging and central detector (precise tracking)



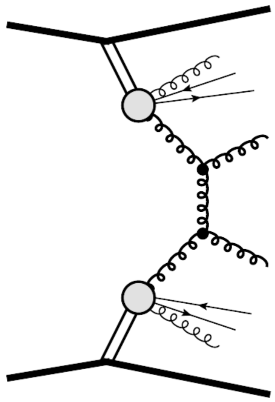
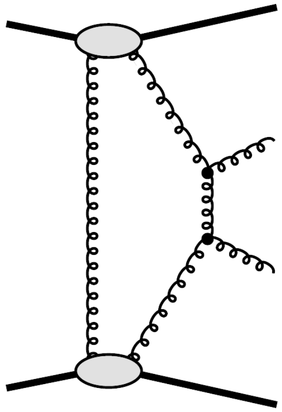
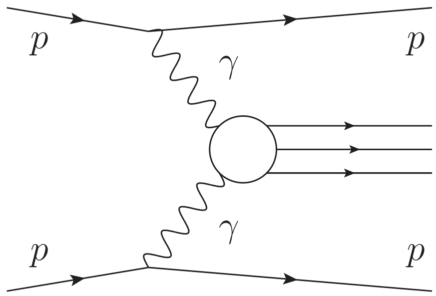
Medium Lumi IV: Jet gap jet events in diffraction with proton tagging

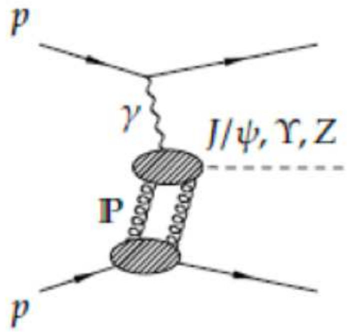
- BFKL (Balitsky Fadin Kuraev Lipatov) allows for QCD prediction (valid at short distances, hard perturbaitive region) for final states with rapidity gaps
- Needs special tests to get clean signals (jet-gap-jet, Mueller Navelet)
- Interest in BFKL also for more fundamental questions, e.g. connection with gravity
- Study BFKL dynamics using jet gap jet events
- Measure the ratio of the jet gap jet to the dijet cross sections: sensitivity to BFKL dynamics (advantage of CASTOR in CMS)





Exclusive diffraction with tagged protons

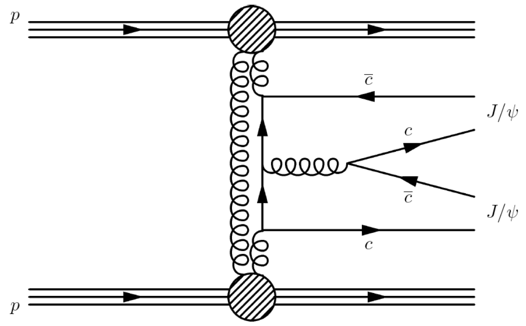




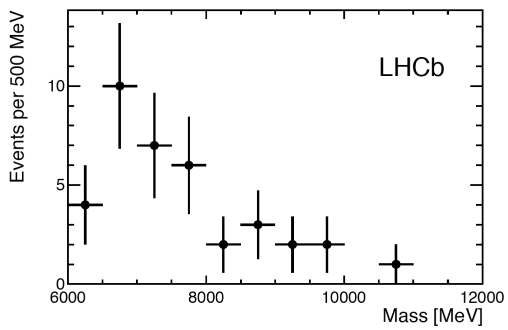


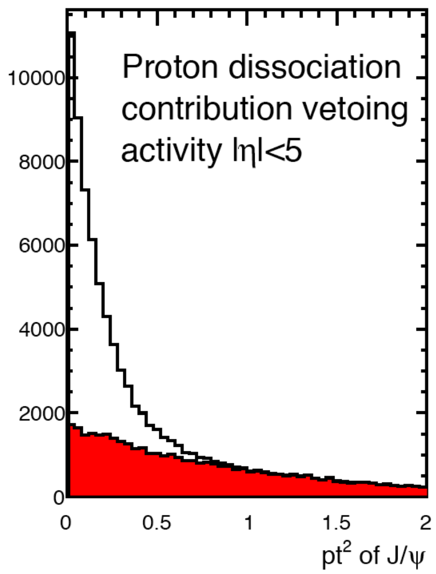
- Many exclusive channels can be studied at medium and high luminosity: jets, χ_C, charmonium, J/Ψ....
- Requires both proton tagging (background control) and measurement inside central detector (using precise tracking for vector mesons as an example)
- Possibility to reconstruct the properties of the 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
- Central exclusive production is a potential channel for BSM physics: sensitivity to high masses up to 1.8 TeV (masses above 400 GeV, depending how close one can go to the beam)

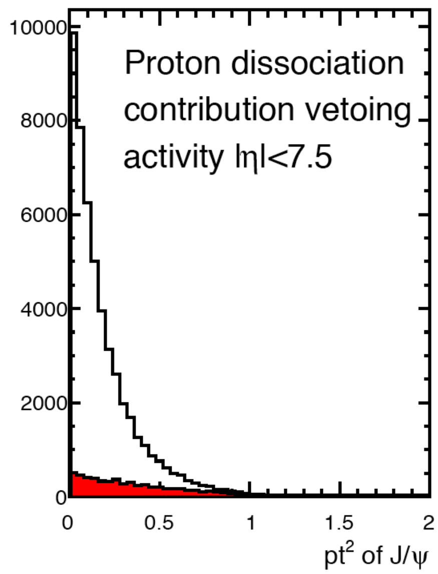
Low-Medium Lumi V: Exclusive vector mesons - LHCb

- Measurement of vector mesons: very clean sample, example of LHCb, no proton tagging (charmonium with 3 fb^{-1})
- Measurement performed in parallel with theory developments
- Herschel: Scintillators being installed in LHCb in order to get a better control of non exclusive background (some scintillators in the forward region already installed in CMS as well as CASTOR)
- Such channels are sensitive to new physics: if one has a medium mass resonance, (glueball or tetraquark state or exotic), it could lead to a bump in such a spectrum



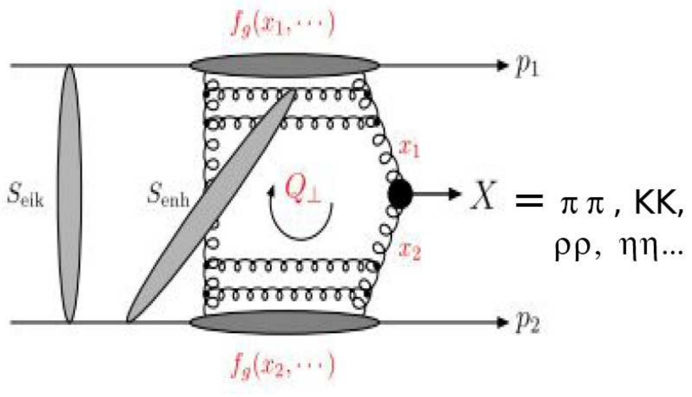


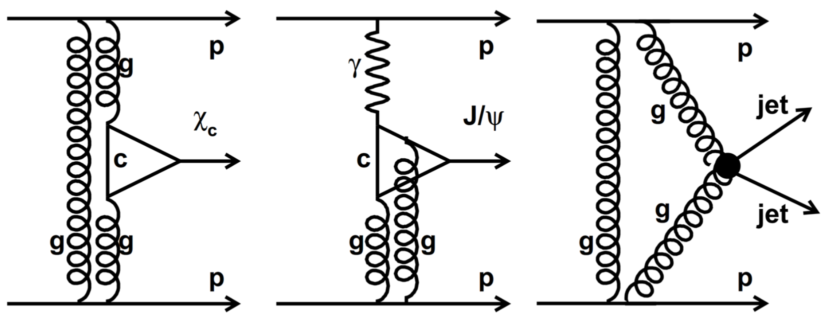




Low-Medium Lumi VI: Exclusive state measurements

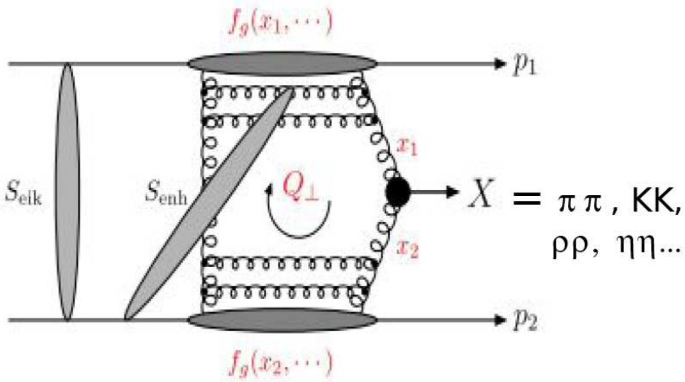
- Many exclusive states can be measured in high β^* runs in CMS/TOTEM-ALFA/AFP, and in standard runs in LHCb
- ALFA and CMS/TOTEM ($\beta^* \sim 90$m): sensitivity to low mass exclusive production (CT-PPS and AFP acceptance starts at ∼300 GeV)
- CMS/TOTEM-ALFA/AFP: Detect both protons, information from central detector, particle Id (pions, kaons with tracker), timing detectors
- Search for glueball states and probing low x gluon down to $x \sim 10^{-4}$
- With 1 pb^{-1}: confirmation of unobserved possible $f_0(1710)$ and $f_0(1500)$ decay modes and first cross-section $\times$ branching ratio estimates for f-states
- With 5-10 pb^{-1}: cross-section $\times$ branching ratio estimates for all three $\chi_{C,0,1,2}$ states, comparison with perturbative QCD
- Low mass exclusive dijet production: M_X >60 GeV, cross section of $\sim$ 100 pb
- Complementarity between LHCb and ATLAS-CMS/TOTEM results!

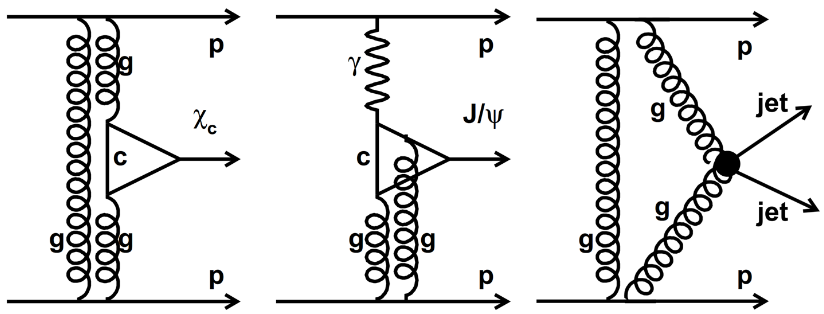




Low-Medium Lumi VII: Glueball?

- LHC (CMS/TOTEM-ATLAS/ALFA) has now the possibility to discover/exclude glueballs at low masses
- 1-10 GeV masses can be probed diffractively ($\xi \sim 10^{-4} - 10^{-3}$), ensuring pure gluonic exchanges
- About 5-10 pb^{-1} needed: 1 week of data taking
- Complementarity between forward proton and central detectors: ATLAS/CMS can reconstruct masses of 4 charged particles in the tracker with a resolution of 20-30 MeV (observing for instance $f_0(1710) \rightarrow \rho\rho$)
- Check the $f_0(1500)$ or $f_0(1710)$ glueball candidates (in excess of the meson SU(3) multiplet and resonances compatible with glueball in terns of mass, spin, parity, decay channels)
- Lattice calculations predict a $0++$ glueball at 1.7 GeV with a ∼100 MeV uncertainty, favoring the $f_0(1710)$ candidate





Conclusion: Running conditions 2015-2016 and beyond

- 2015:
  - No pile up, multiplicity and energy flow measurement in the very forward region: LHCf data in spring
  - High β^*, no pile up: total cross section, elastic... (TOTEM, ATLAS/ALFA)
  - High β^*, very low pile up (μ=0.1): 5 to 10 pb^{-1} (ATLAS/ALFA, CMS-TOTEM): low mass diffraction
- 2016:
  - High β^*, no pile up: total cross section.(TOTEM, ATLAS/ALFA)
  - High β^*, low pile up (μ =1), 10 to 100 pb^{-1} (ATLAS/ALFA, CMS-TOTEM), requires timing detector with moderate resolution (50 ps or so): low mass diffraction
- 2017 and beyond: Low β^* and low pile up (CT-PPS, ATLAS/AFP), understanding for high luminosity running: high mass diffraction and exploratory physics, : to be rediscussed when more experience with forward detectors obtained, background constraints
- LHCb and ALICE interested in taking data in injection β^* during those runs (low luminosity, calibration...
- ATLAS (like CMS-TOTEM) is now investigating the physics reach of one week of data taking at $\beta^* \sim$90 m in 2015 with 5 to 10 pb^{-1} of data