ATLAS Forward Proton (AFP) project

status

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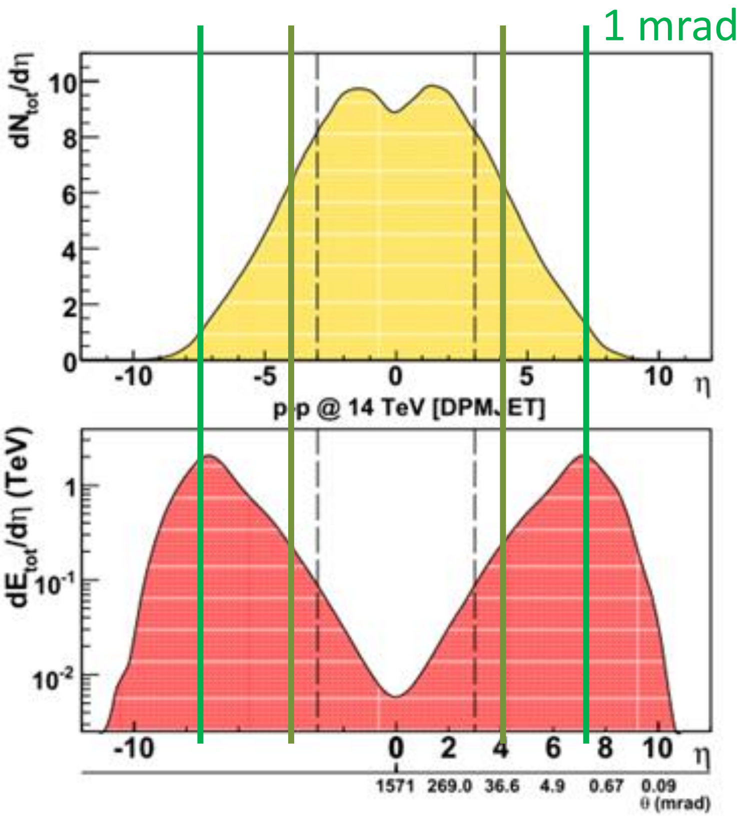
on behalf of the ATLAS Forward Proton group

forward physics

at proton colliders like the Large Hadron Collider (LHC) at CERN, Geneva, protons typically interact inelastically, i.e. as collisions between the proton's constituent quarks and gluons

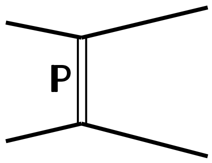
many of the proton remnants go down the beam pipe at small angles (mrad)



forward physics

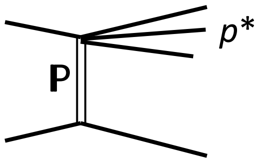
however, in a fraction of p-p collisions, one or both protons stay intact:

- **elastic scattering** (~ 25% of σ total):
  - single pomeron ($\mathbb{P}$) exchange
  - appreciable only at very small (μrad) angles

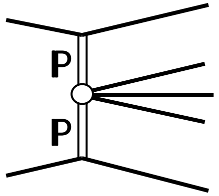


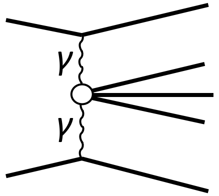
$\mathbb{P}$:= pomeron; a color-less object with *Q*-numbers of the vacuum; a “gluon ladder”

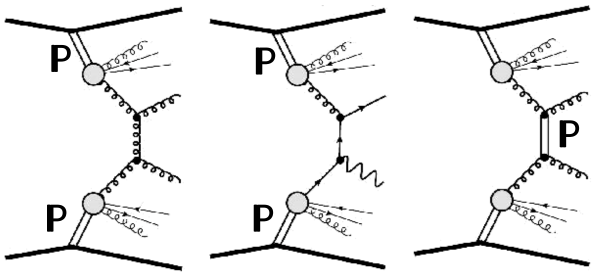
- **diffraction** (~ 20% of σ total):
  - soft, non-perturbative QCD processes



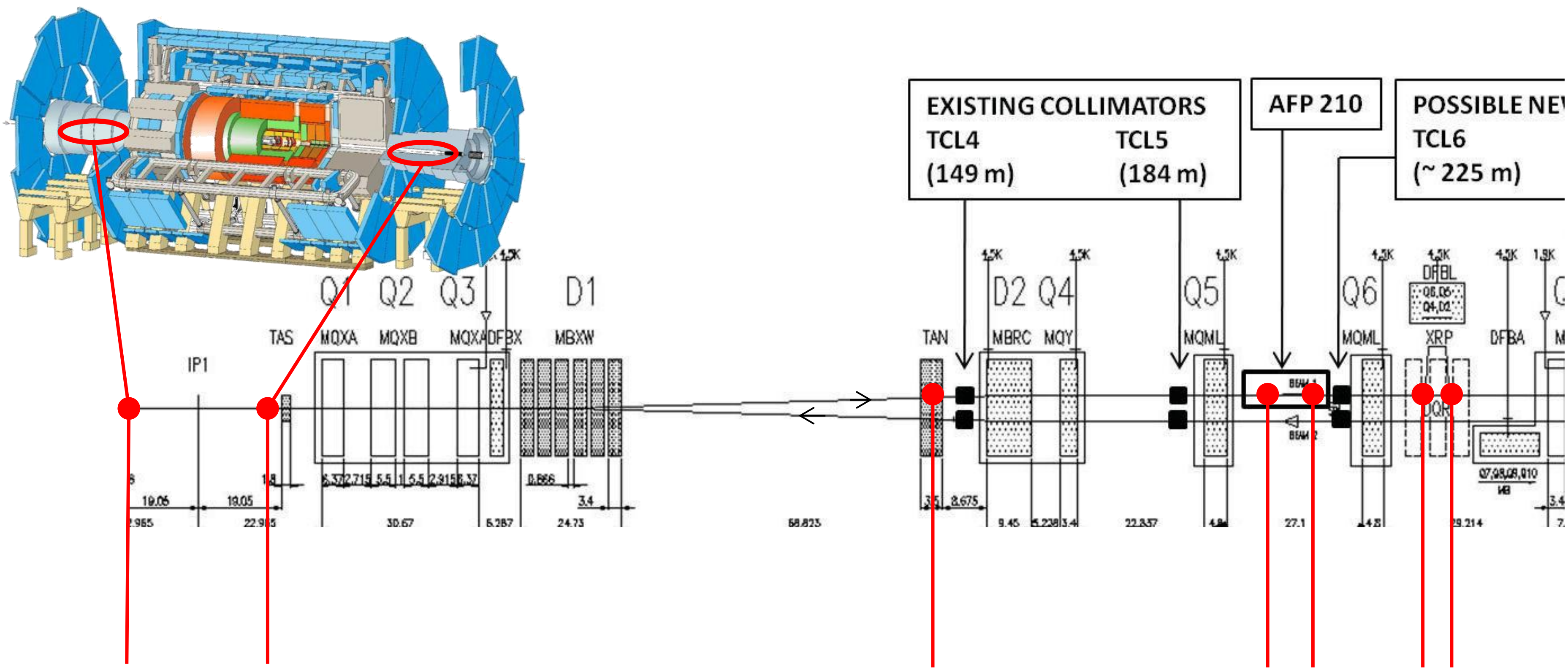
- **hard central diffraction** (<<1%):
  - double pomeron and double photon exchange
  - accessible to QCD (and QED) predictions
  - measure the structure of pomeron
  - must measure proton energy loss ξ & angle(s)







ATLAS Forward Detectors project



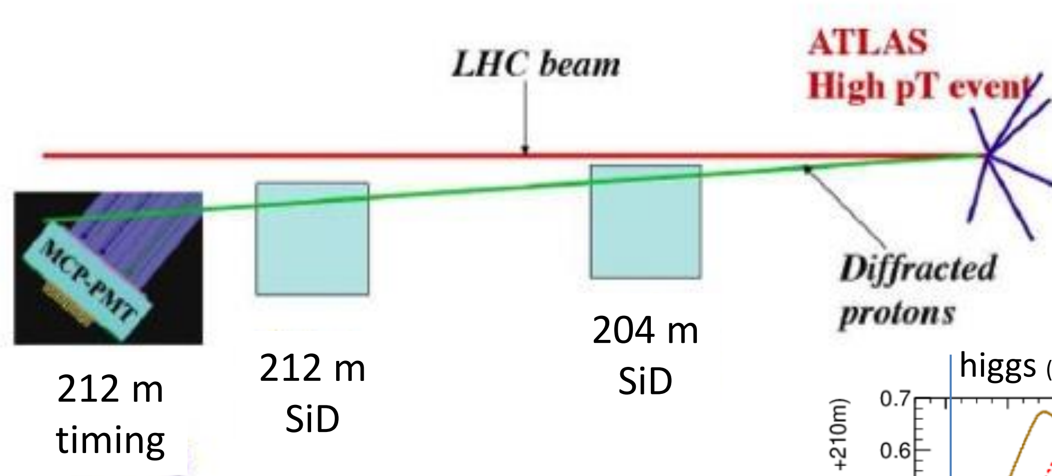
LUCID
~17m
proton remnants and low
p_T particles

ZDC
140m
proton / ion remnants: γ, π^0, n

AFP
202m-212m
diffractive
protons

ALFA
237m-241m
elastic
protons

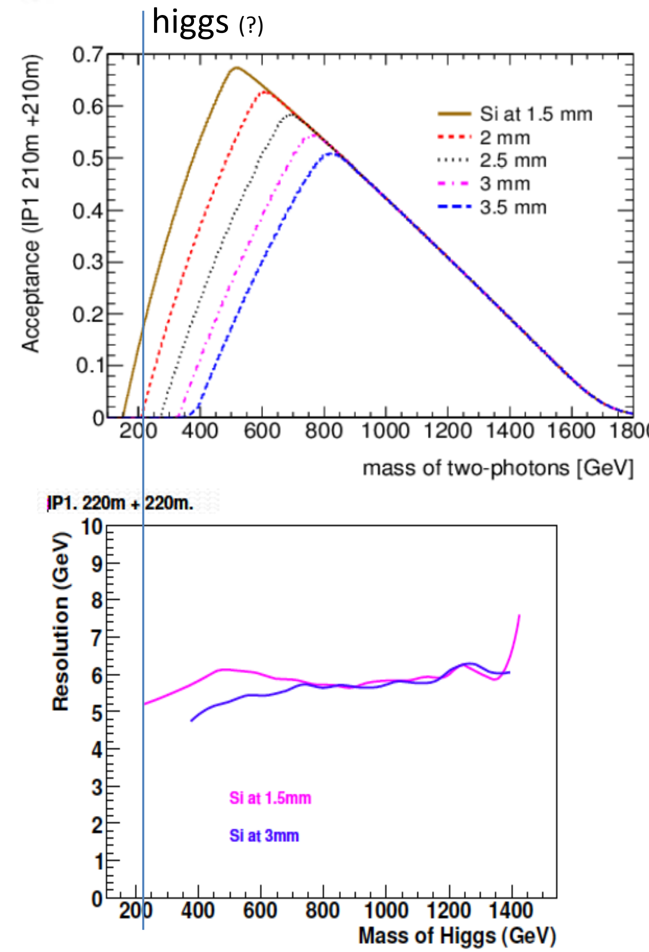
AFP



- purpose:
  tag and measure diffractive protons at ~ 210 m (two arms)

- precision **mass spectrometer**,
  in case of exclusive production $M = \sqrt{\xi_1 \xi_2 s}$

- detectors
  - radiation hard "edgeless" 3d Silicon detectors with ~ μrad angular resolution for proton tracks reconstruction
  - high performing timing detectors



AFP – key ingredients

- **optics & background** (see Samah's talk about ALFA)
- **movable** devices – getting really close to the beam…
- **slim-edged** detector – 3d SiD
- **fast timing** detector – TiD
- **integration** - DCS, DQA, … (not covered)
- and all this for… understanding of **physics**

optics & background

several items:

alignment, calibration, background, acceptance

belong here, but absolutely critical is

time for understanding of beam conditions/optics

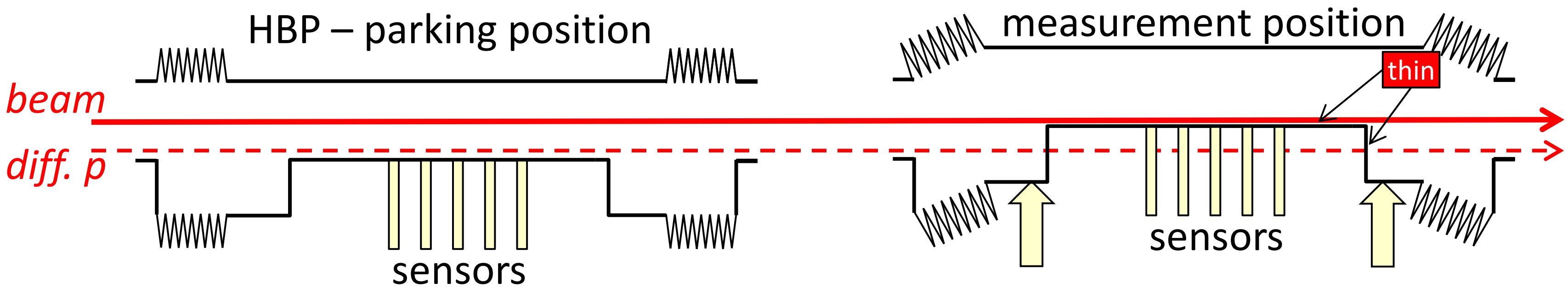
background sources:

1. IP: single diffraction pile-up
2. secondary interactions in upstream beam elements
3. beam halo

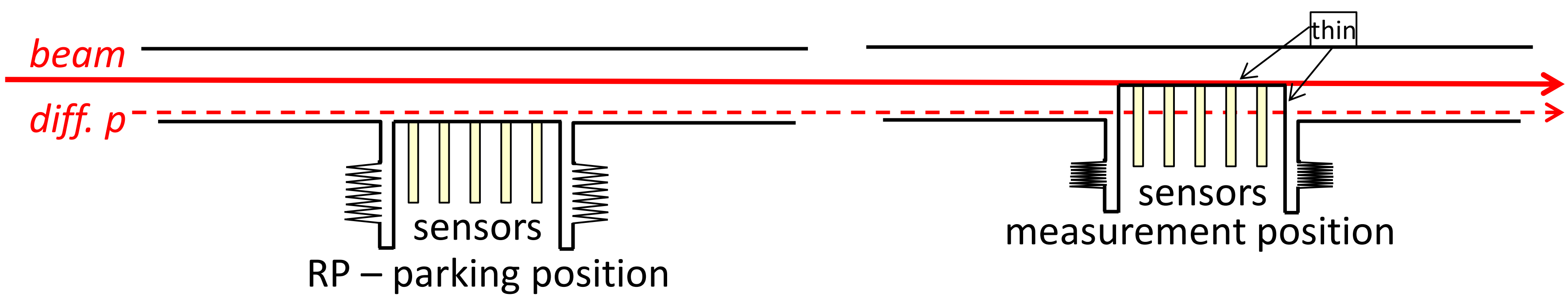
– we are analyzing ALFA run at $\beta^* = 0.55$ m
– we are simulating the high-μ environment with $\beta^* = 0.55$ m optics

getting really close to the beam …

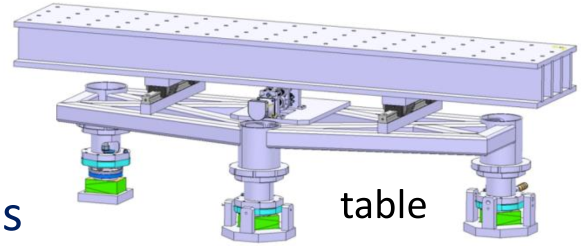
- **Hamburg Beam Pipe**: movable section of beam pipe with thin window facing the beam (“floor”) and entry/exit windows:



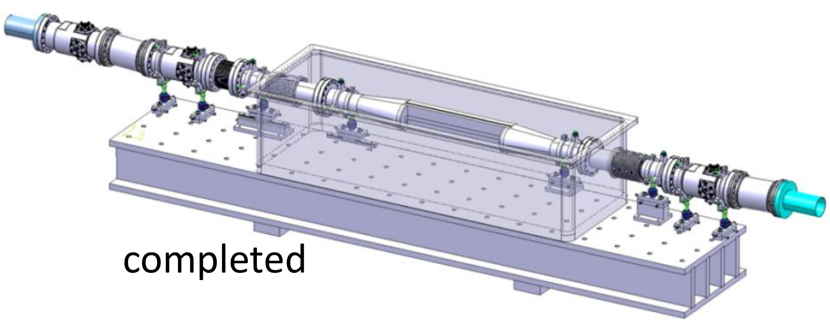
- **Roman Pot**: movable UHV insert entering the beam aperture with thin “floor” and entry/exit windows:

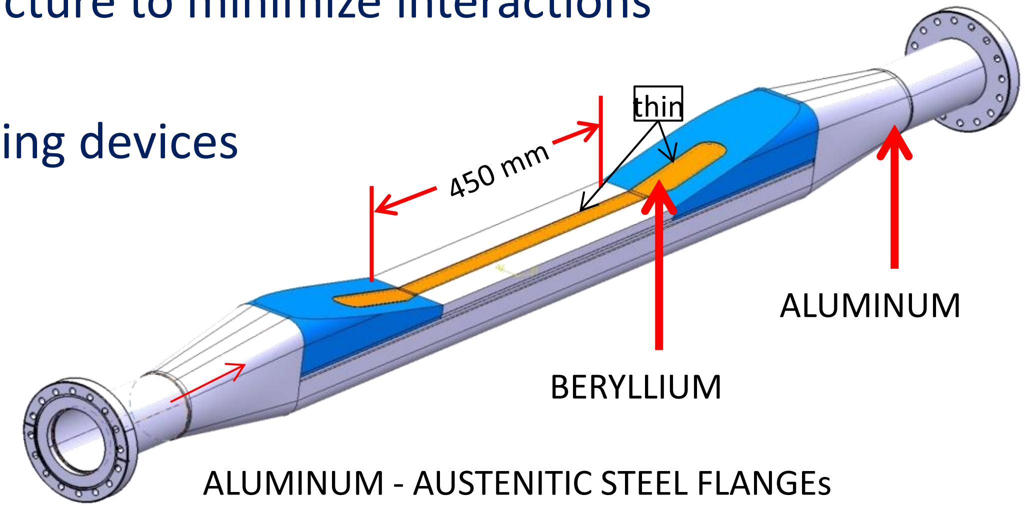


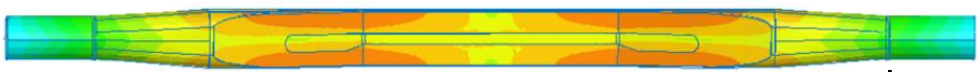
AFP Hamburg Beam Pipe (HBP) solution



- tilted windows (11°) minimize beam coupling and losses
- Be windows and floor, and Al structure to minimize interactions and multiple scattering
- ample space for tracking and timing devices







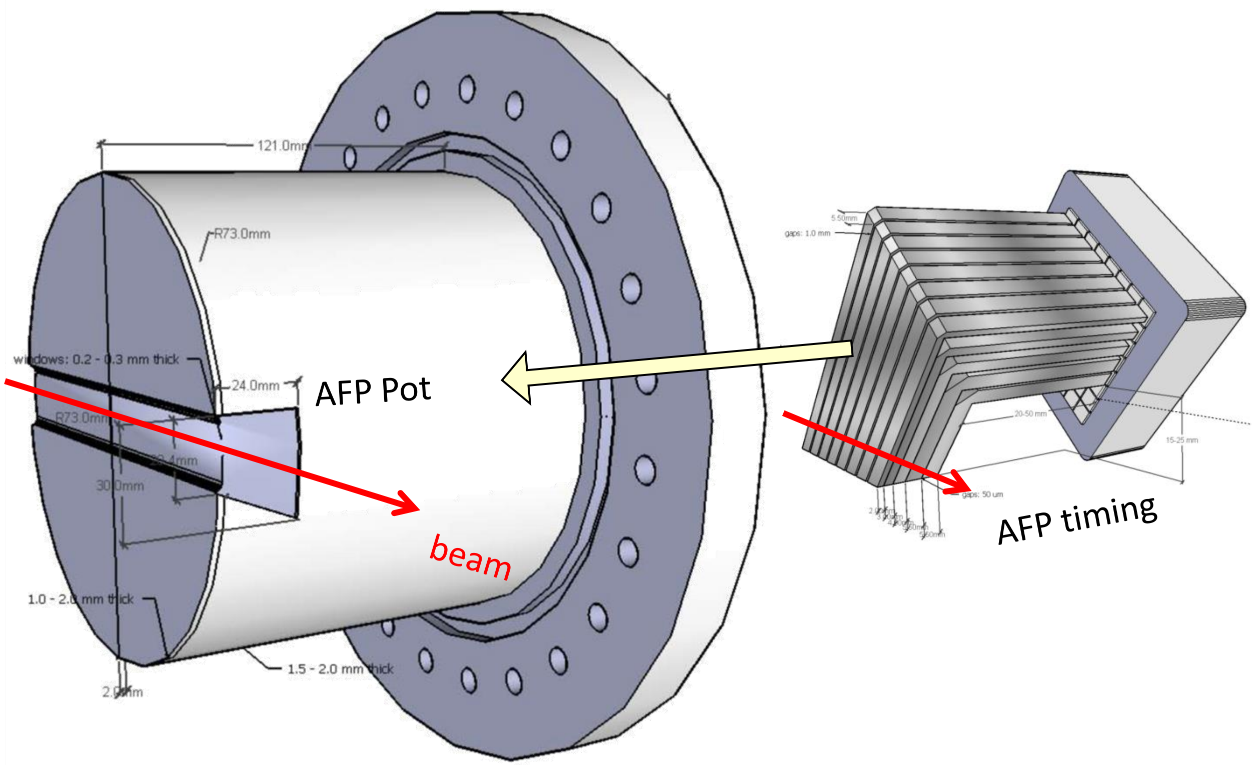
results of detailed RF simulations:

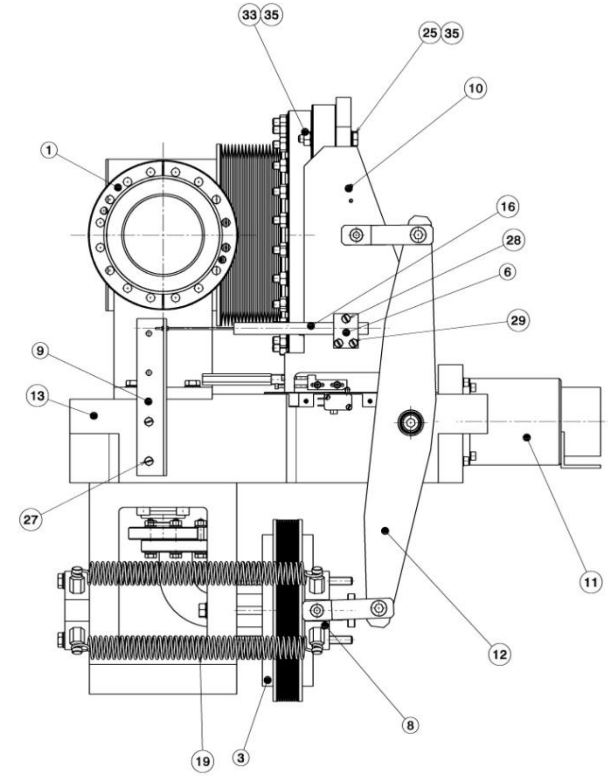
- impedance Z_{long} is at the level of 0.5%/station at 1 mm from the beam ☺
- similar for Z_{trans} ☺
- power loss (heating) is manageable ~ 30 W, mostly in conical sections
- bellows are not yet included, but we are confident we can minimize their effect

AFP Roman Pot & station solution

AFP Pot adaptation from TOTEM design

– shown with a possible timing detector





TOTEM horizontal RP station (beam view)

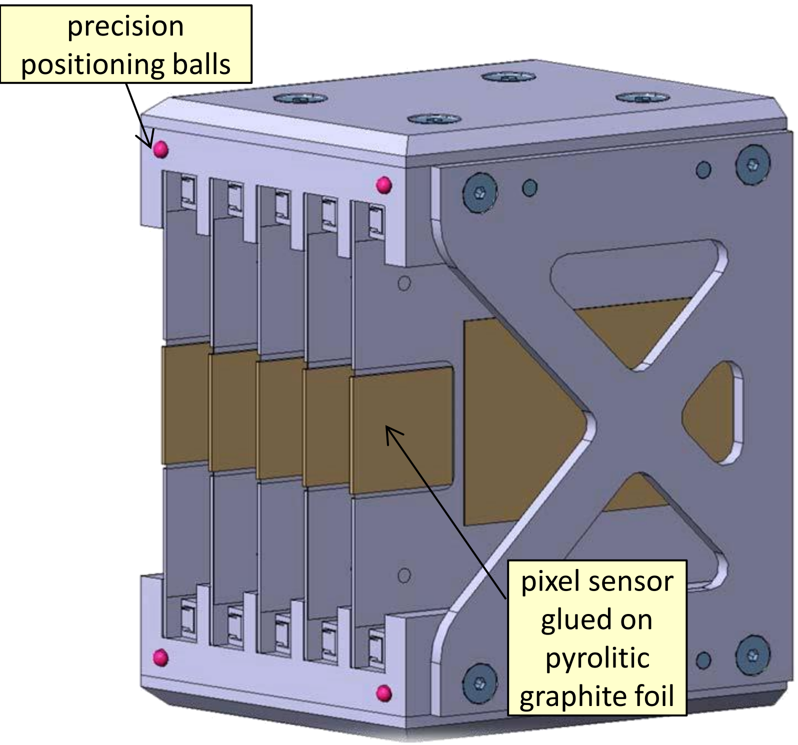
copy RP station design of ALFA & TOTEM:

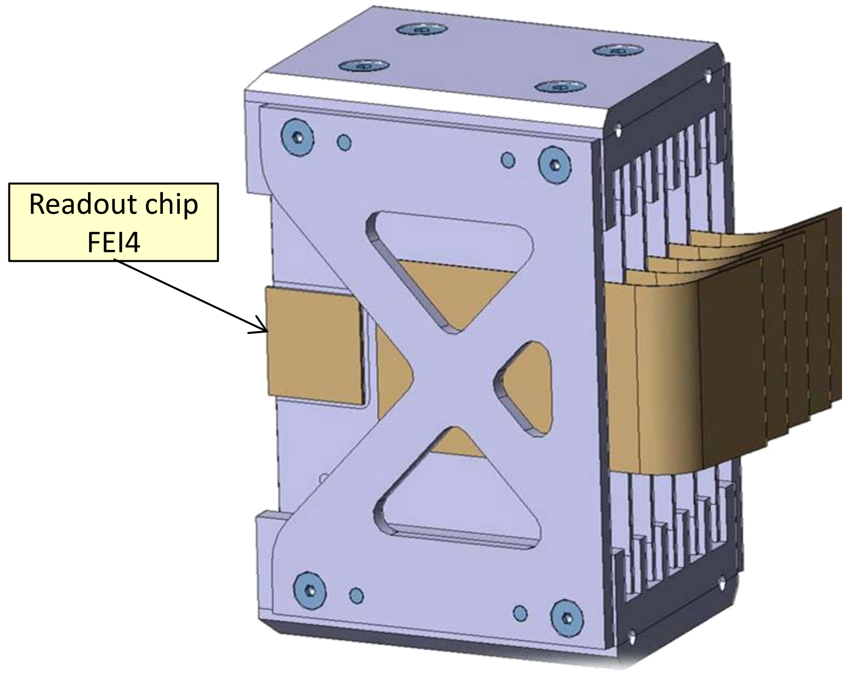
– ample operational experience
– known cost and construction & installation procedures

edgeless tracking detector – 3d SiD

AFP will use ATLAS IBL pixel sensors bonded with FE-I4 readout chips

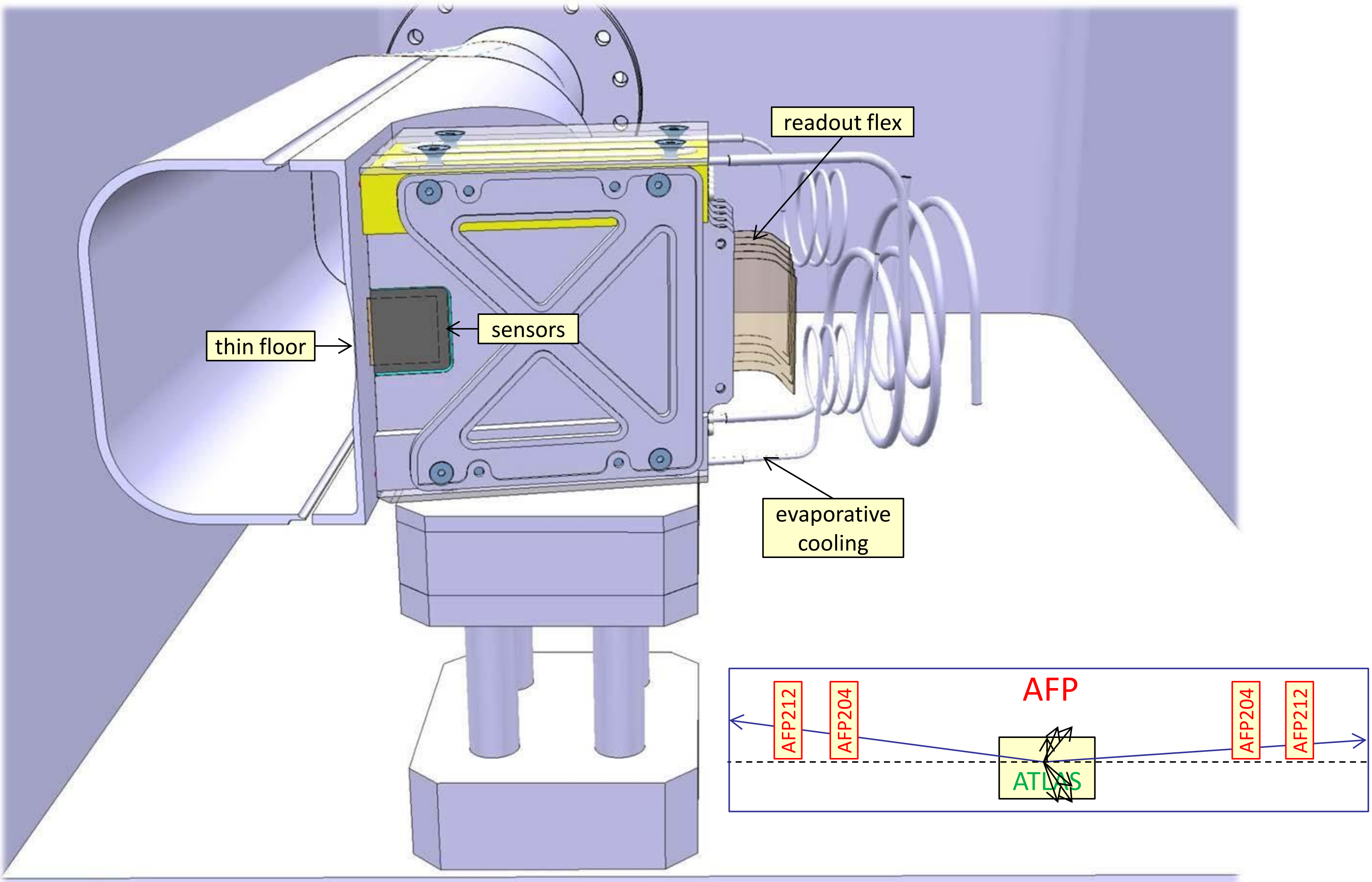
- 50 µm × 250 µm pixels size, rotated by ~ 13°, eliminating the inefficiency due to electrodes
- future: edgeless (2-10 µm dead edge w.r.t. actual 100 µm) 3d pixel sensors -> closer to beam





AFP Detector R&D: P. Sicho et al.

AFP – HBP plus tracker (SiD)

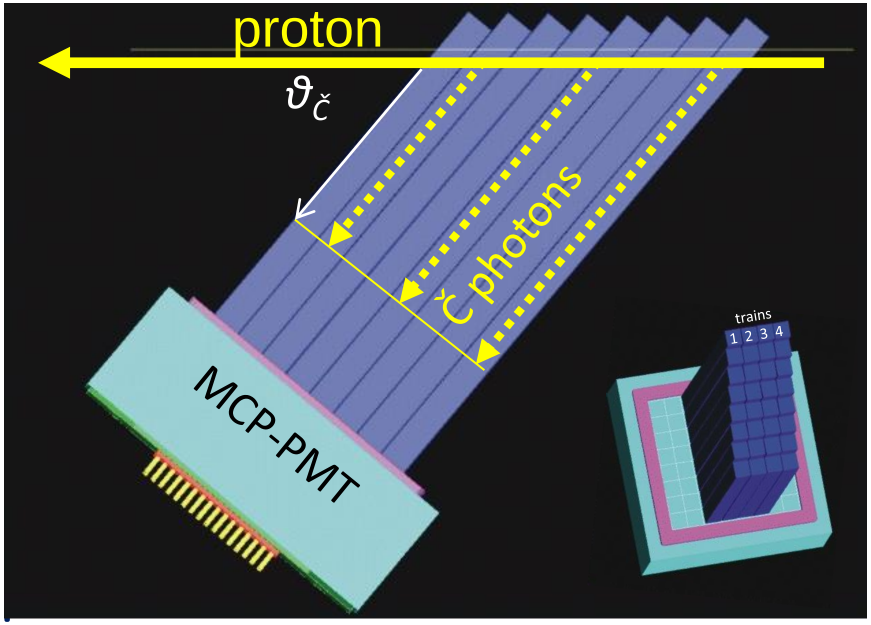


AFP fast Time-of-Flight (fToF)

QUARTIC concept: M. Albrow for FP420 (joint ATLAS / CMS effort) (2004)

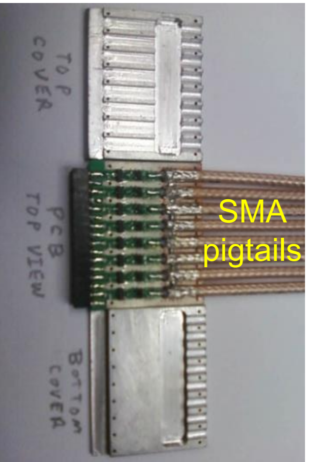
based on Nagoya Detector

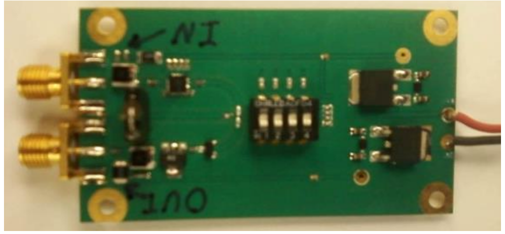
- initial design:
  4 trains of 8 Q bars: 6mm × 6mm ×100mm
- mounted at Cherenkov angle $\theta_{\check{C}} \simeq 48°$
- isochronous – Cherenkov light reaches tube at ~ same time for each bar in a train
- arrival time of proton is multiply measured: bar + readout resolution less stringent!
  - e.g. 30 ps / bar -> 11 ps for train of 8 bars



2011 DOE Advanced Detector research award for electronics development:

8-Channel Preamplifier (PA-a)





PA-b Programmable Gain Amp

CFD Daughter Board

HPTDC Board

Detector & PMT R&D: U Texas at Arlington (A. Brandt et al.);
Electronics R&D: Stony Brook (M. Rijssenbeek et al.)

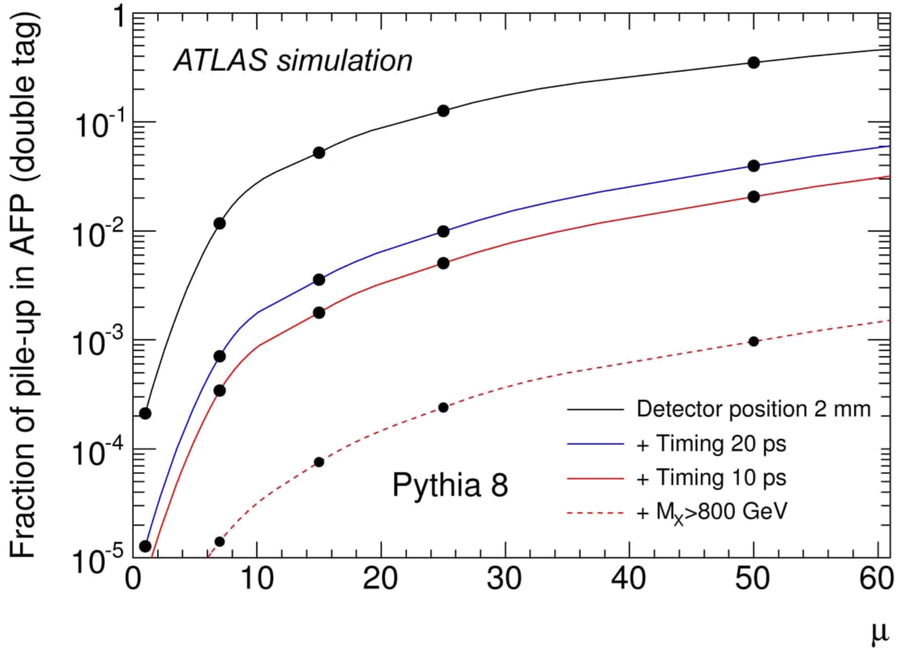
fToF

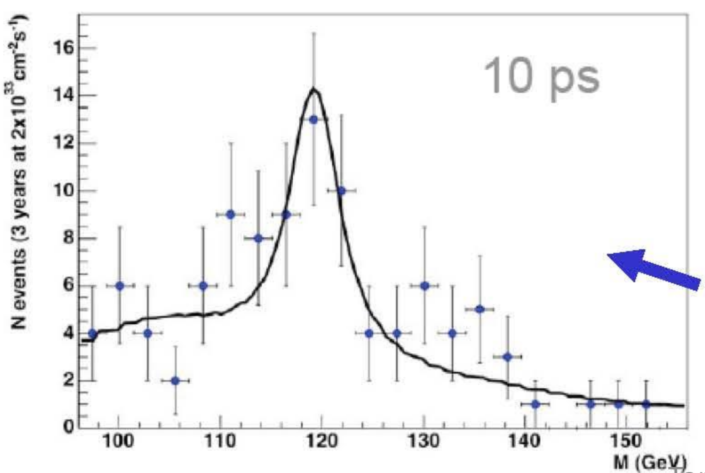
main CEP background: overlap of SD protons with non-diffractive events

= “pile-up” background

can be reduced by:

- central mass matching:
  - $M_{central} = M_{AFP} = (s\,\xi_{Left}\,\xi_{Right})^{1/2}$
- ToF:
  - $z_{vtx} = c(t_{Left} - t_{Right})/2$
  - e.g.: $\sigma_t = 10$ ps -> $\sigma_{zvtx} = 2.1$ mm
- invented for/by FP420:





JHEP 0710:090,2007

Mhmax scenario, 420+420

m_A=120 GeV, tanβ=40

$\sigma_{h \to bb}$=17.9 fb

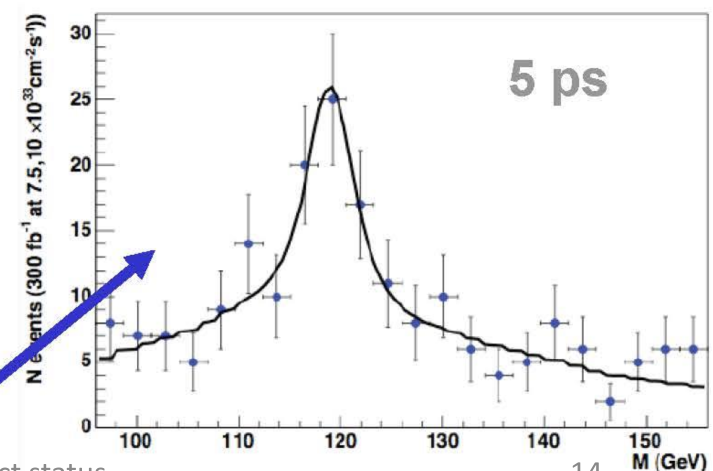
60 fb^{-1} at 2x10^{33}cm^{-2}s^{-1}

(significance=3.5σ)

150 fb^{-1} at 7.5x10^{33}cm^{-2}s^{-1}

plus 150 fb^{-1} at 10^{34} cm^{-2}s^{-1}

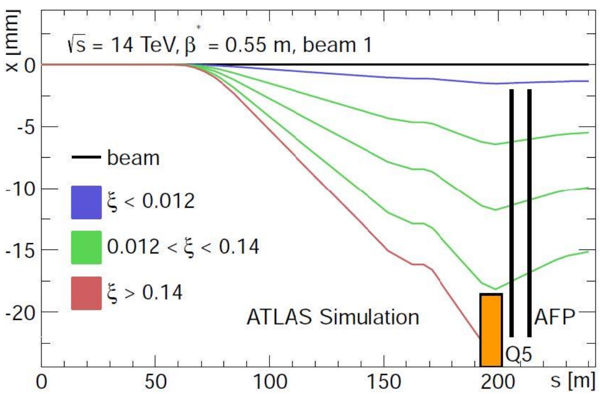
(significance=4.5σ)



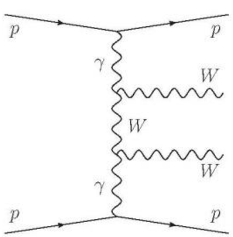
diffractive protons in AFP

number of protons per 100 fb^{-1} (~1 LHC yr) per Si pixel (50 µm × 250 µm):

– proton energy loss ξ is related to x:

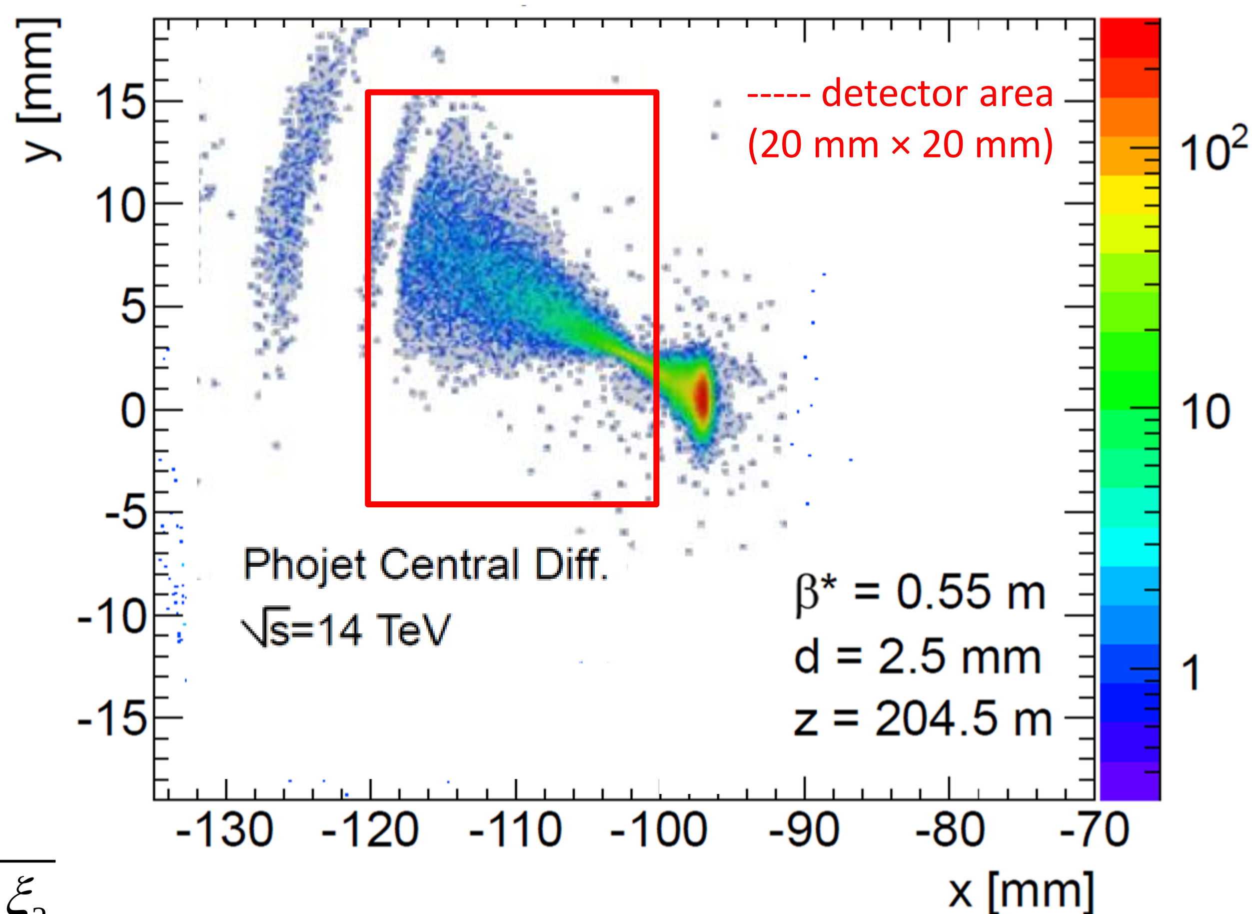


– central mass M is related to both protons' energy losses ξ_1, ξ_2:



$$M_{\mathrm{AFP}} = 2\, p_{beam} \sqrt{\xi_1 \xi_2}$$

e.g. $\xi = 0.01 \;\Rightarrow\; M = 160$ GeV



AFP program based on luminosity (see Olda's & Christophe talks)

1) low luminosities

- < 1 pb^{-1}– 10 pb^{-1}, $\mu < 0.5$ (reduction of background from pile-up)
- soft diffraction, pA runs, SD (dijets/W/..) – particle production, etc.

2) medium luminosities

- hundreds of pb^{-1}, $\mu = 0.5$
- hard diffraction DPE, pomeron structure – double tag-timing needed

3) high luminosity

- hundreds of fb^{-1}, μ = 50-100
- exclusive production, anomalous quartic coupling $\gamma\gamma WW$,
  detailed study of electroweak symmetry breaking, exclusive DPE jets
  (increase of temporal and spacial granularity of TiD improves efficiency and rejection)

AFP major physics interests

from **Progress Report of the AFP detector**

- The existence of rapidity gaps within the event is a hallmark of diffractive processes, and has long been of theoretical interest. By tagging the events with the scattered proton, we can study the **rapidity structure of diffractive events** in a relatively unbiased way. AFP also makes possible the **measurement of the double differential cross section $d^2\sigma/d\xi dt$**, where ξ is the momentum lost by the proton, and t is the four-momentum transfer squared.

- A **variety of single-diffractive processes** can be studied in which the diffractive structure is probed by a parton in the second proton. These include **single diffractive production of W, Z, and jets**, which all have sufficient cross sections to be measured in a modest special run. These are well defined measurements, making use of standard ATLAS triggers, simply adding a proton tag at Level 1 if necessary. In fact, when the proton ID is in place, all analyses can use a proton finder routine to examine their diffractive counterparts, since the AFP detectors can be read out for all events.

- The **pomeron** is often viewed as gluon 'ladder', but hard diffractive interactions indicate **a partonic structure** that also includes quarks and enable this to be studied in detail. In some respects the **pomeron** resembles **a strongly interacting photon**, in that it undergoes both direct and resolved interactions. In special runs, we can focus on the resolved process, due to its relatively high cross section as compared to the direct-direct production of quark dijets. Finally, **diffractive events involving a hard photon** and jet give an alternative direct measurement of the quark content of the pomeron.

- **High-luminosity** running allows access to **rarer processes** and will **focus on direct point-like aspect of photons and pomerons**. Forward proton tagging allows the LHC to function as a **energy-tunable gluon-gluon or photon-photon collider**. In **Central Exclusive Production** (CEP), recently measured by CDF, the entire momentum loss of the protons goes into the creation of the central system, providing a particularly clean environment to search for and characterize any new resonance. Since the central system is produced in a $J^{PC} = 0^{++}$ state, backgrounds from di-quark production are suppressed, and the mere observation of a resonance determines its quantum numbers.

- AFP provides 5 GeV per event **mass resolution in CEP**. This is more **precise** than typical direct measurements using the central detector, and independent of the nature of the central system, thereby opening a window to the observation and measurement of challenging final states. The central state needs to be identified, but not necessarily well measured.

thanks Valery!

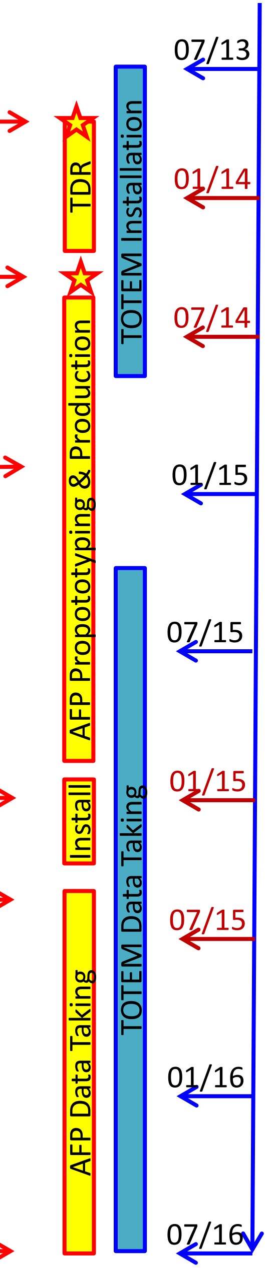
- The **two-photon production of W pairs** has a relatively large cross section and **anomalous couplings** should be measurable in this process with the 210 m stations during normal high luminosity data taking, or limits put upon them. This approach has already been *used successfully by CMS* to improve existing anomalous coupling limits by about two orders of magnitude. Proton tagging will allow another two orders improvement in these limits.

- An hypothesized process with **two protons and a central rapidity gap between a forward-backward jet pair**, while interesting in its own right, also would be important to measure since it could mimic the tagging jets used to identify vector boson fusion (VBF) processes, and contribute an overlap background to VBF that would be difficult to measure without AFP.

- **Diffractive processes** can also be measured in the context **of heavy-ion collisions**, and open up a new program of study in this field.

AFP future

- 2013-2015:
  - Sep 2013: **AFP approval**, start TDR
  - **<u>Jun 2014:</u>** AFP TDR approval; **final go-ahead** for AFP
    - start order/construction of RPs
  - Support TOTEM with insertion of 1+1 Horizontal RPs
    - Jul 2013: Expression of Support by LHC Forward Physics Working group ??
  - 2015: Measure & evaluate backgrounds at P5
  - 2014-15: prep work for AFP installation
  - Xmas 2015: Install 2+2 Horizontal RPs in ATLAS
    - RP 204m: tracking; RP 212m: tracking + (modest) timing
- 2016-2017 (Phase 0)
  - 2016: Measure & evaluate backgrounds at ATLAS
  - 2016-17: Low-μ Physics
  - **<u>Aug 2016 – Jan 2017: Decision point:</u>** HBP or Timing in 3rd RP ?
  - **<u>Aug 2016 – Jan 2017: Decision point:</u>** AFP420 ?
- 2018-2021 (Phase 1)
  - 2018 (LS2): Final AFP installation
  - 2019-21: AFP Data taking



backup?

request to the Diffractive Community

formulated by Michael Rijssenbeek (Calabria meeting)

need strong support from the diffractive community to build a diffractive program with tagged protons at the LHC

- high-pT physics program has top priority
- diffractive physics is generally seen as 'dirty' and not leading to new insights …
- without support from the full experimental community, funding will not be available …

the LHC Forward Physics Working group must make its opinion and arguments clear to the **full** LHC physics community (LHCC; ATLAS, CMS, …)

request to the Diffractive Community

1st practical step:

declare strong support for TOTEM to put in 1+1 RPs during LS1

- experimental exploration of the backgrounds (simulations can only go so far)
- test the fast time-of-flight concept in a harsh environment
- must happen in 2014 so that one can learn with the machine

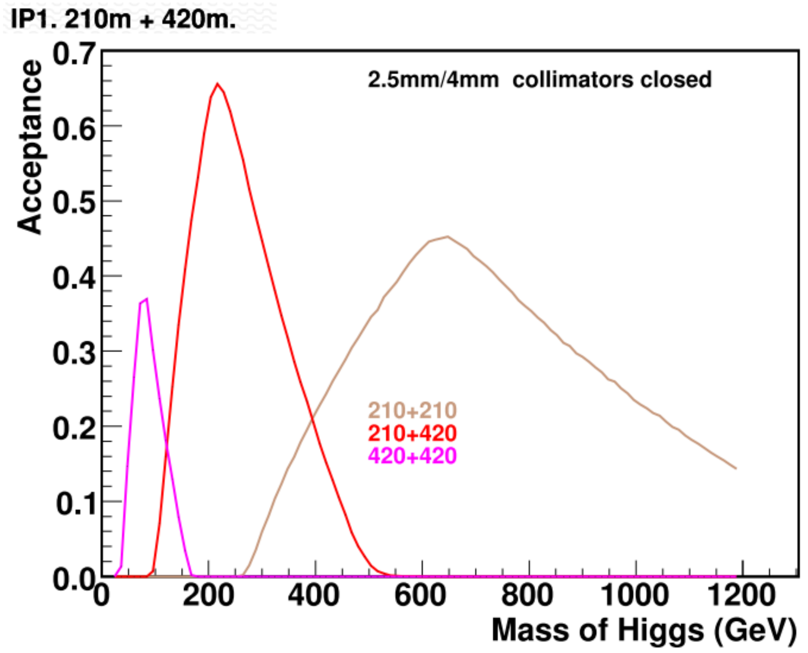
2nd practical step:

formation of a Technical LHC-FP sub-group

- discuss/consult on backgrounds
- discuss/collaborate on fast Time-of-Flight detectors
- …

why “yes” for 420?

considerations of Andrew Brandt



1) **210+420 acceptance is much better** than 210 alone acceptance, so you can pursue the maximum physics program

2) operating **close to the beam is more difficult**