The ATLAS AFP Detector

Christophe Royon
IRFU-SPP, CEA Saclay

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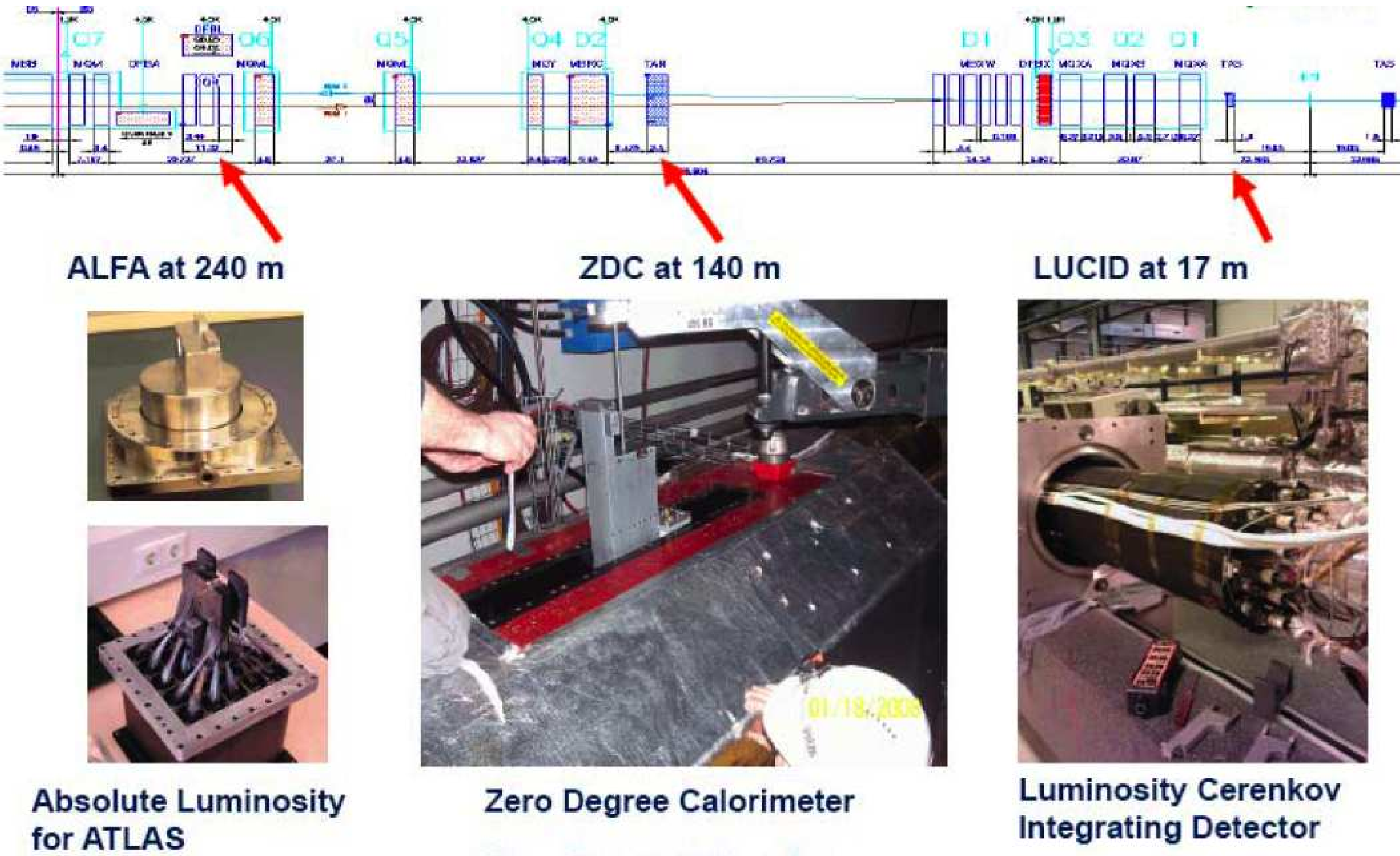
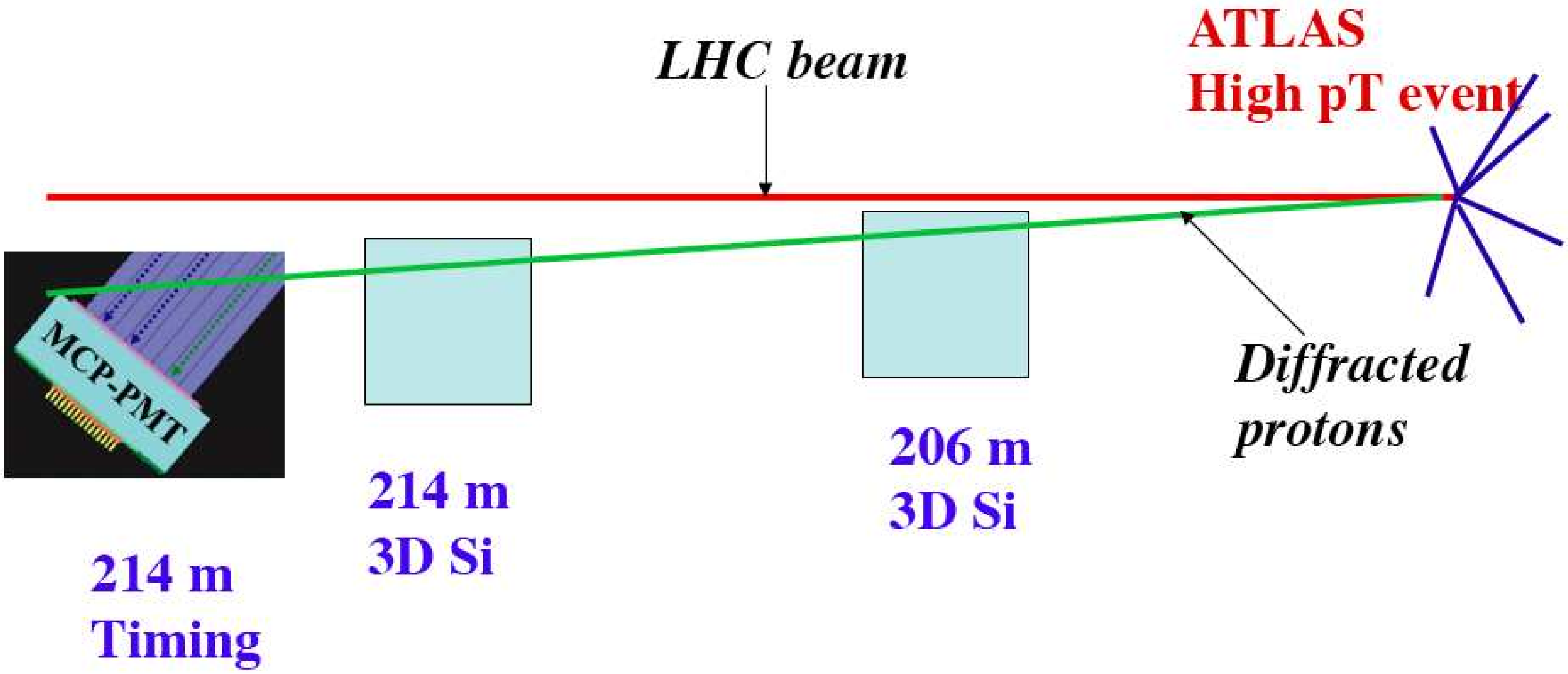
Forward detectors in ATLAS



- ALFA
- ZDC
- LUCID

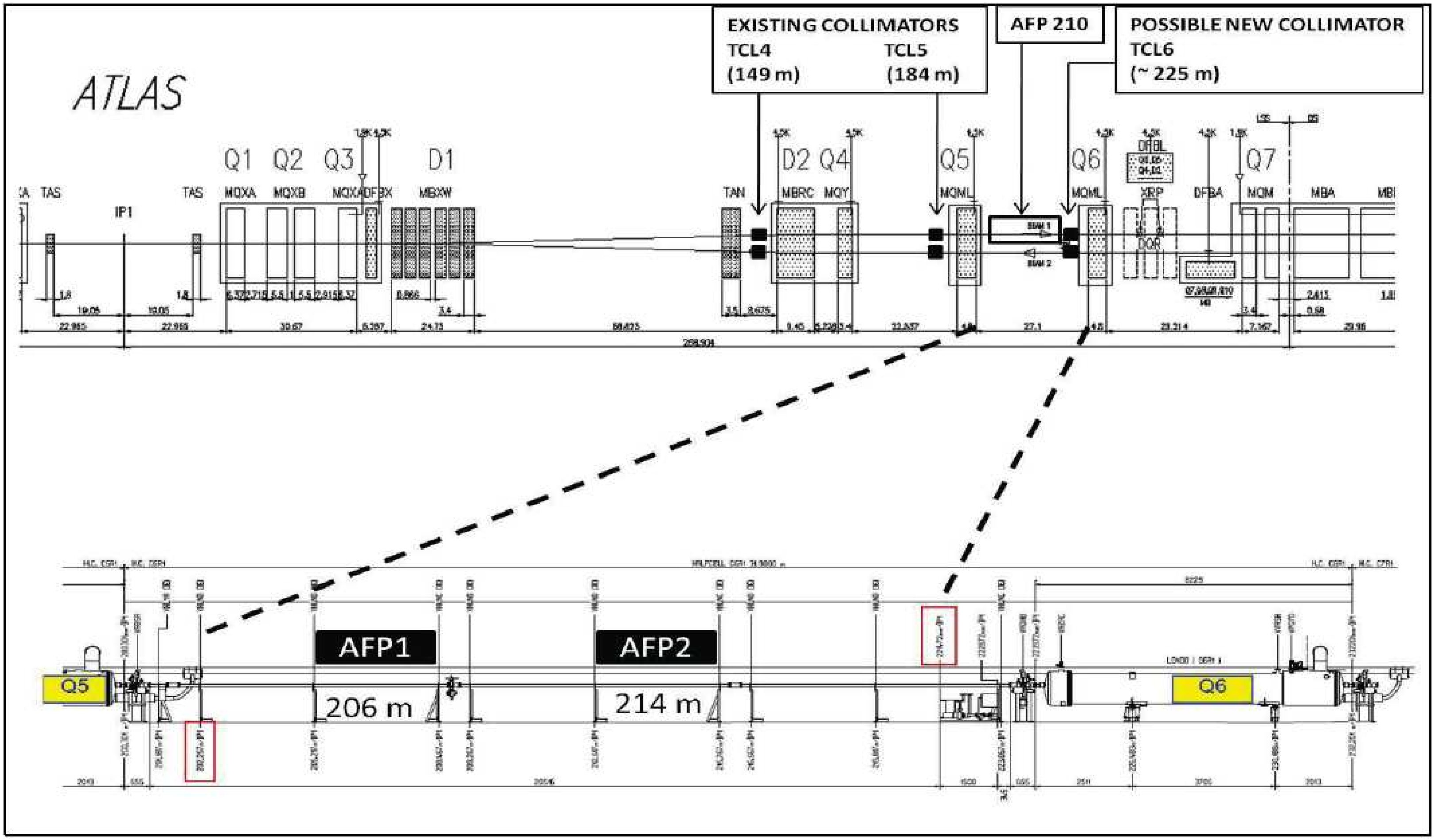
What is AFP?



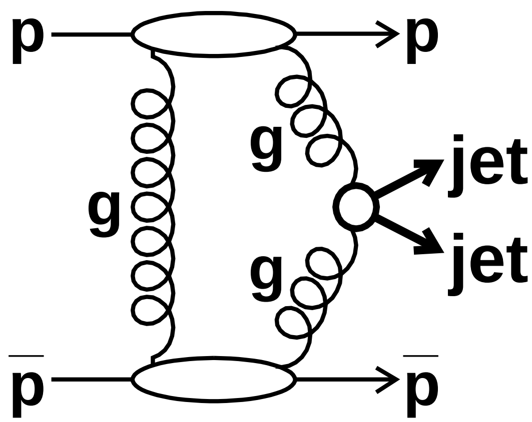
- Tag and measure protons at $\pm$210 m
- Trigger: Rely on ATLAS high p_T L1 trigger (high mass events) and possibility of triggering on intact protons in AFP
- AFP detectors: Radiation hard "edgeless" 3D Silicon detectors, 10 ps timing detectors
- Allows running both in high pile up conditions (proton timing consistent with originating from the primary vertex) and at low luminosity (special runs): Access to rare processes (anomalous couplings, exclusive events) and standard QCD (SD, DPE)

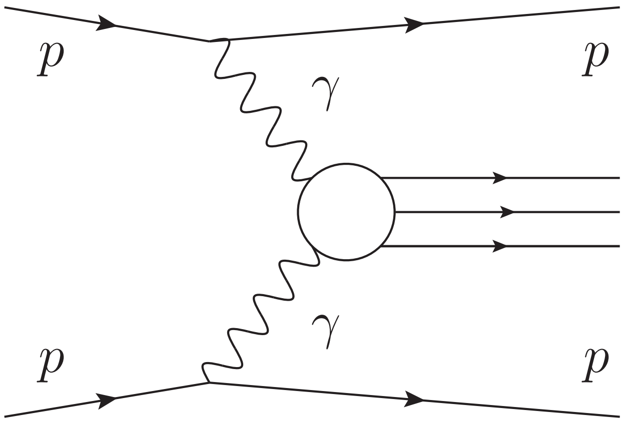
AFP location (phase I)

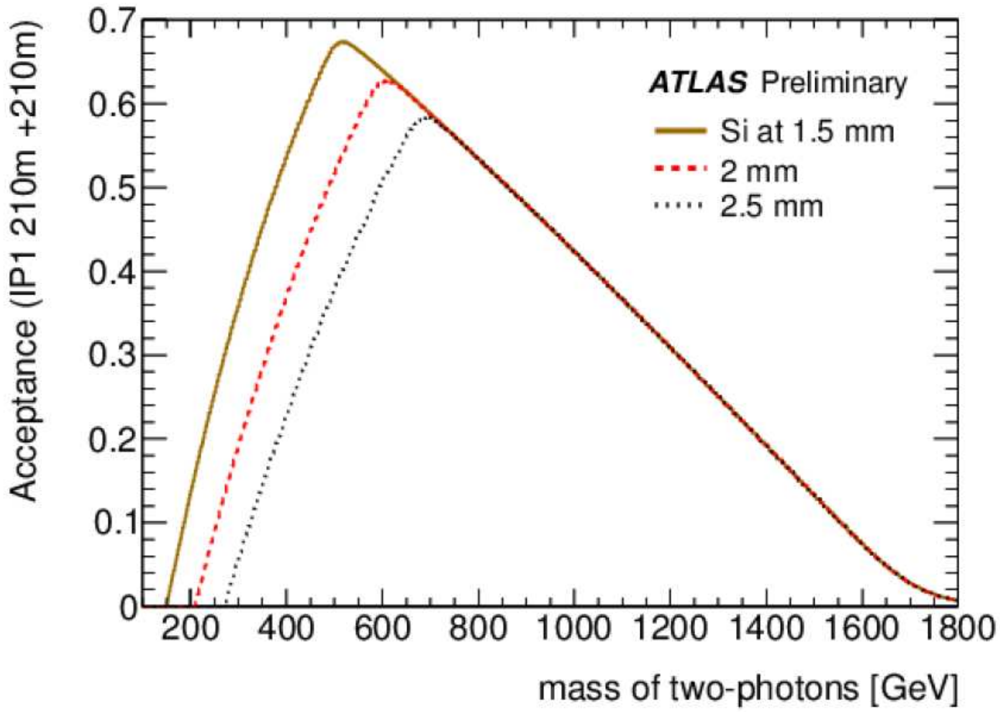
- AFP: two stations at 206 and 214 m
- Movable beam pipes or roman pots host Si and timing detectors



AFP acceptance in total mass



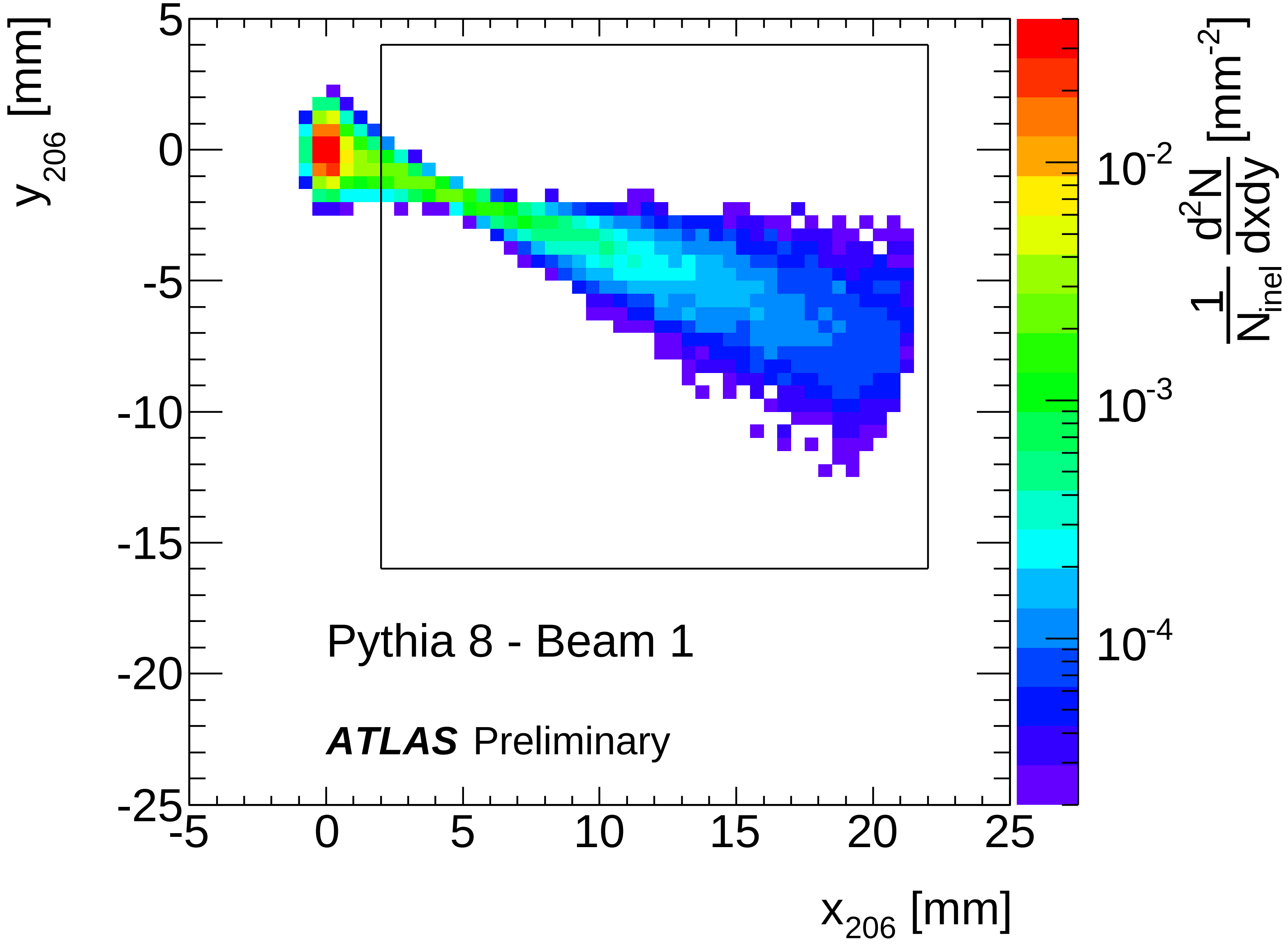




- Increase sensitivity to (new) physics in ATLAS due to color singlet or photon exchanges as well as QCD measurements
- Sensitivity to high mass central system, X, as determined using AFP
- Very powerful for exclusive states: kinematical constraints coming from AFP proton measurements

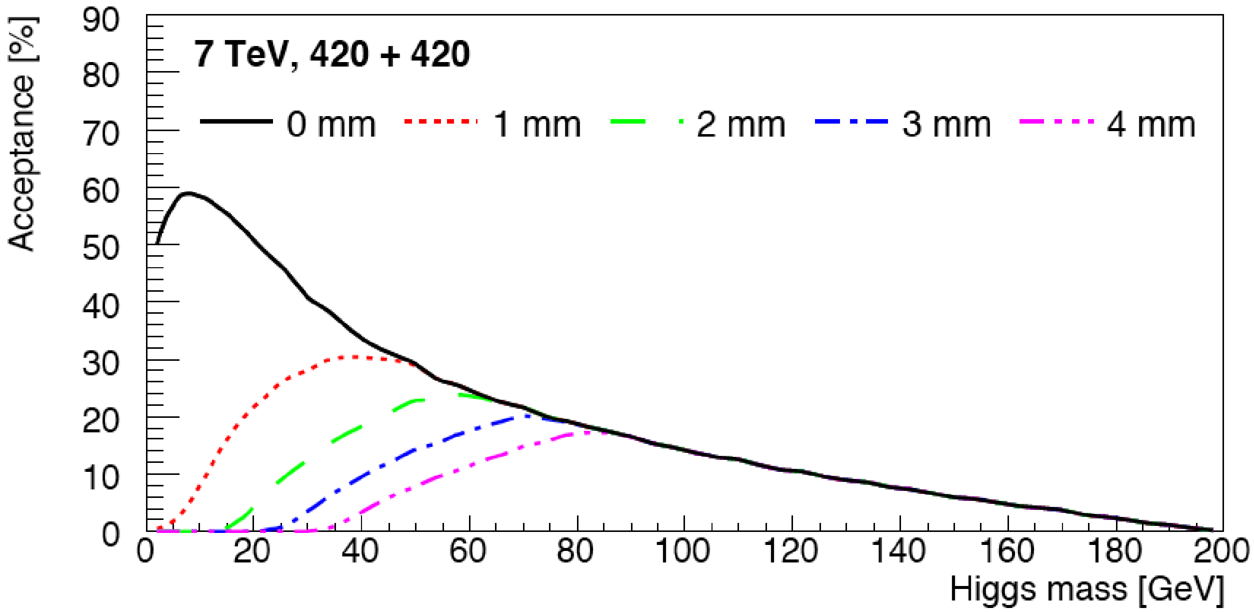
ATLAS Forward Physics detector acceptance

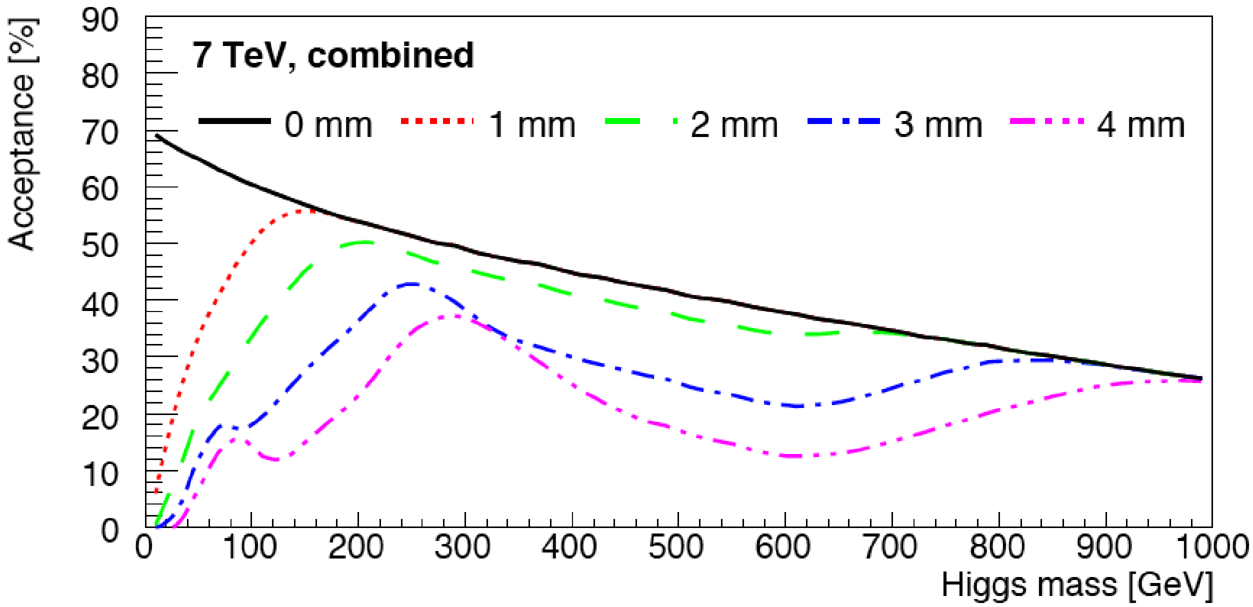
Positions of proton detected by AFP and rates observed in the detectors



Possible upgrades of AFP: add 420 m detectors

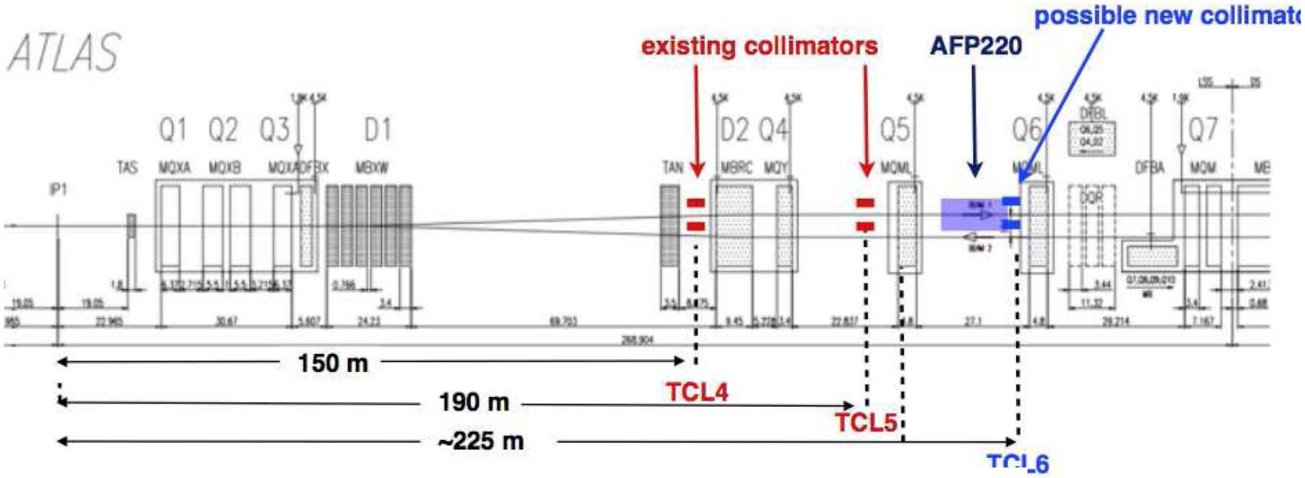
- Detectors at 420 and 210 m allow to increase the acceptance at low masses (NB: acceptance slightly smaller in CMS than in ATLAS)
- Possibility to increase the acceptance at high mass by having additional detectors close to ATLAS

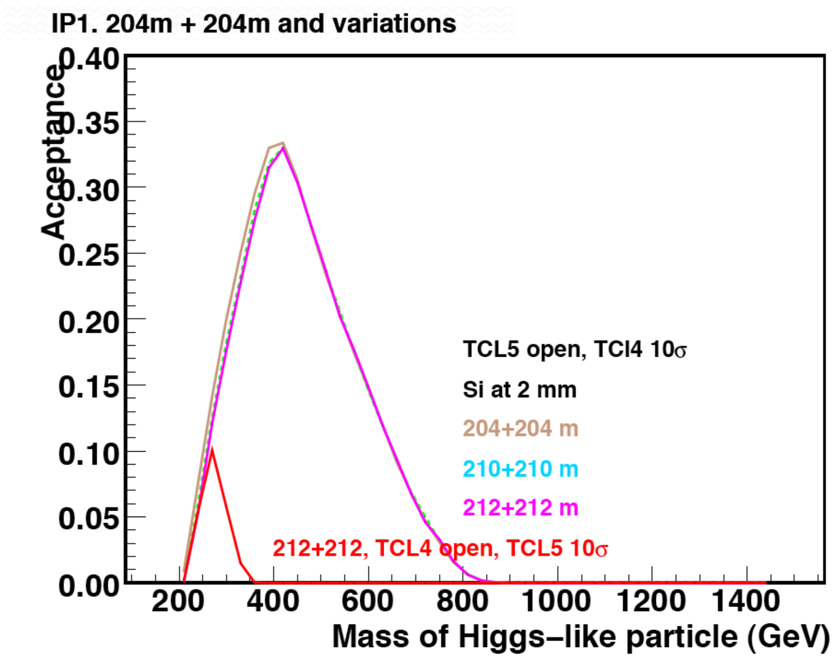




Collimator positions

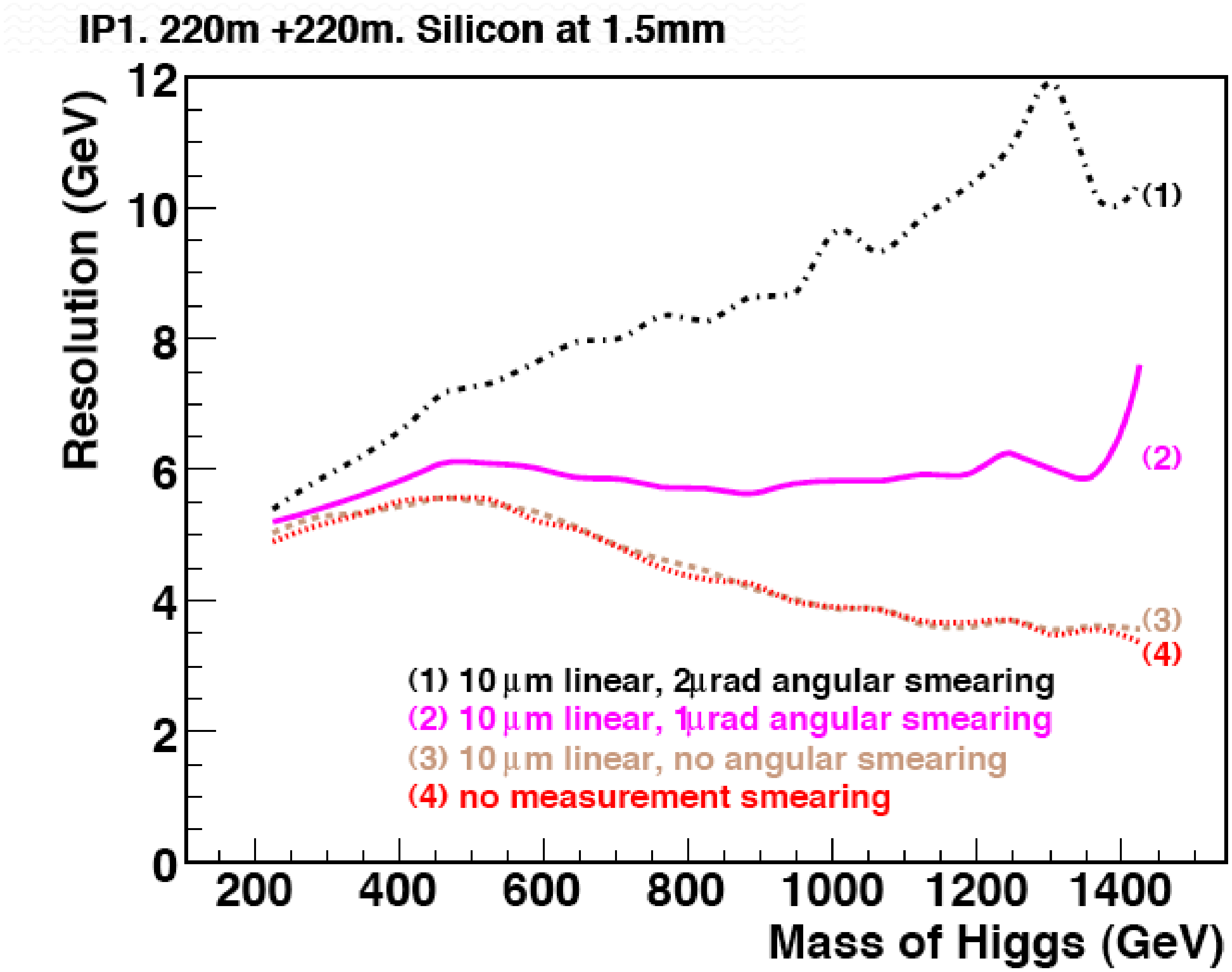
- Present collimator strategy (TCL4 and TCL5 in closed position in front of AFP) at high luminosity kills all acceptance at 210 m since diffracted protons hit the collimators
- Proposal for an alternative: TCL4 and TCL5 opened respectively at 30 σ (10 σ with present scheme), and 50 σ (10 σ now)
- Additional collimator TCL6 behind AFP can be closed at 10 σ





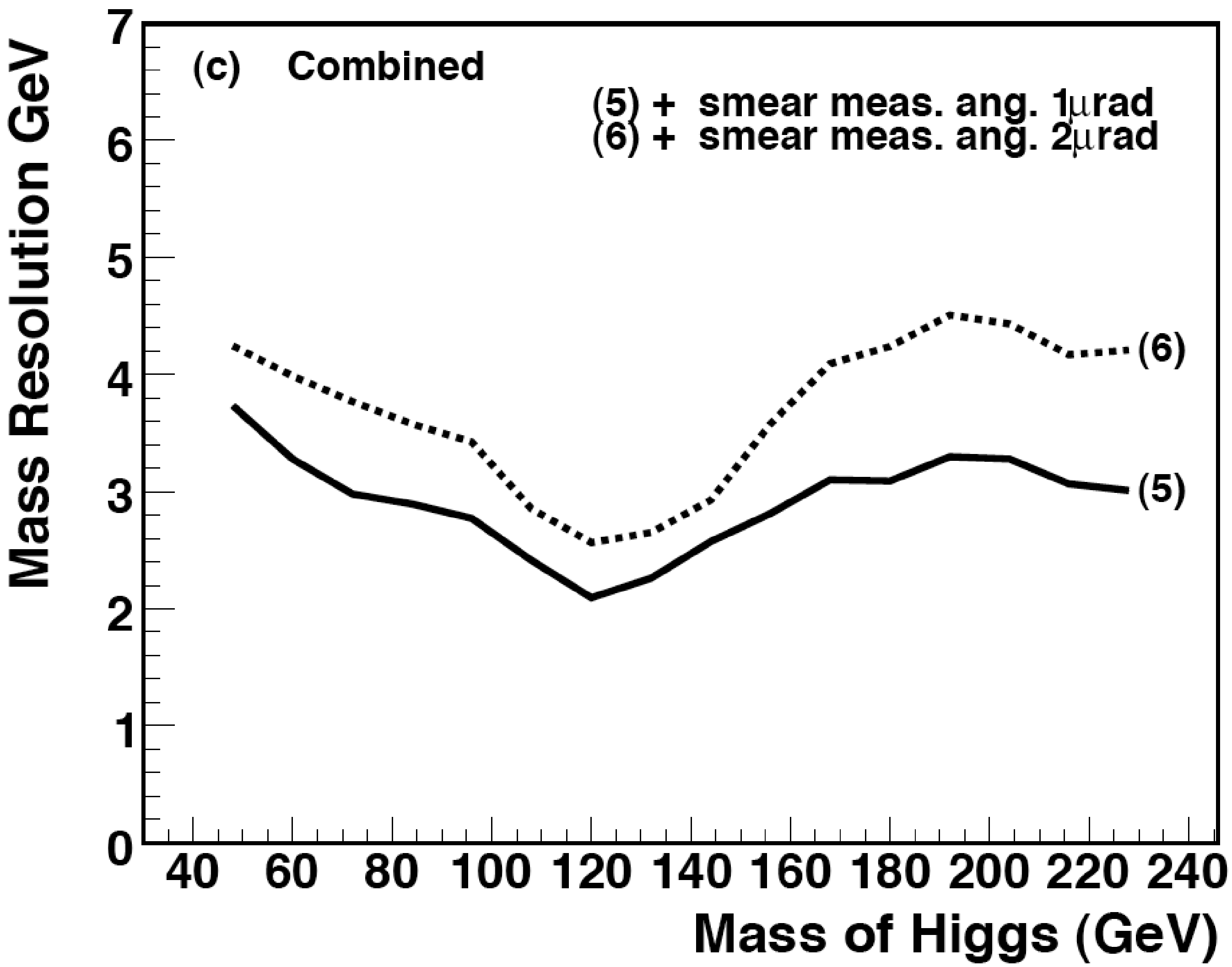
Mass resolution (210 m)

- Mass resolution better than 1% at high mass if we have 1 μrad angular resolution
- Resolution blows up for an angular resolution larger than 2 μrad
- Important to have two stations to measure angles, 8 meters between the two stations



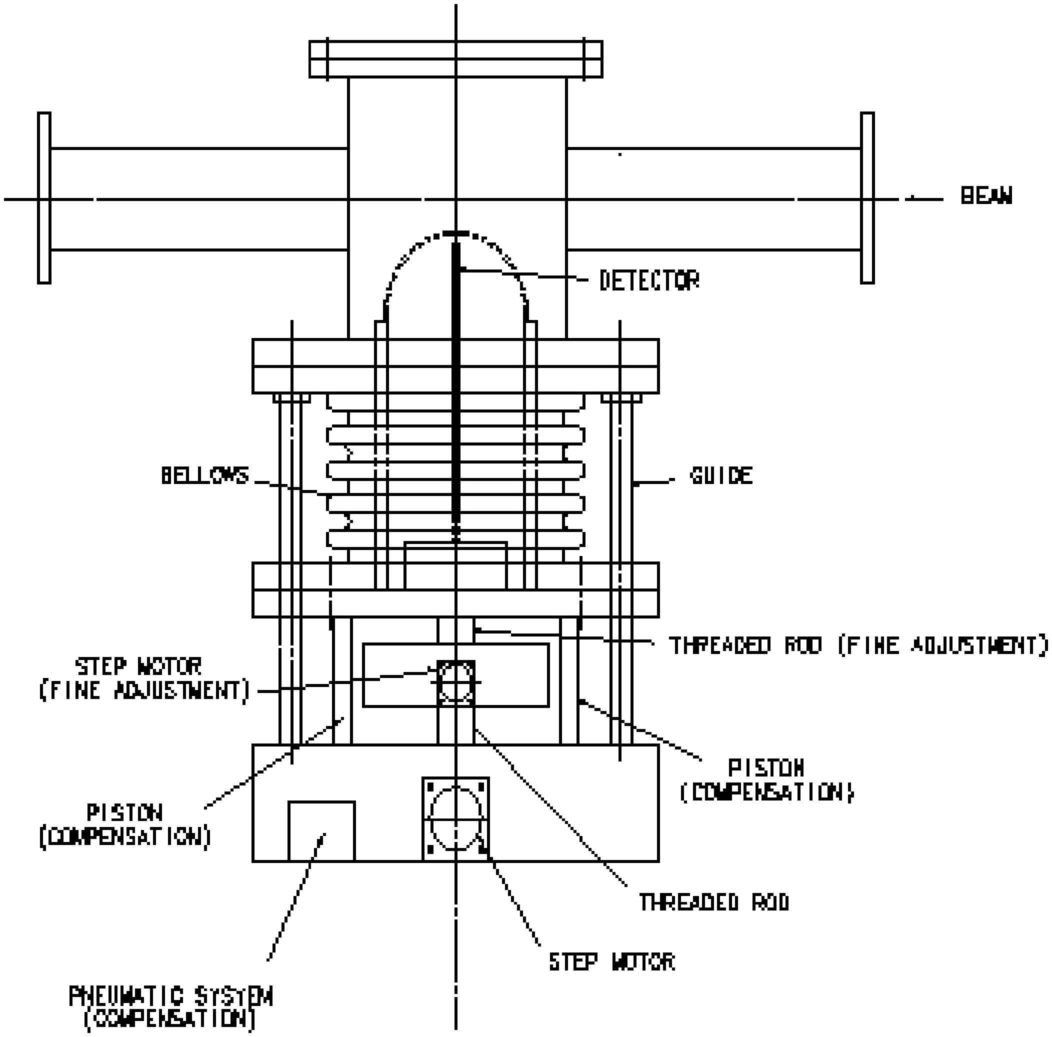
Mass resolution (420 and 210 m)

- Mass resolution of the order of 3% at low mass for 210 and 420 m detectors together (for instance in the region of the Higgs boson)
- Important to have two stations to measure angles, 8 meters between the two stations



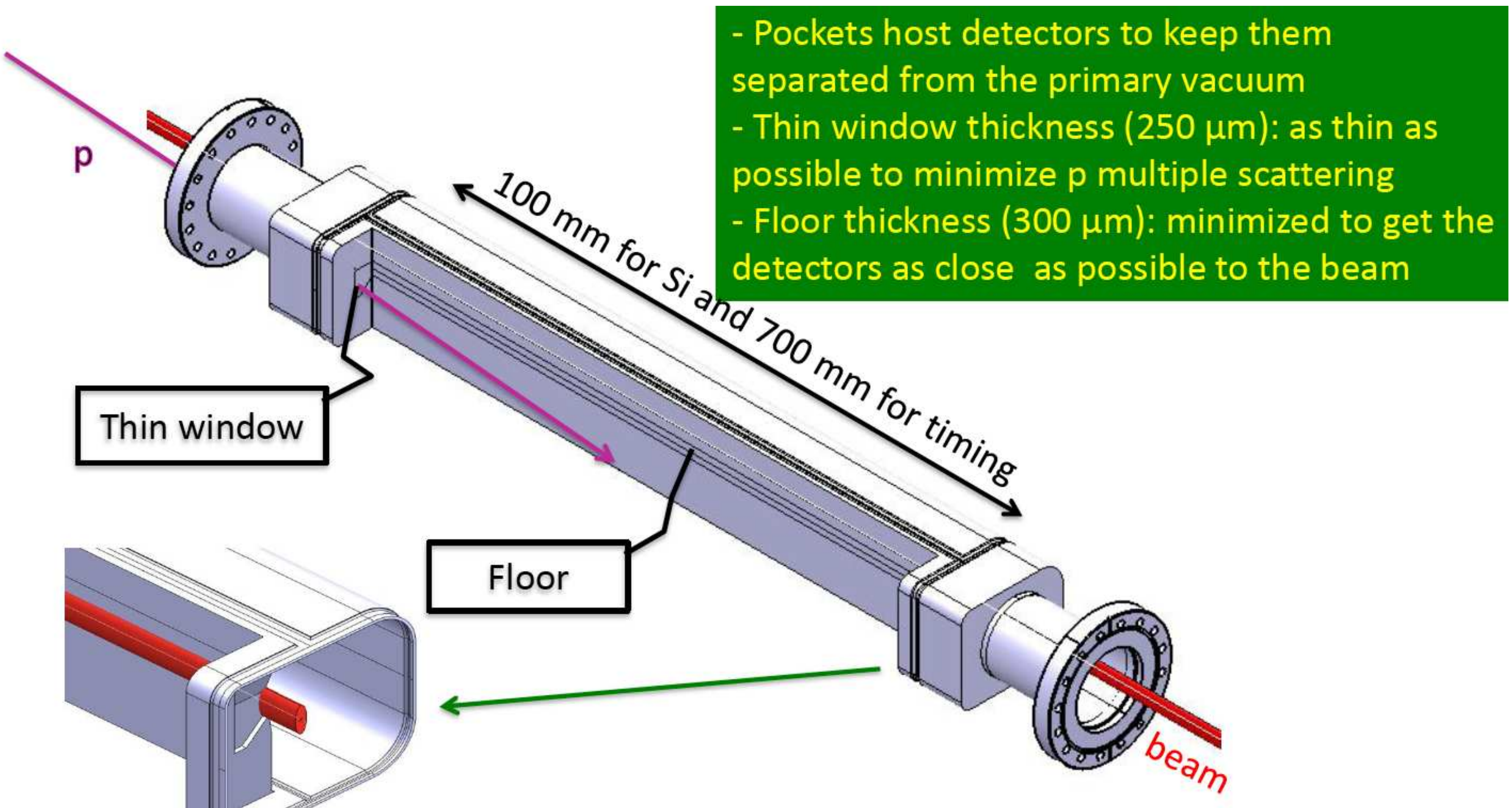
Roman pots

- Detect intact protons in dedicated detectors called roman pots
- Roman pots: Traditional detector to detect intact protons, used previously at HERA, Tevatron and in ALFA, TOTEM at the LHC
- Inconvenient: Limited space available for detectors (especially for timing), impossible to use at 420 m (in the cold region of the LHC)

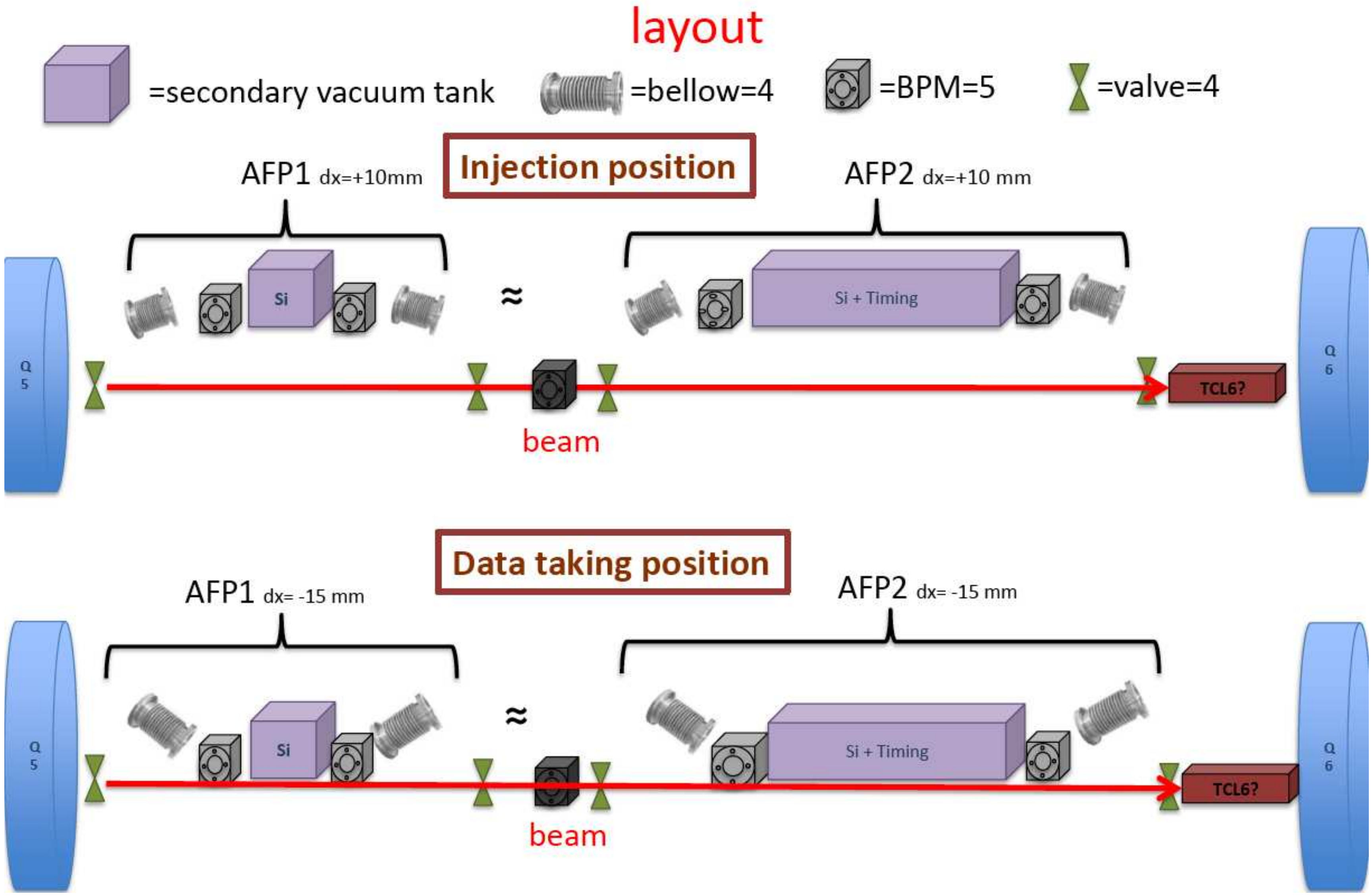


Movable beam pipes

- allow precise and repeatable movement of detectors close to the beam by $\sim$ 25 mm (HERA, Louvain, CERN)
- minimum deformation, thin vacuum window (detector a few mm from the beam)
- use standard LHC components (bellows...)
- Choose movable beam pipe technique: less mechanical stress than roman pots since a fixed vacuum volume is maintained
- The movable beam pipe is treated as an instrumented collimator from the LHC point of view which does not go as close to the beam as the collimator, uses same motors

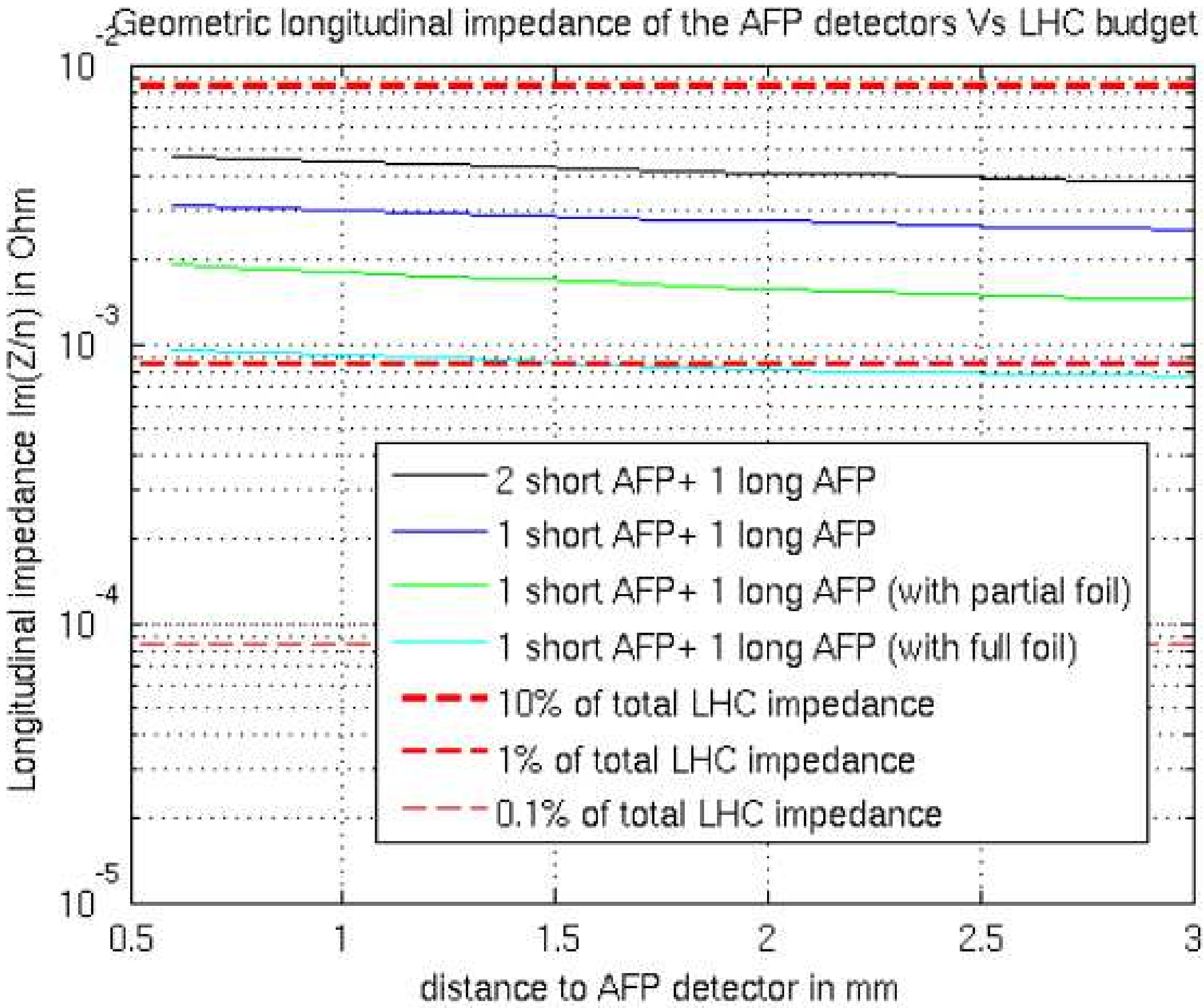


Movable beam pipe: functional specifications



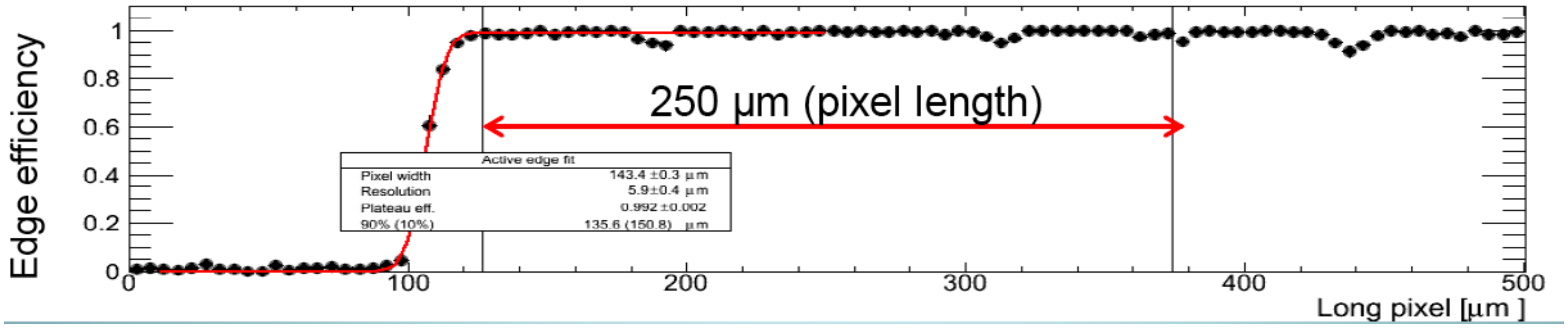
Movable beam pipe: LHC impedance impact

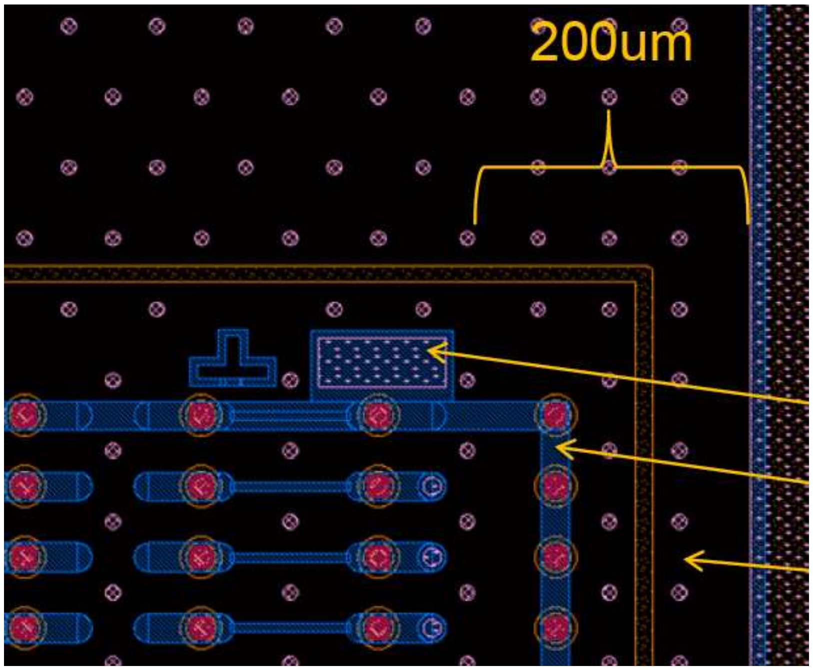
- Needs to be below 1% of the LHC impendance so that it can be approved without issues
- With the present design, we are above 1% limit



Detector I: 3D Si detector

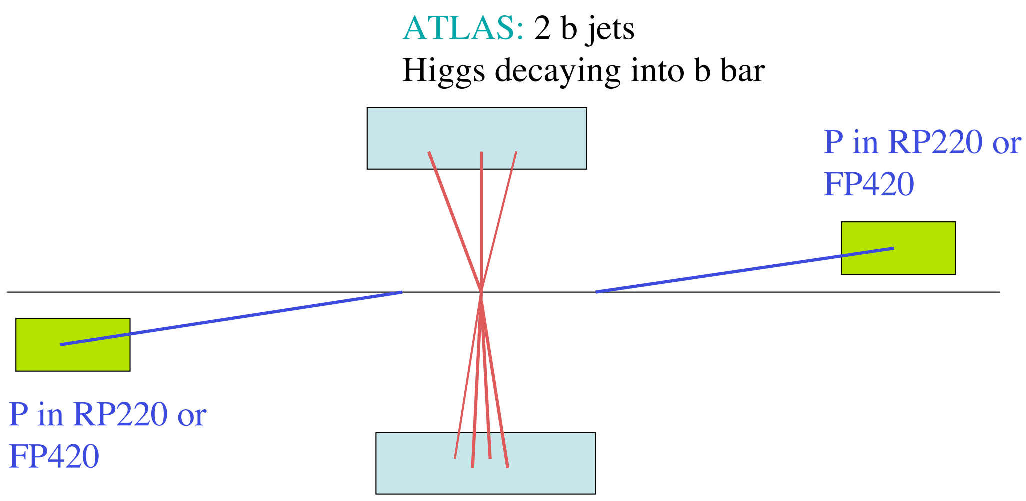
- Key requirements for the Si detector
  - Spatial resolution of 10 (30) μm in x (y) direction over the full detector coverage (2 cm $\times$ 2 cm); Angular resolution of 1 μrad
  - Minimal dead space at the edge and radiation hardness
- Sensors: double-sided 3D 50$\times$250 micron pixel detectors with slim-edge dicing (dead zone of 80 microns instead of 250)
- Possible upgrade with 3D edgeless detectors by 2020

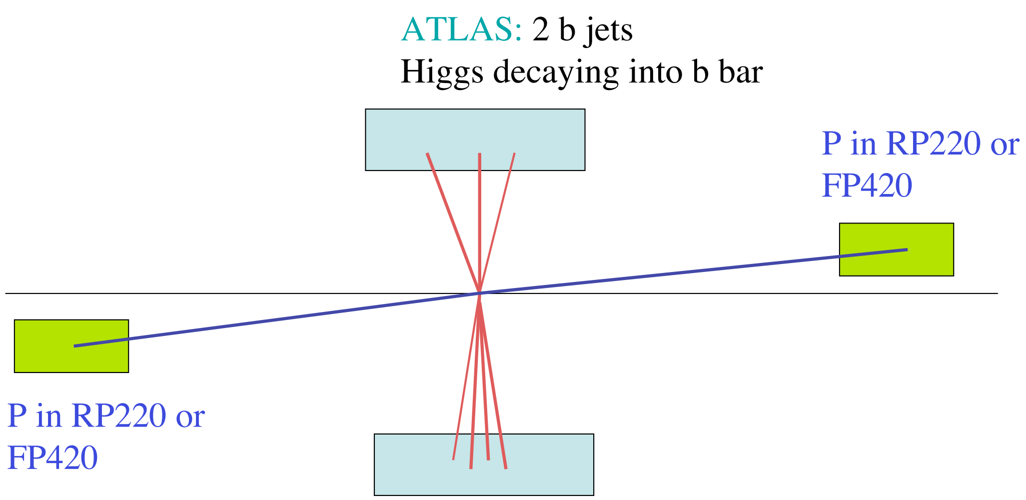




Why do we need timing detectors?

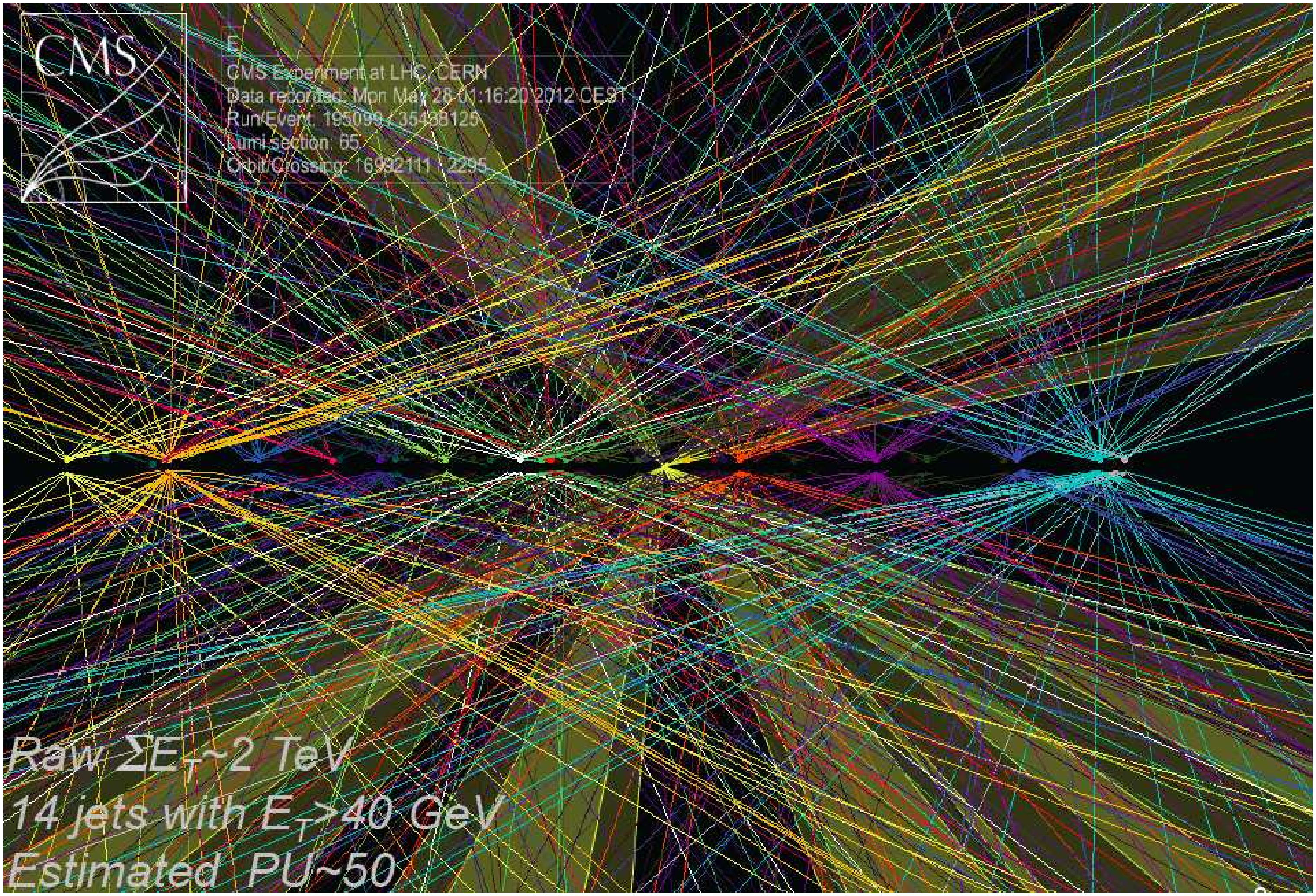
We want to find the events where the protons are related to hard event production and not to another soft event (up to 35 events occuring at the same time at the LHC!!!!)





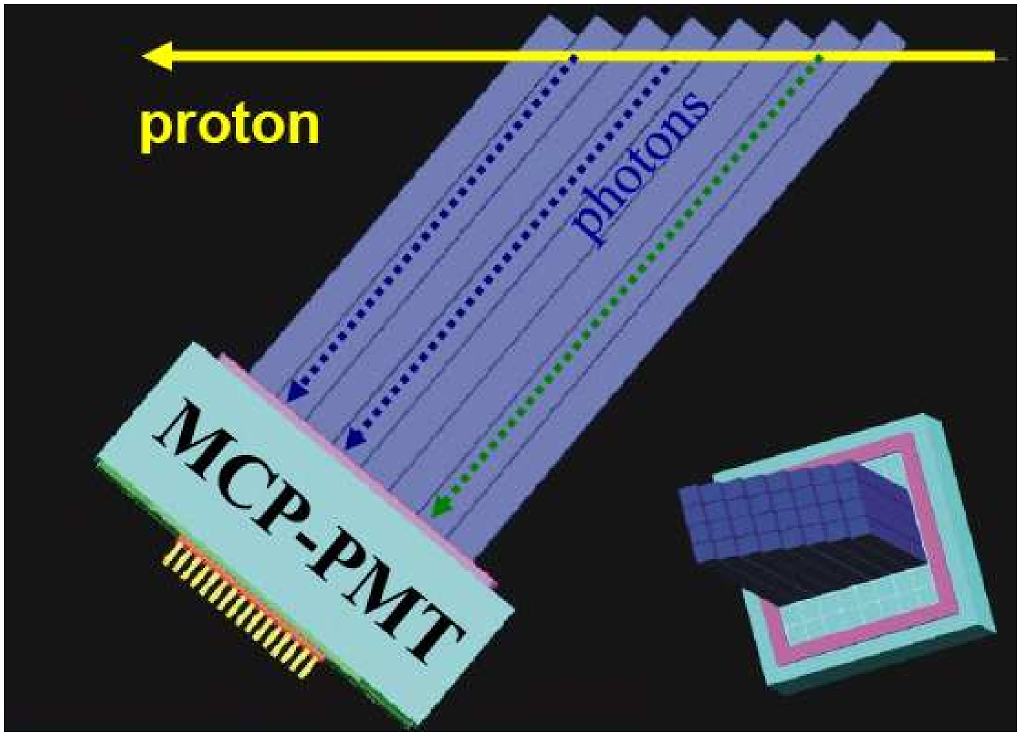
Pile up!

Many interactions occur in the same bunch crossing



Detector II: timing detectors

- Measure the vertex position using proton time-of-flight: suppresses high pile up events at the LHC (50 events in the same bunch crossing), allows to determine if protons originate from main interaction vertex
- Requirements for timing detectors
  - 10 ps final precision (factor 40 rejection on pile up)
  - Efficiency close to 100% over the full detector coverage
  - High rate capability (bunch crossing every 25 ns)
  - Segmentation for multi-proton timing
  - level 1 trigger capability
- QUARTIC has 4$\times$8 array of quartz bars; Each proton passes through eight bars in one of the four rows and one only needs a 30-40 ps measurement/bar since one can do it 8 times



How to achieve 10-20 ps timing resolution?

- Present achievement: $\sim$14 ps with one QUARTIC (8 times the same measurement with 8 bars)
- Future achievement (minor modifications) $\sim$ 7 ps with two QUARTICS
- Longer term achievements: a few ps for readout Chip, better spatial resolution ($\sim$ 1 mm^2)

Component	δt(ps) Current	δt(ps) Projected (8 ch +cable)	Improvement	δt(ps) Phase 0 (8 channels)
Radiator (fused silica bar) ~10 pe's	22	22	Optimize radiator	17
MCP-PMT (64 channel 25 um Planacon)	20	20	10 um tube	15
CFD	5	5	-	5
HPTDC	16	16	-	15
Reference Clock	-	3	-	3
Total/bar	34	34		28
Cable		15%	retune CFD	5%
Total/ detector	14	14	-	10

Saclay: Improving the time resolution of the readout chip

- Development of a fast timing chip in Saclay SAMPIC:
  - Uses waveform sampling method
  - Sub 10 ps timing, 1GHz input bandwidth, no dead time for targeted data taking
  - Low cost: 10 $ per channel
- New ideas for pixelisation: APDs, SiPM, Diamonds...

$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3 f_s \cdot f_{3dB}}}$$

	U (dynamic)	Δu (noise)	f_s (sampling freq)	f_{3db} (cutoff frequency)	Δt (timing resolution)
Actual chips (SAM...)	100 mV	1 mV	2 GSPS	300 MHz	~10 ps
	1 V	1 mV	2 GSPS	300 MHz	1 ps
	100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
Targeted chip	1V	1 mV	10 GSPS	1 GHz	0.5 ps

Conclusion

- AFP detectors to be installed in 2015 Winter shutdown if approved
- AFP aims at detecting intact protons in ATLAS: increases the physics potential of ATLAS (QCD, search for extra-dimensions in the universe via anomalous couplings between γ, W, Z, for magnetic monopoles...
- Detector: Movable beam pipe or roman pots; 3D Silicon position detectors (10-15 μm precision); Timing detectors (Quartz or diamond detector, SAMPIC electronics)
- Many applications especially in PET imaging (Manjit Dosanjh)