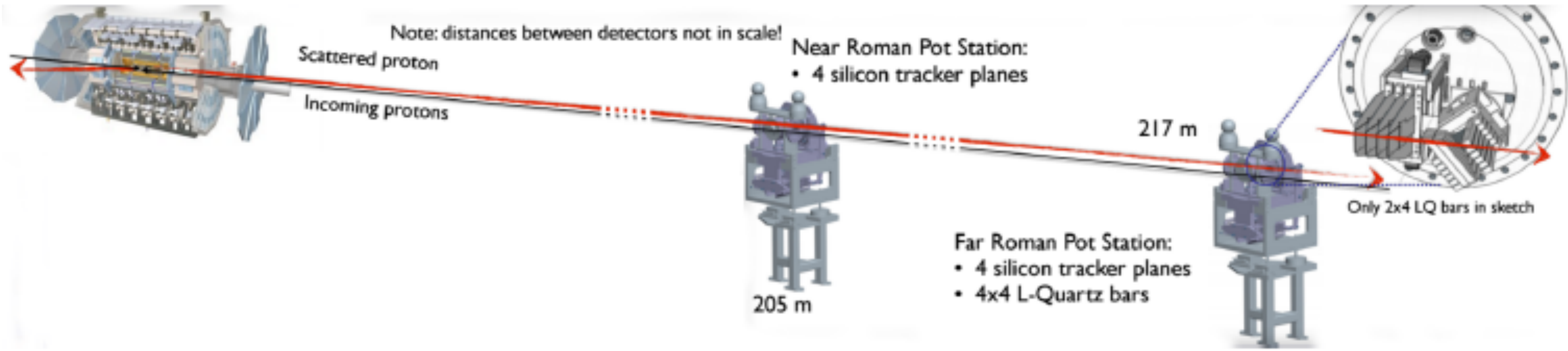
ATLAS AFP: Status and Prospects

Paul Newman
(University of Birmingham)
for the ATLAS Collaboration

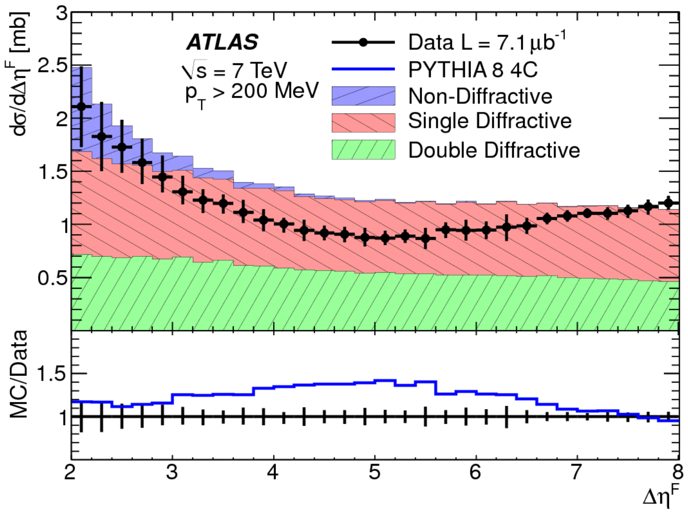
LHC Forward Physics Workshop,
Madrid 21 March 2018

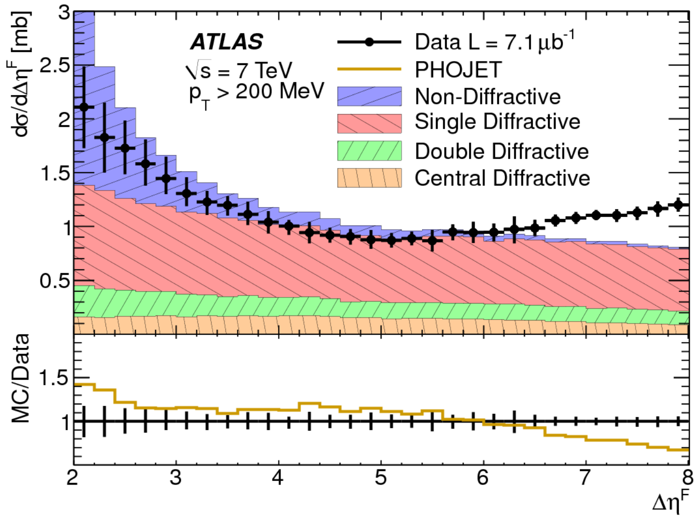


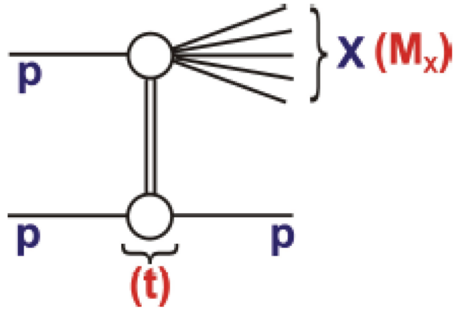
ATLAS Diffractive Rapidity Gap Results

Existing ATLAS data dogged by lack of proton tagging …

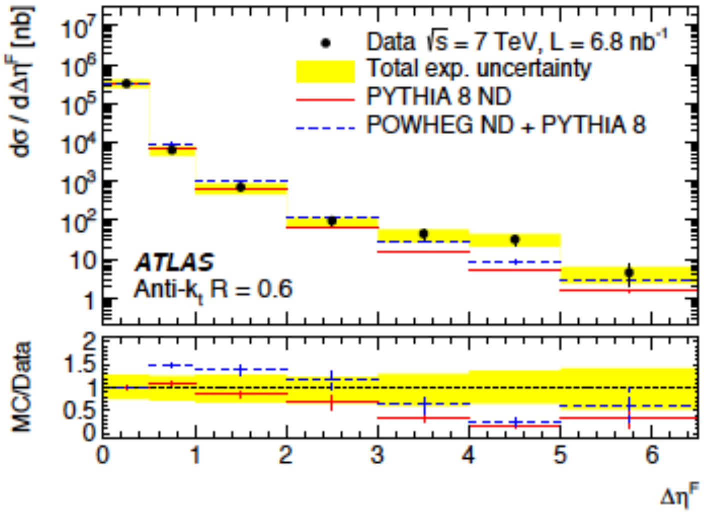
Inclusive single diffractive dissociation: DD, ND contributions?

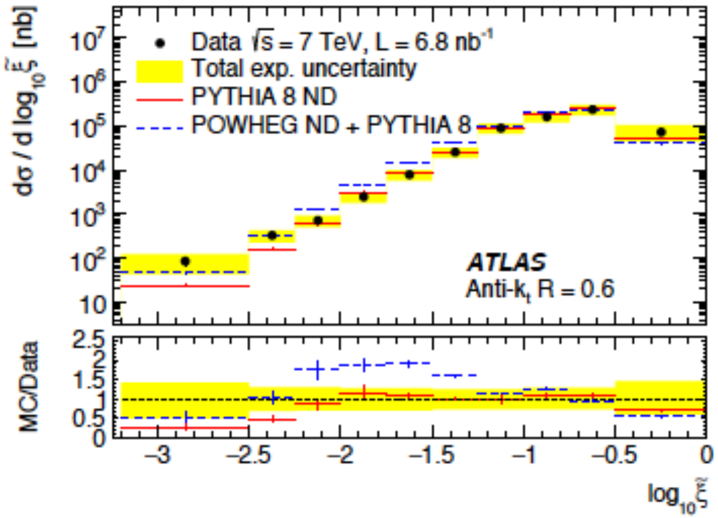


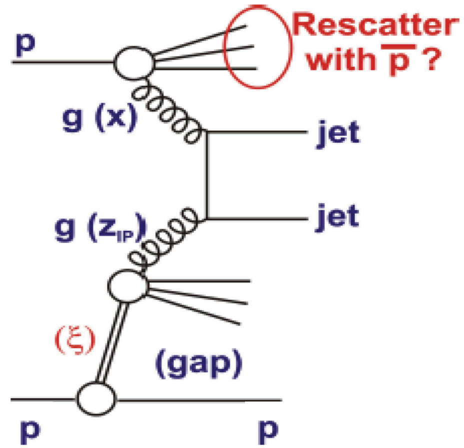




Single diffractive dijets: Signal barely visible above ND



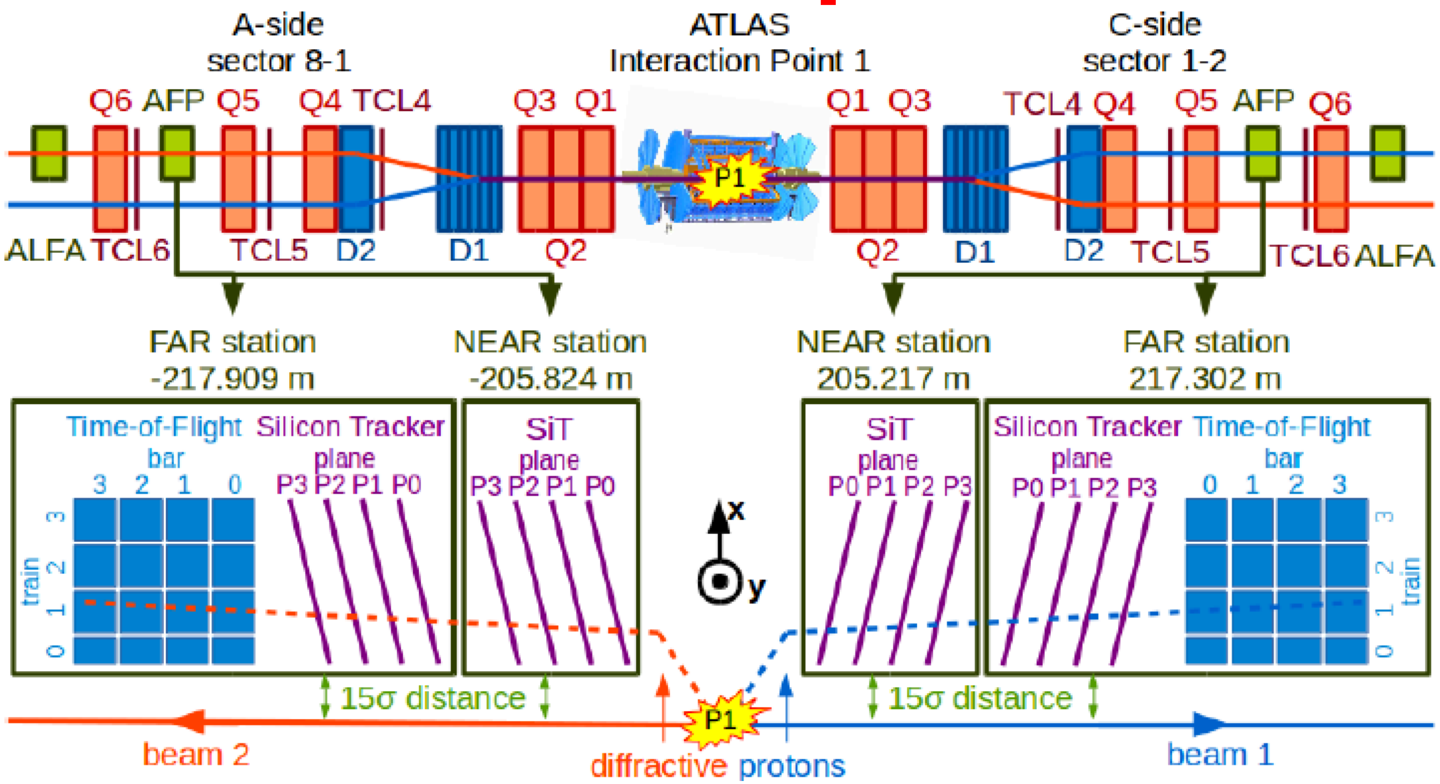




Proton Spectrometers in ATLAS

ALFA: pairs of Roman pots housing non-rad-hard scintillating fibres. Vertical approach to beam → σ_{tot}, soft diffraction

[See Per Grafstrom on Friday]



AFP: pairs of Roman pots with silicon precision spatial detectors & Cerenkov time-of-flight detectors to suppress pile-up (vertex constraint). Horizontal approach to beam → high lumi physics

- Phase 1 (2016) single side
- Phase 2 (2017-) double sided

AFP Detectors

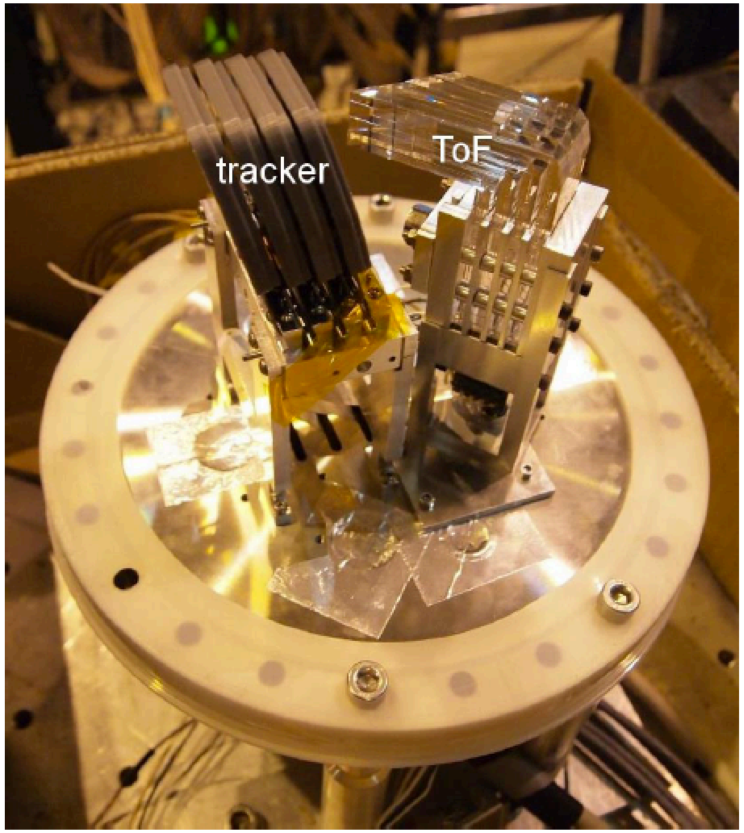
Tracking: four slim-edge 3D pixel sensor planes per station (IBL)

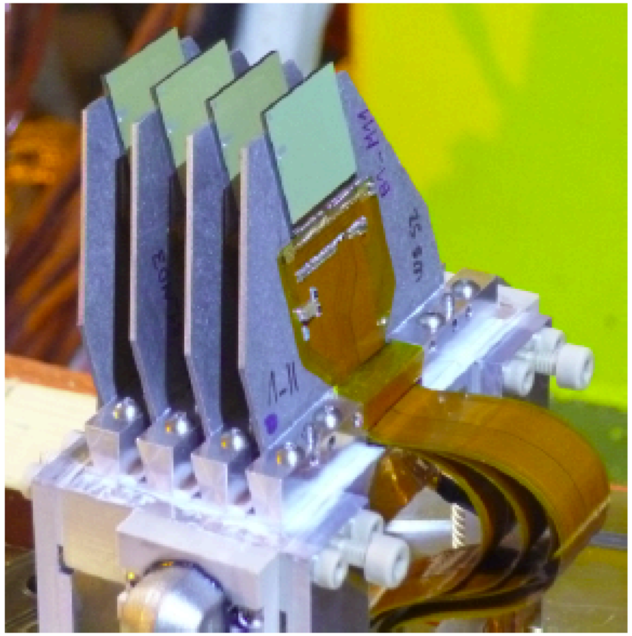
- Pixel sizes 50x250 μm
- 14^{o} tilt improves x resolution (hence ξ)

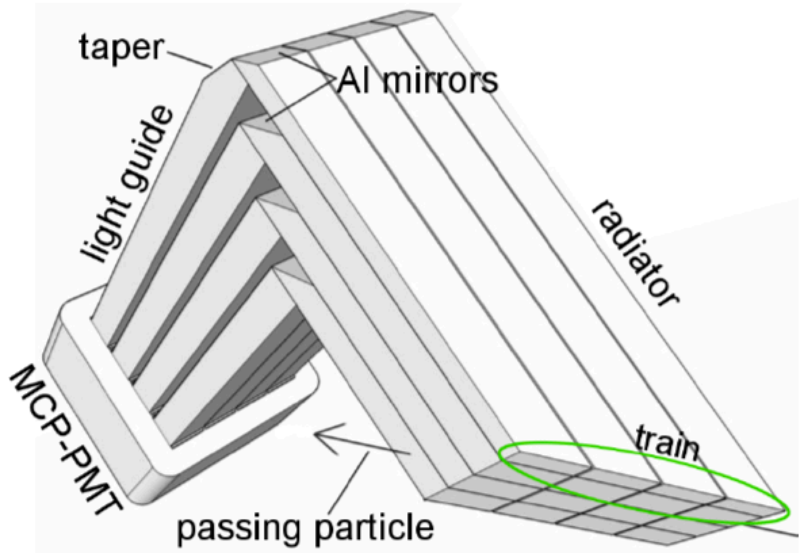
  → δx = 6 μm, δy = 30 μm
- Trigger capability

Timing: 4x4 quartz bars at Cerenkov angle to beam. Light detected in PMTs

→ expected resolution 25ps

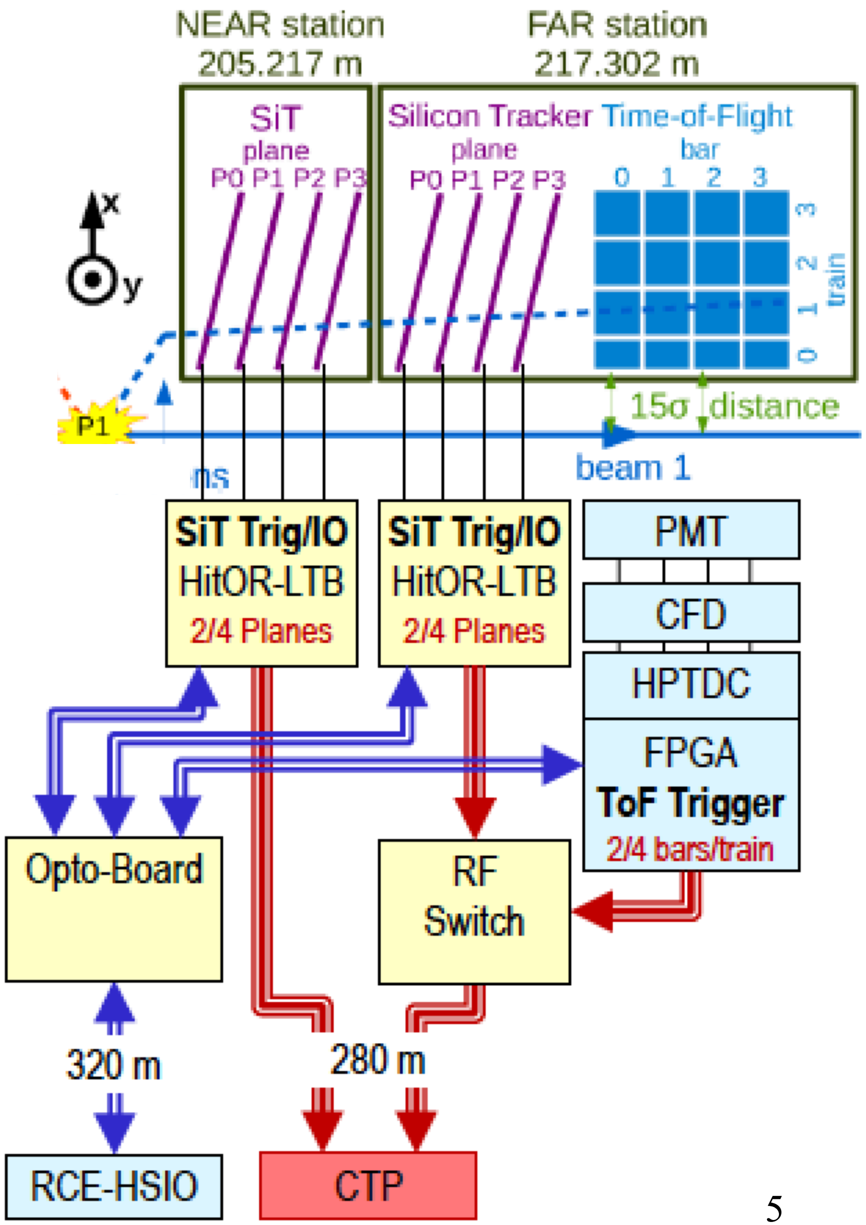


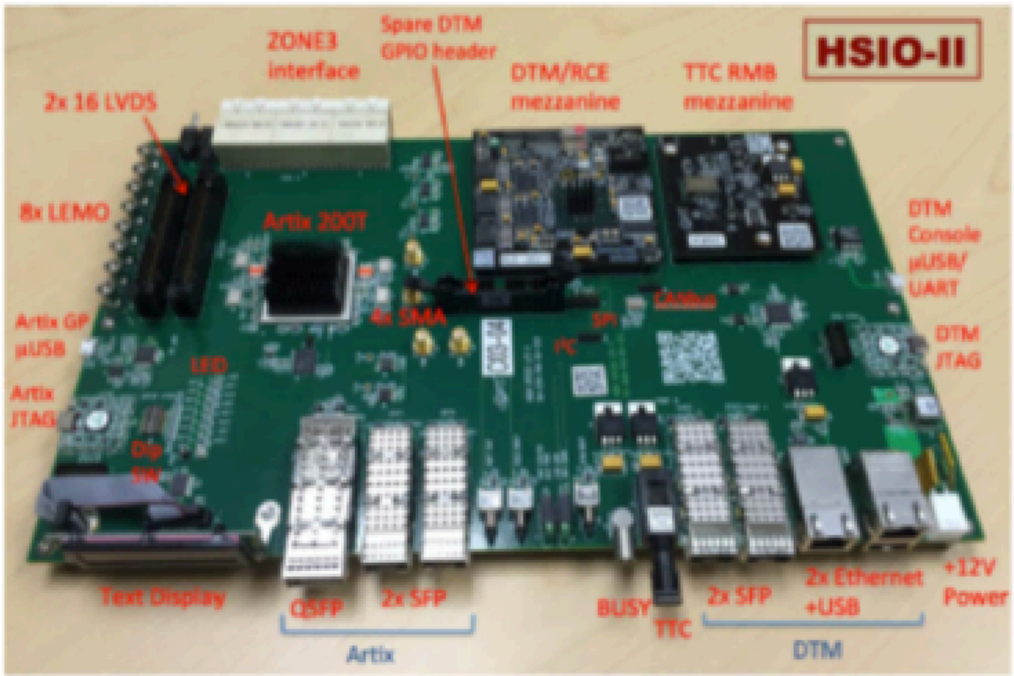




Trigger and Data Acquisition

AFP fully integrated into ATLAS TDAQ system and able to deliver first level triggers within the 85 bunch crossing latency (fast air-core cables) according to field-programmable criteria.



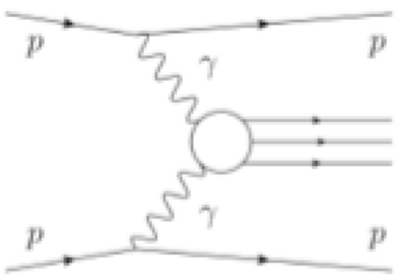


Acceptance

- Spectroscopic effect of beam optics gives dispersion in ξ and t.

- Excellent ξ resolution, via x

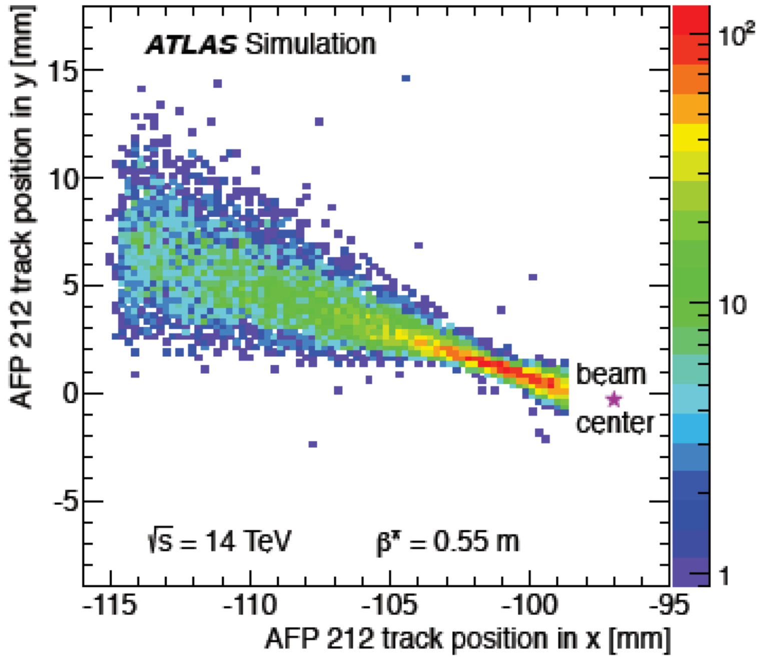
… translates into excellent mass resolution on exclusively produced states.

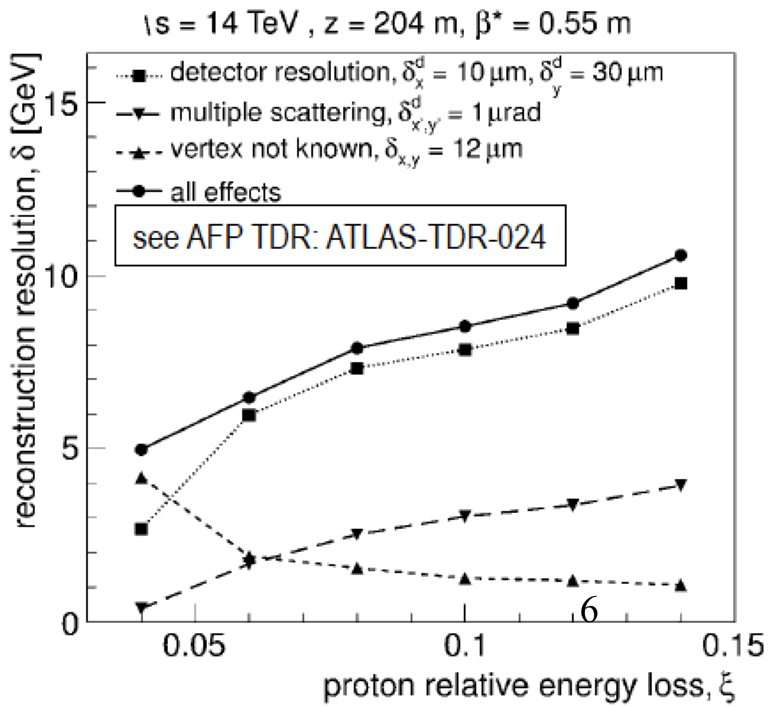


$$m = \sqrt{s\xi_1\xi_2}$$

Beautifully illustrated in the following [with thanks to Maciej Trzebinski]

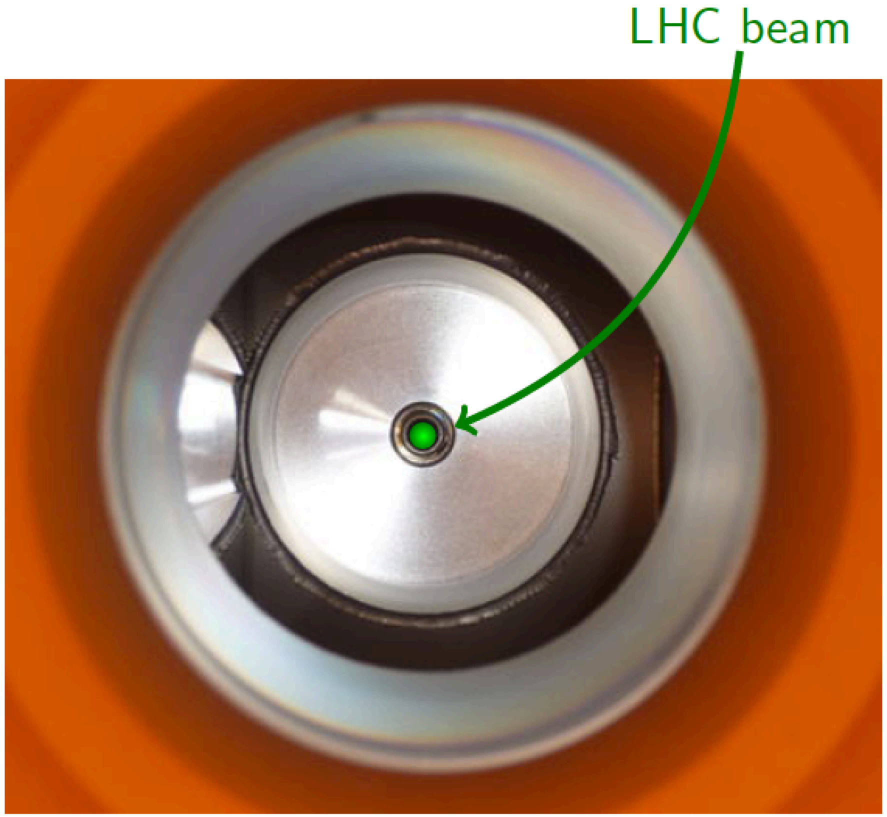
AFP



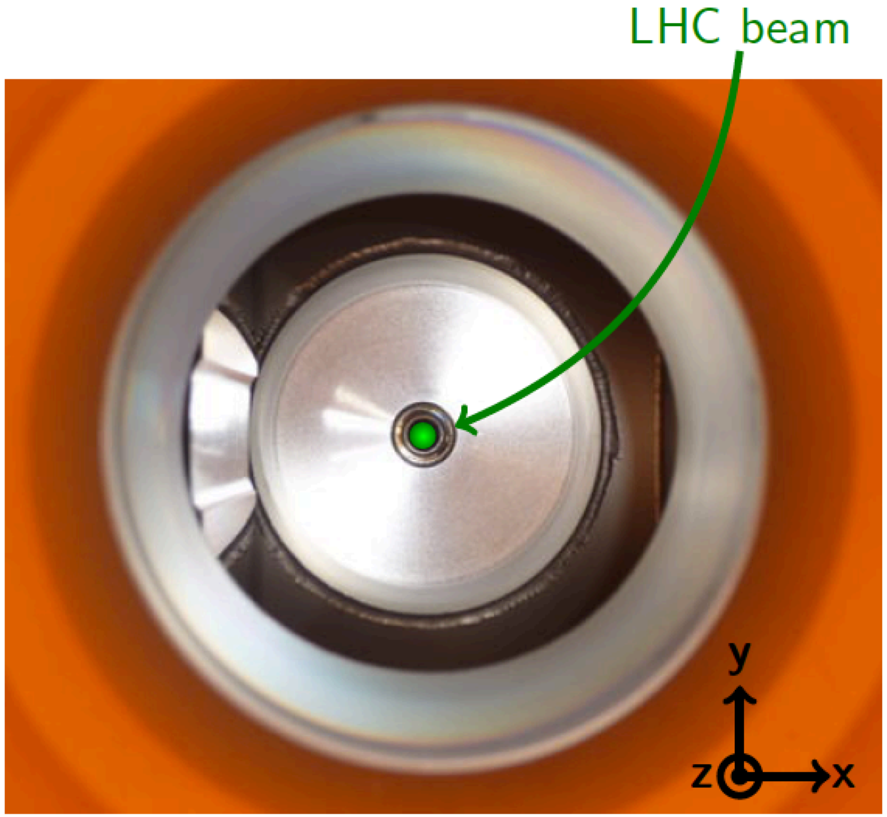


Advantages of Roman Pot Technology

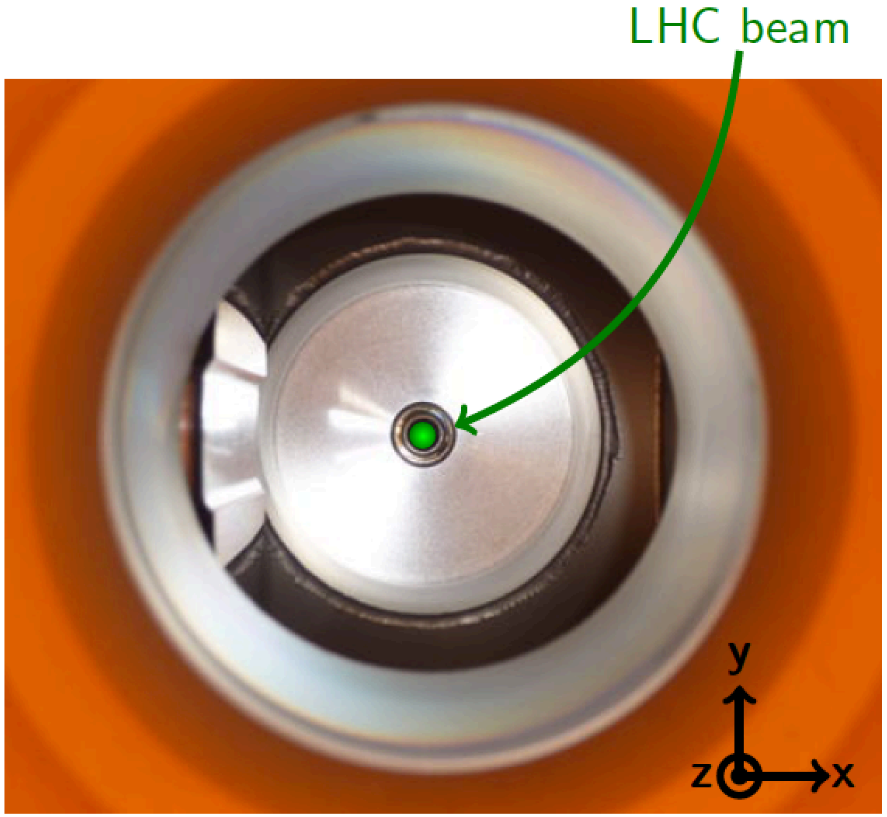
Advantages of Roman Pot Technology

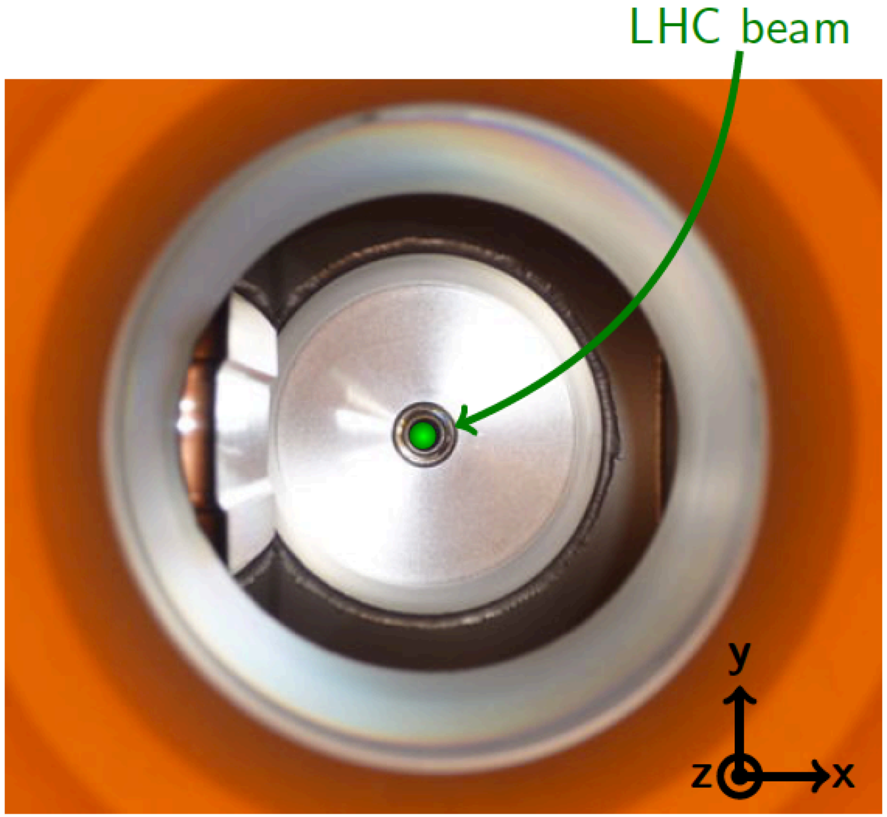


Advantages of Roman Pot Technology

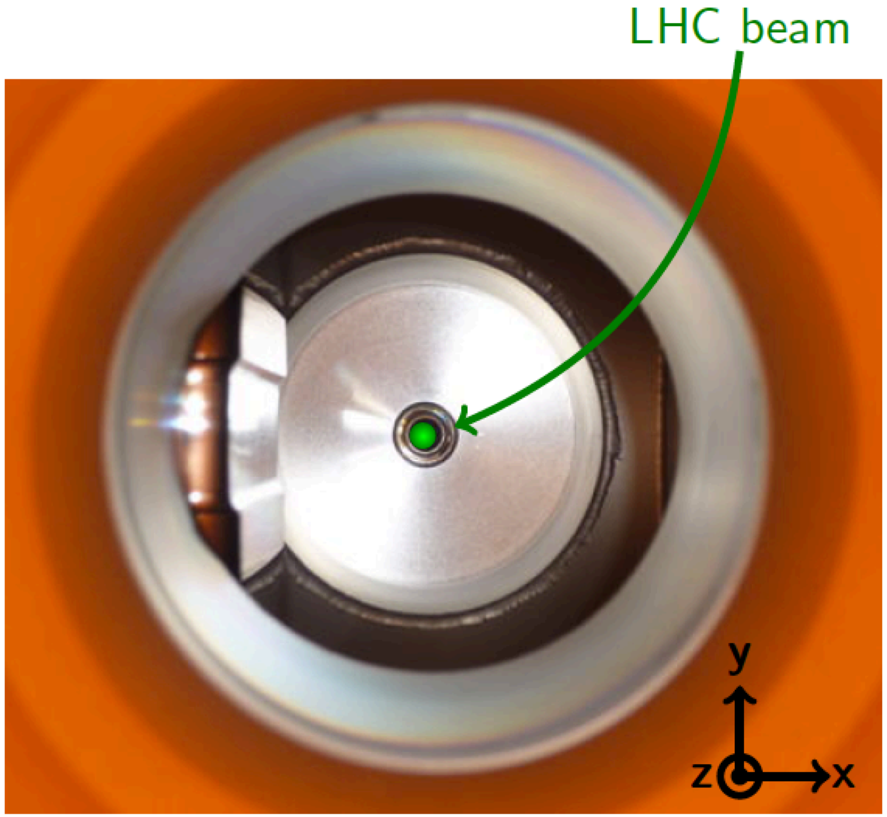


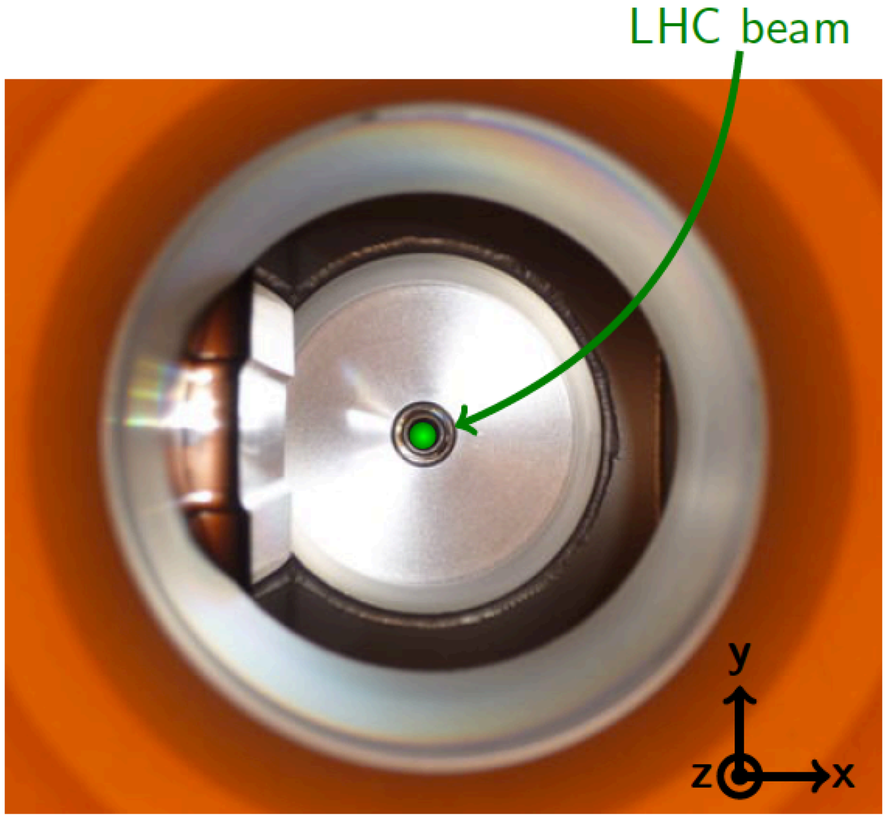
Advantages of Roman Pot Technology

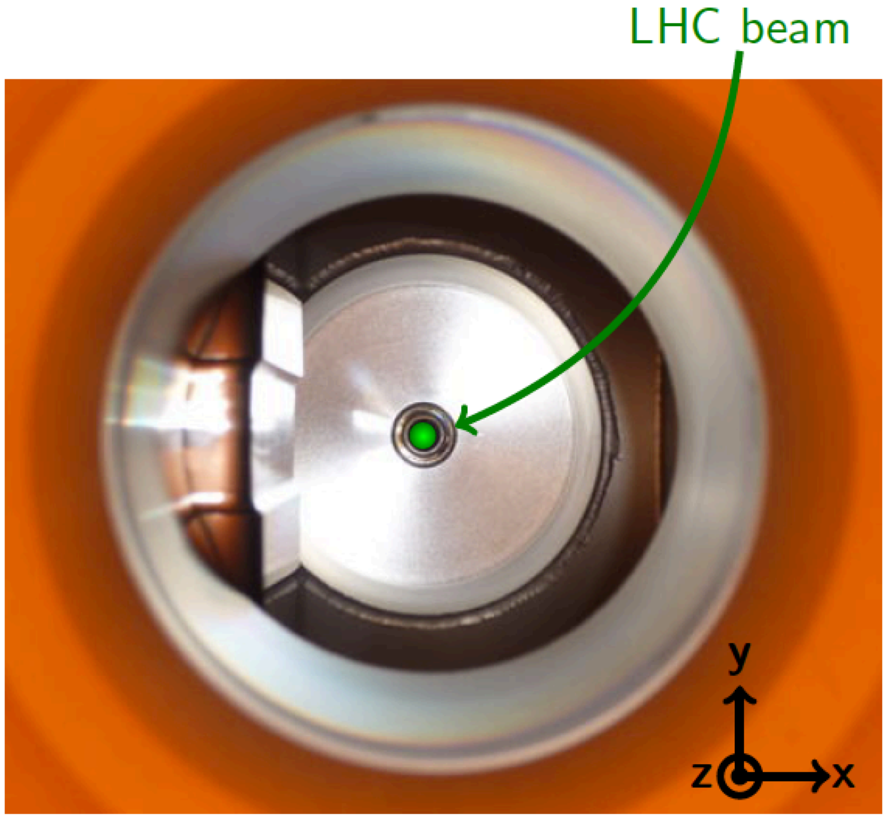


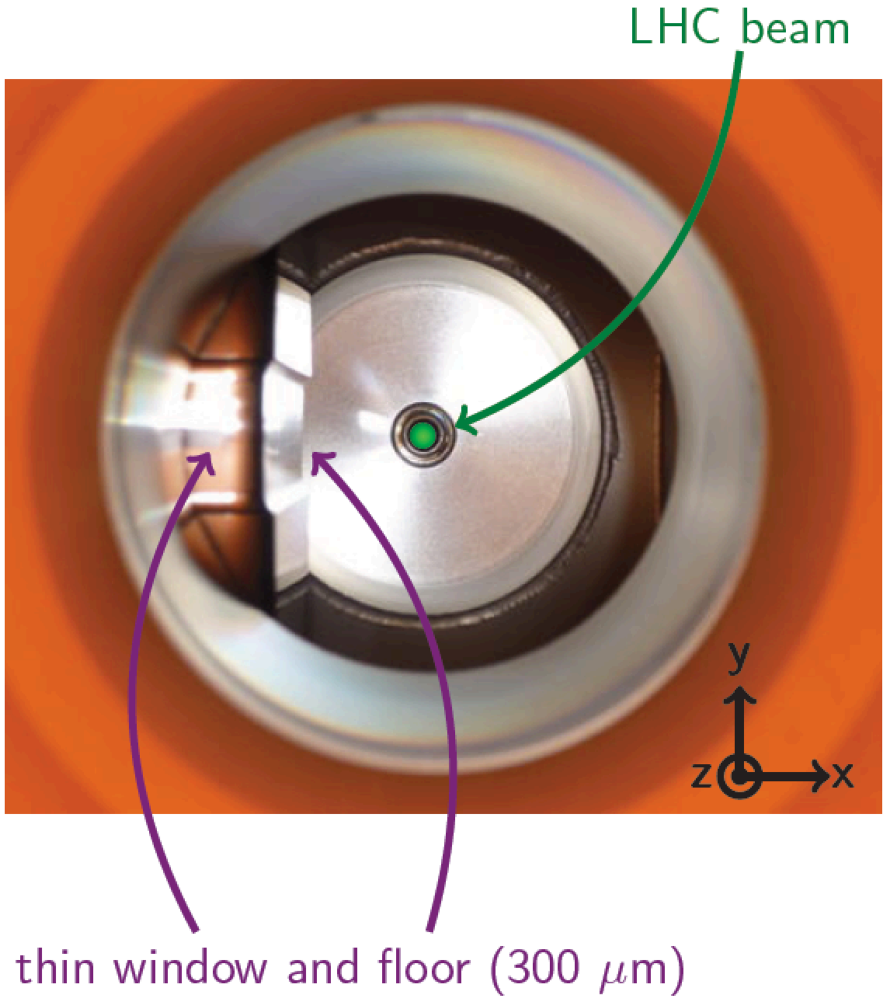

LHC beam
y
z
x

Advantages of Roman Pot Technology

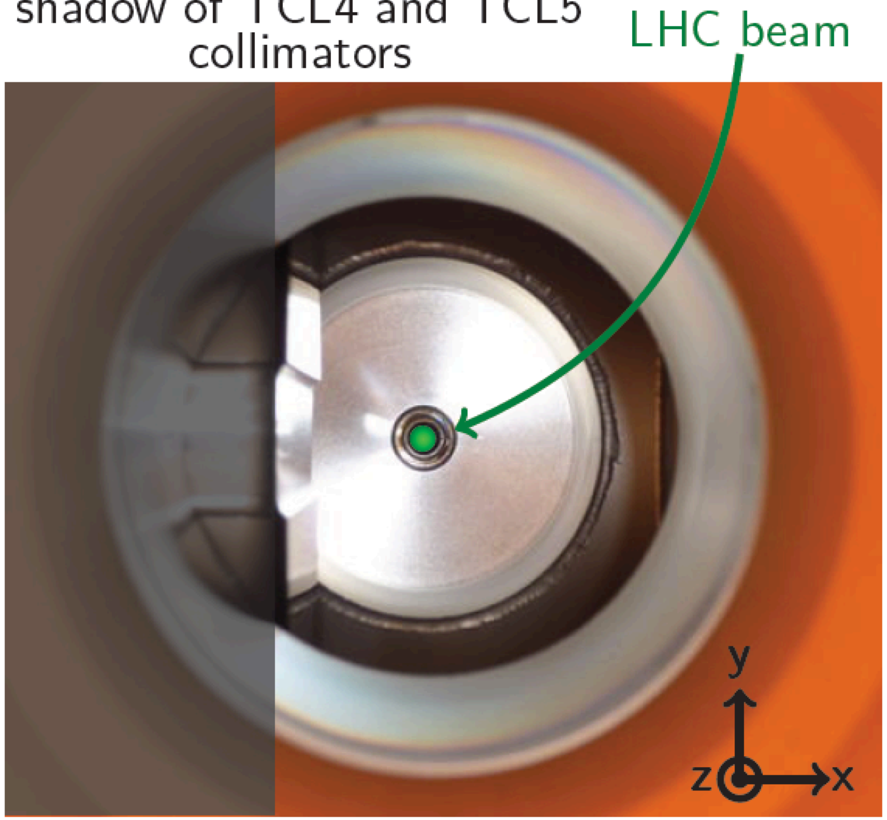



LHC beam
y
z
x


LHC beam
y
z
x

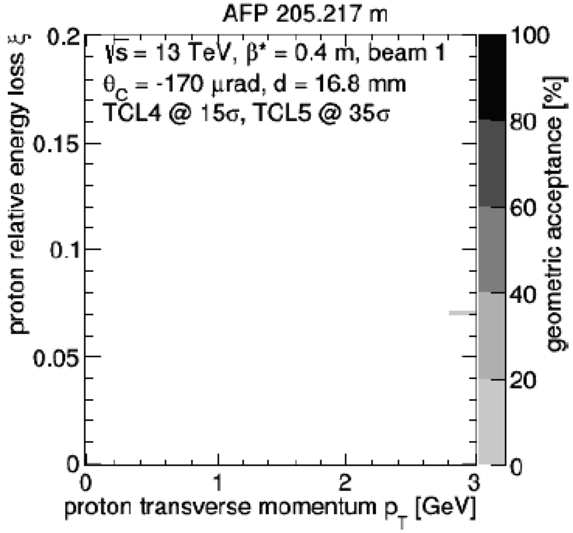

LHC beam
y
z
x
thin window and floor (300 μm)

shadow of TCL4 and TCL5 collimators

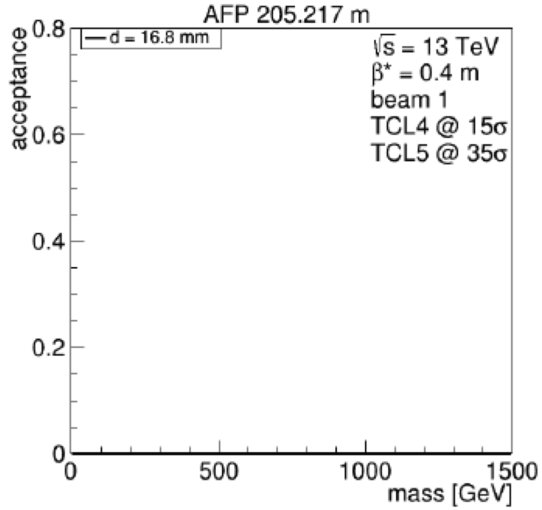


thin window and floor (300 μm)

Geometric acceptance:



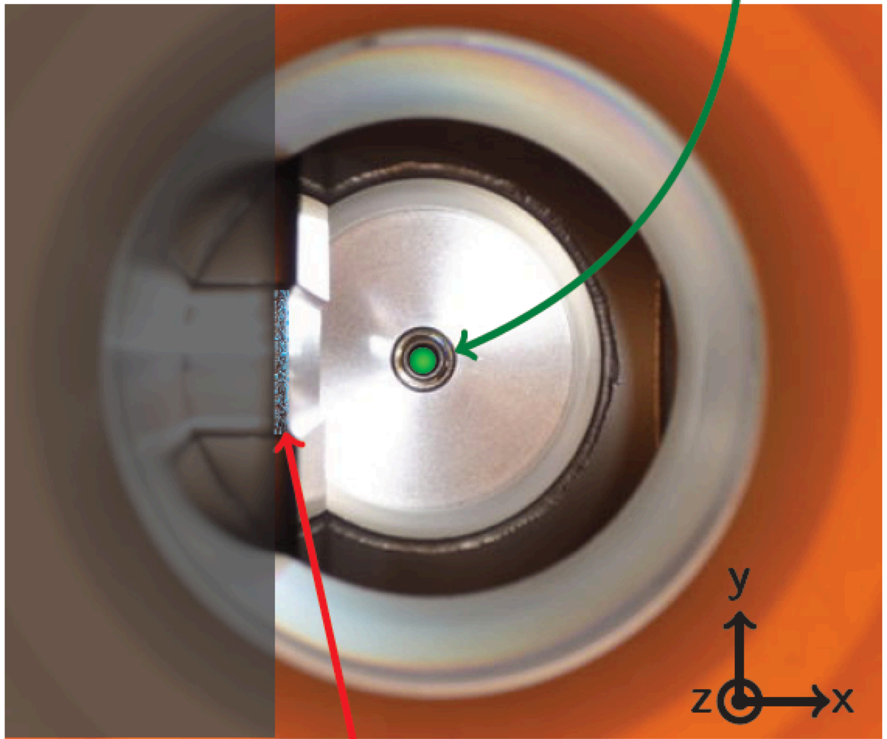
Mass acceptance:



Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

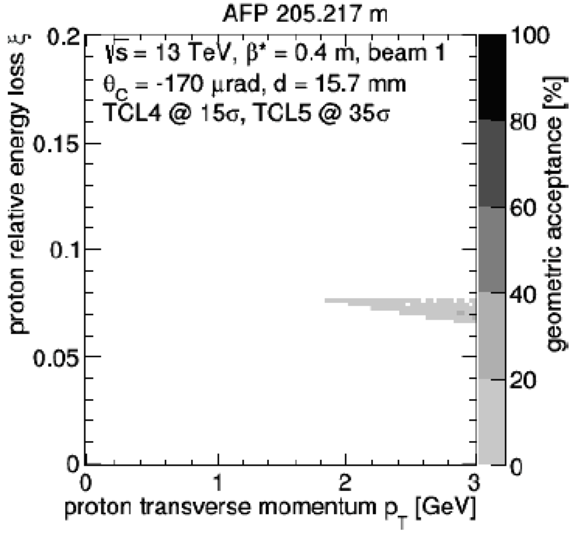
LHC beam



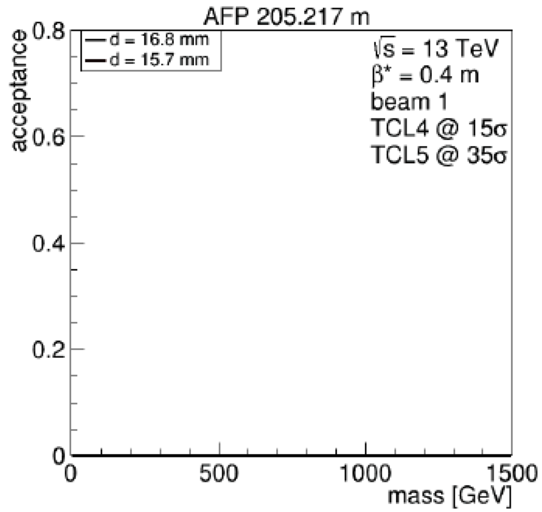
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



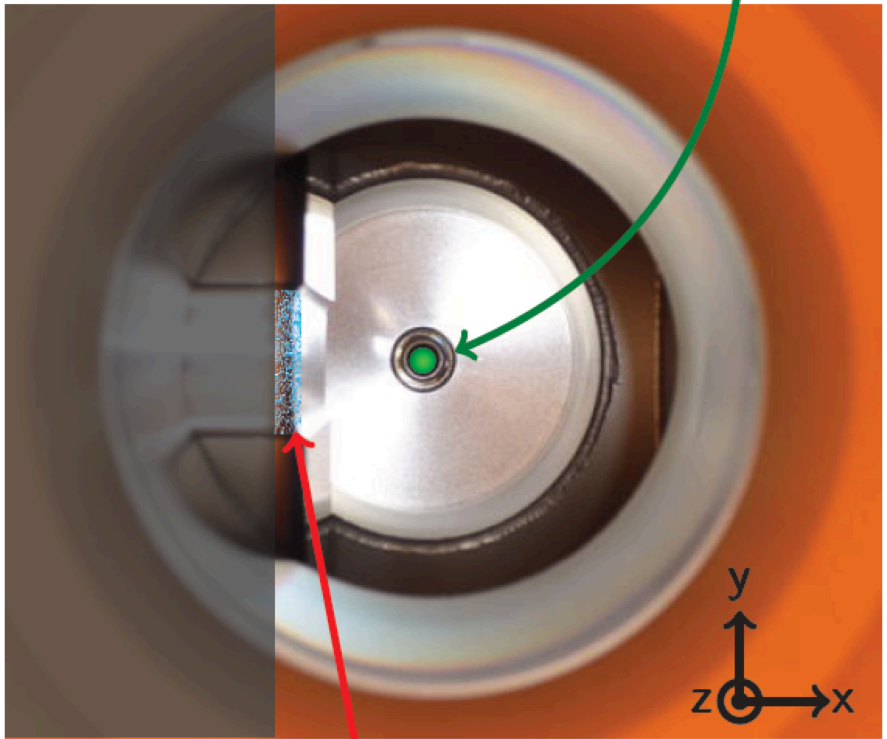
Mass acceptance:



Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

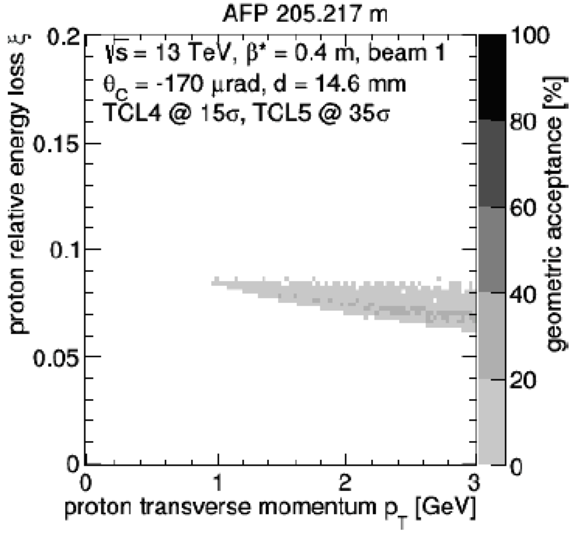
LHC beam



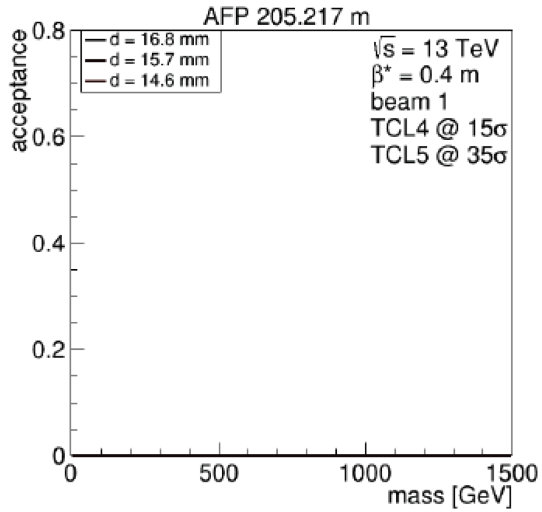
diffractive protons

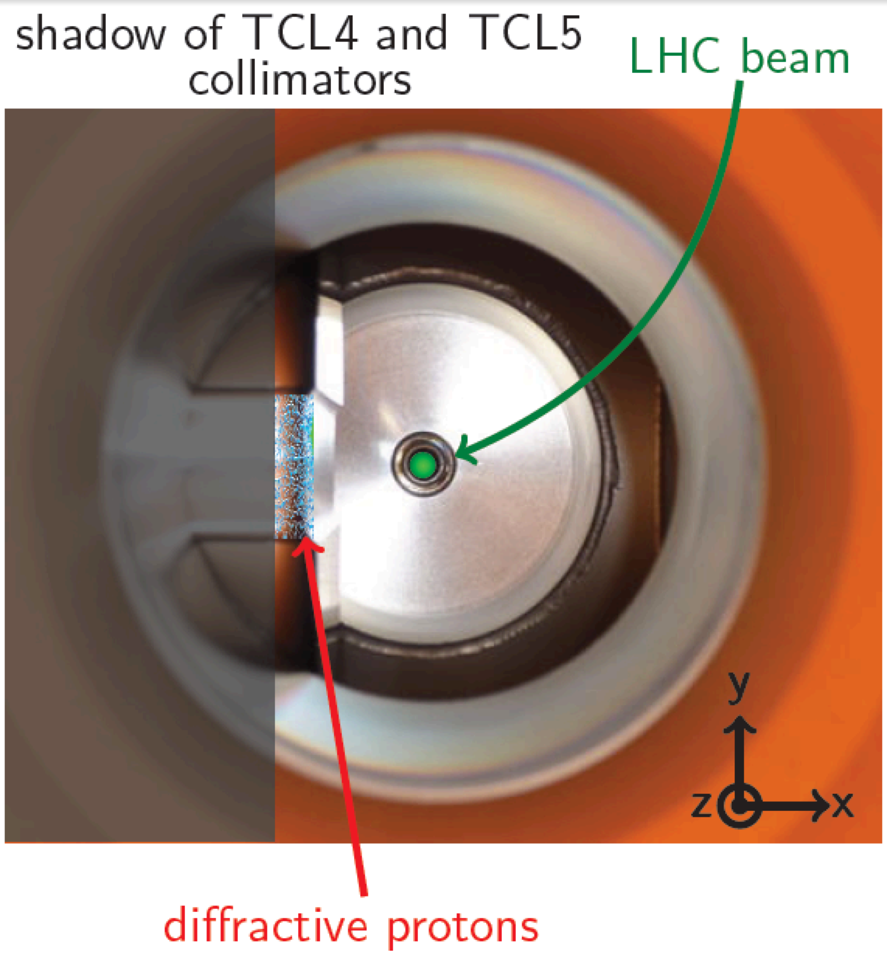
thin window and floor (300 μm)

Geometric acceptance:



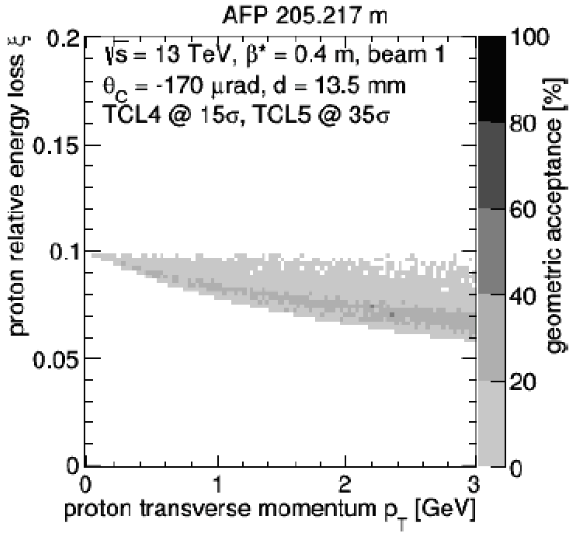
Mass acceptance:



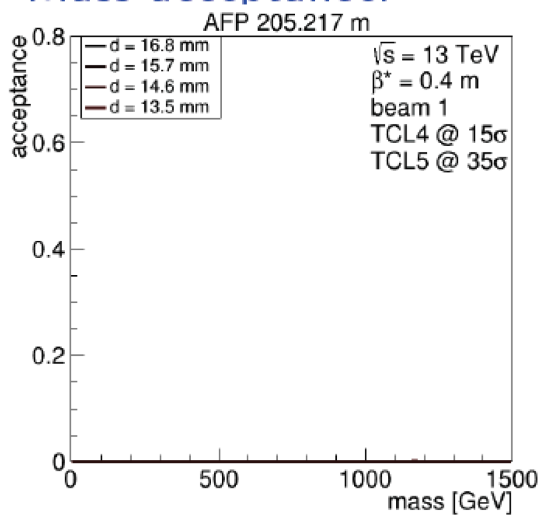


thin window and floor (300 μm)

Geometric acceptance:



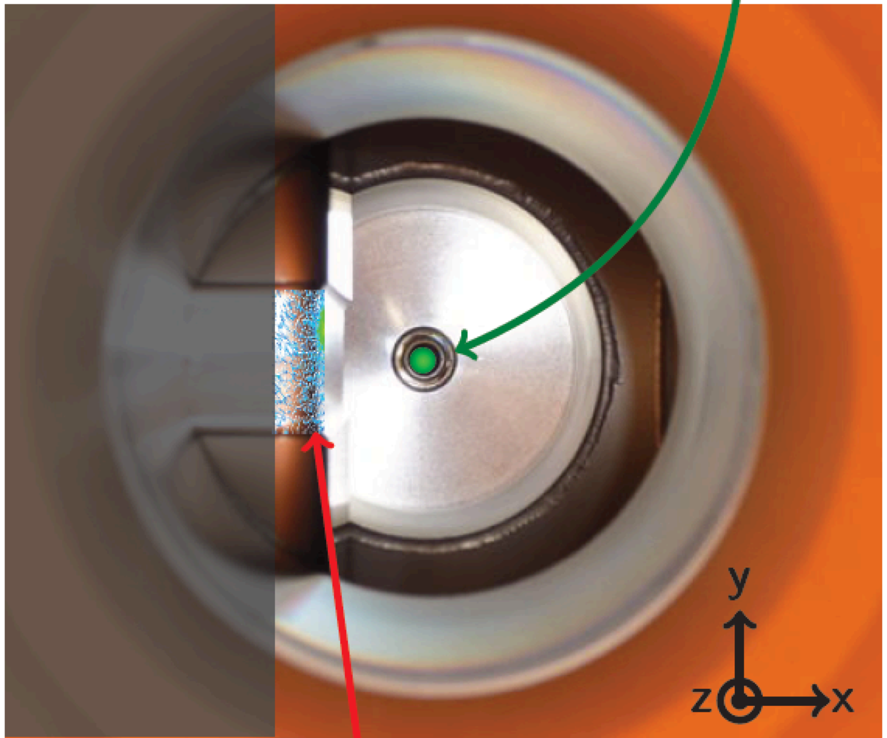
Mass acceptance:



Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

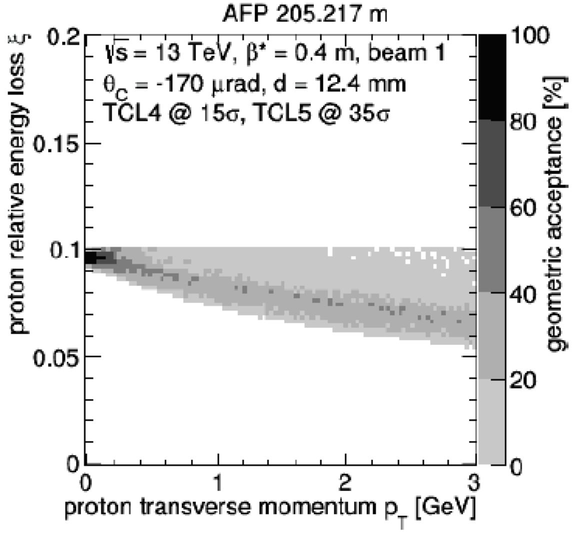
LHC beam



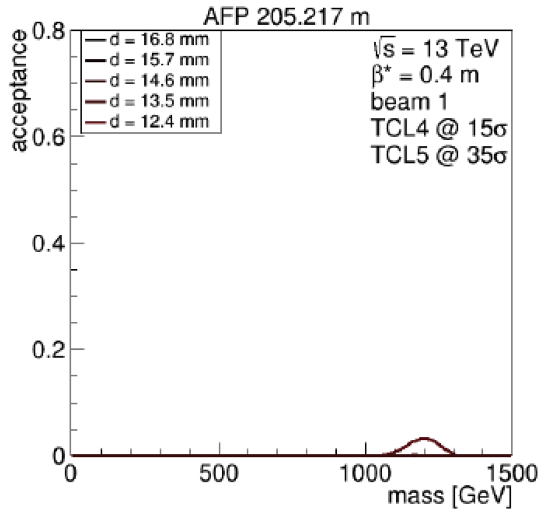
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



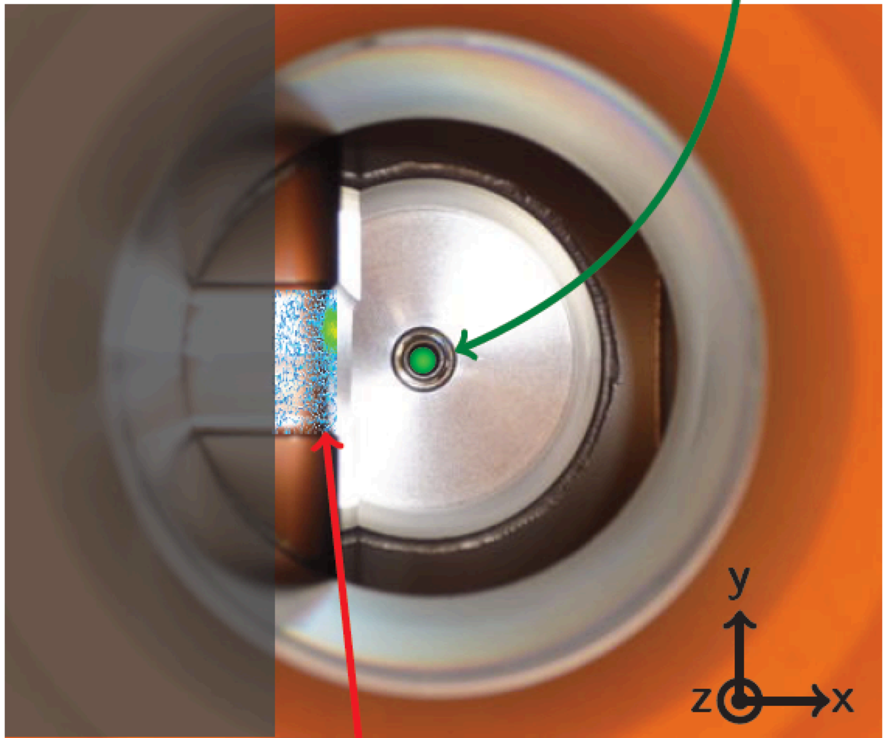
Mass acceptance:



Advantages of Roman Pot Technology

shadow of TCL4 and TCL5 collimators

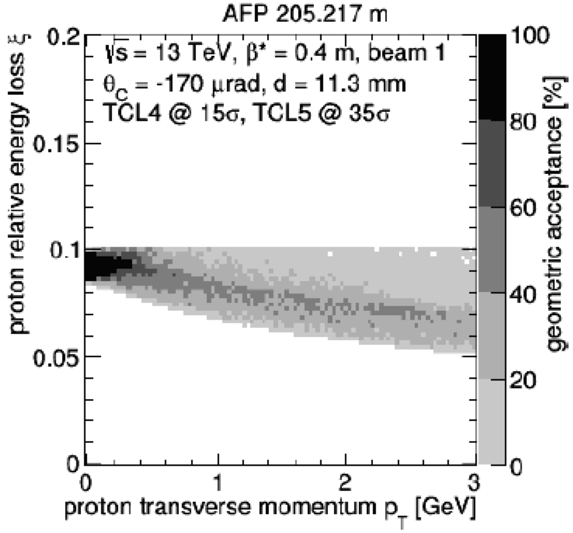
LHC beam



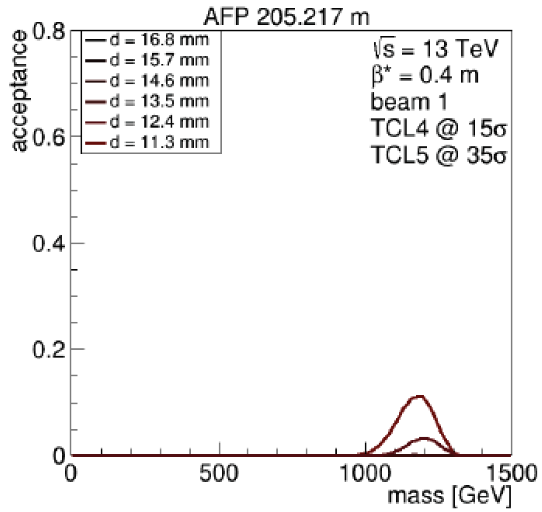
diffractive protons

thin window and floor (300 μm)

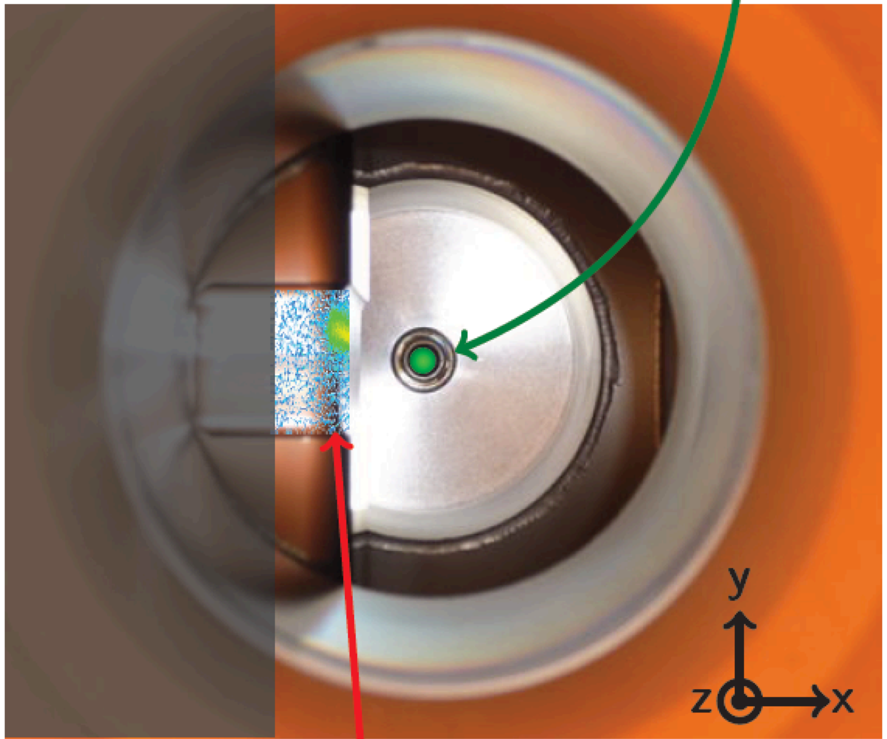
Geometric acceptance:



Mass acceptance:

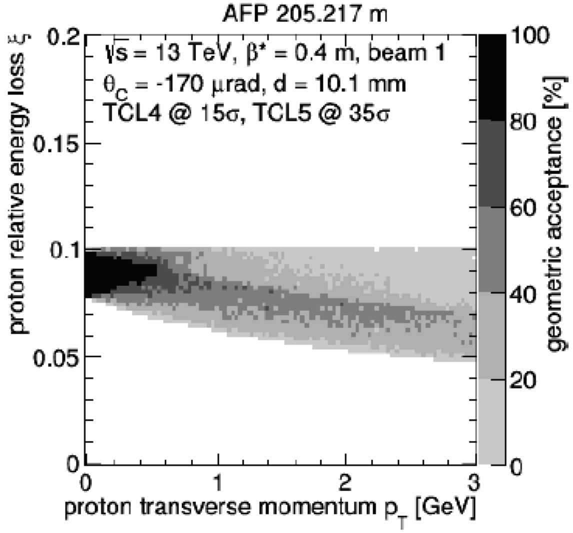


Advantages of Roman Pot Technology

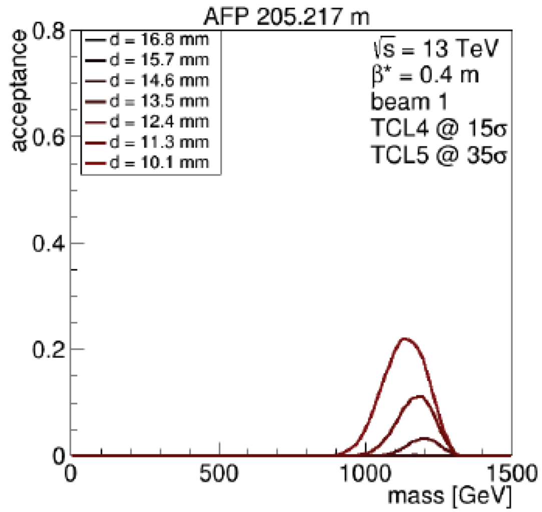


thin window and floor (300 μm)

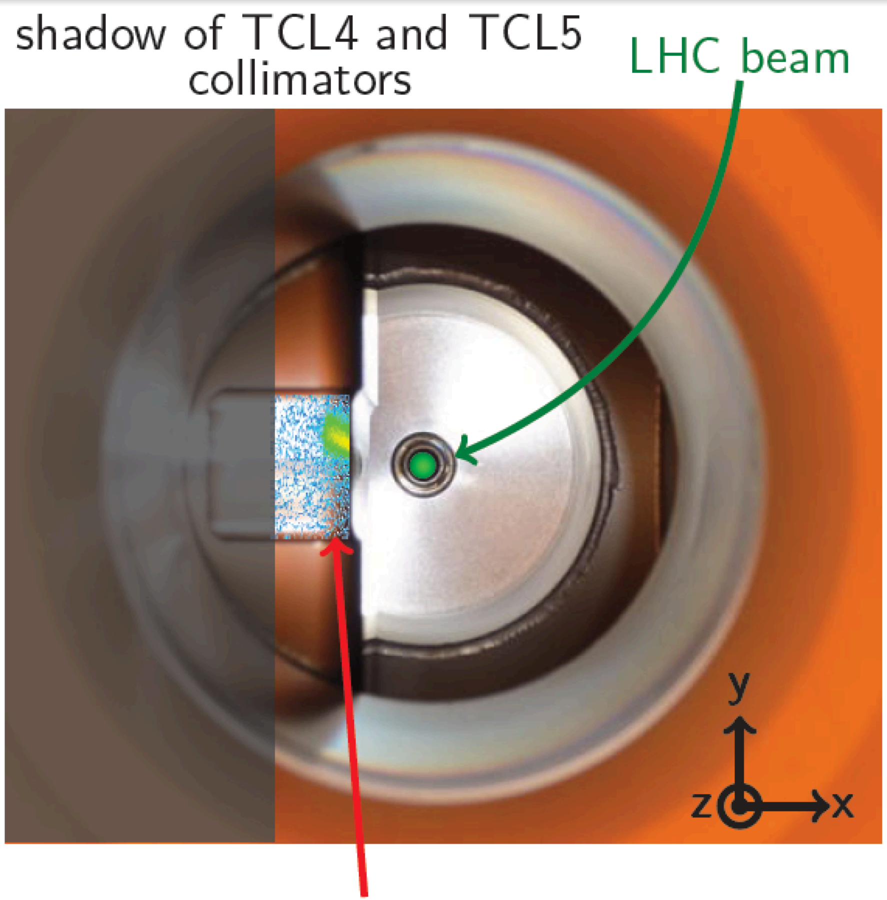
Geometric acceptance:



Mass acceptance:

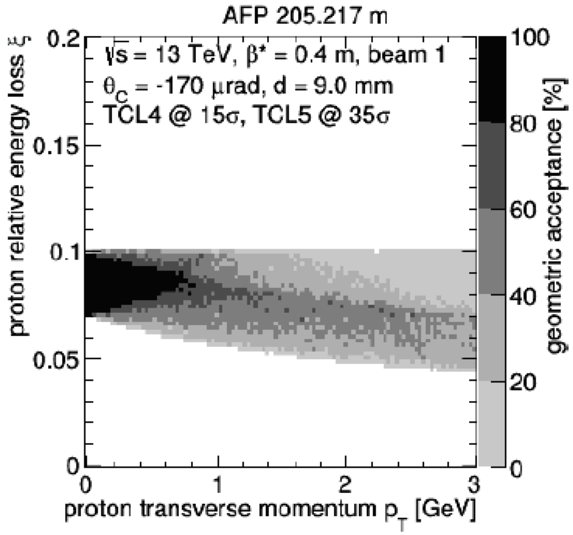


Advantages of Roman Pot Technology

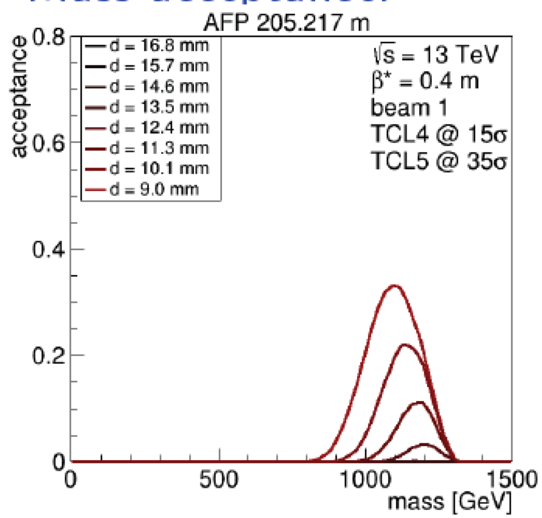


thin window and floor (300 μm)

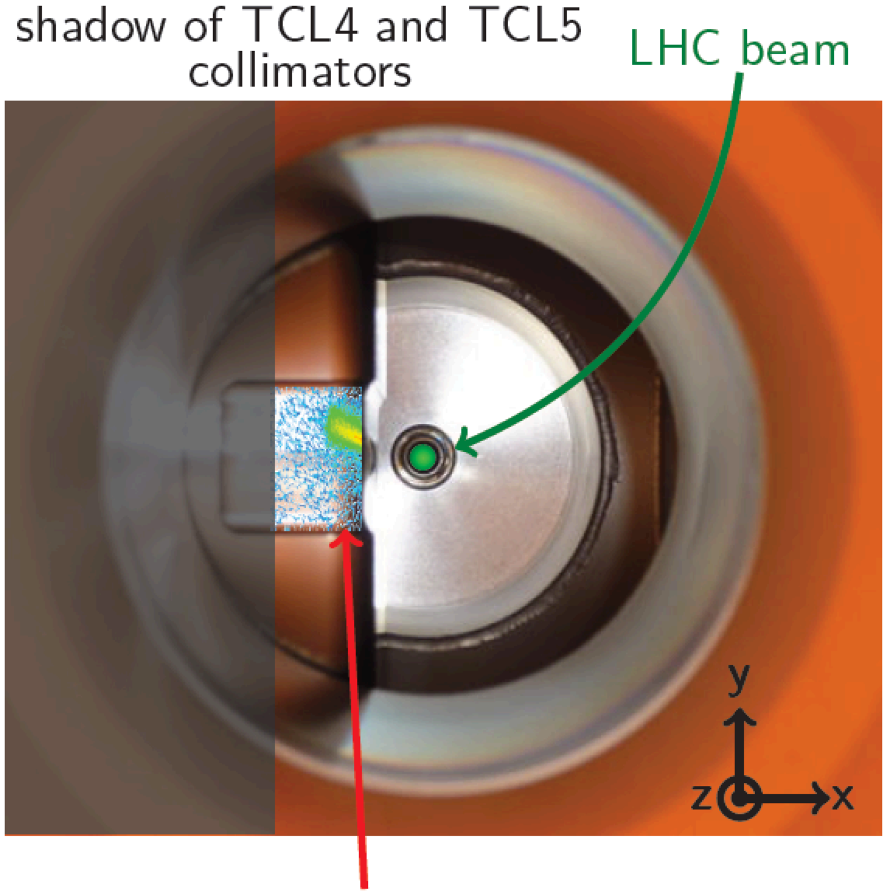
Geometric acceptance:



Mass acceptance:

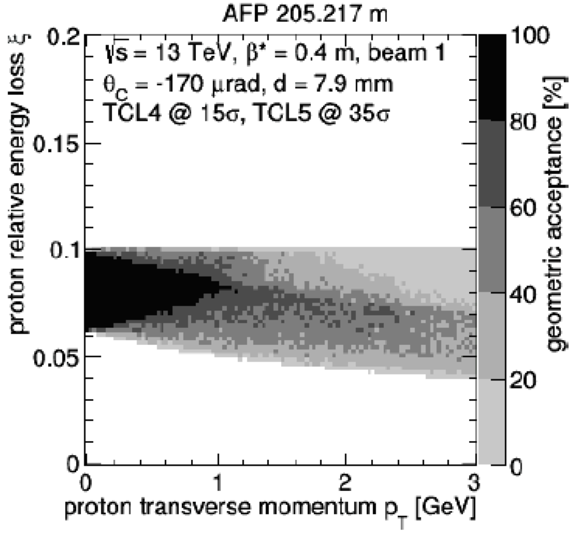


Advantages of Roman Pot Technology

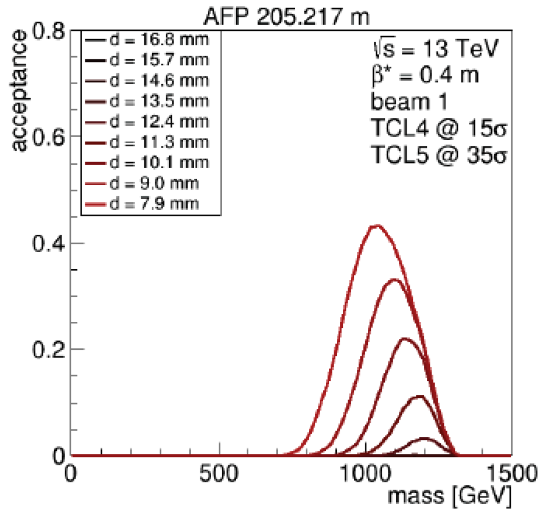


thin window and floor (300 μm)

Geometric acceptance:

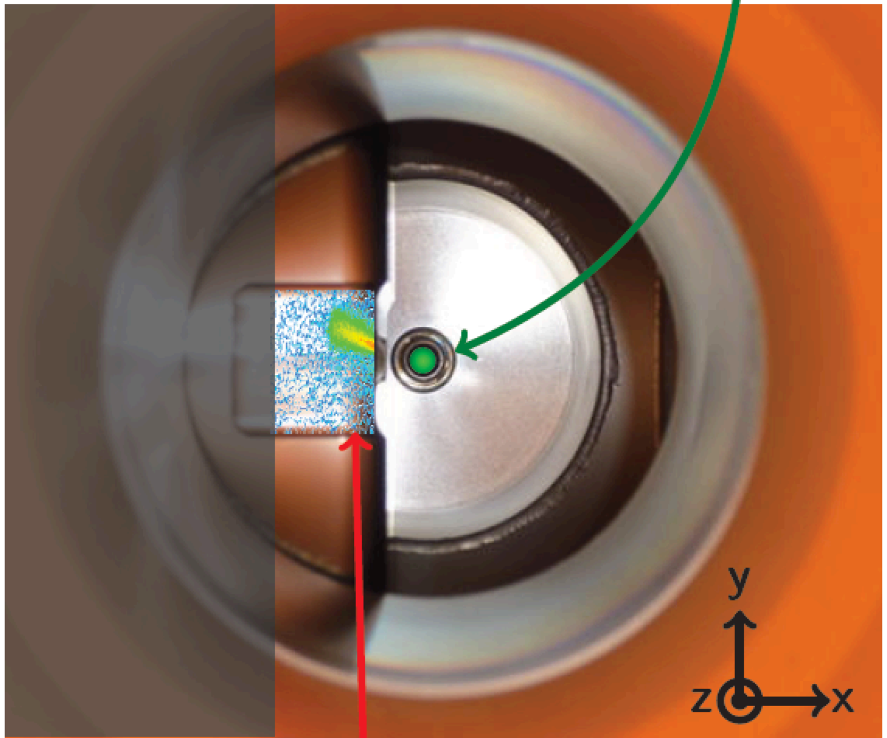


Mass acceptance:



shadow of TCL4 and TCL5 collimators

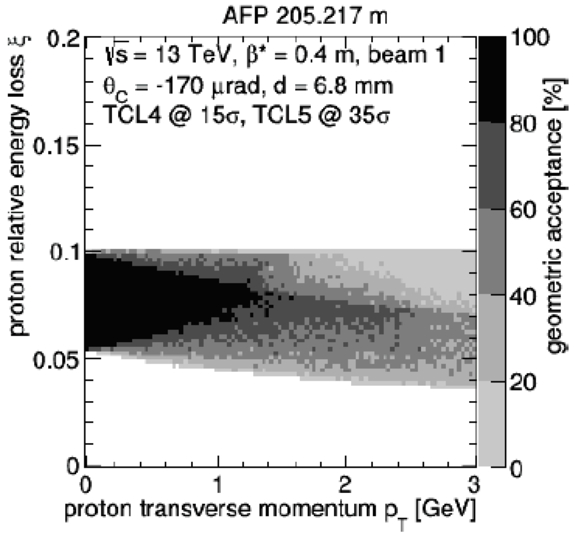
LHC beam



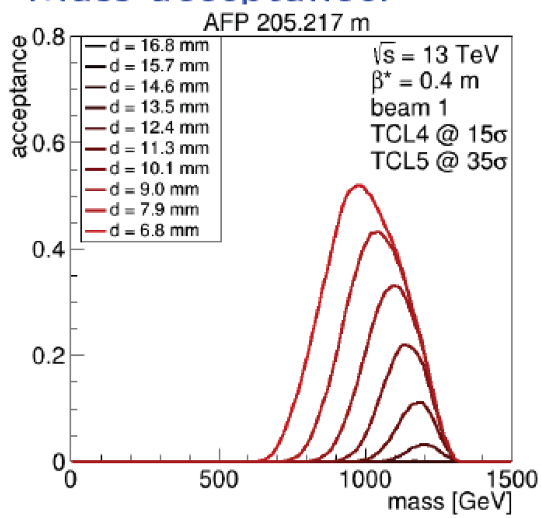
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:

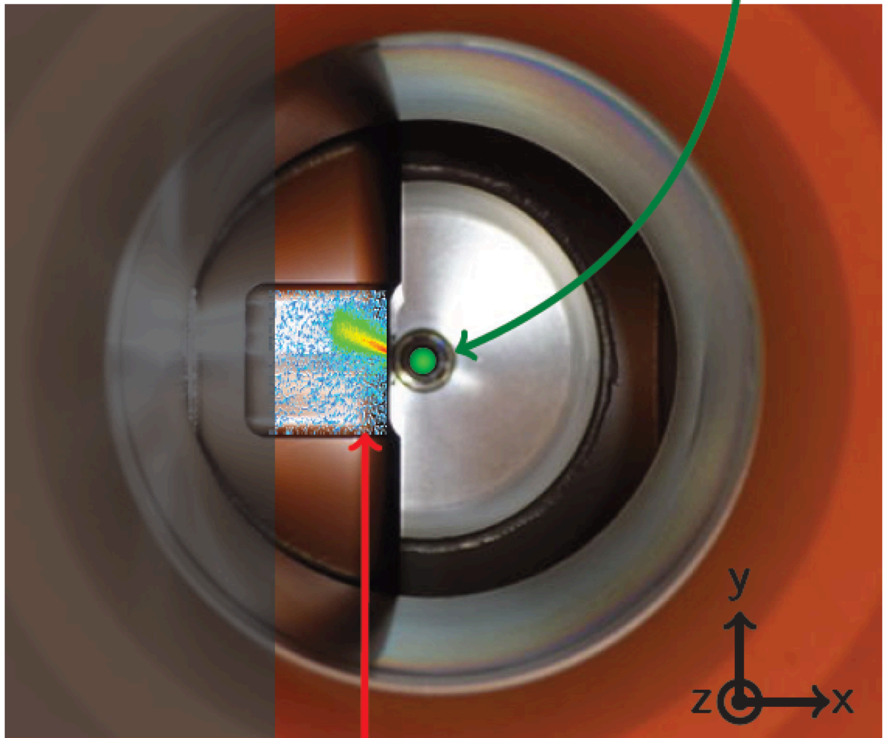


Mass acceptance:



shadow of TCL4 and TCL5 collimators

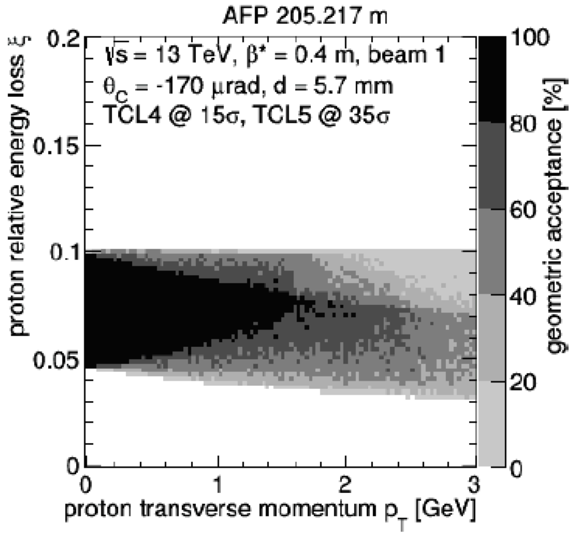
LHC beam



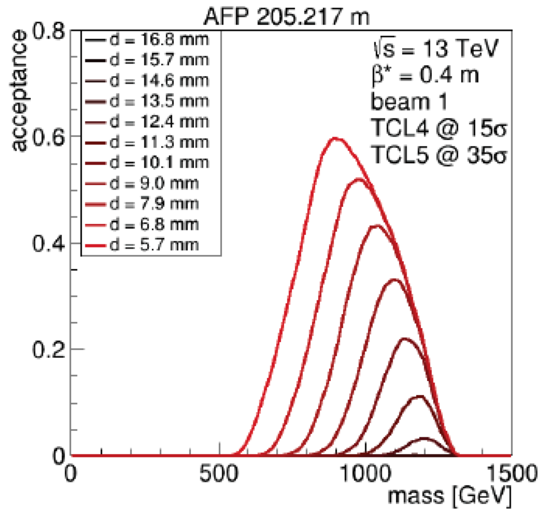
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:



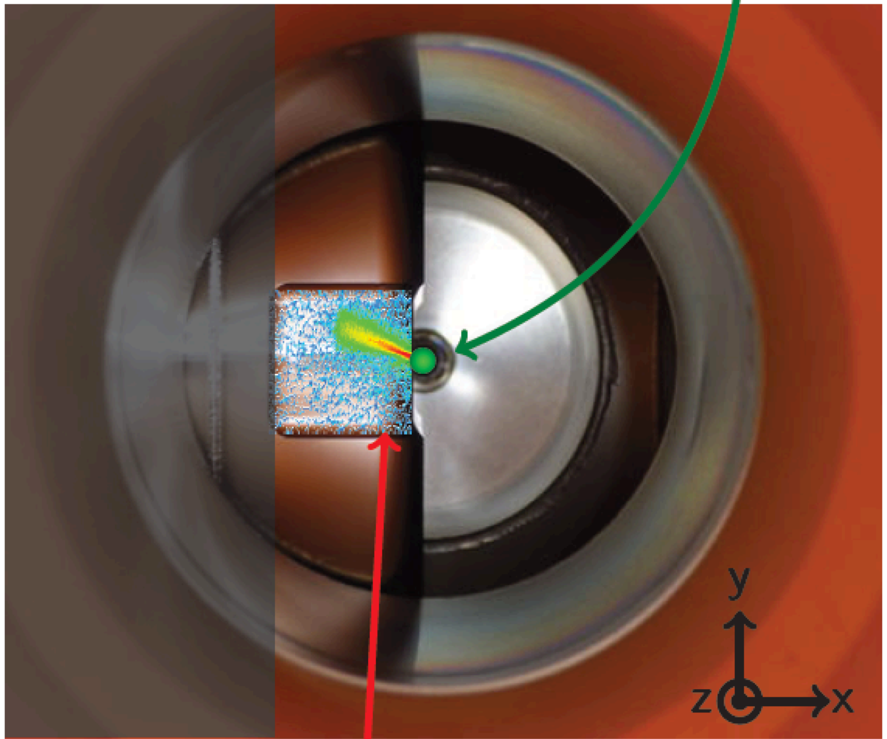
Mass acceptance:



Advantages of Roman Pot Technology

shadow of TCL4 and TCL5
collimators

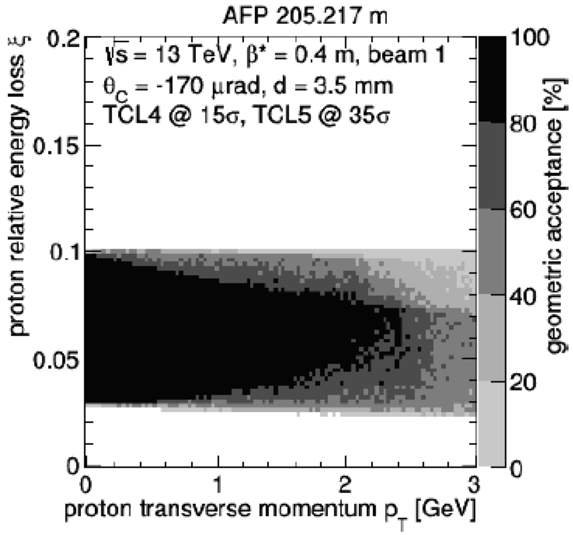
LHC beam



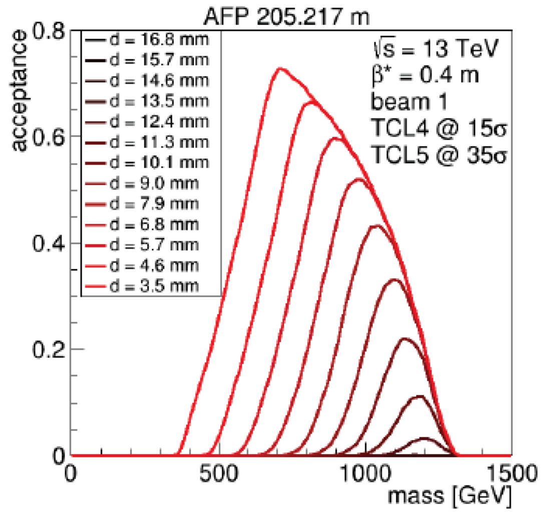
diffractive protons

thin window and floor (300 μm)

Geometric acceptance:

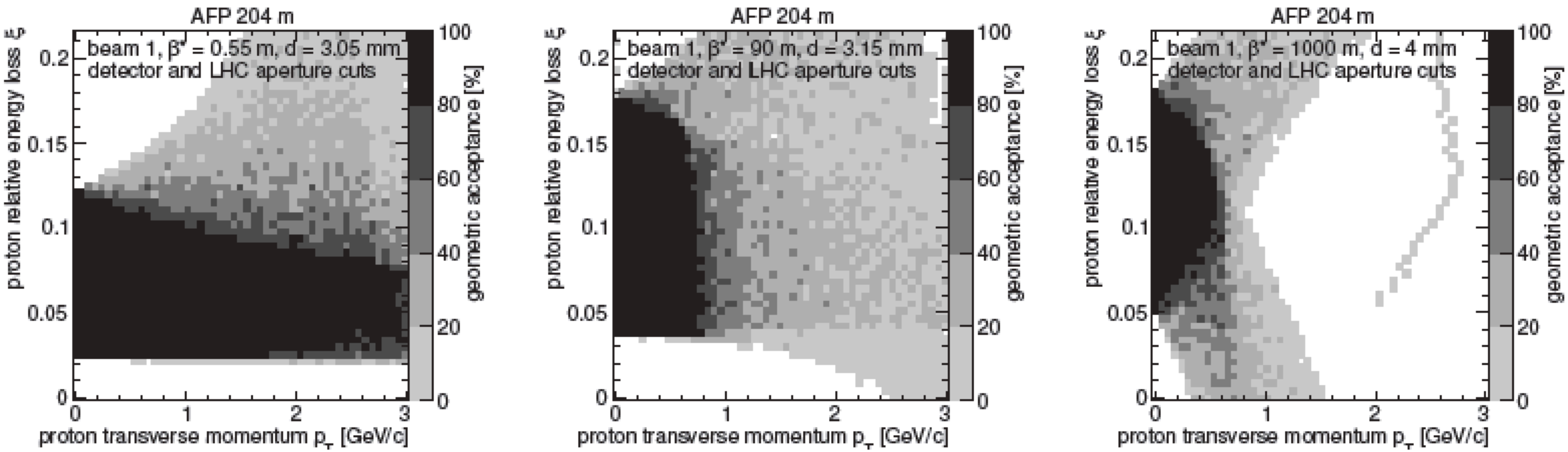


Mass acceptance:



Acceptance for Different Beam Set-ups

Acceptance is a strong function of beam conditions
By increasing β*, change acceptance, reduced luminosity, but can approach closer to the beam
(Collimator restriction at large ξ not shown)



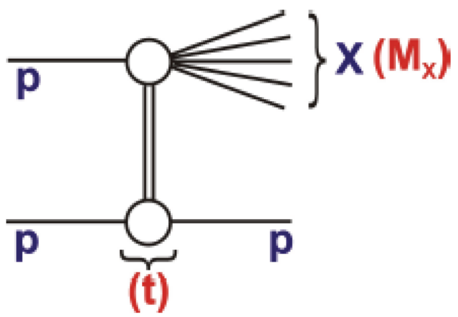
$\beta^* = 0.55$ m	$\beta^* = 90$ m	$\beta^* = 1000$ m
nominal (*collision*)	special (*high-β^**)	special (*high-β^**)
distance: 15σ	distance: 5σ	distance: 5σ

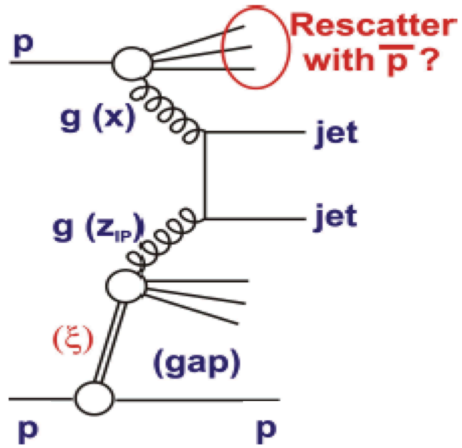
Special runs at high , low lumi have little / no pile-up and easier trigger conditions

AFP Physics Programme 1 – Special Runs

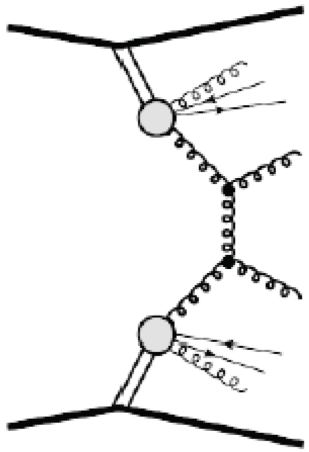
→ Soft phenomenology → Diffractive PDFs → Gap survival

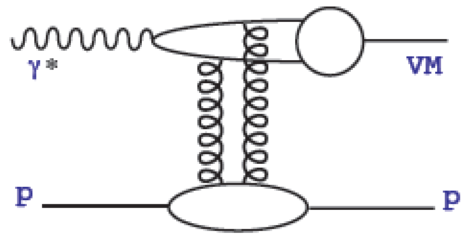
Single Tags: Single diffractive dissociation





Double Tags: Inclusive central production and low mass exclusive production

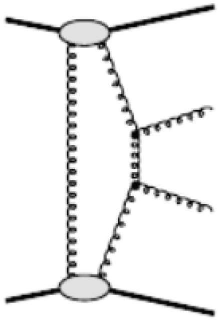


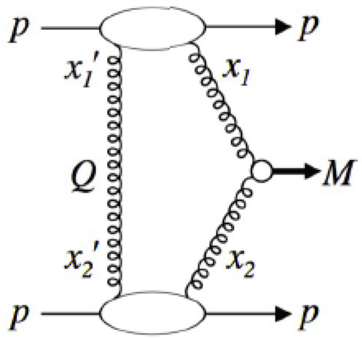


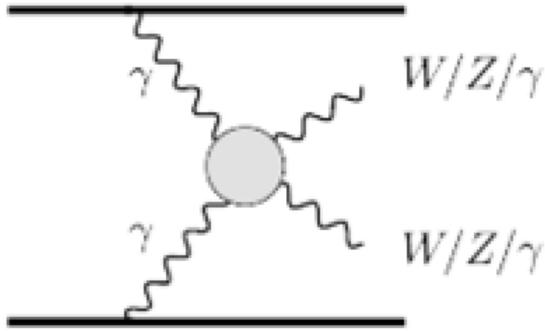
- Inclusive differential cross sections
- Particle flow and spectra, event shapes
- Resonance searches (eg glueballs)
- Hard scattering with jets, heavy flavour, W, Z signatures
- Ultra-peripheral collisions → diffractive photoproduction
- Heavy ion physics (p in pA, nuclear fragments in AA)

AFP Physics Programme 2 - Nominal Runs

→ Uncharted QCD territory → Rare and exotic EW physics
→ Searches for New Physics

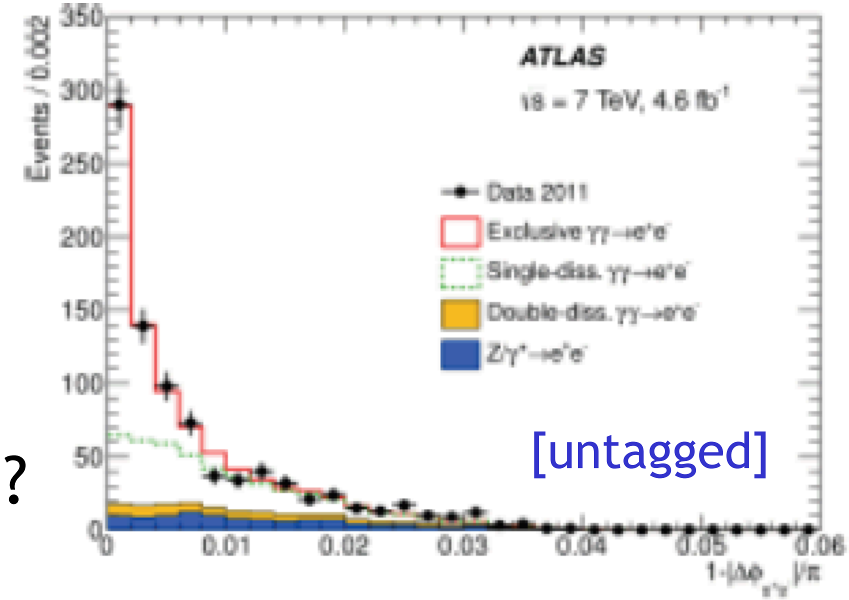






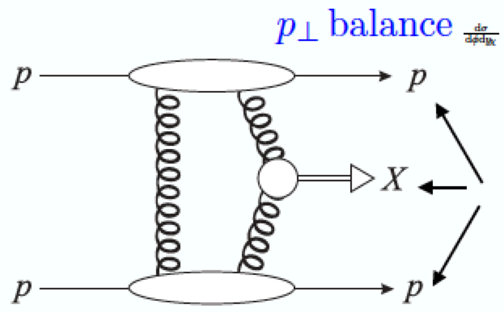
- **<u>Central Exclusive QCD Production</u>** of dijets, γ-jet and other strongly produced high mass systems

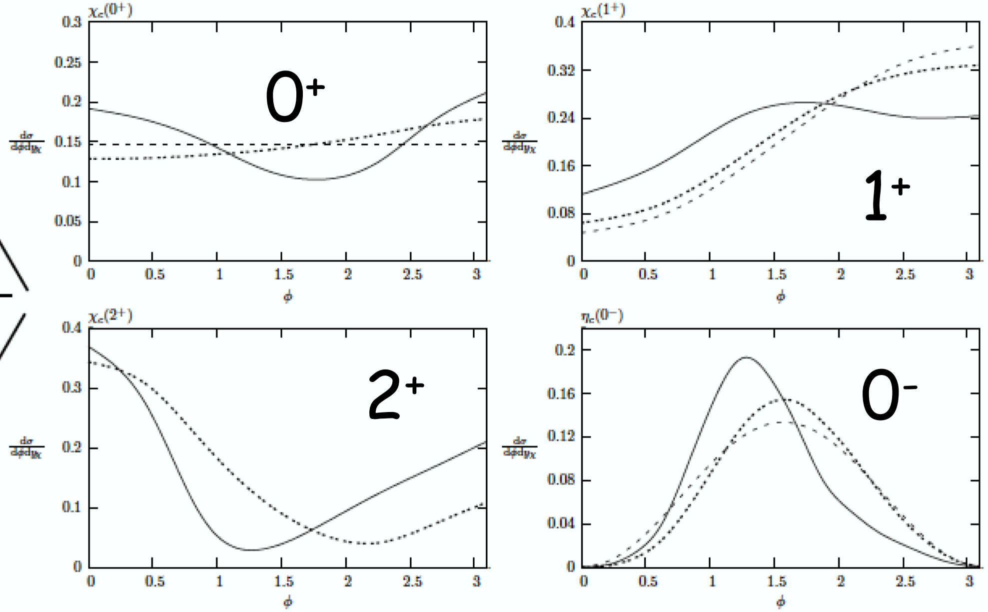
- **<u>Two photon physics</u>** → exclusive dileptons, dibosons & anomalous multiple gauge couplings, exclusive t-tbar → top mass via threshold scan?



- **<u>Searches for new heavy particles</u>** (axions, WIMPS, charged and double-charged Higgs, vector-like fermions …)

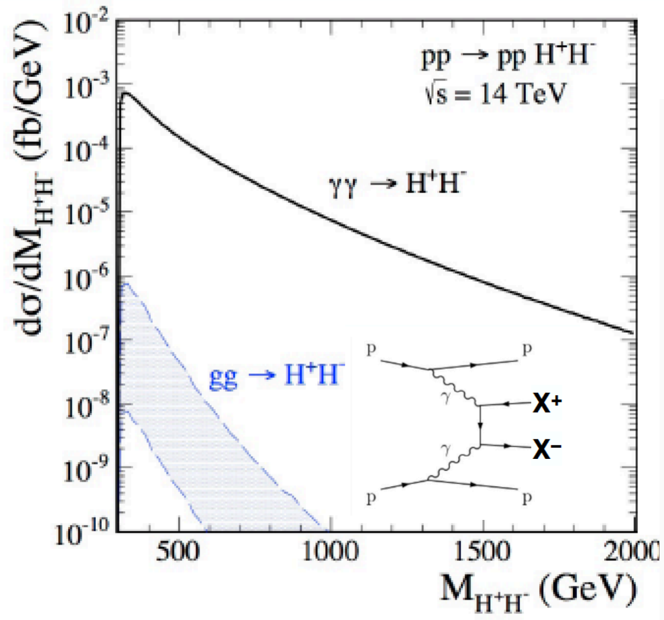
Nominal Runs ctd

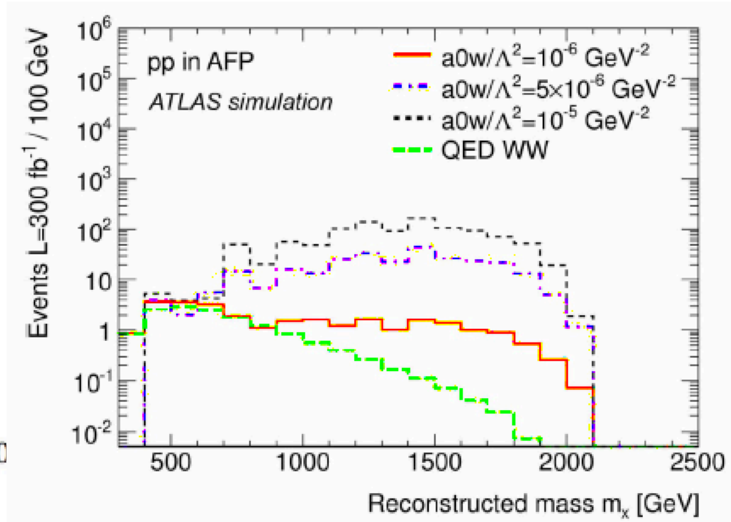


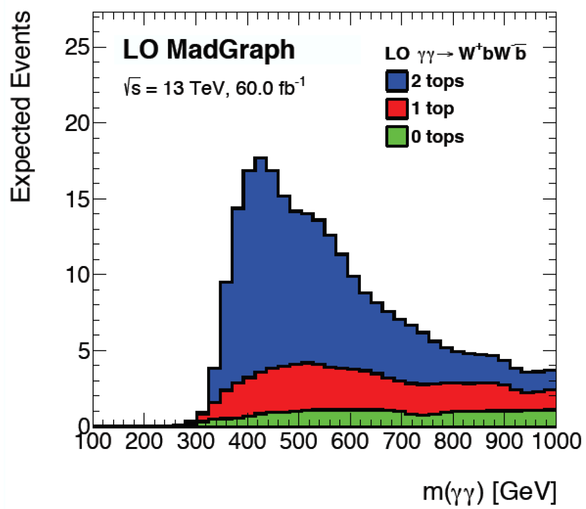


- Spin parity analysis via angular distributions between outgoing protons [KMR]
- Pair produced BSM states (eg $H^{+/-}$, Lebiedowicz, Szczurek)
- $\gamma\gamma \rightarrow WW$, best sensitivity to anomalous quartic coupling
- Top mass via threshold scan in exclusive $\gamma\gamma \rightarrow tt$ (Howarth)

… but event rates are always v. small!







AFP Operation So Far

2016

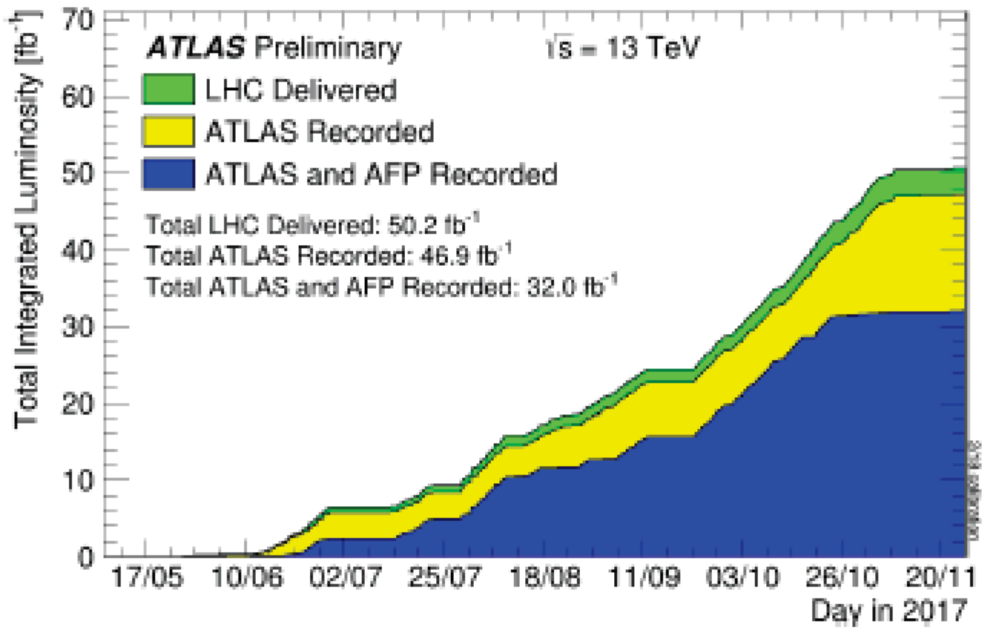
- $\sqrt{s} = 13$ TeV, $\beta^* = 0.4$ m
- Only two stations installed (one side)
- Only single tagged events
- Data taken during BBA:
  - two runs
  - closer to the beam than during standard running
  - very useful for alignment and optics studies
- Data taken during special runs:
  - $\mu \sim 0.03$:
    - int. lumi.:~40 nb^{-1}
    - main goal: soft diffraction
  - $\mu \sim 0.3$:
    - int. lumi.:~500 nb^{-1}
    - main goal: low-p_T jets
- Data taken during standard runs: AFP was inserted only when the number of bunches was not greater than 600 (ramp-up)

2017

- $\sqrt{s} = 13$ TeV, $\beta^* = 0.3$ and 0.4 m
- Full system ready
- Single and double tagged events
- Data taken during BBA:
  - two runs
- Data taken during special runs:
  - $\mu \sim 0.05$:
    - int. lumi.:~65 nb^{-1}
    - main goal: soft diffraction
  - $\mu \sim 1$:
    - int. lumi.:~640 nb^{-1}
    - main goal: low-p_T jets
  - $\mu \sim 2$:
    - int. lumi.:~150 pb^{-1}
    - goals: hard diffraction
- Data taken during standard runs: AFP was inserted on regular basis, usually few minutes after stable beams were declared

2017 Performance / 2018 Programme

- AFP operated routinely through most of high luminosity running, approaching beam to 11.5σ + 0.3mm by the end

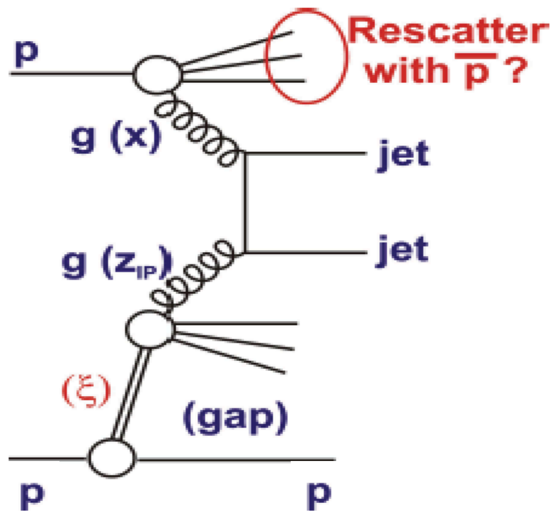


- Periods of stand-alone running for ToF commissioning

- 32fb^{-1} accumulated in total in 2017.
  - → Tracking detectors and DAQ functioning well
  - → Problems with ToF … poor efficiencies of PMTs

- Winter shutdown work completed; AFP is ready for restart.
- ToF problems still under study
  - → aim to implement in first technical stop (June 18).
  - → initial physics focus on lepton and photon signatures

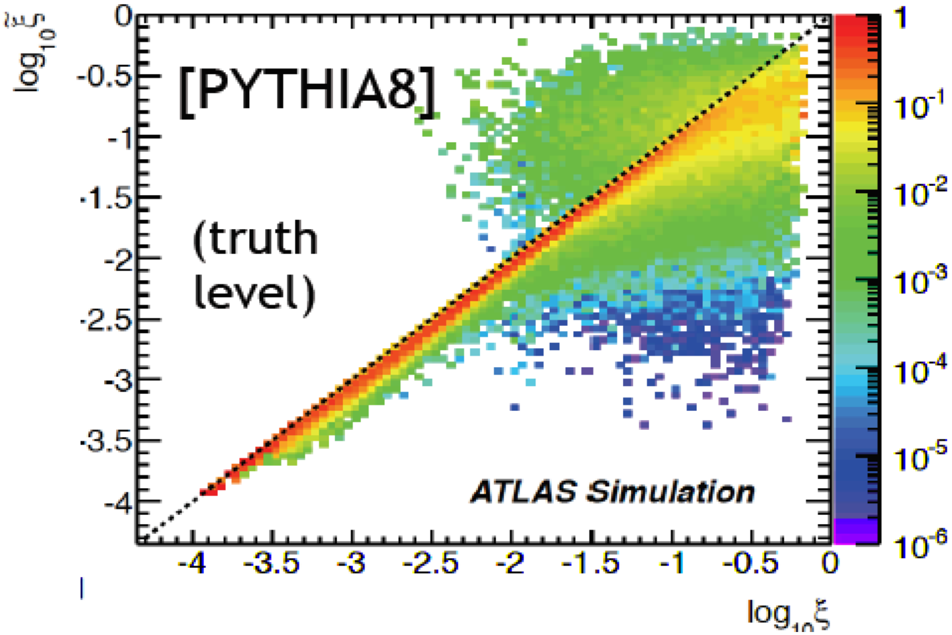
First Physics Study: Single Diffractive Dijets

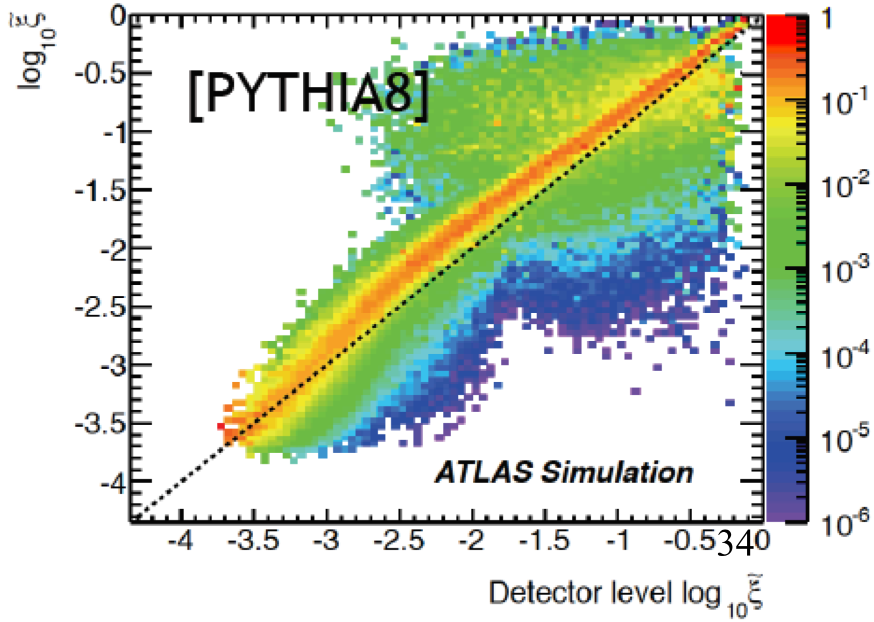


… using techniques from ATLAS rapidity gap based analysis …

$$\tilde{\xi} \simeq M_X^2/s = \sum p_T e^{\pm\eta}/\sqrt{s} \quad = \xi_{Cal} \text{ here}$$

… well resolved and good rec-truth correlation over wide range





Data and Selection

Special run taken in October 2016, μ ~ 0.3, $\beta^* = 0.4$ m

Trigger:

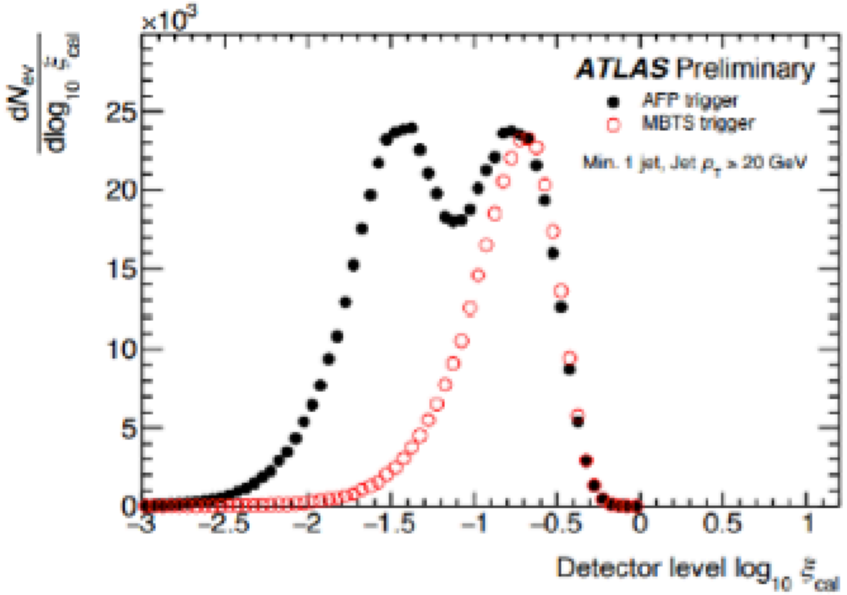
- signal sample – triggered with AFP (SiT, near and far)
- background sample – triggered with minimum bias trigger

Event selection:

- at least one jet with $p_T > 20$ GeV and $|\eta| < 3$
- exactly one reconstructed primary vertex
- at least two tracks associated with vertex
- for signal sample – clean signal in AFP (no more than one cluster in each plane, at least 5 planes with a cluster)

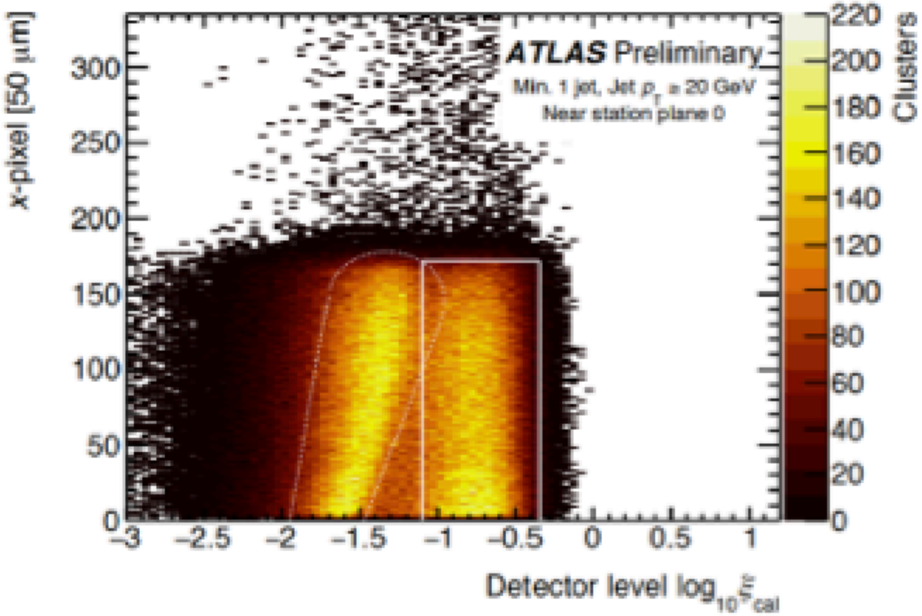
Results

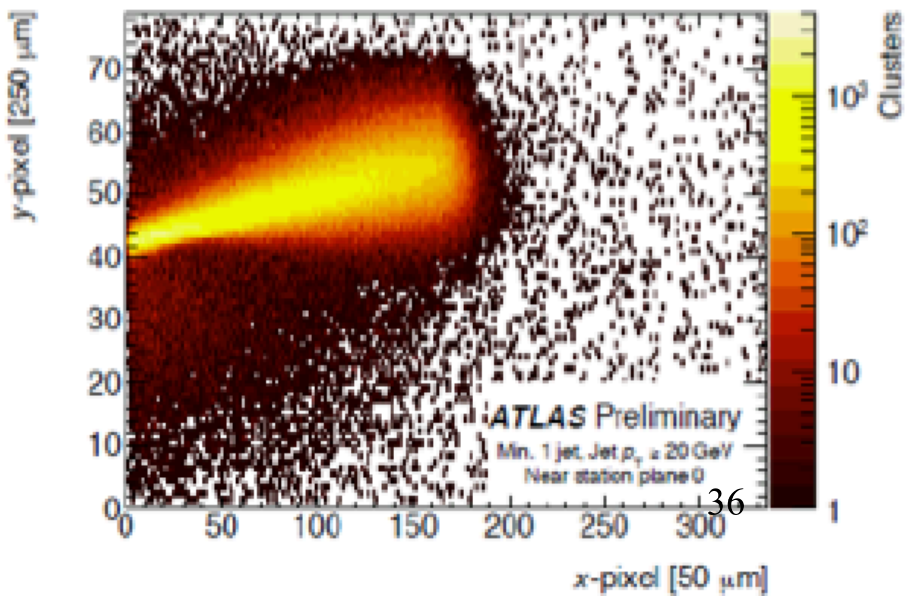
Clear enhancement in low ξ_{Cal} diffractive region for AFP-triggered data over MBTS data + common pile-up contribution



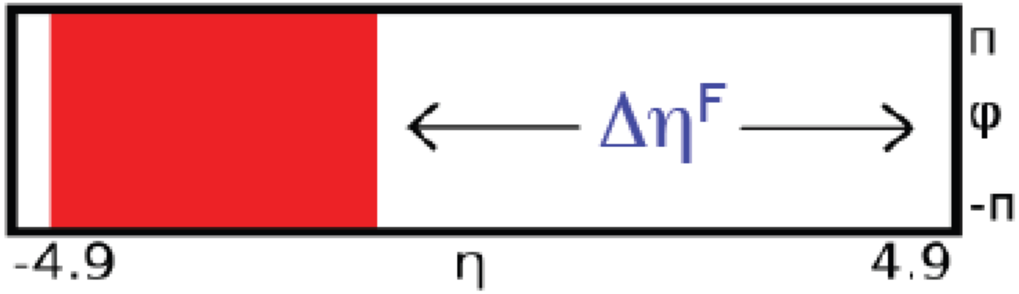
Low x data exhibit expected x-y correlation in AFP pixels and correlation between pixel x position and ξ_{Cal}

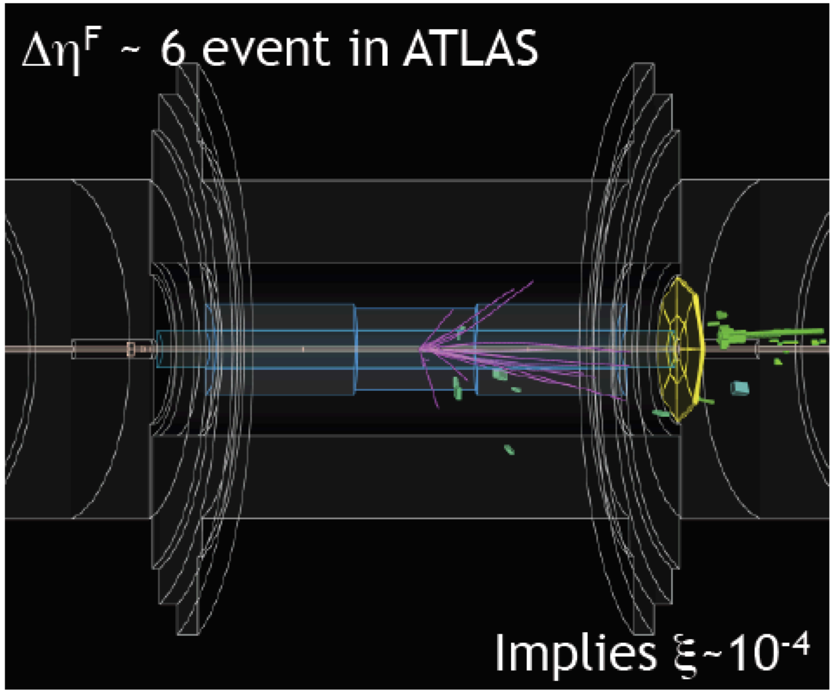
→ Clear diffractive signature





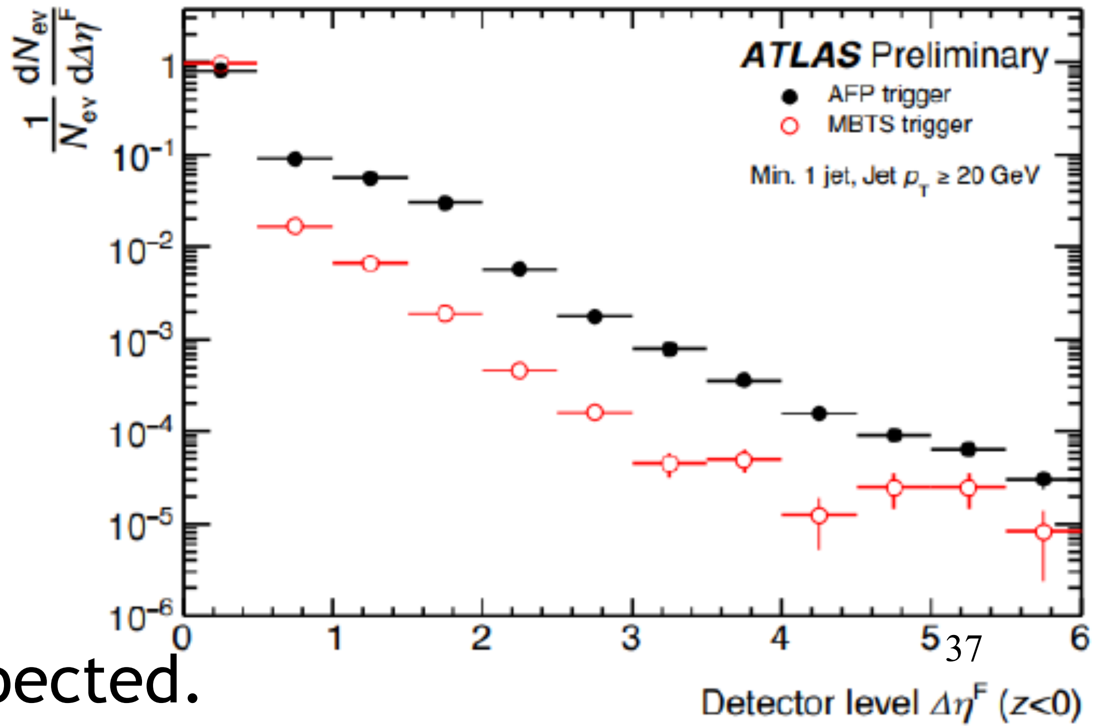
Rapidity Gaps?





$\Delta\eta^F$ defined by size of empty region between edge of calorimeter acceptance and first calorimeter cell above noise threshold or central track.

Clear enhancement of high $\Delta\eta^F$ tail in AFP-triggered data
→Correlation between proton-tags and gaps as expected.



ATLAS Proton Spectrometry at HL-LHC?

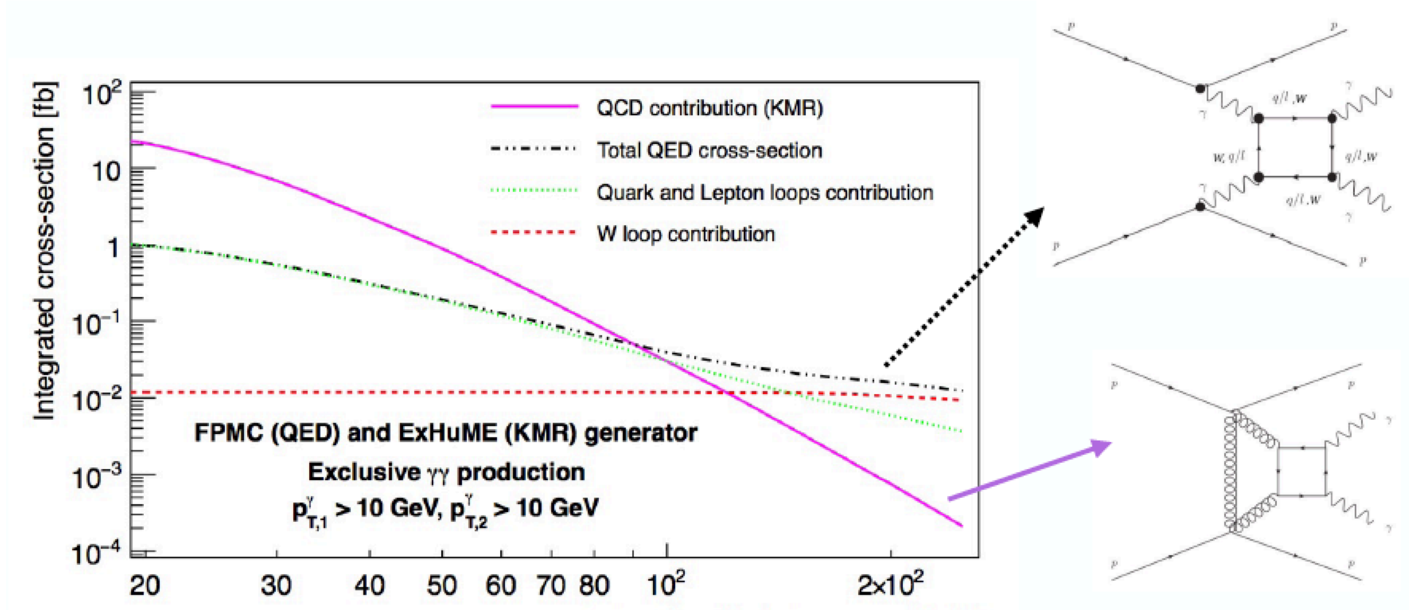
- Physics case and technical feasibility of running at pile-up of 200 post LS3 are under investigation

  → 3000 fb^{-1} by late 2030s?

Motivation:

- Observing many AFP processes marginal at SM rates pre-HL-LHC
- $\gamma\gamma$ dominates at large mass … need smaller ξ for QCD processes

e.g. light-by-light scattering

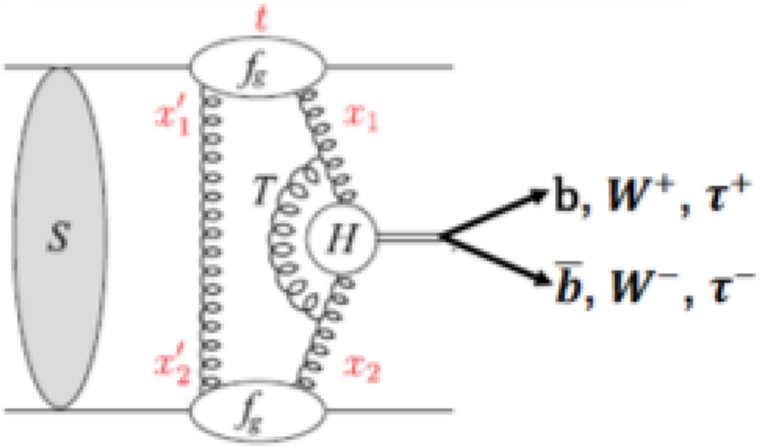


Fichet et al, arXiv:1411.6629

=> O(1) event/100fb^{-1} at m($\gamma\gamma$)>200 GeV

[Slide from M. Mangano]

More HL-LHC Physics Motivation



Exclusive Higgs production

- High resolution on mass,
- b-bbar mode
- 0^{++} confirmation, CP structure,
- QCD production mechanism.

→ Search for high mass recurrences with AFP-like set-up
→ SM Higgs would need stations in cold section (cf FP420)

QCD Central Exclusive Production

- eg High stats exclusive jets

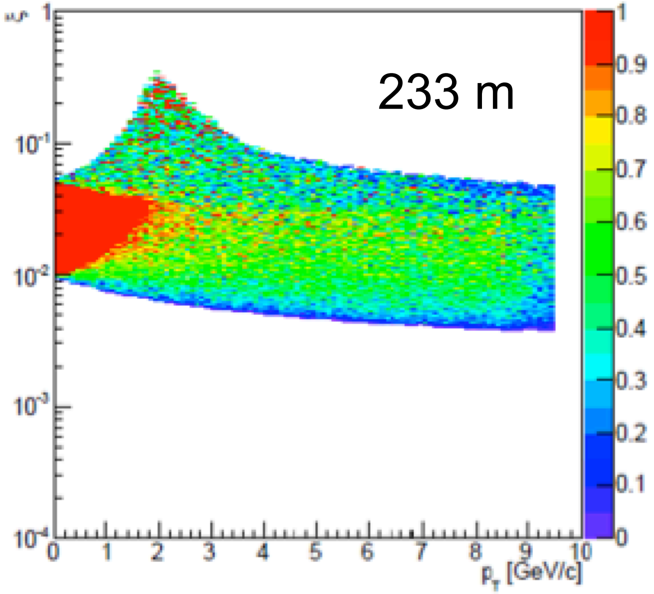
Exotica in $\gamma\gamma$ Processes

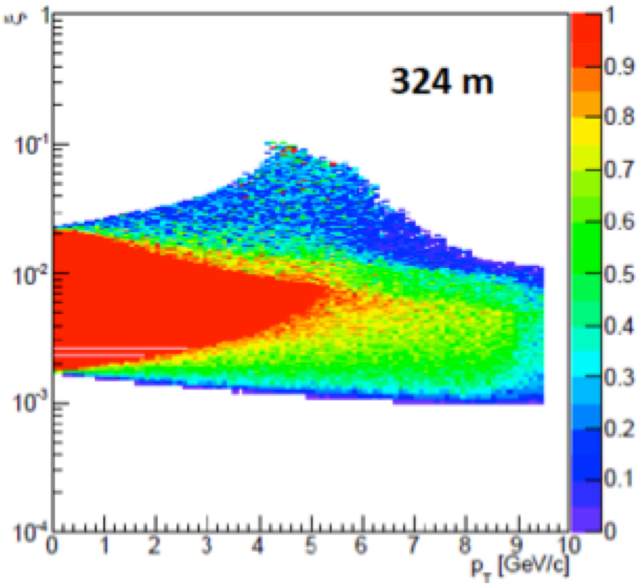
- eg high stats $\gamma\gamma$ → dibosons, $\gamma\gamma$ → invisibles (Dark Matter)

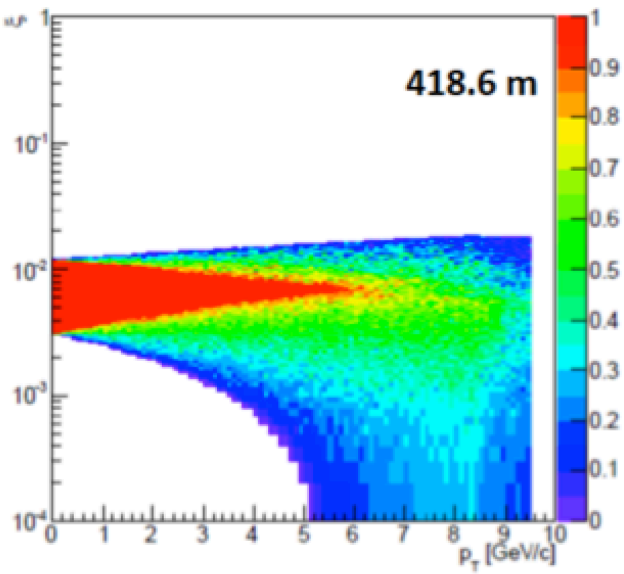
Potential for ongoing special runs programme

First Studies with nominal HL-LHC Optics

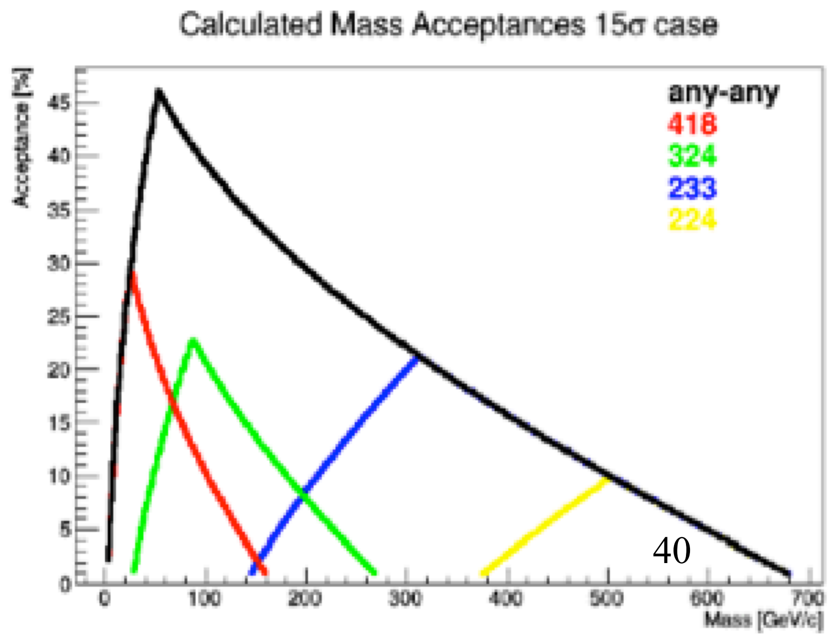
Acceptances for 2x2cm detector @ 15σ+0.5mm, no collimators







233m: Reduced ξ acceptance relative to that now in AFP region



324,420m: Attractive ξ acceptance extending into SM Higgs region and very wide t range at possible deployment points in cold sections

Summary

- AFP operated in 2017 as two sided system and took 32fb^{-1} under nominal running conditions

- Tracking detectors performing well

- Timing detectors still being commissioned → operation expected in second half of 2018

- First physics study (single sided) → observation of diffractive dijets

- Rich run 2 and 3 physics programme, diffraction / QCD, $\gamma\gamma$, exotics

- Studies of prospects for HL-LHC system are underway