Lessons from ATLAS Roman Pot Operation and Challenges at the HL-LHC Era

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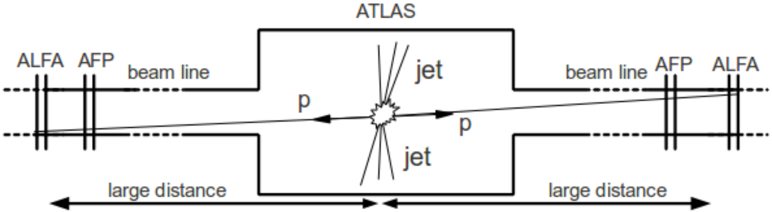
Intact protons → natural diffractive signature → usually scattered at very small angles (μrad) → detectors must be located far from the Interaction Point.

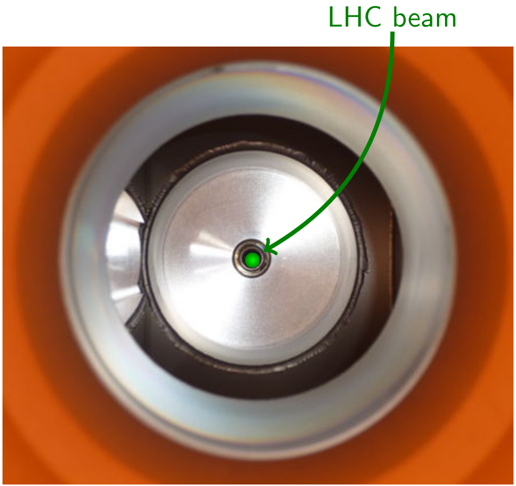


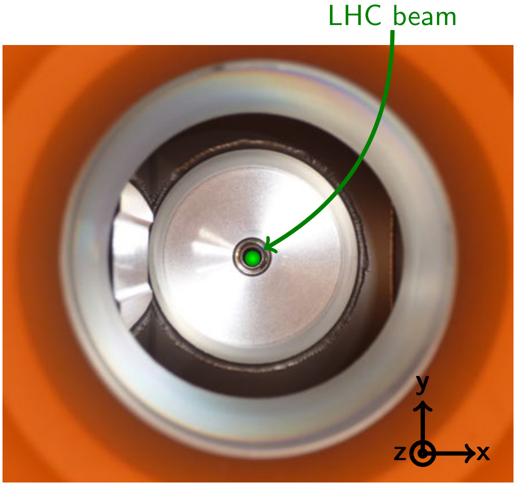
ALFA

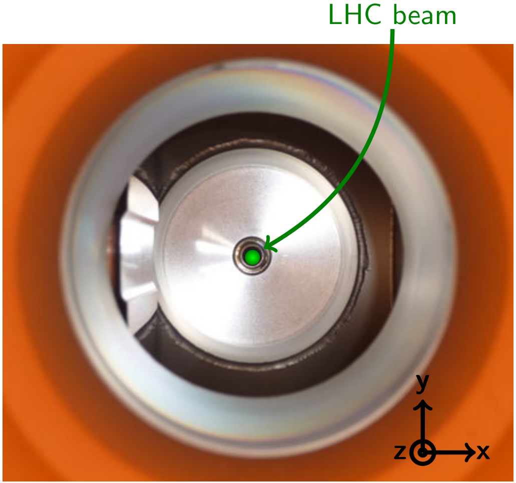
- **A**bsolute **L**uminosity **F**or **A**TLAS
- 240 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- vertically inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = \sigma_y = 30\ \mu$m
- in operation between 2011 and 2023

AFP

- **A**TLAS **F**orward **P**roton
- 210 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- horizontally inserted Roman Pots
- tracking detectors, resolution: $\sigma_{x/y} = 6/30\ \mu$m
- timing detectors, resolution: $\sigma_t \sim 25$ ps
- in operation since 2016 (one side) / 2017 (full set)


LHC beam


LHC beam
y
z
x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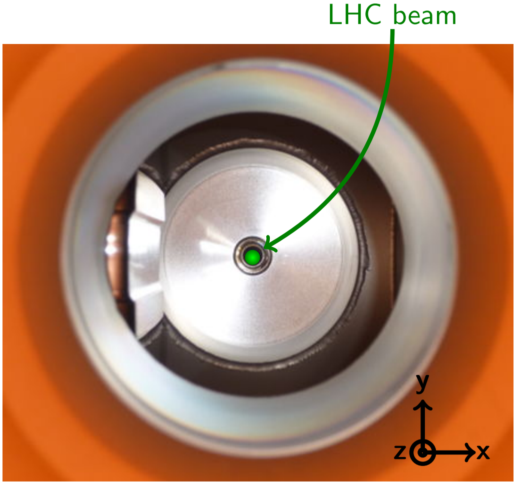
LHC beam
y
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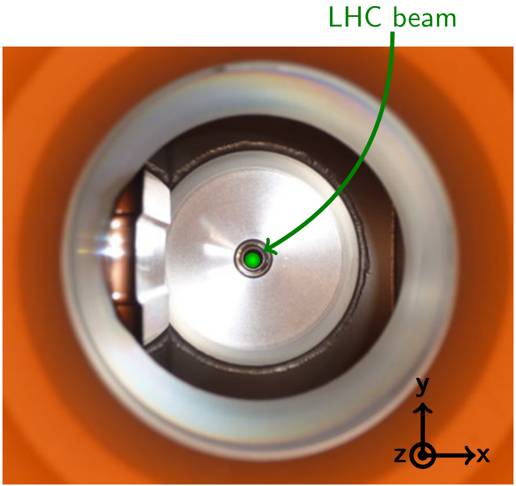
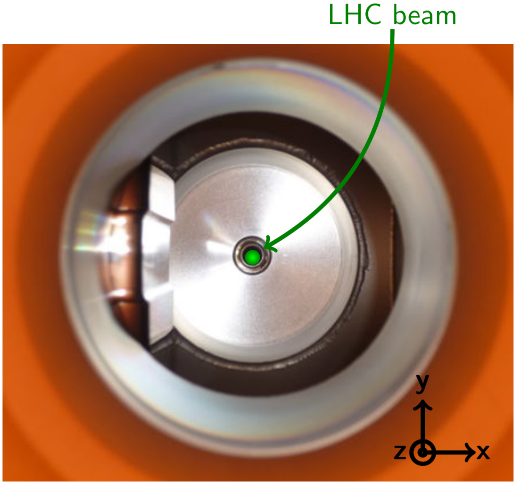
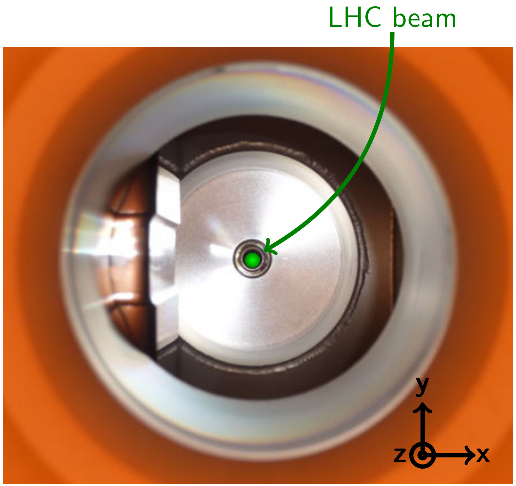
Properties of Roman Pot Technology




LHC beam
y
z
x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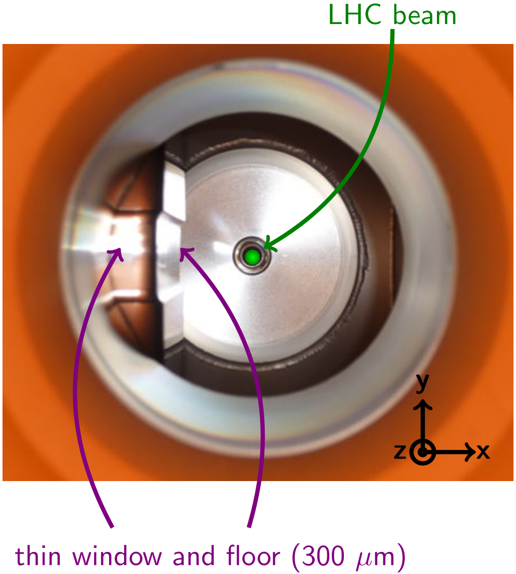
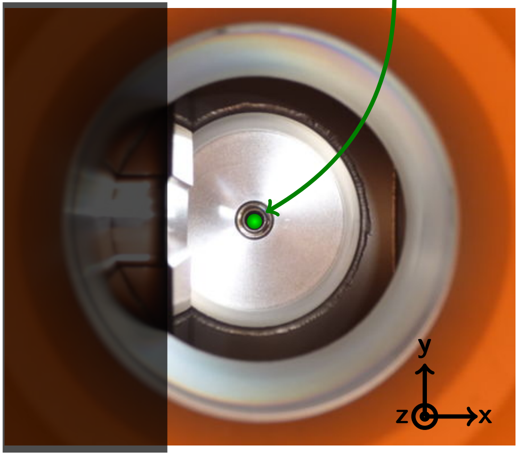

LHC beam
y
z
x
thin window and floor (300 μm)



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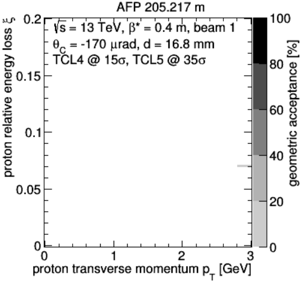
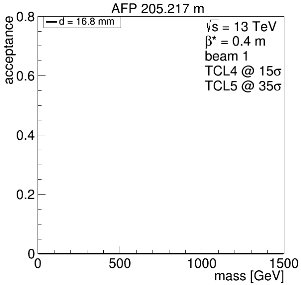


Geometric acceptance:

ratio of protons with a given (ξ, p_T) that reached the detector to the total number of the scattered protons having given (ξ, p_T)

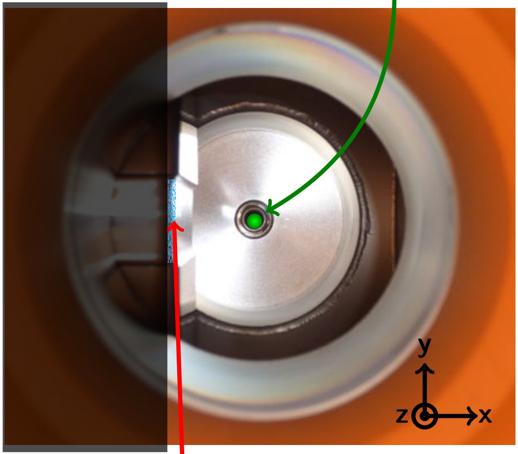


Mass acceptance:

mass of central system when both protons are tagged in Roman pot

shadow of TCL4 and TCL5 collimators

LHC beam



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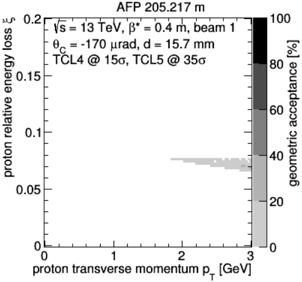

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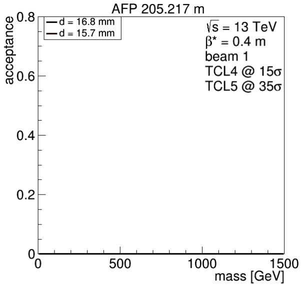

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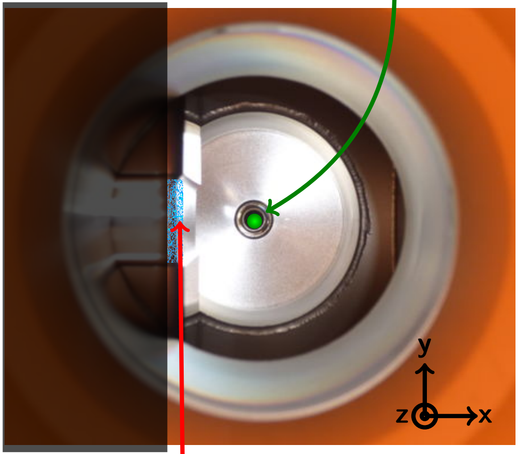

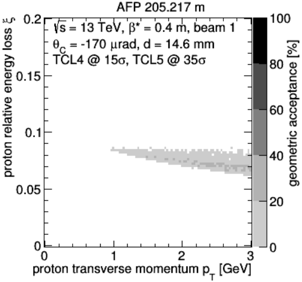

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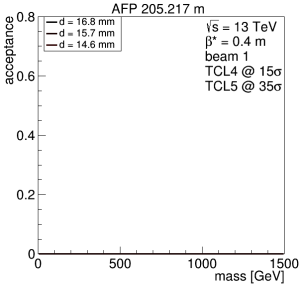

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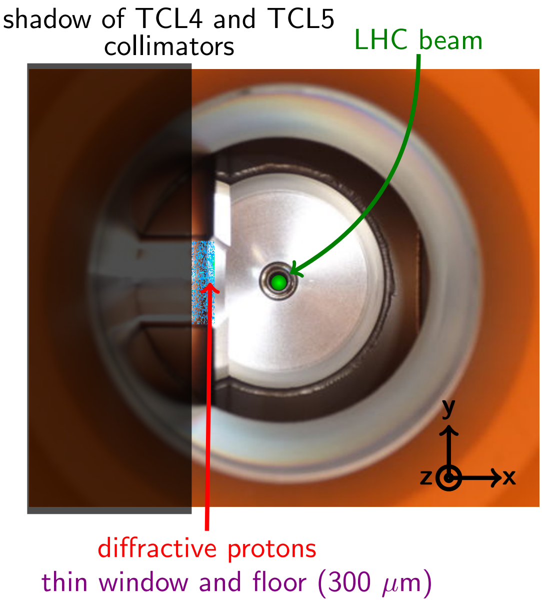

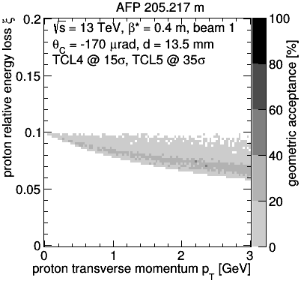

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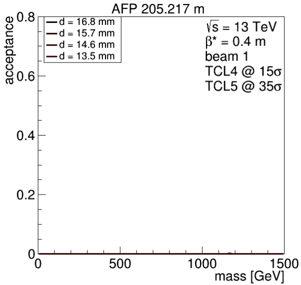

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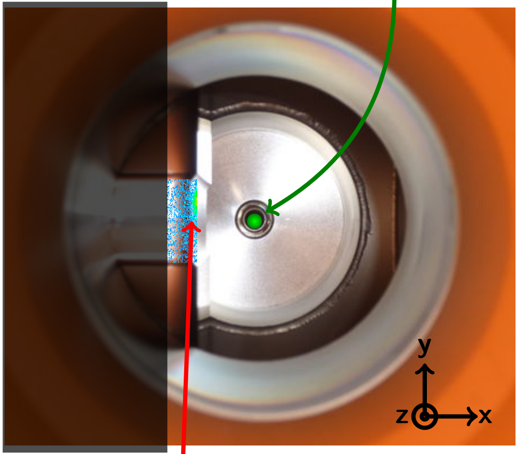

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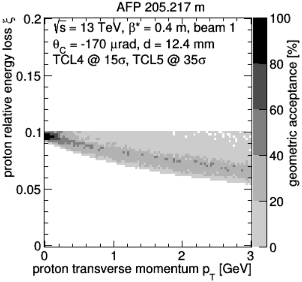

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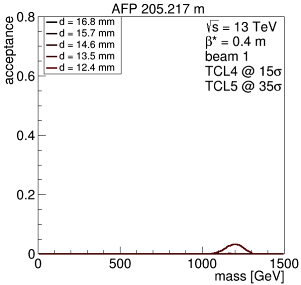

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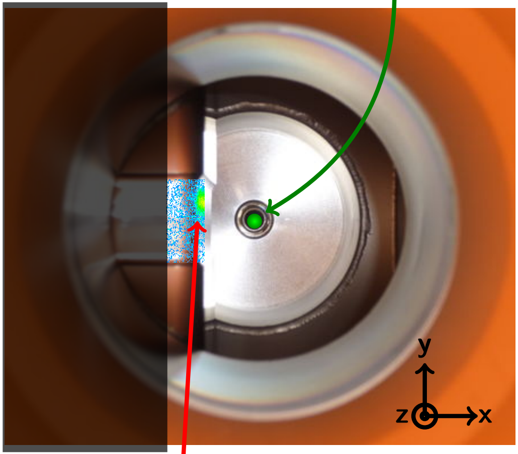

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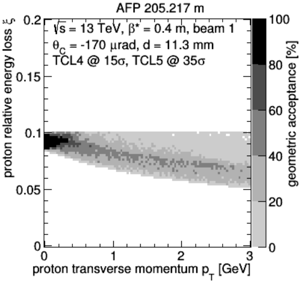

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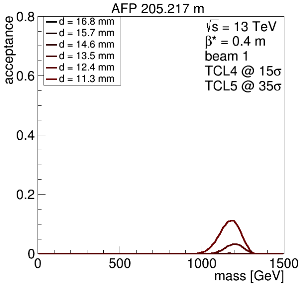

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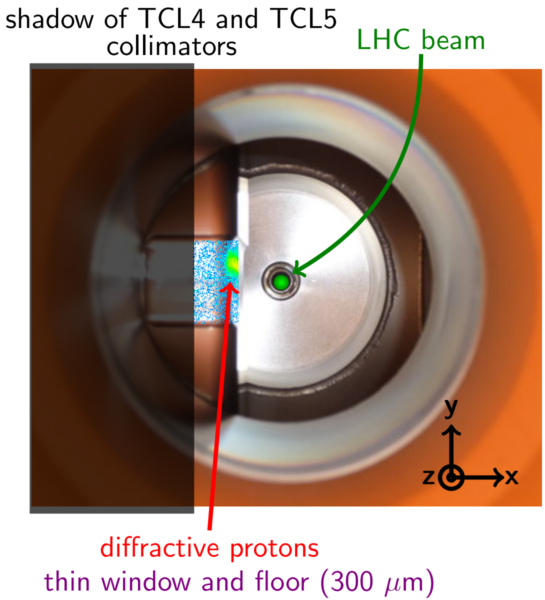

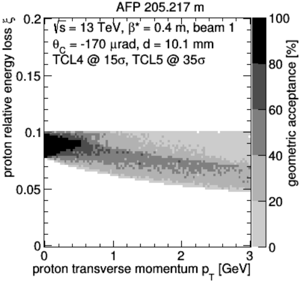

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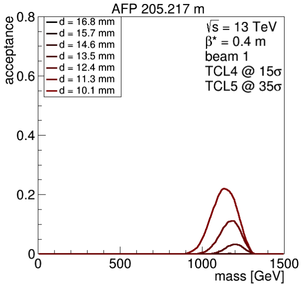

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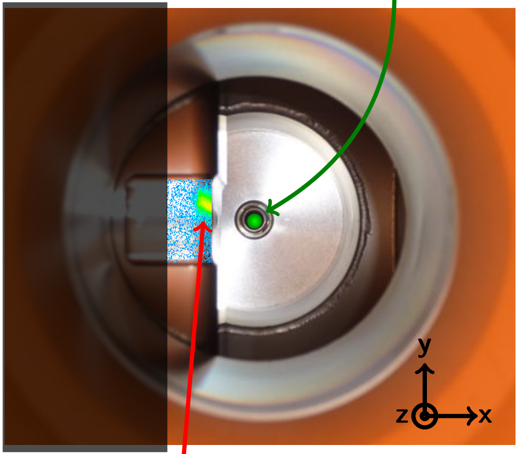

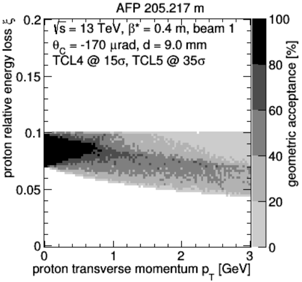

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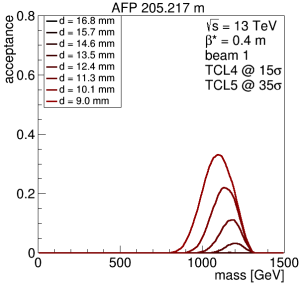

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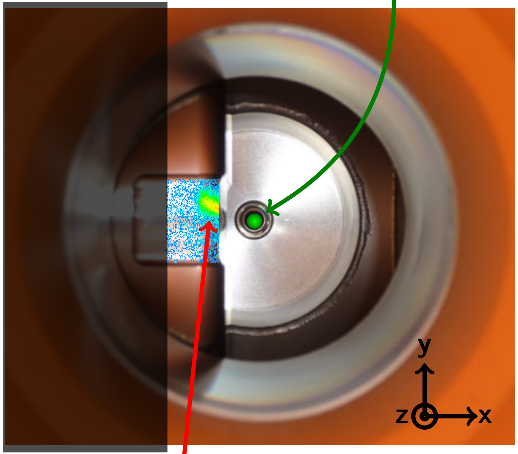

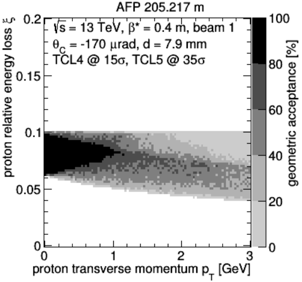

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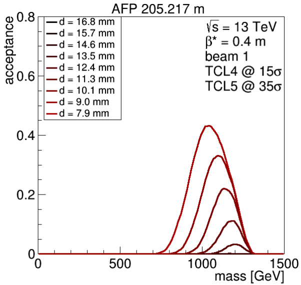

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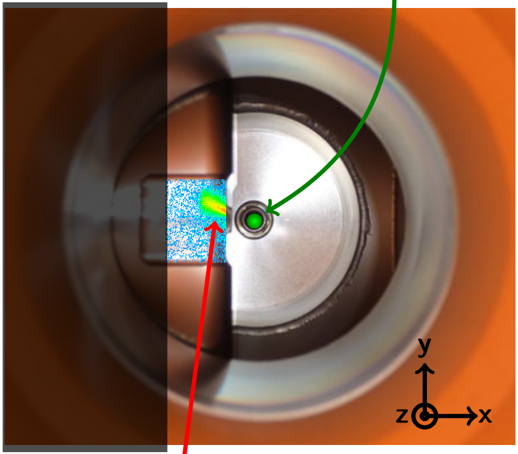

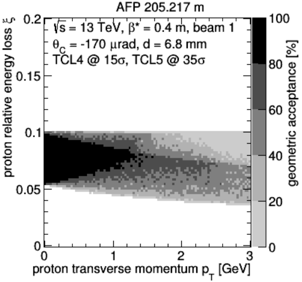

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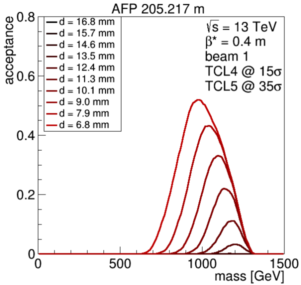

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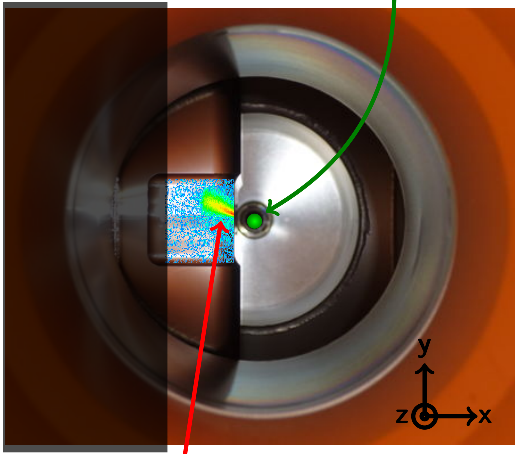

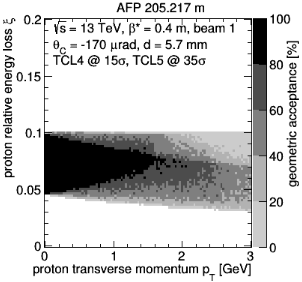

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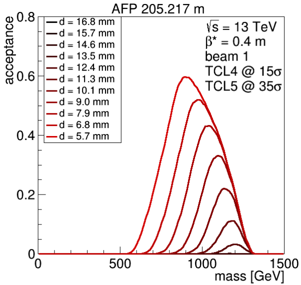

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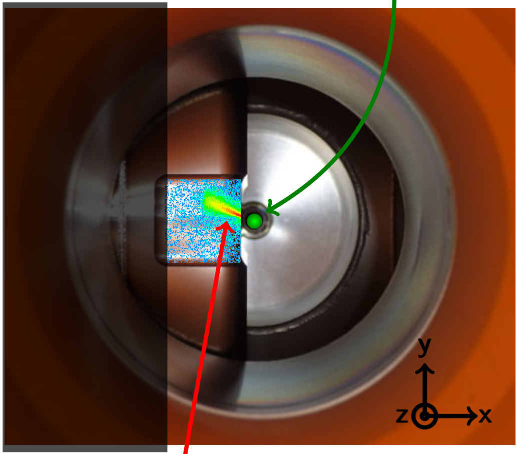

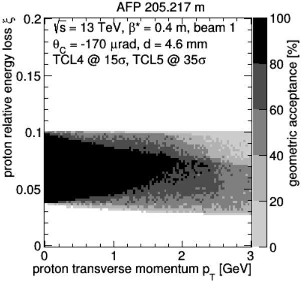

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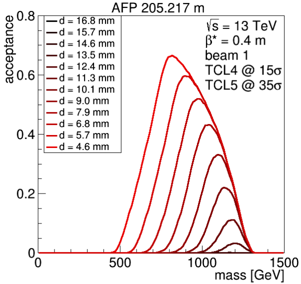

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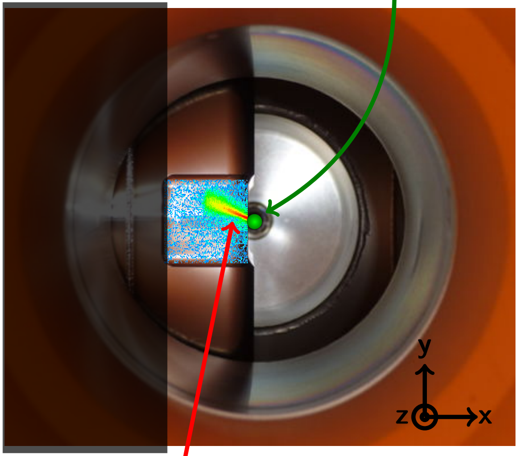
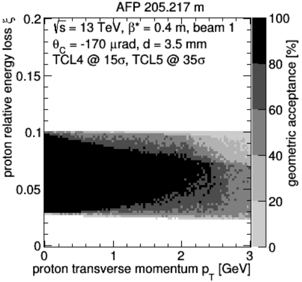


diffractive protons

thin window and floor (300 μm)



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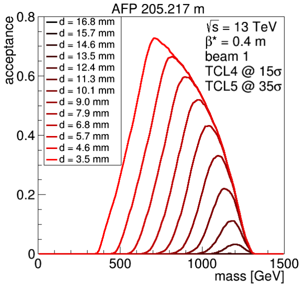

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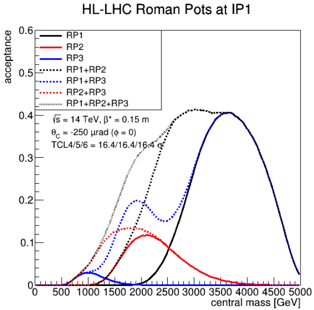
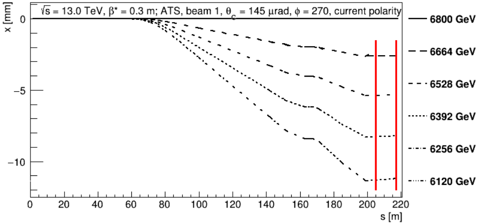
- LHC optics is of primal importance for Roman pots as it defines the acceptance.
- The layout of HL-LHC is very challenging and advanced → possibilities to change it (*e.g.* to move magnets) may be limited.
- Still, even with fixed layout several optics are usually possible → there should be a space for optimisation.
- Change of optics once detectors are installed may have a huge impact on physics programme:
  - example 1: inversion of inner triple polarity in vicinity of ATLAS (discussed to happen in 2024, but fortunately postponed to 2025) would kill AFP data-taking as there will be no acceptance,
  - example 2: optics considered for HL-LHC at IP1 (horizontal crossing angle) resulted in acceptance only for very high masses limiting the physics programme.



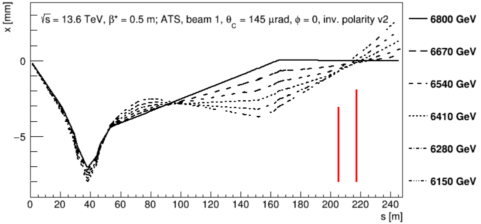
current settings

(assumed during detector design and installation)

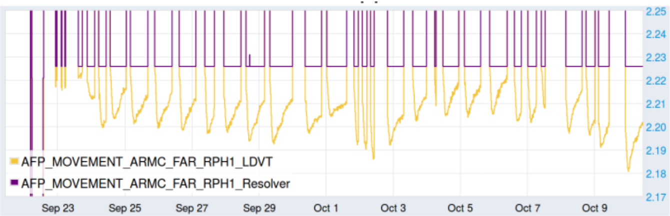


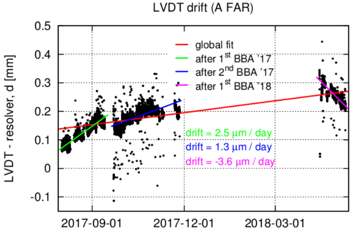
inverted triplet polarity

(proposed by LHC in order to reduce radiation on triplet)



- Operation of Roman Pots require great care:
  - they are one of few ATLAS sub-detectors which malfunction can dump the LHC beam,
  - they can also block the LHC injection permit (*e.g.* when not returned to HOME position).
- The above trigger the need of a dedicated 24/7 detector expert present on site (within 30 min reach of ATLAS cavern):
  - not "one-man-job" – a pool of on-call experts is needed; in 2023 we had 9 people sharing this duty,
  - dedicated training is needed, including on-site practical lessons (*e.g.* oxygen mask training, mandatory visits to tunnel to show the "problematic" places).
- Known design issue: position of detectors is monitored by a single Linear Variable Differential Transformer (LVDT):
  - there were cases of short "spikes" in the readout (milliseconds long) which caused station extraction and even beam dump in some cases,
  - over time a mysterious (=not yet understood) drift was observed which also may lead to extraction/dump.
- Future designs of movable devices should contain 2 LVDTs to cross-check their readout.

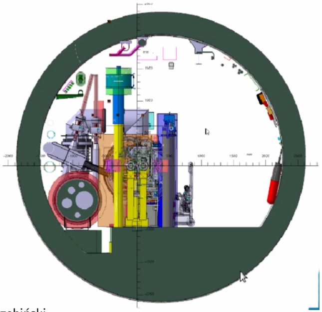


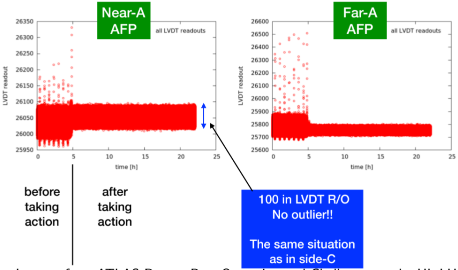


- AFP has long 23 cables per side (38.5 km in total; see table) for services in the ATLAS cavern (slow control, trigger, data-acquisition, *etc.*). ALFA has similar amount (21.6 km in total).
- In addition, there are services located in the RR alcoves (tunnel) which also need connection: vacuum pumps and cooling. Plus electronics to readout detectors installed on pots and in their vicinity.
- Layout of HL-LHC in vicinity of IP1 is much different from what we have now → there is much less space for cables!

- One should carefully plan how detectors can be connected. Example:
  - in 2018 we had an issue of AFP being automatically extracted during the run,
  - very serious issue not only due to loss of data, but also because it could cause the beam dump,
  - after many investigations it turned out that there was a correlation between extraction and moments when vacuum pump was being switched on/off,
  - it turned out that this is due to vacuum and motor signals routed in the same bundle,
  - re-routing vacuum signals via the spare cable solved the issue.
- Trigger may be an issue: latency is a serious factor to be considered during design.

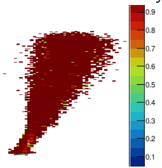
Cable name	construction	ϕ [mm]	length [m]
AFP DATA/TTC	8 x 12 fibres	12	310
Fast Trigger/Clock SiT	coaxial	28	300
Fast Trigger ToF	coaxial	28	300
LV cable SiT	AWG10, 4 tw.pairs	22	400
LV cable SiT	AWG10, 4 tw.pairs	22	400
LV cable ToF	AWG10, 4 tw.pairs	22	400
LV cable ToF	AWG10, 4 tw.pairs	22	400
LV cable spare(ToF)	AWG10, 4 tw.pairs	22	400
Opto-VVDC	AWG14, 7 tw.pairs	18.7	400
AuxPWR (Vreg)	AWG14, 7 tw.pairs	18.7	400
HV cable SiT	AWG26, 18tw.pairs	13.8	400
HV cable ToF	AWG26, 18tw.pairs	13.8	400
Spare	AWG18, 4tw.pairs	12	400
Environmental 1	0.5mm2, 24tw.pairs	21	400
Environmental 2	0.5mm2, 24tw.pairs	21	400
Air-cooler1 CTRL	AWG18, 6tw.pairs	14	400
Air-cooler2 CTRL	AWG18, 6tw.pairs	14	400
CANBUS	1mm2, 9tw.pairs	17.4	400
Stepper motors	AWG 16, 7tw.pairs	16.3	400
LVDT, resolver	0.5mm2, 24tw.pairs	21	400
microswitches	0.5mm2, 9tw.pairs	13.5	400
general spare	AWG 16, 7tw.pairs	16.3	400
general spare	AWG 16, 7tw.pairs	16.3	400
secondary vacuum	0.5mm2, 9tw.pairs	13.5	60
general spare	AWG18, 6tw.pairs	14	60
general spare	AWG18, 6tw.pairs	14	60
secondary vacuum pipe	flexible vacuum pipe	~25mm	60
Aircooler FS1 control pipe	multitube		60
Aircooler FS2 control pipe	multitube		60
Aircooler NS1 control pipe	multitube		60
Aircooler NS1 control pipe	multitube		60



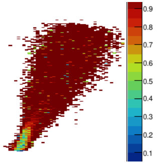


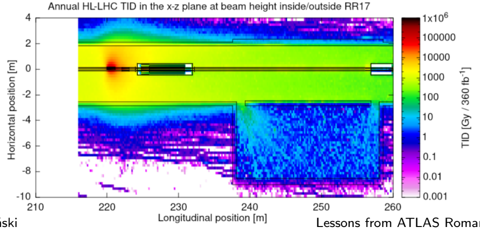
- Pots are located in the LHC tunnel:
  - detectors must be radiation hard and very reliable → there may be days/weeks w/o access possibility,
    - ALFA was not designed to be a radiation-hard device (the idea was to install it only for special runs, like ZDC) and barely survived to 2023 high-β^* data-taking,
    - AFP observed a "burnout" in SiT detectors → to be compensated by increase of bias voltage, but eventually detectors must be replaced.
  - experts need special, dedicated trainings to access (on top of training needed for ATLAS service cavern),
  - going to the tunnel just after LHC operation requires special preparation (*e.g.* presence of a person from Radiation Protection team, asking for access (IMPACT) in advance).
- All items installed in the tunnel are "automatically" classified as radioactive → constraints on work with such parts (*e.g.* special lab needed).
- Radiation levels in tunnel are non-negligible:

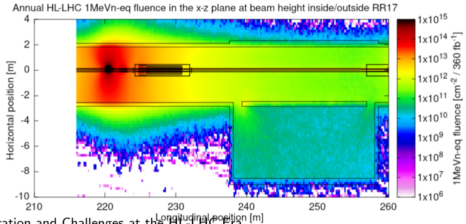
Good SiT efficiency:



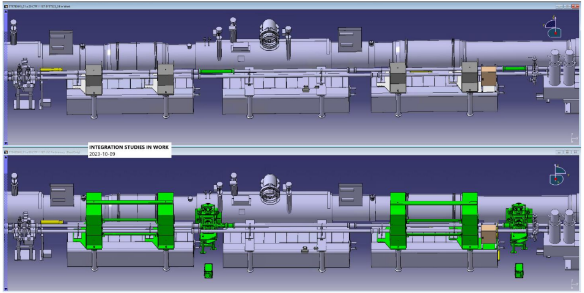
Radiation damage effect:



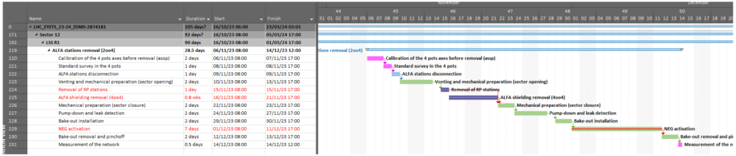




- Work on detectors must be agreed not only with ATLAS, but also with LHC teams.
- Example: organization of ALFA deinstallation during this Year End Technical Stop:
  - Draft integration differential scheme (to be included in the ECR) prepared by EN-ACE-INT:

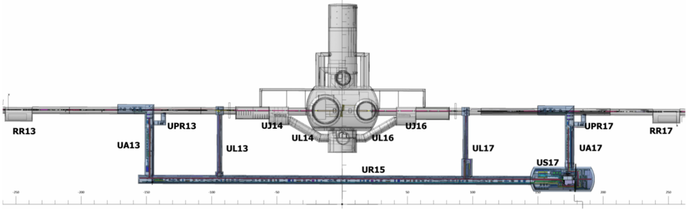


  - The latest schedule approved today during the LHC Coordination meeting:

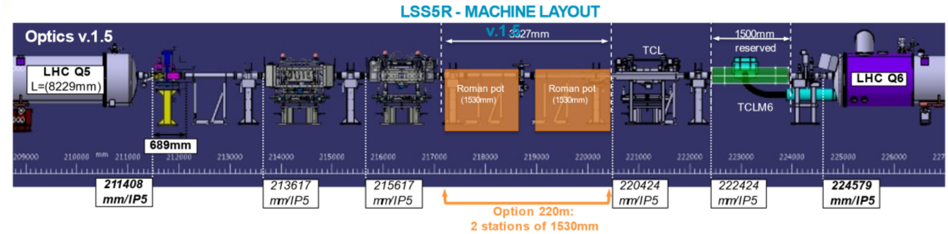


	Name	Duration	Start	Finish
0	LHC_EYETS_23-24_EDMS-2874181	105 days?	16/10/23 06:00	23/03/24 03:01
171	Sector 12	92 days?	16/10/23 08:00	05/03/24 17:00
192	LSS R1	90 days	16/10/23 08:00	01/03/24 17:00
219	ALFA stations removal (2oo4)	28.5 days	06/11/23 08:00	14/12/23 12:00
220	Calibration of the 4 pots axes before removal (assp)	2 days	06/11/23 08:00	07/11/23 17:00
221	Standard survey in the 4 pots	1 day	08/11/23 08:00	08/11/23 17:00
222	ALFA stations disconnection	1 day	09/11/23 08:00	09/11/23 17:00
223	Venting and mechanical preparation (sector opening)	2 days	10/11/23 08:00	13/11/23 17:00
224	Removal of RP stations	1 day	15/11/23 08:00	15/11/23 17:00
225	ALFA shielding removal (4oo4)	0.8 wks	16/11/23 08:00	21/11/23 17:00
226	Mechanical preparation (sector closure)	2 days	22/11/23 08:00	23/11/23 17:00
227	Pump-down and leak detection	2 days	24/11/23 08:00	27/11/23 17:00
228	Bake-out installation	2 days	29/11/23 08:00	30/11/23 17:00
229	NEG activation	7 days	01/12/23 08:00	11/12/23 17:00
230	Bake-out removal and pinchoff	2 days	12/12/23 08:00	13/12/23 17:00
231	Measurement of the network	0.5 days	14/12/23 08:00	14/12/23 12:00

- New, special features of HL-LHC design, *e.g.* all elements at straight section mounted on movable tables for the remote alignment.
- HL-LHC would require much more services than LHC:
  - limits on cables (already mentioned),
  - limits on space – example around IP1:



(a)



- ATLAS has wide experience in operation of detectors in the tunnel:
  - ALFA (2011–2023),
  - AFP (since Run 2),
  - ZDC (since Run 1).
- Having of Roman pots is very challenging, especially at the HL-LHC era!
- Few lessons:
  - Importance of Optics.
  - Detector Operation.
  - Services in Tunnel.
  - Constraints due to Detector Location.
  - Action Scheduling.
  - HL-LHC Constraints.
- I will be happy to share my experience of pot operation: `maciej.trzebinski@cern.ch`