PPS @ HL-LHC: Status Report

LHC Forward Physics Meeting

25 October 2022

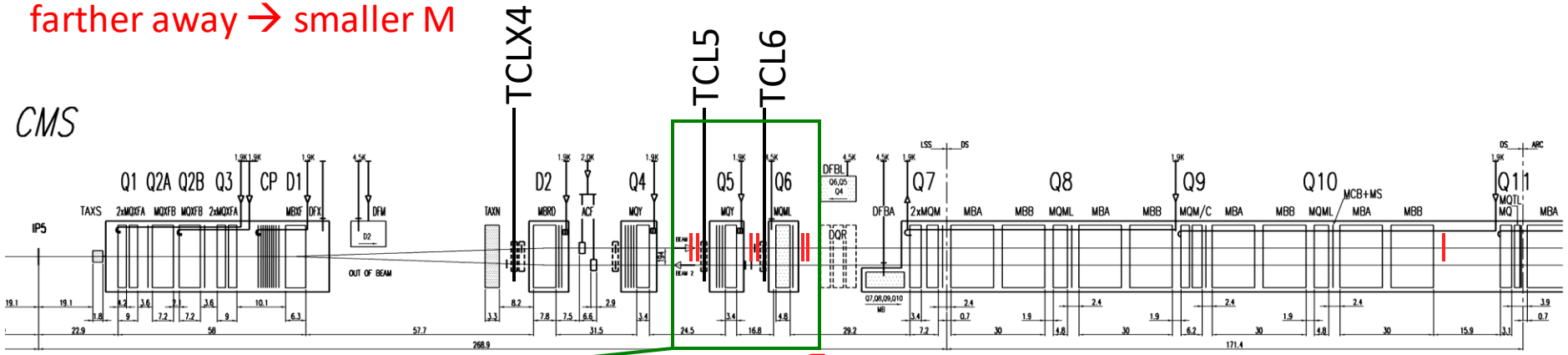
Mario Deile
on behalf of
The CMS Collaboration

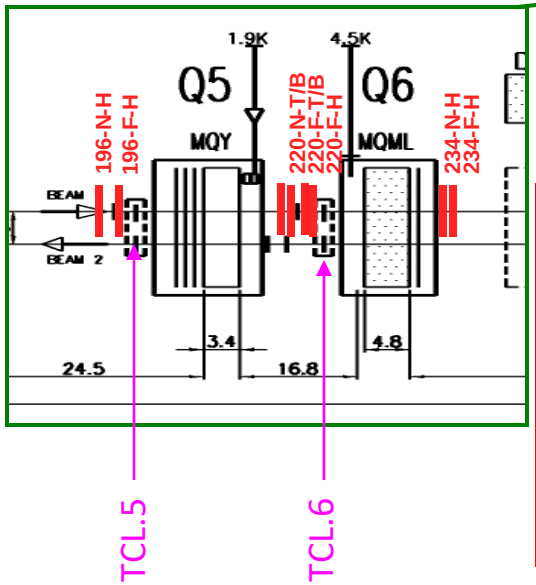
PPS @ HL-LHC: Proposed Layout

(on both sides of IP5, shown here: Sector 5-6)

Locations from maximisation of accepted central mass range:

farther away → smaller M





- **"warm region"**:
  suitable for Roman Pot technology
- in each location 2 horizontal pots (single-sided) with a few metres lever arm
- @ 220 m: also 2 vertical pairs

- **"cold region"**:
  needs cryogenic bypass
- signal protons between beam pipes
  → limited space

→ new developments needed

→ second stage (LS4)

Total: 2 x 10 jaws (warm region) + 2 x (1–2) jaws (420m) = 22 – 24 jaws

→ similar to present day (26) → similar services (cables, cooling)

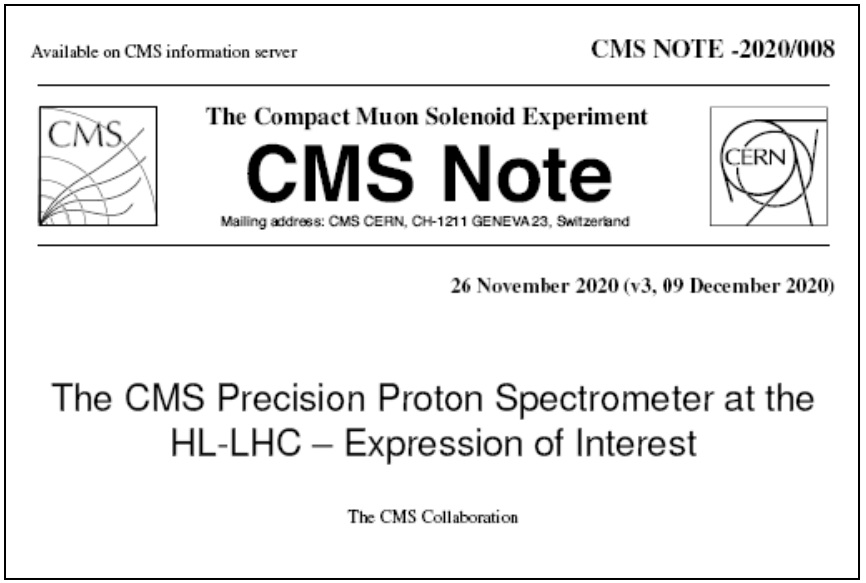
PPS @ HL-LHC: Project History

Dec. 2020:

Expression of Interest published as CMS NOTE-2020/008:

https://cds.cern.ch/record/2750358

http://arxiv.org/abs/2103.02752



Available on CMS information server

CMS NOTE -2020/008

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

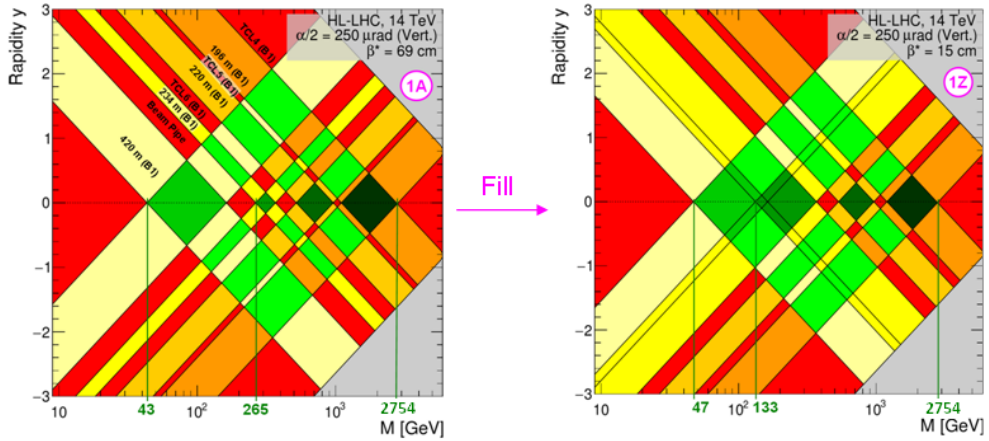
26 November 2020 (v3, 09 December 2020)

The CMS Precision Proton Spectrometer at the HL-LHC – Expression of Interest

The CMS Collaboration

- 4 locations on both sides of IP5 :
  - just before TCL5 (~ 196 m): high masses
  - just before TCL6 (~ 220 m): intermed. masses
  - just after Q6 (~ 234 m): lower masses
  - 420 m: lowest masses

Station	M_{min} [GeV] @ $y = 0$	M_{max} [GeV] @ $y = 0$
196 m	1100.87–1197.80	2754.27
220 m	519.89–533.18	962.70
234 m	264.96–132.80	368.11
420 m	43.38–47.04	162.66



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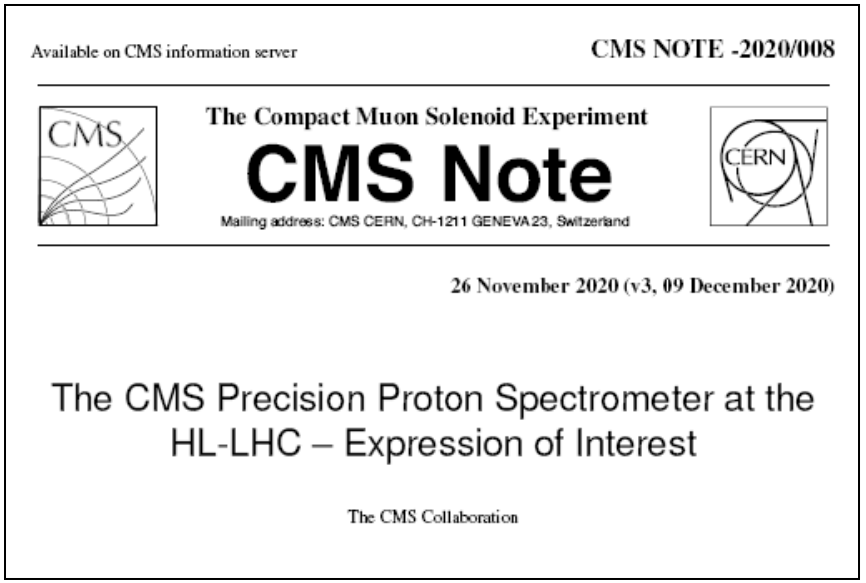

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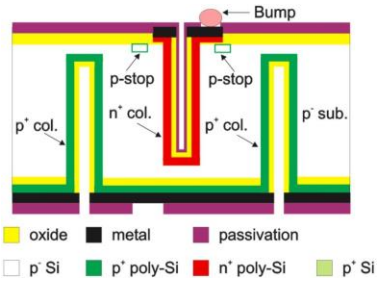
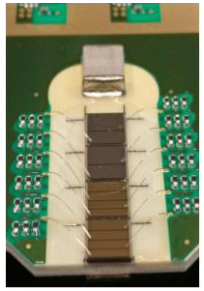
420 m	43.38–47.04	162.66

- Detector technologies presently studied:
  - Tracking: 3D silicon pixel detectors (like in Run 2/3)
  - Time of Flight (to resolve pileup with multiplicity $\mu \leq 200$):
    - Diamond detectors (like in Run 2/3)
    - UFSD (LGAD) from CMS MTD-ETL

3D Si Detectors



Run 2 Diamonds

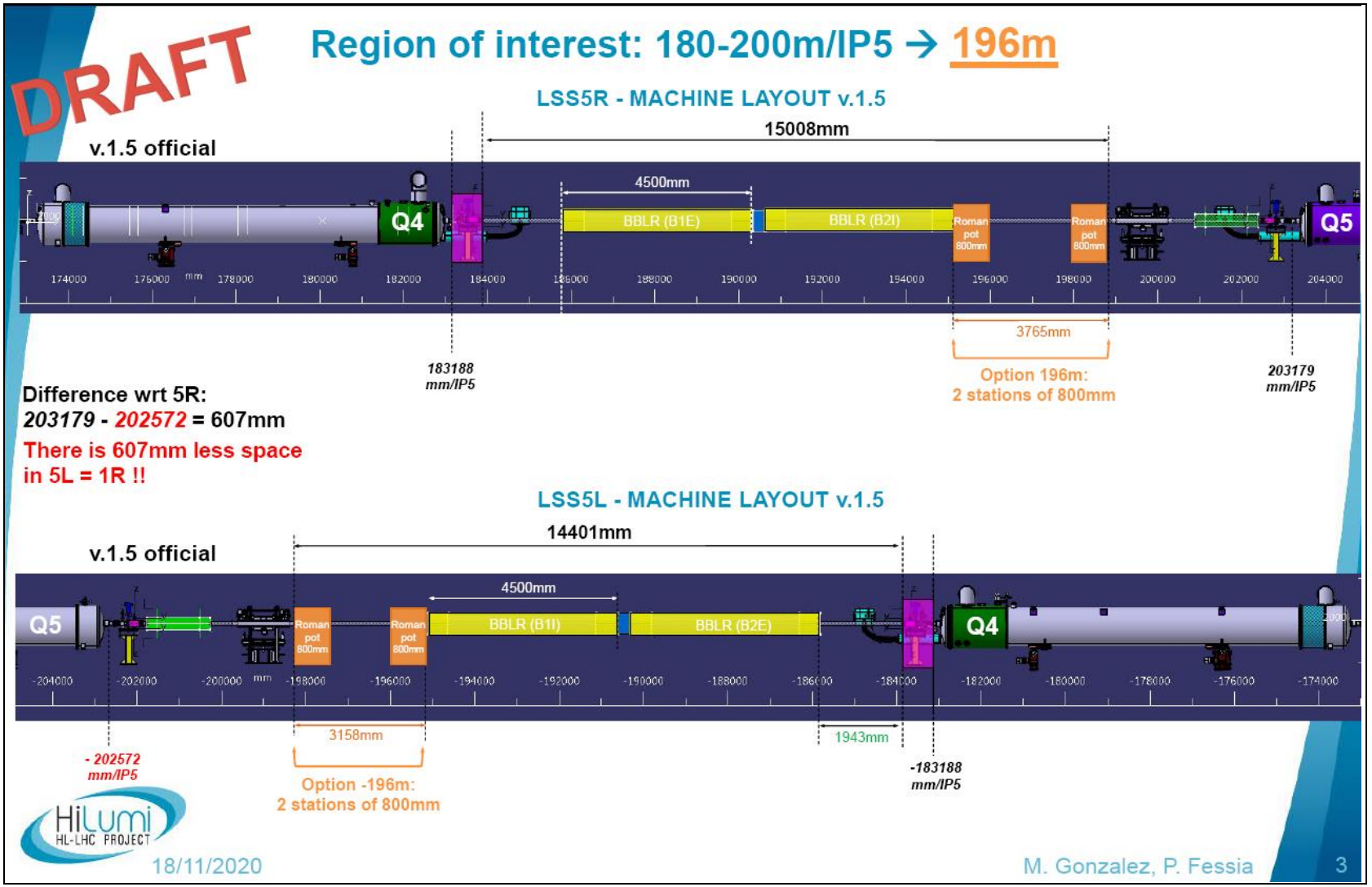


PPS @ HL-LHC: Project History

2021:

- Continued collaboration with machine layout team
  - → space reservations, preliminary integration studies now separately for sectors 4-5 and 5-6
  - → identification of main difficulties, but no show-stoppers by principle
  - → space for cables reserved

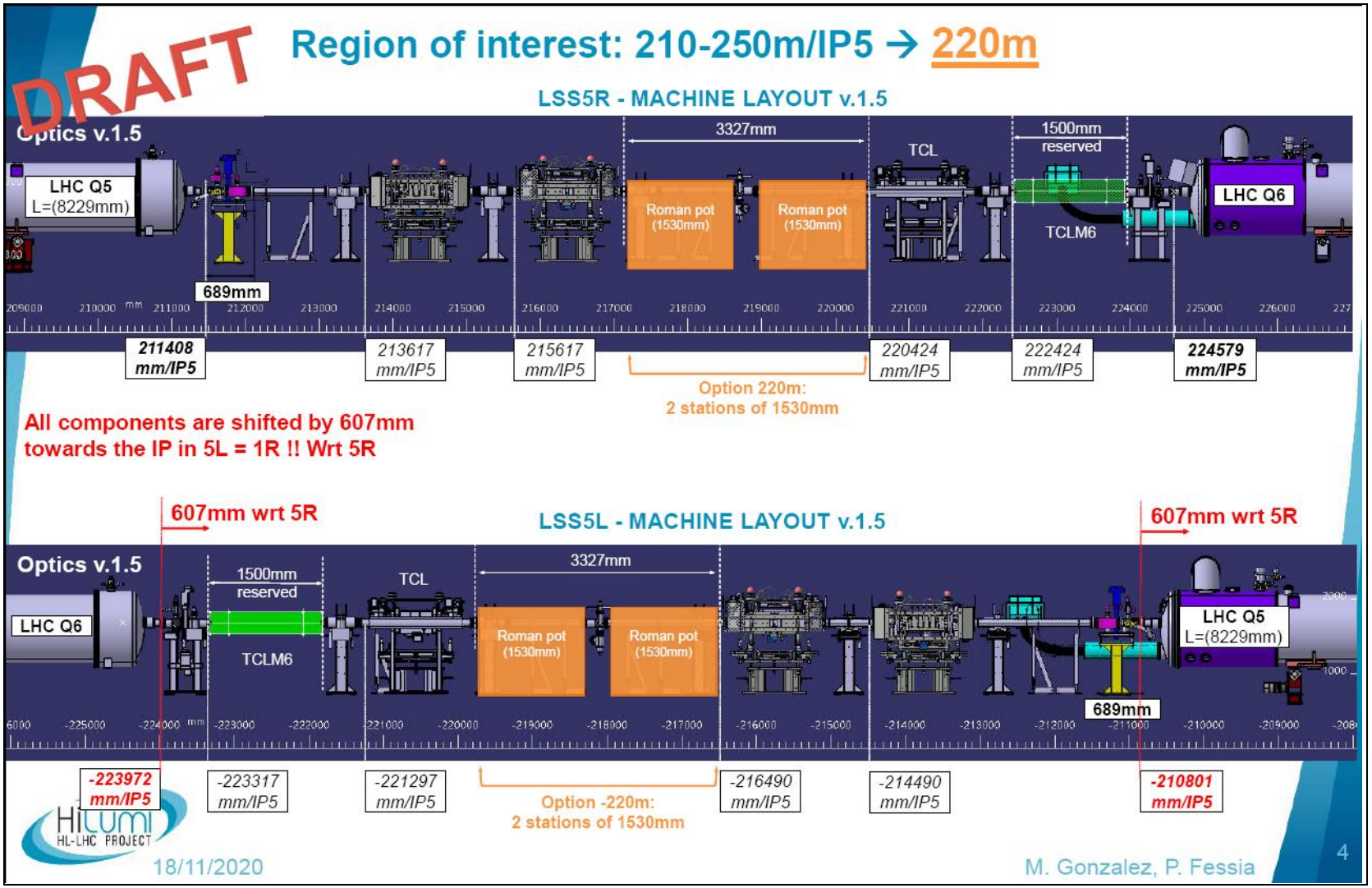
Sector 5-6



Sector 4-5

Difficulty: these stations (like all beamline elements between –Q5 and +Q5) needs to be on remote-controlled movable (x-y)-alignment platforms

Sector 5-6

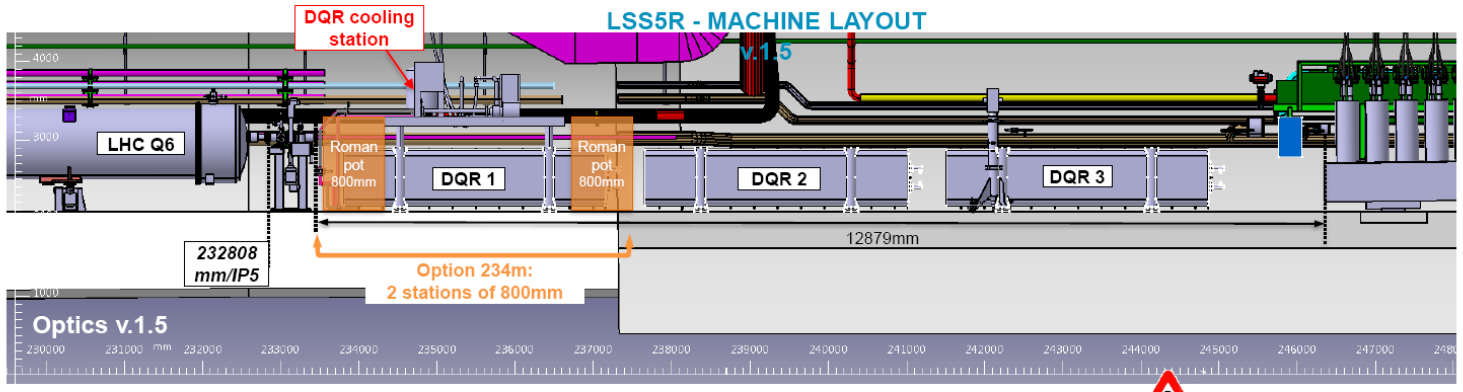


Sector 4-5

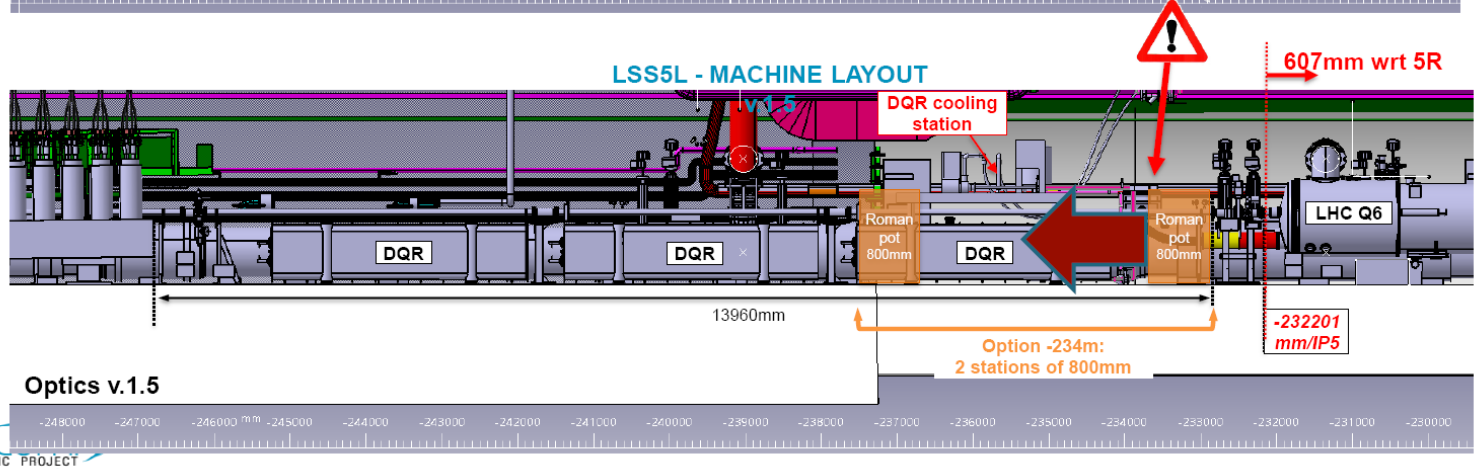
- Only in this station: 2 vertical pairs for alignment and optics calibration
- To mounted on (manually adjusted) alignment platform

Region of interest: 210-250m/IP5 → 234m

Sector 5-6



Sector 4-5



18/11/2020

- Difficulty: this station needs DQR relocation;
  different options under study by P. Fessia et al. (see e.g. TREX meeting 17 Dec. 2021)
- To mounted on (manually adjusted) alignment platform

PPS @ HL-LHC: Recent Evolution

2021:

- Continued collaboration with machine layout team
  → space reservations, preliminary integration studies now separately for sectors 4-5 and 5-6
  → identification of main difficulties, but no show-stoppers by principle
  → space for cables reserved

- Update of performance studies:
  - optics/layout version 1.3 → 1.5
  - new operational scenario (levelling scheme, collimation strategy)

  → more detailed acceptance numbers (year by year), but no drastic changes
  → EoI assessments still valid

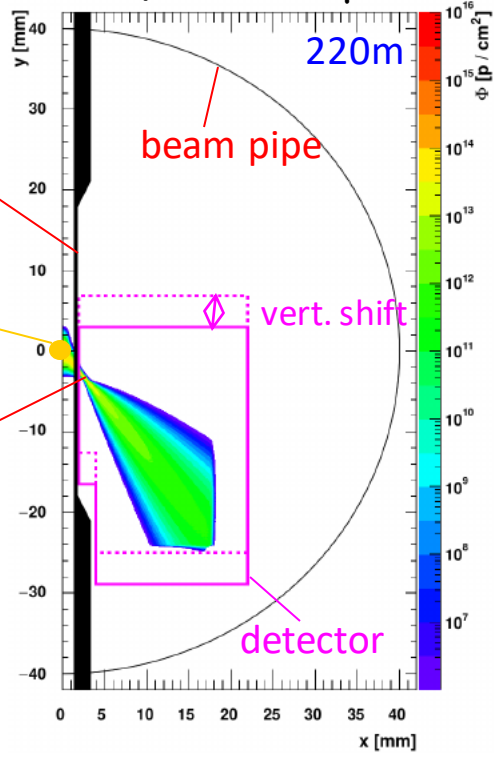
- Using HL-LHC fluence maps: Refinement of requirements on
  - detector vessel (pot)
  - detector segmentation (via occupancy arguments)
  - vertical shifts of detector packages for radiation dilution

Need for New Detector Vessels

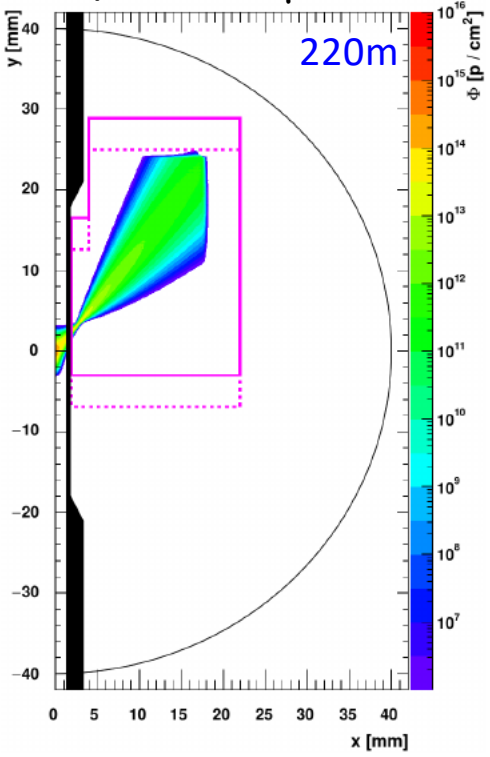
Fluence maps (after 1 fb^{-1})

for vertical crossing angle

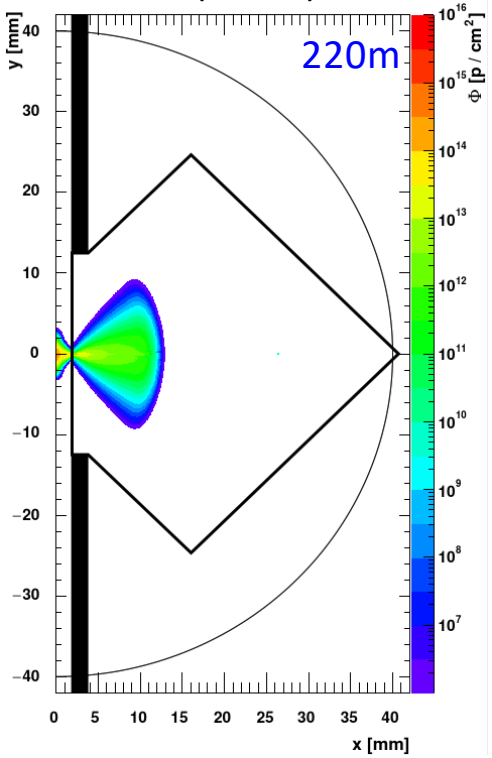
$\alpha/2$ = +250 µrad



$\alpha/2$ = -250 µrad



Comparison:
horizontal crossing
(Run 2):



- defines detector coverage needed (larger for vertical beam crossing)
- quantification of required vertical detector shifts inside pots from radiation hardness of detector candidates (tracking: 3D silicon pixels, timing: LGAD or diamonds)
  → requirements on size of thin window

→ new detector vessels: shape and size identical to present pots, only thin window changes
  → developments ongoing

PPS @ HL-LHC: Recent Evolution

2022:

- January / February:
  presentations @ Chamonix meeting and in the HL-LHC Executive Committee with CERN directorate

- Tight funding situation → New strategy:

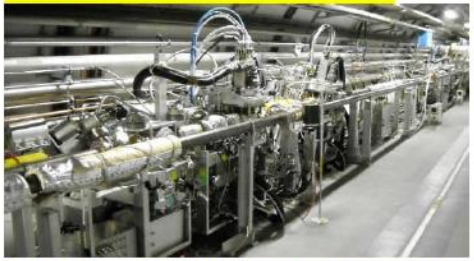
Most components of present Roman Pot system can be reused without significant loss in performance.

PPS @ HL-LHC: Reuse of Present Roman Pots

Inventory: enough RP units available to equip the 2 x 3 “warm” locations.

Present availability

RP station in the tunnel



Total: 8 triple station and 2 horizontal;
10 horizontal units; 2 cylinder. housing, 24 rec.

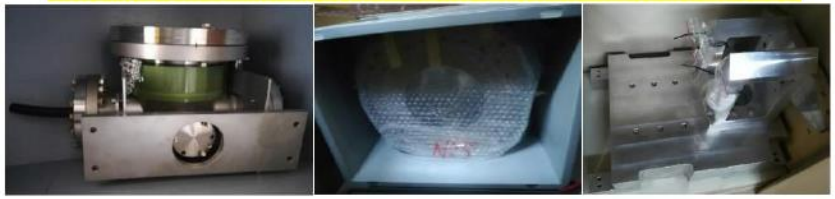
RP station in H8

2 horizontal units;
1 cylindrical housing, 1 rec. housing (revalidate)

RP station in CMS RP room

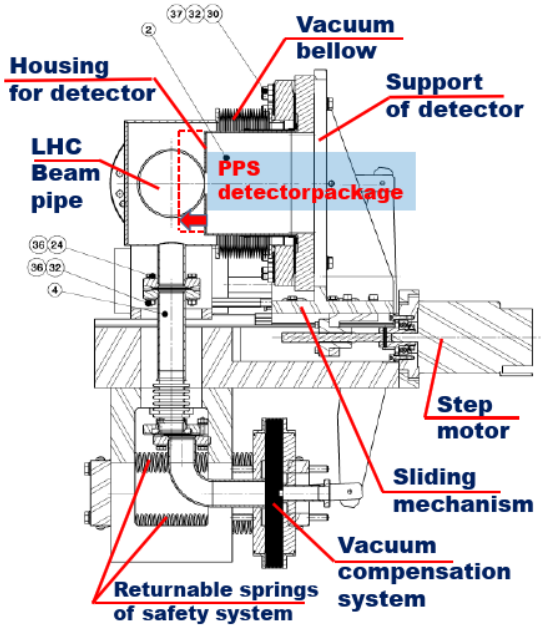
1 horiz. units; 2 rec. housings

Components for horizontal unit in plastic boxes in 226



3 new VP vac. chambers | 1 new cyl. housing | 1 new horiz. unit

Availability: Numbers of RP station: 9 standard triple, plus 5 horizontal units (?);
Total numbers of horizontal units: 14 (8 tunnel + 3 P.5 + 2 H8 + 1 B.226);
Number of detector housing: 26 rectangular, 4 cylindrical (2 tunnel, 1 B226, 1 H8 (revalid.)



Being studied in detail: mandatory component replacements. Examples:

- precision screws of motorization
- detector packages
- detector vessels (new requirements on thin window geometry)

→ all “transparent” from machine integration point of view

Machine Integration

Most urgent activity!

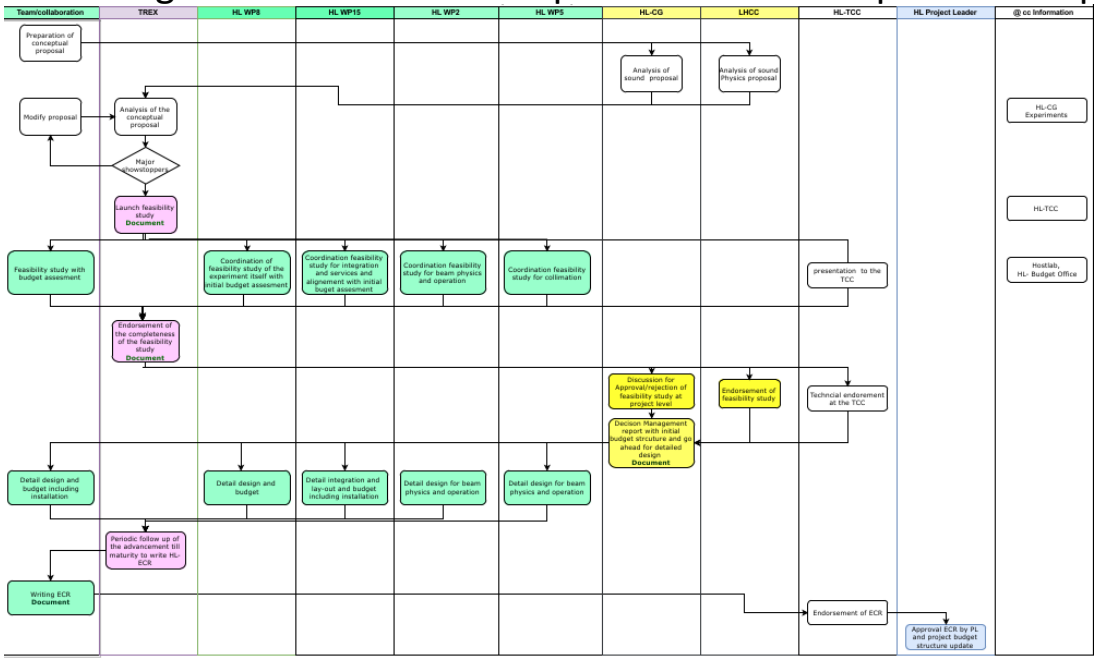
PPS integration now following the standard HL-LHC process for new experiment equipment:

EoI

We are here

TREX

ECR



idea, concept, no evident showstoppers

feasibility and initial budget assessment

detailed design and final budget

Appropriate forum: **TREX meetings** ("**T**unnel **R**egion **EX**periments")

→ Aims:

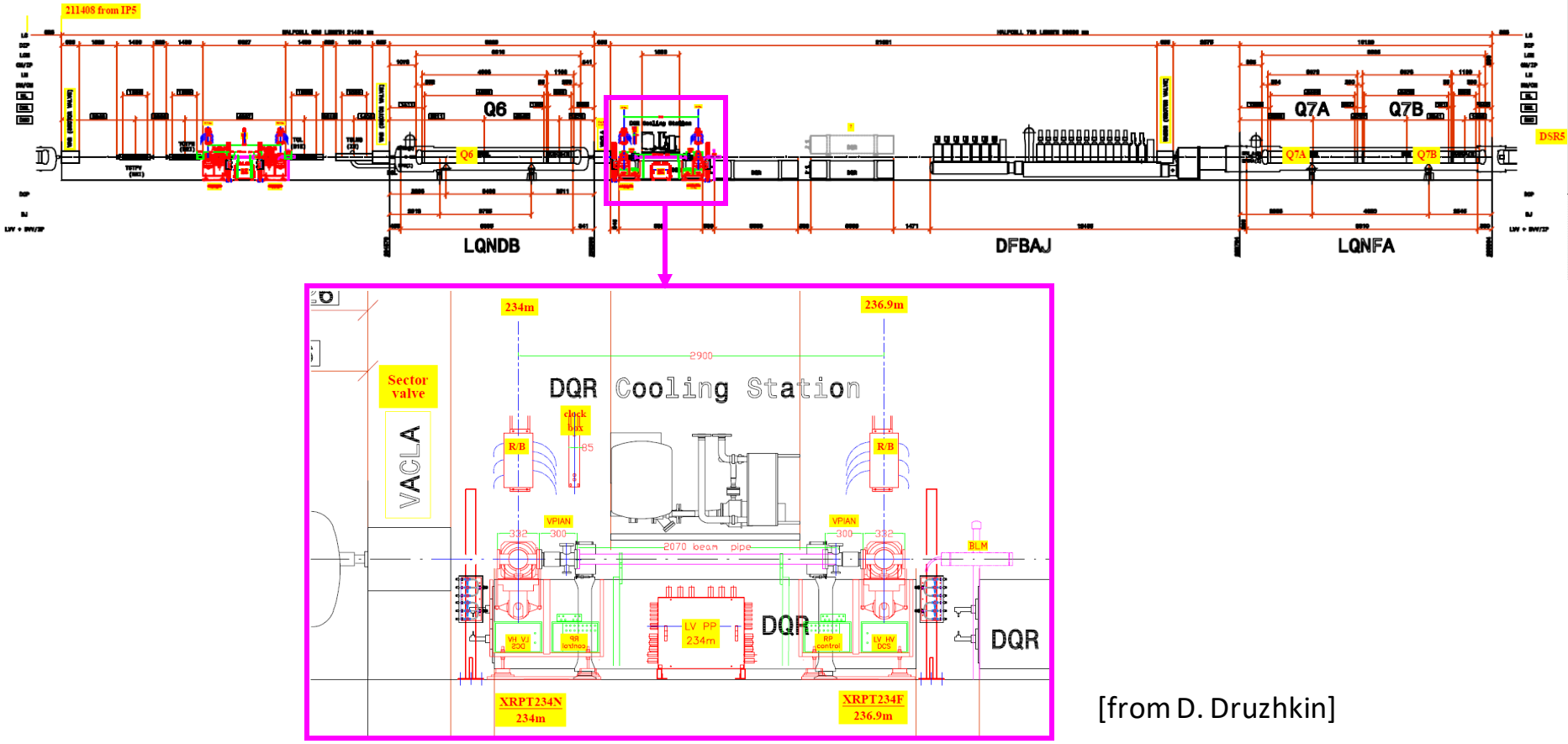
- **Engineering Change Request document (ECR)** as commonly used by the machine, for CMS purposes: ECR embedded in a larger document with updated performance numbers
- detailed integration with future optics version 1.7 (present version: 1.5)
- after integration of XRP units: adaptation of service components (e.g. patch panels) to available space
- material and work for integration → budget assessment for machine interface

Later: TDR including also physics and detectors

TREX: First Round

June 2022: first TREX meeting focussing on PPS@HL-LHC:

PPS input: integration drawing iteration 0 based on optics 1.5 and RP drawings



[from D. Druzhkin]

Detailed integration process deferred to dedicated subgroup meetings:

1. Vacuum group (TE-VSC): establish exact XRP positions, beam pipe connections, vacuum equipment
2. Survey + Alignment group (BE-GM-ASG): movable alignment platforms, wire alignment, XRP compliance with new alignment procedures

→ two rounds of meetings done

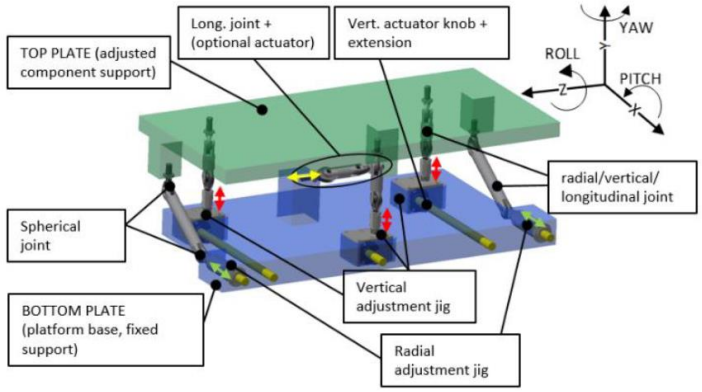
Highlight from Survey & Alignment Meeting: Movable Platforms

All stations need to be on movable alignment platforms.

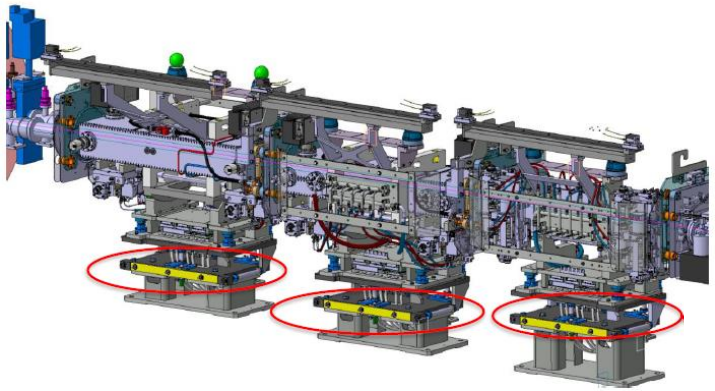
- 196 m stations: remote-controlled platform versions
- 220, 234 m stations: manually adjusted platform versions

Amplitude = ±2.5 mm needed

Received toolkit for custom-design of **Universal Adjustment Platform (UAP), i.e. (x,y)-Table**

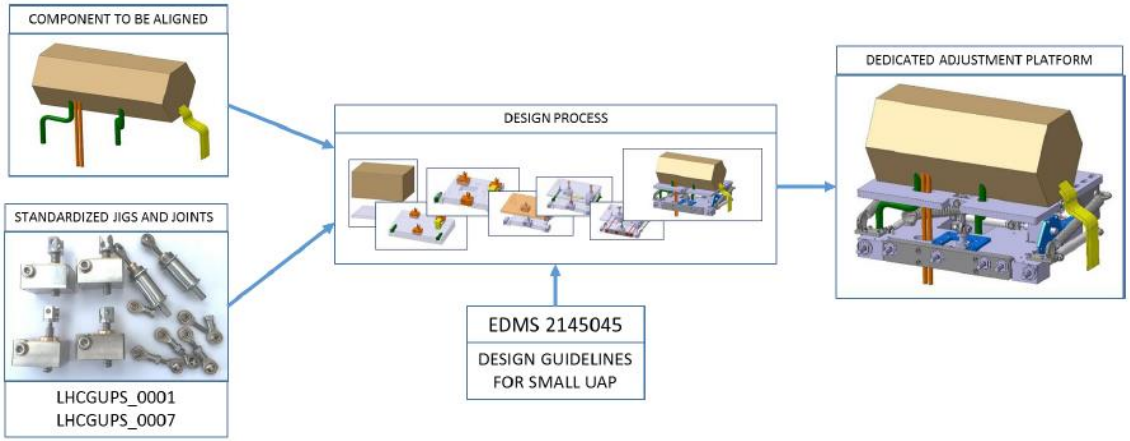


Example: D2-TAXN collimators support



UAP = design framework with standard components, adaptable to individual beamline elements

(a bit like LEGO)



being designed by us

Summary

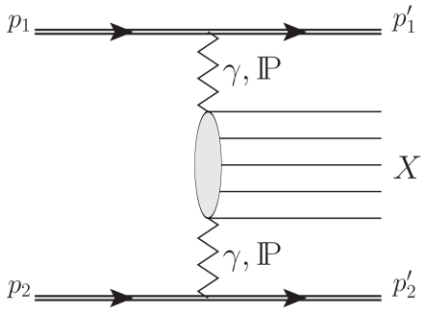
- Reuse most components of present-day Roman Pots to adapt to funding limitations
- Performance calculations updated from EoI → no major changes
- Machine integration studies now in the framework of TREX meetings
  Discussions on integration details ongoing with
  - vacuum group
  - survey & alignment group

  → aiming at ECR document
- Internal development of new RP detector vessel with identical outer specs as the present vessels
  → transparent for machine integration
- Later: TDR combining all aspects of the project

The End.

Appendix

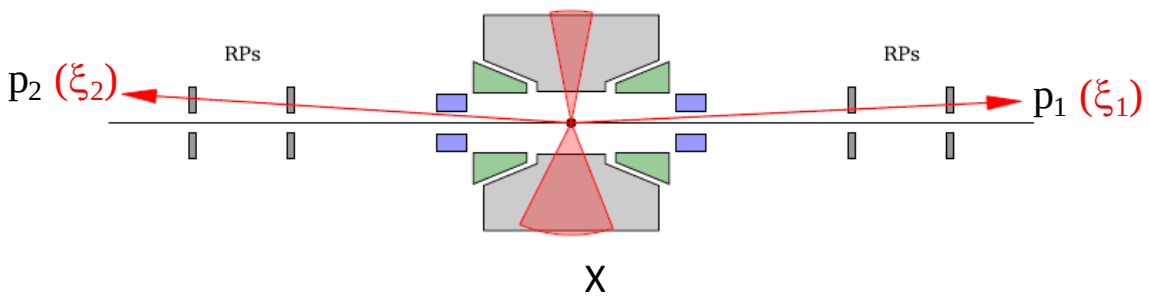
Reminder on PPS Physics: Central Exclusive Production (CEP)



($\xi_1 = \Delta p_1 / p$)

(mass M)

($\xi_2 = \Delta p_2 / p$)



Surviving protons → redundant kinematic information on the central system X.

- **Fractional momentum losses (ξ_1, ξ_2) via proton tracking**

  → Reconstruction of mass and rapidity of central system

$$M_X^2 = \xi_1 \, \xi_2 \, s \qquad y_X = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

- **Transverse momenta ($p_{T,1}$, $p_{T,2}$) via proton tracking**

→ momentum balance with central system useful for event selection:

$$p_{T,X} + p_{T,1} + p_{T,2} = 0$$

- **Longitudinal vertex position via proton time of flight (ToF)**

→ important for resolving pileup (up to μ = 200 at the HL-LHC)

Central Exclusive Production at Different Mass Scales

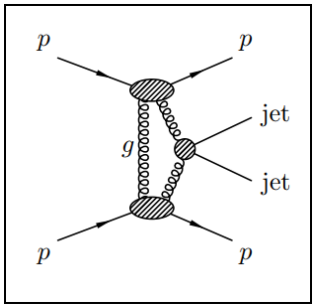
with 420 m station

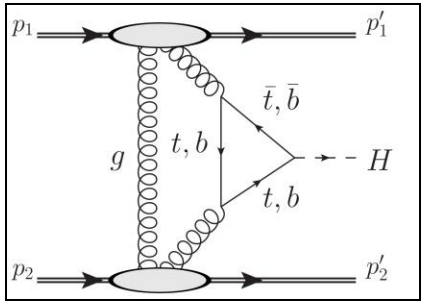
0 – few 10 GeV | **45 – few 100 GeV** | **few 100 GeV – few TeV**

very low mass
(mesonic resonances, glueballs)
needs special high β* optics
→ **done in Run 2,**
not for HL-LHC,
not discussed here

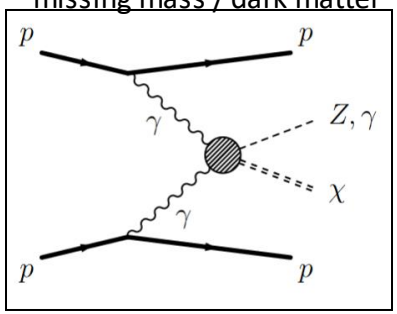
low mass (gg and γγ exch.)
SM studies: exclusive Higgs, dileptons
WW
exclusive jj
missing mass / dark matter,
t tbar

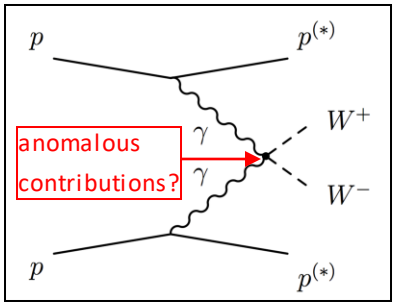
high mass (γγ exch. dominant):
BSM searches: Axion-like particles, anomalous gauge couplings (γγWW, γγZZ)





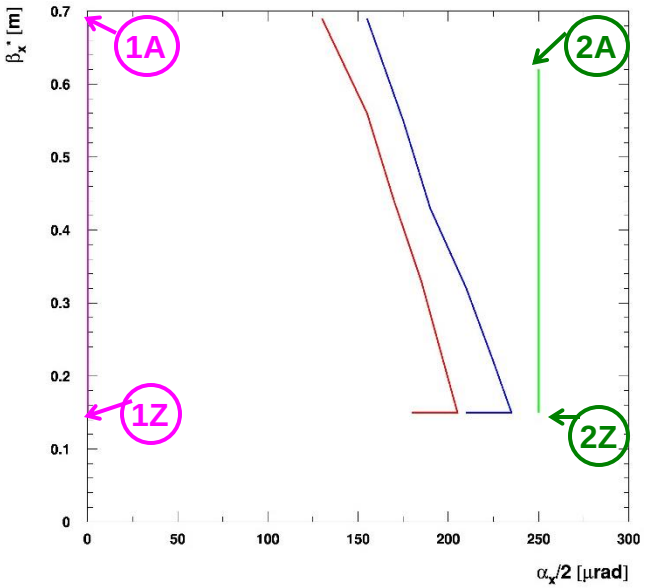
missing mass / dark matter





The PPS and AFP HL-LHC projects are for **standard beam optics and conditions**, **no special runs**, except alignment and calibration fills (few hours)

Acceptance in the Mass – Rapidity Plane



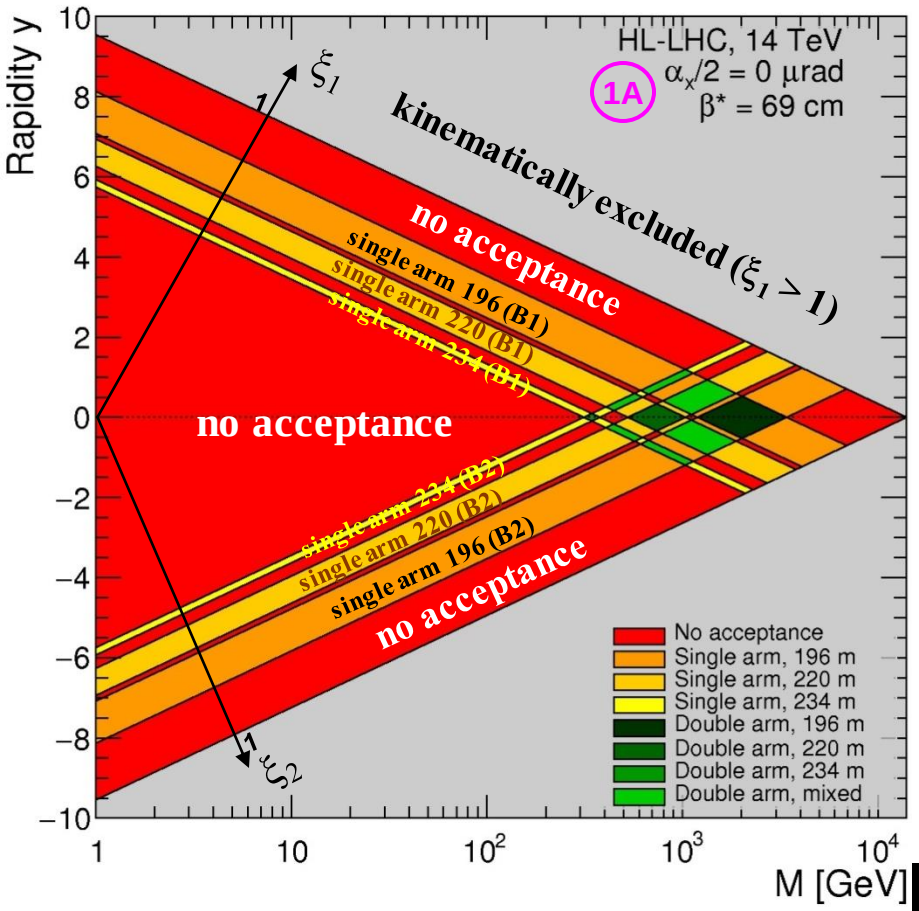
Labels (1A), (1Z), (2A), (2Z)
= start and end points of any vertical
and the simplest horizontal trajectory

For each point ($\alpha_x/2$, β_x^*):

Acceptance for central exclusive events is defined in 2-dim space (ξ_1, ξ_2)
or equivalently – after basis rotation – in (M, y):

$$M^2 = \xi_1 \xi_2 s \qquad y = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

$$\ln \frac{M}{\sqrt{s}} = \tfrac{1}{2}(\ln \xi_1 + \ln \xi_2) \qquad y = \tfrac{1}{2}(\ln \xi_1 - \ln \xi_2)$$



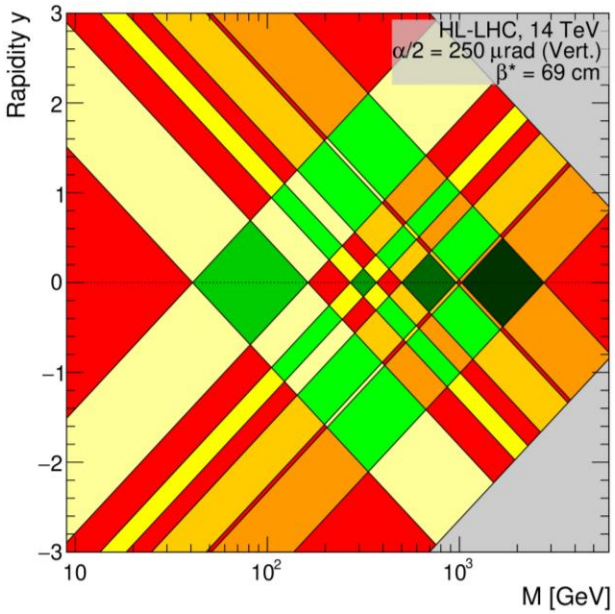
Note on p_T:
The M-y plot is for proton $p_{T,1} = p_{T,2} = 0$
Fixed non-zero p_T would shift the contours.

Acceptance in Mass – Rapidity Plane (new settings)

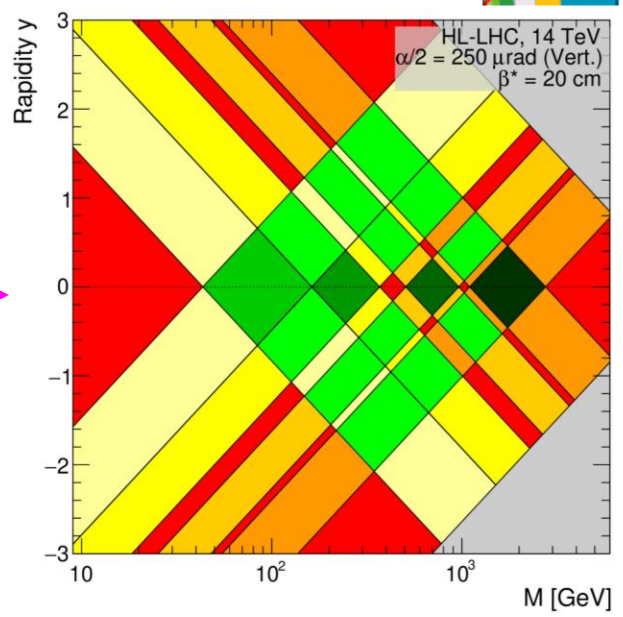
Vertical crossing in IP5

$$\ln\frac{M}{\sqrt{s}} = \tfrac{1}{2}(\ln\xi_1 + \ln\xi_2)$$

$$y = \tfrac{1}{2}(\ln\xi_1 - \ln\xi_2)$$

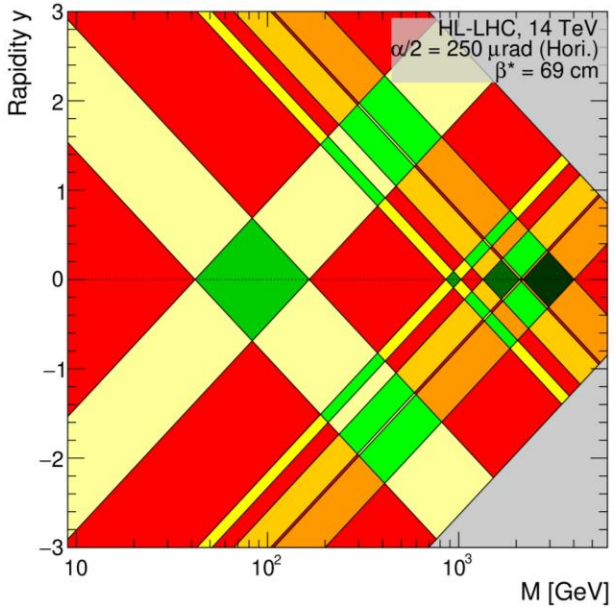


Fill

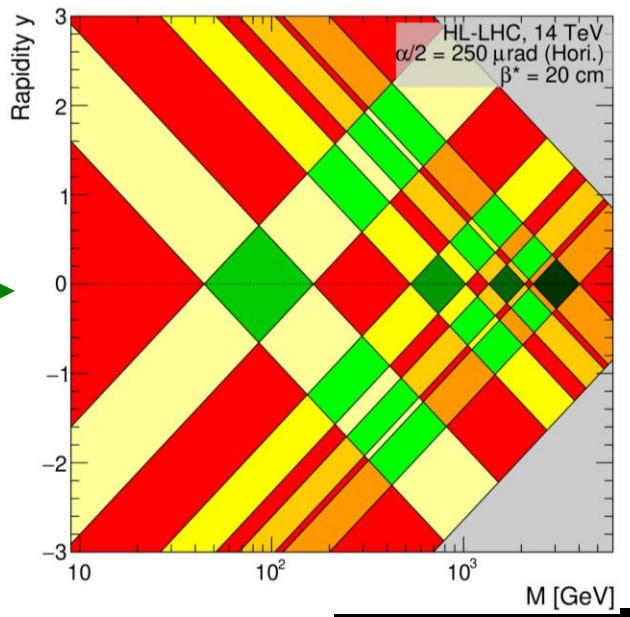


Horizontal crossing in IP5

Large gaps !

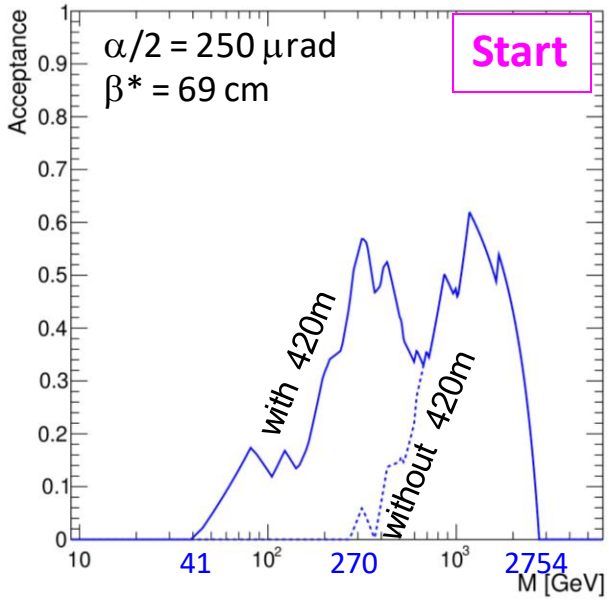


Fill



PPS Mass Acceptance (new settings)

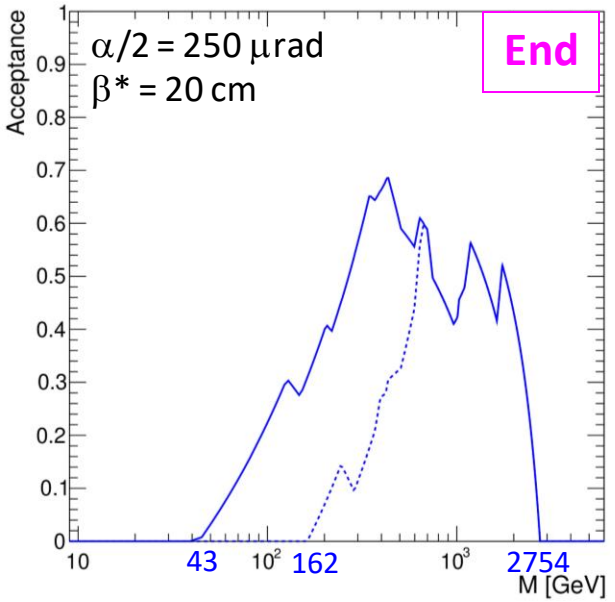
assuming flat rapidity distribution in region $\xi_1, \xi_2 < 0.3$

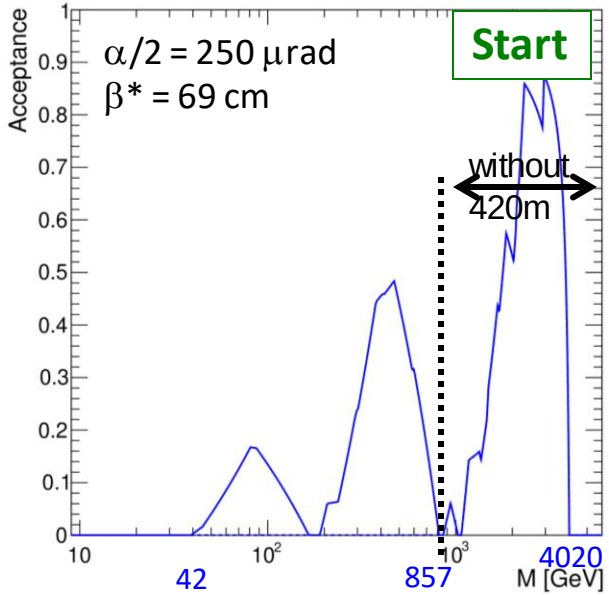


Vertical crossing in IP5
(decided for implementation)

Evolution along the Fill

(luminosity levelling)





Horizontal crossing in IP5
(for comparison)

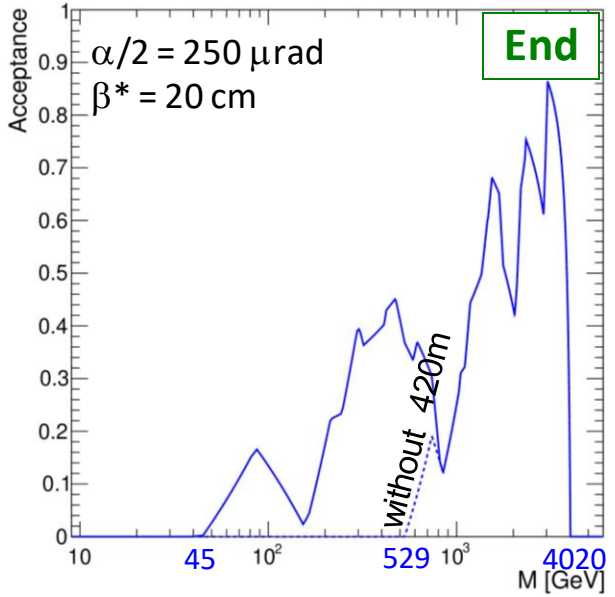
Evolution along the Fill

("baseline" luminosity levelling trajectory)

Dispersion:

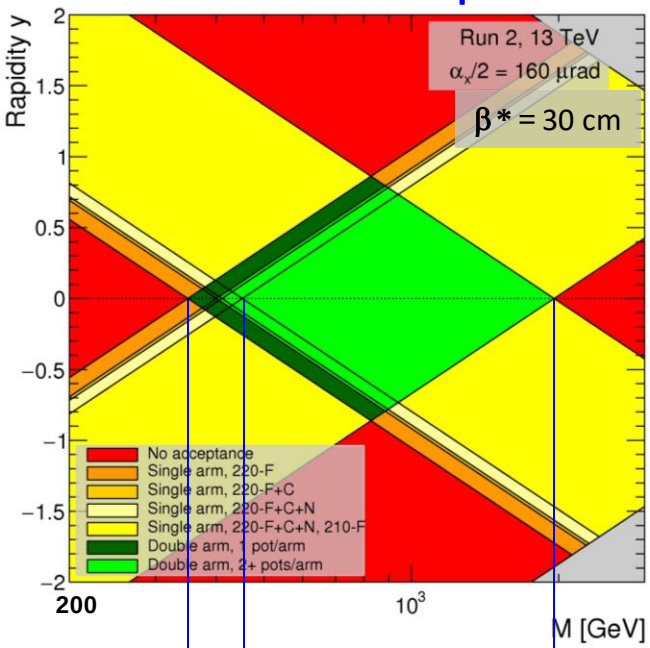
$D_x = D_x(0) - D_x' \ \alpha_x/2$

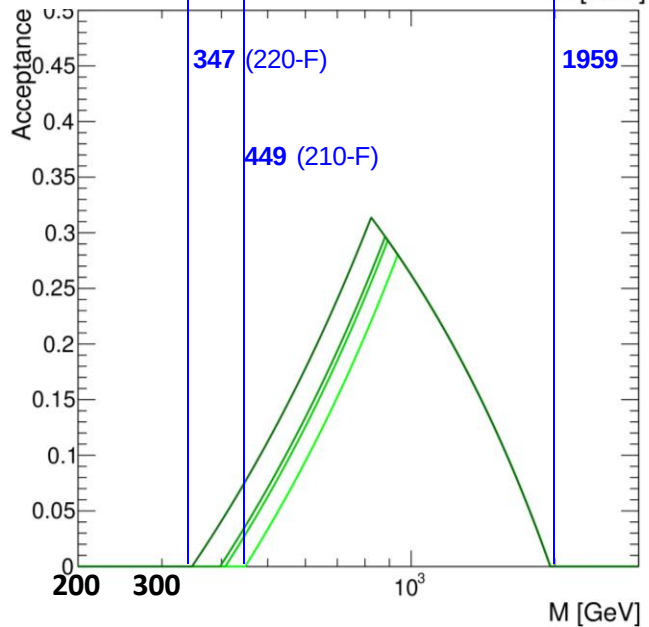
(X-angle **reduces** D_x !)



Comparison Mass-Rapidity Acceptance Run 2 / HL-LHC

2018 Nominal Optics





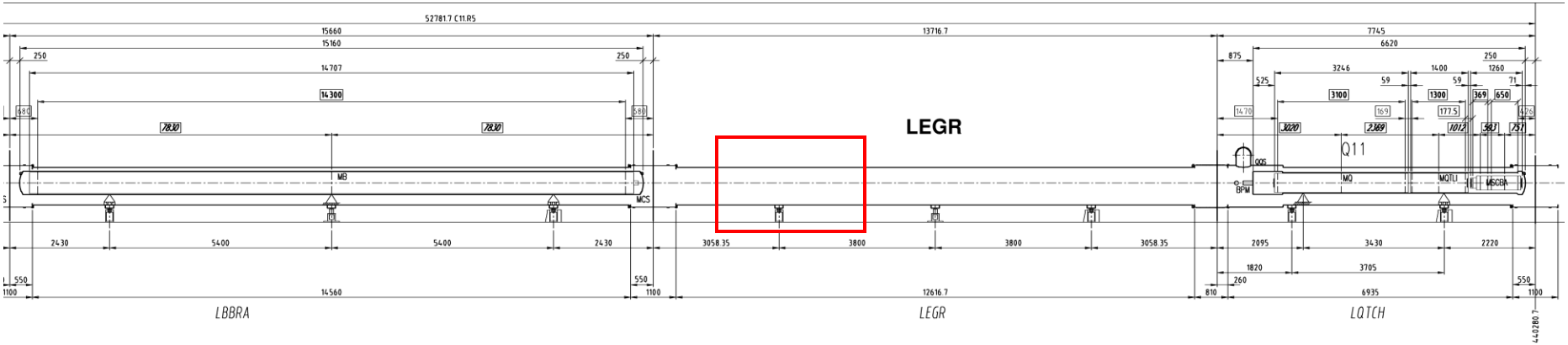
HL-LHC (vertical crossing):

without 420 m: 133 GeV – 2.7 TeV
with 420 m: 43 GeV – 2.7 TeV

Physics programme allows
a staged installation (420 m later)

The 420 m Station

Necessary for masses < 200 GeV (e.g. exclusive Higgs production)

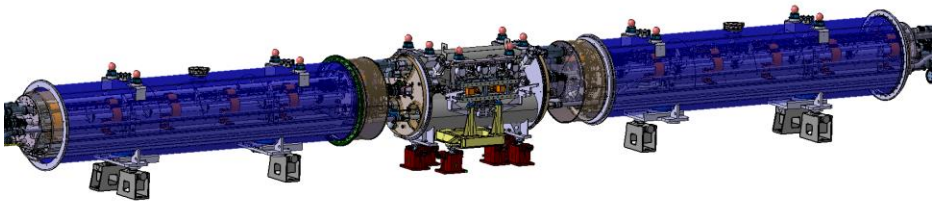


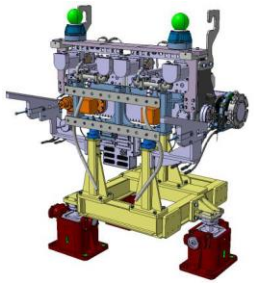
- Region with an empty cryostat ("missing magnet")
- Signal proton tracks are between the 2 beampipes (positive dispersion)

→ Not suitable for present Roman Pot technology → needs special development

Ideas:

- Re-use connection cryostat from TCLD integration or cryostat designed for the old FP420 project
- Detector vessel options:
  - mini Roman Pot
  - modified TCLD
  - moveable beampipe





TCLD

Second-stage project for installation in LS4