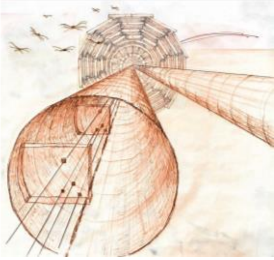
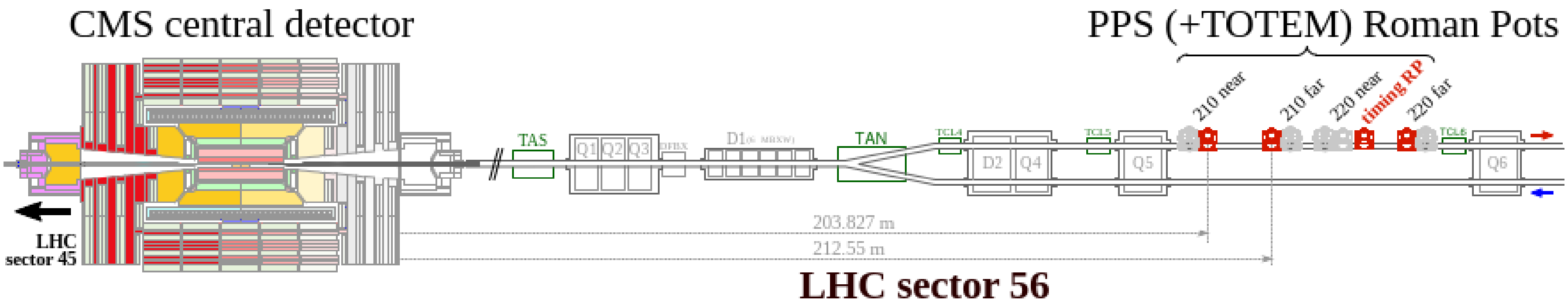
Diffraction and Low-x 2024 workshop, 8÷14/09/2024. Palermo, Sicily



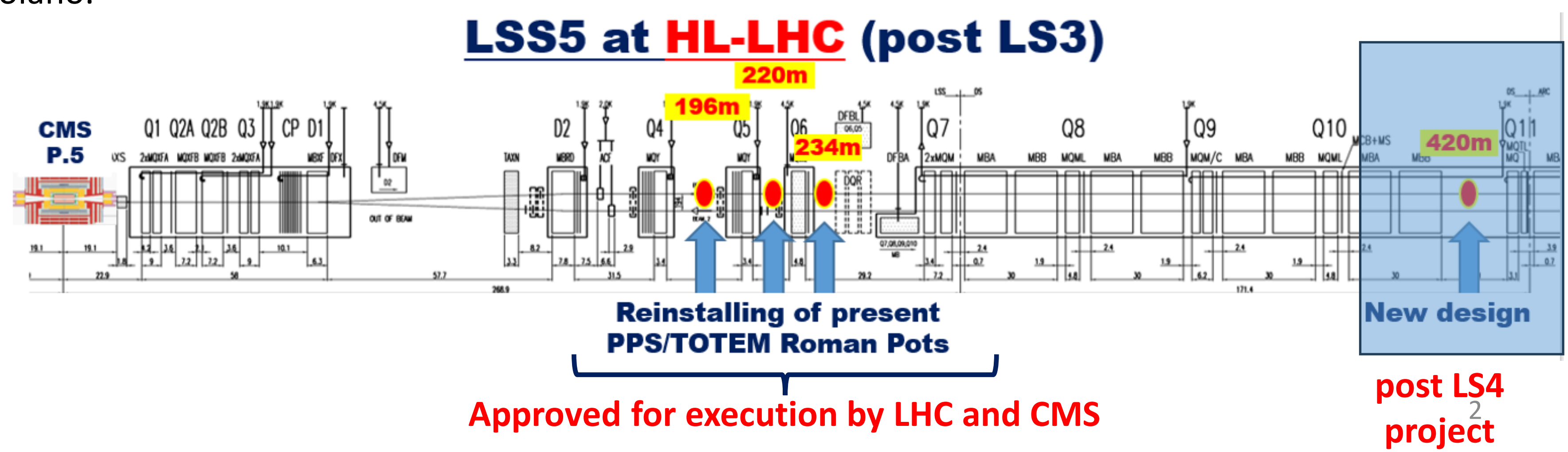
New CMS Precision Proton Spectrometer (PPS2) at HL-LHC

D.Druzhkin
on behalf of the CMS collaboration

The CMS Proton Precision Spectrometer (PPS) measures both, tracking and timing information of the scattering protons and allows to reconstruct the proton momentum loss and longitudinal position of the proton interaction vertex.
The PPS setup has been installed in 2014 for LHC Run2 and Run3 and will work until the end of LHC Run 3. The data has been collected successfully since 2016.

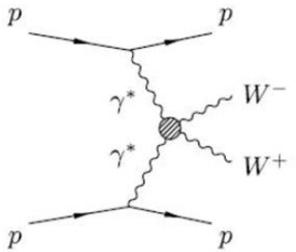


A new proton spectrometer (called PPS2) has been proposed for HL-LHC. This new setup will match the new geometry and parameters of the HL-LHC accelerator. The proposal was approved by CMS and CERN in 2023.
The detailed info on PPS2 EoI (https://cds.cern.ch/record/2750358); see also the yesterday's talk by A.Solano.



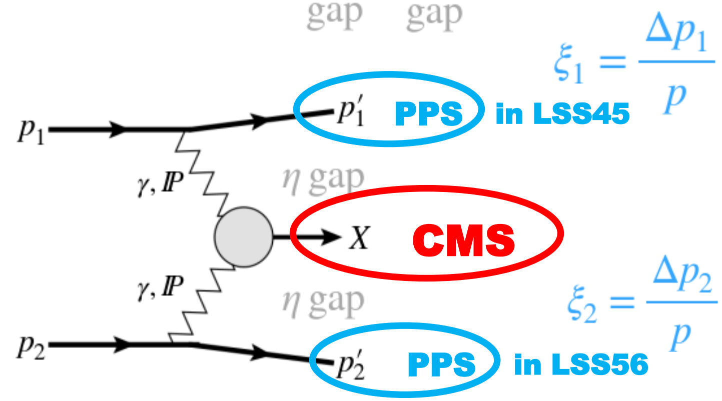
Physics motivation

1. EWK. LHC as photon-photon collider

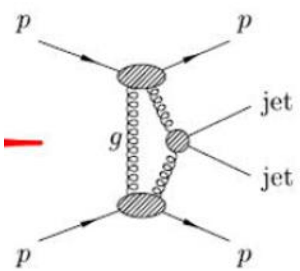


- Measure $\gamma\gamma \rightarrow W^+W^-$; e^+e^-; $\mu^+\mu^-$; $\tau^+\tau^-$.
- Search for $ZZ\gamma\gamma$; $\gamma\gamma\gamma\gamma$ coupling.

$$p + p \rightarrow p \underset{\text{gap}}{\oplus} X \underset{\text{gap}}{\oplus} p$$

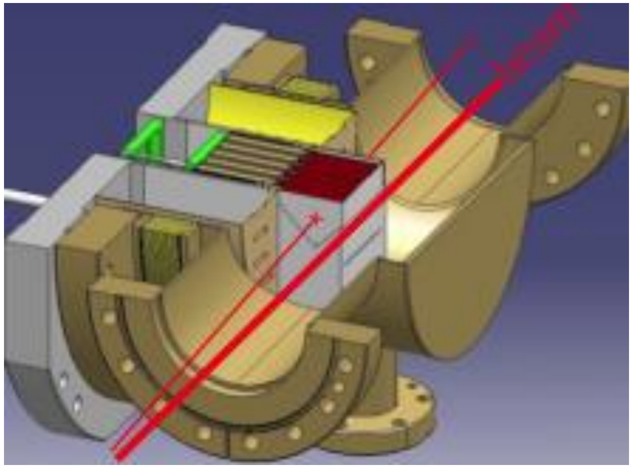


2. QCD. LHC as gluon-gluon collider



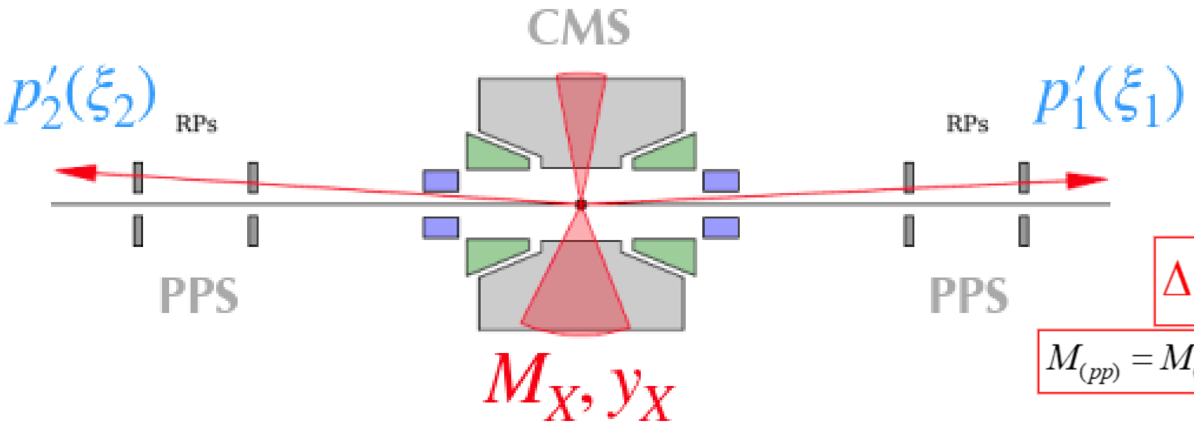
- Exclusive two and more jet events.
- Gluon jet samples with small quark jet component.
- Proton structure (GPDs) investigation.

$$M_X = \sqrt{\xi_1 \xi_2 s} \quad y_X = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$



3. BSM. Search for new resonances in CEP

General scheme for exclusive production



$$\Delta\eta_{1,2} = -\ln \xi_{1,2}, \quad M^2 = \xi_1 \xi_2 s$$

$$M_{(pp)} = M_{(central)}; P_{T,Z(pp)} = P_{(central)}; vertex_{(pp)} = vertex_{(central)}$$

Kinematic coverage. HL-LHC (Run4).

Diffractive Mass acceptance limits

Vertical Crossing-Angle				
Station	$\lvert\xi_{min}\rvert$	$\lvert\xi_{max}\rvert$	M_{min} [GeV] @ y = 0	M_{max} [GeV] @ y = 0
196 m	0.0786−0.0856	0.1967	1100.87−1197.80	2754.27
220 m	0.0371−0.0381	0.0688	519.89−533.18	962.70
234 m	0.0189−0.0095	0.0263	264.96−132.80	368.11
420 m	0.0031−0.0034	0.0116	43.38−47.04	162.66

Horizontal Crossing-Angle				
Station	$\lvert\xi_{min}\rvert$	$\lvert\xi_{max}\rvert$	M_{min} [GeV] @ y = 0	M_{max} [GeV] @ y = 0
196 m	0.1654−0.1779	0.2871	2316.15−2490.07	4018.94
220 m	0.0984−0.1014	0.1488	1377.48−1419.13	2083.04
234 m	0.0564−0.0312	0.0732	789.48−437.07	1024.60
420 m	0.0032−0.0034	0.0118	44.55−48.20	165.28

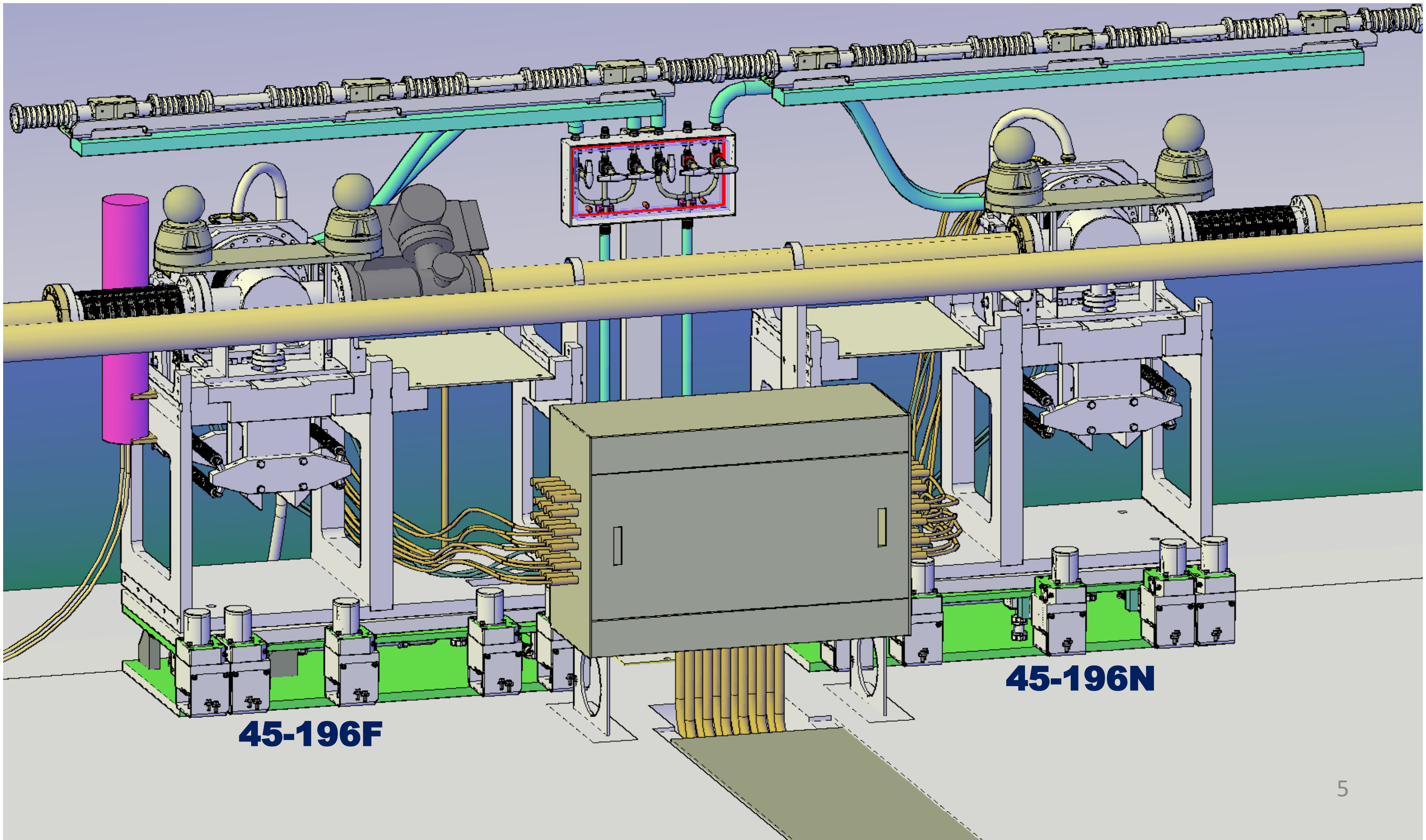
Points of maximum proton fluence Φ (after 1 and 300 fb^{-1})

Station	x_{peak} [mm]	y_{peak} [mm]	$\Phi[p/cm^2]$ (1 fb^{-1})	$\Phi[p/cm^2]$ (300 fb^{-1})
196 m	9.9	−11.6	$0.18\ (0.19) \times 10^{13}$	$5.4\ (5.7) \times 10^{14}$
220 m	4.5	−5.7	$0.98\ (0.99) \times 10^{13}$	$2.9\ (3.0) \times 10^{15}$
234 m	2.3	−2.7	$4.7\ (4.4) \times 10^{13}$	$1.4\ (1.3) \times 10^{16}$
420 m	6.8	0.2	$2.0\ (2.0) \times 10^{13}$	$6.0\ (6.0) \times 10^{15}$

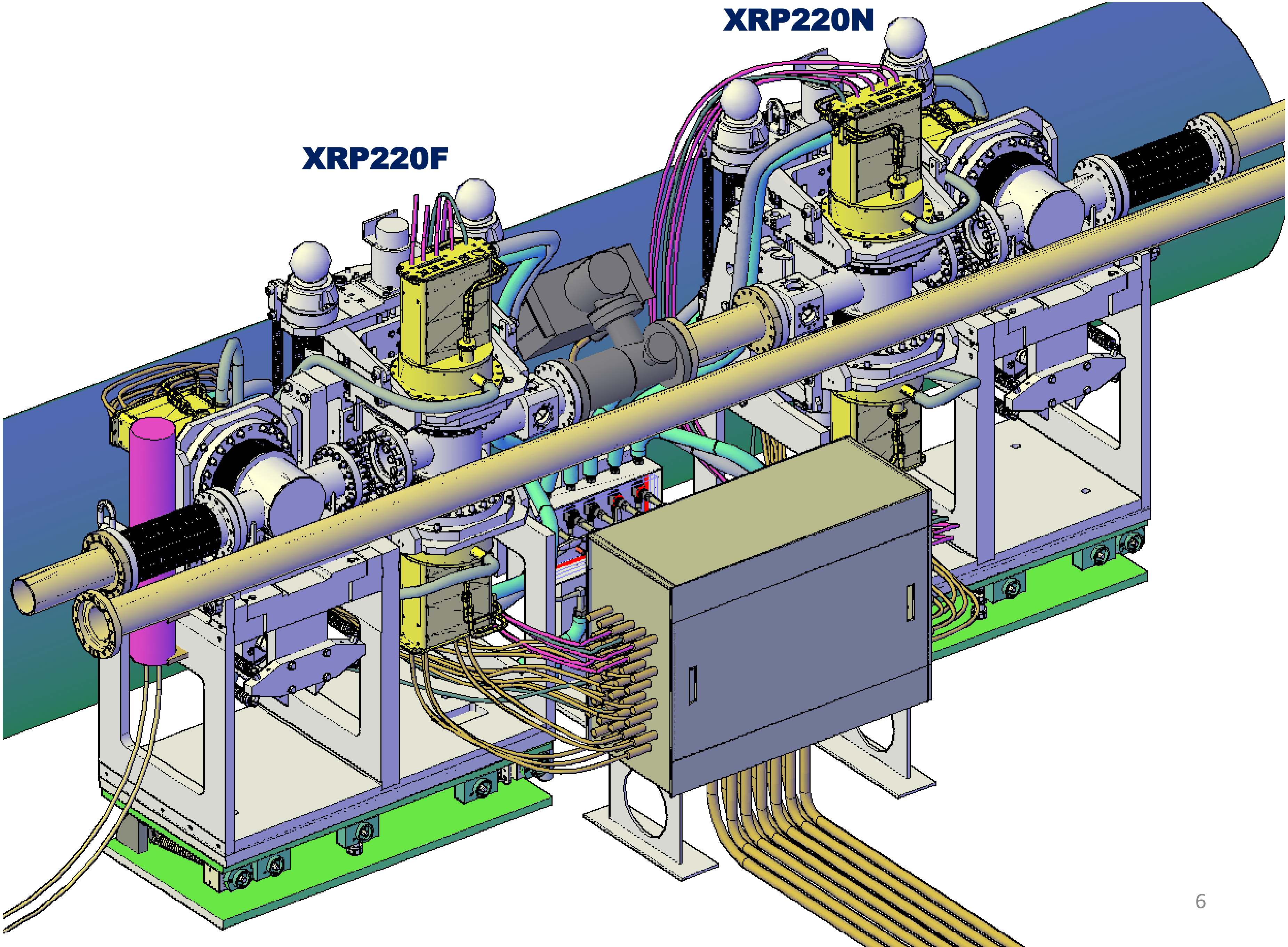
from EoI: https://cds.cern.ch/record/2750358?ln=en

The PPS2 stations will be installed in the LHC tunnel symmetrically around the CMS detector (IP5) at 196 m, 220m and 234m; they are grouped by 2 detectors in each point. All issues with the installation of PPS2 stations and related equipment in the tunnel have been agreed upon and approved with HL-LHC management.

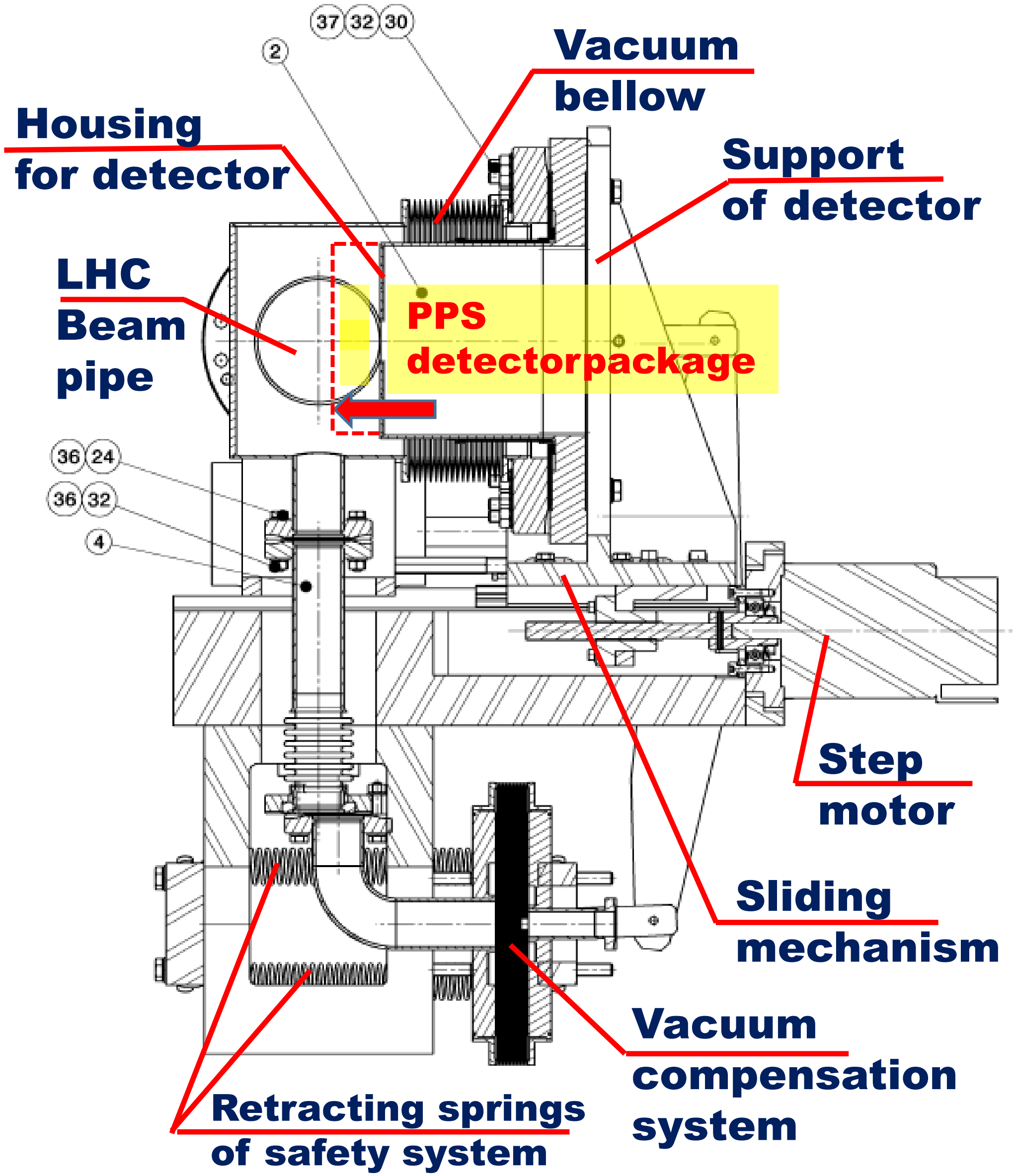
Placement of 2 detectors at 196m. The same design for 234m. The arm between two detectors is shorter then in present PPS.

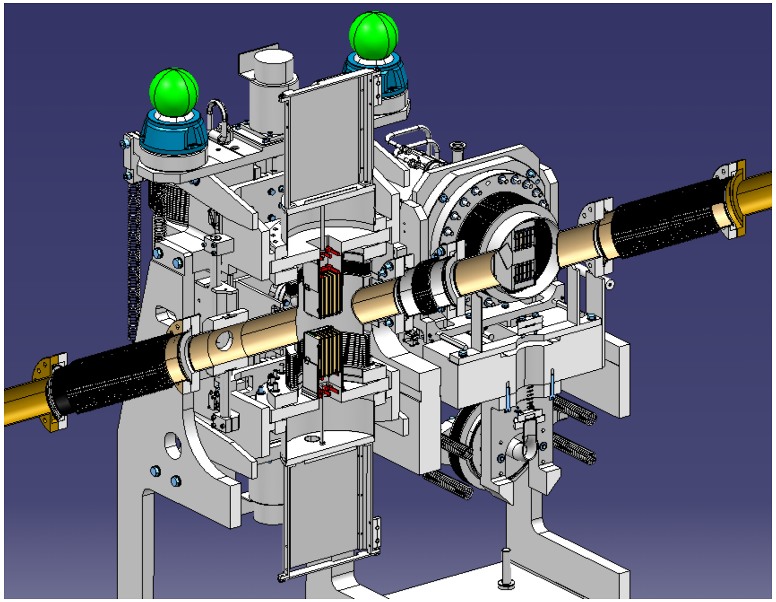


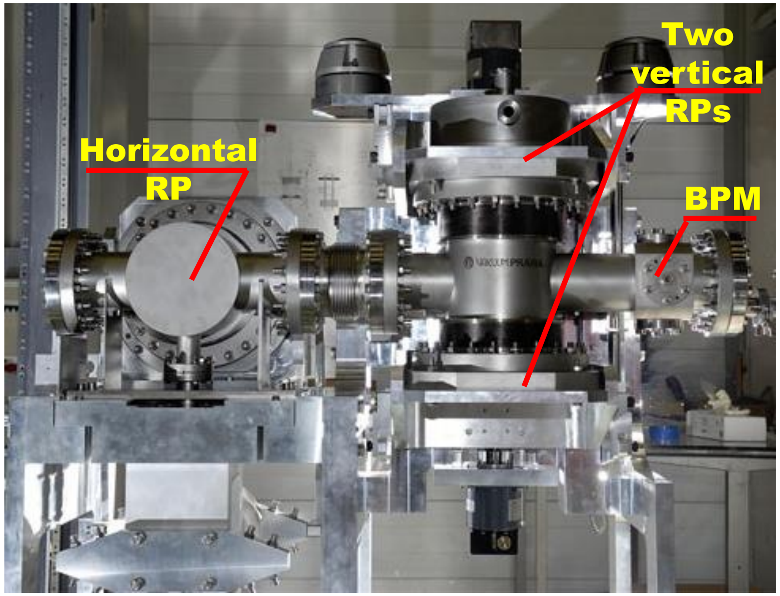
Placement of 2 detectors at 220m



Mechanical structure of Roman Pot for PPS/PPS2

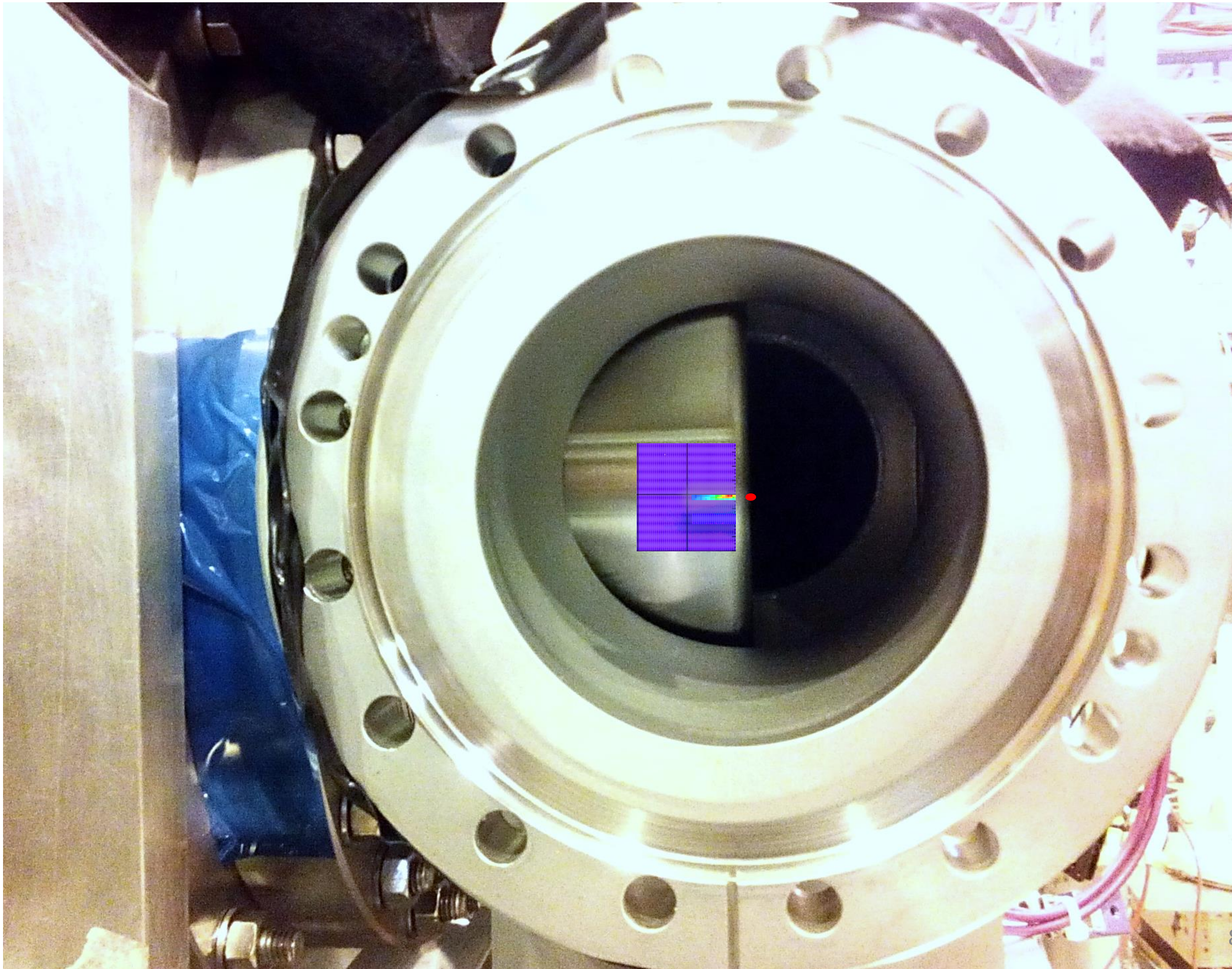




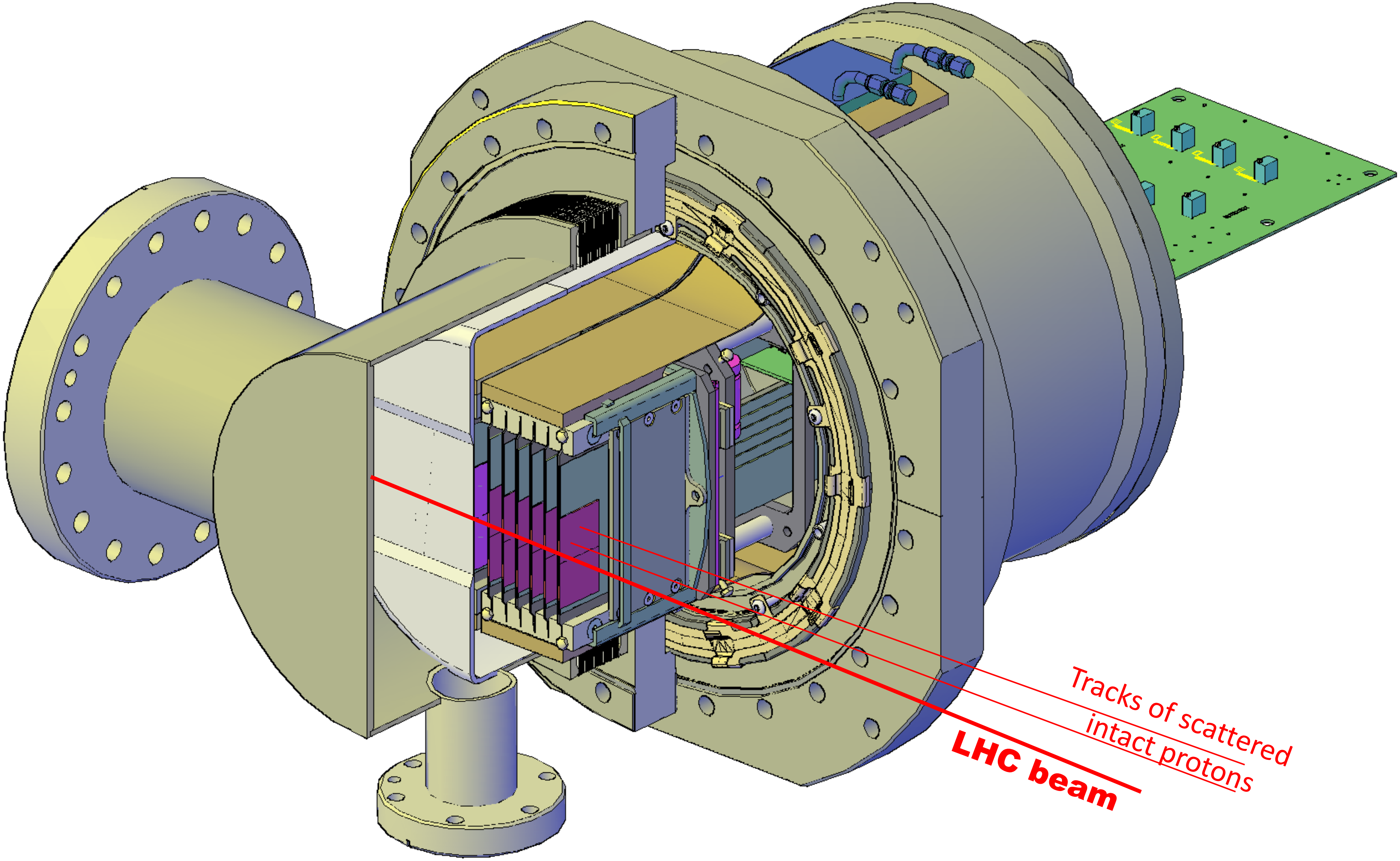


- The housing separates the detectors and LHC beam pipe.
- The thickness of the front wall is 500 μm to minimize material traversed by the protons
- To avoid pressure on the thin wall, a secondary vacuum is present in the detector volume.

Location of sensors and scattered proton tracks relative to the LHC beam (in vacuum tube)

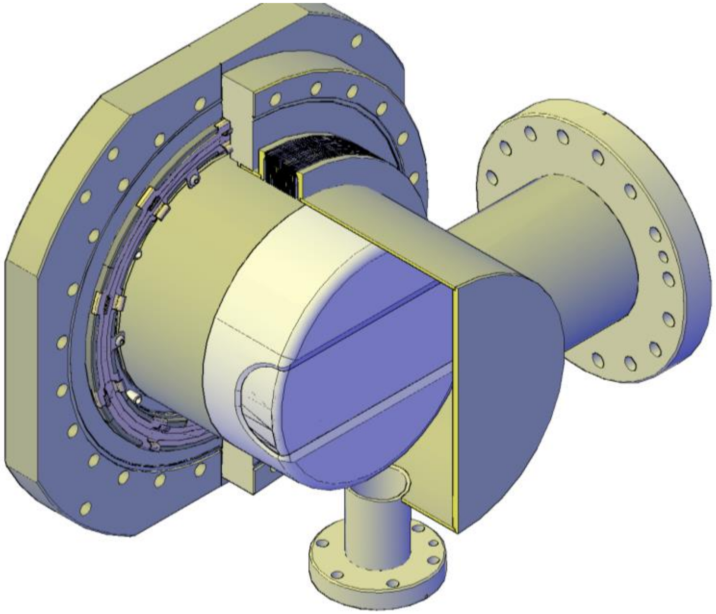


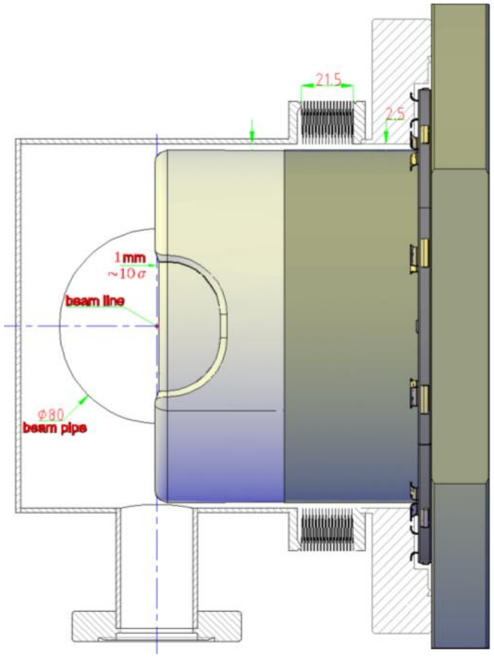
PPS2 Detector on HL-LHC beam

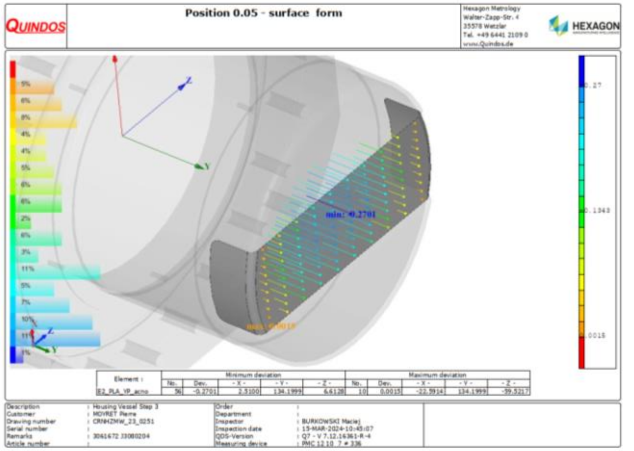


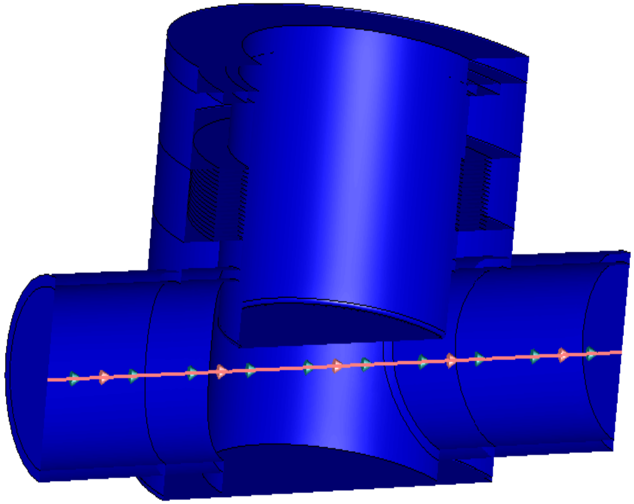
The PPS2 detectors can be installed and removed for maintenance without disturbing the LHC vacuum.

New Housing vessel for PPS2 detector package







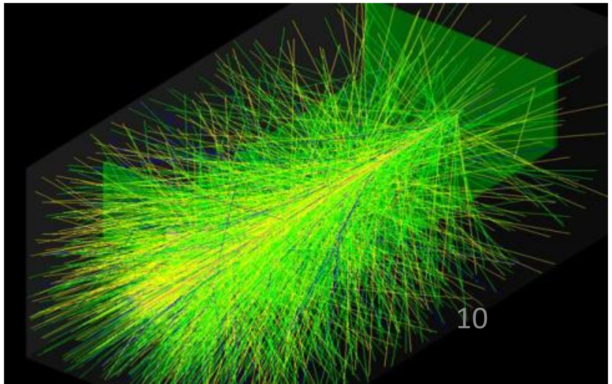


The housing vessel is a key part of the project: it separates the LHC vacuum from the detector volume. The PPS2 vessels will have a wider thin window than those in the present PPS.

A new vessel has been designed that meets the HL-LHC requirements.

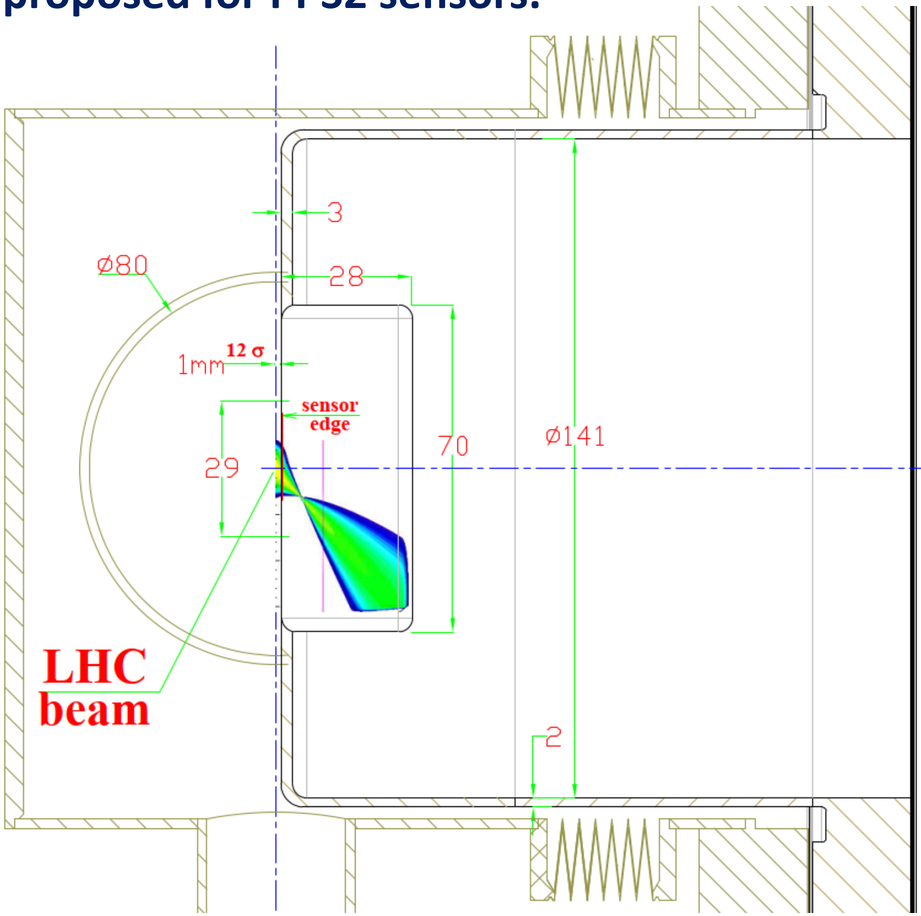
Simulation and optimization have been performed:
- Proton beam compatibility – Impedance study;
- Interaction of the protons with the vessel walls – mass budget. GEANT;
- Strength and deformation of the vessel under vacuum. Cyclic loads. ANSYS;
- Effect of thermal load. Cooling of the housing and detector.

Various tests confirming the design and simulations have been or are being performed.

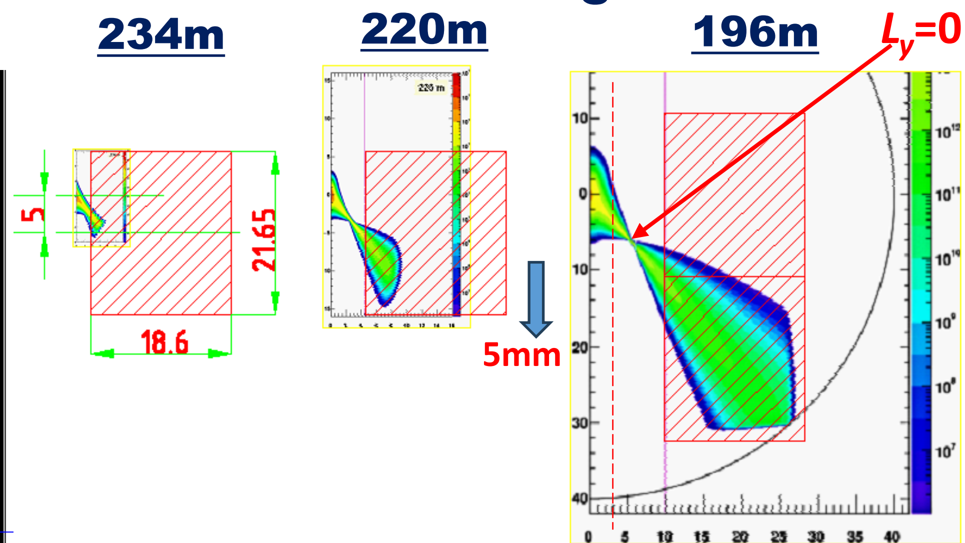


PPS2 sensors position vs tagged proton hit map

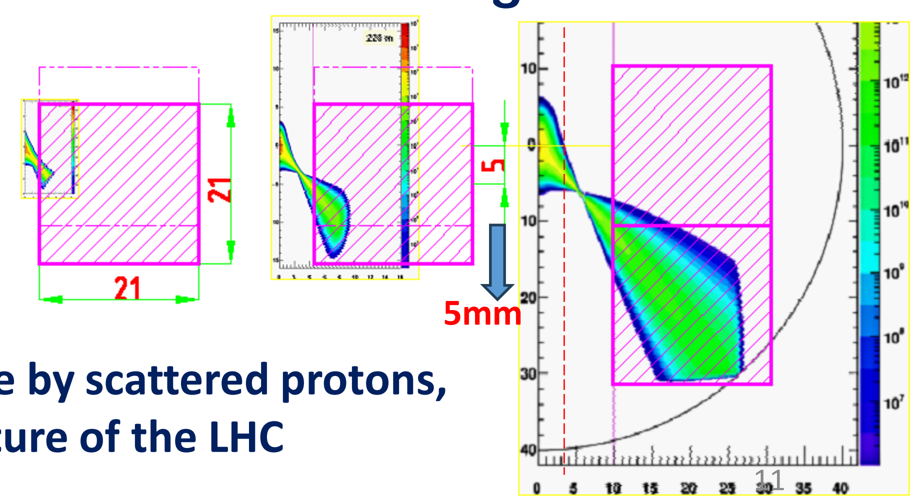
A silicon pixel technology (tracking) and Low Gain Avalanche Detector (timing) was proposed for PPS2 sensors.



RPIX – Si-Pixel (with CROCv2) tracking



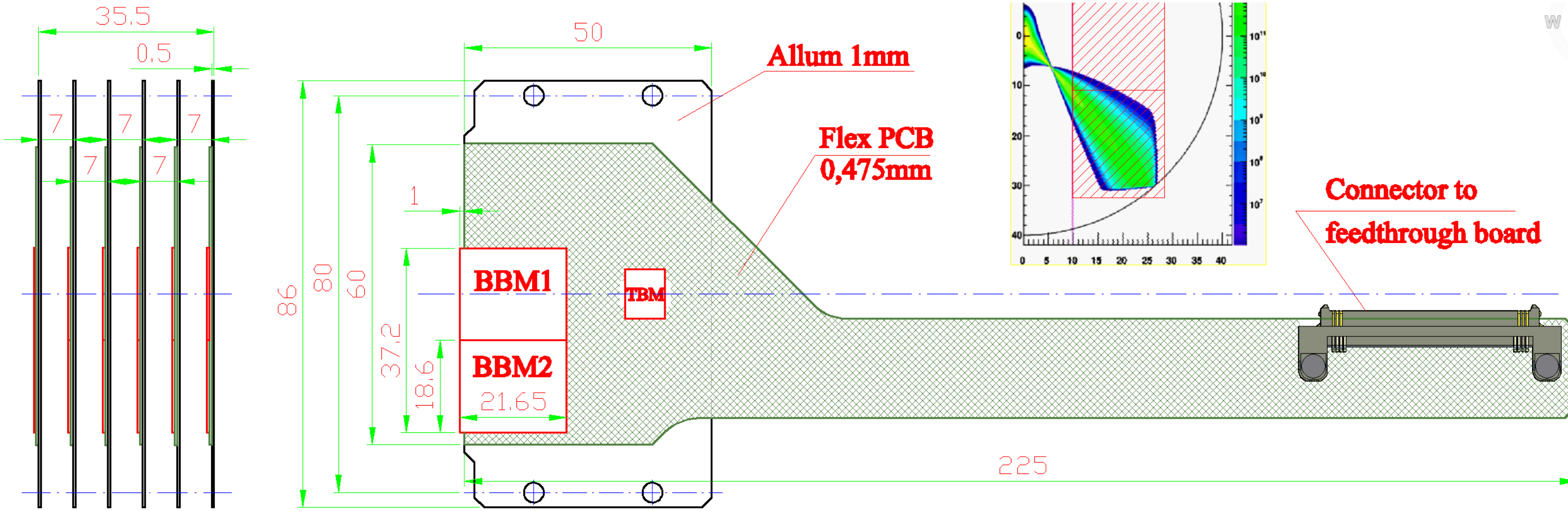
LGAD (with ETROC2) timing



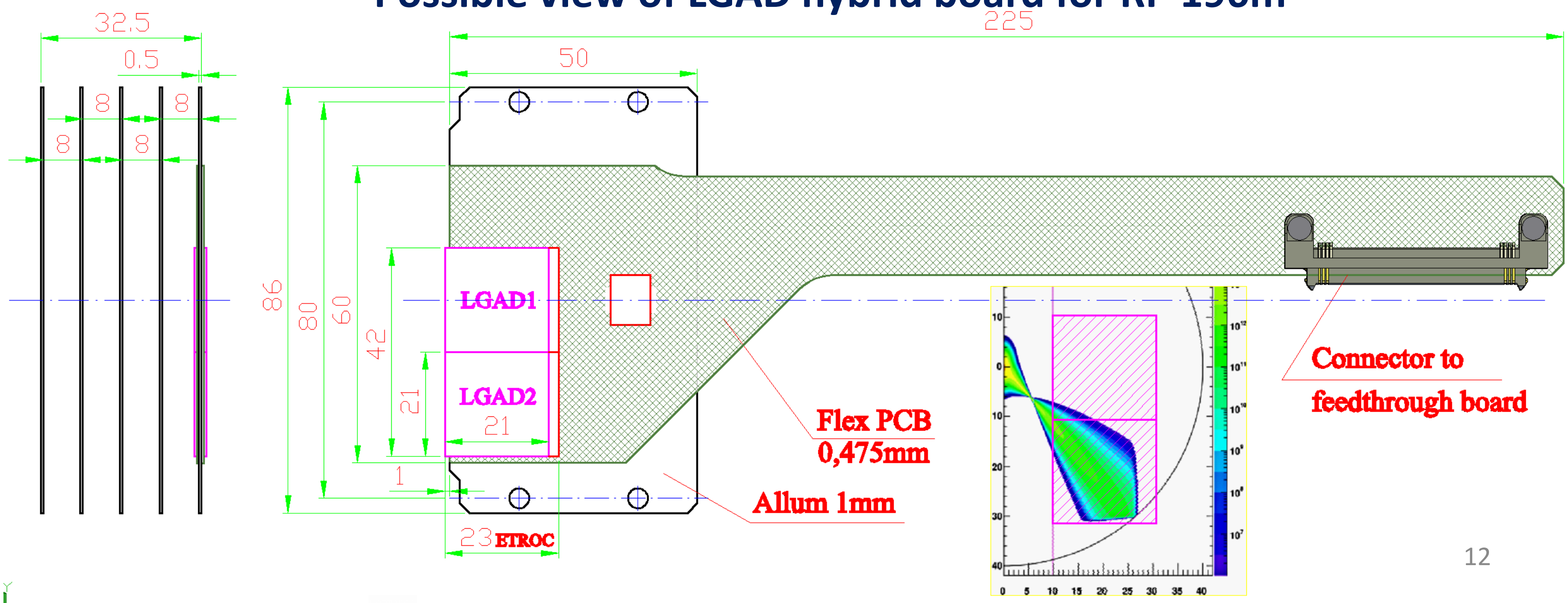
The PPS2 sensors cover the entire area reachable by scattered protons, which is limited by the collimators and the aperture of the LHC

Optics, M.Deile, from ECR v.1

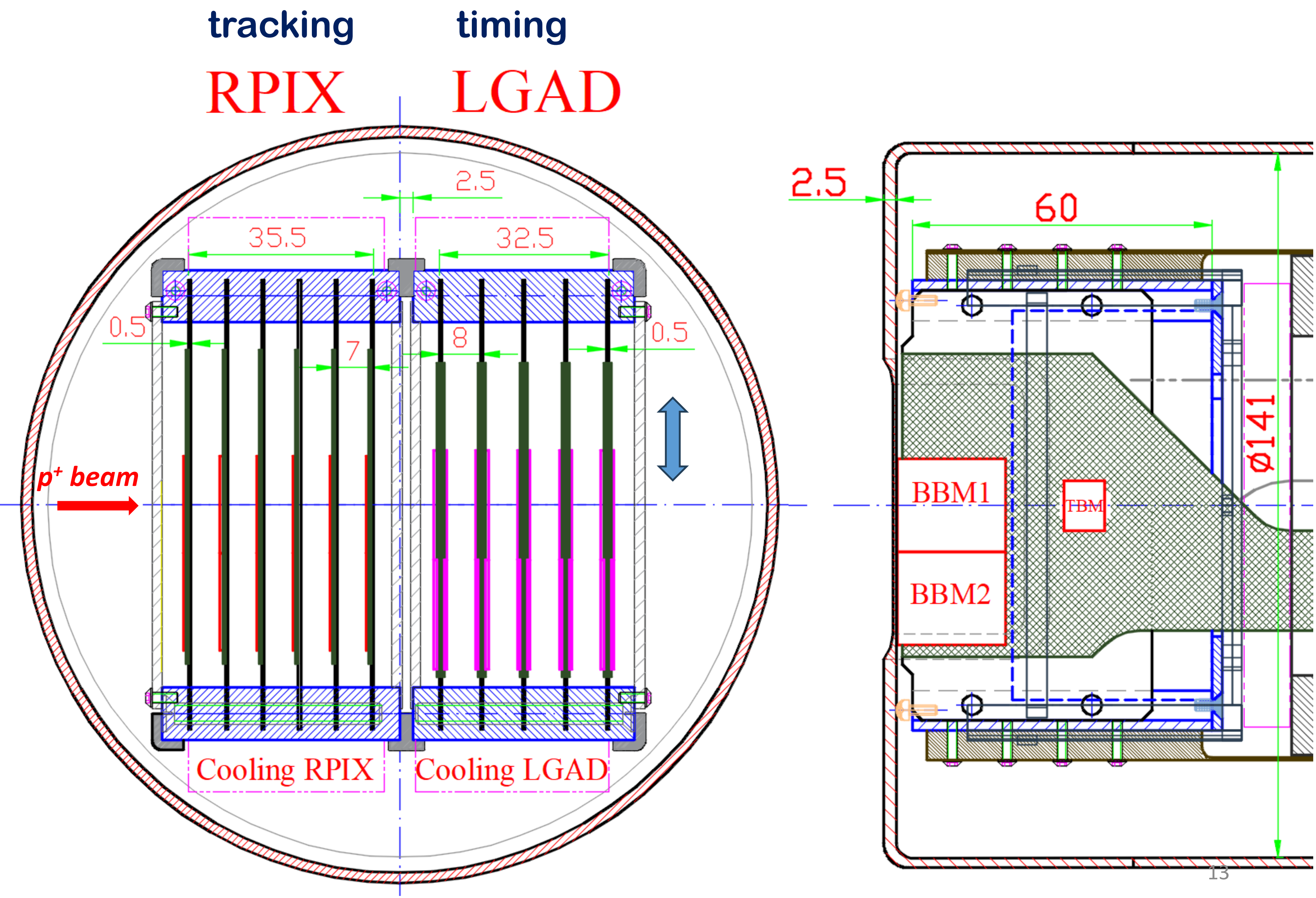
Possible view of RPIX hybrid board for RP 196m

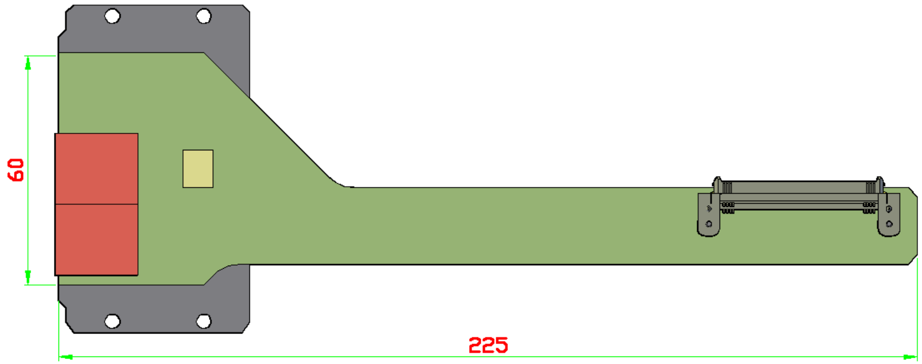


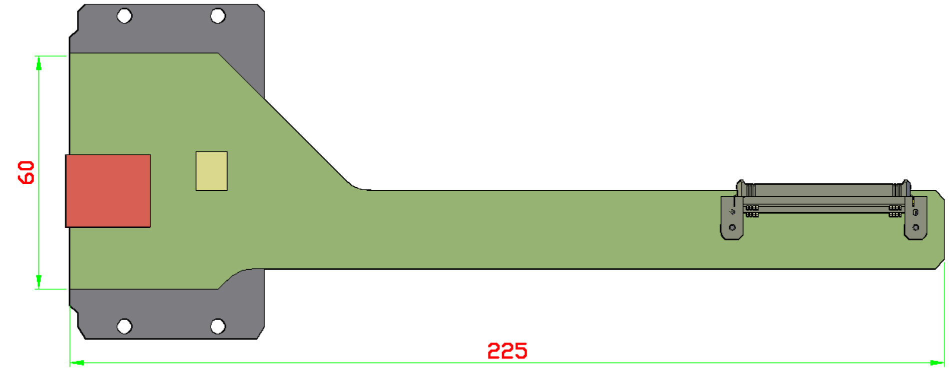
Possible view of LGAD hybrid board for RP 196m

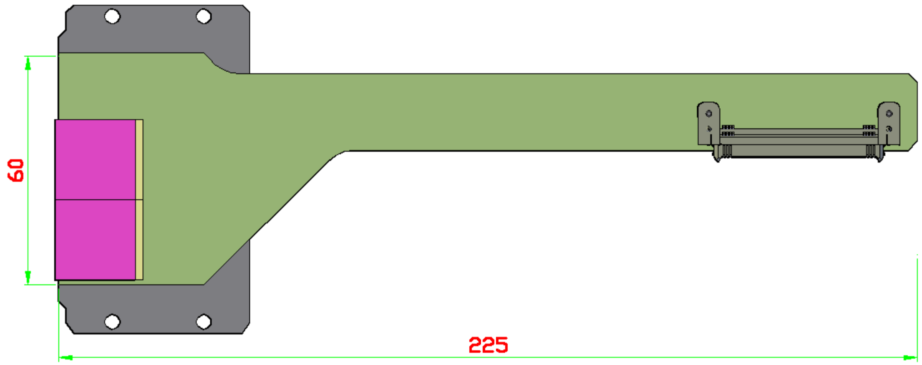


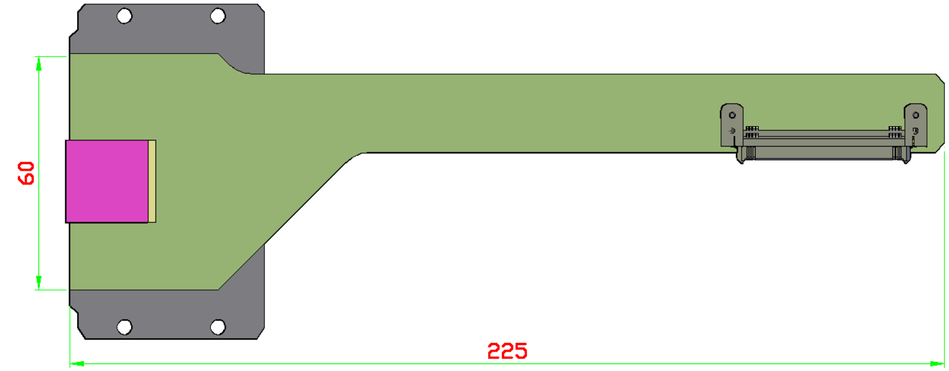
PPS2 detector package

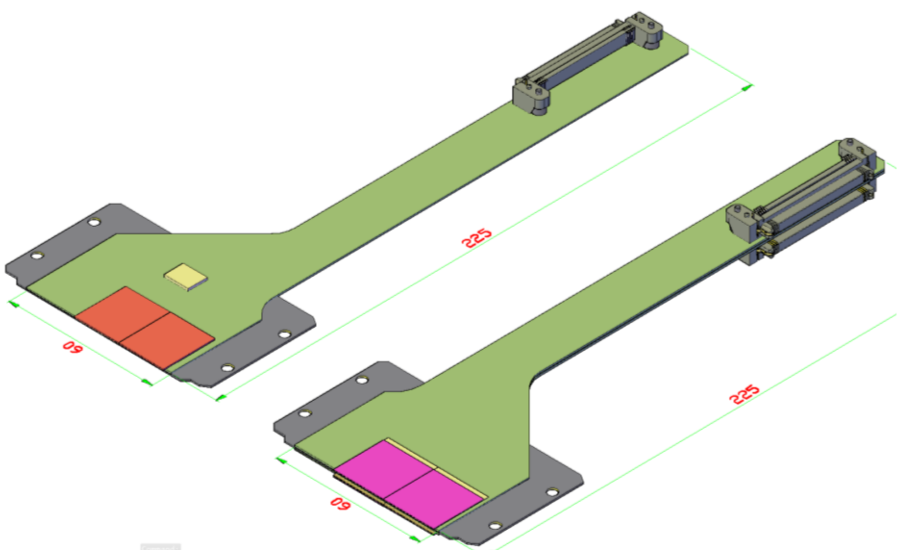




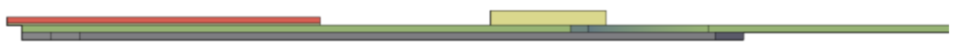








RPIX hybrid board



- aluminium: 400 um; (500um)
- silicone glue: about 50 um;
- silicon: ~400 um (~210 um chips + ~180 um sensor);
- ~100 um adhesive acrilic film;
- PCB: 225 um polyamide + ~50 um copper + ~200 um acrilic film
- small sparse SMD passive components + tin solder

LGAD hybrid board

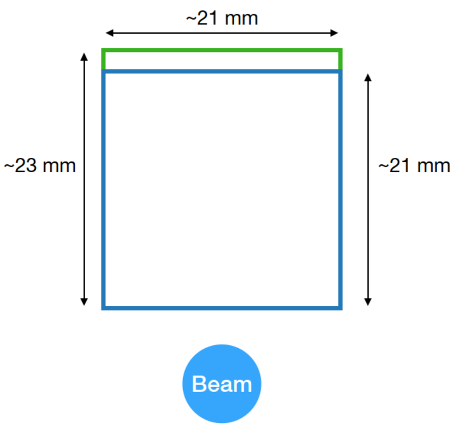
- aluminium: 400 um; (500um)
- silicone glue: about 50 um;
- PCB: 225 um polyamide + ~50 um copper + ~200 um acrilic film
- LGAD+ETROC as a single block of silicon with 0.5 mm thickness

Present PPS RPIX hybrid board

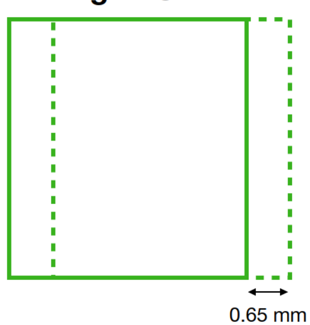
Legend:
- LGAD
- ETROC

PPS2 - LGAD/ETROC

Top View

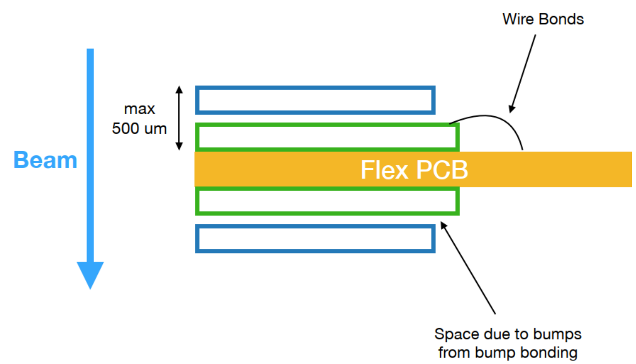


Top/Bottom Alignment



nb: Dimensions in this view not yet well defined

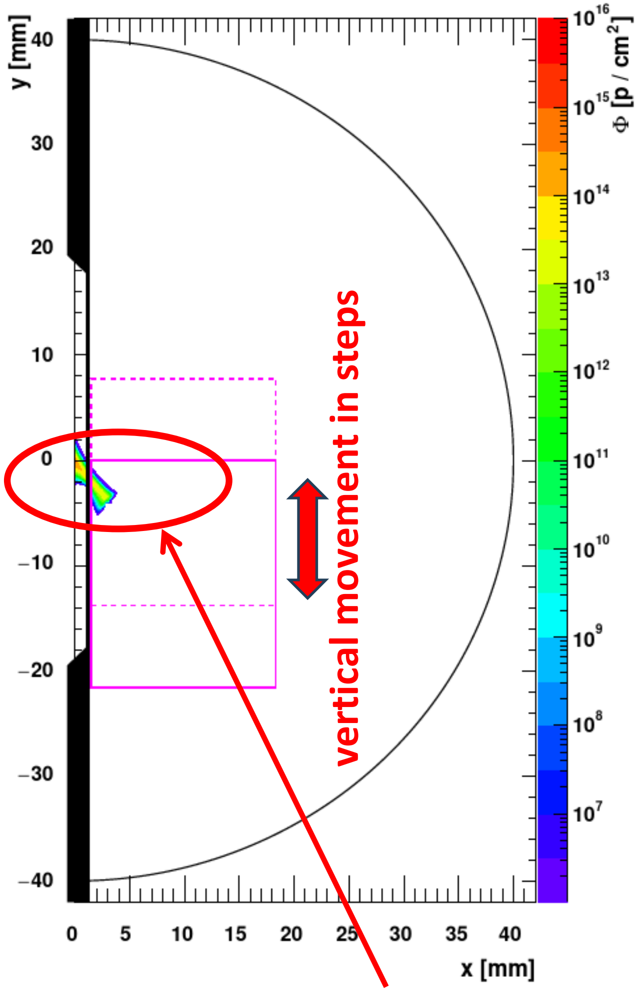
Side View



nb: Dimensions in this view not yet well known

Cristóvão B. da Cruz e Silva

Radiation levels in PPS2 detector volume (simulation)



Max proton fluence after 1 fb^{-1}
9.9×10^{13}

Max proton fluence after 300 fb^{-1}
2.9×10^{16}

(for XRP234)

Area where radiation damage to the sensor and chip occurs.
A mechanism is foreseen that moves the sensors vertically as they become damaged.

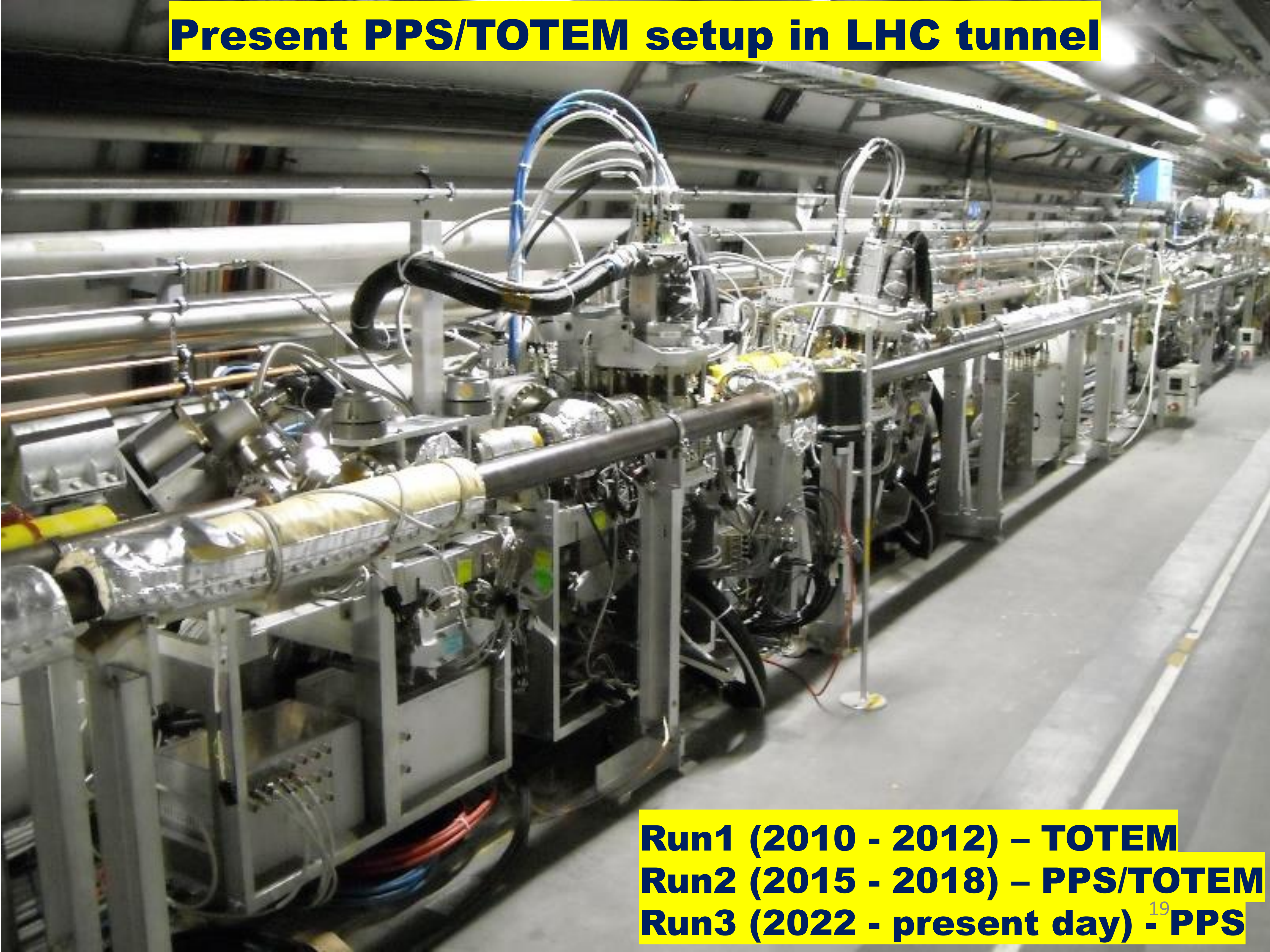
This mechanism allows the detectors to work for one year of HL-LHC operation.
The mechanism has already been tested in the present PPS setup.

Conclusion:

- **PPS has been operational since 2016. Data taking and analysis are ongoing.**
- **PPS2 has been approved by CMS and CERN in 2023.**
- **Work on the PPS2 project has started.**
- **The project is being integrated in the HL-LHC schedule. All conditions set by the HL-LHC project are met.**
- **The PPS2 stations have to be fully completed and operational within LS3 (present schedule: 2026 - 2028).**
- **The project has to be fully completed (with installation of all detectors) by 2029.**

Back-up slides

Present PPS/TOTEM setup in LHC tunnel

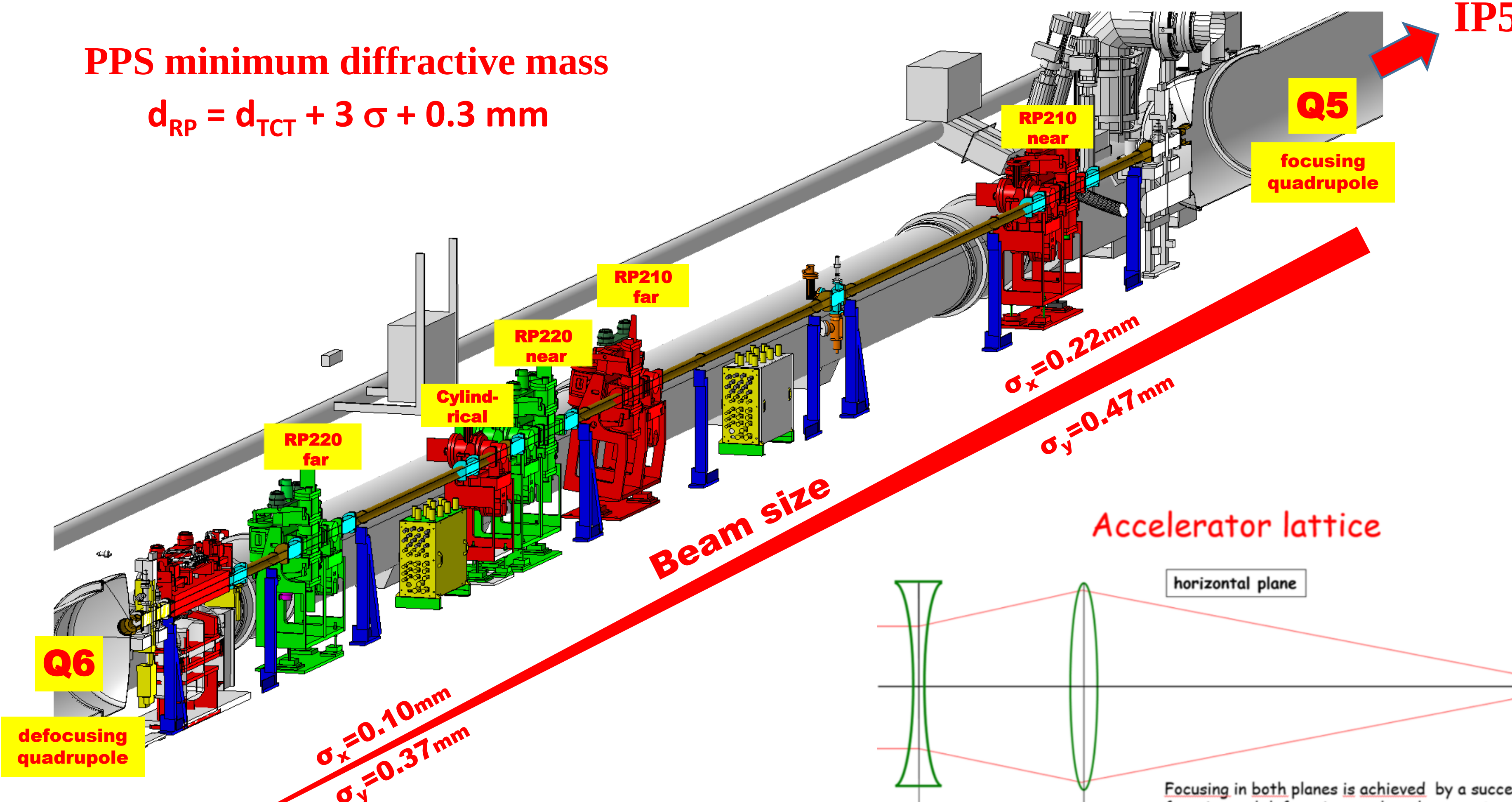


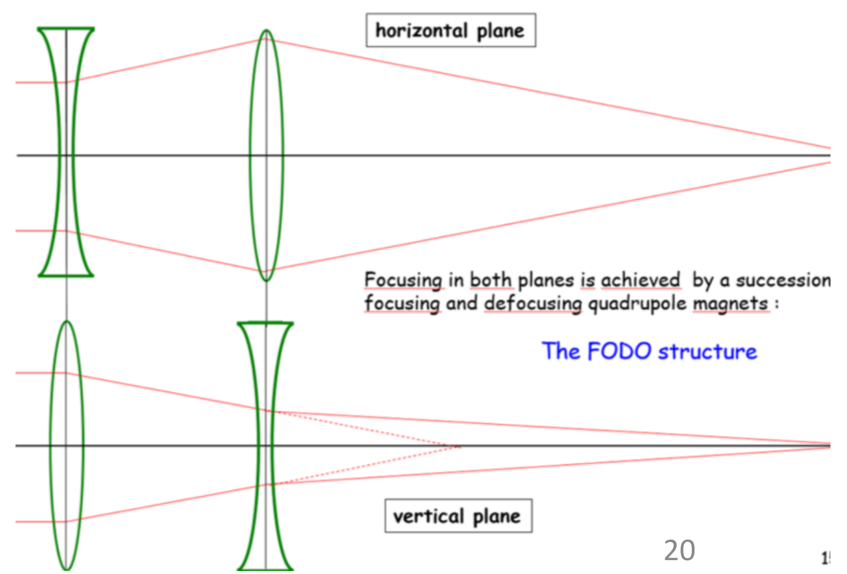
Run1 (2010 - 2012) – TOTEM
Run2 (2015 - 2018) – PPS/TOTEM
Run3 (2022 - present day) - PPS

Present PPS detectors positions on LHC beam line

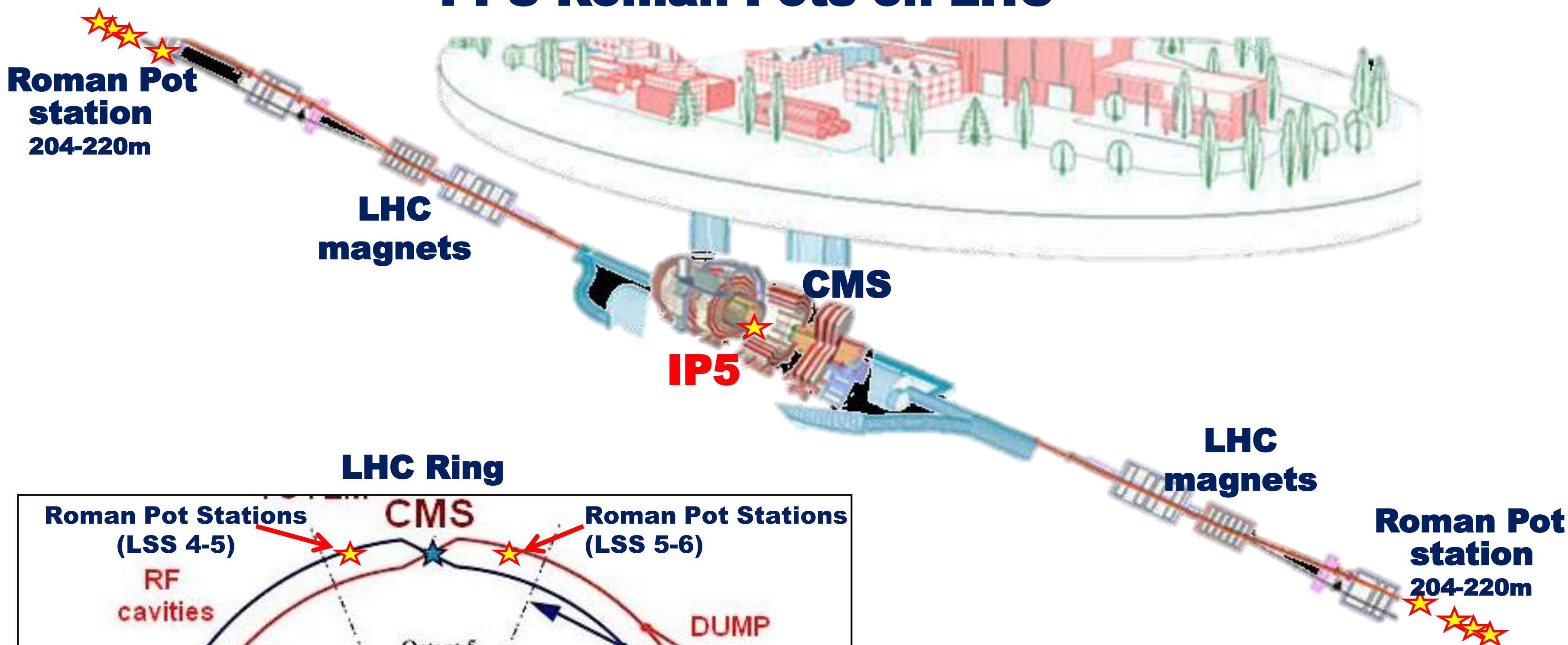
PPS minimum diffractive mass

$$d_{RP} = d_{TCT} + 3\,\sigma + 0.3\text{ mm}$$

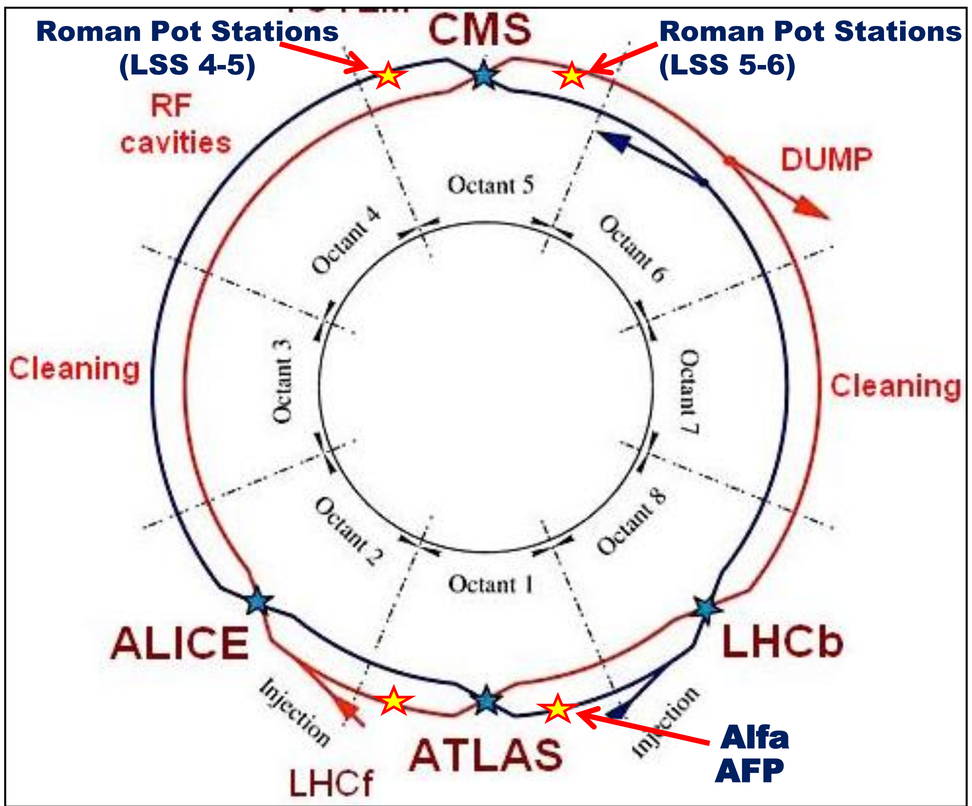




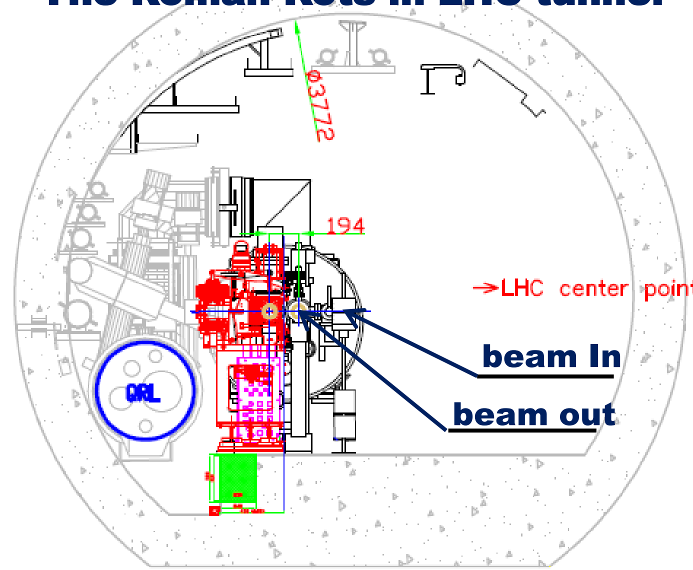
PPS Roman Pots on LHC



LHC Ring



The Roman Rots in LHC tunnel

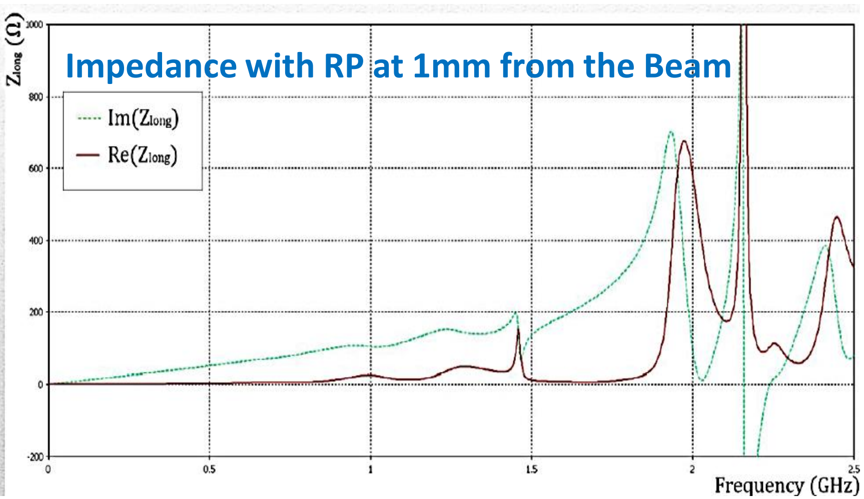


Impedance study

new simulation is started with Benoit's group

The passage of the beam close to XRP produces electromagnetic fields that interact with the vacuum chambers (beam pipe, roman pots flanges) and can lead to:

- Bean energy loss
- Beam instabilities
- Excessive heating of the equipment



IMPEDANCES OF THE TOTEM RPs (2/3)

Nicola Minafra

	$Z_\parallel^{eff}/n$ (mΩ)	% to total LHC current impedance (90 mΩ)	$\bar{Z}_\perp^{eff}$ (KΩ/m)	% to total LHC current impedance (25 MΩ/m)	Heating (W)
Present RP 1)	1.7	1.9%	80	< 0.3%	62
Rotated RP 2)	2.6	2.9%	20	< 0.1 %	241
Cylindrical RP 3)	1.1	1.1%	50	< 0.2 %	13
Cu shielded RP 4)	1.2	1.3%	70	< 0.3 %	10

Imaginary part

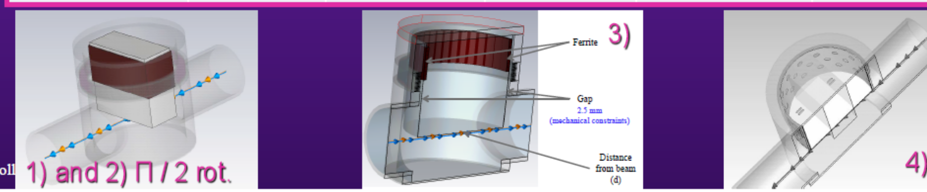
Imaginary part

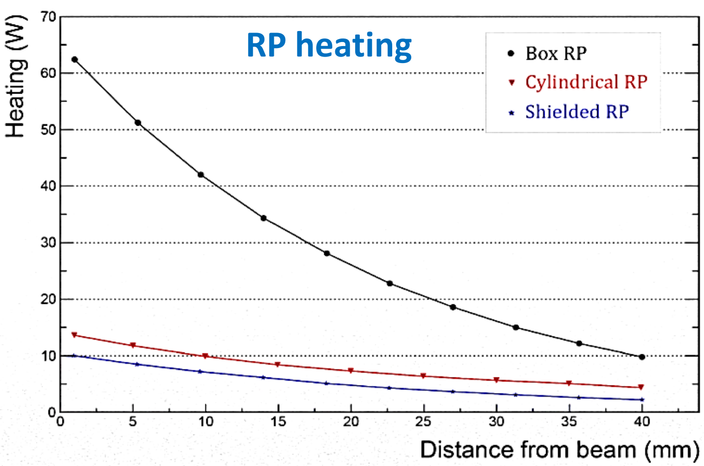
35% better

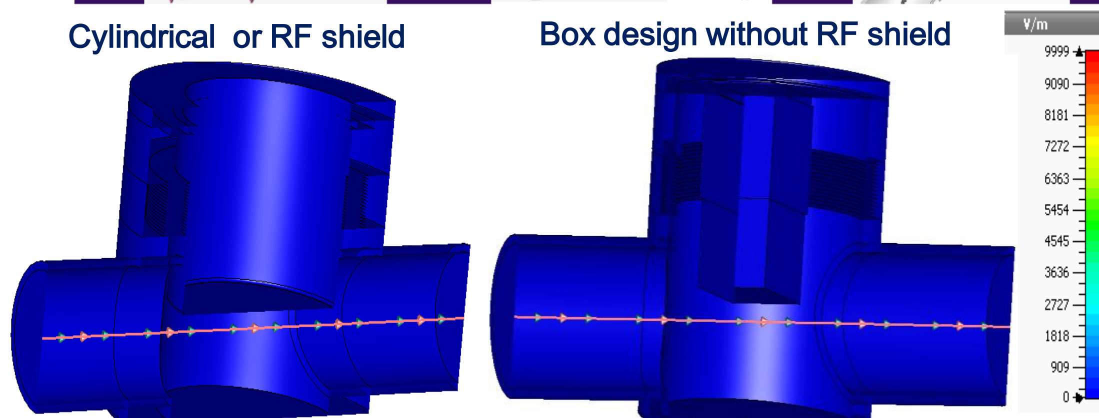
~ × 5 better

30% better

~ × 6 better

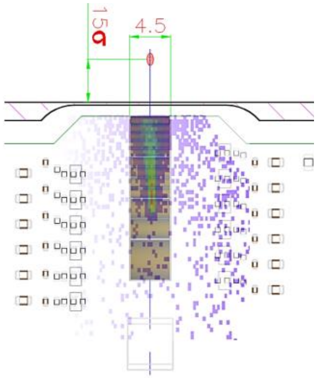




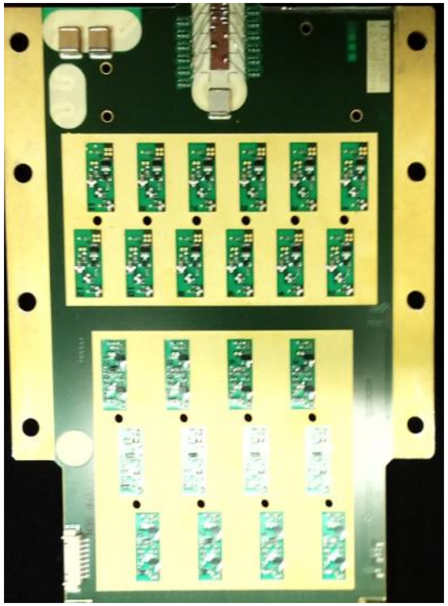


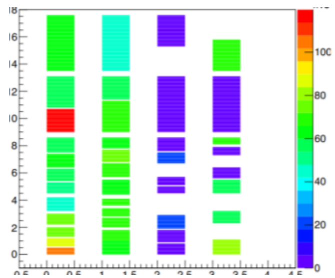
N.Minafra

Types of sensors used by PPS/TOTEM in LHC Runs 1, 2, 3

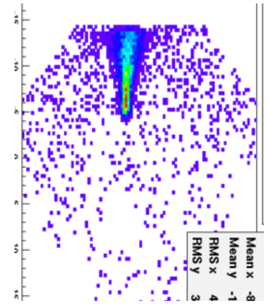


Diamond
4.5mm

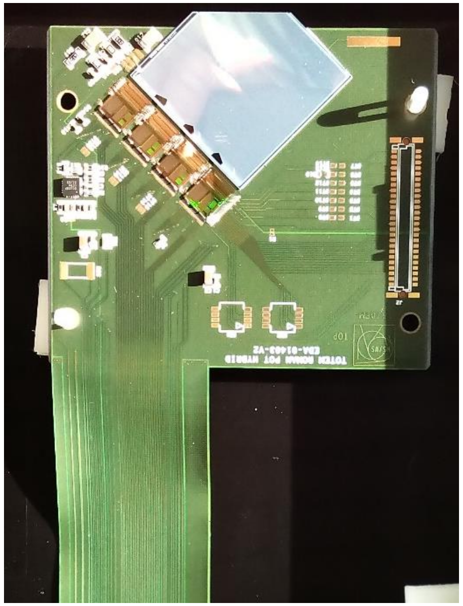


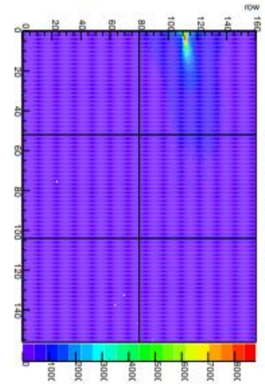


UFSD
6mm



Si-strip
22mm





RPIX (3D-Si)
16 mm

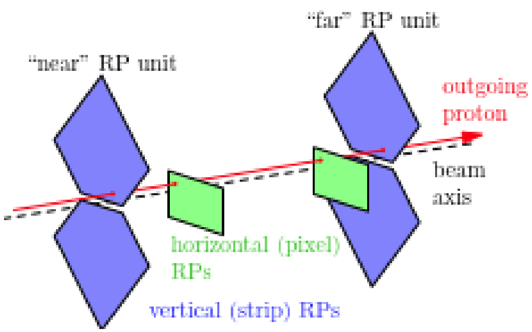
Reconstruction of proton tracks

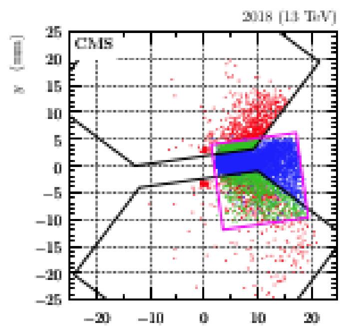
Set of two arms of forward detectors with both tracking and timing to observe scattered protons from CMS interaction point: Matching between CMS central detector and PPS is the key!

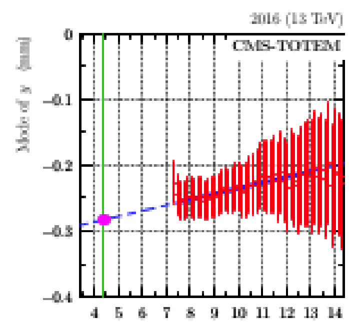
PRO-21-001 JINST 18 (2023) P09009

The reconstruction of proton tracks provides the input to determine the proton kinematics:

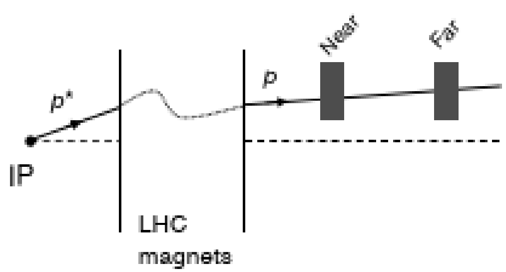
1. Alignment in a multi-level procedure with movable RPs and parameters determined for every fill.







2. The proton momentum loss (ξ) determined using reconstruction of tracks taking into account LHC optics via **transport matrix**.

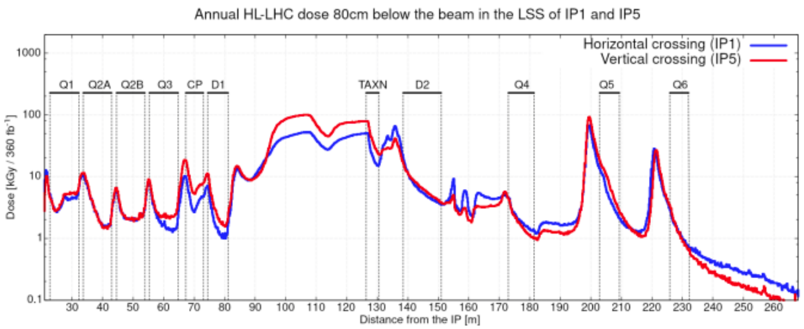


$$x = x_D(\xi) + v_x(\xi)x^* + L_x(\xi)\theta_x^*$$

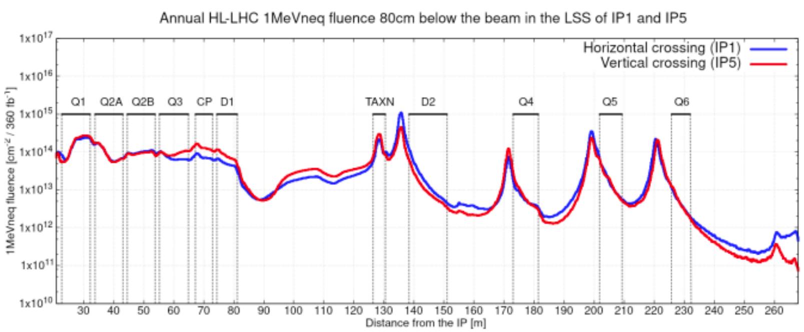
$$y = y_D(\xi) + v_y(\xi)y^* + L_y(\xi)\theta_y^*$$

Radiation level specification for HL-LHC

EDMS NO.	REV.	VALIDITY
2302154	1.0	VALID
REFERENCE: LHC-N-ES-0001		

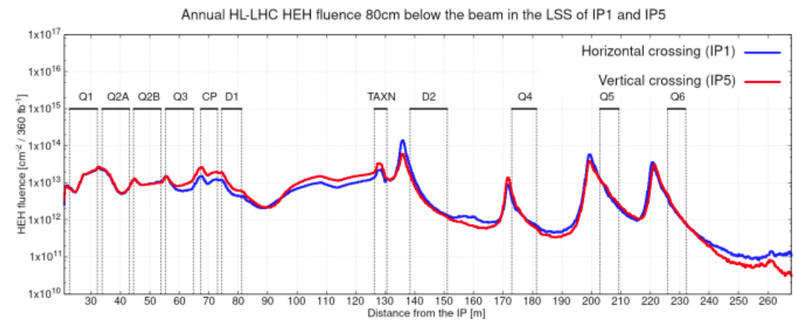


(a)

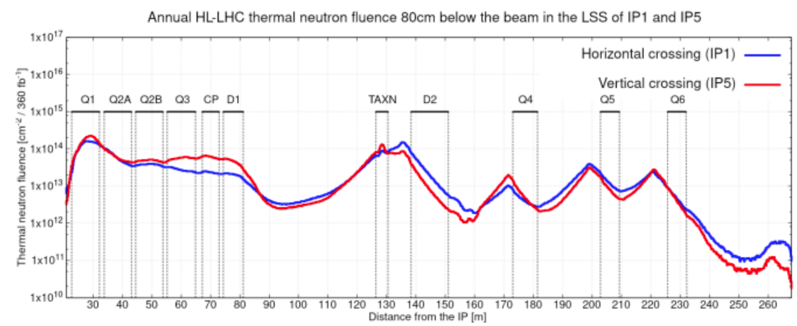


(b)

Fig. 2.3: Expected radiation levels below the cryostat in the LSS area of IR1 and IR5 for an annual integrated luminosity of $360\ \mathrm{fb}^{-1}$ during proton operation as a function of the distance from the IP. Figure 2.3a presents the TID levels, while Figure 2.3b shows the profile of the 1-MeV neutron equivalent fluence.



(a)



(b)

Fig. 2.4: Expected radiation levels below the cryostat in the LSS area of IR1 and IR5 for an annual integrated luminosity of $360\ \mathrm{fb}^{-1}$ during proton operation as a function of the distance from the IP. Figure 2.4a presents the HEH fluence, while Figure 2.4b shows the profile of the thermal neutron fluence.