THE CMS PRECISION PROTON SPECTROMETER (PPS) PROJECT FOR THE HL-LHC

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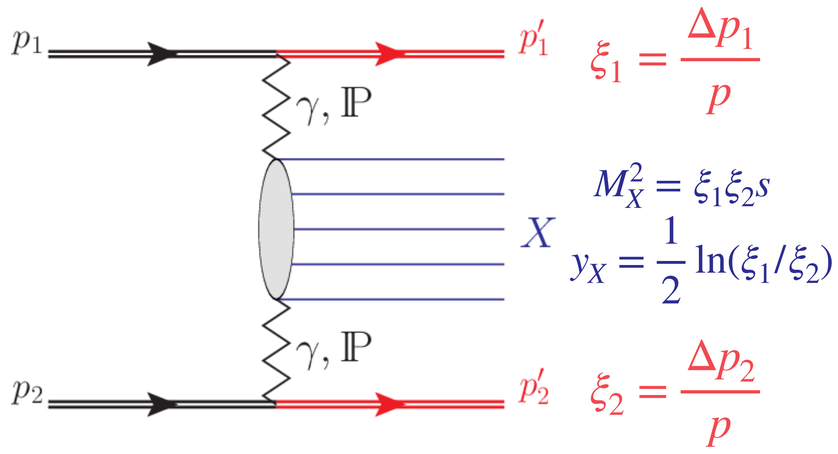
(on behalf of the CMS and TOTEM Collaborations)

Physics motivation

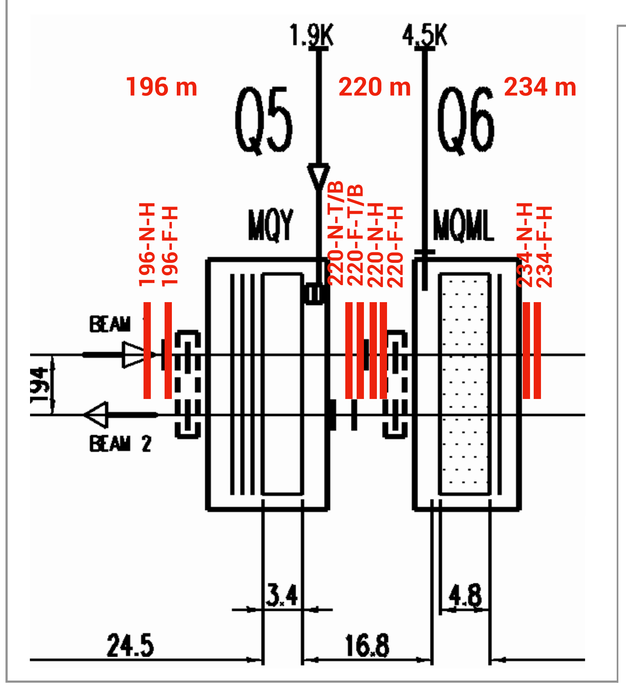
- PPS dedicated to measure **Central Exclusive Production (CEP)** via QCD/QED interactions to investigate rare processes in the Standard Model and search for evidences of New Physics.
- Such processes result in a central system X plus intact protons scattered in the forward direction at small angles [1].

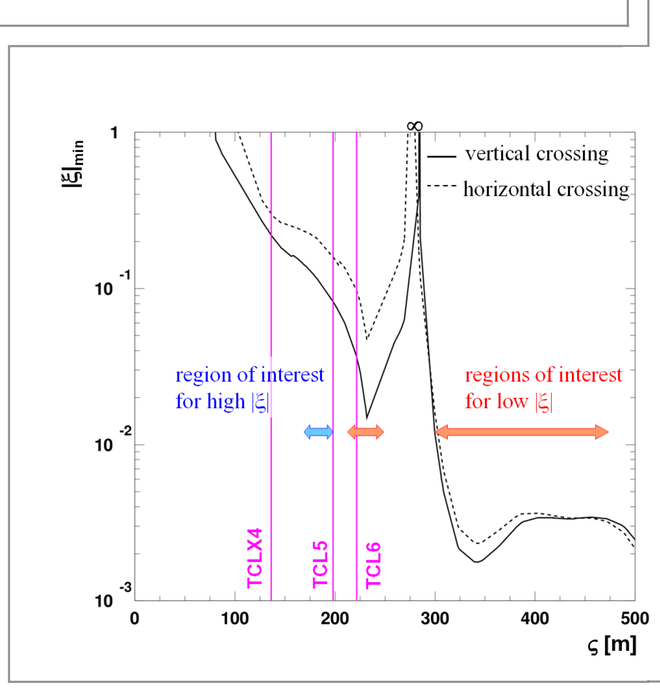


- While the CMS central detector measures M_X and y_X, the near-beam detectors of PPS measure the fractional momentum loss ξ of the protons, from which M_X can also be extracted. This provides **kinematic matching**.
- Clean event tagging with intact protons is achieved by imposing tranverse momentum balance and having an accurate longitudinal vertex position via proton Time of Flight, thus **strongly suppressing pile-up events**, as seen with the Run-2 data [2].

Roman pot stations

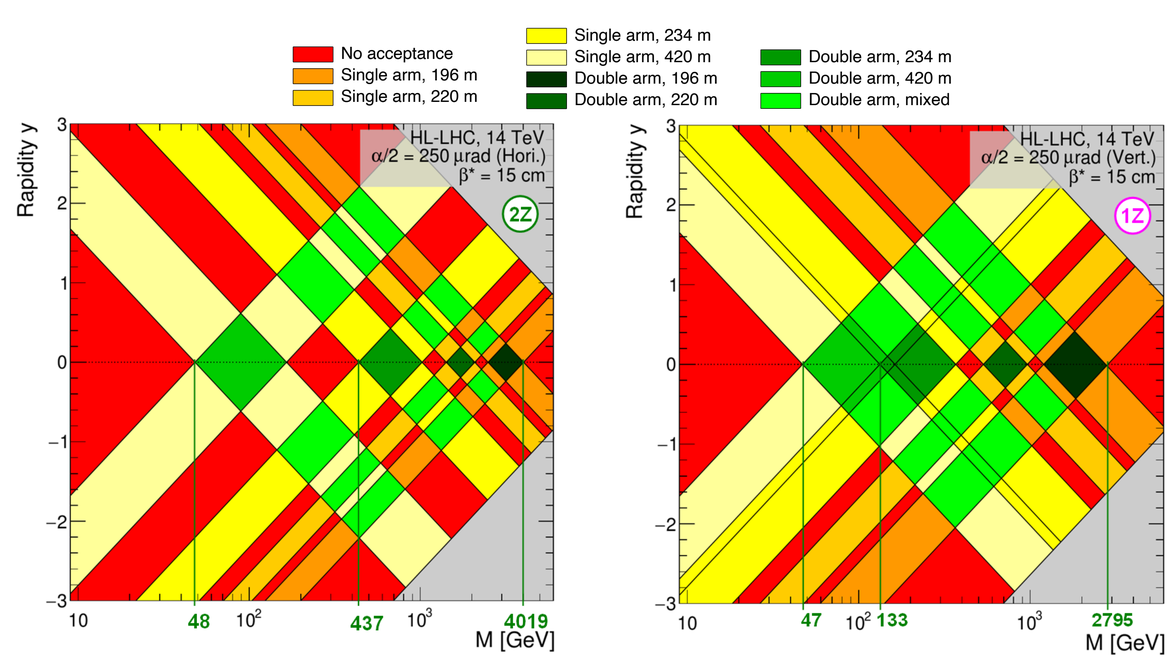
- Plan for three stations on each side of CMS for Phase-2, comprising the region from 196 m to 234 m [3].
- The proposal includes horizontal detectors for tracking and timing plus vertical detectors at 220 m for alignment and calibration. These three stations would be based on **the Roman Pot technology** positioned around Q5 and Q6 magnets (see below).
- Additional stations at ~420 m **to extend the lower mass acceptance**, although requiring other technologies due to the cryogenic area and challenges of tagging protons in between beam pipes.





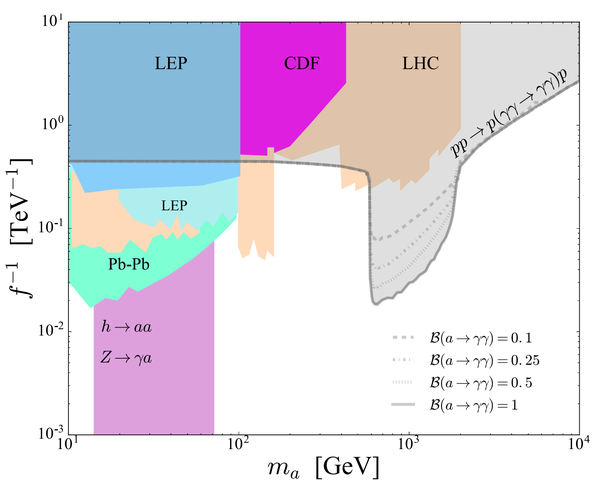
Performance

- Best detector acceptance is achieved with sensors approaching the beam horizontally.
- The min/max mass acceptances are derived from Phase-2 optics and machine parameters. The figure on the left shows the minimum accepted |ξ| as function of the longitudinal distance (ς) from IP5 for distinct beam crossing planes, where vertical crossing is the preferred option.
- M_X and y_X acceptances are extracted for single- and double-arm proton tagging (center). Although single-arm provides larger mass acceptances, **clean events demand double-arm detection**, which extends the lower M_X region down to ~100 GeV for three stations or ~40 GeV with all stations.

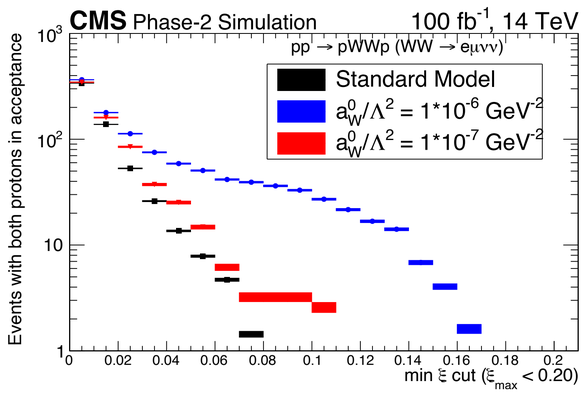


Physics perspectives (High-mass BSM searches, γγVV and aQGC, Exclusive ττ, Diffractive CEP, Higgs physics, Exclusive $t\bar{t}$, Photoproduction, and much more!)

- BSM scenarios may be explored with γγ processes at TeV scale.
- PPS may be sensitive to BSM mediators with strong coupling to photons, like **axion-like particles (ALP)**.
- ALP exclusion limits can be extended to TeV masses with PPS already with 300 fb^{-1}.
- Direct/indirect searches for SUSY, Z+X, and dark matter with invisible decays can profit from the γγ production mode for final states up to ~2 TeV.



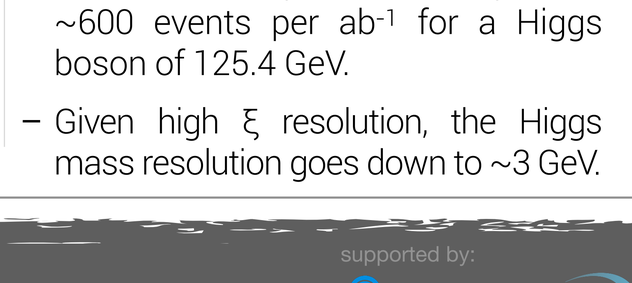
- Proton tagging may enhance the investigation of **anomalous quartic gauge couplings (aQGC)** in γγVV processes.
- The longer tail in mass distribution is dominated by aQGC events, where PPS provides good sensitivity at large ξ.



- In comparison to the Run-1 results, PPS could provide enough events to enhance such limits by $\mathcal{O}$**(100)** [3].
- Other rare processes like γγγγ and γγγZ could be investigated with proton tagged events.

- **Standard Model** shows that γγ processes dominate at high masses.

- Lower ξ_{min} acceptance provides an increased rate of double-tagged events by $\mathcal{O}$**(10^4)**: 47 γγμμ events per fb^{-1} and 72 γγWW events per 100 fb^{-1}.



- **CEP Higgs production** is possible given the enhanced sensitivity provided by proton tagged events with stations at 420 m.

- The mass acceptance would provide ~600 events per ab^{-1} for a Higgs boson of 125.4 GeV.
- Given high ξ resolution, the Higgs mass resolution goes down to ~3 GeV.

References

[1] M. Albrow *et al.* "CMS-TOTEM Precision Proton Spectrometer". CERN-LHCC-2014-021, TOTEM-TDR-003, CMS-TDR-13

[2] "Proton reconstruction with the CMS Precision Proton Spectrometer in Run 2". CMS-PAS-PRO-21-001, TOTEM-NOTE-2022-001

[3] "The CMS Precision Proton Spectrometer at the HL-LHC – Expression of Interest". arXiv: 2103.02752 [physics.ins-det]

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