Technical Requirements from CMS

Assumptions about LHC evolution (used in detector design)

Reminder of upgrade strategy and timeline

Pile-up mitigation

CMS @ HL-LHC : Upgrade justification and overview

Machine Interface questions

V. forward detectors in the LSS : LS1 onwards

Common project/engineering office

Conclusion

Assumptions about LHC: 2012 onwards

assumed performance evolution, mean pile-up <μ> are highest estimates

Repairs during LS1: allow LHC to operate at or near nominal E_{cm} = 14 TeV

Following LS1: *initial low lumi runs to measure cross sections (few x100 pb-1)*
restricted pile-up running at 50ns for quick search (few x 1fb-1)? : tbd.
rapidly approach operation at design luminosity & bunch spacing (25ns)

Subsequently, luminosity expected to reach :
≤ 2 x nominal before LS2, with ∫L.dt ≤ 150fb-1
≤ 2.5 times nominal before LS3, with ∫L.dt ≤ 500fb-1
} <μ> = 50-80

Following LS3: luminosity expected to reach :
~ 5 times nominal (levelled) with ∫L.dt eventually ≥ 3000fb-1, <μ> ≤ 140

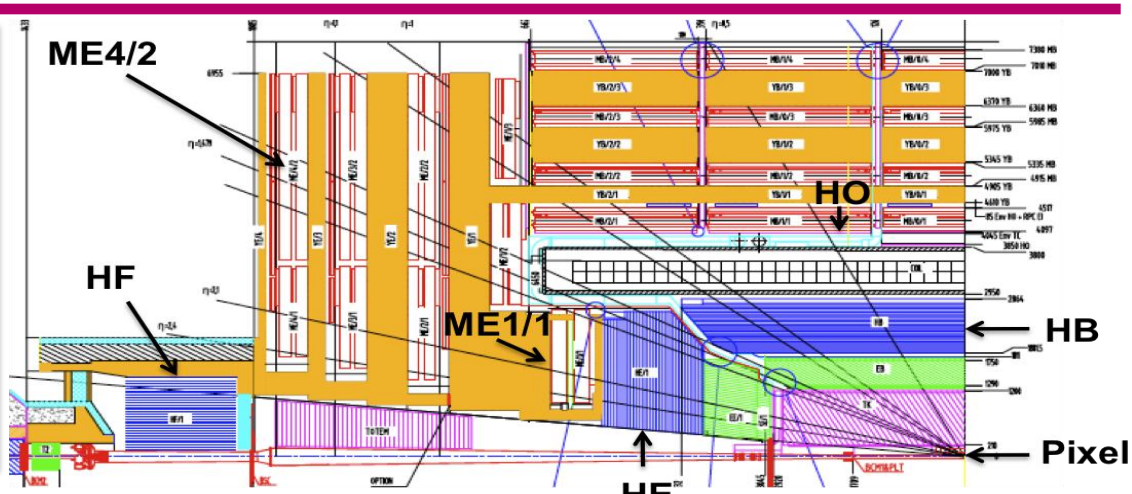
In the 2030's, HE-LHC, if proven technically feasible, may deliver:
300fb-1 at E_{cm} = 33 TeV

Coherently with above, to ensure longevity and maintain existing physics performance for the increased pile-up and radiation loads resulting from luminosities up to 5x design:
CMS will implement a phased programme of detector consolidation & upgrade

CMS upgrades in 2 phases

Phase 1: in production for LS1

- Complete muon coverage (4'th endcap layer)
- Improve muon operation (1'st endcap layer), and barrel drift tube electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD→SiPM)
- DAQ1 → DAQ 2
- Overhaul common systems for long-term



LS1(22mo) LS2 (14mo) LS3 (24-36mo)

Phase 1: up to end LS2 (LOI app. Sep 12)

- TDR's approved:4 layer Pixel tracker (install in YEETS 2016-17), HCAL electronics/granularity
- TDR in 2013: L1-Trigger
- Preparatory work during LS1
  - New beam pipe (for 4 layer pixel tracker)
  - Test slices: *Pixel(CO2 cooling), HCAL, L1-trig*
  - Install ECAL optical splitters
    - *L1-trigger upgrade in parallel with run.*

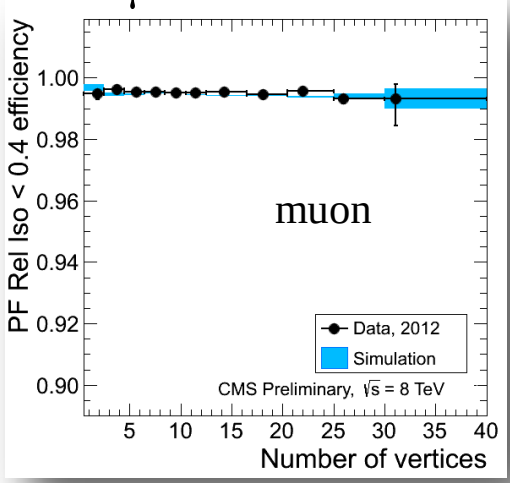
Phase 2 Upgrades (Tech.Proposal in 2014)

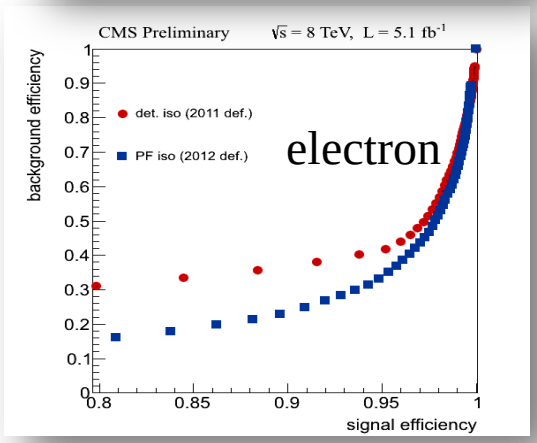
- Tracker Replacement, Track Trigger
- Endcap/Forward region improvements : Calorimetry, Muon system and tracking
- Further Trigger upgrade
- Further DAQ upgrade
- Many obsolescence/lifetime replacements
- Shielding/beampipe for higher aperture

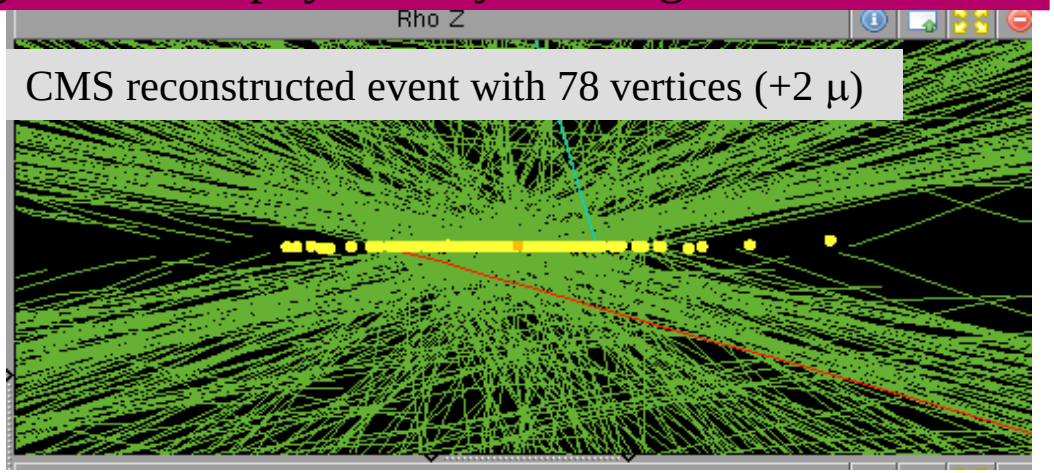
Pile-up mitigation

relieve stress on trigger, computing resources, physics object recognition

eg CMS μ and e isolation using P flow







CMS reconstructed event with 78 vertices (+2 μ)

Current strategies run out of steam for <μ> > 40

→**need 25ns** (plus detector upgrades)

Pile-up density is a key parameter :

options to spread out the vertex distribution?

Max length of luminous region limited by detector (dimensions, pointing geometry etc.)

Transverse spread impacts on secondary vertex tagging

Maintaining physics performance

Evolution of the detectors towards HL-LHC (and HE-LHC)

CMS was designed for 10 years of $L = 10^{34}\ cm^{-2}s^{-1}$ (25ns) for $\int L.dt \leq 500 fb^{-1}$

a) $\int L.dt = 500\text{-}3000\ fb^{-1}$: enhanced radiation tolerance and simple longevity will require:
mandatory replacement of certain detectors, electronics & ancillary systems
irrespective of whether lumi expected is ≤ 2 times or ≤ 5 times nominal.

b) $L = 5 \times 10^{34}\ cm^{-2}s^{-1}$ (25ns): pileup mitigation will involve :

- tracking over extended range of η
- higher granularity and better angular measurement in the reconstruction
- use of exceptionally good timing measurements (vertex association)
- more information and more sophisticated processing in the trigger

to maintain selection power with acceptable rates

- algorithm performance degrades with pile-up:

eg μ: increased background rates from accidental coincidences
e/γ: at fixed efficiency, reduced QCD rejection from isolation

- solution in general is to reconstruct more detail of the event earlier in the trigger process.

The new trackers and calorimeters required will involve a decade of R & D and construction, followed by 2-3 years of shutdown for installation. Have to assume a + b in design.

CMS LS3 —> 2030+

Phase 2 upgrade: Technical proposal in 2014

For operation beyond ~ ∫L.dt = 500 fb^{-1}

—> substantial changes to some detector elements become *mandatory*

In particular **-new tracking systems, radiation & rate tolerant,contributing to trigger, extending to higher η** —> compulsory, already being designed

- major revision of calorimetry, at least in the endcap and forward regions where radiation damage will become severe. v. likely
- enhancement of muon system, improving performance and robustness of trigger and reconstruction, recovering degradation due to age possible
- **major revision of beampipes and shielding systems to accommodate increase in quadrupole and TAS apertures** **forced**
- introduction of highly accurate time of flight detectors combined with extended calorimetry and tracking for forward physics. v. likely
- completely revised trigger systems to maintain selection efficiency at low momentum. compulsory
- high bandwidth DAQ replacing obsolete technologies compulsory
- corresponding computing infrastructure compulsory

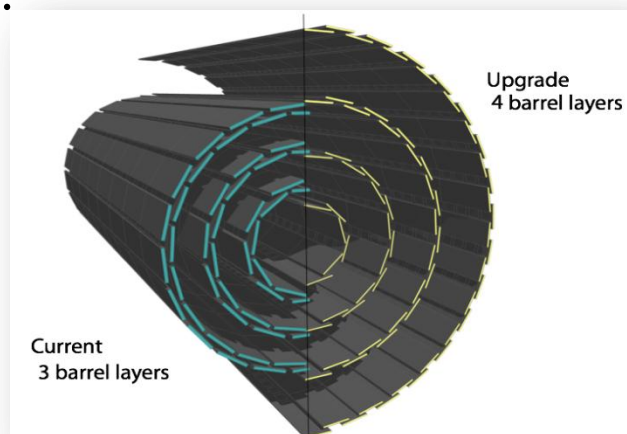
HL-LHC machine interface questions

Can we improve estimates on when low β quads will need to be replaced?
If this drives LS3, could affect: tracker upgrade installation (eg LS3 or LS4)
pace of forward shielding & calorimetry upgrades

How active will the TAS's be (say for L= 2.5 x 10^{34}) when replaced and are the techniques to extract them available?

What are the aperture requirements along the length of the experimental beampipes once the TAS aperture is increased (assuming no change in mechanical & survey tolerances)? CMS CT2 pipe replacement is challenging. Maintaining the rule to keep central beampipes in the shadow of the TAS would have profound implications:

-force the first pixel layer further from ip than it is now
worse impact parameter resolution
affects pile-up tolerence
-re-build to provide (at least) new 4'th layer at higher radius



Is active protection (BCM systems) adequate?

HL-LHC machine interface questions

What are the consequences of various beam pathologies (D1 failure, crab failure etc) for beam losses in the experiment (given a particular beampipe diameter)?

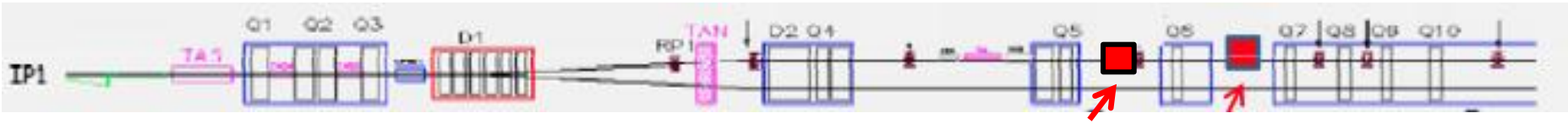
What can we expect for beam-gas and beam-halo backgrounds at HL-LHC?

- any implications for vacuum, collimation?

v. forward physics detectors: ≥ LS1

i)TOTEM is approved to repeat the σ_{tot} measurement at or near E_{cm} = 14 TeV, low lumi, high β*
will use Roman pots ~ 210m from pt 5;
if ~147m pots not used, could be replaced by TCL4.
ii) ZDC will be installed for every HI run. (activation!!)

Two new proposals to operate very forward detectors at P5 at high luminosity (access to rare processes).

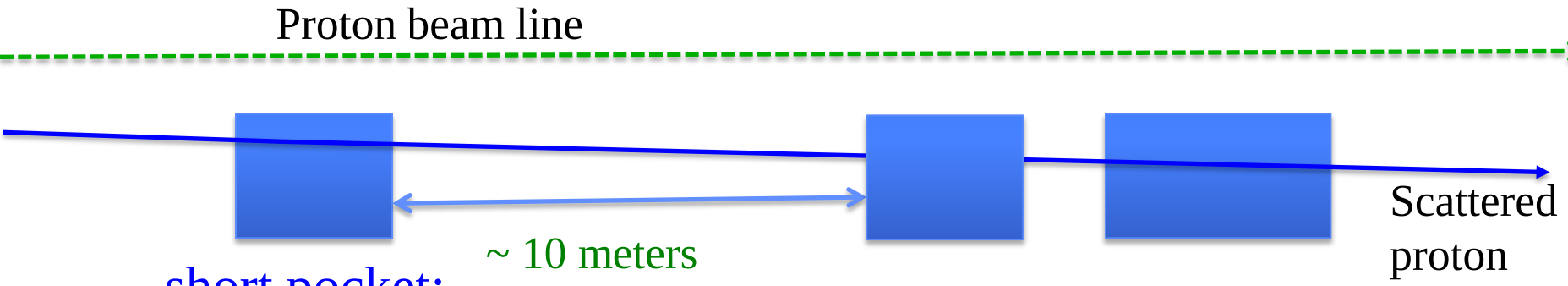


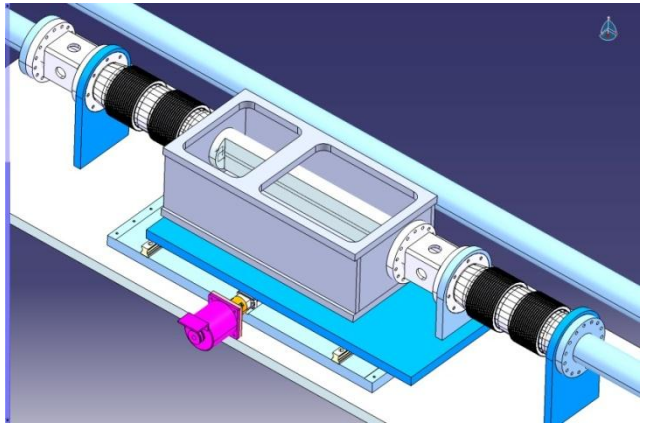
iv iii

iii) CMS (HPS) is considering installing 2 Hamburg pipe systems around 240m from pt5
iv) CMS/TOTEM are discussing installing Roman pots (from 147m) 200-220m from pt 5

both rely on precision tracking and timing to measure diffractively scattered protons

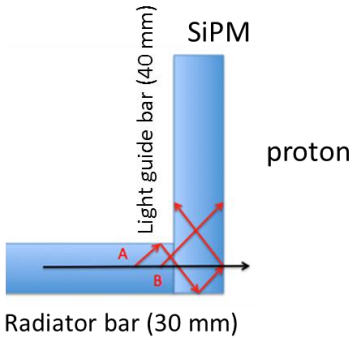
High Precision Spectrometer at 240m





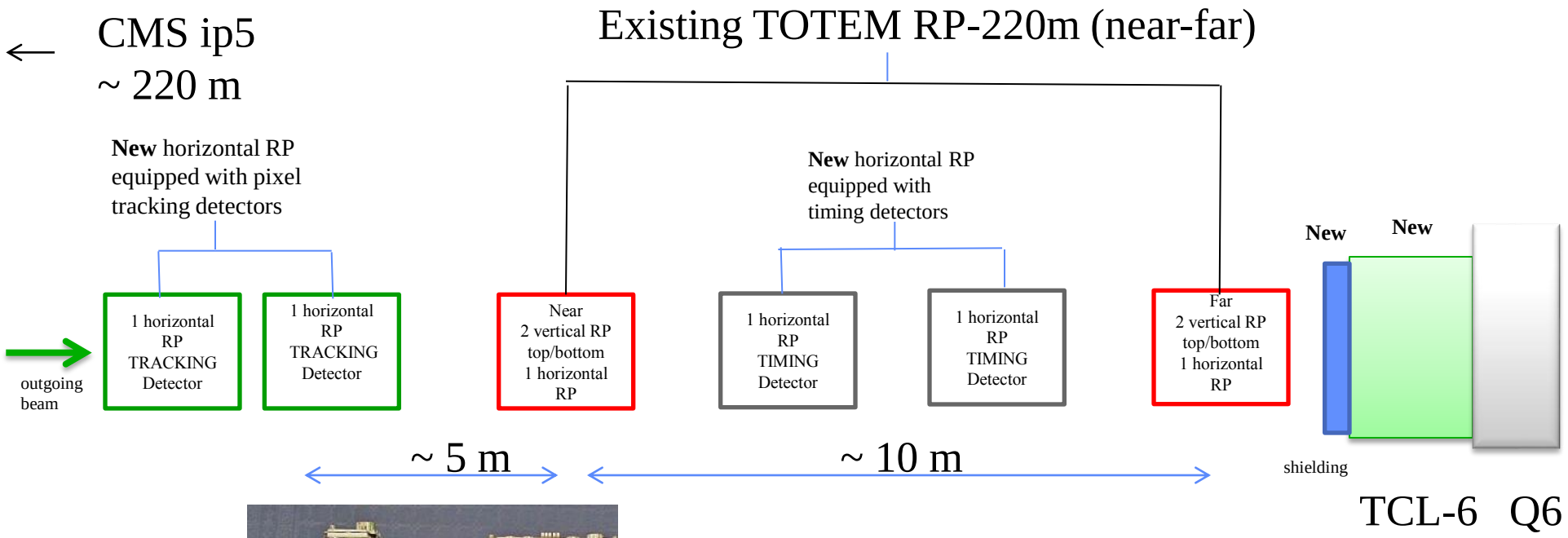
Tracking for momentum measurement:
pixel detector, 2 stations.

Timing for background rejection:
Quartz Cherenkov counters.



Technical Proposal received by Upgrade Coordination
Follow-up proposal for station at 420m to be anticipated for LS2 or beyond.

CMS-TOTEM 6-pot system 220m



Studying : integration
: turning pots thru 90 deg for timing dets.
: detector access
: trigger and DAQ implications

Technical Proposal imminent

v. forward physics detectors: ≥ LS1

CMS internal approval of proposals if

: good physics case

: technical feasibility proven

eg impedance

machine integration

timing precision achievable

trigger & DAQ integration feasible

: sufficiently strong community for physics exploitation

Preparatory installations in LS1 will be requested:

defensive request from CMS (now) would be :

TCL4 (providing TOTEM wish to remove pots at 147m)

TCL6

aggressive request might include:

dummy pipes for later substitution by HPS Hamburg pipes

installation at ~220m of RP's removed from 147m

Not obvious at this stage that such a physics programme could be justified beyond LS2

Common project/engineering office

Mechanism for Pooling Resources for:

- Radiation Simulation
  - beam backgrounds & pathologies
  - fluence and dose rate
  - activation
  - shielding evaluation
- Engineering
  - shielding & cavern interface design
  - beampipe evaluations (eg Hamburg pipe)
  - beampipe new materials research
  - remote & robotic handling
    - design &/or procurement
- Instrumentation
  - beam monitors
  - (including abort systems in experiments)
  - radiation/environment monitors
    - (eg fibre based)

Conclusion

25 ns operation mandatory for pileup conditions beyond those now being encountered

Pile-up density to be considered
- some levelling mechanisms are better than others
- "re-design of luminous region" may offer some additional possibilities.

Timing and consequences of aperture increase need to be thought through in detail.

Common structure (engineering office) may be a way of providing resources for the activities of various existing structures (LEB, LBS etc)

Layout change requests: limited at the moment to precautionary changes in forward region (TCL 4, TCL6)

options for forward detector systems being evaluated
- will take time (few months)
- space reservation would be prudent.