CMS Phase 2 upgrade: the MIP Timing Detector (MTD)

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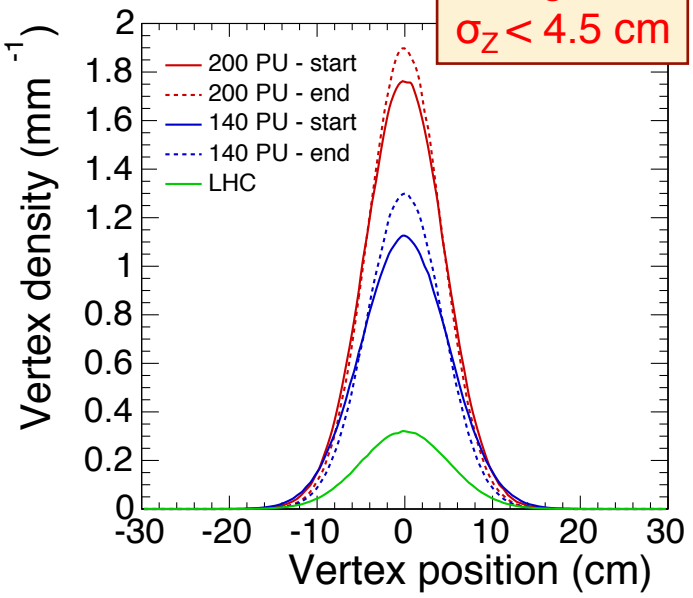
OUTLINE

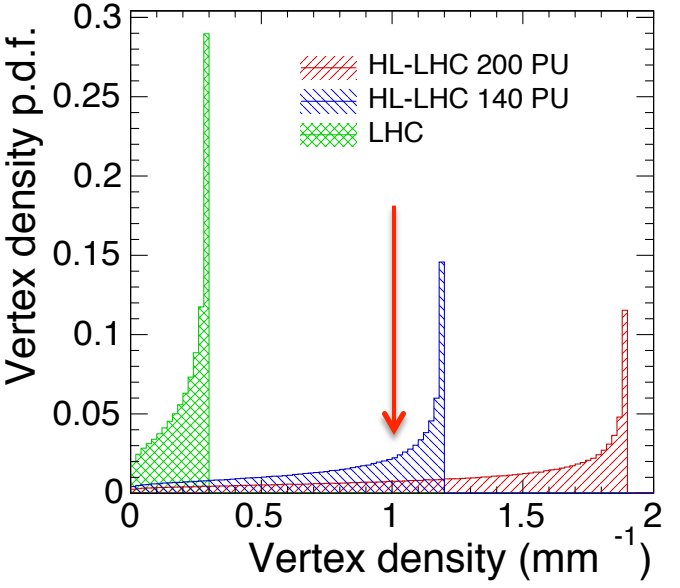
- Motivation and performance requirements
- Technologies
- Status of the proposal, project structure and engagement

Motivation

- **HL-LHC: upgrade of LHC and injectors**
  - Baseline:
    - $L_{inst} = 5.0 \times 10^{34}\ cm^{-2}\ s^{-1}$ (140 pileup)
  - Ultimate:
    - $L_{inst} = 7.5 \times 10^{34}\ cm^{-2}\ s^{-1}$ (200 pileup)
    - **Luminosity leveling**: trade-off between integrated luminosity (amount of data) and experiment performance
- **CMS event reconstruction dependent on *track assignment* to vertices**
  - Substantial pileup contamination at vertex densities **> 1 event/mm**
- **Maintaining 50 PU performance at high pileup benefits the full CMS program at the HL-LHC**

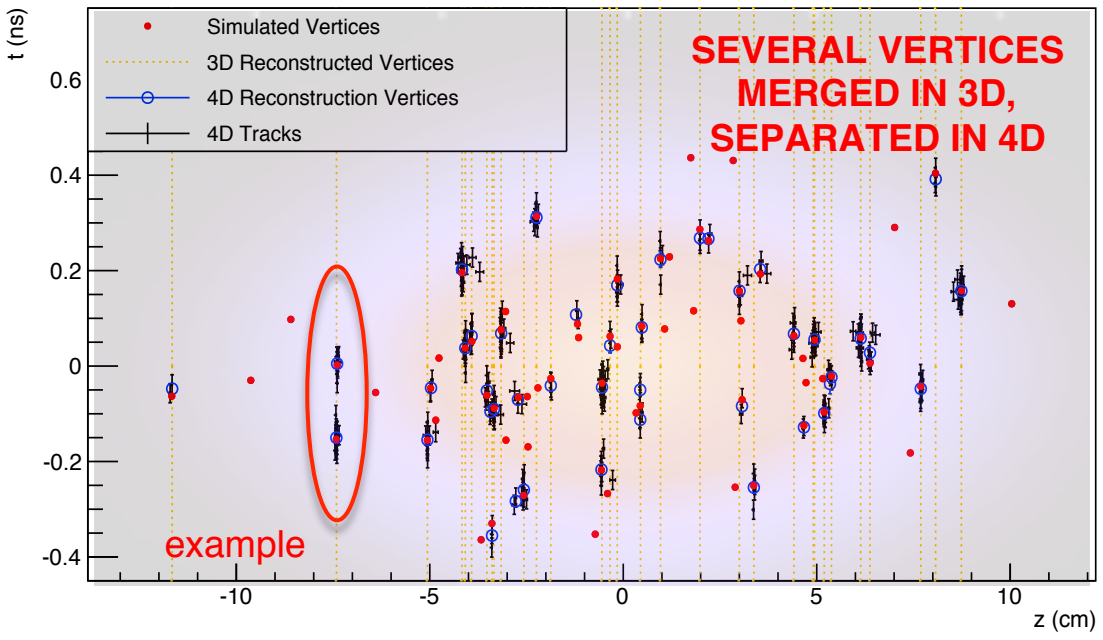
Luminous region $\sigma_Z < 4.5$ cm

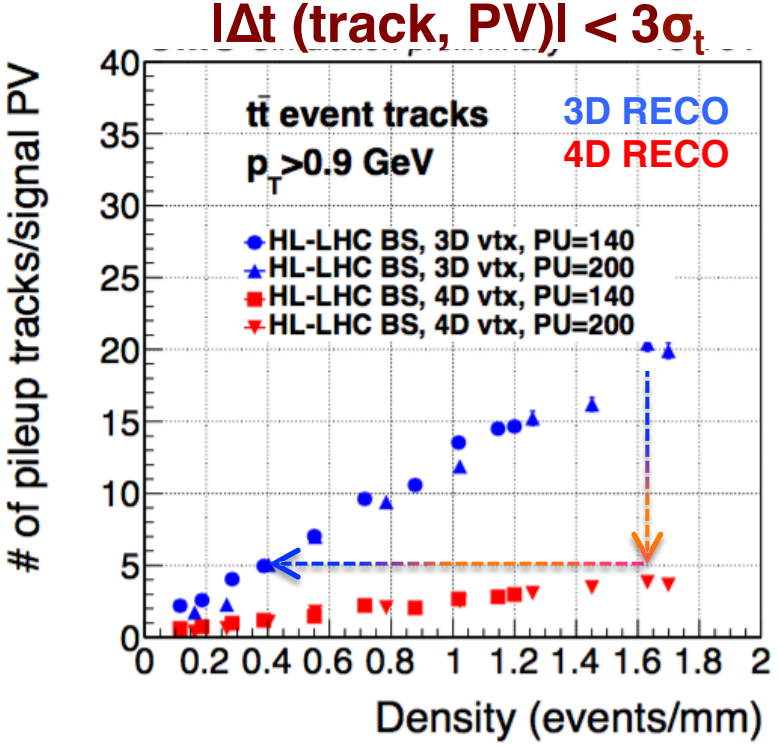




Pileup mitigation with track-timing

[50 PU event display to ease eye analysis]



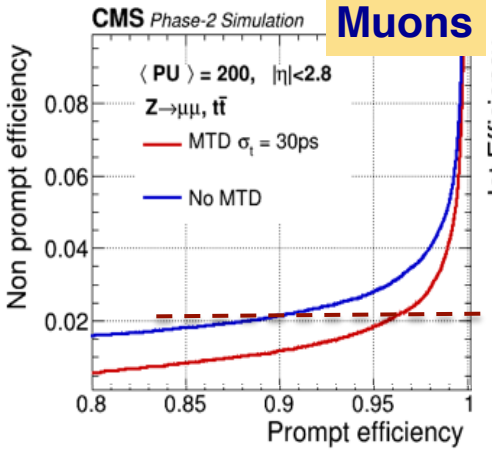


- **"Dissect" the luminous region in time**
  - Space-time vertex reconstruction with **30 ps RMS** per-track
  - Beam-spot time spread ~**180 ps RMS** (constant over the fill)
- **Recover LHC (40 PU) track purity of vertices**

Snapshot of the reconstruction benefits

- **Performance losses at 200 PU entirely offset with timing**
  - Efficiency gains (5–10%) compound in multi-object final states
  - Background reduction boosts sensitivity of measurements and searches

Muons



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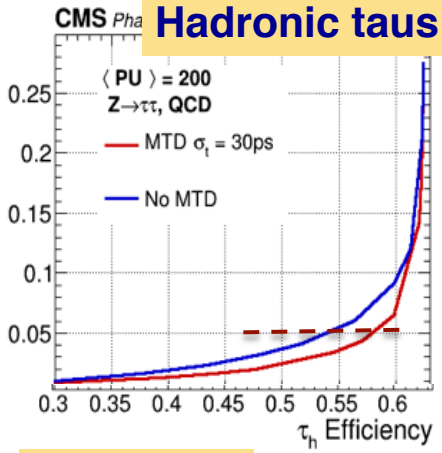
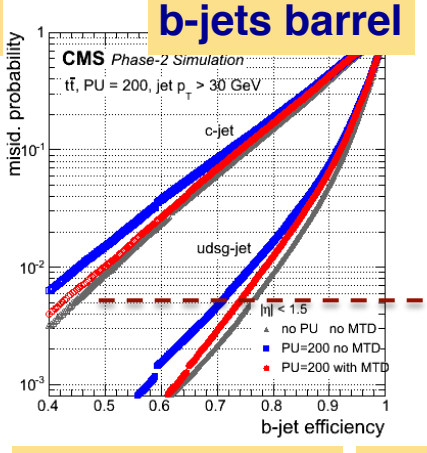
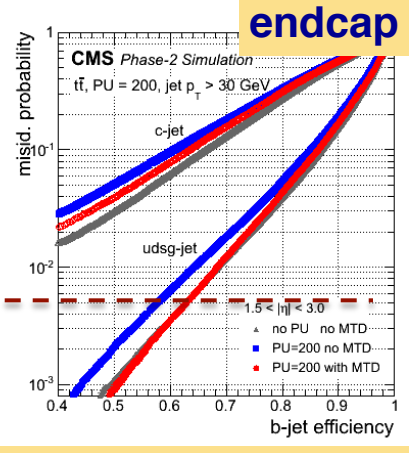


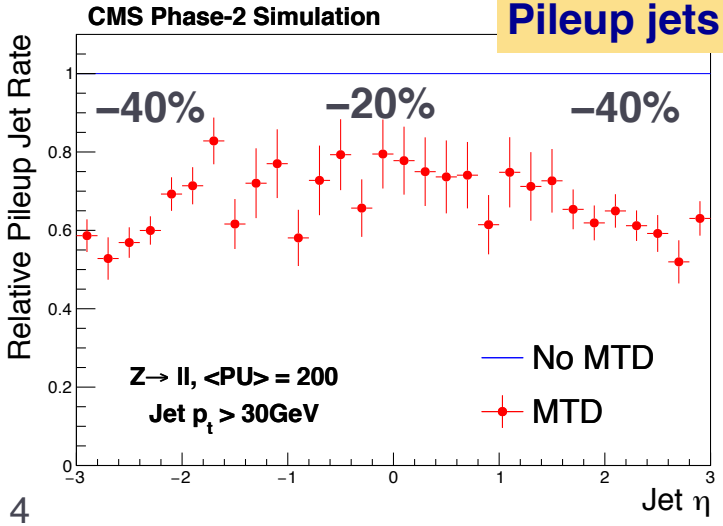
b-jets barrel



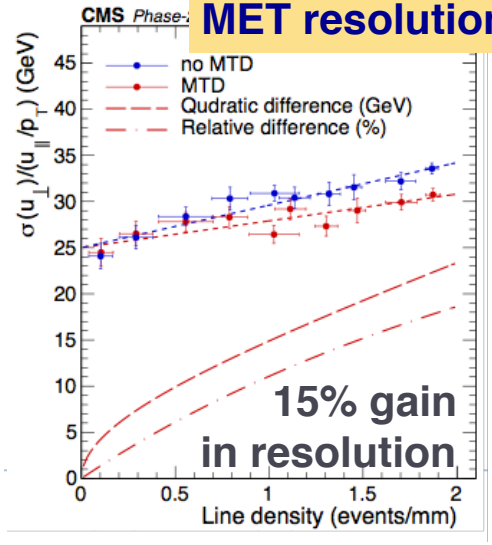
endcap



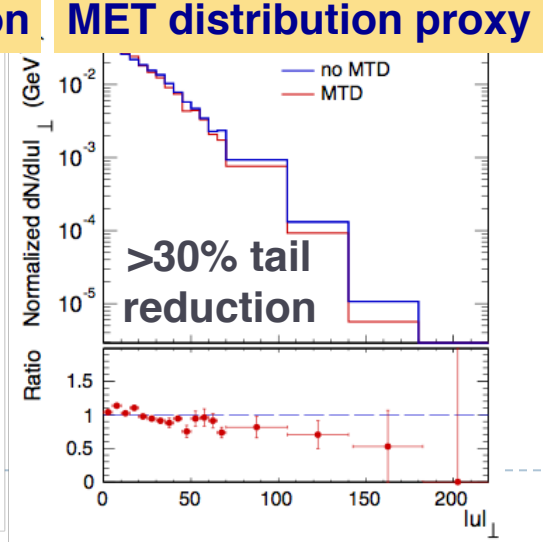
Pileup jets



MET resolution



MET distribution proxy



Summary of the MTD Technical Proposal (*)

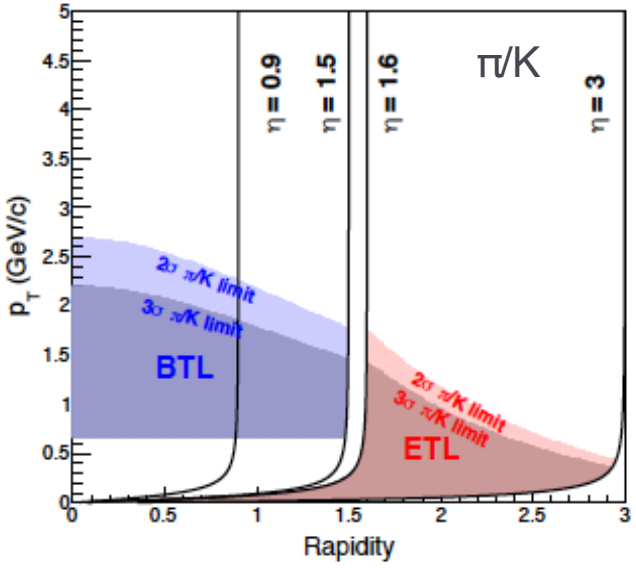
Signal	Physics measurement	MTD Impact
H→γγ H→4leptons	**+25%** statistical precision on xsecs → Couplings	Isolation Vertex identification
VBF+H→ττ	**+30%** statistical precision on xsecs → Couplings	Isolation VBF tagging, MET
HH	**+20%** gain in signal yield → Consolidate searches	Isolation, b-tagging
EWK SUSY	**40%** reducible background reduction → +150 GeV mass reach	MET
Long Lived Particles (LLP)	Peaking Mass Reconstruction → Unique discovery potential	β_{LLP} from timing of displaced vertices

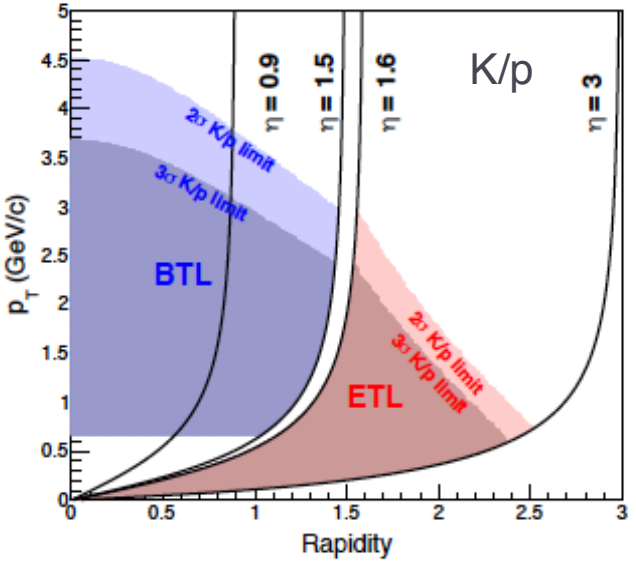
- **There is a beautiful physics case for a hermetic timing detector with 30 ps time resolution**
  - Across a wide range of observables and across the HL-LHC program
  - Leveraging gains across the full pseudo-rapidity coverage
- **20-30% increase in effective integrated luminosity**

CERN-LHCC-2017-027 ; LHCC-P-009: https://cds.cern.ch/2296612

PID with the MTD

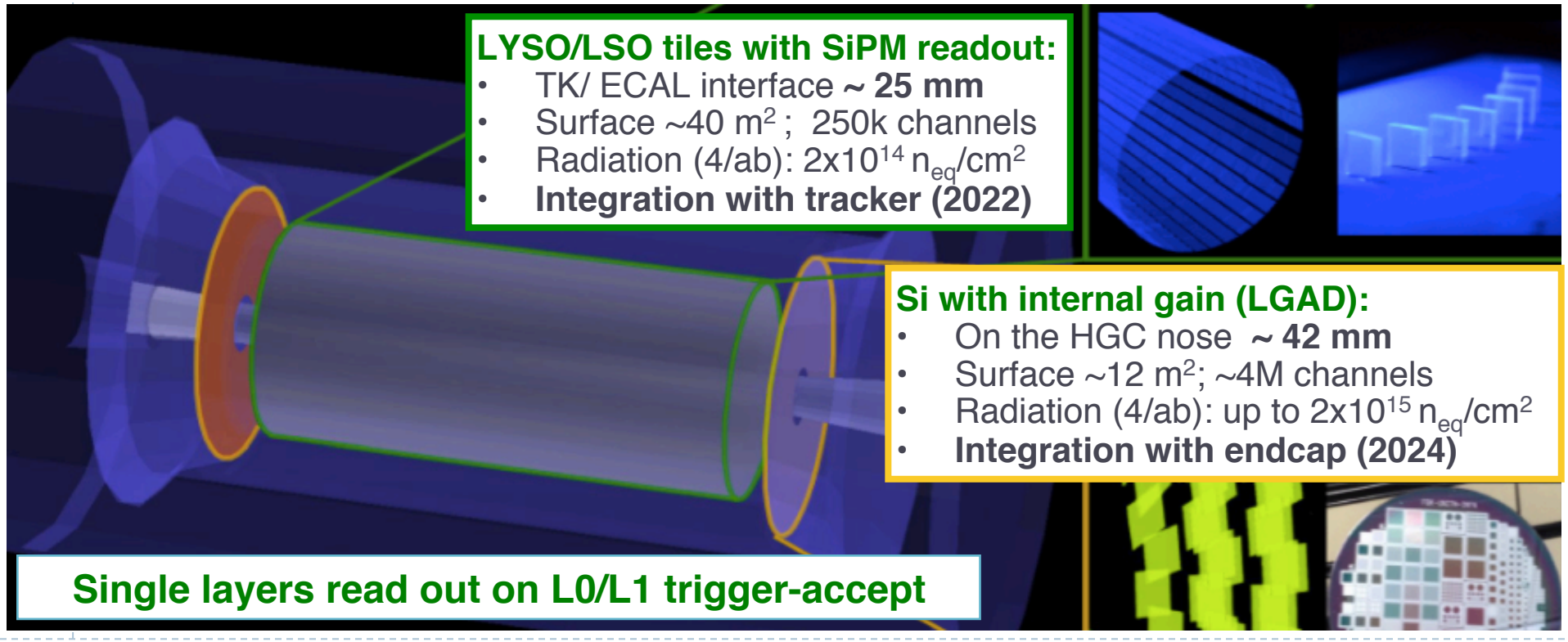
- **Physics case being extended HI physics in Run-4 (LS3 to LS4)**
  - The CMS-MTD with 30 ps would almost match ALICE at central rapidities (|y|<0.9) and extend PID coverage to |y|=2.9
  - A resolution of 50 ps would still provide acceptance gain and a better separation than the STAR-TOF experiment
- **The physics case will be included in the TDR**
  - Must achieve 30 ps in (central) BTL in Run4 (limited radiation damage)





MTD requirements and technology choice

- Hermetic timing detector with 30 ps resolution on charged tracks
- Cost effective design over large area
- Radiation tolerance
- Minimal impact on calorimeter and tracker performance
- Mechanics and service compatible with existing upgrades



Main detector aspects

Barrel timing layer: (BTL)

- Operation at T = –30 °C (CO_2 cooling common with TK)
- **LYSO :** 11.5x11.5 mm^2
- **Custom SiPM:** active area < 16 mm^2
- **ASIC: TOFHiR** *[adapted from TOFPET2]*
- LE discrimination with amplitude measurement for time walk correction
- Challenge: SiPM Dark Count Rate and sensor design

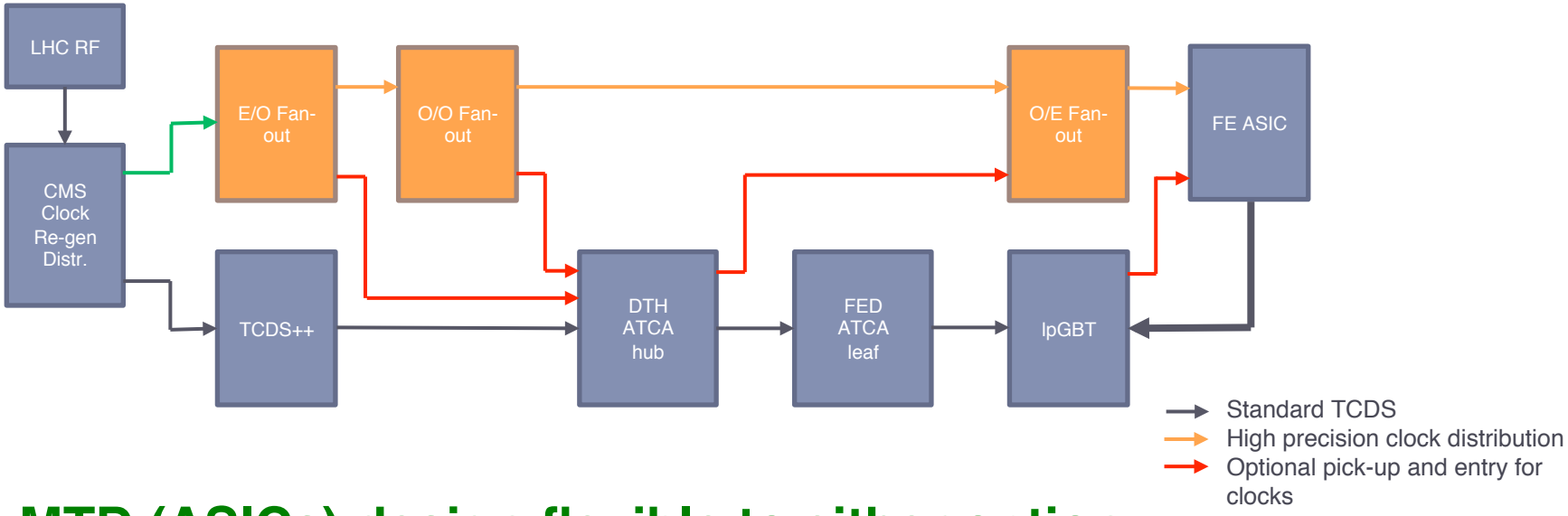
Endcap Timing layer (ETL)

- Operation at T = –20 °C (CO_2 cooling common with HGC)
- **LGAD pad size: 1x3 mm^2**
- Ganging 3 to 1 at $|\eta|>2.1$
- **ASIC**: Exploit libraries, and expertise from RD53 (65 nm)
- Ongoing design study (preamp + Disc + ToA and TDC)
- Challenge: Scale to large area and readout chip with <30 ps

- **Control cards with power, clock distr., control and data links (lpGBT)**
  - Data volume (zero suppression): **1.2 Tb/s BTL + 2.4 Tb/s ETL**
- **Level-1 trigger up-scope option:**
  - Exploit data from regions of interest upon L0 from other systems
  - Requires adjustments of the ASIC logic

Clock distribution

- **One dedicated clock fibre per readout region**
  - Clock entry local to the lpGBT and front-end ASICs
- **LHC RF clock distributed via the back-end**
- **Two parallel approaches (CMS wide effort)**
  - **Option 1:** Exploit the clock encoded within the control links (lpGBT)
  - **Option 2:** Deploy a separate clock path with dedicated fan-out chip under specification



- **MTD (ASICs) design flexible to either option**

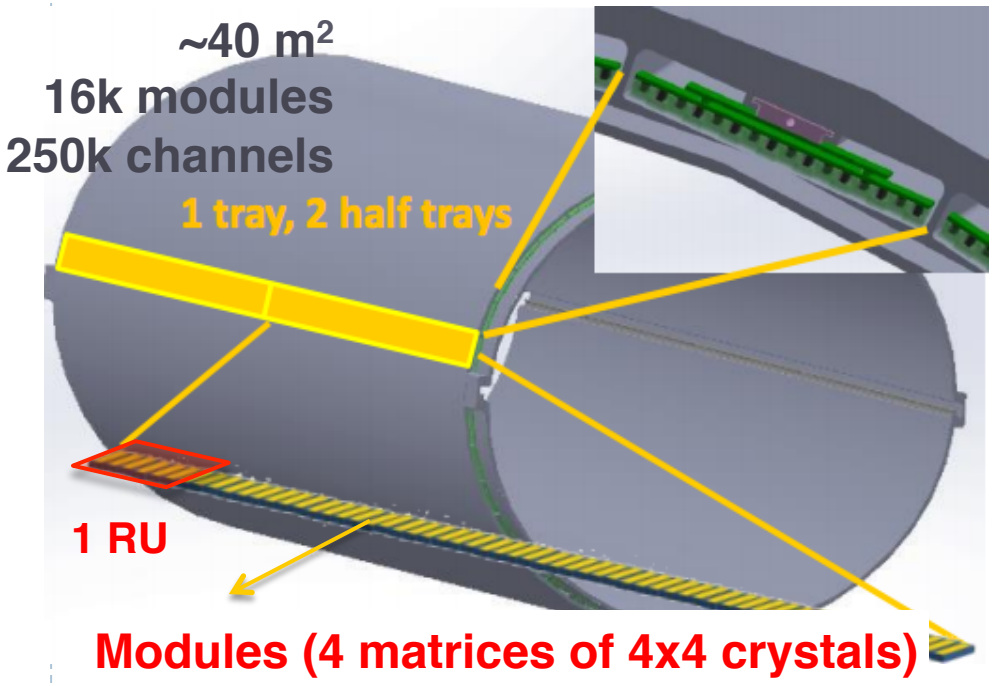
Project status

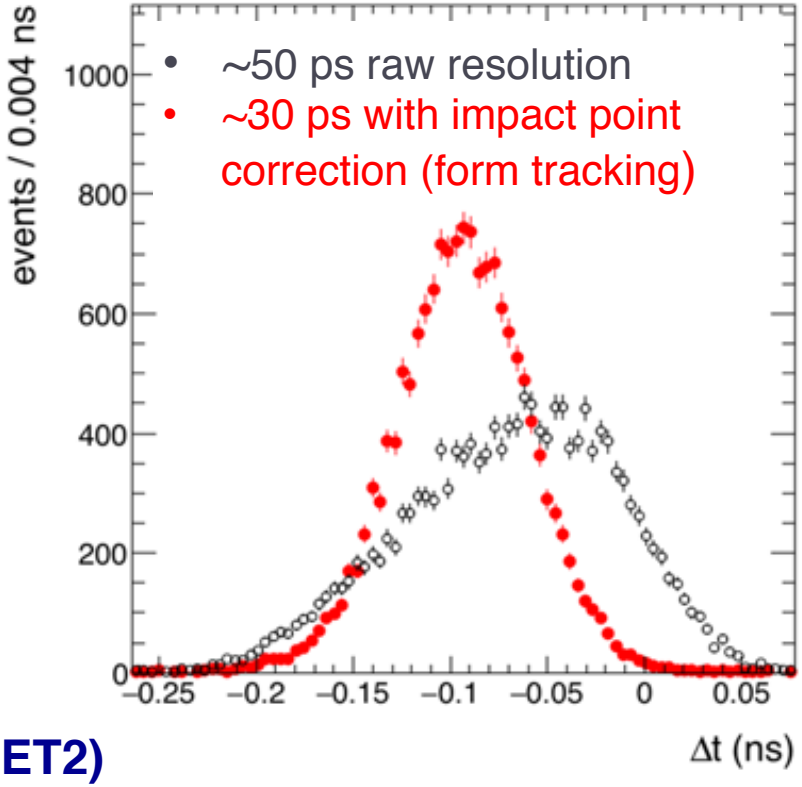
- **Technical proposal submitted Nov. 2017:**
  - LHCC March 1: recommendation to proceed to a TDR (endorsed by CERN RB March 7, 2018)
- **Technical design report in preparation (Feb 2019)**
  - Completion of R&D on sensors and layout optimization
  - Definition of the construction model, quality assurance and check
- Capitalize on existing projects for power systems, back-end and DAQ

- **Engagement and commitments for construction being defined**
  - Opportunities: BTL QA and assembly (crystals, FE boards, etc.)
    ETL sensors QA, module assembly, FE hybrid
    >> Power system (BTL and ETL) and back-end **<<**
    >> Mechanical structures **<<**
- **Integration schedule (+ 6 moths on BTL)**
  - **Barrel**: Integrates with the Tracker → Must be completed by Oct 2023
  - **Endcap**: Integrates with HGCal → Must be completed by Dec 2024

BTL layout

- **LYSO/LSO:Ce + SiPMs embedded in the tracker support tube**
  - CO_2 cooling at ~ –30 ^{0}C (limit SiPMs self-heating and dark rate)
  - Nominal geometry: **11.5x11.5x4 mm^3 tile with central SiPM 4x4 mm^2**

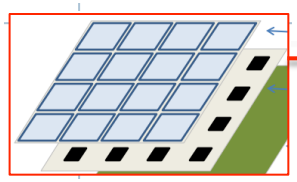




- **Read out TOFHIR chip (adapted from TOFPET2)**
  Leading edge timing + amplitude meas.

R&D ongoing to mitigate the need to rely on tracking

Construction flow and opportunities



SiPM Mounting on Boards

Sensors

Crystals

SiPM

SiPM Boards

Mechanics

Tray Mechanics

Electronics

ASIC

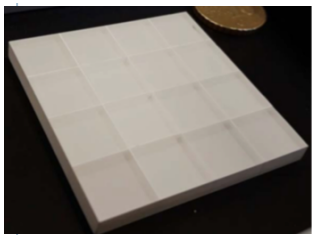
Cables & Fibers

CC Boards

FE Boards

R&D and component acquisition

CRYSTAL MATRICES PROCUREMENT, QA AND QC DURING



Sensor Boards aka Modules

Q2/2021

RU Units

BASELINE THREE CENTRES

Production in multiple centers

Tray Integration

Q4/2021

@TIF in CERN

Detector Integration

Q1/2022

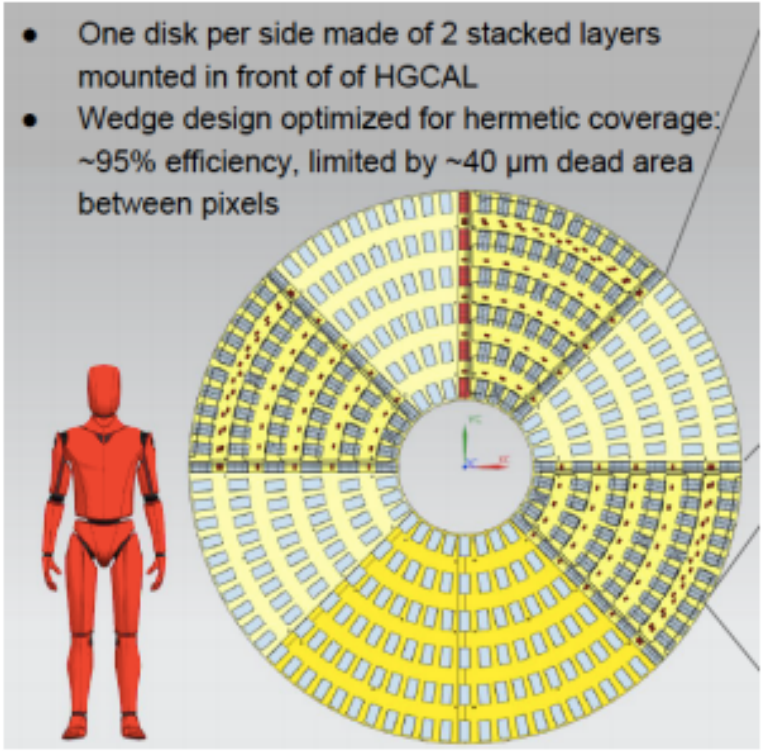
ASSEMBLY

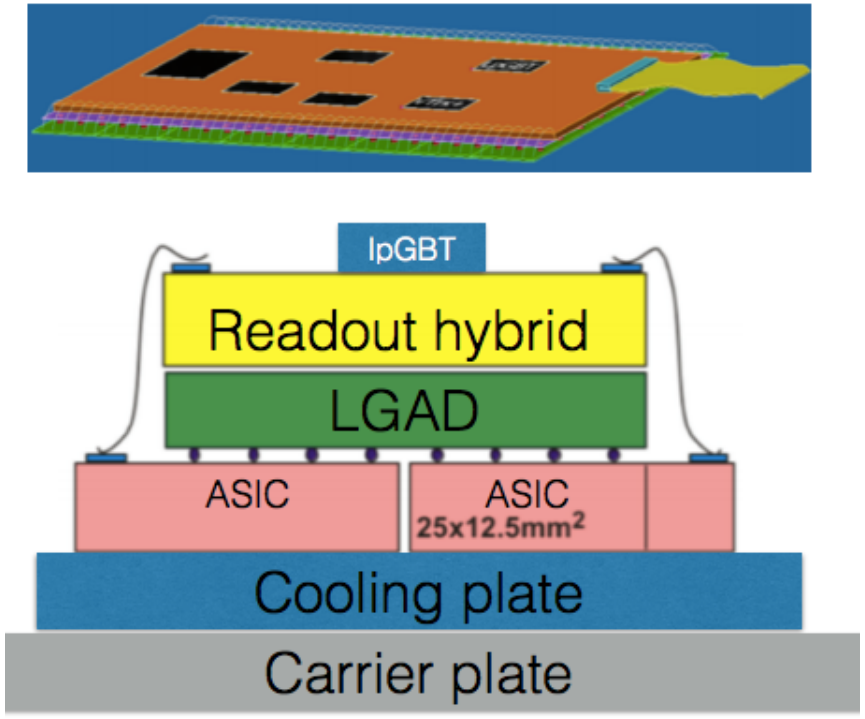
- PRODUCTION CENTRE
- INFRASTRUCTURE FOR SYSTEM TESTS (DAQ)
- INTERGATION AT TIF

FRONT END BOARD PRODUCTION AND TESTING

MECHANICAL STRUCTURES
* TST MODIFICATION

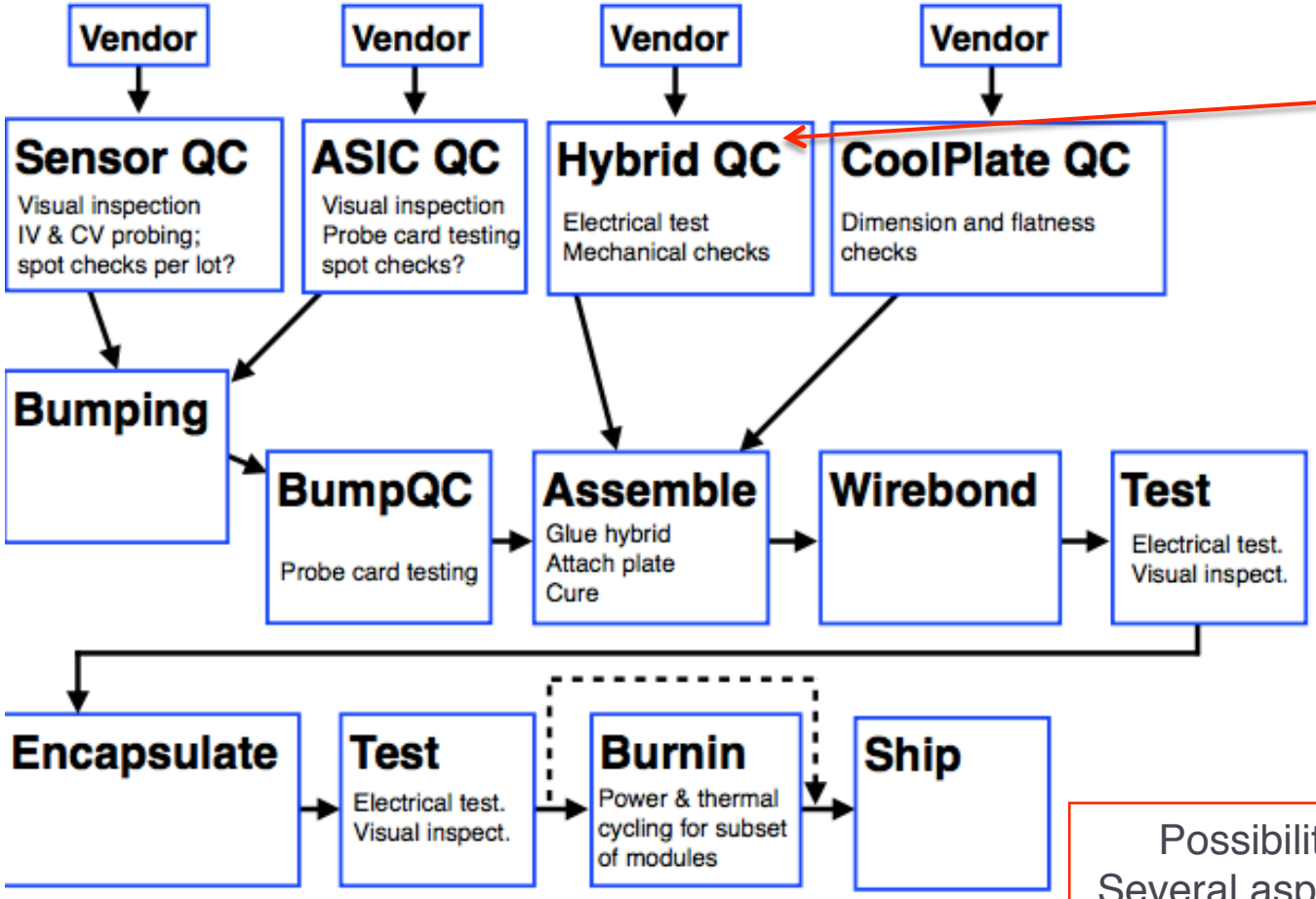
ETL layout





- **Low gain avalanche diodes (LGADs) mounted on the HGCal nose**
  - LGAD qualified in beams at irradiation levels needed for HL-LHC
  - Nominal geometry: 4.8 x 9.6 cm^2 modules with 1x3 mm^2 pads
  - ASIC: Preamp + Time-pick-off and TDC similar to ALTIROC1 (ATLAS) but in 65 nm

Construction flow and opportunities



Development and QC

ASSEMBLY
- Ideally two production
- centres: US + Europe

CONTRIBUTION TO PRODUCTION CETRE ASSEMBLY AND QC STEPS LABOR

Possibility of engagement in Several aspects of the engineering and production

Summary

- **A TP was approved**
  - The MTD can provide substantial performance gain at HL-LHC
  - Expression of interests from 34 institutions were collected

- **A TDR is being prepared**
  - Commitments are being defined and there is plenty of opportunities to engage in
    - finalizing the detector design
    - contributing to the construction and validation process in both technologies (more in ETL than BTL)
    - design and commissioning of the mechanical infrastructure, the power system (BTL and ETL) and the DAQ