[CMS – Italia – Piacenza
29 Novembre 2017]

Mip Timing Detector

Il progetto, le performance e i nostri impegni

- **3 Apr 2017**: MTD incluso nell'*upgrade scope* di CMS
- **27 Nov 2017**: Technical Proposal consegnato a LHCC
  - https://goo.gl/m9ZZqW

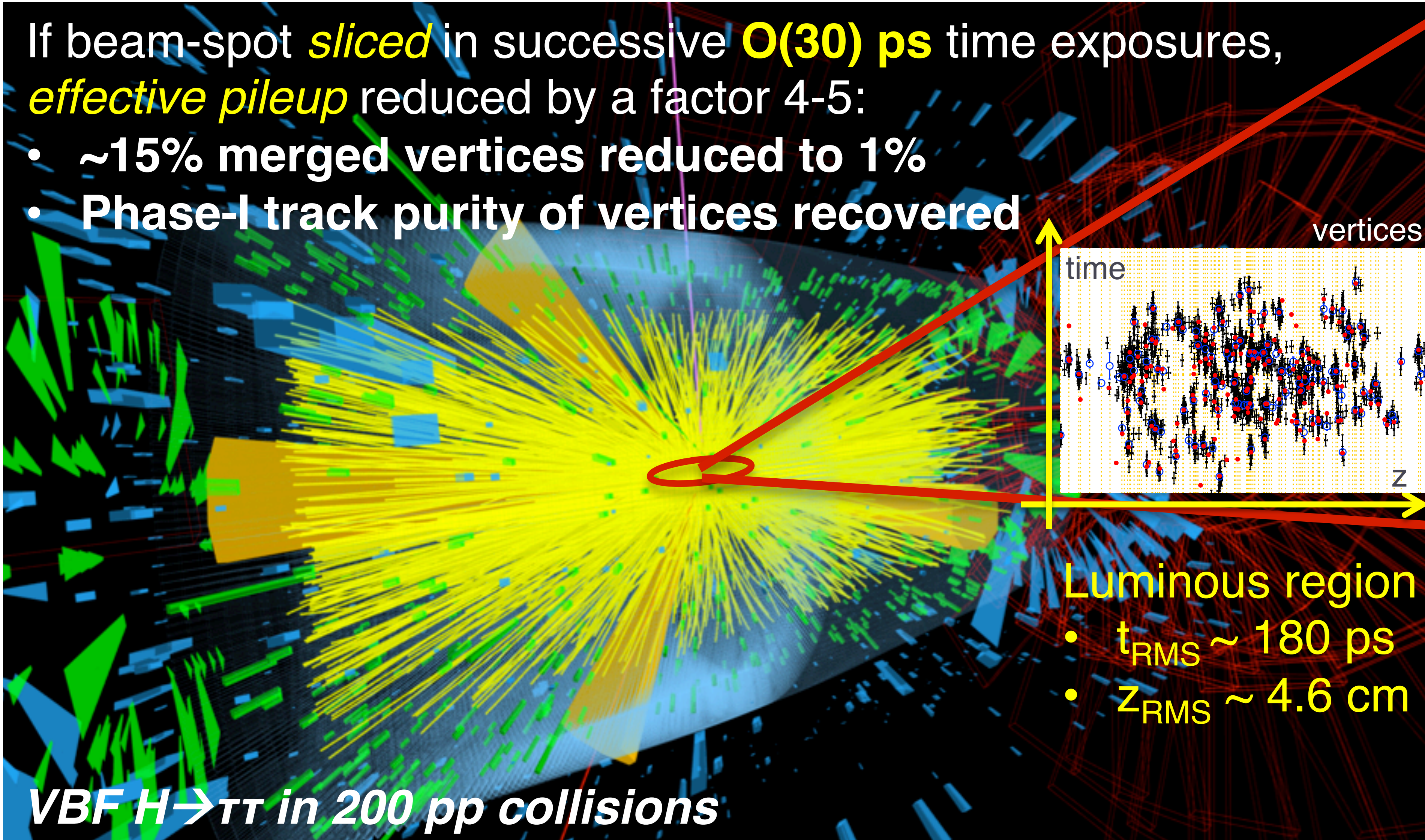
- **27 Feb 2018**: LHCC *feedback*
- **Q4 2018**: Technical Design Report

[T. Tabarelli de Fatis]

Basic motivation: extend performance at high pileup

If beam-spot *sliced* in successive **O(30) ps** time exposures, *effective pileup* reduced by a factor 4-5:

- **~15% merged vertices reduced to 1%**
- **Phase-I track purity of vertices recovered**



Luminous region

- $t_{RMS} \sim 180$ ps
- $z_{RMS} \sim 4.6$ cm

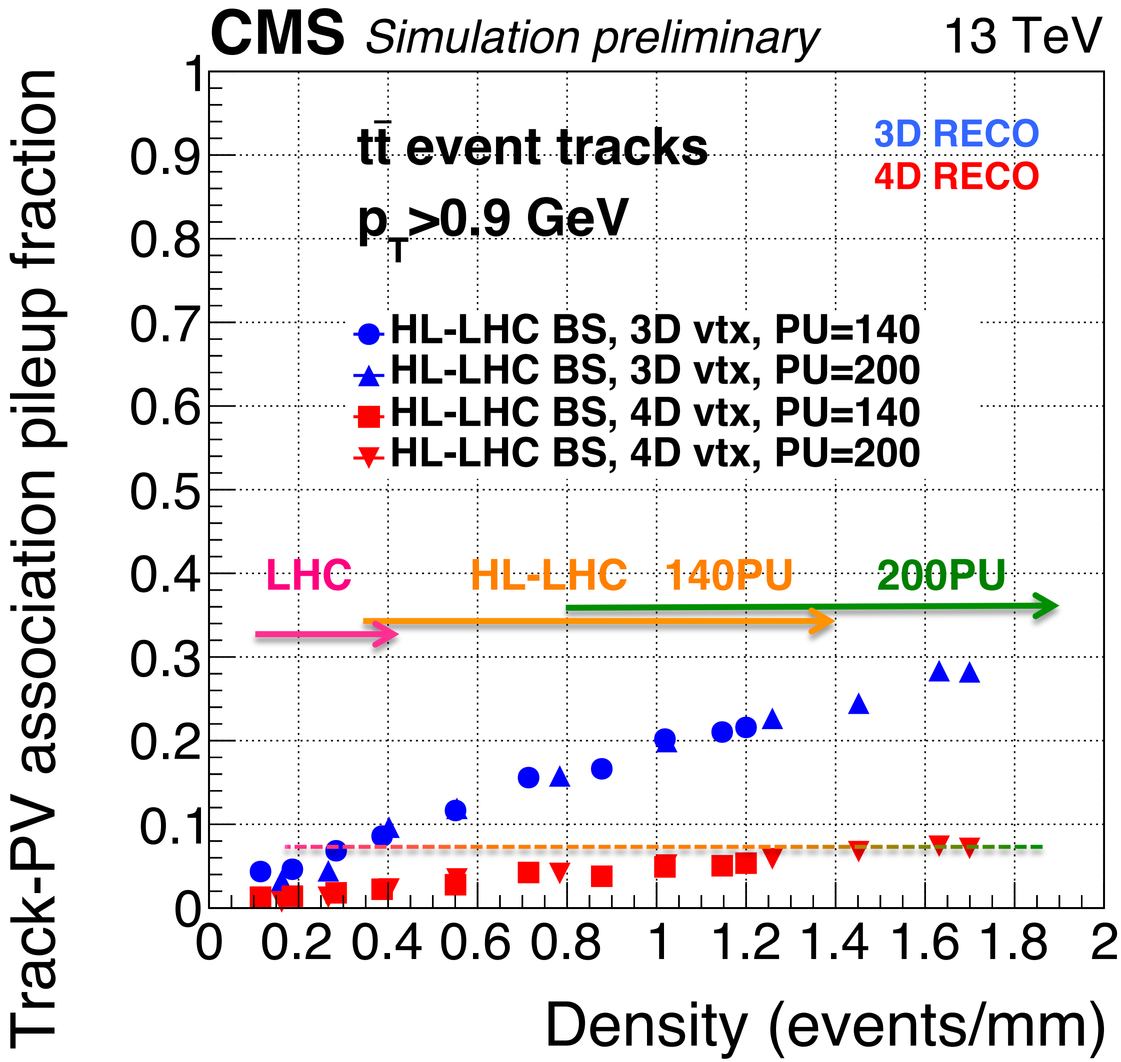
VBF H→ττ in 200 pp collisions

Elements of the timing upgrade of CMS

- **Calorimeter upgrades: precision timing of showers**
  - High energy photons in ECAL
  - All photons and high energy hadrons in HGCal

- **Mip Timing Detector: precision timing of tracks**
  - A single layer between the tracker and the calorimeters
- Acceptance: |η|<3.0 ps
- p_T>0.7 GeV barrel; p>0.7 GeV endcap

Track-vertex association – with track timing



- **With timing, 'effective vertex density' down to LHC level !**

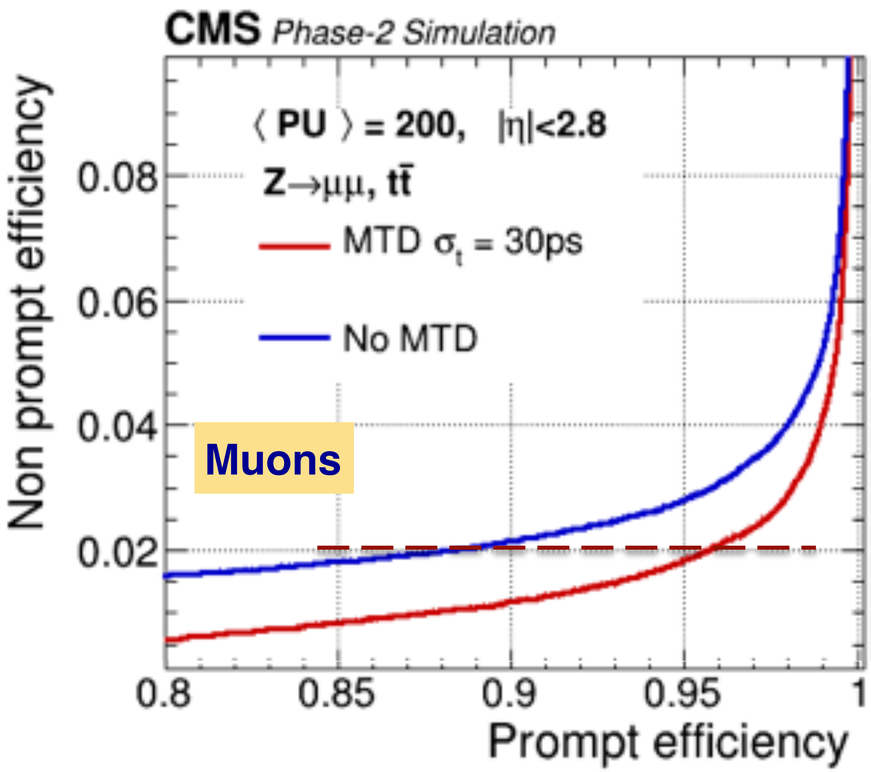
1. Cleaner isolation cones
2. Improved primary and secondary vertex reconstruction
3. Improved jet and p_T^{miss} reconstruction

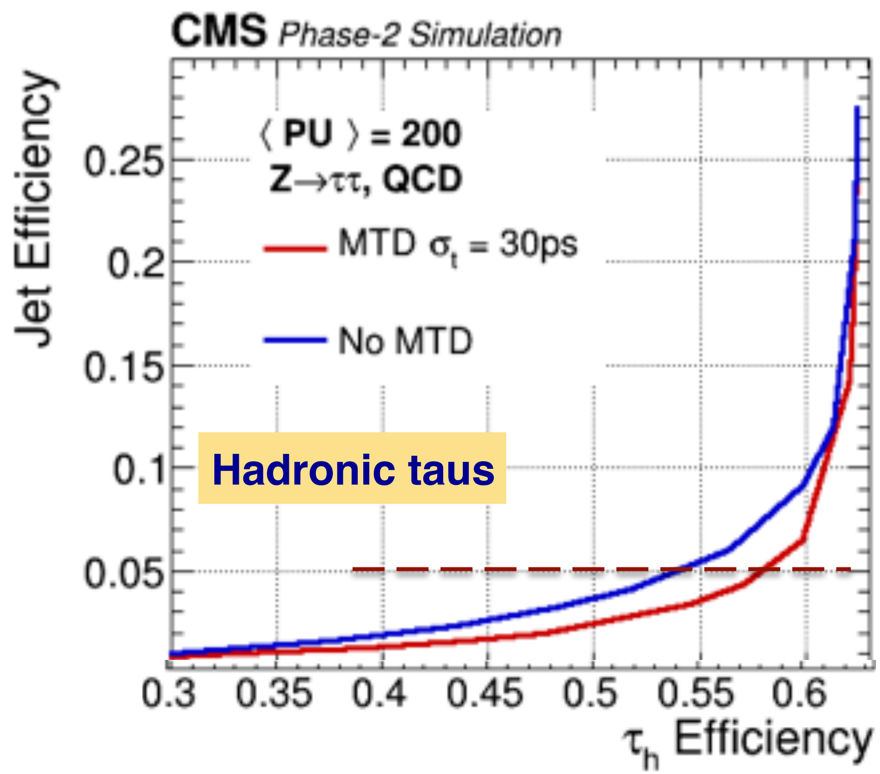
- **Boost performance of several observables**

Particle isolation: ROC curves

New

Track association with vertex: $\Delta t < 90$ ps





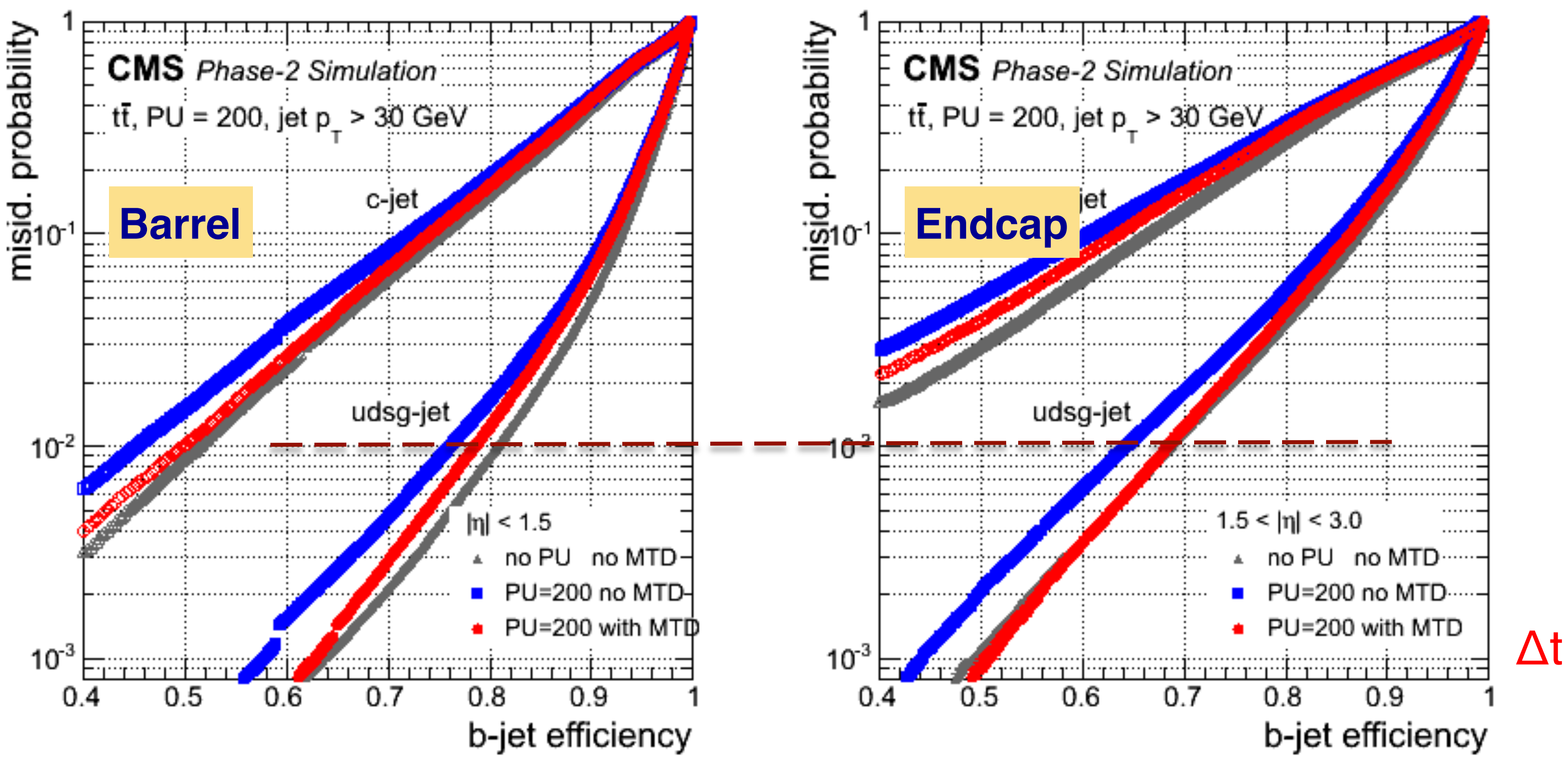
- **Isolation efficiency up by 7 ÷ 10% per lepton (*)**
  - Acceptance gain in searches and precision measurements
  - *[Gain amplified on multi-particle final states]*

(*) at constant background rejection power]

b tagging with timing

New

- **Efficiency up 4-6% at constant background rejection of 1% for light jets from removal of spurious secondary vertices**
  - inclusion of timing in the b-jet algorithm ongoing
- *[Gain ~ to the power N – for multi-particle final states]*

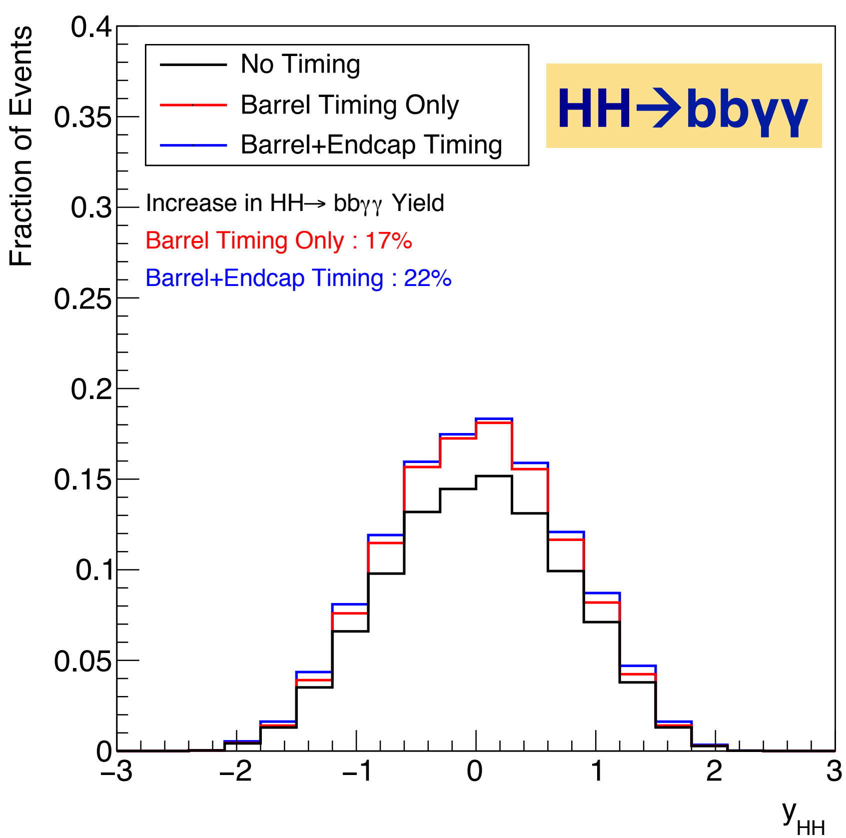


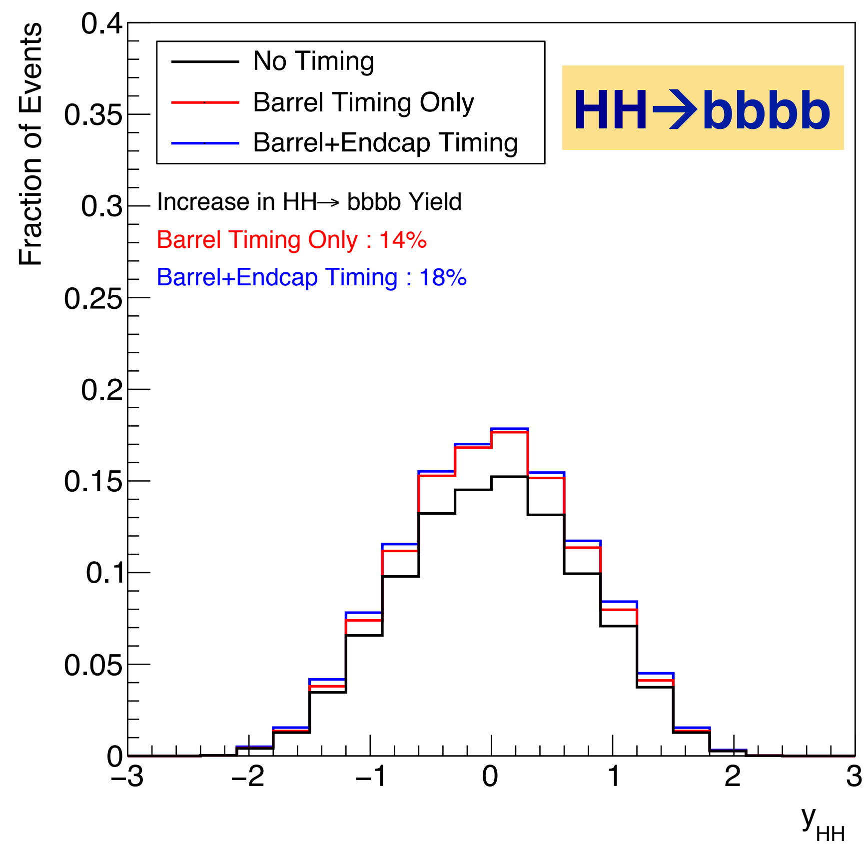
Δt < 90 ps

di-Higgs acceptance projections

New

- **Gain in signal yield ~20% in multi-object final states**
  - *[at constant rejection power for reducible background]*
- Large impact from barrel MTD (*central signatures*)



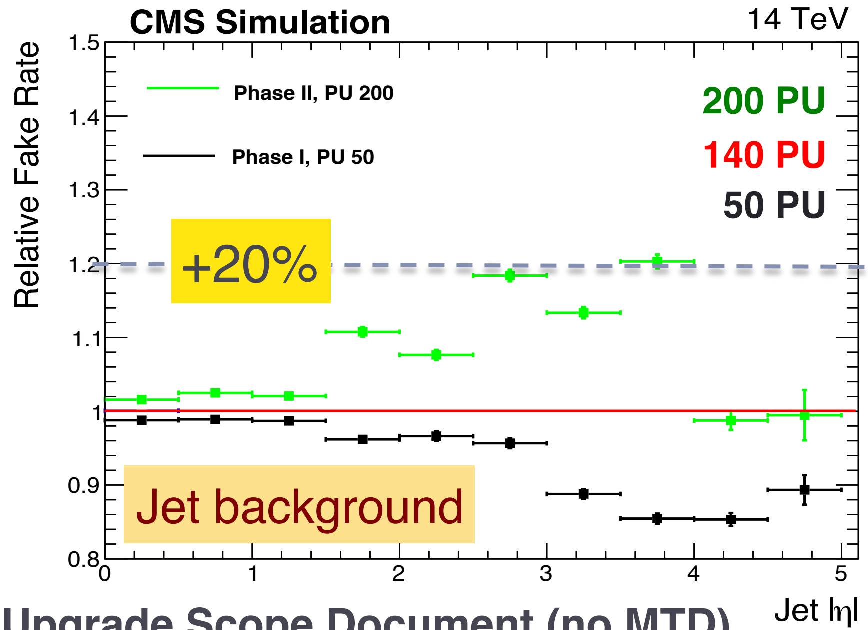


- *Similar gain also for H→ZZ→4leptons: +25% (not shown here)*

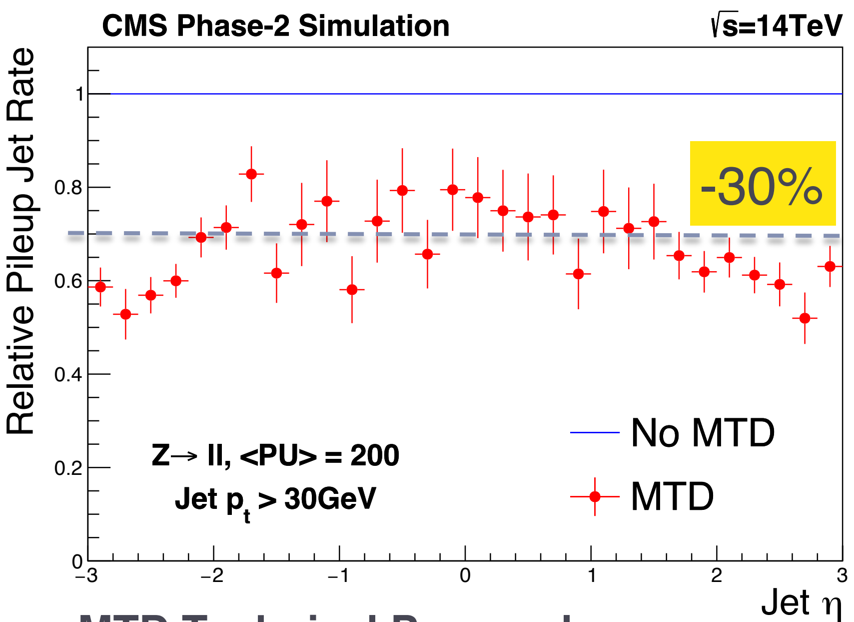
Projections for VBF + H → ττ

New

- **Performance gain from timing (S/√B) :**
  - **+30%** from isolation
  - **+30%** from VBF tagging [pileup jet rejection]
  - **+10%** from di-tau mass resolution [p_T^{miss} resolution]
- Timing offsets performance degradations from 140 to 200 PU
- Large impact from endcap MTD



Upgrade Scope Document (no MTD)

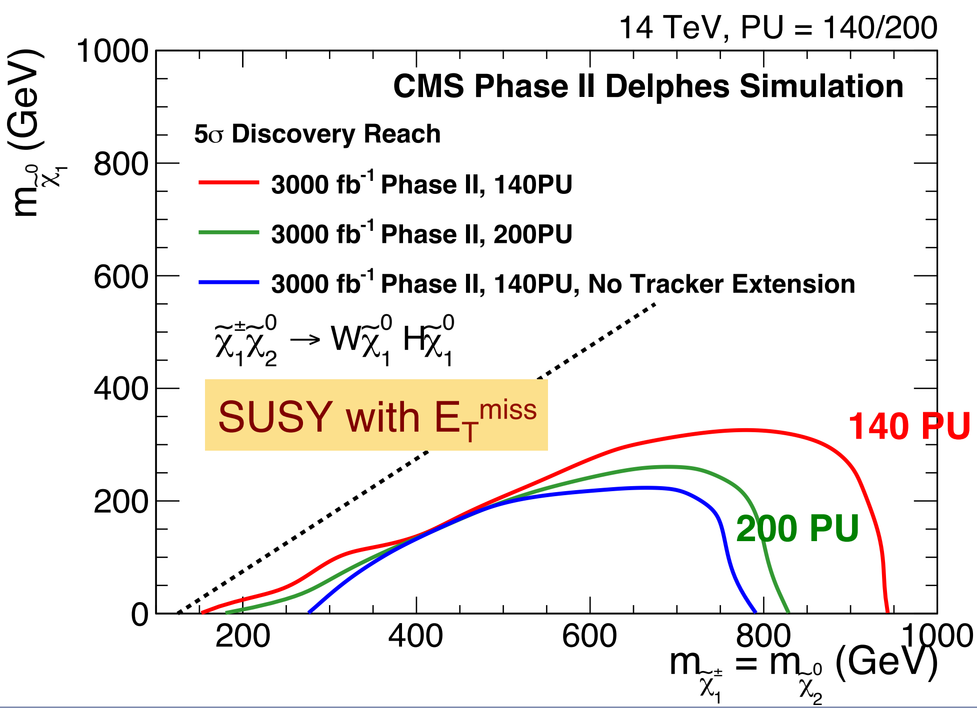


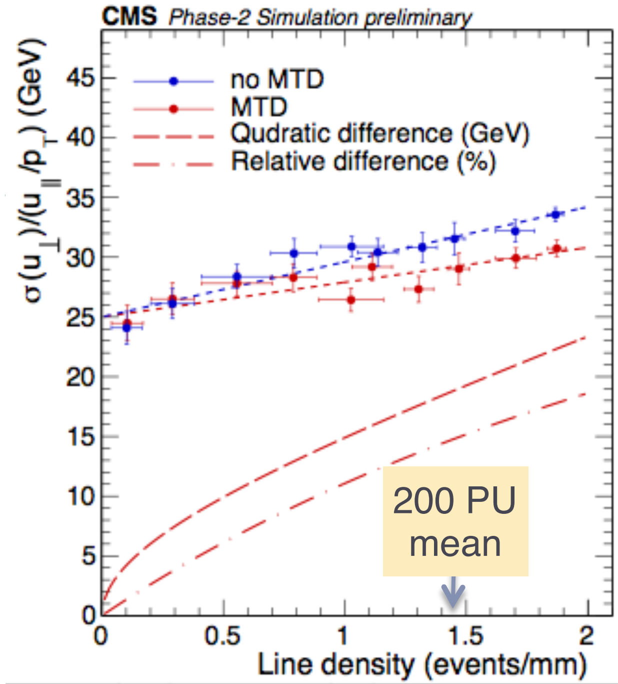
MTD Technical Proposal

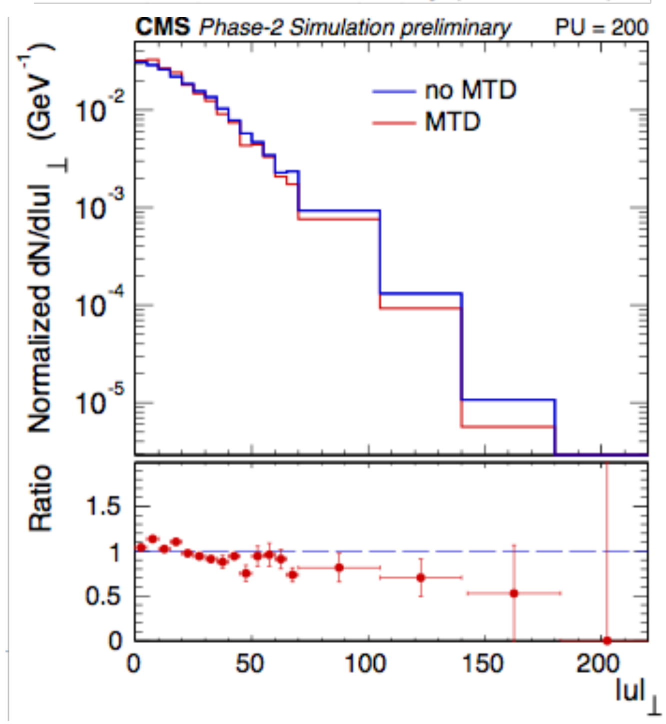
Missing p_T performance

- **With MTD:**
  - MET Resolution improved: ~15%
  - MET Tails reduced: 40% beyond 150 GeV
- **Extend physics reach in searches of massive invisible particles : +150 GeV**

- **CMS Upgrade Scope document (no MTD)**
  - Sensitivity spoiled by MET tails from pileup





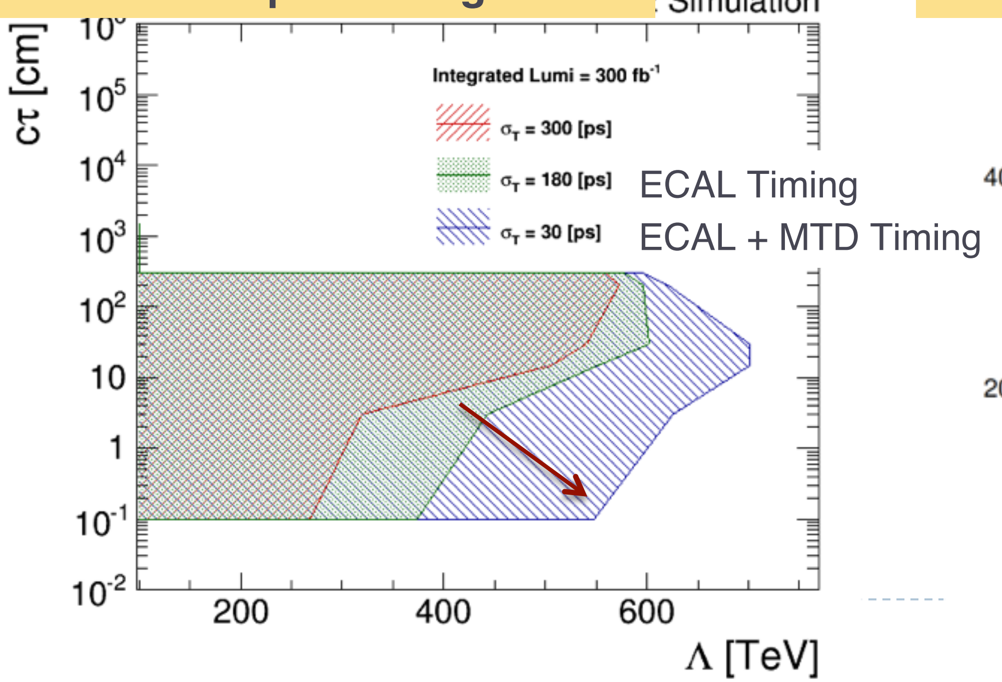


Searches for long-lived particles (LLP)

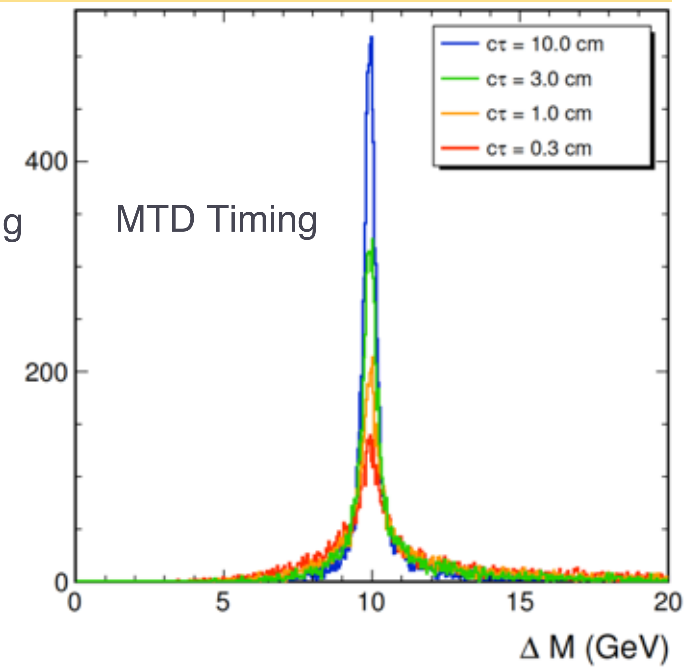
New

- **New capabilities afforded by the MTD (examples):**
  1. Ability to measure decay *time* in addition to decay length
     - Extended acceptance for massive LLP
  2. Ability to reconstruct LLP velocity from the space-time information of the primary and decay vertex
     - Peaking observable from constraint on the decay kinematics

1. Neutralino to photon + gravitino



2. Chargino-neutralino (degeneri)



Sinossi

Tavola 1.1 dal TP

Signal	Detector requirement	Analysis impact	Physics impact
$H \to \gamma\gamma$	30 ps photon and track timing • barrel: central signal • endcap: improved time-zero and acceptance	$S/\sqrt{B}$: +20% - isolation efficiency +30% - diphoton vertex	+25% (statistical) precision on cross section
VBF+ $H \to \tau\tau$	30 ps track timing • barrel: central signature • endcap: forward jet tagging • hermetic coverage: optimal p_T^{miss} reconstruction	$S/\sqrt{B}$: +30% - isolation efficiency +30% - VBF tagging +10% - mass (p_T^{miss}) resolution	+20% (statistical) precision on cross section (upper limit or significance)
HH	30 ps track timing • hermetic coverage	signal acceptance : +20% b-jets and isolation efficiency	Consolidate HH searches
$\chi^{\pm}\chi^{0} \to W^{\pm}H + p_T^{miss}$	30 ps track timing • hermetic coverage: p_T^{miss}	$S/\sqrt{B}$: +40% - reduction of p_T^{miss} tails	+150 GeV mass reach
Long-lived particles	30 ps track timing • barrel: central signature	mass reconstruction of the decay particle	unique sensitivity to split-SUSY and SUSY with compressed spectra

Higgs boson physics

Searches

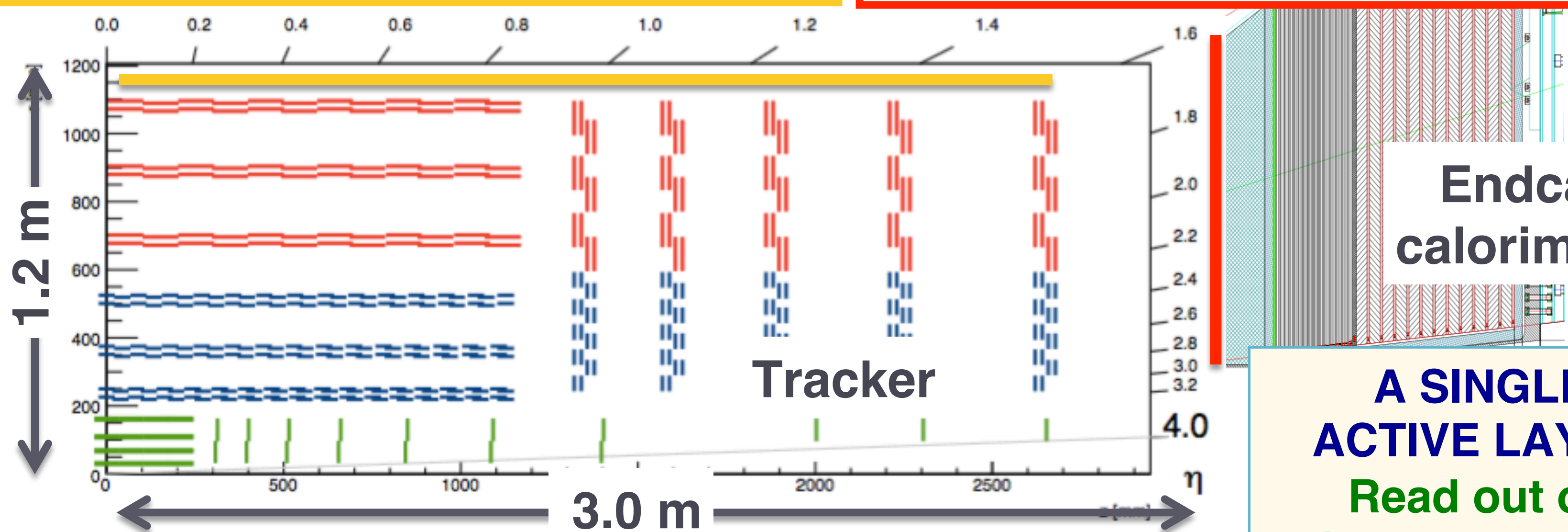
- **MTD: improves the full range of Phase-2 physics**
  - ~20-30% improvements across all measurements
  - Recovery of performance for MET-tail based searches
- Enhanced capability for reconstructing the secondary vertices of long-lived particles (LLPs)
  - Resonance reconstruction for LLPs (novel method)

MTD: design and technologies

- Hermeticity: barrel (|η|<1.48) and endcap (1.6<|η|<2.95)
- Radiation: **$2x10^{14}$ (barrel)** and **up to $2x10^{15}$ neq/cm^2 (endcap)**
- Minimal impact on calorimeter performance
- Mechanics and services compatible with existing upgrades

LYSO/LSO tiles with SiPM readout:
- TK/ ECAL interface **~ 25 mm thick**
- Surface ~40 m^2
- Integration with tracker - 2022

Si with internal gain (LGAD):
- On the CE nose **~ 60 mm thick**
- Surface ~12 m^2
- Integration with endcap - 2025

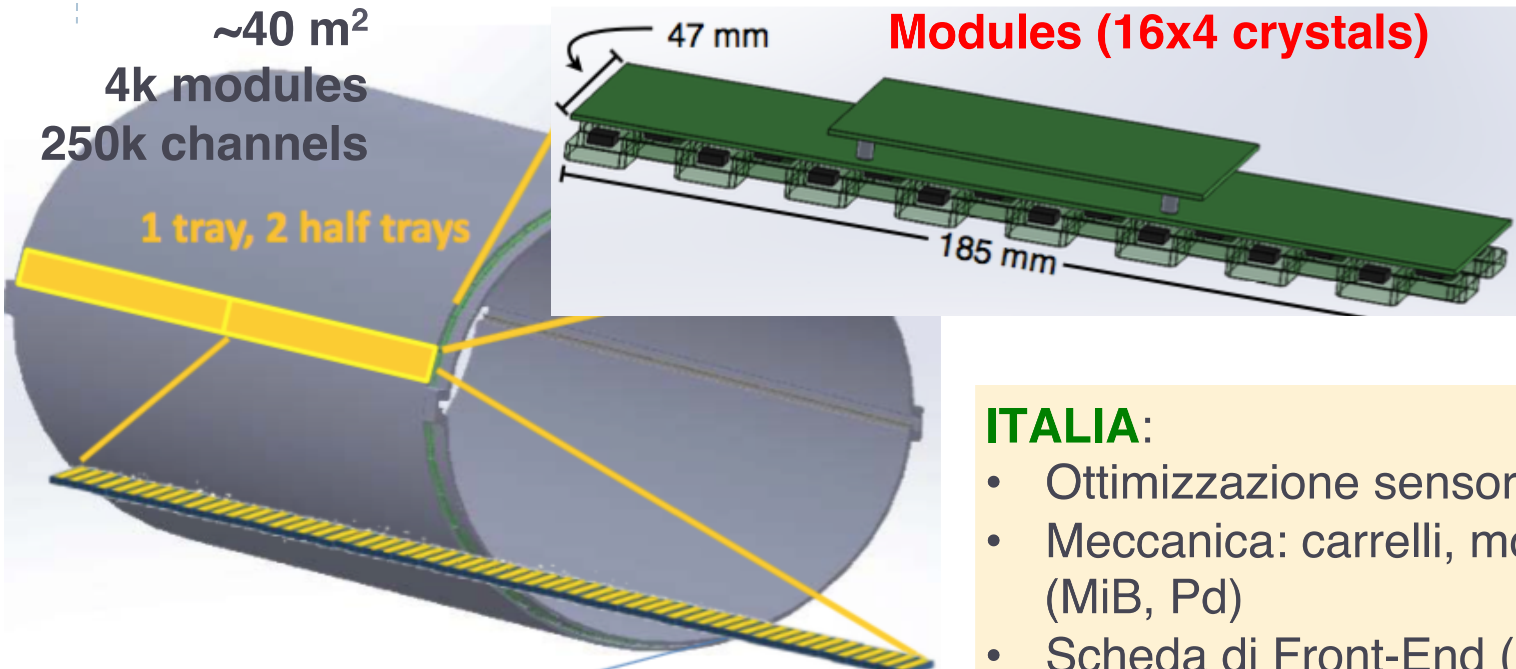


A SINGLE ACTIVE LAYER
Read out on L0/L1 trigger-sccept

Barrel timing layer (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)
- **“Production-ready” and scalable technology**

~40 m^2
4k modules
250k channels

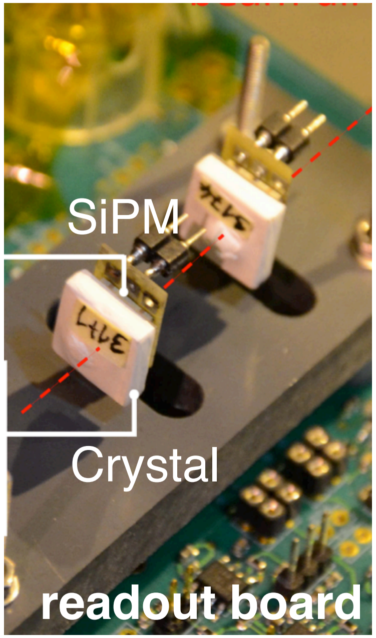


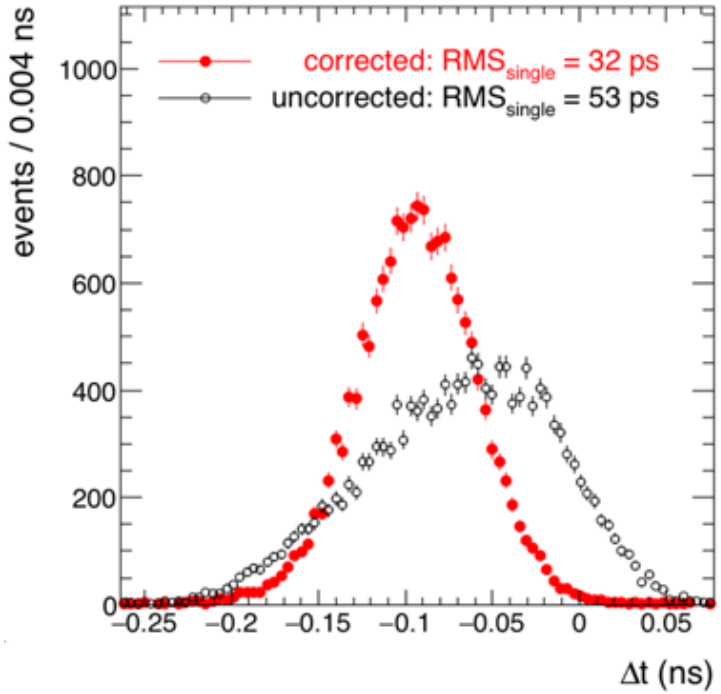
- 3% occupancy (0.5 mip threshold)
- **Adapt TOFPET2 ASIC (TOFHiR)**
- Leading edge timing + amplitude meas.

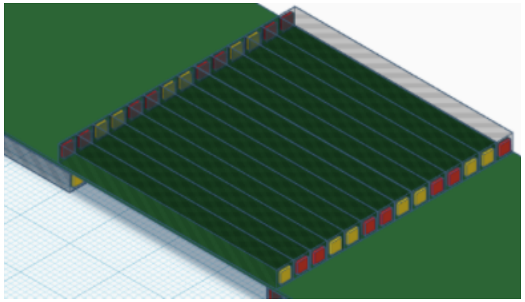
ITALIA:
- Ottimizzazione sensori (MiB, Rm1)
- Meccanica: carrelli, moduli e cooling (MiB, Pd)
- Scheda di Front-End (MiB)
- Simulazione e ricostruzione (TS)
- Produzione: MiB, Rm1, Pd

BTL R&D per il TDR

- **Production-like geometries qualified in test beams**
  - Need correction for hit position with nominal geometry :
    - 11x11x4 mm^3 + SiPM 4x4 mm^2
    - Tracker z resolution insufficient (at low p_T)
  - R&D1: Custom SiPM (sparse SPAD pitch over the full crystal area)
  - R&D2: Crystal slabs with double-end readout

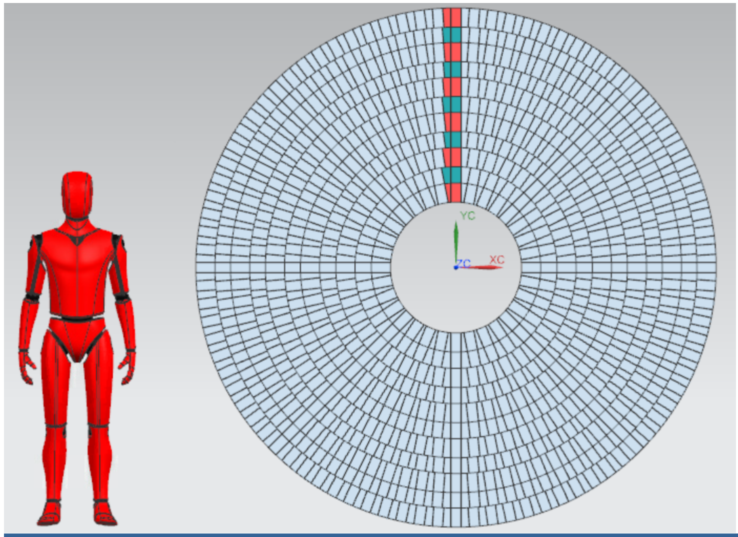


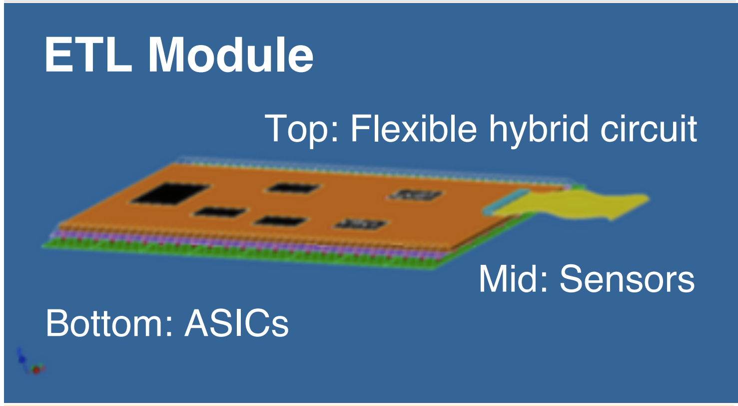




Endcap timing layer (ETL) layout

- **Low gain silicon detectors (LGADs) on HGCal nose**
  - Emerging technology available from at least three foundries
- **Double-disk structure**
  - Similar to tracker TEDD
  - Al wedges with embedded cooling pipes (CO_2 cooling at ~ –30 ^{0}C)
- **Sensors on both disk sides**
  - Nominal geometry: **4.8 x 9.6 cm^2 modules with 1x3 mm^2 pads**
    - Single layer hermetic coverage
    - ~3-5% occupancy
  - ASIC under development

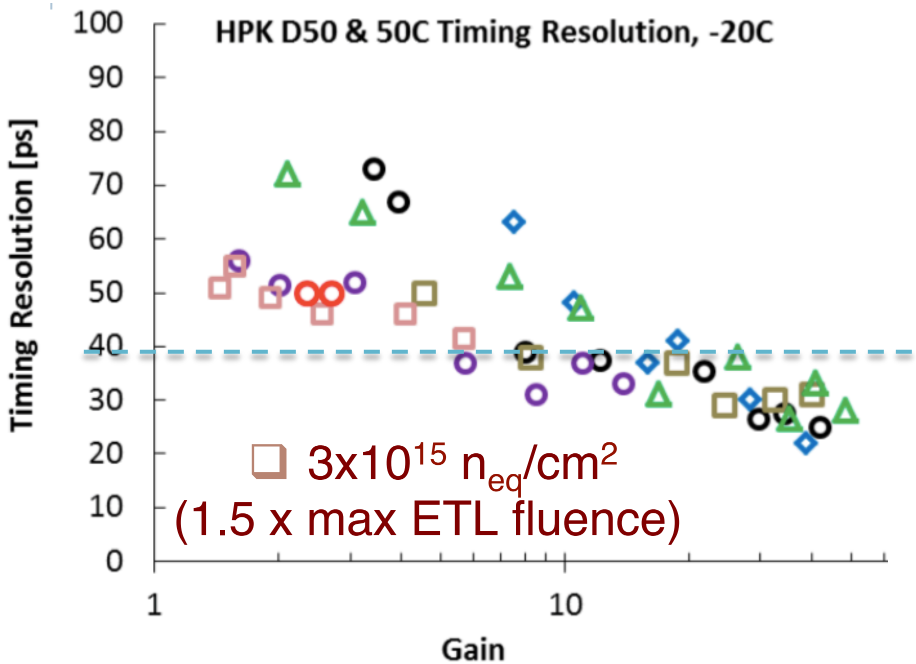


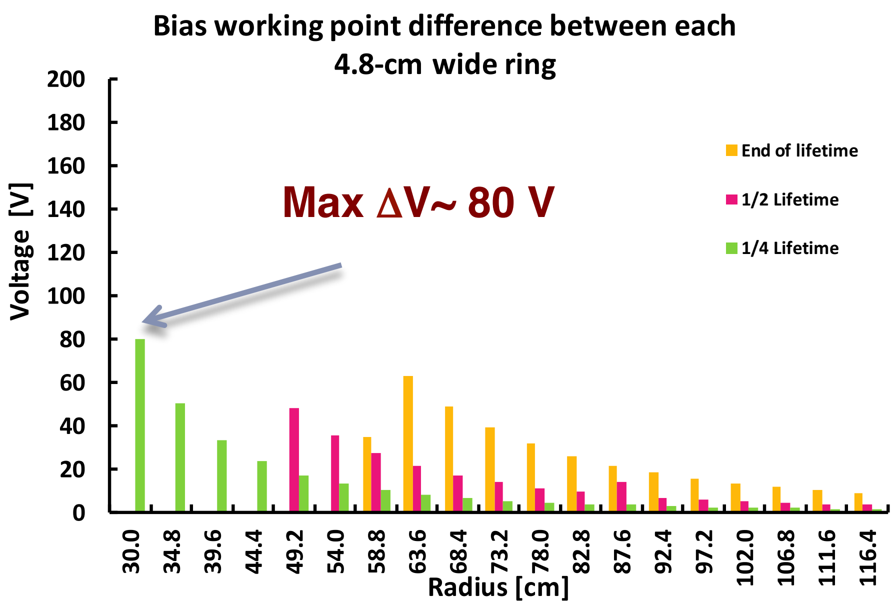


ITALIA:
- Sviluppo sensori (To, Ge)
- Produzione (To)

Sensors qualification and R&D (I)

- **Irradiation studies with single pad LGADs:**
  - LGAD can deliver < 40 ps timing resolution for entirety of HL-LHC
  - Need compensation of gain loss with increased external bias





- R&D1: Bias scheme for individual pads
- R&D2: Multi-pad sensors (uniformity, yield, fill factor)

Collaborazione e interessi italiani

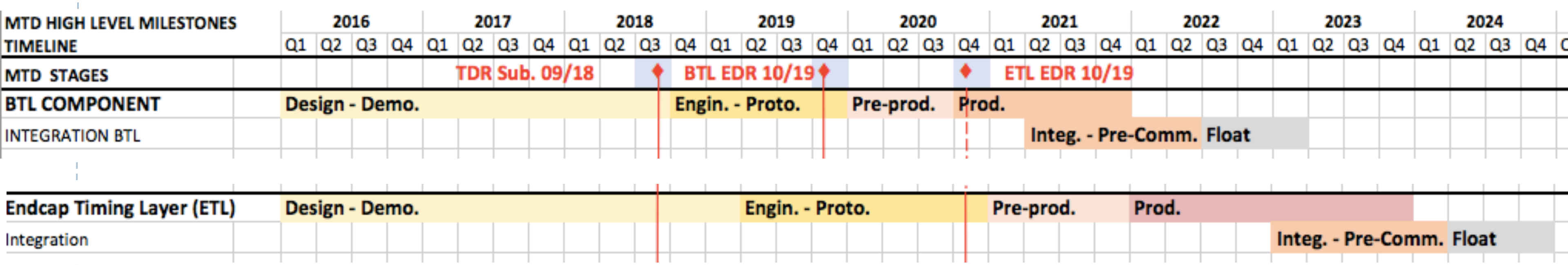
- **Tabella 4.5 dal Technical Proposal (post CWR):**
  - *Expressions of interest e* impegni R&D fino al TDR
  - *Commitments* per la costruzione saranno definiti nel TDR

Se diventa progetto CMS:
Attività MTD con RA Italia

Tasks	Expressions of interest
Barrel sensors	INP-BY, DEB-HU, MiB-IT, Rm-IT, ViU-LT, NSU-RU, CERN, Caltech-US, FU-US, UI-US, PU-US, UVa-US
Barrel modules and integration	MiB-IT, Pd-IT, Rm-IT, ETHZ-CH, Caltech-US, MIT-US, PU-US, UVa-US
Barrel front-end electronics	LIP-PT, MiB-IT, ETHZ-CH, KSU-US
Endcap sensors	HIP-FI, KIT-GE, Ge-IT, To-IT, IFCA-SP, USe-SP, UCSB-US, FNAL-US, FSU-US, UIC-US, KU-US
Endcap modules and integration	To-IT, BU-US, FNAL-US
Endcap front-end electronics	FNAL-US, USe-SP
Back-end electronics and trigger	MIT-US, UW-US
CMS and MTD clock distribution	IRFU-FR
Simulation and reconstruction	Ts-IT and others

- Responsabilità sviluppo sensori LGAD
- Coordinamento (interinale) del (proto)progetto

Prossime tappe



- *Feedback da LHCC – Febbraio 2018*

- **TDR – Fine 2018**
  - Dimostrazione dei componenti principali
  - Definizione dei *commitment*

- **EDR – 2019 (BTL) / 2020 (ETL)**
  - Construction timeline for ETL stretched
  - Two years more than BTL should enable to complete the necessary R&D on sensor and on the ASIC development