Development of Crystal+SiPM Sensors for the Central CMS MIP Timing Detector

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on behalf of the CMS collaboration

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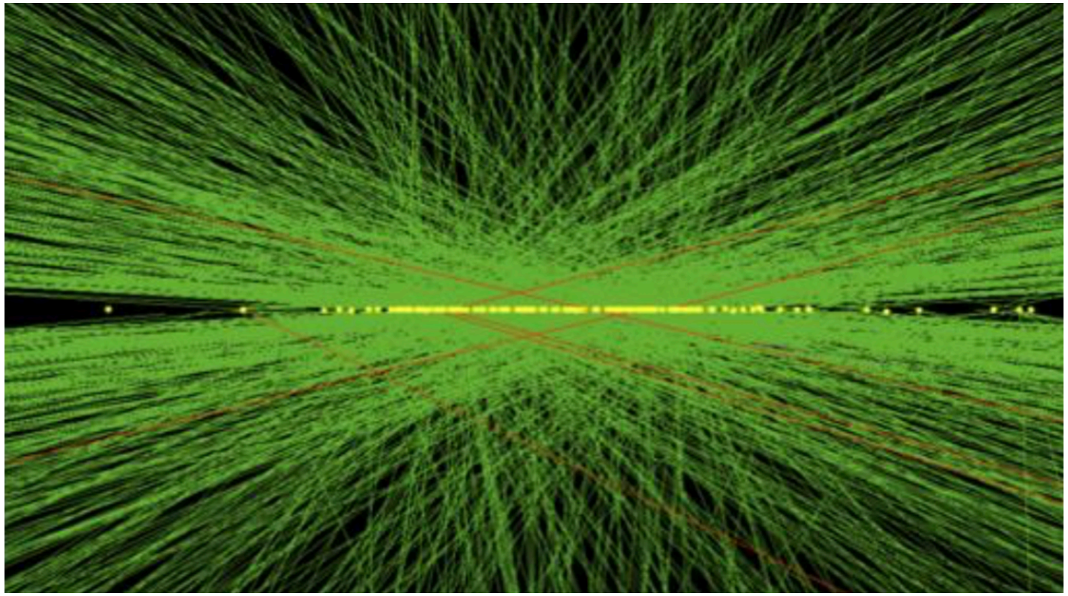
Outline

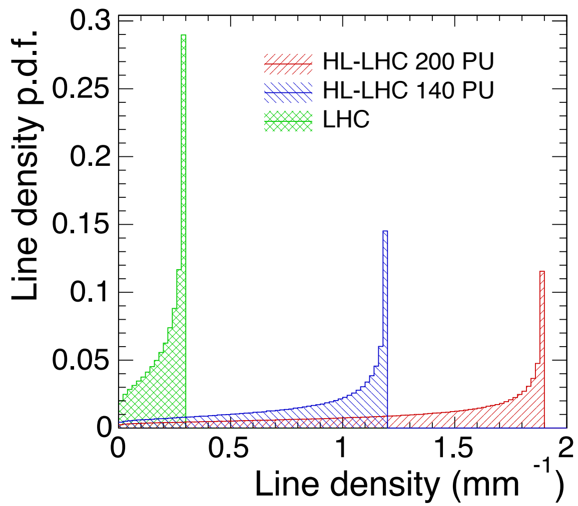
- Motivation for a MIP timing detector in CMS
- Description of the proposed detector
- Results of test beam studies on single sensors
- Ongoing R&D for a uniform time response

Why a MTD ?

HL-LHC: ***L*** 5.0 - 7.5 10^{34} Hz/cm^2 140 - 200 pile up (PU)   (now ~50 PU)



The interaction are spread by σ_z~ 4.5 cm along the beam axis, resulting in a high density of interaction vertices

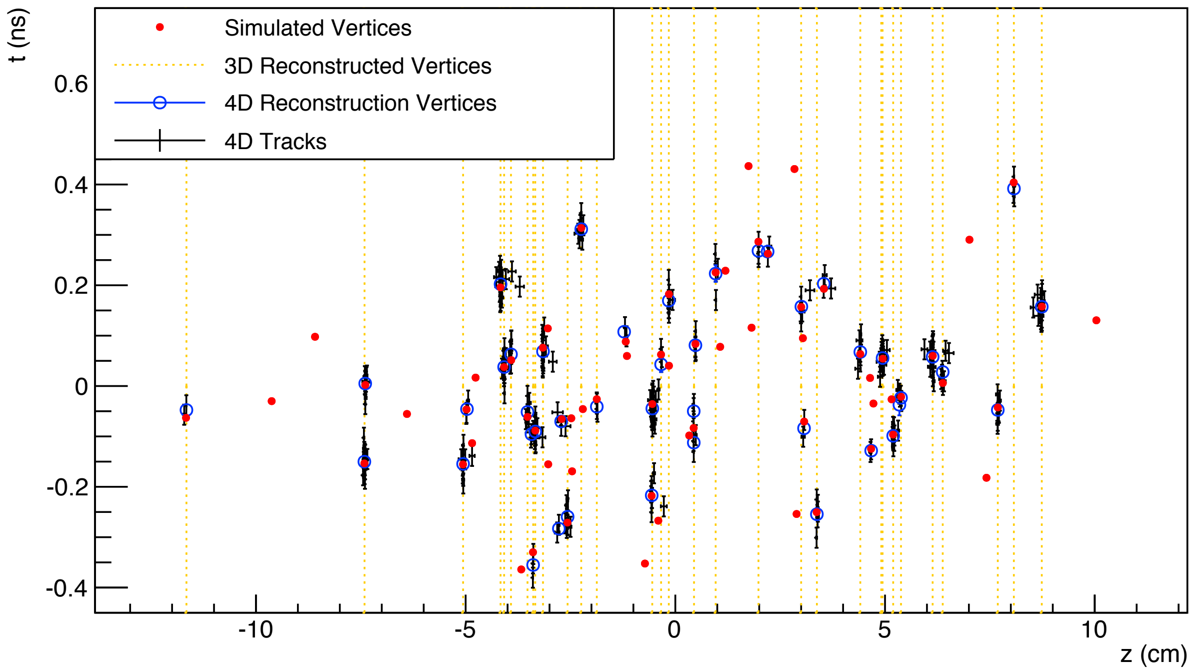


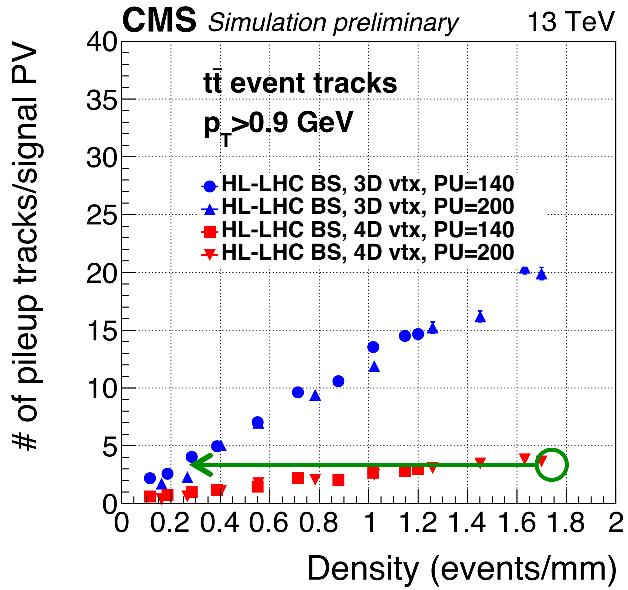
Incorrect assignment of track to the interaction deteriorates the performance of the reconstruction of vertices, jets and missing E_T and the identification (isolation) of leptons and photons.

Why a MTD ?

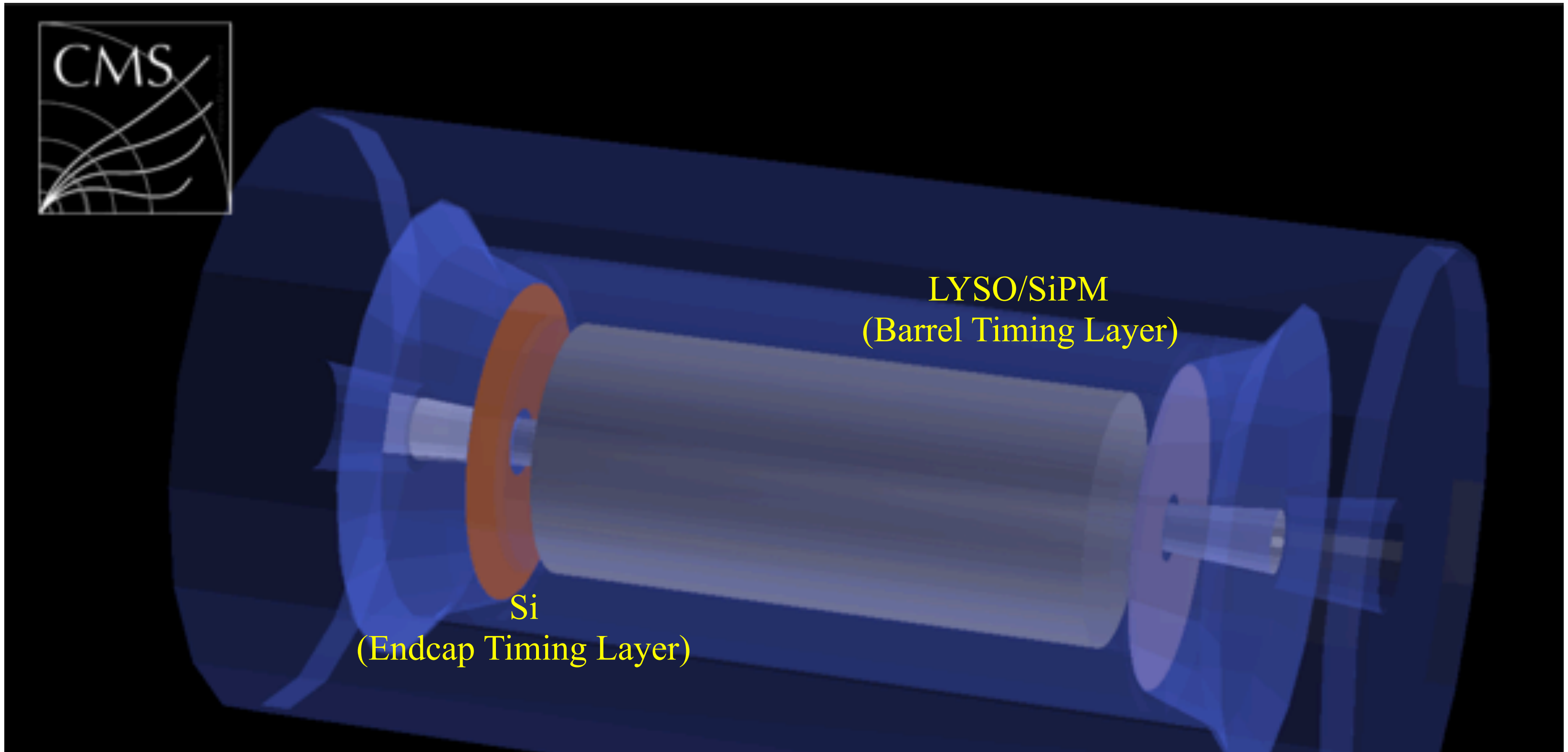
The interactions in a bunch crossing have a time dispersion of about 180 ps.

Measuring the timing of each track with a ~30 ps accuracy can help to distinguish the tracks from different interactions, enabling a 4-D reconstruction that reduces the "effective" pileup down to the present conditions.





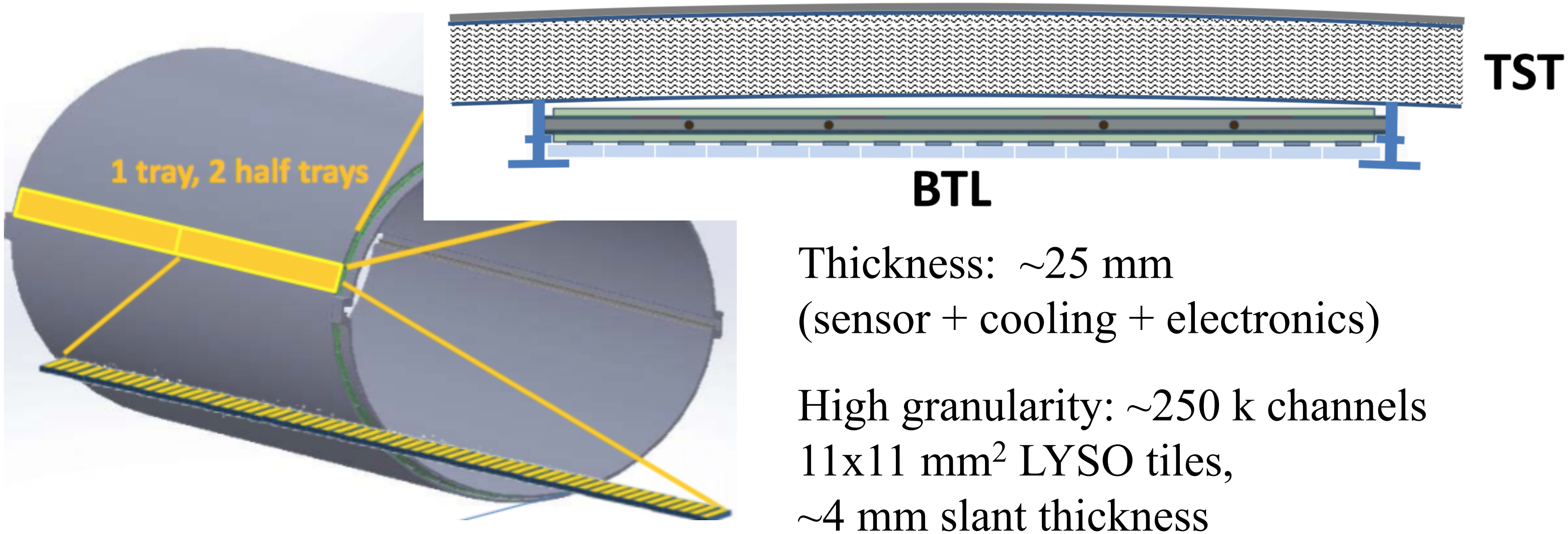
The proposed MTD detector



- **A dedicated layer for the timing of tracks placed just outside the tracker**
  - MIP timing with **30 ps precision**
  - **Acceptance, barrel: η|<1.45 and p_T>0.7 GeV**

The proposed BTL detector

A layer of LYSO:Ce tiles, readout by SiPM, to be installed in the tracker support tube



Thickness: ~25 mm
(sensor + cooling + electronics)

High granularity: ~250 k channels
11x11 mm^2 LYSO tiles,
~4 mm slant thickness

Area: ~40 m^2

Cooling : ~ -30 °C, liquid CO_2

Power consumption: ~0.5 kW/m^2

Readout: fixed threshold discriminator, based on the commercial TOFPET2 chip

Bandwidth : two timestamps and amplitude ~ 1.2 Tb/s

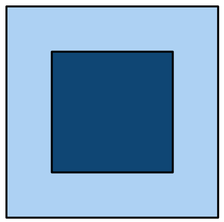
Radiation Hardness

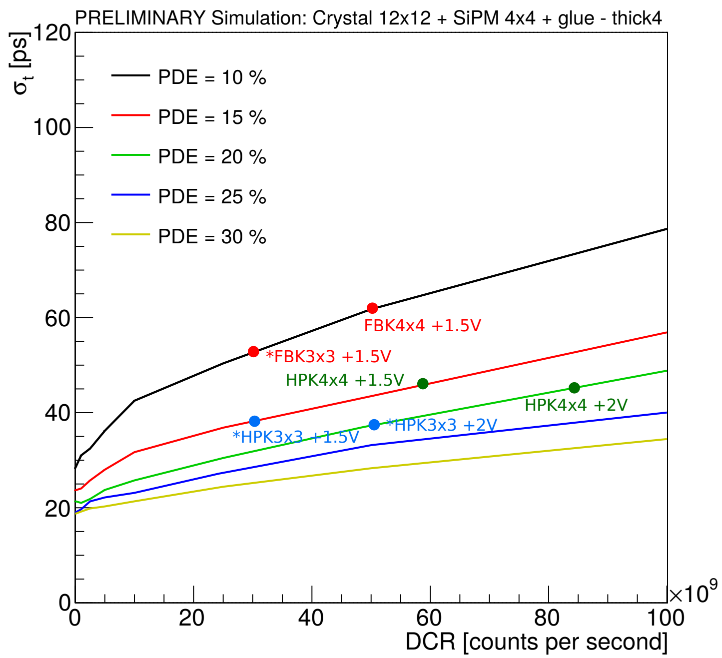
Radiation levels at the end of HL-LHC (4000 fb^{-1}):
Fluence : 1.7-2.0 10^{14} n_{eq}/cm^2, dose 18-25 kGy , varying with η.

LYSO: fast (60 ps rise, 40 ns decay) and bright (40000 ph/MeV)
Proven to be enough radiation hard.

SiPM:
Operating a -30 °C helps in reducing the DCR. Still expected O (1-5 GHz/mm^2) DCR by the end of HL-LHC

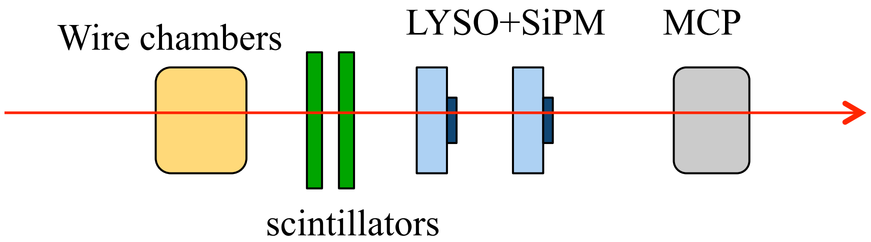
SiPM size smaller than LYSO tile to reduce DCR and the power consumption due to dark current: 4x4 mm^2 SiPM over 11x11mm^2 tiles



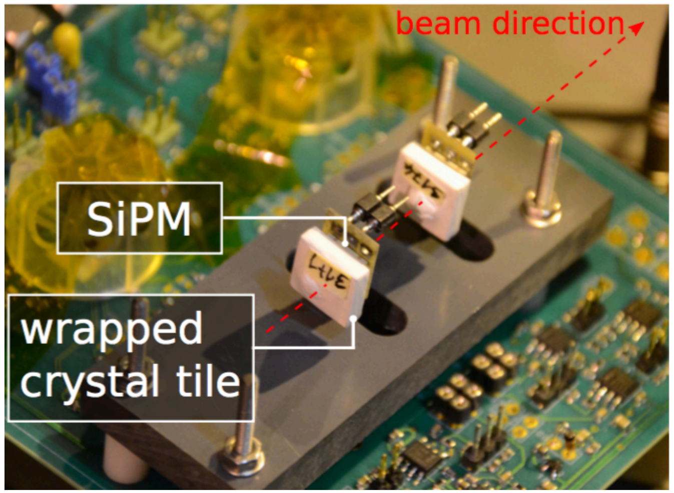


Test beam setup

Testing **single sensor** with geometry *close to the final one*



MCP : reference timing with $\sigma \sim 15$ ps



SiPM signal discriminated with a dedicated ASIC (NINO) (timestamp from a leading edge discriminator)

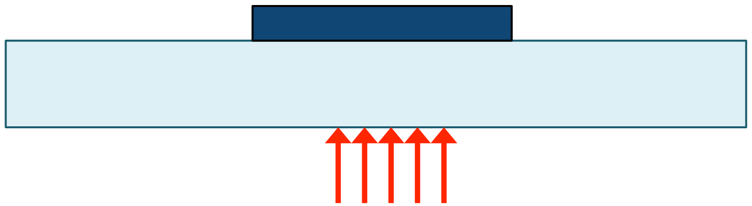
Readout with a CAEN-V1472 digitizer (5Gsamples/s)

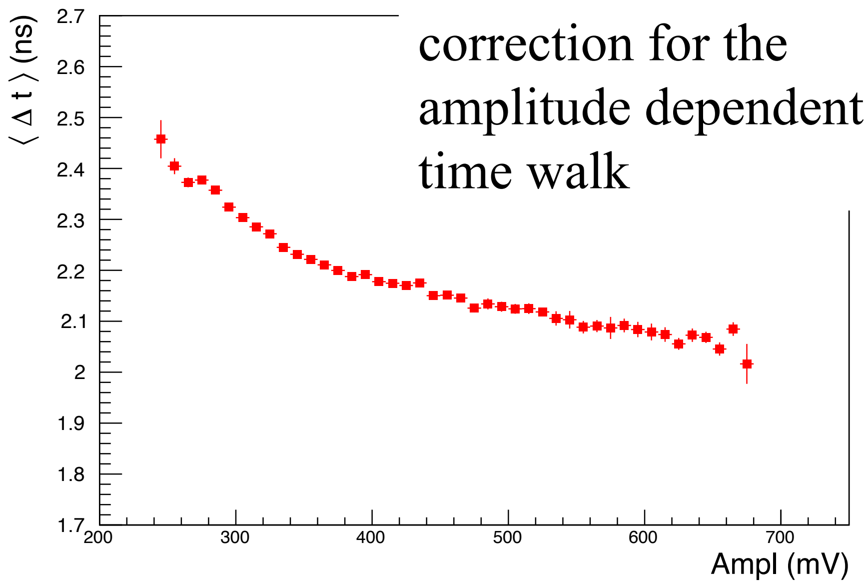
Timing resolution comparing the two sensors or w.r.t. the MCP

SiPM from different producers and with different active area and PDE tested

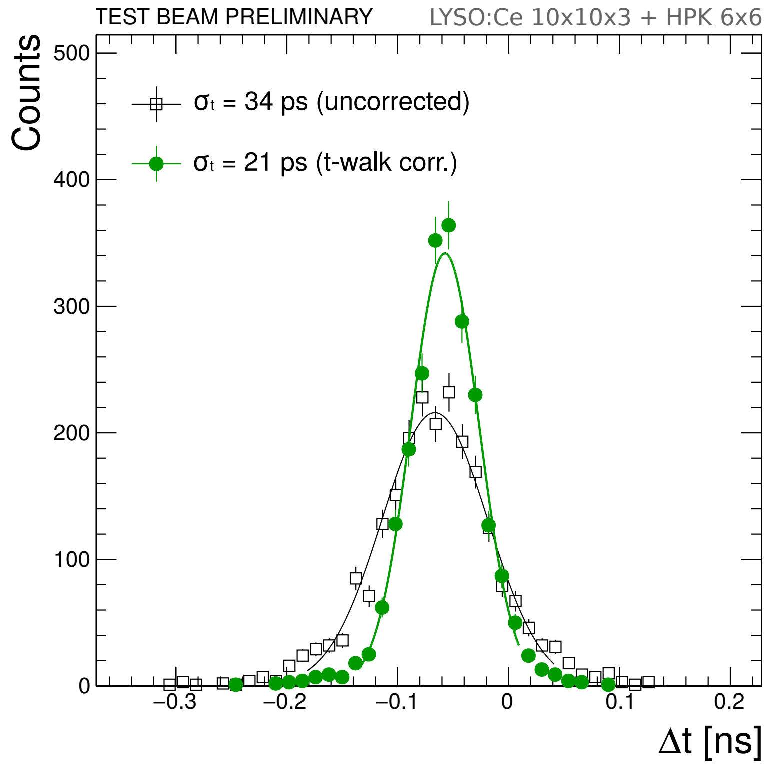
Time resolution

Selecting particles impacting on a $3x3\ mm^2$ spot in the center of the tile





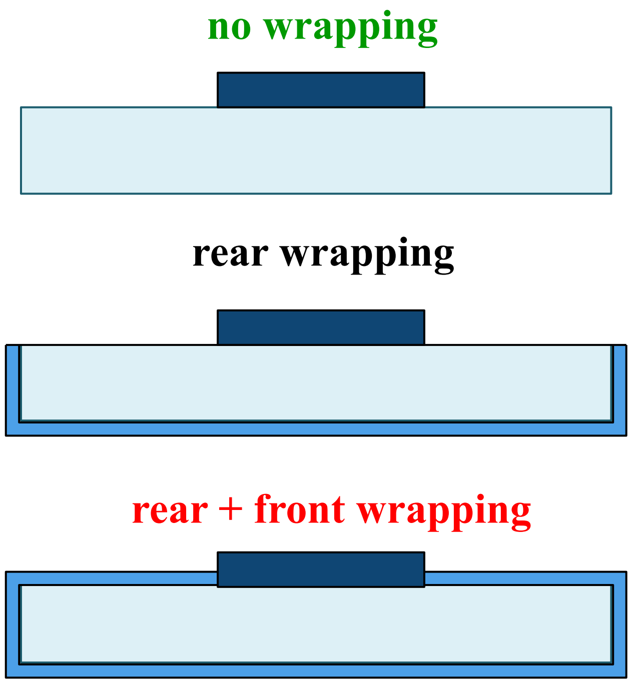
correction for the amplitude dependent time walk

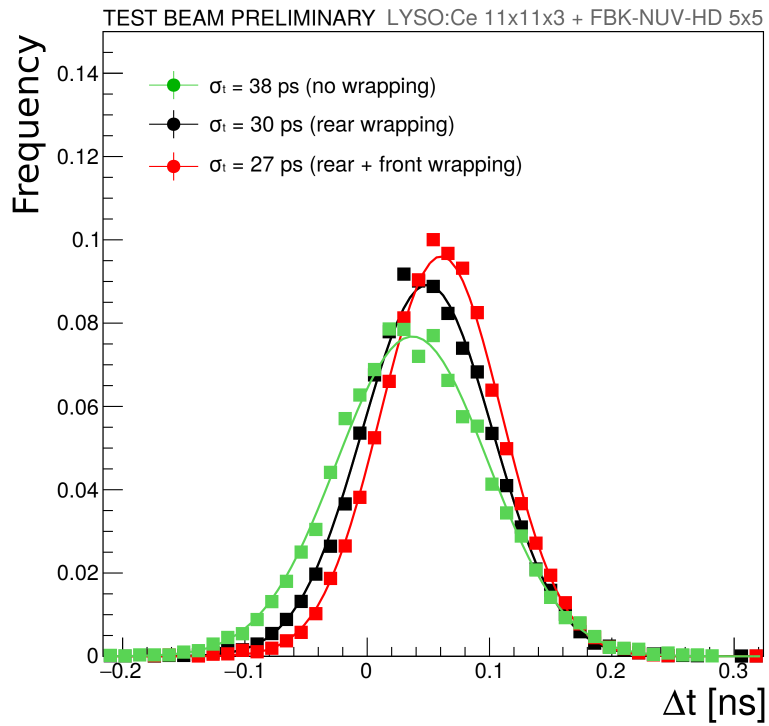


$\sigma \sim 20$ ps with a $6x6\ mm^2$ SiPM on a $10x10\ mm^2$ tile after time walk correction

Time resolution

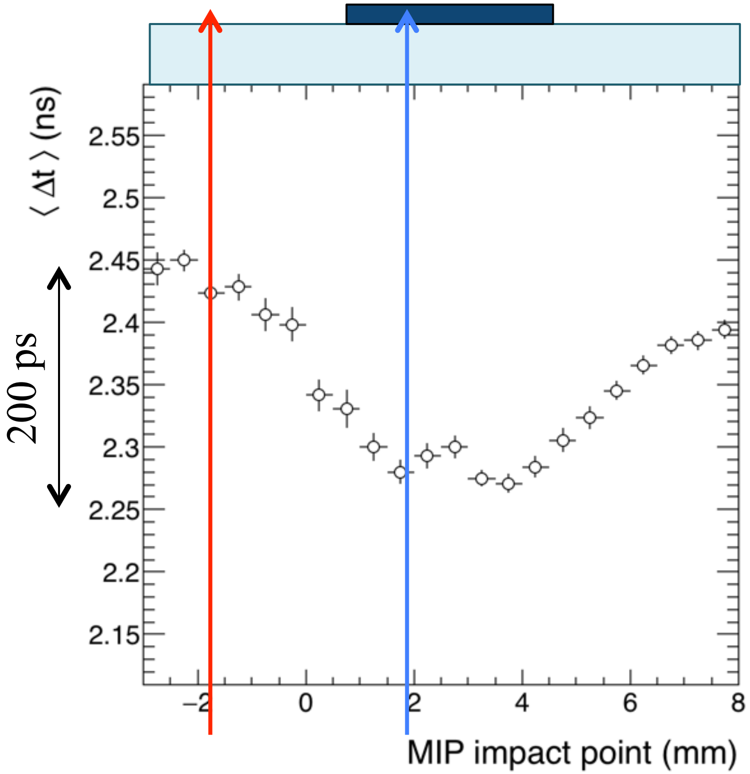
Test of different wrapping conditions (teflon) to improve the light collection and the timing resolution

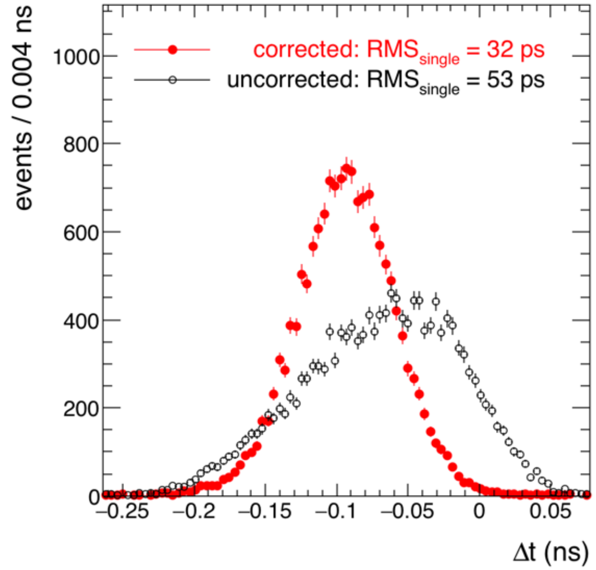




Significant improvement of LC with wrapping.
Optimize the wrapping configuration and procedure

Time response vs impact position





Similar variation observed also in the G4 simulation

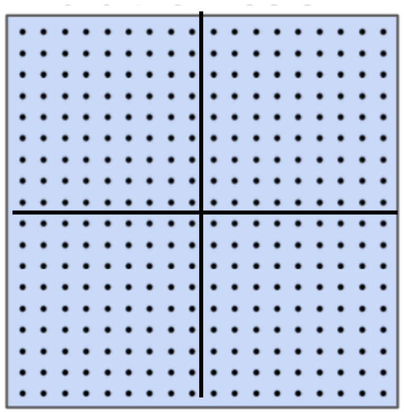
accuracy on the impact point < 1mm needed for an effective correction

After correction σ close to the one for central impinging particles

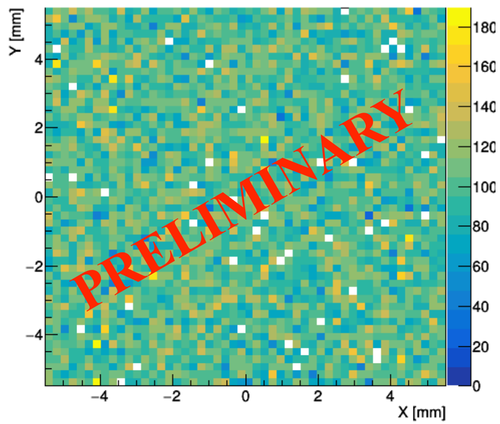
Difficult to achieve the required resolution on the impact point in the detector for large η and low p_T tracks

Mitigating the position dependency : LASC

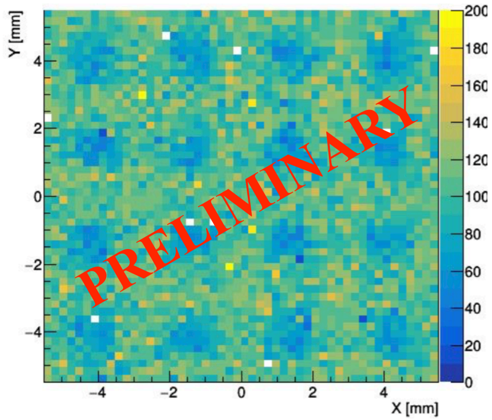
Develop a more uniform coverage of the tile surface with the same SiPM active area to reduced position dependence.
Use either a grid of 16 1x1 mm2 SiPM, or a Large-Area-Sparse-Cell SiPM with the active cells sparse all over the the tile surface
Needs to determine the light collection efficiency



Simulation



Simulation

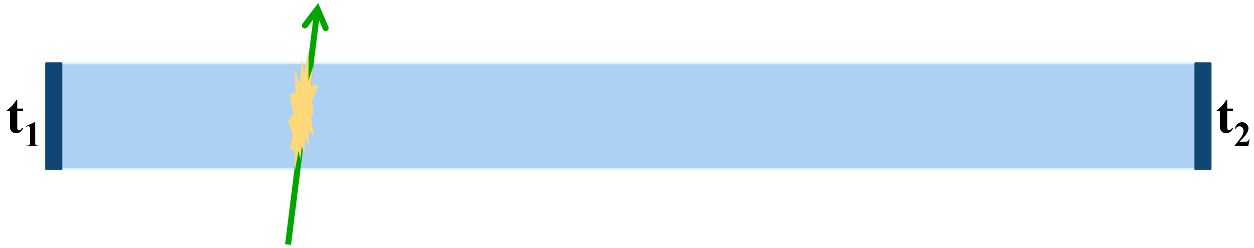


Technical design defined with producers for prototypes with different pitches and cell sizes, also tailoring the technology to improve the radiation tolerance

Delivery of the first samples expected in summer

Mitigating the position dependency : crystal bars

Using elongated crystals 3x3x50 mm^3, readout by 3x3 mm^2 SiPM at the two ends

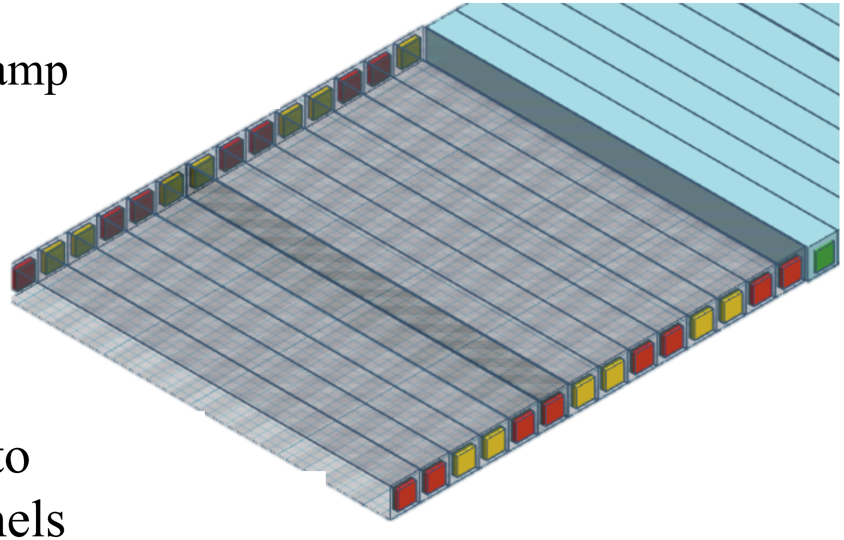


Same overall crystal volume and SiPM surface

Impact position along the bar from the time difference at the two ends $\Delta t = t_1 - t_2$.
Timestamp of the track from the average timestamp $t_{av} = (t_1+t_2) / 2$

Expected small dependency of t_{av} from the impact point along the bar.

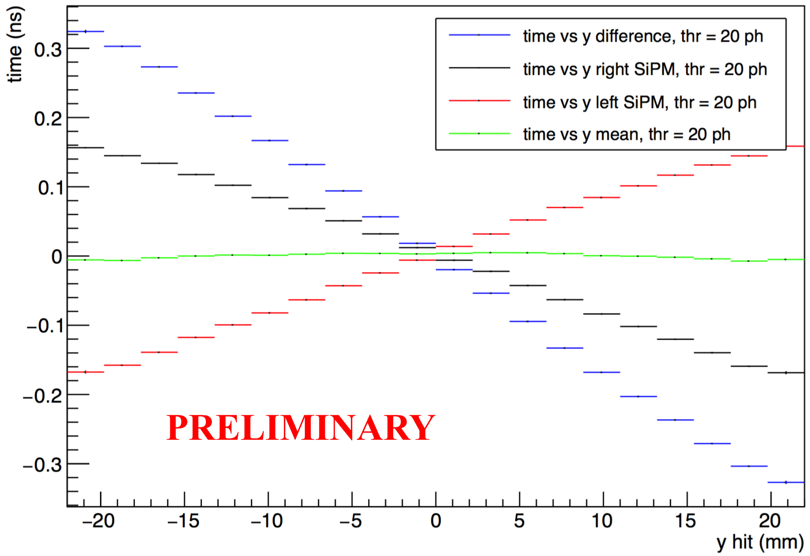
Staggered pairing of SiPMs at the two end to maintain the same number of readout channels

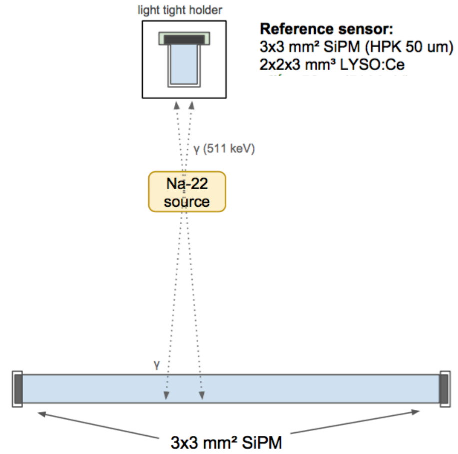


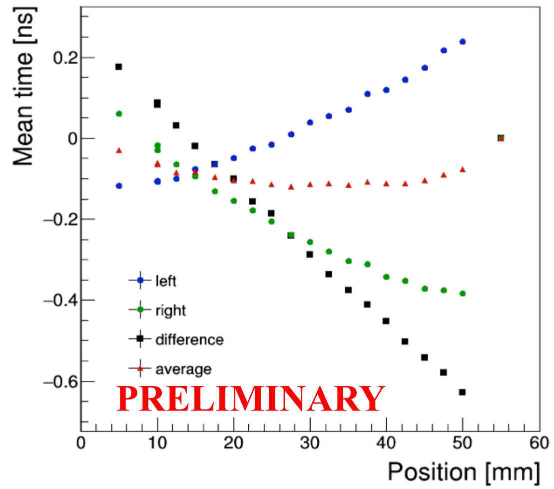
Mitigating the position dependency : crystal bars

Preliminary results from a G4 simulation and measurements with a Na^{22} source support the feasibility of the method.

G4 simulation with π







Measurement of the performances with MIPs in a test beam is needed

Summary

The effective pile-up of the HL-LHC can be kept to the present running condition if single tracks are time tagged with a ~30 ps accuracy

CMS is developing a TDR for a detector dedicated to the measurements of the tracks timing with such an accuracy

This represents an extreme challenge considering the large surface to be covered, the harsh radiation environment of HL-LHC, the sustainability, the requirements of compatibility with the planned upgrade of the CMS detector, in terms of schedule, mechanics, powers consumption, data volume

Two different technologies has been identified for the barrel and the endcaps

Summary

For the barrel the chosen technology consists of LYSO tiles readout by SiPM

Results from tests with particle beams on single sensors with close-to-final geometry suggests that the technology can meet the requirements.

Further optimization of the scintillator, the light collection, the radiation hardness and the readout electronics are under study.

A timestamp dependency on the impact position (with an overall variation of ~200 ps) has been observed in test with the initially proposed geometry.

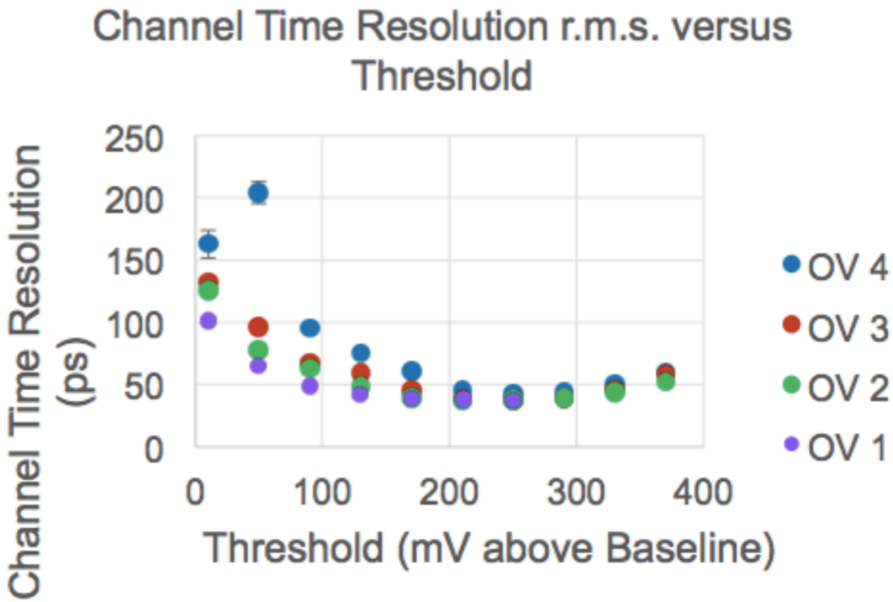
Two possible solutions to mitigate it have been identified, LASC SiPM or crystal bars geometry, and will be scrutinized in details in the next months

Backup

TOFHiR ASIC

Development for the BTL of a new ASIC, TOFHIR, based on the TOFPET ASIC

TOFPET2 readout of BTL-like sensor tested with particle beam



Optimal resolution of ~37 ps, expected to reach ~25 ps (obtained with the NINO) in TOFHiR with modifications to the TDC and tailoring of the slew rate.