PM2018 – 14-th Pisa Meeting on advanced detectors

Low Gain Avalanche Diodes for Precision Timing in the CMS Endcap

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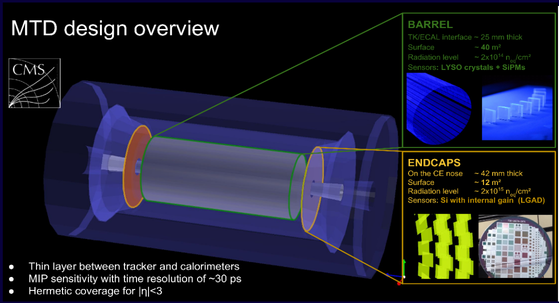
On Behalf of CMS Collaboration

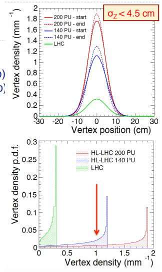
CMS PHASE-2 hermetic MIP Timing Detector



Motivation

HL-LHC: upgrade of LHC and injectors

- Baseline: $L_{inst} = 5.0\times10^{34}$ cm^{-2} s^{-1} (140 pileup)
- Ultimate: $L_{inst} = 7.5\times10^{34}$ cm^{-2} s^{-1} (200 pileup)

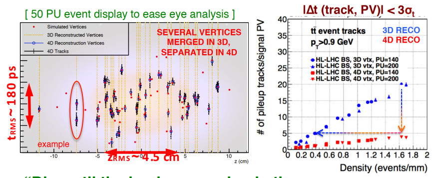


Selection(*): |Δz(track, PV)| < 1 mm

- Optimized for track-PV association
- Substantial pileup contamination at vertex densities > 1 event/mm

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**

Recover LHC (40 PU) track purity of vertices

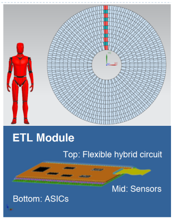
CMS Endcap Timing Layer (ETL)

Endcap Timing Layer - ETL

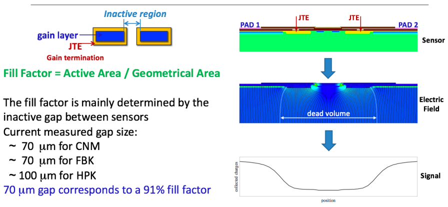
Low gain silicon detectors (LGADs) on HGCAL nose
- Coverage: **1.5 < |η| < 3.0**

Double disk structure
- Similar to Tracker TEDD
- Al wedges with embedded cooling Pipes (CO_2 at -30 °C)

Single layer hermetic coverage
- Sensors on both disk sides
- 3-5% occupancy



Fill Factor Status



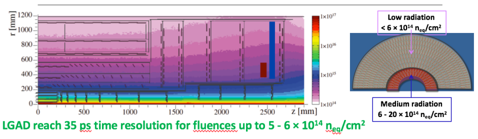
Fill Factor = Active Area / Geometrical Area

The fill factor is mainly determined by the inactive gap between sensors

Current measured gap size:
- ~ 70 µm for CNM
- ~ 70 µm for FBK
- ~ 100 µm for HPK

70 µm gap corresponds to a 91% fill factor

Expected Radiation for ETL Life Time



LGAD reach 35 ps time resolution for fluences up to 5 - 6 × 10^{14} n_{eq}/cm^2

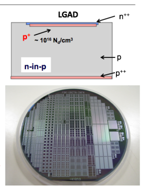
Low radiation: radius 50 - 130 cm → 4.8 m^2, ~ 90%
Medium radiation: radius 30 - 50 cm → 0.5 m^2, ~ 10%

- Higher Bias values can compensate for the gain reduction
- Carbon doped gain layer mitigates the B deactivation inside the gain layer

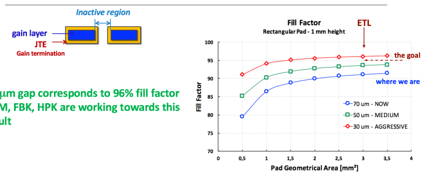
Sensor State of the Art

R&D ITALIA: Sensor development (To, Ge)

- LGAD operated with gain $O(10)$ for sufficient S/N
- Small pixel area to cope with the high occupancy at high h values
- High radiation tolerance up to ~ $3\cdot10^{15}$ n_{eq}/cm^2
- LGAD are routinely produced by 3 vendors (CNM, FBK, HPK)
- The time resolution of thin (~ 50 µm) LGAD is 30-35 ps



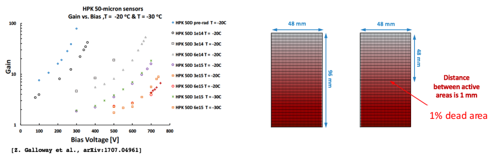
Fill Factor Plans



→ 30 µm gap corresponds to 96% fill factor CNM, FBK, HPK are working towards this result

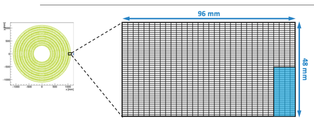
Radiation Effects on Boron-Doped LGAD

- Irradiation decreases the gain layer active doping → less gain
- Increase bias to compensate gain loss → recover good time resolution



- Splitting the sensors mitigates the gain reduction due to irradiation but reduces the fill factor

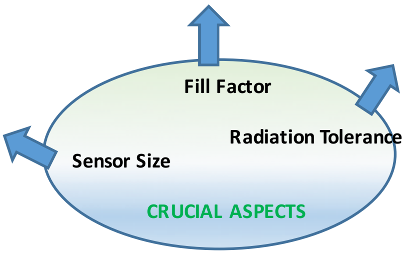
Sensor Strategy



- The 3 vendors plan to produce first demonstrator of large area LGAD sensors in 2018

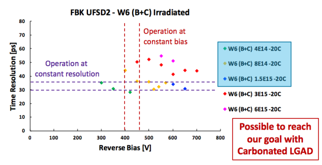
1/16 of the full ETL sensor
→ 1 read-out chip size

Final Goal:
- Production system of 2624 sensors → **1400 6-inch wafers**
- Each sensor is **48x96 mm²** with **1536 pads**,
- Each pad is **1x3 mm²**



Time Resolution with Carbon

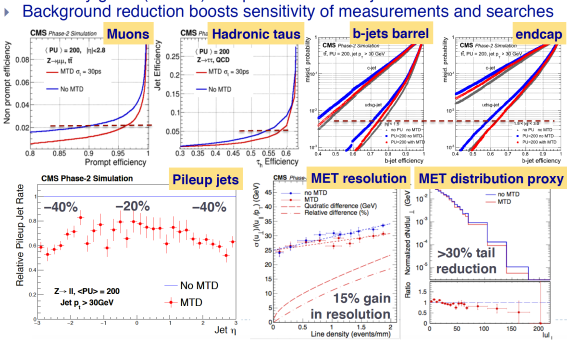
CMS goal for silicon Endcap Timing Layer
Time resolution between 30-35 ps unchanged till 4000 fb^{-1} - 1E15 n_{eq}/cm^2



Timing Detector expected performances

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



Physics Impact

Higgs boson physics / Searches

Signal	Detector requirement	Analysis impact	Physics impact
$H\rightarrow\gamma\gamma$	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+ $H\rightarrow\tau\tau$	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
$\chi^{\pm}\chi^{0}\rightarrow W^{\pm}H+p_T^{miss}$	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

- **MTD: improves the full range of Phase-2 physics**