The High-Granularity Calorimeter HGCal for CMS Phase II Upgrade

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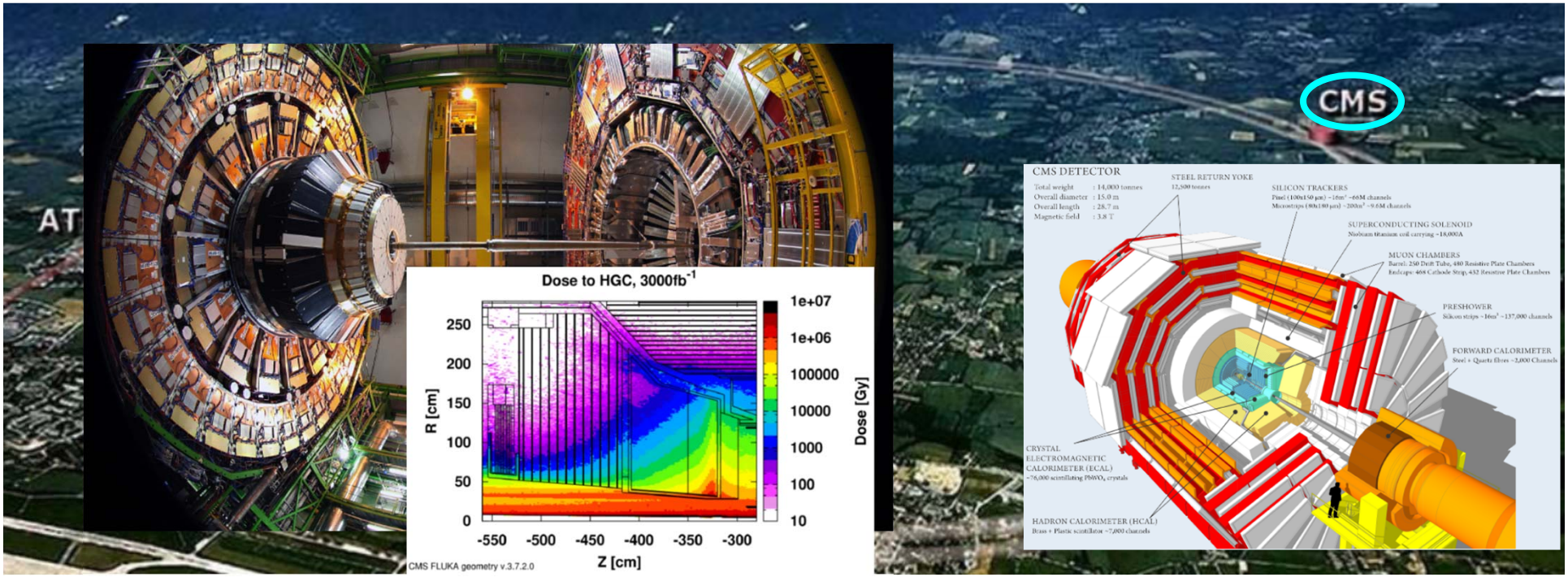
Updated for 170524 PPE all group meeting (Edinburgh)

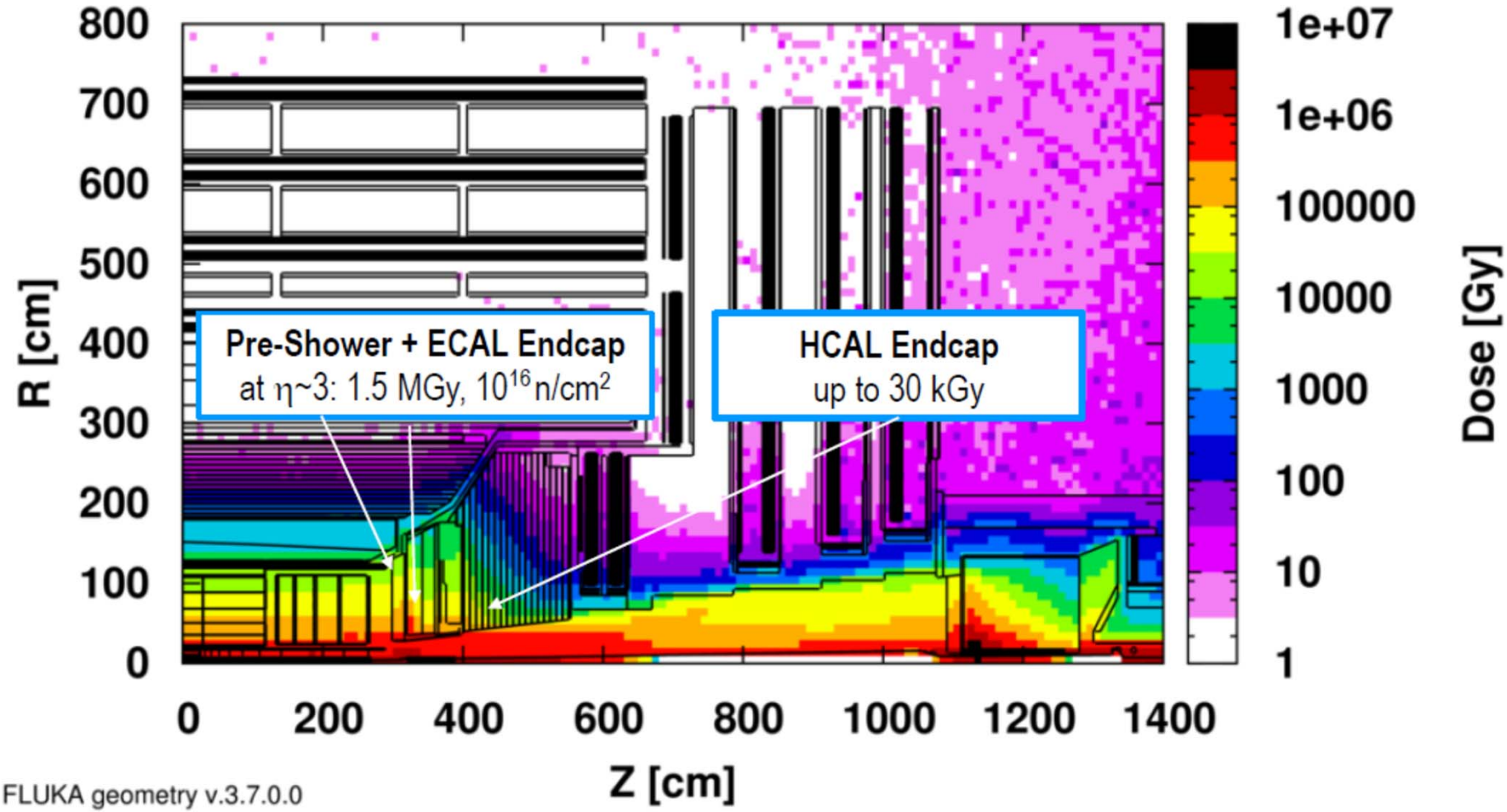
17 Jan @ AFAD 2017, IMP, Lanzhou, China



Current CMS Endcap Calorimeters: Up to 500 fb^{-1}

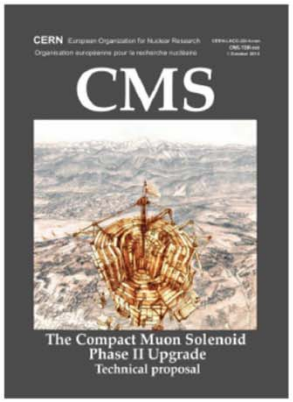
Preshower: 2xPb/Si (cold); ECAL: $PbWO_4$ (warm); HCAL: Brass/Scintillator

3000 fb-1 Absolute Dose map in [Gy] simulated with MARS and FLUKA



CMS FLUKA geometry v.3.7.0.0

Compounding Challenge: Pile-Up (PU)



Technical Proposal
CERN-LHCC-2015-010

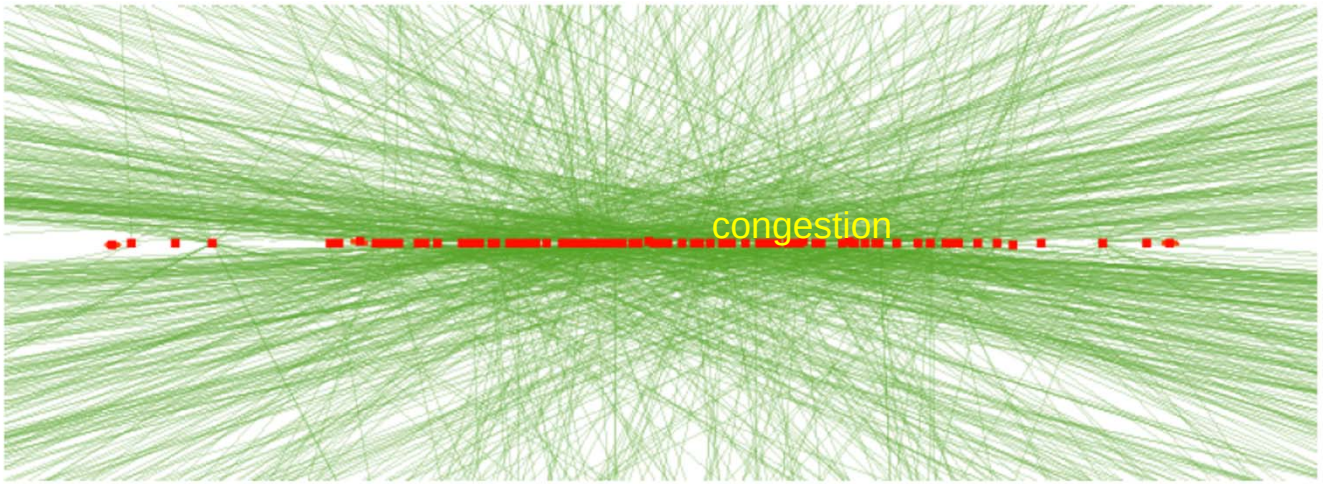


Figure 9.1: An event display showing reconstructed tracks and vertices of a simulated top-pair event with additional 140 interactions overlaid for the Phase-II detector.

HL-LHC: ⟨PU⟩ = 140 Interactions per bunch crossing (every 25 ns)
Up to 200 (for 7×10^{34} cm^{-2}s^{-1}) + out-of-time

Challenges for L1 Trigger, Reconstruction (Particle Flow) & Computing

e.g. VBF/VBS; HH(→ γγ) ... Endcap Calo Important [*future trend*]

Maintain/Improve current performance in *much harsher* environment

→ High Granularity "Imaging" (Particle Flow) Endcap Calorimeter

HGCal for CMS Phase II Upgrade

I. CMS Phase II Endcap Calorimetry

Radiation / Pile-Up ➔ **H**igh **G**ranularity **Cal**orimeter

II. Sensor and Front End Electronics

Sensor; ASIC challenge: SKIROC2 to SKIROC2_CMS

III. Beam Tests and Timing Tests

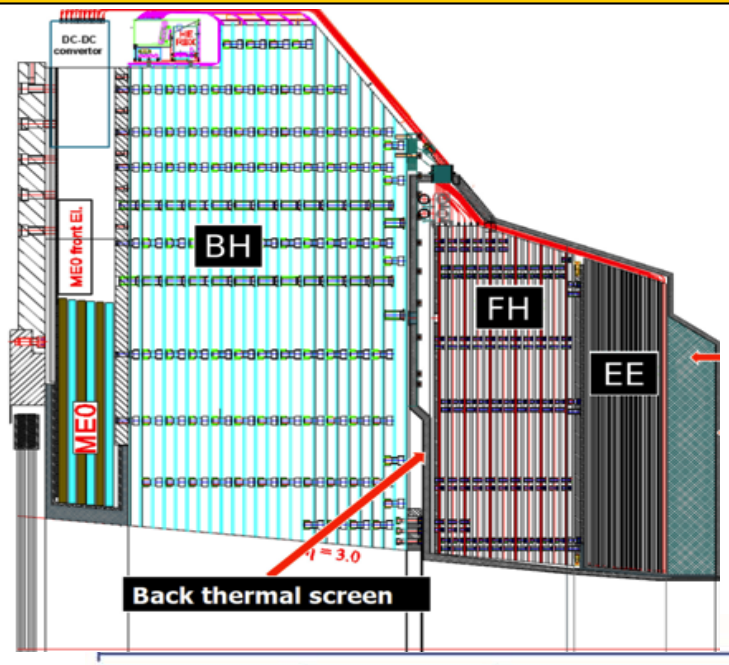
FNAL and CERN Beam Tests; Timing and Layer Tests

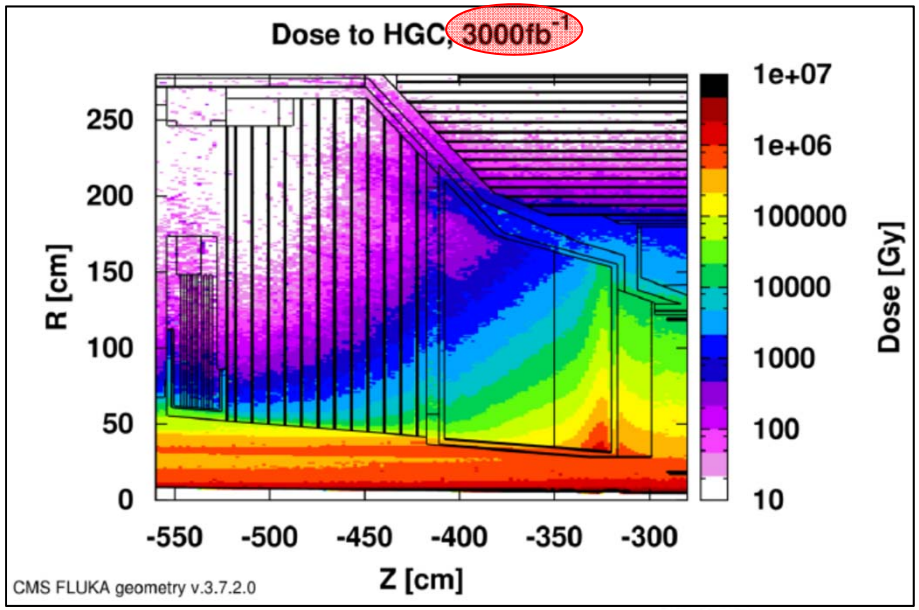
IV. Towards TDR ~ Nov. 2017

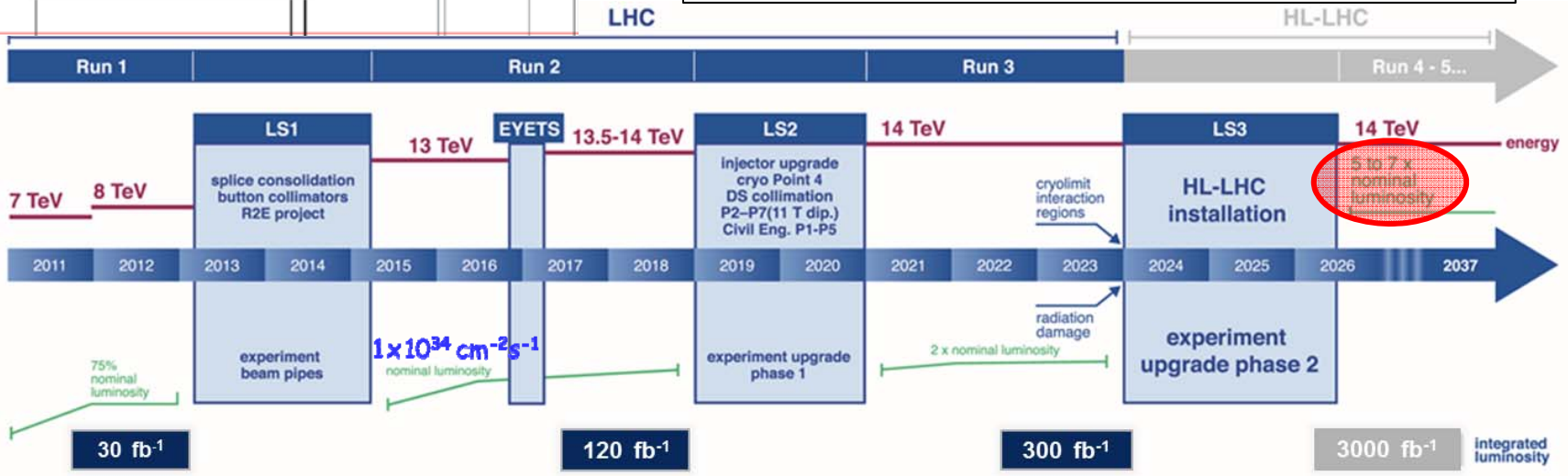
Beam Tests for Full System Performance

V. Summary

I. CMS Phase II Endcap Calorimeter: HGCal

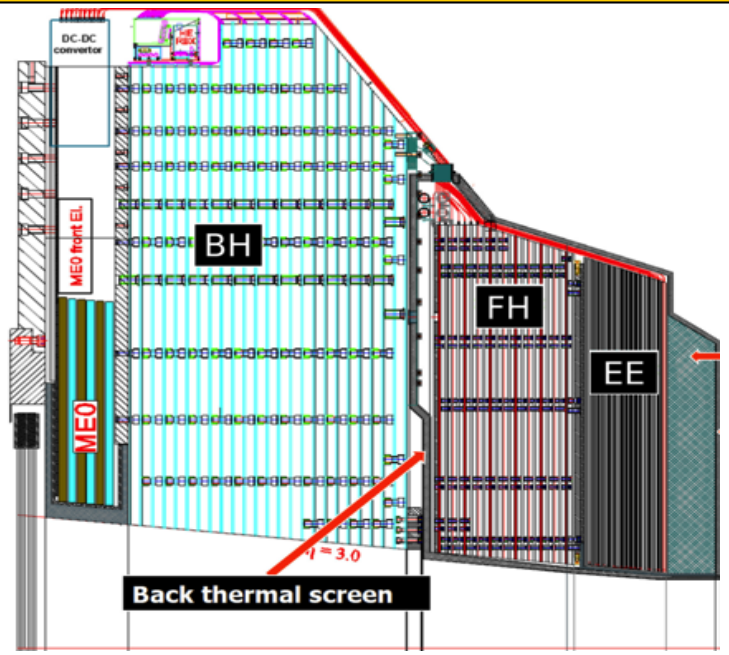






Phase I ⇒ Phase II ⇒

HGCal in a nutshell



Construction:
- Hexagonal Si/absorber Modules
- Modules on copper cooling plates
  → wedge-shaped Cassettes
- Cassettes integrated into structures
  [decision finalized ~~soon~~]

Key parameters:
- 593 m^2 of silicon
- 6M ch, 0.5 or 1 cm^2 cell-size
- 21,660 modules (8" or 2x6" sensors)
- 92,000 front-end ASICs
- Power at end of life ~ 120 kW

Three separate parts:

EE – Si with W (~~Pb?~~) absorber, 28 sampling layers: 25 X_o, ~1.3 λ
FH – Si with Stainless Steel absorber, 12 sampling layers: ~3.5 λ
BH – Scintillator w/ Stainless Steel absorber, 11 sampling layers: ~ 5.5 λ

> 10 λ

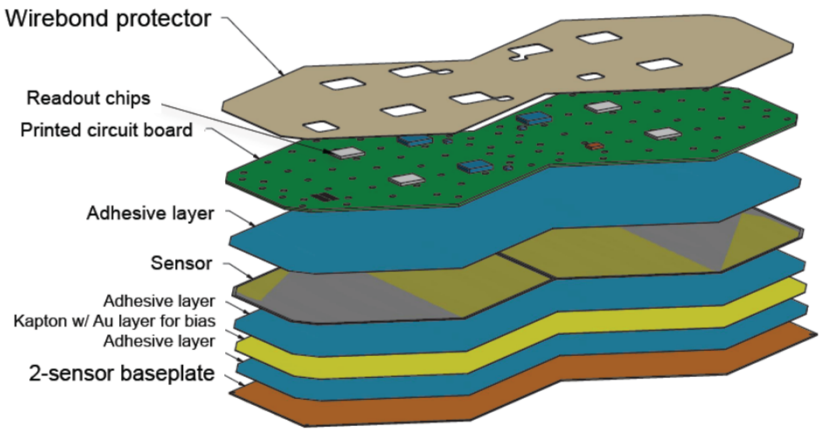
EE and **FH** operate at –30 °C using bi-phase CO_2 to mitigate radiation damage

[All Cold Endcap being considered ~~↔ BH Active Material~~]

Si where needed

HGCal Module, Cassette, Structure

Modules
Si, PCB, F.E. chip, baseplate



Construction:
- Hexagonal Si/absorber Modules
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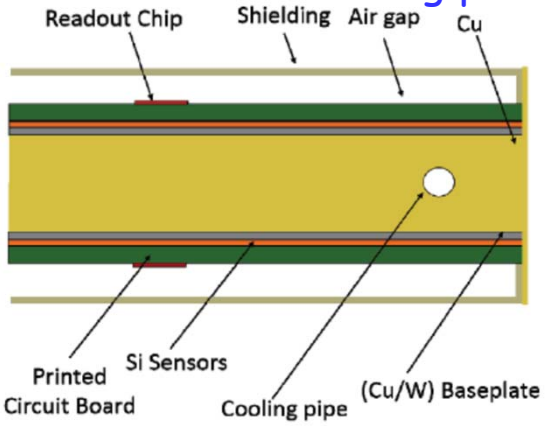
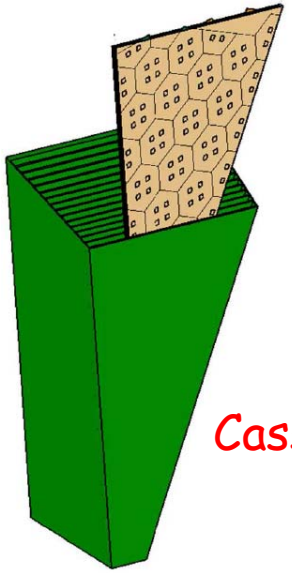
  → wedge-shaped Cassettes
- Cassettes integrated into structures
  [~~decision finalized soon~~]

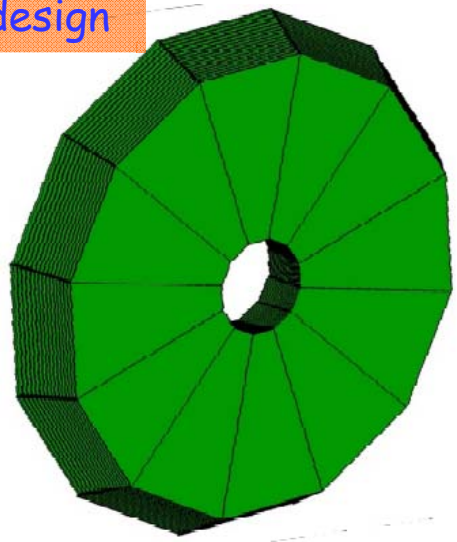
full disk design

Modules on Cu cooling plate





Cassettes

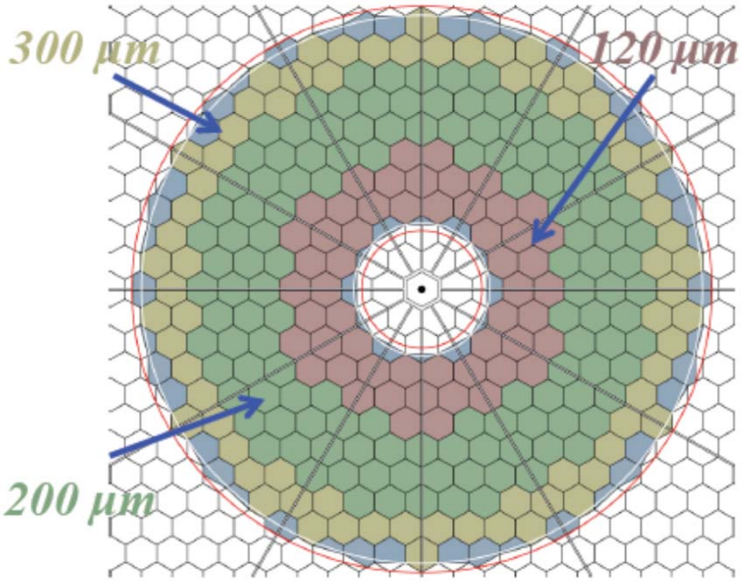


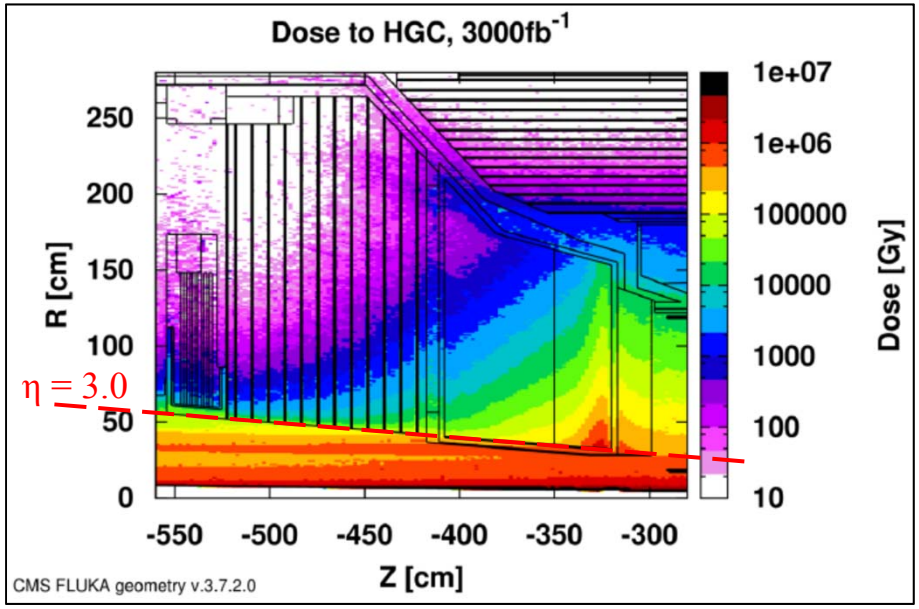
EE

TP: ~~carbon-fiber~~ ~~alveolar~~ structure

[Cassettes as part of structure?]

II. Sensor and F.E. Electronics





To cope with Radiation/PU

- η-dep. depletion depth
- η-dep. cell size

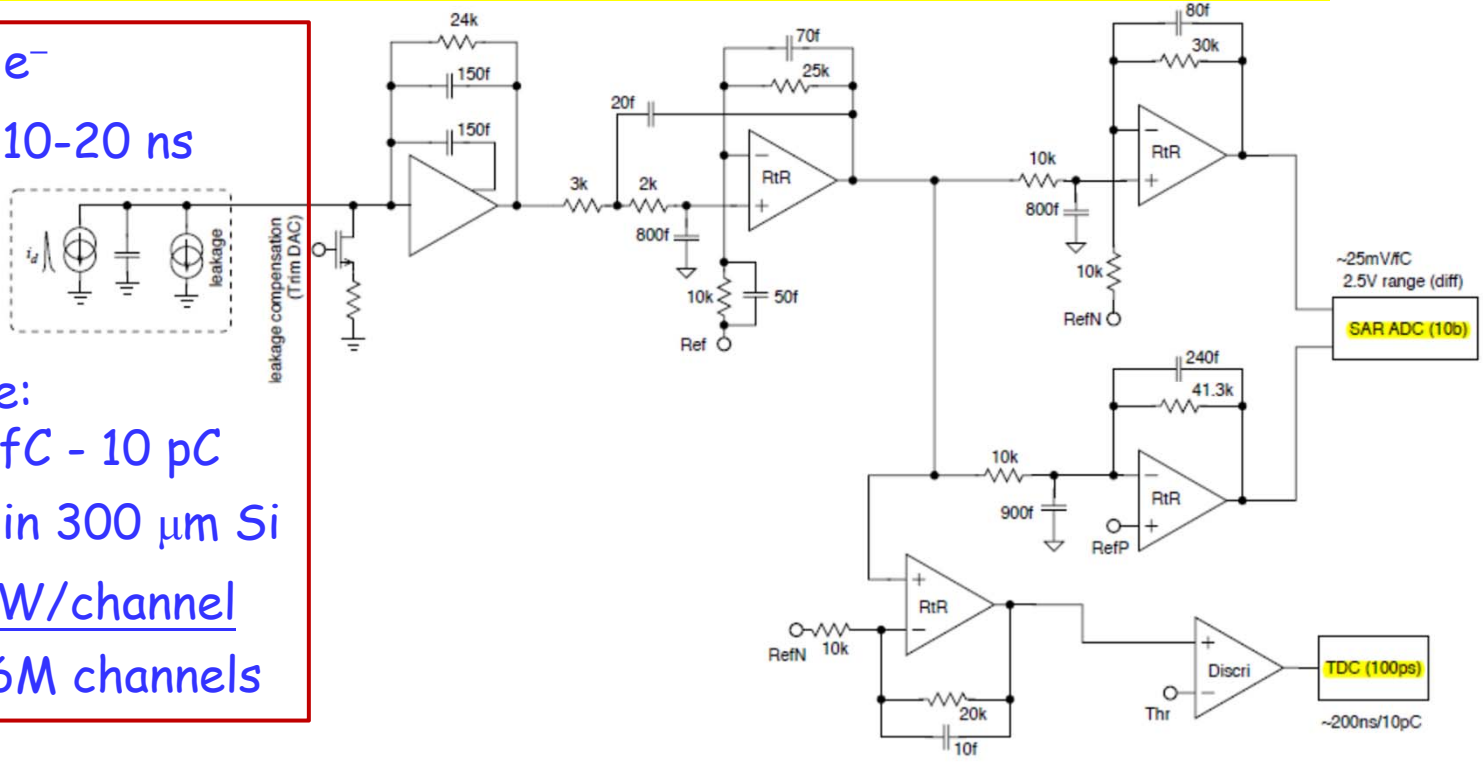
6" **HPK** p-on-n: Test Beam 2016
8" **Infineon/HPK** n-on-p:
being fabricated

Thickness	300 μm	200 μm	100 μm
Maximum dose (Mrad)	3	20	100
Maximum n fluence (cm^{-2})	6×10^{14}	2.5×10^{15}	1×10^{16}
EE region	$R > 120$ cm	$120 > R > 75$ cm	$R < 75$ cm
FH region	$R > 100$ cm	$100 > R > 60$ cm	$R < 60$ cm
Si wafer area (m^2)	290	203	96
Cell size (cm^2)	1.05	1.05	0.53
Cell capacitance (pF)	40	60	60
Initial S/N for MIP	13.7	7.0	3.5
S/N after 3000 fb^{-1}	6.5	2.7	1.7

F.E. ASIC

Challenge: Large Dynamic Range @ Low Power and Low Noise

- Noise ~ 2000 e^-
- Shaping Time 10-20 ns
- Dynamic Range:
  1-100 fC & 50fC - 10 pC
  ~ 3000 MIP in 300 μm Si
- Power: ~ 10 mW/channel
  ~ 100 kW / 6M channels



Baseline:
Charge + Time-over-Threshold (ToT)
- 10-bit ADC, 12-bit TDC:
  Existing/tested design
- 20 ns peaking time

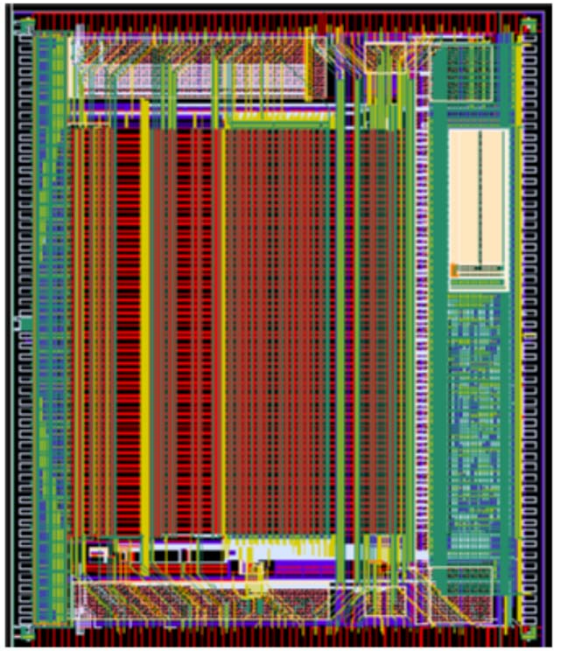
T (μm)	C (pF)	I_d (μA)	N (e^-)
300	40	≈ 0	1600
	40	3.5	1750
200	60	≈ 0	2100
	60	5.2	2250
100	60	≈ 0	2100
	60	10.5	2400

	Power (mW)
Preamp.	2.0
Shaper	1.5
ADC	1.0
TDC	4.0

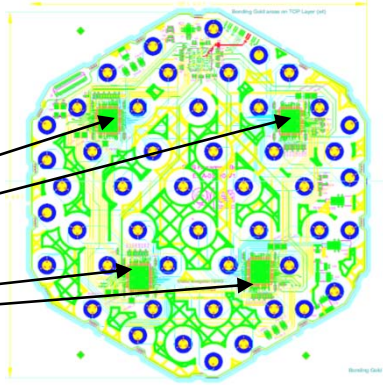
F.E. ASIC: Strategy Forward

Start: CALICE SKIROC2, Beam Test 2016 → SKIROC2_CMS

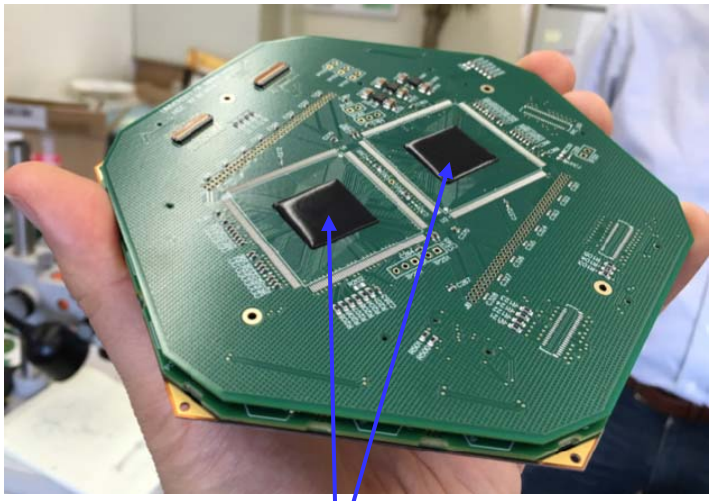
- Modify to include most required functionalities
  - 0.35 μm AMS technology (non rad-hard)
  - 25 ns shaper (instead of 200 ns)
  - 40 MHz sampling ADC (cross calibration)
  - Timing: ToA(rrival), ToT with < 50 ps resolution
  - Received Summer 2016, prelim. results good
    to be used Test Beam 2017
- "Test Vehicles" (TV): TSMC 130 nm
  - TV1 received Sept., prelim. results good
  - TV2 (8-channel) to be submitted
    (ADC + ToT + Trigger sums)
  - submit first 64-channel ASIC by June 2017
- New thin CERN-PCB "Hexaboard"
  Can take 4 SKIROC2_CMS



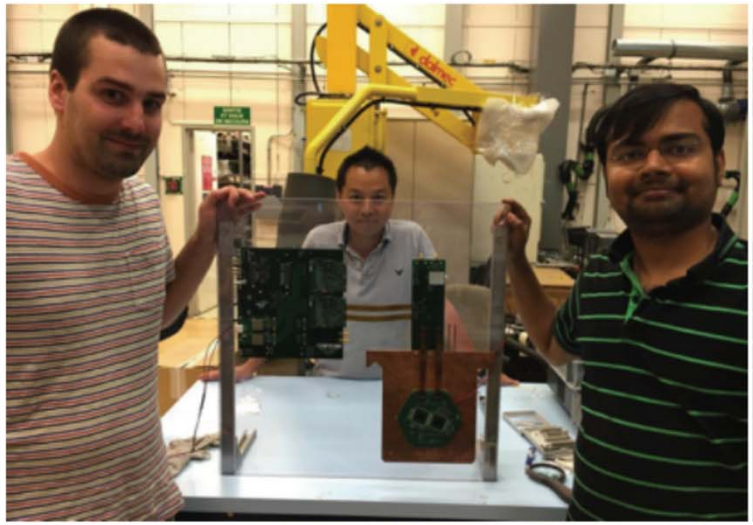
Towards "HGROC"

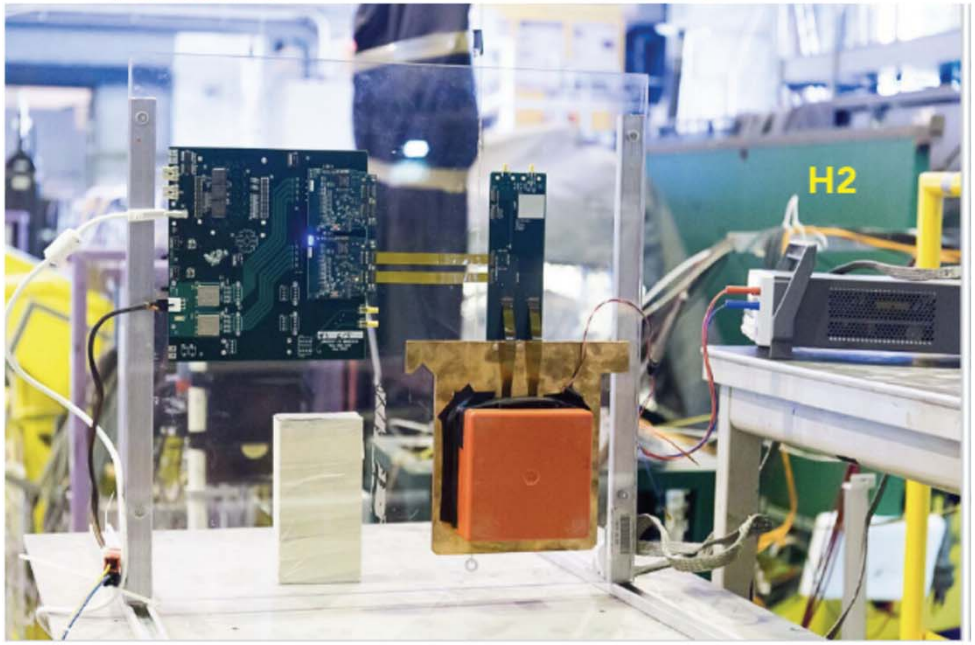


III. Beam Tests and Timing Tests



SKIROC2 designed
by OMEGA lab for ILC, not
the final F.E. ASIC for CMS



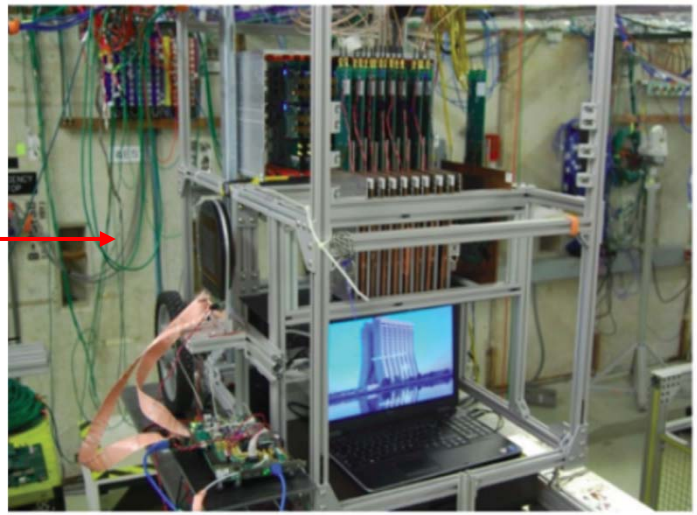


Beam Test: FNAL and CERN in 2016

FNAL

- 15 X_0 with 16 layers
- e^- beam at 4-32 GeV
- p at 120 GeV

Beam

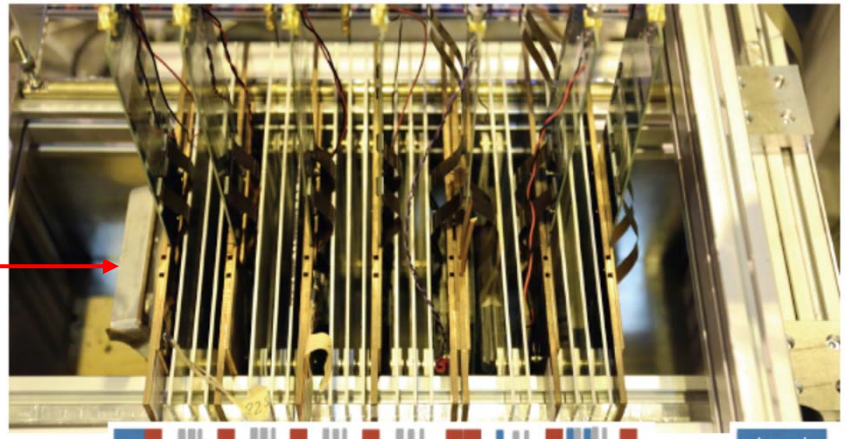


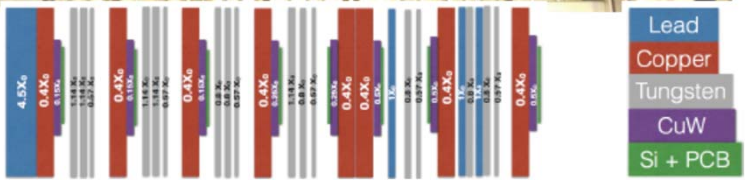
Basic double sided structure repeated eight times

CERN

- up to 27 X_0 with 8 layers
- e^- beam at 25-250 GeV
- π/μ at 125 GeV
- vary # X_0's

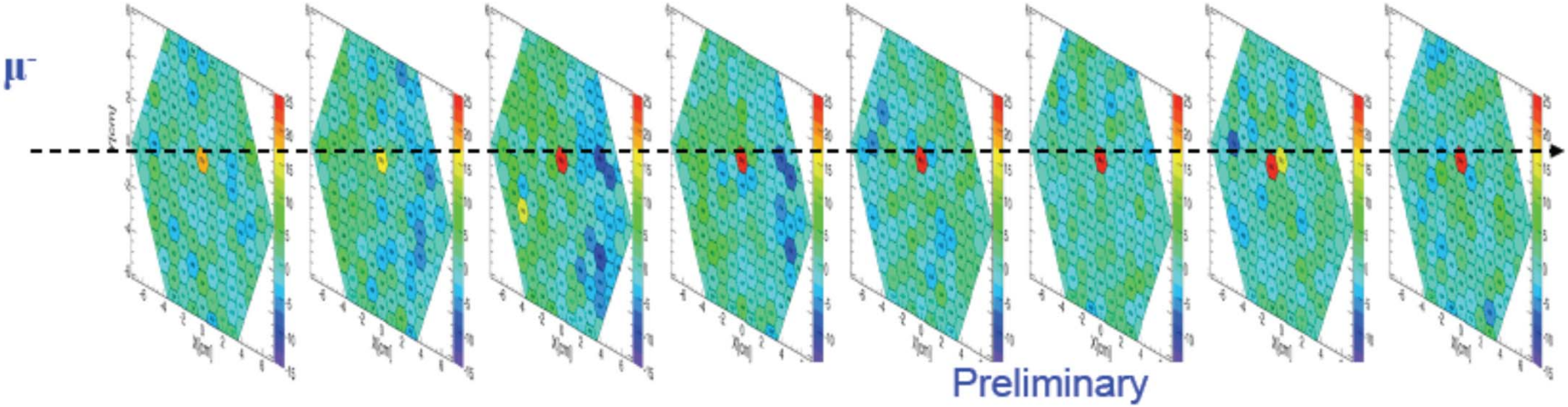
Beam





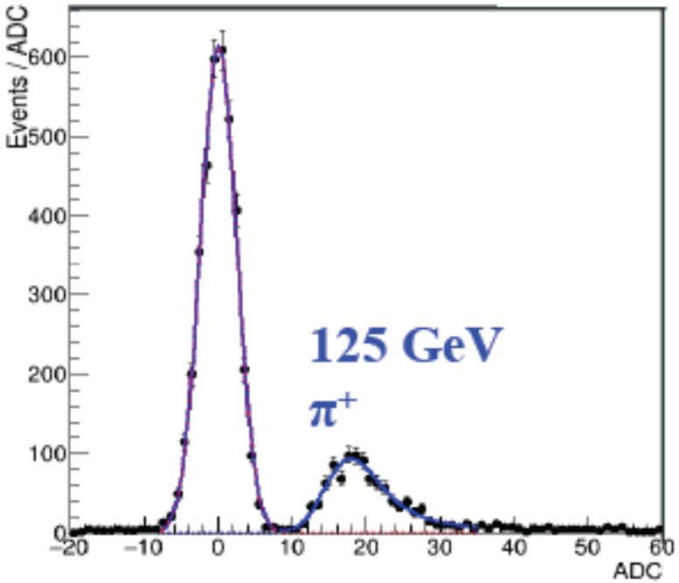
Beam Test: FNAL and CERN in 2016

6″ p-on-n 200 μm



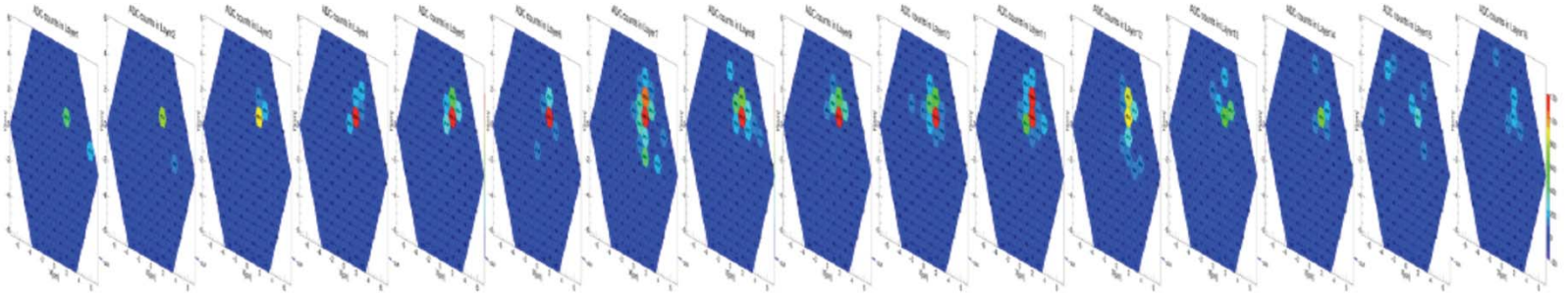
Preliminary

Pedestal noise ~ 2.4 ADC
MIP ~ 17.9 ADC
S/N ~ 7.4



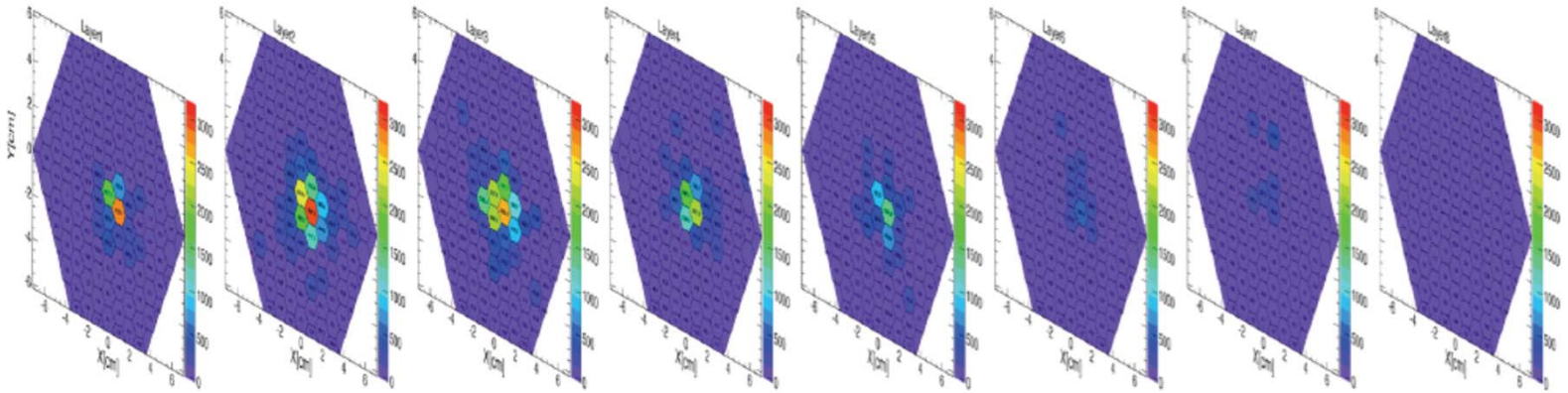
Beam Test: FNAL and CERN in 2016

32 GeV
e^-



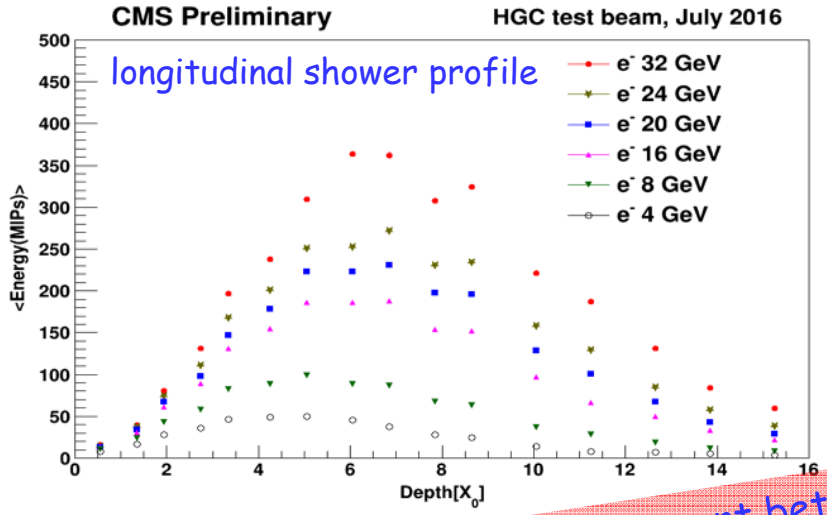
0.6X0 1.4X0 2.0X0 2.8X0 3.4X0 4.3X0 5.1X0 6.1X0 6.9X0 7.9X0 8.7X0 10.1X0 11.3X0 12.7X0 13.9X0 15.3X0

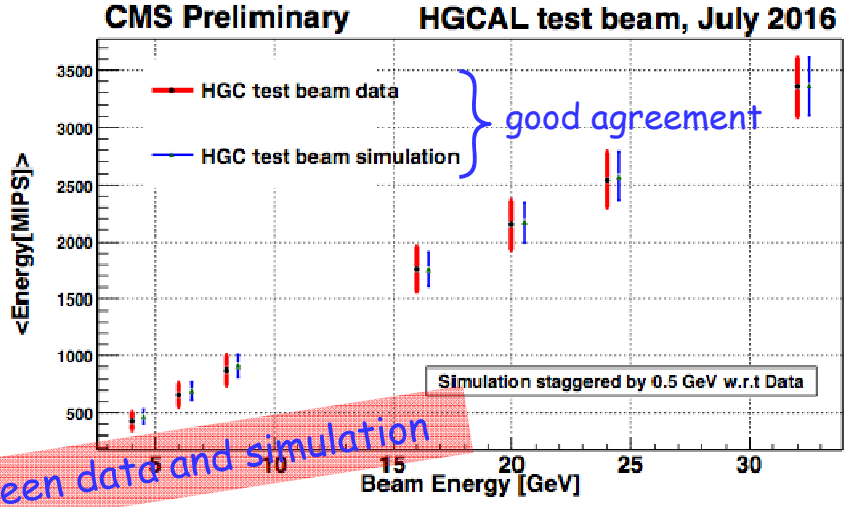
250 GeV
e^-



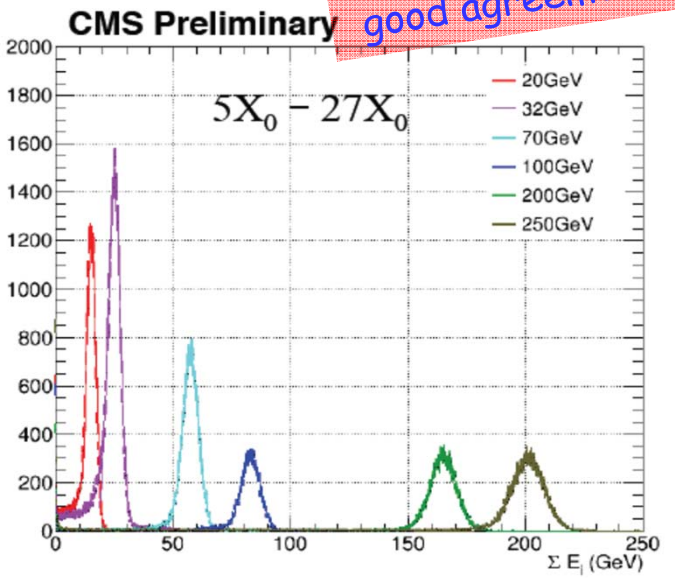
L1 : 5.1X0 L2 : 8.5X0 L3 : 11.9X0 L4 : 14.7X0 L5 : 17.2X0 L6 : 18.7X0 L7 : 21.1X0 L8 : 27.07X0

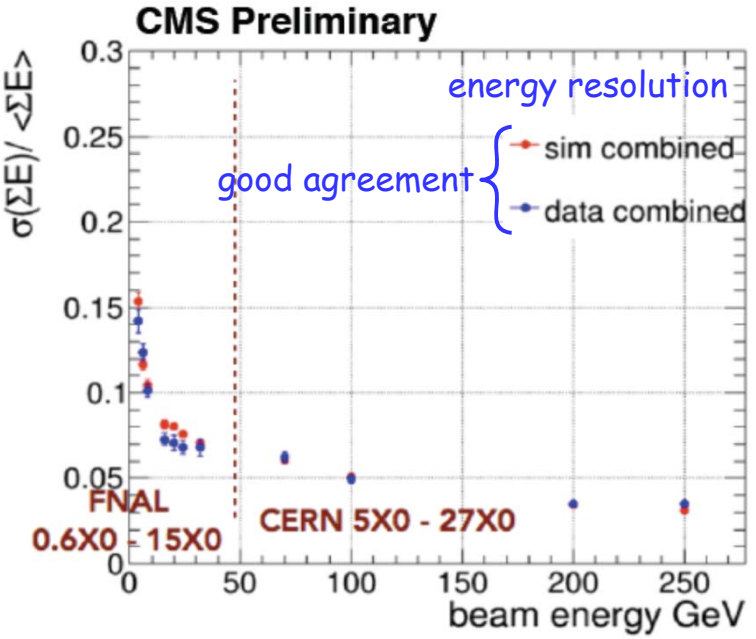
Beam Test: FNAL and CERN in 2016





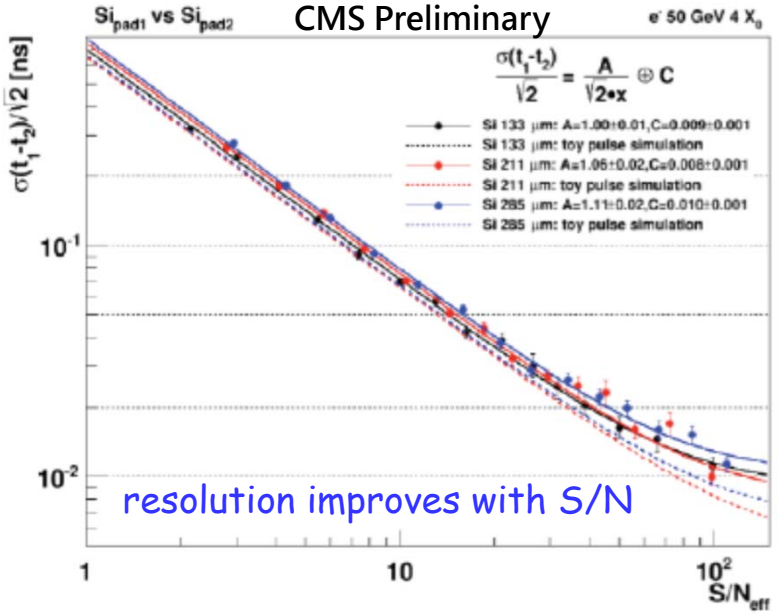
good agreement between data and simulation

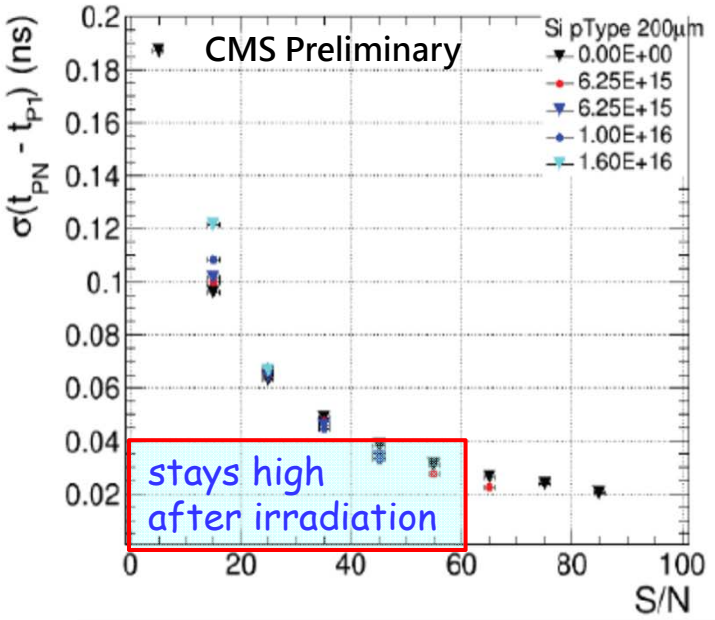


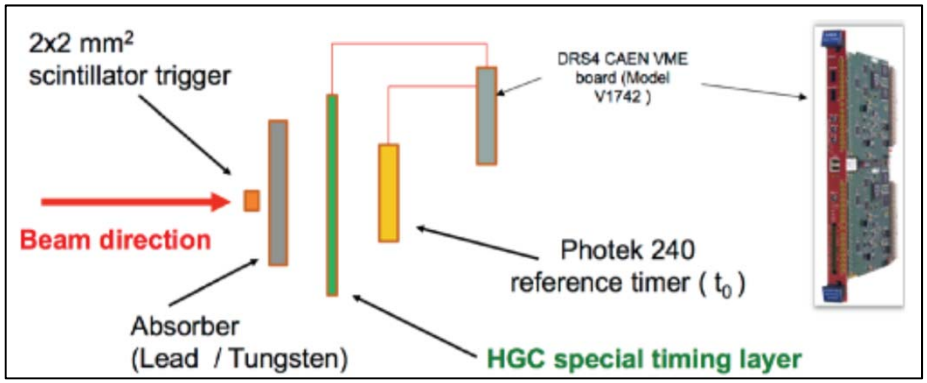


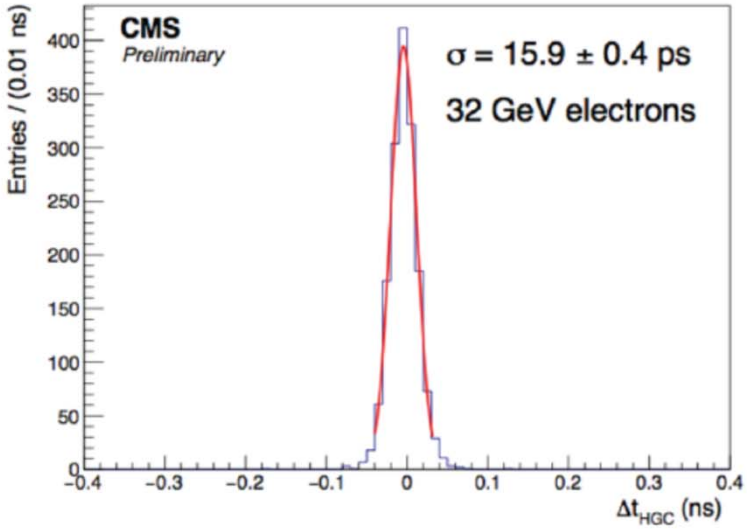
Timing Resolution and Layer Tests

All about PU mitigation …





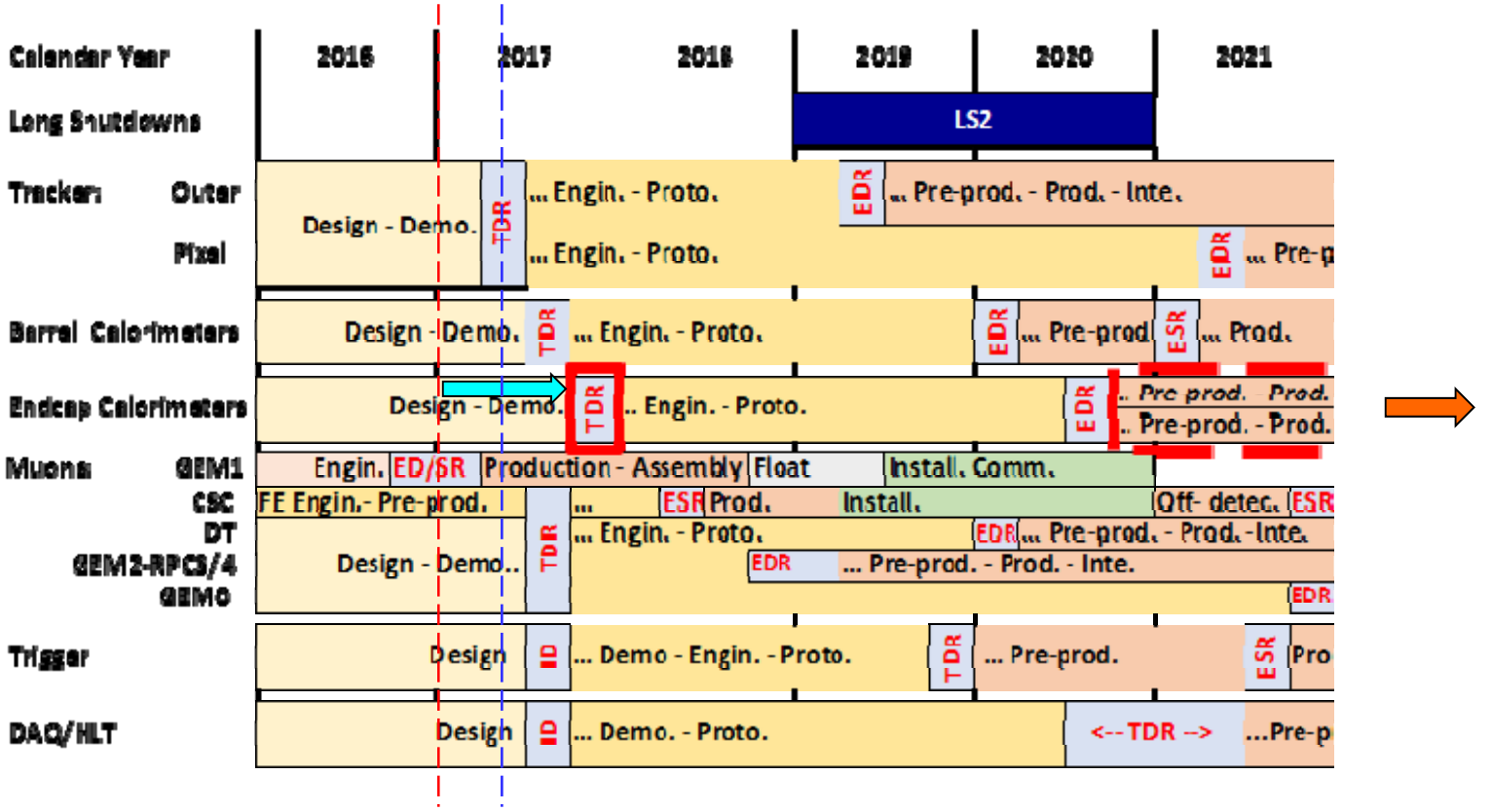




Precision around 16 ps, scale with S/N;
Analysis of 250 GeV data ongoing.

IV. Towards TDR ~ Nov. 2017

TDR in 11/2017! Not that far away ...



Many critical activities ongoing; and, decisions, decisions ...

➔ Validation of overall design in beam tests

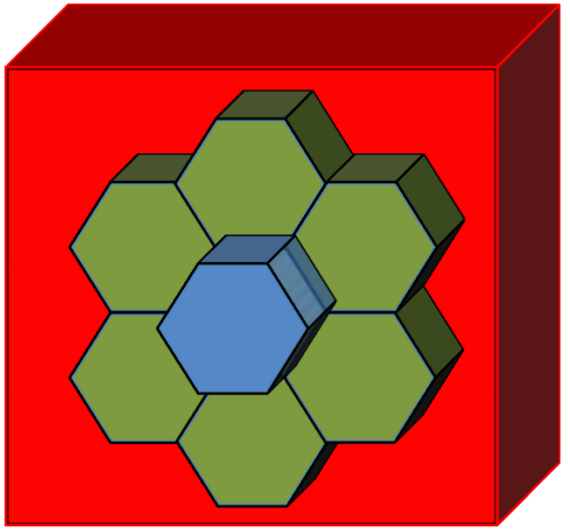
Beam Tests in 2017 towards TDR

EE: ~ 1 λ, 28 layers, 26 X_0,
single 6" Si hex module

FH: ~ 4 λ, 12 layers "daisy" of
7 x 6" Si hex modules

BH: ~ 5 λ, CALICE AHCAL prototype

~ 14000 channels



Prelim. Schedule: *tight!*

- Commission new Modules/DAQ @ FNAL
  March/April
- **EE** performance tests @ CERN ~ May
- → **EE + FH** performance tests @ CERN ~ June
- **EE + FH + BH** perform. tests @ CERN ~ July

w/ SKIROC2_CMS ASIC
→ Full System Perform.
Timing of showers

Need continuous access to FNAL
Potential Stress: Beam Time @ CERN (in short supply!)

V. Summary: HGCal for CMS Phase II

- HGCal, **H**igh **G**ranularity **Cal**orimeter selected in 2015 by CMS to face Radiation / Pile-Up challenges at HL-LHC
  - → Timing precision < **20 ps** (irradiated) for "**imaging**" **Si**-calorimetry
- Rapid progress in R&D, thanks to CALICE (ILC) starting point
- Si-based 40 sampling layers of EE + FH (cold)
  - Mechanical structure fixed ~~soon;~~ BH ~~may~~ also become "cold"
  - 6" or 8" wafers for sensor; evolving to SKIROC2_CMS ASIC "HGROC"
  - Developing Automated Module Assembly (need 21660 + spare)
- Beam Tests for Full System Performance among many critical activities in 2017 towards TDR, due 11/2017 ←

Thank you!