CMS Timing Detectors in Phase-2

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On behalf of the CMS Collaboration

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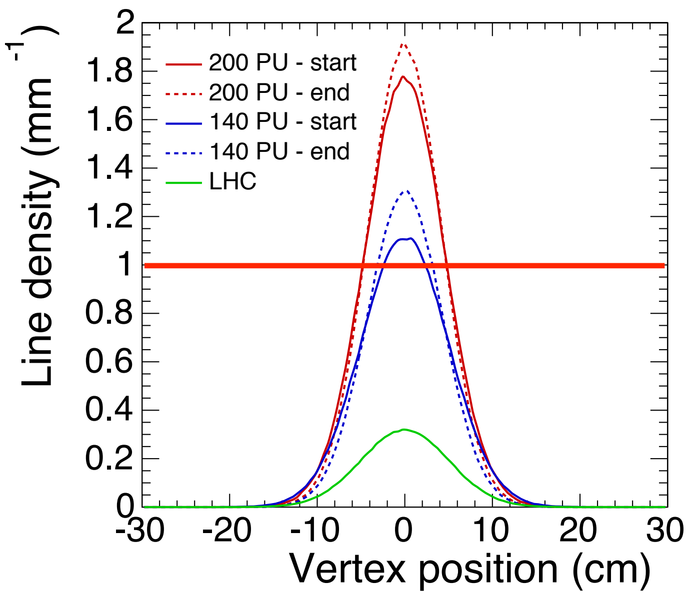
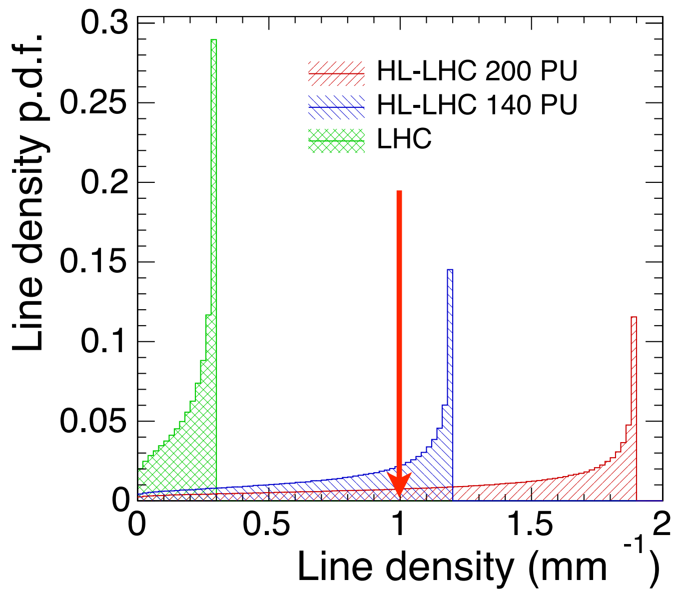
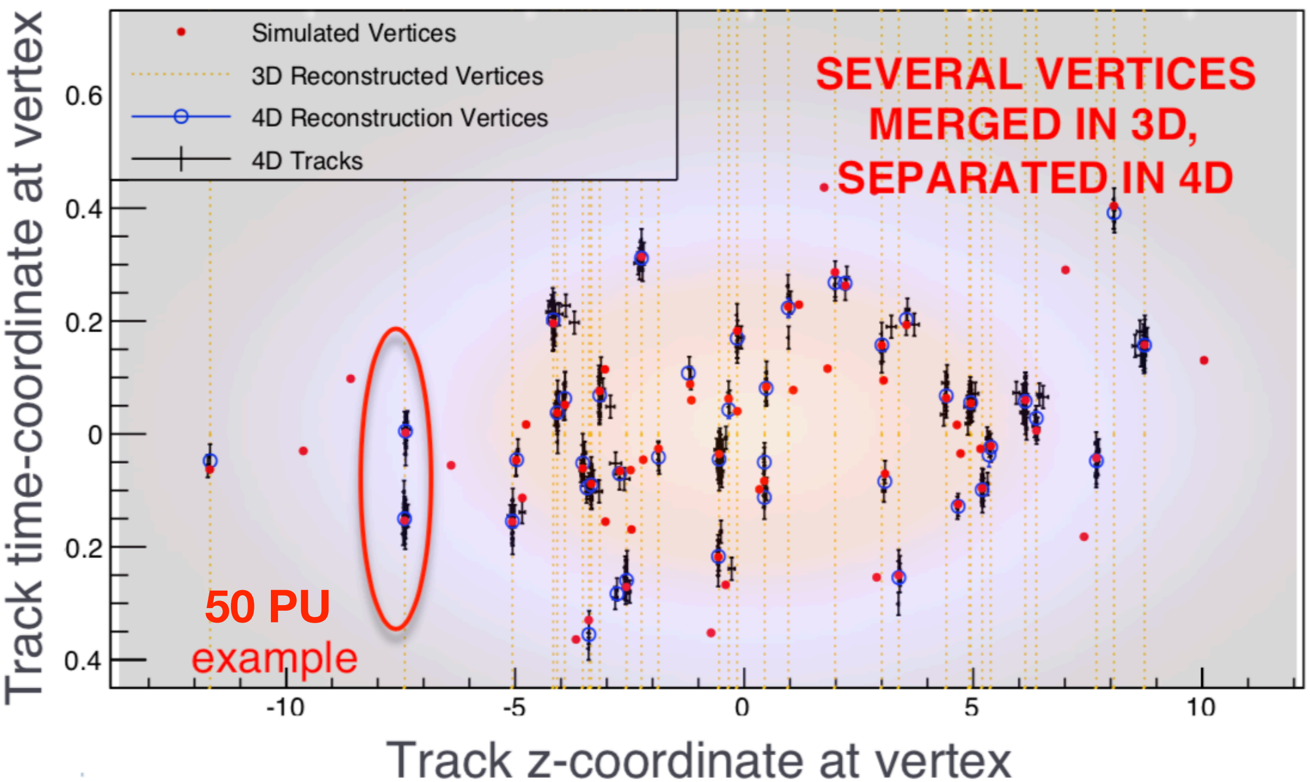
High Track Density @ HL-LHC





- HL-LHC luminosity:
  - L_{inst} (start) = 5.0 · 10^{34} cm^{-2} s^{-1} (140 PU)
  - L_{inst} (goal) = 7.5 · 10^{34} cm^{-2} s^{-1} (200 PU)
- CMS GED relies on track-vertex assignment
  - With vertex density higher than 1 mm^{-1} → **significant** PU contamination
  - Degradation in **whole** event reconstruction
- **Challenge**: keep current performance @ HL-LHC
  - **Full** physics program would benefit

Timing: An Extra Dimension for Vertexes



Basic idea:
vertexes overlapping in z might not overlap in time

σ(t)	Effective PU
None	200
30 ps	33
45 ps	50
60 ps	70

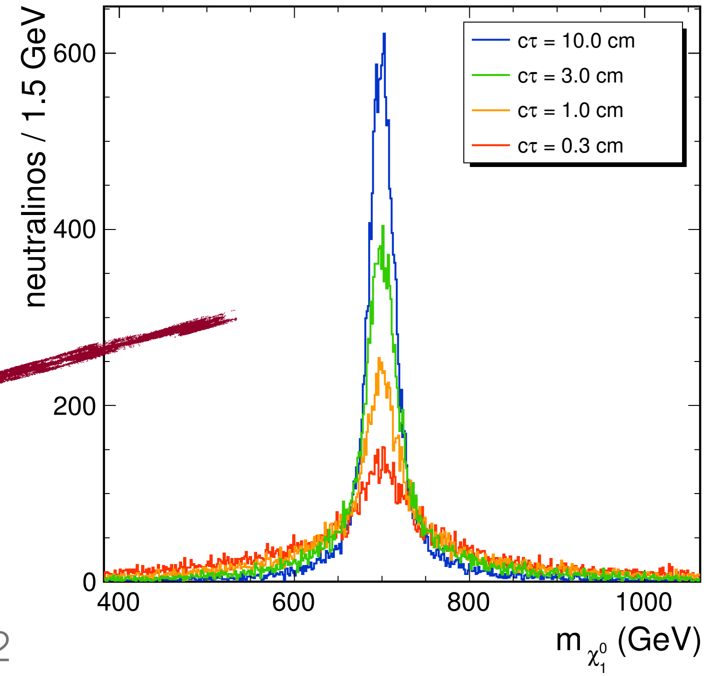
- Luminous regions has time RMS ~ 180 ps
- Better time resolution → better separation
  - Can be used to effectively **reduce PU**

Need $\sigma_t \lesssim 60$ ps for real benefit

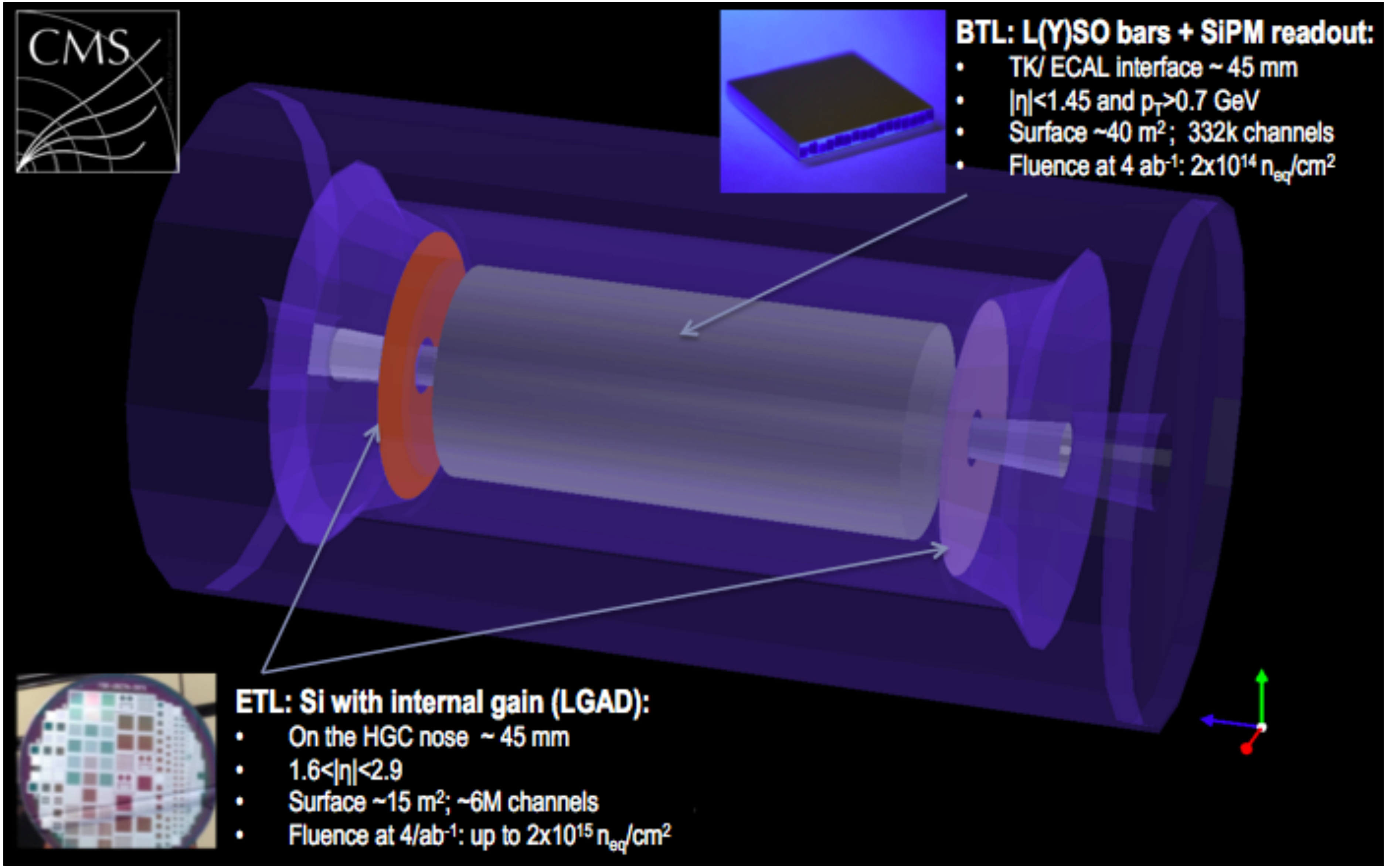
Benefits of 30ps Timing to CMS Physics

Signal	30ps Timing Benefits	Physics Impact
H→γγ (*)	Photon isolation, vertex choice	+25% precision on cross-section
VBF + H→ττ	Isolation, VBF tagging, ME_T resolution	+20% precision on cross-section
HH	Isolation, b-tagging	+20% signal efficiency
SUSY	Reduce MET tails	-40% irreducible BG

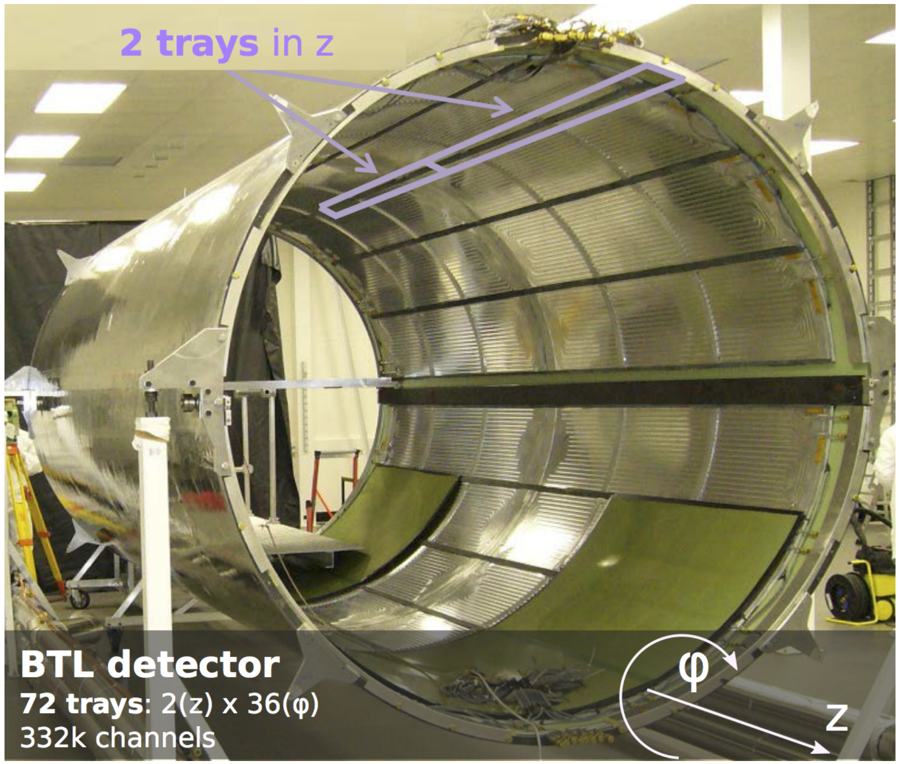
- Benefits across **many** physics channels
  - Overall: +20-40% **effective** integrated lumi
- **New** physics opportunities
  - Reconstruct **mass of tracks** (LLP, HSCP)
  - TOF PID: **exclusive flavour** physics in Pb-Pb

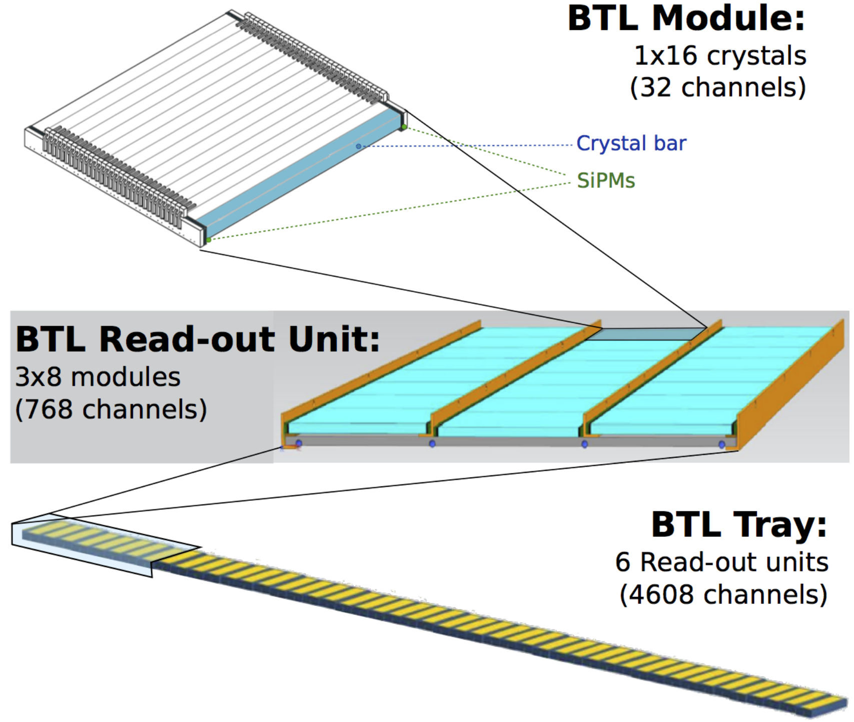


Two Timing Layers: BTL and ETL



BTL Integration and Geometry

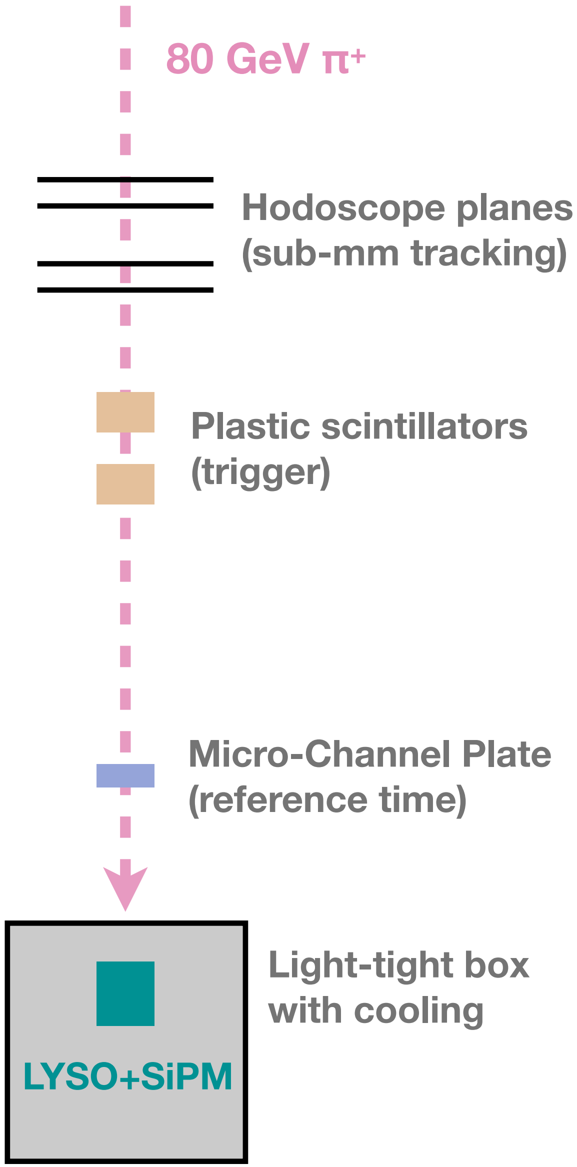


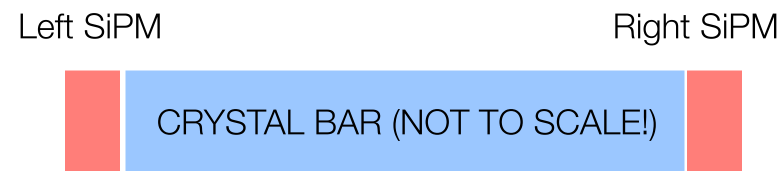


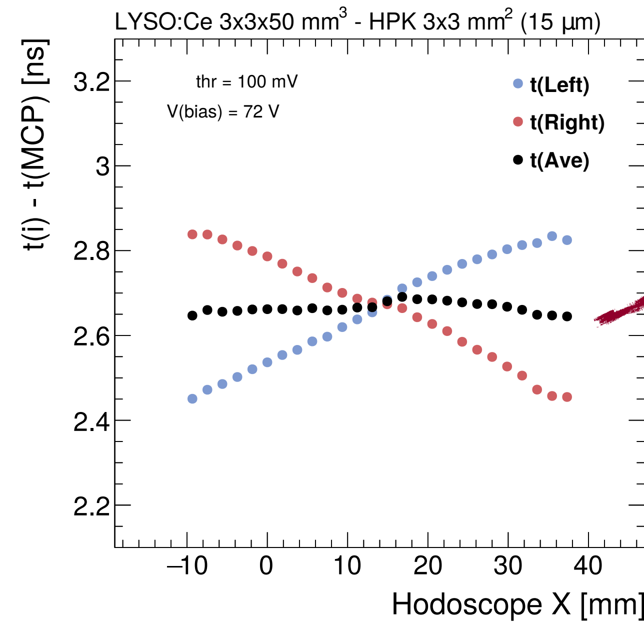
- Integrated with **tracker**
  - Will share services (cooling) and schedule

- Arrays of LYSO crystal bars (50×3 mm^2)
  - Aligned in z direction
  - Read out by 2 SiPMs (one per side)

Beam Tests: 30 ps Resolution Achieved!

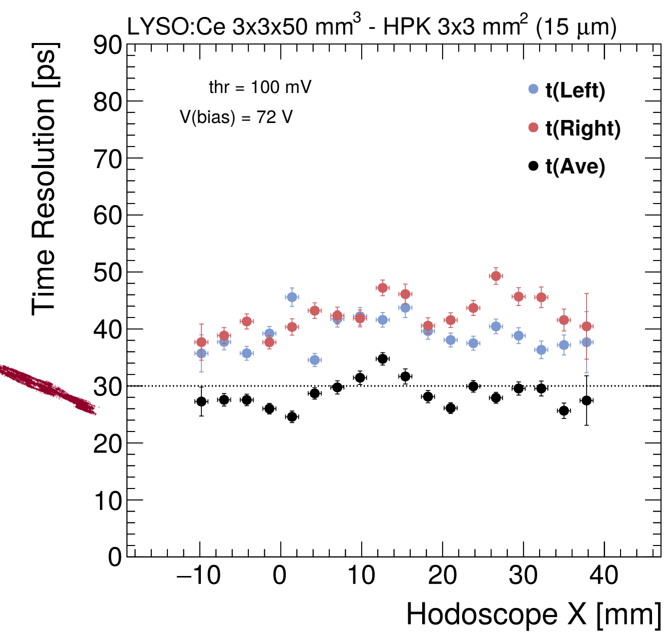




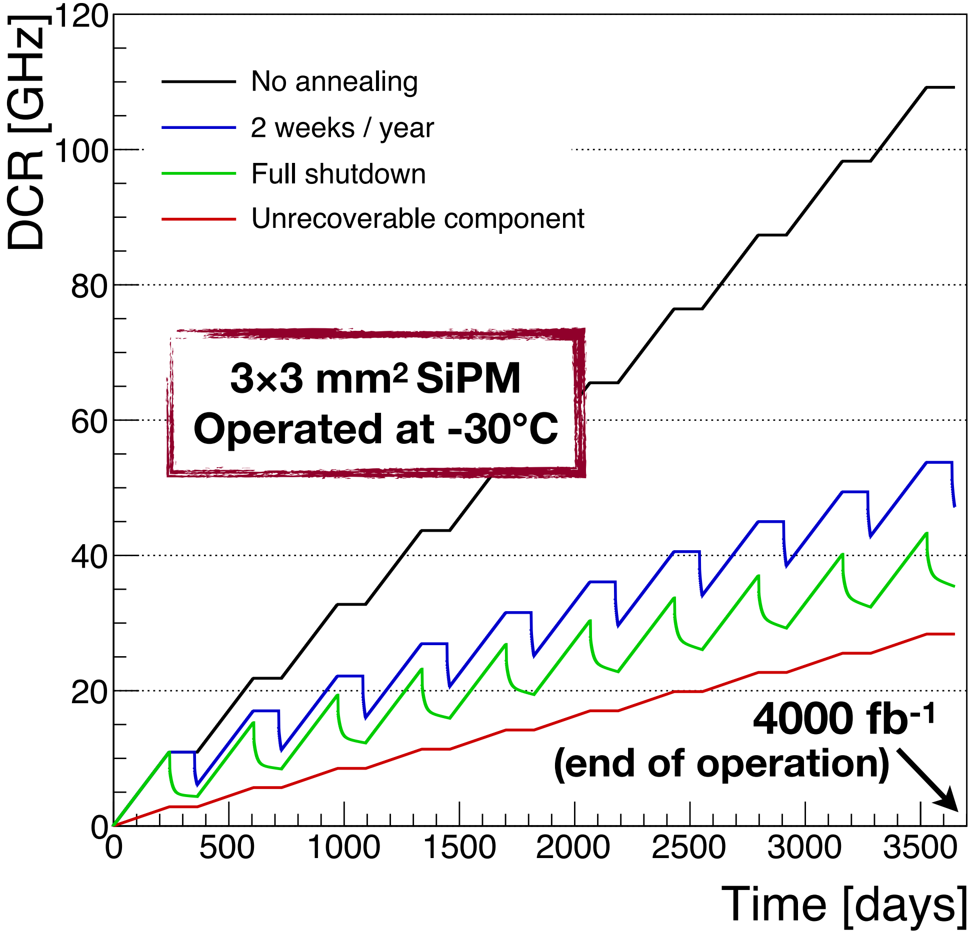


Arrival time on SiPM proportional to distance

Achieved 30 ps resolution
Uniform across bar length



Radiation Damage on SiPMs: Dark Current



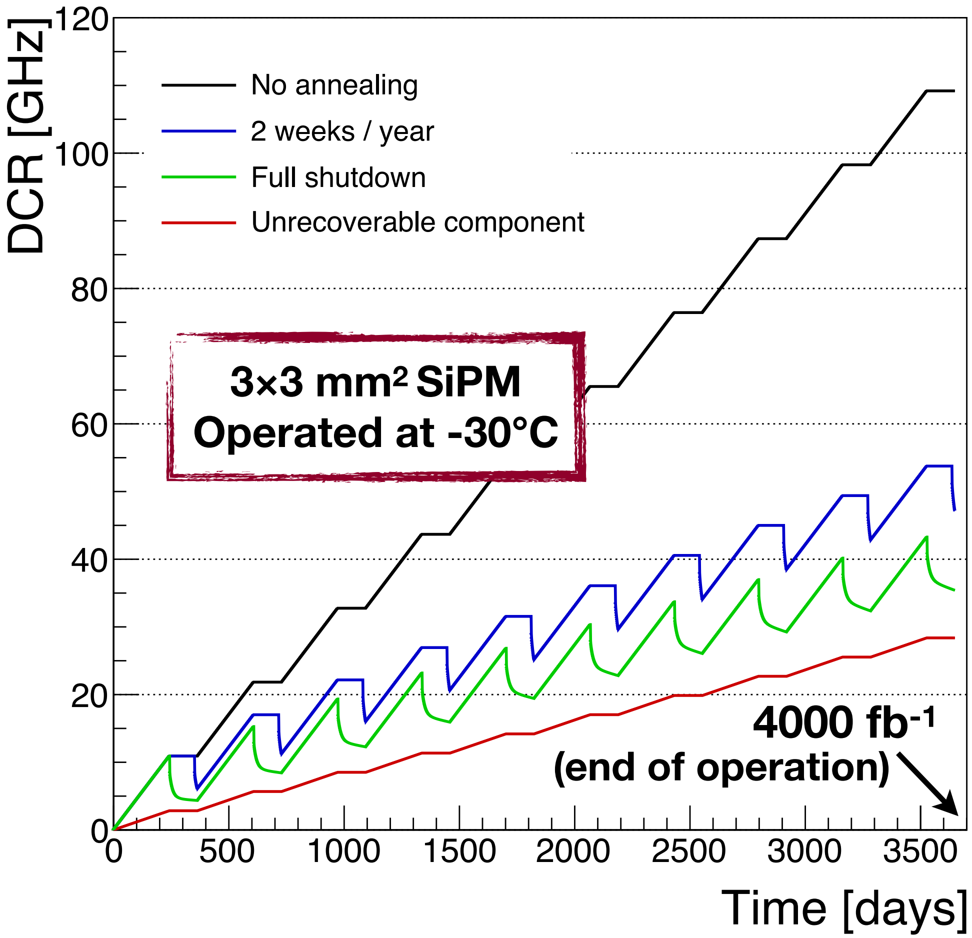
decreasing V_{bias}

~40% decreasing PDE ~20%

- Radiation creates crystal **defects** in Si
  - Mid-gap states → dark current
- Room temp. **annealing** heals defects
  - Will anneal during yearly shutdown
  - Longer annealing, **more** recovery
  - Tied to **tracker** schedule
  - Two weeks / year **guaranteed**
- DCR will **increase** power usage
  - To stay in budget will **lower V_{bias}**

(…hence PDE)

Radiation Damage on SiPMs: Dark Current



decreasing V_{bias}

~40% decreasing PDE ~20%

- Ra… Si
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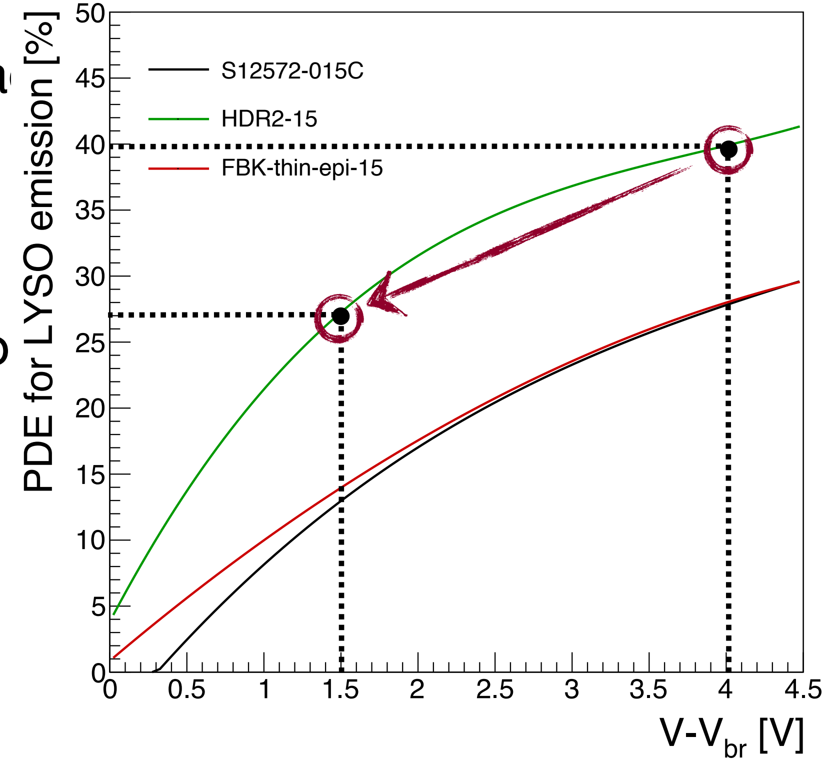
  - Two weeks / year **guaranteed**



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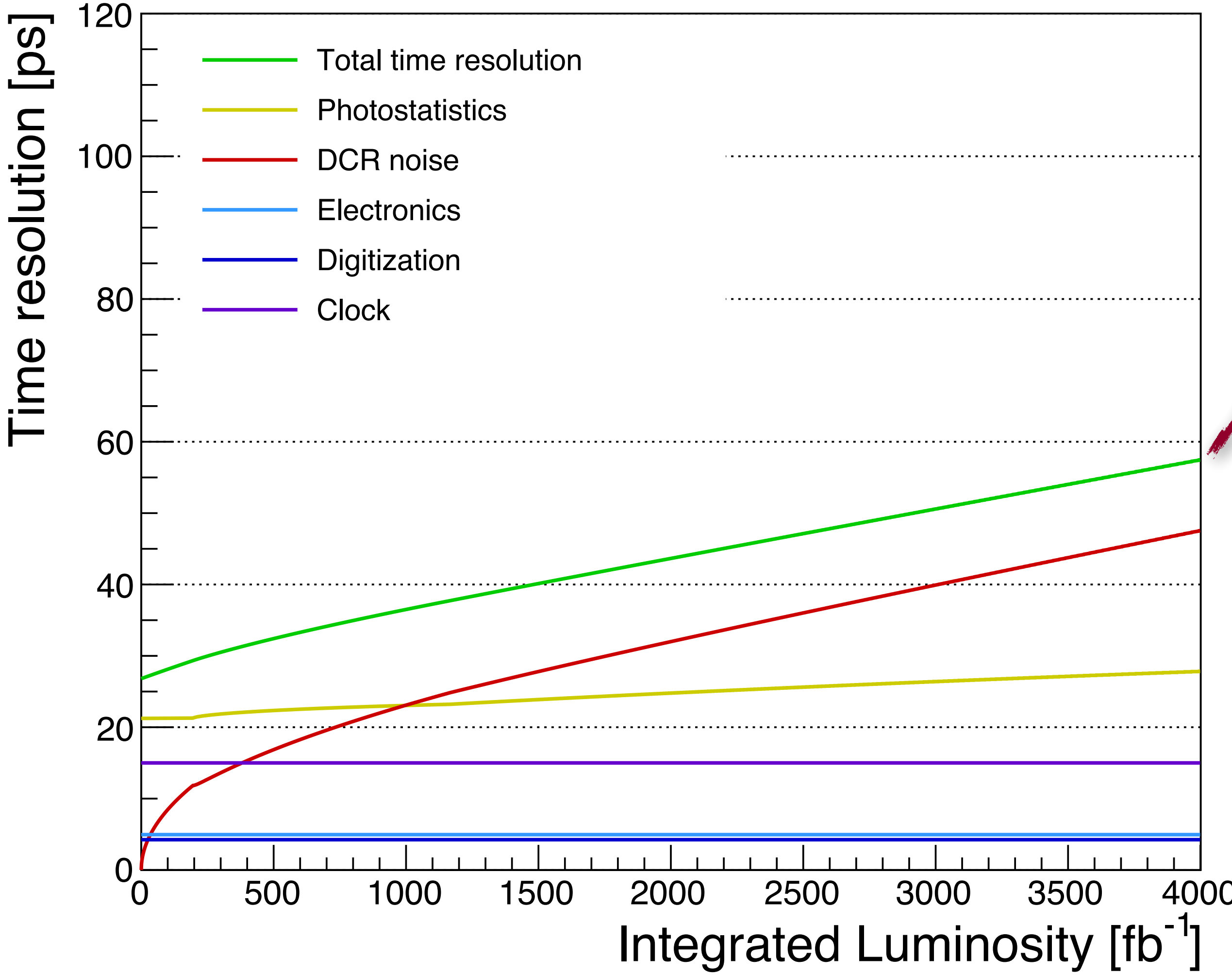
Expected Evolution of Timing Resolution



End-of-operation resolution < 60 ps

Mean resolution ~ 45 ps (throughout HL-LHC)

Endcap Timing Layer: the Radiation Challenge

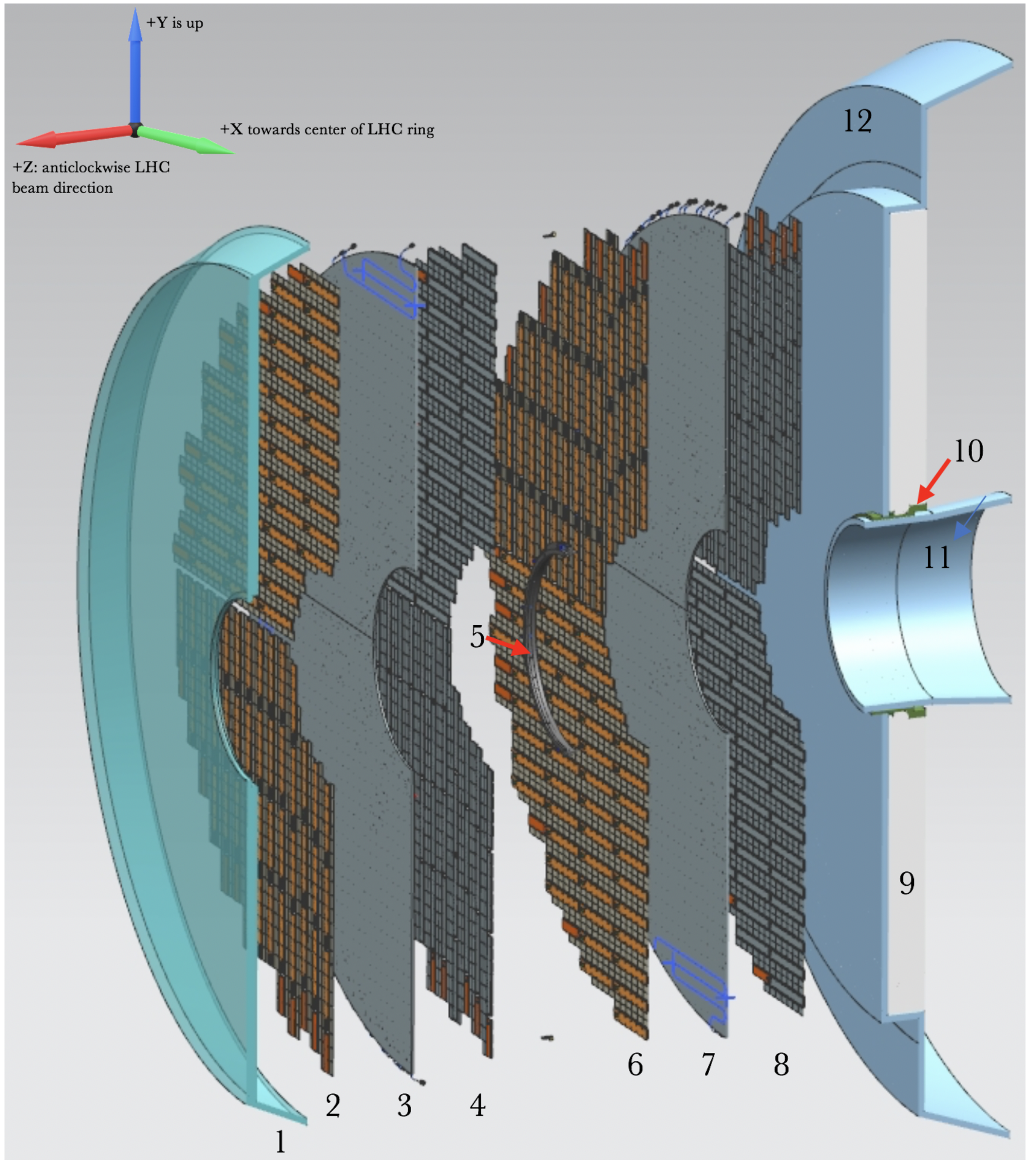
- ❖ ETL will cover $1.6 < |\eta| < 3.0$
  - **Higher** radiation dose
  - Highly **non-uniform** in $|\eta|$
- ❖ SiPMs not radiation hard **enough**
  - Will use silicon LGADs (Low Gain Avalanche Detectors)
  - Internal gain: 10-30

AFTER 4000 fb^{-1}

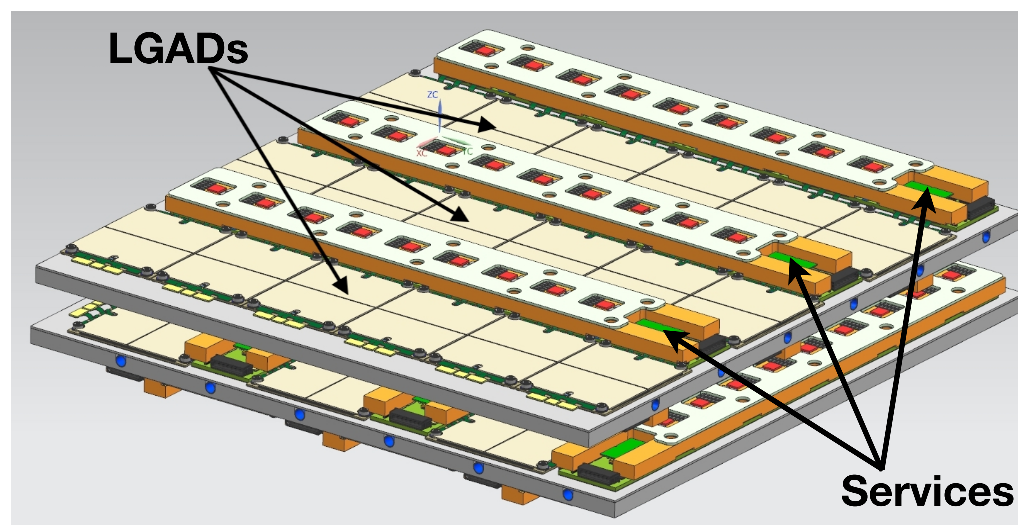
	$\|\eta\|$	Hadron Fluence (n_{eq}/cm^2)	Dose (kGy)
BARREL	0	$1.7\cdot10^{14}$	16
BARREL	1.15	$1.9\cdot10^{14}$	21
BARREL	1.45	$2.0\cdot10^{14}$	25
ENDCAP	1.6	$1.1\cdot10^{14}$	25
ENDCAP	2	$2.4\cdot10^{14}$	75
ENDCAP	2.5	$6.6\cdot10^{14}$	260
ENDCAP	3	$1.7\cdot10^{15}$	690

×30

Endcap Timing Layer Layout and Geometry

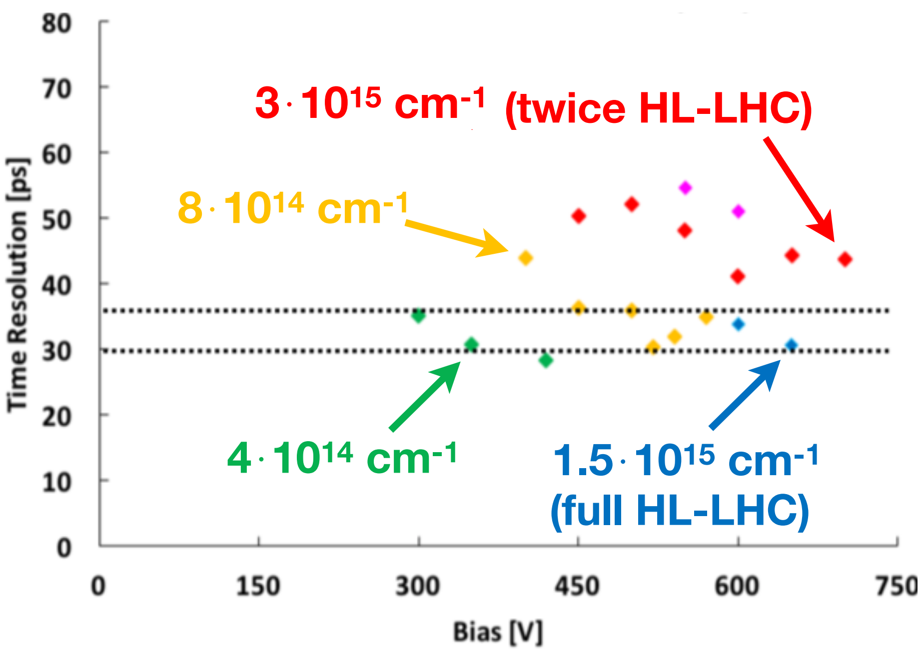


- **Two** disks of LGADs (two hits)
  - 50 ps resolution on single hit
  - So 30-40ps with two hits
- Each disk: LGADs on **both faces**
  - 90% acceptance per disk



30-40ps Resolution Throughout HL-LHC

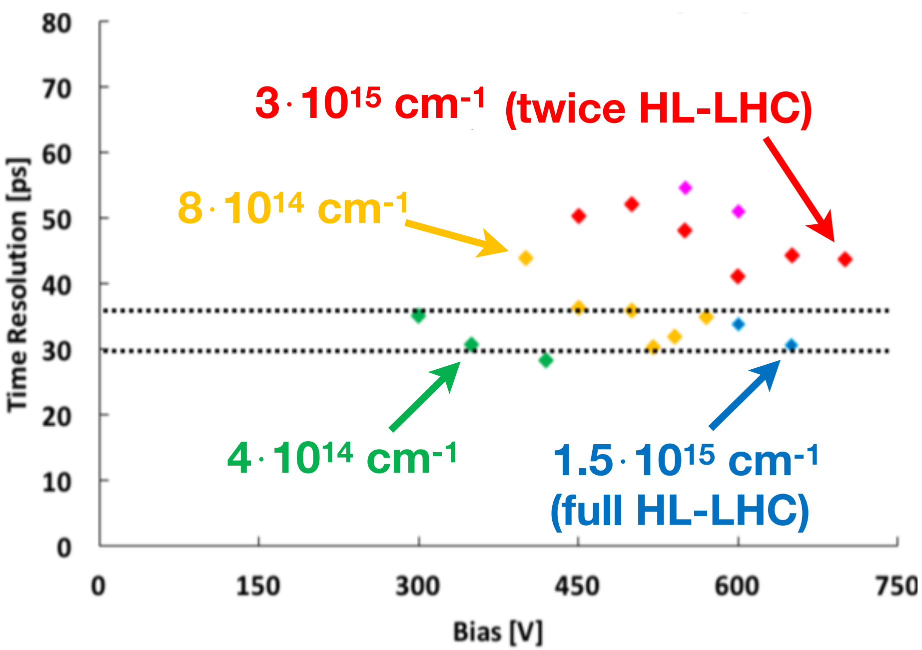
Irradiation Studies on LGADs



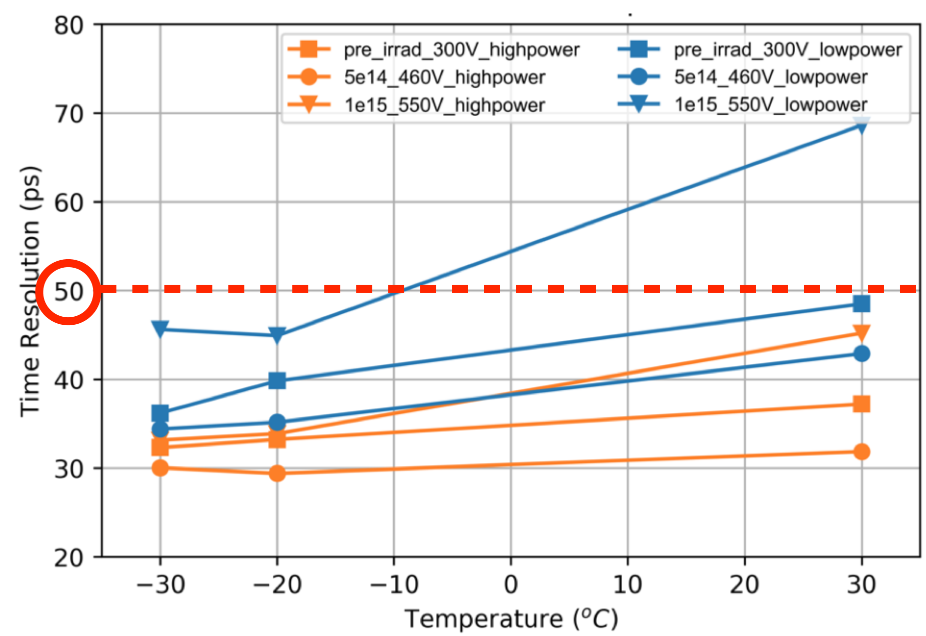
- LGAD time resolution < 40 ps **throughout** HL-LHC operations
  - σ_t ~ 40-50 ps with **double** dose

30-40ps Resolution Throughout HL-LHC

Irradiation Studies on LGADs



LGAD+ASIC Simulated Performance



- LGAD time resolution < 40 ps **throughout** HL-LHC operations
  - σ_t ~ 40-50 ps with **double** dose

- ASIC+LGAD: σ_t < 50 ps (one hit)
  - **Two** hits, so $\sigma_t < 50/\sqrt{2} = 35$ ps
  - Better σ_t with **higher** power

Conclusions

- CMS upgrade for HL-LHC: adding a **timing detector** for charged particles
    - Target: **30-40 ps** time resolution, hermetic coverage
- **Full** CMS physics program would benefit
    - 6× PU reduction, +20-40% effective luminosity, new searches
- **Successful** R&D campaigns both for barrel and endcap timing layers
    - $\sigma_t < 30$ps **achievable**, degrading to only 40-60ps at end of operation
- **Looking forward** to detector assembly and commissioning!

Additional Material

Fast and Radiation-Hard Electronics

- Readout electronics ASIC: **TOFHIR**
  - Based on TOFPET2 board used in LYSO TOF-PET
  - Adapted for **higher rates** and **radiation tolerance**
  - Leading edge discriminator + amplitude measurement
- Each board has 6 ASICs
  - Each ASIC powers 32 SiPMs
- **Extensive** testing on final prototypes ongoing in 2019-2020