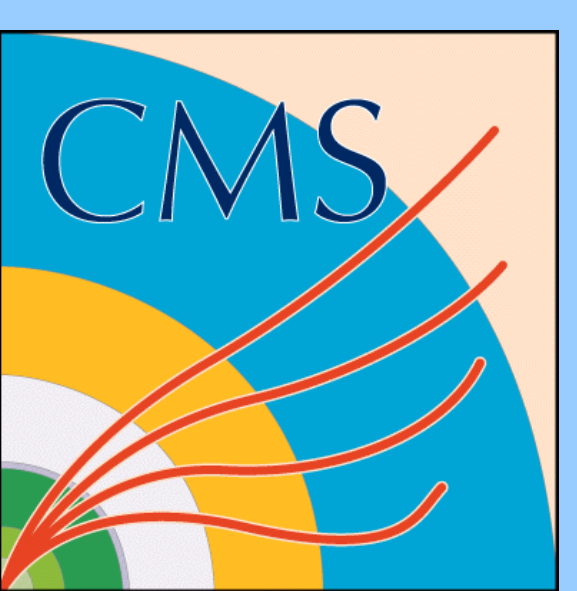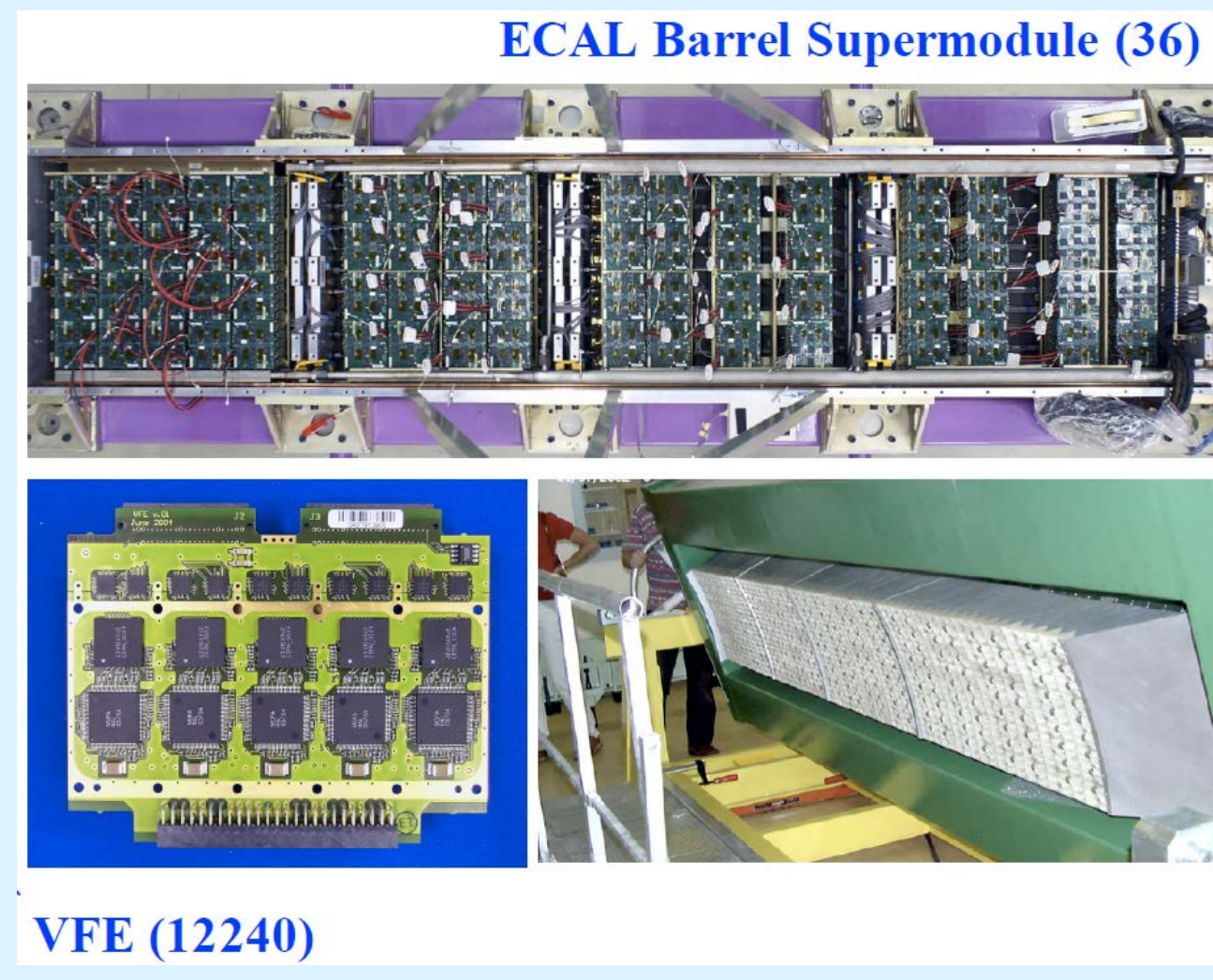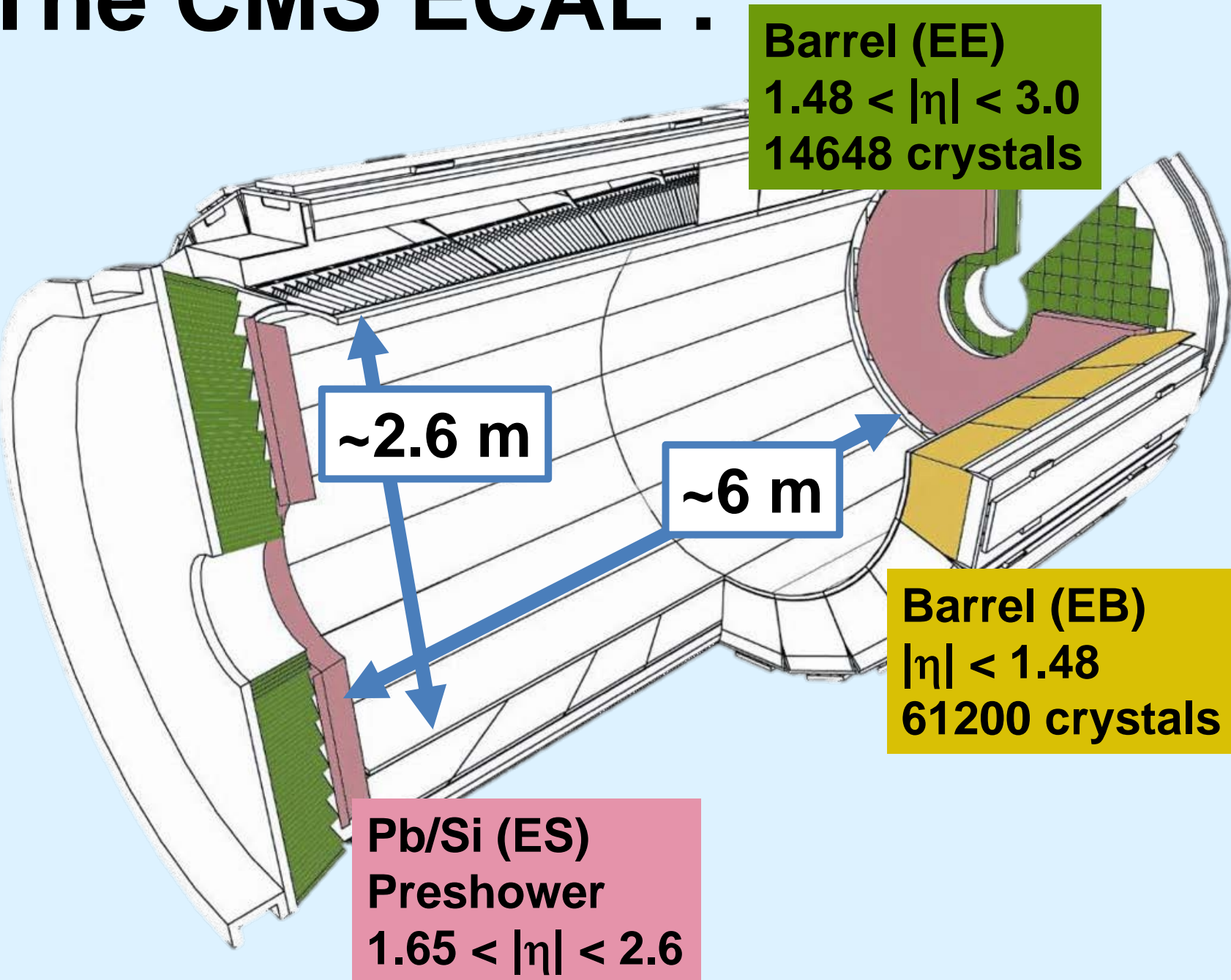# Design studies for the Phase II upgrade of the CMS Barrel Electromagnetic Calorimeter

The CMS ECAL :

Barrel (EE)
1.48 < |η| < 3.0
14648 crystals

Barrel (EB)
|η| < 1.48
61200 crystals

Pb/Si (ES) Preshower
1.65 < |η| < 2.6

~2.6 m

~6 m

ECAL Barrel Supermodule (36)
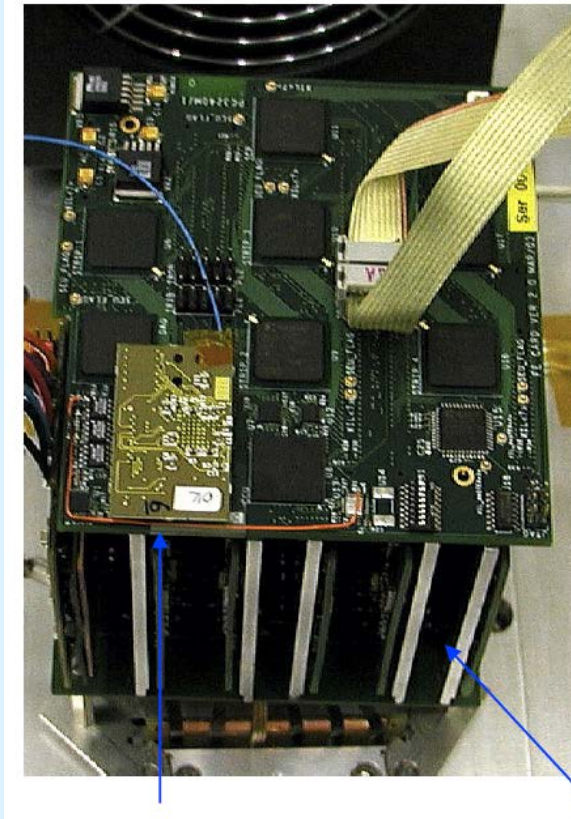
VFE (12240)

Trigger Tower (2448)

FE (2448)

➢ Trigger Tower (TT) : 5x5 array of crystals, basic VFE unit.
➢ Very Front End (VFE) : 5 identical readout channels with pre-amplifier (MGPA), 43 ns shaping time, 12 bit ADC
➢ Front-End (FE) : Data pipeline & transmission
➢ Separate readout for data & trigger
➢ 40 MHz readout of 2448 TT, 100 kHz readout of 61200 channels (single crystal).

Physics at the HL-LHC :

$H \rightarrow \gamma\gamma$ discovery @ LHC

$H(bb)H(\gamma\gamma)$ discovery @ HL-LHC

Vacuum stability of Universe

VBF $H \rightarrow \gamma\gamma$ event at 200 PU

High luminosity LHC will collect 3 ab^{-1} integrated luminosity over 10 years at 5x10^{35} cm^{-2}s^{-1} to probe the Higgs sector at the per-cent level.

LHC
E = 7-14 TeV
L = 1·10^{34} cm^{-2}s^{-1}
<PU> ~ 40-60
≥ 50 fb^{-1} per year
300-500 fb^{-1} total

HL-LHC
E =14 TeV
L = 5·10^{34} cm^{-2}s^{-1}
<PU> ~ 140
250 fb^{-1} per year
3000 fb^{-1} total

Target for CMS ECAL Phase II upgrade at HL-LHC :

Maintain physics performance for H→γγ at 5x higher luminosity and pile-up (PU), increased radiation levels and adjusting to the increased first level trigger rate of 750 kHz at 12.5 μs latency.


Upgrade strategy & implementation :

➢ PbWO$_4$ Crystals, APDs, mother boards, & overall mechanical structure will remain
➢ Reduce temperature from 18° C to 8° C
➢ VFE similar, but change shaping + digitization
➢ FE card becomes pipeline, most processing off-detector
➢ Same data stream for trigger & data
➢ Full detector readout with upgraded links
➢ Off-detector electronics upgraded to higher transfer rates & generation of trigger primitives

REPLACE

KEEP
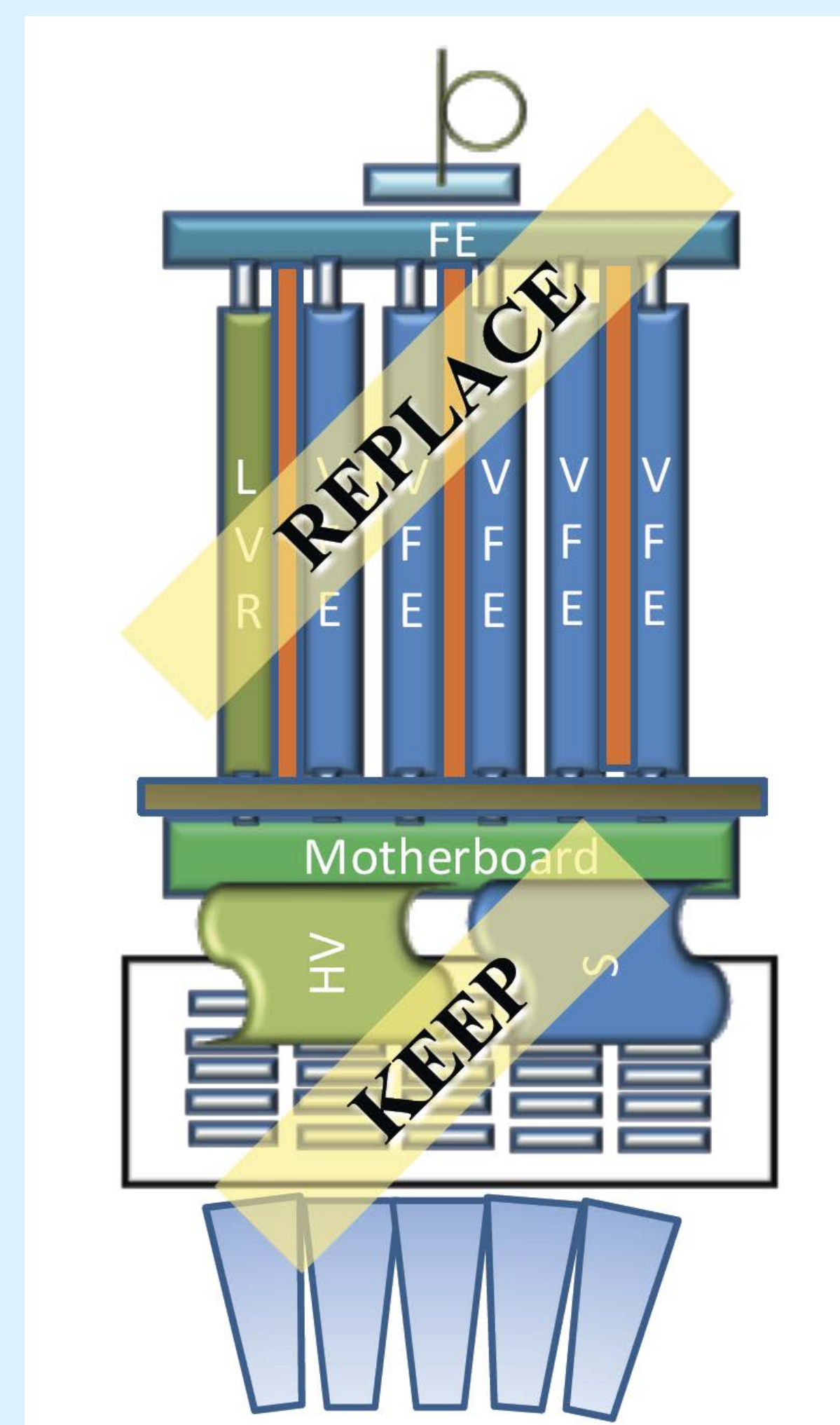
➢ FE : Move L1A pipeline off-detector with arbitrary trigger latency
➢ Trigger primitive generation off detector - single crystal granularity. **See poster by Nabarun Dev.**
➢ Data links from detector to readout cards updated to versatile link w/ GigaBit Transceiver (GBT) ⇒ full granularity readout for the trigger
➢ Potentially more advanced topological filtering of anomalous events

➢ VFE : Re-designed ASICs to optimize shaping time & sampling ⇒ reduce impact of noise, out-of-time PU, spikes, precision timing.
➢ Pulse shaper/preamplifier ASIC options : Trans Impedance Amplifiers (TIA) or iteration of current architecture (MGPA, CR-RC), optimized for 130 nm process, faster shaping & additional spike rejection logic. **See poster by Sema Zahid.**
➢ ADC: Multi-channel ADC with ~12 bit resolution, sampling rate up to 160 MHz
➢ Prototype boards undergoing lab & test beam measurements, Simulation studies ongoing to optimize shaping time & sampling rate

## Performance of the upgraded detector :
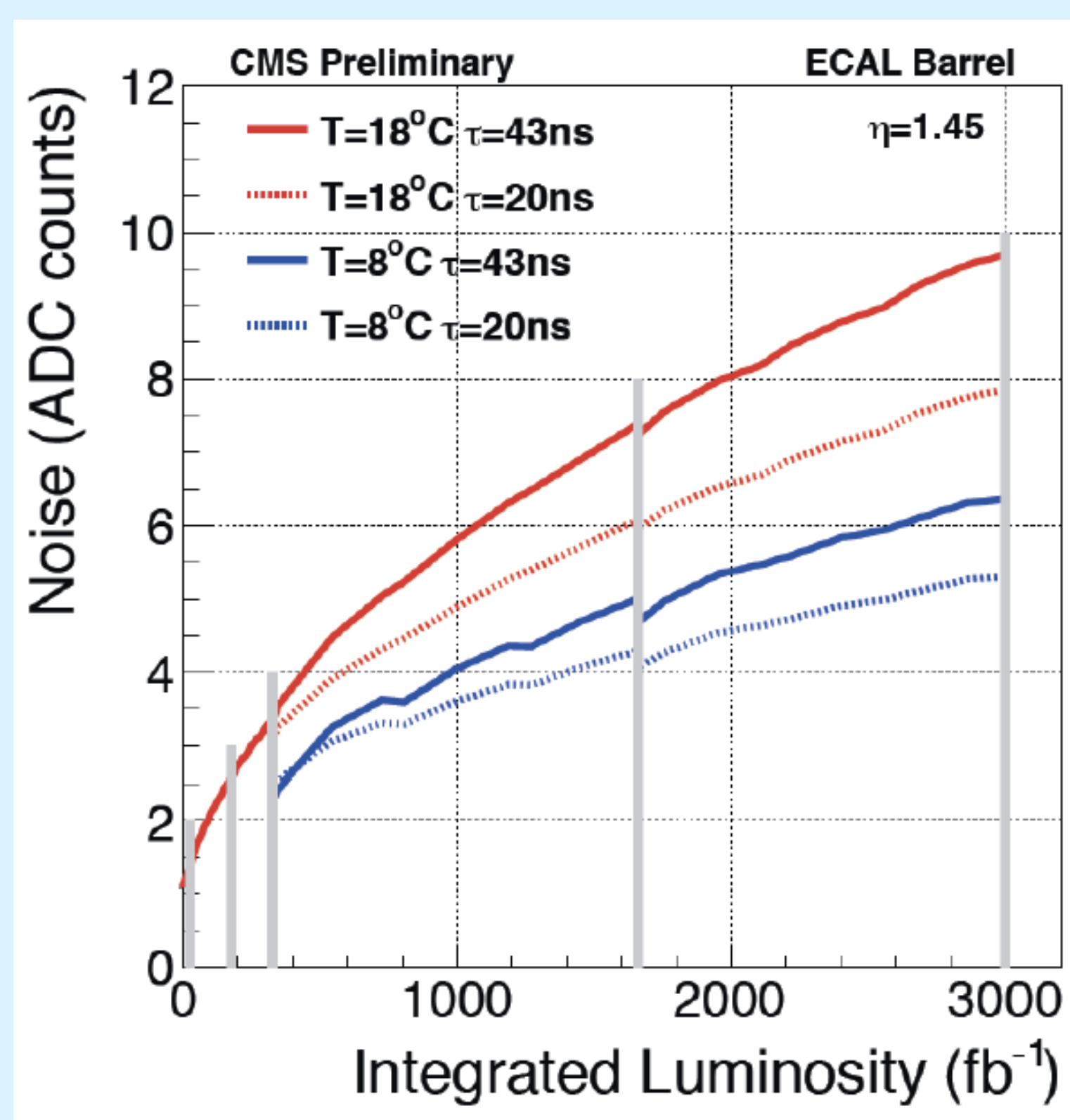
Noise reduction :

➢ APD dark current increases with integrated lumi due to irradiation → noise increase ×10 (~400 MeV/channel) after 3000 fb^{-1}.
➢ Mitigate by operating EB colder: 18° C → 8° C, reduce noise by 35%
➢ Shortening the signal shaping time in VFE will also reduce noise

CMS Preliminary — ECAL Barrel

T=18°C τ=43ns
T=18°C τ=20ns
T=8°C τ=43ns
T=8°C τ=20ns

η=1.45

CMS Preliminary — ECAL Timing TB 2015

APD1 MGPA G6, 43ns shaping
APD2 MGPA G6, 21.5ns shaping

$\frac{N}{A/\sigma_{noise}} \oplus C \oplus 0.025$

N: 16.4 ± 0.2 ns
C: 0.027 ± 0.001 ns

Test Beam Data

σ_t (APD-MCP) [ns]

A/σ_{noise}

PbWO$_4$ scintillation
intime APD spike

Spike rejection :

➢ Anomalous signals (spikes) are energy deposits directly into APD bulk. Create fake EM-like pattern.
➢ Spike rejection currently rejected at L1 using coarse topological algorithm
➢ Efficiency will degrade to unacceptable levels at HL-LHC due to noise & PU
➢ Upgrade for better spike rejection using pulse shape & finer granularity L1
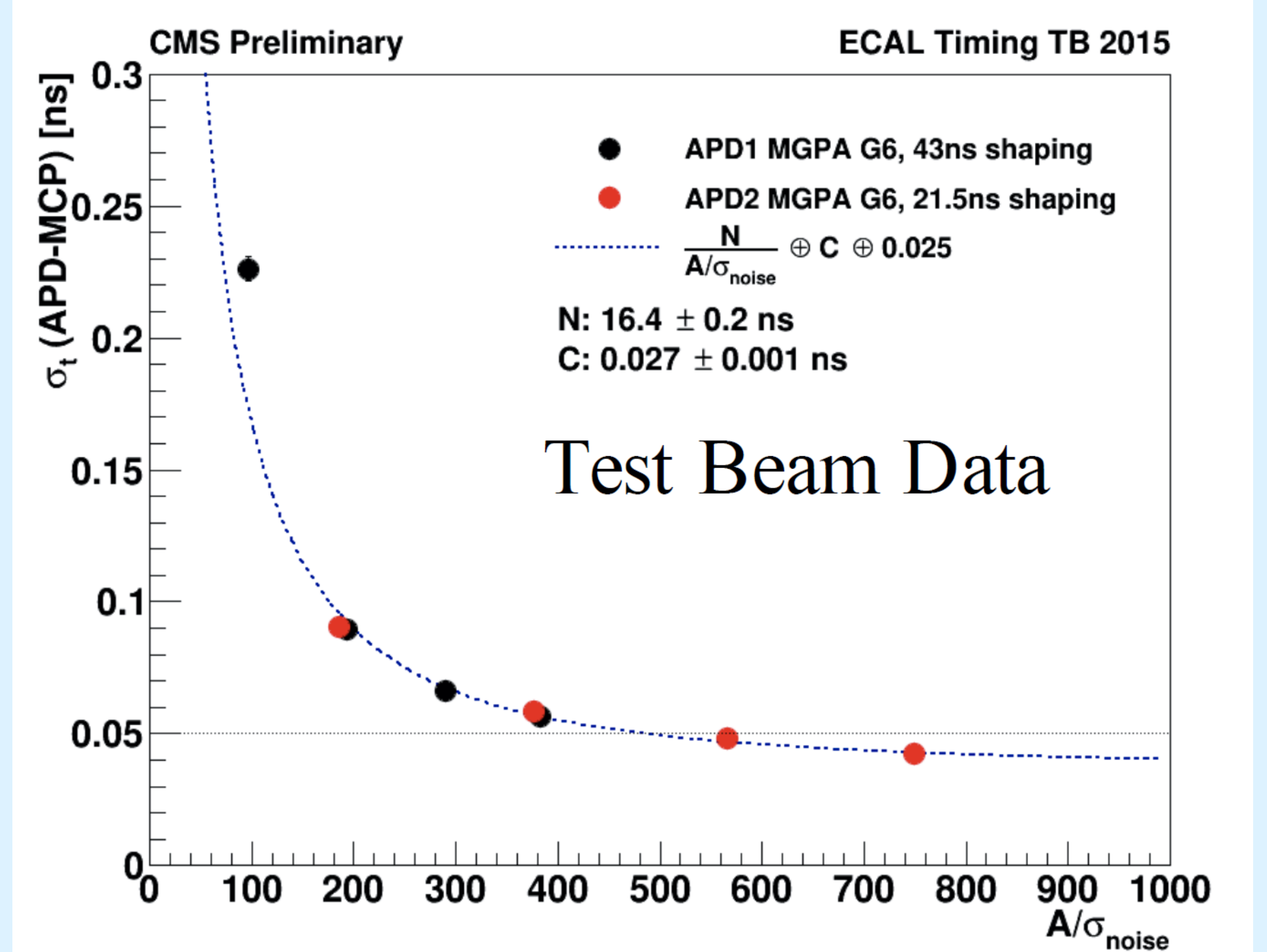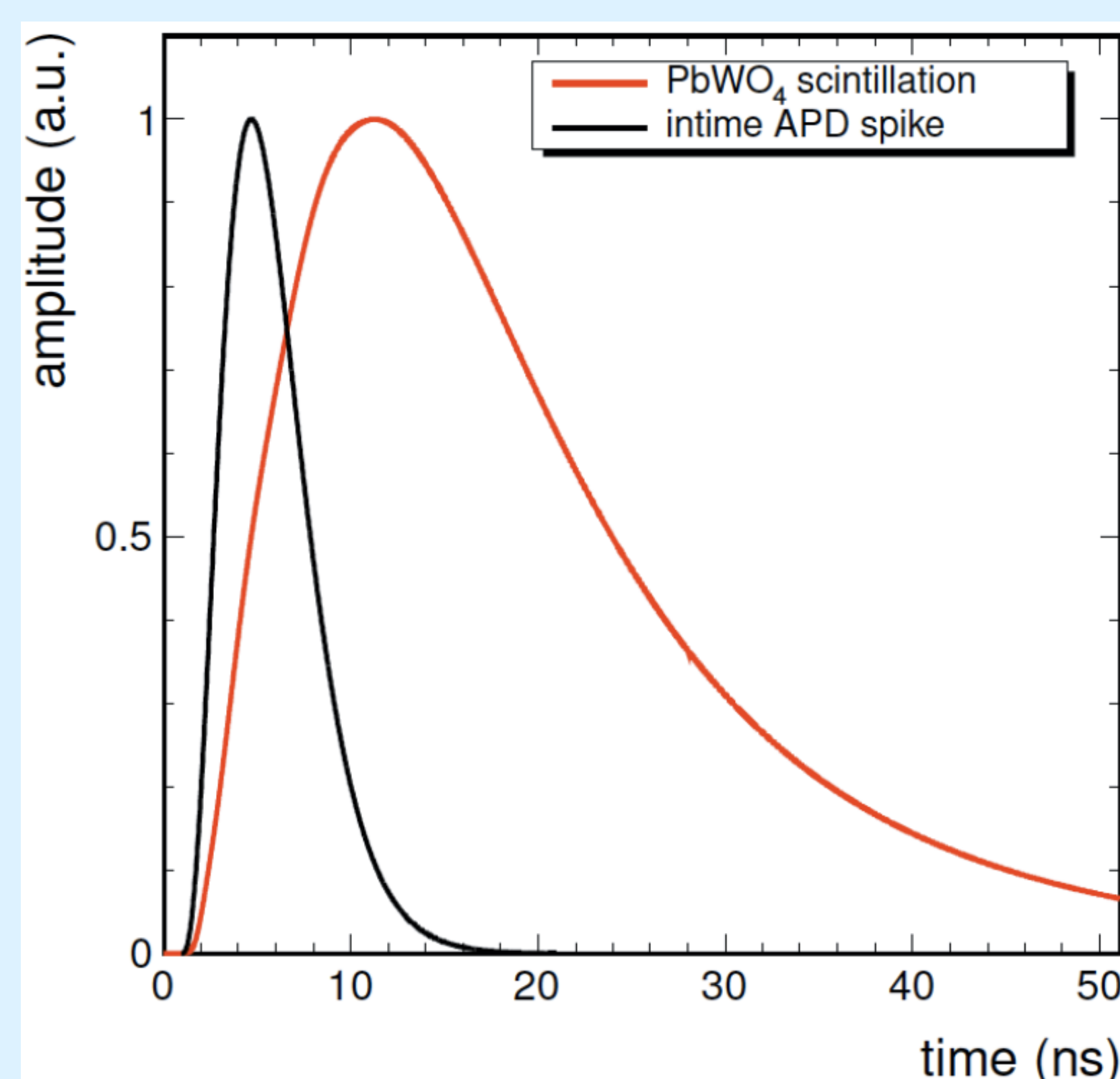
Precision timing @ 30 ps :

➢ Intrinsic timing resolution of PbWO$_4$+APD is < 30 ps, as measured at test beam. **See poster by Vincenzo Ciriolo.**
➢ Use cases for precision timing : Vertex resolution for H→γγ, subtraction of neutral energy from PU that enters EM clusters, identification of PU jets
➢ New system designed to approach 30 ps timing precision for high energy EM signals