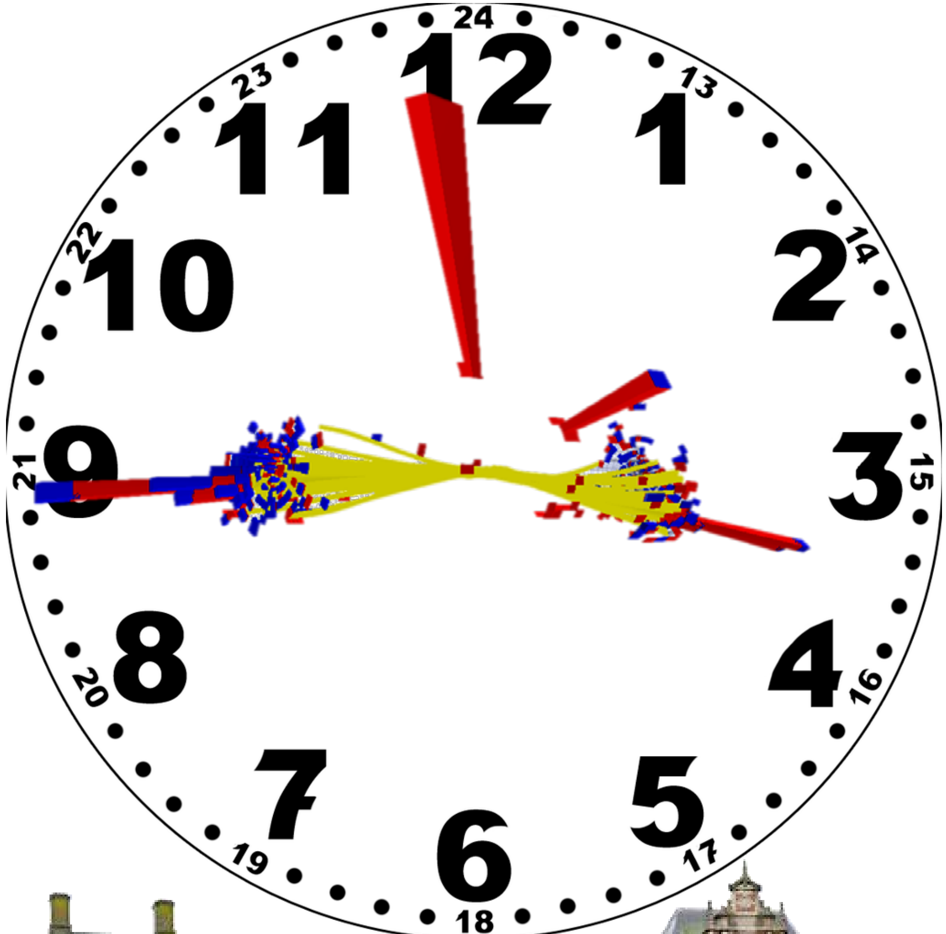


Timing performance of the CMS electromagnetic calorimeter and prospects for the future

TIPP2014, Amsterdam, 02.06.2014

Adi Bornheim

Caltech

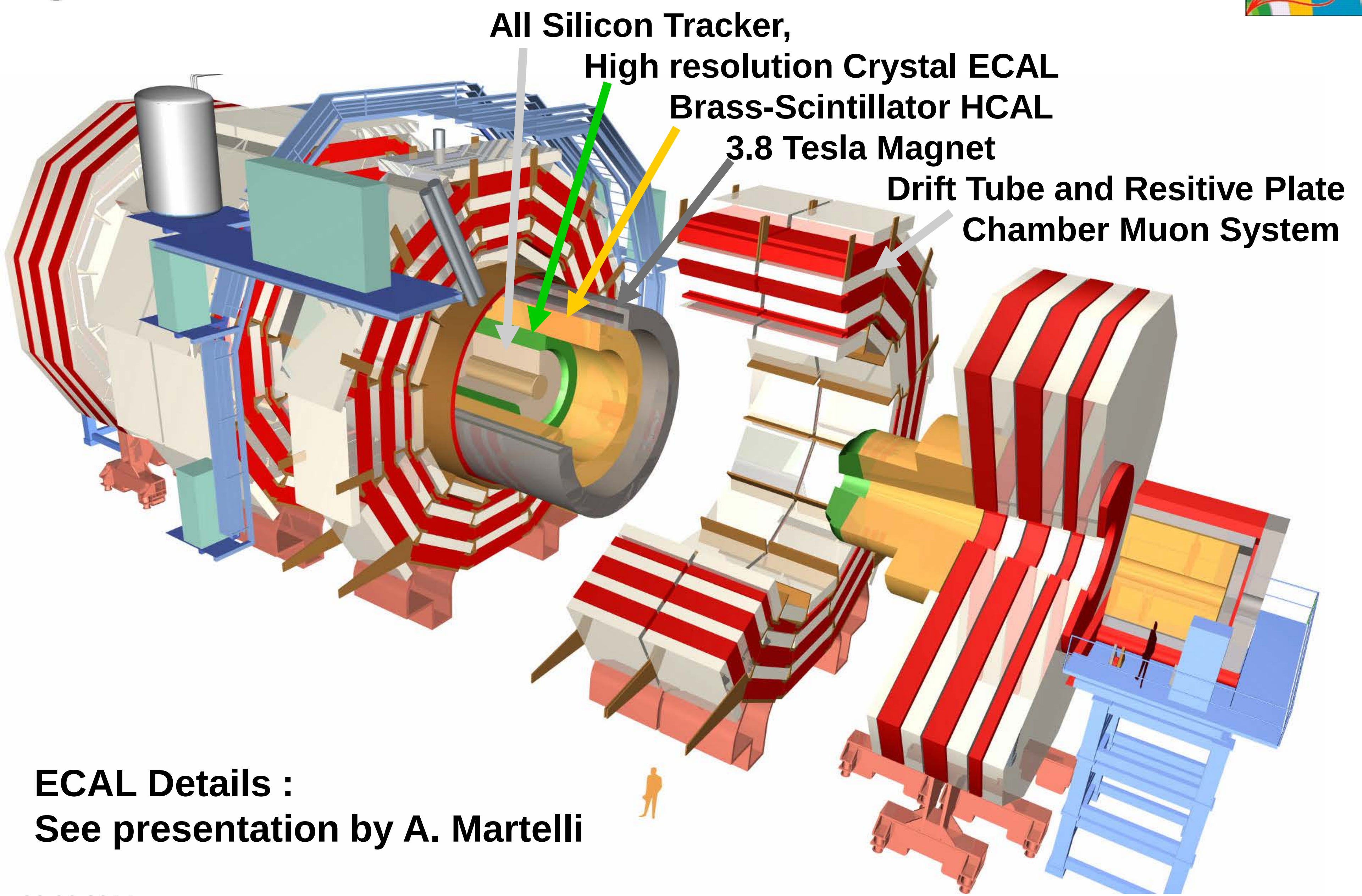
On behalf of the CMS Collaboration

The CMS Collaboration

Precision Timing with CMS ECAL

- Introduction
- The CMS ECAL
- Timing Measurement & Performance
- Plans and prospects for High Luminosity LHC
- Summary

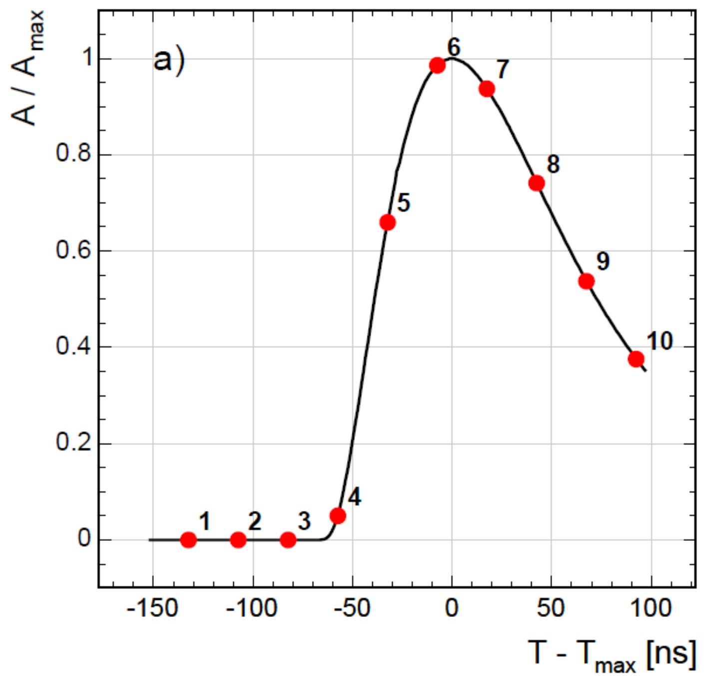
The CMS Detector

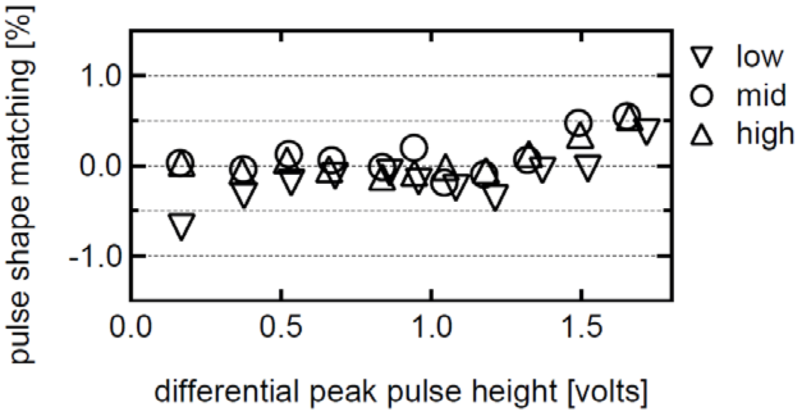


ECAL Details :
See presentation by A. Martelli

CMS ECAL Readout

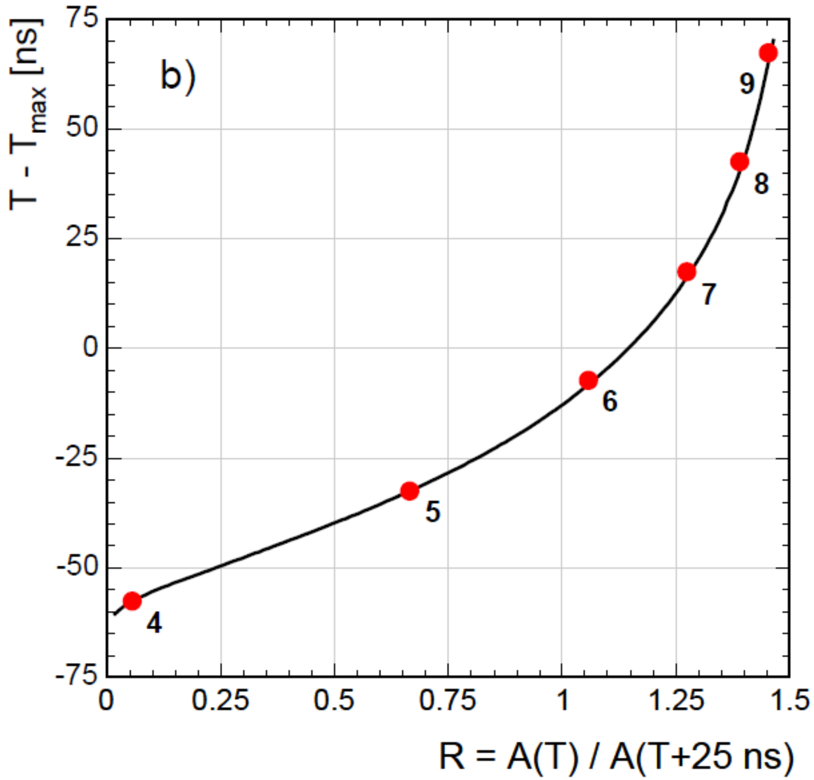
- Optimized for excellent energy resolution. 25 ns LHC bunch spacing.
- Low noise preamplifier :
  - 40 ns shaping time
  - 40 MeV noise per channel (barrel)
  - 1 ADC count noise per sample
- On-detector ADC :
  - 40 MHz sampling
  - Currently 10 samples readout (programmable)
- A matrix of 5x5 crystals share a common clock distribution (readout unit – RO).
- Pulse shapes stable and reproducible within 1%.
- CMS $PbWO_4$ crystals have 80% of scintillation light emitted within 10 ns.





Time reconstruction

- Time information is extracted from ratio R=A(T)/A(T+25 ns) of consecutive samples.
- Pedestal samples (1 to 3) are not considered.
- Highest precision from sample 5 in the rising edge of the pulse.
- Online timing synchronized among channels to approximately 1 ns. Sufficient for online operation.
- Each channel calibrated offline every couple of months during the 2011/12 LHC run one.

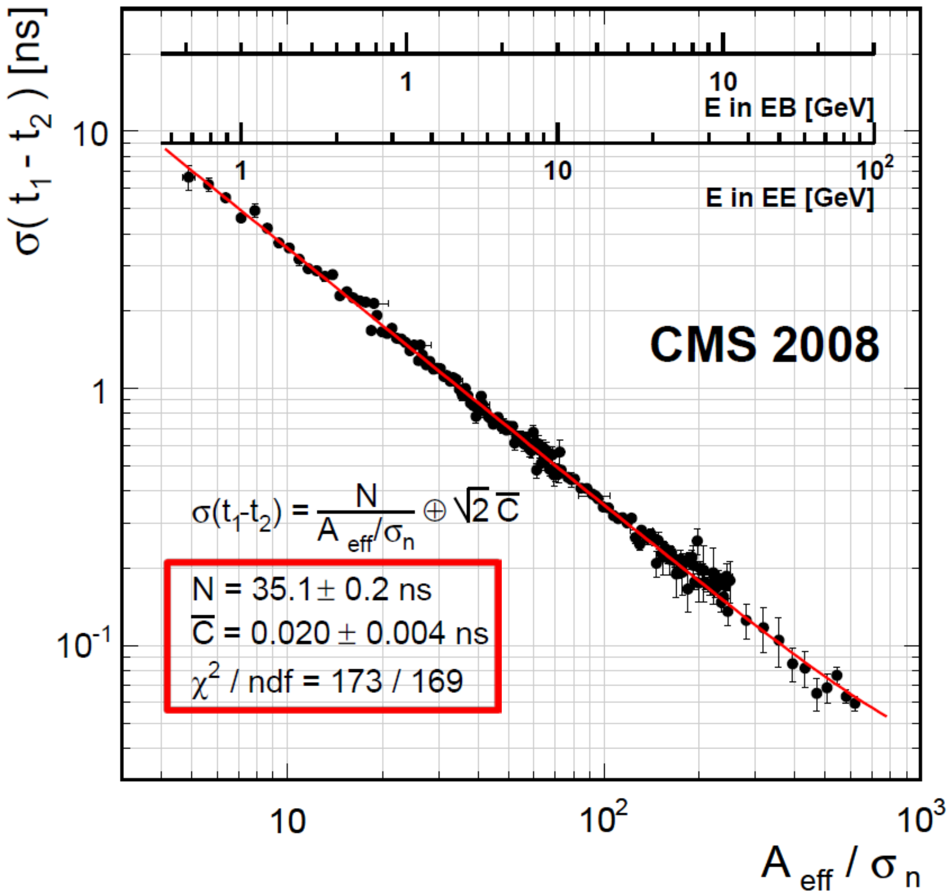


- Current offline usage : Background rejection (instrumental, physics, accelerator), optimize energy reconstruction.

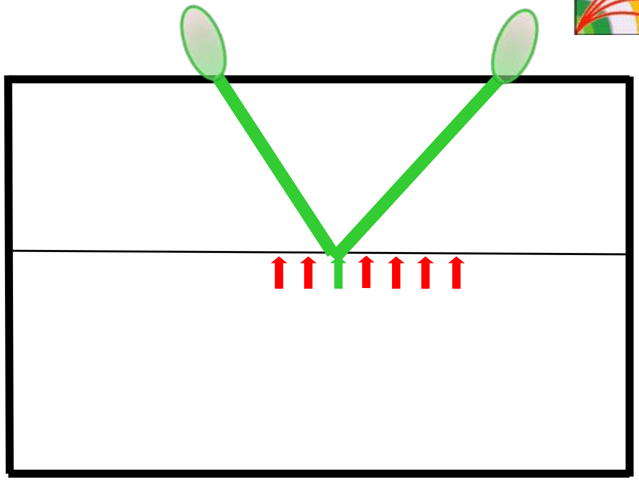
Test Beam Performance

Test beam results :

- **Timing performance $\sigma(t_1\text{-}t_2)$ measured time of adjacent crystals in a shower from a high energy electron.**
- **Constant term of the resolution found to be 20 ps from a fit of $\sigma(t_1\text{-}t_2)$ vs A_{eff}/σ_n .**
- **At 20 GeV, approximately 80 ps resolution.**

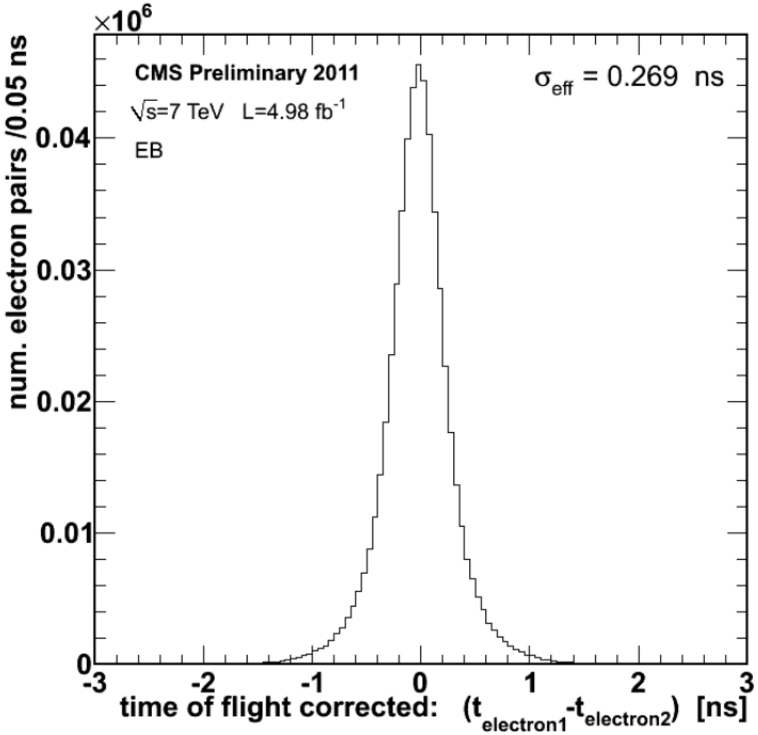


Timing Resolution in pp Collisions



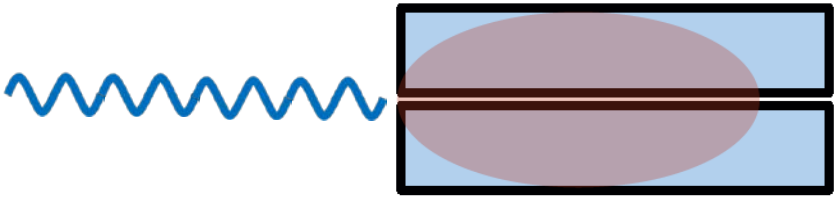
Results from pp collision data at LHC :

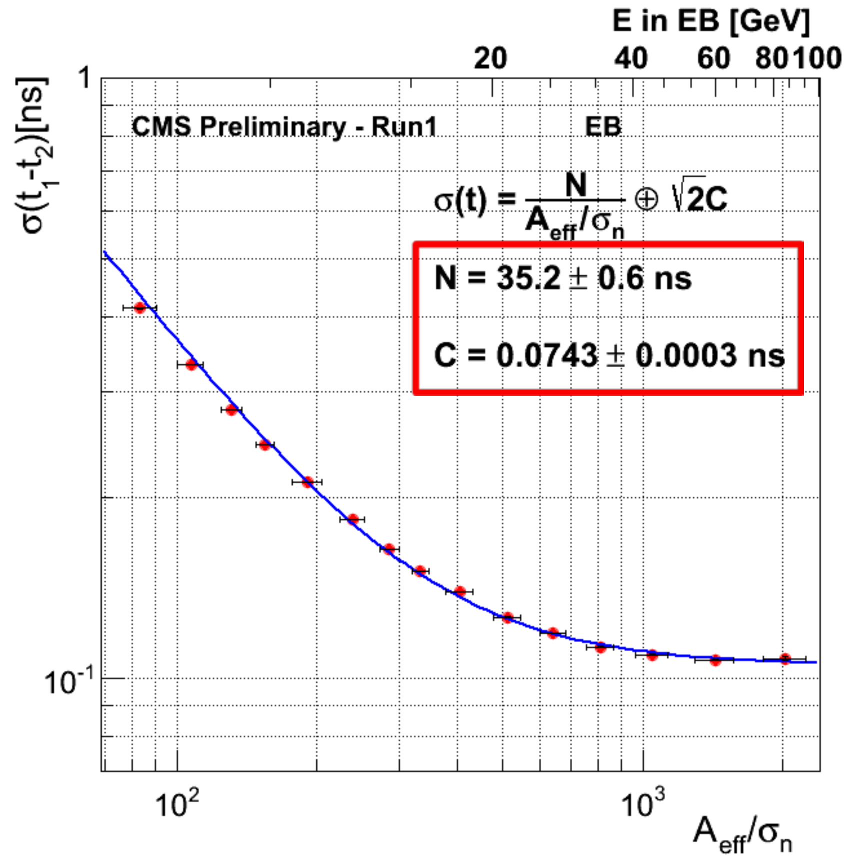
- Reconstruct time of two electron showers from a Z→ee decay.
- Ensures common origin of two objects.
- Width of the time difference found to be ~270 ps, single channel resolution ~190 ps.
- Without path length correction : 380 ps spread.



Several effects not present in test beam :
Channel-to-channel dependency of :
Pulse shape, calibration, clock distribution and stability, etc.

Single shower time resolution in-situ





Results from pp collision data at LHC :

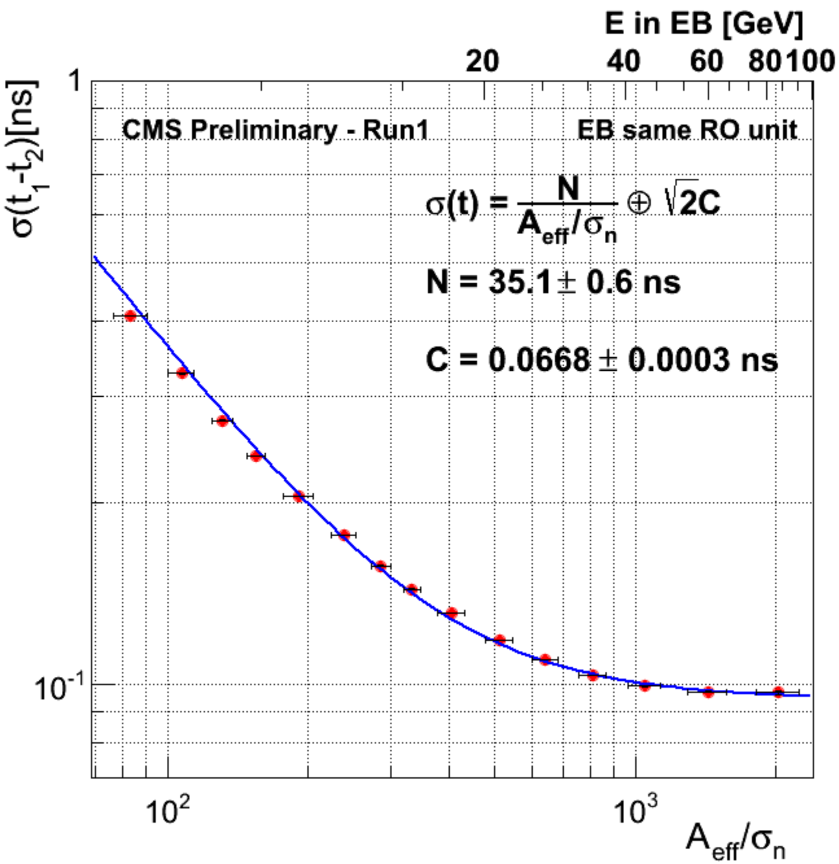
- **Use the relative time resolution of adjacent crystals in photon showers.**
- **Constant term of the resolution measured to be 75 ps.**
- **Energy dependence nicely reproduces test beam results.**
- **Much closer to test beam performance.**

Impact of readout chain

Results from pp collision data at LHC :

- ➢ **Restricting previous study to photons which are contained in crystals sharing the same read out unit.**
- ➢ **Constant term of the resolution improves to 67 ps.**

⇒ **Clock distribution and stability has significant impact. May be optimized for CMS Phase II upgrade.**

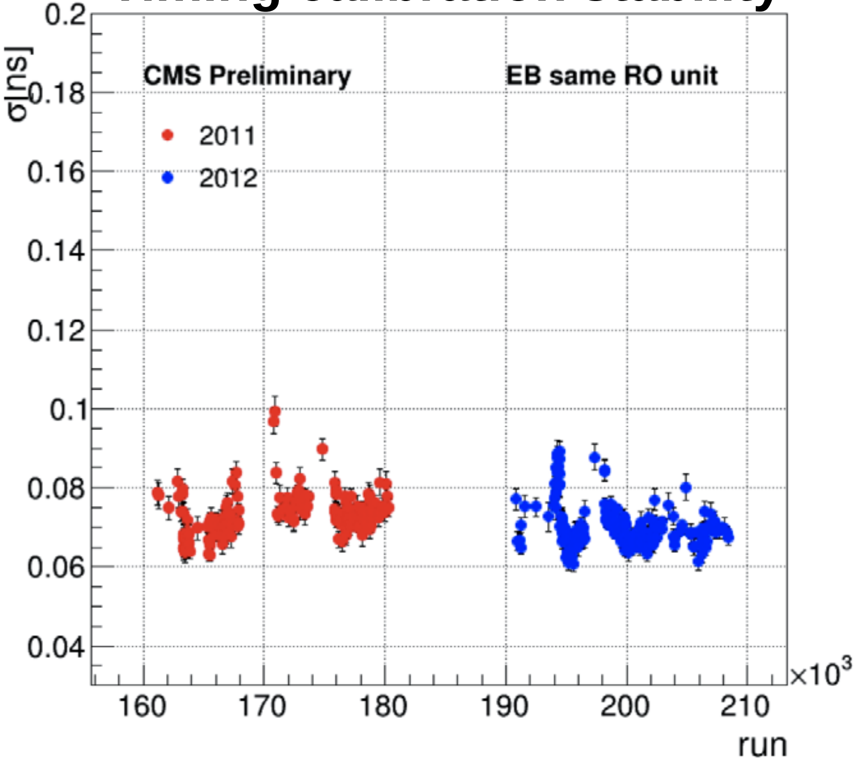


Calibration and Stability

Results from pp collision data at LHC :

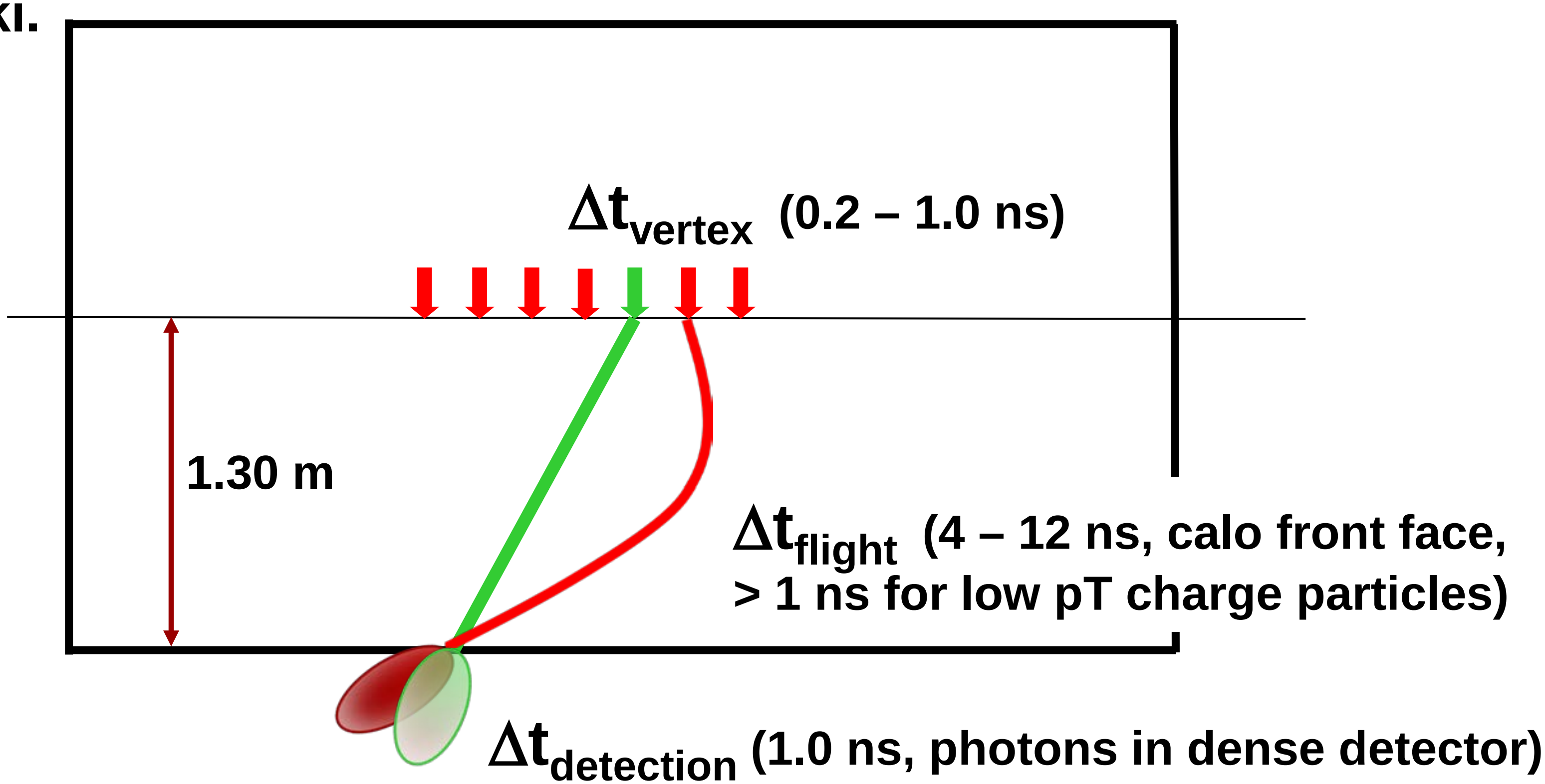
- **Timing response of each calorimeter cell calibrated from collisions data.**
- **Calibration repeated every few months during the 2011/12 data taking.**
- **Main effect to correct for is jump of mean time for sets of readout units.**
  ⇒ Latching units to clock.
- **Linearity of time response calibrated from data.**
- **Further optimization of the calibration currently being investigated.**

Timing calibration stability



Prospects for HL-LHC

- **Very good time resolution of CMS ECAL has triggered R&D effort towards a detector with improved performance for High-Luminosity LHC & CMS Phase II.**
- **Target performance : Resolution of a few 10 ps per ECAL channel.**
- **CMS plans to replace current ECAL barrel electronics and complete forward calorimeter. ⇒ Poster presentation by M. Planer and talk by B. Bilki.**

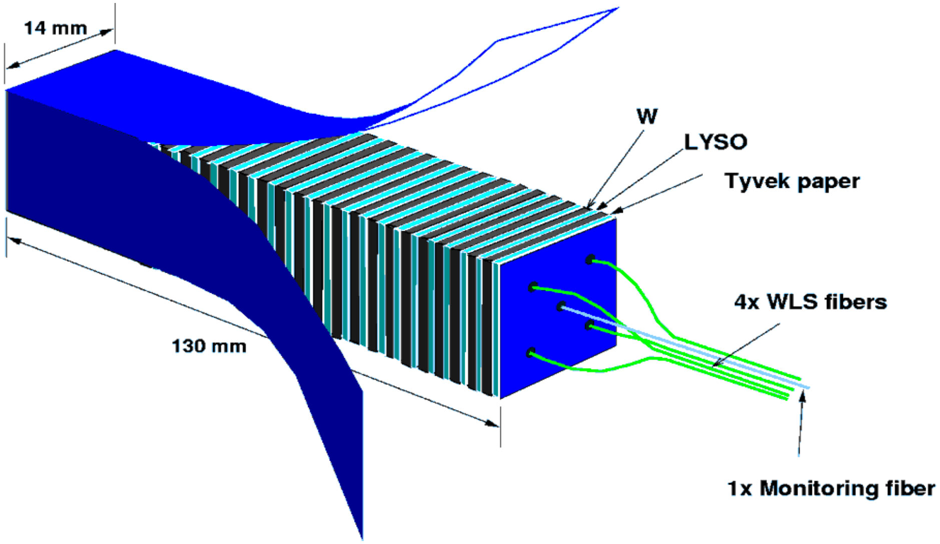


Detector Options for CMS Precision Timing

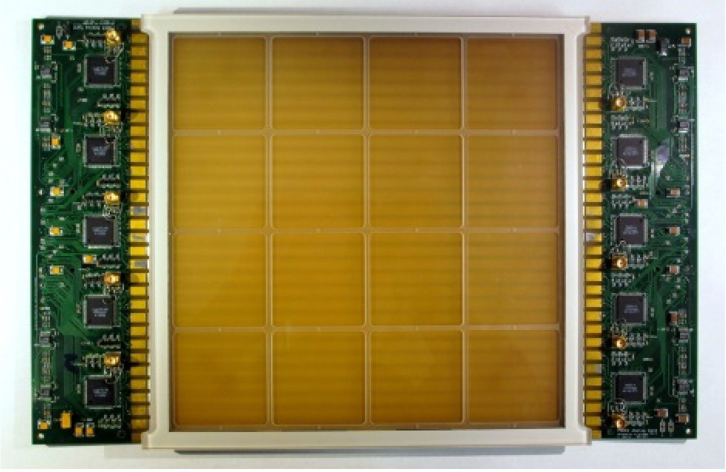
Several R&D projects in CMS geared towards high precision timing capabilities.

- **ECAL barrel (reuse crystals and photo detectors) : optimize readout.**
- **For endcap (complete rebuild) : Extract precision timing from a scintillator based calorimeter as for current ECAL. LYSO/W and CeF/W options under study. See presentation by A. Apresyan (Thursday).**
- **Alternatively, dedicated timing layer in forward detector. Large area MCPs and silicon based options being investigated.**

CMS LYSO/W Shashlik design

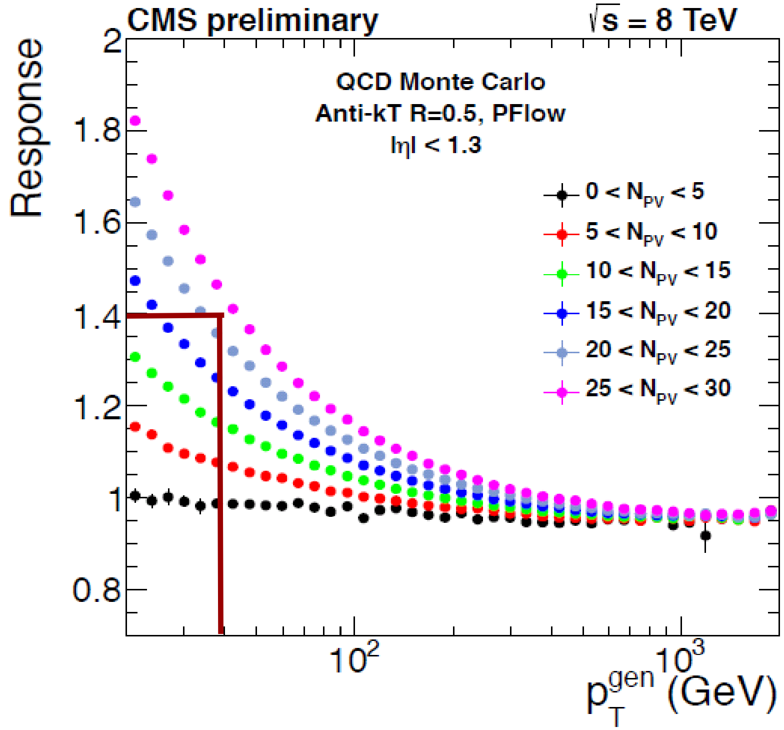


LAPPD large area MCP



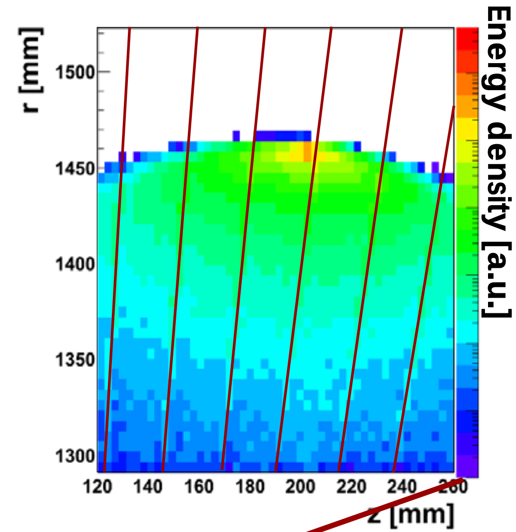
Jet reconstruction with precision timing

- At HL-LHC, expect 140 to 200 simultaneous proton collisions.
- Jets in forward direction will be contaminated with very large amounts of energy from pile-up, exceeding actual jet energy.
- Current mitigation techniques have to be adjusted to high PU.
- Neutral jet component particularly challenging.
- Precise timing allows to reject pile-up energy.

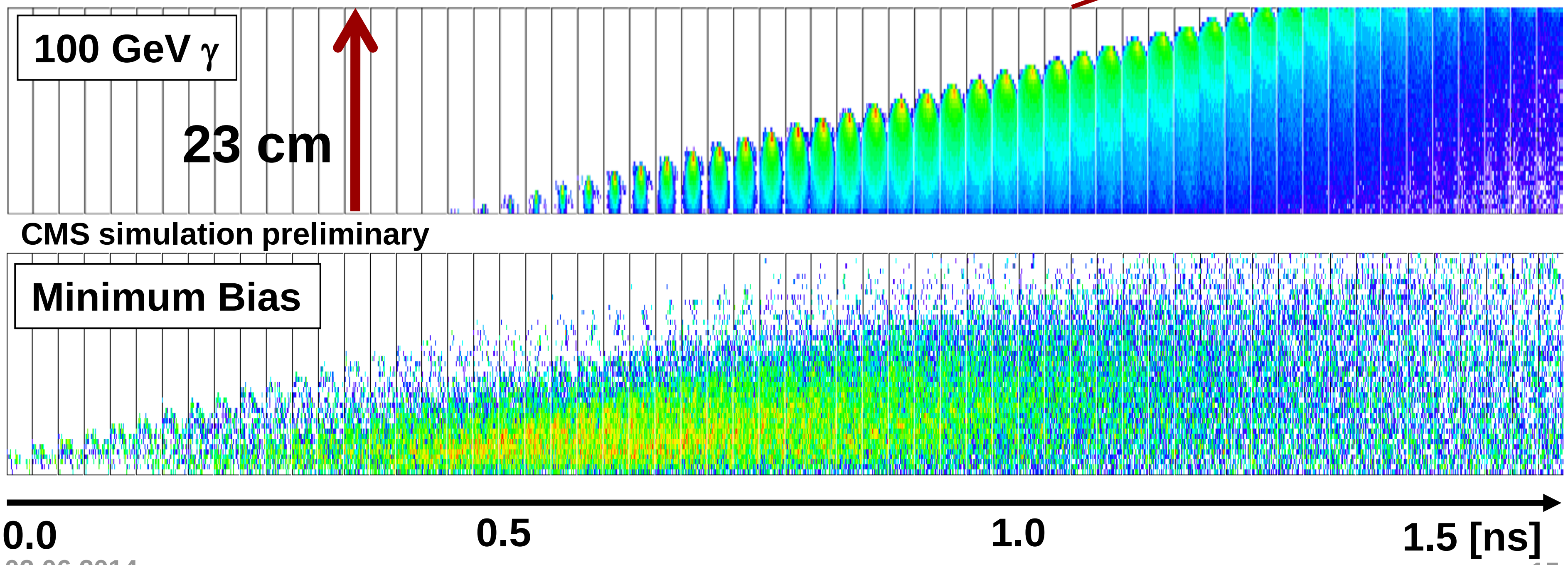


Pile-Up Mitigation with Precision Timing

- We use detailed timing information from GEANT simulation.
- Have to consider 4D time evolution of the shower and signal propagation inside the calorimeter.
- Studies ongoing to validate that the time structure simulated matches the data.

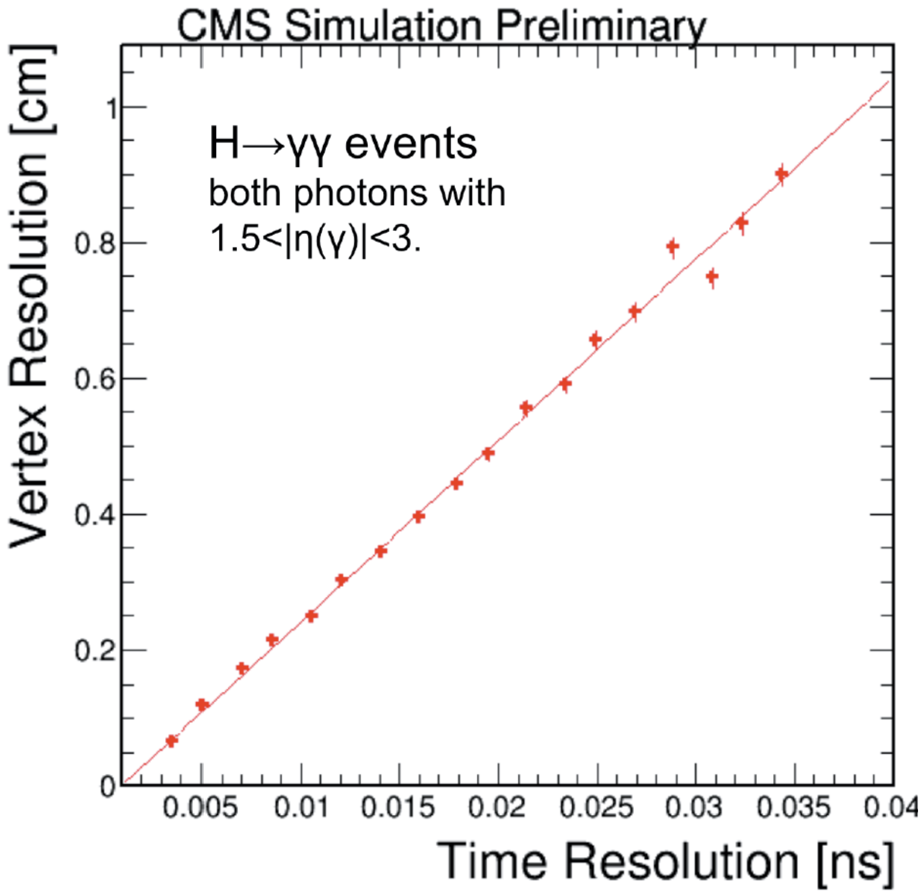


Time evolution of a shower from photon (min bias) in CMS ECAL



Example Study : H→γγ Vertex

- **Adapt CMS simulation package to store timing with the precision of ~1 ps – default is 300 ps.**
- **Validation on H→γγ events : Use 4D information of two photons to calculate vertex location of the H decay.**
- **Find expected performance. For time resolution <40 ps resulting vertex resolution better than in current analysis.**



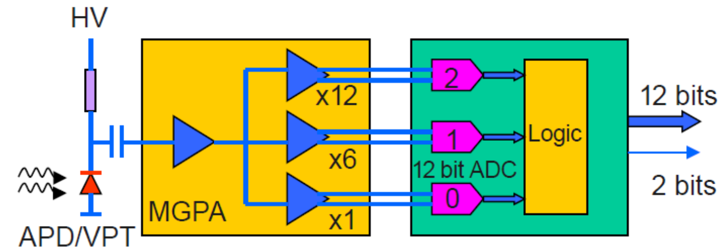
Summary

- The CMS ECAL achieves a timing resolution of 180 ps for high energy electromagnetic energy deposits in proton collisions at LHC.
- The constant term of the timing resolution in adjacent crystals of the same shower was found to be 20 ps in the test beam and below 70 ps in collision data.
- Improvements to the ECAL barrel readout chain and a rebuilt of the endcap calorimeter offer opportunities to improve the single shower timing resolution to a few 10 ps for CMS Phase II upgrade.
- Benefits of a precision timing detector for the CMS event reconstruction at HL-LHC are currently being studied.
- R&D on precision timing calorimeter for HL-LHC is ongoing.

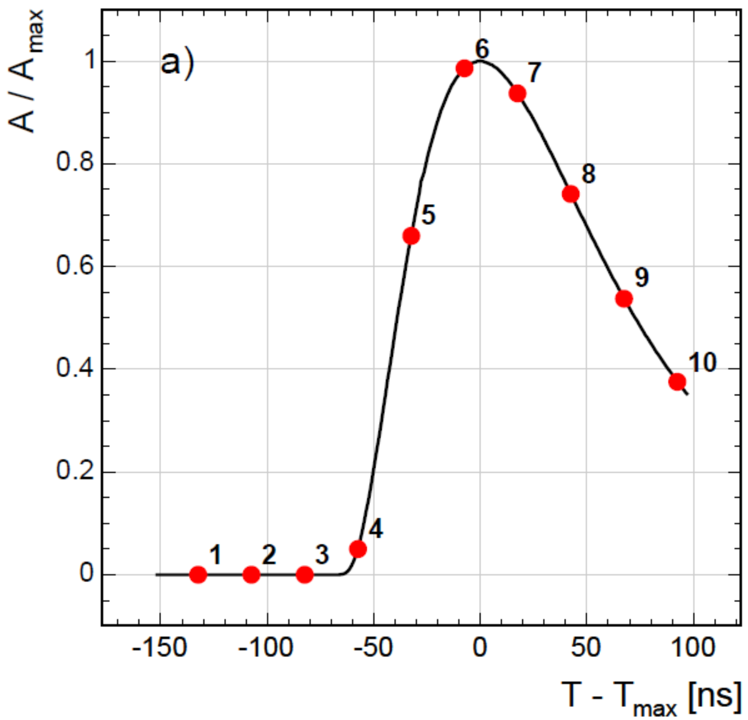
Backup

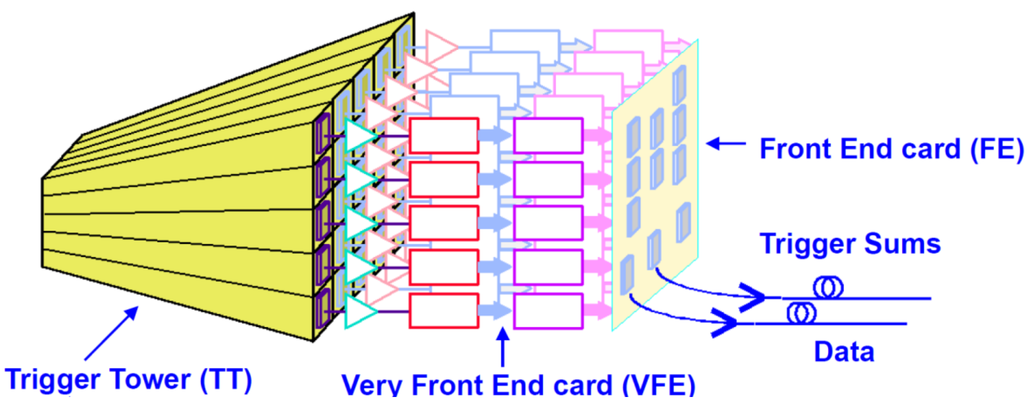
CMS ECAL Readout

- Low noise preamplifier :
  - 40 ns shaping time
  - 40 MeV noise per channel (barrel)
  - 1 ADC count noise per sample
- On-detector ADC :
  - 40 MHz sampling
  - Currently 10 samples readout (programmable)
- A matrix of 5x5 crystals share a common clock distribution (readout unit – RO).



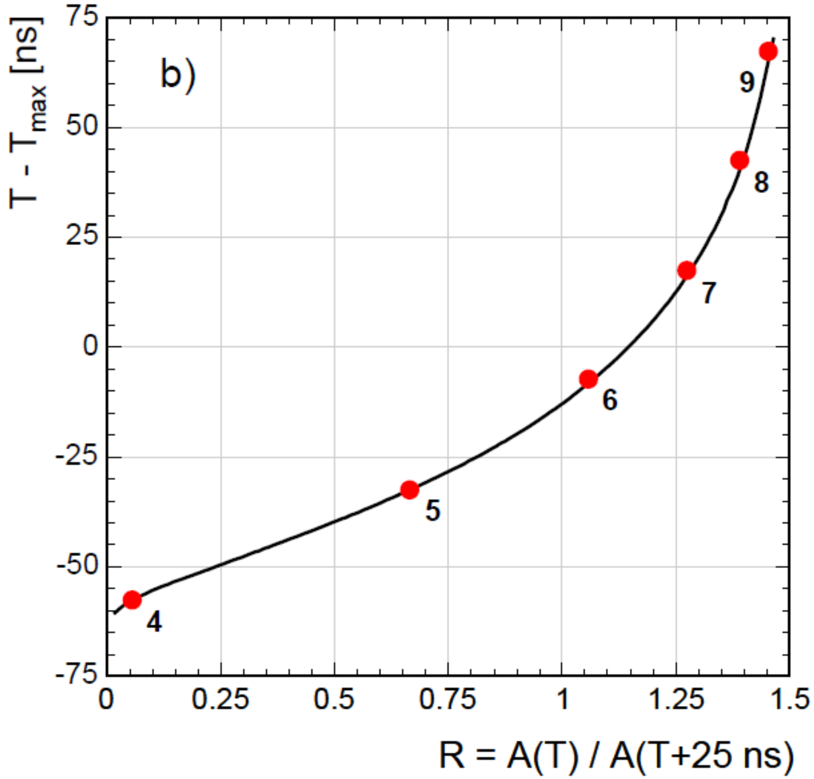
VFE architecture for single channel
0.25 μm IBM CMOS process





Time reconstruction

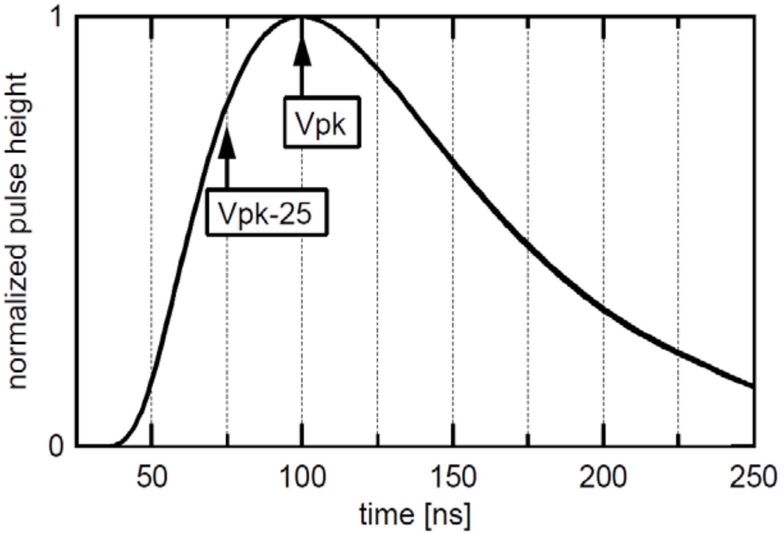
- Time information is extracted from ratio R=A(T)/A(T+25 ns) of consecutive samples.
- Pedestal samples (1 to 3) are not considered.
- Highest sensitivity from sample 5 in the rising edge of the pulse.
- Online timing synchronized among channels to approximately 1 ns. Sufficient for online operation.
- Each channel calibrated offline every couple of months during the 2011/12 LHC run one.

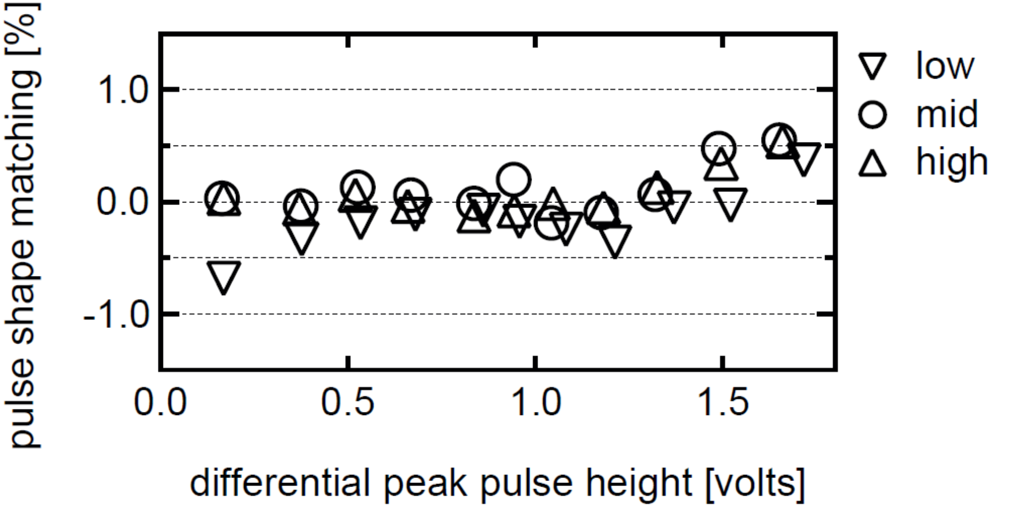


- Current offline usage : Background rejection (instrumental, physics, accelerator), optimize energy reconstruction.

Pulse Shaping

- Pulse shaping optimized to achieve 0.5% resolution for the constant term of the energy resolution.
- Design target : Pulse shape reproducible and stable within 1%.
- Collateral benefit : Very precise timing extraction from the 10 samples.





$PbWO_4$ Scintillation kinematics

- Scintillation light decay kinematics of $PbWO_4$ depend on the doping and many other external parameters.
- CMS $PbWO_4$ crystals have 80% of the scintillation light emitted within 10 ns of the start of the shower.
- Precise measurements of the rise time are sparse.
- Details of the decay time spectrum more complex, often described by 3 time constants.