Thanks to

P. Antonioli (ALICE)
A.M. Henriques Correia (ATLAS)
N. Harnew (LHCb)
C. Tully (CMS)
S.Fartoukh (LHC)

Large Area Timing Detectors

Tommaso Tabarelli de Fatis (CMS)
Università and INFN di Milano-Bicocca

Large area timing detectors at (HL)-LHC

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- **Conventional use of timing detectors:**
  - Particle identification in Time-of-Flight systems
- *One successful example at LHC:*
  - ALICE - TOF: 80 ps over 140 m^2
    [low rate environment ~ 0.1 kHz / cm^2]
- *One R&D ongoing for LHC detector upgrades:*
  - LHCb -TORCH: aim at ~15 ps per track
    [higher rate environment ~ 1 hit / cm^2 every 25 ns]

- **Proposed use of timing detectors at HL-LHC:**
  - Pileup mitigation with combined time and vertex reconstruction
- Potential and feasibility being considered by ATLAS and CMS
- ***Focus of this talk***

Vertex density at HL-LHC

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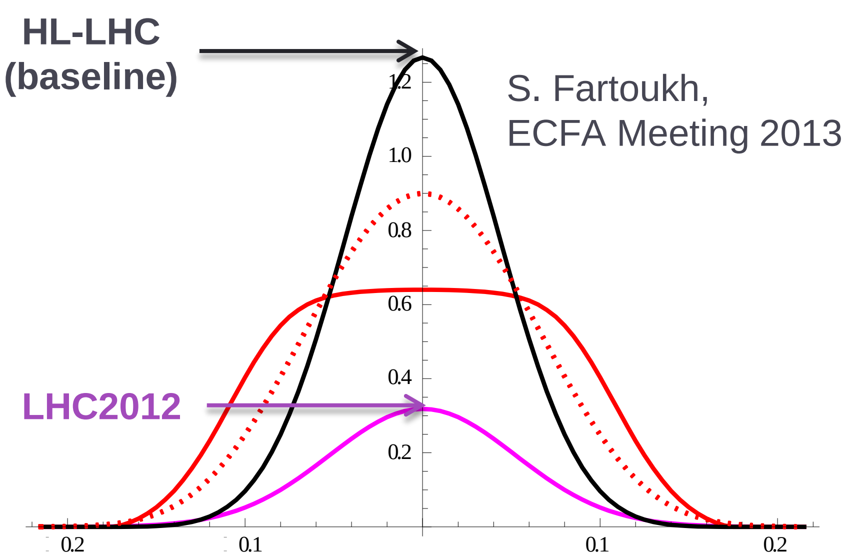
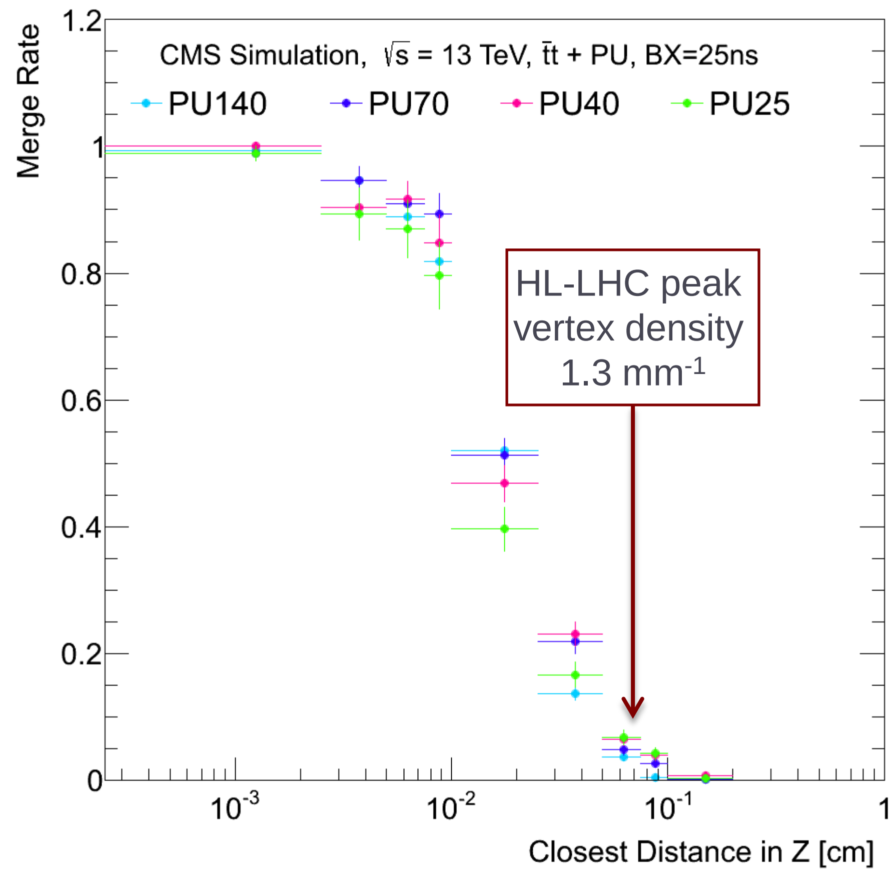
- **At densities >1 mm^{-1} individual (charged) particle association to an event vertex becomes strained**
  - About 10% of vertices merged at 140 pileup (baseline optics)



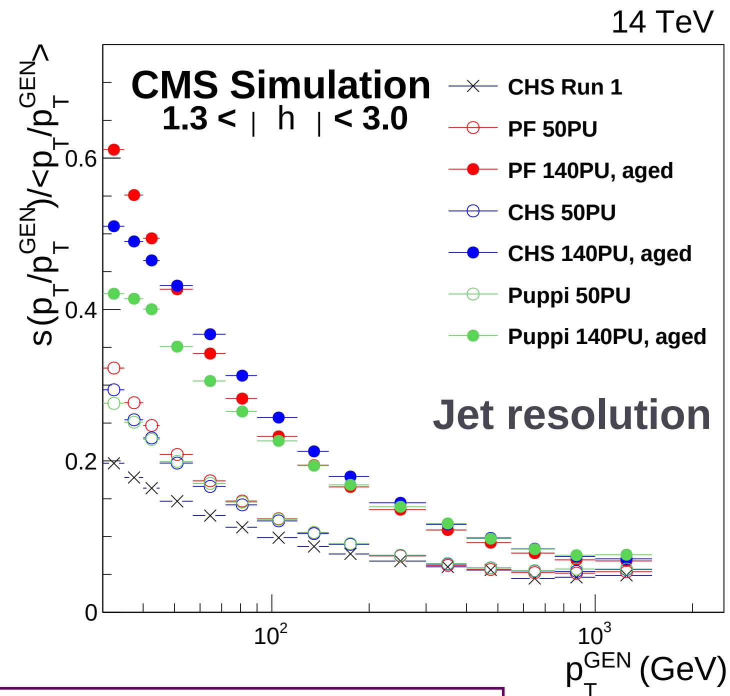


[CMS Tracking performance studies, 2014]

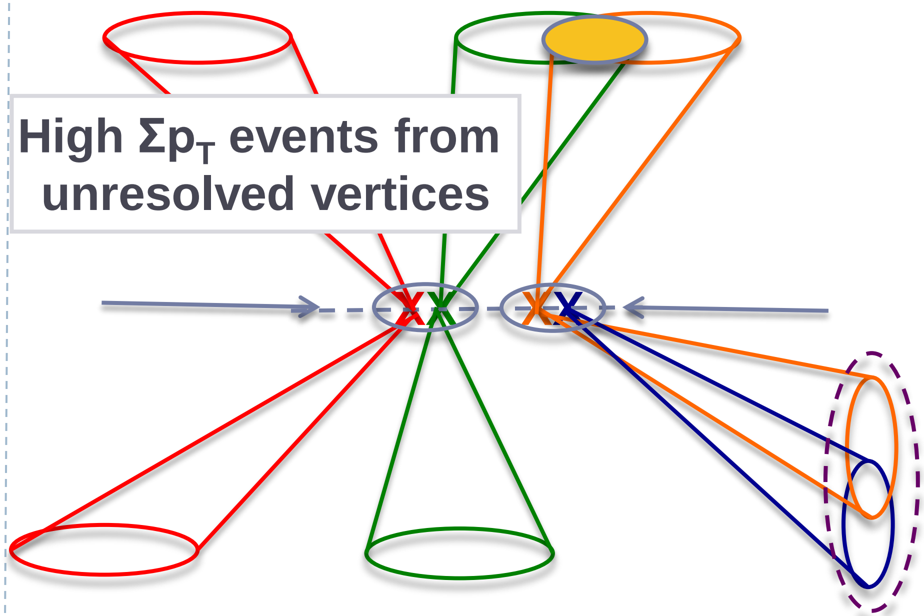
  - Peak density: 1.3 (1.8) mm^{-1} for 140 (200) collisions per BX

Event reconstruction challenges

Extra energy in jets / isolation cones from overlap of (neutral) particles



High Σp_T events from unresolved vertices



Merged jets from spatially unresolved vertices

- With timing information for photons and charged tracks (vertex time):
  - Correct association of photons to jets
  - Improved jet definition / Identification of merged jets
  - Track / vertex compatibility

e.g. M.Mannelli, ECFA 2013; S.White, arXiv 1309.7985

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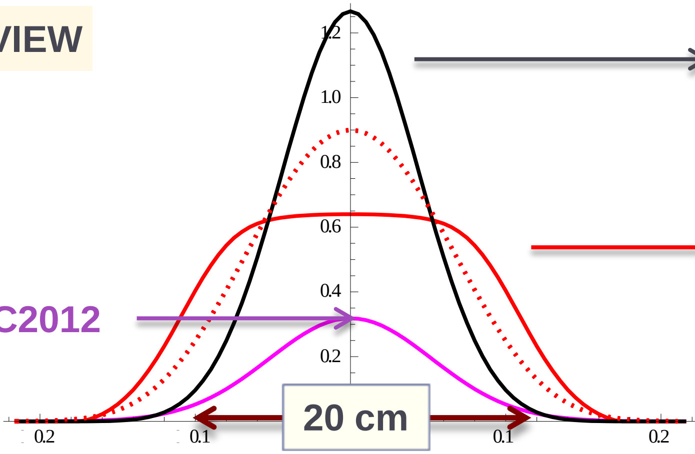
Dissect collisions with time

- **Spread of collision time ~ 160 ps**
- **‘Effective *pileup*’ similar to current LHC with ~20 ps resolution**
  - *[or can read this as “with better timing could stand even higher pileup”]*

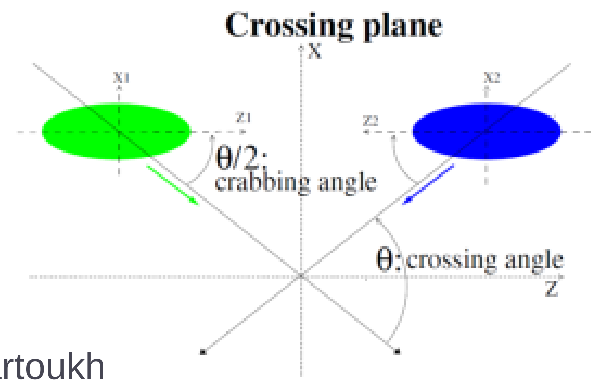
Z-VIEW



LHC2012

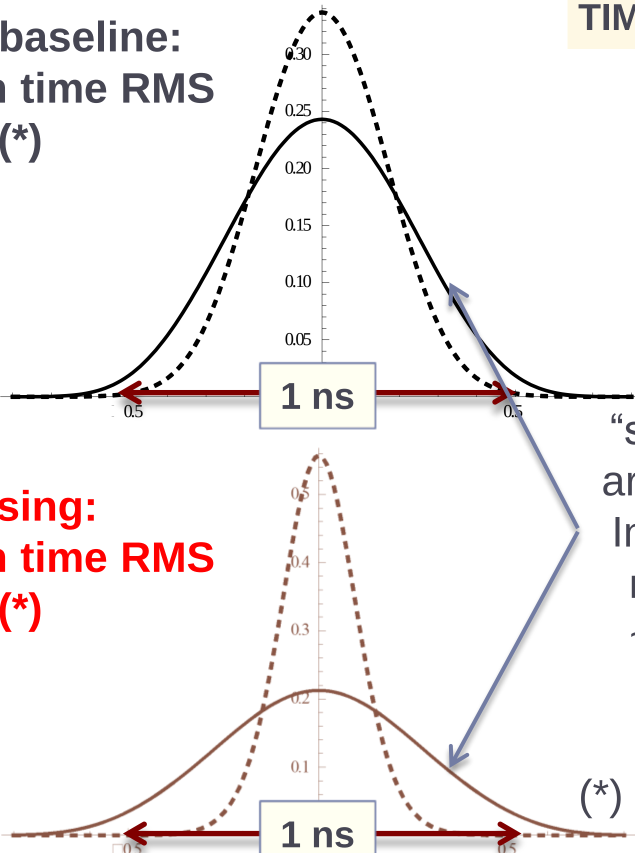
HL-LHC baseline: Collision time RMS ~160 ps (*)

Crab kissing: Collision time RMS ~100 ps (*)



S. Fartoukh

TIME-VIEW



“spread of arrival time In forward regions” ~250 ps

(*) At fill start

Example study: individual particle time

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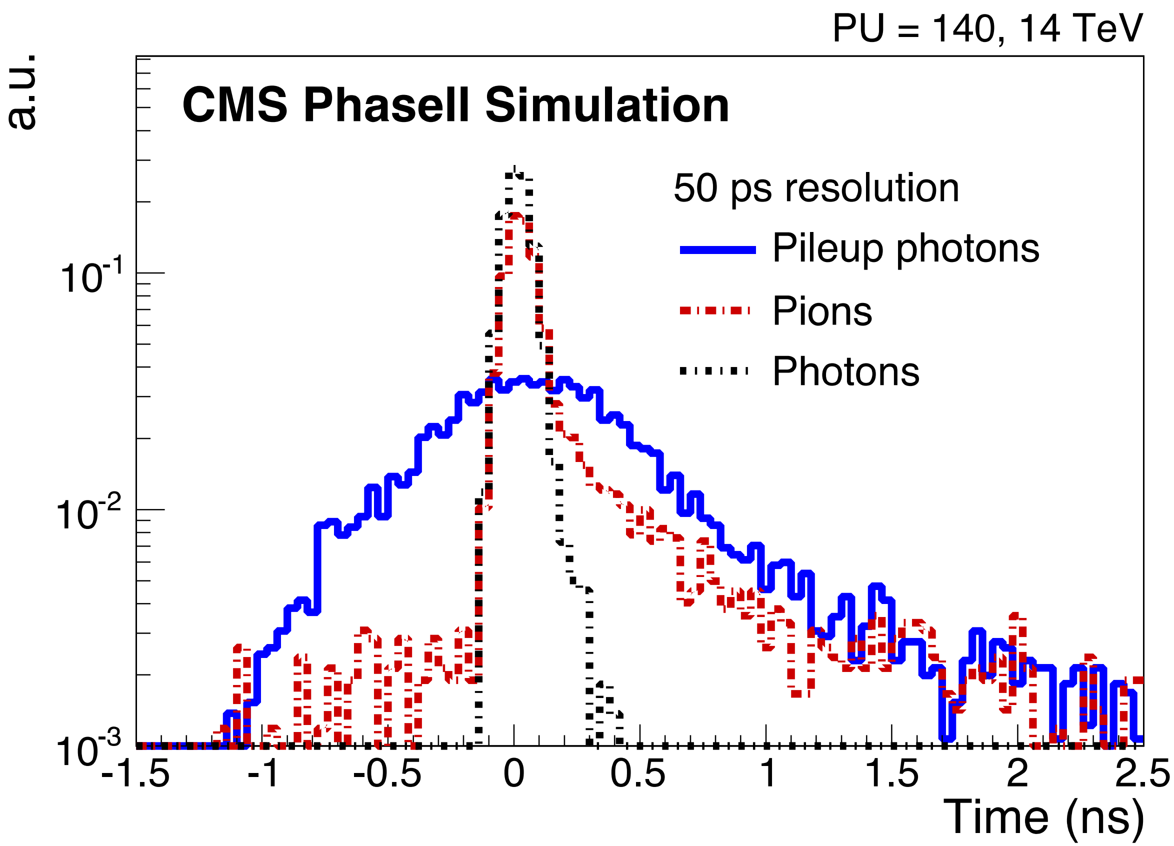
Time spread of prompt and pileup photons and pions at ECAL

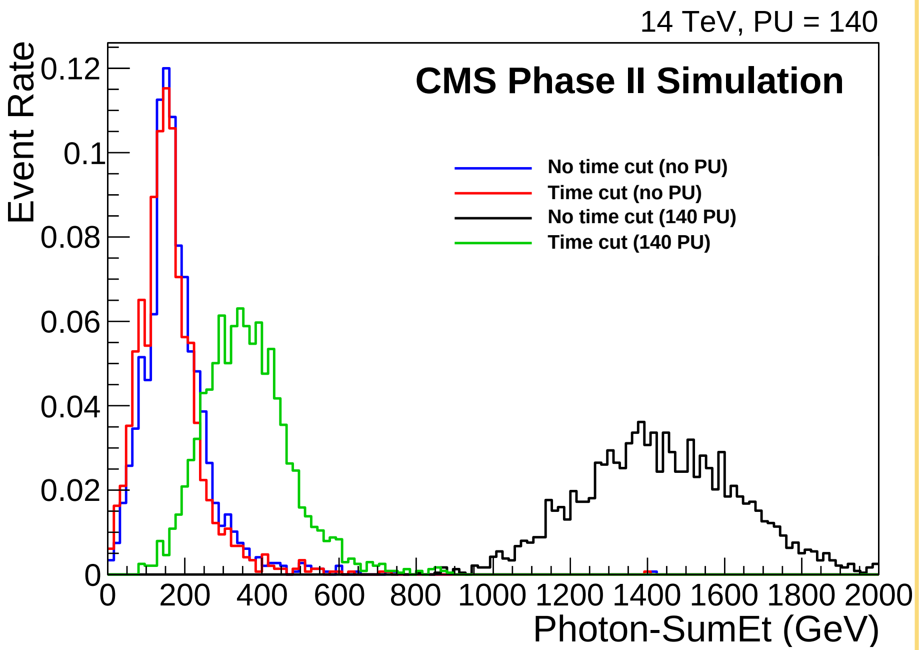


- TOF from the primary collision vertex to the ECAL cell
- [No dedicated timing detector]
- Assumed time resolutions ~ 50 ps
- Photon/pion time from cluster with highest energy deposition

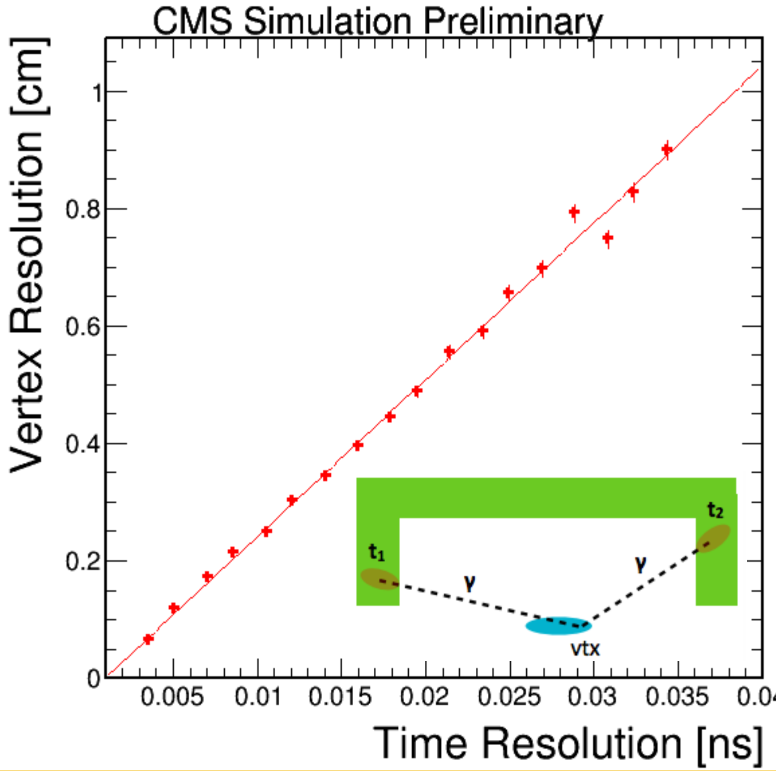
Example study: H -> γγ

[CMS CR-2014-074]

Total photon transverse energy (ΣE_T):
→ effective removal of *pileup* photons



By product of fast timing:
→ diphoton vertex location



- **Has to identify benchmark signatures to quantify performance gain**

Time resolution ATLAS/CMS – Run I

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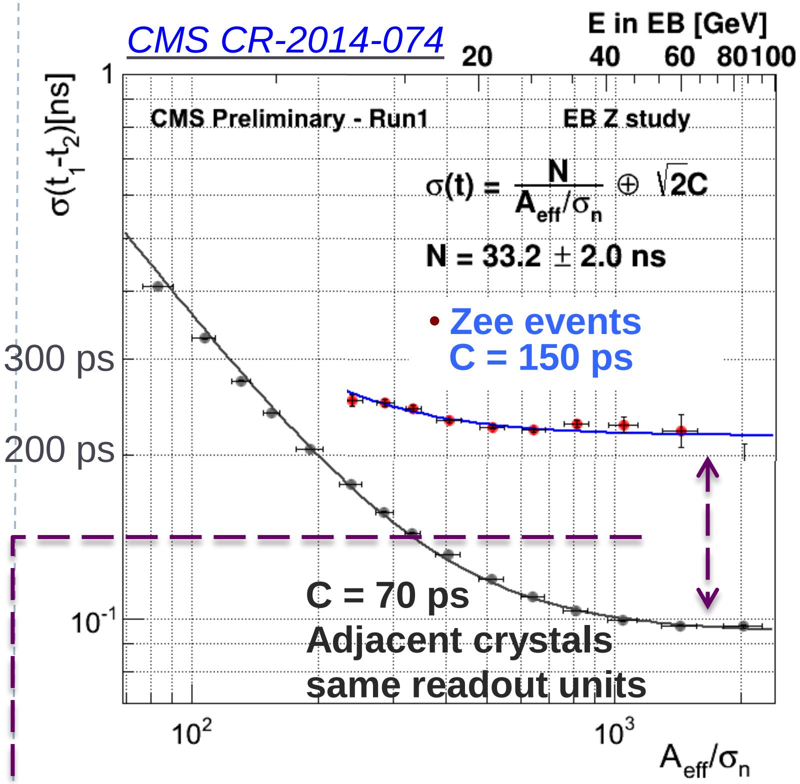

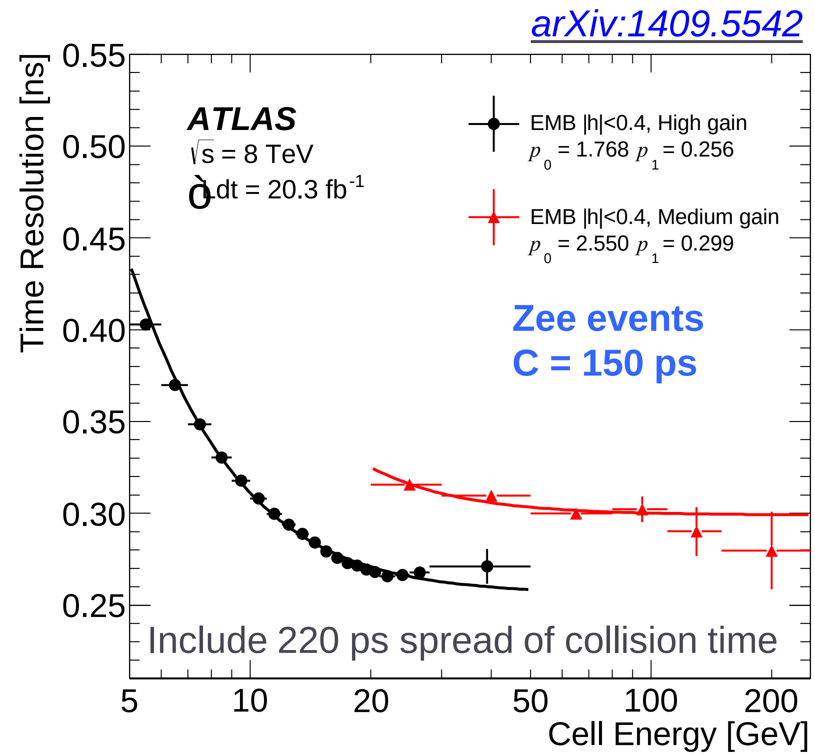

- **Similar time resolution in ATLAS and CMS**
  - Clock jitter, time calibration stability, …
  - Below ~20 GeV resolution dominated by noise term
    - Insufficient for pileup mitigation purposes

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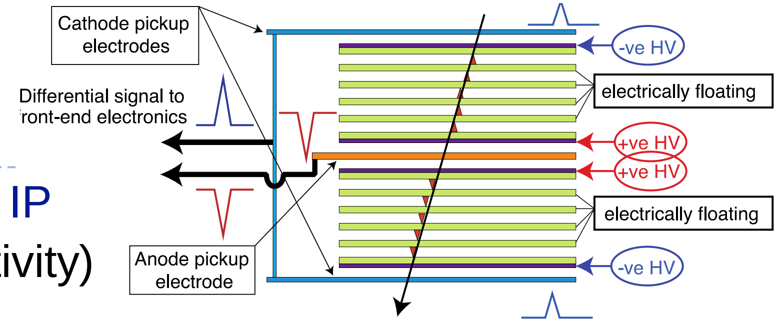
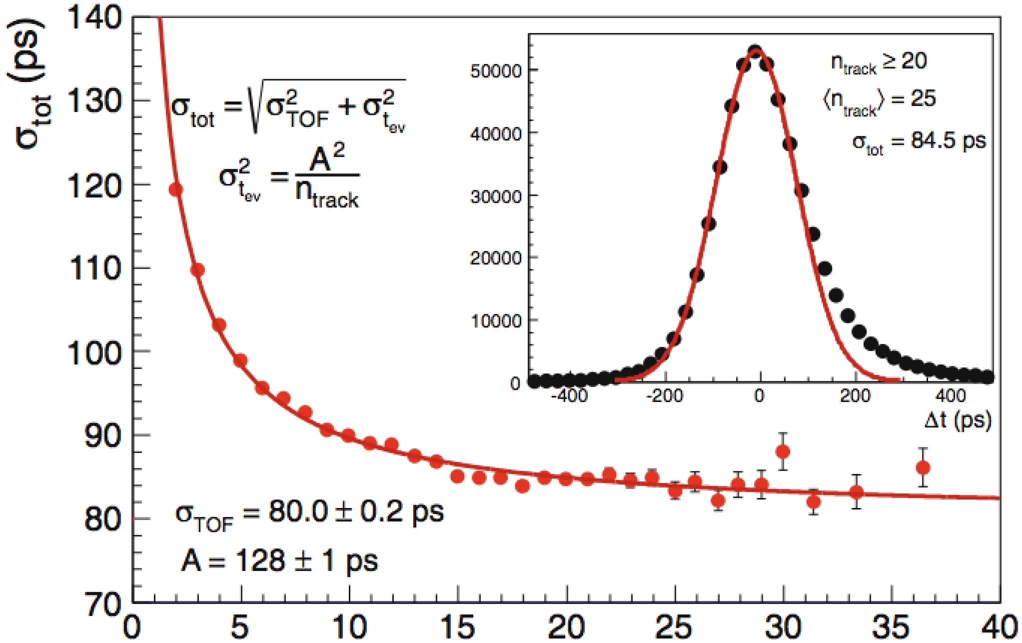
ALICE TOF



- **140 m² of Multigap RPCs** at 3.7 m from the IP
  - Rate capability ~100 Hz/cm² (glass resistivity)
- **Fast readout electronics (10⁵ channels)**
  - Leading edge disc. with time-over-thresh correction (NINO)
  - HPTDC time to digital converter

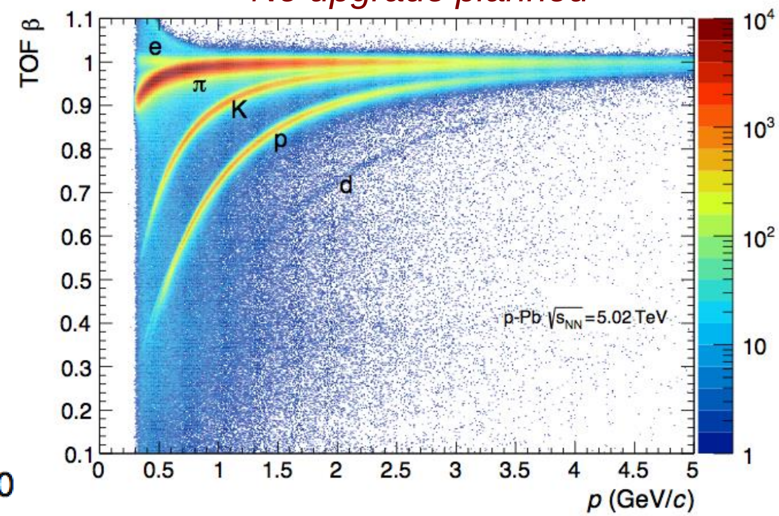
[Aghinolfi et al. NIM A533 (2004) 183]
[J.Christiansen, 2004]

- **Single particle resolution *in situ*: 80 ps (aimed 100 ps)**
  - *40 ps at test beam + time-walk in pads, clock, channel calibration, …*



arXiv:1402.4476

Performance matches design
[can still improve calibration]
No upgrade planned



LHCb – TORCH R&D

[LHCb, NIM A 639 (2011) 173]

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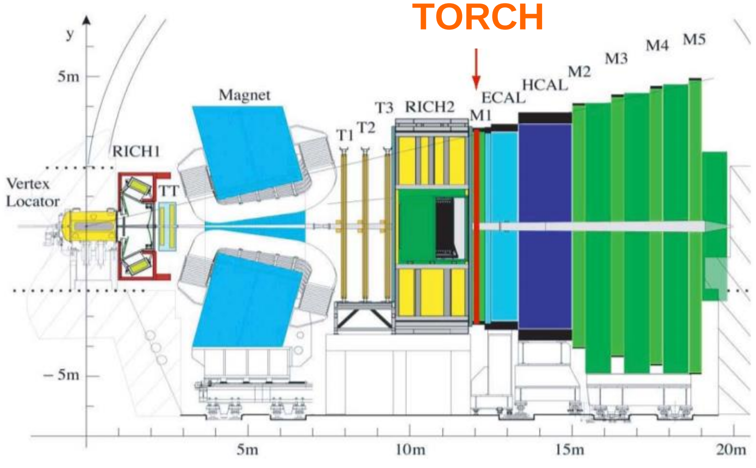
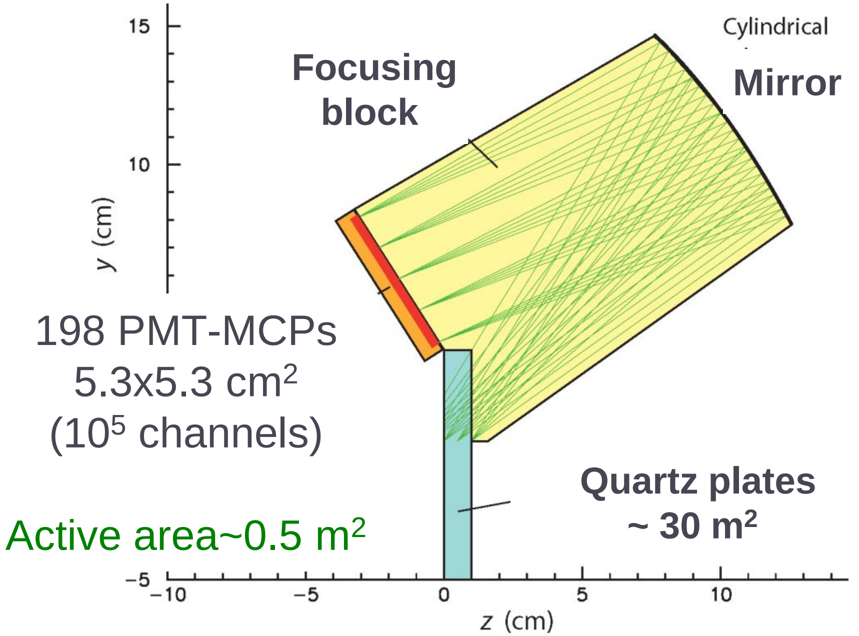
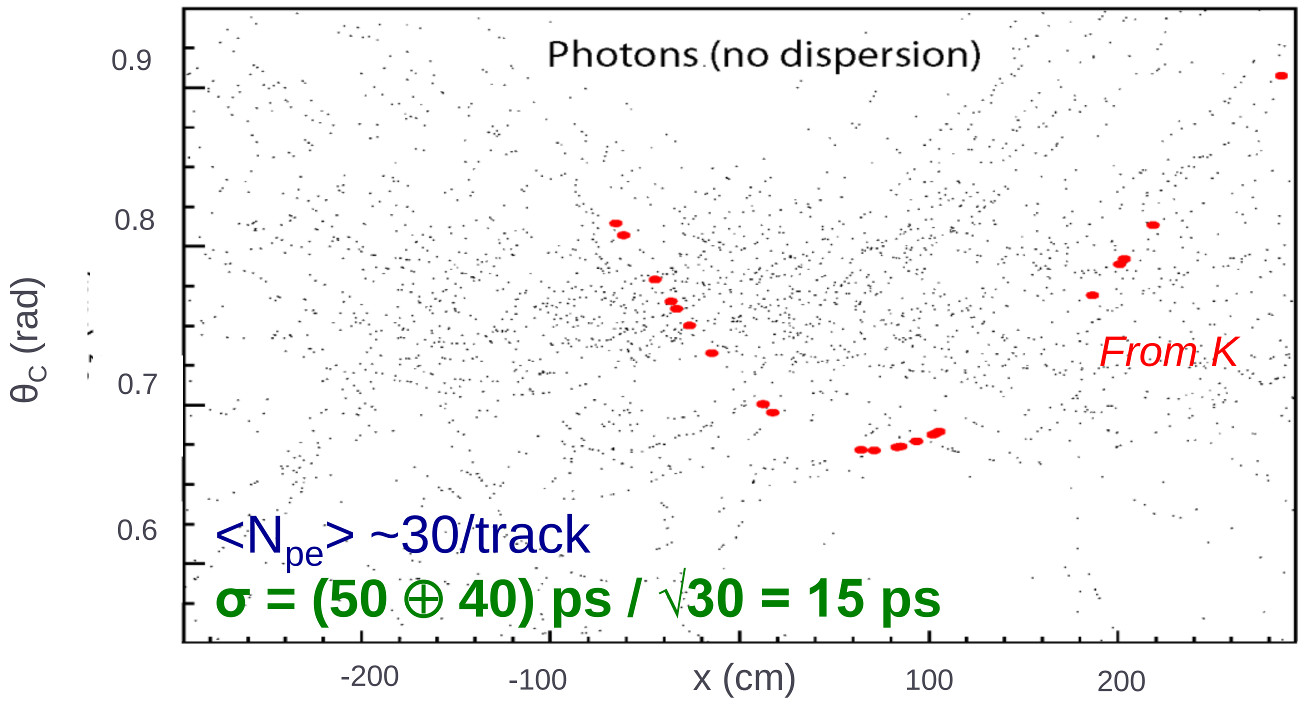
- **TOF using Cherenkov emission readout via total internal reflection**
  - Position measurement of detected photons to correct time for photon path
  - Residual spread ~**50 ps** (defines pixel size)
- **Photon detector: pixelated PMT-MCPs**
  - Readout chain based on NINO + HPTDC
  - $\boldsymbol{\sigma_{p.e.}}$ **~ 40 ps** (including readout)





LHCb – TORCH R&D

- **Boost precision with multiplicity [i.e. system aspects < 10 ps]**



- **Proposal to LHCb upon completion of the R&D phase (by 2016)**
  - Customized pixel size, high active area, extended PMT-MCP lifetime, …

Detector concepts ATLAS/CMS Upgrade

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- **Timing of photons to ~20 ps**
- **Timing of vertices (< 20 ps) from charged particles**
  - Granularity of order 1 cm^2 (time-walk, occupancy, shower size)
  - Active area of order 10 m^2 (endcap only) for ~10^5 channels
  - Rate capability: 10^6-10^7 Hz
  - Radiation hardness: 10 Mrad – $10^{15}/cm^2$

I. **Shower Max –** *dedicated layer(s) embedded in the EM calorimeter or from the full longitudinal EM energy profile*

II. **Timing Layer –** *a low-mass accompaniment to a silicon tracking system situated in front of a calorimeter system*

III. **Pre-shower –** *front compartment of the electromagnetic calorimeter - balancing low occupancy MIP identification with EM showering*

ATLAS Phase II options for timing

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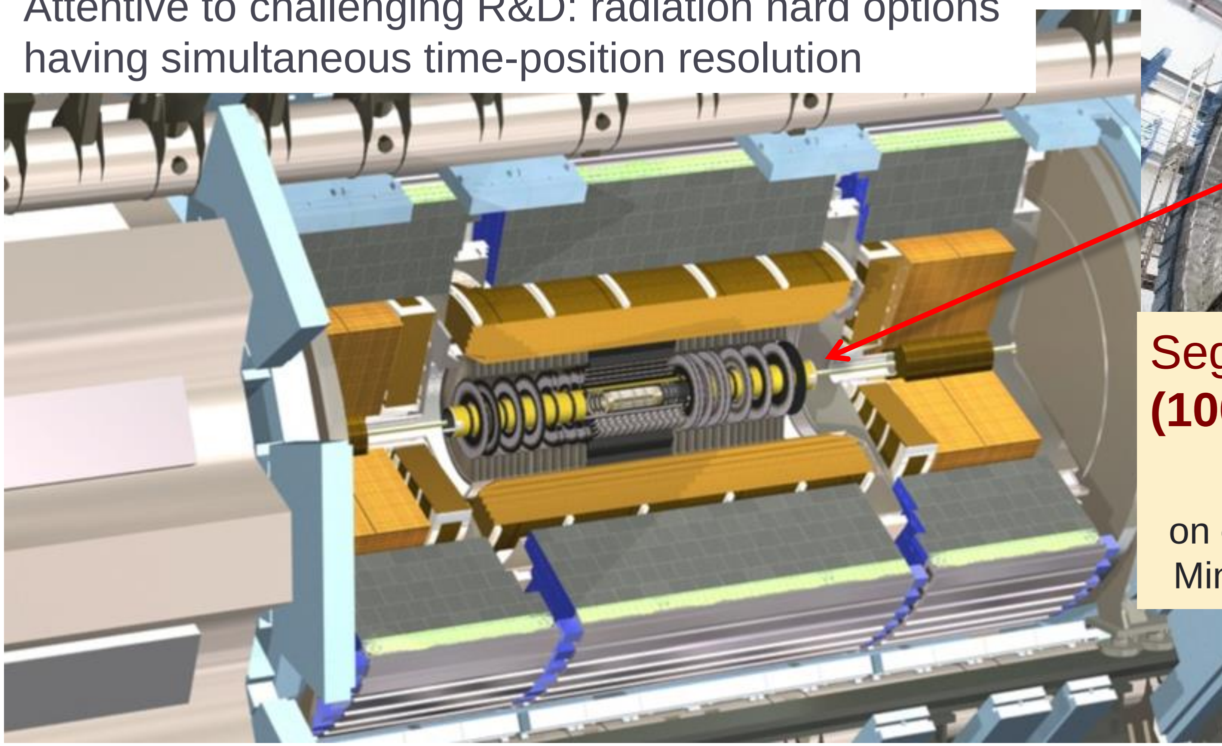
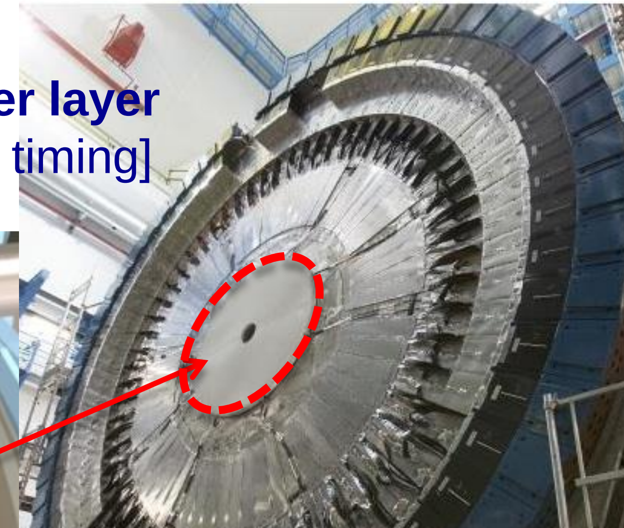
- **Options for a fast timing layer in front of the endcap calorimeters:**
  I. **Tracking extension**
  II. **Pre-shower or highly segmented calorimeter layer for e/γ ID** [e.g. Si/W layers with high-precision timing]

Attentive to challenging R&D: radiation hard options having simultaneous time-position resolution





Segmented timing detectors
(100 μm; ~10ps) at 2.5<η<4

Area ~ 5 m² (5 cm depth)
on each z-side from removal of the Minimum Bias Trigger Scintillators

From A.M. Henriques Correia

- Expected performance assessment and recommendations by ~March 2015

CMS Phase II options for timing

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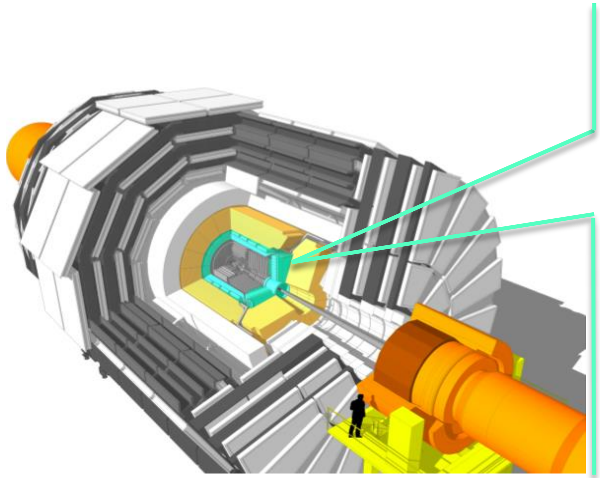

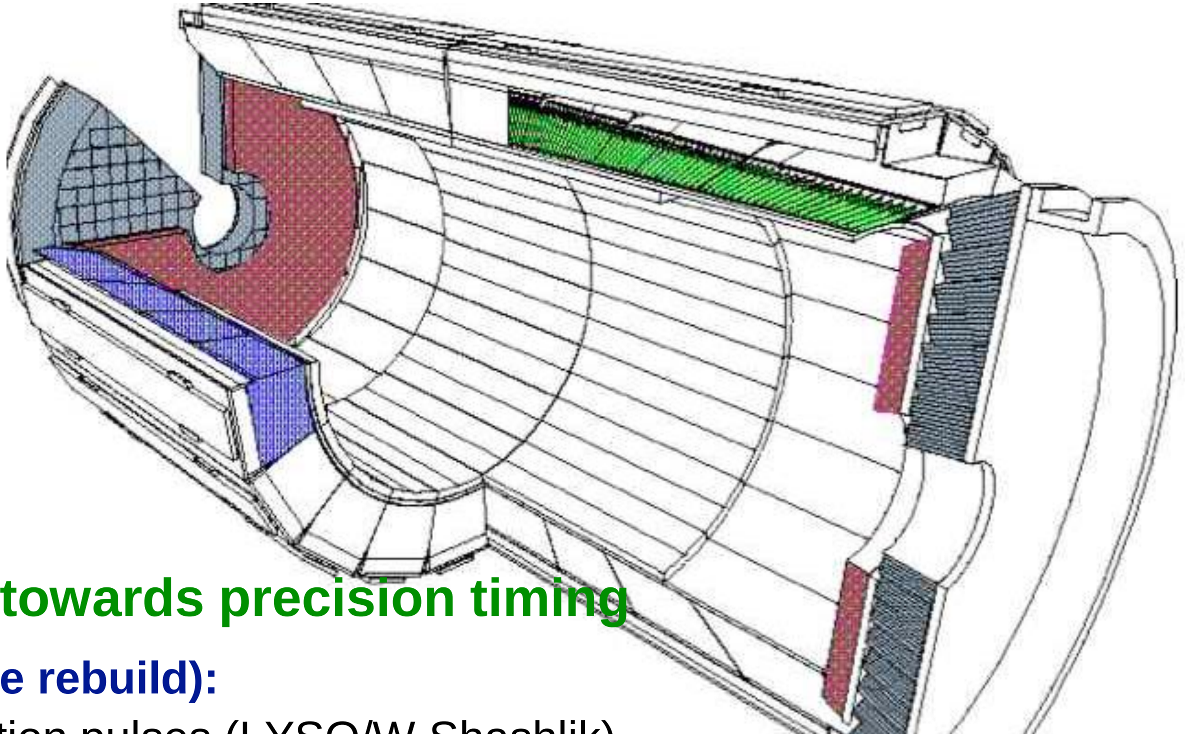

- **Several R&D projects towards precision timing**
  - **ECAL endcap (complete rebuild):**
    I. Timing from scintillation pulses (LYSO/W Shashlik)
    II. Dedicated timing layer (W/Si sampling calorimeter)
    III. Timing layer in a preshower (either calorimeter)
  - ***Barrel: may optimize ECAL readout electronics***
    - *[thin timing layer at the end of the tracker?]*

$1.5 < \eta < 3$
~7 m^2 each side

- Performance assessment and recommendations by ~ September 2015

Detector technologies: some examples

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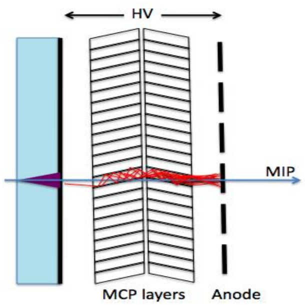
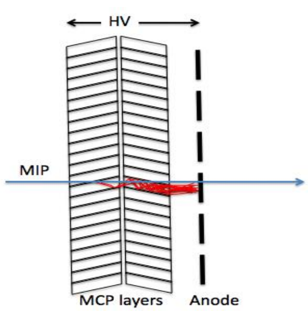
Micro-channel plate detectors

- Coupled to a Cherenkov radiator:

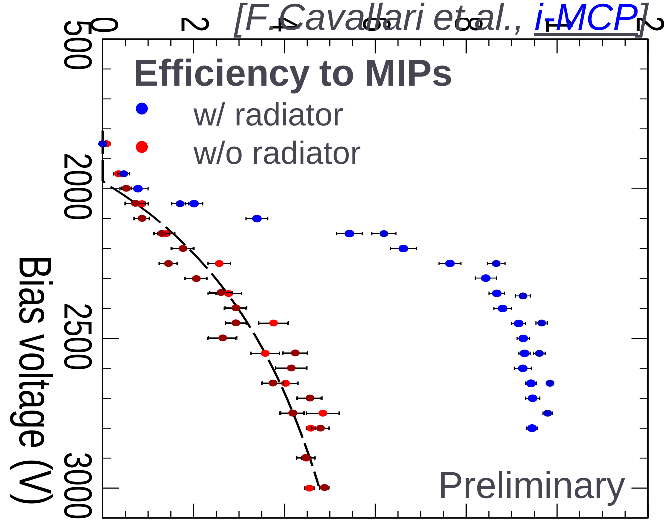


  - **20-30 ps in shower detection at beam tests**
    - *[A.Ronzhin et al, NIM A 759 (2014) 65]*
  - Confirms results on MIPs with PMT-MCPs obtained by several groups *[e.g. ALICE FIT-T0+, W.Riegler, ALICE Upgrade, this Workshop]*

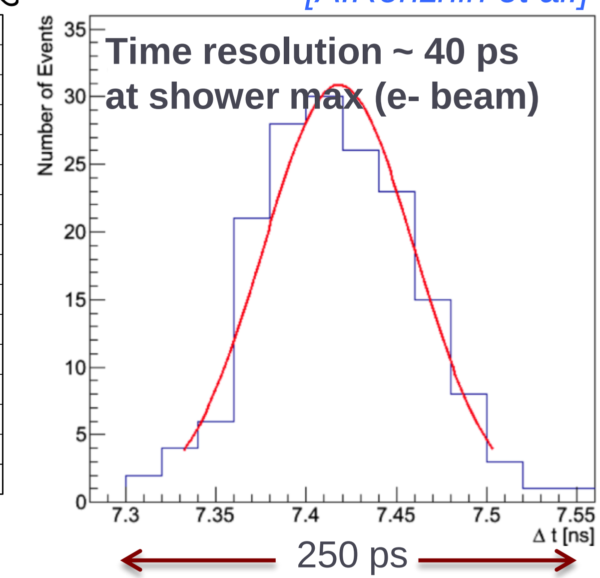
- Secondary emission device:



[F.Cavallari et al., i-MCP]



[A.Ronzhin et al.]



Detector technologies: some examples

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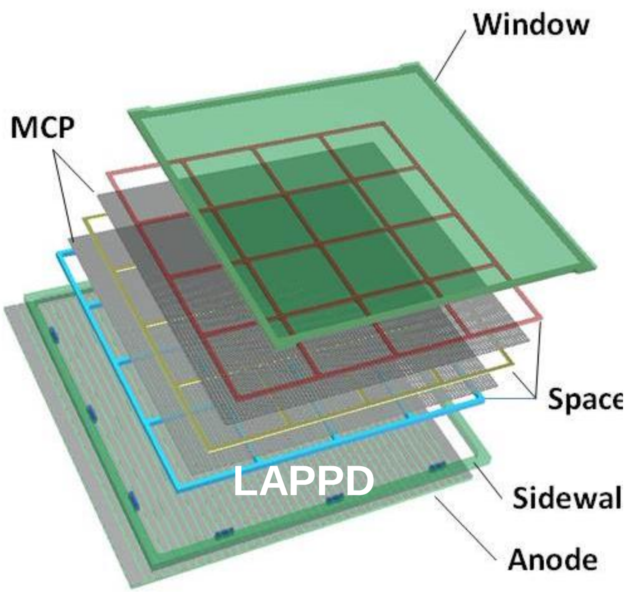
Micro-channel plates R&D aspects

- *Operation in Magnetic field (tested up to 2 T)*
- *Need lifetimes above 50 C/cm^2 (x 10 TORCH)*
  - Achieved >5 C/cm^2 in PMT-MCPs with Atomic Layer Deposition (ALD) coatings
    [e.g. PANDA ToF: A.Lehmann et al., NIM A718 (2013) 535]

R&Ds in several groups (not only LHC)

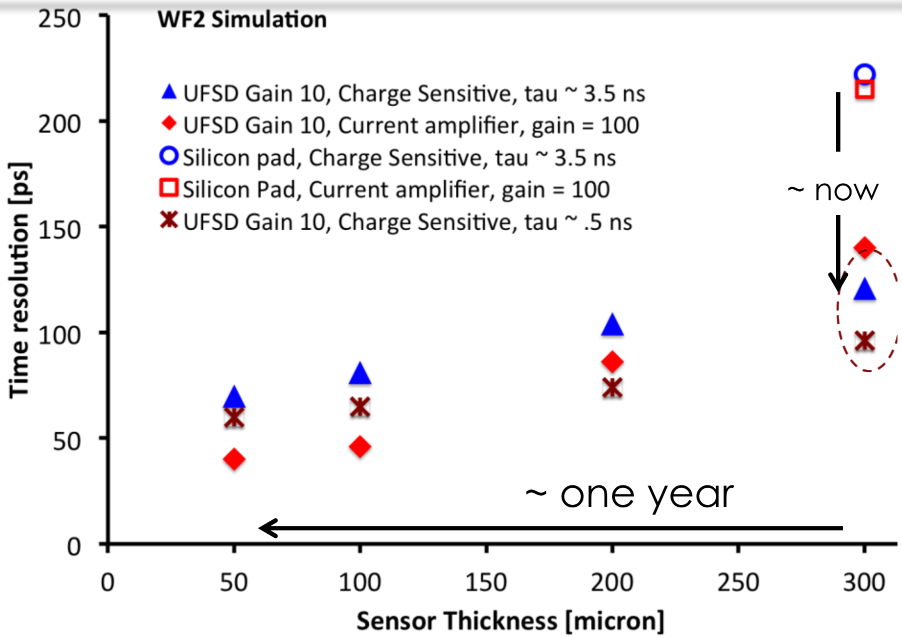
- LAPPD collaboration → R&D towards mass production of large area MCPs
  [LAPPD Docs: http://psec.uchicago.edu/]



Detector technologies: some examples

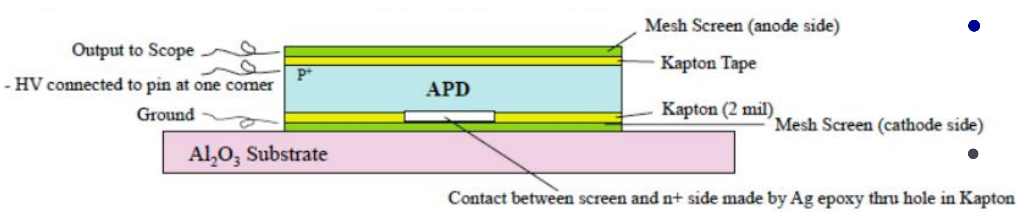
Si sensors with amplification

- *Fast response in wide pixels*
- *Radiation hardness, …*



- **Ultrafast (thin) Silicon Detector (low gain)**
- *R&D for the upgrade of the CT-PPS (CMS/Totem) timing detector*
- *Small size pixels*

[N.Cartiglia, CERN Seminar, 2014]



- **High gain APDs with capacitive coupling to an external mesh**
- Fast timing over wide (1 cm^2) pixels

[S.White, arXiv 1409.1165]

Detector technologies: some examples

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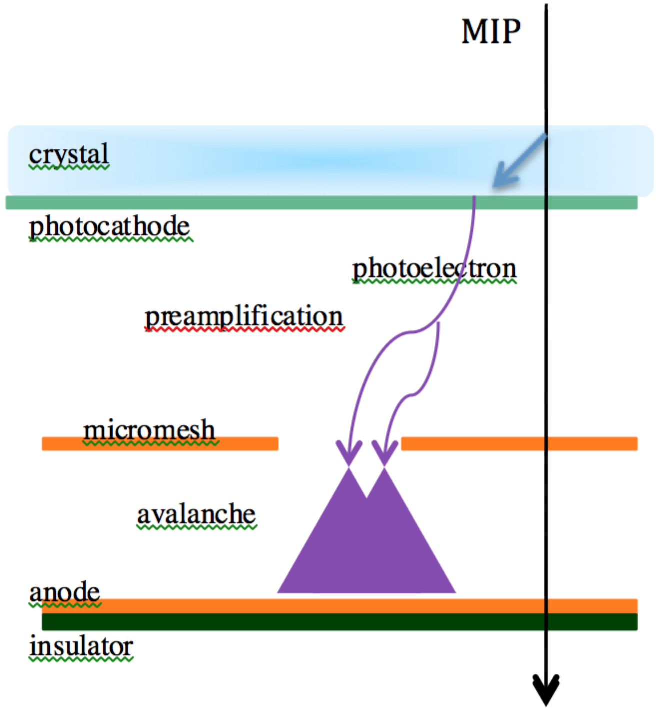
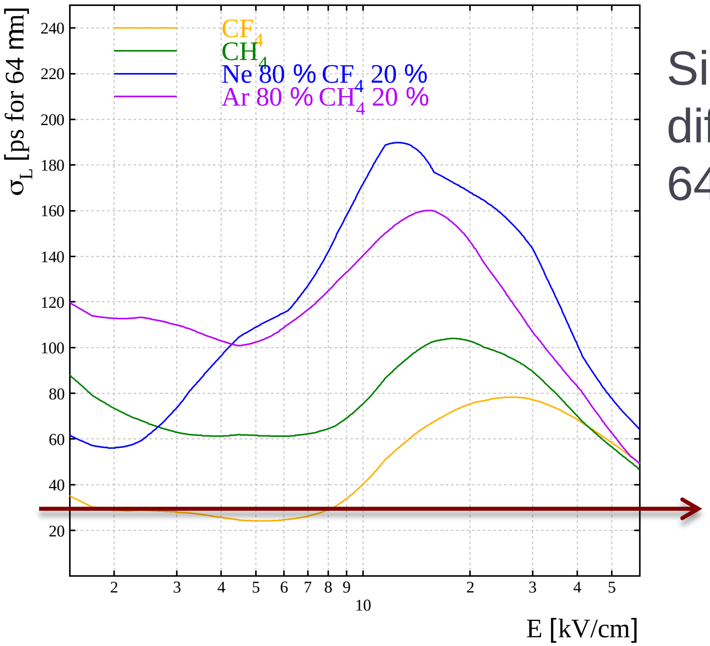
- **GasPMT: thin gas-detector (Micromegas) with radiator window**
  - Localize primary ionization in photocathode
  - Resolution determined by longitudinal diffusion in the gas





Simulation of diffusion term: 64 µm gap

30 ps

[S.White, arXiv 1409.1165]

Electronics and system aspects

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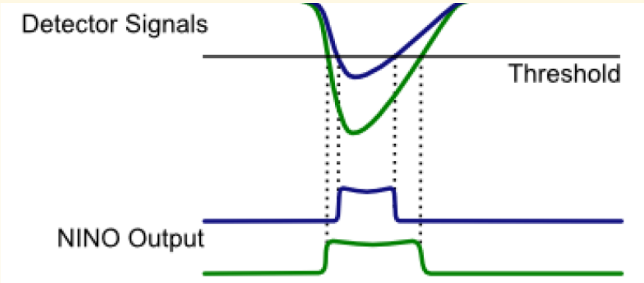
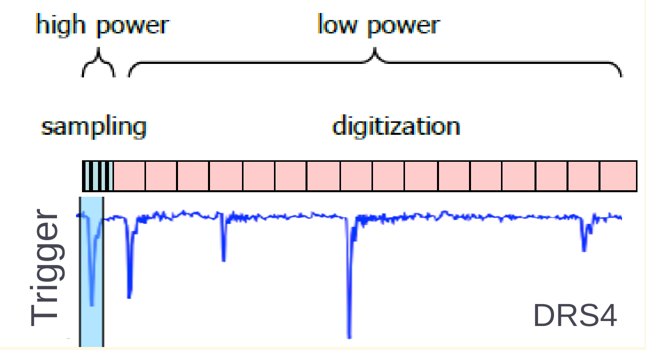
- **Readout electronics**

I. **Analog pulse discrimination + TDC**
- Reference: NINO + HPTDC ~ 20 ps
- Alternative ASICs discs *[Claro-CMOS]* and FPGA-TDCs *[GSI-TRB3]*



II. **Fast ADC + digital pulse discrimination**
- Switched capacitor array to sample in synch with beam crossing
- Digitization between triggers
- Several options available *[TARGET / Hawaii, SAMPIC Lal/Irfu, PSEC4 / Chicago, DRS4 / PSI, …]*



- *R&D: rad-hardness, speed, power, technology optimization, …*

- **System aspects: clock distribution jitter, stability, …**
  - Remote clock synchronization to better than 20 ps:
    - White Rabbit (CERN) - remote clock synch with Ethernet technology
    - Universal Picosecond Timing System: 20 ps – including long term stability

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- **ALICE-TOF**: Successful example of fast timing on a large area
  - **80 ps on 10^5 channels** - No upgrade planned
- **LHCb TORCH R&D:** TOF concept using Cherenkov emission
  - **Aim at 15 ps on 10^5 channels** - Completion of R&D in 2016

- No fundamental limitations to pileup mitigation with fast timing detectors in CMS and ATLAS
  - Different devices could match desired performance
    - Usual radiation hardness issues
  - Clock distribution, relative calibration and stability to 10 ps over 10^5 channels could be the challenge

- Has to verify advantage and incremental gain in performance beyond current pileup suppression methods

- Complete feasibility study by spring / summer (ATLAS / CMS) 2015