Pile-up Mitigation Using Calorimeter Time At HL-LHC

P. Meridiani

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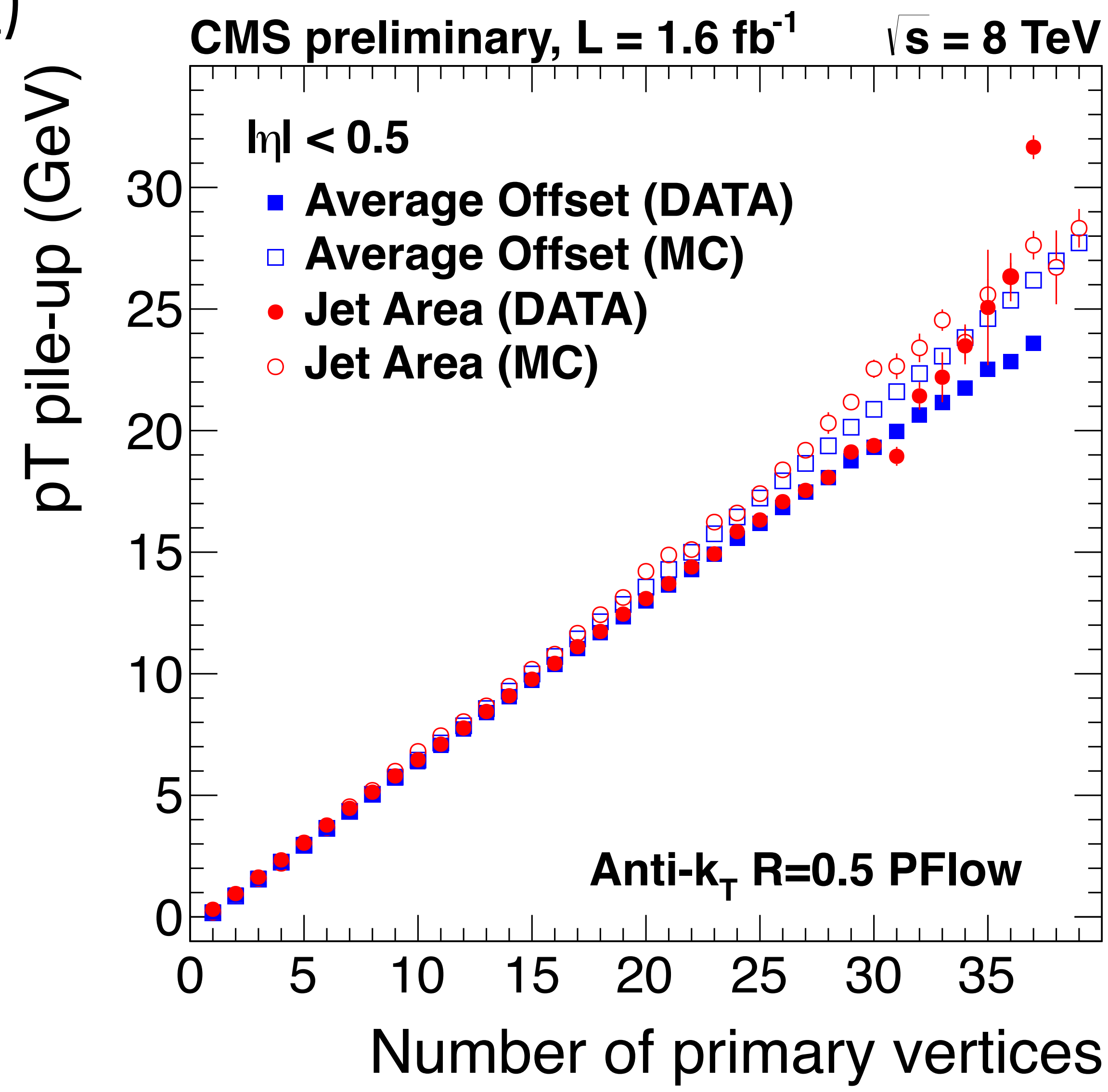
PILE-UP @ HL-LHC

- Particles from 140 PU vertices will spoil **physics object performance @ HL-LHC** (efficiency, resolution, fakes)
  - **%30-40 of the energy in a Jet comes from photons or neutral hadrons**
  - For Jet 0.5 cone **>70 GeV PU energy for 140 pile-up vertices**
  - Average response can be corrected but resolution compromised
  - Similar issues for object isolation and MET

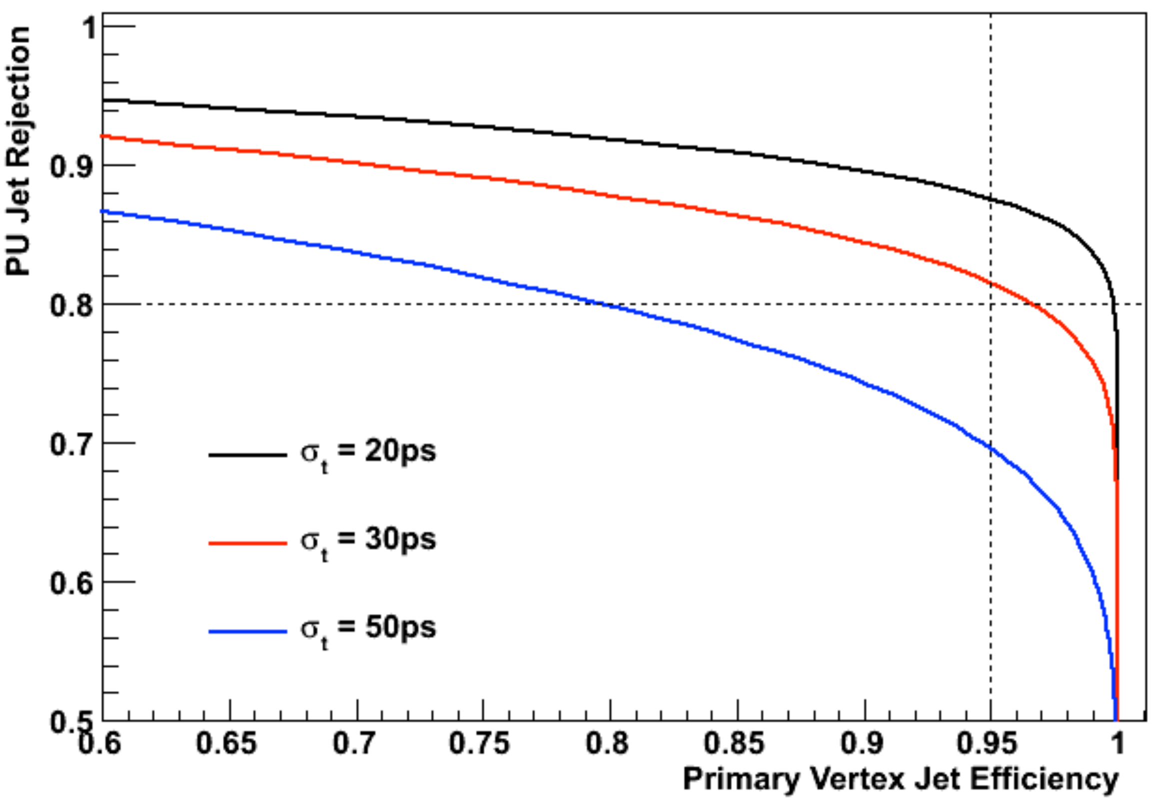


- Will affect the physics reach for key processes to be studied @HL-LHC
  - VBF, WW scattering: low pT jets in forward region $|\eta|>2$
  - $H(\rightarrow\gamma\gamma)H(\rightarrow bb)$: photon ID+isolation, mass resolution

Pile-up Mitigation: ECAL ToF

- **Time-of-flight for ECAL energy deposits can help to mitigate pile-up**
  - Use time-of-flight to associate ECAL energy deposits to different interaction vertices
- Required precision:
  - **Single ECAL hit precision of 20-30ps allow to associate an energy deposit within 1cm in endcap region**
  - **Reduction of pile-up contribution in physics objects >5 depending on luminous size region**
    - detailed simulation studies are on-going in CMS

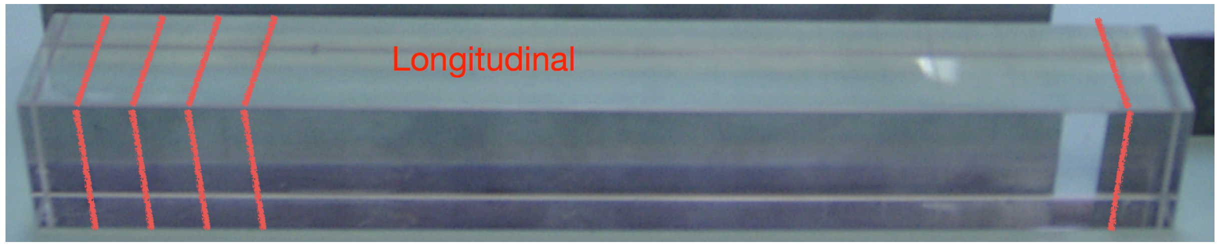
PU Jets rejection with ECAL time for $|\eta_{JET}|>1.5$
(assuming PU distributed as gaussian with 250 ps)



- **Possible object application**:
- **Object identification**: identify PU jets looking at ToF of most energetic hits in the jet
- **Single hit cleaning**: Improvements to EM,JET, MET, isolation...
- **Particle-Id**: photon vs π^0 looking at time distribution in a cluster

PRECISION ECAL TIME: PROPOSED IMPLEMENTATION

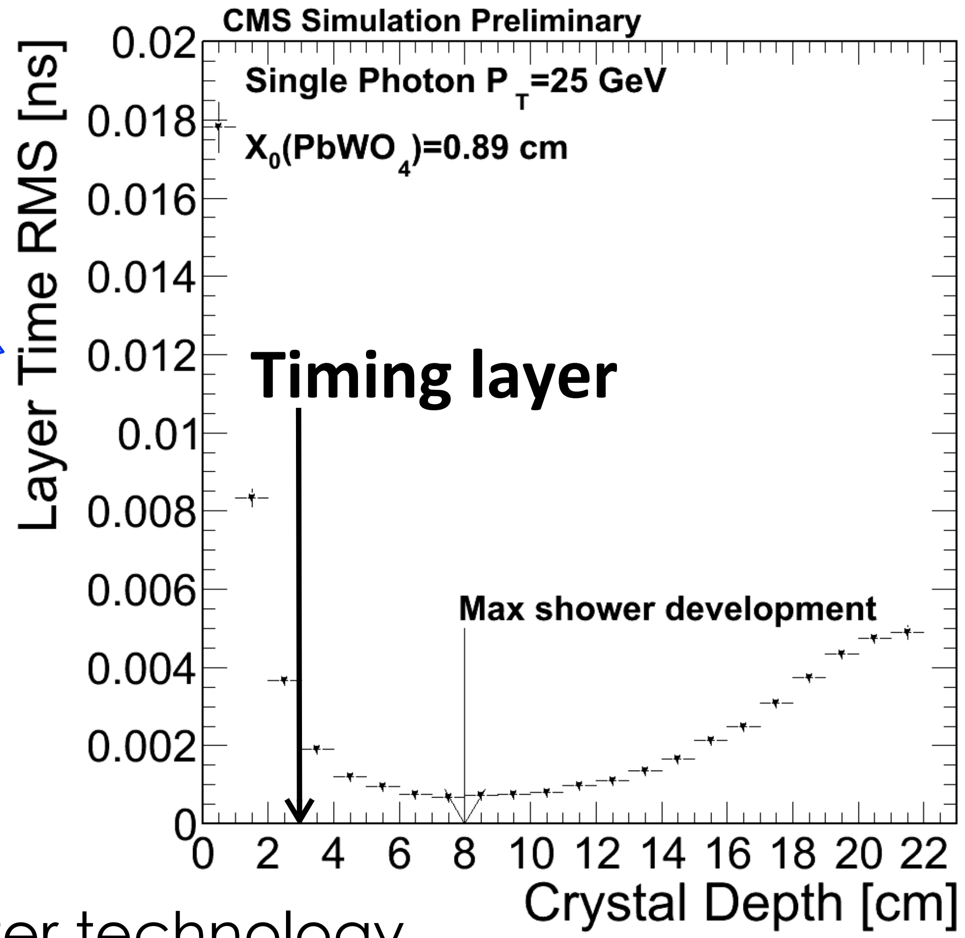
- **Current performance from ATLAS and CMS ECAL (design goal 1ns) ~200ps (Z→ee)**
  – understanding of current limitations (clock distribution) beneficial for the proposal of a new detector



Geant4 simulation of $PbWO_4$ crystals with 1cm layers to optimize detector configuration

Shower propagates longitudinally at c: look at spread of mean time in 1cm layer

A device after 2-3 radiation lengths can have an intrinsic resolution <10ps



- **Build a timing detector as a "pre-shower"**
  – decoupled from the choice of the calorimeter technology
- **Necessary to measure also ToF of single charged particles**
  – 2D time vs z reconstruction of each vertex

Which Detectors For O(10)ps Timing?

- O(10)ps time resolution and high rate capable detectors (O(10) MHz/cm^2 charged in forward region)
- **Micro-channel plate PMTs**
  - 10-30ps available for several commercial devices
  - Expensive (8-9 k$ for 50x50 mm^2 detectors)
- **Alternative: silicon detectors**
  - NA62 GTK showed a resolution of ~150ps for 200μm planar silicon detector
  - **To reduce noise jitter, silicon detectors with gain**
    - LGAD (developed inside the RD50 collaboration)
    - Hybrid APD: HAPD (Hamamatsu), Micromega+APD (S. White)

I-MCP

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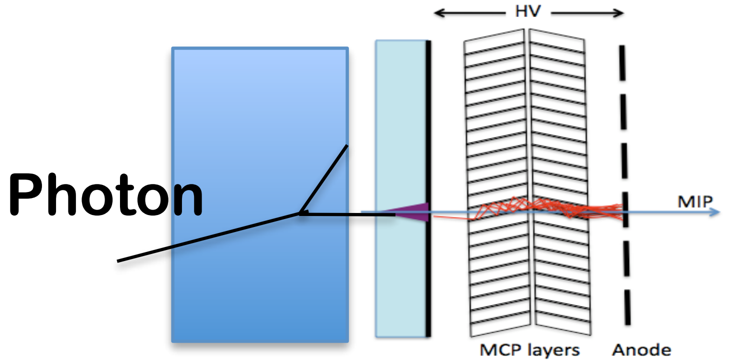
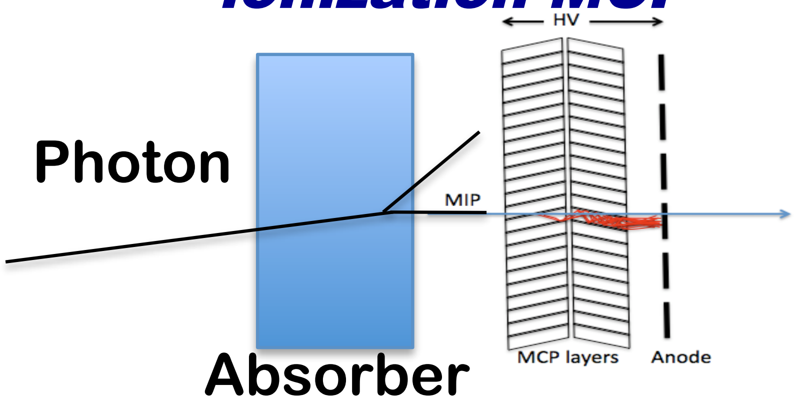
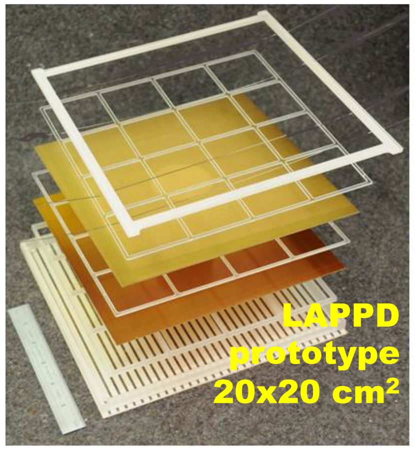
- **MCP as a MIP detector**
  - **PMT-MCP**: high efficiency using Cherenkov light in quartz/glass window
  - **I-MCP**: no photocatode, direct ionization in the MCP. Efficiency up to 70%, more radiation hard then PMT-MCP
- **Large area to be covered** (forward calorimeters ~10 m^2)
  - cannot use commercially available MCP (cost)
  - LAPPD collaboration developed large area MCP
    - up to 20x20 cm^2 capillary glass MCP with atomic layer deposition (ALD)
    - Anode can be segmented to achieve required granularity

Classical PMT-MCP+Absorber



"ionization-MCP"

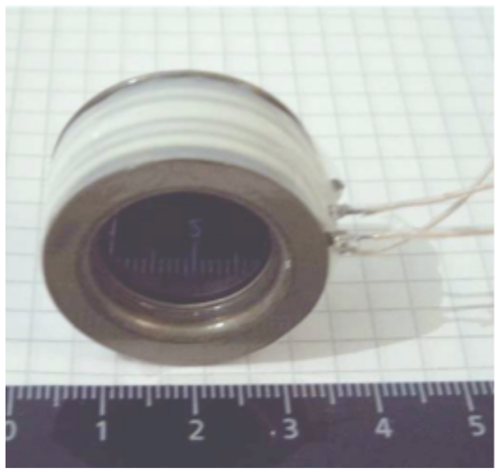


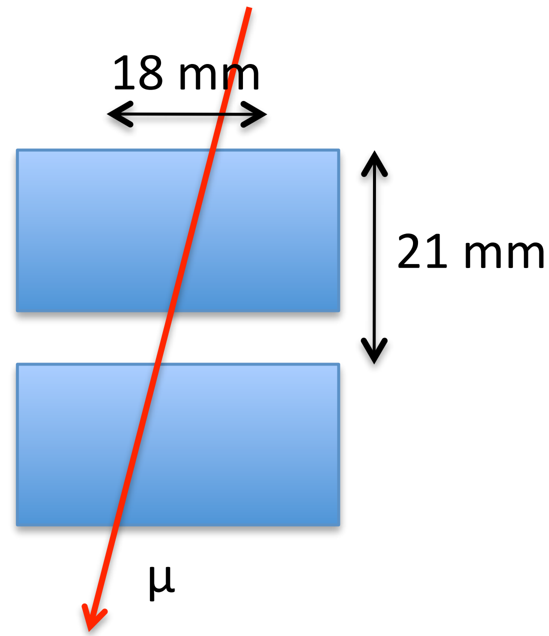


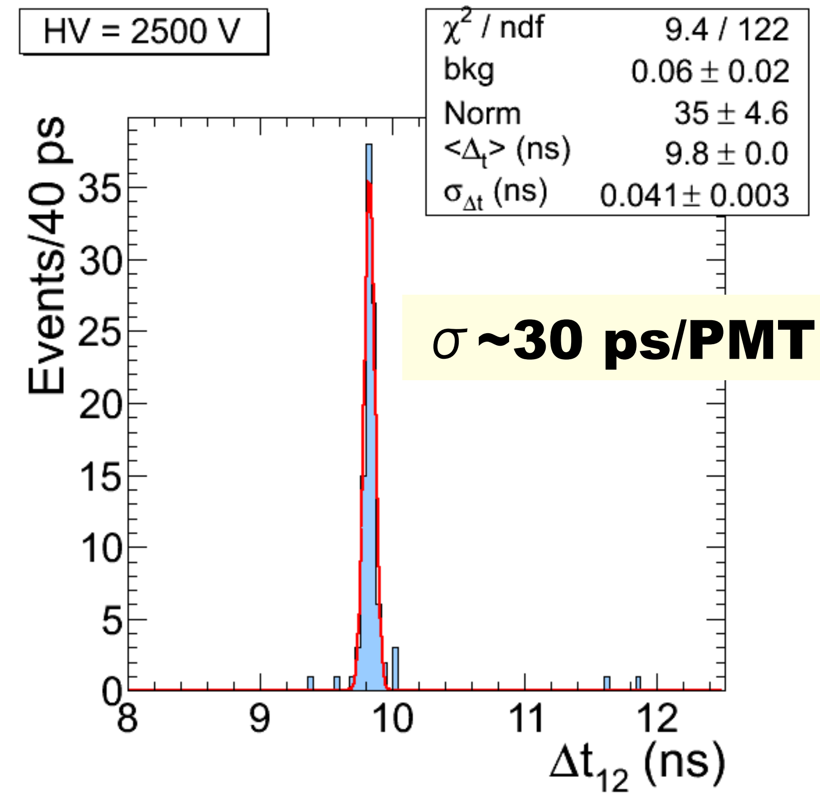
CSN V funded project: MIB+RM+TS
BINP expressed interest to join the collaboration
Coordinator: T. Tabarelli De Fatis

PRELIMINARY STUDIES AT MIB

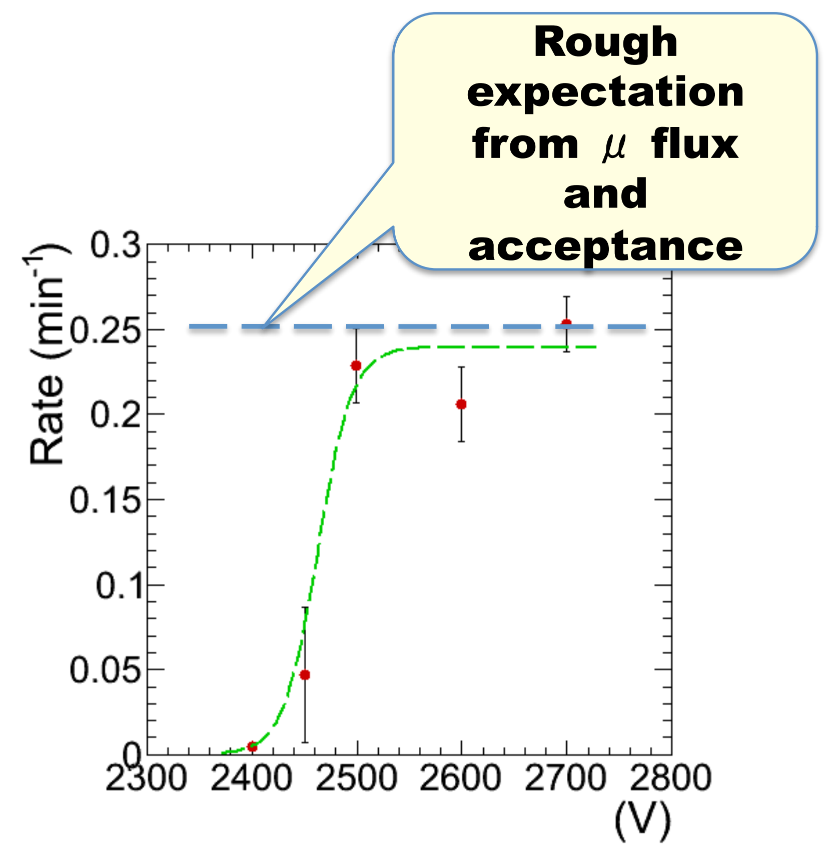
MCP samples from BINP Novosibirsk (M. Barnyakov)
NIM A598 (2009) 160-162



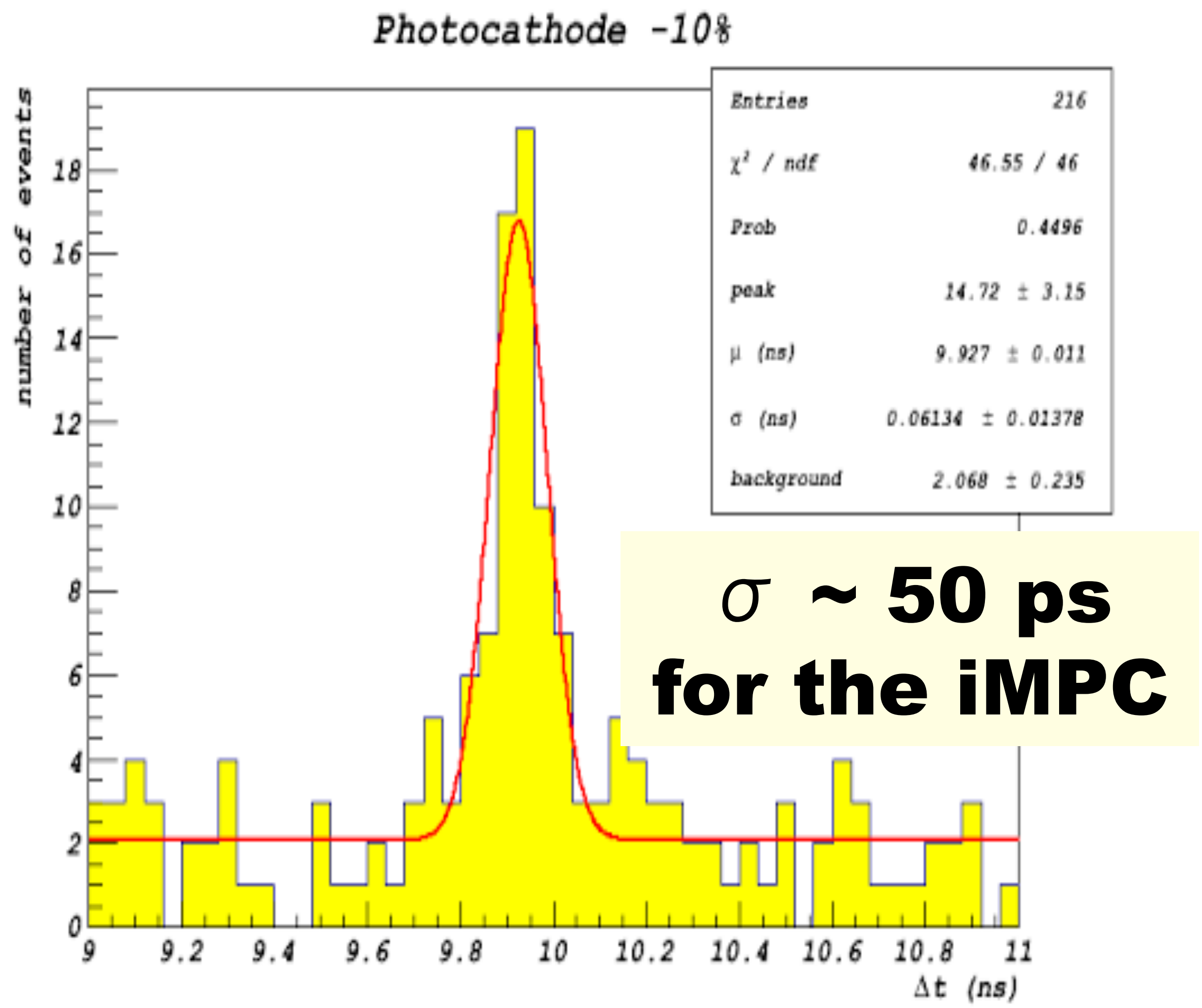




- Coincidence of 2 MCPs with cosmics
  Measure ΔToF
- PMT-MCP: Exploit optical window as Cherenkov radiator
  - ~<4> p.e. expected
- **30 ps achieved in PMT-MCP configuration**



PRELIMINARY TEST OF I-MCP



- **First preliminary test of the I-MCP concept**
- Same setup as before but collection of photoelectrons inhibited on one MCP
- **50ps time resolution on a single MIP, compatible with the time resolution expected for a single electron**

I-MCP Plan

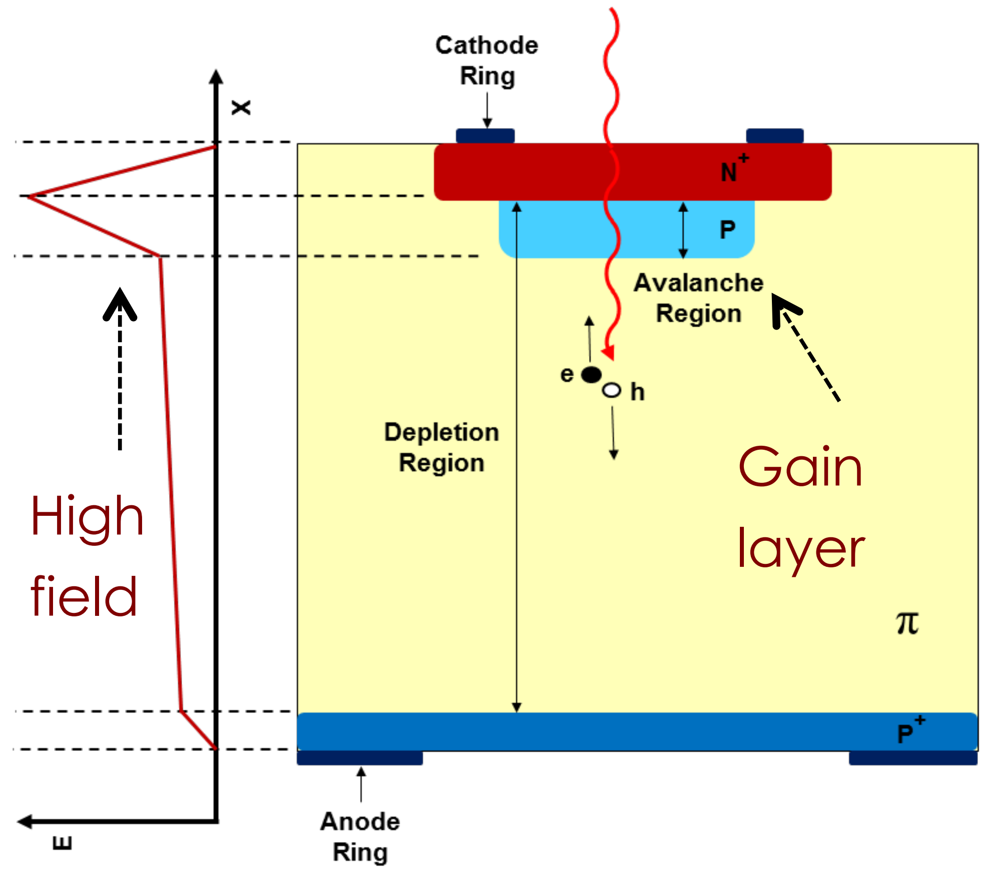
- Workplan (2014 & 2015)
  - **Time resolution and efficiency for an I-MCP in test beam and cosmic benches**
    - Test beam are scheduled in May & October @ LNF BTF
  - **Detector response model**
    - Can be used in detailed simulation for HL-LHC
  - **Radiation hardness**
    - **I-MCP** configuration should be **more radiation hard the PMT-MCP**
    - PMT-MCP lifetime affected by ion-feedback on photo-catode (due to residual gas in the MCP, proportional to extracted charge)
      - ➡ PANDA showed encouraging life-time results (no loss up to 2 C/cm^2) with MCP with ALD and improved vacuum (Photonis XP85112)
  - **Variation of response with B-field**
    - In forward region axial B-field, angle will change with $|\eta|$

ULTRA FAST SILICON DETECTORS

Pixelated silicon detector with low internal gain (LGAD)

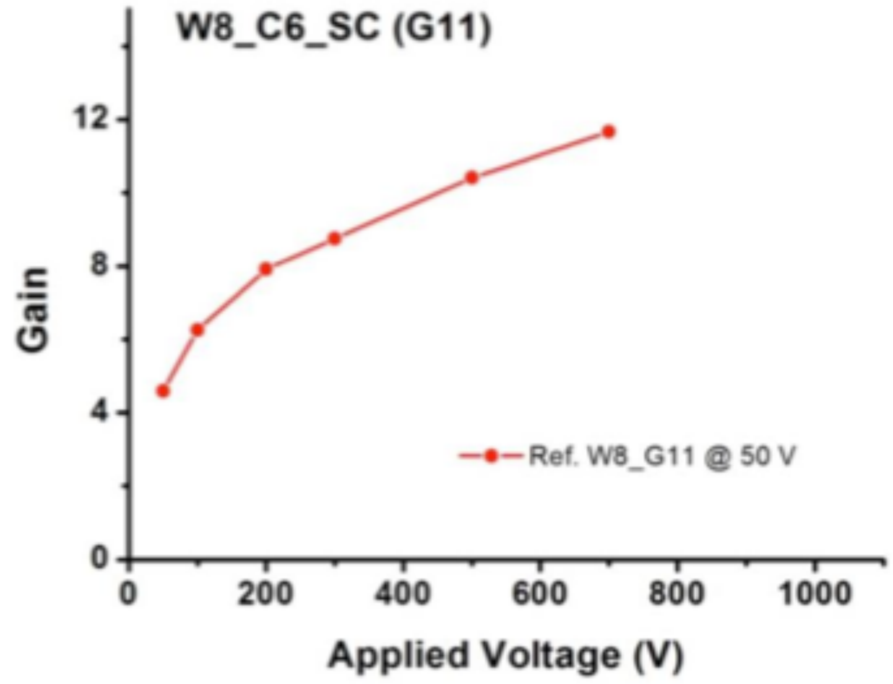
Gain: Add an extra deep p+ implant

➔ High local field generates multiplications



Prototype UFSD show good gain (~ 10)

Currently manufactured by CNM, FBK interested in joining the effort.



Radiation hardness: gain decreases with high radiation.

Need to find alternative dopant to Boron:

Aluminum, Indium?

CSN V funded project: TO+FI+FBK
Coordinator: N. Cartiglia

UFSD: CALORIMETER TIMING

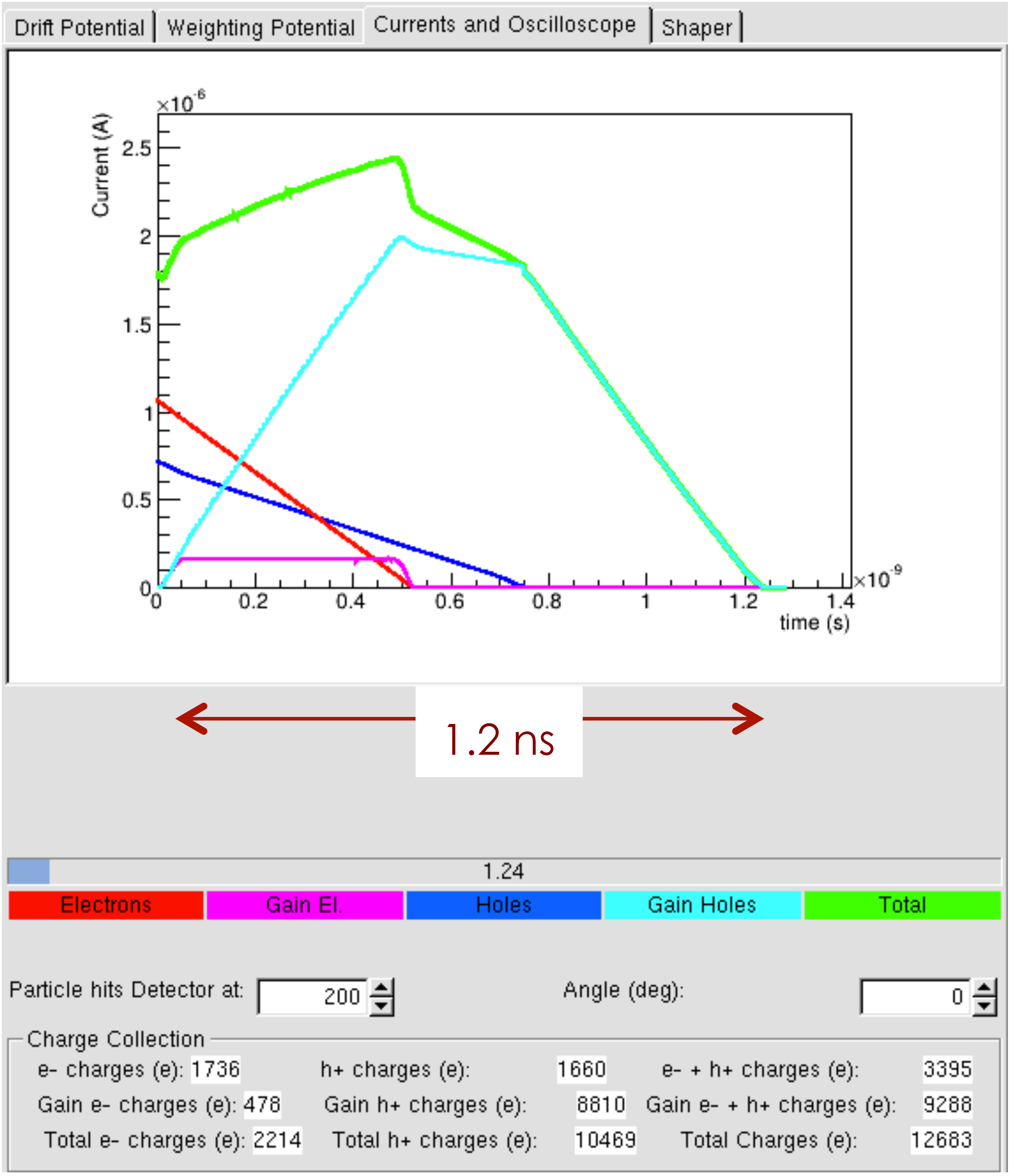
Basic principle: large signals reduce time walk and jitter, allowing for better timing determination.

Detailed timing capability depends on design ➔ simulation of 200x200 micron pixels indicates a resolution of ~20 ps

The use of large LGAD for calorimeter timing is a possibility, requires R&D to validate the idea

- Pixel size to be chosen for optimal ECAL timing
- Large area diodes will have higher capacitance (requires more complex timing)

Simulation of a 50 micron thick detector with gain = 4:

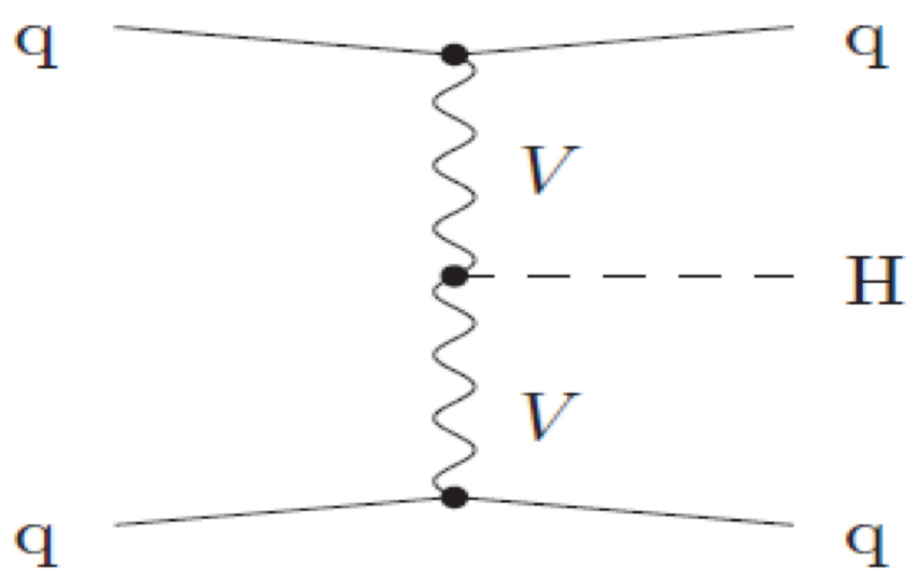


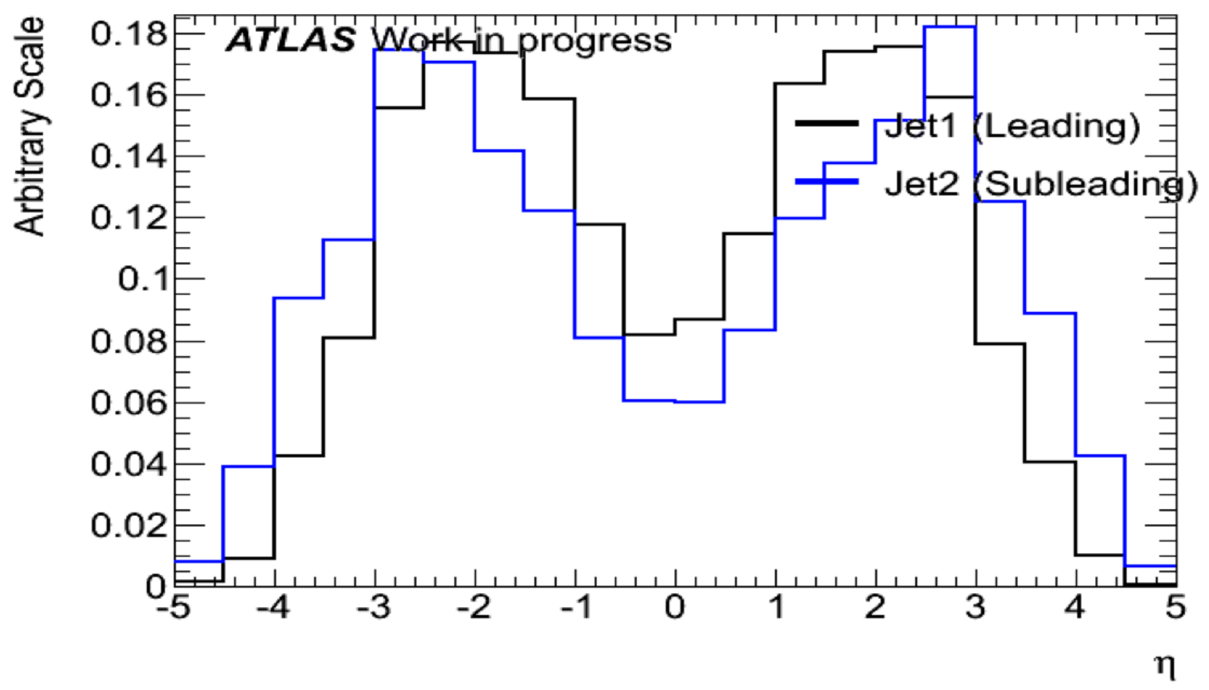
CONCLUSION

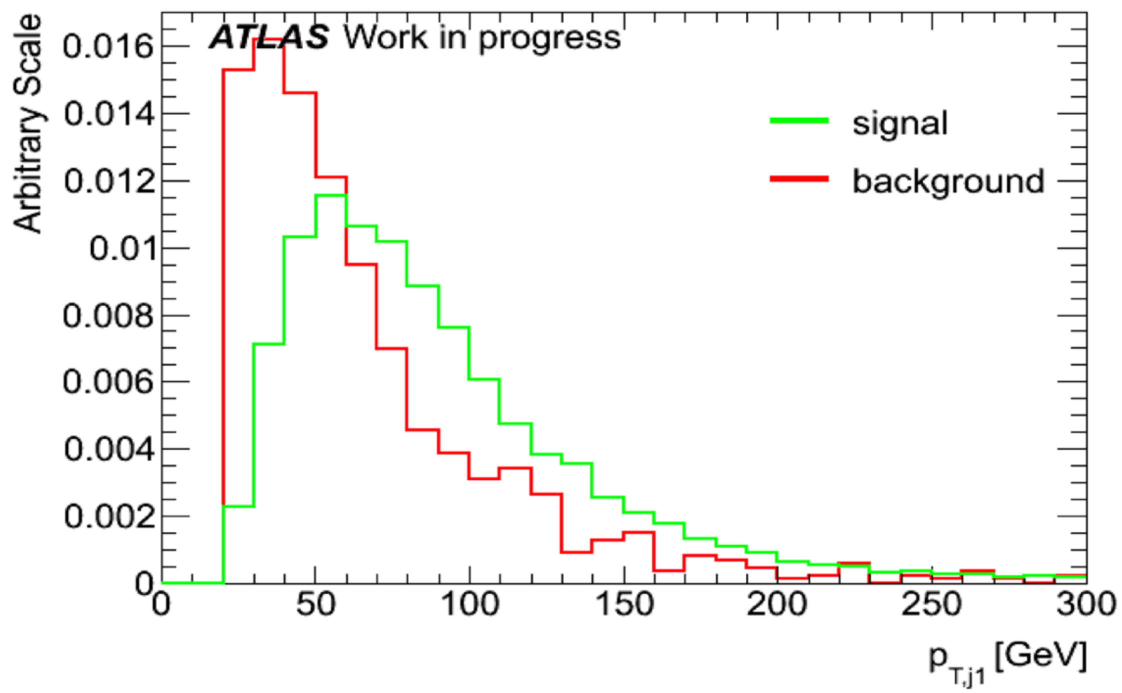
- **Physics reach of HL-LHC will be compromised without new handles on PU reduction**
- **Precision timing can give an additional powerful handle to mitigate PU effects (especially in endcap region)**
  - **Single hit resolution of 20-30ps is needed**
  - Simulation studies are on going to have clear assessment of the full potential. **Potentially a rejection factor of 5 for PU hits**
- **Time of an EM shower can be measured with a "preshower" detector after few radiation lengths**
  - Decoupled from calorimeter technology
- **2 R&D projects in CSN V are working on suitable detectors**
  - I-MCP: ionization MCP
  - UFSD: ultra fast silicon detectors

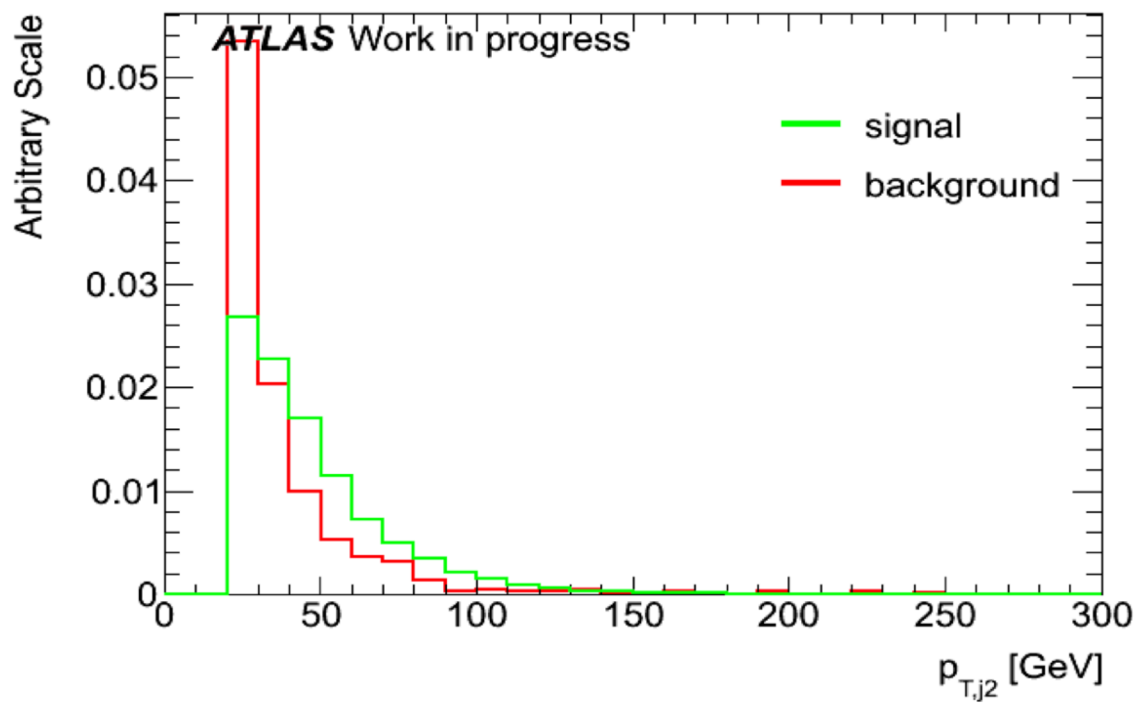
BACKUP

VBF Jet Kinematics

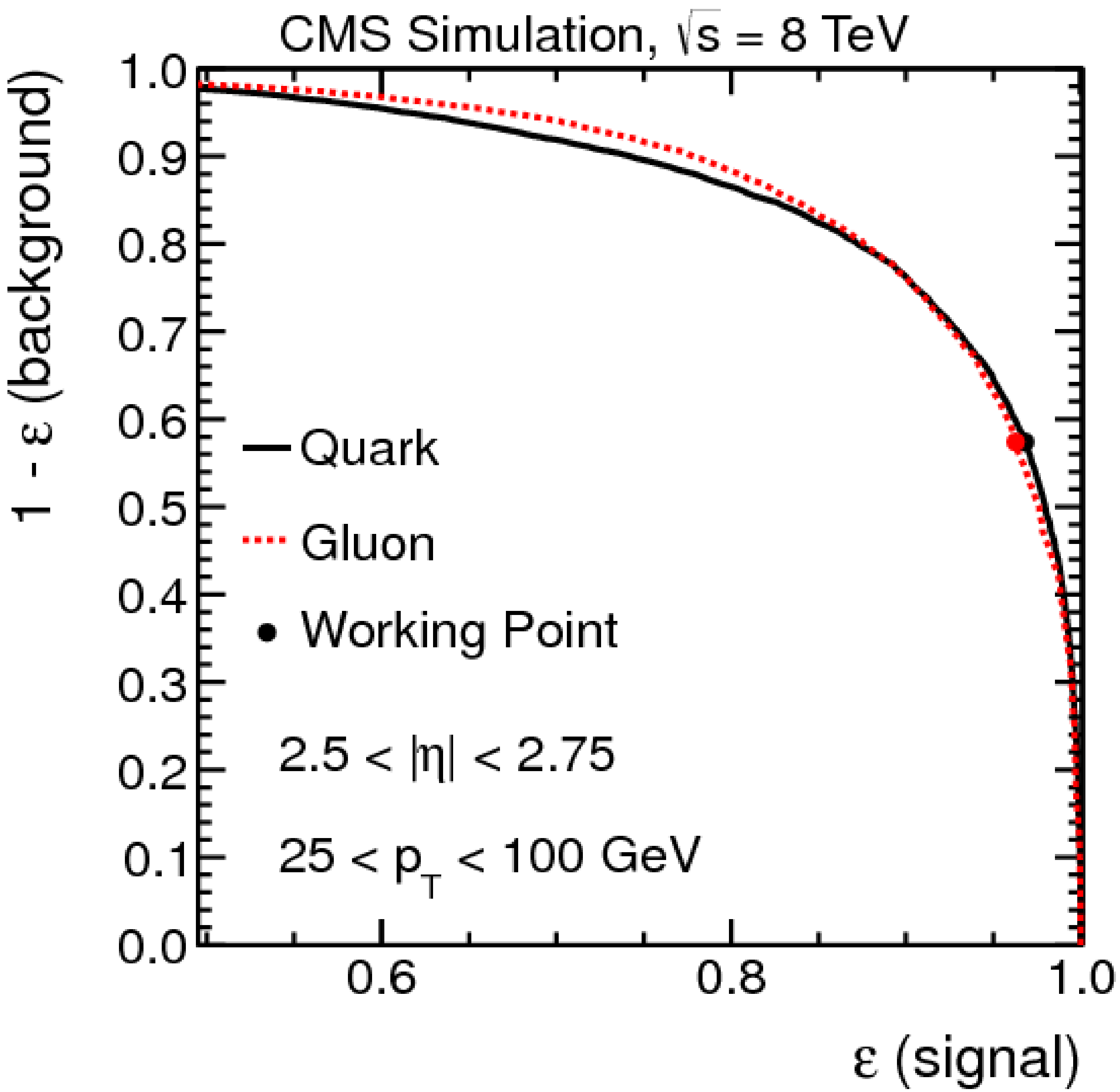






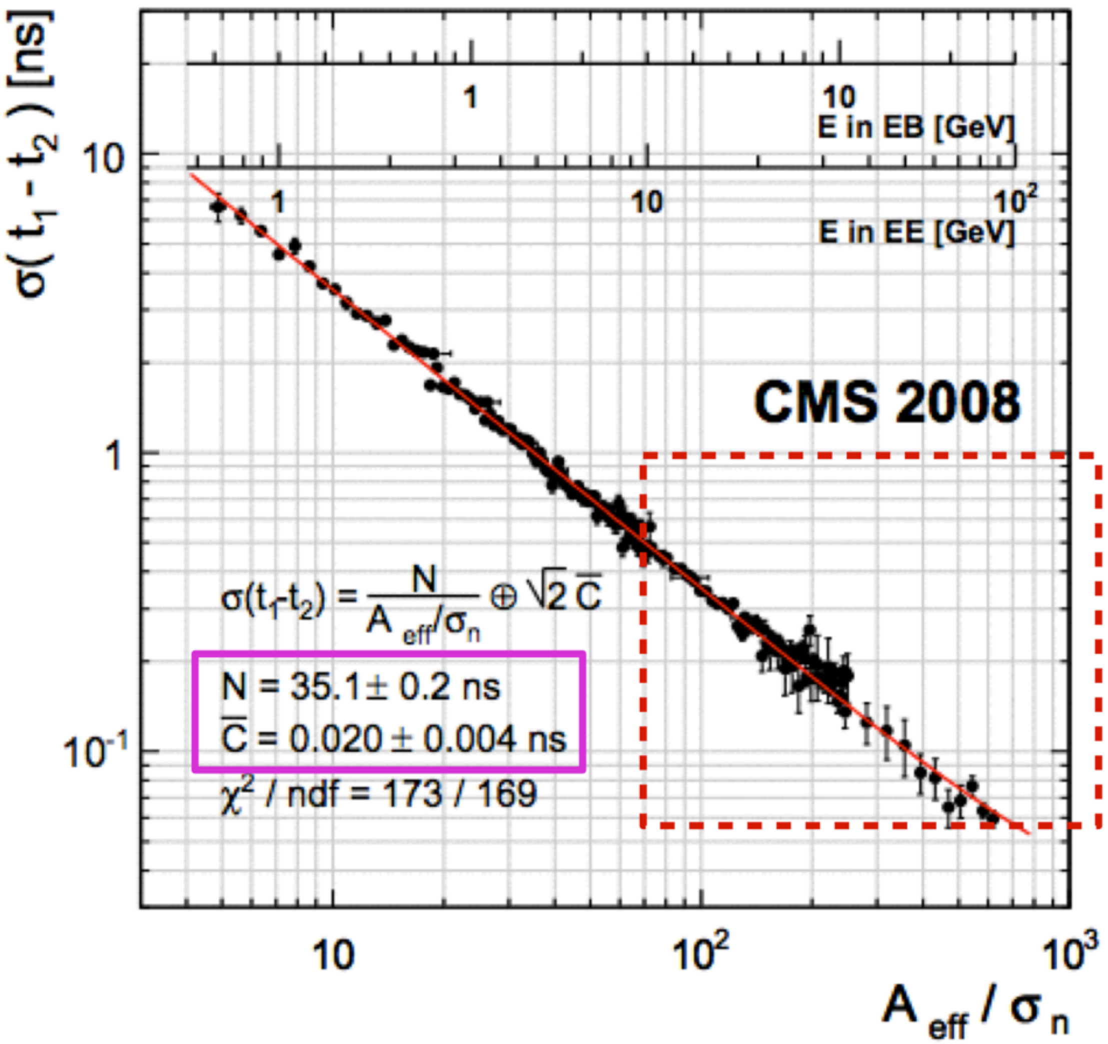


CMS Pile-UP Jet Rejection In Fwd Region



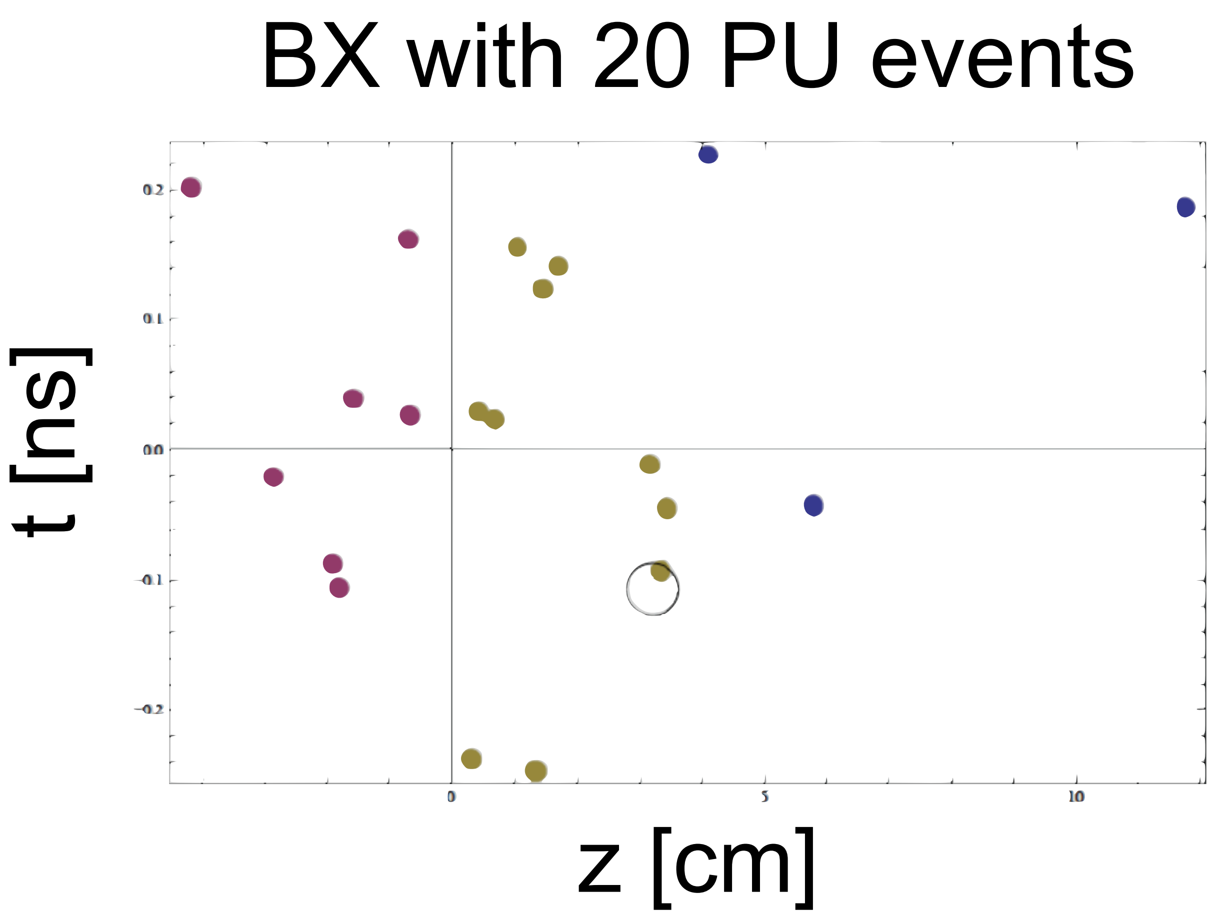
Current ToF Performance in ECAL (CMS)

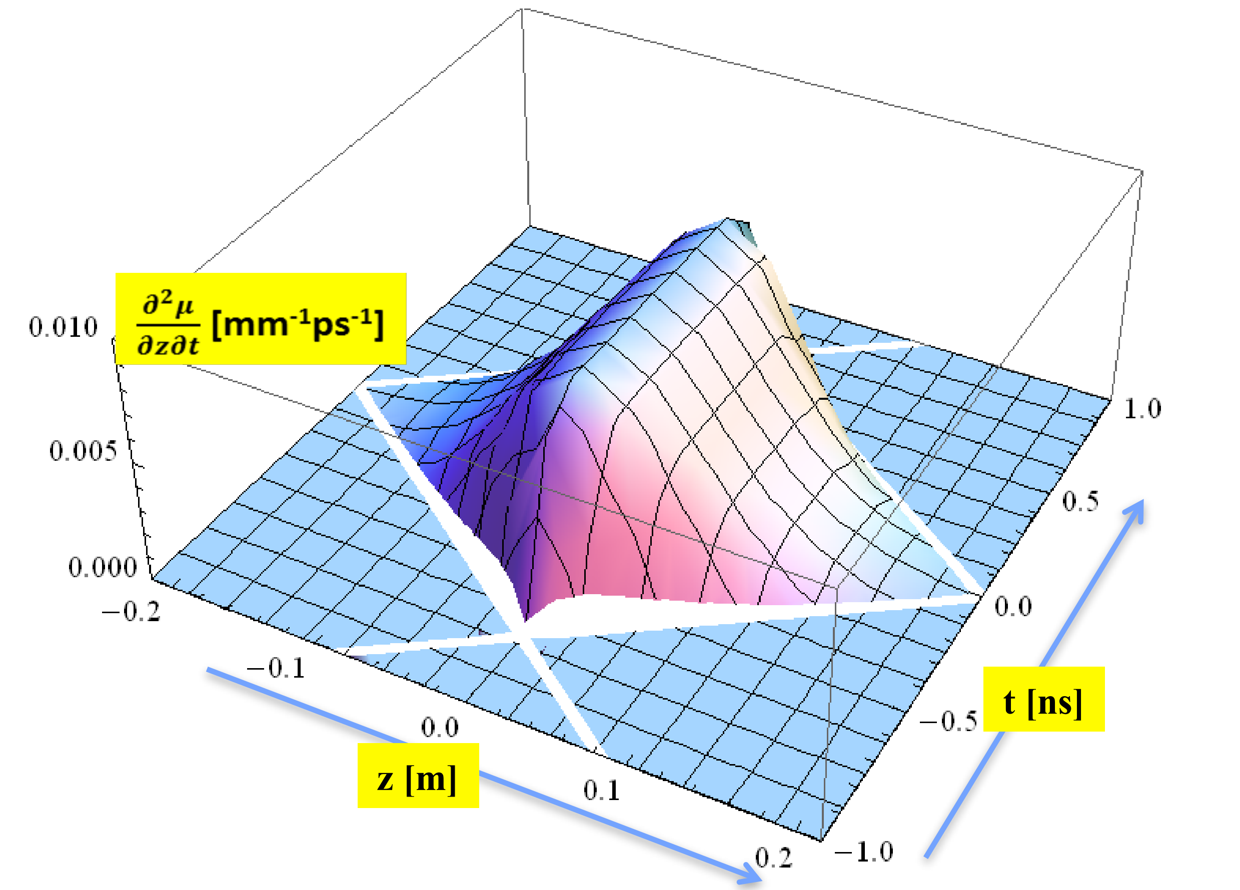
- Taking here CMS ECAL as an example (that I know better)
  - Intrinsic time resolution for an EM shower as measured in test beam <100ps for E>10 GeV
  - However best resolution currently achieved ~190ps in CMS ECAL barrel (similar for ATLAS)
  - Origin of the limiting factors is being studied
    - Run by run variation
    - Non-linearity vs amplitude
    - Time-intercalibration
    - Electronics
  - Understanding of these effects is crucial before proposing a new timing detector at the LHC



Vertex Time and Z spread And Correlation

- To exploit ToF interaction vertices have to be reconstructed in 2D space (t-z)
  - Typical interaction time spread for baseline HL-LHC with CRAB cavities ~200ps
  - CRAB kissing schema (add CRAB cavities also in the || plane) being discussed as an alternative schema for controlling the pile-up density
    - Bunch interaction time shortened (proportionally to the angle in the || plane)
    - $d^2\mu/(dzdt)$ will change during the fill:CRAB cavities are used for luminosity leveling (PU-density leveling)
  - Rectangular vs gaussian bunches will change the PU-density profiles





Longitudinal sampling an EM shower with I-MCP

- A. A. Derevshchikov et al. Preprint IFVE 90-99, Protvino, 1990
- Not exploited for timing.
- Amplitude measurement:

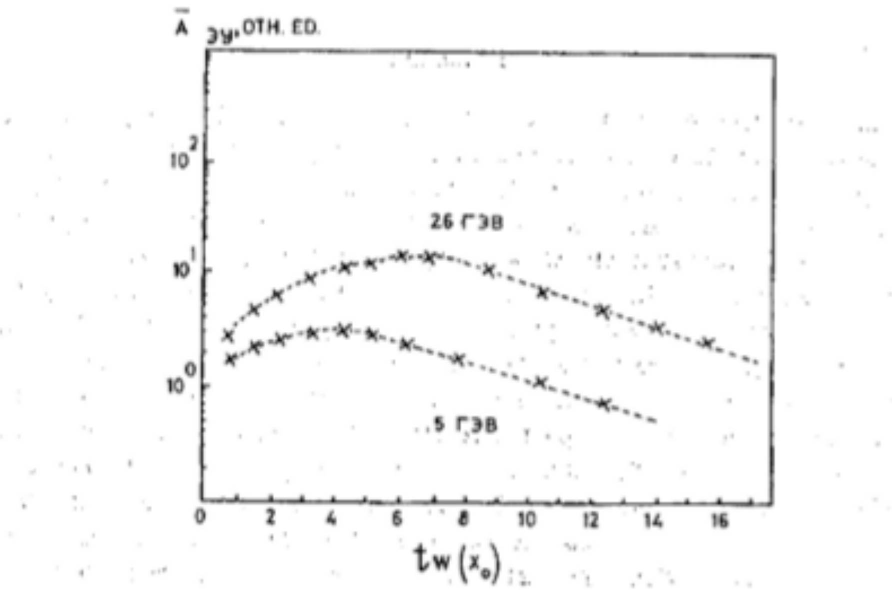
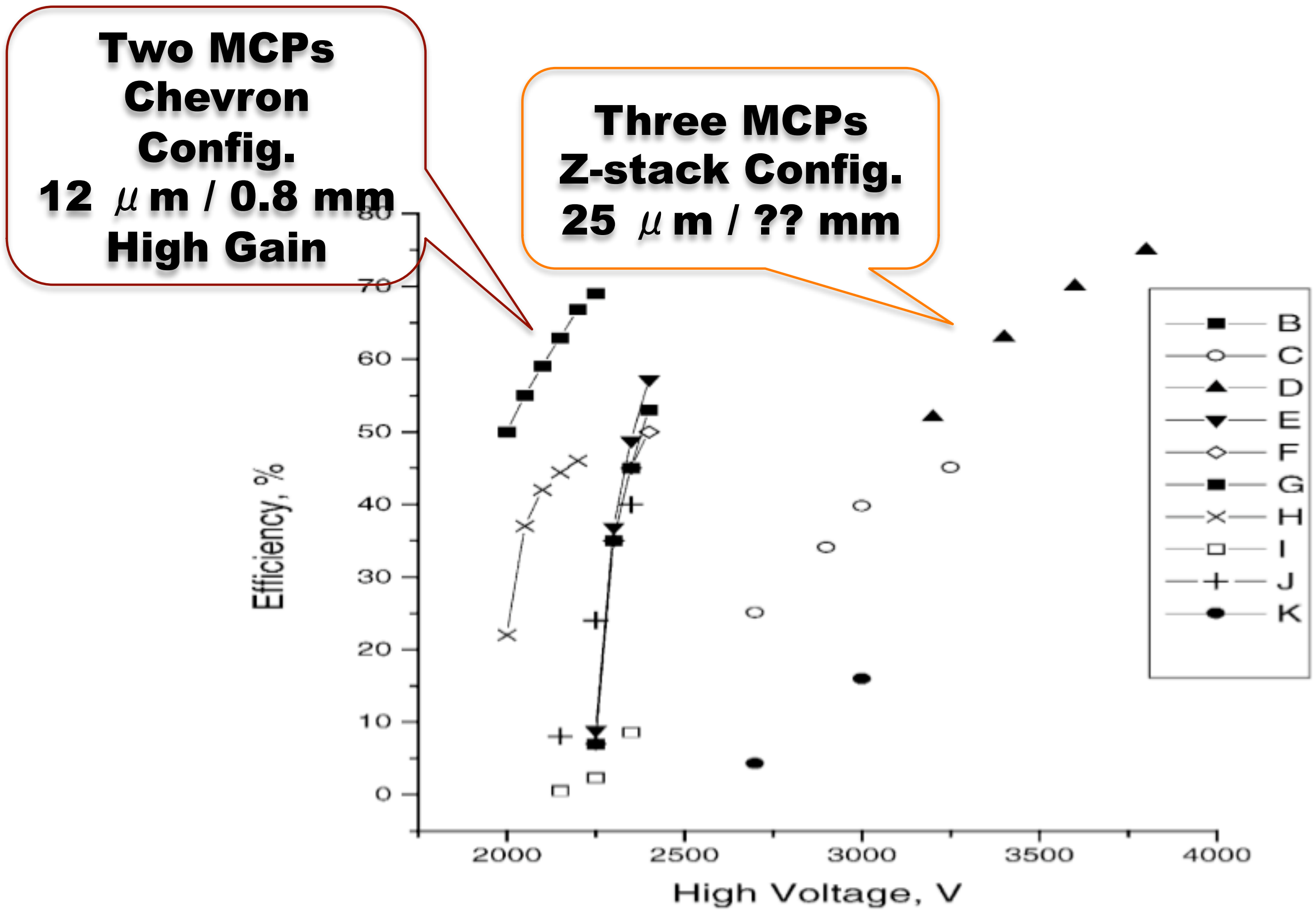


Fig.3. Shower longitudinal development for electron energy 5 and 26 GeV, measured by MCPs.

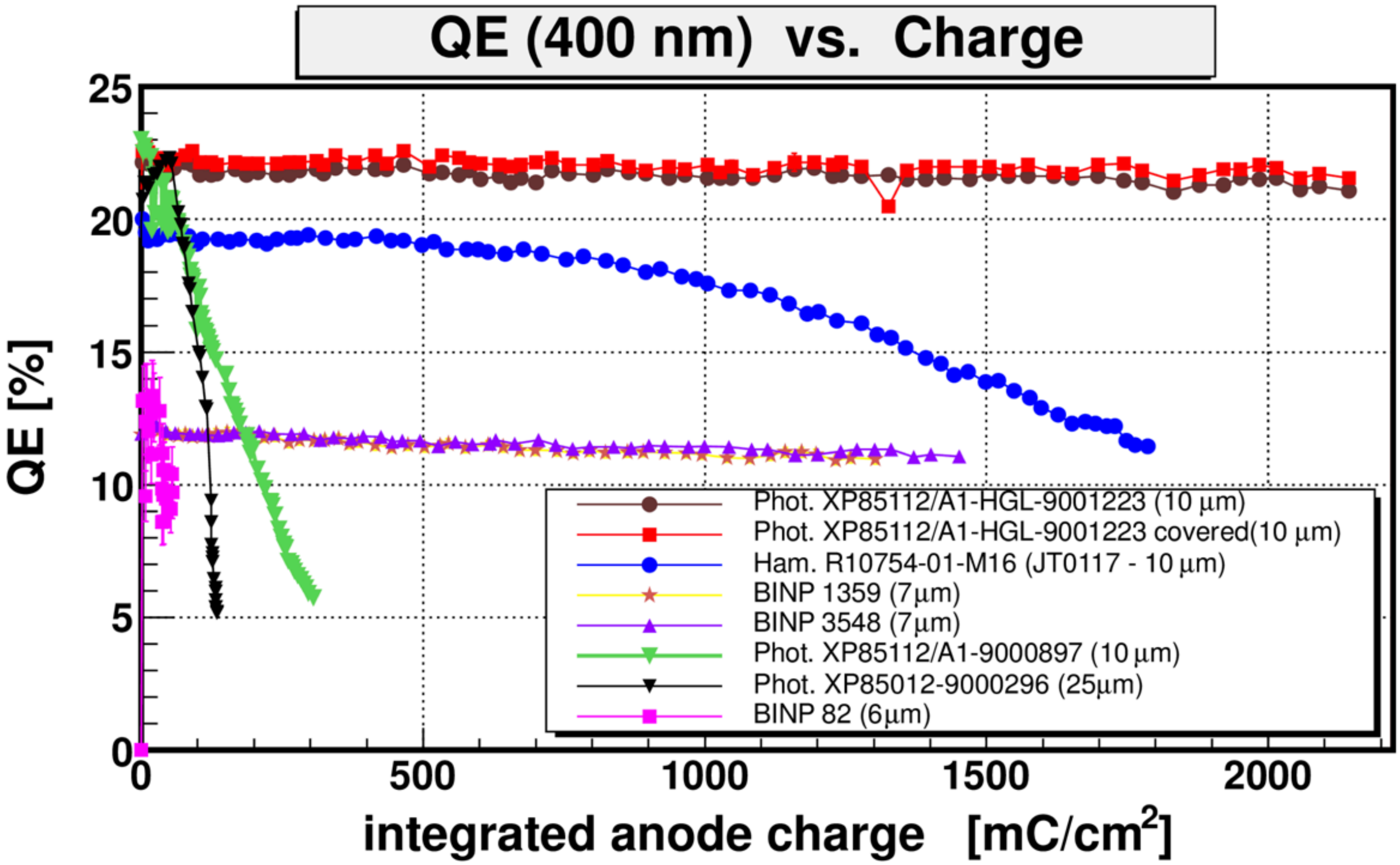
T0/centrality detector for ALICE

Bondila et al, NIM A478 (2002) 220

reached >70% efficiency for MIP detection



IMPROVEMENTS OF MCP LIFETIME



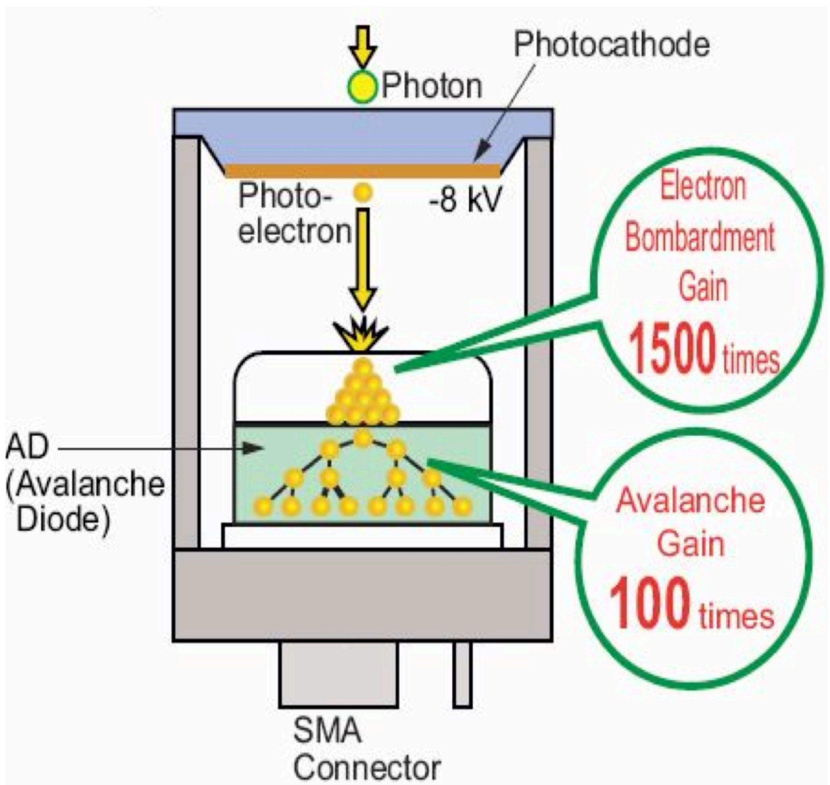
A. Lehman
https://agenda.infn.it/getFile.py/access?contribId=37&sessionId=9&resId=0&materialId=slides&confId=4148

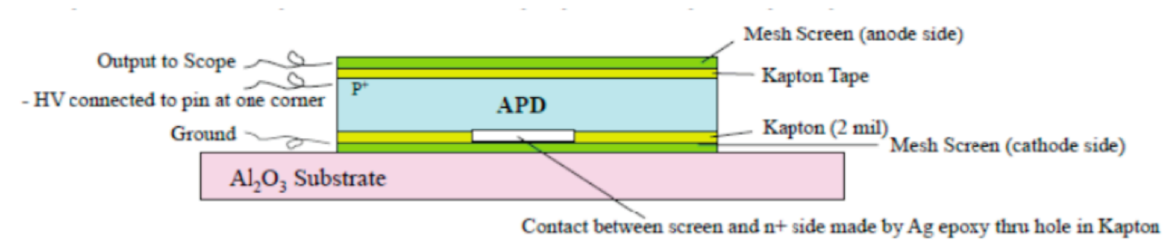
Hybrid APD Configurations

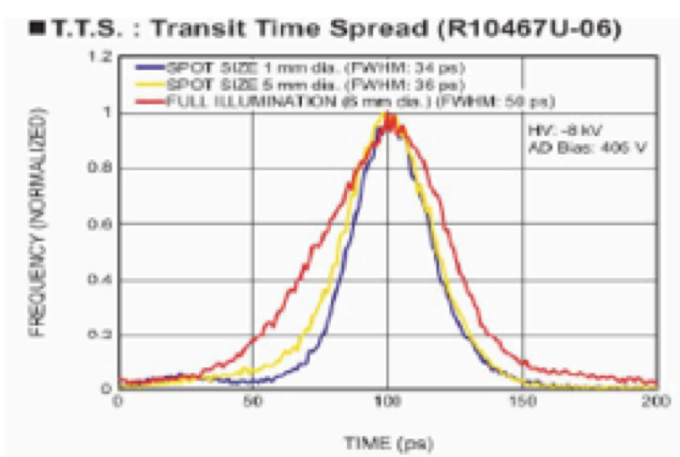
S. White: http://arxiv.org/pdf/1309.7985.pdf

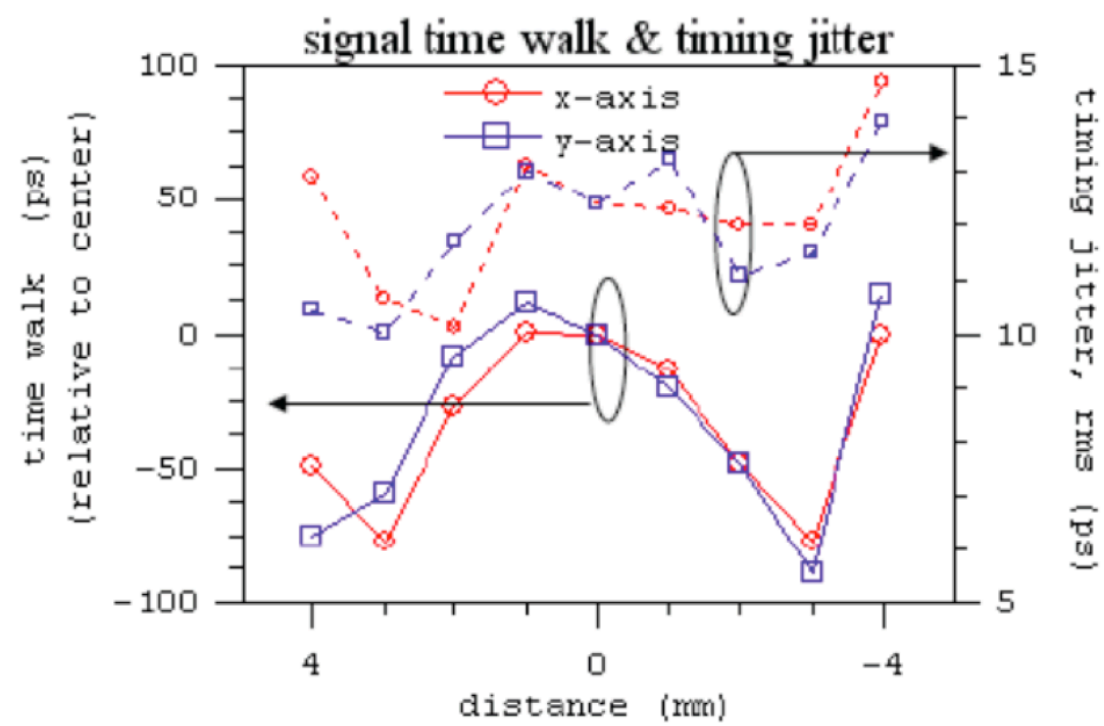
Hybrid APD (Hamamatsu R10467)

MicroMegas (for field generation) + APD









UFSD: References

Several talks at the 22nd and 23rd RD50 Workshops:

23rd RD50: https://indico.cern.ch/event/265941/other-view?view=standard
22nd RD50: http://panda.unm.edu/RD50_Workshop/

9Th Trento Workshop, Genova, Feb 2014.

F. Cenna "**Simulation of Ultra-Fast Silicon Detectors**"

N. Cartiglia "**Timing capabilities of Ultra-Fast Silicon Detector**"

Papers:

[1] N. Cartiglia, **Ultra-Fast Silicon Detector**, 13th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD13), 2014 JINST 9 C02001, http://arxiv.org/abs/1312.1080

[2] H. Sadrozinski, N. Cartiglia et al., **Ultra-fast Silicon Detectors**, NIM-A, RESMDD12 proceeding (2012), Firenze, http://dx.doi.org/10.1016/j.nima.2013.06.033