DIRECT TESTS OF A PIXELATED MICROCHANNEL PLATE AS THE ACTIVE ELEMENT OF A SHOWER MAXIMUM DETECTOR

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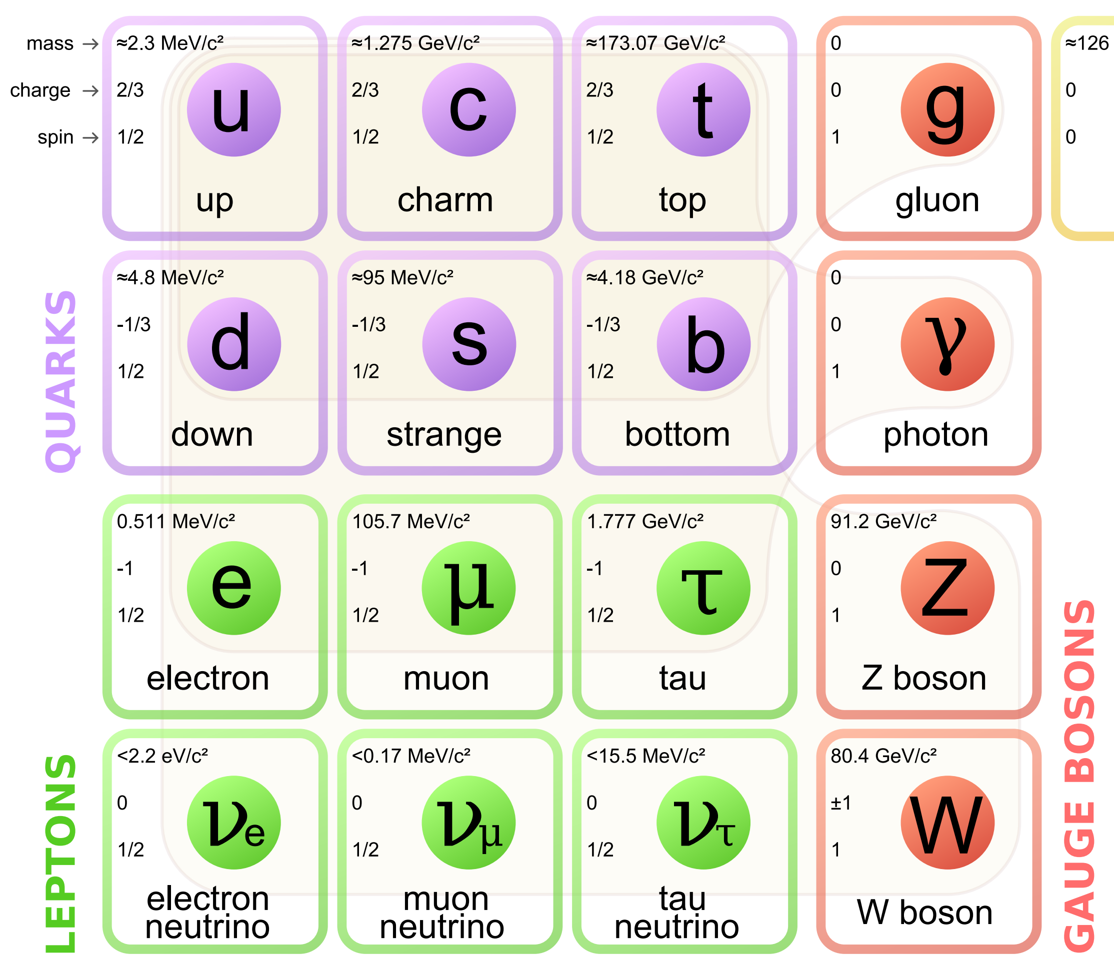
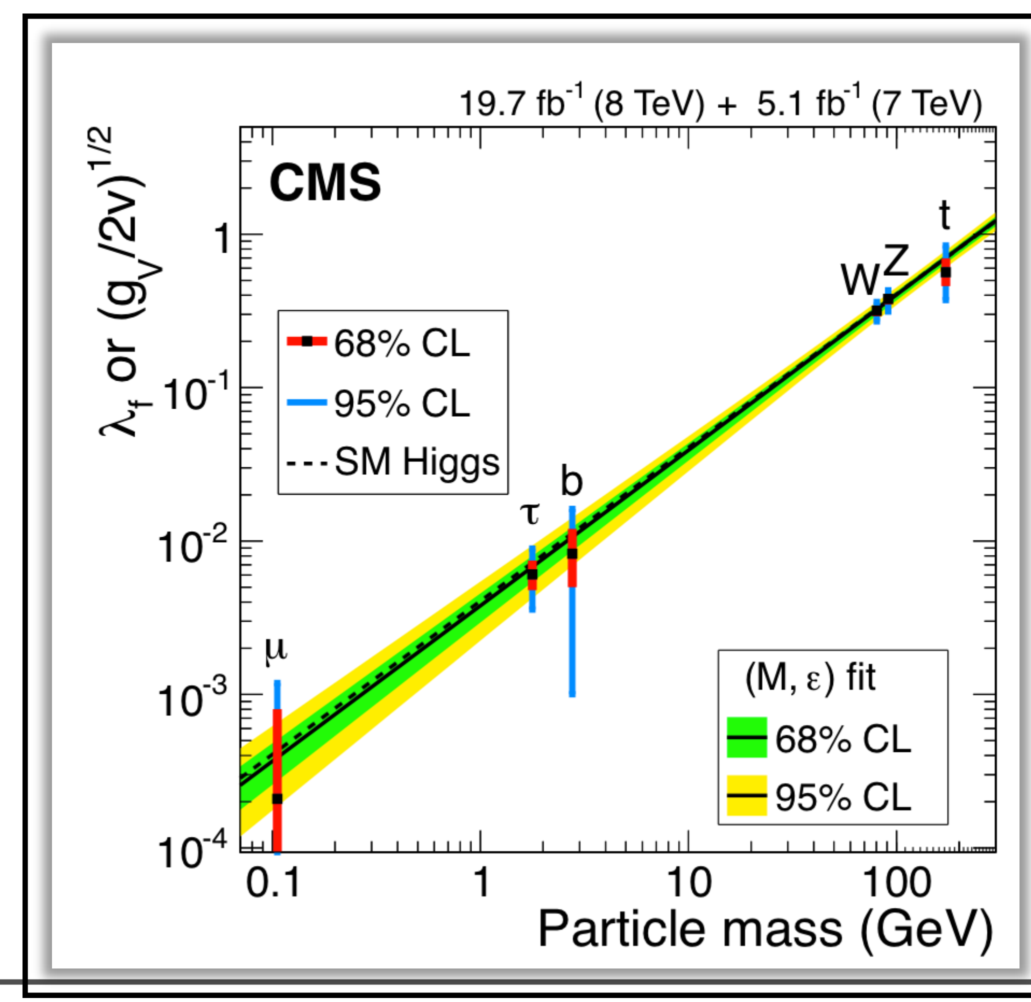
OUTLINE

- Introduction
  - High luminosity particle colliders challenges
  - Precision timing as an option to overcome them
- MCP-based secondary emission calorimeter challenges
- Results using a pixelated MCP-base secondary emission calorimeter
  - Position resolution
  - Time resolution
- Summary and Conclusions

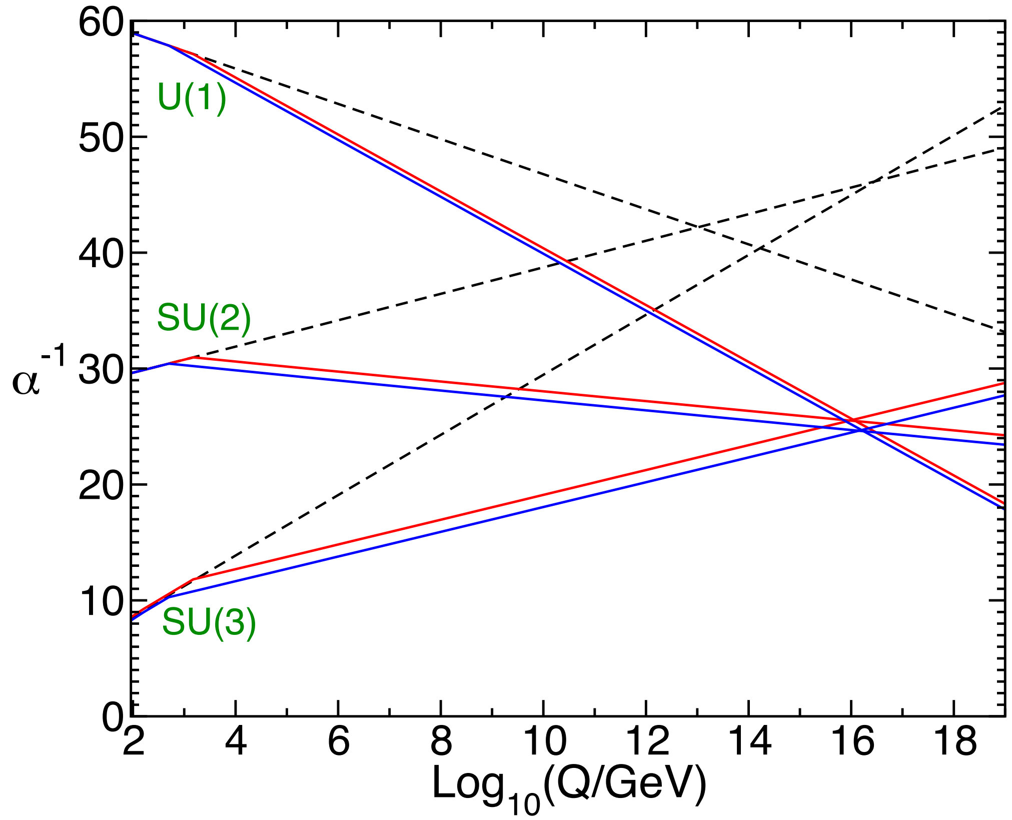
PARTICLE PHYSIC TODAY

- One missing piece of the puzzle, the Higgs boson
- Higgs mechanism spontaneously breaks the electroweak symmetry
  $\Rightarrow$ W and Z bosons become massive
- Recently discovered at the LHC, m_H = 125 ± 0.24 GeV
- Measured properties are compatible to that of SM Higgs.



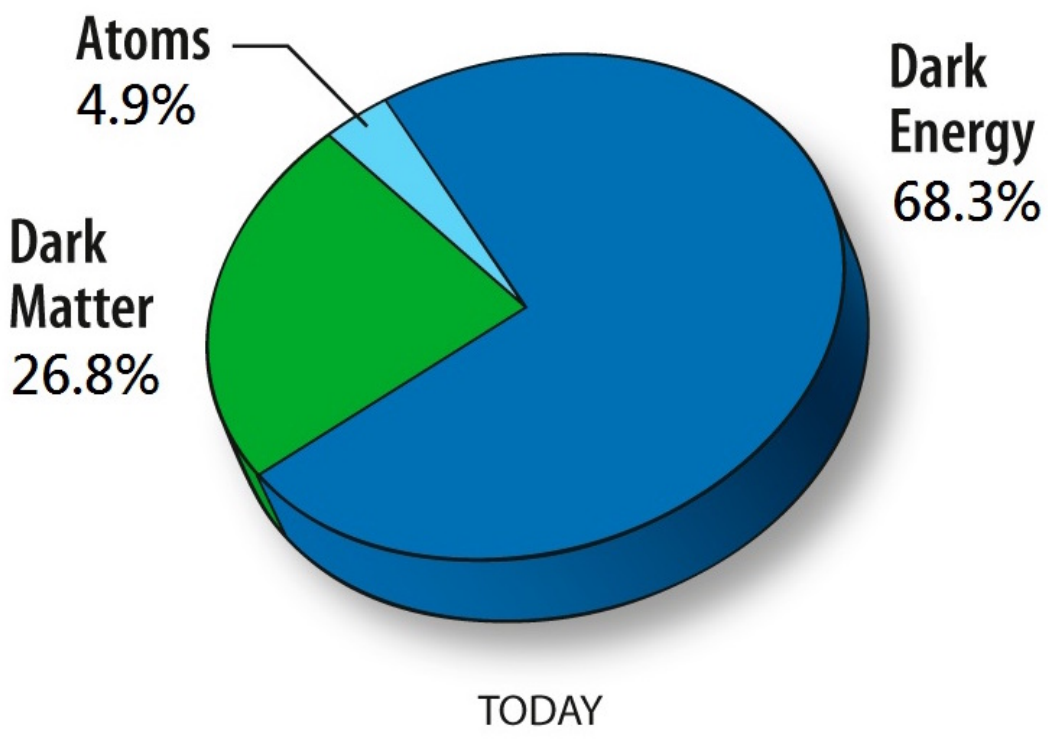


Unification of coupling constants @ M_{pl}



Very crucial questions remain unanswered

Dark matter candidate

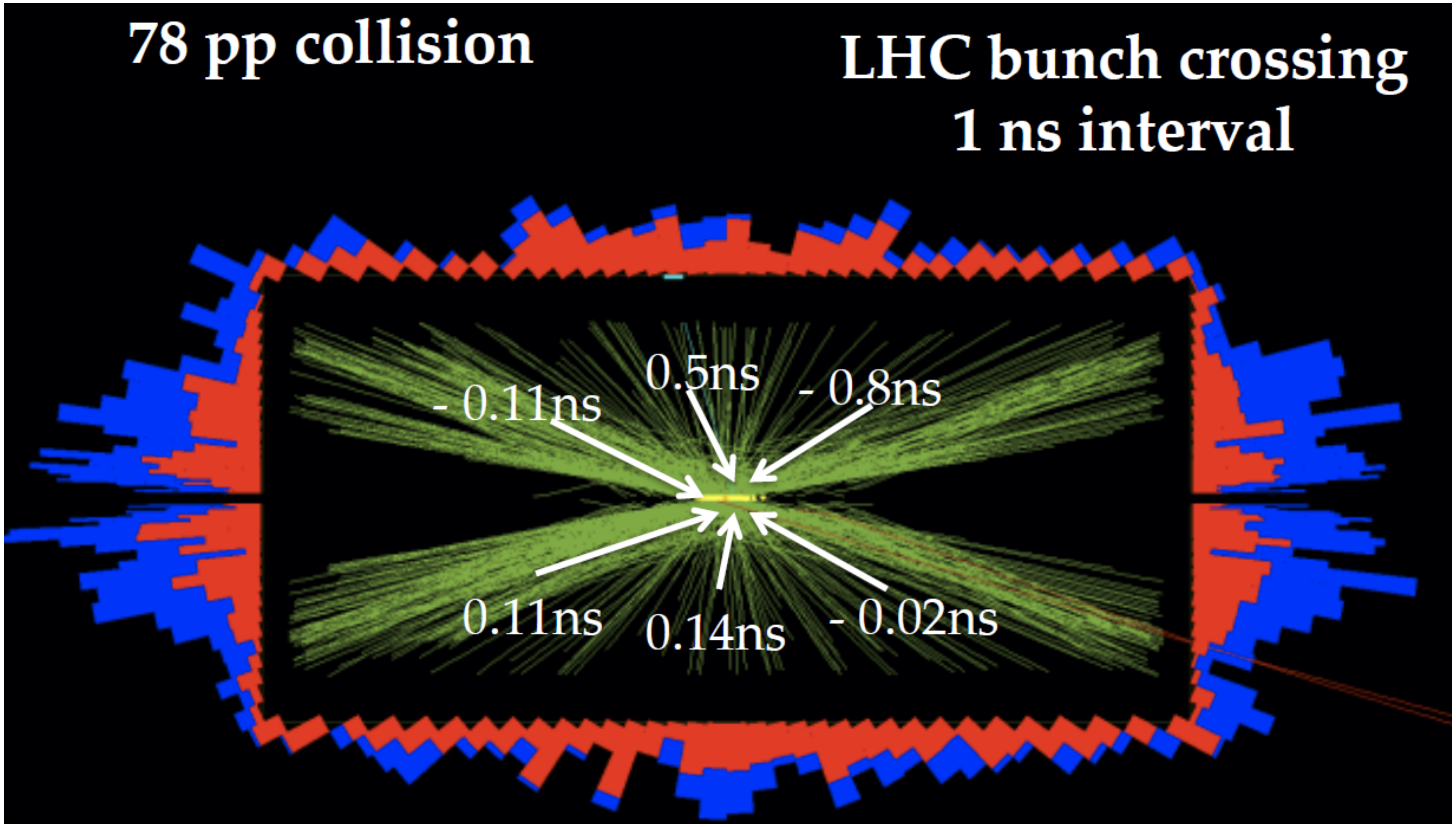


Dark matter accounts for 27% of the total energy budget of the universe

HIGH LUMINOSITY ENVIRONMENTS

- The LHC and possible future colliders will play a key role in answering those questions
- In all cases high instantaneous luminosities (larger than 10^{34} cm^{-2}s^{-1})
  - HL-LHC: aiming at 10^{35} cm^{-2}s^{-1}
  - Future collider: even higher in order to probe rare processes

High Luminosity ⇒ High pileup



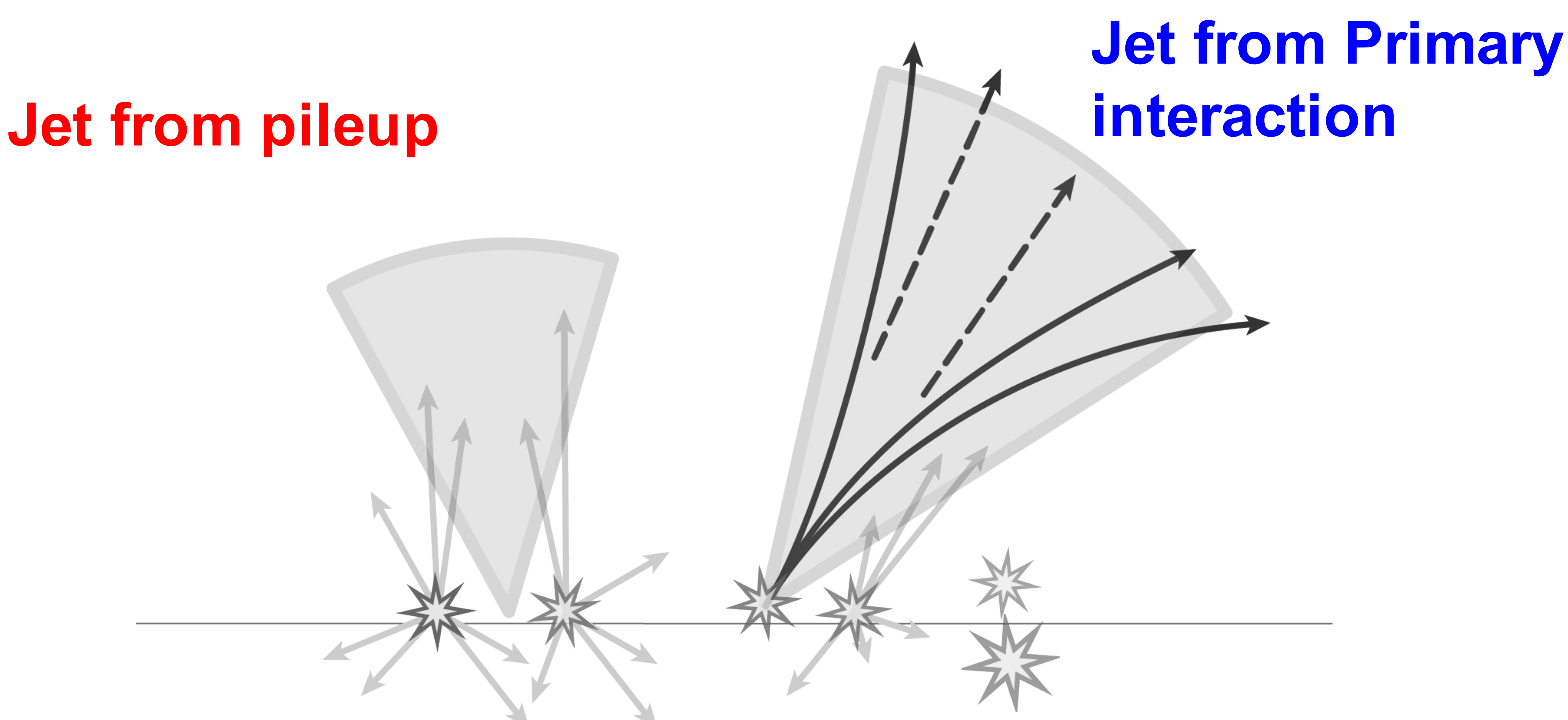
Multiple pp collisions close to each other: deteriorate physics performance.

Up to 140 pileup interactions at the HL-LHC

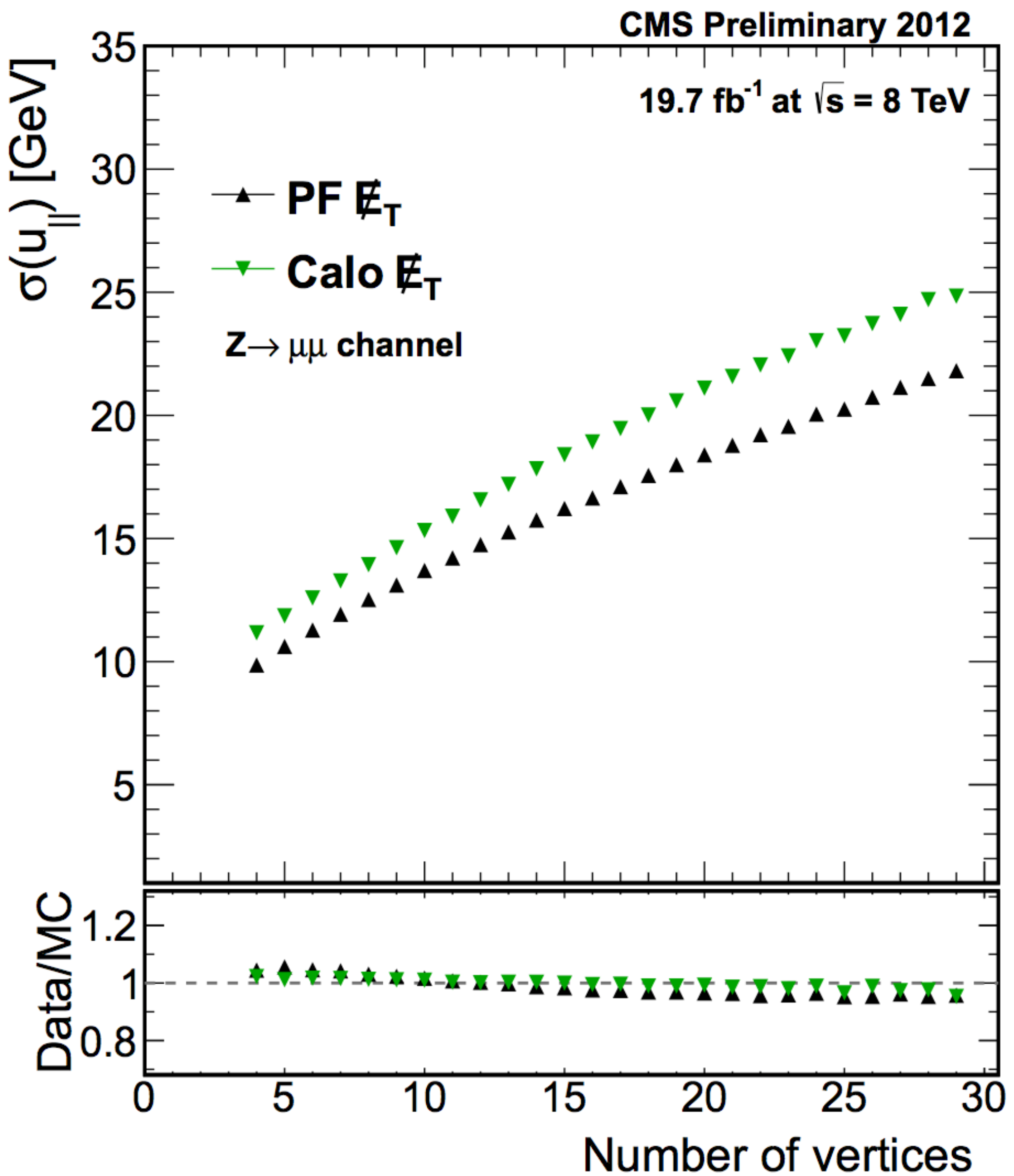
see A. Apresyan talk

Many challenges come with high pileup:

- Jets from pileup could be associated with the main interaction
- Pileup particle merging with particles coming from main interaction
- Vertices could overlap in the longitudinal direction



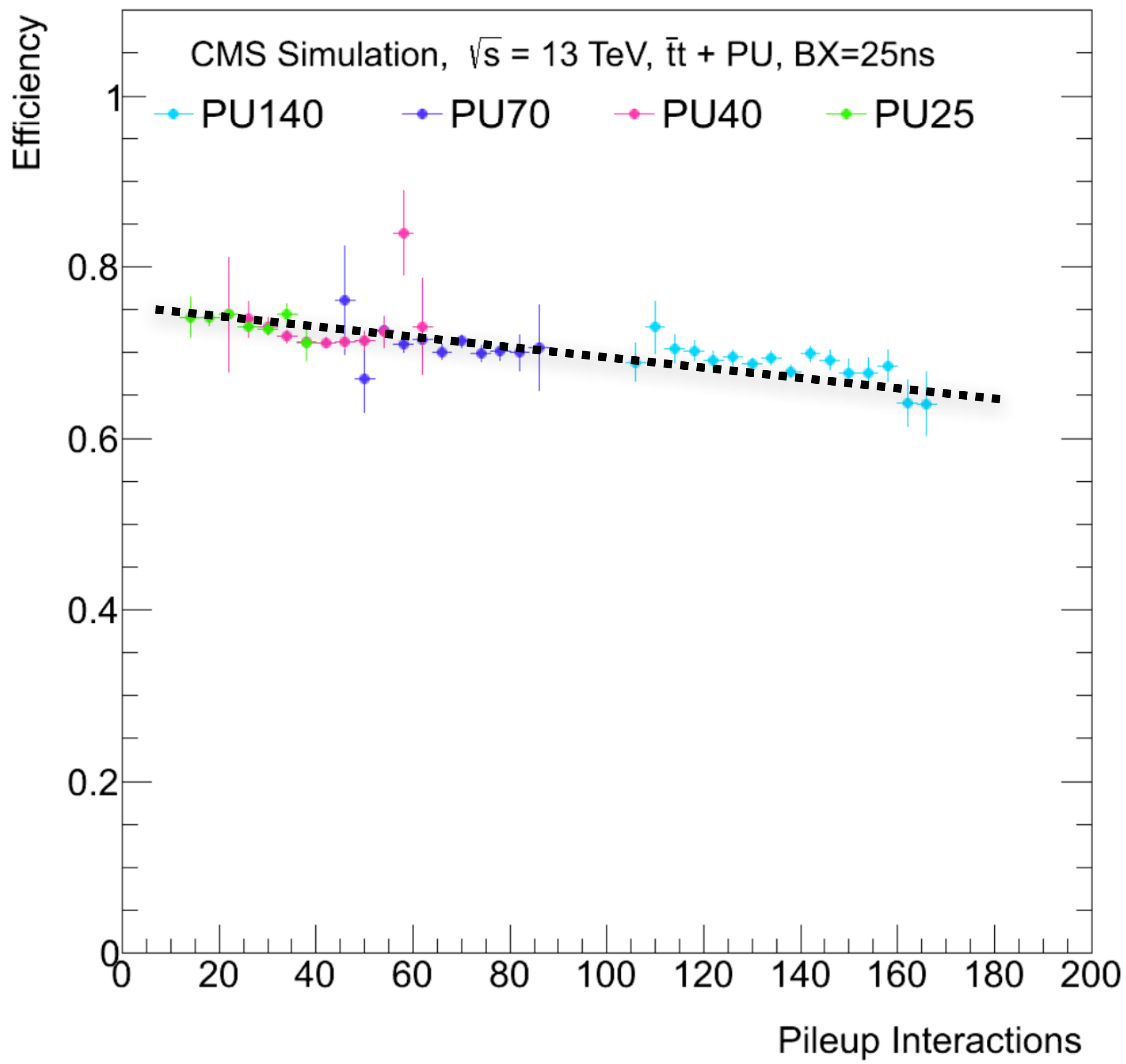
Missing transverse energy is very important for many BSM physics searches

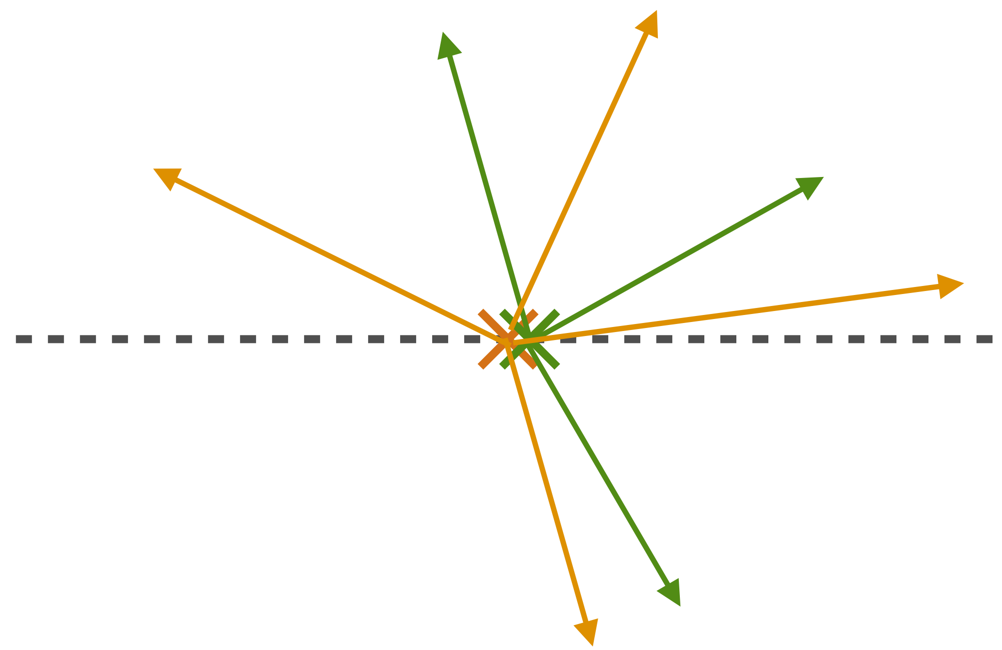


- Every pileup interaction contributes ~ 3 GeV to the missing E_T resolution
- At 140 pileup interactions, the missing E_T resolution due to pileup will be ~40 GeV

pileup particles significantly contribute to the missing E_T resolution

Tracking based vertexing also starts to suffer at such high pileup conditions



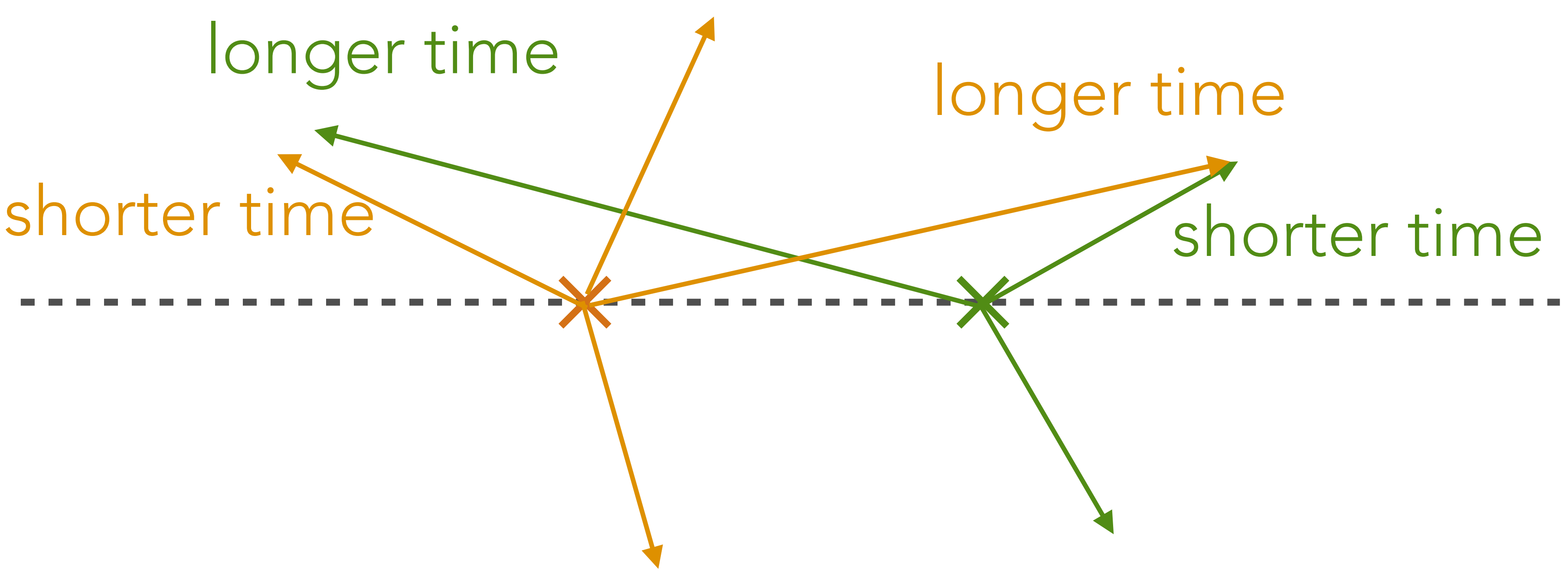


start to have overlapping vertices

A possible solution is to use precision timing

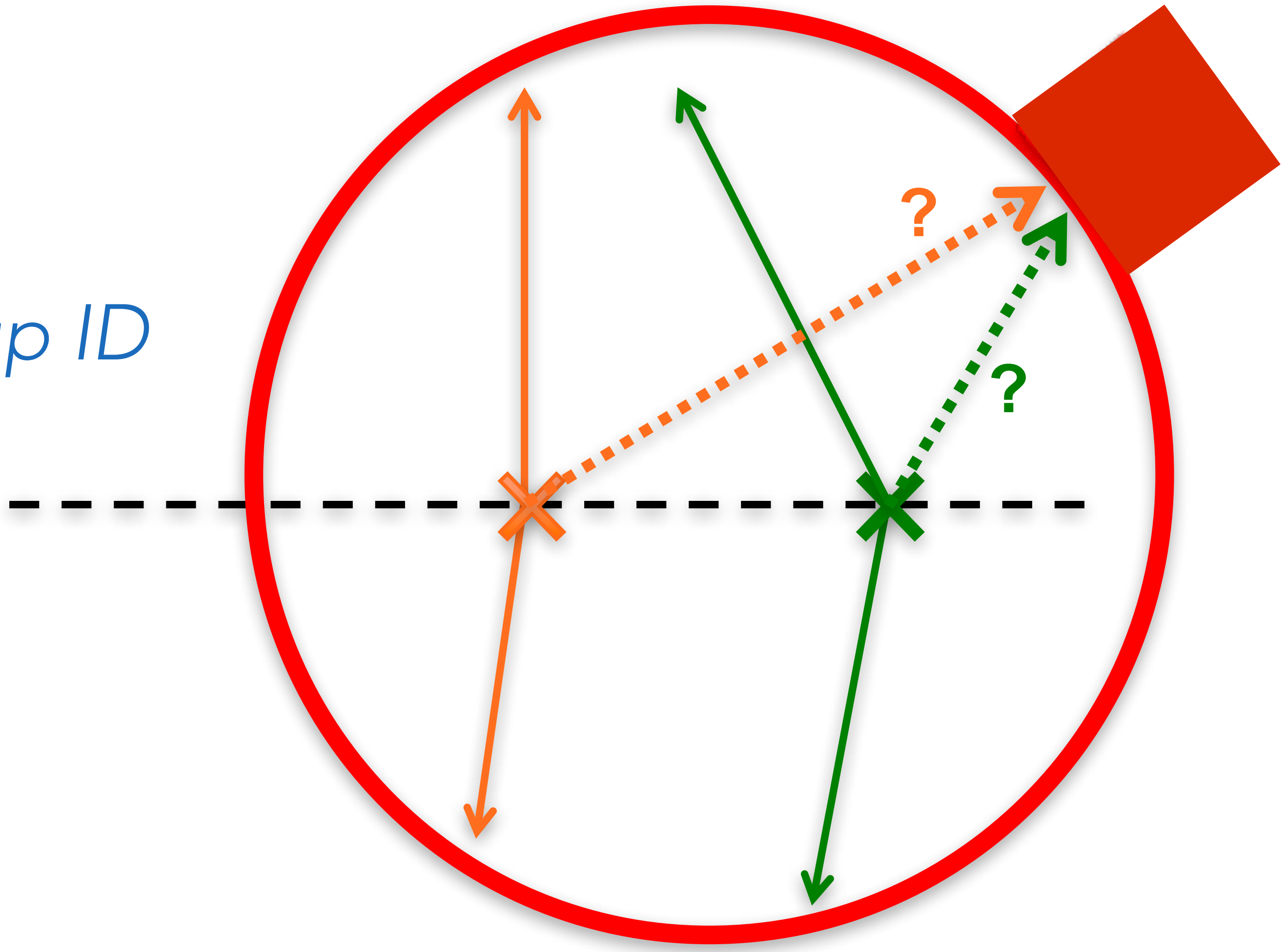
measure time stamp of a particle at the detector → then → Identify from what vertex it was produced

see A. Apresyan talk



Precision timing information could be use to identify pileup particles (pileup ID)

I: object level pileup ID

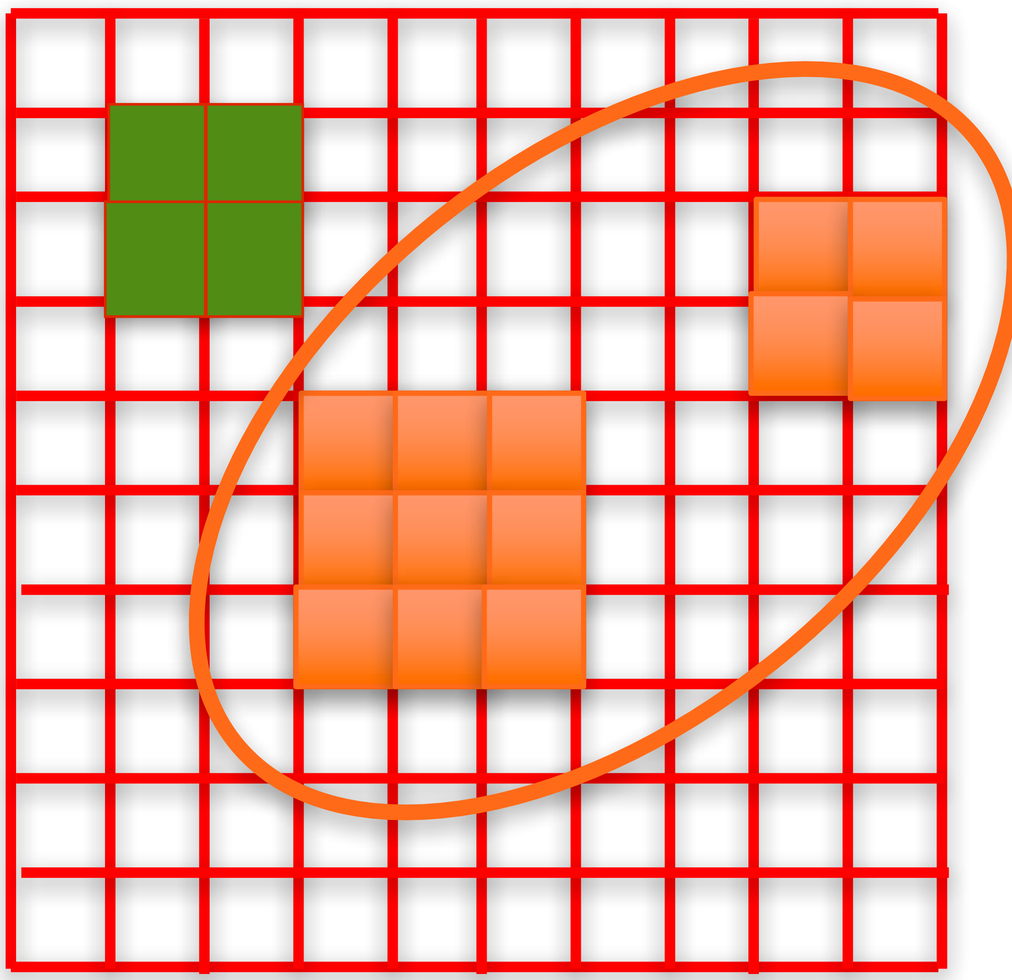


record charged particle, photon, and jet time stamps

check time stamp consistency with primary vertex

Precision timing information could be used when clustering single hits in the calorimeter

II: single hit pileup ID



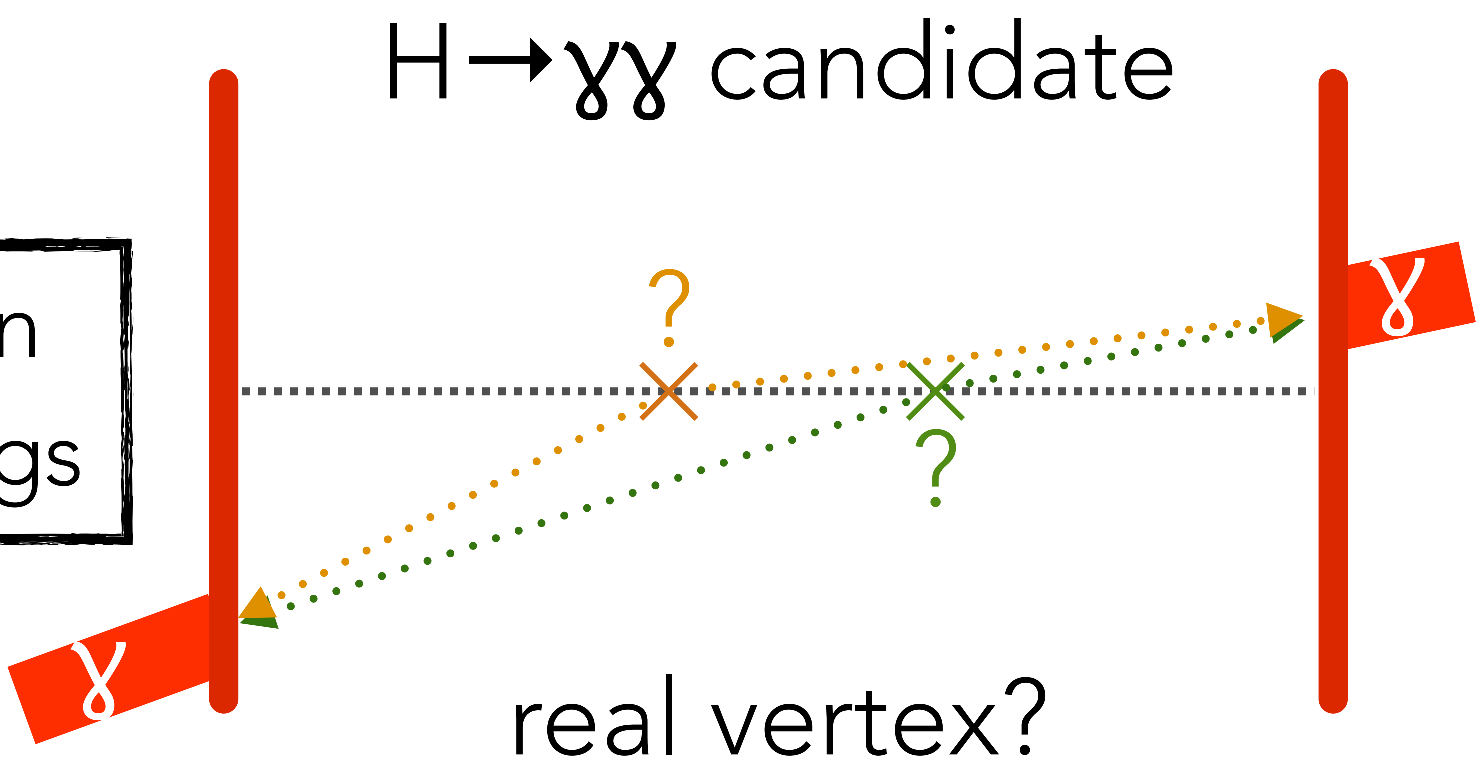
at 140 pileup, neutral particle contribute up to 100% of the energy in a 50 GeV jet

Precision timing could be used to reconstruct the primary vertex when only neutral particles are present

III: event level vertexing

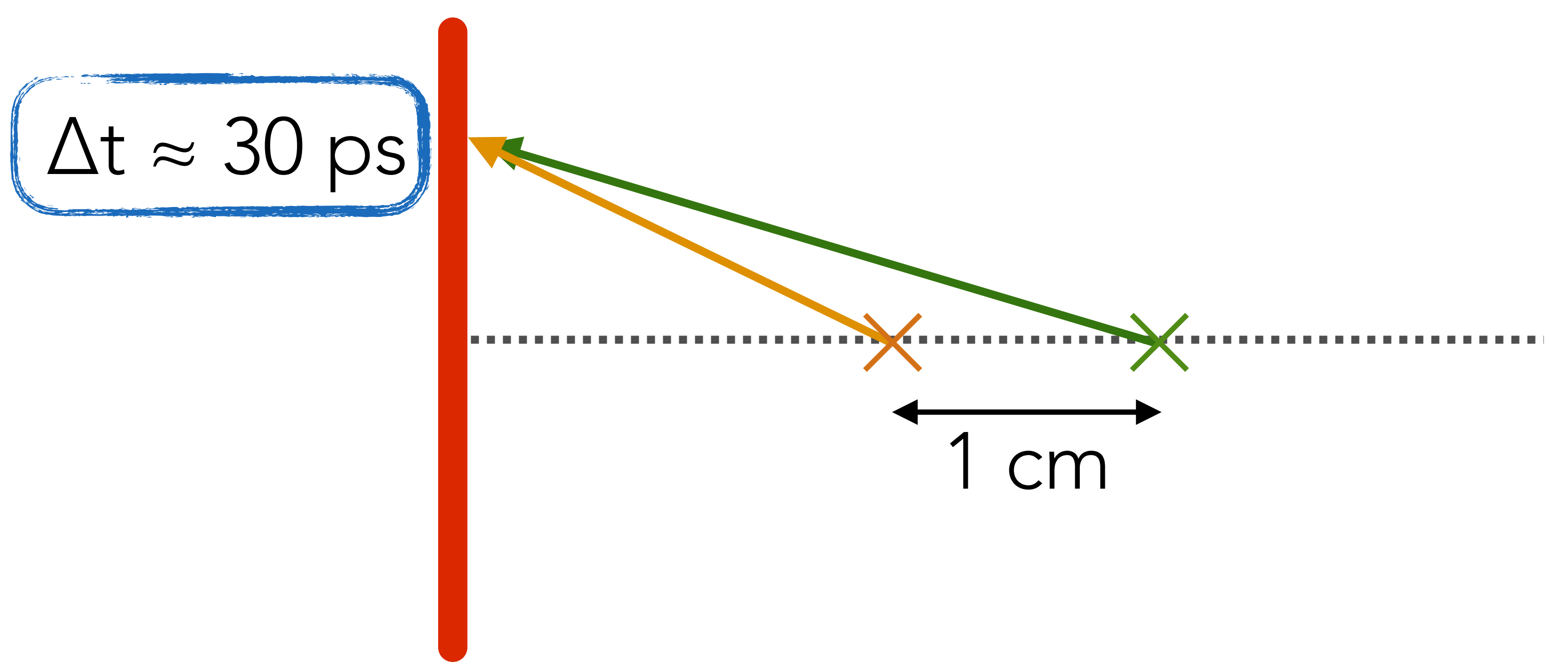
fundamental for precision measurements of the Higgs

see A. Apresyan talk



How precise does the timing measurement need to be?

- Particles travel at near the speed of light
- 1 cm is equivalent to ~33 ps
- To distinguish pileup interactions separated by 1 cm requires a time resolution of ~30 ps
- Typical collider beam-spots are ~10 cm ⇒ *rejection factor of 10*

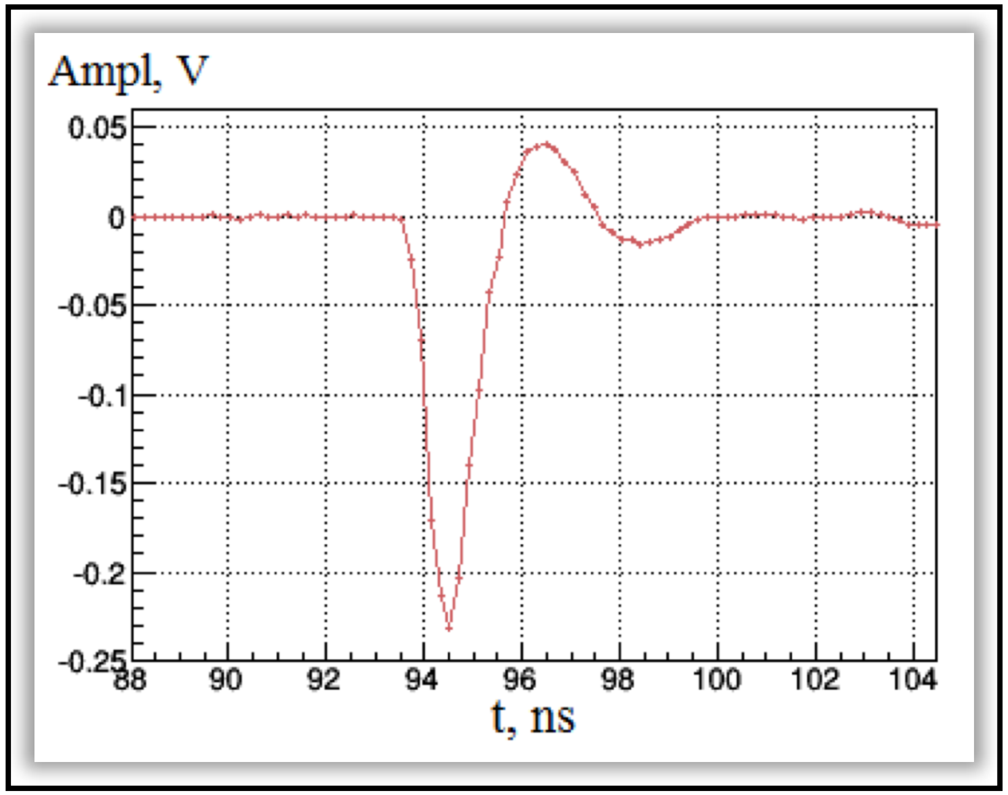


Multichannel Plate as the Active Element of a Shower Maximum Detector, Part I

SECONDARY EMISSION CALORIMETER

Secondary emission calorimeters provide some intrinsic advantages:

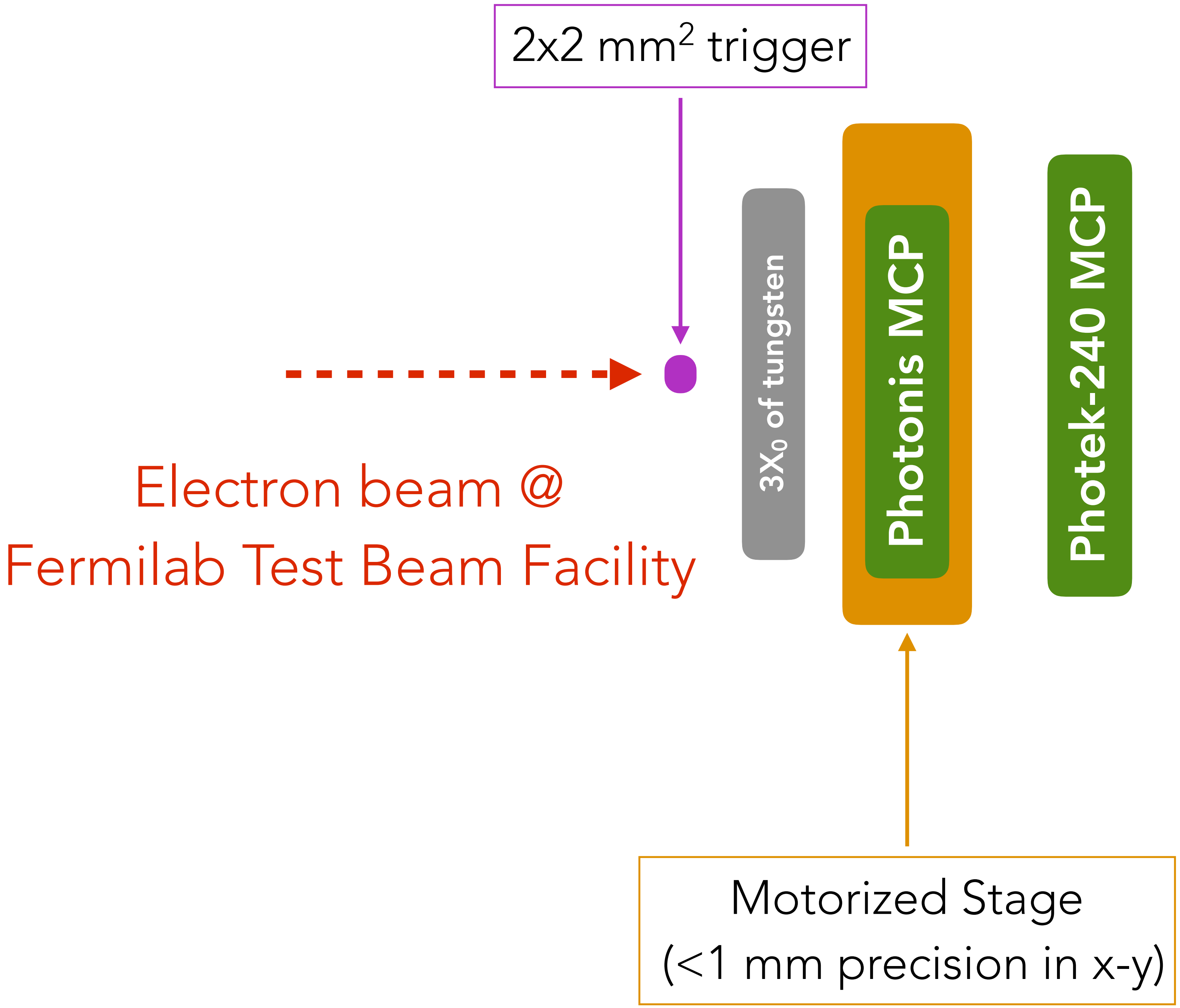
- MCP are radiation hard
- No optical transparency issues
- No optical transport issues
- Intrinsically fast:
  - Signal formation and decay are fast (full pulse in a few ns)
  - Major advantage for future colliders (enables higher bunch crossing rate)



MCP example pulse:

2 ns pulse width

NIM. A 828 (2016), pp. 1–7



MCP-BASED SECONDARY EMISSION CALORIMETER

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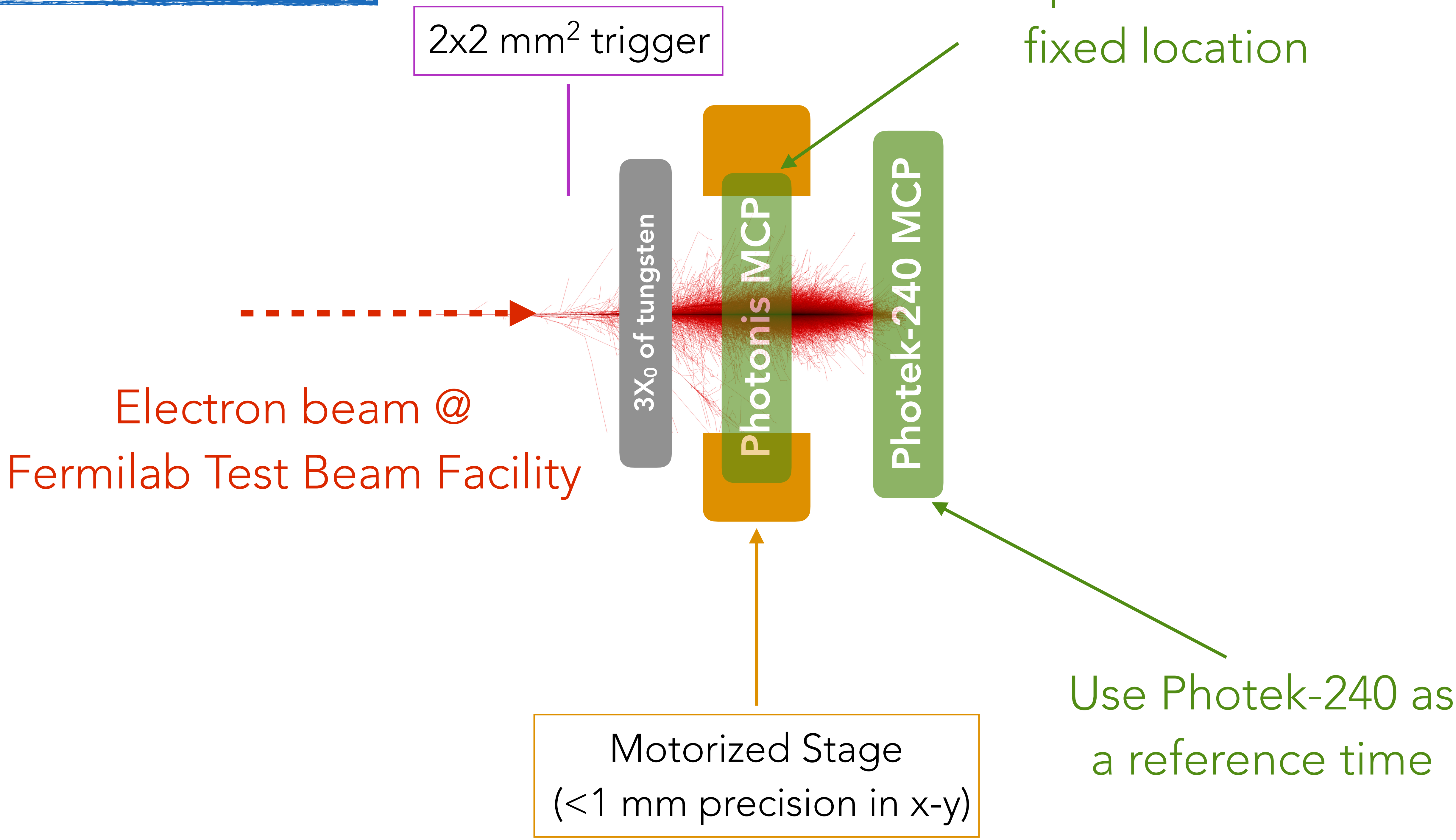
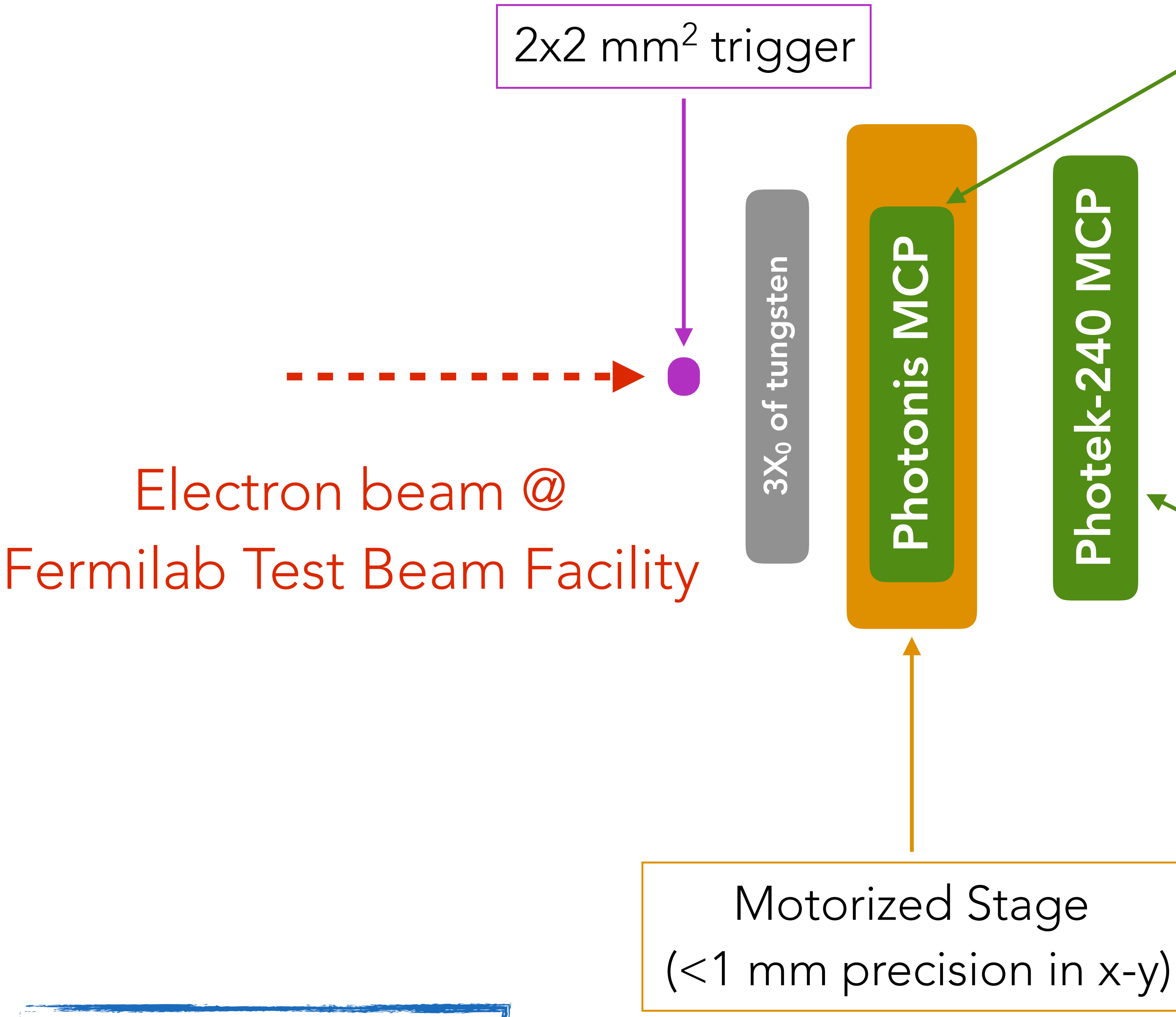
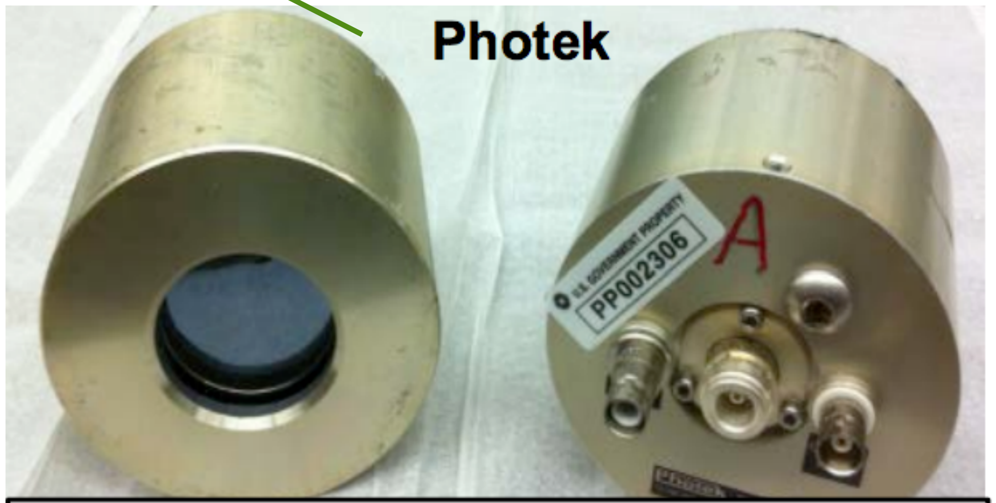


MCP DETECTORS



25 μm pore size; 5.3x5.3 cm^2 active area; 64 pixels (8x8), 6.5 mm pitch per pixel; rise time ~0.6 ns, pulse width ~1.8 ns.



10 μm pore size, 41mm aperture, PC-MCP distance ~5mm, rise time~60 ps, SPTR~40 ps

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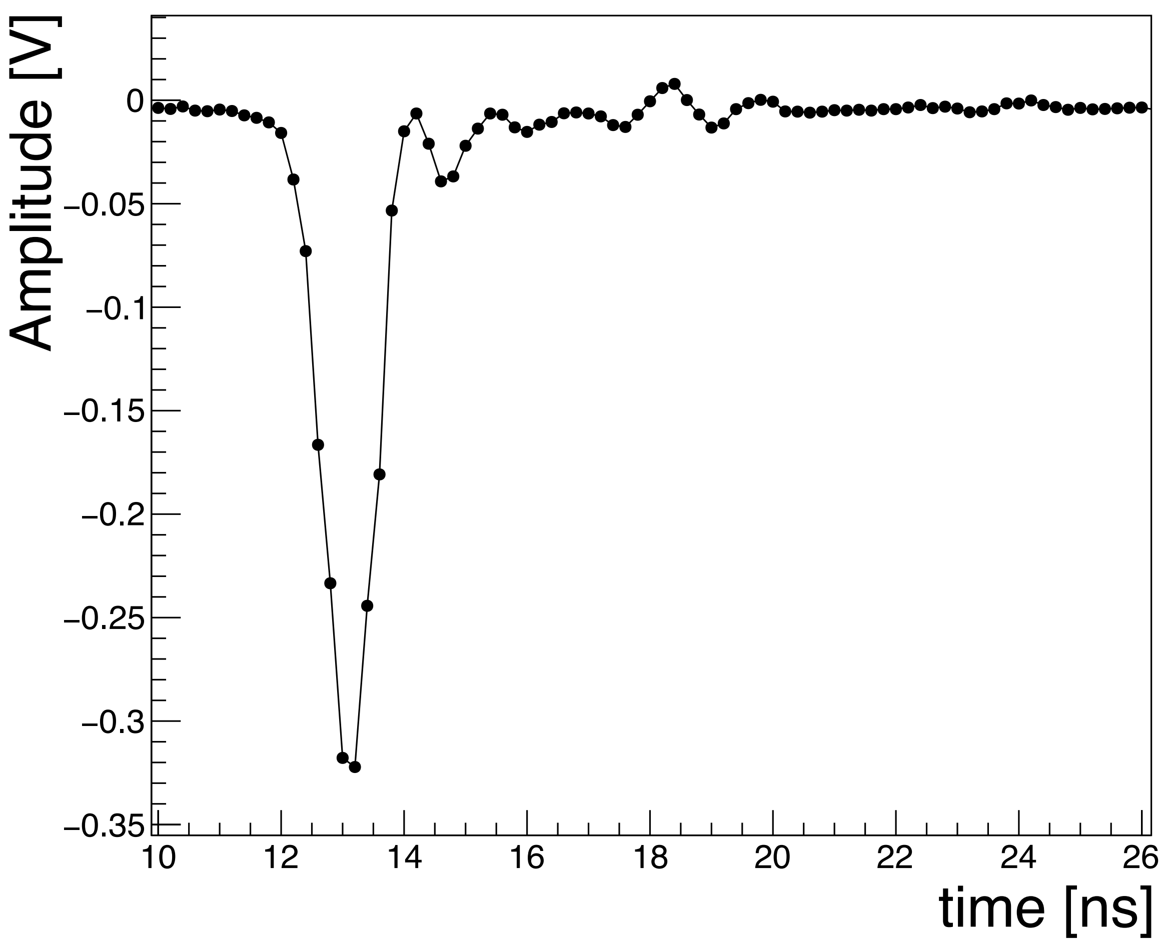
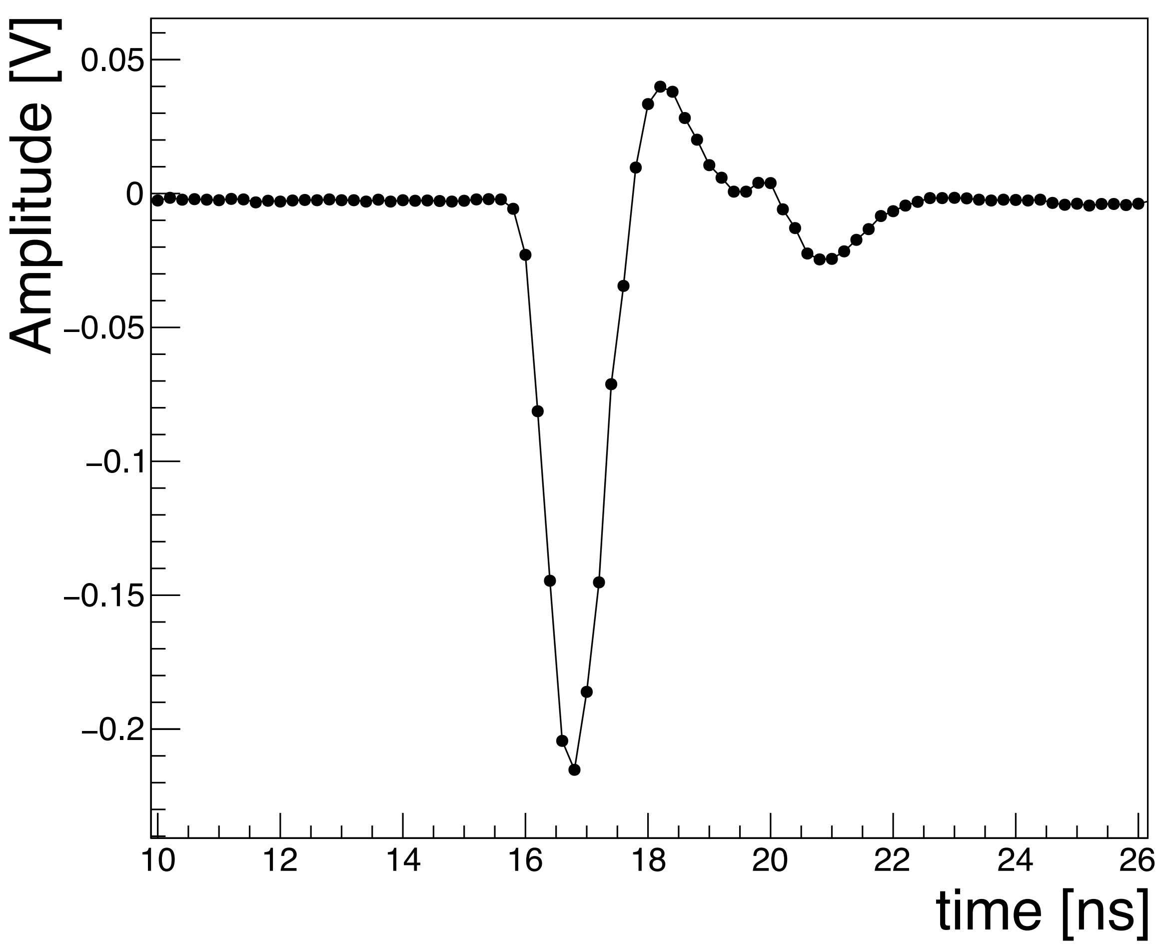
MCP signal pulses in this setup

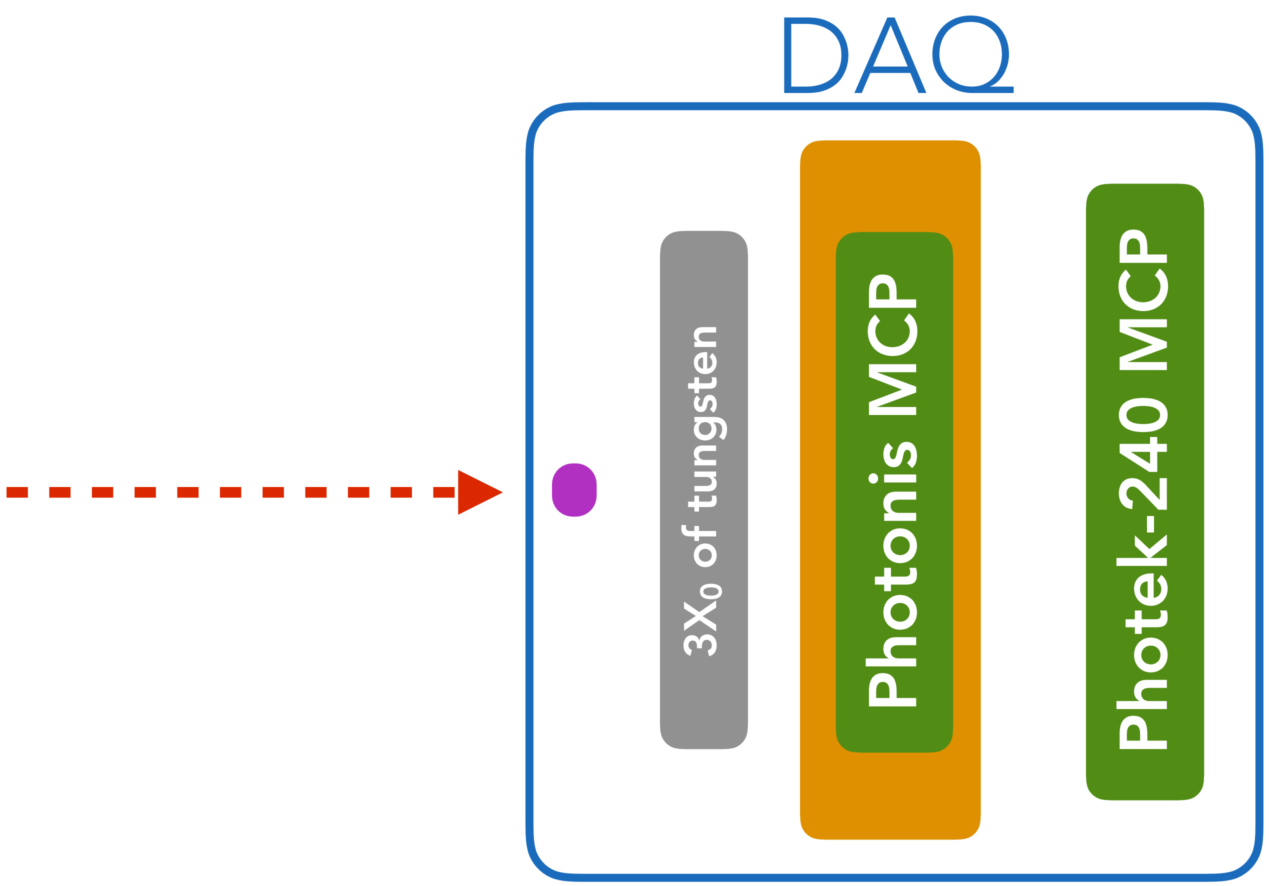


Photonis MCP pixel



Photek-240 MCP

Different sources contribute to the time resolution



relevant source — II: Photonis MCP + Shower

other sources

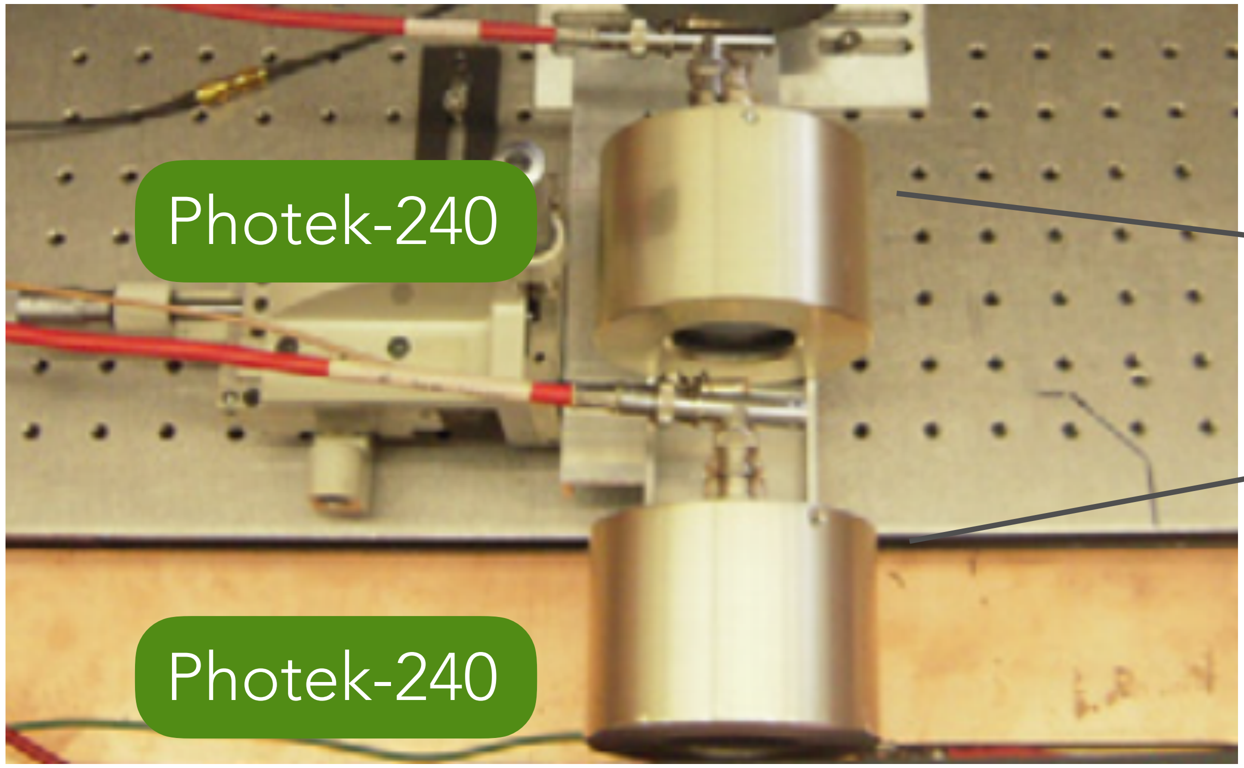
I: shower fluctuations

II: Reference Timer

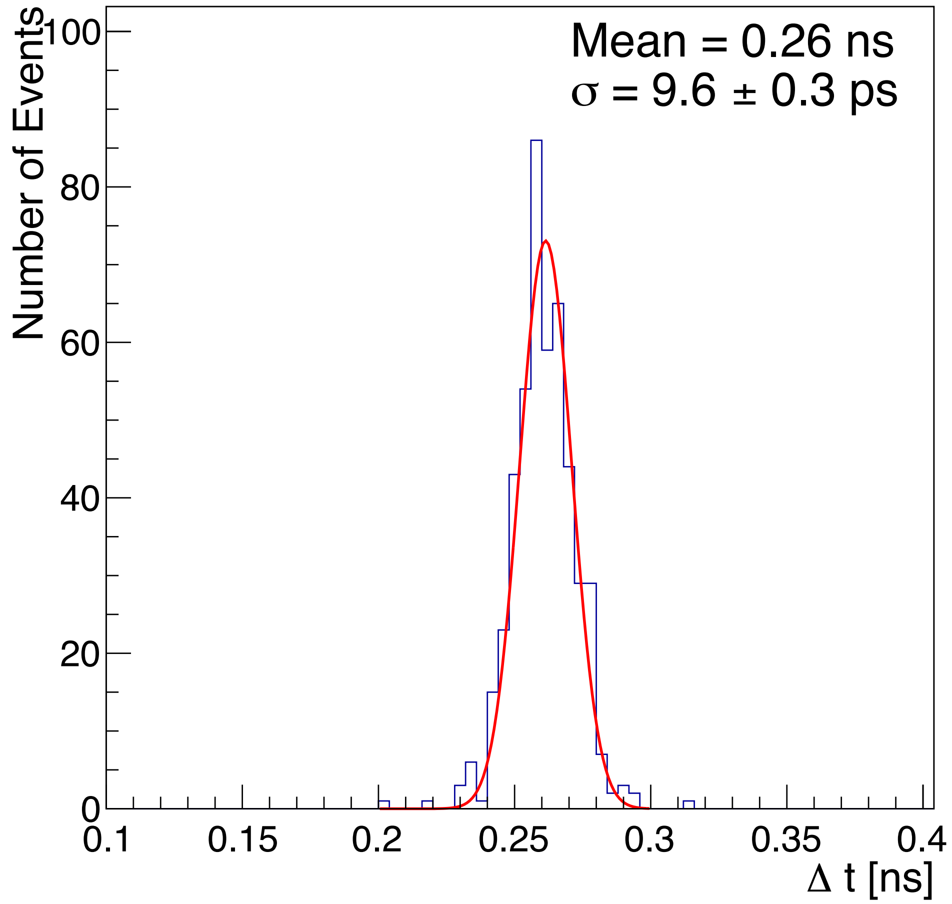
III: Digitization/DAQ

REFERENCE TIMER

- Measure ~10 ps time-of-flight resolution
  - Single device time resolution ~6 ps
- Excellent reference timer for subsequent measurement



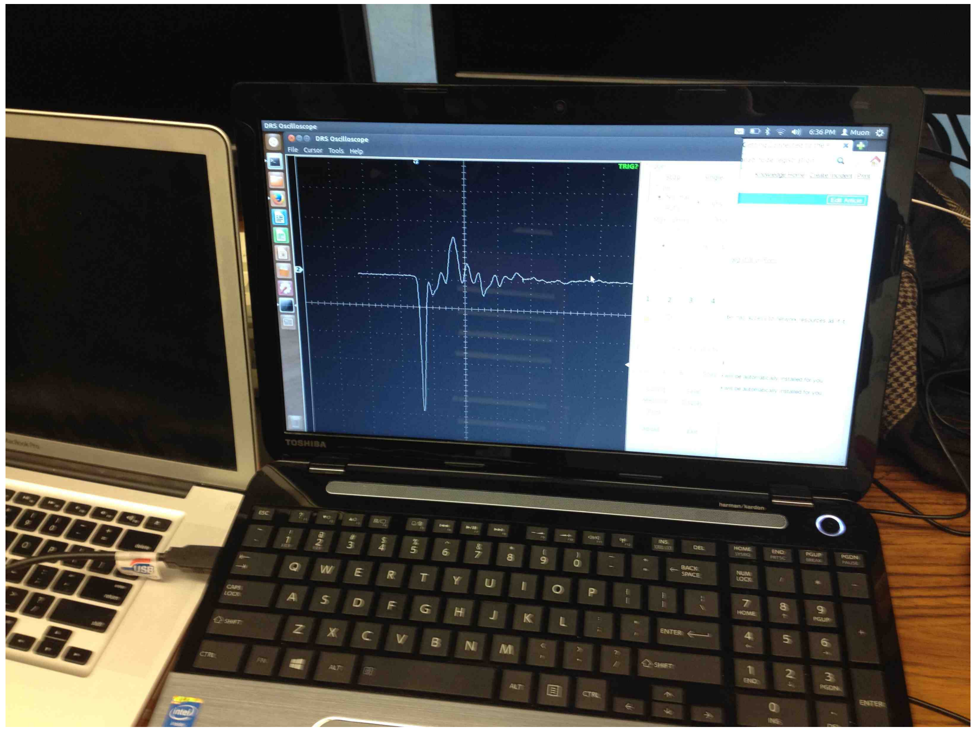
Beam direction
(120 GeV protons)



Study of the timing performance of micro channel plate photomultiplier for use as an active layer in shower maximum detector.", *NIM A, 795 (2015) p. 288-292*

DIGITIZATION AND DAQ

- Use DRS4 (Domino-Ring-Sampler) Evaluation Board developed by Stefan Ritt at PSI for MEG2 experiment
- 750 MHz of analog bandwidth
- 5 Gsamples/s (i.e. 200 ps per sample)
- Well validated software and scope applications
- Measured electronic time resolution to be about 5 ps



scope application

DRS4 Units

DIGITIZATION AND DAQ

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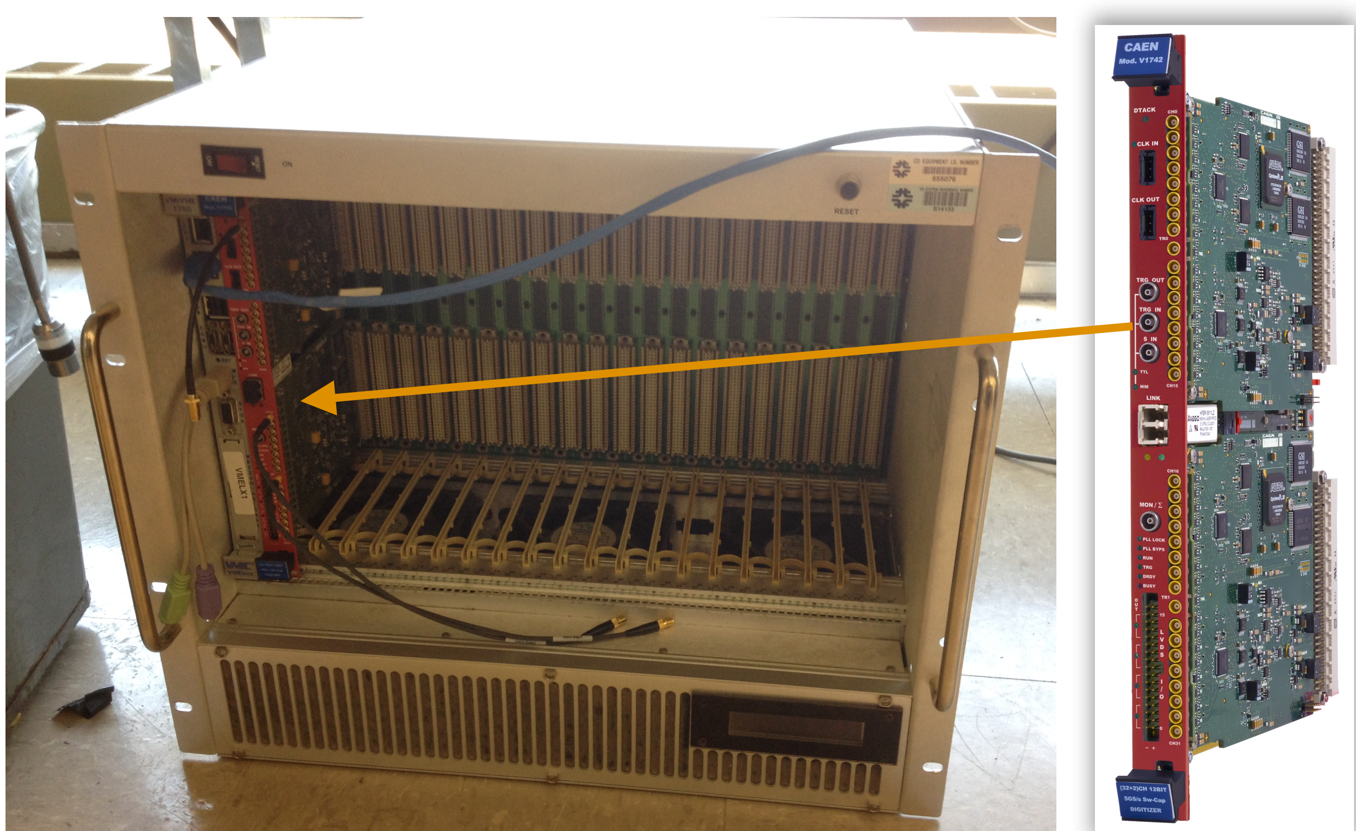
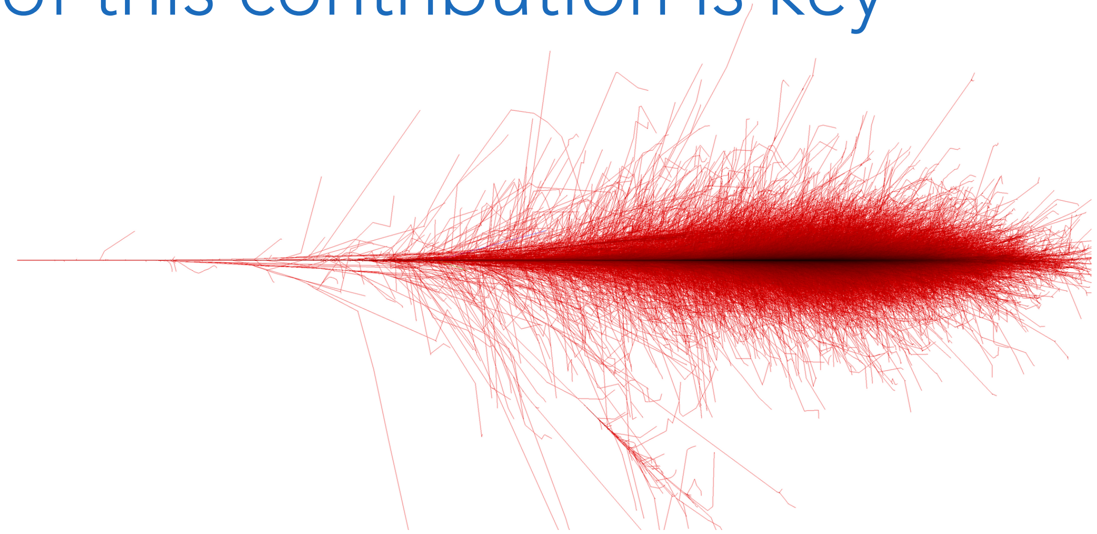
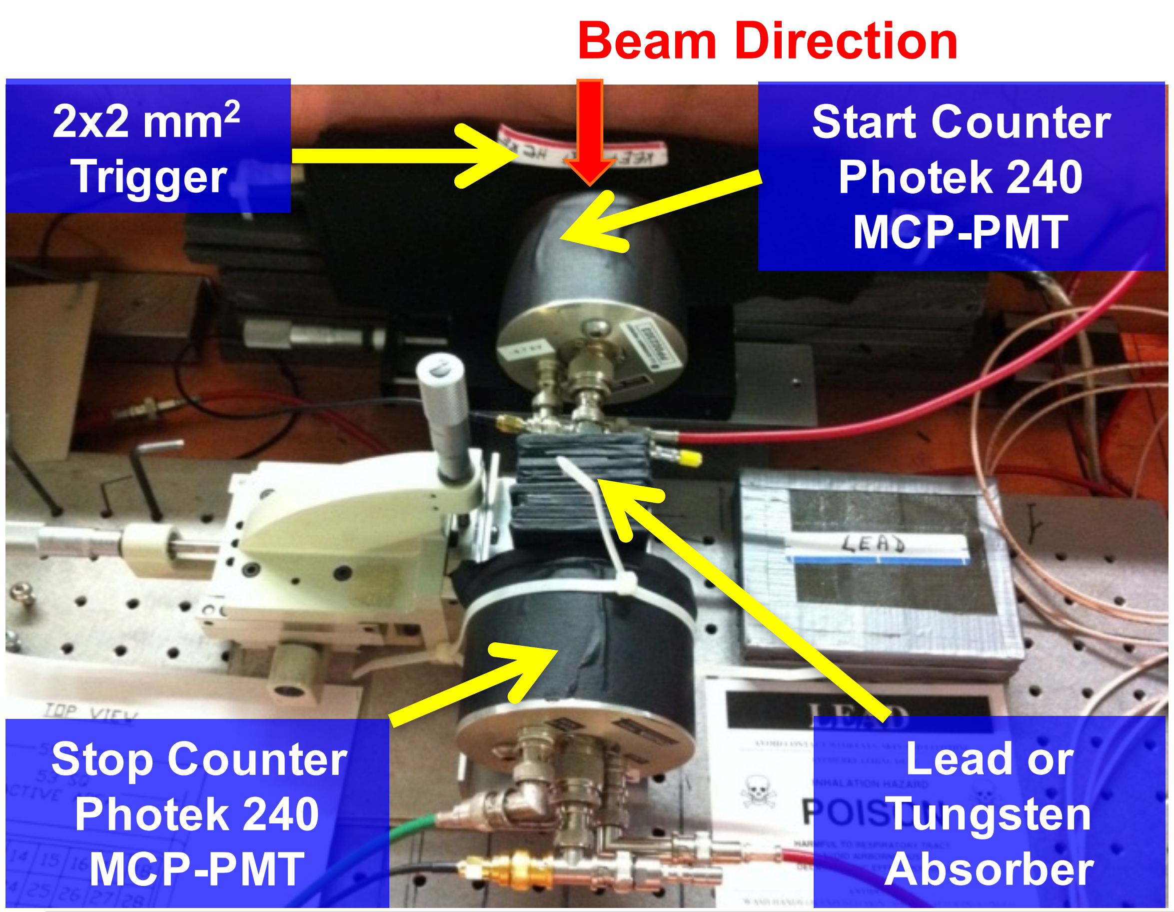


Also available as a crate module: 32+4 channels

SHOWER FLUCTUATIONS

- Shower fluctuation may result in time jitter on the signal pulses
- Quantification of this contribution is key

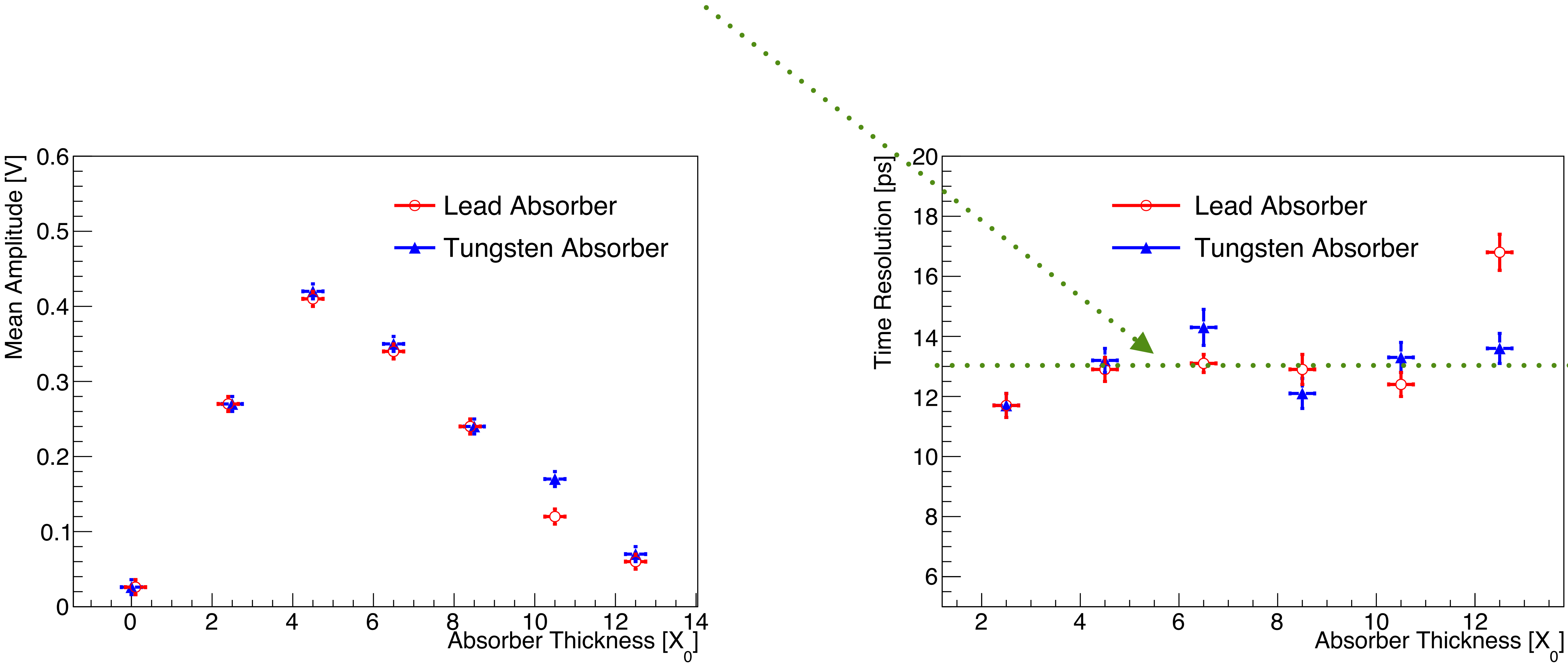




- Measure time jitter for a prototype sampling calorimeter with precision time capability
- Use Photek-240 as reference
- Use Photek-240 to detect shower secondaries

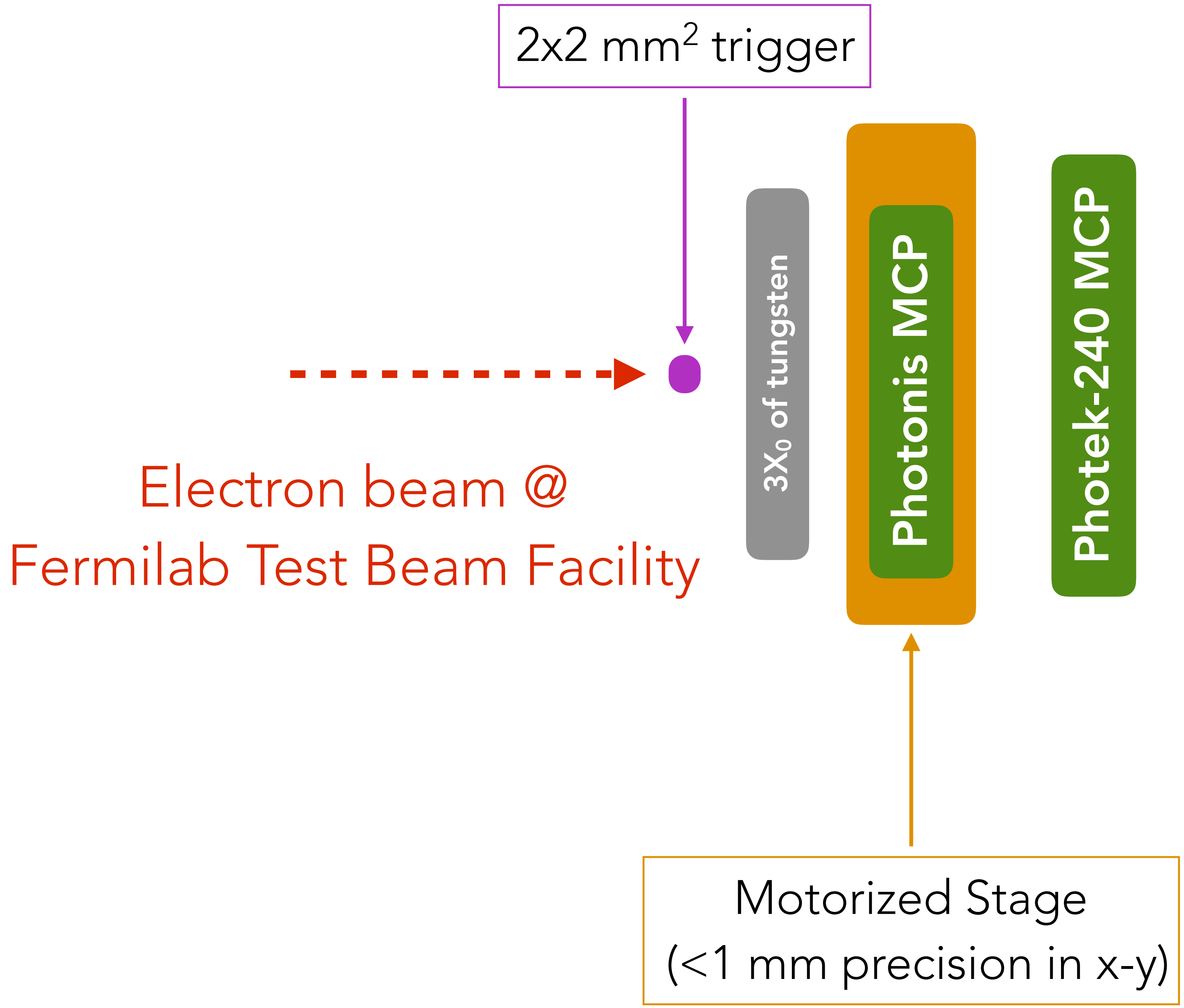
SHOWER FLUCTUATIONS

- We measured the time resolution throughout the shower at ~13 ps
- Suggest that shower fluctuations contribute less than 10 ps to the time jitter — taking into account the detector jitter.



Study of the timing performance of micro channel plate photomultiplier for use as an active layer in shower maximum detector.", *NIM A, 795 (2015) p. 288-292*

Multichannel Plate as the Active Element of a Shower Maximum Detector, Part II


2x2 mm^2 trigger
3X_0 of tungsten
Photonis MCP
Photek-240 MCP
Electron beam @
Fermilab Test Beam Facility
Motorized Stage
(<1 mm precision in x-y)

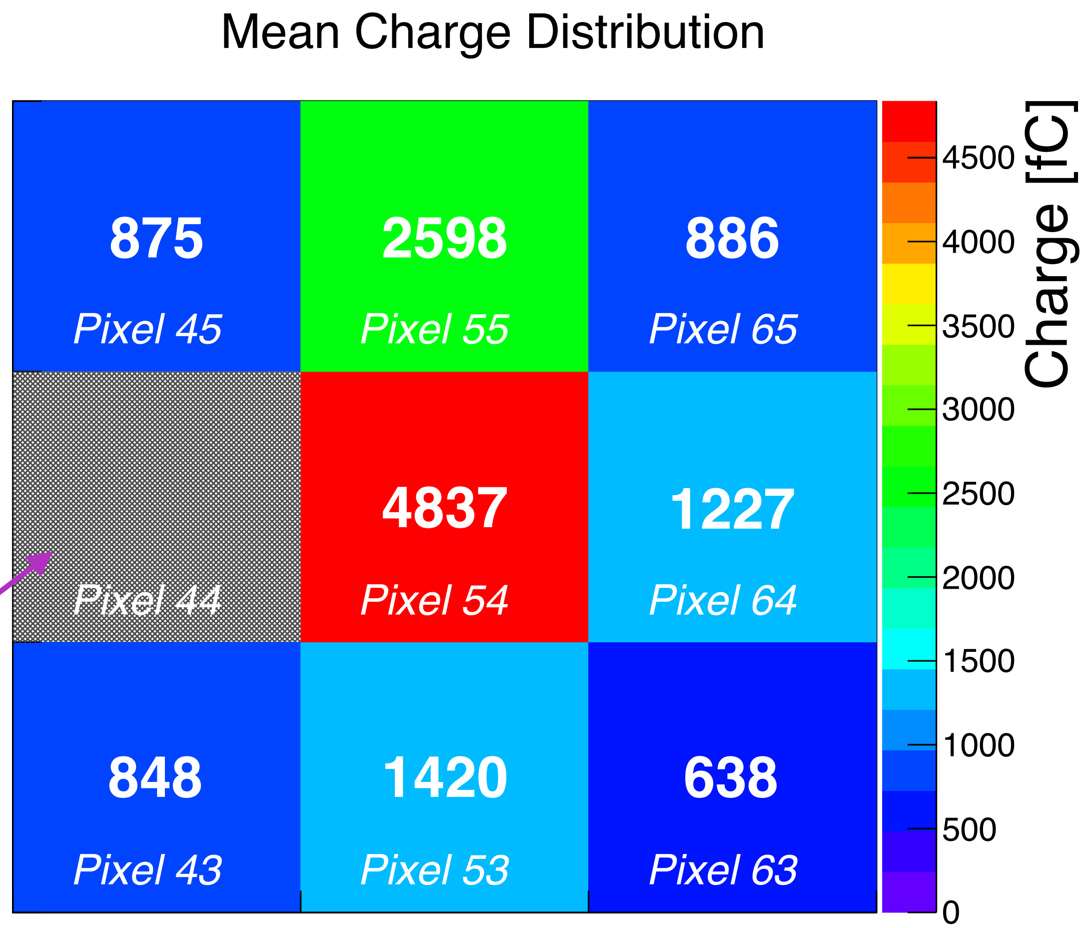
SHOWER POSITION RECONSTRUCTION

NIM. A 828 (2016), pp. 1–7

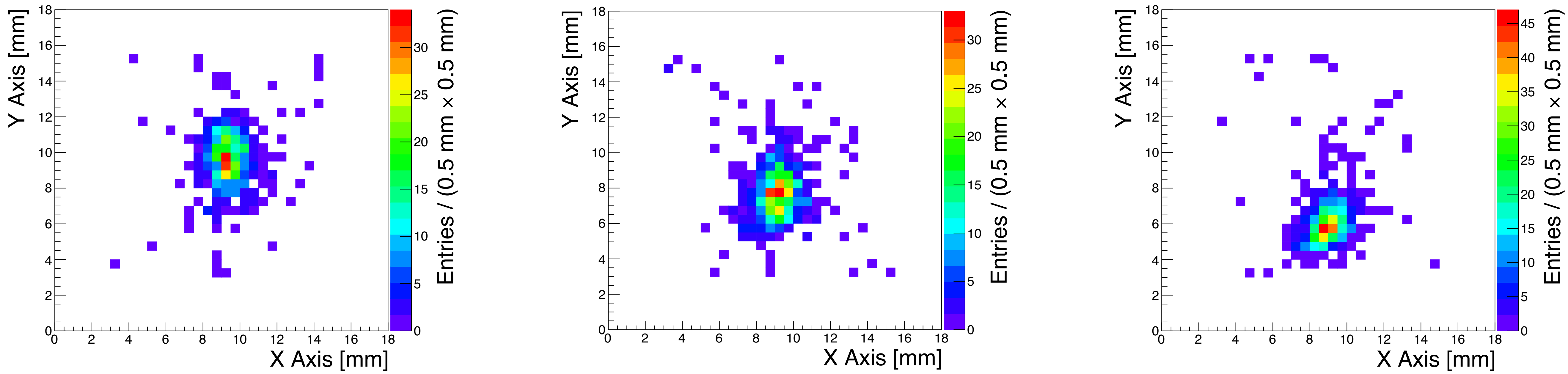
Use only 9 pixels of the 8x8 matrix

$$\vec{\mathbf{p}} = \frac{\sum_{i\in \text{pixels}} Q_i \vec{p}_i}{\sum_{i\in \text{pixels}} Q_i}$$

event-by-event shower mean position reconstruction



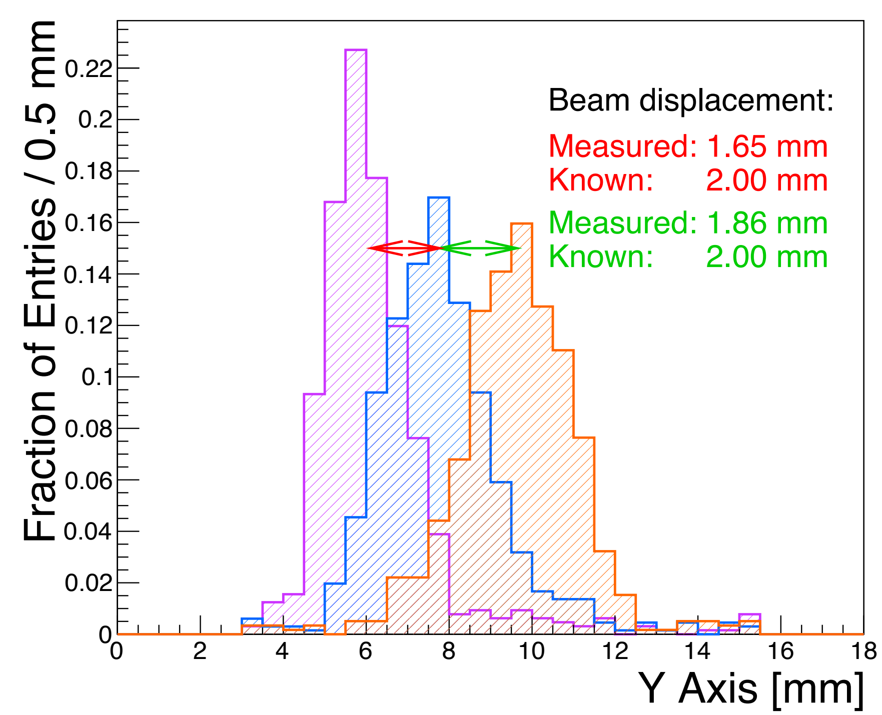
Unfortunately one pixel was dead



$$\vec{\mathbf{p}} = \frac{\sum_{i \in \text{pixels}} Q_i \vec{p_i}}{\sum_{i \in \text{pixels}} Q_i}$$

event-by-event shower mean position reconstruction

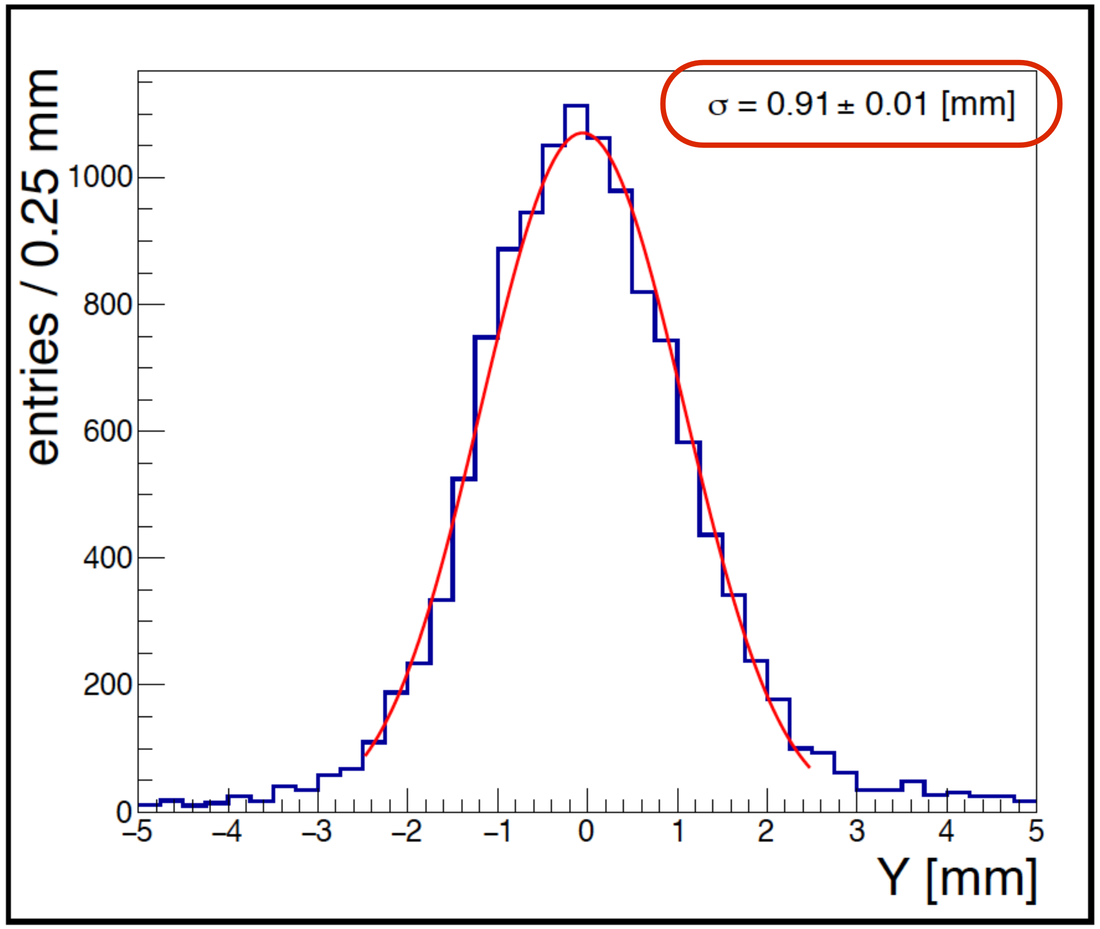
Shower positions are on average well reconstructed



SHOWER POSITION RESOLUTION

- Model the shower position as the convolution of the beam profile with a Gaussian (resolution)
- We fit the data to extract the resolution (width of the Gaussian)

  - Obtain a position resolution of ~1 mm
  - Recall that each pixels is 5.9 mm in size



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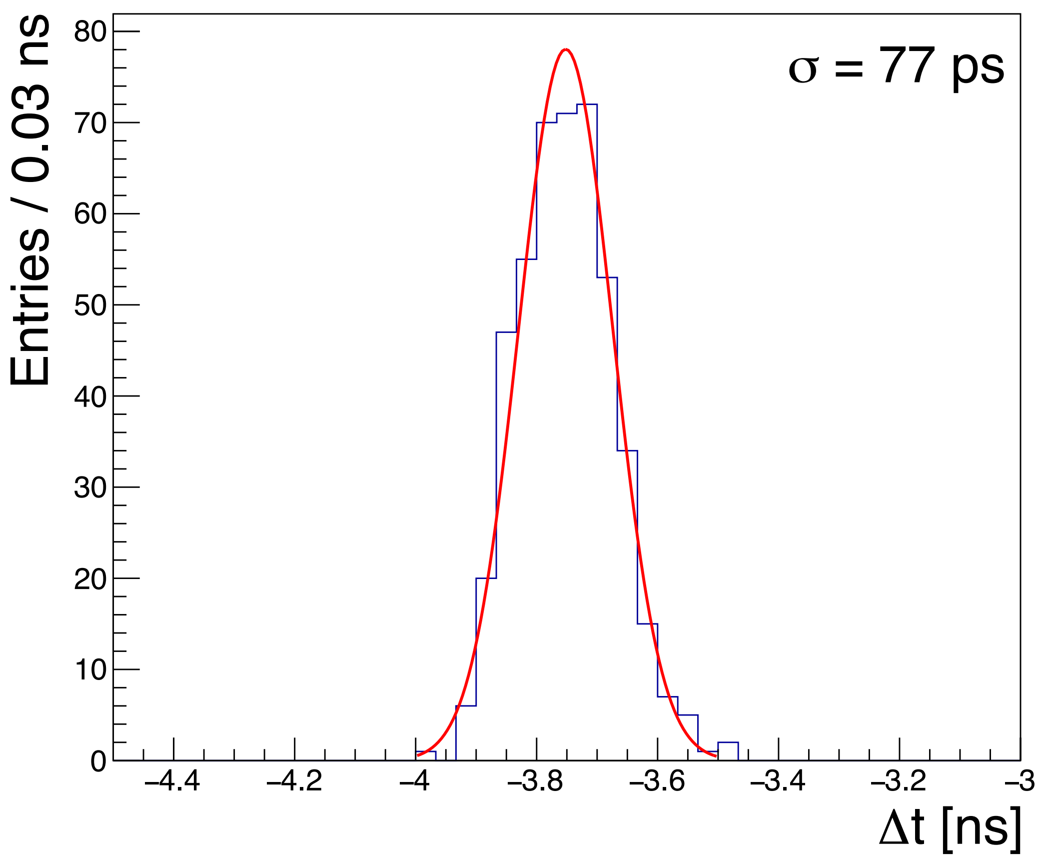
Look at individual and combined time resolution

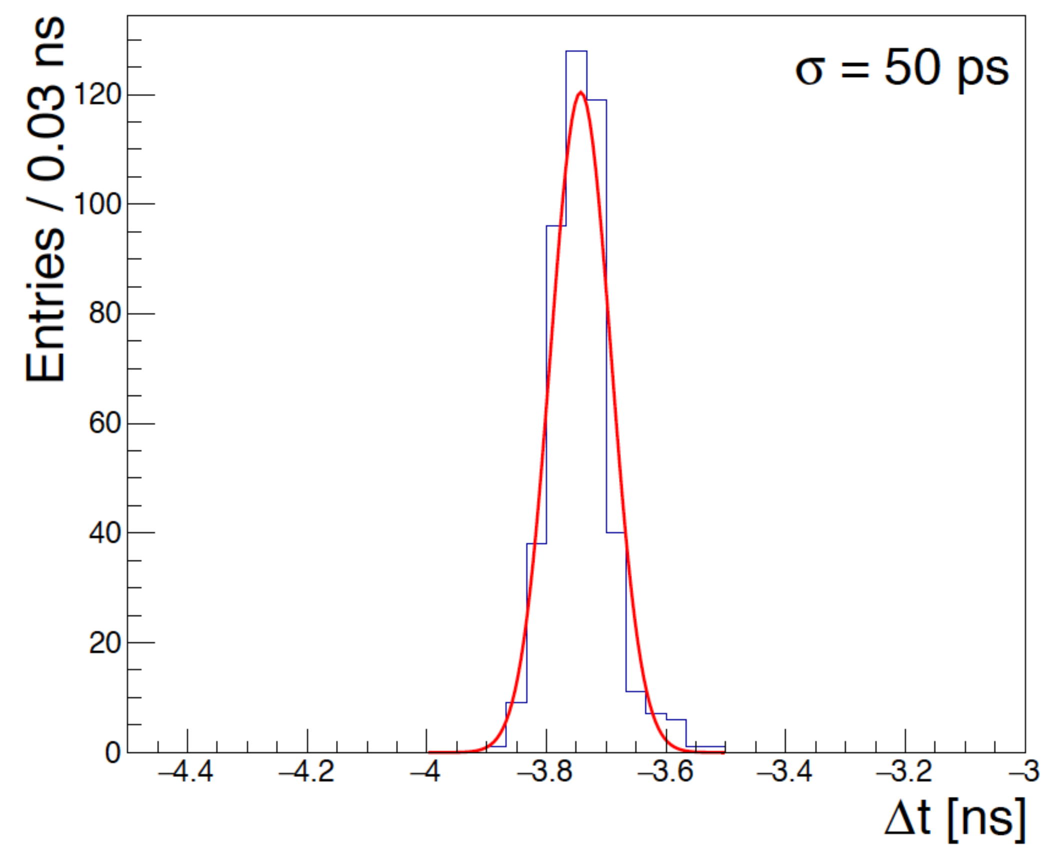
single pixel time resolution



combine all pixels

combined time resolution

$$t = \frac{\sum_{i \in \text{pixels}} Q_i t_i}{\sum_{i \in \text{pixels}} Q_i}$$



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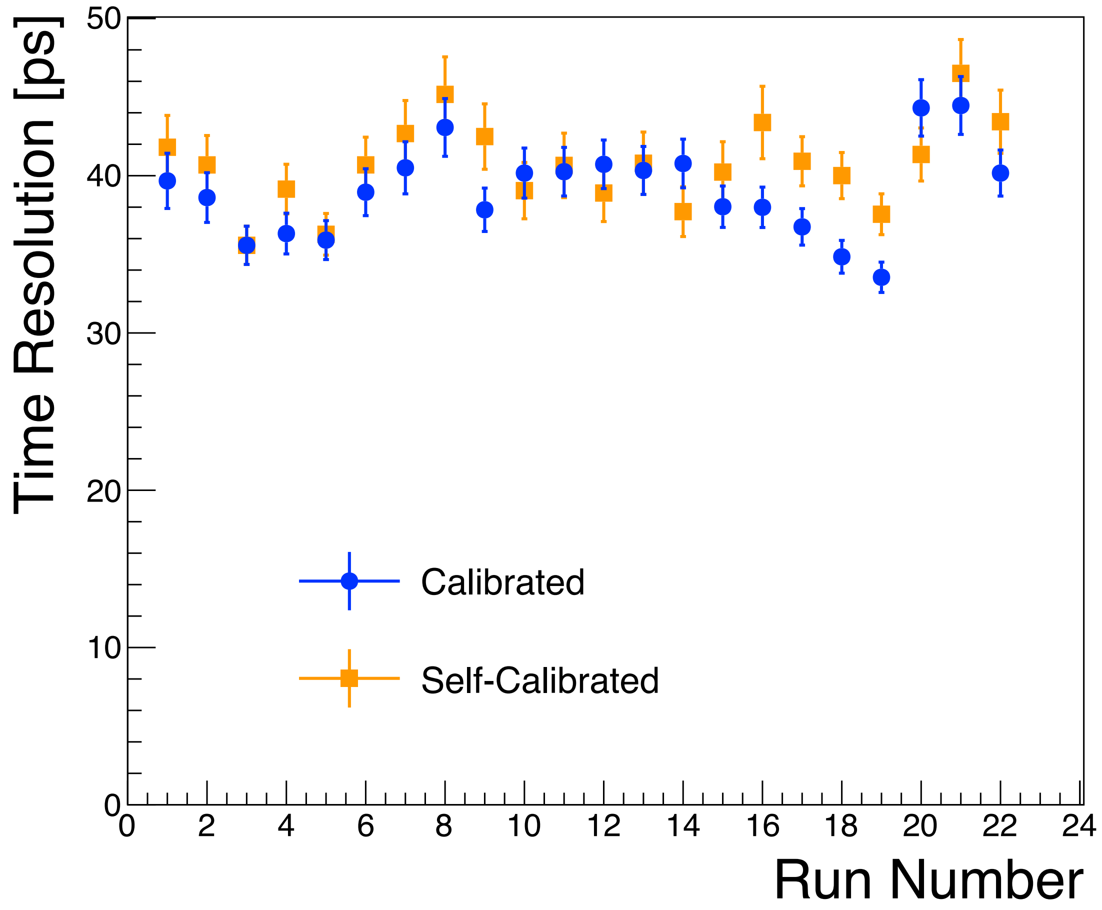
Combined time resolution at the level of 35-40 ps when using pixelated information



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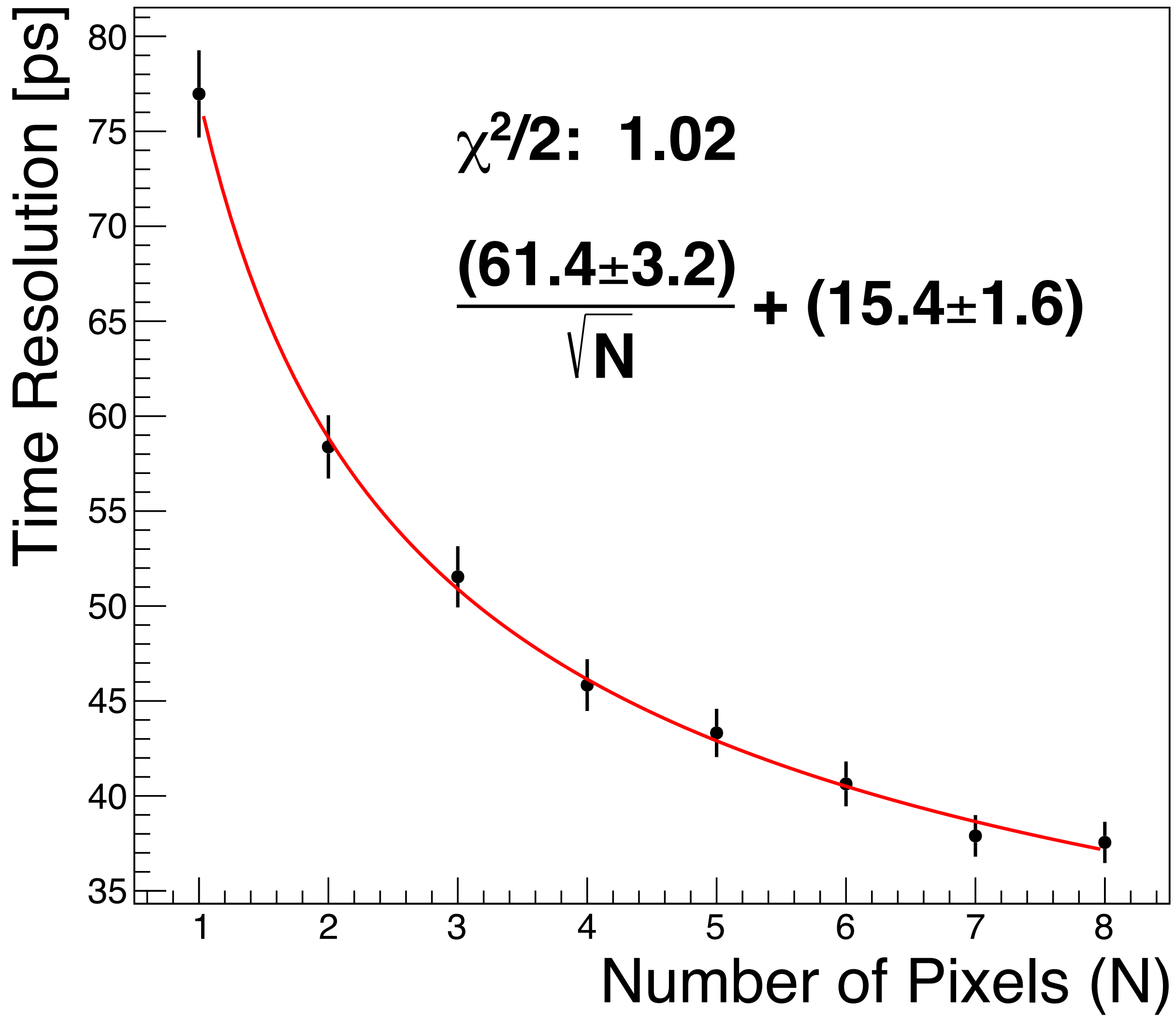
TIME RESOLUTION

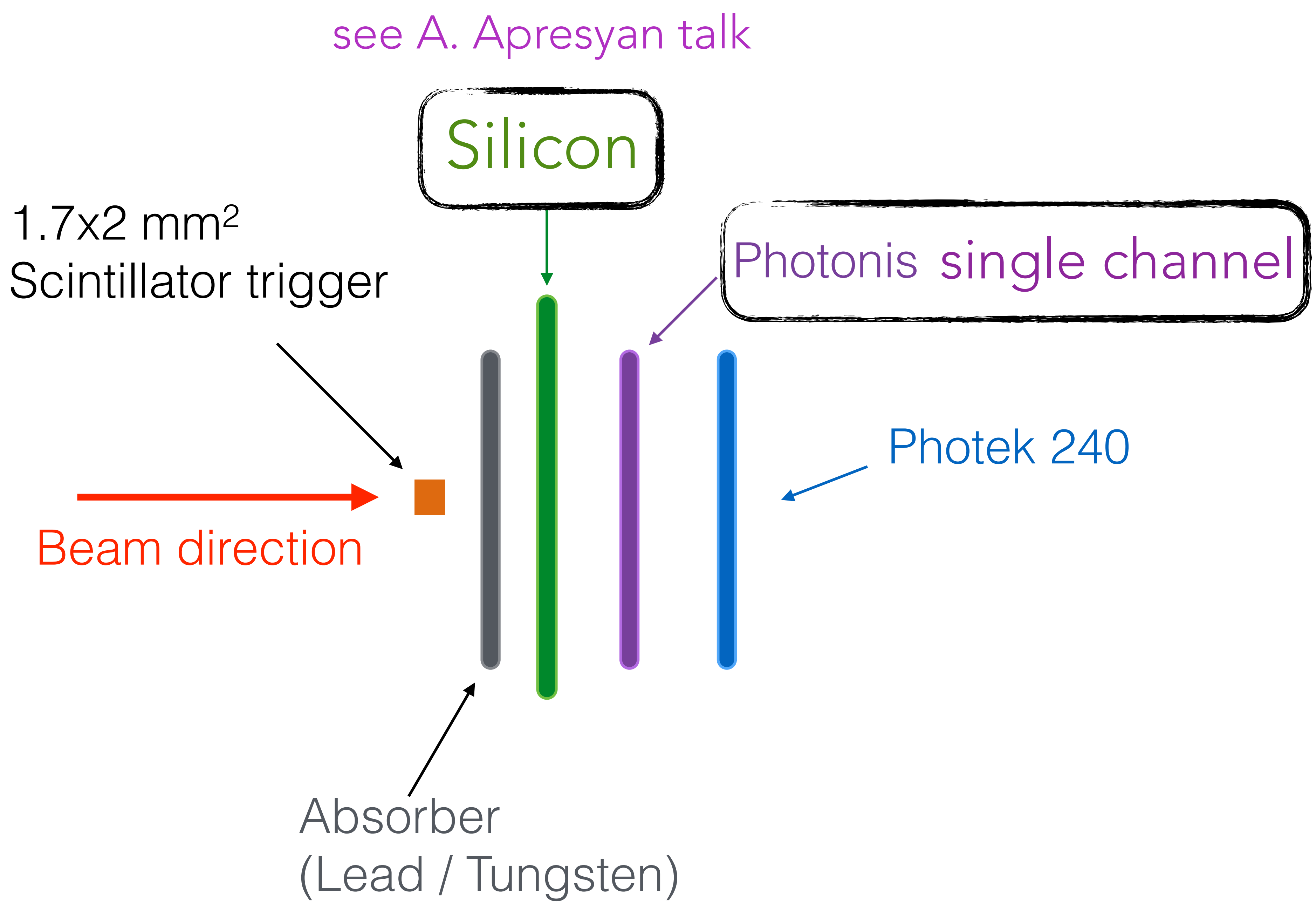
We look at the effect of combining the pixels



- Each additional pixel improves the time resolution
- Time resolution is consistent with a $A/\sqrt{N} + B$ distribution

Important to add transverse information in calorimetric device

Combine two timing layer to improve time resolution



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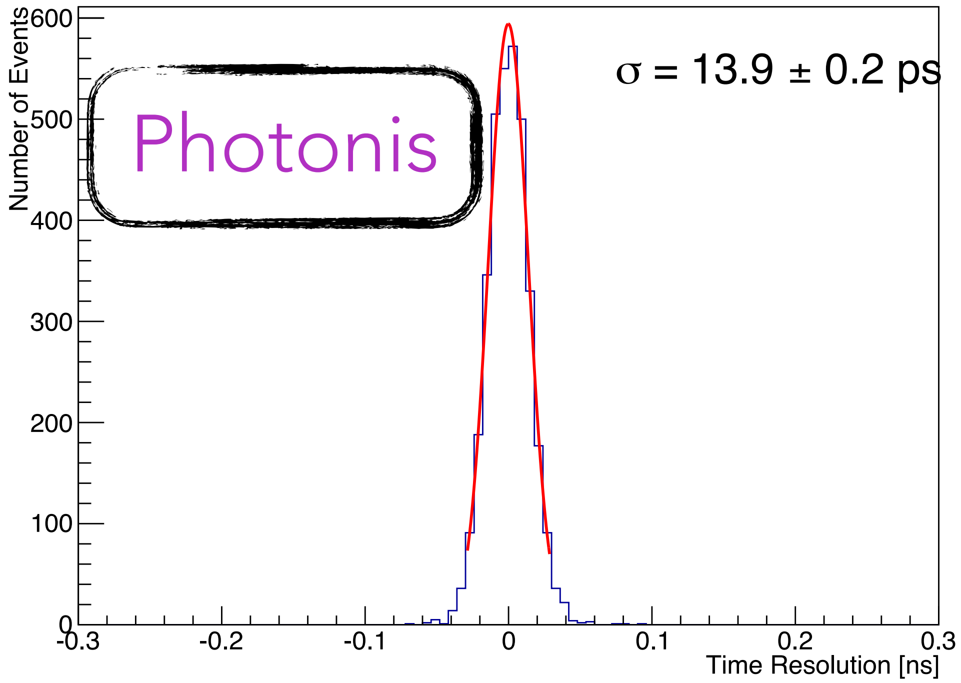
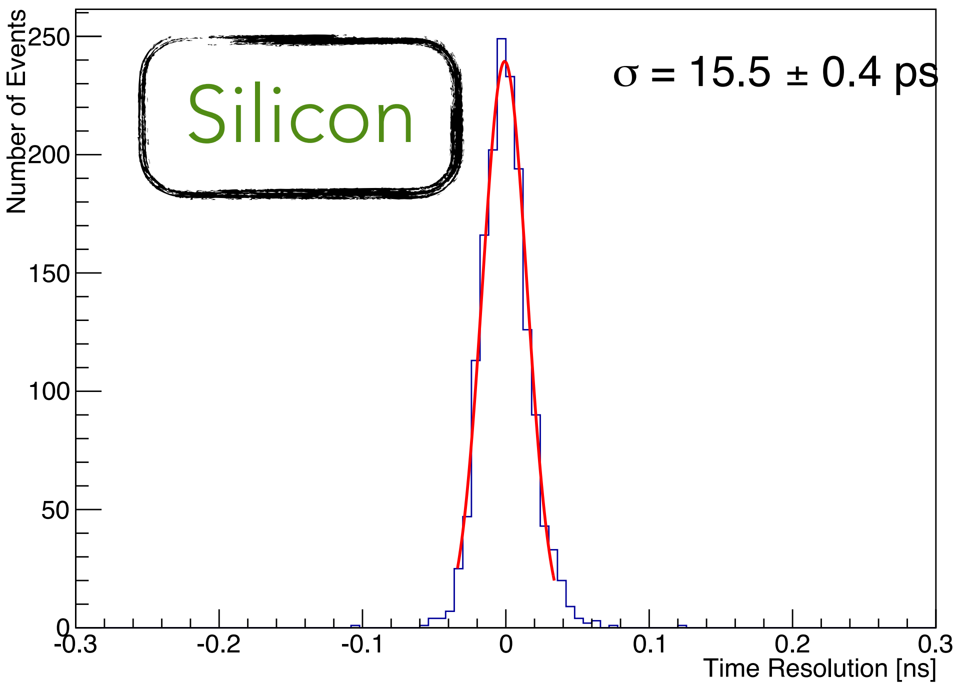
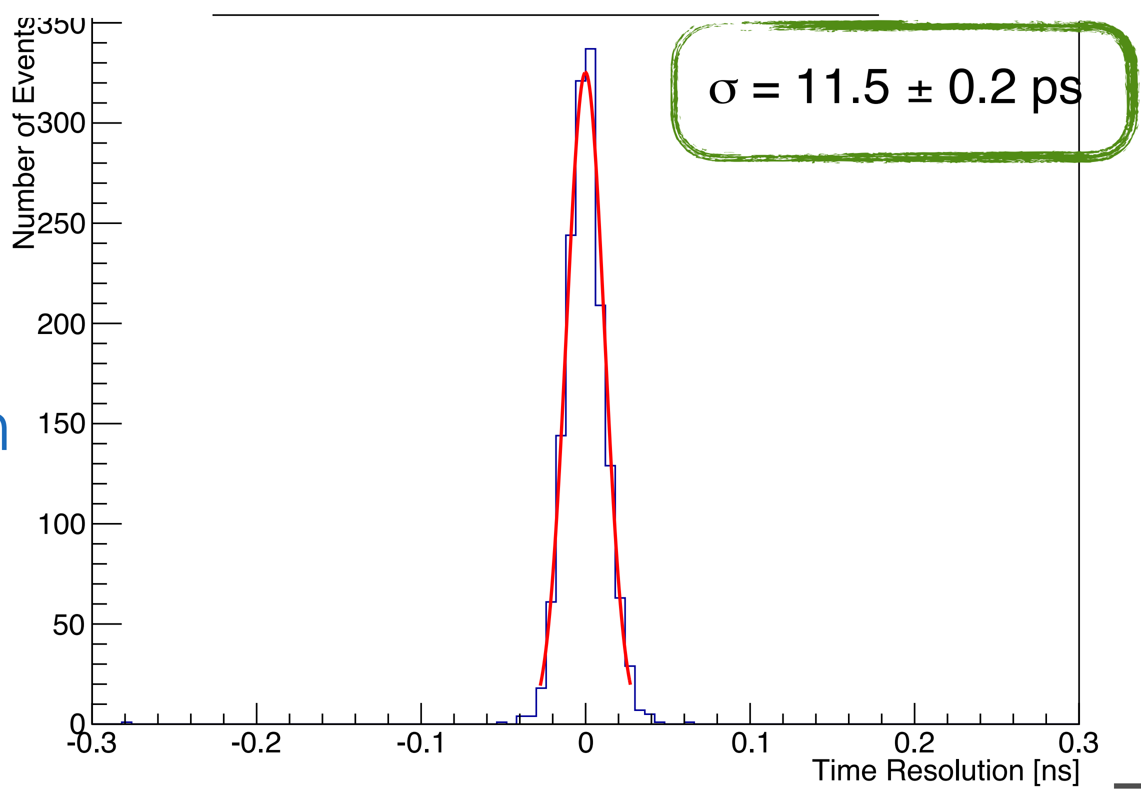




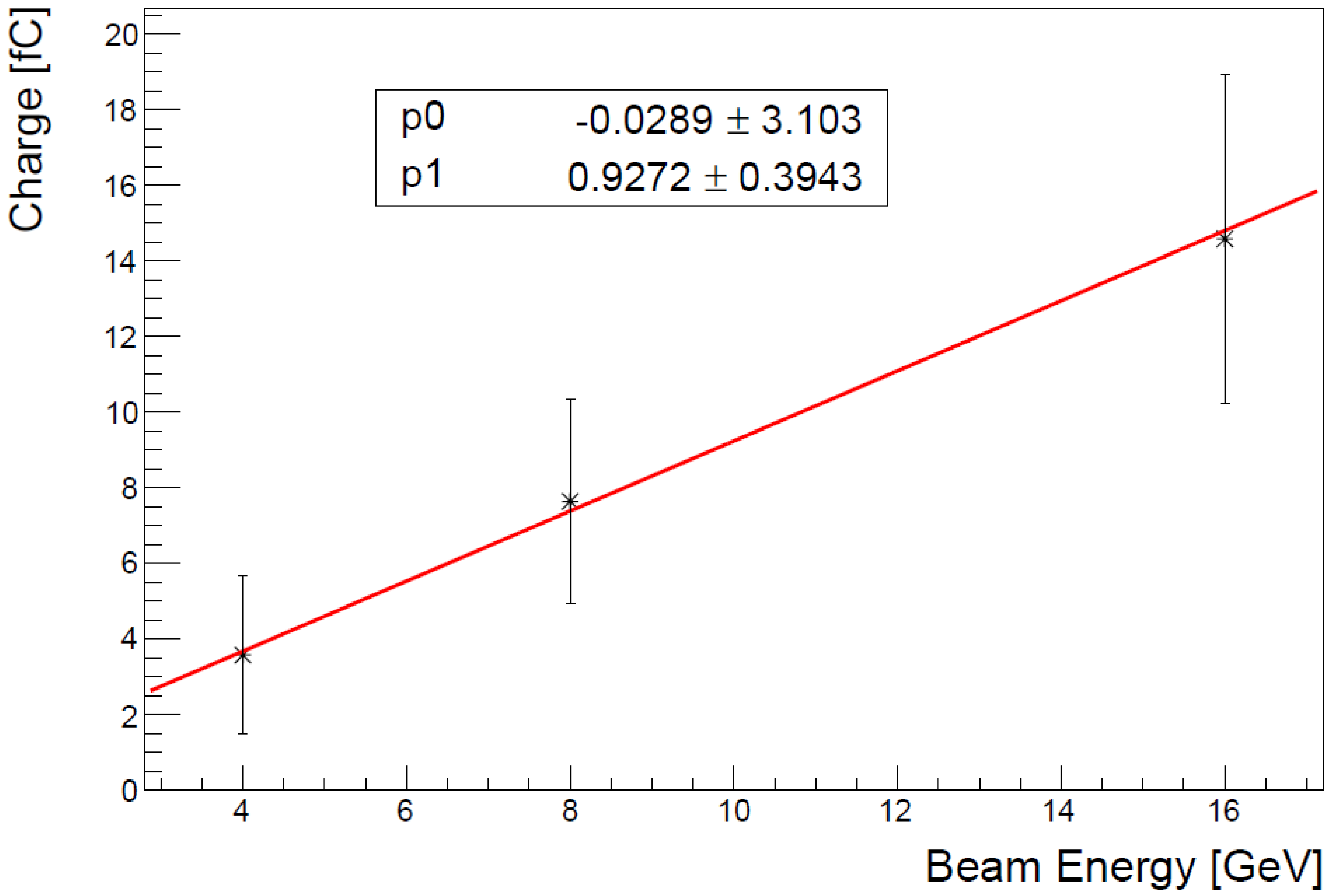
Two layer combination improves time resolution



SUMMARY

- MCP-based secondary emission calorimeters are a real possibility
- They open a new window into precision timing calorimetry
- Beam test of pixelated of Photonis MCP shows good position resolution
- Transverse information improves the time resolution
- Final time resolution is ~35-40 ps; the 30 ps goal for HL-LHC is around the corner

CHARGE VS BEAM ENERGY



charge correction