Test beam results of microchannel plates in "ionisation-mode" for the detection of single particles and electromagnetic showers

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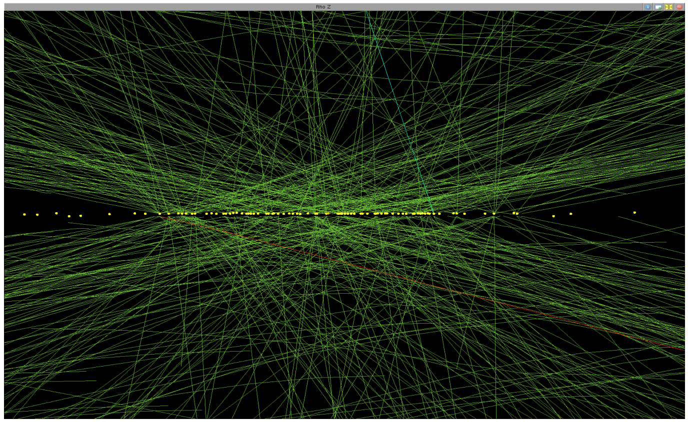
Introduction



Hadron colliders: several collisions per beam crossing

LHC: ~25 pp coll/bx

Target: identify interesting events in this high-rate environment

So far: associate particles to event vertices
→ remove tracks and energy deposits not associated to the hard-interaction

HL-LHC (2023): ~140 coll/bx (spread: 200 ps) → Very challenging!!

Possible solution → fast timing with MCP, to aid event reconstruction

Precise time reconstruction of charged particles and photons

Exploit high multiplicity (em shower/jets) for a fully efficient detector

Preshower configuration, or timing layer embedded in the calorimeter

Resolution of ~20 ps needed

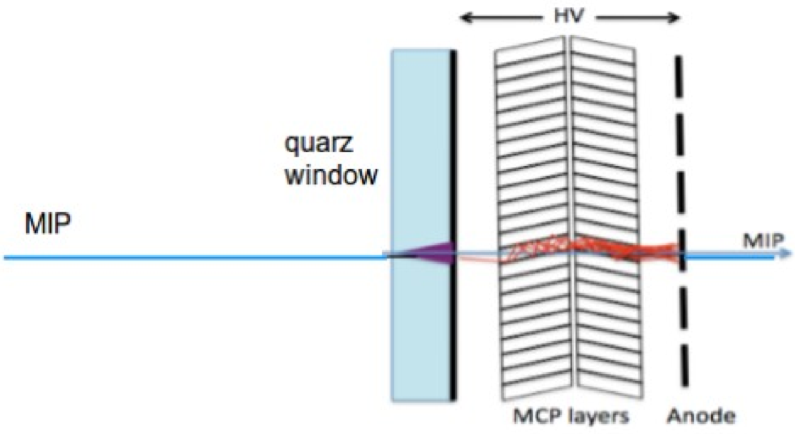
A viable solution: the i-MCP

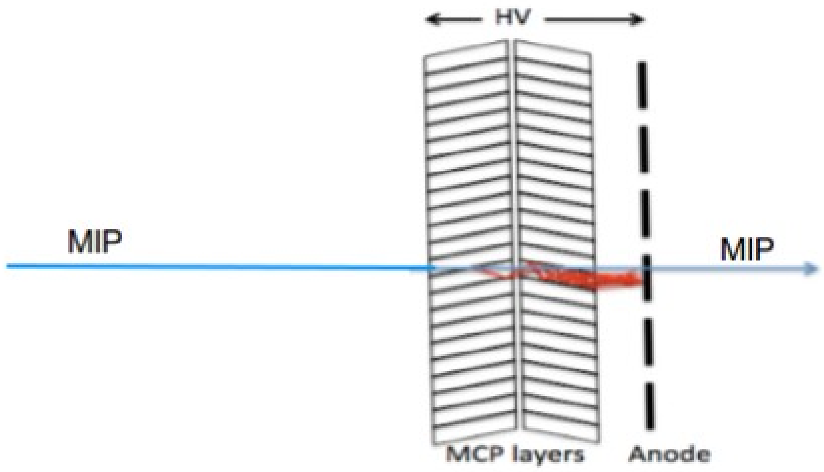
MCP (Microchannel plates)

Matrix of tiny channels (diameter: a few μm), usually made by lead glass, working as dinode photomultiplier

PMT-MCP mode:

Excellent time response (~20 ps)
→ photocatode suffers from radiation damage
(loss of quantum efficiency)





"ionization"mode (i-MCP)

Secondary emission inside the MCP layers

No photocathode:
- more robust detector
- easier assembling
- potentially more radiation hard

→ **Need to test the performance**

Test Beam

Performance of i-MCP devices investigated in two test-beam campaigns:

- BTF (Frascati, Italy) – May 2014
- H4 @ SPS NA (CERN) – October 2014

Test beam @ CERN:

Electron beam with energy [10,200] GeV

Already tested @ BTF:

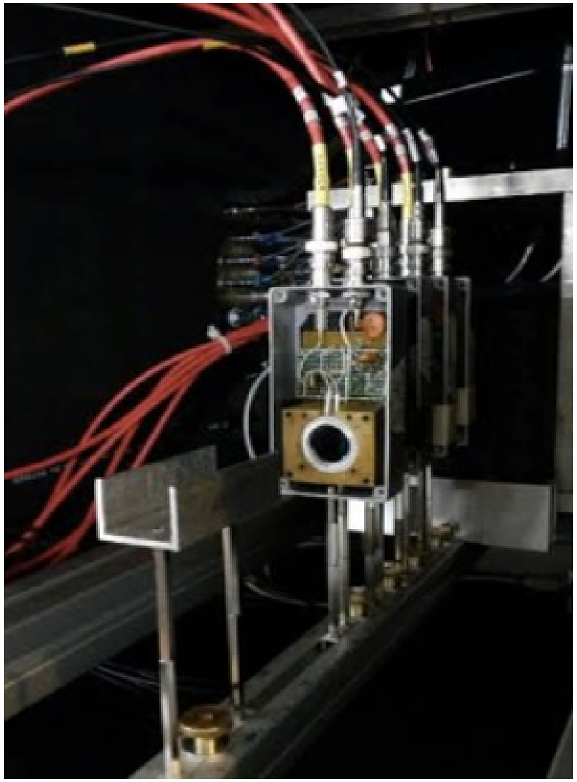
- **Double layer MCP**: two MCP layers in a V-shape → **max eff. to single particle: ~50%**

Two new prototypes:

- **Z-stack**: three MCP layers in a Z-shape
- **Enhanced Secondary Emitter (SEE)**: secondary emission from MCP surfaces enhanced after particular treatment

Lead adsobers, used to test MCP properties in response to em showers

One double-layer MCP used as trigger and reference for time measurement



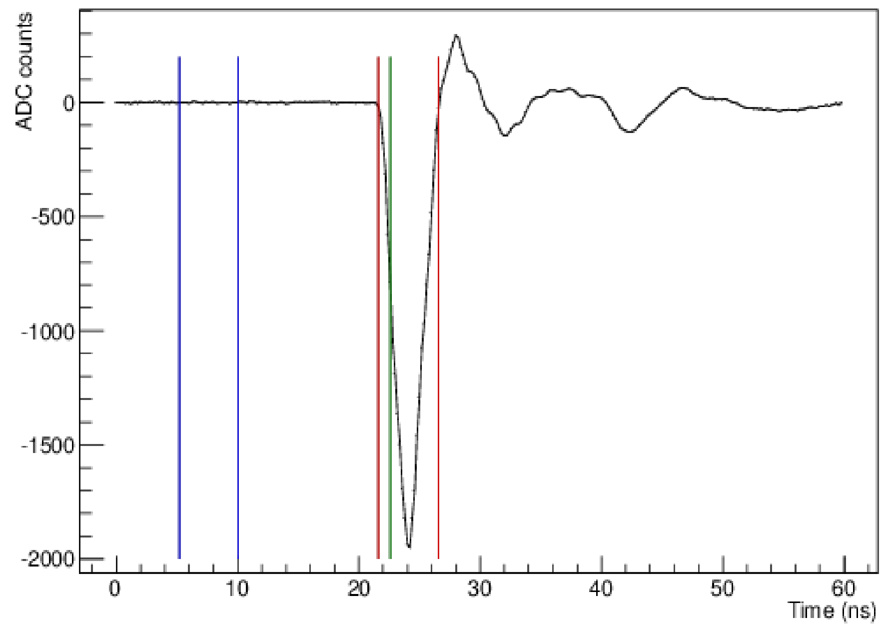
Analysis

Typical MCP-pulse: 1 ns rise-time

Charge: the integral of the pulse within a 5 ns window (red window)

Time: time corresponding to the 50% of the max amplitude, computed via constant fraction method (green line)

Noise: integral of the baseline (blue window)
event accepted if charge > 5 RMS(noise)

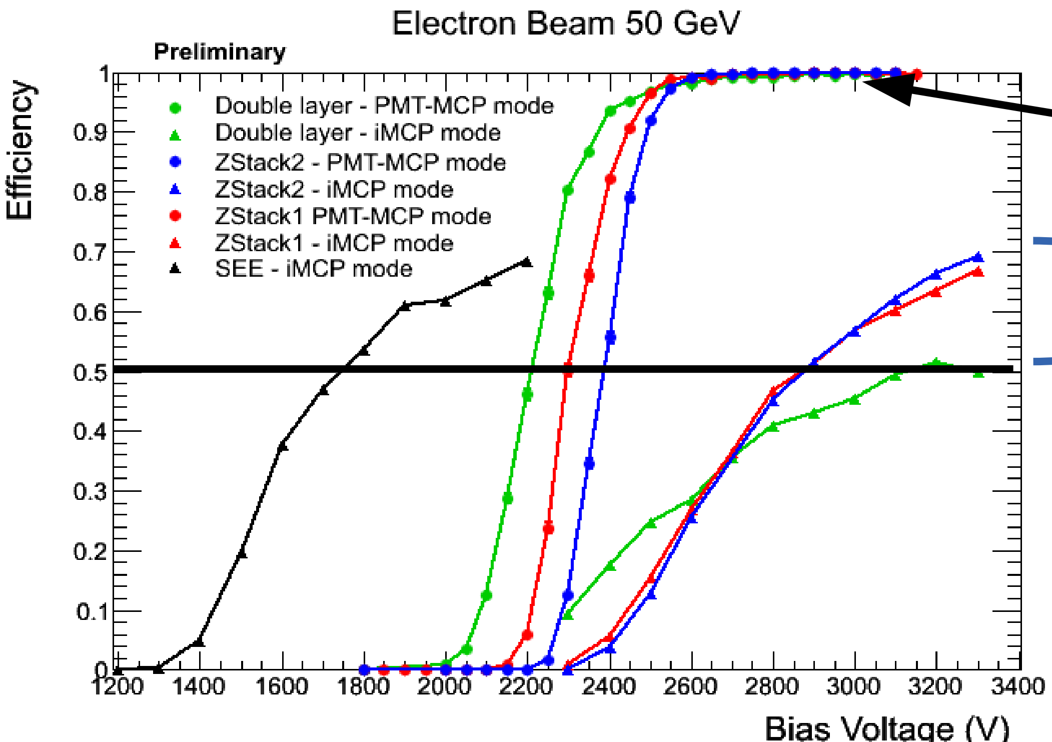


Detection Efficiency to single electrons

$$\epsilon = \frac{N_{MCP}}{N_{trig}}$$

NMCP: # of events which pass the selection in the MCP under test (and the trigger)

Ntrig: # of events which pass the selection in the trigger MCP



Max efficiency in PMT-MCP mode: 1

i-MCP: Zstack and SEE

Gain of 20% with respect to the double-layer prototype

Max efficiency to single electrons: ~70%

Response to electromagnetic showers

Electromagnetic showers: high track multiplicity

→ increase efficiency

Put i-MCP layers after 2-3 X0 (e.g: in a preshower configuration)

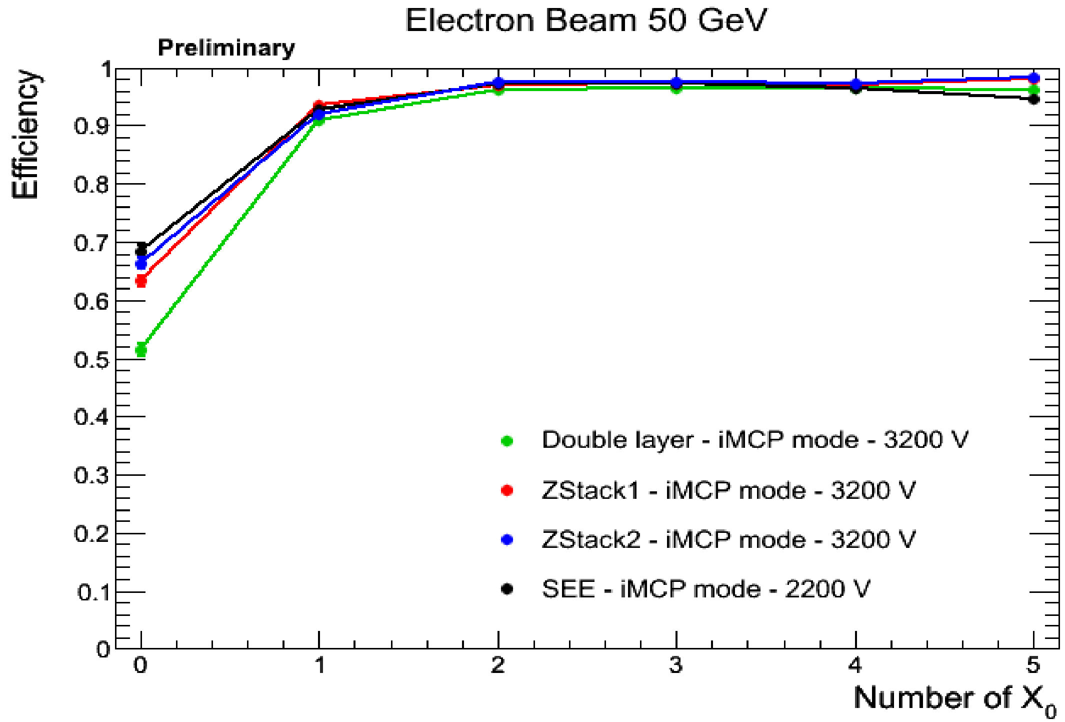
Lead absorbers placed in front of the detectors, to generate the shower

→ Scan in X0:

i-MCP efficiency:

~90 % after 1 X0

~100 % after 2 X0!

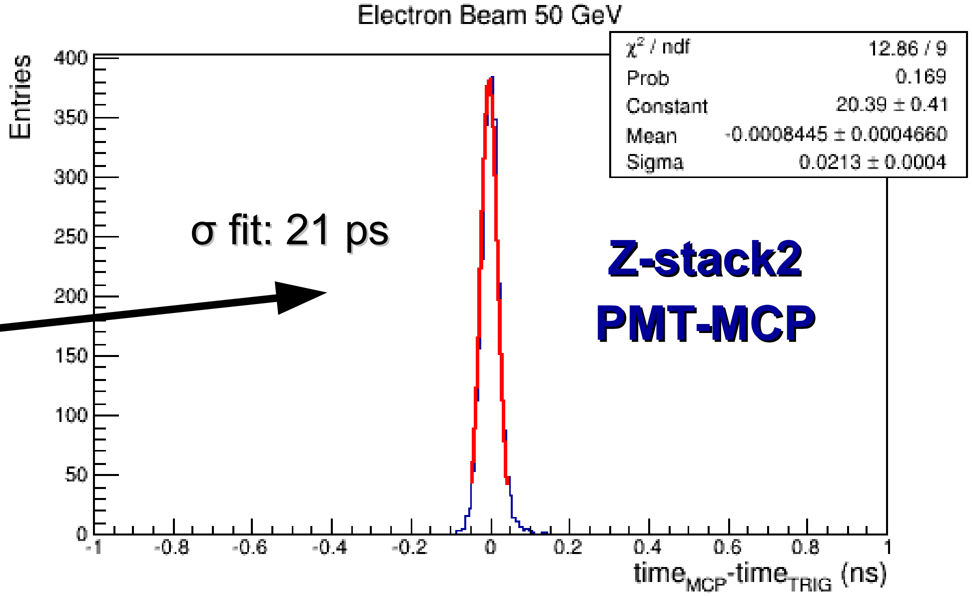


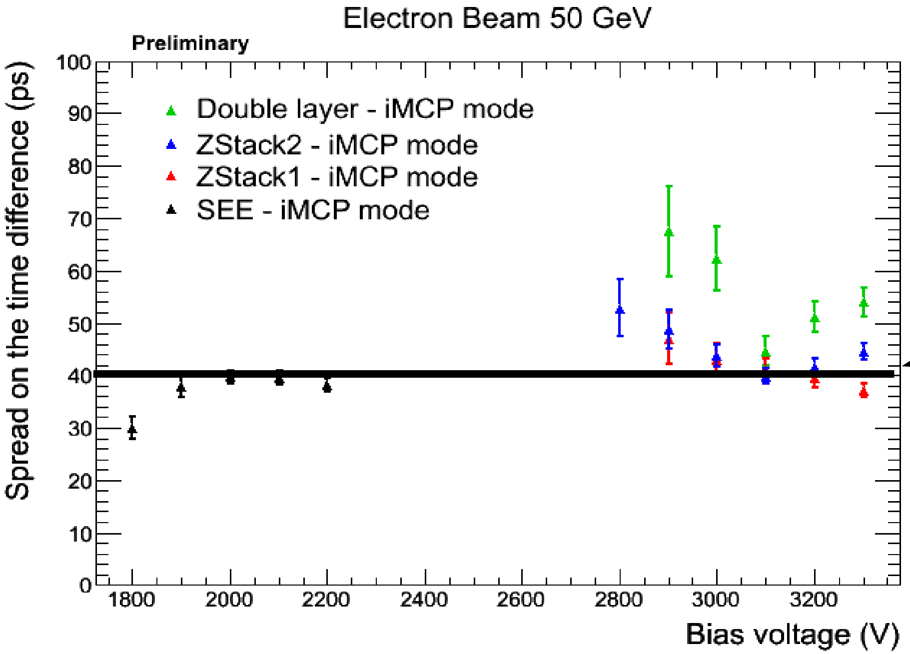
Timing performance (single electrons)

Timing distribution:
$t_{MCP} - t_{TRIG}$

Assuming $\sigma_{z\text{-stack}} \sim \sigma_{trig}$
→ $\sigma_{trig} \sim 15$ ps

σ fit: 21 ps





RESULTS

Spread of the time difference: 40 ps

→ estimated resolution of single detector:
~ 35 ps

Timing performance in electromagnetic showers

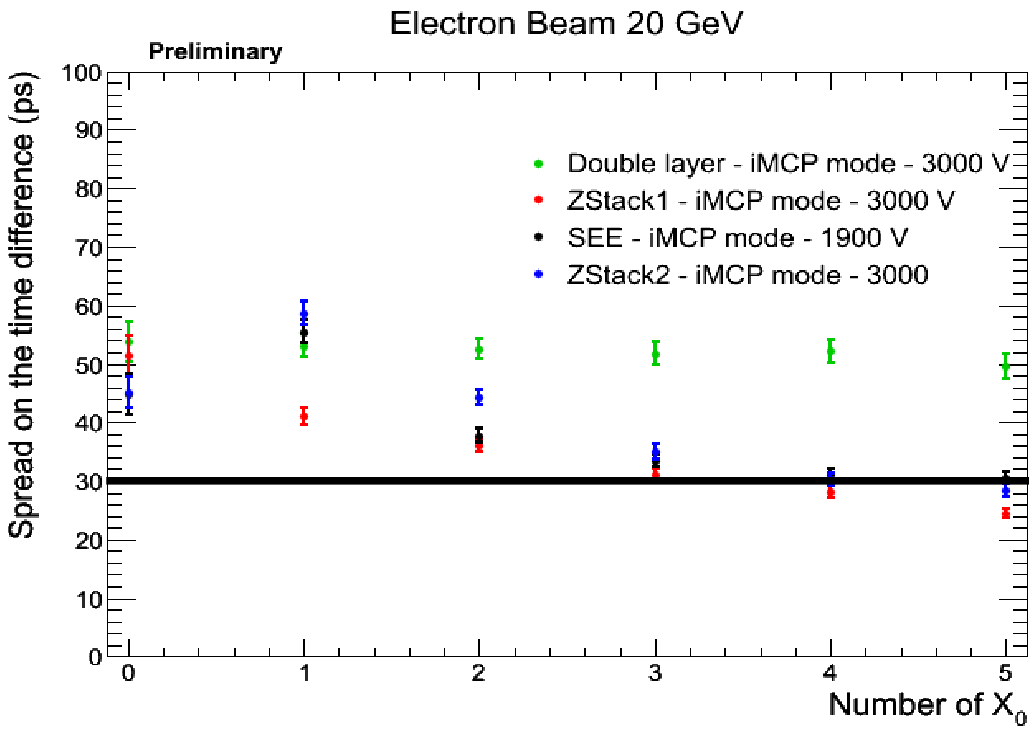
RESULTS

Improvement in resolution due to the higher track multiplicity

At 2-3 X0:

RMS of time difference: 30 ps

→ estimated resolution on single detector: **~25 ps**



Conclusion

Several i-MCP devices have been characterized in test beam at CERN

Excellent properties have been verified, in terms of detection efficiency and time response

- i-MCP detectors show **70% of detection efficiency** to single electrons

The value increases to 100% in response to electromagnetic shower at 2-3 X0

- Time resolution at the order of **~35 ps in response to single electrons, ~25 ps in response to electromagnetic shower**

→ iMCP: excellent candidate to reconstruct time of photons and vertices (from energy deposits associated to charged tracks) with high precision
→ could aid in event reconstruction in high-rate enviroment

Other test beams will follow:

- test new prototypes (increase efficiency to single particles)

- radiation tolerance tests

Backup

Efficiency to photons