Test beam results of MCP in "ionisation mode" for detection of single charged particles and EM showers

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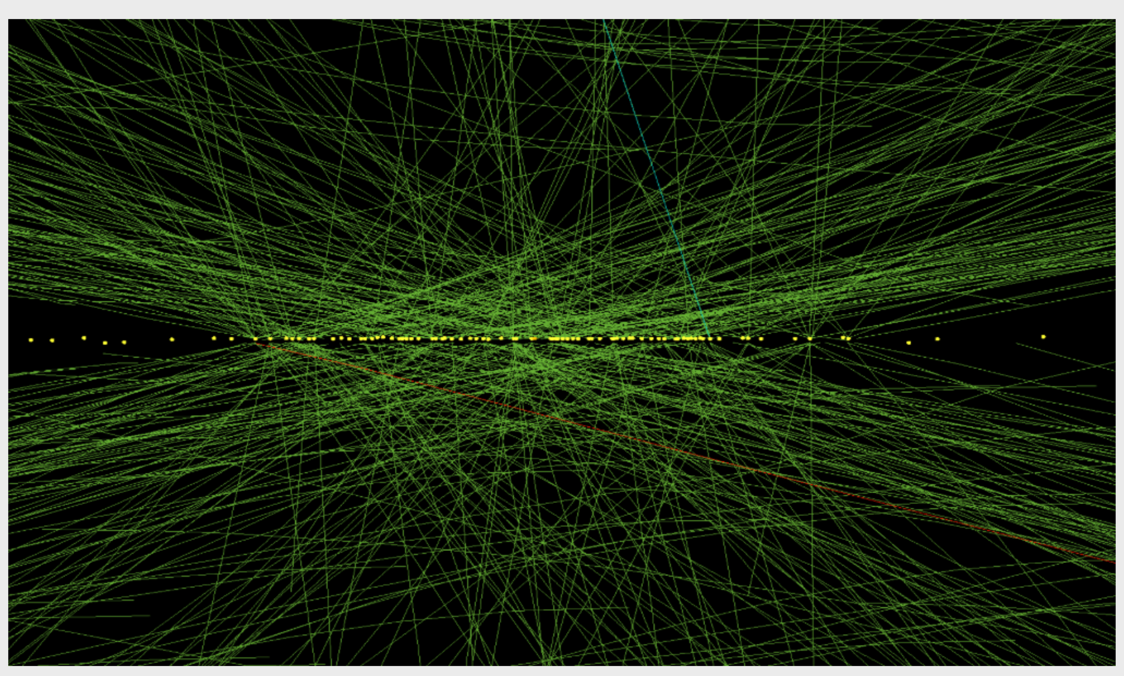
Abstract

i-MCP is an R&D project aimed at the exploitation of secondary emission of electrons from the surface of micro-channel plates (MCP) for fast timing of charged particles and showers in high rate environments.
The usage of MCPs in "ionisation" mode has long been proposed and is used extensively in ion time-of-flight mass spectrometers. What has not been investigated in depth is their use to detect the ionizing component of showers.
The fast time resolution of MCPs exceeds anything that has been previously used in calorimeters, and, if exploited effectively, could aid in the event reconstruction at high luminosities.
Results from tests with electrons with energies up to 150 GeV of MCP devices with different characteristics will be presented, in particular detection efficiency and time resolution.

Pile-up @ future hadron colliders



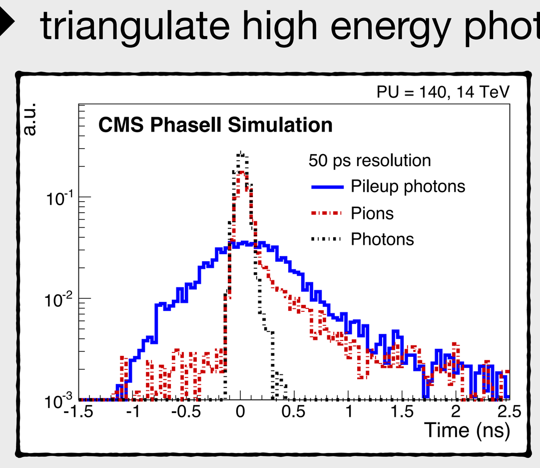
Pile-up at hadron colliders: several interactions per bunch-crossing. LHC Run1 ~ 25 PU

HL-LHC (2024): 140 PU. Time spread ~200ps

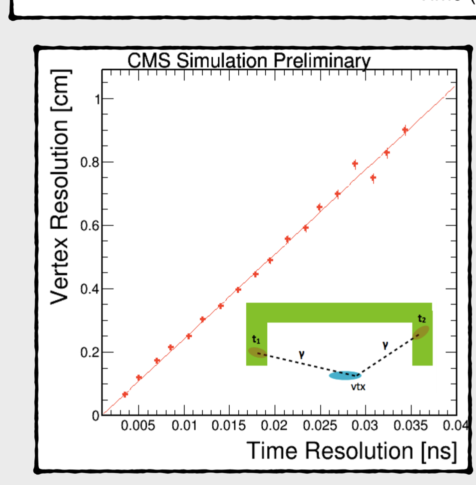
Significant deterioration of forward calorimeter performance is expected in very dense environment

Idea: use time-of-flight information in calorimeters to aid the full event reconstruction [1]

- ➡ pile-up mitigation: remove energy deposits in calorimeters not associated to the hard interaction (e.g. pile-up jets identification, improve MET resolution…)
- ➡ triangulate high energy photons from Higgs decay



Already 50ps TOF resolution sufficient to get a good rejection in forward EM calorimeter for pile-up photons

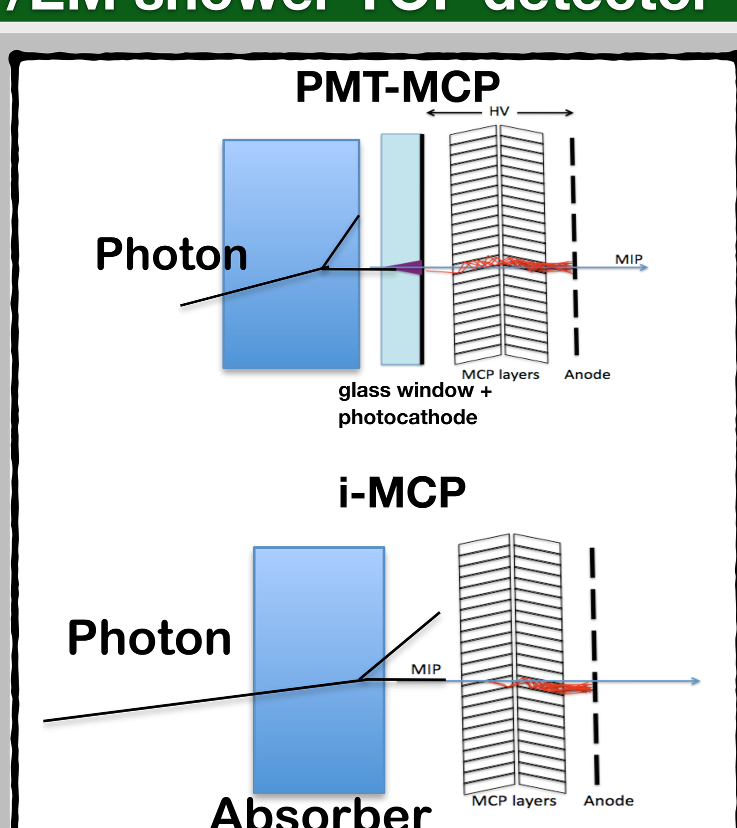


~30ps TOF resolution on high energy photons allows to identify di-photon production vertex with precision better then 1cm

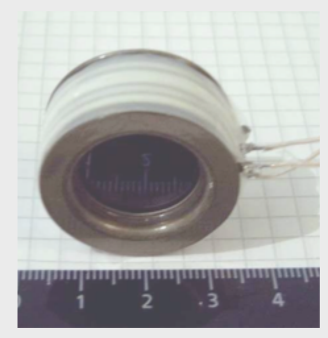
MCP as MIP/EM shower TOF detector

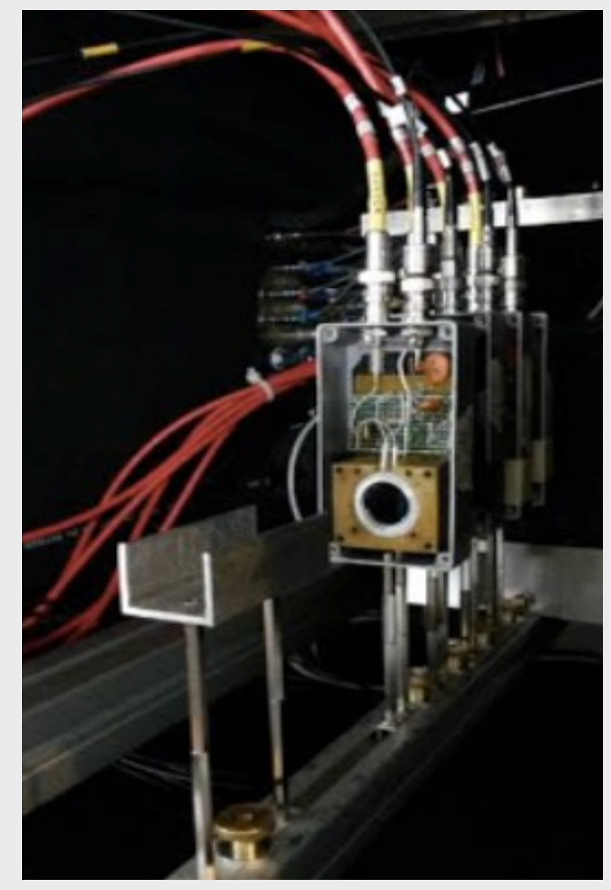
PMT-MCP mode
- ➡High efficiency & excellent time resolution (<20ps)
- ➡Issues: lifetime + radiation hardness of photocatode

i-MCP mode
- ➡ Secondary emission in the MCP, no photocathode
- ➡ Potentially more radiation hard, robust/easier assembly



i-MCP test beam setup





2 test beam campaigns:
- **BTF @ LNF** (e- 491 MeV)
- **H4 @ CERN SPS NA** (e- 10-200 GeV)

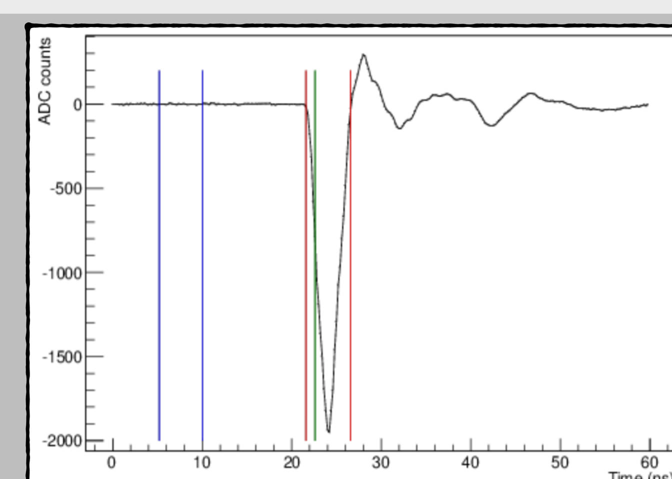
1 PMT-MCP: trigger and reference for time measurement (15ps)

Different MCP device configurations tested in i-MCP mode:
- ➡**2 MCP layers (d/L=1:40) chevron** (V) configuration
- ➡**3 MCP layers (d/L=1:40) Z-stack** configuration
- ➡**2 MCP layers (d/L=1:40), MCP surface chemically treated to enhance SEE, chevron** (V) configuration

Devices from Ekran FEP (Novosibirsk). When photocathode is present, collection of photo-electron inhibited with retarding potential

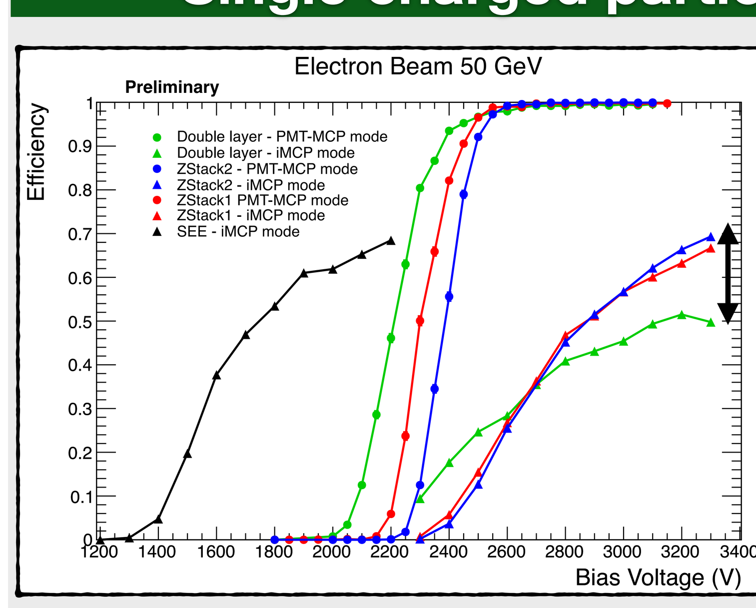
Signals digitised @ 5 GS/s using CAEN V1742 based on PSI DRS4 chip

Typical risetime ~0.7-1ns depending on the device



Informations extracted from each MCP waveform
- ➡**Integrated charge:** 5ns window
- ➡**Baseline & noise:** signal accepted if charge > 5 noise RMS
- ➡**Time:** emulated CFD @ 50% max amplitude

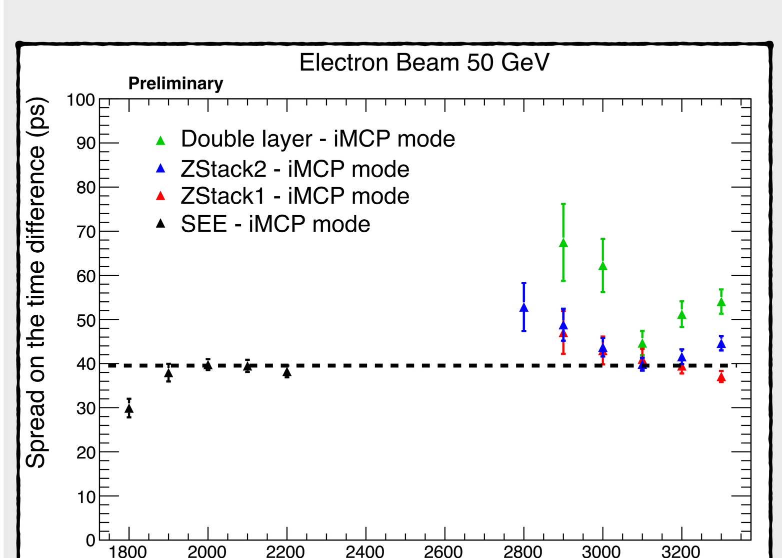
Single charged particle results



PMT-MCP mode:
100% efficiency

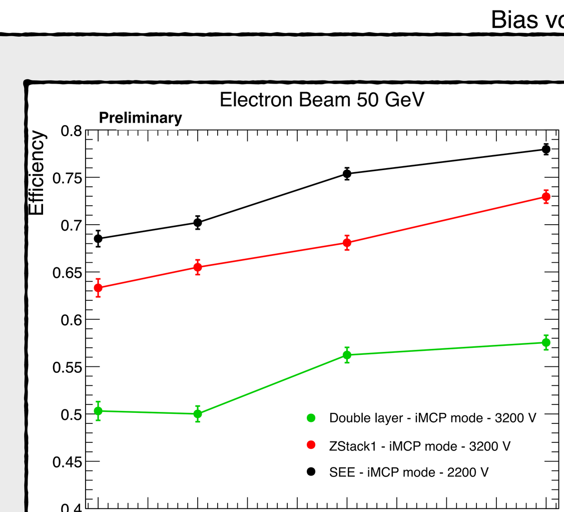
Z-stack & enhanced SEE i-MCP mode:
~ 70% efficiency

20% improvement over standard chevron configuration



σ(t_{TRIG}-t_{MCP}) ~ 40 ps for Z-stack & enhanced SEE:

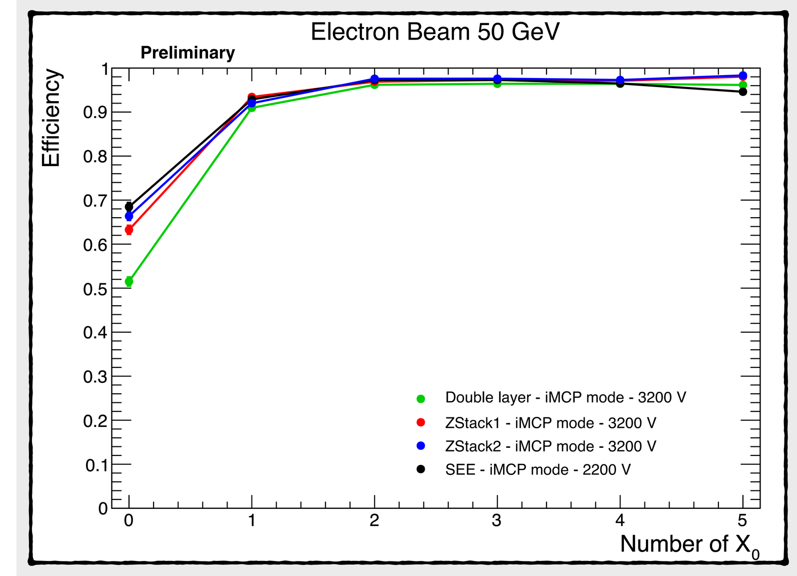
35ps resolution on single charged particle for a single detector



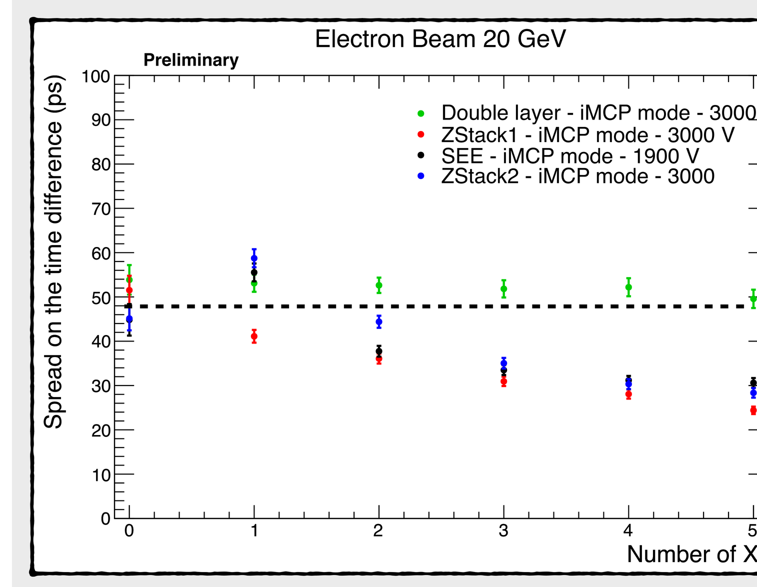
~10% increase in single particle efficiency when MCP @ 45° wrt beam line direction

Electron shower results

Configurable absorber used to test EM shower response: 1X_0 thick lead plates (1-7 X_0)



Use i-MCP detector in preshower configuration:
100% efficiency for EM showers after 2-3 X_0

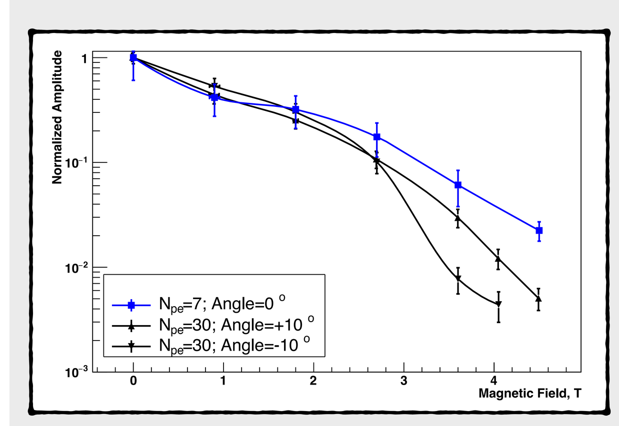


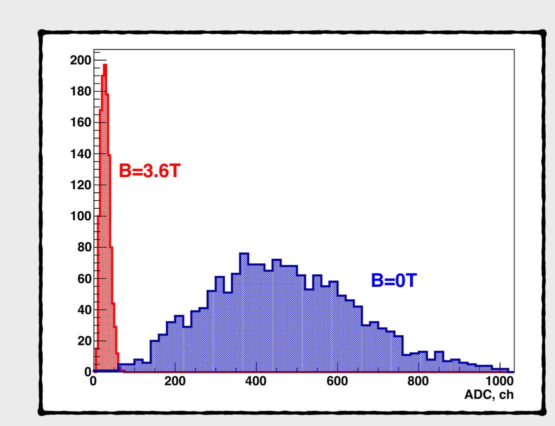
σ(t_{TRIG}-t_{MCP}) ~ 30 ps for showers:
25ps resolution for a single EM shower

Magnetic field tolerance

Test performed @ BINP
Superconducting coil: 0-4.5T

Picosecond laser on PMT-MCP (8μm)
λ=823nm
pulse width 30ps (FWHM)
10-30 photoelectrons per pulse





Moderate loss up to 3T, bigger losses beyond that: loss ~ factor 15 for axial field @ 4T
Expected to scale with pore size: to be checked with 4 μm pores

Conclusions & next steps

i-MCP detector offers an excellent candidate for a fast, efficient and radiation hard detector to be used in future hadron colliders
- ➡**single charged particle:** reached **~70% efficiency** with **35ps** time resolution
- ➡**EM showers**: **100%** after 2 X_0, **25ps** time resolution

i-MCP can be integrated in a pre-shower device independent of the EM calorimeter technology used
- ➡ EM energy resolution contribution to be fully verified

R&D is progressing further. MCP configurations under test
- ➡ higher aspect ratio MCP (1:90)

References

[1] T. Tabarelli de Fatis "Large Area Timing Detectors", 2nd ECFA HL-LHC Workshop
[2] L. Brianza et al., "Response of micro channel plates to single particles and to electromagnetic showers", arXiv: 1504.02728, submitted to NIMA

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