Micro-channel plates in ionization mode as a fast timing device for future hadron colliders

A.Barnyakov[a,b], M.Barnyakov[a,b], L.Brianza[c], F.Cavallari[d], V.Ciriolo[c], D.Del Re[d], S.Gelli[d], A.Ghezzi[c], C.Gotti[c], P.Govoni[c], A.Katcin[a,b], M.Malberti[c], A.Martelli[c], B.Marzocchi[c], P.Meridiani[d], G.Organtini[d], R.Paramatti[d], S.Pigazzini[c], V.Prisekin[a,b], S.Rahatlou[d], C.Rovelli[d], F.Santanastasio[d], T.Tabarelli de Fatis[c]

[a] Budker Institute of Nuclear Physics, Novosibirsk, Russia

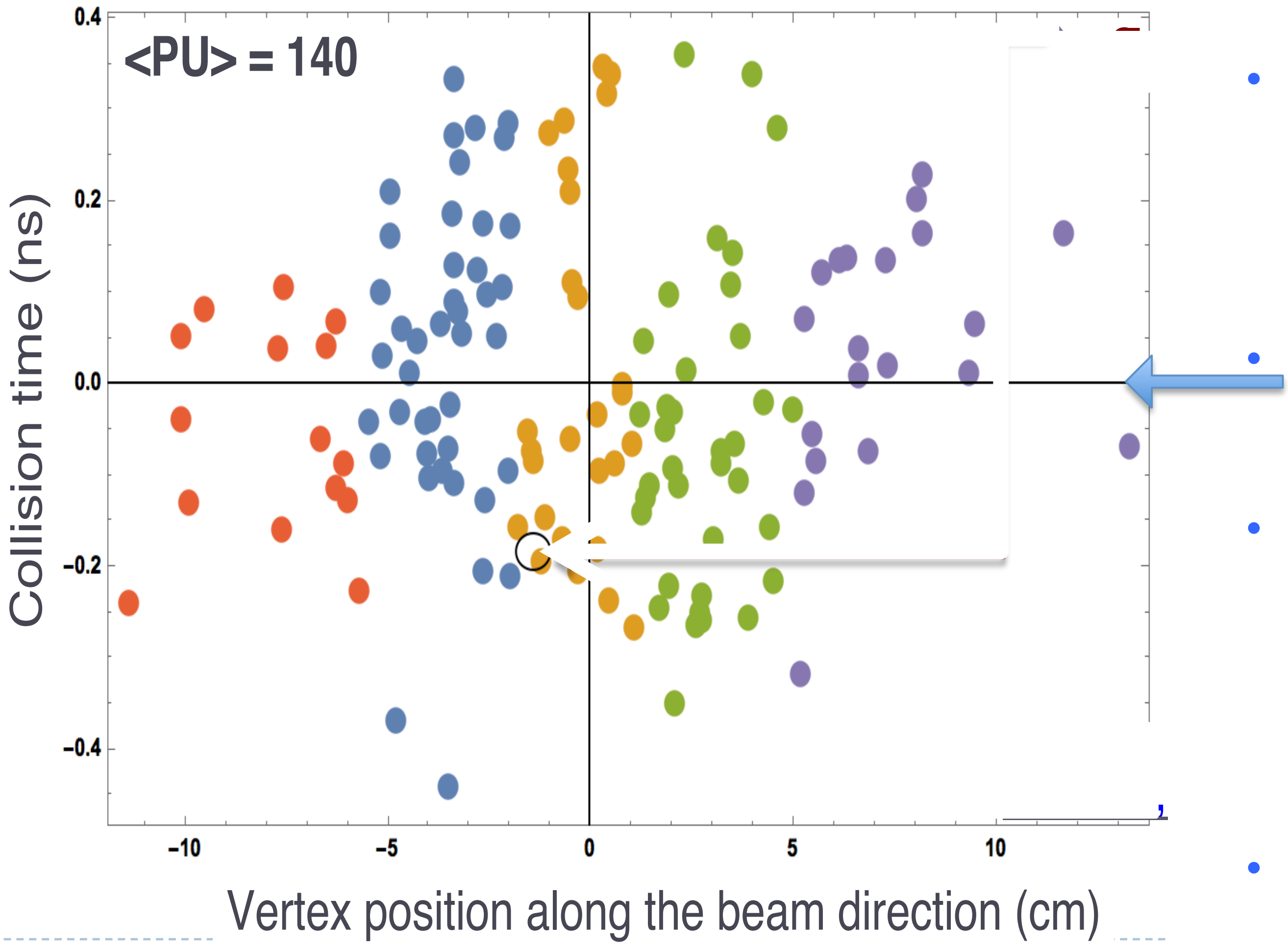
[b] Novosibirsk State University, Novosibirsk, Russia

[c] Università di Milano Bicocca and INFN, Sezione di Milano-Bicocca, Milano, Italy

[d] Università di Roma "La Sapienza" and INFN, Sezione di Roma1, Rome, Italy

INSTR17

Fast timing device development motivation: I - pileup supression

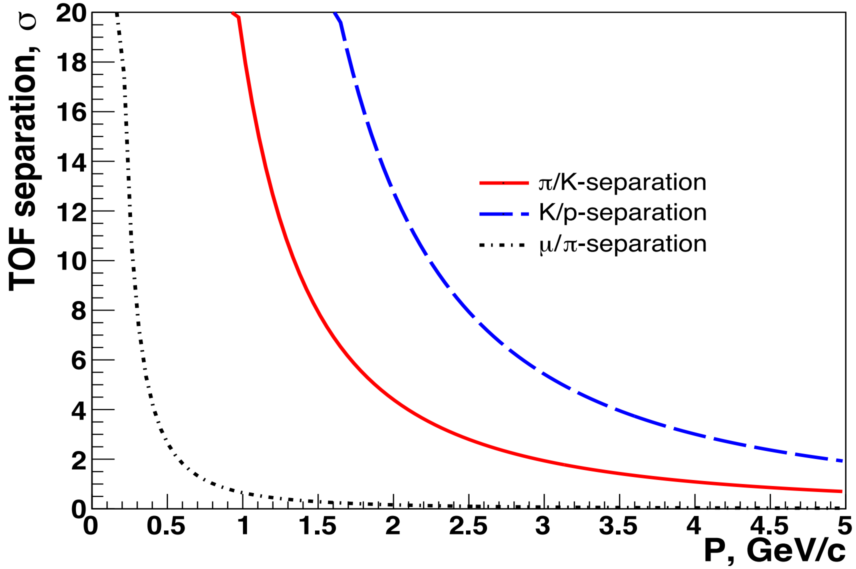


- Future hadron colliders are expected to have hundreds of concurrent interactions in the same bunch crossing.
- At HL-LHC ~200 proton-proton interactions are expected.
- Time-of-Arrival measurement of two particles allows us to calculate ***z*** and ***t*** of the vertex

  ($\sigma_t \approx 20ps \rightarrow \sigma_z \approx 6mm$)
- For 3 or more particles (eg. jets), minimize numerically

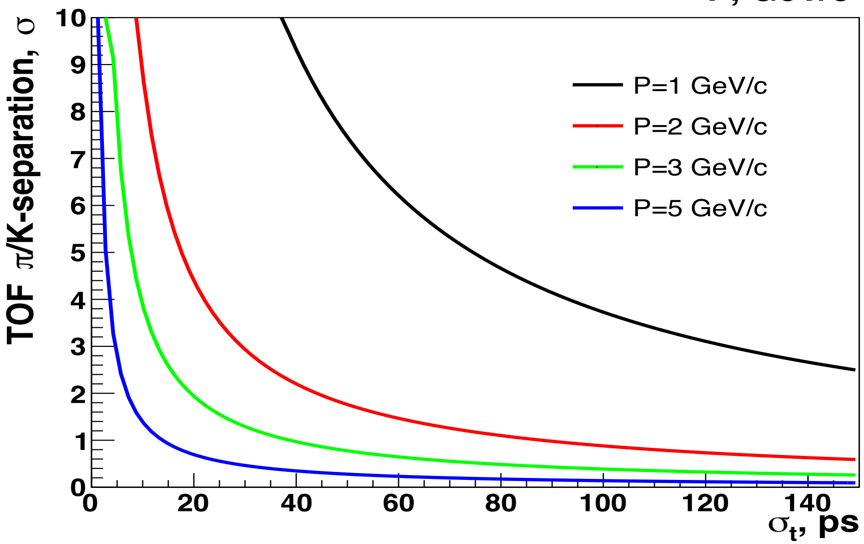
$$\chi^2 = \Sigma_{i=1,2}[t_i^{meas} - t_i(z)]^2 / \sigma_i^2$$

Fast timing device development motivation:
II - PID with TOF approach



$$\frac{dm}{m}=\sqrt{\left(\frac{dp}{p}\right)^2+\gamma^4\left\{\left(\frac{dt}{t}\right)^2+\left(\frac{dL}{L}\right)^2\right\}}$$

$$\frac{\Delta t_{AB}}{\sigma_t}=\frac{L}{c\sigma_t}\left\{\sqrt{1+\left(\frac{m_A c^2}{p}\right)^2}-\sqrt{1+\left(\frac{m_B c^2}{p}\right)^2}\right\}$$



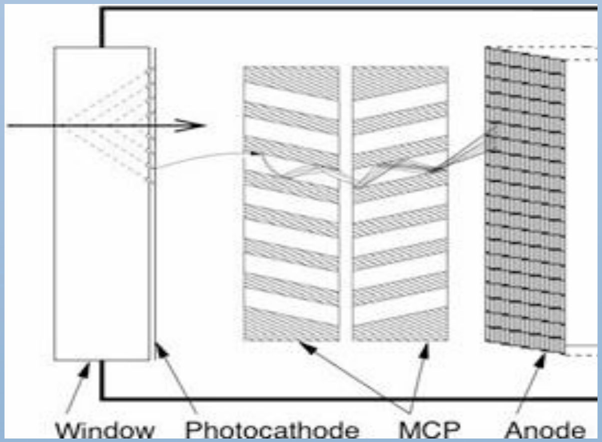
- $L=1$ m
- $\sigma_t=20$ ps

K/P-separation ≥ 3σ up to 4 GeV/c
π/K-separation ≥ 3σ up to 2.5 GeV/c
μ/π-separation ≥ 3σ up to 0.45 GeV/c

Two possibility of MCP devices application

PMT mode

- The best time resolution was achieved with MCP PMT and quartz Cherenkov radiator: $\sigma_t \approx 5ps$
  (K. Inami, et al., NIMA 560 (2006) 303)
- Good immunity to axial magnetic fields
- Photocathode ageing due to ion-feedback is the most limitation of its application in the future colliders with high luminosity.

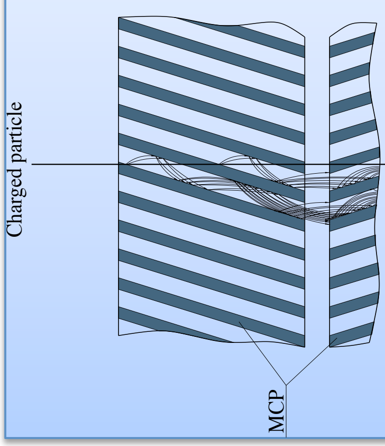


Stable photocathode & Cherenkov radiator

MCP based devices with Cherenkov radiator and long lifetime photocathode.

(See poster #30 "Development of MCP based particle detector")

Ionization mode (i-MCP)



MCP without photocathode (i-MCP) could be more stable, robust and cheap.

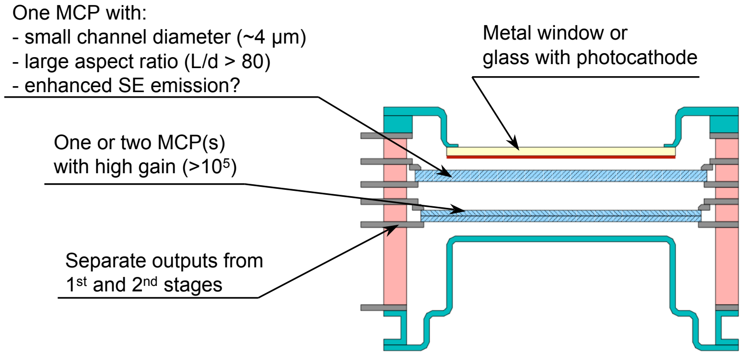
MIP detection efficiency measurements

Beam test facilities

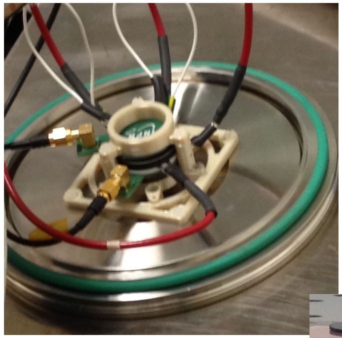
- BTF LNF (Frascati):
  - Electron beam E_{beam}=500MeV
  - Beam transvers size ~ 1.5mm
- H4 SPS (CERN)
  - Electron beam E_{beam}=25÷50GeV
- ExBeam (BINP):
  - Electron beam E_{beam}=0.1÷3GeV
  - For trigger and time reference two MCP PMT based Cherenkov counters are used
- DAQ:
  - Scintillator counter is used for trigger
  - MCP PMT coupled with Plexiglas Cherenkov radiator (Reference) is used for T_0 determination and efficiency evaluation ($\sigma_{T0} \approx$ 20ps)
  - Scintillation fiber hodoscope is used for particle position determination
  - CAEN V1742 digitizer (based on DRS4) is used for amplitude and time measurements
- Results from different test beam facilities are in good agreement

BINP design:

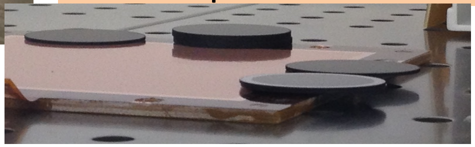
- lateral dimensions: ø31mm and ~20mm height;
- Ø of sensitive area is 18mm
- Photocathode
- One or two MCP stage consists of 1 or 2 MCPs



MCPs from Photonis (Milano and Roma designs):

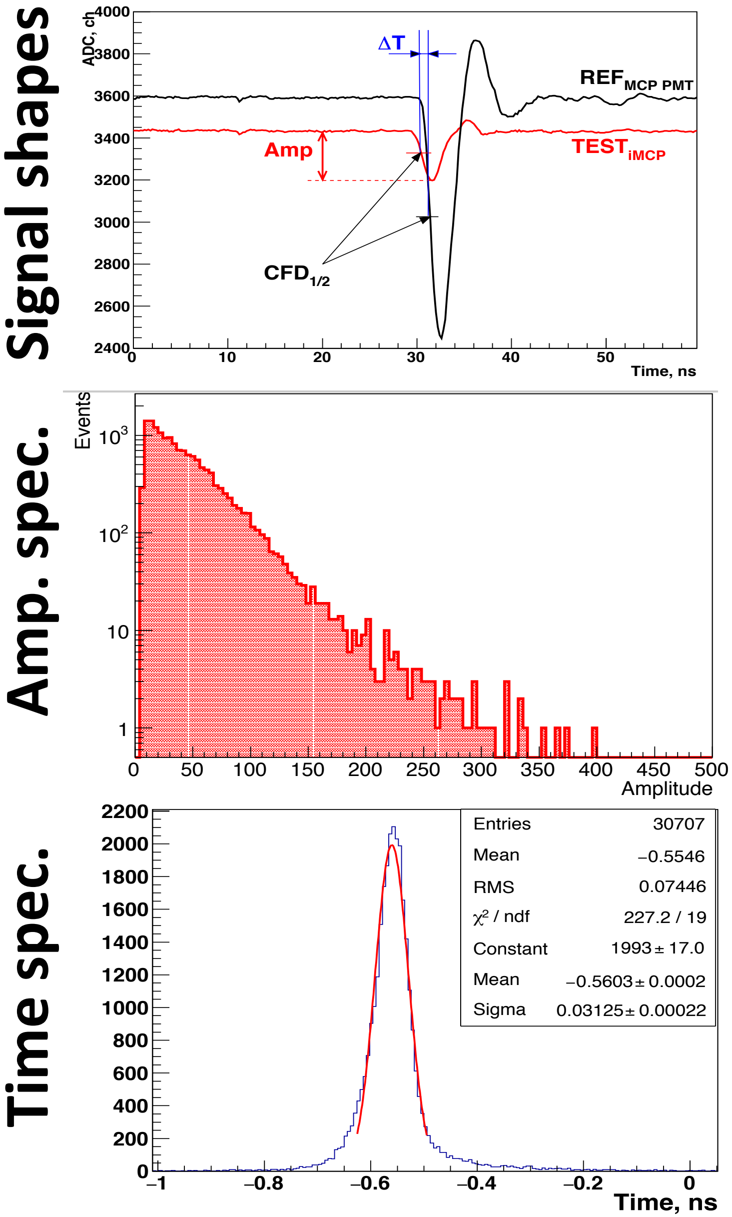


- Ø(MCP) = 25mm;
- 2nd stage – 1MCP (25μm;L/ø=40)
- 1st stage is different (1 or 2 MCPs; 5,8,15,25μm; L/ø=80)
- No photocathode

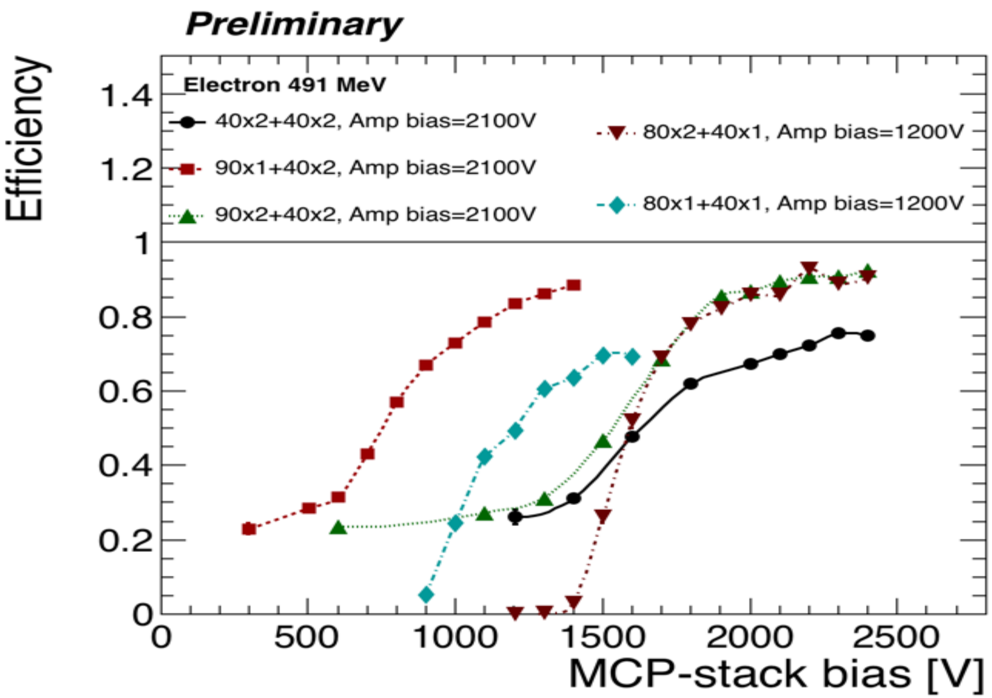


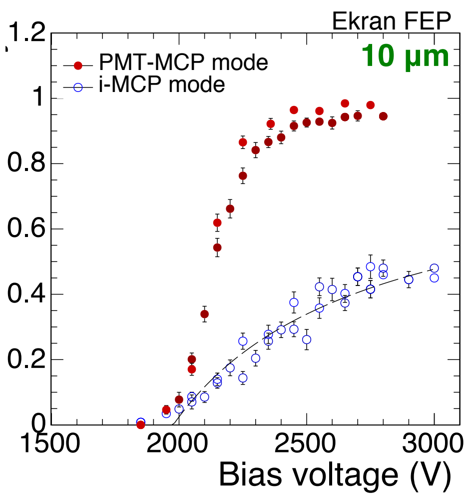
Data processing procedure

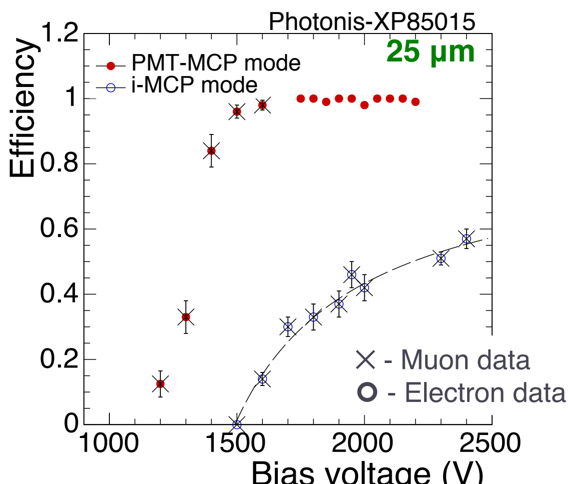
- The ***efficiency*** is the ratio between the events number recorded by the device and the total number of electrons produced a signal in the reference device.
- The time of each signal is extracted with a constant fraction discriminant (***CFD***) method.
- The ***time resolution*** is extracted from the distribution of the difference between the time measured by the device and the reference detector.
- The $\boldsymbol{\sigma_t}$ of the gaussian fit is quoted as time resolution and so includes contribution from both the prototype device and the reference detector.



Single particle detection efficiency







Tested exemplars features

- 40x2+40x2 –
  - 1st stage is 2MCP; 7µm; L/ø=40
  - 2nd stage is 2MCP; 7µm; L/ø=40
- 90x1+40x2 –
  - 1st stage is 1MCP; 3.5µm; L/ø=90
  - 2nd stage is 2MCP; 7µm; L/ø=40
- 90x2+40x2 –
  - 1st stage is 2MCP; 3.5µm; L/ø=90
  - 2nd stage is 2MCP; 7µm; L/ø=40
- 80x2+40x1 –
  - 1st stage is 2MCP; 25µm; L/ø=80
  - 2nd stage is 1MCP; 25µm; L/ø=40
- 80x1+40x1 –
  - 1st stage is 1MCP; 8µm; L/ø=80
  - 2nd stage is 1MCP; 25µm; L/ø=40

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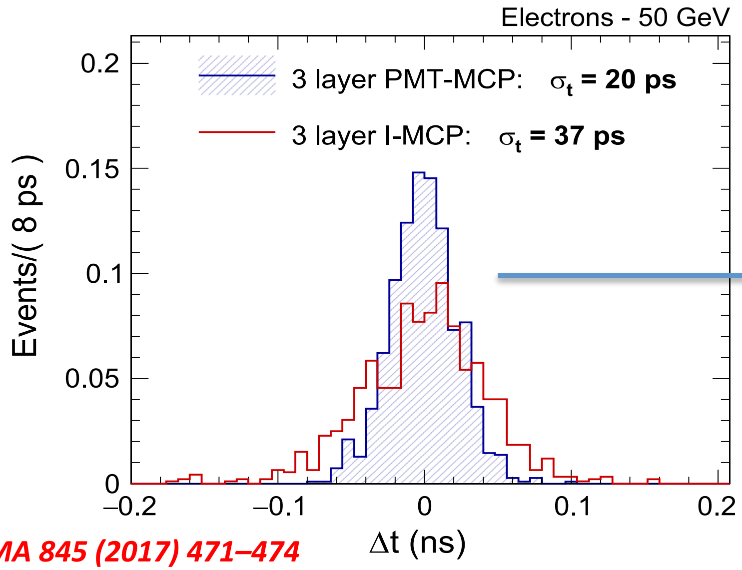
Timing properties

MCP PMT vs i-MCP



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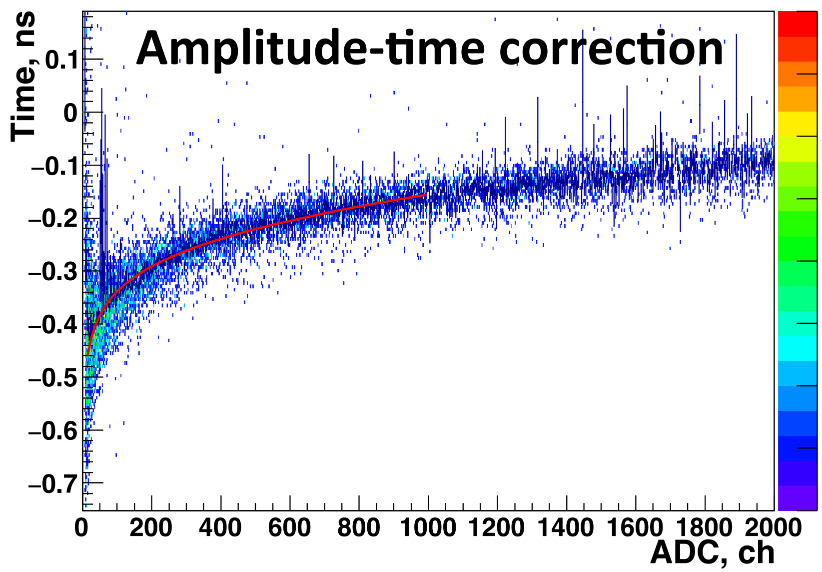
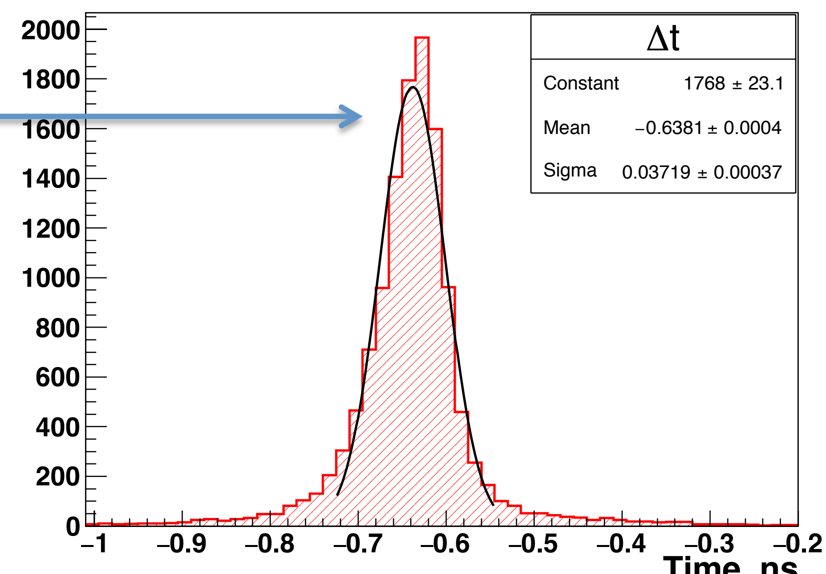
- In i-MCP mode secondary emission and amplification start inside the MCP layers.
- The length of the amplification region depends on the depth of secondary emission action.
- Amplitude-time correction is needed.
- Worse time resolution is obtained due to a larger fraction of small amplitude signals for which the time measurement is degraded by noise effects.

The same exemplar

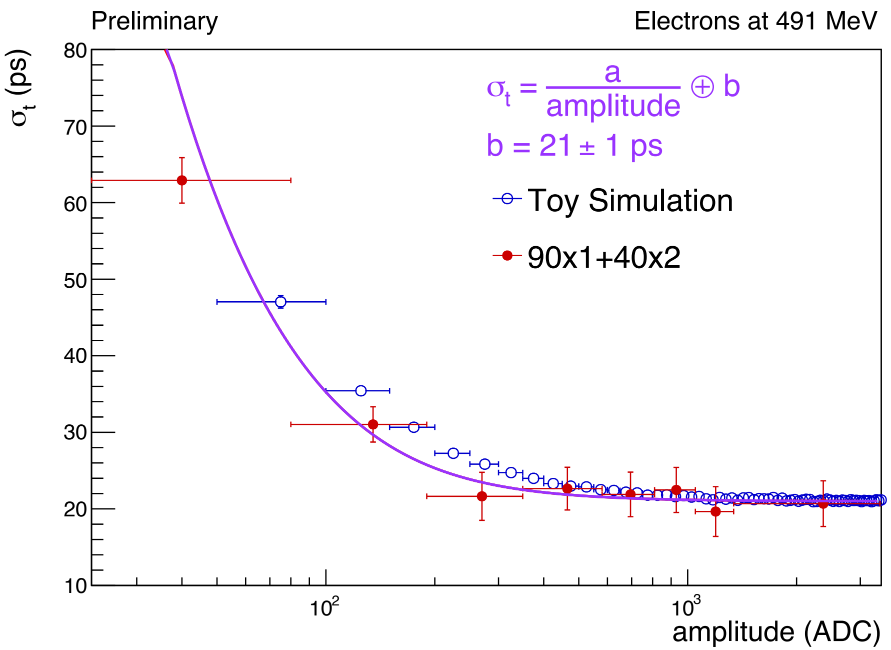
Amplitude-time correction

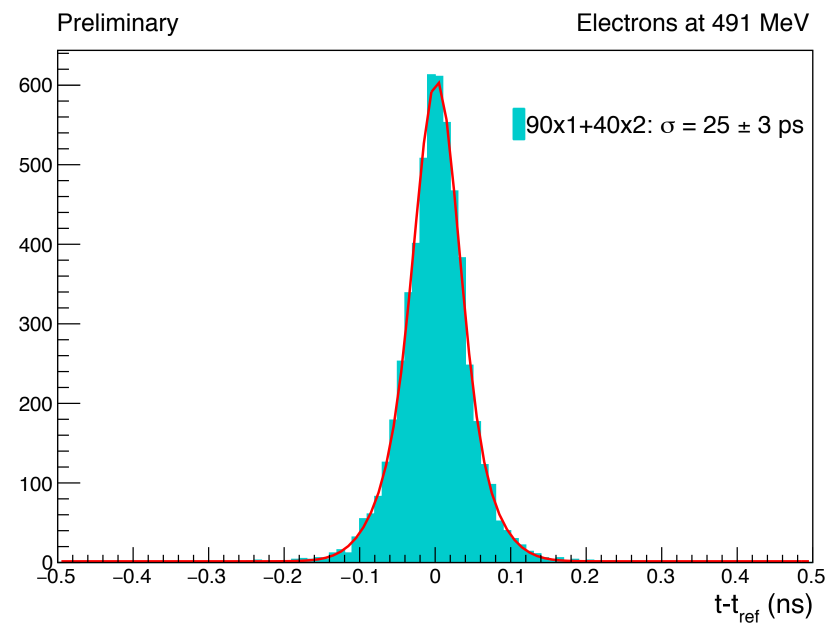


BINP test beam result



Timing properties



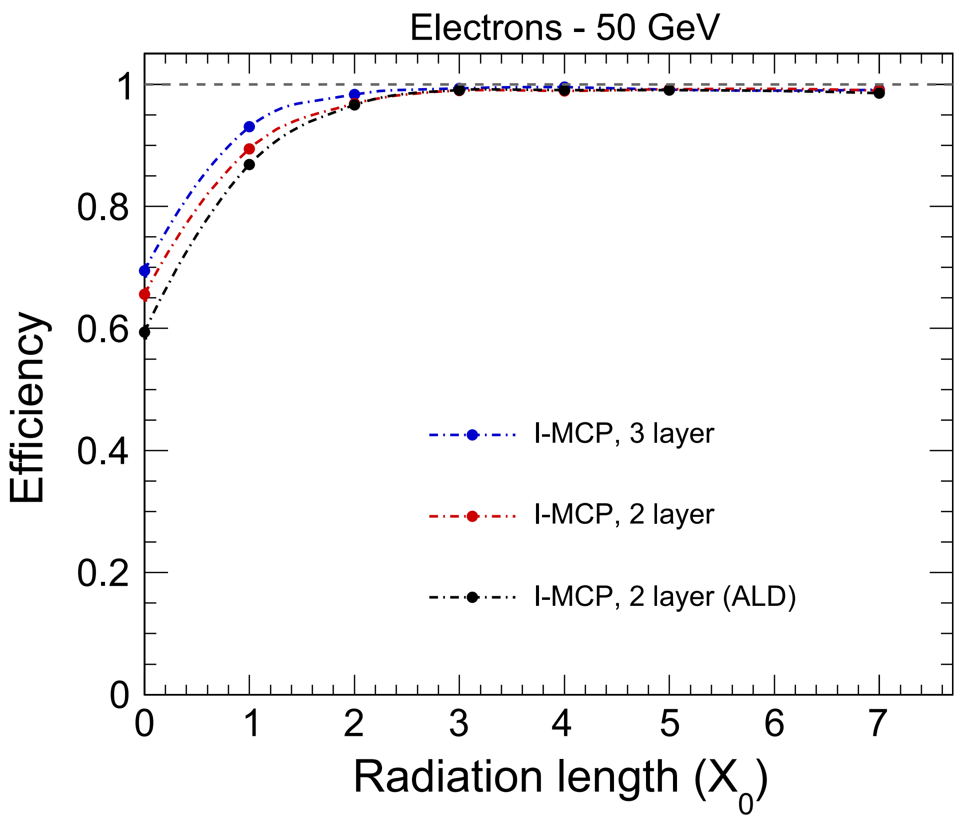


- $\sigma_t^{(REF)} \approx 23 \pm 2$ps is subtrated.
- Amplitude-time correction is applied.
- Threshold ~20 ADC channels.
- CFD with 50% of amplitude is used.
- In PMT mode σ_1 is measured with PiLas (jitter 4ps; t_{puls}=35ps).
- σ_1 is presented without (and with) subtraction of electronics impact.

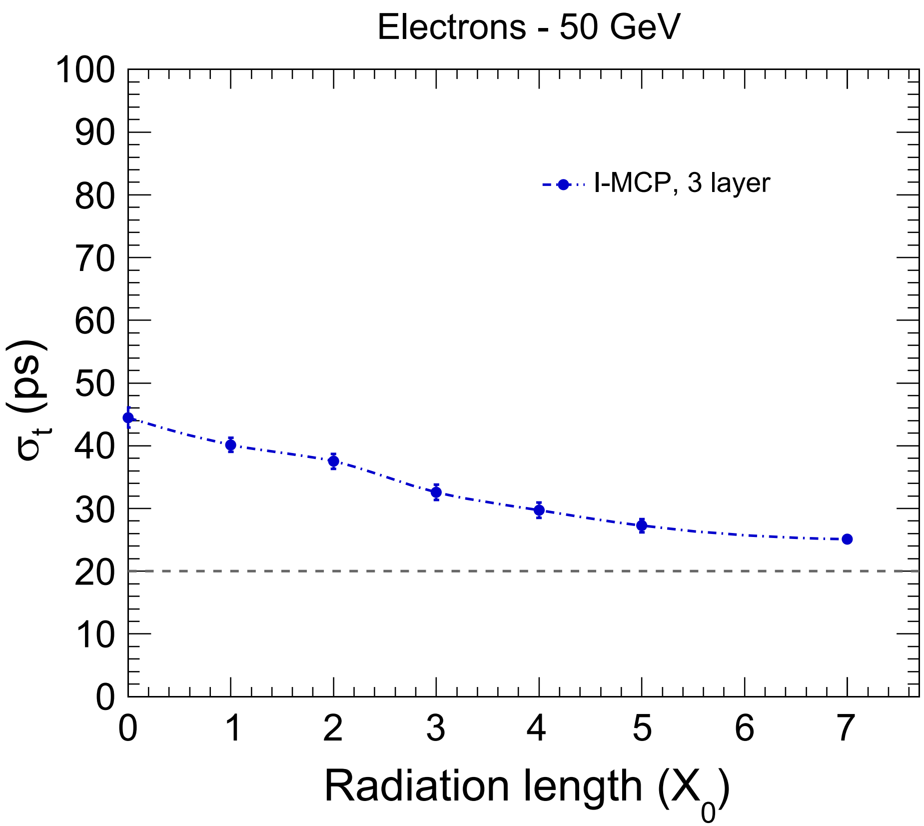
ID_{tube}	σ_t, ps	Const. term, ps	PMT σ_1, ps
(40x1+40x2)	25±3	20±2	29±2(22±2)
(90x1+40x2)	25±3	21±1	30±2(24±2)
(40x2+40x2)	44±2	29±2	28±1(21±1)
(90x2+40x2)	47±3	27±4	46±5(42±5)

Response to electromagnetic showers

Detection efficiency



Time resolution



Efficiency after $2X_0$ is close to 100%

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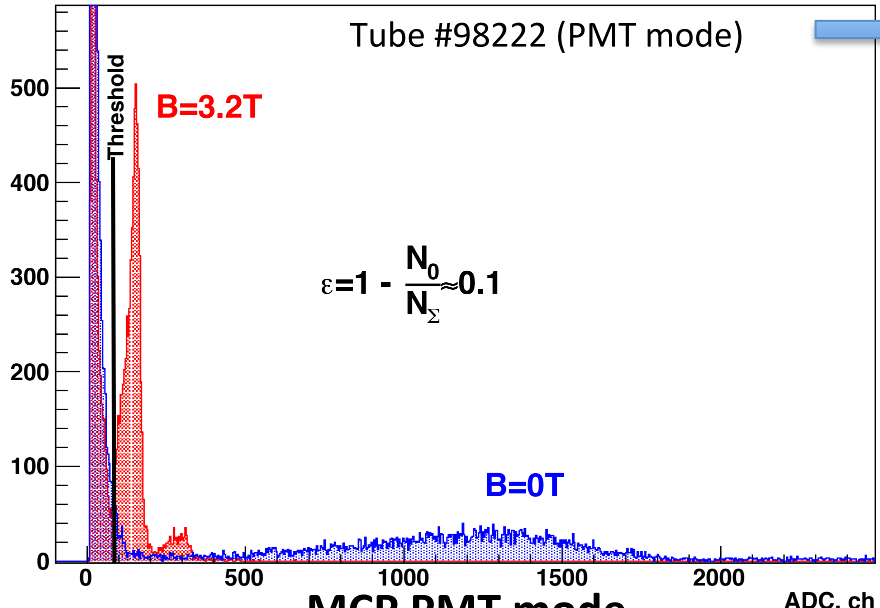
Time resolution after $7X_0$ still larger than in MCP PMT mode

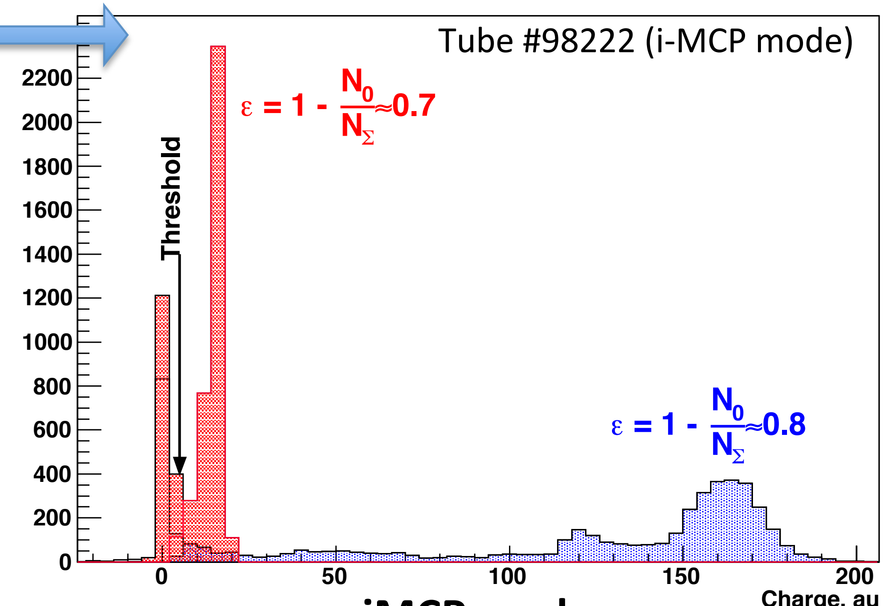
Magnetic field effects

- Direct measurements of i-MCP detection efficiency in magnetic fields is very complex task.
- To estimate influence of magnetic fields we use our MCP PMT measurements in magnetic fields with PiLas. (See poster #27 "Microchannel plates phototubes in high magnetic field")
- Tube #98222 (2MCP with L/ø=90 + 2MCP with L/ø=40) in ionization mode demonstrates detection efficiency 80÷90%. Its detection efficiency decrease are expected even in axial magnetic fields.
- Time resolution i-MCP in magnetic field is expected worse. For accurate estimation numerical simulation of electrons dynamic in MCP with magnetic fields is under developing. (See poster #11 "Numerical simulation of fast photo detectors based on microchannel plates")



MCP PMT mode

Recalculation



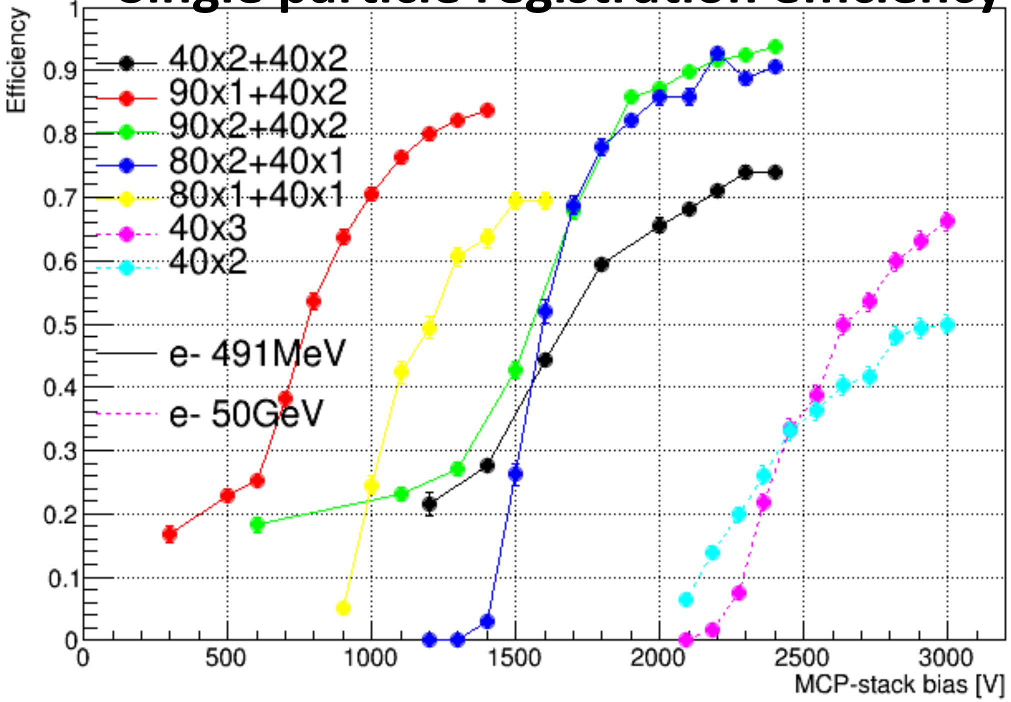
iMCP mode

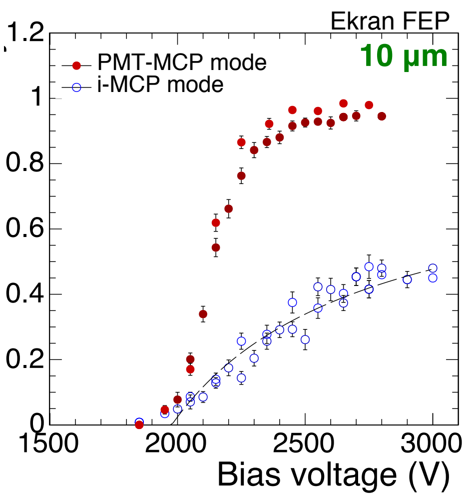
Summary

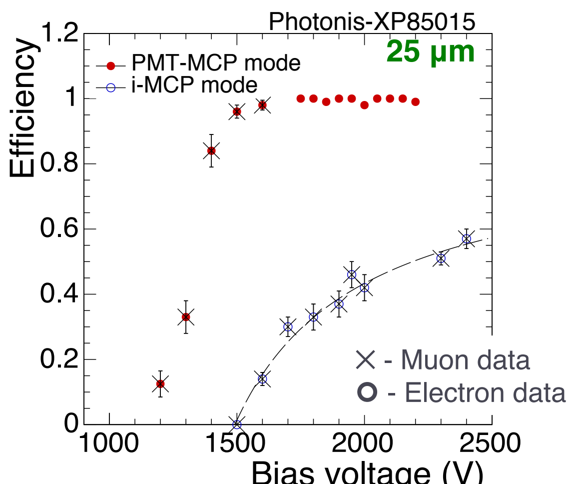
- MCP based devices working in ionization mode (i-MCPs) could provide MIP detection efficiency up to 90% with time resolution better than 50ps. The best tested exemplars consists of 3 or 4 MCPs:
  - First two MCP's stage with increased aspect ratio (L/ø=80÷90) works as electrons emitter;
  - Second stage (one or two MCPs) works as amplifier .
- Axial magnetic fields lead to some degradation of detection efficiency of these exemplars. It is possible to do some optimization of such devices construction which could help to improve their immunity to magnetic fields.
- Detection efficiency close to 100% for EM shower after few radiation lengths ($\geq 2X_0$) is demonstrated. This open the possibility to use i-MCPs as a timing layer in a sampling calorimeter or to use it in a pre-shower device.

Single particle detection efficiency

Single particle registration efficiency







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- 90x2+40x2 –
  1st stage is 2MCP; 3.5μm; L/ø=90
  2nd stage is 2MCP; 7μm; L/ø=40
- 80x2+40x1 –
  1st stage is 2MCP; 5μm; L/ø=80
  2nd stage is 1MCP; 25μm; L/ø=40
- 80x1+40x1 –
  1st stage is 1MCP; 5μm; L/ø=80
  2nd stage is 1MCP; 25μm; L/ø=40
- 40x3 – 3MCP; 7μm; L/ø=40
  (Standard Z-stack MCP PMT)
- 40x2 – 2MCP; 7μm; L/ø=40
  (Standard V-chevron MCP PMT)

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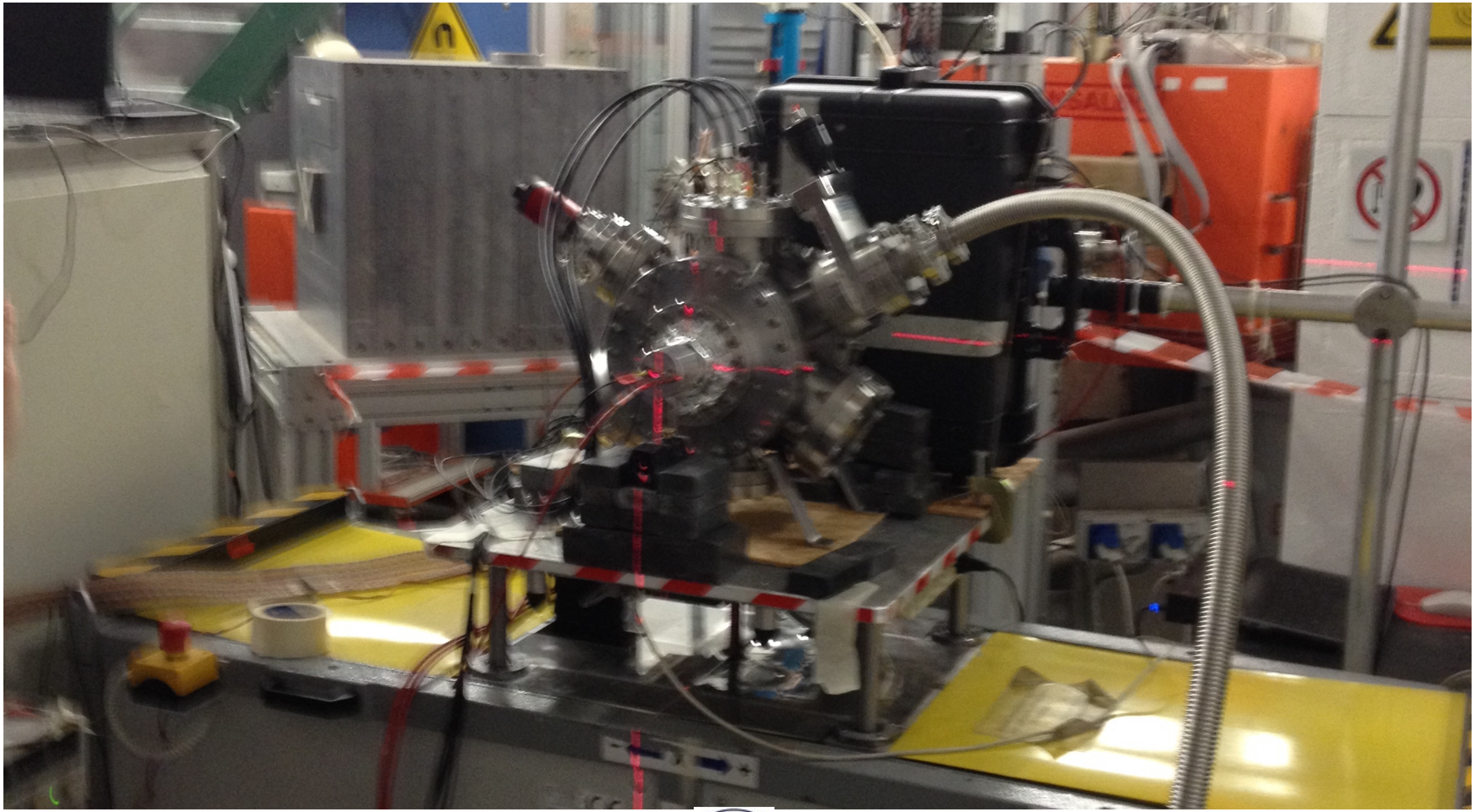
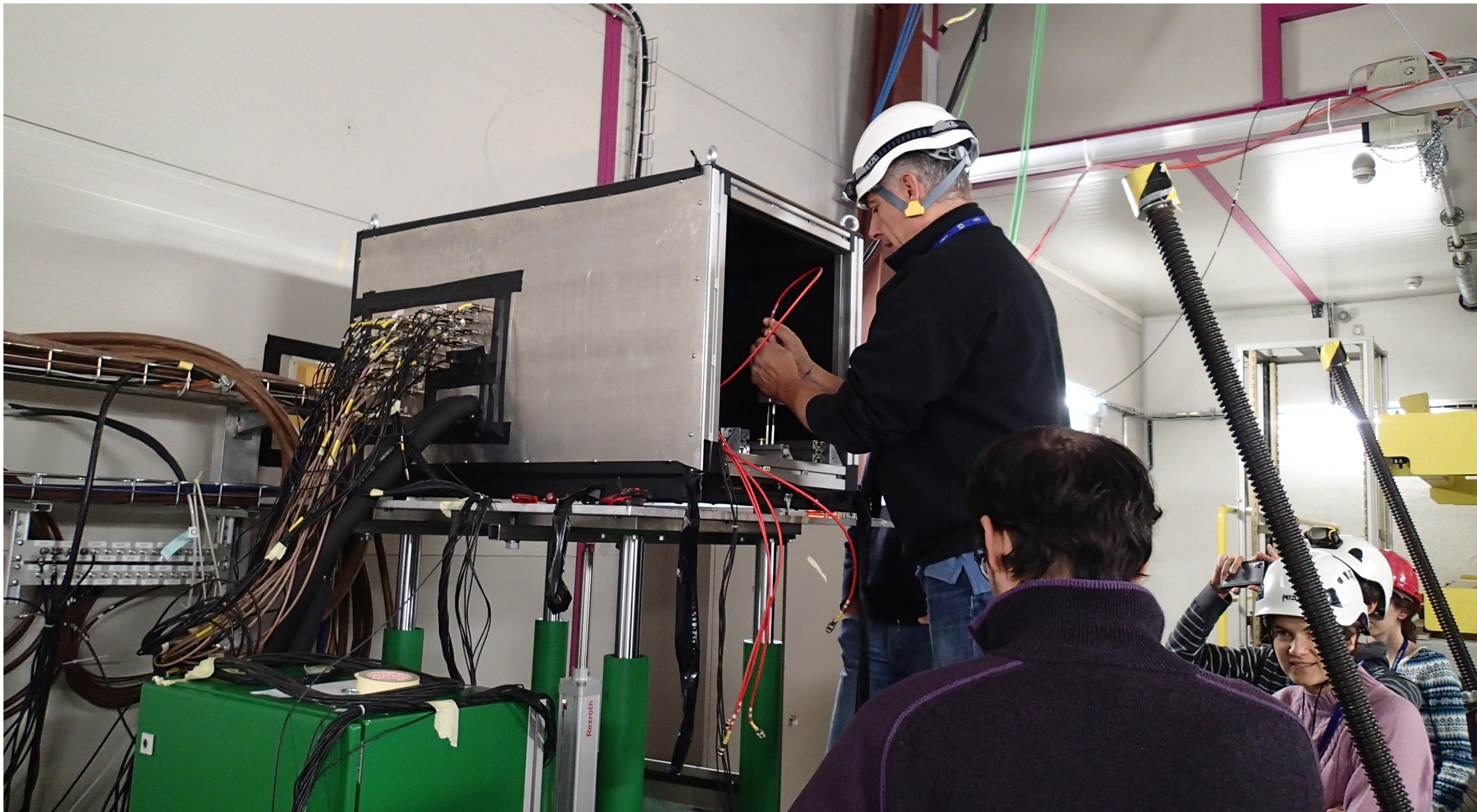
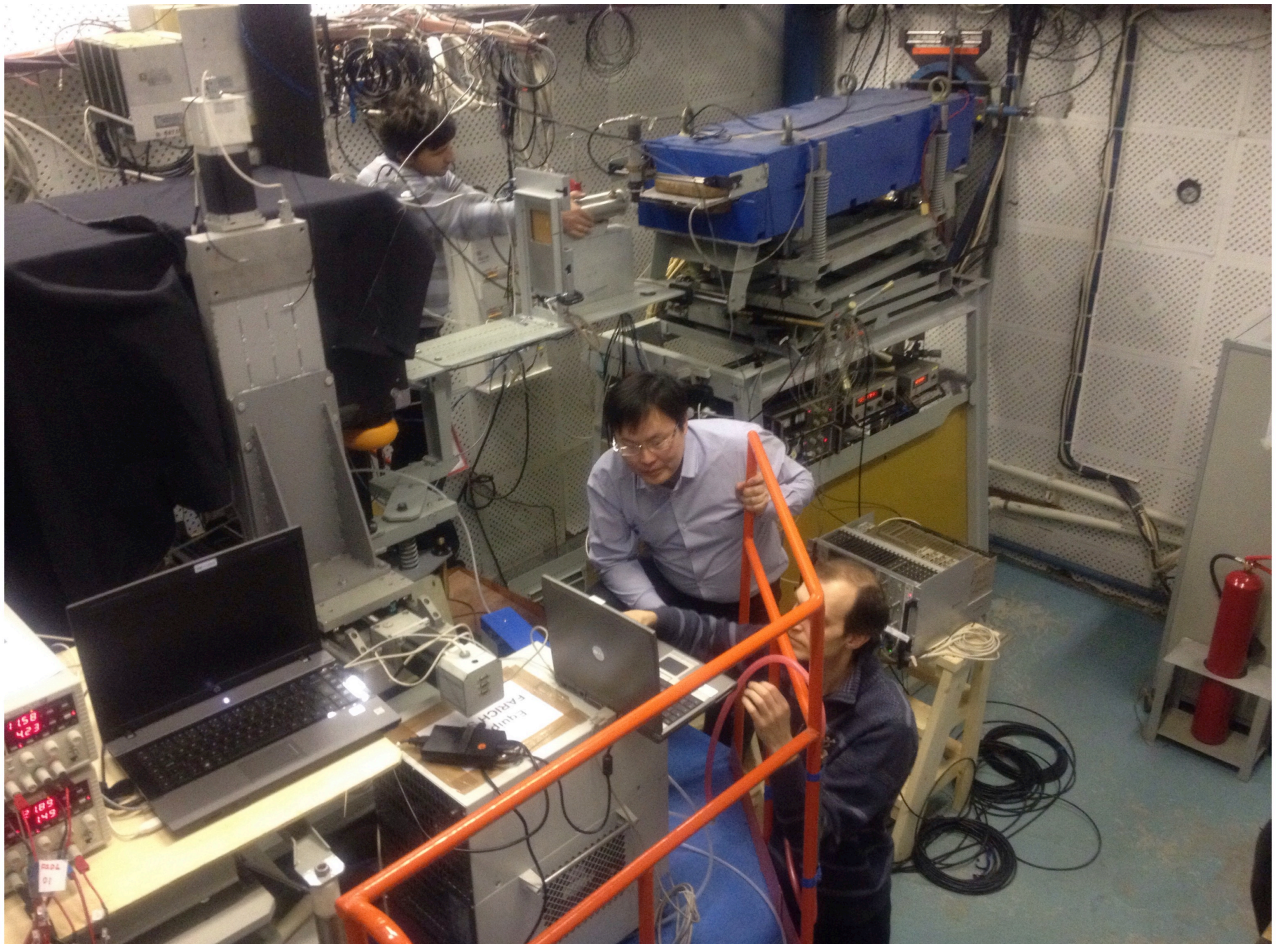
BTF LNF (Frascti)



H4 SPS (CERN)



ExBeam (BINP)



R&D prospects (2 steps)

- Optimization iMCP design to improve properties in magnetic fields:
  - Optimal gapes between 1st and 2nd stages of MCPs and voltage distribution;
  - Cs-treatment of MCPs to increase amplification for compensation gain drop in magnetic fields.

- Large area device development: scalable design from standard size MCPs with increased aspect ratio.