I-MCP: IONIZATION MICRO-CHANNEL PLATES FOR FAST TIMING OF SHOWERS IN HIGH RATE ENVIRONMENTS

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Executive summary

- **We propose an R&D program of a detector element based on micro-channel plates (MCP) to sample the ionizing component of electromagnetic showers**
  - Extensively used in ion time-of-flight mass spectrometers
  - Never exploited in depth to detect the ionizing component of showers
- **The fast time resolution of MCPs exceeds anything that has been previously used in calorimeters**
  - Aid in the event reconstruction at high luminosities and occupancies
  - Can meet requirements for HL-LHC experiments
- **Solution attractive due to recent technological progress in MCP production**

- **Expected outcome:**
  - Proof-of-concept and design of a radiation-hard module (~300 kGy and 10^{16} n/cm^2) with extreme time resolution (<50 ps) to be embedded in a sampling calorimeter (e.g. as a preshower)
  - This solution would factorize the quest for precision timing from the technological choice of the full calorimeter
- **Potential applications to:**
  - Monitoring with precision event timing of high intensity beams

Problem identification and opportunity

- **High-Luminosity LHC (> 2020)**
  - Luminosity, interactions/beam crossing (pileup), and radiation levels ~10 times than target design of current detectors
  - Upgrade necessary for several detectors, including **calorimetry in the forward direction**, and trigger

- **General goals in calorimetry**
  - Lepton/photon identification and isolation at **$p_T \sim O(m_H/2)$**
  - Resolution on MET: key signature of 'new physics'
  - Good jet reconstruction in the forward direction

- **Performance degraded by pileup**
    - about 140 interaction vertices per beam crossing
  - **Mitigation possible with extreme time resolution on shower deposits**
    - Spread of vertex time ~ 300 ps (bunch length)
    - 'Effective occupancy' similar to current LHC for time resolution ~30 ps

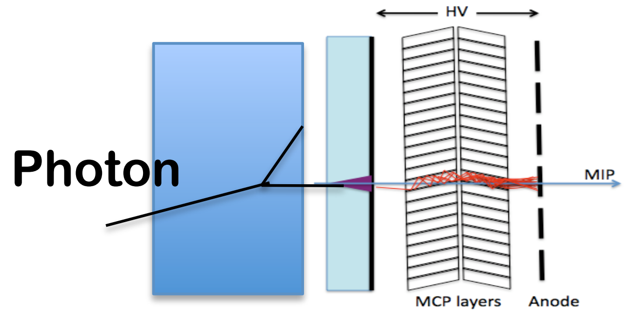
Technical approach: (ionization) micro-channel plates

- **One (or more) layer(s) embedded in the calorimeter for fast timing of showers (<50 ps)**
  - *Possibly a preshower*: quest for precise timing decoupled from the choice of the calorimeter technology

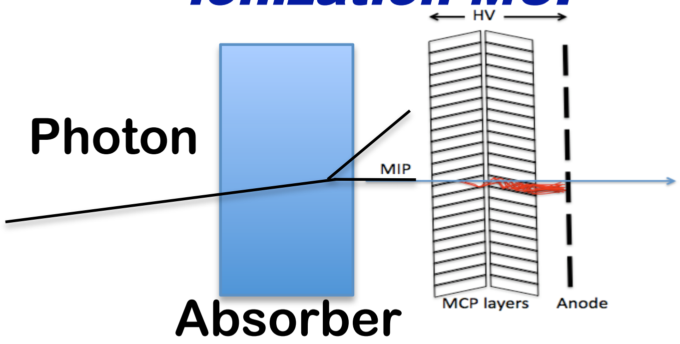
- **Exploit MCPs as m.i.p. detector**
  1. **PMT-MCP**: Very fast (O(10 ps)), high efficiency to m.i.ps through Cerenkov emission in the quartz/glass window
  2. **"Ionization-MCP"**: efficiency to m.i.p.s **>70% with at least σt=75 ps**
     - NIM A 478 (2002) 220

- **Option 2 could be sufficient to sample a shower with high m.i.p. multiplicity; it would dispense the photocathode, simplifying the design and assembly**
  - Early proposal for calorimetry : A. A. Derevshchikov et al. Preprint IFVE 90-99, Protvino, Russia, 1990.

Classical PMT-MCP+Absorber



"ionization-MCP"



Longitudinal shower profile with iMCP

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

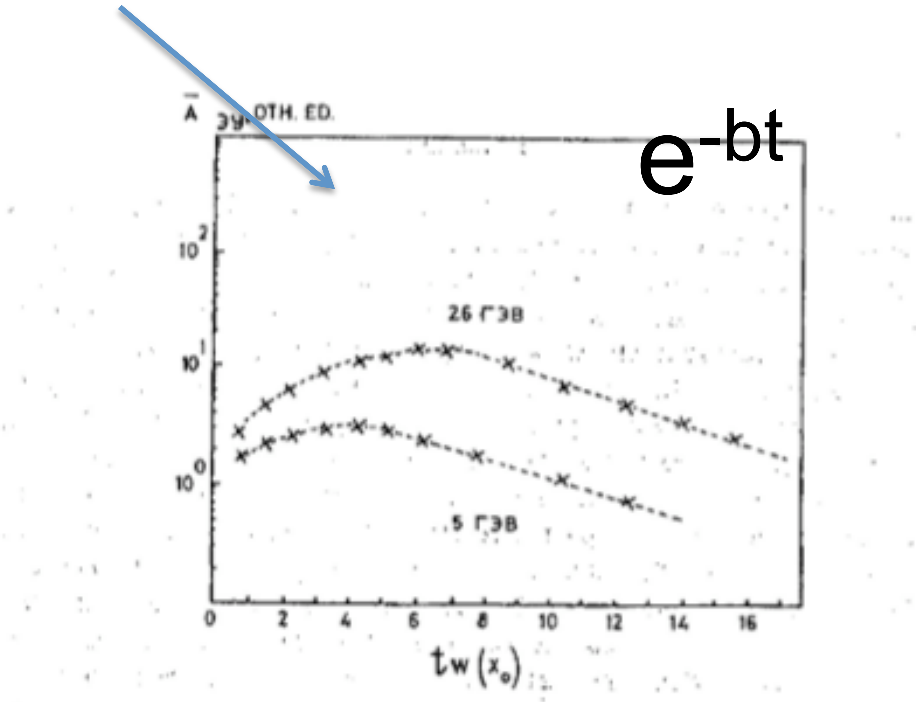
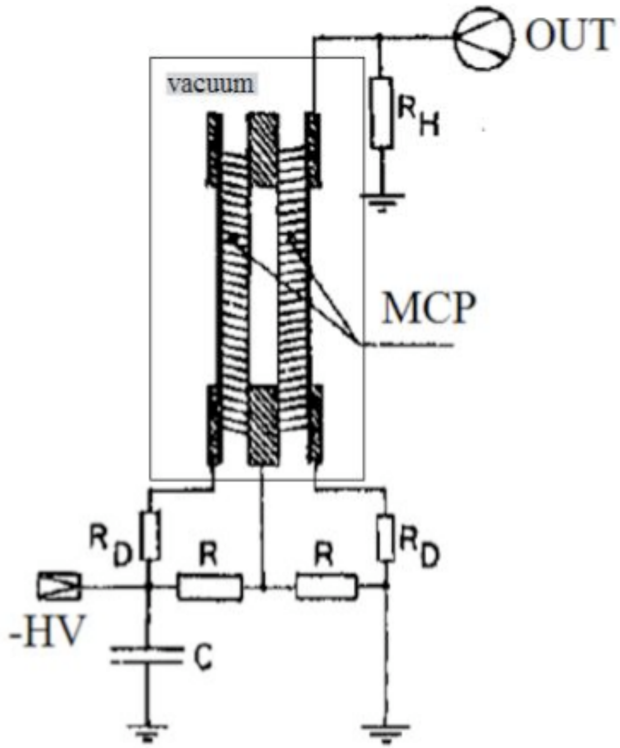
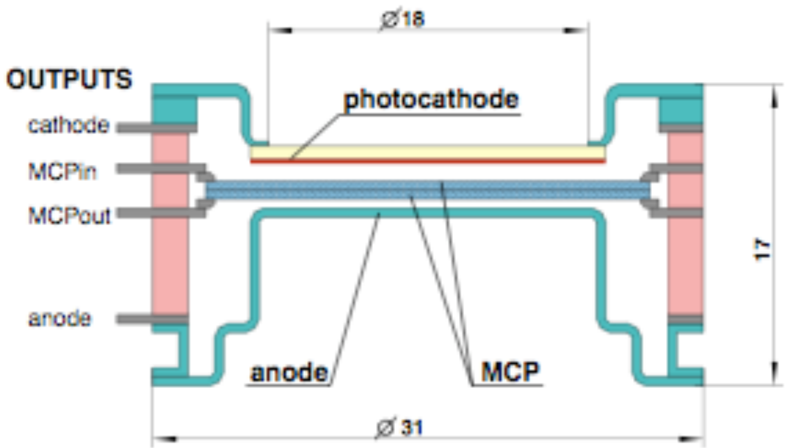


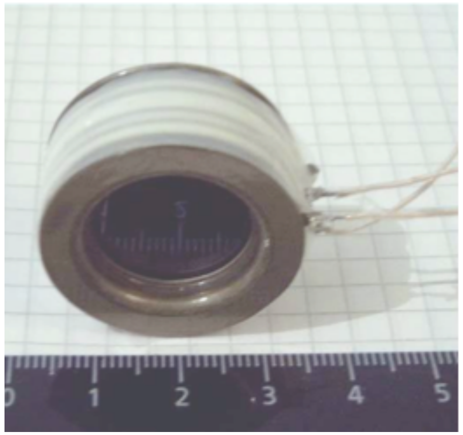
Fig.3. Shower longitudinal development for electron energy 5 and 26 GeV, measured by MCPs.

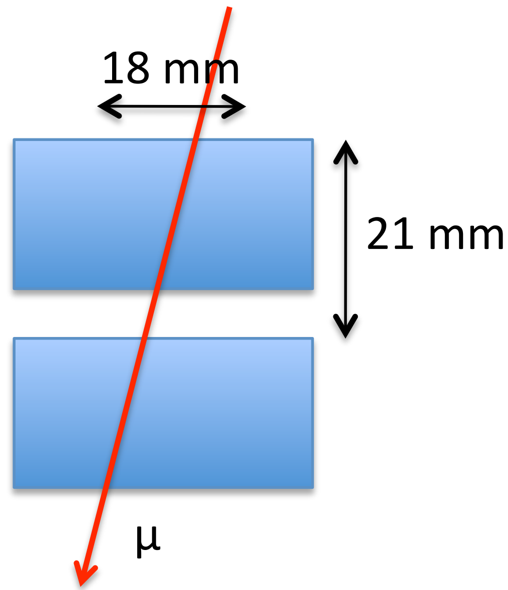


Preliminary test bench at MiB

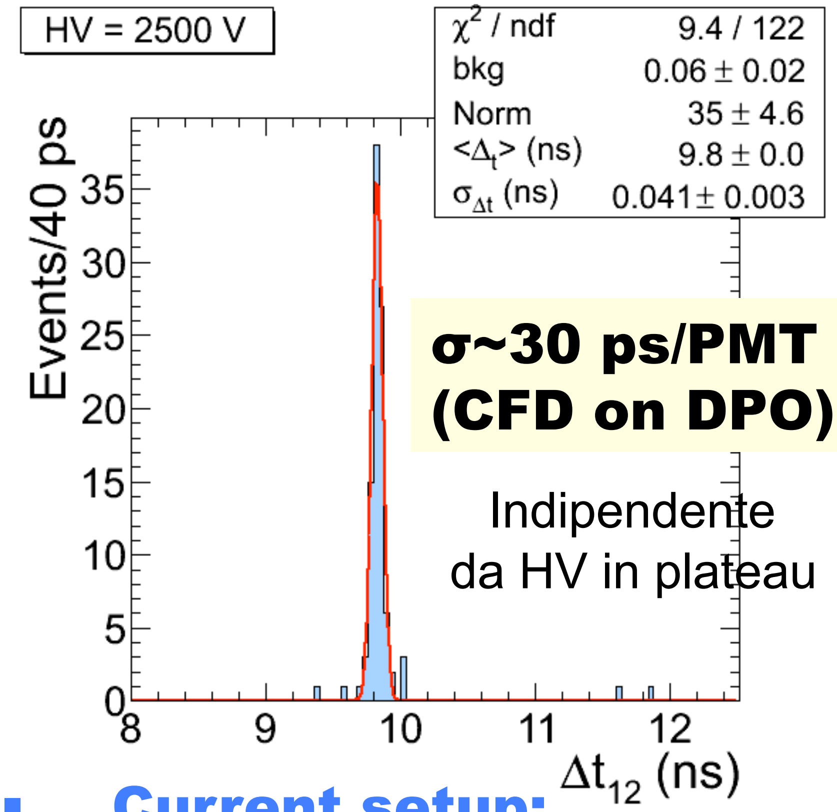
- **Allestimento preliminare di un *test bench* a Milano Bicocca per raggi cosmici (costo zero, eccetto FTE)**
  - Due PMT-MCP in prestito (M.Barnyakov, INP, Novosibirsk)
    - Caratteristiche Lehman et al. NIM A595 (2008) 173; Barnyakov et al. A598 (2009) 160
  - Bias (HV CAEN) e readout (DPO – Tektronix - 2.5 GHz) con strumentazione esistente
  - Misure di Δt per eventi in coincidenza tra due tubi
    - Tasso di coincidenze atteso ~ 0.25 min^{-1} = 15 / hour





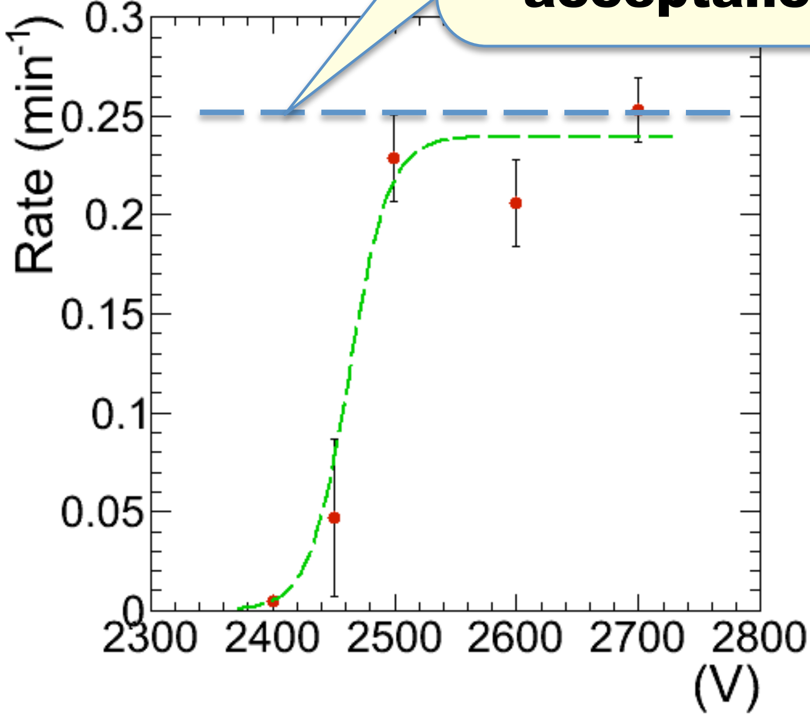


Preliminary results



σ~30 ps/PMT (CFD on DPO)

Indipendente da HV in plateau



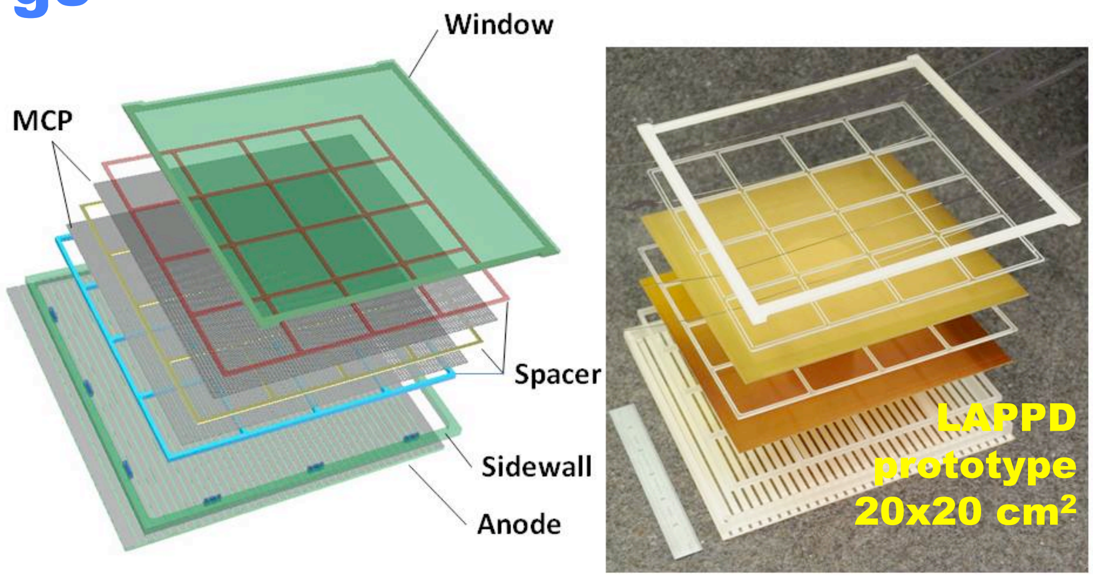
Rough expectation from μ flux and acceptance

- **Current setup:**
  - Exploit the optical window as Cerenkov radiator
  - <p.e.>~4 (1.2 mm with n=1.56; Q.E~10%, ΔE~1 eV)
- **Next: test secondary emission from MCP surface**
  - *Inhibit photoelectron collection with reverse photocathode bias*

State of the art on (PMT)-MCPs

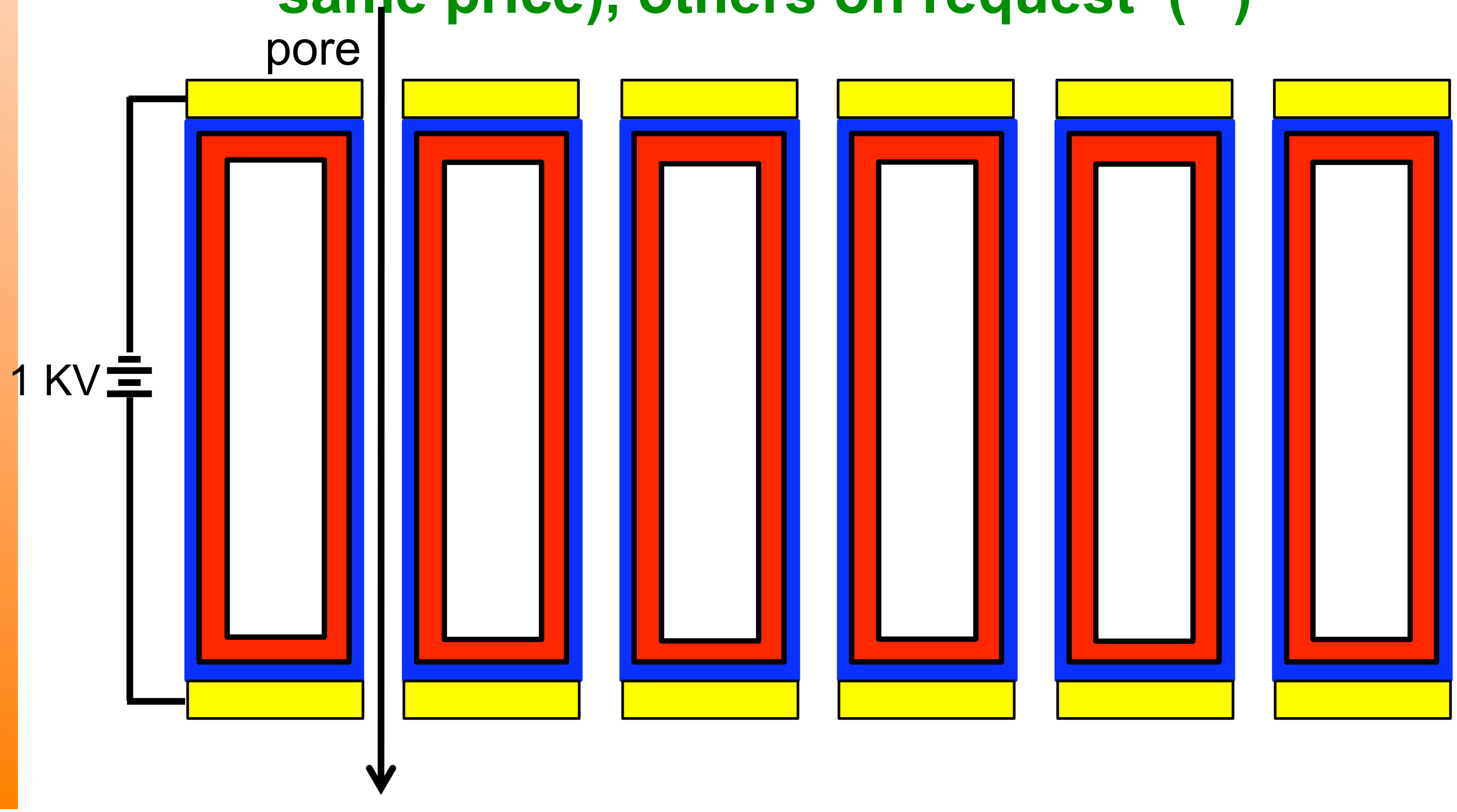
- **PMT-MCPs well known and available off-the-shelf at some cost (~ 8000 $ for a ~50x50 mm2) unsuited for large scale application**

- **A new technology mature for mass production of large surface MCPs**
  - LAPPD collaboration (see e.g. this talk)
  - MCP wafers of glass capillaries with atomic layer deposition (ALD) of high resistivity layers available from **Incom, Ltd.**



MCP Wafers: Incom Ltd.

- **MCP wafers: 1.6 k$ / wafer + IVA**
  - Wafer 5x5 cm^2 (10x10 cm^2 ~ 4.5 k$ / wafer)
  - **Pore size/pitches 10 μm/12 μm or 25μm/30 μm (*)**
  - Resistivity from ALD layer thickness tunable on request
  - **Emissive coating Al_2O_3 (default), MgO (available at the same price), others on request (**)**



- Resistive
- Emissive
- Conductiive

coatings on a glass wafer (with capillaries)

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→ **Test more than one geometry and coating:**
  - ~ 24 wafers for a minimal set

Dimensions	Pore Size	Quantity	Unit Pricing	
50mm x 50mm x 0.60mm	10 micron	12	$	1,600
50mm x 50mm x 0.80mm	20 micron	12	$	1,600
50mm x 50mm x 1.20mm	20 micron	12	$	1,700
100mm x 100mm x 0.60mm	10 micron	12	$	4,200
100mm x 100mm x 0.80mm	20 micron	12	$	4,200
100mm x 100mm x 1.20mm	20 micron	12	$	4,400
	Gain Measurement		$	1,500

Can be converted in a formal quote in ~2 weeks (delivery time ~3 months)

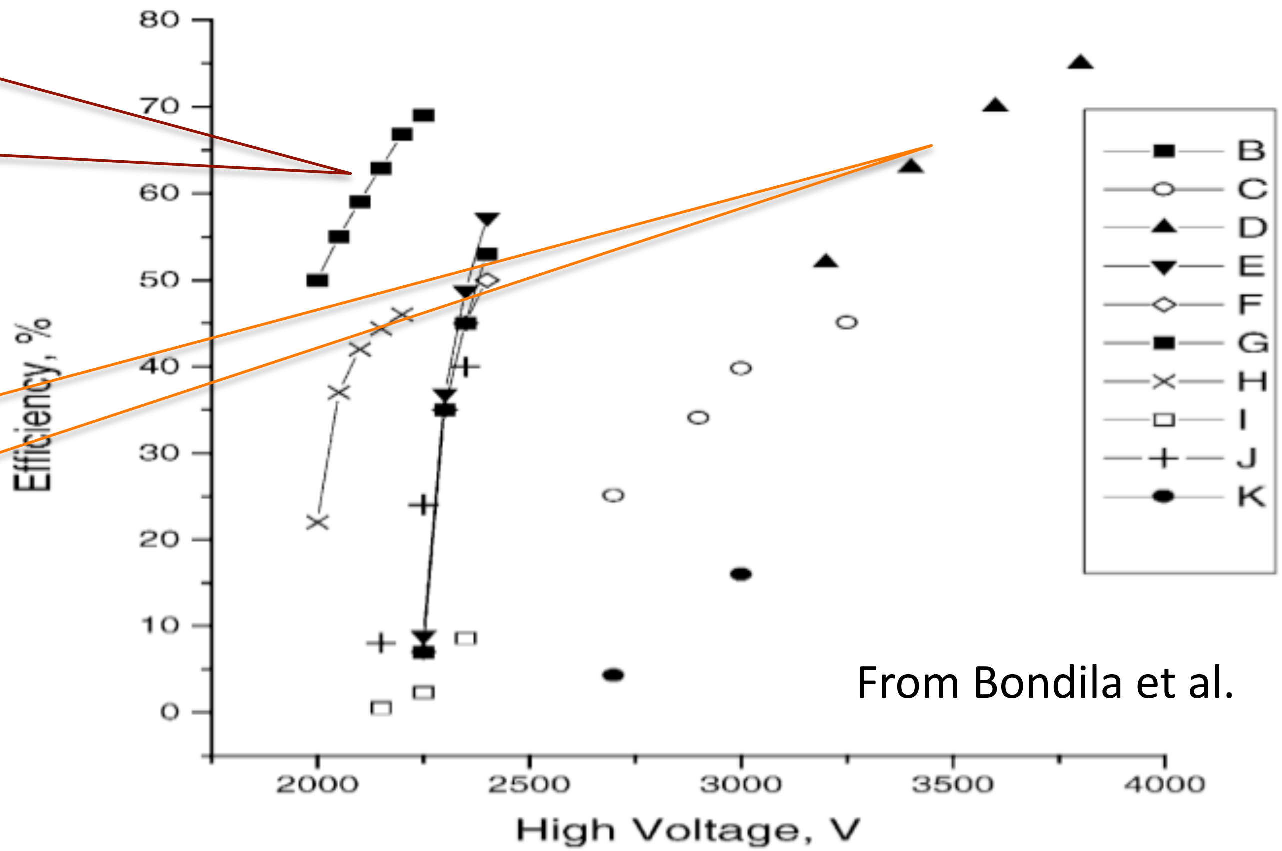
(*) Smaller pores and high thickness enhance MIP efficiency, according to [Bondila et al., NIM A478 (2002) 220](#) (the only available test of the i-MCP concept with MIPs)

(**) Higher emissivity with MgO coating than Al_2O_3 (with dependence on the thickness)

→ *NEED TO TEST MORE THAN ONE OPTION*

Two MCPs Chevron Config. 12 µm / 0.8 mm High Gain

Three MCPs Z-stack Config. 25 µm / ?? mm



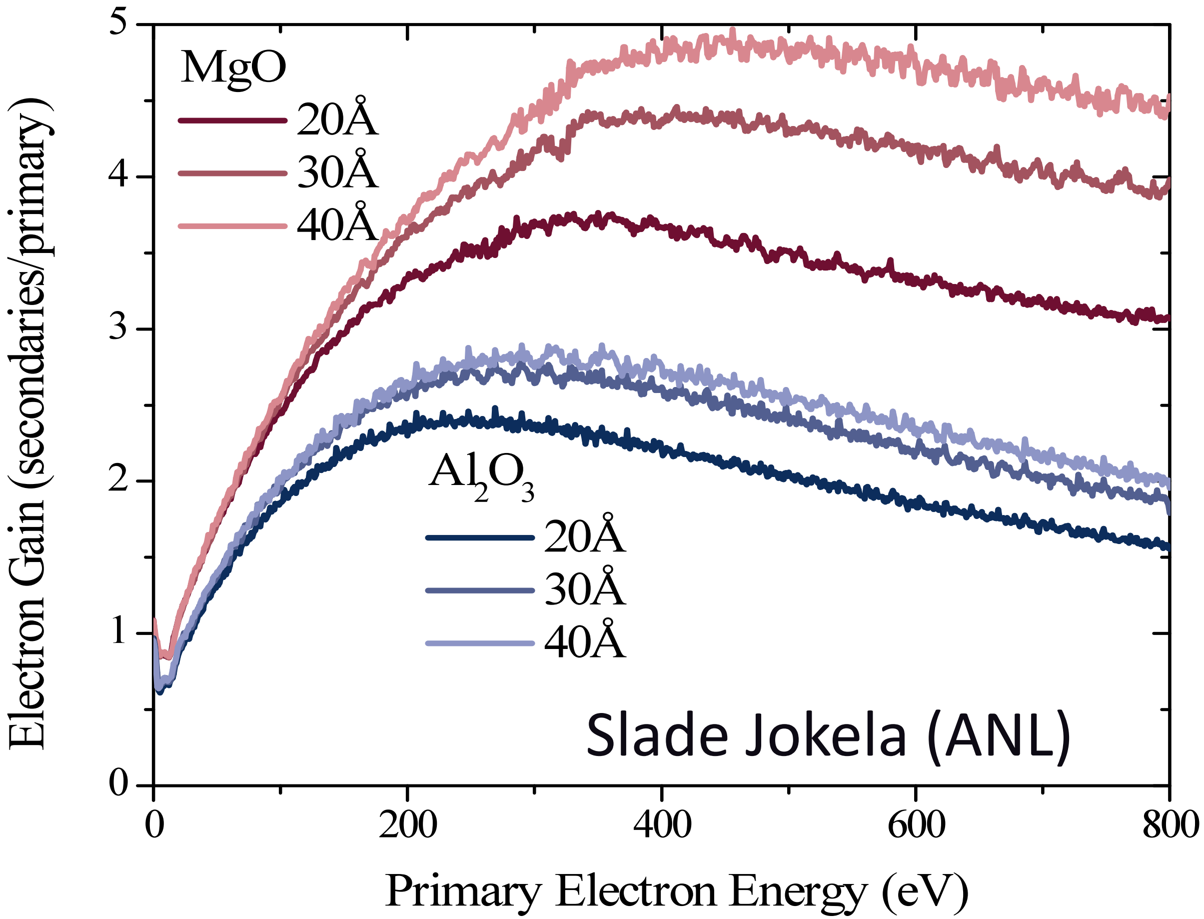
From Bondila et al.

(*) Smaller pores and high thickness enhance MIP efficiency, according to Bondila et al., NIM A478 (2002) 220 (the only available test of the i-MCP concept with m.i.p.s)

(**) Higher emissivity with MgO coating than Al_2O_3 (with dependence on the thickness)

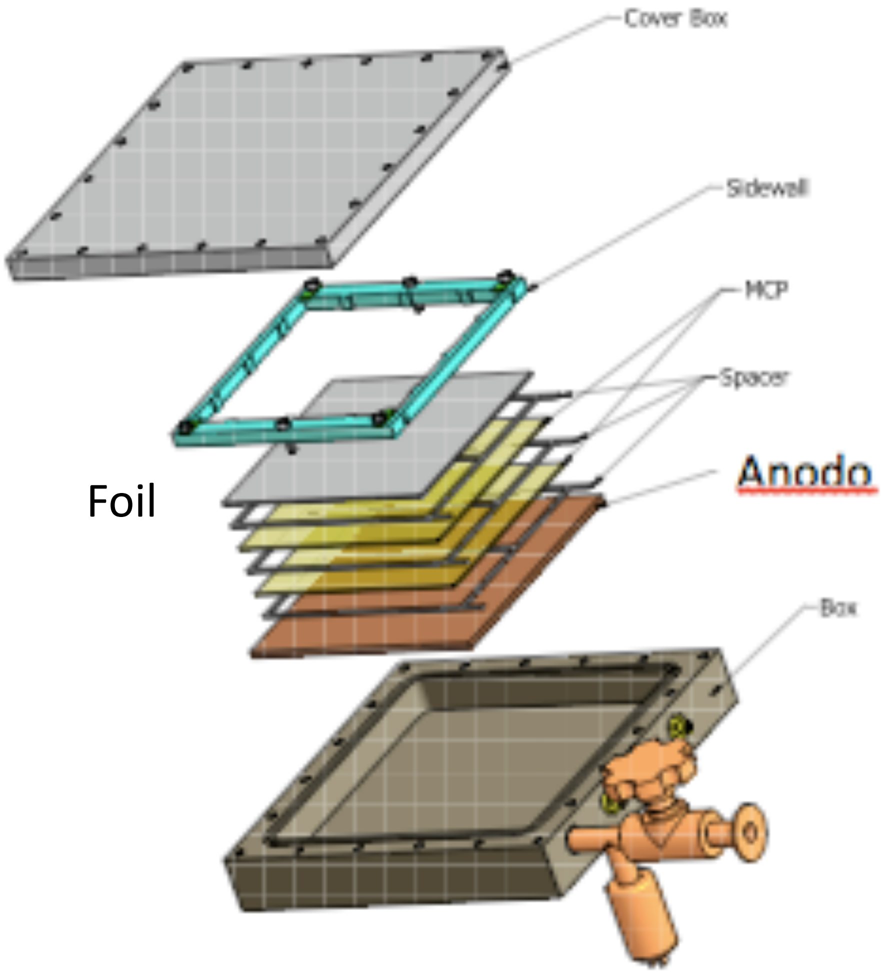
→ NEED TO TEST MORE THAN ONE OPTION

Note : this is far from m.i.p. regime (~3 MeV for electrons)



Mechanics and electronics for tests

- **Vacuum tight boxes:**
  - Host up to three wafers (two in the figure)
    - Chevron or Z-stack configuration
  - Housing for an additional emissive layer (foil) to enhance efficiency
- **Anode readout and electronics**
  - 4x4 pads to cover the full surface (~1x1 cm^2 / pad)
  - Merged at readout to test the full surface
    - Independent readout (of a fraction of them) to map local response
  - Minimum: 16 electronic channels
    - Discrete components
    - Monolithic CLARO-CMOS if available



Summary on R&D plan and expected outcome

- **Detailed R&D plan:**
  - **Test of the i-MCP concept with cosmic rays:**
    - different pore sizes, aspect ratios and coatings
  - **Characterization of response to showers at BTF (LNF):**
    - efficiency, timing, amplitude, rate capability, and response vs the sampling depth
  - **Radiation hardness qualification**
    - Neutron and γ irradiation at ENEA Casaccia (protons at CERN 2015)
    - First exposure up to ~1/3 HL-HLC (100 kGy, 10^{15} n/cm^2)
    - Further exposures to verify response evolution up to HL-LHC fluences
  - Development of a detector response model
    - For application-specific design optimization
- **Expected outcome:**
  - **Proof-of-concept and design of i-MCP prototypes for fast timing of electromagnetic showers**
    - Contingency: MIP efficiency could be enhanced though Cerenkov emission in an optical window
  - Exploitation of a cutting edge technology, with potential applications in other fields [e.g. beam monitors with fast timing]