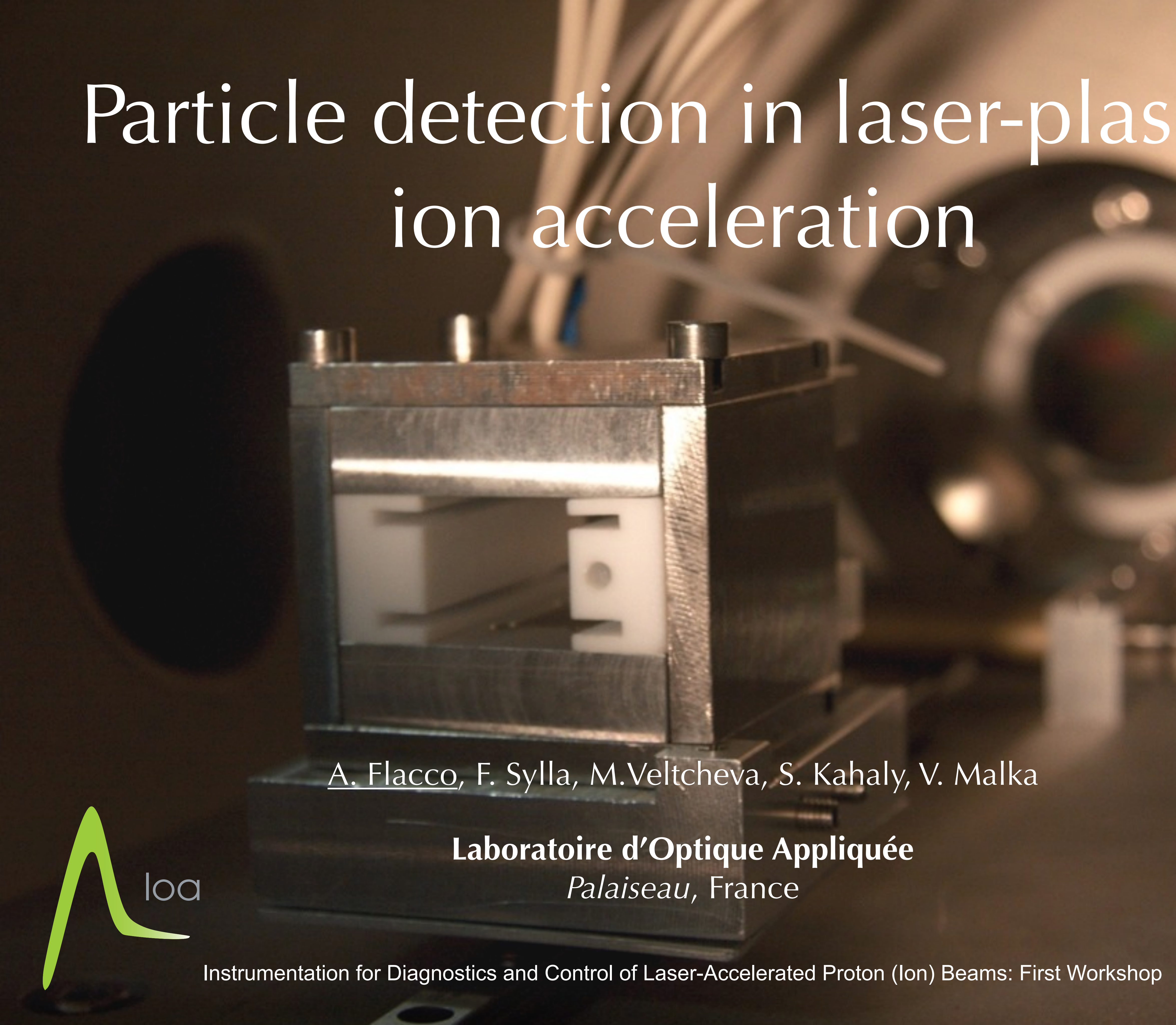

Particle detection in laser-plasma ion acceleration

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Palaiseau, France

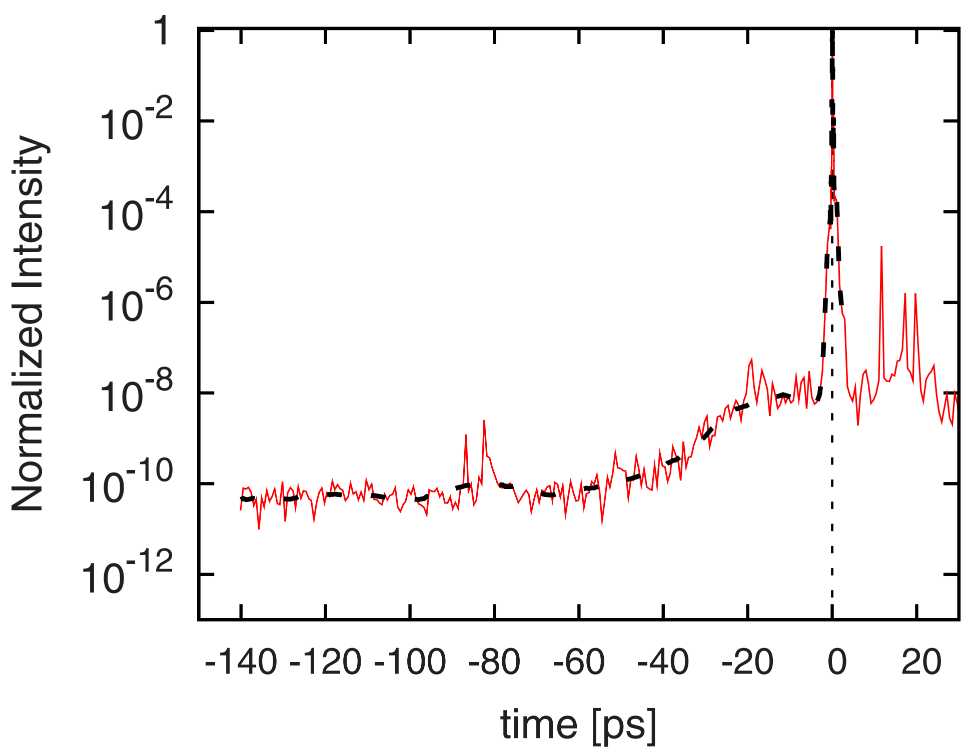
Instrumentation for Diagnostics and Control of Laser-Accelerated Proton (Ion) Beams: First Workshop

Source de Particules par Laser

Outline

- Experimental activity in LOA: present and future
- Detecting laser-accelerated particles
- Activities on ion detectors: MCP/TP, problems, calibration, analysis
- Conclusions

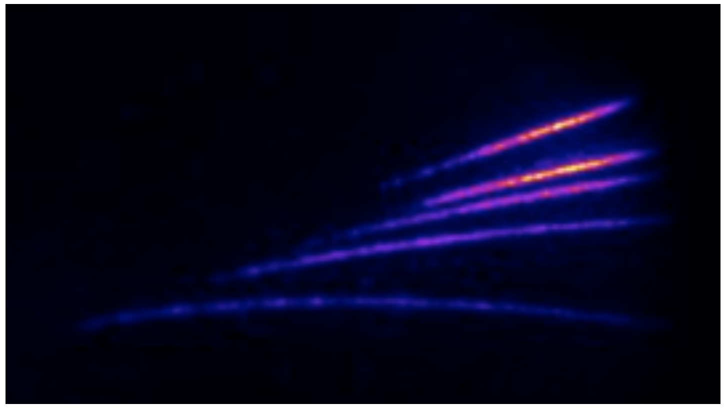
Salle Jaune multi-terawatt laser source (*present*)

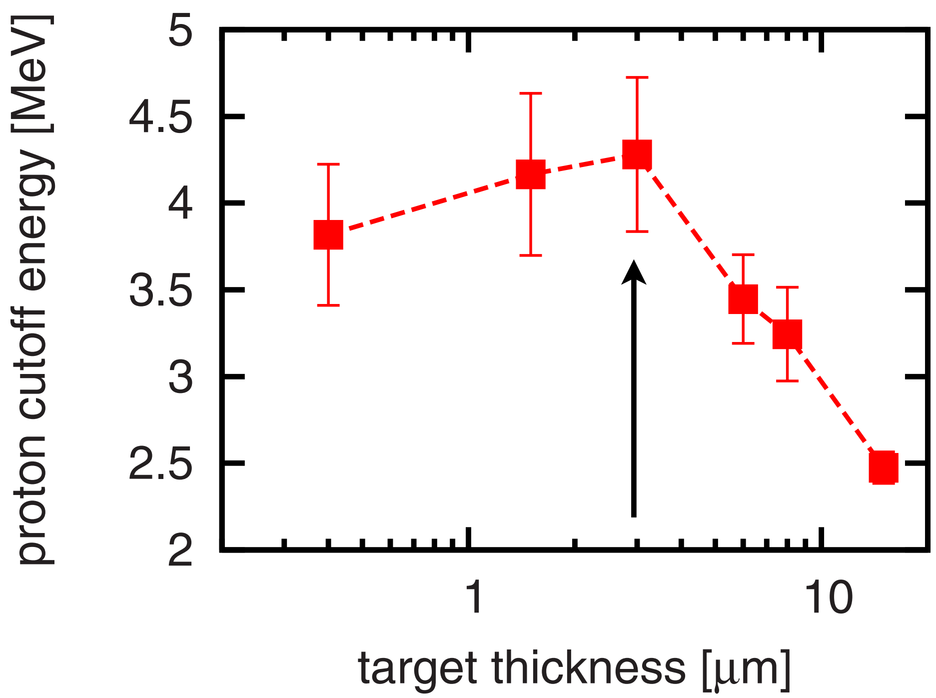


$\tau = 30\text{fs}$

$E_L = 0.8\text{J}$

$I_0 = 4 \times 10^{19}\, W/cm^2$





XPW: incoherent pedestal level is strongly reduced. Cleaner interaction conditions at high repetition rate.

Improved stability of the proton kinetic energy: 4% *rms*!

Near future in LOA

Two ongoing projects foresee power improvements in LOA:

ERC-Paris Upgrade the Salle Jaune laser facility to 200TW (upgrade starts 2011)

SAPHIR Source of High Intensity Laser Accelerated Protons for Radiotherapy

Collaborative project between multiple partners from research and industry. Timeline (i) the installation of a 200TW laser system in LOA, (ii) its upgrade to 500TW and 1PW in 5 years. Aims: be able to define a prototype for a laser based proton accelerator. T_0: 2010!

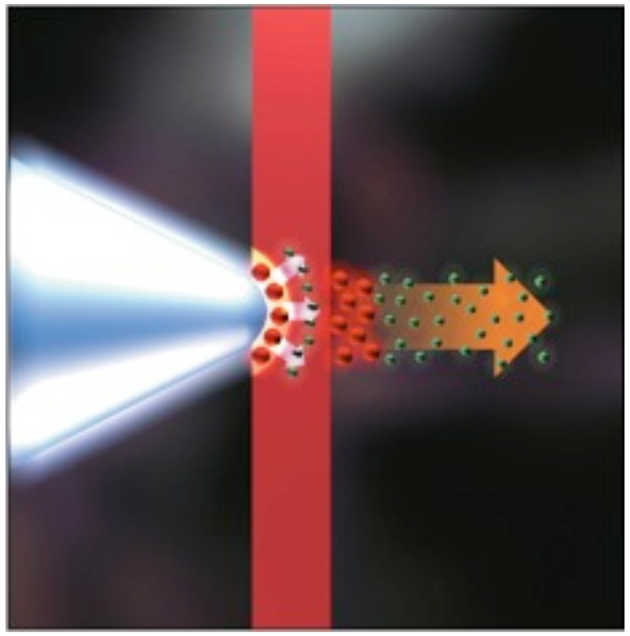
New challenges for ion detection!

(concept, design, implementation)

5MeV (protons) ⟶ **?**

Detection of laser accelerated particles

High intensity laser-plasma interaction: extremely rich set of products:



Photons (X,γ)

Harmonics

Several Ion Species

Electrons

Molecules ($Fe_2O_3^+$, SiO_2^+)

Atoms

Laser!

Different charge states

Extended masses and velocities range

Different interaction with materials (unwanted interactions, radioprotection)

- Continuous spectra: necessity of spectral analysis
- Wide angle emission: tradeoff between spatial and spectral measurements

Most known radiation sensitive devices/materials are:

- Dose integrators (CR39, RCF, image plates)
- Scintillating materials (inorganic or organic)
- Micro-Channel plates

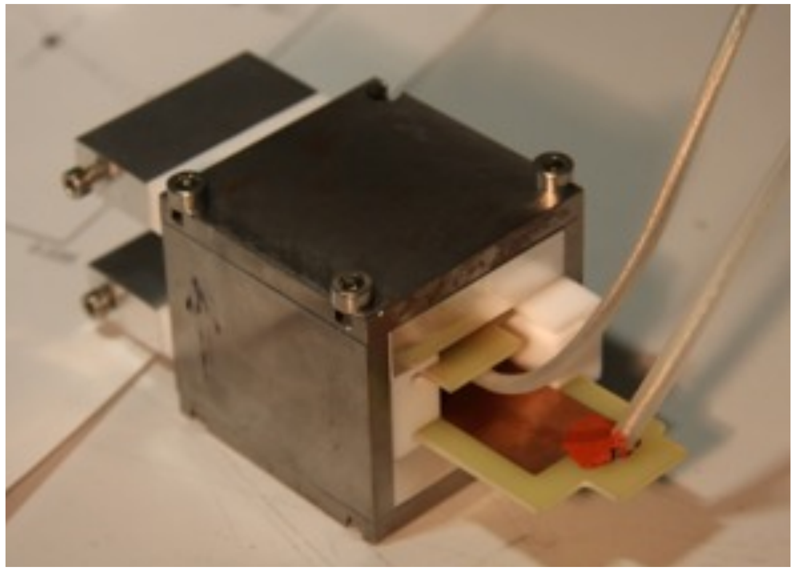
Selection of species

Continuous spectrum resolution (fine effects)

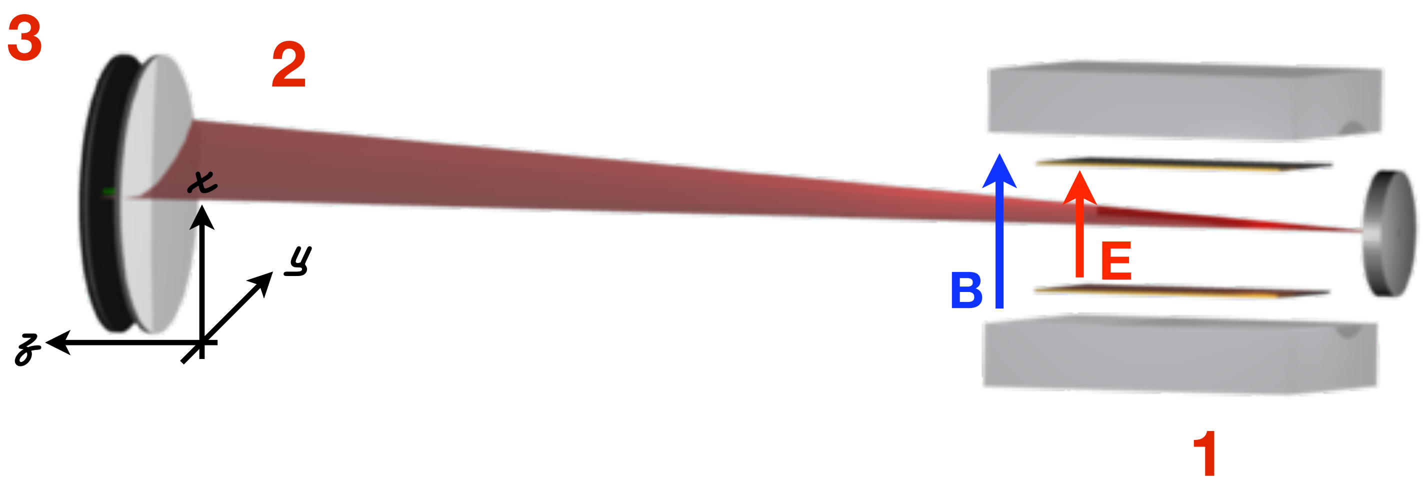
Real time!

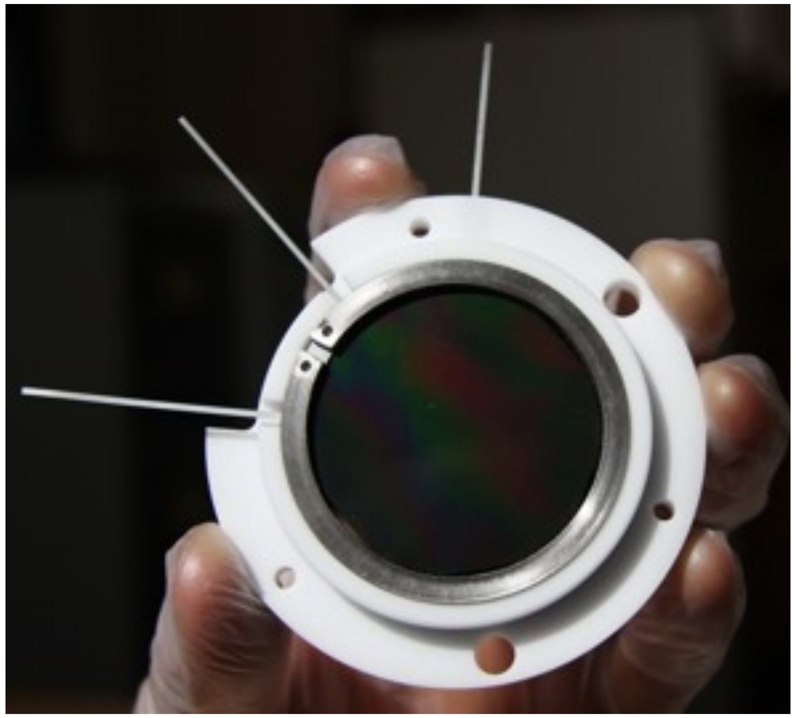
Parasites signals

Thomson Parabola with Microchannel Plate



The main proton/ion diagnostic in LOA: MCP/TP





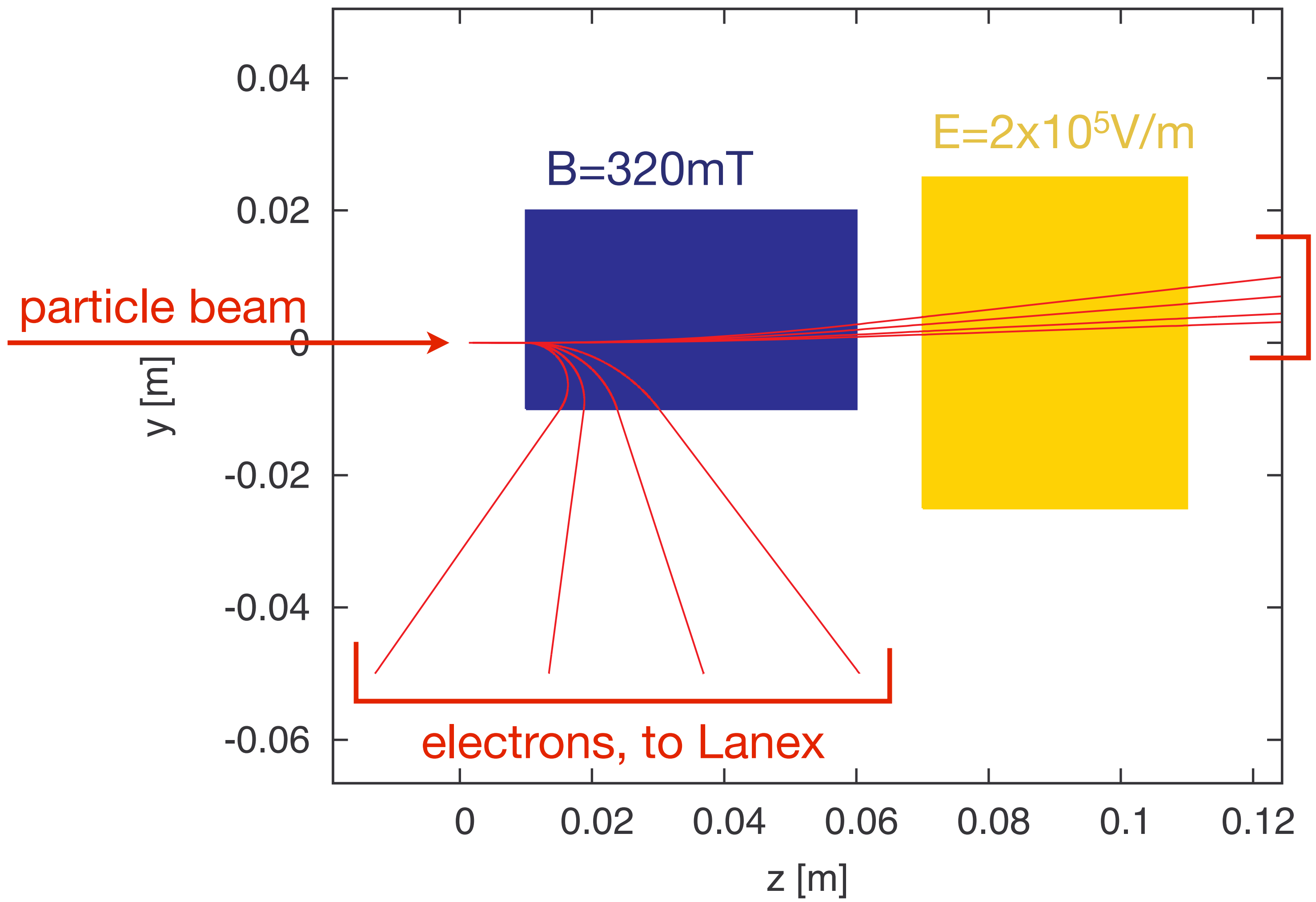
Thomson Parabola:

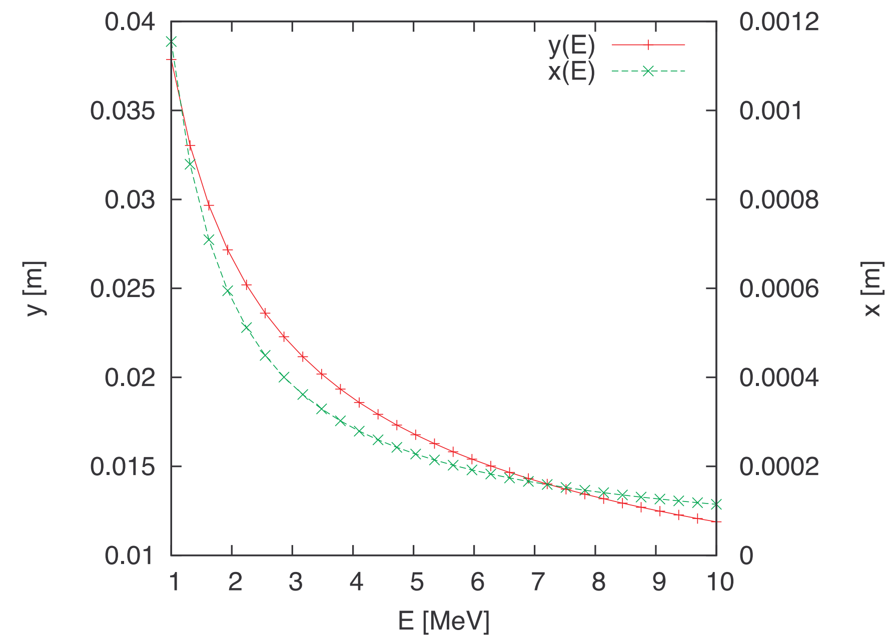
- standard configuration: permits separation of all ion species, gets rid of many “unwanted” particles
- spectral information, no spatial information
- very small aperture

MicroChannel Plate:

- very sensitive (secondary particles!), read in real time, fast
- cannot be used for imaging (sensible to almost everything)
- experimentally demanding (vacuum, HV, price)

1: Thomson Parabola Design





Developements:

- Ad-hoc numerical solutions for design, realization and exploitation of the parabola

Magnetic field:

- stackable magnets: lower field magnets are preferred (same mount from 80mT to 0.7T)
- B can increase along z
- field is mapped by 1mm^2 Hall probe to run simulations and analyze spectra

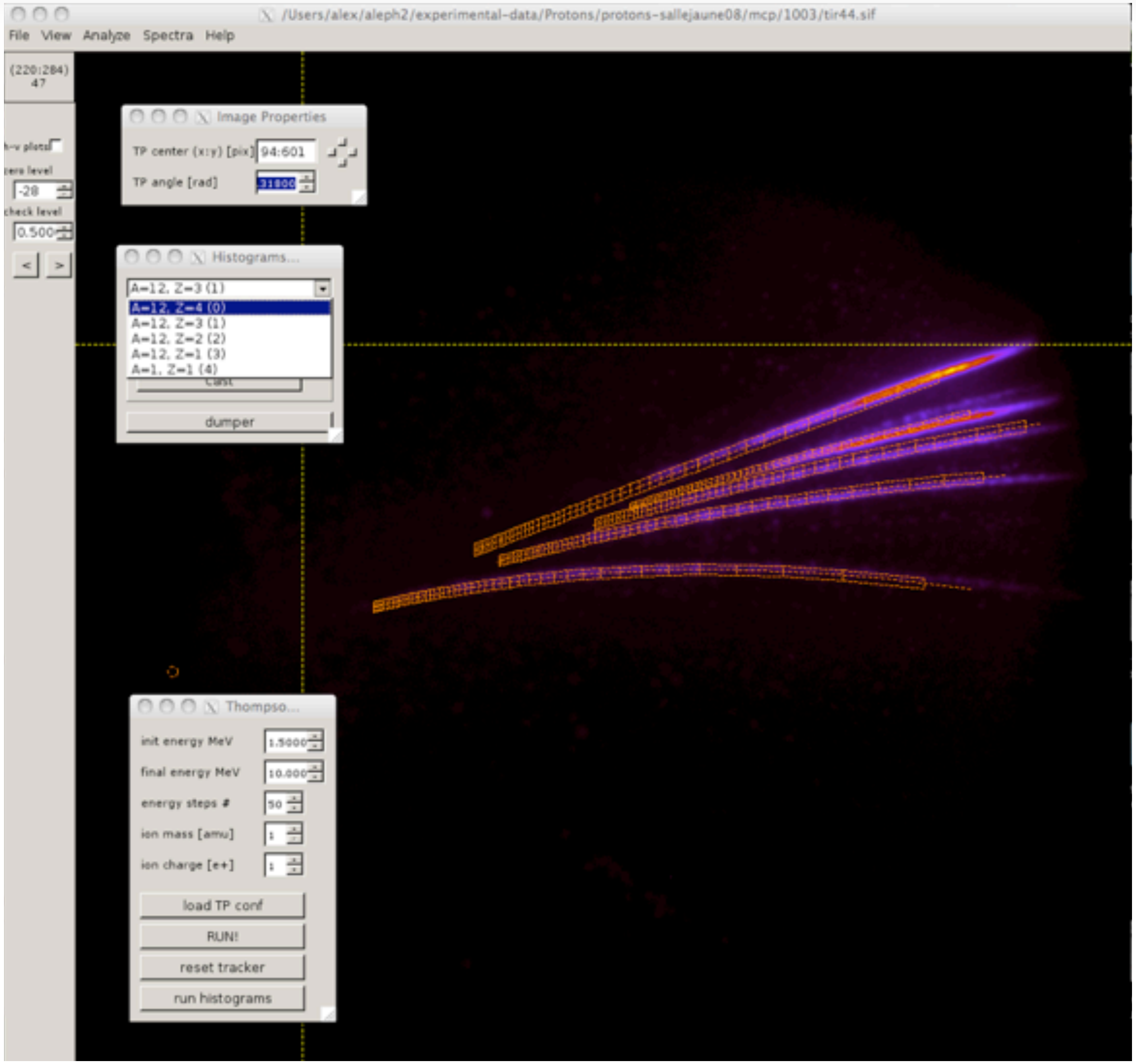
Electric field:

- better resolution with external, wide plates
- 2mm thick copper gave the best results
- precision: up to isothopes discrimination!!

2: TP track analysis: **ImagLab**

C++/Qt software solution for complete TP management:

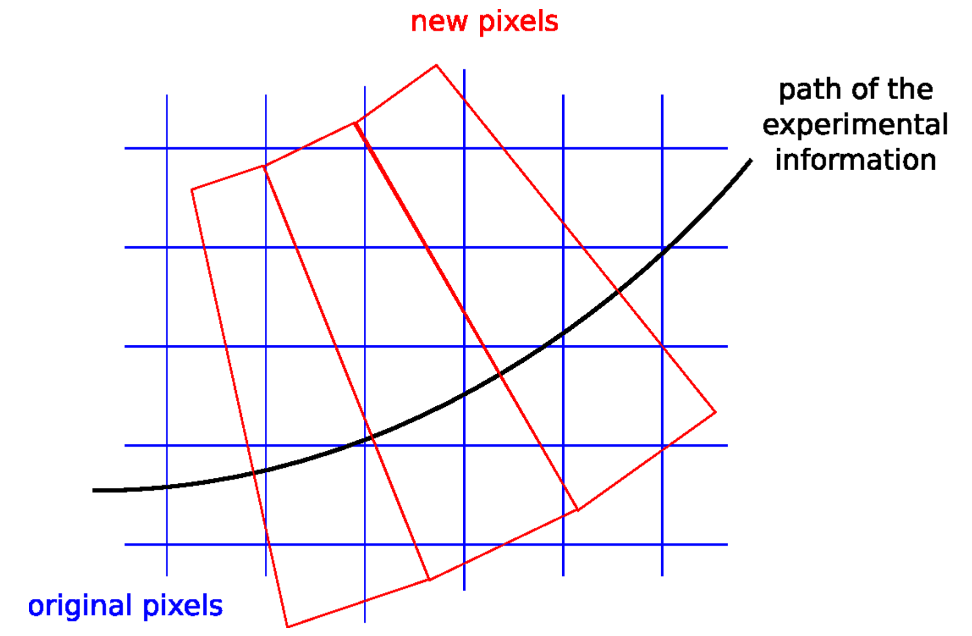
- direct control of acquisition CCD camera (Andor or PCO)
- online tracking (RK8) of test particles through the TP setup (with relativistic corrections for electrons)
- complex setups possible (multiple E, B fields, 3D numerical maps)
- batch analysis of multiple tracks at same time
- supports absolute calibration (MCP, camera)
- scriptable



ImagLab: workflow

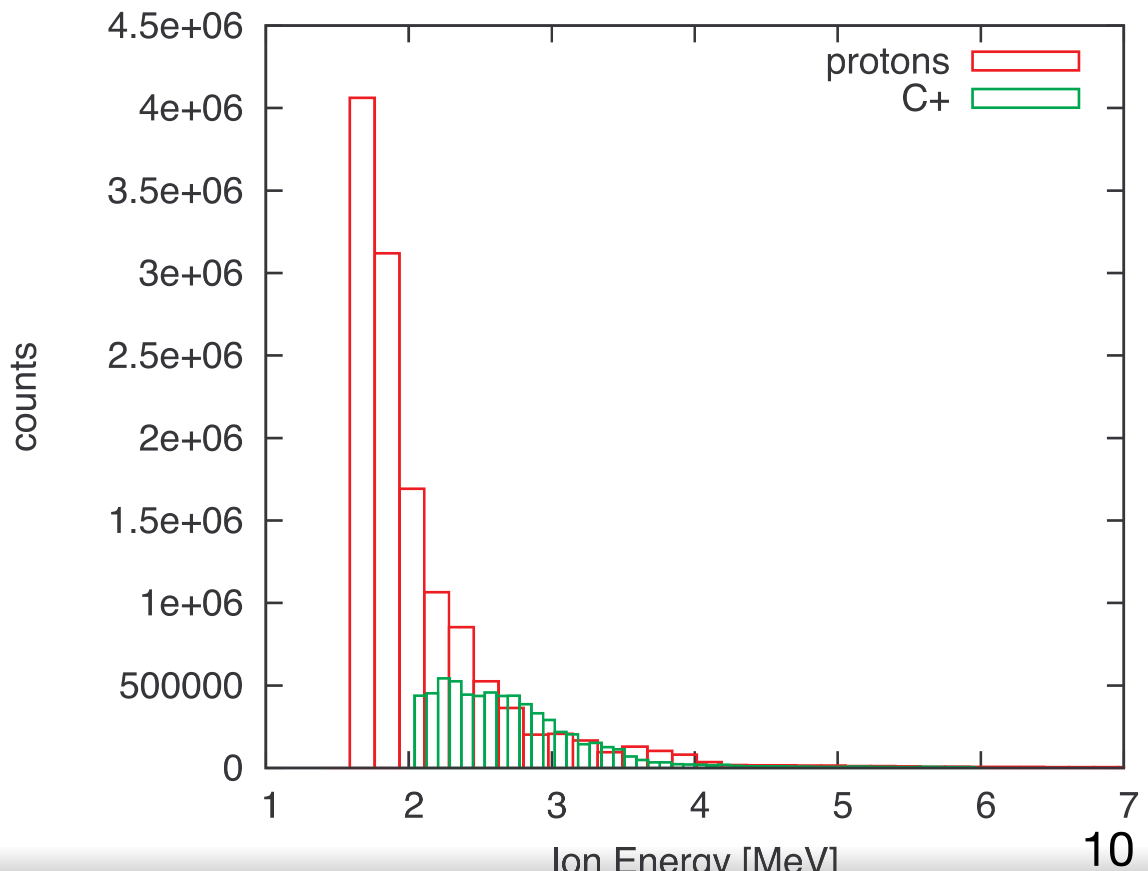
New TP configuration

Text file input deck → Calculate impacts for test particles (RK) → Calculate (MC) pixels to bins correspondence → Saves map

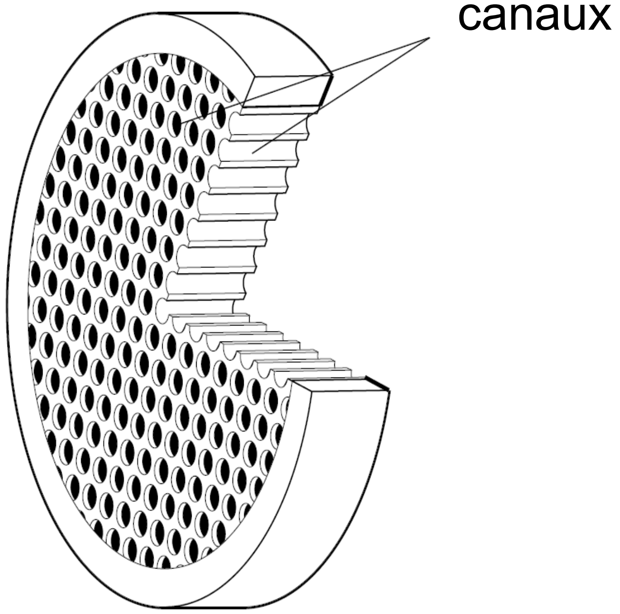


Online/Offline Data Analysis

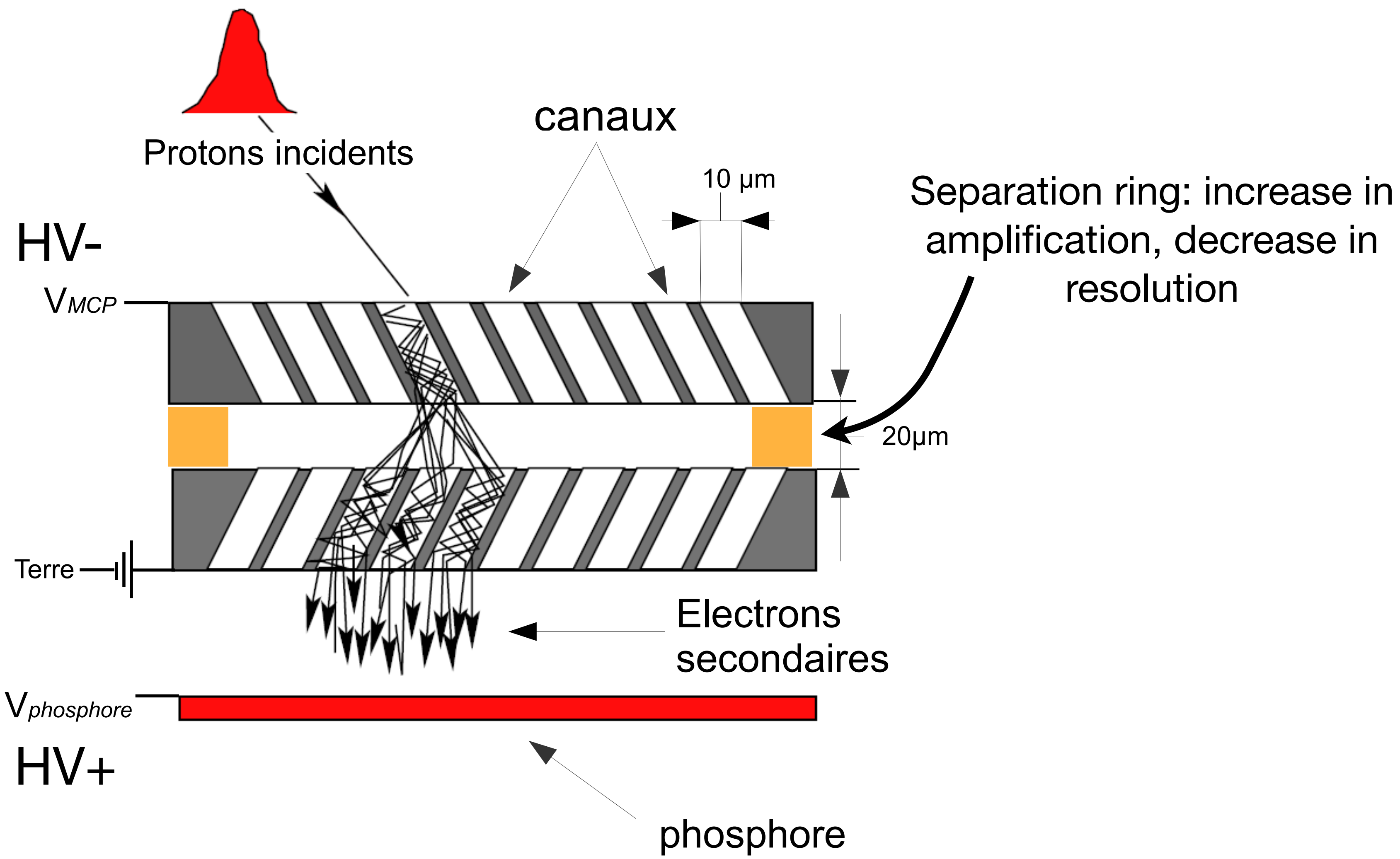
MAP (specific to TP, contains different particles) + Exp. image → Spectrum (+scripts)



3: MCP structure

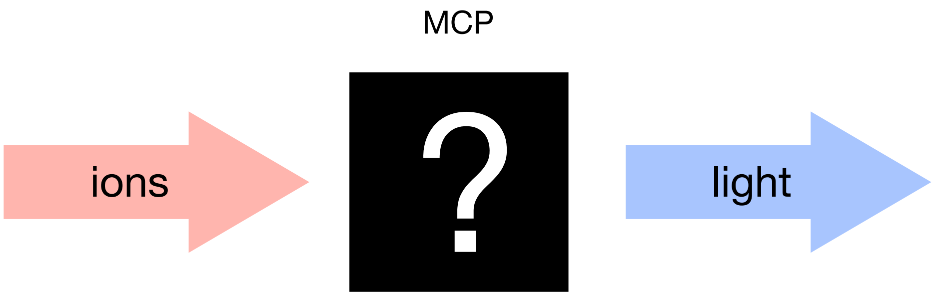


Shéma de la structure d'une MCP



Calibrate?

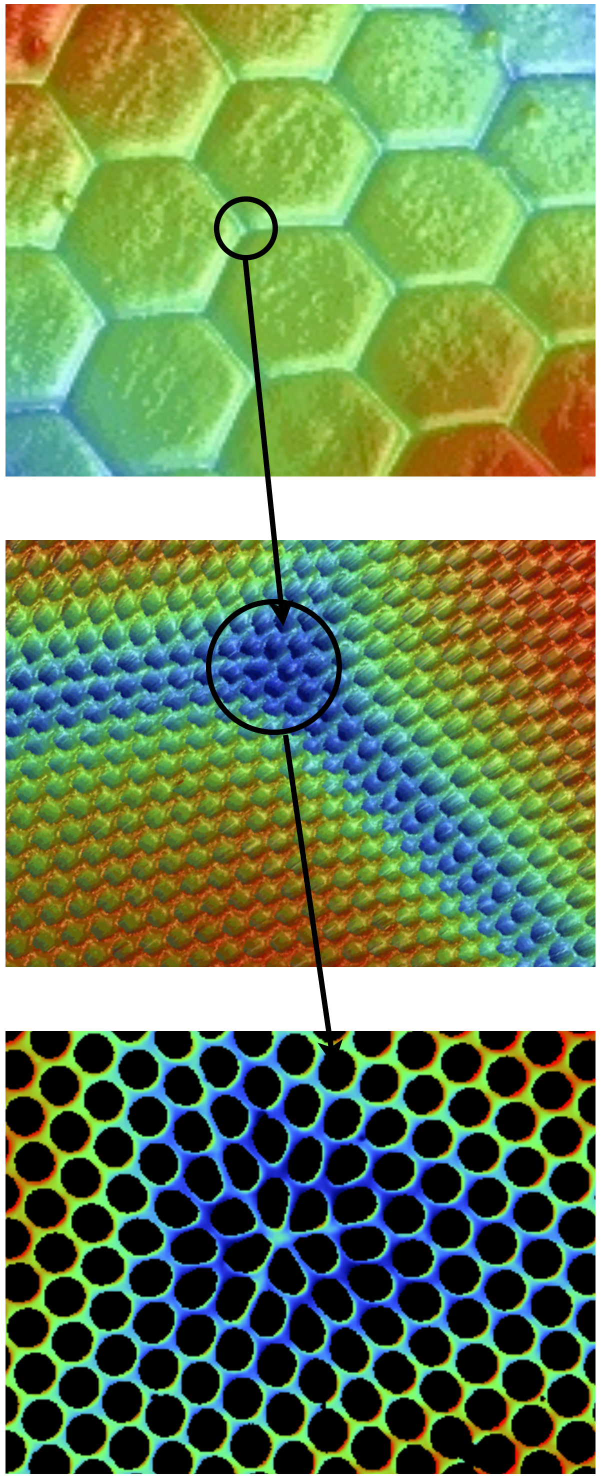
MCP Calibration



Calibration:

$$n_{ph} = \eta\left(m, q, K\right) \cdot n_p$$

MCP surface details (AFM)



Color scale: red to blue ~ 0.1μm

channel plate:

- MCP is a set of fused macro-fibers on hex geometry. Honeycomb periodicity: ~700μm (typ)
- Variable thickness and conversion efficiency can be observed along junctions
- Open Area Ratio (OAR, typ > 56%): *channel surface* over *bulk surface*, NOT constant (variable cross section). Proper to ***each*** plate.
- Cleanliness (water) can affect amplification: pumping time?

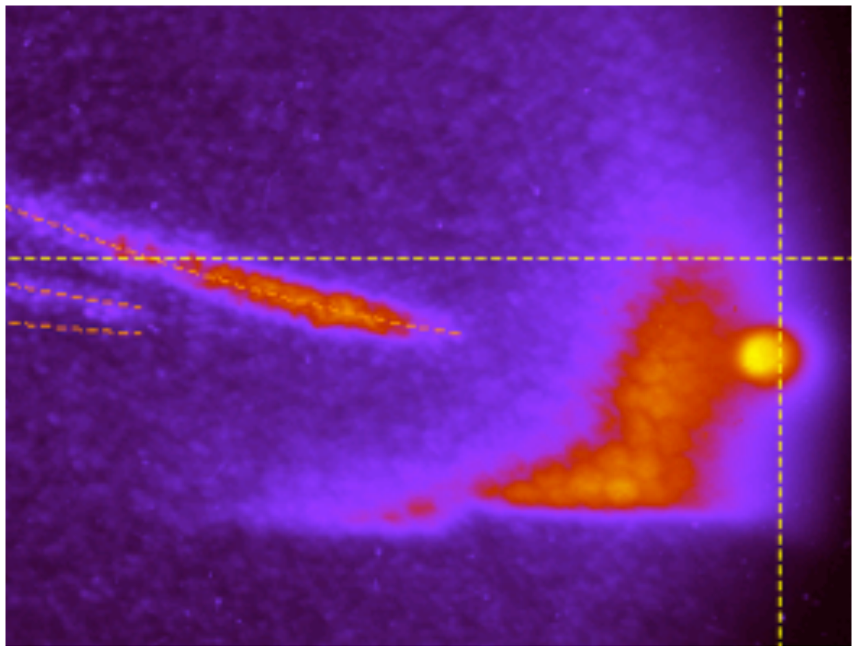
image formation on the phosphor:

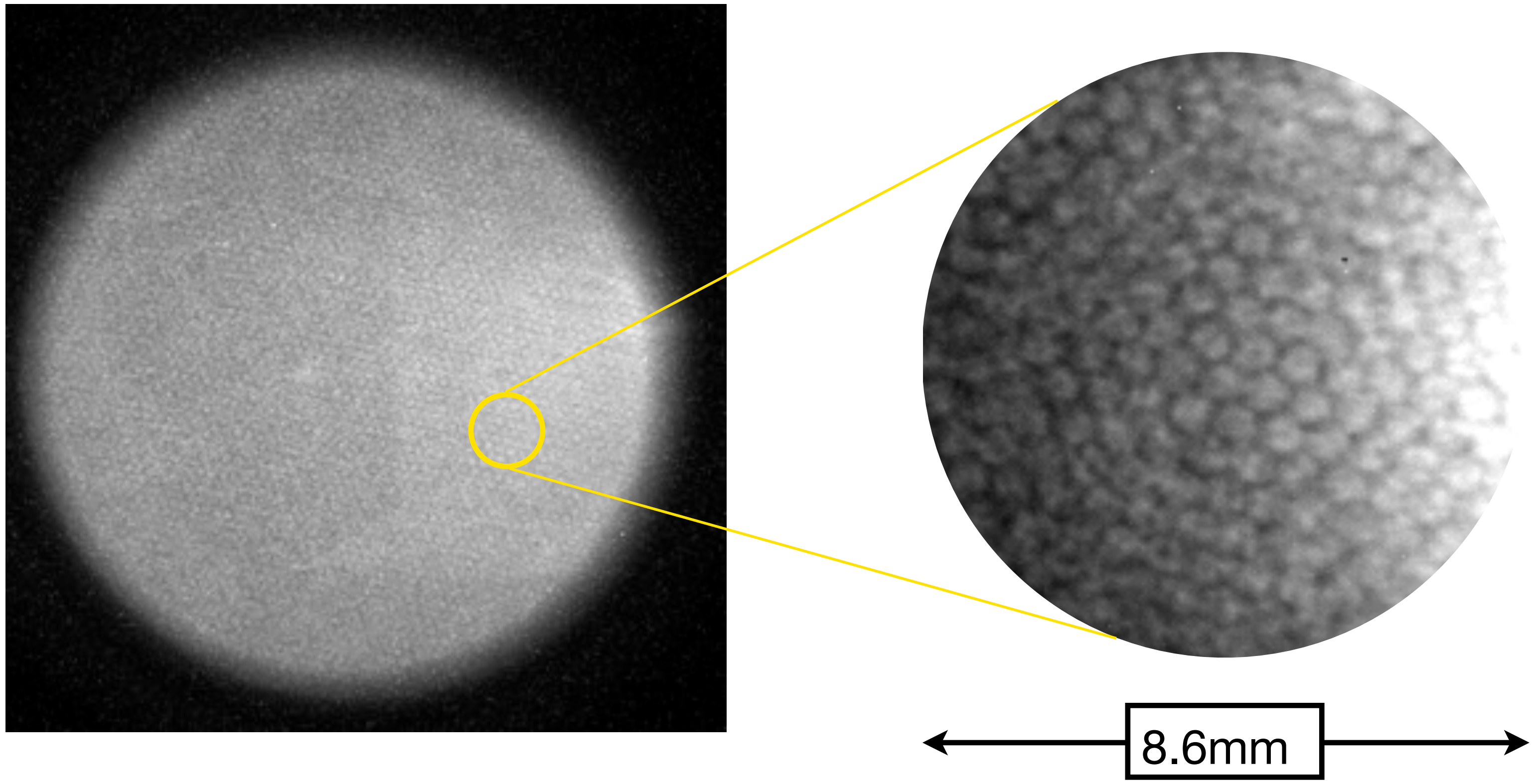
- presence/absence of the amplifier ring in Chevron stack
- phosphor voltage affects gain ***and*** spatial resolution
- image transport: phosphor can be strongly polychromatic. Presence/absence of back-reflector.

care should be taken when observing details on MCP images!

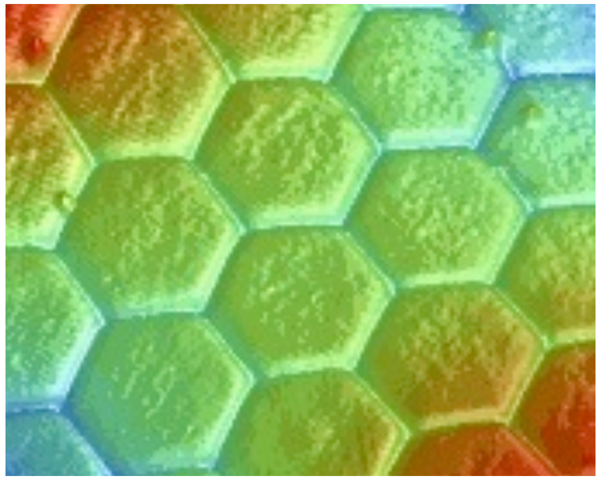
Source: SCINER/DelMar Ventures, San Diego, CA

MCP Honey Comb





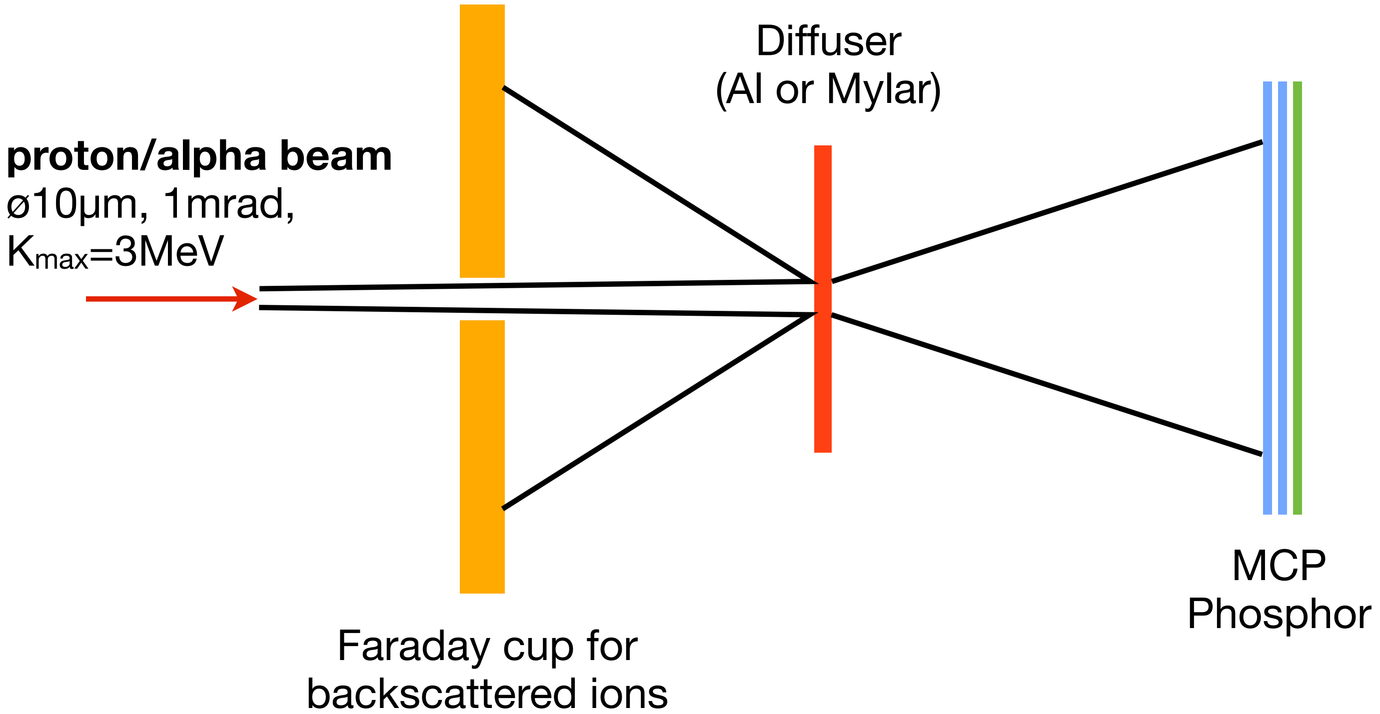
MCP surface detail (AFM)

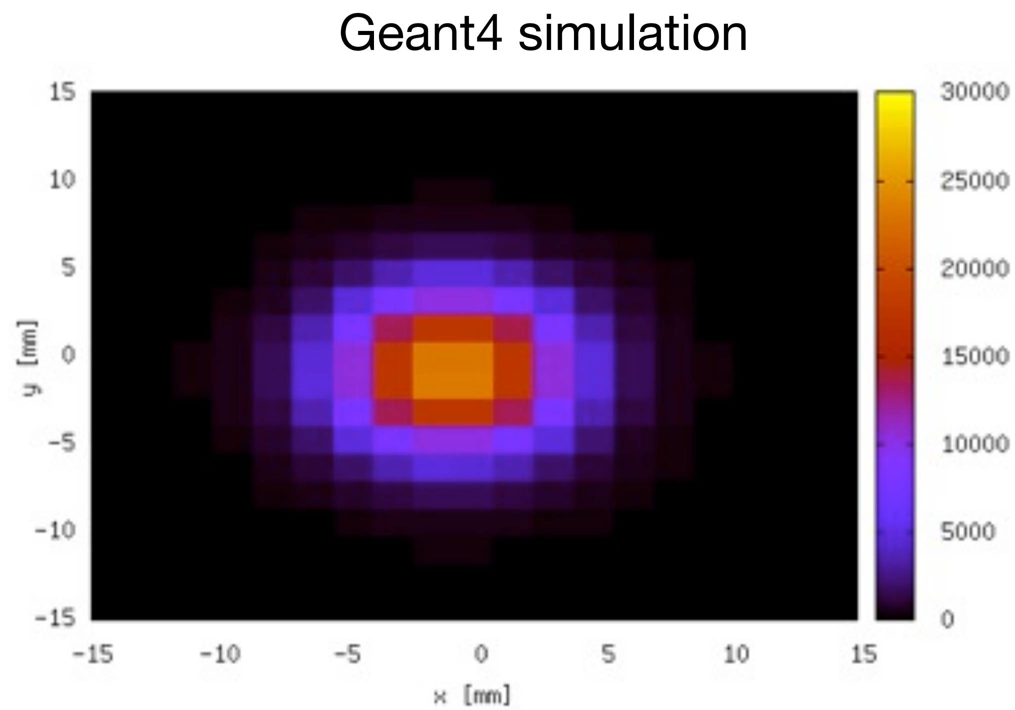


The honeycomb structure becomes evident in particular irradiation conditions. Nevertheless:

- the shown images were far from MCP saturation
- in the imaged conditions, the spatial scale is comparable to the observed TP track

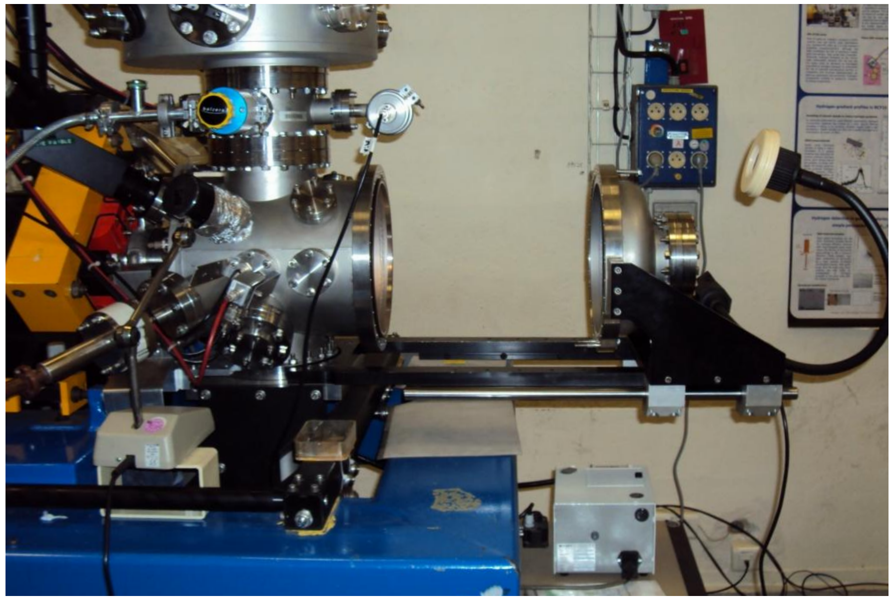
MCP Calibration





Correlate number of emitted photons against MeV of deposited dose for protons and alpha particles up to 3 MeV (Bragg peak still inside the detector)

- Continuous or bursted ion beam up to 10^{12} p/sec
- Measure of the backscattered number of particles
- Measure the behavior in (i) current, (ii) energy, (iii) position (OAR) for different MCP parameters
- Correlation between channel angle and incoming particle angle



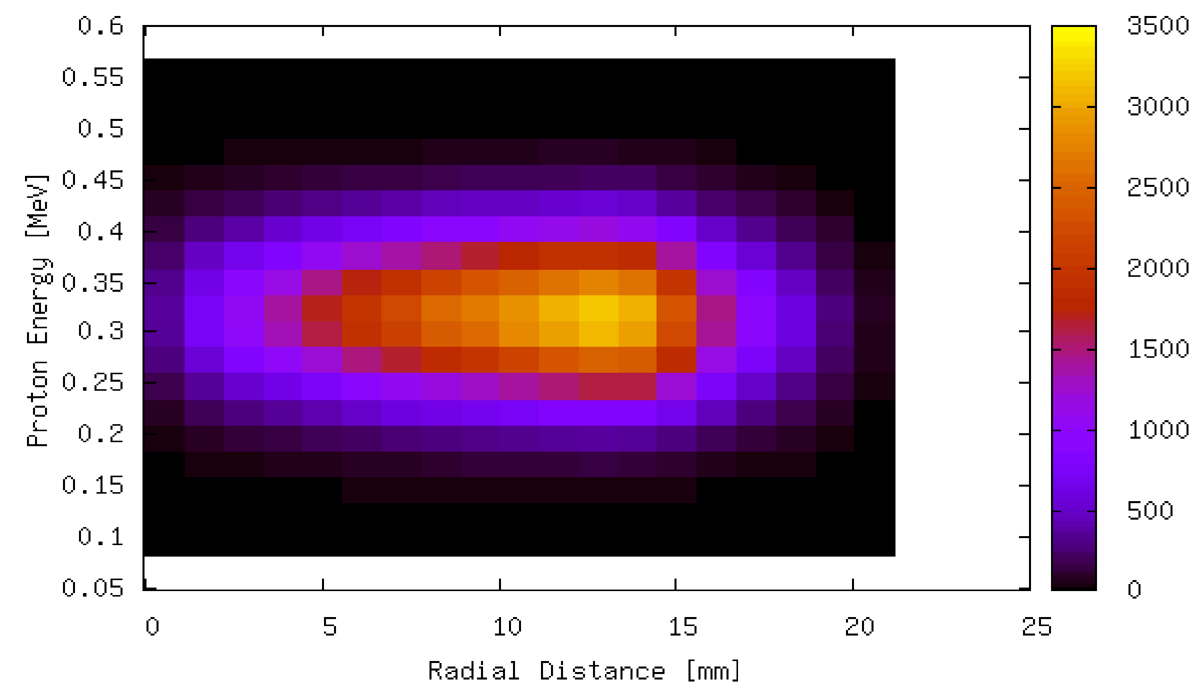
MCP Calibration II

Preparation of the experiment: Geant4 simulations

Needed parameters:

- particle surface density (σ_p)
- particle kinetic energy

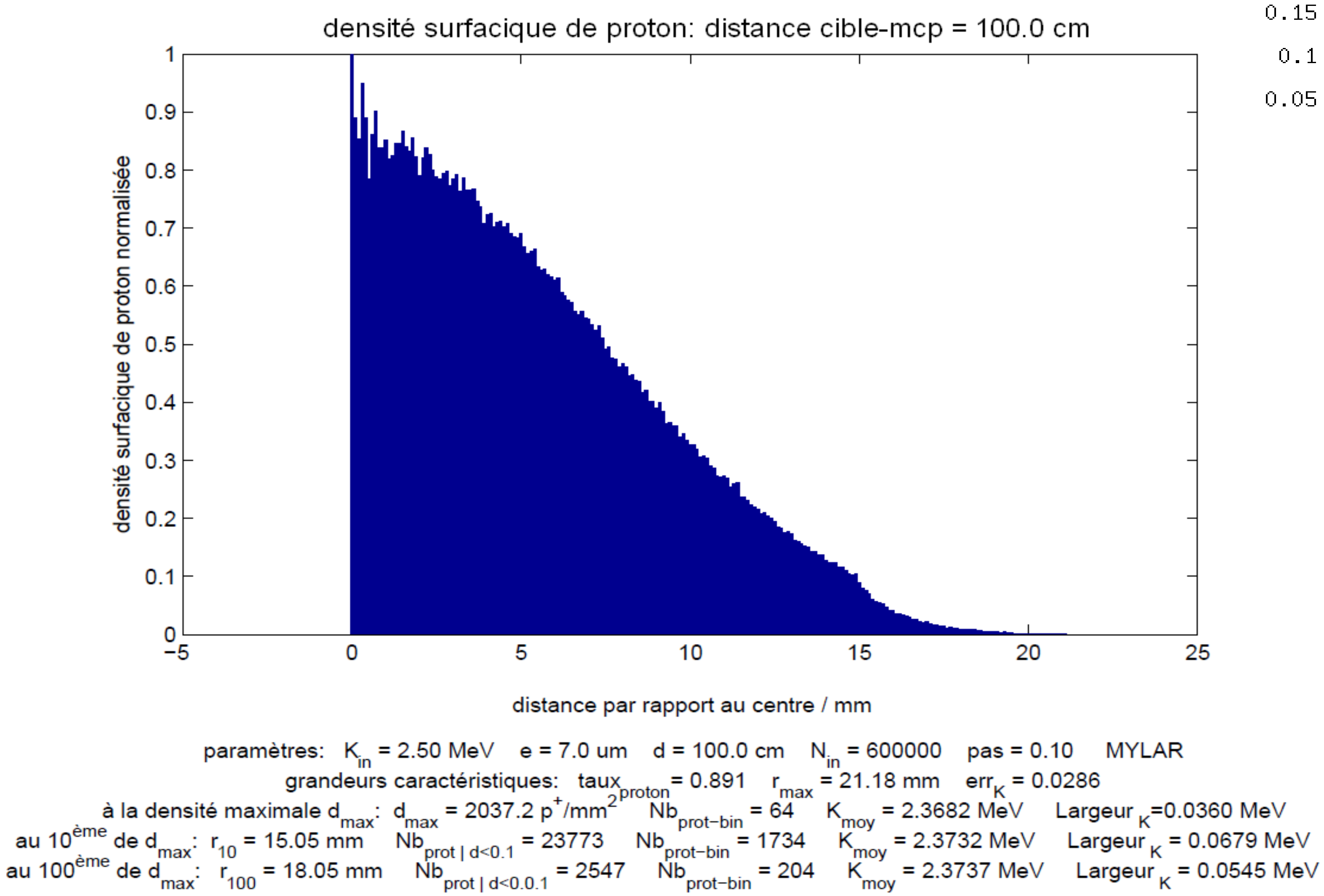
varying MCP distance, particle energy and diffuser thickness



Searched conditions on σ_p over MCP radius:

- almost constant
- two orders of magnitude

Spectrum increase is taken in account as error on the measurement.

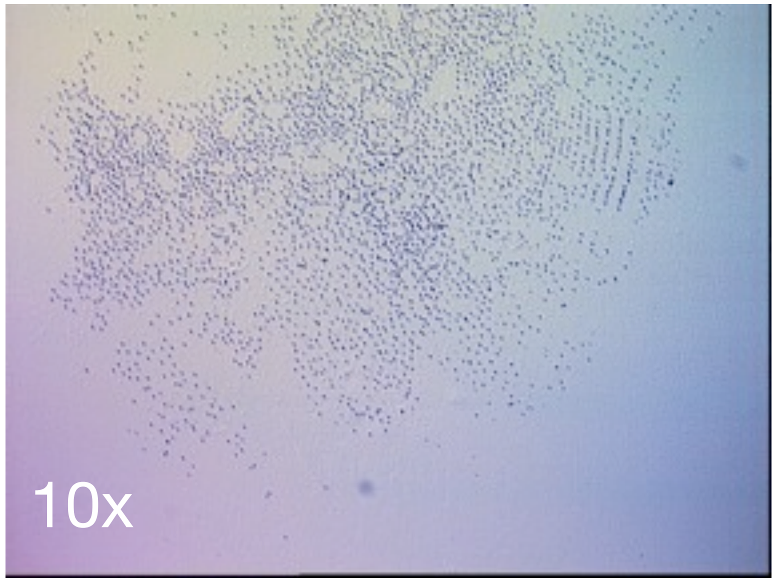


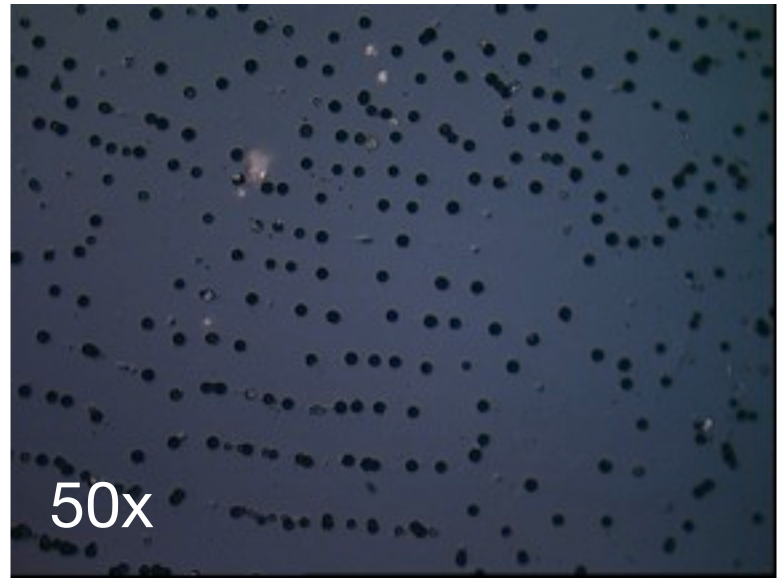
Conclusions

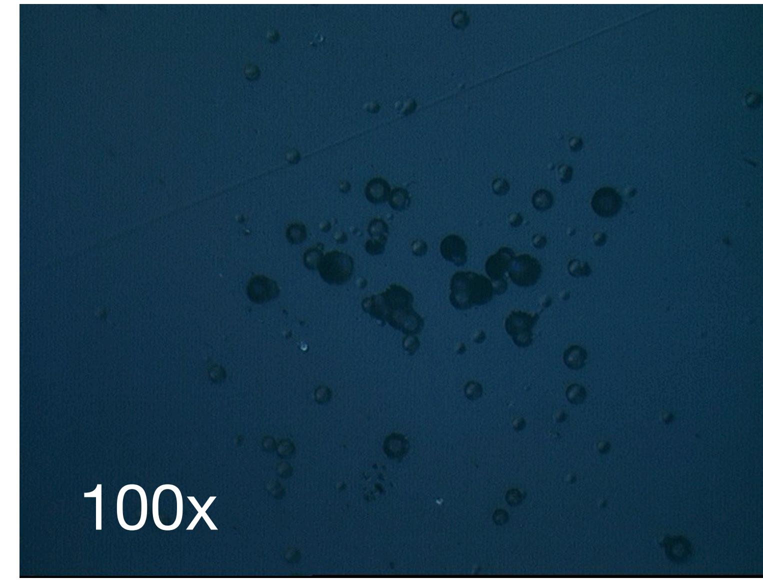
- Products from laser-plasma interaction are various, not a single detection solution.
- Real time spectral measurements: we found MCP/TP to work best (with caveats)
- Important activity on design, characterization, analysis
- Necessity: better understand the detector to be able to calibrate it


Thank you!

Laser effects on CR39







- The impact appear only AFTER etching (not ablation)
- Initial part of the pit evolution during etching: comparable to ion signal
- Threshold around 10^{11}W/cm^2 at 30fs (SJ: z=5cm!!)

- Appears more easily on the BACK surface of the CR39 foil (always mark sides!)
- May show purely optical effects (e.g. interference patterns)