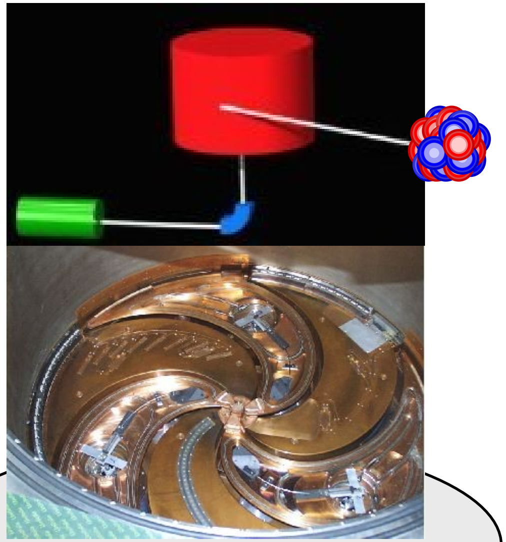
Low intensity beam diagnostics at INFN - LNS

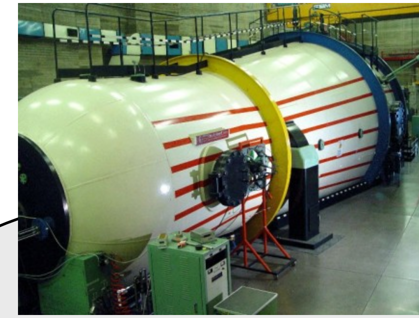
L. Cosentino
INFN - Laboratori Nazionali del Sud

EURISOL-NET (ENSAR/NA03) Working Group

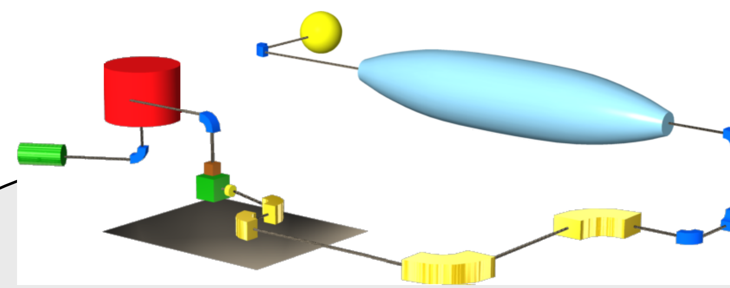
Accelerators at LNS



Superconducting Cyclotron
<80MeV/amu



Tandem 15MV



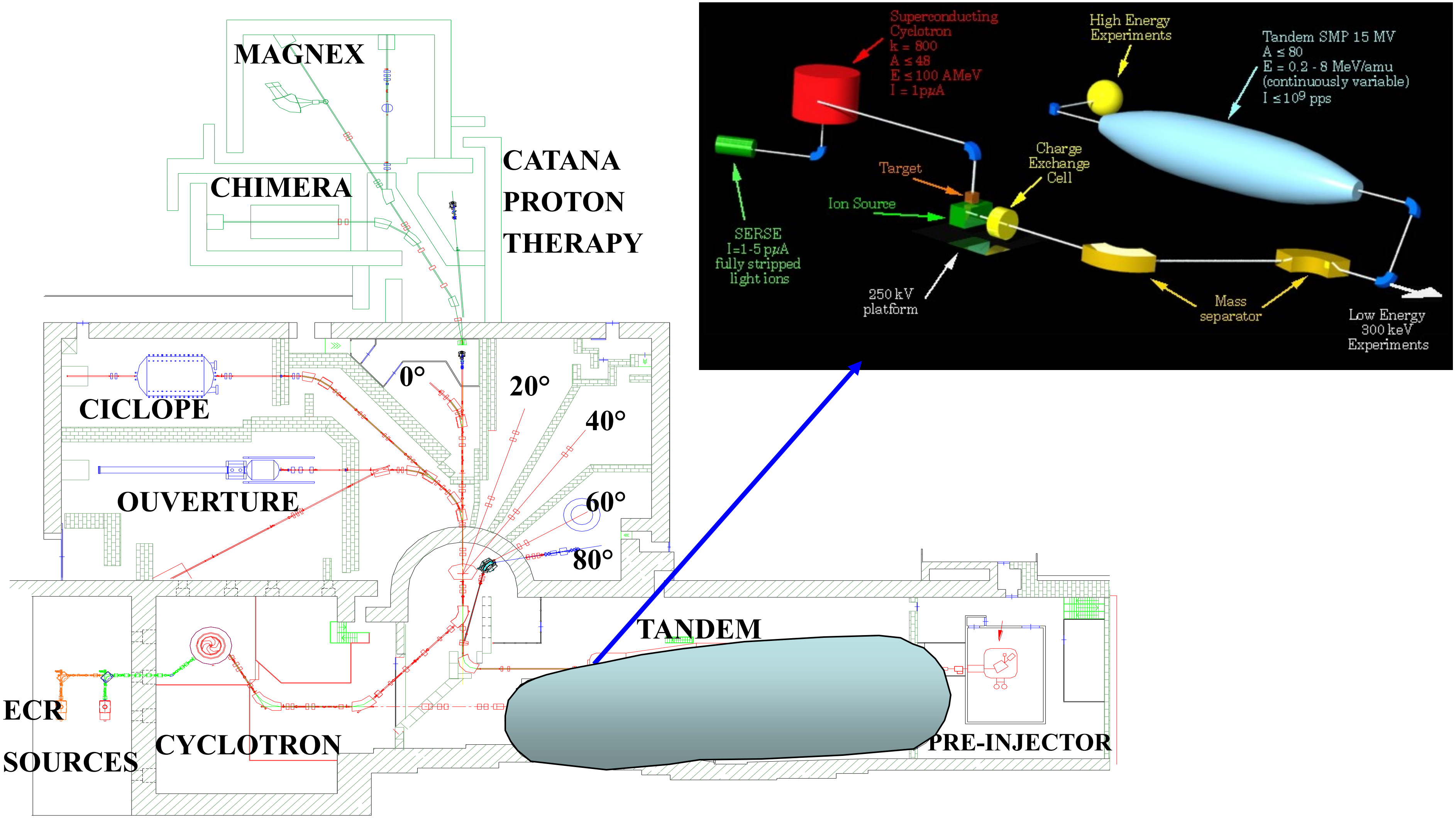
EXCYT facility: ISOL radioactive ion beams

Enegy ranges: 10keV ÷ 300keV
Tandem energy

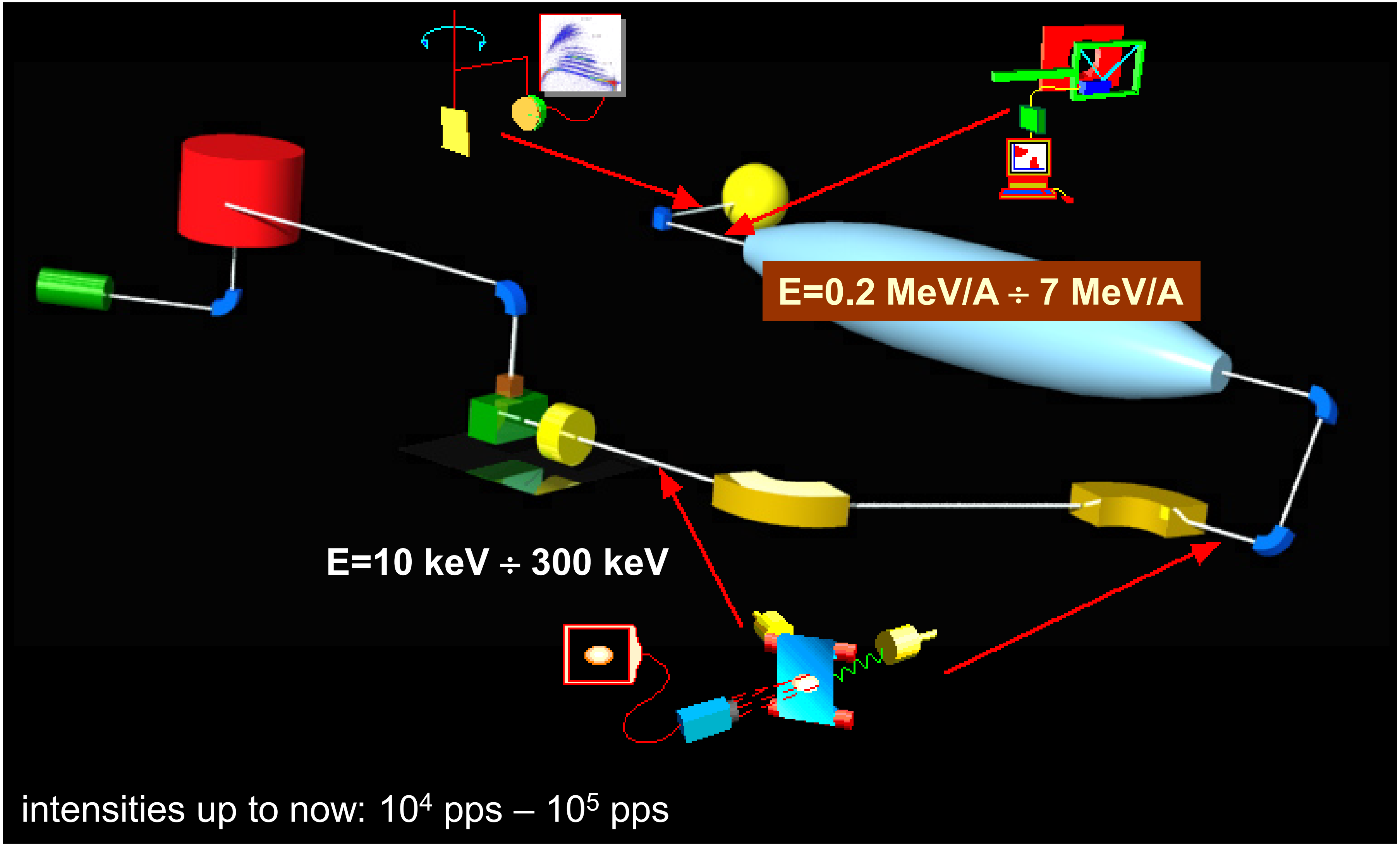
FRIBs: in-flight fragment separator

RIBs at the Cyclotron energy

LNS layout : the Excyt facility



EXCYT diagnostics



Very low energy/low intensity beams

The ordinary electromagnetic techniques approach their **intrinsic limitations**, mainly due to:

- electronic noise
- triboelectric noise
- signal contamination due to secondary electron emission

Low S/N ratio

Possible solutions

- increase the sensitivity
  - reduce noise by better design and shielding (can be complex and expensive)
- increase the signal
  - a possibile way to increase the signal is to use **particle detectors**: they are sensitive to the energy released by each particle of the beam

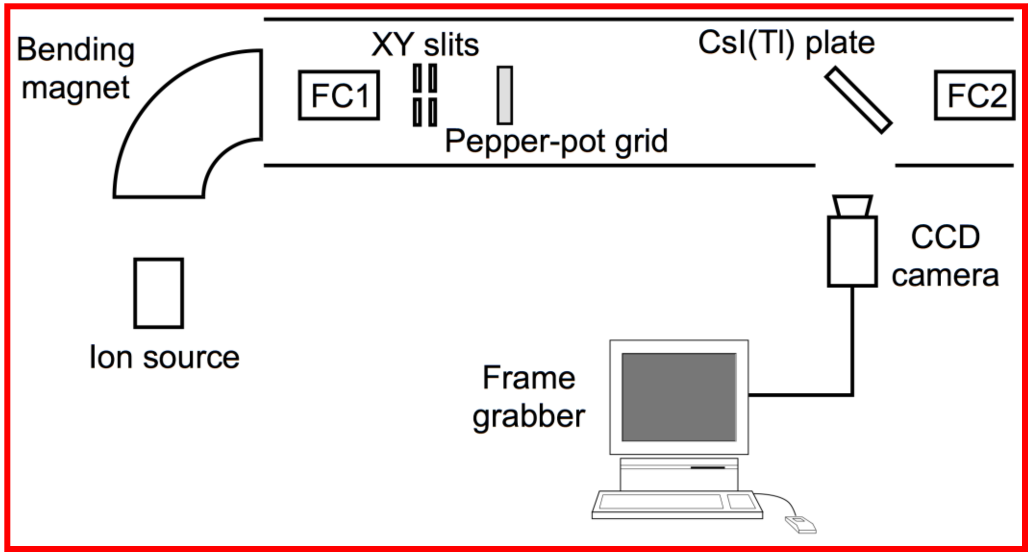
Available techniques

in use at LNS

- Gas detectors
- Diamond
- Others: Cherenkov, etc.

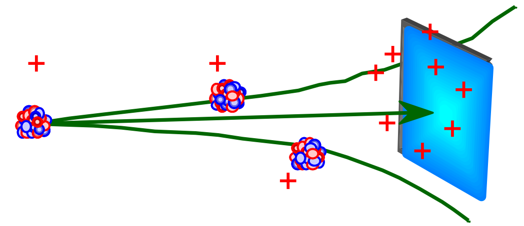
Low energy beam Imaging with CsI

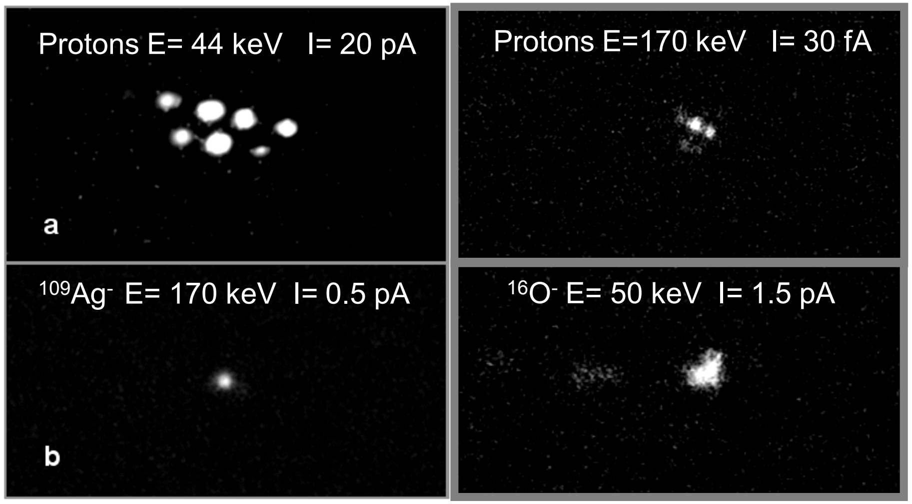
beam imaging: CsI(Tl) scintillating plate with CCD video camera

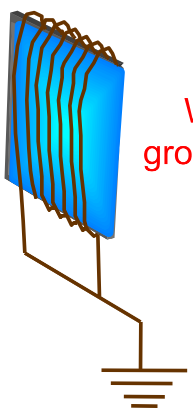


beam diagnostics of very low-energy and low-intensity ion beams from the Tandem injector at LNS

CsI(Tl) is an insulator and gets charged-up





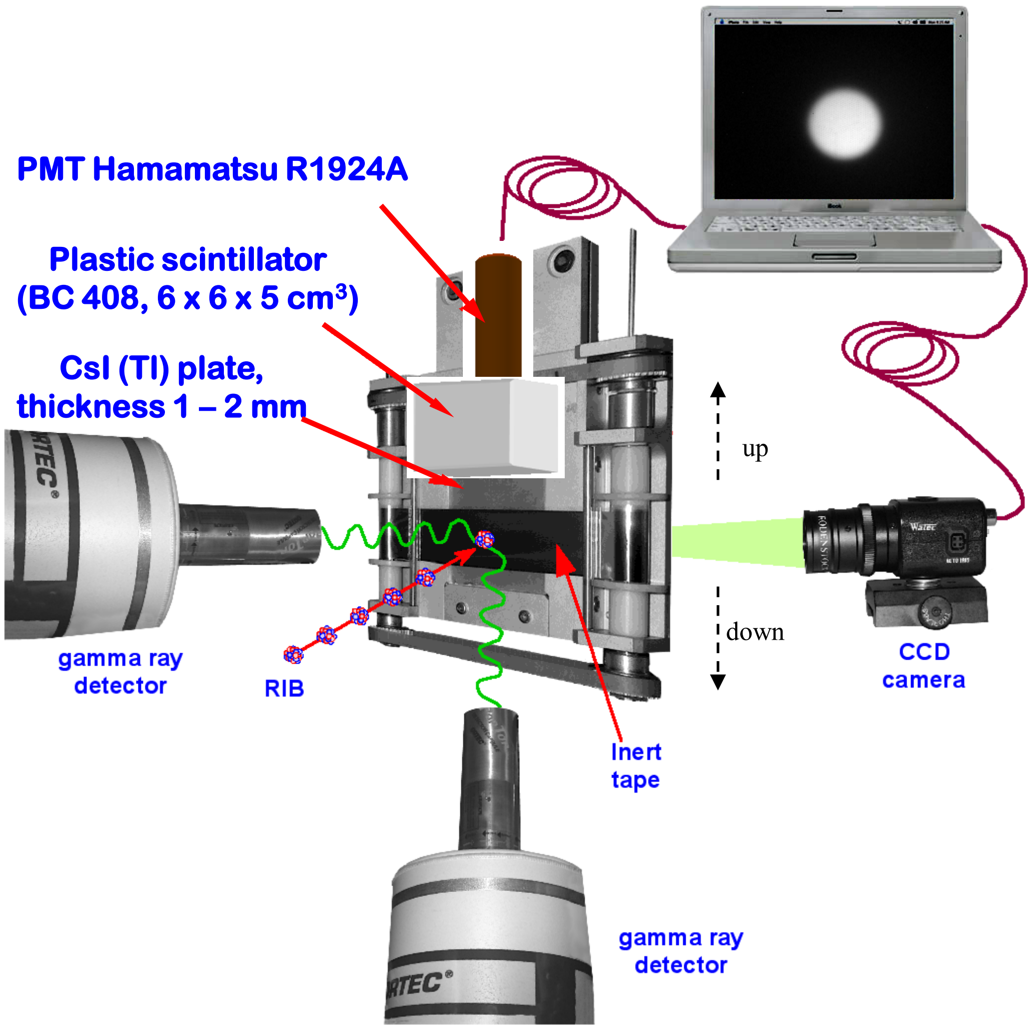


We wound it with a grounded conductor wire

NIM B 211 (2003) 443

Diagnostics for Low Energy RIBs

LEBI:
Low Energy Beam Imager / Identifier



three different heights

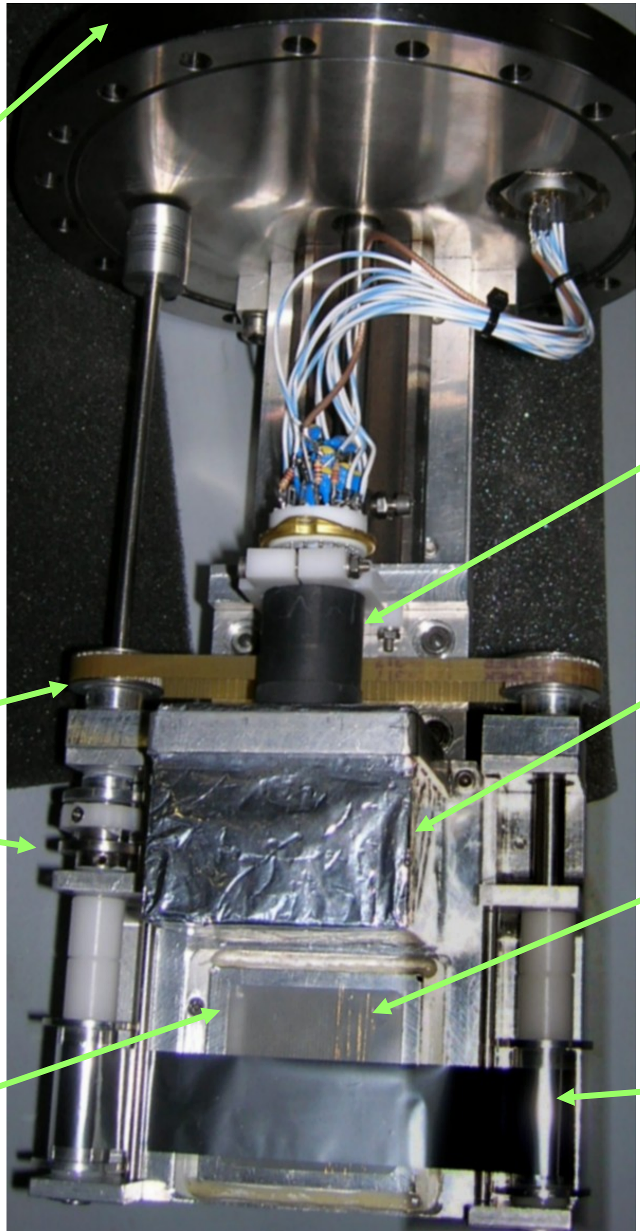
- Imaging of Stable (pilot) beams
- Imaging of radioactive beams
- Beam rate measurement
- Decay curve reconstruction

LEBI is our solution for diagnostics of low energy radioactive beams.

NIM A 479 (2002) 243

NIM A 622 (2010) 512

Diagnostics for Low Energy RIBs



step motor

Photomultiplier

Plastic scintillator
BC 408

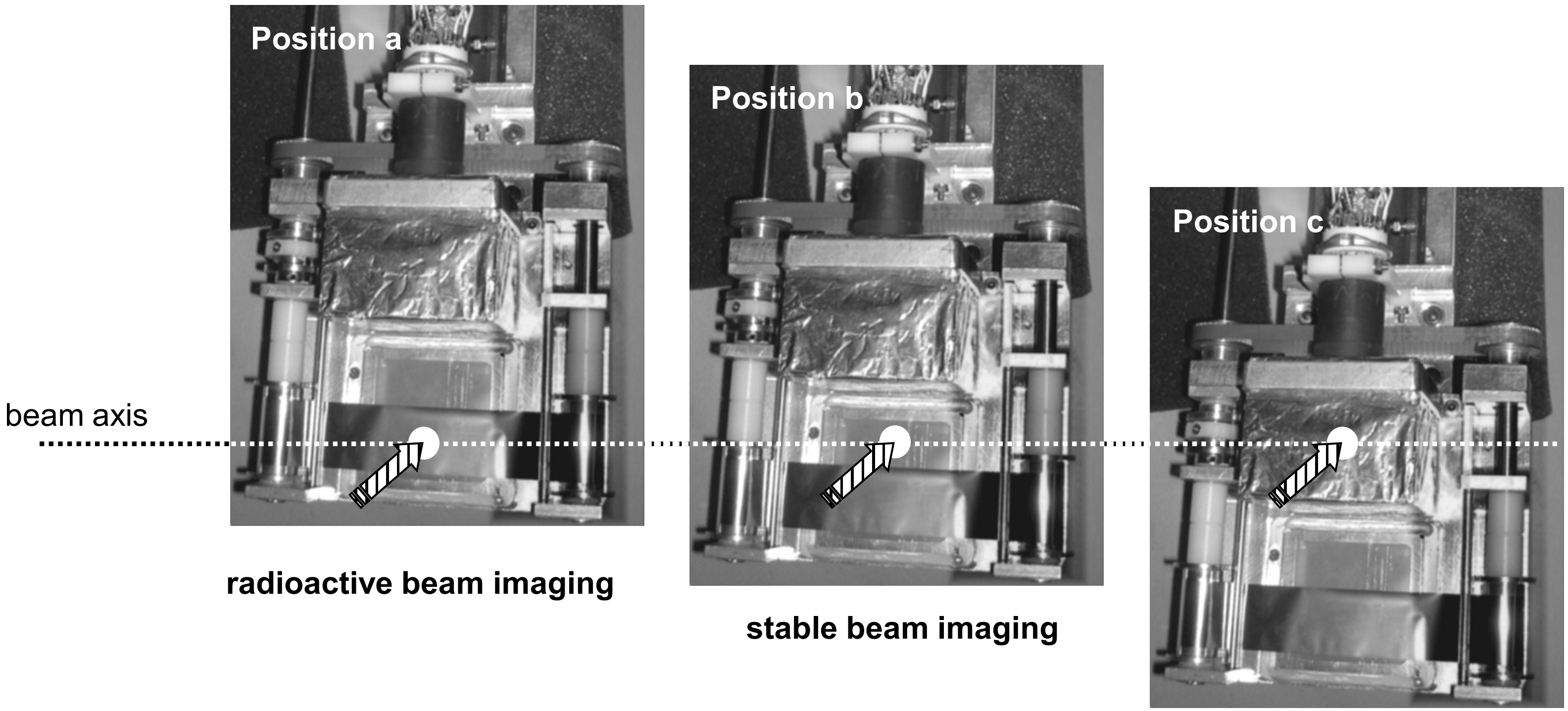
tape transport system

CsI (Tl) plate

mylar tape 6 μm

metallic grid
tungsten wires

Three working positions



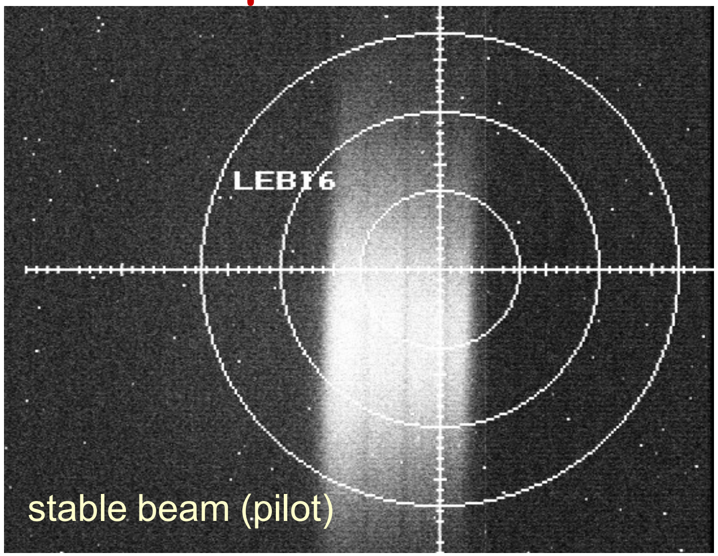
radioactive beam imaging

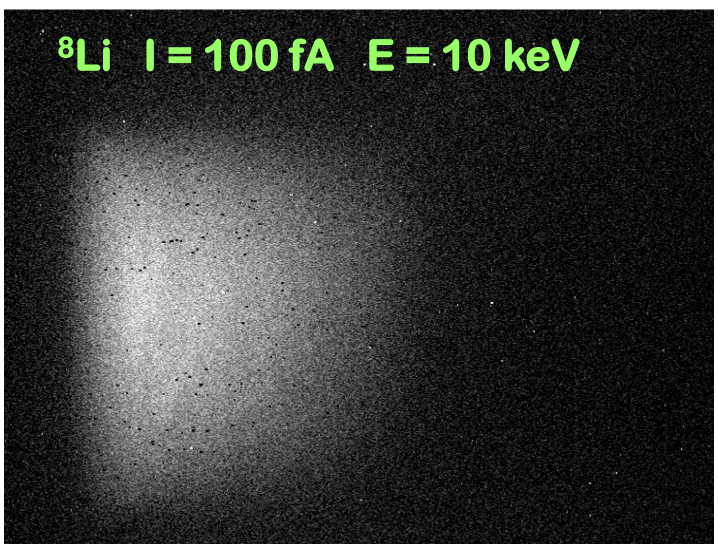
stable beam imaging

beam counting/identification

LEBI
Low Energy Beam Imager/Identifier

^{7}Li I = 10 pA E = 10 keV



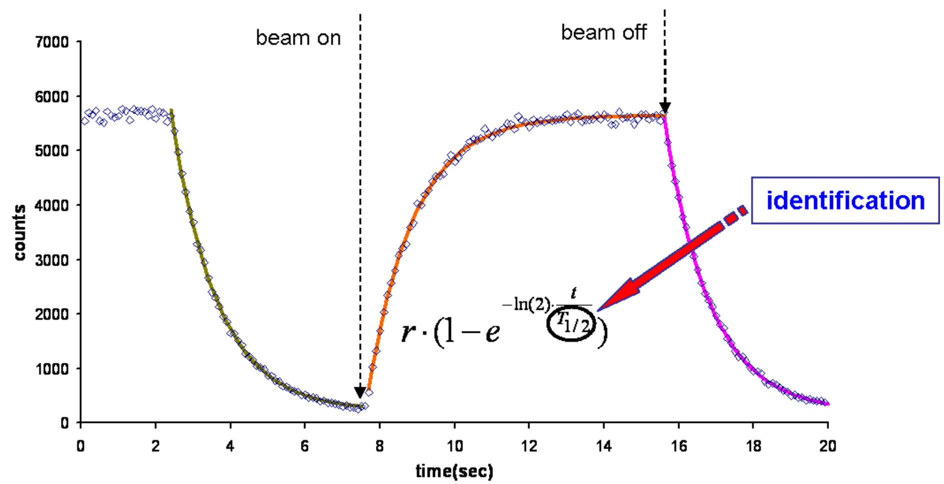


energy range
10 keV ÷ 300 keV

Sensitivity for beam imaging

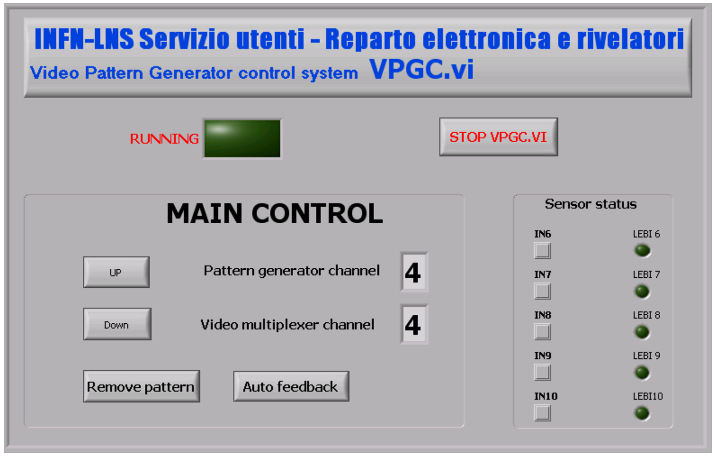
- $E_{threshold}$ = 5 keV
- $I_{stable\ beam}$ ~ 10^4 pps/mm^2
- $I_{radioactive\ beam}$ ~ 10^3 pps/mm^2
- resolution < 1mm

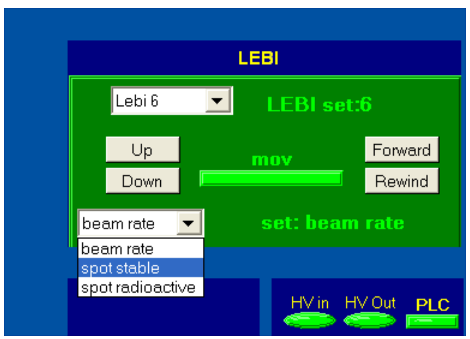
decay curve of β particles

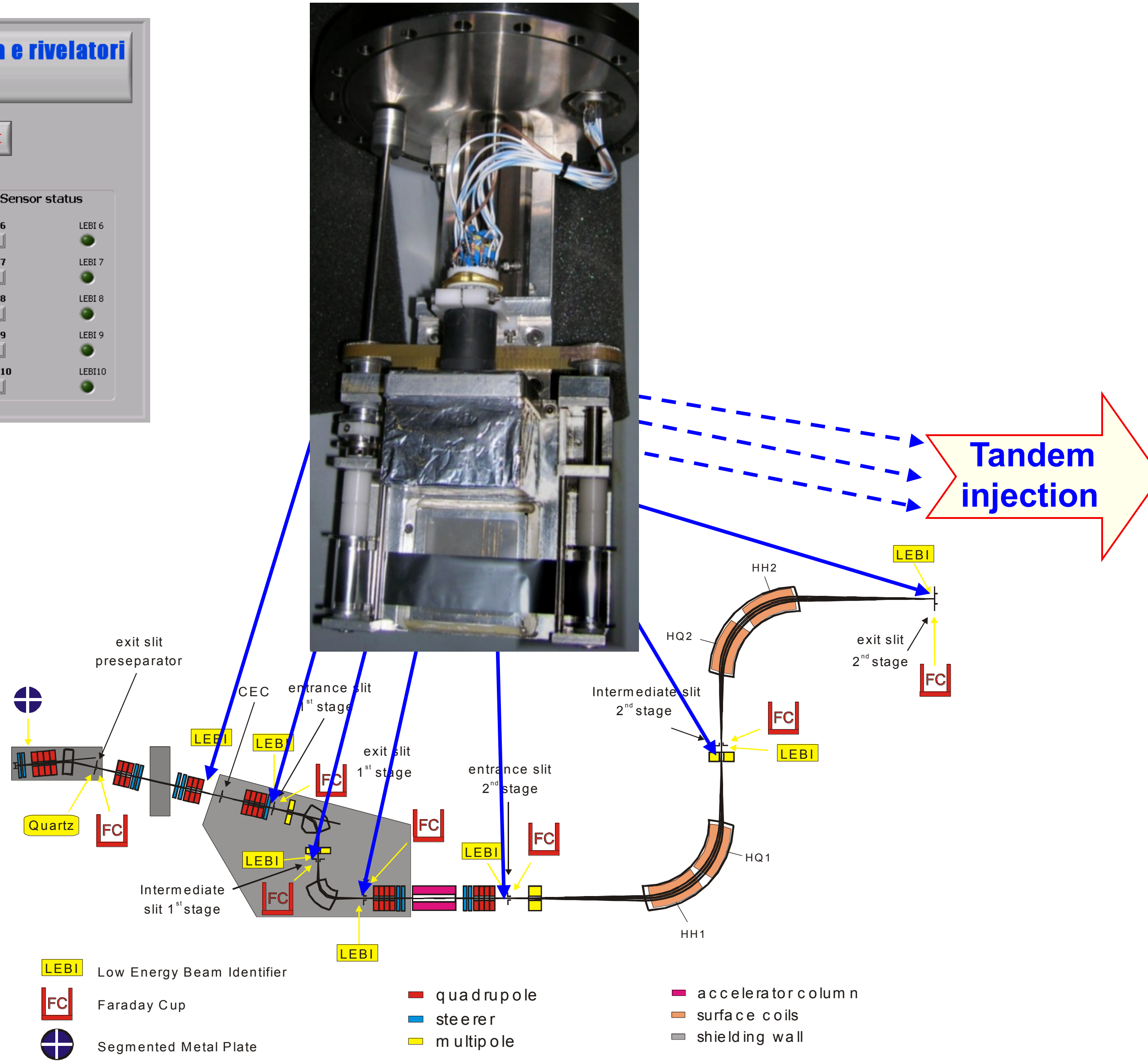


radioactive beam

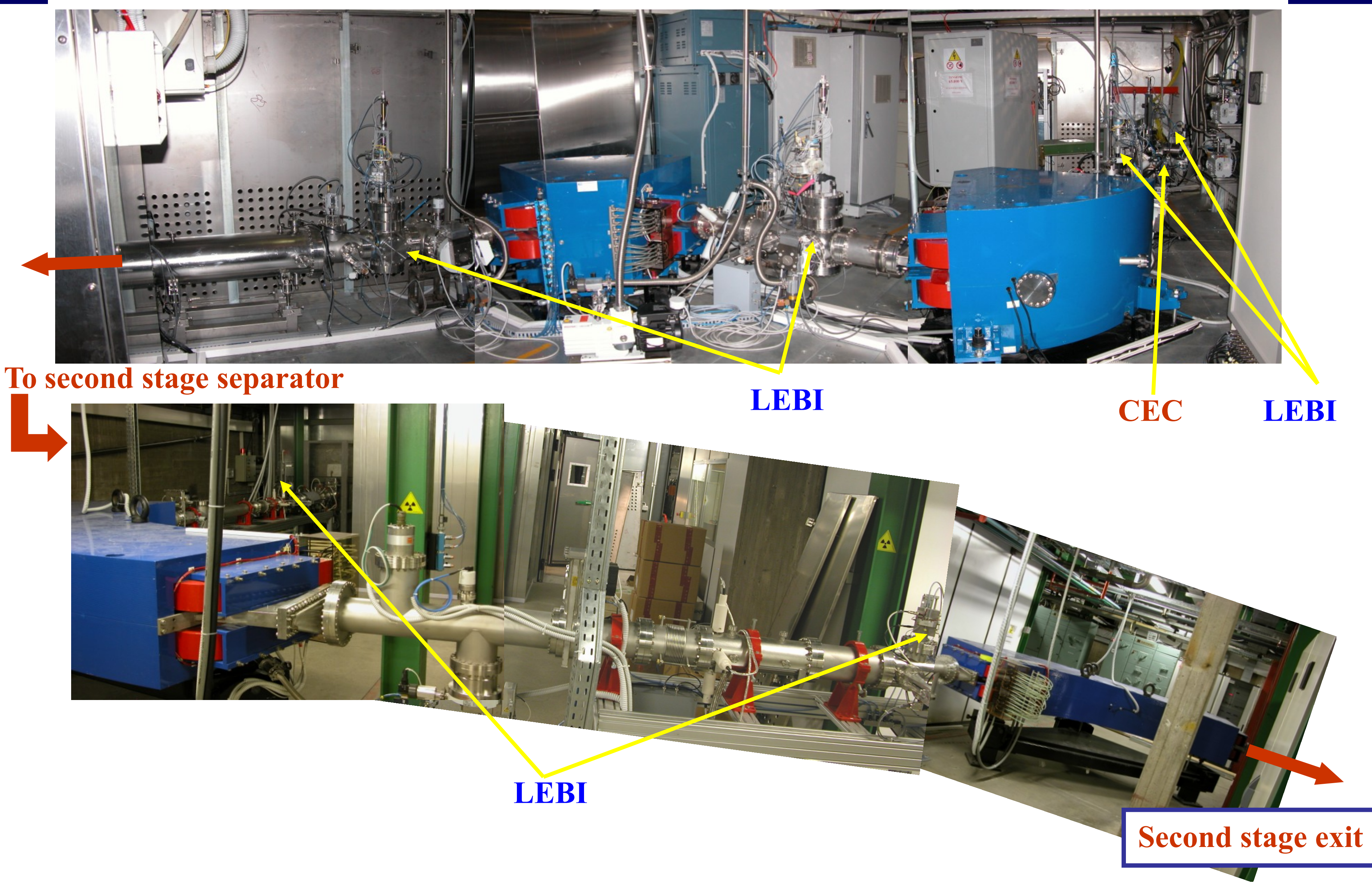
10 LEBI working along the EXCYT beam line



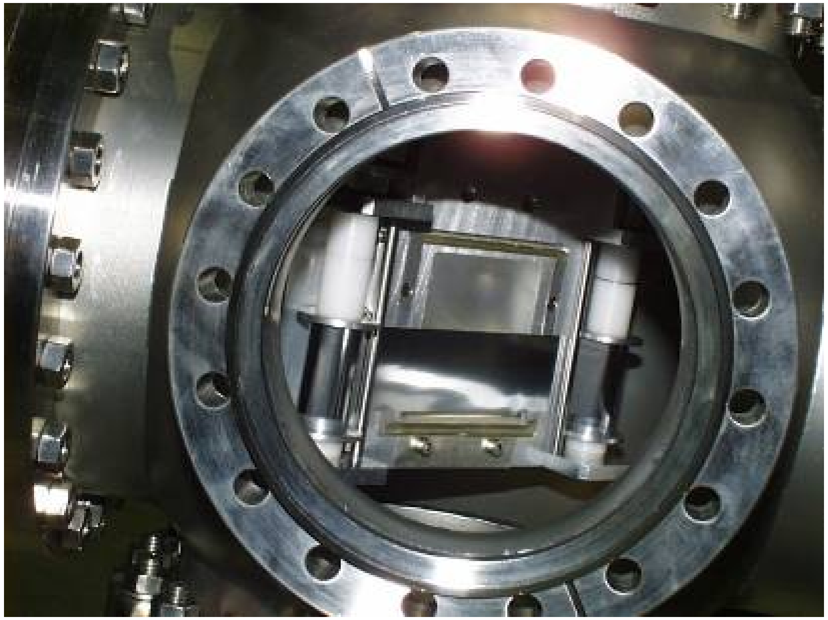




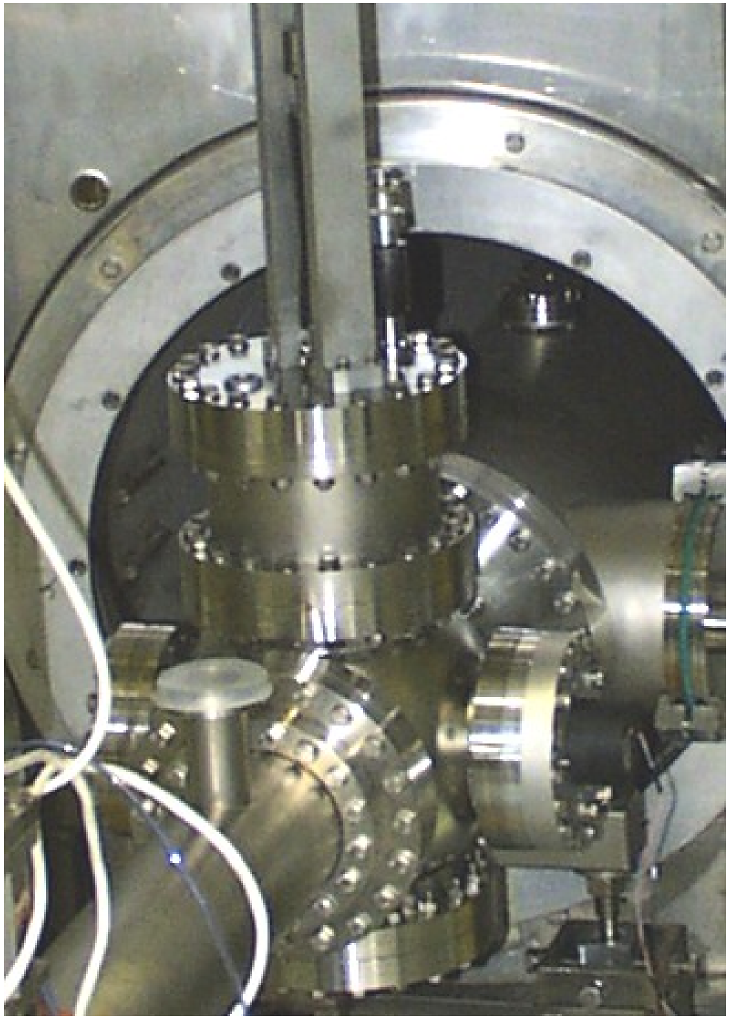
First and Second stage of the isobaric mass separator



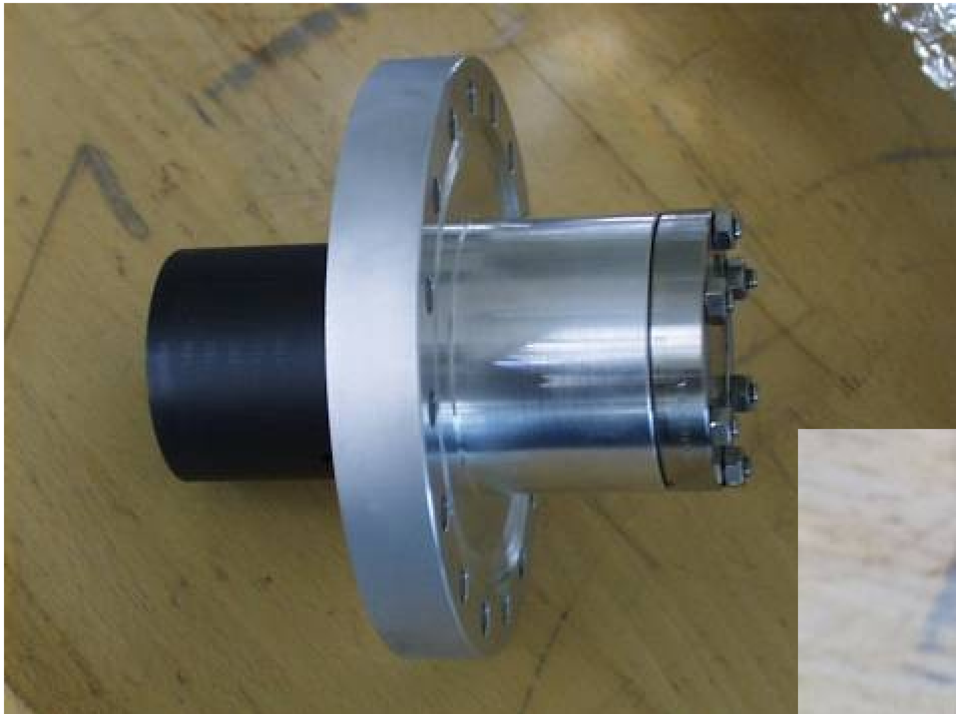
Elements of LEBI

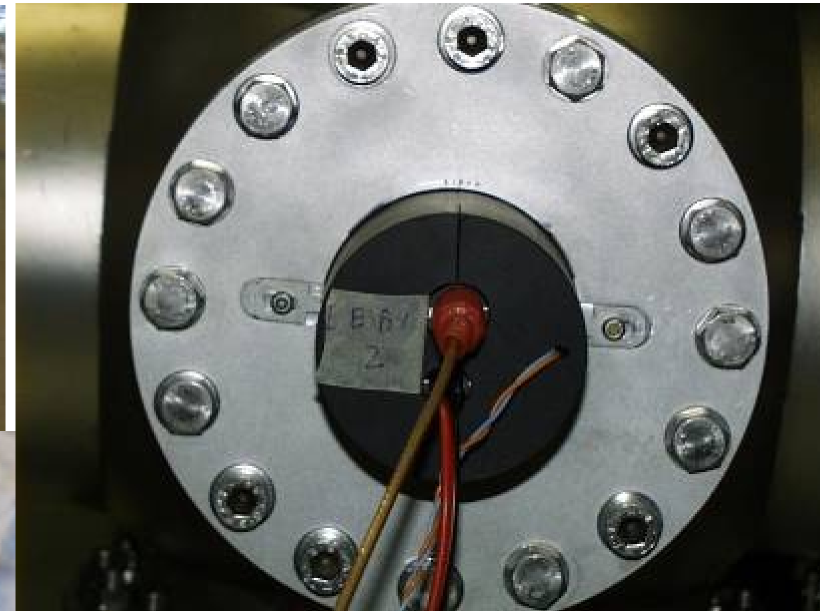


The scintillator screen is placed at 45° respect to the beam axis.



CCD camera





compact video camera

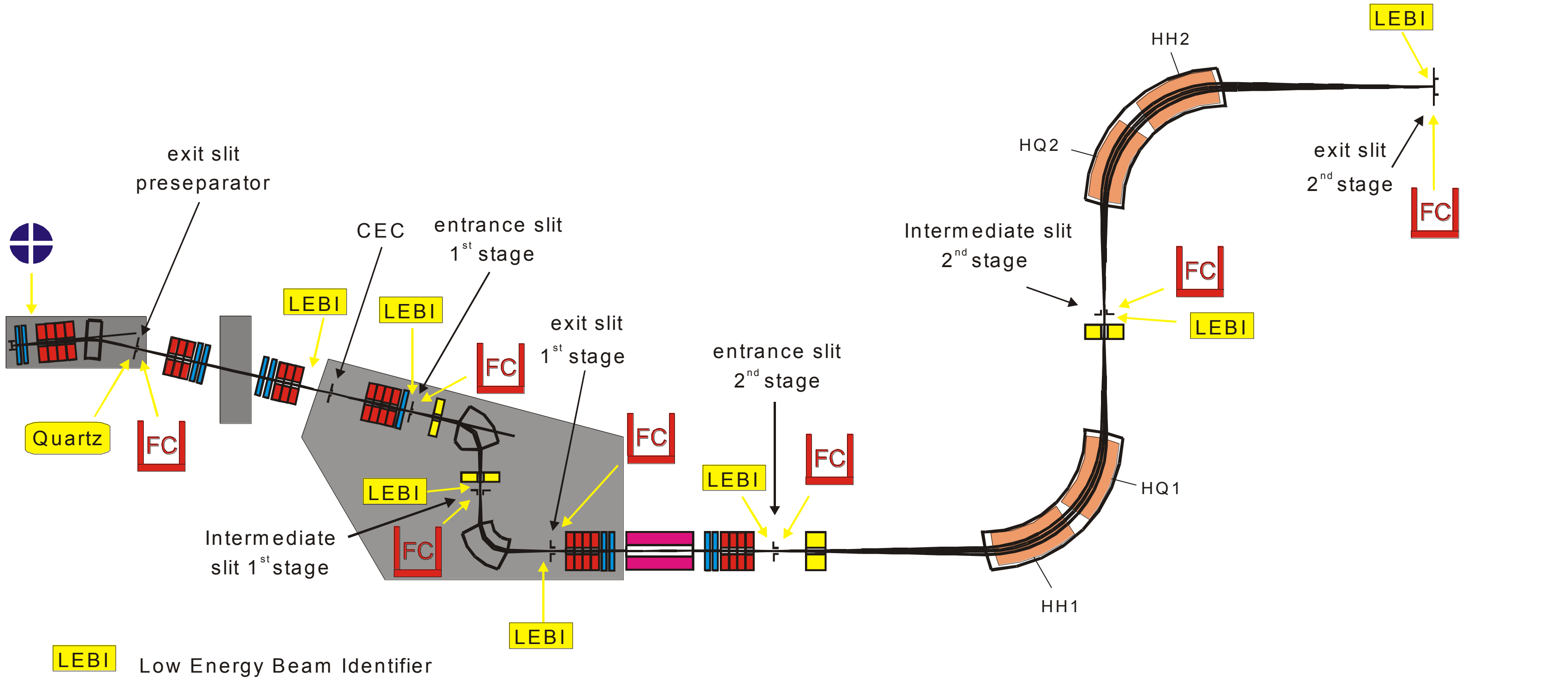
ccd camera watec 902H

- sensitivity 10^{-4} lux
- spatial calibration
- reference of the beam axis

EXCYT transmission factors

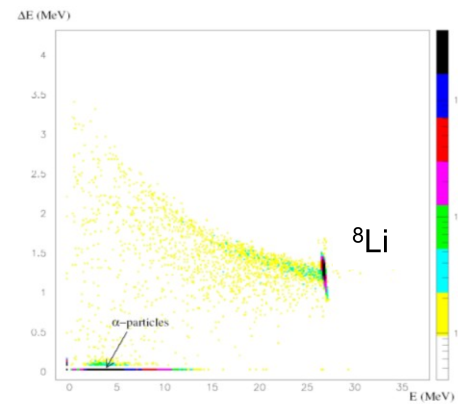
October 2008

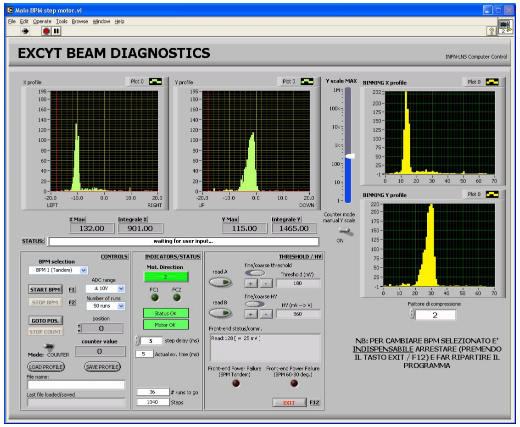
Primary beam power	LEBI1 (pps) $^{8}Li^{+}$	CEC (10 keV) $^{8}Li^{-}$	Through platforms $^{8}Li^{-}$	Through 2^{nd} stage	Tandem entrance	Through Tandem @7MV	On target $^{8}Li^{3+}$
		2.8%	100%	100%	100%	47%	70%
100watt	$5.4 \cdot 10^{6}$	$1.5 \cdot 10^{5}$	$1.5 \cdot 10^{5}$	$1.5 \cdot 10^{5}$	$1.5 \cdot 10^{5}$	$7.0 \cdot 10^{4}$	$5.0 \cdot 10^{4}$

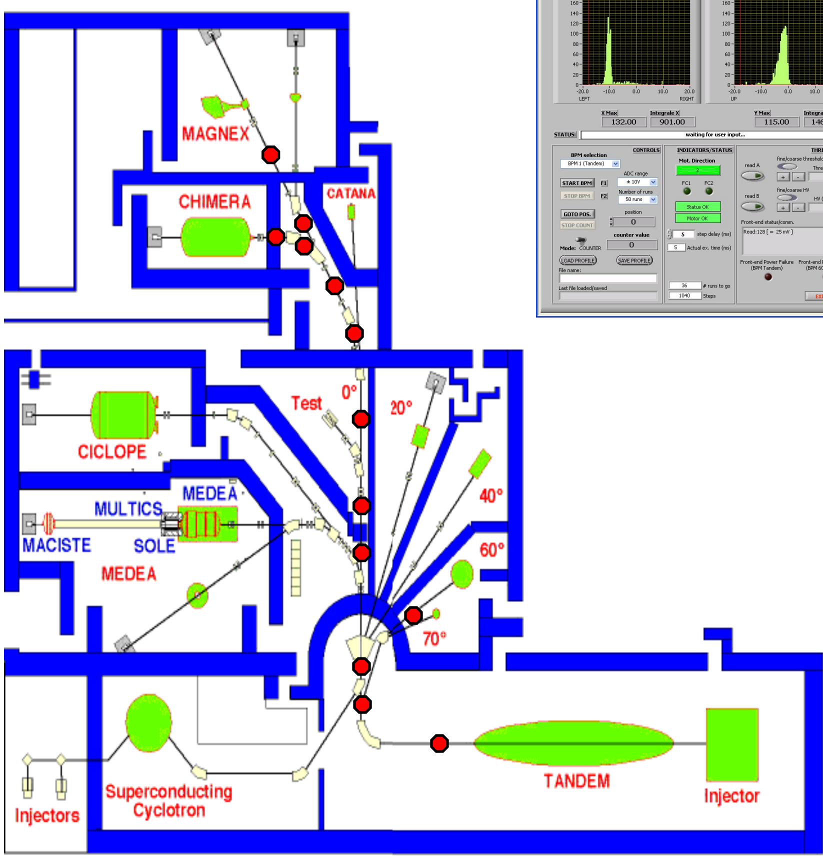


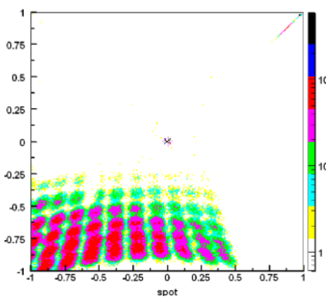
Diagnostics for accelerated (Tandem) RIBs

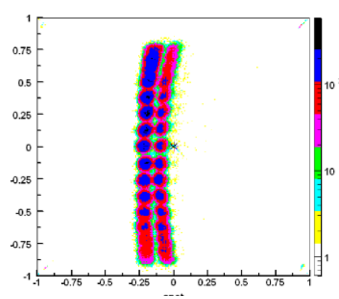
Low intensity diagnostics (sensitivity down the single particle, upgraded during 2010 for providing the long beam lines (Magnex and Chimera)

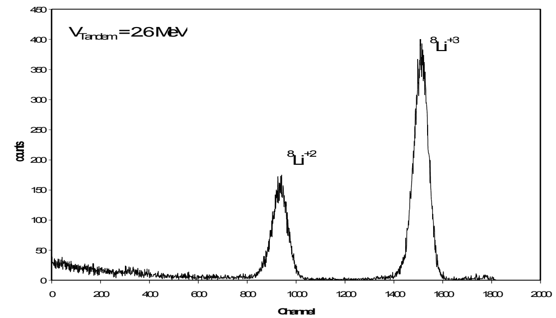






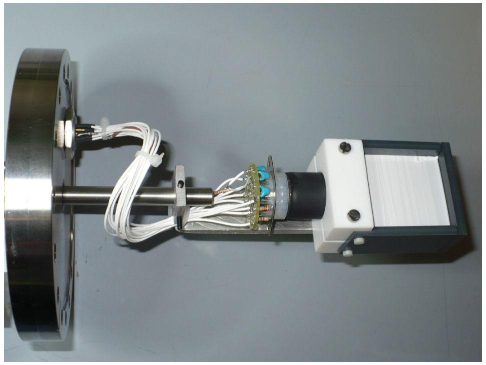


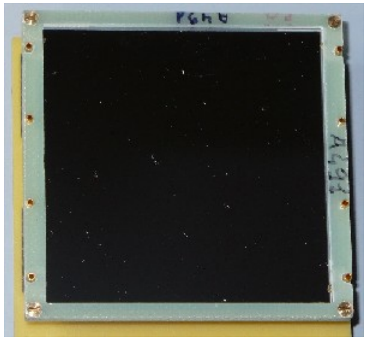




Diagnostics for accelerated (Tandem) RIBs

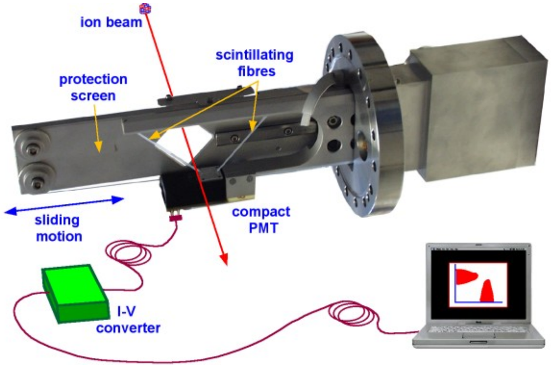
Plastic scintillators for beam intensity measurements



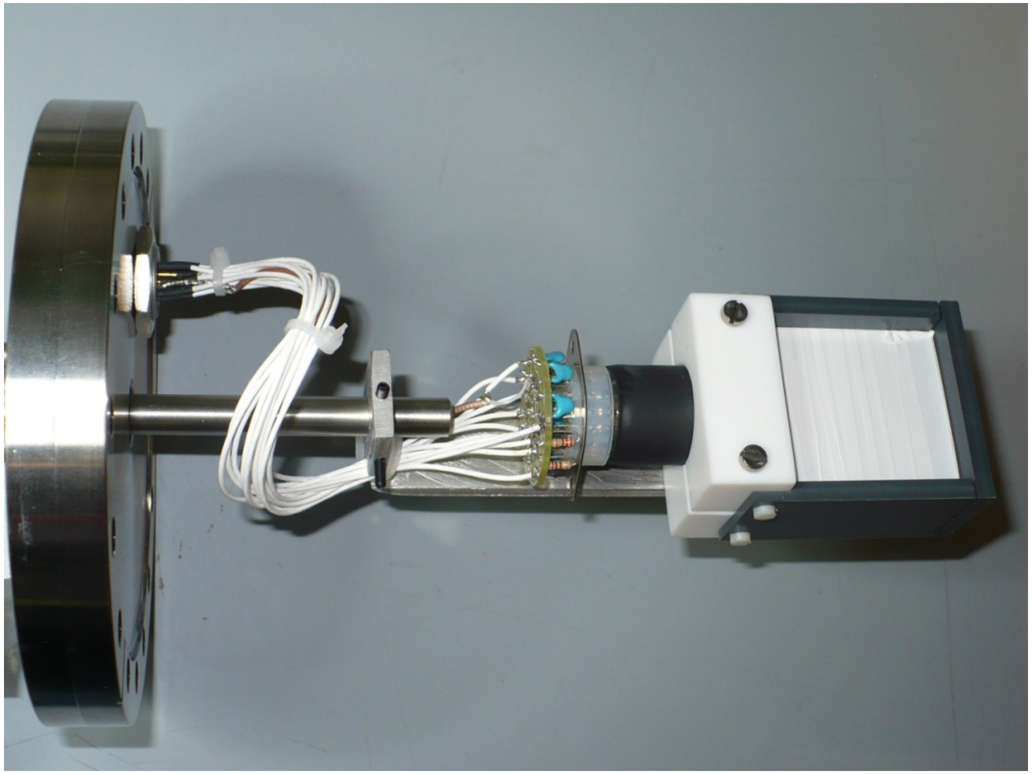


Position sensitive silicon detectors
- 2D beam profile monitor
- beam energy spectra
- identification of the beam particles ($\Delta E - E$)

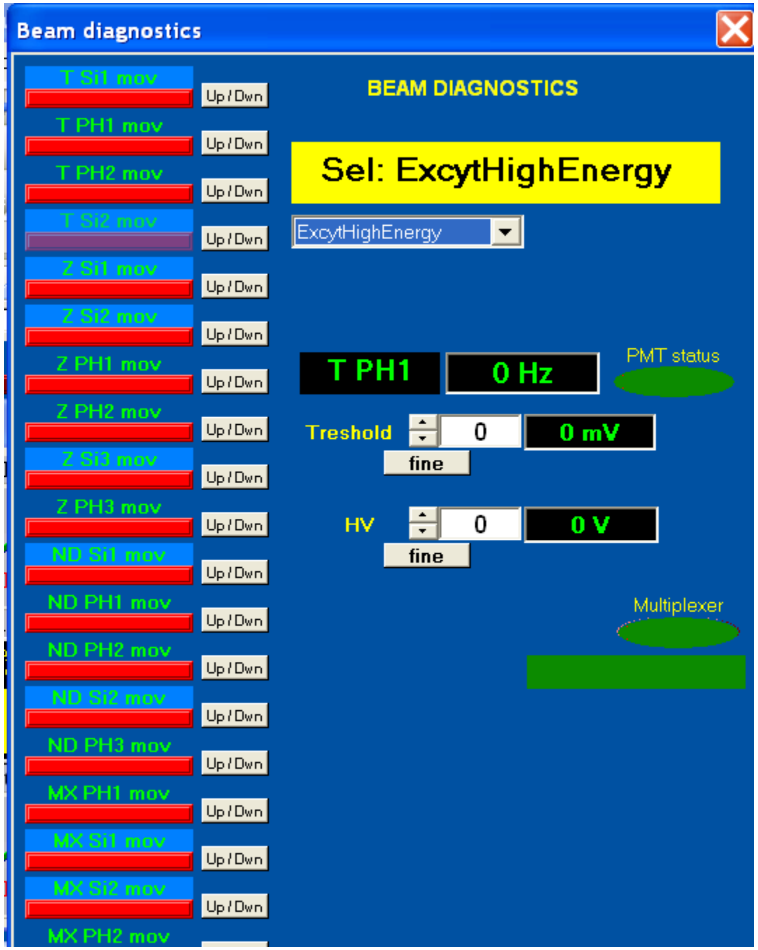
Beam profile monitor (FIBBS) based on a pair of scintillating fibres scanning the beam



Beam counting



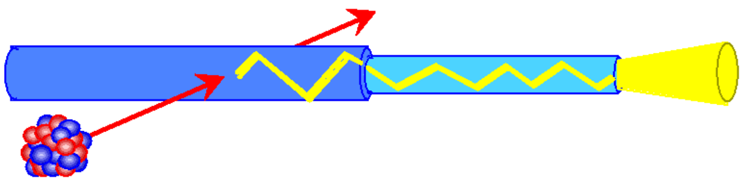
Plastic scintillator (BC408) optically coupled to a small PMT, working in pulse counting mode

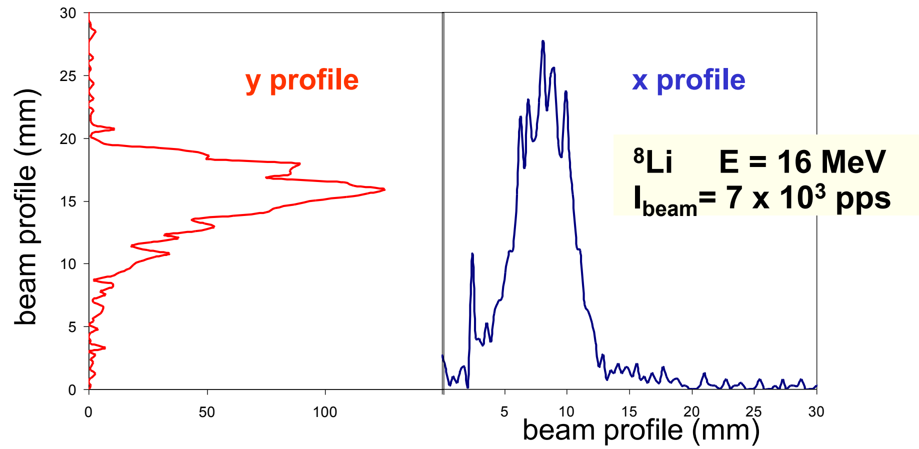


Intensity below 10^6pps

1D beam scanning

This technique consists of scanning a beam with scintillating fibres, in order to produce the 1D intensity distribution





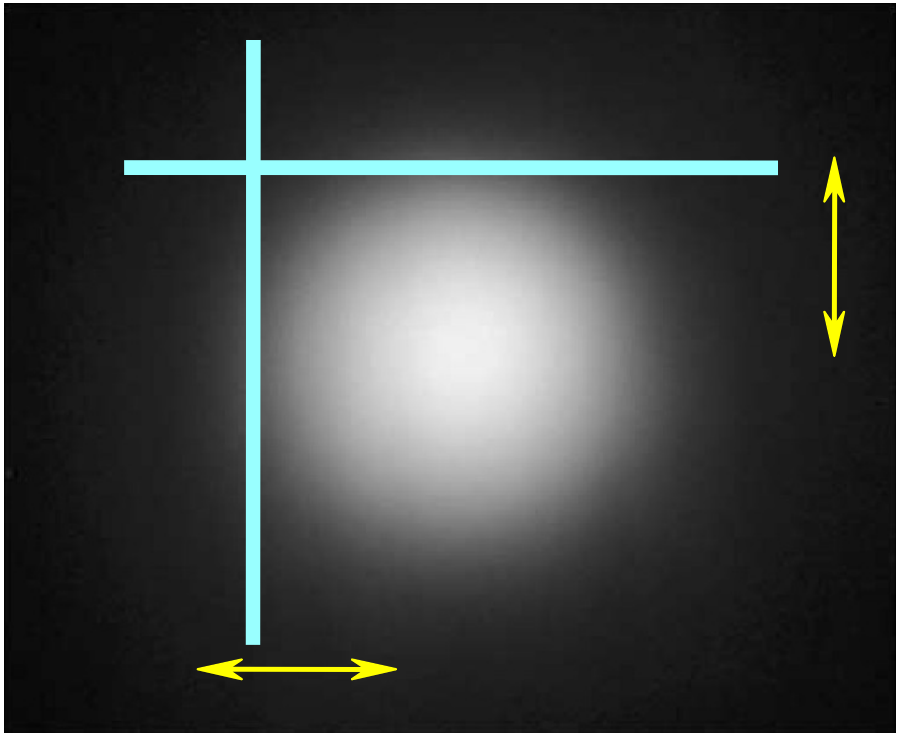
Light collection efficiency at one end: ≈3.5%

- Light yield is of the order of 10000 photons/MeV. For charged particles is lower (quenching).

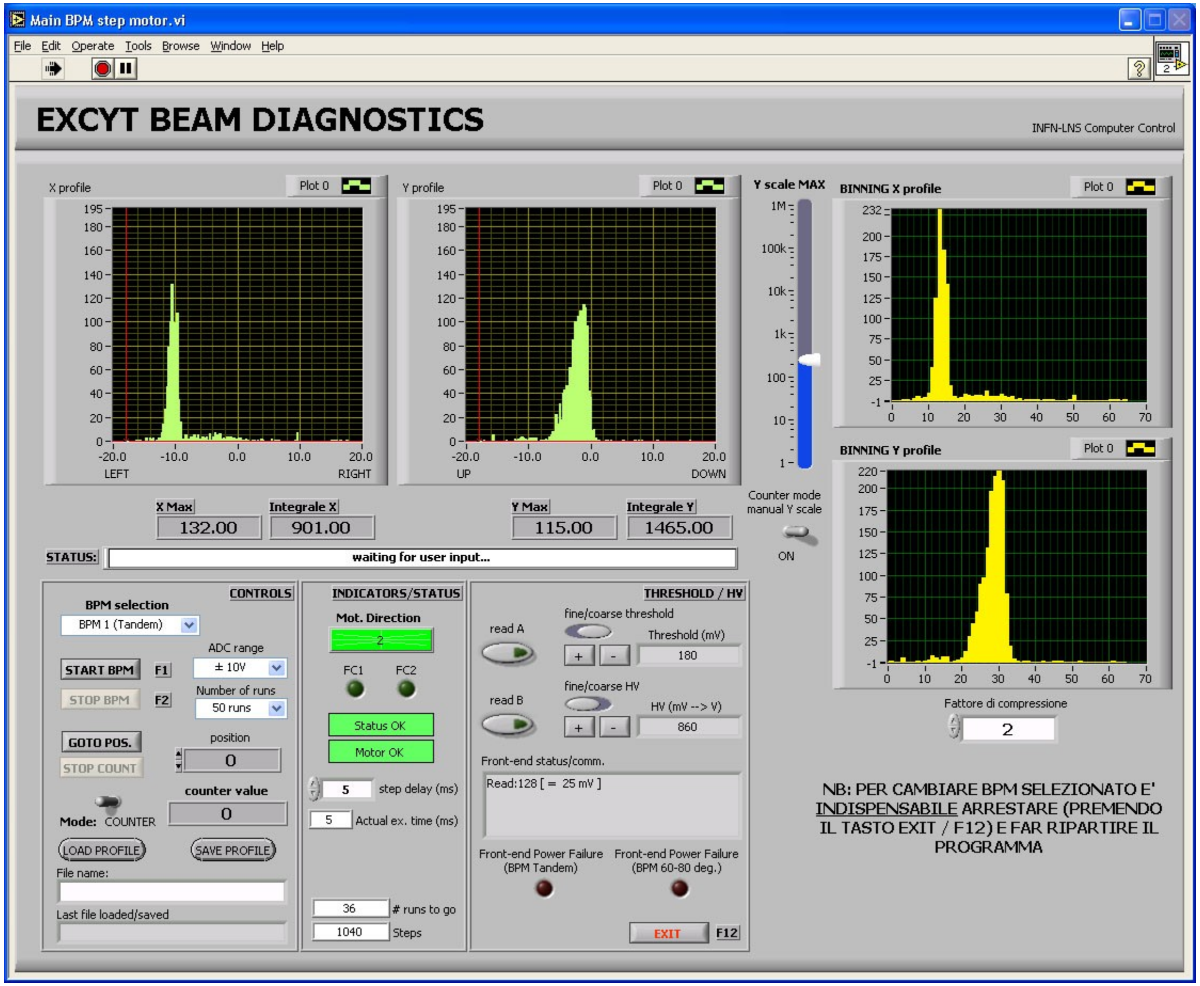
•Plastic scintillating fibre: fast (3ns), not rad-hard, L_{at}≈3.5m, λ≈435nm

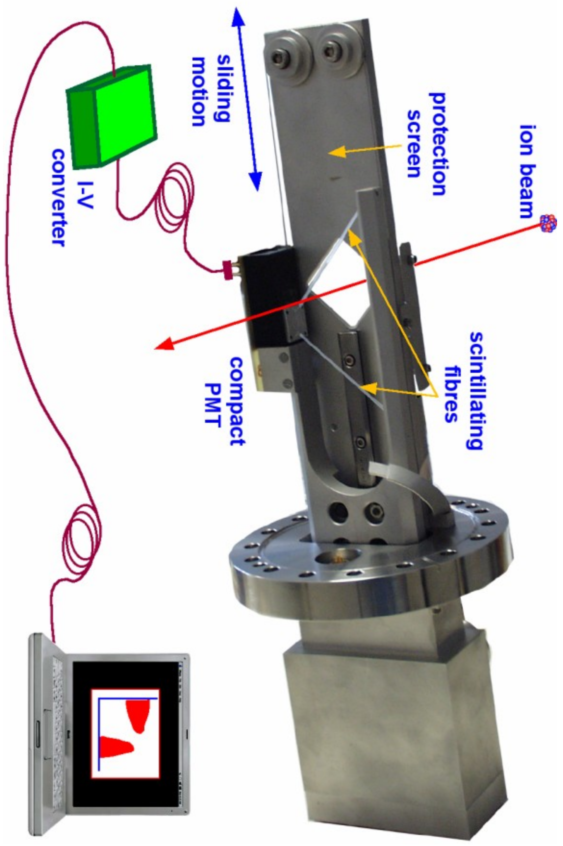
•Tb-glass scintillating fibre: slow (4ms), rad-hard, L_{at}≈10cm, λ≈550nm

•Ce-glass scintillating fibre: fast (40ns), not rad-hard, L_{at}≈2cm, λ≈400nm



FIBBS (Fibre Based Beam Sensor)





Fibres diameter: 300 ÷ 500 μm

Glass fibres for intensity over 10^6 pps

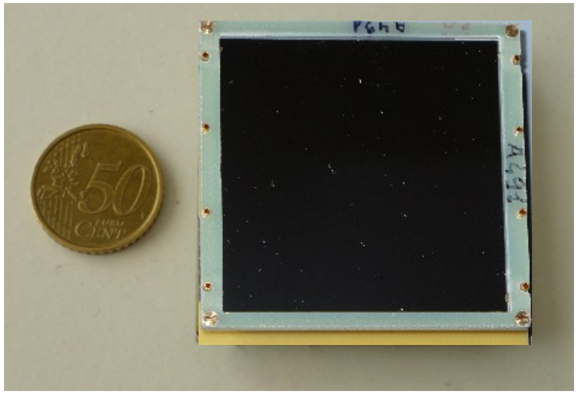
Plastic fibres for lower intensity

Position sensitive silicon detector

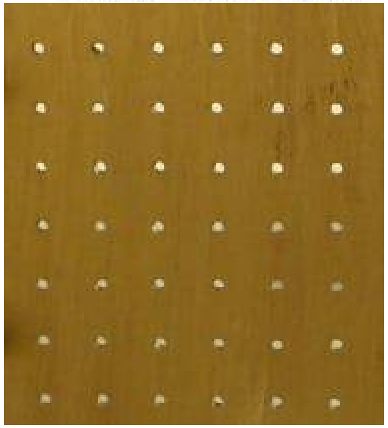
position sensitive silicon telescope for RIB identification and profiling

- 2D beam profile monitor
- beam energy spectrum
- identification of the beam particles ($\Delta E - E$)
- read-out from the back and the 4 corners
- charge division algorithm for position evaluation

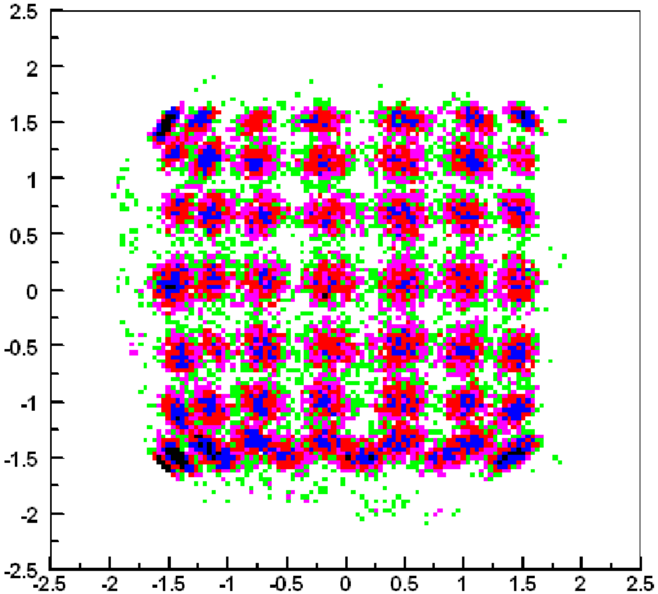
5cm x 5cm Si detector



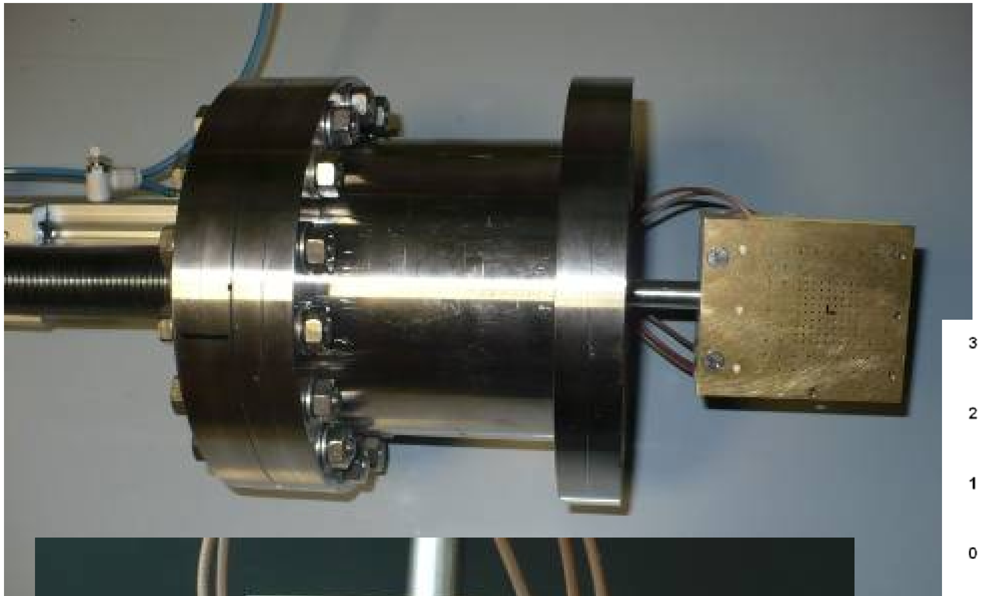
multi-hole mask

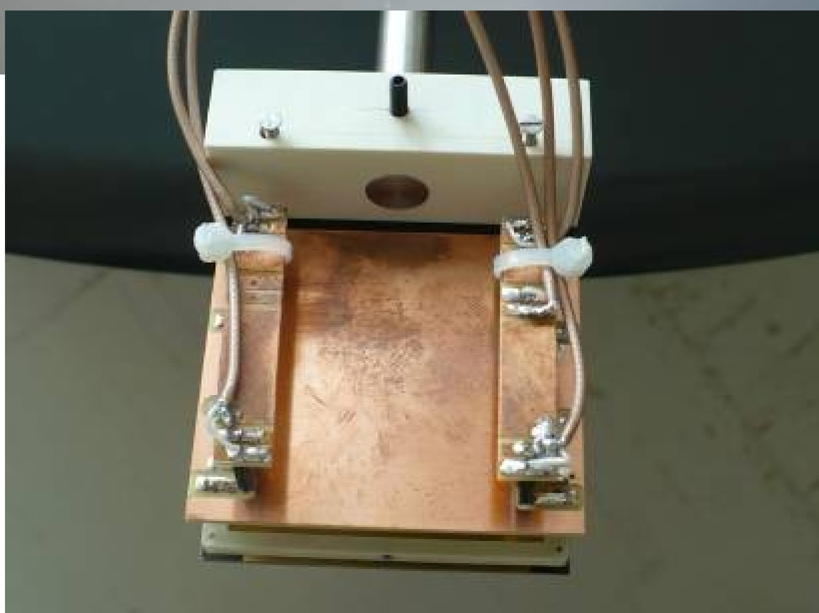


reconstruction of the hole mask put in front of the detector for calibration



Position Sensitive Silicon Detector

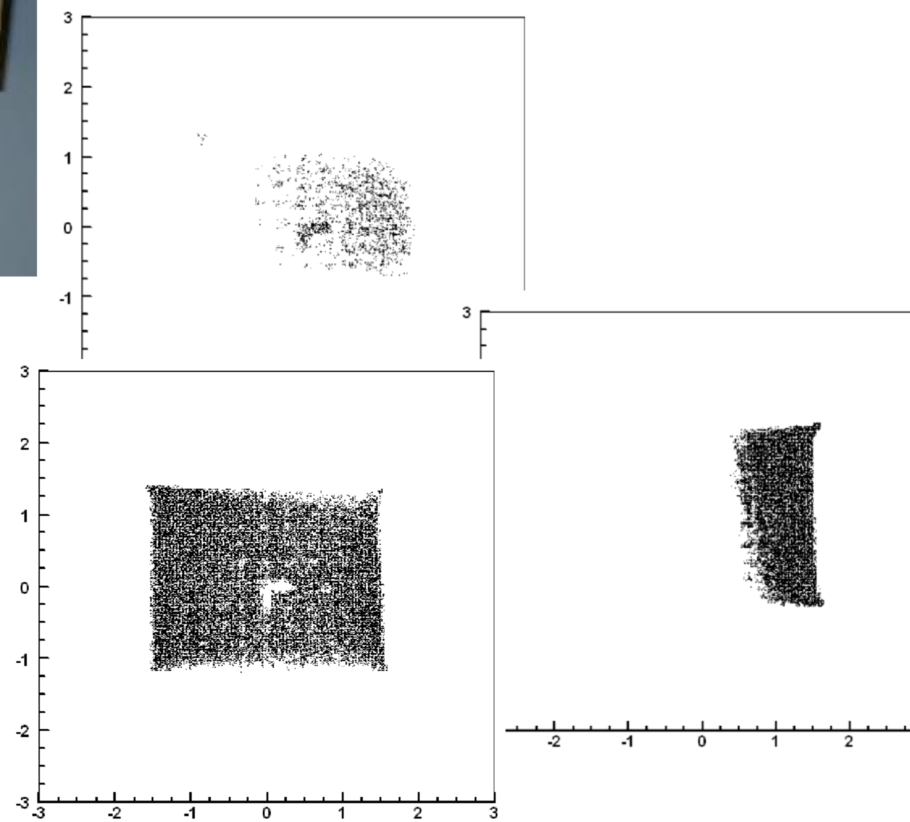




Real time beam imaging. Fast acquisition system based on VME modules

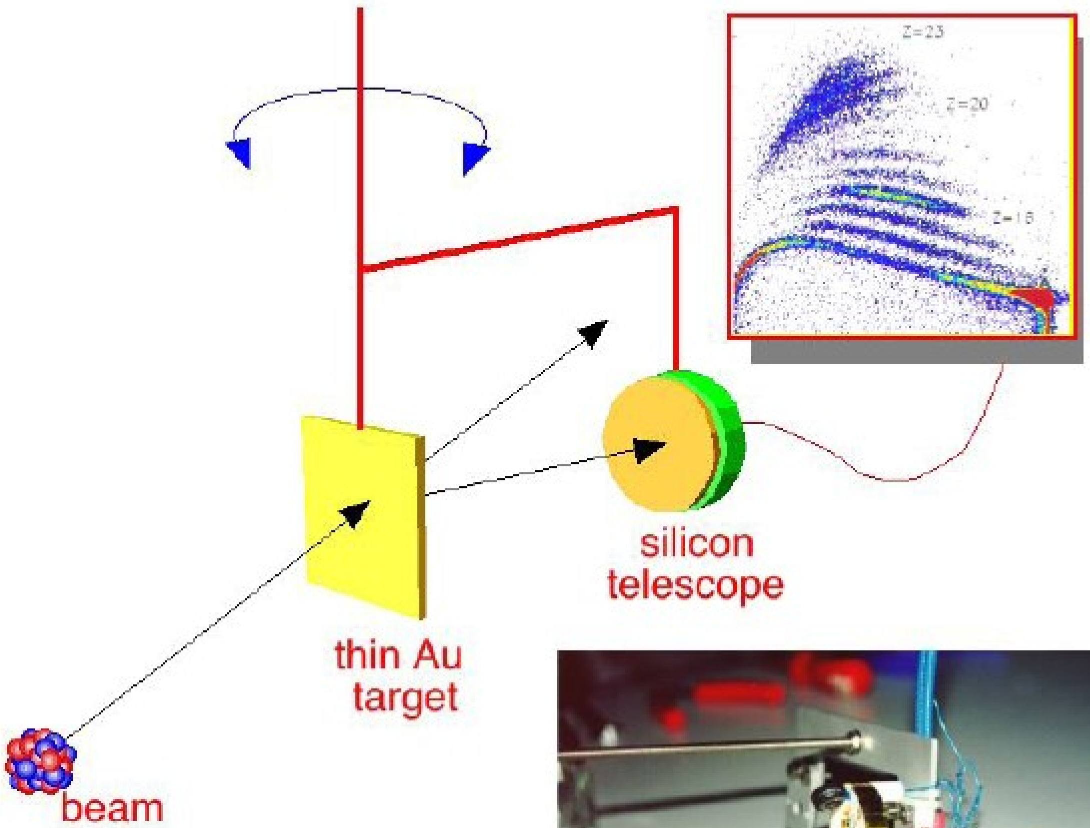
particle position reconstructed by 4 signals from the PSSD corners. Spatial resolution 1 – 2 mm

The beam intensity must be kept below 10^4 pps

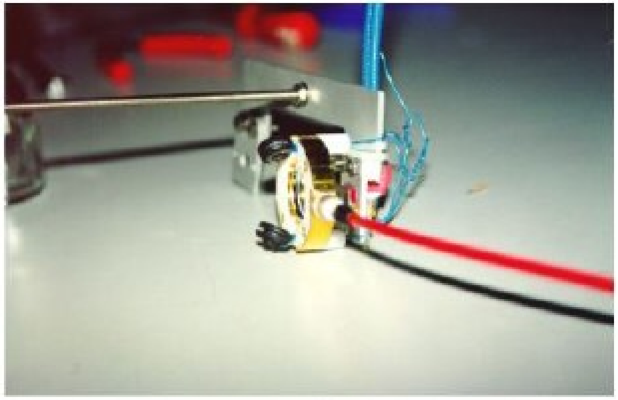


Silicon telescope

telescope for RIB identification

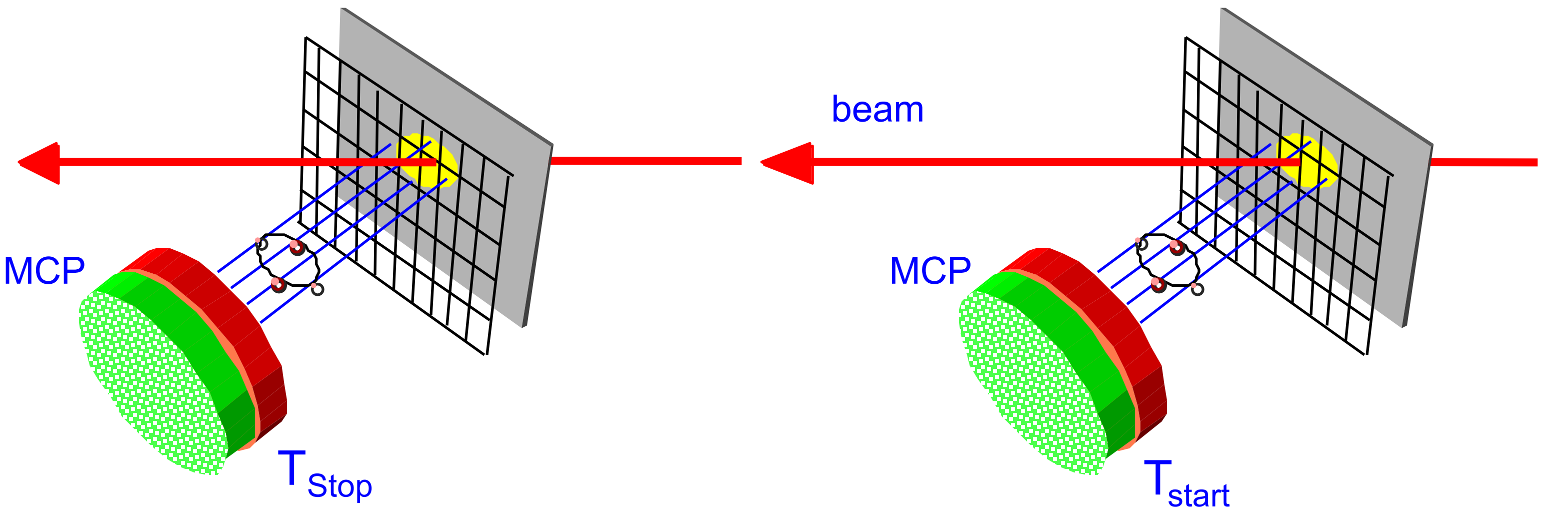


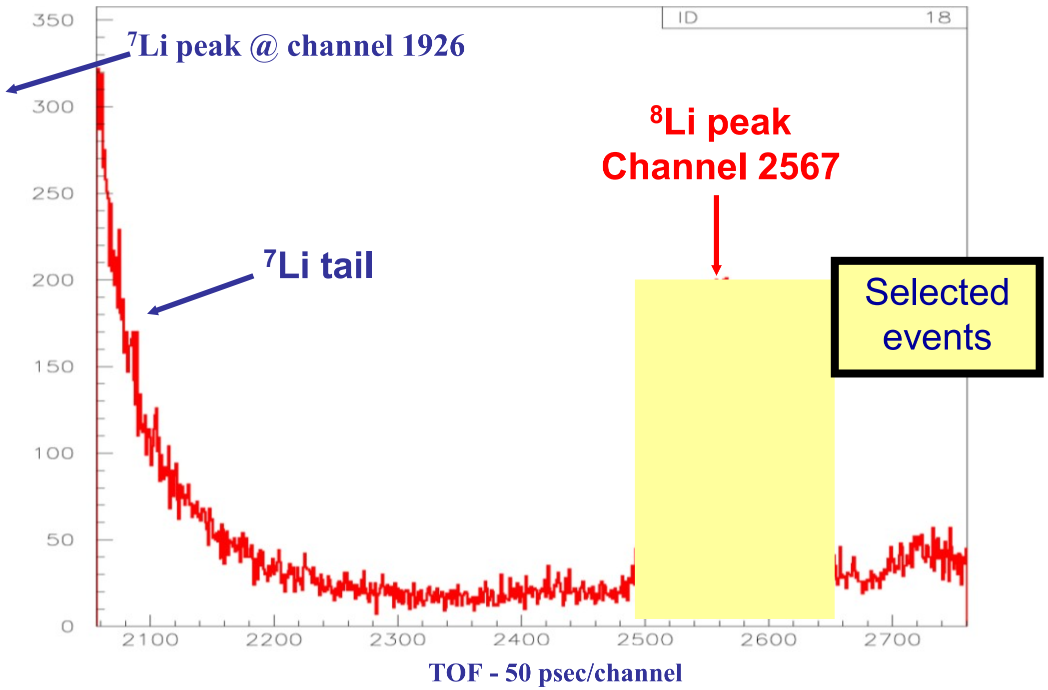
- signal due to energy loss: Bethe & Bloch...
- average energy to produce an e/h pair: 3.62 eV
- radiation hardness /cost: low
- ease-of-use & reliability: sufficient
- suitable for specific applications



- thickness ≈ 50 + 500 μm
- unambiguous identification of isotopes by elastic scattering
- at low beam intensity can be used directly on the beam
- intensity measurement by means of counting rate
- cost: reasonable

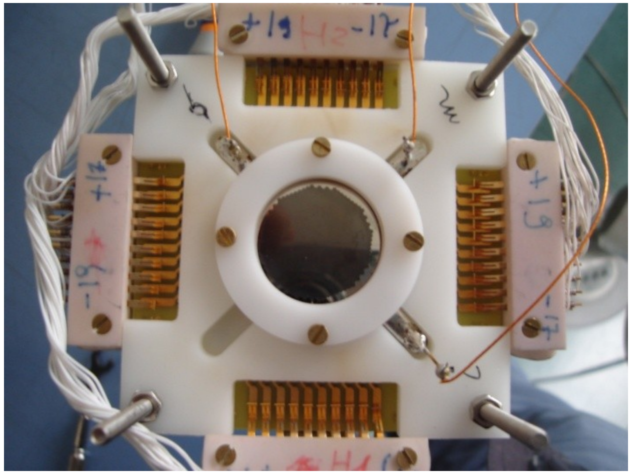
Ions Tagging with Time Of Flight

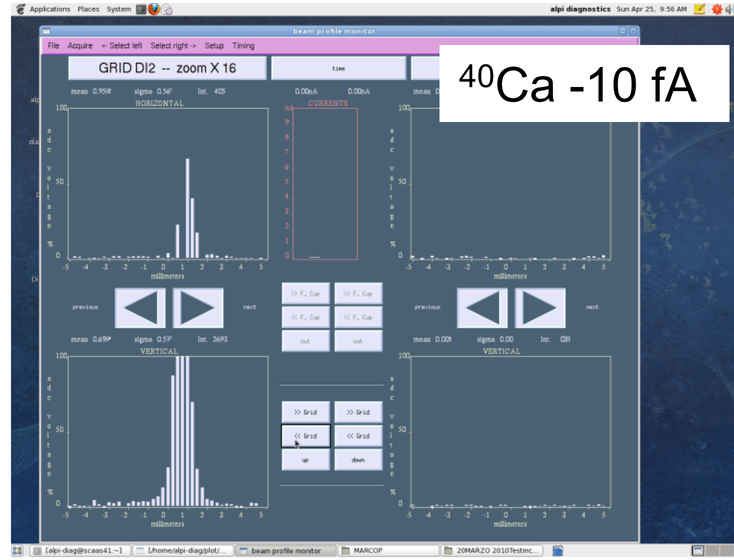


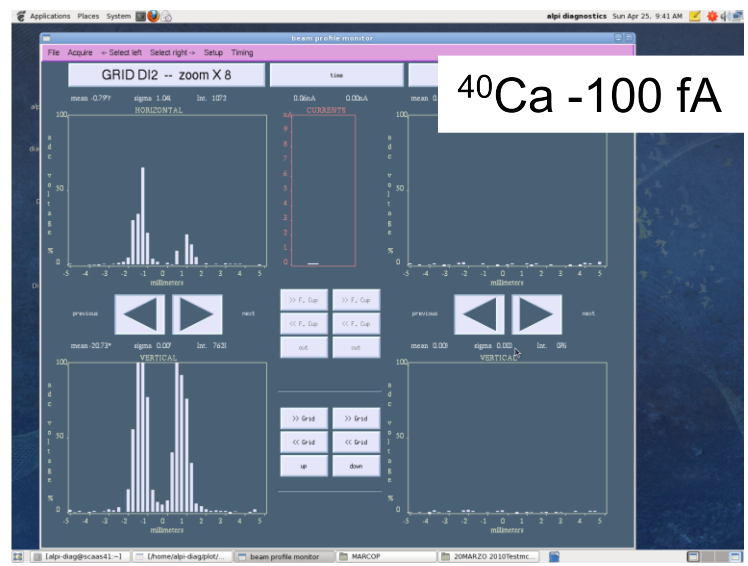


- On-line discrimination between ions having same energy but different mass.

1D Beam profile monitor based on MCP for SPES







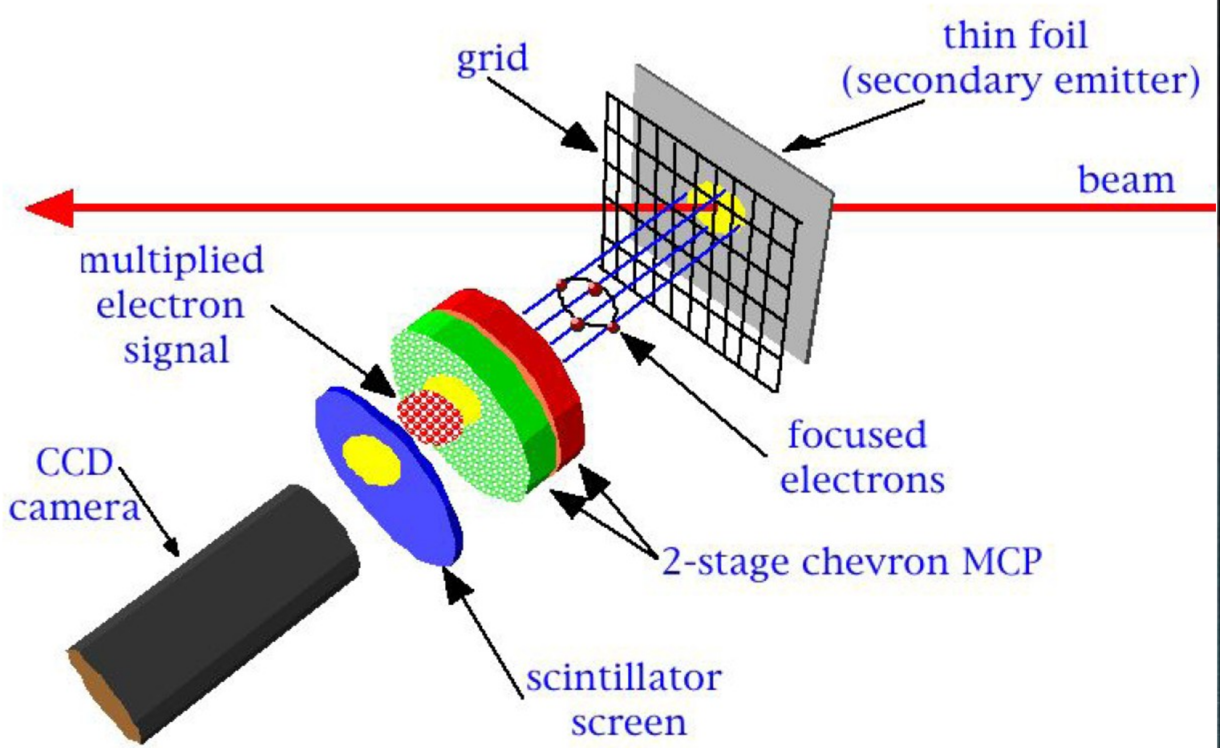
System developed in Legnaro LNL, based on a MCP placed directly on the beam line, with a position sensitive anode. Less than 10^5pps/cm^2 measured profile sensitivity.

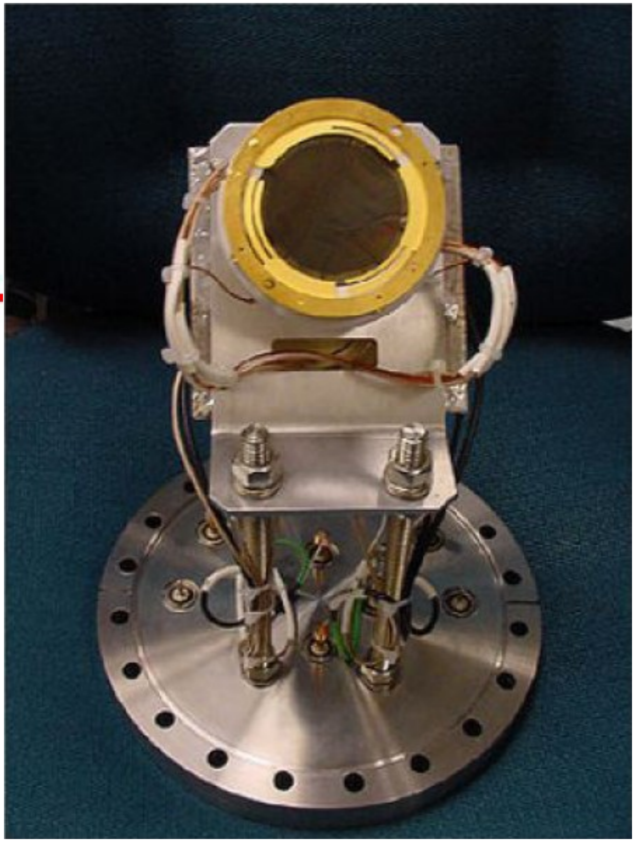
Wire step = 0.75 mm

MCP for beam imaging

2D-imaging secondary emission detectors

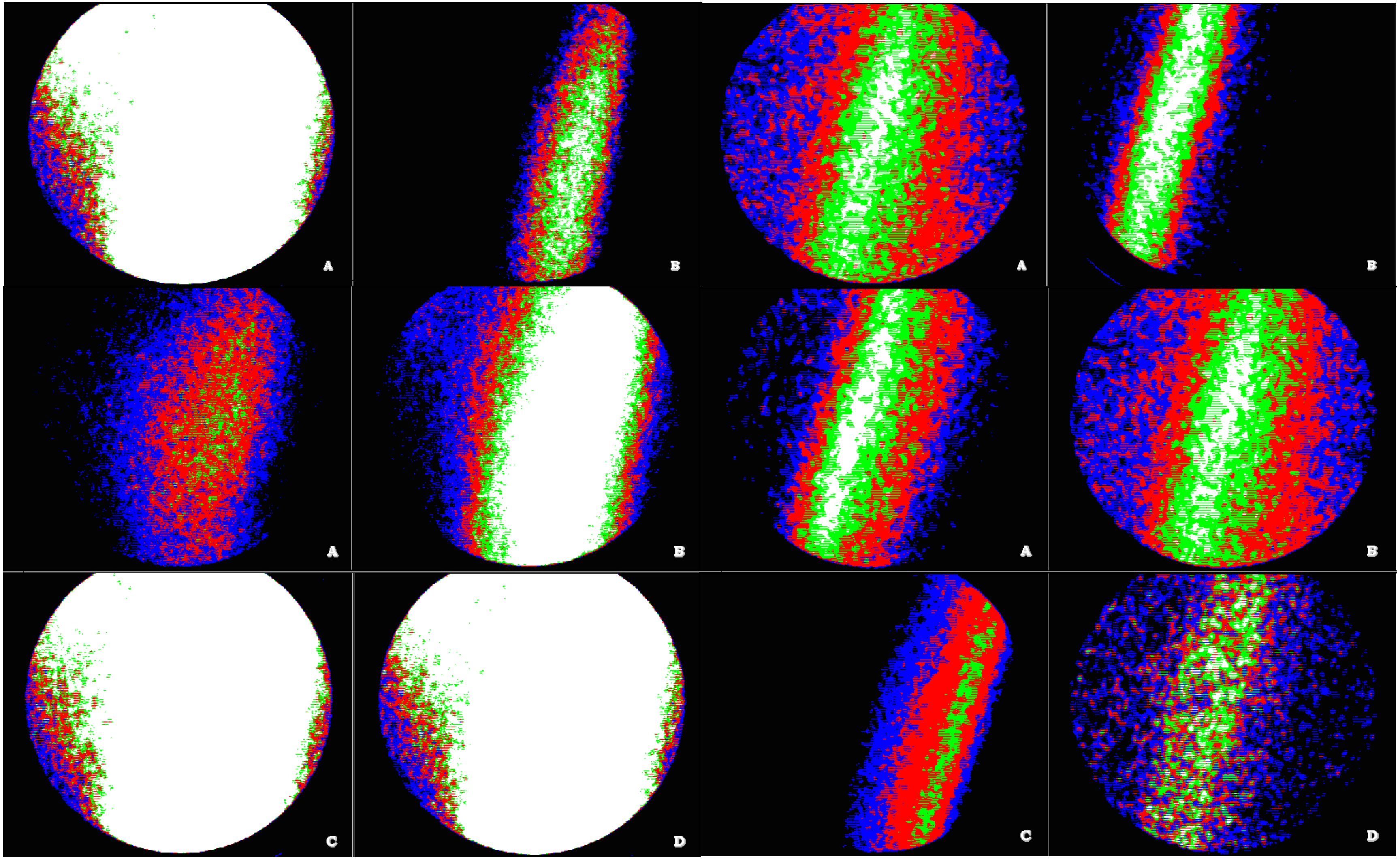
built and tested at LNS



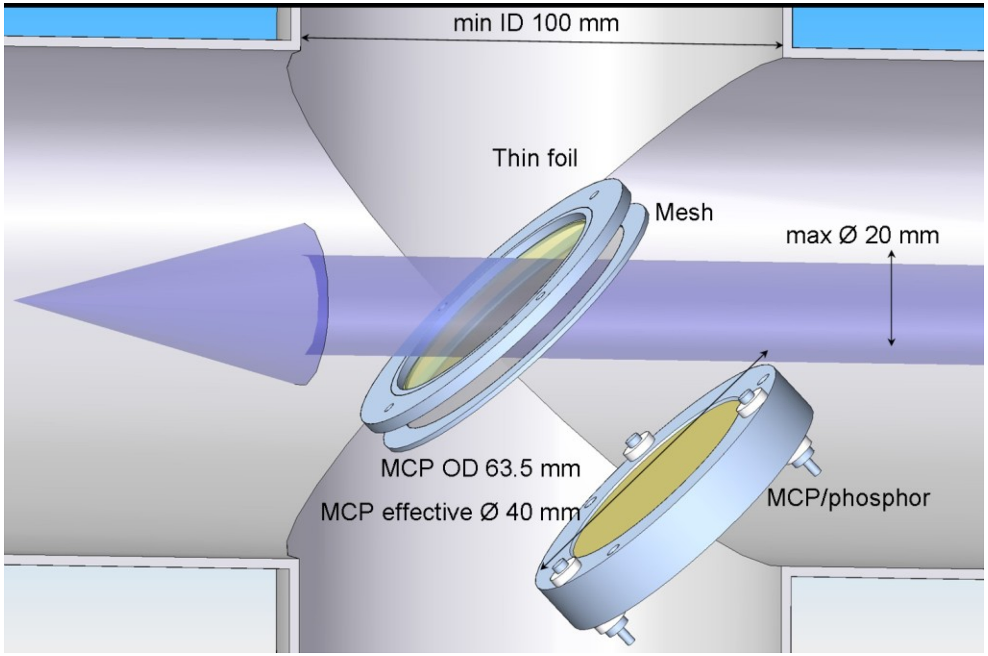


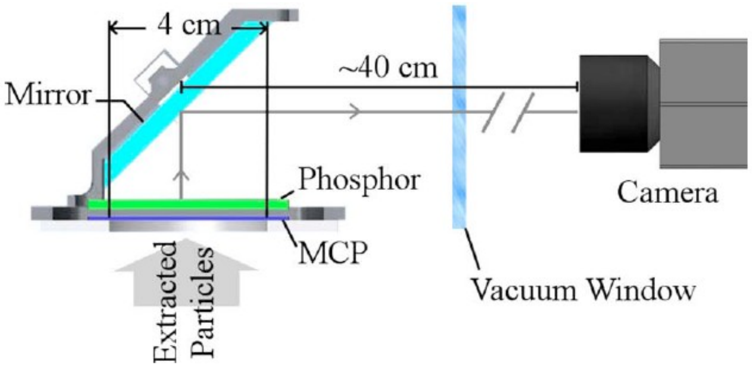
MCP for beam imaging

The technique is appealing but unfortunately the devices are quite delicate and expensive



MCP for beam imaging





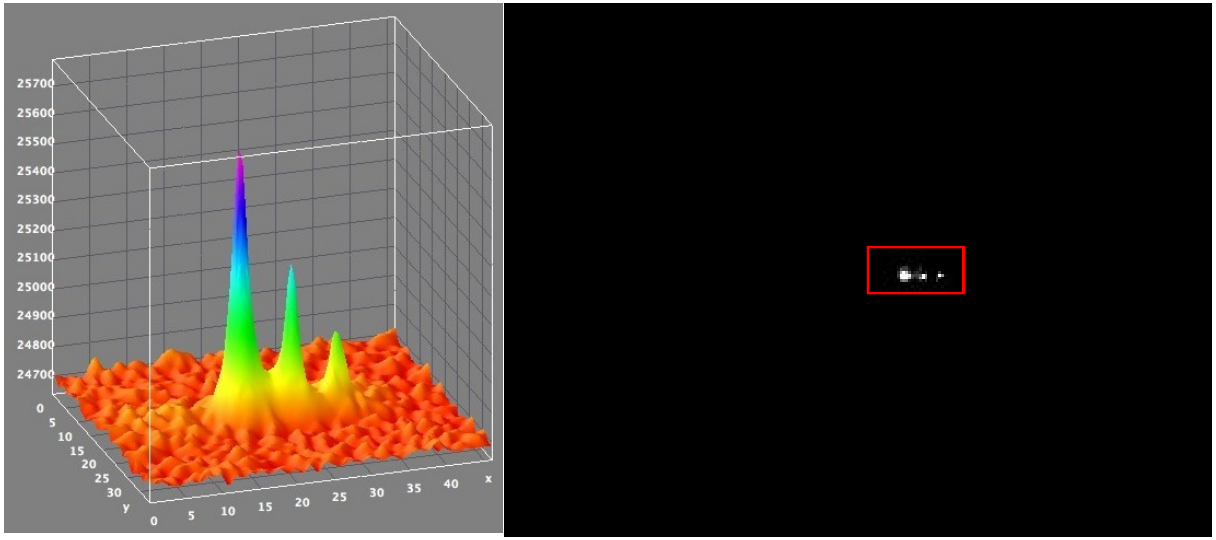
LNS in the DITANET european network

New diagnostics challenge

DIagnostic **T**echniques for future particle **A**ccelerators **NET**work

antiproton beam diagnostics at FAIR?

high performance photocamera
Chroma CX3 14-bit cooled CCD



screen = CsI (Tl)

beam = protons

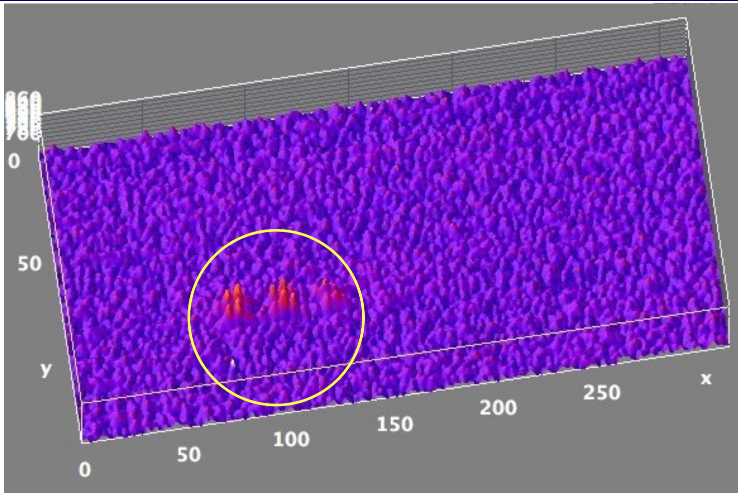
E = 200keV

I ≈ 2.5fA (10^4 pps)

$t_{exposure}$ = 20s

Rev Sci Instrum. 2010 Oct;81(10):103302

LNS in the DITANET european network



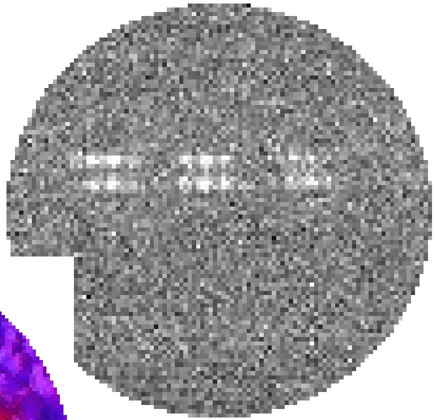
screen = CsI

beam = protons

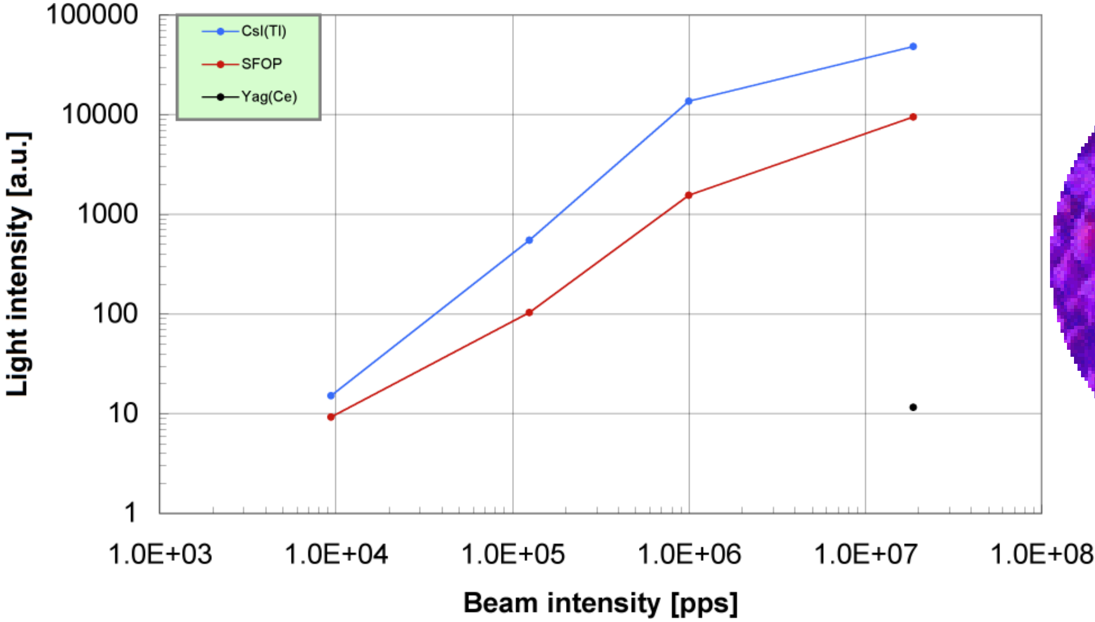
E = 50keV

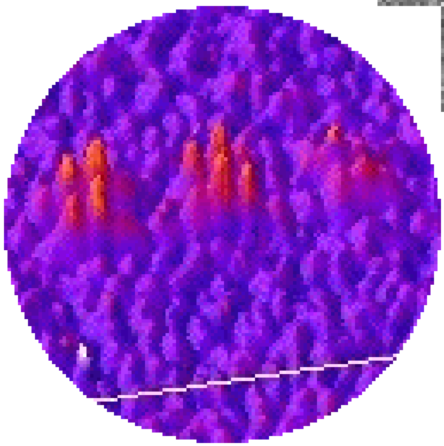
I ≈ not measurable

$t_{exposure}$ = 60s



toward single particle imaging....!!!





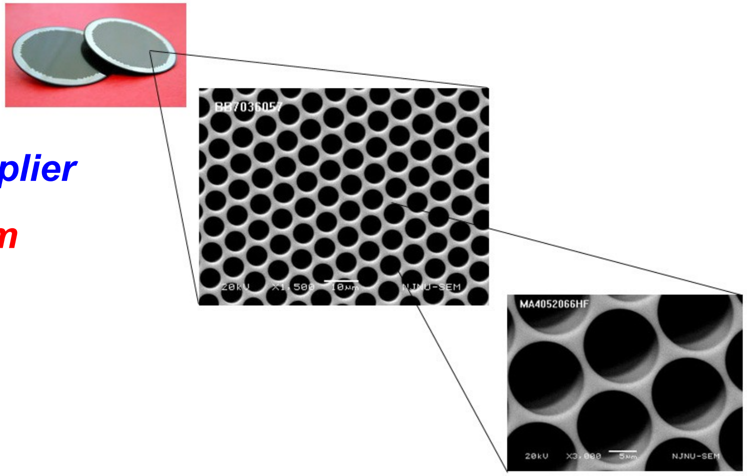
beam attenuated through a fine mesh, pitch ≈ 0.1mm

Conclusions

- several different technologies tested/employed at LNS for L.E.L.I. ion beams
- in general each specific problem needs a specific solution
- scintillators are a tradeoff solution between robustness, ease-of-use, and cost
- CsI(Tl), doped glass, and plastics (in some cases) offer good performance
- R&D activity is going towards the development of diagnostic devices for the SPES facility.

How to improve the sensitivity: the MCP

What is a MicroChannel Plate?



it is a mesh of photocathodic microchannels

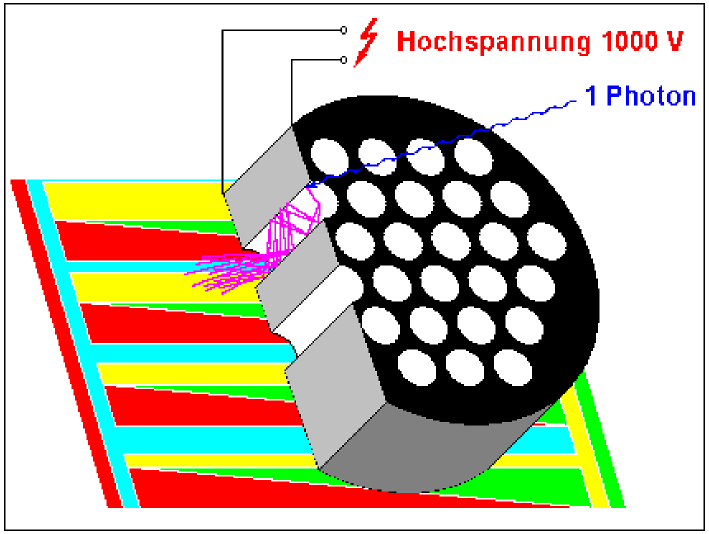
each channel is a microscopic continuous electron multiplier

operated at high voltage (up to 5000V), in high vacuum

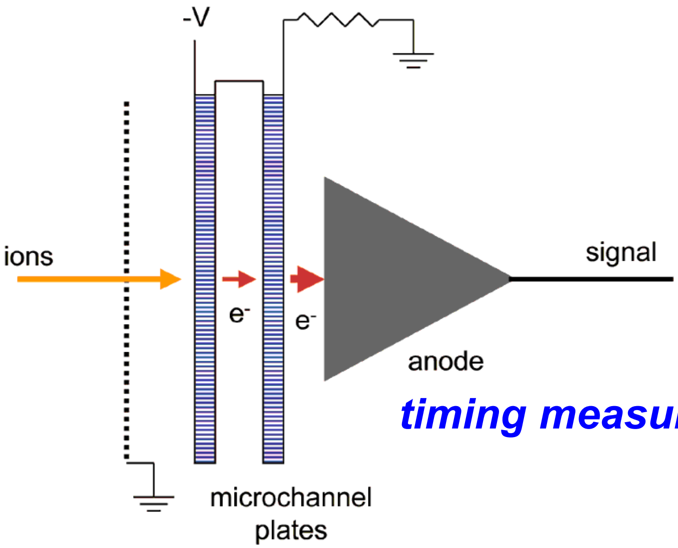
rather delicate and quite expensive

sensitive to photons, electrons, ions

best timing (even below 100ps)



profile measurement



timing measurement

Spiral 2 beam imaging

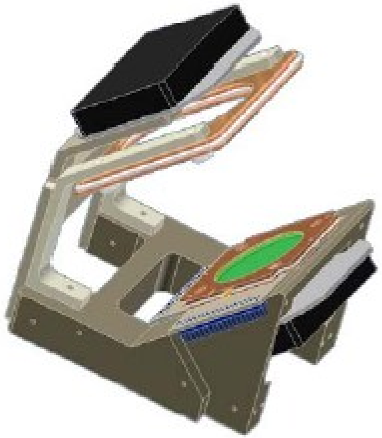
- **Emissive Foil Monitor**

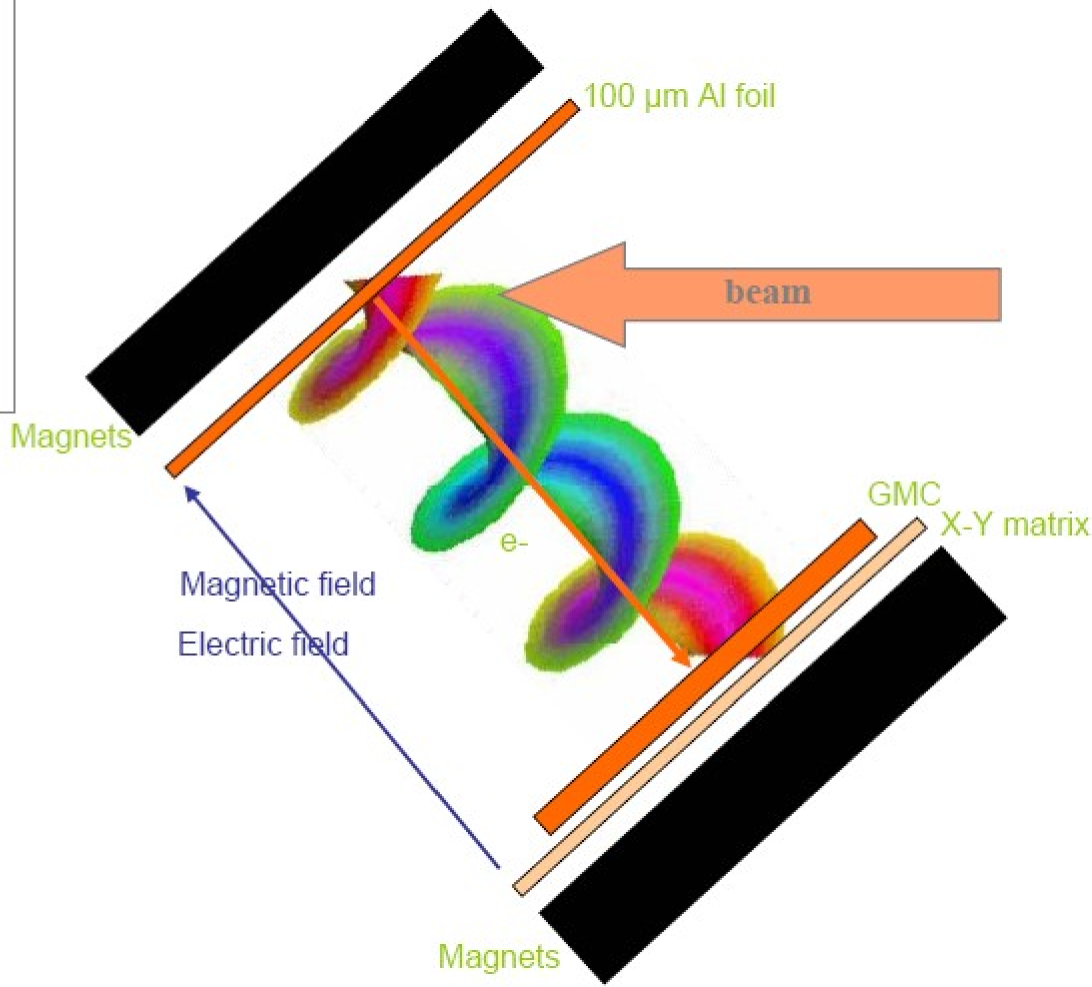
Principle : secondary emission on Al foil, amplification by microchannel plates, reading informations on X-Y matrix

Energy range : up to 10 KeV

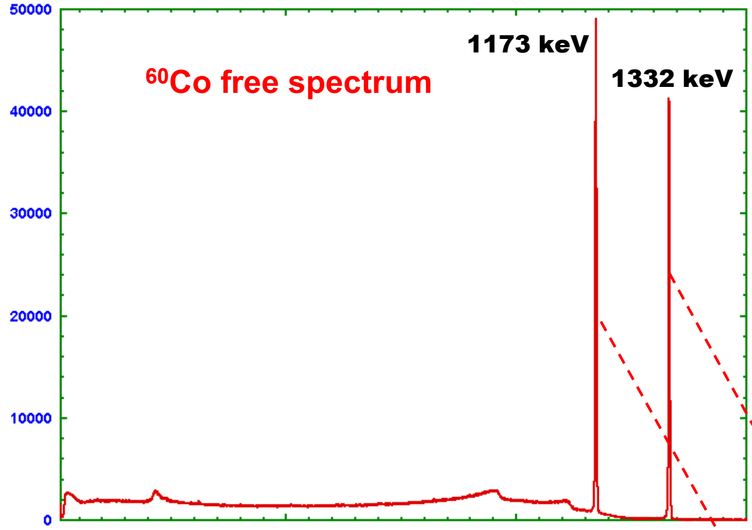
Intensity range : from 10 pps to 10^9 pps

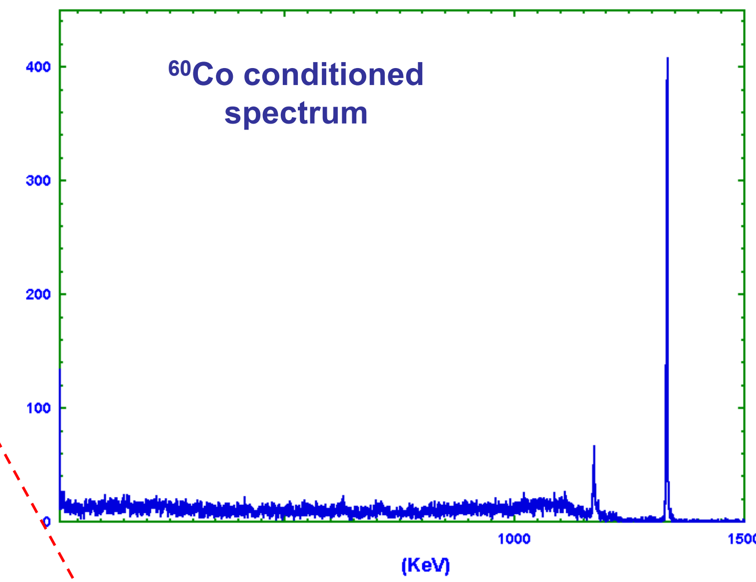
Location lines : from 1+ line to GANIL Experimental rooms

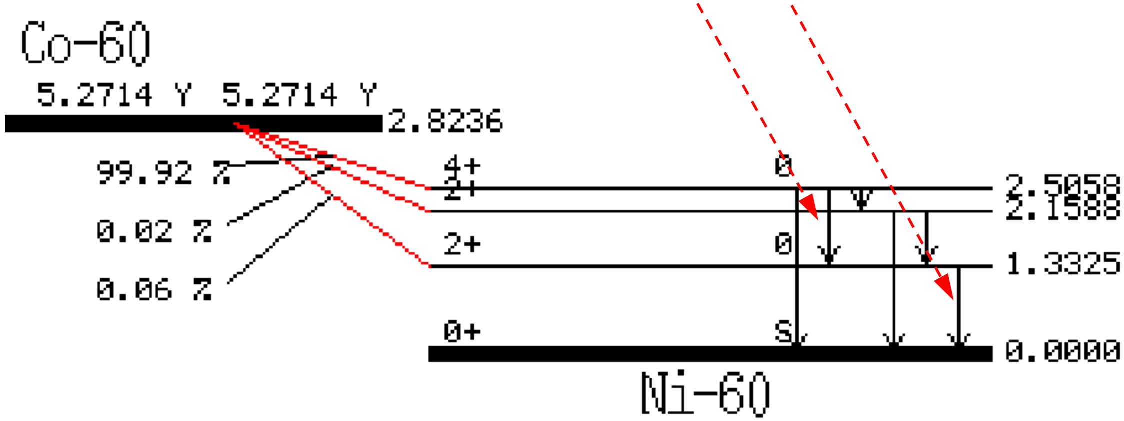


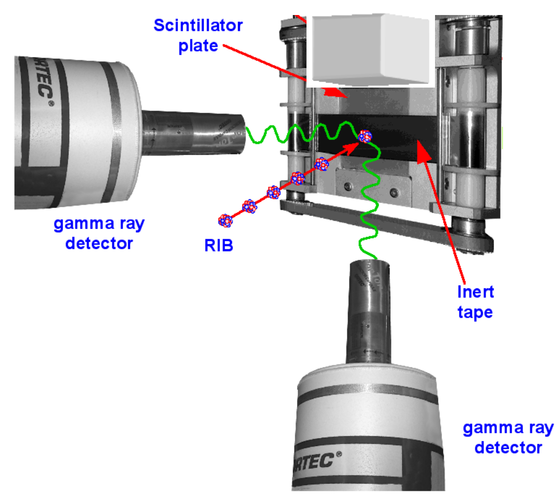


Gamma ray spectroscopy with two germanium detectors

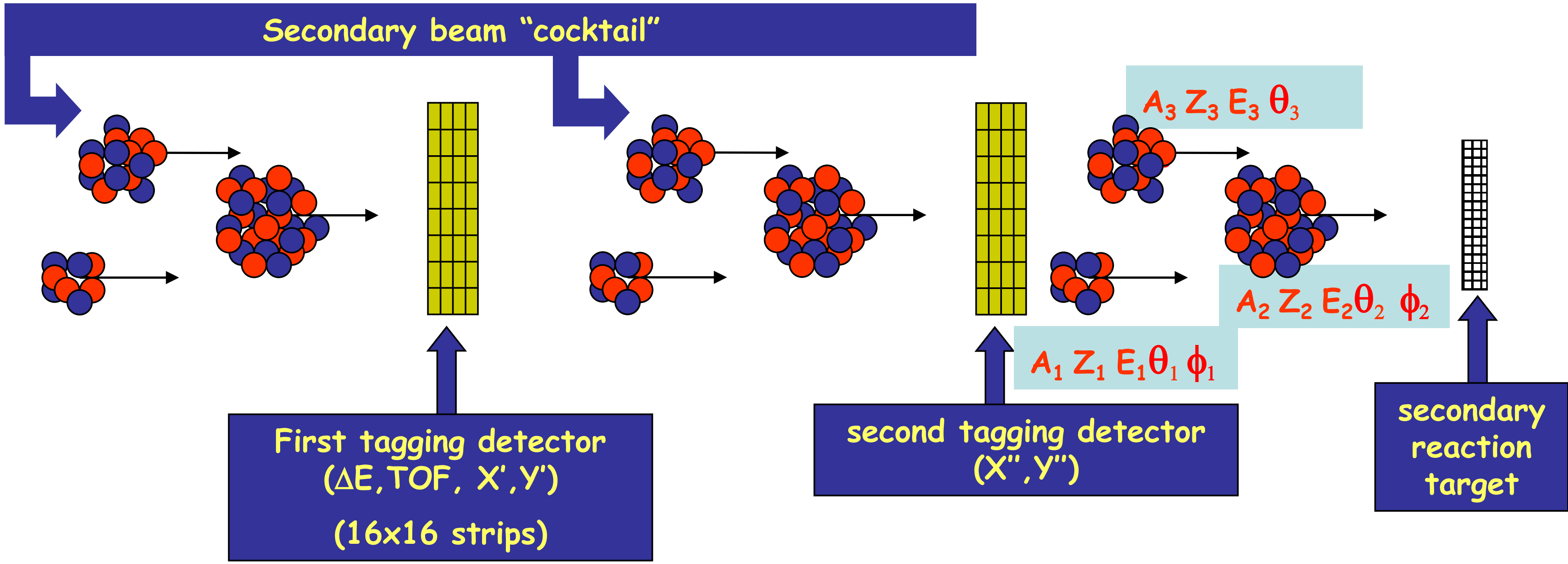






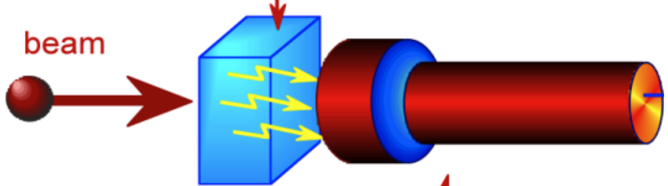


Tagging and tracking



Scintillators

- signal due to energy loss with emission of scintillation photons
- average energy to produce a photon ≈ 10-100 eV (gamma and electrons)
- average energy to produce a photon ≈ 100-1000 eV (ions)
- radiation hardness /cost: sufficient for plastics, excellent for inorganic scintillators
- ease-of-use & reliability: excellent

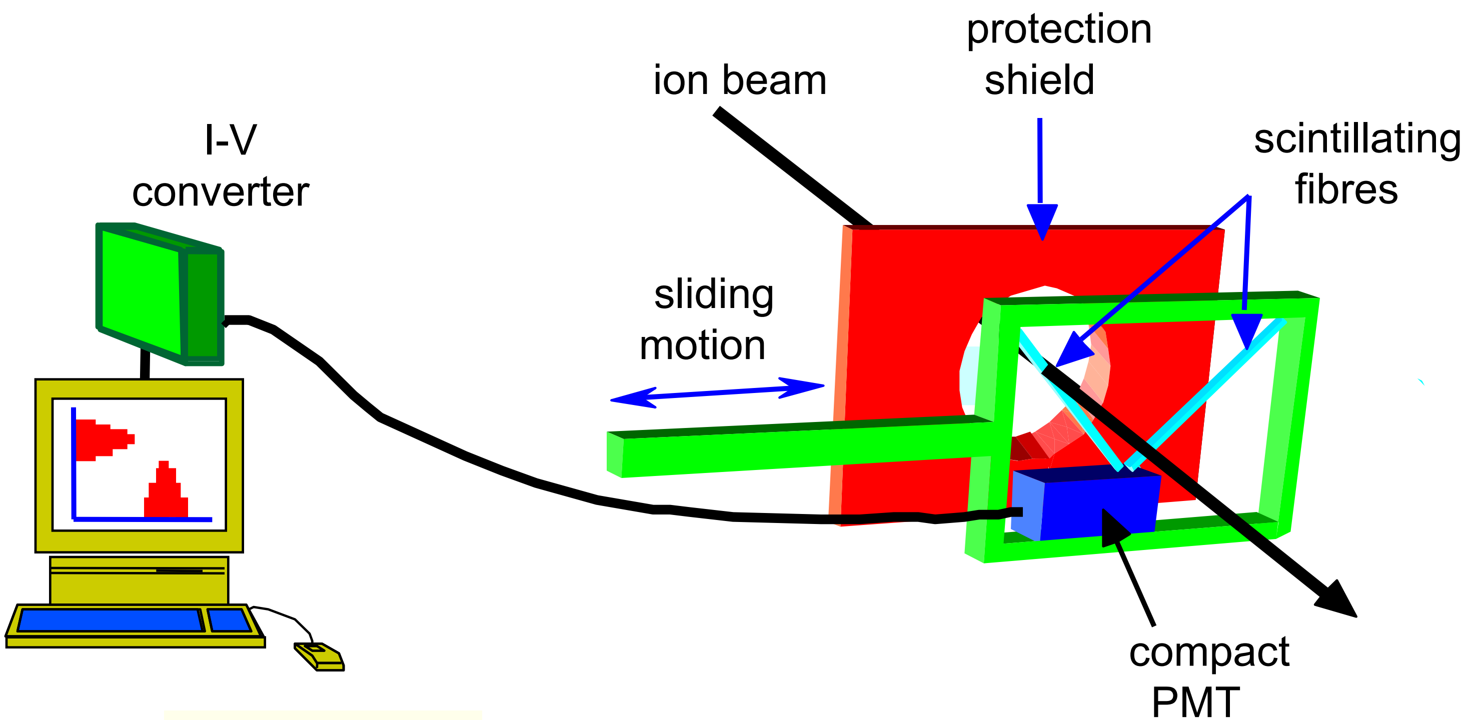


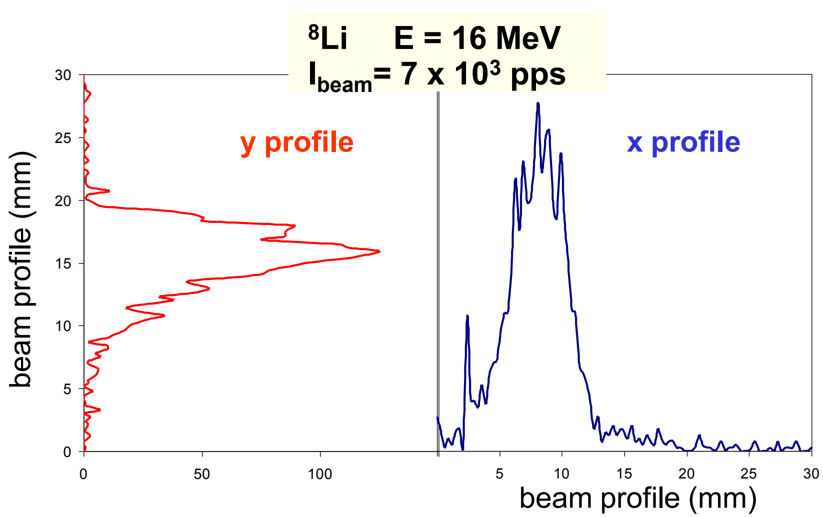
- organic scintillators (plastics: NE110, NExxx, BC404, BC408, BCxxx, fibres, etc.)
- inorganic crystals (CsI, BaF, YAG,YAP, LSO, LYSO, LaBr, etc.)
- doped glasses (with Tb, Ce)

Relevant parameters

- Light decay time (pulse duration)
- Emitted light spectrum
- Attenuation length
- Light yield
- Radiation hardness
- Physical and chemical properties (heat and electric conductivity, thermal stability, melting point, heat dissipation)

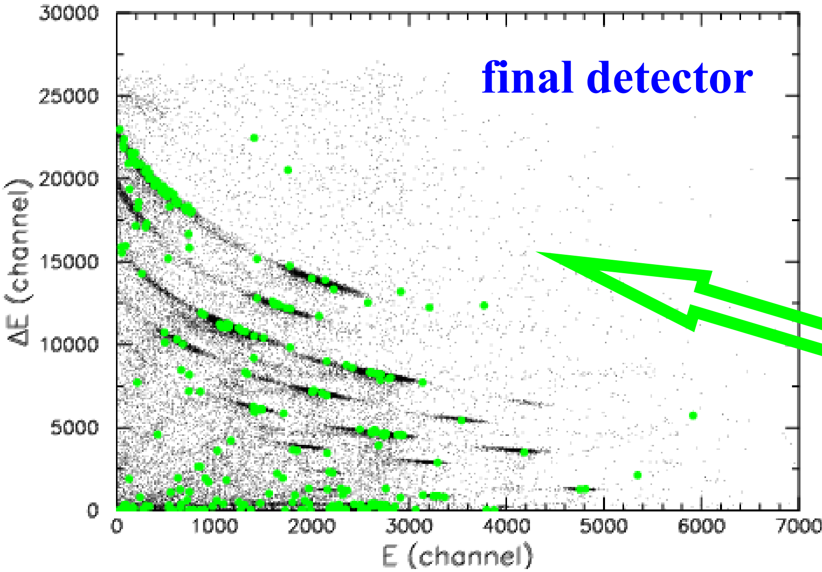
FIBBS (Fibre Based Beam Sensor)

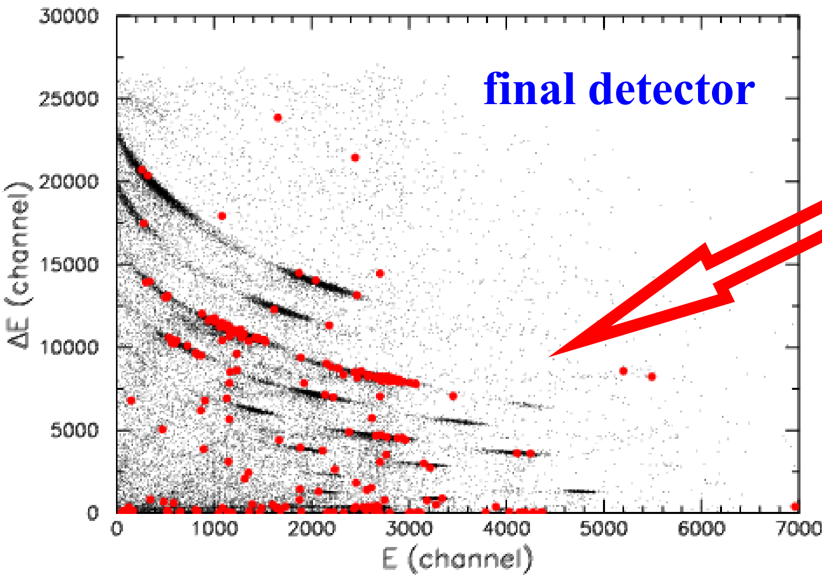




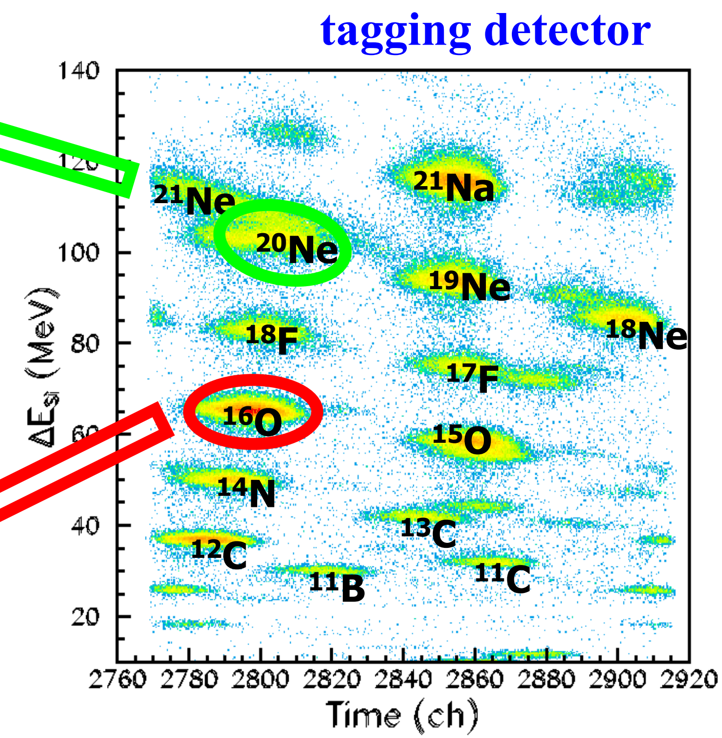
NIM A 419 (1998) 83

Projectile Selection: Tagging Procedure

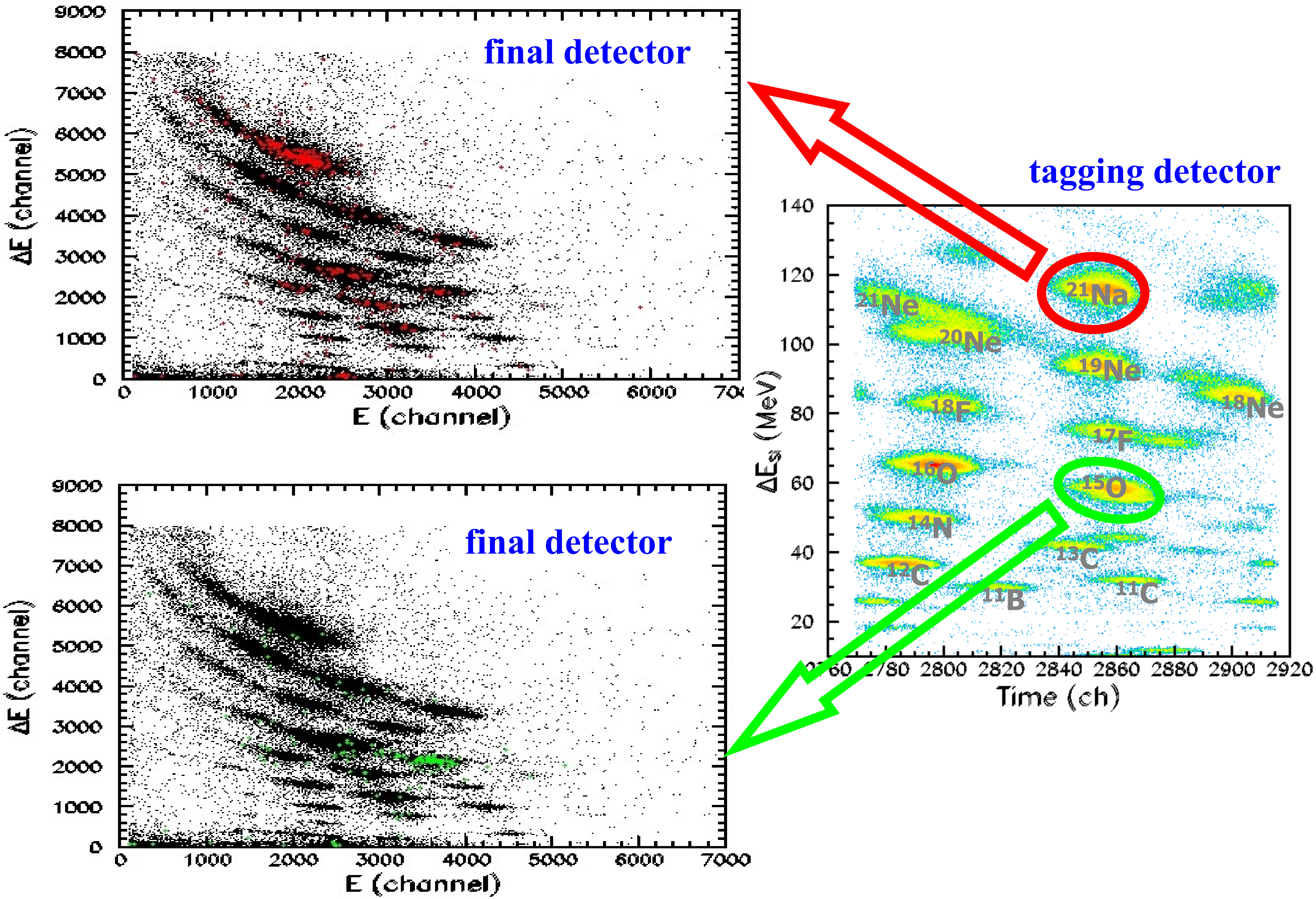




Identification can be checked looking to the ΔE-E scatter plot in forward detectors

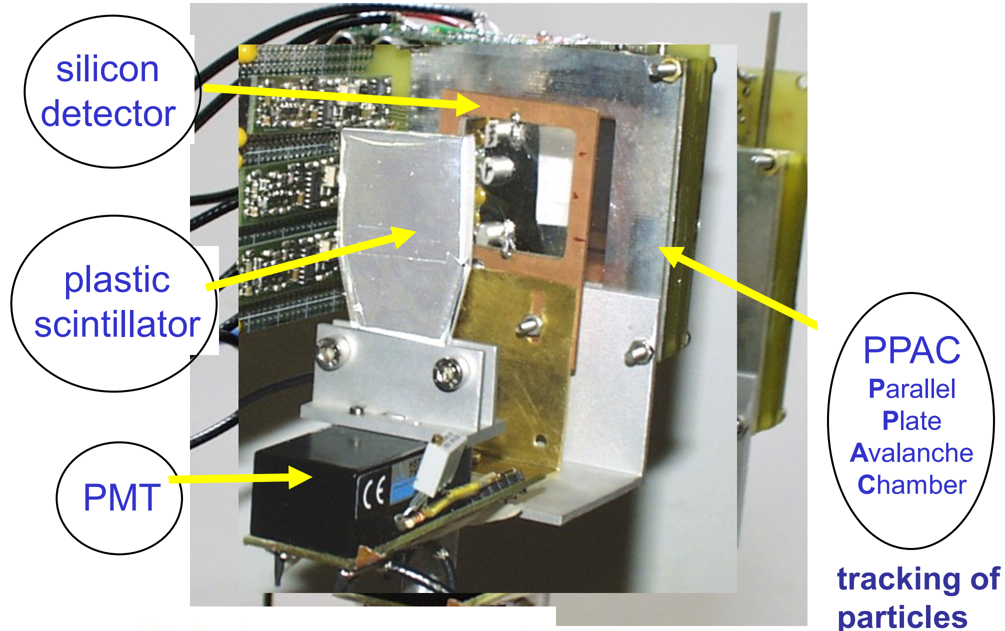


Tagging Procedure

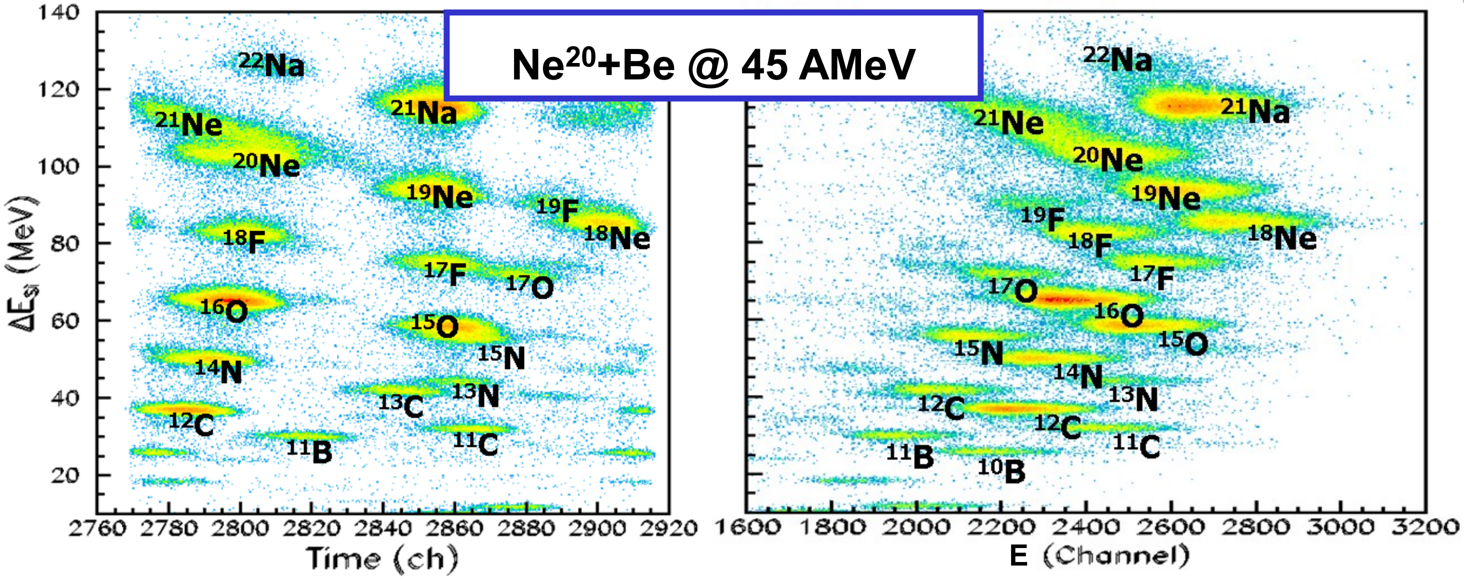


In-flight production of radioactive beams (FRIBs)

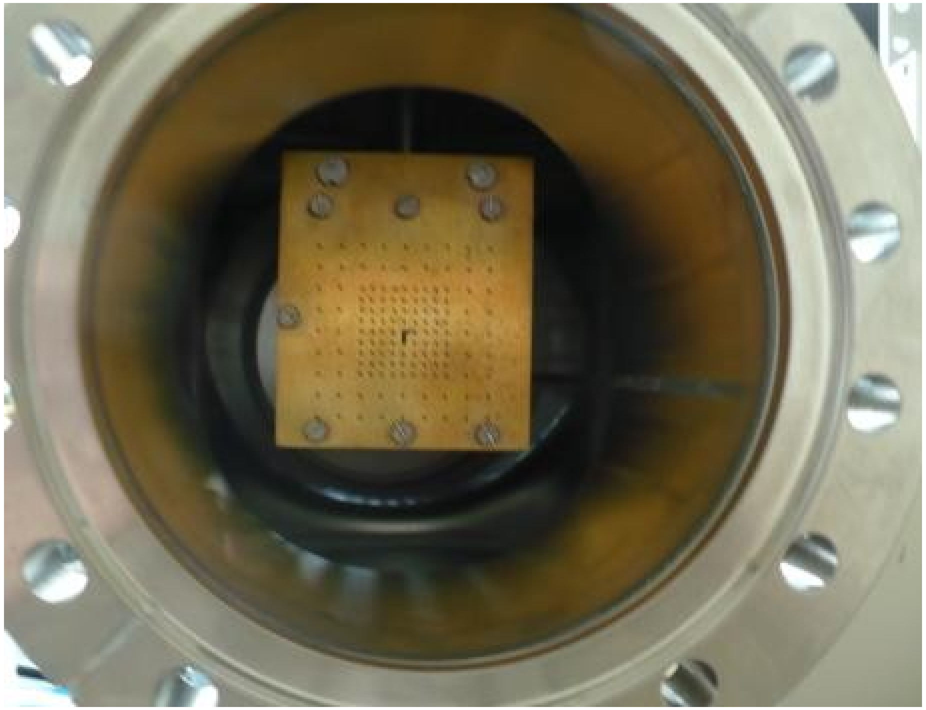
Detector used in FRIBs points, for monitoring the beam and tagging the particles

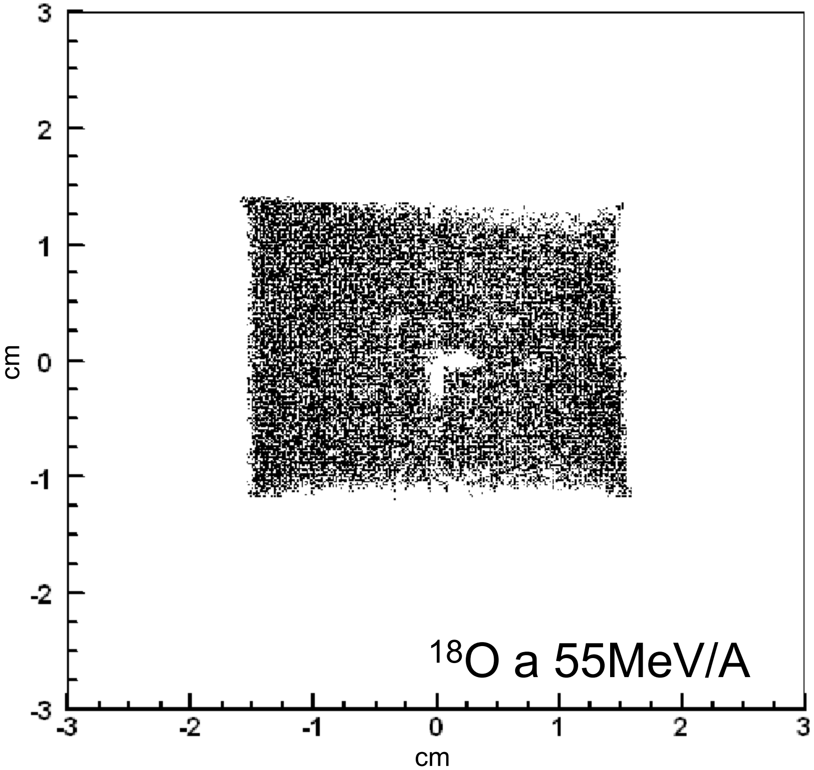


tracking of particles

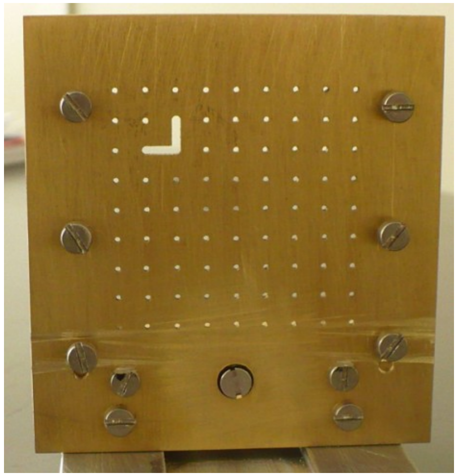


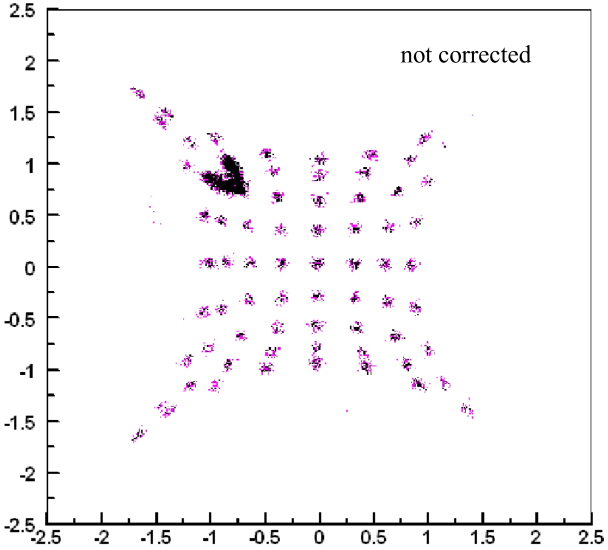
CS energy (FRIBs beams)

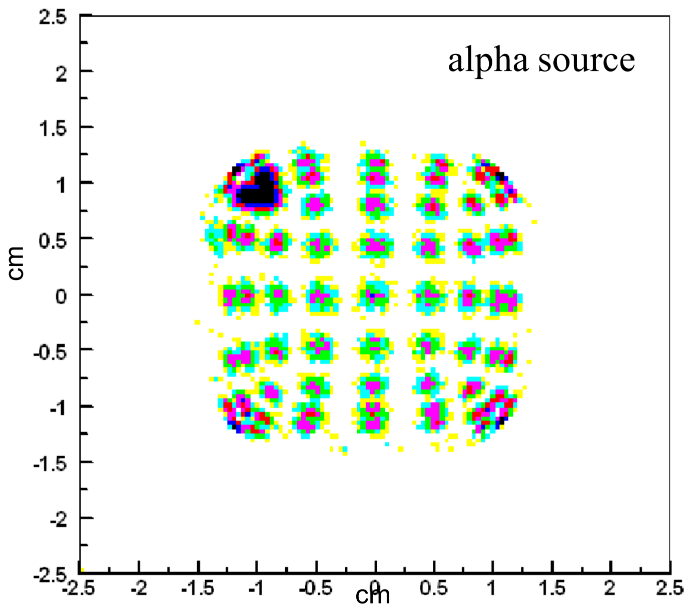




Tandem energy







real time correction of the shape distortion