Diagnostic Devices for Radioactive Ion Beams at INFN - LNS

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INFN - Laboratori Nazionali del Sud

SPES2010 International Workshop

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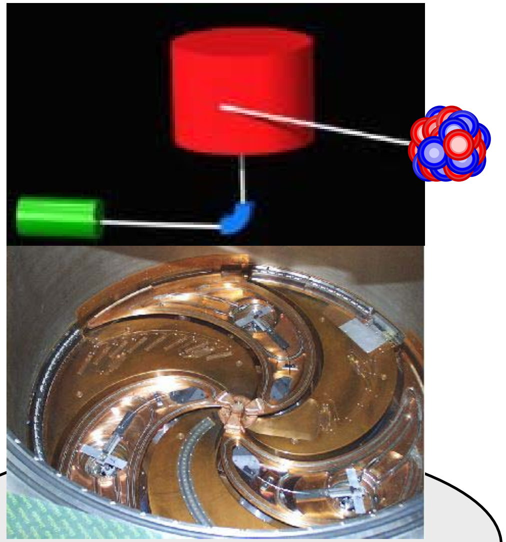
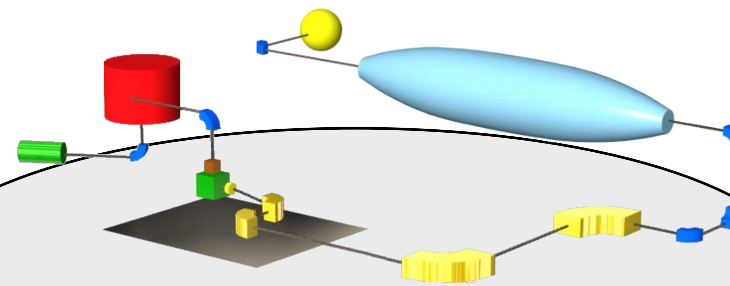
Accelerators at LNS



Superconducting Cyclotron
<80MeV/amu

Tandem 15MV



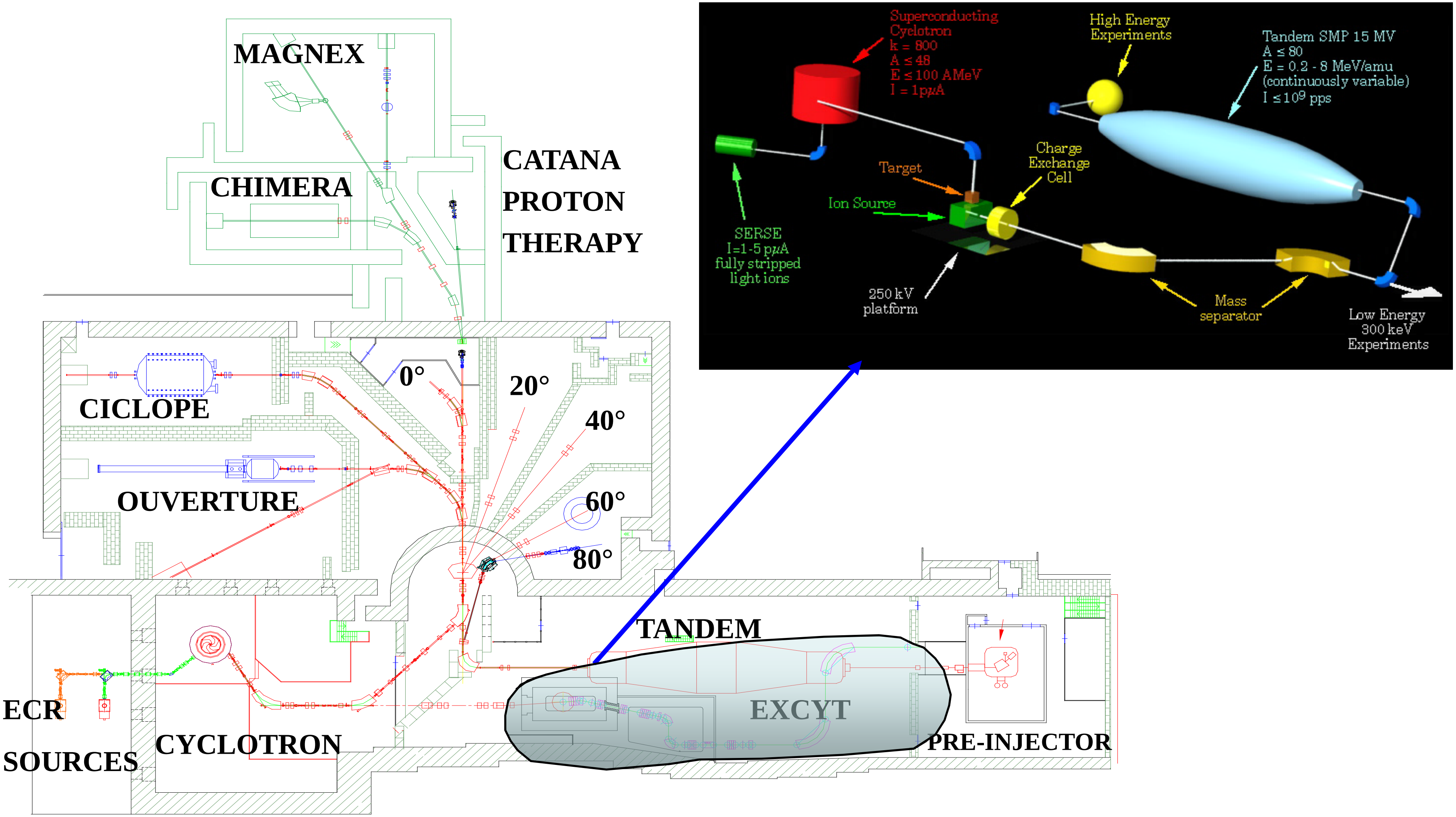
EXCYT facility: ISOL radioactive ion beams

Enegy ranges: 10keV ÷ 300keV
Tandem energy

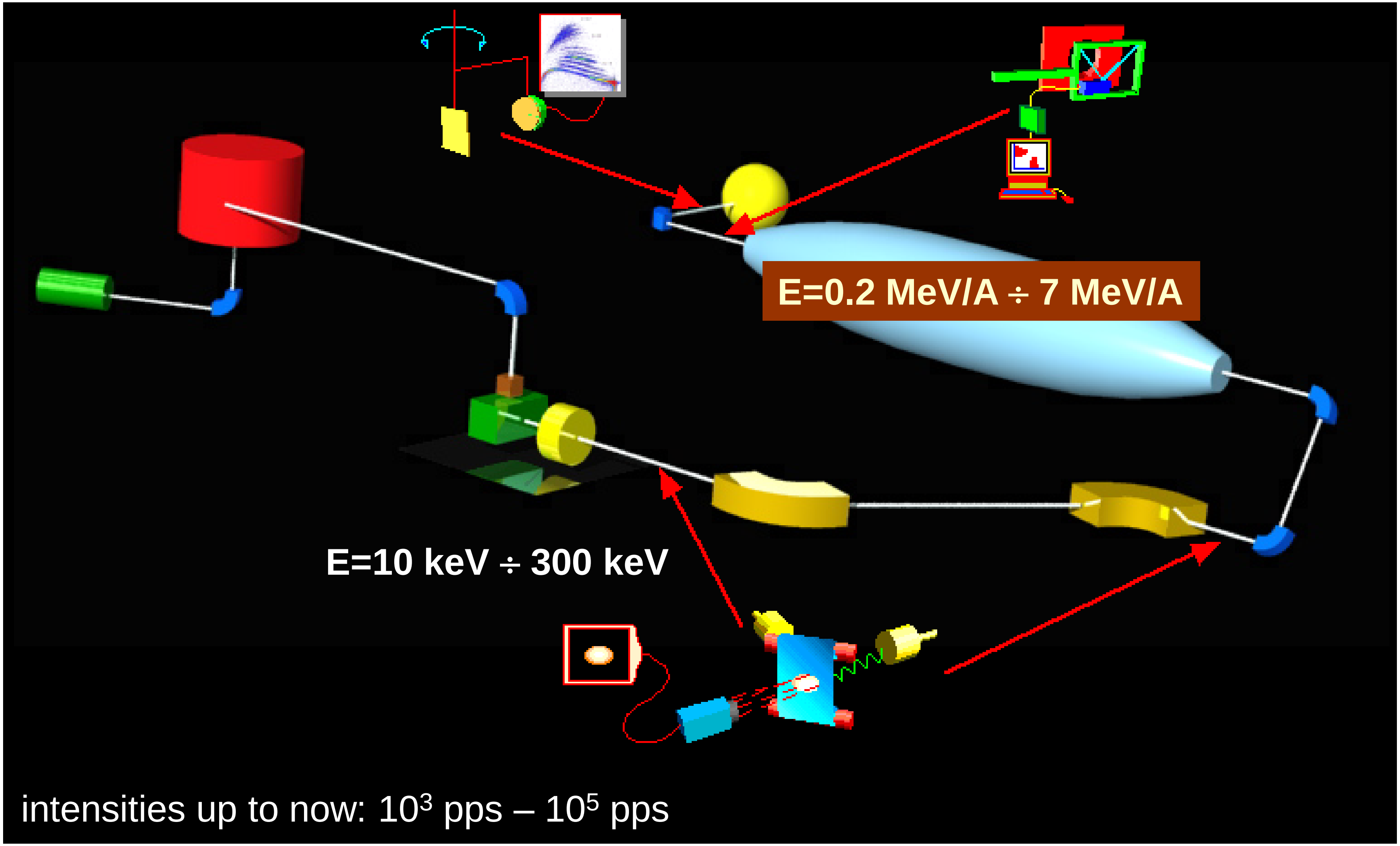
FRIBs: in-flight fragment separator

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 is to use **particle detectors**

Available techniques

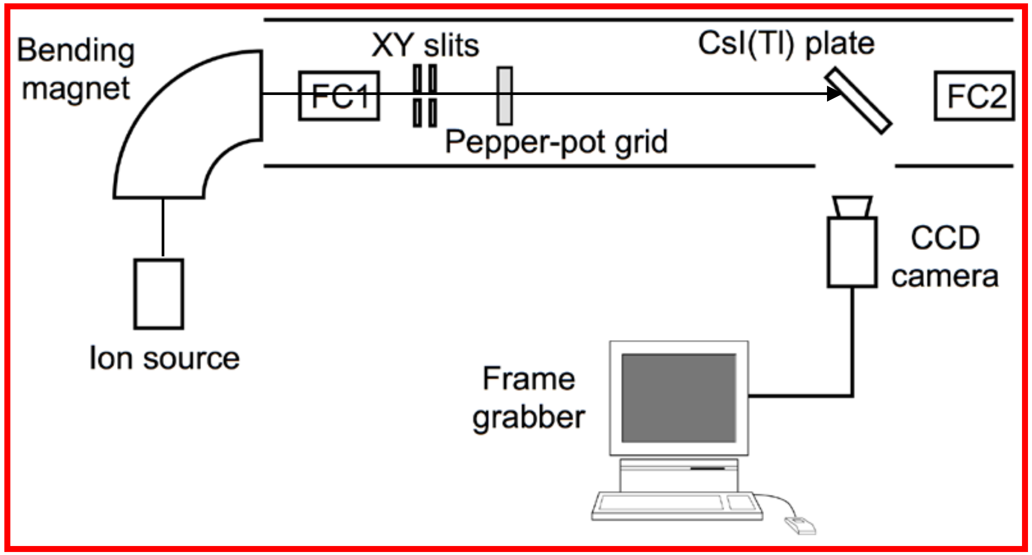
- Semiconductors
- Scintillators
- Secondary emission
(with physical amplification, e.g.: MCP)

in use at LNS

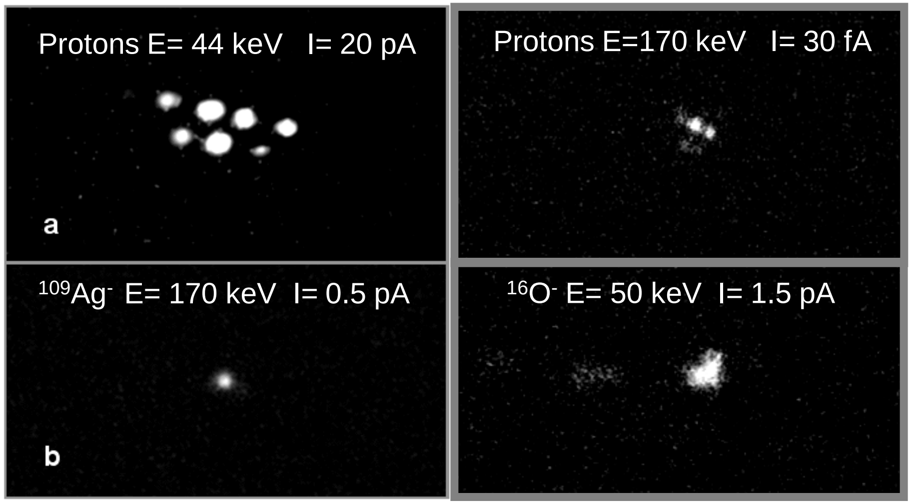
- Gas detectors
- Diamond
- Others: Cherenkov, etc.

Low energy beam Imaging with CsI

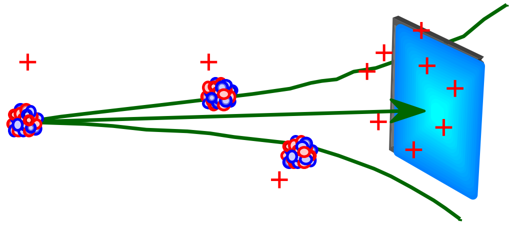
beam imaging: CsI(Tl) scintillating screen and high sensitivity CCD video camera

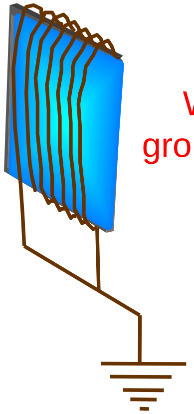


beam diagnostics of very low-energy and low-intensity ion beams from the Tandem injector at LNS



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



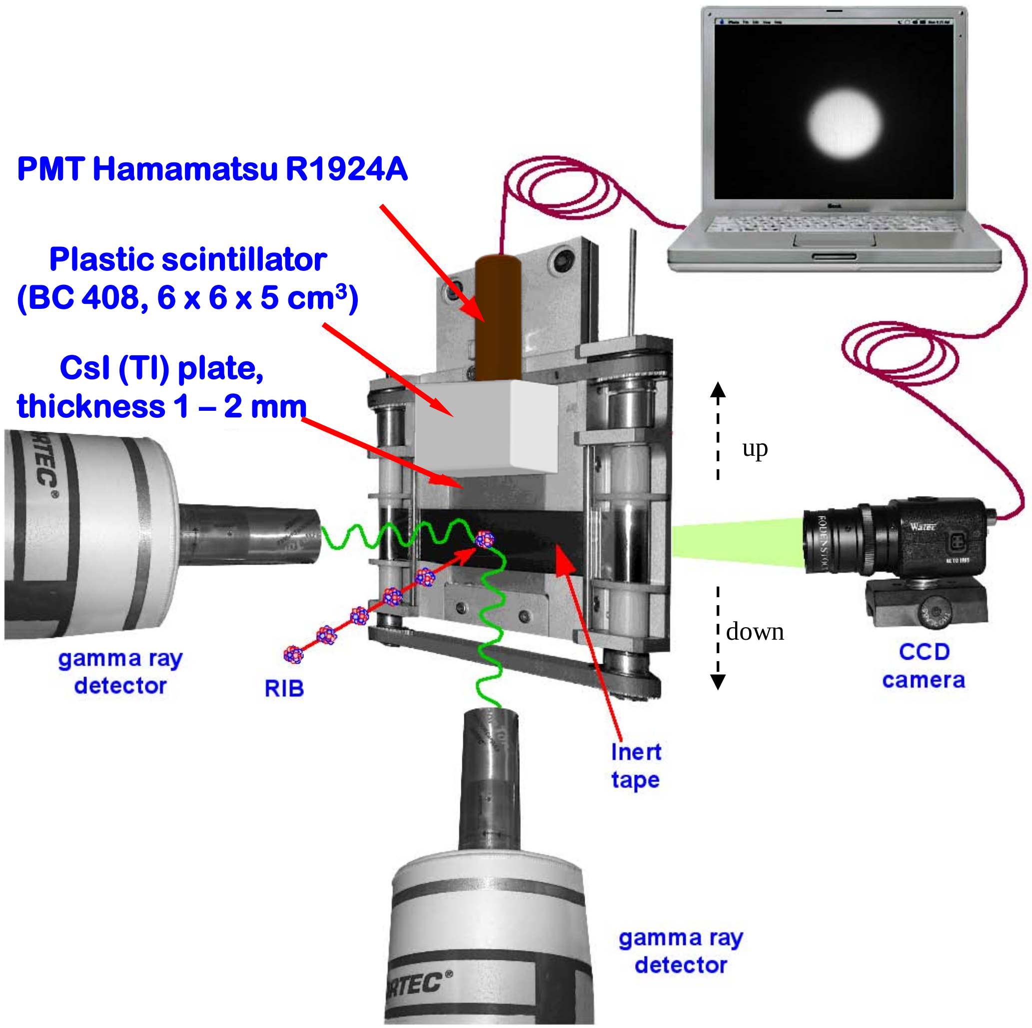


We wound it with a grounded conductor wire

NIM B 211 (2003) 443

Diagnostics for Low Energy RIBs

LEBI:
Low Energy Beam Imager / Identifier



three different heights

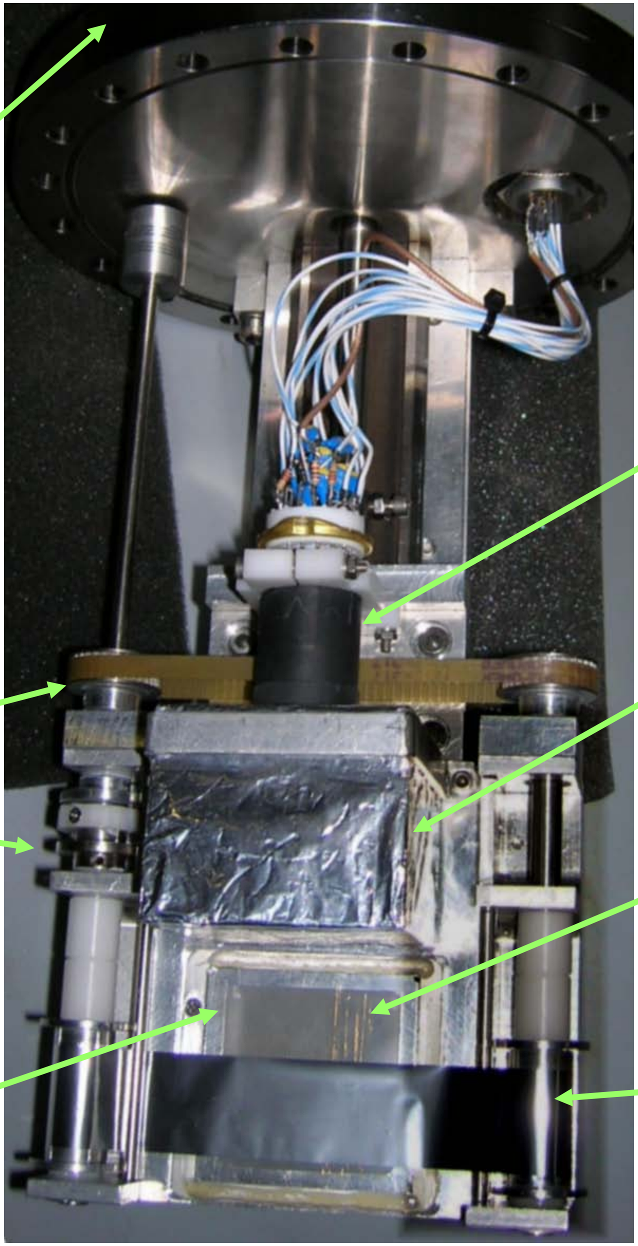
- Imaging of Stable (pilot) beams
- Imaging of radioactive beams
- Beam rate measurement
- Decay curve reconstruction

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

NIM A 479 (2002) 243

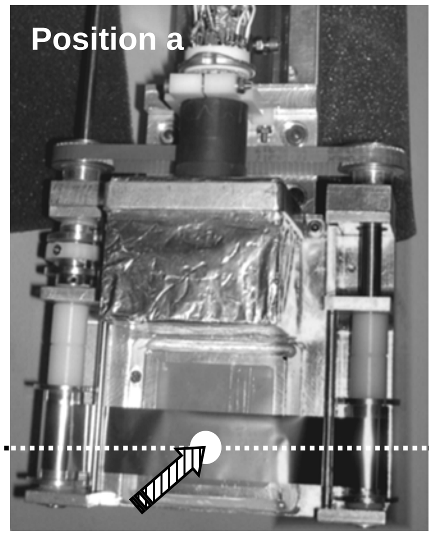
NIM A 622 (2010) 512

Diagnostics for Low Energy RIBs

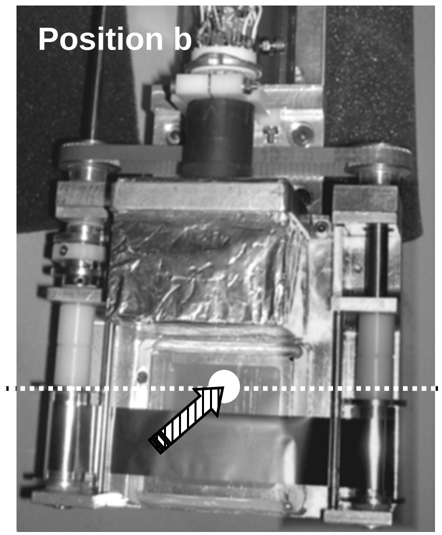


Three working positions

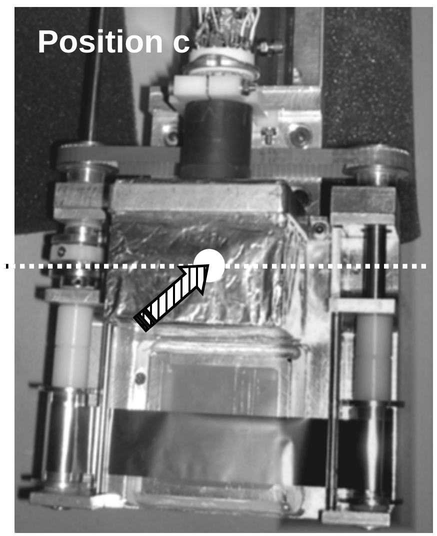
beam axis



radioactive beam imaging



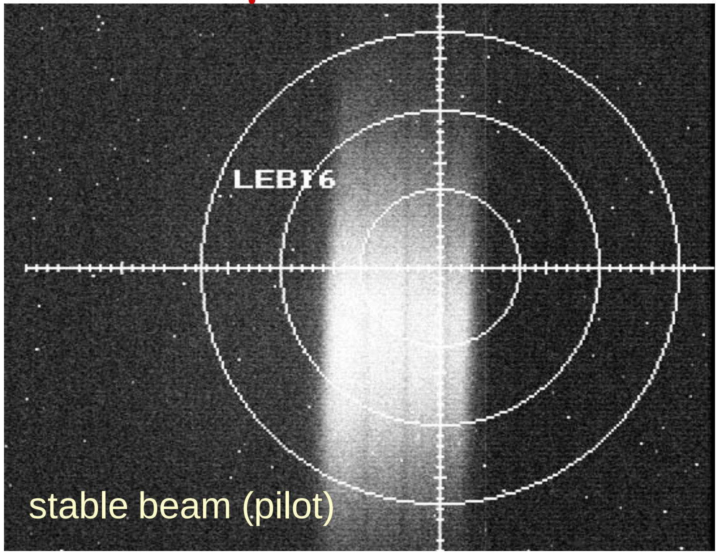
stable beam imaging



beam counting/identification

LEBI
Low Energy Beam Imager/Identifier

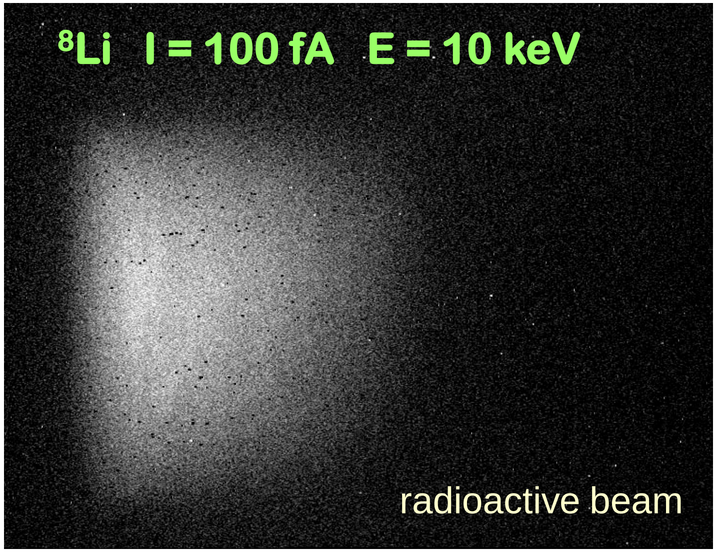
^{7}Li I = 10 pA E = 10 keV

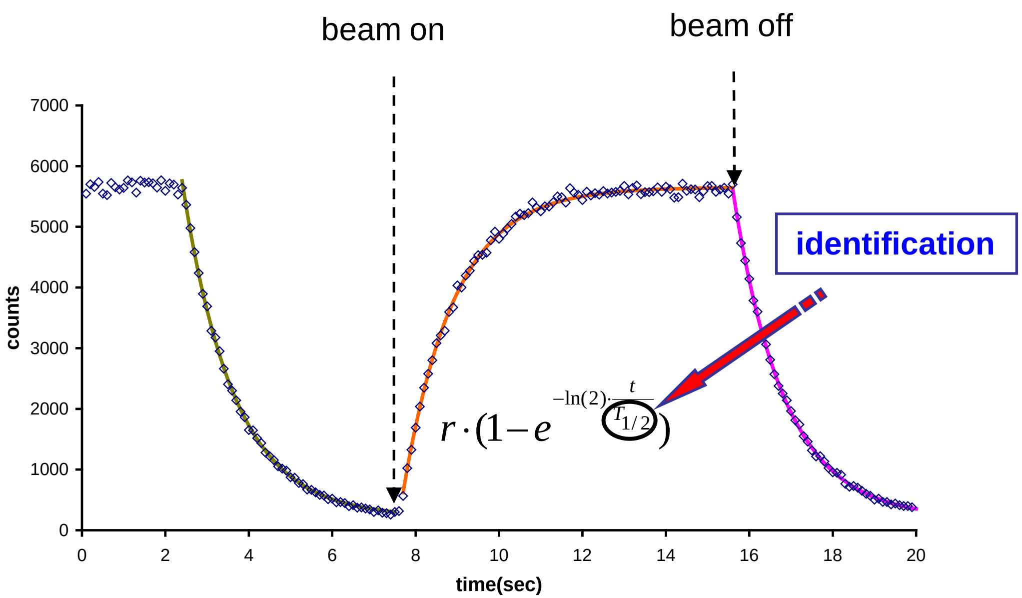


energy range
10 keV ÷ 300 keV

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





$$r \cdot (1 - e^{-\ln(2)\cdot\frac{t}{T_{1/2}}})$$

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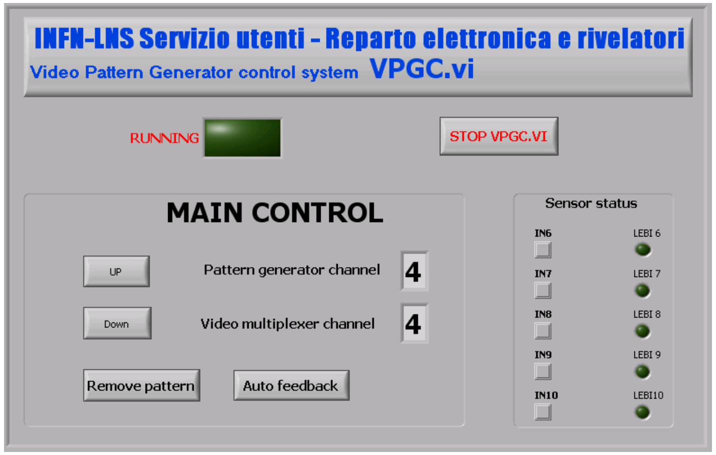
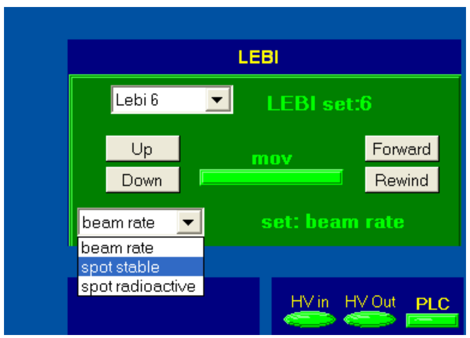
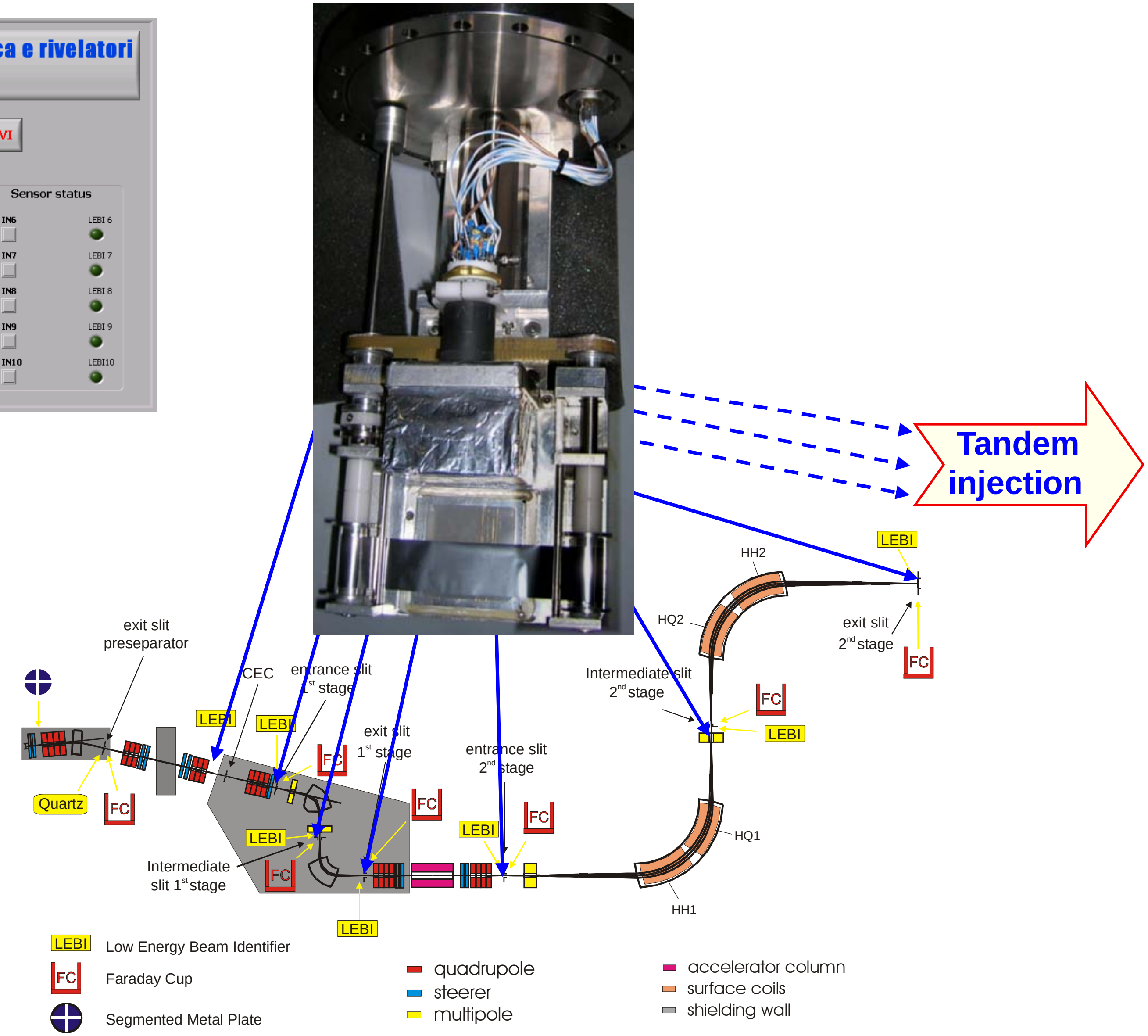
10 LEBI working along the EXCYT beam line



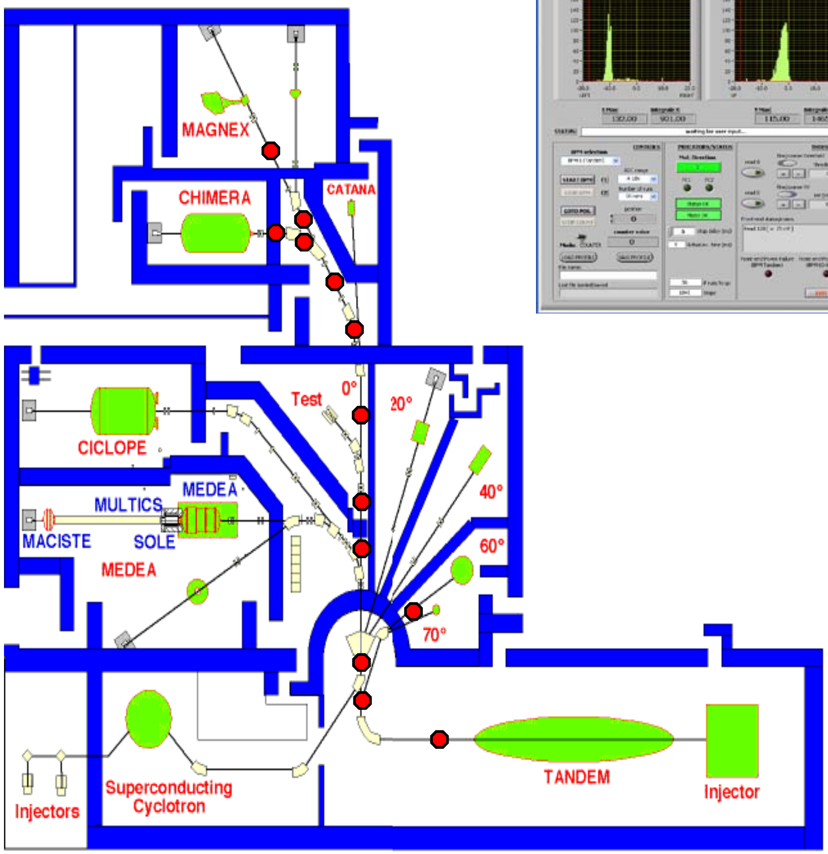


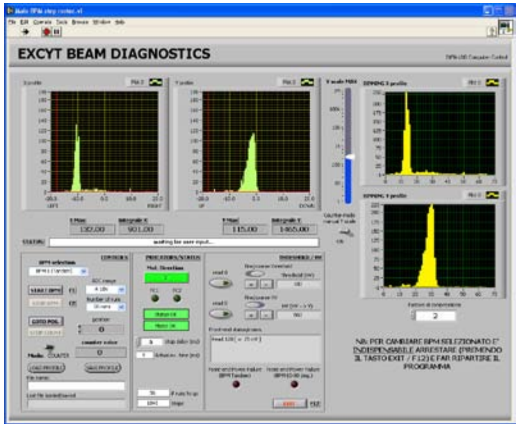
Graphical User Interface extremely easy to use

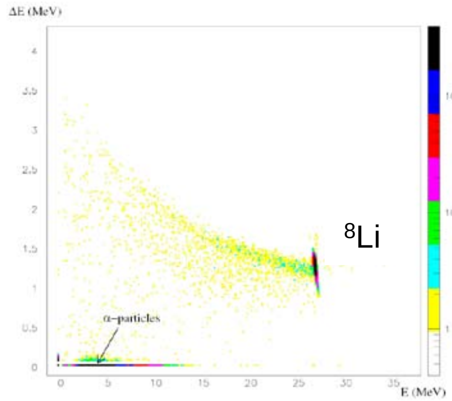


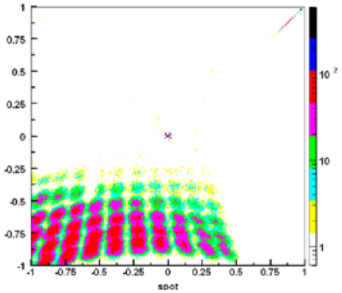
Diagnostics for accelerated RIBs

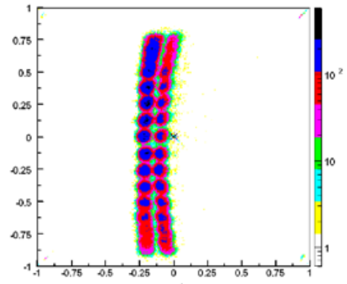
Low intensity diagnostics (sensitivity down the single particle, upgraded during 2010 for providing the long beam lines (Magnex and Chimera)

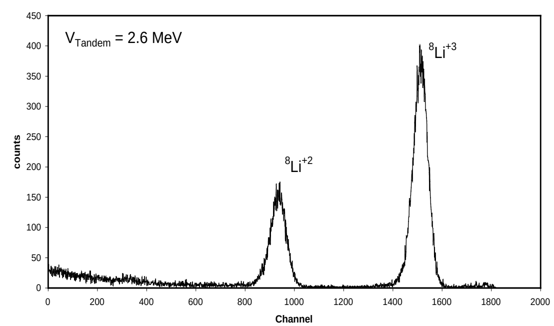




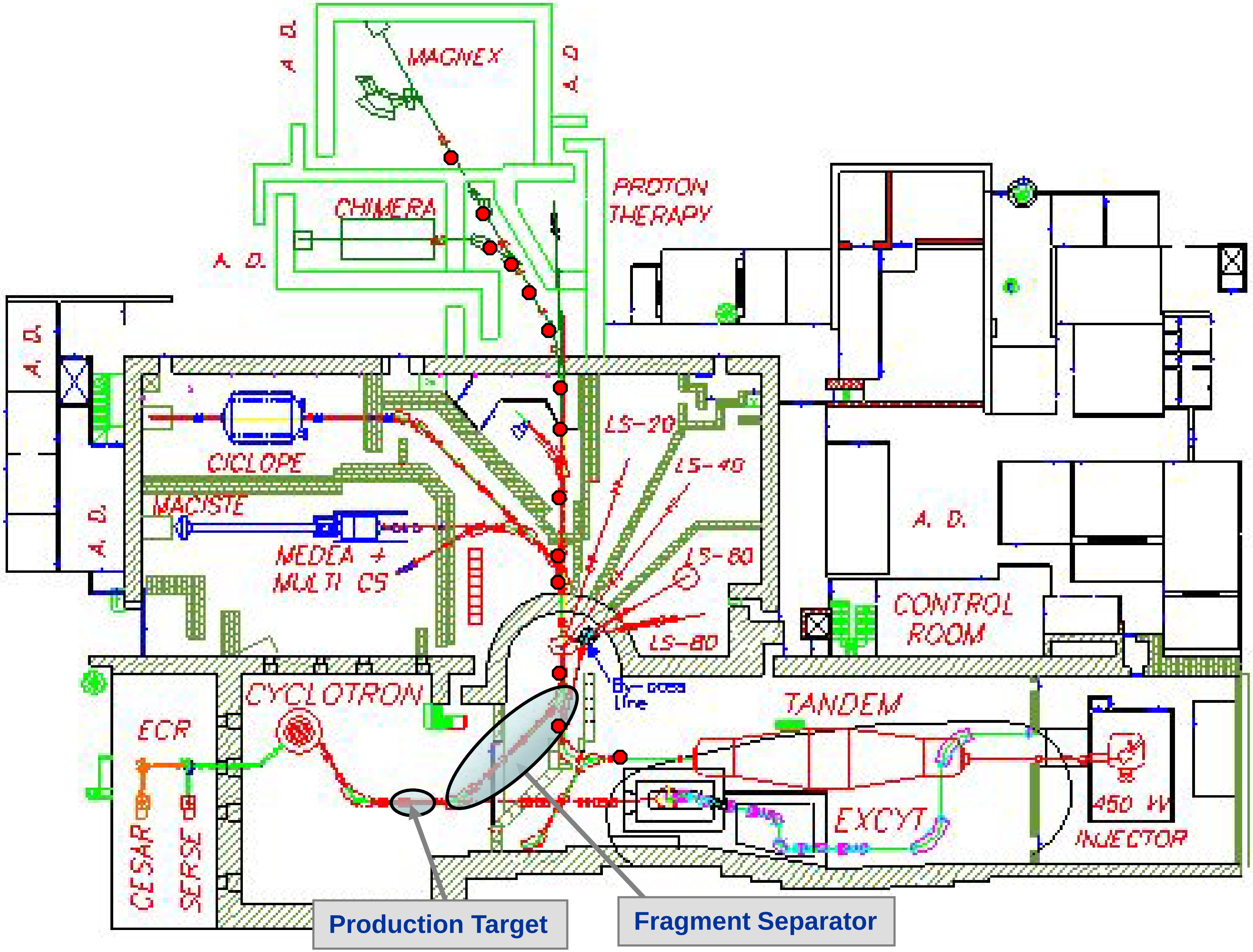






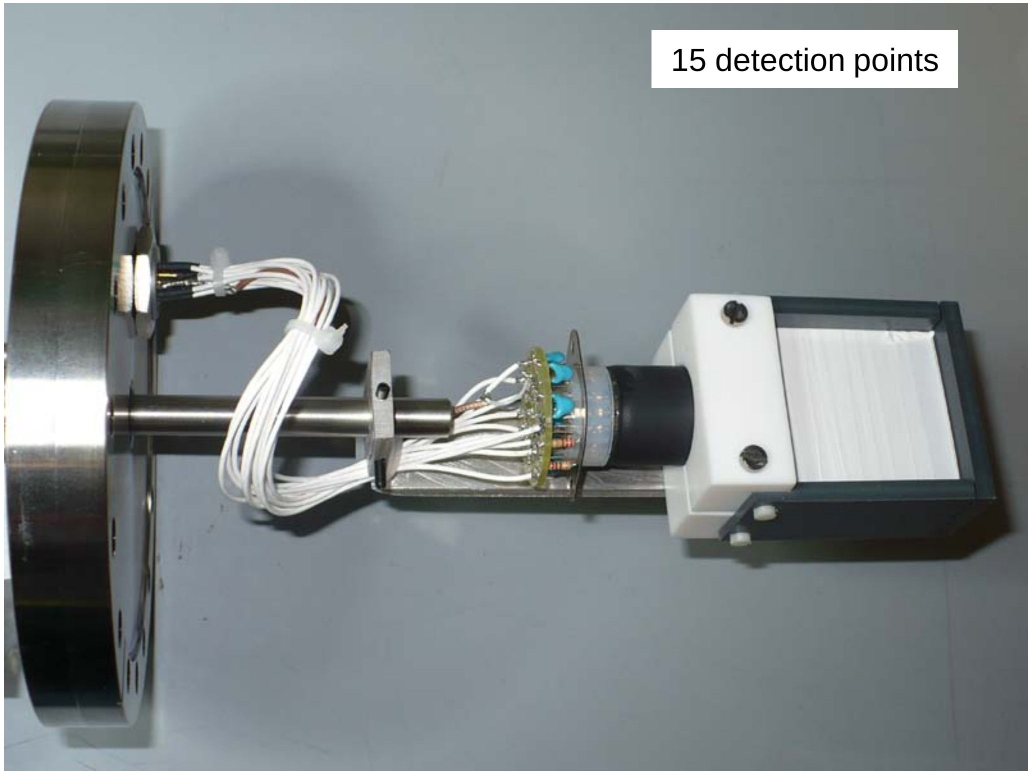


Same diagnostics for In-flight production of radioactive beams

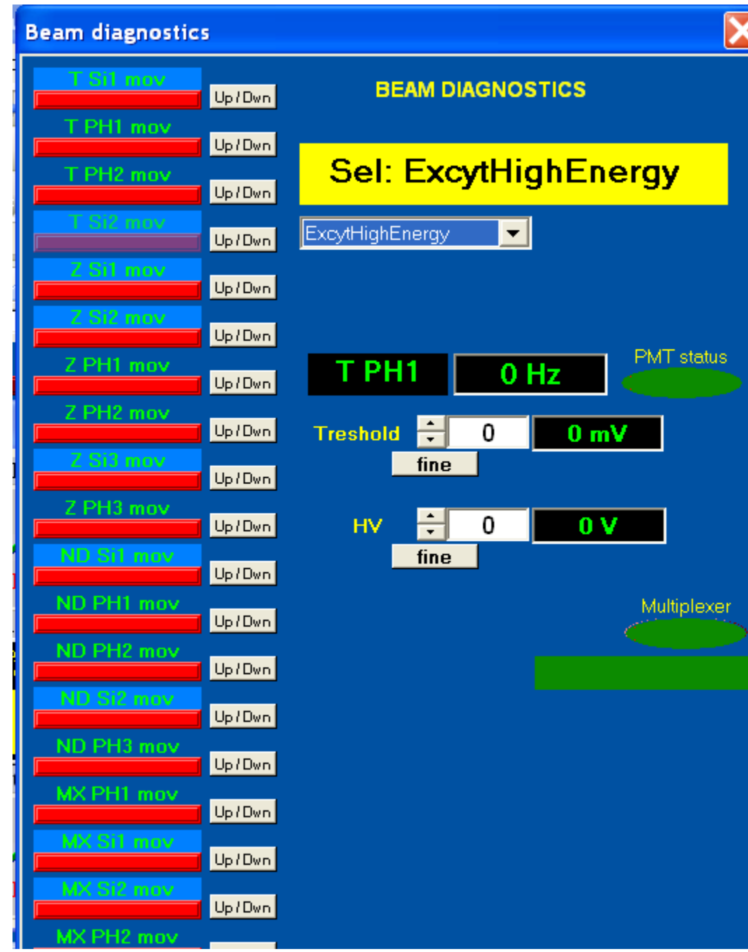


G. Raciti et al, NIM B 266 (2008) 4632

Beam counting



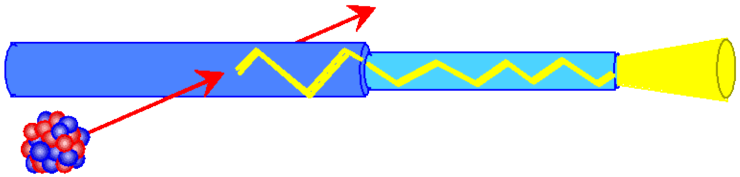
Plastic scintillator (BC408) optically coupled to a small PMT, working in pulse counting mode

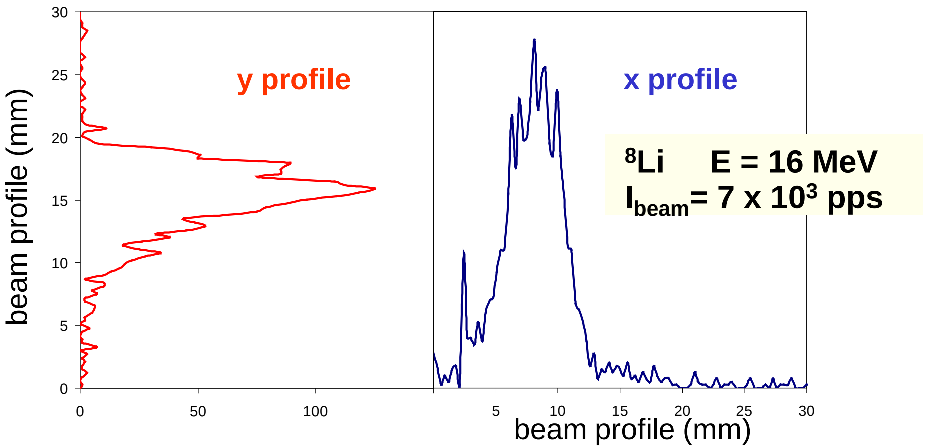


for beam intensity below 10^6pps

1D beam X-Y profiles

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





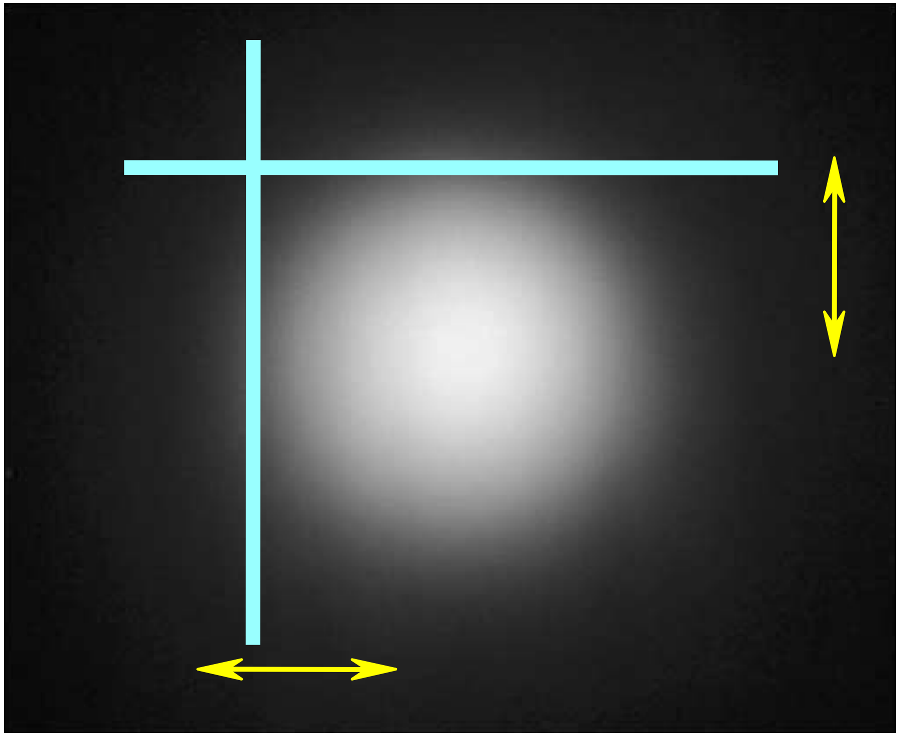
Light collection efficiency at one end: ≈3.5%

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

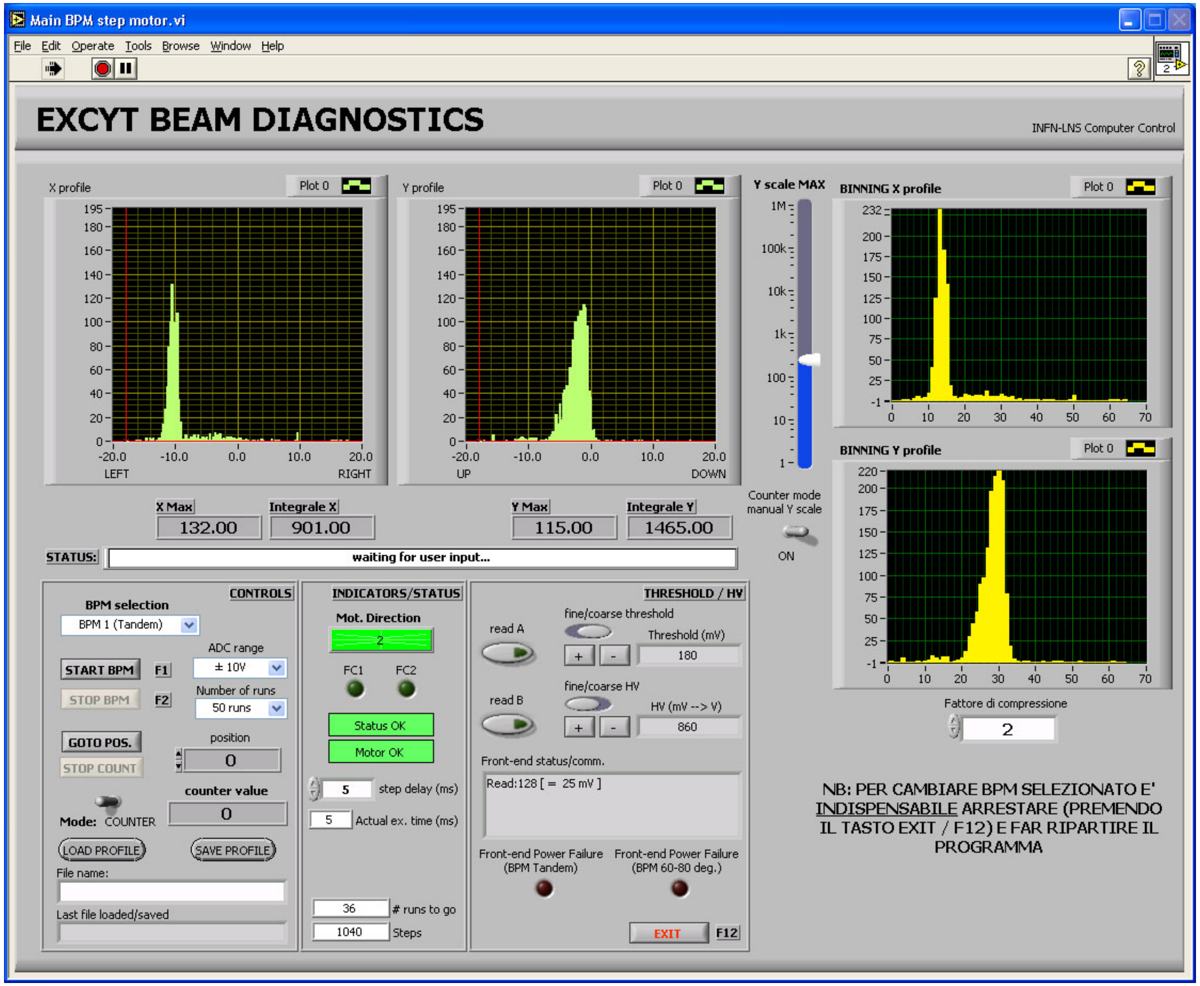
•Plastic scintillating fibre: fast (3ns), not rad-hard, L_{at}≈3.5m, λ≈435nm

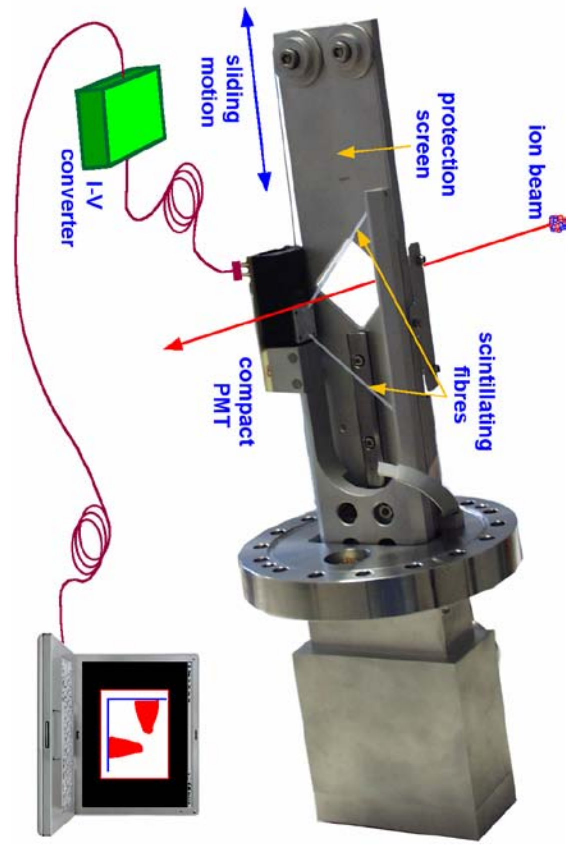
•Tb-glass scintillating fibre: slow (4ms), rad-hard, L_{at}≈10cm, λ≈550nm

•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

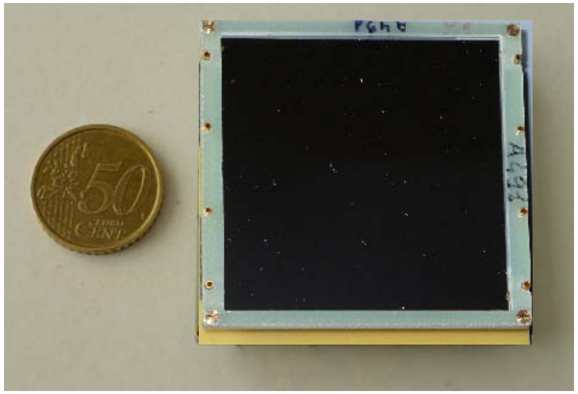
Plastic fibres for lower intensity

Position sensitive silicon detector

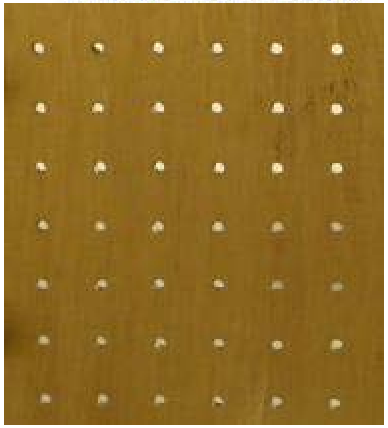
position sensitive silicon telescope for RIB identification and profiling

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

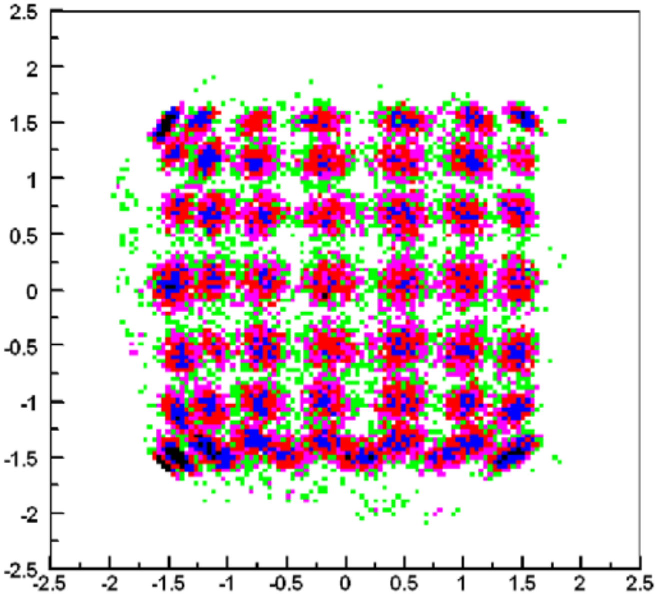
5cm x 5cm Si detector



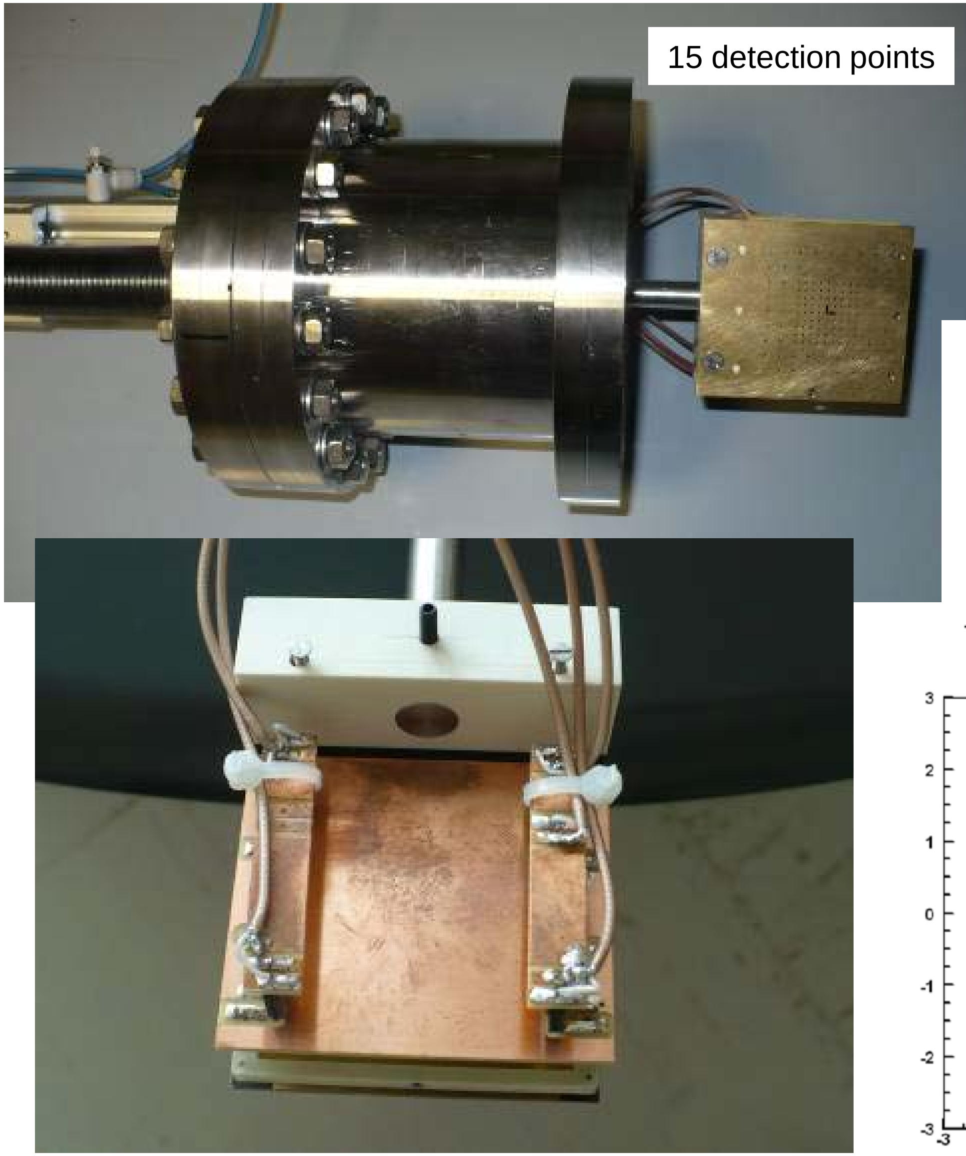
multi-hole mask



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



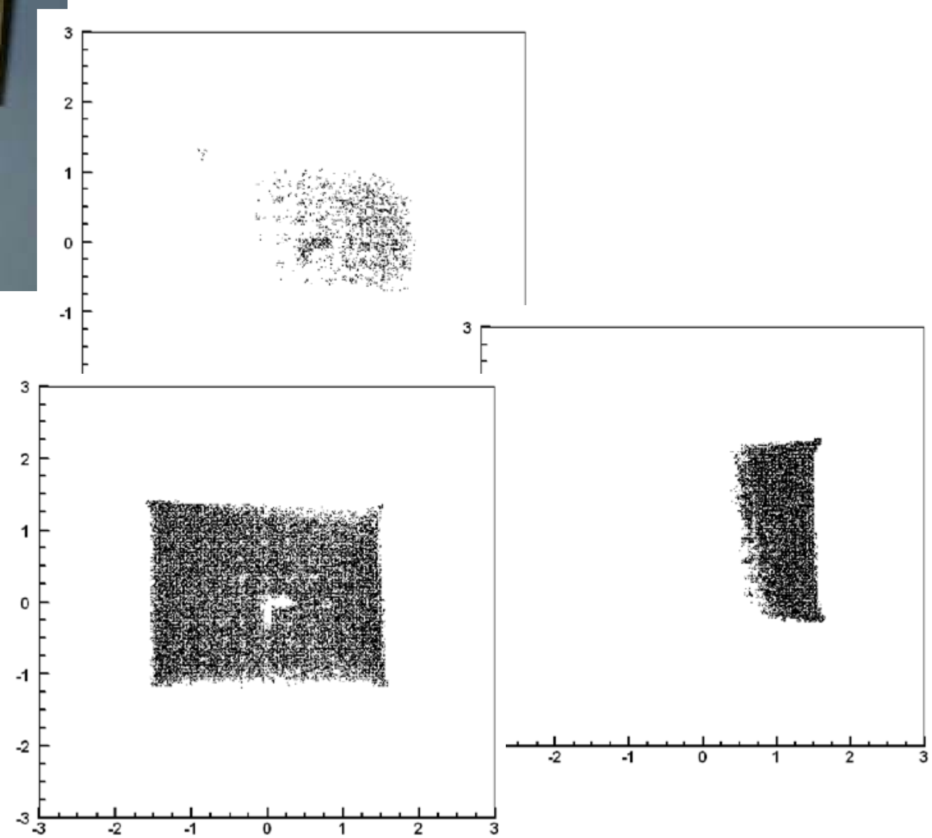
Position Sensitive Silicon Detector



<u>Real time beam imaging</u>.

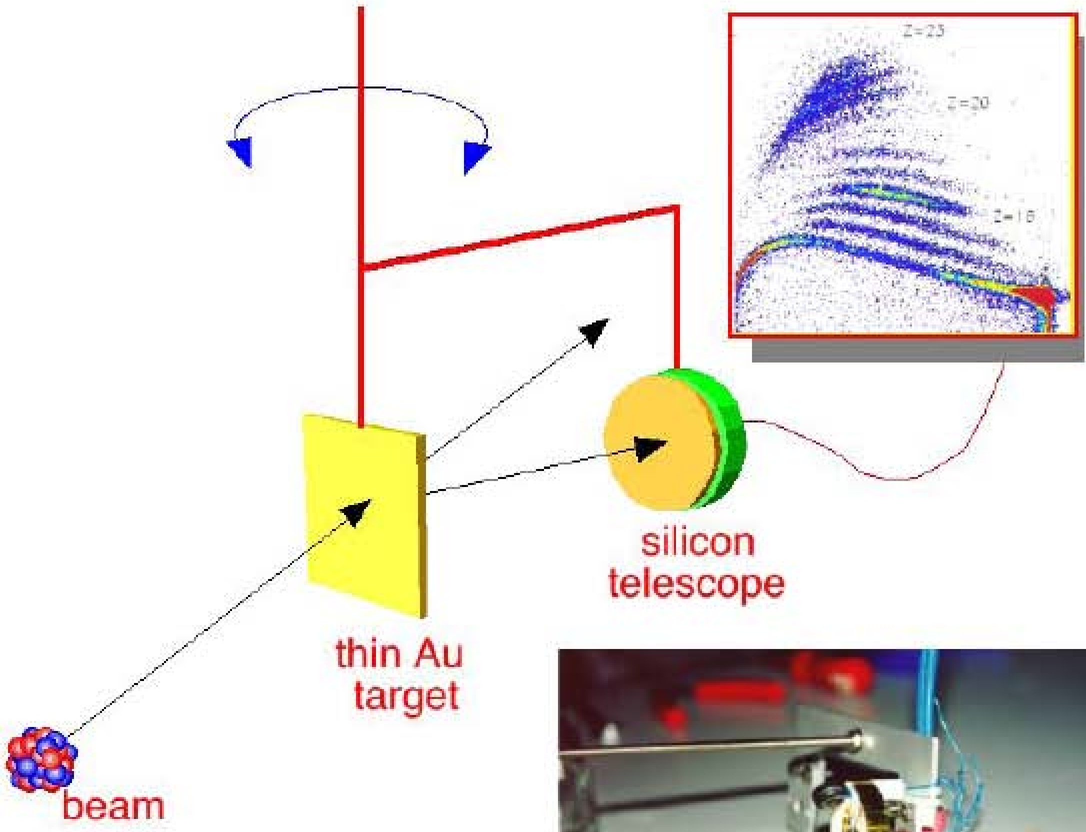
particle position reconstructed by 4 signals from the PSSD corners. Spatial resolution 1 – 2 mm

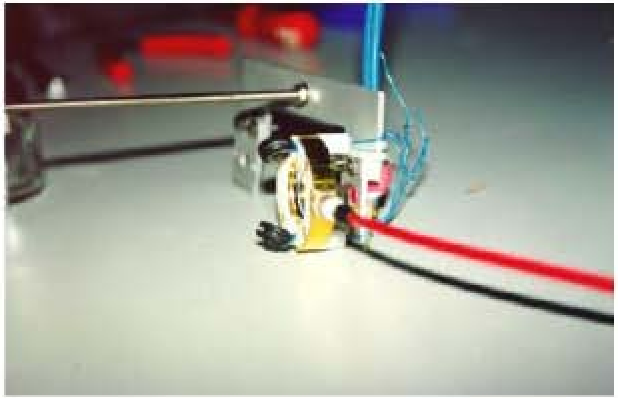
The beam intensity must be kept below 10^4 pps



Silicon telescope

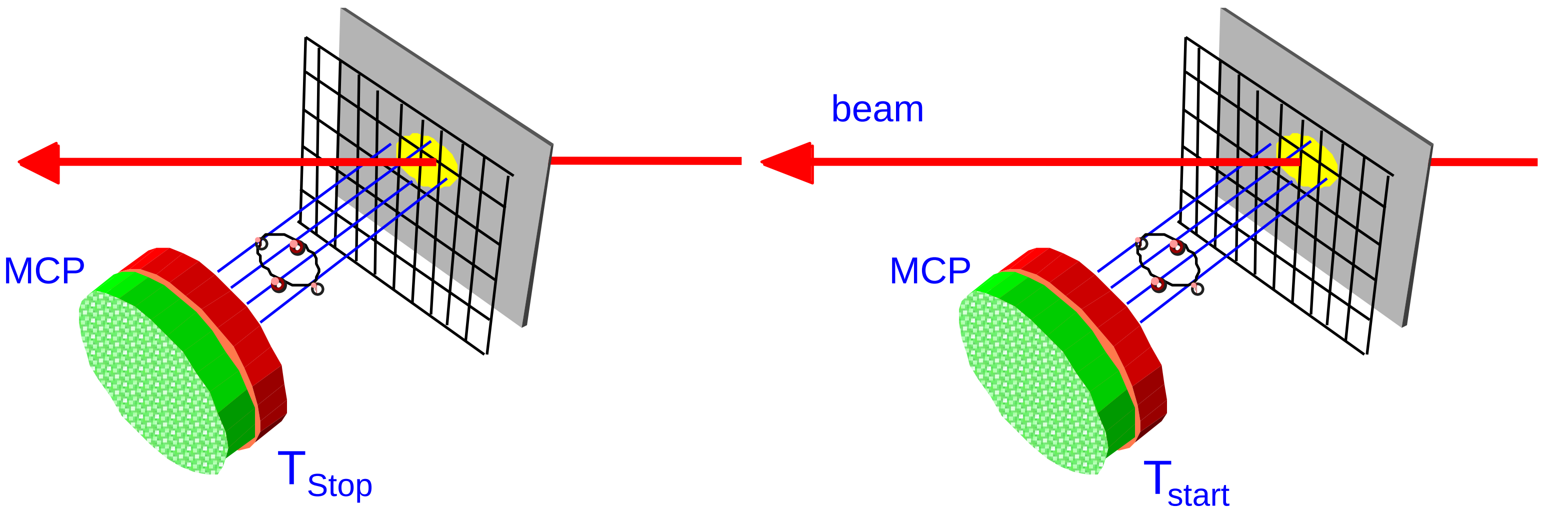
telescope for RIB identification

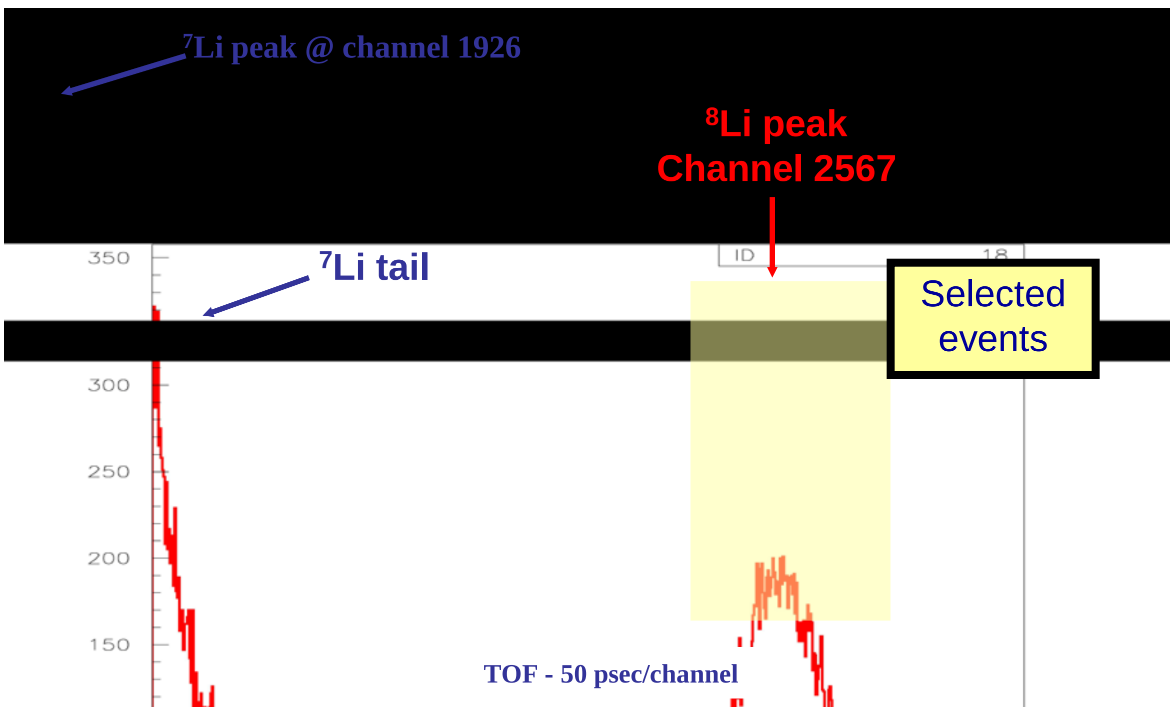




- thickness ≈ 50 + 500 μm
- unambiguous identification of isotopes by elastic scattering
- at low beam intensity can be used directly on the beam
- intensity measurement by means of counting rate
- cost: reasonable

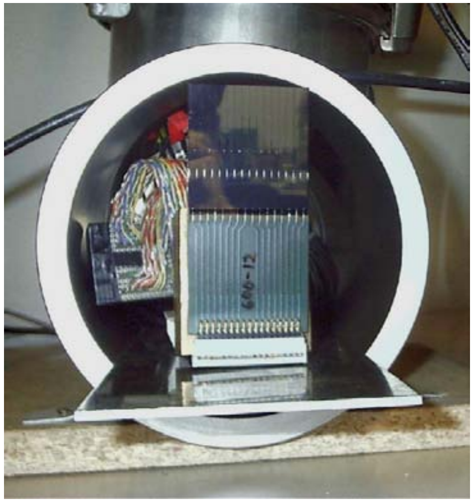
Ions Tagging with Time Of Flight





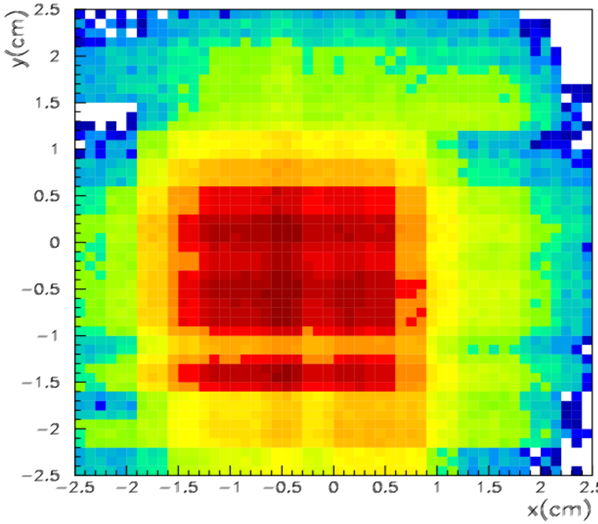
On-line discrimination between ions having same energy but different mass.

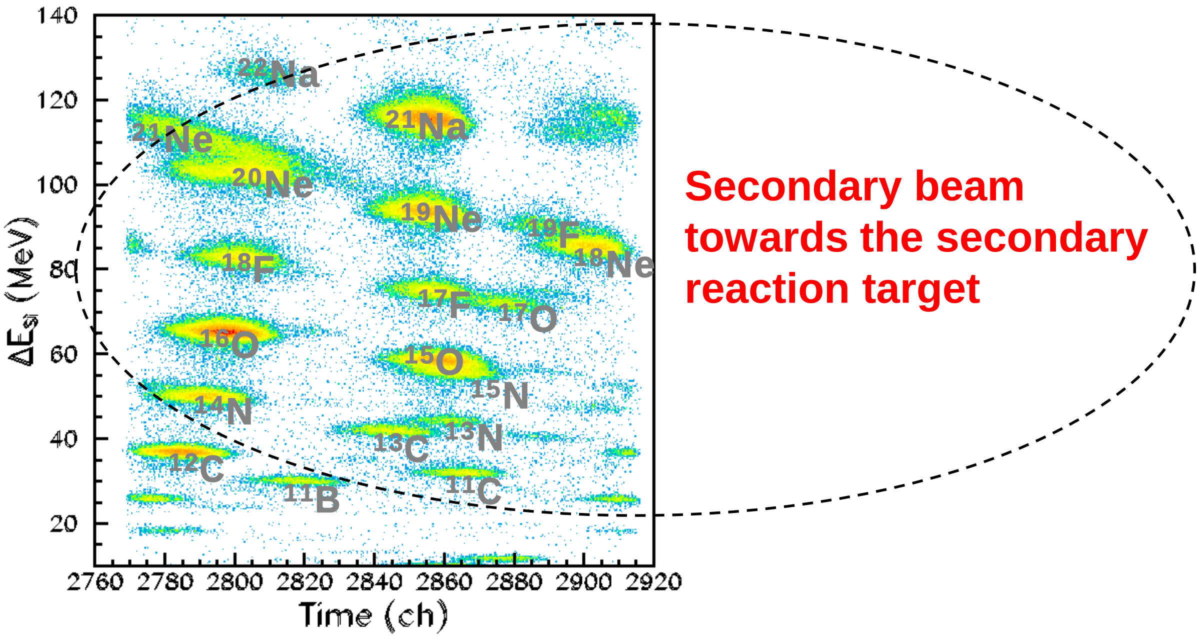
Multi-strip silicon detector for ions tagging



16x16 X-Y strips
5 x 5 cm^2

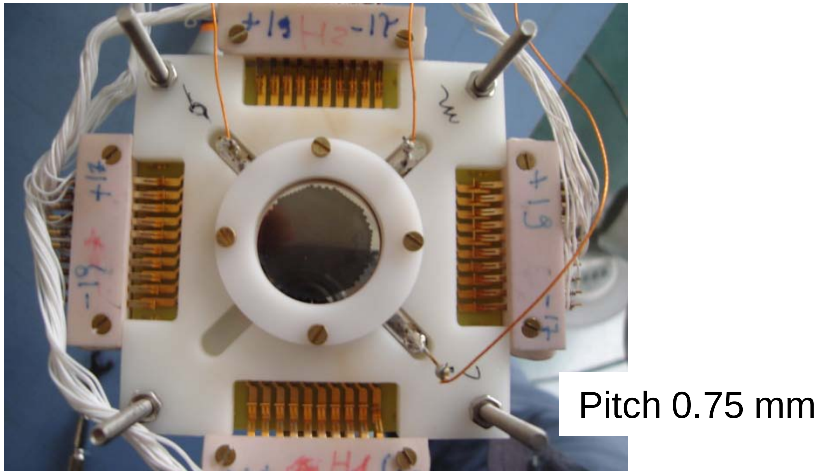
Time reference can be given by the RF or by a MCP





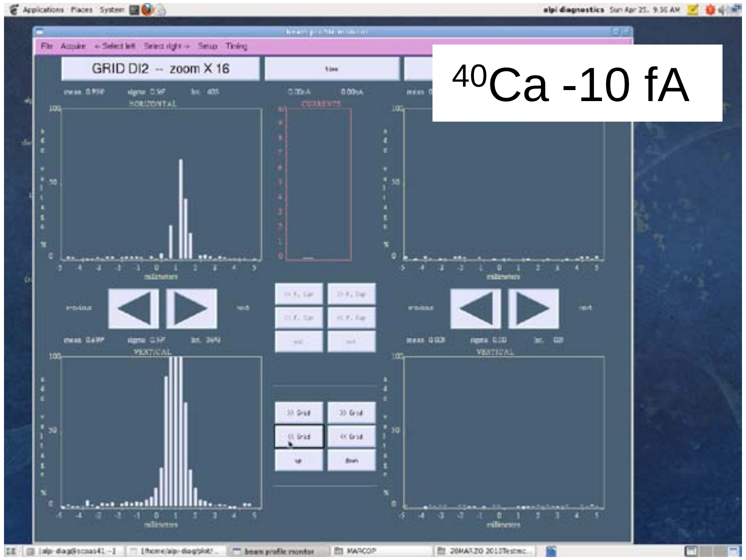
Secondary beam towards the secondary reaction target

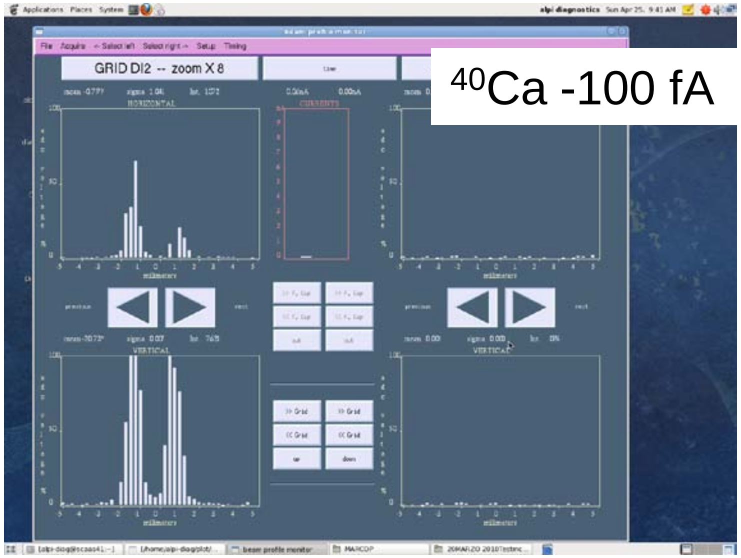
1D Beam profile monitor based on MCP for SPES



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.

Tested successfully at LNS with a 50 keV ^{16}O beam.

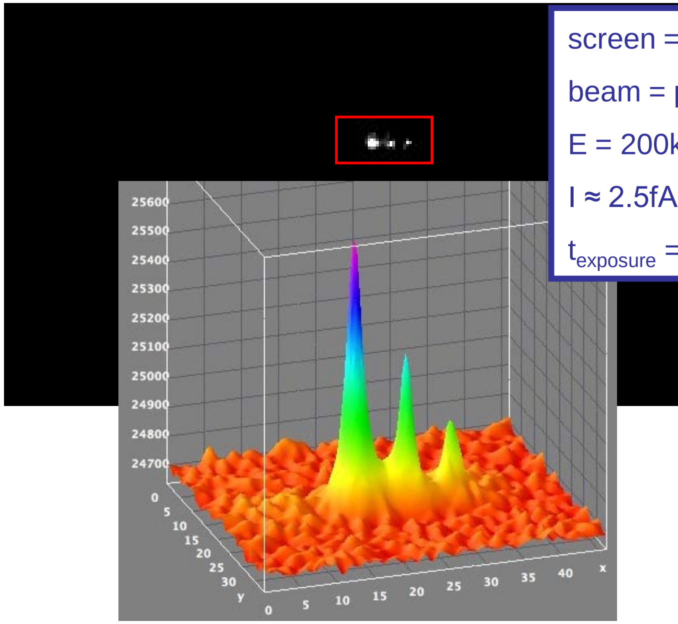




New diagnostics challenge: LNS in the DITANET european network

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

antiproton beam imaging at FAIR? We need sensitivity below 1fA



screen = CsI (Tl)

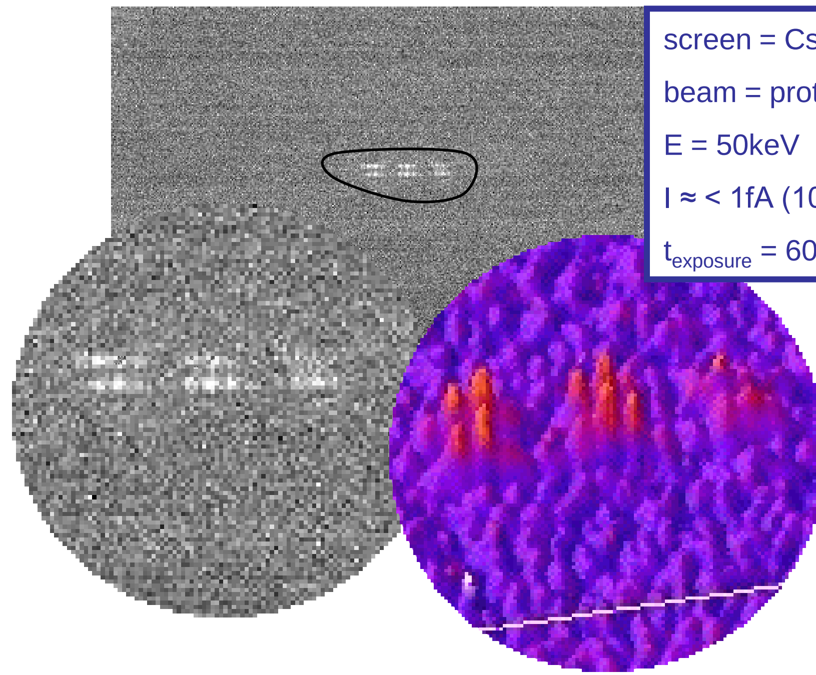
beam = protons

E = 200keV

I ≈ 2.5fA (10^4 pps)

$t_{exposure}$ = 20s

high performance photocamera Chroma CX3 14-bit cooled CCD



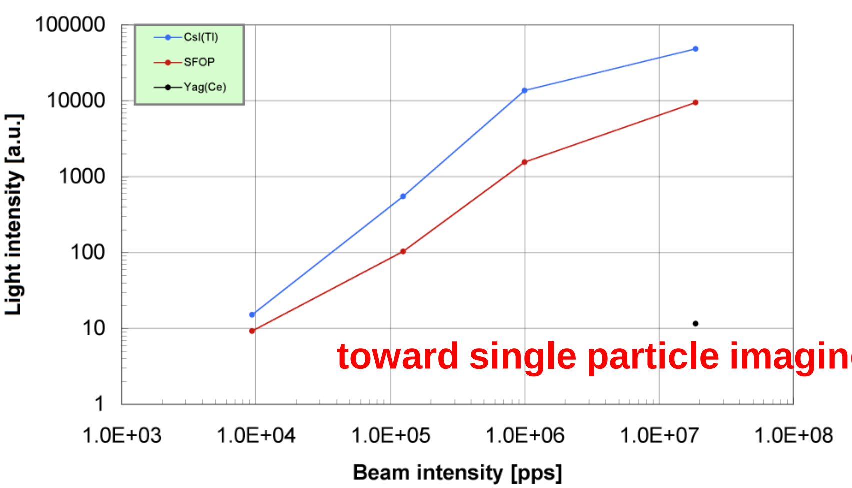
screen = CsI (Tl)

beam = protons

E = 50keV

I ≈ < 1fA (10^3 pps)

$t_{exposure}$ = 60s



toward single particle imaging....!!!

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

Conclusions

•several different technologies tested/employed at LNS for RIBs

•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

Outlooks

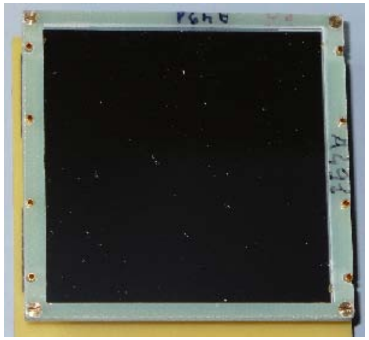
R&D activity towards diagnostic devices for the SPES facility.

Diagnostics for accelerated RIBs

Plastic scintillators for beam intensity measurements

15 detection points

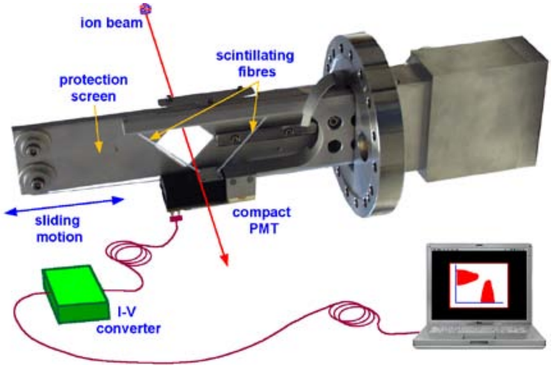
15 detection points



Position sensitive silicon detectors for real time beam imaging

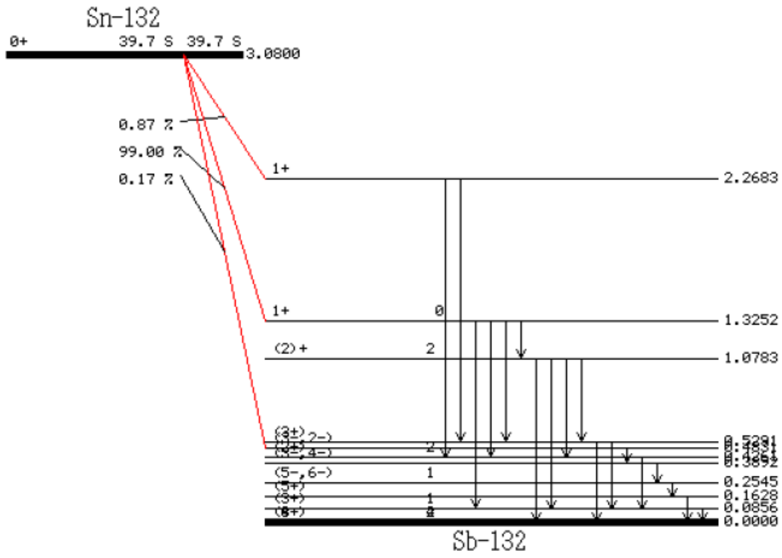
Beam profile monitor (FIBBS) based on a pair of scintillating fibres scanning the beam

3 detection points



SPES beam: Sn-132

132SN B- DECAY (39.7 S)



Parent state: G.S.
Half life: 39.7 S(5)

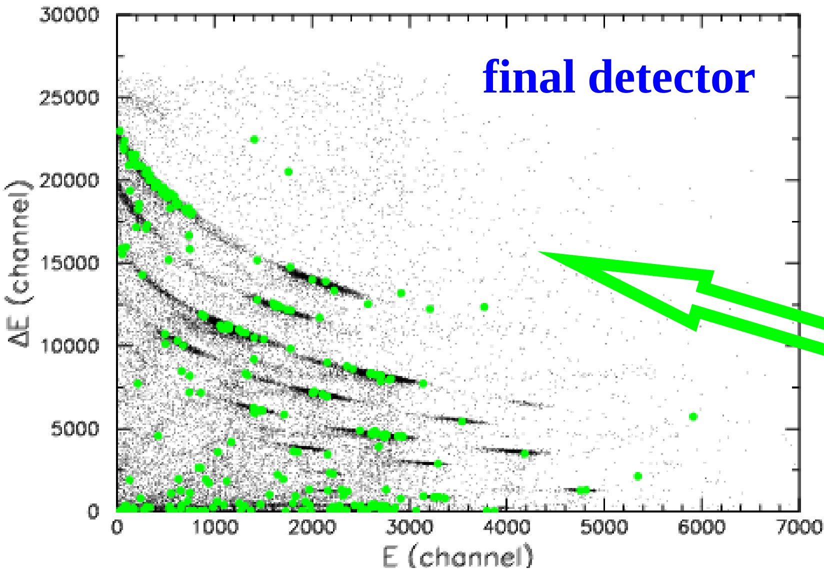
Beta ray:

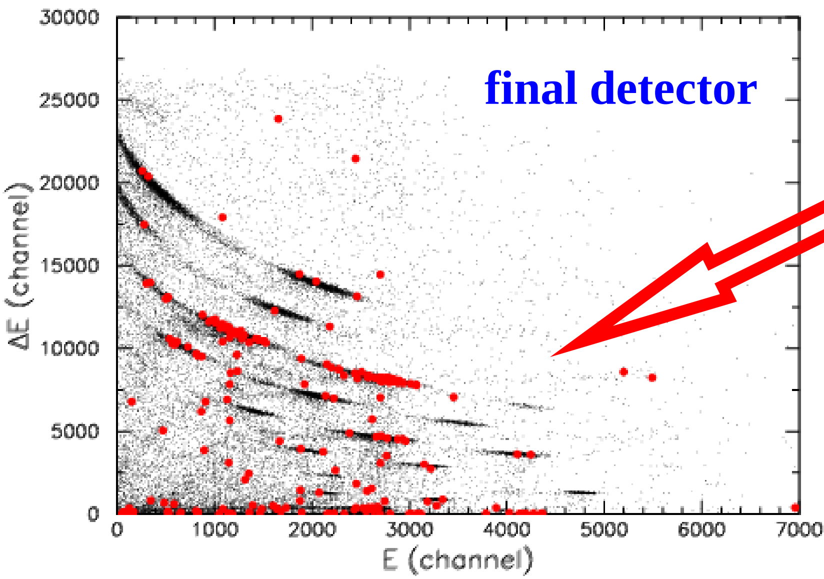
Max.E(keV)	Avg.E(keV)	Intensity(rel)	Spin	0+
2596.9(-)	1056(19)	0.17(LT)		(3-,2-)
1760(40)	672(18)	99(4)		1+
811.7(-)	271(16)	0.87(6)		1+

Gamma ray: for absolute intensity multiply by 0.492(9)

Energy(keV)	Intensity(rel)
85.58(8)	98(2)
91.7(2)	0.17(3)
93.9(2)	0.20(2)
134.7(2)	0.24(3)
162.8(2)	0.15(7)
246.87(5)	86(4)
340.53(5)	100
443.5(2)	0.46(4)
529.09(6)	4.3(4)
549.23(7)	4.7(4)
652.31(6)	5.5(4)
710.7	0.13
795.7(2)	0.63(4)
816	-
870.1	0.02
899.04(5)	91(5)
992.66(8)	75(4)
1078.3(1)	5.1(3)
1239.63(5)	19.8(10)
1739.10(25)	0.26(6)
1842.22(25)	1.5(1)

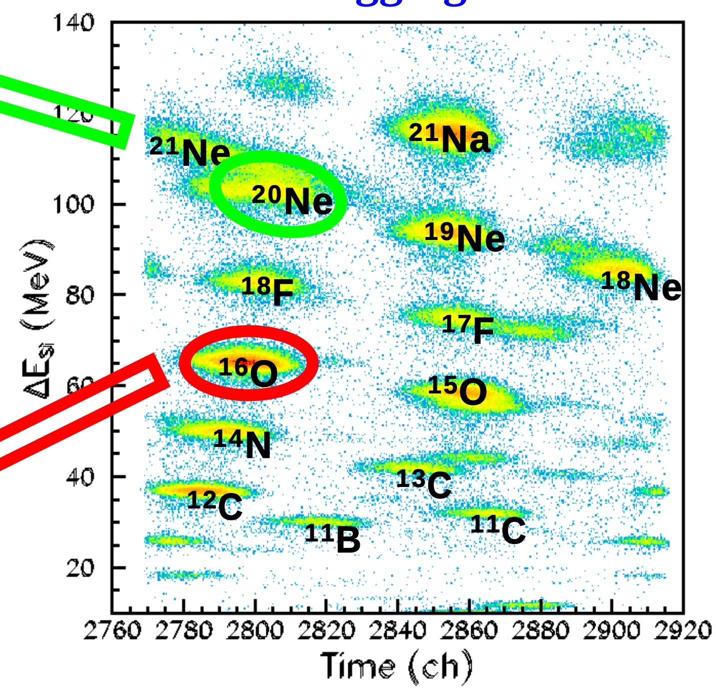
Projectile Selection: Tagging Procedure





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

tagging detector

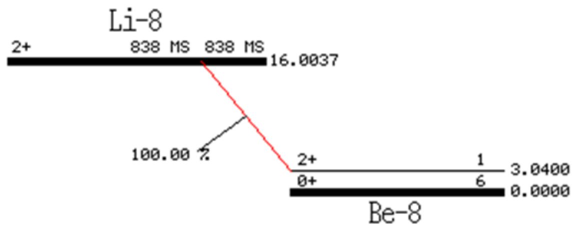


Thanks to the Chimera group

Identification of ^{8}Li by means of the decay curve

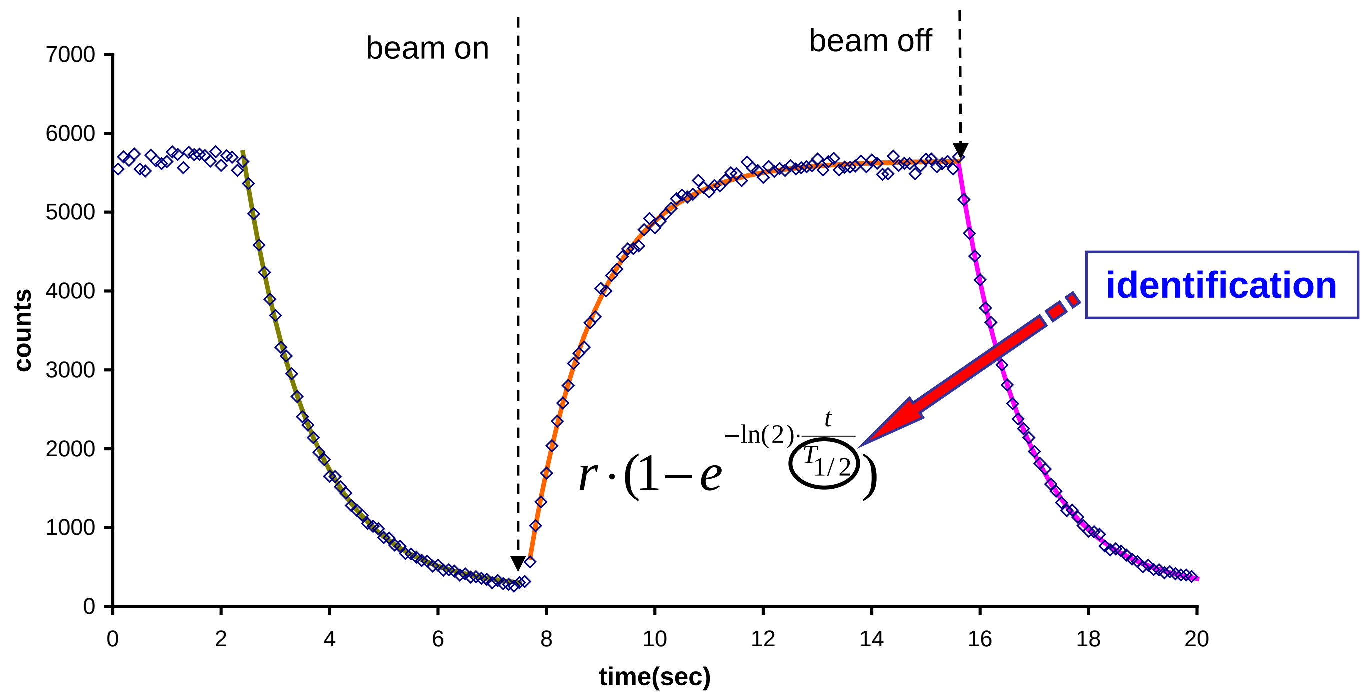
8LI B- DECAY

```
Parent state: G.S.
Half life: 838 MS(6)
Q(gs): 16003.7(8) keV
Branch ratio:        1.0
```

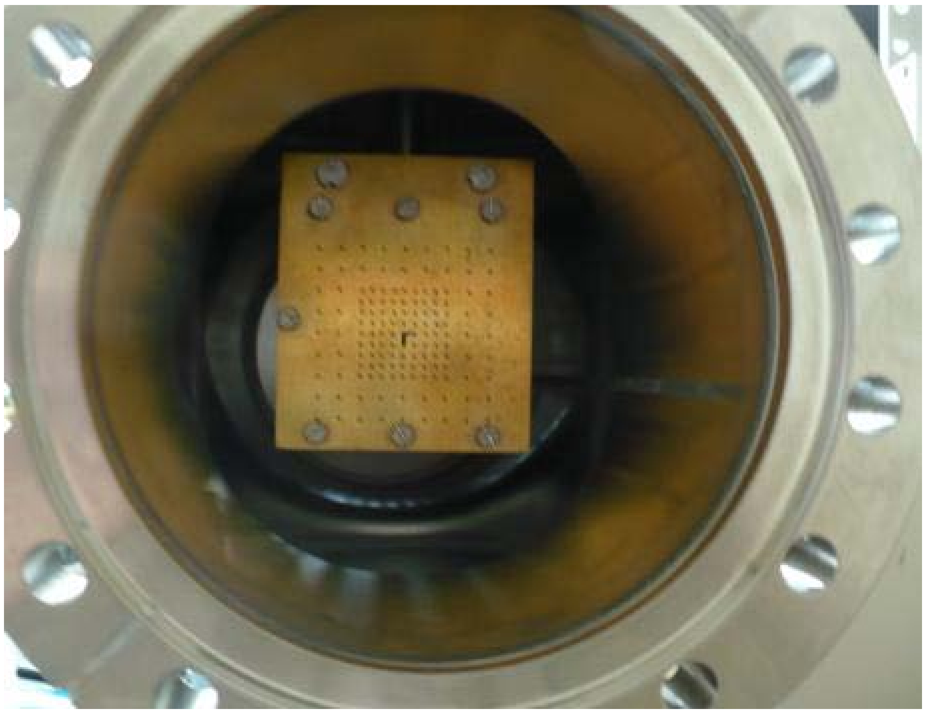


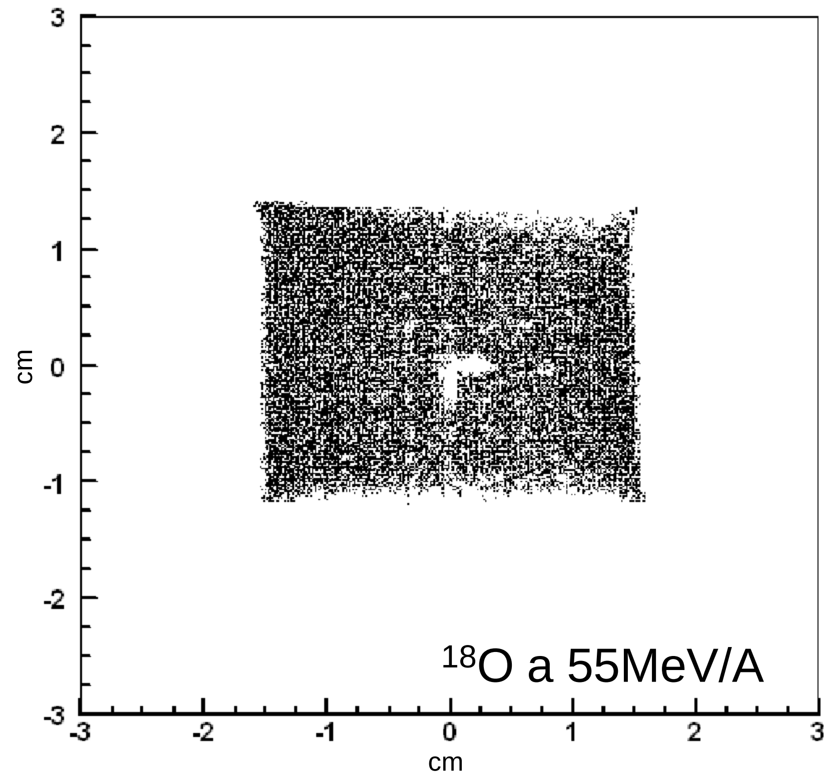
Beta ray:

Max.E(keV)	Avg.E(keV)	Intensity(rel)	Spin	2+
12963.7(-)	6243(15)	100(AP)		2+

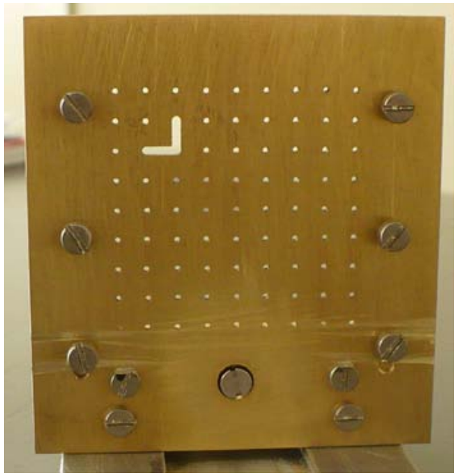


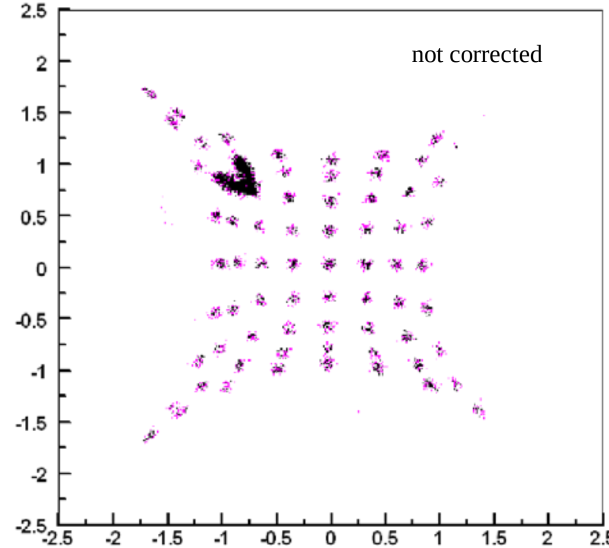
CS energy (FRIBs beams)

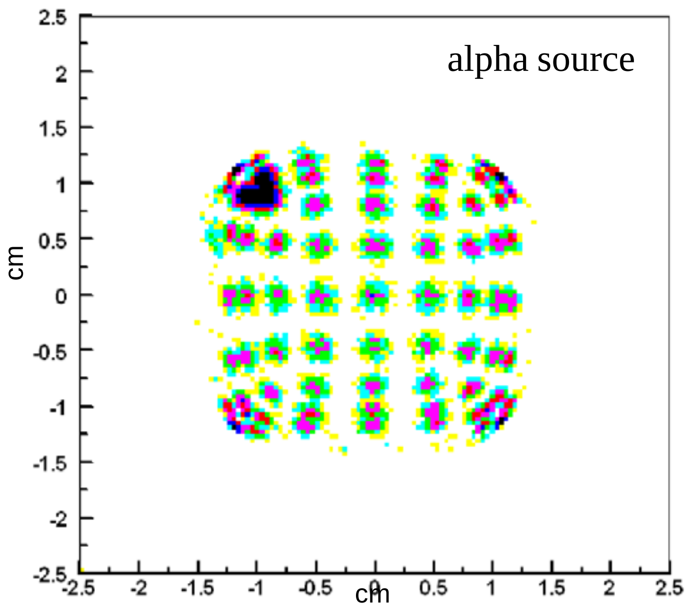




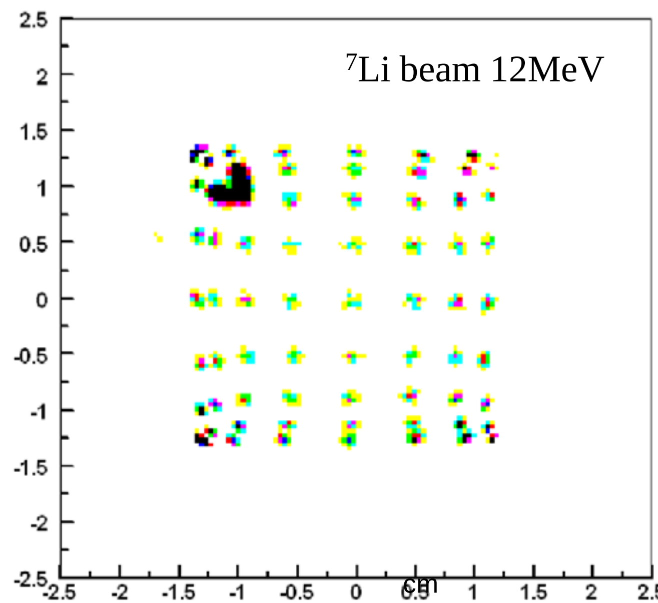
Tandem energy



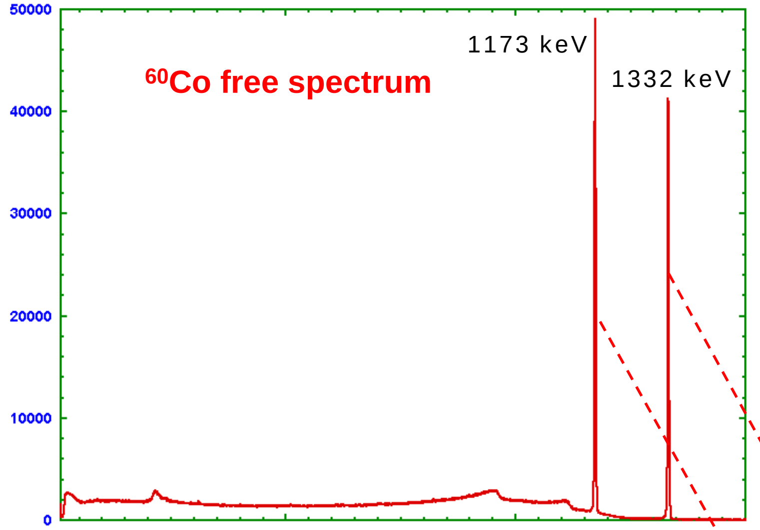


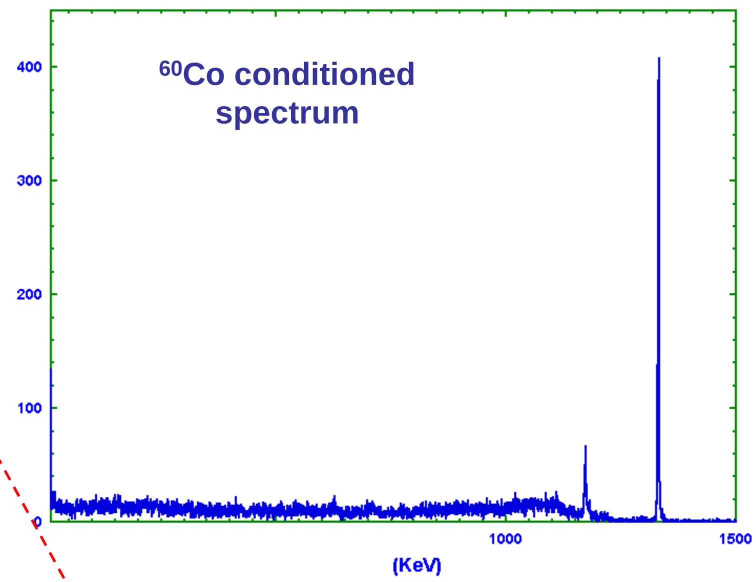


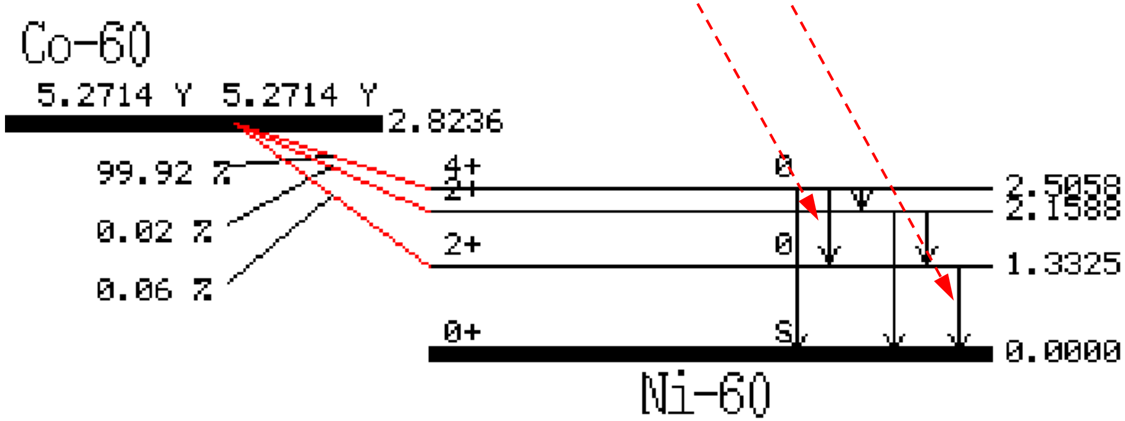
real time
correction of the
shape distortion

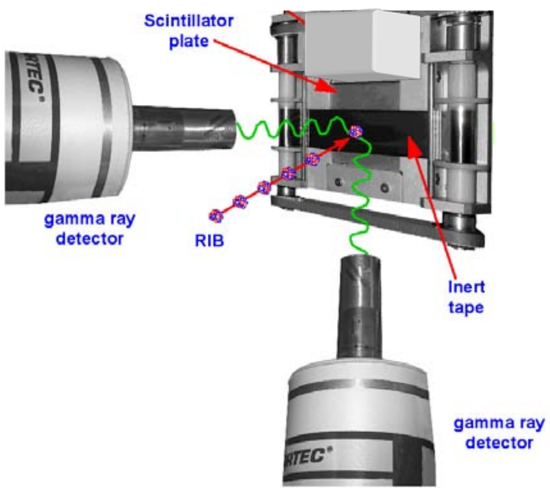


Gamma ray spectroscopy with two germanium detectors









Set-up for new beams

Nuclide	Half life	Possible contaminants (M/ΔM)	Average energy of beta (keV)	Gamma peaks (keV)	Detectors to be used
^{8}Li	0.838 s	^{8}B (3800)	6243	No peaks	Plastic scintillator. Spectra reconstruction.
^{9}Li	0.178 s	^{9}C (2120)	A lot of beta's	No peaks	Plastic scintillator. Difficult for threshold estimation. Too short half life.
^{10}C	19.255 s	^{10}Be (3020), $^{10}B^*$ (2560)	No beta's	718, 1021	CsI and germanium. Peaks recognition.
^{11}C	20.39 min	^{11}Be (1080), $^{11}B^*$ (5170)	385.6	No peaks	Plastic scintillator. Spectra reconstruction.
^{15}C	2.449 s	$^{15}N^*$ (1430), ^{15}O (1990)	4649, 2032	5297	Plastic scintillator and germanium
^{15}O	112.24 s	$^{15}N^*$ (5070), ^{15}C (1990)	735	No peaks	Plastic scintillator. Spectra reconstruction.
^{19}O	26.9 s	^{19}N (1410), $^{19}F^*$ (3670)	2200 (4%), 2103 (45.4%), 1442 (54.4%)	A lot of peaks	Plastic scintillators and germanium. Difficult for threshold estimation.
^{20}O	13.51 s	^{20}N (1040), ^{20}F (4890), ^{20}Na (6110), ^{20}Mg (1350)	1197	1056	Plastic scintillators (spectra reconstruction) and germanium.

Set-up for new beams

Nuclide	Half life	Possible contaminants (M/ΔM)	Average energy of beta (keV)	Gamma peaks (keV)	Detectors to be used
^{17}F	64.49 s	^{17}N (2680)	740	No peaks	Plastic scintillator. Spectra reconstruction.
^{18}F	109.77 min	^{18}N (1370), $^{18}O^*$ (10130)	250	No peaks	Plastic scintillator. Spectra reconstruction.
^{20}F	11.16 s	^{20}Na (2710), ^{20}O (4880), ^{20}Mg (1060)	2481	1633	Plastic scintillator and germanium
^{25}Al	7.183 s	$^{25}Mg^*$ (5440), ^{25}Na (52700), ^{25}F (1150), ^{25}Si (1830)	1460		Plastic scintillator. Spectra reconstruction.
^{29}Al	6.56 min	^{29}Mg (3570), ^{29}Na (1300), $^{29}Si^*$ (7340), ^{29}P (21360), ^{29}S (1790)	1023 (90%), 670 (3.8%), 490 (6.3%)	Several peaks with energy > 1200 keV	Plastic scintillators and germanium. Difficult for threshold estimation.
^{33}Cl	2.511 s	$^{33}S^*$ (5500), ^{33}P (5760), ^{33}Si (60100), ^{33}Ar (2640)	2096	No appreciable peaks	Plastic scintillator. Spectra reconstruction.

Set-up for new beams

Nuclide	Half life	Possible contaminants (M/ΔM)	Average energy of beta (keV)	Gamma peaks (keV)	Detectors to be used
^{34}Cl	1.526 s (spin 0^+), 32.00 min (spin 3^+)	^{34}S* (5760), ^{34}P (270490), ^{34}Si (7060), ^{34}Ar (5220)	– 0^+: 2052 – 3^+: 1099 (28.4%), 555 (25.6%)	– 0^+: no peaks – 3^+: a lot of peaks	Easy (Plastic scintillator. Spectra reconstruction) if the 0^+ is favourite
^{38}Cl	37.24 min	^{38}S (12040), ^{38}P (2310), ^{38}Ar* (7190), ^{38}K (35500), ^{38}Ca (4570)	2244 (57.6%), 1181 (10.5%), 420 (31.9%)	1642 (31.9%), 2167 (42.4%)	Plastic scintillators and germanium. Difficult for threshold estimation.
^{39}Cl	55.6 min	^{39}S (5470), ^{39}P (2120), ^{39}Ar (10550), ^{39}K* (9060), ^{39}Ca (14380)	A lot of beta's	A lot of gamma's.	Plastic scintillators and germanium. Difficult for threshold estimation.
^{40}Cl	1.35 min	^{40}S (7910), ^{40}P (1940), ^{40}Ar* (4980), ^{40}K (6230), ^{40}Ca* (5110), ^{40}Sc (5300)	A lot of beta's	A lot of gamma's.	Plastic scintillators and germanium. Difficult for threshold estimation.

* Stable isotope