The accelerators at LNS – INFN and diagnostics aspects of the radioactive beams

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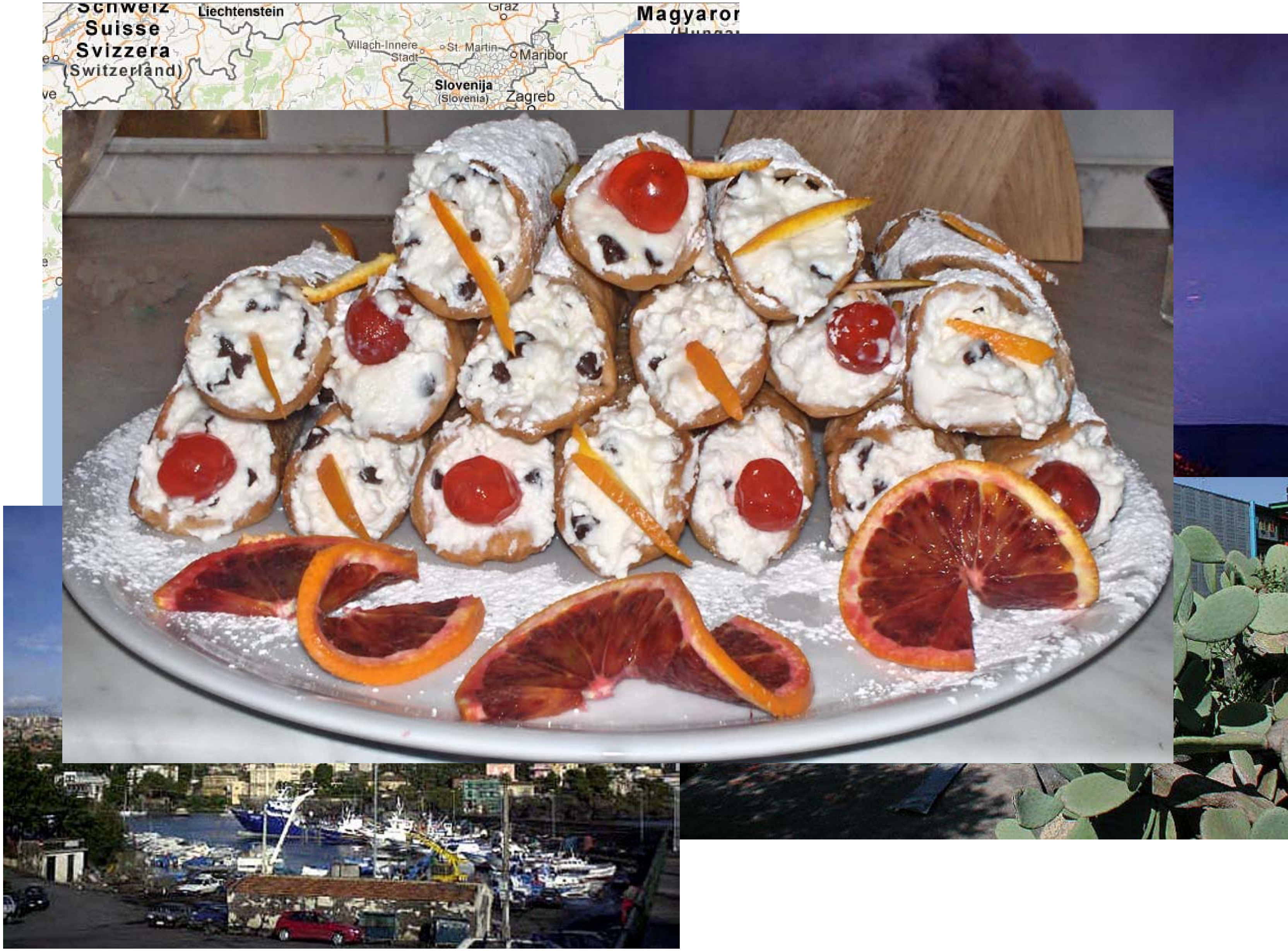
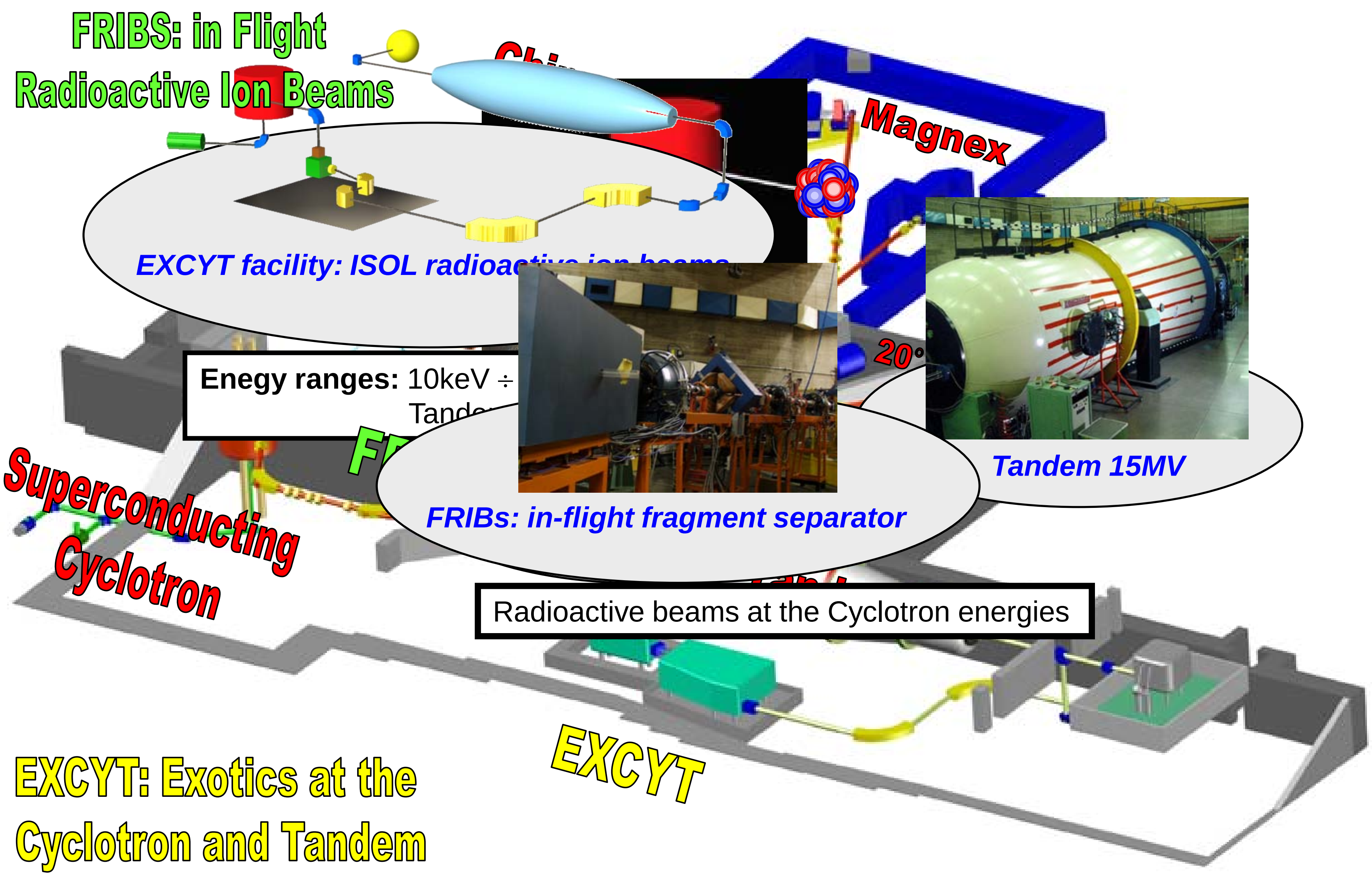
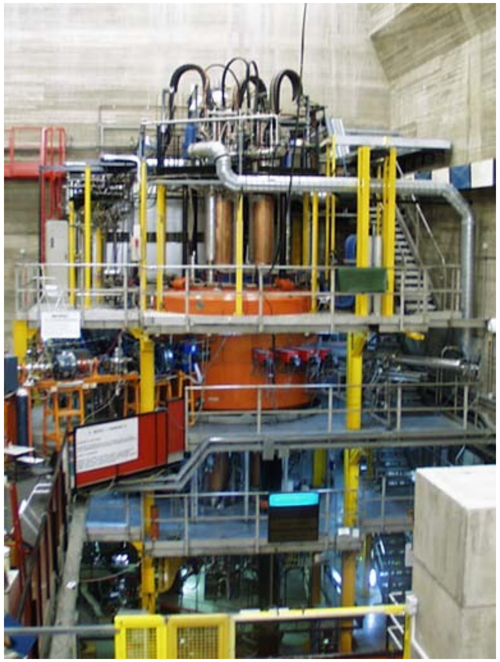

Suisse
Svizzera
(Switzerland)
Liechtenstein
Graz
Villach-Innere Stadt
St. Martin
Maribor
Slovenija
(Slovenia)
Zagreb

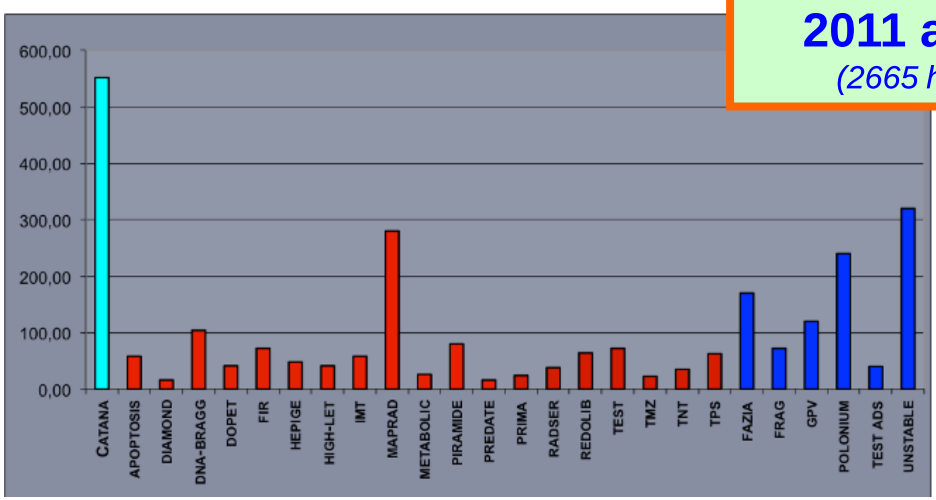
LNS lay-out: accelerators and experimental halls



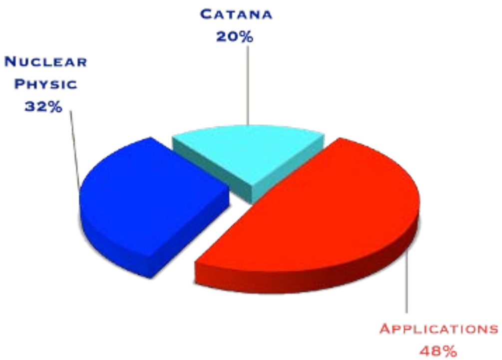
Superconducting Cyclotron

- **Strong focusing three-sector machine Kb = 800 and Kf = 200**
- **Superconducting Nb-Ti coils cooled down to 4.2 K in an LHe bath.**
- **Magnetic field at the center ranges from 2.2 to 4.8 T**
- **Operational range of the radio frequency between 15 and 48 MHz**
- **Two ECR ion sources: SERSE and CAESAR**
  - **SERSE is a highly performing superconducting source, producing beams with high charge states and intensities much higher than room temperature sources**
  - **The CAESAR is a conventional ECR ion source for lighter ions with moderate charge states**





2011 activity
(2665 hours)

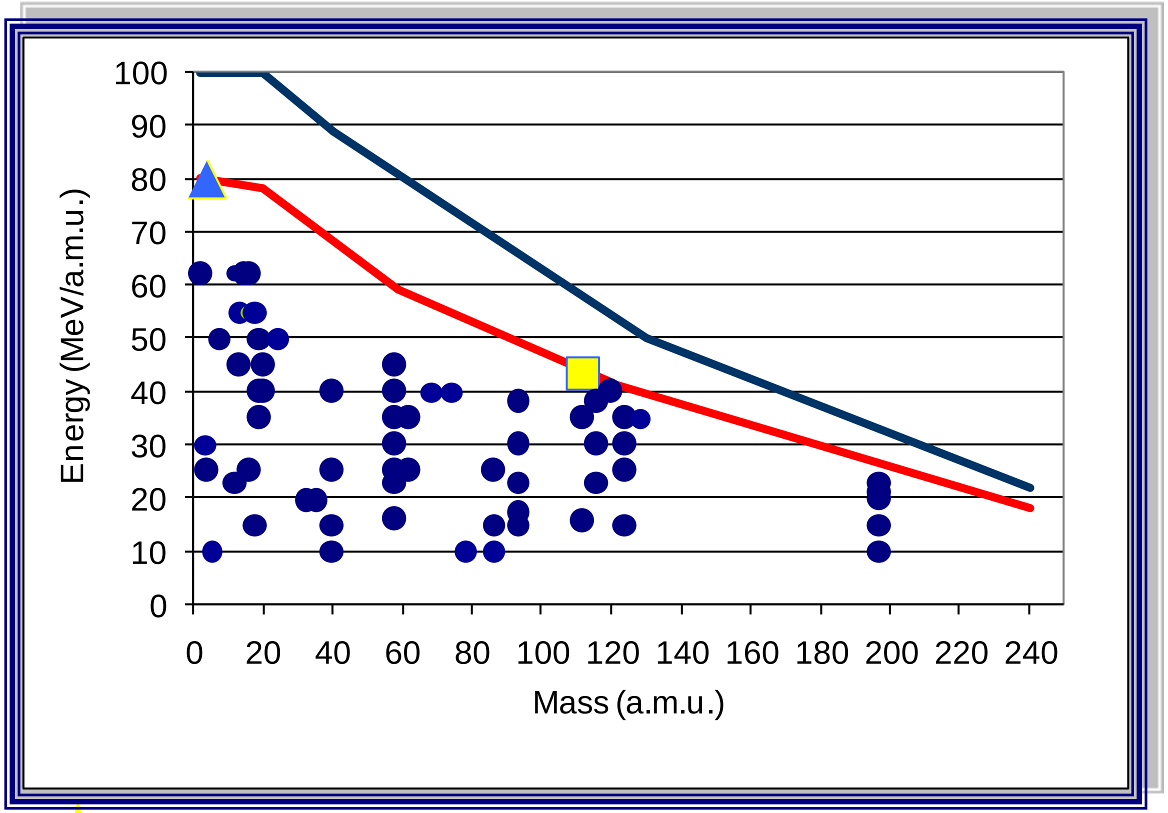


32%
Nuclear Physics

20%
Catana (protontherapy for eye melanoma)

48%
Applications

Superconducting Cyclotron



^{4}He 80 MeV/a.m.u.

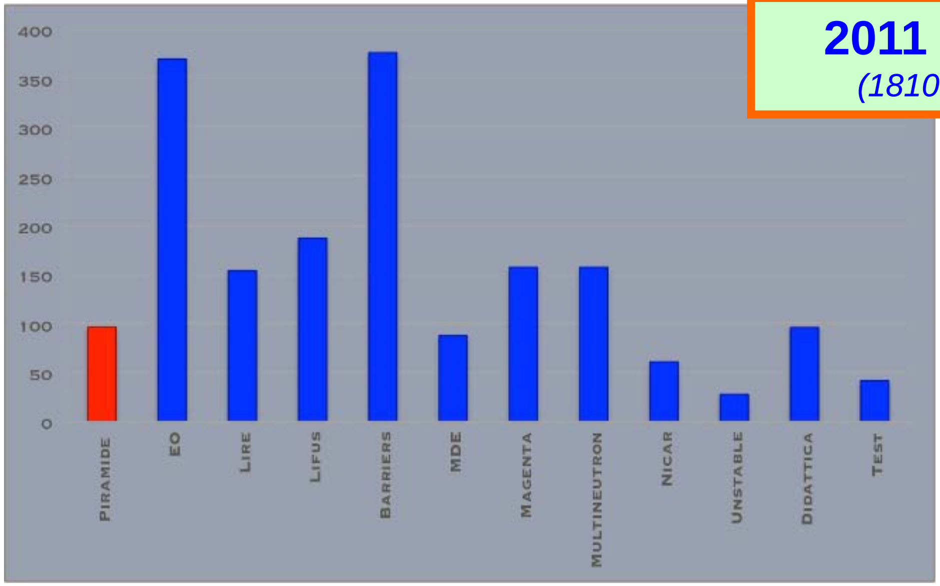
^{112}Sn 43.5 MeV/a.m.u.

developed beams

^{A}X	E (MeV/a.m.u.)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^{+}$	35,62,80
^{4}He	25,80
He-H	10, 21
^{9}Be	45
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{36}Ar	16,38,42
^{40}Ar	15,20,40
^{40}Ca	10,25,40,45
^{48}Ca	10,45
^{58}Ni	16,23,25,30,35,40,45
^{64}Ni	25,35
^{68,70}Zn	40
^{74}Ge	40
^{78}Kr	10
^{84}Kr	20
^{86}Kr	10,15,20,25
^{93}Nb	15,17,23,30,38
^{112}Sn	15.5,35,43.5
^{116}Sn	23,30,38
^{124}Sn	15,25,30,35
^{129}Xe	20,21,23,35
^{197}Au	10,15,20,21,23
^{208}Pb	10

High Voltage Tandem 15 MV

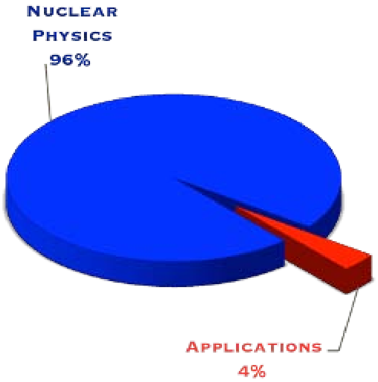
- *operating range 2.5 – 15 MV*
- *charging system based on the belt*
- *SF6 insulating gas (6 atm)*
- *transmission next to 90%*
- *pre-injection voltage up to 450 kV*
- *well suitable for nuclear astrophysics*
- *used as a booster for ISOL beams (EXCYT)*



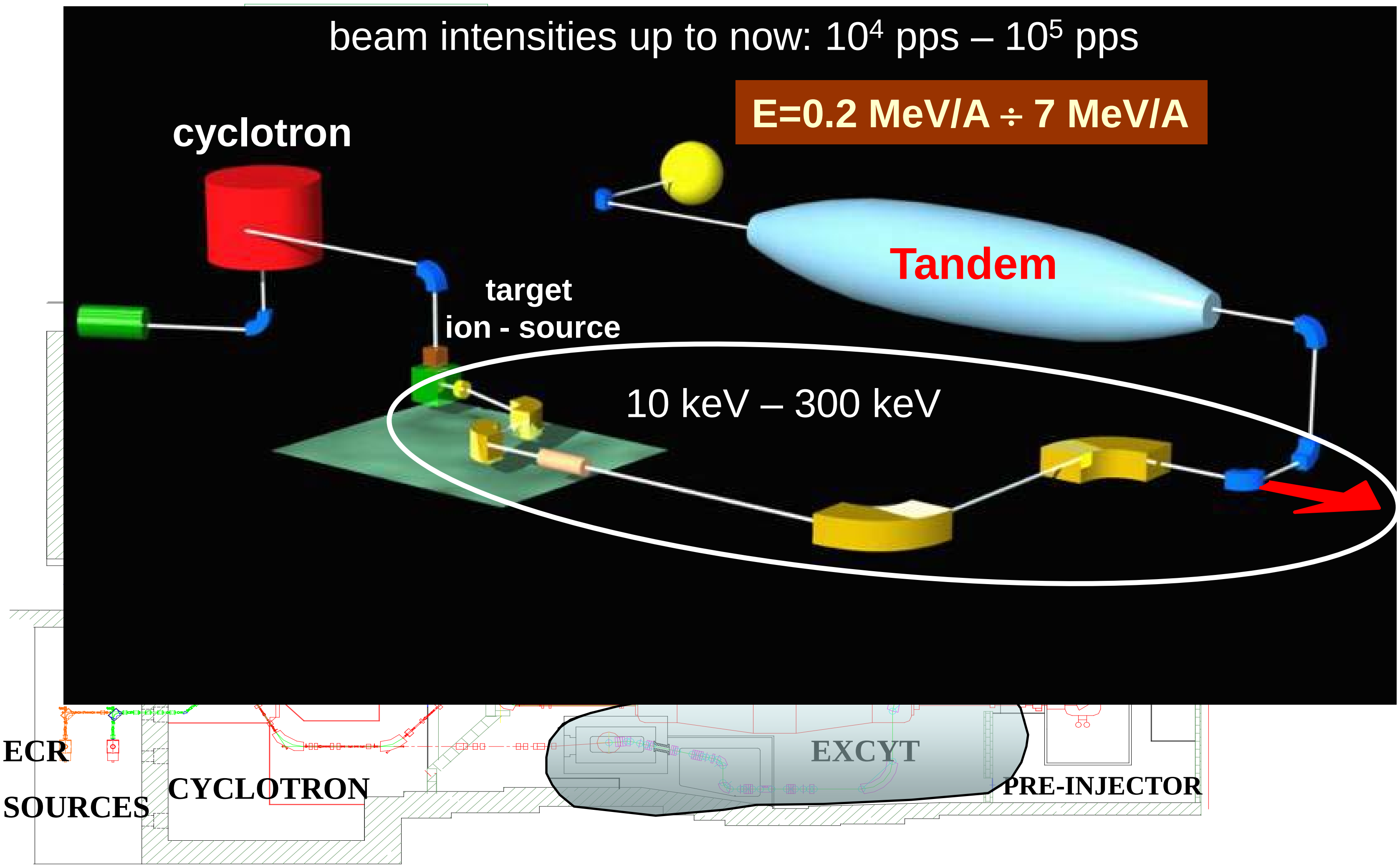
2011 activity
(1810 hours)

96% Nuclear Physics

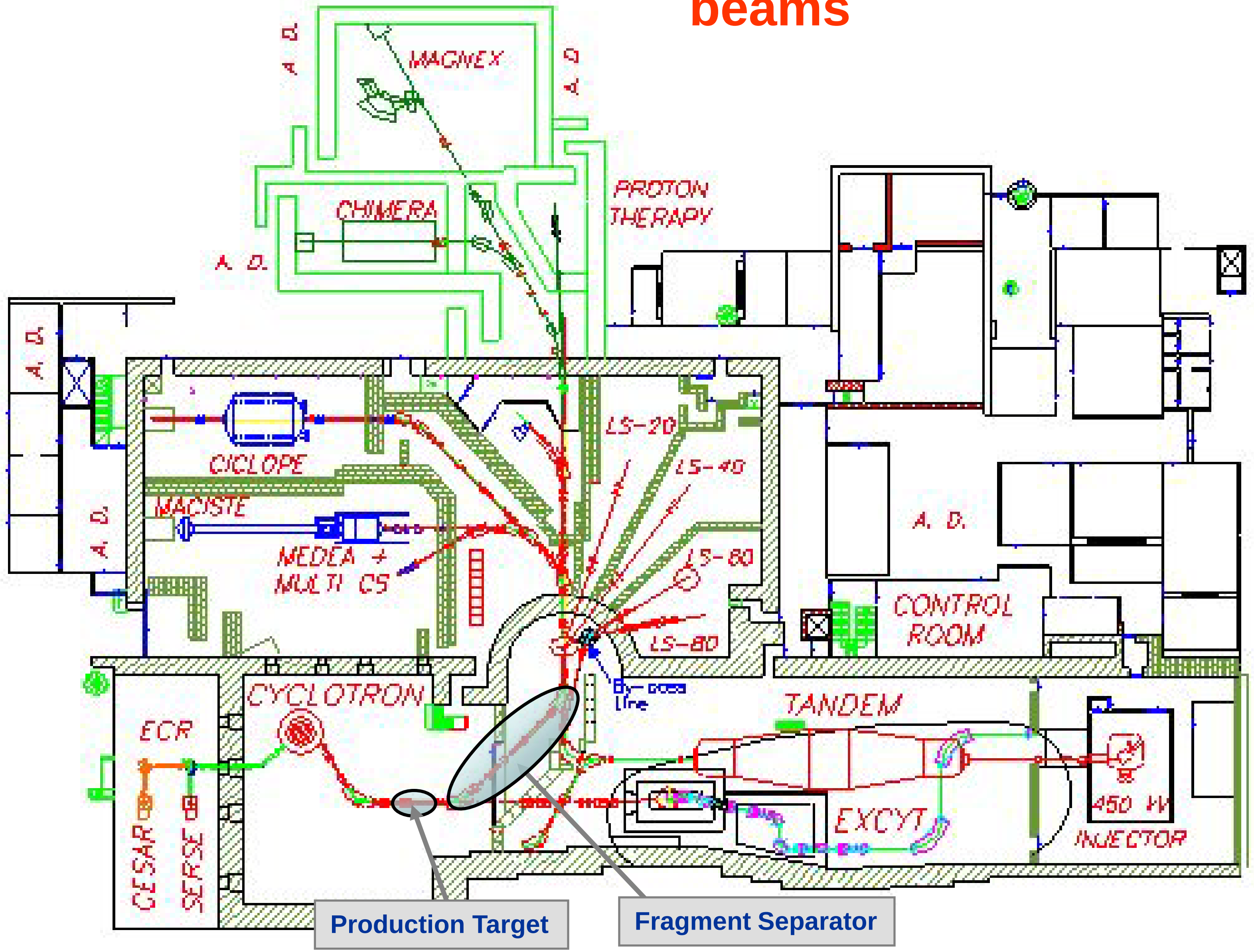
4% Applications



The Excyt ISOL facility

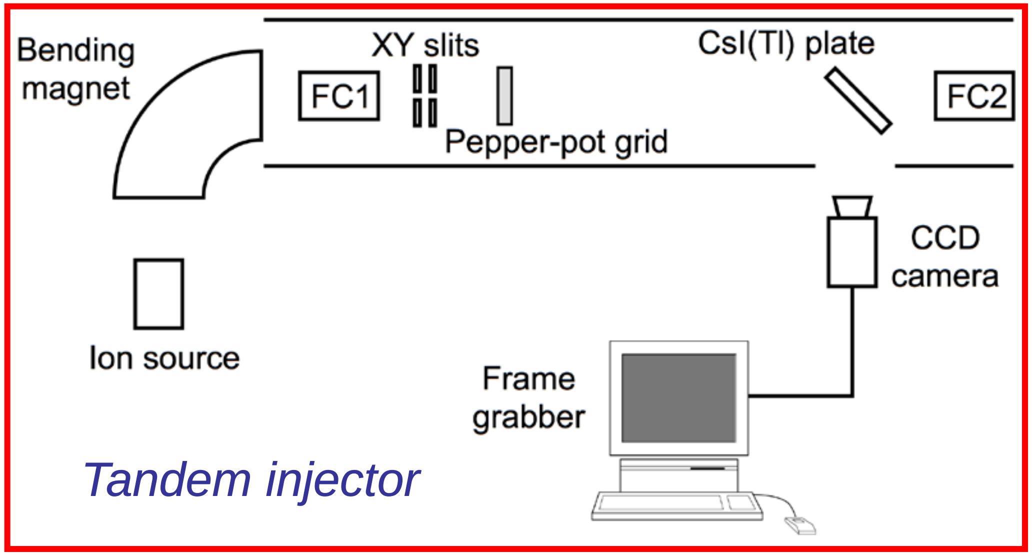


FRIBS: In-flight production of radioactive beams



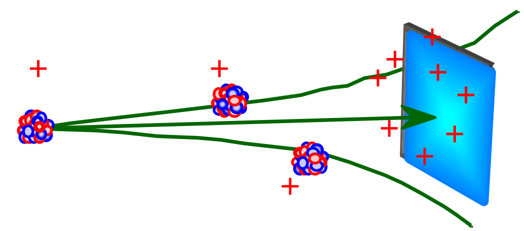
Diagnostics for low intensity radioactive beams

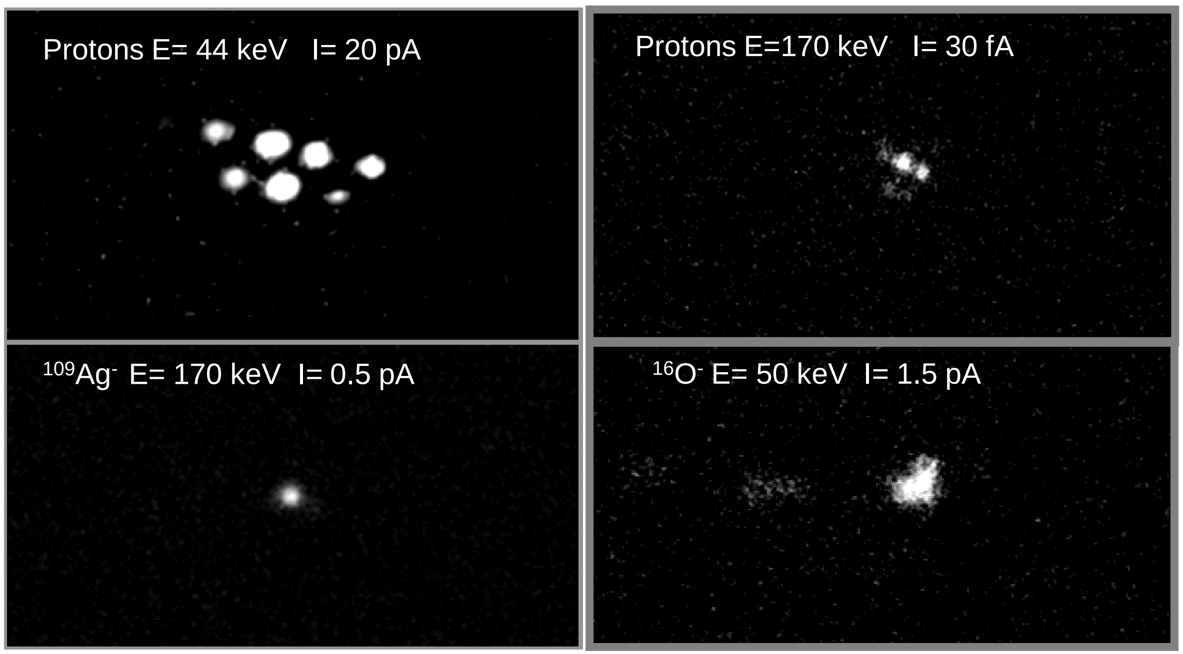
Low energy (>10 keV) beam imaging with CsI(Tl) screens



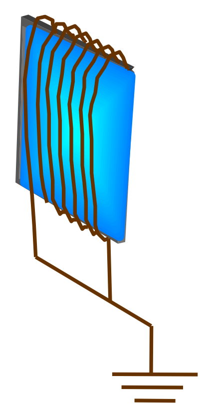
High light yield of CsI(Tl) ~ 65000 photons/MeV

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





grounded conductor wire



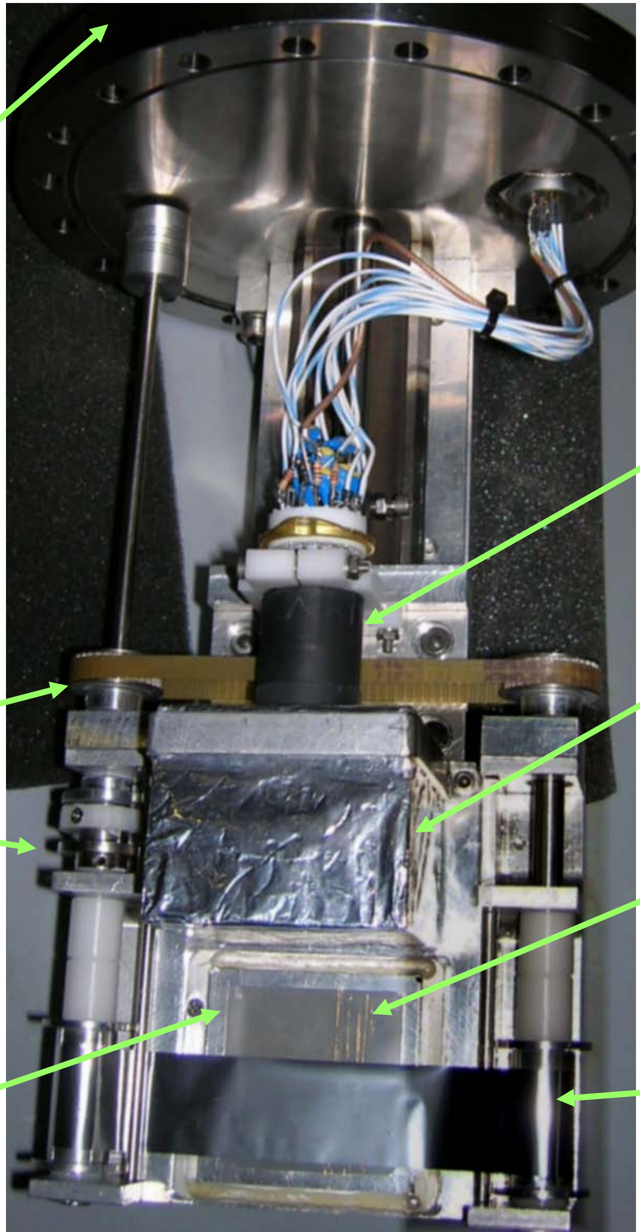
Diagnostic device for EXCYT Low Energy RIBs

step motor

Photomultiplier

Plastic scintillator
BC 408

tape transport system



CsI (Tl) plate

metallic grid
tungsten wires

mylar tape 6 μm

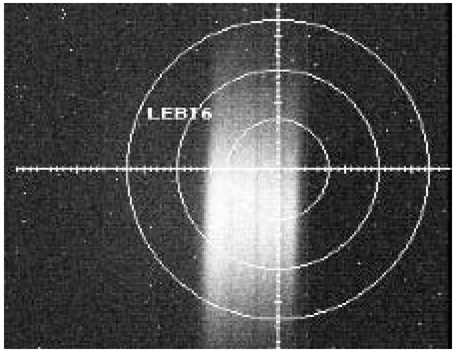
Beam diagnostics in the EXCYT beam line

Sensitivity for beam imaging

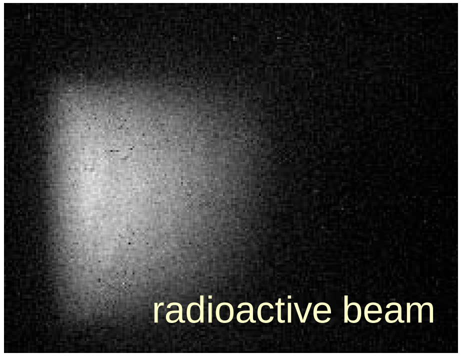
- $E_{threshold}$ = 5 keV
- $I_{stable\ beam}$ ~ 10^4 pps/mm^2
- $I_{radioactive\ beam}$ ~ 10^3 pps/mm^2

resolution < 1mm

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

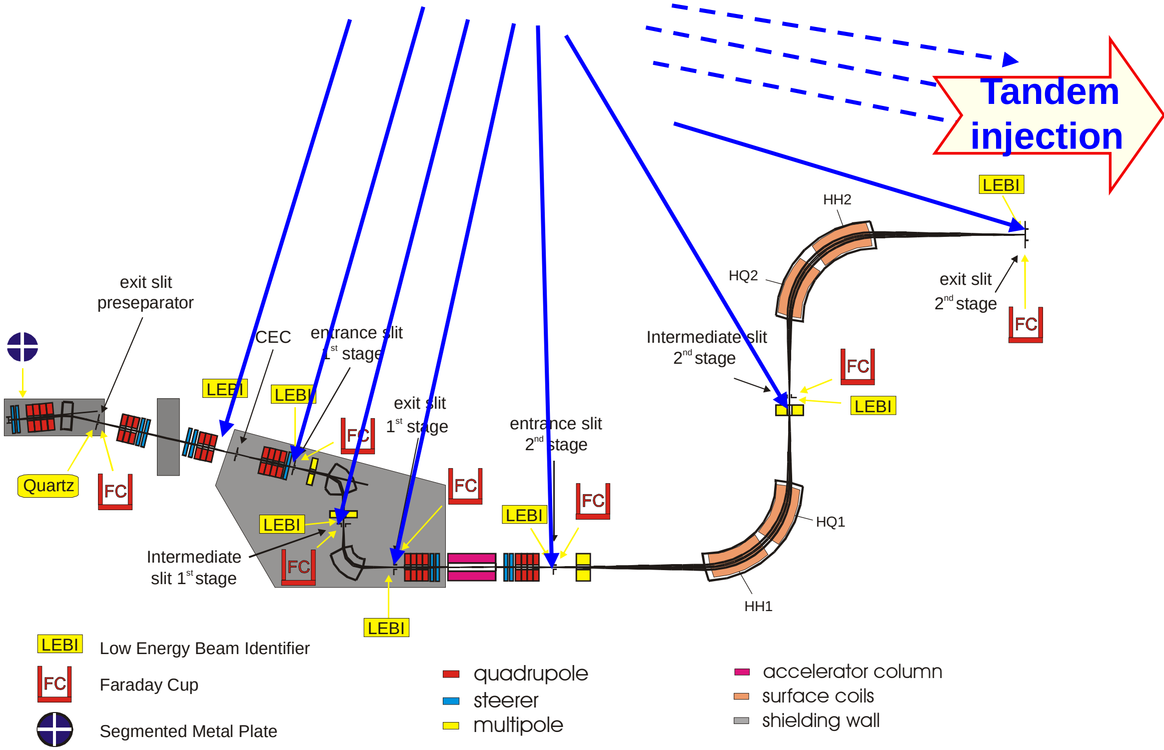


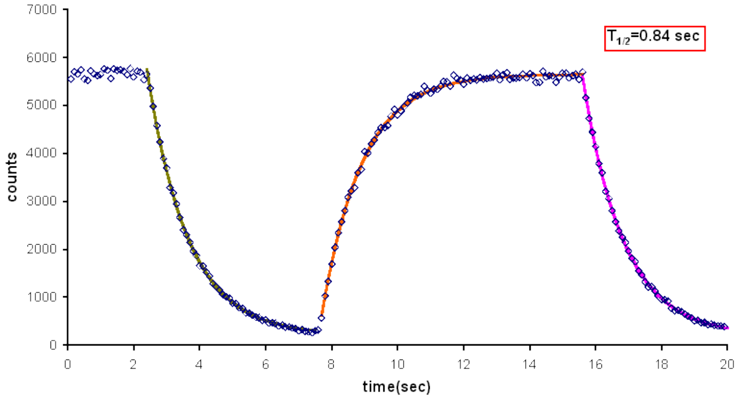
^{8}Li I = 100 fA E = 10 keV



Imaging of Stable (pilot) beams

- **Imaging of radioactive beams**
- **Beam rate measurement**
- **Decay curve reconstruction**

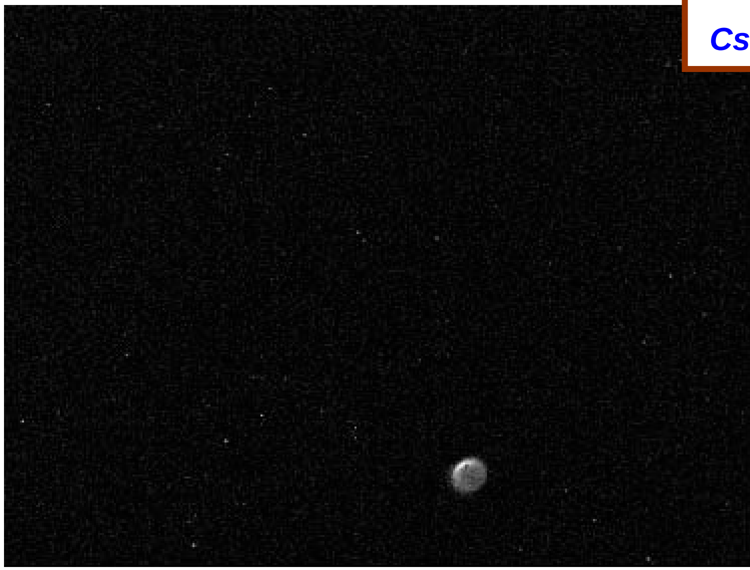


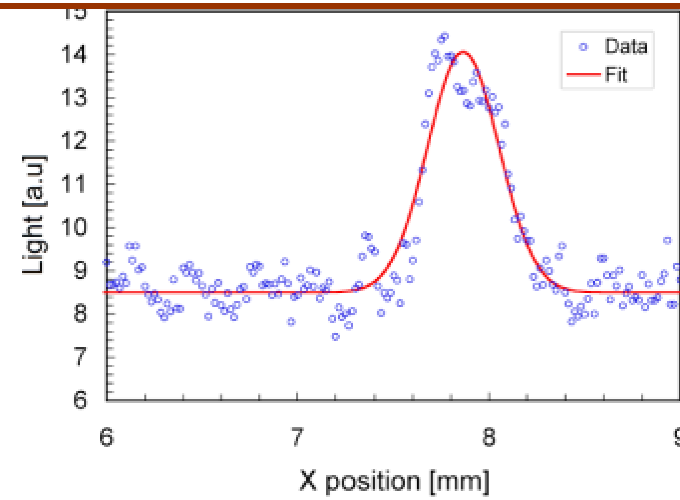


Ultra-thin CsI(Tl) Scintillating screens

test with protons at LNS 180 keV, 5 pA

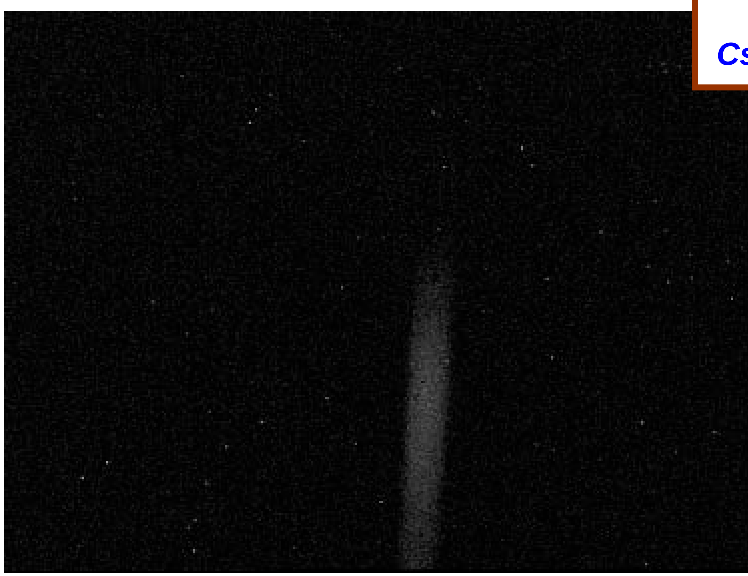
CsI(Tl) ultra-thin scintillator (3 microns) **standard video CCD**

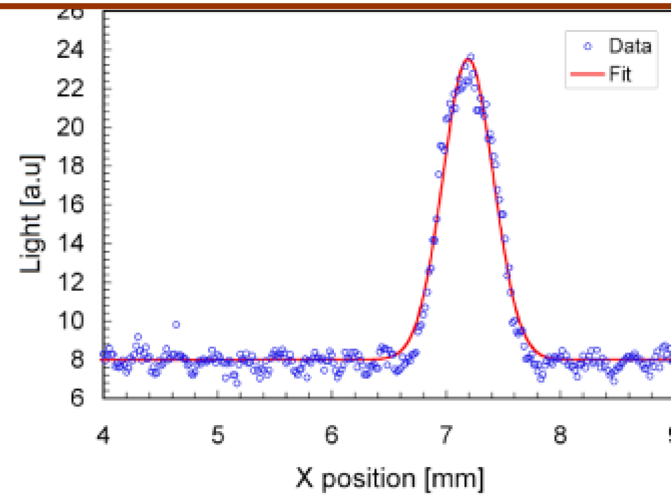




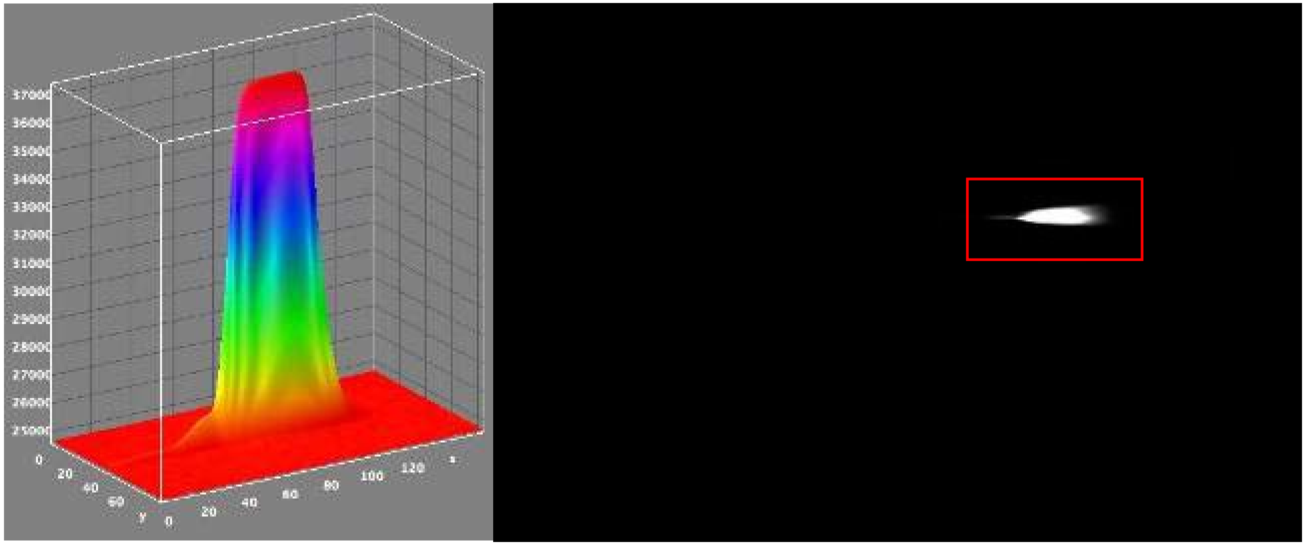
test with protons at LNS 20 keV, 700 pA

CsI(Tl) ultra-thin scintillator (3 microns) **standard video CCD**





Scintillating screens for very low beam intensity with a cooled CCD still camera



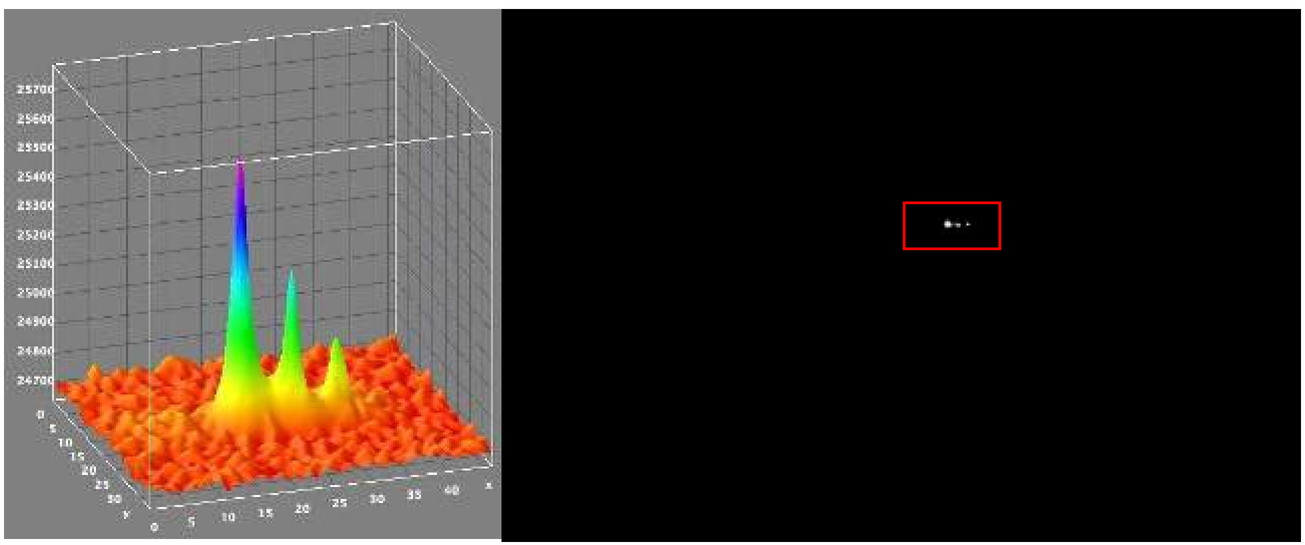
screen = CsI(Tl)

beam = protons

E = 50keV

I ≈ 5pA

$t_{exposure}$ = 60s



screen = CsI (Tl)

beam = protons

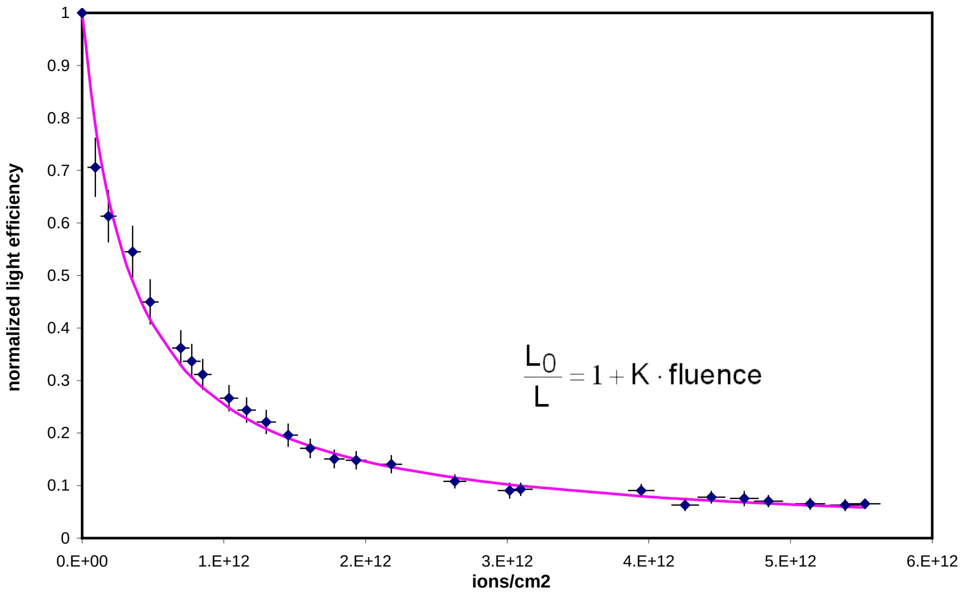
E = 200keV

I ≈ 2.5fA

$t_{exposure}$ = 20s

Radiation damage in CsI(Tl) screens

scintillating light vs. fluence for a 100keV ^{16}O beam

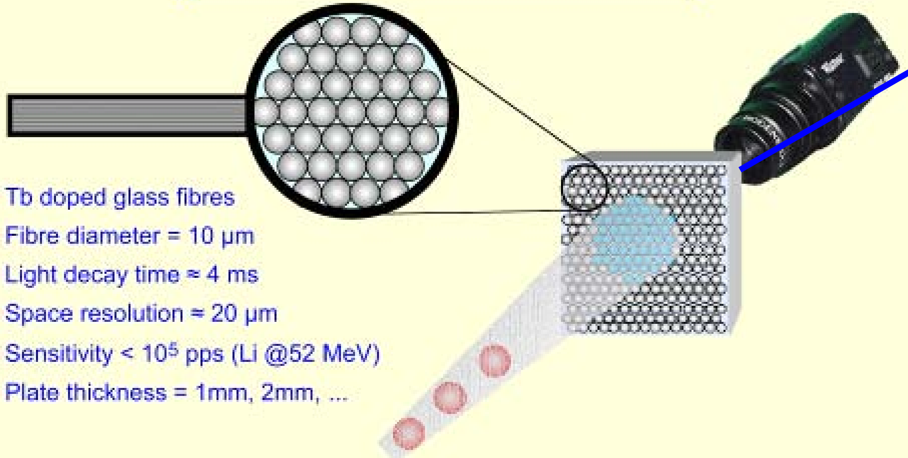


A 1mm thick screen was continuously irradiated for 6 h.
A set of pictures was acquired while verifying that in the mean time the overall beam intensity was constant at the reference value of 1.3 pA.
The light efficiency drops to 10%.

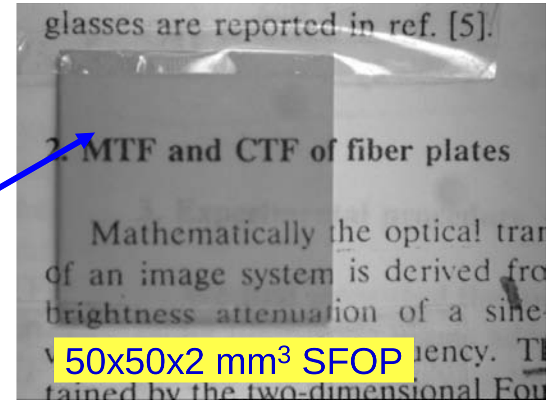
6 hours

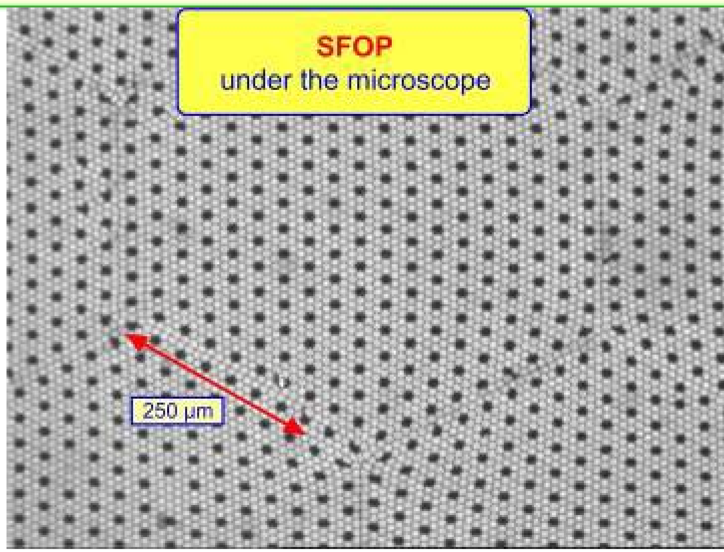
Micro-beam diagnostics: the SFOP

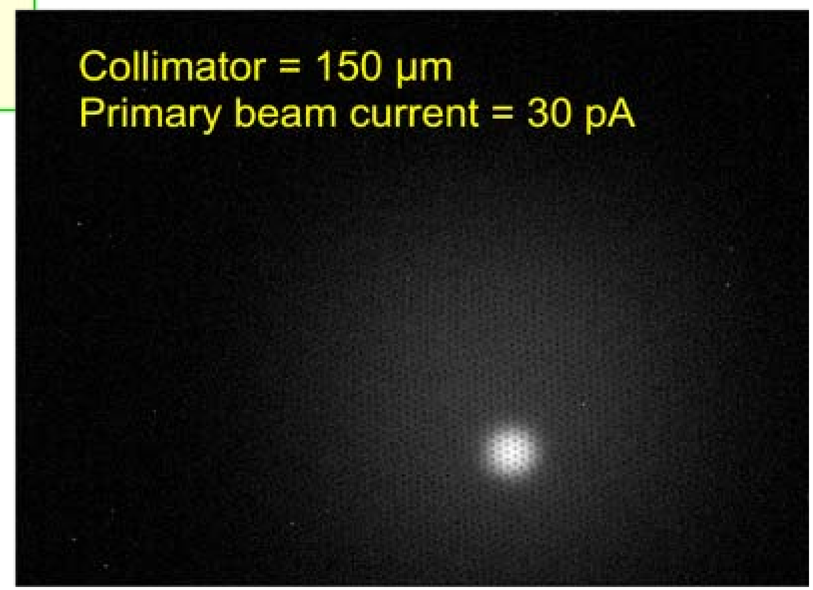
SFOP
Scintillating Fiber Optic Plate



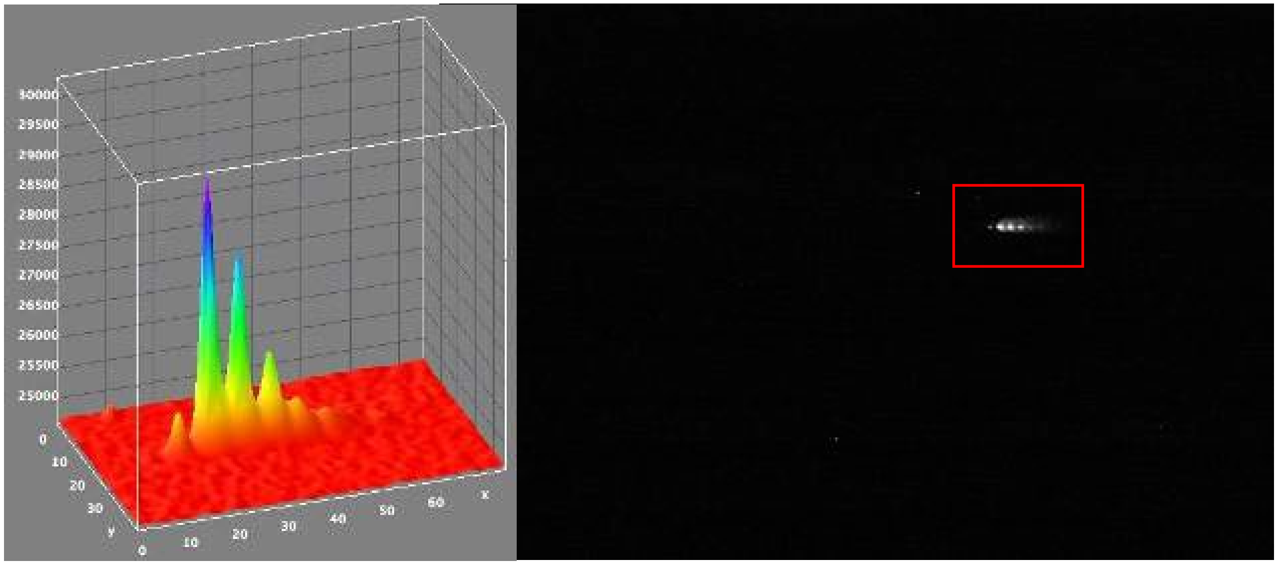
- Tb doped glass fibres
- Fibre diameter = 10 μm
- Light decay time ≈ 4 ms
- Space resolution ≈ 20 μm
- Sensitivity < 10^5 pps (Li @52 MeV)
- Plate thickness = 1mm, 2mm, …







Scintillating screens for very low beam intensity with a cooled CCD still camera



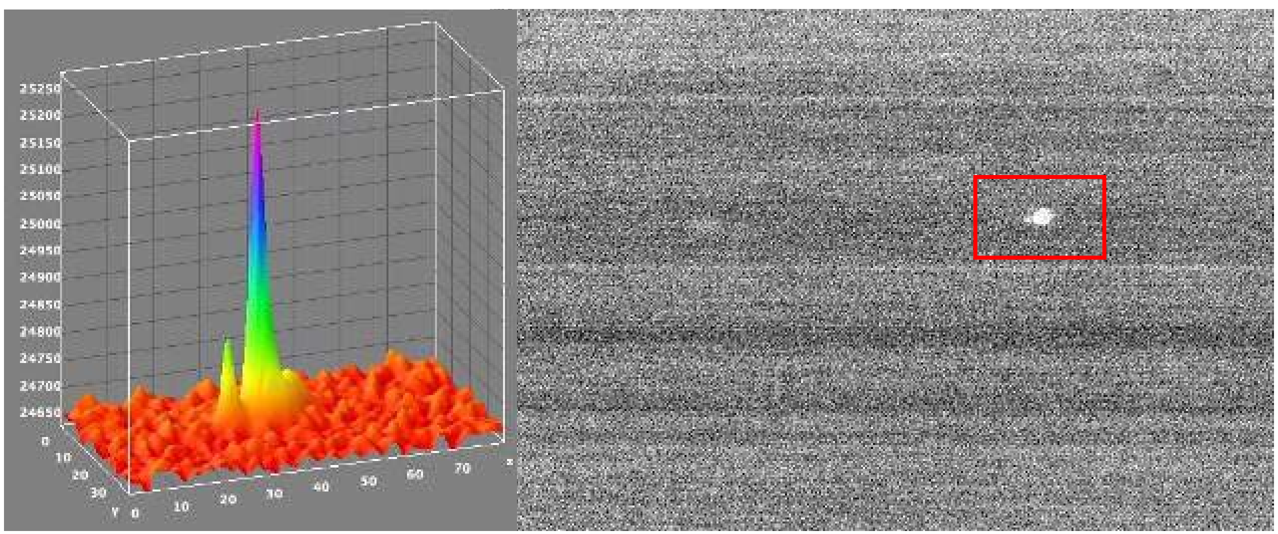
screen = SFOP

beam = protons

E = 200keV

I ≈ 50fA [5pA/100]

$t_{exposure}$ = 20s



screen = SFOP

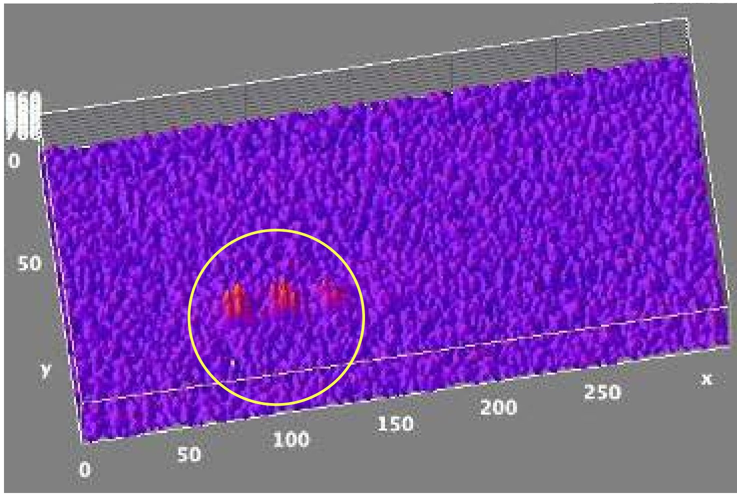
beam = protons

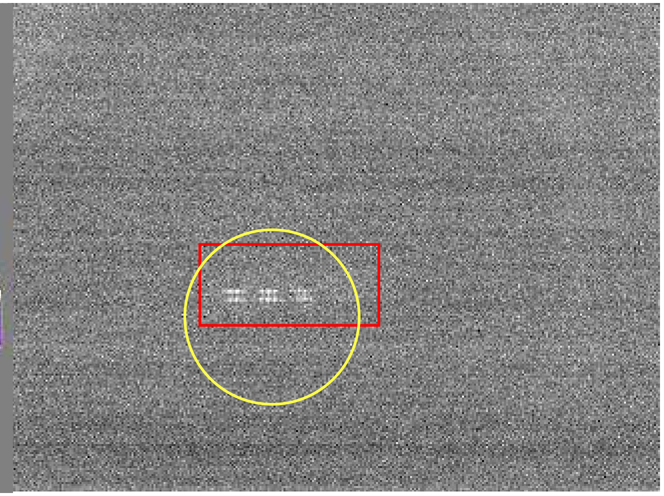
E = 200keV

I ≈ 2.5fA [5pA/2000]

$t_{exposure}$ = 20s

cooled CCD still camera





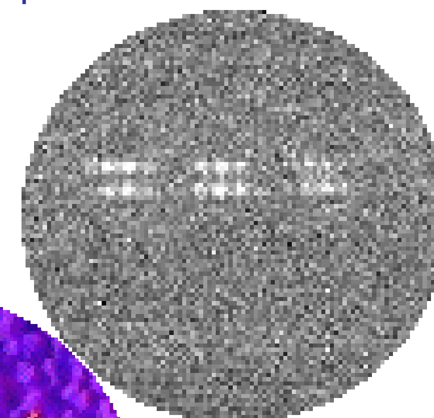
screen = CsI

beam = protons

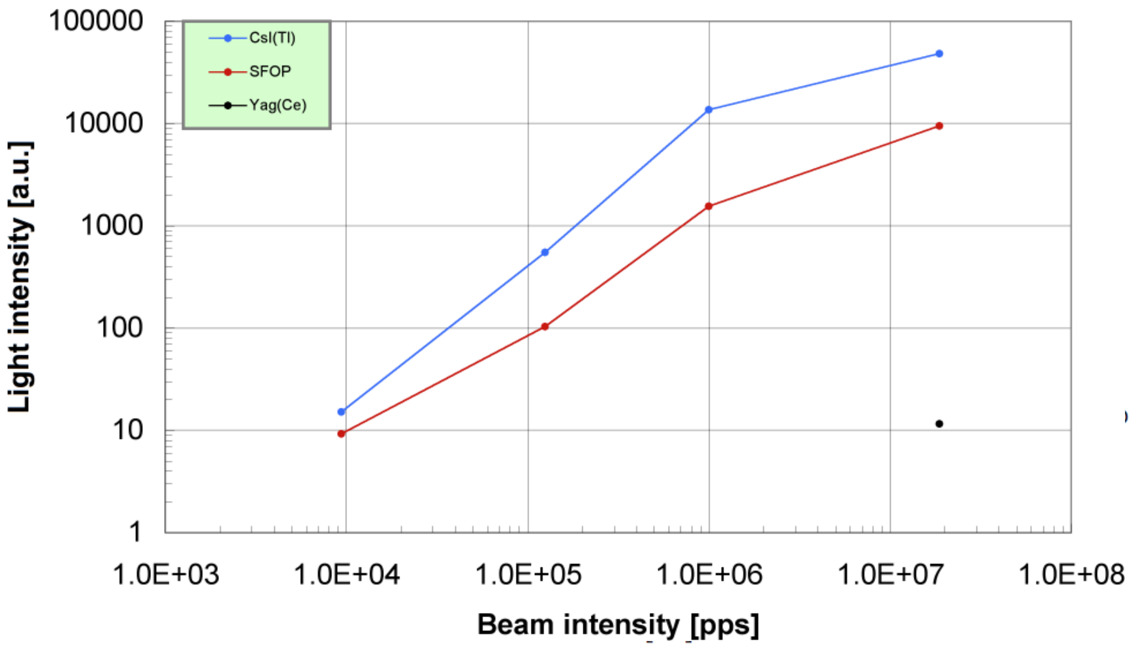
E = 50keV

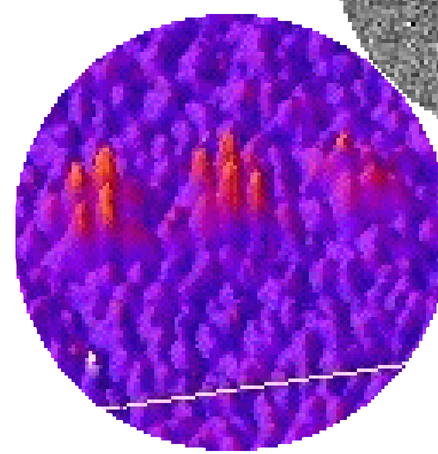
I ≈ not measurable

$t_{exposure}$ = 60s



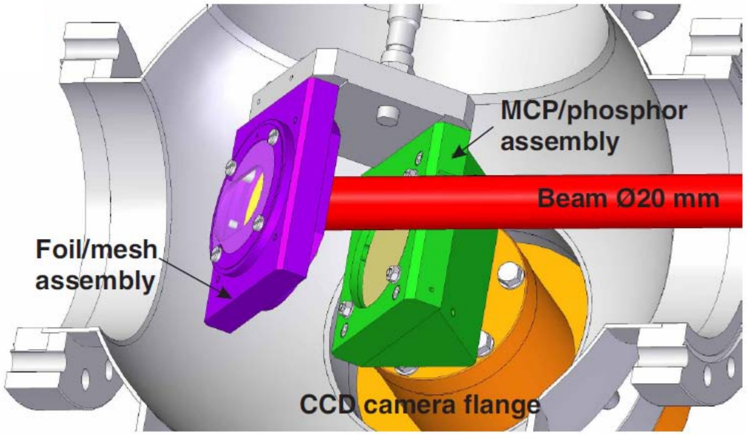
toward single particle imaging....!!!



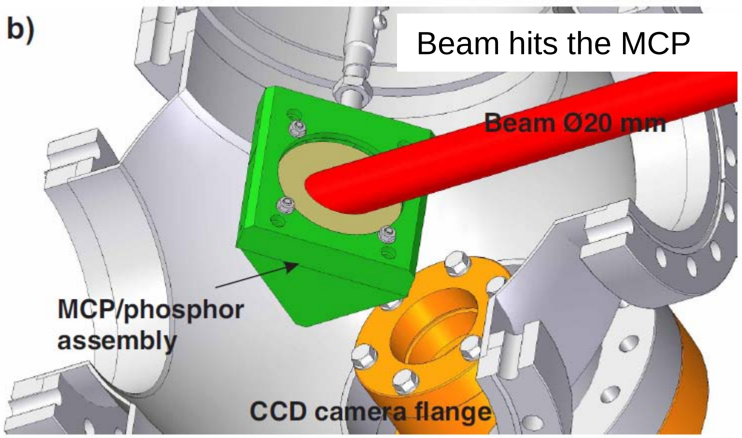


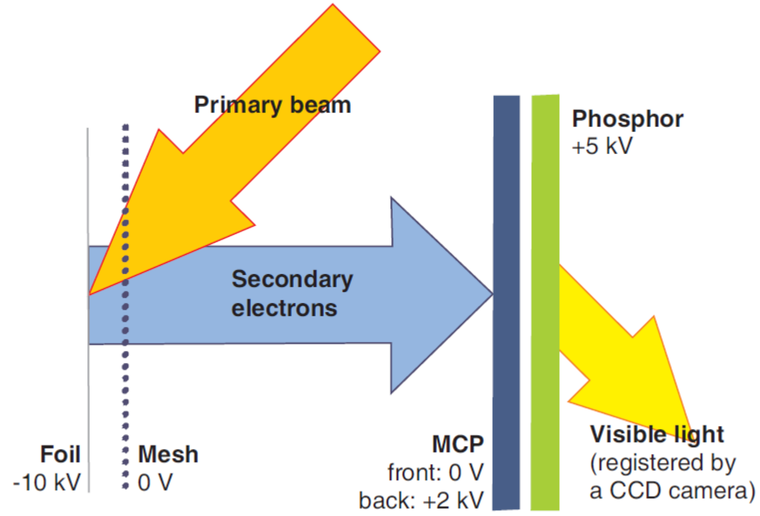
beam attenuated through a fine mesh, pitch ≈ 0.1mm

Microchannel Plate (MCP) for beam imaging

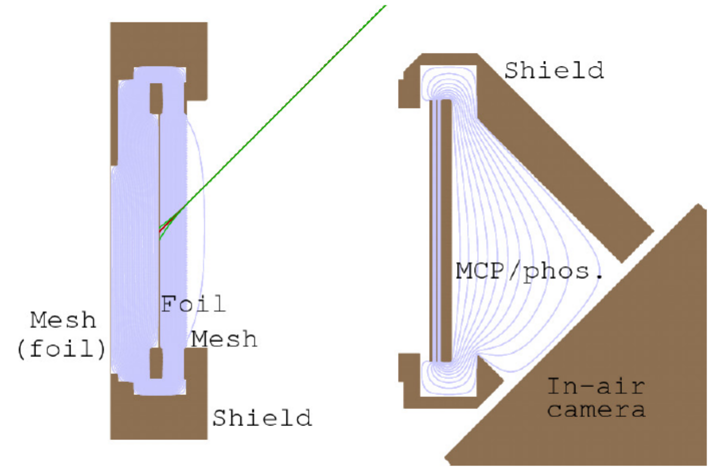


b)





Deflection of Low Energy Beams



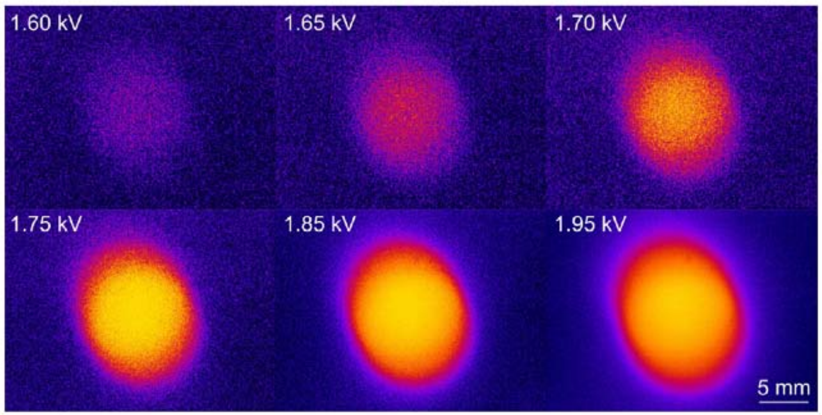
300 keV protons/antiprotons/H^- ions:	< 0.1 mm
20 keV protons:	< 1 mm
20 keV antiprotons/H^- ions:	3-5 mm

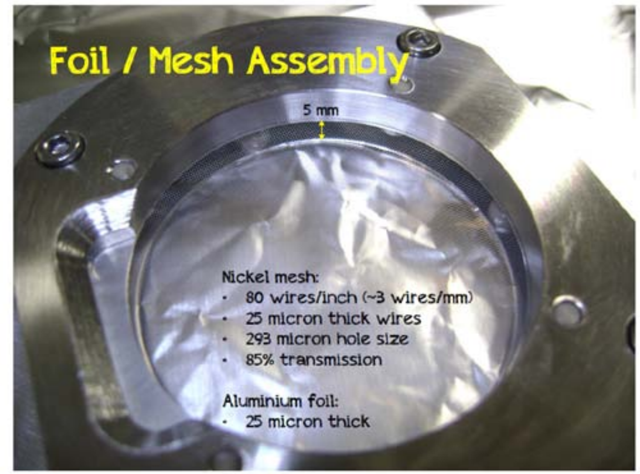
MCP for beam imaging

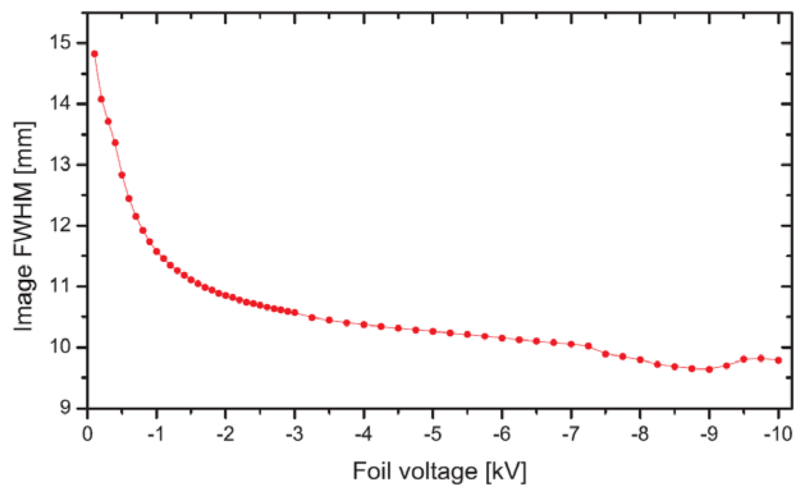
(proton beam with the Tandem injector at LNS)

proton beam 180 KeV
Intensity < 0.1 pA

different MCP gains

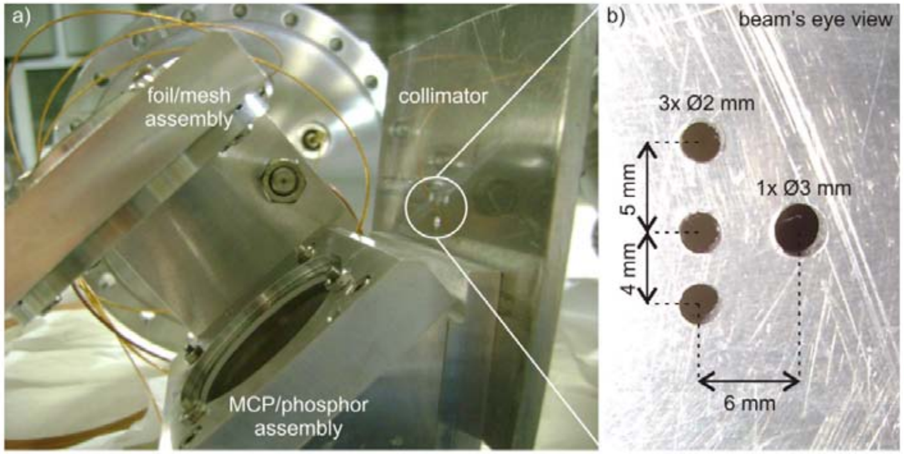




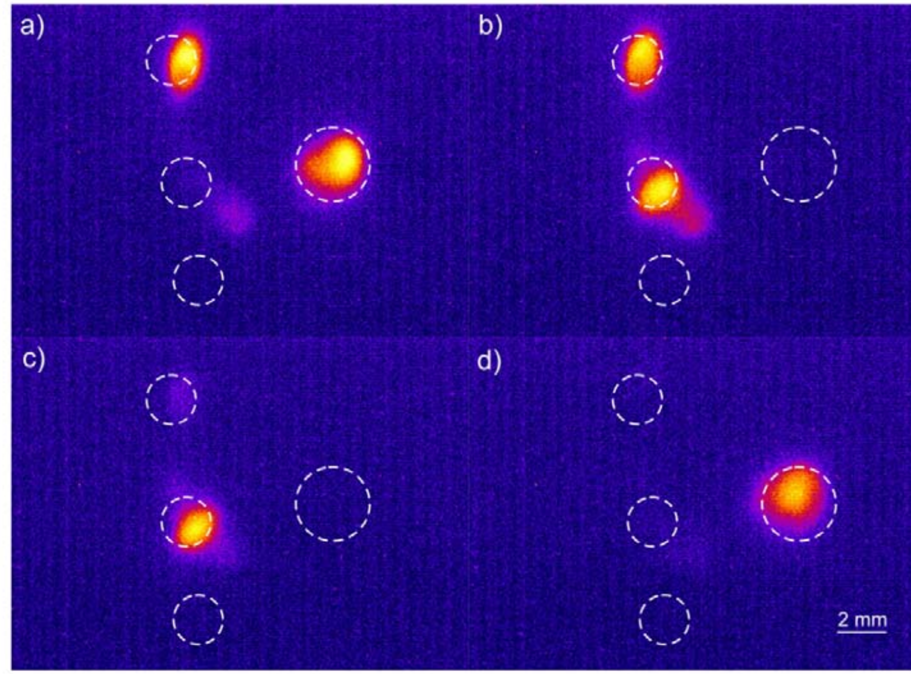


foil voltage

MCP for beam imaging with a mask



different beam steering

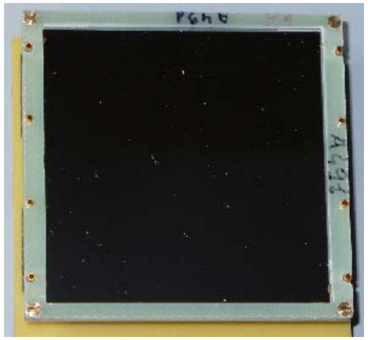


Further studies

- SEM/MCP sensitivity
- radiation hardness
- reliability/robustness

Diagnostics for accelerated RIBs

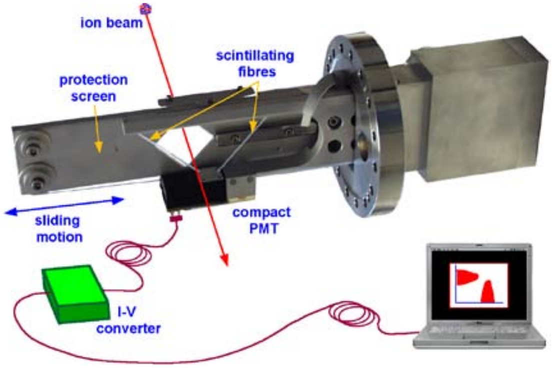
Plastic scintillators for beam intensity measurements



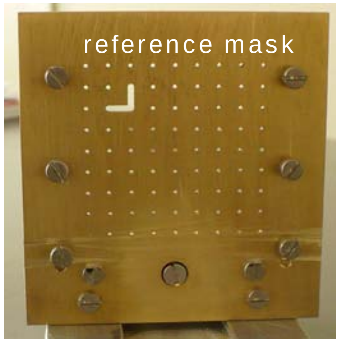
Position sensitive silicon detectors (PSSD)

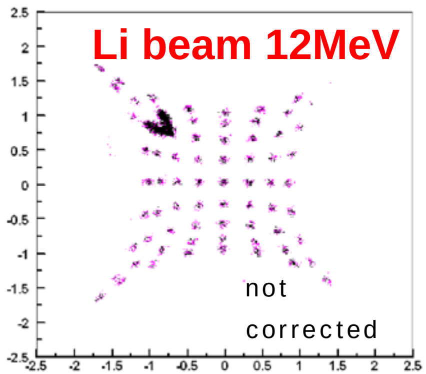
- **2D beam profile monitor**
- **beam energy spectra**
- **identification of the beam particles (ΔE – E)**

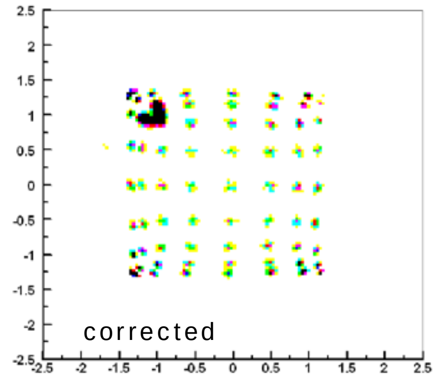
Beam profile monitor (FIBBS) based on a pair of scintillating fibres scanning the beam

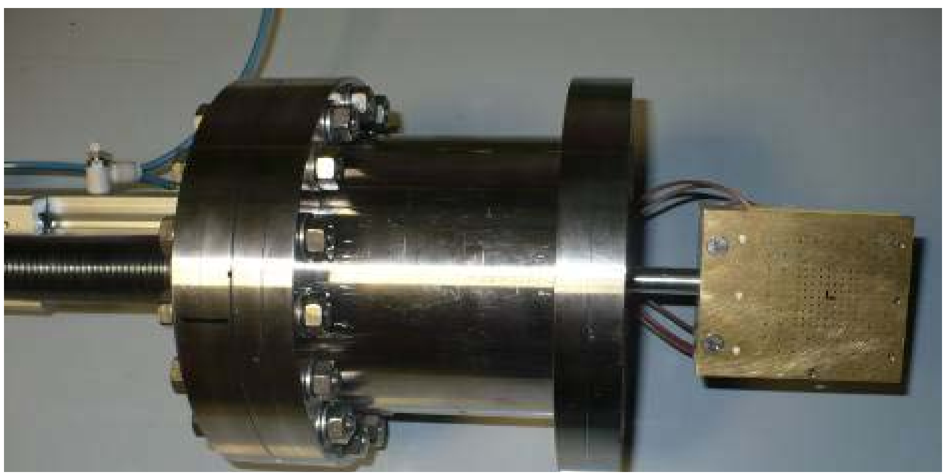


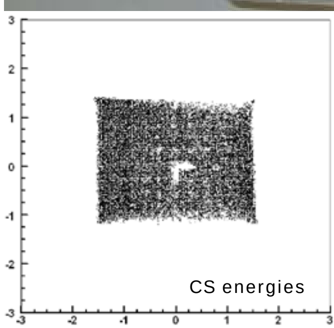
Position Sensitive Silicon Detectors

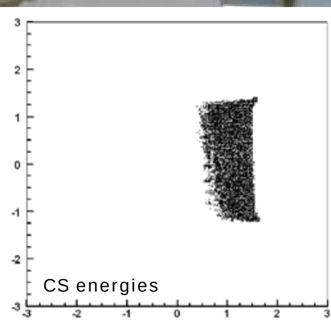


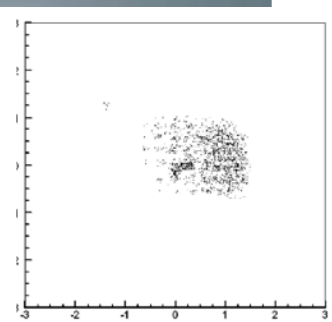












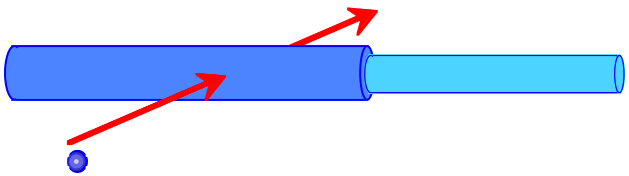
Real time beam imaging. Fast acquisition system based on VME modules

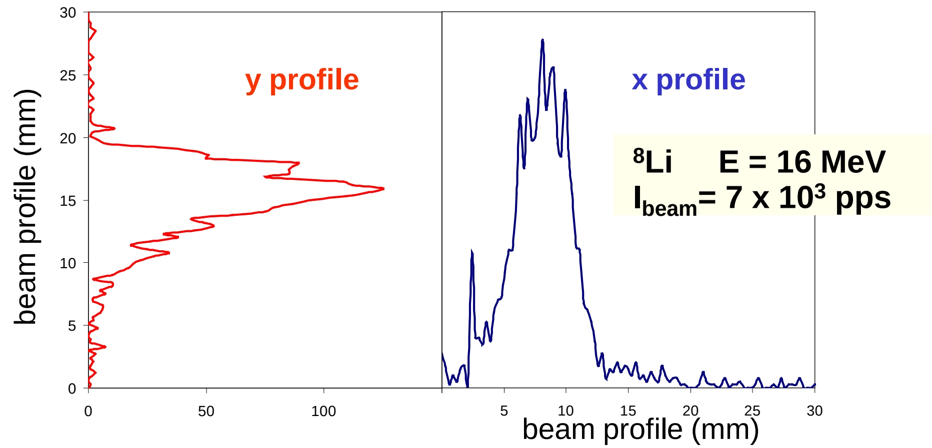
particle position reconstructed by 4 signals from the PSSD corners. Spatial resolution 1 – 2 mm

intensity range: a few pps to 10^4pps

1D beam scanning

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





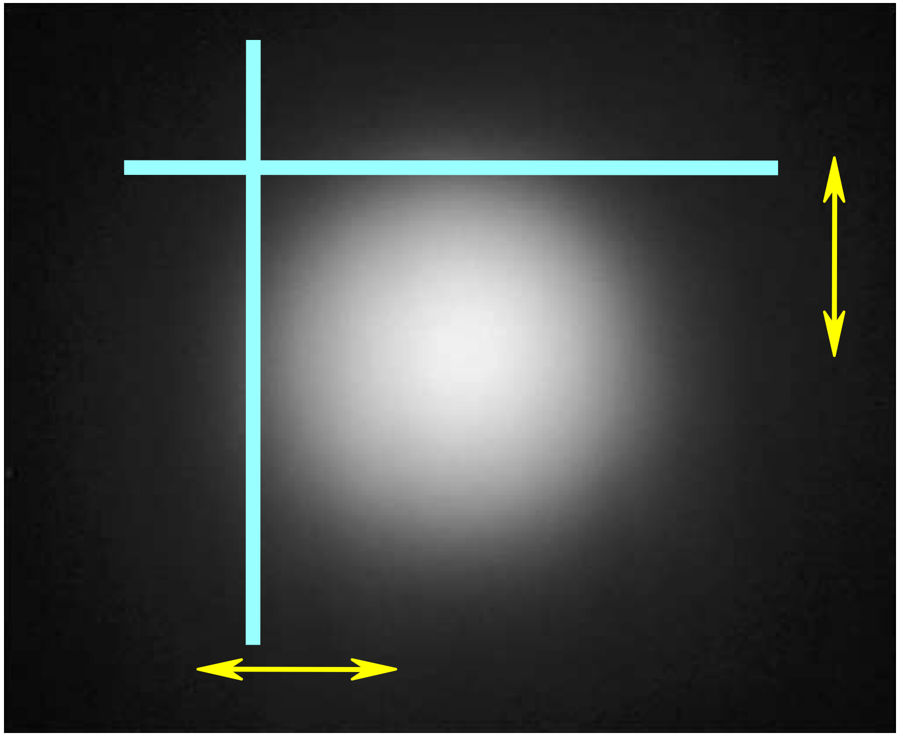
Light collection efficiency at one end: ≈3.5%

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

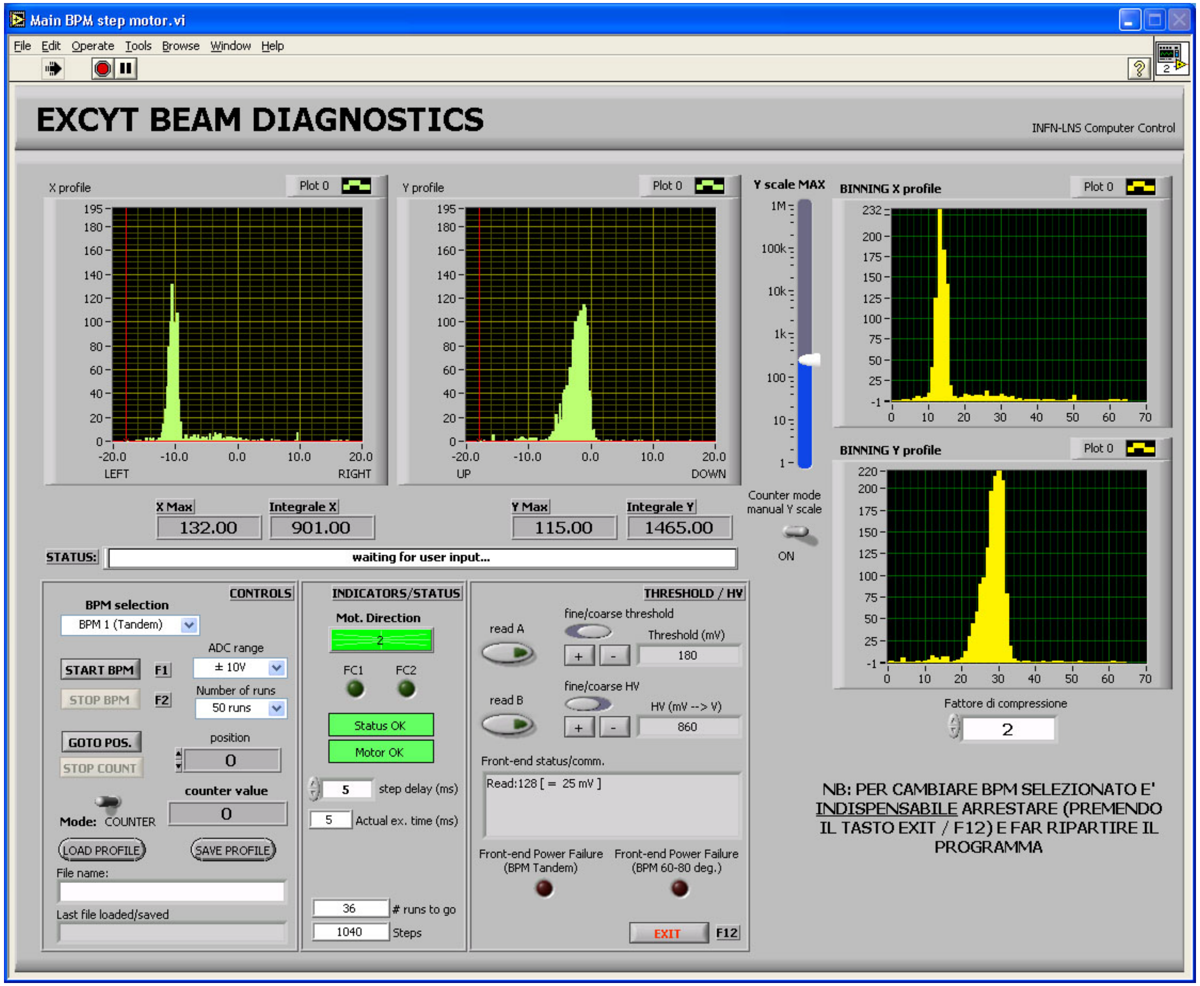
•Plastic scintillating fibre: fast (3ns), not rad-hard, L_{at}≈3.5m, λ≈435nm

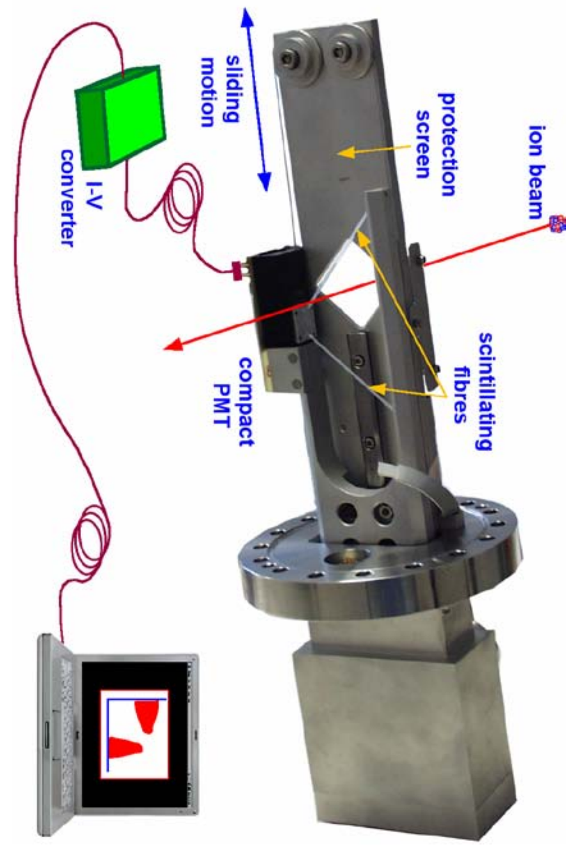
•Tb-glass scintillating fibre: slow (4ms), rad-hard, L_{at}≈10cm, λ≈550nm

•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

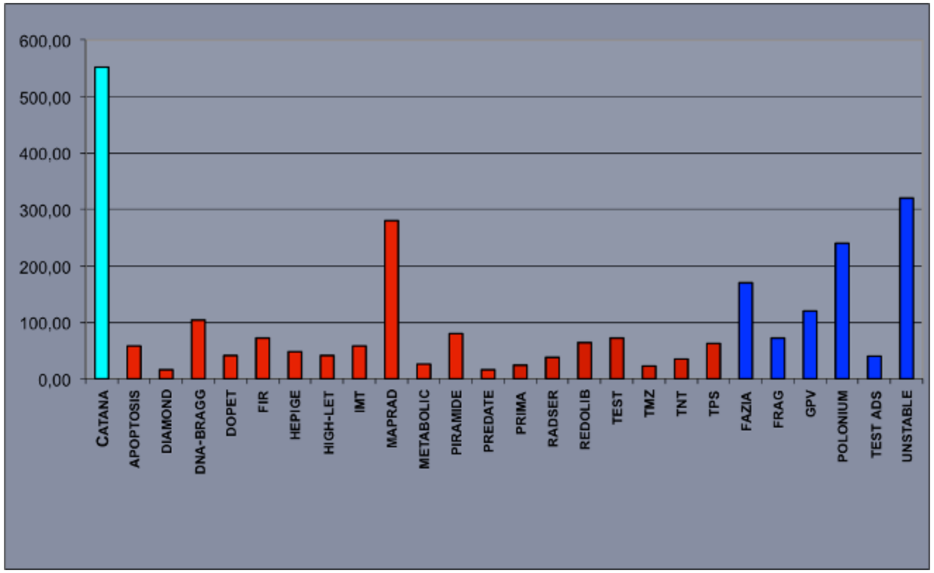
Conclusions

we are moving for developing a compact diagnostic device based on MCP and silicon detectors, in order to measure beam intensity, beam shape, time of flight and energy loss for ion identification (beam tagging)

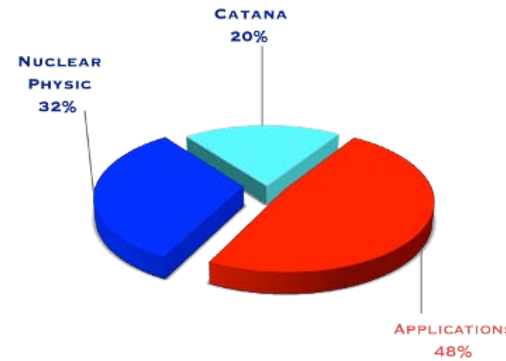
Thanks to the colleagues working in beam accelerators and ion sources!

Thank you for your attention

Use of the Cyclotron and Tandem beams in 2011



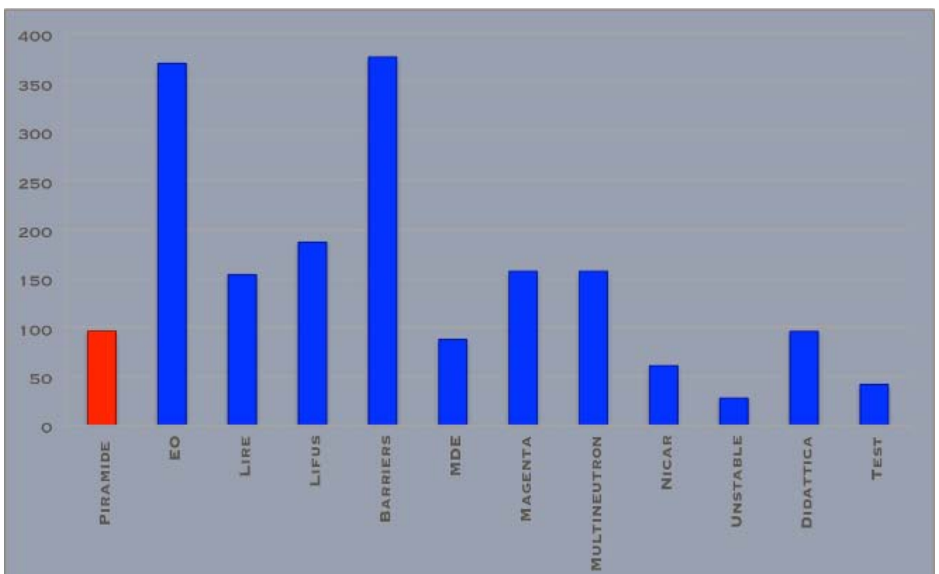
Cyclotron
2665 h



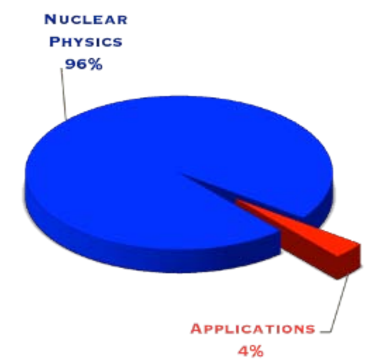
32%
Nuclear Physics

20%
Catana (protontherapy for eye melanoma)

48%
Applications



Tandem
1810 h



96%
Nuclear Physics

4%
Applications

EXCYT beam diagnostics: LEBI

Low Energy Beam Imager-Identifier

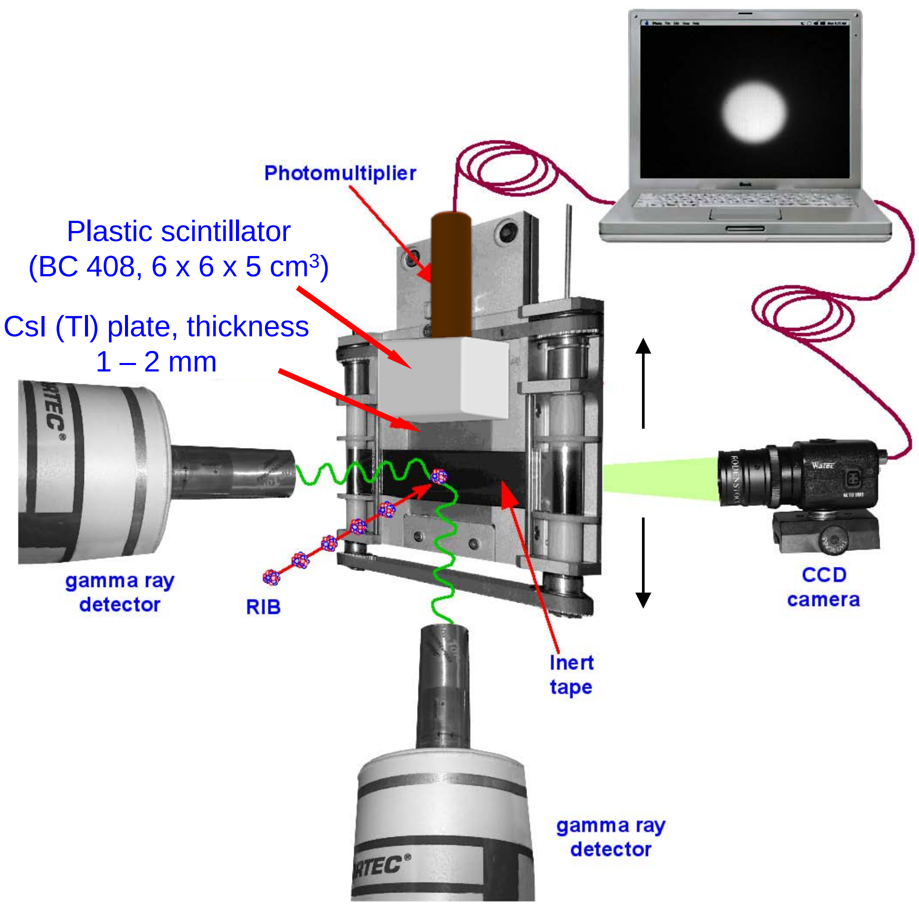
A complex diagnostics station that combines several techniques for beam detection and identification

CsI(Tl) plate + CCD camera for direct imaging of stable beams

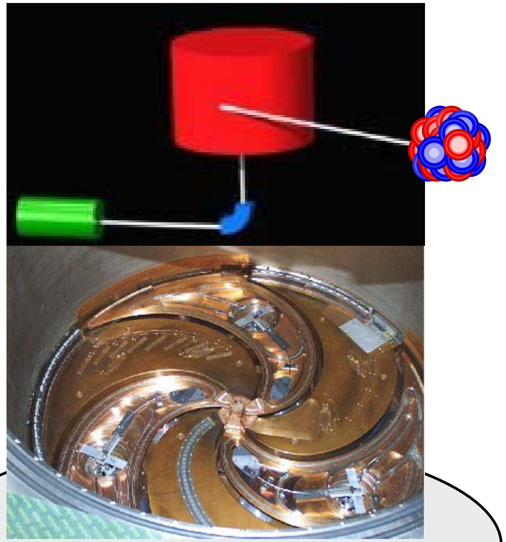
CsI(Tl) plate + CCD camera for beta-ray imaging of implanted RIBs

Plastic scintillator + PMT for radioactive decay counting of implanted RIBs (determination of $T_{1/2}$)

Gamma detectors for RIBs spectroscopic fingerprinting

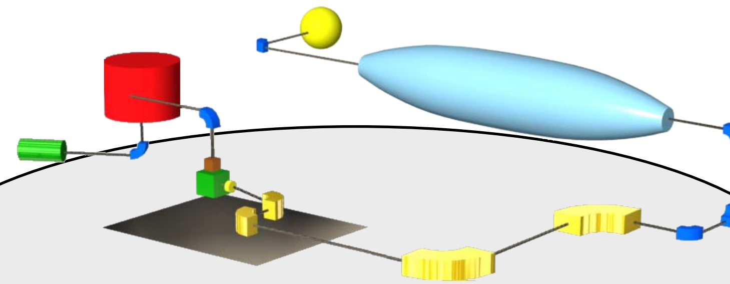


Accelerators and facilities at LNS



Superconducting Cyclotron
<80MeV/amu

Tandem 15MV



EXCYT facility: ISOL radioactive ion beams

Enegy ranges: 10keV ÷ 300keV
Tandem energy

FRIBs: in-flight fragment separator

Radioactive beams at the Cyclotron energies