Luigi Cosentino

Detectors for Imaging and Ion Beam Diagnostics at LNS

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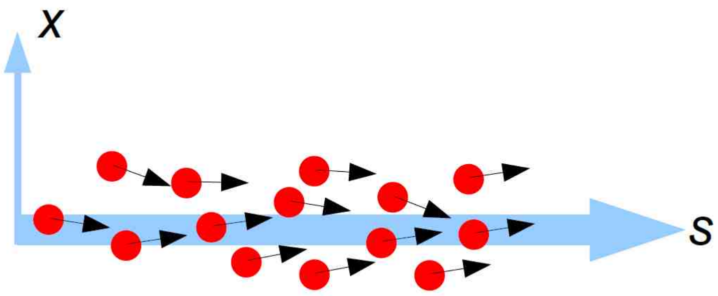
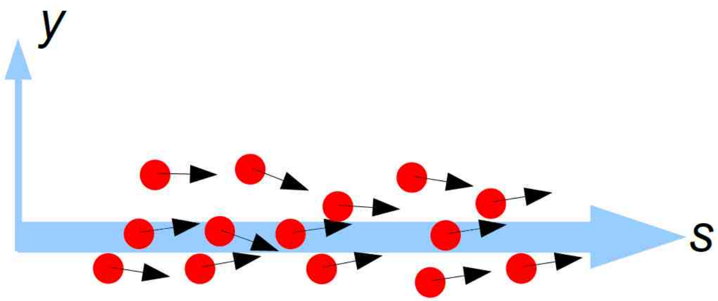
Fascio di particelle

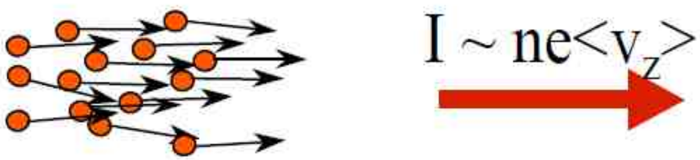




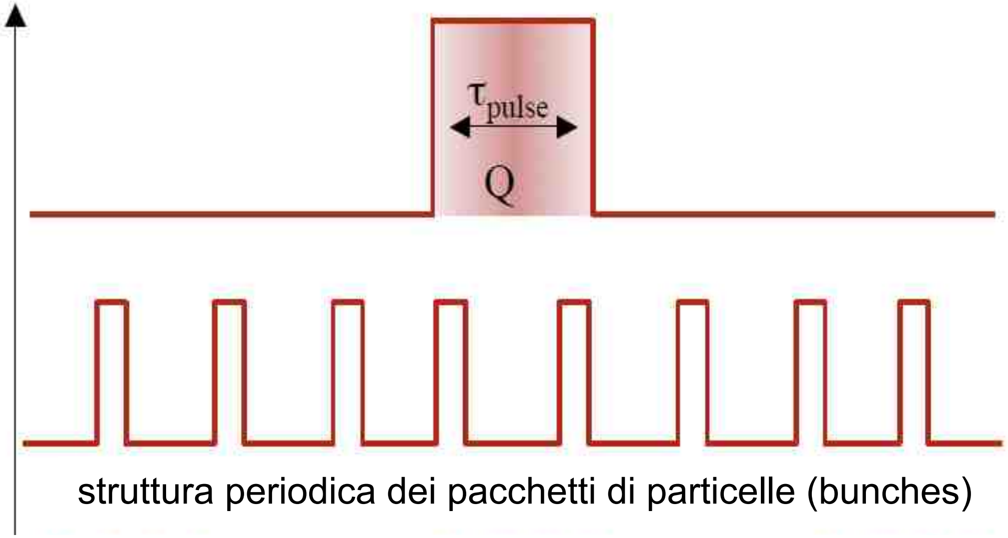
A beam of atoms or subatomic particles that have been accelerated by a particle accelerating device, aimed by magnets and focused by lens.
(font: thefreedictionary.com)

A particle beam is a stream of charged or neutral particles, in many cases moving at near the speed of light.
(font: Wikipedia)

Intensità del fascio



$$Duty\ factor = \frac{\sum \tau_{pulse}}{T}$$



$$I_{peak} = Q / \tau_{pulse}$$

$$I_{ave} = Q_{tot} / T$$

struttura periodica dei pacchetti di particelle (bunches)

Profilo del fascio nel piano trasverso alla direzione del moto

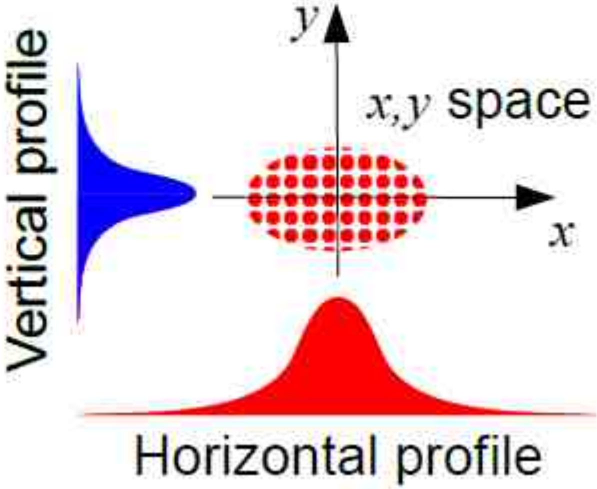
Particles distribution: $i(x,y)$

Profiles:
$$\begin{cases} Prof_H(x)=\int_{-\infty}^{+\infty} i(x,y)\,dy \\ Prof_V(y)=\int_{-\infty}^{+\infty} i(x,y)\,dx \end{cases}$$

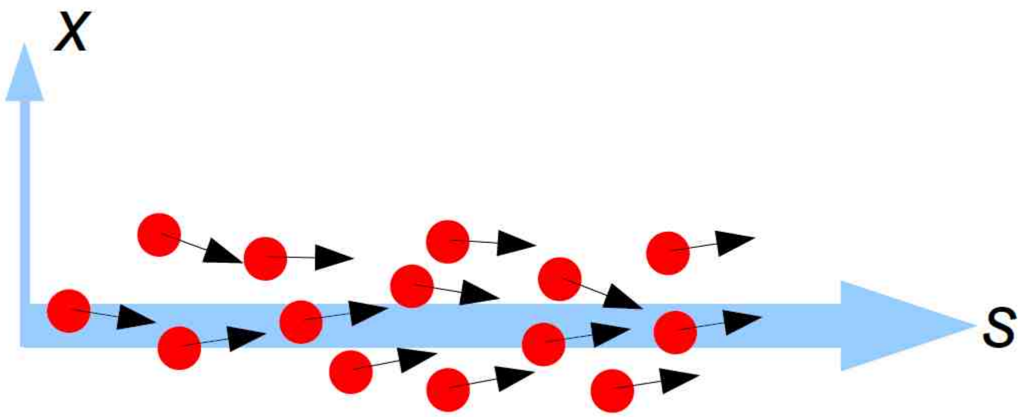
Typically $i(x,y)$ is Gaussian:
N_0= total number of particles

$$i(x,y)=\frac{N_0}{2\pi\sigma_x\sigma_y}e^{-\left(\frac{x^2}{2\sigma_x^2}+\frac{y^2}{2\sigma_y^2}\right)}$$

$$\Rightarrow \begin{cases} Prof_H(x)=\frac{N_0}{\sqrt{2\pi}\sigma_x}e^{-\frac{x^2}{2\sigma_x^2}} \\ Prof_V(y)=\frac{N_0}{\sqrt{2\pi}\sigma_y}e^{-\frac{y^2}{2\sigma_y^2}} \end{cases}$$

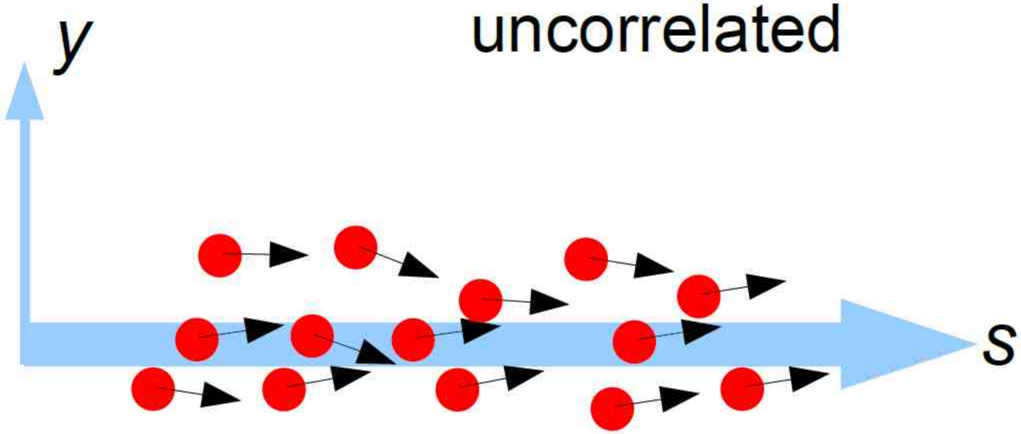


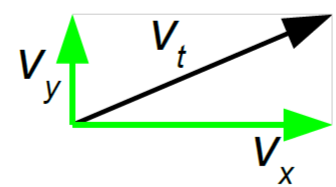
Come si propaga il fascio di particelle

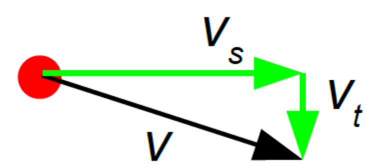


- Velocity has 2 components
  - *Transverse* $v_t = v_x \hat{x} + v_y \hat{y}$
  - *Longitudinal* v_s
- Transverse components also called x' and y'

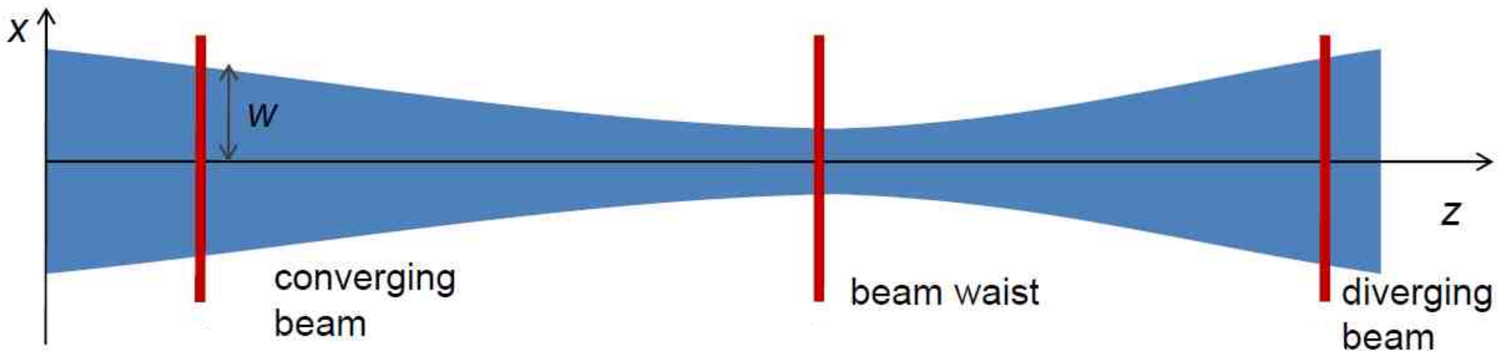
v_x, v_y and v_s are normally uncorrelated





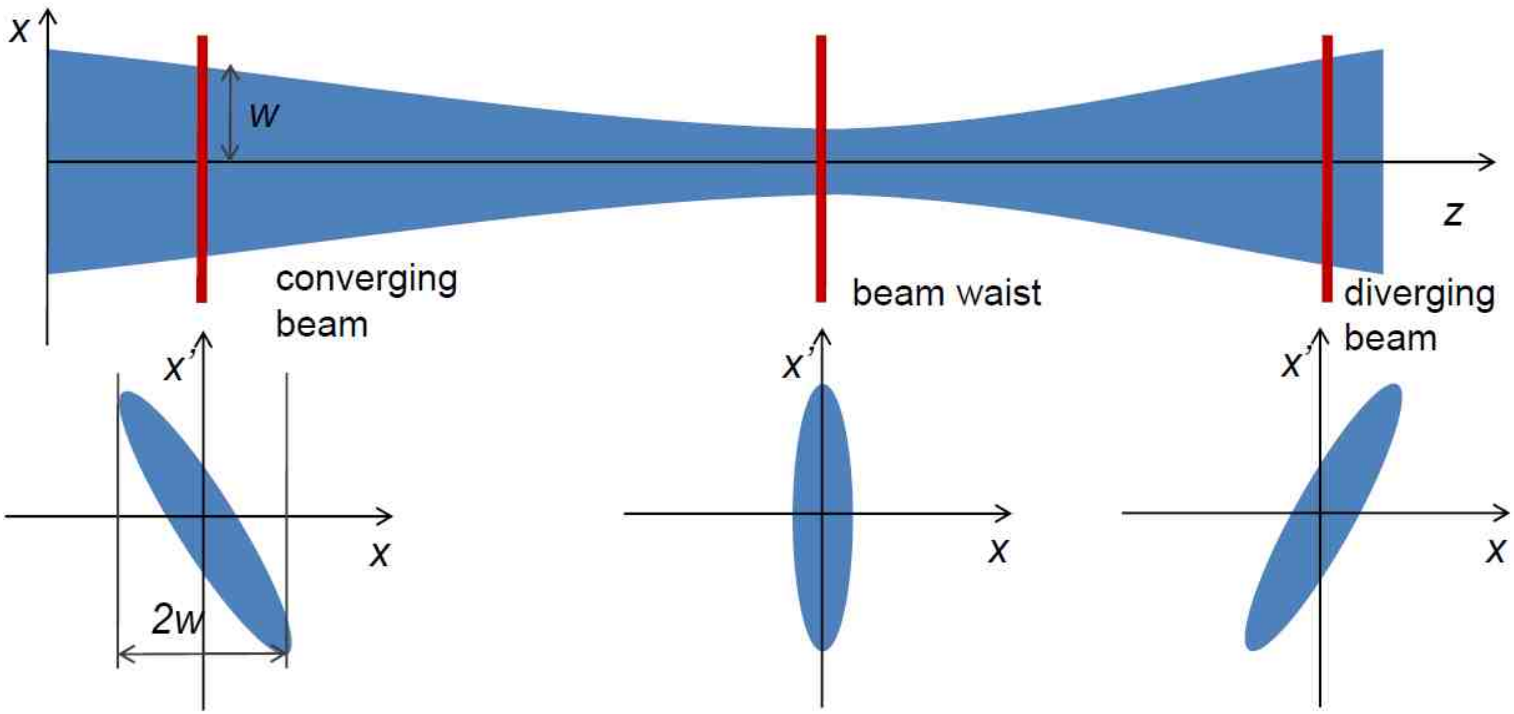


Come si propaga il fascio di particelle



Courtesy of Hans Braun

Come si propaga il fascio di particelle



Along a beamline the orientation and aspect ratio of beam ellipse in *x, x'* plane varies, but area $\pi\varepsilon$ remains constant

<u>Commonly used units for emittance</u>

mm·mrad, m·rad, μm, m, nm

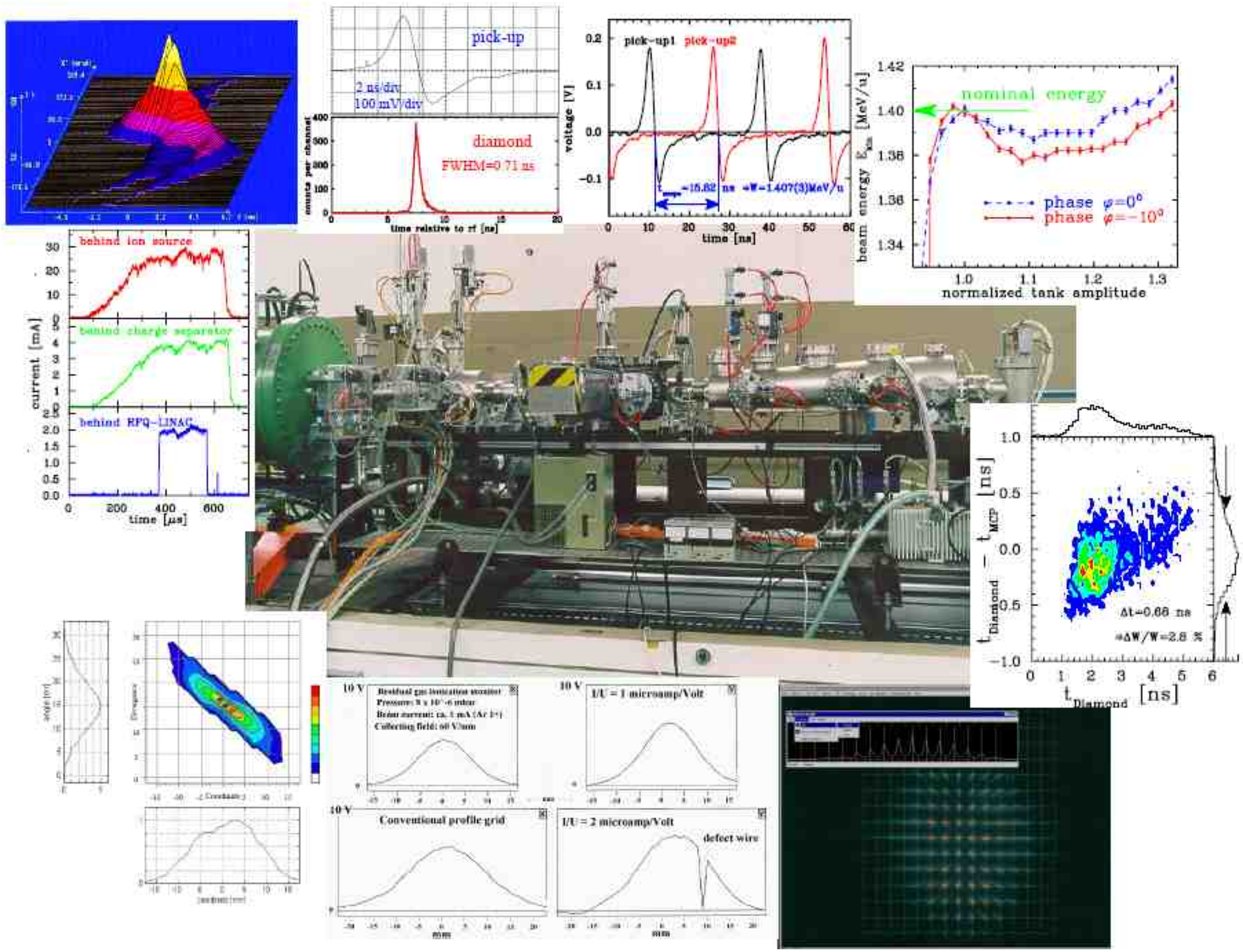
1 mm·mrad=10^{-6} m·rad=1μm=10^{-6} m=10^{3}nm

Often a π is added to the unit to indicate that the numerical value describes a surface in x, x' space divided by π, i.e. 1 π·mm·mrad

The units for normalised emittance are the same as for geometric emittance

Courtesy of Hans Braun

Per ottimizzare il trasporto e di conseguenza la trasmissione lungo tutta la linea di fascio, è necessario misurare i parametri di interesse con appositi dispositivi di diagnostica.



Courtesy of Peter Forck

Diagnostica dei fasci di particelle

Ogni sistema di diagnostica deve essere:

- **affidabile**
- **veloce**
- **ergonomico (strumenti alla portata degli operatori di macchina)**

Most of the diagnostic instrumentation is based on one of the following physical processes:

- **The electro-magnetic influence of moving charges** on the environment as described by classical electro-dynamics. The technique is based on a voltage or current measurement on a low or high frequency scale.

- **The Coulomb interaction of charged particles penetrating matter.** The energy release due to electronic stopping gives the dominant fraction of the detected signal.

- **The nuclear- or elementary particle physics interaction** between the accelerated particles and a fixed target or between colliding beams. From the known cross sections, the beam quantity can be deduced.

- **The interaction of the particles with a photon beam**. The technique is based on lasers, their associated optics and on detectors used for high energy physics.

- **The emission of photons by accelerated charges.** This diagnostic is only important for relativistic particles, i.e. electrons or very highly energetic protons. The technique is based on optical methods spanning the visible range up to the x-ray region.

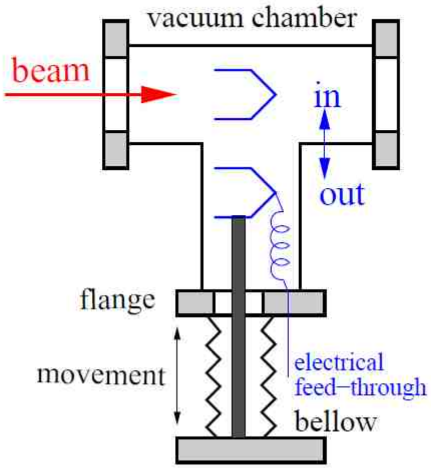
Diagnostic devices and quantity measured

Instrument	Physical Effect	Measured Quantity	Effect on beam
Faraday Cup	Charge collection	Intensity	Destructive
Current Transformer	Magnetic field	Intensity	Non destructive
Wall current monitor	Image Current	Intensity Longitudinal beam shape	Non destructive
Pick-up	Electric/magnetic field	Position	Non destructive
Secondary emission monitor	Secondary electron emission	Transverse size/shape, emittance	Disturbing, can be destructive at low energies
Wire Scanner	Secondary particle creation	Transverse size/shape	Slightly disturbing
Scintillator screen	Atomic excitation with light emission	Transverse size/shape (position)	Destructive
Residual Gas monitor	Ionization	Transverse size/shape	Non destructive

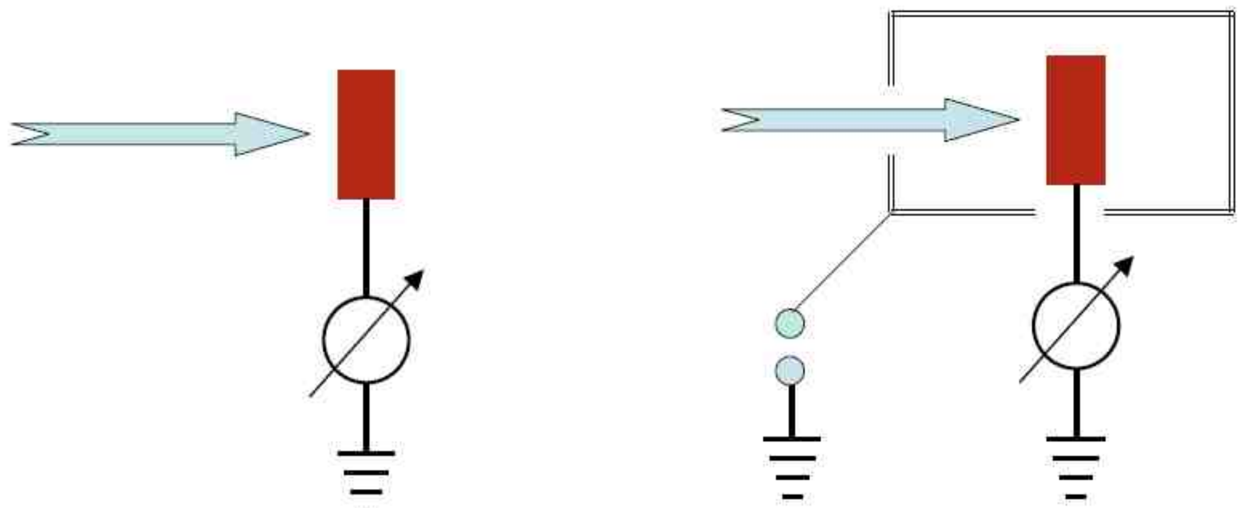
Intensità di corrente

La tecnica più semplice per misurare l'intensità del fascio

Collecting the charge: Right & wrong way



The Faraday cup



Simple collector

Proper Faraday cup

I_{beam} > a few pA

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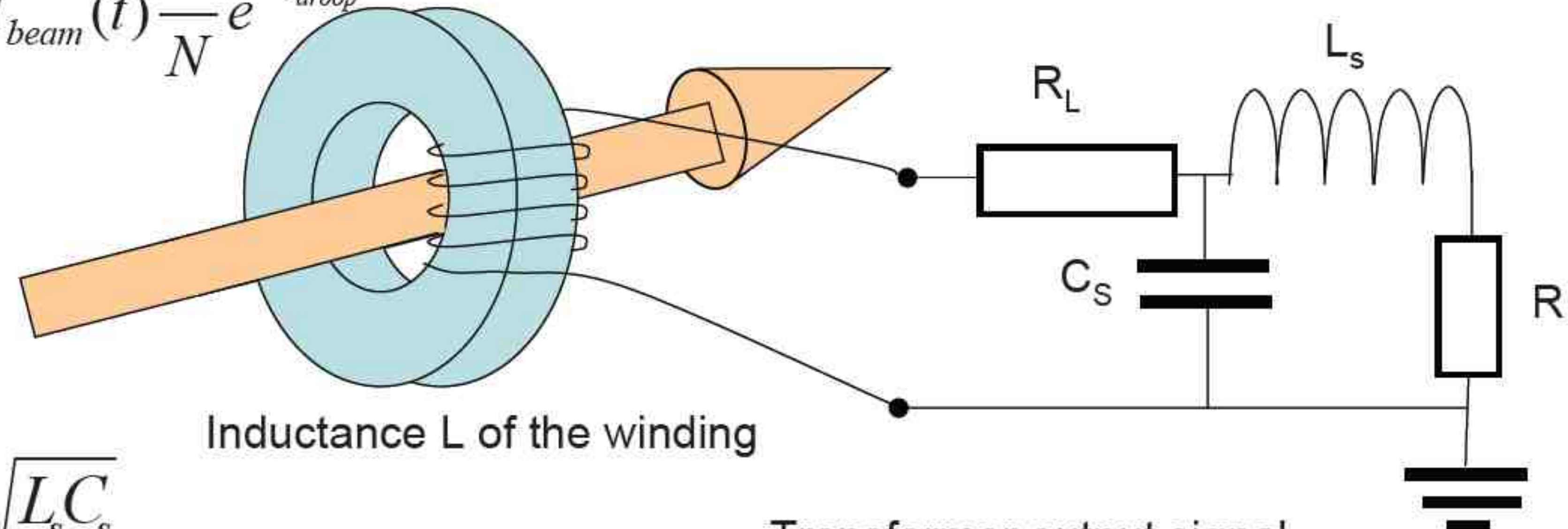
Misure non distruttive della corrente di fascio. Intensità elevate!

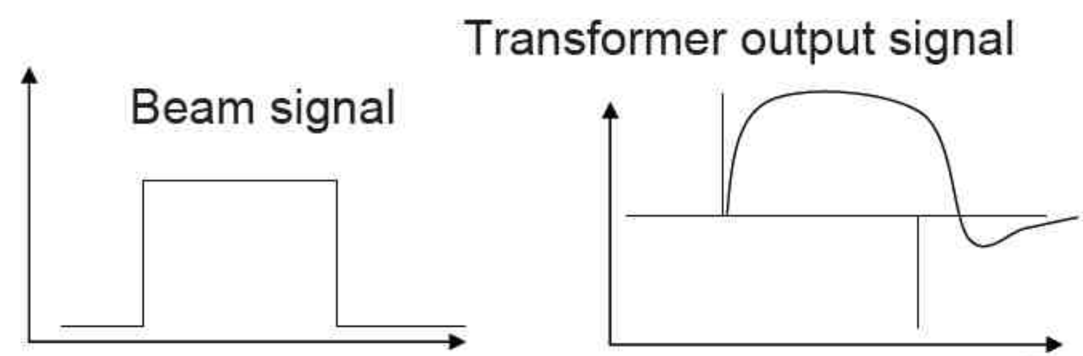
Trasformatore

$$U(t) = I_{beam}(t)\frac{R}{N}e^{-\frac{t}{\tau_{droop}}}$$



$$\tau_{rise} = \sqrt{L_s C_s}$$

$$\tau_{droop} = \frac{L}{R + R_L}$$

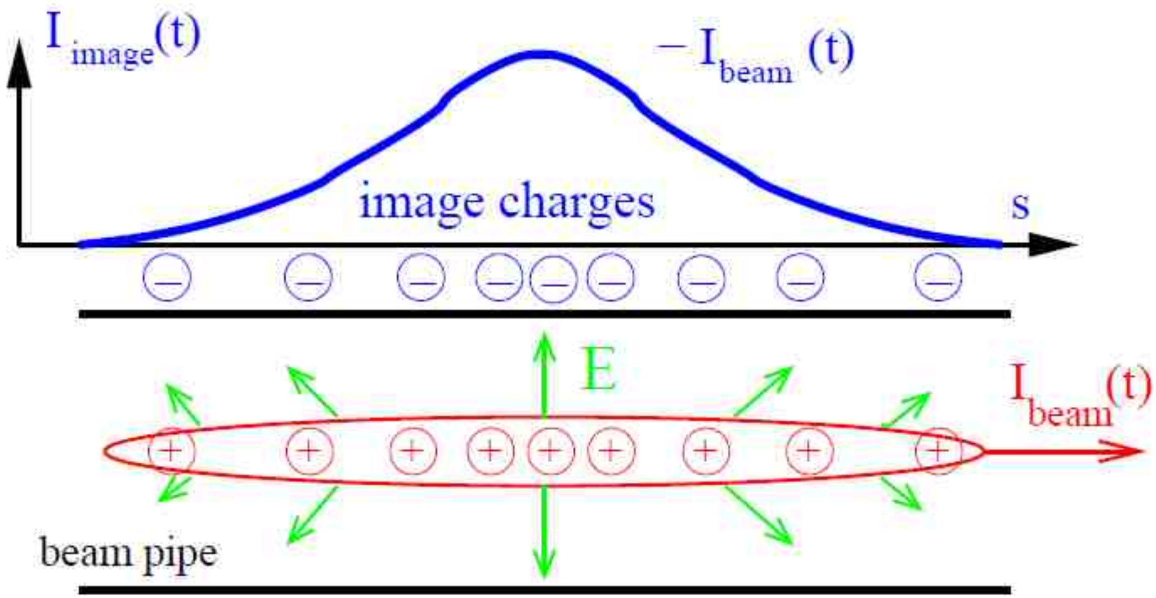


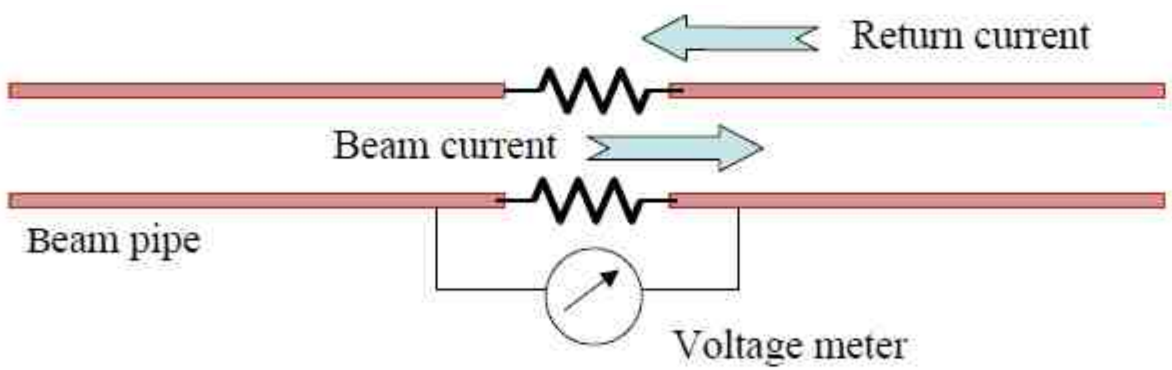
I_{beam} > several μA

U. Raich CERN Accelerator School Zakopane 2006

Misure non distruttive di corrente di fascio. Intensità elevate!

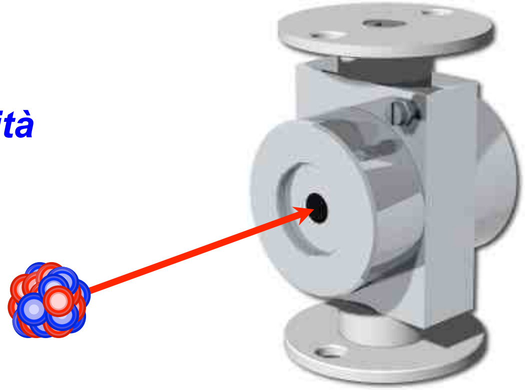
Wall Current Monitor





Diagnostica per fasci di basse intensità (I < 1pA): Rivelatori di particelle

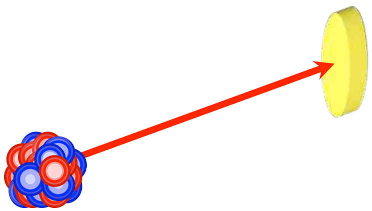
Con la Faraday cup si è sensibili alla carica raccolta, che integrata nell'unità di tempo fornisce la corrente



Esempio:

in un fascio di $^{16}O^{1+}$ a 1MeV, per ogni ione raccolto da una FC, la carica prodotta è pari ad un elettrone

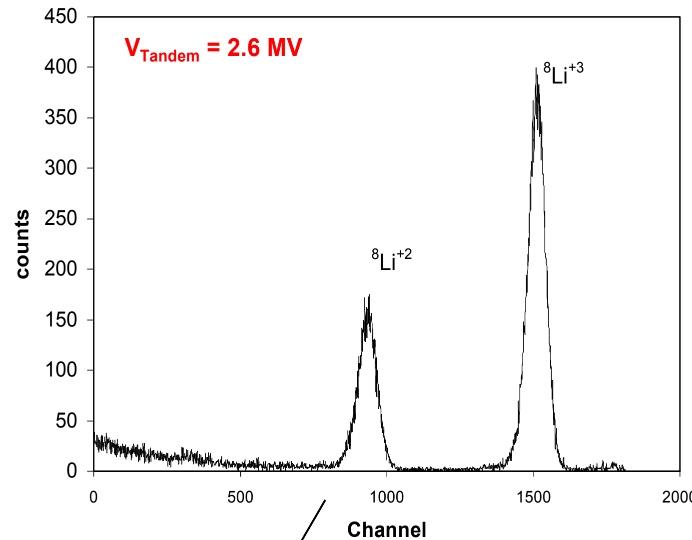
Con un rivelatore di particelle, si è sensibili all'energia rilasciata dalla particella.

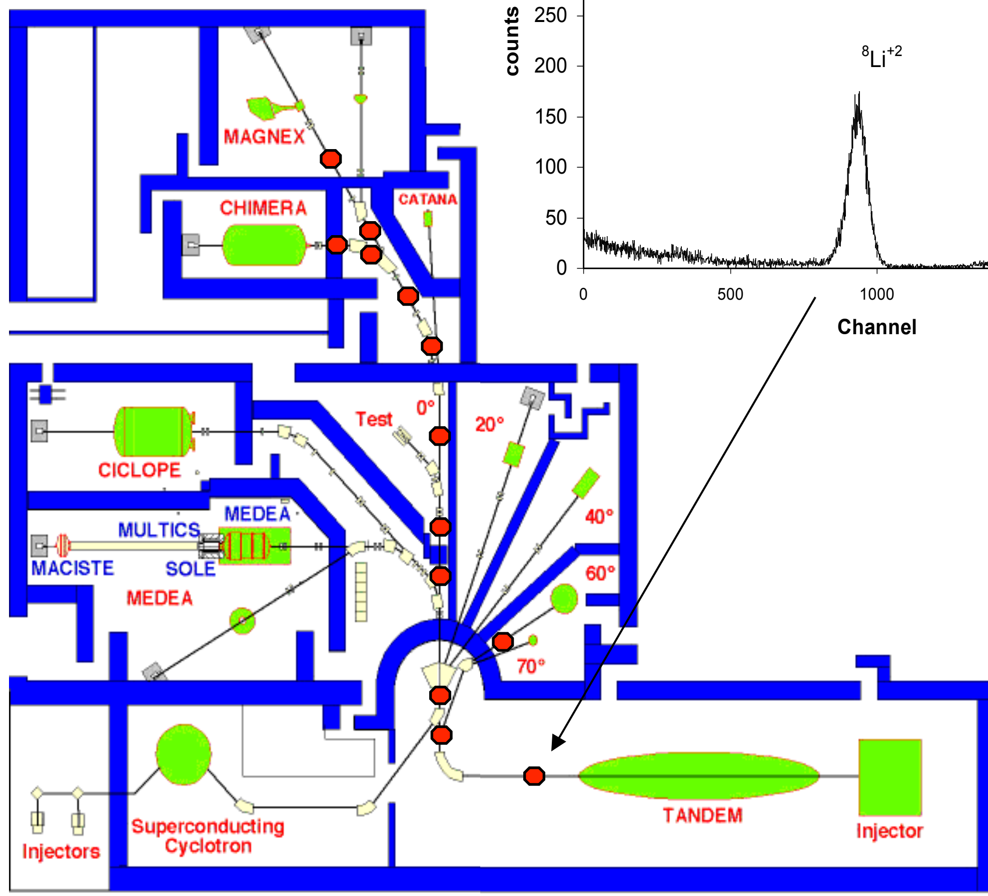


lo stesso ione in un rivelatore al silicio produce una carica di:

1MeV/3.62eV = 276000 elettroni!

Rivelatori al silicio per diagnostica di fasci radioattivi ai LNS (I << 1pA)





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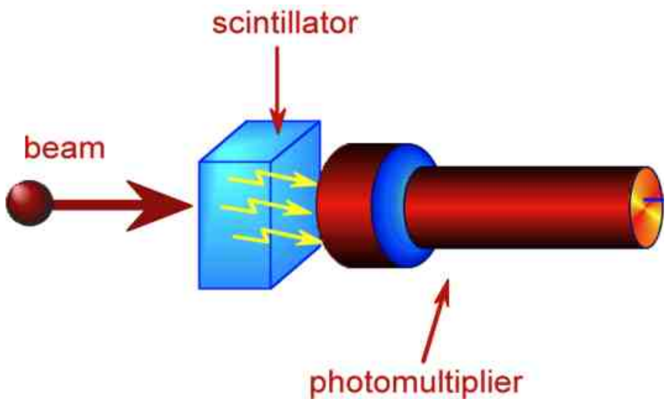
Scintillatori

- 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



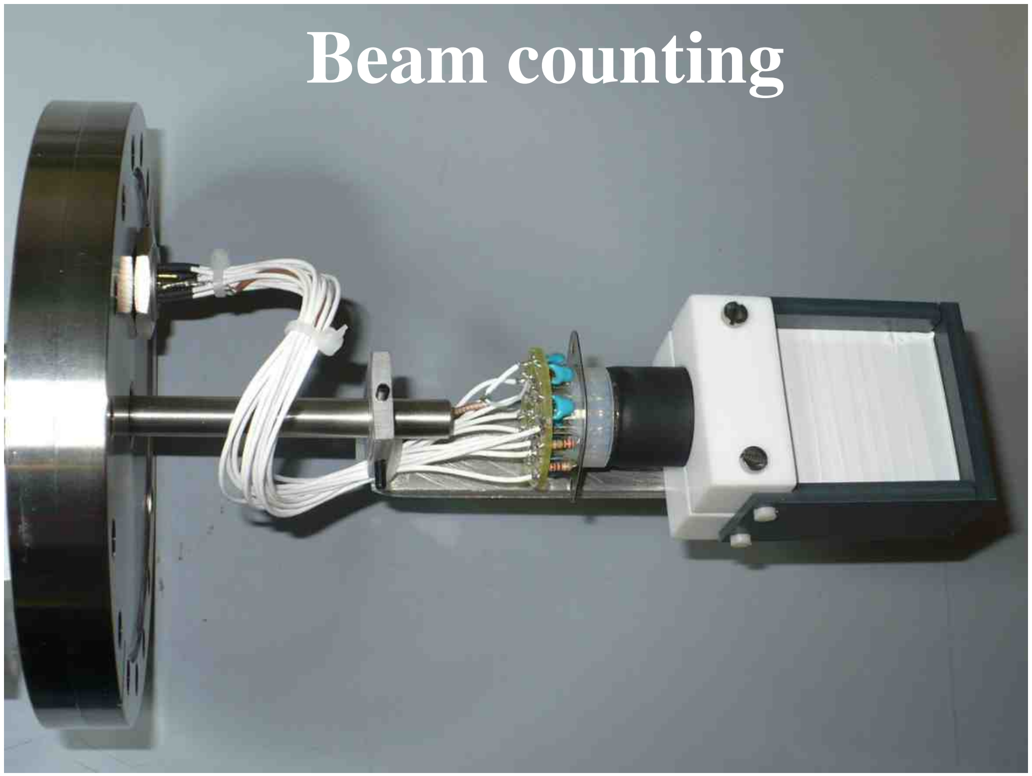
- organic scintillators (plastics: NE110, NExxx, BC404, BC408, BCxxx, fibres, etc.)
- inorganic crystals (CsI, BaF, YAG,YAP, LSO, LYSO, LaBr, etc.)
- doped glasses (with Tb, Ce)

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)

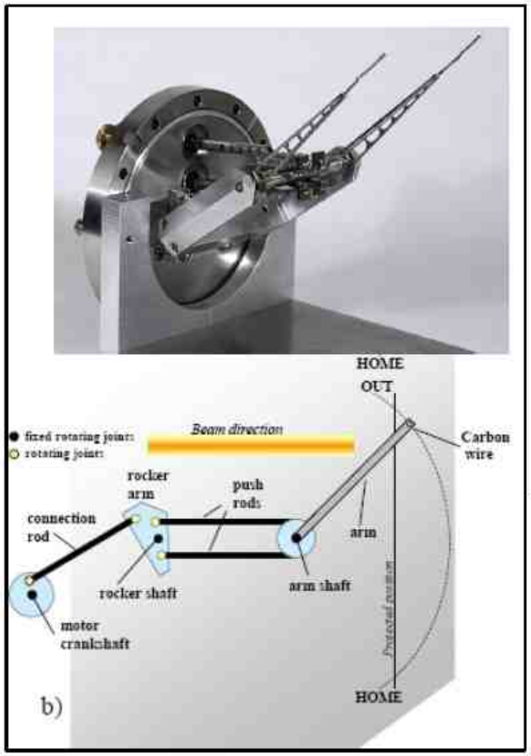
Misura di intensità dei fasci radioattivi ai LNS ($10 \div 10^6$ pps)

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

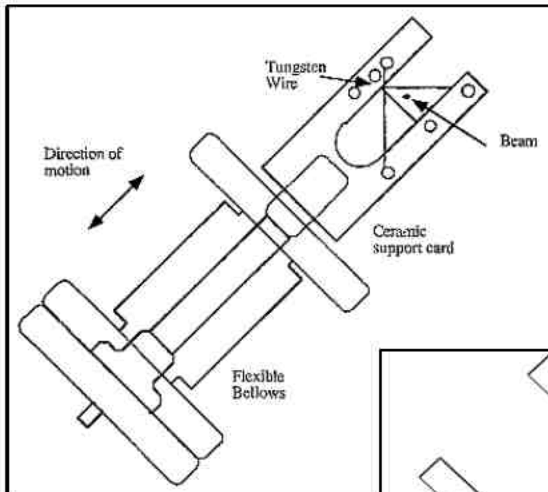


Profili del fascio sul piano trasverso

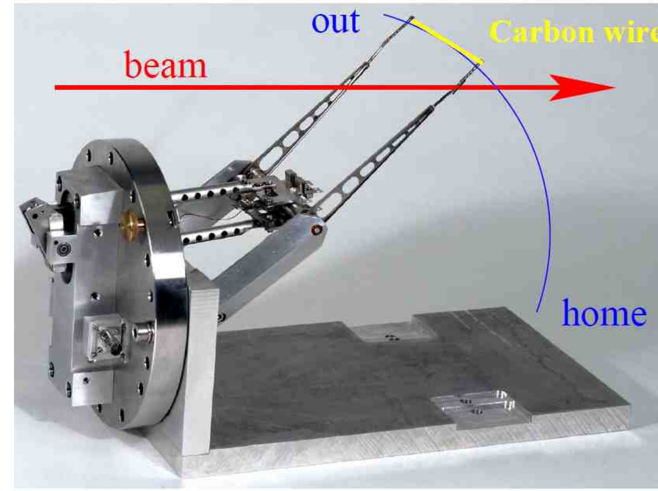
Profili monodimensionali: wire scanner

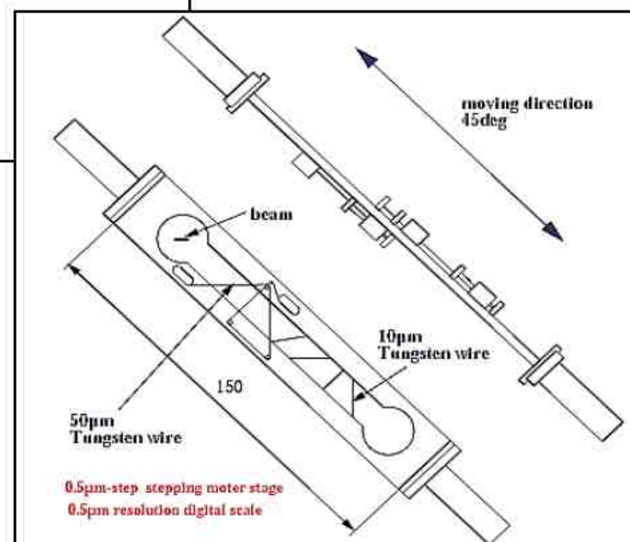


CERN “flying wires”



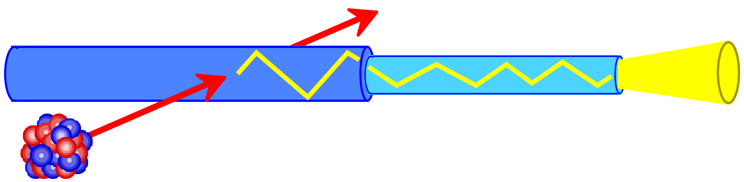
SLAC SLC high resolution 3 axis scanners





$$\sigma^2_{beam} = \sigma^2_{meas} - 4 \cdot r^2_{wire}$$

Fibre scintillanti per aumentare la sensibilità



Light collection efficiency at one end: ≈3.5%

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

- Light yield of the order of 10000 photons/MeV (gamma rays and electrons)
- the light yield for charged particles is lower: quenching

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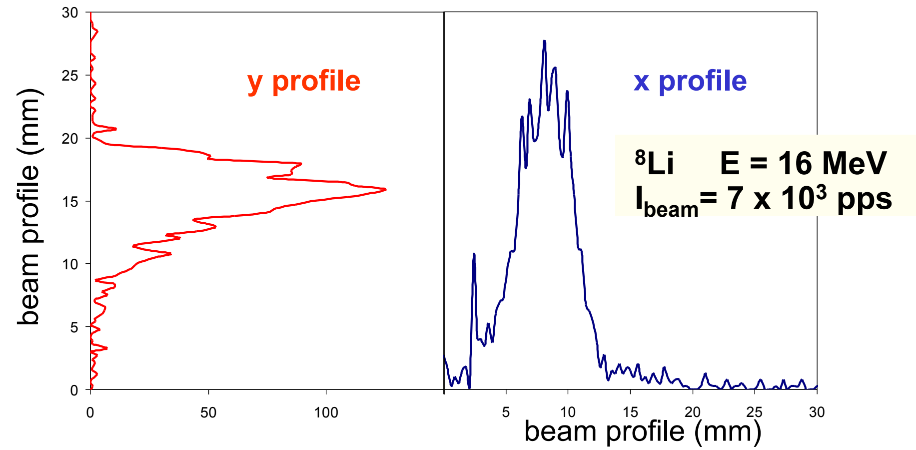
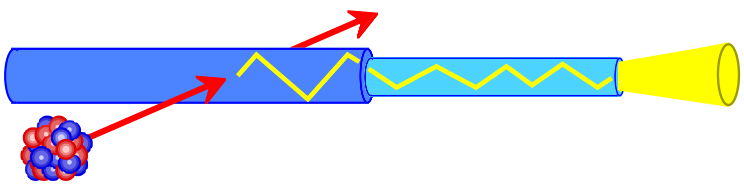
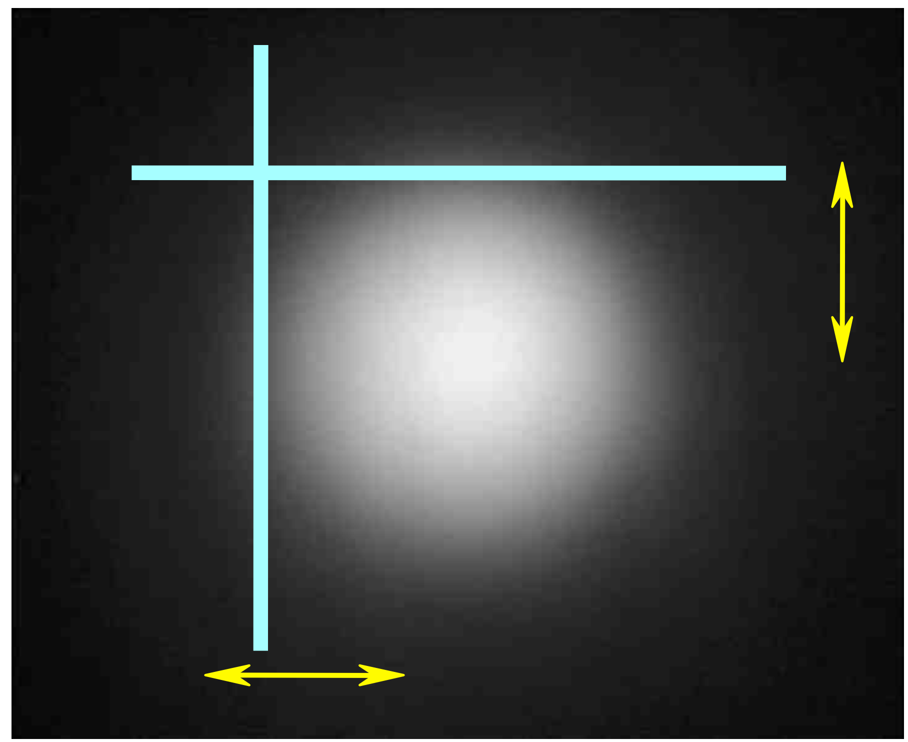
...con i fasci radioattivi dei LNS

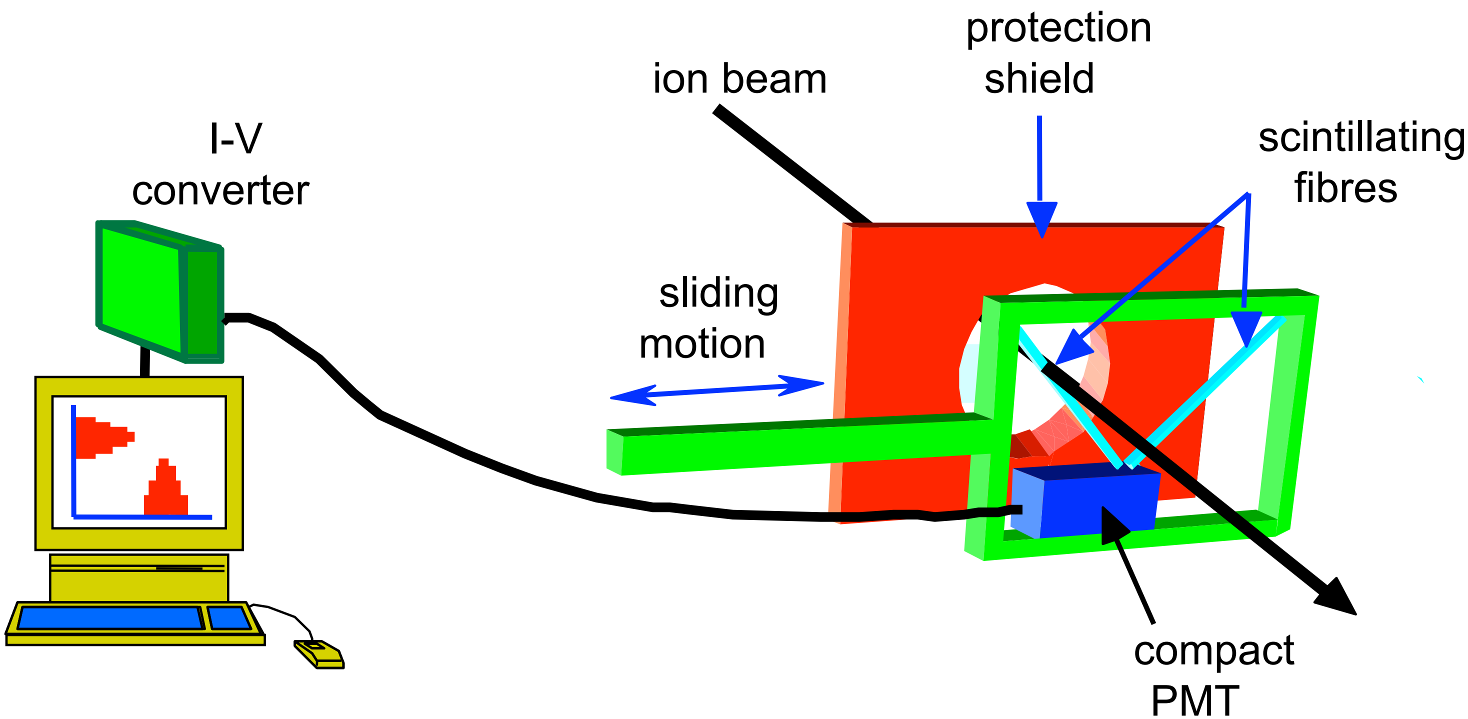
scanning a beam with scintillating fibres, in order to produce the 1D intensity distribution



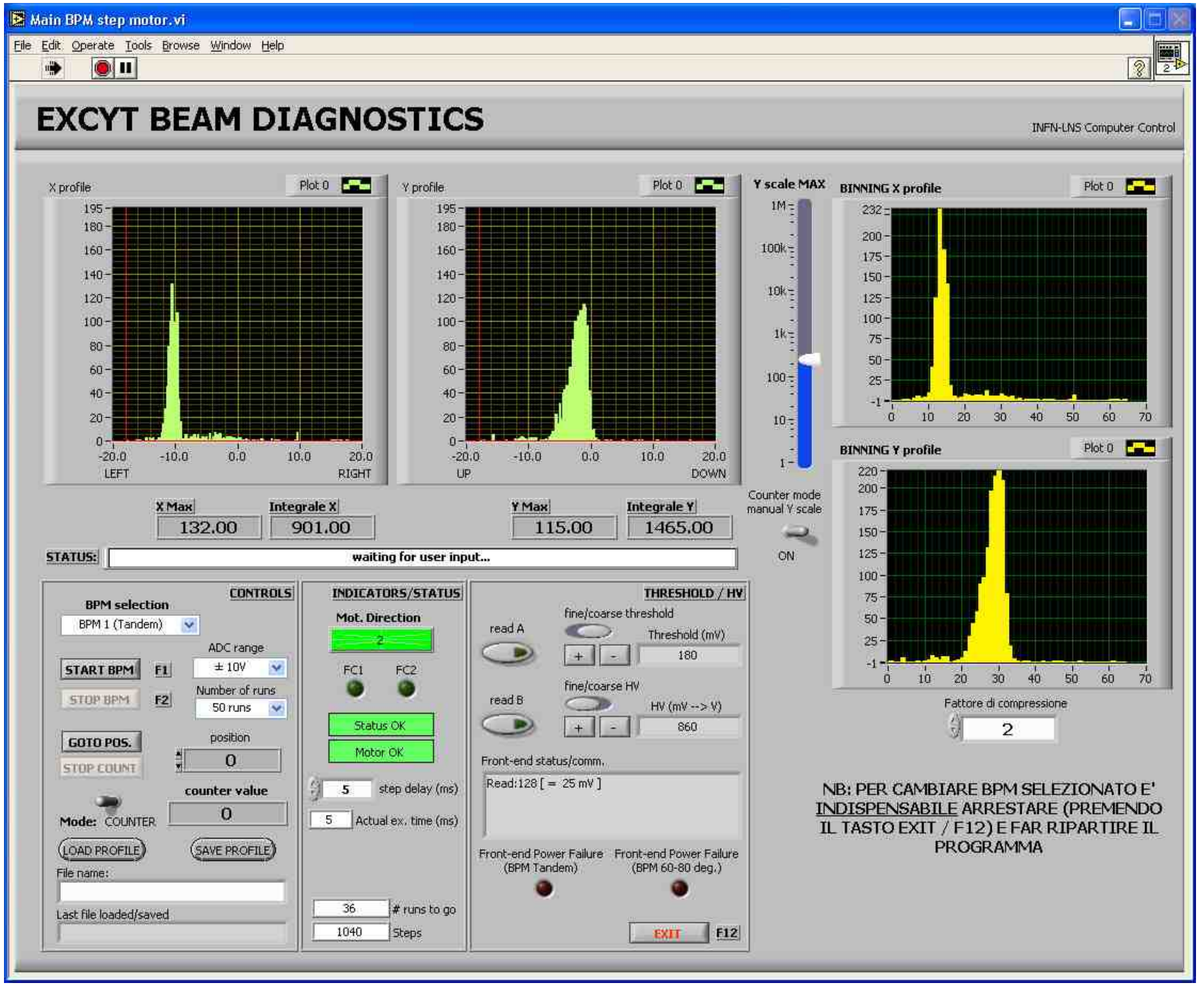


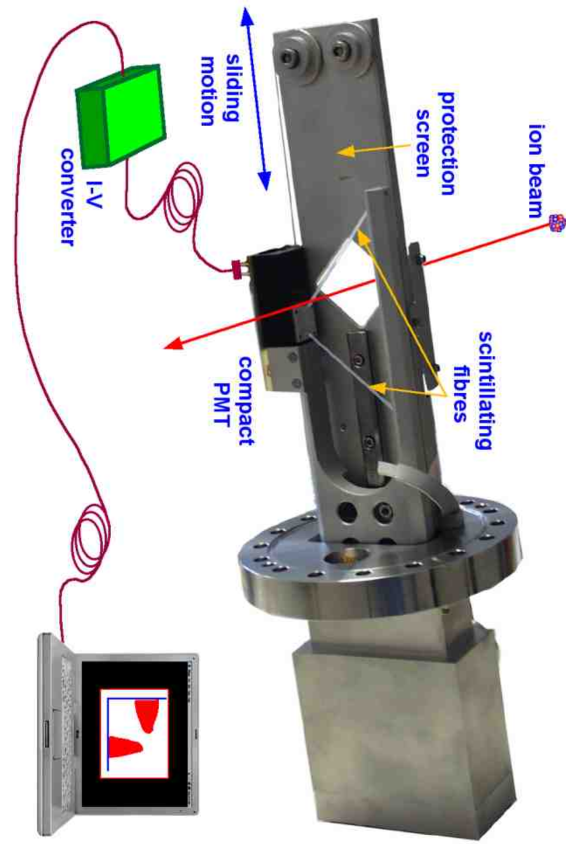


FIBBS (Fibre Based Beam Sensor)



FIBBS (Fibre Based Beam Sensor)





Fibres diameter: 300 ÷ 500 μm

Glass fibres for intensity over 10^6 pps

Plastic fibres for lower intensity

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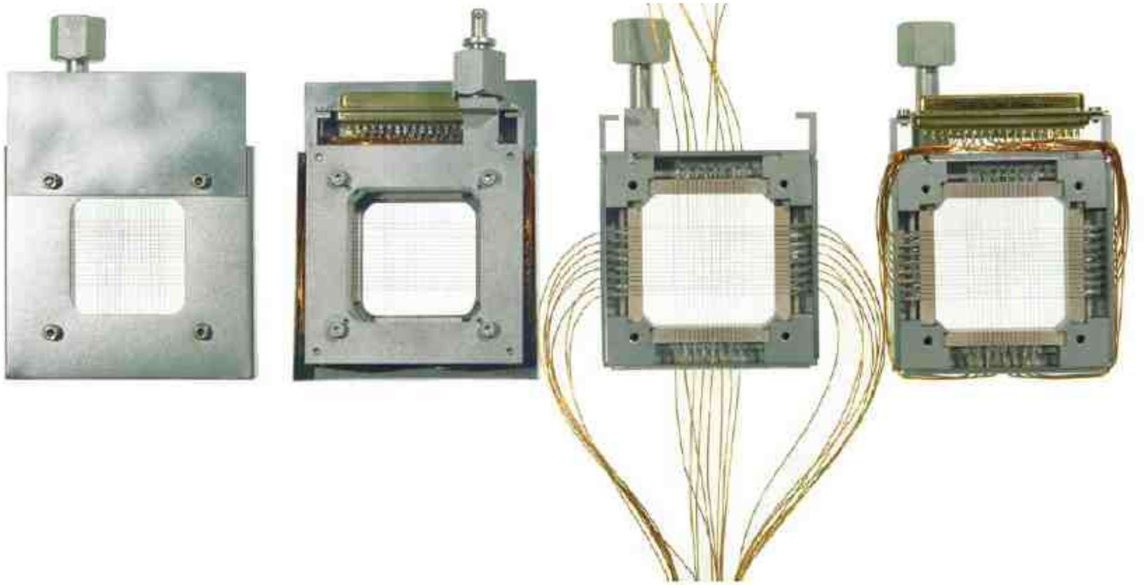
Misure di profili con griglie



Profile grid for both planes with 15 wires spaced by 1.5 mm each in a different steps of the manufacturing. The individual wires are insulated with glass-ceramics. The device is mounted on a pneumatic feed-through to move it in and out of the beam (not shown).

Diameter of the wires	0.05 to 0.5 mm
Spacing	0.5 to 2 mm
Length	50 to 100 mm
Material	W or W-Re alloy
Insulation of the frame	glass or Al_2O_3
number of wires	10 to 100
Max. power rating in vacuum	1 W/mm
Min. sensitivity of I/U-conv.	1 nA/V
Dynamic range	$1{:}10^6$
Number of ranges	10 typ.
Integration time	1 μs to 1 s

Typical specification for a profile grid used at proton and heavy ion LINACs.

Utilizzati nella linea di iniezione assiale del CS

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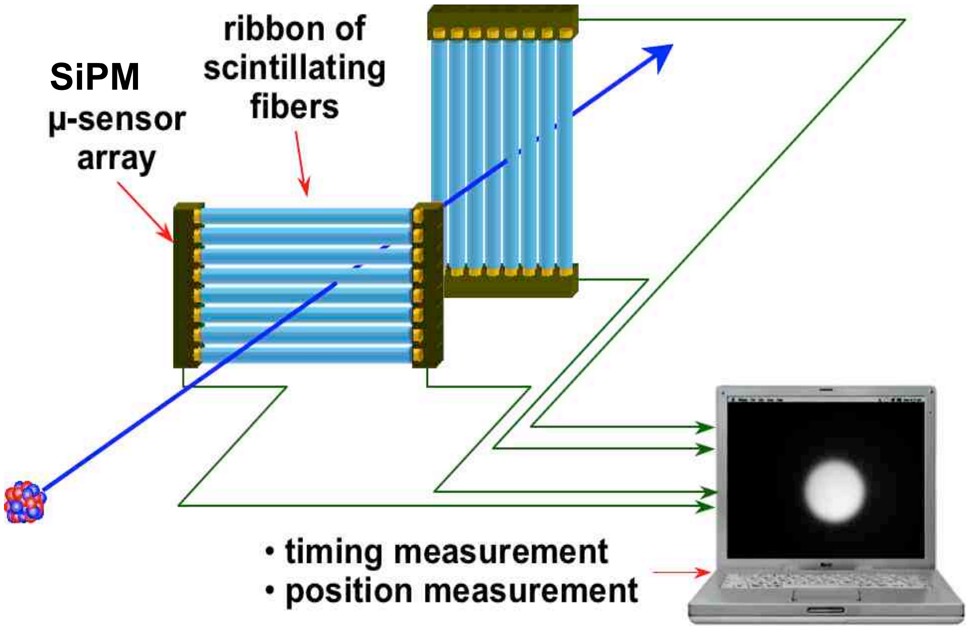
Misure di profili con fibre



particle by particle beam tagging:

time

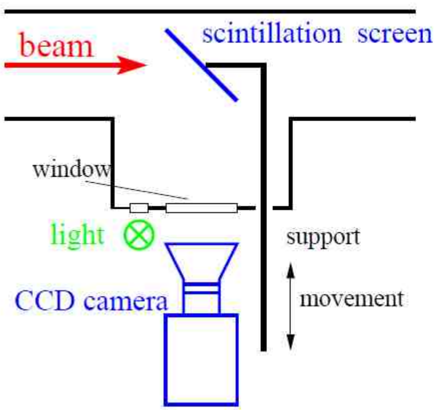
position

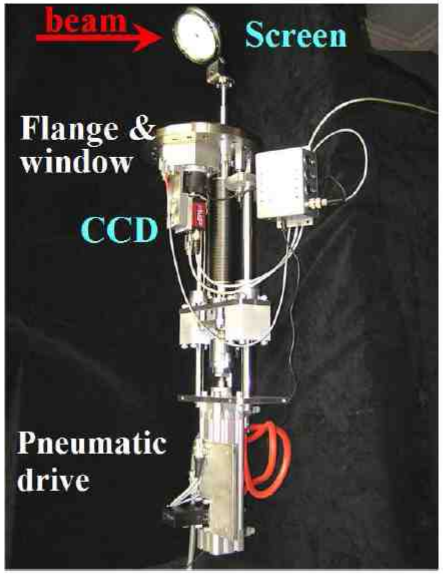
(A, Z) identification

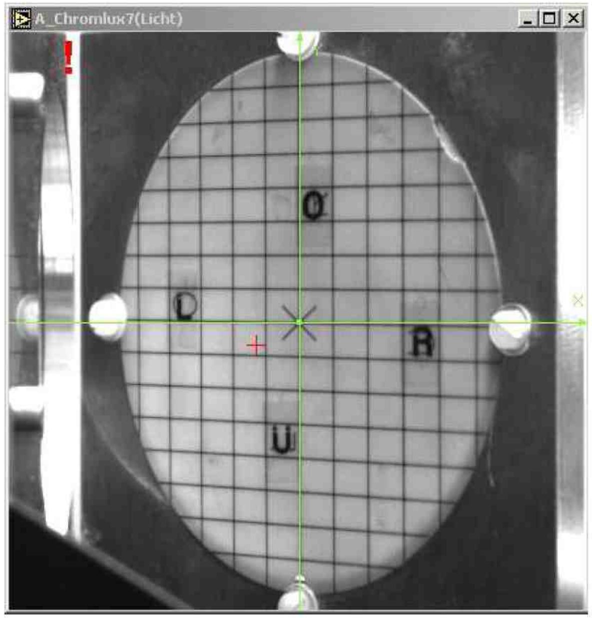
FRIBS?

Imaging del fascio sul piano trasverso

2D beam profile with scintillating screens

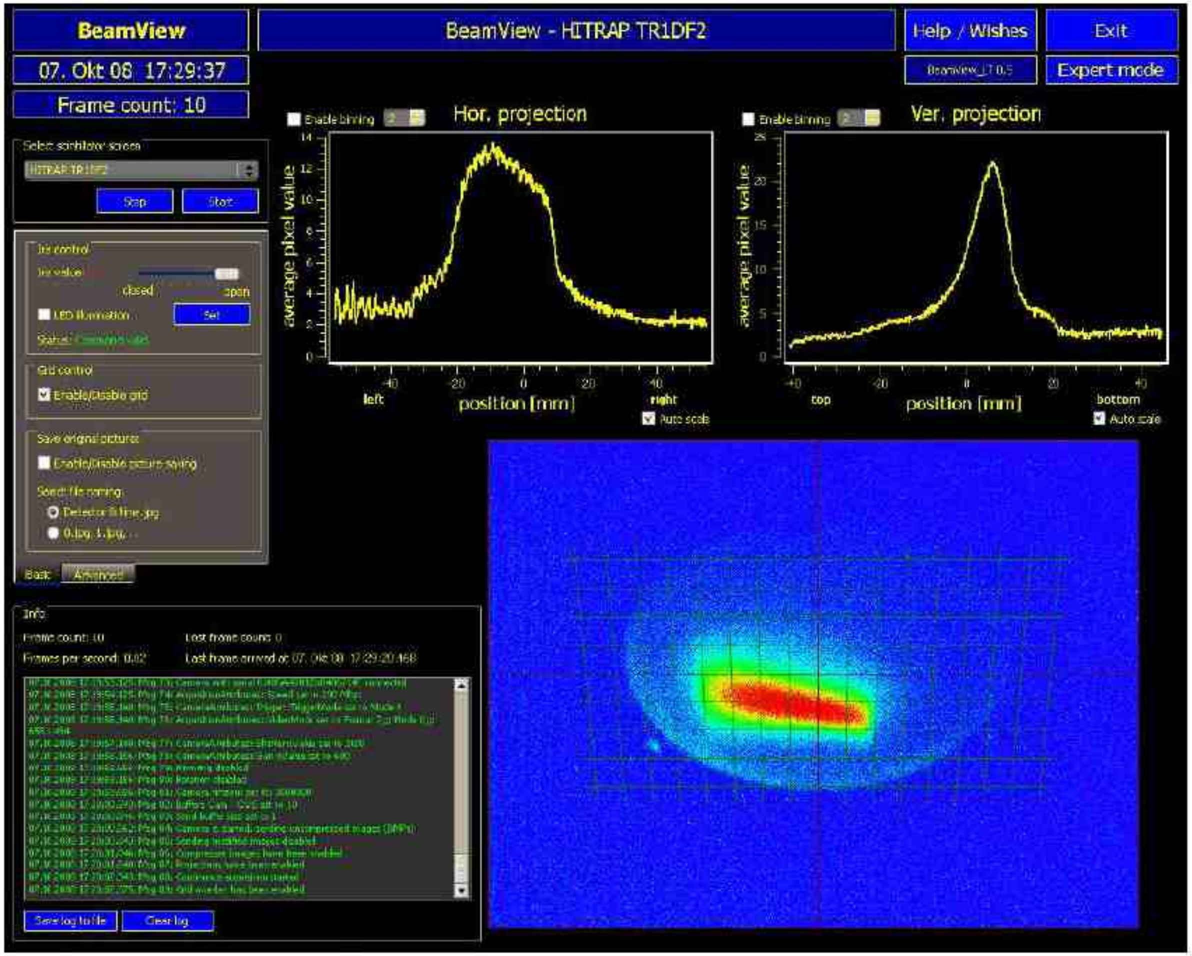






Abbreviation	Material	Activator	max. emission	decay time
Quartz	SiO_2	none	470 nm	< 10 ns
	CsI	Tl	550 nm	1 μs
Chromolux	Al_2O_3	Cr	700 nm	100 ms
YAG	$Y_3Al_5O_{12}$	Ce	550 nm	0.2 μs
	Li glass	Ce	400 nm	0.1 μs
P11	ZnS	Ag	450 nm	3 ms
P43	Gd_2O_2S	Tb	545 nm	1 ms
P46	$Y_3Al_5O_{12}$	Ce	530 nm	0.3 μs
P47	$Y_2Si_5O_5$	Ce&Tb	400 nm	100 ns

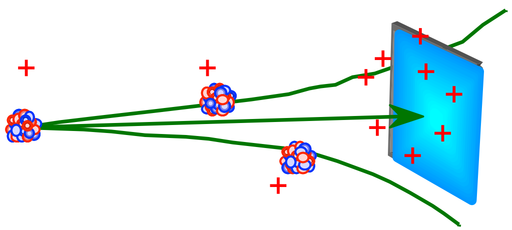
2D beam profiles with scintillating screens

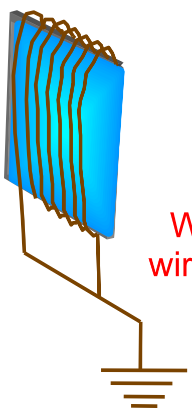


Peter Forck
JUAS 2011
Lecture Notes on Beam Instrumentation and Diagnostics

Low energy /low intensity Imaging at LNS

CsI is an insulator and gets charged-up



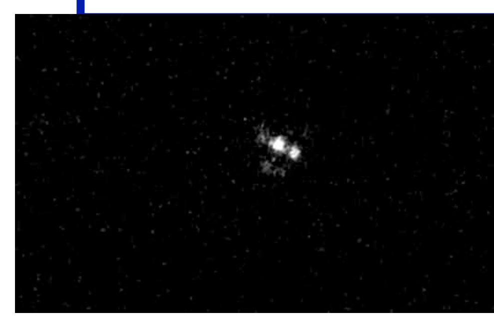


What to do?
We wound it with a conductor wire which was then grounded

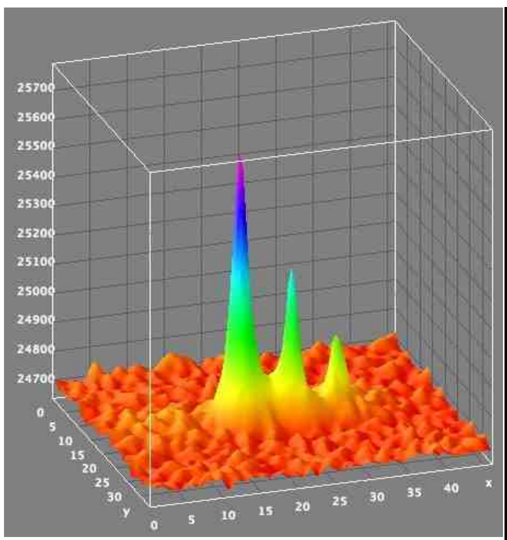
Silver
Current: 4 pA
Energy: 170 keV

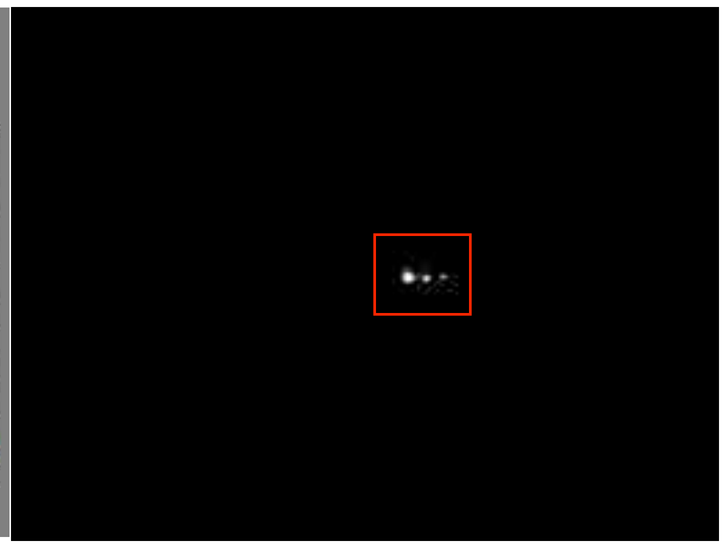
Oxigen
Current: a few pA
Energy: 50 keV

Protons
Current: 0.03 pA
Energy: 170 keV



Increase the sensitivity - cooled CCD camera





screen = CsI (Tl)

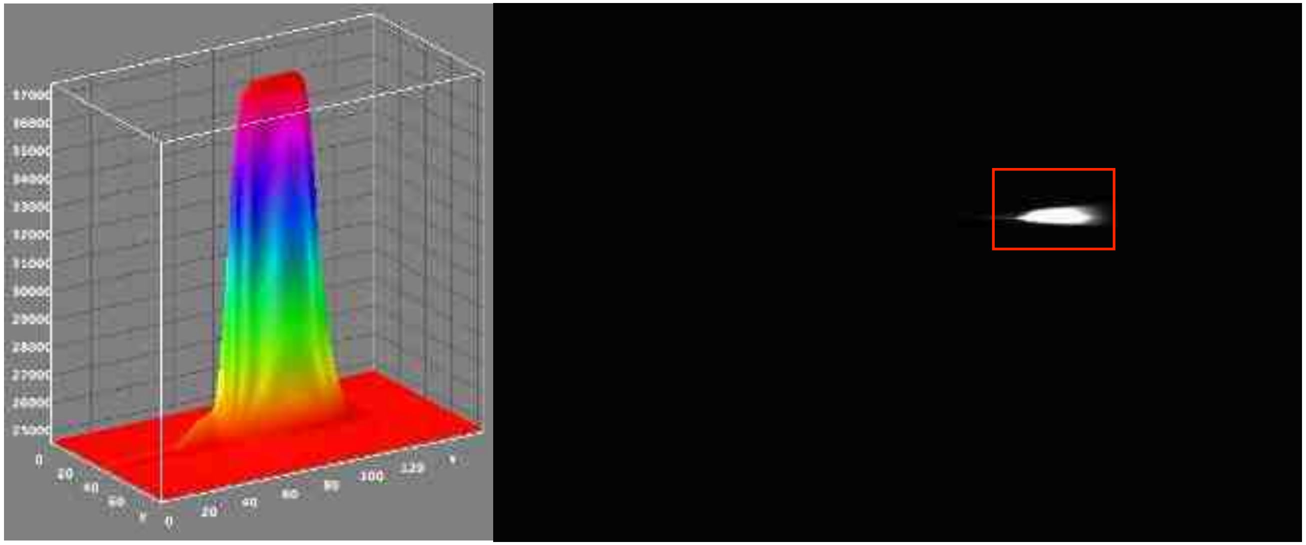
beam = protons

E = 200keV

I ≈ 2.5fA (10^4 pps)

$t_{exposure}$ = 20s

Increase the sensitivity - cooled CCD camera



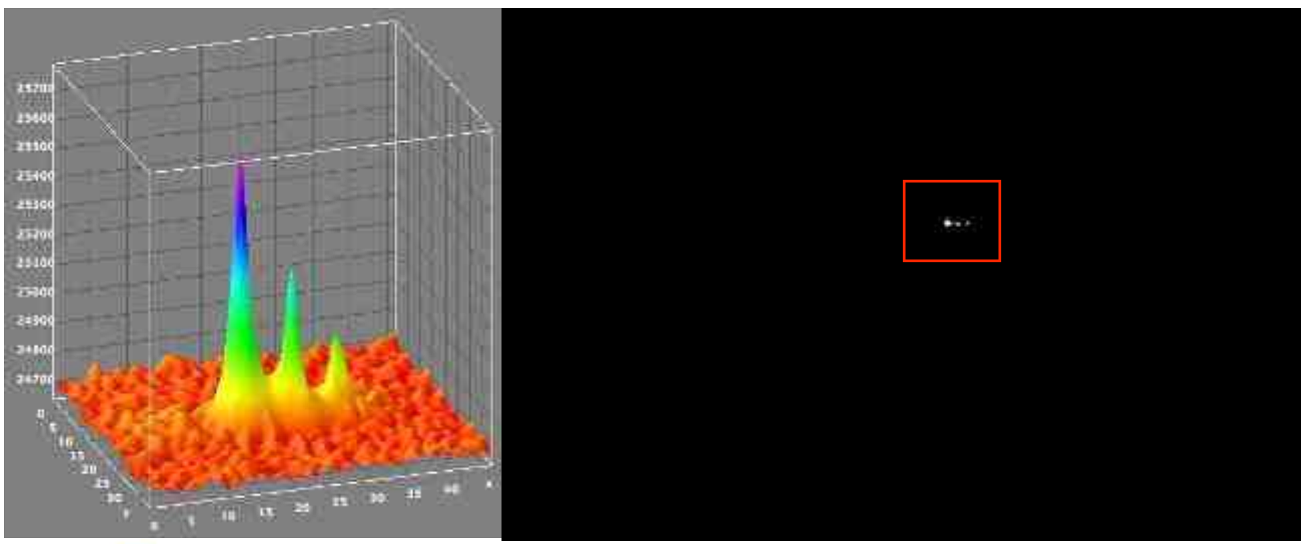
screen = CsI(Tl)

beam = protons

E = 50keV

I ≈ 5pA

$t_{exposure}$ = 60s



screen = CsI (Tl)

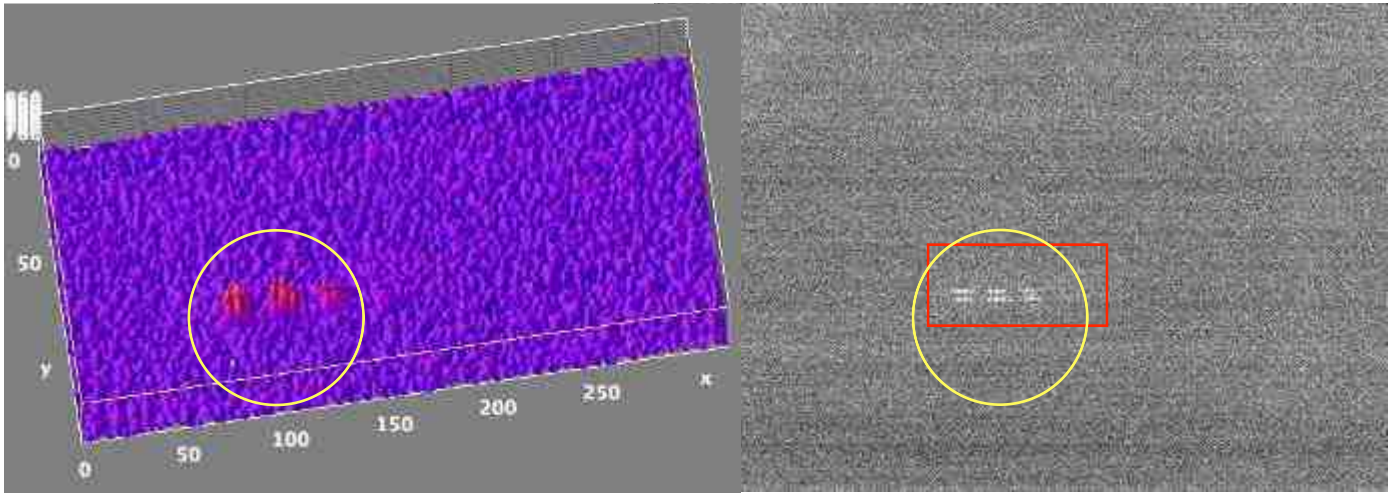
beam = protons

E = 200keV

I ≈ 2.5fA

$t_{exposure}$ = 20s

Increase the sensitivity - cooled CCD camera



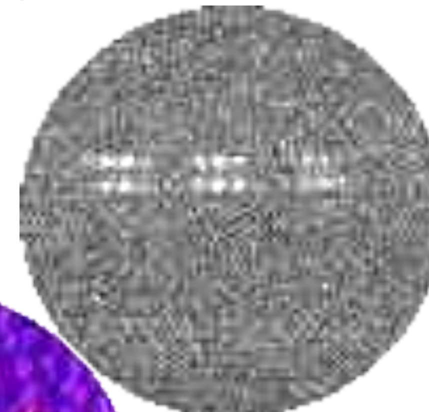
screen = CsI

beam = protons

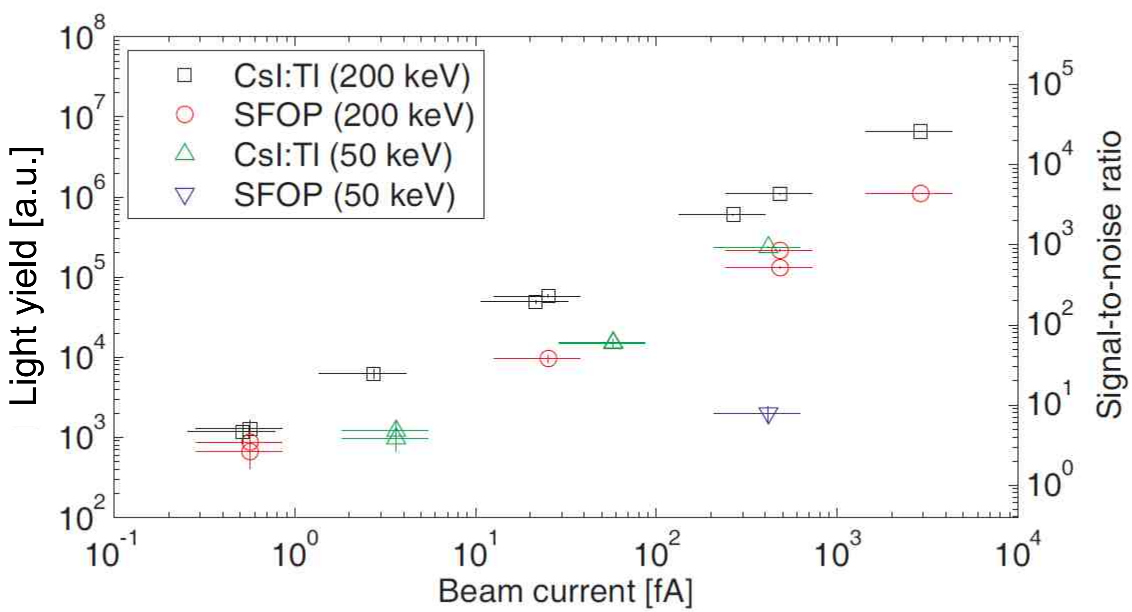
E = 50keV

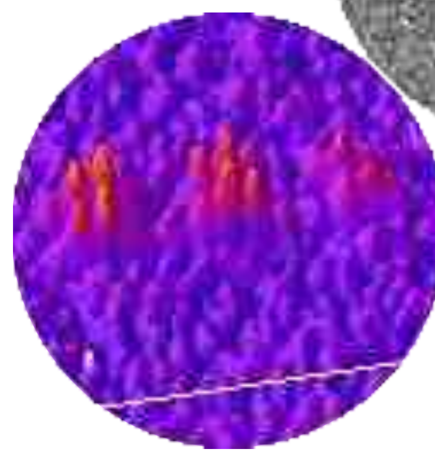
I ≈ not measurable

$t_{exposure}$ = 60s



toward single particle imaging....!!!





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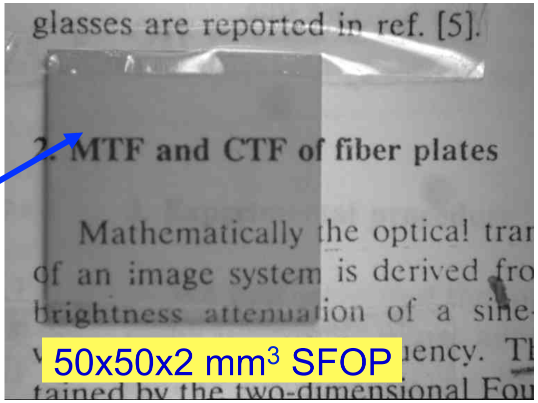
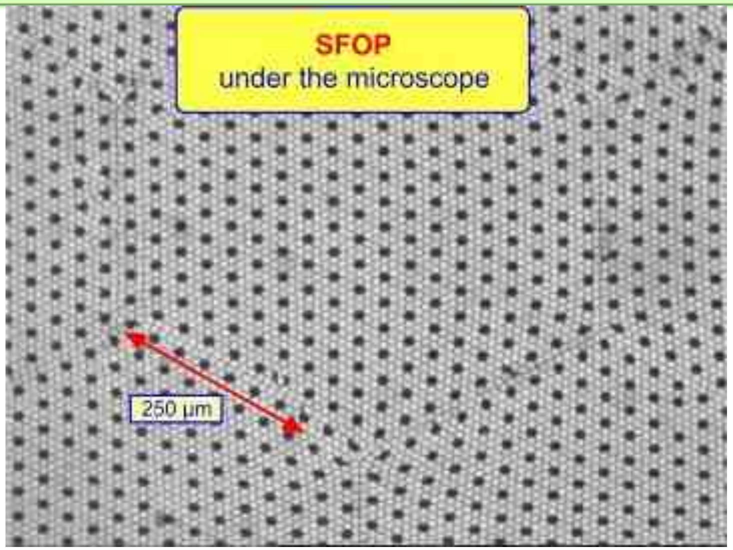
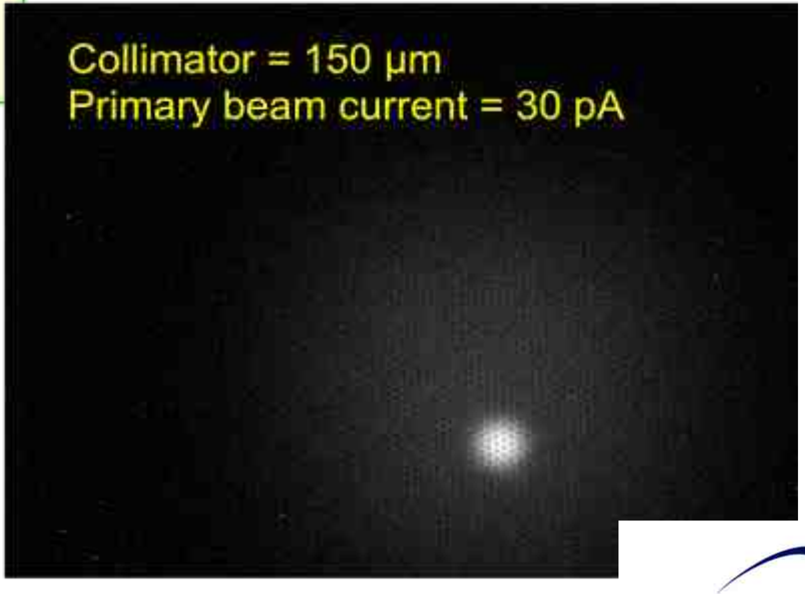
beam attenuated through a fine mesh, pitch ≈ 0.1mm

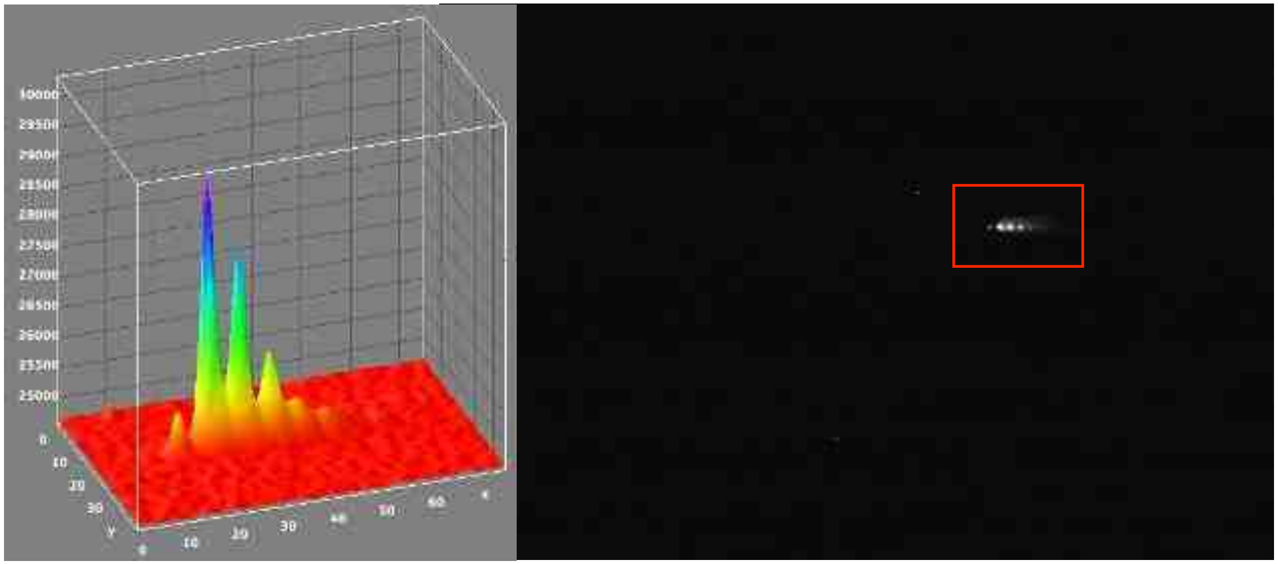
SFOP screens







With the cooled CCD camera



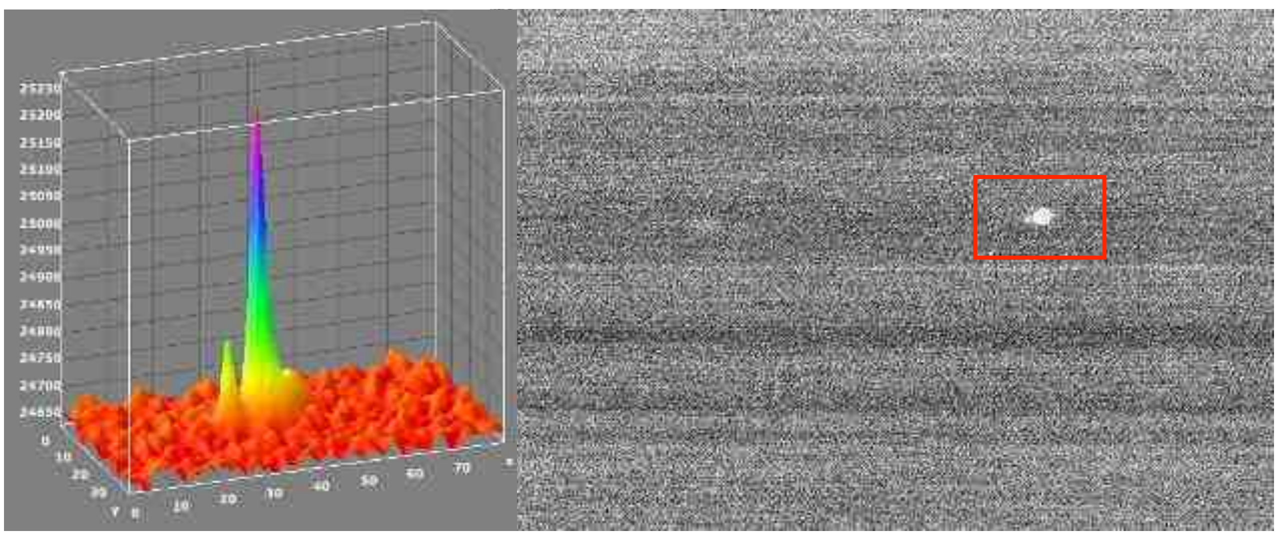
screen = SFOP

beam = protons

E = 200keV

I ≈ 50fA [5pA/100]

$t_{exposure}$ = 20s



screen = SFOP

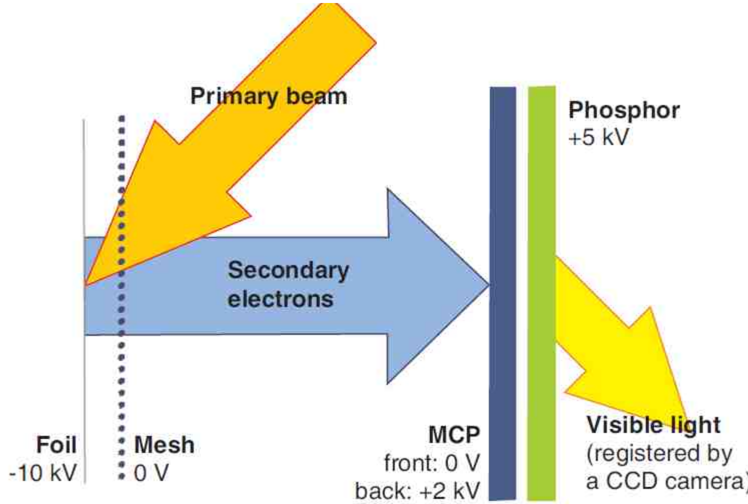
beam = protons

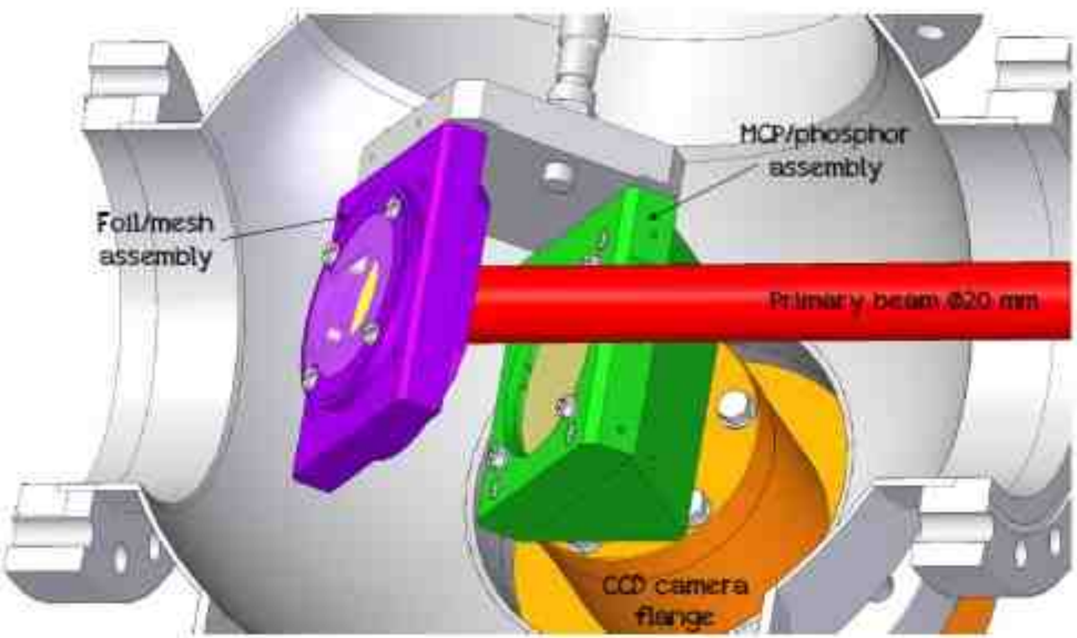
E = 200keV

I ≈ 2.5fA [5pA/2000]

$t_{exposure}$ = 20s

MicroChannel Plate e emissione secondaria per beam imaging di fasci

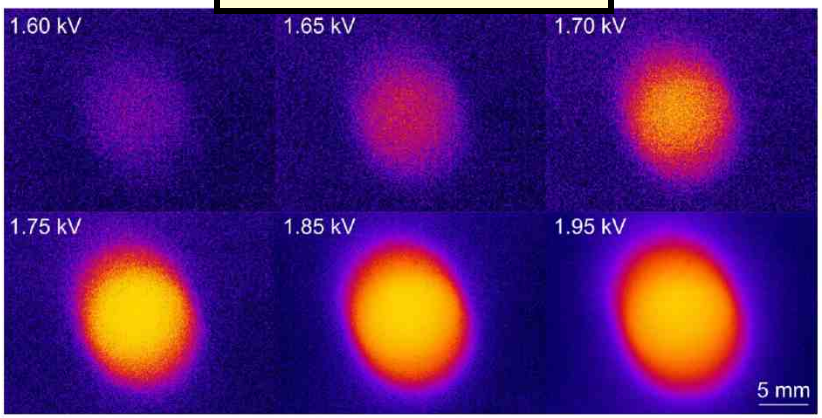


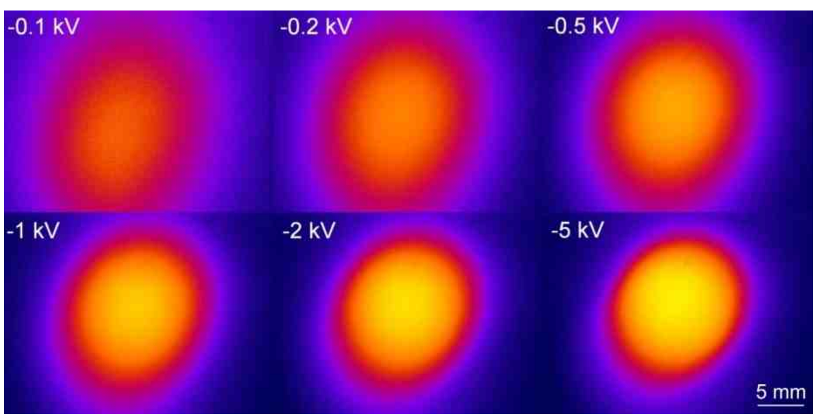


MCP per beam imaging ai LNS

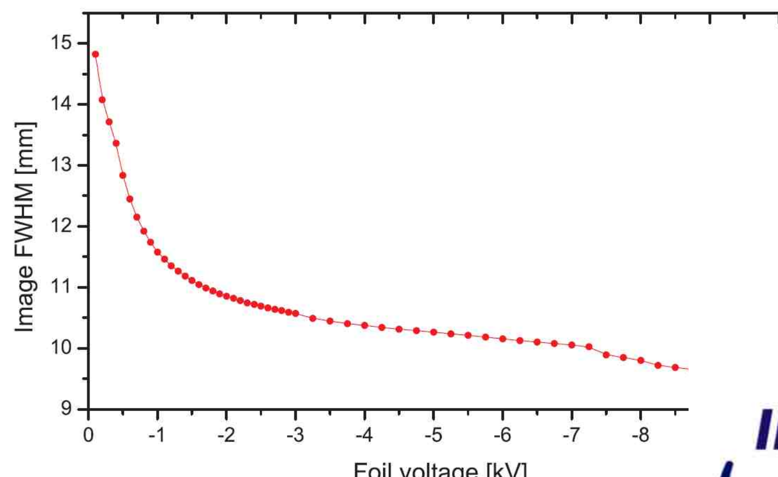
proton beam 180 KeV
Intensity < 0.1 pA

different MCP gains



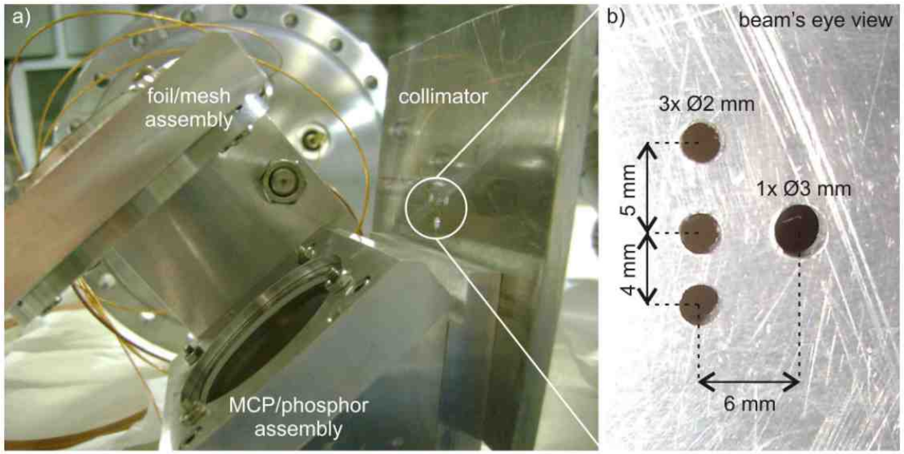


foil voltage

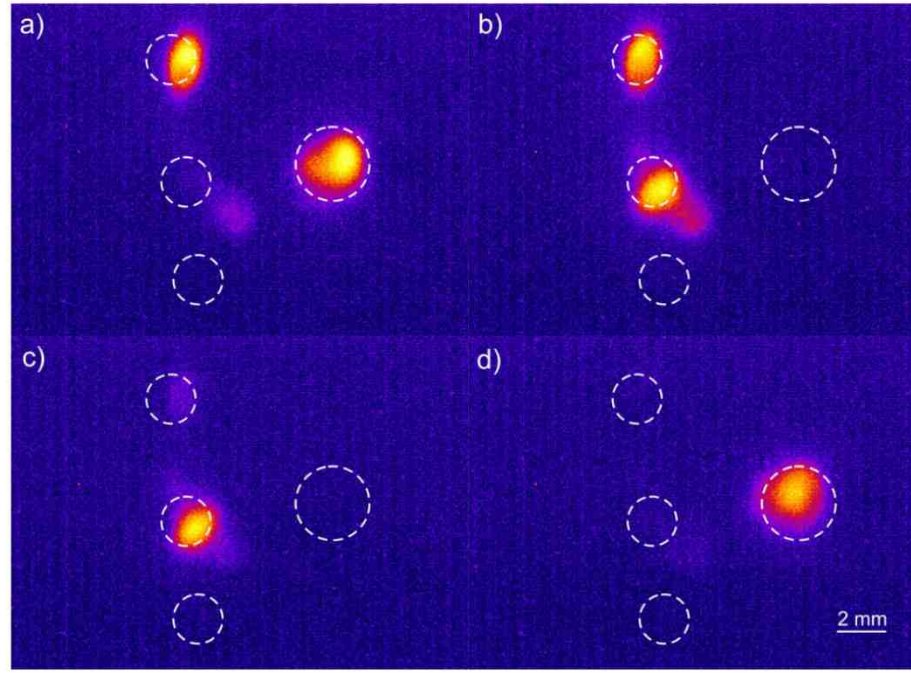


MCP per beam imaging ai LNS

MCP for beam imaging with a mask



different beam steering



Further studies

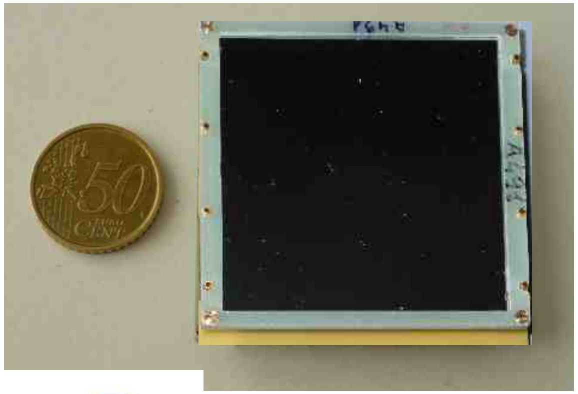
- SEM/MCP sensitivity
- radiation hardness
- reliability/robustness

For very low intensities (<10^4 particle per second)

position sensitive silicon detector

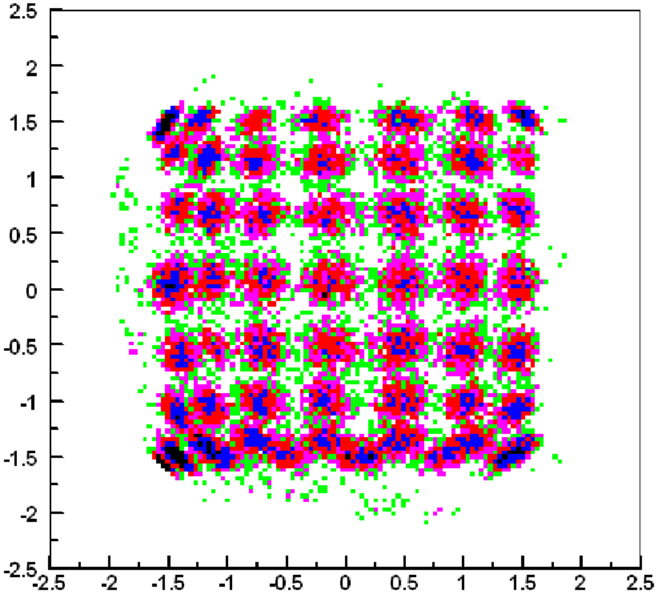
- 2D beam profile monitor
- beam energy spectrum
- identification of the beam particles
- read-out from the back and the 4 corners
- charge division algorithm for position evaluation

5cm x 5cm Si detector



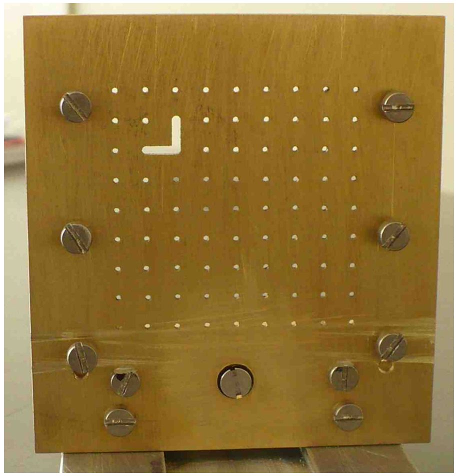
multi-hole mask

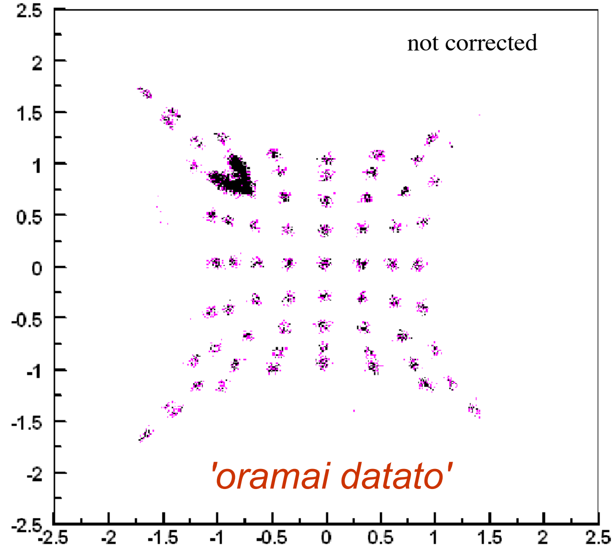
reconstruction of the hole mask put in front of the detector for calibration

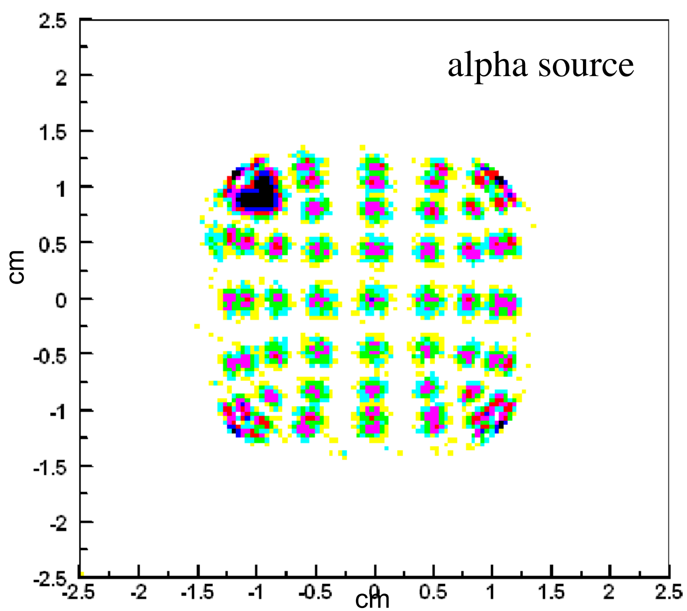


INFN LNS

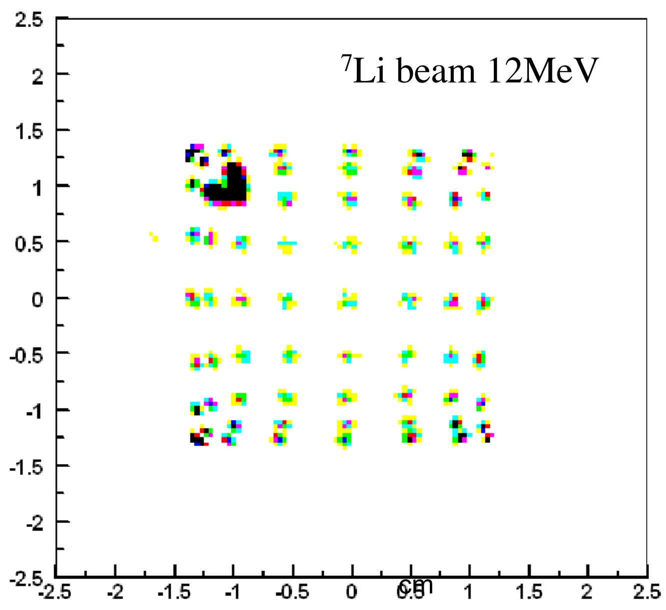
PSSD per fasci tandem e CS







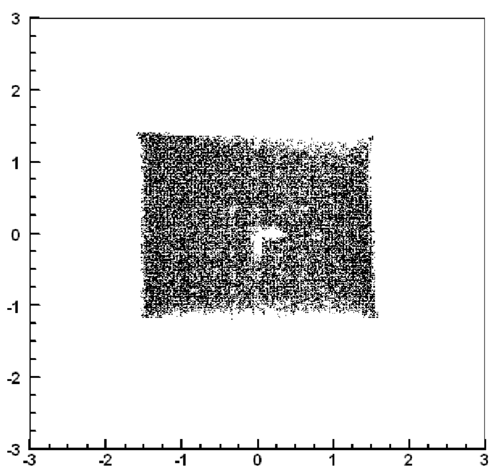
real time correction of the shape distortion

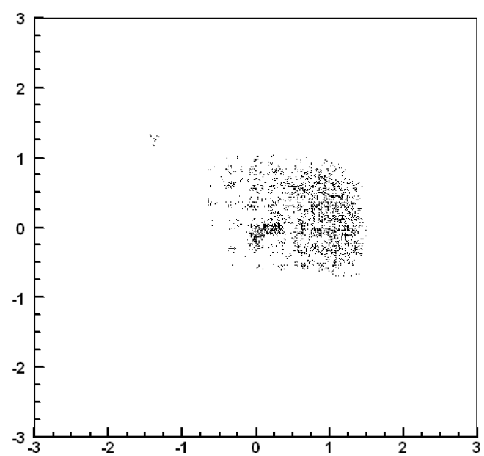


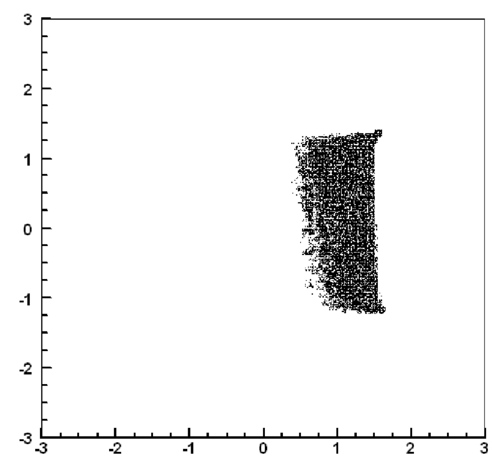
Diagnostics for accelerated RIBs at LNS

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

Spatial resolution 1 – 2 mm

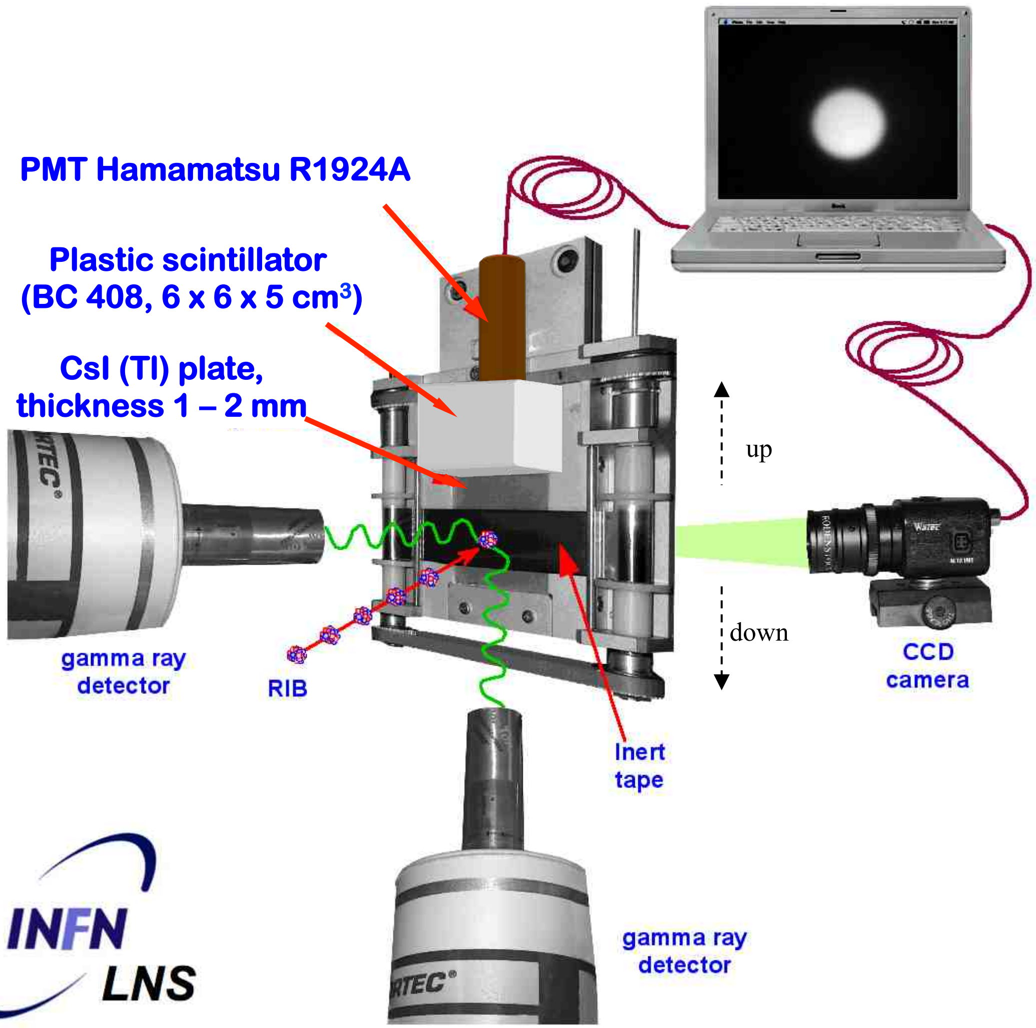






Diagnostics for Low Energy RIBs at LNS

LEBI:
Low Energy Beam Imager / Identifier



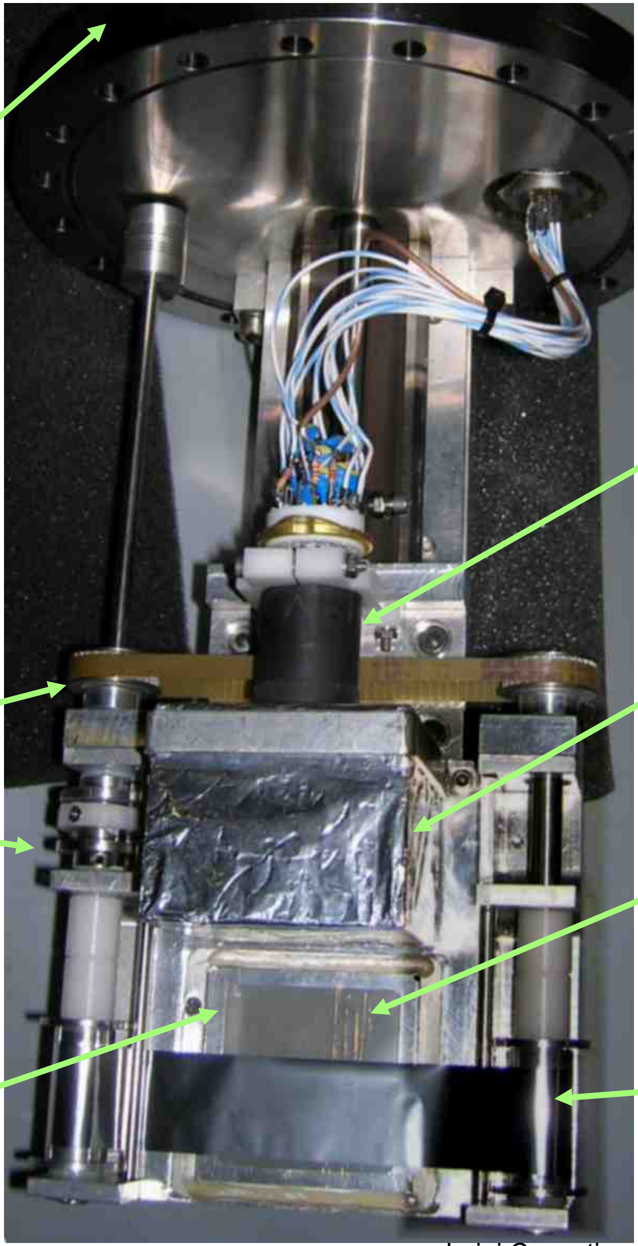
three different heights

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

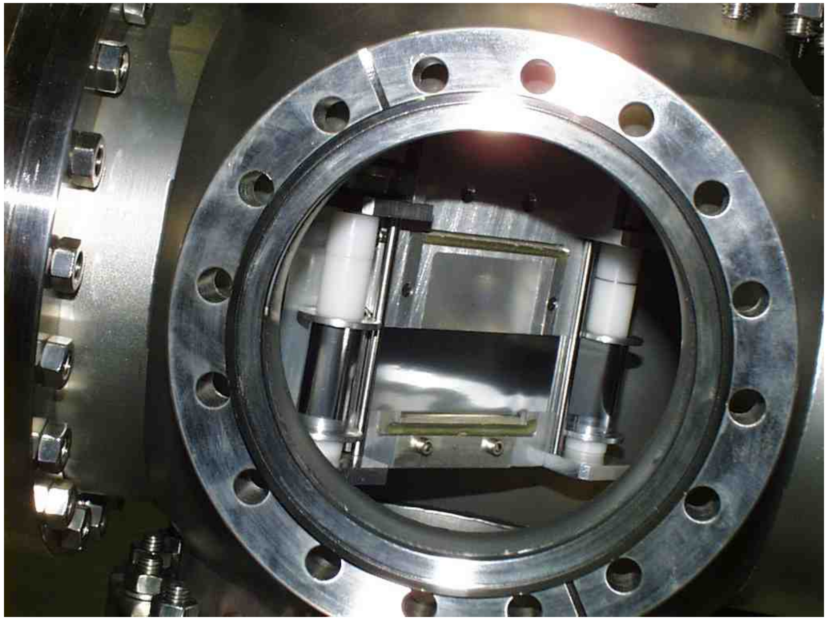
LEBI is our solution for diagnostics of low energy radioactive beams.

INFN LNS

Diagnostics for Low Energy RIBs at LNS



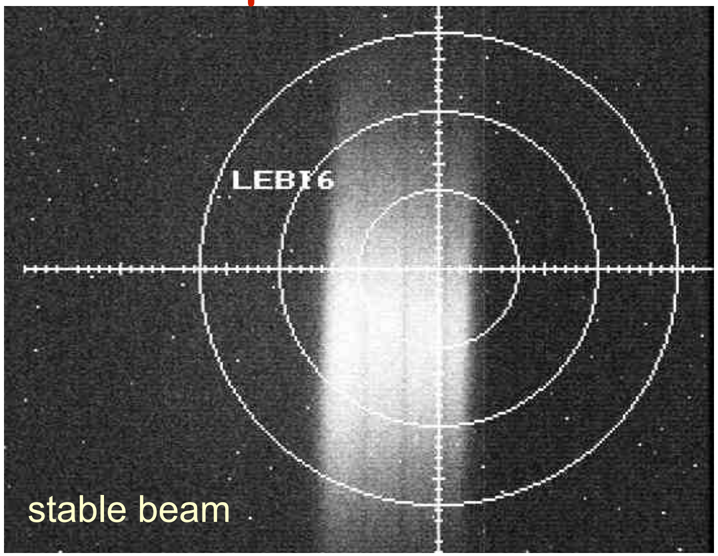
Diagnostics for Low Energy RIBs at LNS

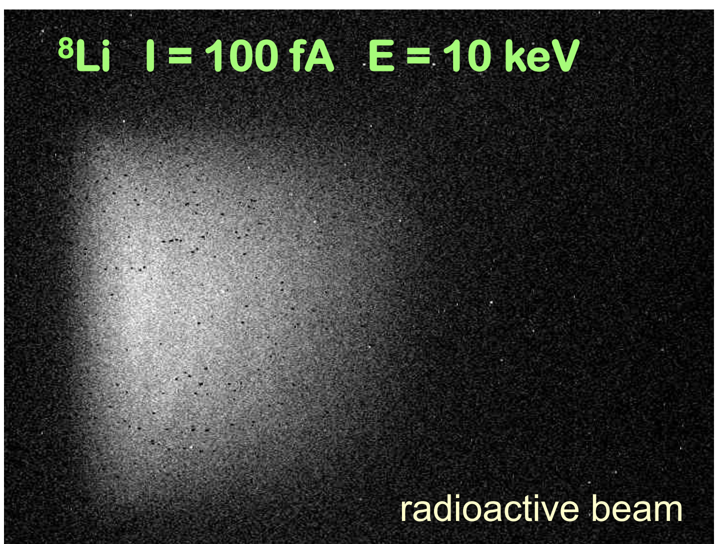


The scintillator screen is placed at 45° respect to the beam axis.

Diagnostics for Low Energy RIBs at LNS

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





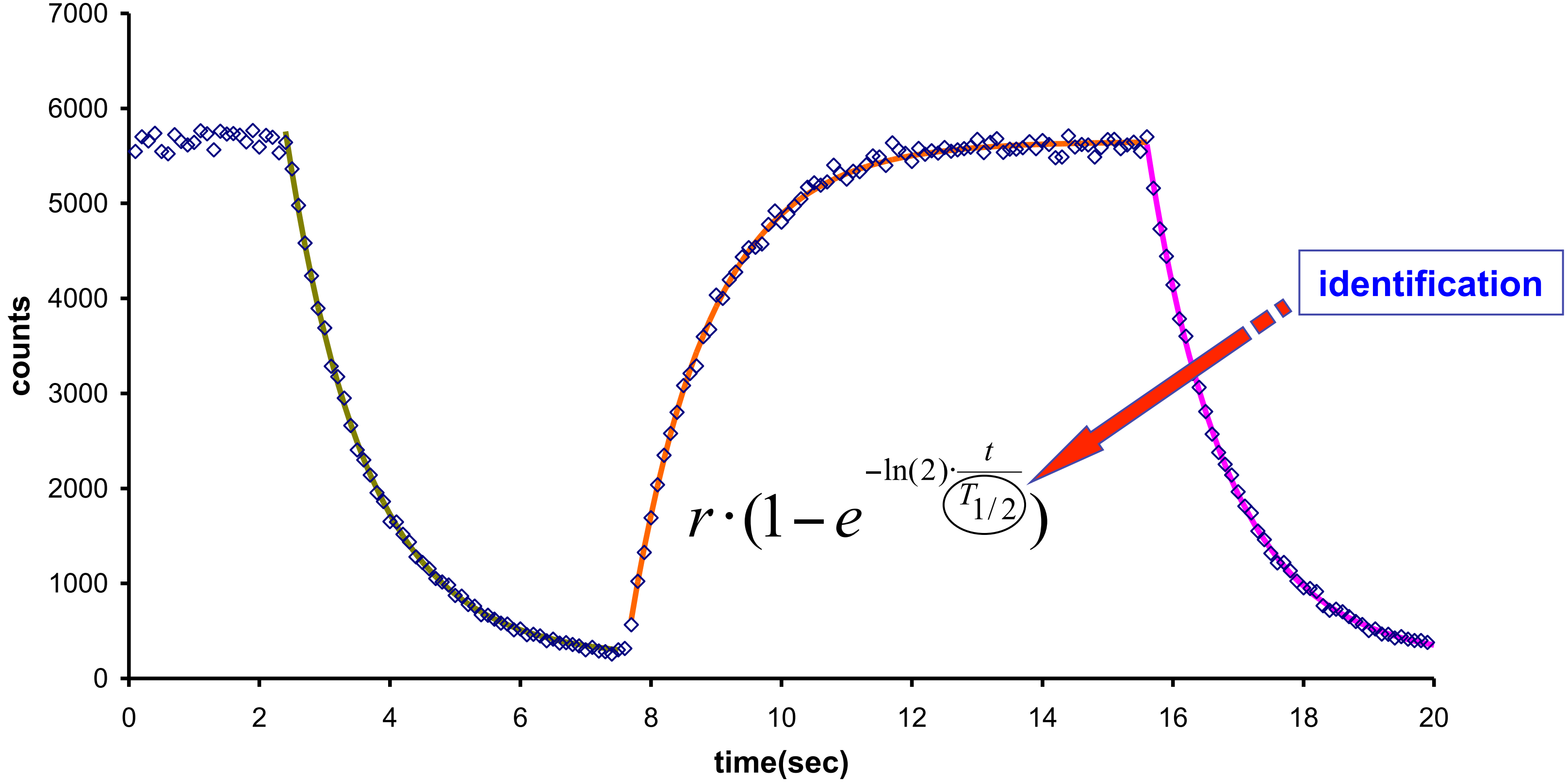
energy range
10 keV ÷ 300 keV

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

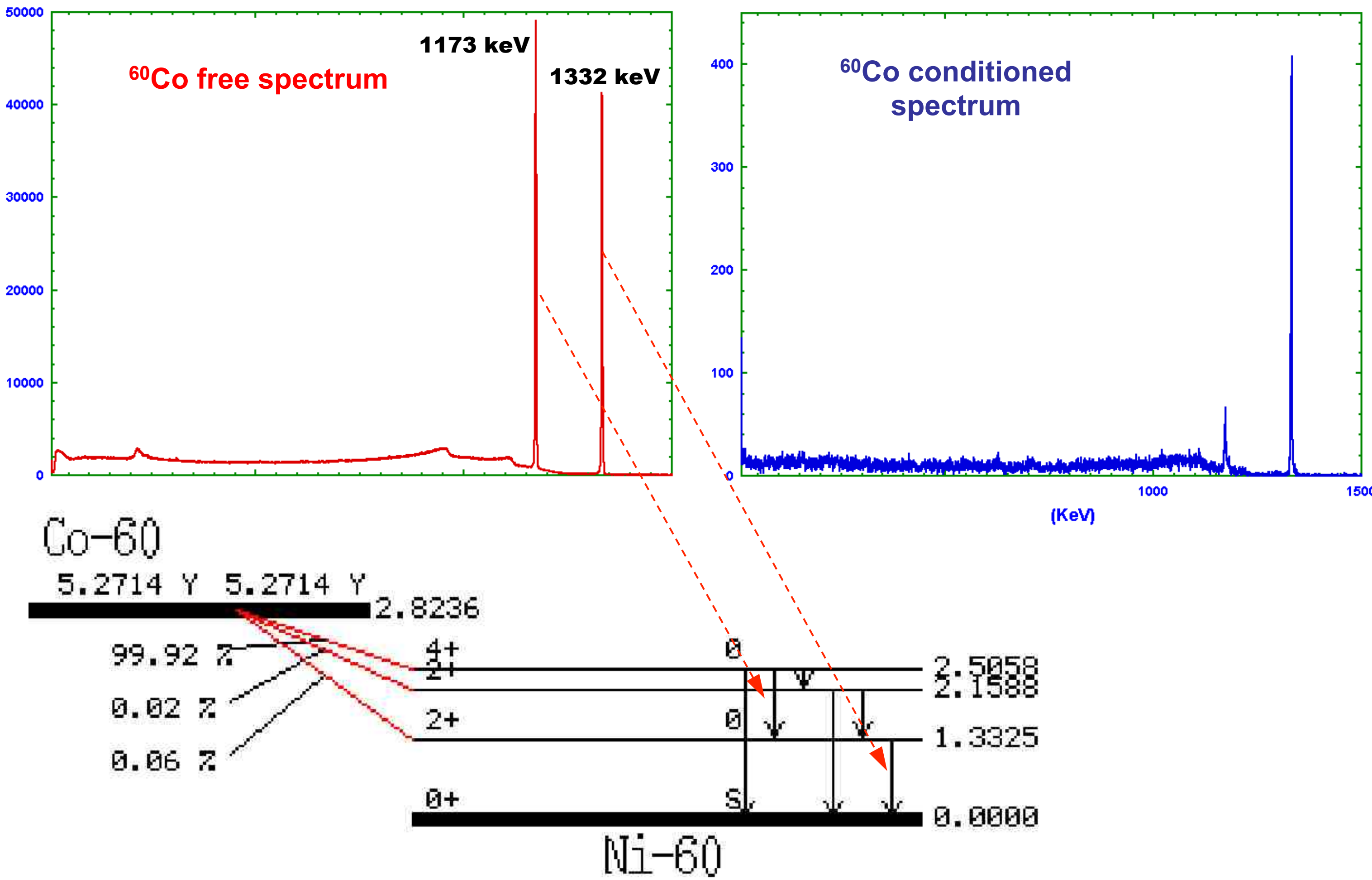
Identification of radionucliede by means of decay curve

^{8}Li beam



decay curve of β particles

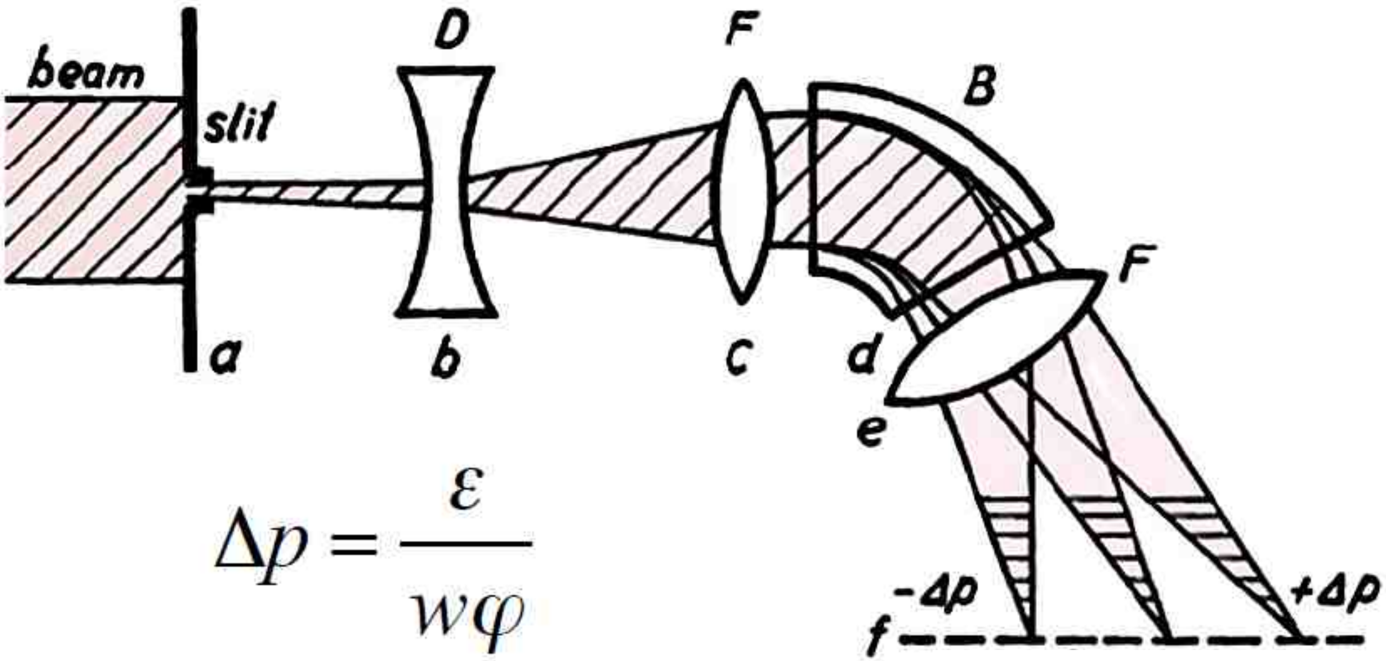
Gamma ray spectroscopy with two germanium detectors



Nella produzione di fasci radioattivi separare il fascio di interesse dai contaminanti

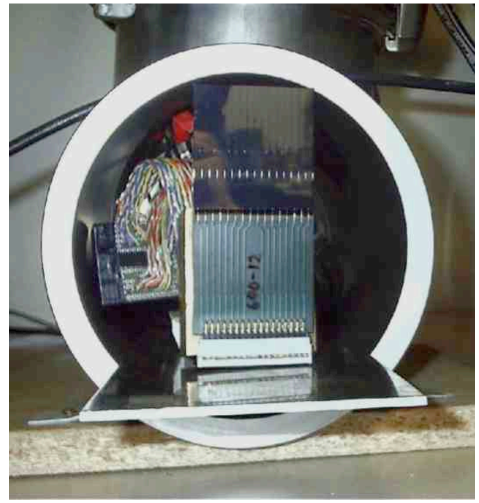
Magnetic spectrometer - for good resolution, Δp one needs

- → small sample emittance ε, (parallel particle velocities)
- → a large beamwidth w in the bending magnet
- → a large angle φ

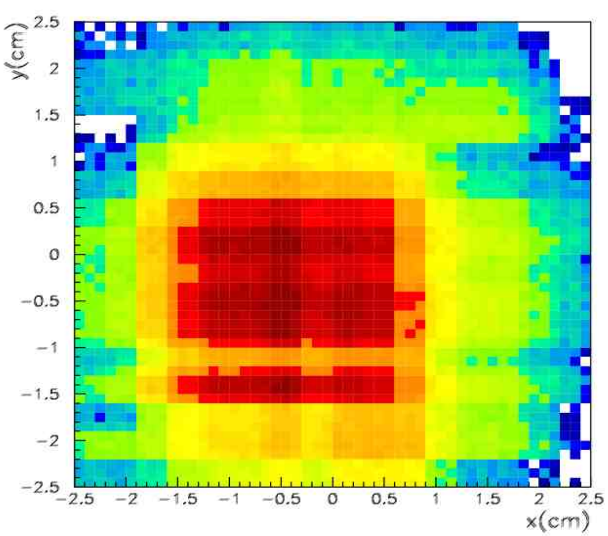


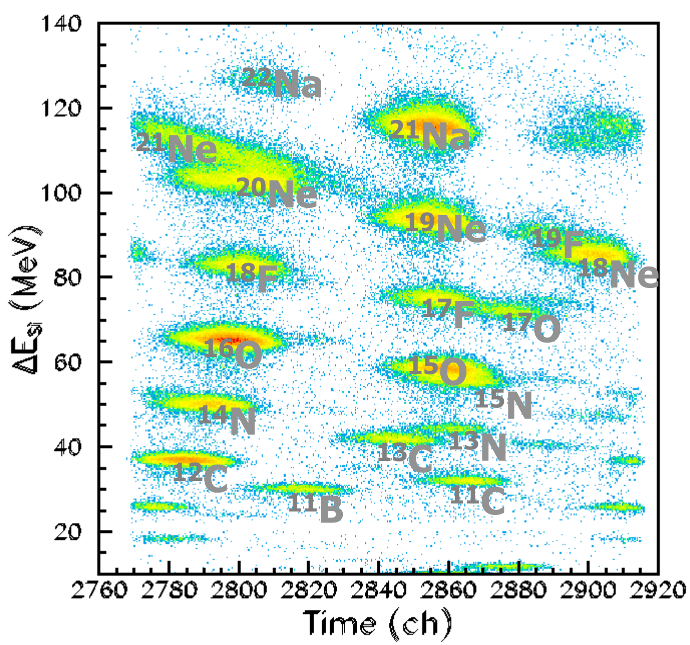
$$\Delta p = \frac{\varepsilon}{w\varphi}$$

Multi-strip silicon detector at LNS for isotope identification

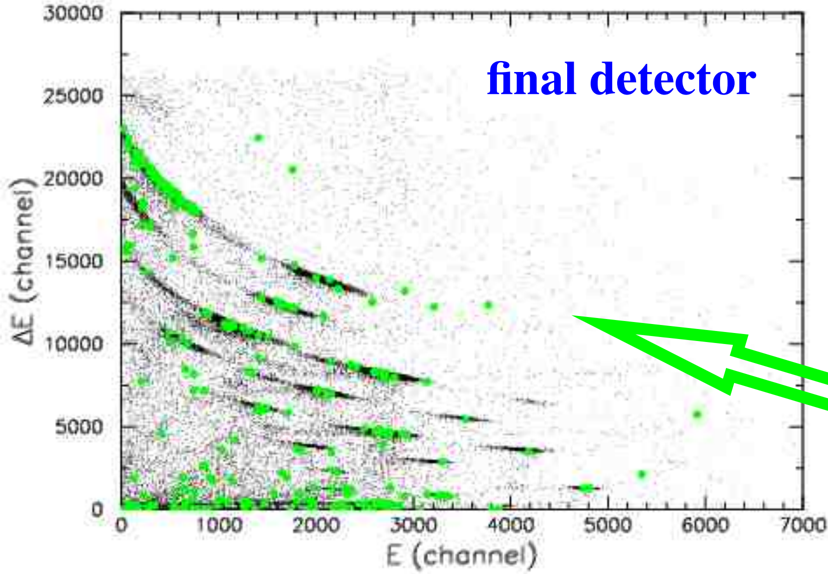


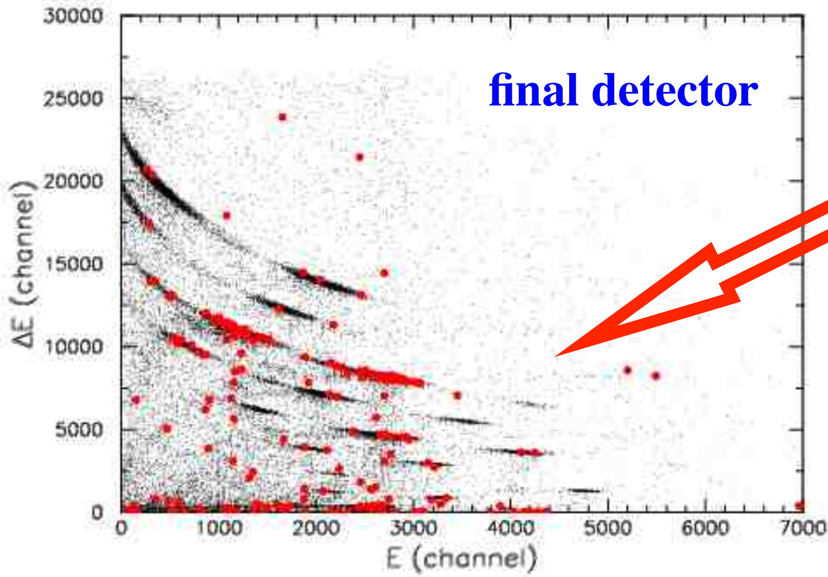
16x16 X-Y strips
5 x 5 cm^2



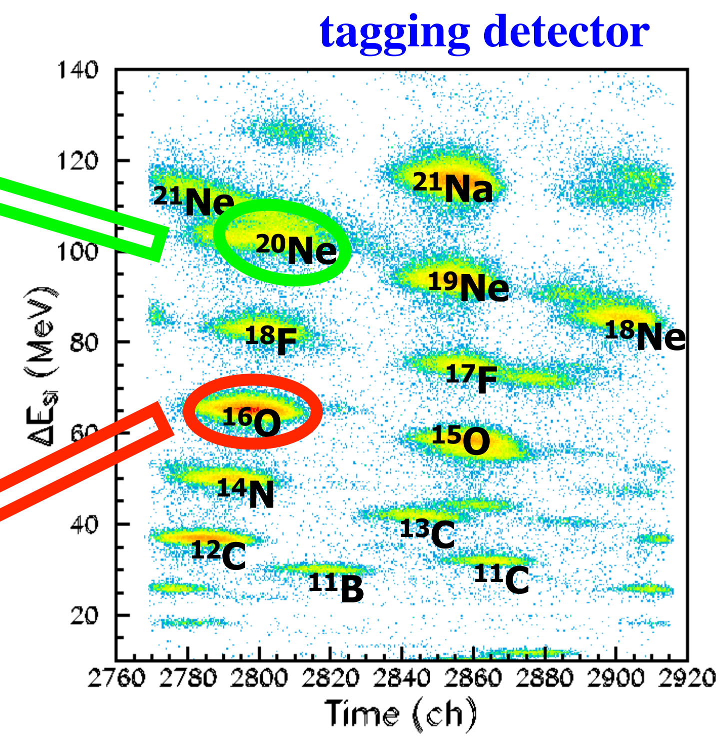


Projectile Selection: Tagging Procedure

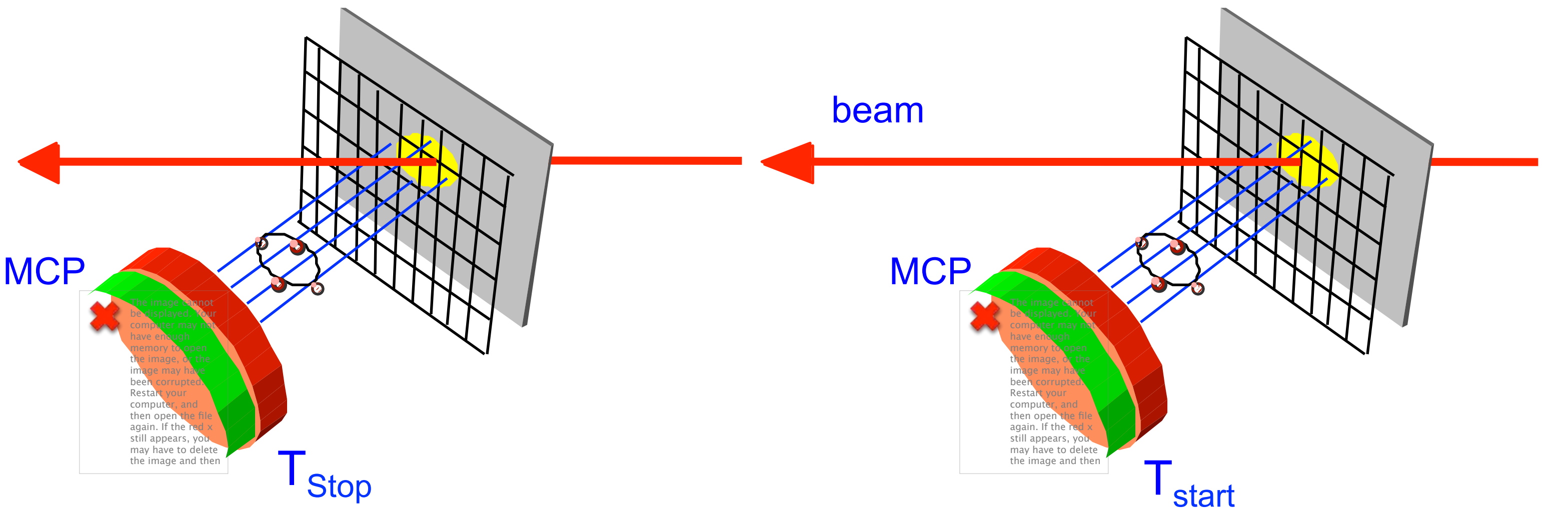


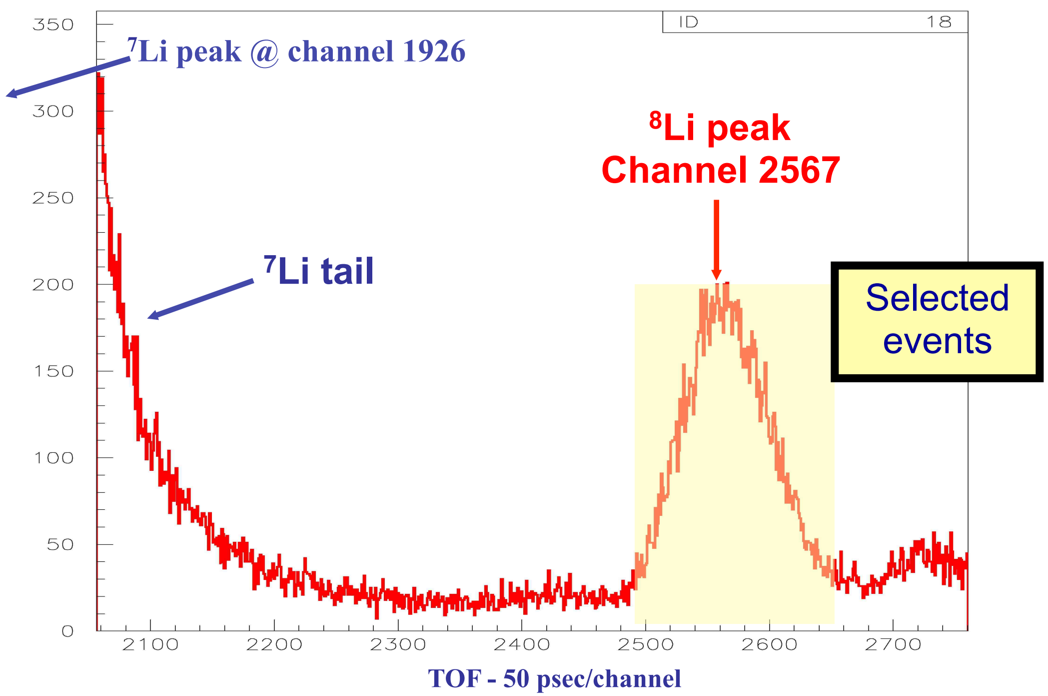


Identification can be checked looking to the **ΔE-E** scatter plot in forward detectors



Ions Tagging with Time Of Flight

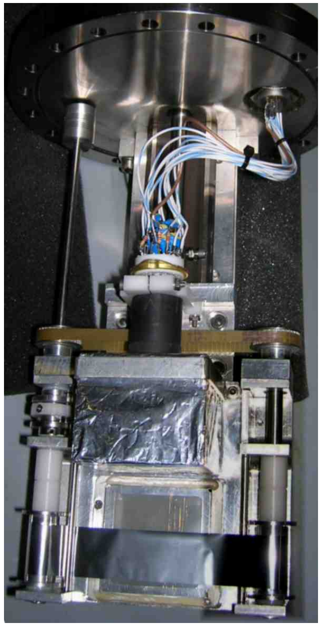


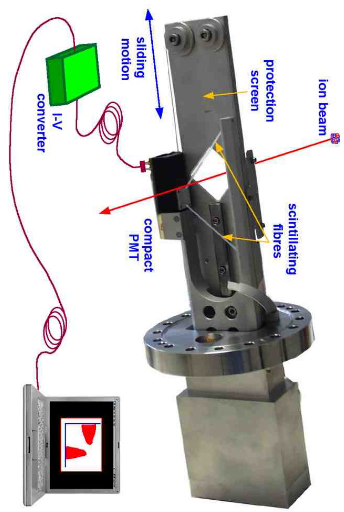


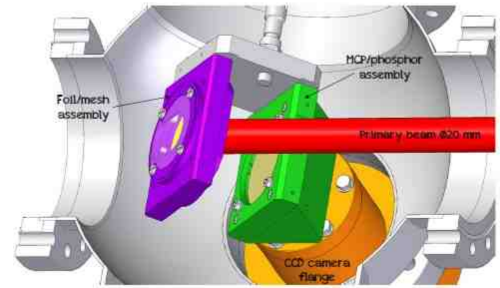
- On-line discrimination between ions having same energy but different mass.

$$TOF \propto \sqrt{A}$$

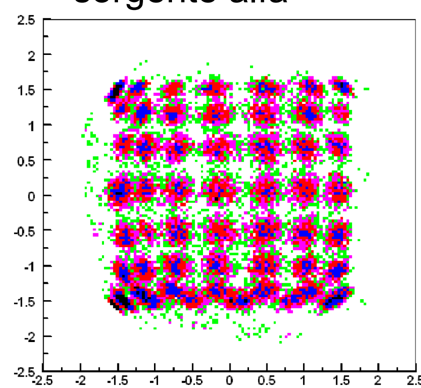
Cosa vedremo in laboratorio



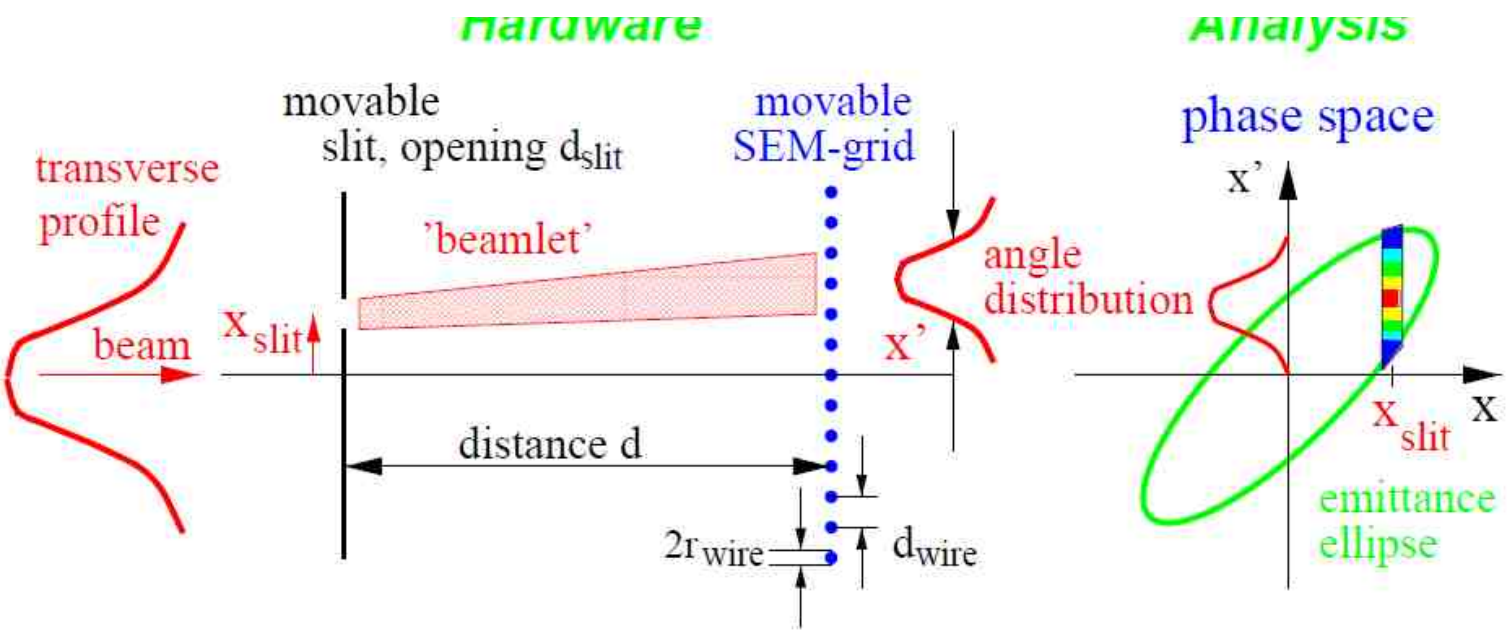




PSD + maschera e sorgente alfa



Come misurare l'emittanza nel piano trasverso



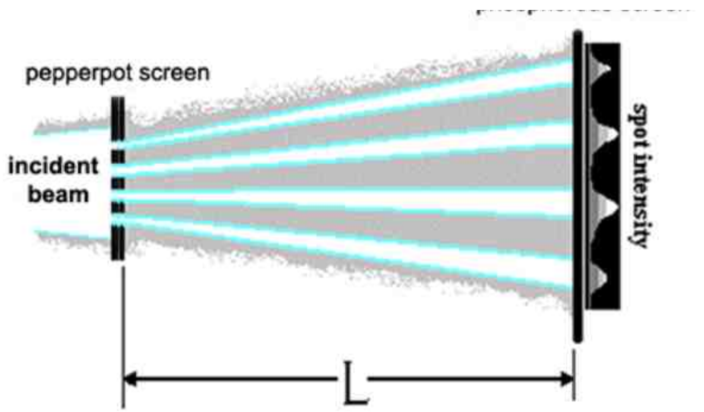
Scheme of a slit-grid emittance measurement device.

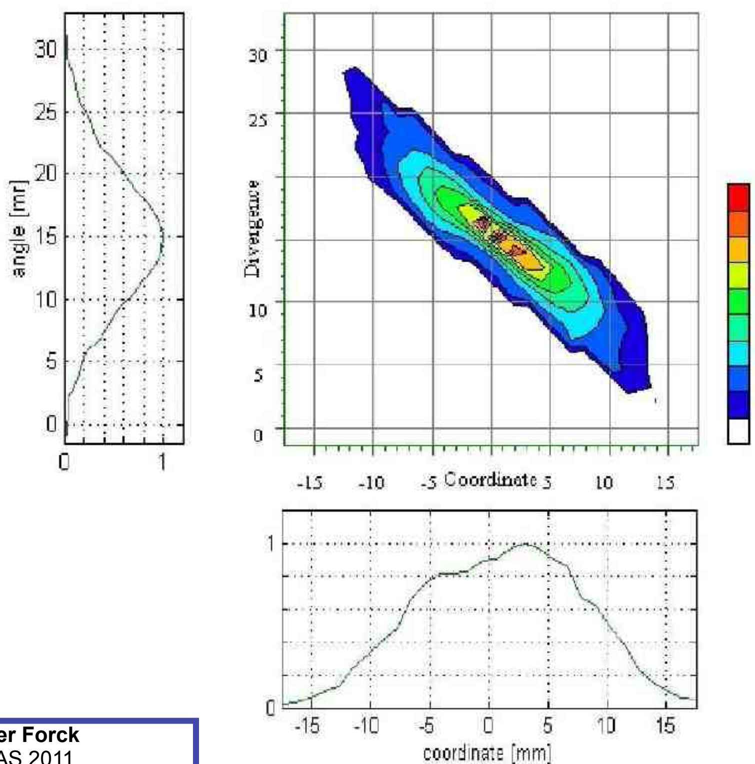
The slit is then scanned trough the beam to get all positions.

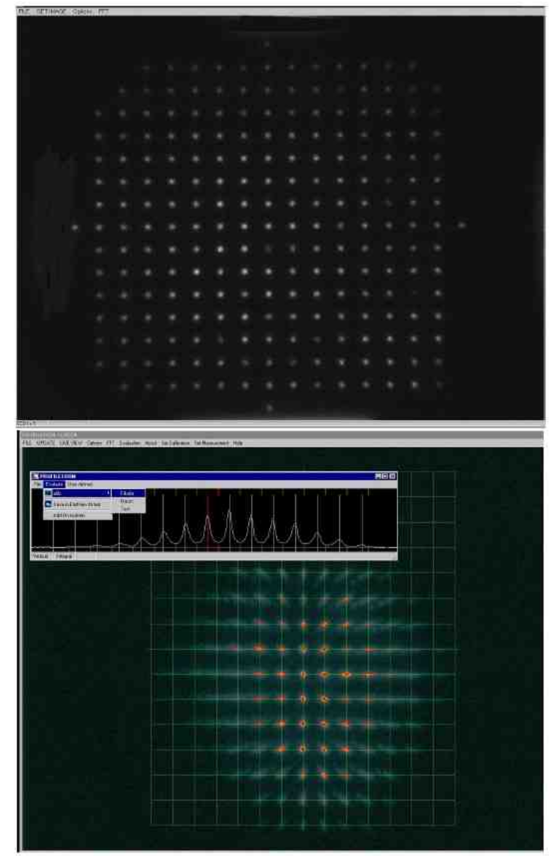
- d_{slit} 0.1 to 0.5 mm.
- The angle x' is determined with a SEM-grid (or other) having a distance from the slit of 10 cm to 1 m, depending on the ion velocity.

$\Delta x = d_{slit}$.
Angle resolution $\Delta x' = (d_{slit} + 2r_{wire})/d$

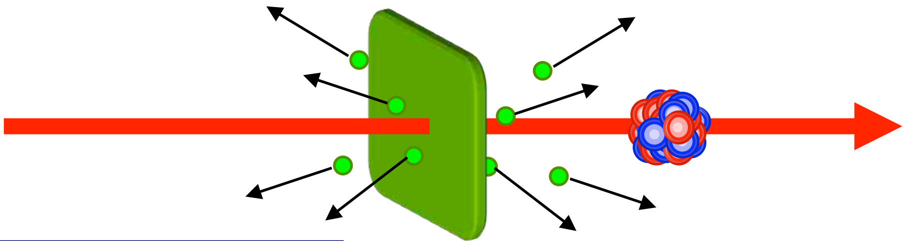
Come misurare l'emittanza nel piano trasverso – pepper pot







Secondary emission detectors



- signal due to (low energy) secondary electron emission
- surface effect, ≈ independent of the crossed thickness, yield proportional to the specific energy loss (Bethe & Bloch); the coefficient varies with the emitting material and with the incident particle
  [E.J.Sternglass, Phys. Rev. 108(1957)1-12; H.G.Clerc, NIM 113(1973)325-331]
- usual wire-based devices are unsatisfactory
- the primary signal needs a physical amplification in order to be used at low beam intensity: channeltron, MCP, ...
- radiation hardness /cost: discrete
- ease-of-use & reliability: sufficient

measured electron production with ions on thin Carbon foils

Ion	E [MeV]	<n> electrons
^{4}He	3.5	8.1
	6.1	5.5
	8.8	3.9
^{16}O	1.8	43
	2.8	50
	5.7	55
	9.6	53
	19.6	45
	29.5	40

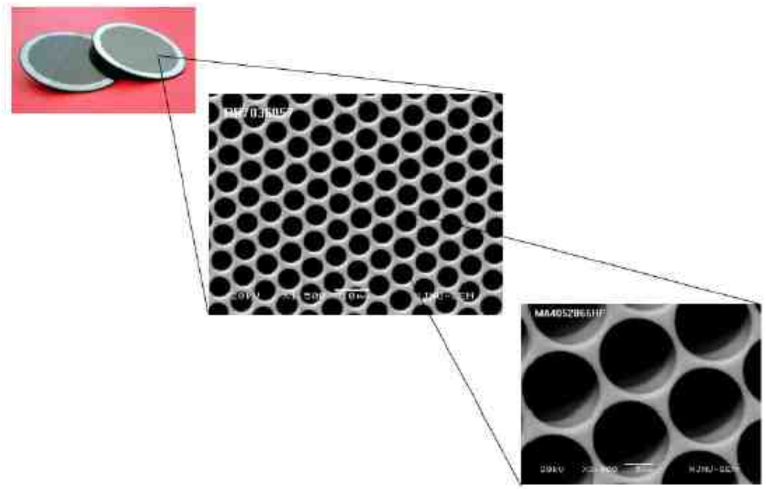
Ion	E [MeV]	<n> electrons
^{32}S	7.5	81
	11.6	92
	14.5	95
	19.5	97
	22.5	97
	26.4	96
	29.6	96
	34.4	93
	43.3	91

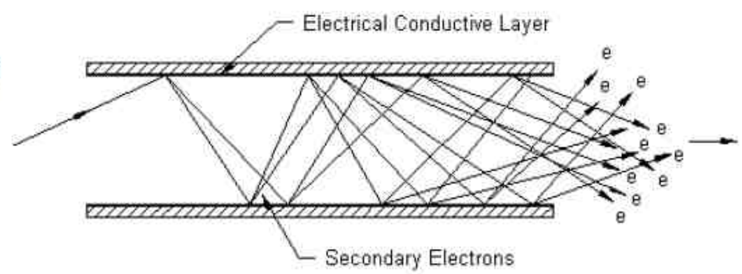
Ion	E [MeV]	<n> electrons
^{127}I	10.2	83
	17.5	113
	20.1	124
	26.7	143
	33.8	163
Light fiss.frag. <Z>=43		73
Heavy fiss.frag. <Z>=55		55

Amplification with Microchannel Plate

Microchannel Plate (MCP)

- Chevron (2x MCPs)
- Channel Ø: 10 μm
- Pitch: 12 μm
- Bias angle: 8°
- Outer Ø: 50 mm
- Active Ø: >40 mm
- Thickness: 0.46 mm each MCP
- Max gain: $>10^7$ @ 2 kV





RIBs Tagging at LNS - CS primary beam

The basic idea is to identify event- by-event the produced ions in:

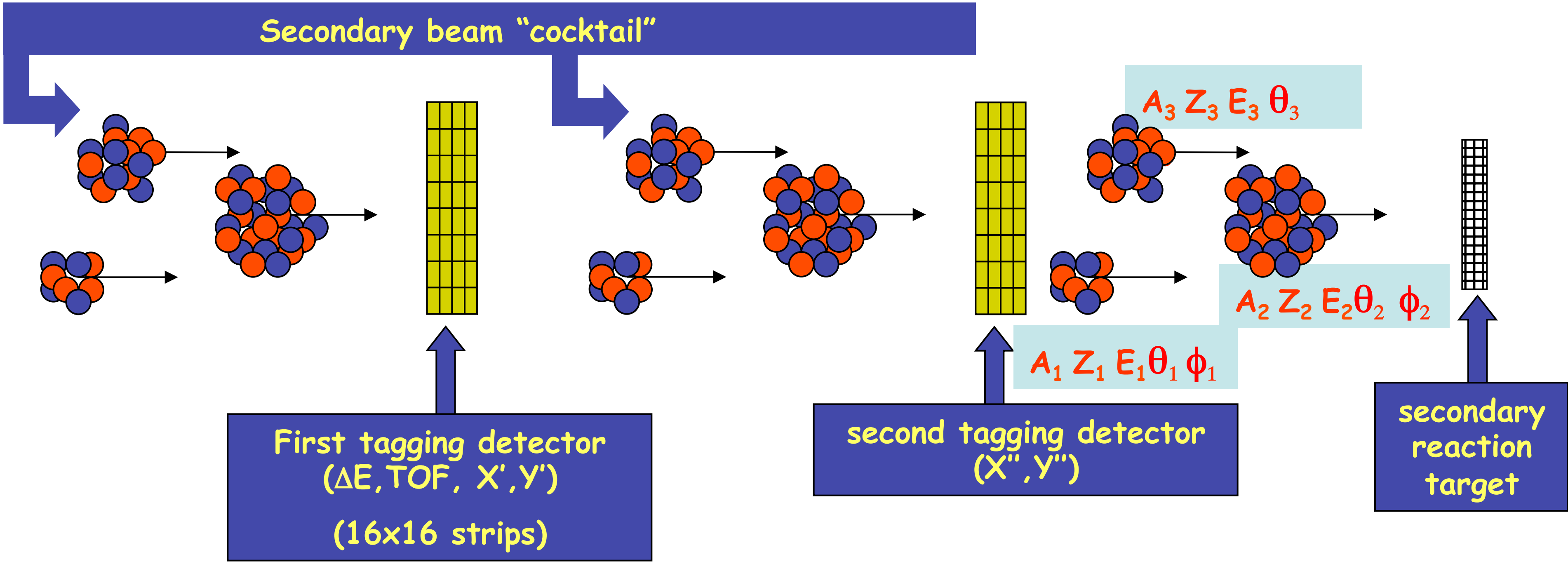
- Charge and mass (Z,A)
- Position (x,y)
- Energy E

with minor modifications of their characteristics:

- Energy (energy loss)
- Direction (straggling)
- Intensity (reactions)

- Convenient for systematic studies
- Allows precise Cross Section measurements
- Depends on the relative yield of "contaminants" for specific reactions

Tagging and tracking



Tagging Procedure

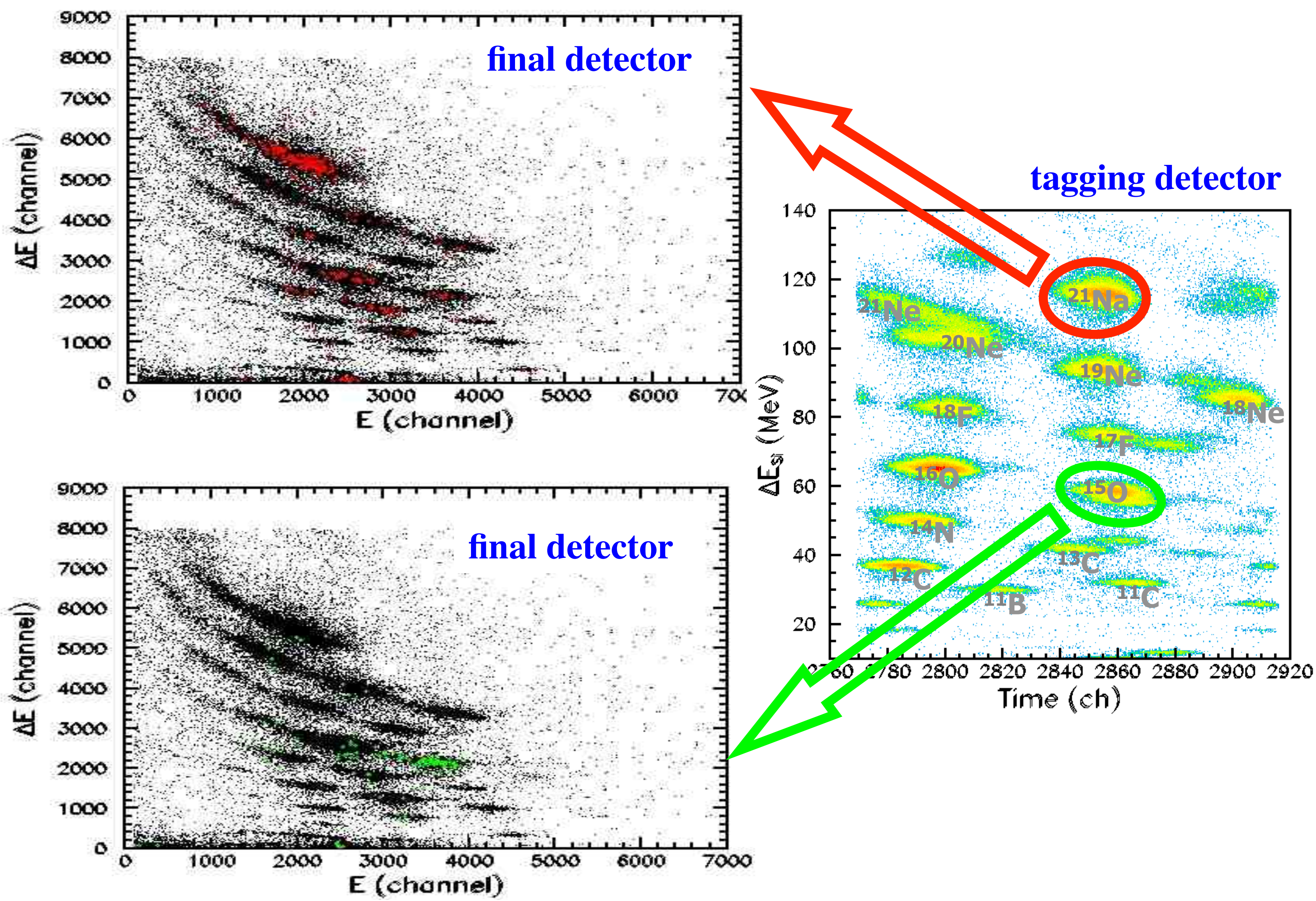
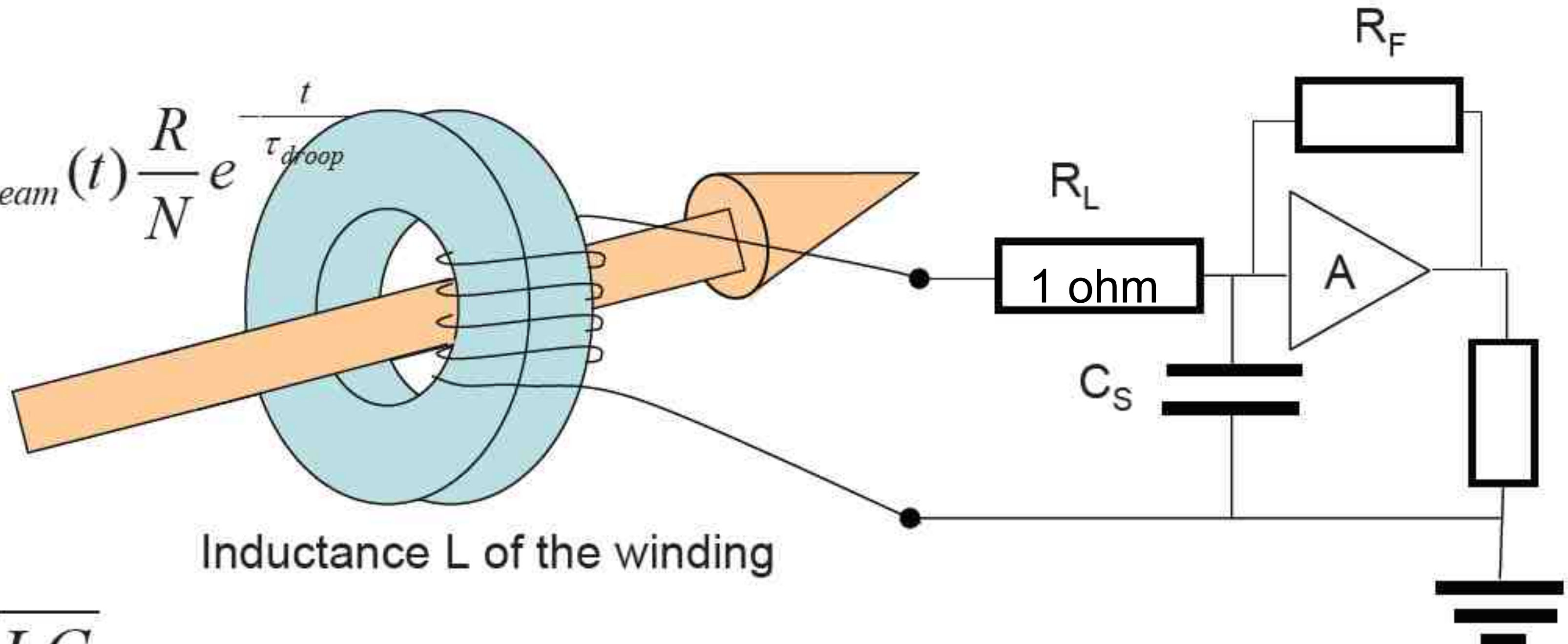


foto prototipo?

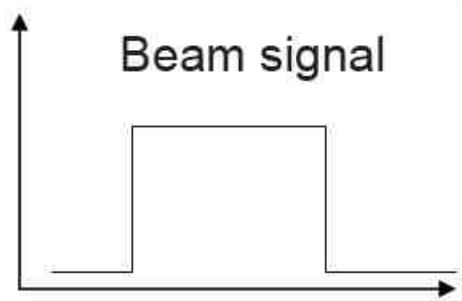
The active transformer

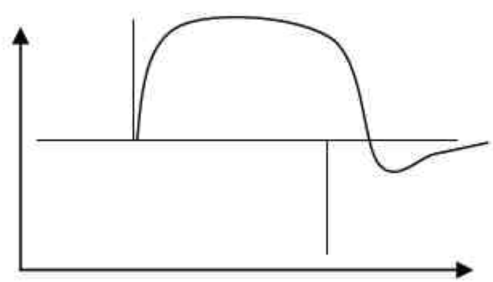
$$U(t) = I_{beam}(t)\frac{R}{N}e^{-\frac{t}{\tau_{droop}}}$$



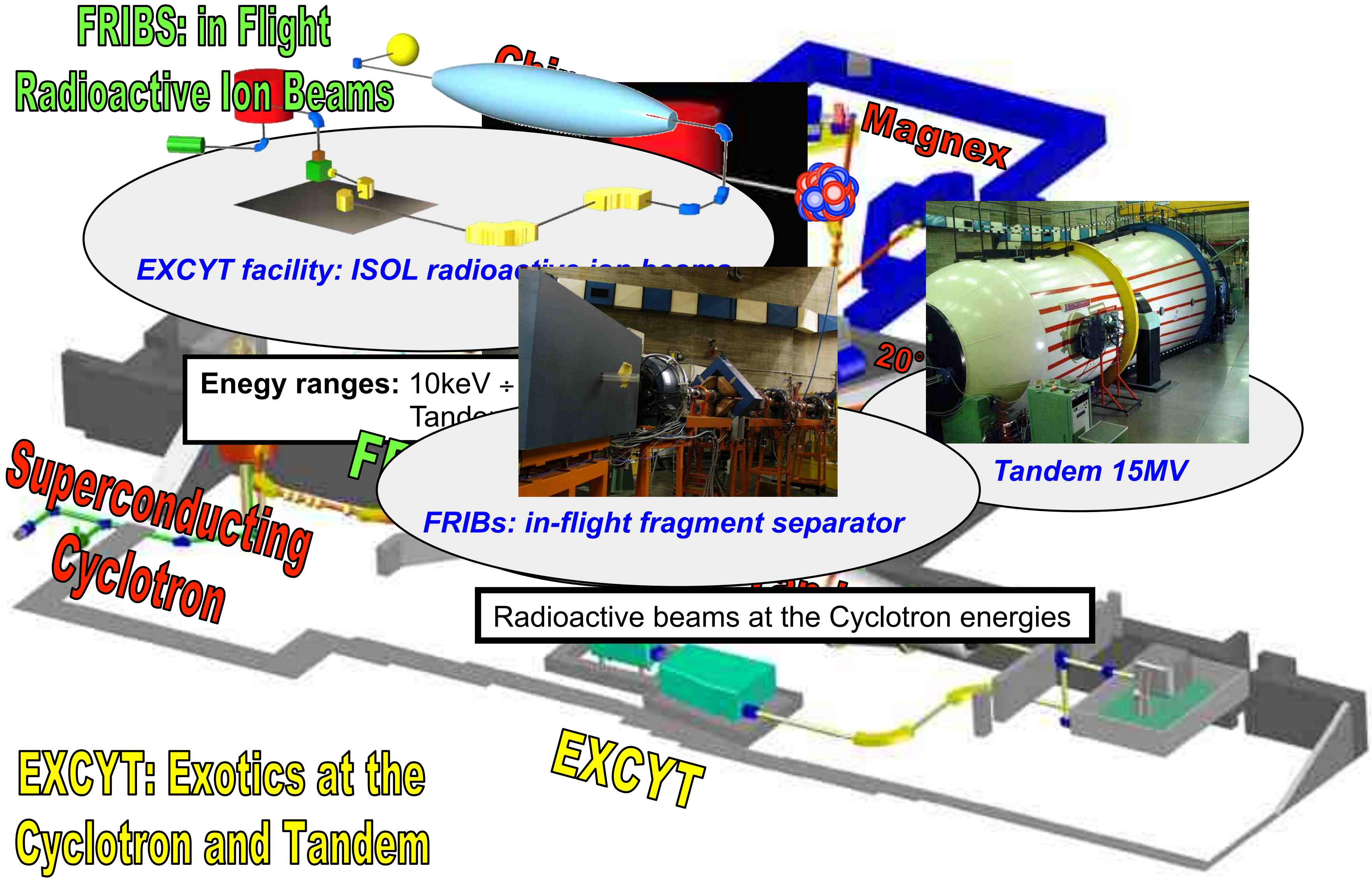
$$\tau_{rise} = \sqrt{L_s C_s}$$

$$\tau_{droop} = \frac{L}{\frac{R_f}{A} + R_L} \approx \frac{L}{R_L}$$

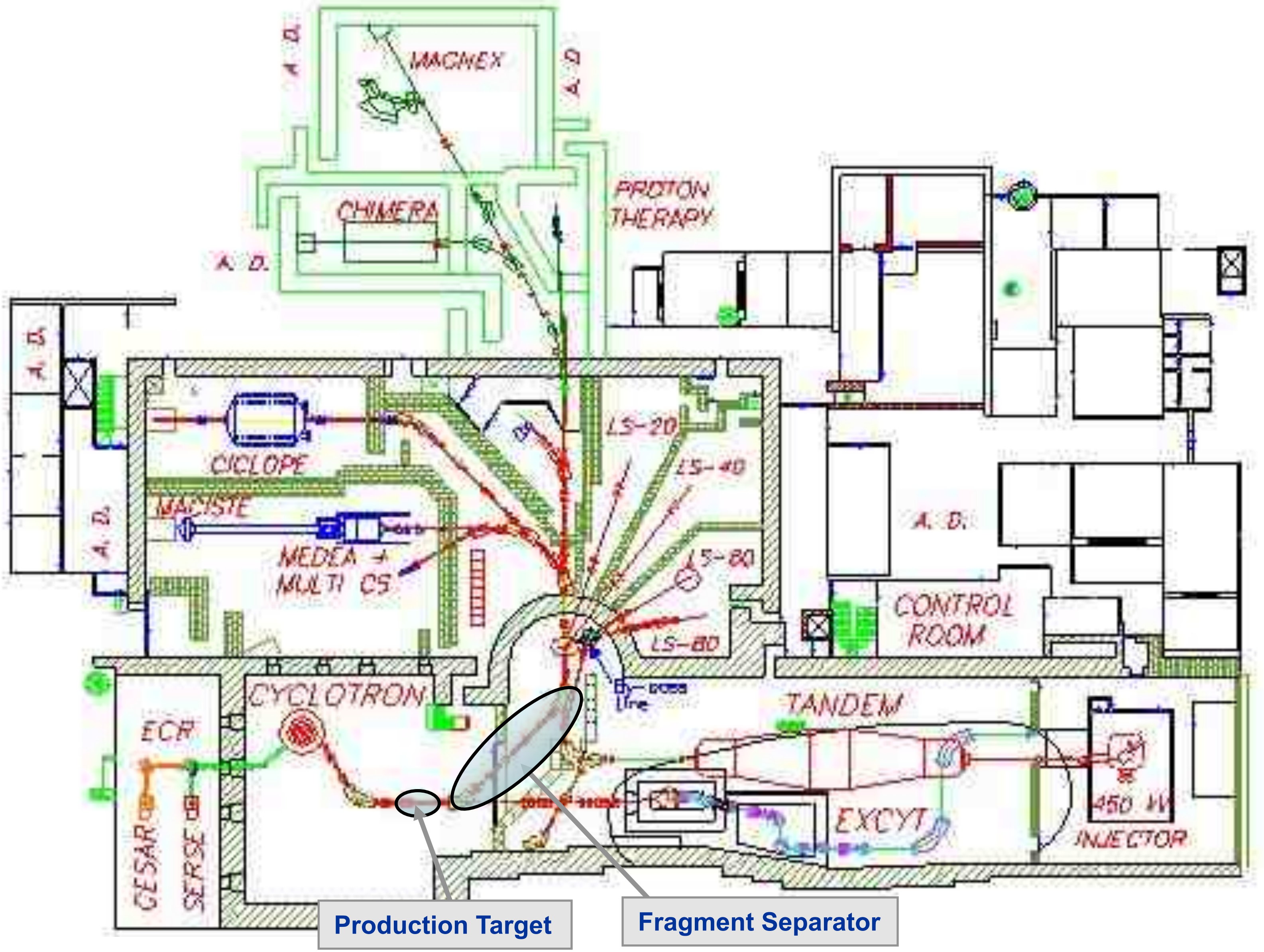




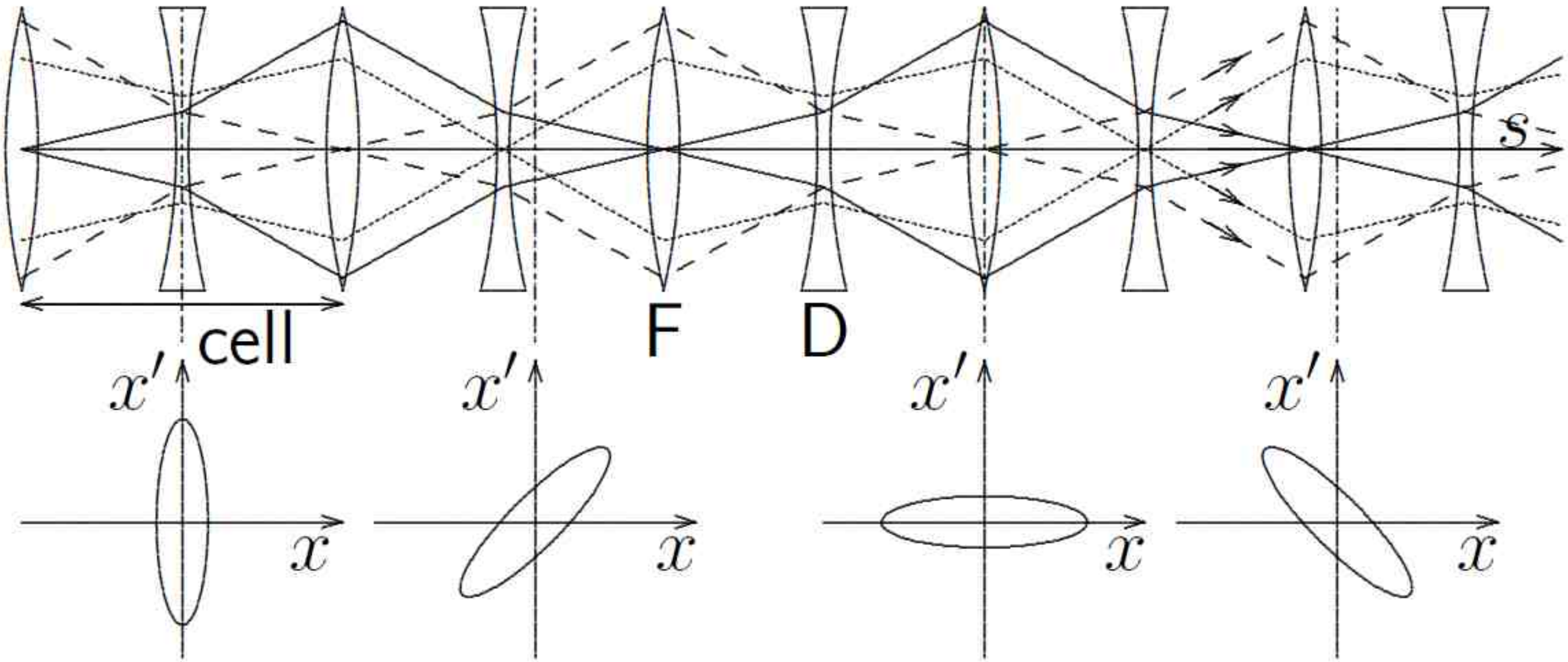
LNS lay-out: accelerators and experimental halls



FRIBS: In-flight production of radioactive beams



ottica dei fasci di particelle



elementi magnetici ed elettrostatici per il trasporto (quadrupoli, esapoli, ecc) = lenti

$$\mathrm{R}_{\mathrm{drift}} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}$$

Horizontal focusing quadrupole with quadrupole constant k and effective length l:

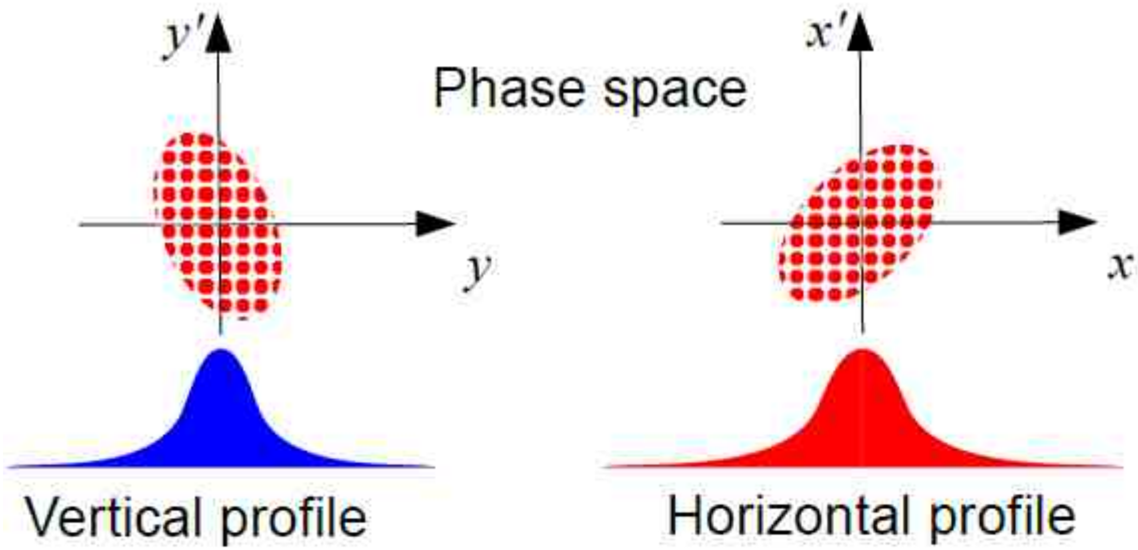
$$\mathrm{R}_{\mathrm{focus}} = \begin{pmatrix} \cos\sqrt{k}l & \frac{1}{\sqrt{k}}\sin\sqrt{k}l \\ -\sqrt{k}\sin\sqrt{k}l & \cos\sqrt{k}l \end{pmatrix}$$

Horizontal de-focusing quadrupole with quadrupole constant k and effective length l:

$$\mathrm{R}_{\mathrm{defocus}} = \begin{pmatrix} \cosh\sqrt{k}l & \frac{1}{\sqrt{k}}\sinh\sqrt{k}l \\ -\sqrt{k}\sinh\sqrt{k}l & \cosh\sqrt{k}l \end{pmatrix}.$$

Emittanza del fascio

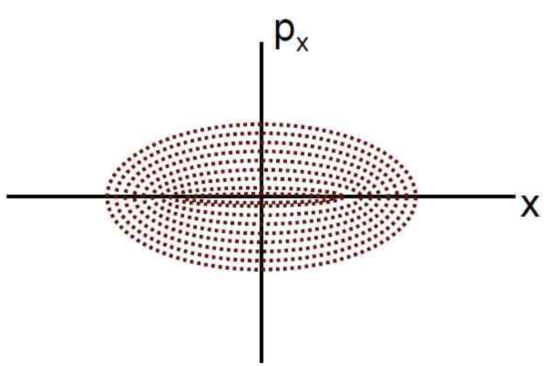
- Take the same plane as before
- Note x, v_x and y, v_y for each particle crossing the plane
- Plot on a 2D chart (x, v_x OR y, v_y) of each particle
- Rename $v_x \rightarrow x'$, $v_y \rightarrow y'$
- Area of the ellipse is an invariant and is called transverse emittance ε_x, ε_y



6-dimensional space for N_b particles

The i[th] particle has coordinates (x_i, p_i), i = x, y, z

The bunch is represented by N_b points that move in time



In most accelerators the phase space planes are only weakly coupled.

→ Treat the longitudinal plane independently from the transverse one

→ Effects of weak coupling can be treated as a perturbation of the uncoupled solution

In the longitudinal plane, electric fields accelerate the particles

According to Liouville, in the presence of Hamiltonian forces, the area occupied by the beam in the longitudinal phase space is conserved

For transverse planes $\{x, p_x\}$ and $\{y, p_y\}$, use a modified phase space where the momentum components are replaced by:

$$p_{xi} \rightarrow x' = \frac{dx}{ds} \qquad p_{yi} \rightarrow y' = \frac{dy}{ds}$$

where s is the direction of motion

RIBs diagnostics at LNS

very low intensities (< 1pA)

Physical motivation

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

...the signal becomes too close to the noise level...

per correnti basse (< 1pA)

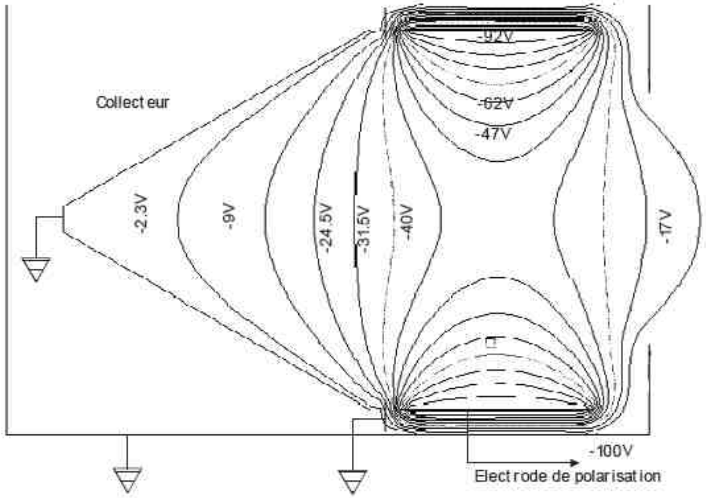
Possible solutions

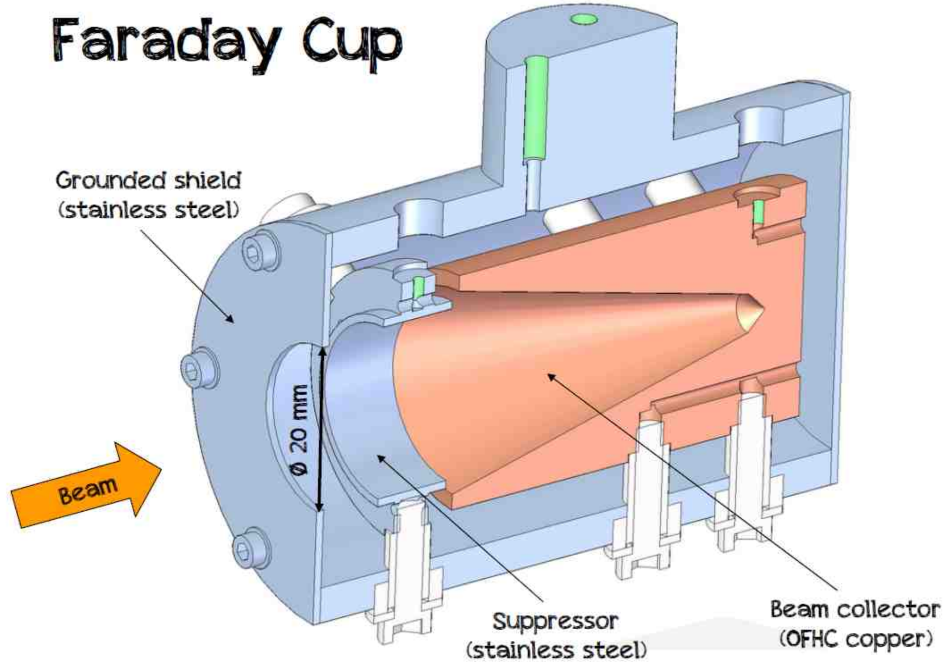
- increase the sensitivity
  - reduce noise by better design and shielding (can be complex and expensive)
- increase the signal
  - a possibile way to increase the signal is to use particle detectors: they are sensitive to the energy released by each particle of the beam

Requirements

- reliable, even if based on particle detectors
- easy-to-use & robust: high level software control, well proven (and cheap) technology
- self calibrating (if possible)

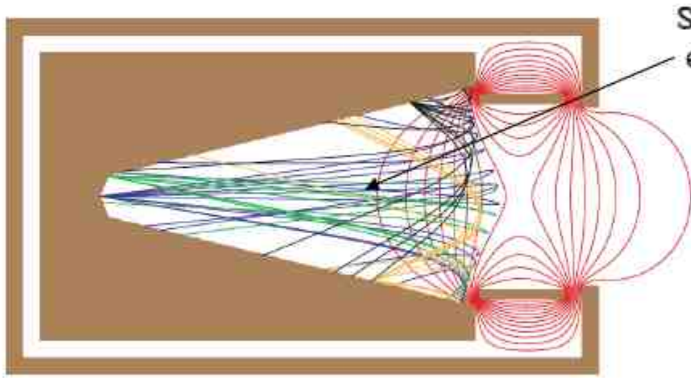
Electrostatic field in Faraday cups



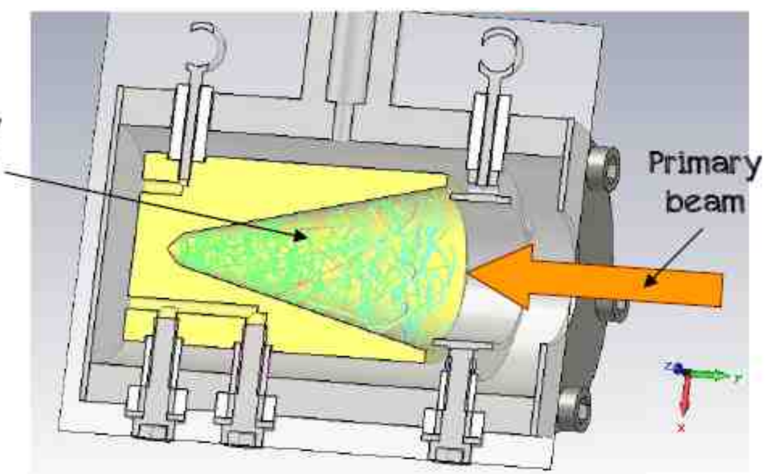


In order to keep secondary electrons within the cup a repelling voltage is applied to the polarization electrode

Since the electrons have energies of less than 20 eV some 100V repelling voltage is sufficient

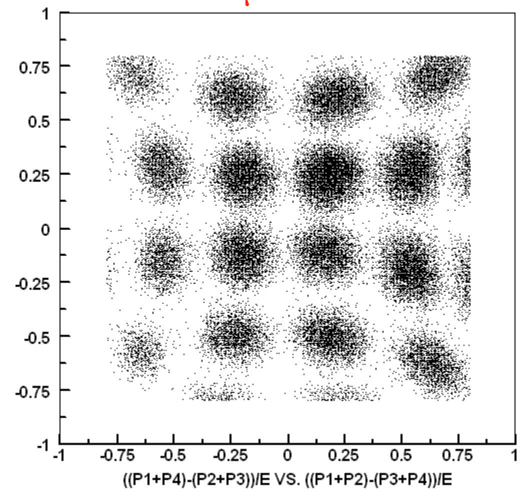


Secondary electrons

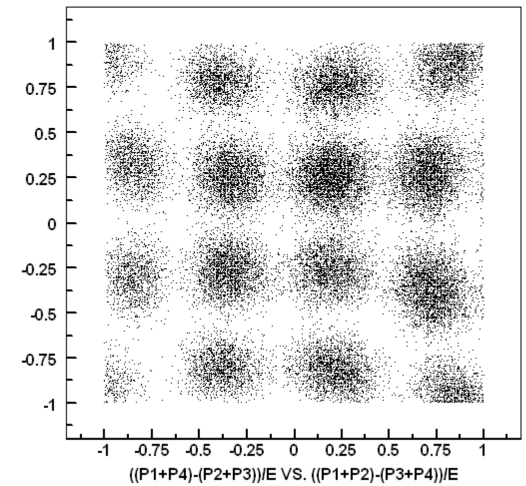


diameter 1.5mm
step 2mm

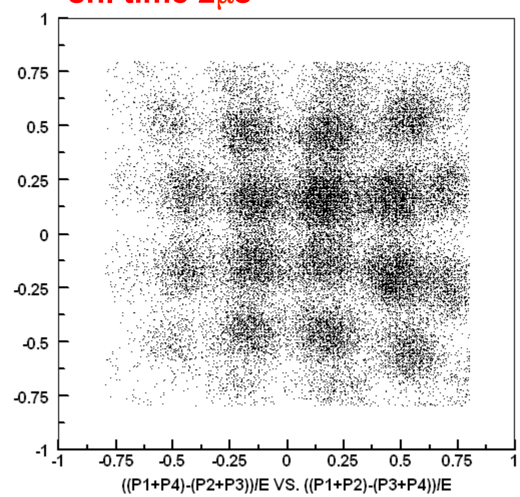
sh. time 0.2μs



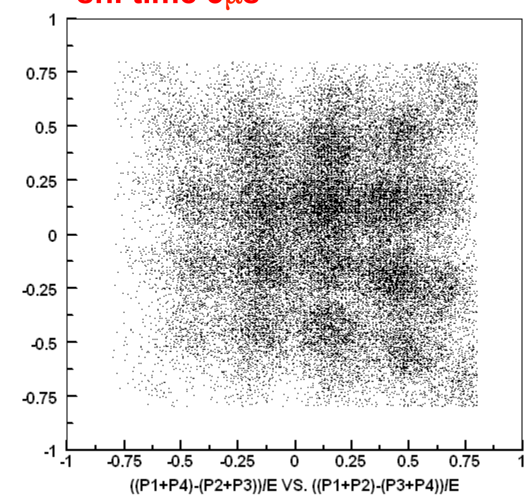
sh. time 1μs



sh. time 2μs



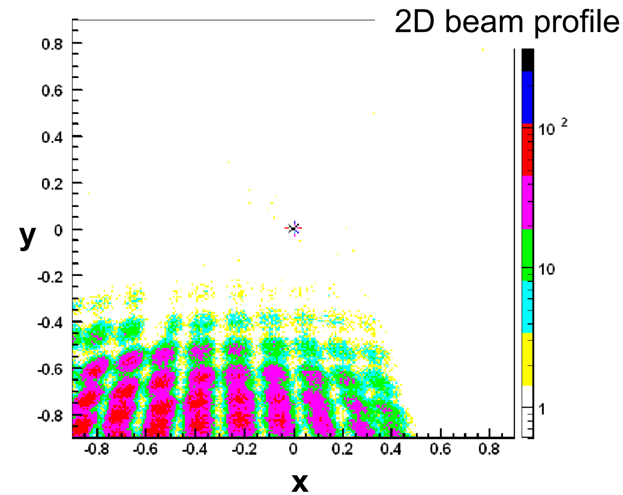
sh. time 3μs

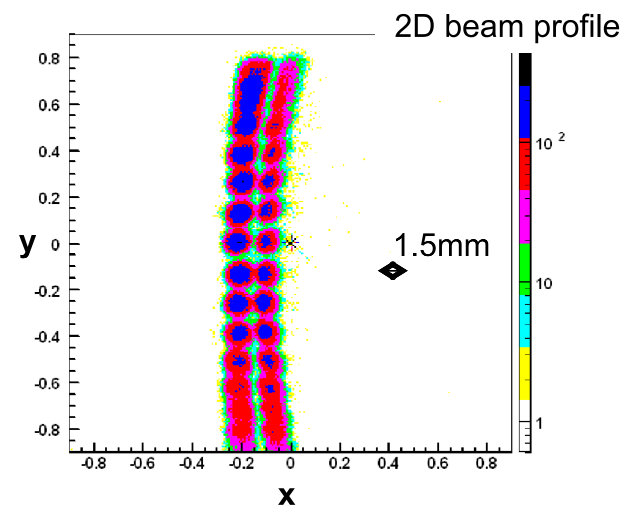


- 2D beam profile monitor
- $\Delta E - E$ identification with telescope

size: 50 x 50 mm^2

- Real time visualization
- User friendly interface



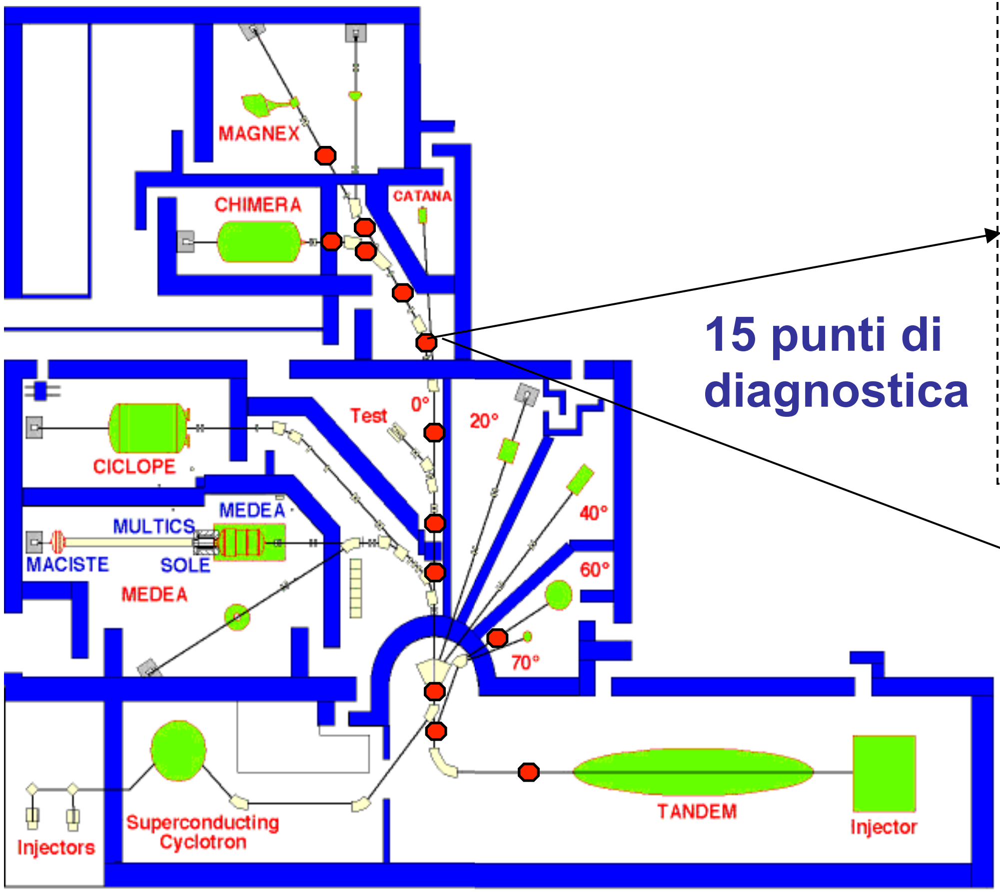


^{8}Li beam – 28MeV – 1kHz

Diagnostics for RIBs (Excyt)

Short term upgrading:

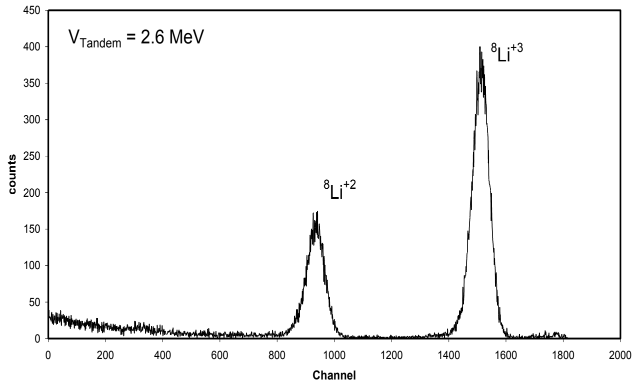
- Provide the long beam lines (Magnex and Chimera) with low intensity diagnostics



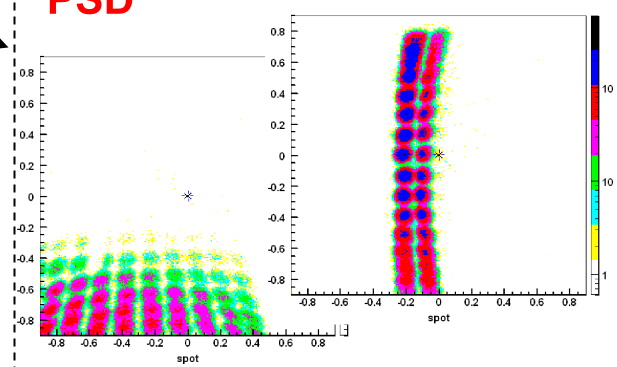
15 punti di diagnostica

PMT + plastic scintillator

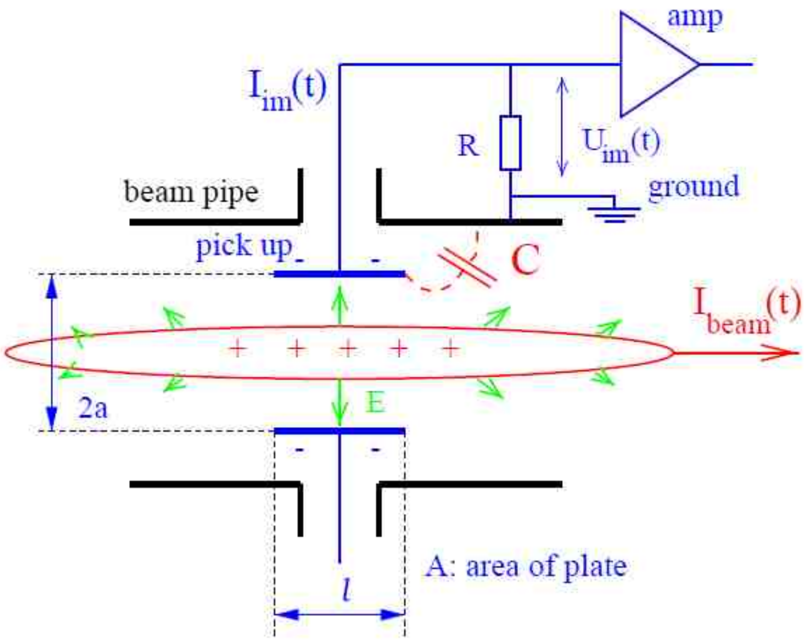
- *counting rate*

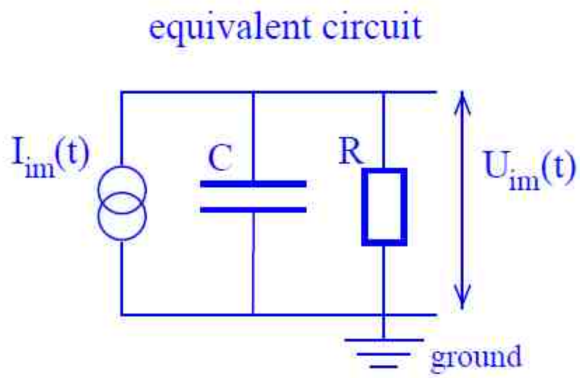


PSD



Position measurement with a capacitive pick-up

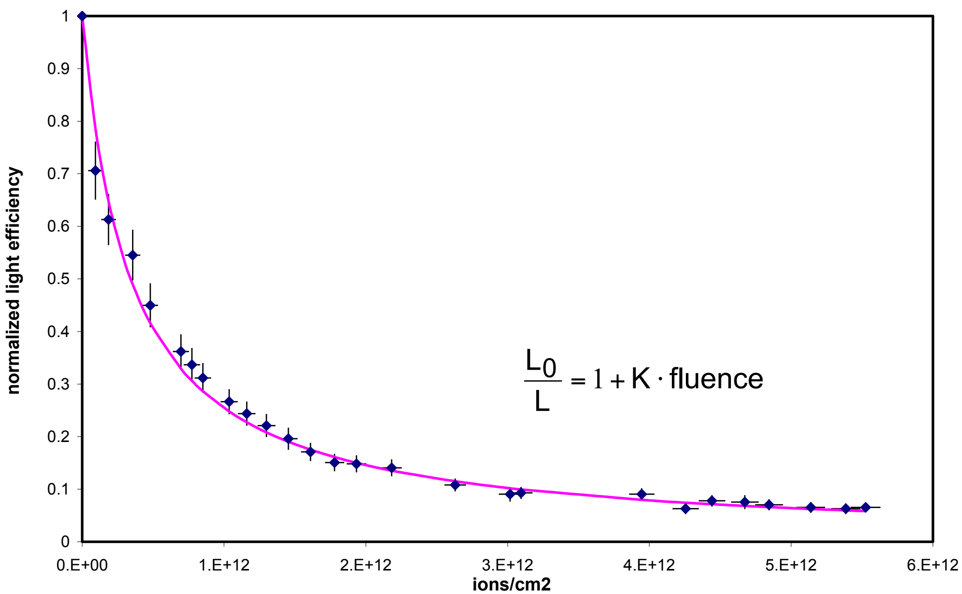




$$I_{im}(t) \equiv \frac{dQ_{im}}{dt} = -\frac{A}{2\pi a l} \cdot \frac{dQ_{beam}(t)}{dt}$$

Radiation damage in CsI(Tl) screens

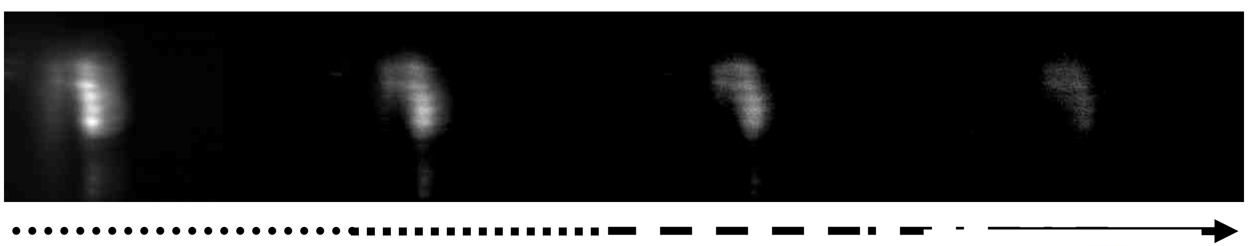
scintillating light vs. fluence for a 100keV ^{16}O beam



A 1mm thick screen was continuously irradiated for 6 h.

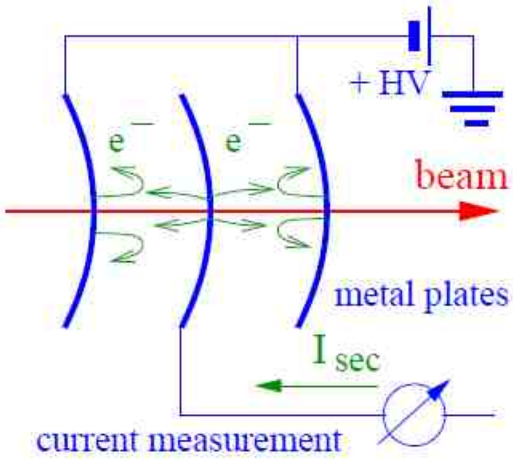
A set of pictures was acquired while verifying that in the mean time the overall beam intensity was constant at the reference value of 1.3 pA.

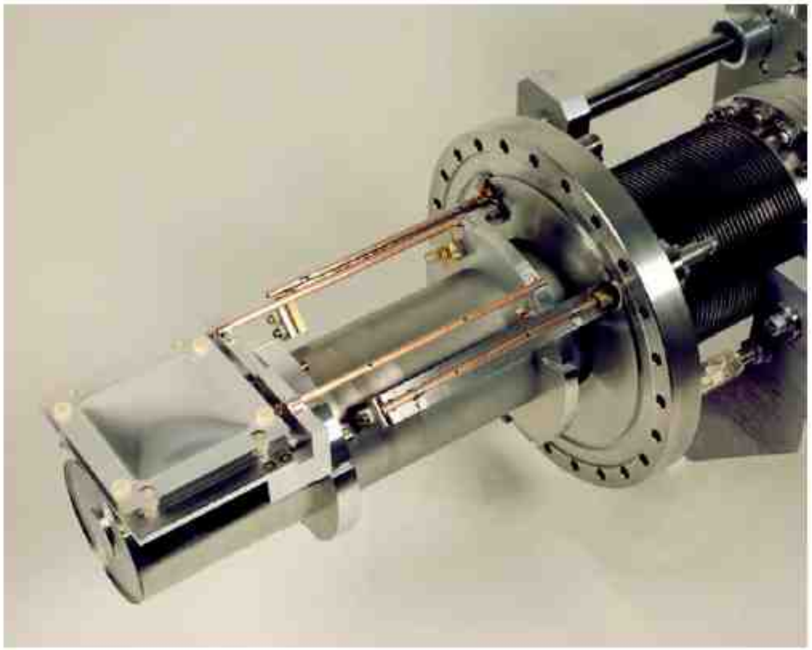
The light efficiency drops to 10%.



6 hours

SEM based beam current measurement





material	pure Al ($\simeq$99.5%)
thickness	100 μm
number of electrodes	3
active surface	80×80 mm^2
distance between electrode	5 mm
voltage	100 V

Beam diagnostics in the EXCYT beam line

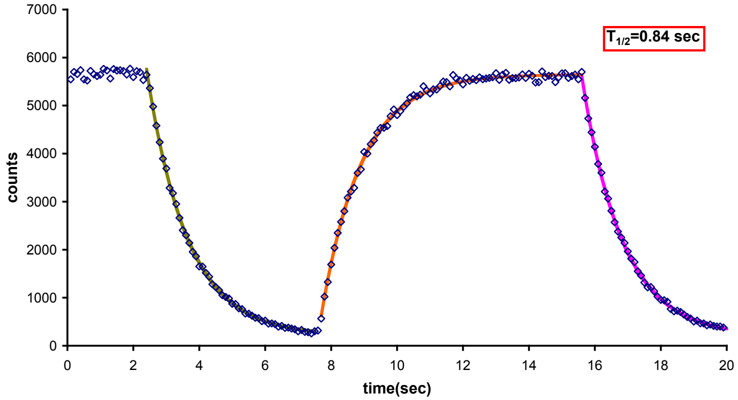
Sensitivity for beam imaging

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

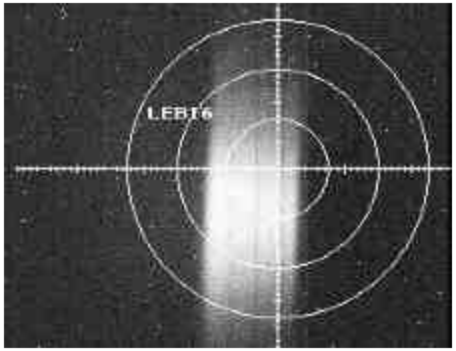
resolution < 1mm

Imaging of Stable (pilot) beams

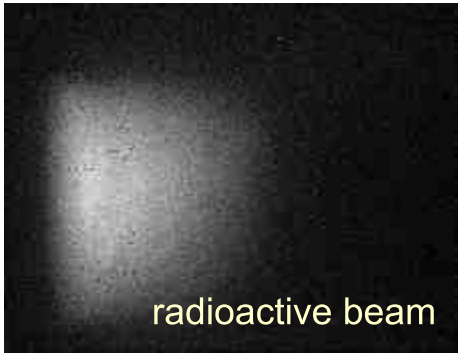
- **Imaging of radioactive beams**
- **Beam rate measurement**
- **Decay curve reconstruction**

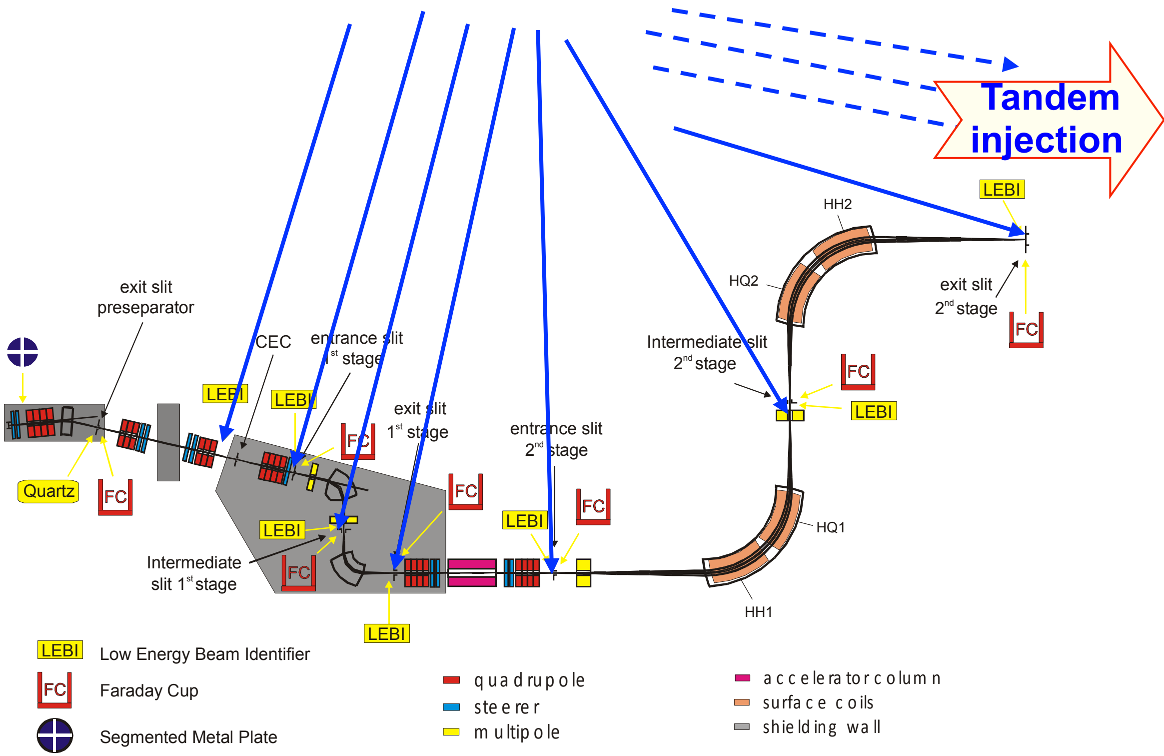


^{7}Li I = 10 pA E = 10 keV

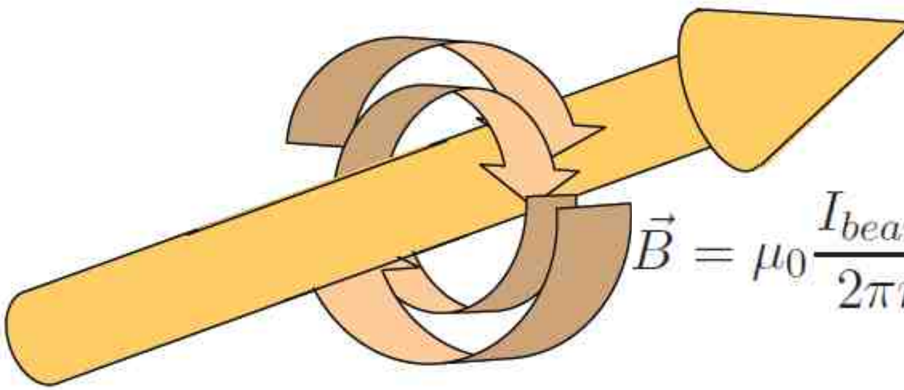


^{8}Li I = 100 fA E = 10 keV





Current Transformers



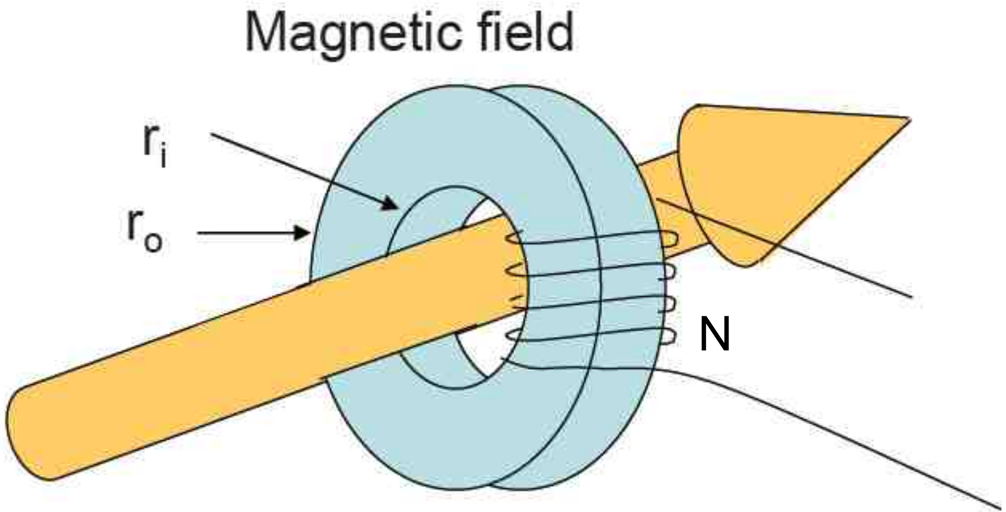
$$\vec{B} = \mu_0 \frac{I_{beam}}{2\pi r} \cdot \vec{e}_\varphi$$

Beam current

$$I_{beam} = \frac{qeN}{t} = \frac{qeN\beta c}{l}$$

Courtesy of U. Raich

Current Transformers



beam = primary winding

Fields are very low

Capture magnetic field lines with cores of high relative permeability

(CoFe based amorphous alloy Vitrovac: $\mu_r = 10^5$)

$$I_{sec} = \frac{N_{prim}}{N_{sec}} \cdot I_{prim}$$

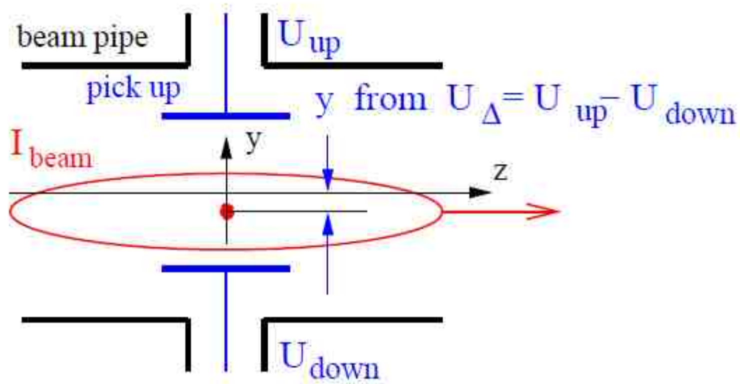
$$I_{sec} = \frac{1}{N} \cdot I_{prim} \quad \text{due to} \quad N_{prim} = 1$$

$$L = \frac{\mu_0 \mu_r}{2\pi} l N^2 \ln \frac{r_0}{r_i}$$

I_{beam} > hundreds of μA

Courtesy of U. Raich

Position measurement with a capacitive pick-up



The deviation of the beam center with respect to the center of the vacuum chamber can be monitored using **four isolated plates or buttons** by determining the difference voltage $\Delta U x = U_{right} - U_{left}$ or $\Delta U y = U_{up} - U_{down}$ of opposite plates.

$$x = \frac{1}{S_x} \cdot \frac{U_{right} - U_{left}}{U_{right} + U_{left}} = \frac{1}{S_x} \cdot \frac{\Delta U_x}{\Sigma U_x} \qquad \text{(horizontal)}$$

$$y = \frac{1}{S_y} \cdot \frac{U_{up} - U_{down}}{U_{up} + U_{down}} = \frac{1}{S_y} \cdot \frac{\Delta U_y}{\Sigma U_y} \qquad \text{(vertical)}$$