Low-energy/low-intensity beam diagnostics detectors: experience at INFN-LNS

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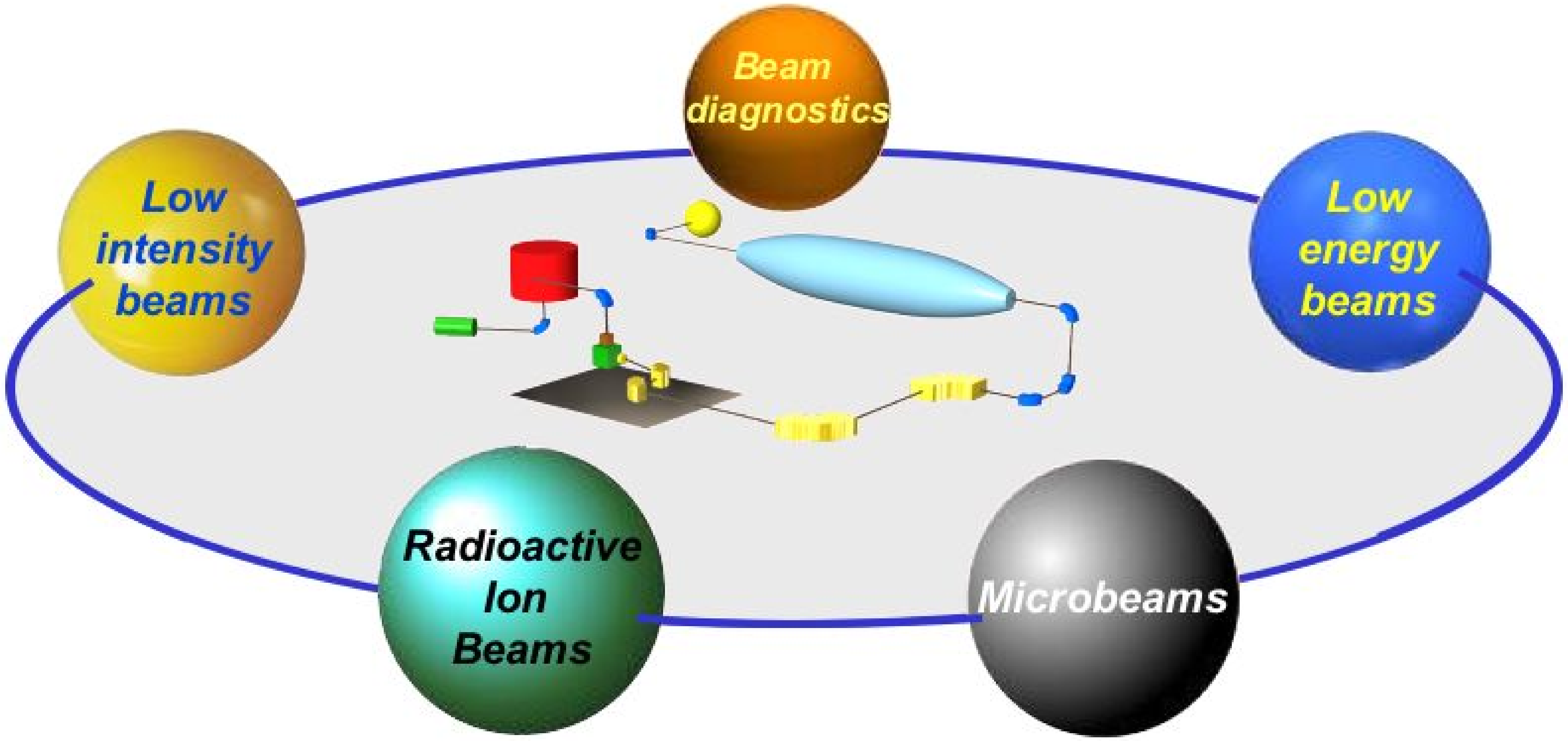
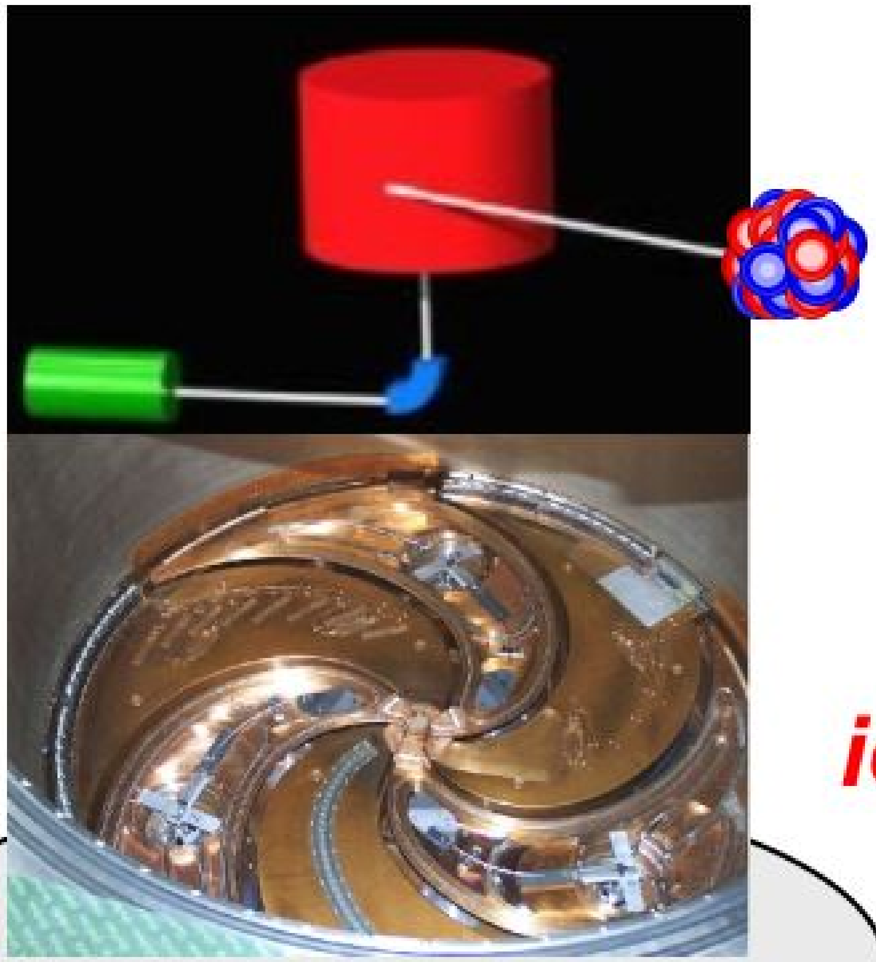
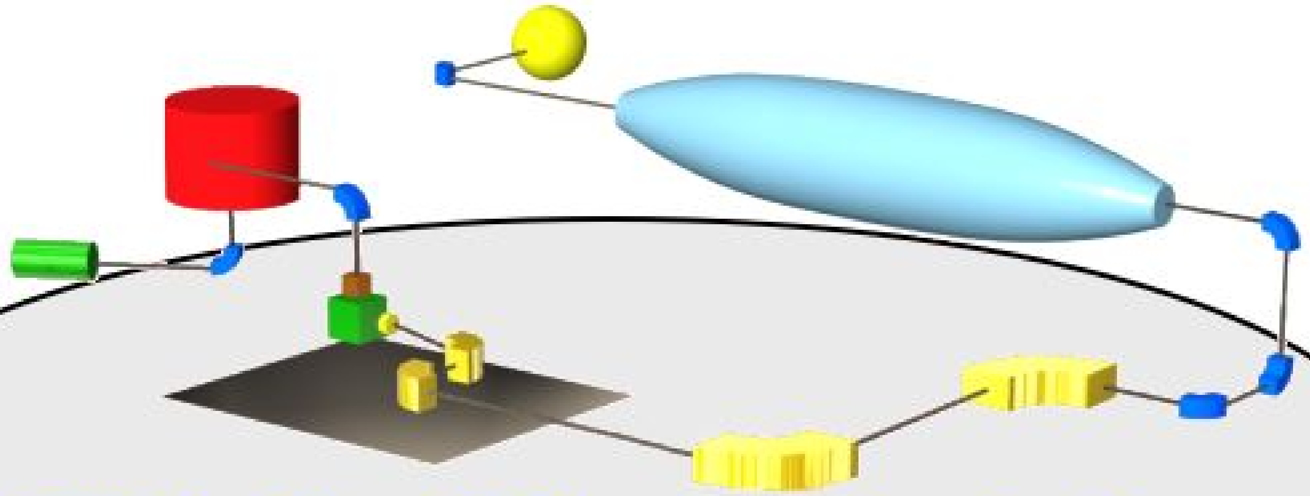




Superconducting Cyclotron
<80MeV/amu

Tandem 15MV

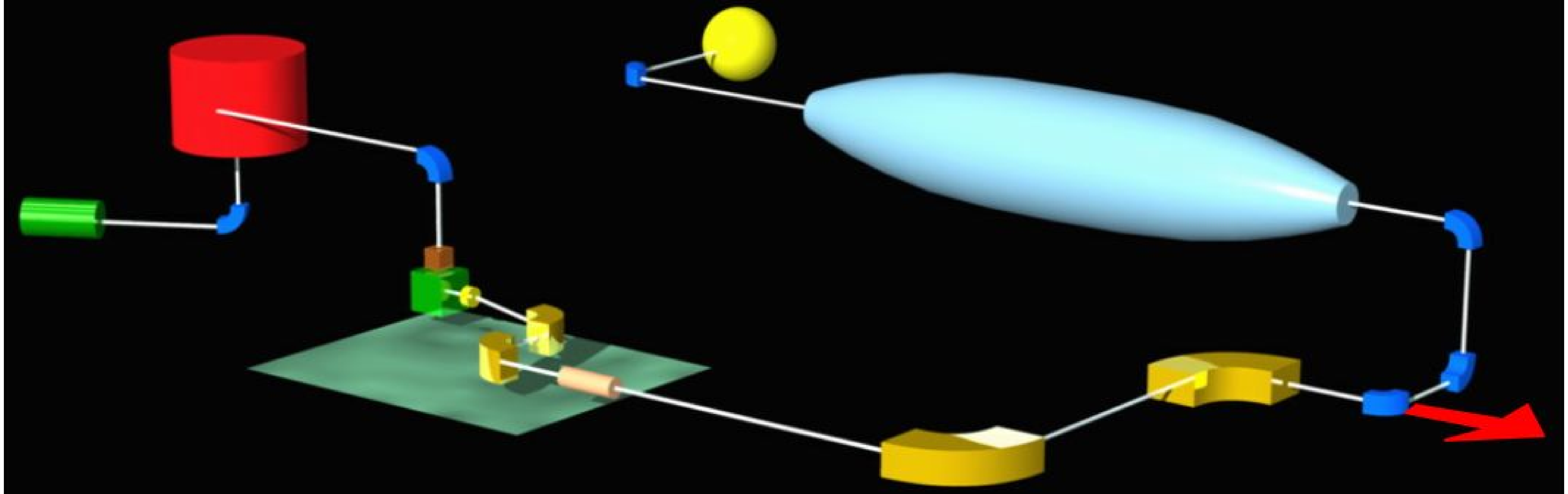
ion accelerators at LNS

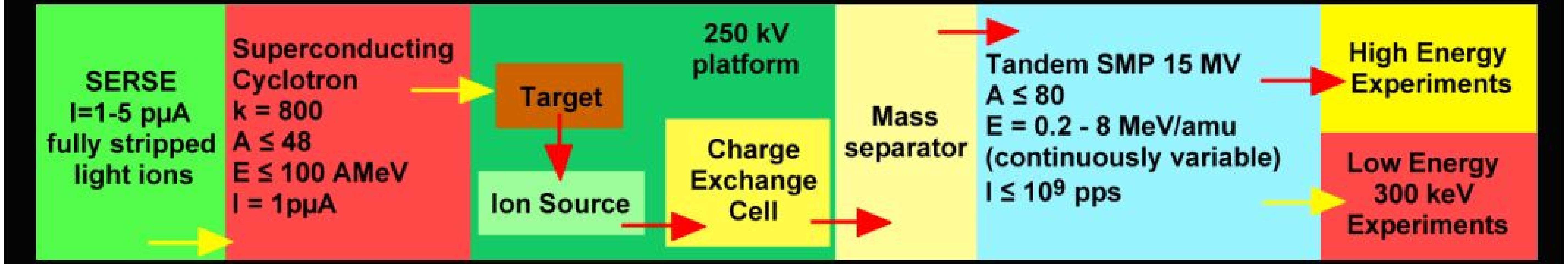


EXCYT facility: ISOL radioactive ion beams

FRIBs: in-flight fragment separator

we started with beam diagnostics for the EXCYT facility...





SERSE
I=1-5 pμA
fully stripped
light ions

Superconducting Cyclotron
k = 800
A ≤ 48
E ≤ 100 AMeV
I = 1pμA

Target

Ion Source

250 kV platform

Charge Exchange Cell

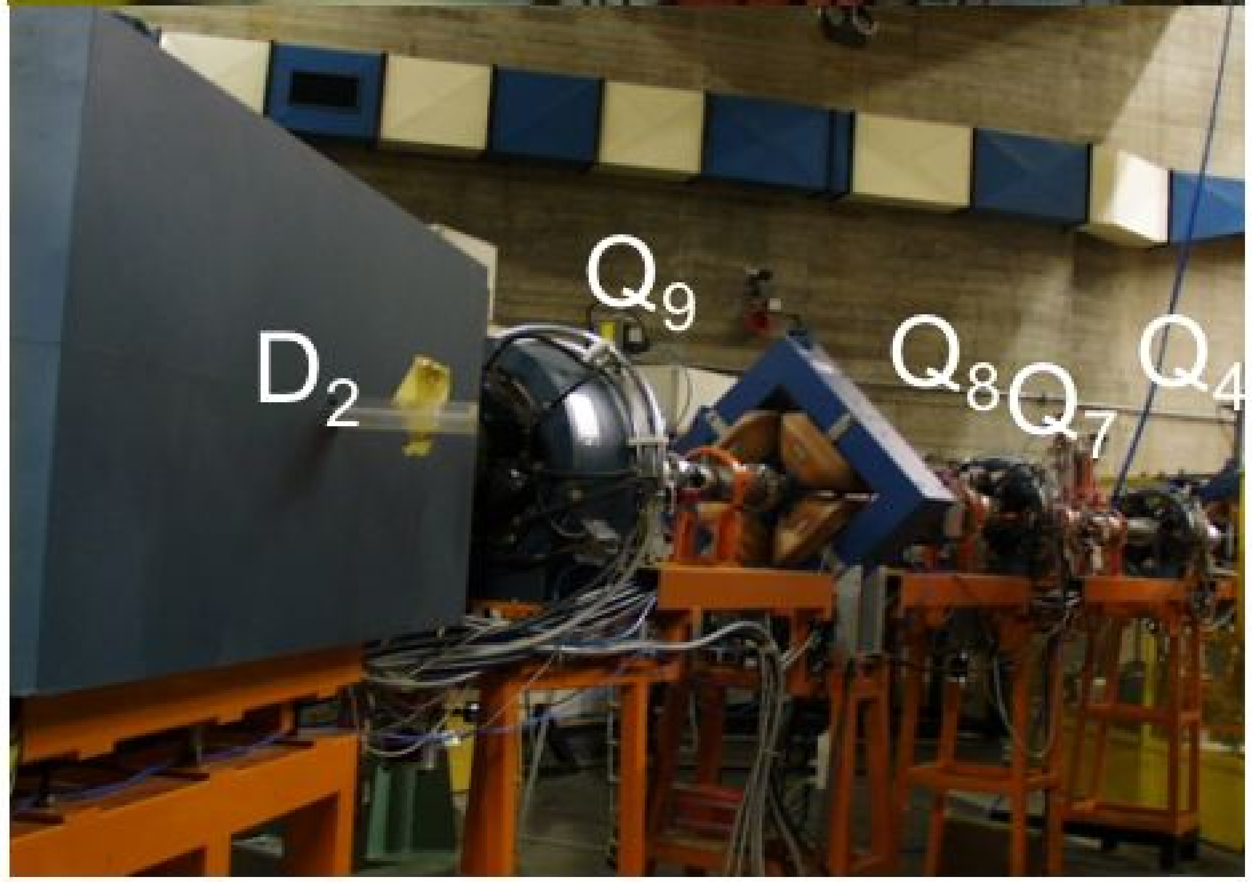
Mass separator

Tandem SMP 15 MV
A ≤ 80
E = 0.2 - 8 MeV/amu
(continuously variable)
I ≤ 10^9 pps

High Energy Experiments

Low Energy 300 keV Experiments

now we deal also with BD for an in-flight fragmentation RIB facility



G.Raciti et al., Experimental Evidence of ^{2}He Decay from ^{18}Ne Excited States, Phys. Rev. Lett. 100, 192503 (2008)

Production Target

^{9}Be (500μm)

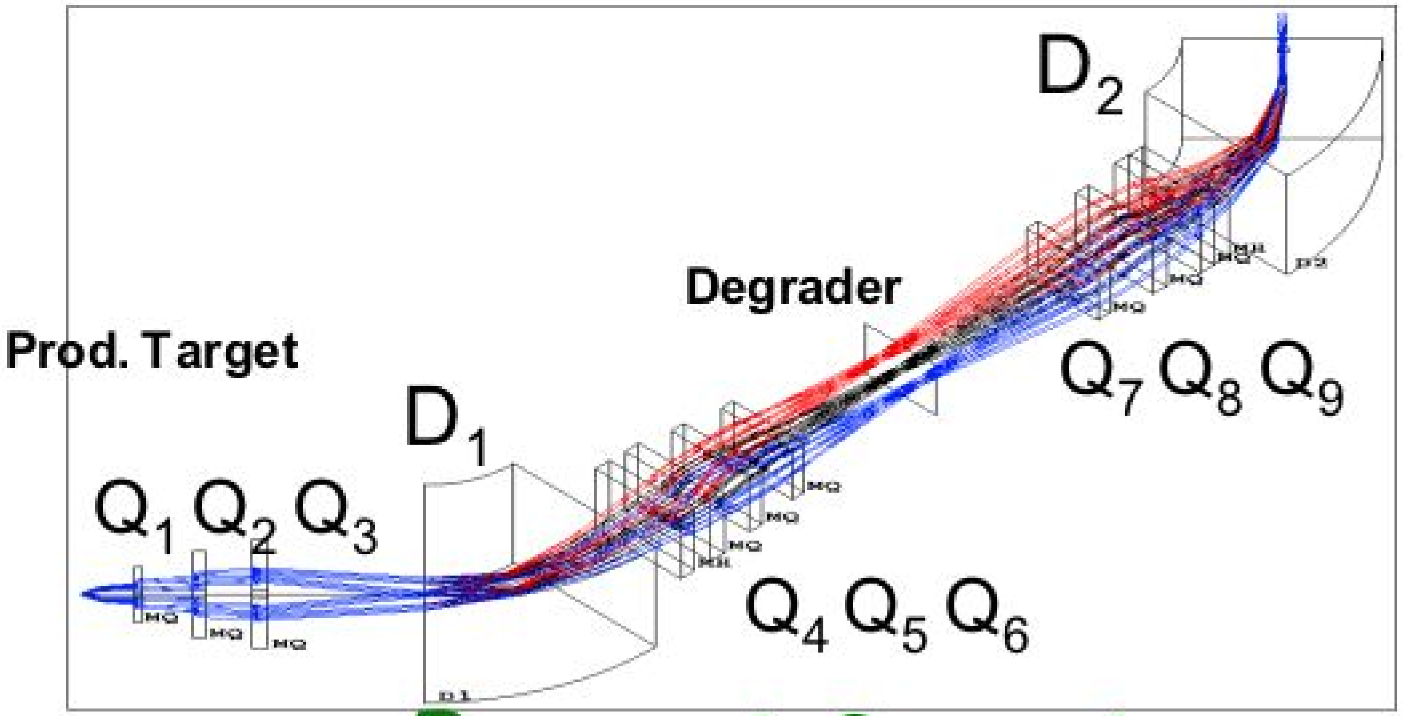
^{40}Ar 40 AMeV
^{12}C 62 AMeV
^{20}Ne 45 AMeV

FRIBs

^{27}Al (100μm)

^{58}Ni 40 AMeV

	ΔΩ (msr)	ΔP/P (%)	R_p	MaxBρ(Tm)	Length(m)
FRIBs	4.0	1.1	800-1500	4.0	23
Present	1.1	0.65	1000	2.7	23
GANIL-LISE	1.0	2.5	800	3.2	18
GSI-FRS	0.7-2.5	1	240-1500	9-18	74
RIKEN	5.0	3	1500	5.76	21
NSCL-A1200 (A1900)	0.8- 8	1.5	700-1500	5.4	22
JINR	6.4	1	4360	4.5	14.5



Fragment Separator

What kind of beams?

• Low-intensity ion beams	$I << 10^9$ particles per second (pps): nuclear physics, irradiations (materials, biological samples, IC), deep implantation, lithography with ions, ion beam therapy,...
• Low-energy ion beams	E < 1 MeV/amu: material analysis, irradiations (materials, biological samples, IC), ion implantation,...
• Low-energy AND low-intensity ion beams	combination of the two previous cases,...
• Microbeams	∅ < 1mm: nuclear physics, material analysis, irradiations (materials, biological samples, IC), deep implantation, lithography with ions,...
• Radioactive ion beams	short-lived unstable nuclei: nuclear physics,...

Can be low-energy AND low-intensity

Why special diagnostics for low-energy low intensity?

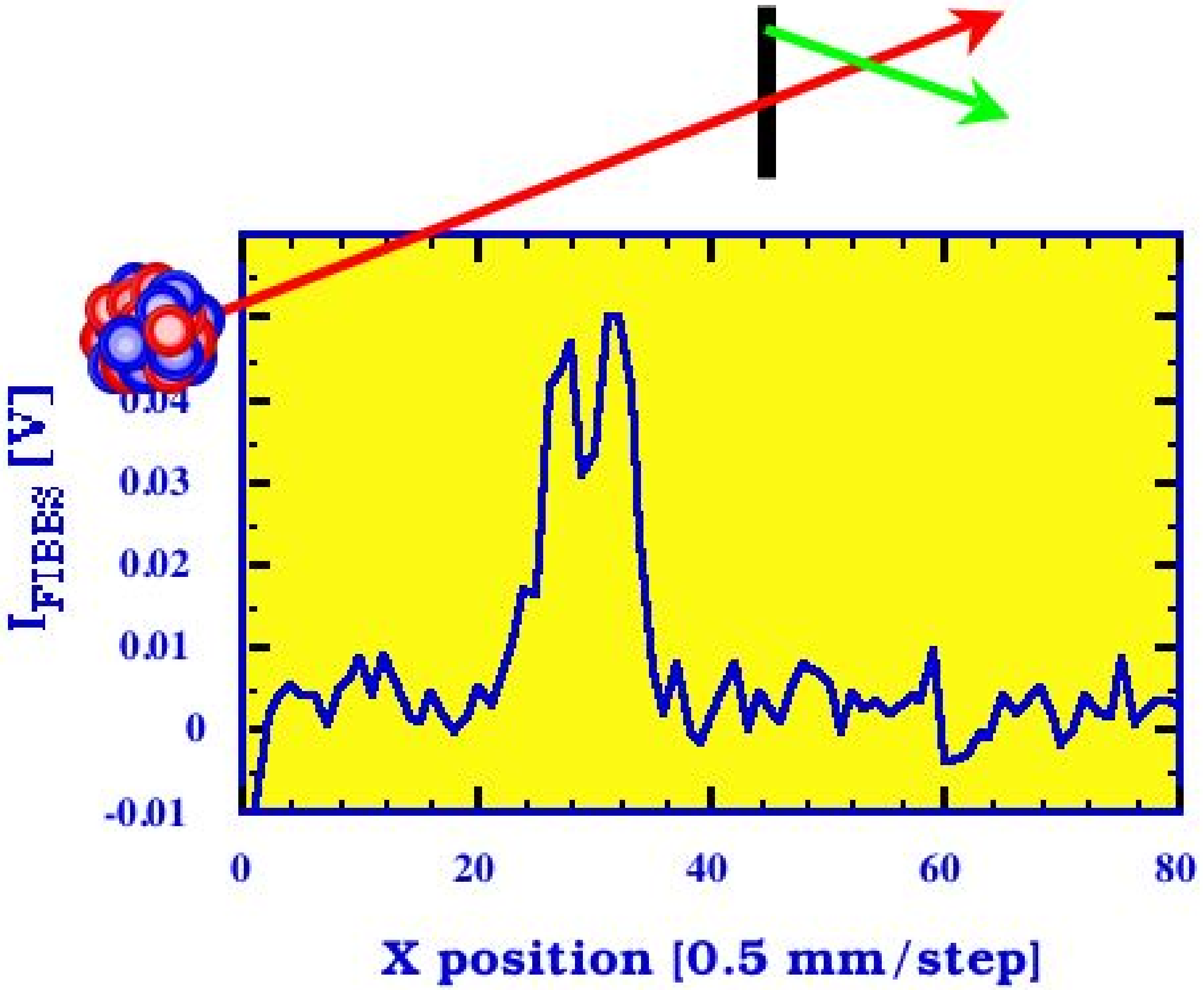
Physical motivation

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

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

The scintillation light yield is low

Low S/N ratio



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

Need of new devices

Possible solutions

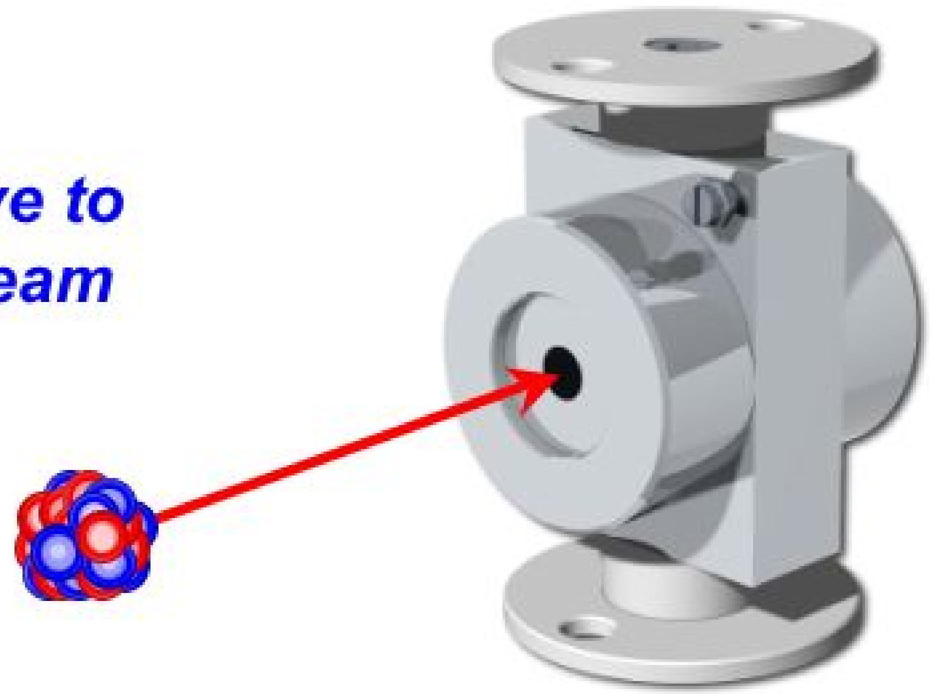
- increase the sensitivity
    - reduce noise by better design and shielding (can be complex and expensive)
- increase the signal
    - a possibile way to increase the signal is to use particle detectors: they are sensitive to the energy released by each particle of the beam

Requirements

- non-interceptive (as much as possible): residual gas, moving wire(s), thin foils, ...
- reliable, even if based on particle detectors
- easy-to-use & robust: high level software control, well proven (and cheap) technology
- self calibrating (if possible)

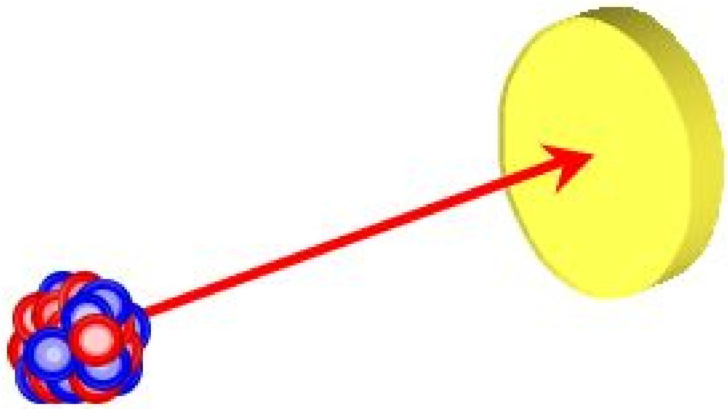
Example

With a Faraday cup we are sensitive to the charge: we just integrate the beam charge per unit time (=current)



an $^{16}O^{1+}$ at 1MeV provides a signal charge of 1 electron

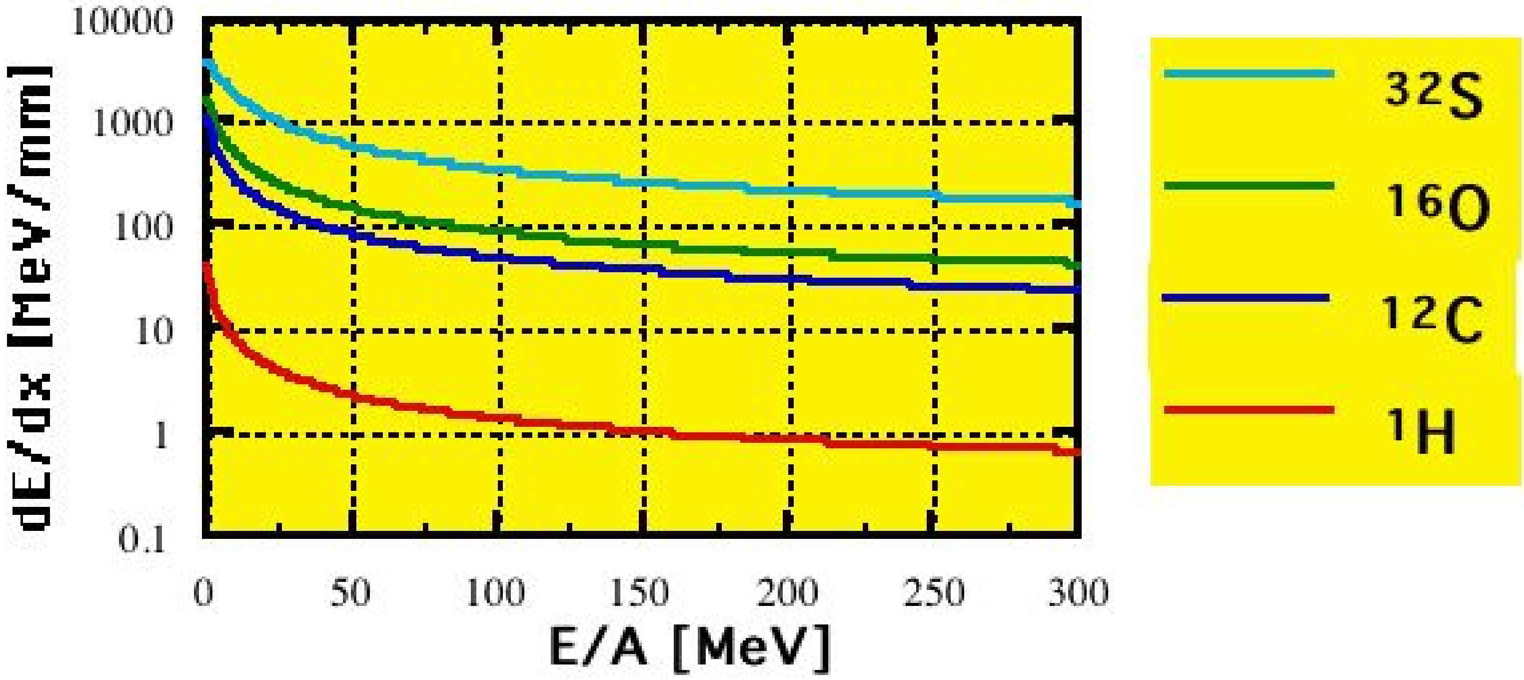
With a silicon detector we are sensitive to the energy released by the ion into the depletion region. The average energy required to create an e/h pair in silicon is 3.62eV: we count the particles per unit time



an $^{16}O^{1+}$ at 1MeV provides a signal charge of 276000 electrons

Problems

- the response is strongly dependent on the beam type and energy: we don't measure anymore the electric current carried by the beam
- the thickness of possible dead layers can introduce a threshold
- radiation damage



Available techniques

- Gas detectors
- Secondary emission (with physical amplification, e.g.: MCP)
- Diamond

🟡

tested at LNS, currently not in use

- Others: Cherenkov, etc.

🔴

investigated, not tested at LNS

- Semiconductors
- Scintillators

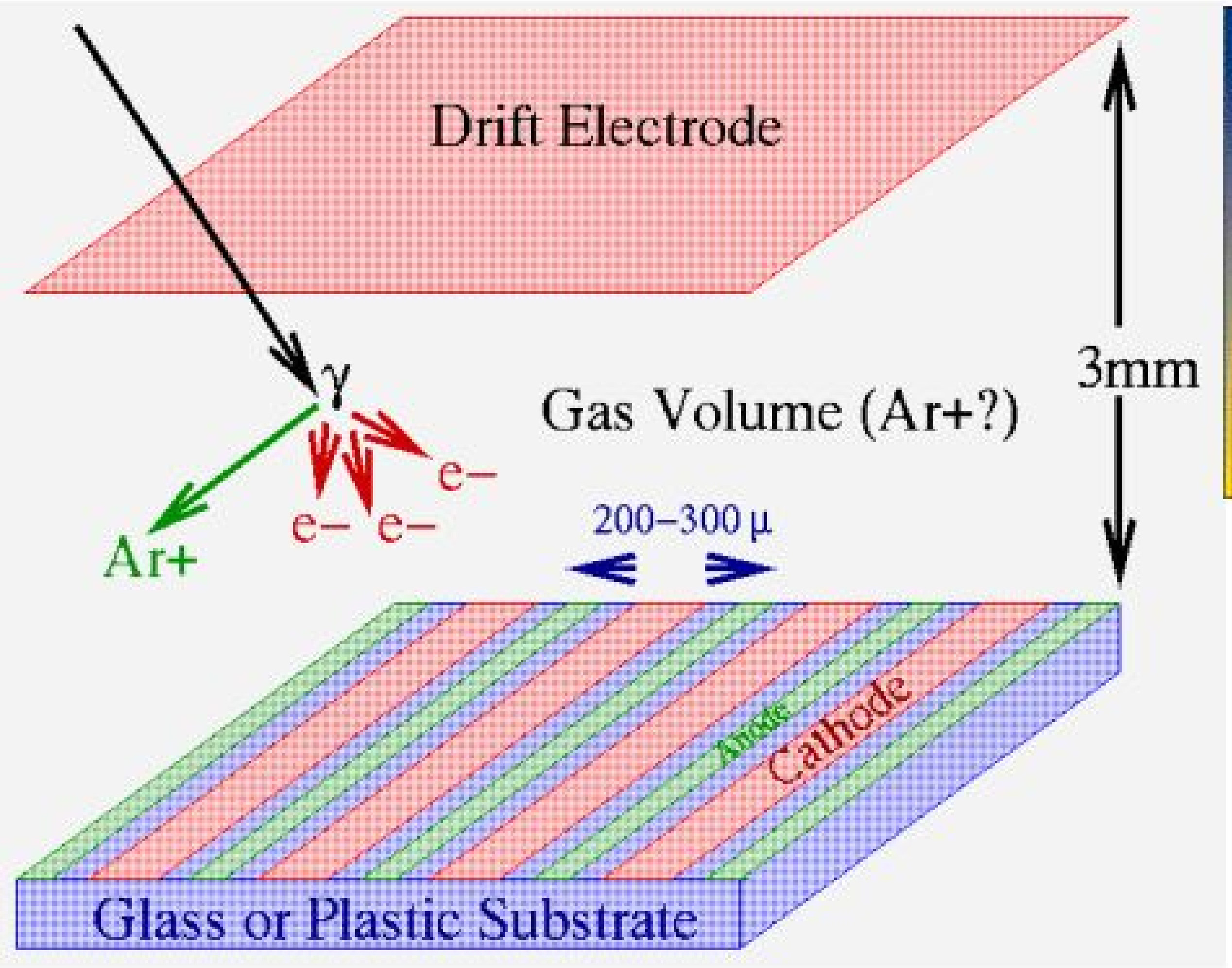
🟢

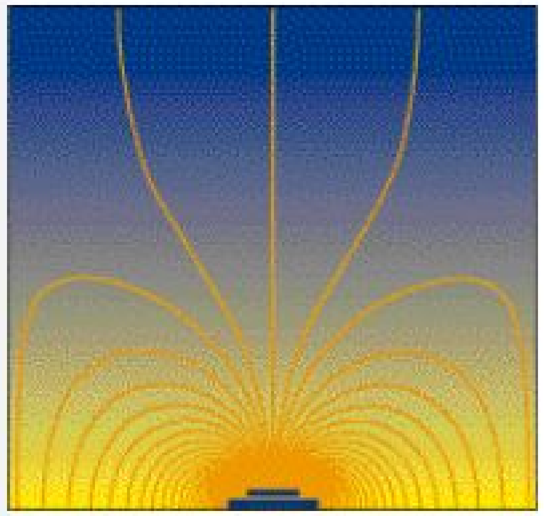
developed, currently in use at LNS

Gas ionization detectors

- signal due to energy loss (with possible charge multiplication)
- ionization chambers: just collection of the produced charge (≈35 eV/ion-pair in air)
- proportional counters: the primary charge is multiplied by a linear multiplication physical process
- avalanche counters: the primary charge is avalanche-multiplied until quenched by suitable mechanisms
- radiation hardness /cost: good
- ease-of-use & reliability: sufficient
- can be used in pulse counting and continuous mode
- suitable for specific applications (e.g. to replace silicon layers for low energy particles)
- needs operational care (gas flow system, stable pressure)

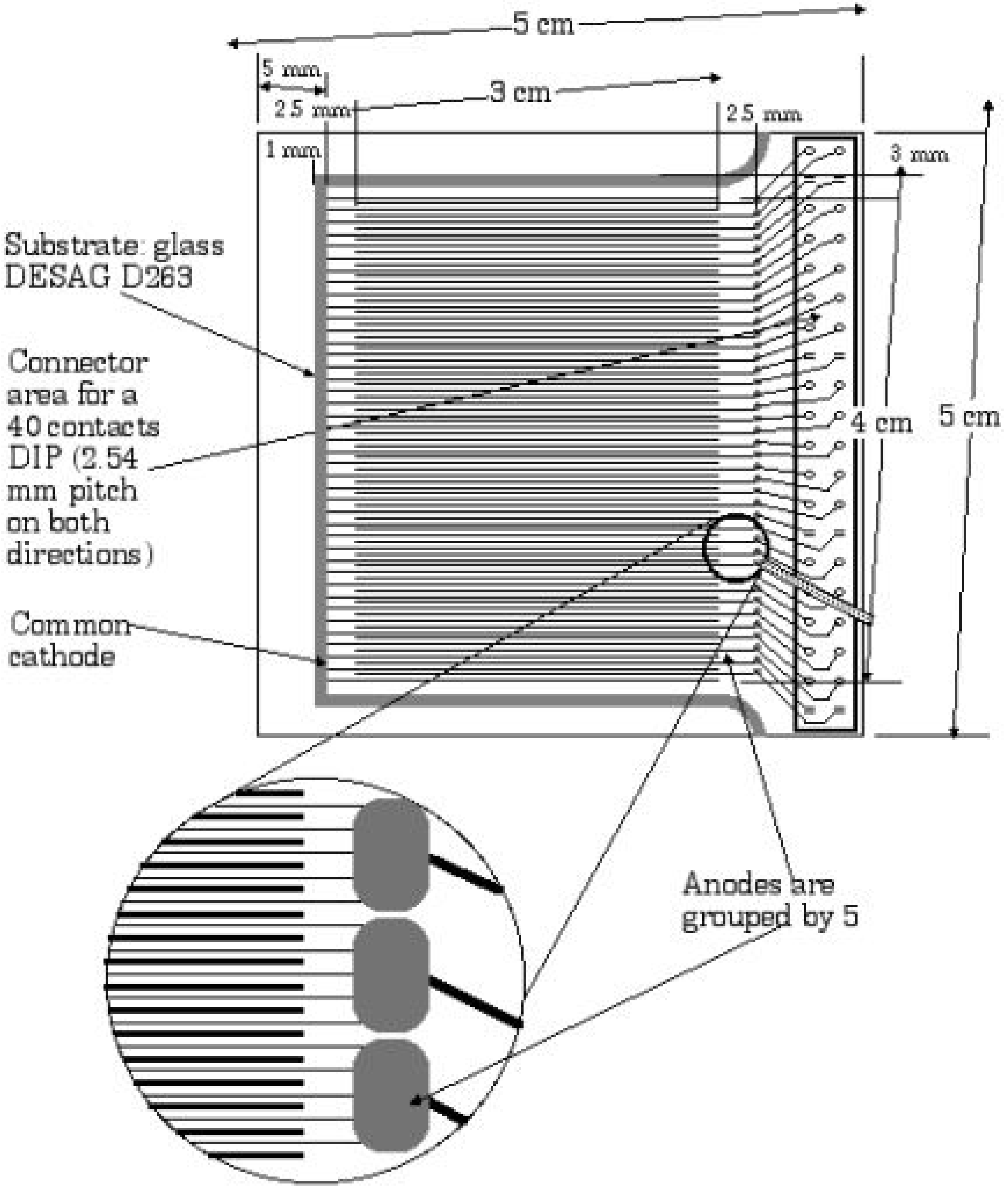
MicroStrip Gas Chamber (MSGC)

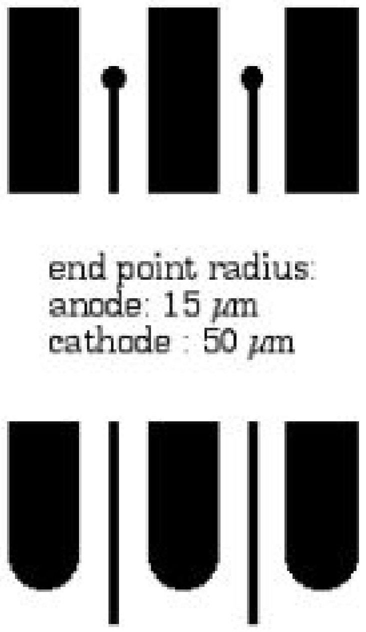




- first built by A.Oed
- F.Sauli et al., CERN; R.Bellazzini et al., INFN Pisa; etc.; particle detector for high energy physics
- very precise (photolithographic process, typically on glass); pitch ≈100-200 µm
- the shape can be chosen quite freely
- the mechanical structure of the detector becomes very simple
- the gas tightness is easy to achieve (e.g.: glue...)
- ease-of-use & reliability: discrete

microstrip plate drawing

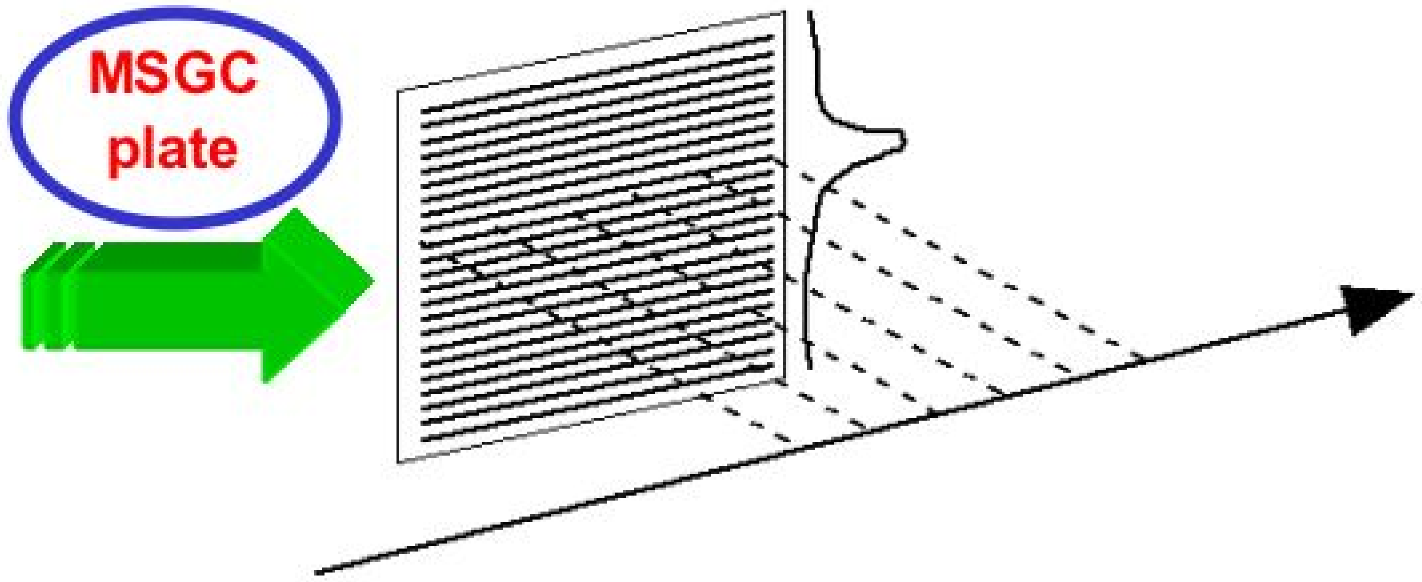




end point radius:
anode: 15 µm
cathode : 50 µm

MOLIBDE
MSGC plate SCALE 2:1
INFN - LNS

Anode width = 10 µm
Cathode width = 100 µm
Anode/cathode distance = 45 µm
Pitch = 200 µm
Substrate size = 50x50x0.5 mm^3
Strips: 0.15 µm thick chromium



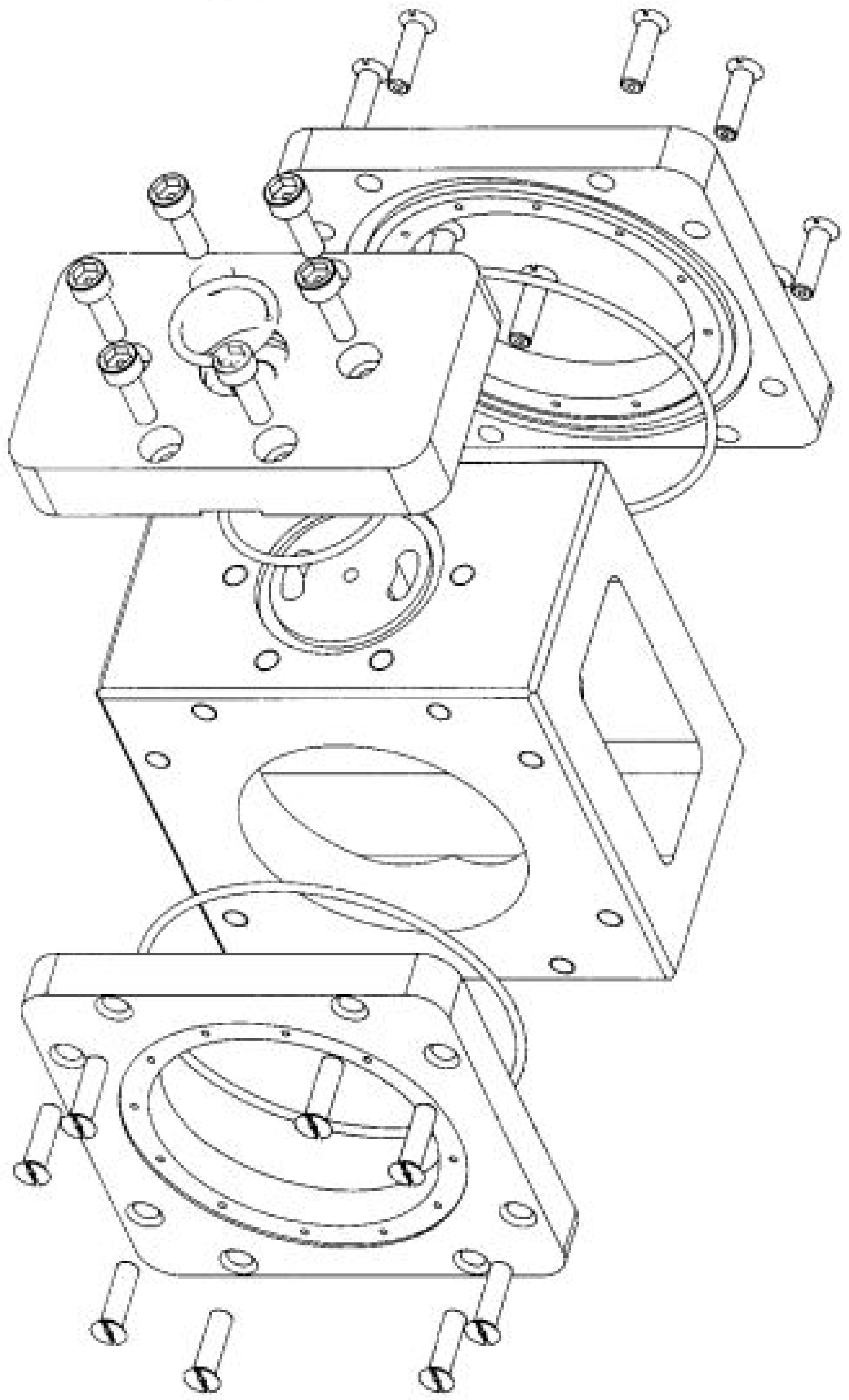
MicroStrip MOLIBDE Chamber

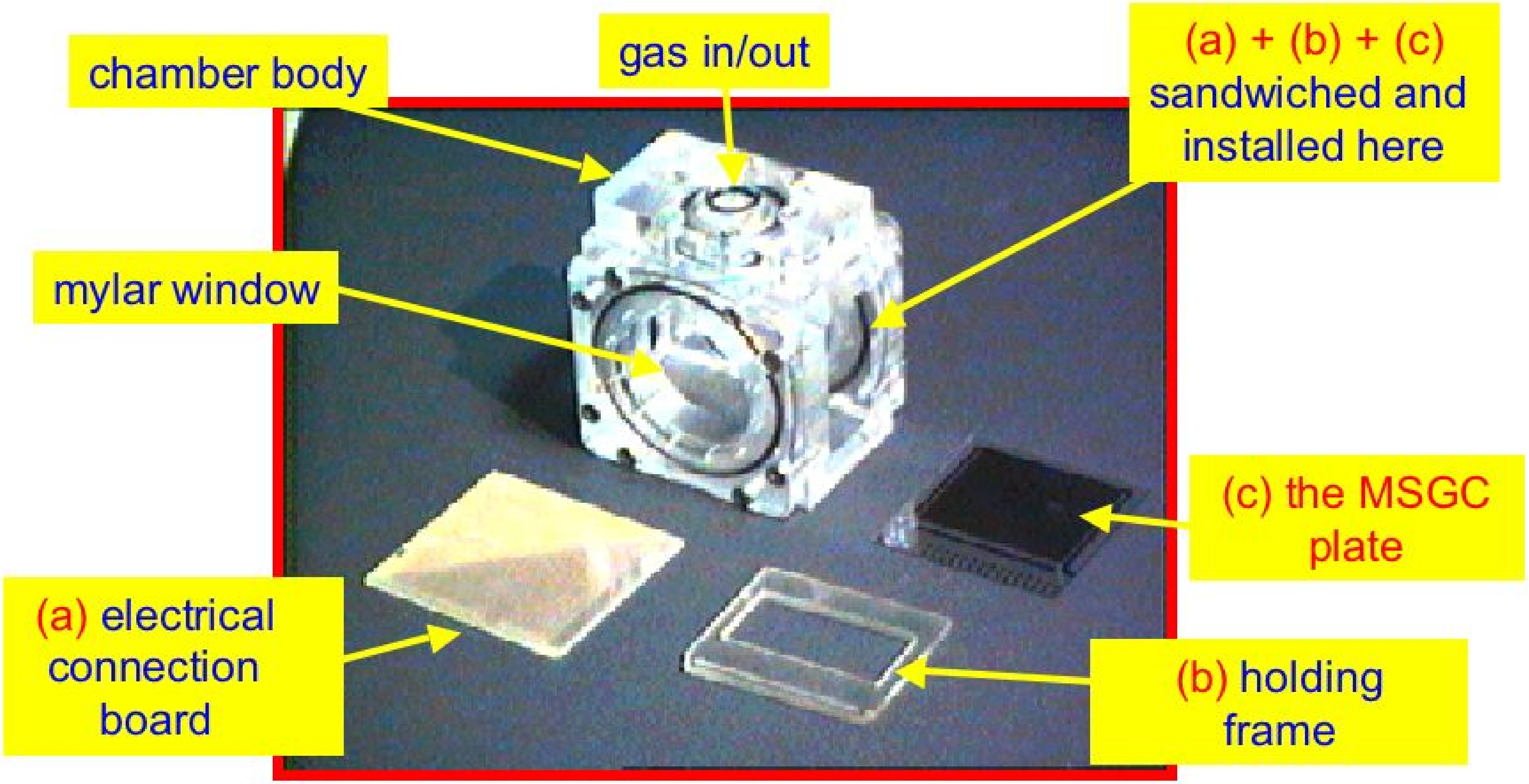
Microstrip Online Low Intensity Beam DEtector

operated in low-pressure nitrogen

just ionization current reading

built and tested at LNS




chamber body

gas in/out

(a) + (b) + (c) sandwiched and installed here

mylar window

(c) the MSGC plate

(a) electrical connection board

(b) holding frame

MicroStrip MOLIBDE Chamber

operated in nitrogen @50mbar

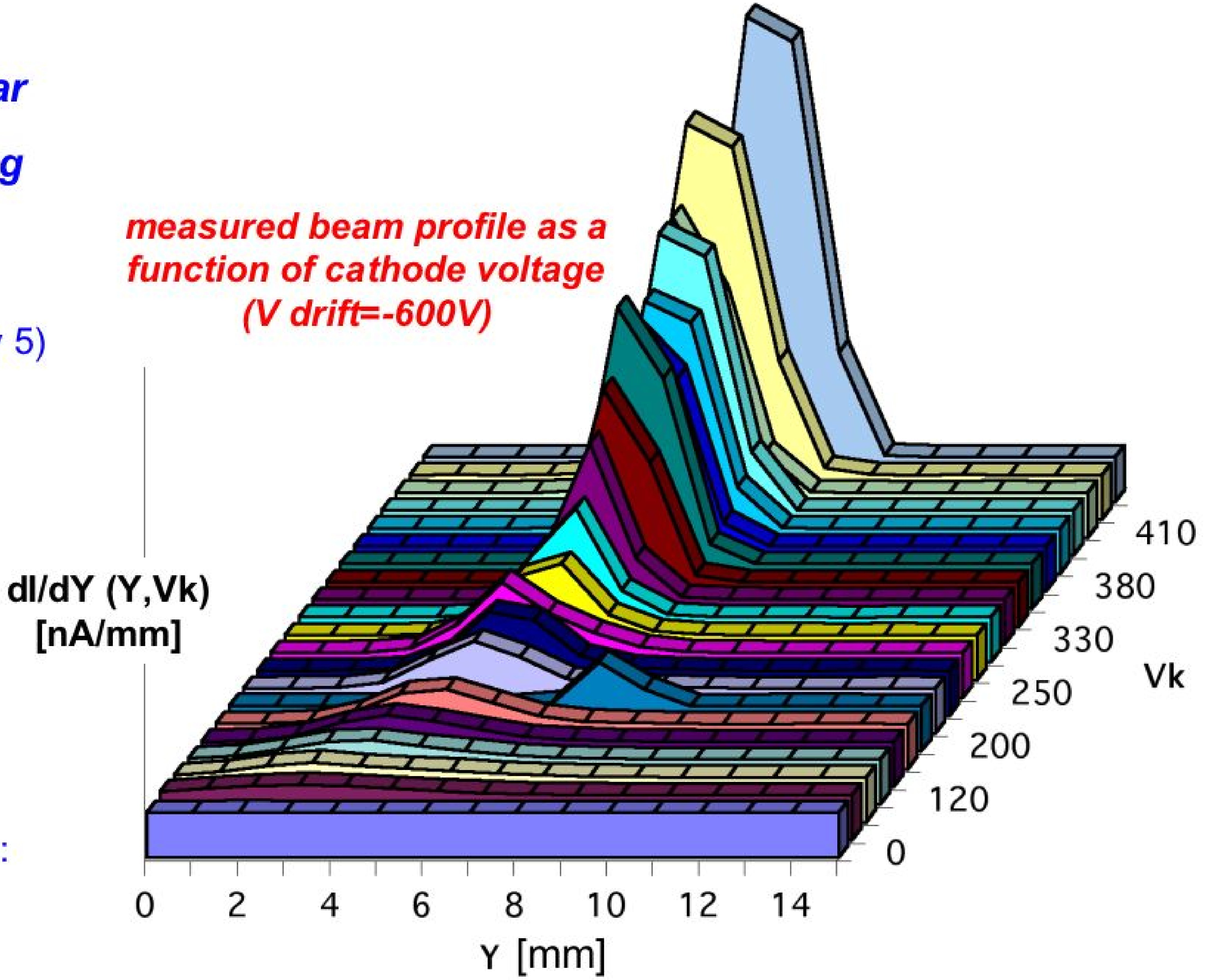
just ionization current reading

Strip pitch:	0.2 mm
Actual pitch:	1 mm (grouped by 5)
Measured width:	0.6 mm (sigma)
	1.4 mm (FWHM)

Beam:	^{12}C
Energy:	87 MeV
Intensity:	10±2 pA
	10^7 pps

Min. sensitivity: 10^4 pps
(in this configuration)
Max. sustainable rate in pulse mode:
10^5 pps

measured beam profile as a function of cathode voltage (V drift=-600V)



Residual gas + MicroChannel Plate: readout by electrodes

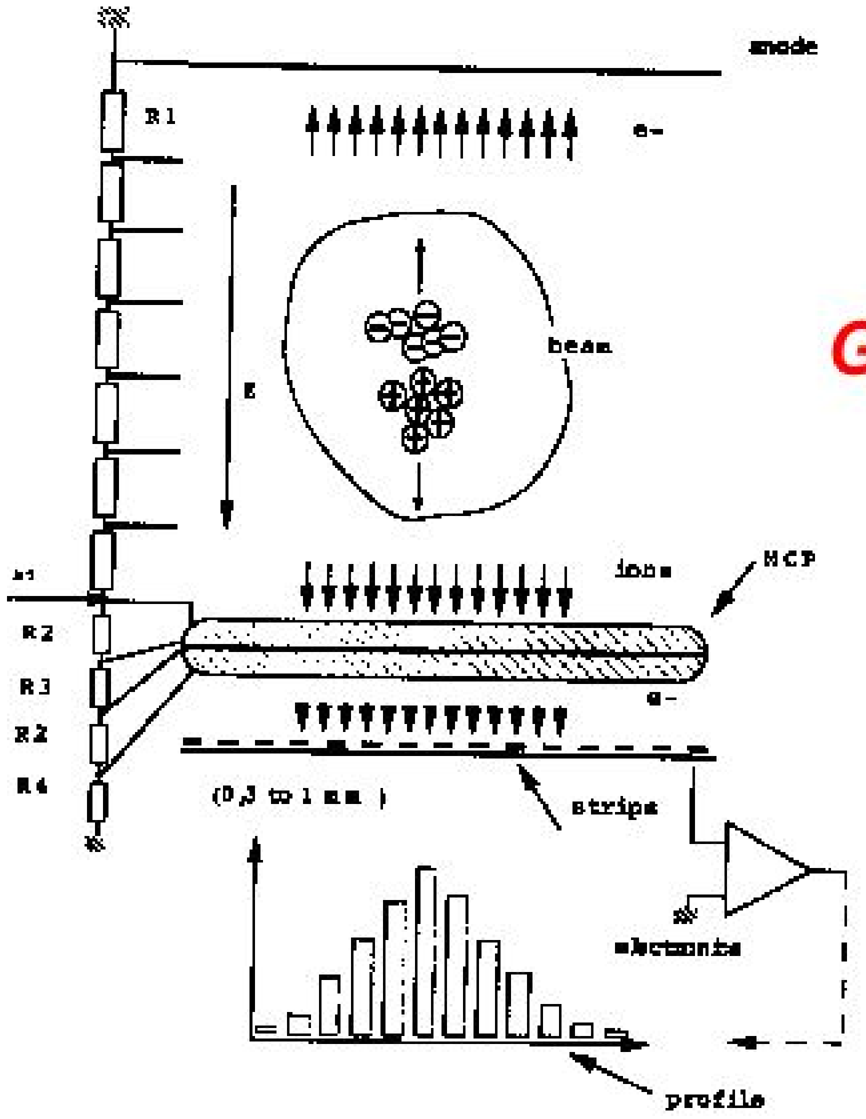
every now and then a beam particle ionizes a molecule of the residual gas inside the beam pipe

pioneering systems developed at GSI and GANIL years ago...

this technique is not suitable for very-low intensity beams

unless...

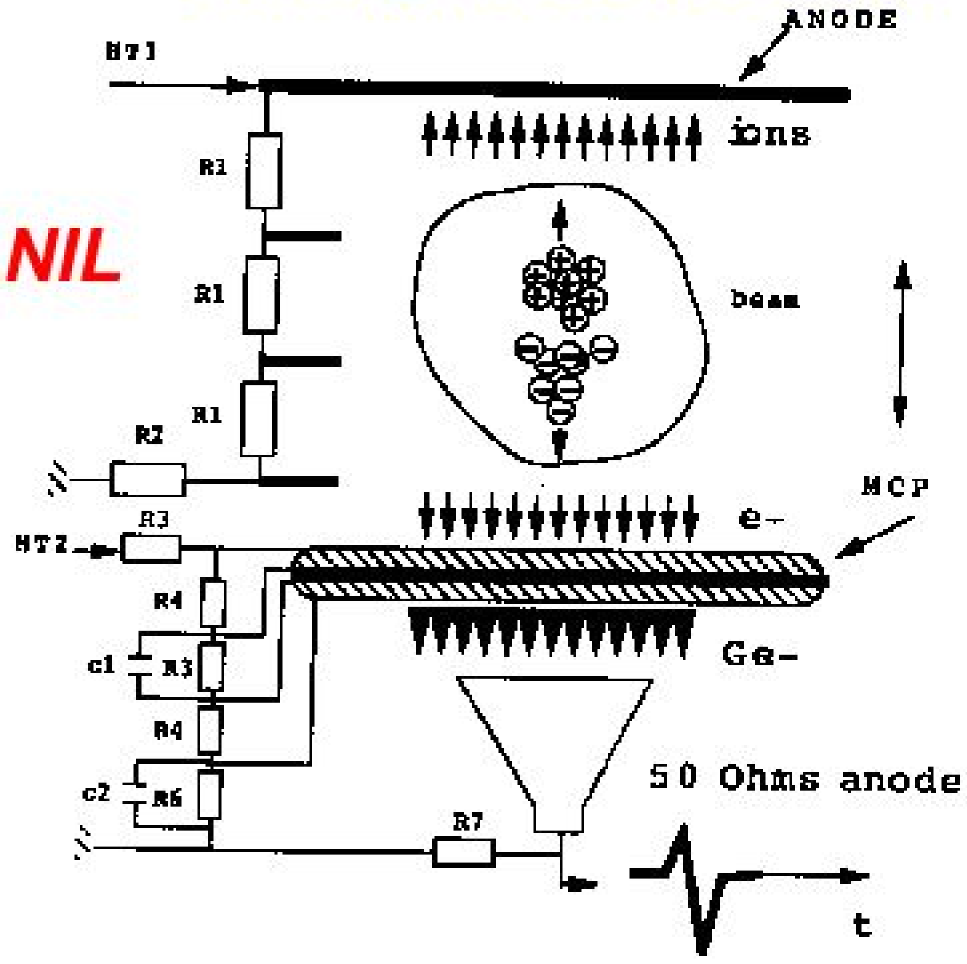
...one employs a beam pipe section with higher pressure



profile measurement

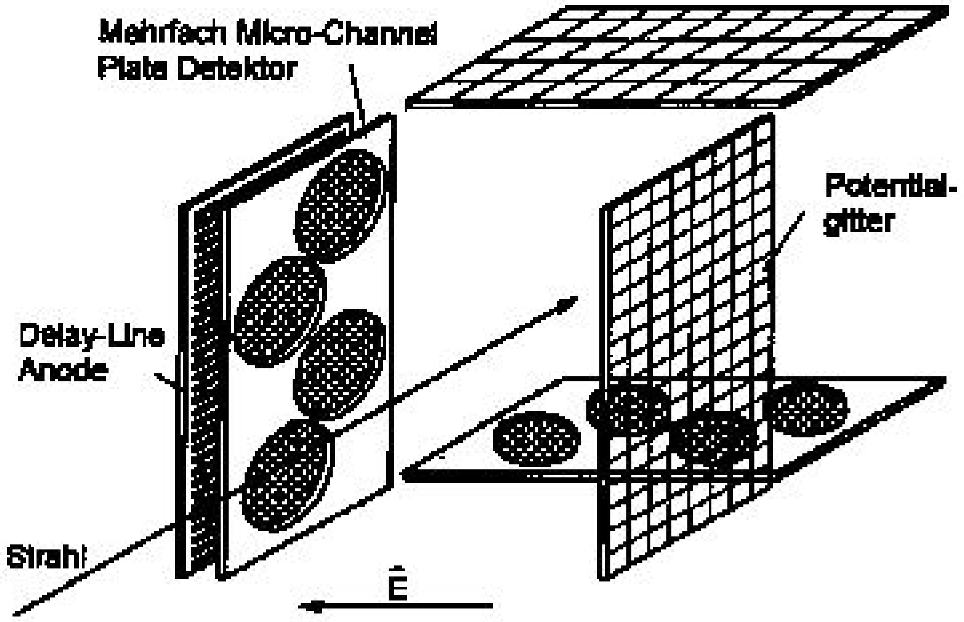
GANIL

timing measurement

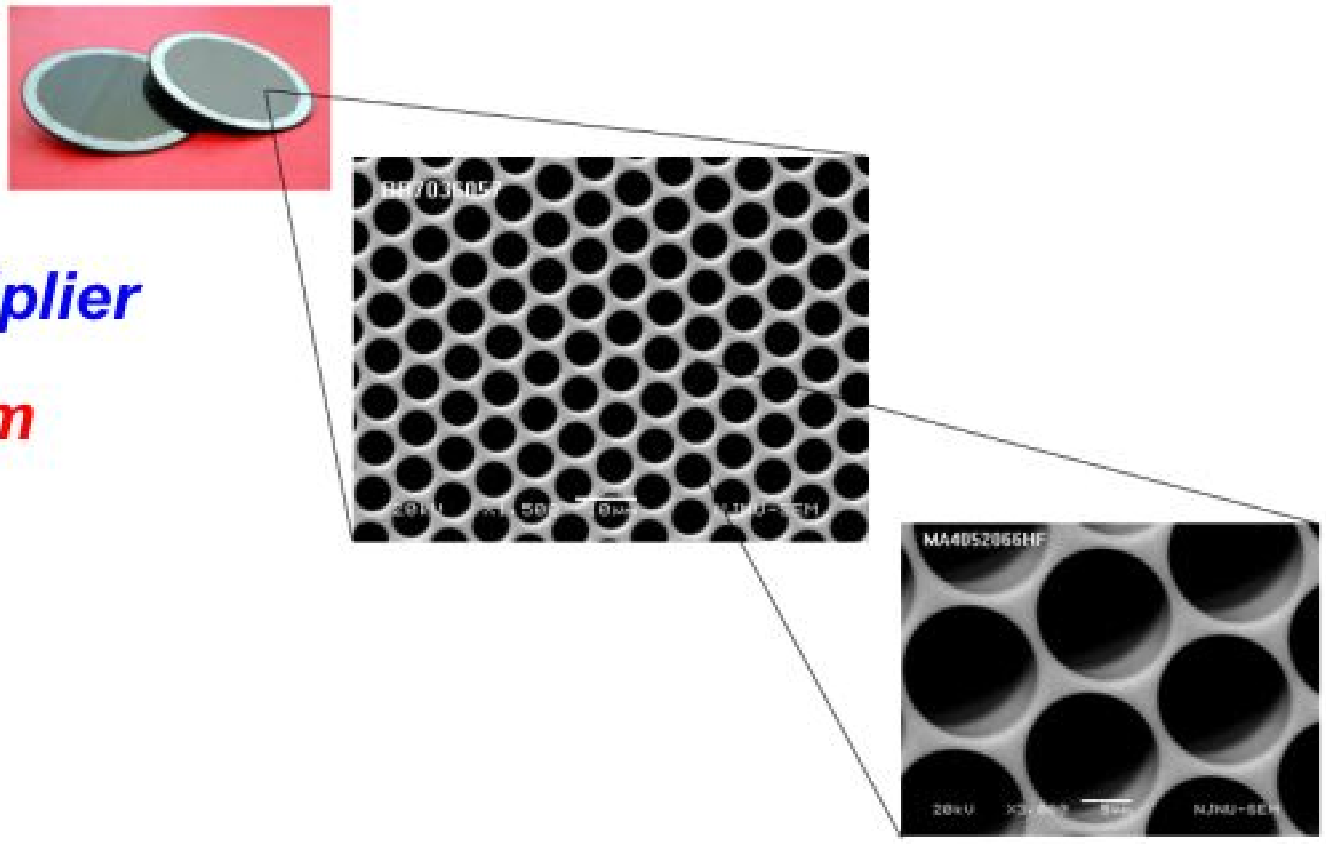


GSI

profile measurement



What is a MicroChannel Plate?



it is a mesh of photocathodic microchannels

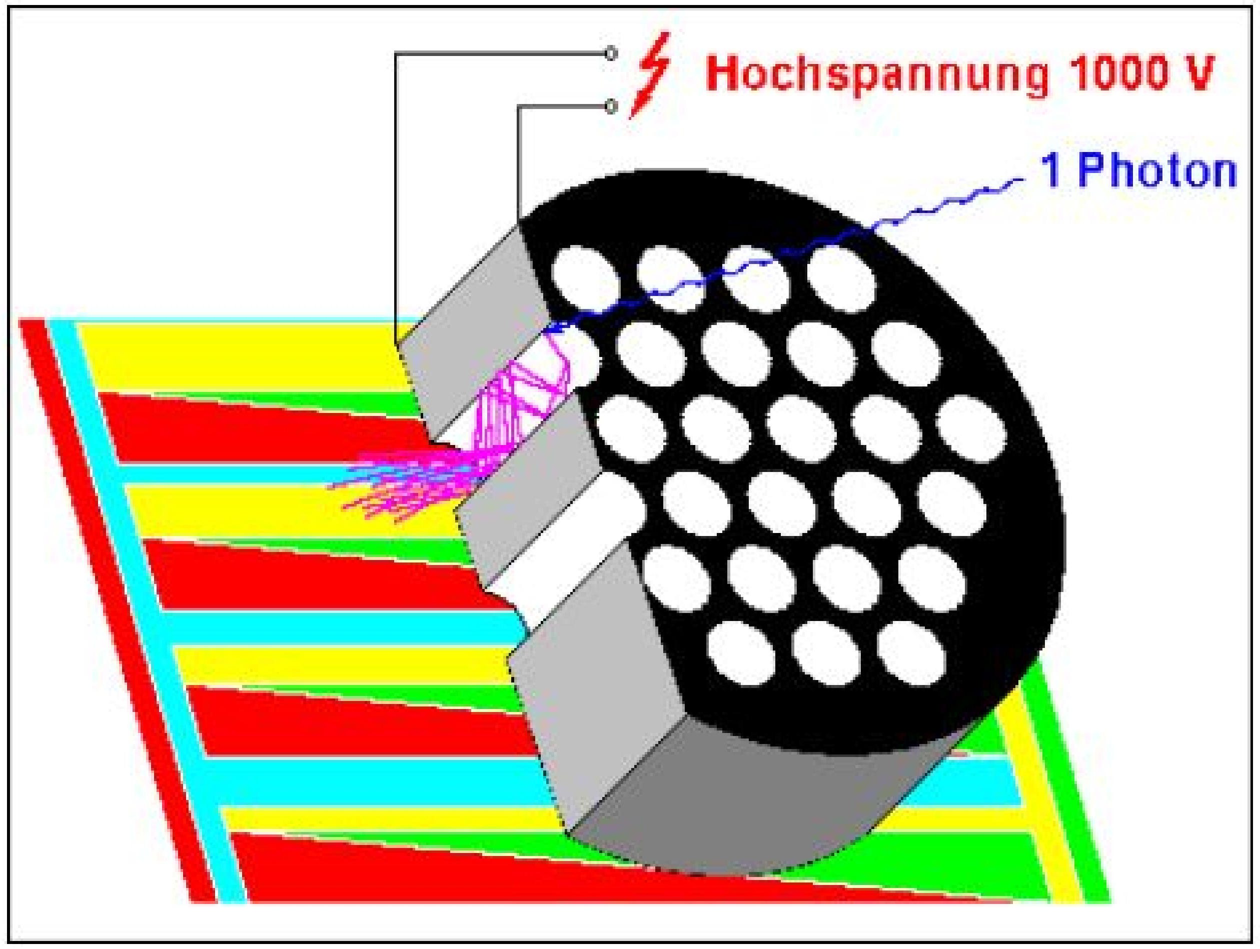
each channel is a microscopic continuous electron multiplier

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

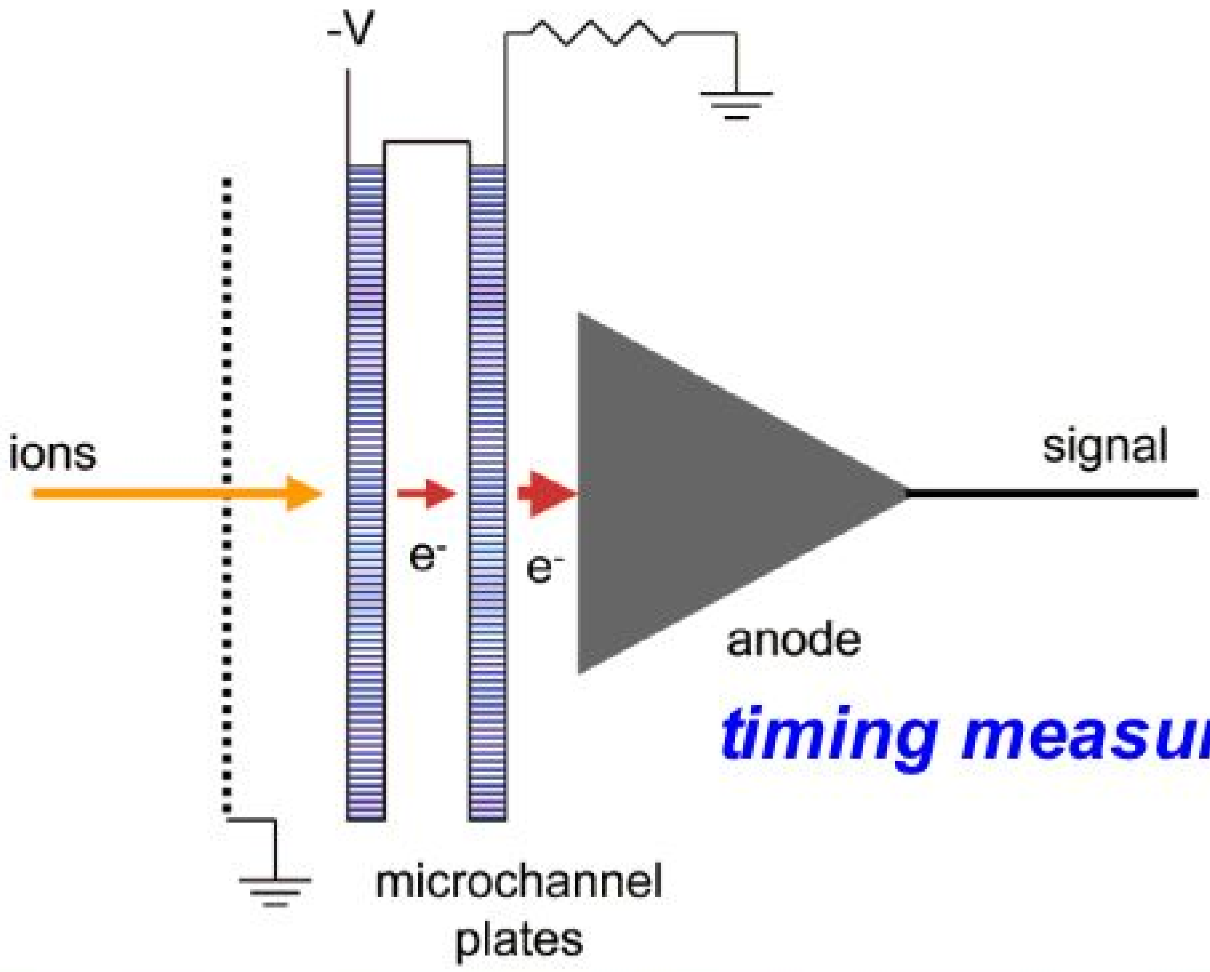
rather delicate and quite expensive

sensitive to photons, electrons, ions

best timing (even below 100ps)



profile measurement



timing measurement

Residual gas + MicroChannel Plate: imaging

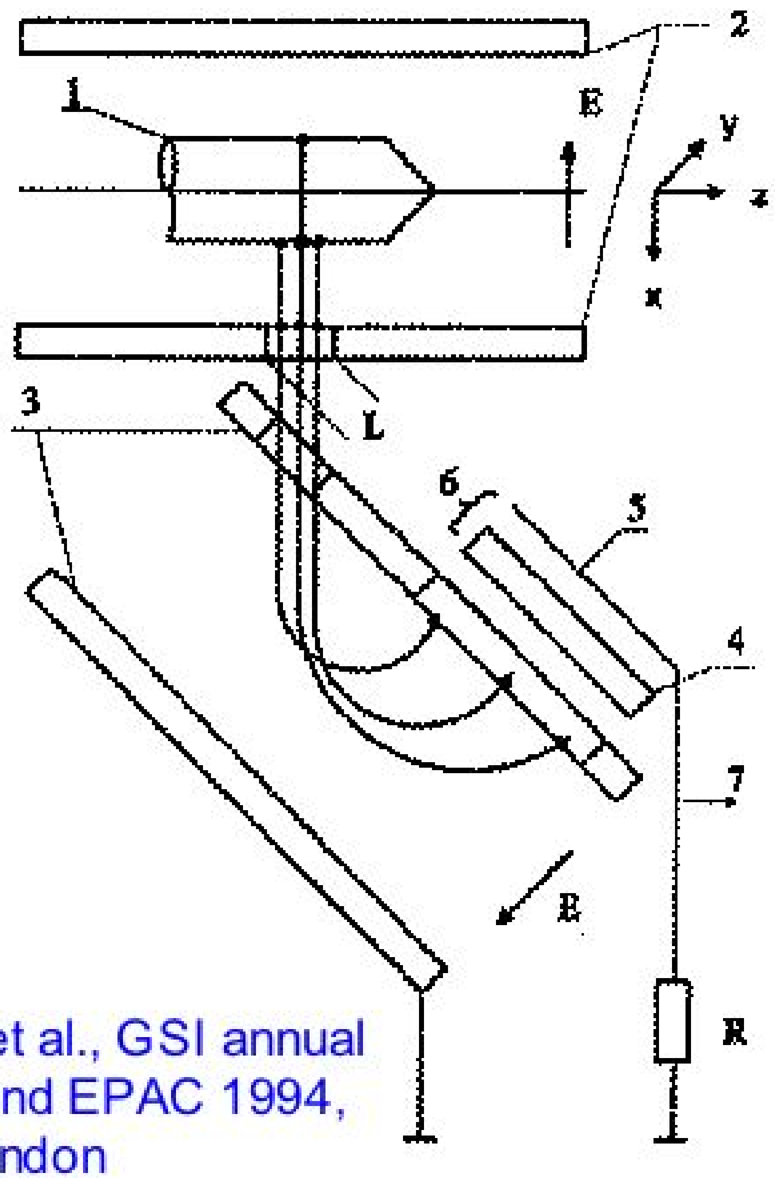
this technique is not suitable for very-low intensity beams

unless...

...one employs a beam pipe section with higher pressure

2D profile, sensitivity limit 10^9 pps

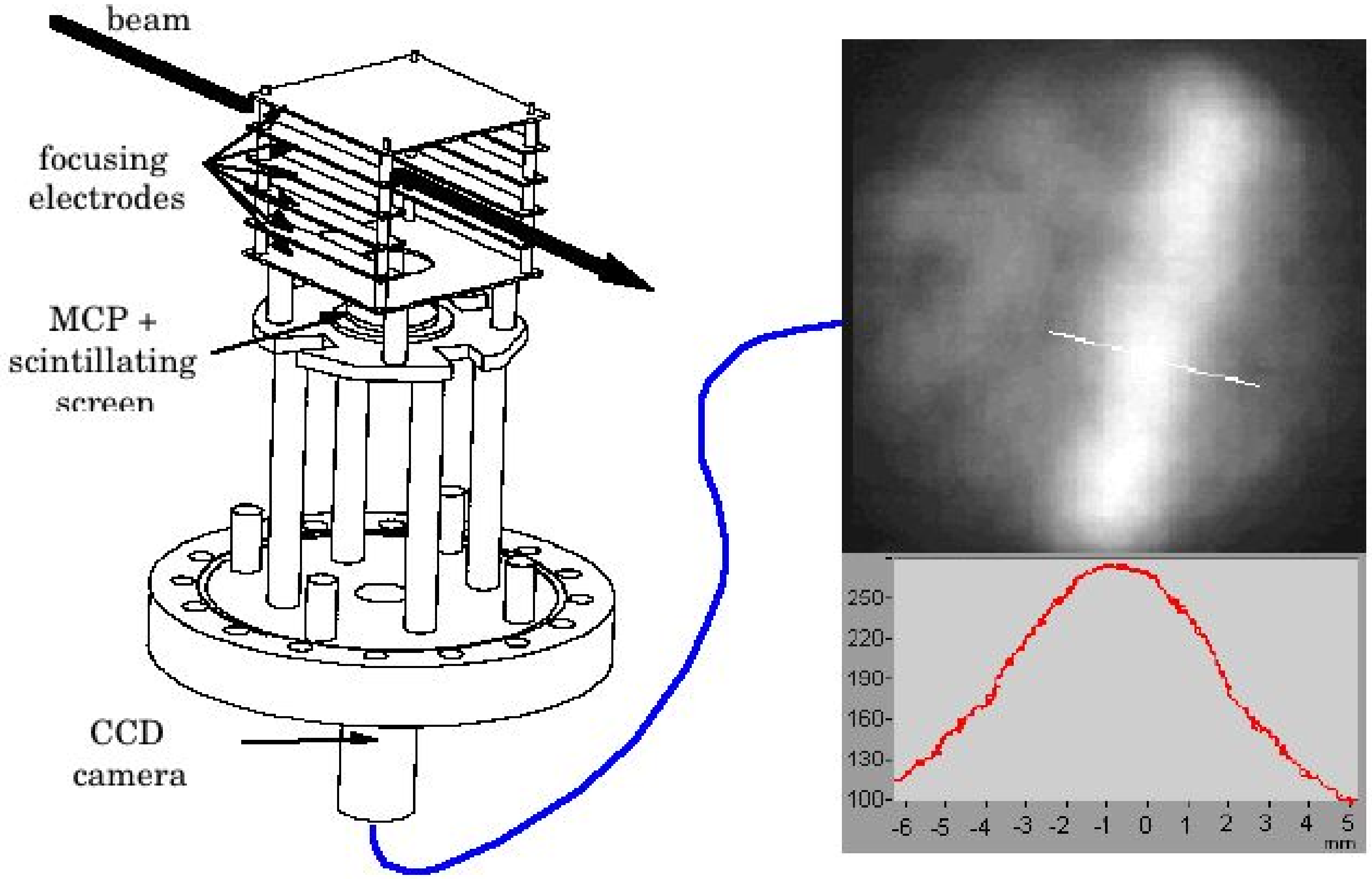
harp-based electron mirror for 2D imaging



V.G.Mihailov et al., GSI annual report 1995 and EPAC 1994, London

1D profile, sensitivity limit 10^8 pps

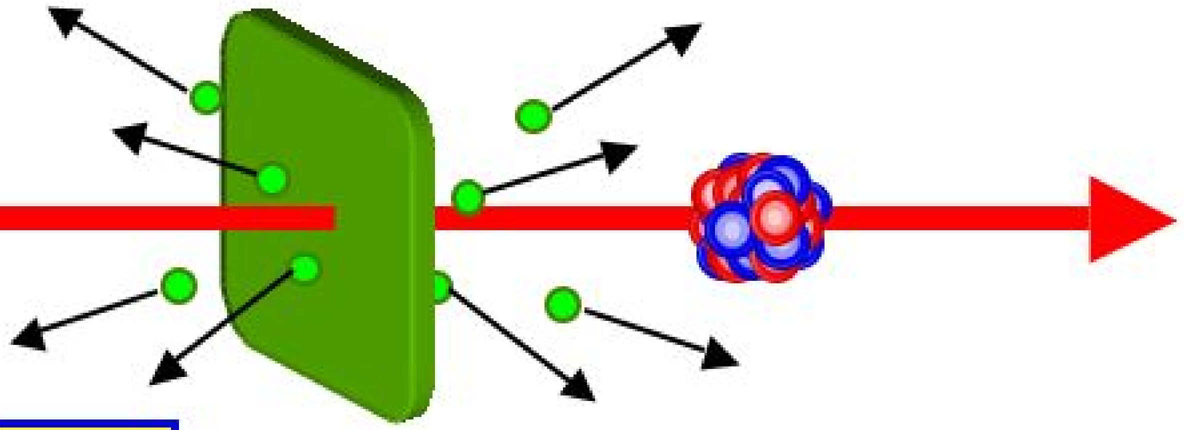
MCP + scintillator + CCD 1D-imaging



built and tested at LNS (1996)

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

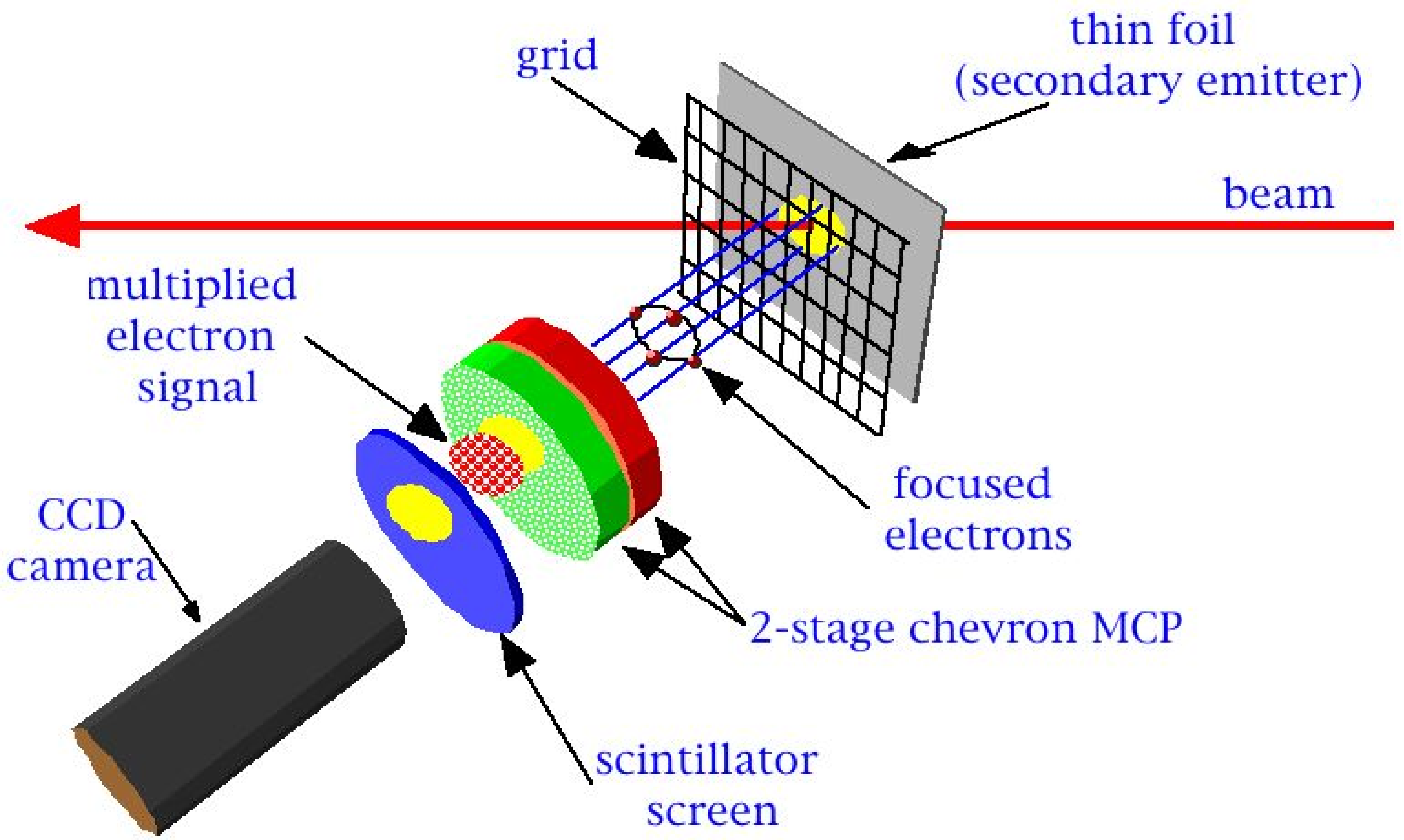
Ion	E [MeV]	<n> electrons
^{4}He	3.5	8.1
	6.1	5.5
	8.8	3.9
^{16}O	1.8	43
	2.8	50
	5.7	55
	9.6	53
	19.6	45
	29.5	40

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

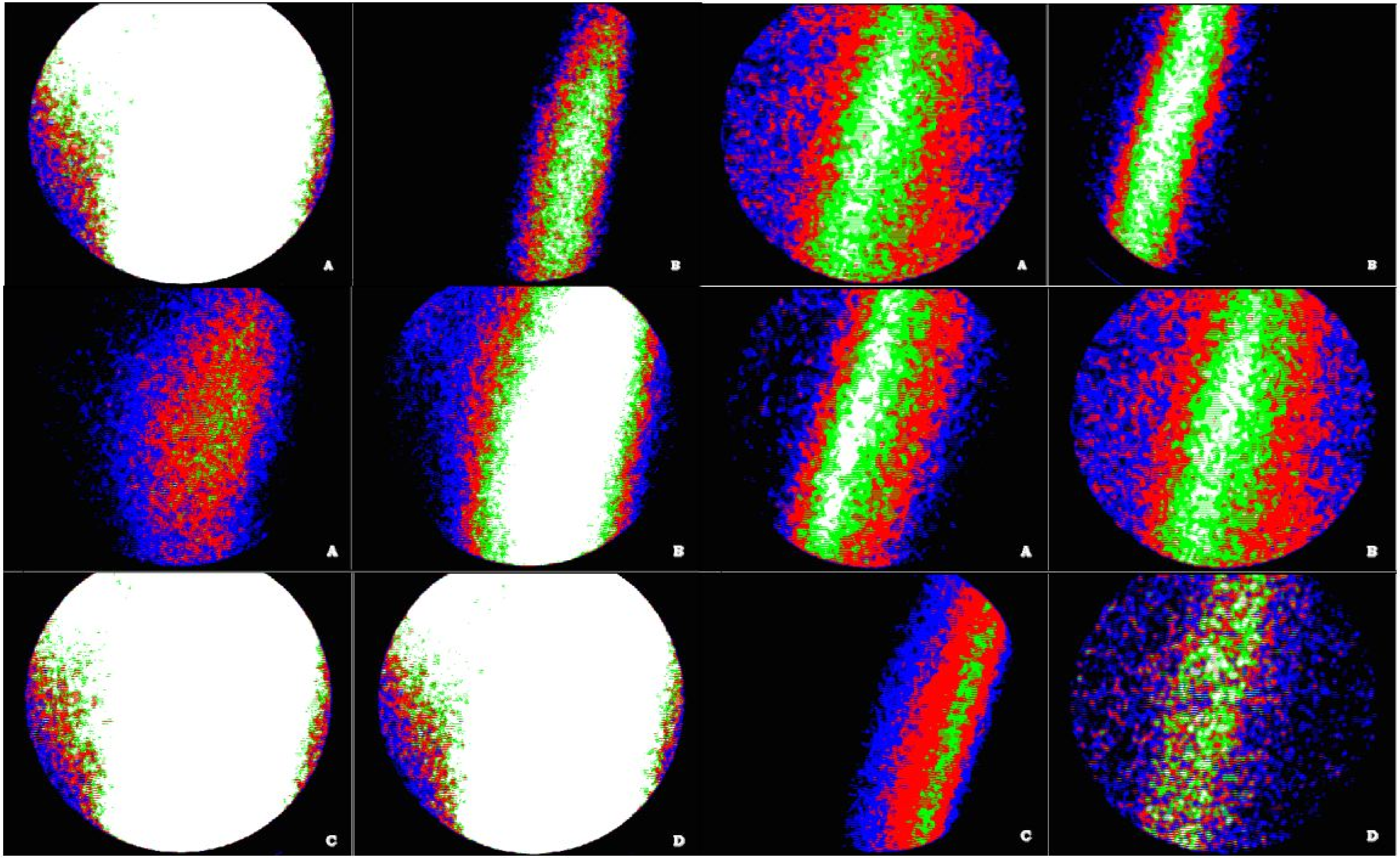
2D-imaging secondary emission detectors

built and tested at LNS



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

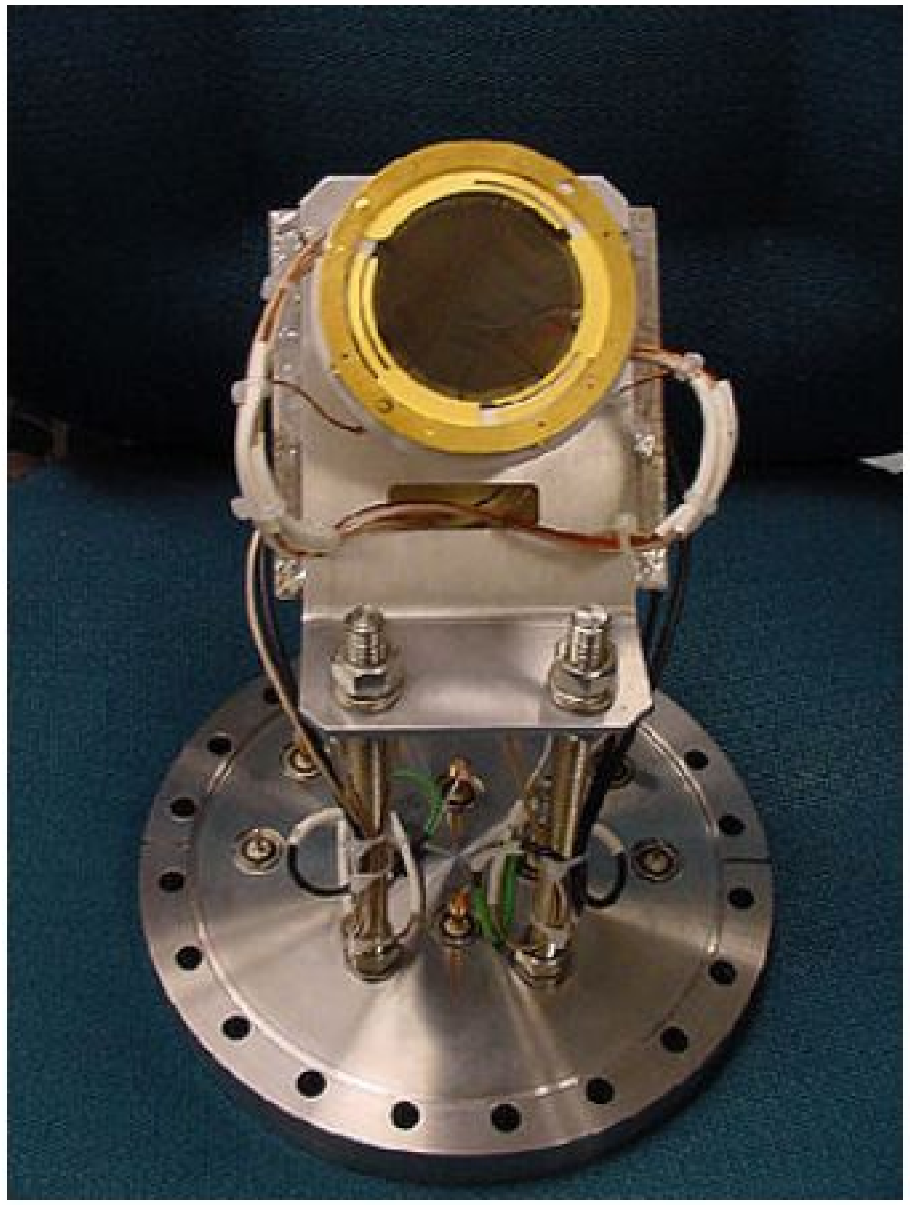
2D-imaging secondary emission detectors: sample images



Secondary emission detectors

and

MicroChannel Plates



Several systems built and installed at LNS:

L.Calabretta

A.Cunsolo

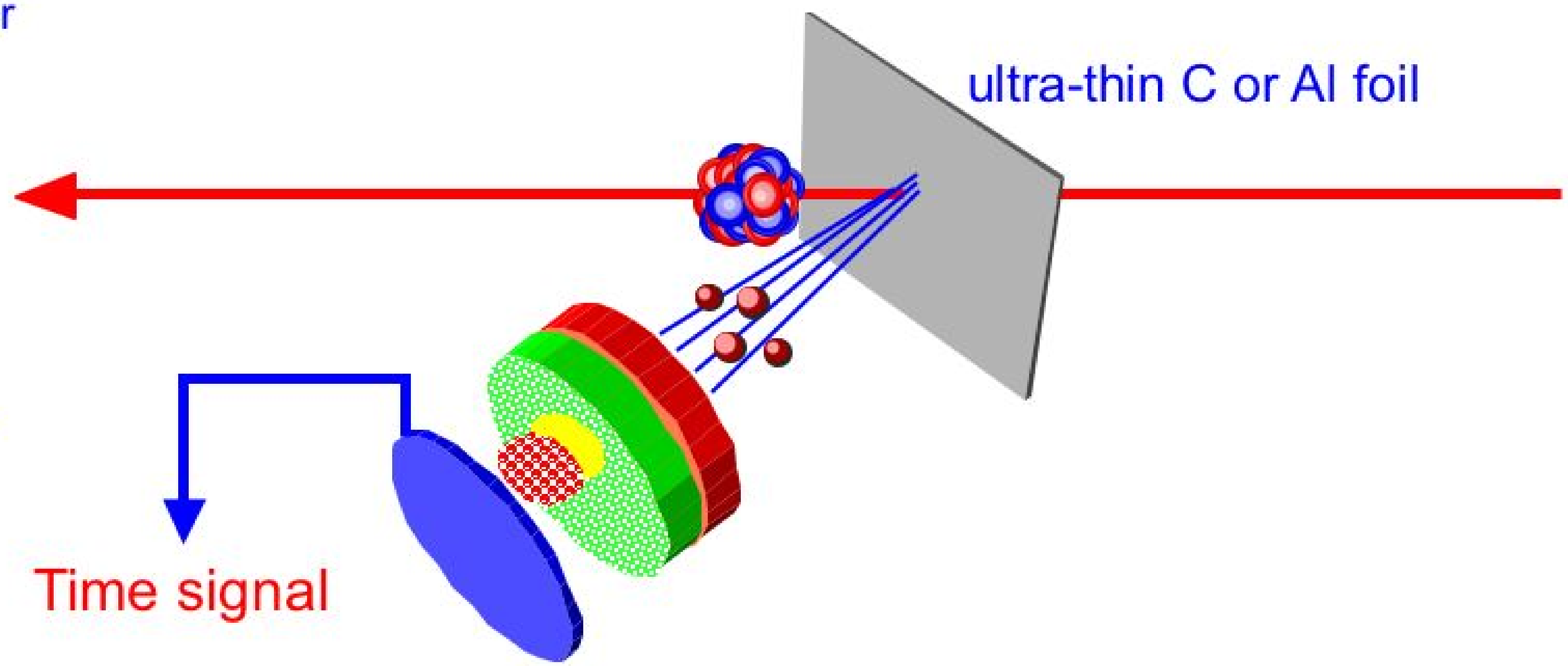
A.Musumarra

S.Cavallaro

....

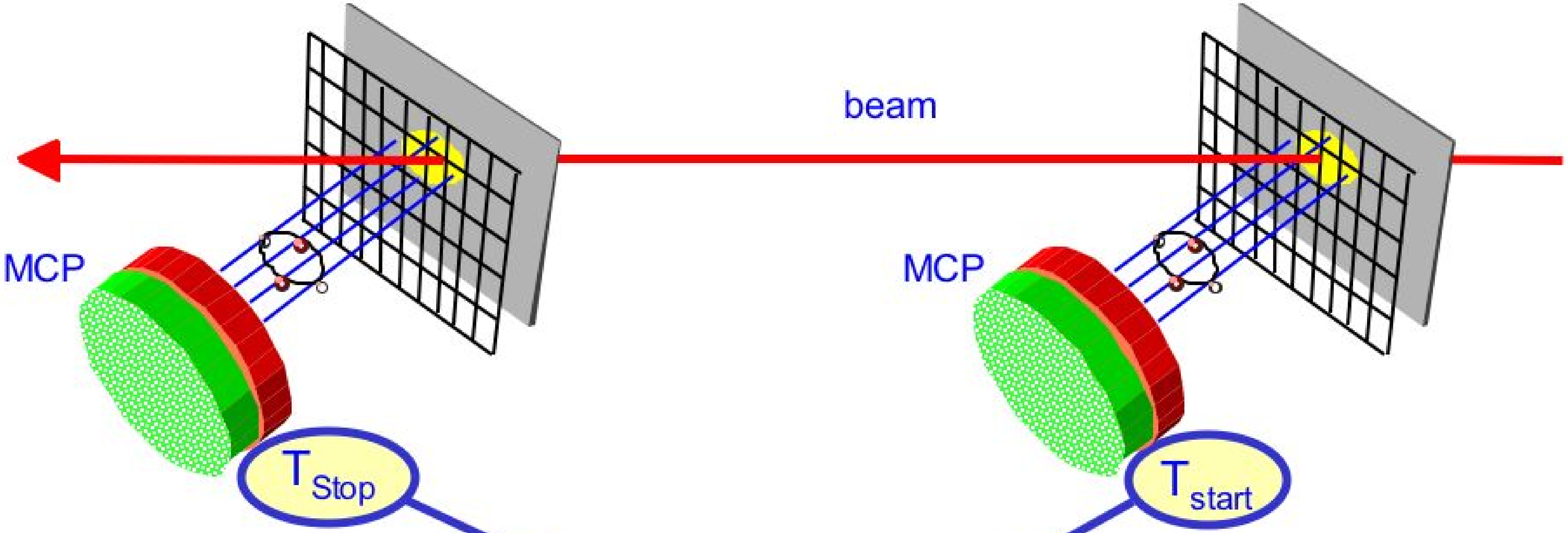
well known technique so far used for time of flight measurement in heavy ion physics:

- H.G.Clerc, NIM 113(1973)325-331;
- J.P.Coffin, P.Engelstein, TOF systems for heavy ions, Bromley vol.7 p.292;
- J.Girard, M.Bolore, NIM 140(1977)279;
- F.Busch et al., NIM 171(1980)71;
- G.D'Erasmo et al.., NIM A234(1985)91;
- W.Starzecki et al., NIM 193(1982)499;
- A.M.Zebelman et al., NIM 141 (1977)439;
- T.Odenweller et al., NIM 198(1982)263;

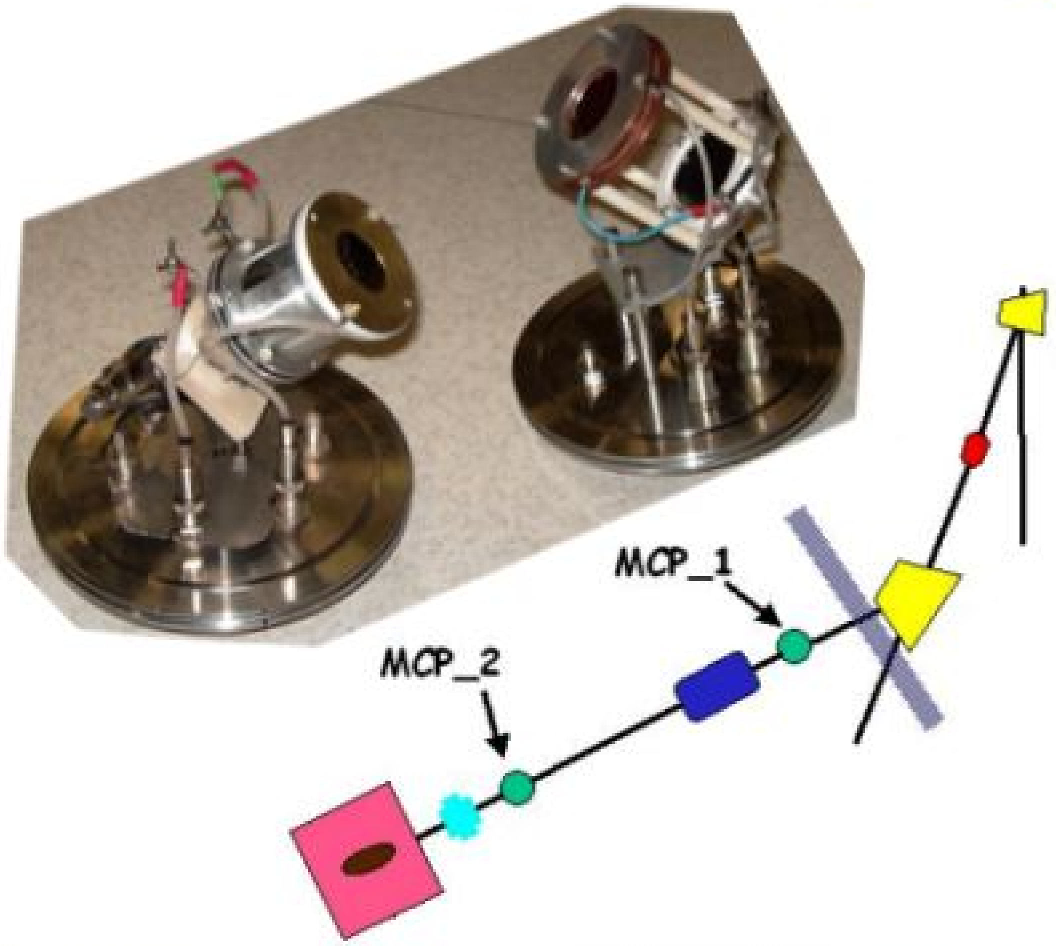


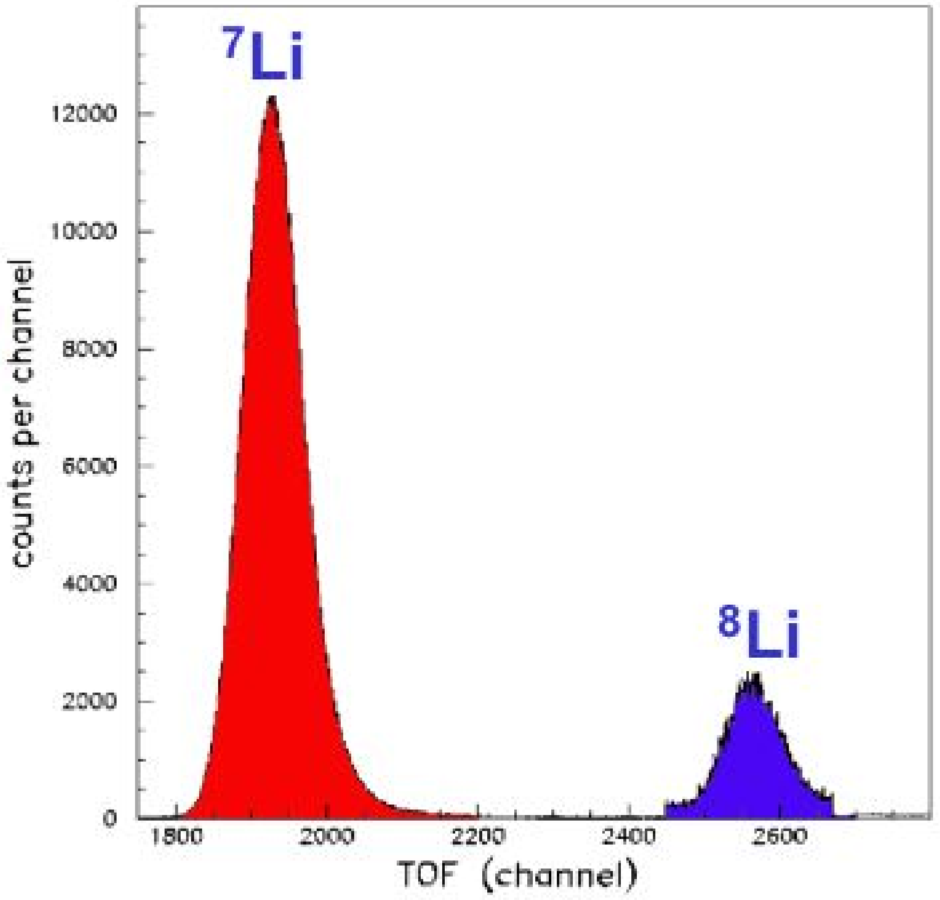
Secondary emission detectors and MicroChannel Plates

In-flight production of ^{8}Li via ^{7}Li(d,p)^{8}Li reaction
beam identification/tagging



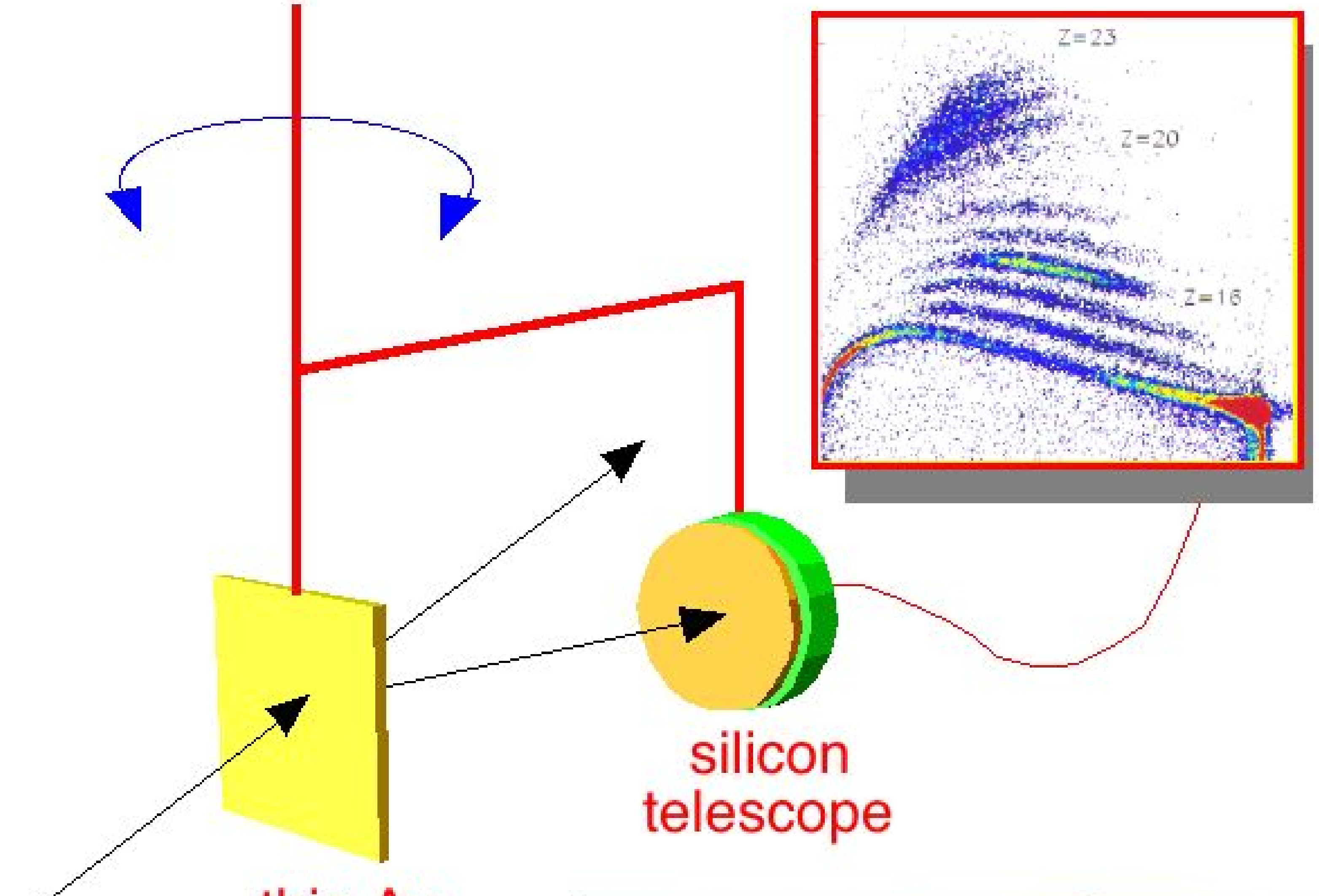
$$\mathrm{TOF} \propto \sqrt{A}$$



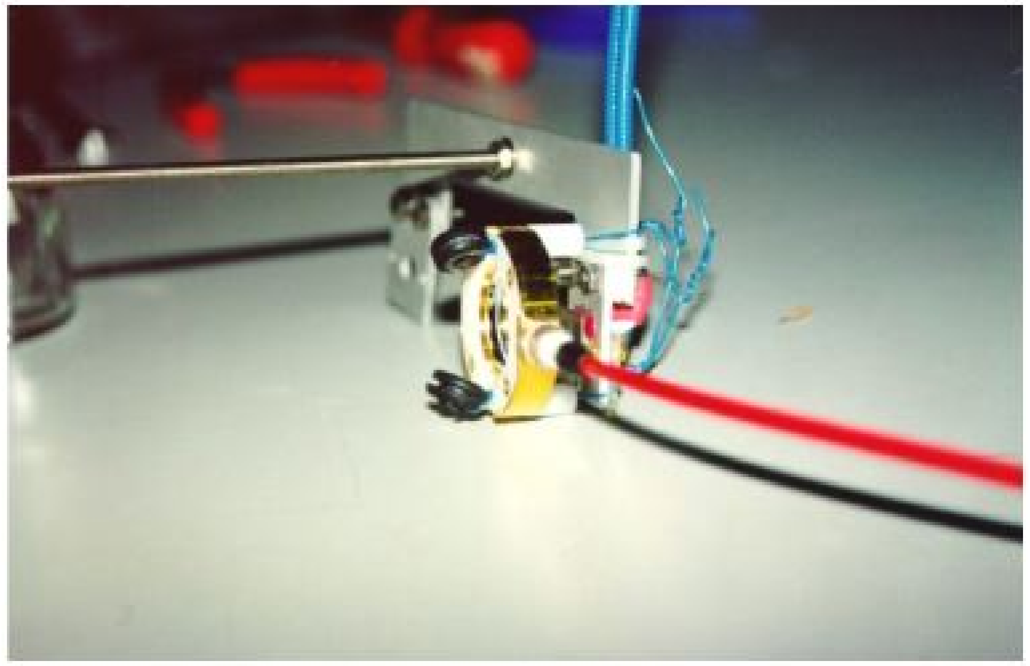


Semiconductors: silicon detectors

telescope for RIB identification



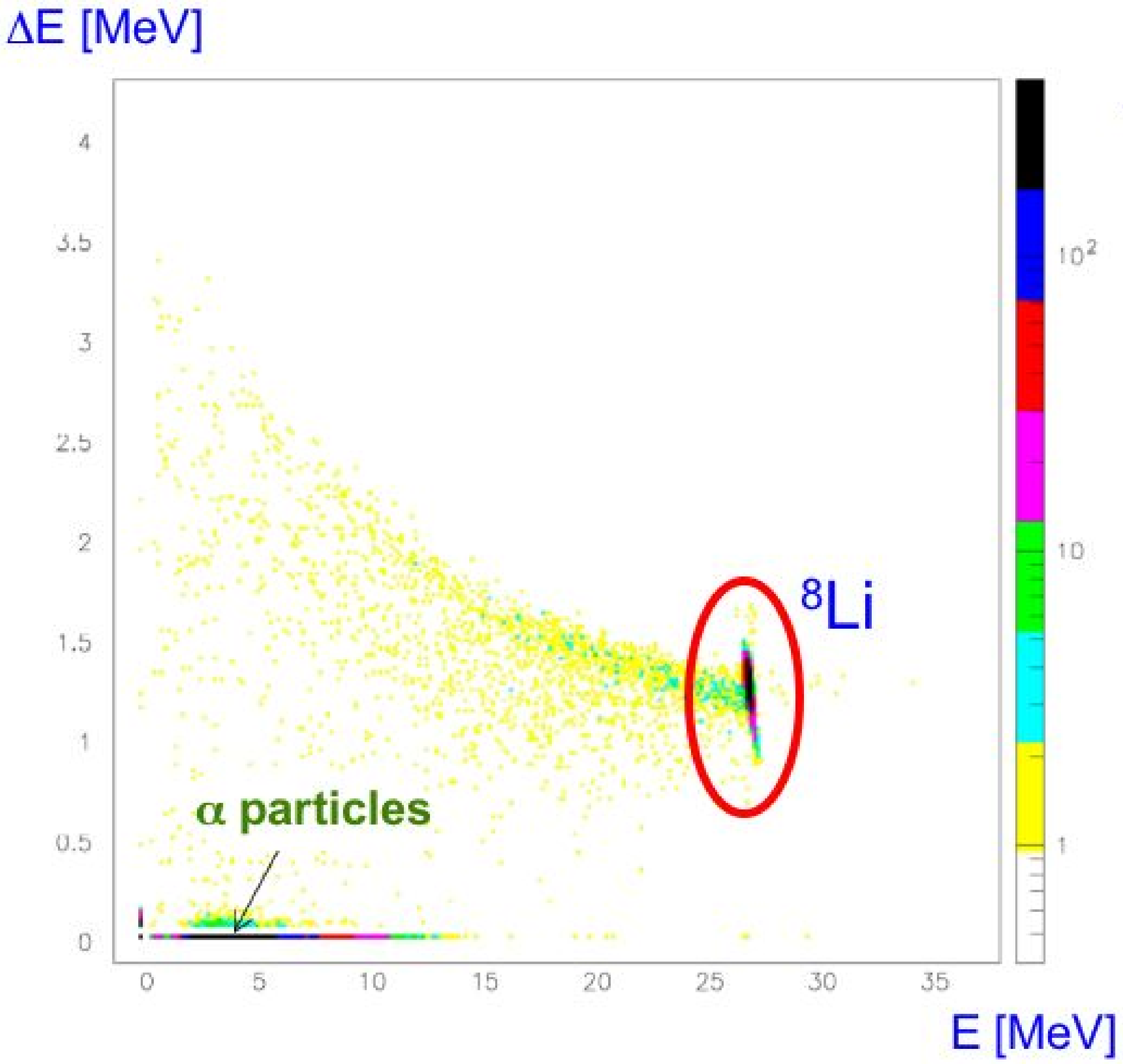
- signal due to energy loss: Bethe & Bloch...
- average energy to produce an e/h pair: 3.62 eV
- radiation hardness /cost: low
- ease-of-use & reliability: sufficient
- suitable for specific applications

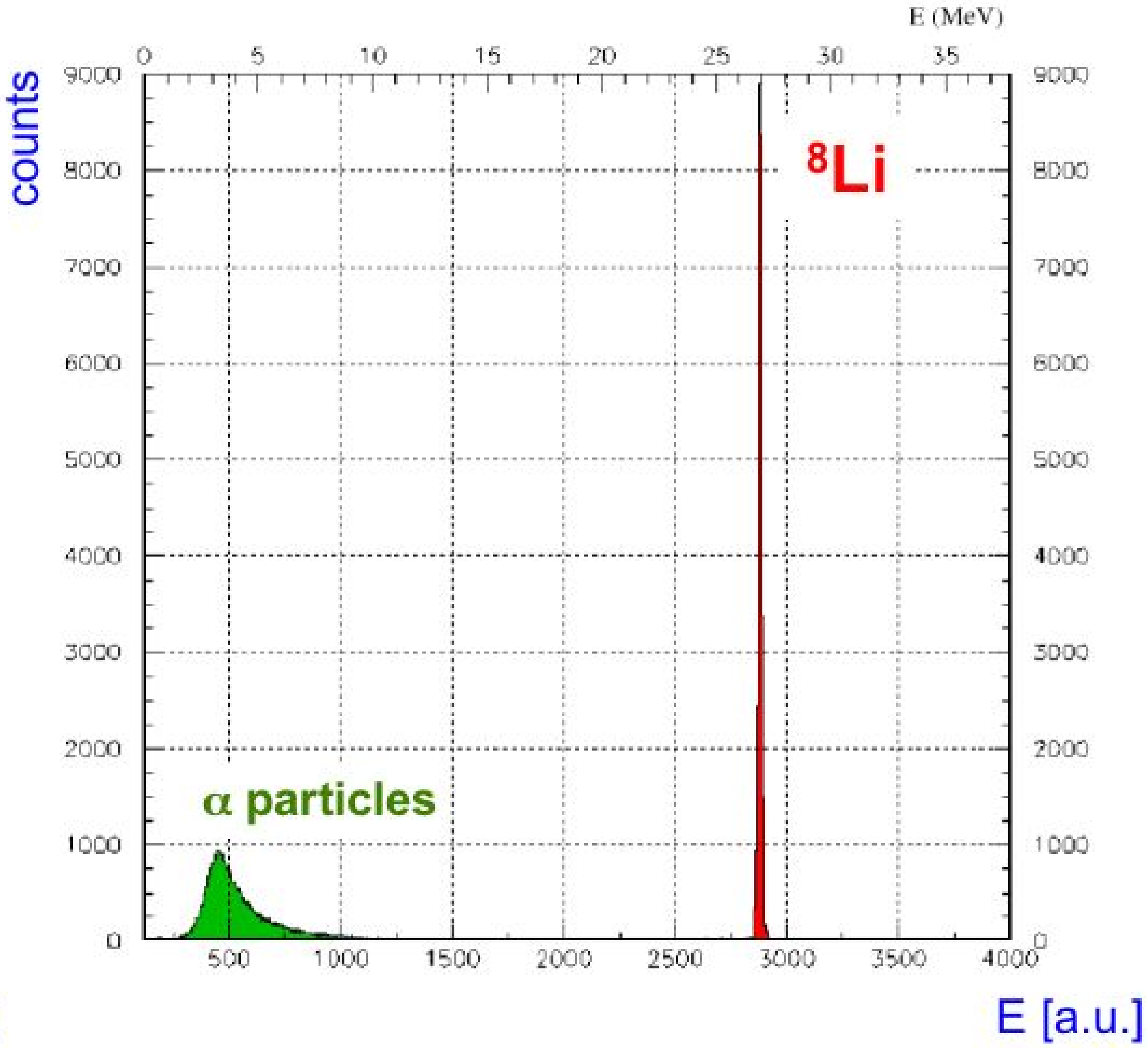


- thickness ≈ 50 + 500 μm
- unambiguous identification of isotopes by elastic scattering
- at low beam intensity can be used directly on the beam
- intensity measurement by means of counting rate
- cost: reasonable

silicon telescope for RIB identification

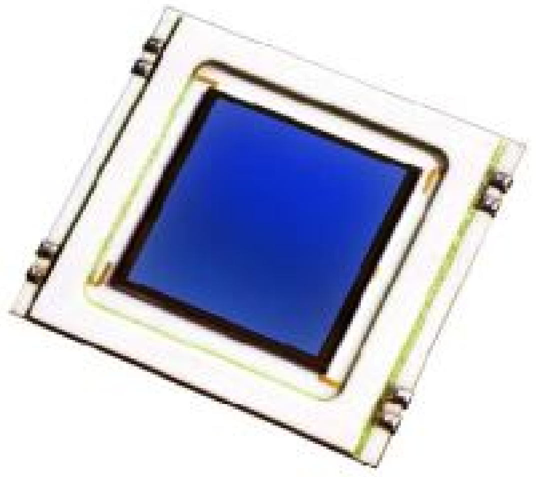
placed directly on the ^{8}Li beam, the experiment request was ***I < 10³ pps***





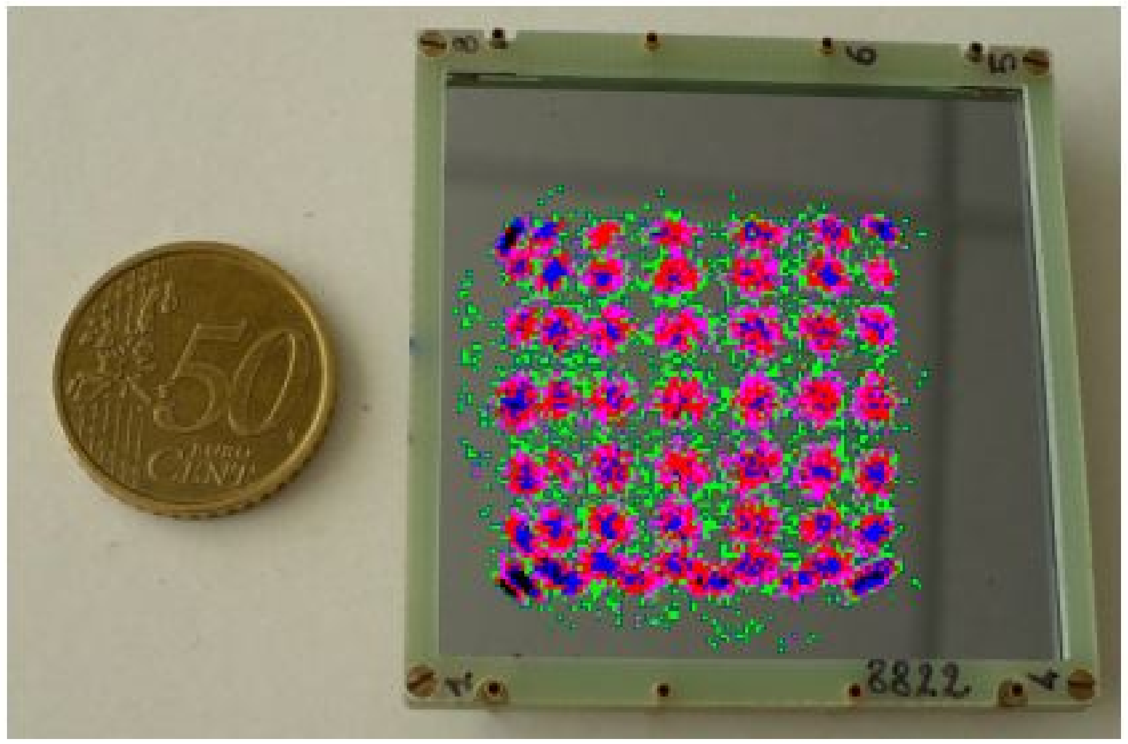
position sensitive silicon telescope for RIB identification and profiling

- 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

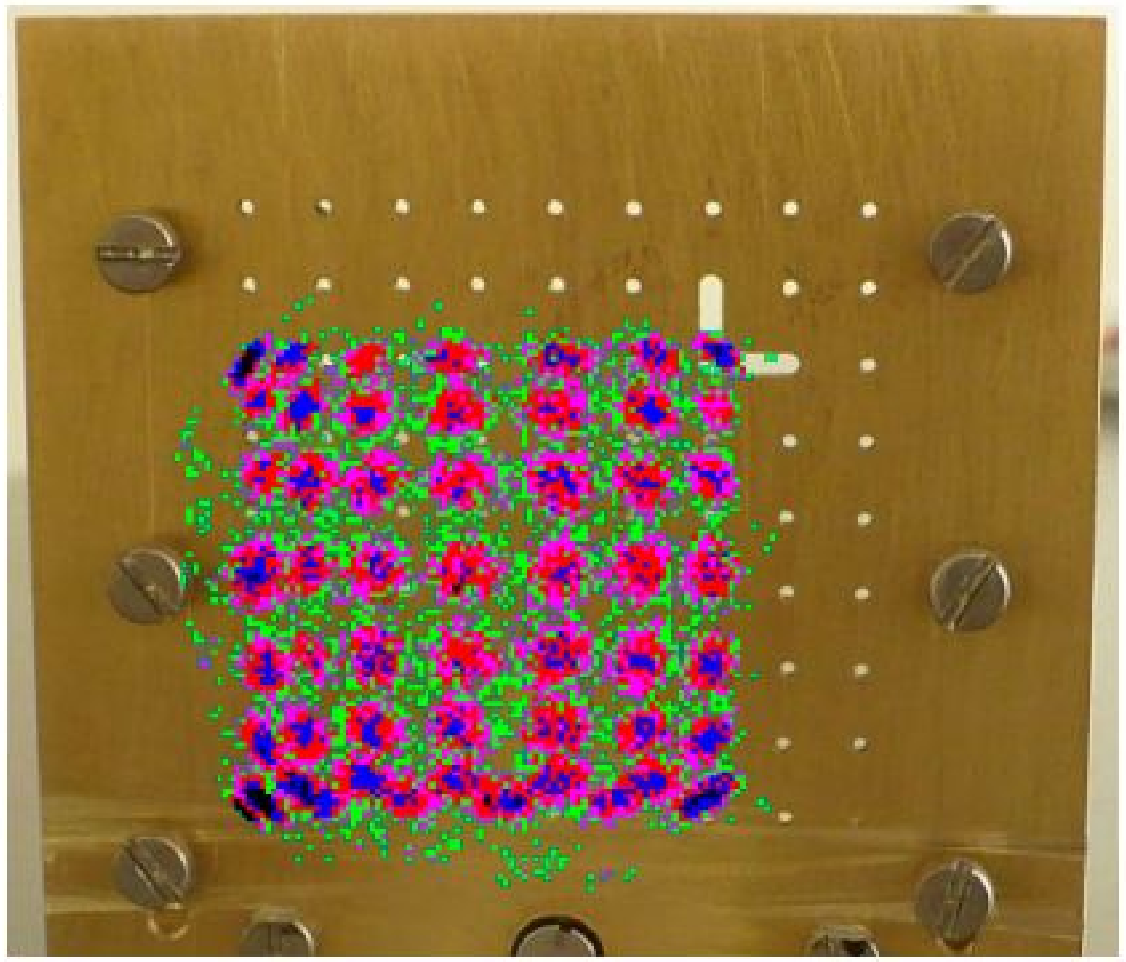


reconstruction of the hole mask put in front of the detector for calibration

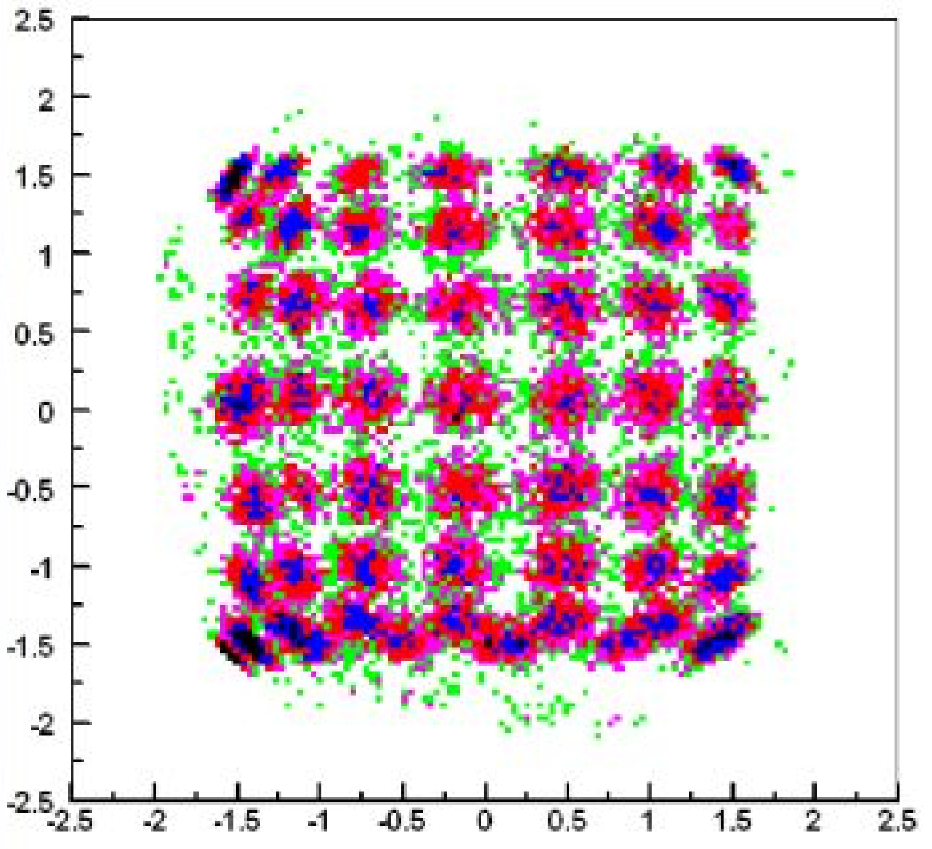
5cm x 5cm Si detector



multi-hole mask

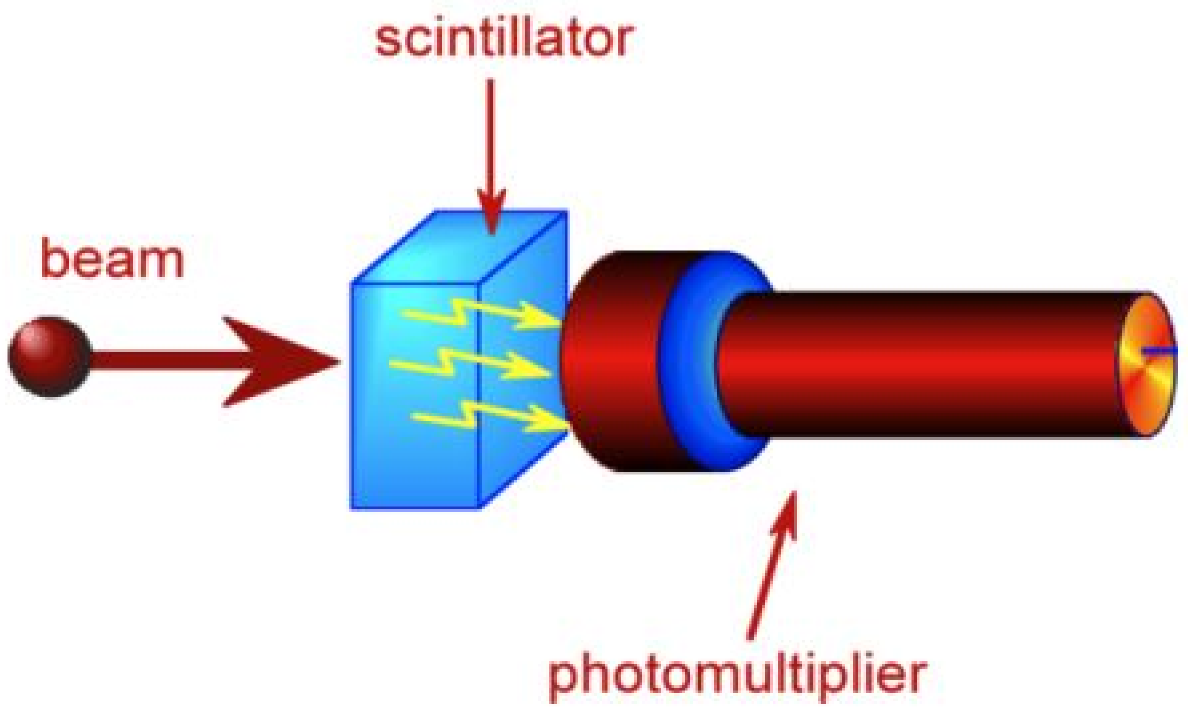


reconstructed beam profile



Scintillators

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

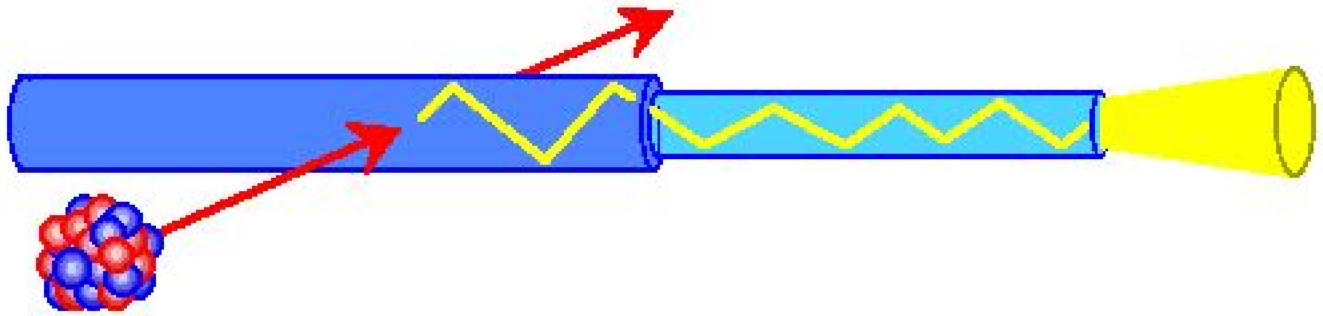


- organic scintillators (plastics: NE110, NExxx, BC404, BC408, BCxxx, fibres, etc.)
- inorganic crystals (CsI, BaF, YAG, LSO, LYSO, LaBr, etc.)
- doped glasses (with Tb, Ce)

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)

scintillating fibres



Light collection efficiency at one end: ≈3.5%

Plastic scintillating fibre: fast (3ns), not rad-hard, $L_{at}\approx3.5$m, $\lambda\approx435$nm

Tb-glass scintillating fibre: slow (4ms), rad-hard, $L_{at}\approx10$cm, $\lambda\approx550$nm

Ce-glass scintillating fibre: fast (40ns), not rad-hard, $L_{at}\approx2$cm, $\lambda\approx400$nm

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

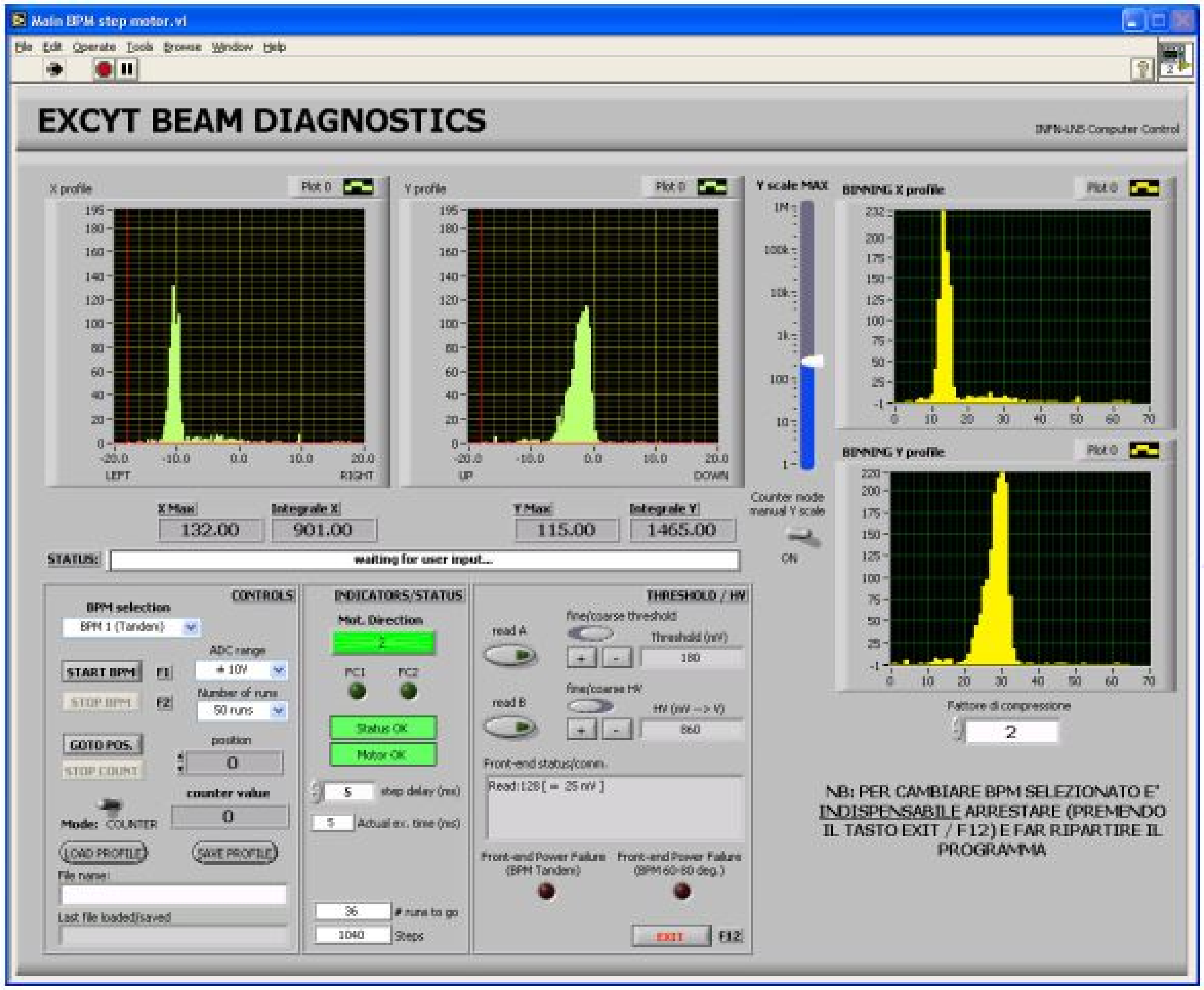
EXCYT beam diagnostics: fibres

FIBBS: fiber based beam sensor

GFIBBS: glass-fiber based beam sensor

Scans the beam in one fast pass (<1s) with two mutually perpendicular fibres

simultaneously reconstructs the X and Y beam profiles



EXCYT BEAM DIAGNOSTICS

INFN-LNS Computer Control

X Max: 132.00

Integrale X: 901.00

Y Max: 115.00

Integrale Y: 1465.00

Counter mode manual Y scale: ON

STATUS: waiting for user input...

BPM selection: BPM 1 (Tandem)

ADC range: ± 10V

Number of runs: 50 runs

position: 0

counter value: 0

Mode: COUNTER

File name:

Last file loaded/saved

Mot. Direction: 2

Status OK

Motor OK

5 step delay (ms)

5 Actual ex. time (ms)

36 # runs to go

1040 Steps

fine/coarse threshold

Threshold (mV): 180

fine/coarse HV

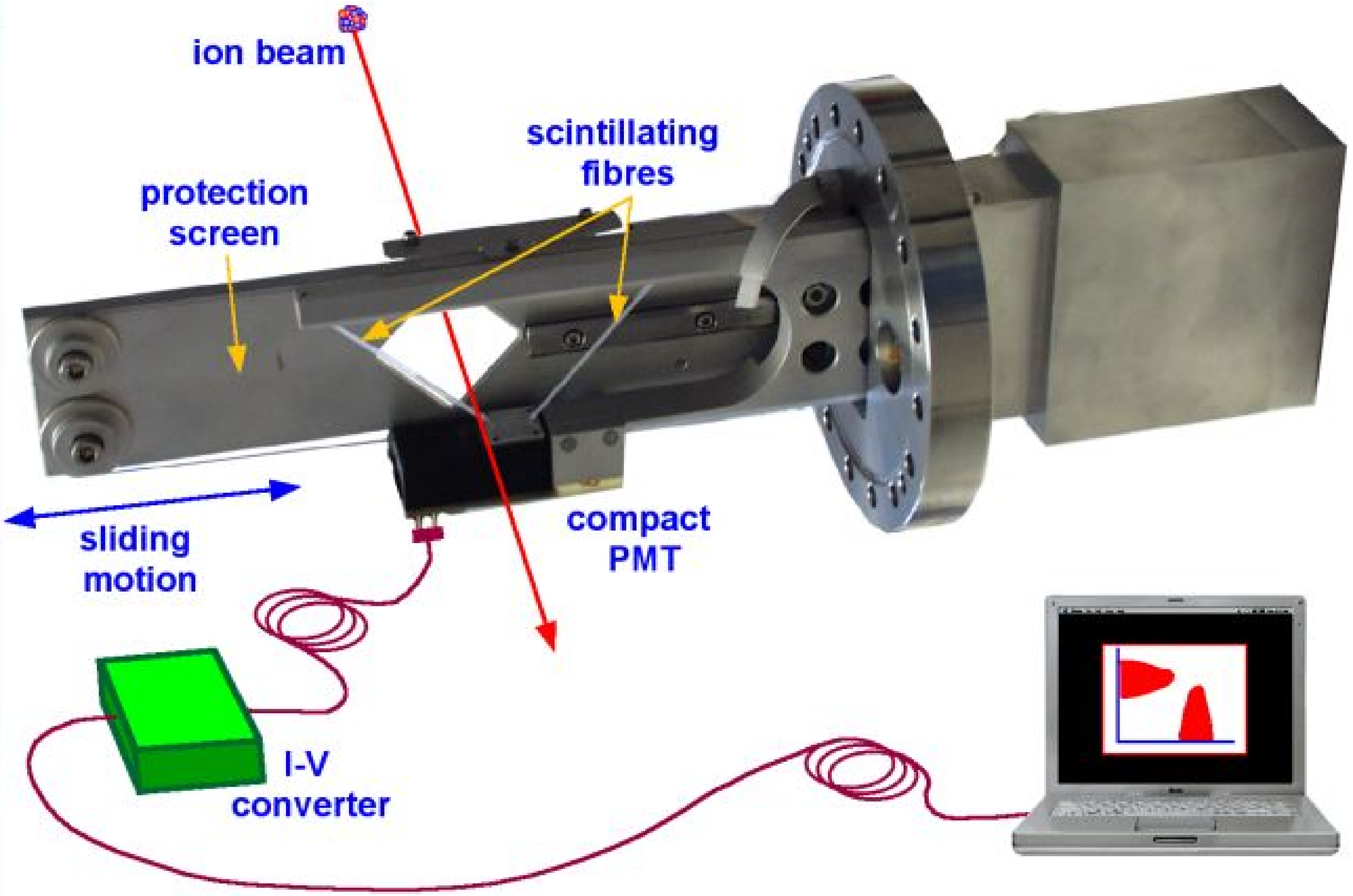
HV (mV --> V): 860

Front-end status/comm.

Read:128 [= 25 mV]

Fattore di compressione: 2

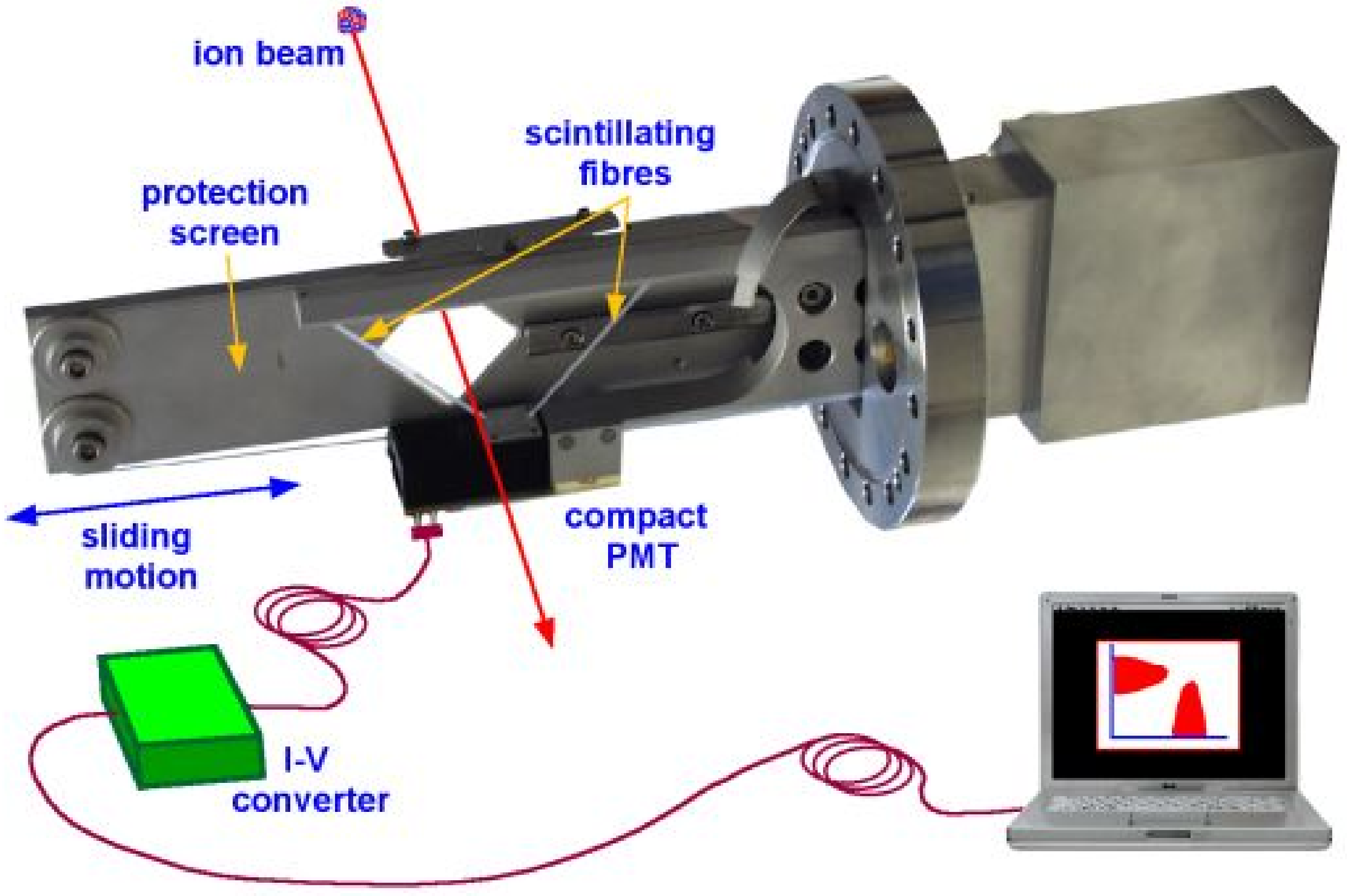
NB: PER CAMBIARE BPM SELEZIONATO E' INDISPENSABILE ARRESTARE (PREMENDO IL TASTO EXIT / F12) E FAR RIPARTIRE IL PROGRAMMA

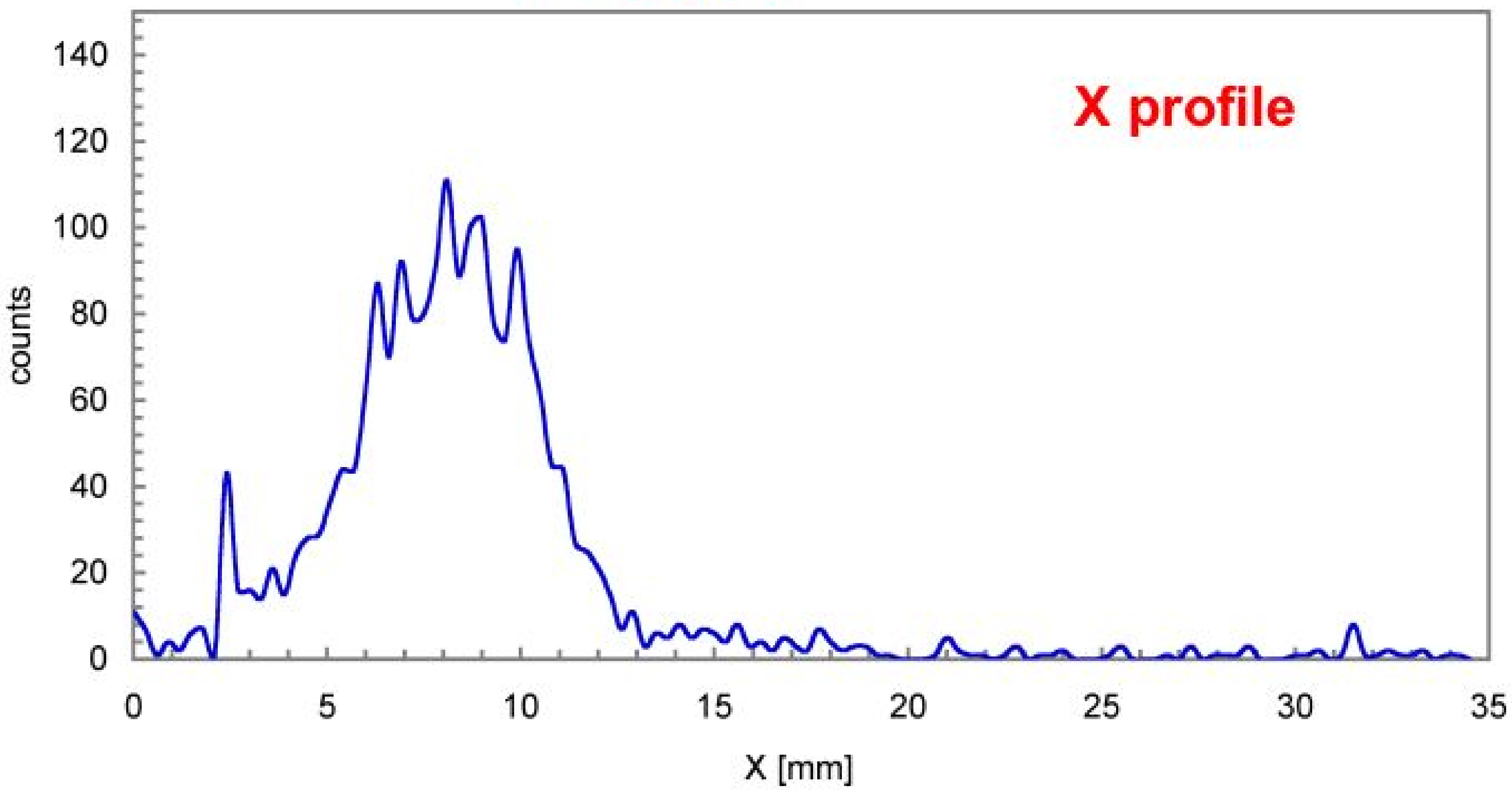


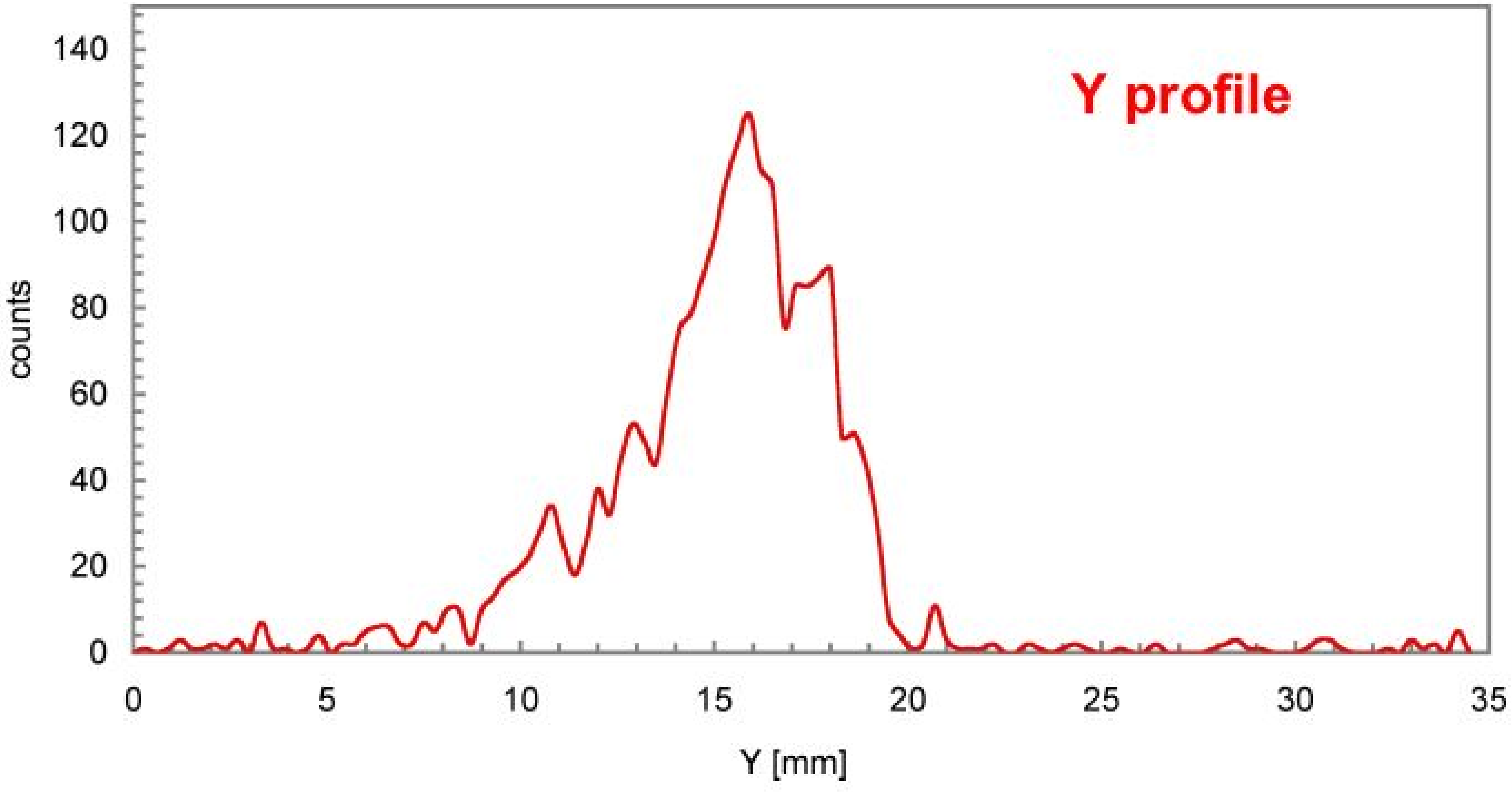
beam: ^{8}Li
I ≈ 7000 pps
E = 12MeV

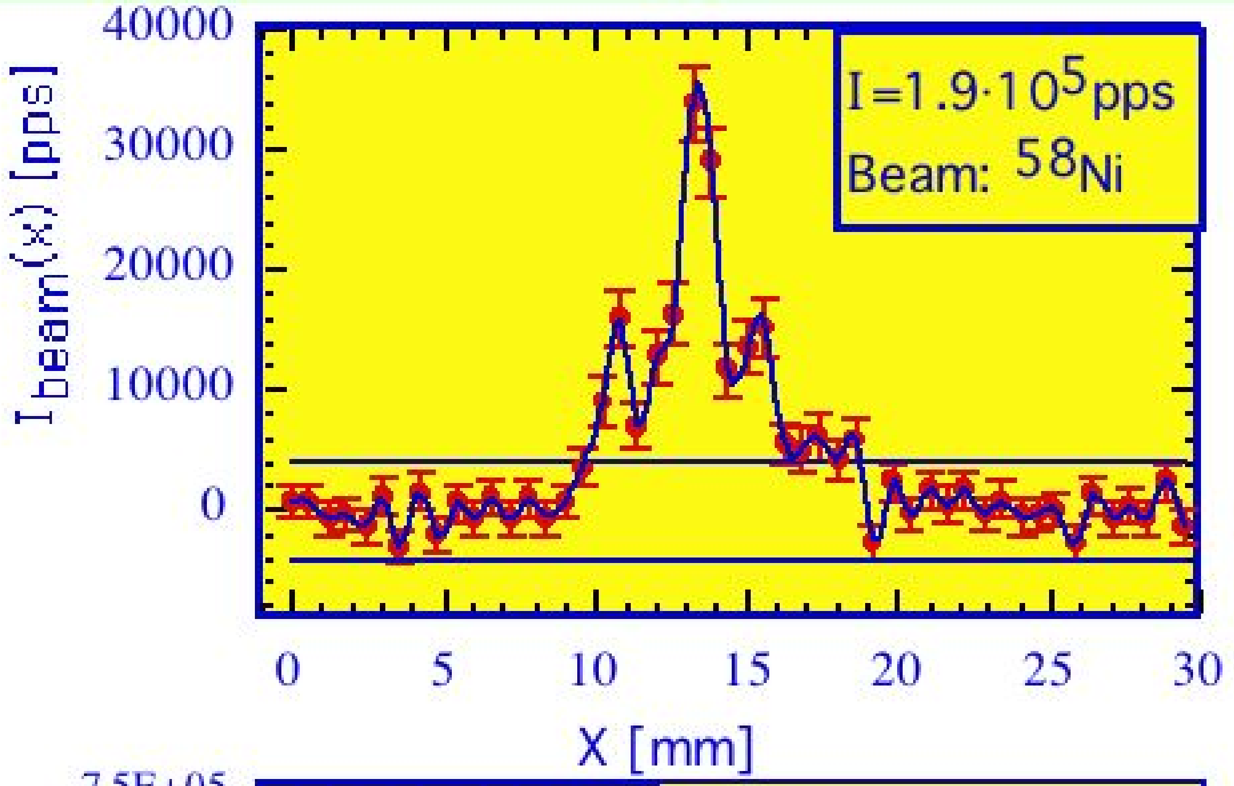
FIBBS results (particle counting)

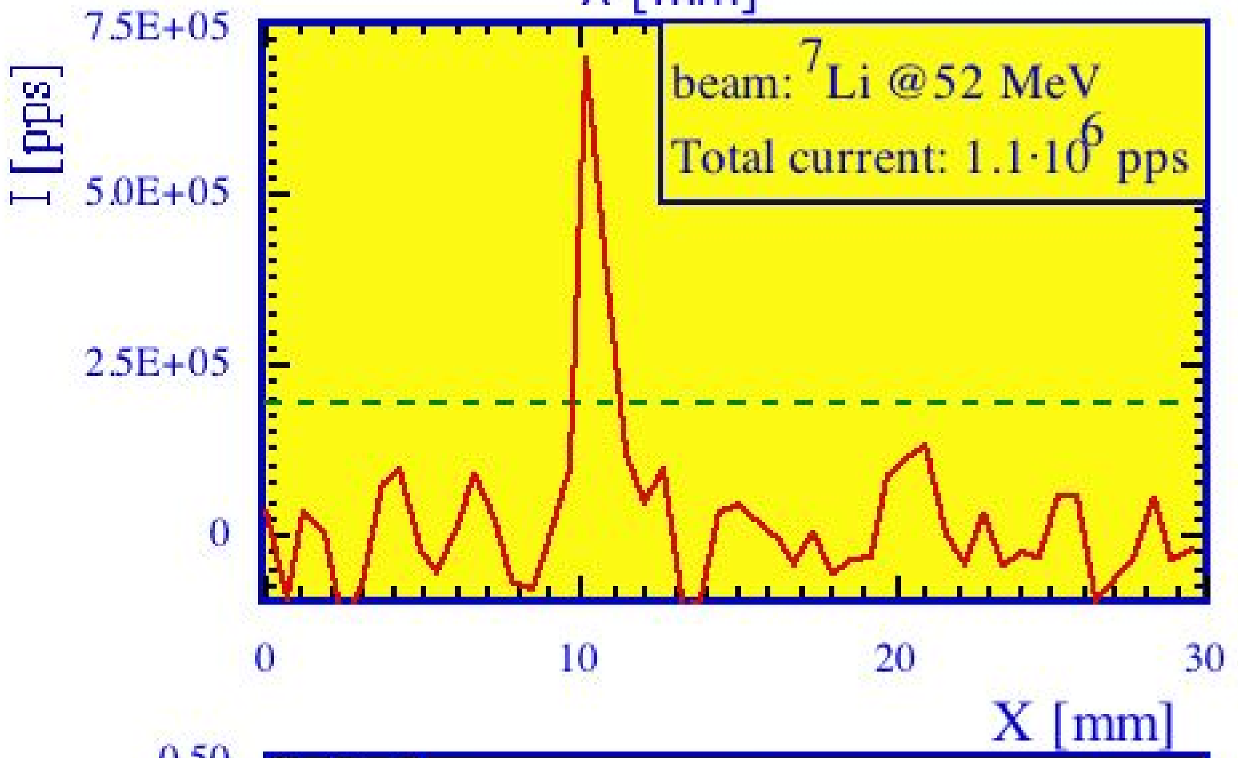
- perfect sensitivity (1 particle)
- limited by low radiation hardness of plastic
- the light yield scales correctly with beam energy (Bethe & Bloch)

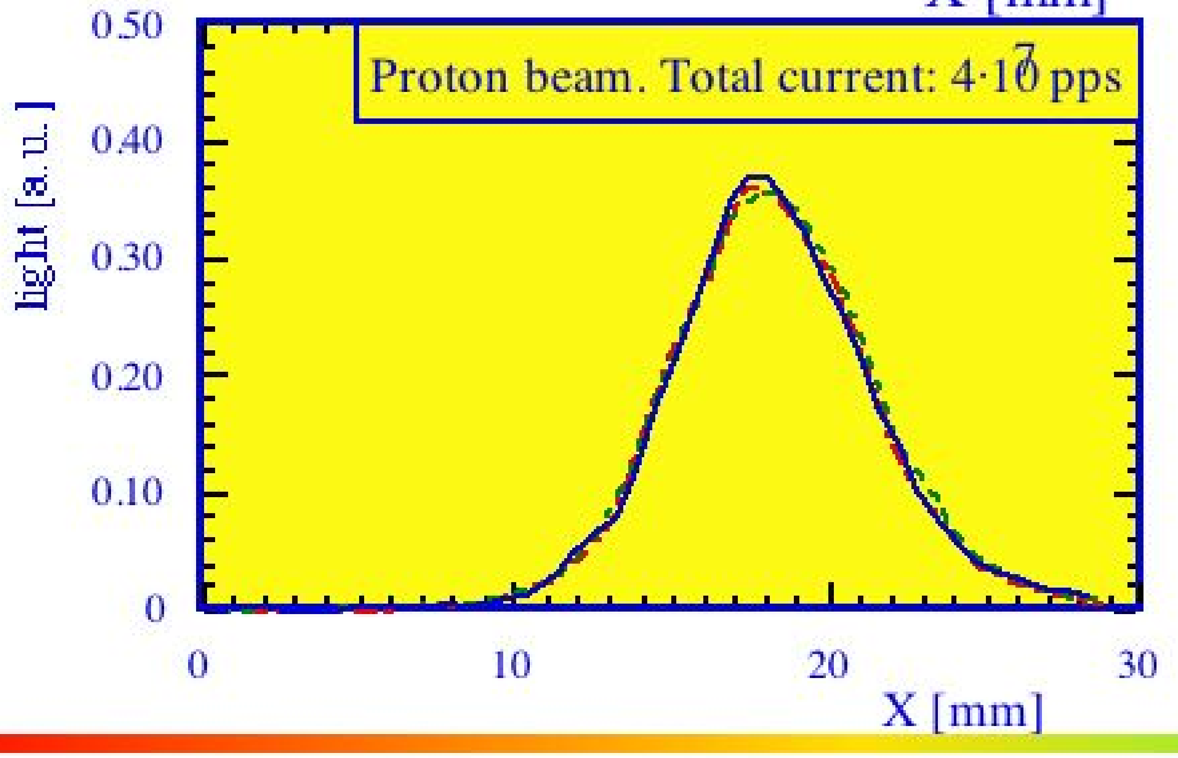






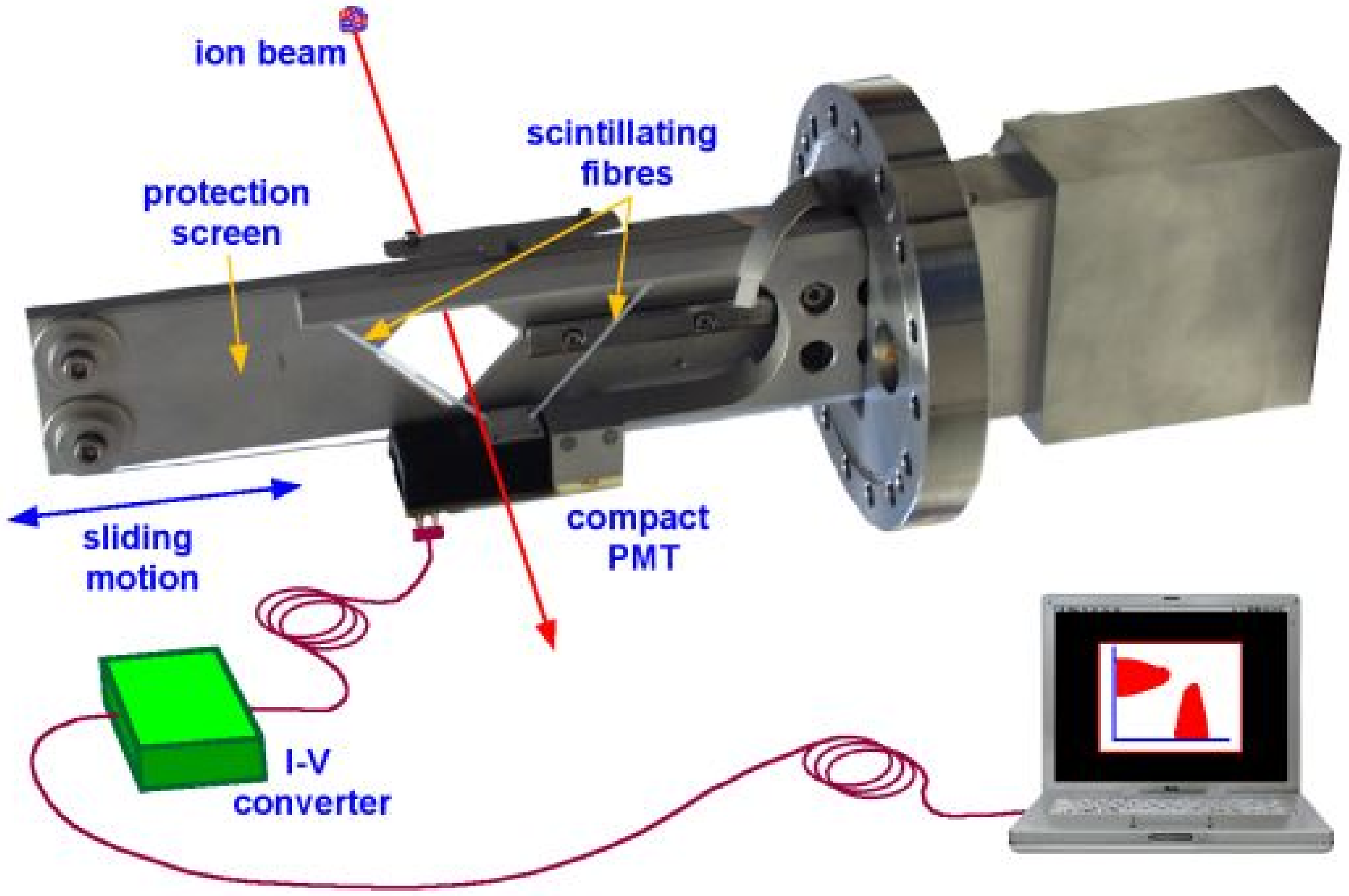






GFIBBS results

- good sensitivity
- good radiation hardness (glass)
- also suitable for ordinary intensity ion beams



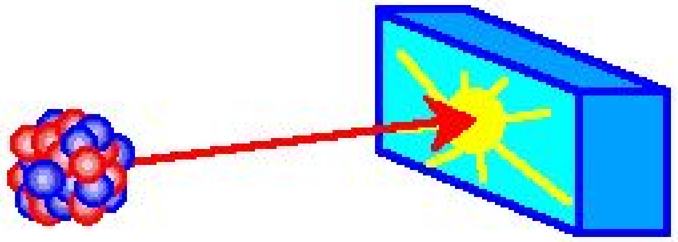
EXCYT beam diagnostics: bulk scintillators

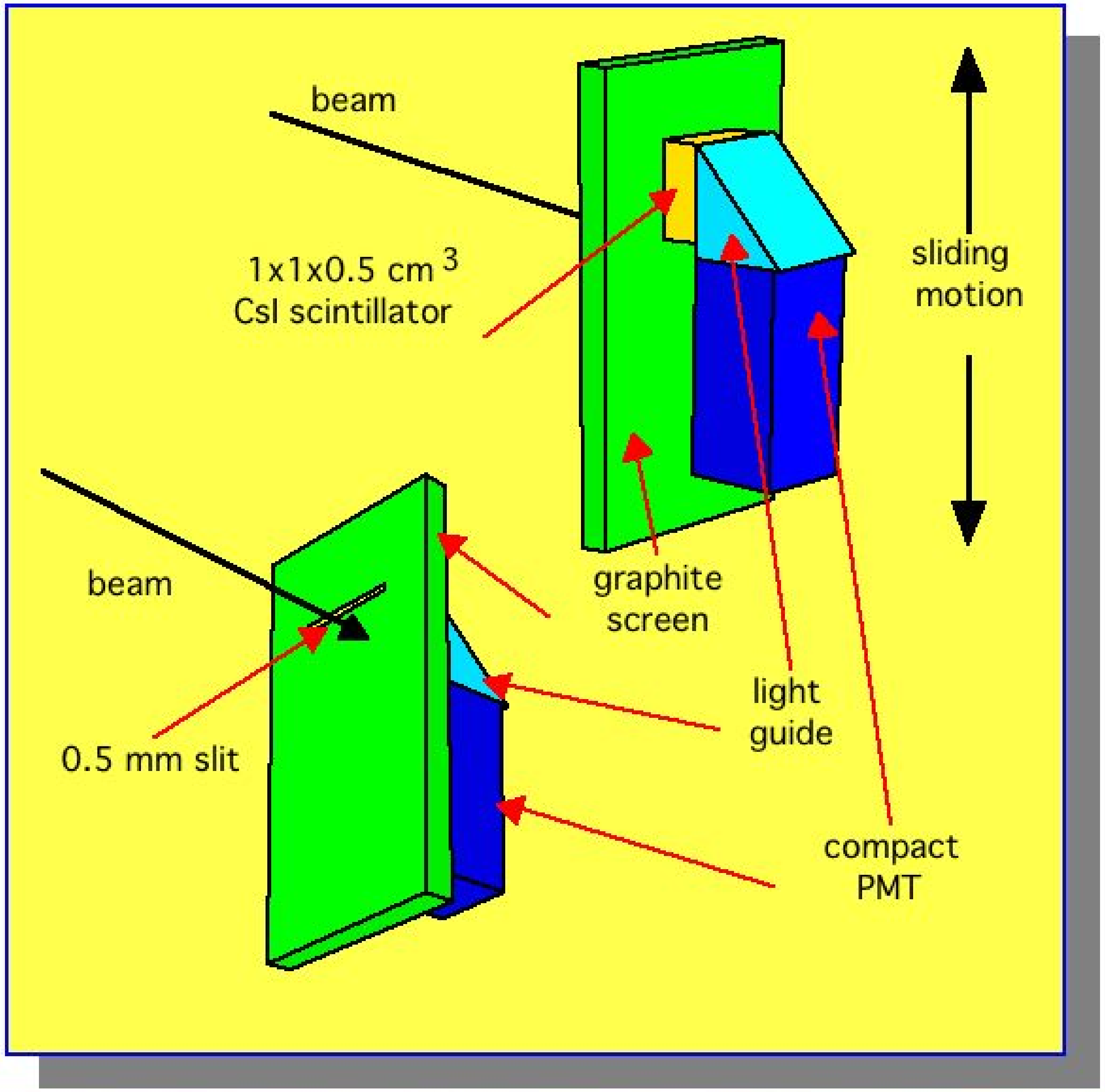
SBBS: scintillator based beam sensor

Scans the beam in one fast pass (<1s) with one slit

reconstructs a 1D beam profile

can be operated in current mode and in pulse counting mode

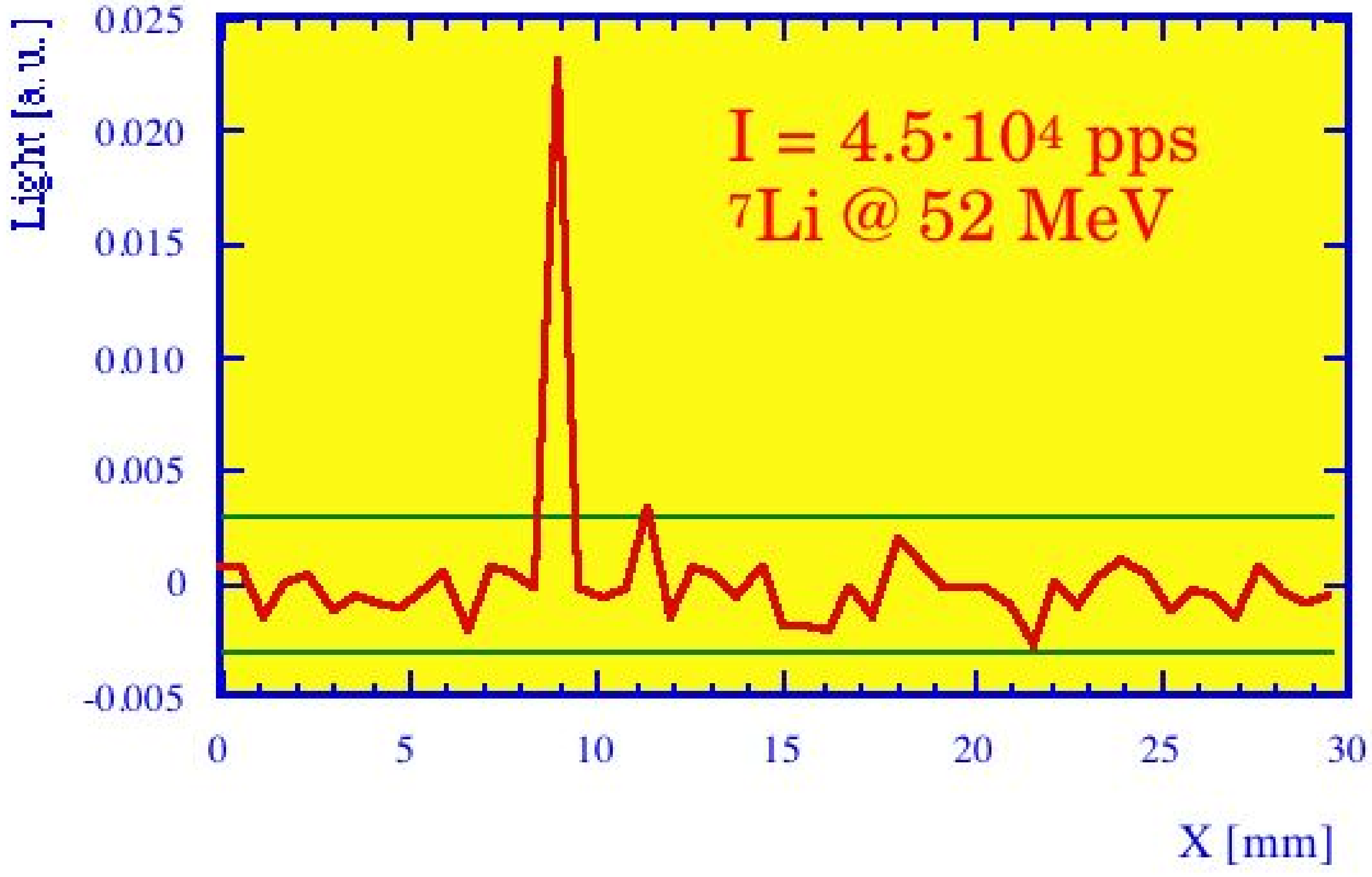




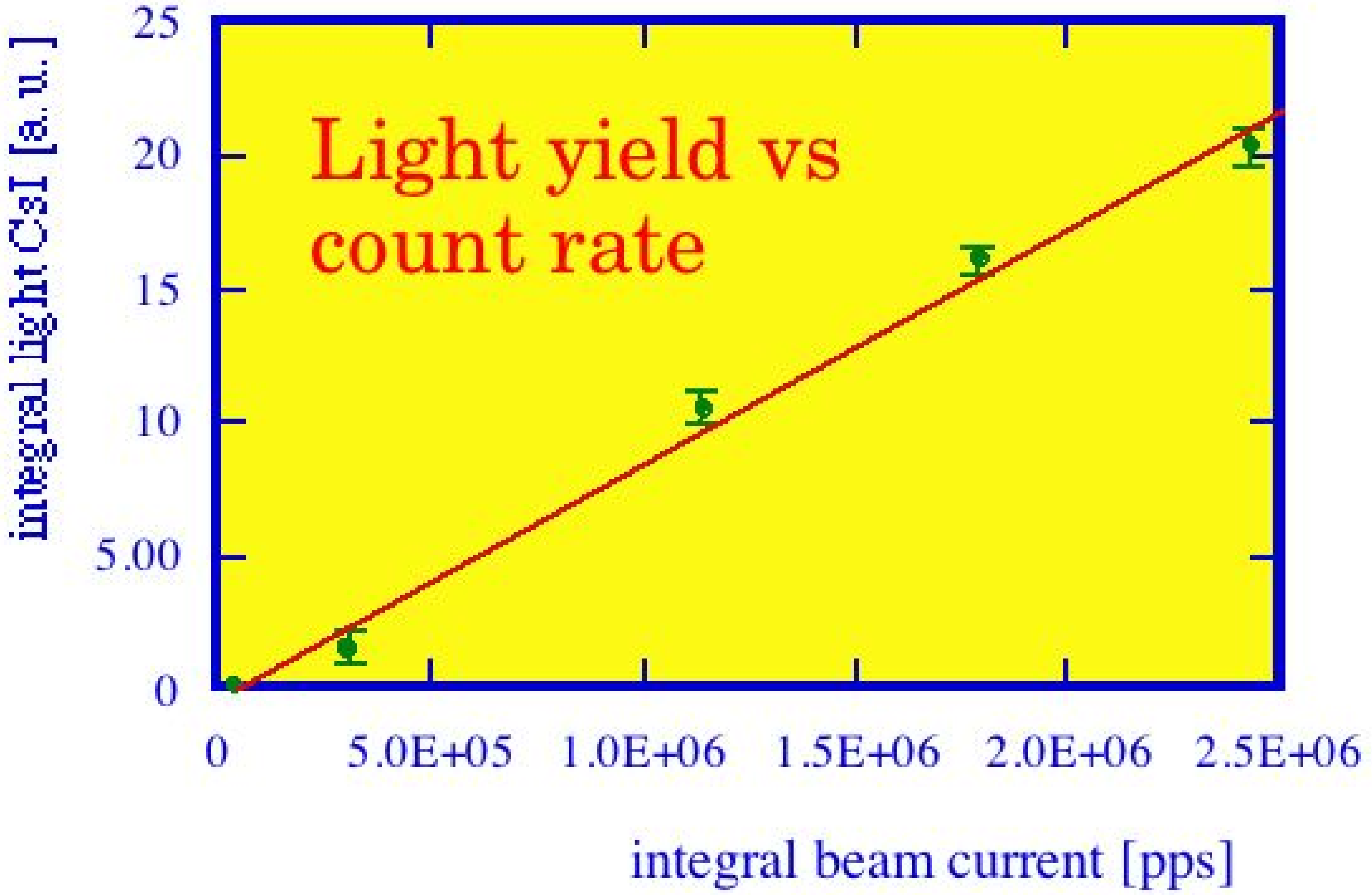
SBBS results with CsI(Tl)

- very good sensitivity
- good radiation hardness
- can be used simultaneously in current and in pulse counting mode:

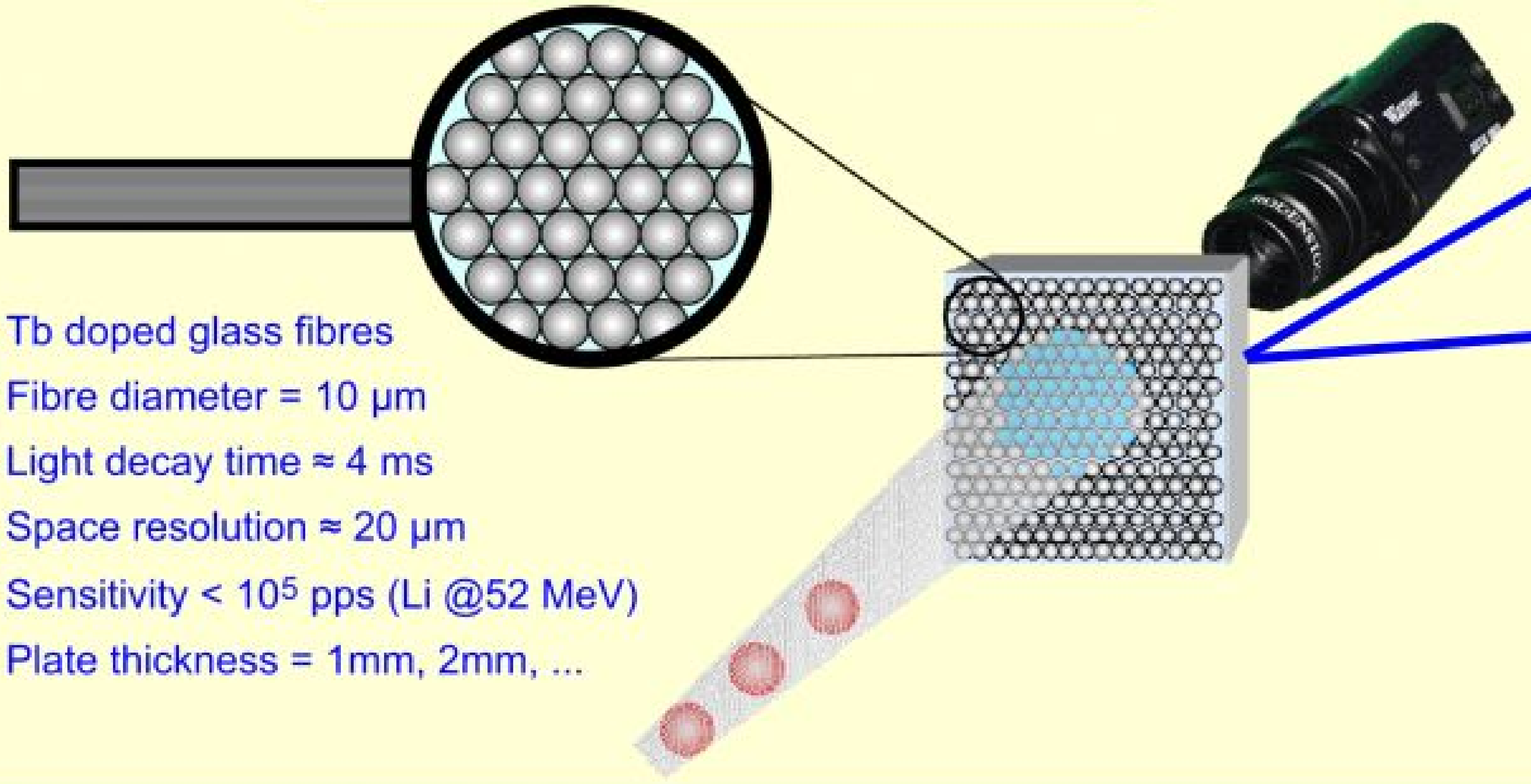
self calibration



by carving 2 perpendicular slits it can measure X and Y profiles in one single scan

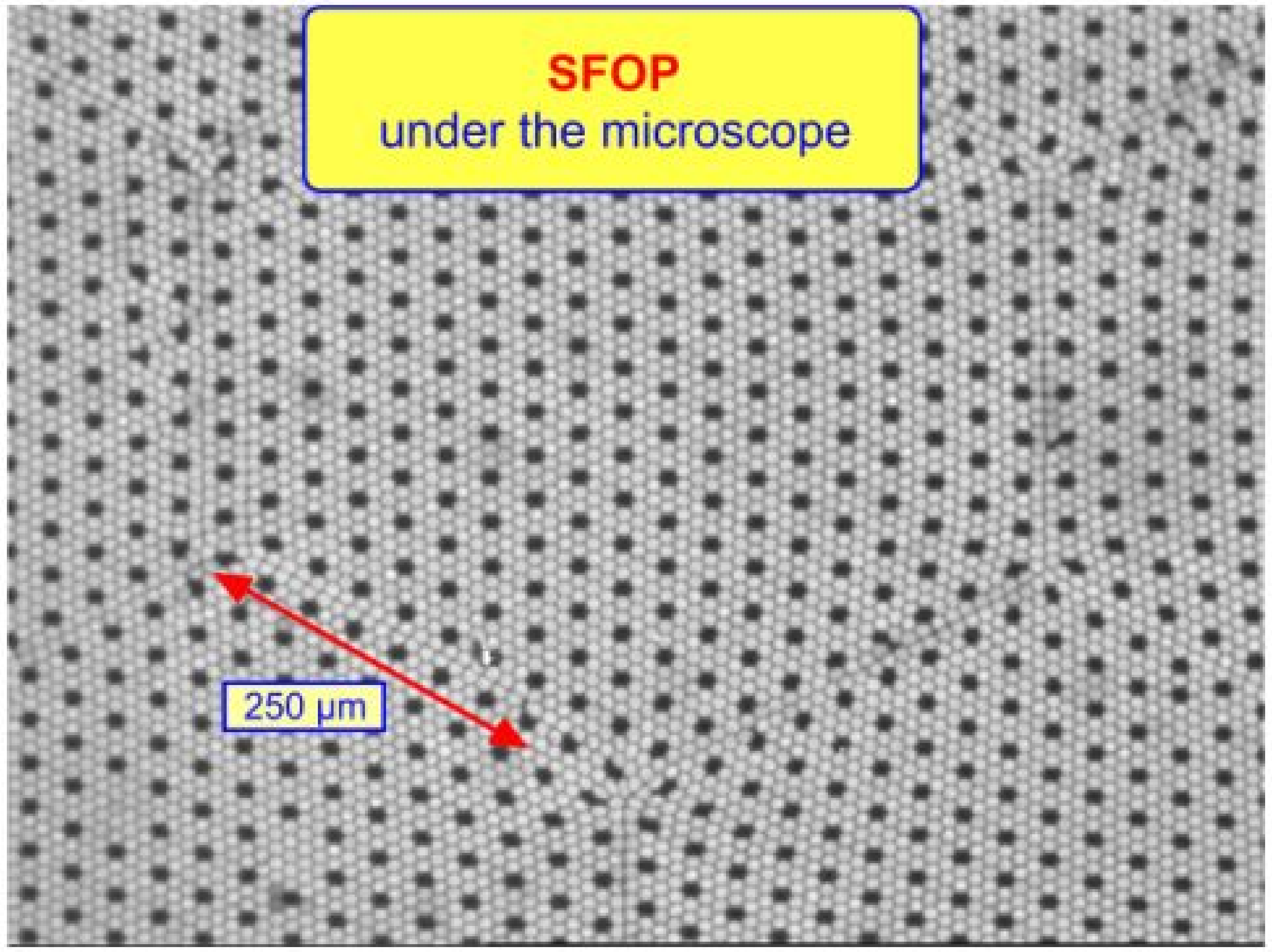


SFOP
Scintillating Fiber Optic Plate



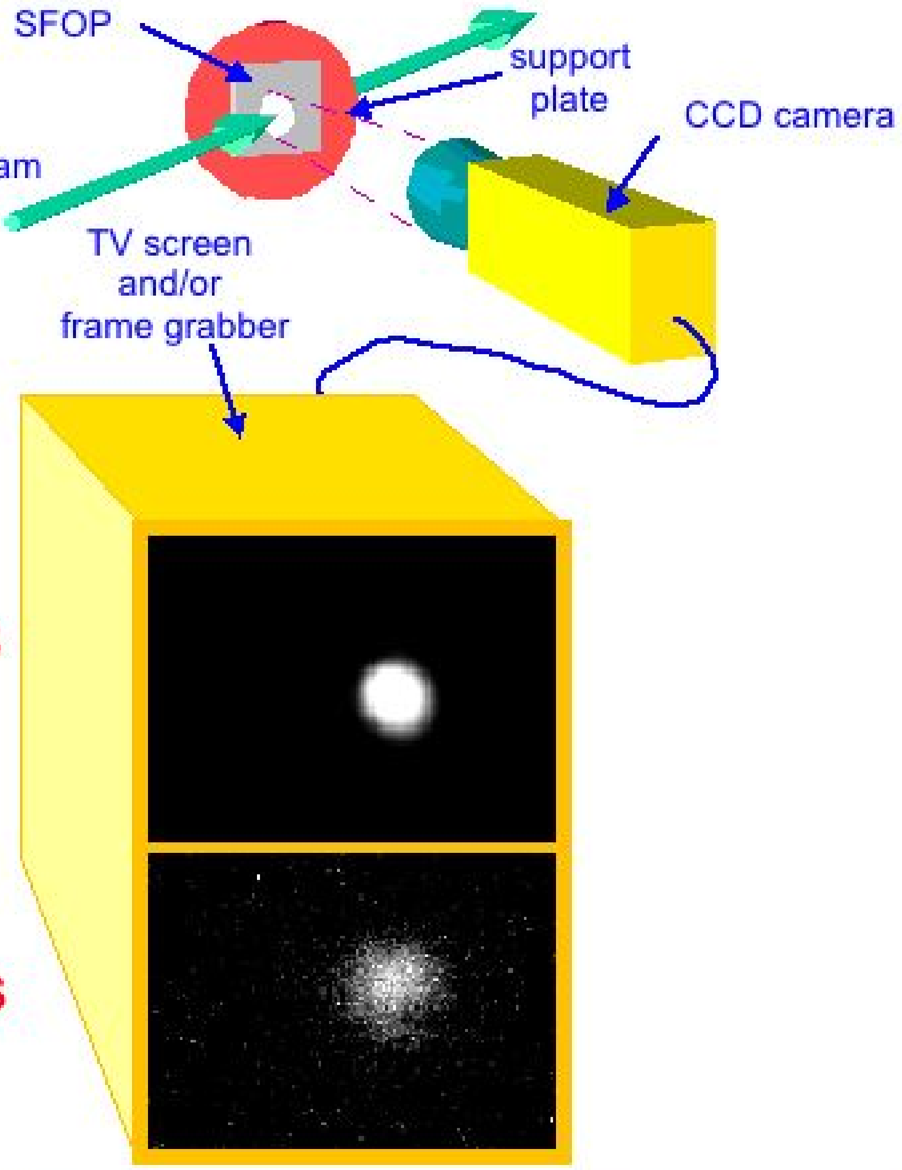
- Tb doped glass fibres
- Fibre diameter = 10 µm
- Light decay time ≈ 4 ms
- Space resolution ≈ 20 µm
- Sensitivity < 10^5 pps (Li @52 MeV)
- Plate thickness = 1mm, 2mm, ...

compact video camera



SFOP
under the microscope

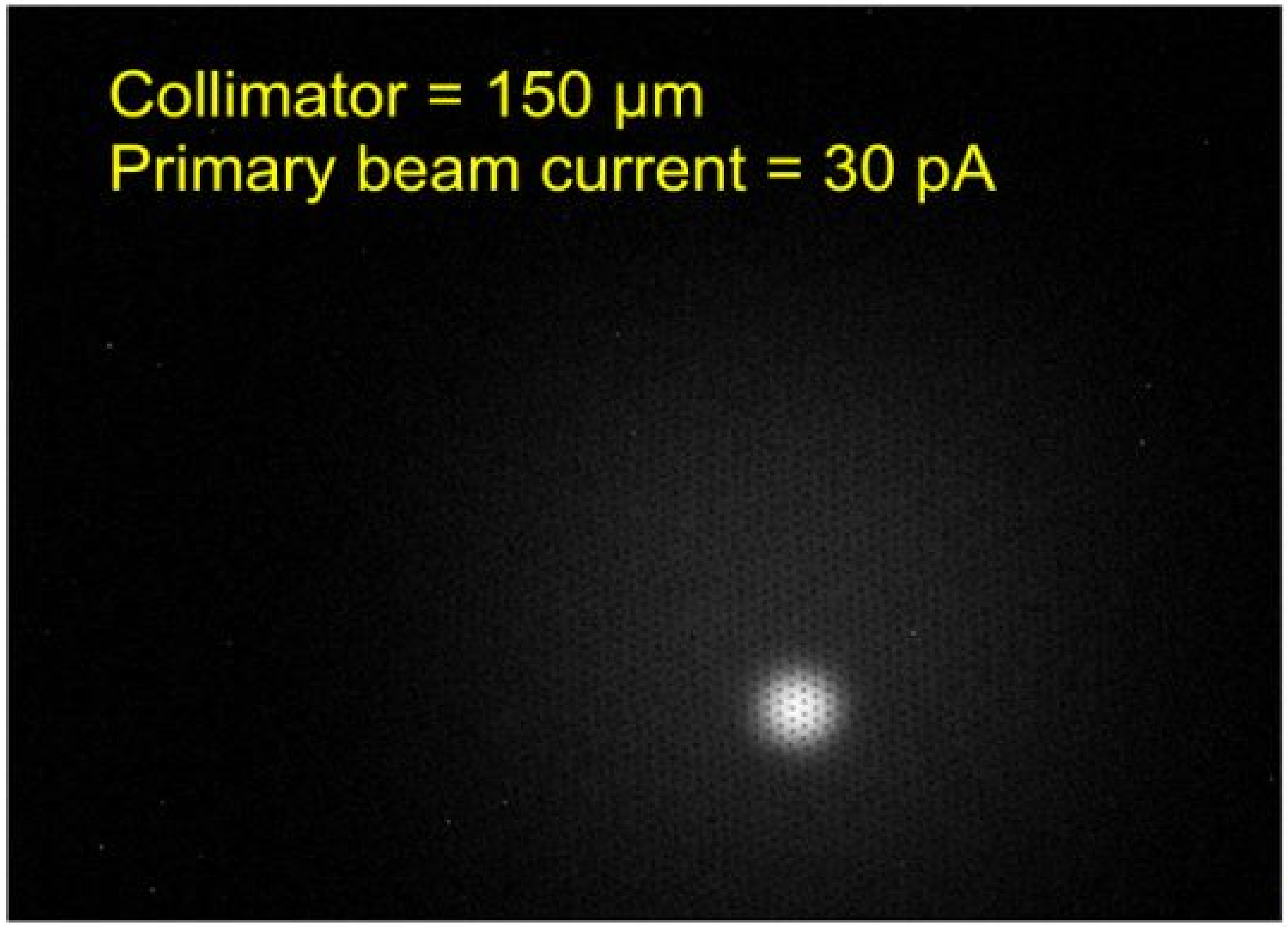
Tb-glass SFOP
2D beam imaging
with ^{7}Li at 52MeV



beam current = $2 \cdot 10^7$ pps

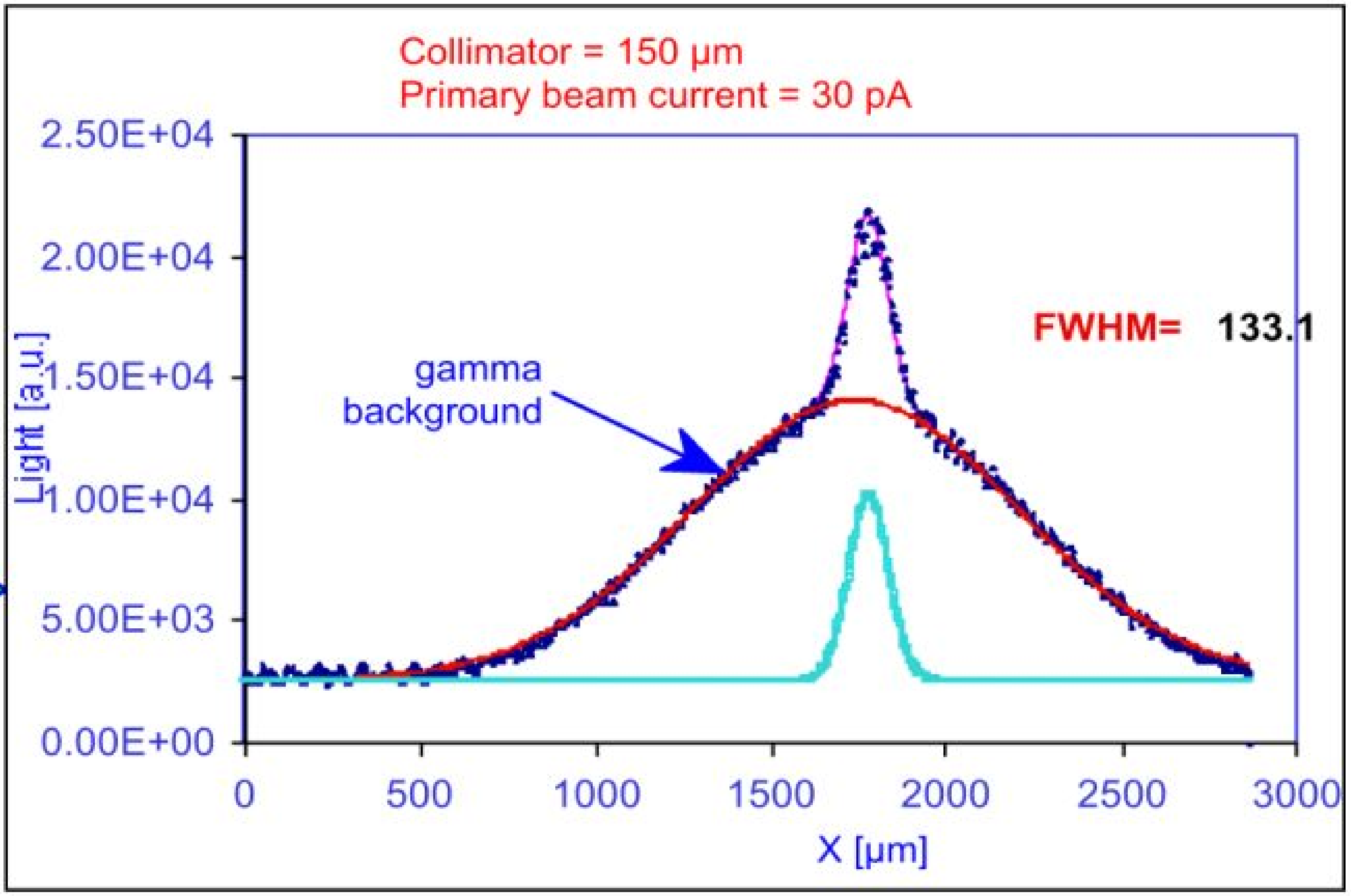
beam current ≈ 10^5 pps

micro-beam diagnostics


Collimator = 150 µm
Primary beam current = 30 pA

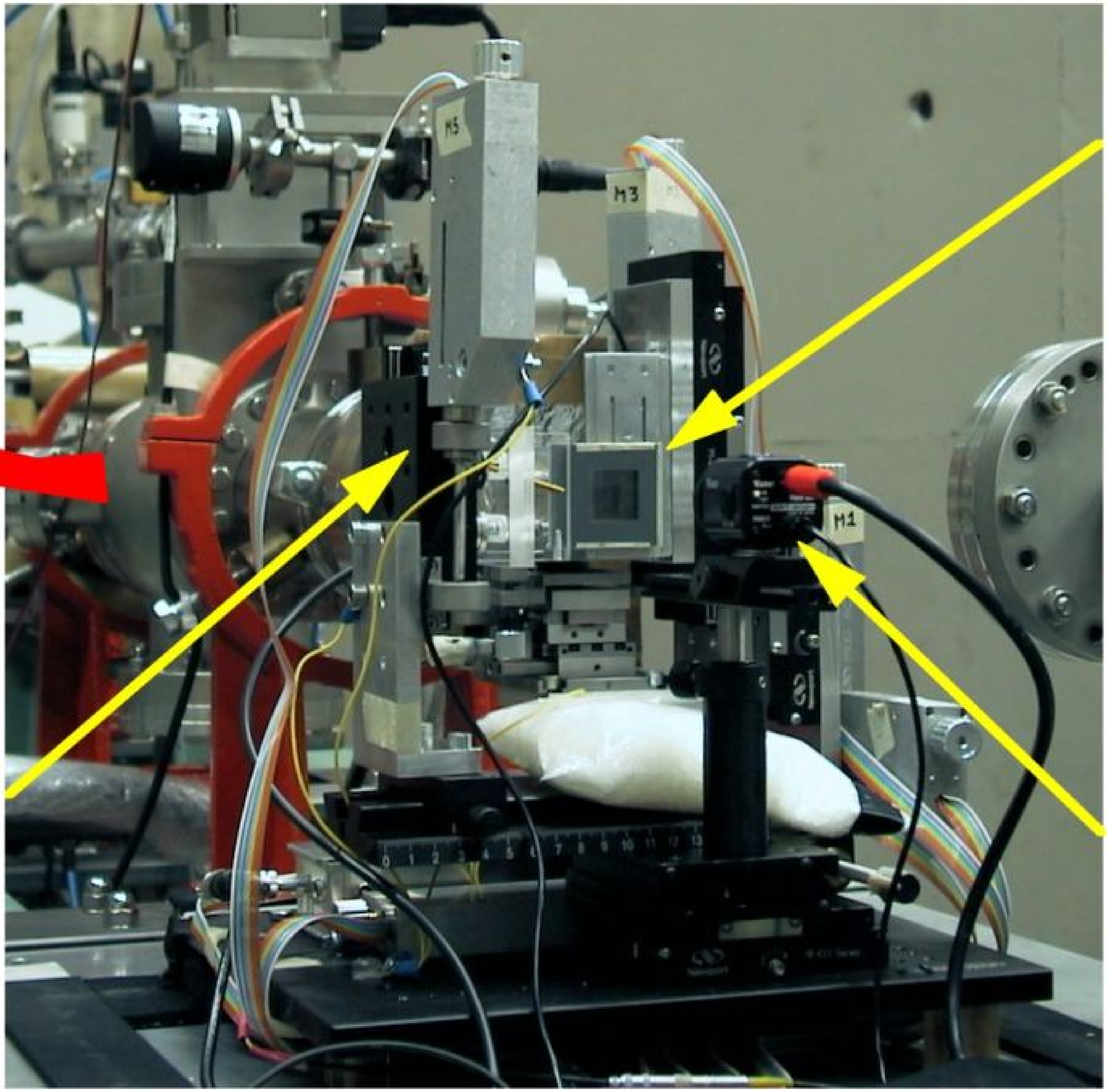
µ-SFOP

Projecting on the X axis we get ...


Collimator = 150 µm
Primary beam current = 30 pA

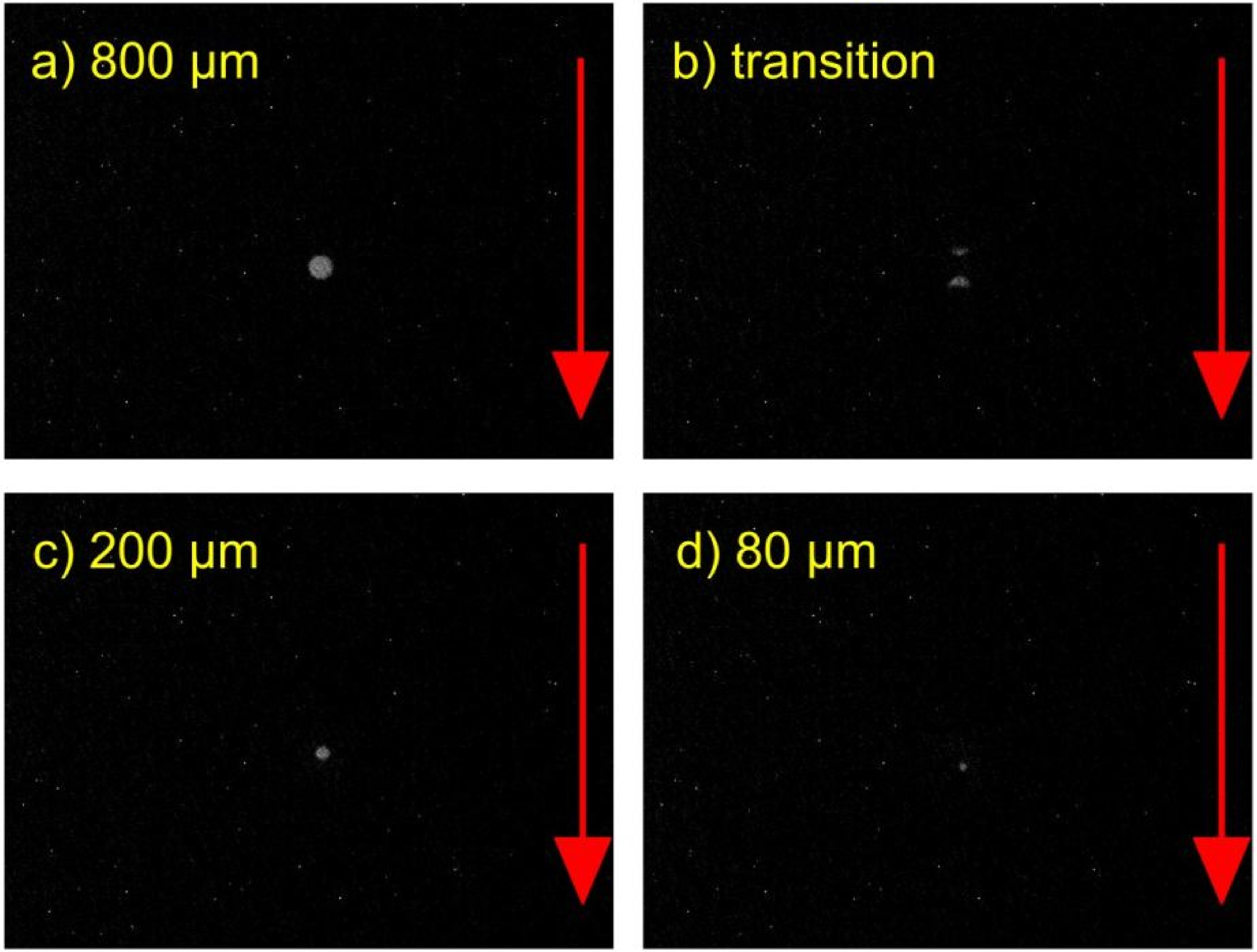
FWHM= 133.1

µ-SFOP



NIMB209(2003)340, L.Cosentino, P.Finocchiaro, A.Pappalardo, A.Hermanne, H.Thienpont, M.Vervaeke, B.Volckaerts, P.Vynck
IEEE_TNS_v50n4_(2003)774, L.Cosentino, P.Finocchiaro, A.Pappalardo, A.Hermanne, H.Thienpont, M.Vervaeke, B.Volckaerts, P.Vynck

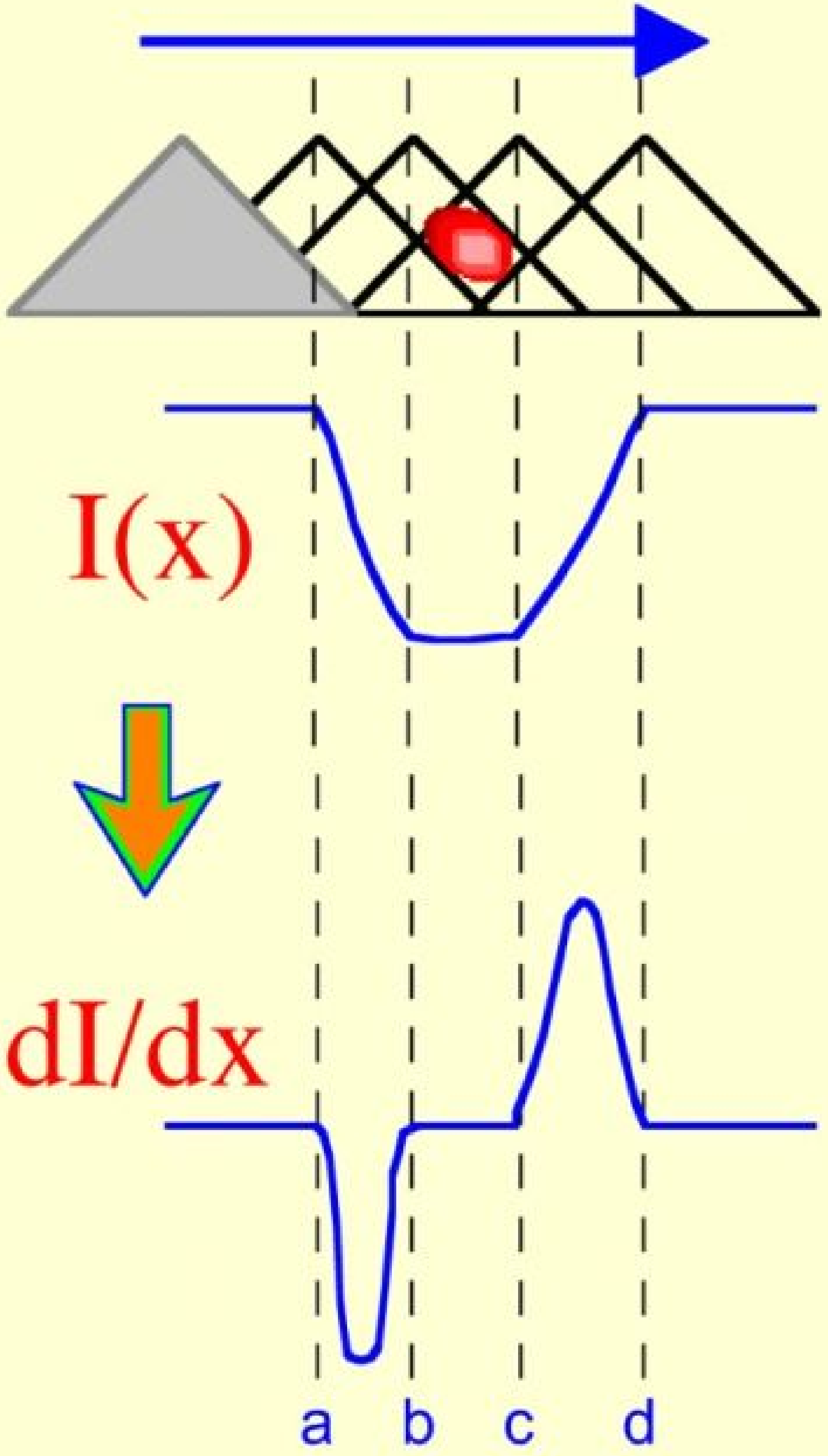
4 frames extracted from a real time movie taken while the multi-collimator mask was sliding down

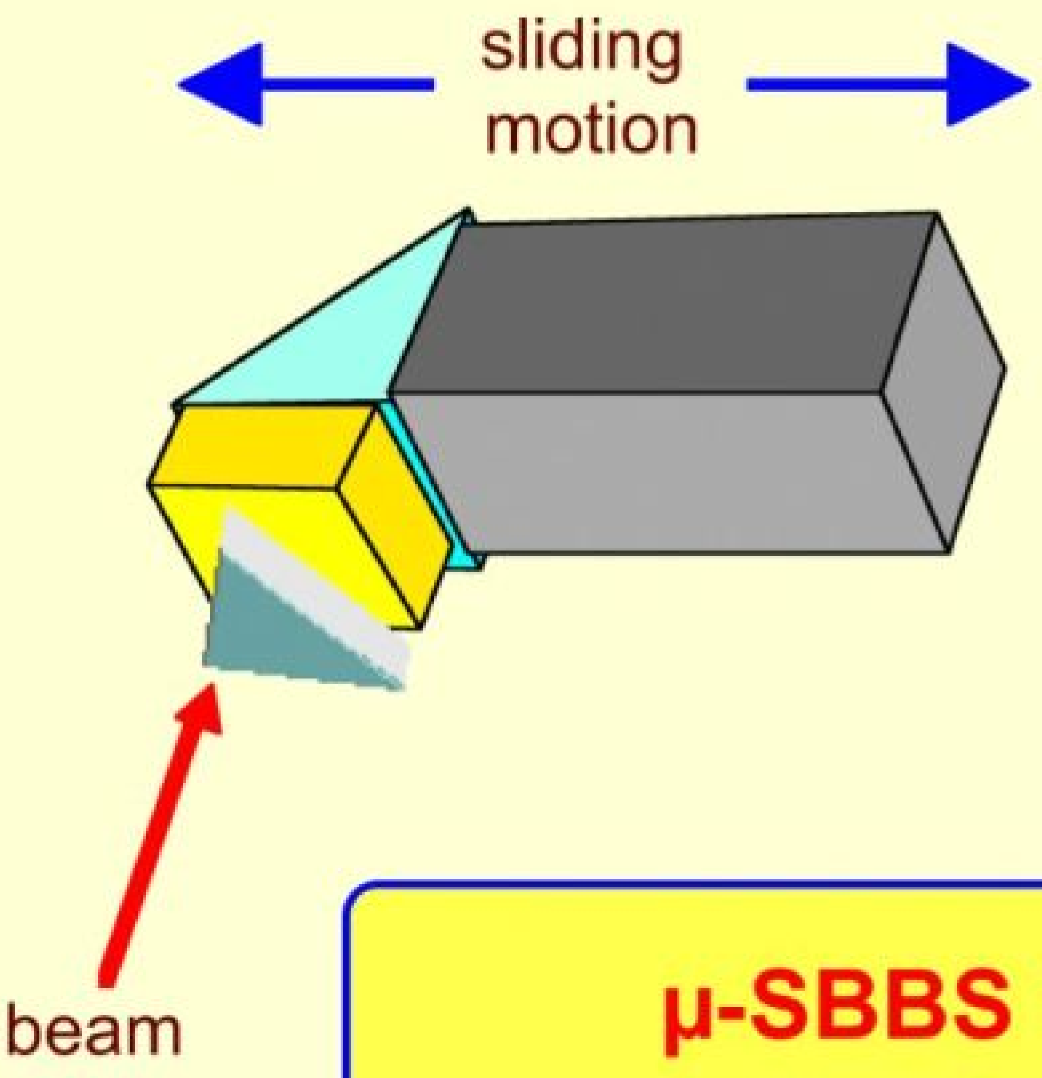


µ-SFOP

The mask slides down, scanning several holes (the CCD lens magnification is low in this run)

we were able to image a beam down to 20µm diameter

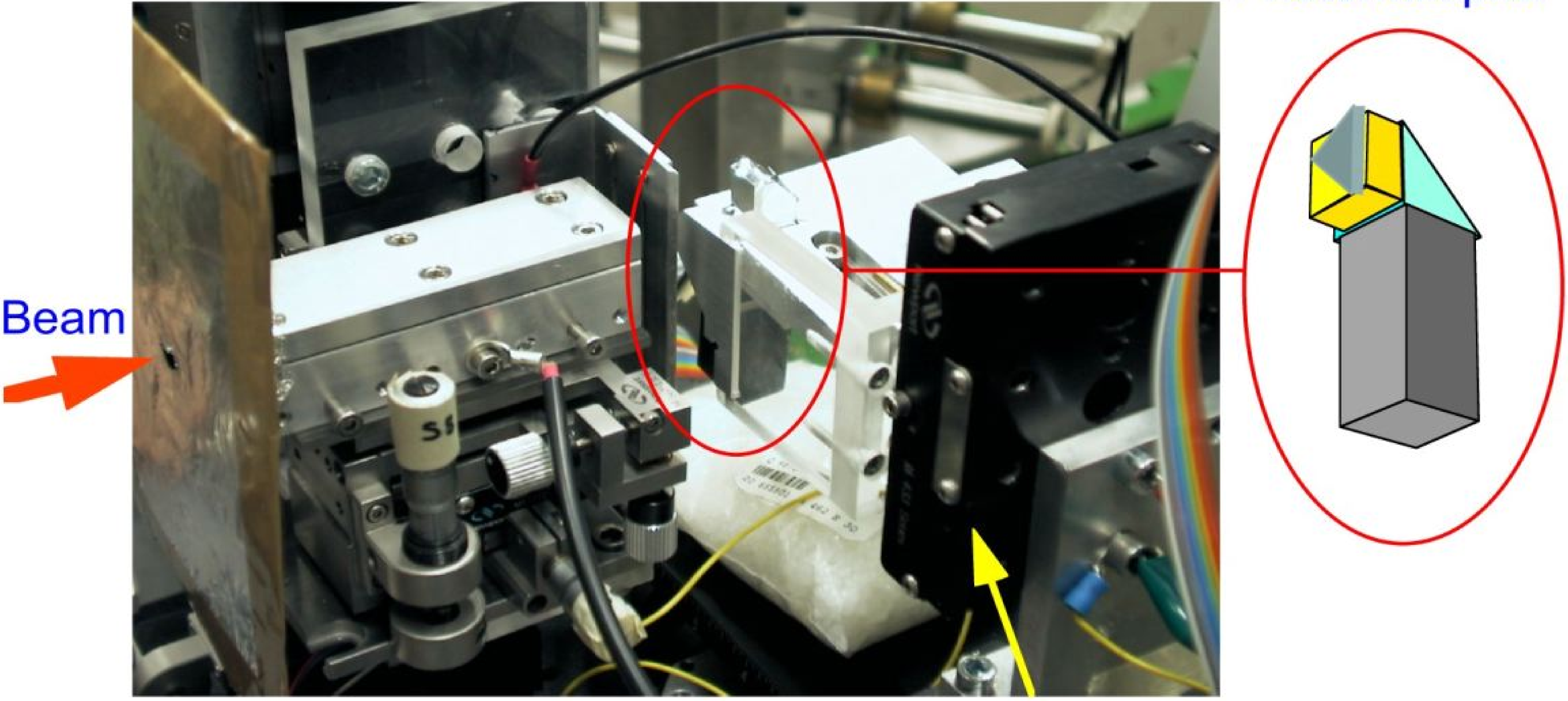




μ-SBBS

The Nickel screen has been replaced by a triangular blade made from thick aluminum

μ-SBBS



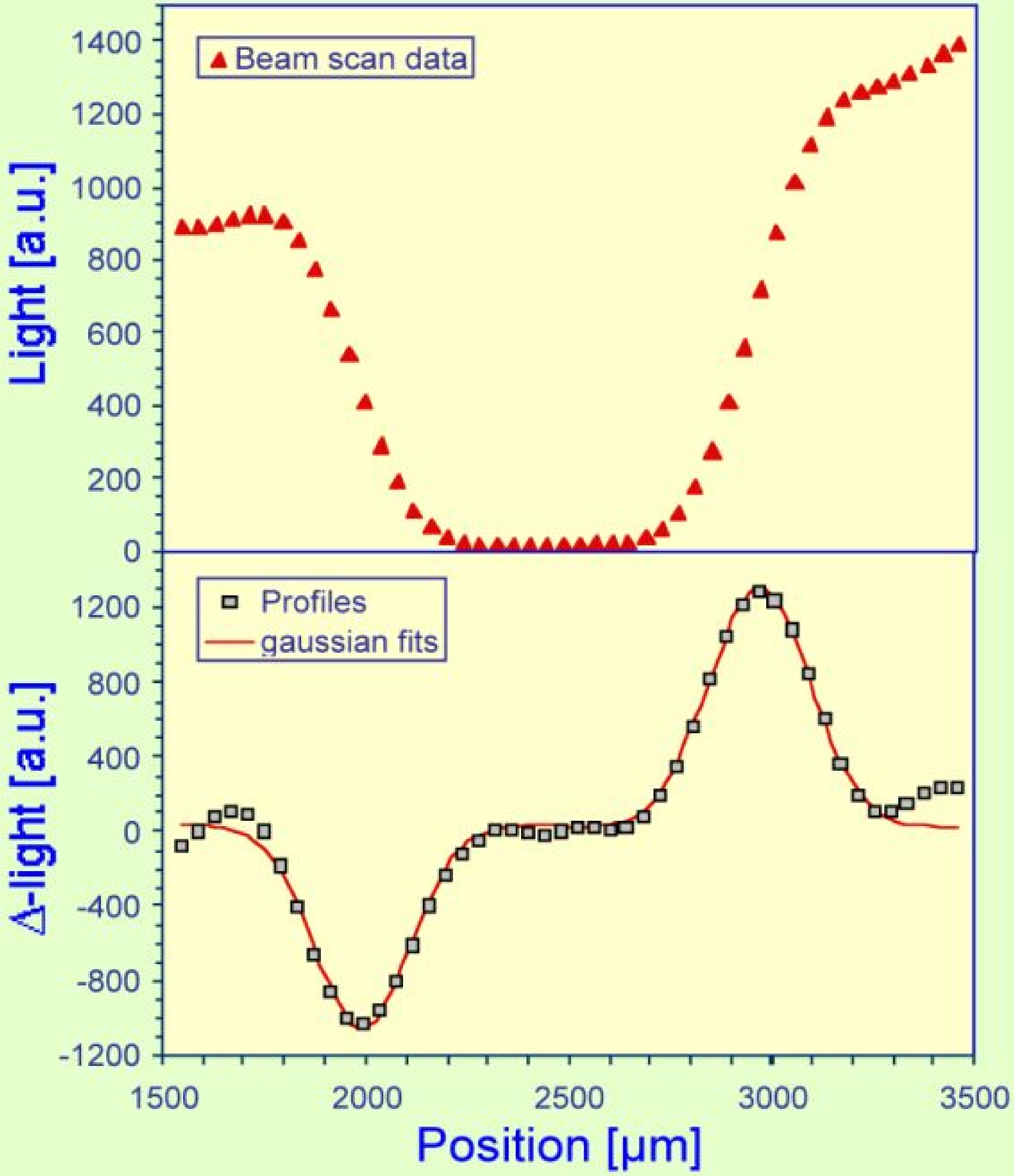
Hamamatsu H5783
Photomultiplier

Beam

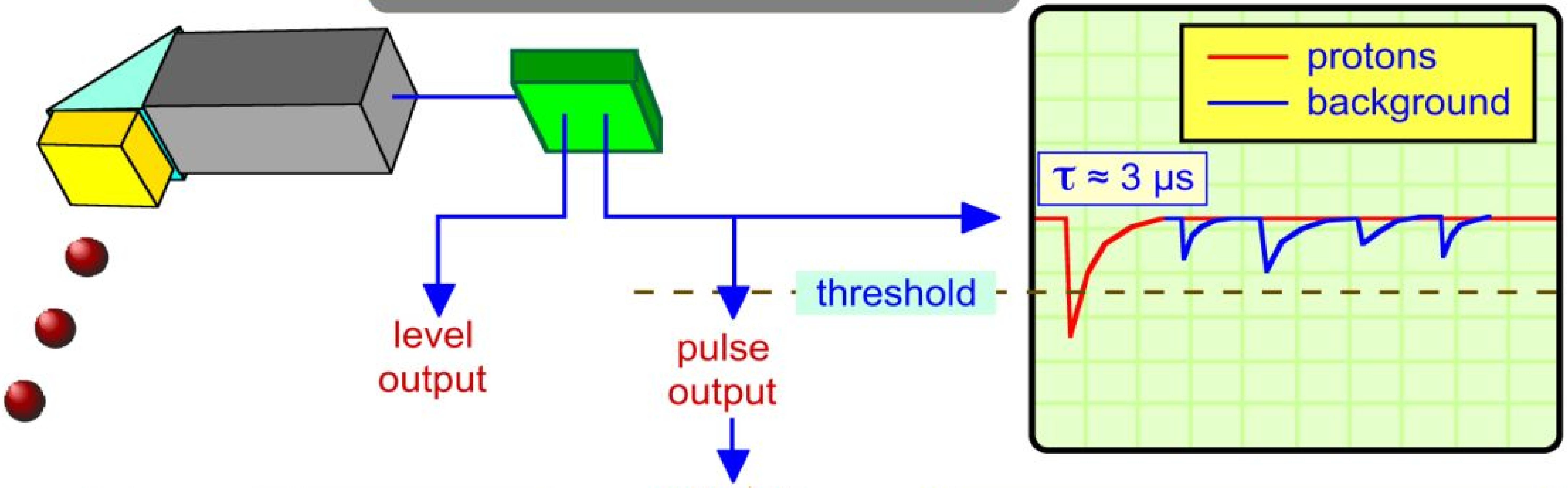
High precision translation stage

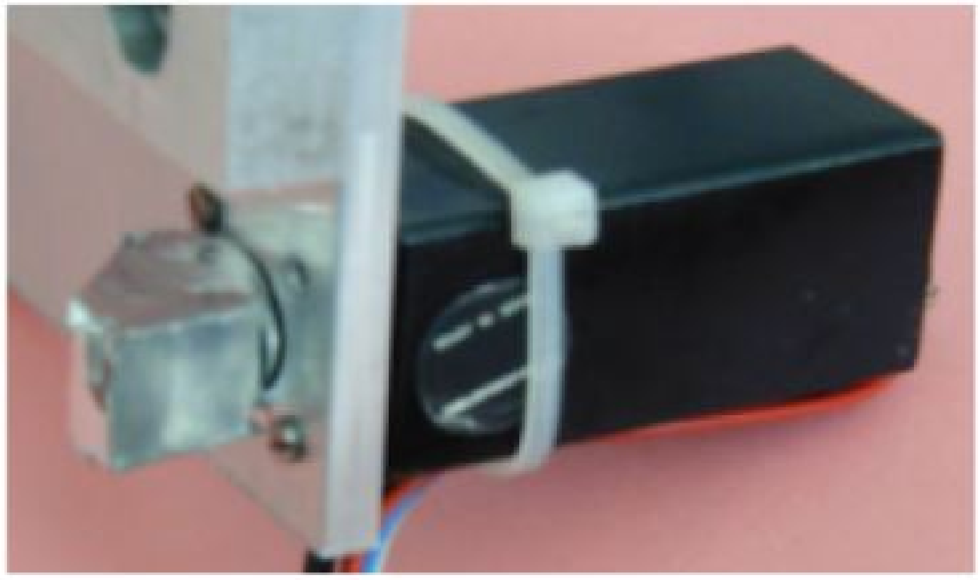
μ-SBBS

In this example the final collimator was a round hole of 500 μm diameter



single particle counting





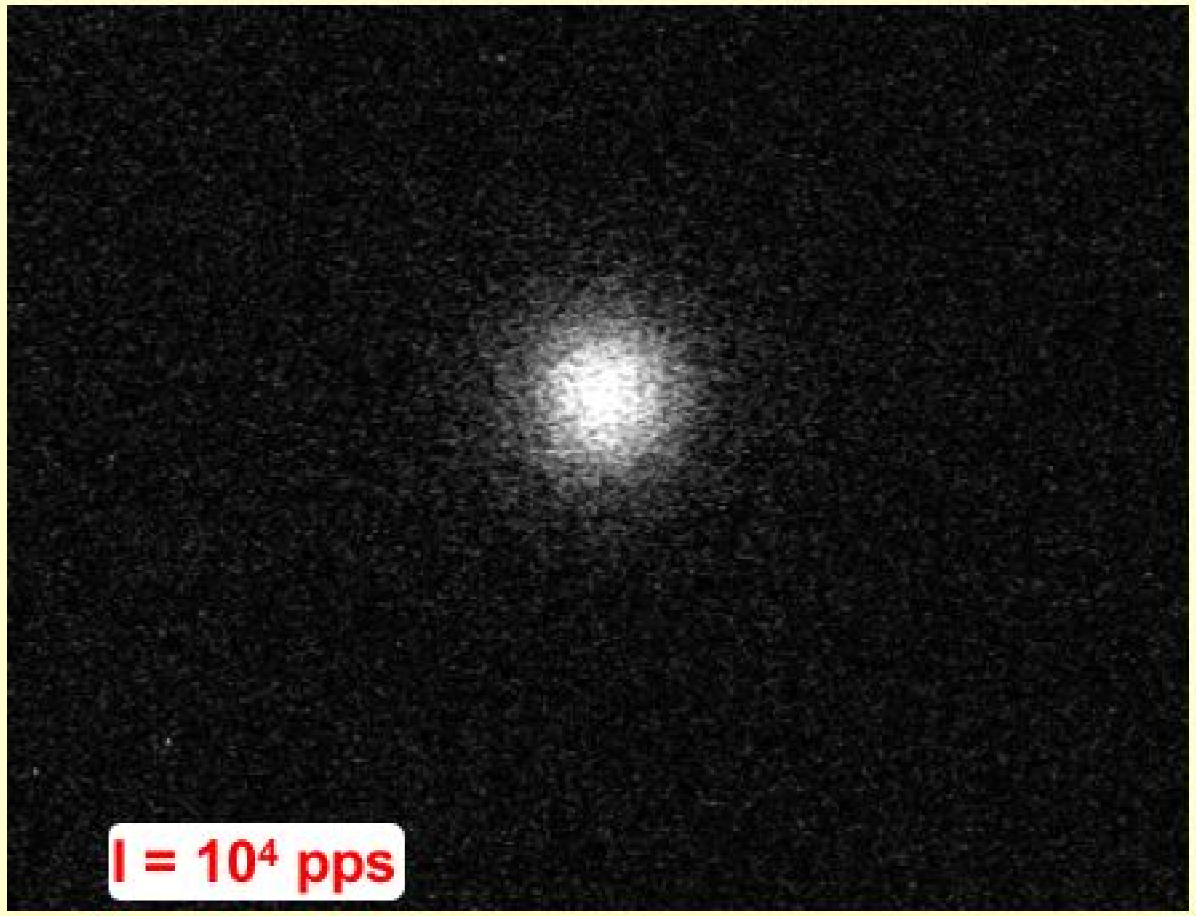
µ-SBBS

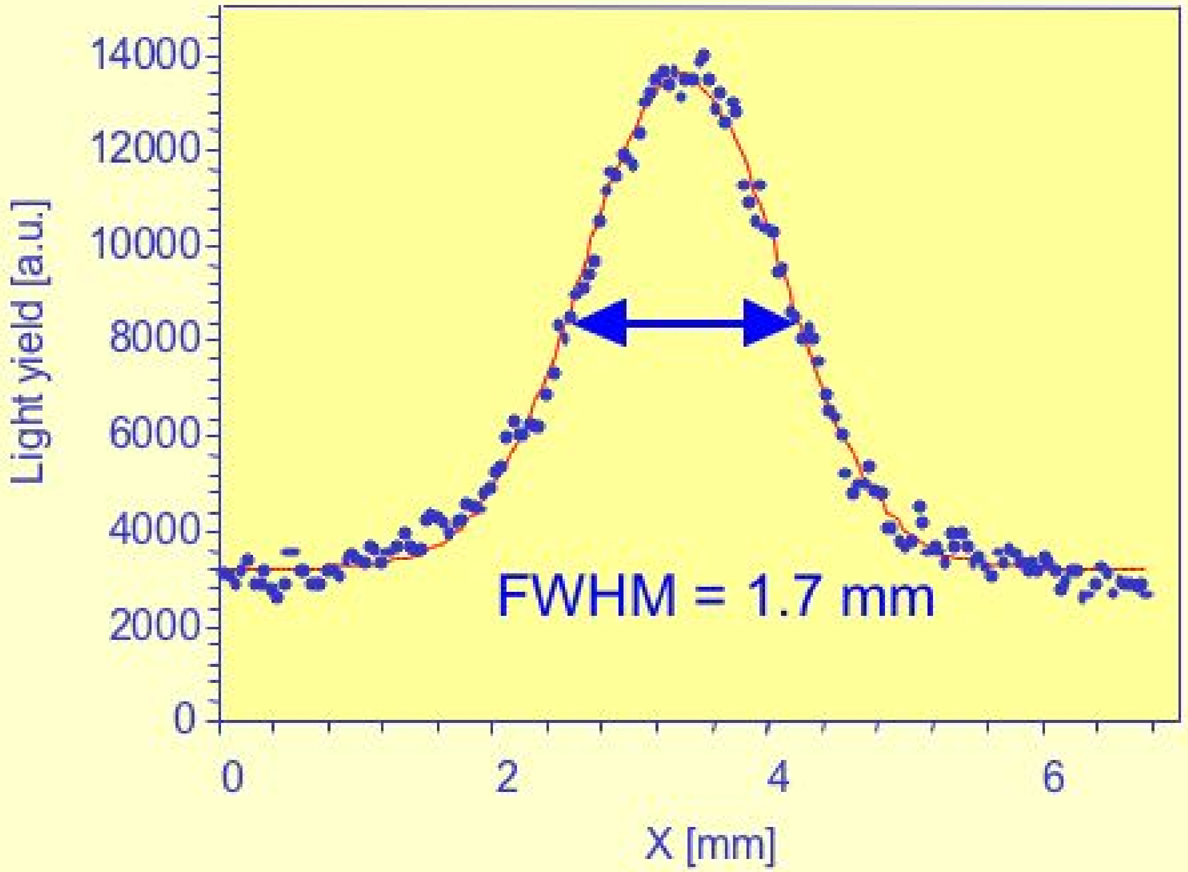
When the beam current is low enough (< 10^5 pps) we can count the beam particles one by one

imaging: CsI(Tl) scintillating plate with CCD video camera
electrons (^{90}Sr beta source)

2 beta particles, endpoint E= 546, 2280 keV

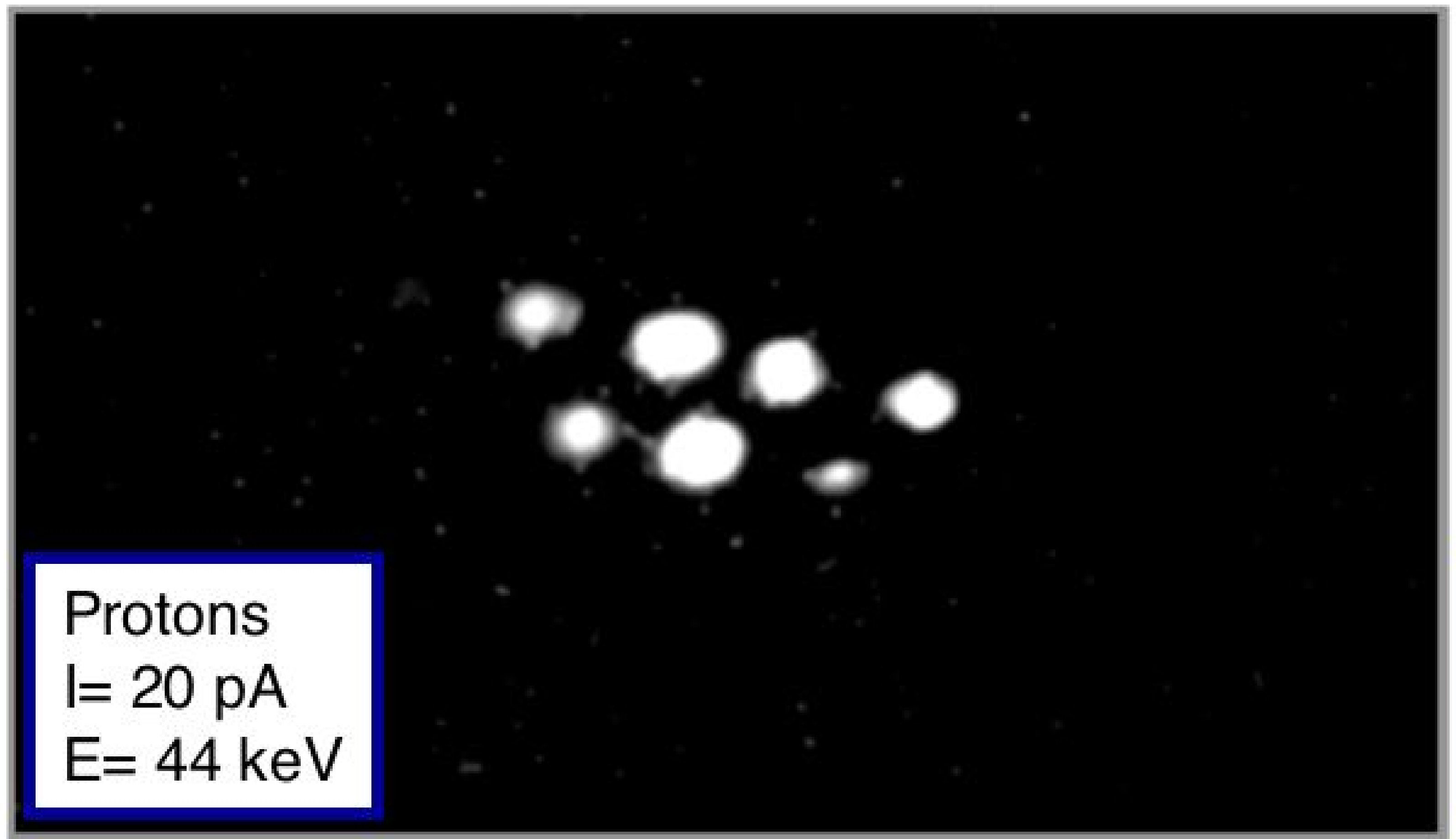
- Collimated source, collimator diameter = 2 mm
- CsI(Tl) scintillator plate 50x50x2 mm^3

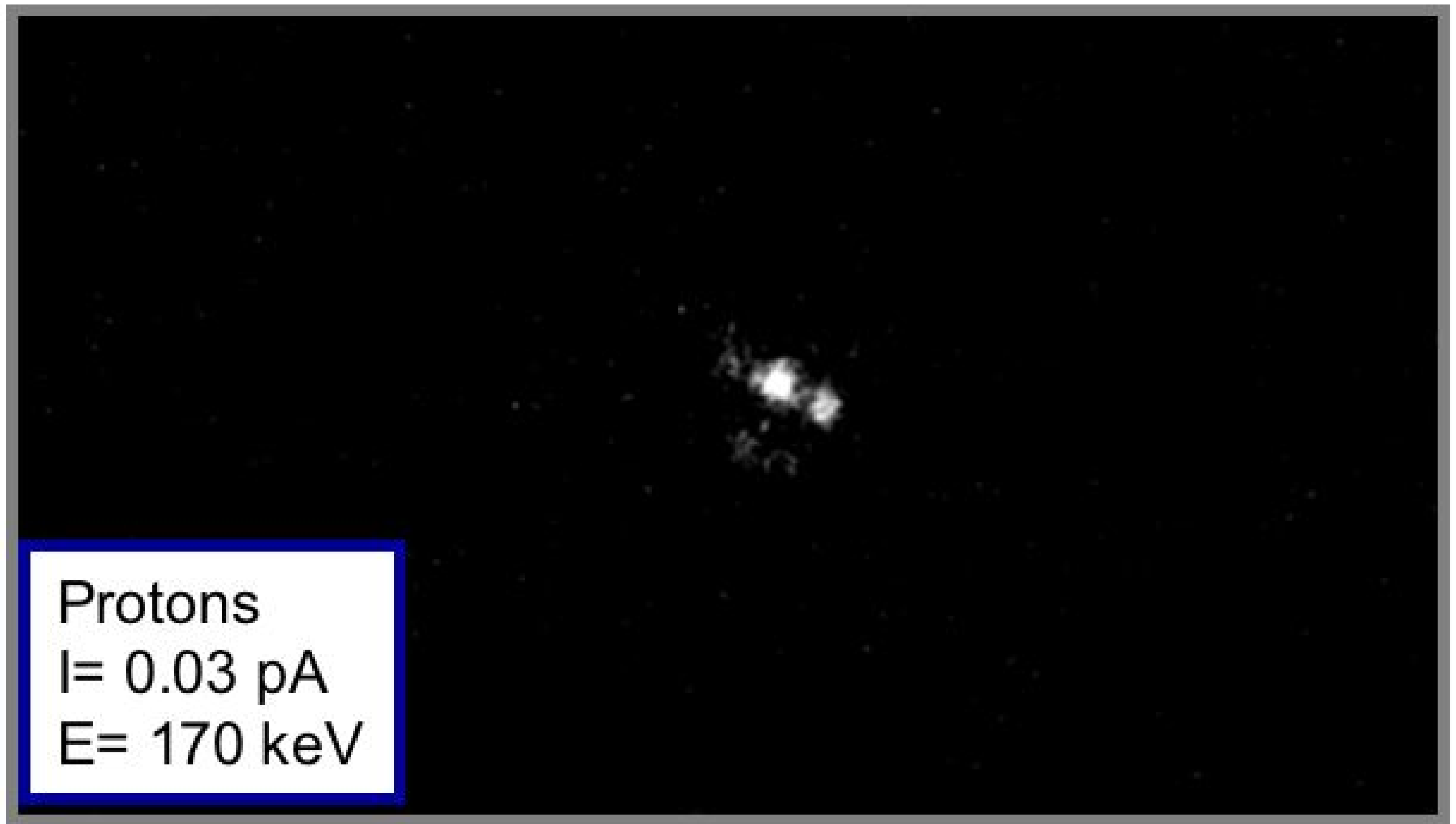

I = 10^4 pps

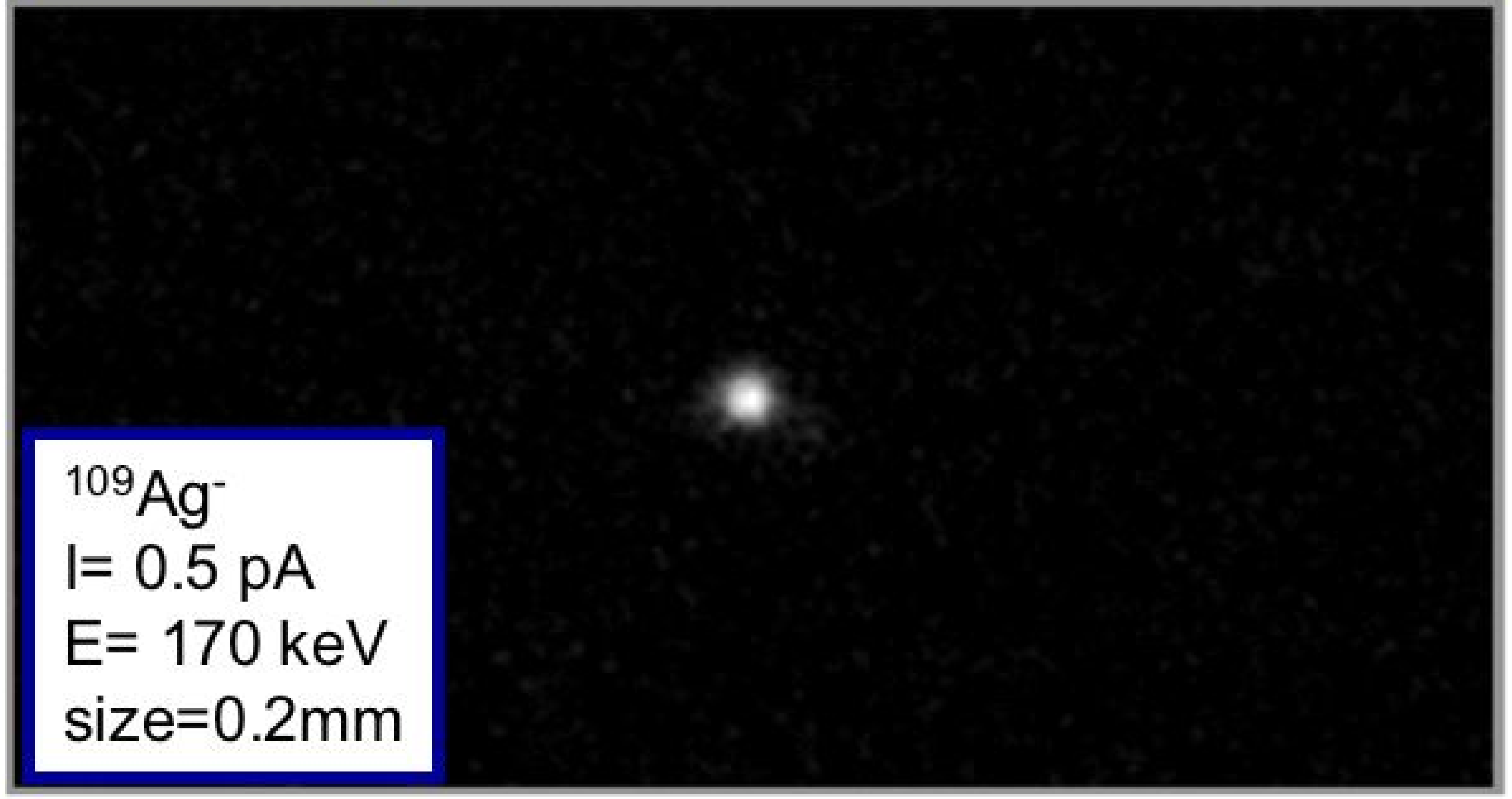


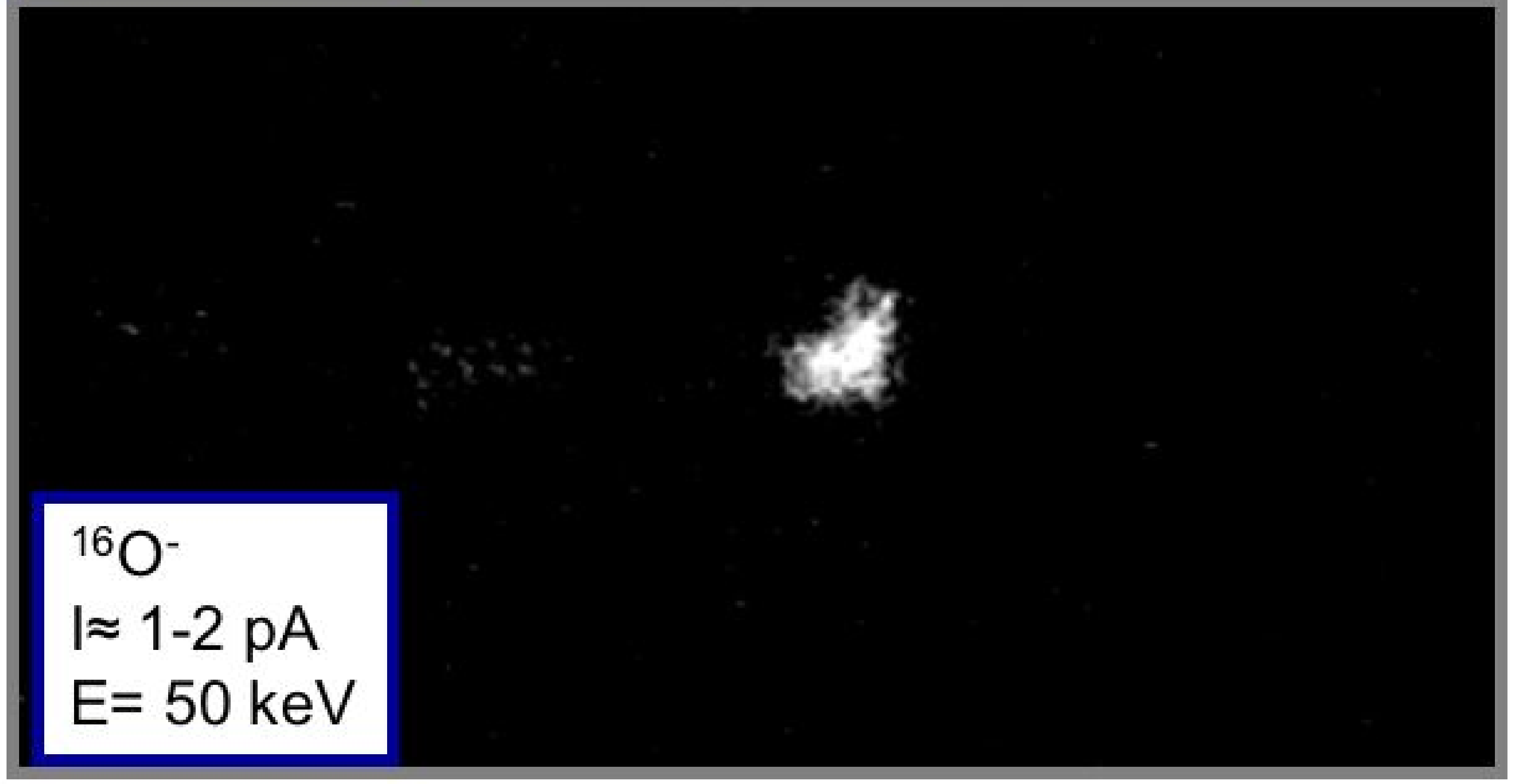
FWHM = 1.7 mm

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

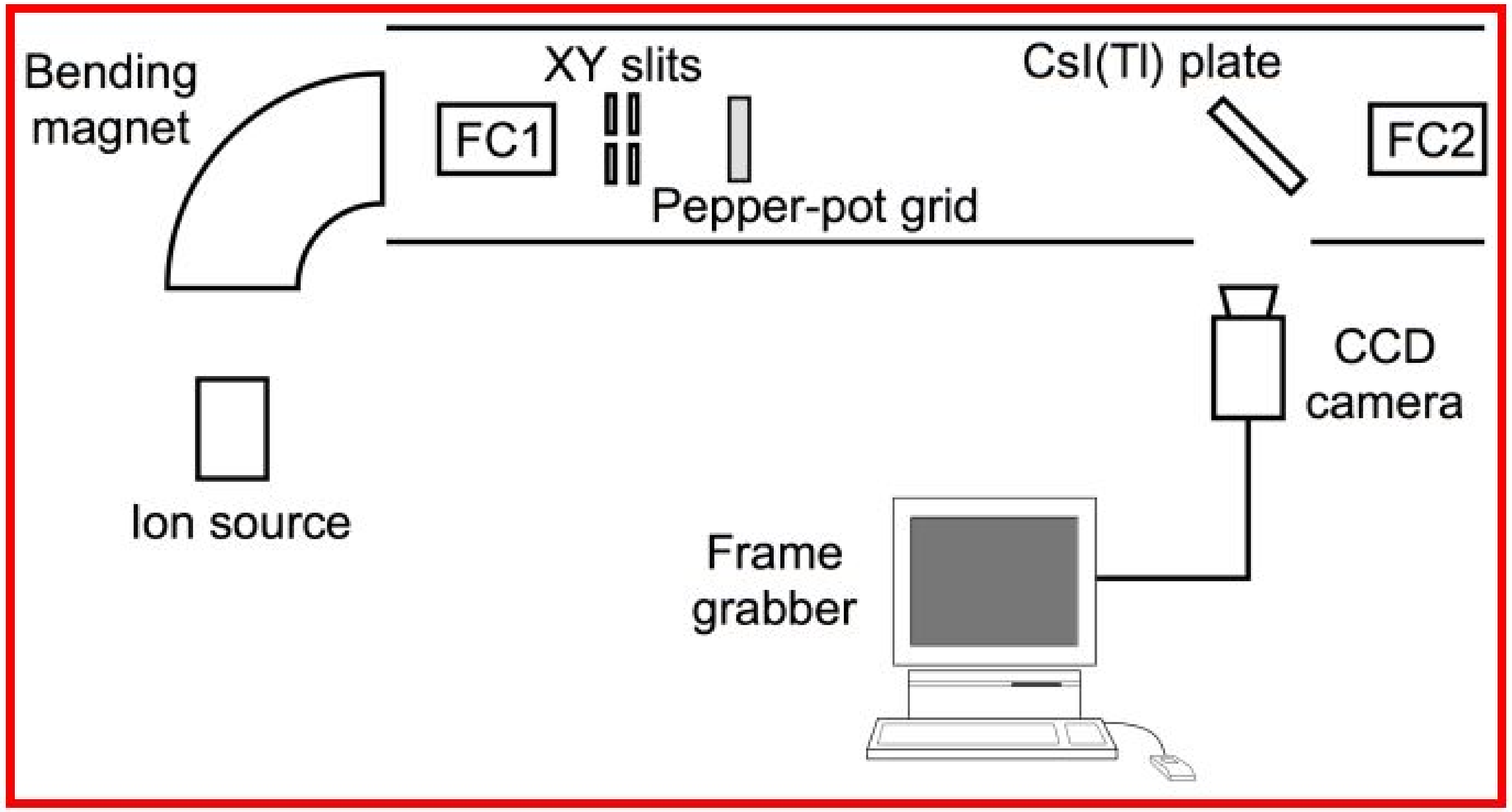

Protons
I= 20 pA
E= 44 keV


Protons
I= 0.03 pA
E= 170 keV


$^{109}\mathrm{Ag}^-$
I= 0.5 pA
E= 170 keV
size=0.2mm


$^{16}\mathrm{O}^-$
I≈ 1-2 pA
E= 50 keV

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



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

This setup allowed us to build the spectrum of the Tandem injector and to identify impurities and species accelerated months before

Mass n.	Ion species	Beam current [nA] FC1	Beam current [pA] CsI(Tl)
12	C^-	-	≈ 1.3
16	O^-	325	CCD saturation
17	$^{17}O^-$	-	≈ 3.2
18	$^{18}O^-, H_2O^-$	-	≈ 2.4
19	F^-	-	≈ 0.3
24	C_2^-	-	≈ 0.4
27	Al^-	-	≈ 3.4
(*) 32	O_2^-, S^-	1	≈ 5.3
34	$^{34}S^-, H_2O_2^-$	-	≈ 5.0
35	Cl^-	-	≈ 3.8
43	AlO^-	48	CCD saturation
58	$^{58}Ni^-$	16	CCD saturation
60	$^{60}Ni^-$	6	CCD saturation
62	$^{62}Ni^-$	-	≈ 4.2
(*) 74	$^{39}K^{35}Cl^-$	2	≈ 9.4
76	$^{39}K^{37}Cl^- + {}^{41}K^{35}Cl^-$	-	≈ 4.2
107	$^{107}Ag^-$	11	CCD saturation
109	$^{109}Ag^-$	9	CCD saturation

EXCYT beam diagnostics: LEBI
Low Energy Beam Imager-Identifier

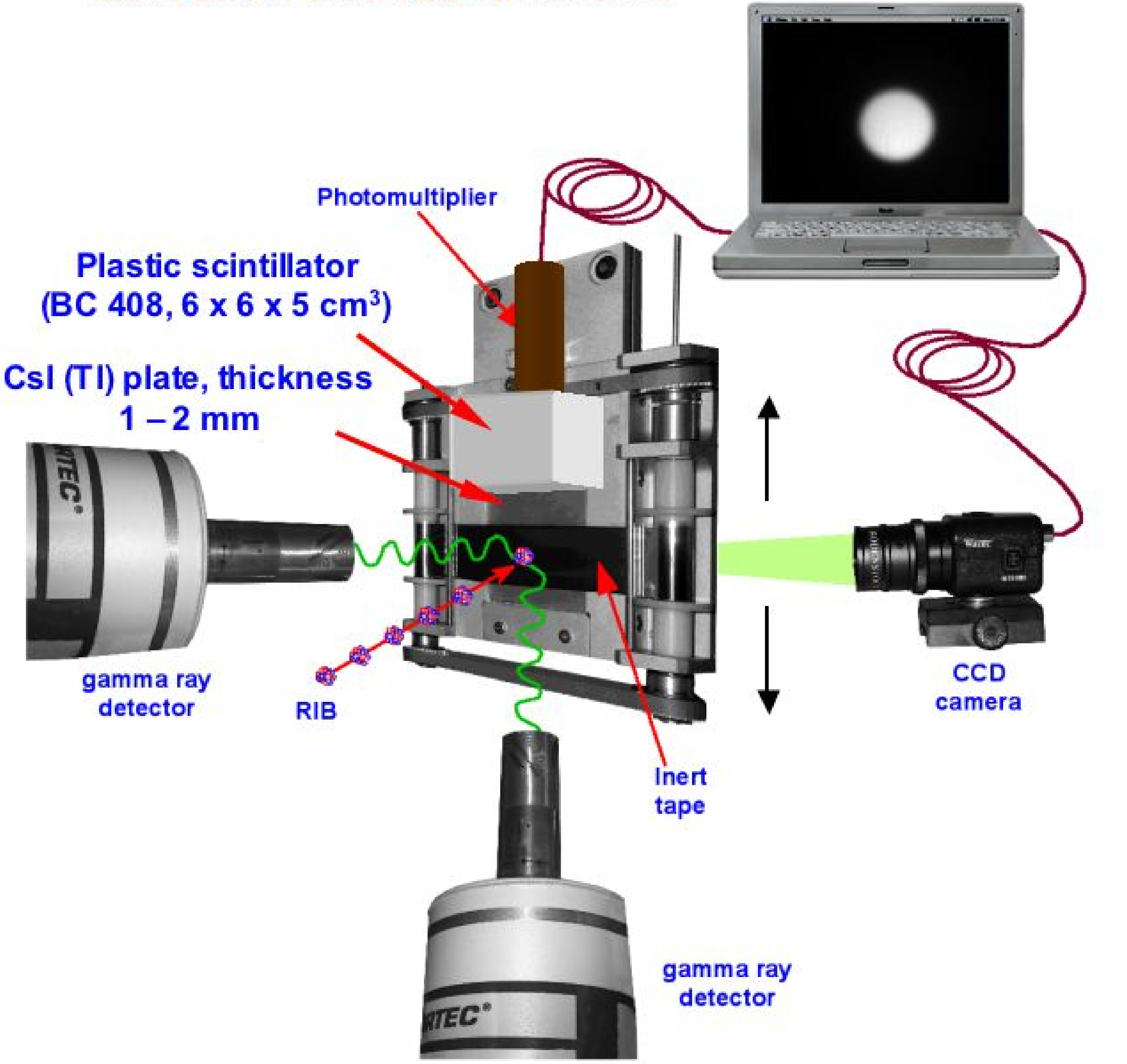
A complex diagnostics station that combines several techniques for beam detection and identification

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

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

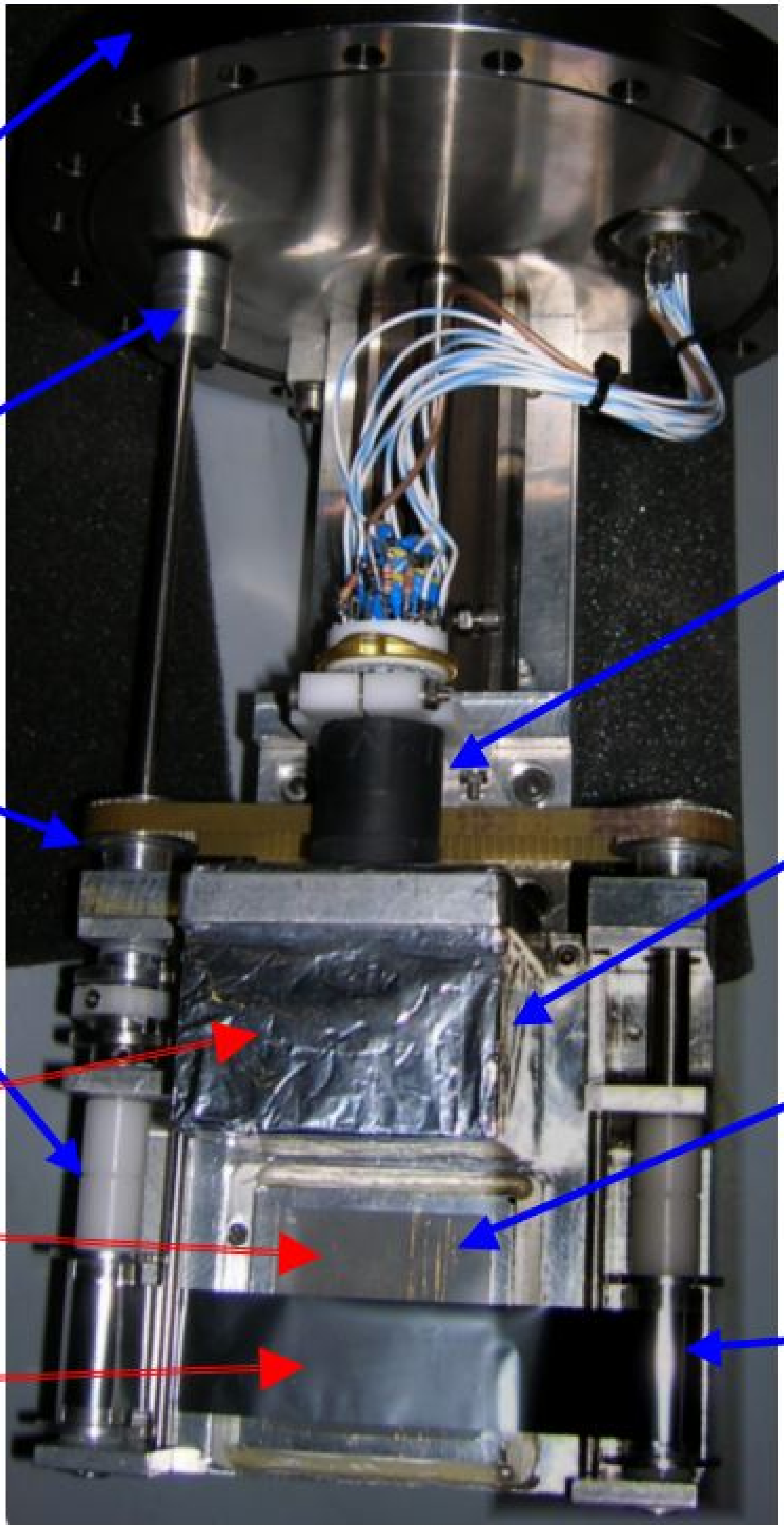
Plastic scintillator + PMT for radioactive decay counting of implanted RIBs (determination of $T_{1/2}$)

Gamma detectors for RIBs spectroscopic fingerprinting



LEBI: Low Energy Beam Imager-Identifier

LEBI is the LNS solution for beam diagnostics of low energy radioactive beams.



step motor

tape transport system

Photomultiplier

Plastic scintillator BC 408

CsI (Tl) plate

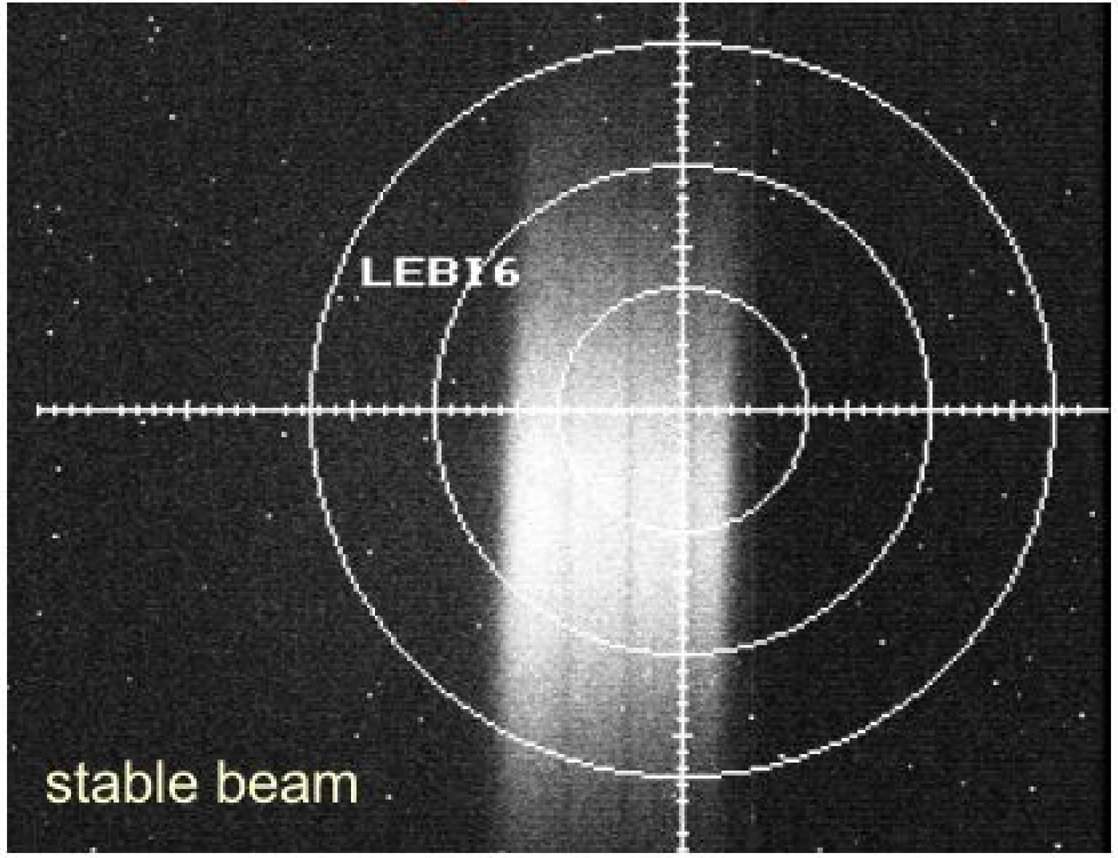
mylar tape 6 μm

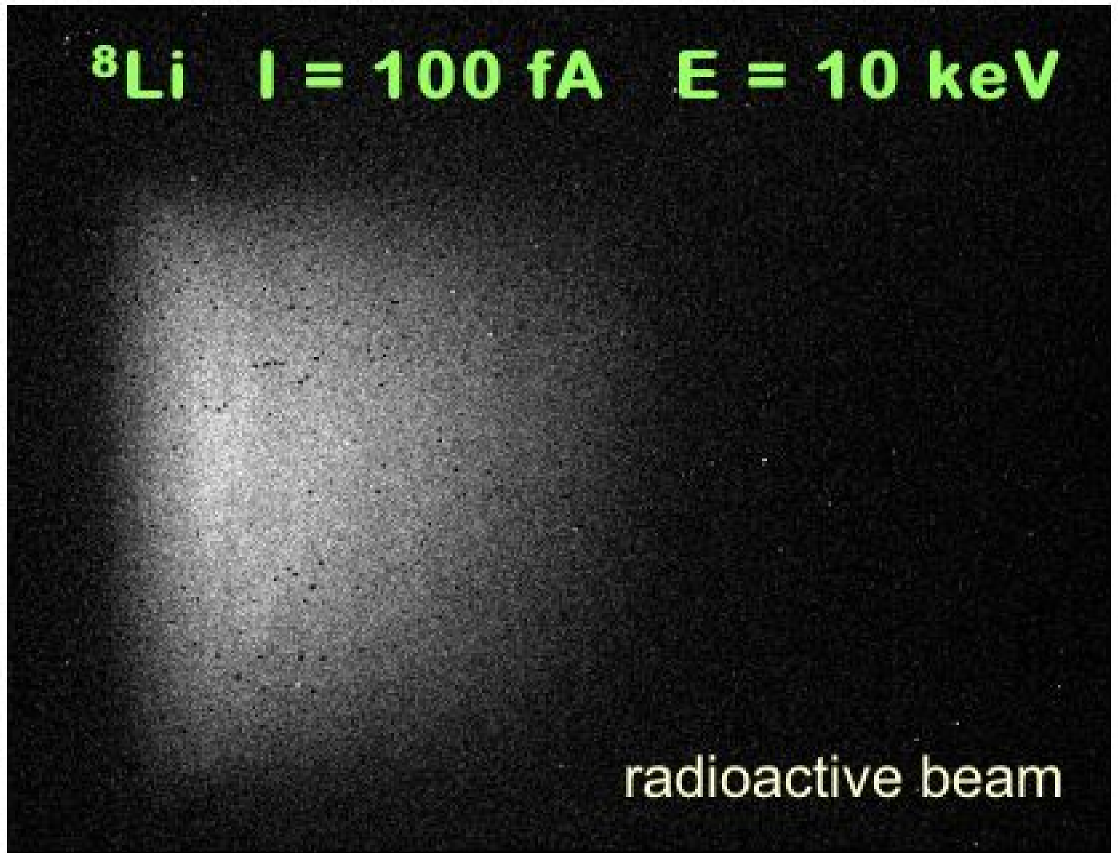
3 measuring positions

- **Beam rate measurement**
- **Imaging of Stable (pilot) beams**
- **Imaging of radioactive beams**

LEBI: *Low Energy Beam Imager-Identifier*

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





energy range
10 keV ÷ 300 keV

Sensitivity for beam imaging

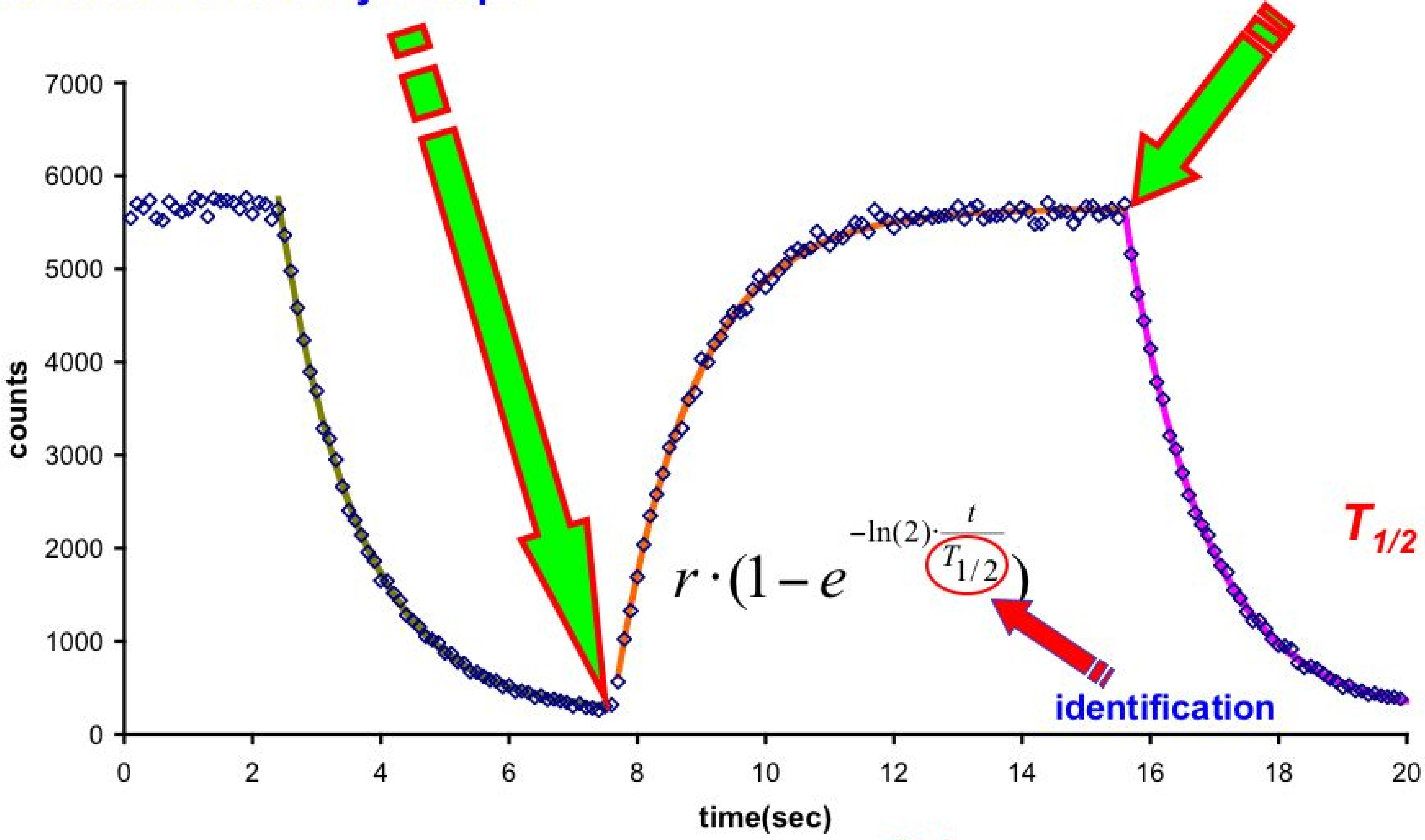
- $E_{threshold}$ = 5 keV
- $I_{stable\ beam}$ = 10^4 pps/mm^2
- $I_{radioactive\ beam}$ ~ 10^3 pps/mm^2
- resolution < 1mm

LEBI: Low Energy Beam Imager-Identifier

Identification of a radionuclide by means of its decay curve

the ^{8}Li beam is switched on:
implantation on the mylar tape

the beam is switched off



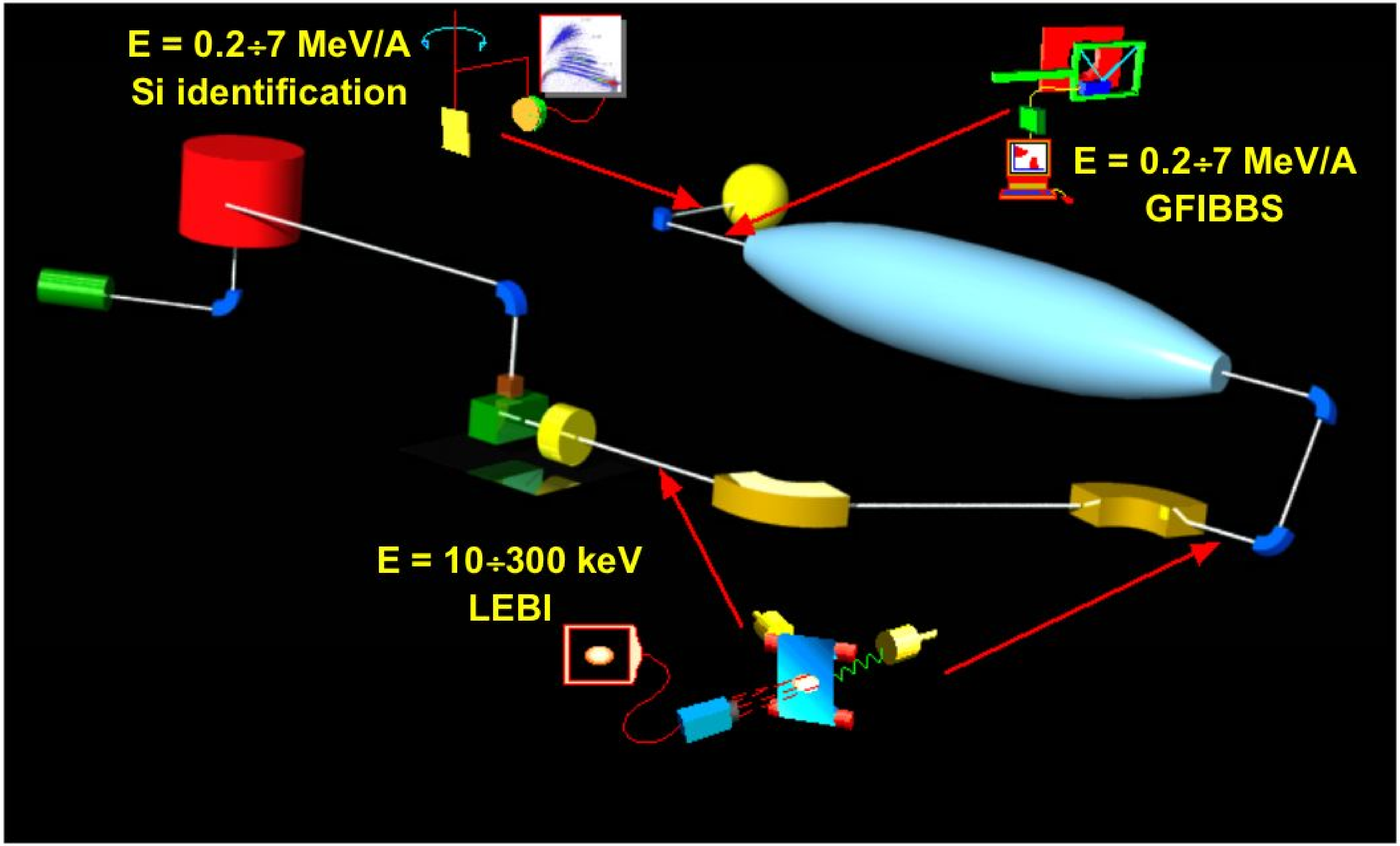
$$r\cdot\left(1-e^{-\ln(2)\cdot\frac{t}{T_{1/2}}}\right)$$

identification

$T_{1/2}$ = 840 ms

β decay curve

EXCYT beam diagnostics: what and where

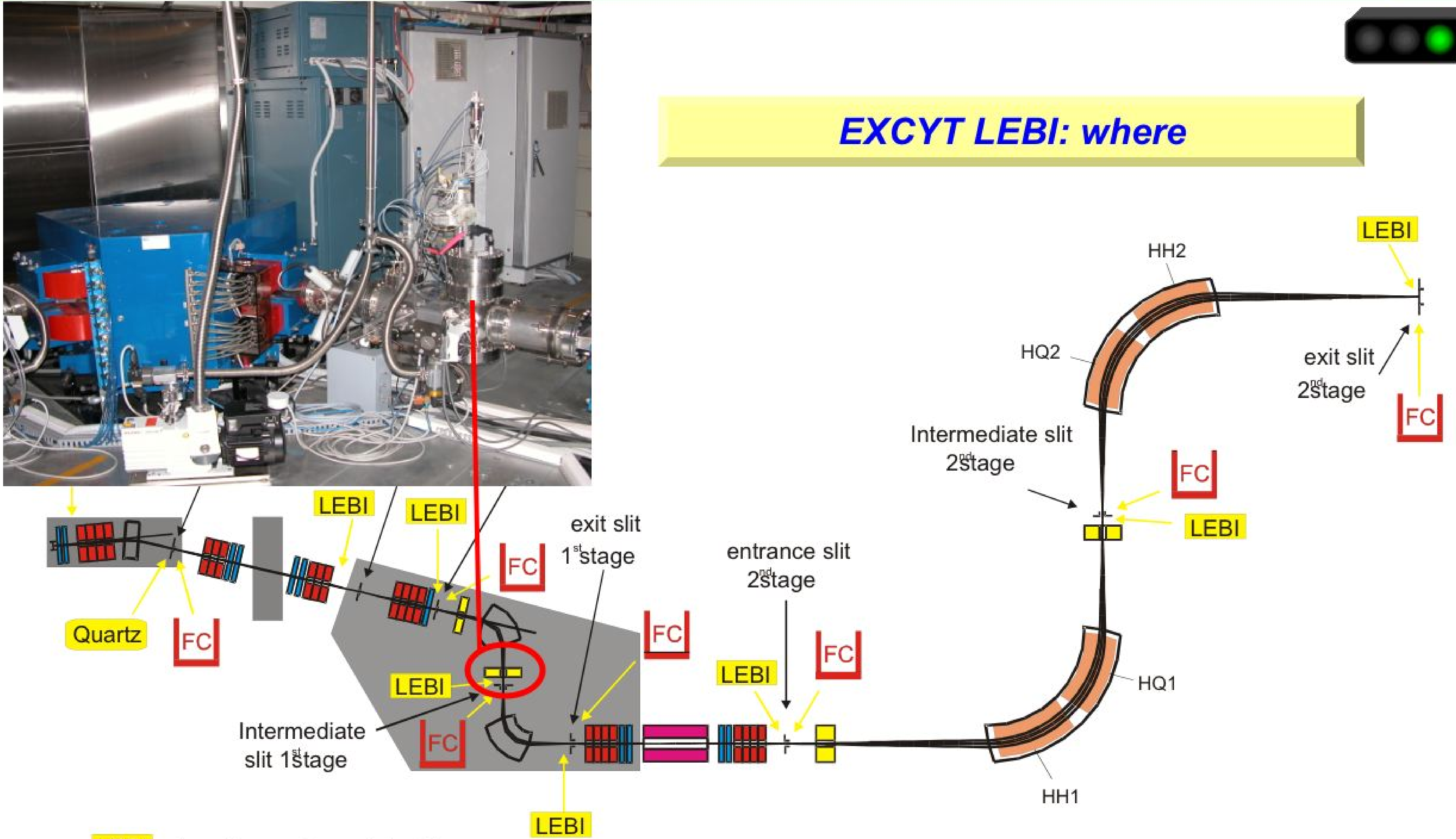


E = 0.2÷7 MeV/A
Si identification

E = 0.2÷7 MeV/A
GFIBBS

E = 10÷300 keV
LEBI

EXCYT LEBI: where

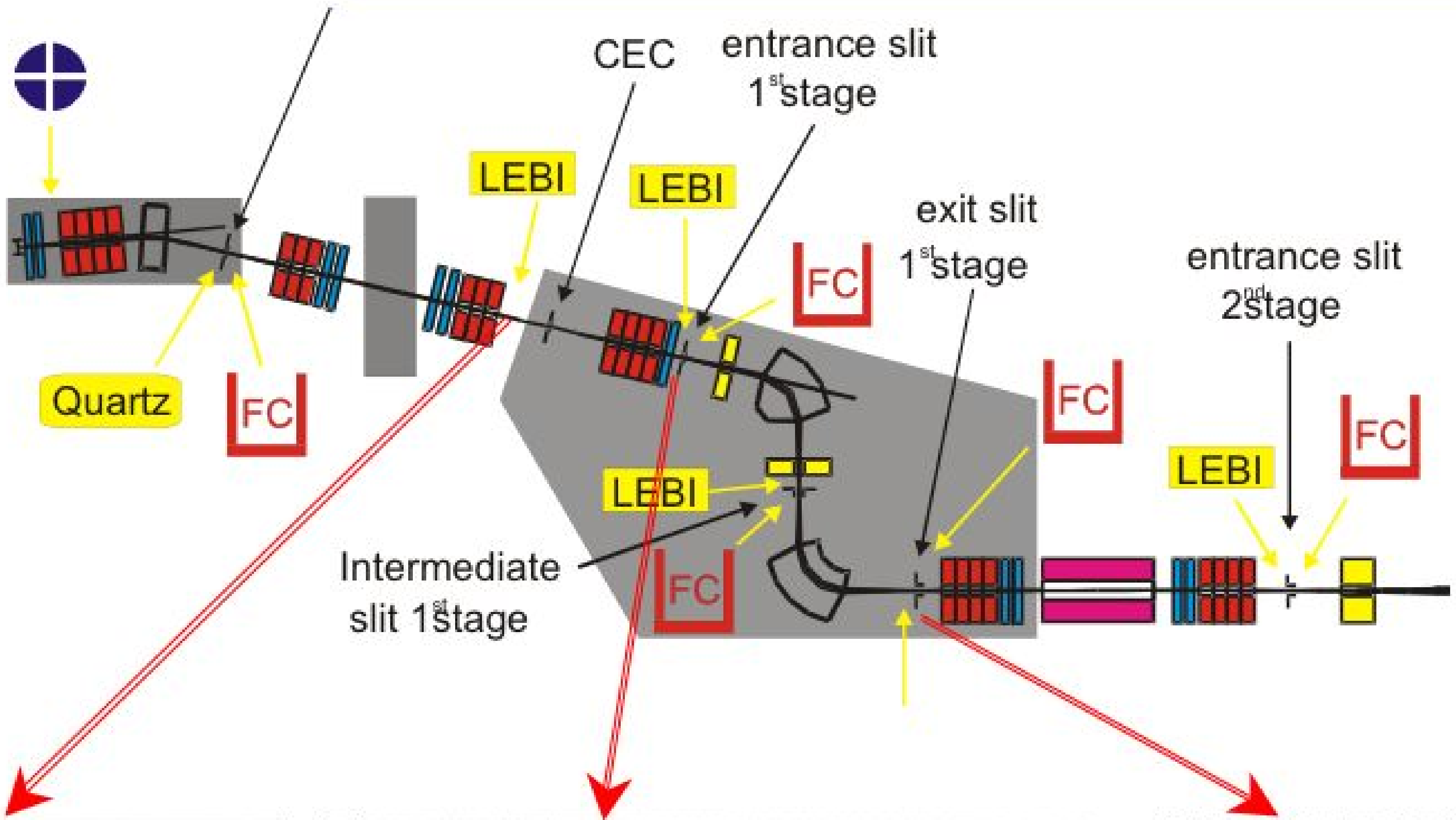


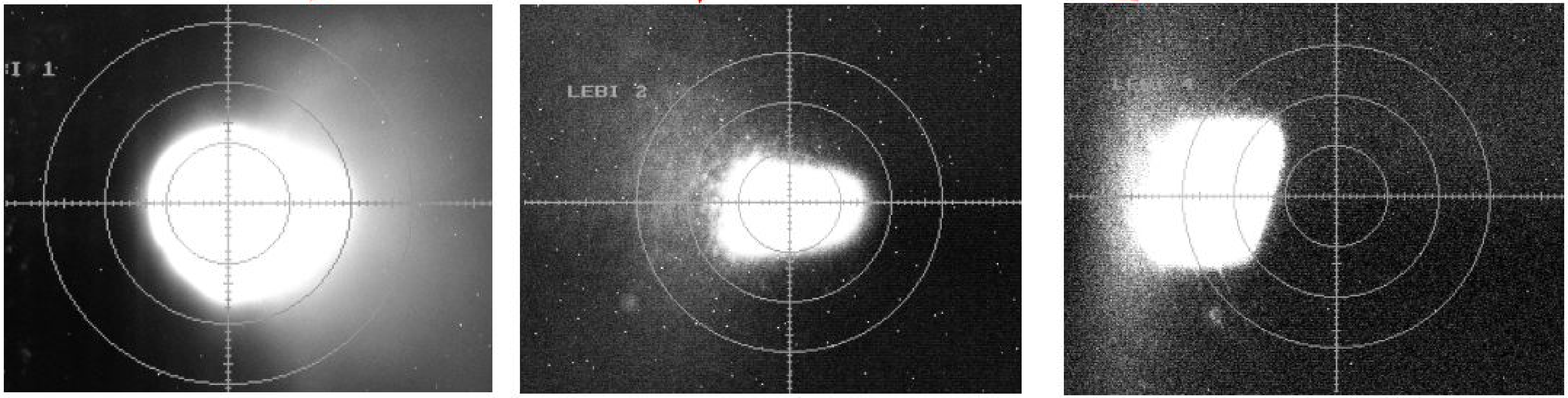
LEBI	Low Energy Beam Identifier
FC	Faraday Cup
⊕	Segmented Metal Plate

- 🟥 quadrupole
- 🟦 steerer
- 🟨 multipole

- 🟪 accelerator column
- 🟧 surface coils
- ⬜ shielding wall

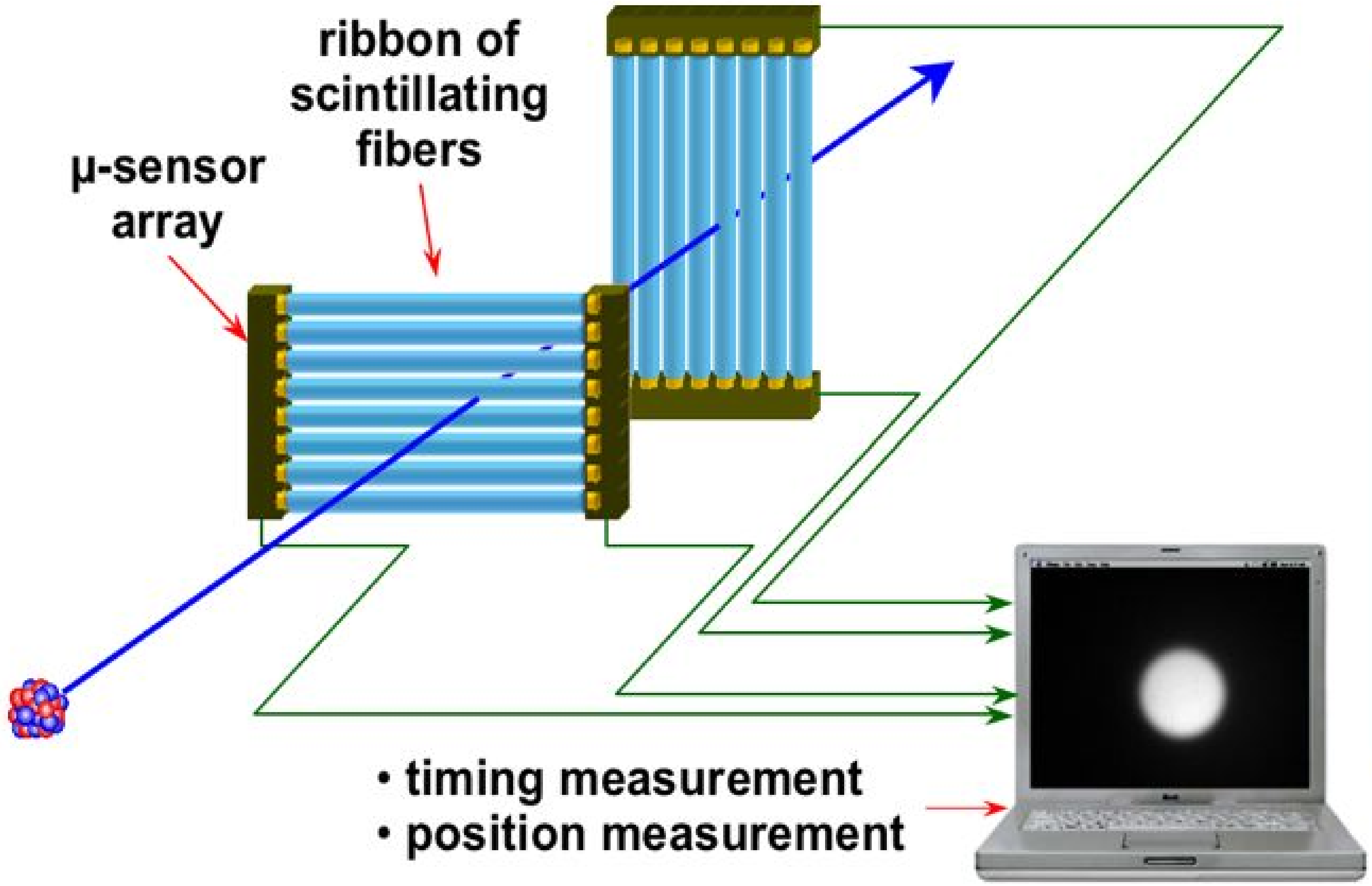
EXCYT LEBI: how fA ^{8}Li "miracle" beam transport





current development

Particle trackers: replacement of wire chambers?



- timing measurement
- position measurement

particle by particle beam tagging:

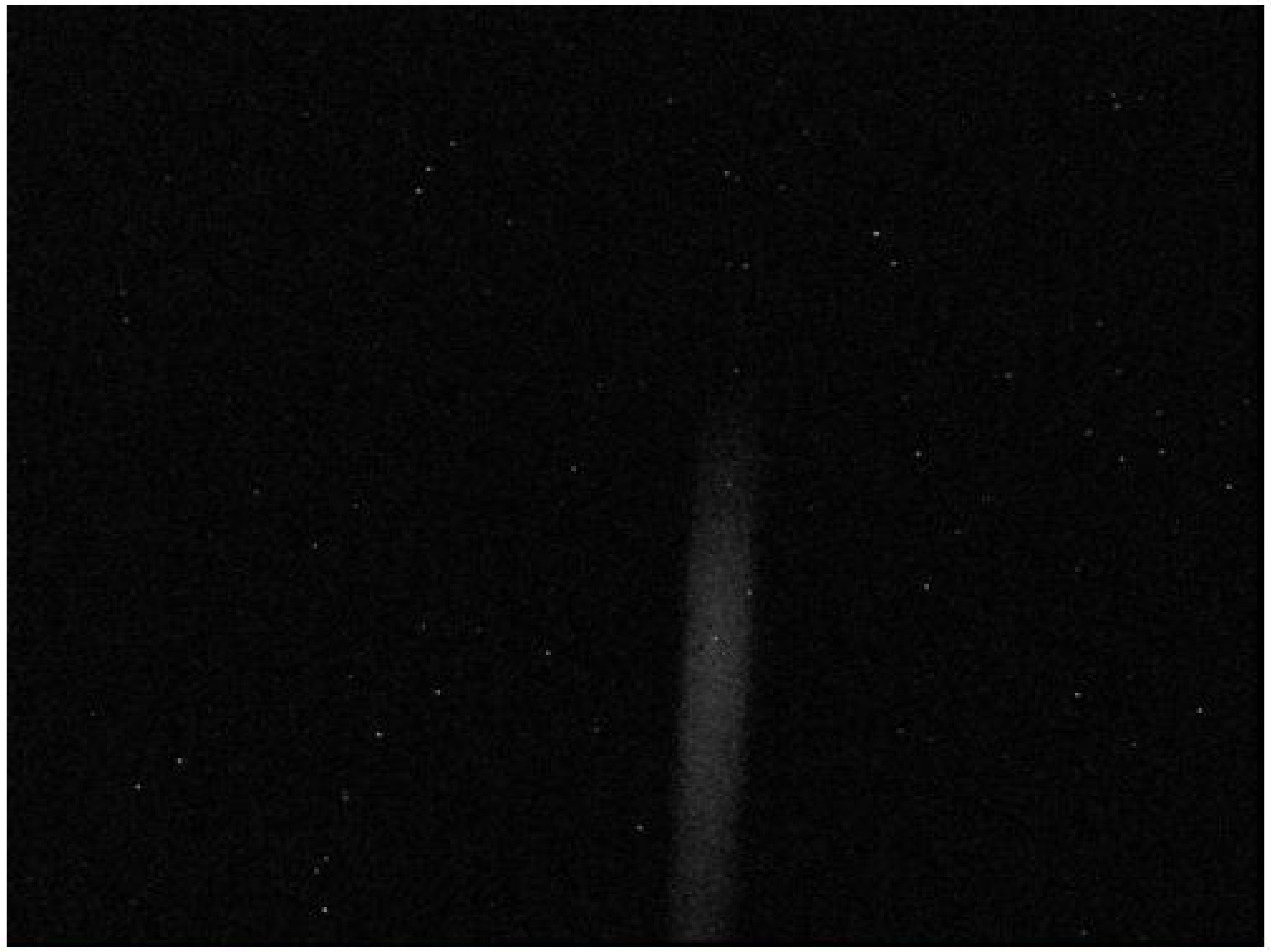
time

position

(A, Z) identification

FRIBS?

New diagnostics challenge



antiproton beam diagnostics at FAIR?

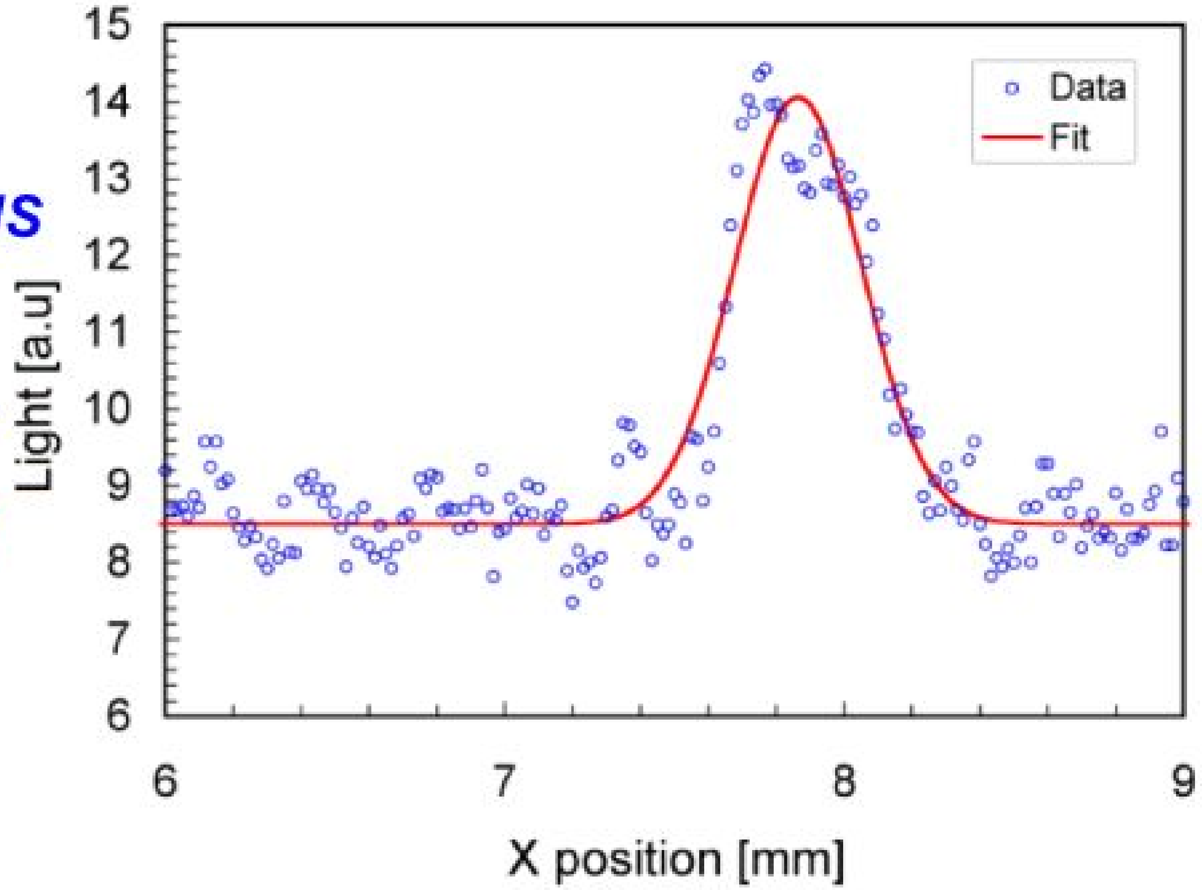
question raised by J.Harasimovicz

test with protons at LNS

180 keV, 5 pA

ultra-thin scintillator

standard video CCD

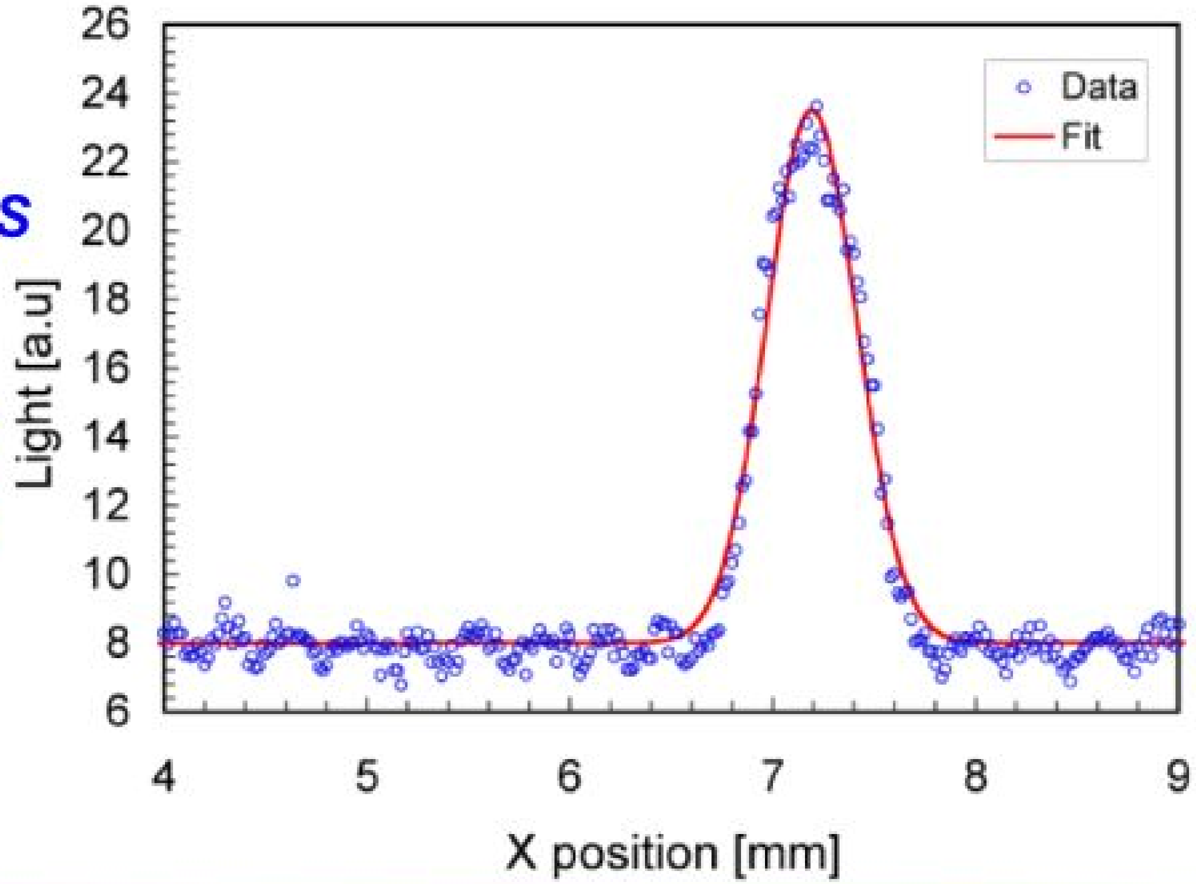


test with protons at LNS

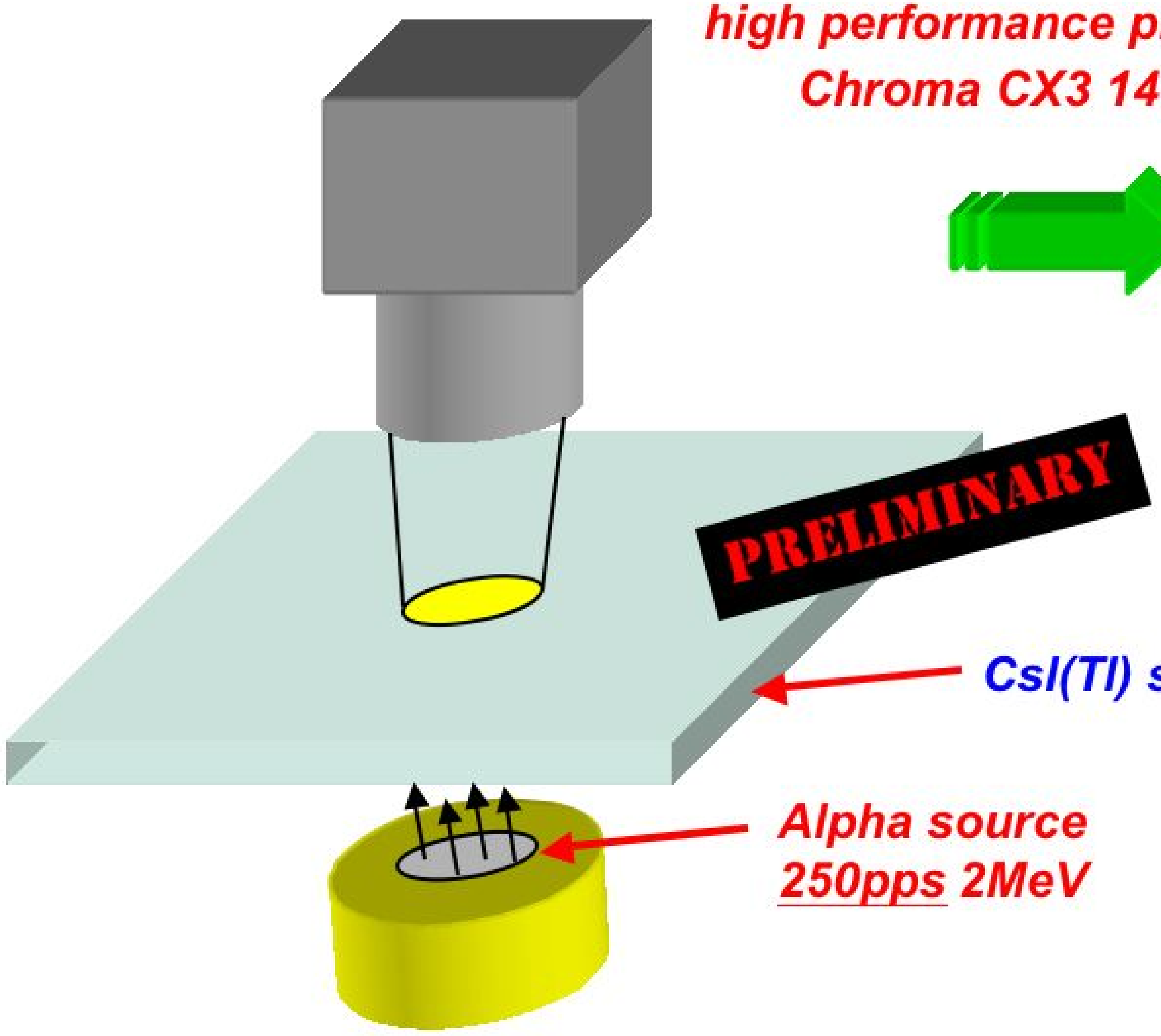
20 keV, 700 pA

ultra-thin scintillator

standard video CCD



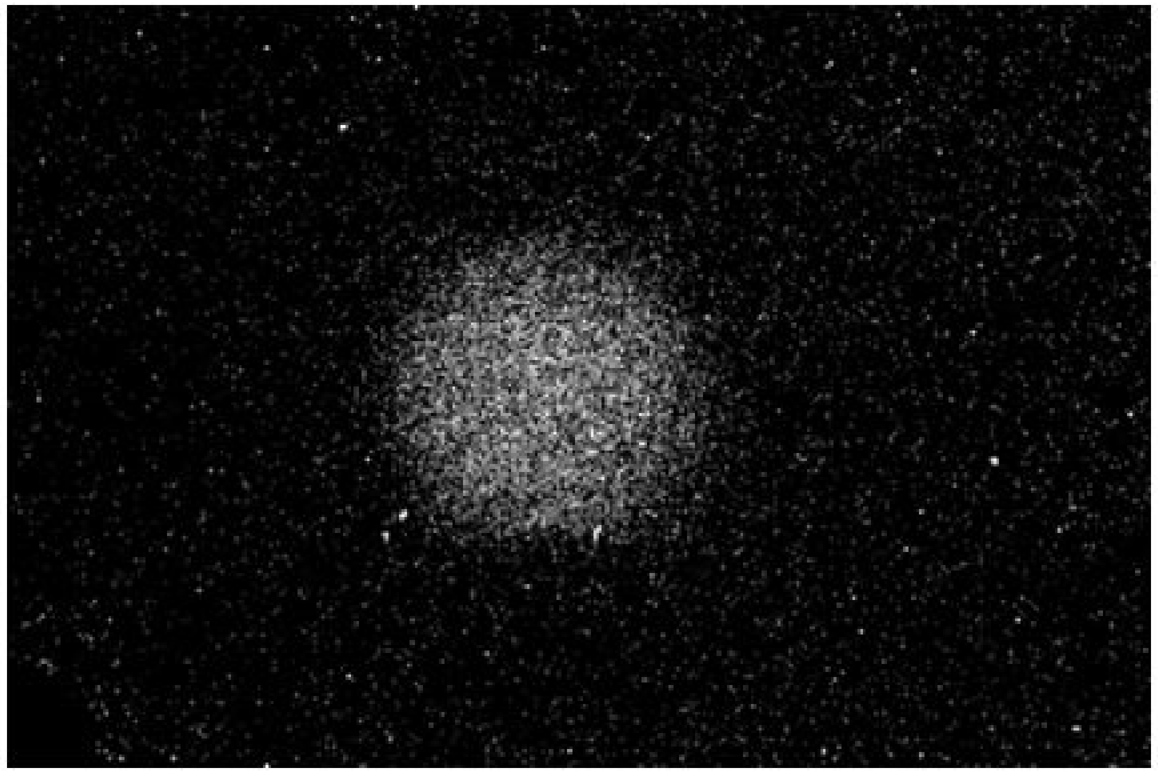
Pushing scintillator imaging to the limits...



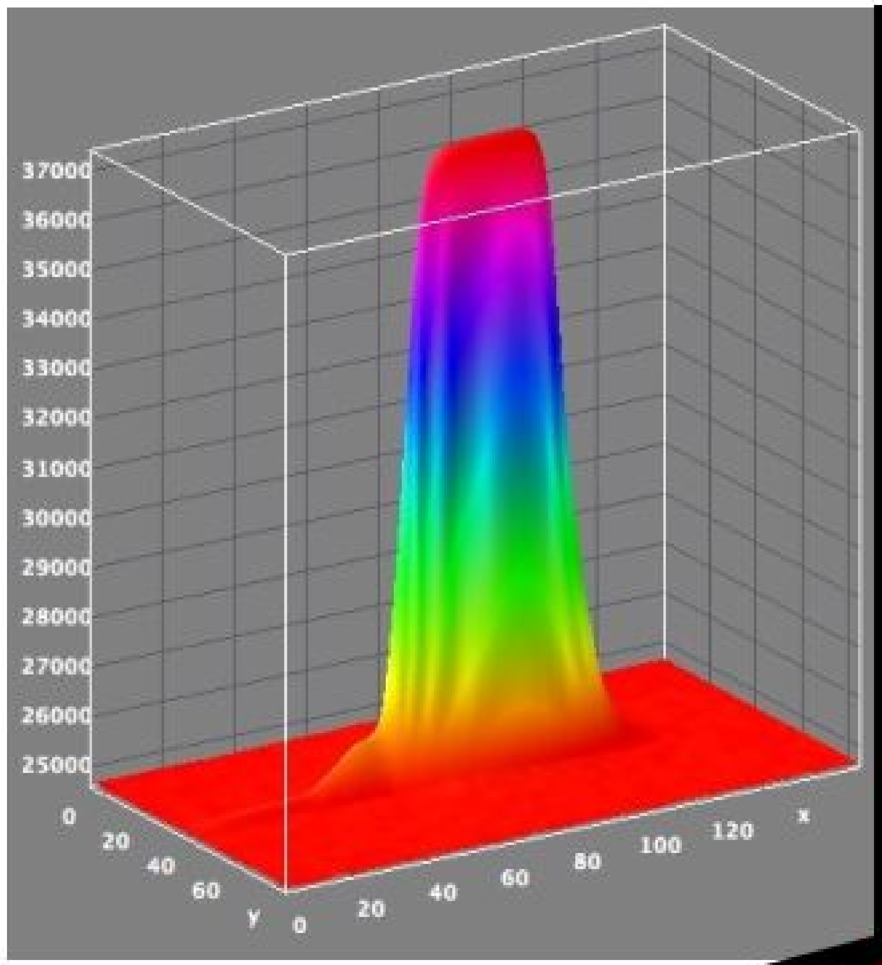
high performance photocamera
Chroma CX3 14-bit CCD

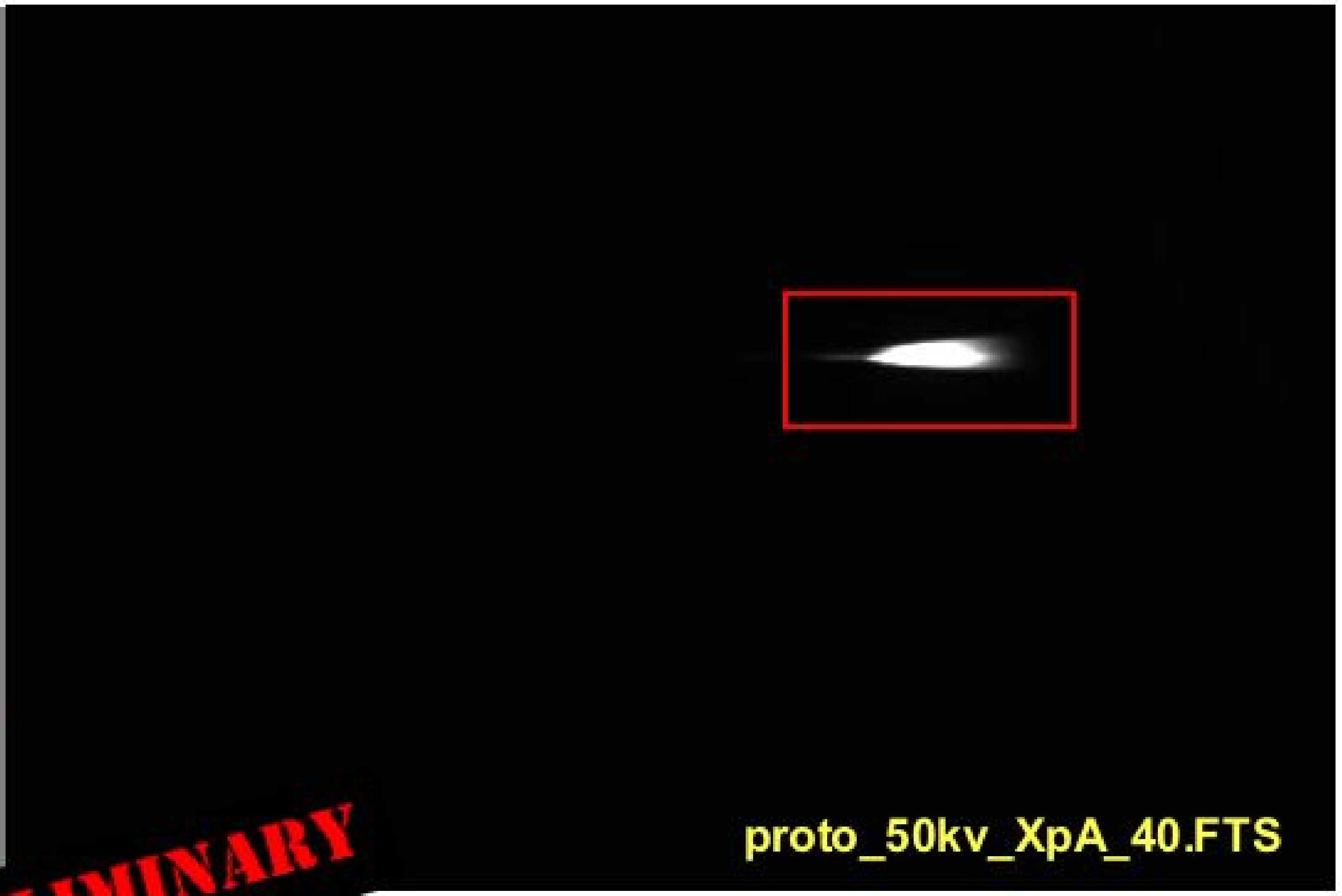
CsI(Tl) scintillator

Alpha source
250pps 2MeV



Last minute test (with J.Harasimowicz)





screen = CsI

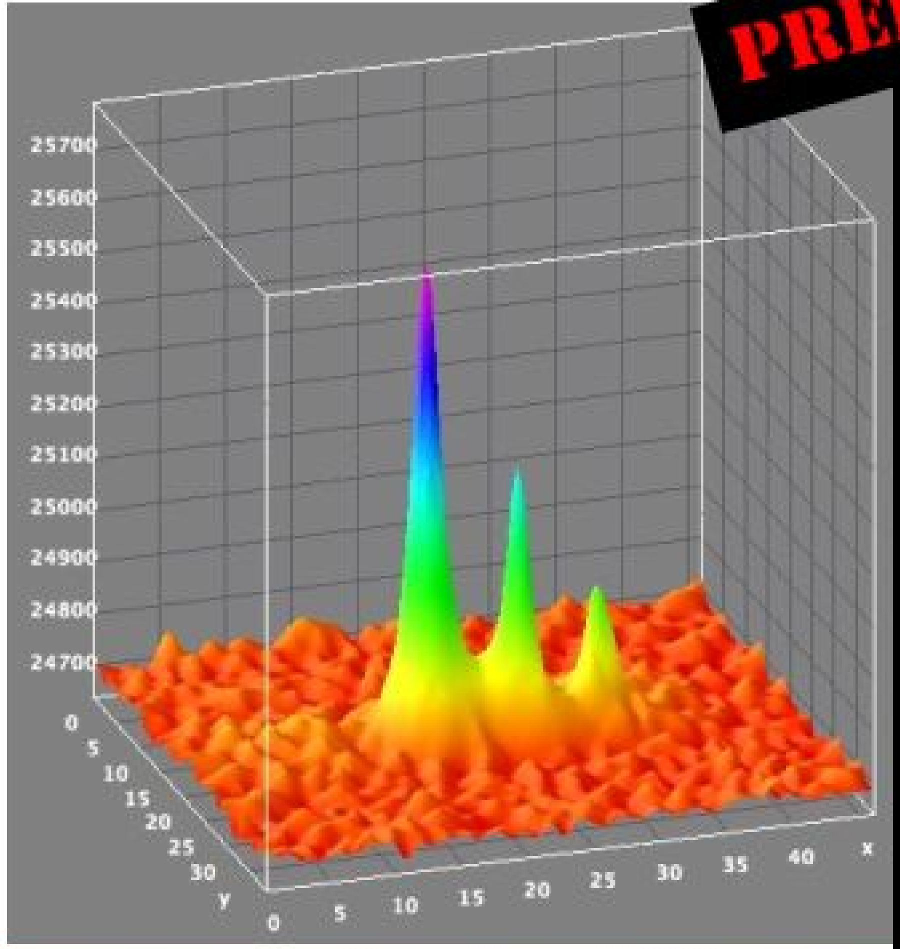
beam = protons

E = 50keV

I ≈ 5pA [100pA/20]

$t_{exposure}$ = 60s

PRELIMINARY



screen = CsI

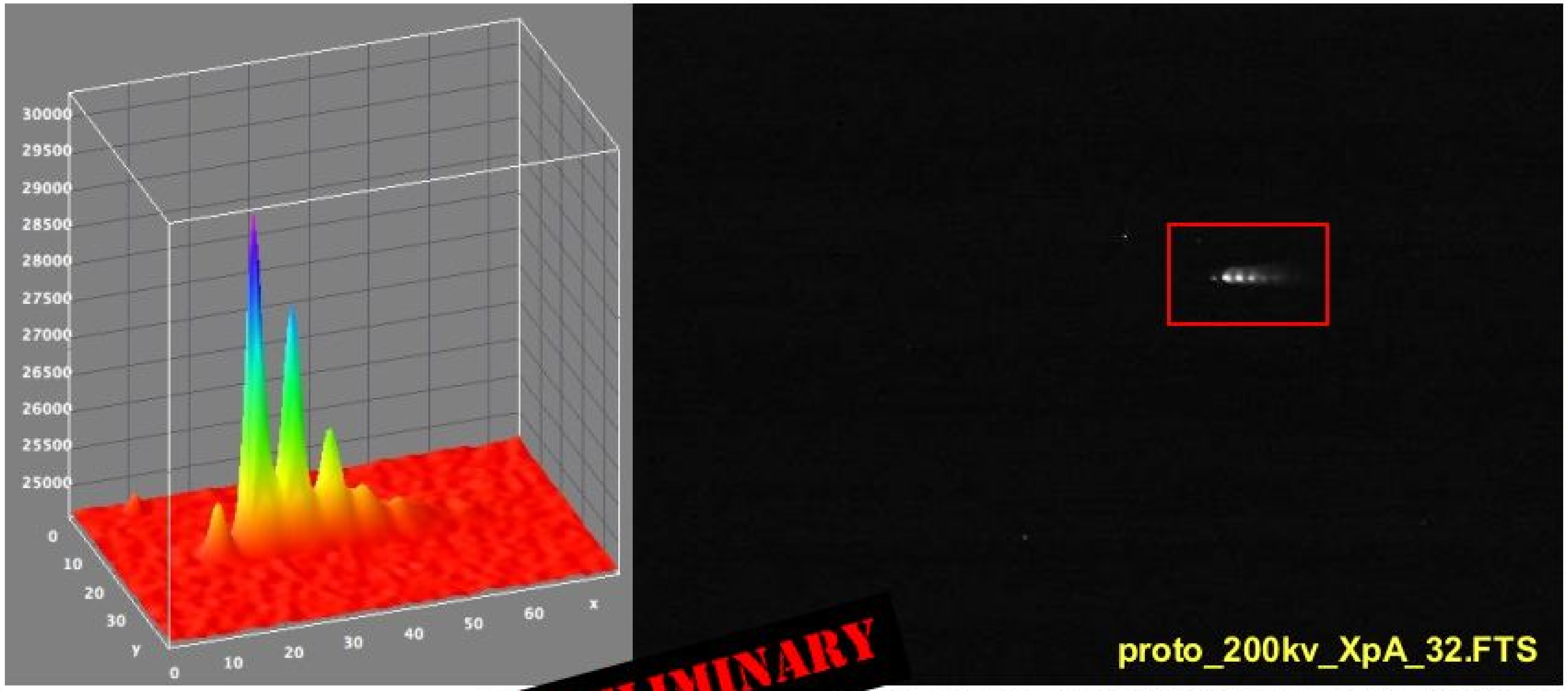
beam = protons

E = 200keV

I ≈ 2.5fA [5pA/2000]

$t_{exposure}$ = 20s

Last minute test (with J.Harasimowicz)



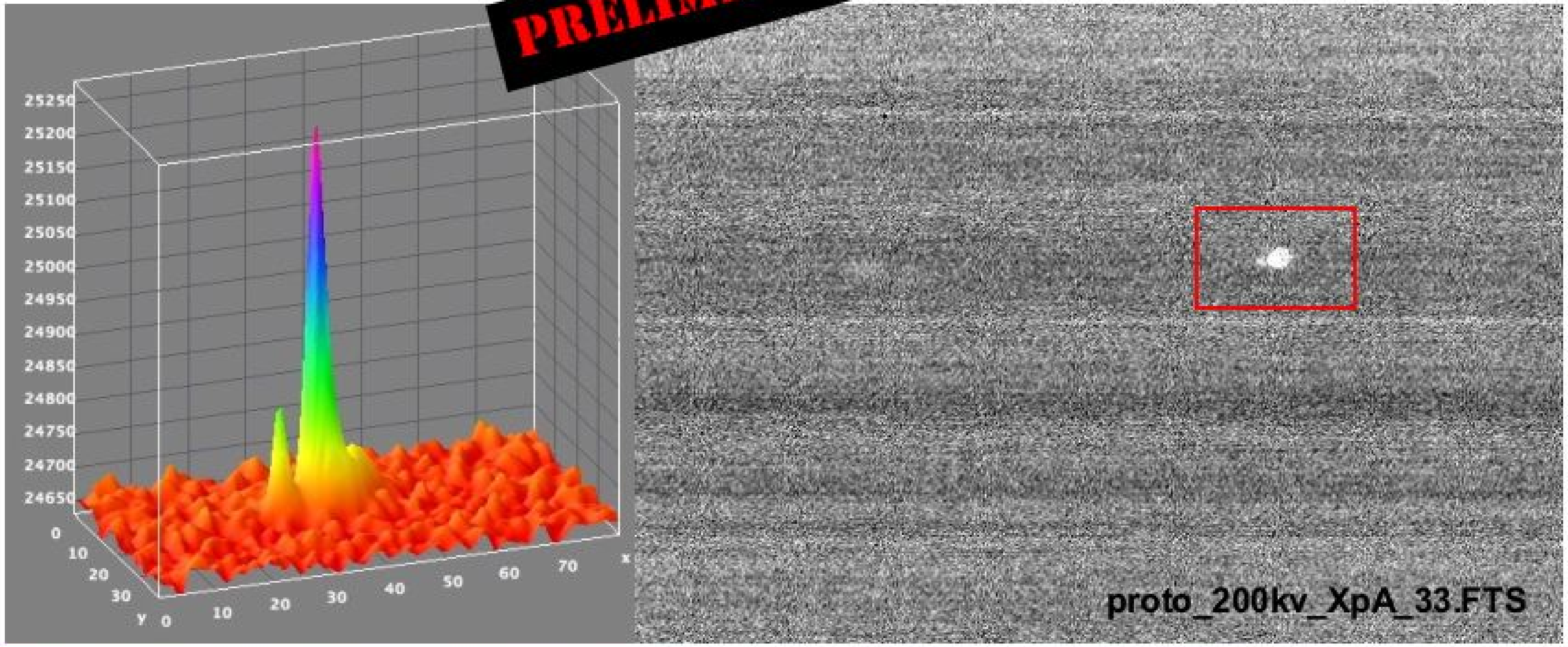
screen = SFOP

beam = protons

E = 200keV

I ≈ 50fA [5pA/100]

$t_{exposure}$ = 20s



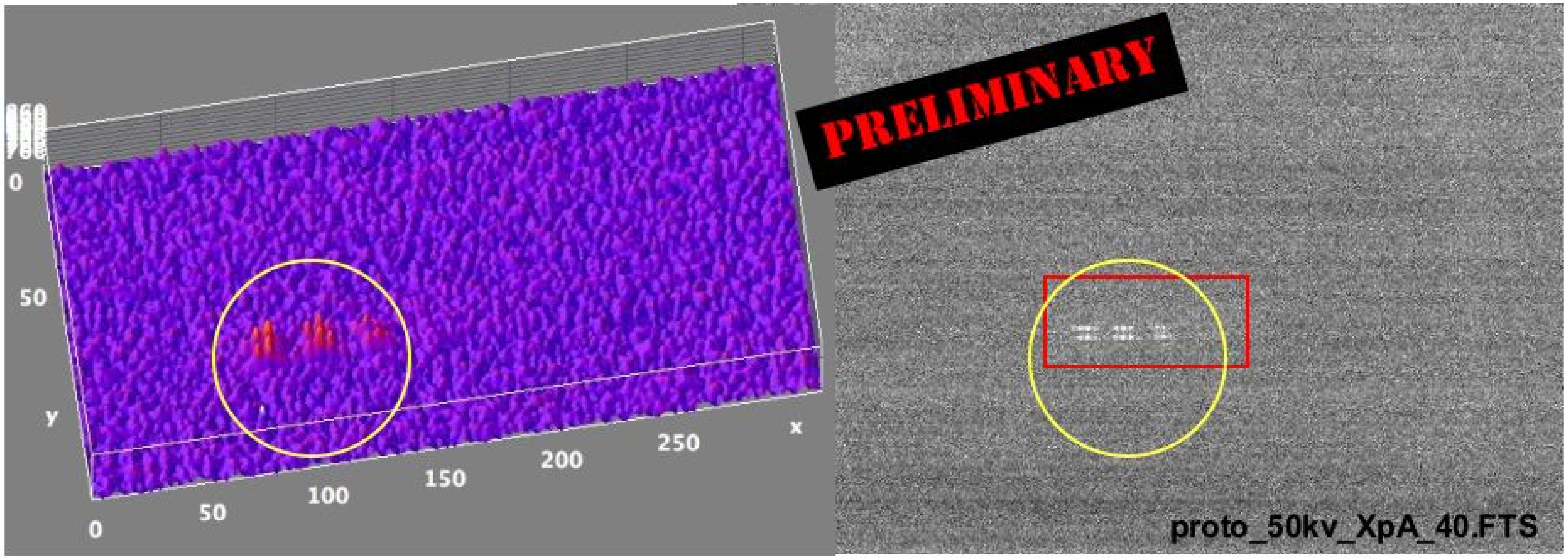
screen = SFOP

beam = protons

E = 200keV

I ≈ 2.5fA [5pA/2000]

$t_{exposure}$ = 20s



screen = CsI

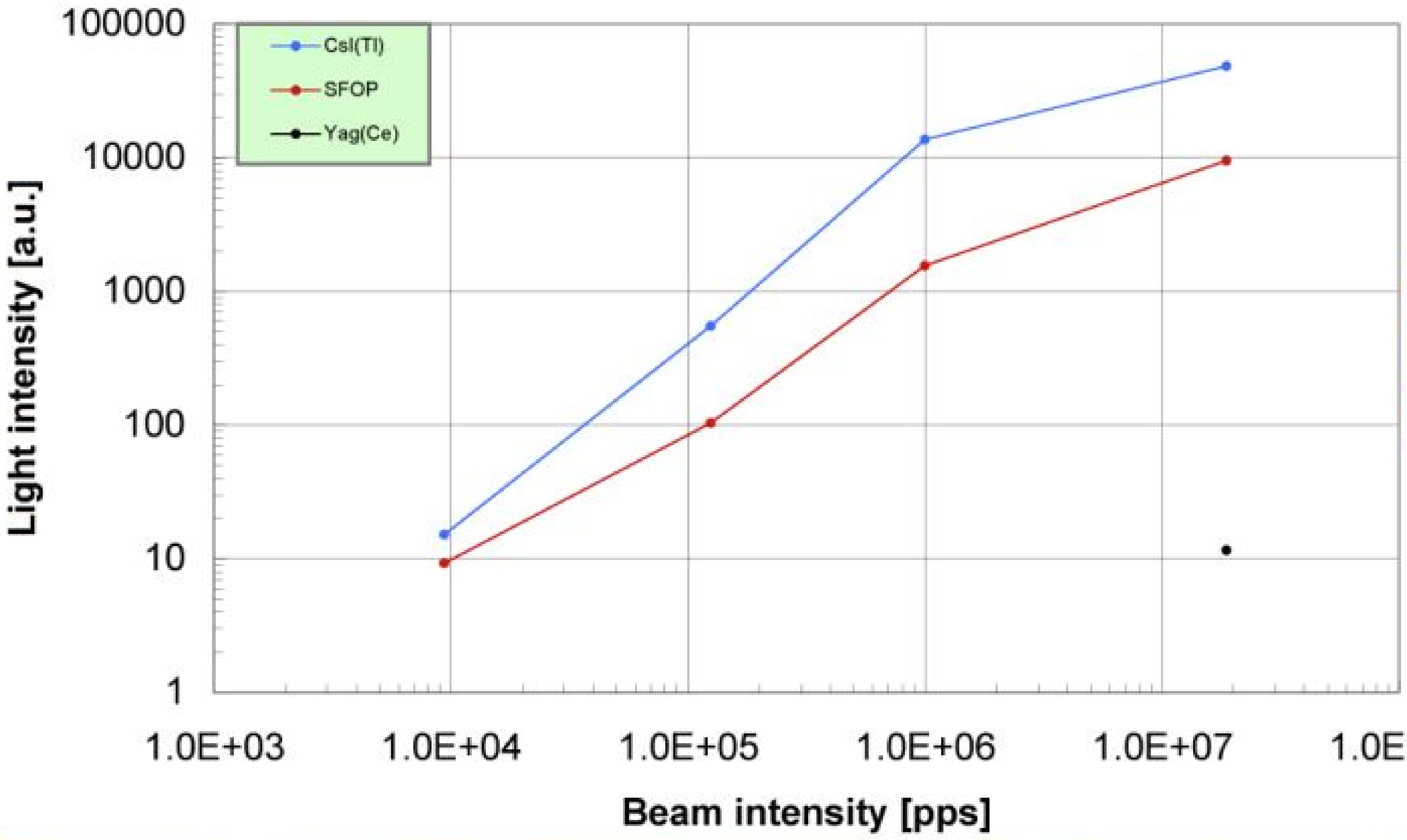
beam = protons

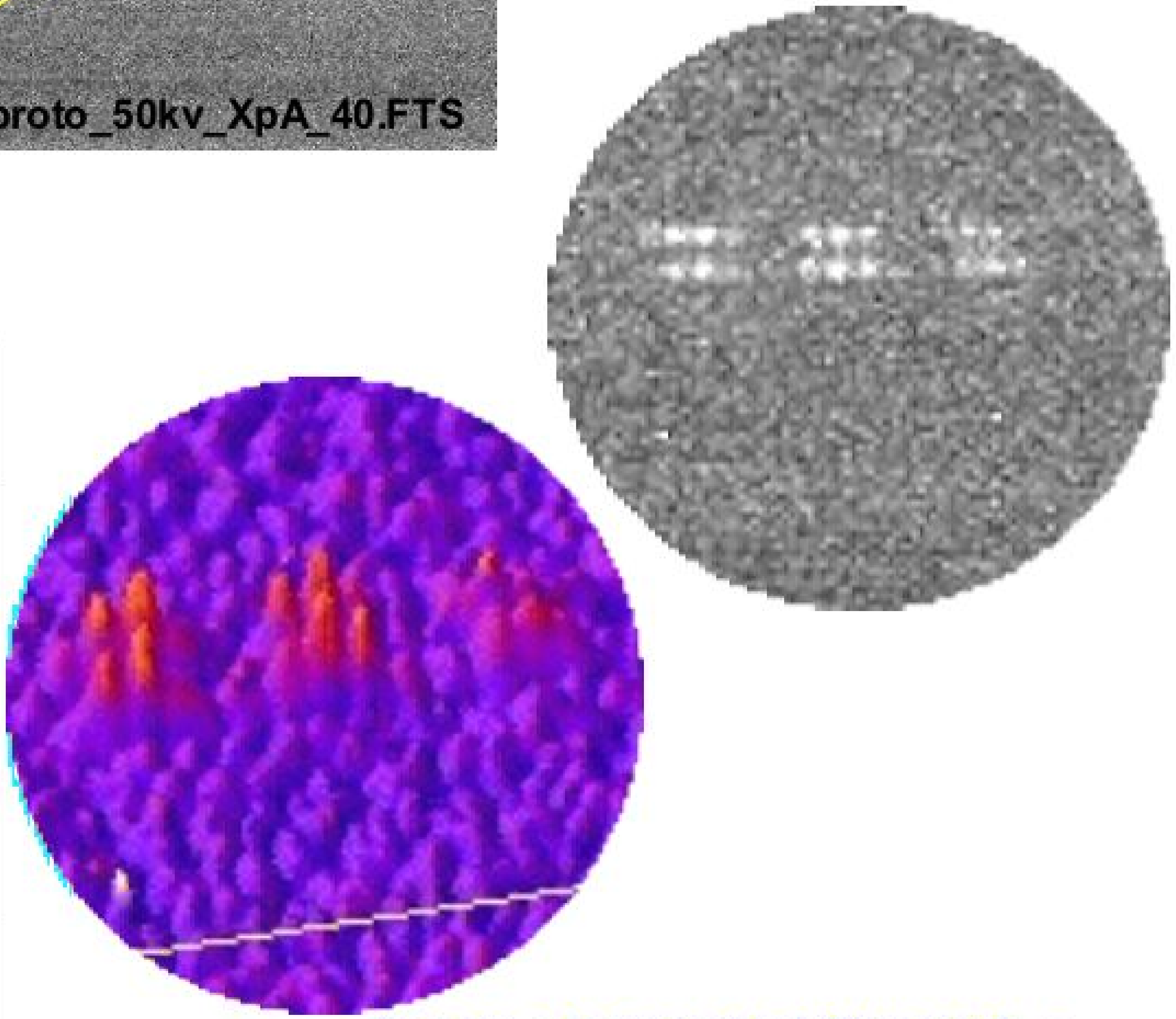
E = 50keV

I ≈ not measurable

$t_{exposure}$ = 60s

toward single particle imaging....!!!





beam attenuated through a fine mesh, pitch ≈ 0.1mm

Conclusions

- several different technologies tested/employed at LNS for L.E.L.I. ion beams
- in general each specific problem needs a specific solution (interceptivity?!?!)
- scintillators are a tradeoff solution between robustness, ease-of-use, and cost
- CsI(Tl), doped glass, and plastics (in some cases) offer good performance
- cheap & compact CCD video cameras show very nice performance
- high performance 14-bit CCD still camera + CsI(Tl) allows top sensitivity

- as for a possible diagnostic tool for antiprotons, a possible bonus could come from their annihilation channels; detailed studies are needed

Thanks for your patience...