Tracking of Heavy Ions

The tracking of heavy ions from an « end user » point of view

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First School on Beam Diagnostics 30.3. - 3.4.2009

DITANET

irfu cea saclay

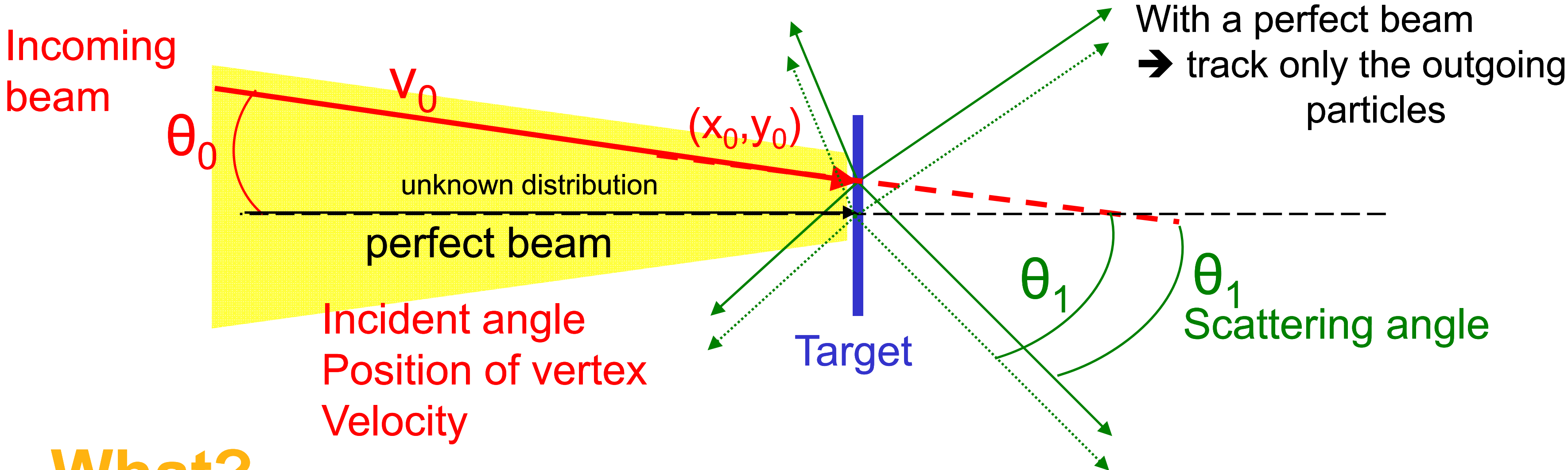
Why measure the ion trajectory ?

Information about the reaction process

→ angular distributions, velocity

Identification of the particle

→ curvature radius in a magnetic field gives momentum



What?

Determine the trajectories of ions before the interaction point

→ positions + time of flight

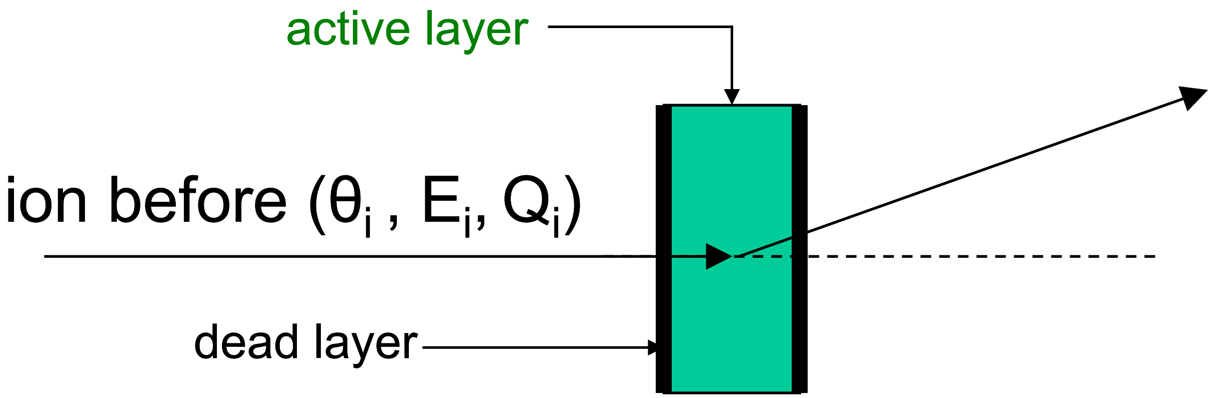
Need a transmission detector, with position and time measurement on an event by event basis

Ion-matter interaction Mainly electromagnetic

enough to detect the ion

BUT

not too much, not to perturb its trajectory



ion after

$\theta_f = \theta_i + \delta\theta$

$E_i = E_i - \Delta E + \delta E$

$Q_f = Q_i + \delta Q$

Energy losses ΔE — can be calculated and corrected in the **active layer** ➔ gives the **detection signal**

Energy straggling δE
Angular straggling $\delta\theta$ — Stochastic processes ➔ **error on measurement**

Charge exchange — Stochastic process ➔ **charge state distribution for E_i < 50MeV/u**

Losses & Straggling : estimations

Energy loss : Bethe-Bloch formula

$dE/dx = k \times (\rho Z/A) \times (z/\beta)^2 \times$ (correction factors)

$(z/\beta)^2$ → Projectile charge state and velocity

$(\rho Z/A)$ → Material charge density

➔ fairly known…

Stragglings

Empirical formulae

Energy: D. Guillemaud-Mueller & al, IEEE 33 (1986)343

Angle: R. Anne & al., NIM B 34 (1998) 295

$<\delta\theta^2> = 0.250Z \times (Z+1) \times (z/A)^2/\beta^4$ [T. Joy, NIM 106 (1973) 237]

$(z/A)^2/\beta^4$ → Projectile charge, mass and velocity

$Z \times (Z+1)$ → Material atomic number

Monte Carlo Code

SRIM (Ziegler & al.)

Charge exchange

Also very empirical…

V.S. Nikolaev et I.S. Dimitrev Phy Let 28A (1968) 277

K. Shima & al., At Data and Nuc Data Tables 34 (1986)357 et 51 & (1992) 173

K. Shima, N. Kuno, M. Yamanouchi Phys Rev A 40 (1989)

R.N. Sagaiadak, A.V. Yeremin NIM B93 (1994) 103

Losses, Straggling and Detection Set-up

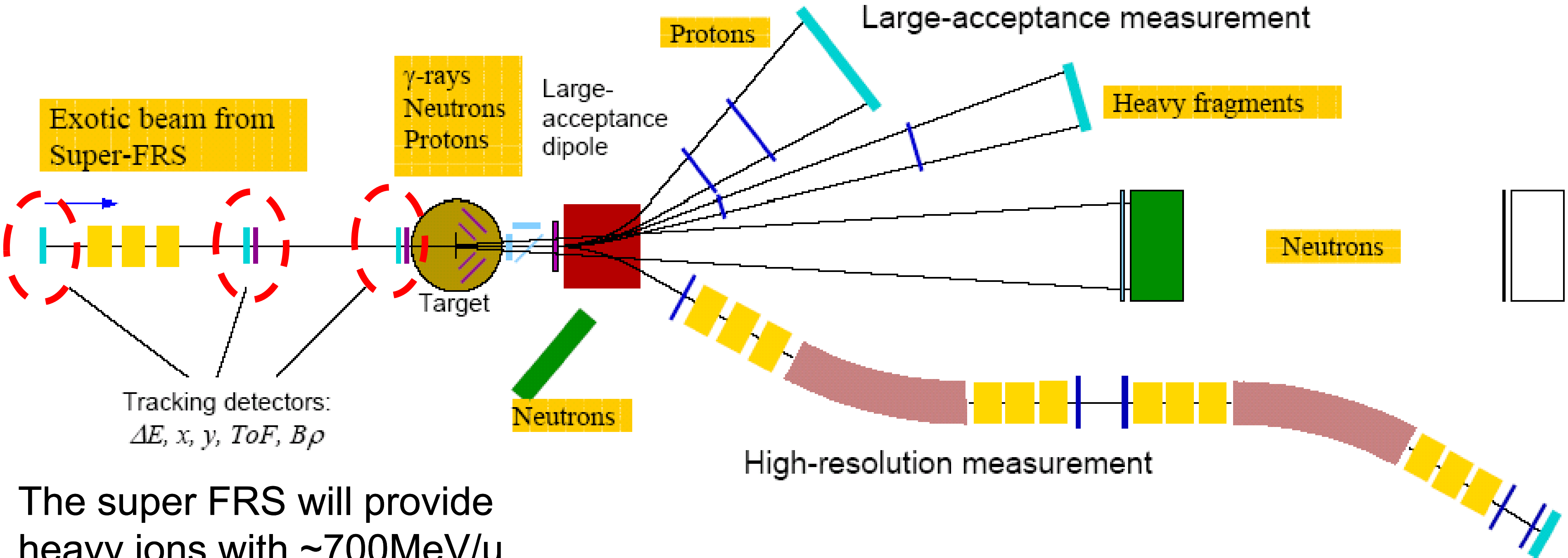
^{40}Ca

Material	500MeV/u	50MeV/u	5MeV/u
2mm BC400 **(scintillating plastic)**	ΔE = 227MeV δE = 0.08MeV/u $\delta\theta$ = 0.4mrad	1385 0.11 3.5	Stopped ! Rg=70µm
0.2mm Silicon **(solid state detector)**	42 0.04 0.27	185 0.03 2.4	Stopped ! Rg=46µm
1cm Ar at 1bar **(gas detector)**	13 0.023 0.17	57.8 0.01 1.5	Stopped ! Rg=7mm
10cm C_4H_{10} at 10mbar **(low pressure detector)**	0.29 0.003 0.014	1.28 0.002 0.11	6.02 0.002 1.14
1µm Mylar© foil **(window)**	0.14 0.002 0.01	0.64 .001 0.10	2.9 0.001 0.93
0.2µm carbon foil **(emissive foil)**	0.02 0.0008 0.004	0.087 0.0006 0.035	0.39 0.0005 0.34

Tool : LISE++ code by O. Tarasov and D. Bazin

Relativistic regime : 500MeV/u Diamond tracking for R^{3}B @ FAIR (2013+)

Sources:
R.Gernhäuser (TU-München)

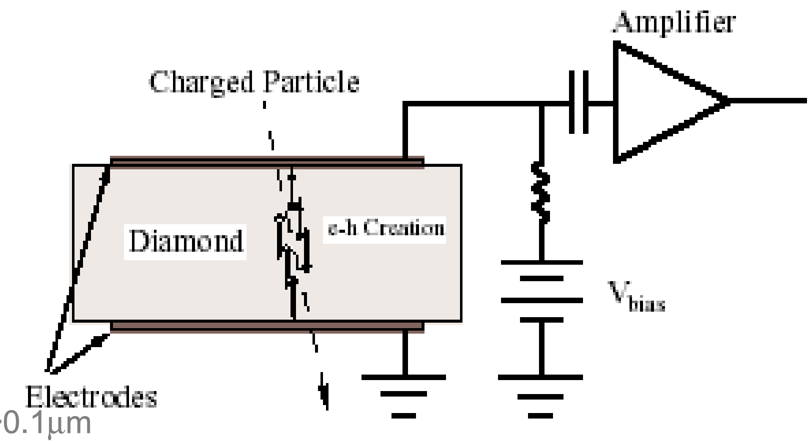


The super FRS will provide heavy ions with ~700MeV/u

Measurement of all kinematic variables in a HI reaction

Different tasks: High resolution tracking in the super FRS, radiation hard (SFRS) 10^6 cm^{-1} s^{-1}
2 x TOF (SFRS – target) (reaction products)

Short characteristics of CVDdiamond detectors



Cr-Au foil ~0.1µm

Fig. 1. A schematic view of a diamond detector.

Diamond as a detector material

- low dielectric constant
- low capacitance
- low noise
- good heat conductivity
  (5 x higher than Cu)
- large band gap of 5.5 eV
- small signal (< half of a Si of similar size)
- high charge carrier velocity saturation
- fast pulse response time

- **Diamond Crystal production**

chemical vapour deposition (CVD)

- commercial production
- ***polycrystalline diamonds (PCD)***
  - thickness 0.5-500mm
  - max size ~ 5x5cm2
  - price ? (100 euro/det.)
- ***single crystal diamond (SCD)***
  - smaller (5x5 mm2)
  - better performance (energy resolution)
  - more expensive (5xPCD)

Source: M. Gorska (GSI)

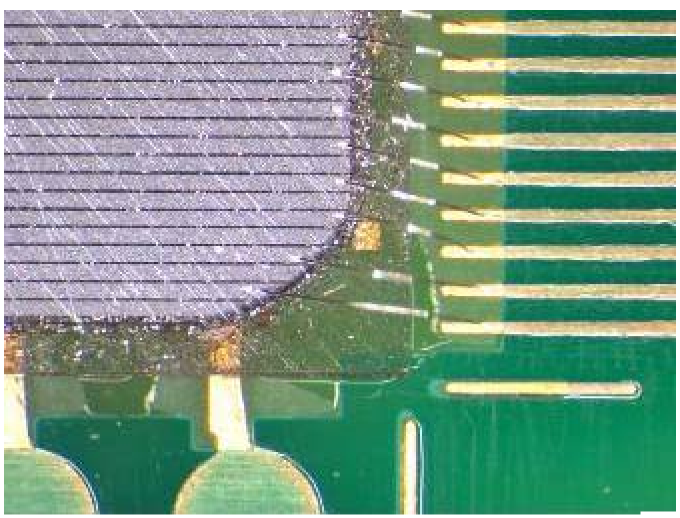
Diamond detectors performance

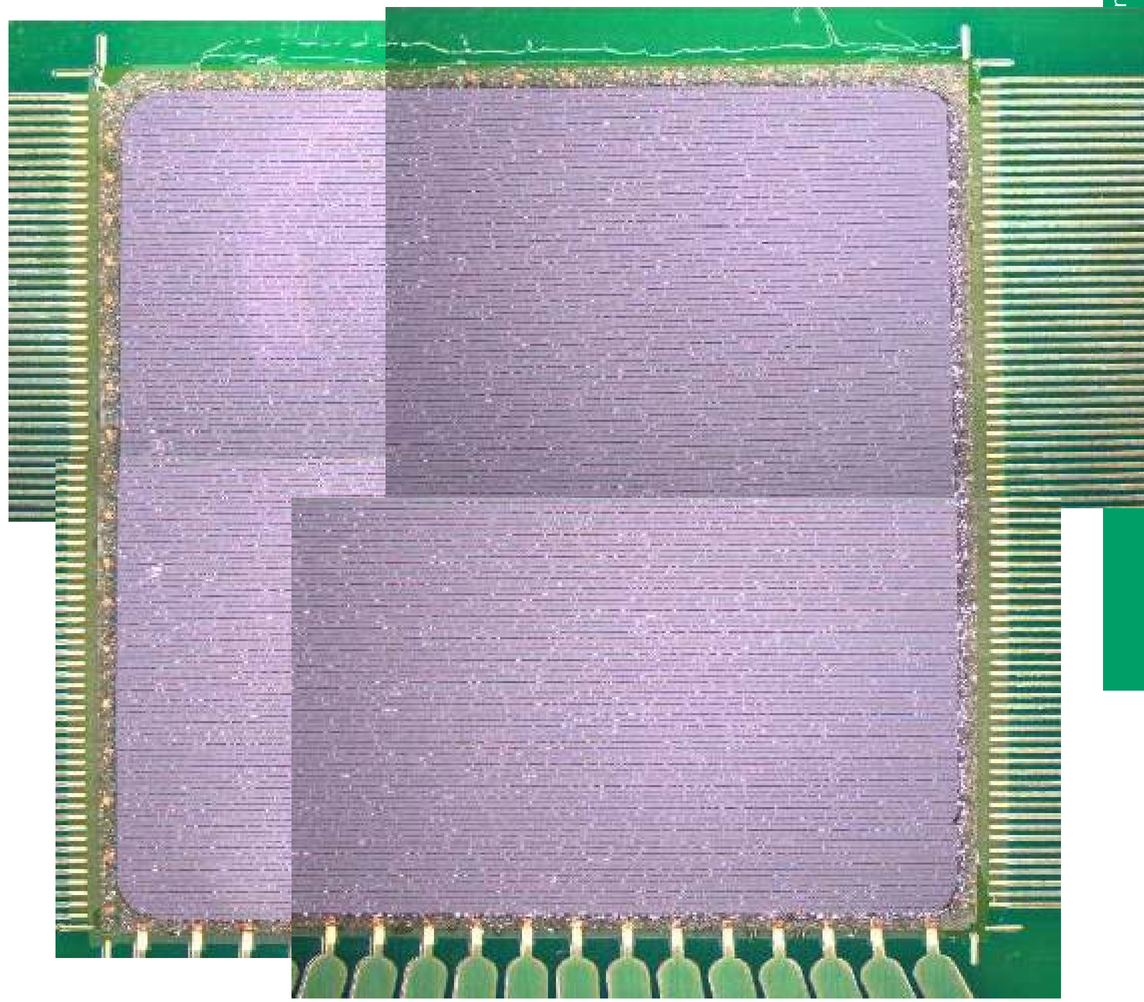
- very fast timing
  pulse risetime: 200 ps
  width: 2ns (PCD) 5ns (SCD)
- operating voltage 1 V/µm
- radiation hardness
  -Tests with $2x10^{15}$ p/cm^2 did not show any significant deterioration of a sig./noise
  -pumping effect (PCD) : improvement with increasing dose
- position resolution
  below 10µm can be achieved with strip detectors X and Y
- efficiency
  70%PCD-100% SCD
- Diamonds as TOF detectors
  tests with 1GeV/u U beam resulted in TOF of σ=20 ps

Current developments : Larger Area Detectors

4 prototypes produced
2 operational
lithography under control

Frontside:
128 strips
170 µm wide 20 µm gap
Backside:
16 strips





25.4 mm

M.Boehmer, TU Muenchen, PhD Thesis (2006)

Virtues & Flaws of diamond detectors

☺

- Radiation hard (>2.15p/cm^2)
- low occupation time ➔ high counting rate 10^{7}pps
- ultra fast signal ➔ time resolution σ = 30ps
- reasonable energy resolution σ = 17keV (single crystal)

☹

- small size, biggest in use 60x40mm^2 [PCD, Cave A @ GSI]
- thickness > 50µm ➔ restricted to high energy
- require high speed electronics

- single crystals have better performances but are smaller (few mm^2) ➔ Mosaic detector ?

➔ very promising technique, lot of developments

Relativistic regime : 500MeV/u
KaBes on the NA48 exp @ CERN (in use)

(Well… they are used for Kaons and not for Heavy ions, but they could be !!!)

B. Peynaud, NIM A 535 (2004) 427

Study of CP violation by the simultaneous detection of K^+ and K^-

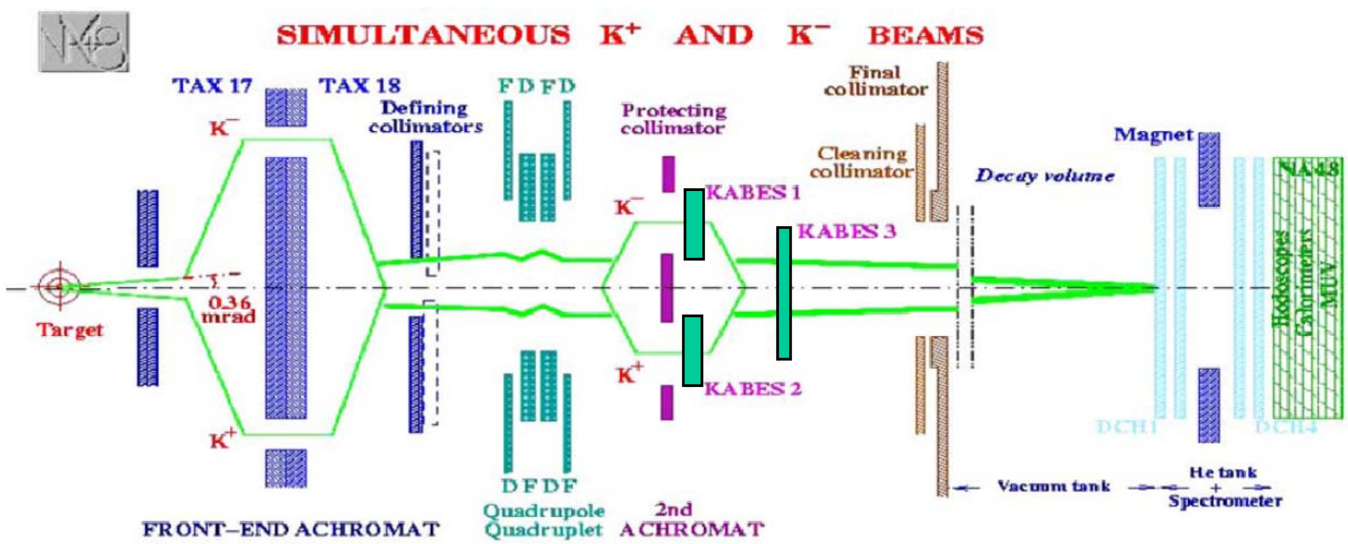


Fig. 1. The K12 charged kaon beam line with KABES and K^+/K^- focusing at the DCH spectrometer.

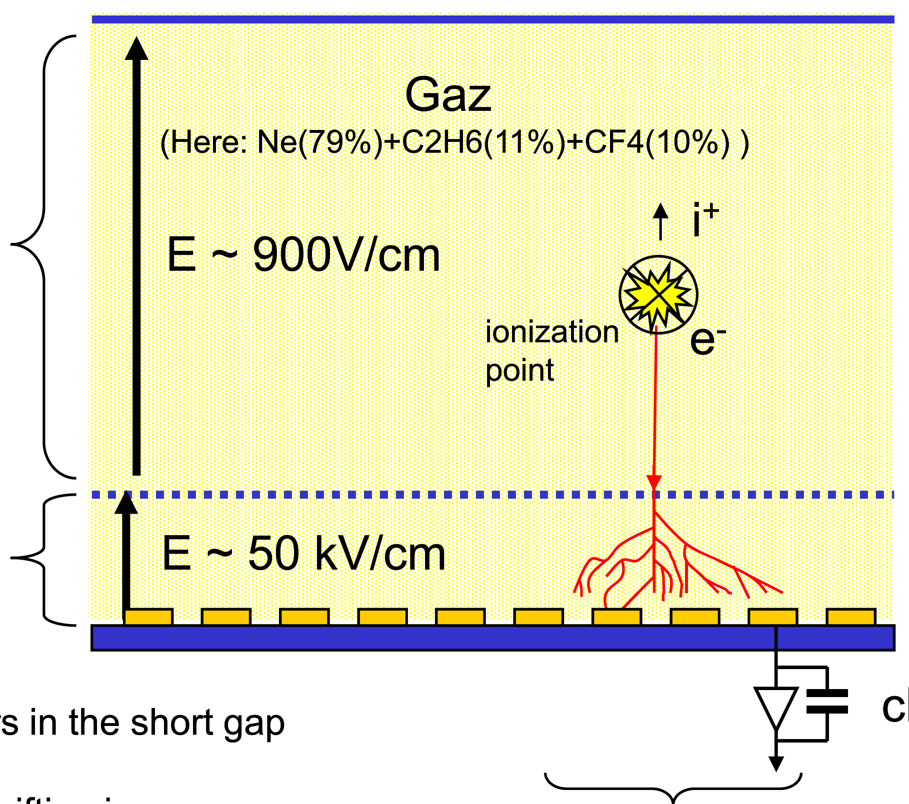
Need to measure trajectories to obtain the momentum of individual Kaons (~60GeV/c)

Time projection Chamber with Micromegas

Drift Region
h=6cm
v_{e-} = 8cm/µs

Drift time
=
Y position

Amplification gap
< 100 µm



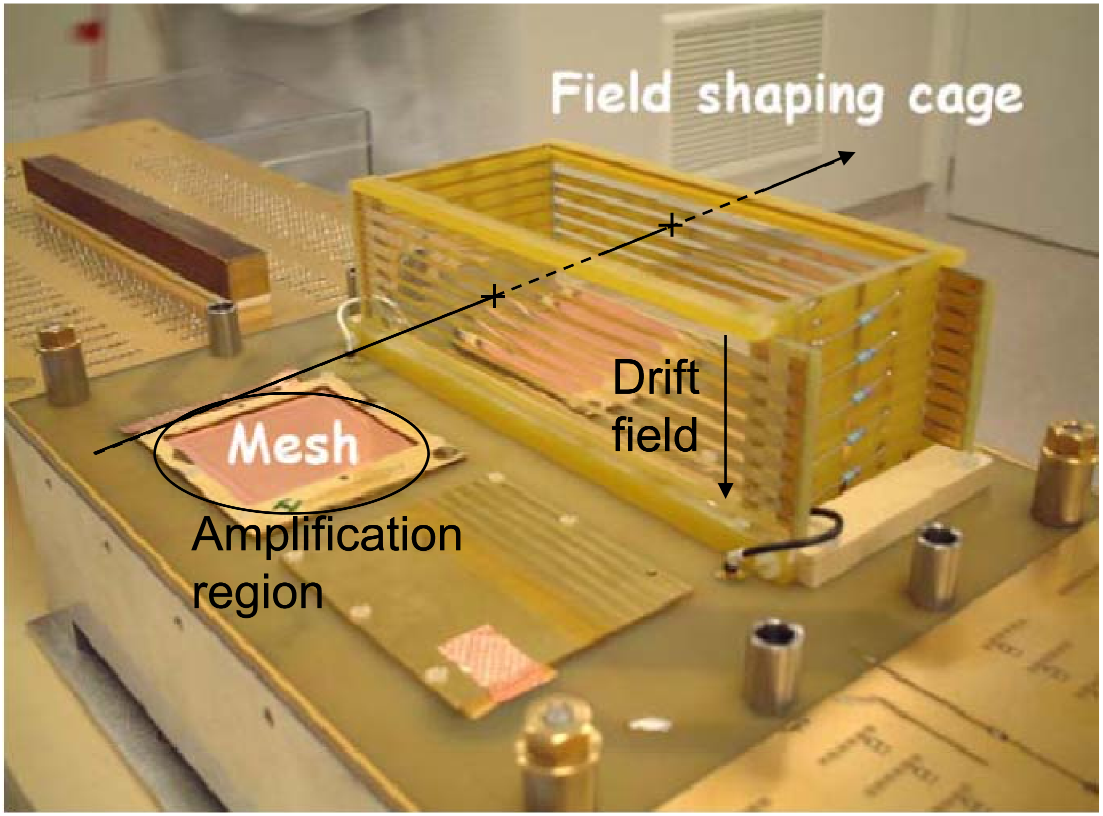
the electrons have a constant velocity in the drift zone

A fast avalanche occurs in the short gap
➔ fast electron signal
➔ no signal from the drifting ions because of the shielding mesh

Each strip gives an independent time signal
➔ high counting rate

2 orthogonal detectors required to have X and Y

KaBes drift chambers for real



Performances

- Time resolution = 0.7 ns (σ)
- Spatial res. of 70 μm
- 40 MHz, expected up to 1GHz
- Efficiency close to 100 %

Virtues & Flaws of Micromegas TPC

☺

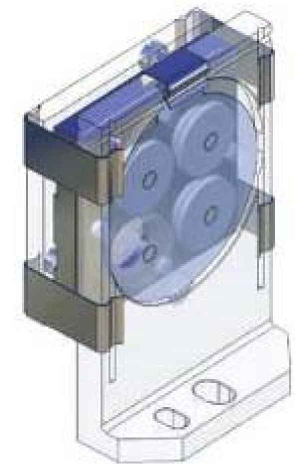
- Radiation hard
- Very high counting rate : up to 10^9pps !
- Very good position resolution < 100µm

☹

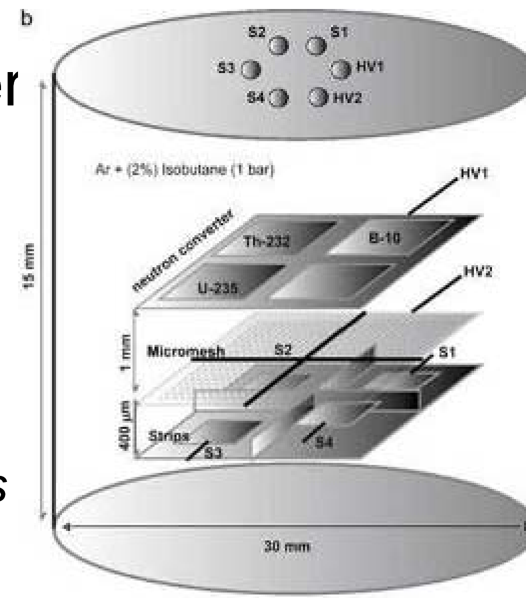
- 1 direction only
- poor energy resolution (~10%)
- need an independent time signal for trigger

Micromegas gas detectors have a wide range of applications since the “drift zone” can include a converter that produce electrons from any kind of initial radiation

c



b



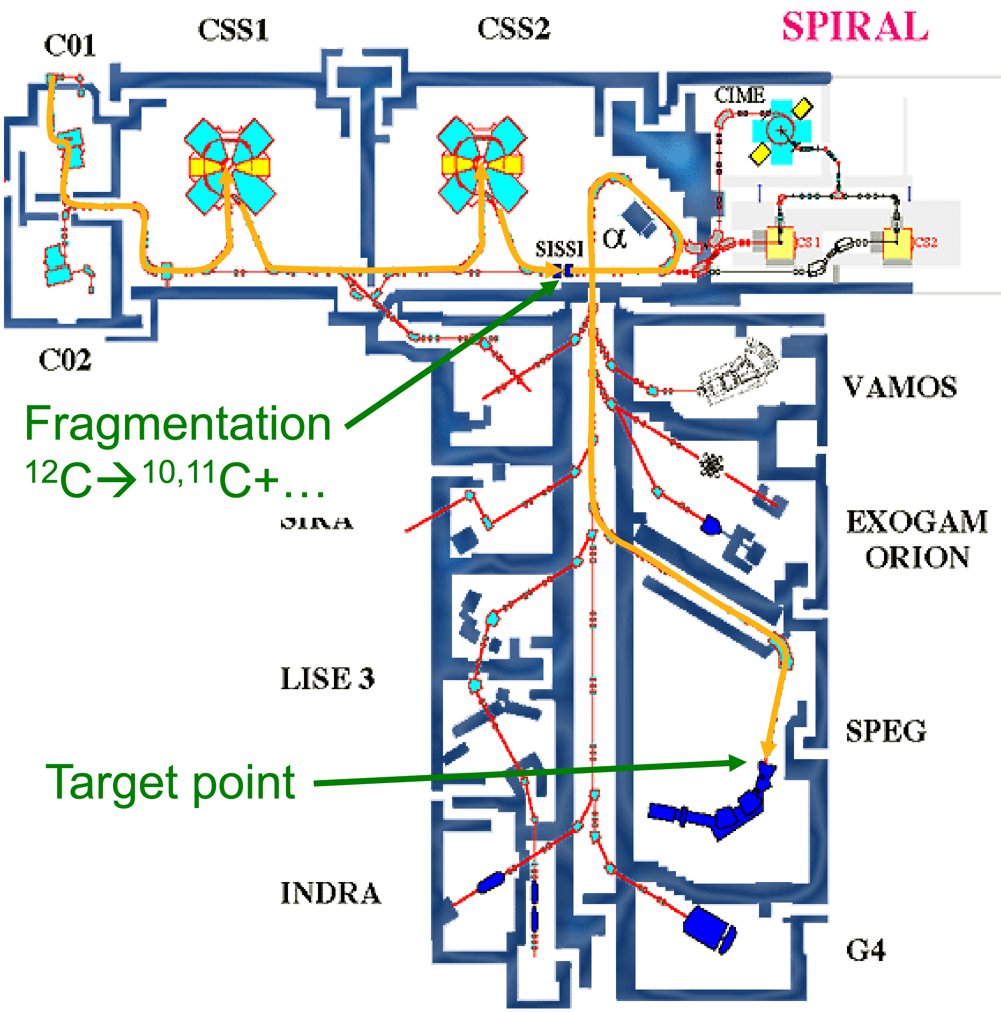
e.g. piccolo micromegas for neutron detection

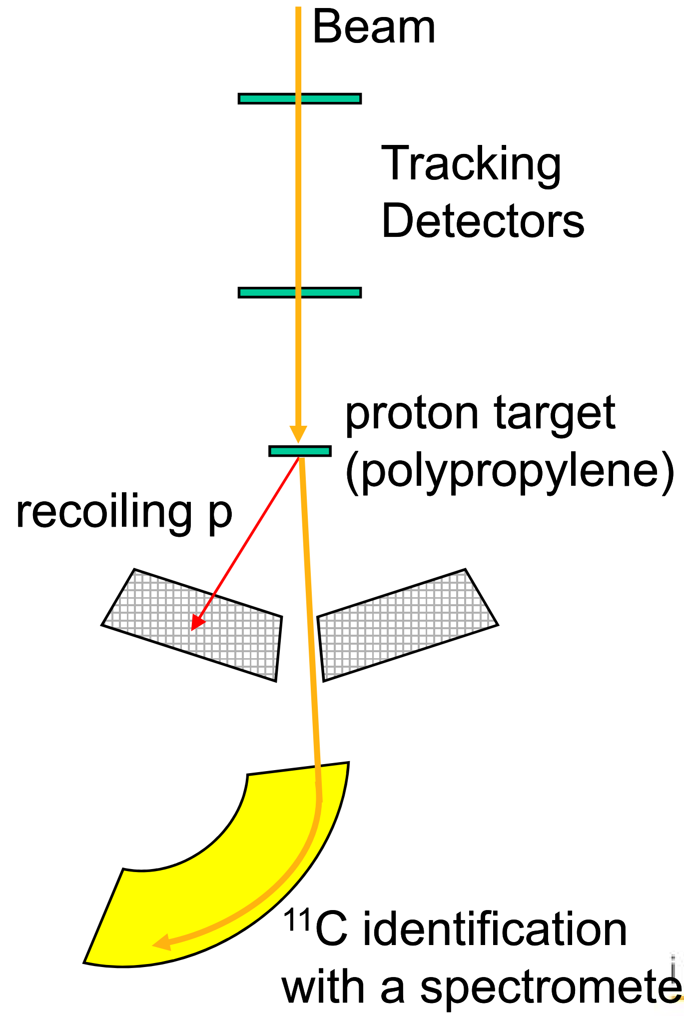
J. Pancin & al. NIMA 592 (2008) 104

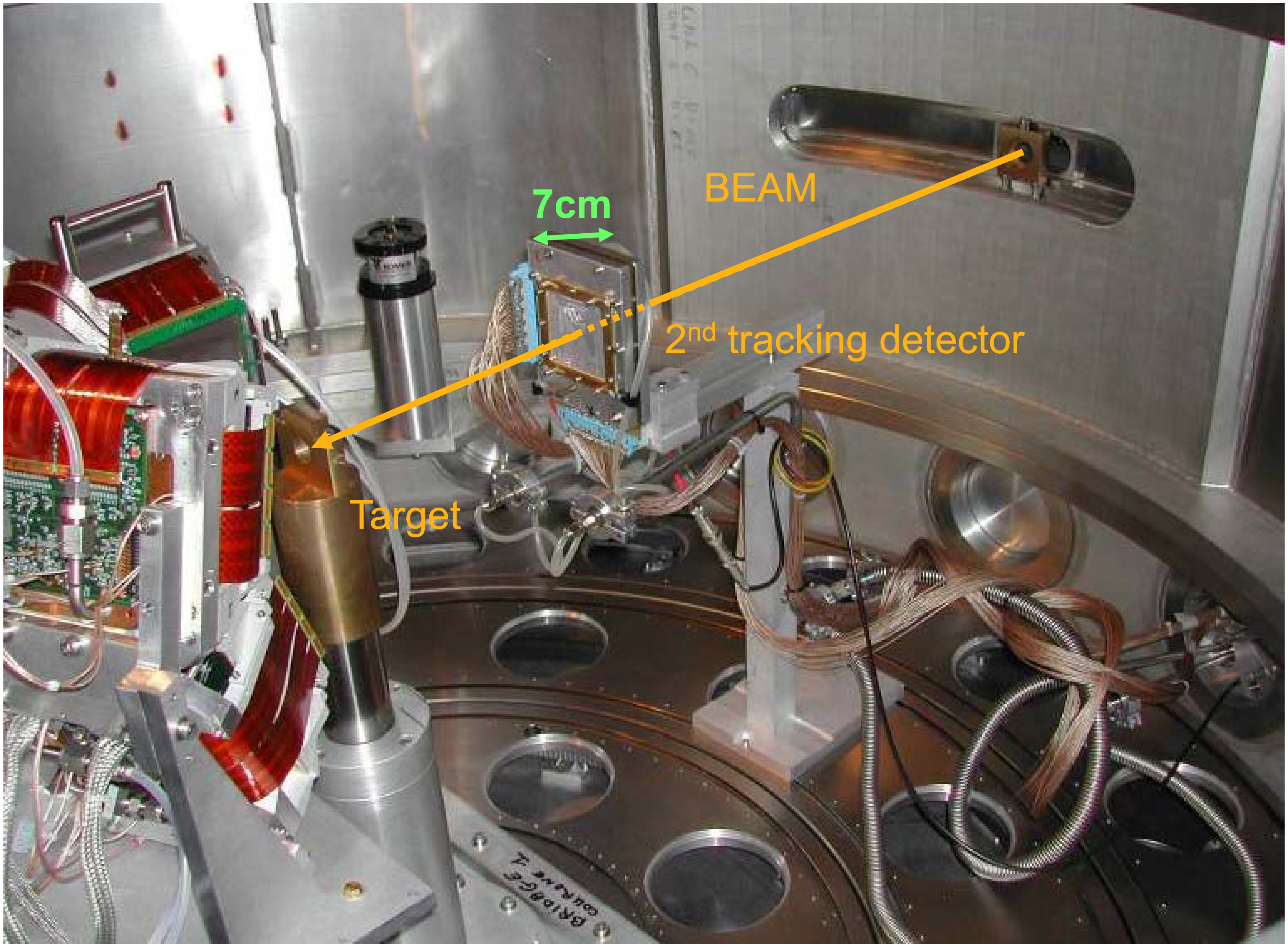
Intermediate energy : 50MeV/u

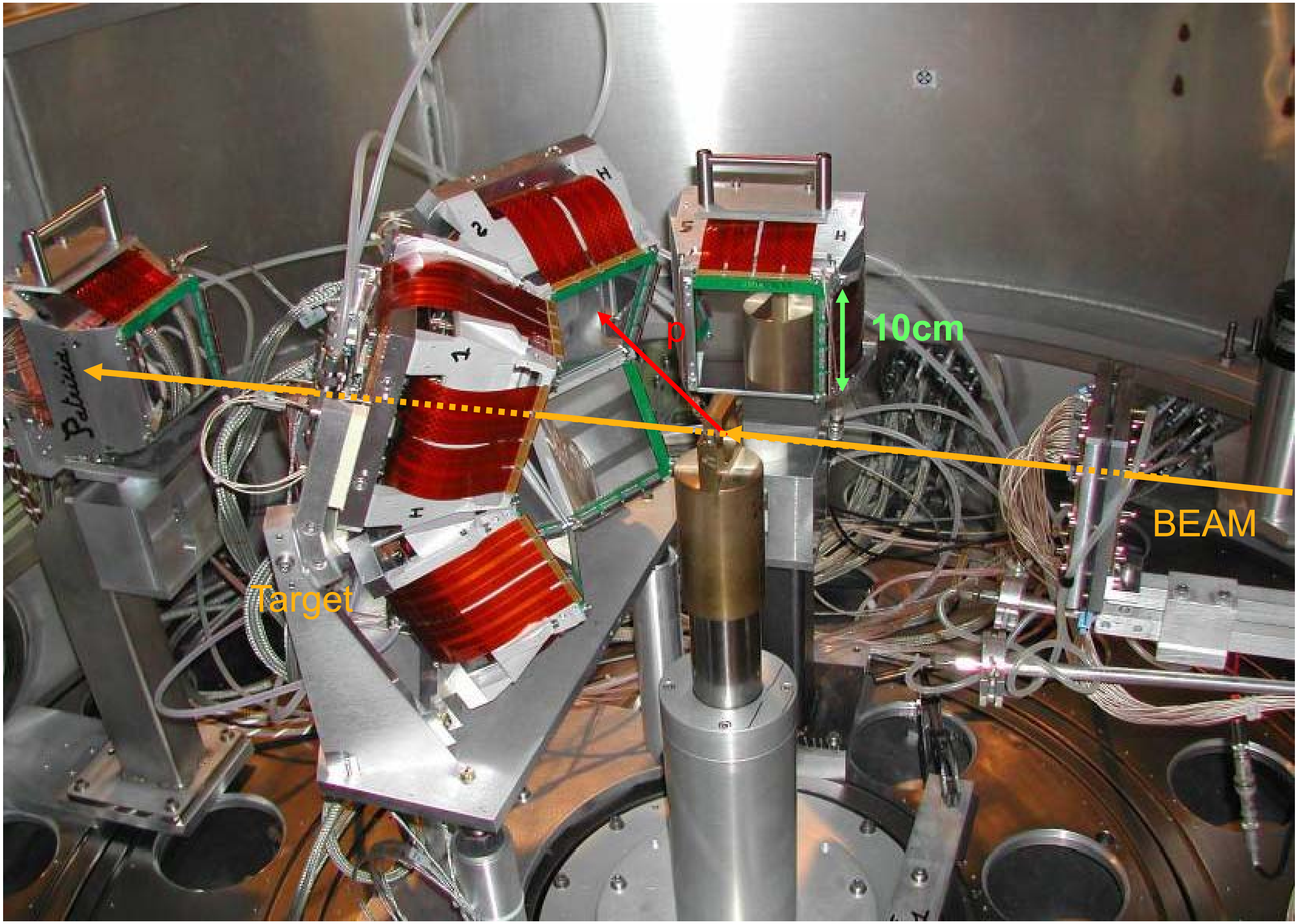
CATS detectors at GANIL (in use)

GANIL facility (Caen, France)



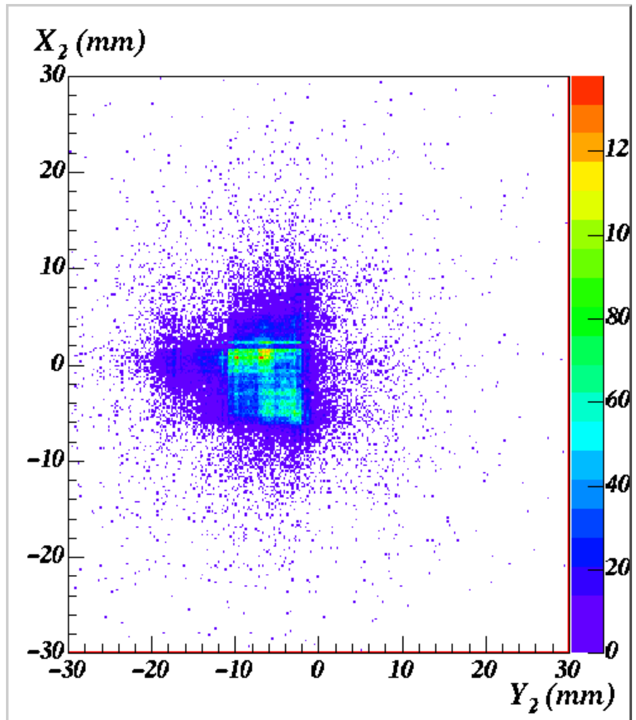



7cm
BEAM
2nd tracking detector
Target

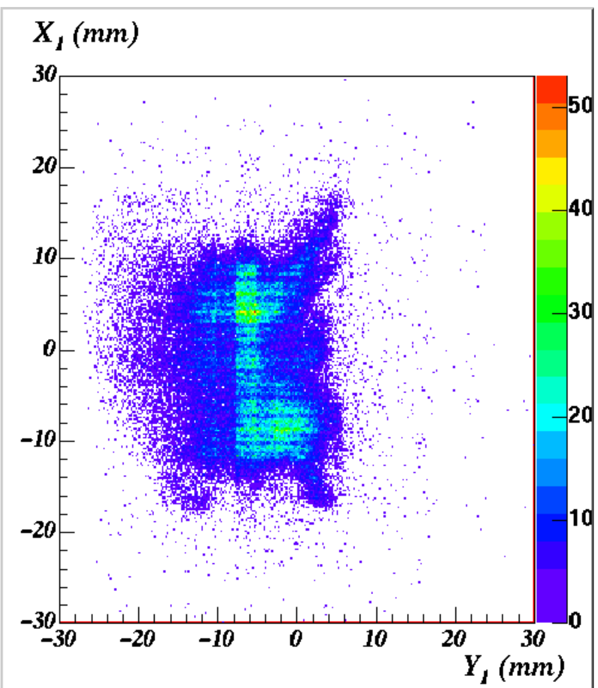

p
10cm
BEAM
Target

Beam trajectories after fragmentation

0.5m before target

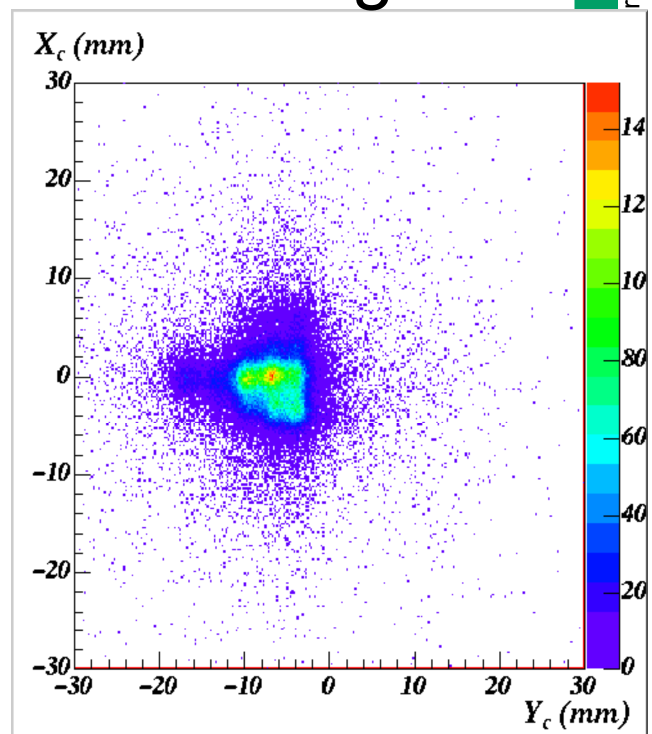


1.5m before Target



Large Beam emittance ~10π mm.mrad
(hor+vert)

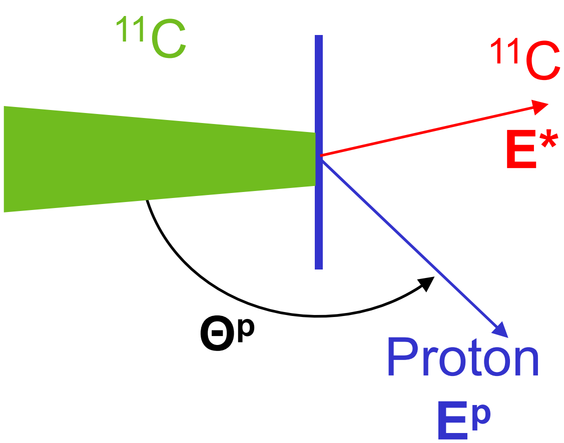
Reconstruction on target



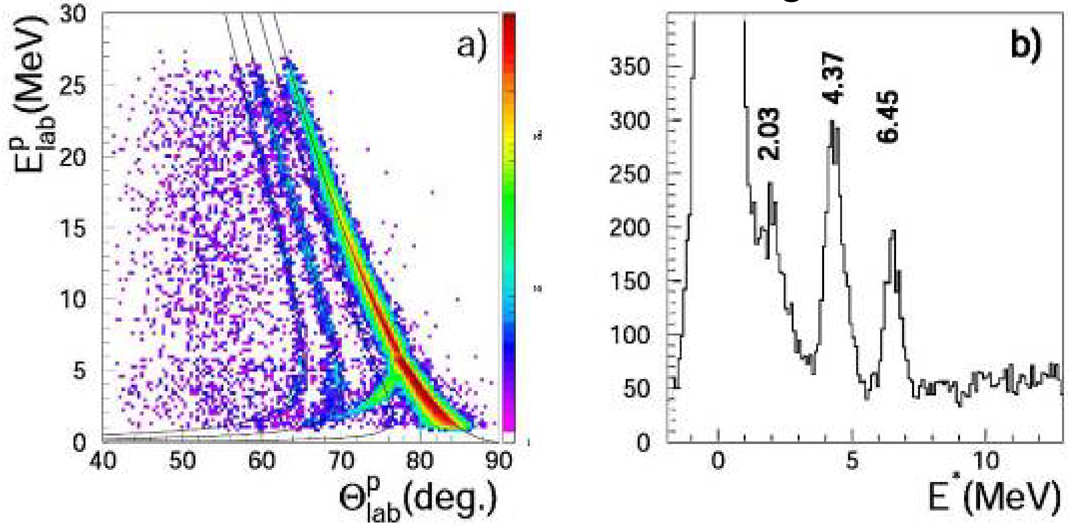
Effect of trajectory reconstruction

$^{11}C + p \rightarrow {}^{11}C + p'$ 40.6 MeV/u

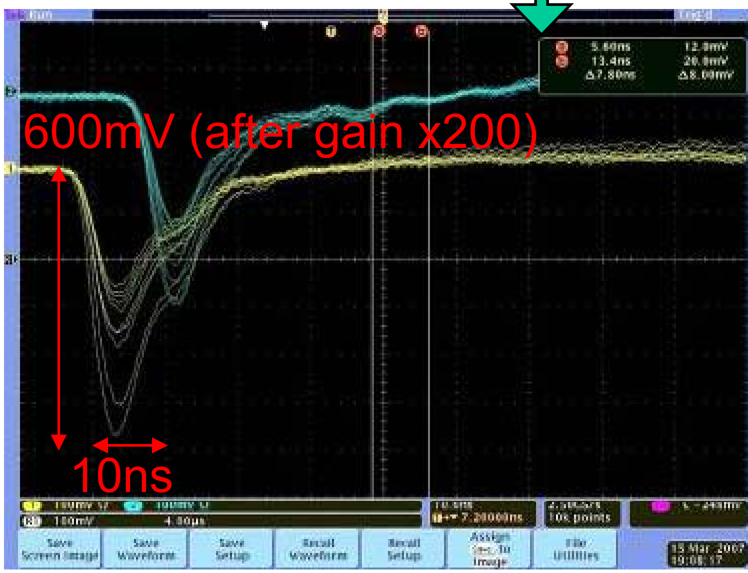
C. JOUANNE
(SPHN) PHD 2002

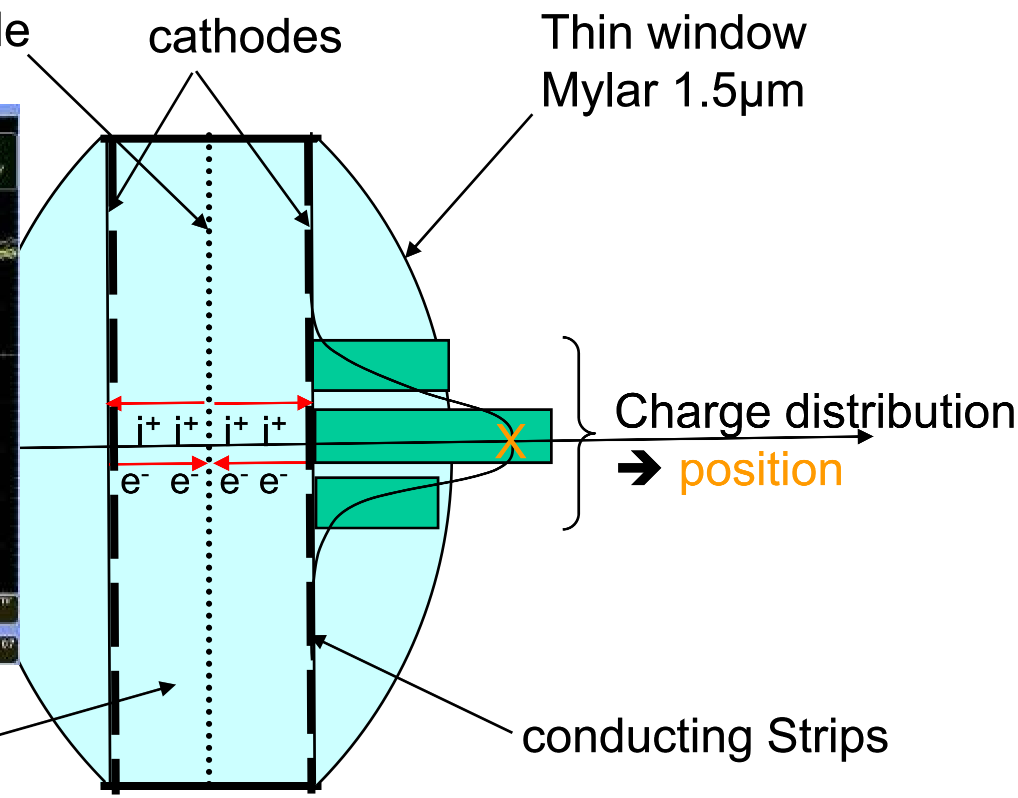


With beam tracking

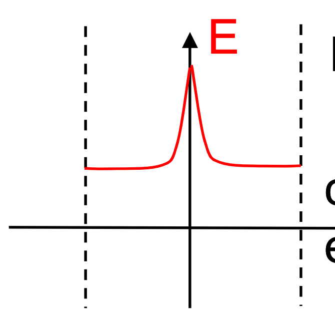


Low Pressure gas detector : basic principles





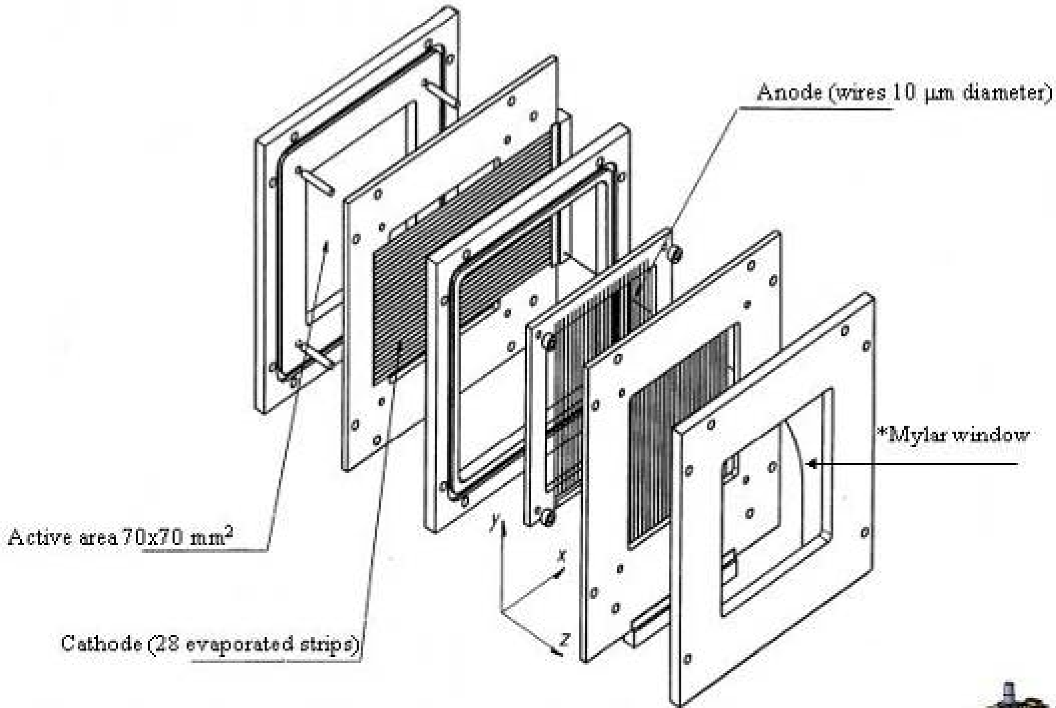
Low pressure (P=4-10 Torr)
gas: CF_4, C_3F_8, iC_4H_{10}

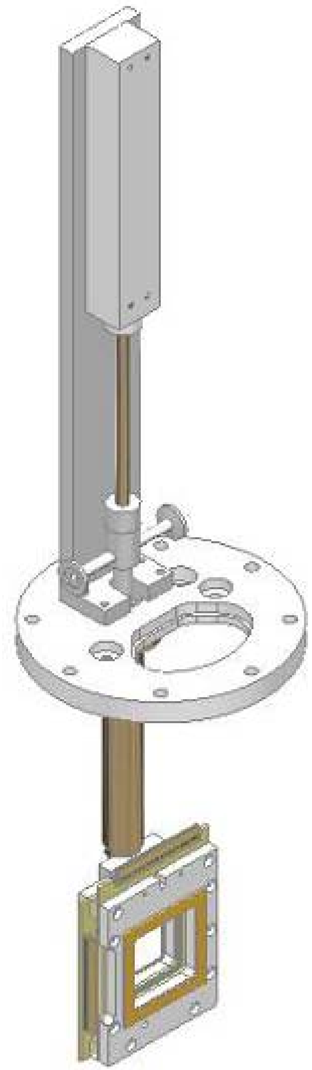


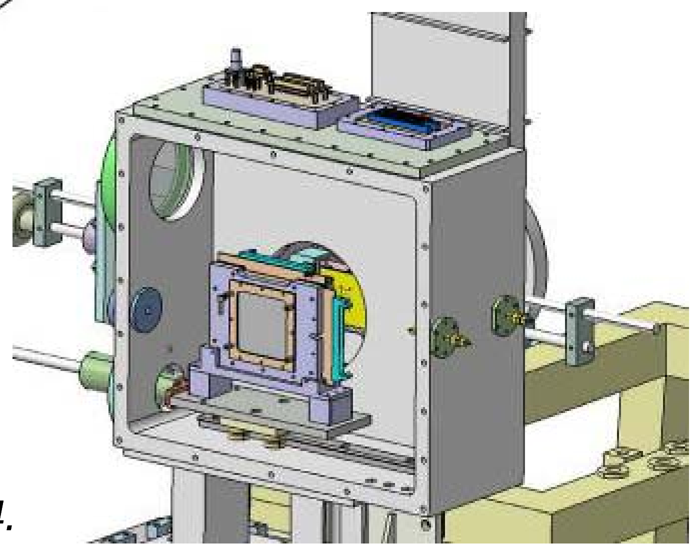
If E/P high enough ➔ avalanche
(>100V/cm/Torr) ➔ amplification

charge movement ➔ induced signal
electrons are rapid ➔ fast signal

Basic CATS/BTD mechanics



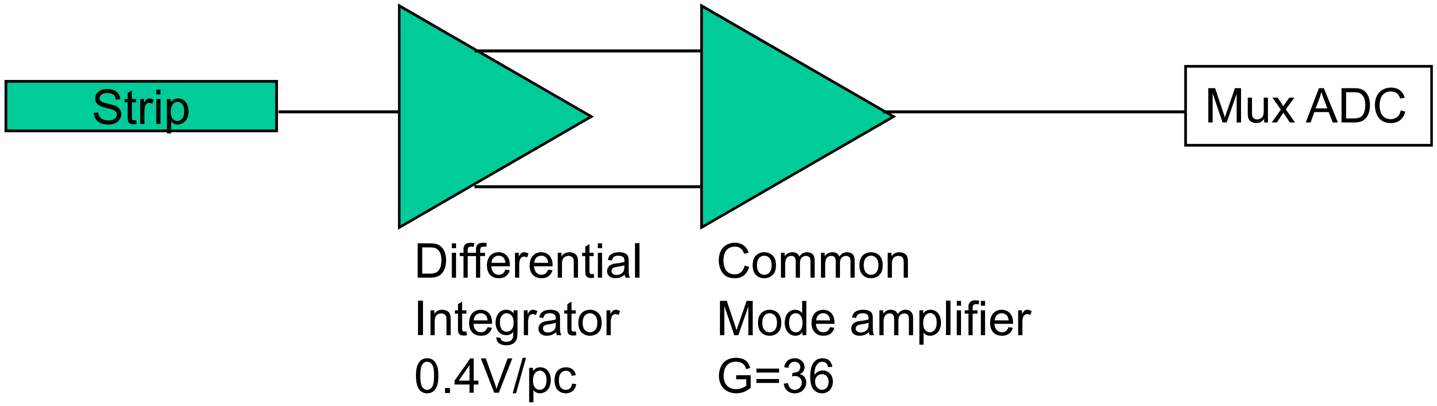




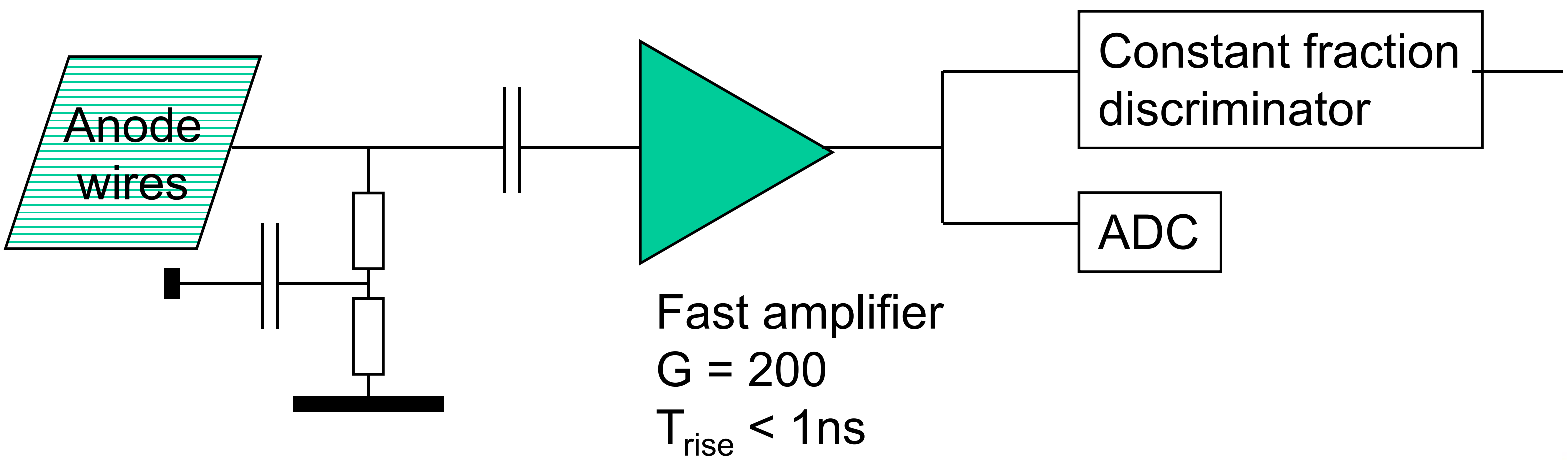
Active area: 7x7cm^2
iC_4H_{10} @ 6Torr
2x28 strips on cathodes
1 fast anode signal

Ottini & al., NIM A, 431(1999) p. 476-484.

Basic CATS/BTD electronics



+ new electronics with individual trigger
➔ 3-5 channels coded instead of 28



Performances

Count rate capability ~ 10^5 pps/cm^2

Low dead time ≅ 1 ms / strip

Spatial Resolution : σ_X, σ_Y ~ 400 µm

Time resolution < 0.5 ns

Efficiency > 90 %

Energy resolution ~ 20%

Virtues & Flaws of Low pressure detectors

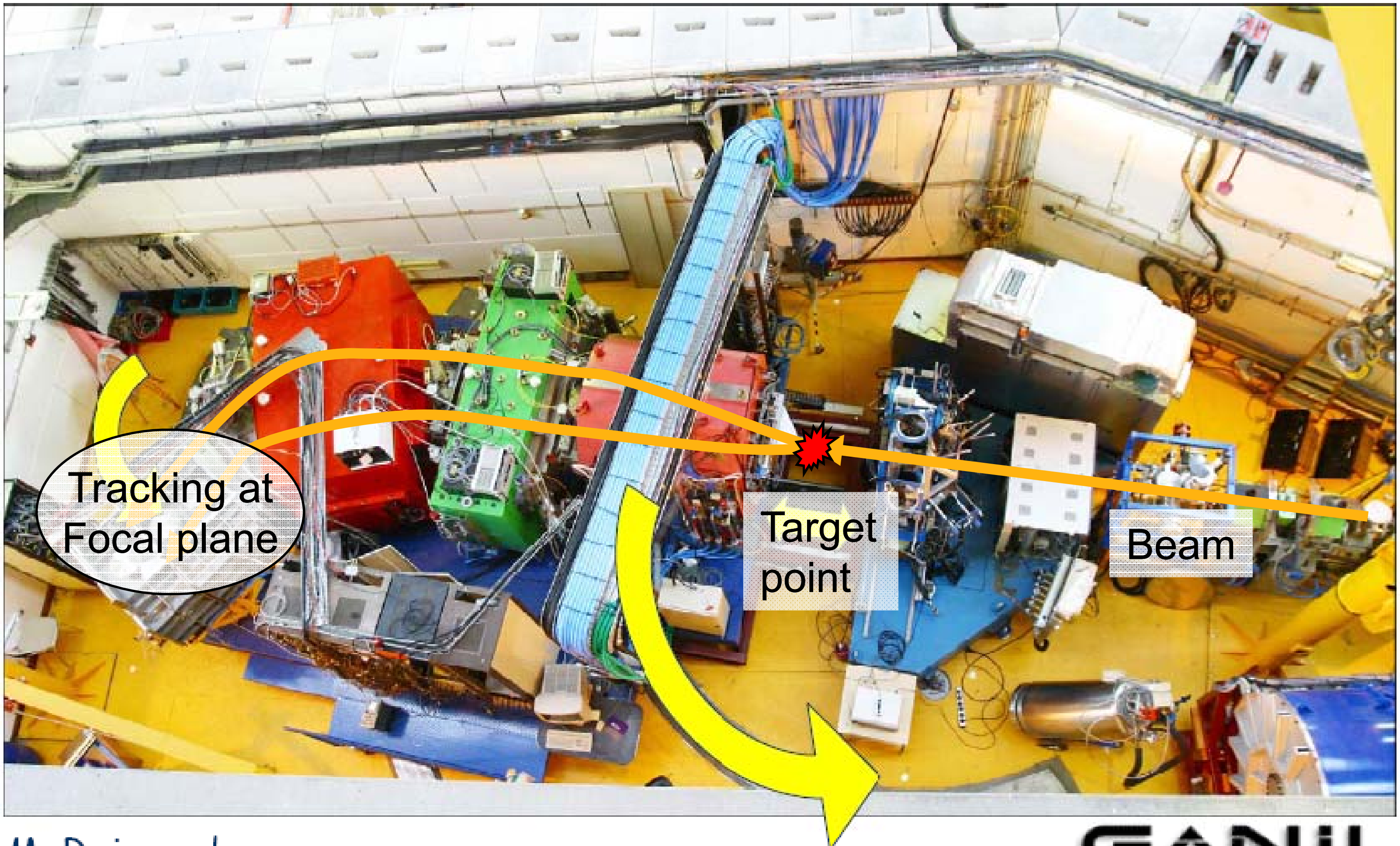
☺

- fast signal ➔ good time resolution σ = 100ps
- good position resolution σ = 100µm
- high detection efficiency (~100%)
- large size available (>100cm^2)
- cheap and can be repaired
- Thin : ~5µm of Mylar (from windows and cathodes)

☹

- vulnerable to discharge : rate < 10^{6}pps
- 1.5µm windows required ➔ E_{ion} > 10MeV/u
- fragile and delicate to use

Very low Energy regime : 5MeV/u
e.g.: SPIRAL/SPIRAL2 radioactive beams
(in use / 2014)

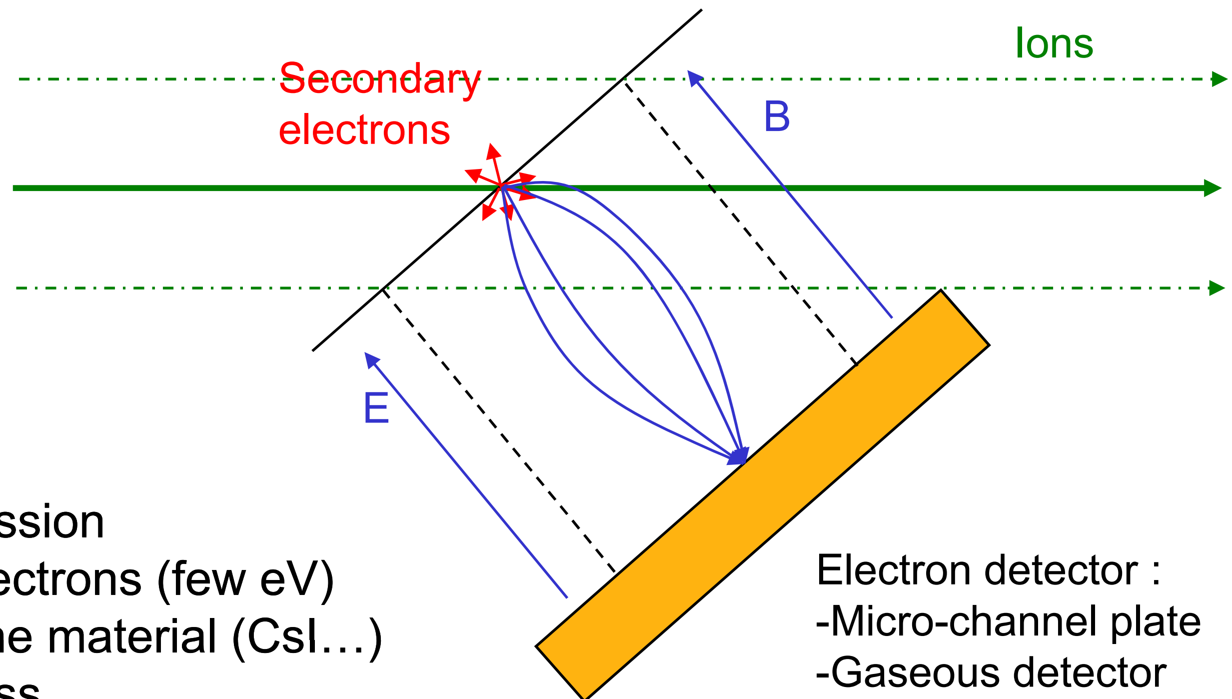


M. Rejmund

Emissive foil Detectors

Emissive foil
(Mylar+Al, Carbon)

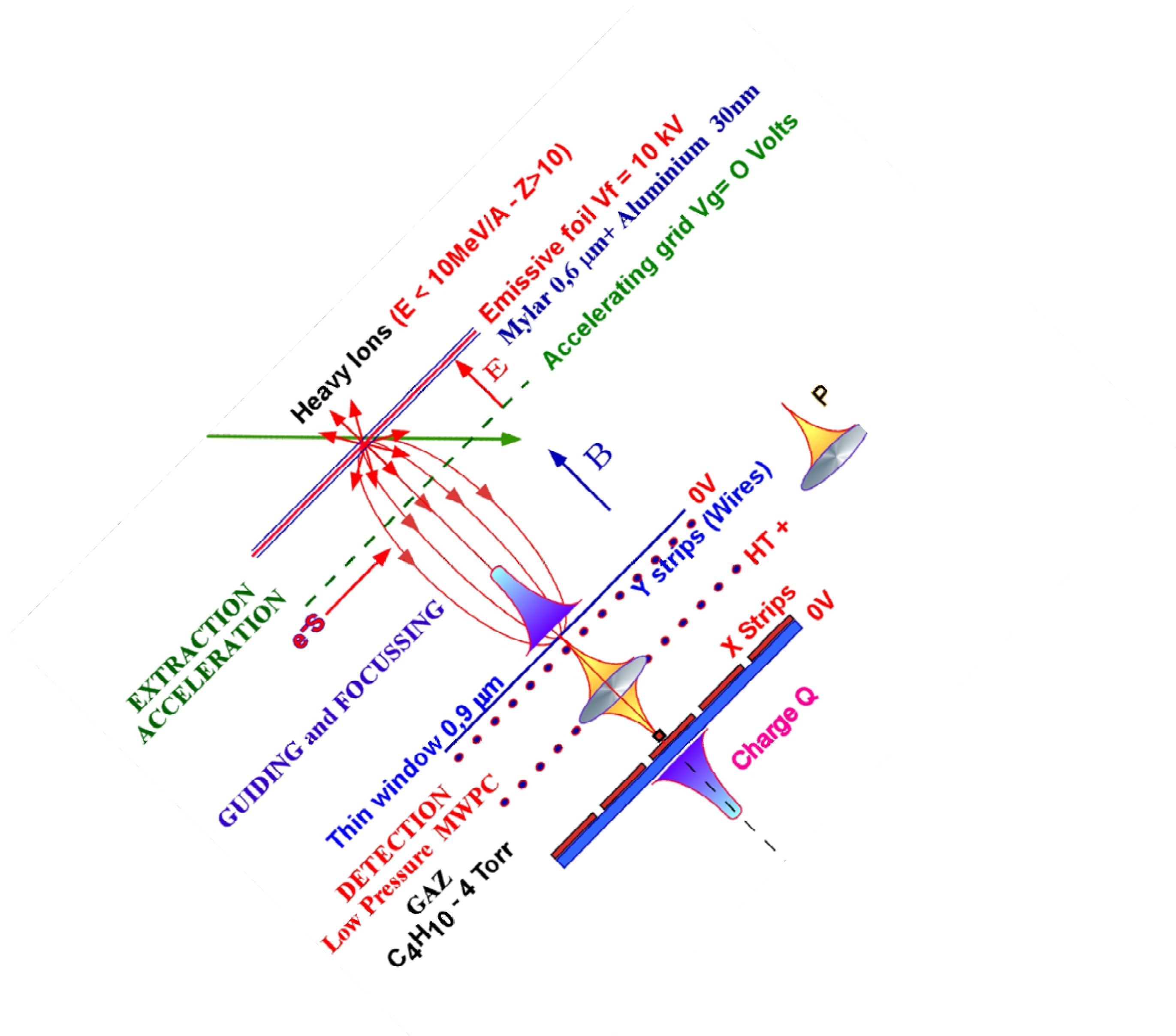
Very low thickness
< 1µm foil

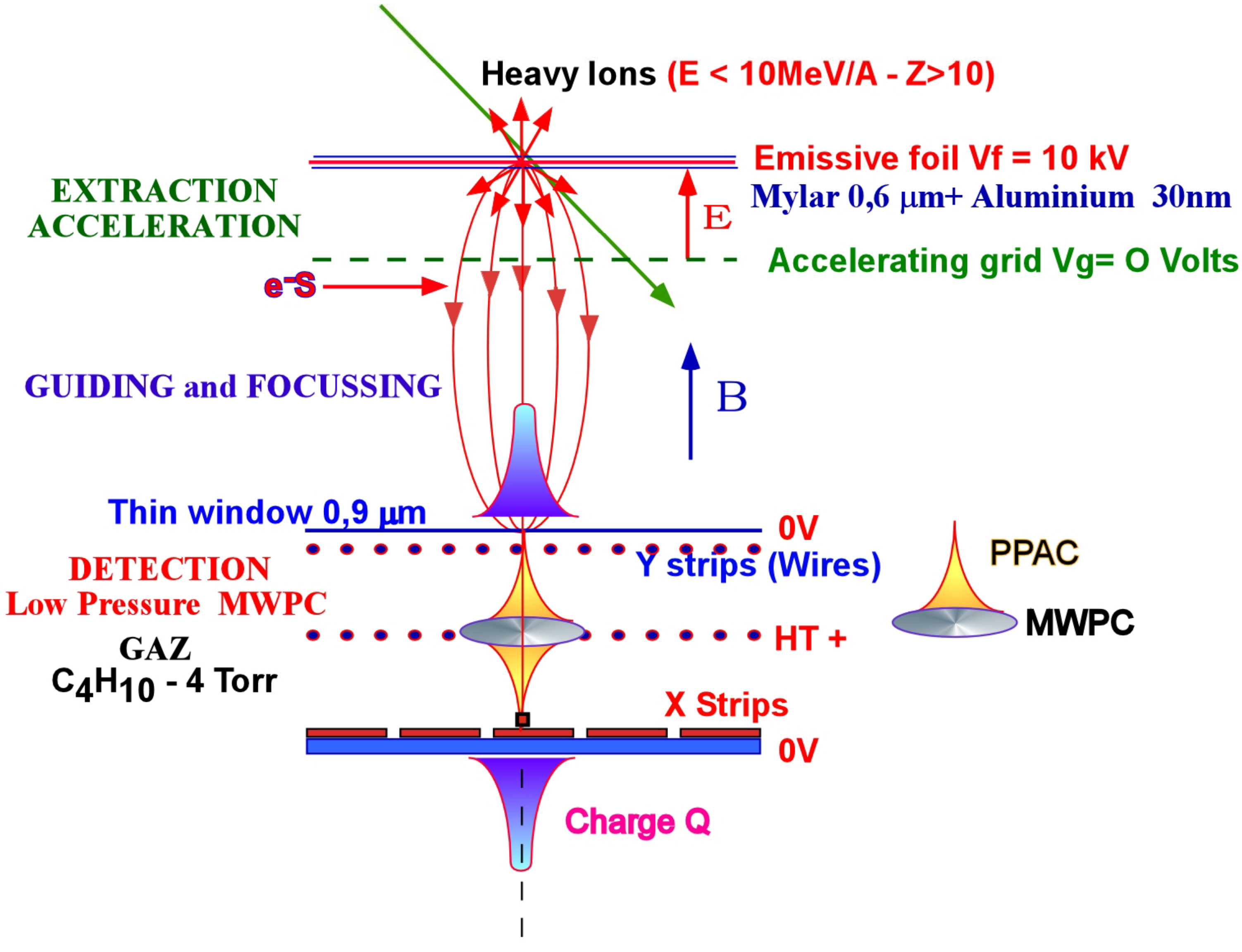


Electron detector :
-Micro-channel plate
-Gaseous detector
-Scintillator
-…

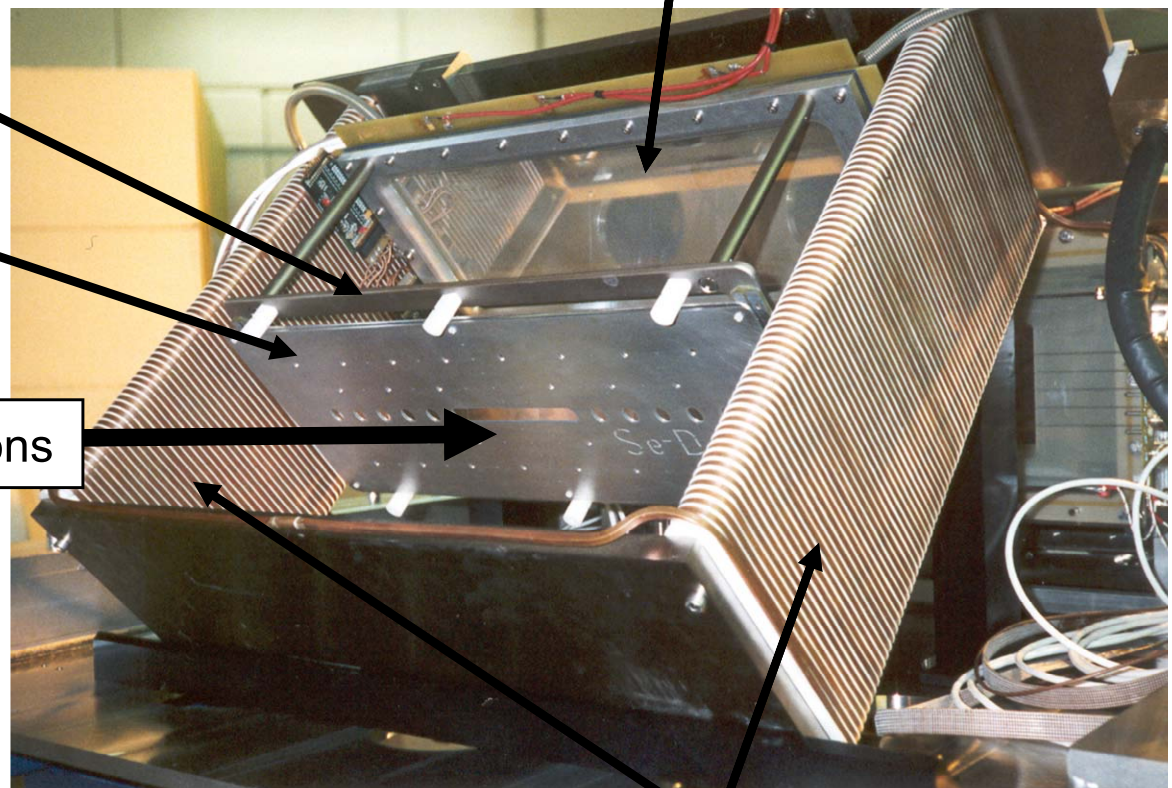
Secondary emission
- low energy electrons (few eV)
- depends on the material (CsI…)
- surface process
- proportional to dE/dx

The Se$^-$D : Secondary electron Detector




Heavy Ions (E < 10MeV/A - Z>10)
Emissive foil Vf = 10 kV
Mylar 0,6 µm+ Aluminium 30nm
EXTRACTION
ACCELERATION
E
Accelerating grid Vg= O Volts
e-S
GUIDING and FOCUSSING
B
Thin window 0,9 µm
0V
Y strips (Wires)
PPAC
DETECTION
Low Pressure MWPC
MWPC
GAZ
C4H10 - 4 Torr
HT +
X Strips
0V
Charge Q

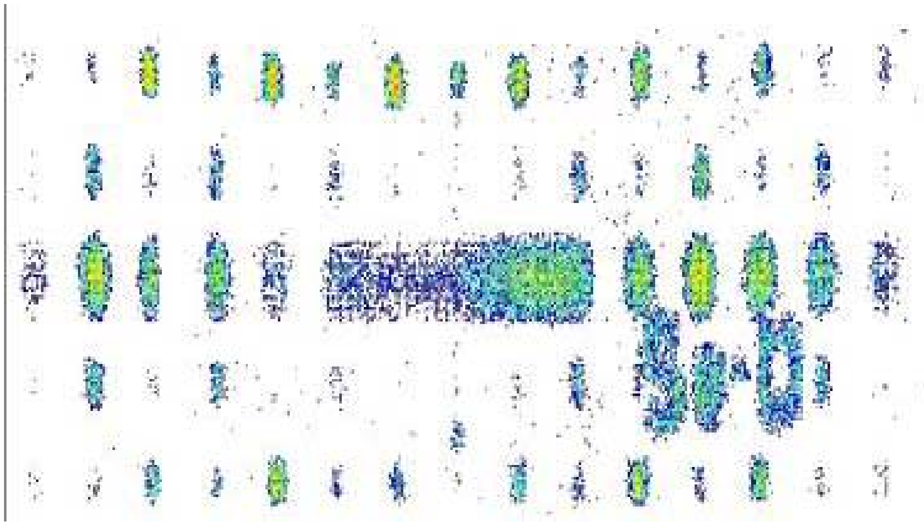
Se⁻D Detector : full size



Focal plane size : 10 x 40 cm^2

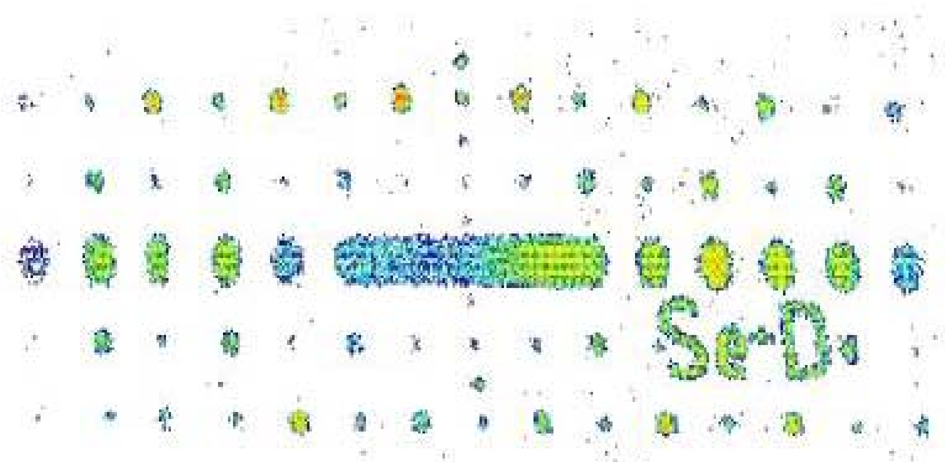
A. Drouart & a.l, NIM A579, (2007) p*1090*

Position reconstruction on the whole focal plane



Position recontruction without B field

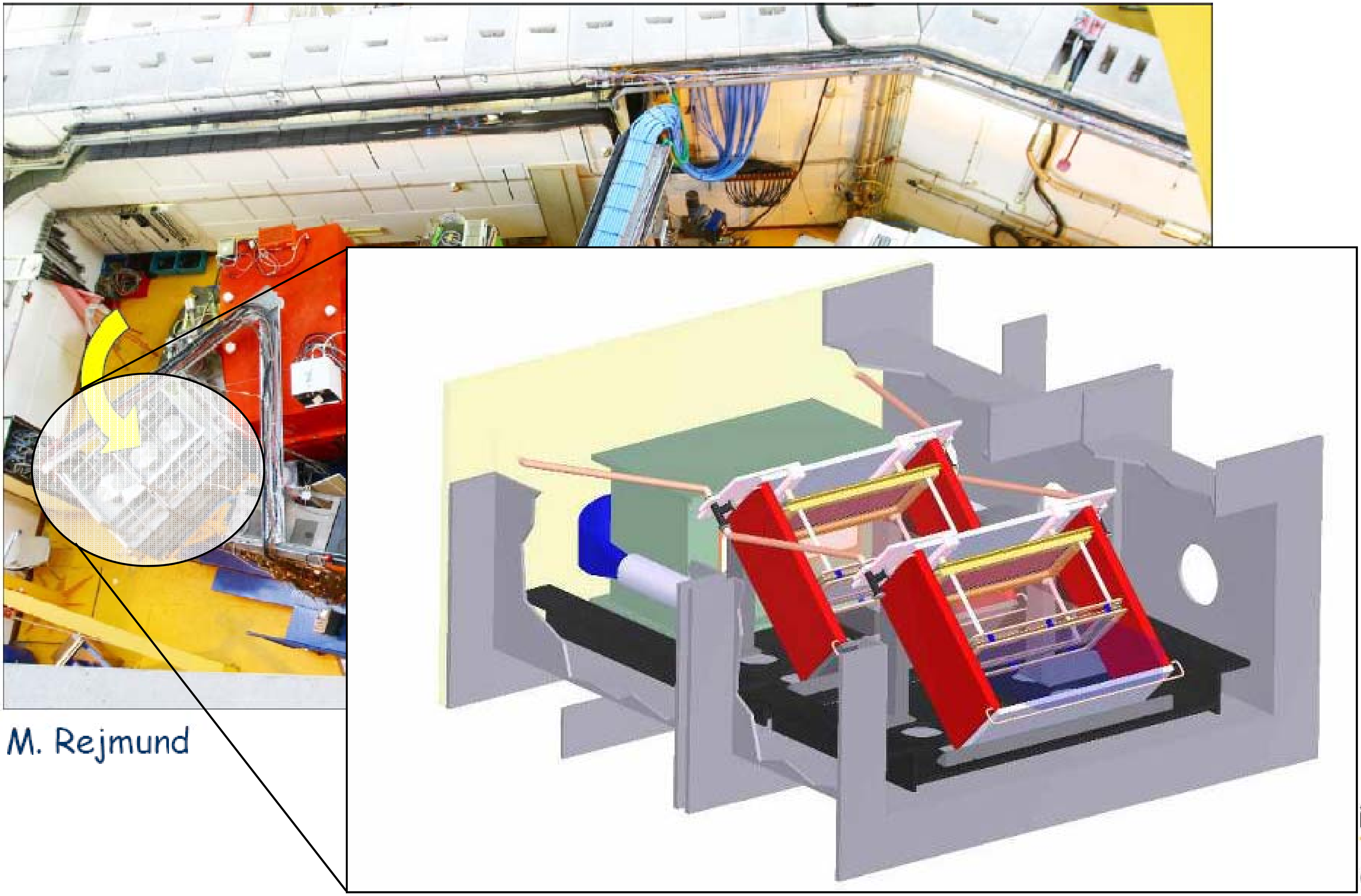
Position resolution
δX = 3.7 mm
δY = 4.8mm



Position reconstruction with B=110Gauss

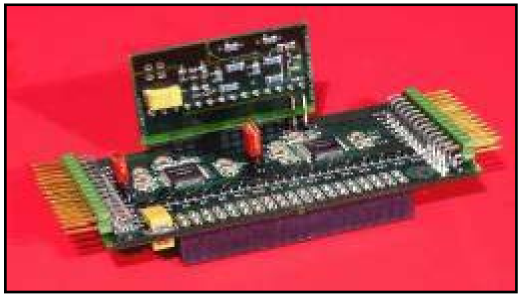
Position resolution
δX = 1.3 mm
δY = 1.8mm

$Se^{-}D$ in VAMOS



M. Rejmund

Se-D front end electronics



Position

Gassiplex 0,7 µm CMOS 16 Channels

Sensibility: 3,6 V/pc

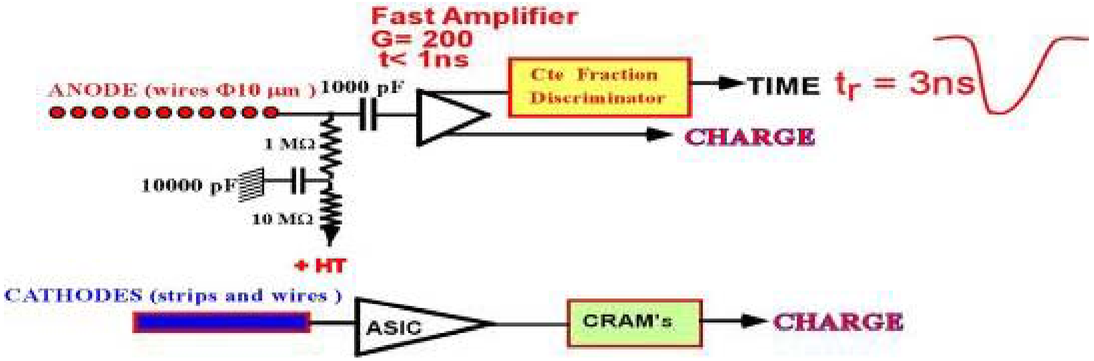
Peaking time: 1,2 µS

Serial Output

Total Channels 150

Timing Channel

Rise Time 4.5 nsec



Results of tests & experiments

Ions	E (MeV/A)	dE/dx (MeV/mm)	Efficiency	Time resolution (FWHM ps)
Heavy Fission frag. Average Z~53	**0.6**	**13800**	**100%**	**250**
Light fission frag. Average Z~45	**1**	**13200**	**100%**	**250**
^{76}Ge	**2**	**10500**	**100%**	**500**
^{24}Mg	**12**	**1050**	**85%**	**800**
^{12}C	**10**	**320**	**75%**	**1000**
Alpha	**1.5**	**160**	**40%(70%*)**	**1200***

Conclusions

-Detector able to cope with a few **10^3pps** (limited by electronics dead time)
- theoretical limit **~10^7pps or more ?**
-Spatial resolution : **1-2mm**
-Time resolution : **1.5ns (light ions) to 300ps (heavy ions Z>40)**
-Total thickness in the beam : 0.6µm Mylar foil = **75µg/cm^2**

Virtues & Flaws of Emissive foil detectors

☺

- detector as thin as it can be
- fast signal ➔ good time resolution σ < 100ps

☹

- poor sensitivity to high energy, light ions
- moderate position resolution σ~600µm
- require high electric field and/or magnetic field
- surface effect ➔ lots of "dead zone"

Characteristics depend on the secondary electron detector

- gas detector : large size
- micro channel plate : high counting rate
- scintillating plastic : easy to use

Conclusions

Beam tracking require event by event measurement and :

- ➔ low thickness not to perturb the incoming ion
- ➔ good position and time resolution
- ➔ cope with high flux of ions

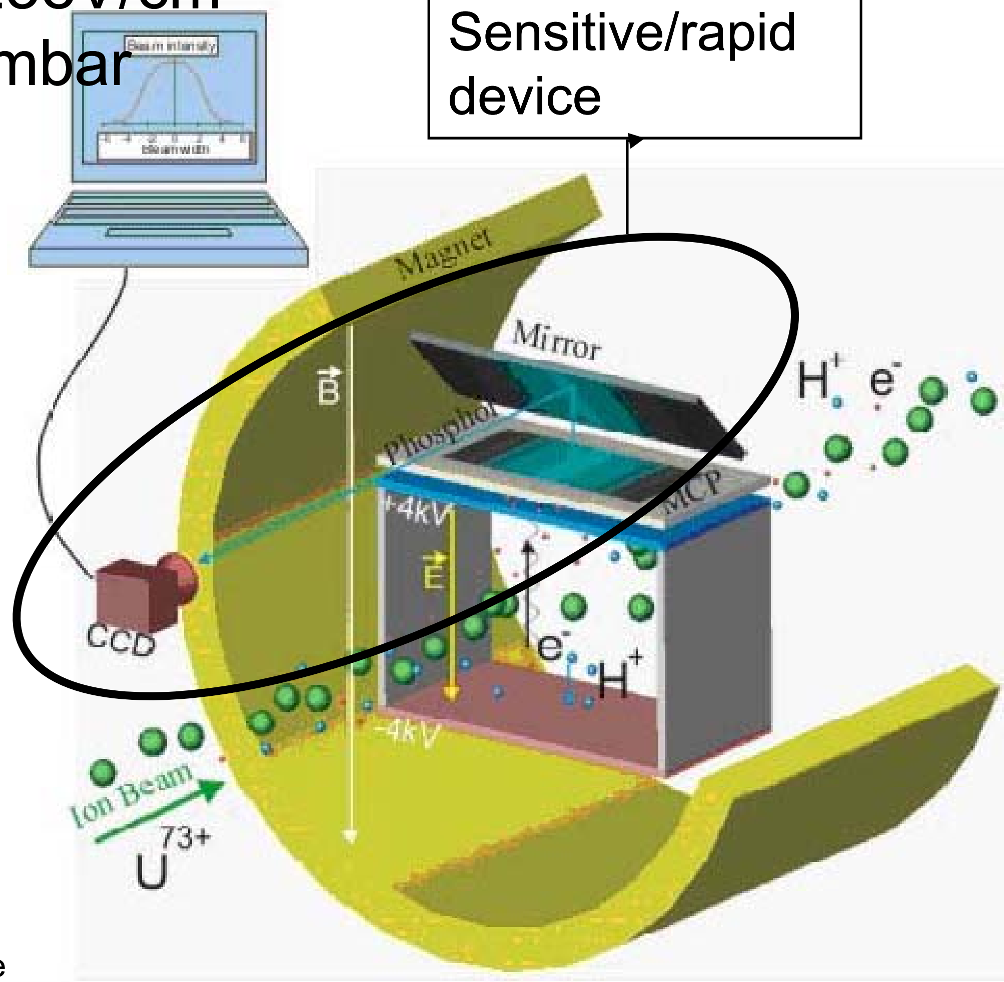
Technique	Regime MeV/u	σ(time) ps	σ(pos.) µm	Max rate Hz
Diamonds	500	30	10 (strip)	10^7
Atm. pressure	500	700	100	10^8
Low pressure	50	500	150	10^5
Emissive foils	5	100	500	10^6

Beyond Conclusions...

Residual gas detectors

For a vacuum in the beam line ~10^{-6}mbar
^{40}Ar @ 3A.MeV looses 23eV/cm
➔ need higher pressure ~10^{-3} mbar
but difficult to contain

Can be replaced by a more Sensitive/rapid device



Existing residual gas detector
@10^{-6}mbar with MCP
(Barabin & al. EPAC2004)