# Magnetic Spectrometers

- Basic Concepts:
  - charged particle moving in magnetic field
  - magnetic dipole
  - magnetic quadrupole

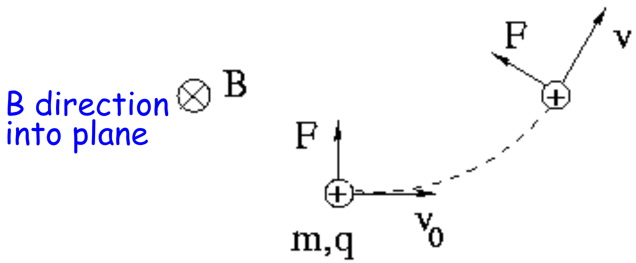
- Mass Spectrometers: **PRISMA (LNL)**

- High Resolution Spectrometers: **SPEG (GANIL)**

- Isotope Separators: **LISE (GANIL), FRS (GSI)**

# Magnetic Rigidity

**Charged particle moving in Uniform Magnetic Field**




$$\vec{F} = q\vec{v} \times \vec{B}$$ **magnetic force**

$\vec{F} \perp \vec{v}$ $\Rightarrow$ changes only $\vec{v}$ direction
( $v = v_0$ ; F is centripetal force)

$$F = qvB = m\frac{v^2}{\rho}$$ → **curvature radius**

Bρ is called **magnetic rigidity**:

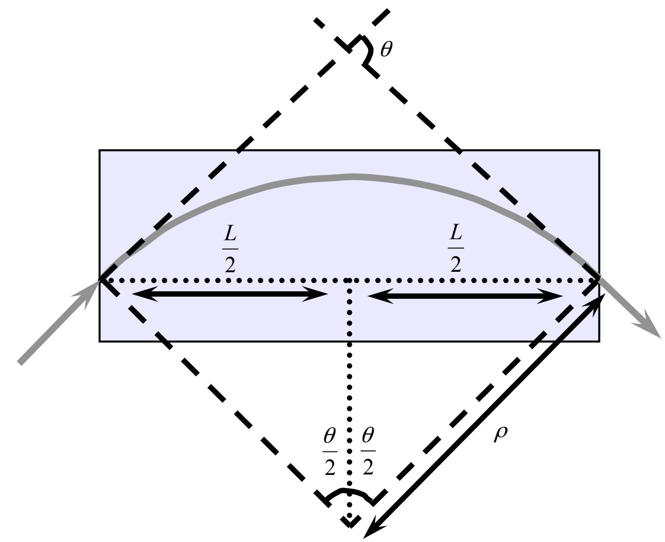
$$B\rho = \frac{mv}{q} = \frac{p}{q} = \frac{Av}{qc^2}$$ → **momentum**

using correct units:

Bρ = 33.356 p [kG m ]
= 3.3356 p [T m] (if p is in [GeV/c])

# Dipole Magnet

a **dipole** with a **uniform dipolar field** deviates a particle by an angle θ

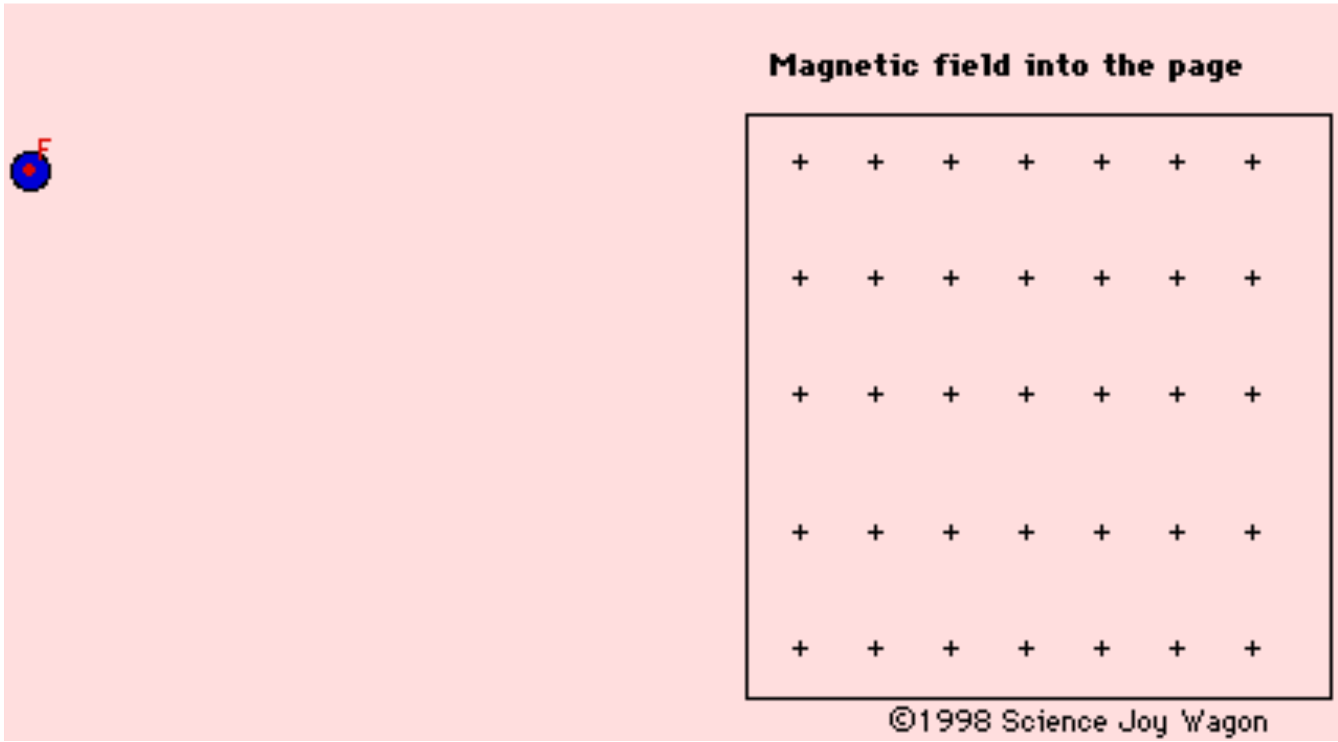


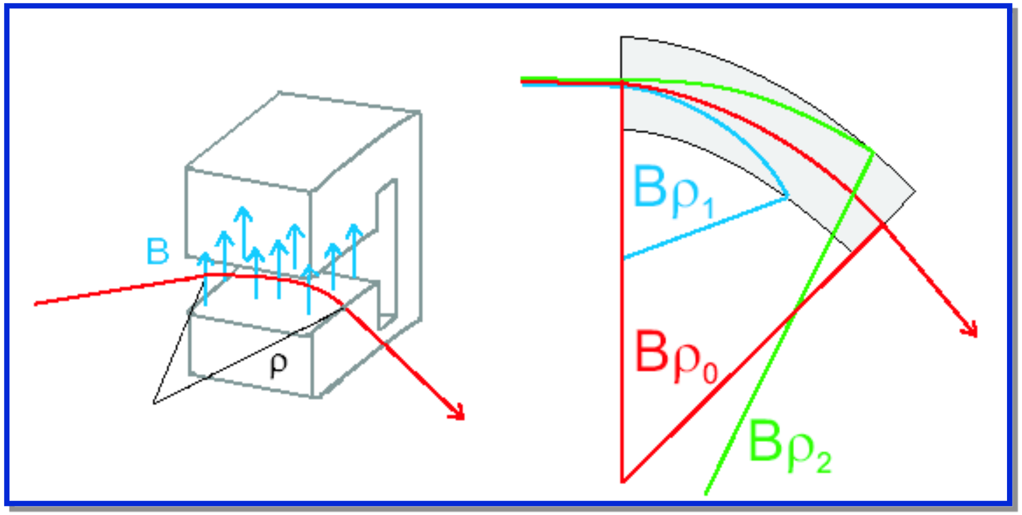

θ depends on length L and field B:

$$\sin\left(\frac{\theta}{2}\right) = \frac{L}{2\rho} = \frac{1}{2}\frac{LB}{(B\rho)}$$

if θ is small:

$$\sin\left(\frac{\theta}{2}\right) = \frac{\theta}{2} \quad \rightarrow \quad \theta = \frac{LB}{(B\rho)}$$


Magnetic field into the page
F
©1998 Science Joy Wagon




## a dipole magnet is the ion-optical equivalent of a prism

- a dipole introduces **dispersion** at any position s
  [a relation between momentum and position]

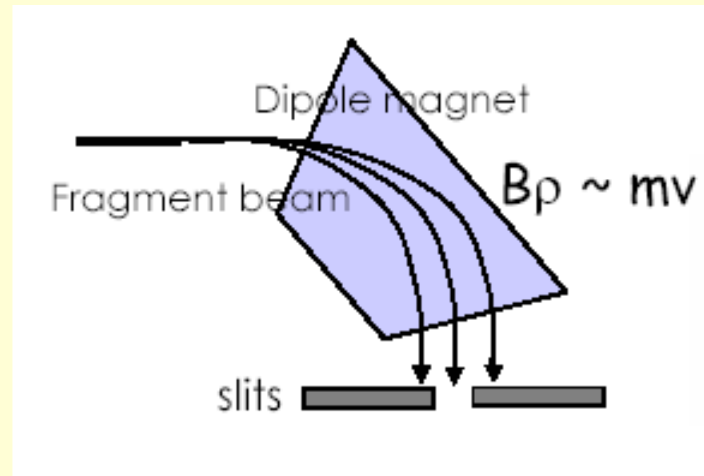
$$\Delta x(s) = D(s).\frac{\Delta p}{p_0}$$

local radial displacement due to momentum spread

dispersion function

- dispersion function D(s) can be calculated:
  it has the unit of **meters**
- beam has a **finite horizontal size**
  (due to momentum p spread)
- normally **NO vertical dipoles**
  ⇒ D(s) =0 in vertical plane

## Dipole Selection

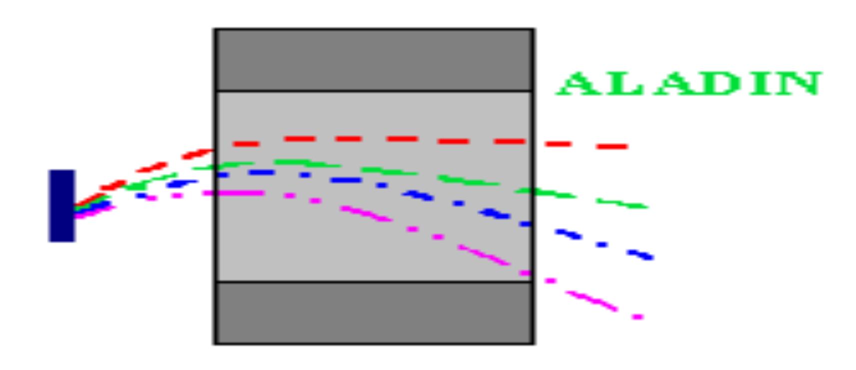


# Examples of Magnetic Dipole

## Large acceptance
(angle & momentum)

**ALADIN (GSI)**

**A Large Acceptance DIpole magNet**




for ***particle velocity evaluation***

$$B\rho = \frac{mv}{q} = \frac{p}{q} = \frac{A}{qc^2}v$$

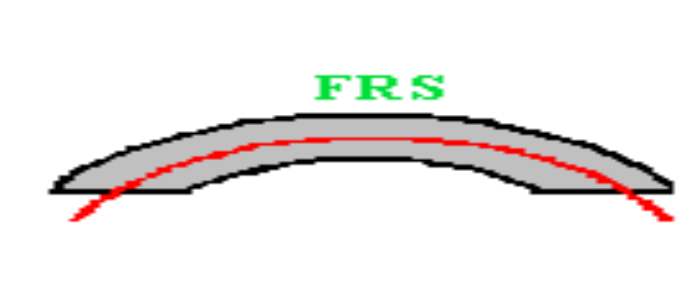
obtained from measurement of particle trajectory ($B\rho$)

already known from independent measurement ($\frac{A}{qc^2}$)

## Limited acceptance
(angle & momentum)

**FRS (GSI)**

**FRagment Separator**




***magnetic selection in A, Z, v:***

only particles with a limited range of bending radii, centered around $\rho_0$, can pass.

[N.B. $\rho_0$ is defined by the geometry of the magnet]

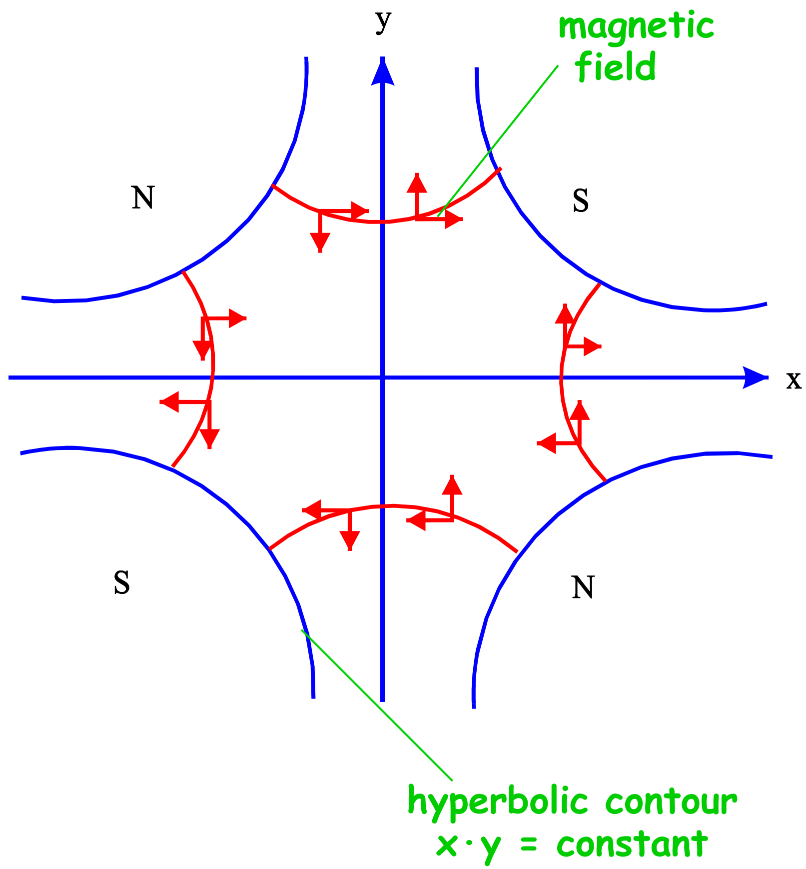
**Dipoles**, constrain the beam to some closed path (orbit)

# Quadrupole Magnet

**focusing of the beam**

a quadrupole magnet has **4 poles**:

- 2 north and 2 south
- **simmetrically** arranged around the centre of the magnet
- **No** magnetic field along the central axis




on the **x-axis** (horizontal)
the field is vertical and given by:

$$B_y \propto x$$

on the **y-axis** (vertical)
the field is horizontal and given by:

$$B_x \propto y$$

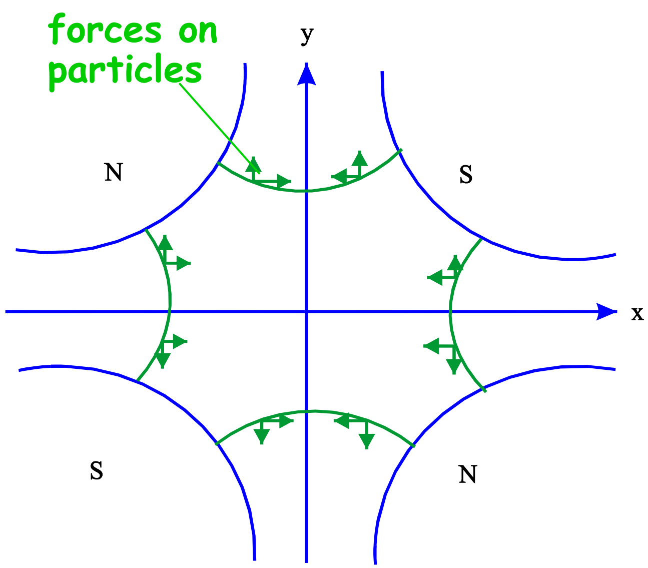
**Field gradient K**

$$\frac{d(B_y)}{dx} \quad (Tm^{-1})$$

# Types of Magnetic Quadrupoles

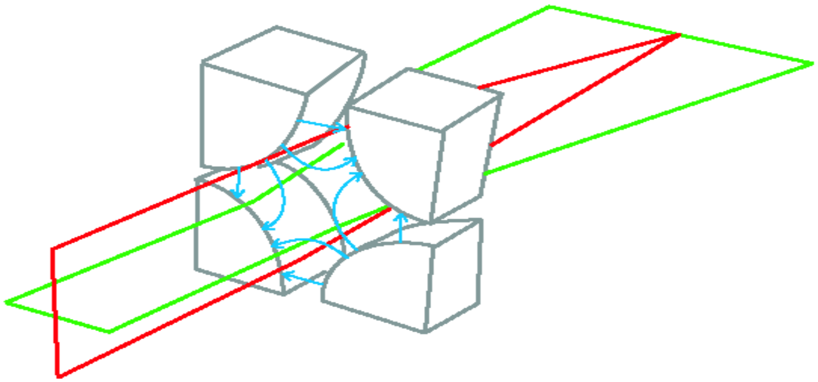
## Focusing Quadrupole (QF)

it **focuses** the beam **horizontally** and **defocuses** the beam **vertically**

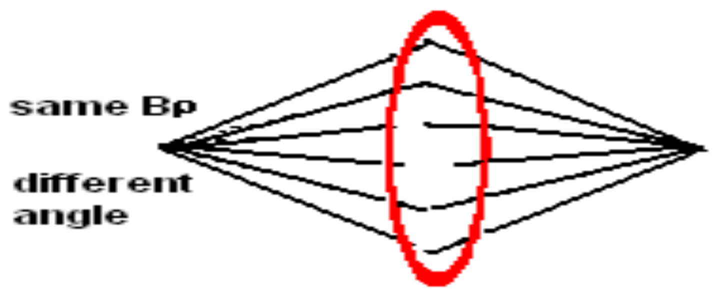



## Defocusing Quadrupole (QD)

rotating the QF magnet by 90° will give **vertical focusing** and **horizontal defocusing**



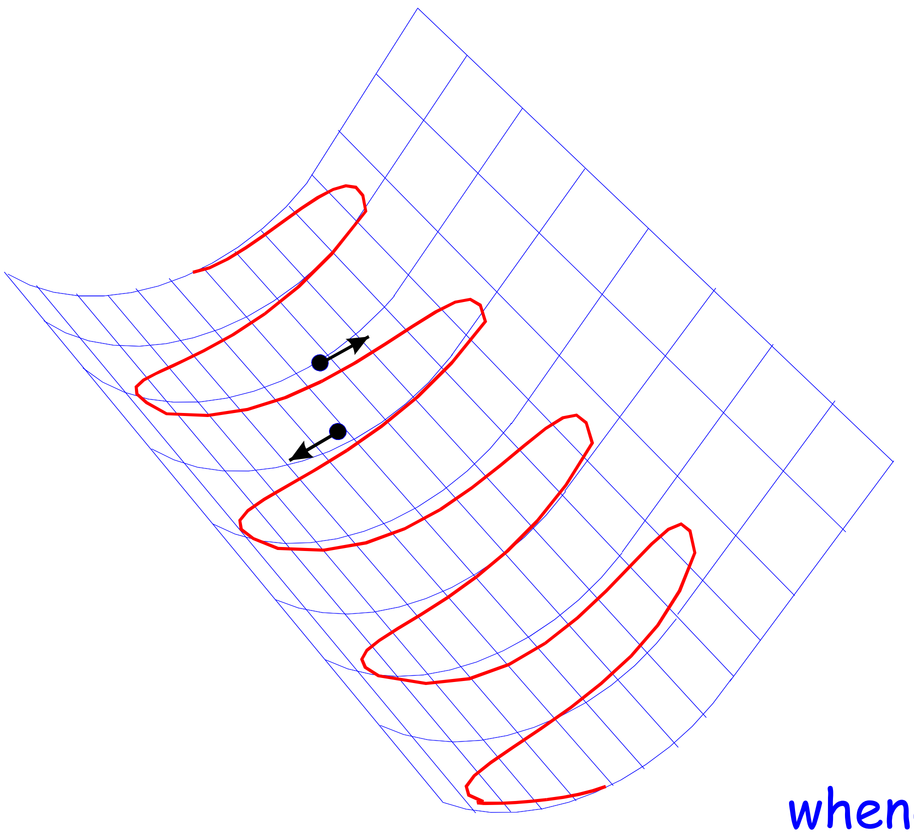
***pair of quadrupoles*** with a drift section in between is the ion-optical equivalent of a lens.




**Focusing and Defocusing Quadrupoles** provide horizontal and vertical focusing in order to **constrain the beam in transverse directions**

# The mechanical equivalent

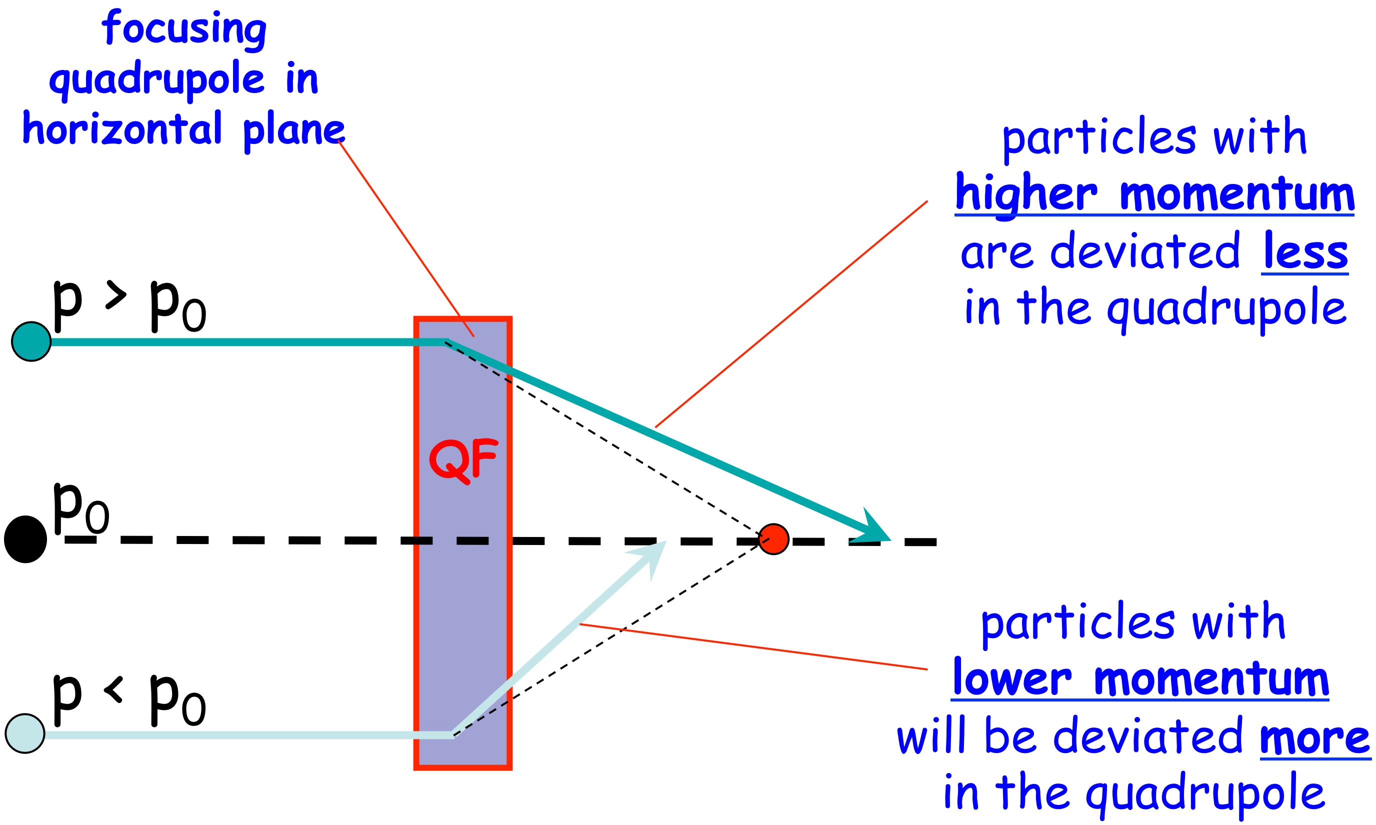
illustration of how particles behave due to the quadrupolar fields



whenever a beam particle diverges too far away from the central orbit ***<u>the quadrupoles focus them back</u>*** towards the central orbit

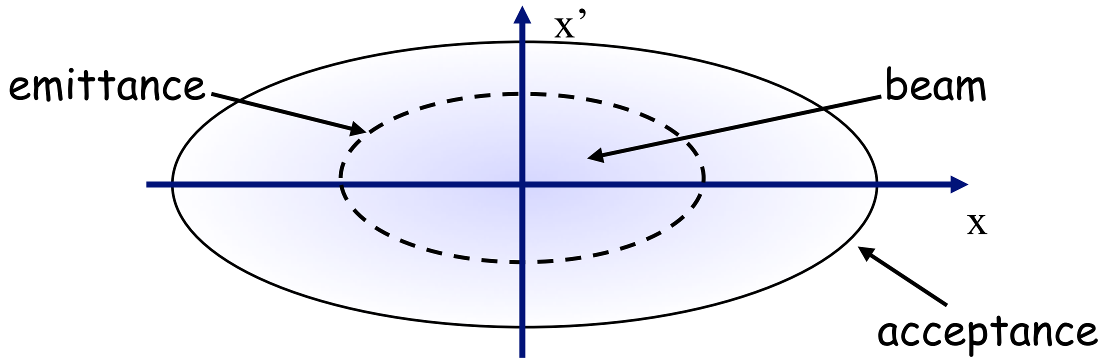
# Other focusing magnets

**Sextupoles:**
correction of chromaticity introduced by quadrupoles



# Beam Emittance & Acceptance

- **observe** all the beam particles at a single position
- **measure** both position and angle
- this gives a large number of points in our **phase space plot**:
  each point represents a particle with co-ordinates x,x'




**emittance** = **area** of the ellipse, which contains all, or a defined percentage, of the particles.

**acceptance** = **maximum area** of the ellipse, which the emittance can attain without losing particles

# Magnetic MASS Spectrometers

**Physics Aim:** attribution of a reaction product to a nucleus

⇒ high efficiency over a wide range of masses and energies

## Examples:

- **binary reactions** 5-10 MeV/A: elastic, inelastic and multinucleon transfer
  ⇒ population of moderately n-rich nuclei
  PRISMA @ LNL, BRS @ EUROBALL

- **radioactive beams**: simultaneus population of many nuclei
  ⇒ wide range of masses, energies, scattering angles
  PRISMA @ LNL(Spes), VAMOS @ GANIL (Spiral)

- **fusion evaporation reactions**: Gas Filled Mode operation
  ⇒ high efficiency and 0° operation
  RITU @ JYFL, PRISMA @LNL

⇒ **need for spectrometer with:**
- large solid angle (up to 100 msr)
- large p acceptance ( ± 10%)
- good mass resolution (via TOF)

# PRISMA (LNL)

## Large Acceptance Spectrometer for Heavy Ions

(A=100-200, E=5-10MeV/A)

Study of *multinucleon transfer* reactions populating moderately n-rich nuclei

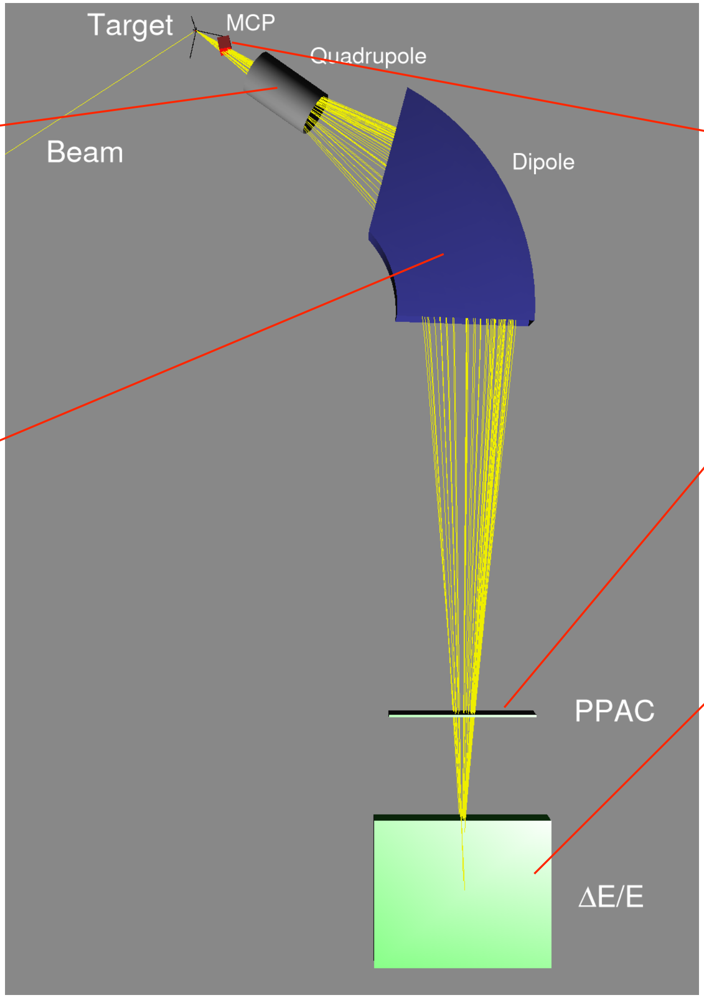
### Optical elements

1. **Quadrupole (QF)**

a singlet
vertical focus of ions
towards dispersion plane

2. **Dipole**

horizontal bending of ions
according to their
magnetic rigidity (Bρ)



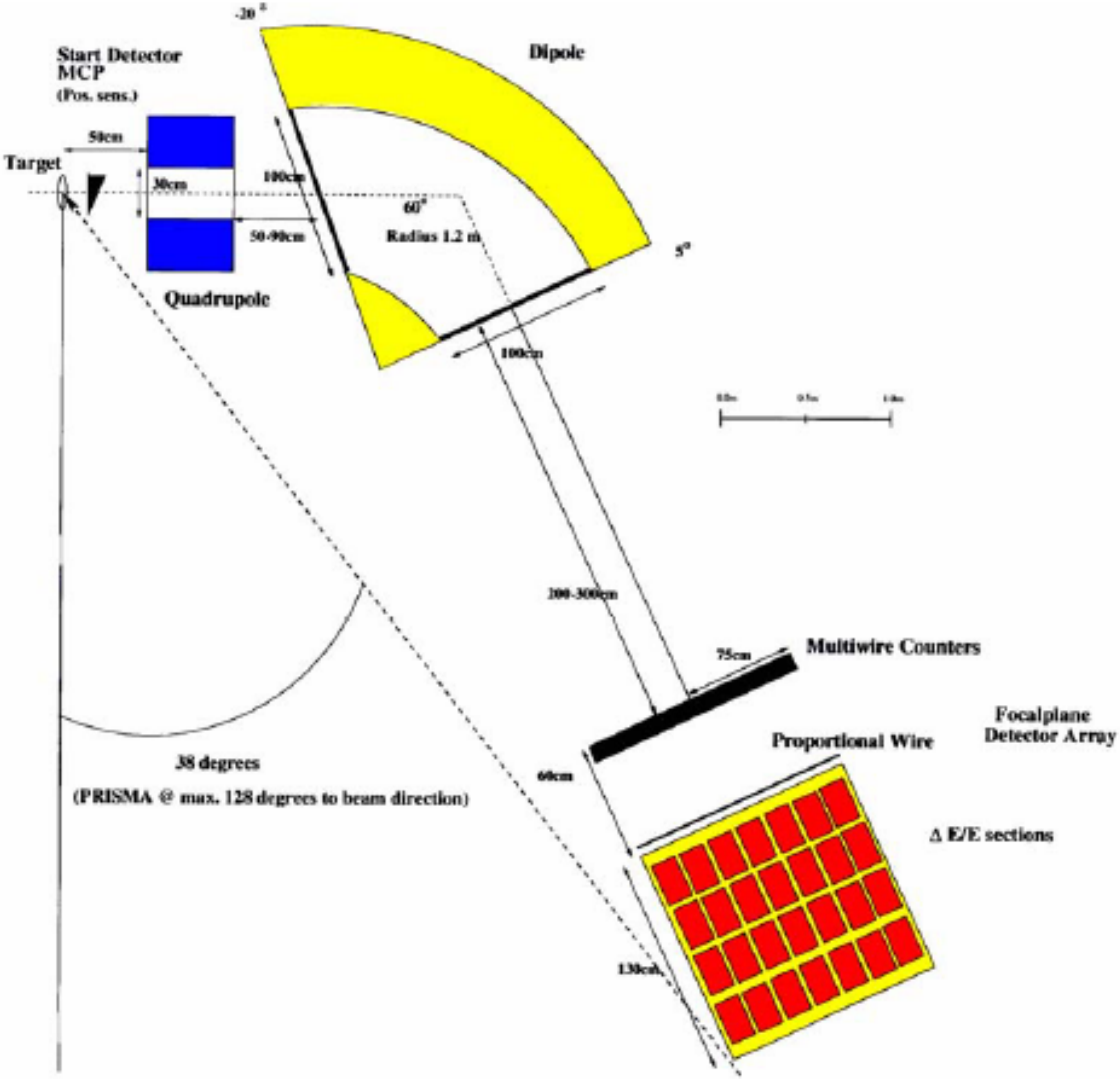

### PRISMA Detectors

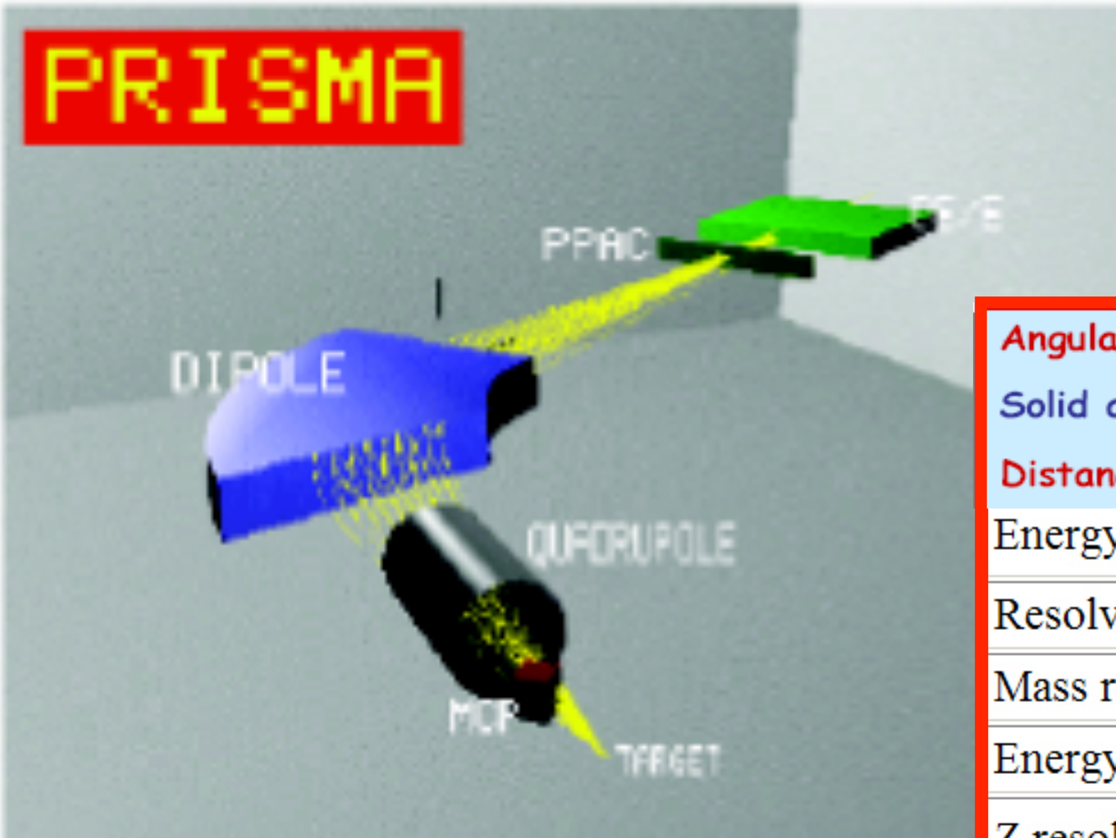
1. **Entrance Detector**
**MCP**
entrance position
$x_s$ - $y_s$, time

2. **Focal Plane Detector**
**PPAC**
$x_f$ - $y_f$, time

3. **Ionization Chamber**
energy loss, total energy

physical event
($x_s$, $y_s$, $x_f$, $y_f$, TOF, ΔE, E)


-20°
Dipole
Start Detector
MCP
(Pos. sens.)
50cm
Target
30cm
100cm
60°
Radius 1.2 m
50-90cm
5°
Quadrupole
100cm
200-300cm
75cm
Multiwire Counters
Focalplane
Detector Array
Proportional Wire
60cm
38 degrees
(PRISMA @ max. 128 degrees to beam direction)
Δ E/E sections
130cm

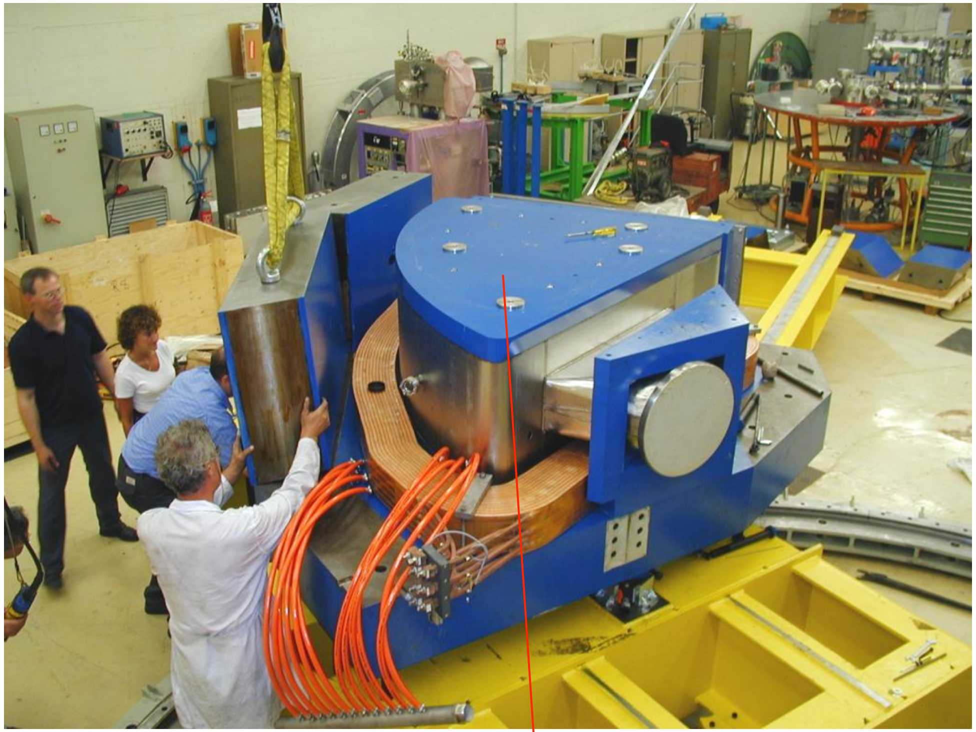



| | |
|---|---|
| Angular acceptances | $\Delta\theta \sim \pm 6°$  $\Delta\phi \sim \pm 11°$ |
| Solid angle | $\Delta\Omega \sim 80$ msr |
| Distance target-FPD | 7 m |
| Energy acceptance | ±20% |
| Resolving power | $p/\Delta p \simeq 2000$ |
| Mass resolution | 1/300 (via TOF) |
| Energy resolution | 1/1000 (via TOF) |
| Z resolution | ≤1/60 |
| Mass energy product | $ME/q^2$=70 MeV amu |
| Kinematical correction | via software |
| Aberration correction | via software |
| Dispersion | 4cm/% |
| Count rate capability | up to $2 \times 10^5$ sec$^{-1}$ |

$(B\rho)_{max}$ → Mass energy product

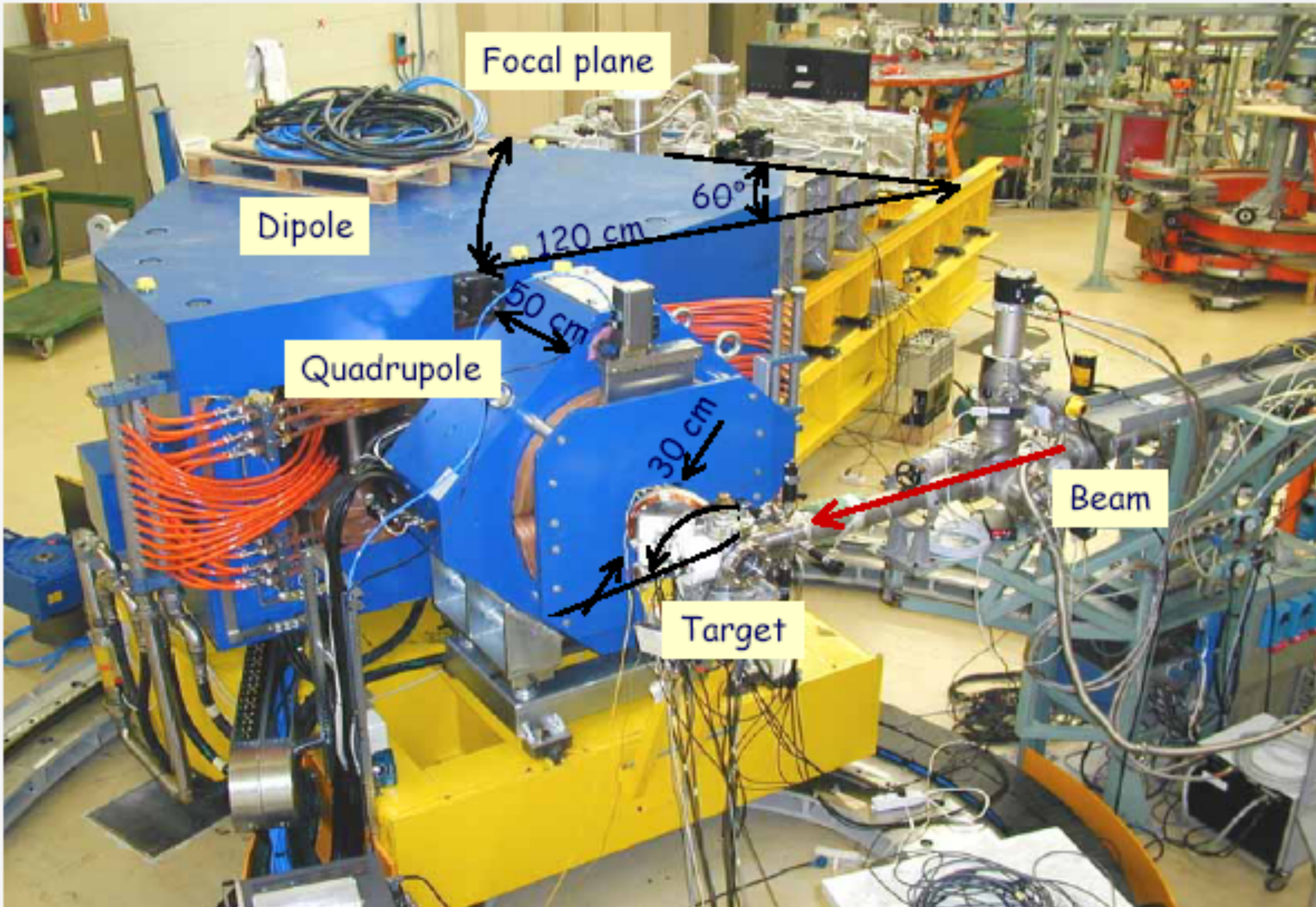

A.M. Stefanini et al., NIMA701(2992)217c
F. Scarlassara et al., NPA746(2004)195c

# Mounting of the DIPOLE



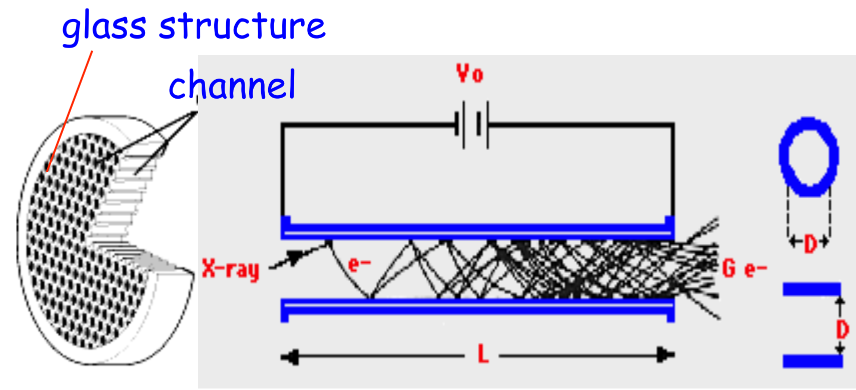
dipole field region
under vacuum

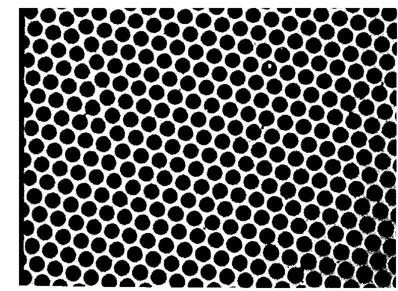
## DIPOLE & QUADRUPOLE


Focal plane
Dipole
60°
120 cm
50 cm
Quadrupole
30 cm
Beam
Target

# Microchannel plates

- compact **electron multipliers** of high gain
  **$G \sim 10^6$-$10^8$**
- used in wide range of
  particle and photon detection systems
- $\sim$ $10^7$ closely packed channels of common diameter
  (formed by drawing, etching, or firing
  in hydrogen, a lead glass matrix)
- typical channel diameter **D~10 μm**
- each channel acts as
  an independent, continuous dinode photomultiplier
- gain **G** increases with **L/D** (typically 75:1 – 175:1)



## performances

- **efficiency**
  not more than 60% for X-rays
  higher for charged particles
- **time-resolution**
  ultra-high: < 100 ps
- **spatial resolution**
  (limited by channel dimensions & spacing): 12-15 μm
- relative **immunity to magnetic fields**:
  single MCP: completely unaffected in B ≤ 0.5 Tesla
  in stack: completely unaffectd by much higher fields

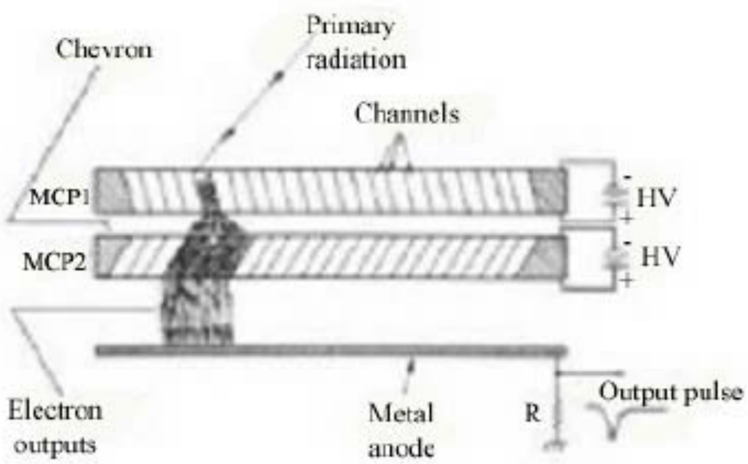
### efficiency

| Type of radiation | | Detection efficiency (%) |
|---|---|---|
| Electrons | 0.2 - 2 keV | 50-85 |
| | 2 - 50 keV | 10-60 |
| Positive ions | 0.5 - 2 keV | 5-85 |
| (H+, He+, A+) | 2 - 50 keV | 60-85 |
| | 50 -200 keV | 4-60 |
| U.V. radiation | 300 - 1100 Å | 5-15 |
| | 1100-1500 Å | 1-5 |
| Soft X-rays | 2 -.50 Å | 5-15 |
| Diagnostic X-rays | 0.12 - 0.2 Å | ~1 |

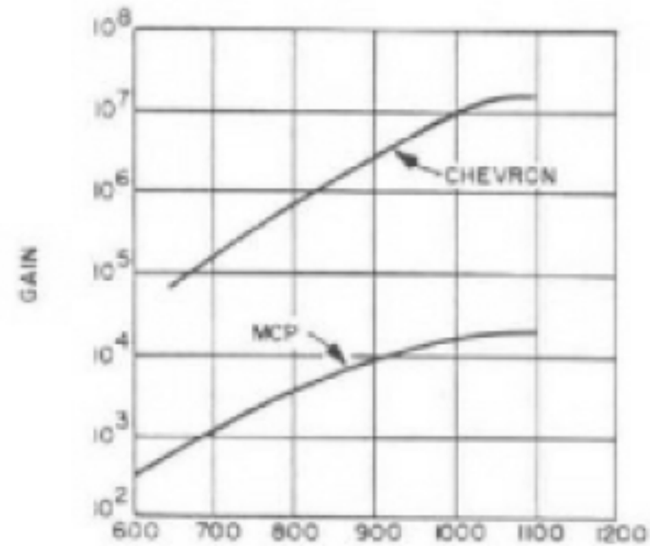
J. L. Wiza, NIMA162(1979)587

# Mostly Used Configuration: chevron ('V' shaped)

## Hamamatsu Rectangular Chevron MCP




Chevron operation (side view)

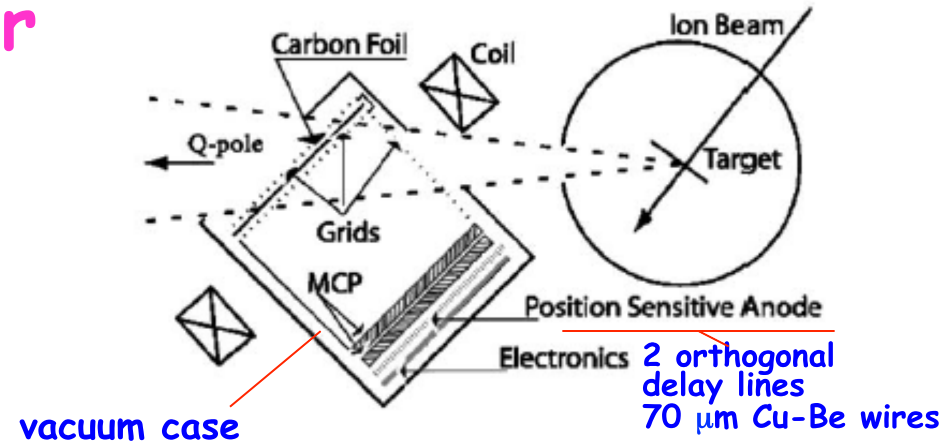


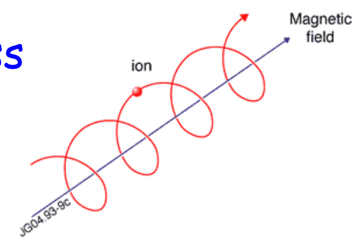

Gain vs voltage characteristic for a straight channel MCP and a Chevron.

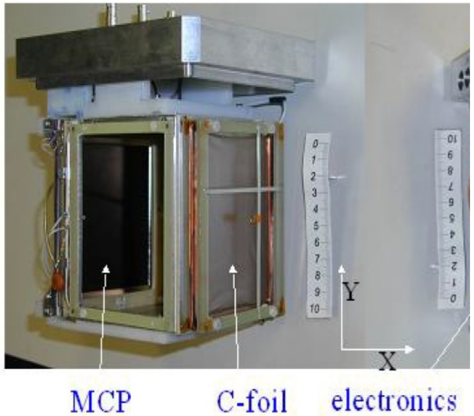
| Chevron configuration: | Ham model F1552 |
|---|---|
| 1. Thickness D | 0.41 μm |
| 2. Channel diameter | 10 μm |
| 3. Channel pitch | 12 μm |
| 4. Bias angle | 8.12 degrees |
| 5. Rise time | 360ps |
| 6. Gain | $10^6$ |
| 7. Effective diameters | 27 mm |

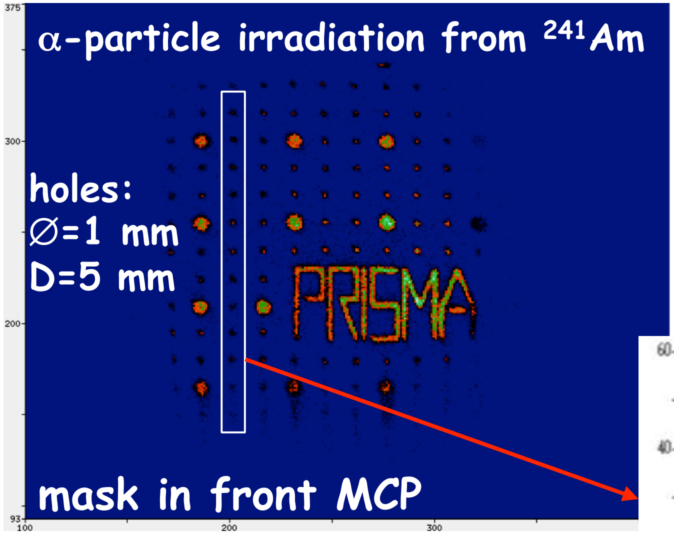
# Entrance Position Detector
## (Micro Channel Plate)

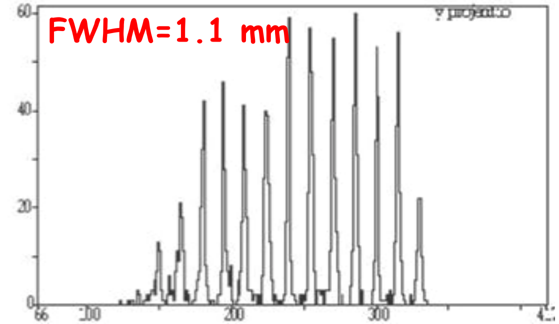
- **active area**: 8x10 $cm^2$ ($\Omega$=80msr)
  ⇒ full coverage of PRISMA spectrometer
  at d = 25cm from target
- **timing resolution** for TOF ~ 350 ps
- **C foil**: 20mg/$cm^2$ thick
- $E_{acc}$ = 30-40 kV/m
- **parallel magnetic field:** B~120 Gauss
  to limit the spread of electron cloud
  preserving particle position infformation

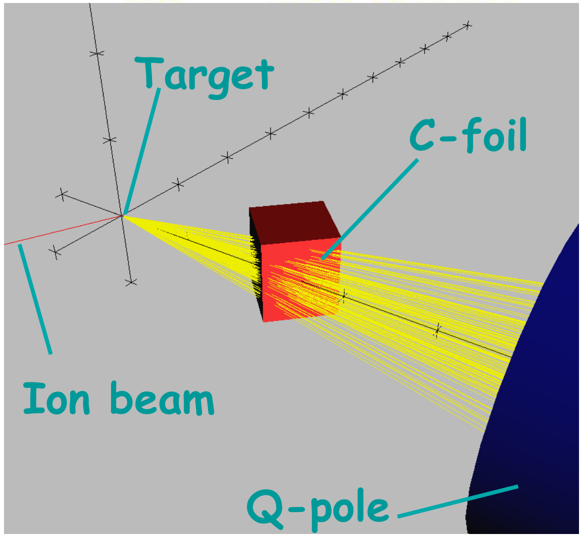


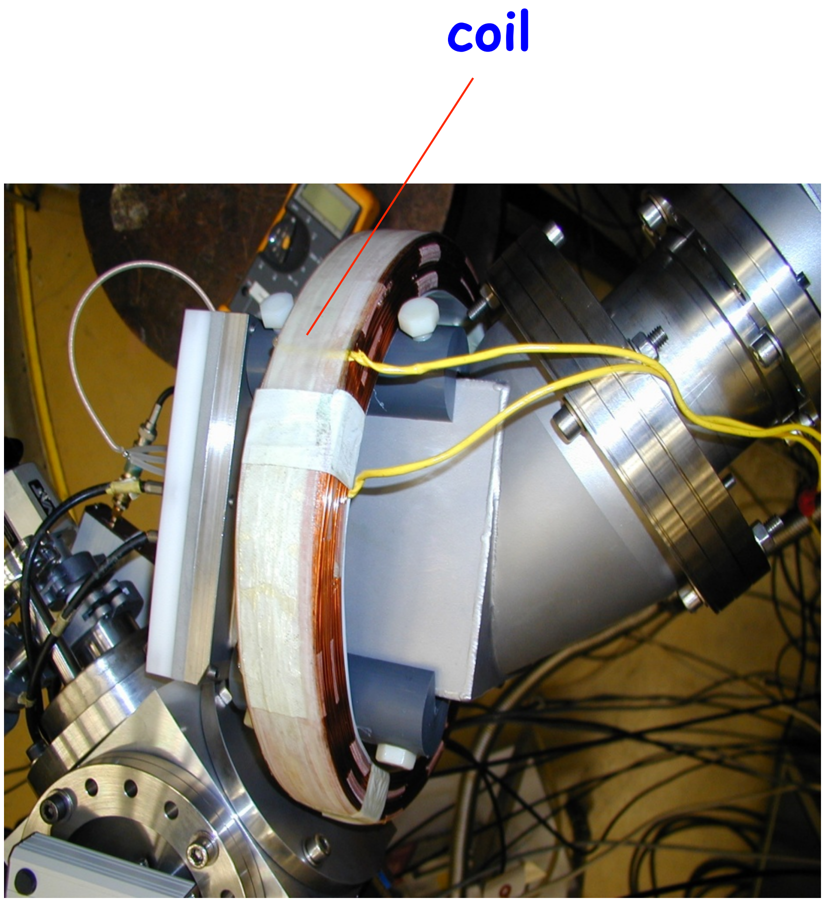



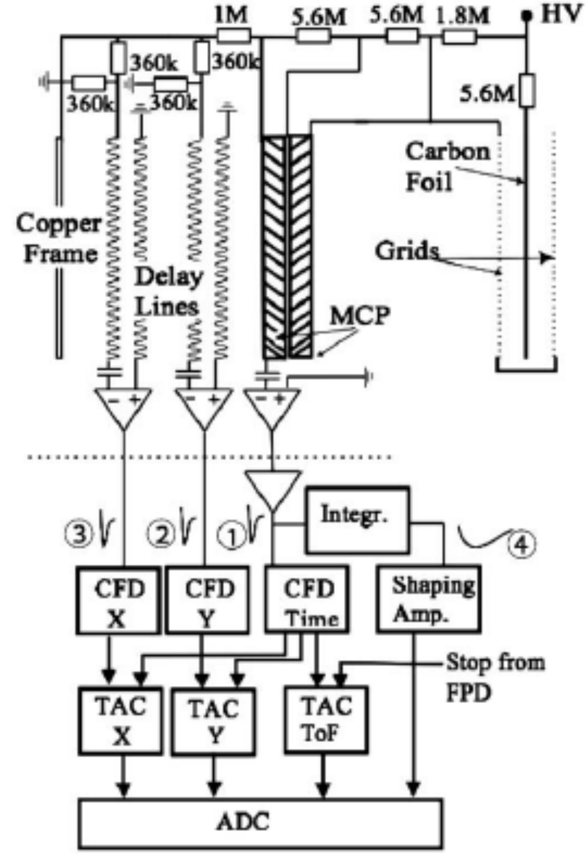



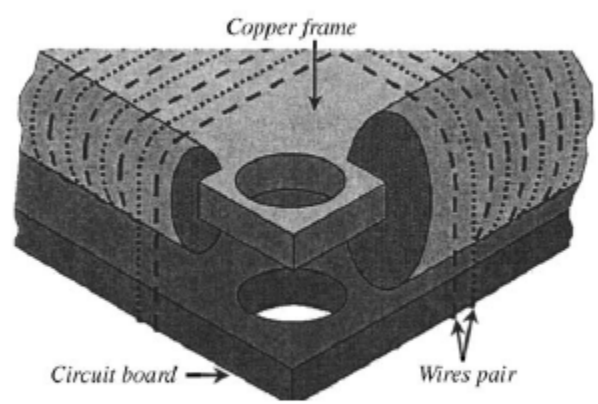




**3 signals:** x, y, time

# Micro Channel Plate




G. Montagnoli et al., NIMA547(2005)455

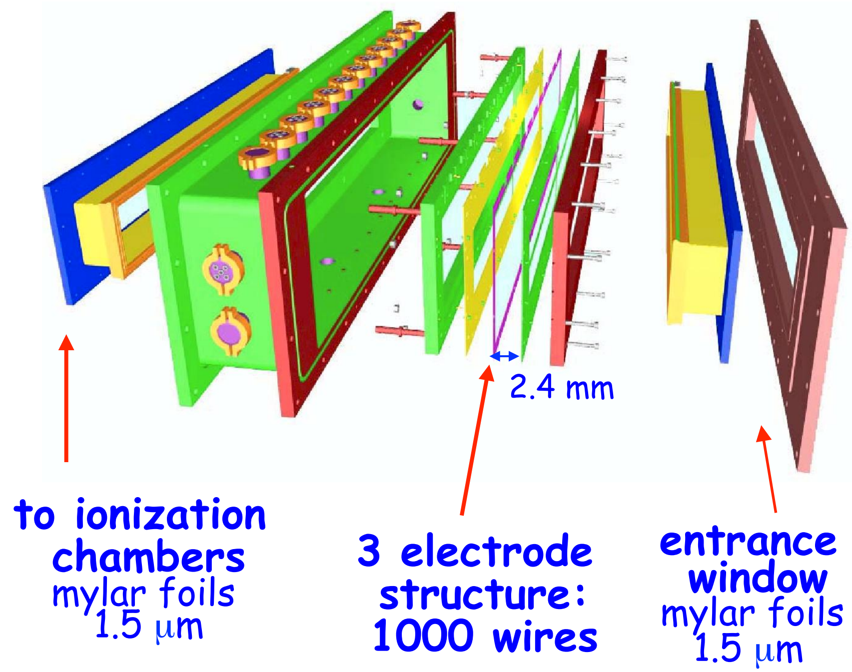
position sensitive anode

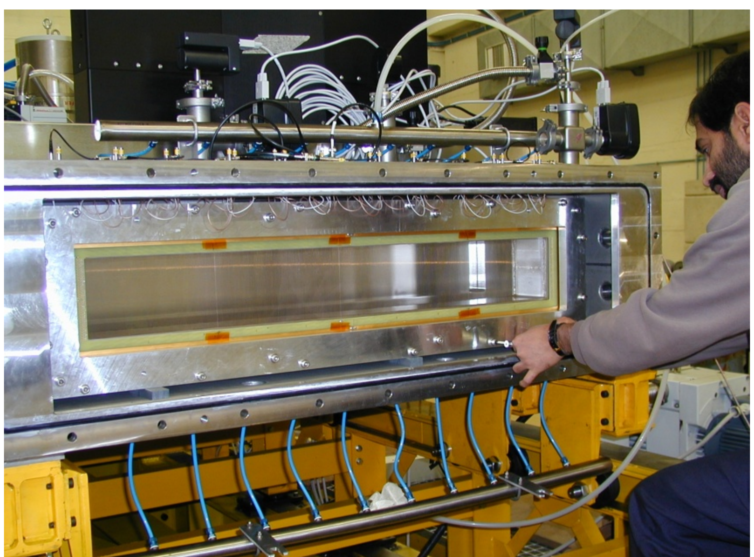
# Focal Plane Detectors: Multi Wire PPAC

- **active area**: 1m x 13 cm
- **3 electrode structure**:

  central cathod & 2 anodic wire planes (X and Y)

- **cathode**: 3300 wires of 20μm gold-plated tungsten
  0.3 mm spacing
  10 independent sections of 10x13 $cm^2$
  negative high voltage: 500-600 V
- **X plane**: 10 sections of 100 wires each, 1mm spacing
- **Y plane**: common to all cathode,
  130 wires, 1 m long, 1mm steps
- **spatial resolution**: ΔX ~ 1mm, ΔY ~ 2mm (FWHM)
- **stop signal for TOF**

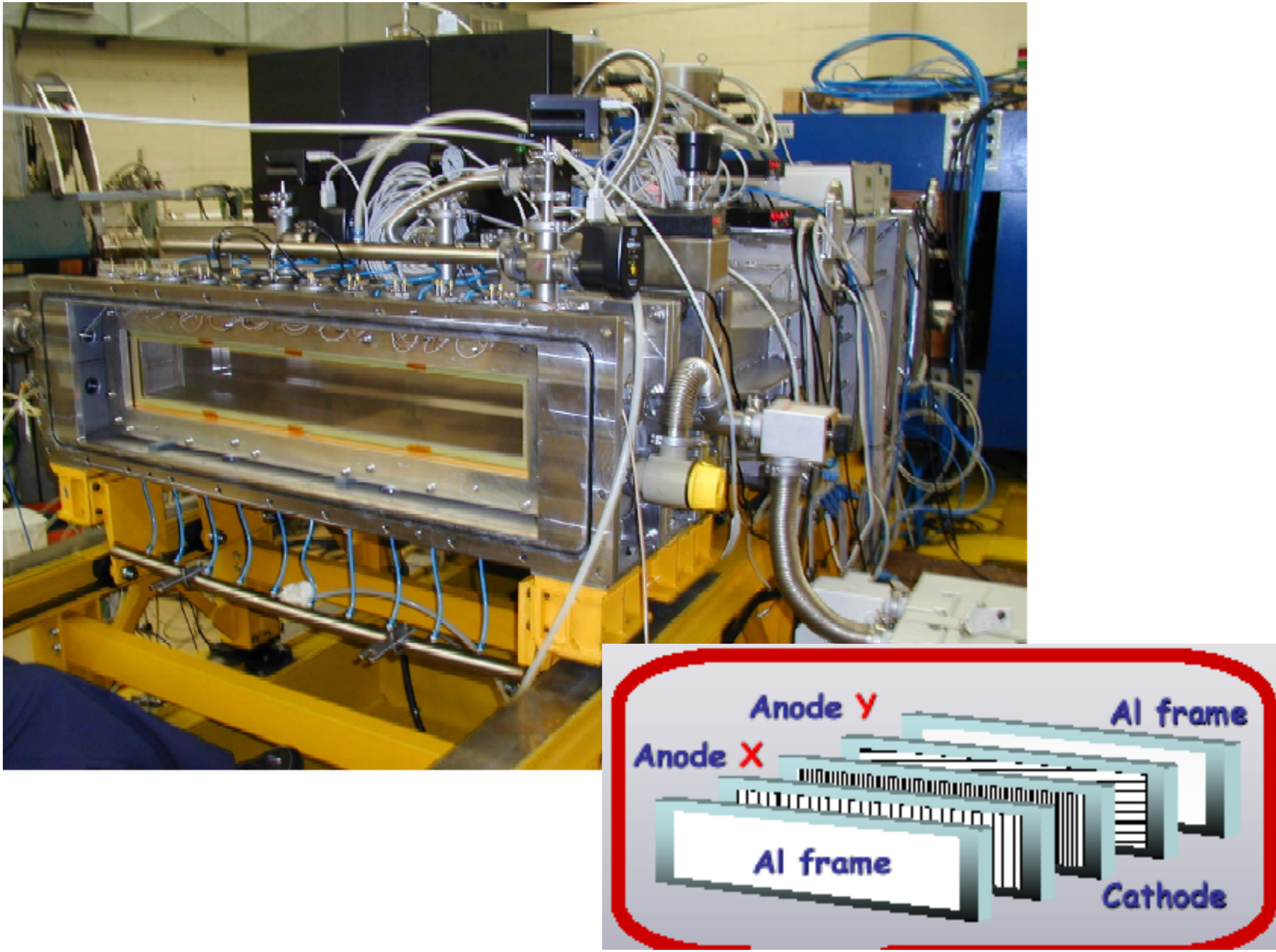


**Filling gas**: $C_4H_{10}$
**Filling pressure**: 7 mbar

**delay-line readout**

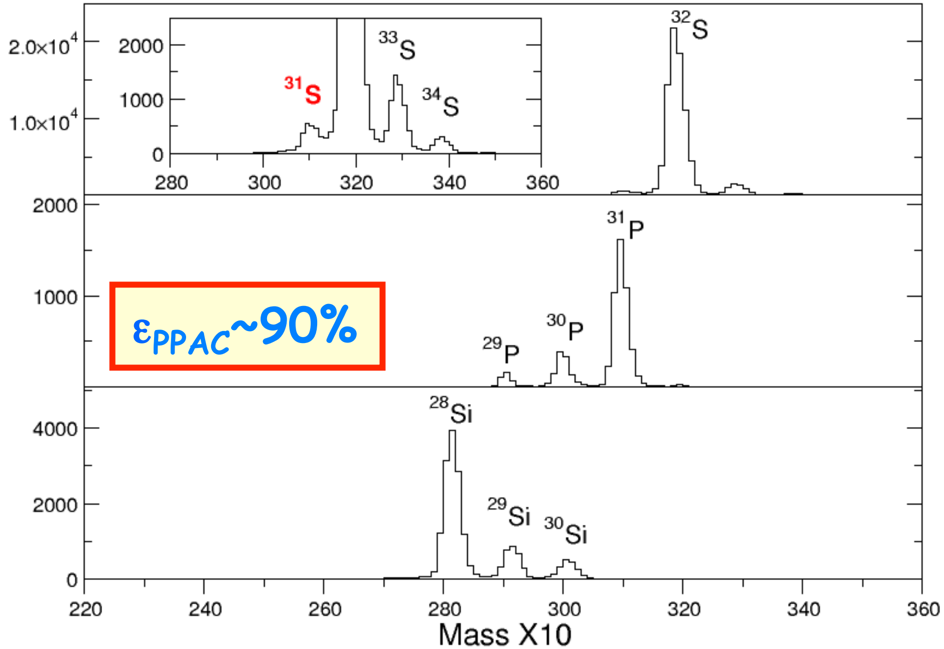
10 x 3 signals ($X_l$, $X_r$, timing)
2 signals ($Y_u$, $Y_d$)



Anode Y
Al frame
Anode X
Al frame
Cathode

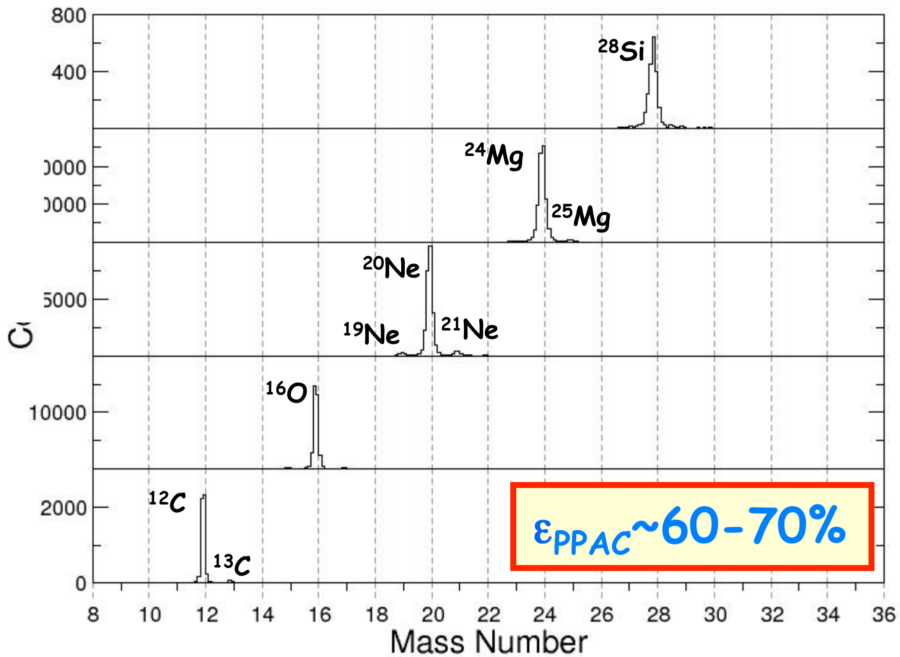
# FPD efficiency for light-ions

**Mass region : A=12-32**



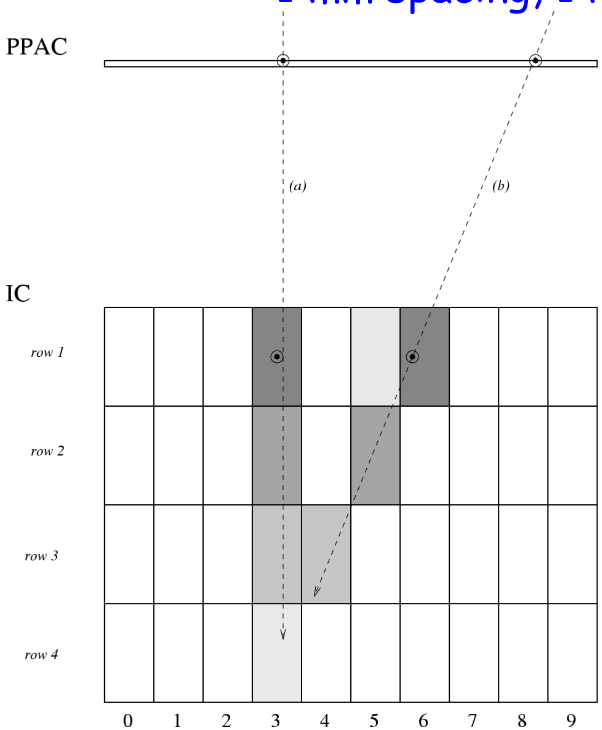

**122 MeV $^{32}S+^{58}Ni$**

**92 MeV $^{24}Mg+^{24}Mg$**

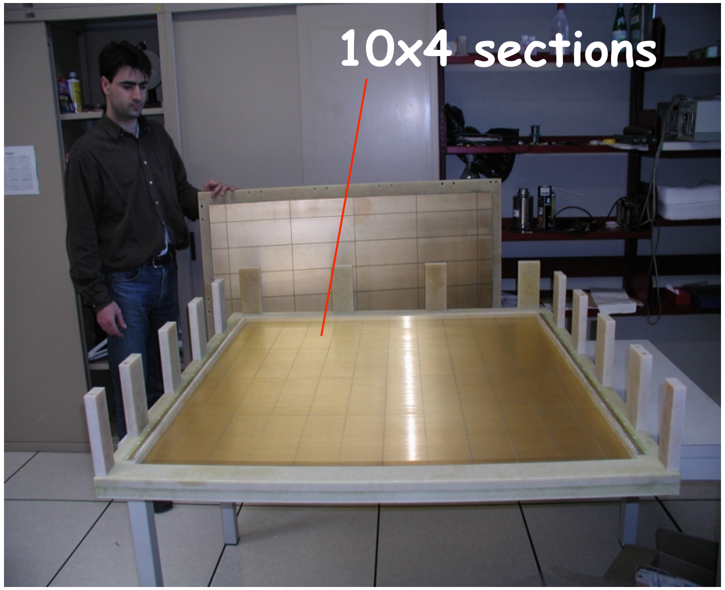


# Focal Plane Detectors: Ionization Chamber

- 10x4 sections (10x25 $cm^2$)
- **depth**: 120 cm
- $\Delta E/E$ < 2%
- **anode** & **cathode**: 10x4 sections
- **Frisch grid**: 1000 wires, 100 μm diameter
  1 mm spacing, 1 m long

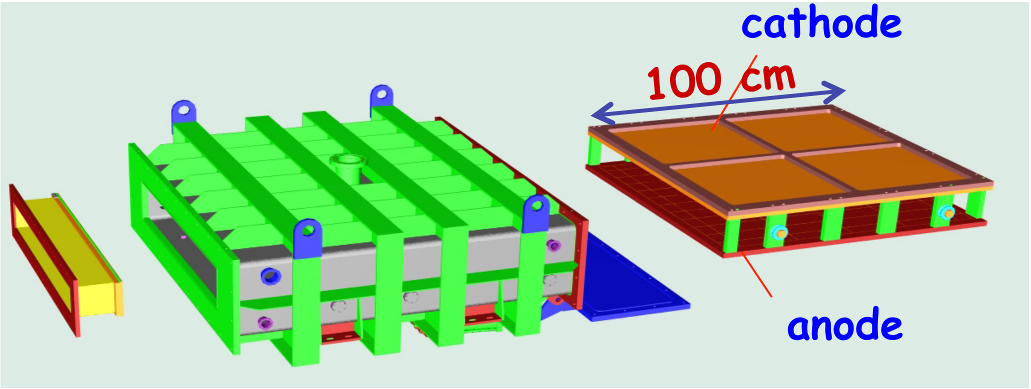



40x2 signals



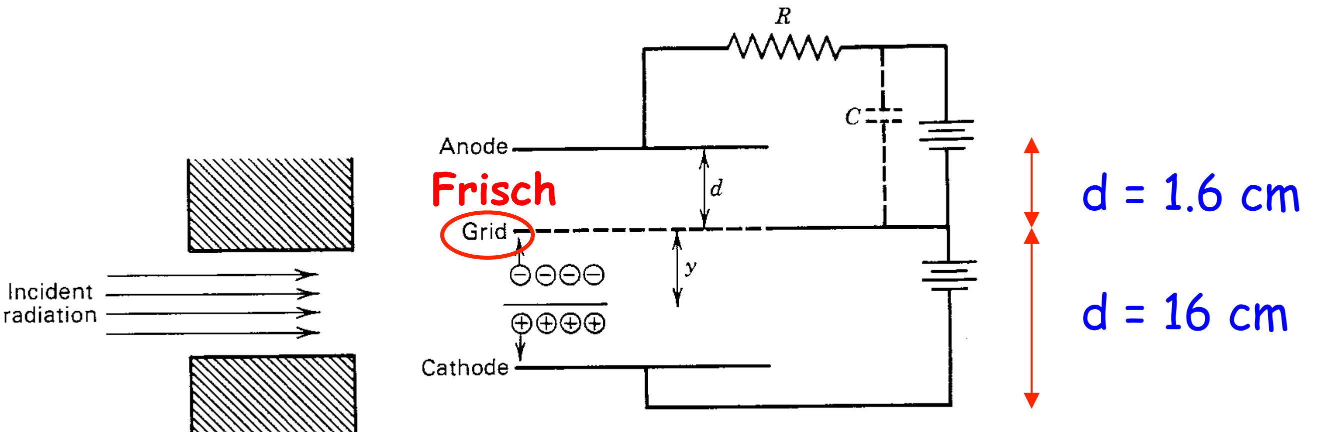

**Filling gas**: $CH_4$, 99% purity
($CF_4$ for energetic heavy-ions)

**Filling pressure**: 20-100 mbar



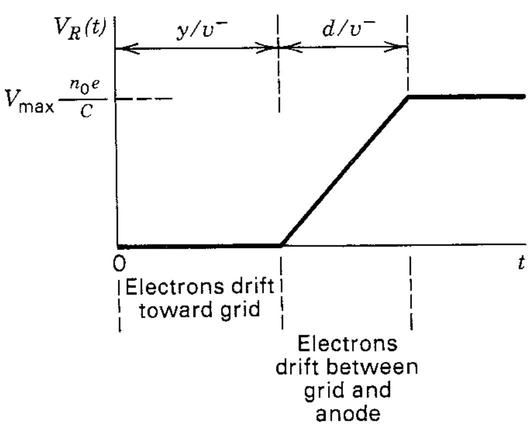
# Ionization Chamber pulse mode operation with Frisch grid

The fine mashing grid removes
the pulse-amplitude dependence on position of interaction



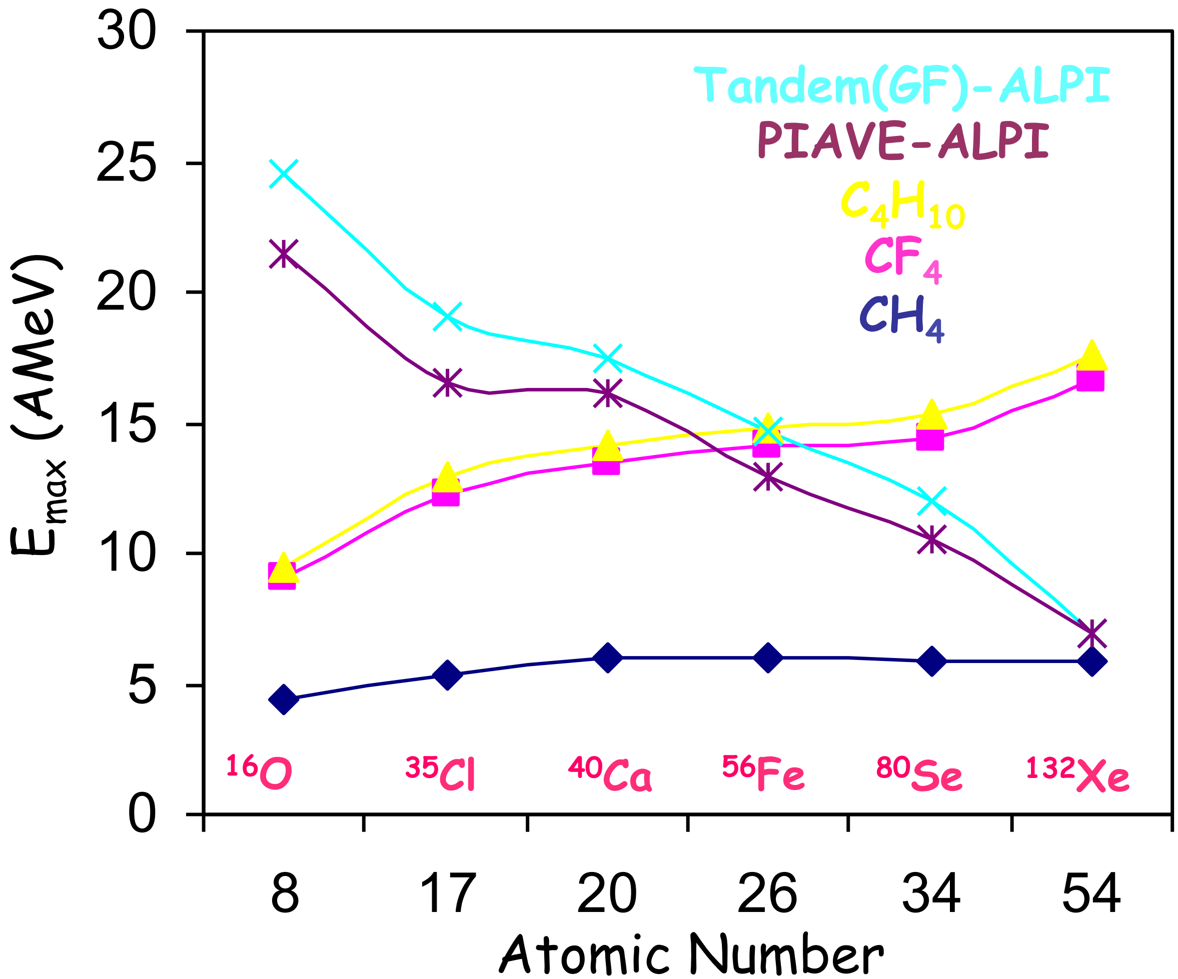

in PRISMA
Ionization Chamber

(a)




(b)

# Maximum energy stopped into the IC




$CF_4$ Si
100 hPa ~ 168 mm

14 AMeV ≤ $E_{max}$ ≤ 16 AMeV

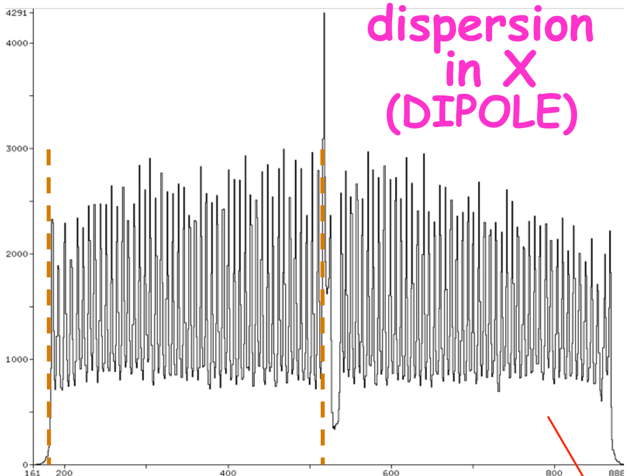
CH4 Si
100 hPa ~ 59 mm

$E_{max}$ ~ 6 AMeV

160 MeV $^{16}O+^{186}W$ PRISMA @ 40° <q>~8
154 MeV $^{16}O$ ions → 110 hPa
$B_{Dipole}$ ~ 68% - $B_{Quadrupole}$ ~ 60%

# Focal Plane Detectors: in-beam tests

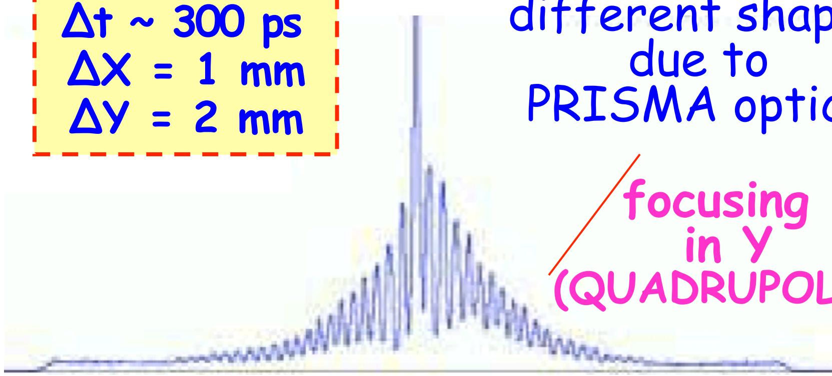
## MWPPAC ($\varepsilon \sim 100\%$)




X position (channels)

different shapes
due to
PRISMA optics

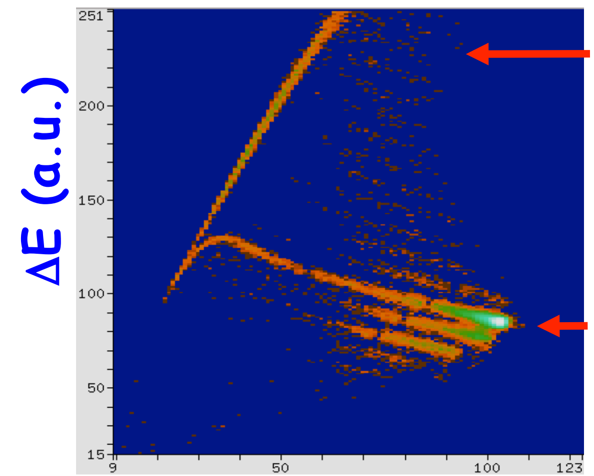
$\Delta t \sim 300$ ps
$\Delta X = 1$ mm
$\Delta Y = 2$ mm



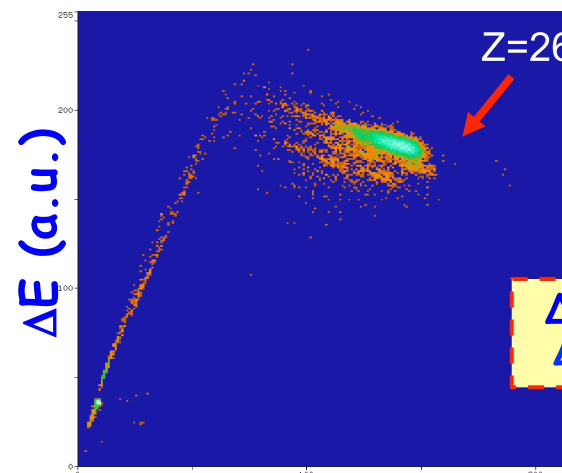

Y position (channels)

## IC

195 MeV $^{36}S + ^{208}Pb$, $\Theta_{lab} = 80^{o}$




240 MeV $^{56}Fe + ^{124}Sn$, $\Theta_{lab} = 70^{o}$



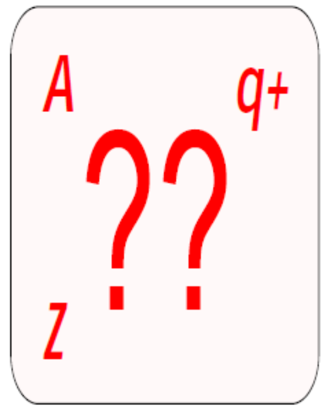

$\Delta E/E < 2\%$
$\Delta Z/Z \sim 60$

E (a.u.)

## L'identificazione delle particelle.

Ricostruire, dai segnali emessi dai rivelatori:

- il numero di massa $A$;
- la carica nucleare $Z$;
- la carica ionica $q$;
- l'energia $E$.




Le relazioni dalle quali si ricavano $A$, $Z$, $q$ ed $E$ sono:

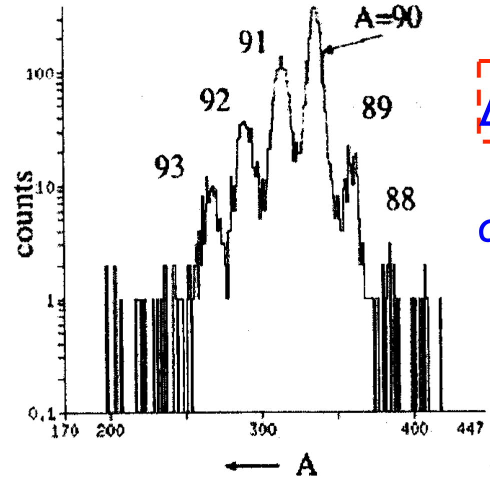
- $\Delta E \sim Z^2 \cdot \frac{A}{E}$
- $tof = s/v$
- $B\rho \sim X \sim v \cdot \frac{A}{q}$
- $E \sim \frac{1}{2} A \cdot v^2$

Grandezze fondamentali sono il rapporto $A/q$ e la rigidità magnetica $B\rho$.

# Mass & Energy reconstruction with PRISMA: via TOF

$M = qB \times \rho / v$

$v = S(\theta)/TOF$




$\Delta A/A = 1/280$

after ion-tracking reconstruction

505 MeV $^{90}Zr + ^{208}Pb$

## ➔ Optical elements + TOF

$B\rho = p/q$

$M/q = (B\rho \times TOF)/S(\theta)$

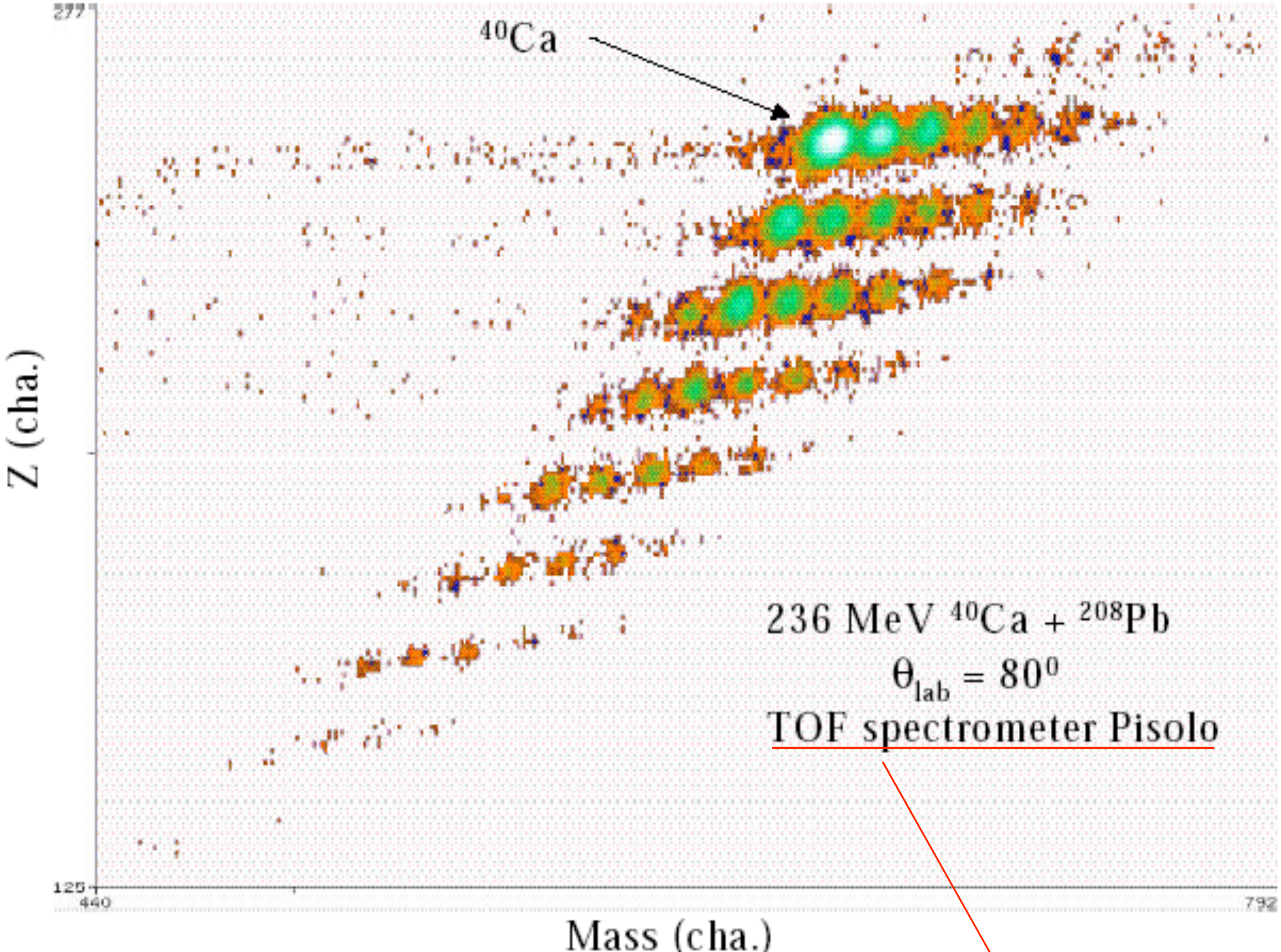
## ➔ Energy loss in IC + residual energy

$$\frac{dE}{dx} \propto \frac{M\,Z^2}{E}$$

$$E\,\Delta E \simeq M\,Z^2$$

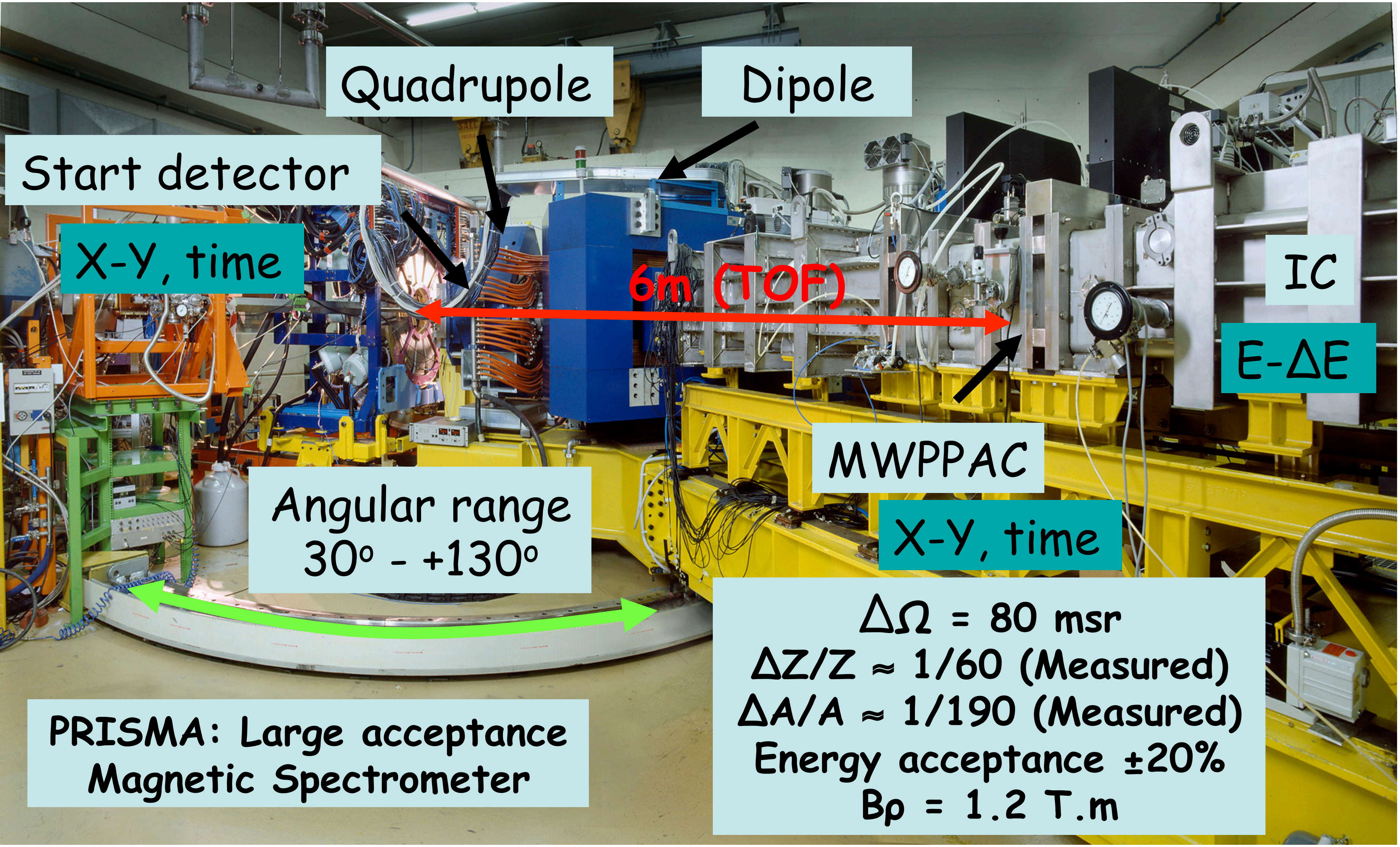
exact identification of mass (**A**) and charge (**Z**) + distinction of charge states (Q)

$^{A}_{Z}??^{q+}$



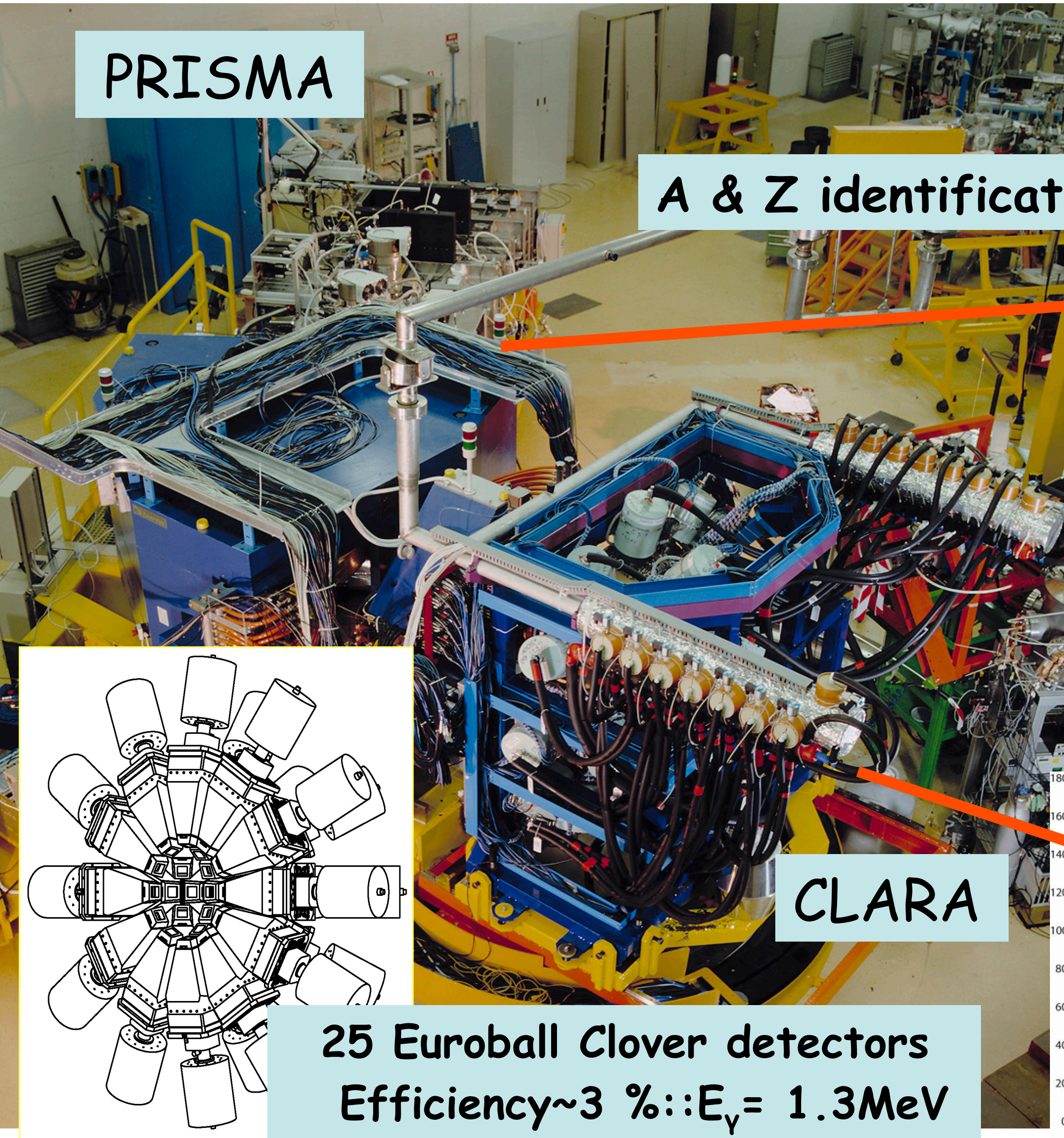

**Similar/better with PRISMA**

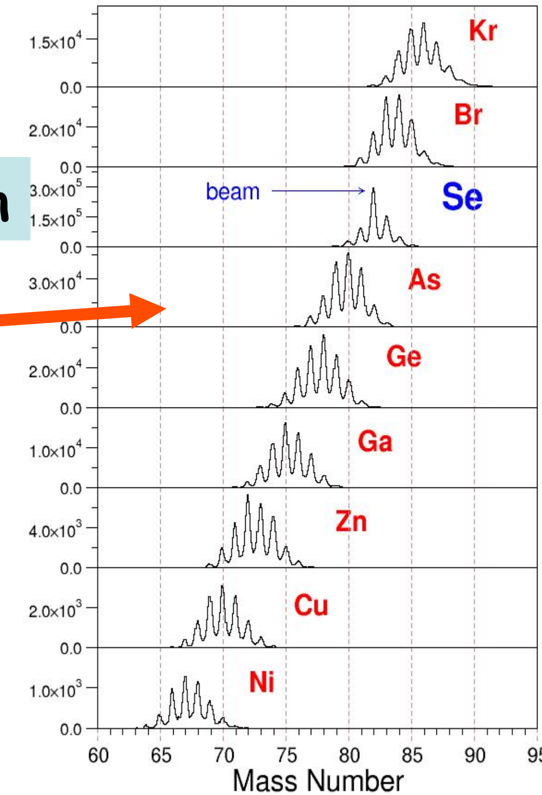
# CLARA-PRISMA setup



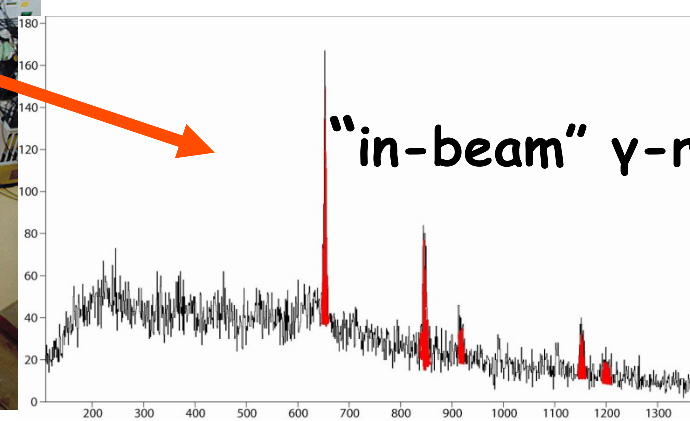

A. Gadea et al., EPJA20(2004)193

# CLARA-PRISMA setup

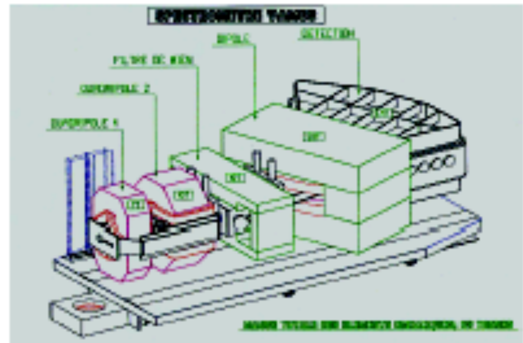


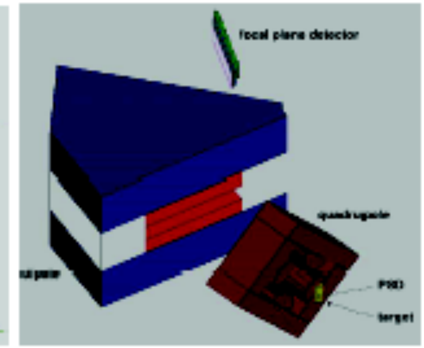




"in-beam" γ-ray



# Other magnetic spectrometers






| | PRISMA | VAMOS | MAGNEX |
|---|---|---|---|
| Solid Angle (msr) | 80 | 100 | 52 |
| Target-FPD (m) | 7 | 7.3 | 5.8 |
| Dispersion (cm/%) | 4 | 2.5 | 3.8 |
| Momentum acceptance | ±10% | ±5% | ±10% |
| Max Rigidity T•m | 1.4 | 1.6 | 1.8 |

# Future Development:
# PRISMA in Gas Filled Mode

**Physics Aim:** measurements of evaporation residues
with small $\sigma$, recoiling at 0°

⇒ ***need for high transmission efficiency***

**Main drawback:** loss of mass & energy resolution

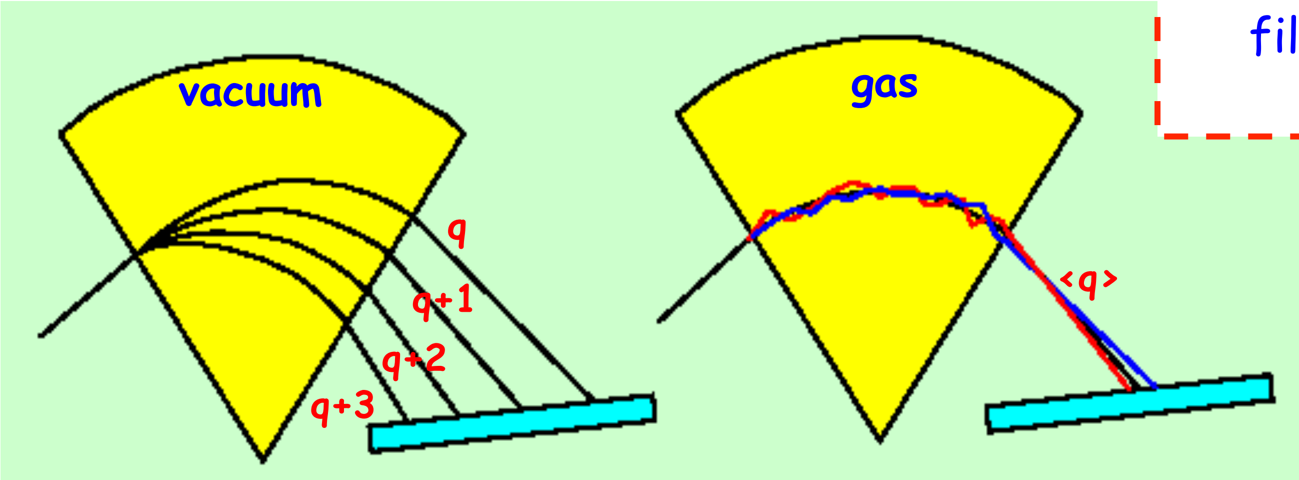
⇒ ***the magnetic spectrometer is used as a separator***

**Existing devices**: RITU (JYFL), TASCA (GSI), …
for heavy element study ($\sigma$ < 1nb)

M. Leino et al., NIMB99(1995)653
T. Back et al., EPJA16(2003)489

# Principle of operation

**high transmission efficiency** can be obtained filling the **dipole region** with a **diluted gas**




- collision between reaction products and gas atoms lead to **charge state focusing**
- trajectory determined by **average ionic charge**

$$B\rho = \frac{mv}{eq_{ave}}$$

$$= \frac{mv}{e\frac{v}{v_0}Z^{1/3}} = 0.0227\frac{A}{Z^{1/3}}Tm$$

$v_0$ = 2.19 $10^6$ m/s  Bohr velocity

$q_{ave} = (v/v_0)\,Z^{1/3}$  Thomas-Fermi model

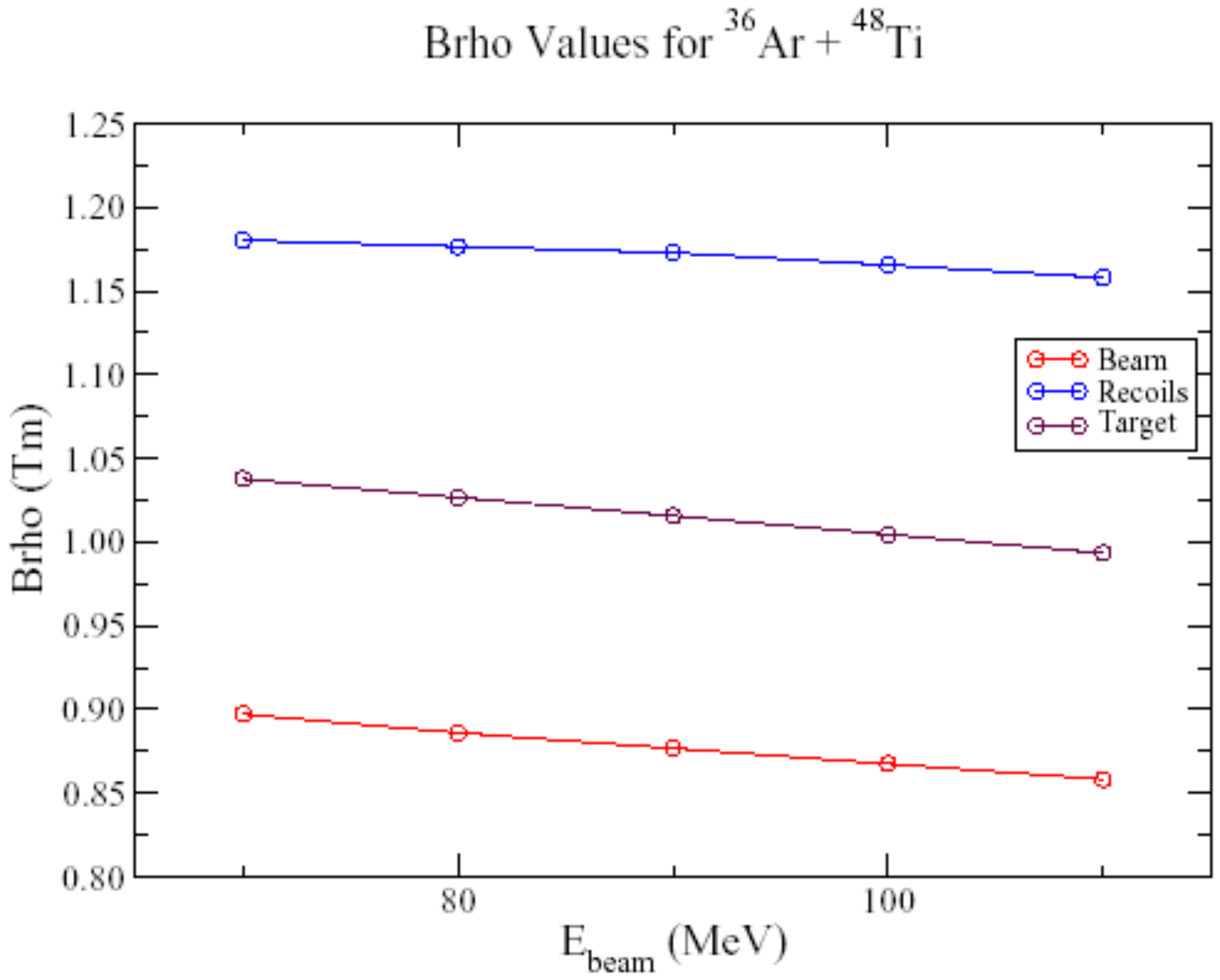
- **B$\rho$** does NOT depend on v
  $\Rightarrow$ **energies merge** !!!
- it can be used to get a **rough estimate** of degree of separation between
  → target-like products
  → fusion evaporation residues

**example:**

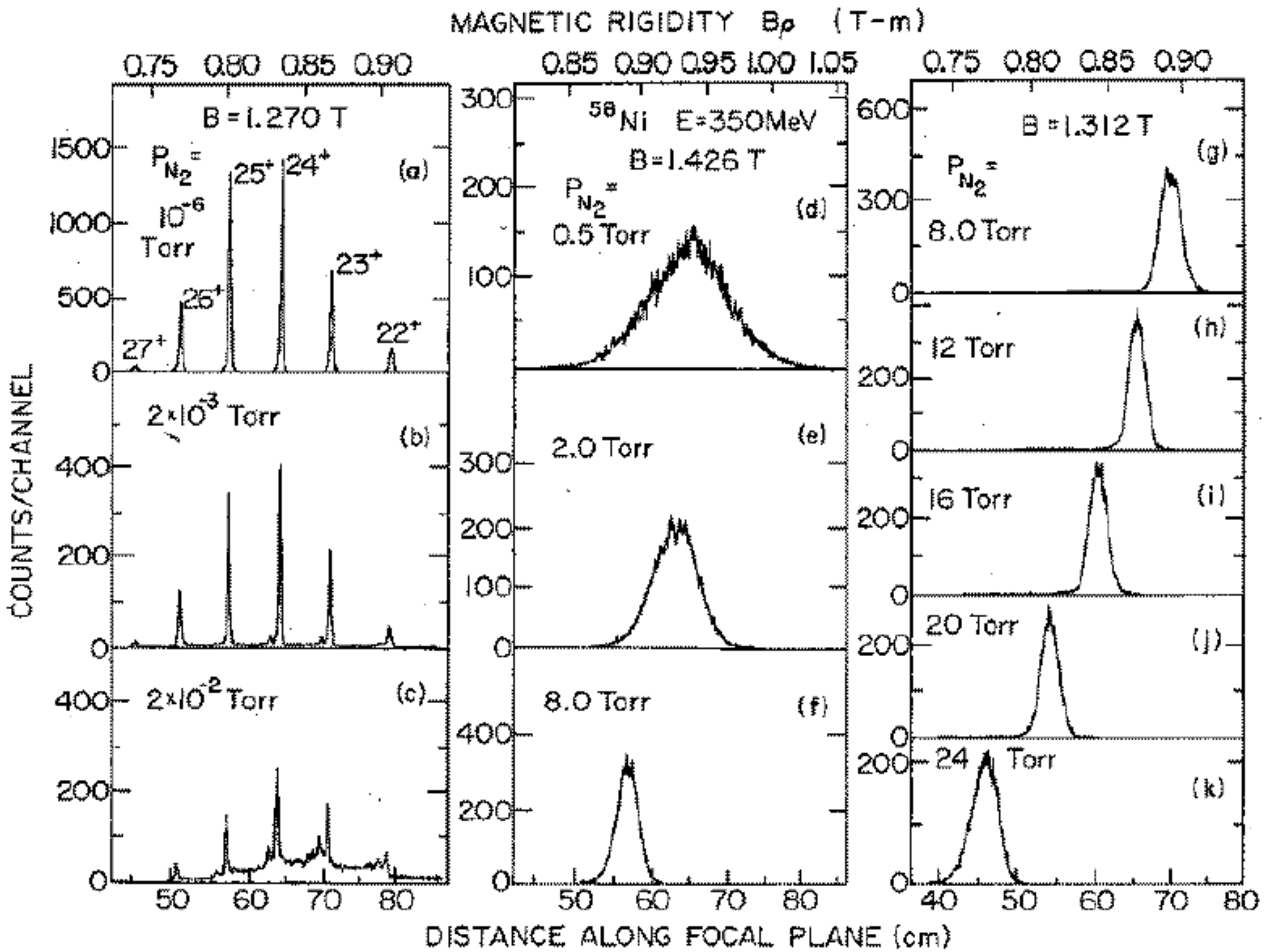
$^{40}Ar + {}^{175}Lu \rightarrow {}^{210,211}Ac + xn$

$$\frac{(B\rho)_T}{(B\rho)_{CN}} = \frac{A_T}{A_{CN}}\left(\frac{Z_{CN}}{Z_T}\right)^{1/3} = \frac{175}{210}\left(\frac{89}{71}\right)^{1/3} = 0.89$$

# Bρ at the Limit



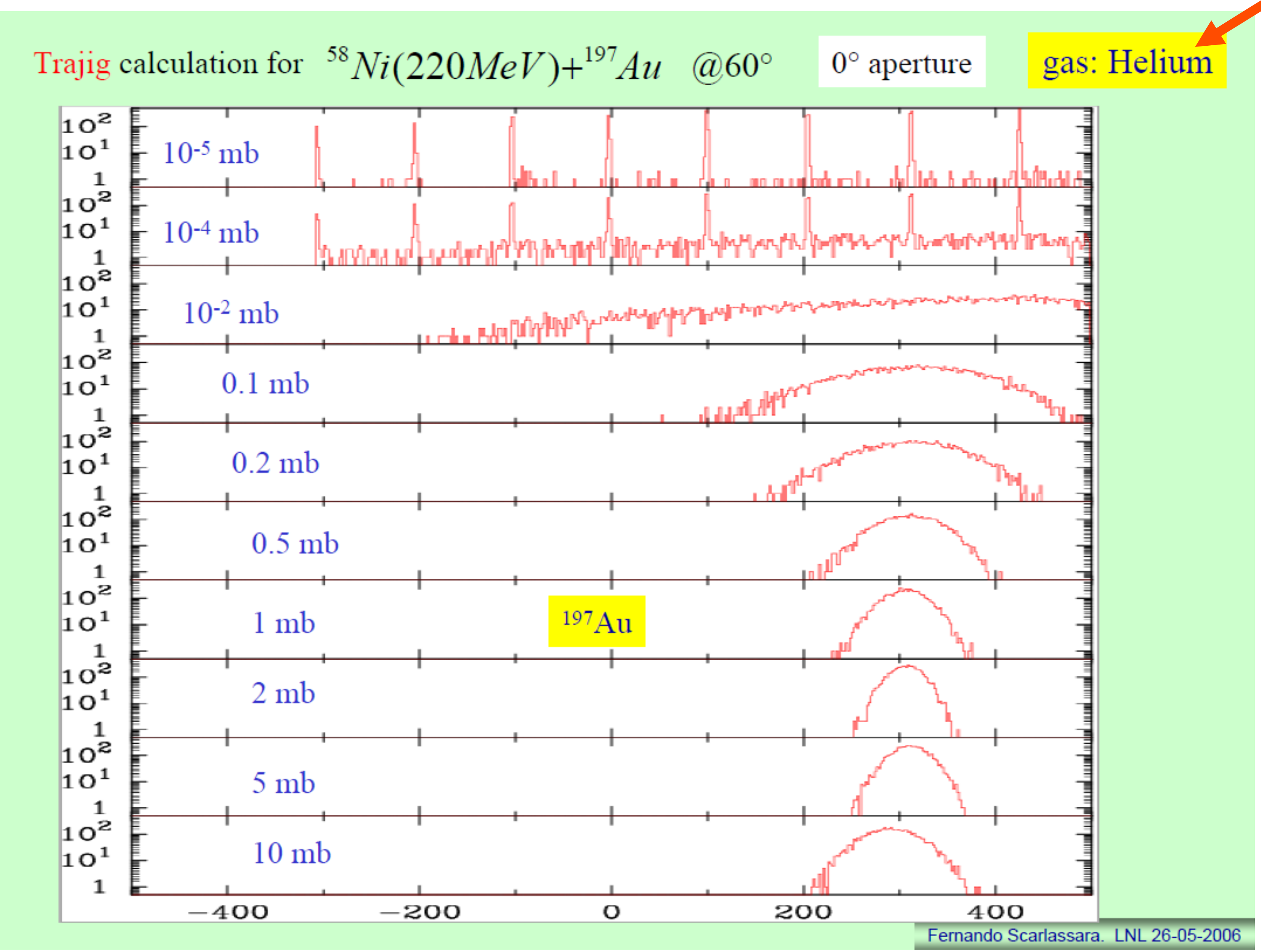
# Focal Plane position spectra for $^{58}$Ni at 350 MeV




- typical GFM pressure: ~ 1 mbar = 0.75028 Torr
- typical gas: H, He

M. Paul et al., NIMA277(1989)418

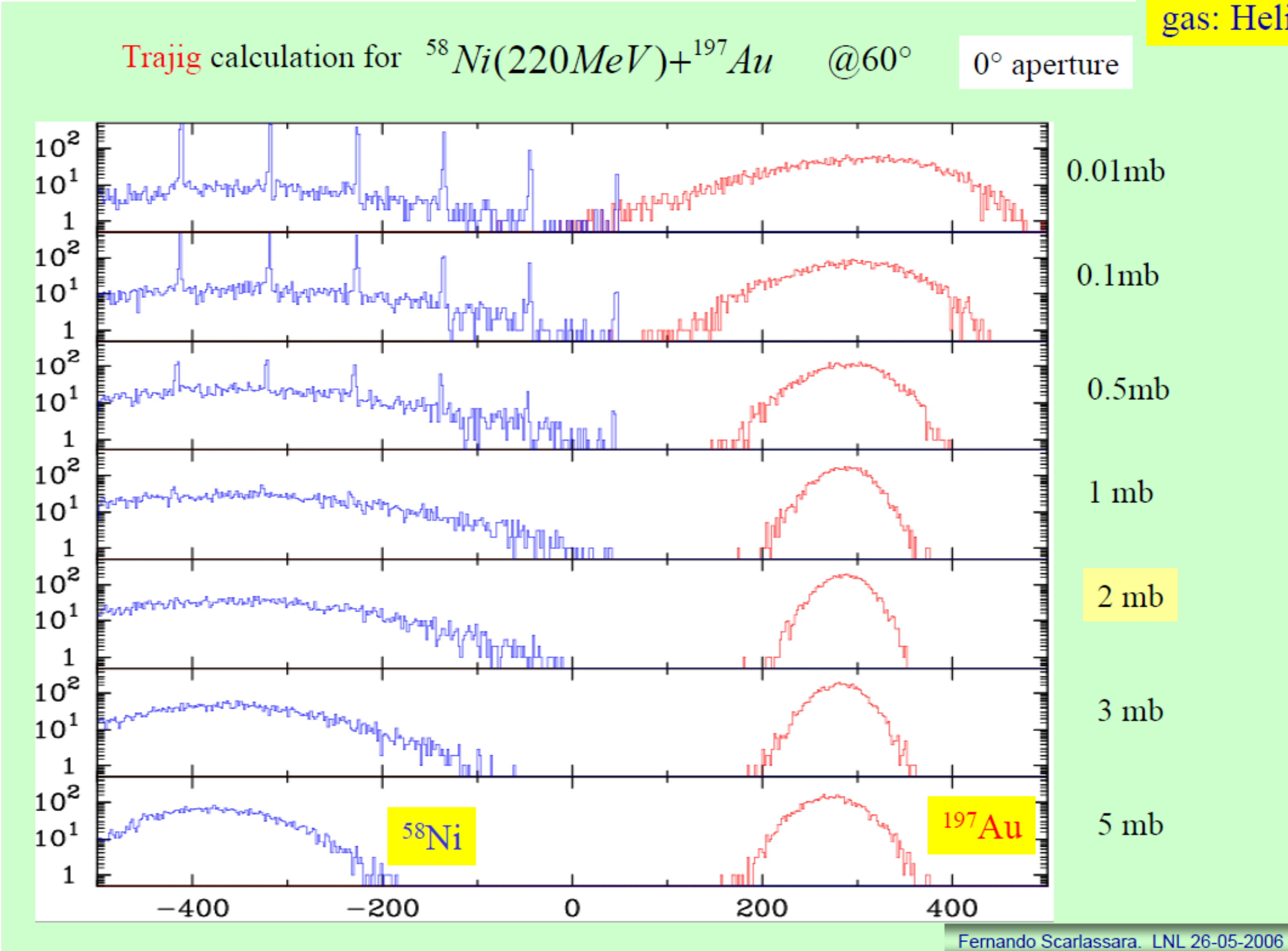
# Simulations for PRISMA @ LNL




Fernando Scarlassara. LNL 26-05-2006

# Simulations for PRISMA @ LNL

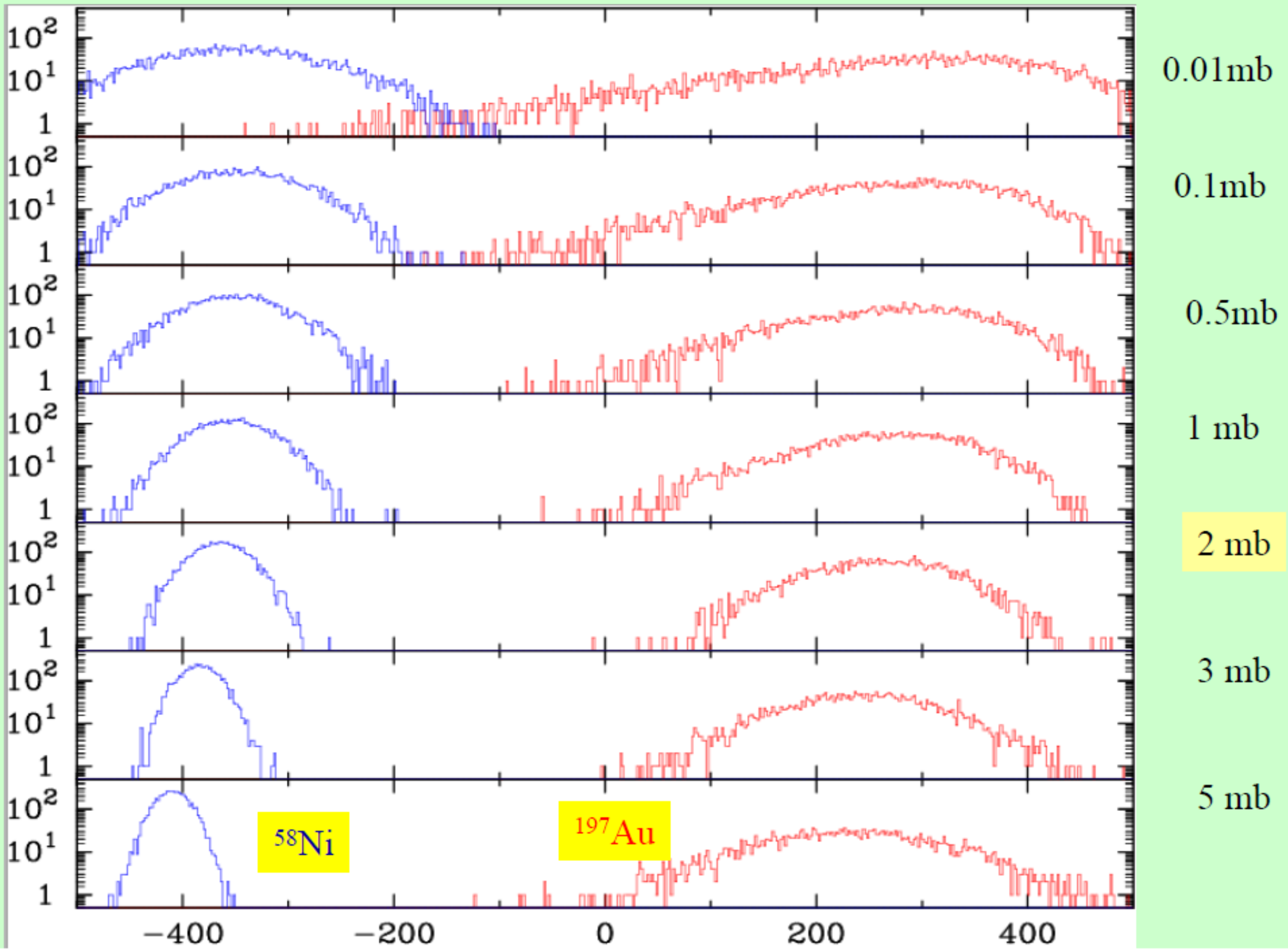
gas: Helium



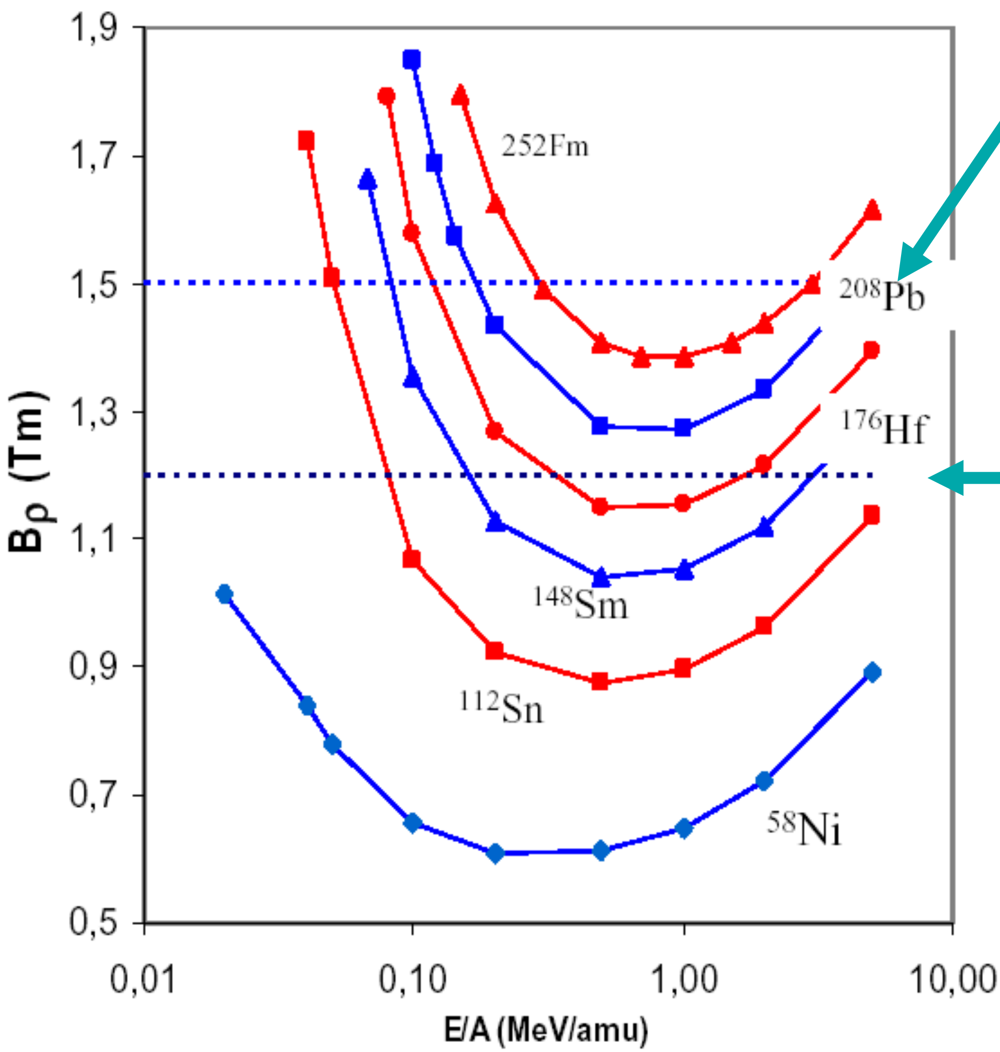

Fernando Scarlassara. LNL 26-05-2006

# Simulations for PRISMA @ LNL

Trajig calculation for $^{58}Ni(220MeV)+^{197}Au$ @60° 0° aperture gas: Argon



# Magnetic Rigidity Limits

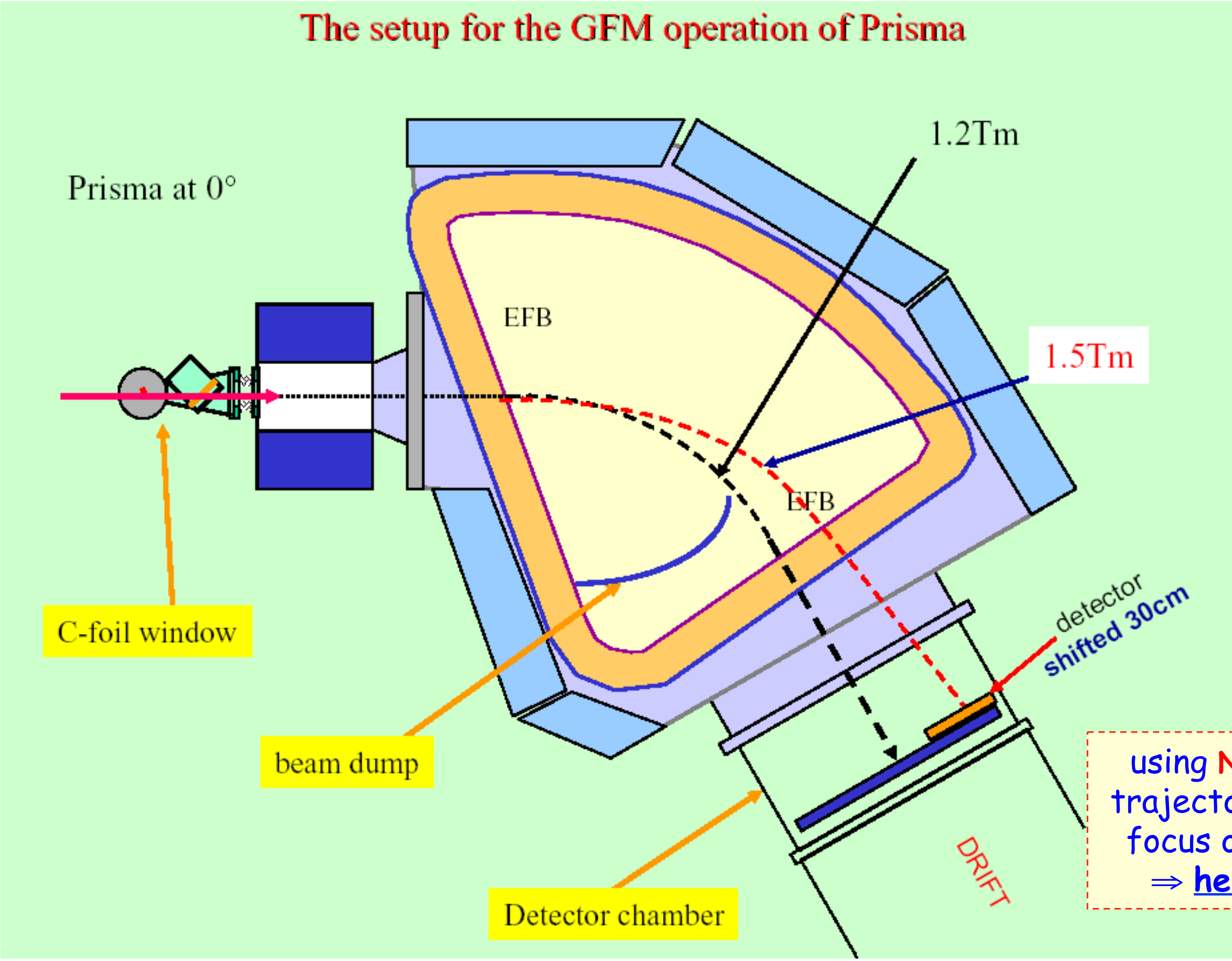



NOT central trajectory
(30 cm shift from center)
Bρ = 1.5 MeV
limitation to $A \leq 200$

PRISMA central trajectory
Bρ ≤ 1.2 MeV
limitation to $A < 180$

In all practical cases,

$$\rho_{BEAM} < \rho_{ER}$$

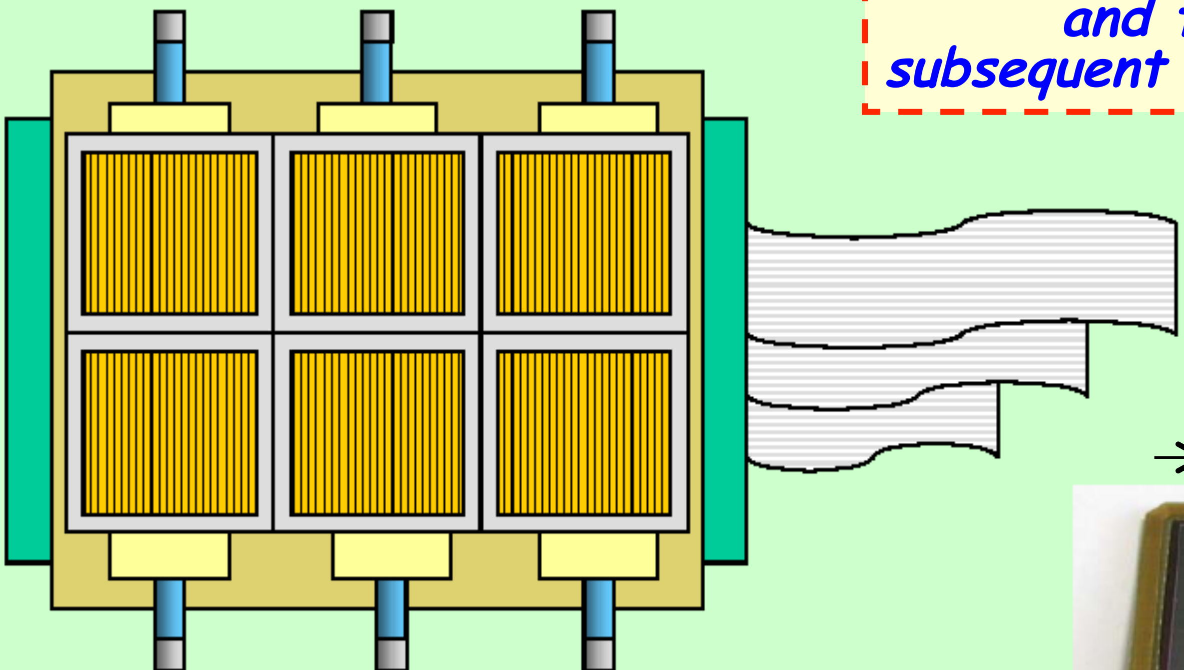



using NOT central trajectories one can focus on larger Bρ
⇒ **heavier ions**

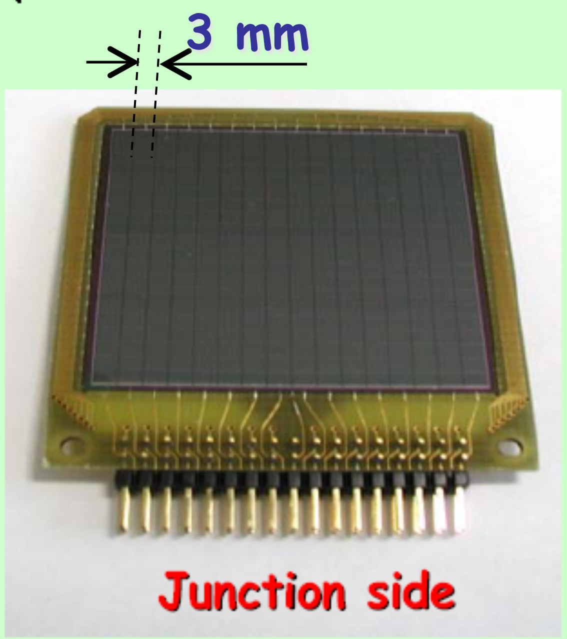
➔ ***40% efficiency to separate reaction products***

# Si strip detectors for the gas-filled mode operation of PRISMA

*to implant reaction products and to measure subsequent $\alpha$, $\beta$ or p emission*



- good energy resolution
- high efficiency
- good spatial resolution

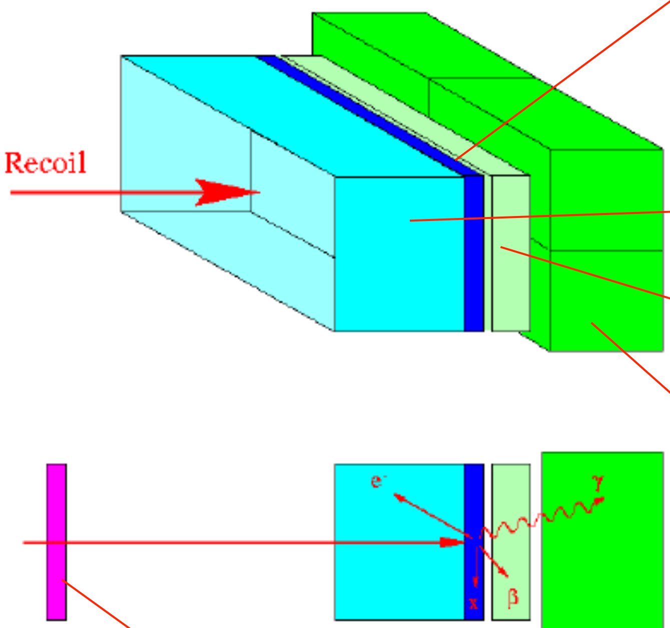



Matrix of 2 x 3 Si detectors
Thickness ~ 300 μm
Active area = 5 x 5 $cm^2$, 16 resistive strips

In the simulations 15x10 $cm^2$ centered at x=+30

# Focal Plane Detectors of RITU (JYFL)

## GREAT Array: decay tagging technique




•1. **Double Sided Silicon Strip Detectors**:
- implantation of reaction products
- and measure of subsequent α, β or p emission

•2. **Si PIN photodiode**:
- measure of conversion electron energies

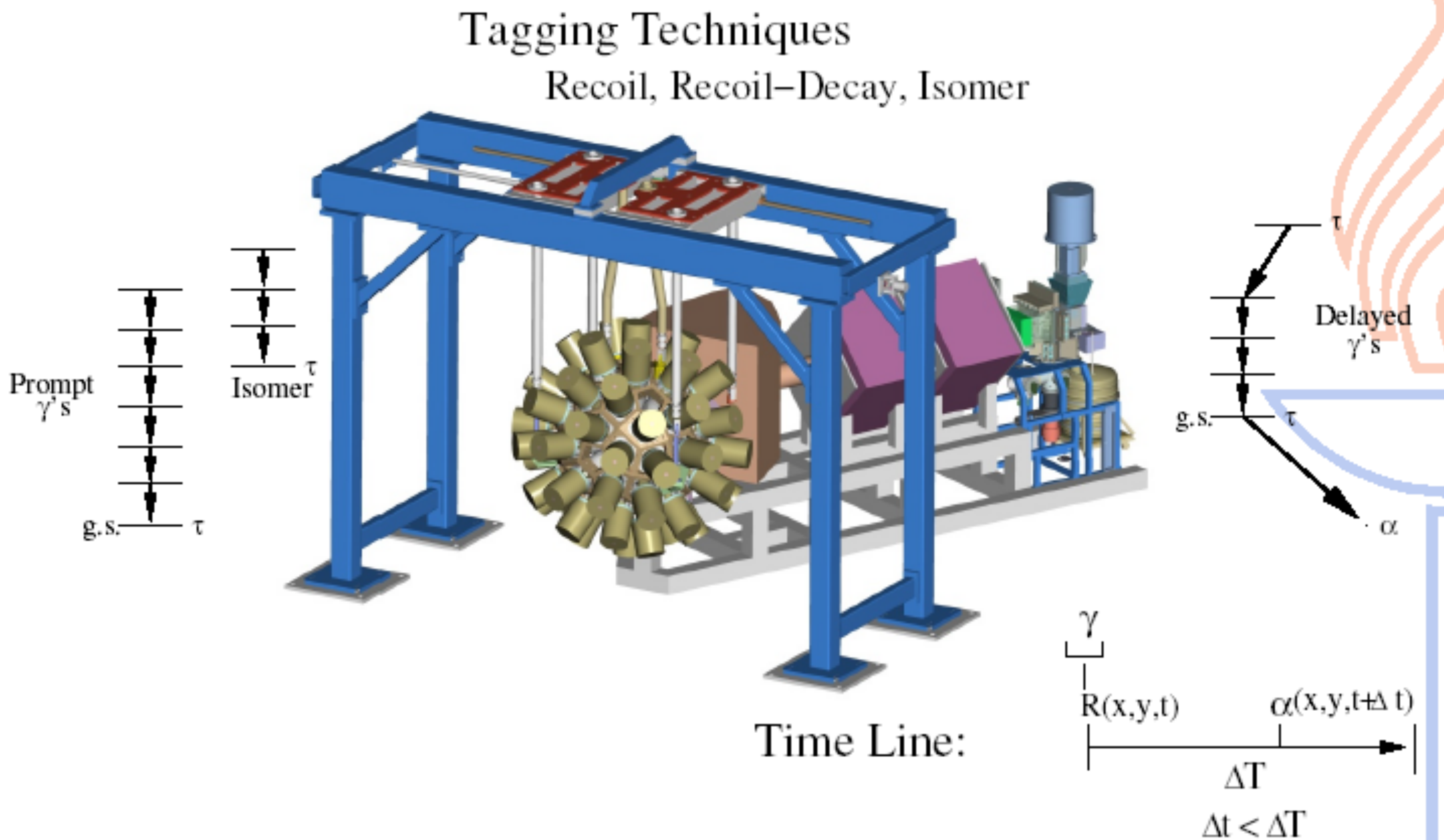
•3. **Double Sided Ge Strip Detectors**:
- measure of X-rays, low-energy γ and β-particles

•4. **High efficiency CLOVER Ge**:
- measure of high-energy γ-rays

•5. **MWPAC**:
- active recoil & beam discriminator
- [also used for rejection of decay particles leaving
- only partial energy in Si and Ge detectors]

R. Page et al., NIMB204(2003)634

# Principles of RDT



# Magnetic High Resolution Spectrometers

**Physics Aim:** high resolution energy/momentum measurements

$\Delta E/E \leq 10^{-5} \Rightarrow \Delta p/p \leq 10^{-4}$

**Example:**

- beam energy up to 100 MeV/A
- few 100 keV energy resolution
- angular distribution with strong forward focusing

for A = 100, 100MeV/A $\Rightarrow \Delta E/E \leq 10^{-5} \Rightarrow \Delta p/p \leq 10^{-4}$

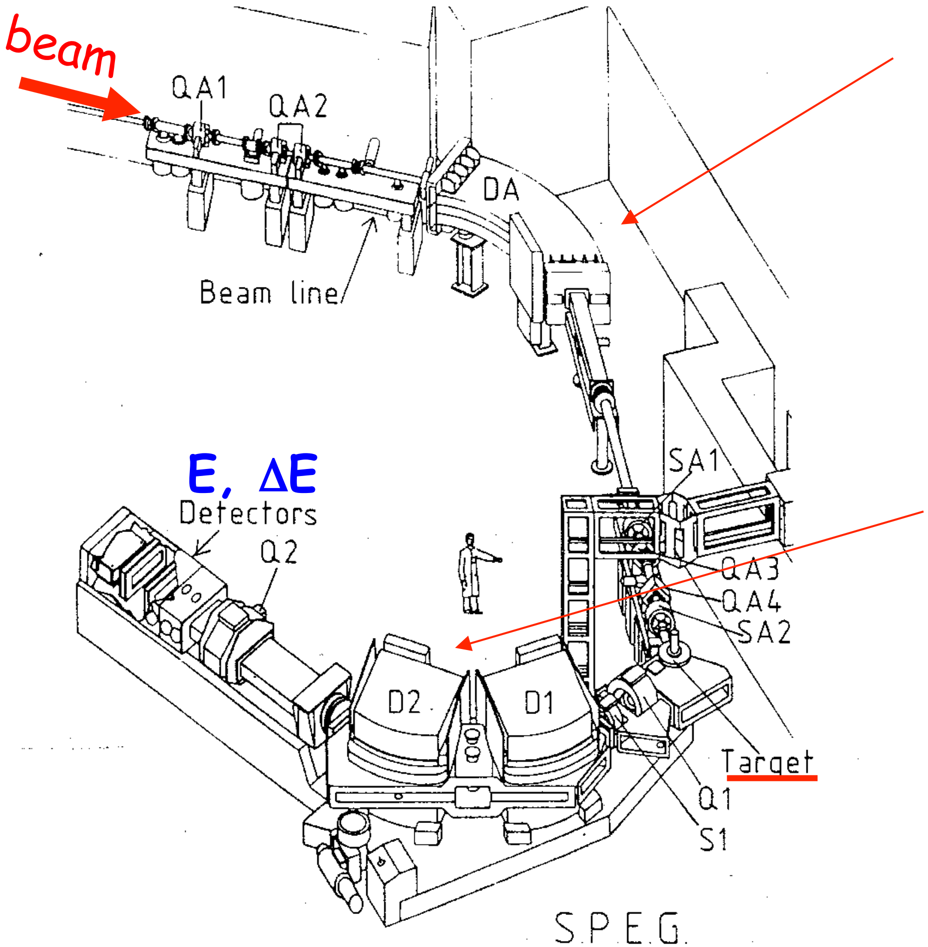
$\Delta p/p$ better than beam momentum resolution $\Delta p/p \leq 5 \times 10^{-3}$
$\Delta p/p$ achievable via TOF with long flight paths $\Rightarrow \Delta L/L \leq 10^{-5} \Rightarrow L \geq 100$ m

$\Rightarrow$ **need for high resolution spectrometer**

# SPEG (GANIL)
## Energy Loss
## High Resolution Spectrometer

Study of *discrete nuclear states* populated in reactions induced by nuclei up to 100 MeV/A

## achromatic device
(i.e final position & angle do not depend on momentum)




### *analysing beam line*

$$F = qvB = \frac{mv^2}{\rho}$$

$$B\rho = \frac{mv}{q} = \frac{p}{q} = \frac{Av}{qc^2}$$

| | |
|---|---|
| dispersion on target | 9.86 m |
| mean bending radius | 3 m |
| mean deflection angle | 75° |
| maximum dipole B | 1 T |

- ➔ Δp/p ± $5\times10^{-3}$
- ➔ emittance $5\pi$ mm mrad
- ➔ object size $4\times4$ mm$^2$

### *energy loss spectrometer*

$$B\rho = \frac{mv}{q} = \frac{p}{q}$$

➔ Δp ~ $10^{-4}$

(from 2 positions measurements)

| | |
|---|---|
| nominal dispersion | 8.1 m |
| solid angle | 4.9 msr |
| mean bending radius | 2.4 m |
| mean deflecting angle | 2x42.5=85° |
| maximum B in Dipoles | 1.2 T |
| analyzed momentum range | 7% |
| length of focal plane | 60 cm |
| angular range | -10° to +105° |

ion identification:
A from TOF
Z from ΔE-E Si telescopes
1.3-1.6 % and 0.8-1.1 % resolution

# determination of magnetic rigidity δ of each ions

L. Bianchi et al., NOMA276(193)509

$$\delta = B\rho = \frac{mv}{q} = \frac{p}{q}$$

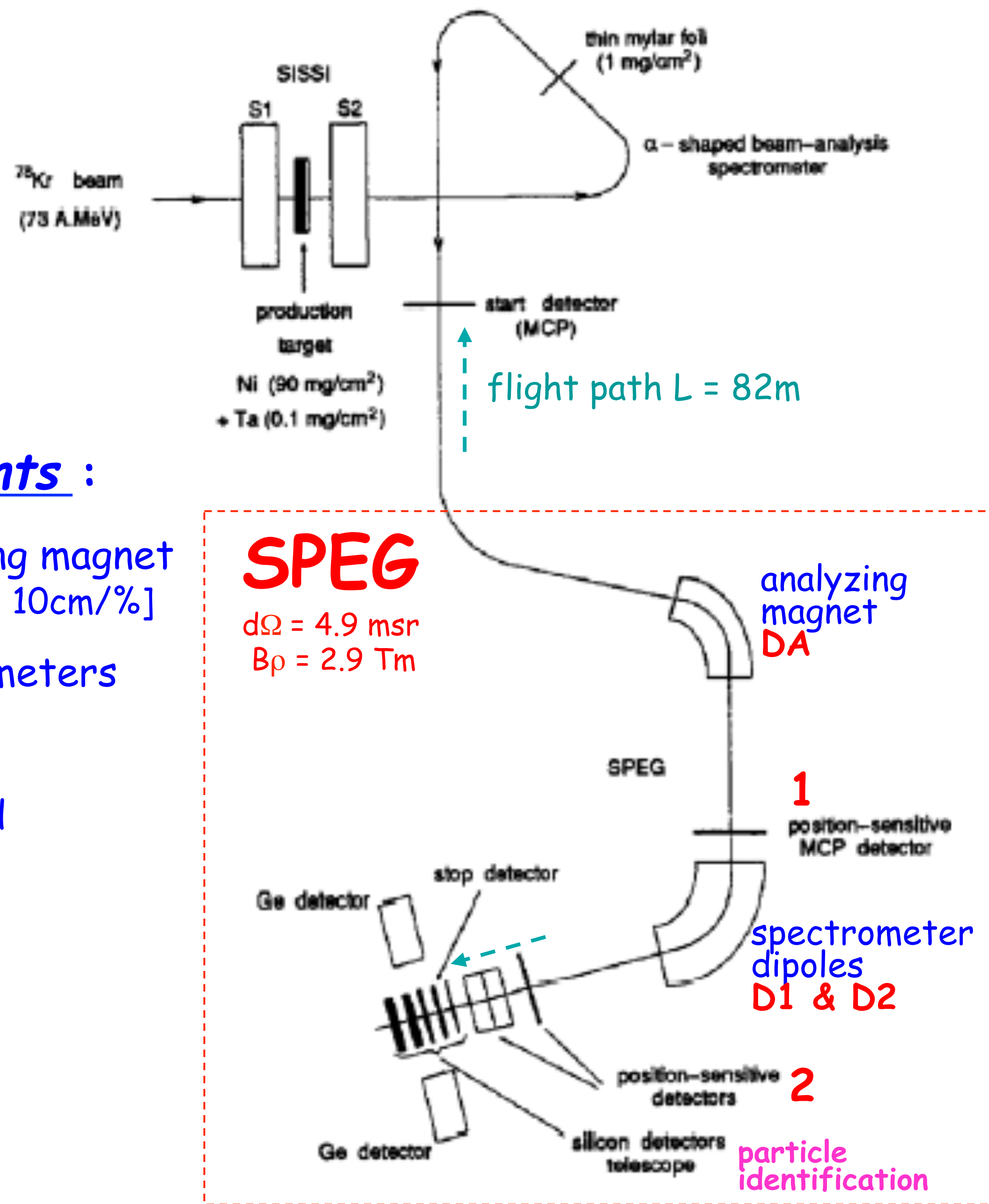
***two horizontal position sensitive measurements*** :

1. MCP at dispersive plane of analyzing magnet [where dispersion in momentum is large: 10cm/%]
2. two drift chambers after spectrometers [$\Delta x \sim 0.6$ mm, $\Delta y \sim 0.5$ mm]

⇒ each ion trajectory is recontructed

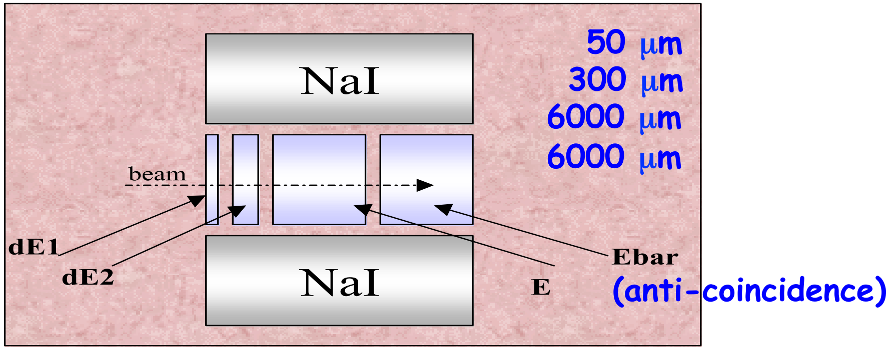
⇒ accurate determination of δ independently of object size

$\Delta p \sim 10^{-4}$



# identification of ions arriving at SPEG focal plane

**Telescope** of 4 cooled silicon detectors




- energy loss $\Delta E = \Delta E_1 + \Delta E_2 = k \frac{Z^2 A}{E_{tot}}$

- total energy $E_{tot} = \Delta E_1 + \Delta E_2 + E$

➔ $E_{tot} \Delta E \propto Z^2 A$

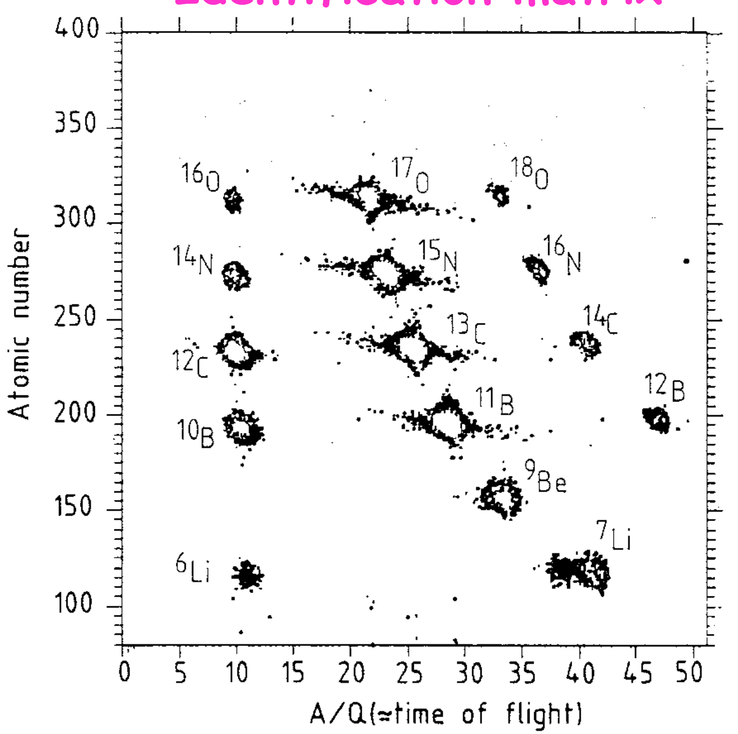
- time of flight ➔ A identification

$$B\rho = \frac{mv}{q} = \frac{p}{q} = \frac{Av}{qc^2}$$

$$\frac{A}{qc^2} = \frac{B\rho}{v} = \frac{B\rho}{L} \times T_{vol}$$

- isomer γ-decay: NaI detectors

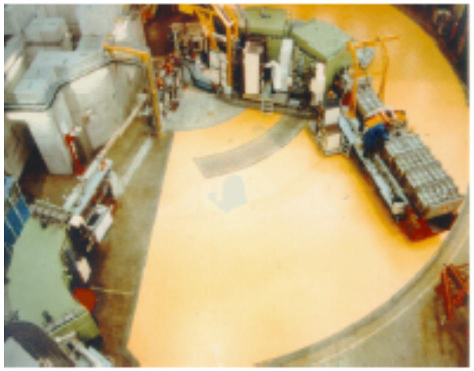
## Identification matrix

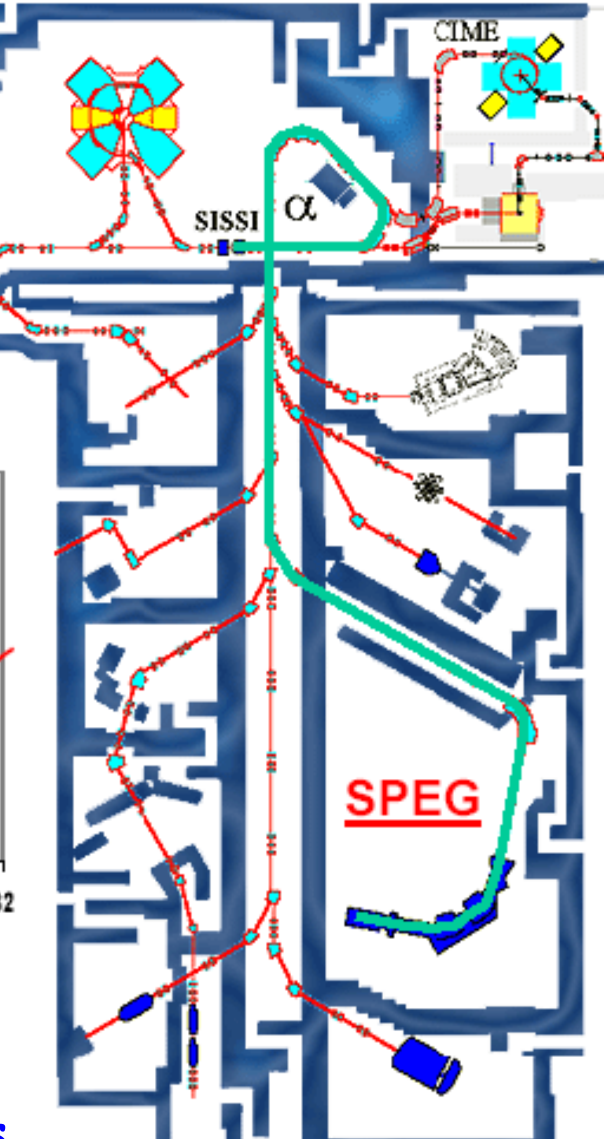



long flight path L = 82 m
time of flight $T_{vol}$ = 700 ns-1.2 μs

➔ **mass resolution** $\Delta m/m \sim 10^{-4}$

# mass measurement programs at GANIL



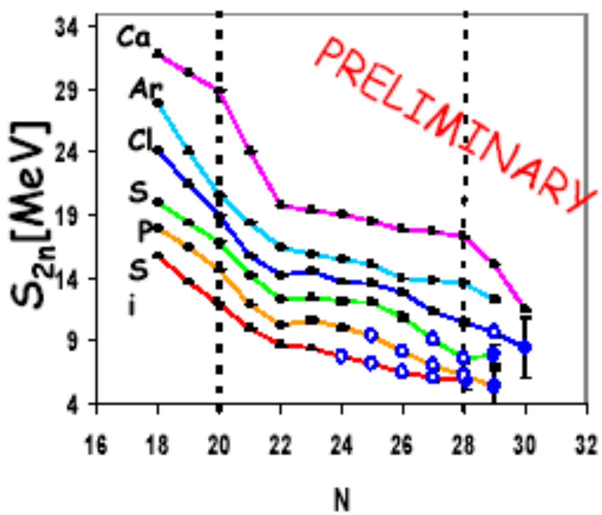



**SPEG**

time-of-flight
+ magnetic rigidity

$m = q\,B\rho\,T/L$

**Resolving power: $10^4$**
***extremely* sensitive**




SPEG2002 data: see talk of H. Savajols

**mass resolution: ± 3 MeV of mass excess**

Sarazin et a., PRL84(2000)5062

# Magnetic Separators

**Physics Aim:** ???

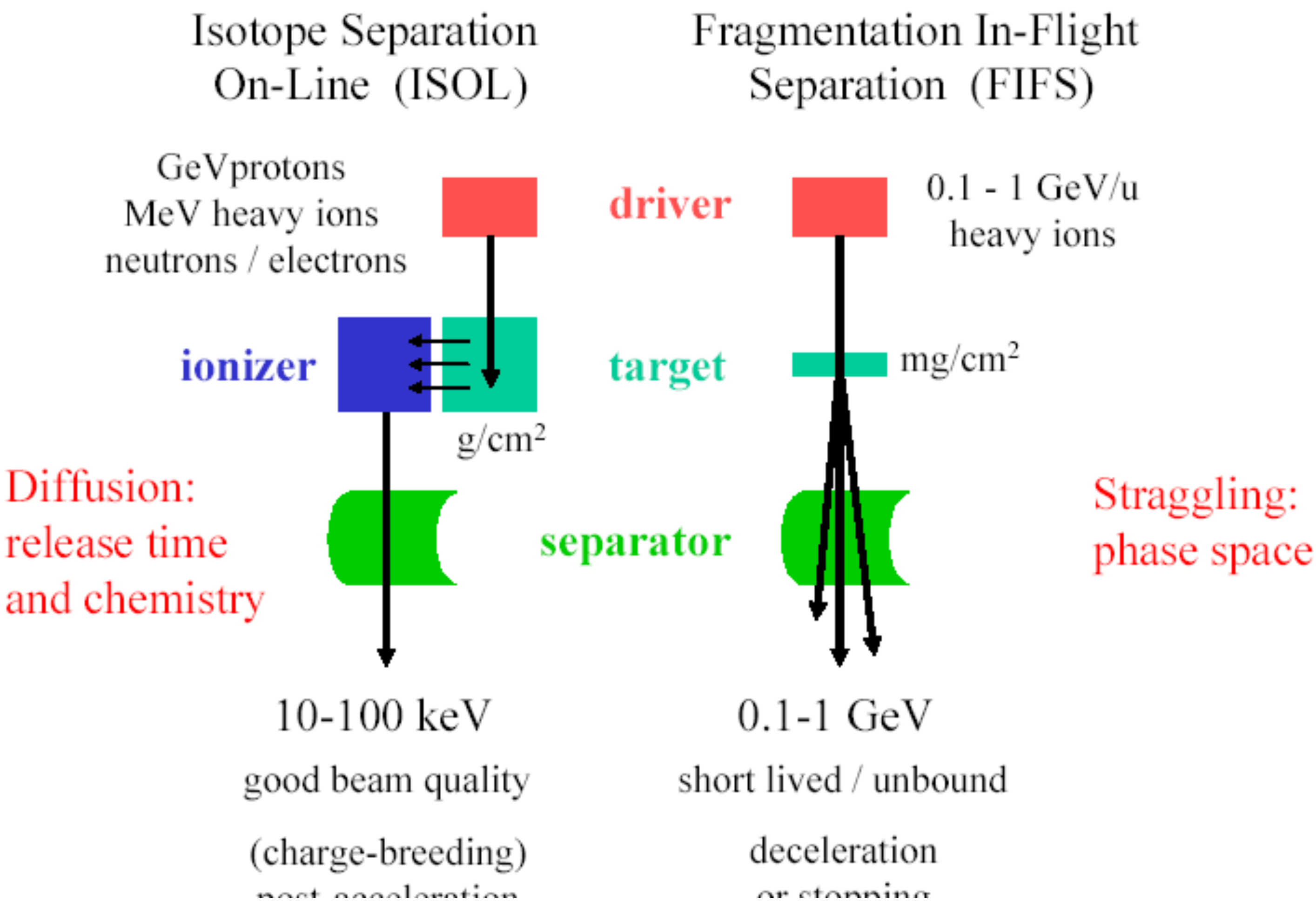
**Example:**

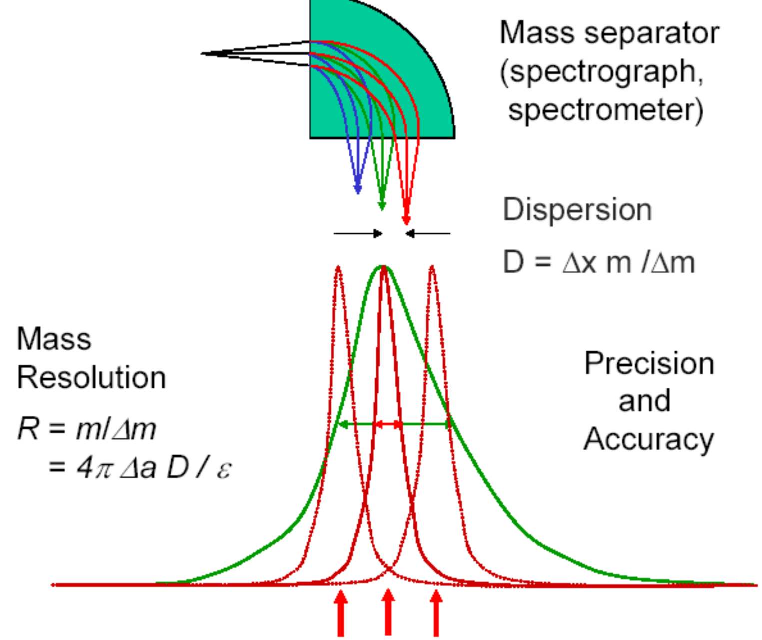
- Radioactive beam ???

-

⇒ **need for ???**

# *Production (and separation) techniques for exotic nuclides*






high resolution *necessary but not sufficient* for high prec

# *Techniques*

| *Indirect* *(energy)* | *Direct* *(mass spectrometry)* | *PRODUCTION SCHEME* |
|---|---|---|
| reactions: $A(a,b)B$ $Q = M_A + M_a - M_b - M_B$ | time of flight: $TOF = (m/q)\,(L/B\rho)$ | FIFS (MeV) |
| decays: $A \rightarrow B + \alpha$ $Q_\alpha = M_B - M_A$ | cyclotron frequency: $f_c = qB/m$ | ISOL (keV) |

better sensitivity

better precision

LISE: achromatic spectrometer

Achromatic spectrometer: position and angle of the ion at the end of the Device (focal plane) DO NOT depend on the ion's momentum.

***OBJECTIVES:***

*The LISE device has 2 principle objectives:*

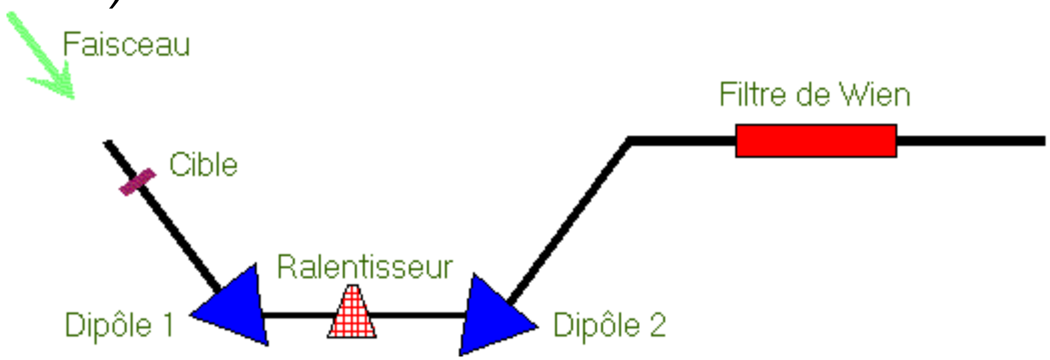
*1) To produce and select radioactive nuclei*

*2) To produce and select highly stripped ions (with few electrons)*

***METHOD OF PRODUCTION OF RADIOACTIVE NUCLEI:***

*The production of radioactive nuclei is carried out using stable nuclei, accelerated by the GANIL accelerator, and projected towards a fixed target which has a thickness of the order of millimetres, eg carbon.*

*(see figure 1).*



**SELECTION DES NOYAUX :**

La sélection des noyaux est réalisée par différents moyens :

- On utilise d'une part la propriété qu'ont les champs magnétiques de dévier les particules chargées. Celles-ci sont d'autant plus déviées que le champ magnétique, la charge électrique de la particule sont grands, et la masse, la vitesse de la particule sont petites. En sélectionnant une certaine déviation on sélection un certain rapport de ces paramètres. Sur LISE nous utilisons deux dipôles magnétiques.
- On utilise d'autre part un procédé ingénieux. On interpose un morceau de matière (le ralentisseur) sur la trajectoire des noyaux produits après la cible (voir la figure 1). Les noyaux traversent une certaine épaisseur de matière, ils sont donc ralentis, c'est-à-dire ils perdent de l'énergie. La quantité d'énergie perdue est fonction de la nature du noyau incident. L'astuce consiste à choisir l'épaisseur du morceau de matière et les champs magnétiques de telle façon que, en fonction de la trajectoire de la particule et de sa nature, seule les noyaux qui perdent la bonne quantité d'énergie sont sélectionnés.
- On utilise finalement un dispositif, appelé filtre de Wien, qui permet, grâce à des champs magnétiques et électriques de sélectionner la vitesse des ions.

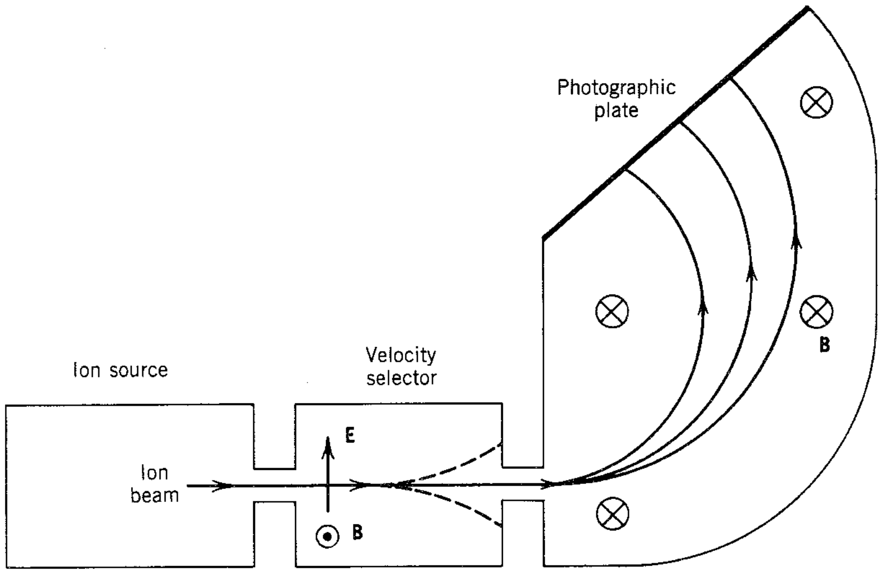



**Figure 3.13** Schematic diagram of mass spectrograph. An ion source produces a beam with a thermal distribution of velocities. A velocity selector passes only those ions with a particular velocity (others being deflected as shown), and momentum selection by a uniform magnetic field permits identification of individual masses.

by the momentum:

$$mv = qBr$$
$$r = \frac{mv}{qB} \tag{3.20}$$

Since $q$, $B$, and $v$ are uniquely determined, each different mass $m$ appears at a particular $r$. Often the magnetic fields of the velocity and momentum selectors are common, in which case

$$m = \frac{qrB^2}{E} \tag{3.21}$$

To determine masses to one part in $10^6$, we must know all quantities in Equation 3.21 to that precision, which hardly seems possible. In practice we could calibrate for one particular mass, and then determine all masses by relative

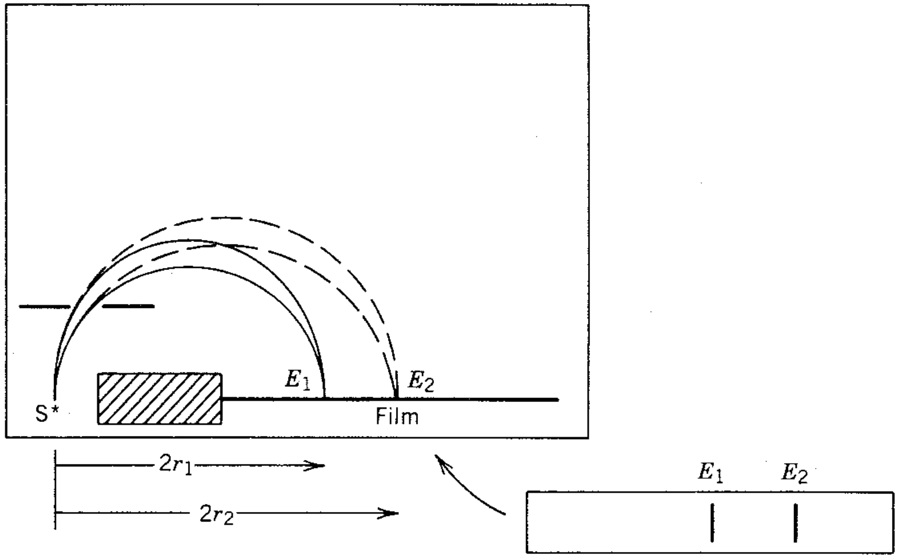



**Figure 7.36** A simple magnetic spectrometer. There is a uniform magnetic field $B$ perpendicular to the plane of the paper. The momentum of the particle determines the radius of curvature $r$ of its path. There is also a focusing effect, as particles emitted in a narrow range of angles are focused to a common point on the film.

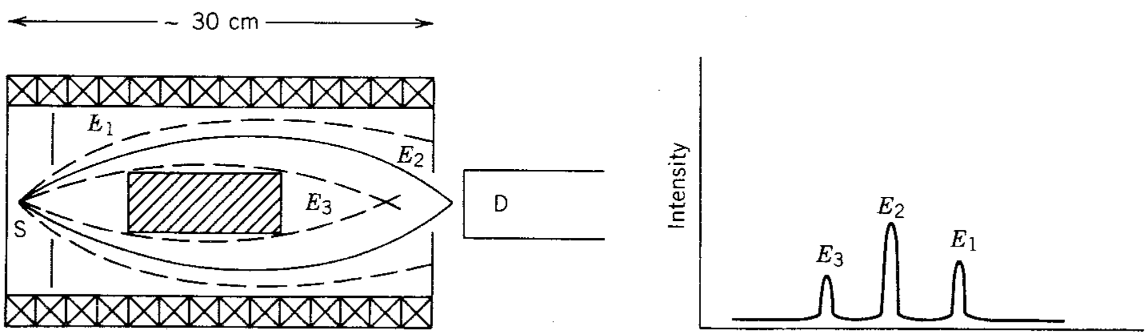
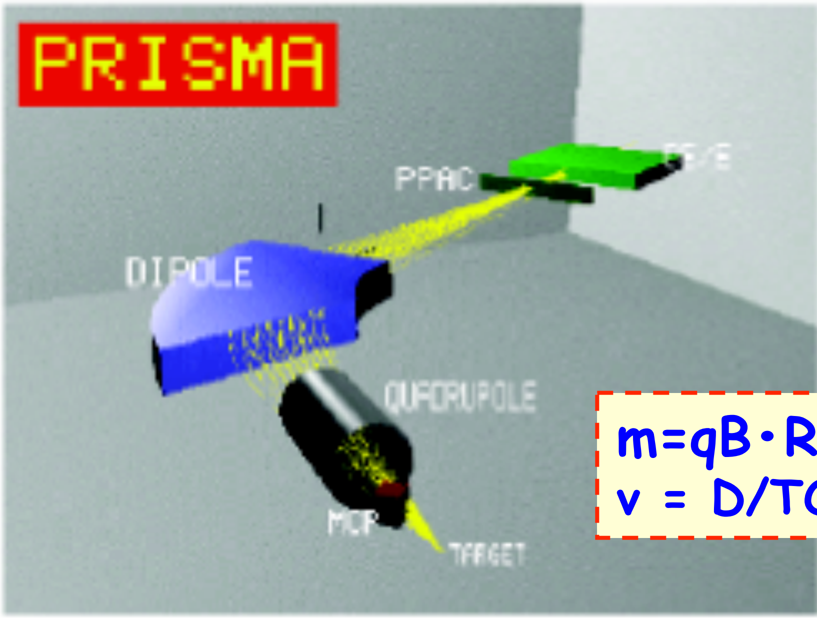
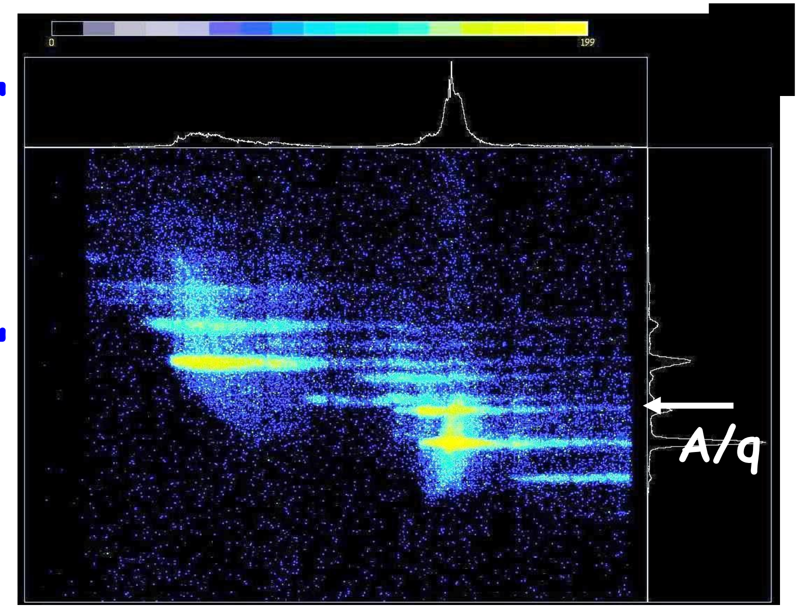



**Figure 7.37** A magnetic "lens" spectrometer designed for electrons. The operation is very similar to that of an optical lens. The coils produce a magnetic field along the axis of the system. Particles of a unique energy $E_2$ are focussed on the exit slit and reach the detector; particles of different energies are not recorded. Changing the current in the coils allows different energy groups to be brought into focus and observed by the detector.

# Mass & Energy reconstruction with PRISMA: via TOF




$m = qB \cdot R/v$
$v = D/TOF$




$$T = \frac{S(\theta)}{v}$$

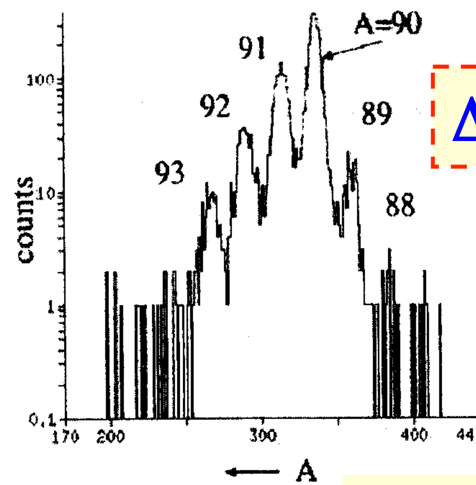
$$B\rho \approx A\frac{v}{q} \approx X$$

$$E = A\frac{v^2}{B\rho(x,\theta)}$$

$$q = \frac{2}{S(x,\theta)} \cdot \frac{ET}{B\rho(x,\theta)}$$

$$\frac{A}{q} = \frac{B\rho(x,\theta)}{s(x,\theta)}T$$

$$E_P = (B\rho)^2 \cdot \frac{q}{(A/q)}$$




$\Delta A/A = 1/280$

after ion-tracking reconstruction

505 MeV $^{90}Zr + ^{208}Pb$