IV Seminario Nazionale Rivelatori Innovativi

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Spettrometri magnetici

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Magnetic spectrometry: Using static magnetic fields to learn about microscopic world

$$\vec{F} = q\vec{v} \wedge \vec{B}$$ Legge di Lorentz

If $\vec{v} \perp \vec{B}$ and $\vec{B}$ is uniform

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

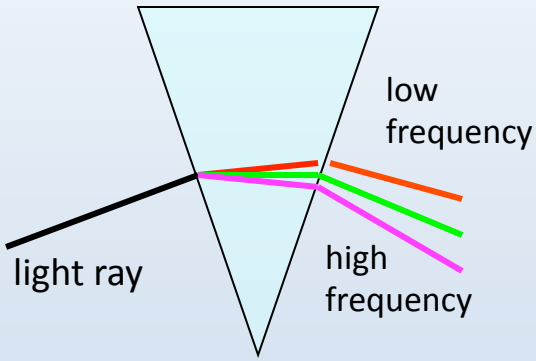
Macroscopic world

Microscopic world

- If B is known, a measurement of ρ corresponds to a measurement of p / q
- If also q is known, by supplemental detectors, one gets information about p (momentum spectrometry)
- If one also knows the velocity of the particle one directly access its mass (mass spectrometry)

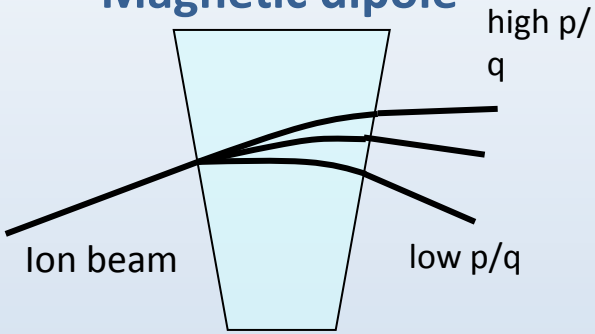
Some analogy

Prism



Deflection depending on the frequency

Magnetic dipole



Deflection depending on p/q

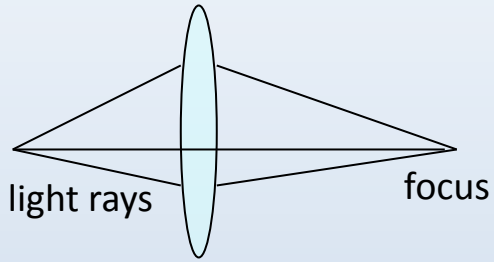
Transform frequency or p/q intervals in position

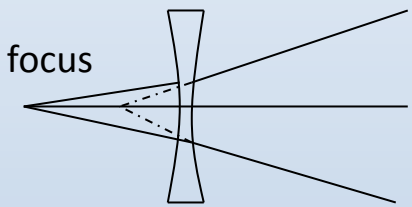
Dispersive elements

May be used as analizers

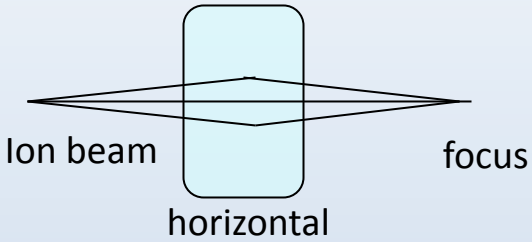
Some analogy

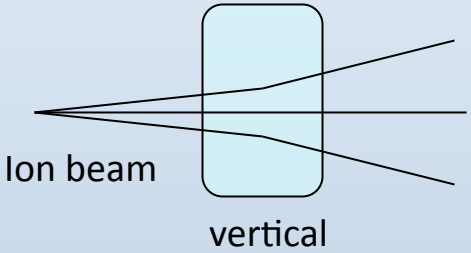
Convergent and divergent lenses





Magnetic quadrupole





To 1st approximation

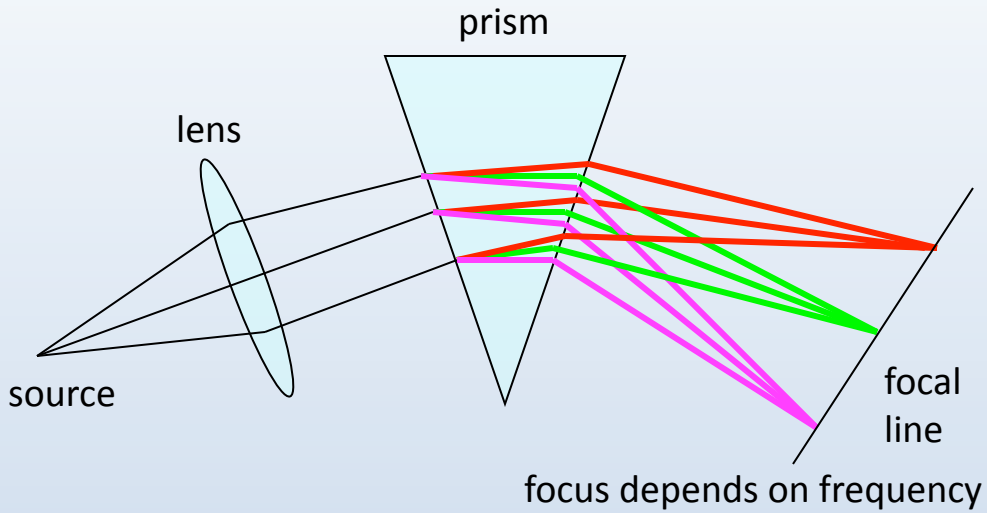
Focus not depending on the frequency

Focus not depending on p/q

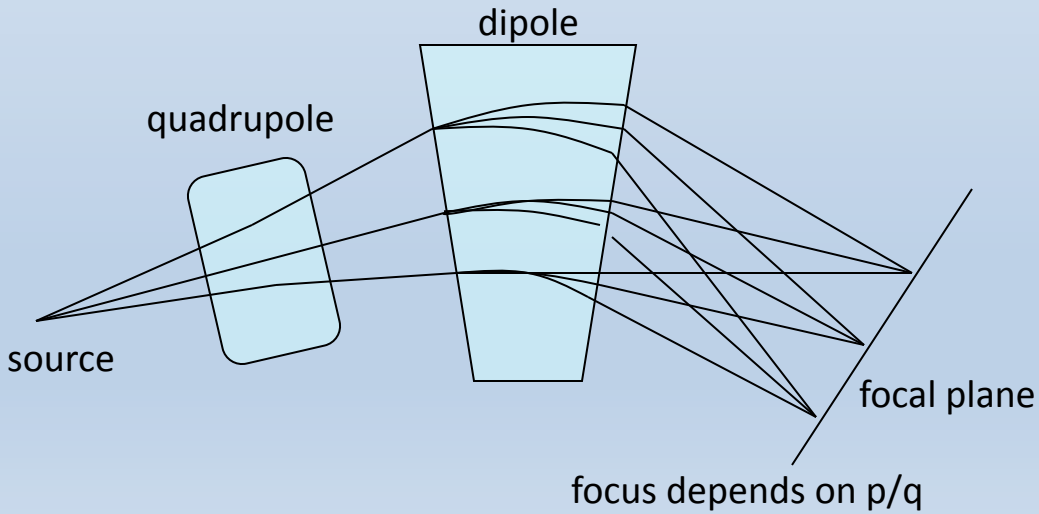
Focusing elements

May be used to concentrate intensity

Light spectrometer



Magnetic spectrometer

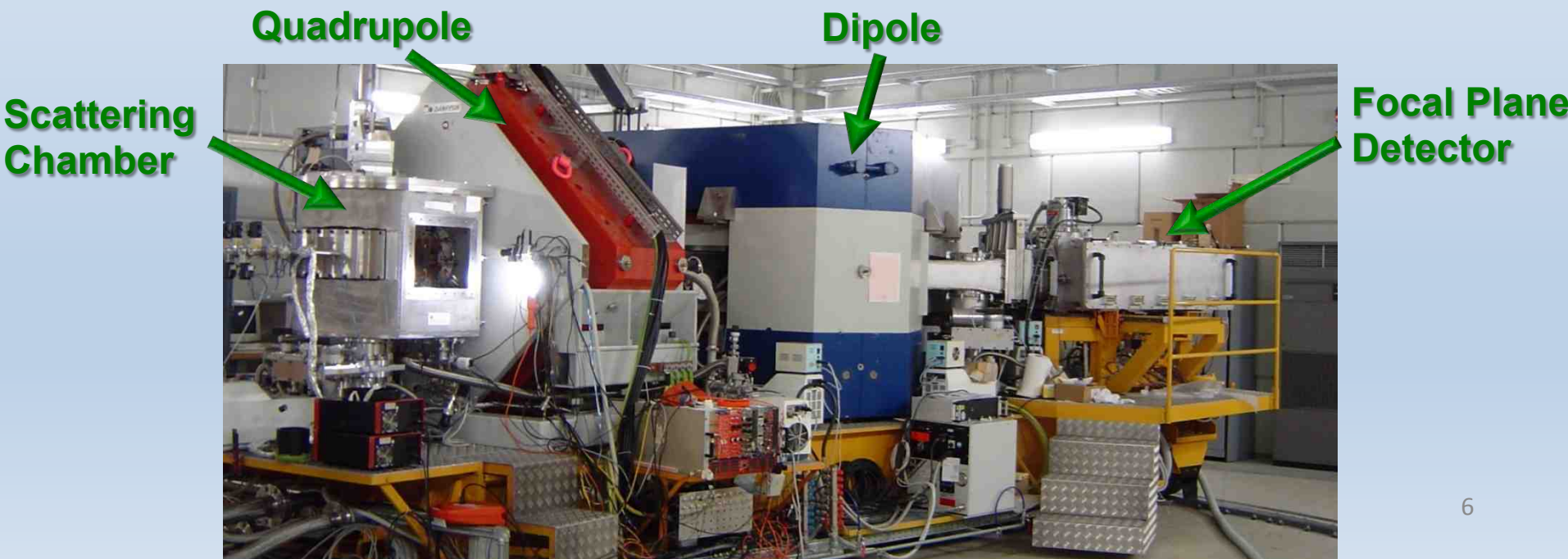


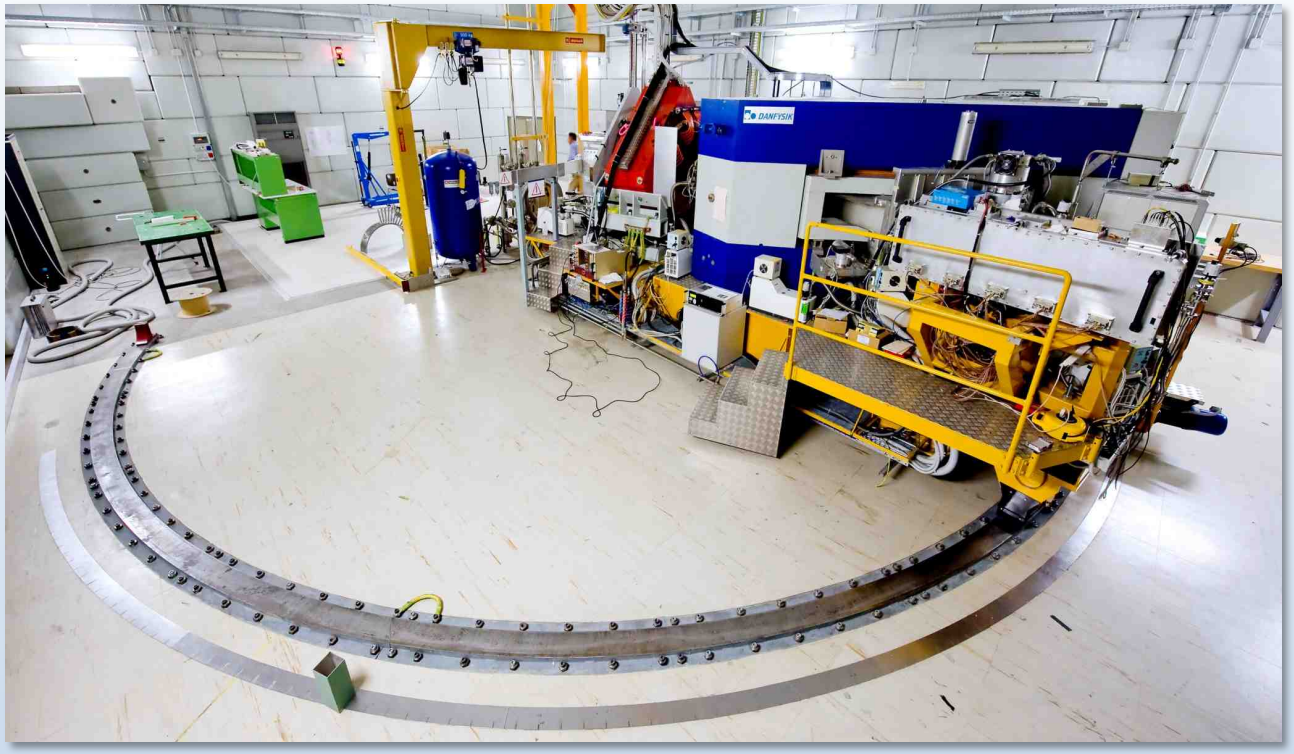
MAGNEX: a QD spectrometer

- **The Quadrupole**: vertically focusing
  (Aperture radius 20 cm, effective length 58 cm. Maximum field strength 5 T/m)

- **The Dipole**: momentum dispersion (and horizontal focus)
  (Mean bend angle 55°, radius 1.60 m. Maximum field ~ 1.15 T)

- **The surface coils**, located between the dipole pole faces and the inner high vacuum chamber, giving tunable quadrupolar and sextupolar corrections





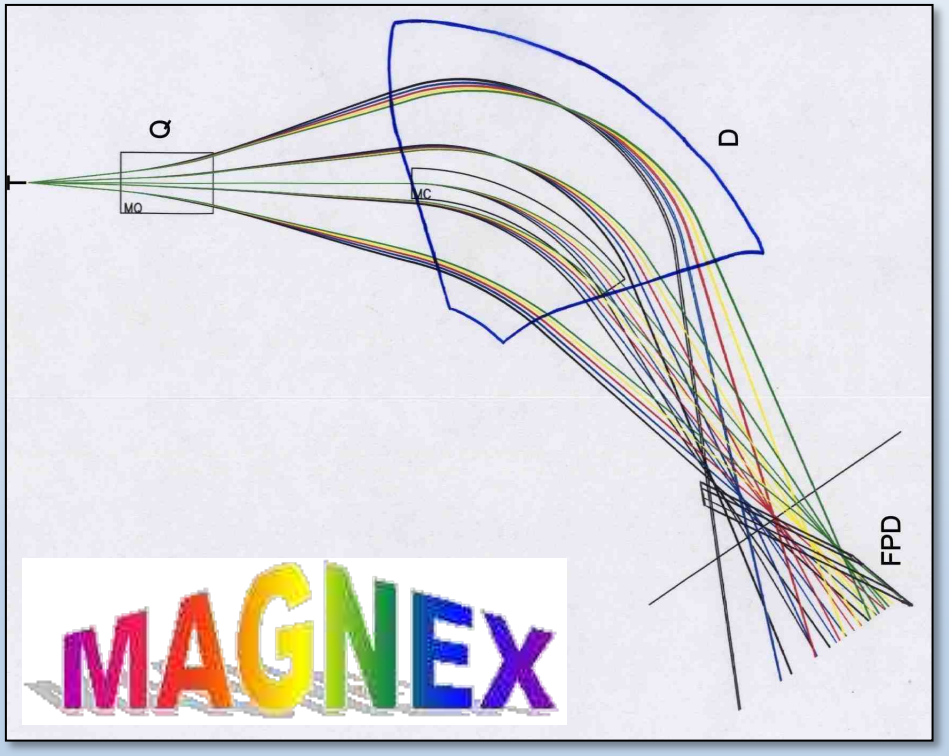
Optical characteristics	Measured values
Solid angle	50 msr
Angular range	–20° - +85°
Momentum acceptance	-14.3%, +10.3%
Momentum dispersion for k= - 0.104 (cm/%)	3.68
Maximum magnetic rigidity	1.8 T m

MAGNEX resolution

Energy $\Delta E/E \sim 1/1000$

Angle $\Delta\theta \sim 0.2°$

Mass $\Delta m/m \sim 1/160$



We have measured in a **wide mass range** (from protons to medium-mass nuclei)

F. Cappuzzello et al., "MAGNEX: an innovative large acceptance spectrometer for nuclear reaction studies" in: Magnets: Types, Uses and Safety, Nova Publisher Inc., New York, 2011, pp 1-63

The large acceptance problem

$$F: \vec{X}_i \rightarrow \vec{X}_f$$

F transport matrix

$\mathbf{X}_i = (\theta_i, y_i, \varphi_i, \delta)$

Large acceptance

Aberrations

$$x_i(f) = \sum_j R_{ij} x_j(i) + \sum_{j,k} T_{ijk} x_j(i) x_k(i) + \ldots\ldots$$

Up to 11th order for MAGNEX

Careful hardware design
(to minimize the aberrations)

Software ray-reconstruction
(to know the aberrations)

Hardware minimisation of aberrations

- Shaping of dipole entrance and exit boundaries

  (8th order polynomial shape)

- Introduction of surface coils in the dipole pole tips
- Rotation of the focal plane detector of 59°
- Shift of the focal plane detector

Software ray-reconstruction

ALGEBRIC RAY-RECONSTRUCTION

- ✓ Solution of the equation of motion for each detected particle
- ✓ Inversion of the transport matrix
- ✓ Application to the final measured parameters

$$F: \vec{\mathbf{X}}_{\mathbf{i}} \rightarrow \vec{\mathbf{X}}_{\mathbf{f}}$$

Inversion of the transport matrix

$$F^{-1}: \vec{\mathbf{X}}_{\mathbf{f}} \rightarrow \vec{\mathbf{X}}_{\mathbf{i}}$$

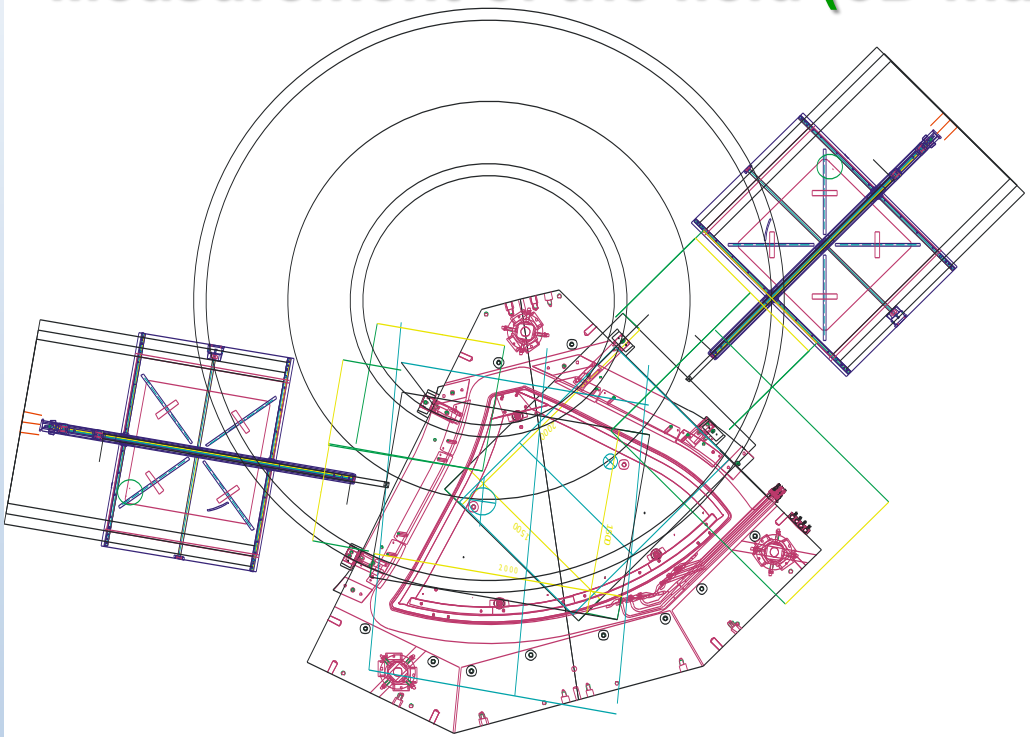
1) Detailed knowledge of the geometry and magnetic field

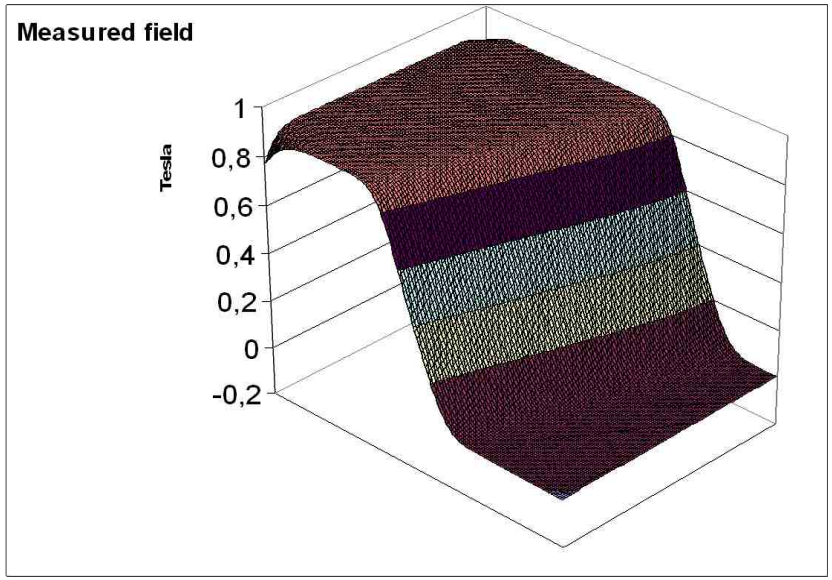
2) Algorithm to transport and invert

3) High resolution measurement at the focal plane (highly performing detectors)

1) Detailed knowledge of the magnetic field

Measurement of the field (3D map)





Interpolation of the field

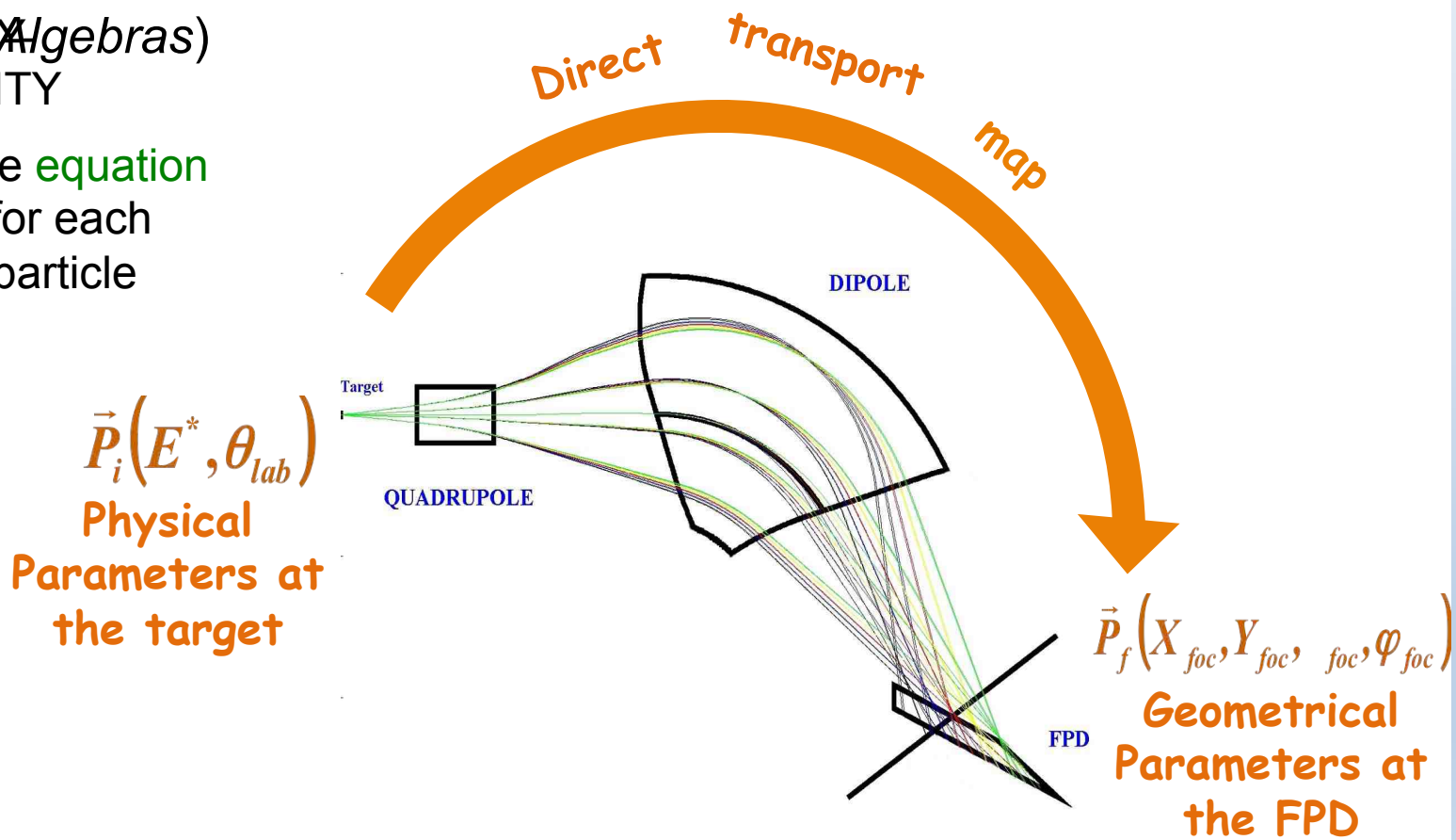
- A.Lazzaro et al., NIMA 570 (2007) 192
- A.Lazzaro et al., NIMA 585 (2008) 136
- A.Lazzaro et al., NIMA 591 (2008) 394
- A.Lazzaro et al., NIMA 602 (2009) 494

2) Algorithm to transport and invert

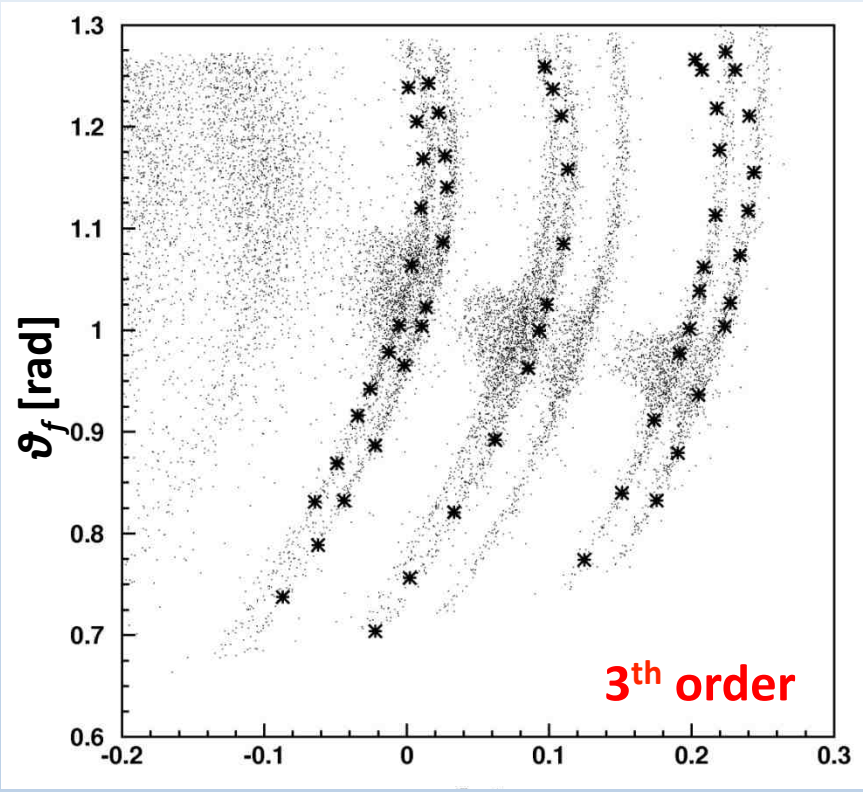
ALGEBRIC
RAY-
RECONSTRUCTION
(*Differential Algebras*)
INFINITY

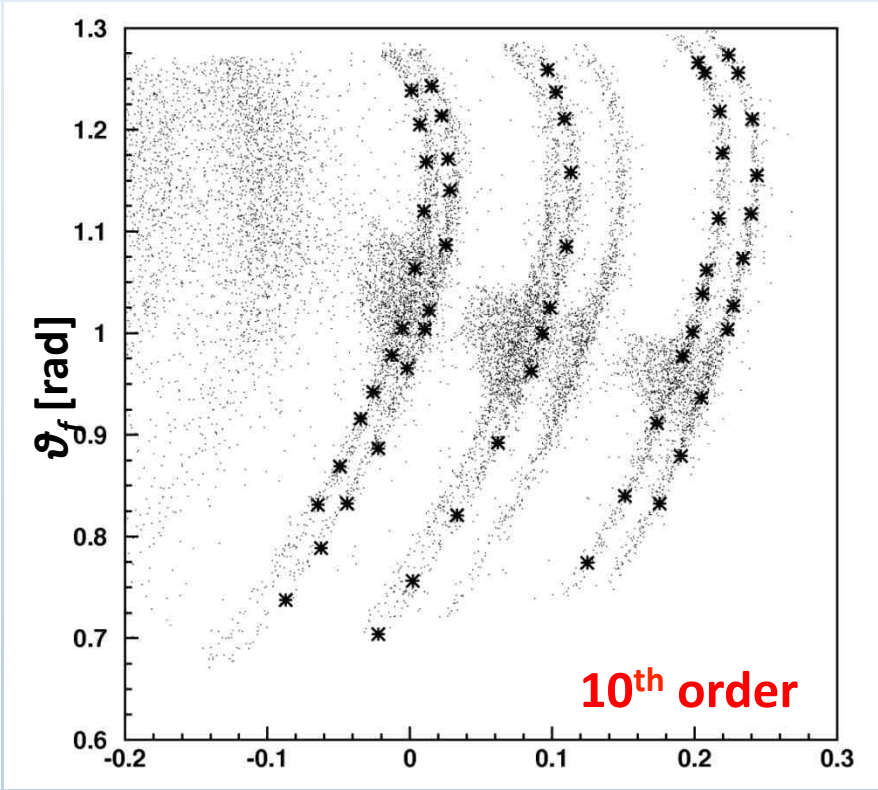
Solution of the equation of motion for each detected particle

$$F : \vec{X}_i \rightarrow \vec{X}_f$$



F. Cappuzzello, et al., NIM A 638, (2011) 74





With condition:

$-0.01 \text{ m} < Y_f < 0.01 \text{ m}$

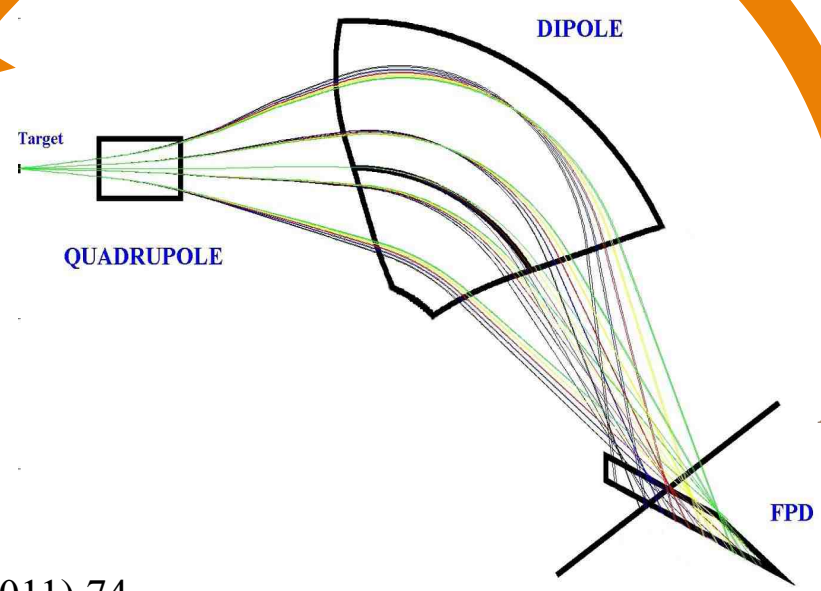
2) Algorithm to transport and invert

ALGEBRIC
RAY-
RECONSTRUCTION
(*Differential Algebras*)
INFINITY

Solution of the equation of motion for each detected particle

$$F^{-1} : \vec{X}_f \rightarrow \vec{X}_i$$

Inverted transport map



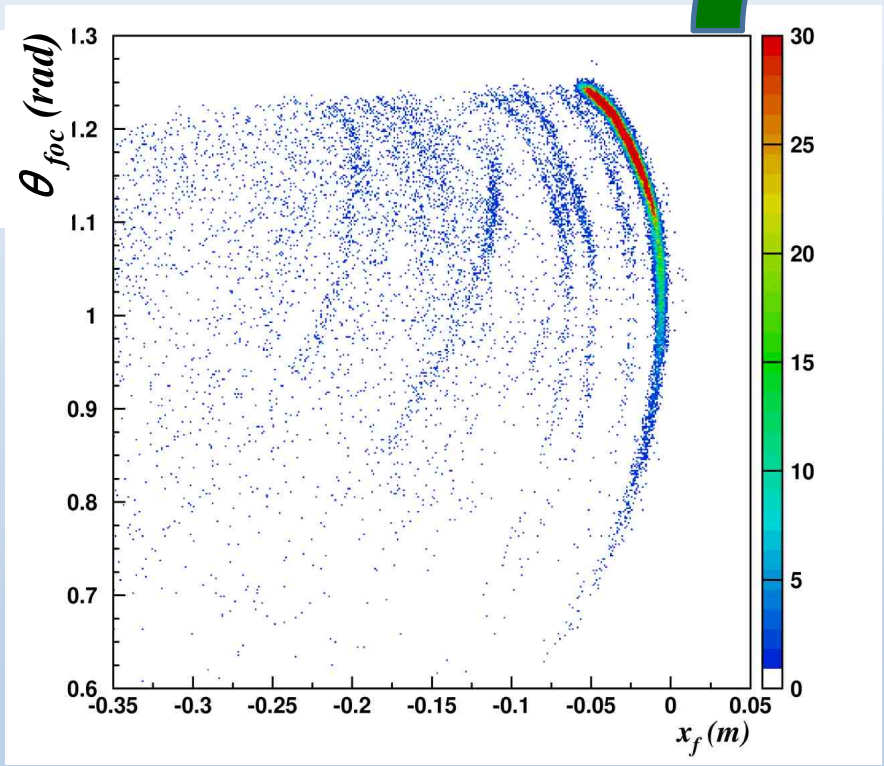
$\vec{P}_i\left(E^*, \theta_{lab}\right)$
Physical Parameters at the target

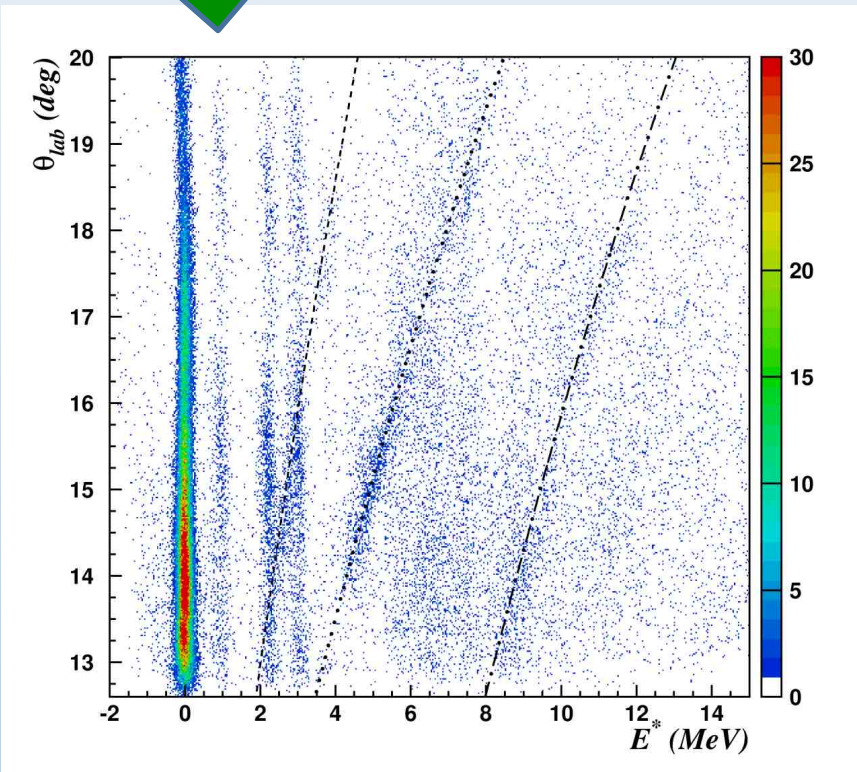
$\vec{P}_f\left(X_{foc}, Y_{foc}, \ _{foc}, \varphi_{foc}\right)$
Geometrical Parameters at the FPD

F. Cappuzzello, et al., NIM A 638, (2011) 74

$^{27}Al(^{16}O,^{16}O)^{27}Al$ at 100 MeV
$13° < \theta_{lab} < 20°$

F^{-1}



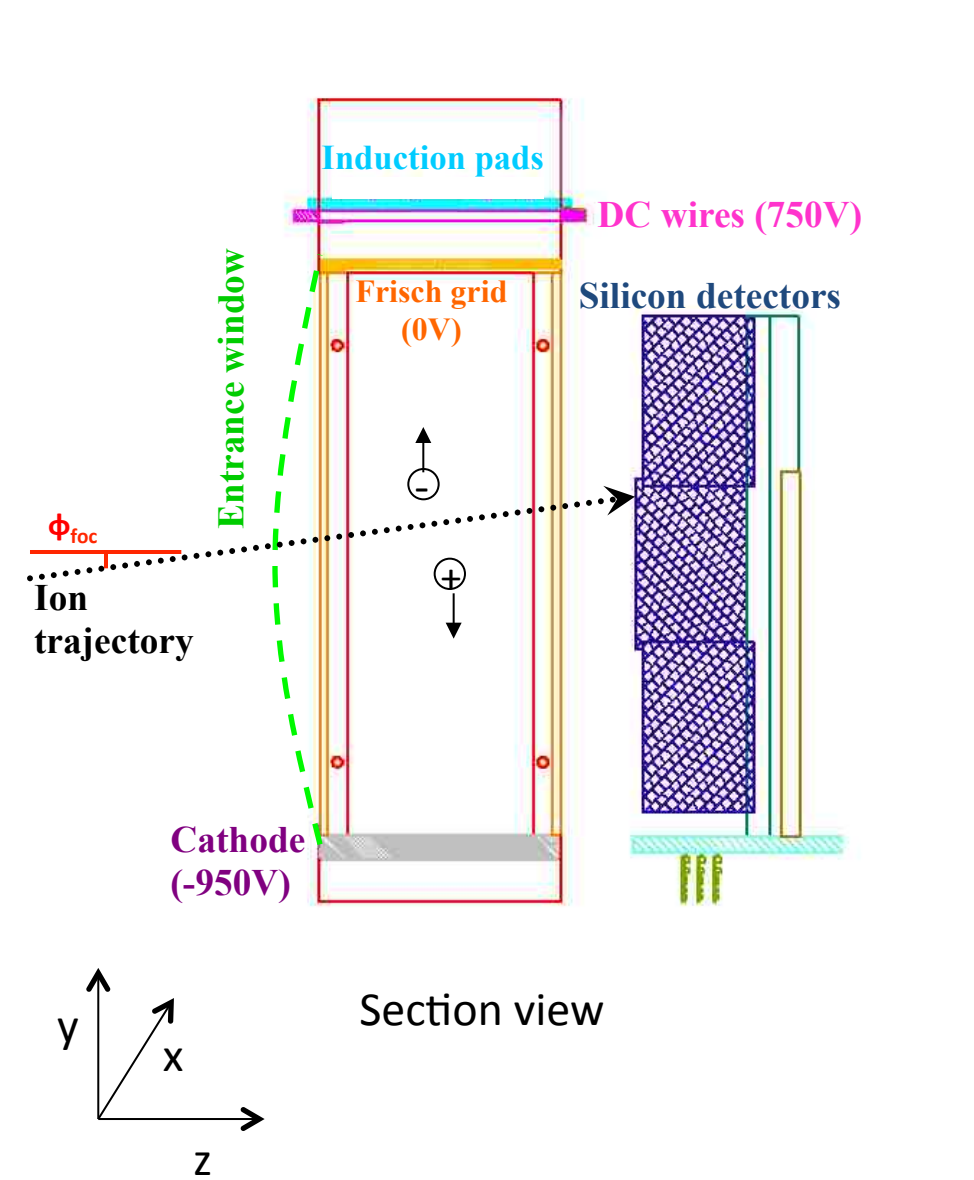


$$E^* = Q - K\left(1 + \frac{M_{ejectile}}{M_{residual}}\right) + E_{beam}\left(1 - \frac{M_{beam}}{M_{residual}}\right) + 2\frac{\sqrt{M_{beam}M_{ejectile}}}{M_{residual}}\sqrt{E_{beam}K}\cos\theta_{lab}$$

M. Cavallaro et al., NIMA 648 (2011) 46-51

F. Cappuzzello et al., NIMA 638 (2011) 74-82

3) MAGNEX Focal Plane Detector



60 Silicon Detectors
→ E_{res}

5 Proportional Wires
→ ΔE

} Ion identification

4 Induction Strip
→ X_1, X_2, X_3, X_4
→ X_{foc}, θ_{foc}

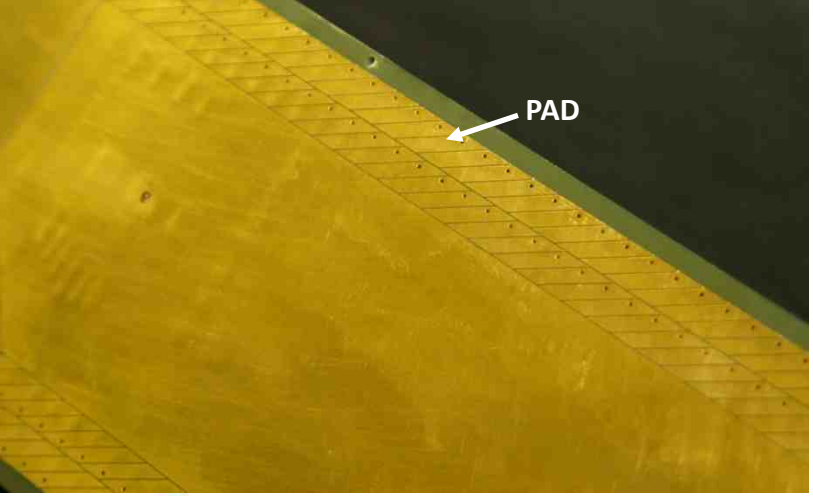
4 Drift Chamber (DC)
→ Y_1, Y_2, Y_3, Y_4
→ Y_{foc}, ϕ_{foc}

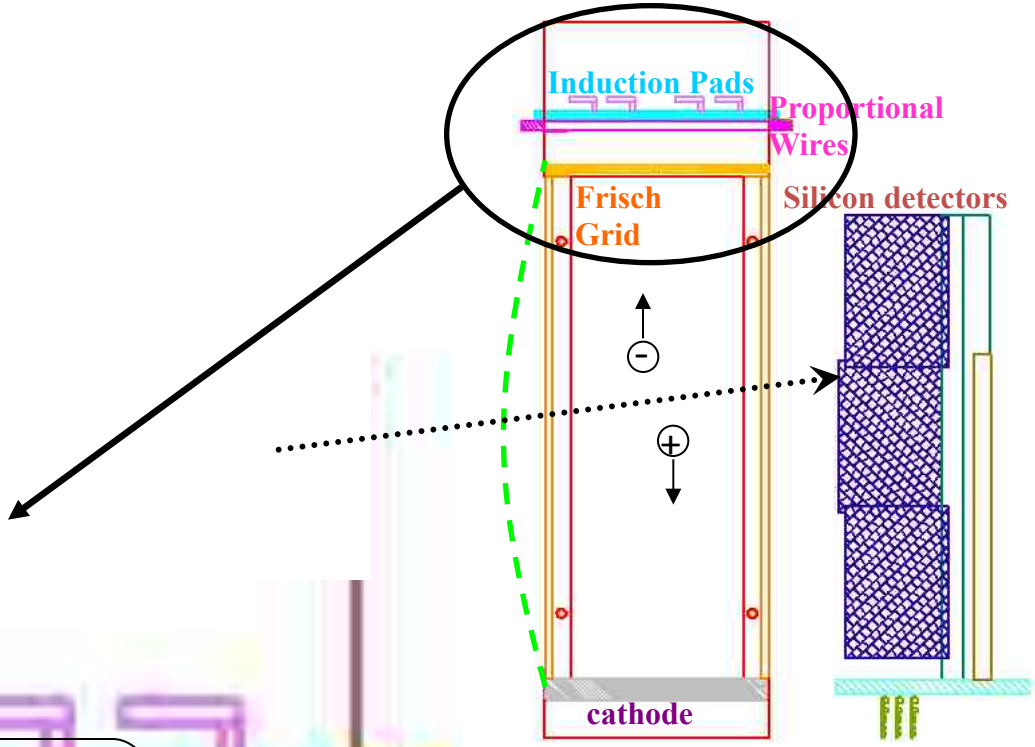
} Ray-reconstruction

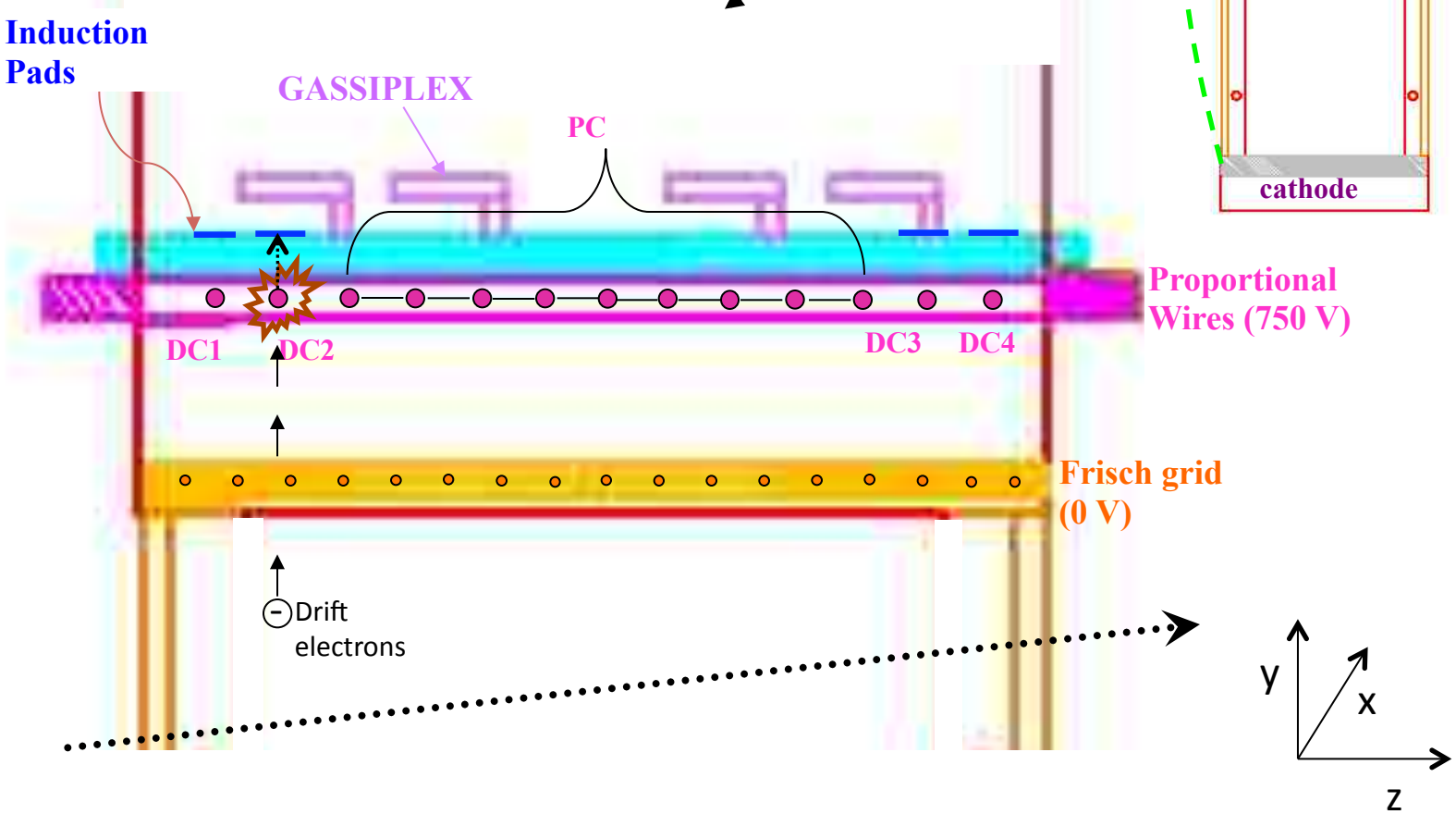
•C.Boiano et al., IEEE 55 (2008) 3563

•M.Cavallaro et al. EPJ A 48: 59 (2012)

•D.Carbone et al. EPJ A 48: 60 (2012)

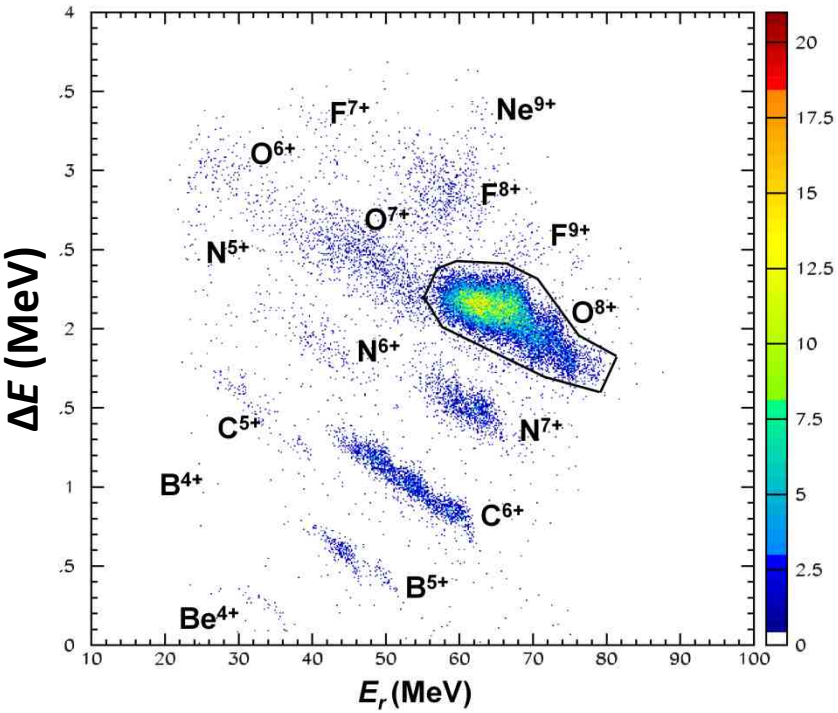

PAD


Induction Pads
Proportional Wires
Frisch Grid
Silicon detectors
cathode


Induction Pads
GASSIPLEX
PC
Proportional Wires (750 V)
DC1
DC2
DC3
DC4
Frisch grid (0 V)
Drift electrons
y
x
z

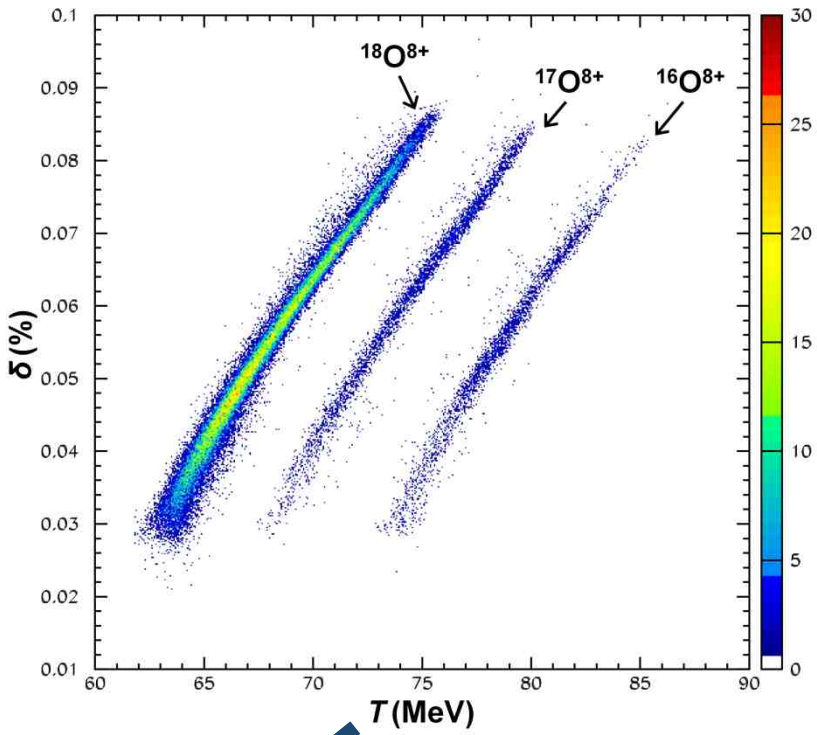
Particle Identification

$^{13}C(^{18}O,^{16}O)^{15}C$ at 84 MeV
$7° < \theta_{lab} < 19°$



Mass resolution $\Delta m/m \sim 1/160$

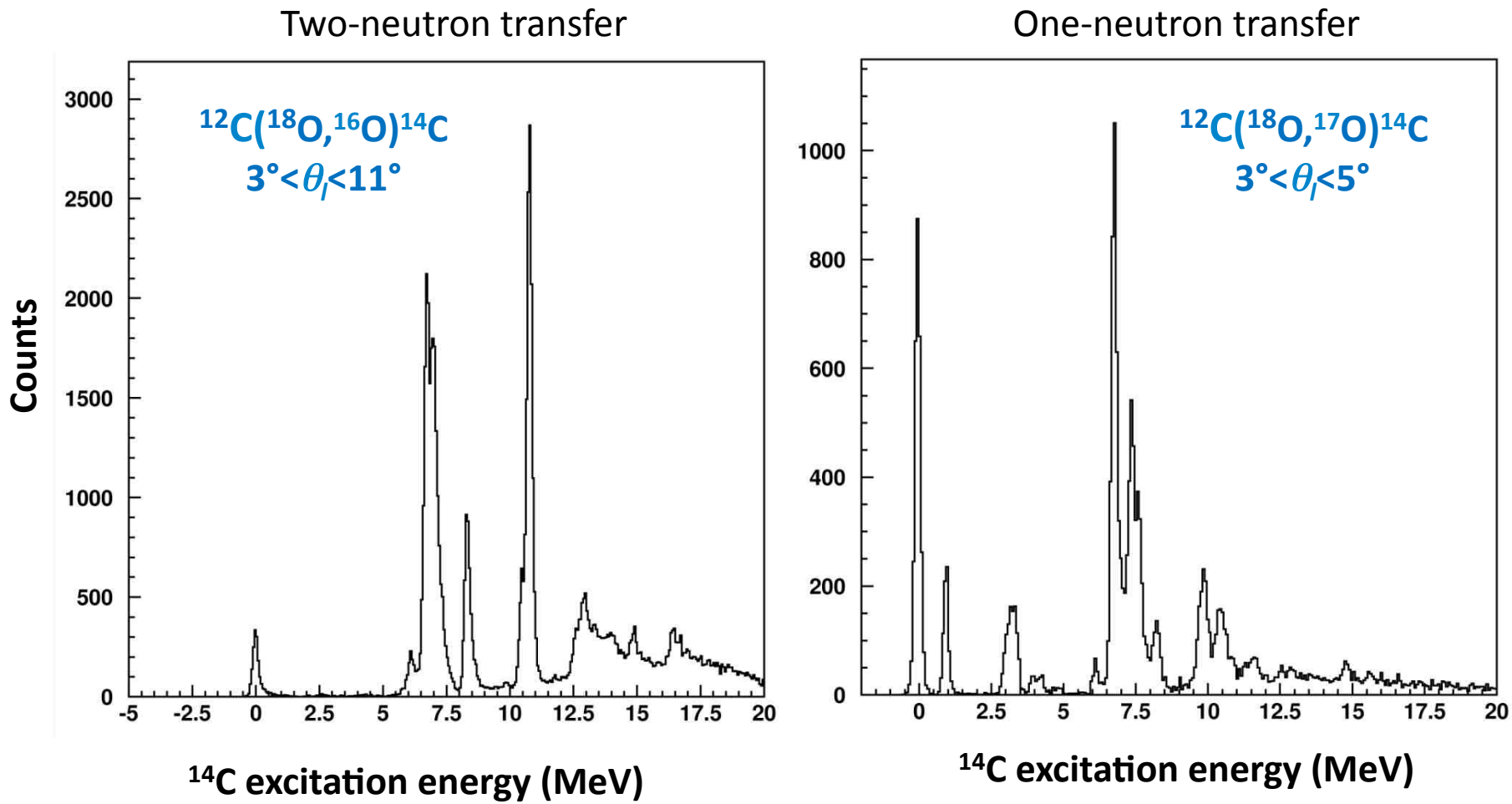
$$B\rho = \frac{p}{q} \rightarrow \frac{\sqrt{m}}{q} = \frac{p_0(\delta+1)}{q\sqrt{2T}}$$



$$T = E_r + E_l + E_d$$

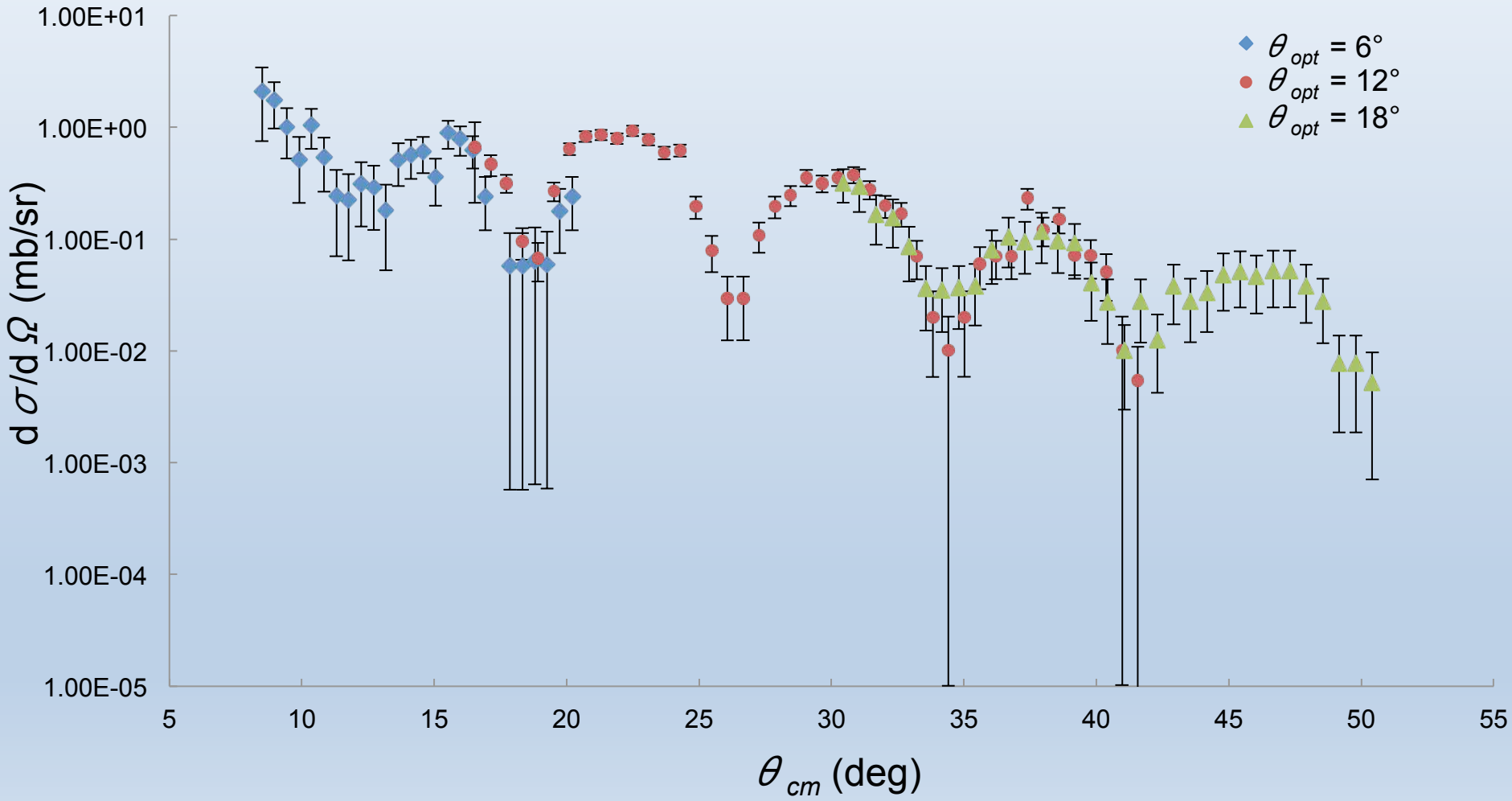
F. Cappuzzello et al., NIM A 621 (2010) 419

Examples of energy spectra

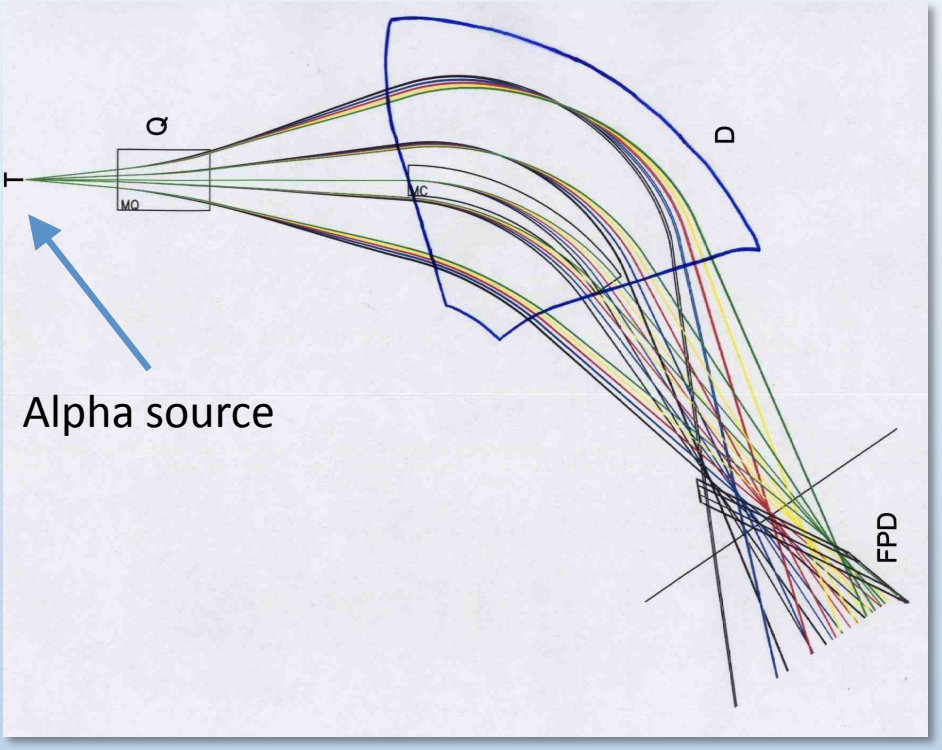


Angular distributions

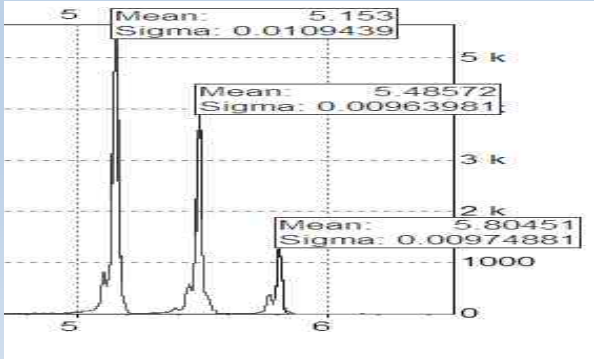
$^{12}C_{g.s.}(0^+) \rightarrow {}^{14}C_{g.s.}(0^+)$ ***L* = 0**



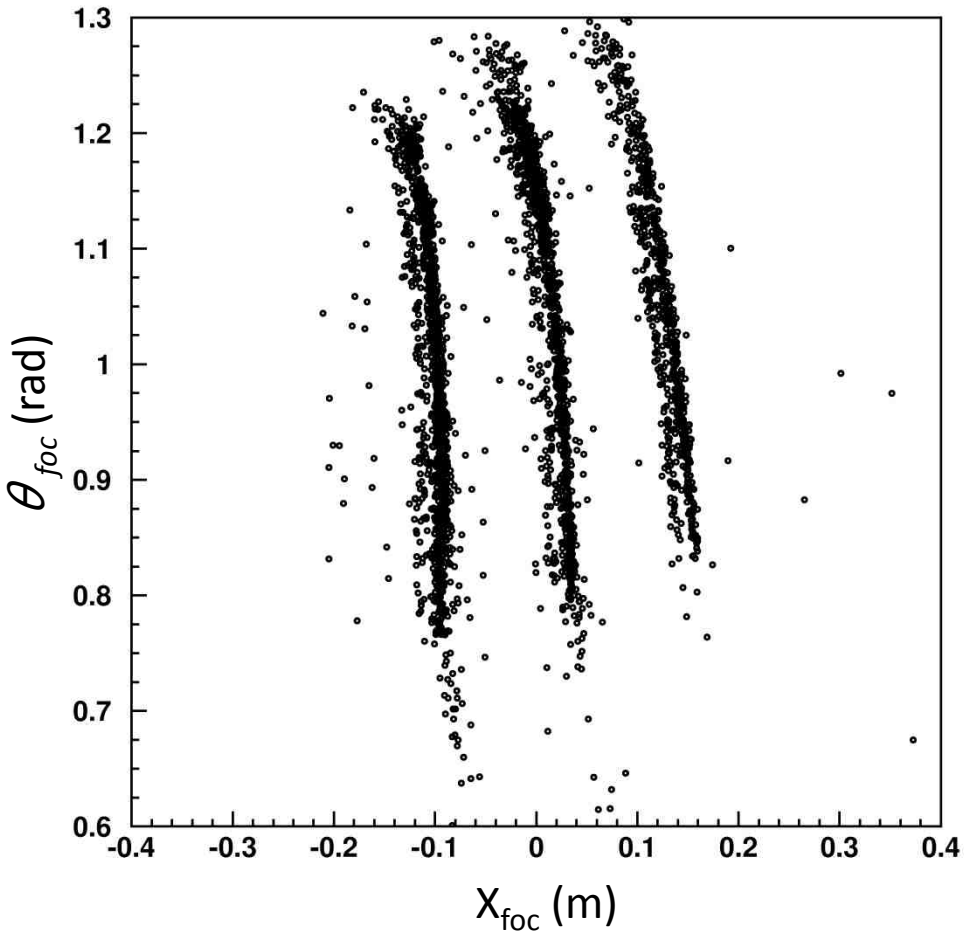
Our experiment:
3-peaks alpha source in the scattering chamber



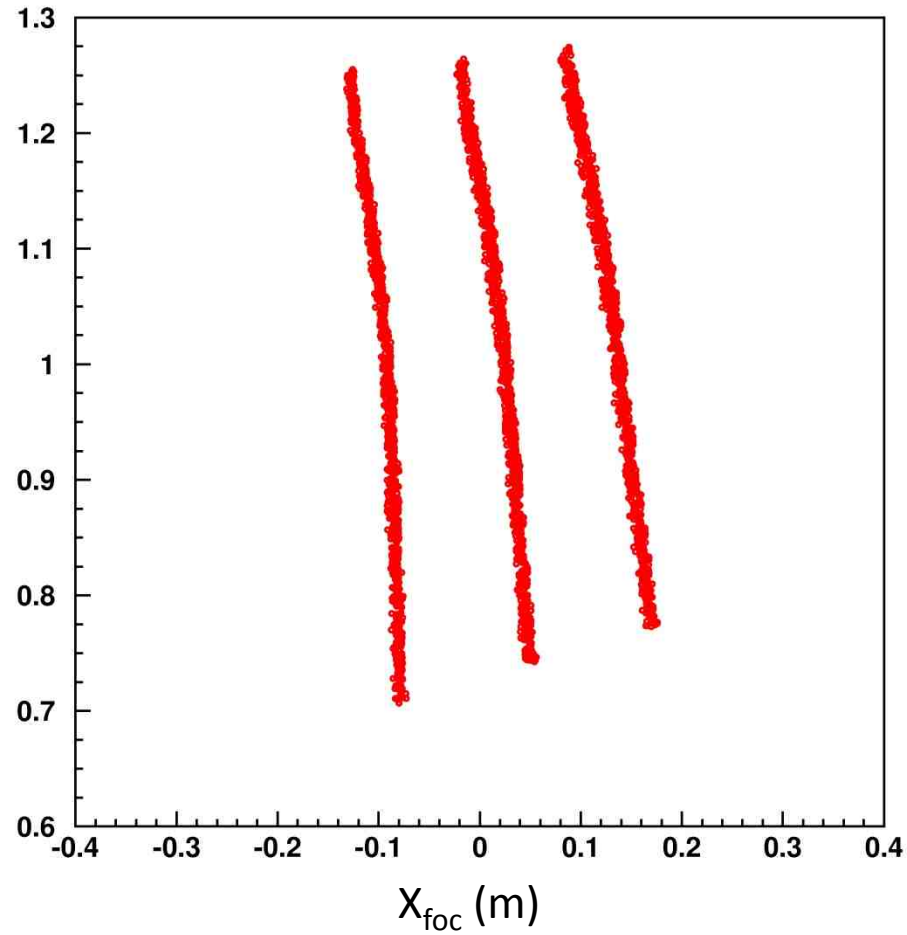
^{239}Pu	5.1566 MeV
^{241}Am	5.4856 MeV
^{244}Cm	5.8048 MeV

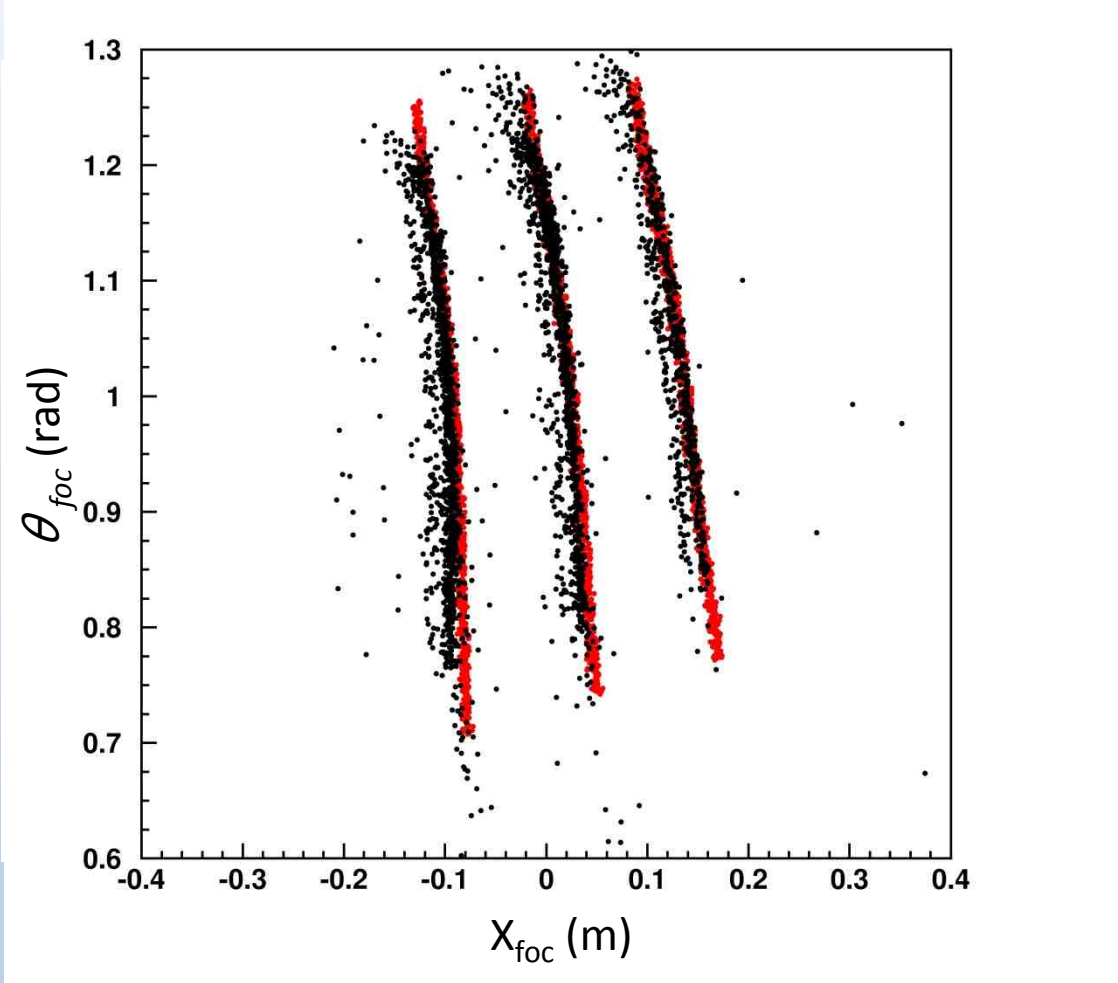


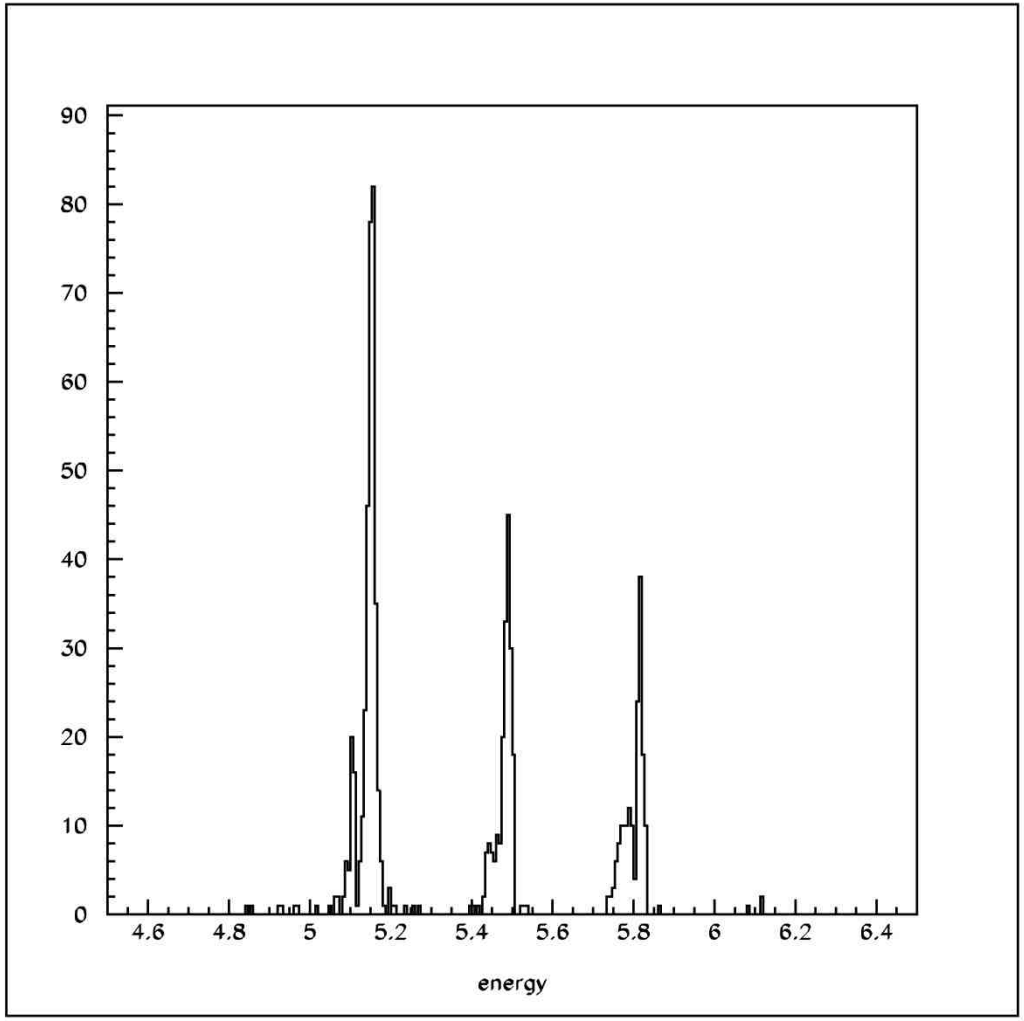
Experiment



Simulation

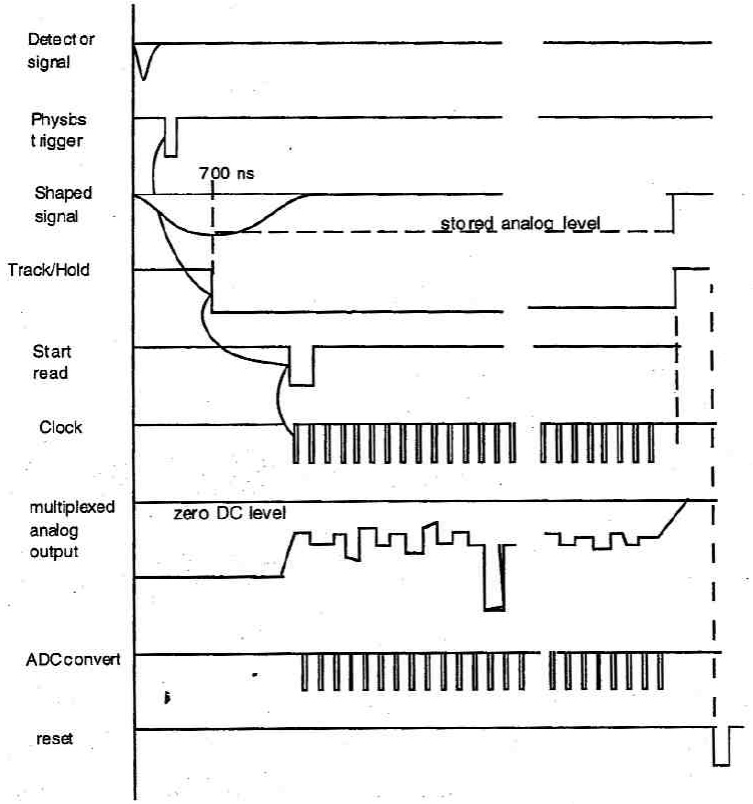


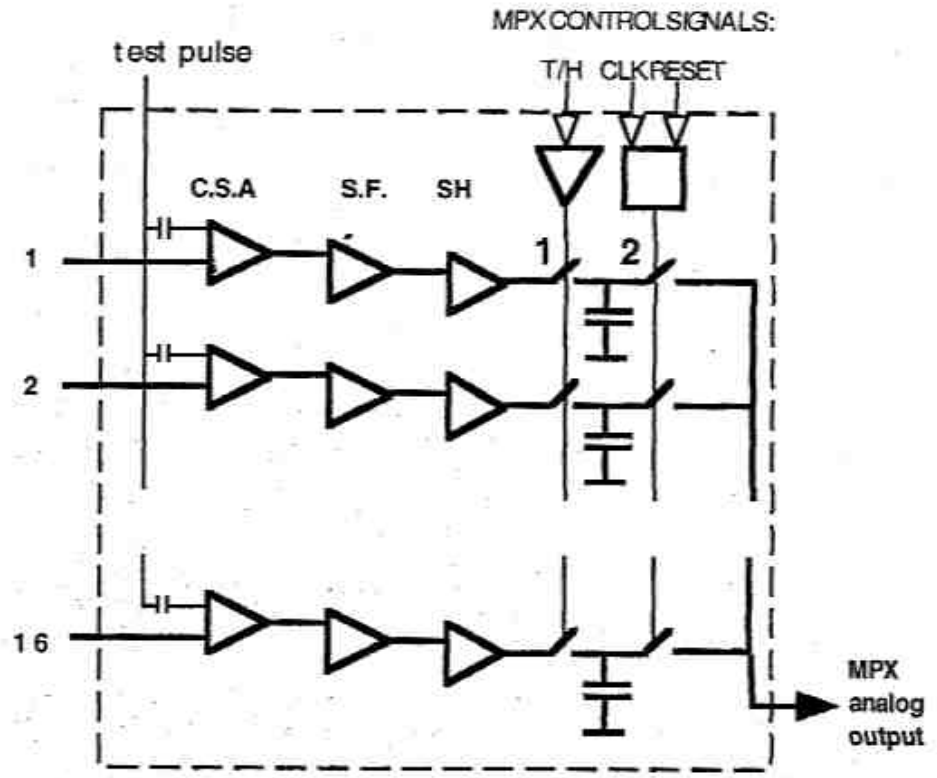

1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
θ_{foc} (rad)
X_{foc} (m)


90
80
70
60
50
40
30
20
10
0
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
energy

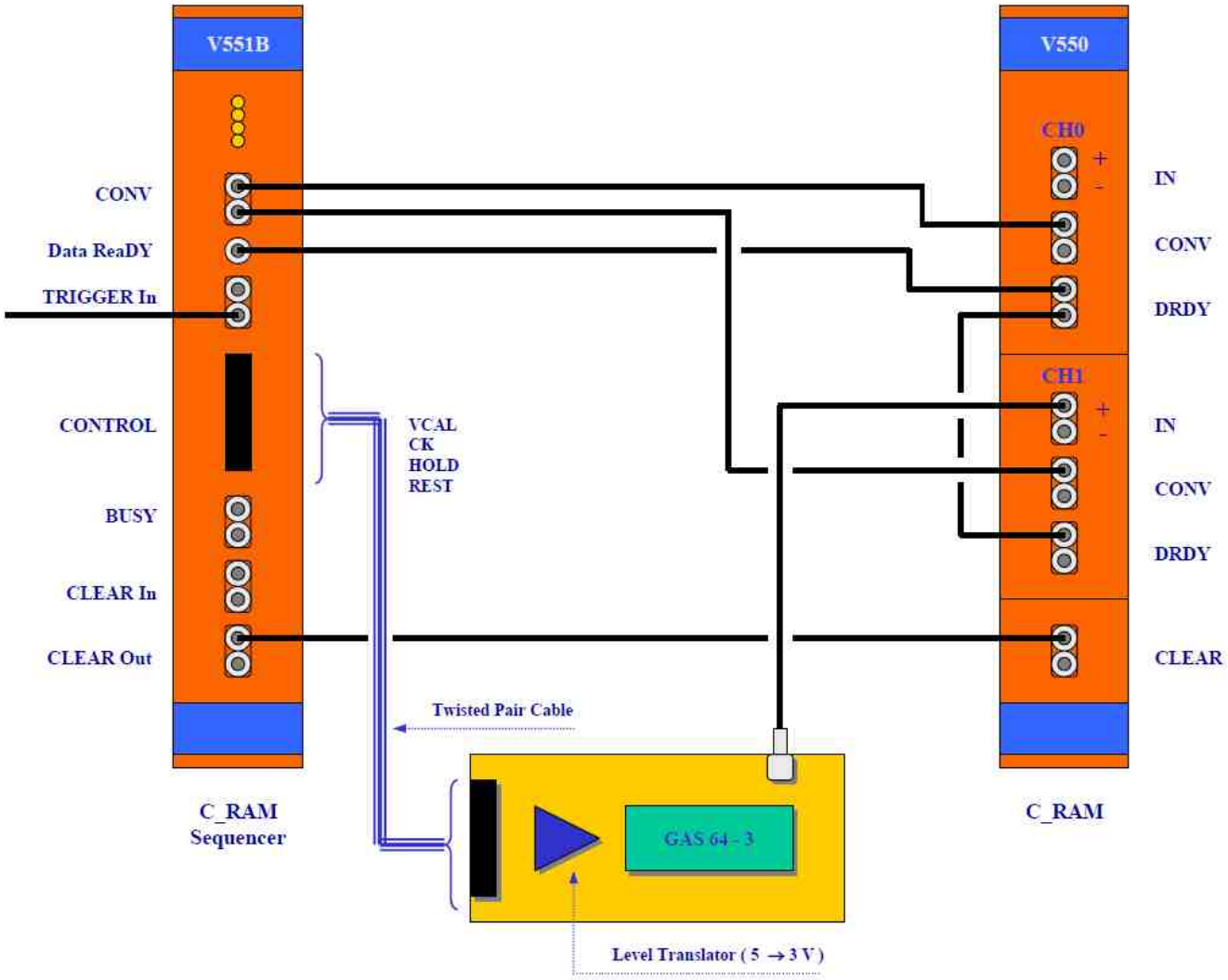
GASSIPLEX

In operation mode, all the switches 1 are **closed** and switches 2 are **open**.
At the occurrence of an event, the capacitors associated to the hit channels are charged up by the corresponding currents. An **external trigger** signal synchronous to that event, is used to generate a **HOLD** signal in order to open all switches at a time corresponding to the peaking time of the shaping amplifiers. Therefore, the maximum signal charges are stored for those channels being hit. As long as the HOLD signal is maintained "on", the switches are open and the charges are kept frozen in the capacitors. As soon as the HOLD signal is released, the switches are closed and the charges lost.
The decision to read out an event (charges stored in the capacitors) is independent on the T/H operation. For that purpose, a **START READ** is generated connected to the event trigger. That signal starts a train of **CLOCK** pulses. The clock train is also sent to the readout module (CONVERT) where the digitization is performed.
As soon as the clock train is over and the digitization performed, a **RESET** signal is sent to the gassiplex repositioning all the switches at their initial positions.





DAQ Test


V551B
CONV
Data ReaDY
TRIGGER In
CONTROL
BUSY
CLEAR In
CLEAR Out
VCAL
CK
HOLD
REST
C_RAM
Sequencer
V550
CH0
+
-
IN
CONV
DRDY
CH1
+
-
IN
CONV
DRDY
CLEAR
C_RAM
Twisted Pair Cable
GAS 64 - 3
Level Translator (5 → 3 V)