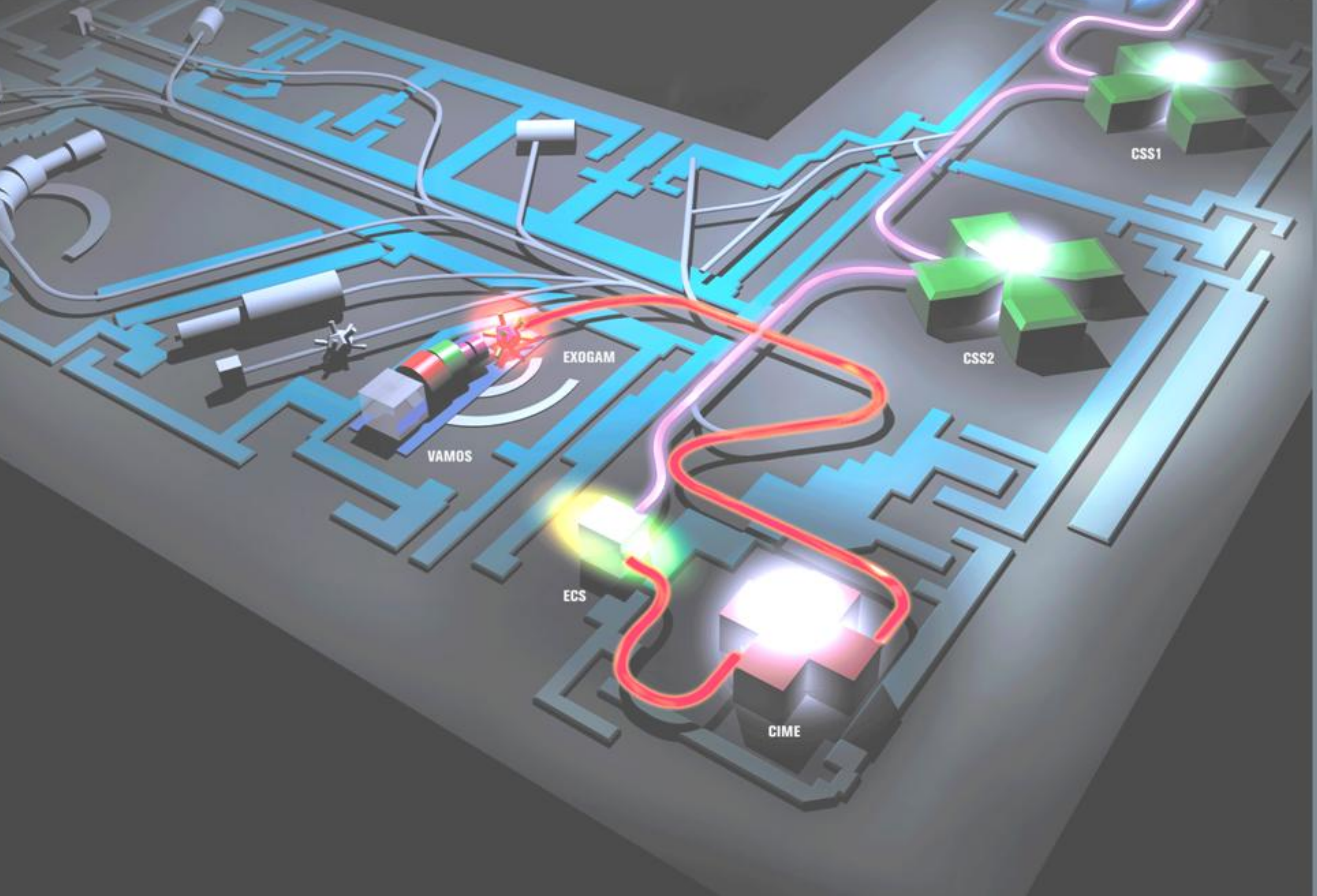
« Analysis at GANIL »
AGATA@VAMOS

Outline

- AGATA @ Ganil - AGATA@VAMOS
  - Gamma ray spectroscopy around the Coulomb barrier
- VAMOS : large acceptance spectrometer
  - VAMOS detection setup
    - Detection what do we measure and how (well)
    - Brief Electronics and DAQ
  - VAMOS Analysis steps
    - Software available, what is to come ?
    - Analysis procedure to get the (A,Z,q)
    - Gamma – Spectra
- « Practical » Session :
  - Try to get back identification from previous data set
  - How to prepare your experiment ?

AGATA @ GANIL
AGATA @ VAMOS

GANIL



AGATA@GANIL

First campaign : AGATA@VAMOS

10 accepted experiments

Spectroscopy, Lifetime measurement, g-factors
of nuclei away from stability

- Fission Fragments (fusion fission, transfer induced)
  - $^{238}U + {}^{9}Be$
- Multi Nucleon Transfer reactions
  - $^{238}U + {}^{64}Ni$, $^{238}U + {}^{48}Ca$, $^{106}Cd+{}^{56}Ni$, $^{18}O+{}^{238}U$, $^{136}Xe+{}^{192}Os$, $^{208}Pb+{}^{100}Mo$

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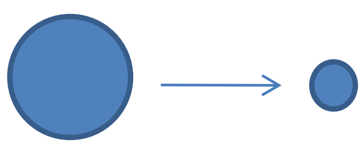
Most experiments in Inverse kinematics
using advantages of the availability of intense (2pnA = 10^{10} pps)
heavy stable beams at GANIL



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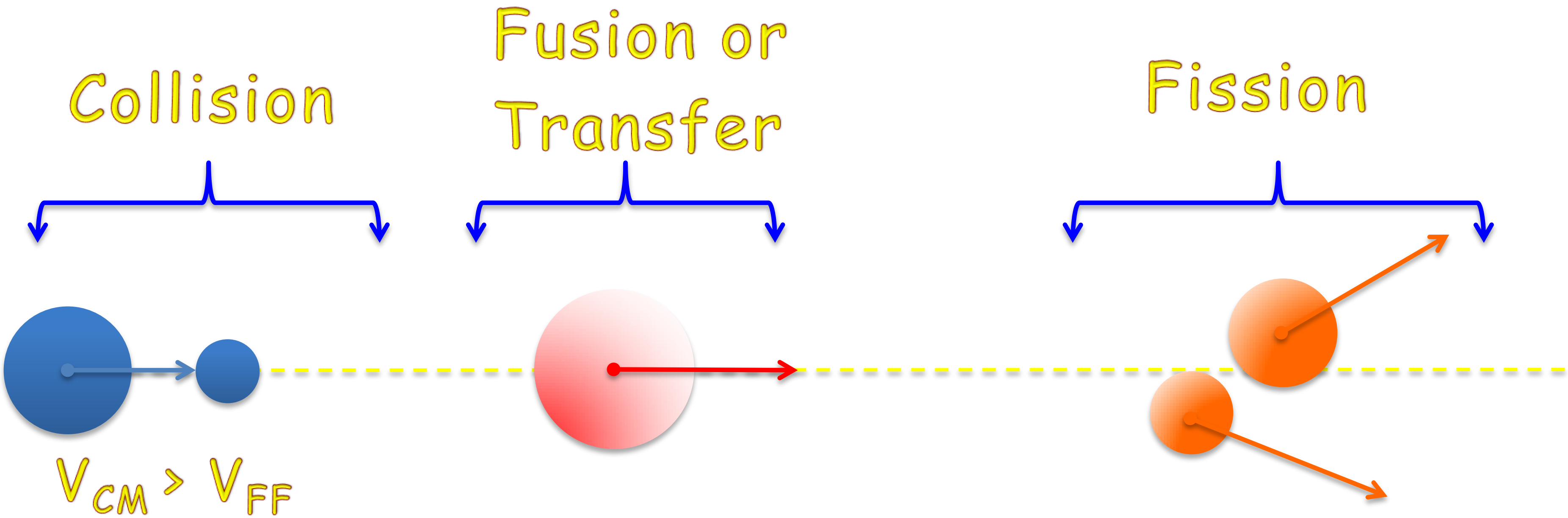
Energies around the Coulomb barrier
(β = 0.1 c)

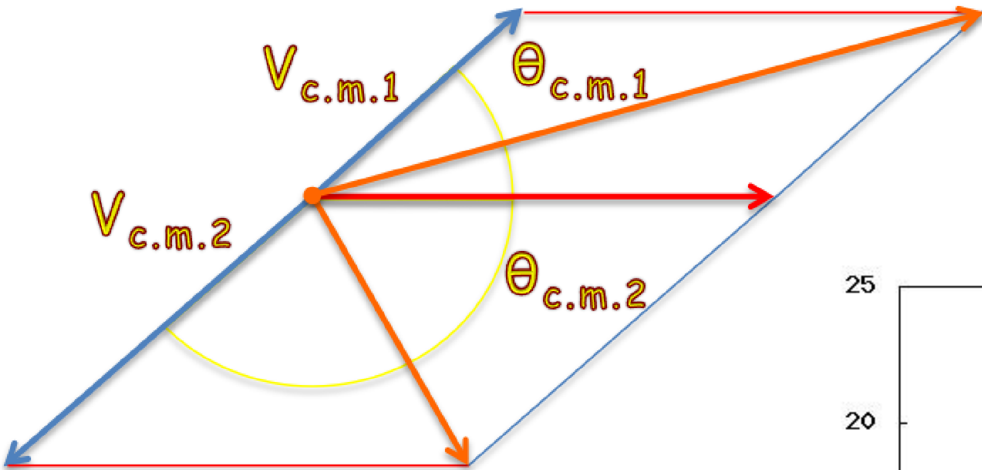
In the Following we will discuss Fission, but most of
discussion is relevant to Multi-nucleon Transfer

Basic steps

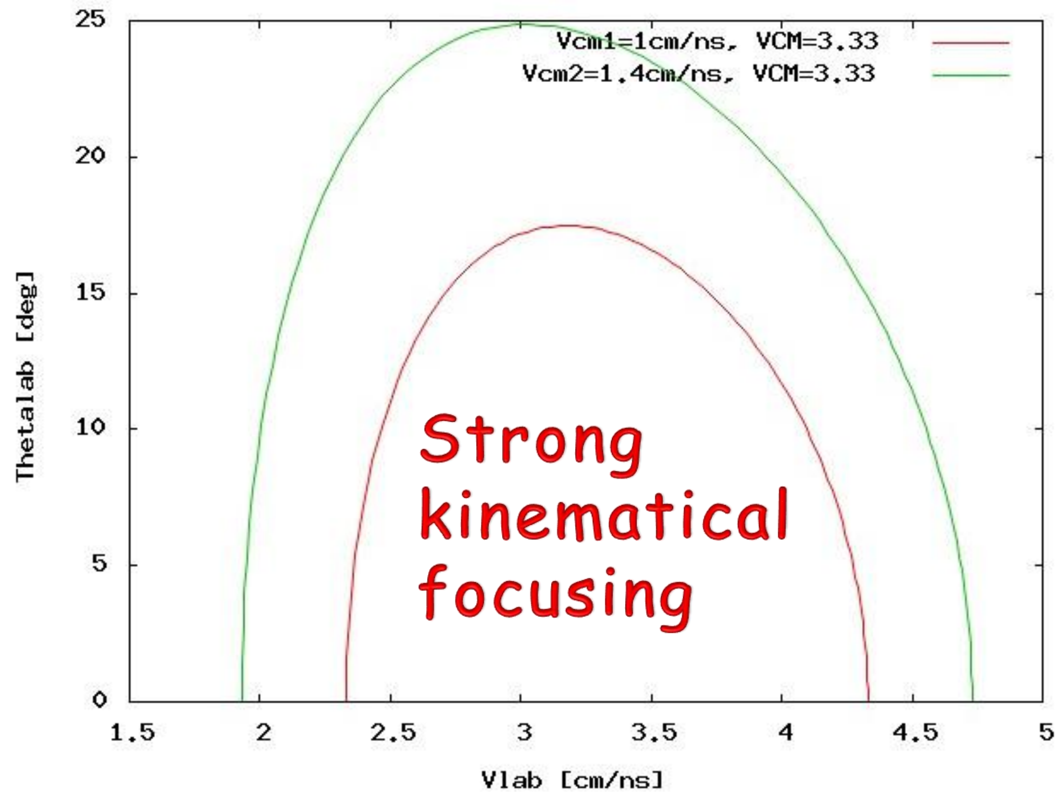


Kinematical situation

v ~ 3 cm/ns
$\beta \sim 0.1$



$V_{CM} > V_{FF}$

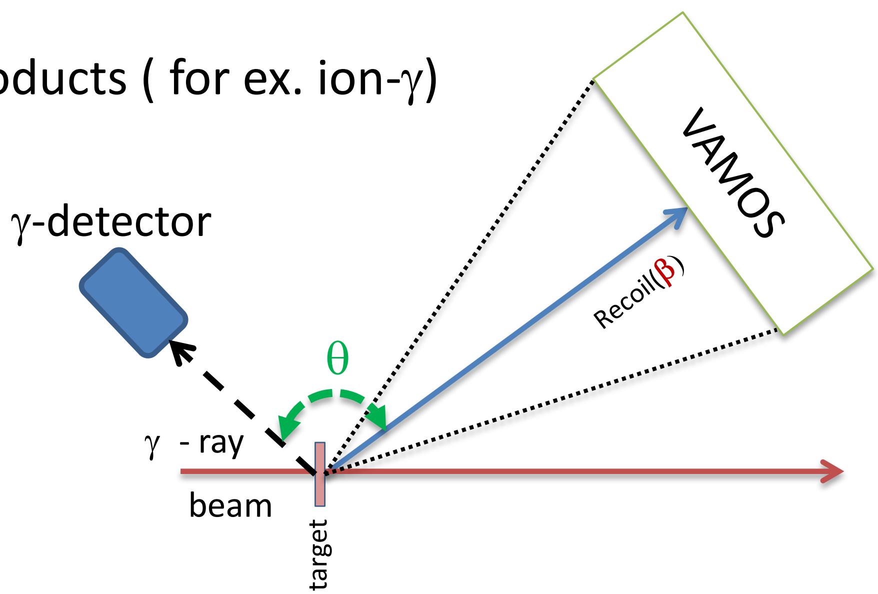


Coupling a magnetic spectrometer to γ-ray spectrometer

- **Ejectile Identification (A,Z)**
  - Charge Number Z
    Energy Loss $\Delta E \sim A Z^2 / E$
  - Mass A :
    $A / q \sim B\rho / v$
    $E \sim A \beta^2$

- **Selectivitity** :
  Trigger condition on reaction products (for ex. ion-γ)

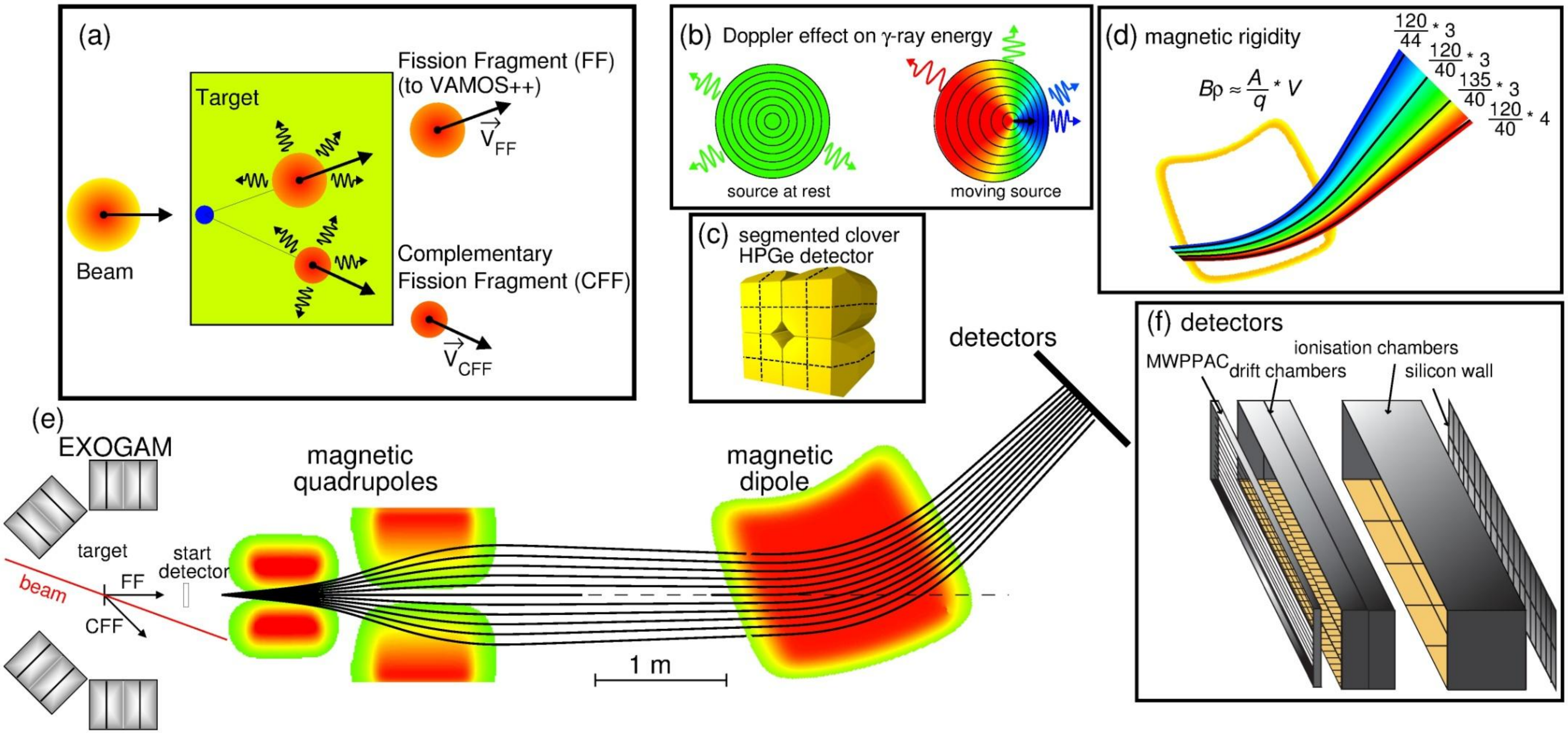
- **Doppler Correction** :
  Ejectile Velocity (vector)
  $E_\gamma = E'_\gamma / (\gamma(1- \beta \cos(\theta)))$



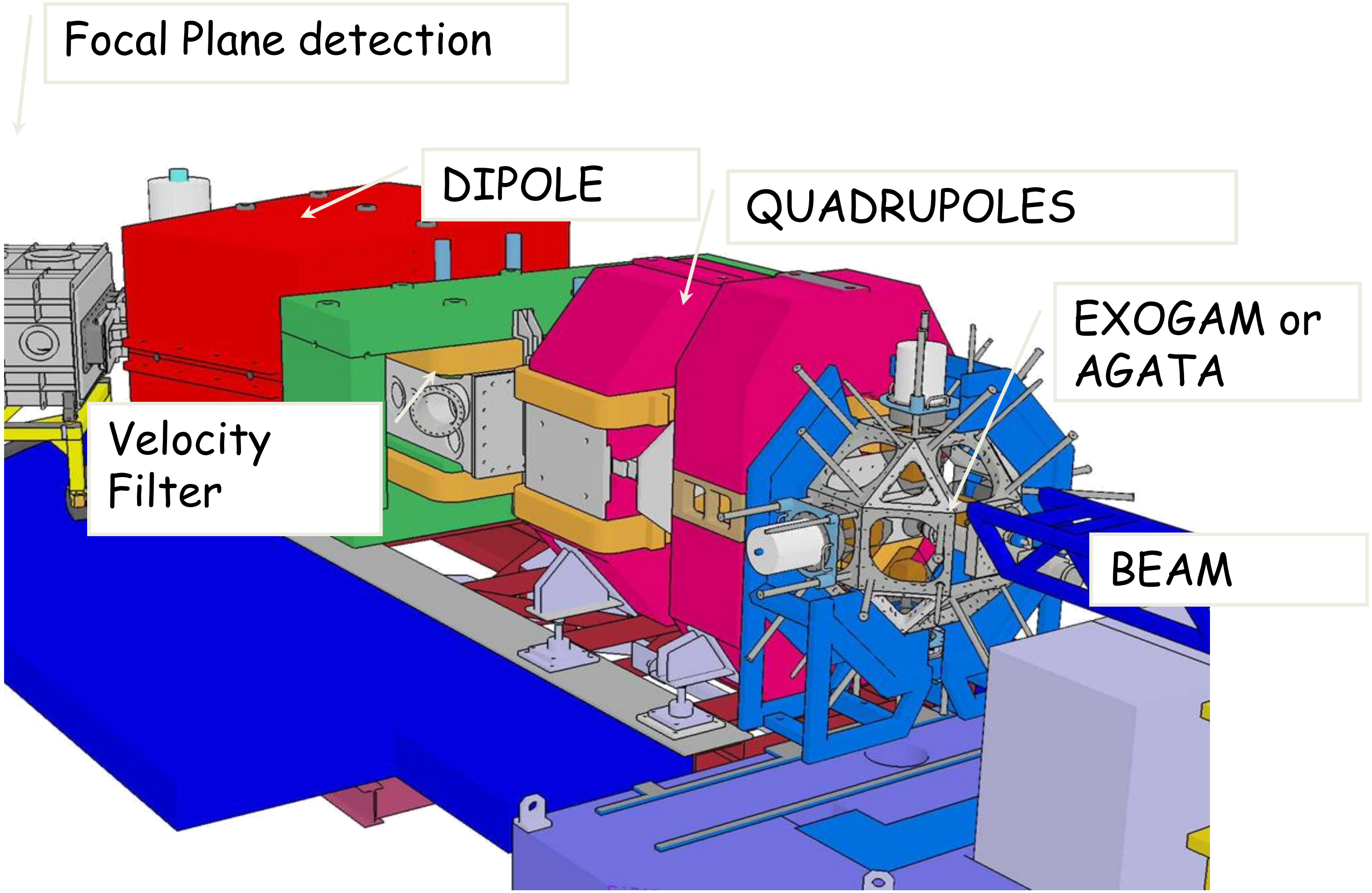
Typical experiment with VAMOS

Overview Exemple with Fission

^{238}U (6,2 MeV/u) + ^{9}Be



VAMOS


Focal Plane detection
DIPOLE
QUADRUPOLES
EXOGAM or AGATA
Velocity Filter
BEAM

VAMOS Spectrometer

Vacuum – Dispersive mode

Horizontal acceptance : +/- 7 deg.

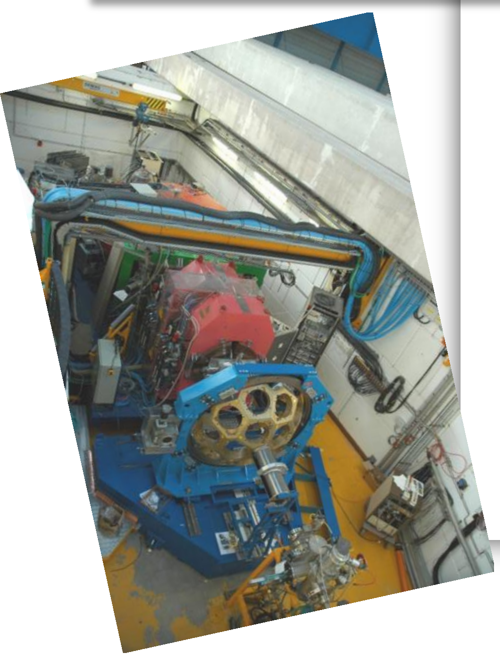
Vertical acceptance : +/- 10 deg.

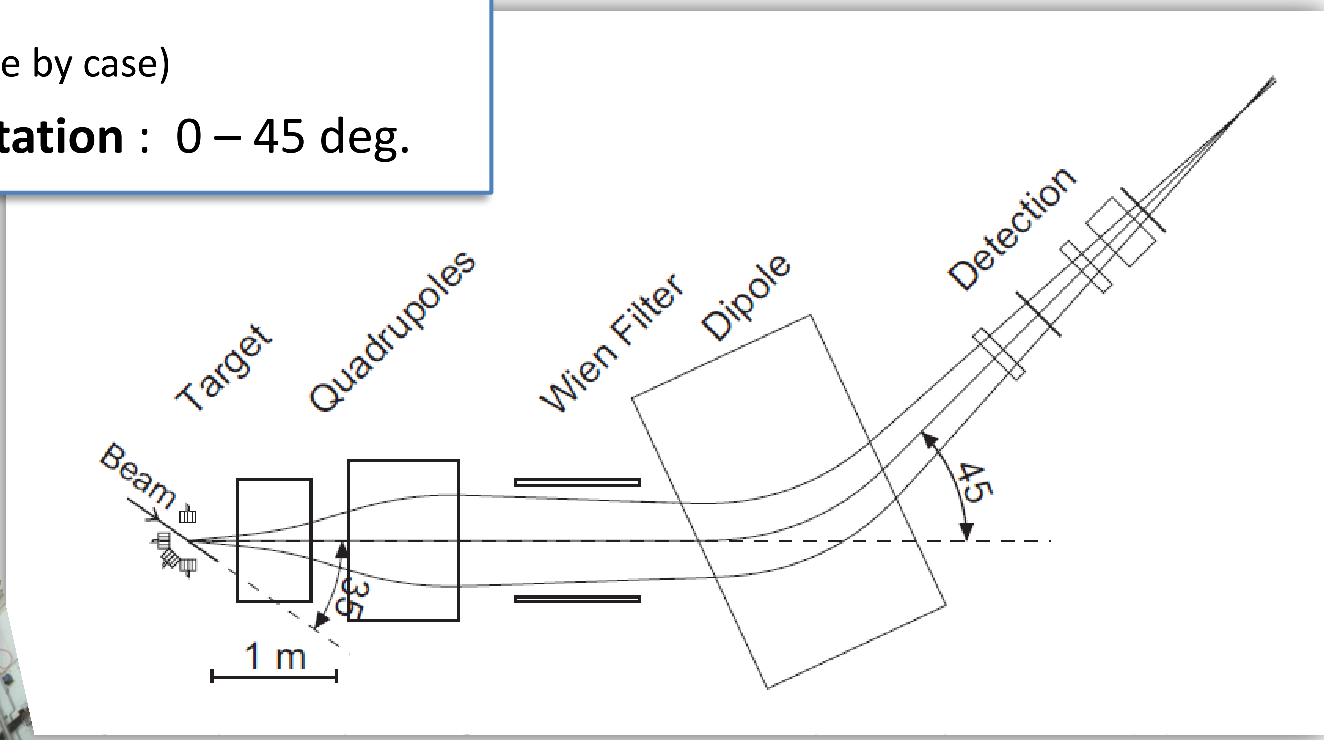
Max Bρ : 1.6 Tm

ΔM/M ≈ 1/220

ΔZ/Z ≈ 1/66 (case by case)

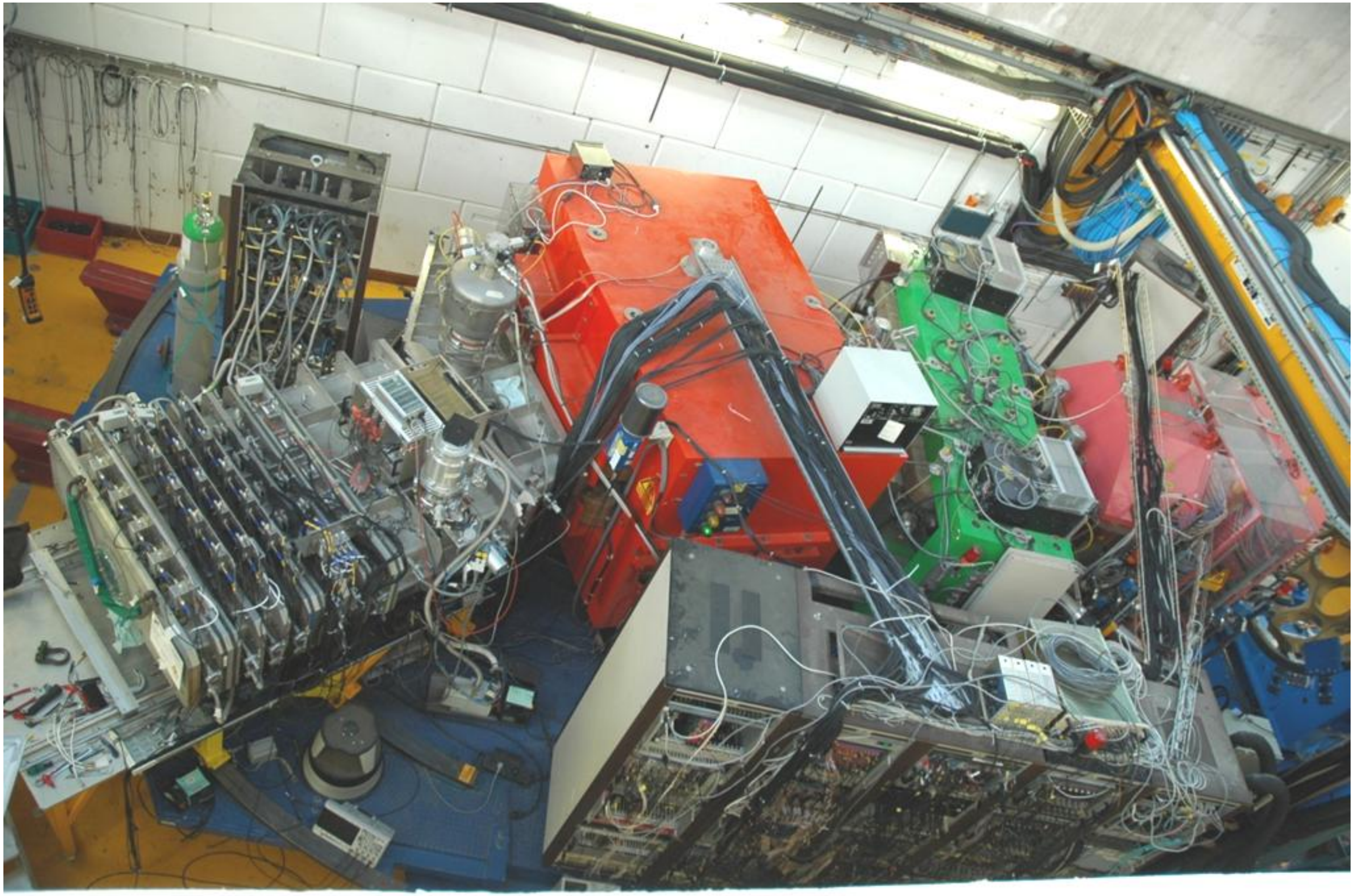
/!\ Angular Rotation : 0 – 45 deg.





S. Pullanhiotan et al. , NIM A 593 (2008) 343
M. Rejmund *et al.,* NIM A 646 (2011) 184

VAMOS



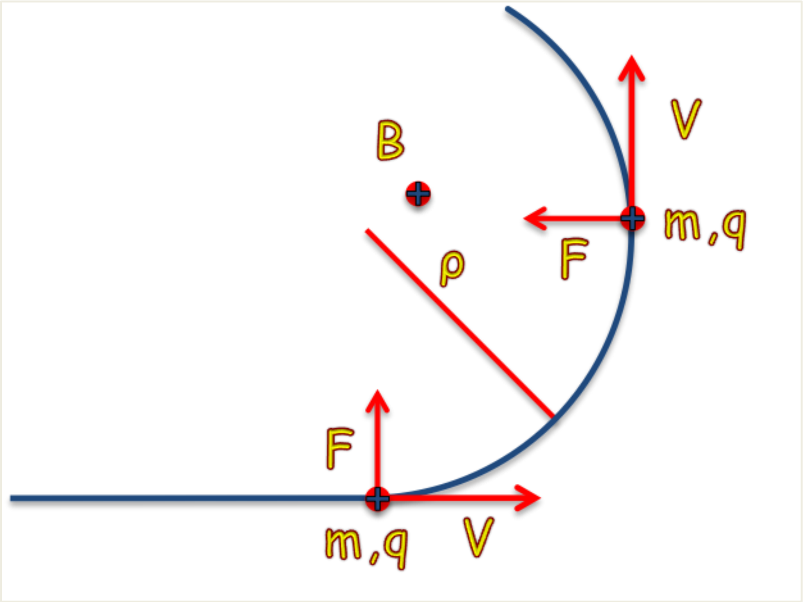
Magnetic spectrometer separator

B - magnetic field
m - mass
q - charge
V - velocity
ρ - curvature radius

$$\vec{F} = q\,\vec{V} \times \vec{B}$$

$$F = q\,V\,B = m\,\frac{V^2}{\rho}$$

$$B\rho = \frac{mV}{q}$$



Bρ is called magnetic rigidity, units [T m]

Dipole magnet introduces the dispersion according to magnetic rigidity Bρ

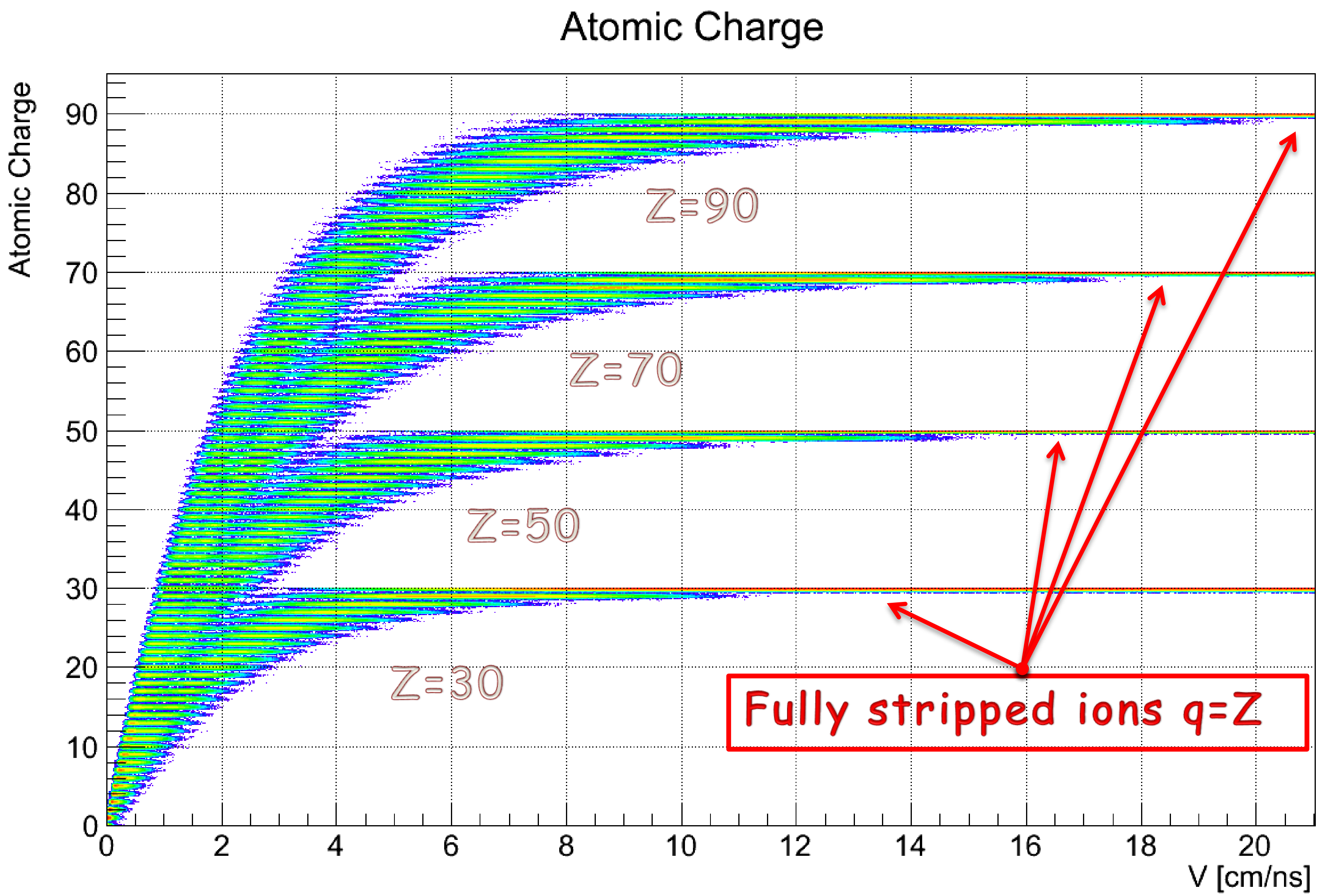
$$B\rho[Tm] = 3.105\frac{A}{q}\beta\gamma$$

$$\beta = V / c$$

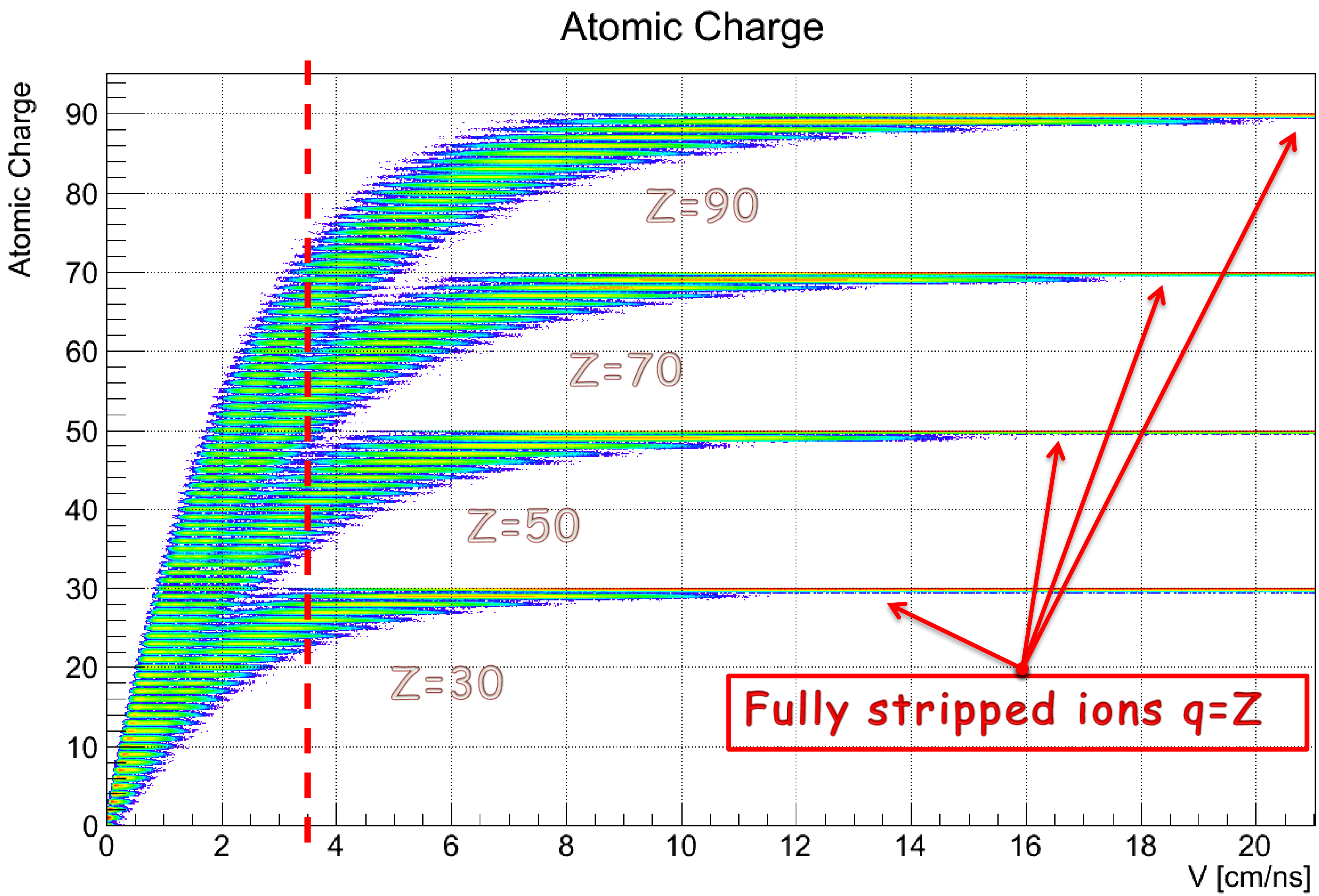
$$c = 29.9792458\ [cm / ns]$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

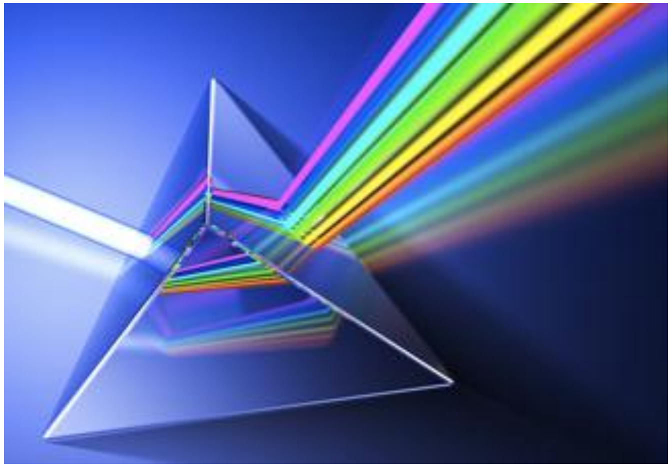
Ions and Atomic Charge



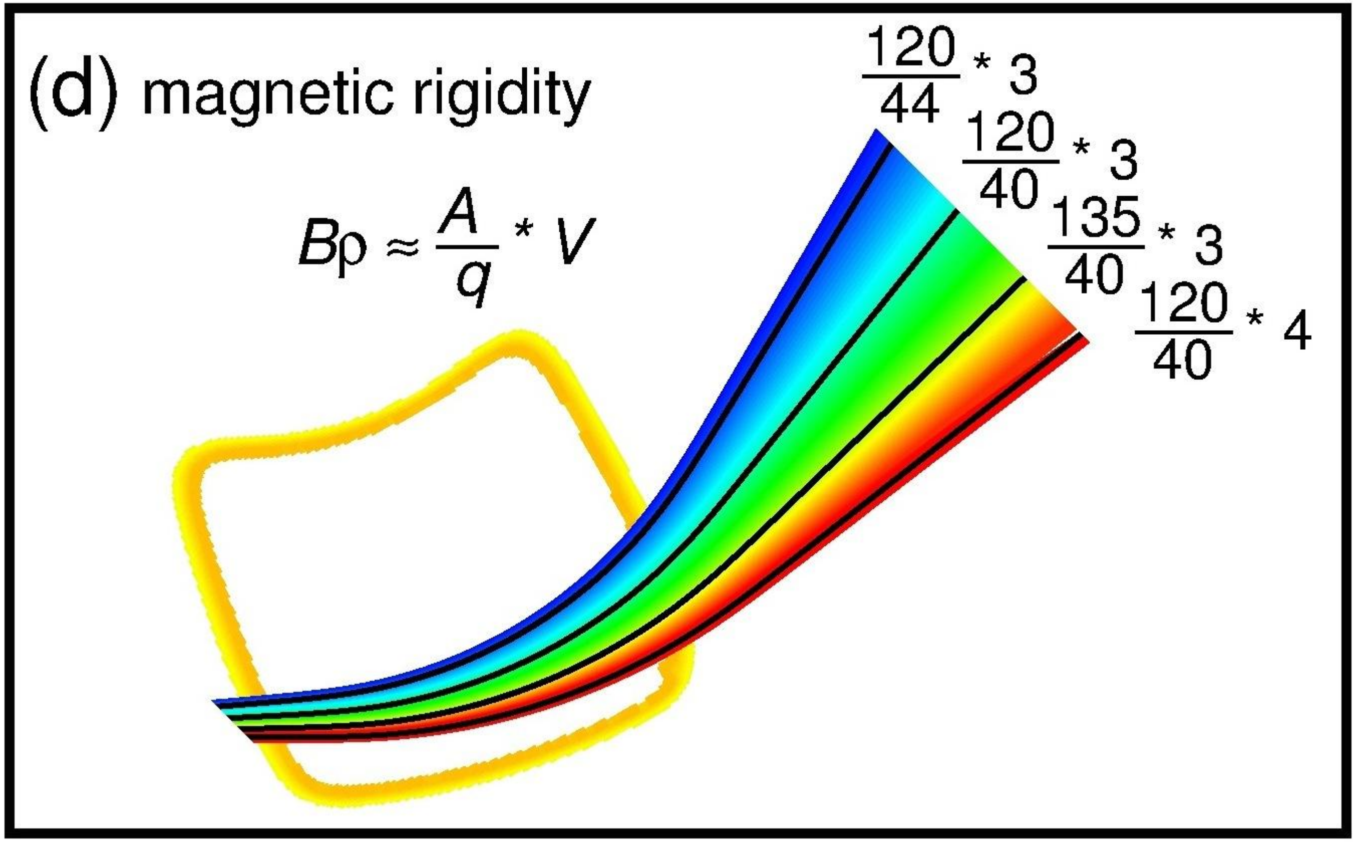
Ions and Atomic Charge



Dipole

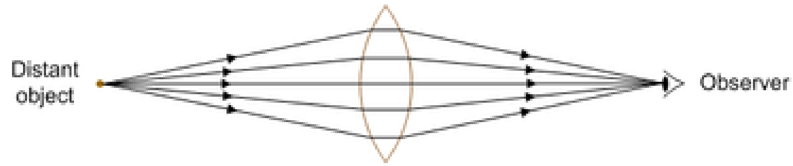


Dispersion - selectivity

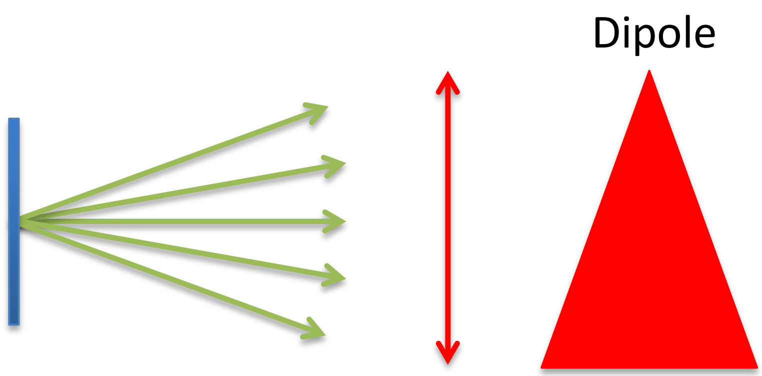


Quadrupole

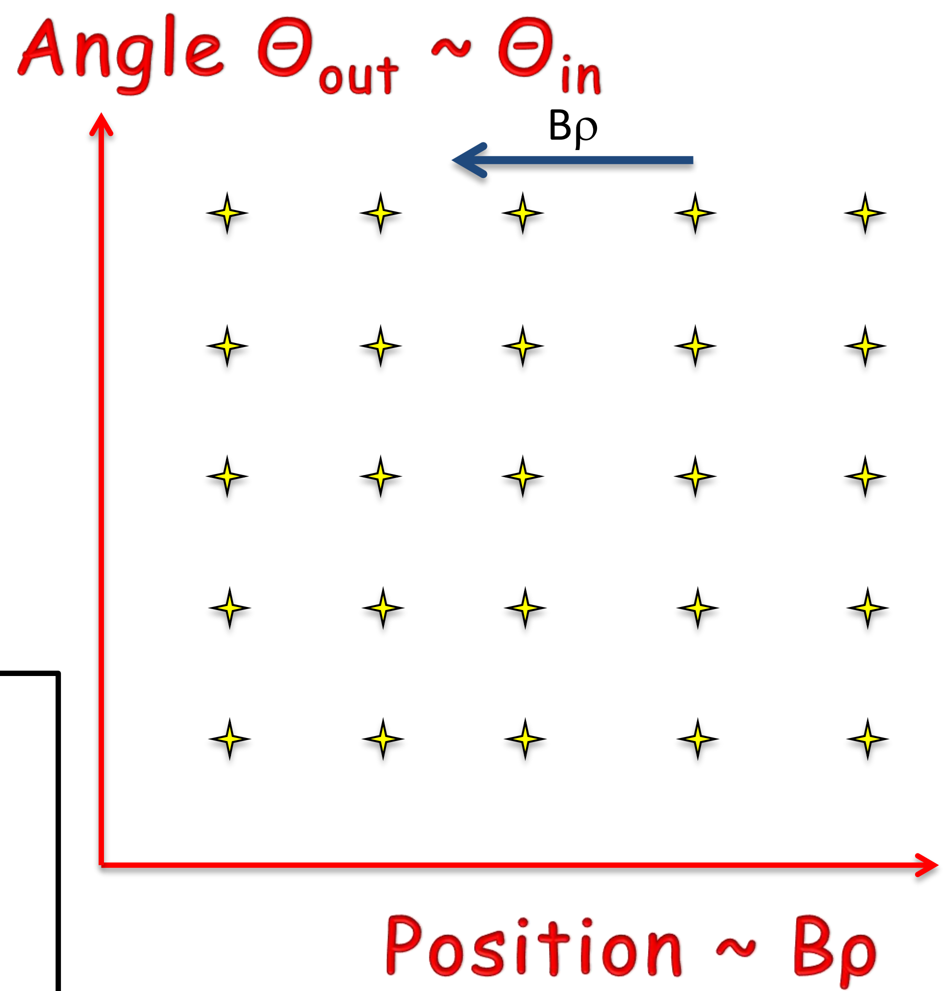
Focusing - acceptance



Ideal optics and VAMOS



Source (target) of ions with different angles (Θ_{in}) and magnetic rigidities ($B\rho$)



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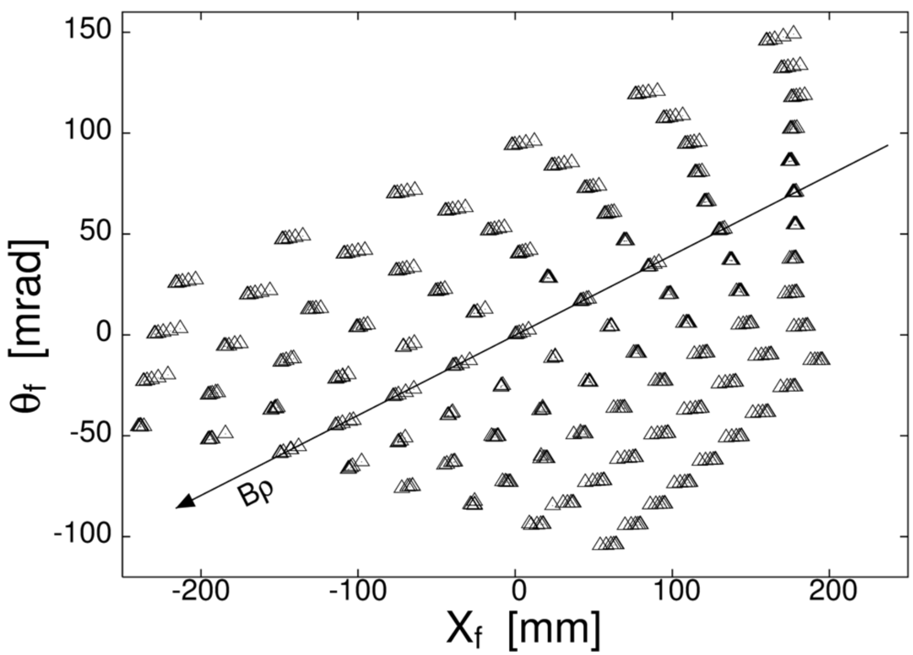
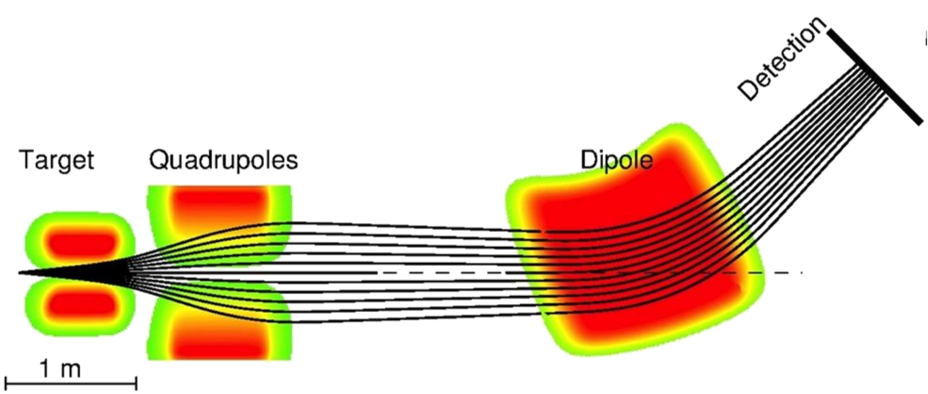
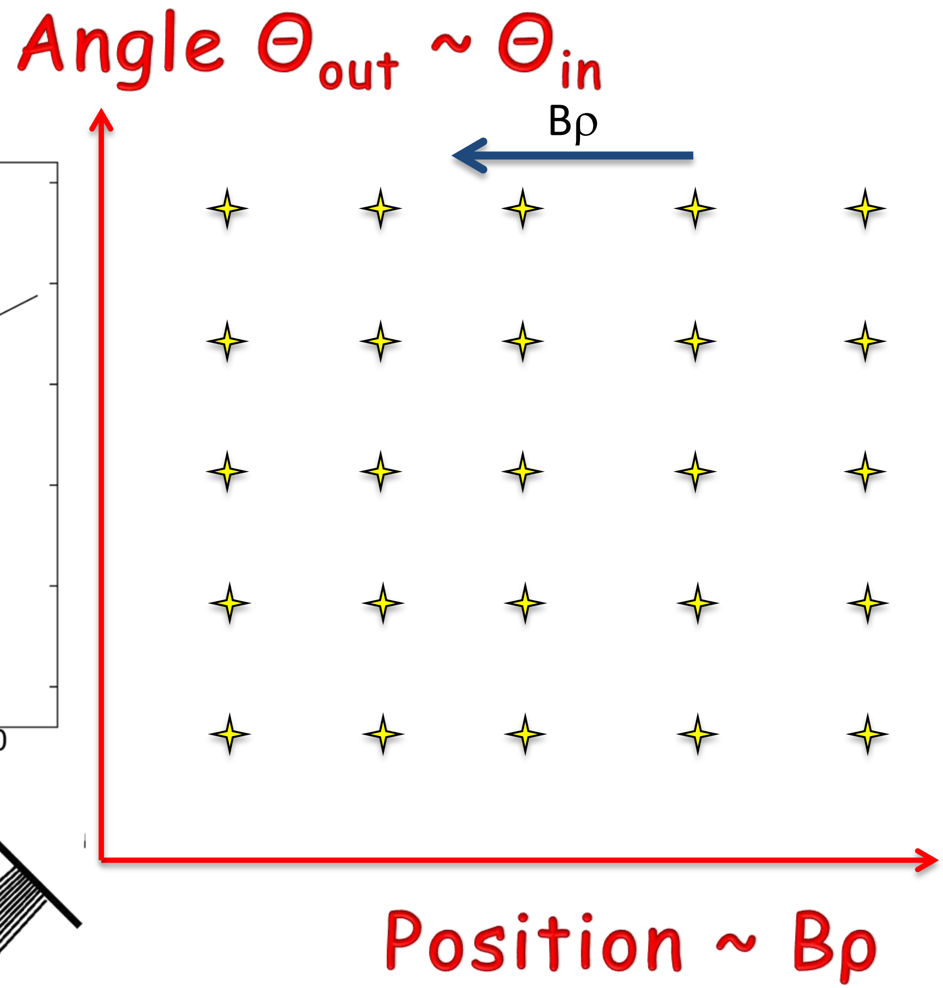
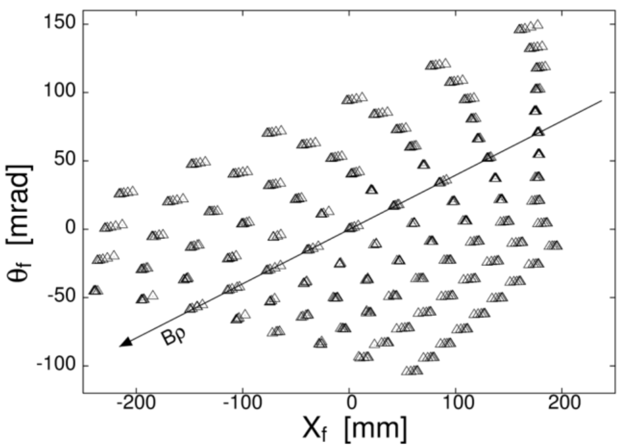






VAMOS Measurement
(Software Spectrometer)

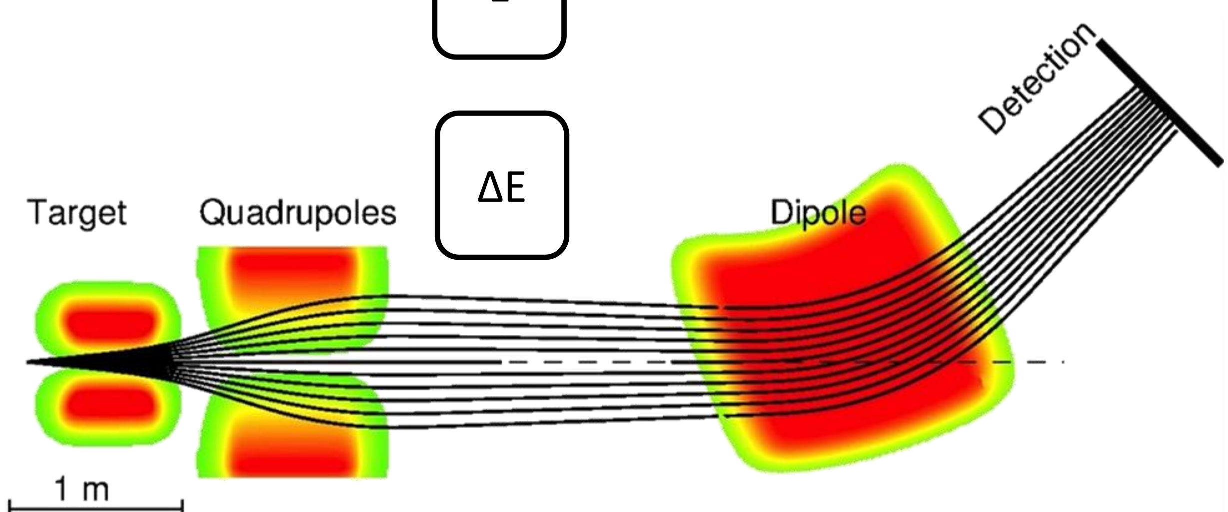
X_f Y_f θ_f ϕ_f



TOF

E

ΔE



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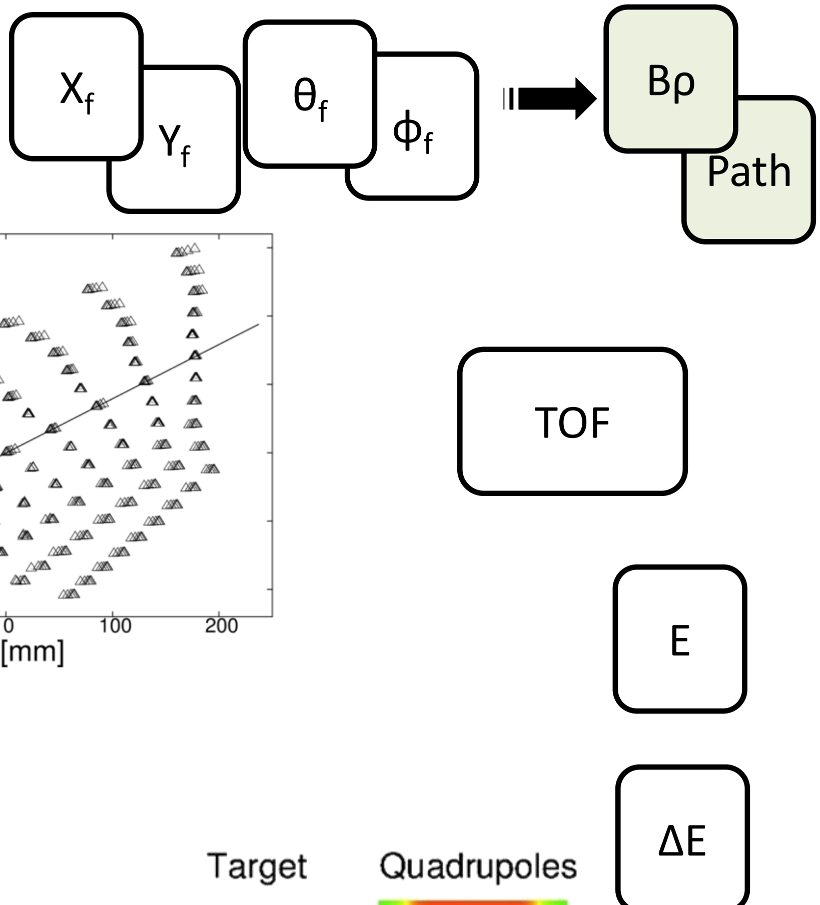

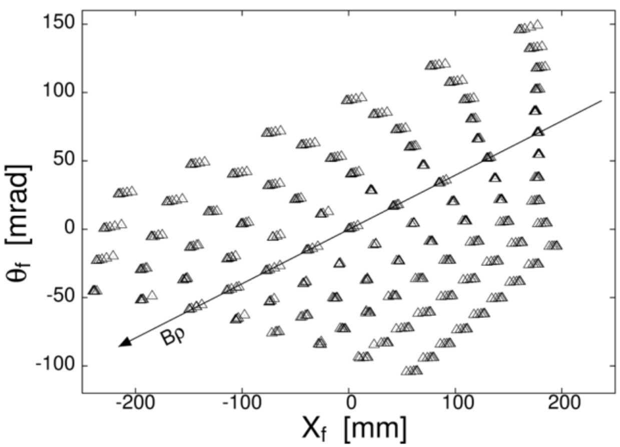

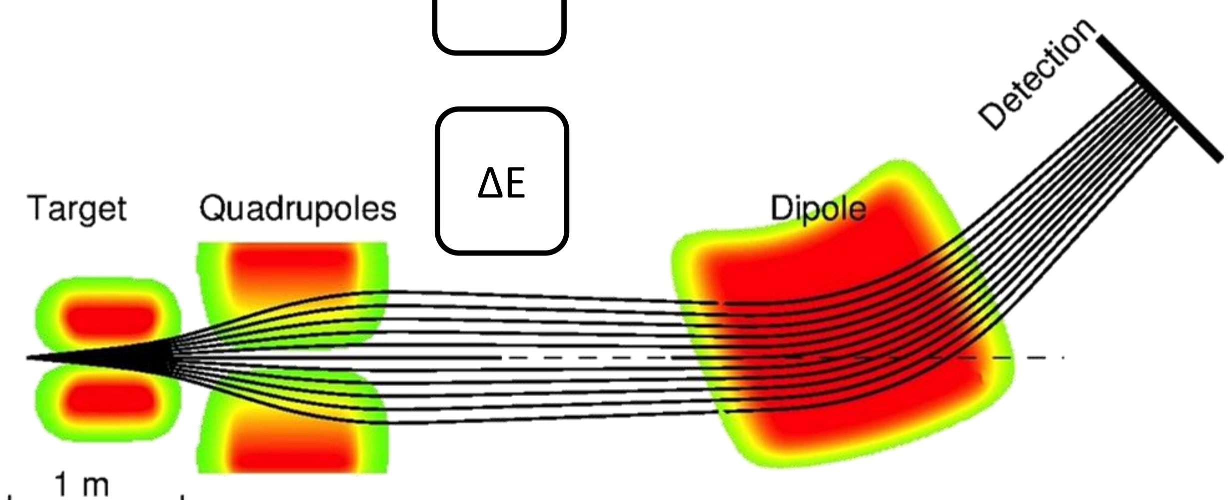

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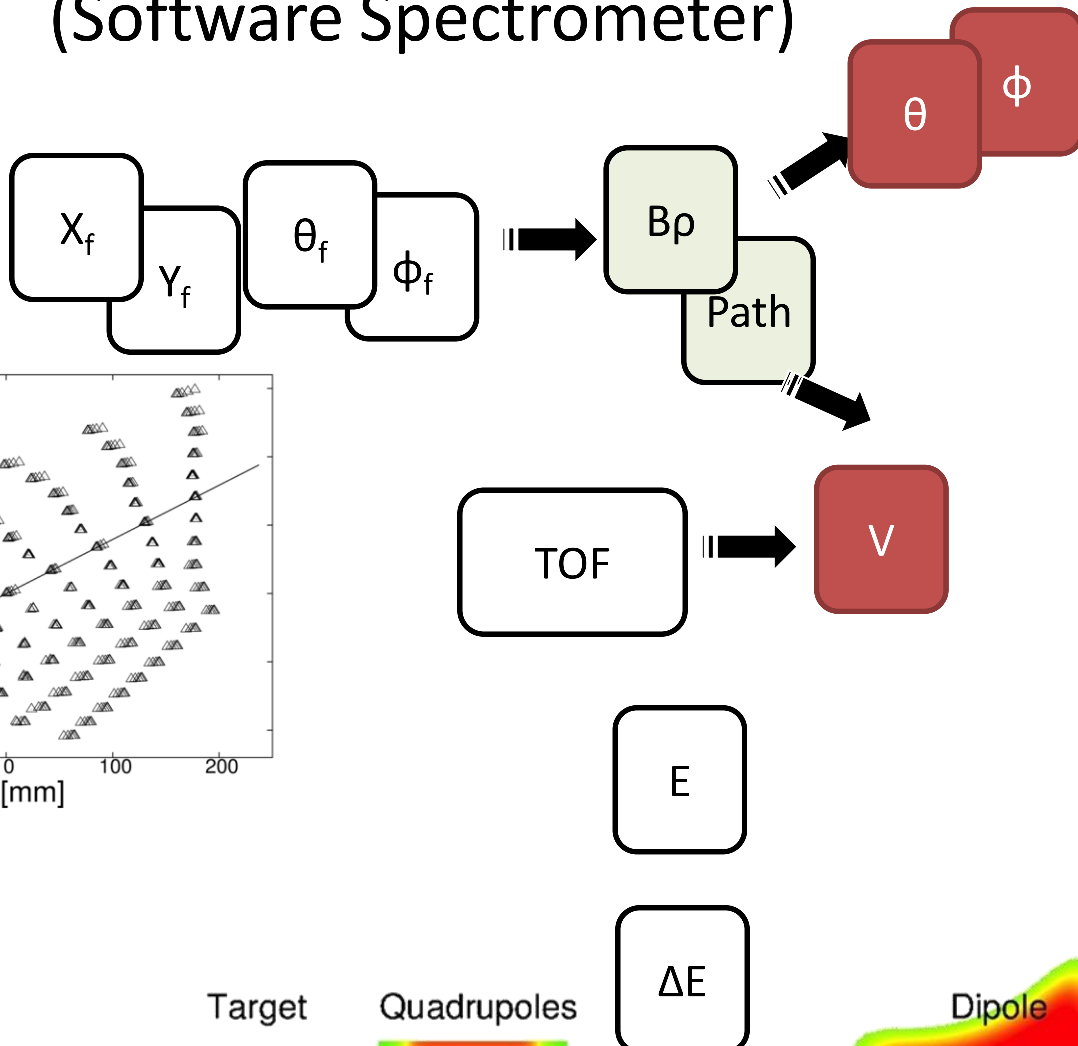

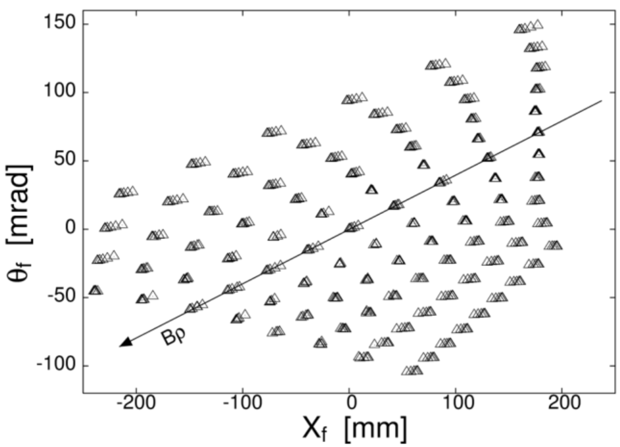

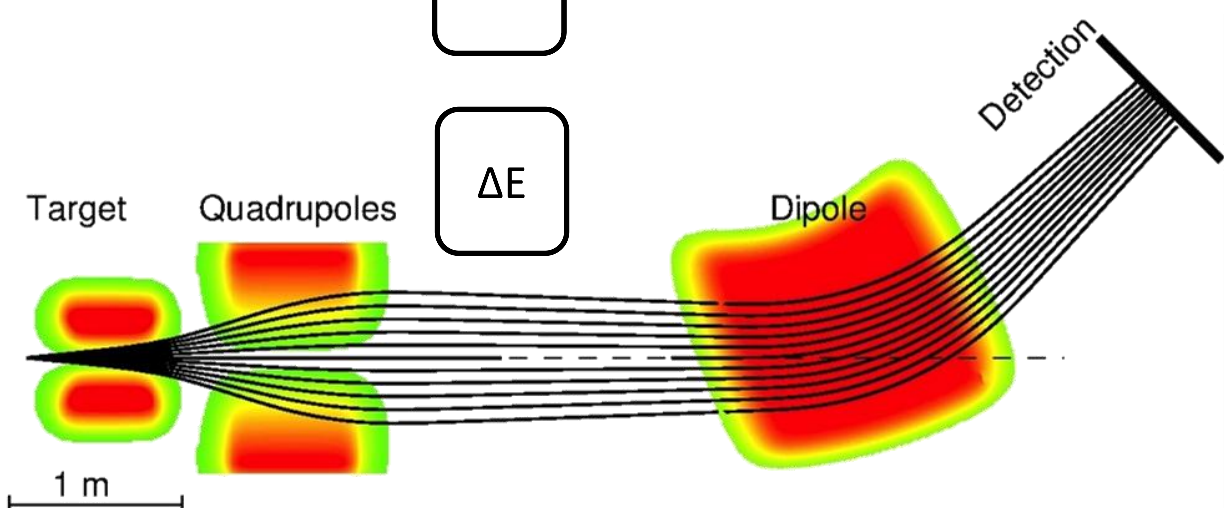

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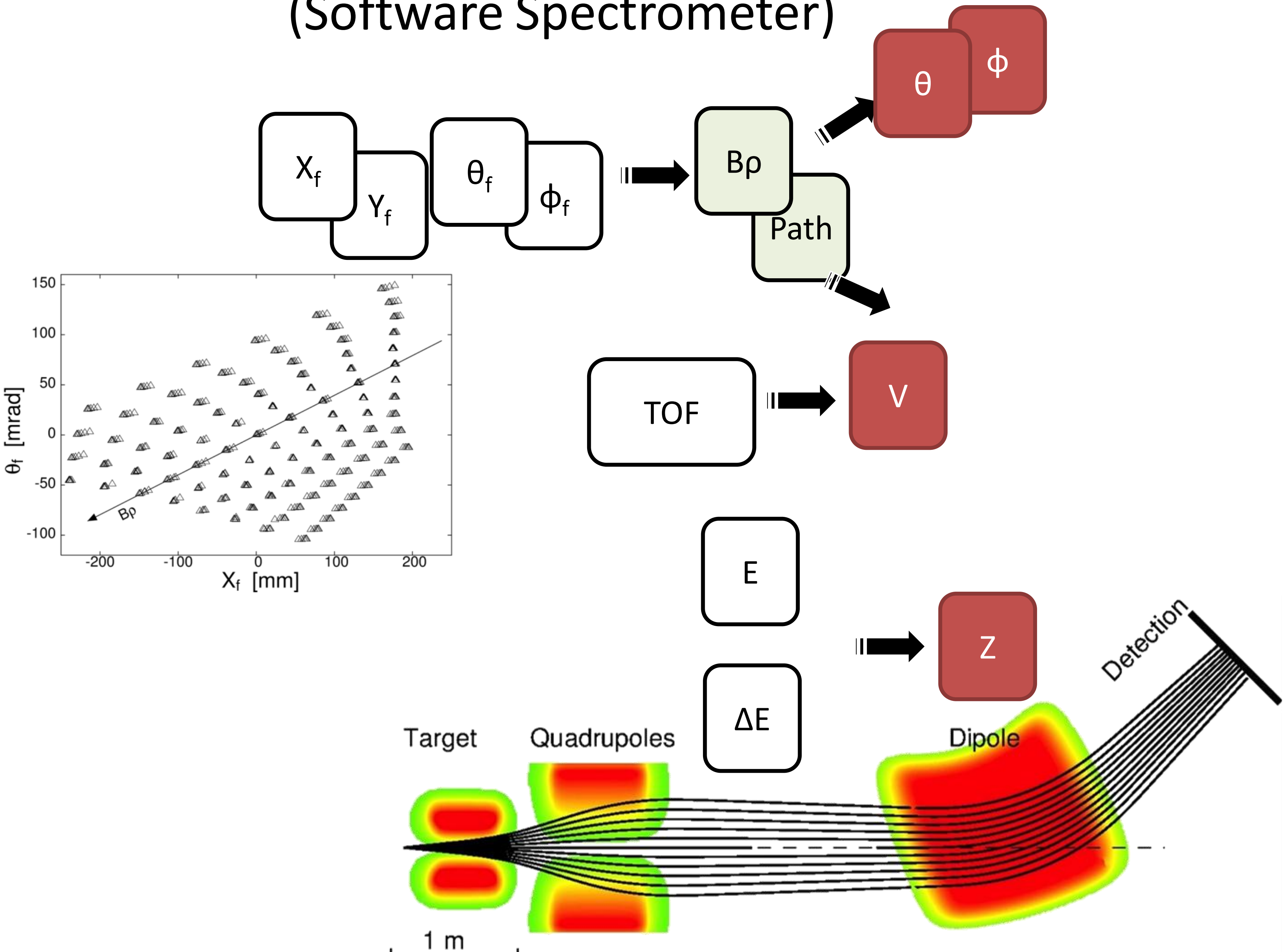

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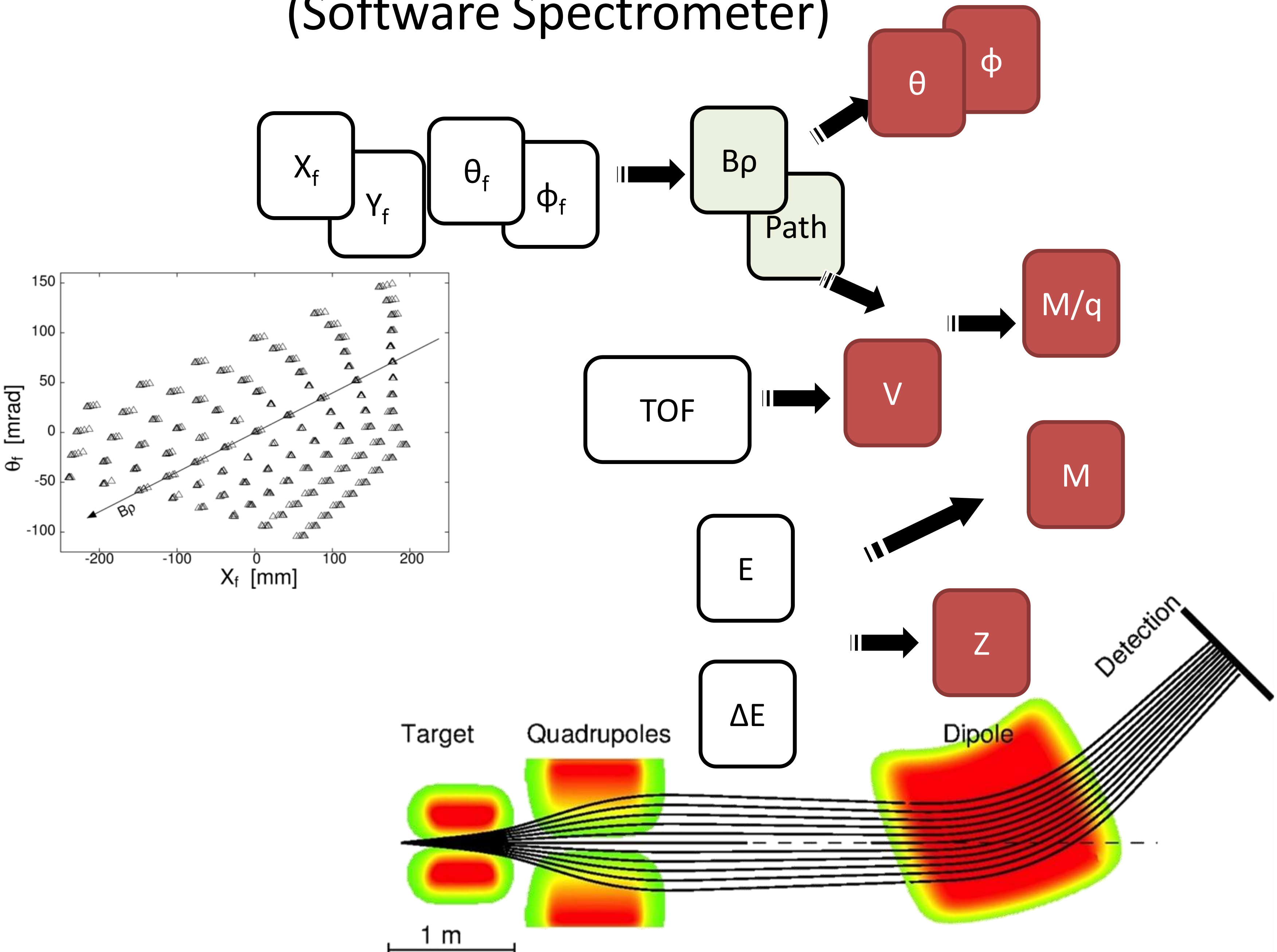

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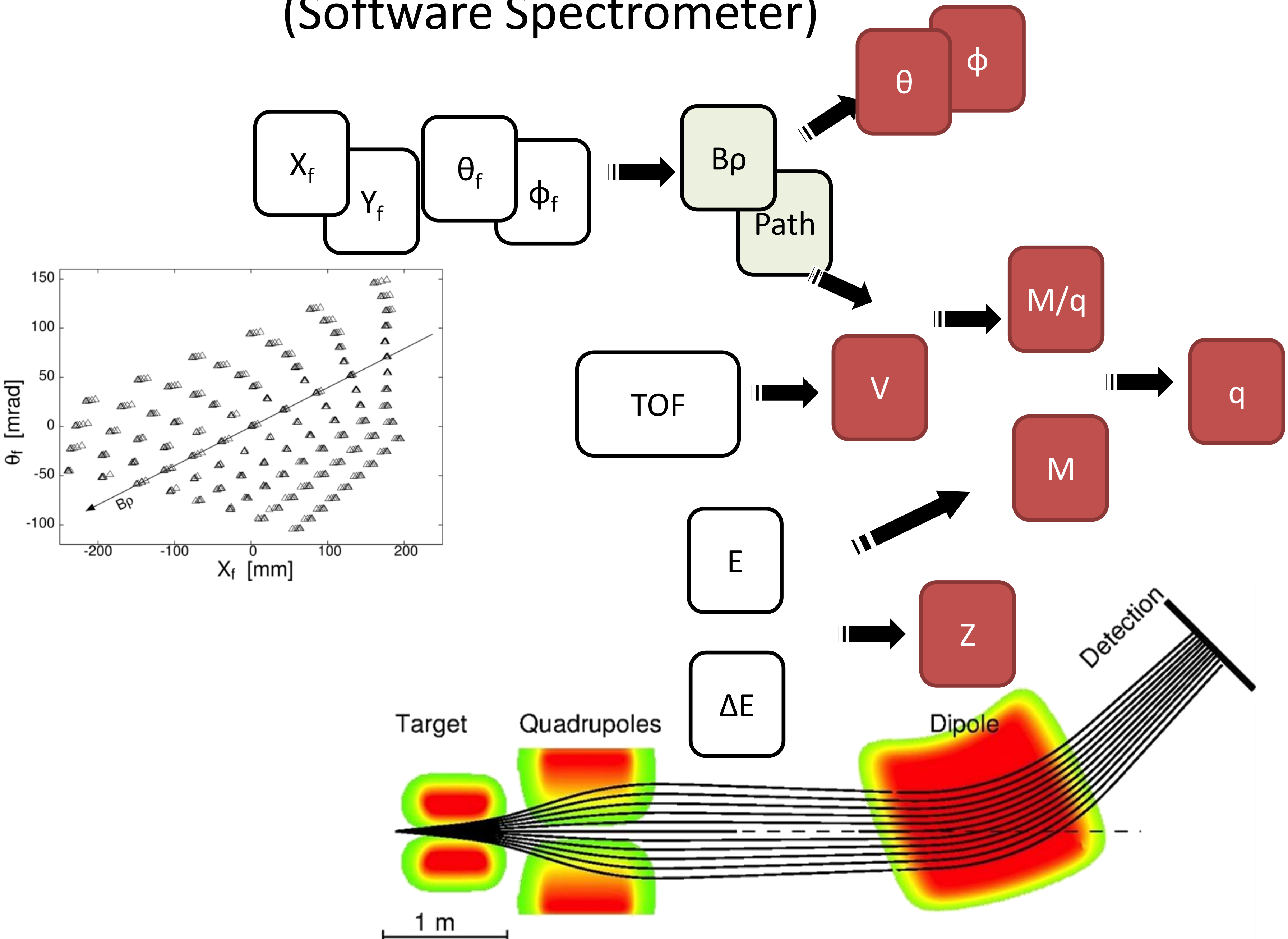
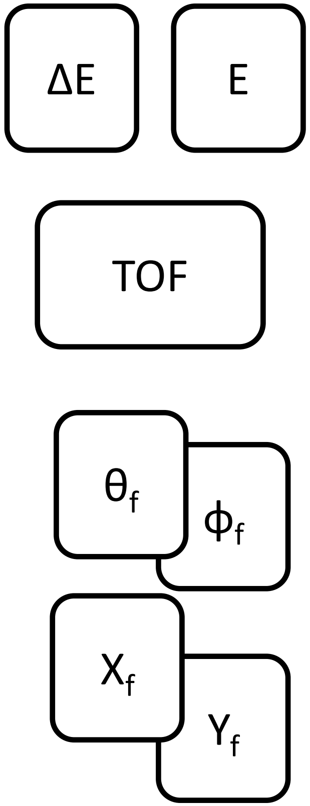


What do we need to measure ?
and how precisely ?



$$\Delta E \sim M\mathbf{Z}^2/E$$

$$M/q = B\rho/(3.105\times\beta\gamma)$$

$$M = 2\,E\,/\,(931.5\times\beta^2)$$

What do we need to measure ?
and how precisely ?

ΔE E

TOF

θ_f ϕ_f

X_f Y_f

$$\Delta E \sim M Z^2 / E$$

$$M/q = B\rho / (3.105 \times \beta\gamma)$$

$$M = 2\,E / (931.5 \times \beta^2)$$

M/q v

$\Rightarrow$Resolution 1/220 = 4 x 10^{-3}

$\Rightarrow$ **Time** resolution

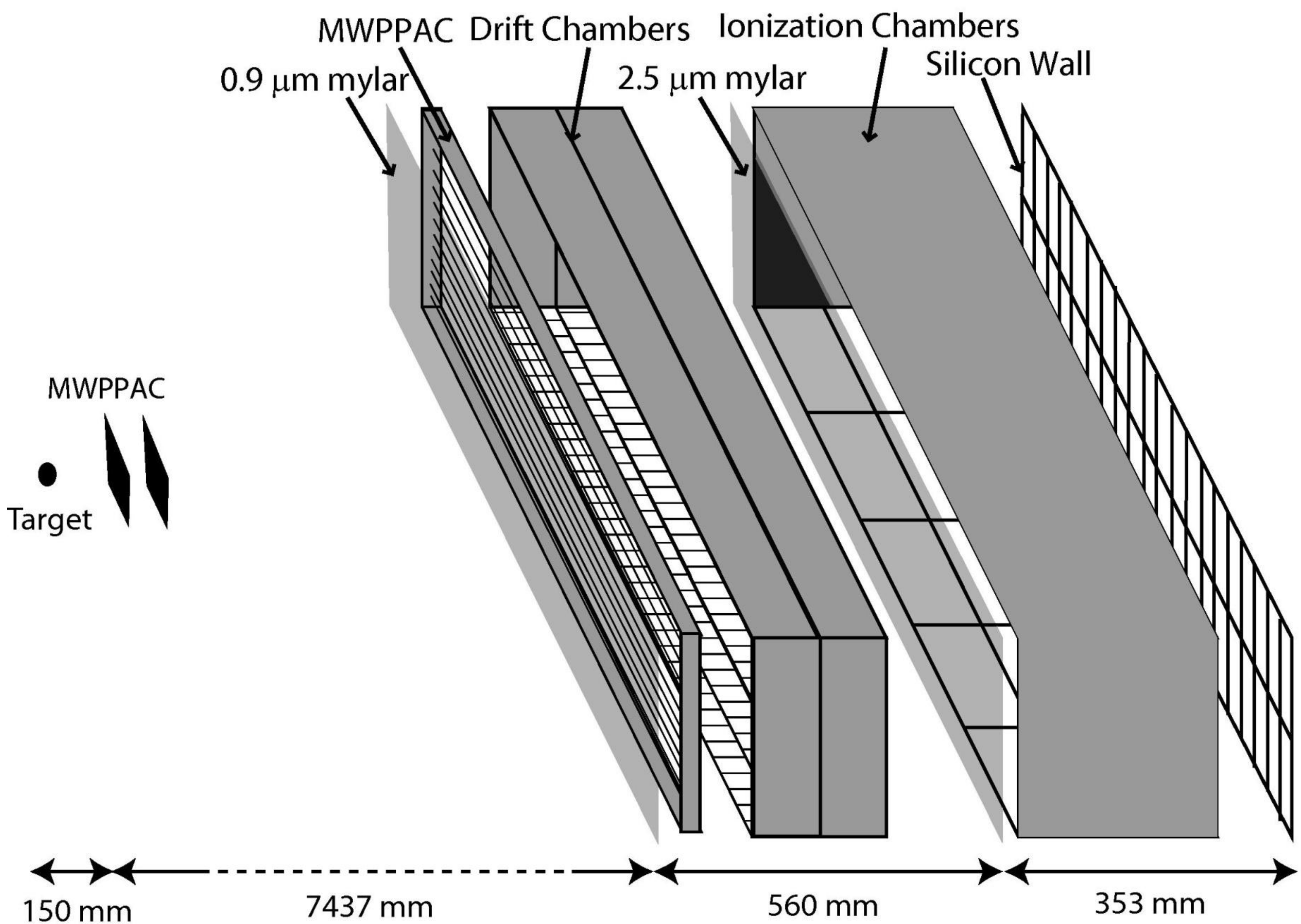
Z q

$\Rightarrow$Resolution 1/66 = 1.5 x 10^{-2}

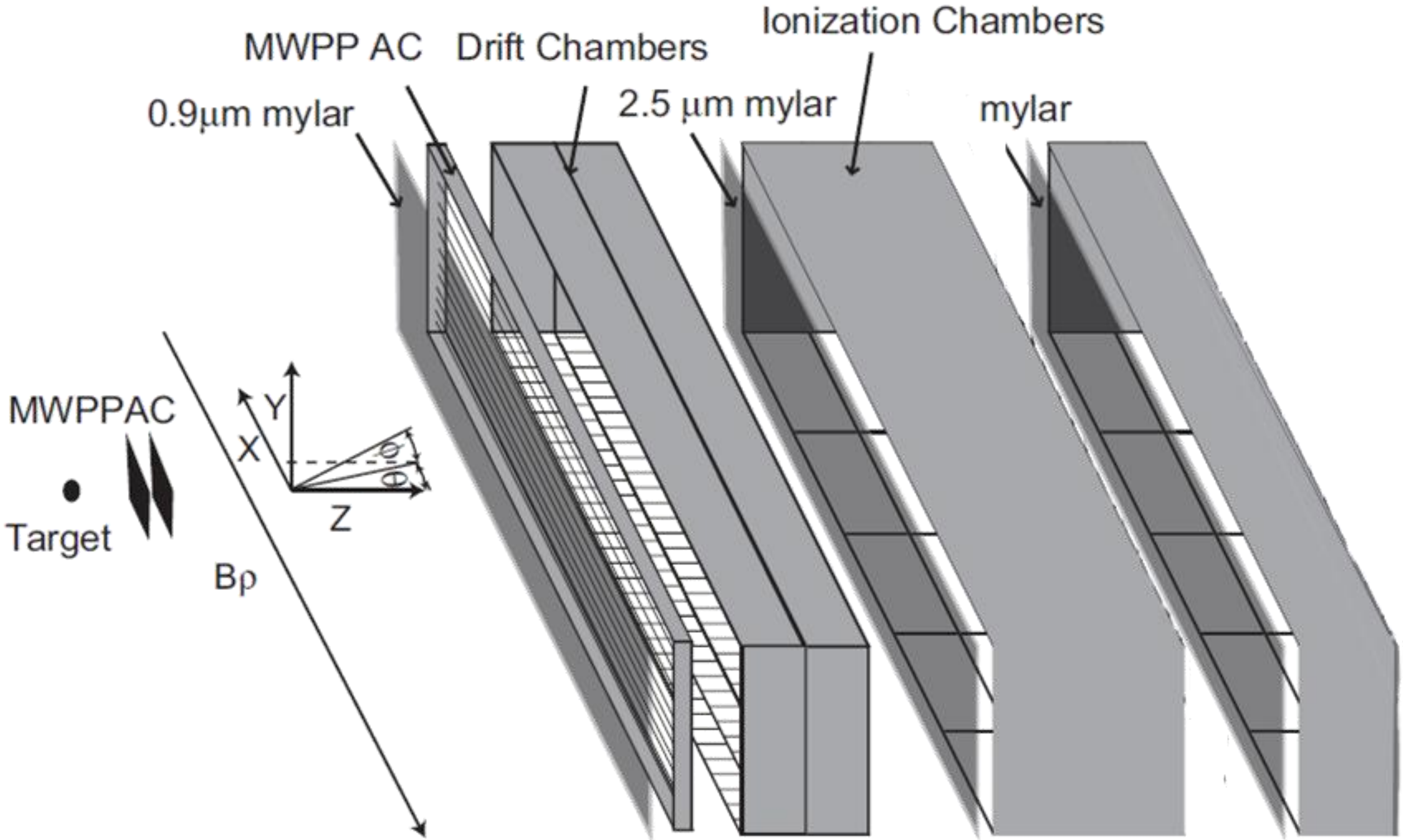
$\Rightarrow$ **Energy** Resolution

VAMOS DETECTION SETUP

VAMOS Detection Setup

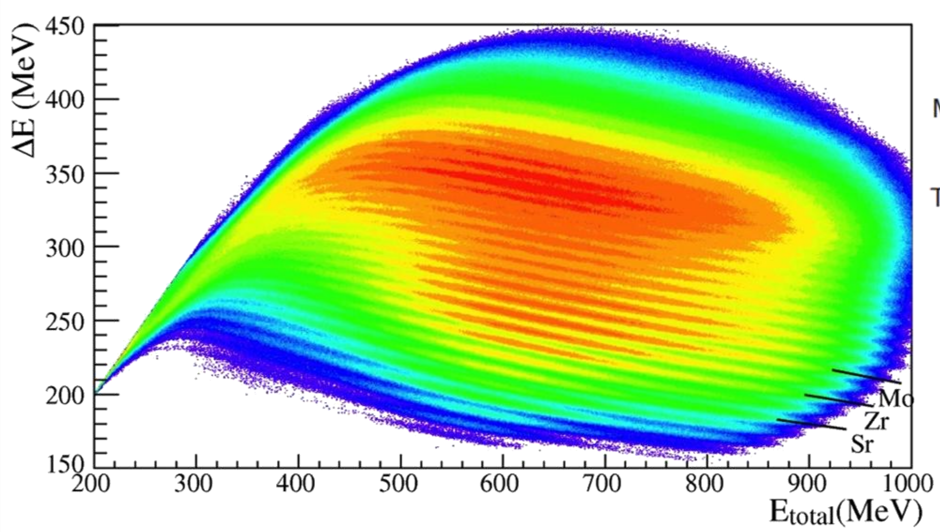


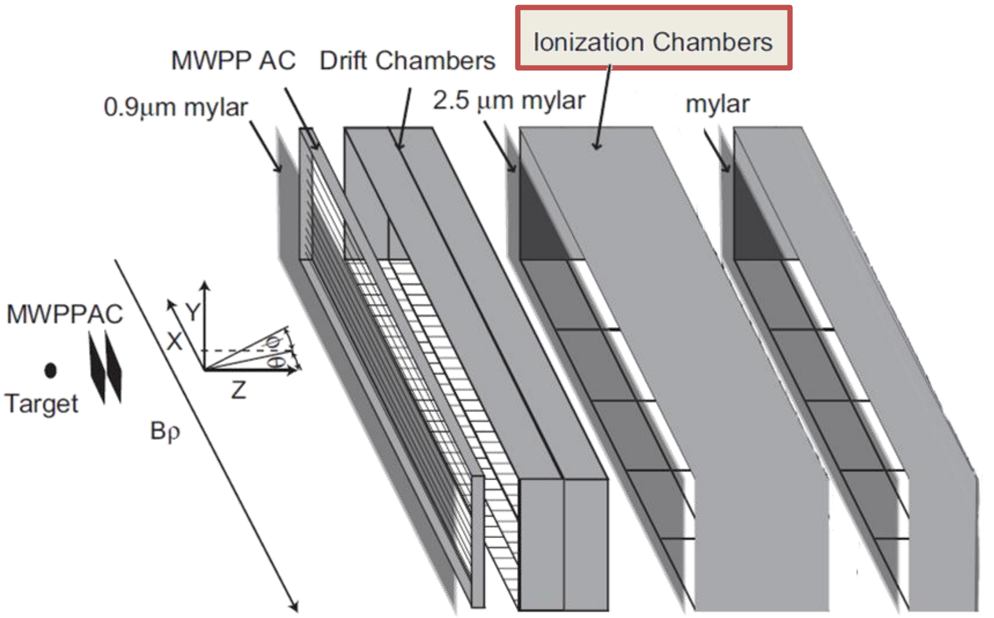
VAMOS Detectors (Upgrade)



Z identification

ΔE – E technique





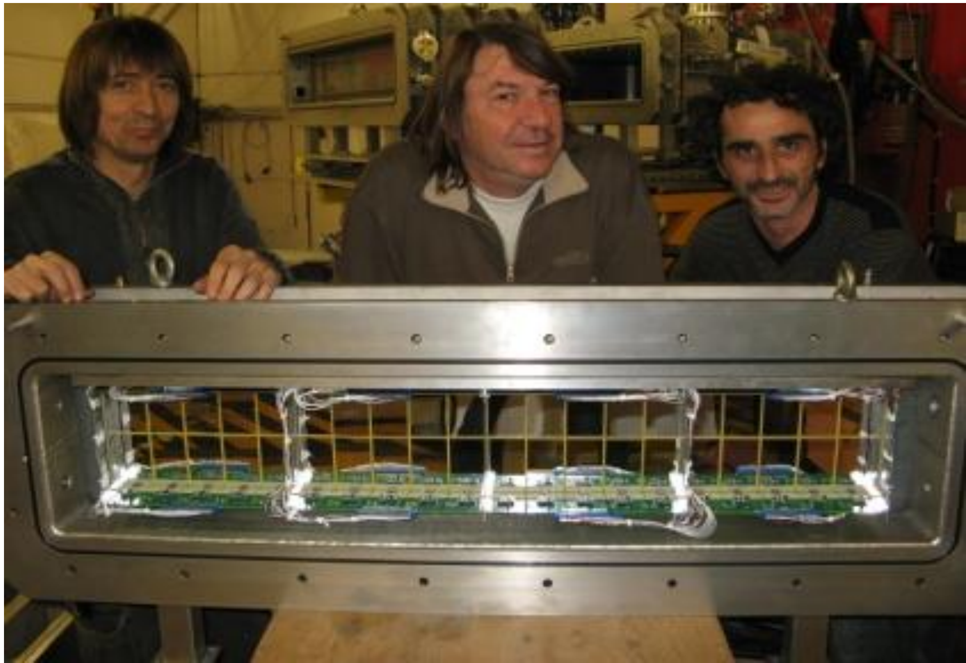
ΔE

Energy Loss : ΔE
Ionization Chambers
3 rows * 5 pads
CF4 (20-60 mbar)

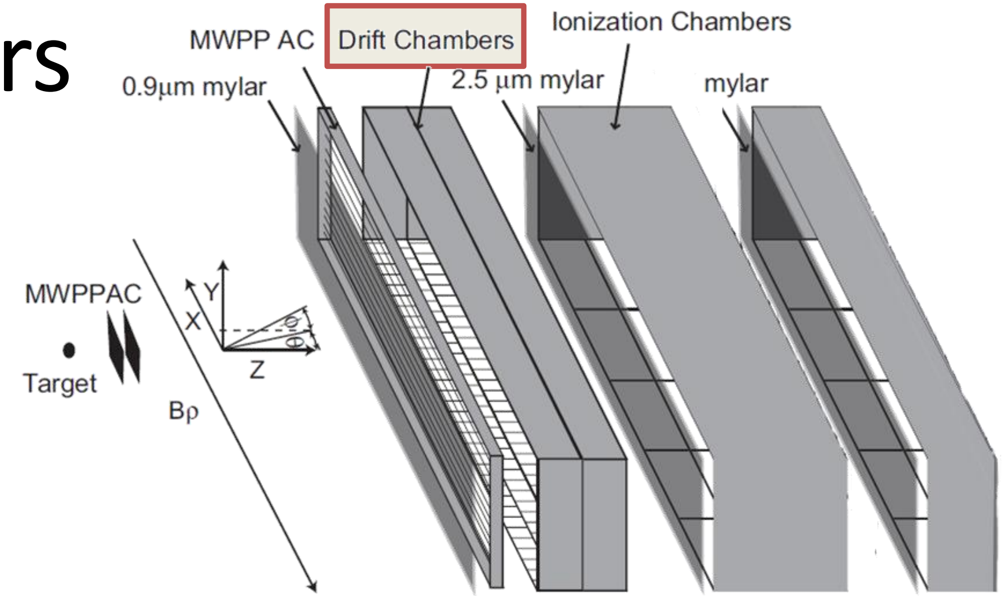
E

Residual Energy E_{res}

- Up to now :
  40 Silicon detectors : 2*20 rows
- **New** : Repalced by 4^{th} IC row (5 pads)
  (CF4 higher pressure 100-400 mbar)



Tracking Detectectors



Isobutane 6 mbar

Pair of Drift Chambers

dispersion 2cm/%

- **X :** 2 rows of 160 Pads
  6.4 mm size
  typically 5-10 pads per ro
- **Y :** 2 drift times

X_1 X_2 X_3 X_4

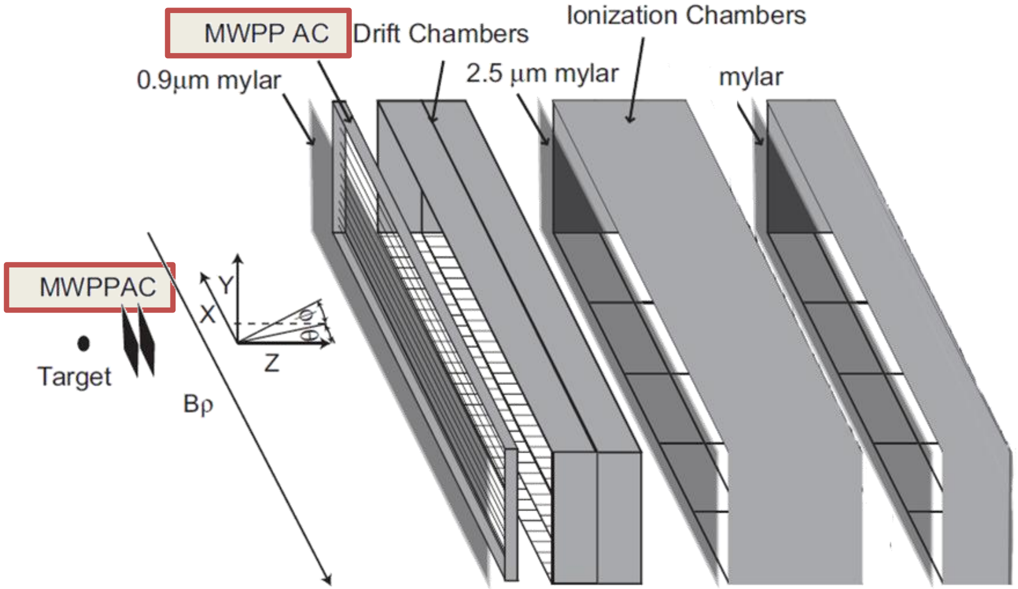
Y_1 Y_2 Y_3 Y_4

Focal reconstruction point

=> Xf, Yf, θ, φ

X_f Y_f θ_f ϕ_f

Time of Flight

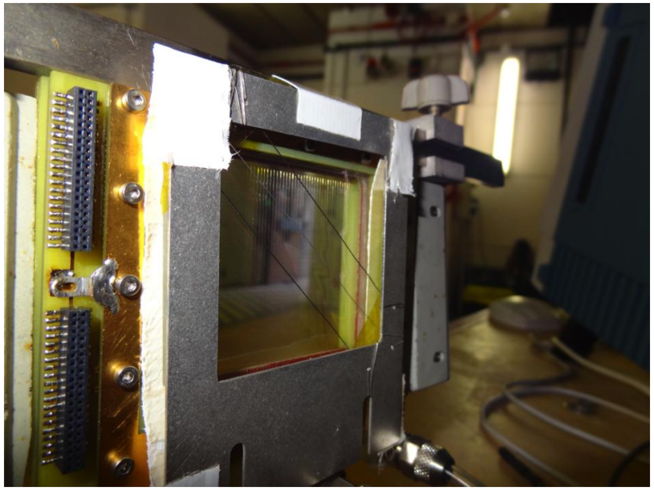


Multiwire detectors

- START : 2 detectors
  15 cm and 25cm from target
- STOP : Focal plane
  (1m x 15 cm)
  20 sections

=> **Flight Path** ~ 7.3 m (200 – 300 ns)

Time resolution ~ 0.5 ns



2 x (time + x and y plane)

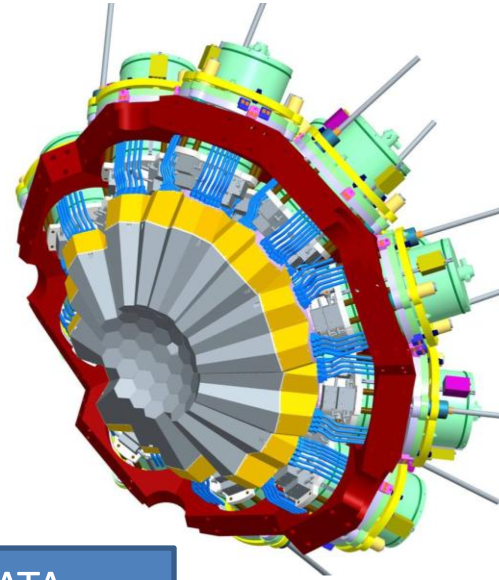
TOF

20 times sections (5 cm)

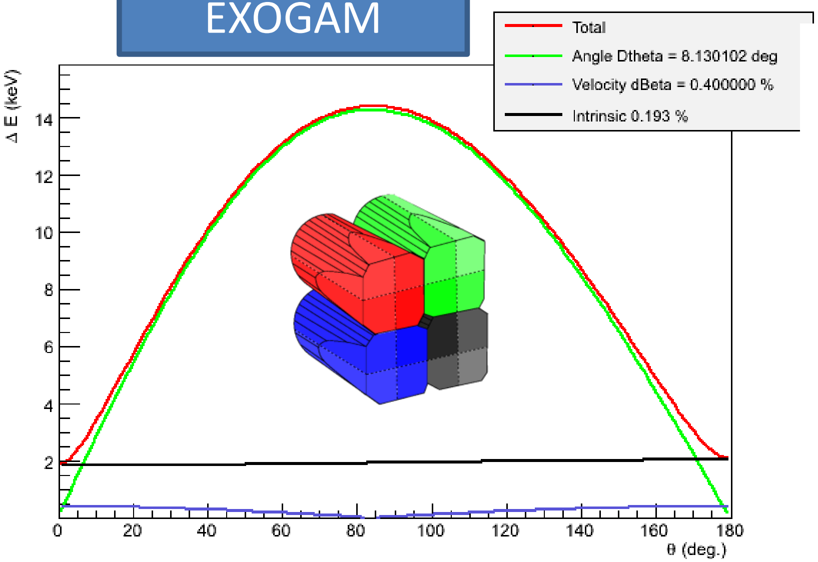
Recoil Angle : Matching AGATA needs

- Start Multiwire to obtain angle
  - AGATA position Resolution ~ 5 mm
    - Distance from target @ GANIL : 14 - 20 cm
    - Angular openning : 1.5° to 2°
  - VAMOS Velocity resolution : $4x10^{-3}$

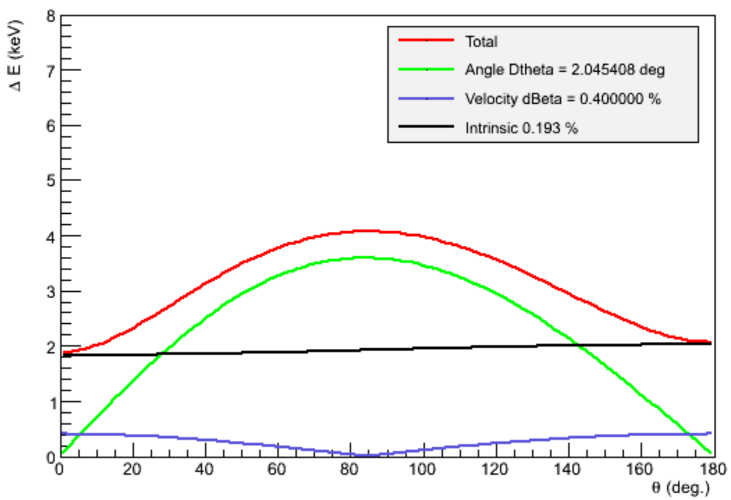
$E_\gamma = E'_\gamma / (\gamma(1 - \beta \cos(\theta)))$



EXOGAM



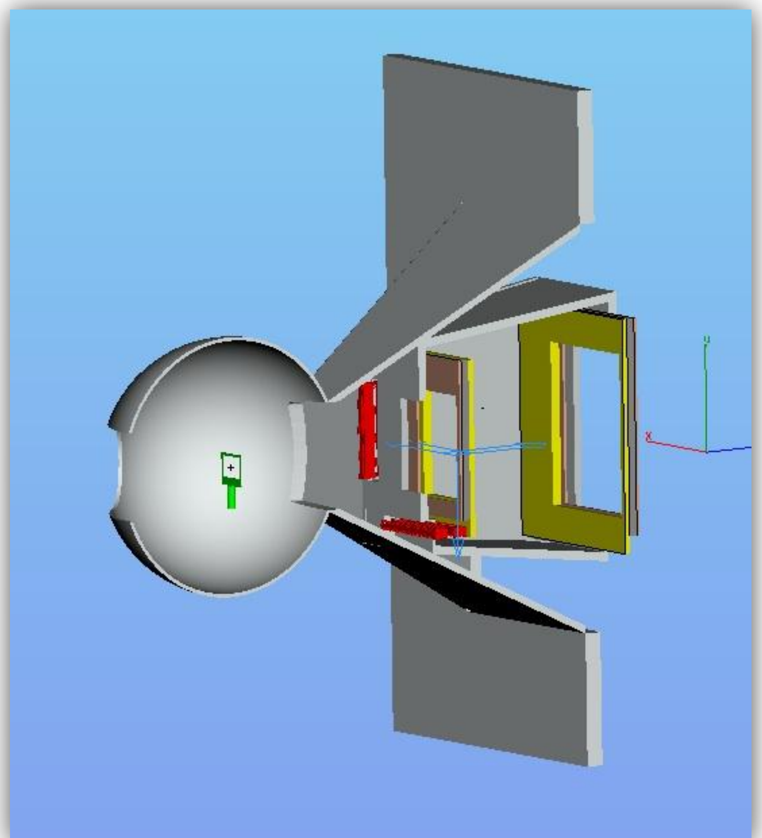
AGATA

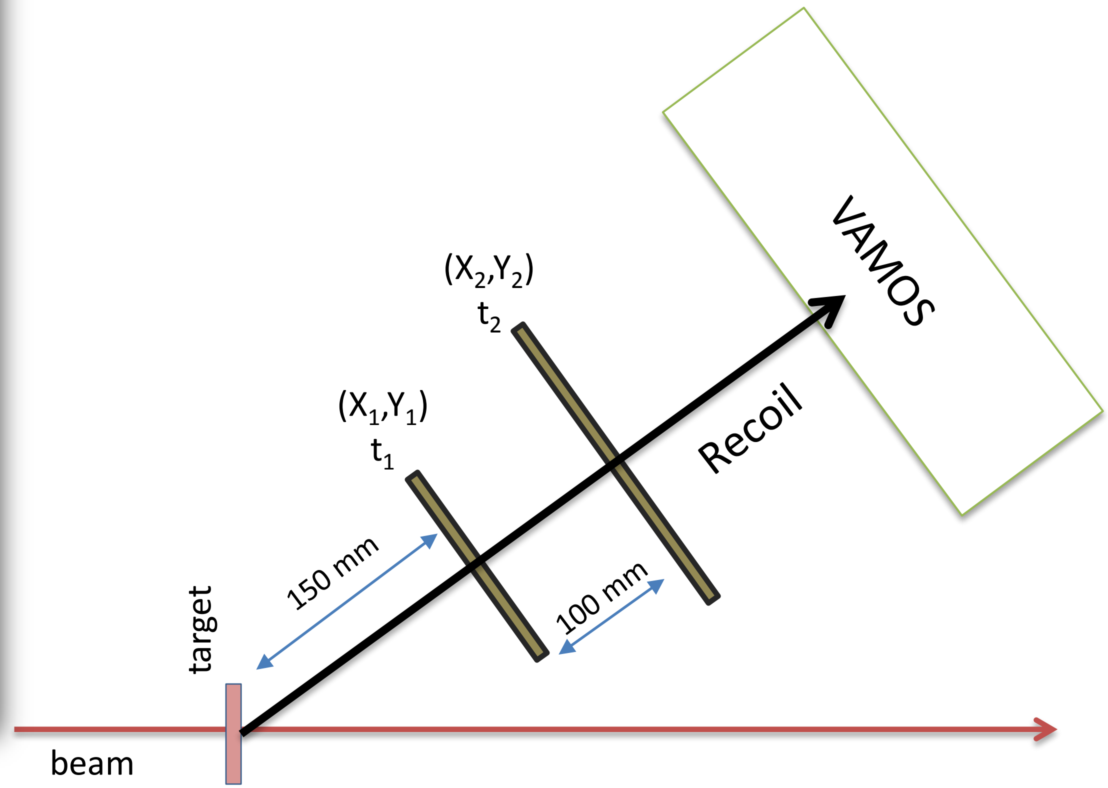


Tracking Multi-wires detector after target

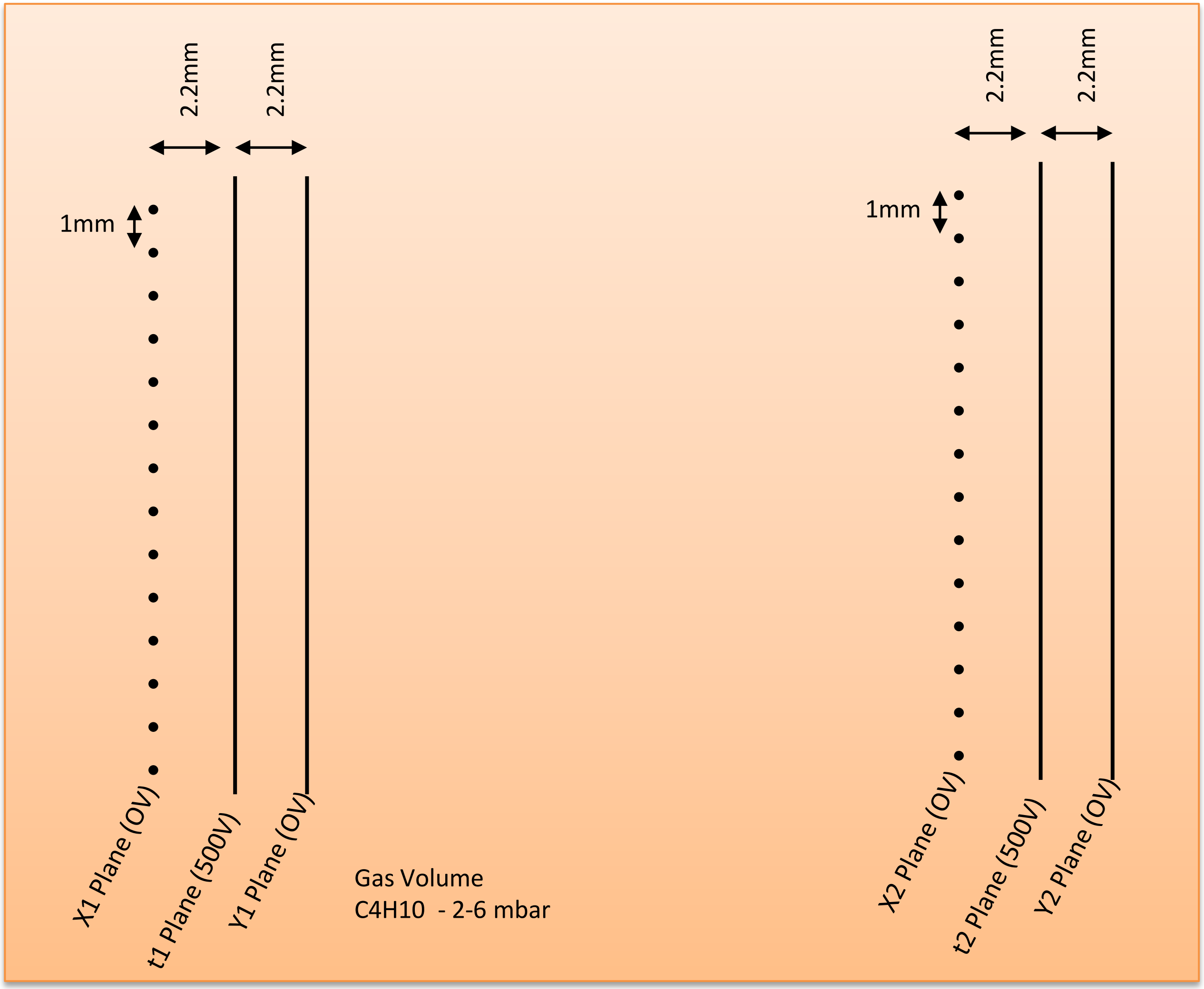
2 sets of multi-wires detectors (x,y)

Placed at the entrance of VAMOS





Schematic view of Start MW



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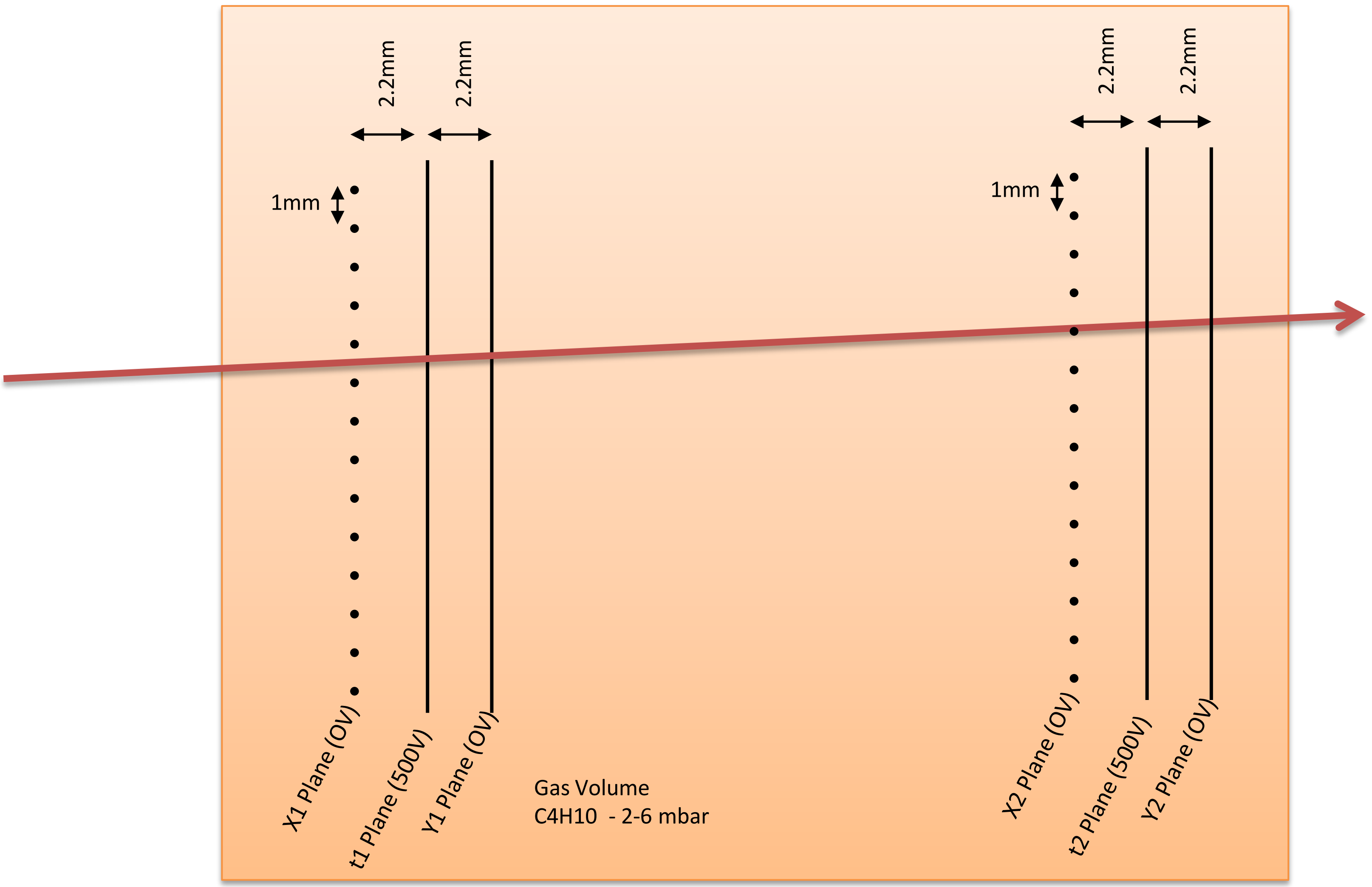
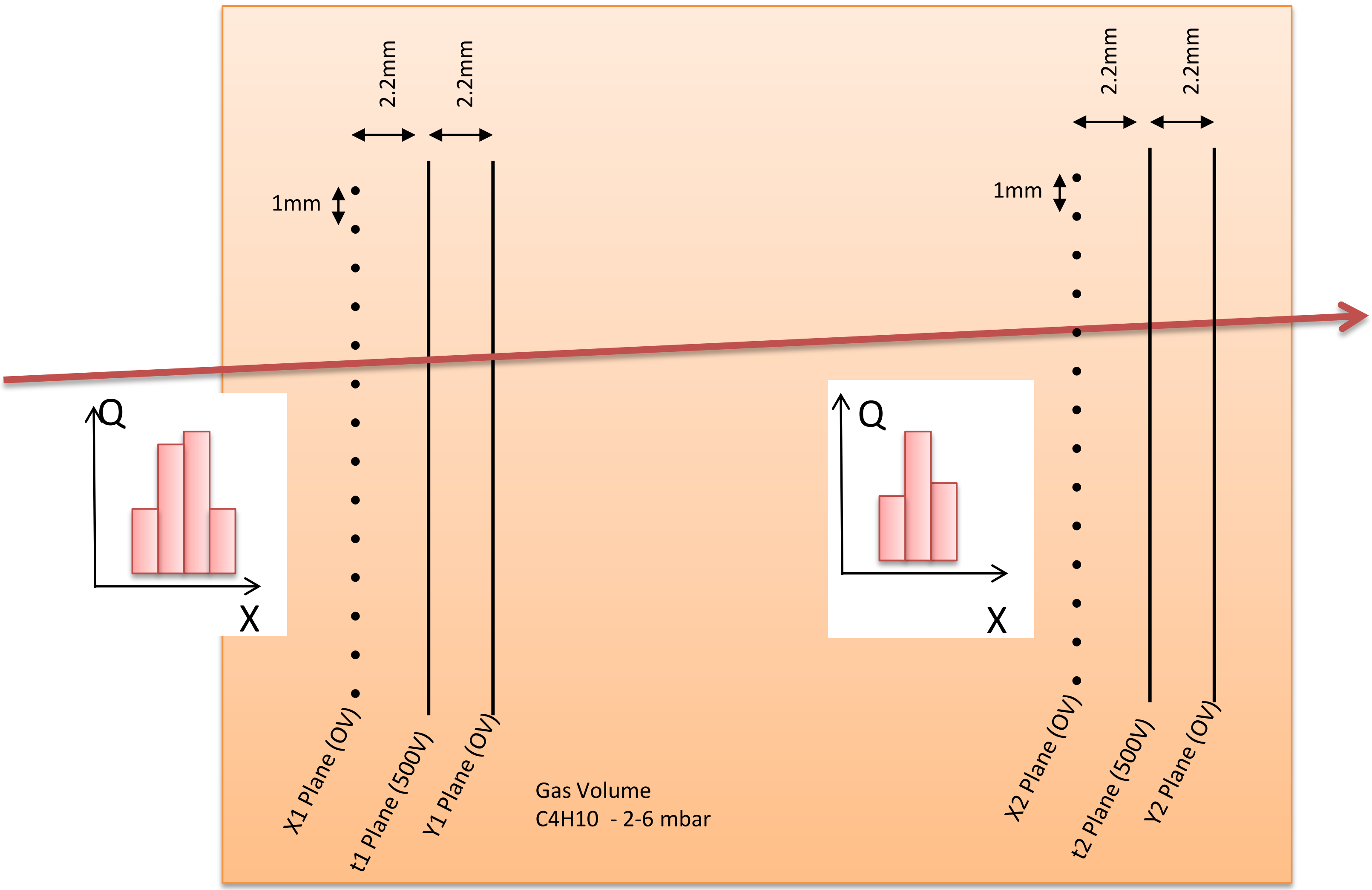
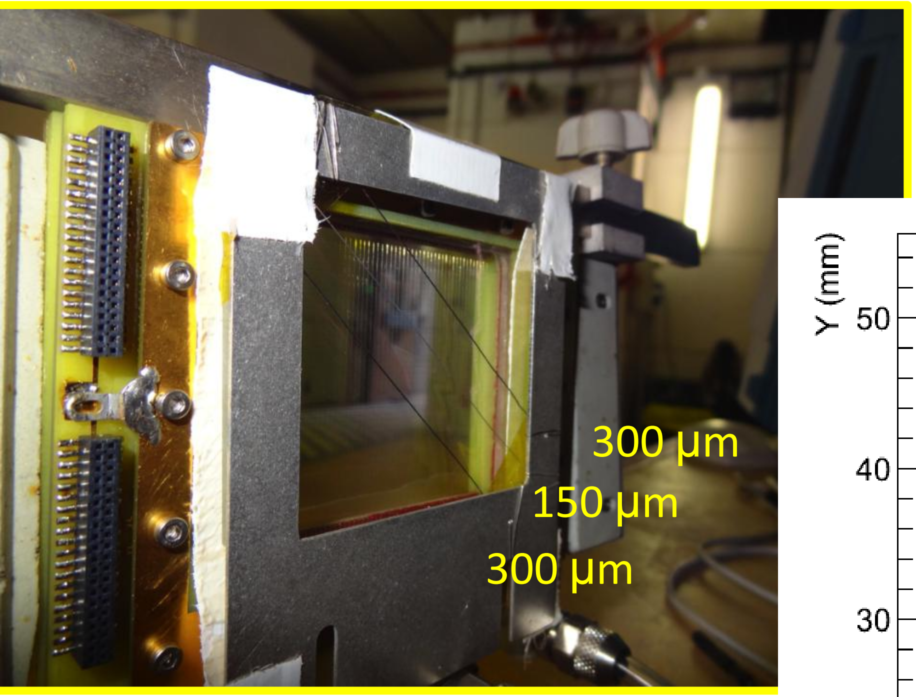
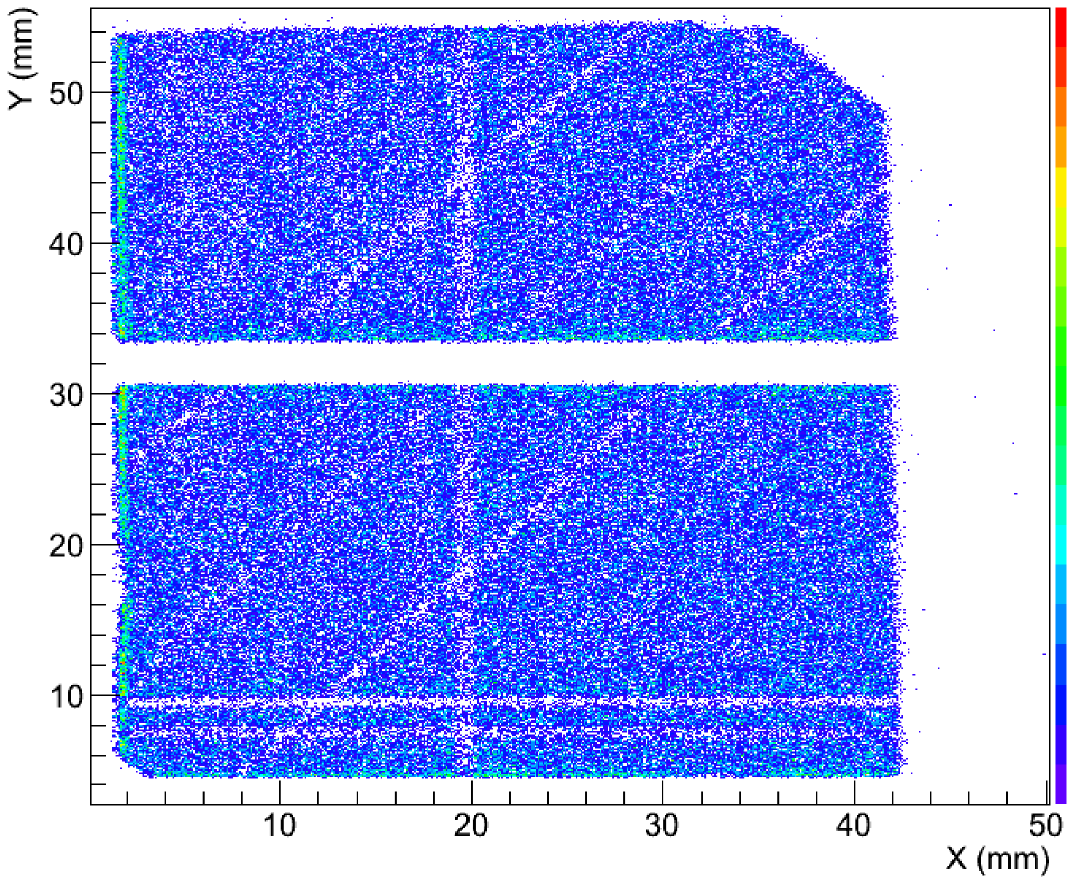


Schematic view of Start MW



Position measurement - Prototype





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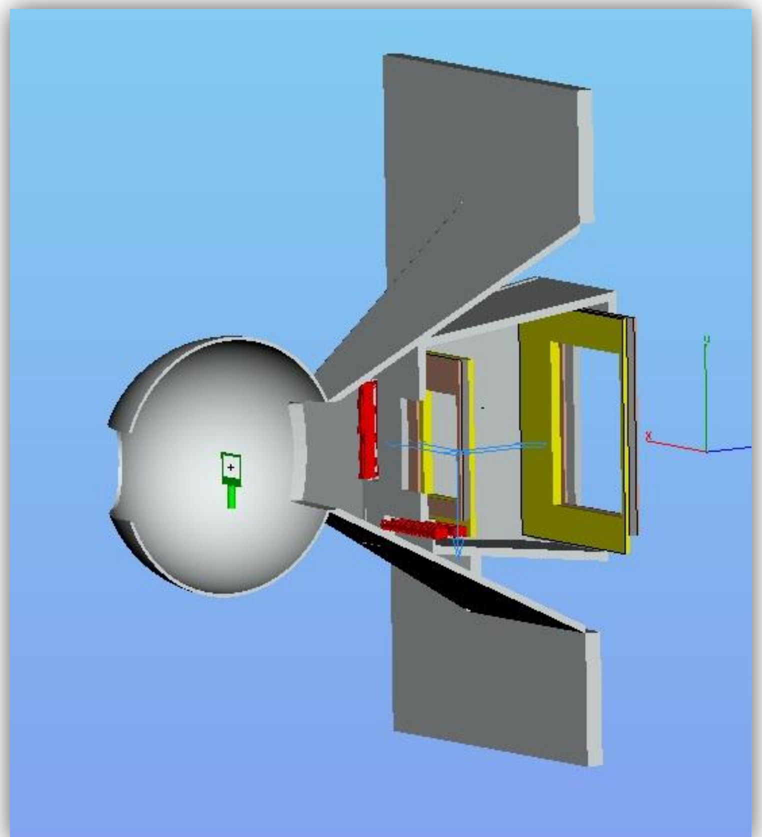
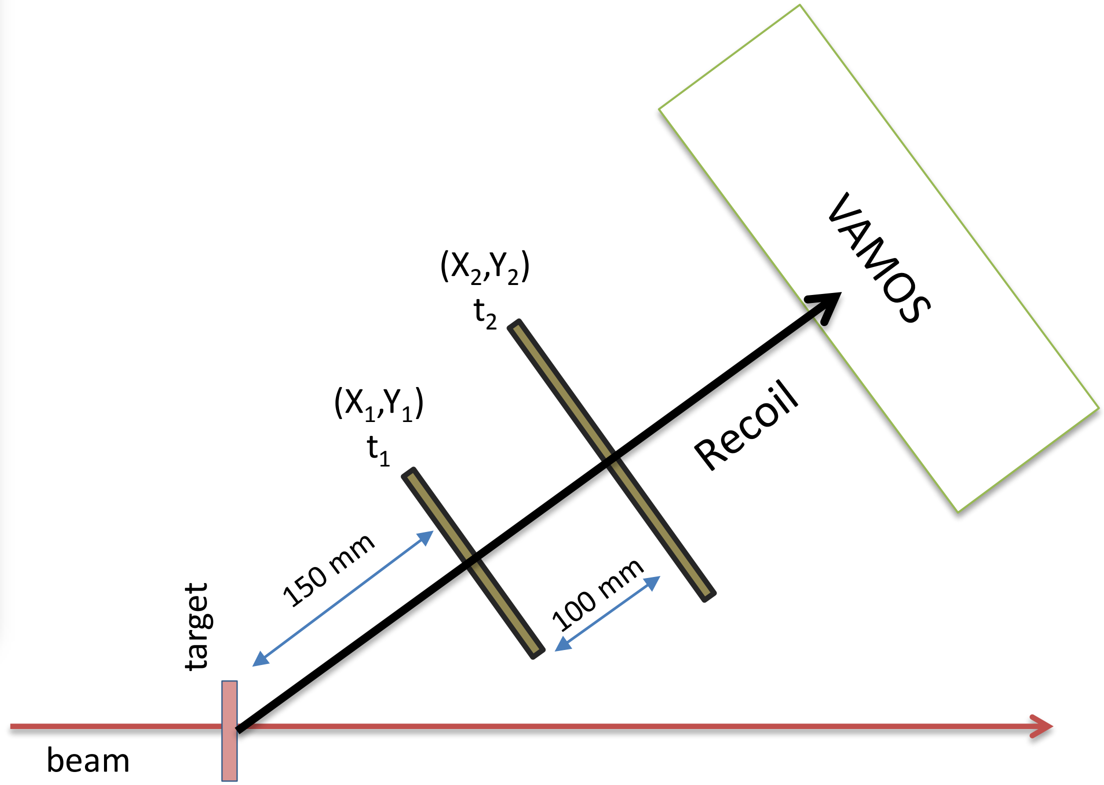
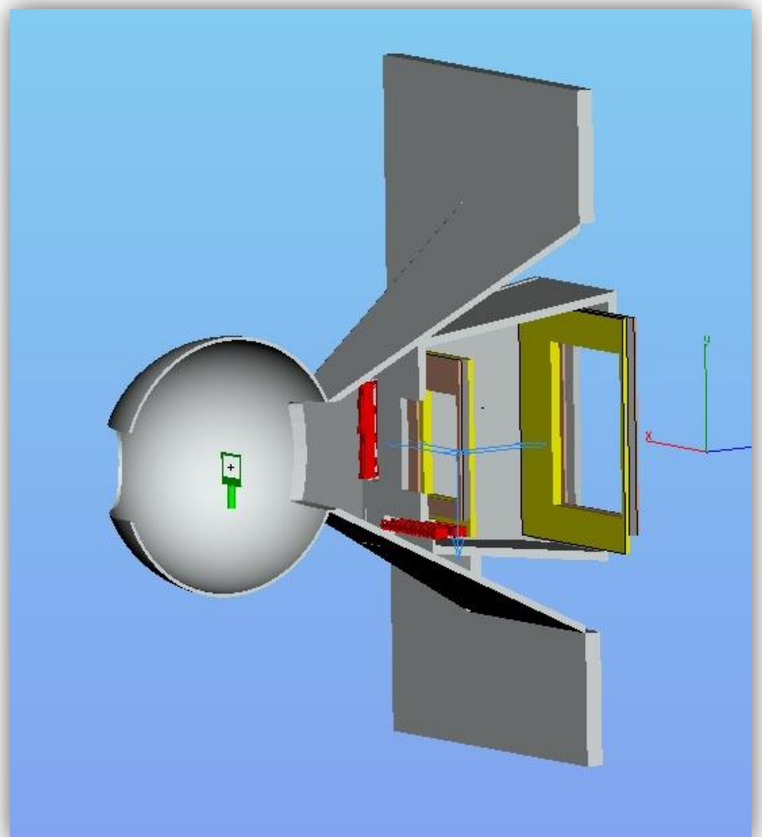


2 sets of multi-wires detectors (x,y)

Placed at the entrance of VAMOS

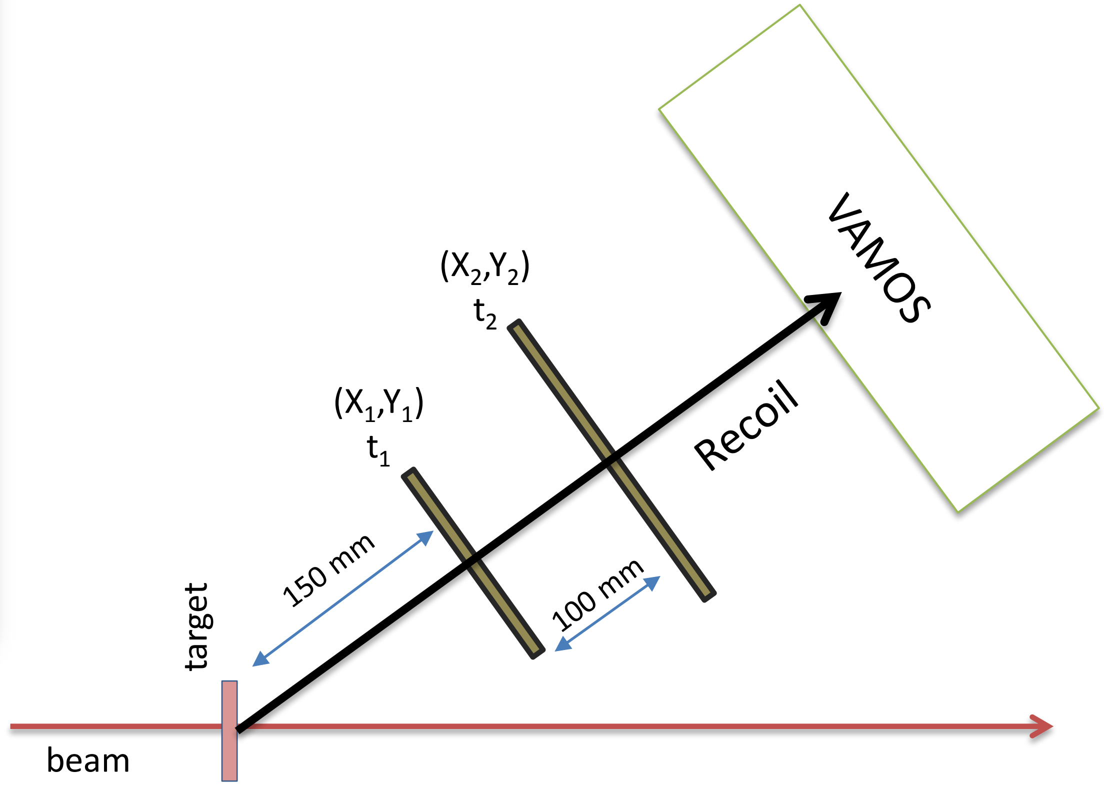


Tracking Multi-wires detector after target



2 sets of multi-wires detectors (x,y)

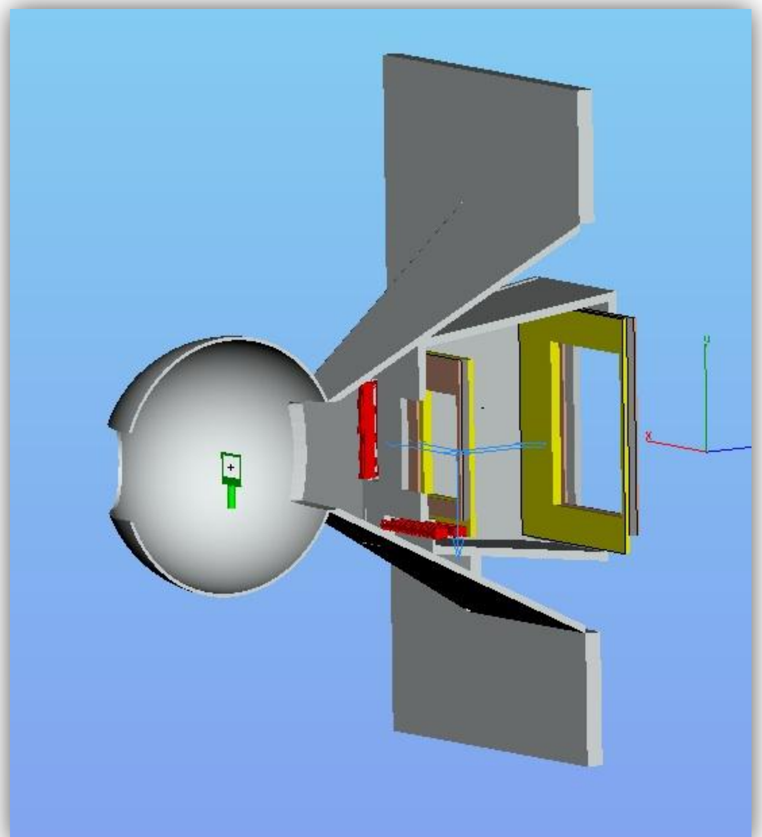
Placed at the entrance of VAMOS



Improved angular resolution for Doppler correction

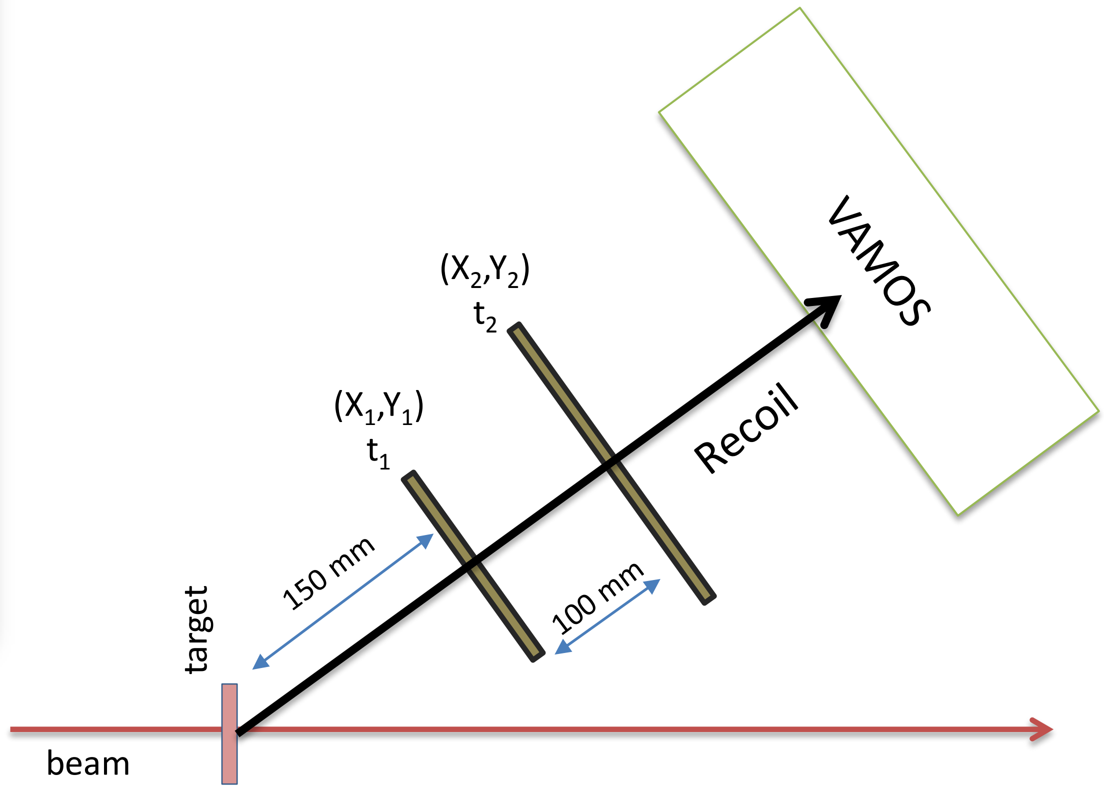
-Recoil: (θ,ϕ) ($<1°$)

Tracking Multi-wires detector after target



2 sets of multi-wires detectors (x,y)

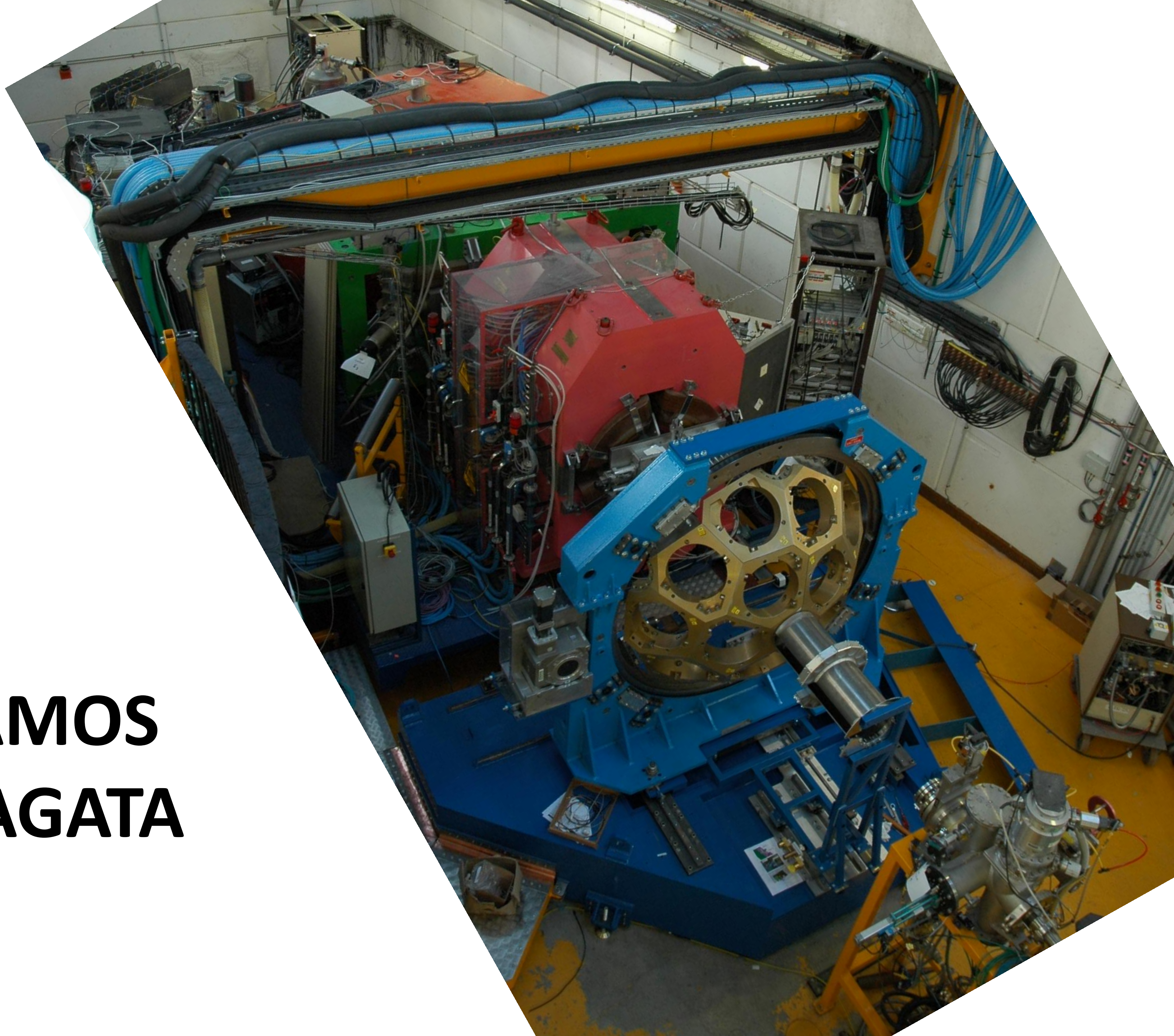
Placed at the entrance of VAMOS



Improved angular resolution for Doppler correction

-Recoil: (θ,ϕ) (<1°)

Target : (x,y) (~1 mm)

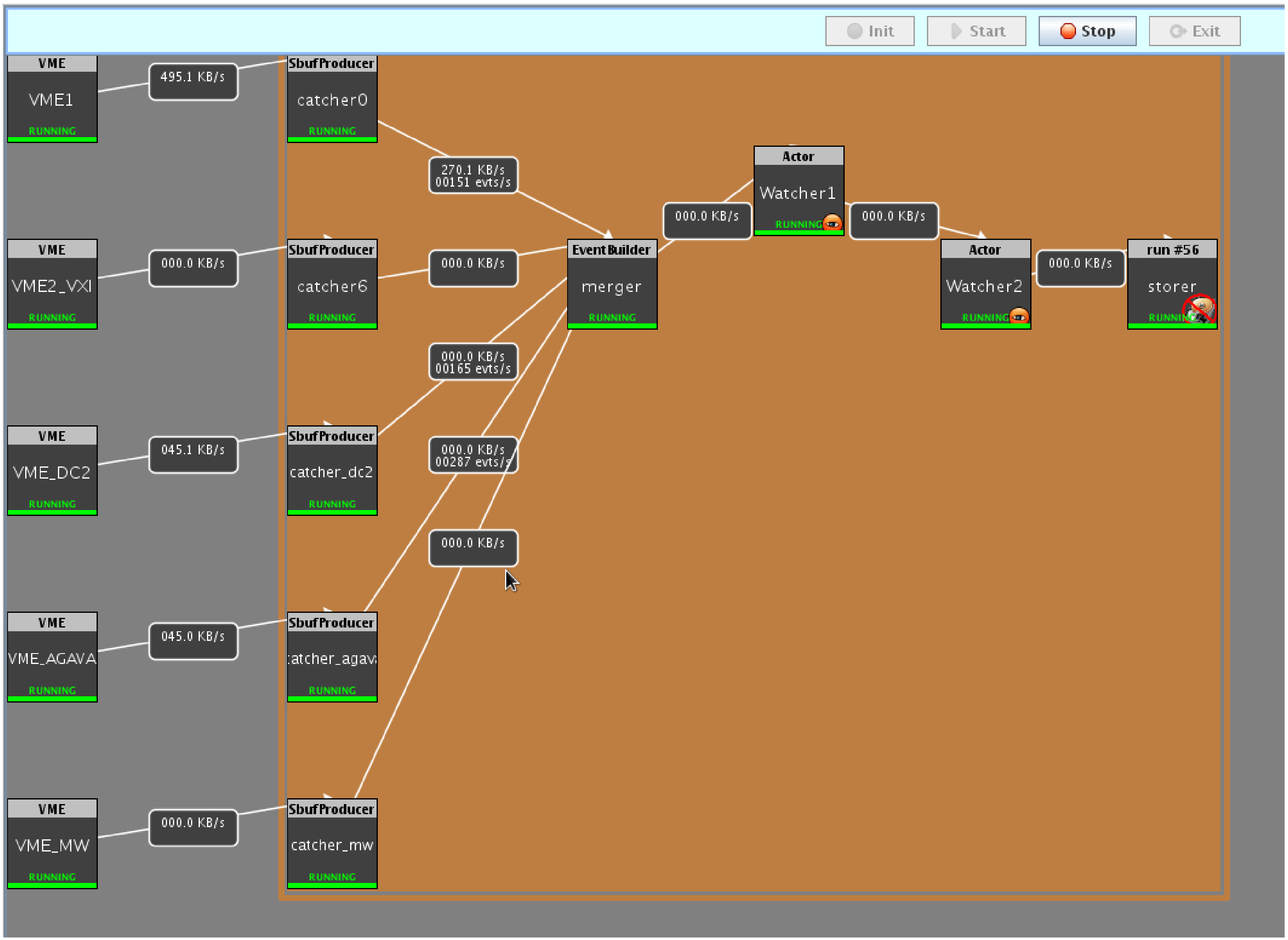


VAMOS
+ AGATA

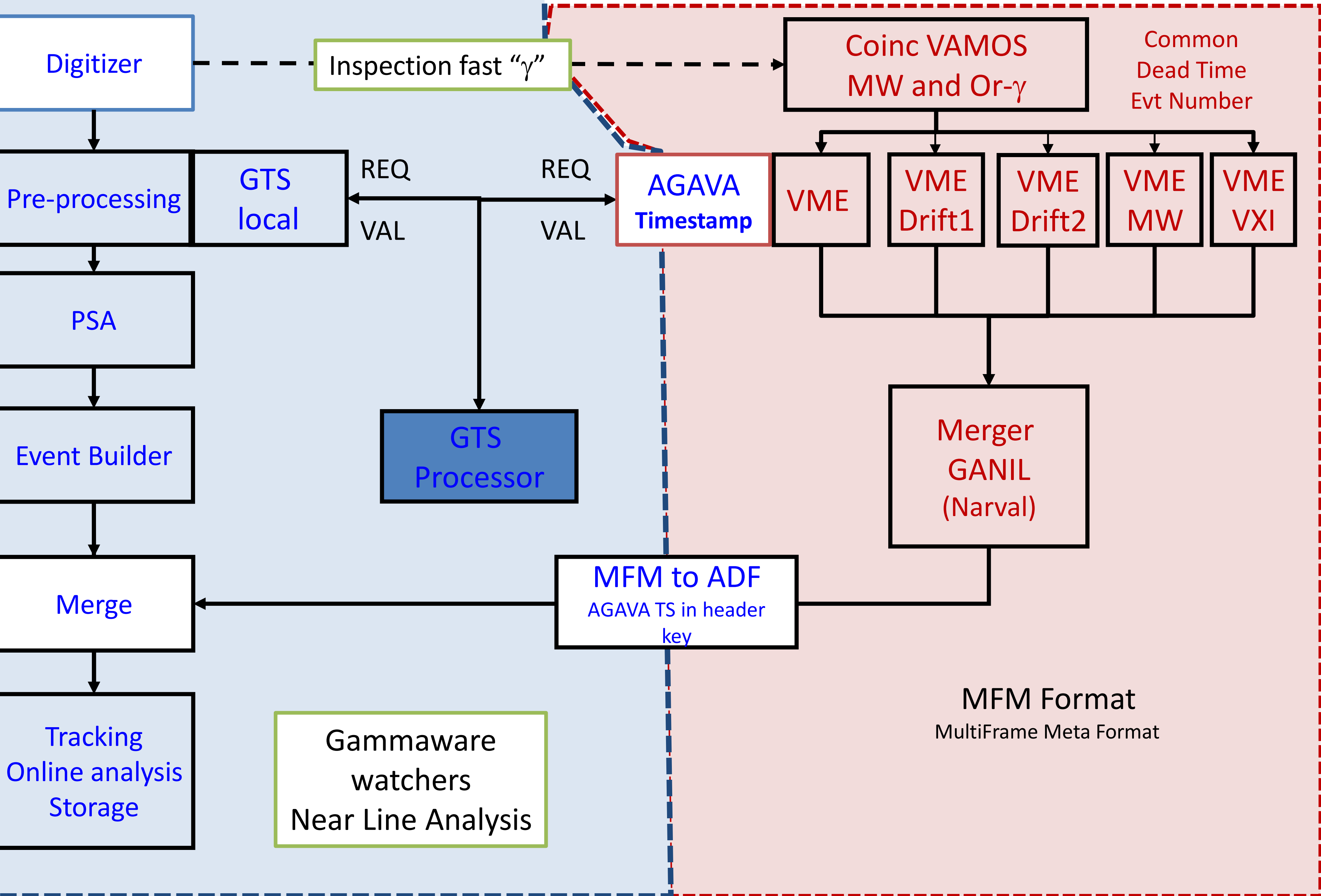
Coupling VAMOS and AGATA

(like AGATA + PRISMA)

Narval Topology for VAMOS



AGATA and VAMOS



VAMOS SOFTWARES AND ANALYSIS

VAMOS Analysis softwares

Offline = Online

- libVamos

  Shared library (C++, ROOT (opt), Cmake)

  $\Rightarrow$ Could be interfaced with any program

  (VAnalysis, your own analysis program, *Watcher GammaWare*, Narval filter ...)

  git version control, doxygen documentation

  Soon available in http://gitlab.in2p3.fr/VAMOS/

- VAnalysis existing analysis software
  - Online Analysis (Narval Watcher, Spy)

    (Histograms Server, Visu with VIGRU software)
  - Offline Analysis (Root Trees, Histograms)

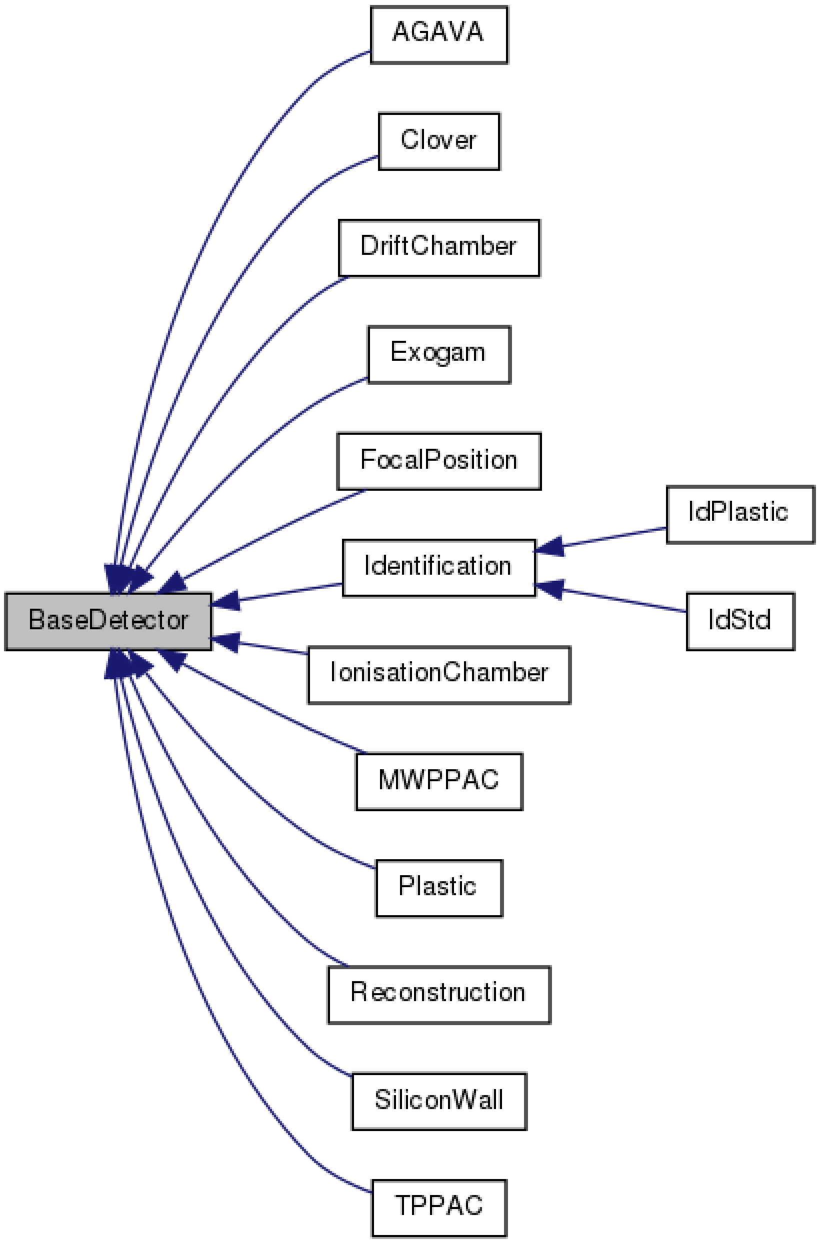
libVamos

Include standard *sorting*, *calibration* and *analysis* procedures for VAMOS detectors

Basic Idea : benefit from inheritance !

- BaseDetector include all standard routines (Add Data, Calibration, Root Histogramming and Trees, …)

  Inherited class for specific needs
  - Detectors
    - Drift Chambers
    - Ionization Chambers
    - MWPPC
    - Silicon Wall
    - TPPAC
  - But also for Analysis methods
    - Focal Position Reconstruction (Combine 4 DriftChambers)
    - Brho Reconstruction (Combine Focal Position)
    - Indentification (Combine Focal Position Reconstruction, IC, E, MW)

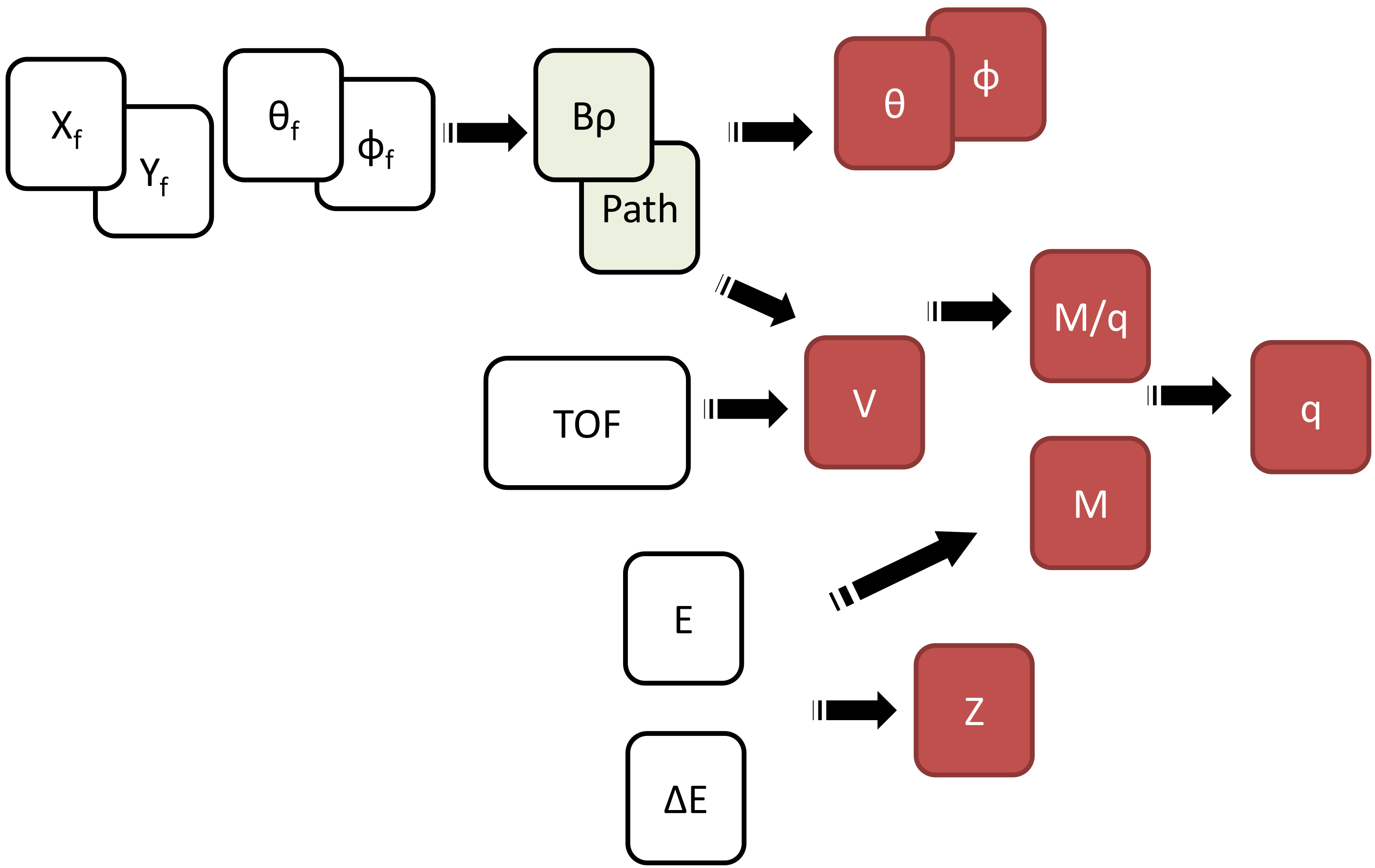


No Data yet from VAMOS + AGATA !

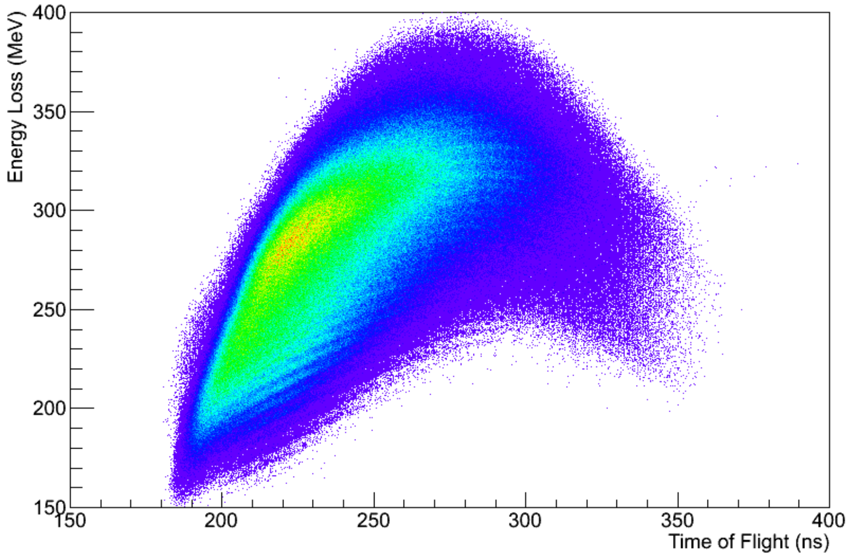
I will save you from installing software

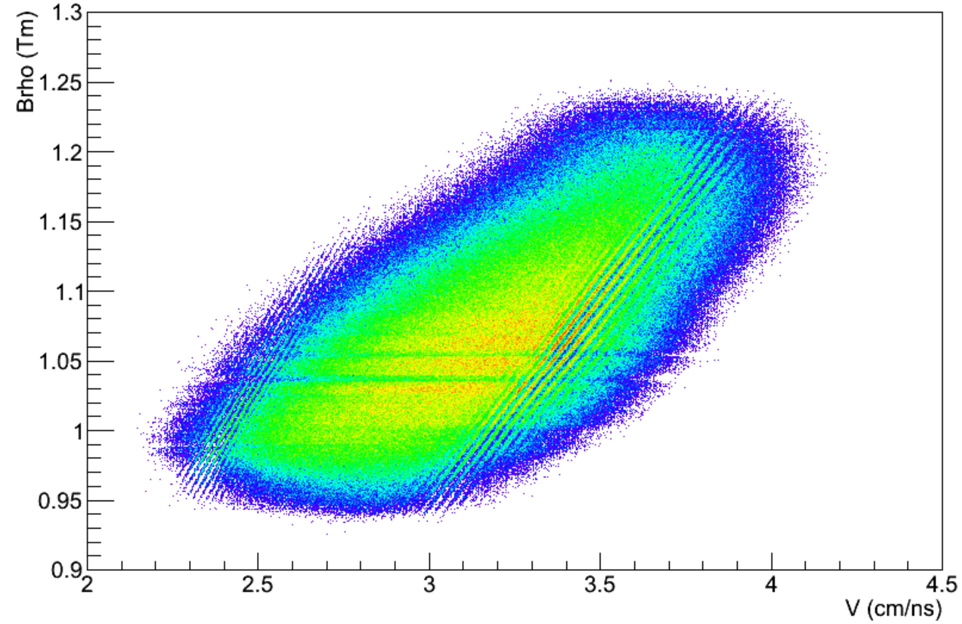
But we will look at previous data
and go step by step

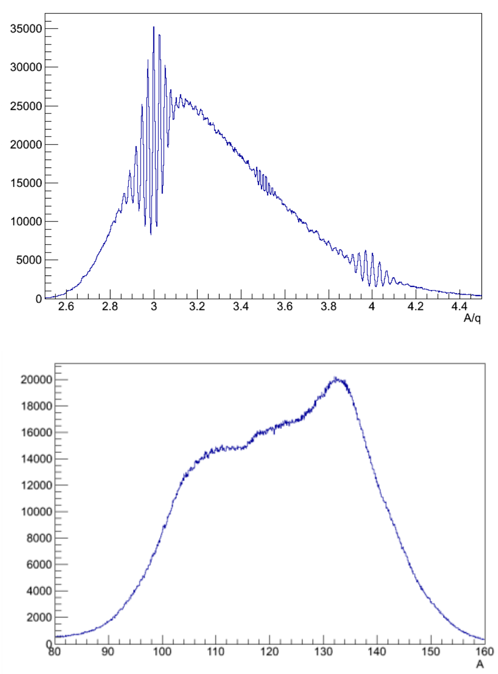
VAMOS Measurement
(Software Spectrometer)

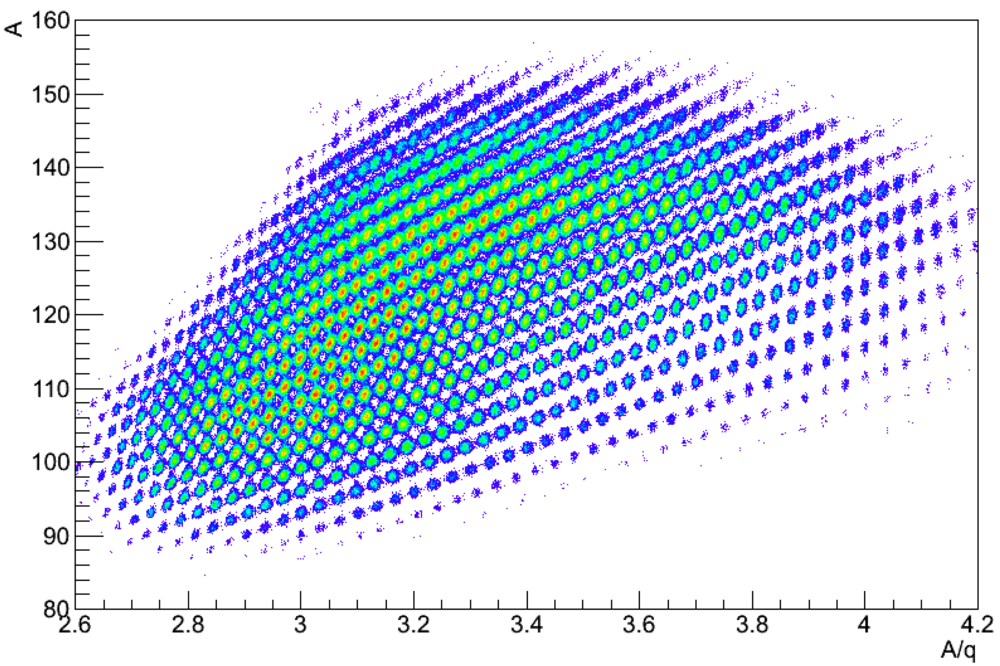


Basic Correlations

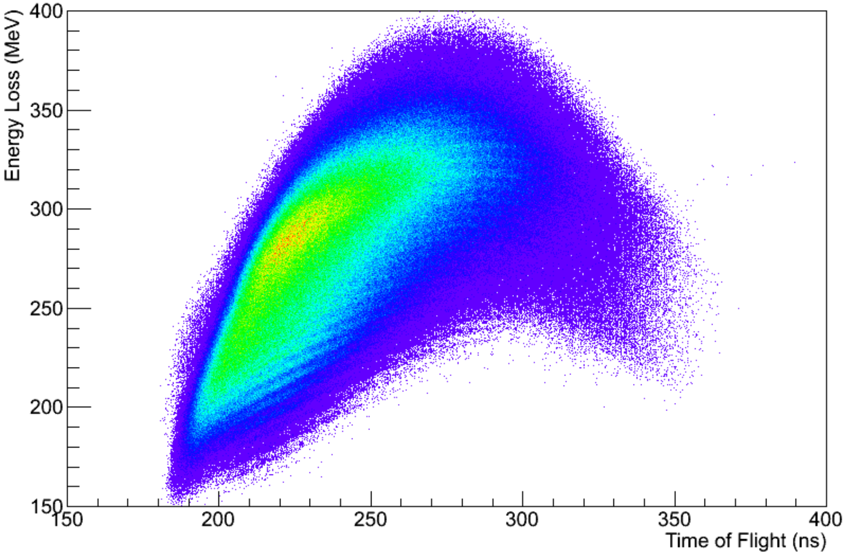


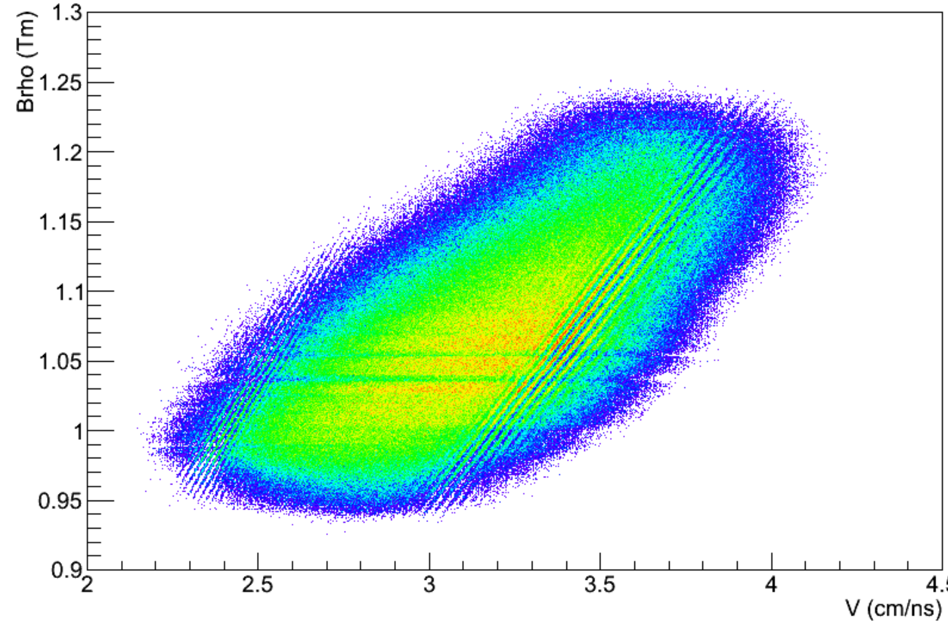


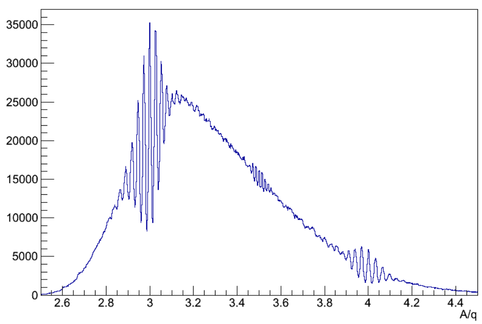


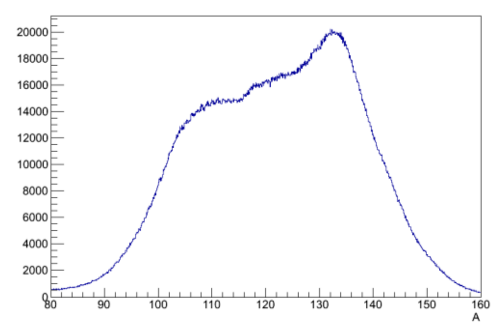


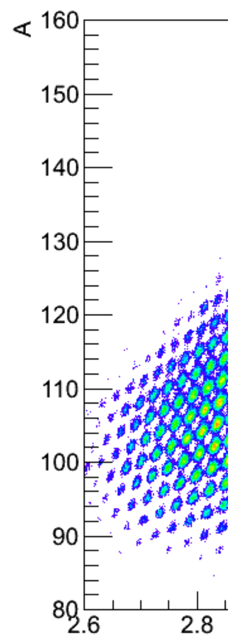
Basic Correlations

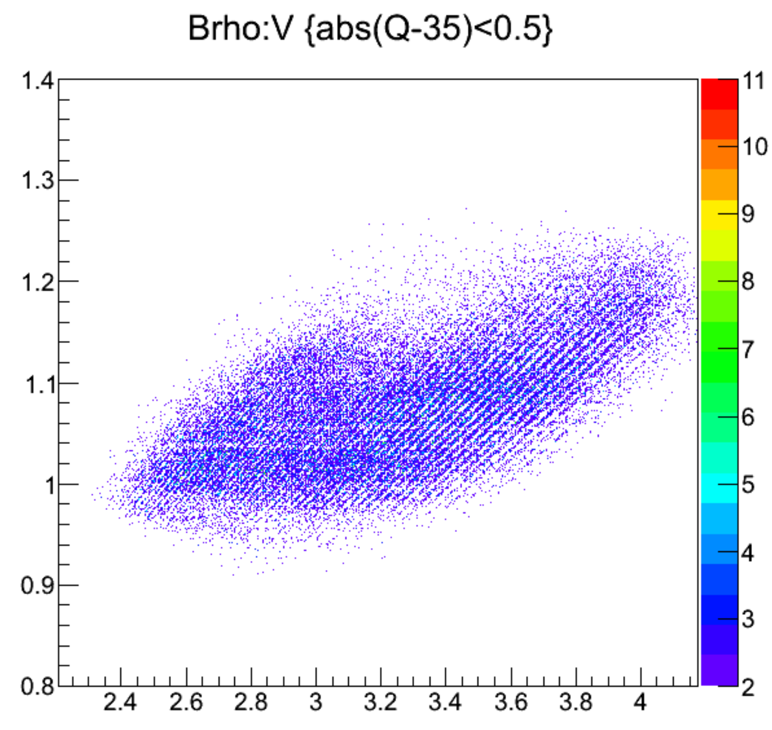




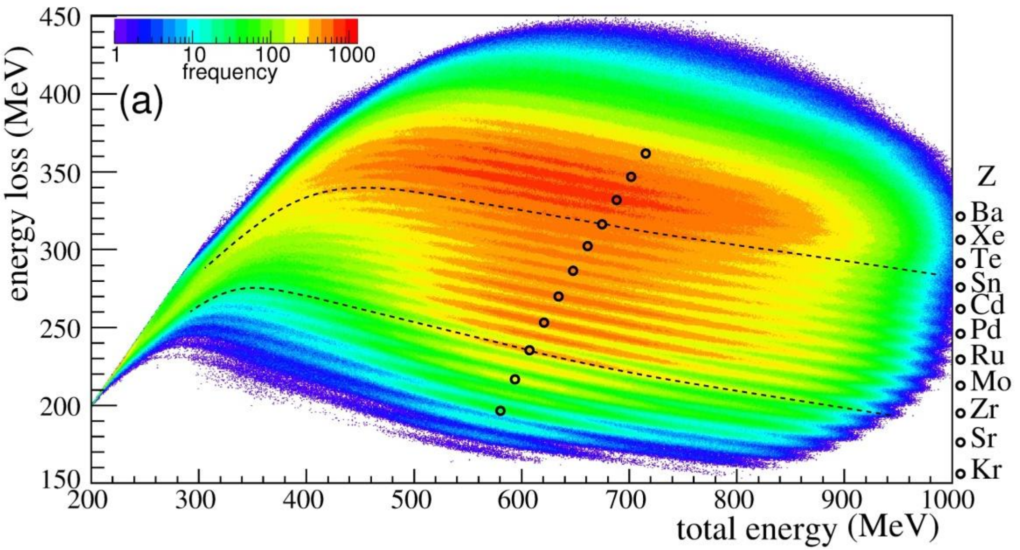


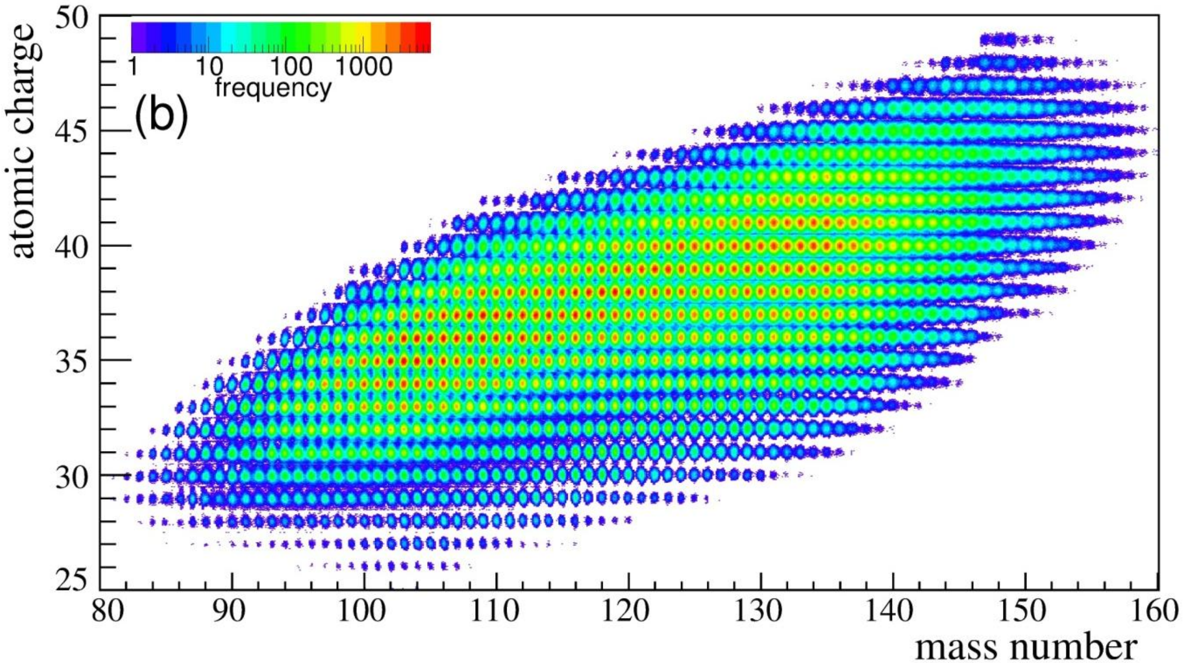






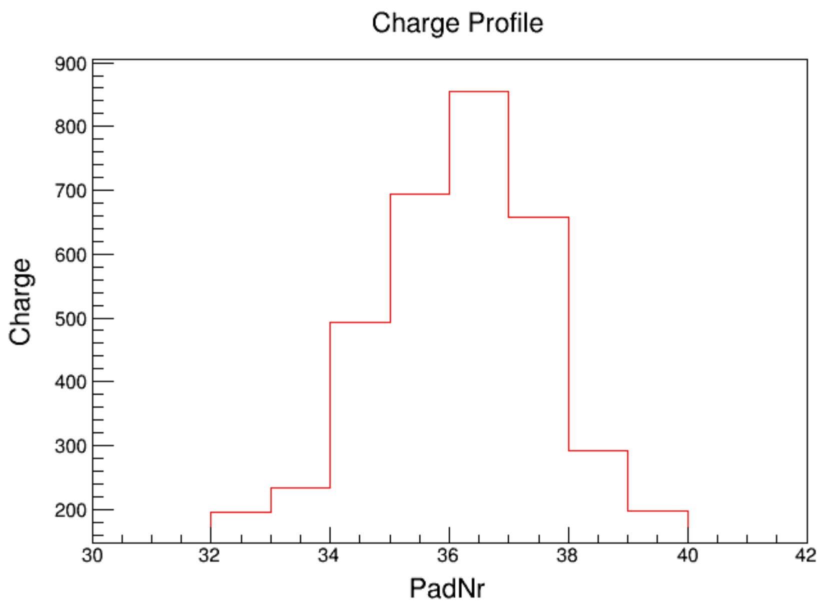
Identification of FFs

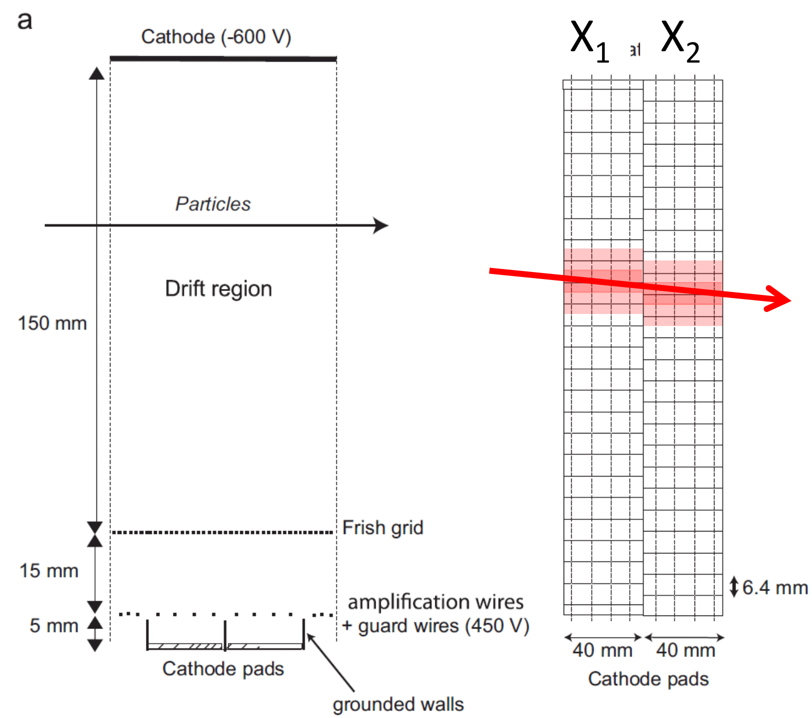




Trajectory reconstruction in DriftChambers

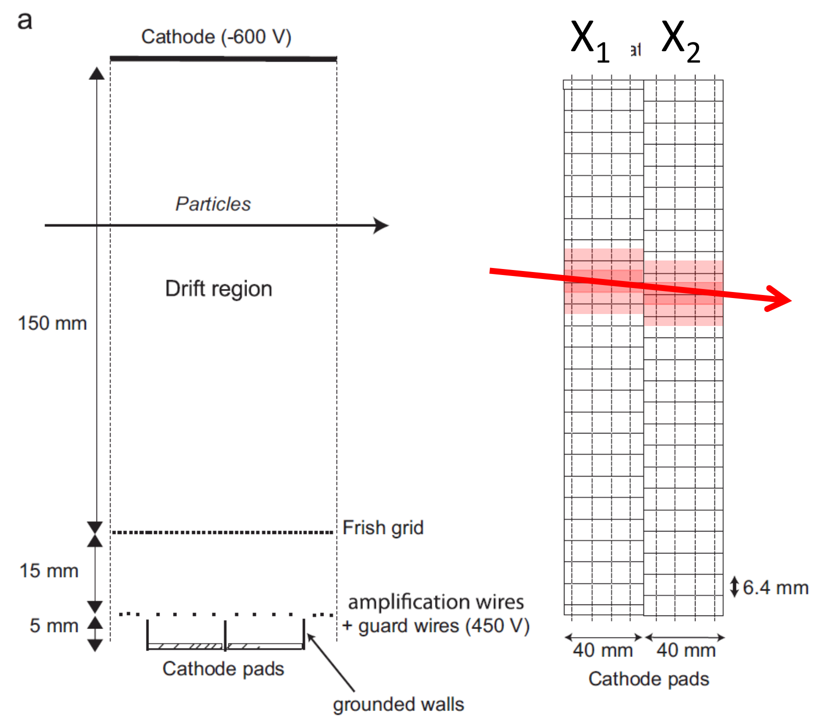
- Charge distributions on Pads
  => (X_1, X_2, X_3, X_4)





Trajectory reconstruction in DriftChambers

- Charge distributions on Pads
  => (X_1, X_2, X_3, X_4)
  Signal on amplification wires
  => 4 drift times (Multiwire – DC Wire)
  => (Y_1, Y_2, Y_3, Y_4)



Trajectory reconstruction in DriftChambers

- Charge distributions on Pads
  => (X_1, X_2, X_3, X_4)
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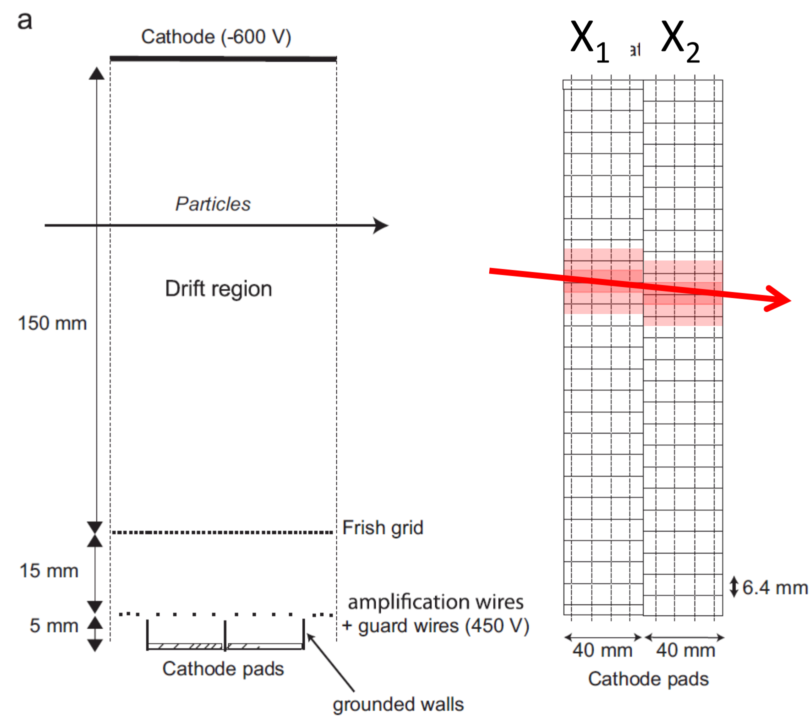
  => 4 drift times (Multiwire – DC Wire)
  => (Y_1, Y_2, Y_3, Y_4)
- Reconstruction at defined plane named « Focal Plane »
  (Our definition 760cm from target)

X_f	Y_f	θ_f	ϕ_f



Trajectory reconstruction in DriftChambers

- Charge distributions on Pads
  => (X_1, X_2, X_3, X_4)
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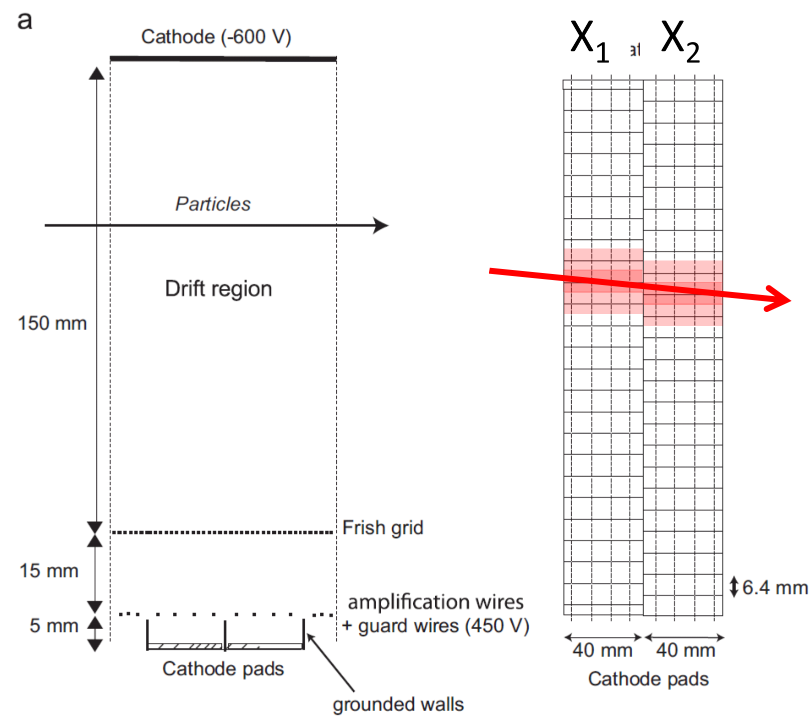


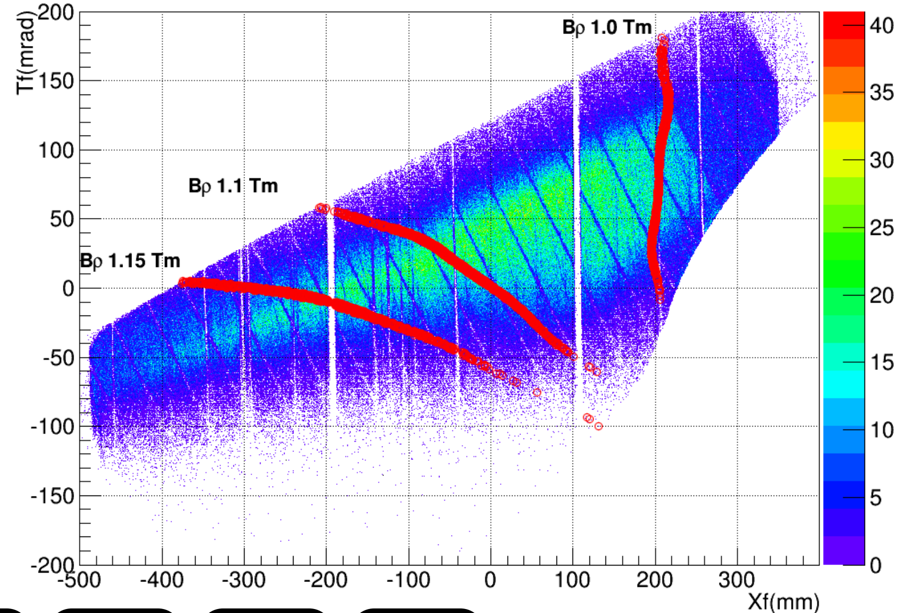
Calibration actions

Pad Calibrations (Gain matching)
Drift Time Calibration
/!\ X and Y references
(surveyors + Direct beam data + dead zones)

Software (Bρ, Path) reconstruction principle

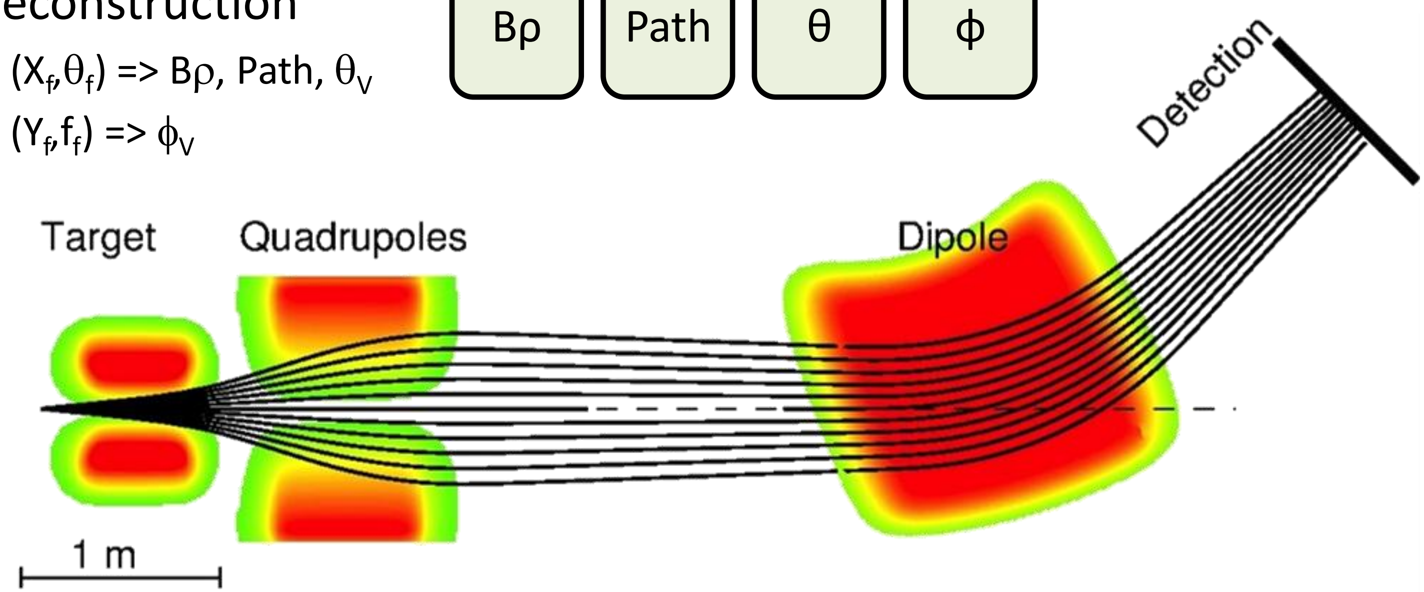
- **Ray tracing** with Zgoubi Software
  - Generate Trajectories ($B\rho,\theta,\phi$) (Field Maps, Given Optics)
  - DataBase of trajectories inputs ($B\rho,\theta,\phi$) to reference « Focal Plane » (760 cm from target) (X_f, Y_f, θ_f, ϕ_f, Path)
  - Build reverse Matrix

(X_f, θ_f , Y_f, ϕ_f) => ($B\rho$, Path, θ, ϕ)



- Event by Event reconstruction
  - From measured (X_f,θ_f) => $B\rho$, Path, θ_V
  - From measured (Y_f,f_f) => ϕ_V

Bρ	Path	θ	ϕ

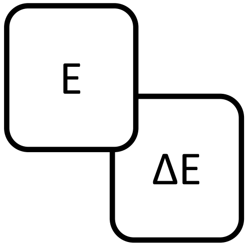


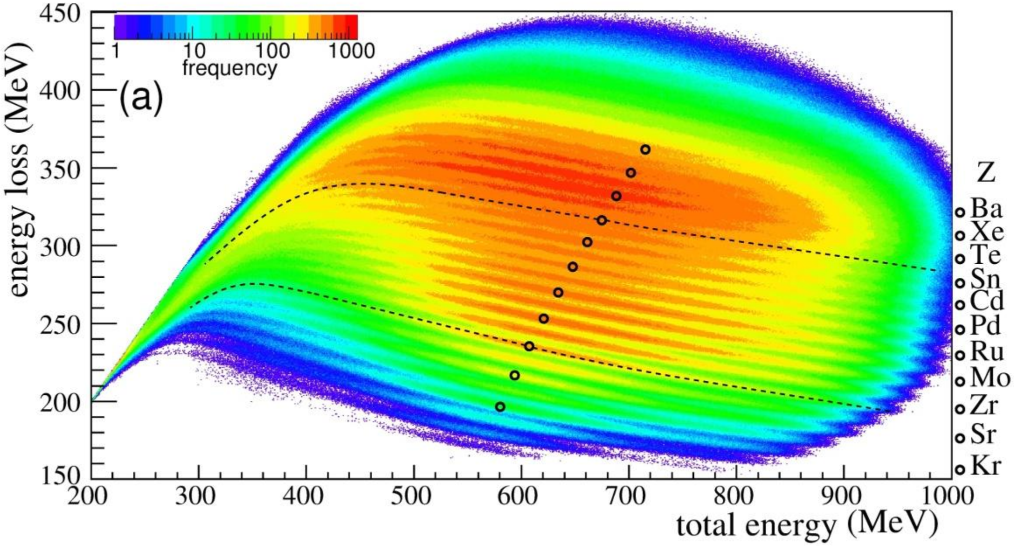
Z identification

ΔE – E technique

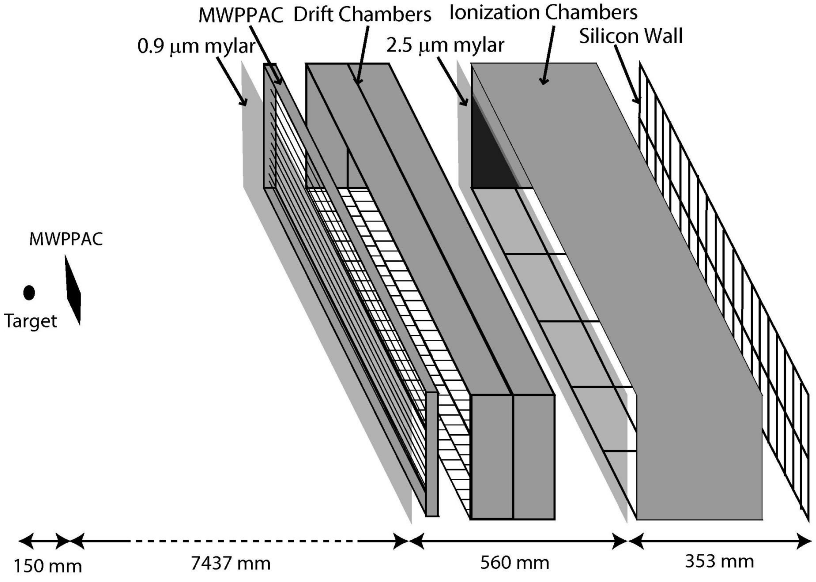
- **Energy Loss : ΔE**

  Ionization Chambers
  3 rows * 5 pads
  CF_4 (20-60 mbar)
  resolution ~ 2 %





- **Residual Energy E_{res}**
  - Up to now :
    40 Silicon detectors : 2*20 rows
  - **New** : Repalced by 4th IC row (5 pads)
    (CF_4 higher pressure 100-400 mbar)



Calibration actions

- **Ionization Chambers**

  3Rows * 5 Pads gain matching
  Overall row calibration

- **Silicon Wall**

  2 Rows * 20 Silicon gain matching

Let's get A and q!

So far, we have

- Trajectory reconstruction : Bρ, Path (D)
- Approximate Energy Calibration (E + ΔE)

Bρ	Path
E	ΔE

$$B\rho[Tm] = 3.105\frac{A}{q}\beta\gamma$$

$$V = D / T$$

$$\beta = V / c$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

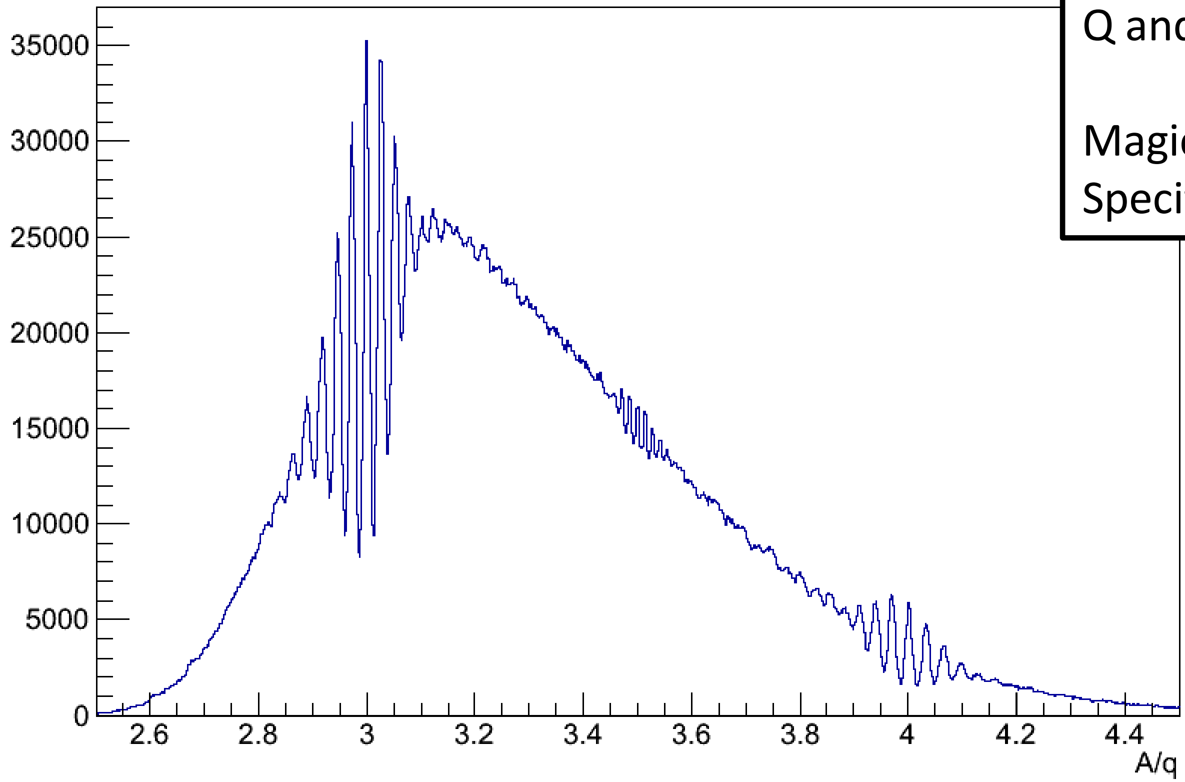
$$c = 29.9792458\ [cm / ns]$$

$$A = \frac{2E}{931.5\beta^2}$$

$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\beta\gamma}$$

We want A and q
we need v !
= > Time of flight calibration

Time of flight



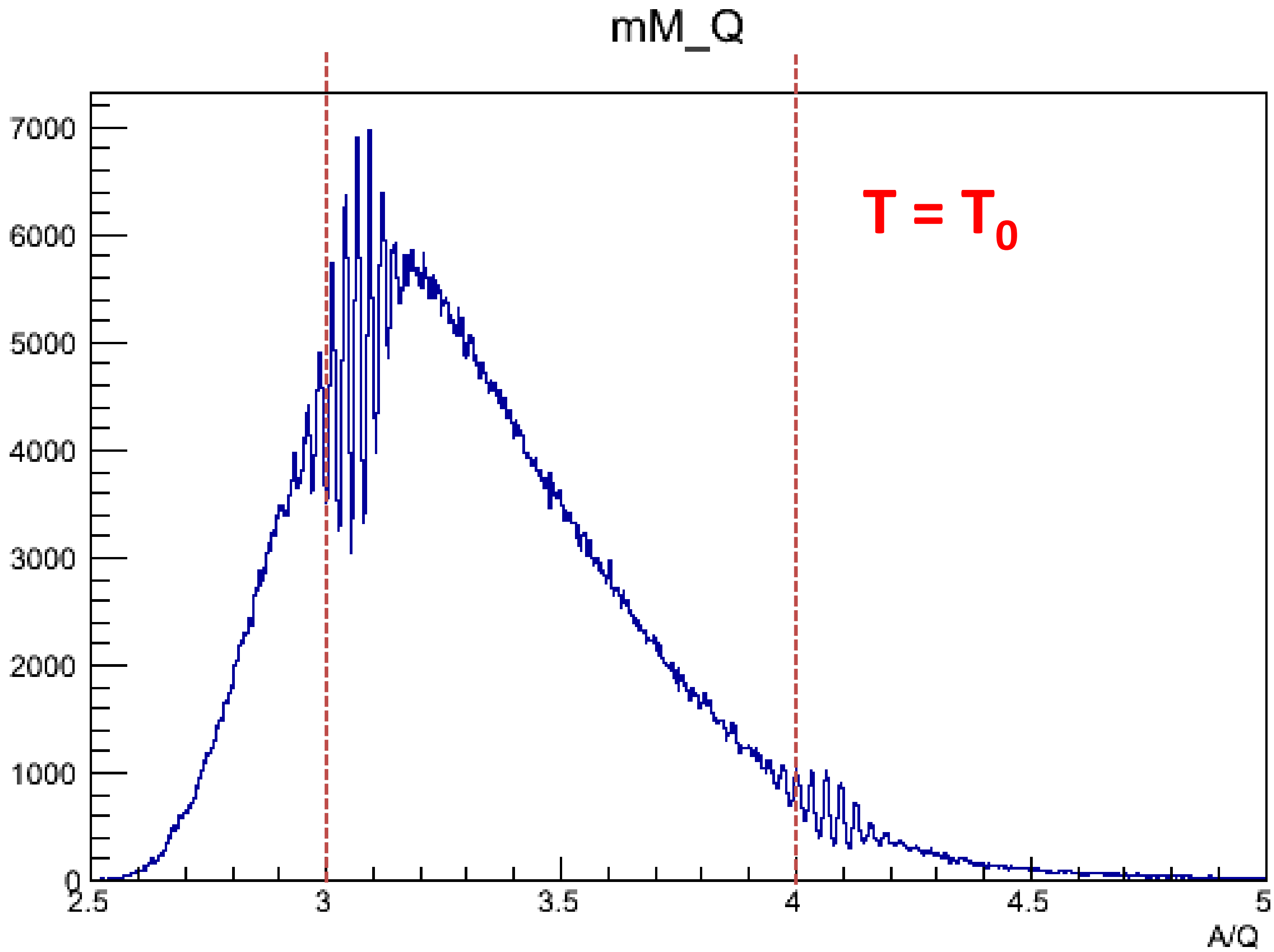
Q and A as integers

Magic numbers of spectrometers
Specific A/Q values = 2,3,4 …

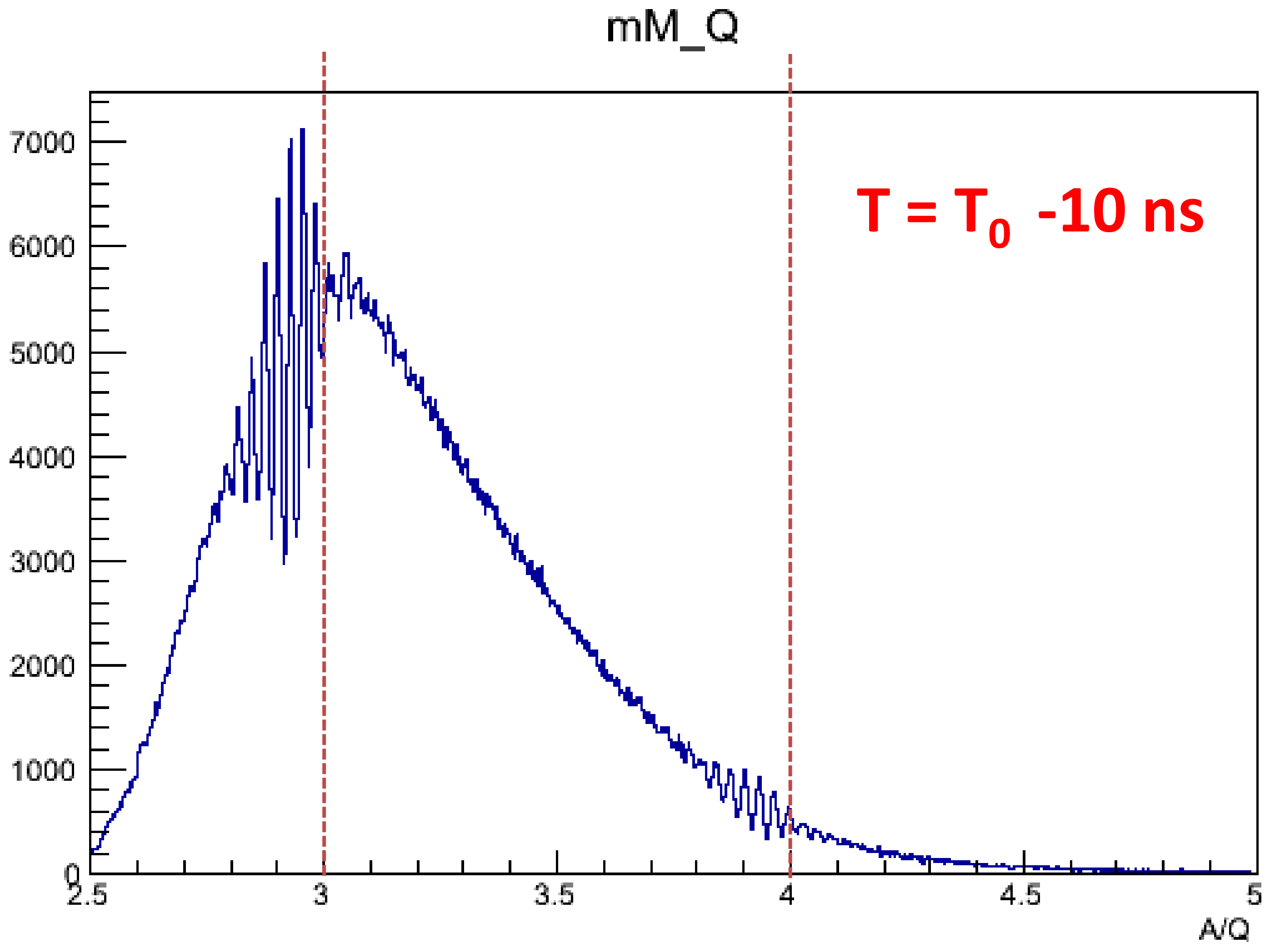
$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\,\beta\gamma}$$

Adjust time offset to match M/Q = 3 and 4
Section by sections

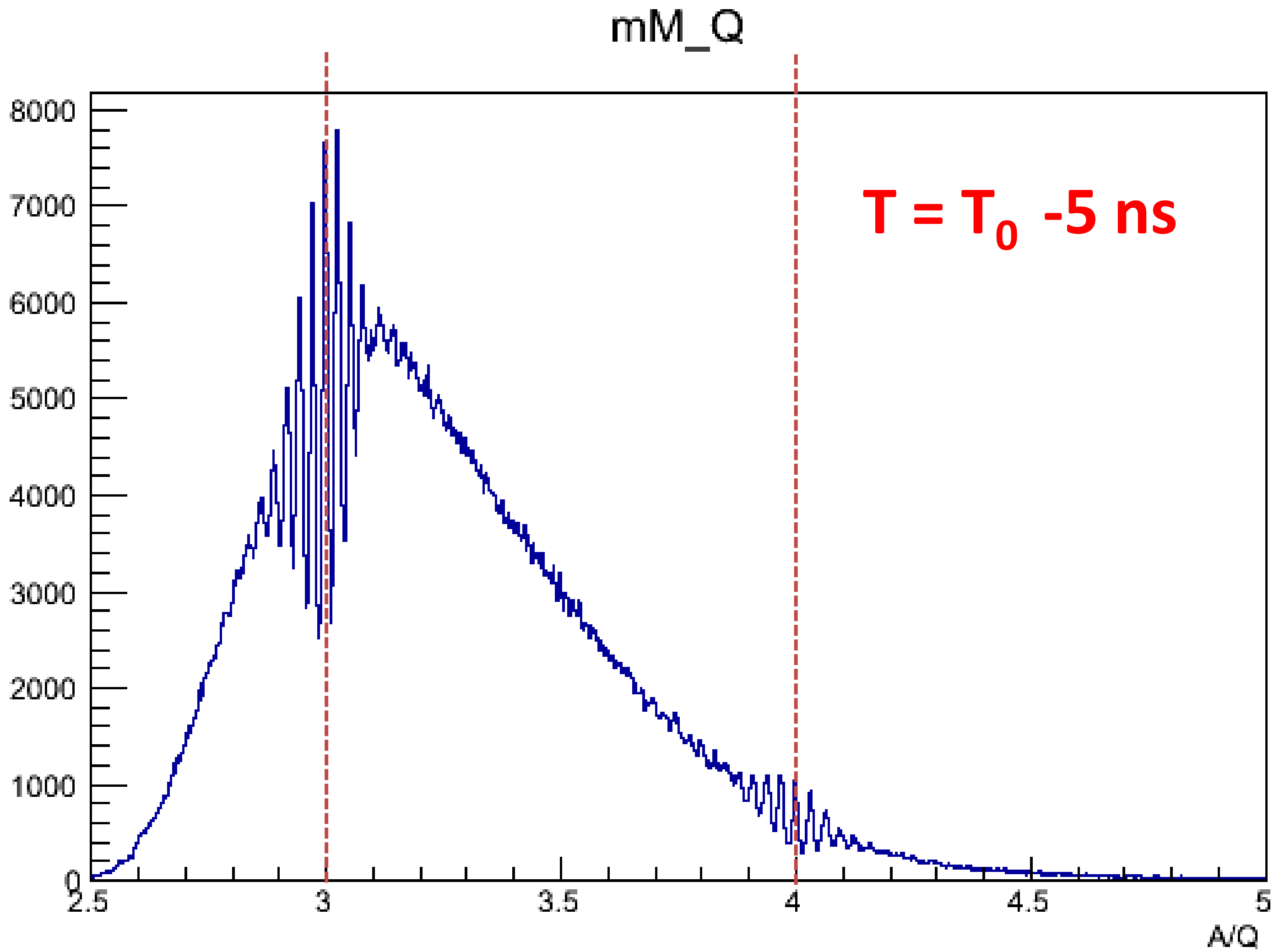
Adjusting TOF



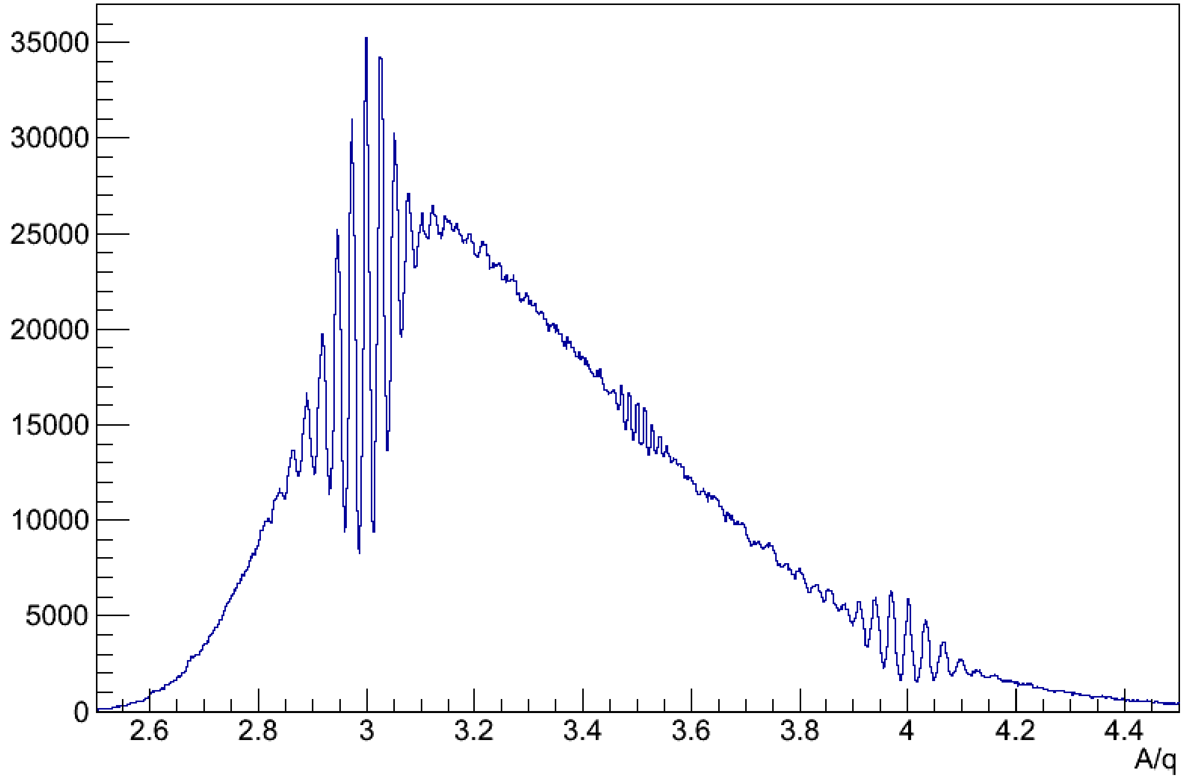
Adjusting TOF



Adjusting TOF



Time of flight



$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\,\beta\gamma}$$

Adjust time offset to match M/Q = 3 and 4
Section by sections

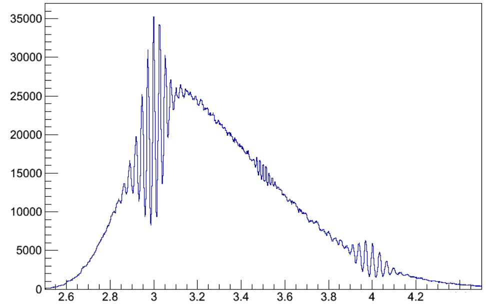
Calibration actions

- **TDC Calibration**
- **For each of 20 sections of MW**

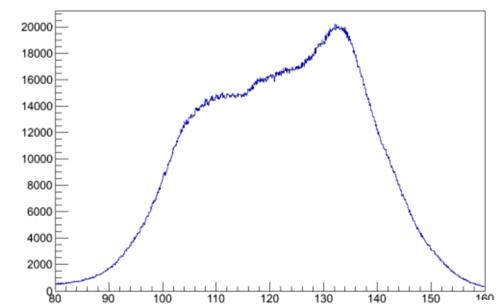
  Time alignement using M/Q and M information

Identify Q

Continuous



A/q

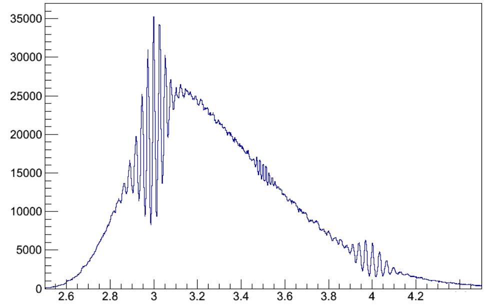


A

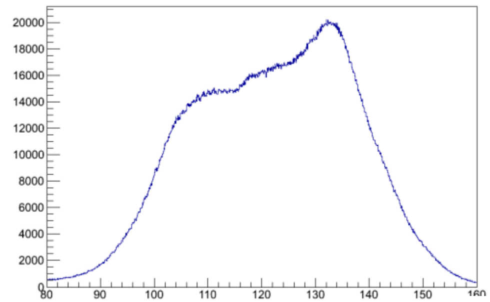
/!\ selected silicon detector !

Identify Q

Continuous

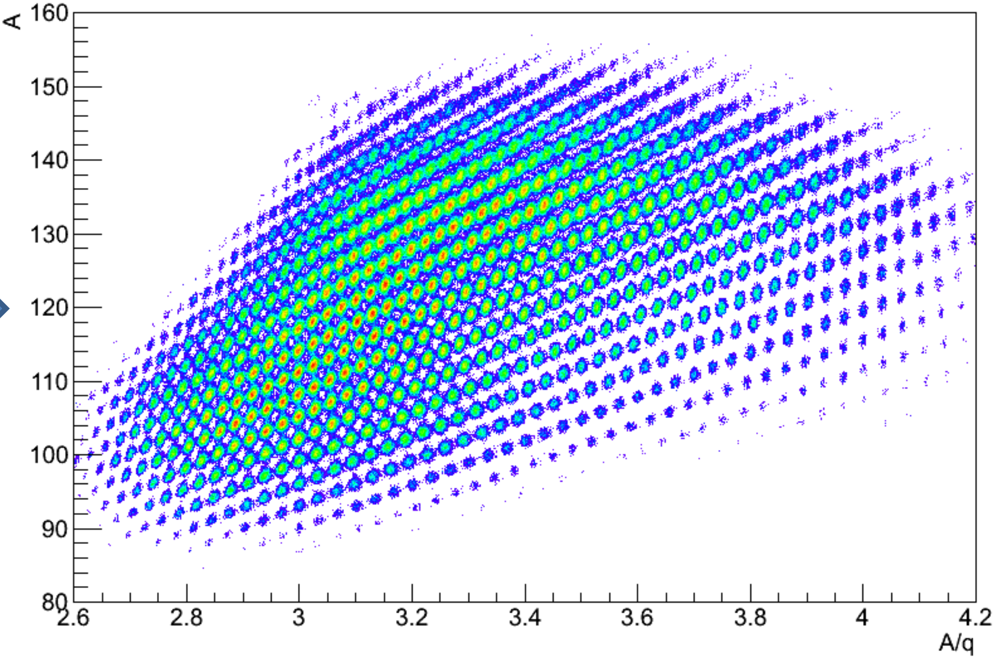


A/q



A

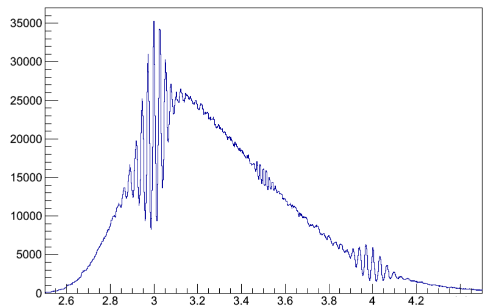
Discrete



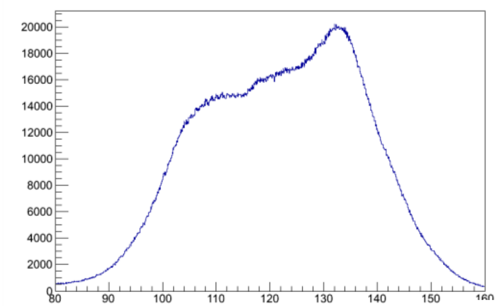
/!\ selected silicon detector !

Identify Q

Continuous

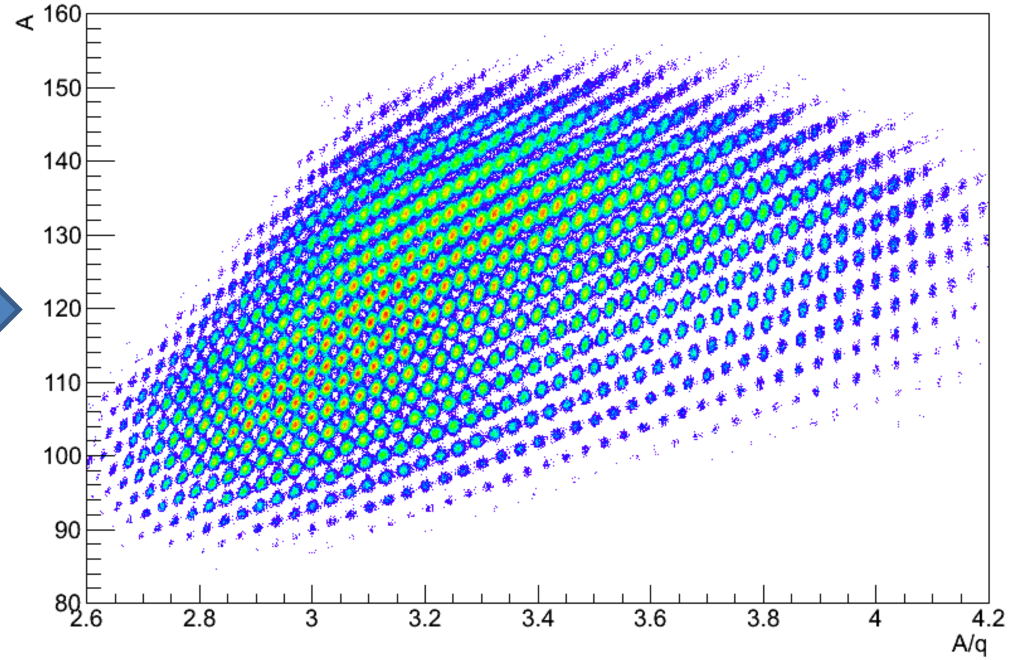


A/q



A

Discrete



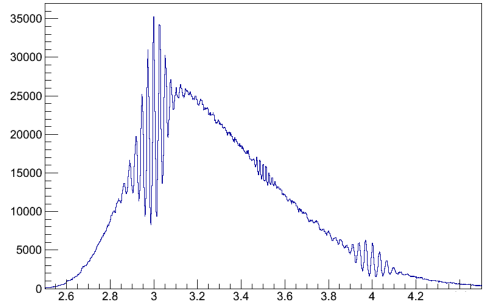
$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\,\beta\gamma}$$

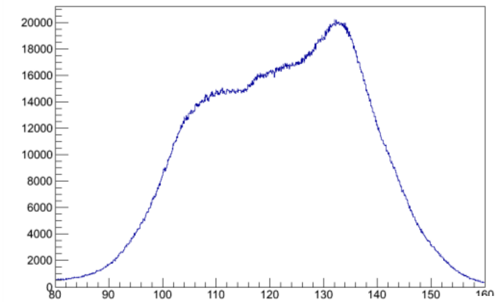
$$A = \frac{2E}{931.5\,\beta^2}$$

/!\ selected silicon detector !

Identify Q

Continuous

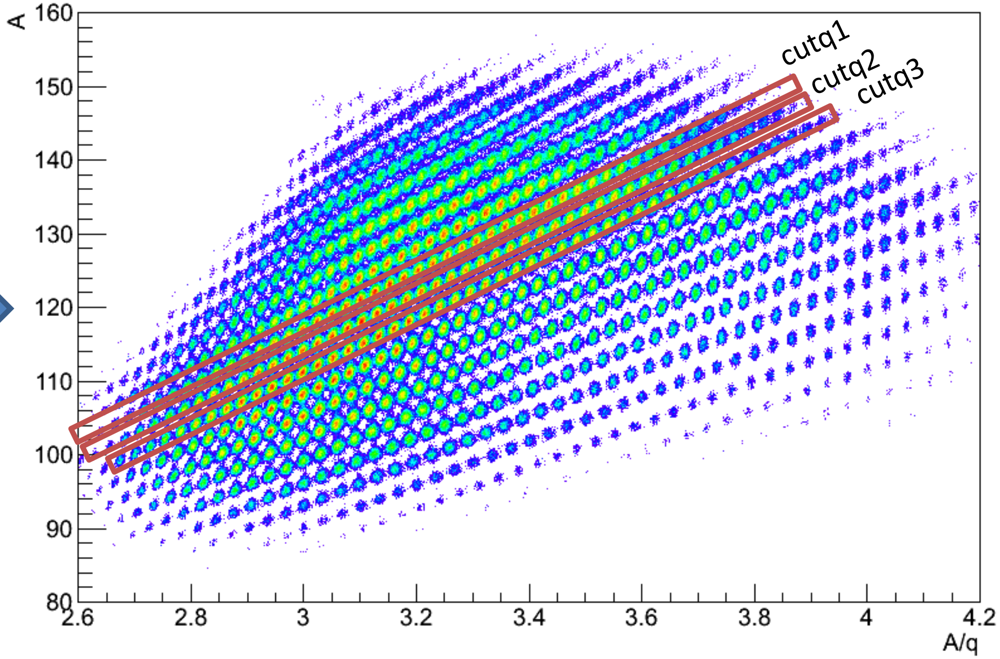




$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\,\beta\gamma}$$

$$A = \frac{2E}{931.5\,\beta^2}$$

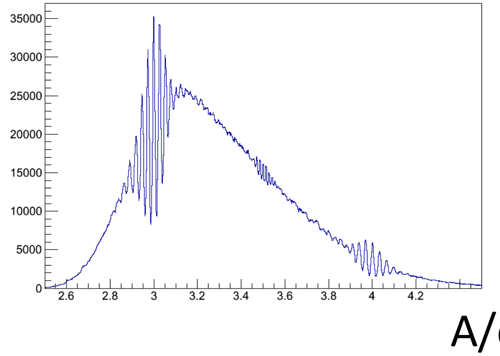
Discrete

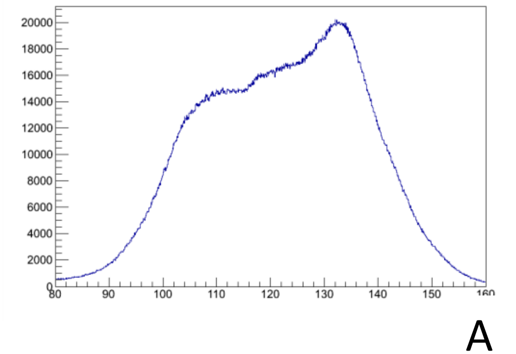


/!\ selected silicon detector !

Identify Q

Continuous

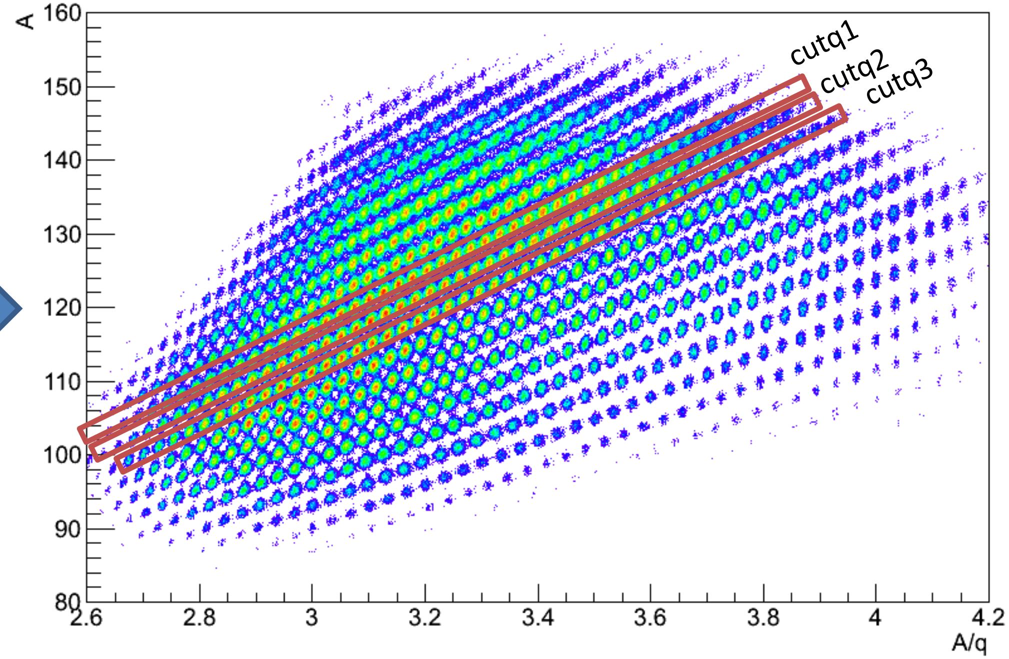




$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\,\beta\gamma}$$

$$A = \frac{2E}{931.5\,\beta^2}$$

Discrete

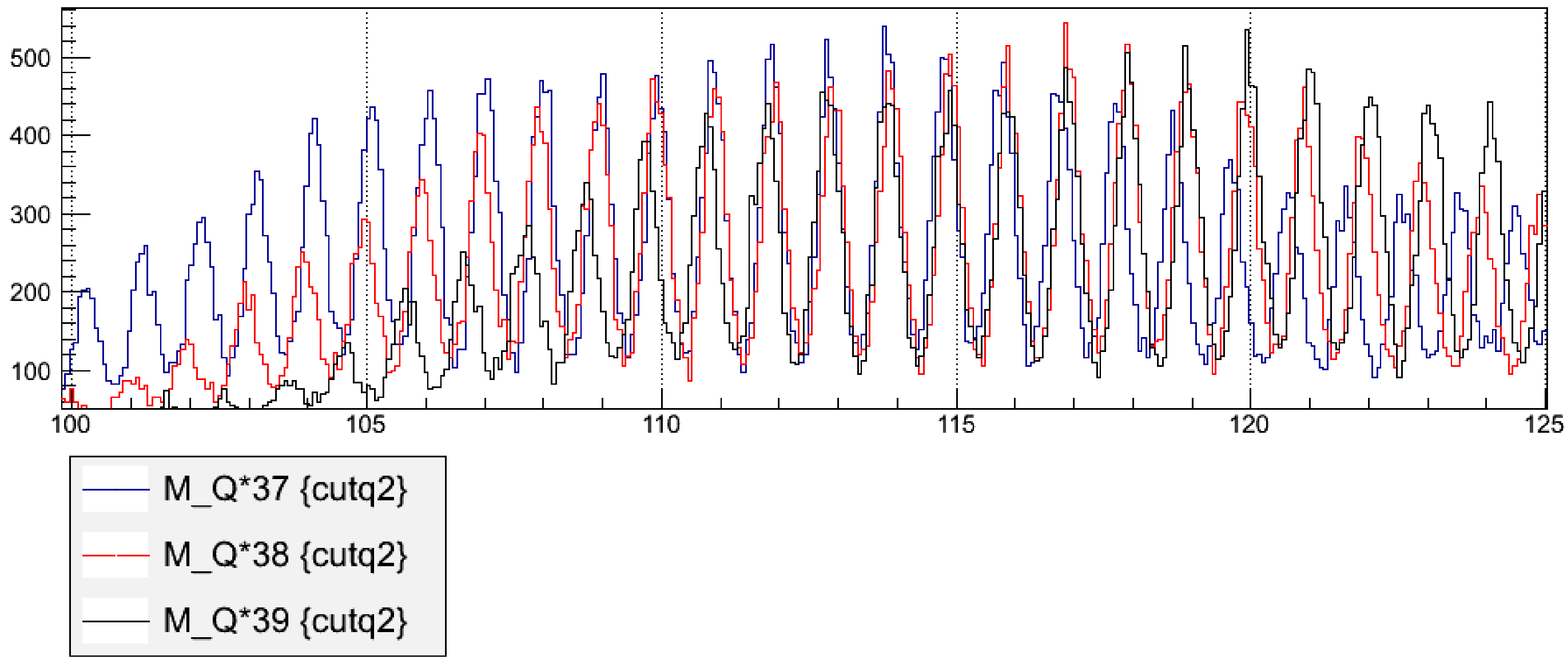


Hypothesis on cutq2 = (37,38 or 39)

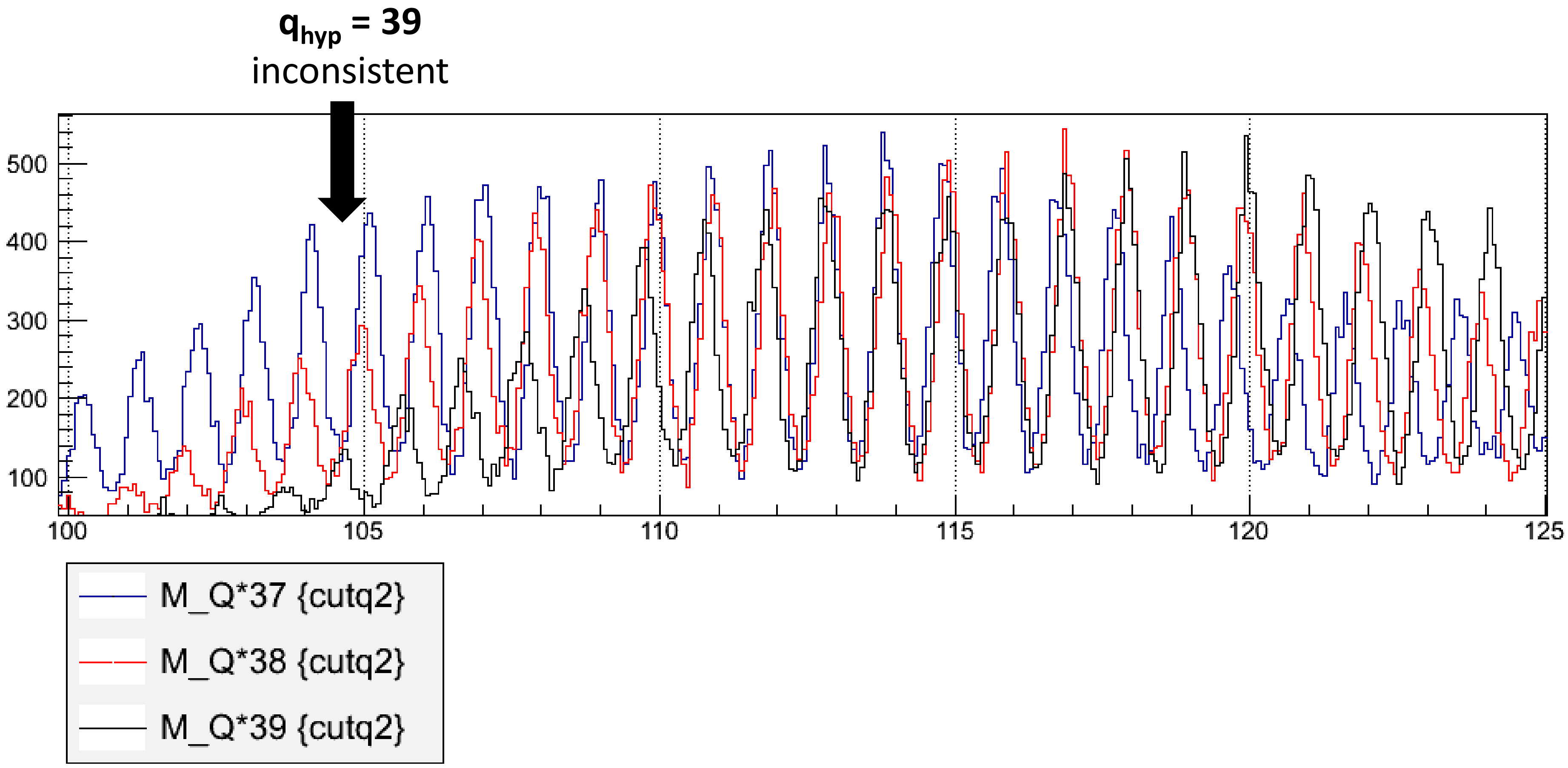
A = A/q * cutq2

/!\ selected silicon detector !

Identify q

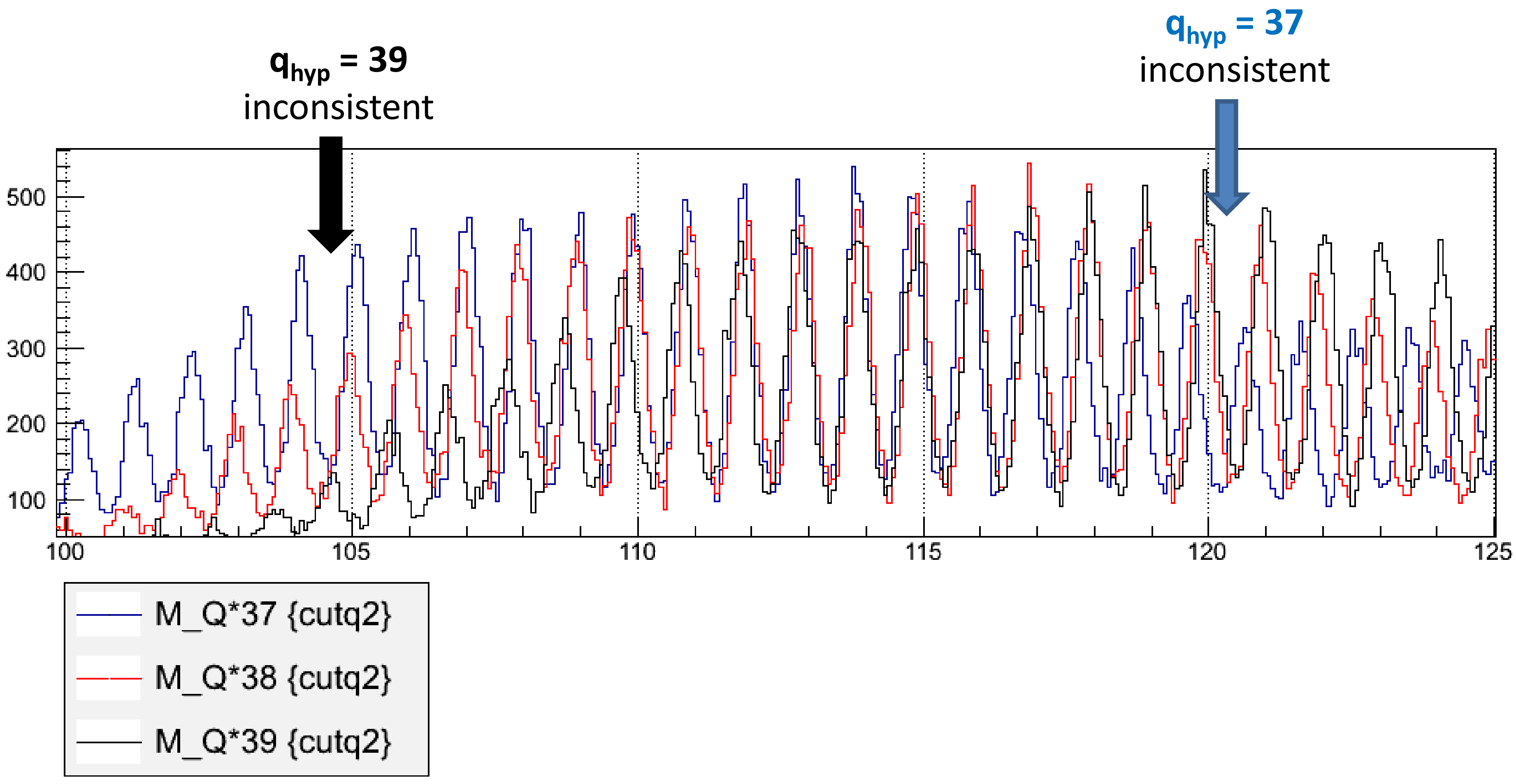

500
400
300
200
100
100
105
110
115
120
125
M_Q*37 {cutq2}
M_Q*38 {cutq2}
M_Q*39 {cutq2}

Identify q



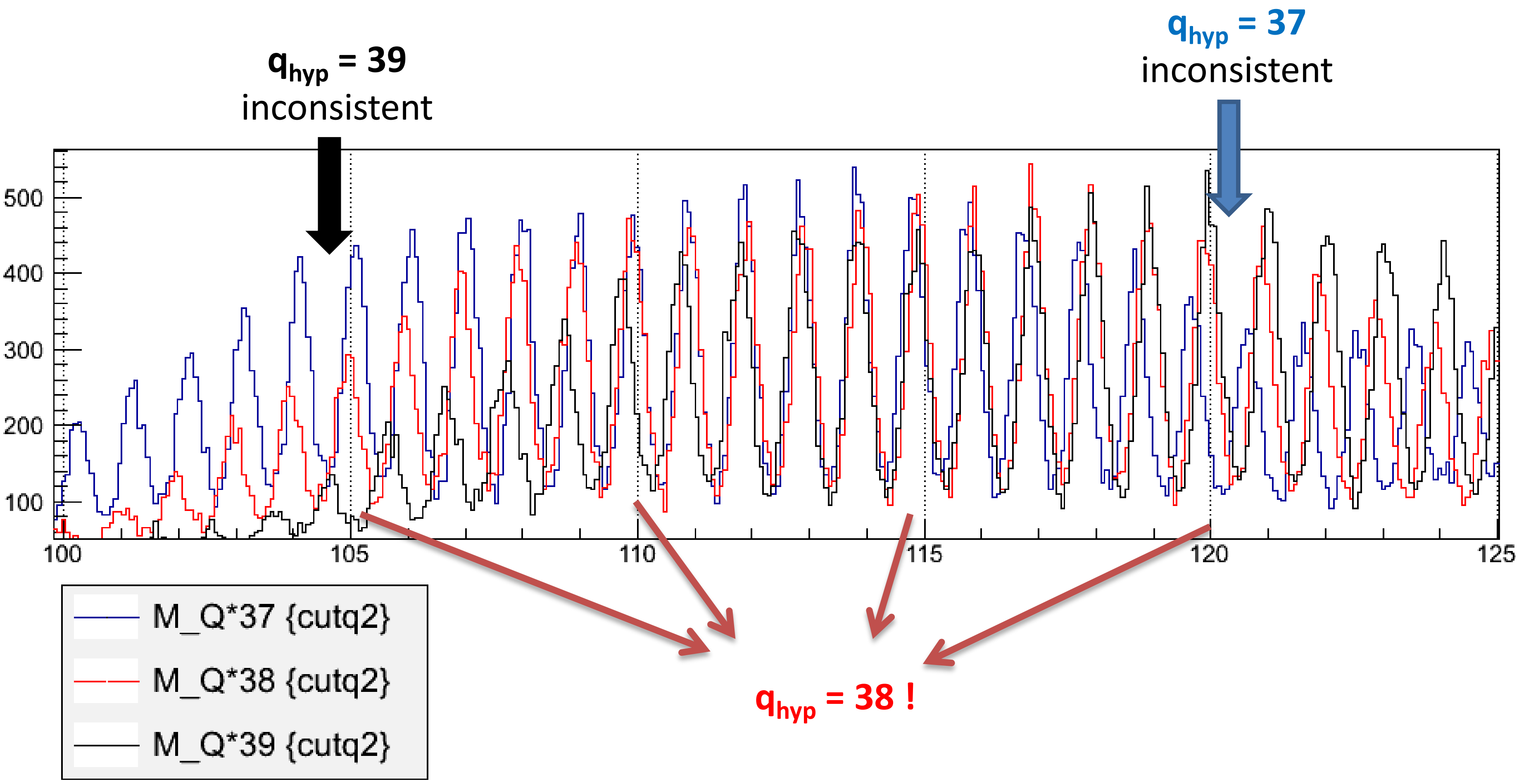
q_{hyp} = 39
inconsistent
500
400
300
200
100
100
105
110
115
120
125
M_Q*37 {cutq2}
M_Q*38 {cutq2}
M_Q*39 {cutq2}

Identify q



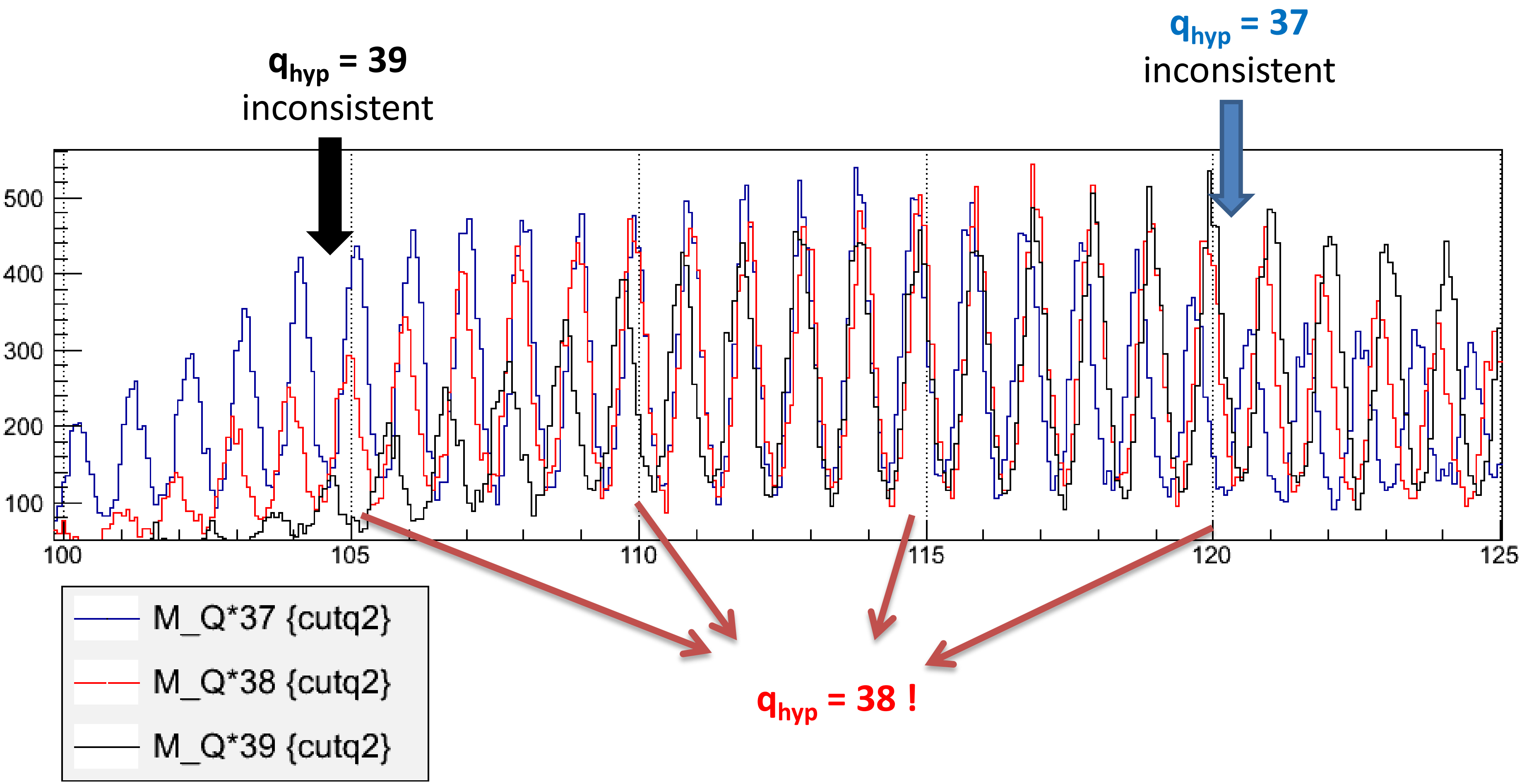
q_{hyp} = 39
inconsistent
q_{hyp} = 37
inconsistent
500
400
300
200
100
100
105
110
115
120
125
M_Q*37 {cutq2}
M_Q*38 {cutq2}
M_Q*39 {cutq2}

Identify q



q_{hyp} = 39
inconsistent
q_{hyp} = 37
inconsistent
500
400
300
200
100
100
105
110
115
120
125
M_Q*37 {cutq2}
M_Q*38 {cutq2}
M_Q*39 {cutq2}
q_{hyp} = 38 !

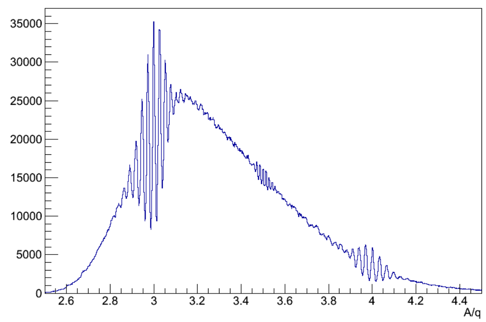
Identify q

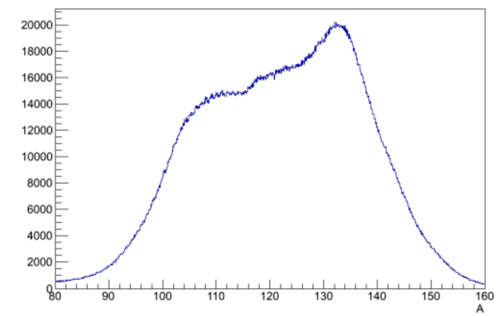


Cross check with two neighbouring q

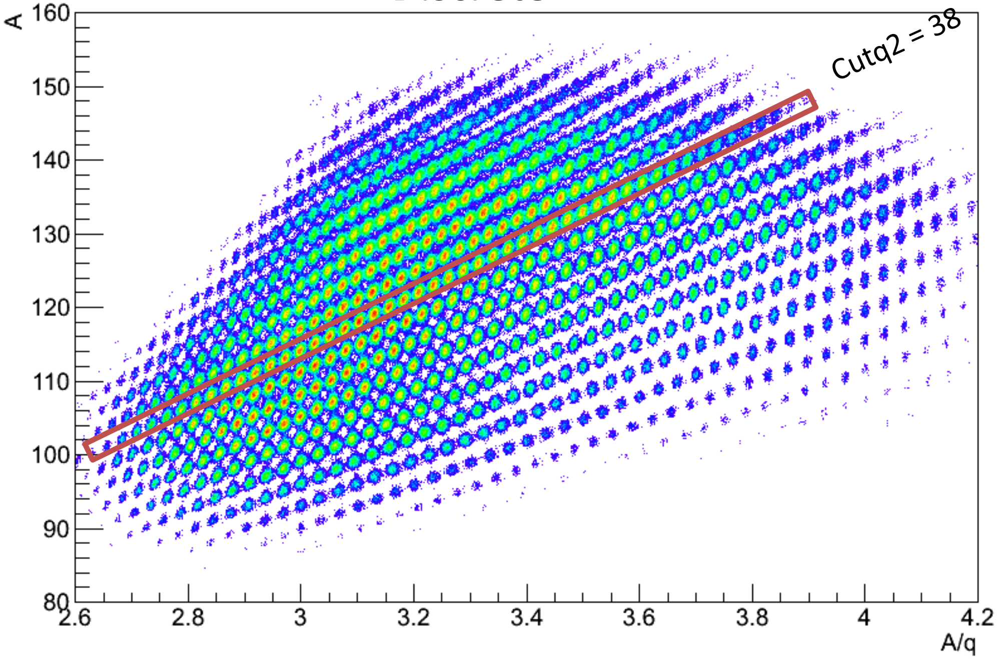
Identify Q

Continuous





Discrete

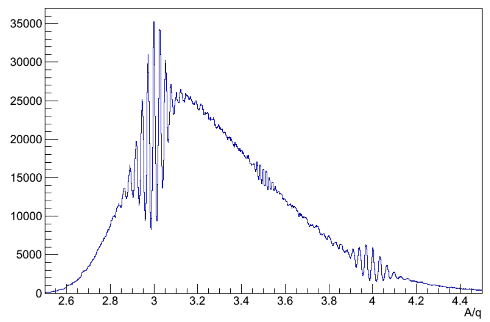


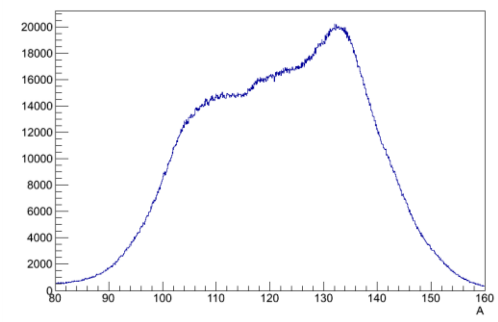
$$\frac{A}{q} = \frac{B\rho[Tm]}{3.105\,\beta\gamma}$$

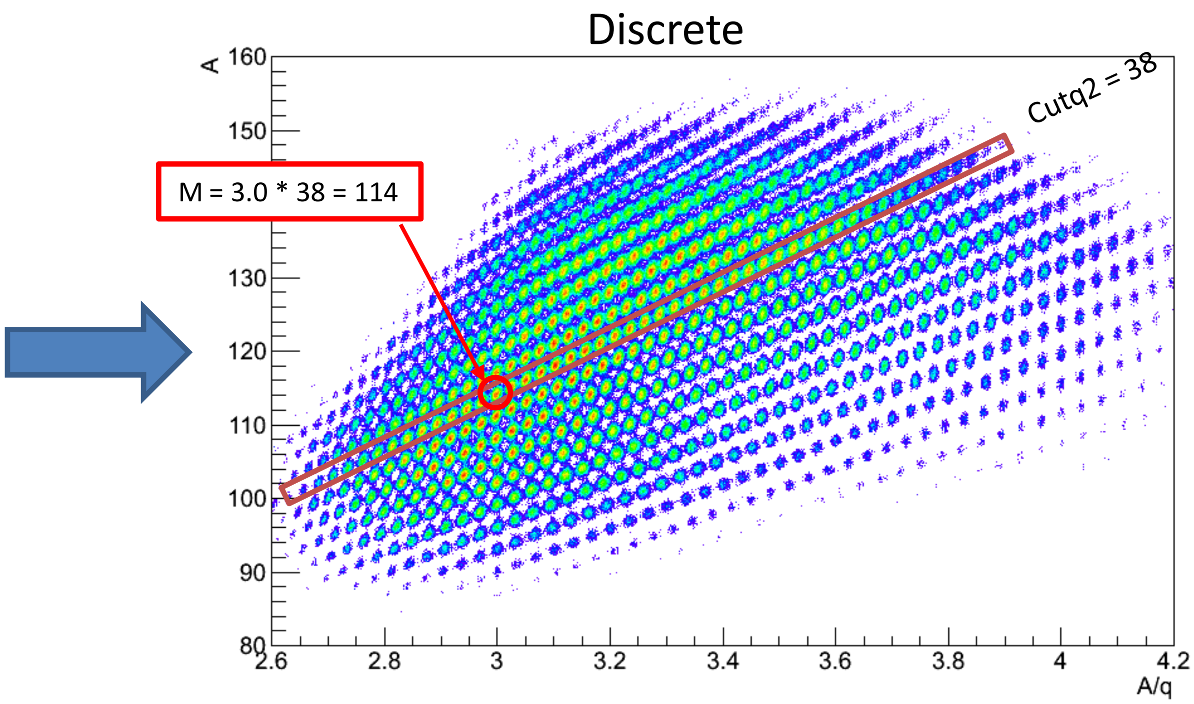
$$A = \frac{2E}{931.5\beta^2}$$

Identify Q

Continuous







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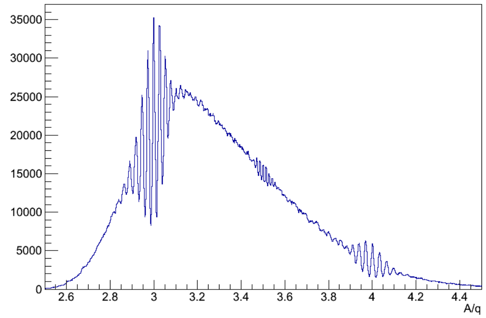
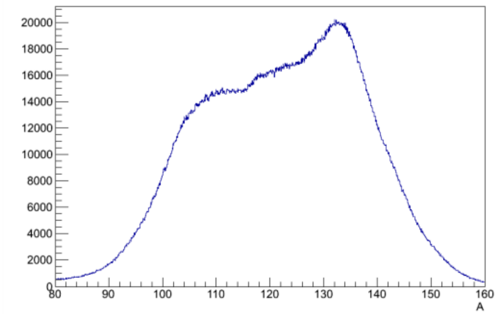
Continuous





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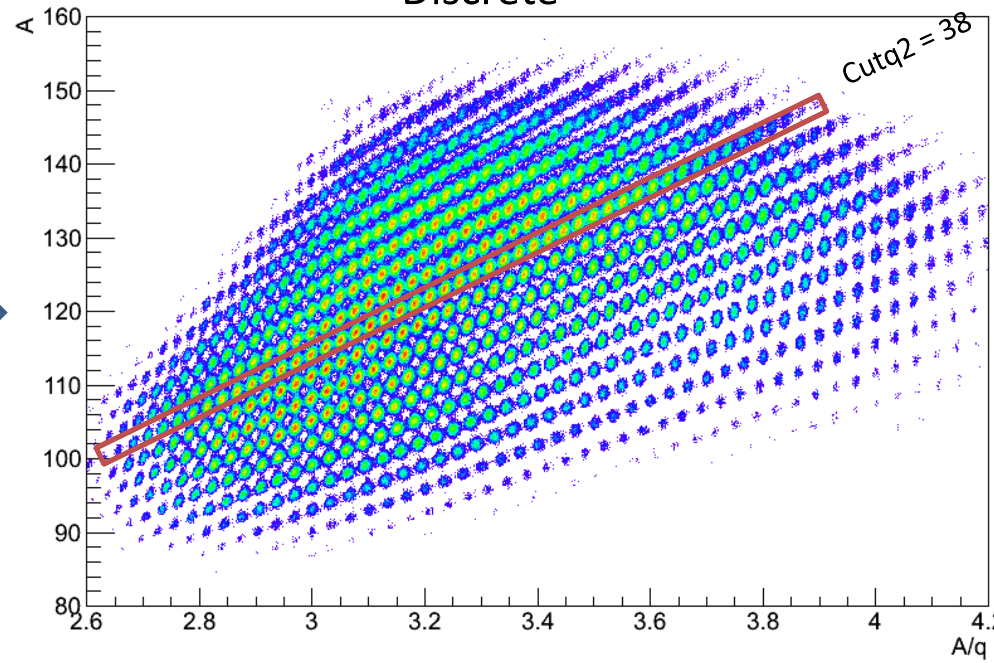

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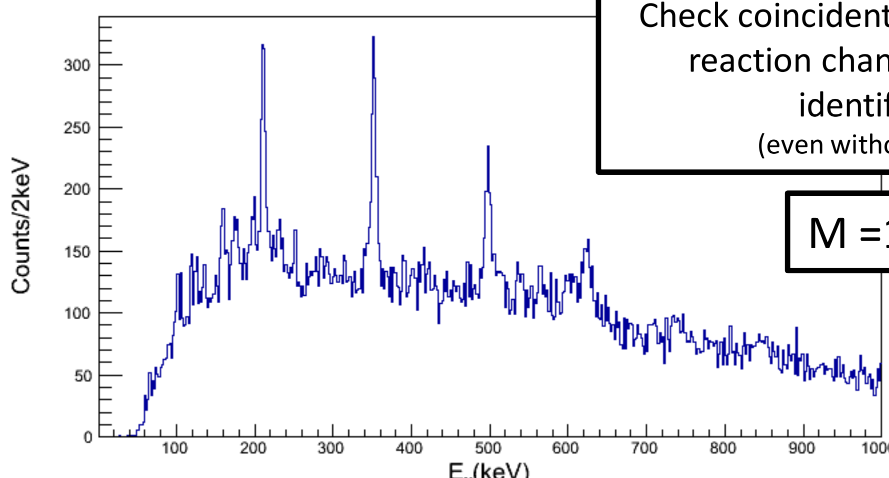


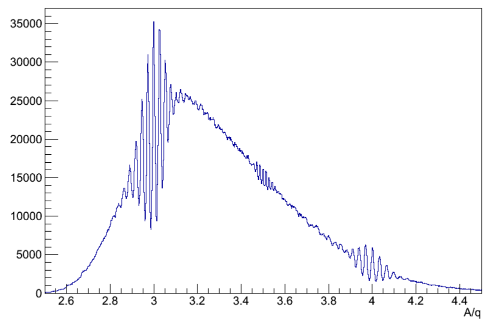
Check coincident γ-ray with strong reaction channel to confirm identification

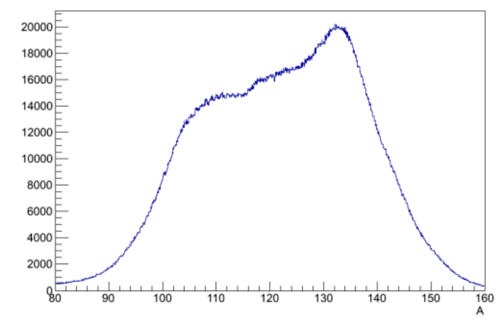
(even without Z gate …)

M =100

Identify Q

Continuous





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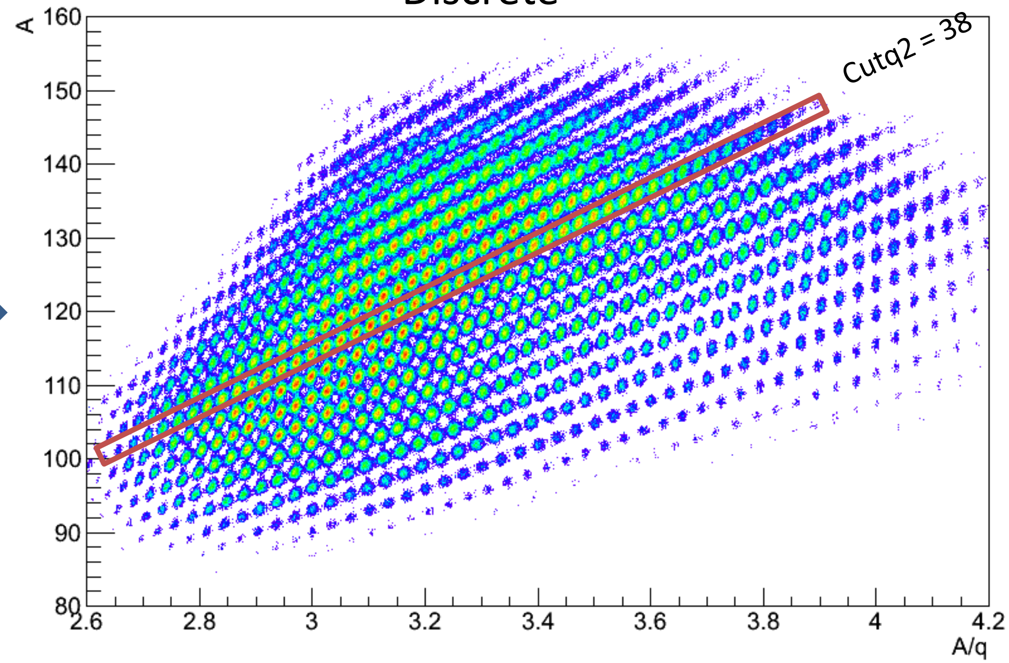

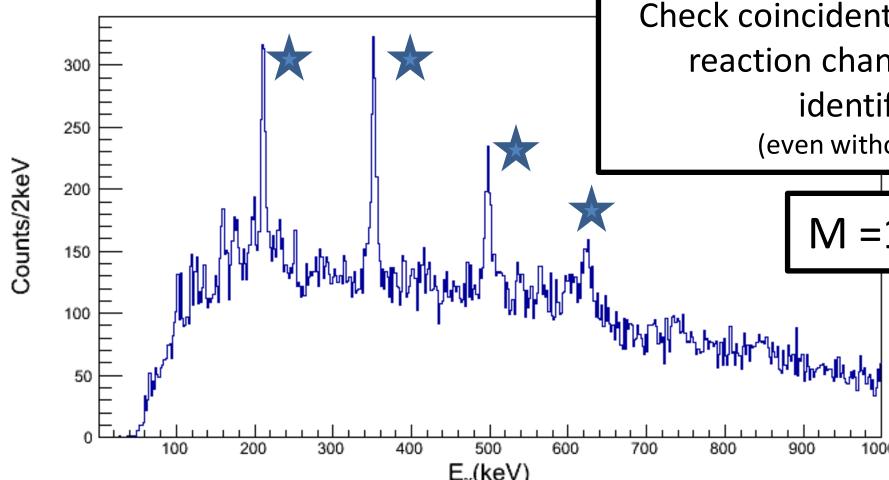

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(even without Z gate ...)

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★ ^{100}Zr

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Repeat for all Sections (t) and pads (E,dE)

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to determine precisely the energy calibrations.

=> To be able to define **A** and **q** as parameters independently of SiNr or MW section

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But also you need to think about these :

- Energy losses in dead layers
- Windows deformation
- Pulse Height Defect
- Time evolution of Pressure, Leakage current (radiation damage)
- …

Offline Analysis!

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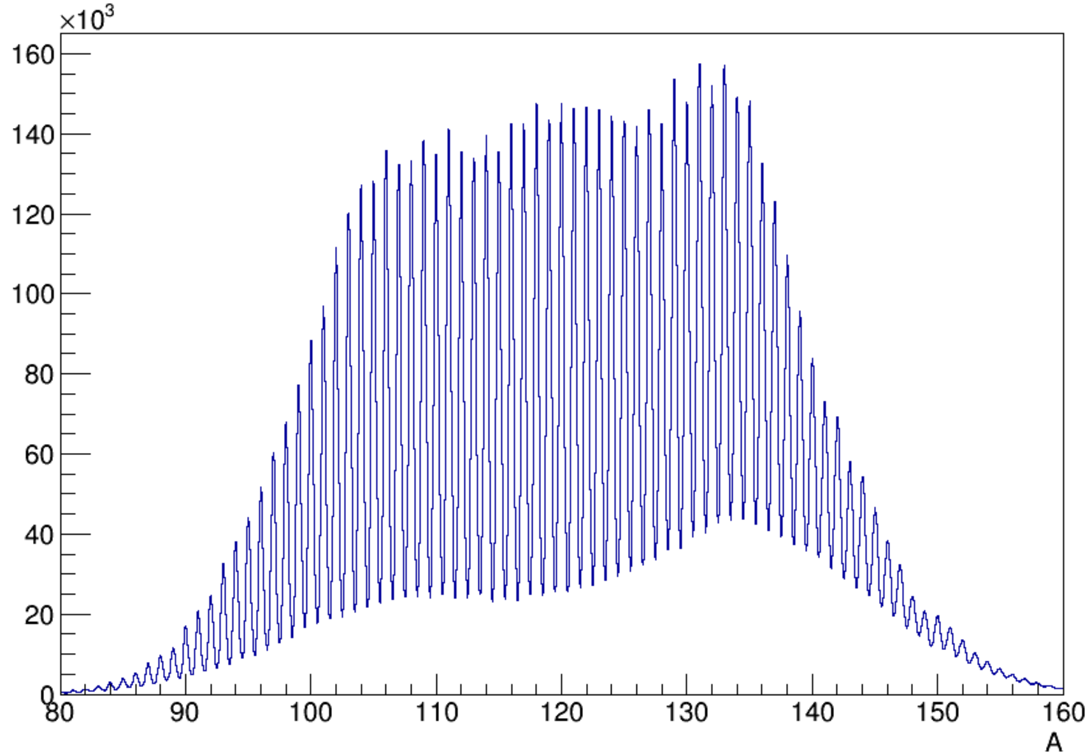
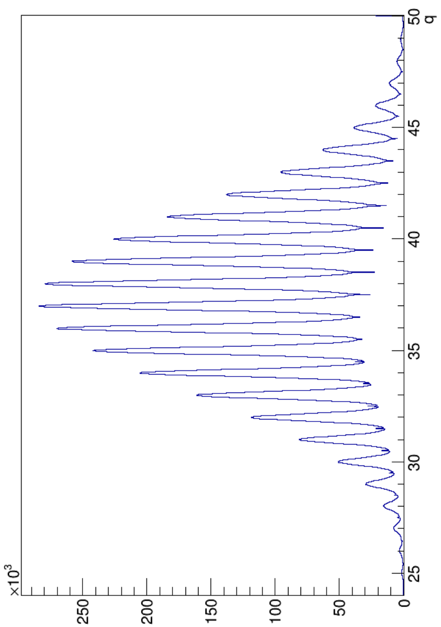
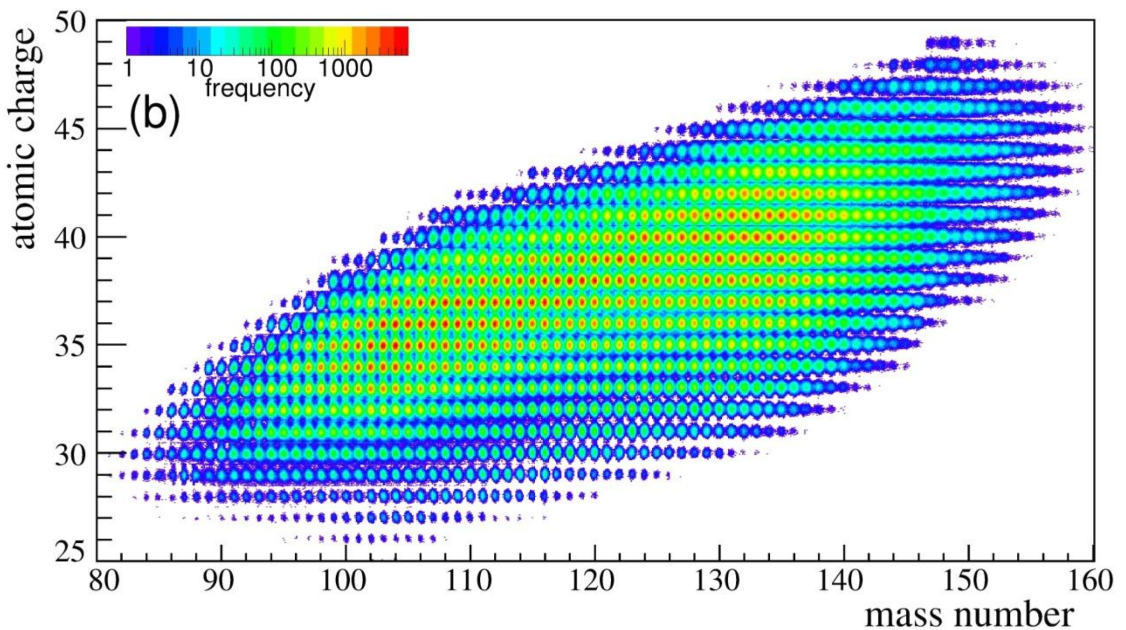
Offline Analysis!

Voila !

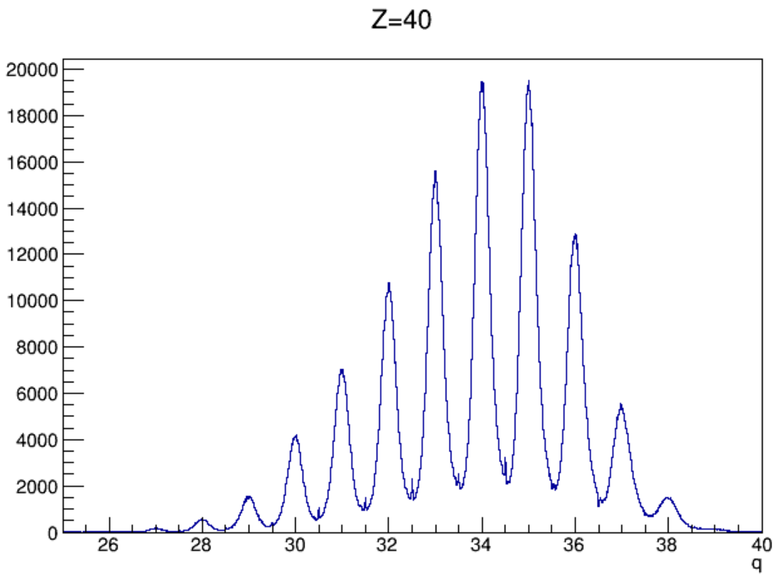
Isotopic identification of fission fragment event by event

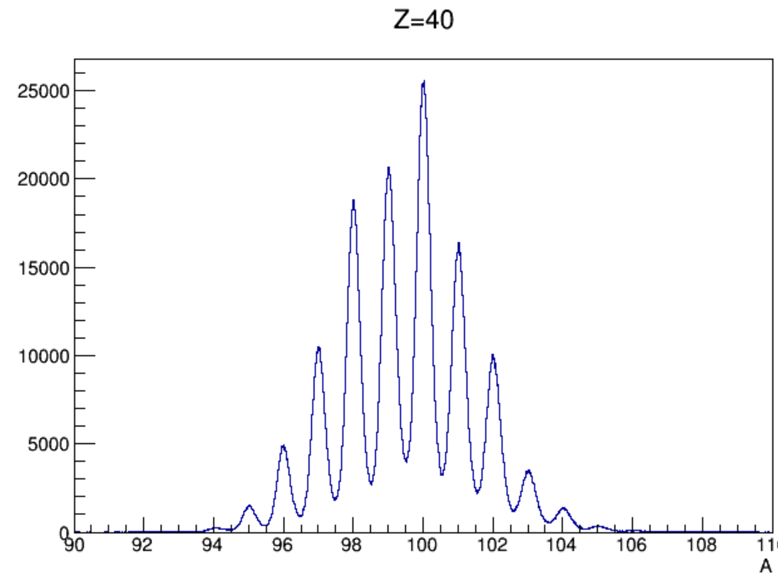


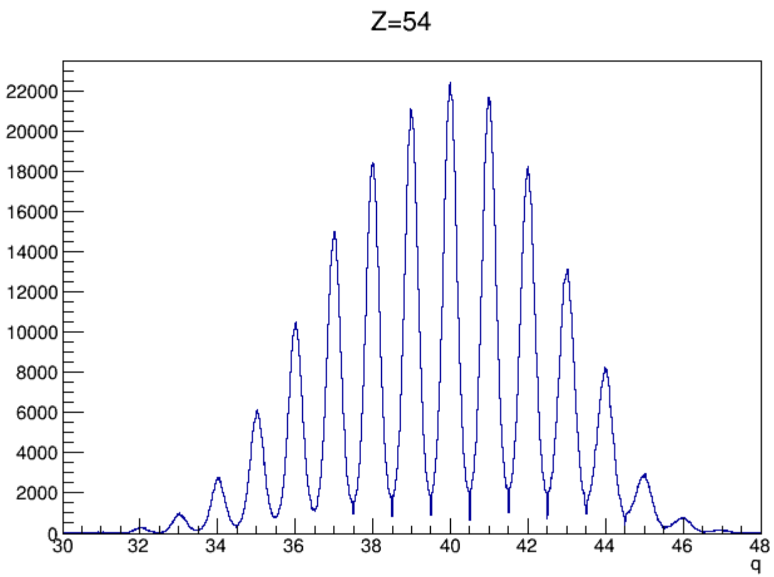


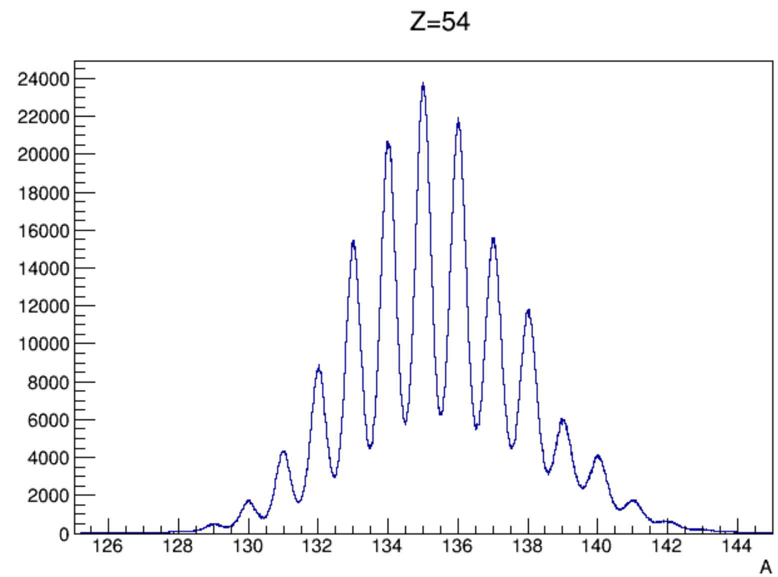


A and q Distributions









Analysis Steps

- Reconstruction of trajectories at the focal plane
- Magnetic rigidity, Path and recoil angles
- Velocity
- E, dE , Etotal
- Mass and Charge states

  ➔A,Z,Q
- Use recoil angle and velocity to make Doppler correction

Questions ?

PRACTICAL SESSION

Practical Session

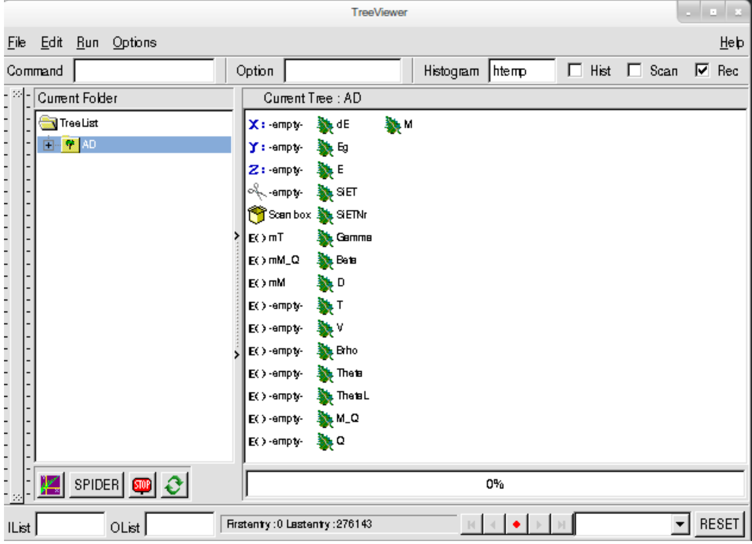
You will identify q from the data set I have prepared

Reduced DataSet from previous experiment
^{238}U+Be -> Fission (VAMOS + EXOGAM)

- simplified data set (one silicon detector, one Multiwire section)
- Representative of few hours of data after startup
- I have uncalibrated the data that it took much time and efforts to calibrate !!!!

- Step 0 : Open Data file – ROOT Tree
- Step 1 : Time Alignment
- Step 2 : q identification
- Step 3 : gamma spectra

Step 0 : Open Data File



- Root OpenTree.cpp
  - In the command line
    - tree->Draw("VariableName>>(1000,1,1000)" ," condition" ,"PlotOpt")
    - tree->Draw("V1:V2>>(1000,1,1000 ,1000,1,1000)" ," condition" ,"PlotOpt")
  - Set of alias variable :
    - mT = TOF
    - mV = mT /D; mBeta = mV/c
    - mM_Q = Brho / 3.105/mBeta/mGamma
    - mM = 2 * (mE + mdE) / (mGamma-1.)
    - mE
    - mdE
    - Eg = Vector of Doppler corrected Gamma Energies
  - Change a variable : tree->SetAlias("mT" , "TOF+10");

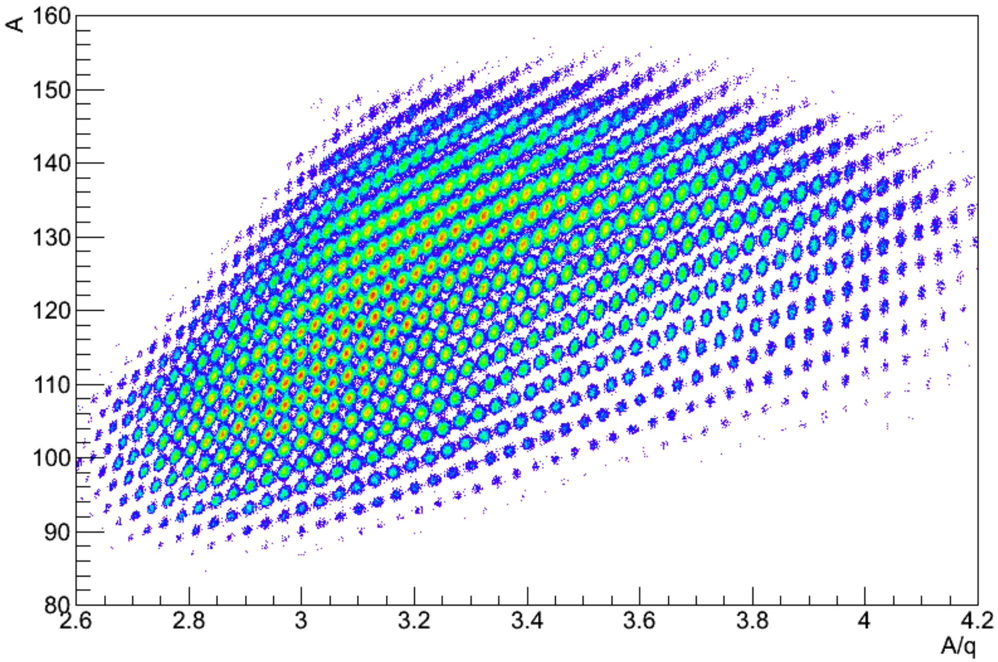
Step 1 :
Do the time alignement to get back M_Q

- Plot M/Q spectra
  - tree->Draw(“mM_Q>>(1000,2.5,5)”)
- Change Time Calibration
  - tree->SetAlias(“mT” ,” TOF+5”);
  - tree->Draw(“mM_Q>>(1000,2.5,5)”);

Find the Offset ?

Step 2 : Identify Q

- PlotM_M_Q()



- Do you see a difference ?
- Is it important ?

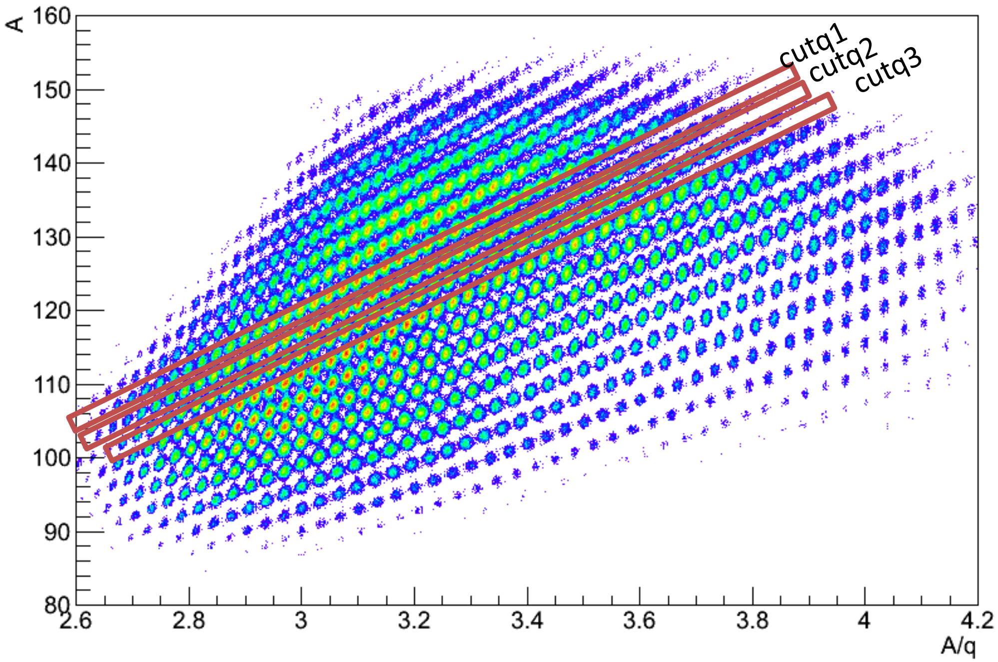
- To Project

tree->Draw(“mM_Q*qhyp>>histo1(1000,80,180)”,” cutname”)

Assign q !

Step 2 : Identify Q

- PlotM_M_Q()



- Do you see a difference ?
- Is it important ?

- To Project

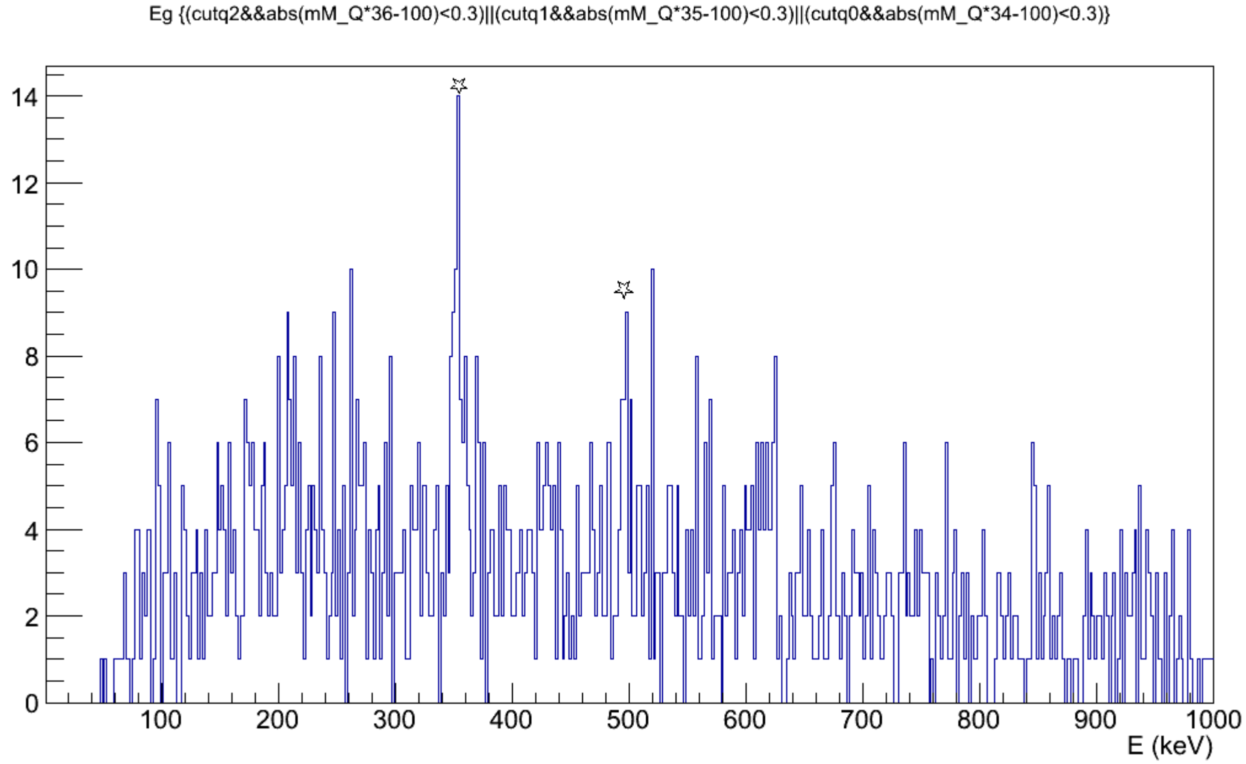
tree->Draw(“mM_Q*qhyp>>histo1(1000,80,180)”,” cutname”)

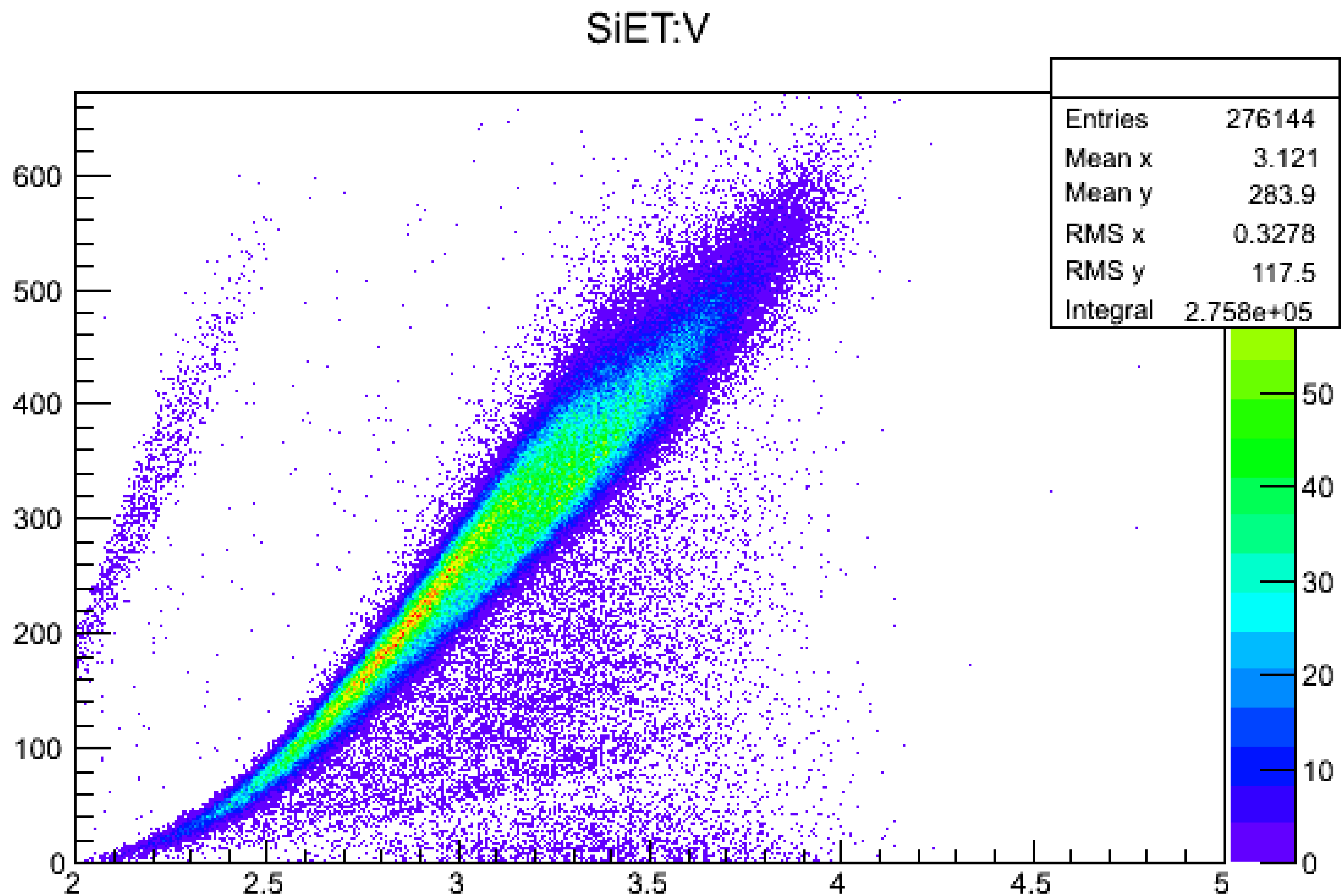
Assign q !

Step3 : gamma Spectra

tree->Draw("Eg>>Eg(1000,80,180)","(abs(mM_Q*q1-100)<0.3&&cutq1)||
(abs(mM_Q*q2-100)<0.3&&cutq2)||
(abs(mM_Q*q3-100)<0.3&&cutq3)")

- ^{100}Zr strongly populated :
  - Eg = 212.9kev, 351.9keV, 497.4 keV,





SiET:V
Entries 276144
Mean x 3.121
Mean y 283.9
RMS x 0.3278
RMS y 117.5
Integral 2.758e+05
0
100
200
300
400
500
600
2
2.5
3
3.5
4
4.5
5
10
20
30
40
50

Before the experiment

- Kinematics Simulations / Acceptance
  - Beam (charge states), Inelastic
  - Residues, Fission, DIC
  - Time of flight ?
- Energy losses
  - Optimize Energy losses for Z identification
    - Pressures
    - Windows
- Specific Trigger ? (standard ion-gamma)

Just before the experiment

- DC Calibrations
  - Electronics Gain matching
  - Thresholds
- MW position Calibrations
  - Electronics Gain matching
  - Thresholds
- IC Calibration
  - Electronics Gain matching
  - Thresholds
- TAC Calibrations

During the experiment

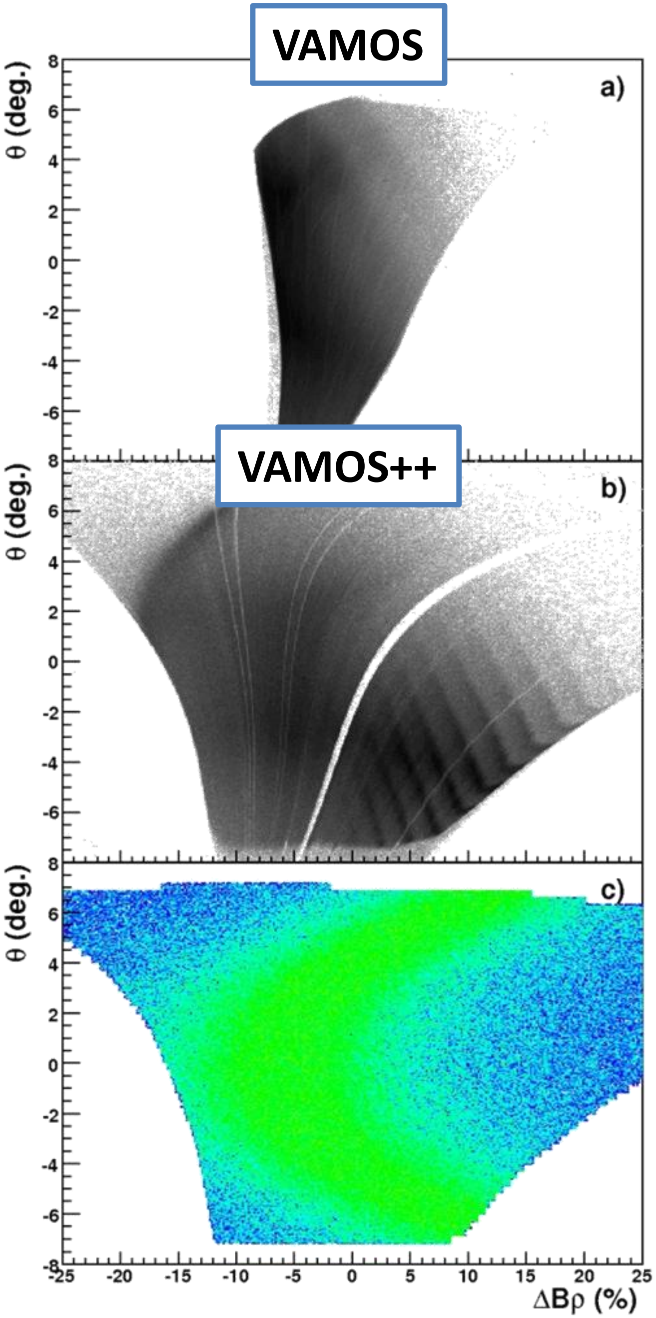
- IC Resolution (! 20 Pads)
- Time MW alignement => M/q resolution (! 20 sections)

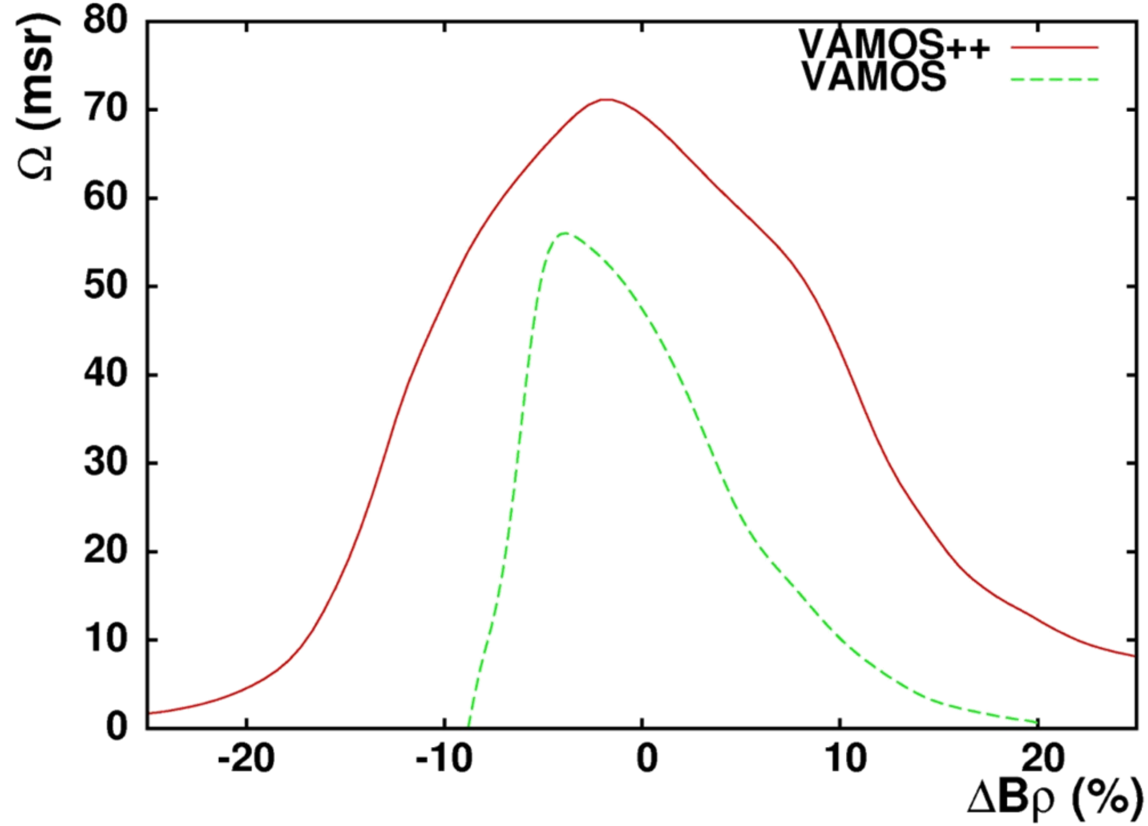
=> Reference Positions in DC

- X
- Y

=> IC Calibrations

Acceptance





Effective solid angle depends on the magnetic rigidity of incoming ion

M. Rejmund et al,
NIM A 646 (2011) 184