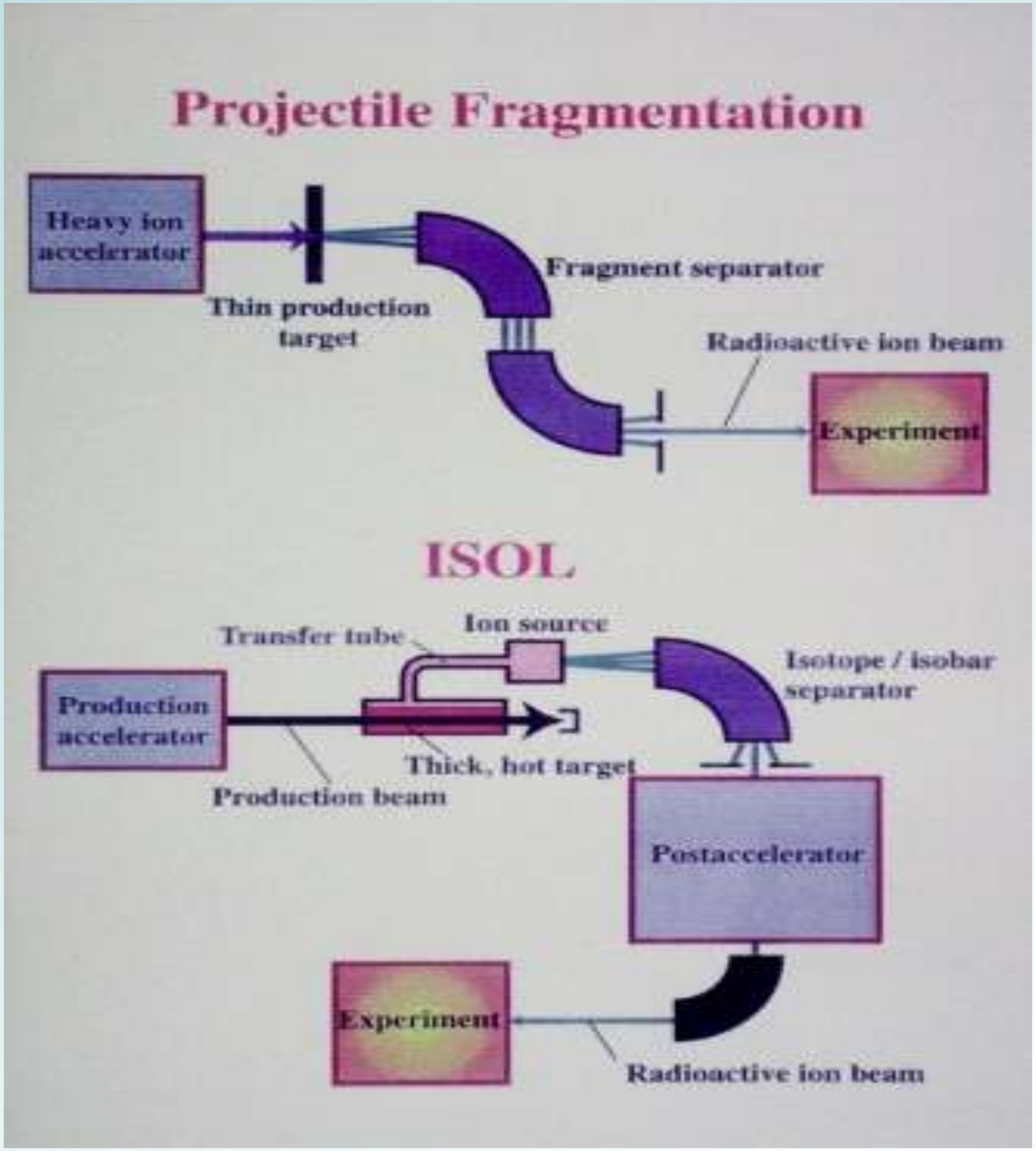
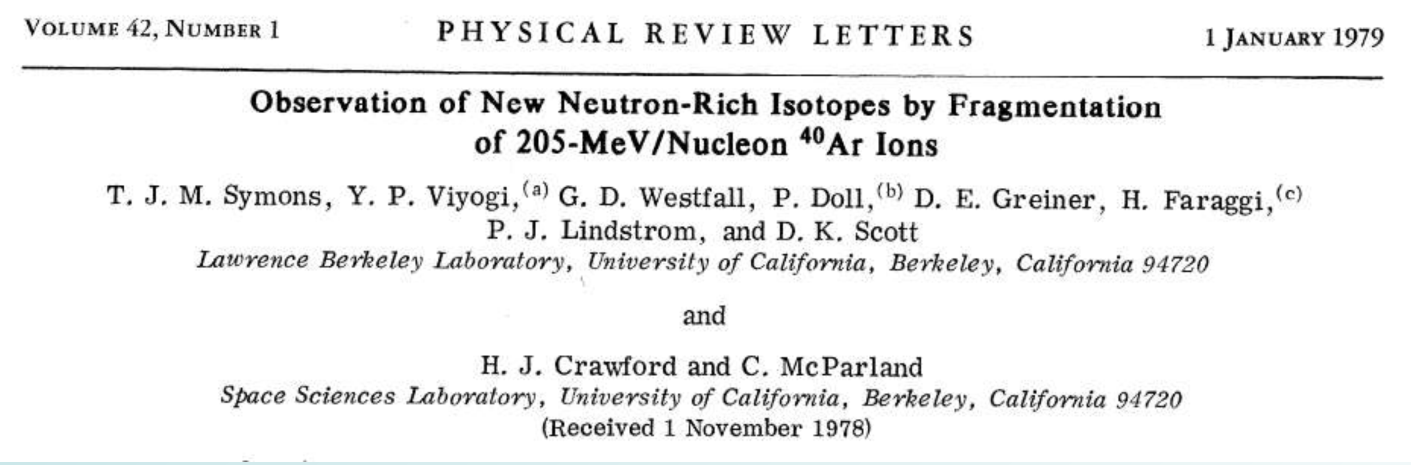
Techniques for radioactive beam production



Sin dagli inizi degli anni 80 ci si è resi conto che le reazioni di frammentazione permettono di produrre fasci esotici



VOLUME 42, NUMBER 1 PHYSICAL REVIEW LETTERS 1 JANUARY 1979

Observation of New Neutron-Rich Isotopes by Fragmentation of 205-MeV/Nucleon ^{40}Ar Ions

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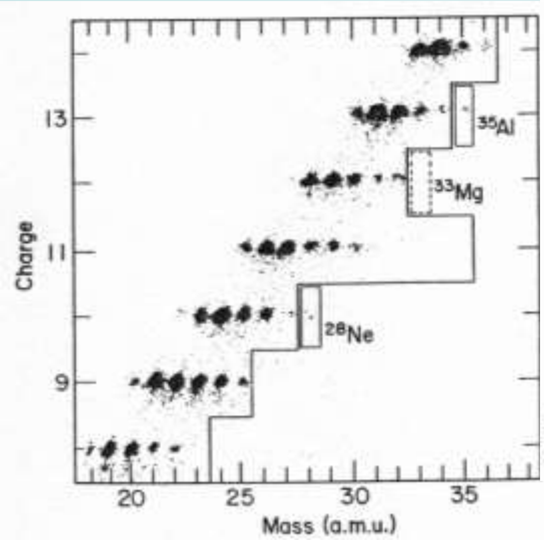
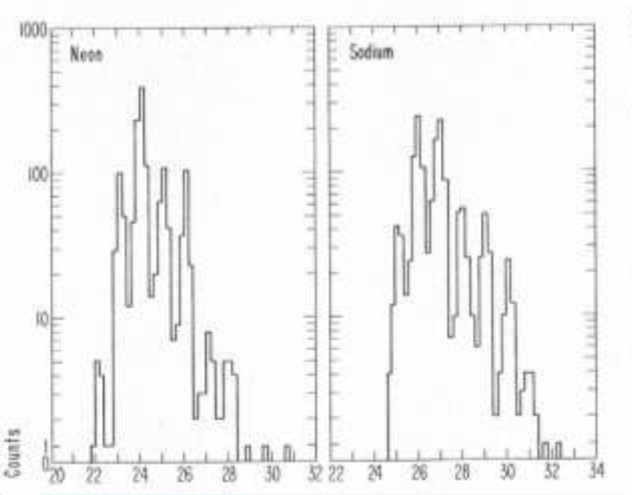
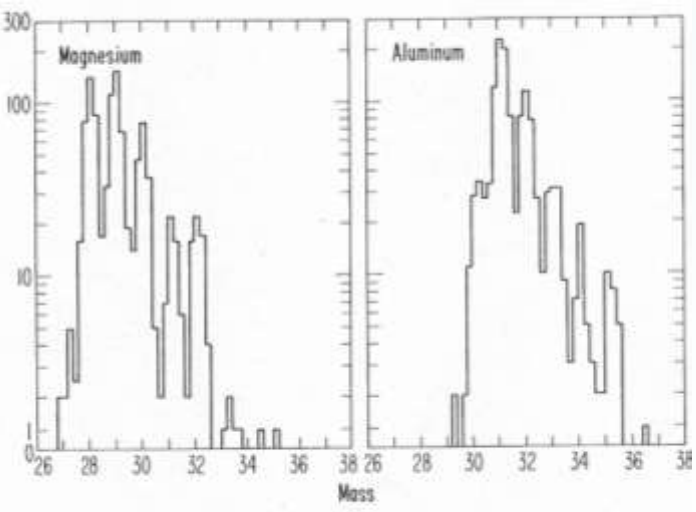
(Received 1 November 1978)



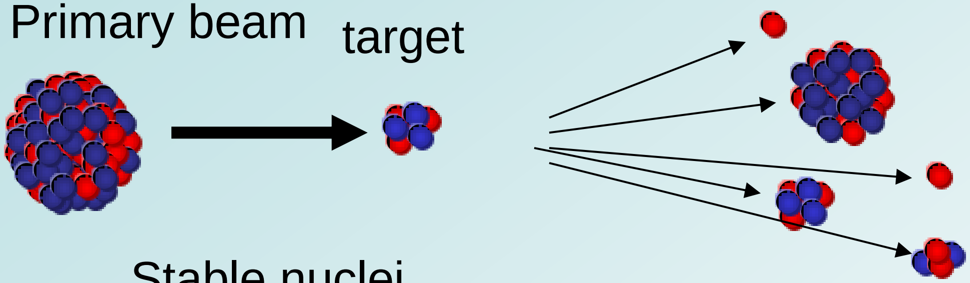




Fragmentation beams: generality

What we need to produce a fragmentation beam?

We need to have an high energy beam to produce fragmentation reactions



Primary beam

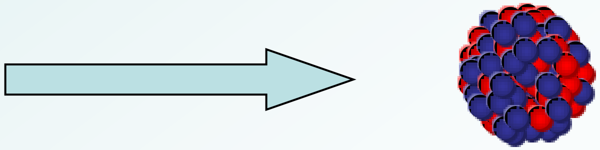
target

Radioactive
&/OR
stable nuclei

Stable nuclei

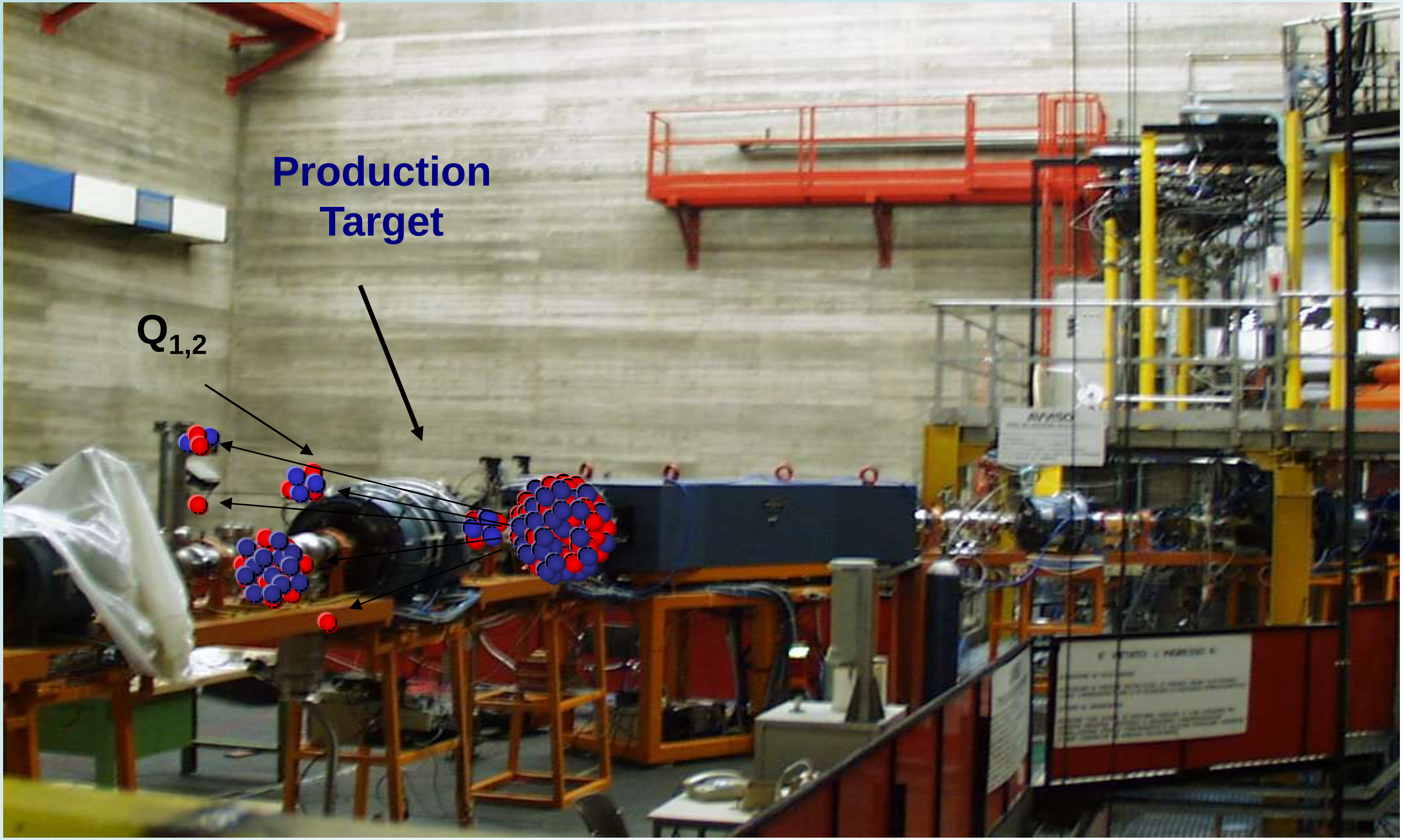
Characteristics of the fragmentation reactions is that fragments are emitted in forward direction with velocity similar to that of the projectile especially if a light target is used

To produce the Beam we use our cyclotron



40-60 MeV/A

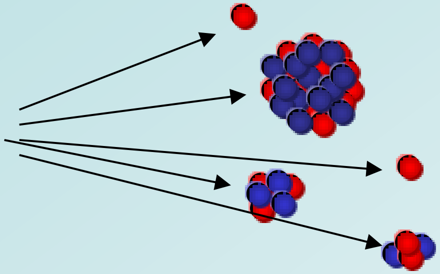
Fragmentation beams : beam production



Production Target

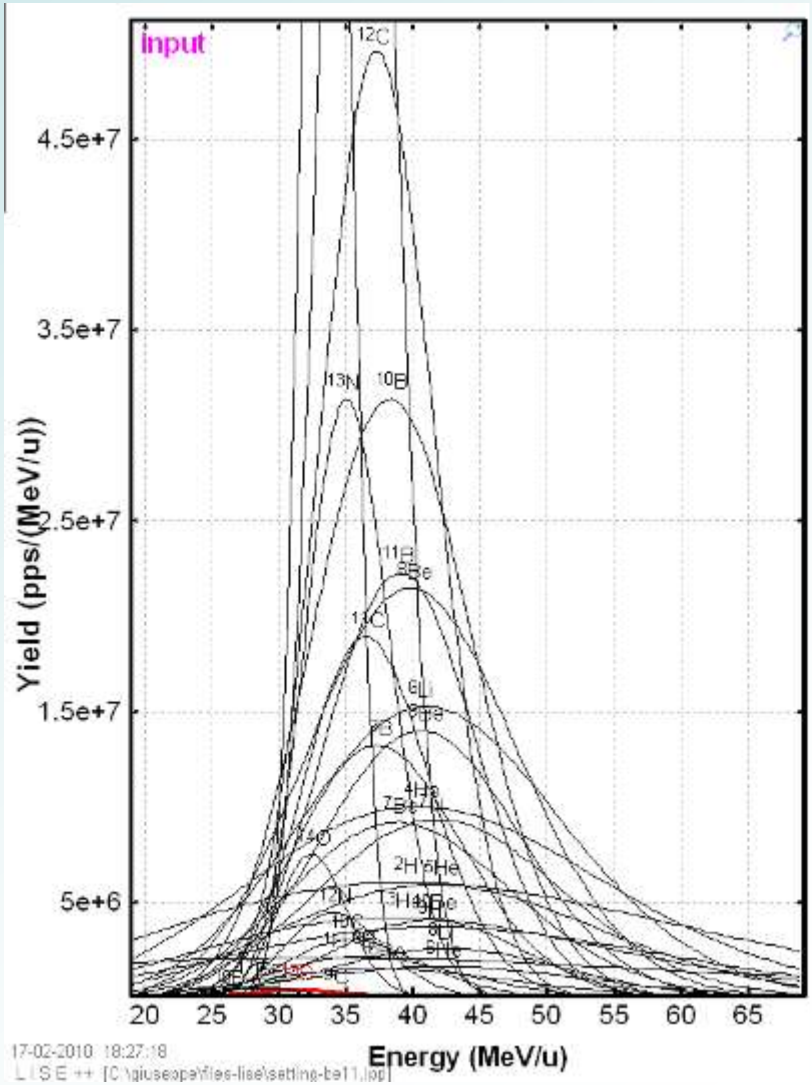
$Q_{1,2}$

Fragmentation beams : energy distribution

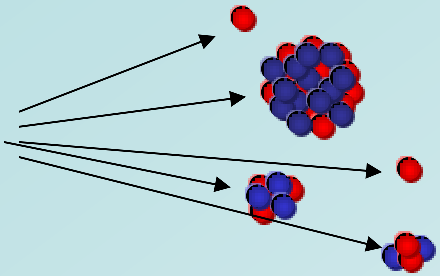


after the collision we produce many beams with some energy and angular spread characteristic of the reaction

$^{16}O + ^{9}Be$ (2.5mm) at 55 MeV/A



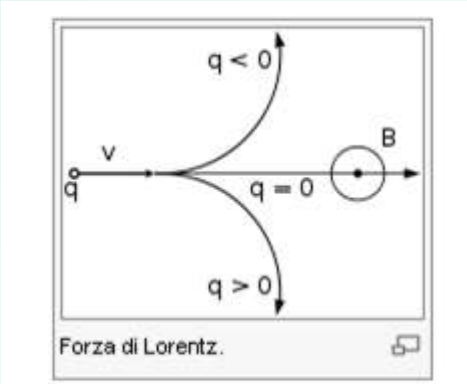
Fragmentation beams :The Lorentz force



The produced fragments are inside the beam tube and see the magnetic field of dipoles quadrupoles and other elements

The Lorentz force will move them along the beam line changing their velocity direction

$$\vec{F}_l = q\vec{v} \times \vec{B}$$



Forza di Lorentz.

$$q \cdot v \cdot B = \frac{mv^2}{r}$$

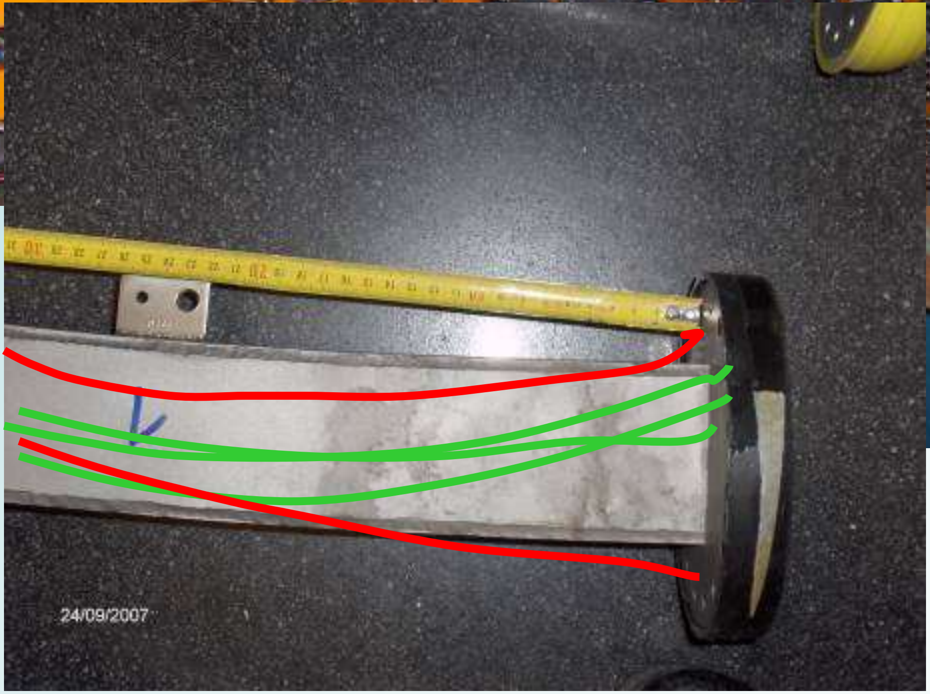
Particles will move along a circular trajectory with radius determined by the interplay between the Lorentz (B) and the centripetal force

$$R = \frac{mv_0}{qB}$$

An important parameter is the BR = mv/q of the particle determining the curvature radius

Fragmentation beams :what is a dipole

Inside a dipole there is a vacuum chamber where all the fragments move with their velocity



This chamber has a finite size, therefore the magnets can accept a range of br all those that are inside the width of the vacuum chamber

Fragmentation beams : How to perform calculations

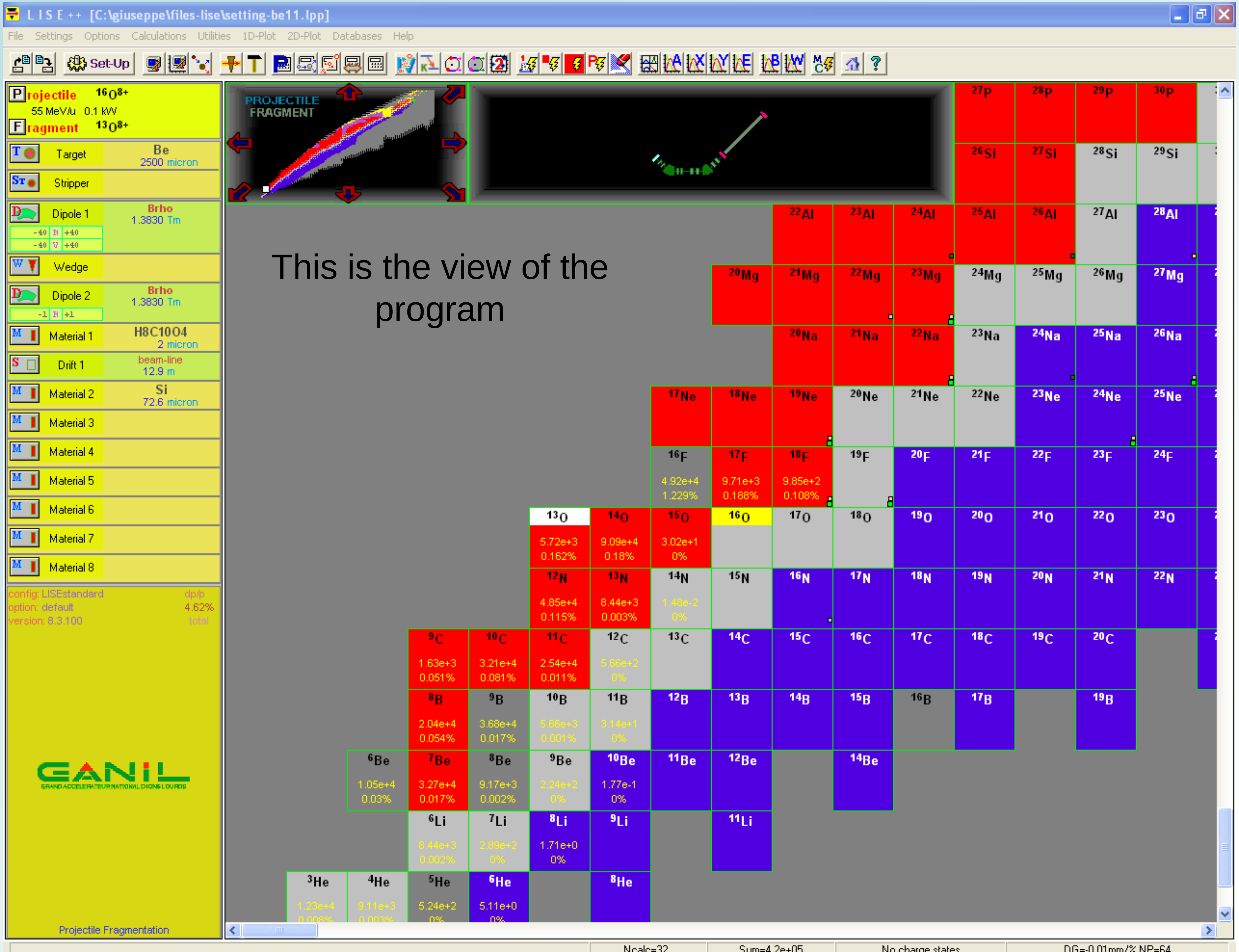
I hope you have understood that once we know the velocity (vector) charge and mass of a particle produced in the fragmentation reaction you can calculate the destiny of such particle inside the beam line – and if you want use this particle as a beam you can adjust the magnetic fields of your beam line to transport it in a place where you have your detector and you can do a reaction

To follow the destiny of a fragmentation beam we can use a program, LISE, able to reconstruct the production of such ions and the transport along a beam line that we can define with the appropriate characteristics

You can get this program free from:

http://groups.nscl.msu.edu/lise/lise.html

Fragmentation beams : The LISE program



L I S E ++ [C:\giuseppe\files-lise\setting-be11.lpp]

This is the view of the program

Projectile	$^{16}O^{8+}$	55 MeV/u 0.1 kW
Fragment	$^{13}O^{8+}$	
Target	Be	2500 micron
Stripper		
Dipole 1	Brho	1.3830 Tm
	-40 H +40 -40 V +40	
Wedge		
Dipole 2	Brho	1.3830 Tm
	-1 H +1	
Material 1	H8C10O4	2 micron
Drift 1	beam-line	12.9 m
Material 2	Si	72.6 micron
Material 3		
Material 4		
Material 5		
Material 6		
Material 7		
Material 8		

config: LISEstandard dp/p
option: default 4.62%
version: 8.3.100 total

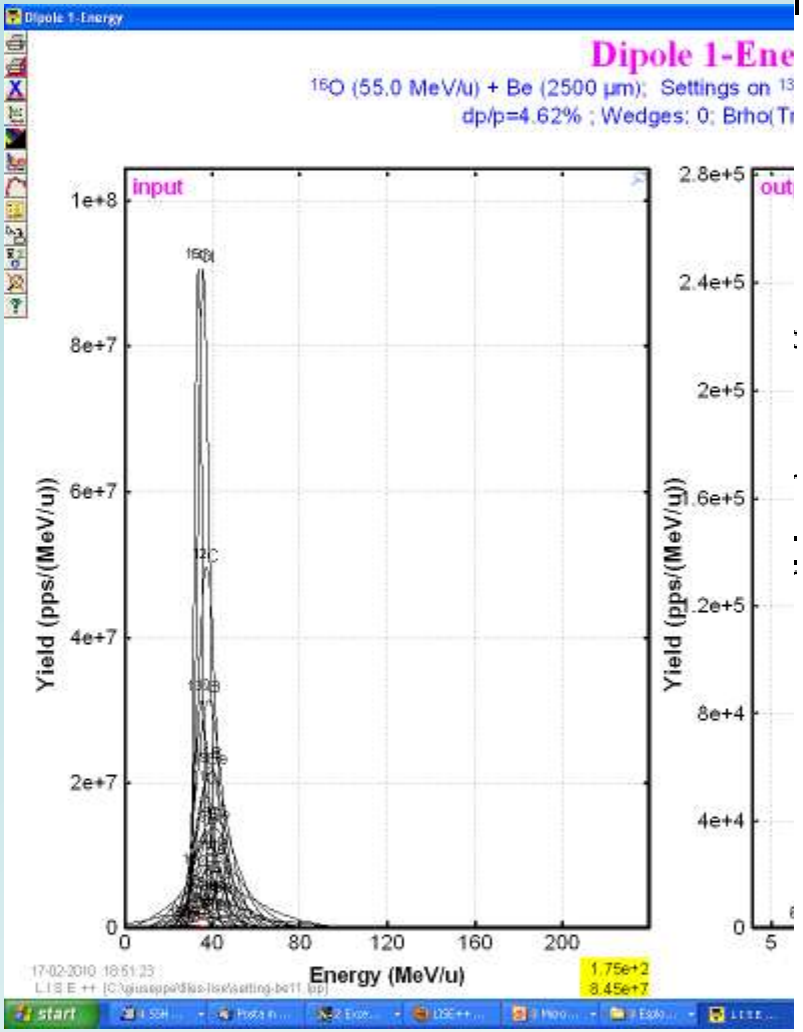
Projectile Fragmentation

											^{27}P	^{28}P	^{29}P	^{30}P
											^{26}Si	^{27}Si	^{28}Si	^{29}Si
								^{22}Al	^{23}Al	^{24}Al	^{25}Al	^{26}Al	^{27}Al	^{28}Al
							^{20}Mg	^{21}Mg	^{22}Mg	^{23}Mg	^{24}Mg	^{25}Mg	^{26}Mg	^{27}Mg
								^{20}Na	^{21}Na	^{22}Na	^{23}Na	^{24}Na	^{25}Na	^{26}Na
						^{17}Ne	^{18}Ne	^{19}Ne	^{20}Ne	^{21}Ne	^{22}Ne	^{23}Ne	^{24}Ne	^{25}Ne
						^{16}F 4.92e+4 1.229%	^{17}F 9.71e+3 0.188%	^{18}F 9.85e+2 0.108%	^{19}F	^{20}F	^{21}F	^{22}F	^{23}F	^{24}F
				^{13}O 5.72e+3 0.162%	^{14}O 9.09e+4 0.18%	^{15}O 3.02e+1 0%	^{16}O	^{17}O	^{18}O	^{19}O	^{20}O	^{21}O	^{22}O	^{23}O
				^{12}N 4.85e+4 0.115%	^{13}N 8.44e+3 0.003%	^{14}N 1.48e-2 0%	^{15}N	^{16}N	^{17}N	^{18}N	^{19}N	^{20}N	^{21}N	^{22}N
		^{9}C 1.63e+3 0.051%	^{10}C 3.21e+4 0.081%	^{11}C 2.54e+4 0.011%	^{12}C 5.66e+2 0%	^{13}C	^{14}C	^{15}C	^{16}C	^{17}C	^{18}C	^{19}C	^{20}C	
		^{8}B 2.04e+4 0.054%	^{9}B 3.68e+4 0.017%	^{10}B 5.66e+3 0.001%	^{11}B 3.14e+1 0%	^{12}B	^{13}B	^{14}B	^{15}B	^{16}B	^{17}B		^{19}B	
	^{6}Be 1.05e+4 0.03%	^{7}Be 3.27e+4 0.017%	^{8}Be 9.17e+3 0.002%	^{9}Be 2.24e+2 0%	^{10}Be 1.77e-1 0%	^{11}Be	^{12}Be		^{14}Be					
		^{6}Li 8.44e+3 0.002%	^{7}Li 2.89e+2 0%	^{8}Li 1.71e+0 0%	^{9}Li		^{11}Li							
^{3}He 1.23e+4 0.008%	^{4}He 9.11e+3 0.003%	^{5}He 5.24e+2 0%	^{6}He 5.11e+0 0%		^{8}He									

Ncalc=32 | Sum=4.2e+05 | No charge states | DG=0.01mm/% NP=64

Fragmenta

And see the effect of the dipole



16O (55.0 MeV/u) + Be (2500 µm); Settings on 13

dp/p=4.62% ; Wedges: 0; Brho(T

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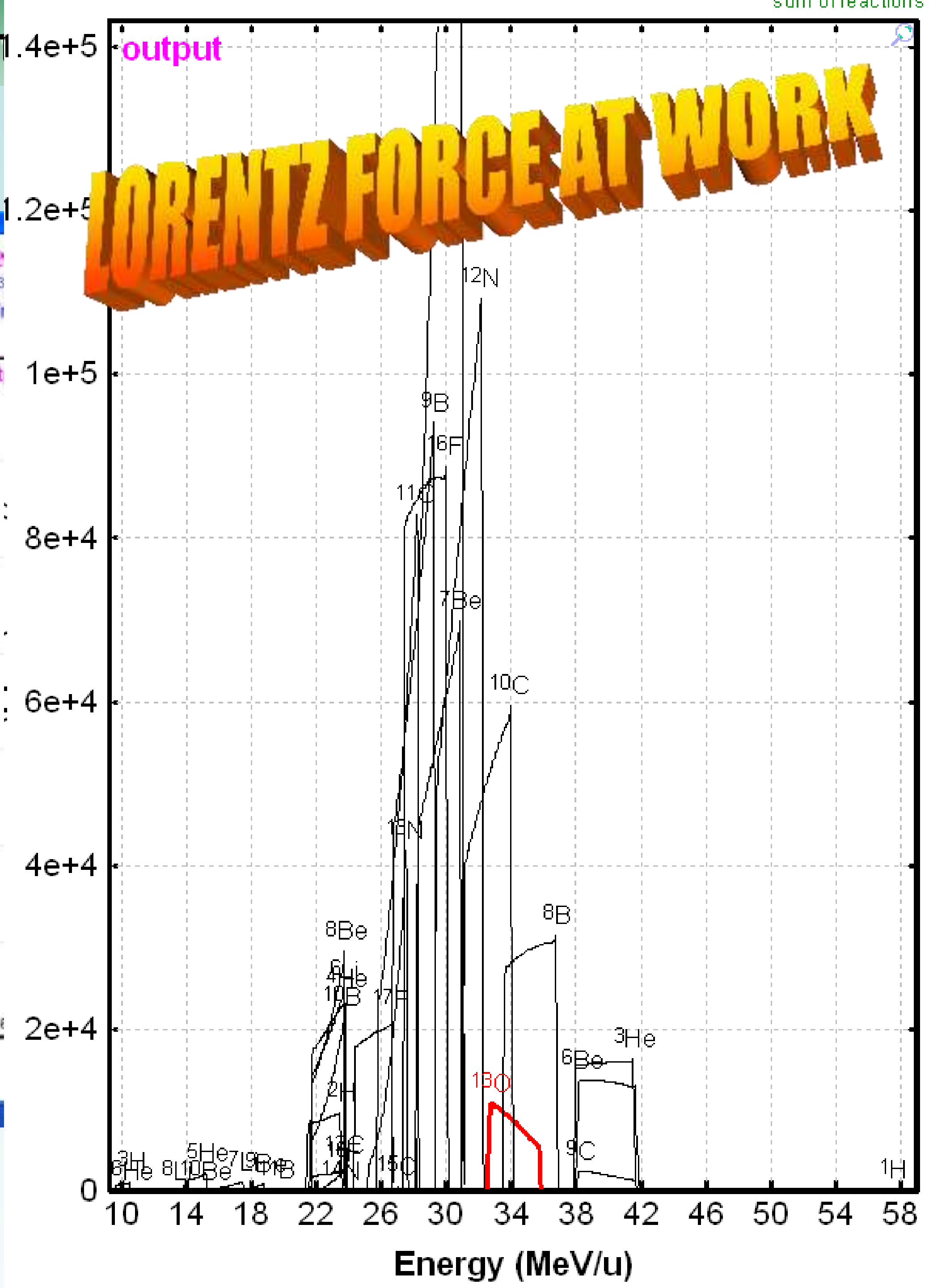
L I S E ++ [C:\giuseppe\dles-lise\setting-be11.lpp]



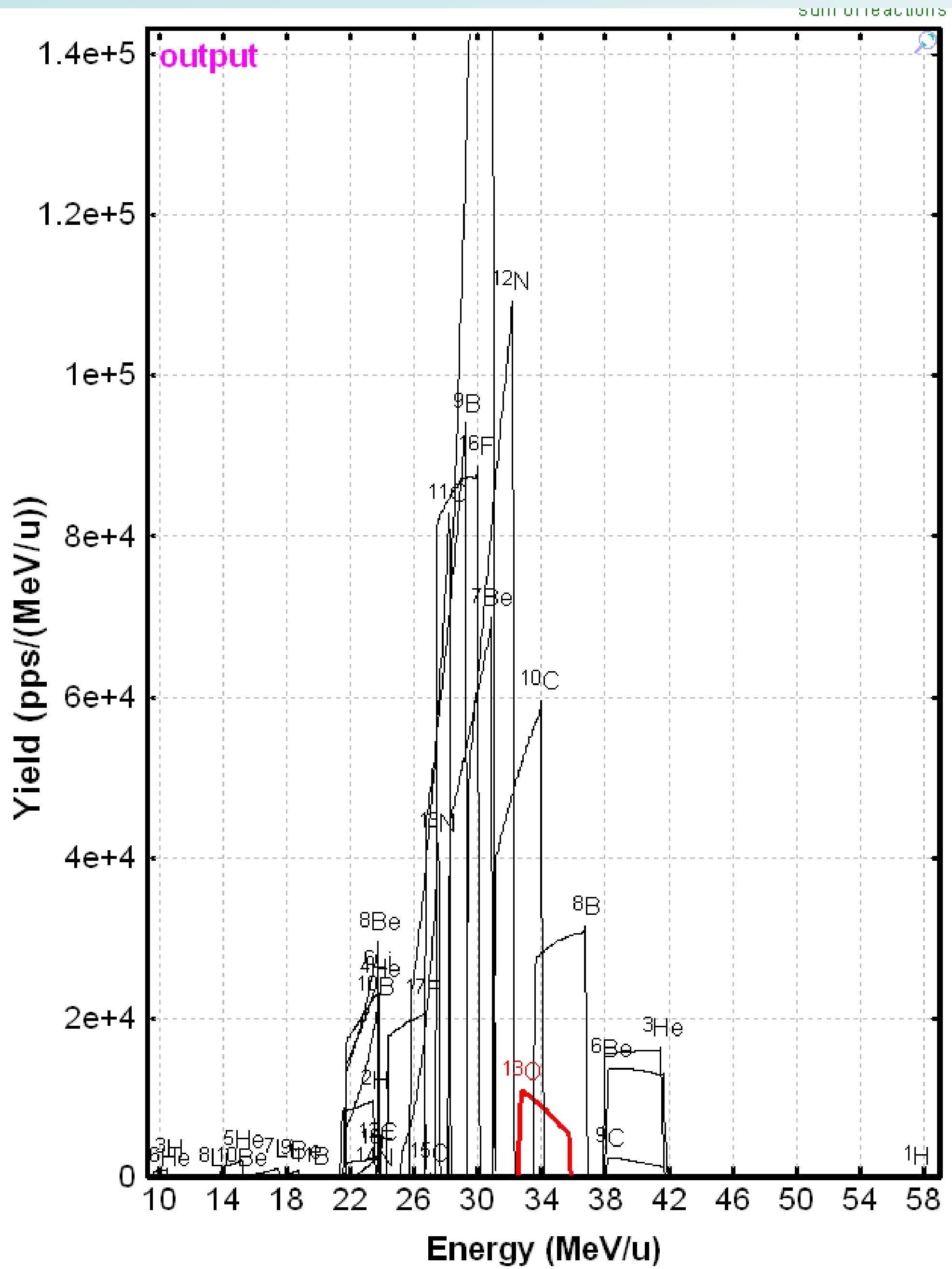
Fragmentation beams : effect of the magnets

What happens?

If we select a magnetic field of the dipole we will select a Bρ i.e. only particles with

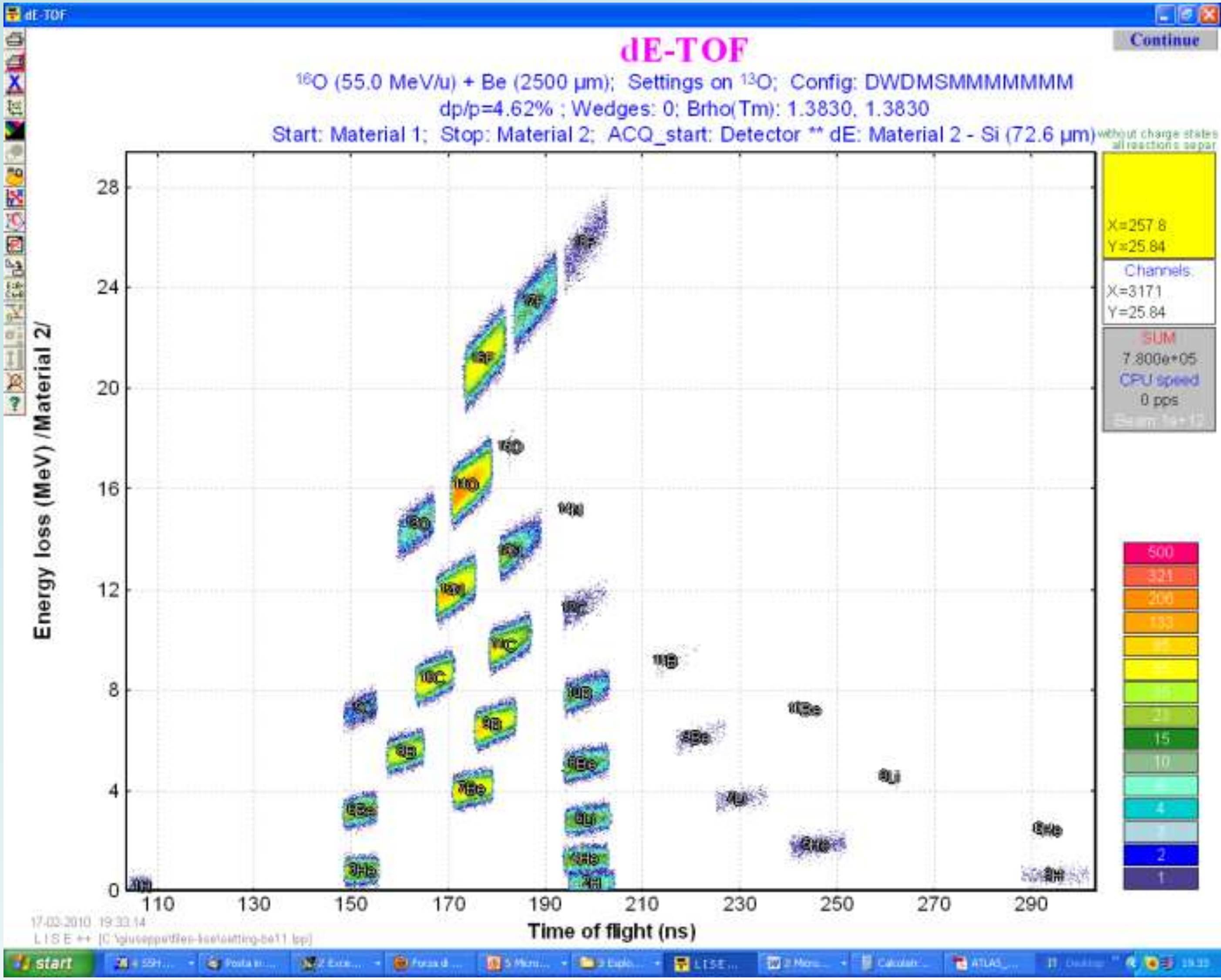
Bρ=MV/Q

The acceptance window of the magnets in x so selects an interval of particles with defined M/Q having a certain ΔV (also the impinging angle obviously play a role V and B are vectors) therefore we select just a window of the production energy spectrum of each particle



Fragmentation beams: final products

We can follow what happens at the end of the fragment separator where we have some detectors to characterize the beam



dE-TOF

^{16}O (55.0 MeV/u) + Be (2500 μm); Settings on ^{13}O; Config: DWDMSMMMMMMM
dp/p=4.62% ; Wedges: 0; Brho(Tm): 1.3830, 1.3830
Start: Material 1; Stop: Material 2; ACQ_start: Detector ** dE: Material 2 - Si (72.6 μm)

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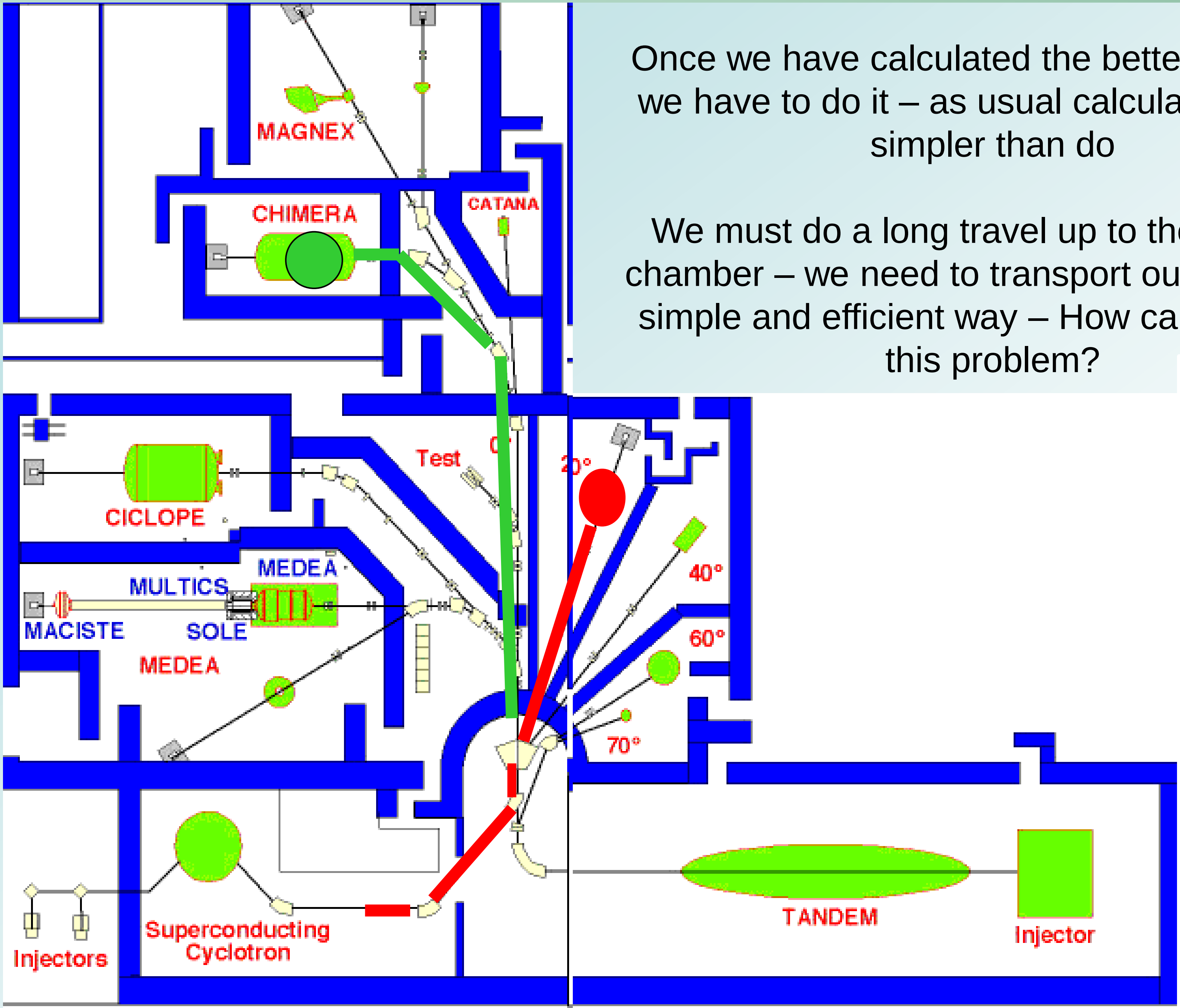
This is a tipical plot that we can produce with LISE showing the produced particles as seen by a detector that gives us the energy loss (ΔE) and the TOF of the produced beams – we will see better later this kind of plot

Transport



Once we have calculated the better transport, we have to do it – as usual calculate is much simpler than do

We must do a long travel up to the reaction chamber – we need to transport our beam in a simple and efficient way – How can we solve this problem?

Transport: how to control?

We know the right magnetic field for the best transport – we have to give the right current to the magnets in order to produce this field!

To do this we need to measure magnetic field every where, difficult and expensive - moreover we have always misalignments and they should be taken into account by the calculation

Practice - we have to look the beam after each element and adjust fields in order to improve the transport.

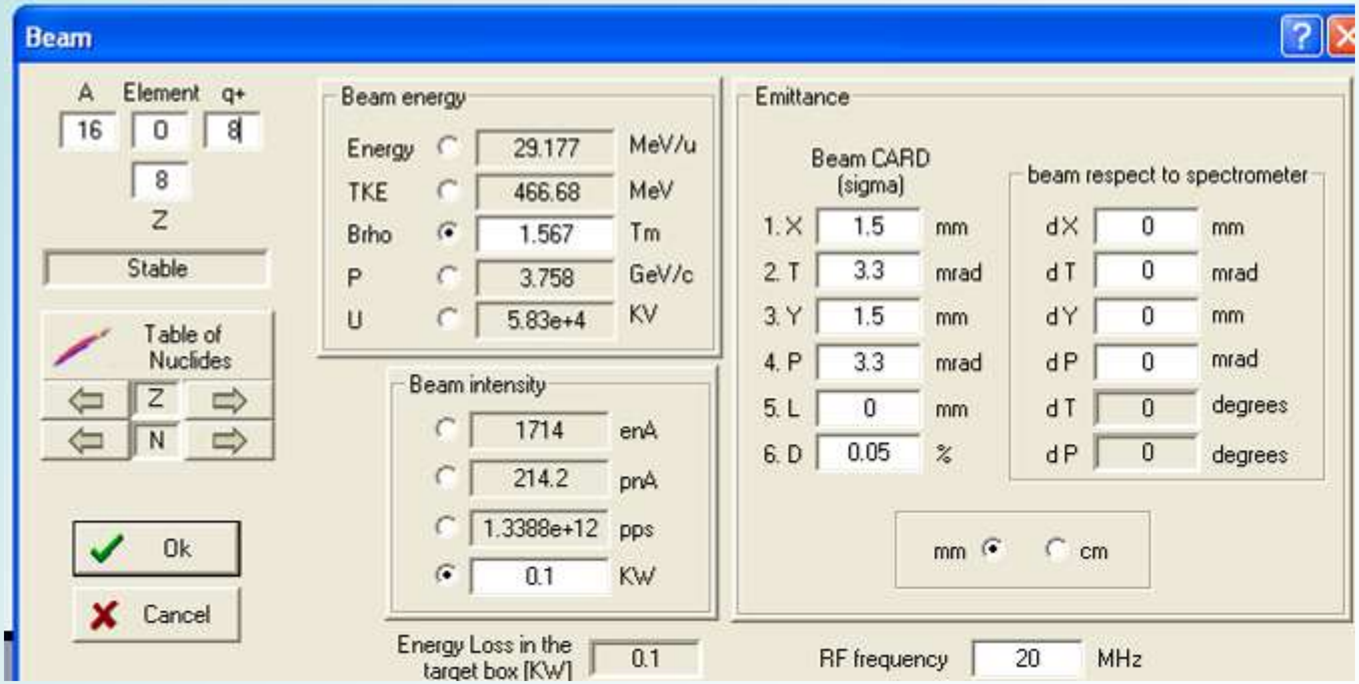
Good idea but the beam has very small intensity even 1000 part/s if we use standard allumina we do not have enough light

The solution to this problem is to built a system to see low intensity beams
However there are other solutions when such a system is not available
One can use a “pilot beam”; a beam with the same magnetic rigidity of the radioactive beam we want to transport

Transport: pilot beam

Use a “pilot beam” a beam with the same magnetic rigidity of the radioactive beam we want to transport

I want to produce and transport ^{13}O using a primary beam of ^{16}O on a target of ^{9}Be 1.5mm thick , with LISE I can calculate what is the best bρ for my system,
it is 1.5673Tm
I have a primary beam of ^{16}O of 55MeV/A charge 6+ i.e. bρ=2.8881 TM
If I insert a degrader I can decrease the V getting the right bρ



A	Element	q+
16	O	8

Z: 8

Stable

Beam energy

Energy	○	29.177	MeV/u
TKE	○	466.68	MeV
Brho	●	1.567	Tm
P	○	3.758	GeV/c
U	○	5.83e+4	KV

Beam intensity

○	1714	enA
○	214.2	pnA
○	1.3388e+12	pps
●	0.1	KW

Emittance

Beam CARD (sigma)			beam respect to spectrometer		
1. X	1.5	mm	dX	0	mm
2. T	3.3	mrad	dT	0	mrad
3. Y	1.5	mm	dY	0	mm
4. P	3.3	mrad	dP	0	mrad
5. L	0	mm	dT	0	degrees
6. D	0.05	%	dP	0	degrees

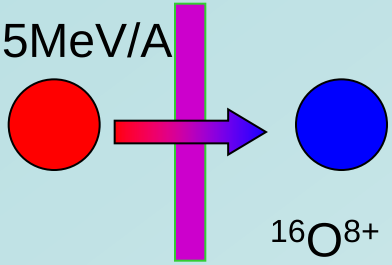
mm ● ○ cm

Energy Loss in the target box [KW] 0.1

RF frequency 20 MHz

I need to reduce the energy of the ^{16}O to 29.177 MeV/A

Transport: pilot beam



$^{16}O^{6+}$

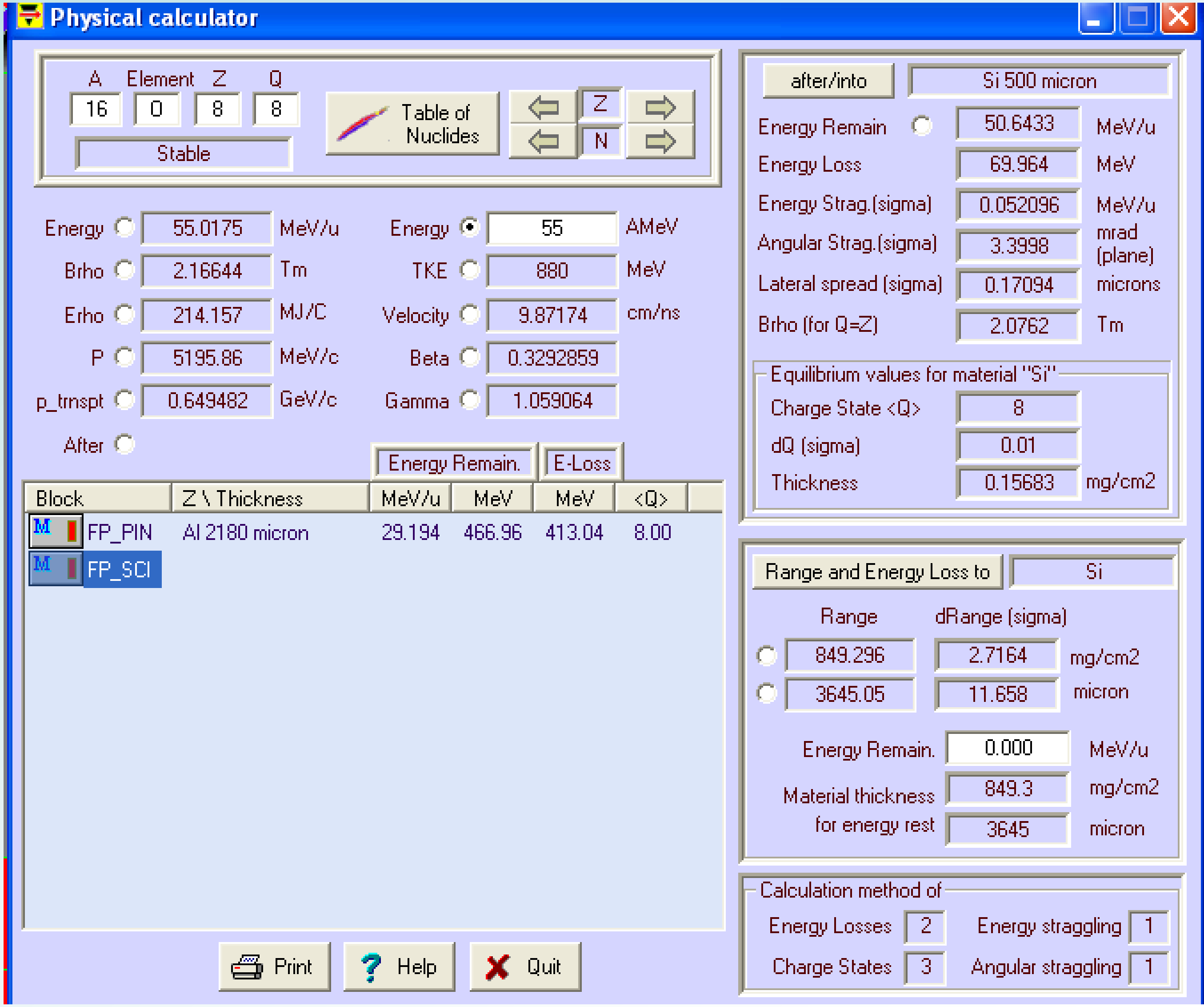
55MeV/A

Al degrader 2.18mm

$^{16}O^{8+}$

29.2 MeV/A

I need O16 of 29.177 MeV → I must insert a degrader of 2.18 mm Al where the primary beam will loose the necessary energy (not only he will be also totally stripped)



Physical calculator

A	Element	Z	Q
16	O	8	8

Stable

Energy ○	55.0175	MeV/u	Energy ●	55	AMeV
Brho ○	2.16644	Tm	TKE ○	880	MeV
Erho ○	214.157	MJ/C	Velocity ○	9.87174	cm/ns
P ○	5195.86	MeV/c	Beta ○	0.3292859	
p_trnspt ○	0.649482	GeV/c	Gamma ○	1.059064	
After ○					

		Energy Remain.		E-Loss	
Block	Z \ Thickness	MeV/u	MeV	MeV	<Q>
FP_PIN	Al 2180 micron	29.194	466.96	413.04	8.00
FP_SCI					

after/into: Si 500 micron

Energy Remain ○	50.6433	MeV/u
Energy Loss	69.964	MeV
Energy Strag.(sigma)	0.052096	MeV/u
Angular Strag.(sigma)	3.3998	mrad (plane)
Lateral spread (sigma)	0.17094	microns
Brho (for Q=Z)	2.0762	Tm

Equilibrium values for material "Si"

Charge State <Q>	8	
dQ (sigma)	0.01	
Thickness	0.15683	mg/cm2

Range and Energy Loss to: Si

	Range	dRange (sigma)	
○	849.296	2.7164	mg/cm2
○	3645.05	11.658	micron

Energy Remain.	0.000	MeV/u
Material thickness for energy rest	849.3	mg/cm2
	3645	micron

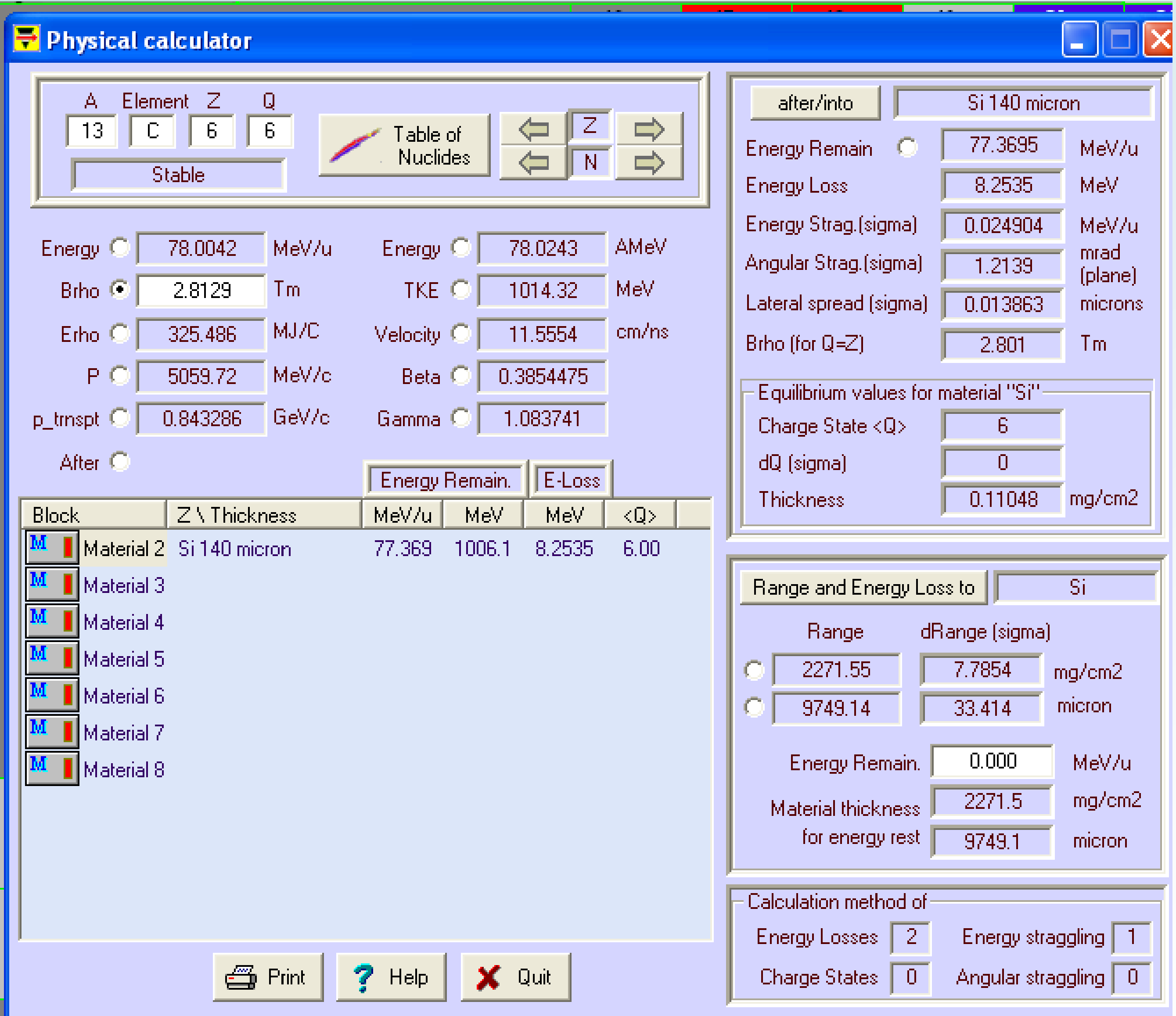
Calculation method of

Energy Losses	2	Energy straggling	1
Charge States	3	Angular straggling	1

Transport : pilot

Now another reaction I want a neutron rich beam, ^{11}Be I can use a ^{13}C primary beam lets use 45 MeV/A beam ^{13}C^{5+}

LISE suggest that the best bρ with a be9 target of 1.5mm is 2.8129 Tm



Physical calculator

A	Element	Z	Q
13	C	6	6

Stable

Energy ○	78.0042	MeV/u	Energy ○	78.0243	AMeV
Brho ●	2.8129	Tm	TKE ○	1014.32	MeV
Erho ○	325.486	MJ/C	Velocity ○	11.5554	cm/ns
P ○	5059.72	MeV/c	Beta ○	0.3854475	
p_trnspt ○	0.843286	GeV/c	Gamma ○	1.083741	
After ○					

Block	Z \ Thickness	Energy Remain. MeV/u	MeV	E-Loss MeV	<Q>
Material 2	Si 140 micron	77.369	1006.1	8.2535	6.00
Material 3					
Material 4					
Material 5					
Material 6					
Material 7					
Material 8					

after/into: Si 140 micron

Energy Remain ○	77.3695	MeV/u
Energy Loss	8.2535	MeV
Energy Strag.(sigma)	0.024904	MeV/u
Angular Strag.(sigma)	1.2139	mrad (plane)
Lateral spread (sigma)	0.013863	microns
Brho (for Q=Z)	2.801	Tm

Equilibrium values for material "Si"

Charge State <Q>	6	
dQ (sigma)	0	
Thickness	0.11048	mg/cm2

Range and Energy Loss to: Si

	Range	dRange (sigma)	
○	2271.55	7.7854	mg/cm2
○	9749.14	33.414	micron

Energy Remain.	0.000	MeV/u
Material thickness for energy rest	2271.5	mg/cm2
	9749.1	micron

Calculation method of

Energy Losses	2	Energy straggling	1
Charge States	0	Angular straggling	0

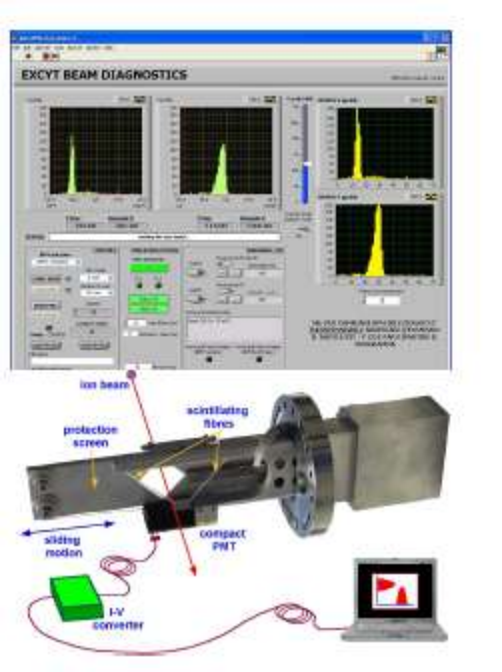
We should have a larger energy we cannot use the degrader

However "fortunately" The bρ of ^{13}C^{5+} 55 MeV/A is: 2.822 Tm Very near to the one necessary so in this case we can use the primary beam as a pilote beam – however this is a little dangerous Imagine what happens if the 9Be is broken, the direct primary beam will arrive in your secondary target

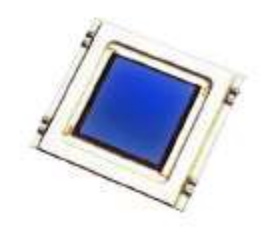
Transport: diagnostic

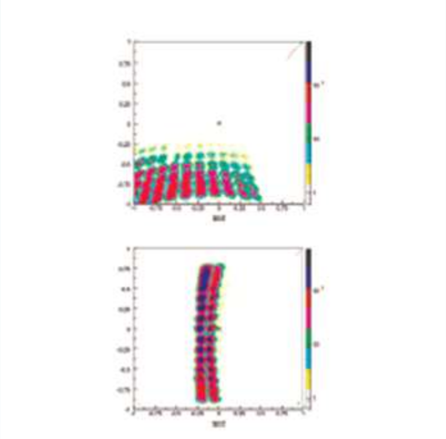
So it is not easy to get a pilot beam what can we do?
Use a dedicated diagnostic system to monitor the beam

At LNS we have different devices to perform this diagnostic
The first one is a scintillating fiber used for EXCYT but a little slow



The new one is based on a simple position sensitive silicon detector that produce a simple picture of the beam spot with very fast refresh with a behavior very similar to an allumina

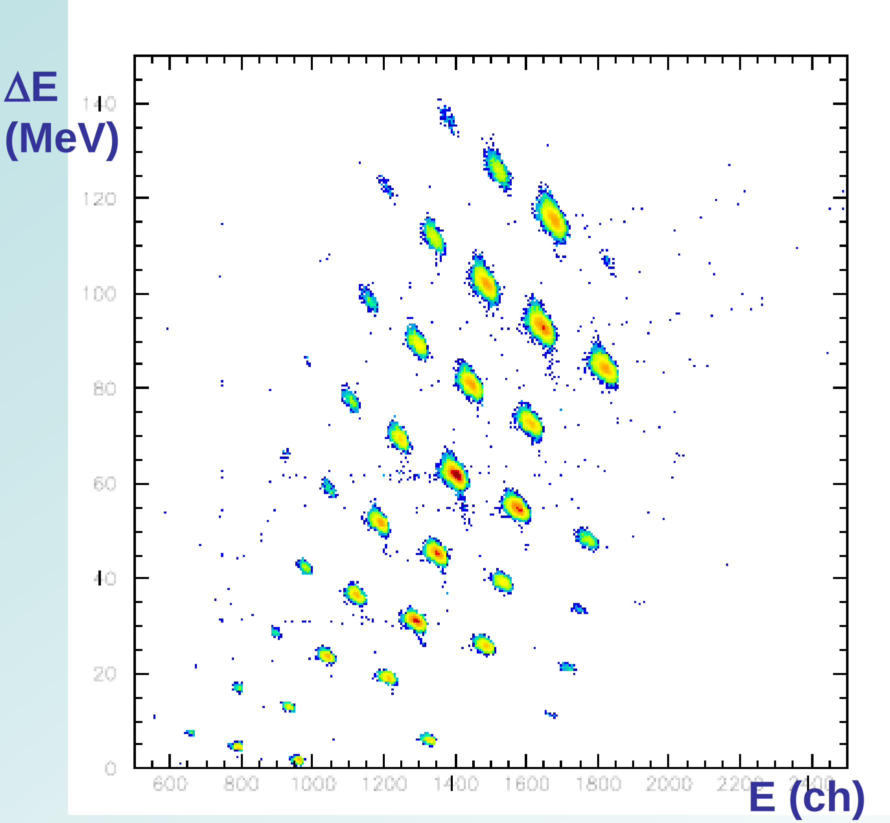




We can also use simple scintillators that work like a faraday cup where one can optimize the transport simply looking to the detector rate

IDENTIFICATION

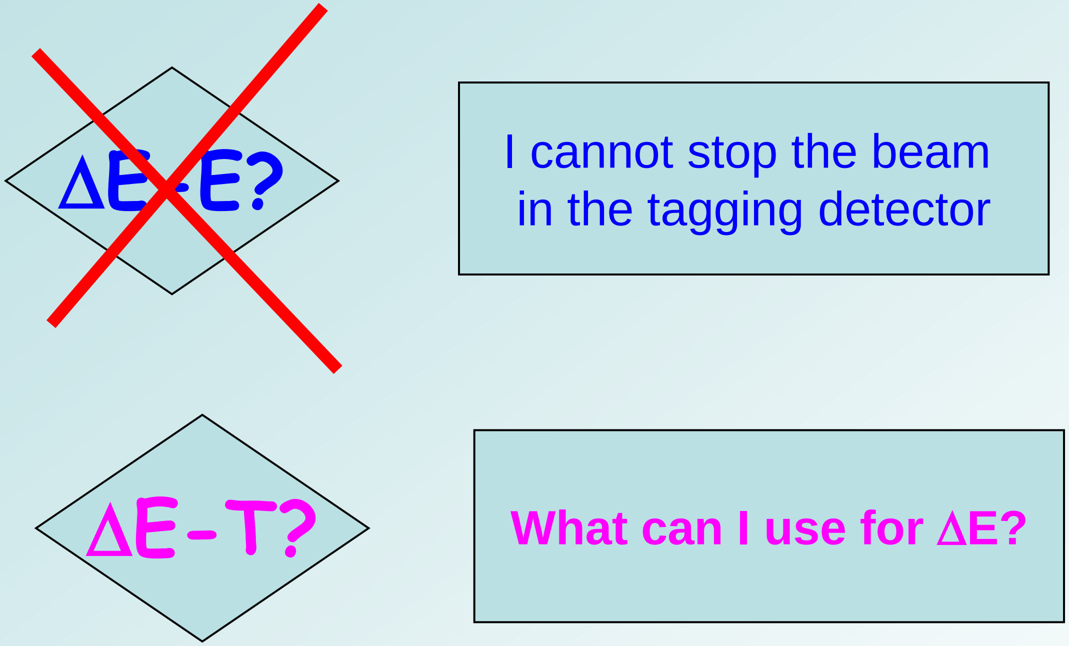
We have produced our beam and we have transported up to the reaction chamber – now we must use it, however this is a complex beam, in reality there are many beams – some time it is possible to clean it producing only one beam – more often this is impossible, so to use it we must identify it event by event



This is for instance a beam produced using 20Ne at 45 MeV/A on a 9Be target When impinge in a telescope we can built a ΔE-E scatter plot and identify the various charges and masses arriving on the target

IDENTIFICATION: flow chart

I cannot change the beam characteristics if I want to use it



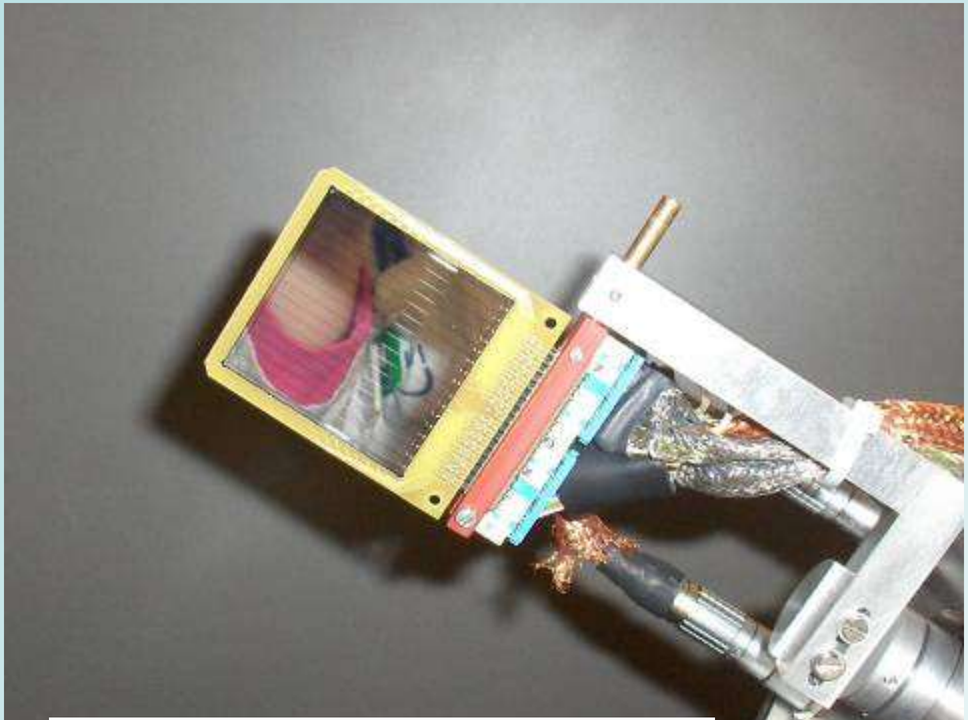
~~ΔE-E?~~

I cannot stop the beam in the tagging detector

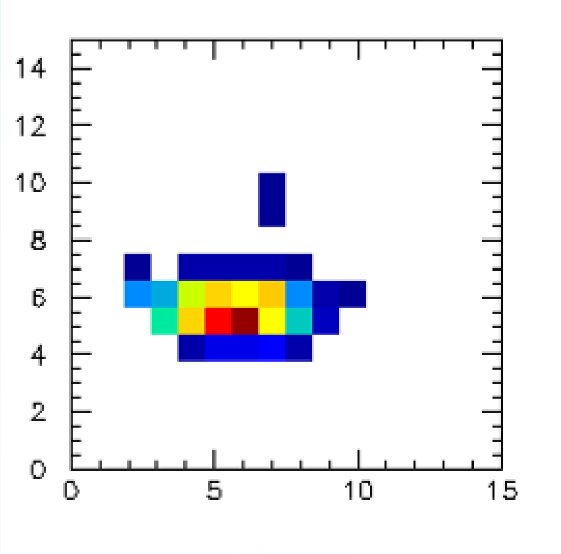
ΔE-T?

What can I use for ΔE?

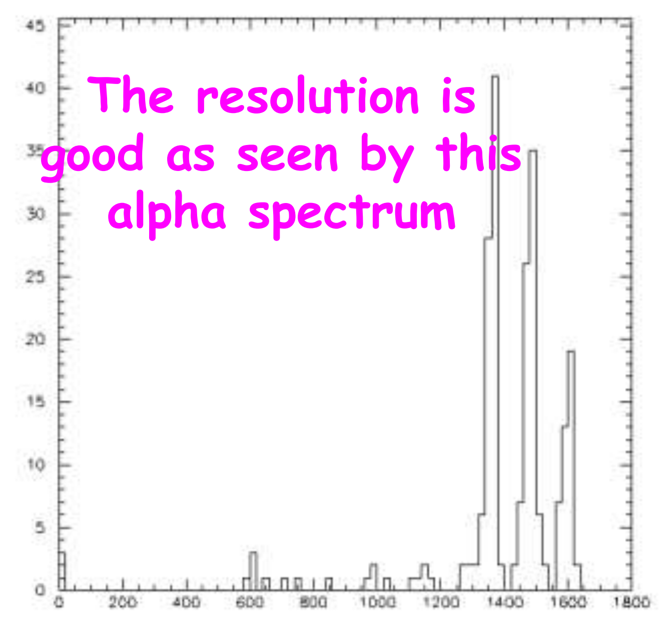
IDENTIFICATION: ΔE position tagging



For the ΔE I can use a X-Y strip detector



From the position of the strip I can get the XY image of the beam (like for the detectors on the diagnostic system)



The resolution is good as seen by this alpha spectrum

IDENTIFICATION: flow chart

~~ΔE-E?~~

I cannot stop the beam
in the tagging detector

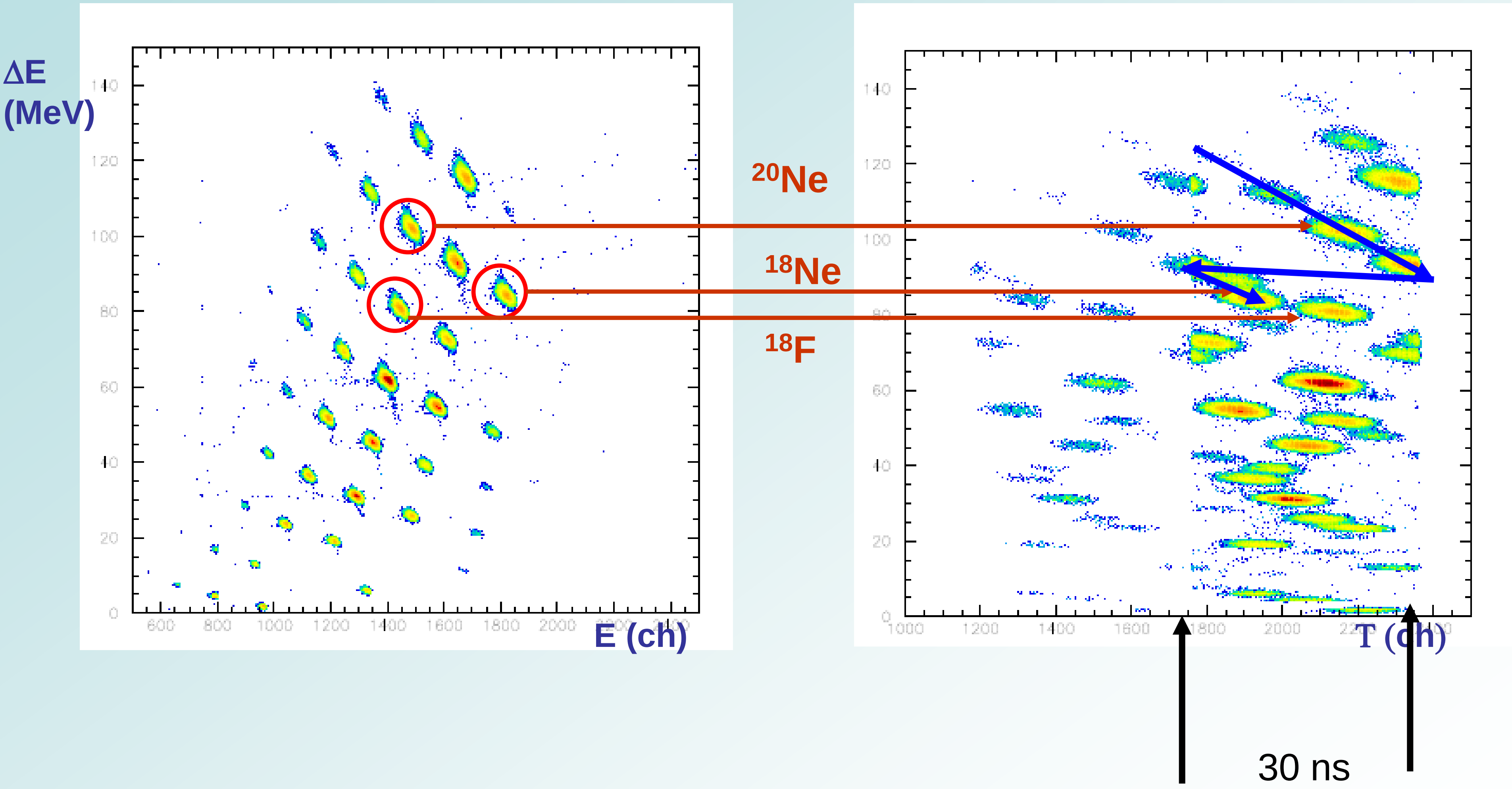
ΔE-T?

Possible but
how can I measure T?

RF

Max time difference
= RF cicle 30ns
Resolution??

IDENTIFICATION: RF time tagging



The identification is possible however there are some ambiguities due to the backbending of the measured times

IDENTIFICATION : flow chart

~~ΔE-E?~~

I cannot stop the beam
in the tagging detector

ΔE-T?

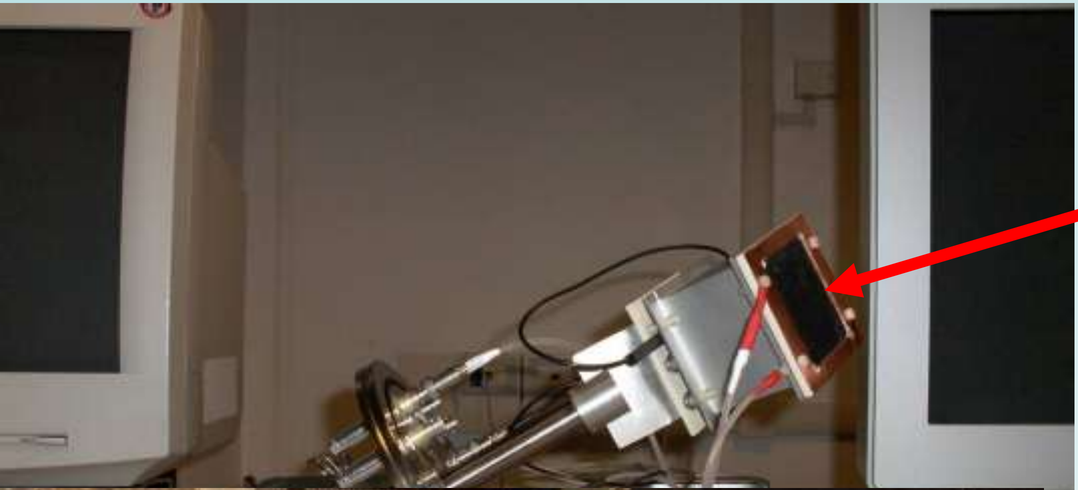
Possible but
how can I measure T?

MCP?

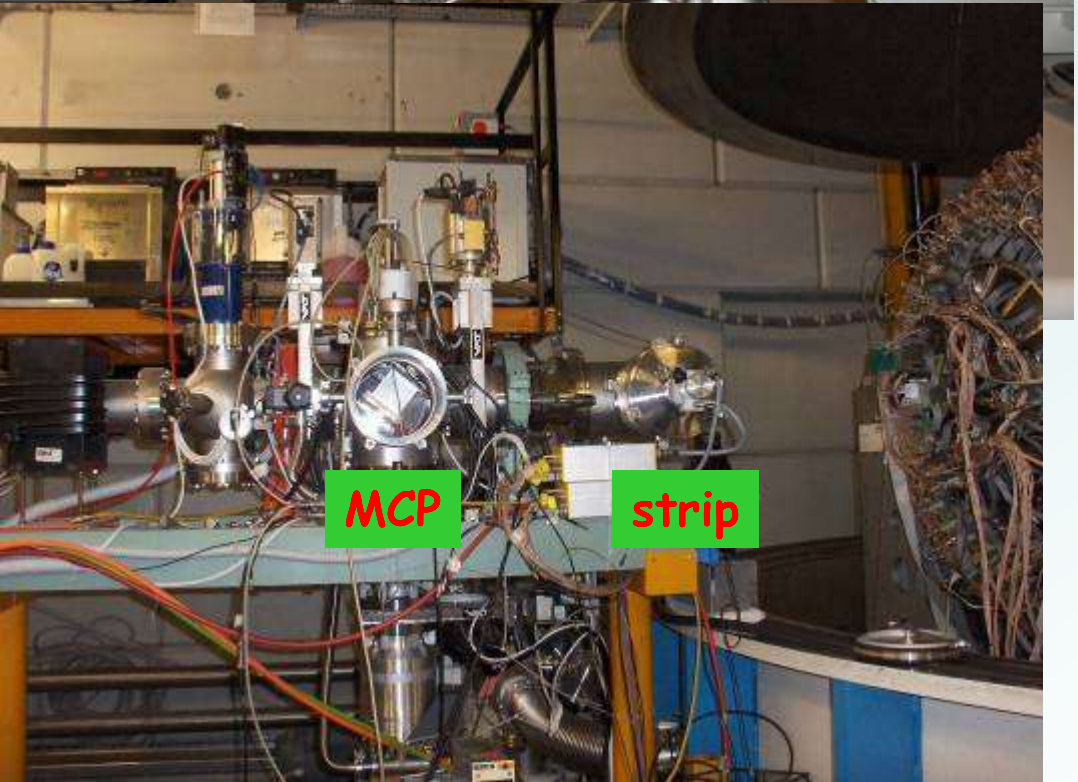
Efficiency???

IDENTIFICATION: MCP time tagging

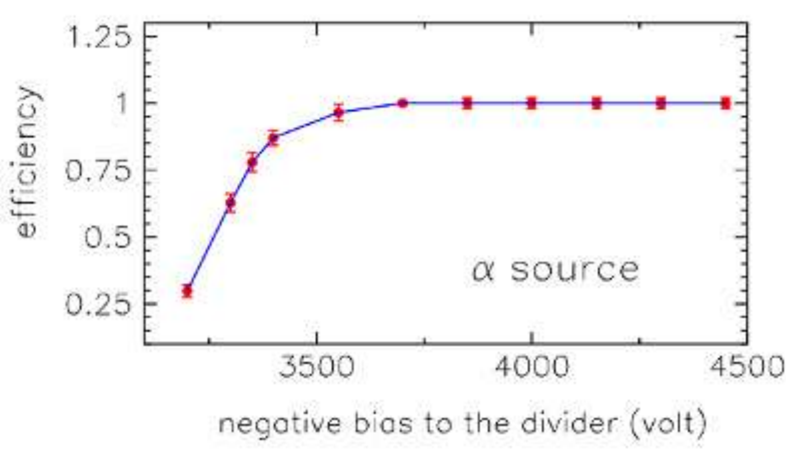
Large surface MCP 44*62 mm^2



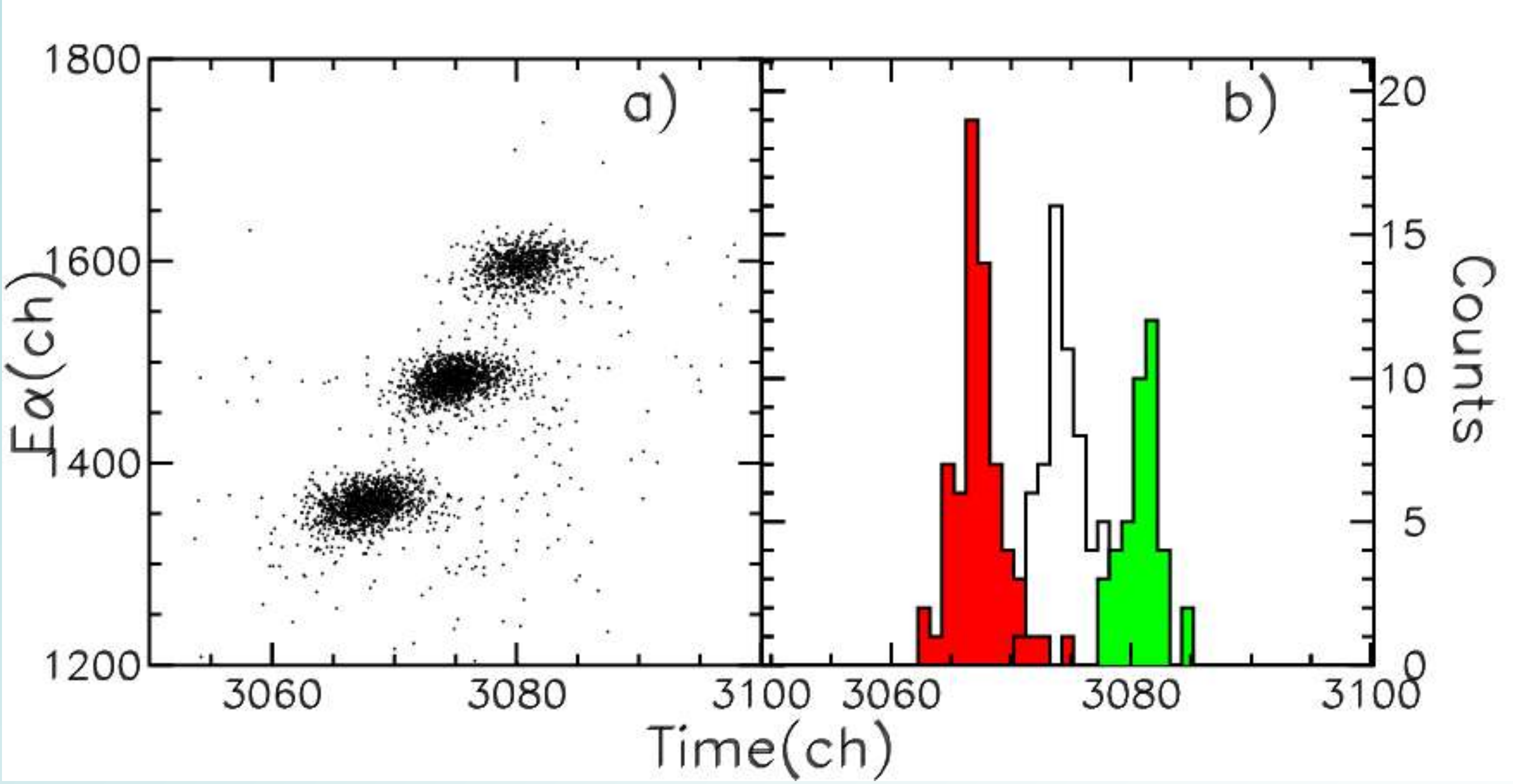
To enhance the electron emission we evaporate on an aluminized mylar foil LiF



We can measure the efficiency with α-source putting MCP and strip at 70cm

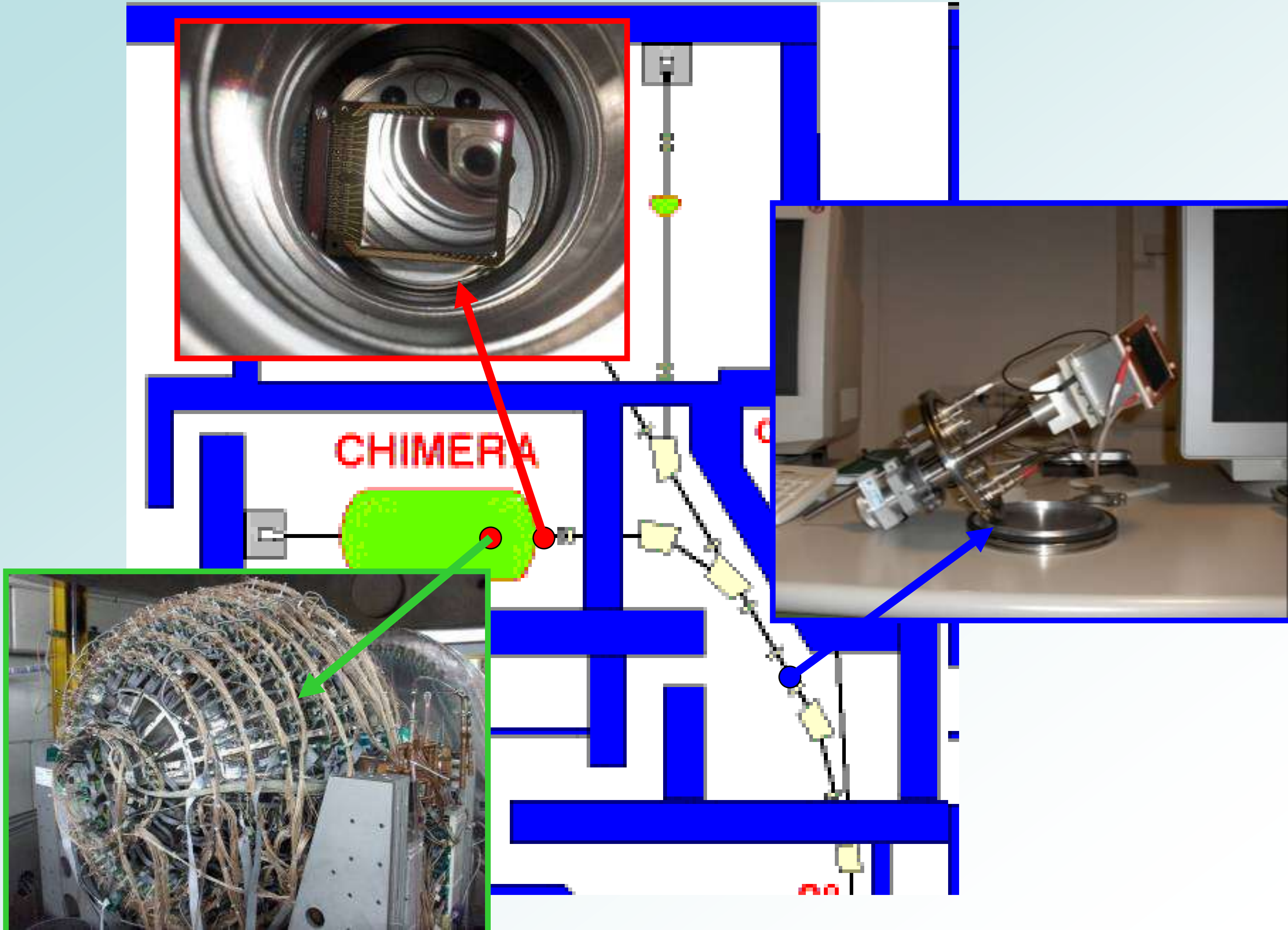


IDENTIFICATION: MCP resolution



We get a good time resolution < 500ps (1 ch TDC 250ps)

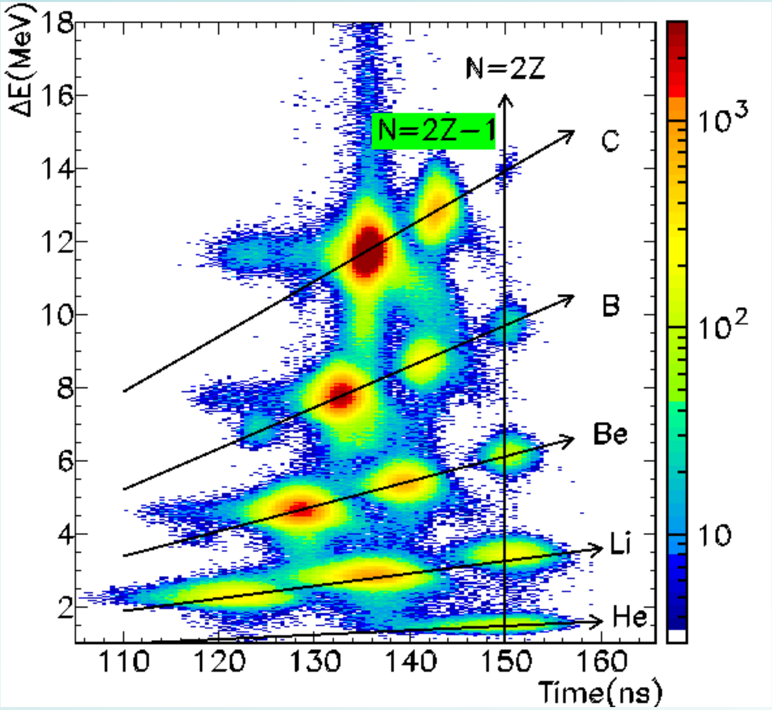
IDENTIFICATION: tagging system layout

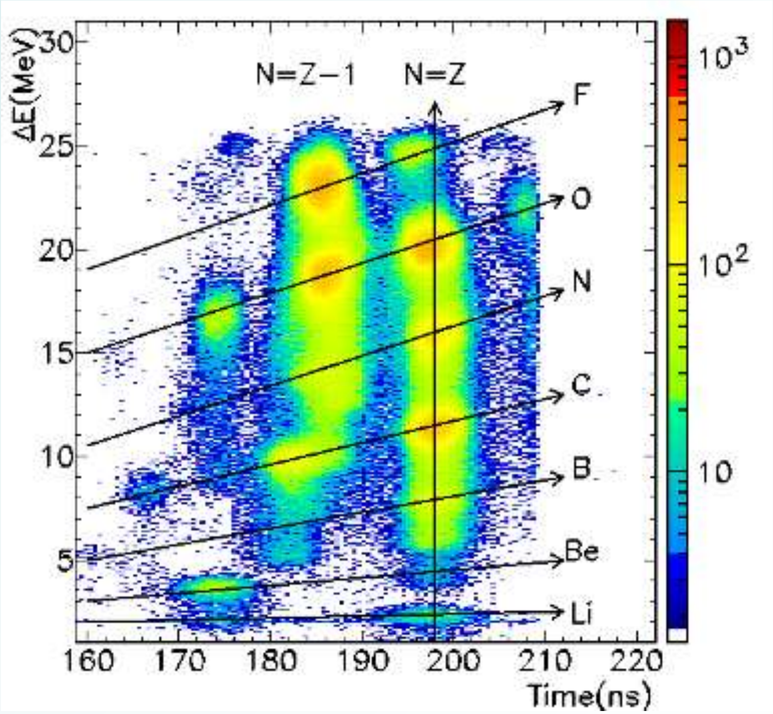


IDENTIFICATION : some results

We did various runs this is with primary beam ^{18}O on target of ^{9}Be 1.5mm and magnet centered on ^{11}Be a strip 140μm thick was used

This is with primary beam ^{16}O on target of ^{9}Be 1.5mm and magnet centered on ^{17}F a strip 70μm thick was used



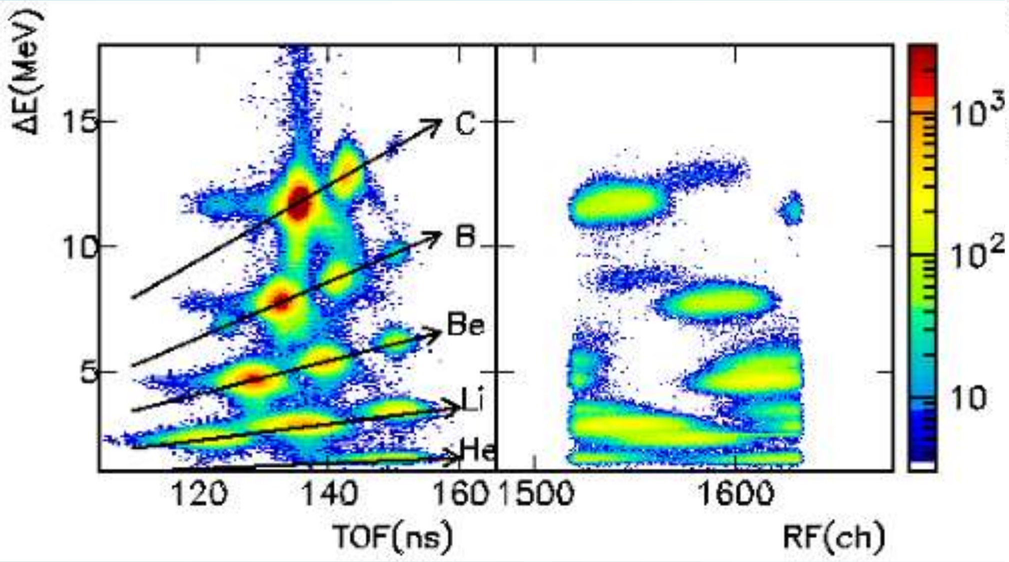


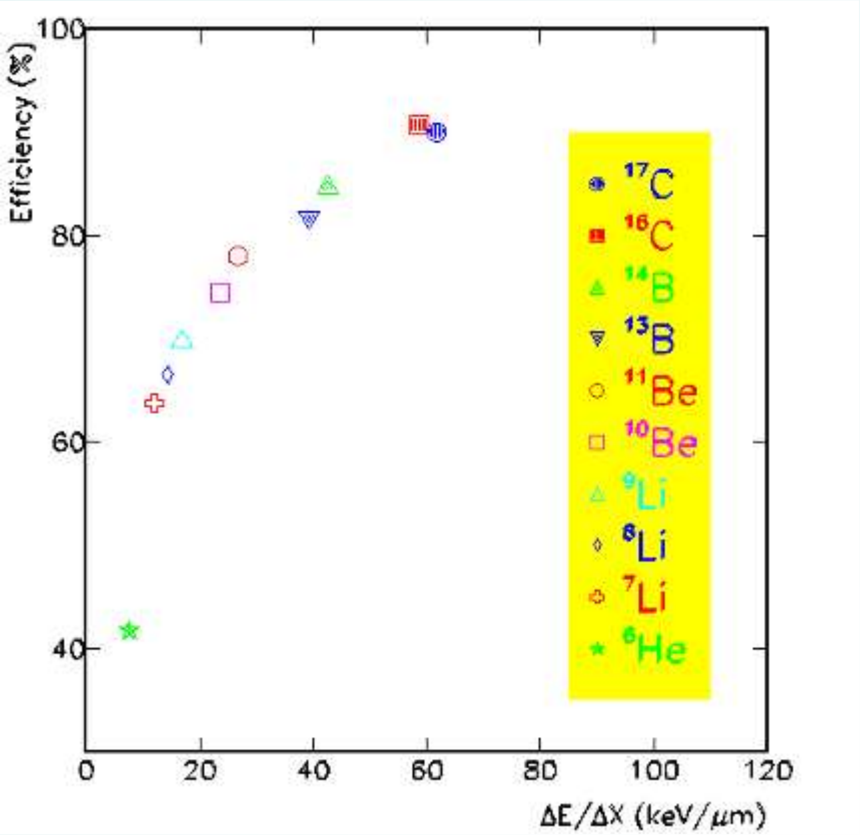
Note some problems due to non uniform detector thickness

IDENTIFICATION : some results

The efficiency of MCP was not 100% as for the alpha source, when MCP is missing identification is not lost because we still have RF

Counting the events for which we do not have MCP we can measure the efficiency

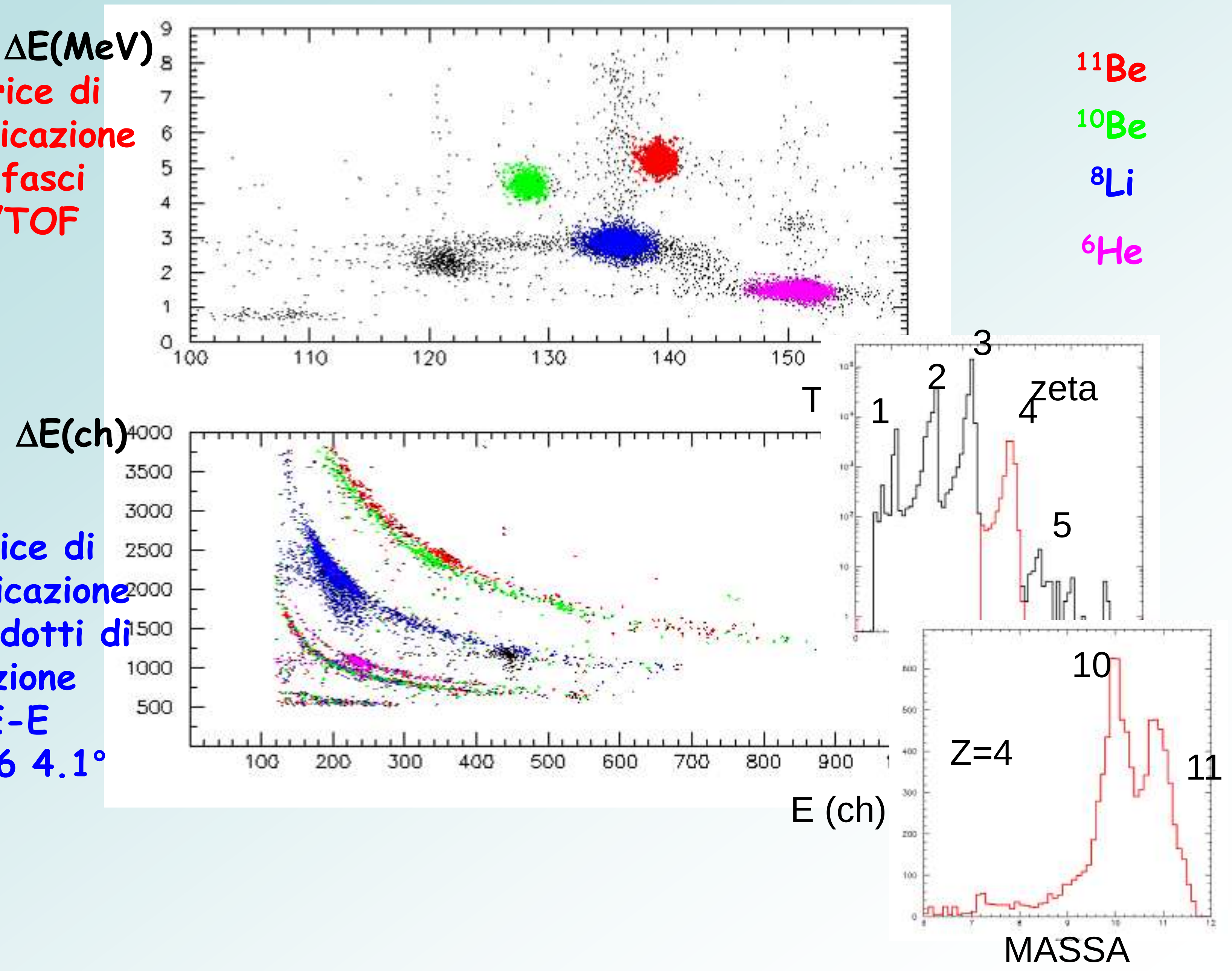




Sistema di Tagging – matrici di identificazione delle reazioni

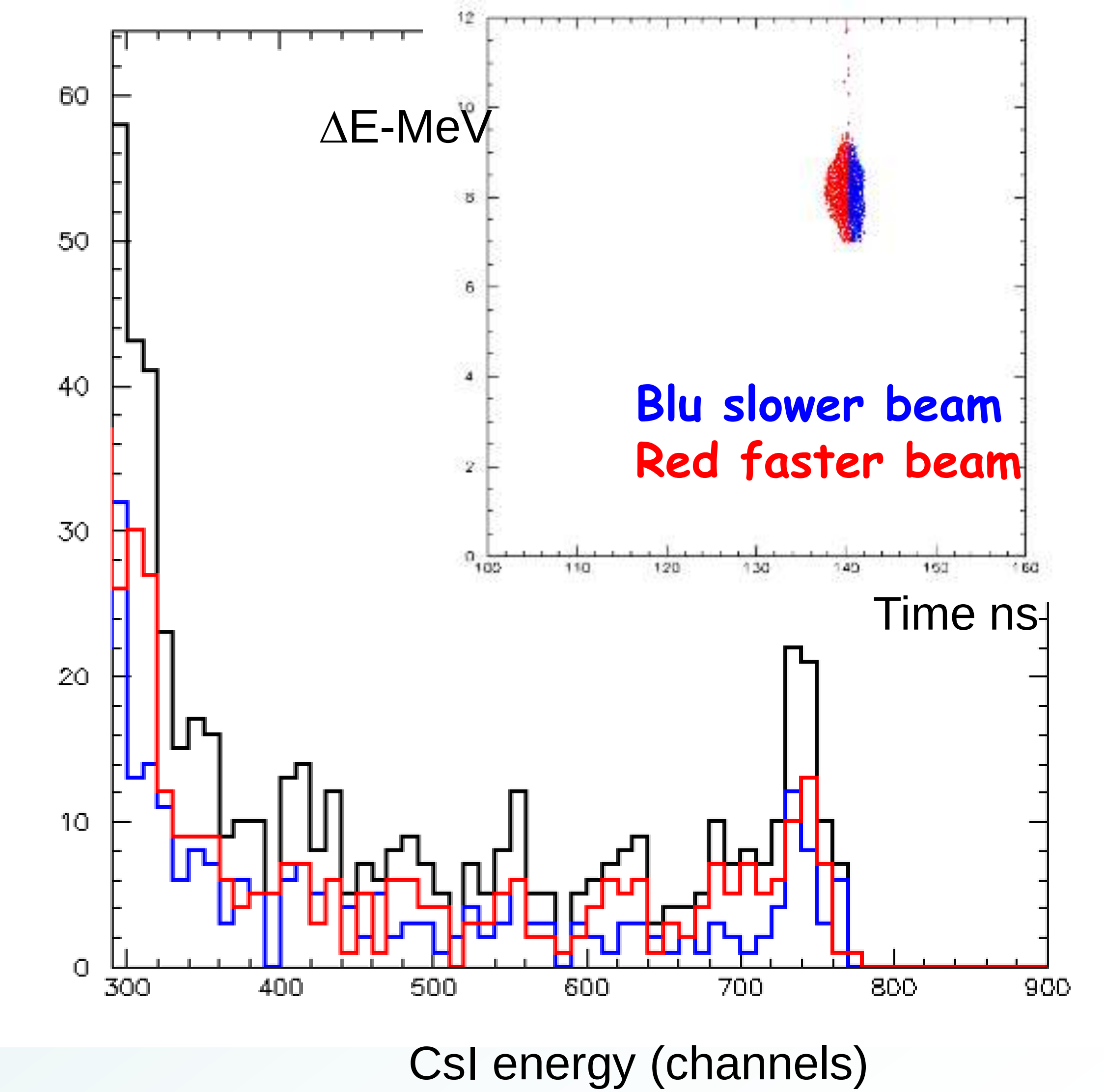
Matrice di identificazione dei fasci ΔE/TOF

Matrice di identificazione dei prodotti di reazione ΔE-E Tel 66 4.1°



IDENTIFICATION : energy tagging

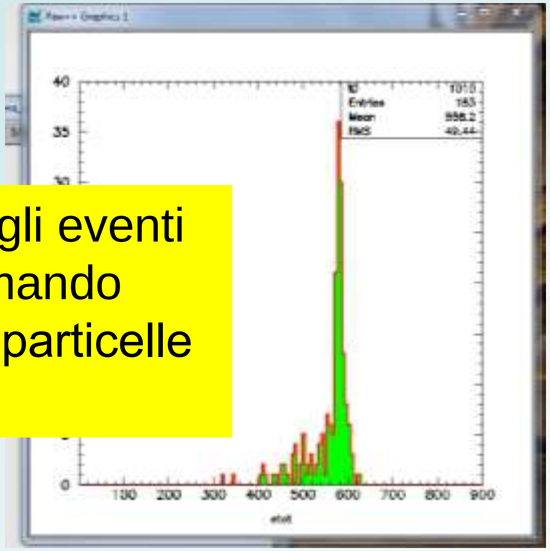
From the time of fligth once well calibrated we can also get the energy of the beam

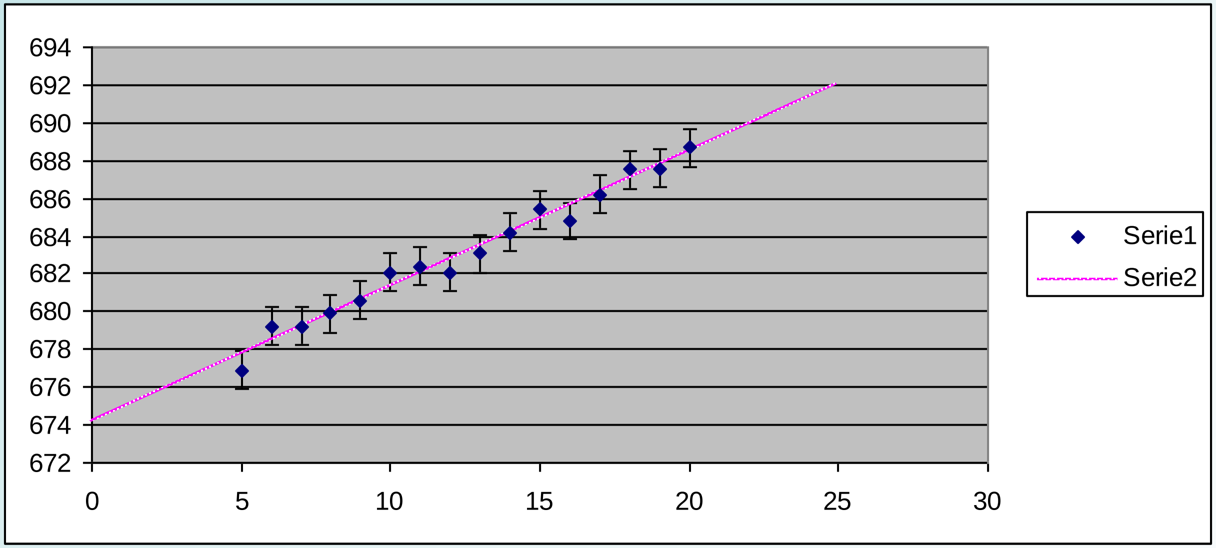


IDENTIFICATION : energy tagging

Un dipolo disperde il fascio in funzione del suo bρ cioè della sua velocità e quindi anche della sua energia

Selezionando gli eventi 13B+p e sommando l'energia delle particelle rivelate etot





Fit posizione picco etot per fascio 13B in funzione della strip la variazione di etot dal fit è

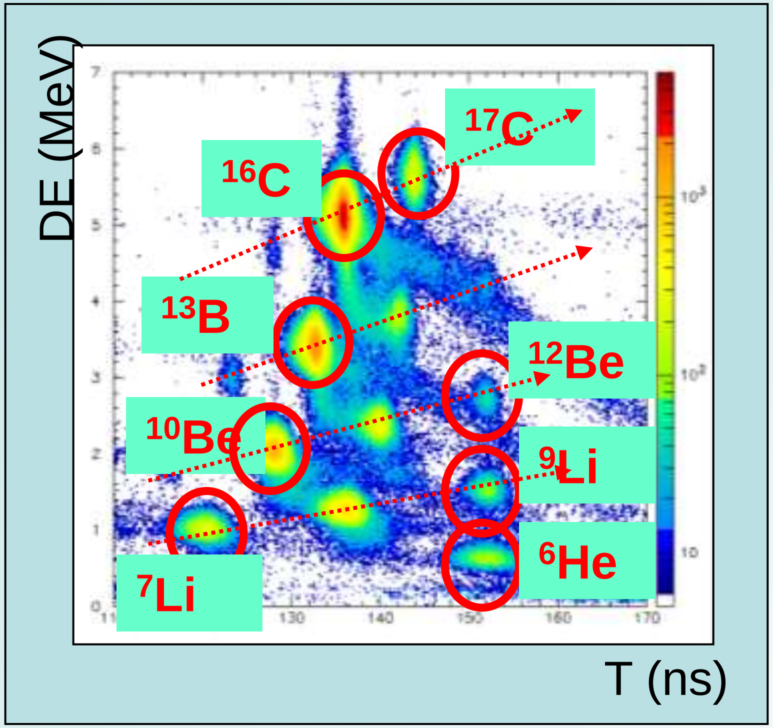
Etot=nstri*0.7154+674.2

Variazione dell'ordine di 0.1% per strip circa 2% su 20 strip in E si confronta bene con 1% in P

Risultati test della nuova linea

I test sono stati condotti con fasci primari di ^{18}O da 55 MeV/A e di ^{36}Ar da 42 MeV/A usando rispettivamente bersagli da 1.5 mm e .5 mm di ^{9}Be

Con ^{18}O sono stati prodotti :

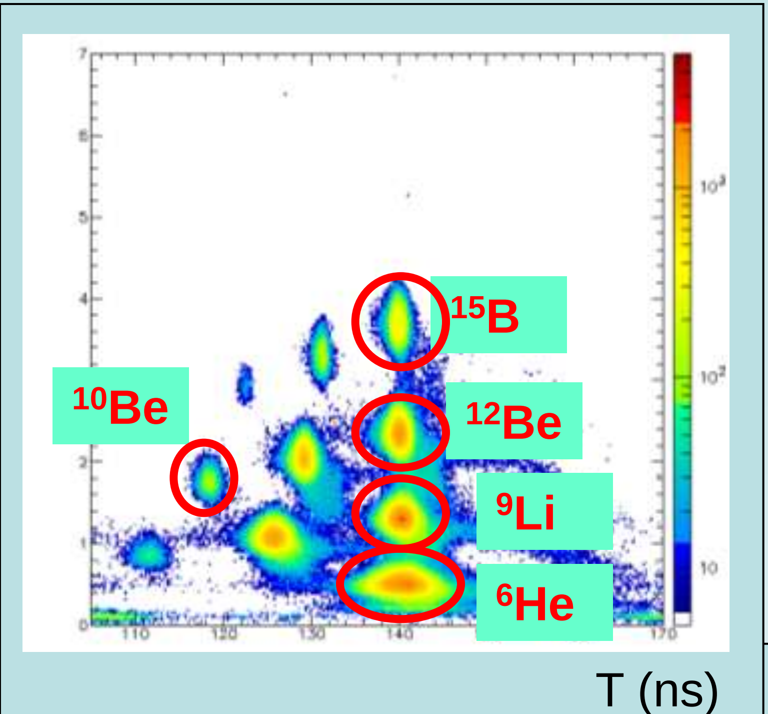


Con un fascio di circa 88W 5.5x10^{11} p/s

Fascio	Khz	
^{16}C	40	
^{17}C	4	
^{13}B	23	
^{11}Be	6	ottimizzato
^{10}Be	21	
^{8}Li	11	

Energie circa 40-50 MeV/A
Finestra impulso ΔP/P <1%

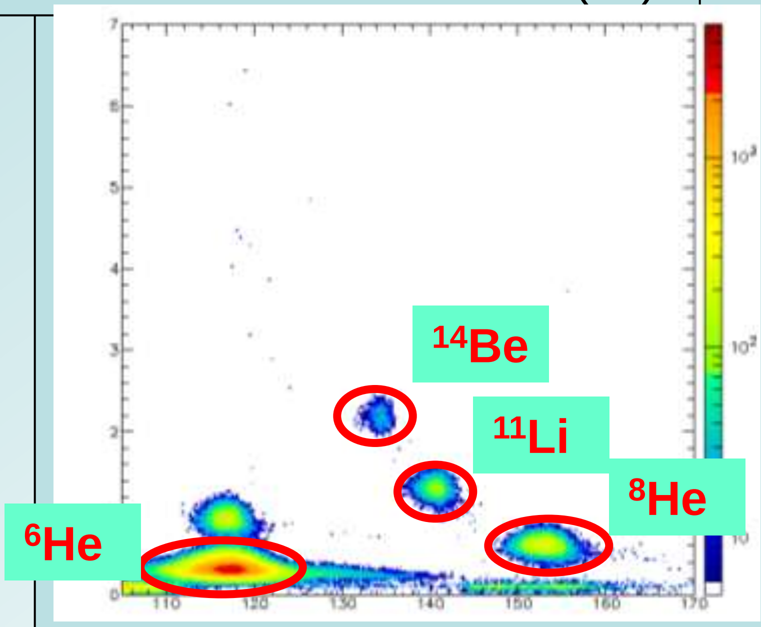
Con ^{18}O sono stati prodotti :



Con un fascio di circa 75W 4.4x10^{11} p/s

Fascio	Khz
^{15}B	0.3
^{14}B	0.9
^{12}Be	1.5
^{11}Be	0.7
^{9}Li	2.0
^{8}Li	1.6
^{6}He	3.8

NB spessore target non ottimo

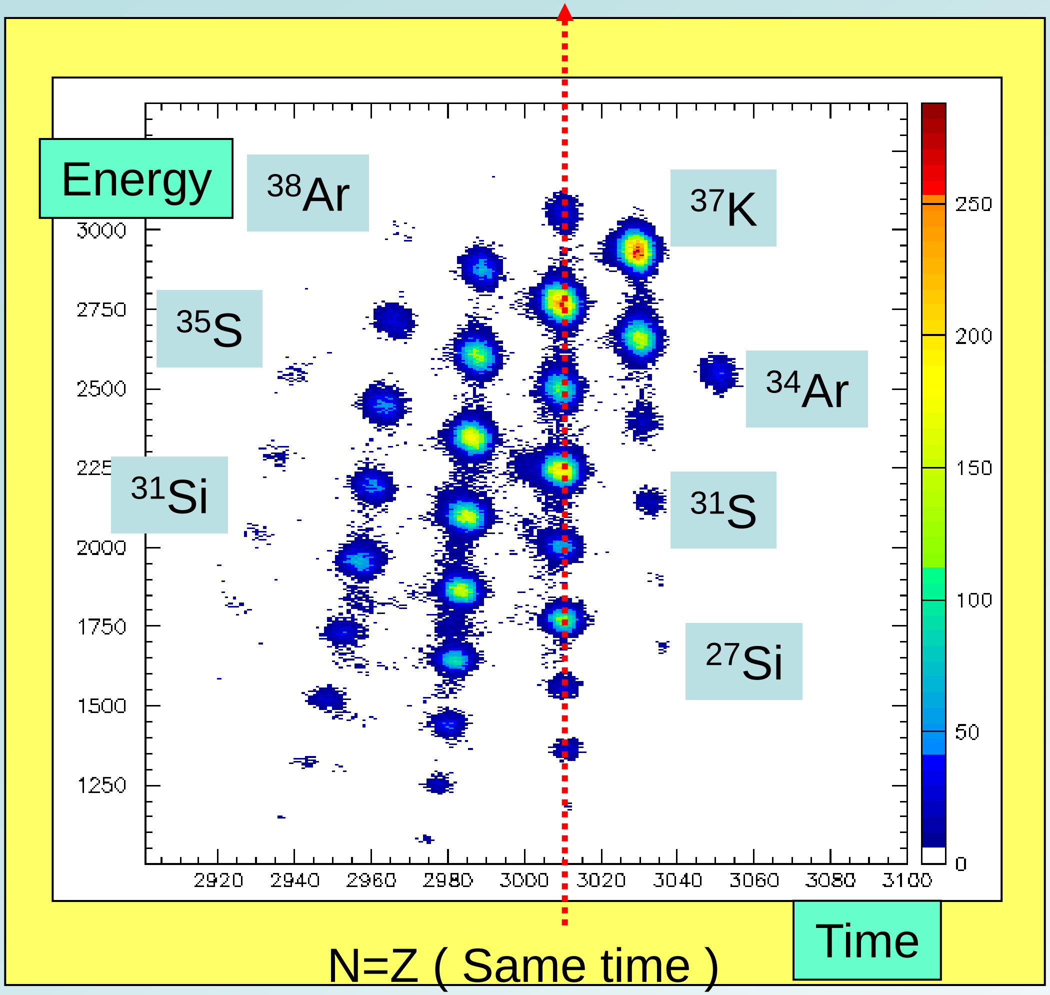


Con un fascio di circa 75W 4.4x10^{11} p/s

Fascio	hz
^{14}Be	4
^{11}Li	20
^{9}Li	40
^{8}He	80
^{6}He	980

Nb spessore target non ottimo (fattore 2)

Primario ^{36}Ar 42 MeV/A



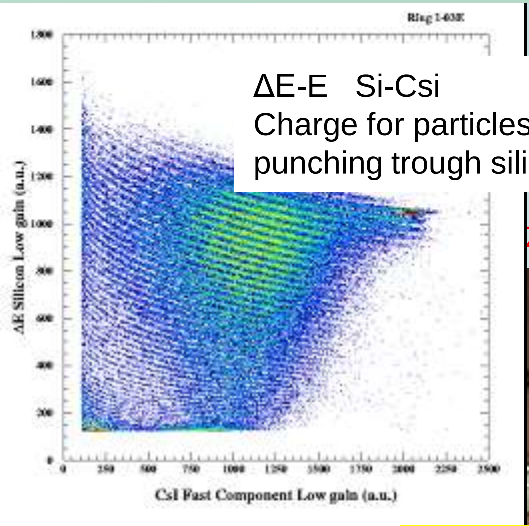
N=Z (Same time)

Con un fascio di circa 25W 1×10^{11} p/s

Fascio	Khz
^{37}K	14
^{36}Ar	12
^{35}Ar	8.5
^{34}Ar	1.8
^{33}Cl	1.5
^{34}Cl	6.5
^{31}S	0.8
^{32}S	10
^{28}Si	5
^{29}Si	6.5

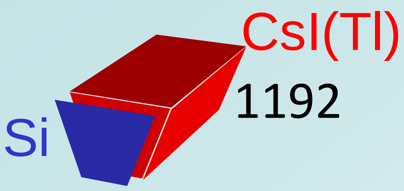
Energie attorno 20-25 MeV/A

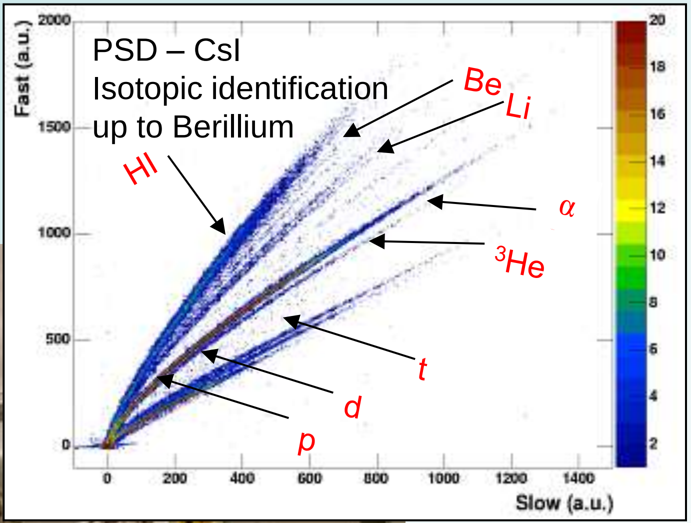
The CHIMERA detector : particle identification methods



ΔE-E Si-Csi
Charge for particles punching trough silicon

Z=50

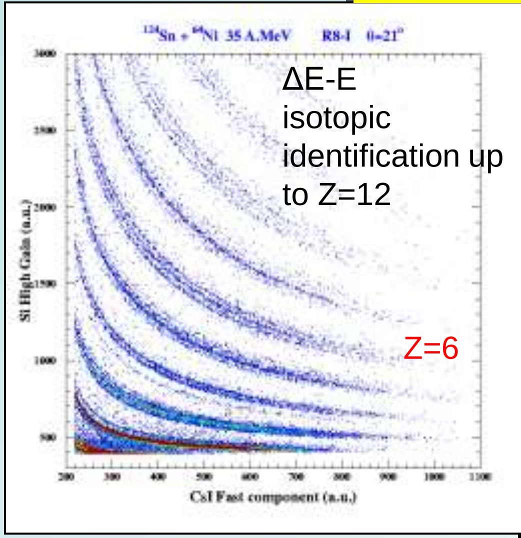




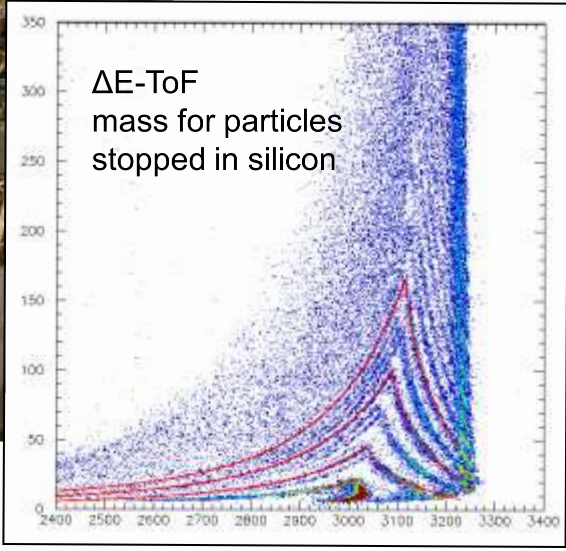
PSD – CsI
Isotopic identification up to Berillium

Δθ=8°

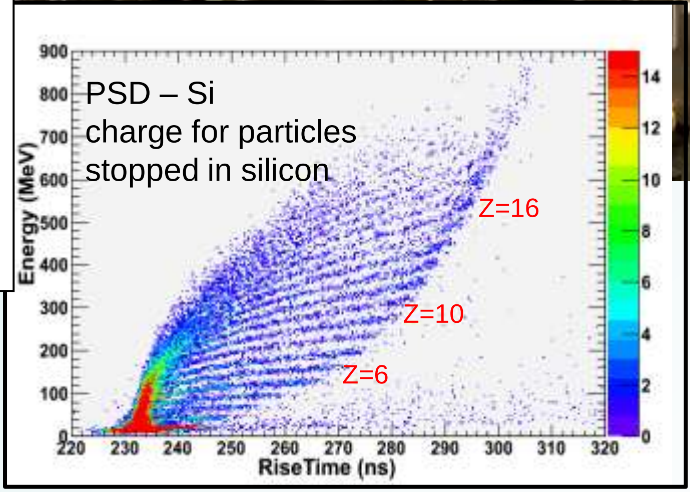
Δθ<1°



ΔE-E
isotopic identification up to Z=12



ΔE-ToF
mass for particles stopped in silicon



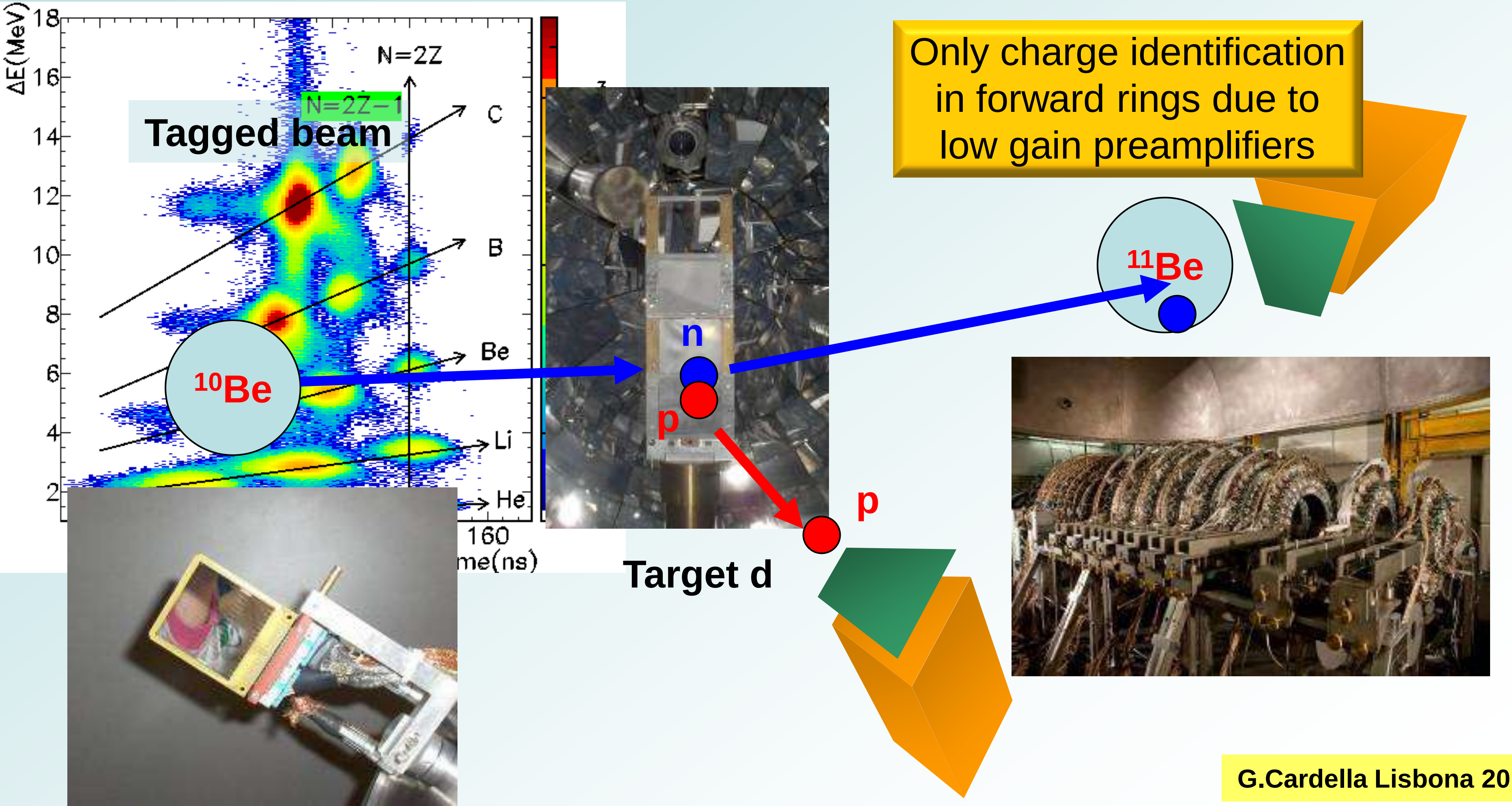
PSD – Si
charge for particles stopped in silicon

G.Cardella Lisbona 2012

-Neutron transfer reactions near halo nuclei -

We want to study elastic scattering and transfer reactions of light nuclei on p, d targets to look for halo or other nuclear structure effects

EVENT SELECTION performed with kinematic coincidences – we measure in binary reactions both reaction partners cleaning the events

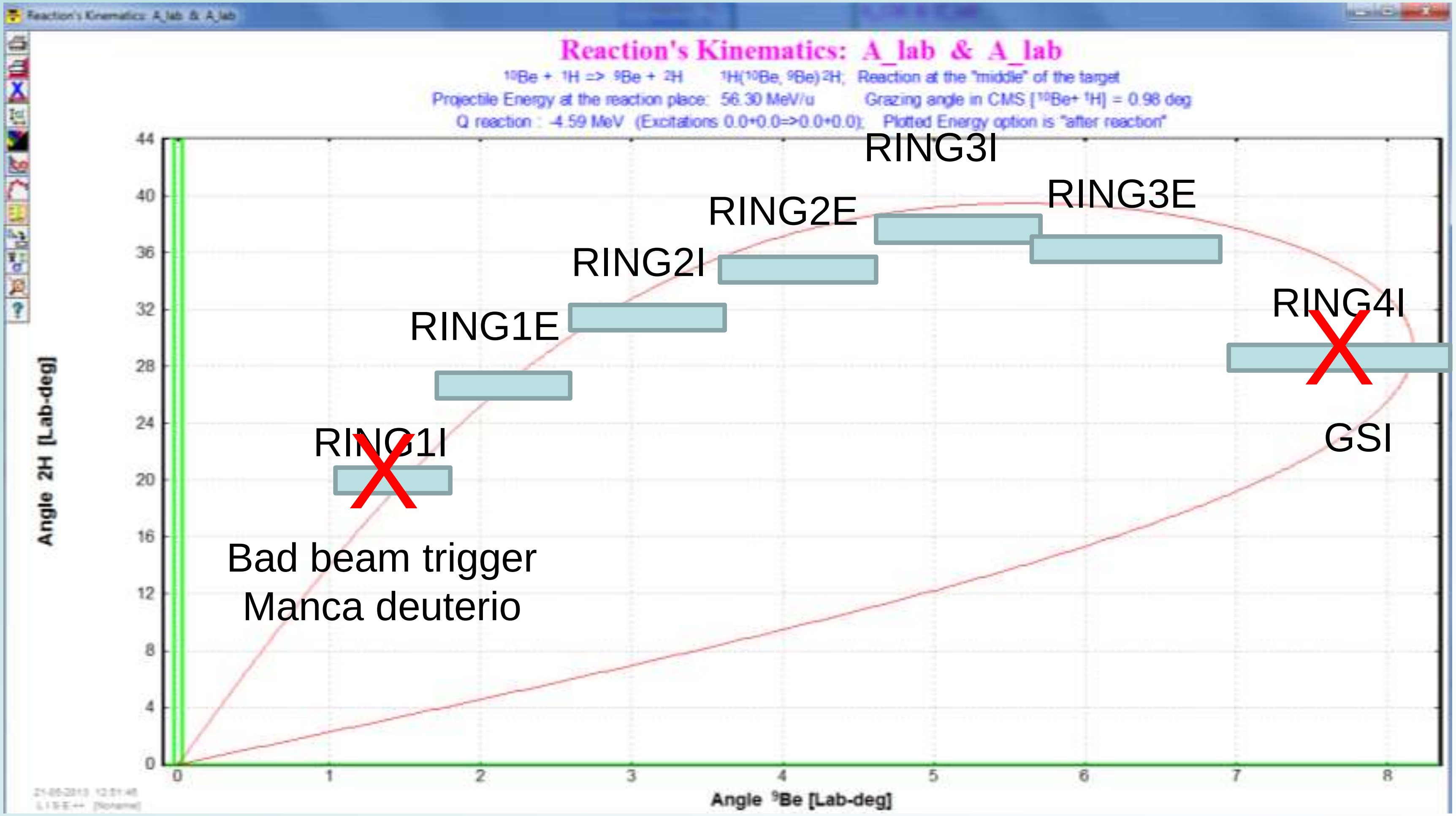


Only charge identification in forward rings due to low gain preamplifiers

G.Cardella Lisbona 2012

-Neutron transfer reactions near halo nuclei -

$^{10}Be + p \rightarrow {}^{9}Be + d$ 56.3AMeV



Reaction's Kinematics: A_lab & A_lab

$^{10}Be + {}^{1}H \Rightarrow {}^{9}Be + {}^{2}H$ $^{1}H(^{10}Be, {}^{9}Be){}^{2}H$; Reaction at the "middle" of the target

Projectile Energy at the reaction place: 56.30 MeV/u Grazing angle in CMS [$^{10}Be + {}^{1}H$] = 0.98 deg

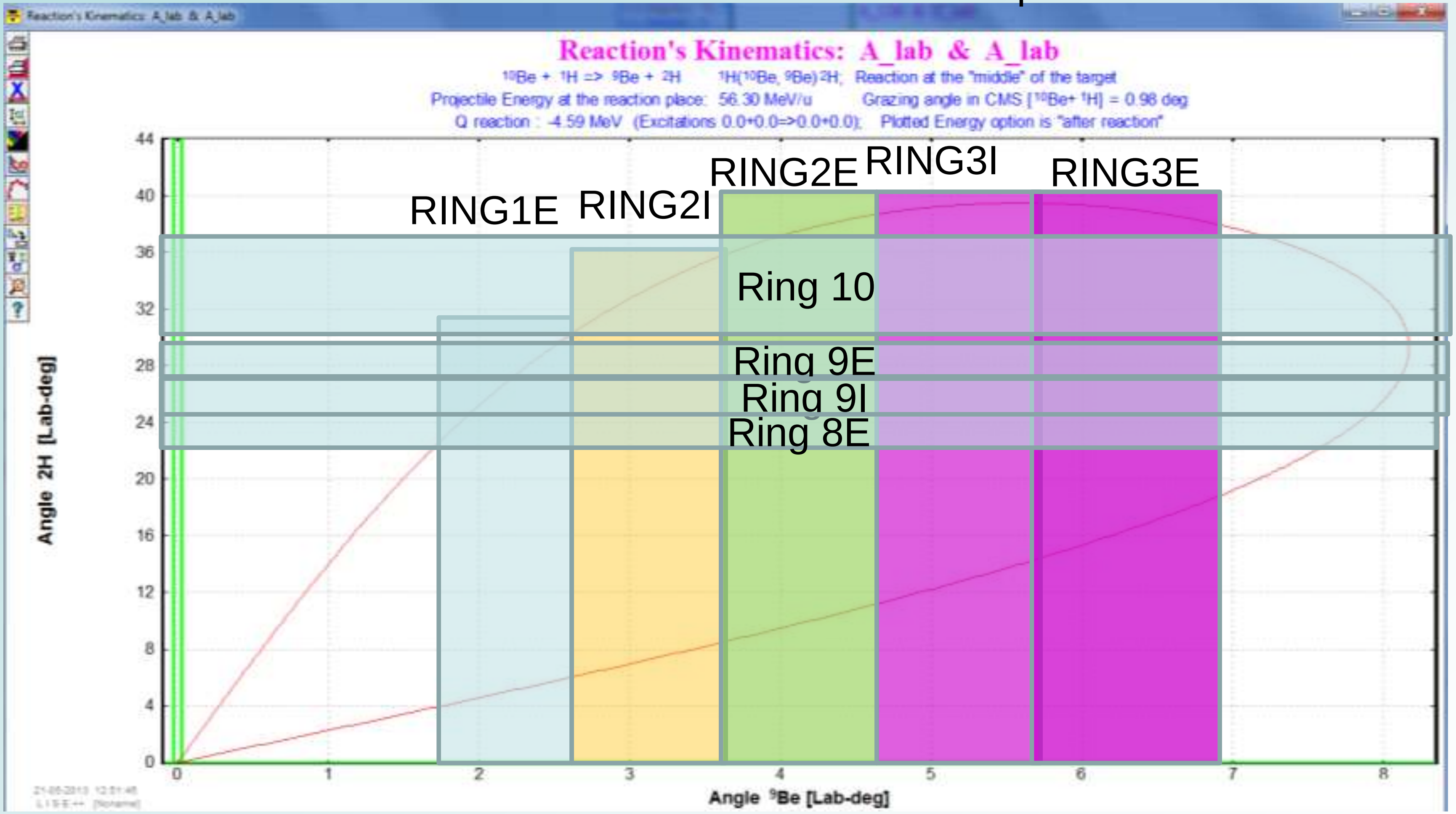
Q reaction : -4.59 MeV (Excitations 0.0+0.0=>0.0+0.0); Plotted Energy option is "after reaction"

Bad beam trigger
Manca deuterio

Solo 5/6 punti per estrarre una decina di parametri dwba !!!!

-Neutron transfer reactions near halo nuclei -

$^{10}Be+p \rightarrow ^{9}Be+d$ 56.3AMeV



Reaction's Kinematics: A_lab & A_lab

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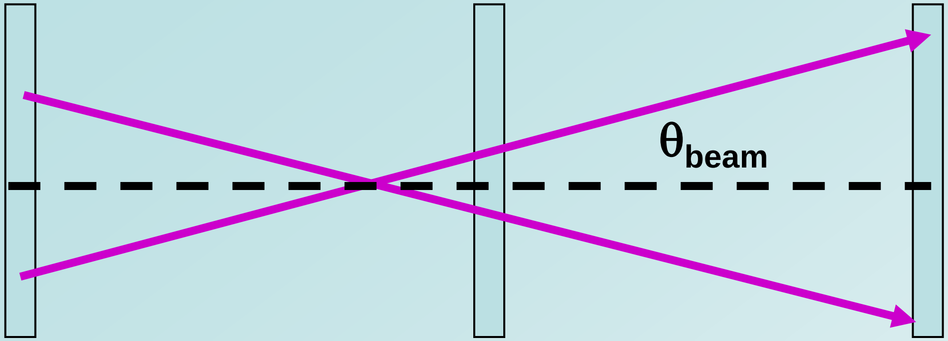
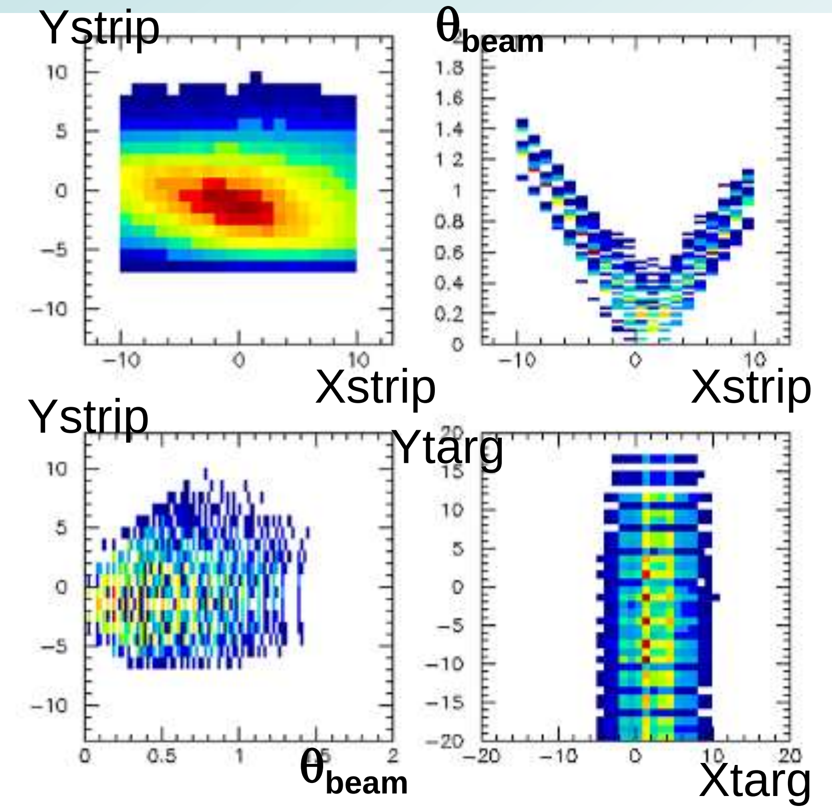
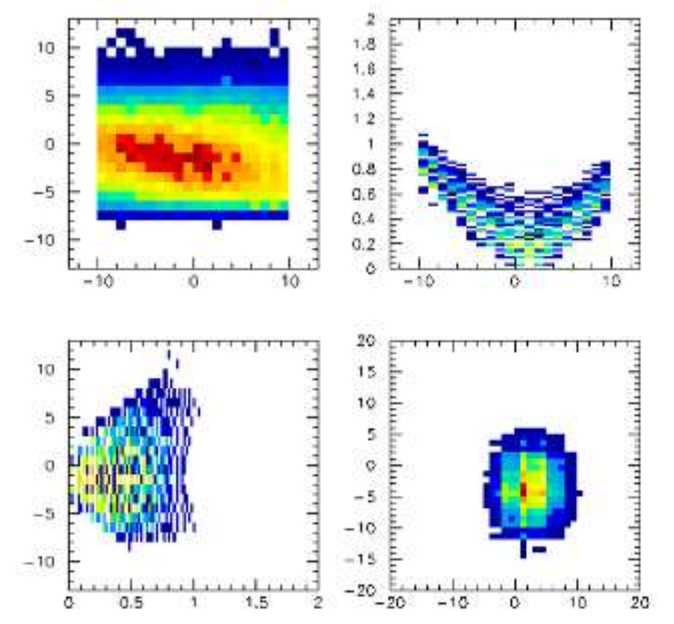
Q reaction : -4.59 MeV (Excitations 0.0+0.0=>0.0+0.0); Plotted Energy option is "after reaction"

Possiamo sfruttare gli incroci con i rivelatori in coincidenza dove riveliamo i deutoni ma si guadagnano solo pochi punti

Production and transport test: beam trajectory

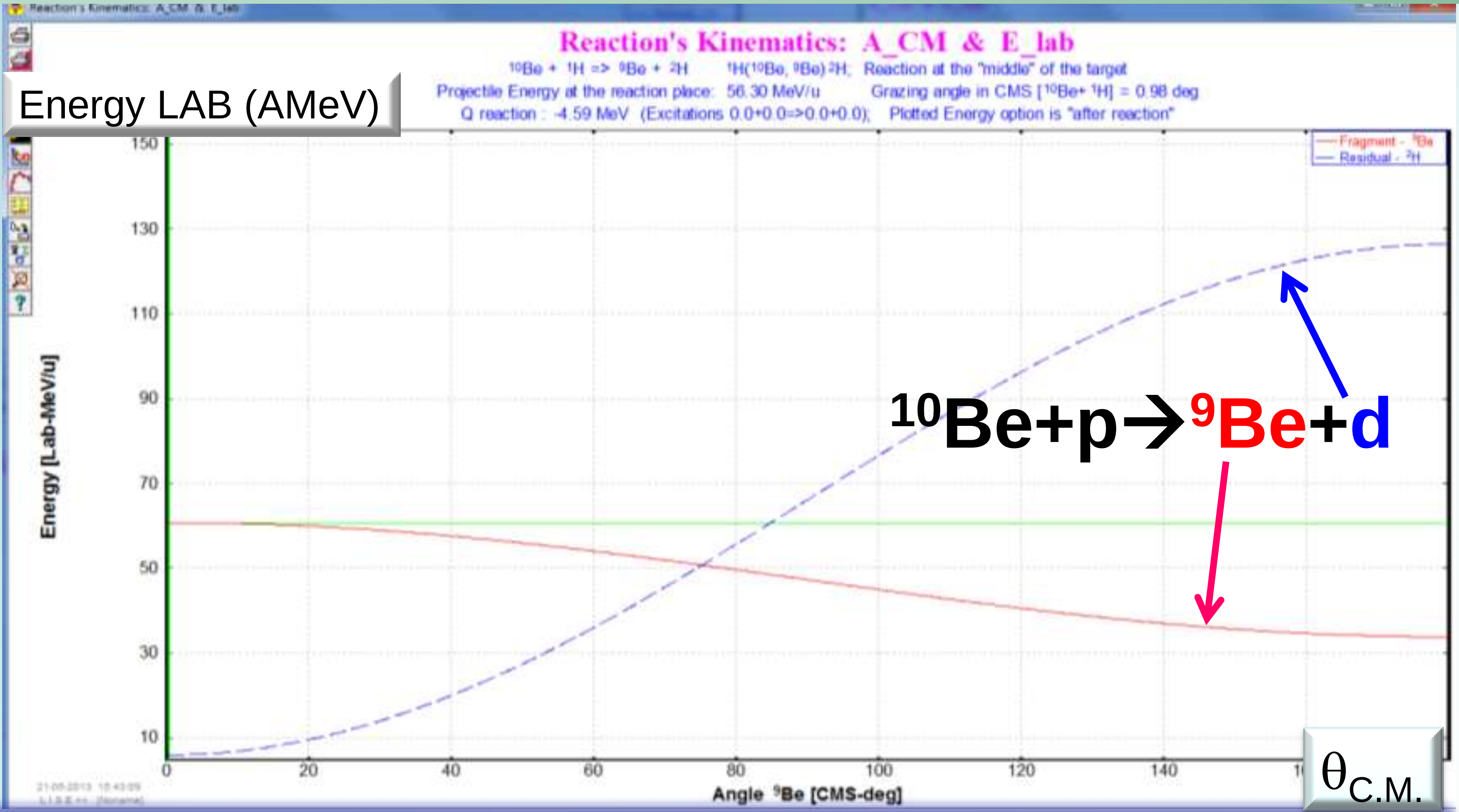






Divergenza del fascio dell’ordine di un grado potremmo utilizzarla per misurare altri punti ma rende molto complesso il calcolo dell’angolo solido

– Advantages of binary kinematics -



Reaction's Kinematics: A_CM & E_lab

^{10}Be + ^{1}H => ^{9}Be + ^{2}H ^{1}H(^{10}Be, ^{9}Be) ^{2}H; Reaction at the "middle" of the target

Projectile Energy at the reaction place: 56.30 MeV/u Grazing angle in CMS [^{10}Be+ ^{1}H] = 0.98 deg

Q reaction : -4.59 MeV (Excitations 0.0+0.0=>0.0+0.0); Plotted Energy option is "after reaction"

Energy LAB (AMeV)

^{10}Be+p→^{9}Be+d

$\theta_{C.M.}$

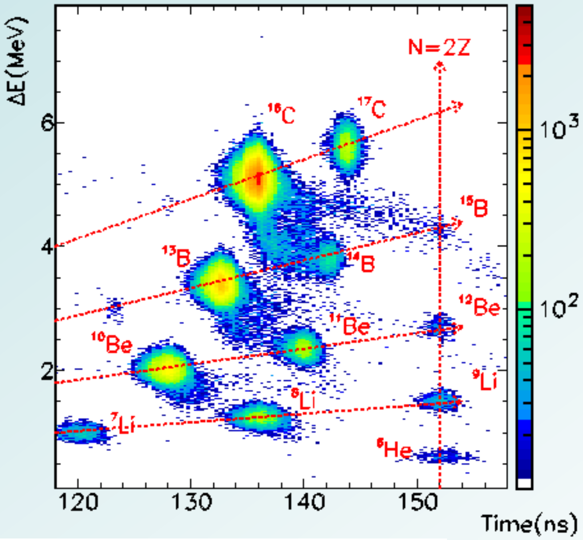
The lab energy of the detected particle determines the CM emission angle

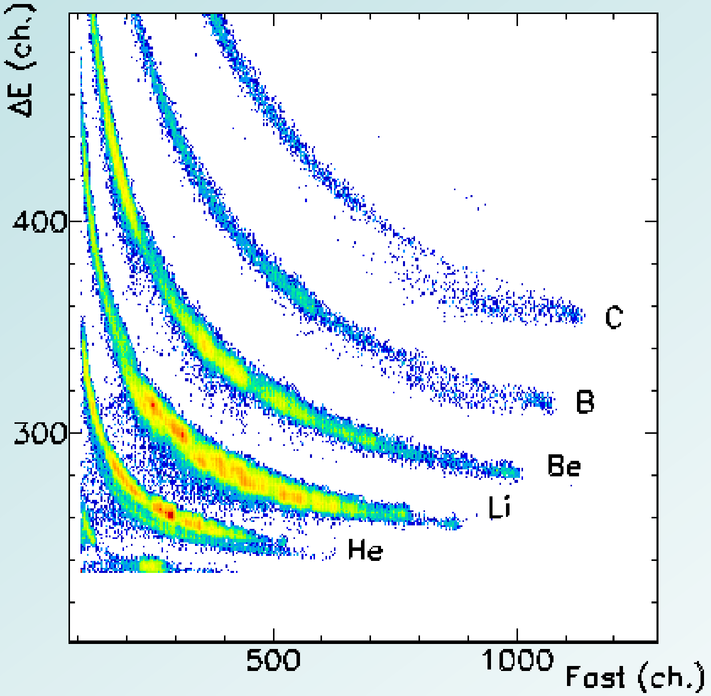
Due to the relatively good energy resolution we can get an angular distribution with much better resolution than the physical steps of our detectors

Come estraiamo la sezione d’urto?

Prima di tutto dobbiamo pulire per bene gli eventi

1) Selezioniamo il fascio incidente
2) Identifichiamo in carica e se possibile in massa le particelle





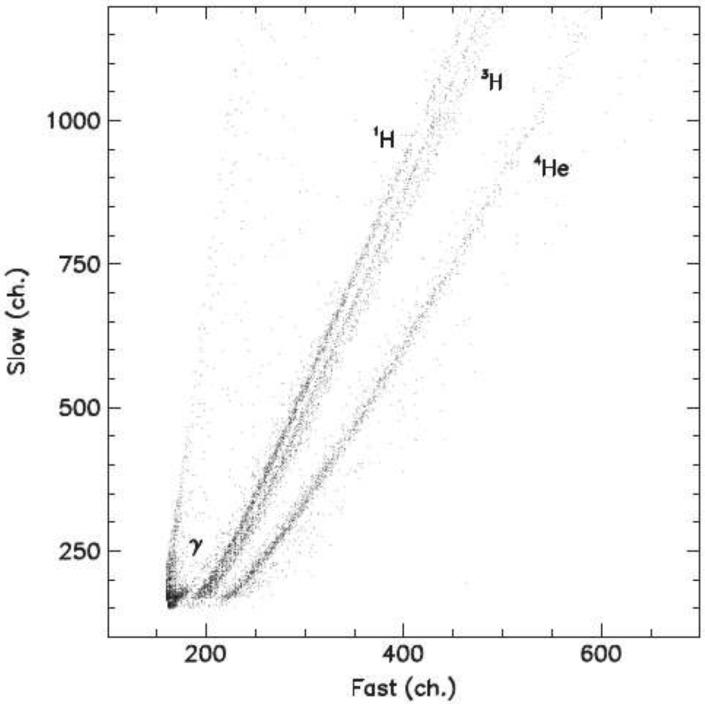
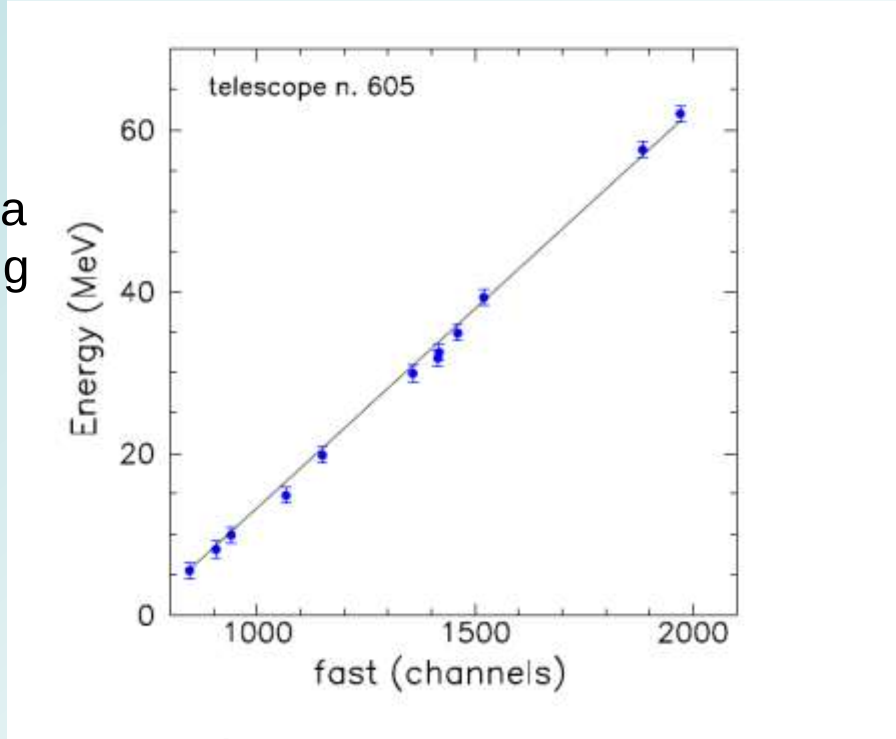
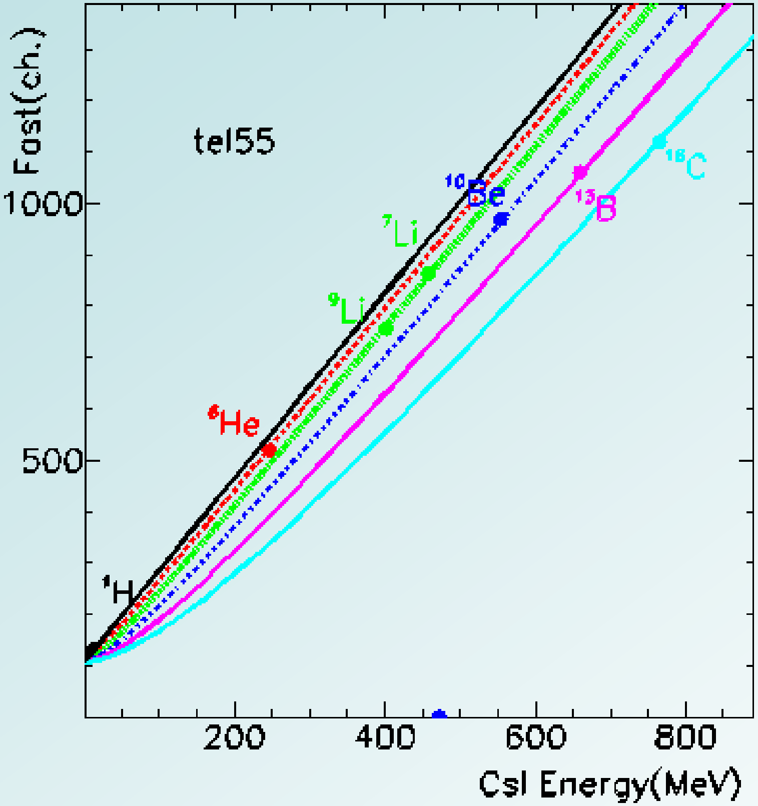


Fig. 4. Fast–slow scatter plot of a telescope at 34°. γ-Rays, proton, deuteron tritons and α-particles are identified.

Come estraiamo la sezione d’urto?
3) Calibriamo in energia le particelle rivelate



Per i protoni/deutoni è abbastanza semplice la risposta è quasi lineare, usiamo vari scattering elastici/inelastici di protoni



Più complessa è la calibrazione degli ioni pesanti a causa di effetti di quenching del segnale legati alla densità di ionizzazione (ioni con carica maggiore hanno una minore resa luminosa relativa

$$L=a_1\{E-a_2AZ^2\ln[(E+a_2AZ^2)/(a_2AZ^2)]\}+a_0$$

Formula di Horn basata sull’ipotesi di Birk

D.Horn et al, NIM A320(1992)273.

J .B . Birks, The Theory and Practice of Scintillation Counting (Pergamon, 1964) 465.

Come estraiamo la sezione d’urto?
3) Imponiamo la coincidenza tra le due particelle e verifichiamo le leggi di conservazione:

i) l’energia finale è uguale all’energia incidente tenuto conto del Q?
ii) Si conserva l’impulso? L’impulso può essere conservato in cinematica binaria solo se le due particelle sono emesse ad un angolo ϕ relativo di 180°

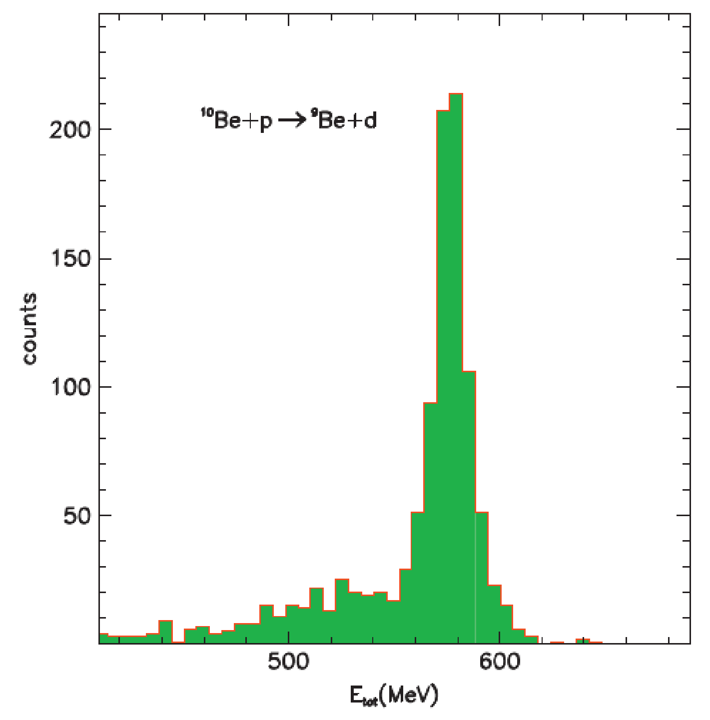


Fig. 6. Total kinetic energy detected in the reaction $^{10}Be+p \rightarrow {}^9Be+d$.

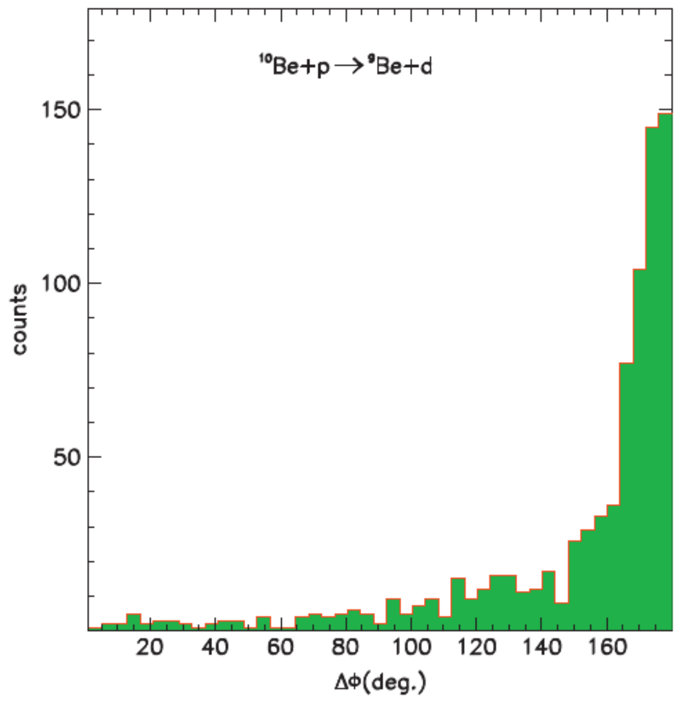


Fig. 5. Relative angle $\Delta\phi$ between the telescopes selected in coincidence in the reaction $^{10}Be+p \rightarrow {}^9Be+d$. The peak at 180° is due to kinematical coincidences.

Selezioniamo quindi solo le coincidenze con etot e $\Delta\phi$ corretti

Facciamo più attenzione all’energia totale il picco è largo almeno 20 MeV a causa delle risoluzioni sperimentali (>1% etot CsI) ΔP beam 1% potremmo popolare livelli eccitati del Be9 e non solo il GS.
Non in questo caso il primo livello eccitato del 9Be ha E*=1.684 MeV decade nel canale 2α+n non avremmo Be nel canale finale

A questo punto otteniamo lo spettro in energia di tutti i deutoni rivelati in coincidenza

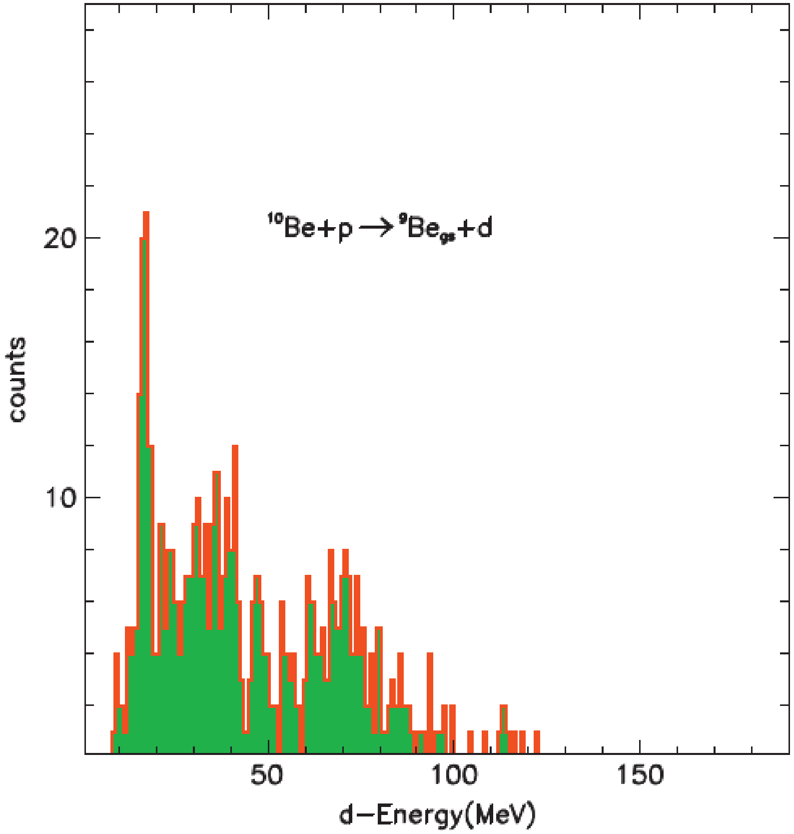


Fig. 7. Deuteron energy spectrum from the reaction $^{10}\mathrm{Be}+\mathrm{p} \rightarrow {}^{9}\mathrm{Be}_{gs}+\mathrm{d}$.

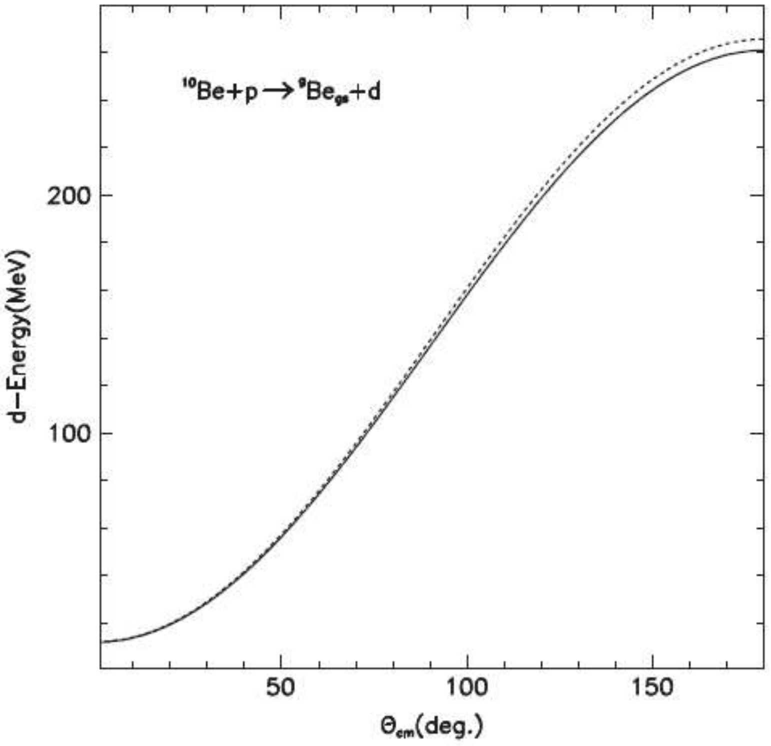


Fig. 8. Kinematical correlation between the deuteron energy and the θ_{cm} in the reaction $^{10}\mathrm{Be}+\mathrm{p} \rightarrow {}^{9}\mathrm{Be}_{gs}+\mathrm{d}$ 58 A MeV (full line). Dashed line is computed for a beam energy of 59 A MeV.

Ogni punto dello spettro in energia può essere convertito in un angolo nel CM occorre fare attenzione al calcolo dell’angolo solido per ottenere dN/dΩ

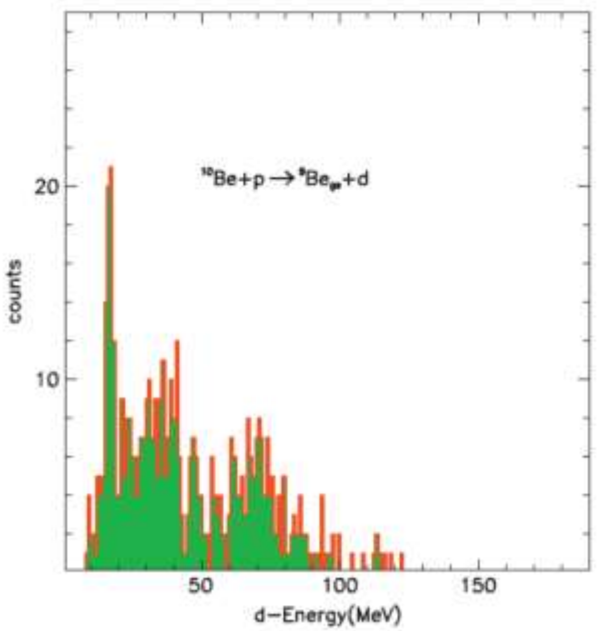


Fig. 7. Deuteron energy spectrum from the reaction $^{10}Be+p\rightarrow{}^9Be_{gs}+d$.

Ogni punto dello spettro è una funzione N(E1,E2) dove E1 ed E2 sono i limiti minimo e massimo di energia che ho imposto nel mio canale

Ho una relazione che lega E a θ, $E(\theta)$ per cui so che E1 corrisponde a $\theta 1$ ed E2 corrisponde a $\theta 2$

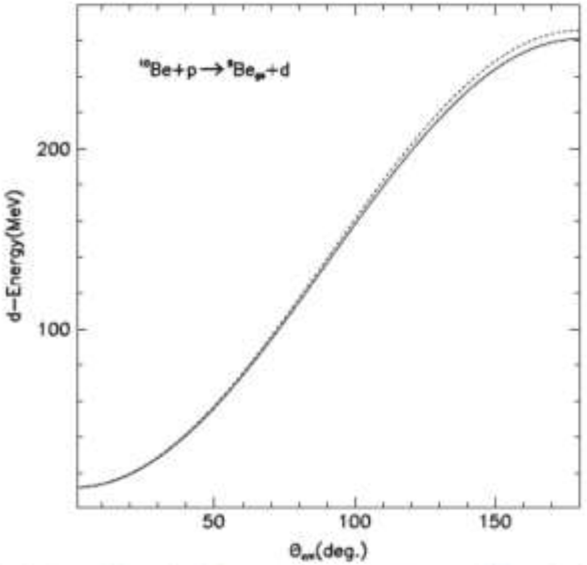


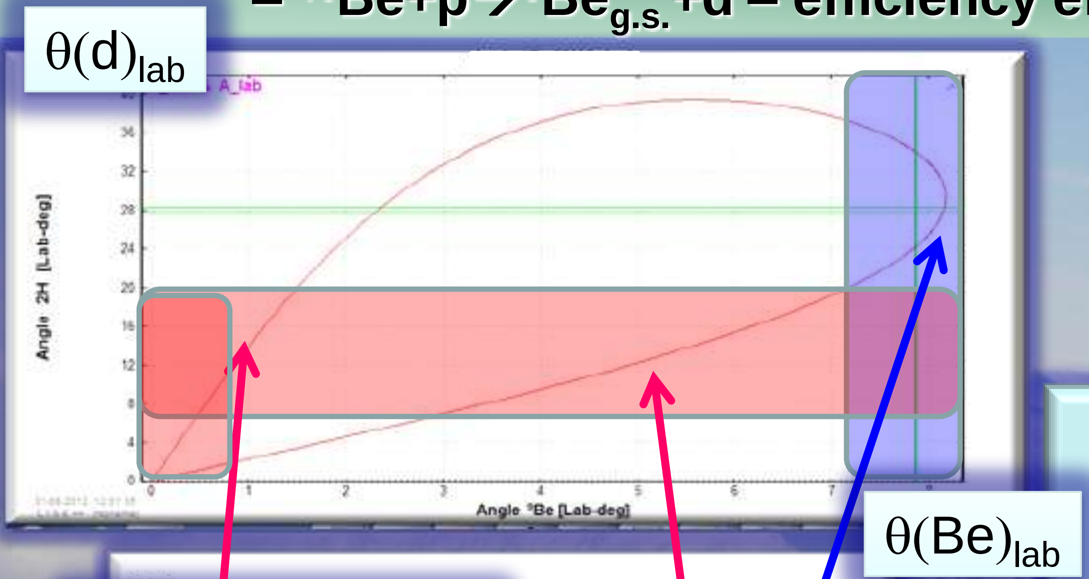
Fig. 8. Kinematical correlation between the deuteron energy and the θ_{cm} in the reaction $^{10}Be+p\rightarrow{}^9Be_{gs}+d$ 58 A MeV (full line). Dashed line is computed for a beam energy of 59 A MeV.

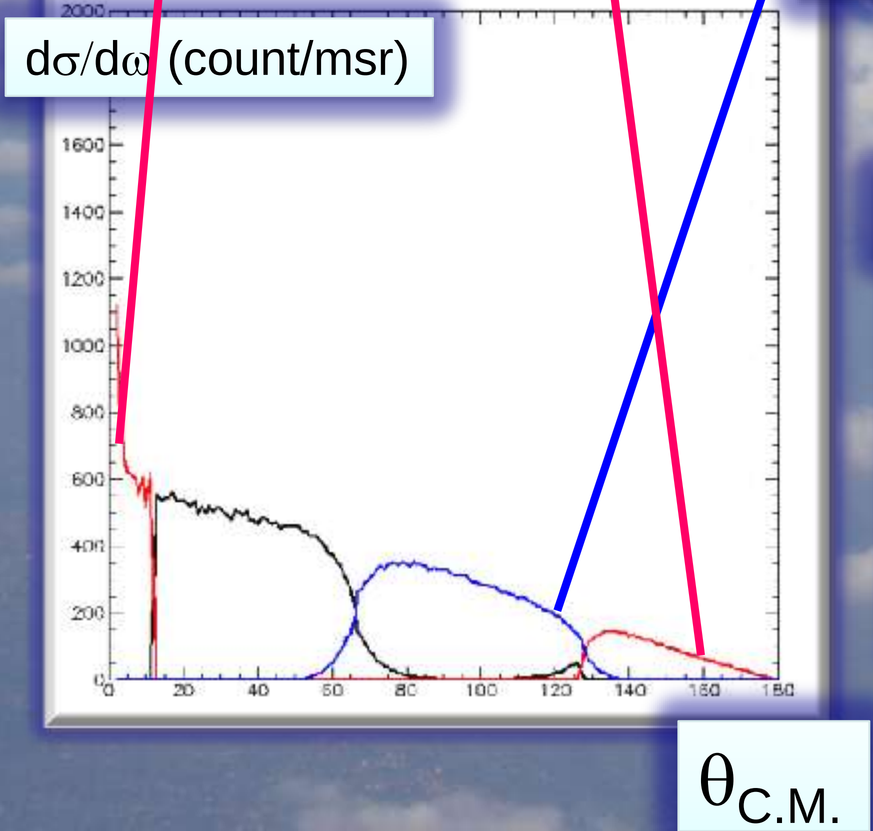
N è quindi il numero di conteggi che ho nel centro di massa tra gli angoli $\theta 1$ e $\theta 2$

Se divido per l'angolo solido sotteso tra $\theta 1$ e $\theta 2$ ottengo $N/D\Omega$

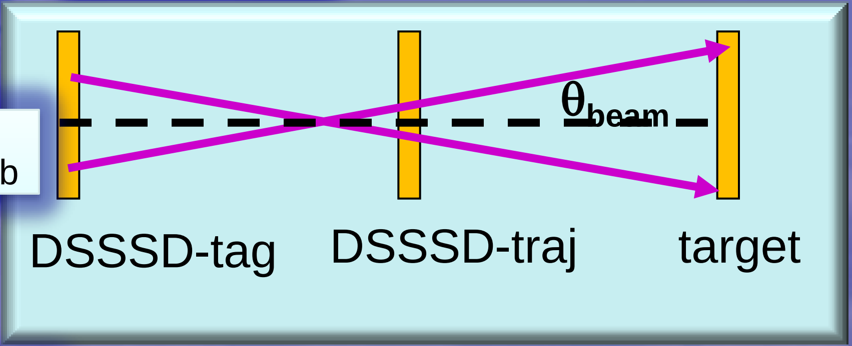
Ho assunto di avere efficienza 100% di modo da calcolare l'angolo solido come l'angolo sotteso dall'arco di sfera tra $\theta 1$ e $\theta 2$ ovviamente occorre correggere per l'efficienza

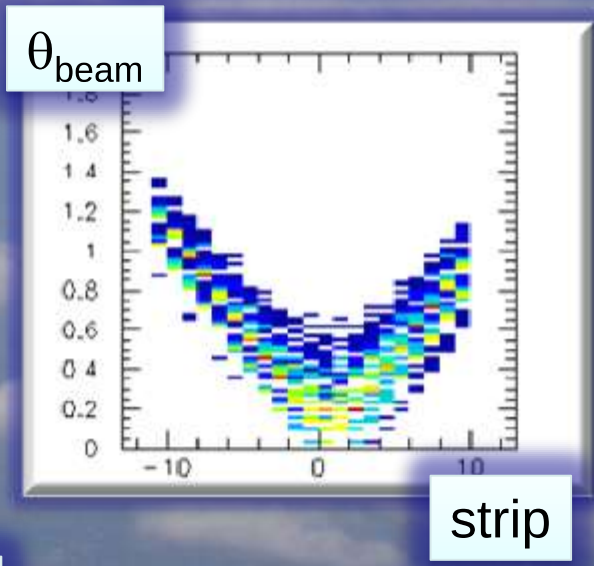
– $^{10}Be+p \rightarrow {}^{9}Be_{g.s.}+d$ – efficiency effect of missing rings -





CHIMERA ring 4-7 were used at GSI for another experiment so we have lost coincidences - we need efficiency correction





Simulations account also for the angular spread of the fragmentation beam

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Alla fine di tutto questo lavoro

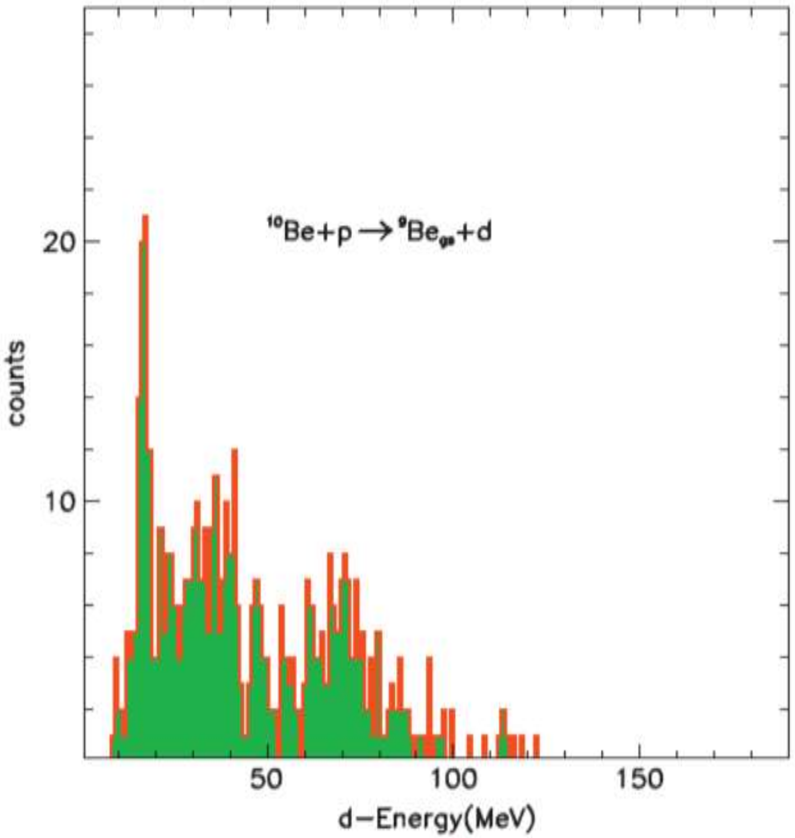

Fig. 7. Deuteron energy spectrum from the reaction $^{10}Be+p \rightarrow {}^{9}Be_{gs}+d$.

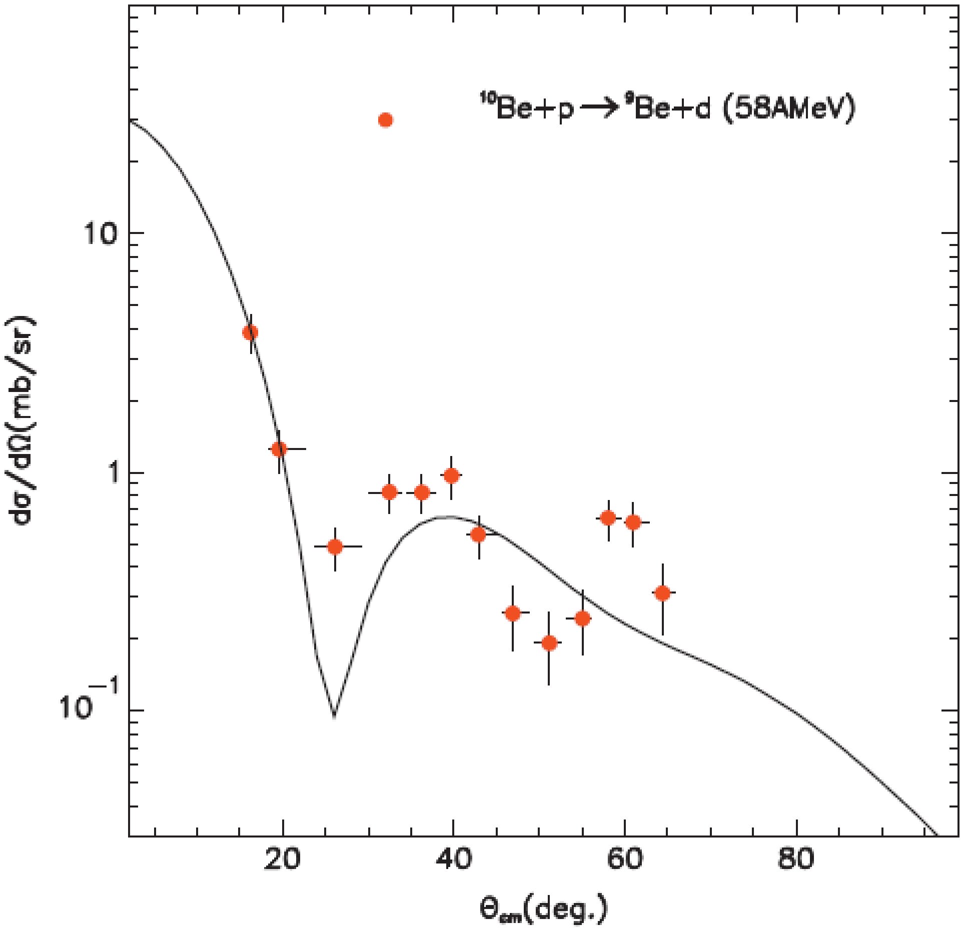

Fig. 9. Angular distribution converted from the deuteron energy spectrum of Fig. 7 (full dots). The line is a standard DWBA calculation following Ref. [32].

Abbiamo raddoppiato il numero di punti e soprattutto ottenuto una notevole risoluzione angolare