Ruhr-Universität Bochum

Lehrstuhl für Physik mit Ionenstrahlen (EP III)
Nukleare Astrophysik
Prof. Dr. C. Rolfs

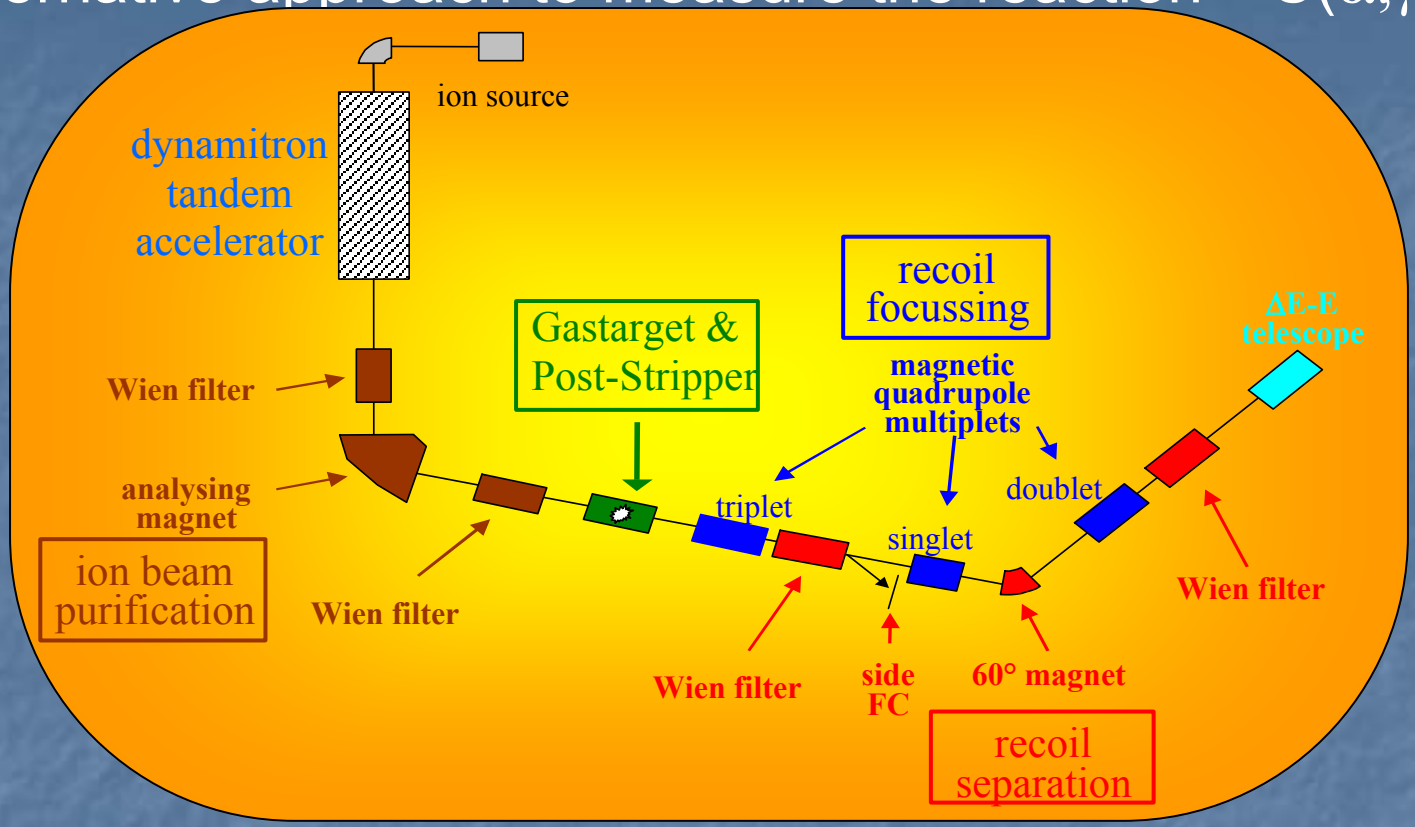
Inverse kinematic studies of $^{12}C(\alpha,\gamma)^{16}O$ with ERNA

Daniel Schürmann

ERNA Collaboration

The Status of $^{12}C(\alpha,\gamma)^{16}O$, the 'Holy Grail' of Nuclear Astrophysics, Caltech 2006/12/15

Recoil Separator ERNA:
an alternative approach to measure the reaction $^{12}C(\alpha,\gamma)^{16}O$



$$N_{recoils\ detected} = N_{projectiles} \cdot n_{target} \cdot \sigma \cdot T_{ERNA} \cdot p_q$$

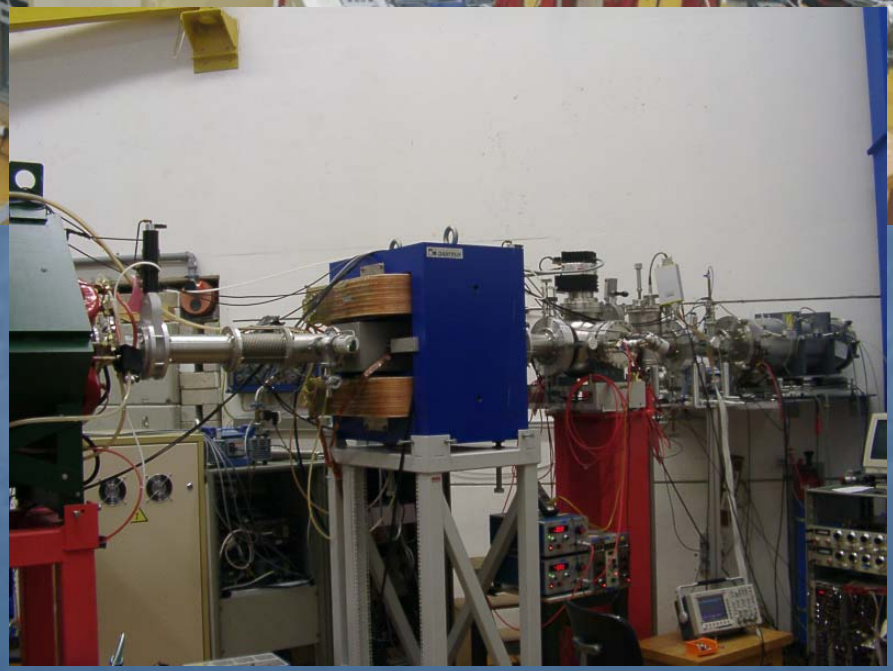
Requirements

- angular / energy acceptance
- knowledge of charge state distribution
- high purity of incoming ^{12}C beam
- suppression of ^{12}C beam

Advantages

- high efficiency ~p_q
- measure σ_{tot}
- independent of γ's
- (mostly) background free
- γ-ray coincidences *possible*

From Caltech to Bochum



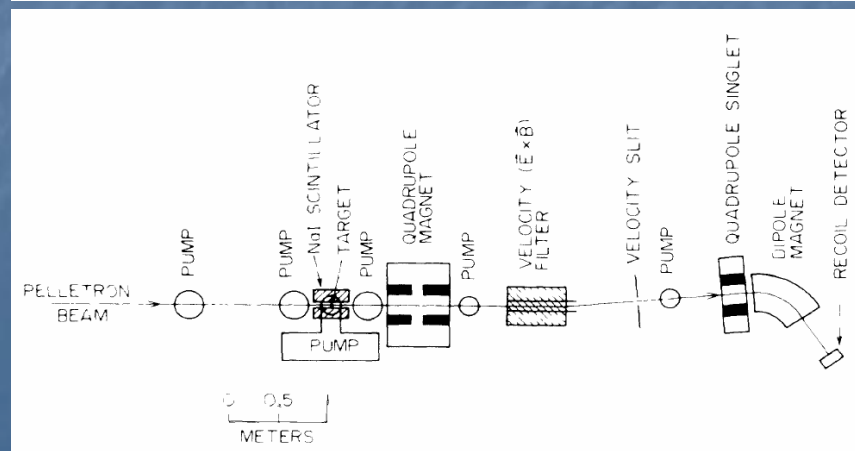
VOLUME 60, NUMBER 15 PHYSICAL REVIEW LETTERS 11 APRIL 1988

Coincidence Measurement of the $^{12}C(\alpha,\gamma)^{16}O$ Cross Section at Low Energies

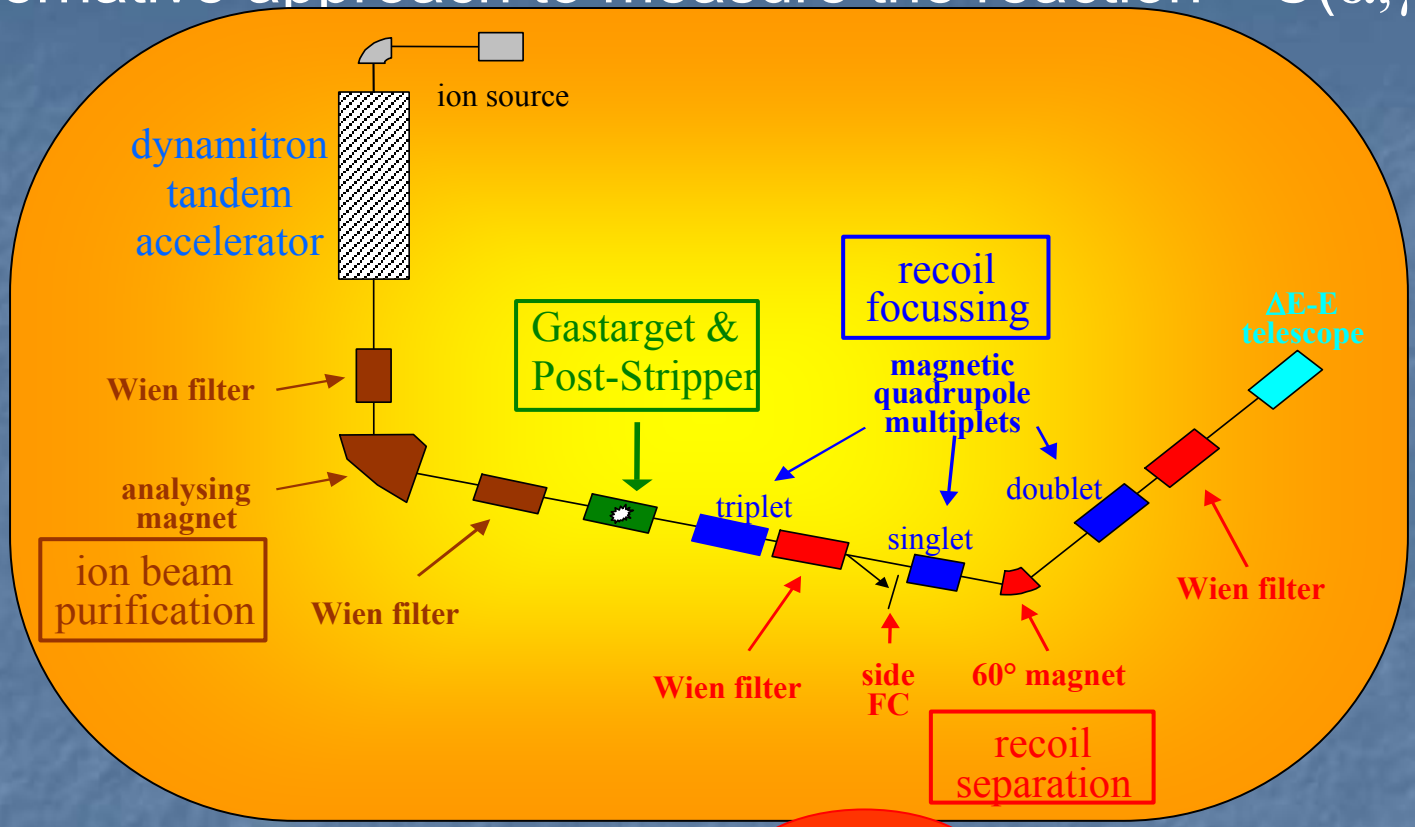
R. M. Kremer,[a] C. A. Barnes, K. H. Chang,[b] H. C. Evans,[c] B. W. Filippone, K. H. Hahn,[d] and L. W. Mitchell[e]

W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125

(Received 14 December 1987)



Recoil Separator ERNA:
an alternative approach to measure the reaction $^{12}C(\alpha,\gamma)^{16}O$



$$N_{recoils\ detected} = N_{projectiles} \cdot n_{target} \cdot \sigma \cdot T_{ERNA} \cdot p_q$$

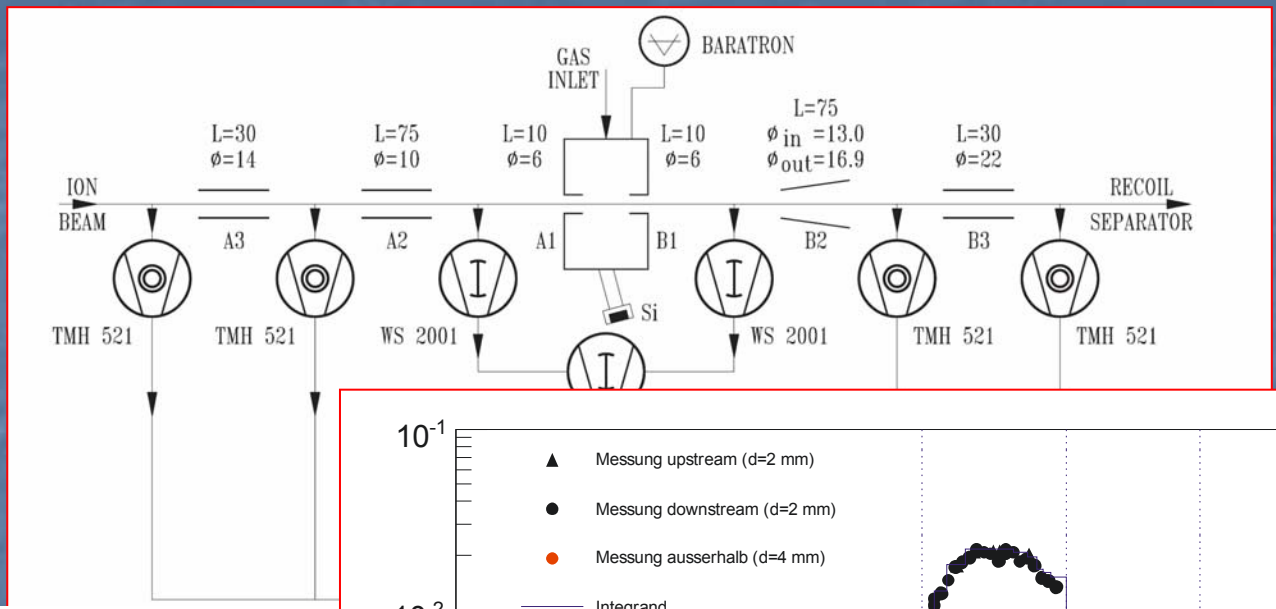
Requirements

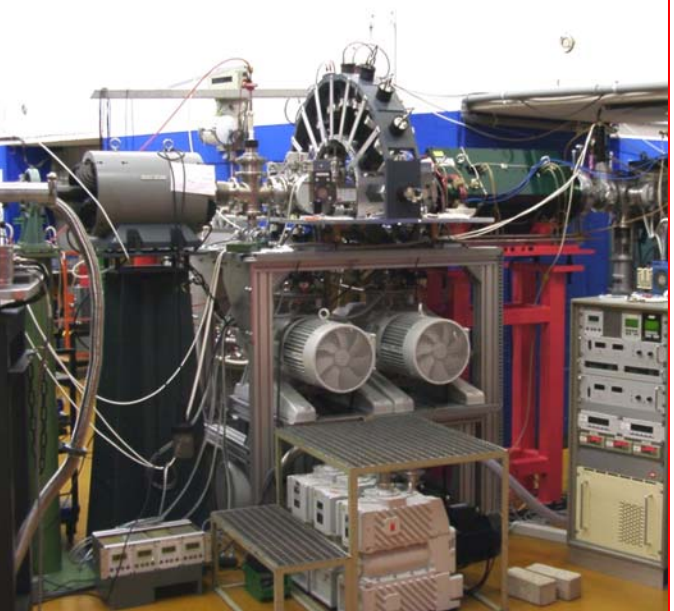
- angular / energy acceptance
- knowledge of charge state distribution
- high purity of incoming ^{12}C beam
- suppression of ^{12}C beam

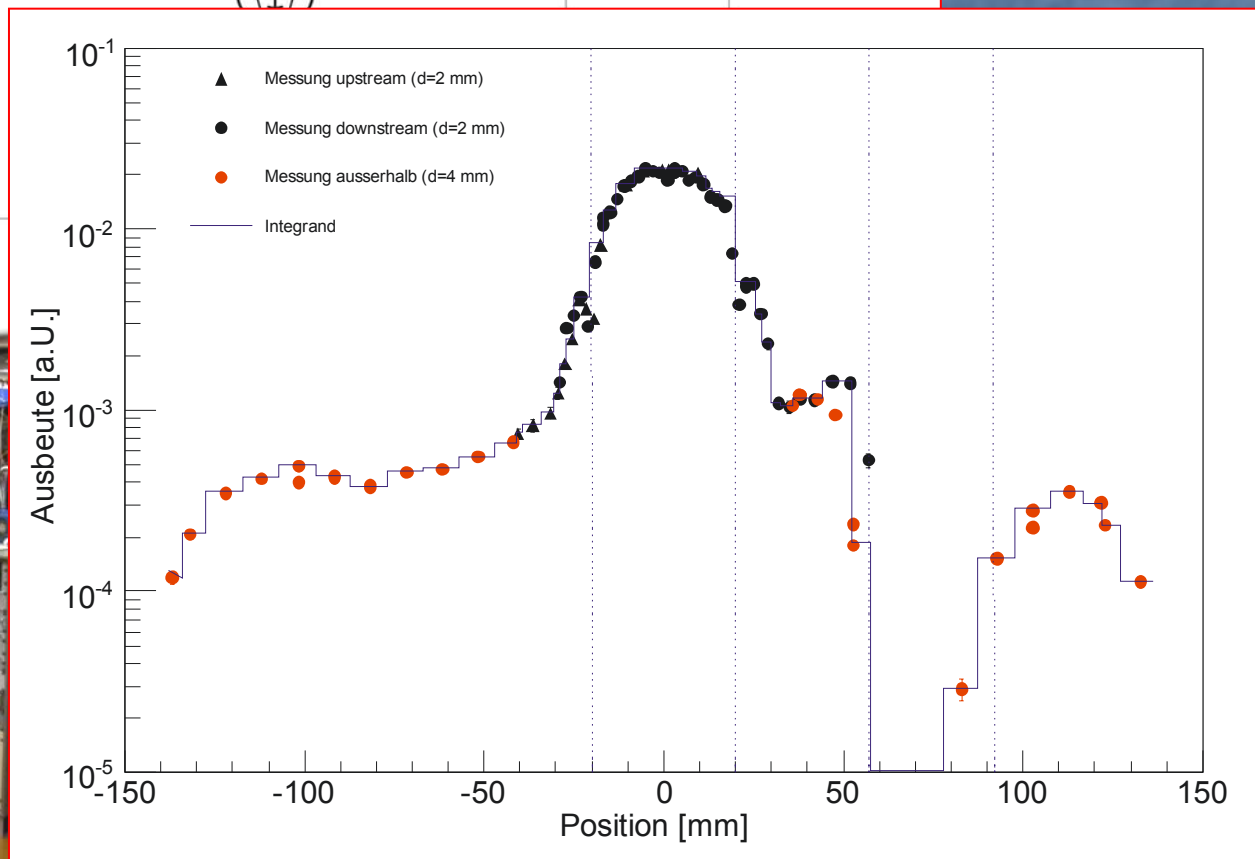
Advantages

- high efficiency ~p_q
- measure σ_{tot}
- independent of γ's
- (mostly) background free
- γ-ray coincidences *possible*

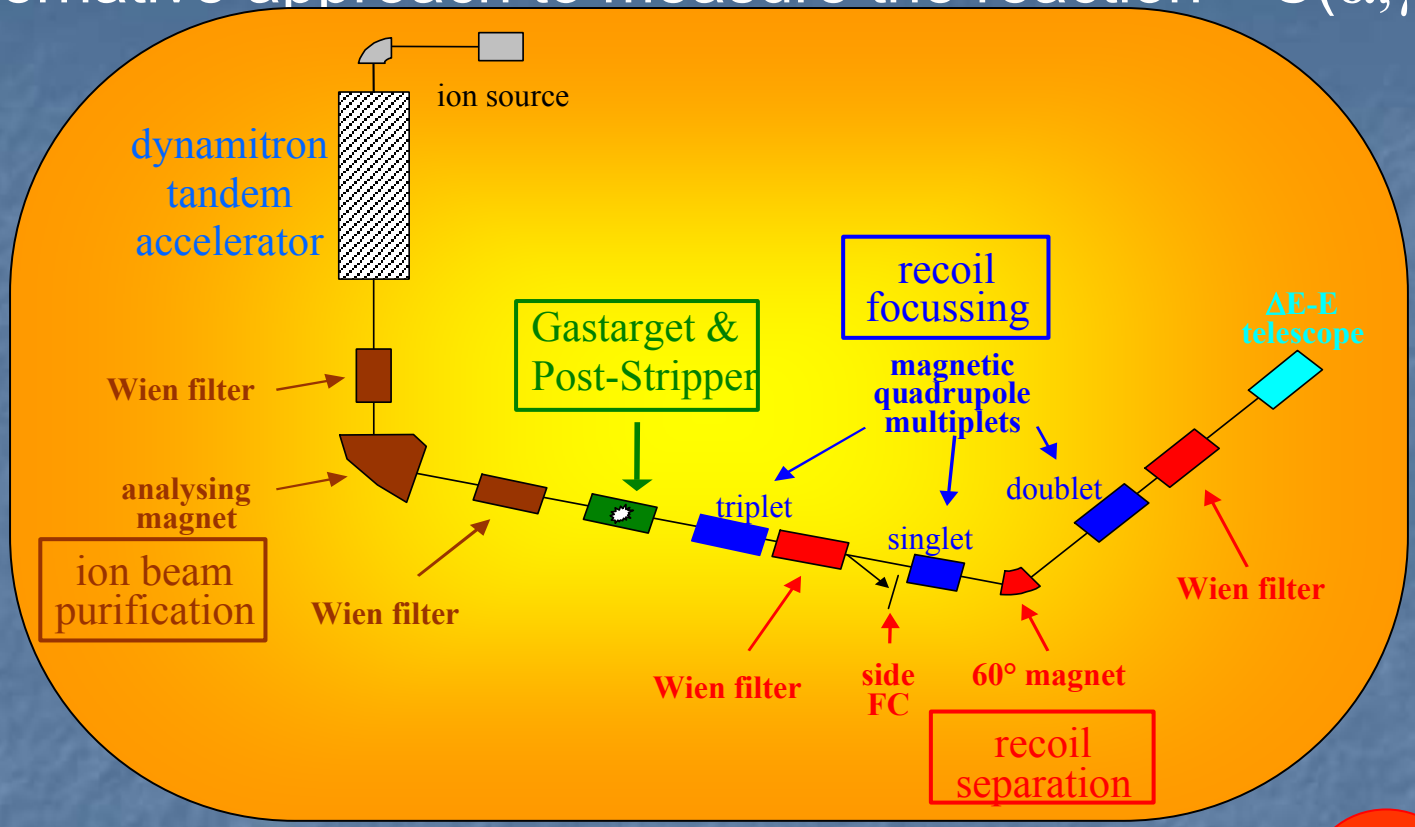
Gastarget


BARATRON
GAS
INLET
L=30
ø=14
L=75
ø=10
L=10
ø=6
L=10
ø=6
L=75
ø in =13.0
ø out=16.9
L=30
ø=22
ION
BEAM
RECOIL
SEPARATOR
A3
A2
A1
B1
B2
B3
Si
TMH 521
TMH 521
WS 2001
WS 2001
TMH 521
TMH 521




Messung upstream (d=2 mm)
Messung downstream (d=2 mm)
Messung ausserhalb (d=4 mm)
Integrand
Ausbeute [a.U.]
Position [mm]
10-1
10-2
10-3
10-4
10-5
-150
-100
-50
0
50
100
150

Recoil Separator ERNA:
an alternative approach to measure the reaction $^{12}C(\alpha,\gamma)^{16}O$



$$N_{recoils\ detected} = N_{projectiles} \cdot n_{target} \cdot \sigma \cdot T_{ERNA} \cdot p_q$$

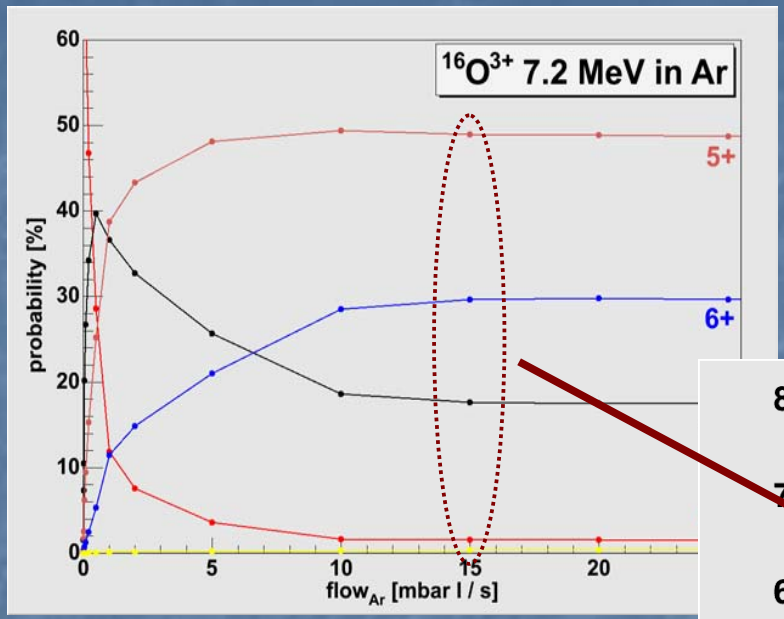
Requirements

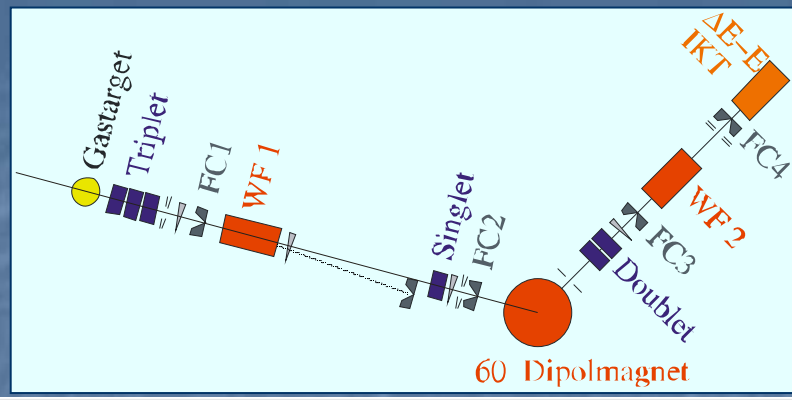
- angular / energy acceptance
- knowledge of charge state distribution
- high purity of incoming ^{12}C beam
- suppression of ^{12}C beam

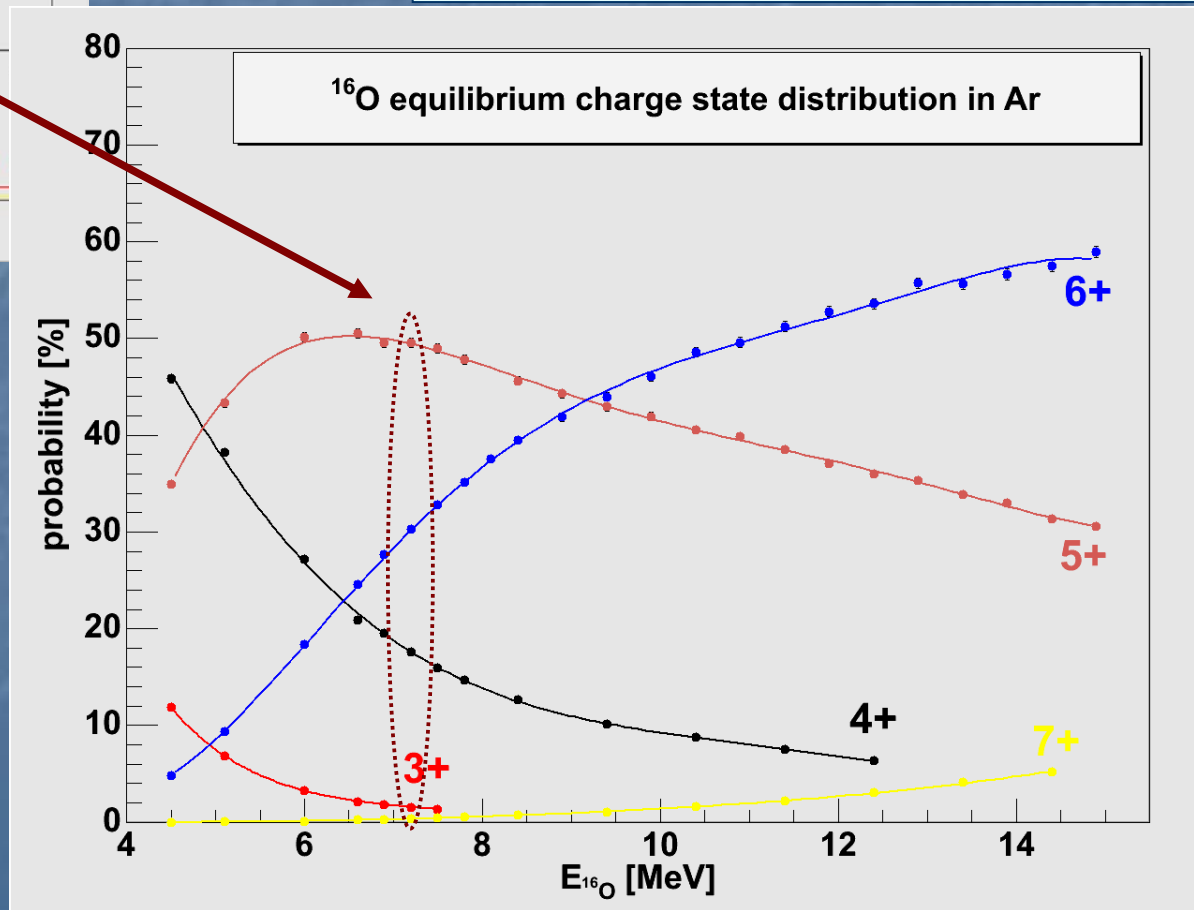
Advantages

- high efficiency ~p_q
- measure σ_{tot}
- independent of γ's
- (mostly) background free
- γ-ray coincidences *possible*

Charge State Distribution

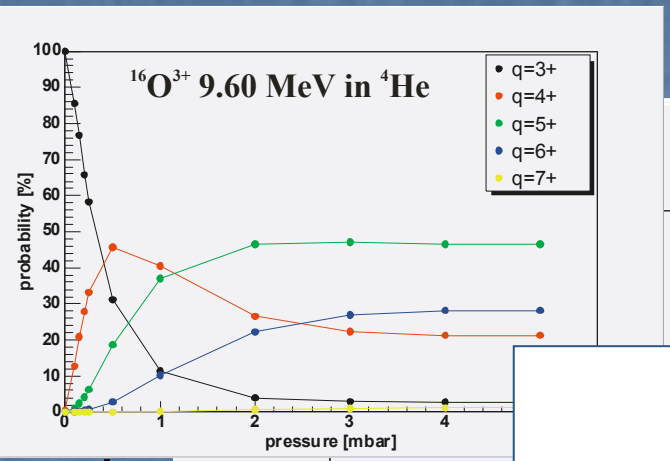






Charge State Distribution

electron loss

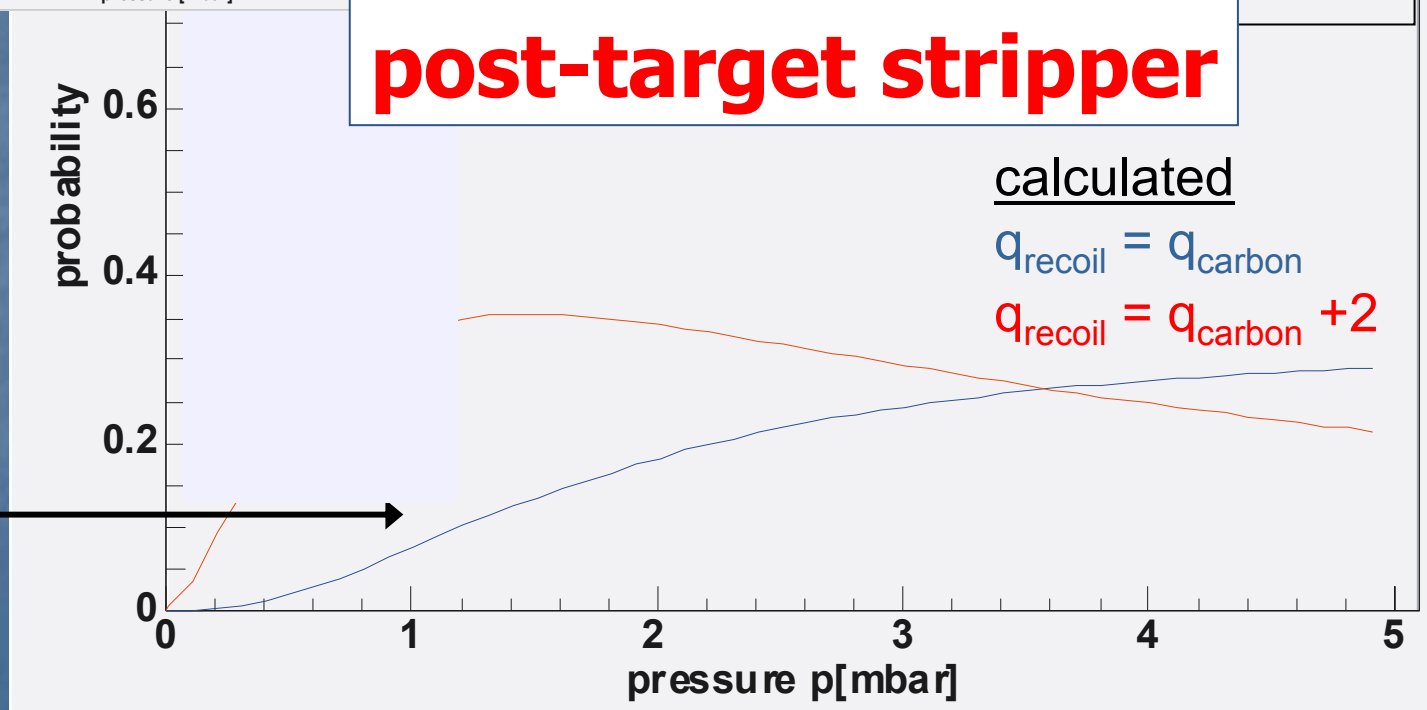


$^{12}C^{3+} \rightarrow {}^{16}O^{6+}$

MeV

Solution:
post-target stripper

integrate

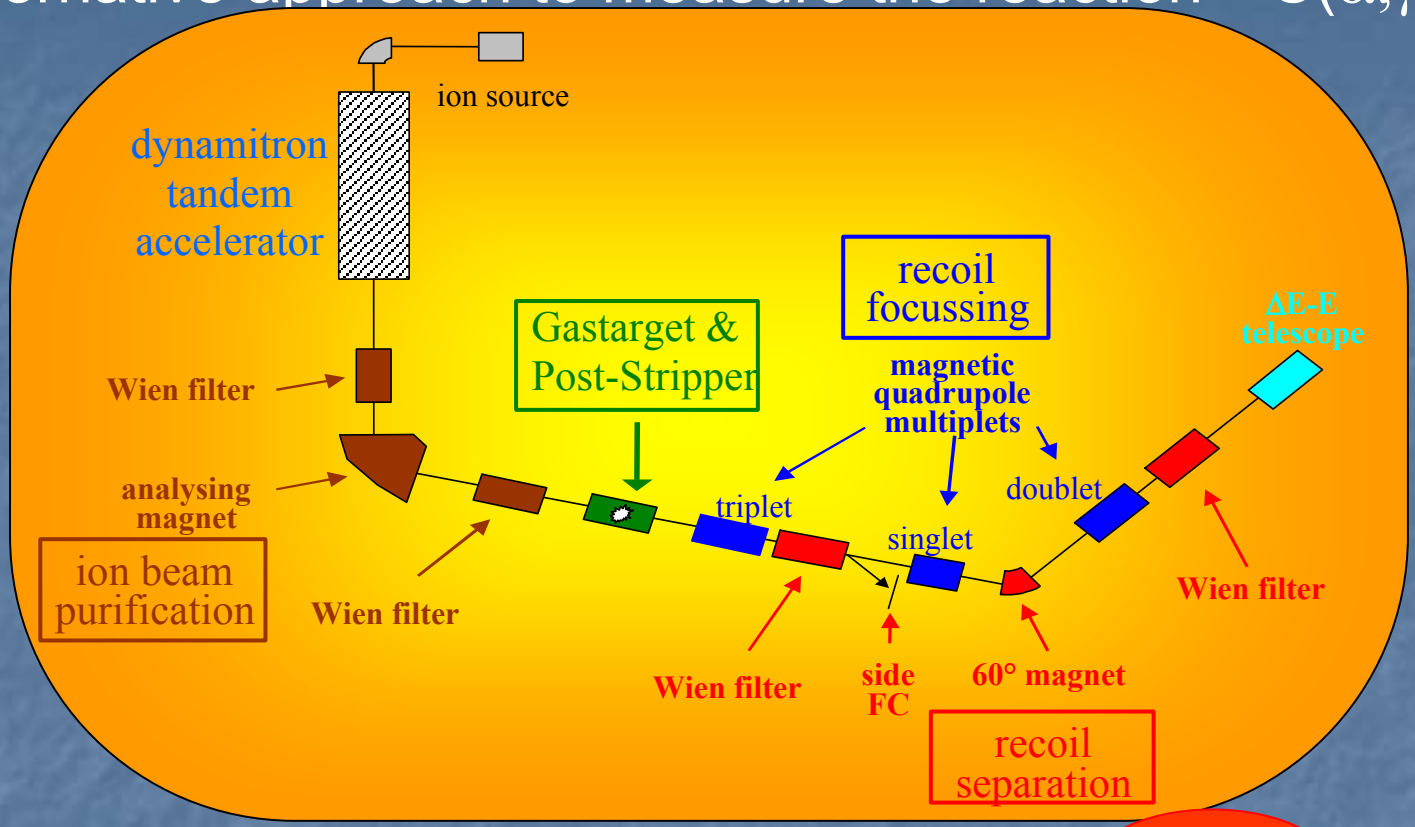


calculated

$q_{recoil} = q_{carbon}$

$q_{recoil} = q_{carbon} + 2$

Recoil Separator ERNA:
an alternative approach to measure the reaction $^{12}C(\alpha,\gamma)^{16}O$



$$N_{recoils\ detected} = N_{projectiles} \cdot n_{target} \cdot \sigma \cdot T_{ERNA} \cdot p_q$$

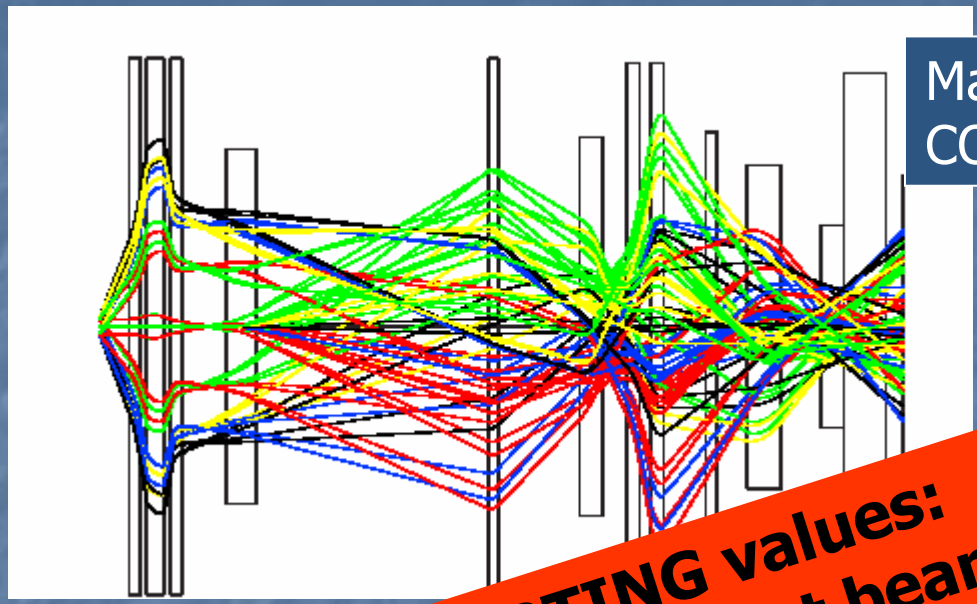
Requirements

- angular / energy acceptance
- knowledge of charge state distribution
- high purity of incoming ^{12}C beam
- suppression of ^{12}C beam

Advantages

- high efficiency ~p_q
- measure σ_{tot}
- independent of γ's
- (mostly) background free
- γ-ray coincidences *possible*

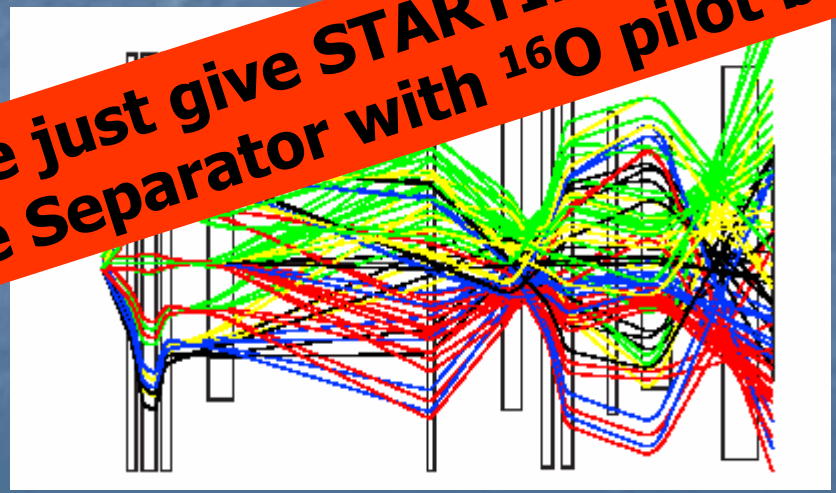
Acceptance



Matrix calculations:
COSY INFINITY

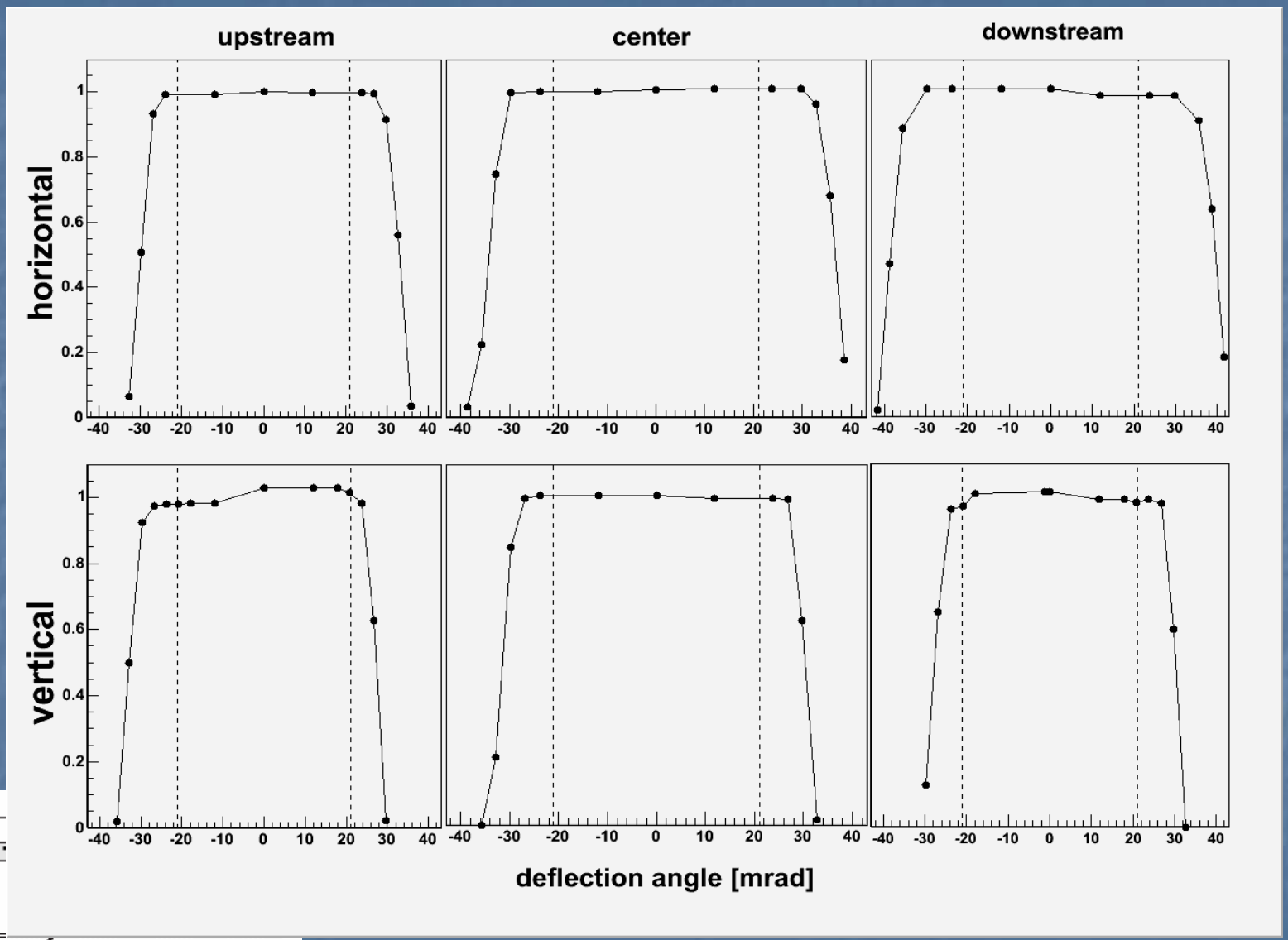
Good tuning

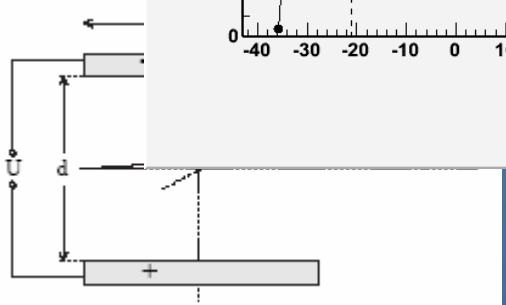
These just give STARTING values:
Tune Separator with ^{16}O pilot beam!



Bad tuning

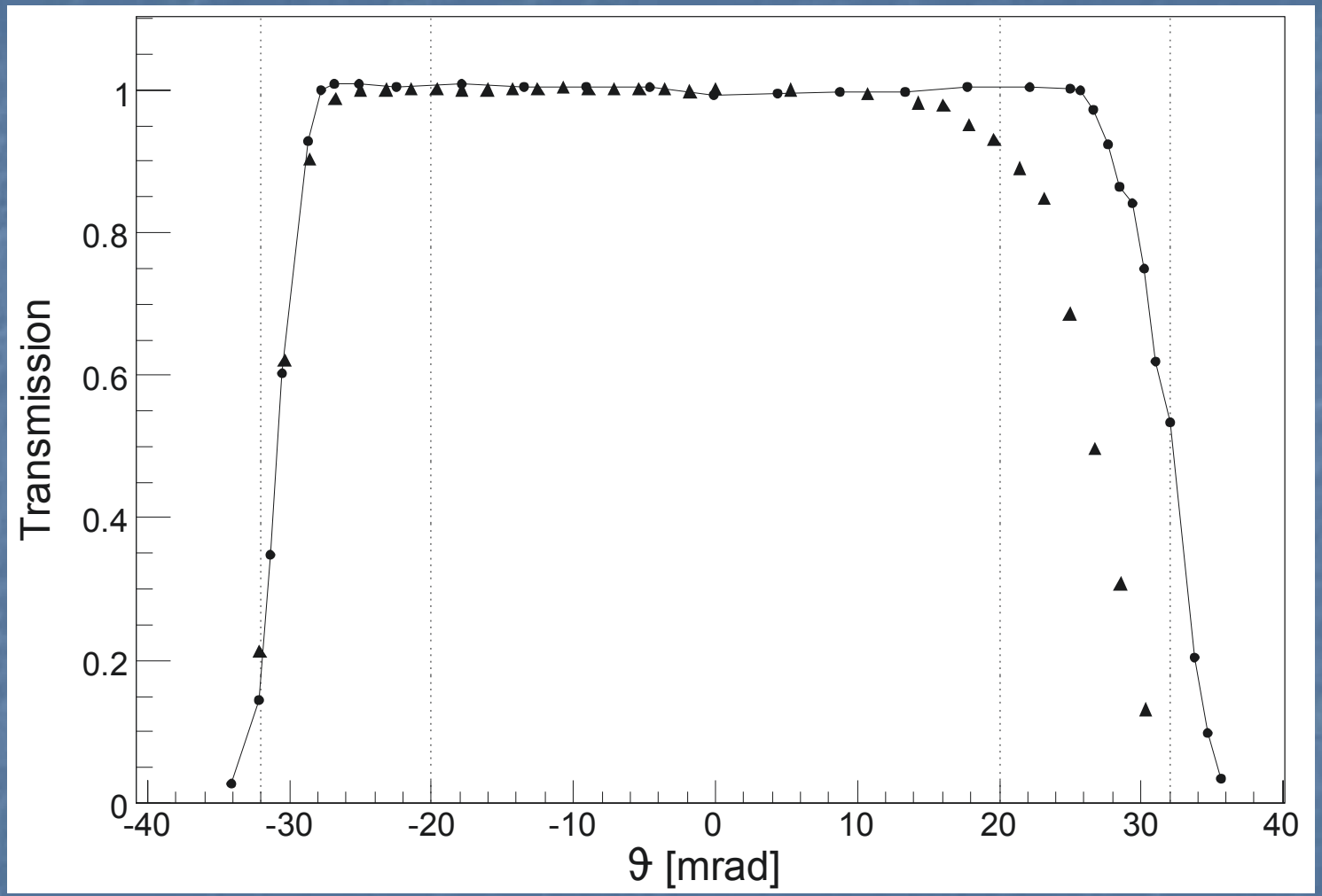
Angular acceptance





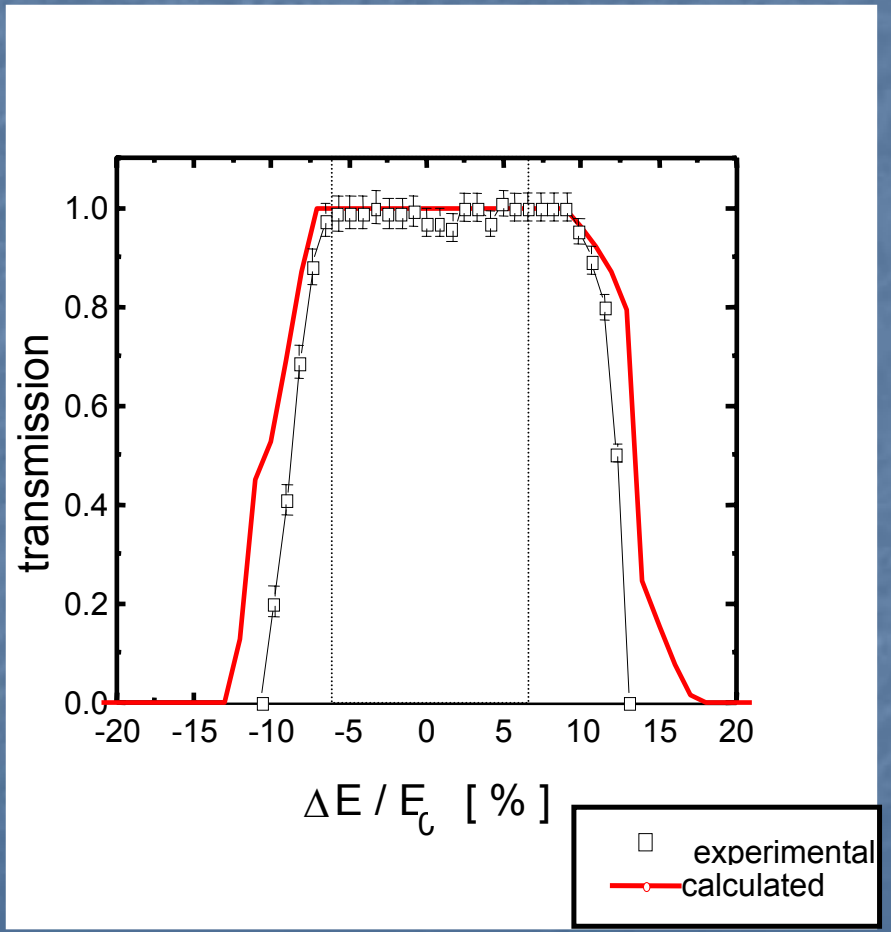
E_{cm} = 2.4 MeV q_{rec} = 6+

Angular Acceptance



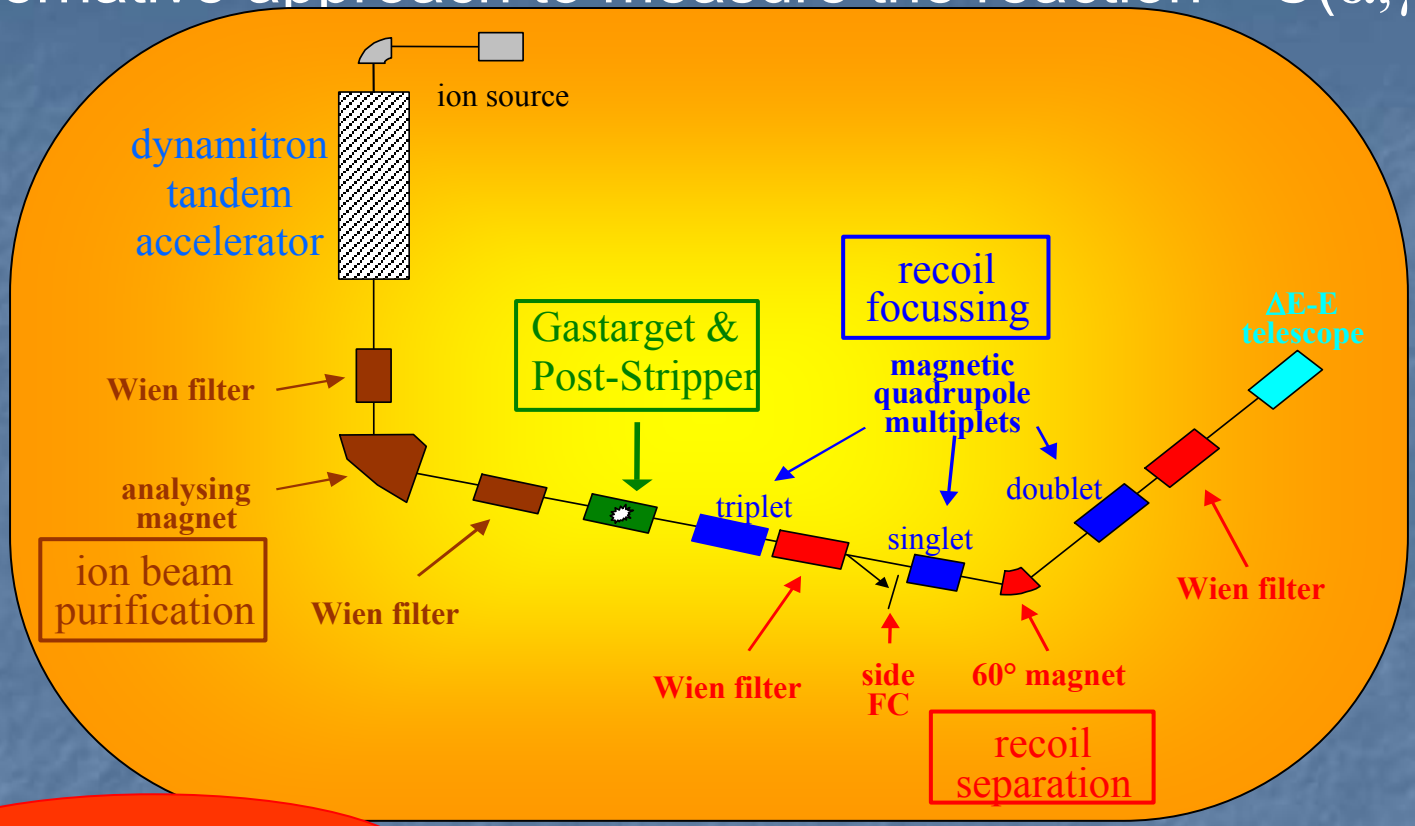
$B_{ext.\ Triplet}$ changed by 0.7% !

Energy Acceptance



by variation of beam energy

Recoil Separator ERNA:
an alternative approach to measure the reaction $^{12}C(\alpha,\gamma)^{16}O$



$$N_{recoils\ detected} = N_{projectiles} \cdot n_{target} \cdot \sigma \cdot T_{ERNA} \cdot p_q$$

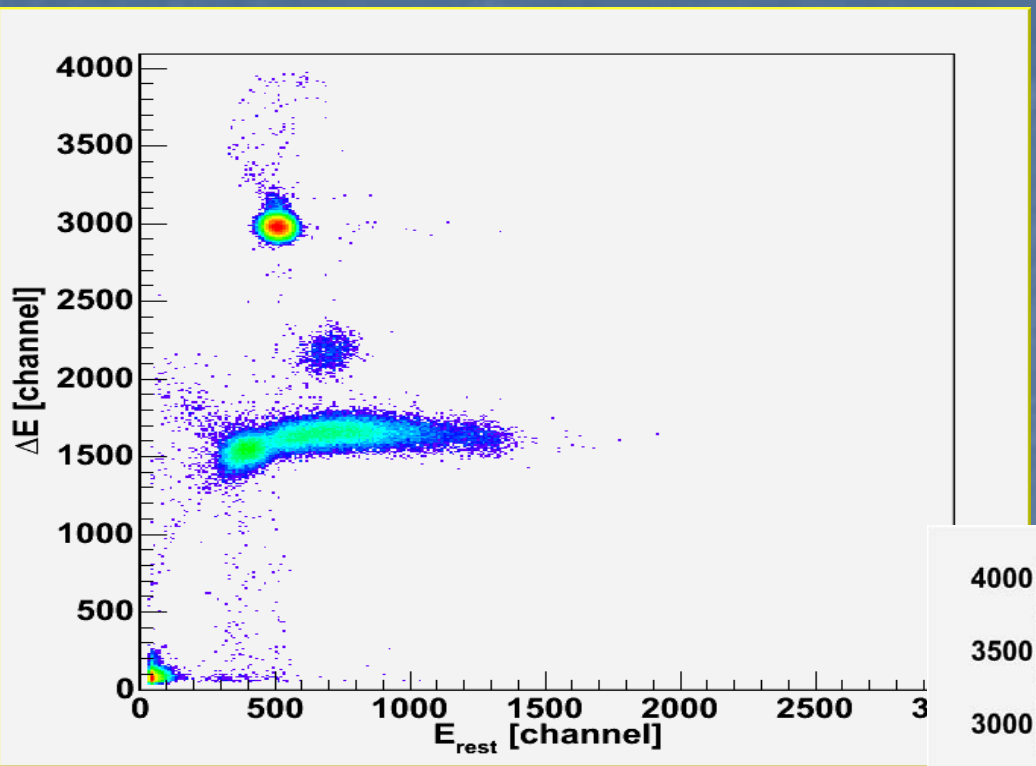
Requirements

- angular / energy acceptance
- knowledge of charge state distribution
- high purity of incoming ^{12}C beam
- suppression of ^{12}C beam

Advantages

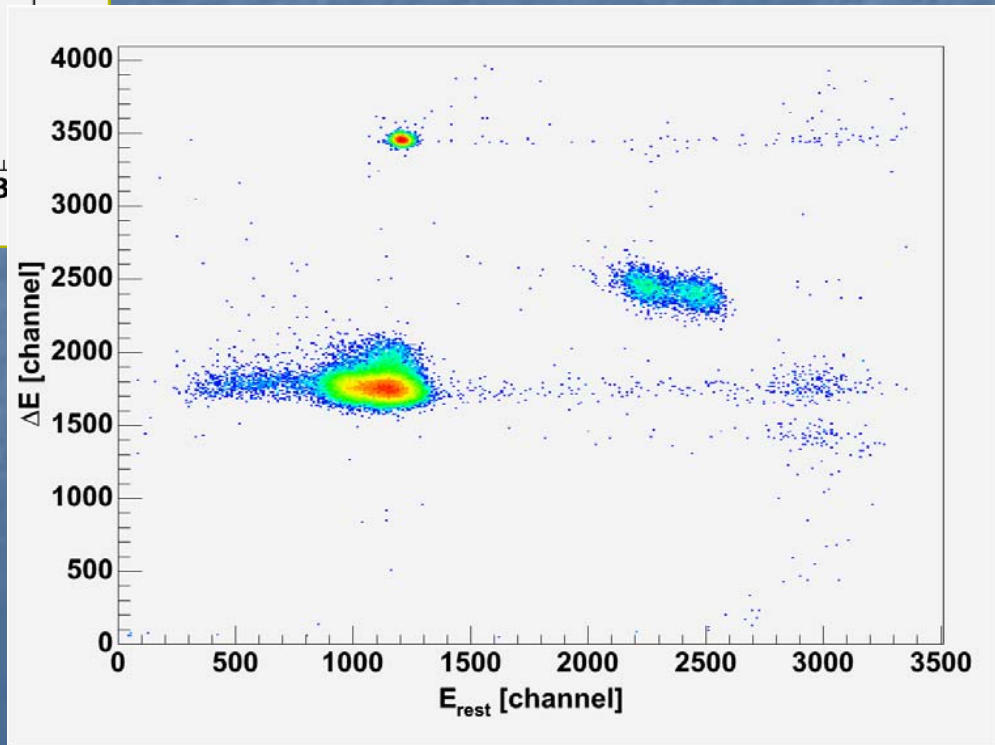
- high efficiency ~p_q
- measure σ_{tot}
- independent of γ's
- (mostly) background free
- γ-ray coincidences *possible*

Typical ΔE-E Spectra

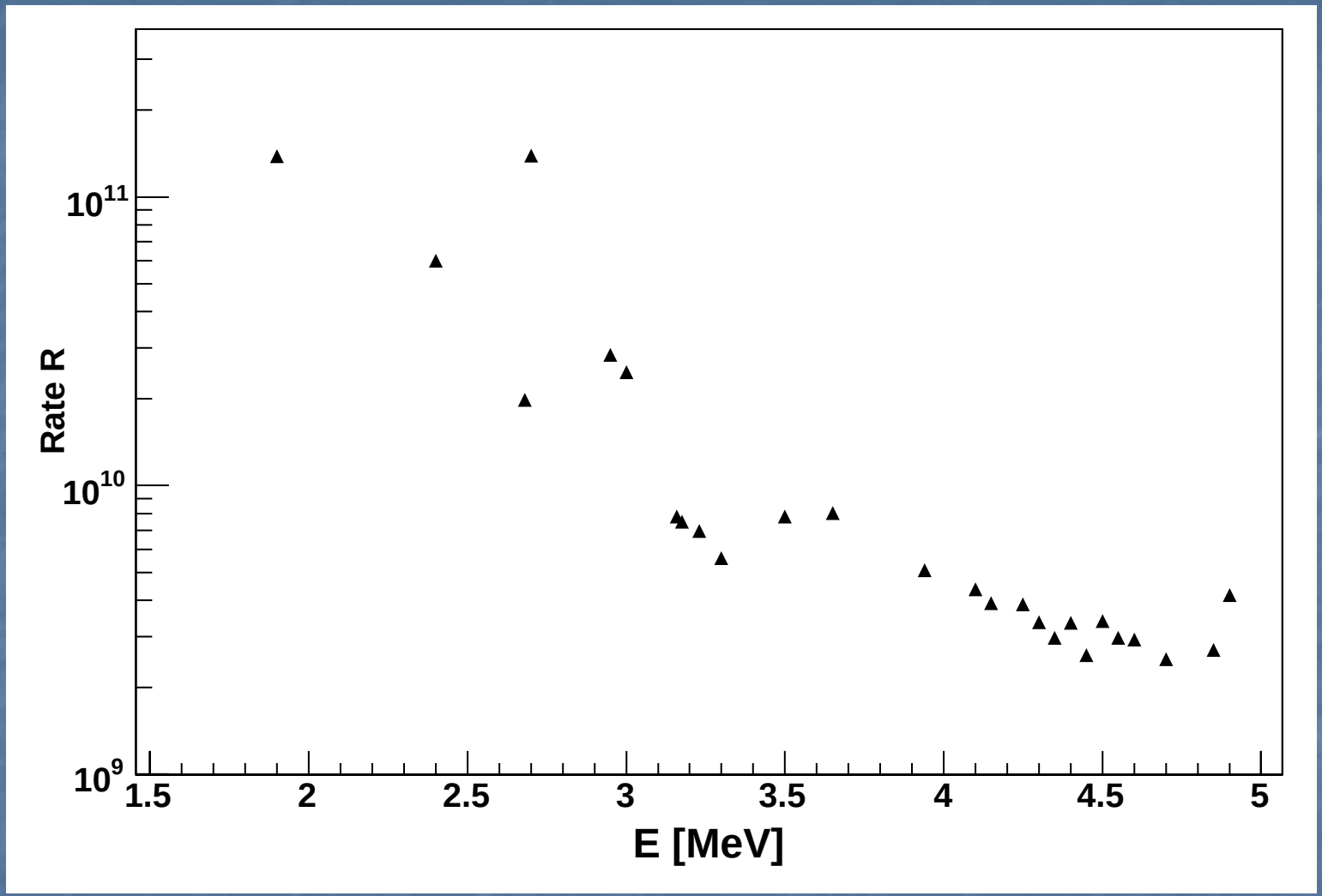


E_{cm} = 4.4 MeV
suppression ~ $3 \cdot 10^9$

E_{cm} = 2.2 MeV
suppression ~ $1 \cdot 10^{11}$

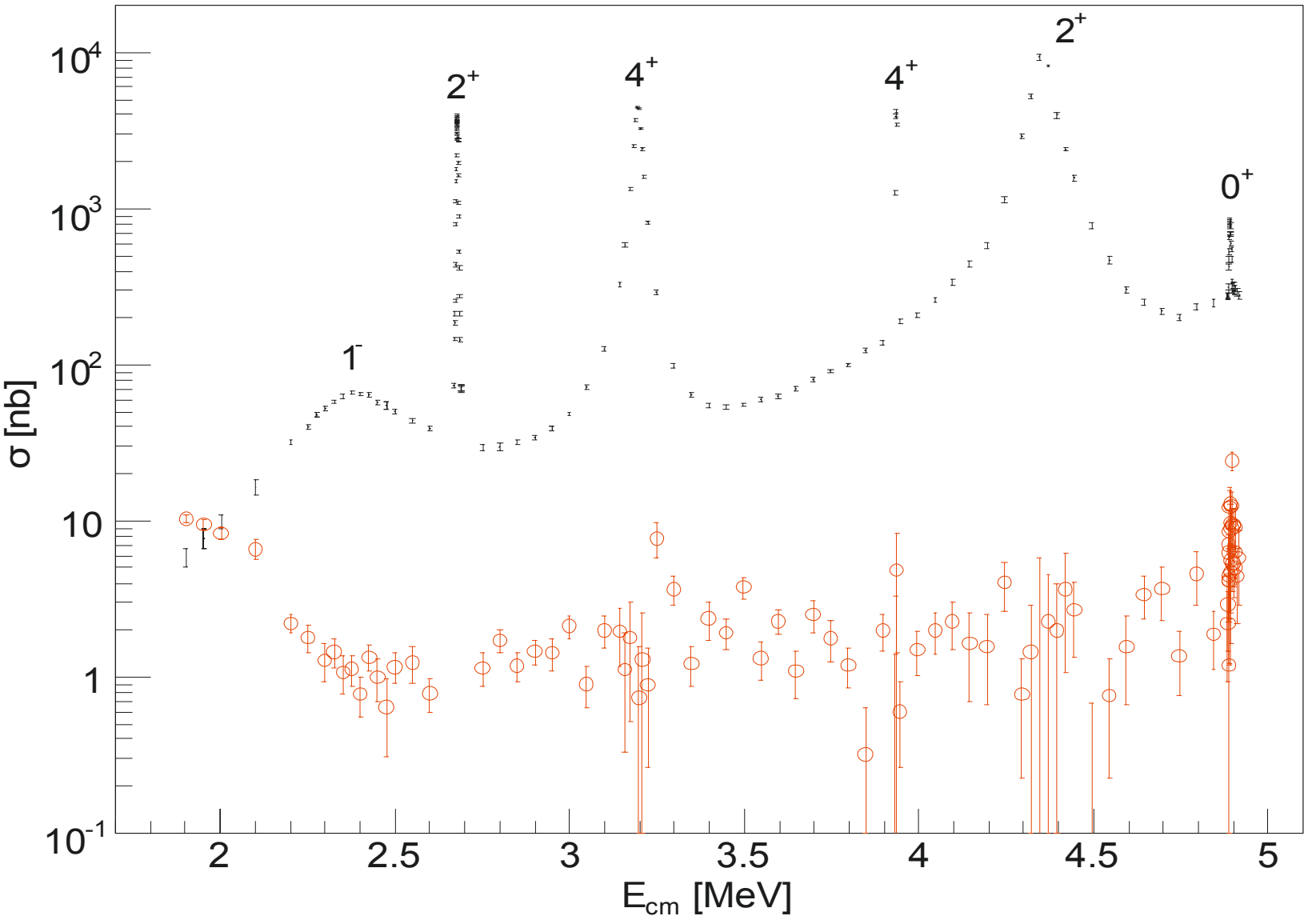


Suppression



$$R = \frac{\#\ \text{beam particles}}{\#\ \text{leaky beam in } \Delta E\text{-}E}$$

$^{12}C(\alpha,\gamma)^{16}O$ total cross section



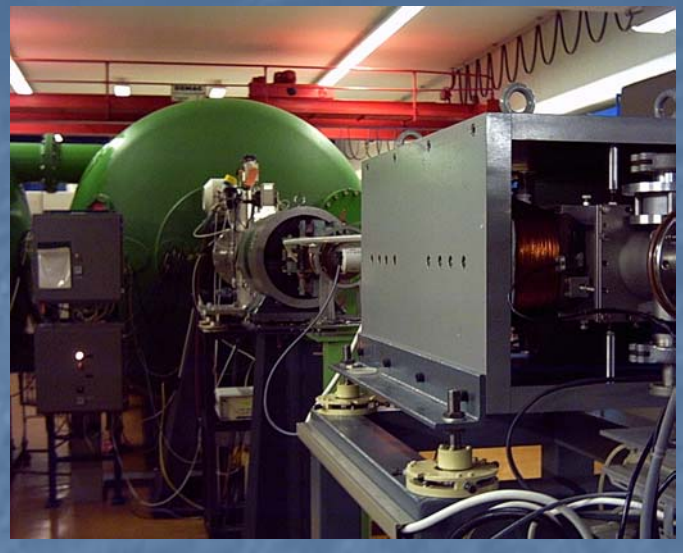
Background ?

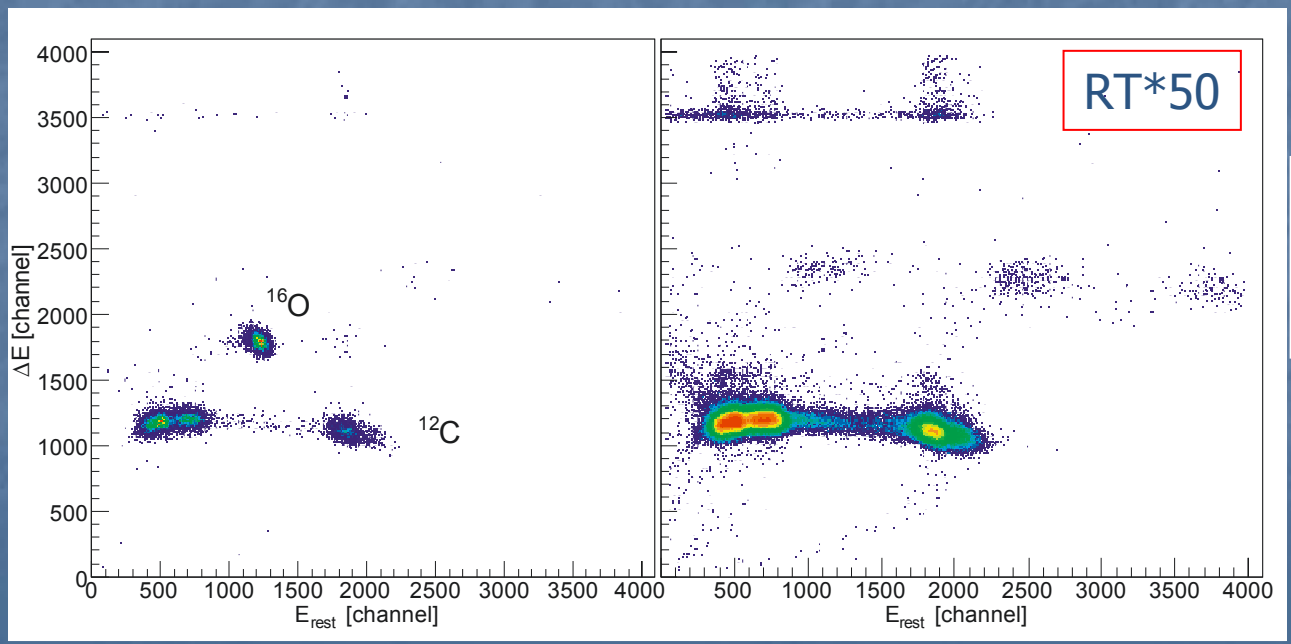
Sources:

- ^{16}O impurities in ^{12}C beam
- scattering of ^{16}O restgas
- $^{12}C + {}^{12}C$

Beam purification system

Wien-Filters



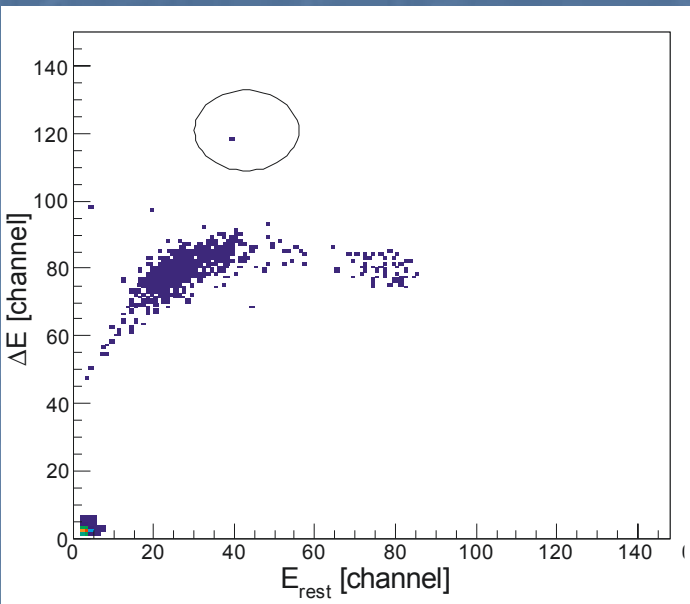


$P_O \sim 10^{-12}$

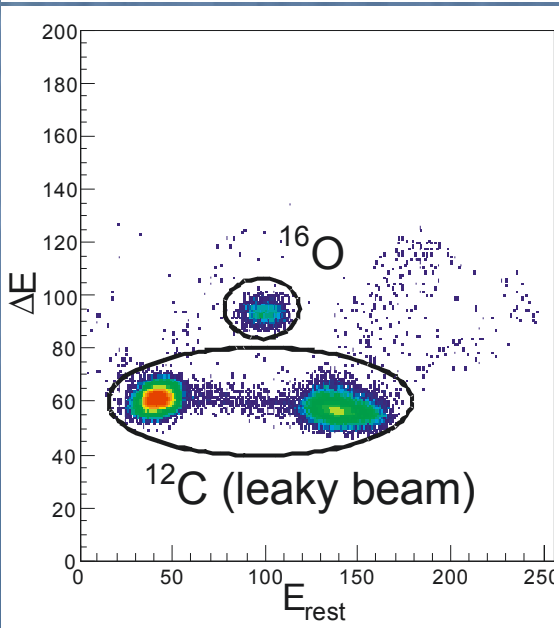
$P_{WF} < 10^{-9}$

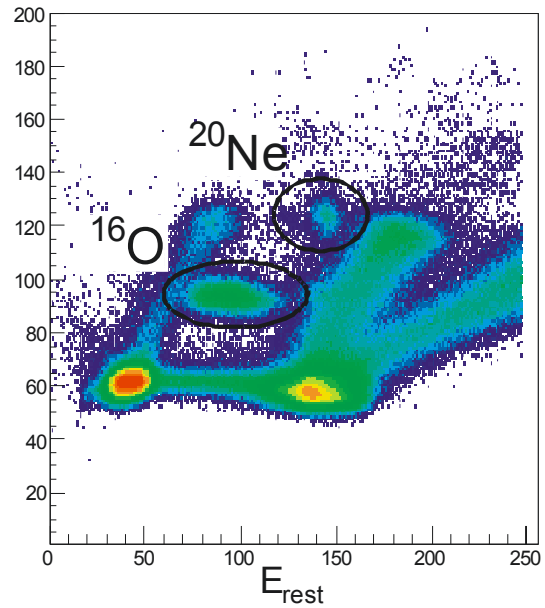
Purification WF: OFF On

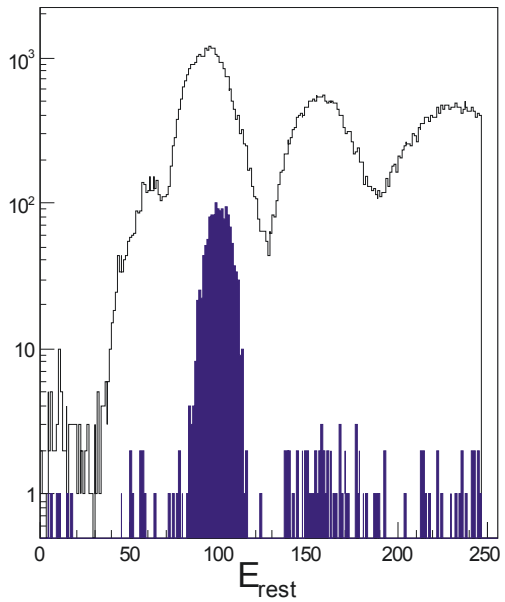
Background: $^{12}C + ^{12}C$



pre target aperture
-> Rate x50







carbon
foil

Background ?

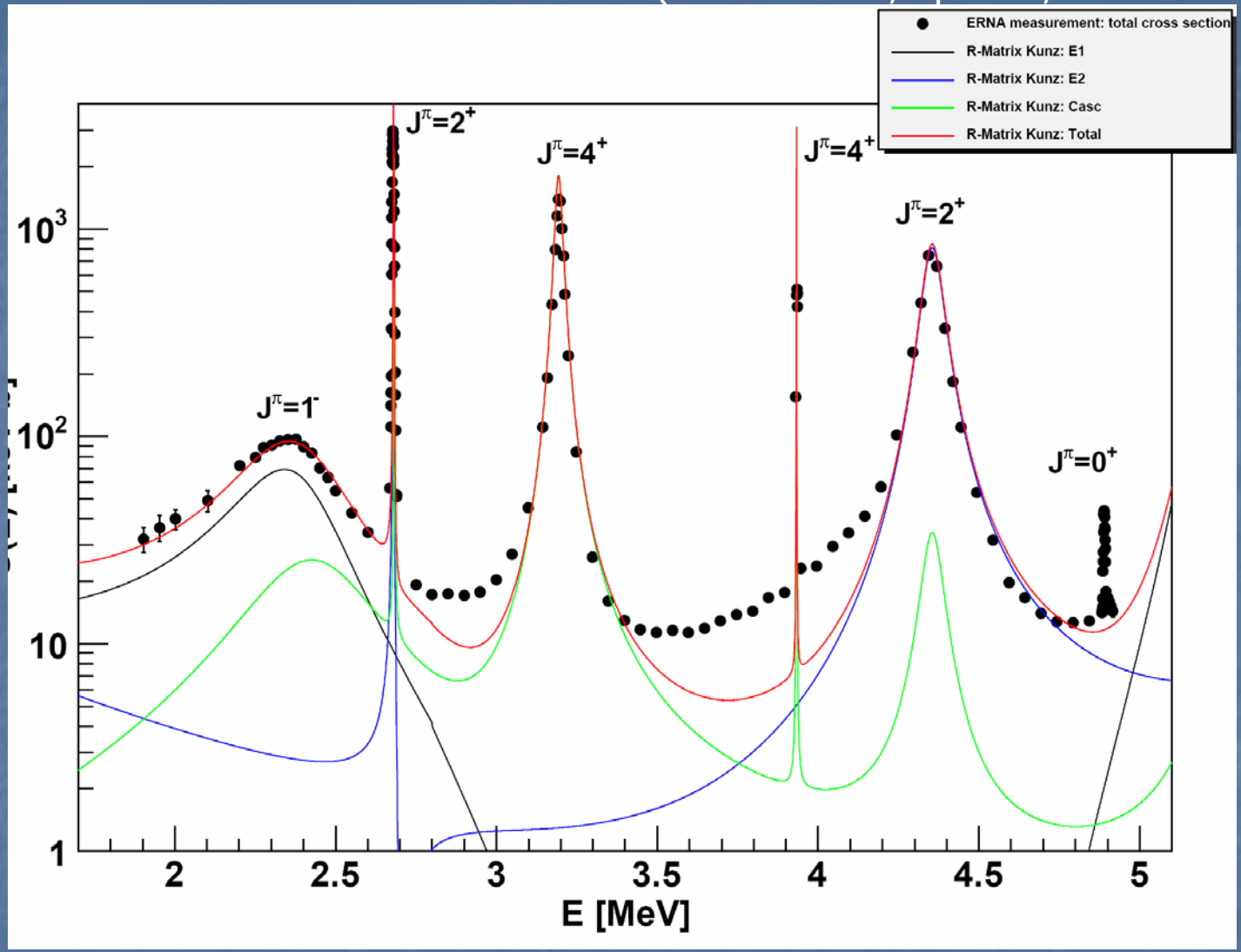
Sources:

- ^{16}O impurities in ^{12}C beam — 10^5 to small
- scattering of ^{16}O restgas — 10^2 to small
- $^{12}C + {}^{12}C$ — **most probably !**

(but: background almost constant)

Comparison ERNA <-> Calculation Kunz. et al.

(Kunz R. et al., ApJ 567, 643-650 2002)



- Basic resonance properties well reproduced
- Clear need for improved (new) R-Matrix calculation

ERNA Collaboration

Bochum

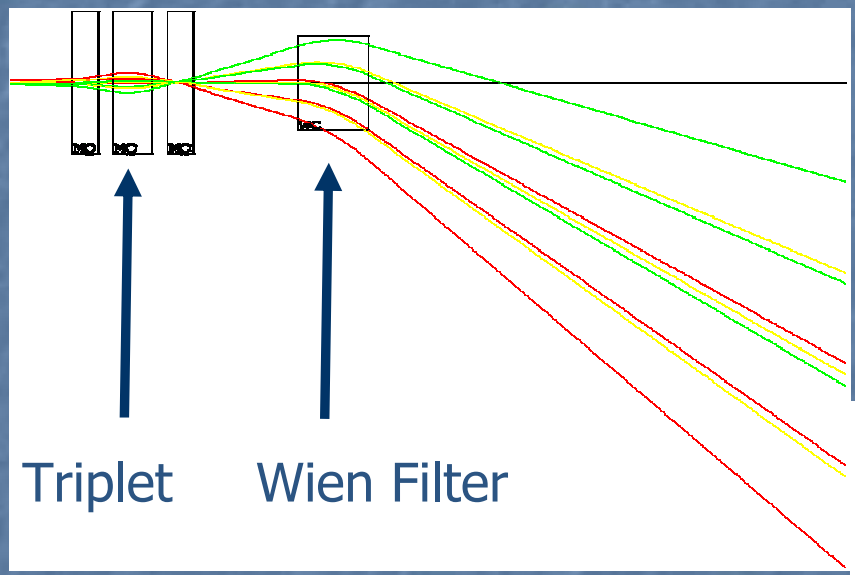
A. Di Leva
R. Kunz
D. Rogalla
C. Rolfs
F. Schümann
D. Schürmann
F. Strieder
H.-P. Trautvetter

Naples & Caserta

N. De Cesare
L. Gialanella
A. D'Onofrio
G. Imbriani
C. Lubritto
A. Ordine
V. Roca
M. Romano
F. Terrasi

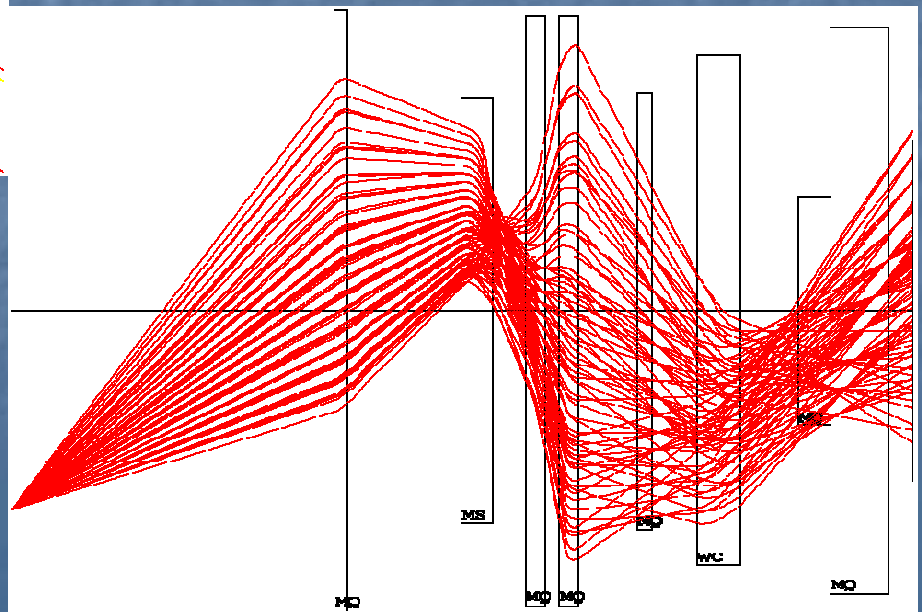
Thank you!

Leaky Beam

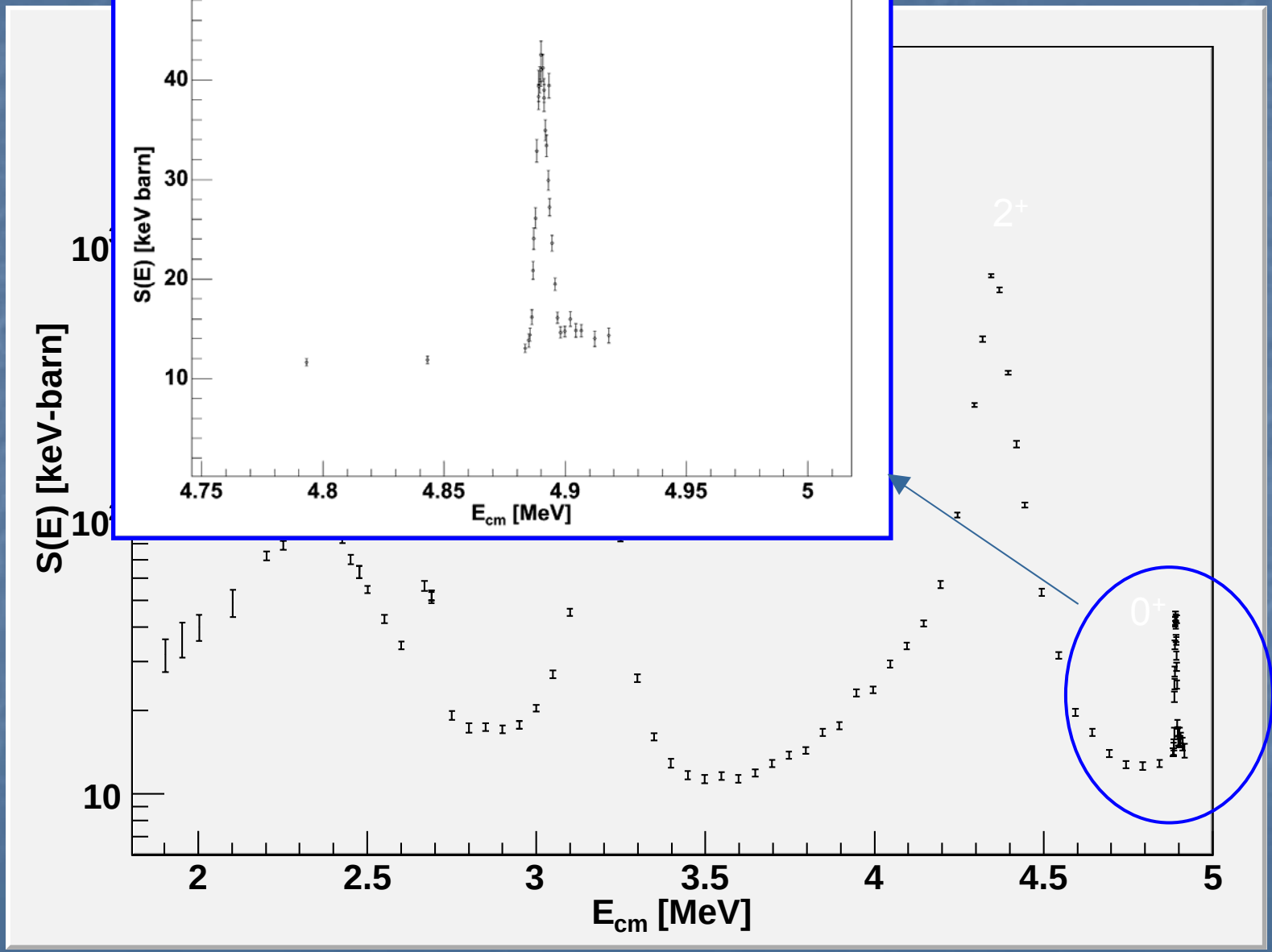


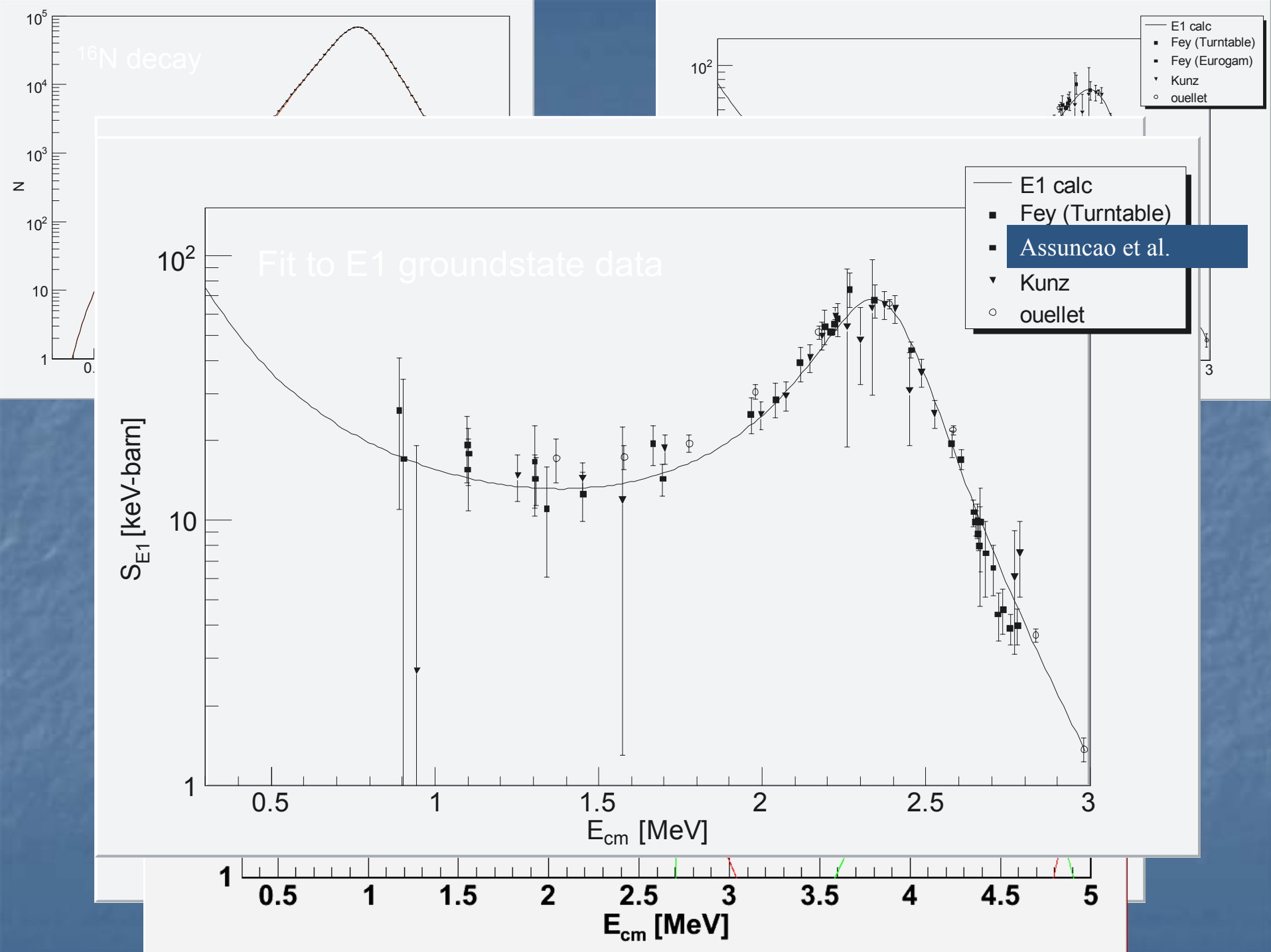
q_{recoil} = 3+

$q_{carbon,\ initial}$ = 6+



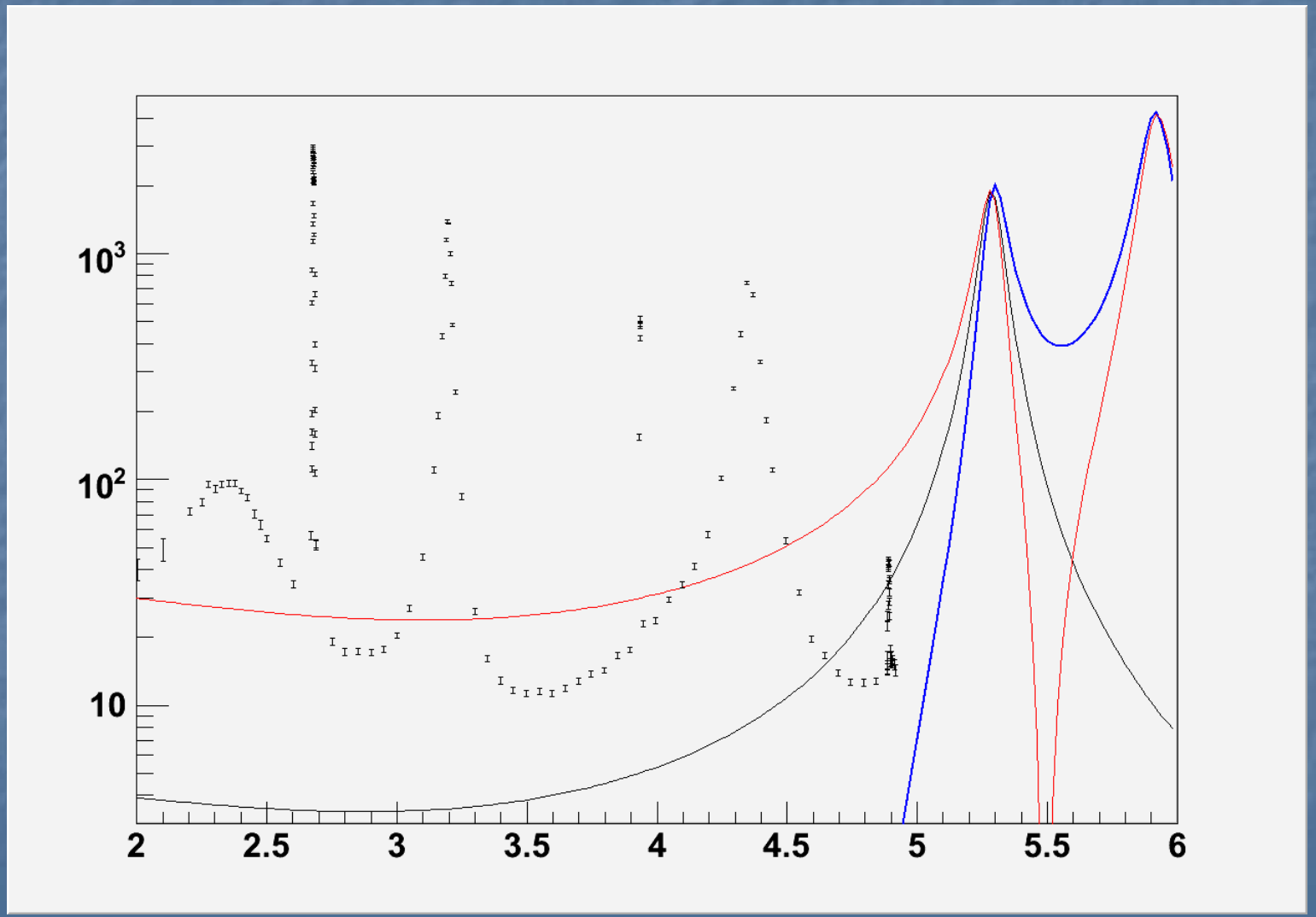
$^{12}C(\alpha,\gamma)^{16}O$ total cross section



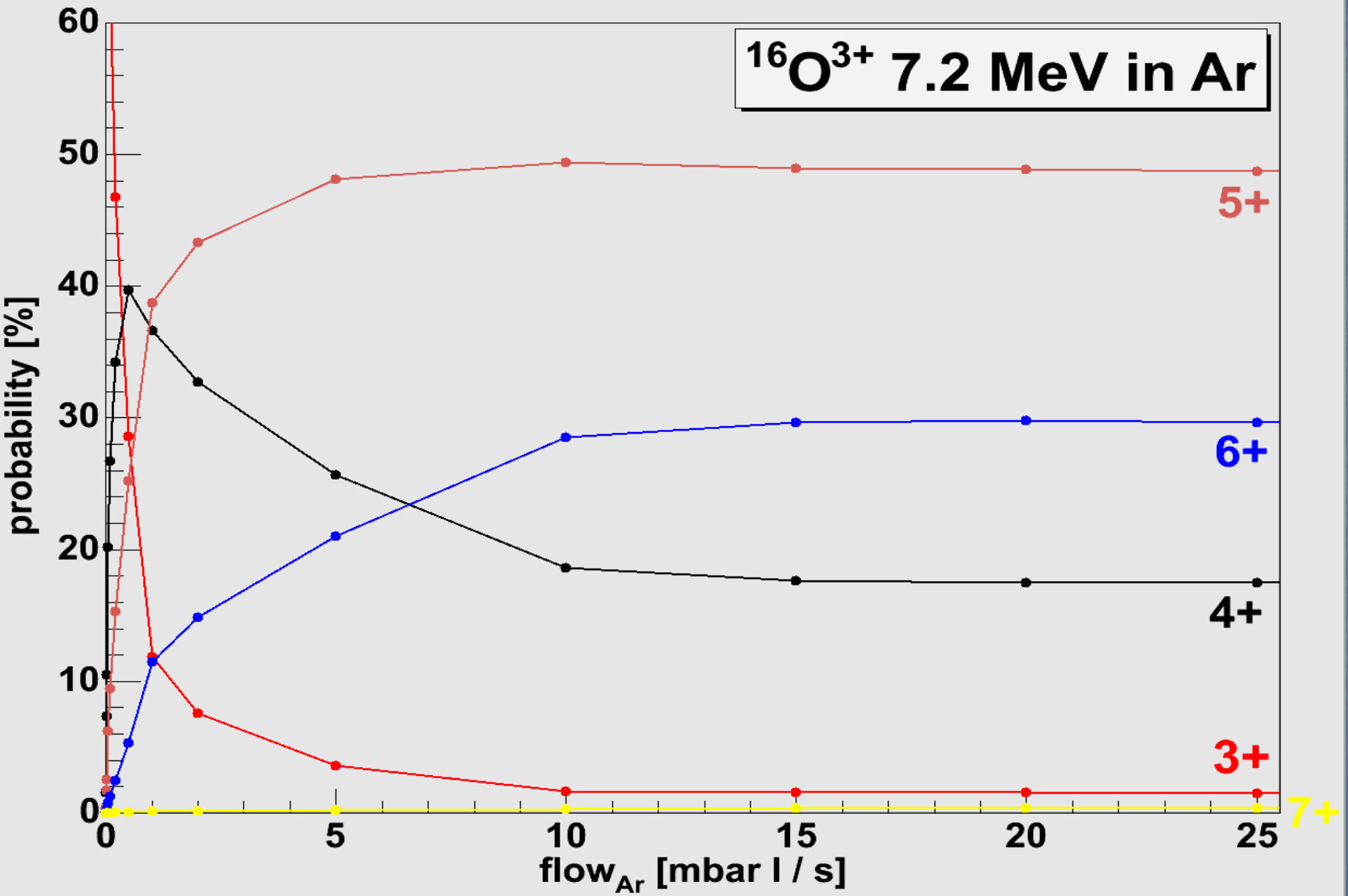

^{16}N decay
N
E1 calc
Fey (Turntable)
Fey (Eurogam)
Kunz
ouellet
Fit to E1 groundstate data
Assuncao et al.
S_{E1} [keV-barn]
E_{cm} [MeV]

E1 groundstate transition:

5-6 MeV states

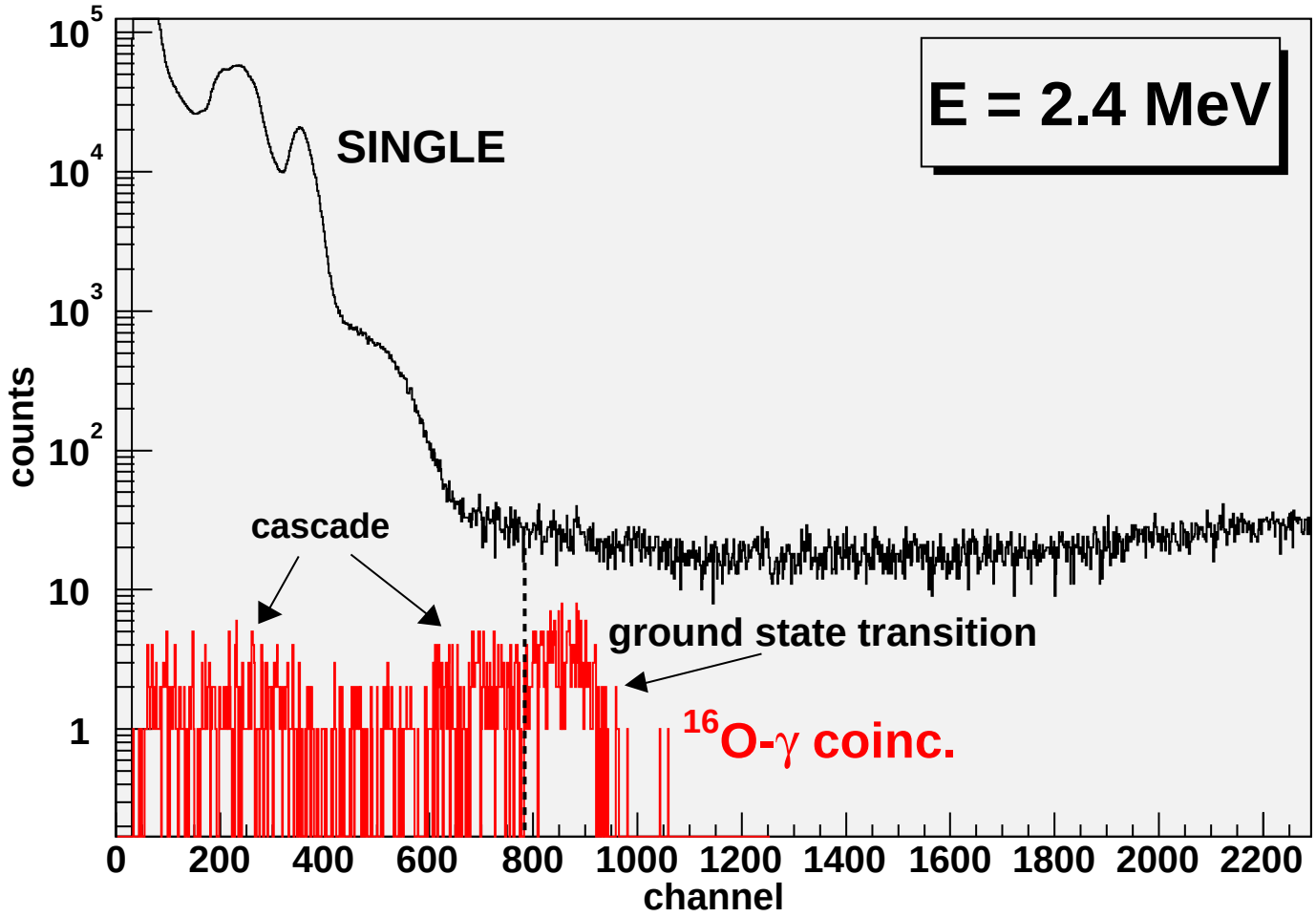


Charge State Distribution



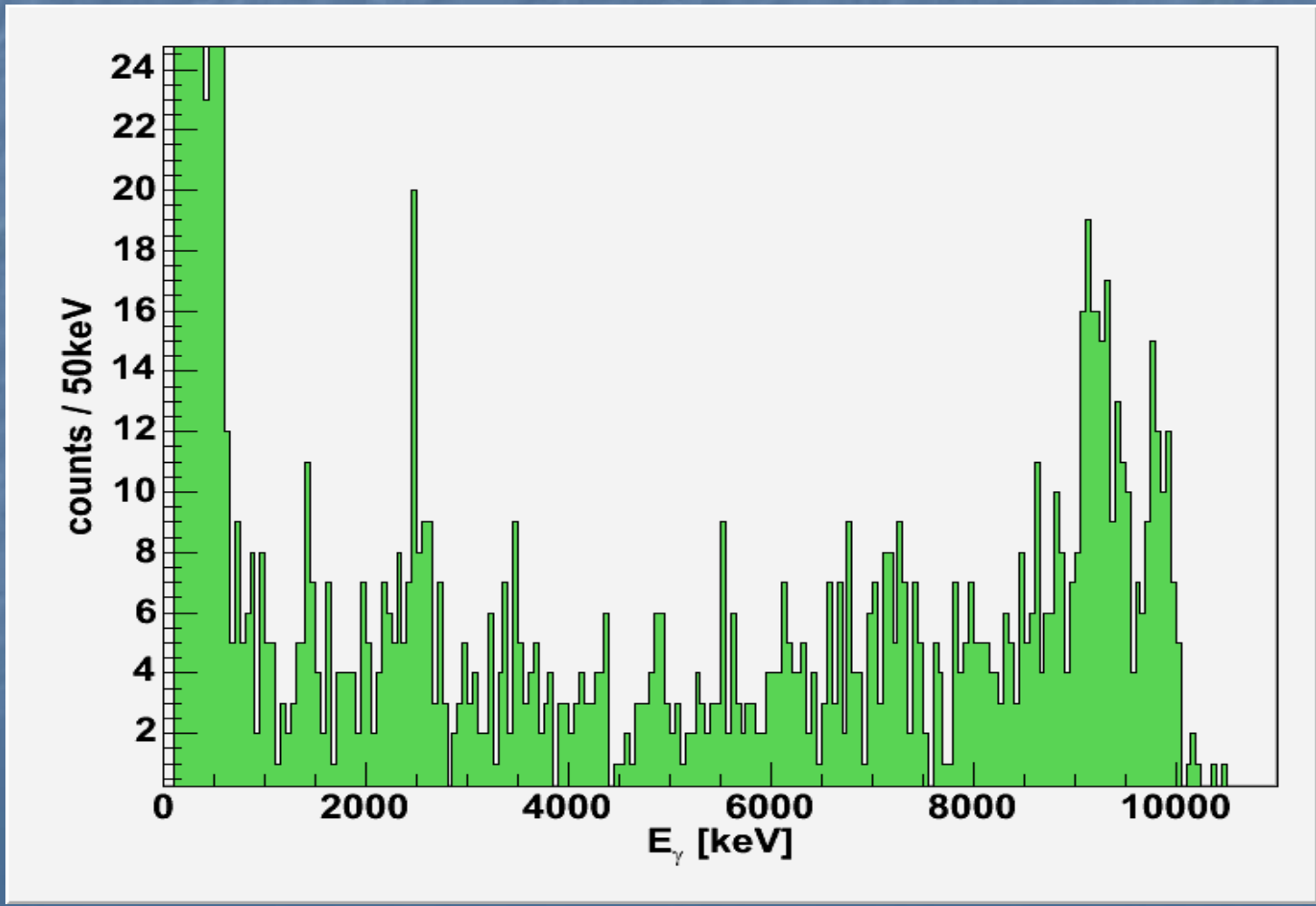
γ-Recoil Coincidences

Ecm = 2.4 MeV (1⁻)
8x BaF_2

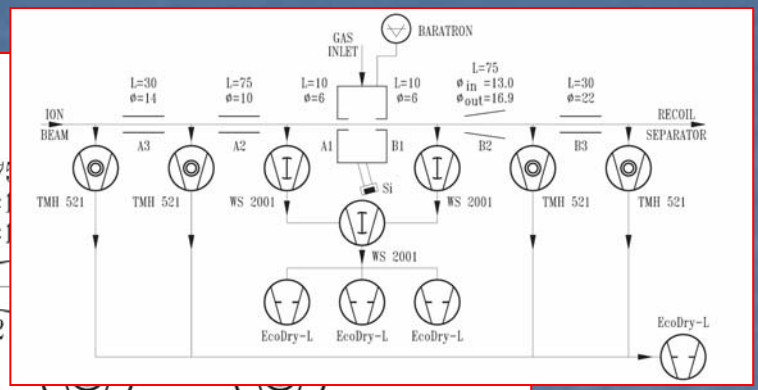


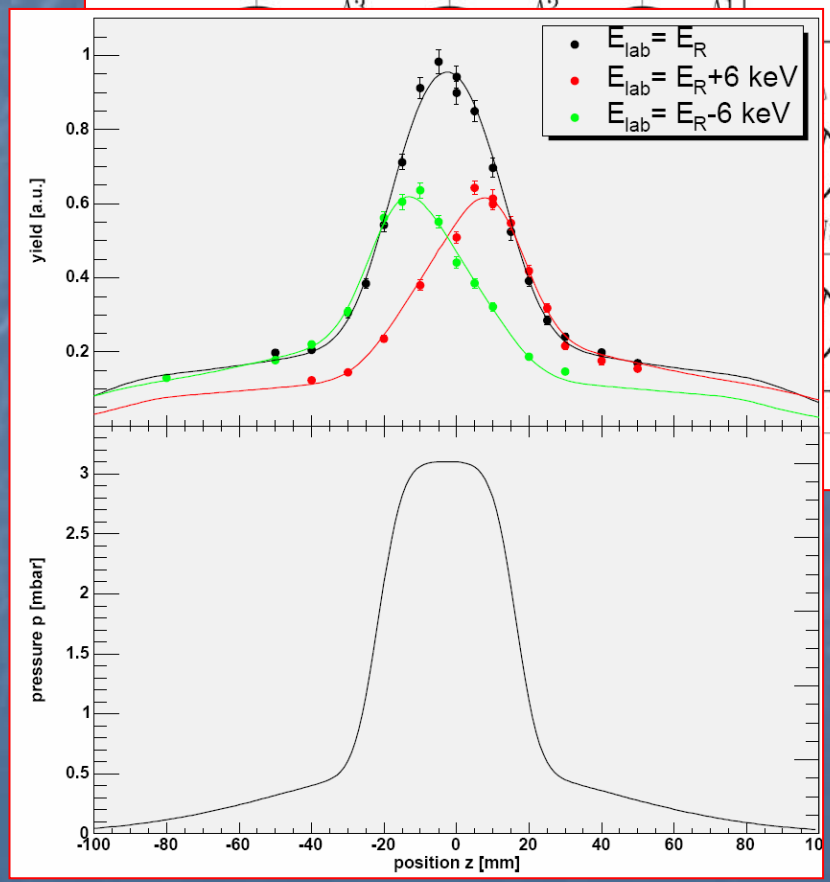
γ-Recoil Coincidences

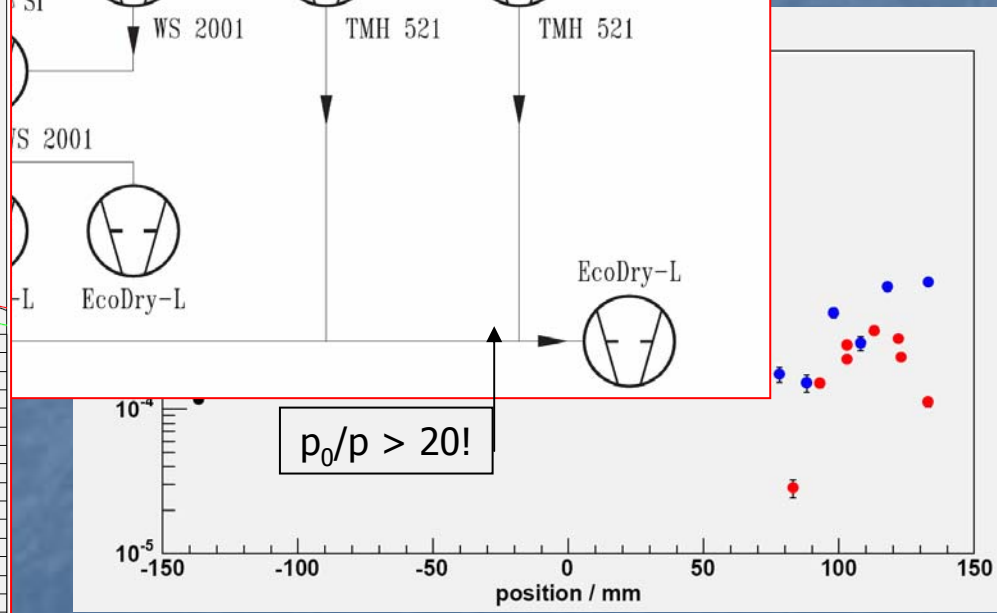
Ecm = 2.4 MeV (1^-)
2“x2“ BGO



Gastarget: pressure profile

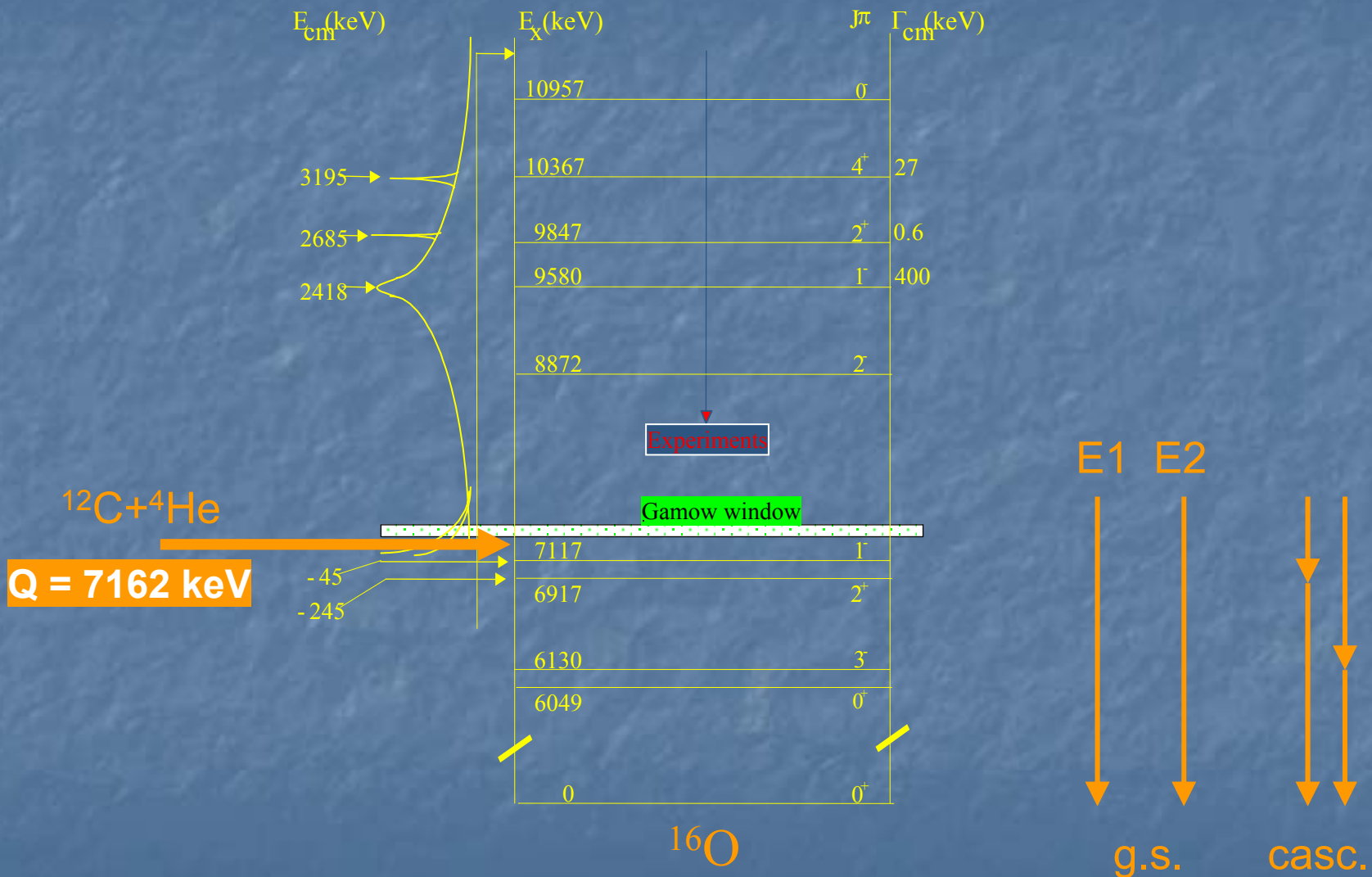


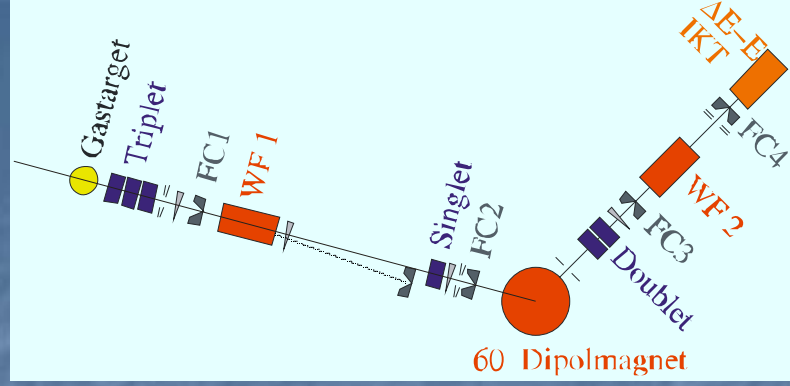




7Li(α,α')
Γ_{cm}=130keV
Independent of stopping powers!

$^{12}C(\alpha,\gamma)^{16}O$ - ^{16}O level scheme




Gastarget
Triplet
FC1
WF 1
Singlet
FC2
60 Dipolmagnet
Doublet
FC3
WF 2
FC4
ΔE-E
TKT