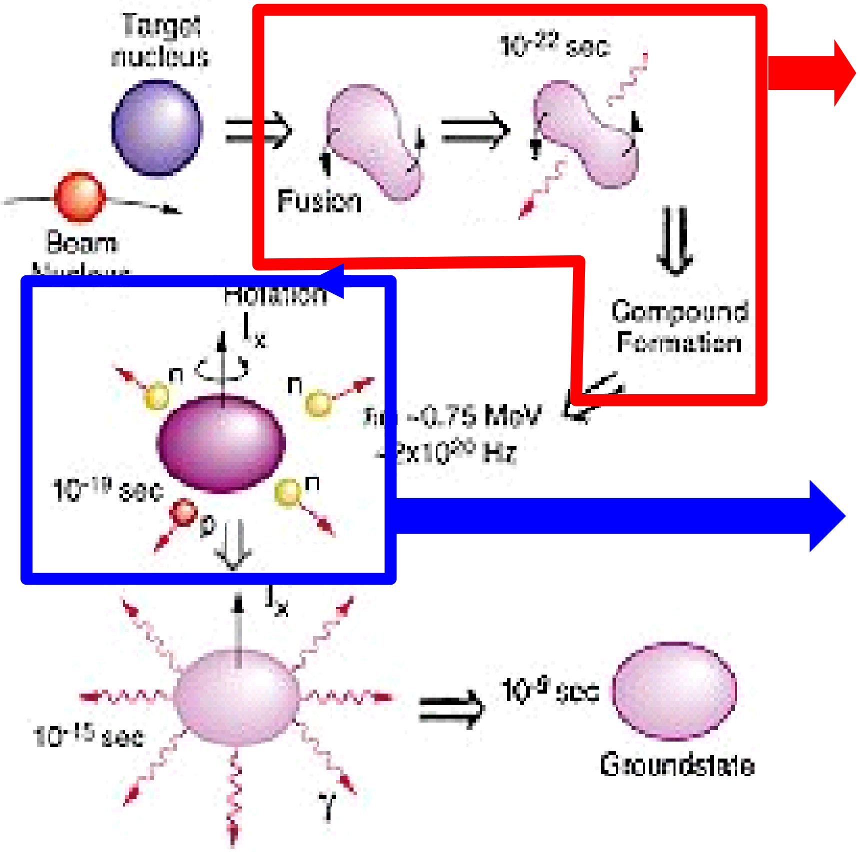
Isospin Mixing at Finite Temperature

OUTLINE

- Heavy Ions Fusion-Evaporation Reactions
  - GDR and Isospin Mixing
  - Garfield + Hector experimental setup
  - Experimental technique
  - Isospin mixing in ^{80}Zr at T~2 MeV
- Conclusions and Perspectives

Dipole gamma emission

Dipole gamma emission



Pre-equilibrium Emission

- if E_{beam} > 10-15 MeV/u $\Rightarrow$ part. emission

- if $N/Z_{target} \neq N/Z_{projectile}$ Dynamical Dipole γ-rays emission

  • Symmetry term in EOS

  • N-N cross section inside the nucleus

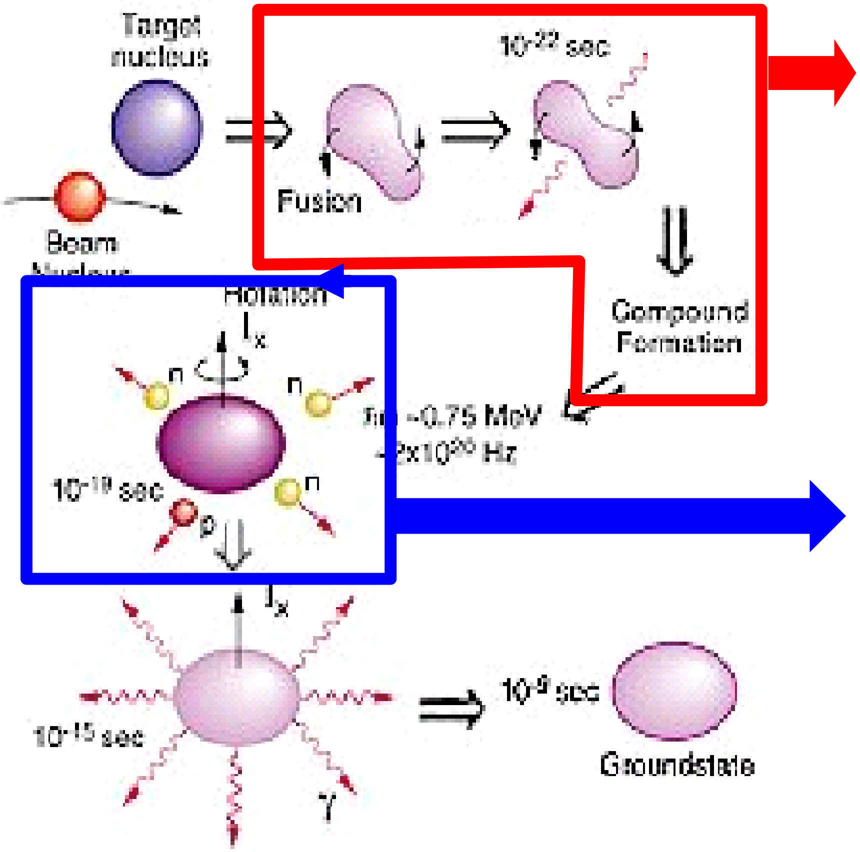
GDR statistical γ-decay

- Nuclear Shape and Deformation at high Temperature and Spin

- Information on the structure of the inital and final state

  - if $T_z(CN)=0 \Rightarrow$ isospin mixing

Dipole gamma emission



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See also talk of A. Giaz

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- N-N cross section inside the nucleus

GDR statistical γ-decay

- Nuclear Shape and Deformation at high Temperature and Spin

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    - if $T_z(CN)=0 \Rightarrow$ isospin mixing

Isospin mixing induced by Coulomb interaction

Physics Case

The Ground State of most of nuclei has Isospin T=Tz=(N-Z)/2

Isospin symmetry in nuclei is broken by Coulomb interaction V_C which mixes states with T and T+1 (T+2,...)

Isospin is an almost good quantum number in nuclear reactions which involve low-lying states.

- Isospin is NOT conserved at moderate excitation energy.
- Isospin is restored as an almost good quantum number in fusion-evaporation reactions (E*>20 MeV):
    - a given reaction will form a CN with a wavefunction which conserve isospin
    - the CN might decay before isospin mixes
        - the degree of isospin mixing of CN state is an interplay between the compound nucleus Decay Width Γ and the Coulomb Spreading Width $\Gamma^{\downarrow}$

$$\alpha^2 \simeq \frac{\Gamma^{\downarrow}}{\Gamma},$$

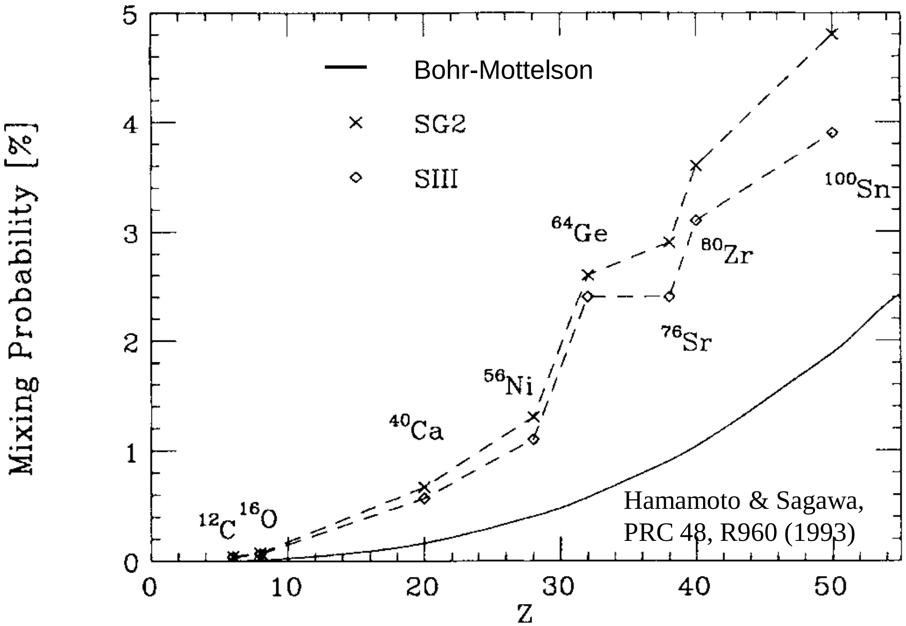
$$\alpha^2_< = \frac{\Gamma^{\downarrow}_< / \Gamma_<}{1 + \Gamma^{\downarrow}_< / \Gamma_< + \Gamma^{\downarrow}_> / \Gamma_>}$$

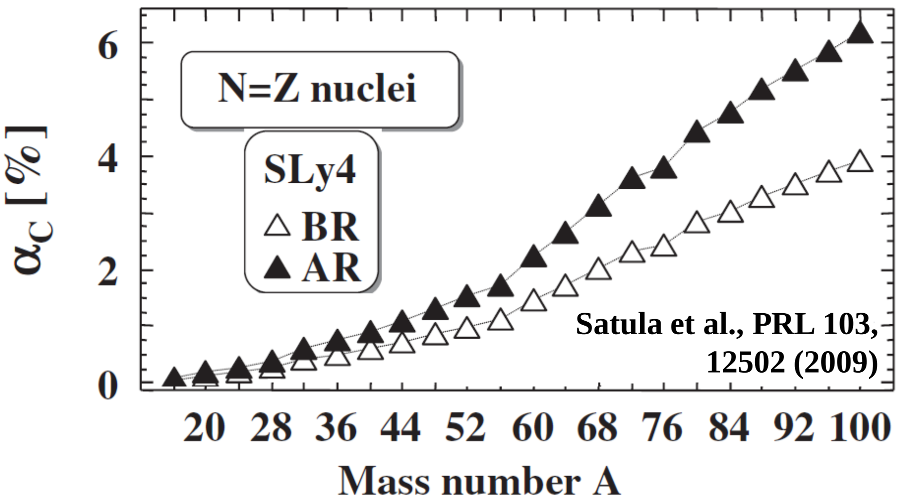
- the Coulomb Spreading Width $\Gamma^{\downarrow}$ defines the timescale for the isospin mixing

H.L. Harney et al rev. Mod. Phys. 58(1986)607 - M.N. Harakeh et al. Phys. Lett. B 176(1986)297 - A.Behr et al. Phys. Rev. Lett. 70(1993)3201

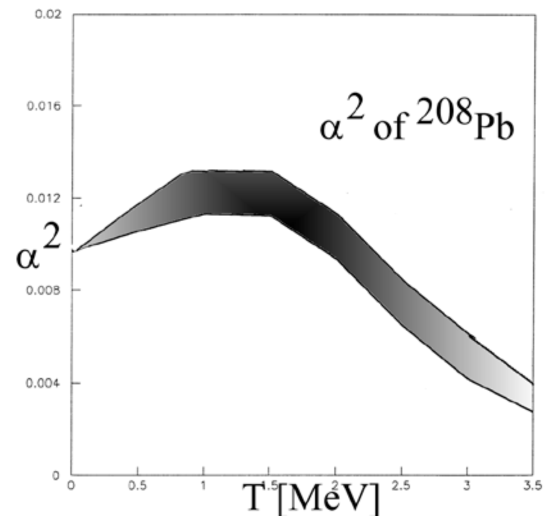
Isospin mixing dependence on Z, A and Temperature

T=0: mixing increases with Z and A

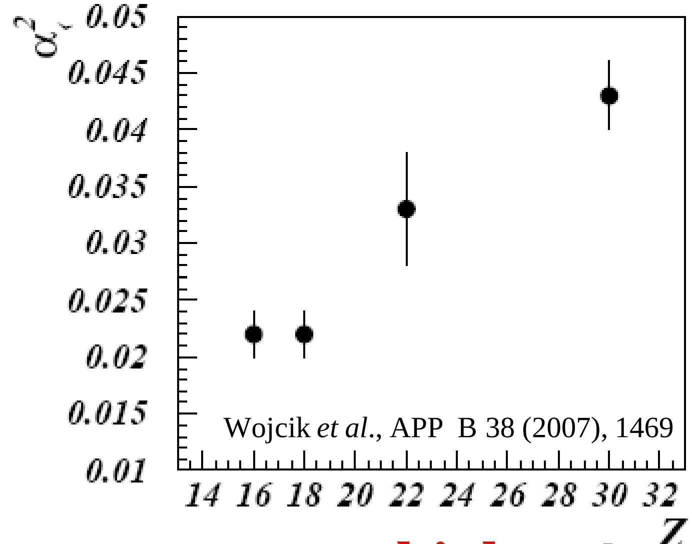




Sagawa *et al.*, PLB 444, 1 (1998)



T>0: increase or saturation for Z > 30?



→ measure at higher A and Z

How we measure Isospin mixing

- We form a $T \neq 0$ Compound Nucleus with a heavy ions fusion reaction

$$^{37}Cl + {}^{44}Ca \Rightarrow {}^{81}Rb^* \qquad E^* = 83\ MeV$$

- We form a $T=0$ Compound Nucleus with a heavy ions fusion reaction

$$^{40}Ca + {}^{40}Ca \Rightarrow {}^{80}Zr^* \qquad E^* = 83\ MeV$$

- We measure the γ-ray yield from the decay of the GDR built on the CN
  - $T = 0$ to $T = 0$ E1 Transition are forbidden
  - $T = 0$ to $T = 1$ E1 transition are allowed but there are much less $T=1$ state available to be populated by GDR decay in respect to $T = 0$ states

<u>This results in a strong inhibition of the GDR γ-decay from the hot ^{80}Zr compound</u>

Isospin mixing, as mix $T=0$ states with $T=1$ states ,will increase the GDR γ yield

<u>Two extreme scenarios</u>

No Mixing $\Rightarrow a^2_< = 0 \Rightarrow$ strong inhibition of the gamma decay channel

Full Mixing $\Rightarrow a^2_< = 1/2 \Rightarrow$ No inhibition of the gamma decay channel

How we measure Isospin mixing

- We form a T=0 Compound Nucleus with a heavy ions fusion reaction

^{37}Cl + ^{40}Ca

- We measure the γ-r t on the CN
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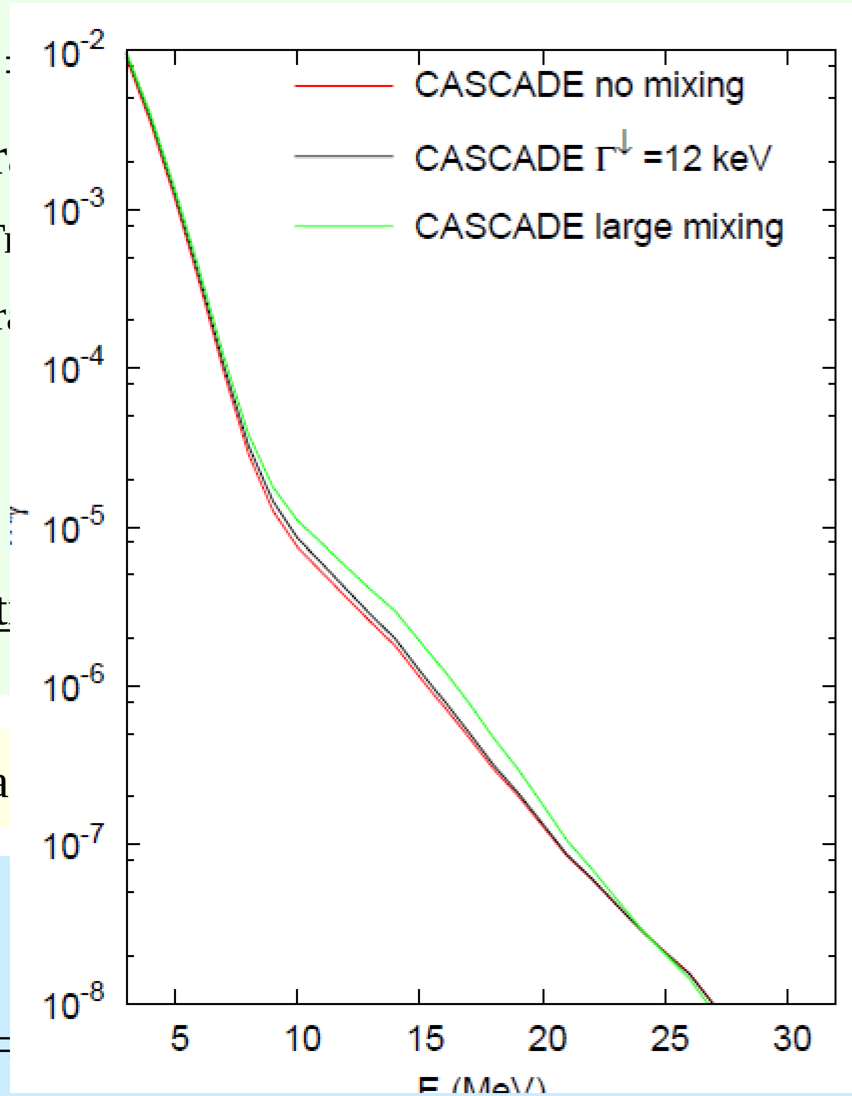


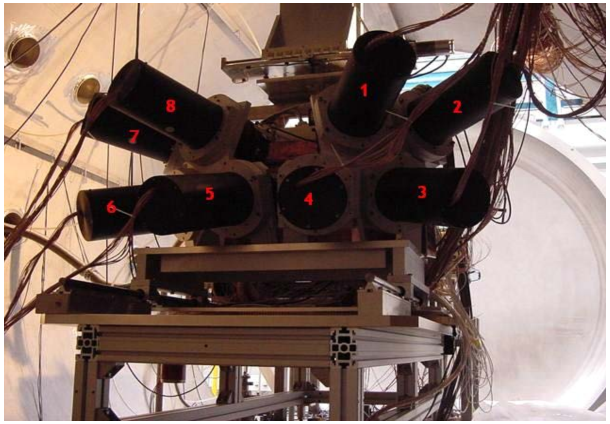
<u>This results in a st hot ^{80}Zr compound</u>

Isospin mixing, a se the GDR γ yield

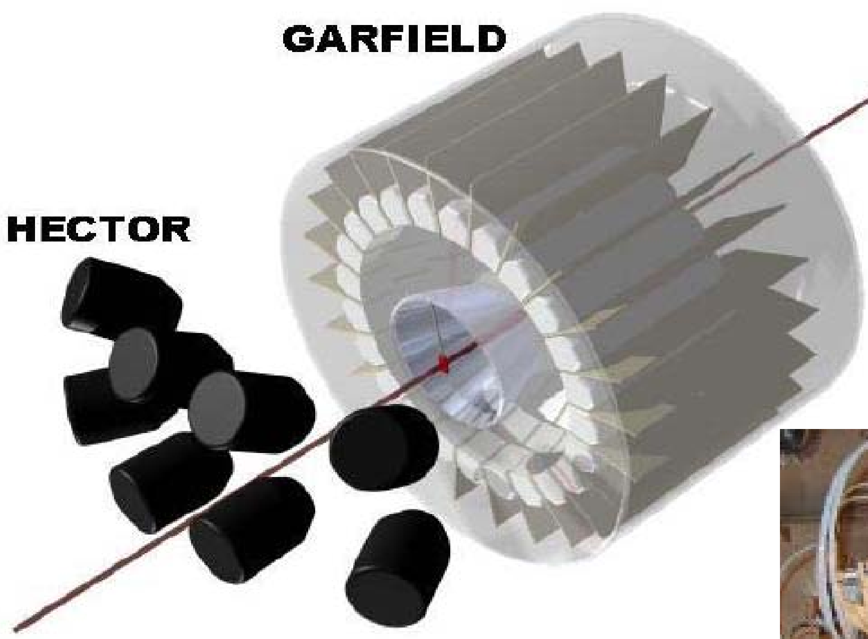
No Mixing ⇒ decay channel

Full Mixing ⇒ $a^2_> = 1$ ⇒ No inhibition of the gamma decay cahnnel

GARFIELD-HECTOR setup at Laboratori Nazionali di Legnaro



HECTOR BaF_2
→ E, ToF of γ



PHOSWICH

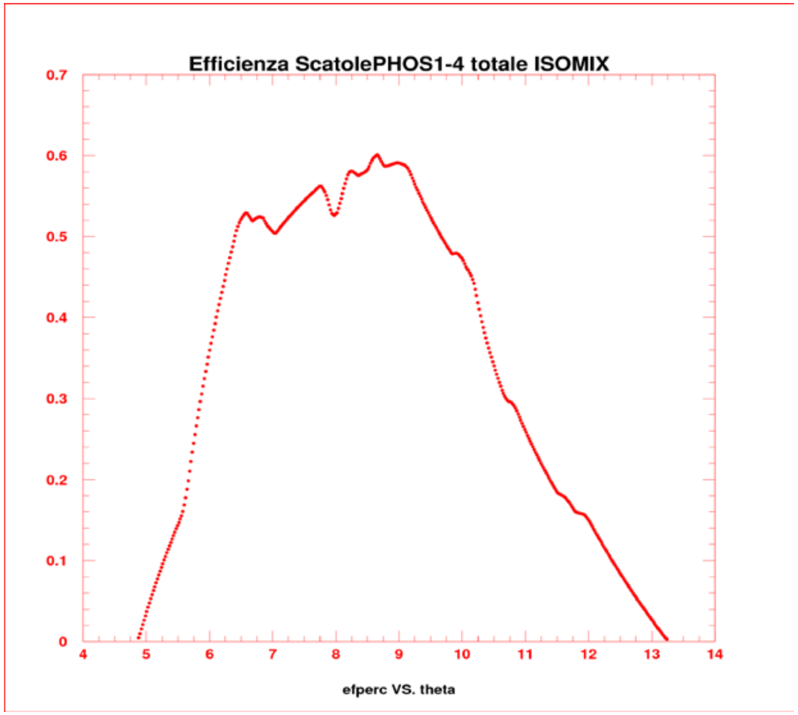
→ residues E, ToF

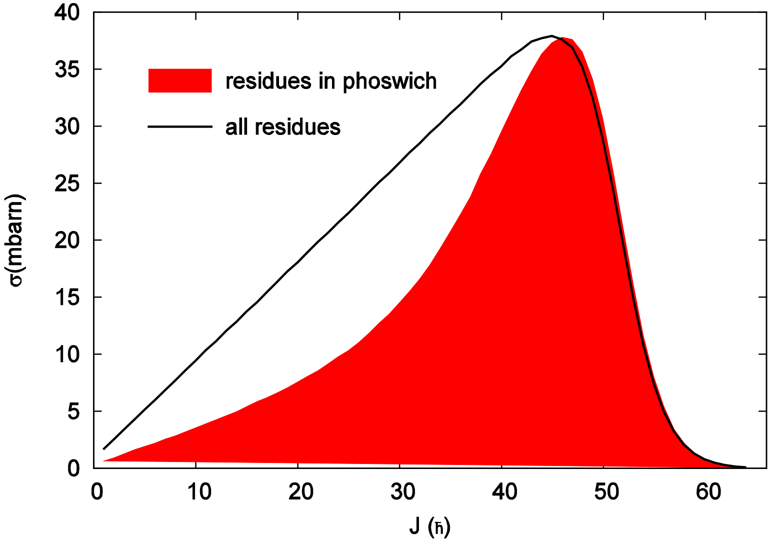
GARFIELD →
ΔE, E of LCP

Statistical Model Analysis: response function of the apparatus

projectile	target	CN	E_{beam}(MeV)	E*(MeV)	I_z
^{37}Cl	^{44}Ca	^{81}Rb	153	83	7/2
^{40}Ca	^{40}Ca	^{80}Zr	200	83	0

The initial spin population of measured ^{80}Zr and ^{81}Rb Compound Nuclei takes into account Phoswich detectors geometry

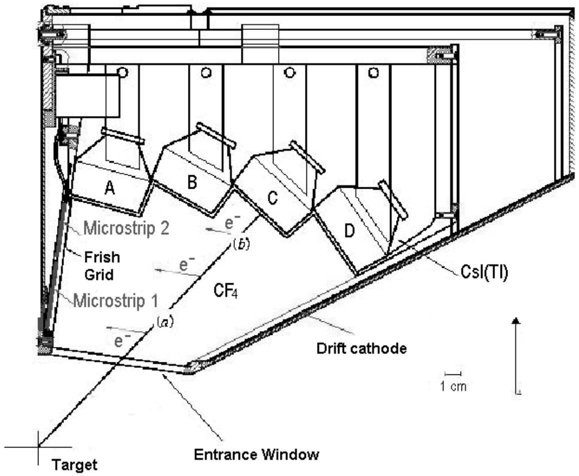




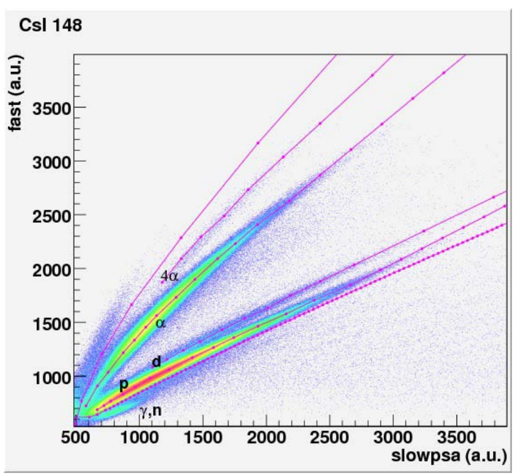
CN	$\langle E_{rot} \rangle$ (MeV)	$\langle E_{rot}^{phos} \rangle$ (MeV)
^{81}Rb	27.5	32.0
^{80}Zr	33.1	37.8

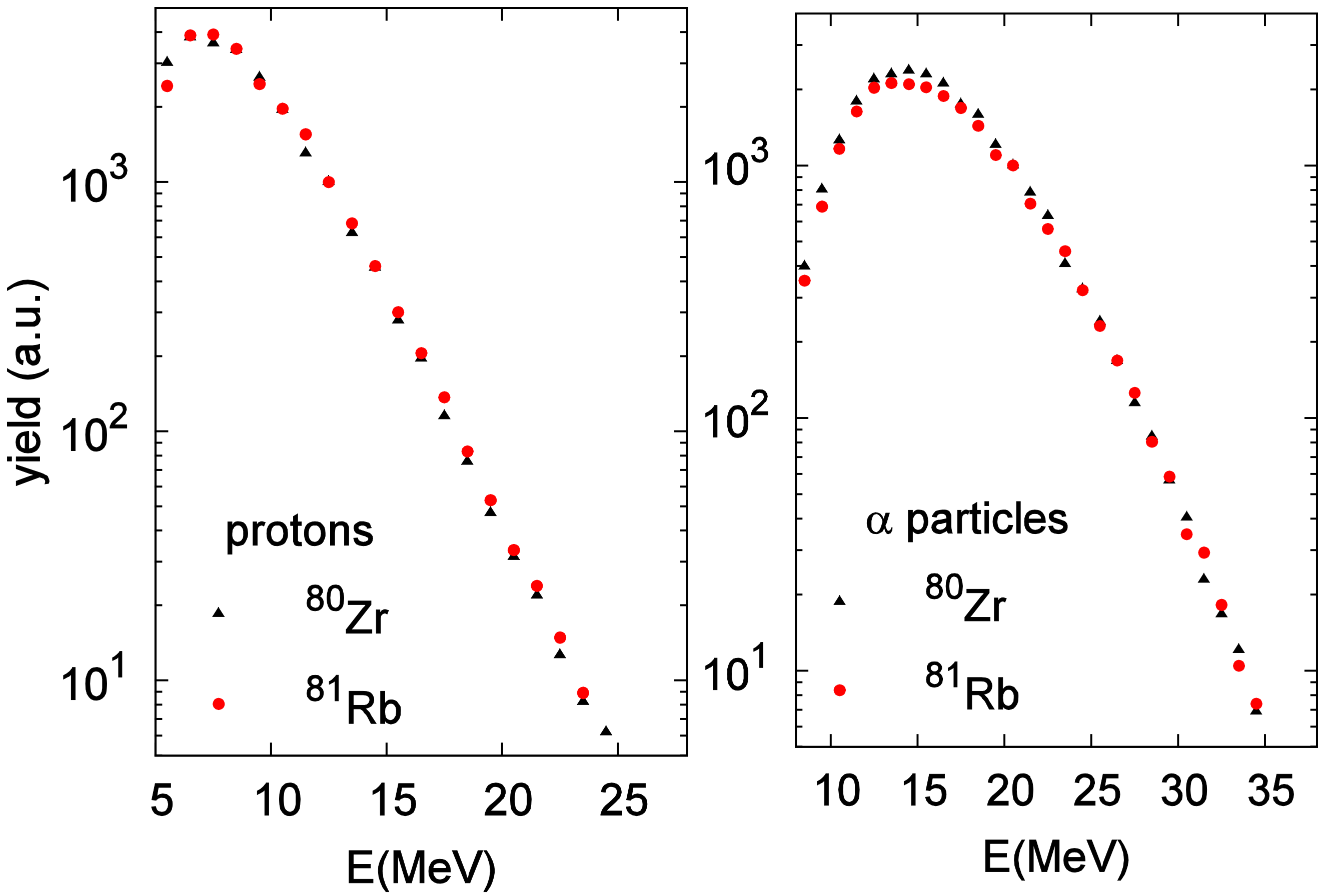
High spin and, consequently, lower E_{int} is favoured by phoswich kinematic selection

Garfield : isotopic identification and energy spectra



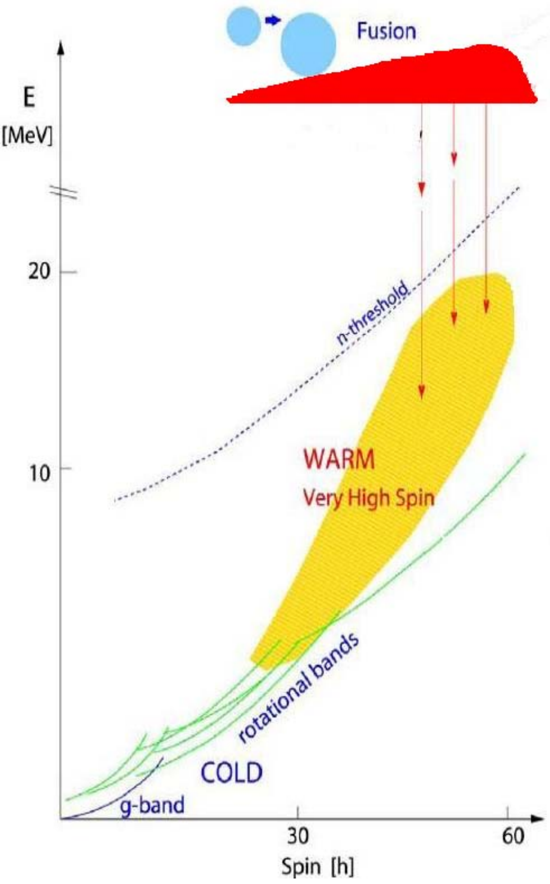
From GARFIELD E-ΔE telescopes it was possible to extract and compare the slope of α and proton spectra in both reactions





Statistical Model Analysis: CASCADE code

Isospin dependence has been introduced in CASCADE simulation of Statistical decay by M.N.Harakeh (PLB 176, 297 (1986)), K.Snover and M.Kicinska-Habior (PRL 70, 3201 (1993))



1) CN spin population with $|<\rangle = |J, I, \pi\rangle, I = I_Z = \dfrac{N\text{-}Z}{2}$

2) Mixing of population with I and $I+1$ according to mixing parameter α^2

3) p, n, α, γ decay according to trasmission coefficients (I dependent)

4) new phase space population and mixing of I and $I+1$

FOR NSTEP

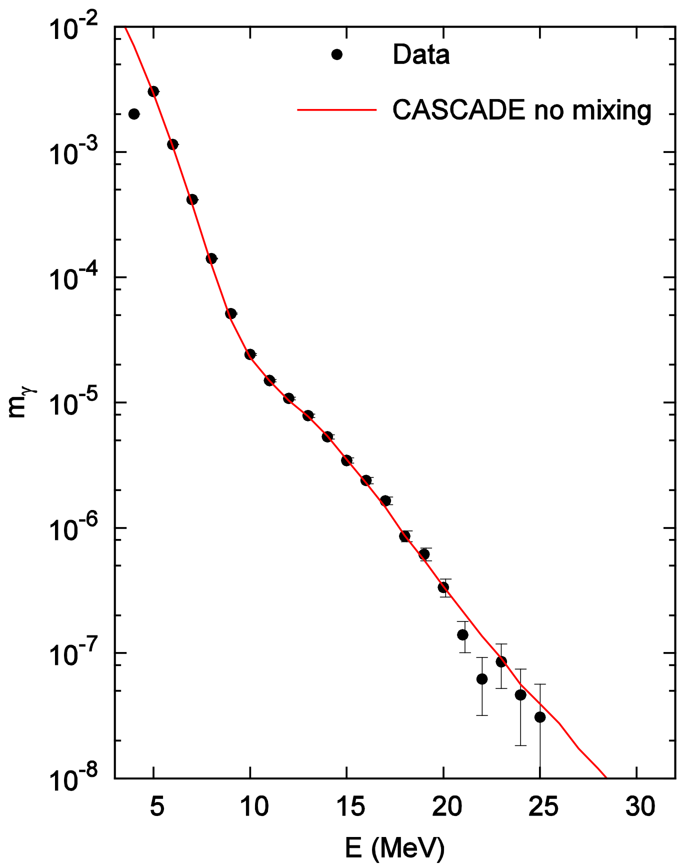
5) residual nuclei (with $E^* \approx 0$)

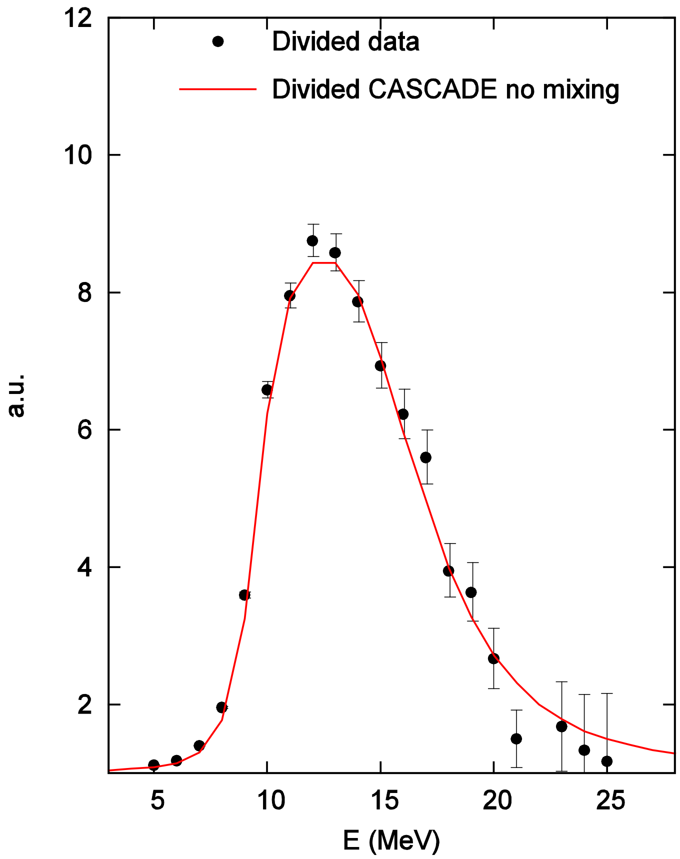
Statistical Model Analysis

The set of parameters giving the best fit has been determined with χ^2 test:

1) Fit of GDR parameters on ^{81}Rb γ-ray spectrum using $\Gamma^{\downarrow}=0$

→ S=90%, E_{GDR}=16.2 MeV, Γ=10.6 MeV

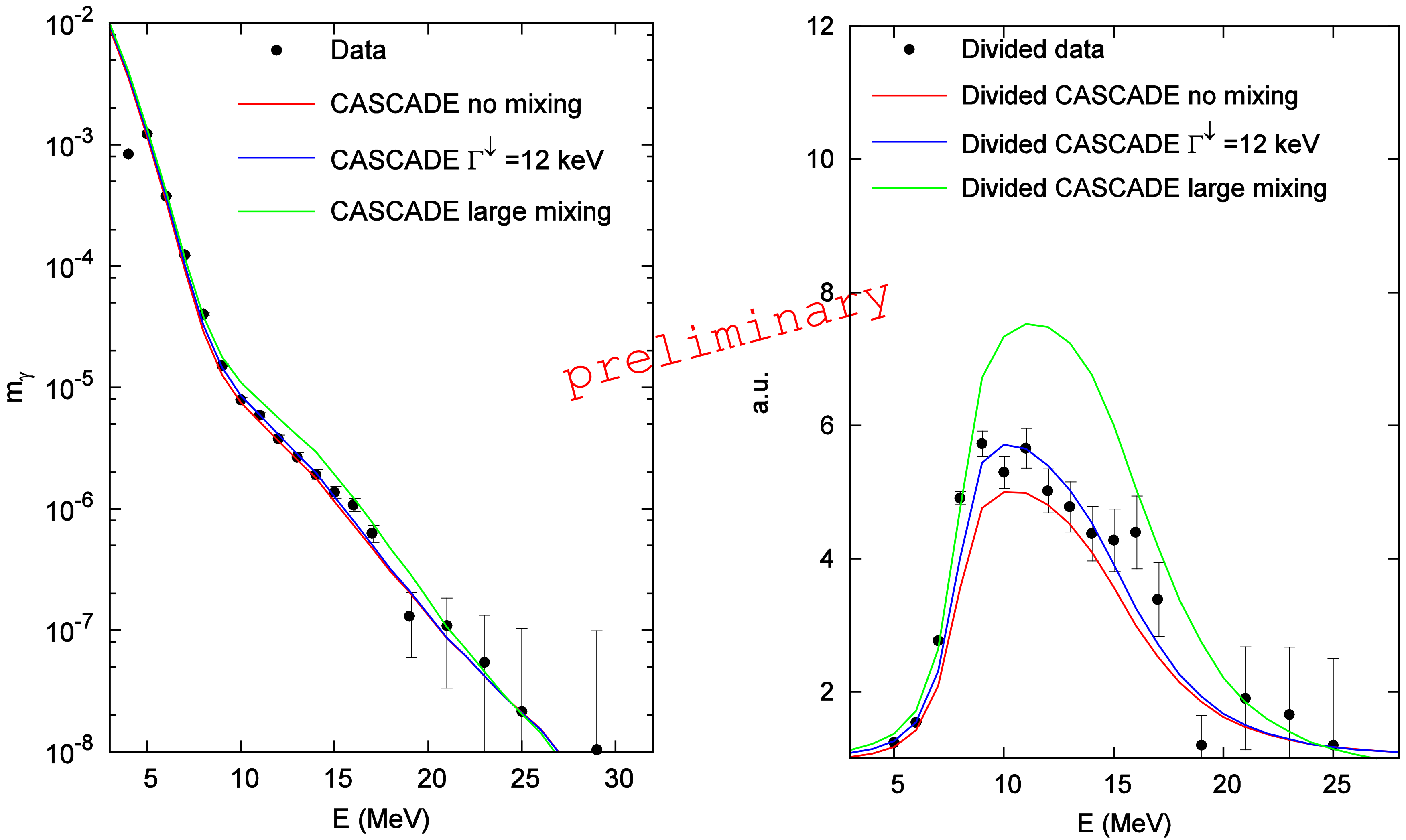




Statistical Model Analysis

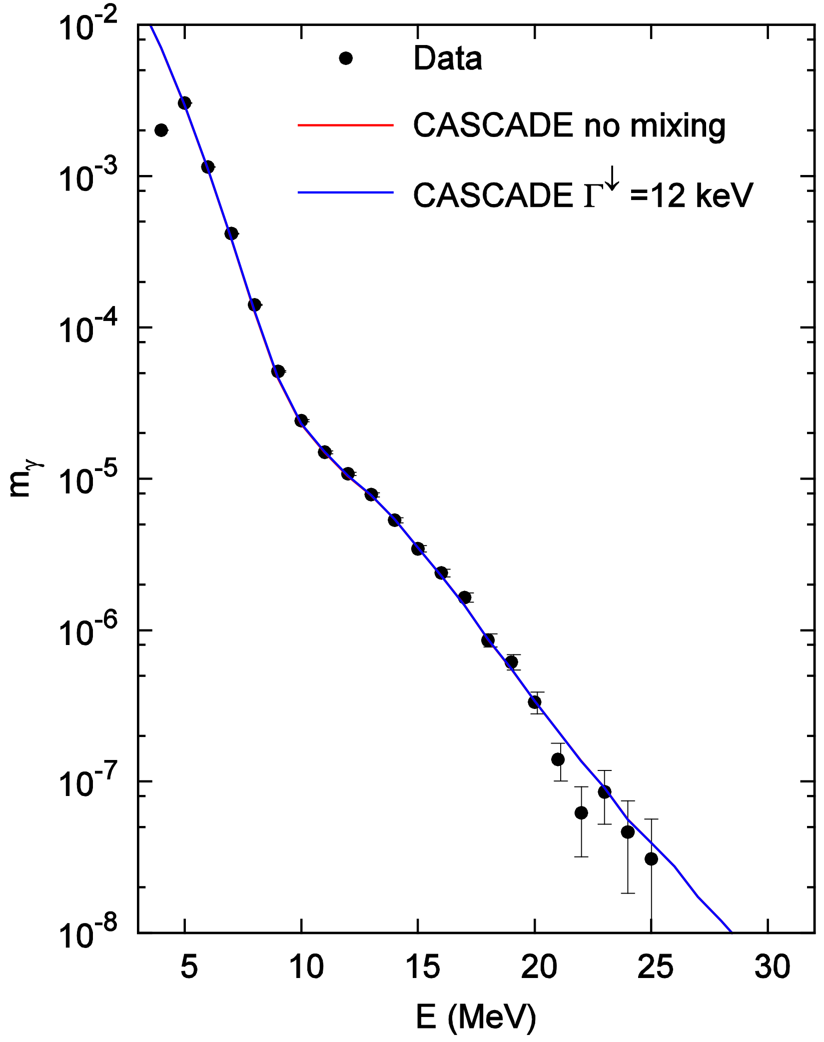
2) Using GDR parameters of 1), fit of $\Gamma^{\downarrow}$ on ^{80}Zr spectrum

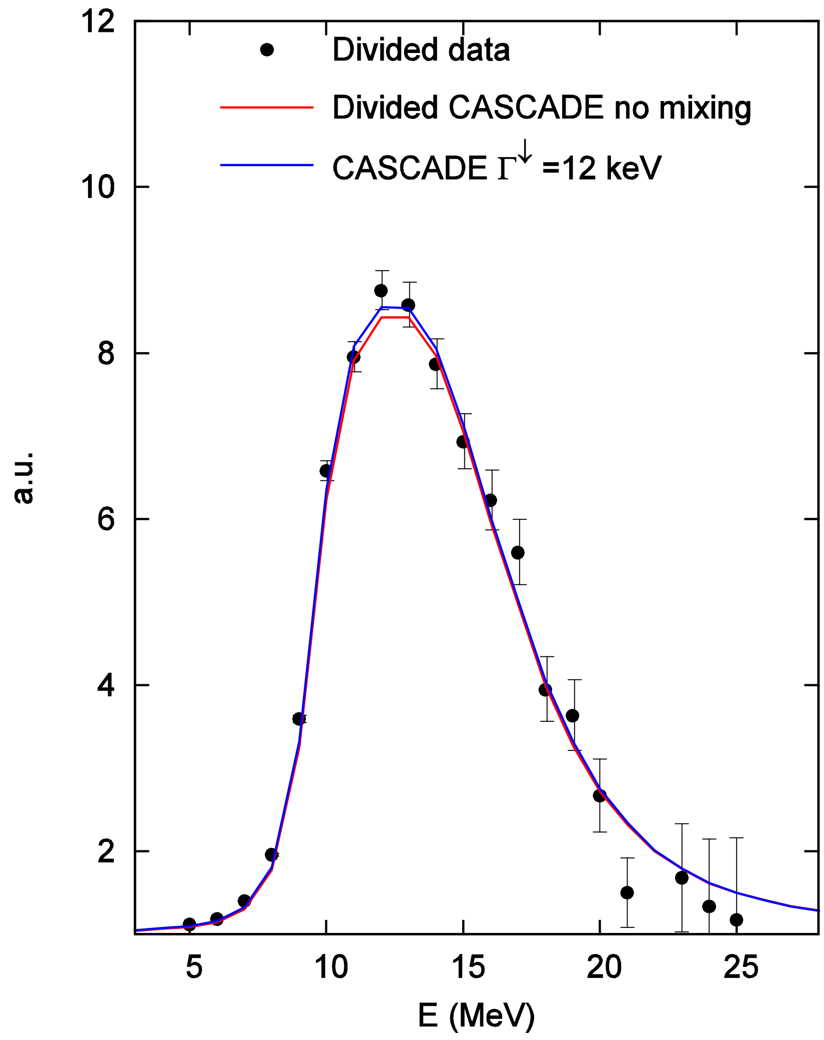
→ $\Gamma^{\downarrow}$=0.010 0.003 MeV corresponding to **$\alpha_{<}^{2}$= 5.0 1.5%**



Statistical Model Analysis of ^{81}Rb γ decay (GDR not hindered)

3) Back to 1) with ^{81}Rb and $\Gamma^{\downarrow}$=12 keV, to check the stability of the fit

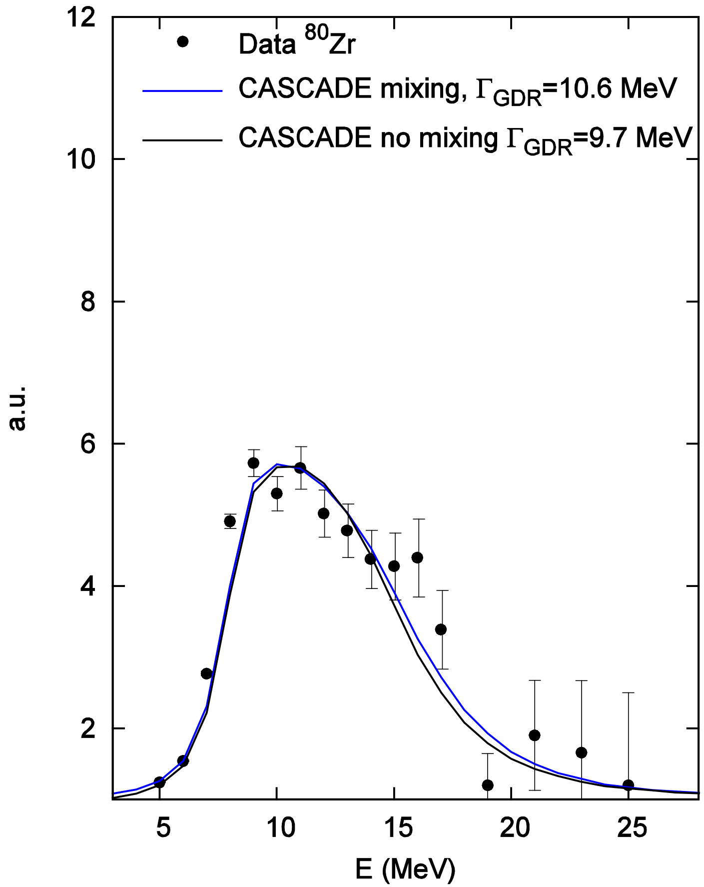




Statistical Model Analysis without mixing

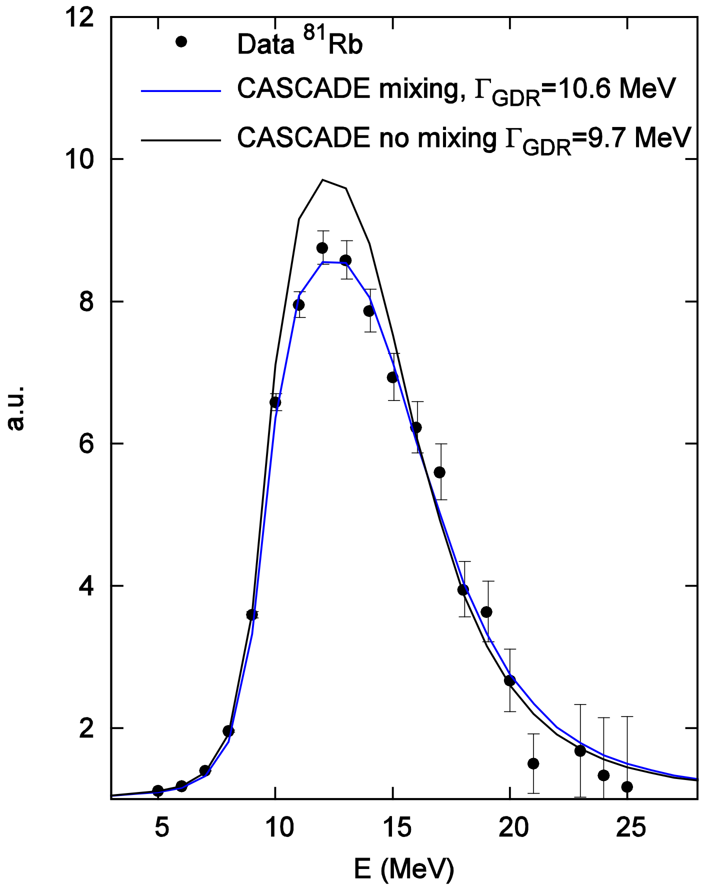
4) Best fit of GDR parameters on ^{80}Zr without isospin mixing

S=90%, E_{GDR}=16.2 MeV, **Γ=9.7 MeV**

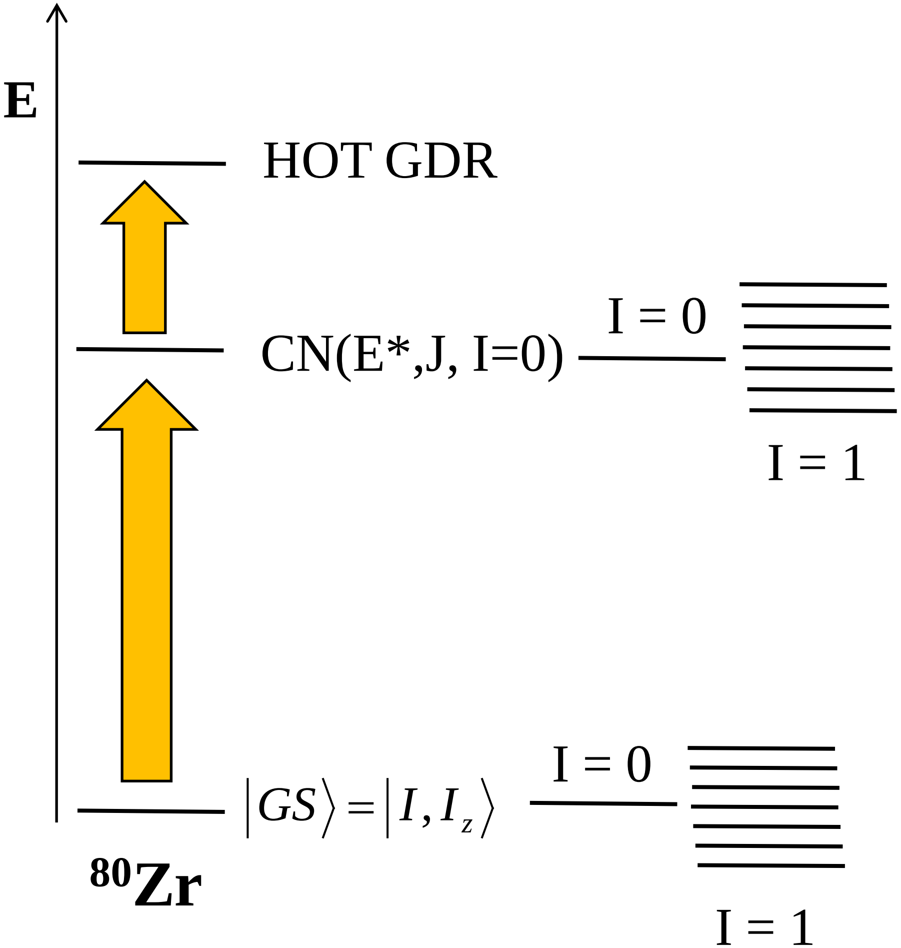


5) Fit ^{81}Rb with Γ=9.7 MeV

Only with isospin mixing both γ-decay spectra can be reproduced simultaneously



Isospin MIXING



$$\Gamma_{\mathbf{Coul}} = \mathbf{10 \pm 3\ keV}$$

There is one mechanism responsible for the mixing. At high excitation energy the scenario is affected by ‘external’ influence’, namely the lifetime of the CN.

Similar scenario as in

- Motional Narrowing

- GDR intrinsic width

$$\Gamma_{\mathbf{IAS}} = \mathbf{9.9\ keV\ \ (in\ {}^{80}Se)}$$

Nuclear Physics A315 (1979) 157-162;

Conclusions:

GDR has been used as a probe/tool to study Isospin Mixing

- Nuclear system: N=Z ^{80}Zr at T~2 MeV
- Coulomb Spreading width has been measured 10±3 keV **(Preliminary)**
  - It is the same value as Γ_{IAS} measured at T=0 in ^{80}Se
- A value of $\alpha^2_{<}$ = 5.0   1.5 % has been exctracted from data **(Preliminary)**
- The measured value is consistent with theory and previous data

Future:

- Extract from data the E*=0 values of α^2
- New experimental data

High energy γ-rays from hot compound nuclei are an important tool to understand reaction dinamics, nuclear structure and symmetries

GARFIELD –HECTOR COLLABORATION:

A.Corsi[1],O.Wieland[7], S.Barlini[2], V.L.Kravchuk[3], G.Baiocco[5], L.Bardelli[2], G.Benzoni[7], M.Bini[2], N.Blasi[7], A.Bracco[1], S. Brambilla[7], M.Bruno[5], F.Camera[1], S. Carboni[2], G.Casini[2] , M.Ciemala[4], M.Cinausero[3], M.Chiari[2], F.C.L. Crespi[1], M.D'Agostino[5], M.Degerlier[3], A.Giaz[1], F.Gramegna[3], M.Kmiecik[4], S.Leoni[1], A.Maj[4], T.Marchi[3], K.Mazurek[4], W. Meczynski[4], B.Million[7], D.Montanari[6], L.Morelli[5], A.Nannini[2], R.Nicolini[1], G.Pasquali[2], S.Piantelli[2], A.Ordine[8], G.Poggi[2], V.Rizzi[3], V.Vandone[1], G.Vannini[5]

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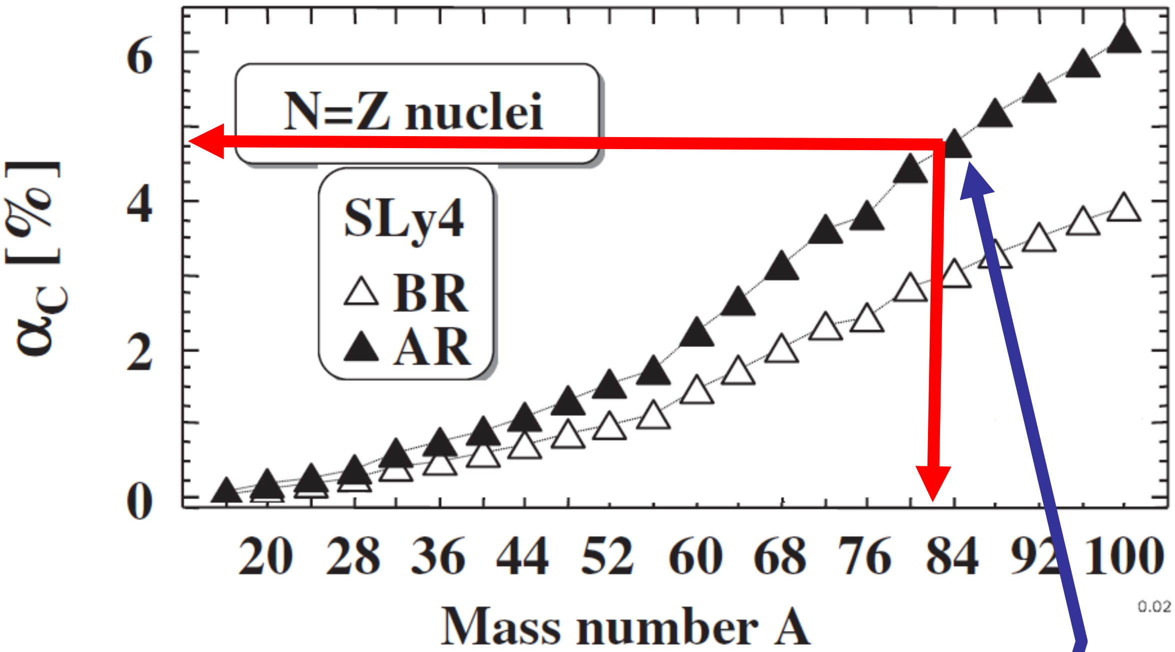
Isospin mixing dependence on Z and Temperature

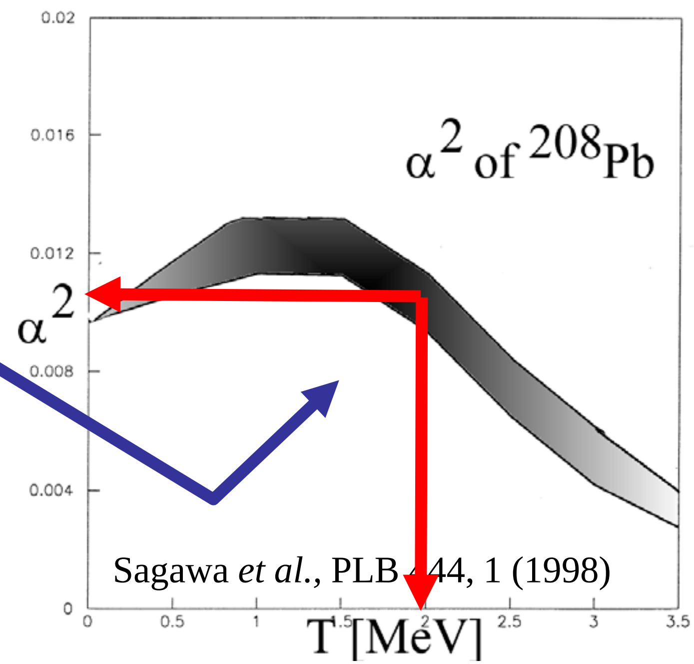


Satula et al., PRL 103, 12502 (2009)

$\Gamma^{\downarrow}$=0.012 0.04 MeV

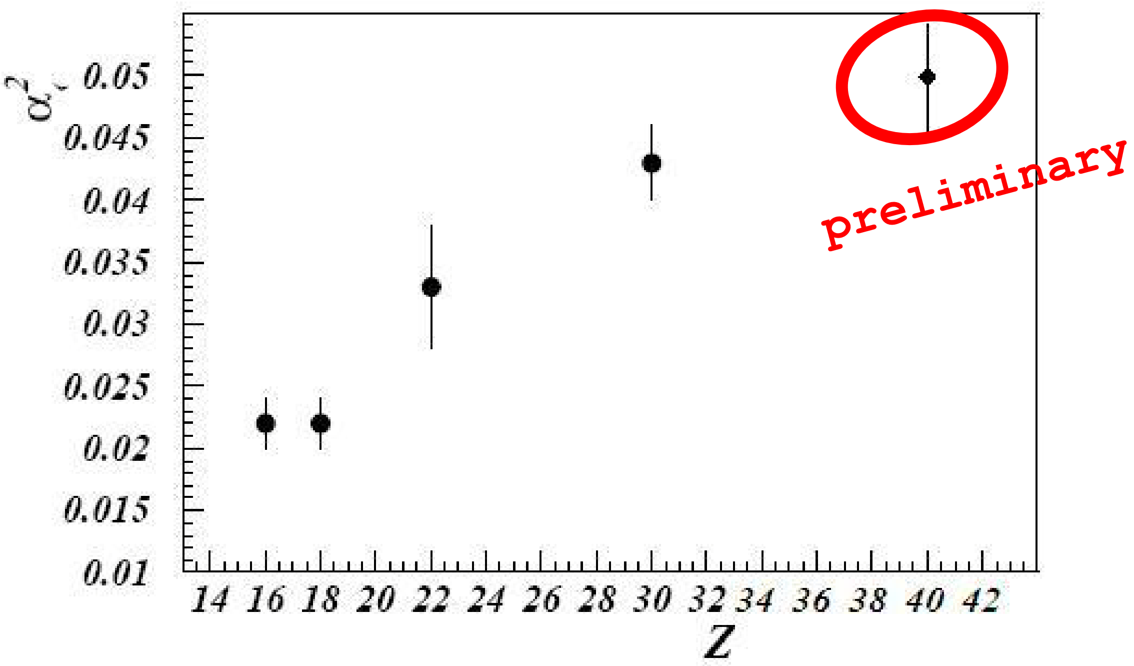
corresponding to

$\alpha_<^2$= 5 1.5%



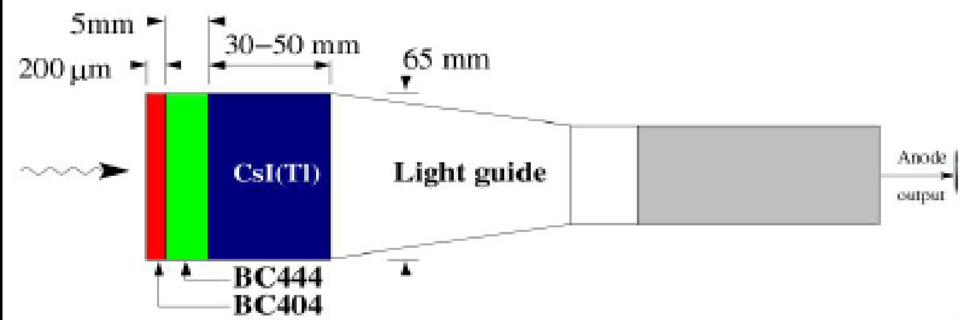
Sagawa *et al.*, PLB 444, 1 (1998)

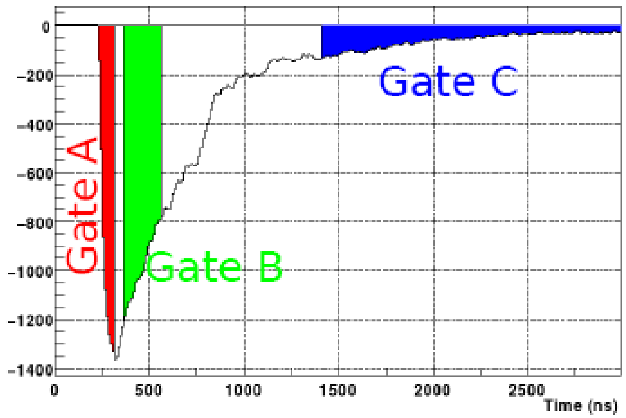
➢ $\alpha_<^2$ at Z=40 obtained from Statistical Model analysis confirms the trend at finite temperature (1.6 < T < 3 MeV)



➢ Extrapolation of $\alpha_<^2$ calculated at T=0 up to T ≈ 2 MeV will be done according to formula in Sagawa *et al.*, PLB 444, 1 (1998)

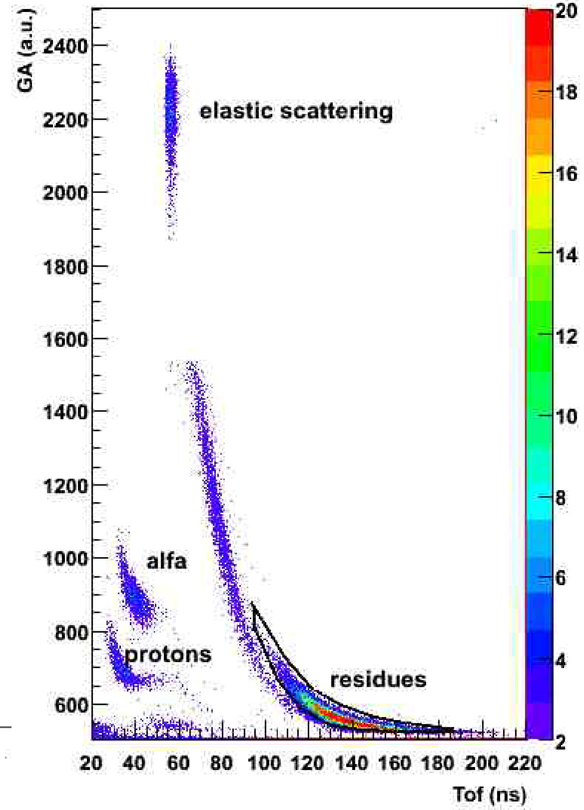
Phoswich: residues and light particles identification in Cl+Ca



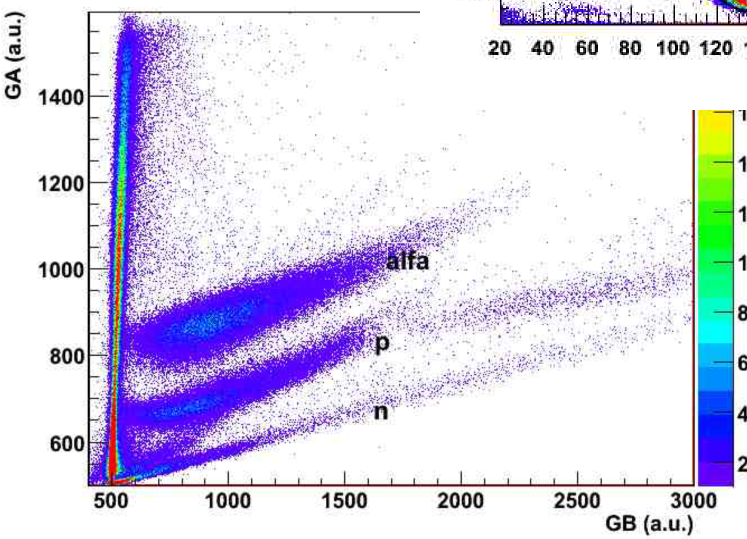


L.Bardelli et al., Nucl. Inst. Meth. A 572 (2007), 882

Identification of fusion- evaporation products in phoswich detectors:



Light particles identification is confirmed by correlation between GA and GB



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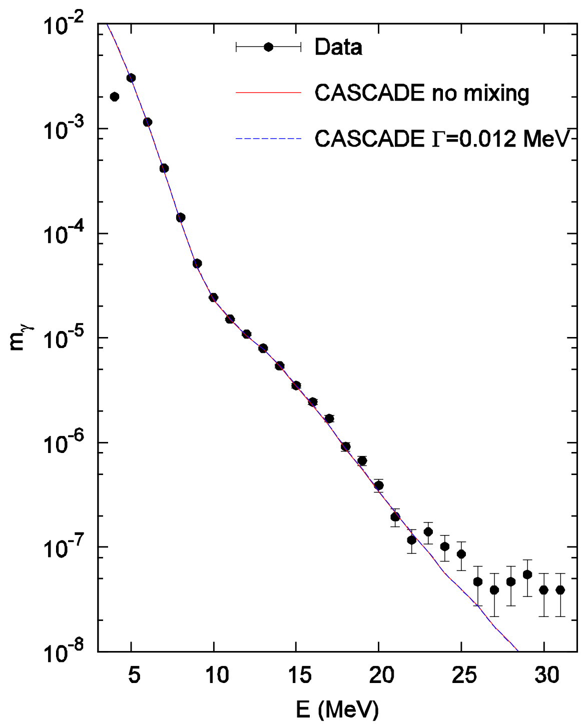
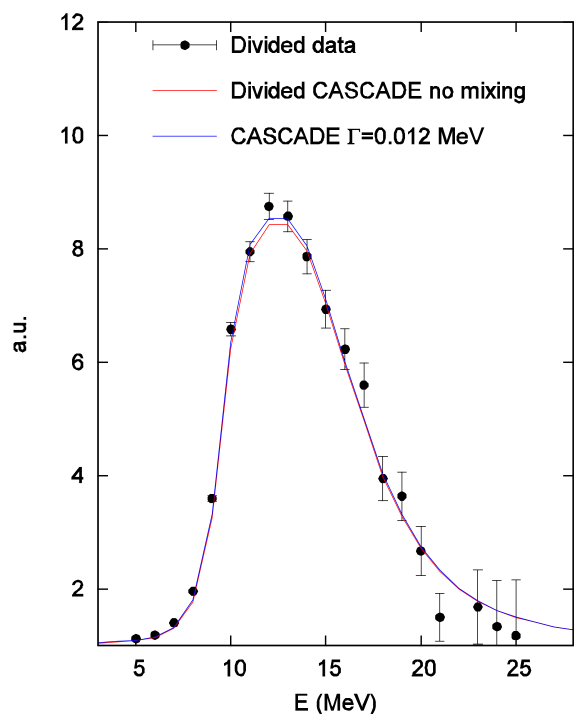
→ Γ↓=0.012 0.04 MeV corresponding to **$\alpha_{<}^{2}$= 5 1.5%**





^{81}Rb γ-ray spectrum

Note that in this case, Γ↓=0 and Γ↓=0.012 MeV do not change the γ-rays spectrum

GARFIELD: layout and calibration procedure

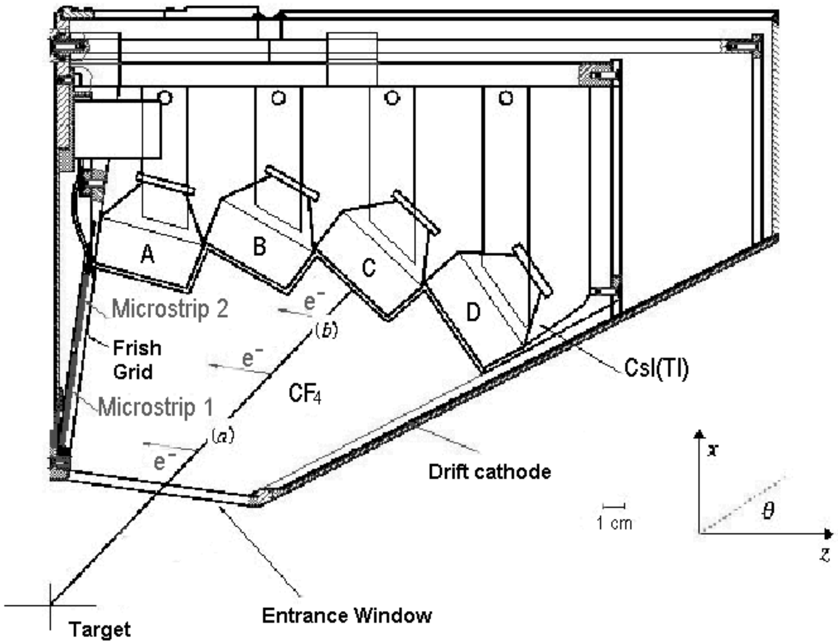
Calibration of CsI:

-calibration of the LO via elastic scattering measurements at different E_{beam}

-Z,A identification via fast-slow correlation

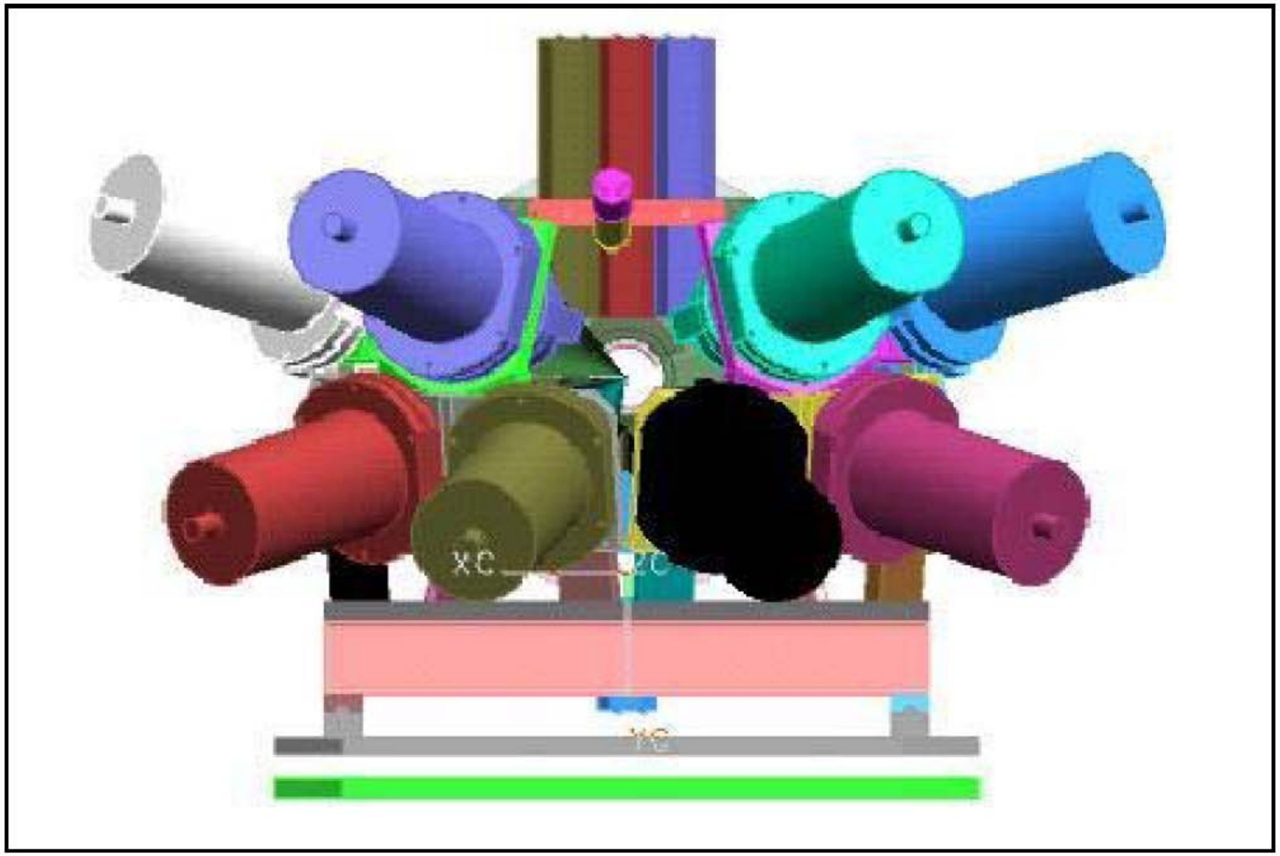
-E=f(LO,A,Z) according to Birks-like formula

-subtraction of ΔE_{loss} in microstrip gas chamber



HECTOR

8 large volume (≈3 dm^3) BaF_2 scintillators, time resolution ≈ 1 ns



Configuration inside GARFIELD scattering chamber (seen by incoming beam)