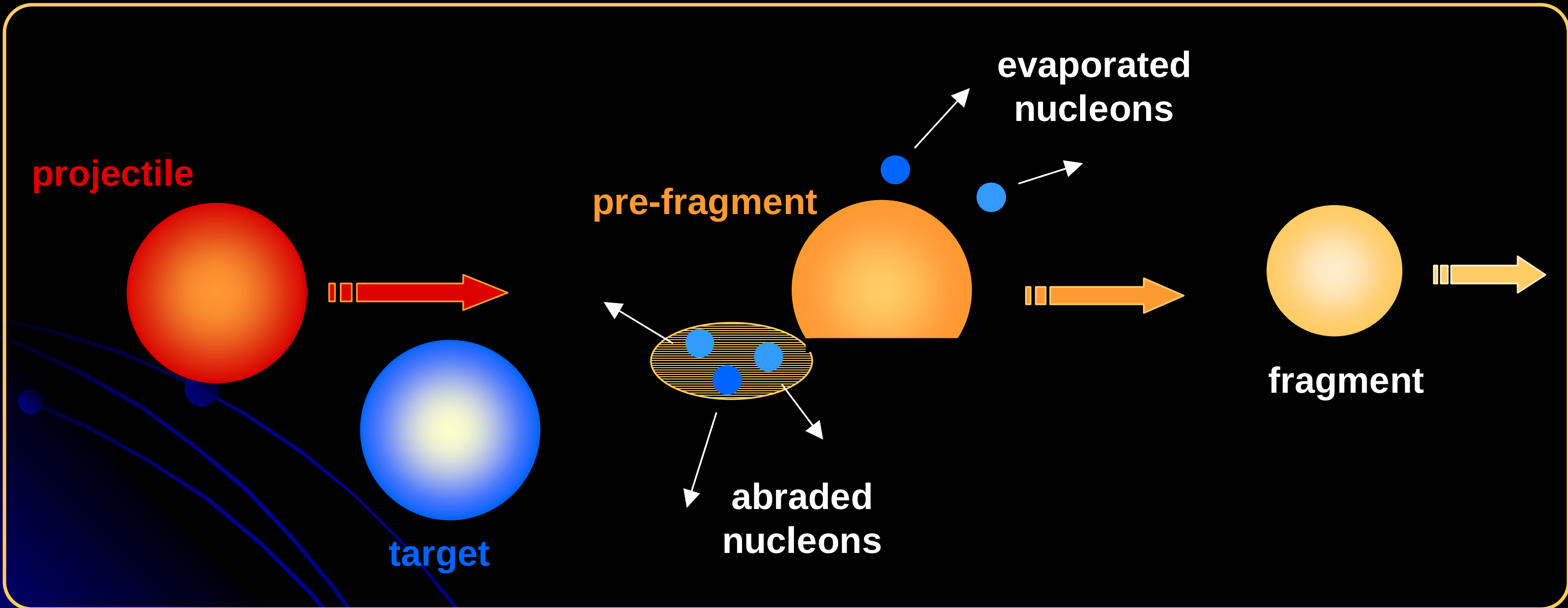
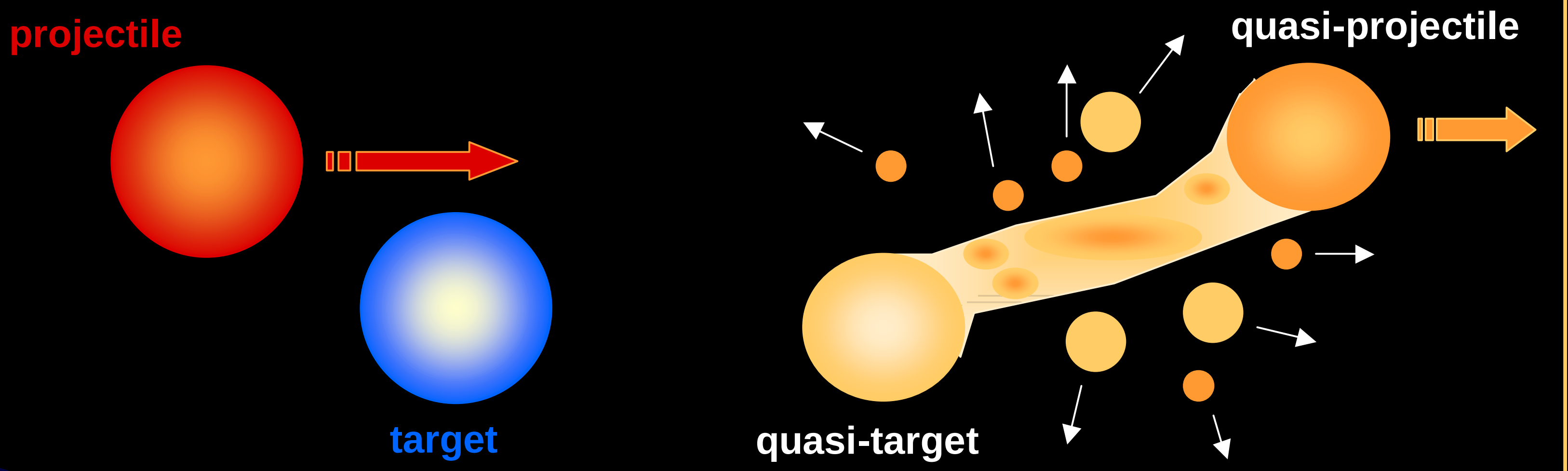
Classification of nuclear reactions / Fragmentation

Definition: Formation of a unique fragment from the peripheral collision of a projectile nucleus with a target nucleus. The impact results in the abrasion of few nucleons. The excited pre-fragment decays by emitting few other nucleons.



Neck emission

In peripheral collisions, at intermediate energies (E_{inc} < 100 AMeV)



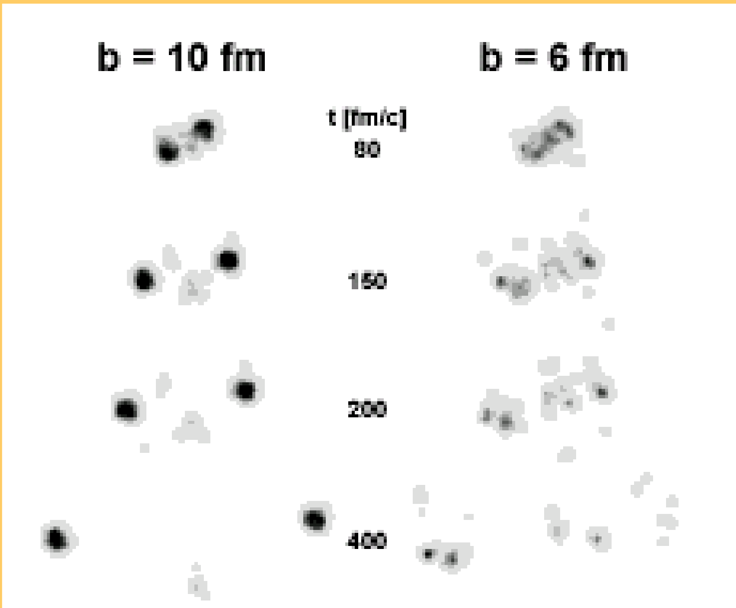
enhancement of the emission of LCP's and IMF's from the intermediate velocity region

→ The neck emission favours the n-rich LCP's.

LCP: Light Charged Particle = p, d, t, ^{3}He, ^{4}He
IMF: Intermediate Mass Fragment = $3 \leq Z \leq 30$

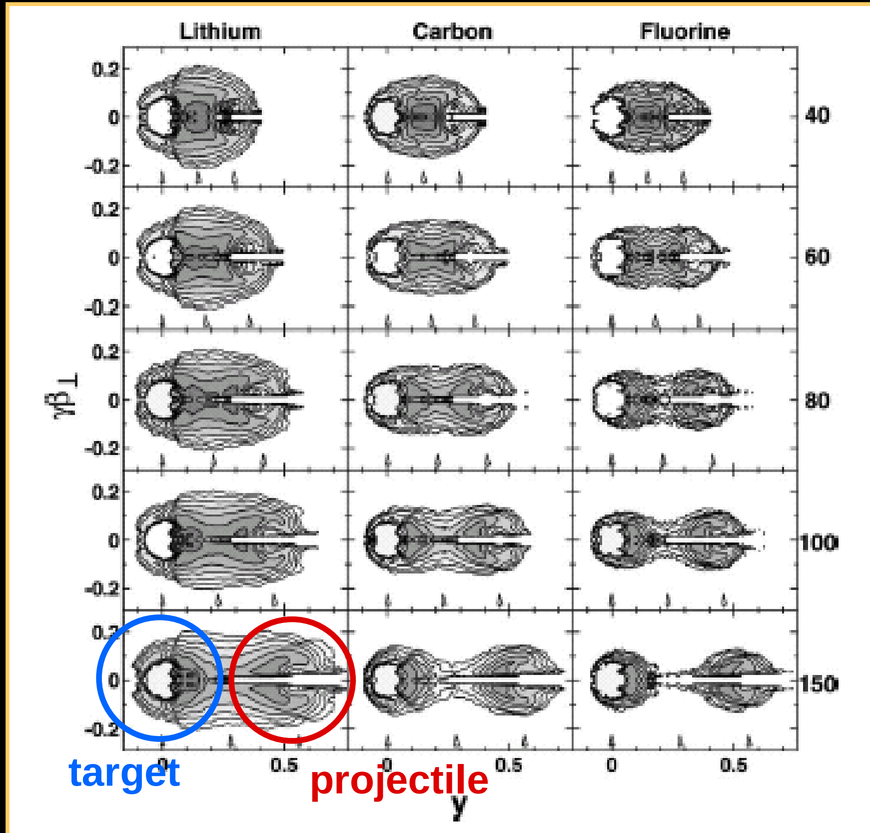
Neck emission

CHIMERA predictions for Au+Au at 80 AMeV



J. Lukasik et al., Proceedings of INPC 2001

Au+Au at 40, 60, 80, 100, 150 AMeV
very peripheral collisions



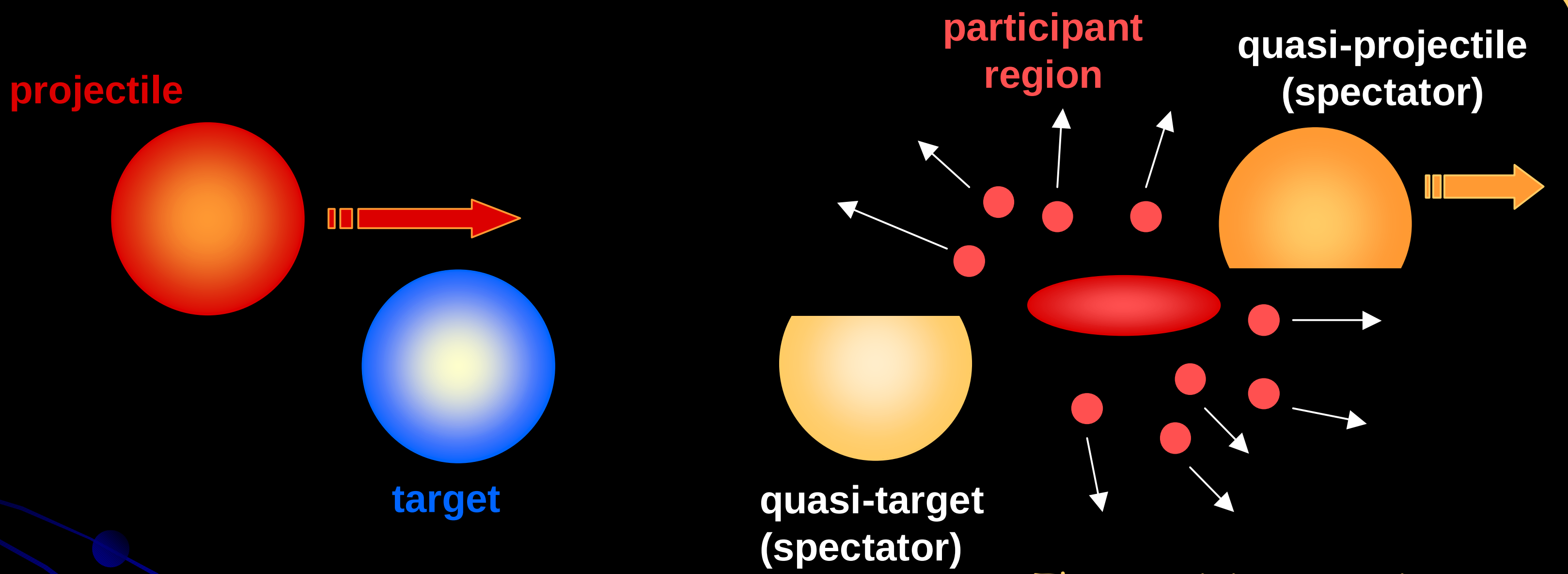
J. Lukasik et al., Phys. Lett. B 566 (2003) 76

The rapidity of a particle corresponds to its velocity for non-relativistic energies

$$y = \frac{1}{2} \ln \frac{E + p_{//}}{E - p_{//}}$$

Participant spectator model

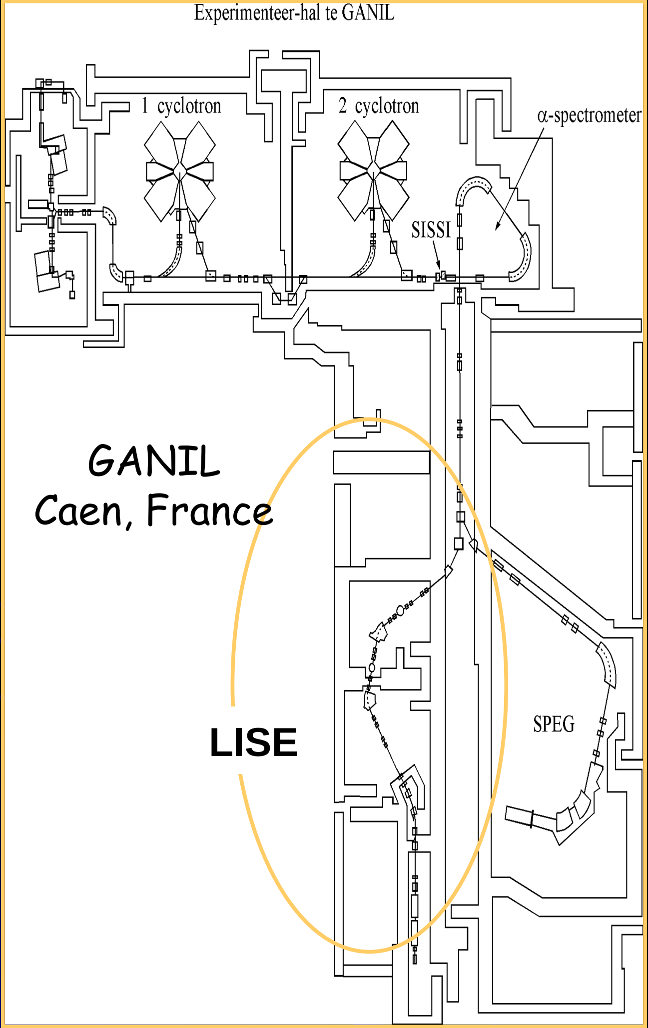
In peripheral collisions, at relativistic energies (E_{inc} > 100 AMeV)

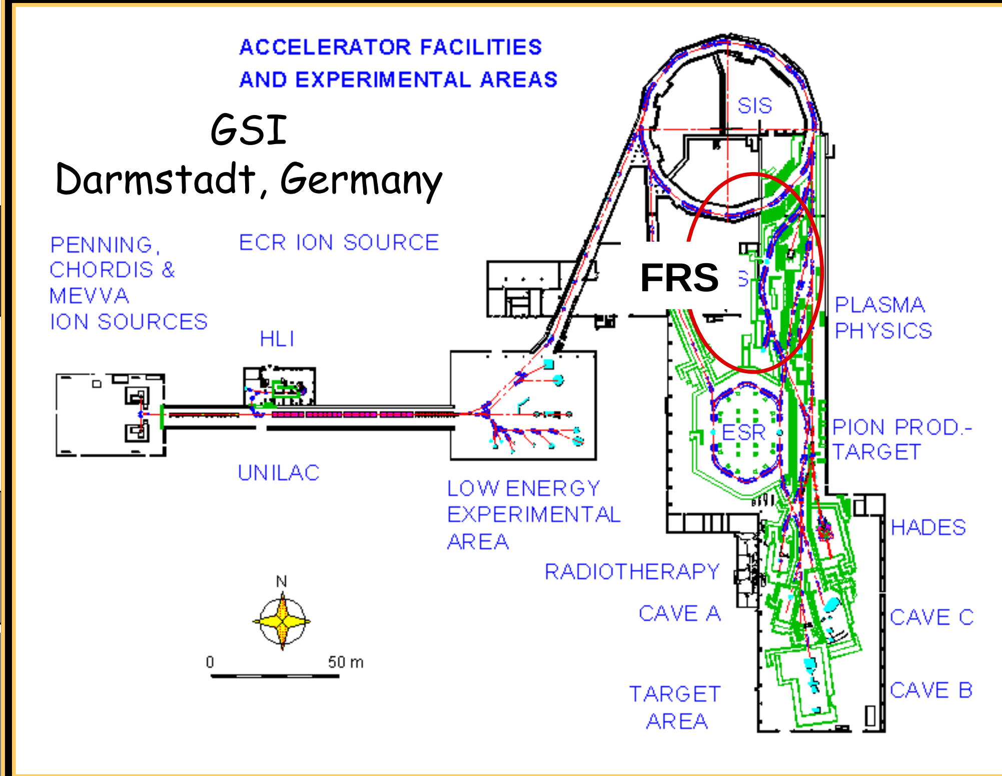


The participant region, very hot and dense, decays emitting only LCP's, mainly nucleons.

Fragment separators

Fragmentation → production of exotic nuclei

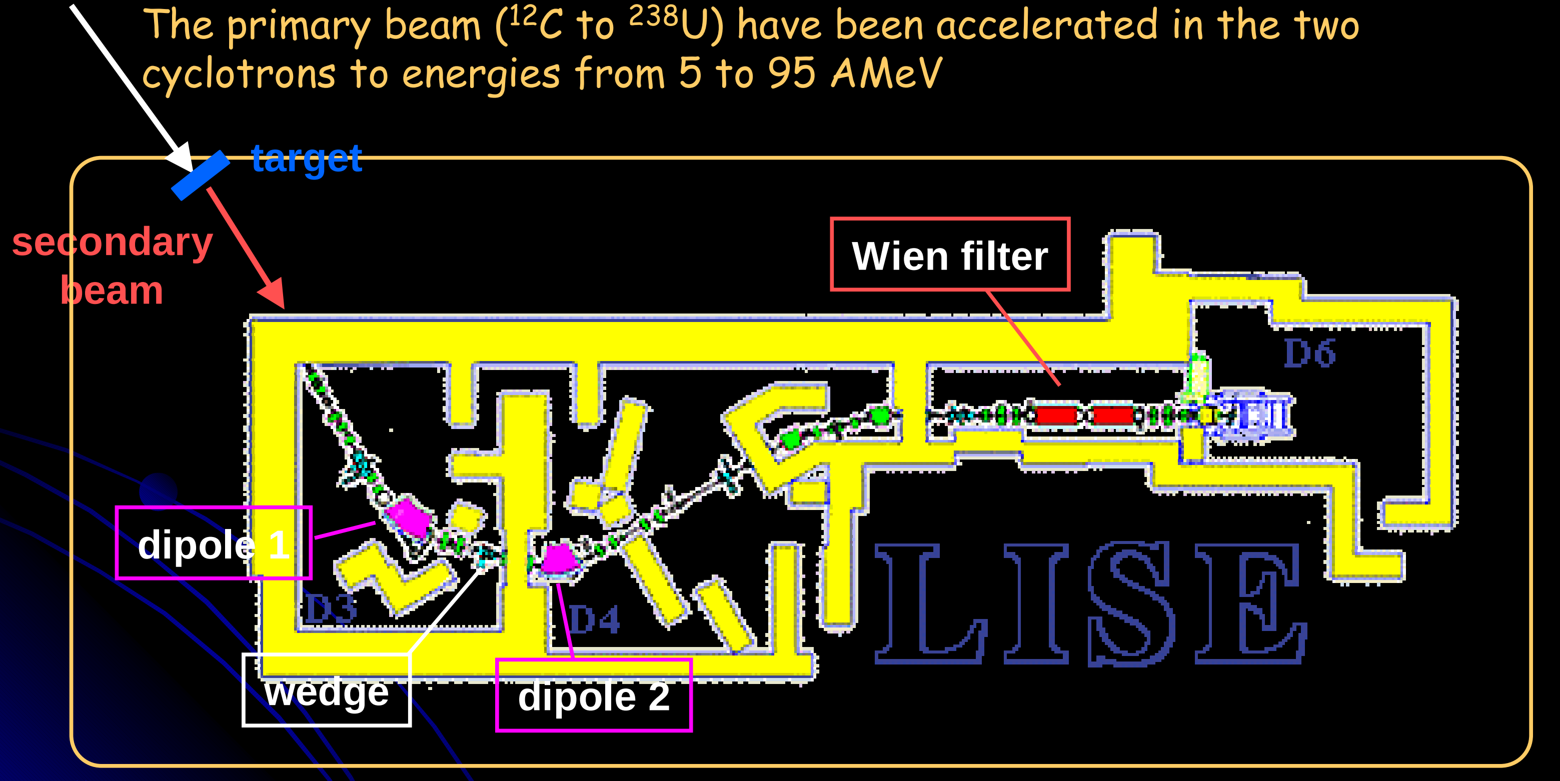




LISE at GANIL

LISE = Ligne d'Ions Super Epluchés (Super Stripped Ion Line)

The primary beam (^{12}C to ^{238}U) have been accelerated in the two cyclotrons to energies from 5 to 95 AMeV

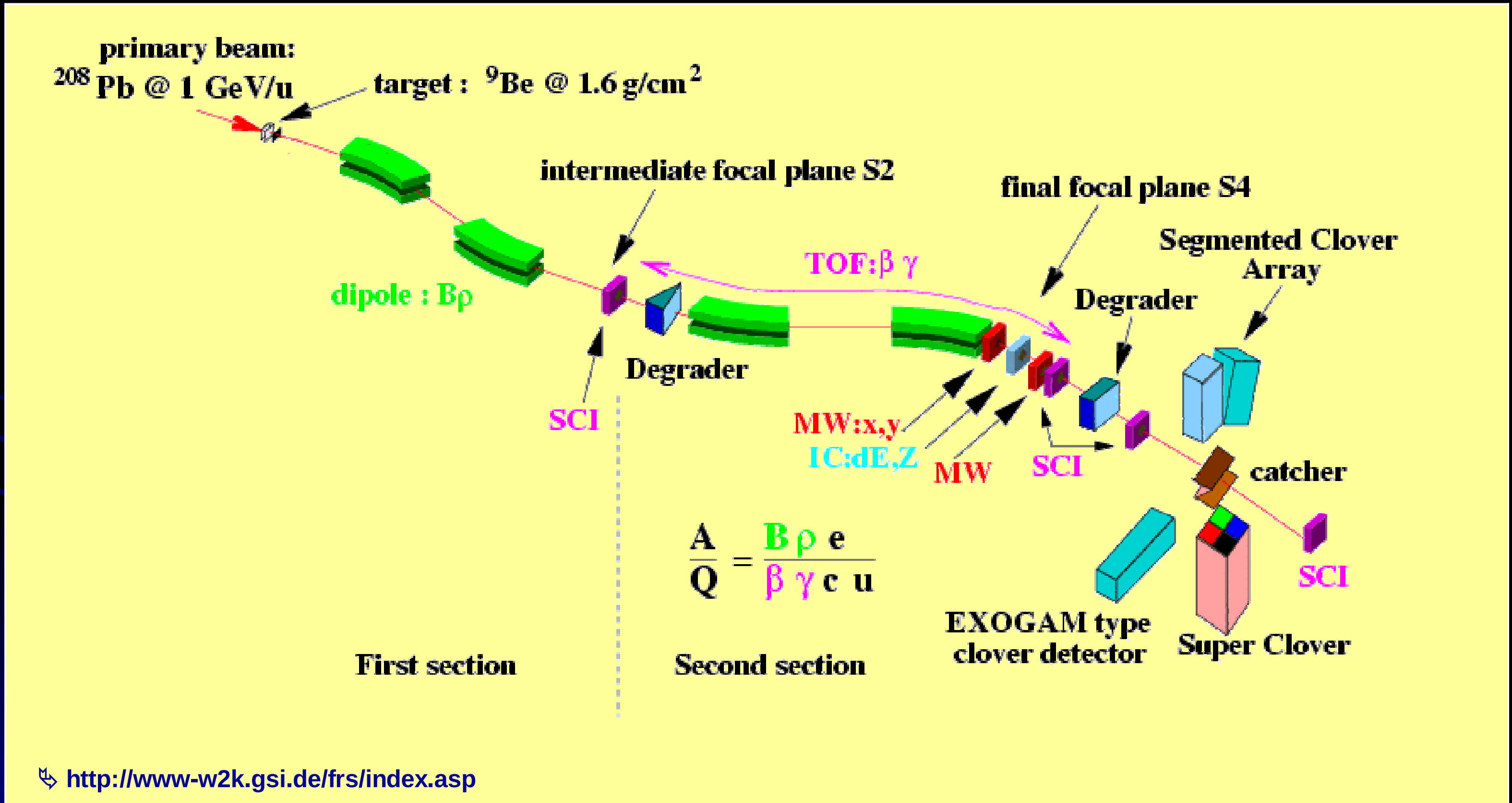


http://www.ganil.fr/lise/lise.html

FRS at GSI

FRS = FRagment Separator

The primary beam (^{12}C to ^{238}U) have been accelerated in the synchrotron SIS to energies from 30 AMeV to 2 AGeV



Fragment selection

Magnetic dipoles

Magnetic selection in mass, atomic number, and speed (A.v/Q).

The dipoles allow a deviation of the ions of the secondary beam according to their charge state, their speed, and mass. The determination of their magnetic rigidity Br is a measure of this deviation.

Non-relativistic formula: $$B\rho = \frac{Av}{Qc^2}$$

Relativistic formula: $$B\rho = \frac{\gamma A \beta}{Qc}$$

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

with Br: magnetic rigidity (Tm)
B: intensity of the magnetic field (T)
r: curvature radius (m)
v: speed of the nucleus (ms^{-1})

c: speed of light
A: nucleus mass (J)
Q: positive ion charge
(Q $\cong$ Z, if fully stripped)

Fragment selection

Degrader (wedge)

Selection in energy loss, on the atomic mass and number (i.e. in A^3/Z^2).

The degrader is located in an intermediate focal plane of the beam line. The secondary beam, still composed of several ions of diverse charge states, is slowed down and purified.

The energy loss in the material is characteristic of the beam particles (selection in v and Z).

The relative energy loss in the degrader is given by:

$$\frac{dE}{E} \cong eK \frac{A^3}{Z^2}$$

with K: constant typical of the degrader
e: thickness of the degrader

A: nucleus mass
Z: atomic number

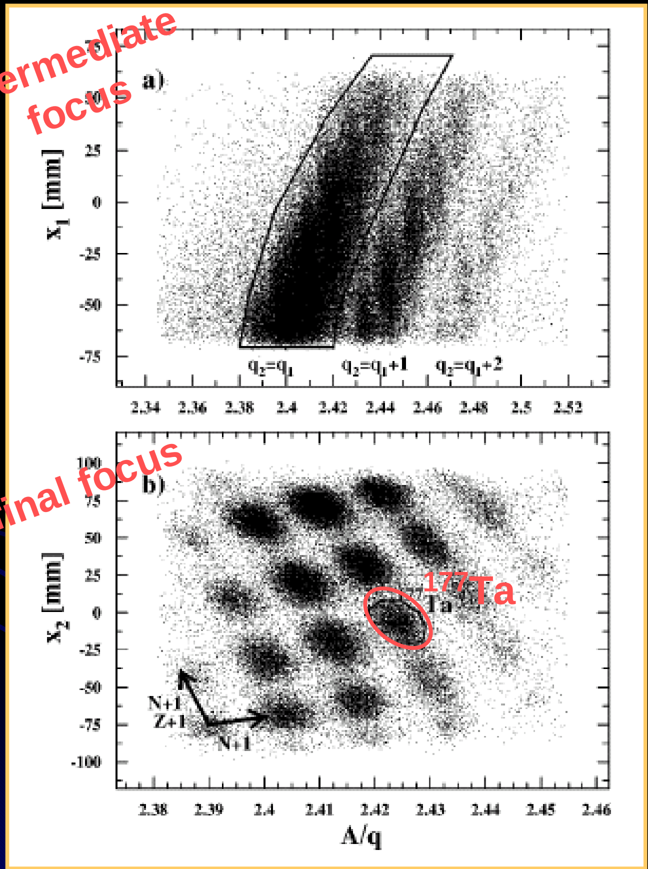
Wien filter

Selection in speed (v).

The electrostatic tank of the filter is divided in 2 subsections which are , each of them, inside a large magnetic dipolar gap. The beam goes then through a region with cross electric and magnetic fields (the direction of the electric field is vertical and the magnetic field's is horizontal) with intensities such that the selected nucleus can continue its trajectory without being slowed down neither deviated of the incident direction of the secondary beam (the forces due to the two fields compensate each other). The other ions are deviated.

Fragment production

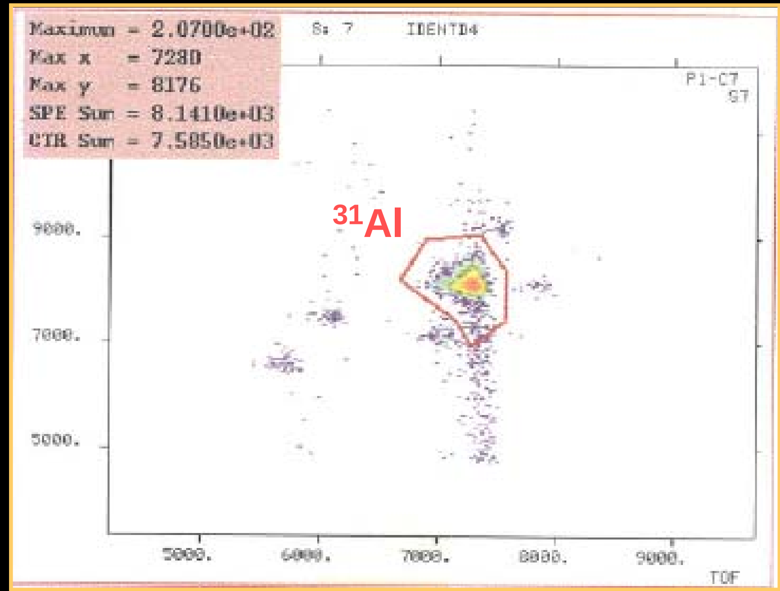
FRS



M.Pfützner et al., Phys. Rev. C 65(2002)064604

LISE

at the end of the beam line

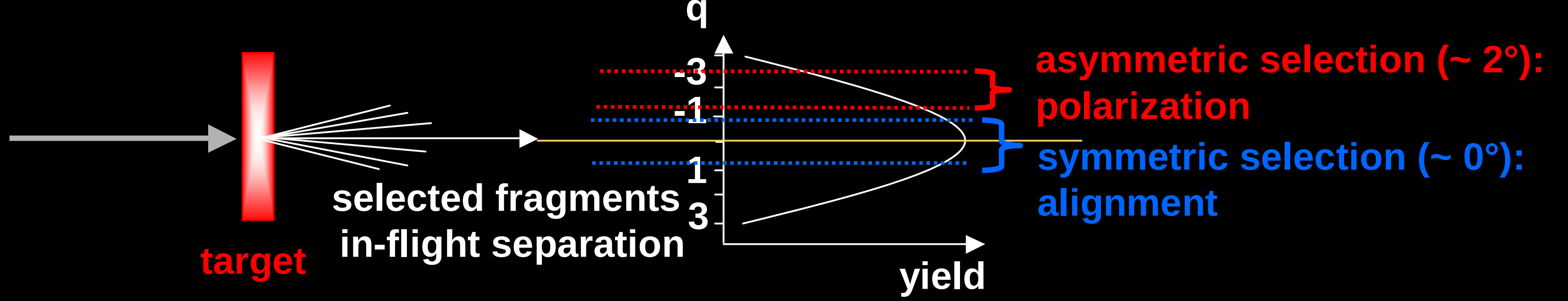


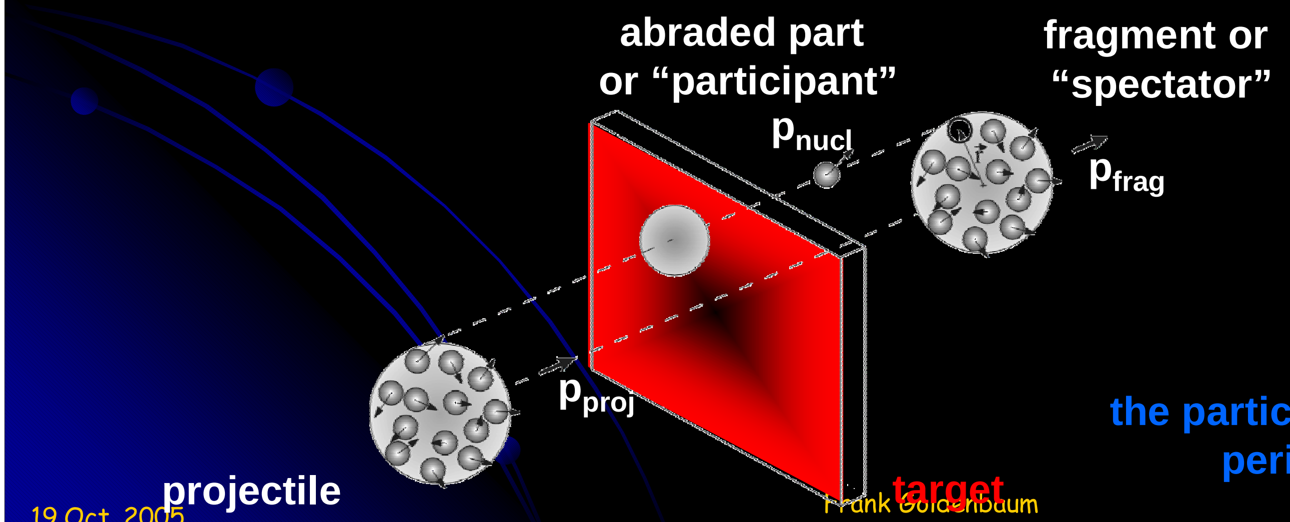
Beam purity: 93%

Spin orientation

In the early 90's, it was discovered the possibility to create spin orientation in exotic nuclei via projectile fragmentation.

Principle: transfer of momentum via nucleon removal in the projectile

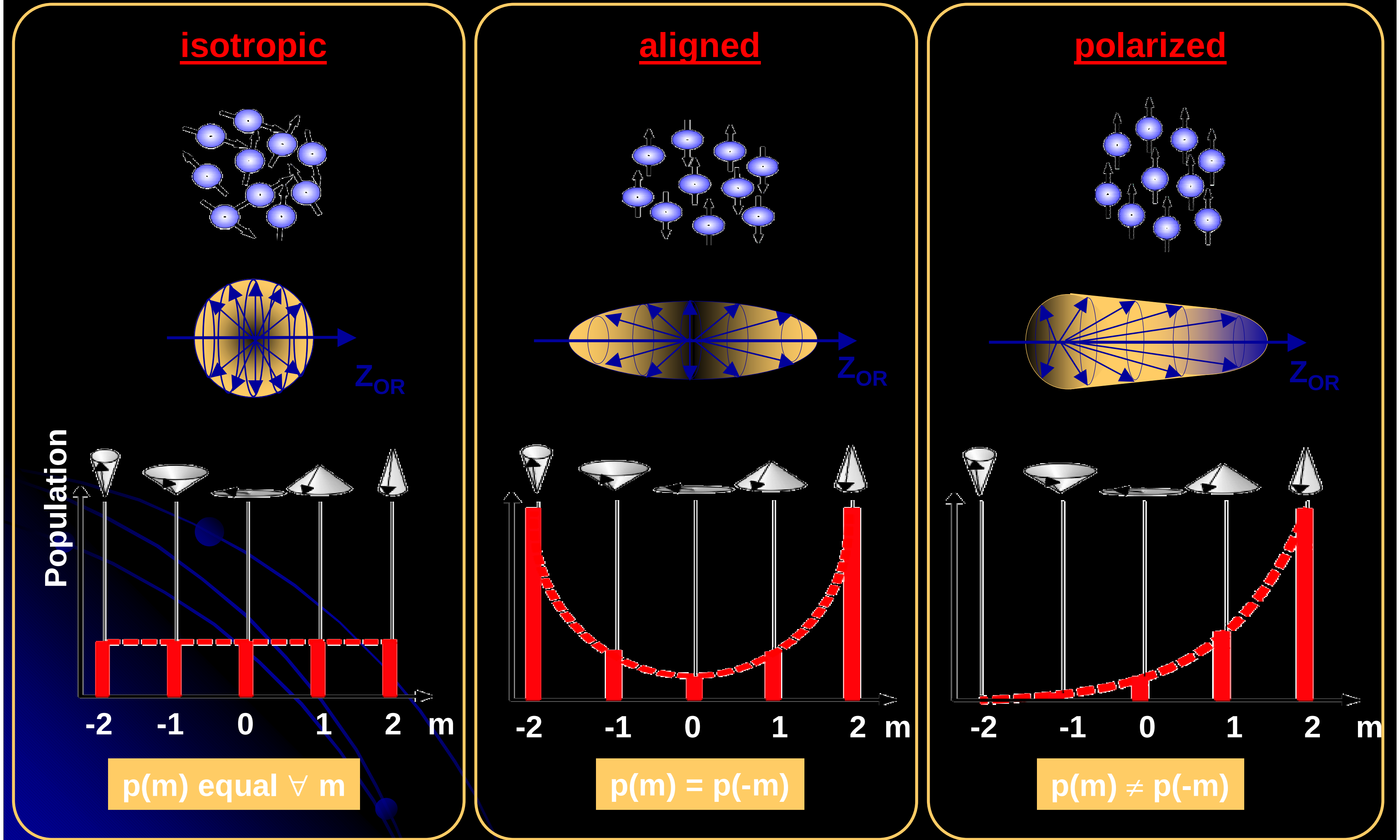




rather low orientation (5-30%)

the participant spectator model:
peripheral collisions

Spin orientation

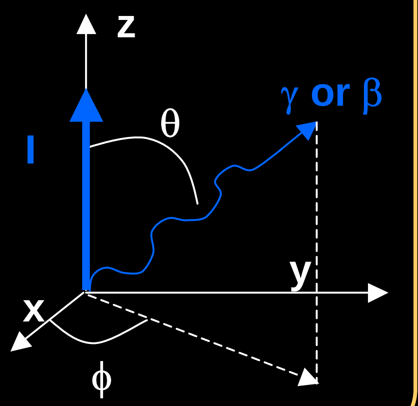


Spin orientation

The direction in which the radiation is emitted by a radioactive nucleus, depends on the direction of its nuclear spin.
This is formally described by the 'angular distribution' function:

$$W(\theta, \phi, t) = \sum_{k,n} \frac{\sqrt{4\pi}}{2k+1} A_k \; B_k^n(t) \; Y_k^n(\theta,\phi)$$

A_k: radiation parameter
$B_k^n(t)$: orientation tensor
$Y_k^n(\theta,\phi)$: spherical tensors



An isotropic ensemble has $B_0 = 1$, all other components are zero.

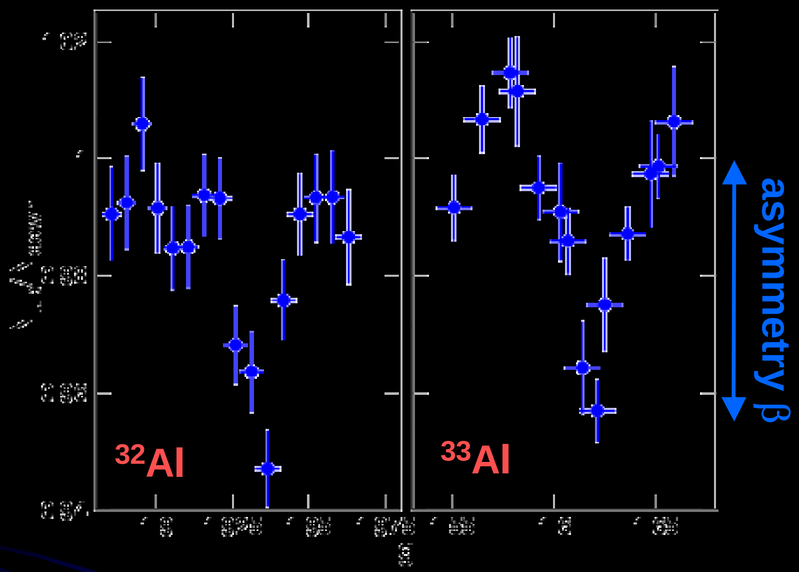
An aligned ensemble has B_k^0 components for k=even, n≠0 components and odd tensors are zero.
→ γ radiation

A polarized ensemble has B_k^0 components for k=odd, k=even and n≠0 components are zero.
→ β radiation

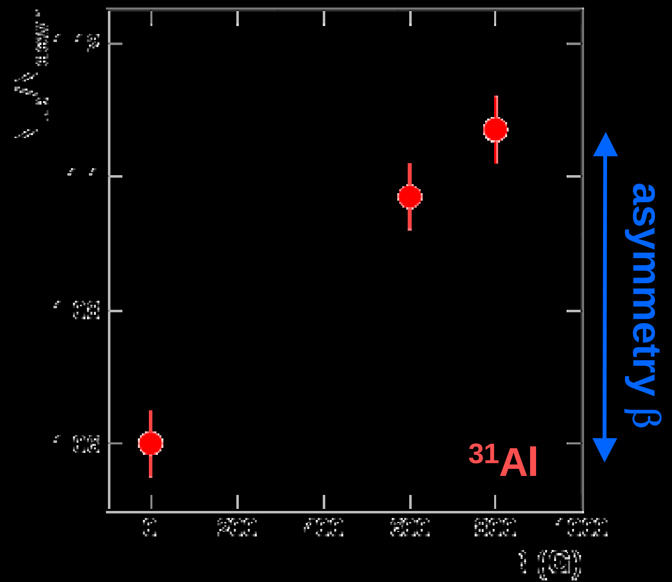
for study of isomers: aligned beam
for study of ground states: polarized beam

Determination of the polarization

β-NMR measurement



B_{high}/B_0 measurement



Experiment E347 of July 2003
P. Himpe, private communication

The amount of polarization is determined from the asymmetry of the β emissions:

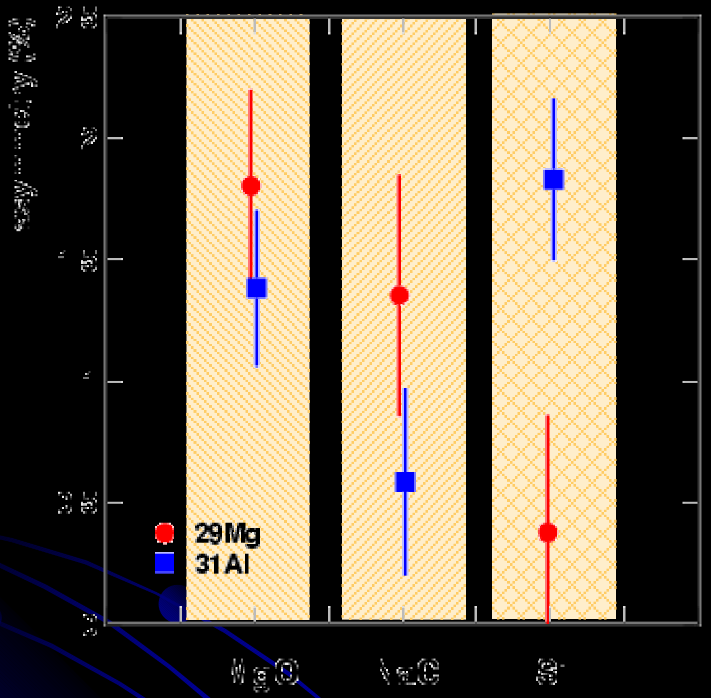
$$N_{up}/N_{down} = \sqrt{(3I/I+1)}\ v/c\ A_1 Q_1 P$$

radiation parameter — **experimental loss**

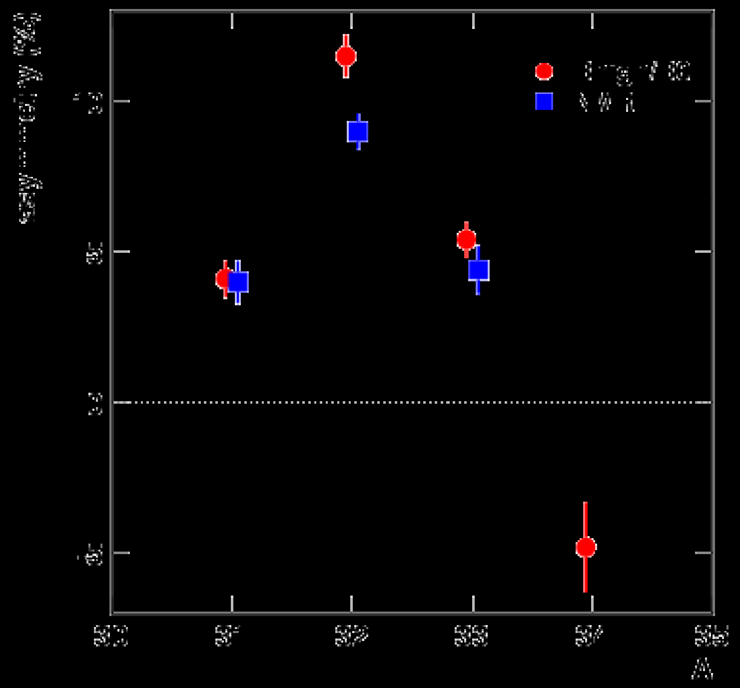
G.Neyens, Rep. Prog. Phys. 66 (2003) 633

Influences on polarization

$^{36}S + {}^{9}Be$ at 77.5 AMeV



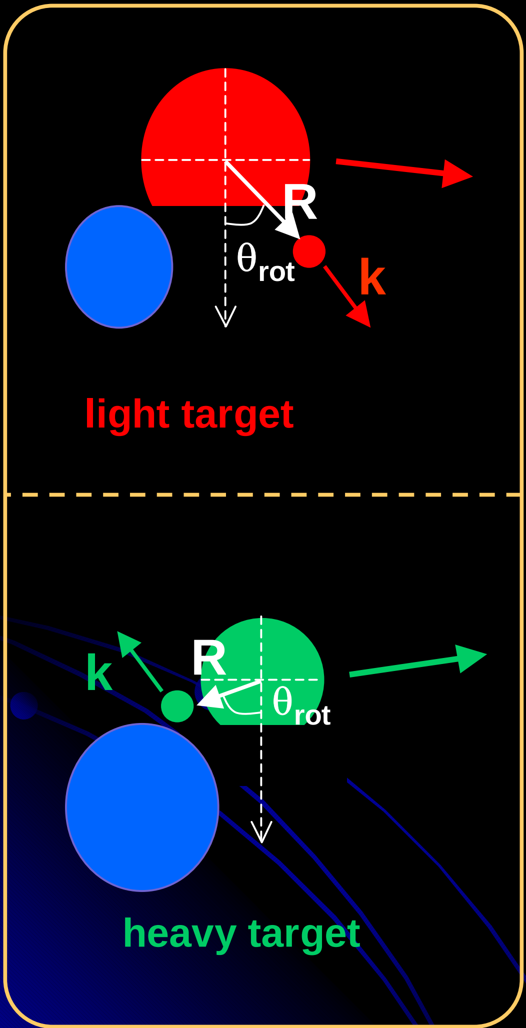
Al isotopes



Influence of
- the crystal host
- the structure of the studied fragment?
  - ^{32}Al ground-state: 1^+
  - ^{31,33}Al ground-states: $5/2^+$

Experiment E347 of July 2003
P. Himpe, private communication

Kinematical model



Polarization

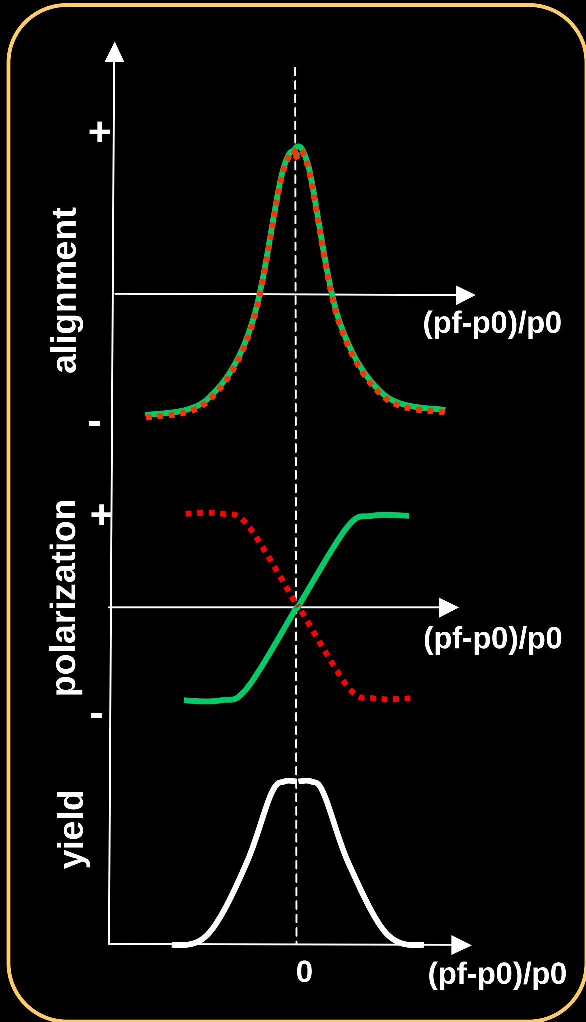
$P = J_z / |J|$

Alignment

$A = (2J_y^2 - J^2) / J^2$

with the angular momentum

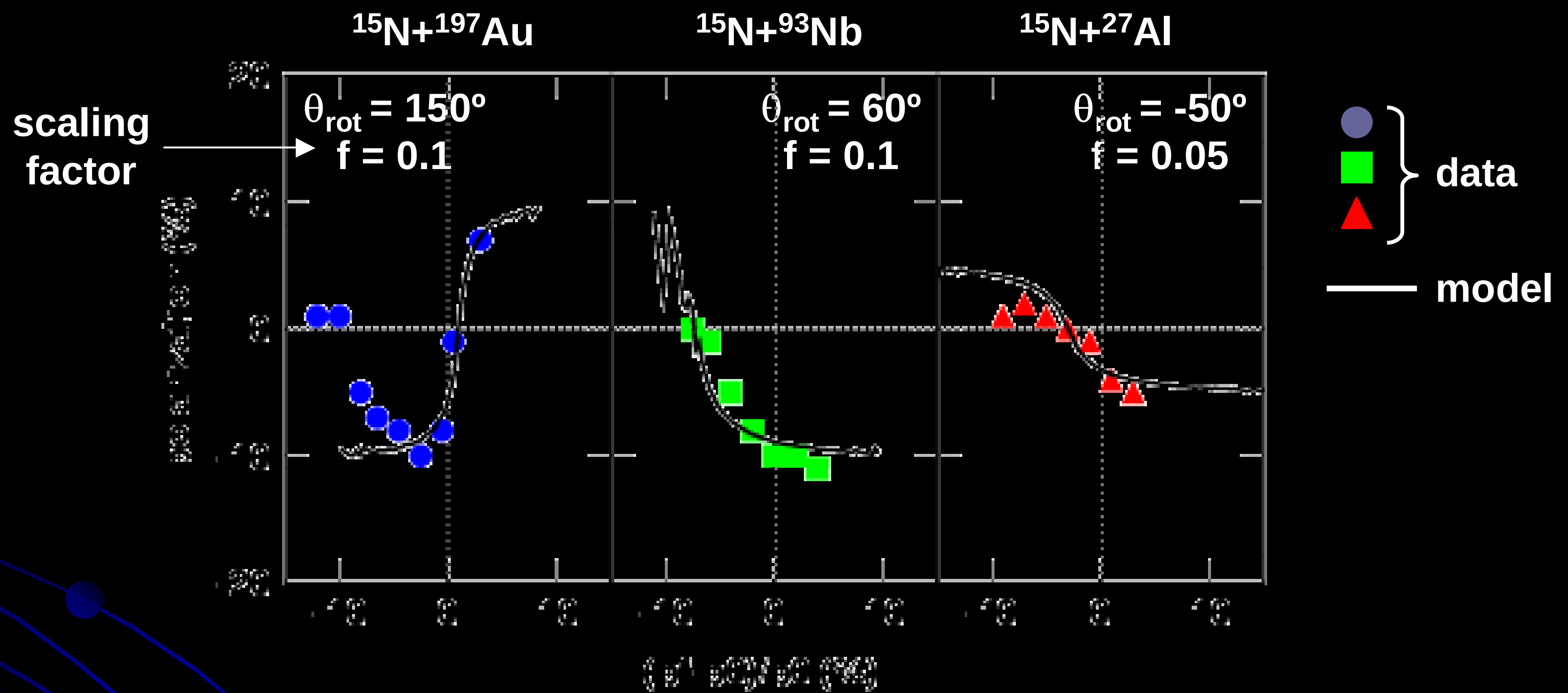
$J = R \times k$



K. Asahi et al., Phys. Lett. B 251(1990)488, H. Okuno et al., Phys. Lett. B 335(1994)29

Polarization vs target size

Polarization of $^{12,13}B$ from the reaction at 68 AMeV of…



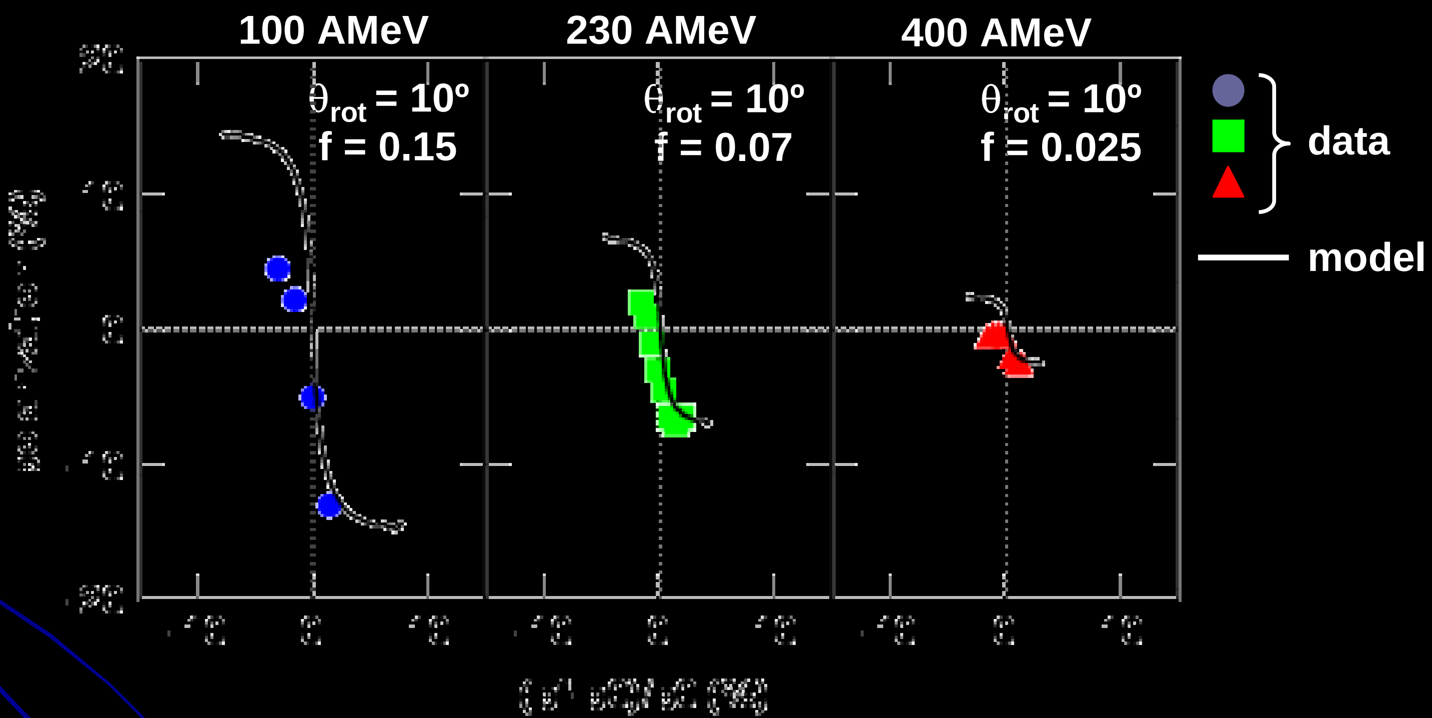
Coulomb repulsion > nuclear attraction → far-side trajectory

Nuclear attraction > Coulomb repulsion → near-side trajectory

H. Okuno et al., Phys. Lett. B 335(1994)29

Polarization vs E_{inc}

Polarization of ^{12}B from the reaction ^{13}C+^{9}Be at…



Increase of the incident energy → **decrease of the amount of polarization**
(and increase of the amount of alignment)

K.Matsuta et al., Hyp. Int. 120/121(1999)713