PARIS @ VAMOS

- Physics program based on fusion reactions for PARIS @ GANIL / SPIRAL2

▪ Jacobi shape transitions :	^{94}Kr (9AMeV) + ^{24}Mg -> ^{120}Cd*
▪ Shape phase diagrams of hot nuclei:	^{140}Xe (5AMeV) + ^{48}Ti -> ^{198}Cd*
▪ Hot GDR studies in neutron rich nuclei:	^{132}Sn (5AMeV) + ^{12}C -> ^{142}Ba*
▪ Isospin mixing at finite temperature:	^{44}Ti (4MeV) + ^{24}Mg -> ^{68}Se*
▪ Onset of multifragmentation:	^{64}Ni (10AMeV) + ^{68}Zn -> ^{132}Ce*
▪ Reaction dynamics:	^{16}O (7AMeV) + ^{197}Au -> ^{213}Fr*
▪ Heavy-ion radiative capture:	^{12}C (2AMeV) + ^{12}C -> ^{24}Mg*

Heavy-ion analyzer mandatory with increasing I_{beam} and decreasing σ's

E.g. - Cross section determination

- Removal of γ-background caused by other channels (fission)

→ **Tagging of the mechanism**

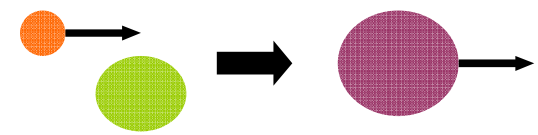
→ **Evaporation residue (A, Z, v, ϑ, φ) identification**

A fusion-ER analyzer for PARIS

Do we have the suited tools ?

- Tasks of the HI device <u>for 0° operation</u>

  - Discrimination between all open reaction channels
    (fusion-evaporation, fission, Coulomb excitation, …)
  - Efficient selection of fusion-ERs
  - Powerful beam rejection !



- Beam/ER separation according to v and/or magnetic rigidity $B\rho$ = Av/Q

Velocity filter @ LISE3
Ω~10msr
no prompt γ-spectroscopy

Velocity × $B\rho$
new device

$B\rho$ selection @ VAMOS
Ω~60msr
prompt γs possible

in vacuum **in gas**

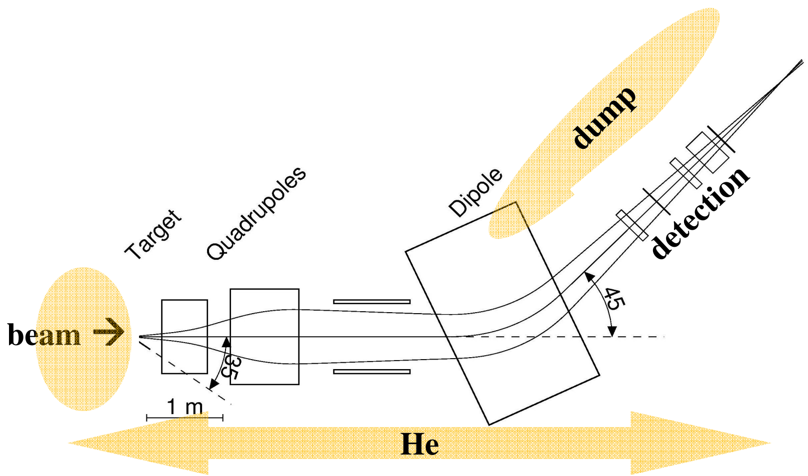
versatile, various kinematics possible
(A,Z,v,ϑ,φ) for A~150 @ 2AMeV

Unusual kinematics:
- symmetric reactions
- inverse kinematics

<u>Key question</u> :

Is sufficient beam rejection achievable via $B\rho_{vacuum}$ or $B\rho_{gas}$ at high I_{beam} ?

The VAriable MOde Spectrometer



✓ Standard $Q_hQ_vD_B$ optics (Pullanhiotan et al., NIMA593(2008)343
- QP's for focalisation -> acceptance
- D for dispersion in $B\rho = Av/Q$

✓ NEW Gas-filled mode (Schmitt et al., in preparation)
- vacuum/gas separation, He filling ~1mbar, beam dump

✓ Focal plane (FP) detection system
- drift chambers (DCs) and/or SeDs
- Ionisation chamber (IC)
- Si wall
- Plastic scintillator

◆ Observables :

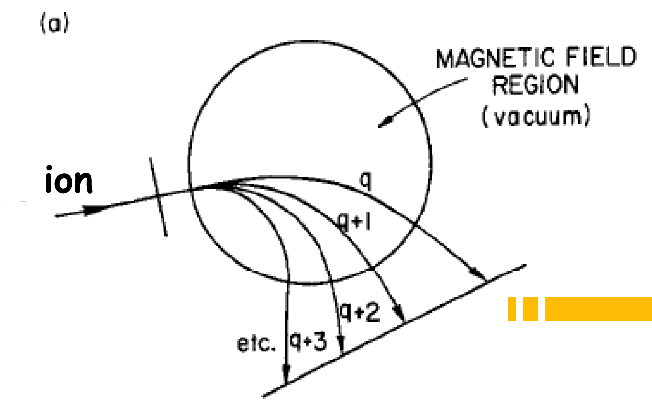
(x, y) from DCs or SeDs → ($B\rho$, ϑ, φ, path ℓ) → velocity vector v } A/Q

T_{of} from RF-SeD, RF-Si or SeD-Si

ΔE from DCs or IC
E_{res} from Si and/or Plastic } (Z, A)

⇒ Selection and/or Identification of the fusion ERs
* large Ω and p acceptance
* accurate (v, ϑ, φ) info

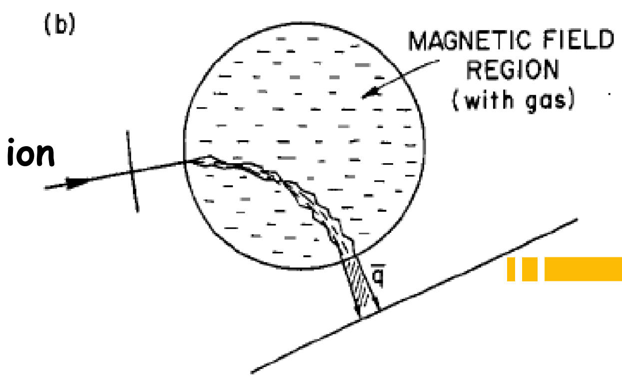
Vacuum / Gas-filled magnets



Behind the target: wide Q_{solid} distribution
Magnetic dipole: dispersion in $B\rho = A \cdot v/Q$

✓ Q_{solid} **distribution transported along vacuum section**
✓ **$B\rho$ for beam and ER overlap**
✓ **Q dispersion**

- Poor beam rejection (sufficient ?)
- Limited transmission (")
- Precise identification $\Delta A/A \sim 150$



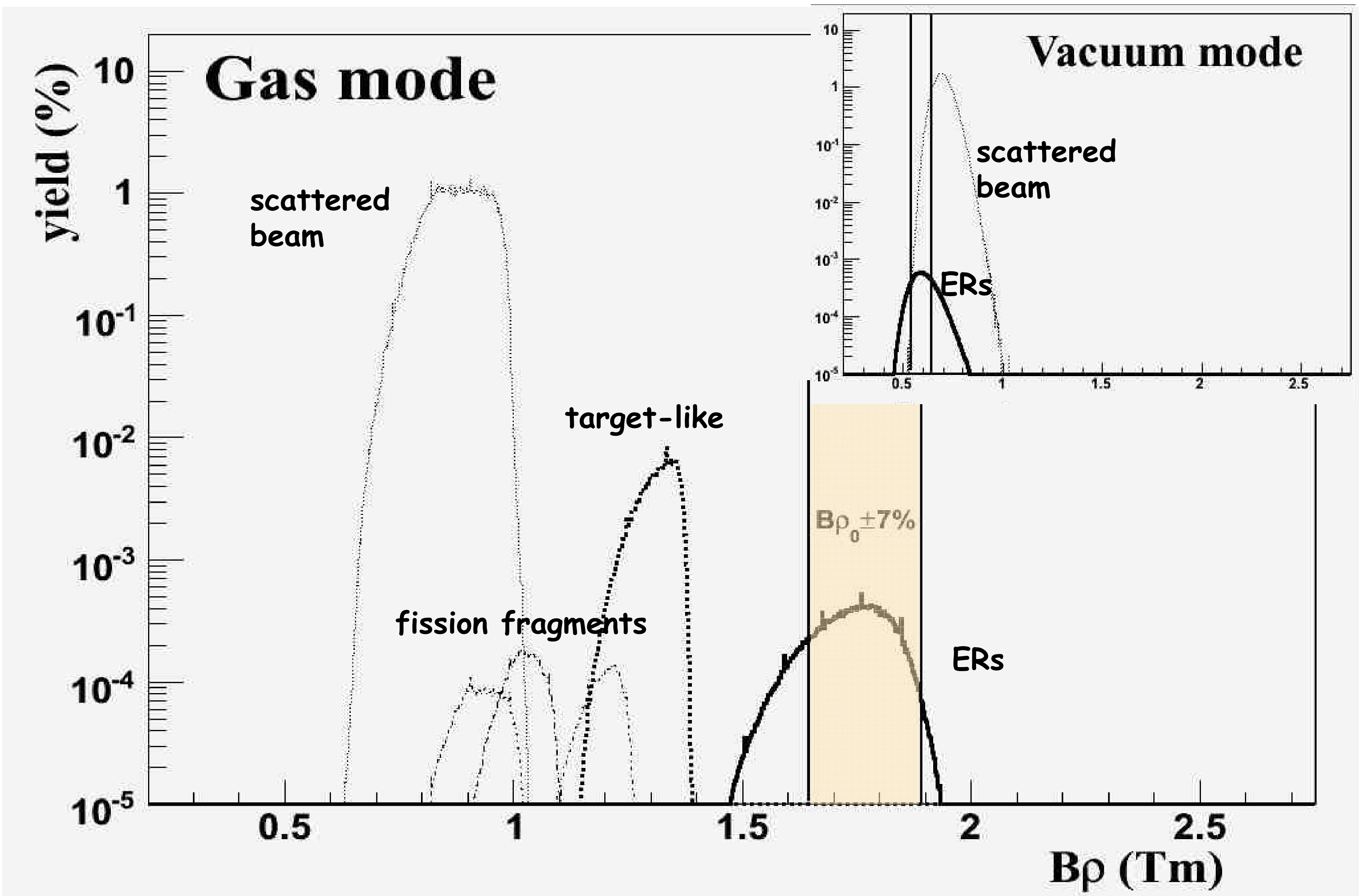
Paul et al., NIM A 277 (1989) 418

Due to ion-gas molecule collisions :

✓ Q_{gas} **reaches a narrow distribution**
✓ $\langle Q \rangle_{gas} \sim v \cdot Z^{1/3}$ **i.e. $B\rho \sim A$ → separator**
✓ Q_{gas} **and v focusing**

- Powerful beam rejection if $A_{beam} \neq A_{ER}$
- High transmission
- Crude identification $\Delta A/A \sim 40$

^{40}Ca (196MeV) + ^{150}Sm

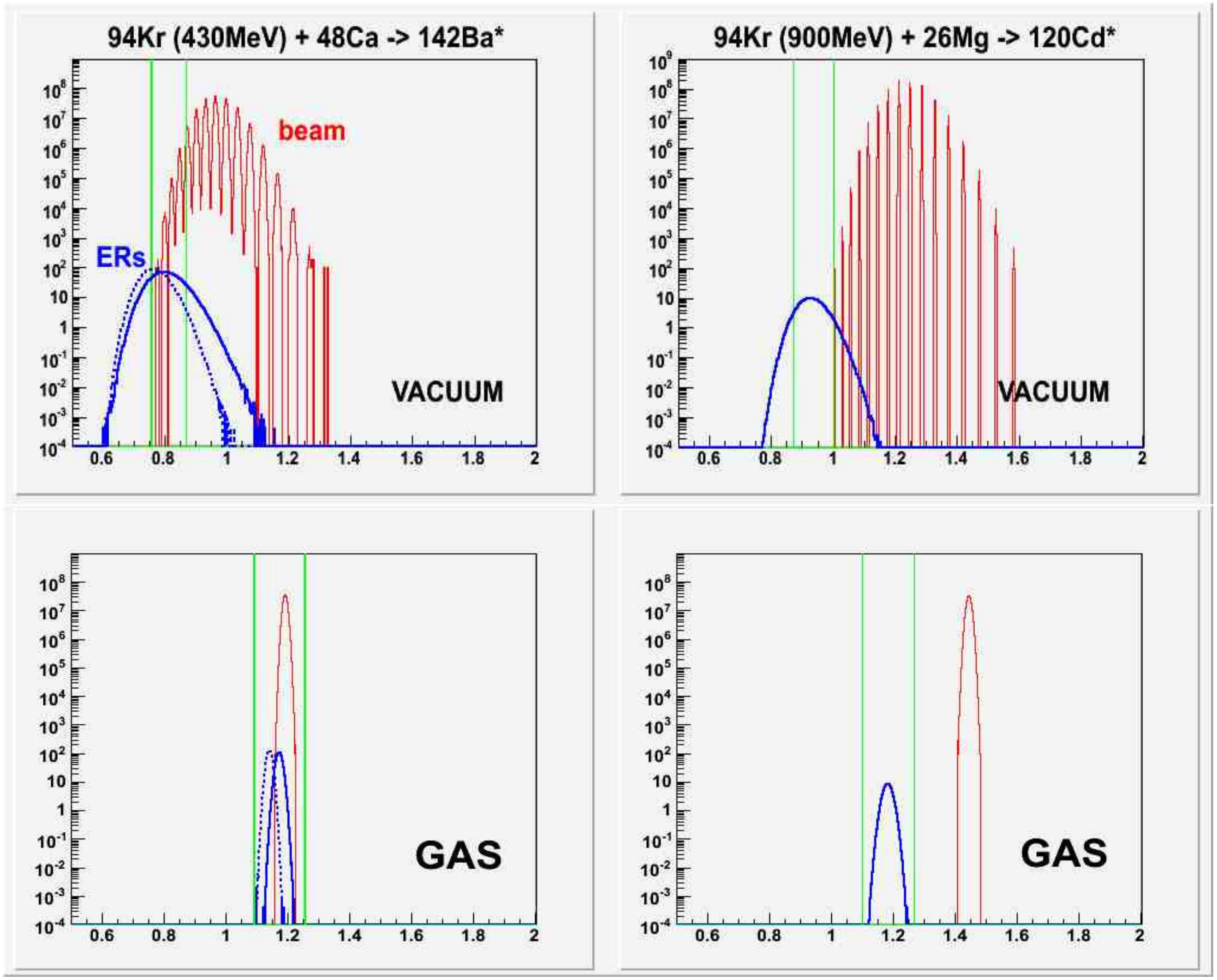


ANAMARI code by Subotic et al., NIM B 266 (2008) 4209

VAMOS for PARIS (1)

Beam rejection and transmission in vacuum/gas

Calculations: Flagship experiment of PARIS, 10^9pps, 1mg/cm^2 target thickness, particular ER channel ~ 100mb



- Beam onto the detector in both cases
- ^{94}Kr + ^{48}Ca feasible at all with high I_{beam} ?

- ^{94}Kr + ^{26}Mg : ok !
- ^{94}Kr + ^{48}Ca : difficult (crucial influence of E_{beam})
- Problem of reliable Q parameterisation
- To be determined by experiment…

VAMOS for PARIS (2)

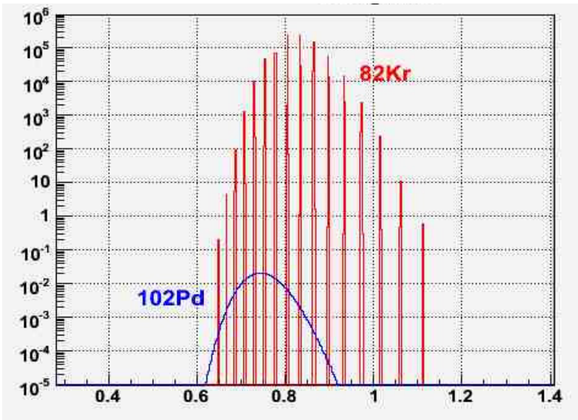
Beam rejection and transmission in vacuum/gas

Previous experiments :

◆ VAMOS in vacuum mode :

^{82}Kr (4.1AMeV) + ^{27}Al (0.5mg/cm^2)

- I_{beam} ~ 10^6pps (beam time ↑)
- mask on part of the detectors (efficiency ↓)



◆ Gas-filled RITU separator :

^{54}Fe (3.3AMeV) + ^{54}Fe (1.1mg/cm^2)
^{78}Kr (4.3AMeV) + ^{96}Ru (0.5mg/cm^2)
^{36}Ar (2.9AMeV) + ^{40}Ca (1.0mg/cm^2)
^{40}Ca (3.0AMeV) + ^{40}Ca (1.0mg/cm^2)
^{54}Fe (3.6AMeV) + ^{58}Ni (1.0mg/cm^2)

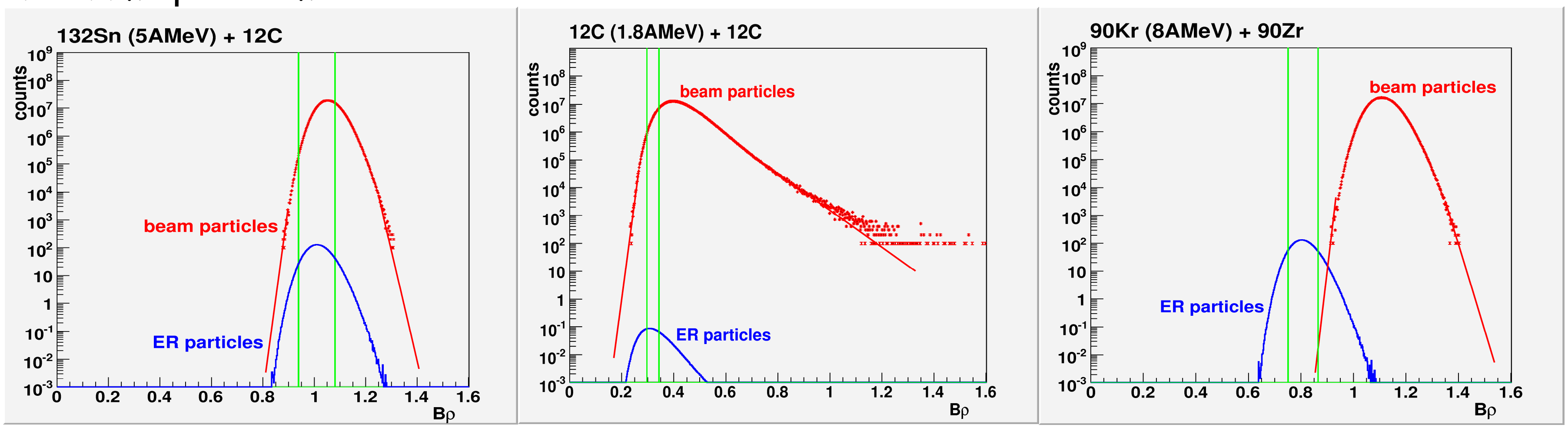
→ Limit ~ reached @ RITU

→ Go beyond @ VAMOS due to larger dispersion ?

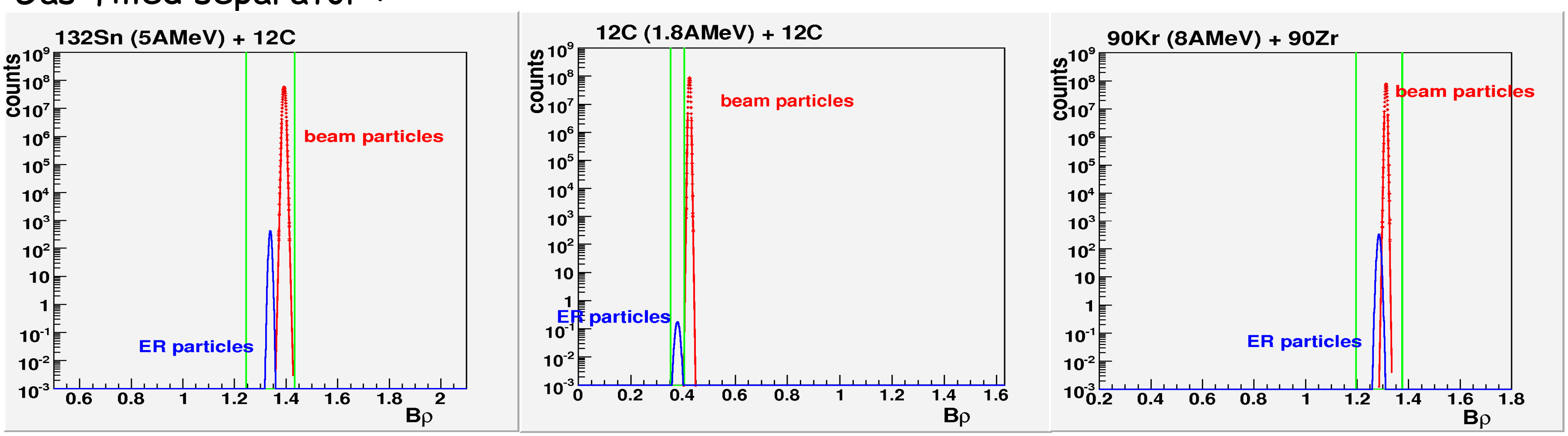
VAMOS for PARIS (3)

Beam rejection and transmission in vacuum/gas

- Vacuum spectrometer :



- Gas-filled separator :



Conclusions

- Challenging kinematics addressed by PARIS physics for ER measurements @ 0°

  - ✓ VAMOS, vacuum or gas-filled, as a powerful separator
    (large acceptance, large dispersion, accurate v)

  - ✓ Feasibility to be evaluated on case-by-case basis (entrance channel, system size, E)
    vacuum mode: asym direct, sym and inverse at high E
    gas-filled mode: asym direct, sym to inverse (except low E for very inverse)

  - ✓ Alternatives :
    - VAMOS at $\vartheta > 0°$
    - Kracow Recoil Filter Detector (→ very welcome in G2 !)
    - other ideas …

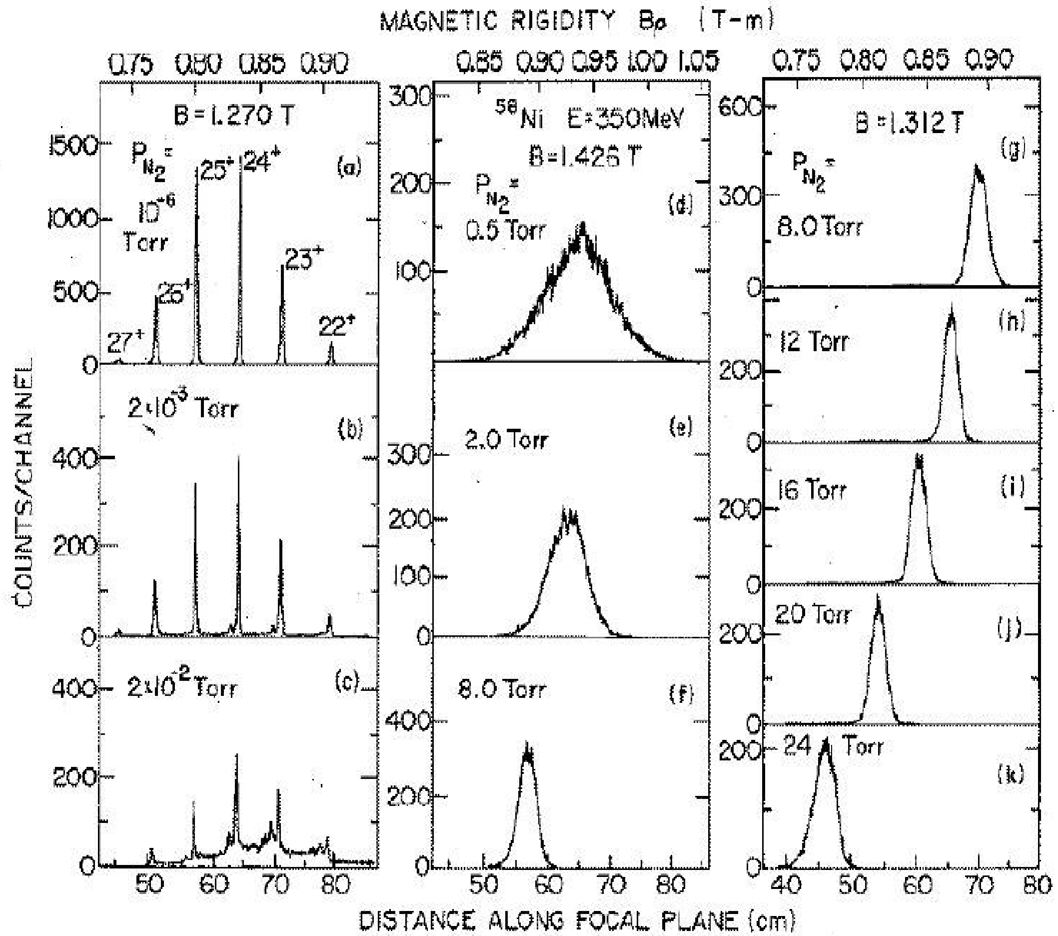
- (Unequaled) gain in sensitivity achievable with a ER analyzer

  - ✓ Tagging based on γ's or light particles difficult, namely with RIBs

  - ✓ Accurate Doppler correction

Charge equilibration

Image size = compromise Q focusing vs. multiple angular scattering



Charge equilibration

Achievable mass resolution at very low pressure ?

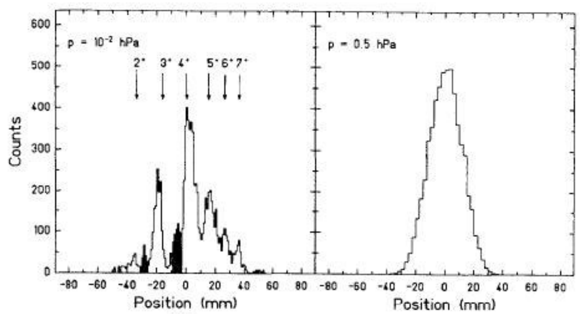


Fig. 2. Measured focal-plane position spectra for ^{215}Ac recoils with an incident energy of $E = 14.5$ MeV measured with HECK at different pressures. The hatched areas denote the satellite peaks mentioned in the text.

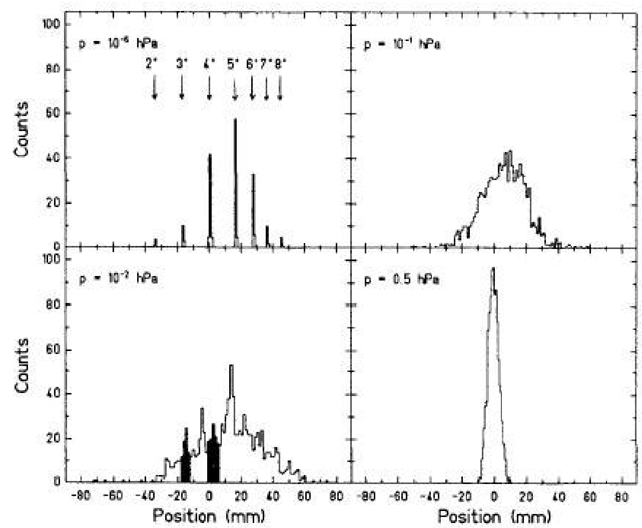
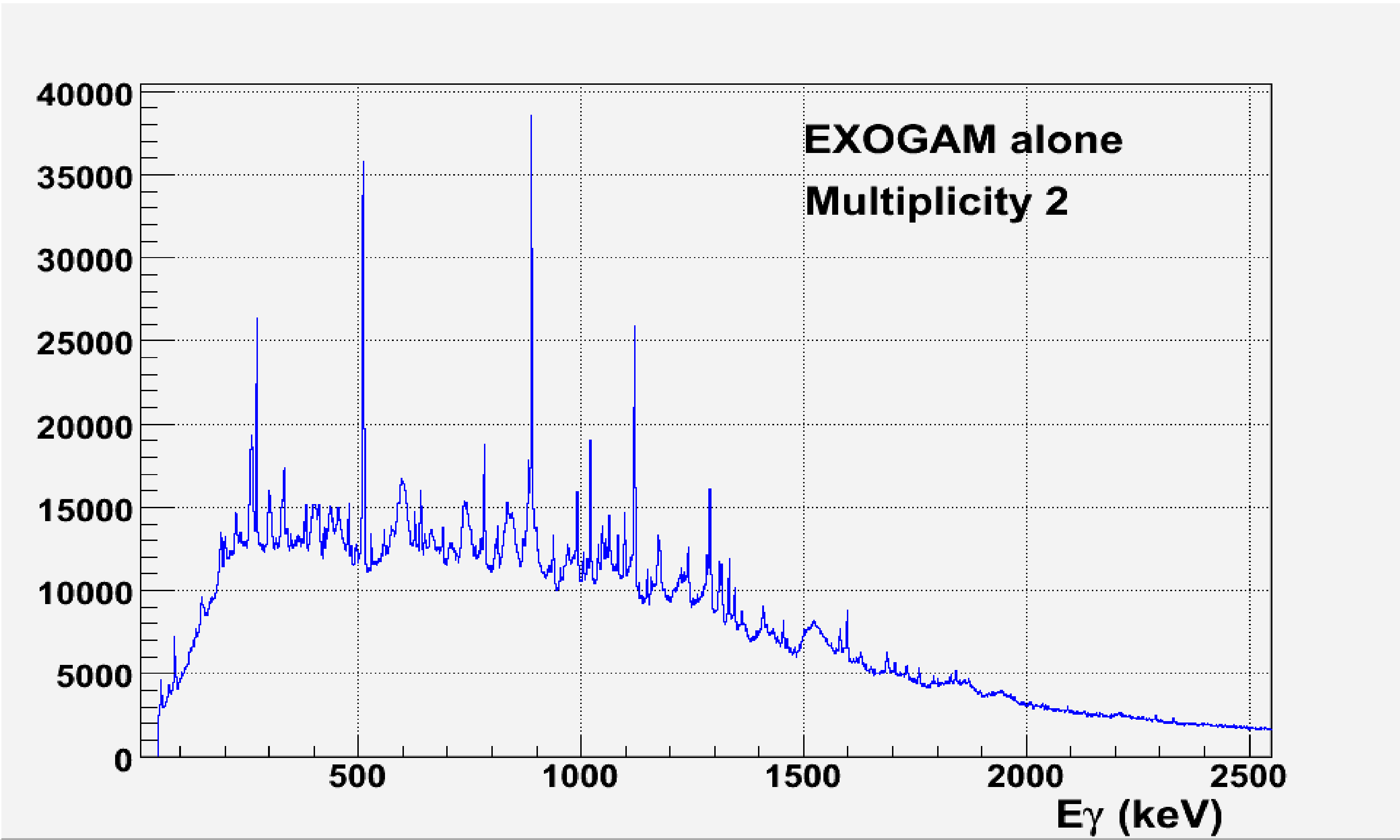


Fig. 3. Position spectra calculated as described in the text for ^{215}Ac ions with an incident energy of $E = 14.5$ MeV along the focal plane of the gas-filled separator. Note the shift in position of the mean value towards smaller q-values due to energy loss in the gas.

Background



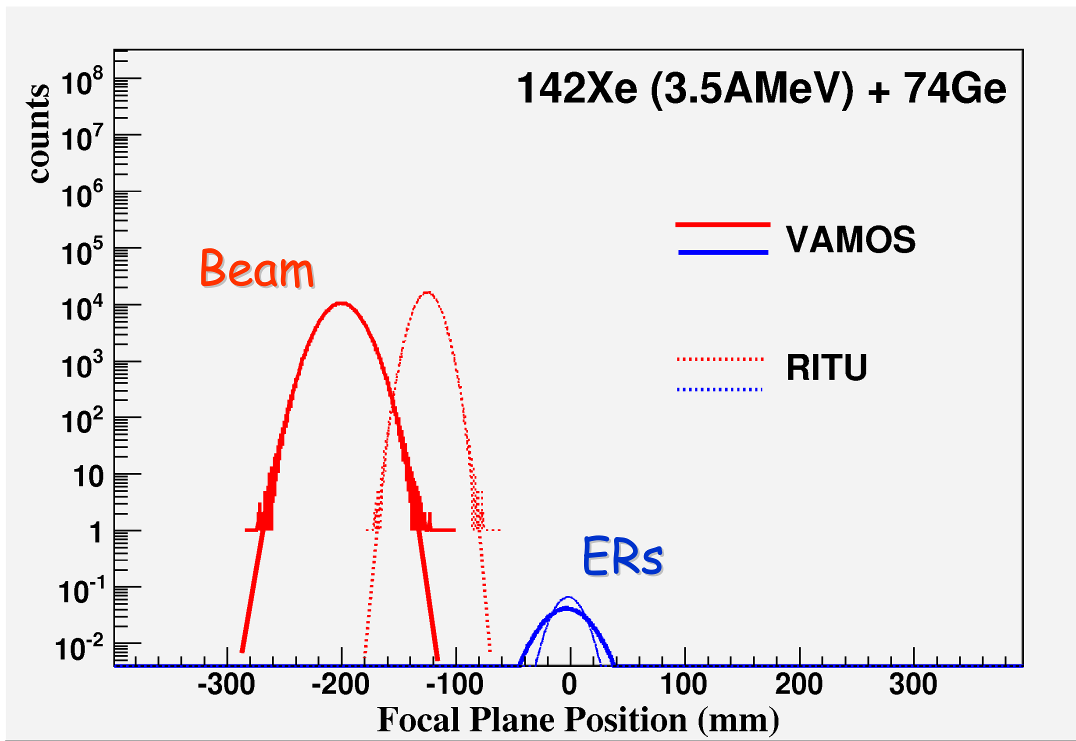
-> Peaks attributed to reactions on C and F

-> In real experiment, (Ca+Sm) ER γ's should clearly be seen with Mγ =2 gate

-> VAMOS mandatory here to have the desired ER in coincidence

RITU vs. VAMOS

Influence of the dispersion on focal plane position



Limitation of the vacuum mode

Difficult operation close to 0°

(fusion but also direct, (in)elatics collisions with heavy beam in inverse kinematics)

⟹ **If $B\rho_{|beam} \approx B\rho_{|product}$: direct beam reaches the focal plane**

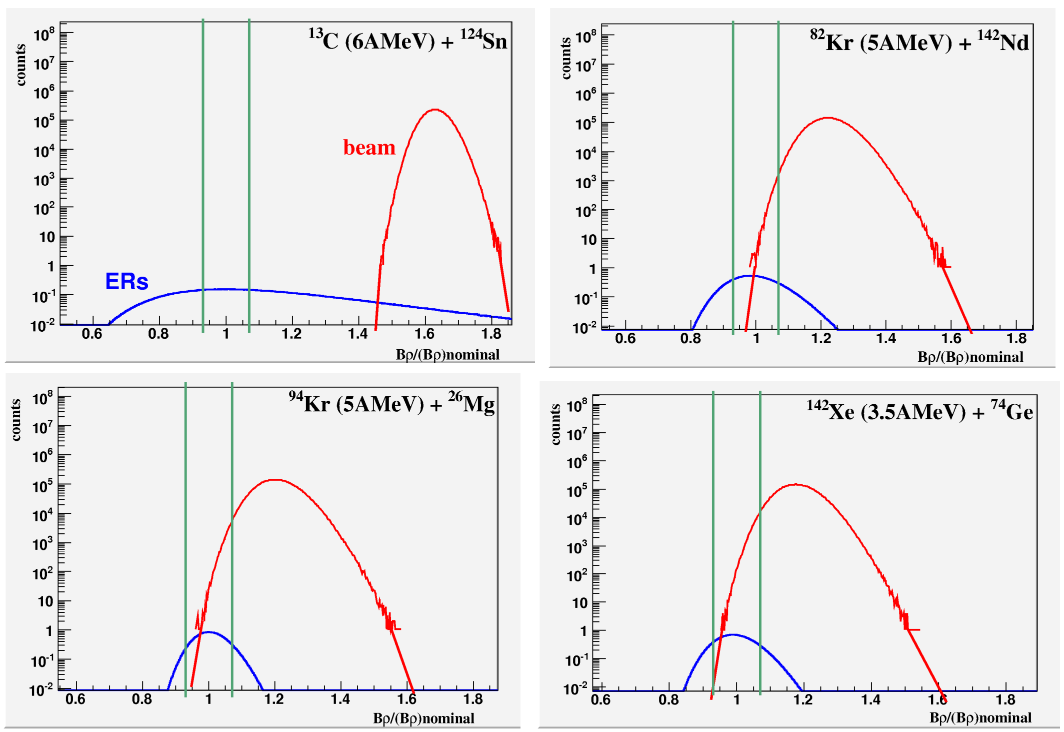
⟹ **Particularly important @ high and SPIRAL2 beam intensities**

<u>Ex: Fusion around the barrier from SPIRAL2 LoI's</u> :

from kinematics

Magnetic rigidity : $B\rho \propto A/Q \cdot v$

from parameterisation



Beam rejection <u>not</u> achievable for

~ symmetric

inverse kinematics

reactions

<u>Alternatives</u>:

WF ? active finger ?

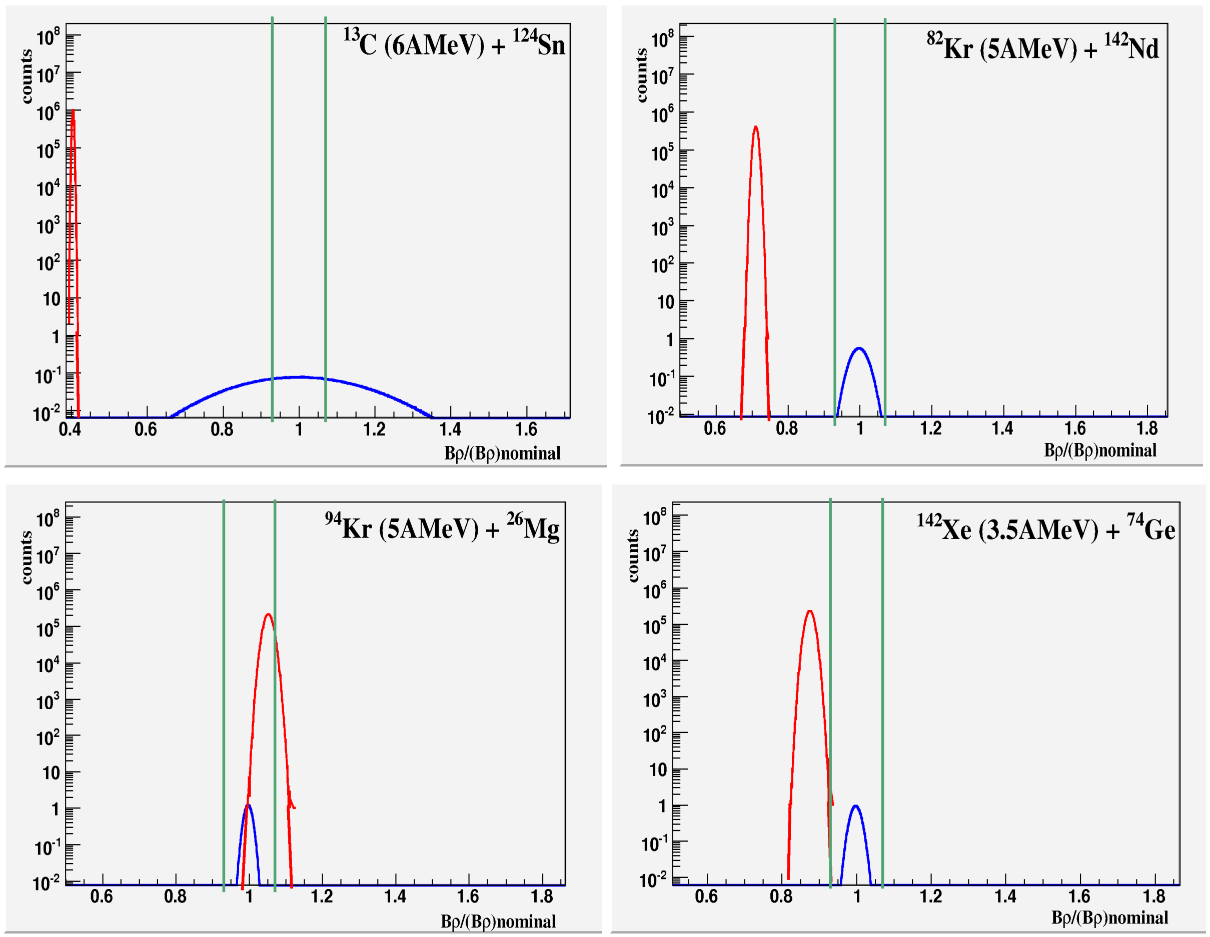
Achievement of the gas-filled mode

Test case: VAMOS filled with He at 1mbar

from kinematics

Magnetic rigidity : $B\rho \propto A/Q \cdot v$

from parameterisation



- ✓ **Asym direct kinematics: ok**
- ✓ **Sym kinematics: ok !!! (…SPIRAL2)**
- ✓ **Gain in collection efficiency**

A gas-mode would definitively extend today's VAMOS capabilities