# Perspectives of high spin γ-ray spectroscopy of heavy nuclei produced in fusion-evaporation reactions using GALILEO/AGATA arrays and the Recoil Filter Detector at stable and radioactive beams

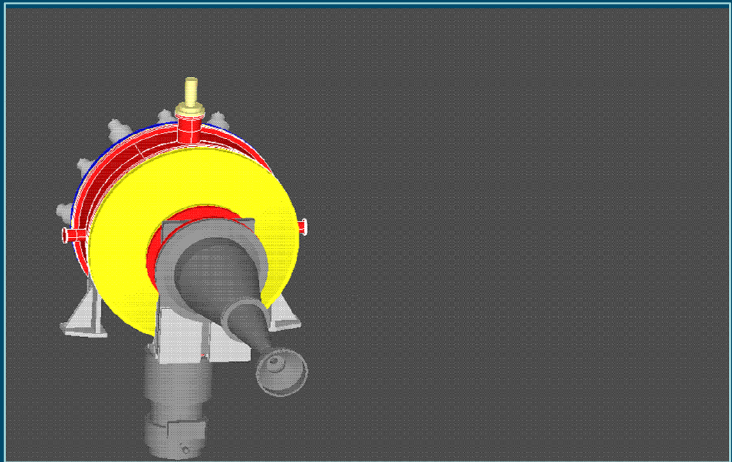
*P. Bednarczyk (IFJ PAN Kraków)*

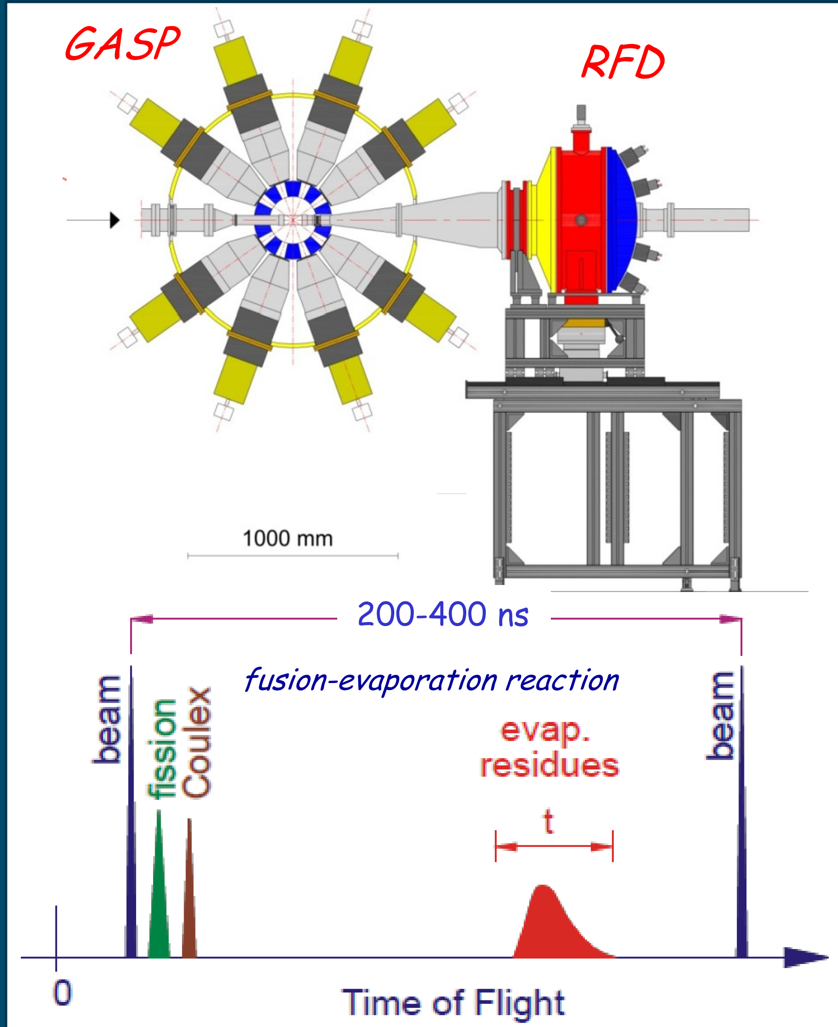
NuSpIn 2016

# Recoil Filter Detector

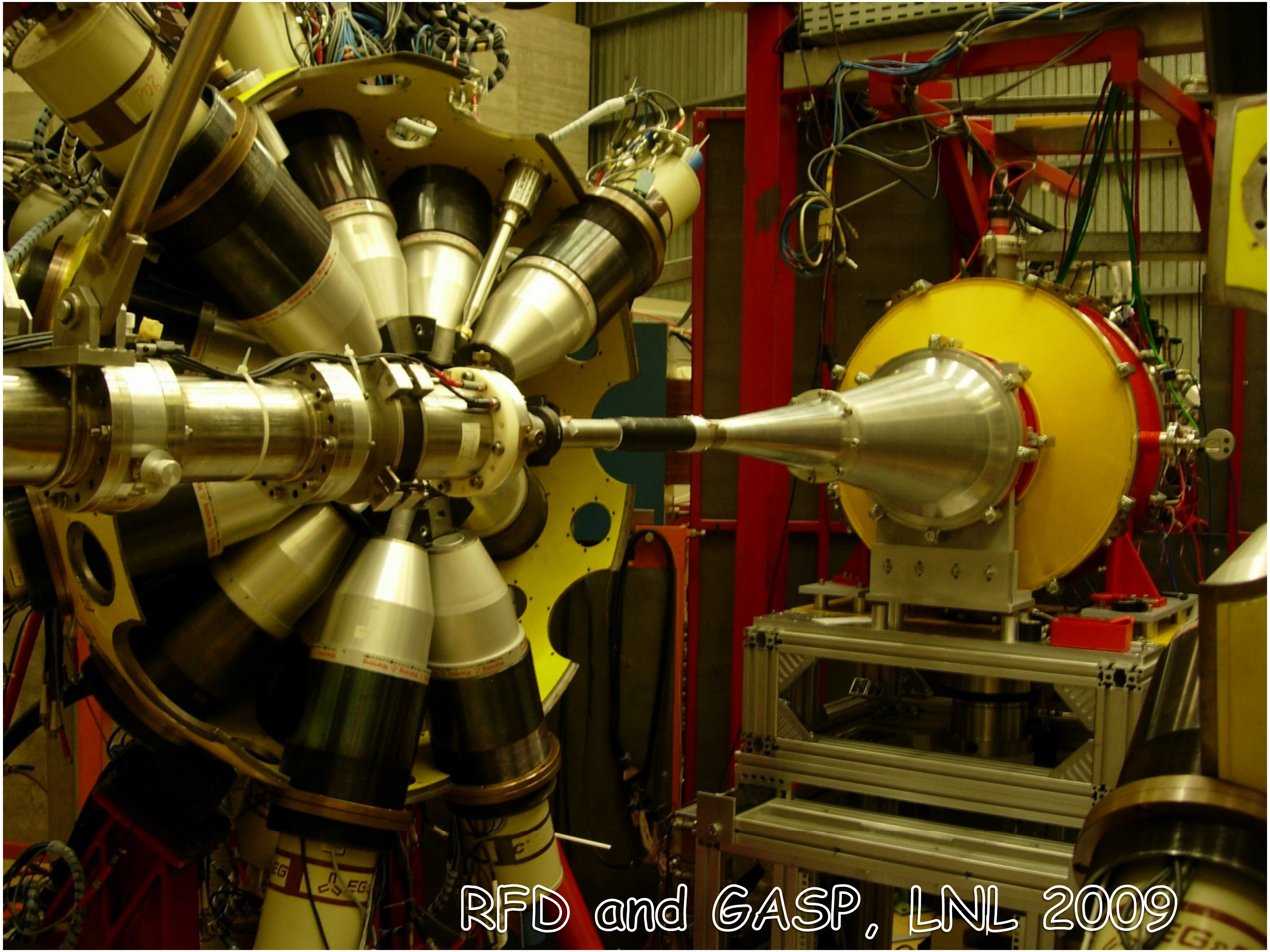
- *Coincidence of ER and $\gamma$-rays*
- *ToF technique allows to deduce actual velocity of a single recoil*
  - *Doppler correction*
  - *Filtering out unwanted reaction channels:*

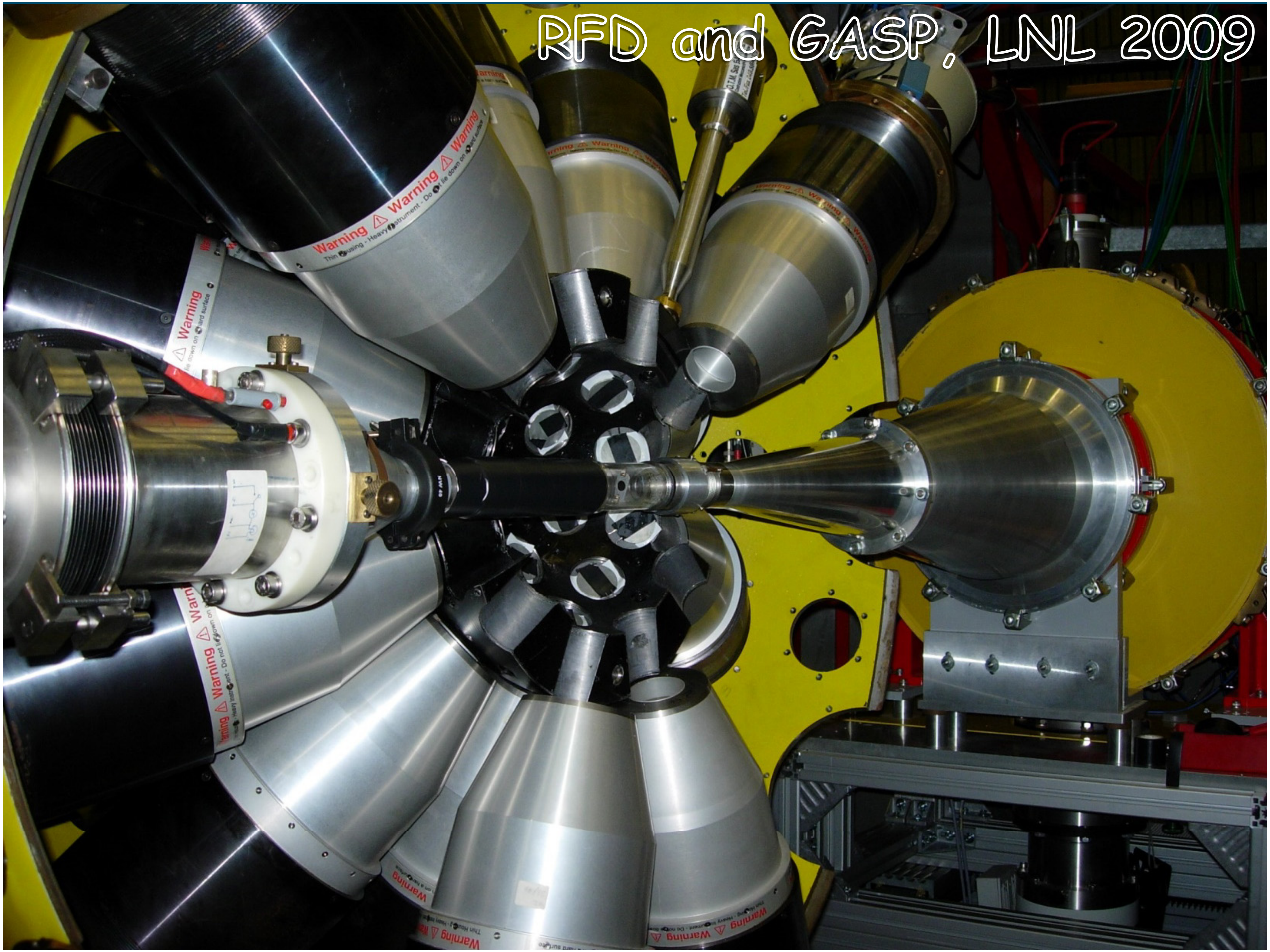
*scattered beam, fission, Coulex,*






*W.Meczynski et al, NIM A580, 1310 (2007)*


RFD and GASP, LNL 2009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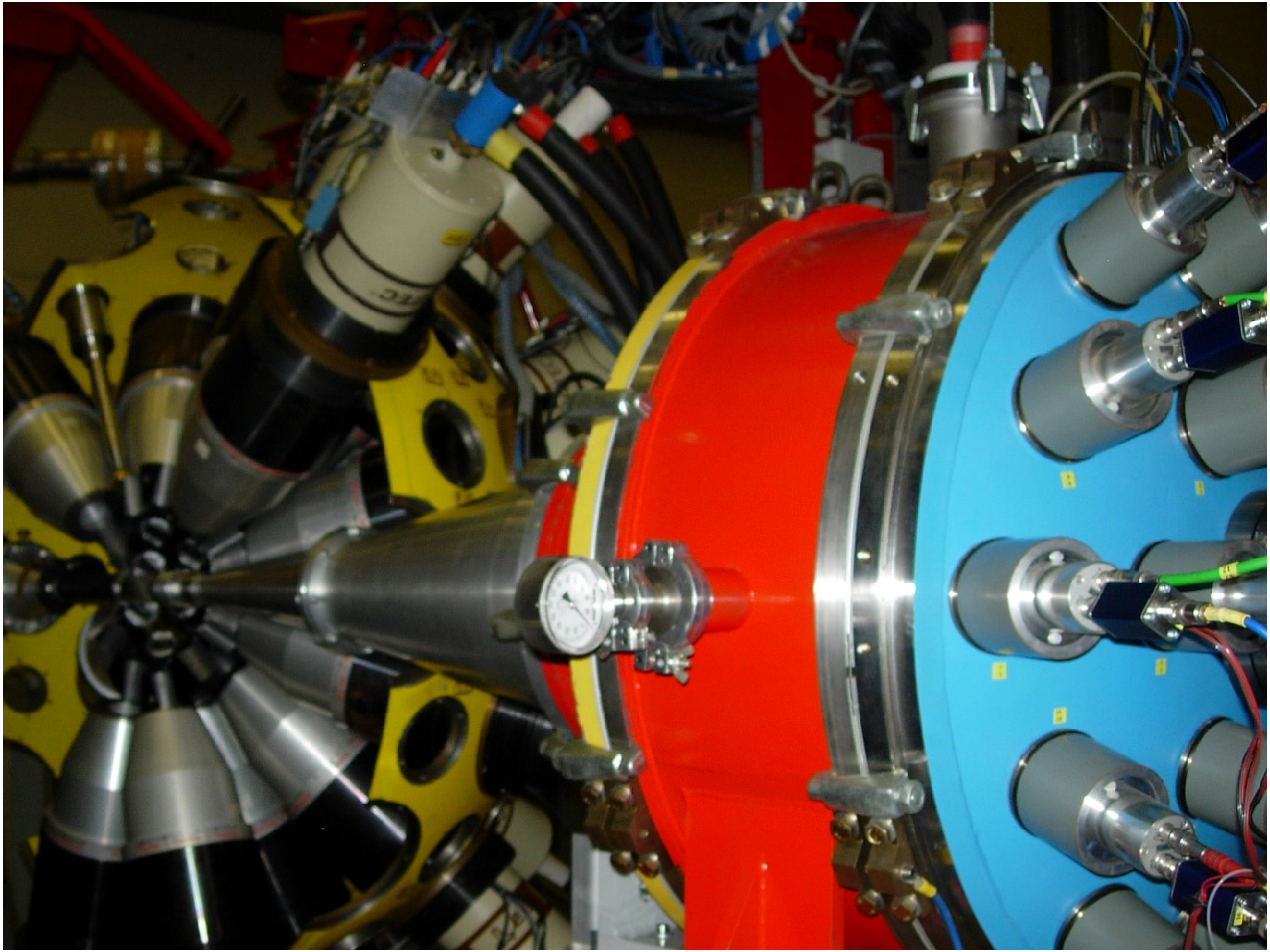
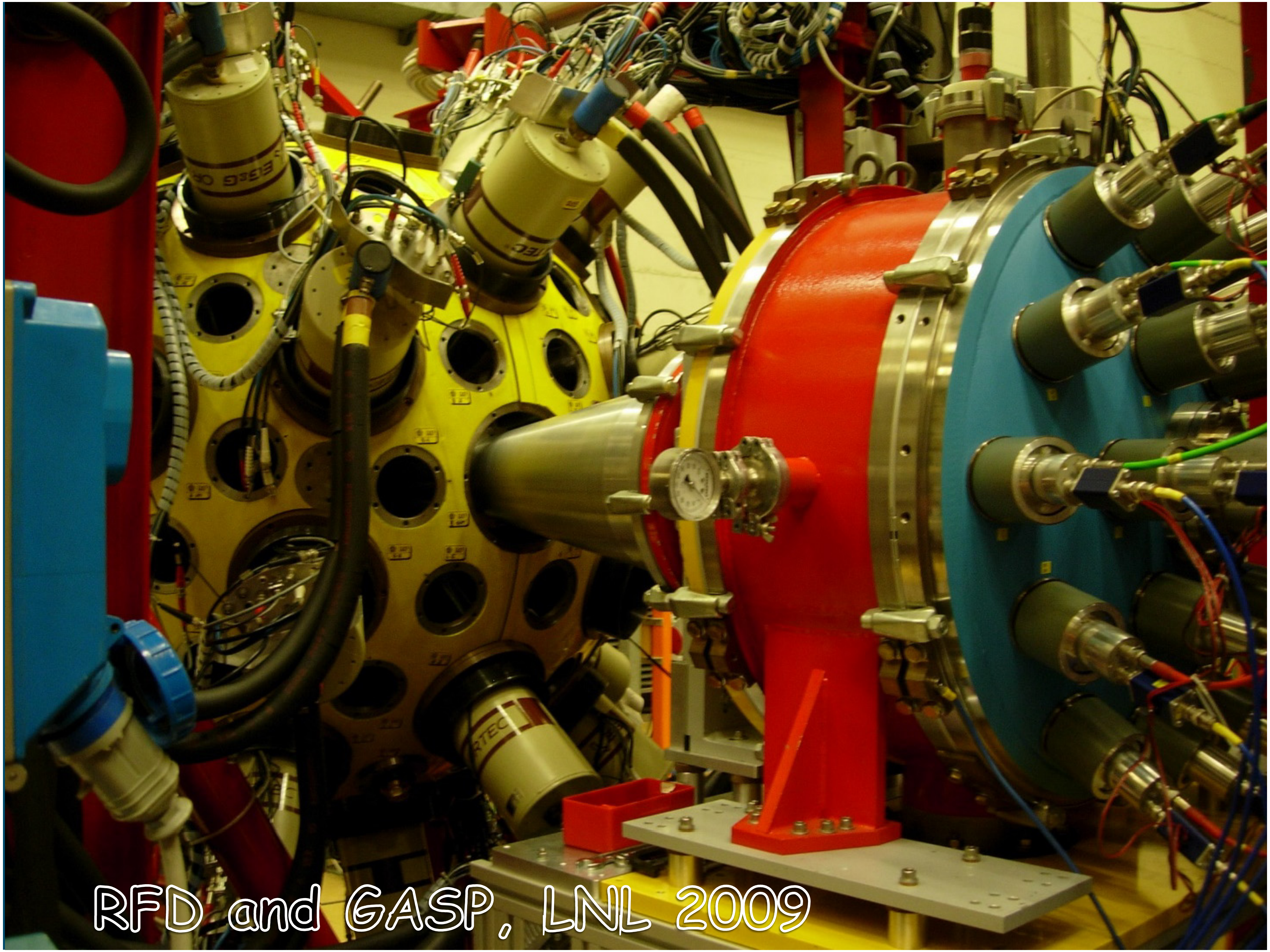
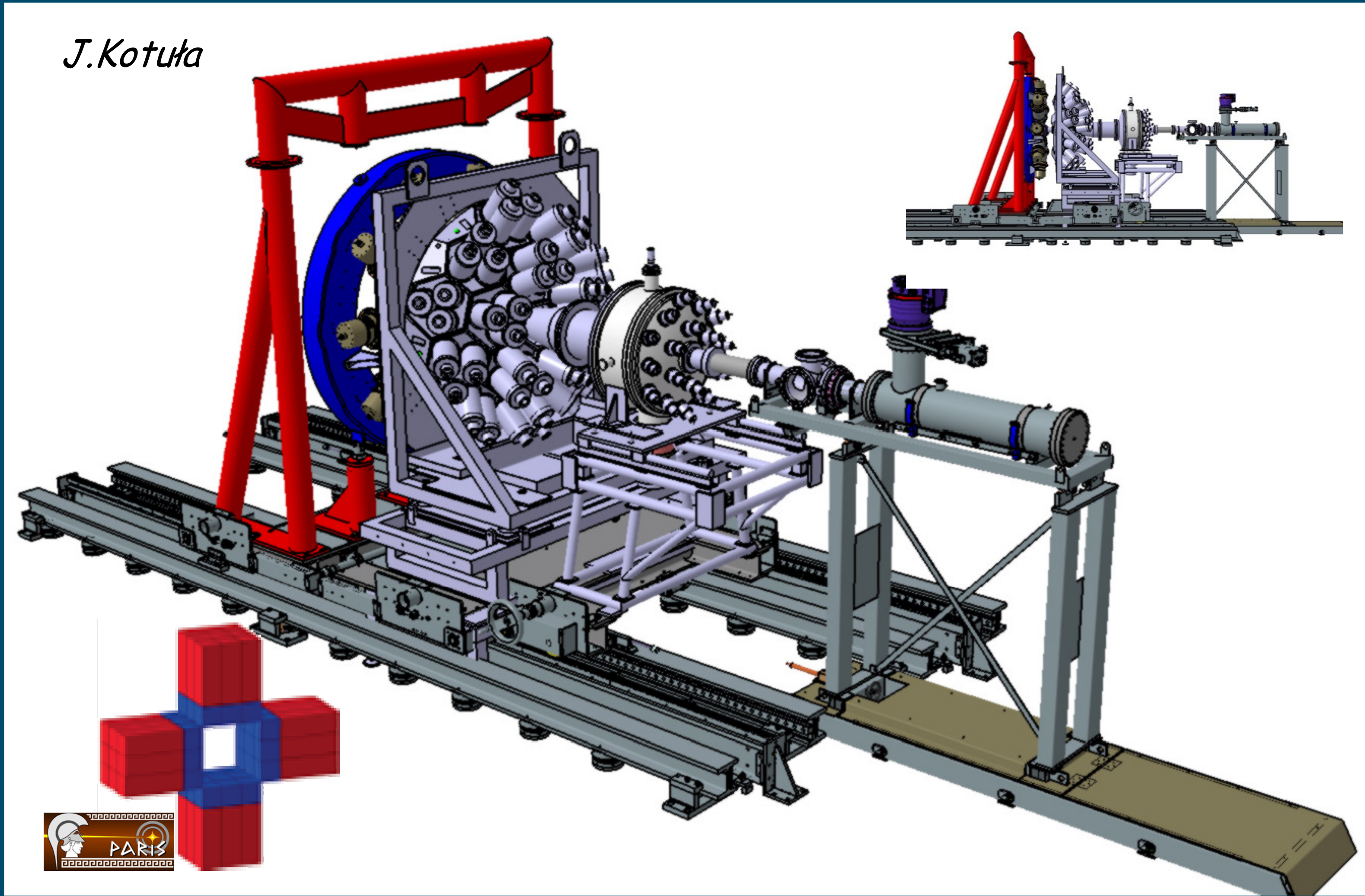




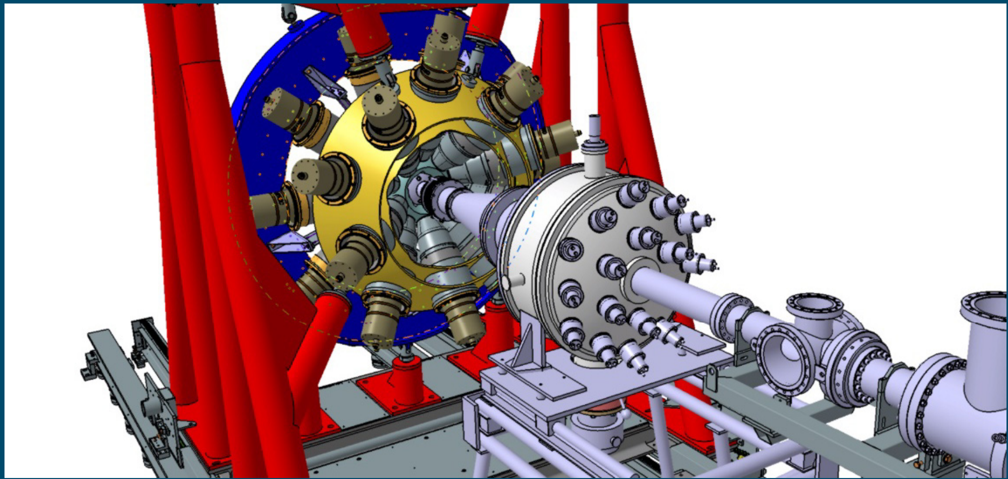
RFD and GASP, LNL 2009

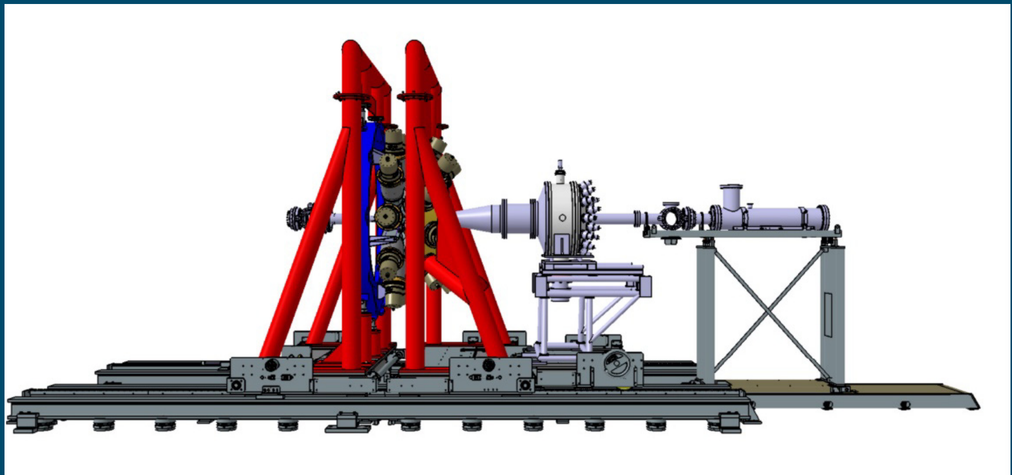
# GALILEO(25) + NWALL/PARIS + RFD



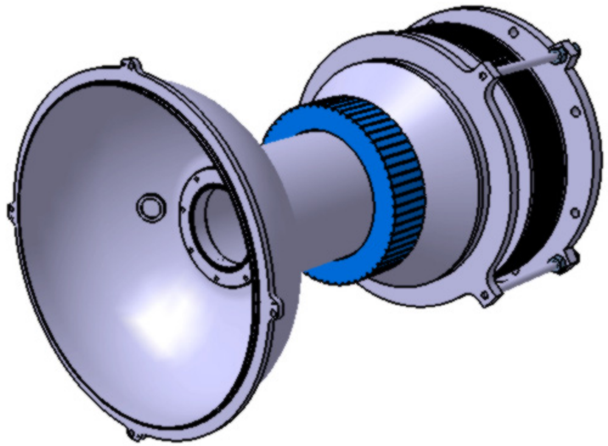

- LoI LNL PAC; setup available in 2016

# GALILEO(35) + RFD





GALILEO-RFD interface



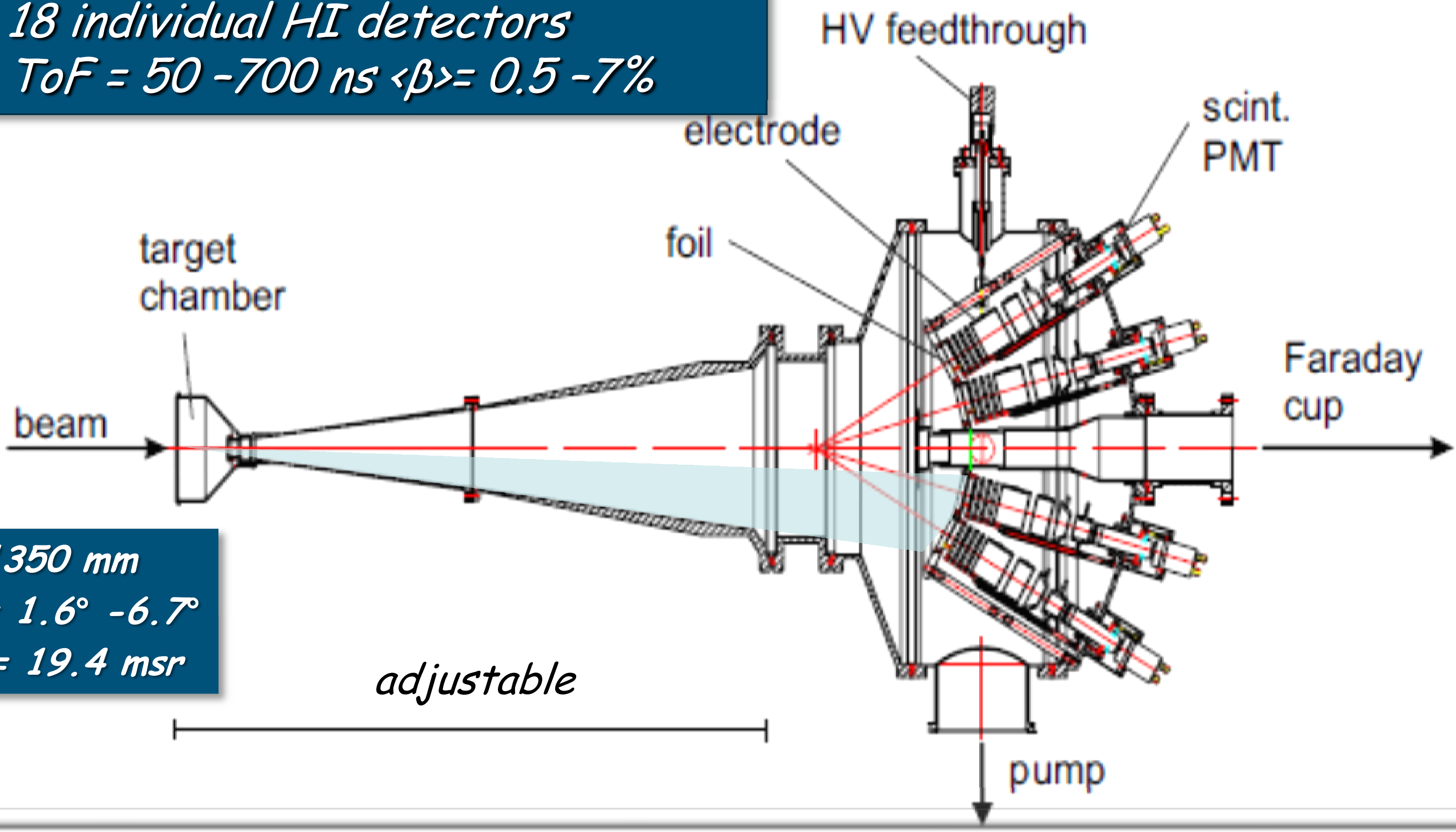
*IFJ PAN/ INFN Milano*

- Compatible with the EUCLIDES chamber

- LoI presented at LNL PAC meeting Feb.2016
- setup available in 2017

# HI Detection Technique

- 18 individual HI detectors
- ToF = 50 -700 ns $\langle\beta\rangle$= 0.5 -7%




*d=1350 mm*
*$\Delta\theta$= 1.6° -6.7°*
*$\Delta\Omega$= 19.4 msr*

- *Detectors don't look directly at the target*
- *Scintillators are far from the beam line*

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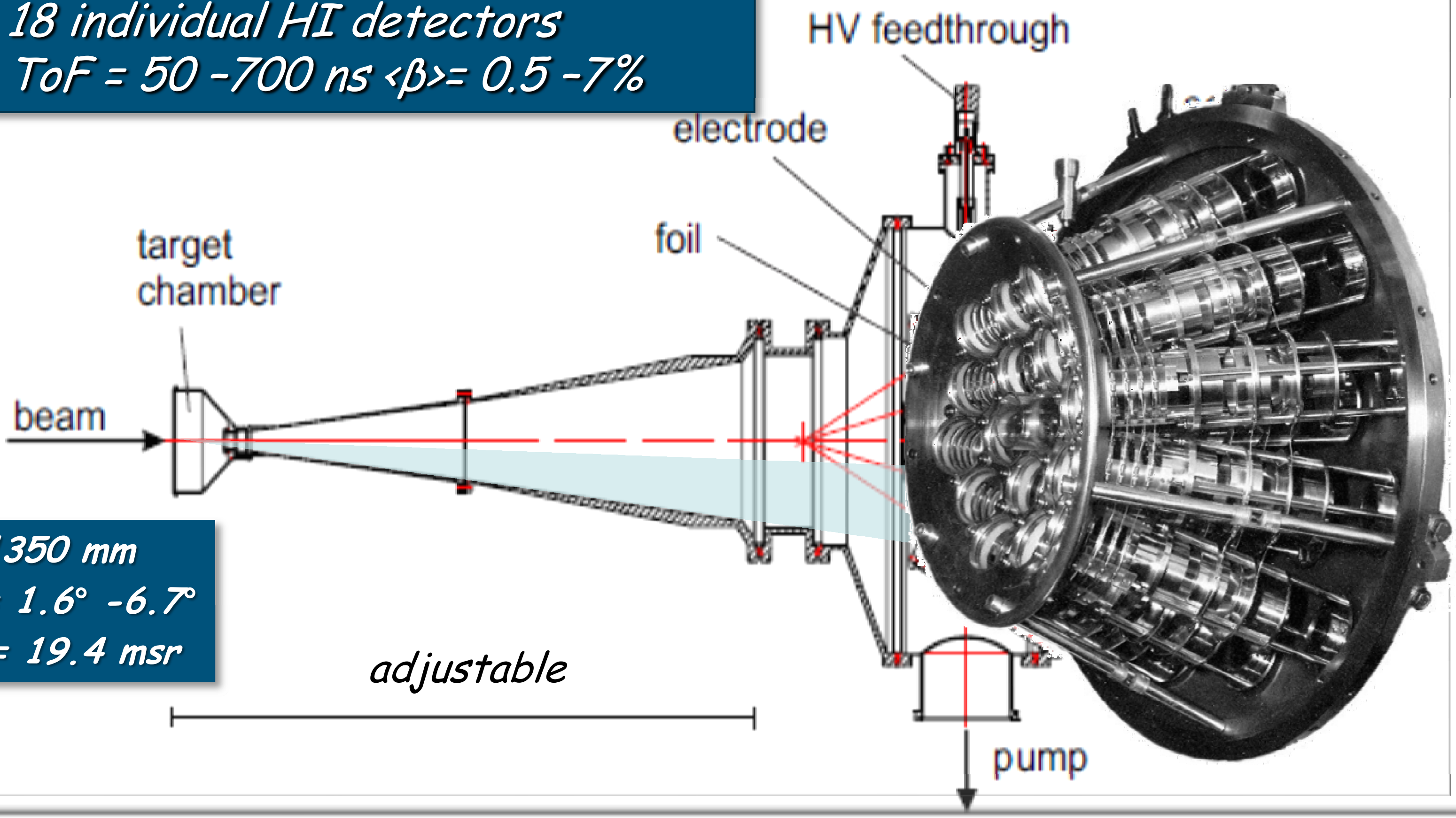


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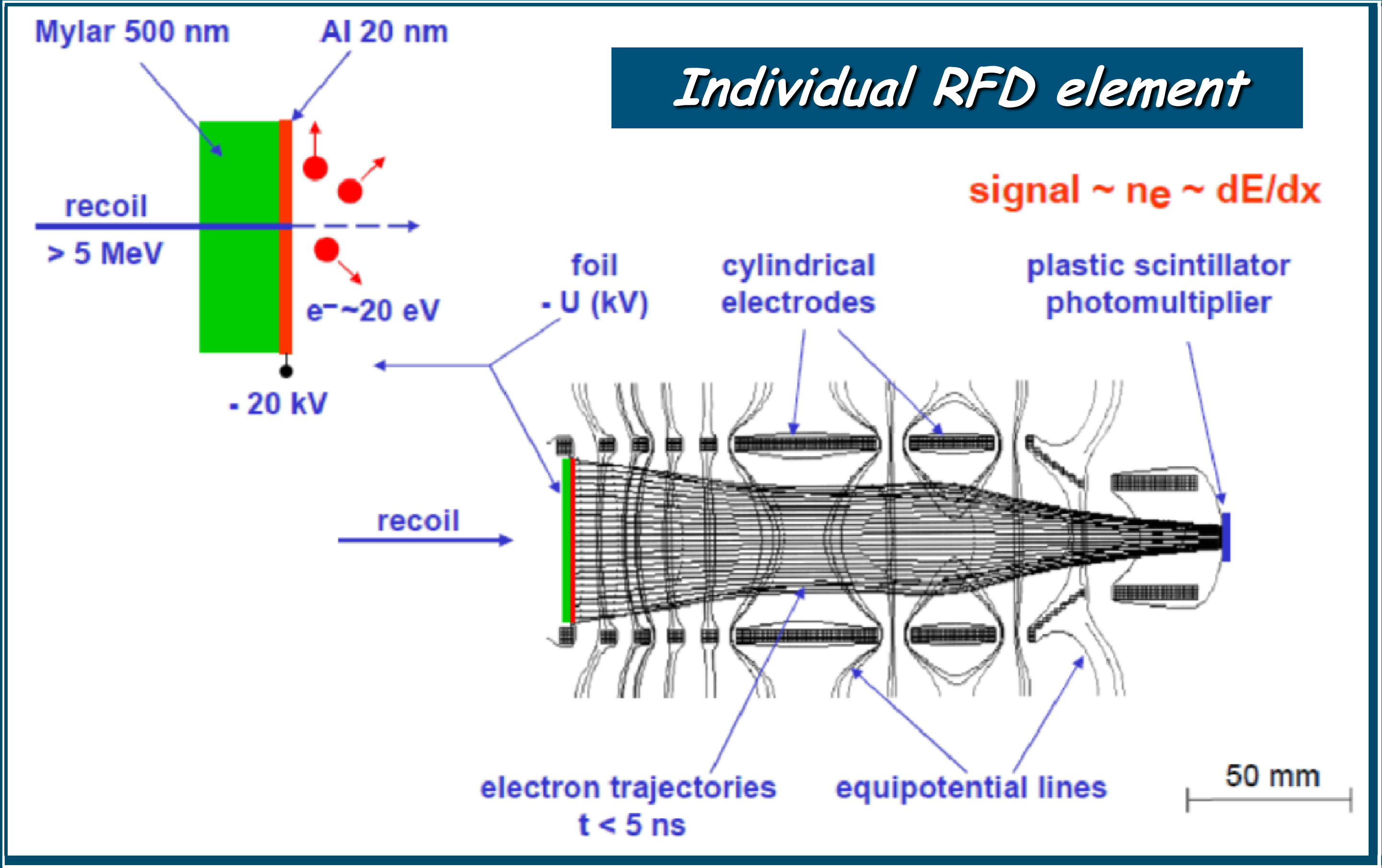
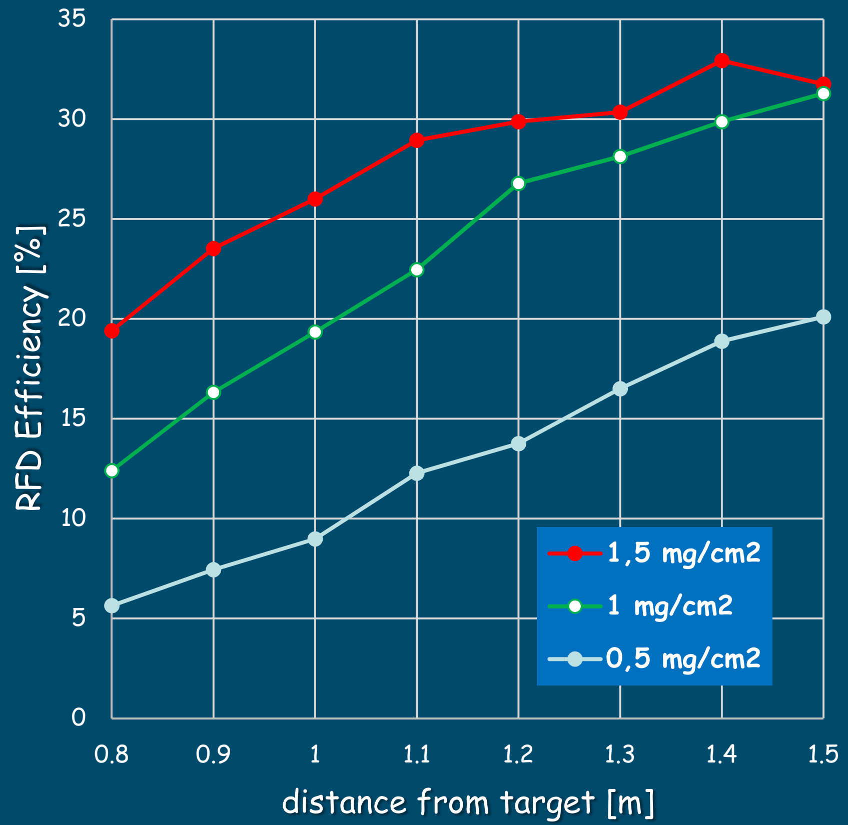
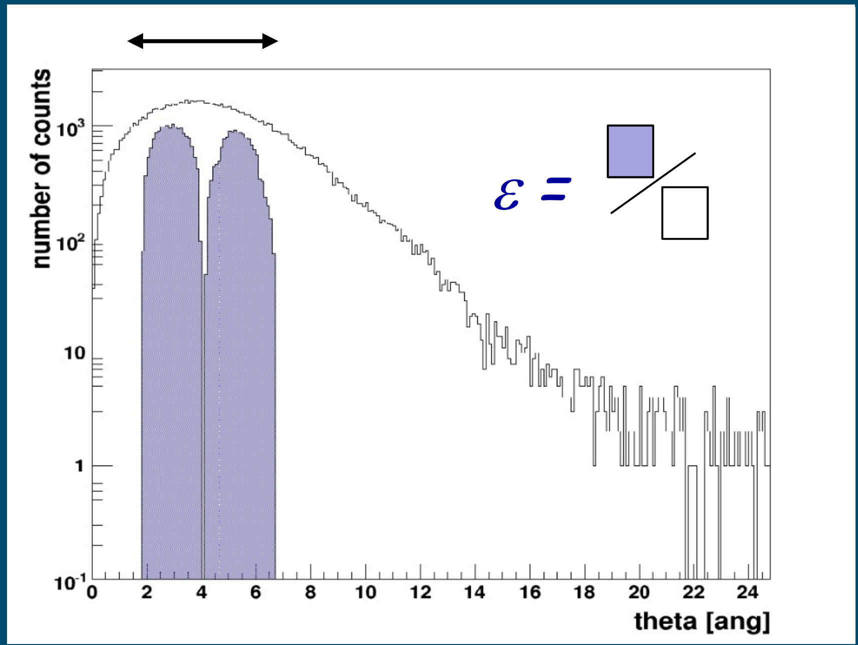



- Single det. rate ~ 5 MHz (mainly scattered beam)
- Recoils ~kHz

# Recoil detection efficiency




$1.6° < \theta < 6.7°$

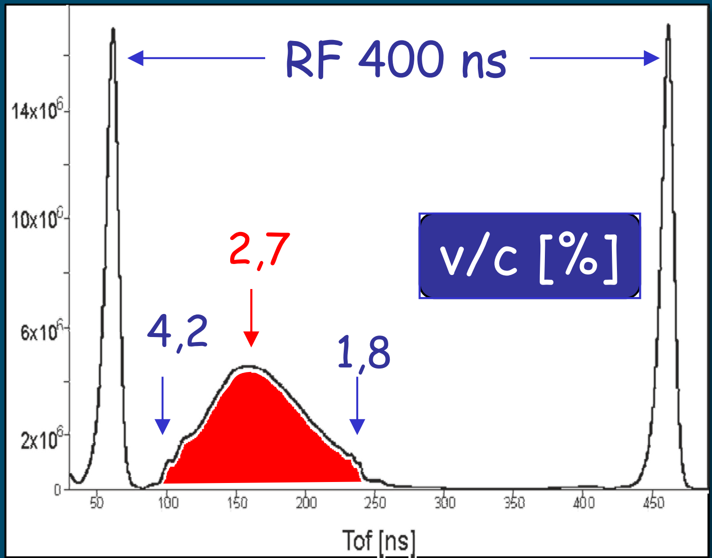


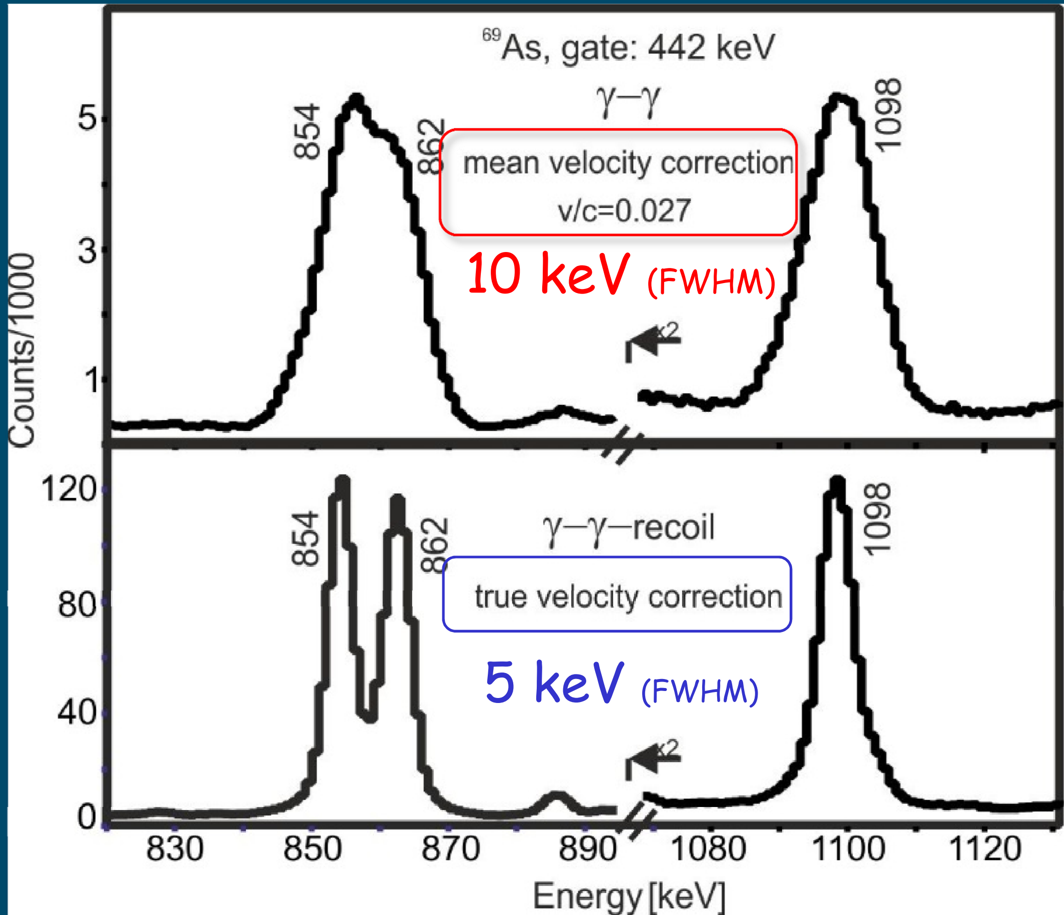

*128 MeV $^{26}$Mg + $^{198}$Pt*

- Optimal distance 1.4 m

# Reduction of Doppler broadening

*M. Matejska-Minda et al. Acta Phys. Pol. **B44** 501 (2013)*
*and PhD thesis (2014), PRC in preparation*



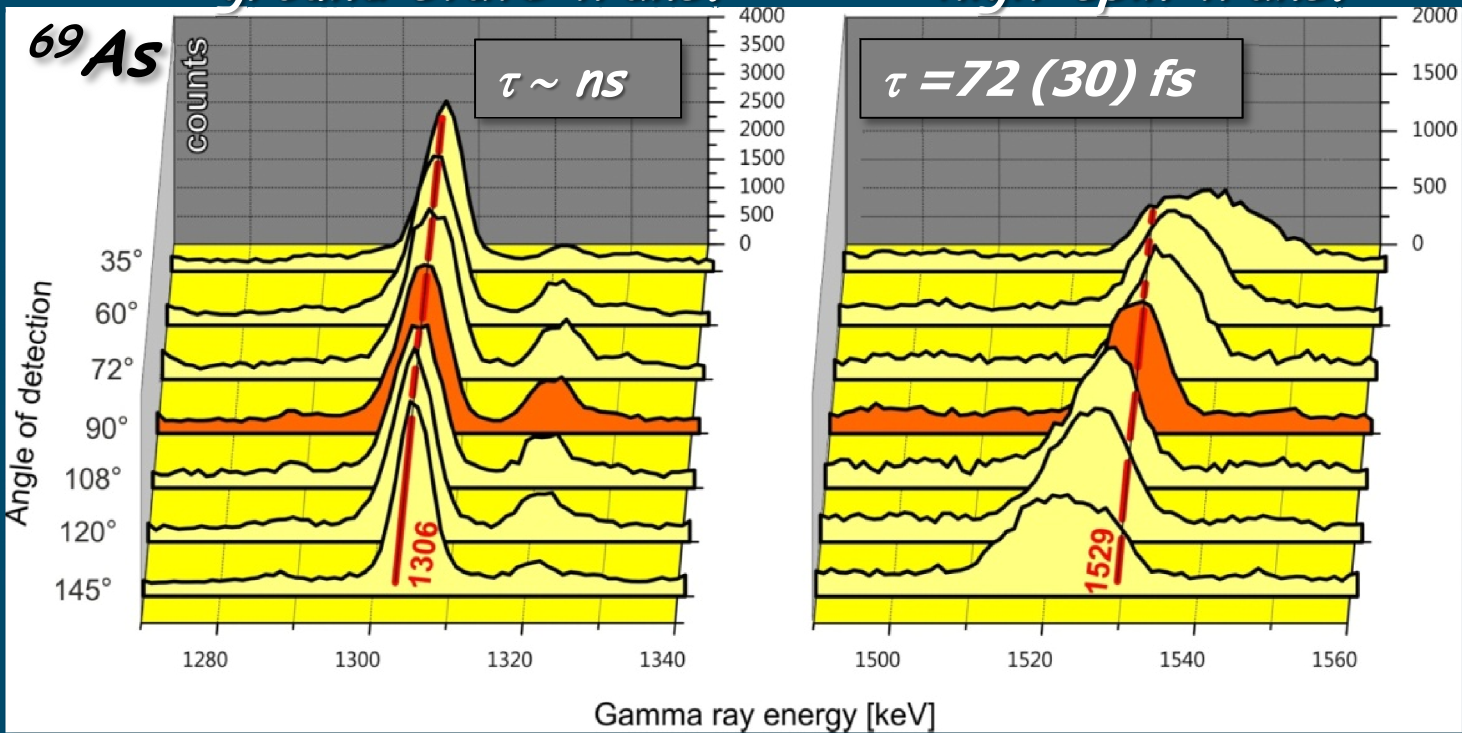

*$^{32}S$ (95MeV) + $^{40}Ca \rightarrow ^{72}Kr$(CN)*

*overall GASP spectrum*

*GASP+RFD, LNL 2009*

# Determination of short lifetimes- DSAM

*ground state trans.* *high-spin trans.*




*Emission in vacuum- „good correction"*

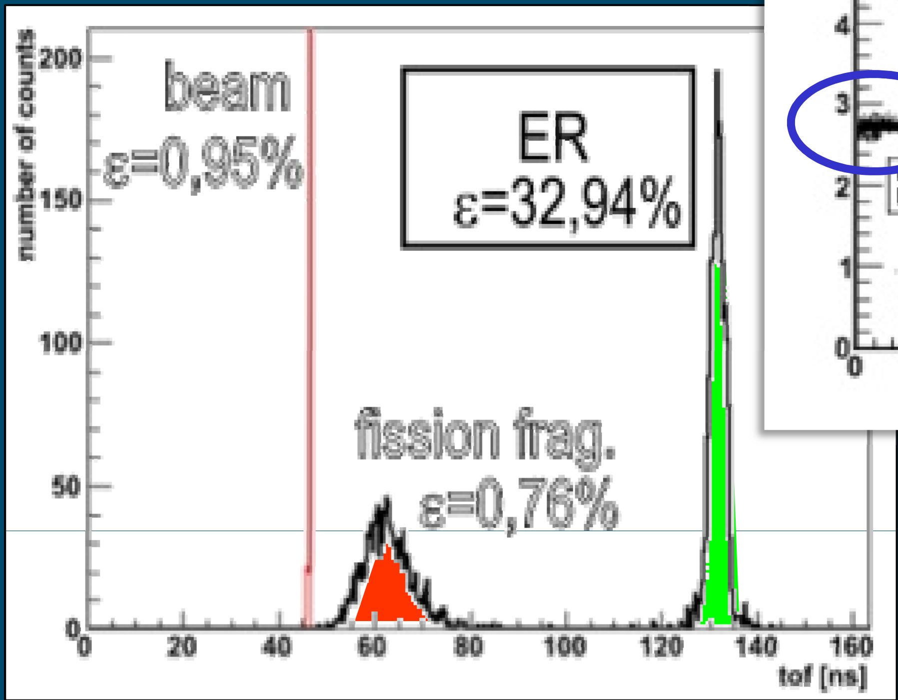
*Emission in target- „wrong correction"*

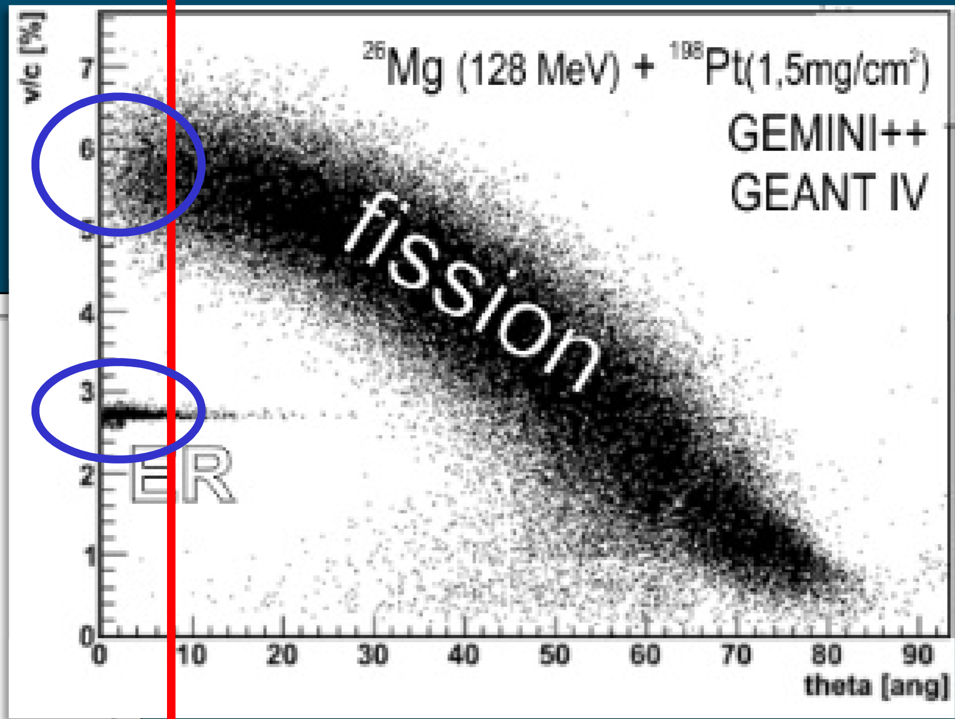
- ❑ lifetime range depends on target thickness
- ❑ 10-1000 femtosecond

$^{40}Ca(^{32}S,3p)^{69}As$

# Supression of the fission background

CN= $^{224}$Th



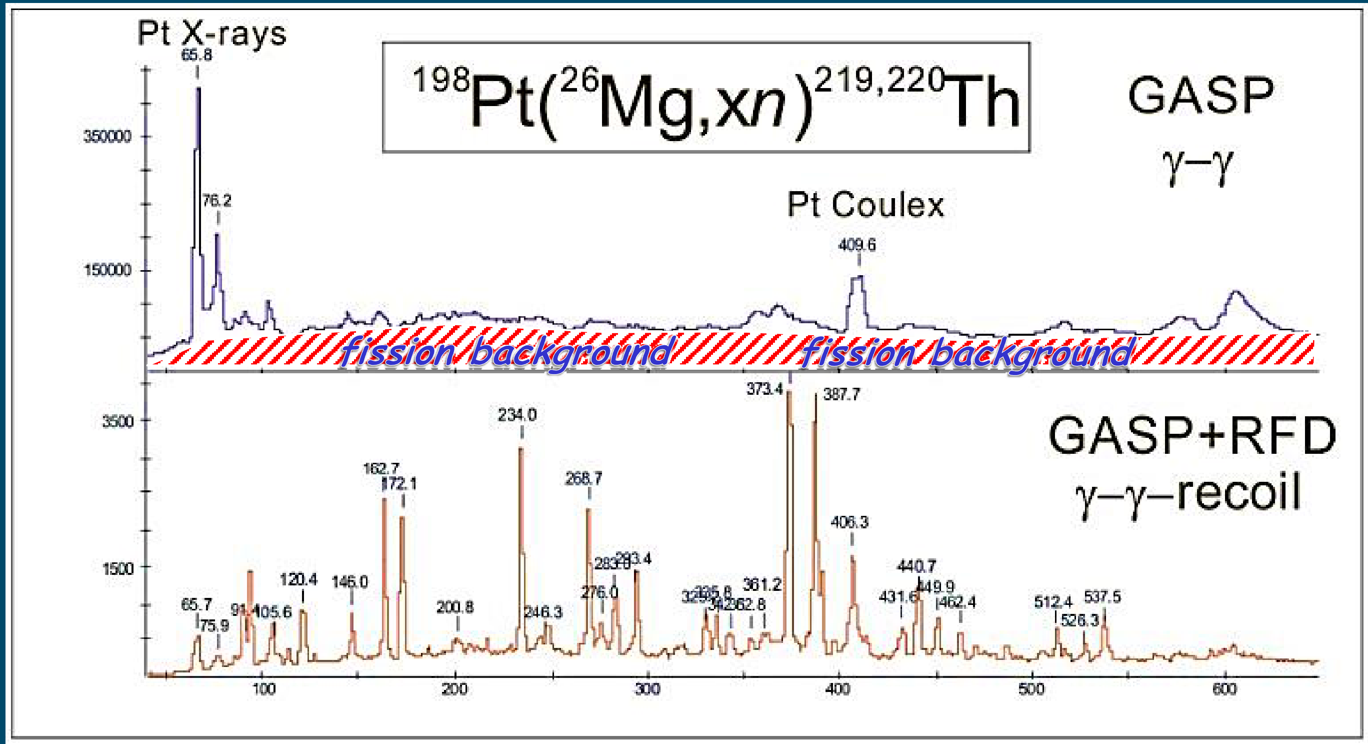

$\sigma_{resid}(^{219,220}Th,...) \sim 10mb$

$\sigma_{fiss} \sim 250mb$ (96%)

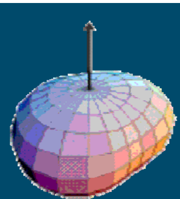
- Simulations

*M.Krzysiek, M.Ciemała*

# Experimental result




Although i ~ 0.1 pnA, we could also see all known transitions from $^{218}$Ra ($\sigma$ < 0.1 mb)

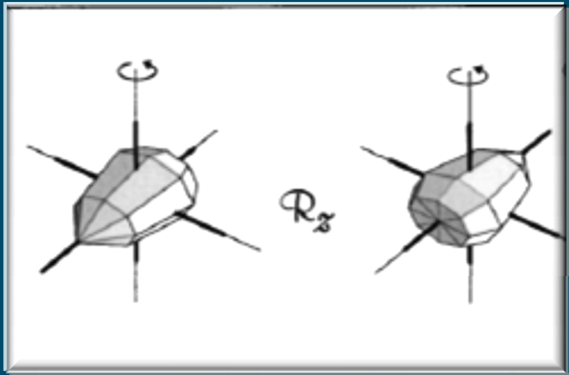


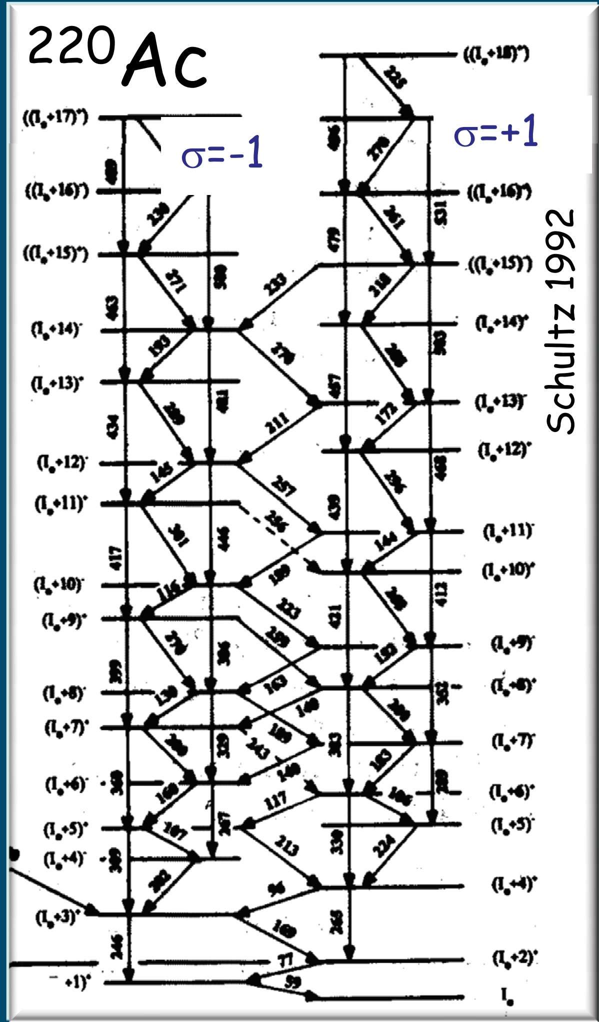
*Heart-shape nucleus*

$^{198}Pt(^{26}Mg,\alpha 2n)\,^{218}Ra$

***GASP+RFD, LNL 2009***

# New insight into octupole deformation with RIB



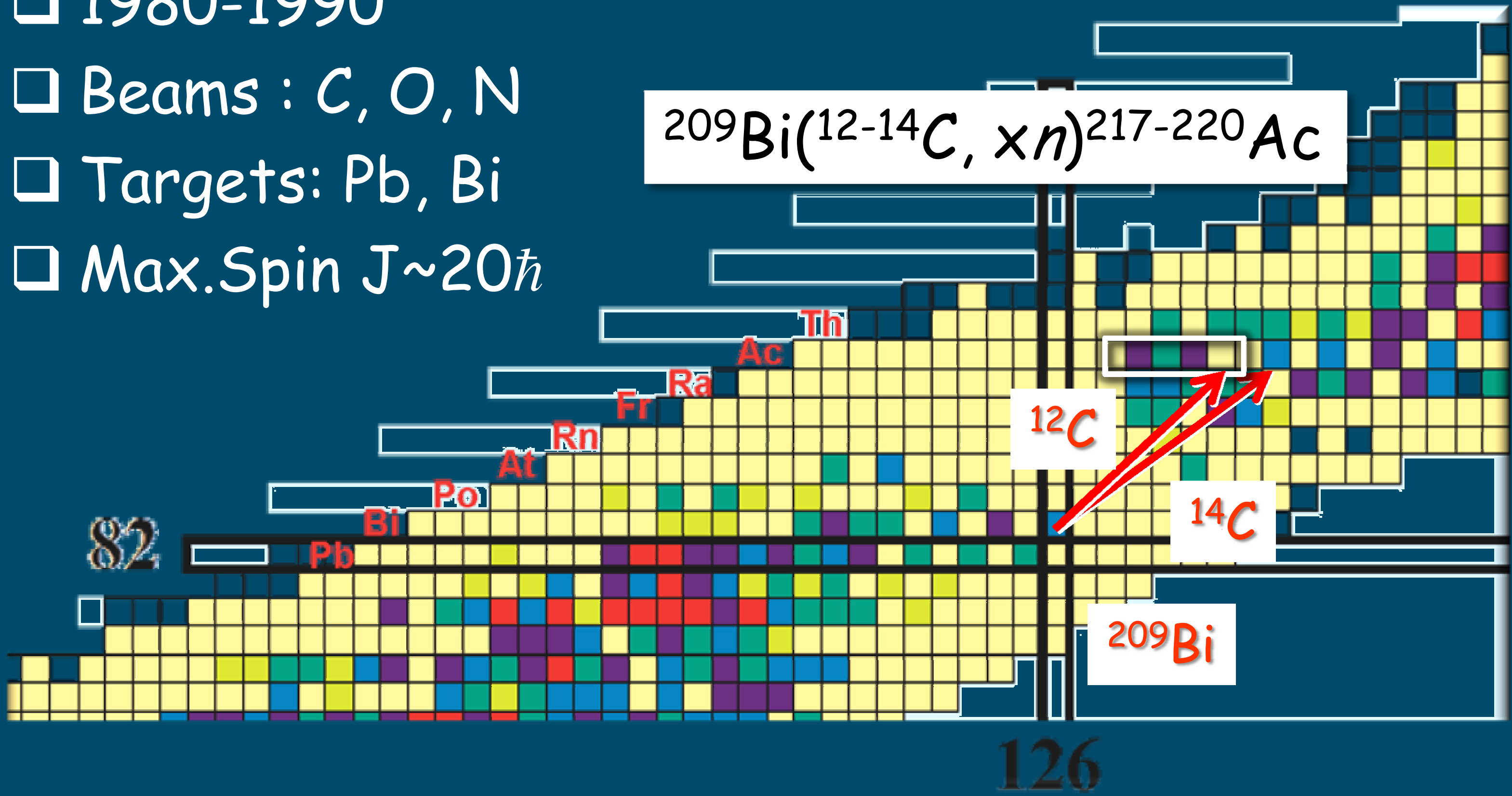

J<20 $\hbar$

Simplex partners

- *Reflection asymmetric shapes*
- Alternative parity bands
- Expected octupole-quadrupole transition at HS

# Investigation of the octupole deformation in actinides

- 1980-1990
- Beams : C, O, N
- Targets: Pb, Bi
- Max.Spin J~20$\hbar$



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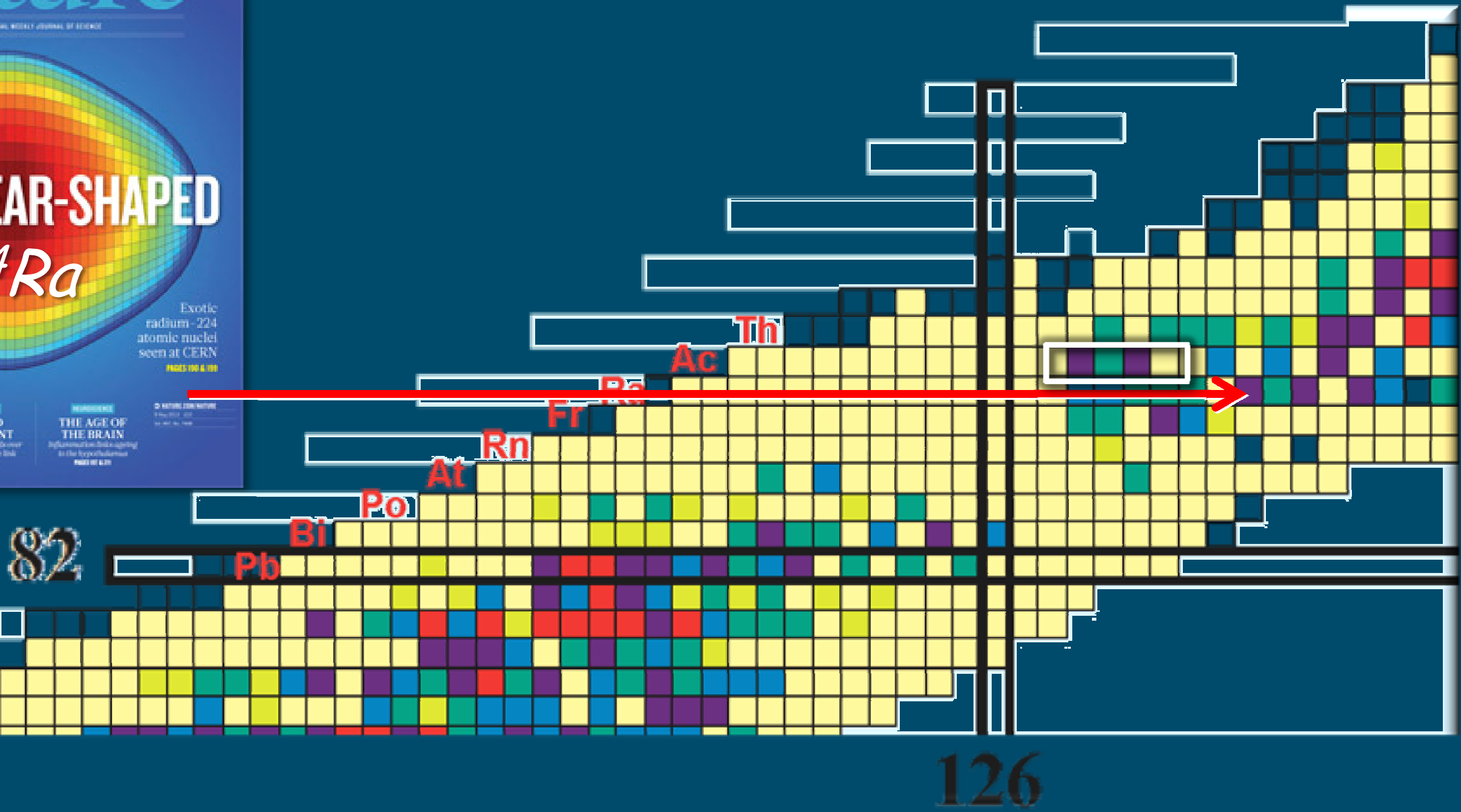
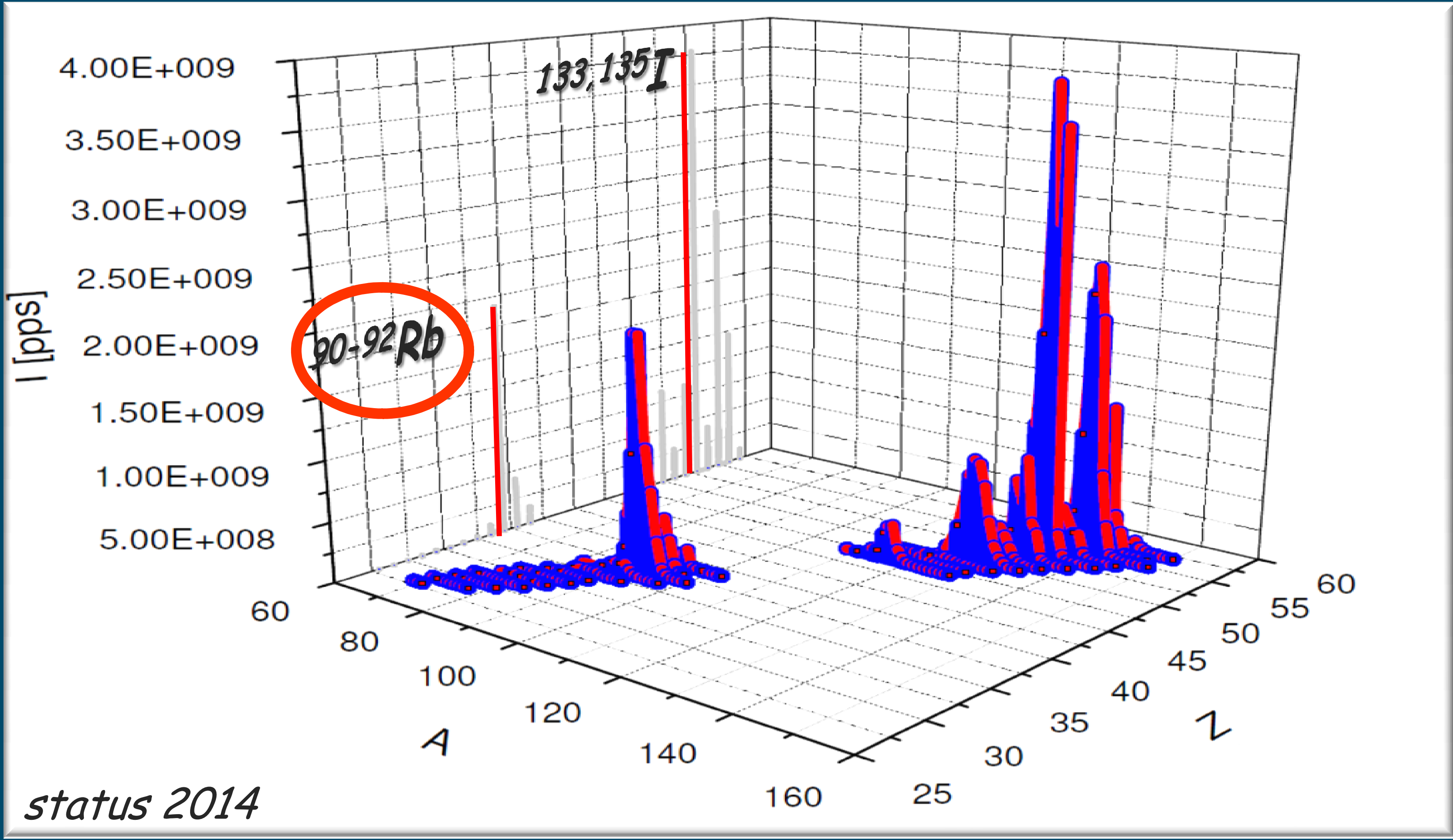


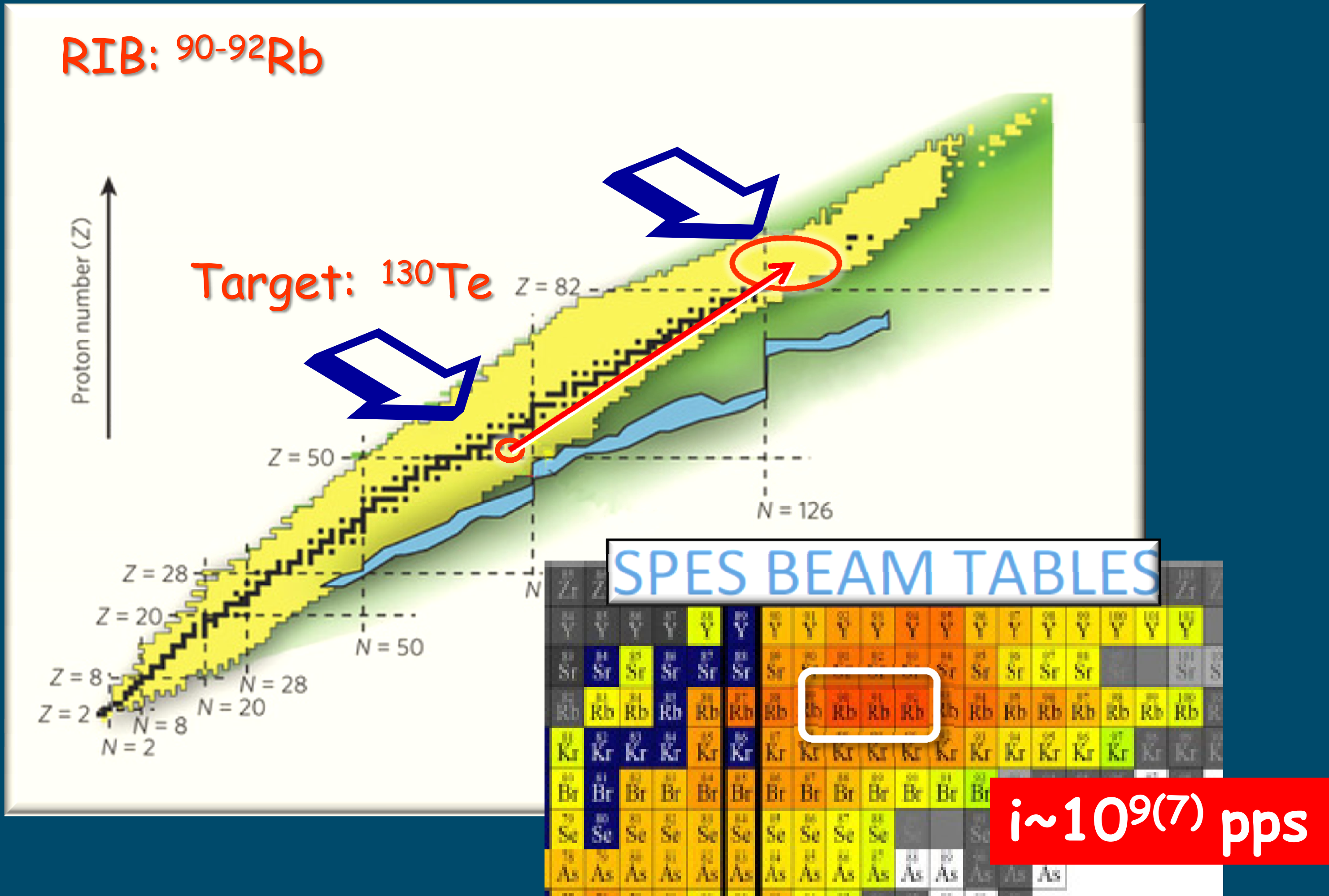

- ❑ RIB COULEX at ISOLDE

Gaffney et al., Nature 497, 199 (2013)

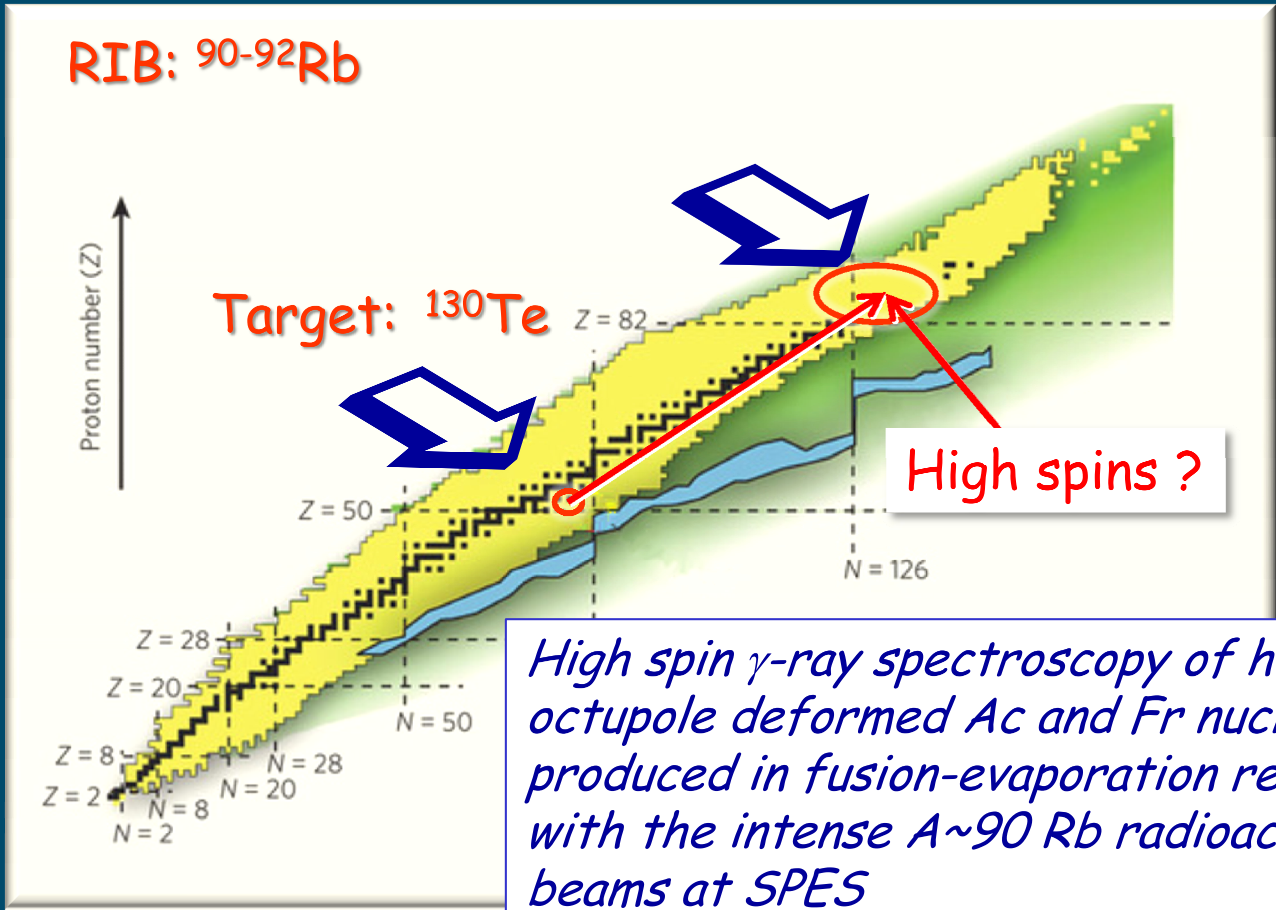
# SPES RI Beams- fission on UCx



# HS in actinides at reach with RIB ?

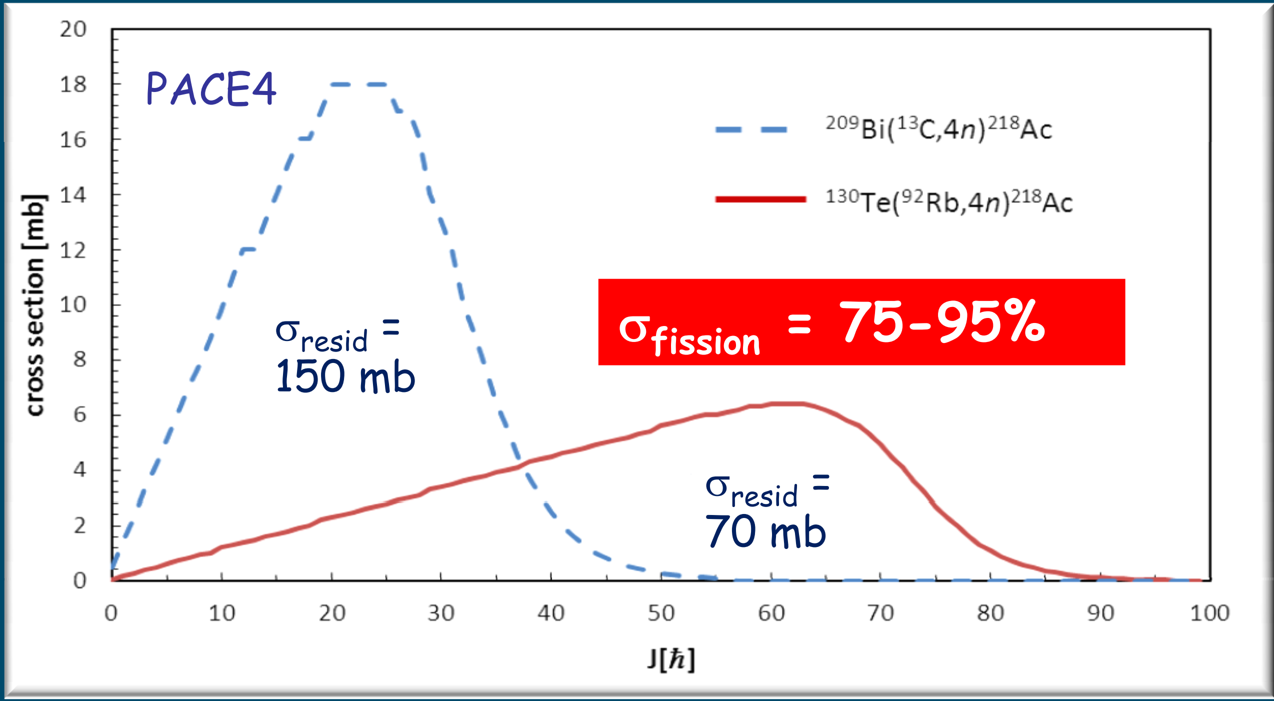


# SPES LOI, LNL 2014




*High spin γ-ray spectroscopy of heavy, octupole deformed Ac and Fr nuclei produced in fusion-evaporation reactions with the intense A~90 Rb radioactive beams at SPES (AGATA/GALILEO+ RFD)*

# High spin states: $^{130}Te(^{92}Rb, 4n)^{218}Ac$




<u>RFD (GALILEO, AGATA)</u>

- Fission supression
- Doppler correction

$E_b$ = 375MeV,

**v/c > 4%**

# Outline of a scientific program

- *Rotational bands and deformation in A=(40-70) nuclei (lifetimes)*
- *HS around $^{100}$Sn (optional- with NW)*
- *Ultra HS in A~130 (Ba) region via inverse kinematics reactions (proof of principle)*
- *HS & octupole deformation in transactinides*
- *Warm rotation in transuranides (with PARIS)*

RIB ?

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# Collaboration*

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*Università degli Studi and INFN sezione di Milano, Italy*

J.F. Smith, K.Spohr,...

*University of the West of Scotland, Paisley, UK*

*Call for LOIs- 2nd half 2016, proposals- 2017

# Summary of RFD advantages

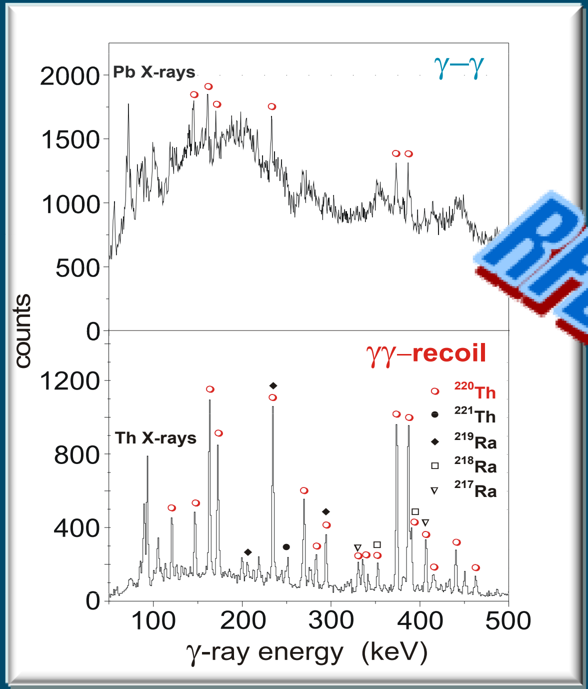
- High efficiency for ER
- Background- projectile and fission rejection
- Doppler broadening minimization
- Estimation of lifetimes in the fs range
- Possibility to couple with other ancillary devices :

  EUCLIDES, (NWALL) , PARIS, plunger,..

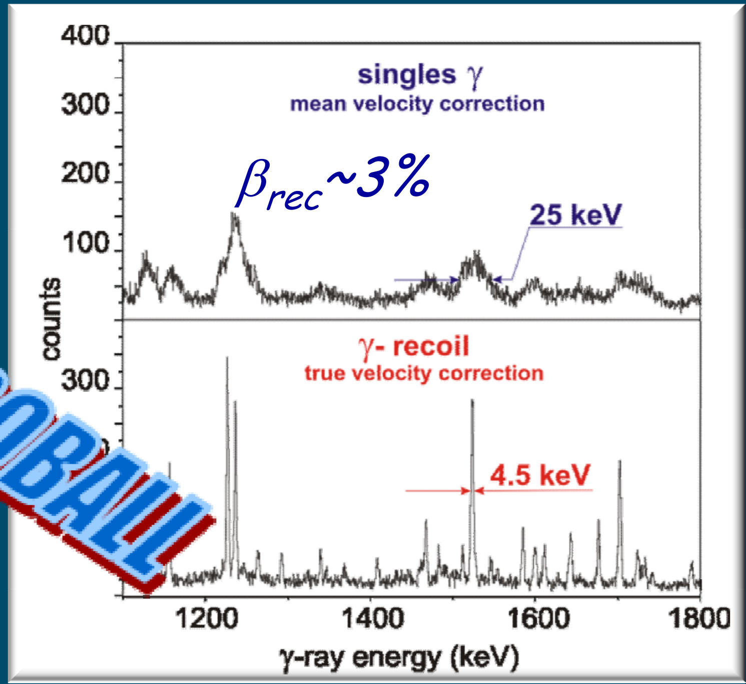
- at RIB (SPES)
  - Negligible radioactivity deposition
  - Not sensitive to any kind of residual radiation

# Improvement of γ-spectra by a coincident recoil detection (with RFD)

*92 MeV $^{16}O$ + 0.4 mg/cm$^2$ $^{208}Pb$*




*68 MeV $^{18}O$ + 0.8 mg/cm$^2$ $^{30}Si$*




RFD+EUROBALL

- *Heavy systems:*
  - ✓ *fission background reduction*
  - ✓ *low cross sections σ ~ 0.1 mbarn*
- *Large recoil velocity:*
  - ✓ *reduction of the Doppler broadening*

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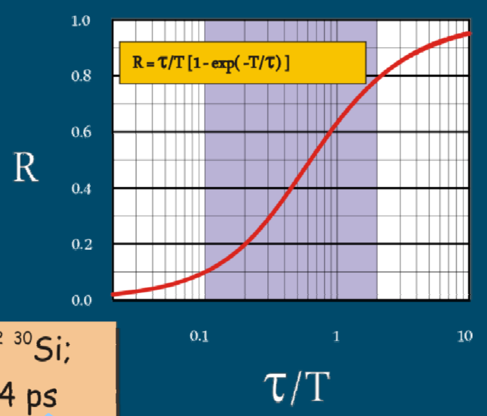
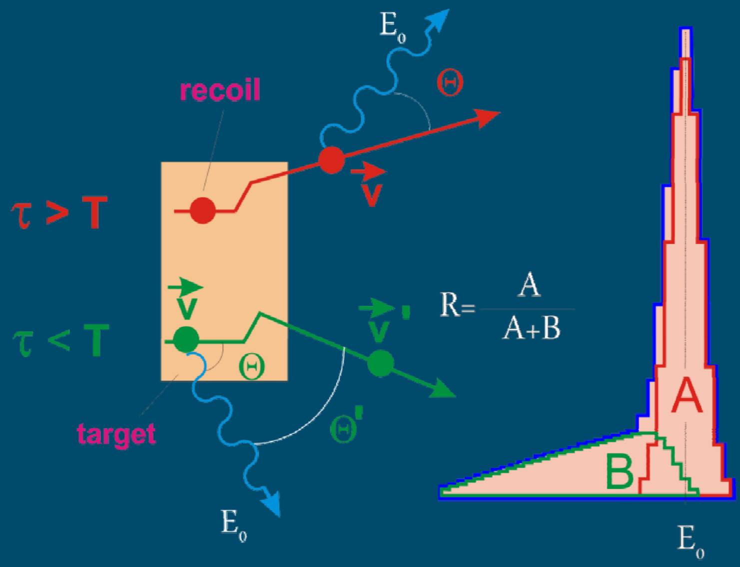
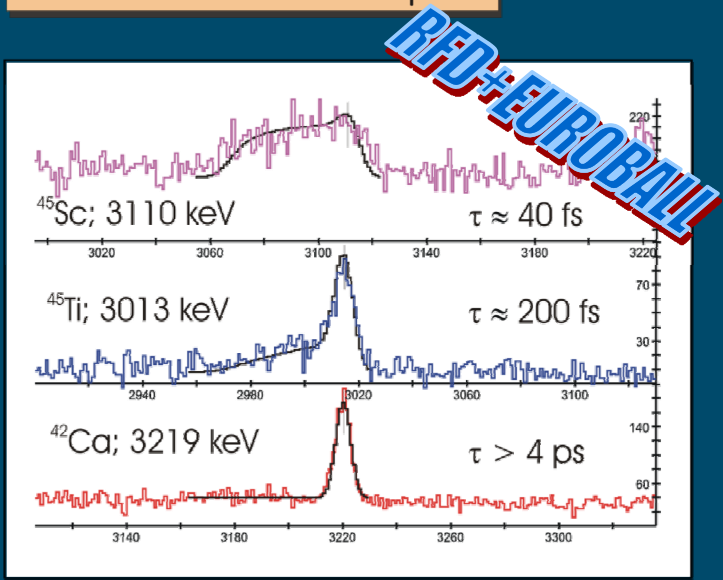
# Estimation of a short lifetime based on the recoil velocity measurement




68MeV $^{18}O$ + 0.8mg/cm$^2$ $^{30}Si$;
Recoil transit time ≈ 0.4 ps




- Energy of a γ-ray emitted in a target (B) is not sufficiently Doppler corrected
- A level lifetime can be expressed by number of decays in vacuum (A) relative to a total γ-line intensity (A+B)