SPES one-day Workshop "Physics at SPES with non re-accelerated beams"

SPES Project

Beta -Delayed Neutron Spectroscopy using Trapped Radioactive Ions

S. Grévy et al.

CENBG - Bordeaux, France

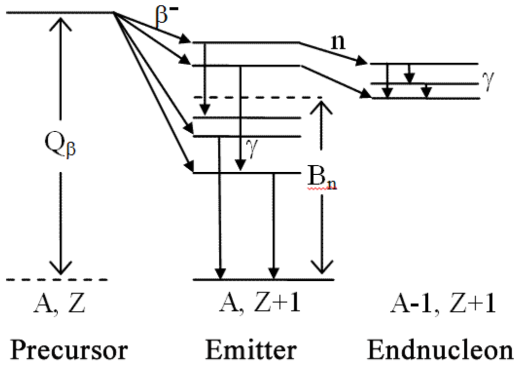
open to discussions/remarks/criticisms/collaborations…

Why Beta-Delayed Neutron Spectroscopy ?

For the most neutron-rich nuclei :

- large Q_β
- small S_n

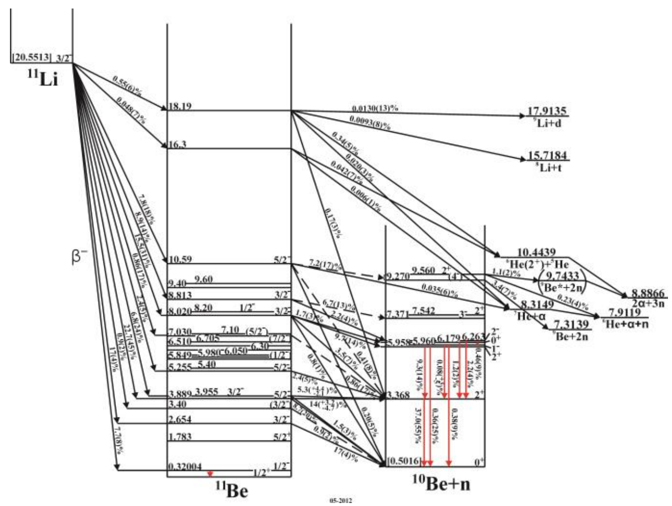
→ β-delayed neutron emission



Experimental data are needed for :

- astrophysics : r process nucleosynthesis of elements heavier than Fe

- nuclear structure : properties of neutron rich nuclei
  - nuclei at the drip line
  - nuclei at the closed shell
  - …



- nuclear energy : reactor design, performance and safety

reactor design, performance and safety		needed accuracy
- delayed neutron fraction → Pn		1-5 %
- average energy !! → energy spectra		< 20%

but neutrons are always difficult to measure….

Beta Delayed Neutron Spectroscopy… without detecting neutrons ☺

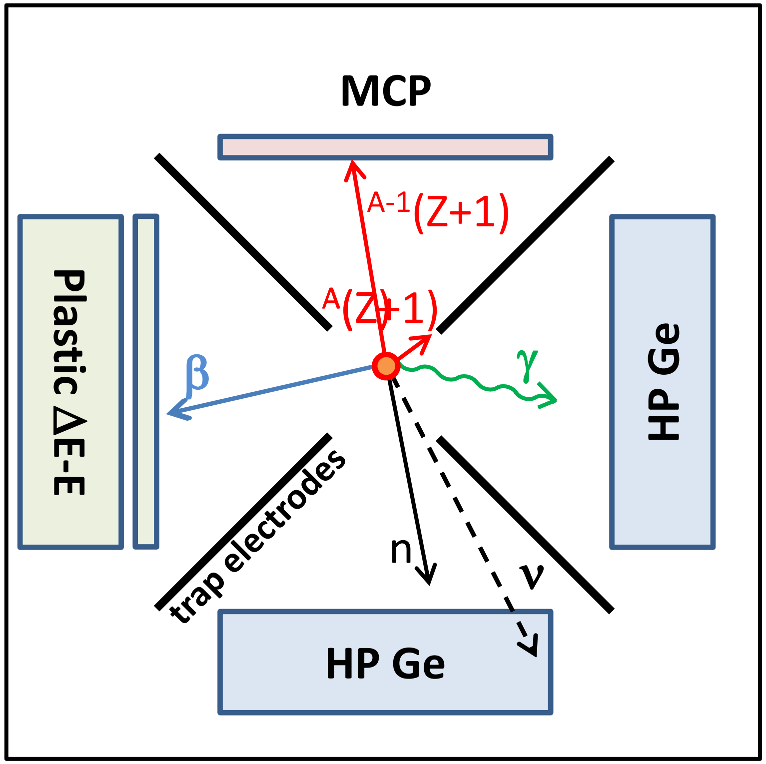
Principle :

By momentum and energy conservation :
TOF of recoiling $^{A-1}(Z+1)$ ←→ neutron energy

- trap the nuclei as ions
- cool by He gas to ~1mm³ volume
- ions decay at rest at the trap center
  - β only : slow recoil
  - βn : fast recoil
- trigger on β's seen by plastic
- Measure recoil TOF to MCP

$^{A}(Z) \rightarrow {}^{A}(Z+1)^{*} + \beta^{-} + \nu$

$\quad \hookrightarrow {}^{A-1}(Z+1) + n$



Mass	Q_β/E_n MeV	HI recoil after β-decay (E / TOF 5cm)	HI recoil after n-emission (E / TOF 5cm)
45	10	< 1.3 keV > 670 ns	217 keV 52 ns
	5	< 360 eV > 1.3 μs	108 keV 73 ns
	2	< 72 eV > 2.8 μs	43 keV 116 ns

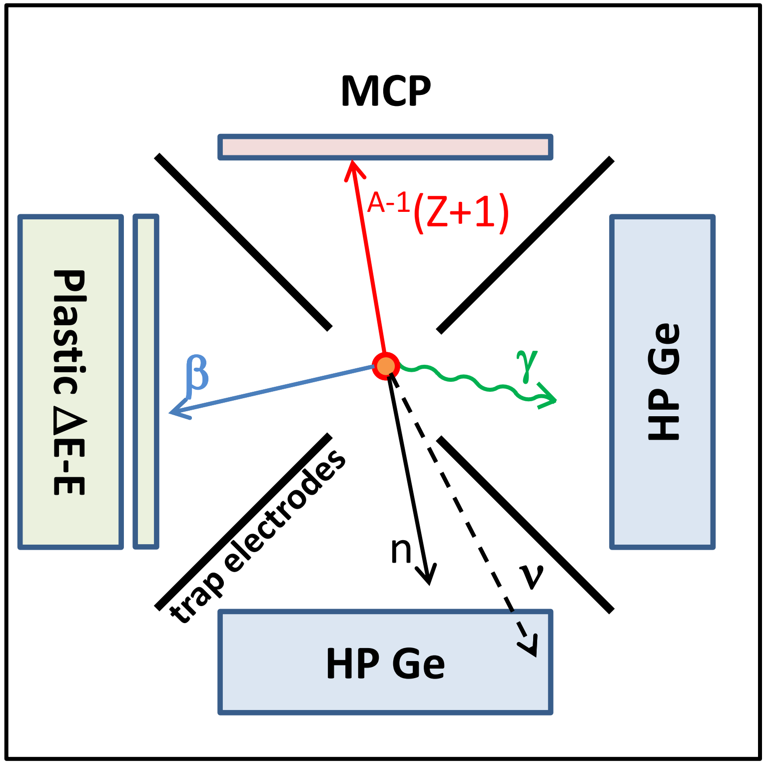
Beta Delayed Neutron Spectroscopy… without detecting neutrons ☺

$^{A}(Z) \rightarrow {}^{A}(Z+1)^{*} + \beta^{-} + \nu$

$\hookrightarrow {}^{A-1}(Z+1) + n$

Advantages : no need to detect neutons

- total efficiency (β-recoil) : up to 5%
- energy resolution (FWHM) : ~3%
- neutron energy threshold : ~30keV
- Gaussian detector response
- almost background free
- no need for γ/n discrimination
- low price
- can be couple to other trap assisted spectroscopy methods (laser polarization…)

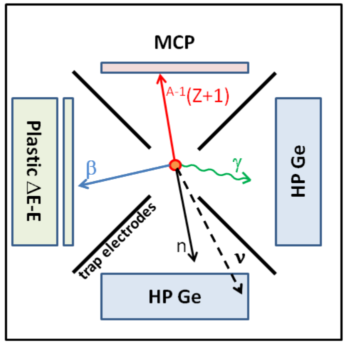


Disavantages :

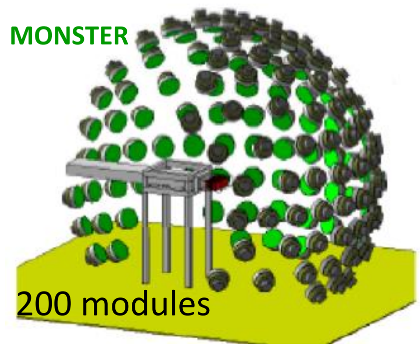
- no 2n capabilities (alone)

Beta Delayed Neutron Spectroscopy… without detecting neutrons ☺

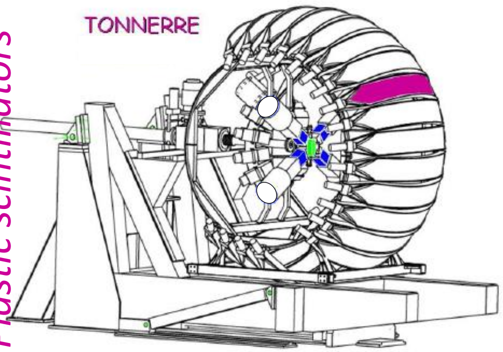
Transparent Paul trap



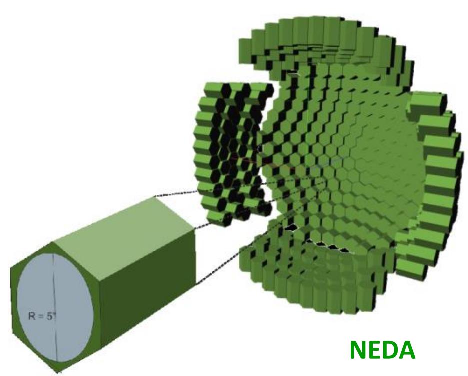
Liquid scintillators

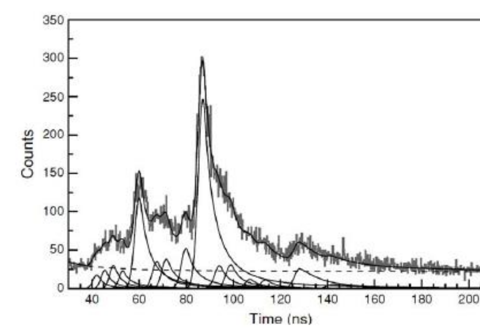


Plastic scintillators



	Transparent Paul trap	Liquid scintillators	Plastic scintillators
Total efficiency	5% (β-recoil)	5%@1 MeV (β&n)	15%@1 MeV (β&n)
Energy resolution	3%	5%	10%
Neutron threshold	30 keV	100 keV	300 keV
Detector response	gaussian	gaussian	problematic line shapes
Background	almost free	yes (γ)	yes (γ)
n/γ discriminations	no need	yes, shape	yes, tof
2n capabilities	no	yes	difficult
Price	low	high	medium





Proof of principle

PRL **110**, 092501 (2013) PHYSICAL REVIEW LETTERS week ending 1 MARCH 2013

β-Delayed Neutron Spectroscopy Using Trapped Radioactive Ions

R. M. Yee,[1,2] N. D. Scielzo,[1] P. F. Bertone,[3] F. Buchinger,[4] S. Caldwell,[3,5] J. A. Clark,[3] C. M. Deibel,[3,6] J. Fallis,[3,7] J. P. Greene,[3] S. Gulick,[4] D. Lascar,[3,8] A. F. Levand,[3] G. Li,[3,4] E. B. Norman,[2] M. Pedretti,[1] G. Savard,[3,5] R. E. Segel,[8] K. S. Sharma,[3,7] M. G. Sternberg,[3,5] J. Van Schelt,[3,5] and B. J. Zabransky[3]

[1]*Physical and Life Sciences Directorate, Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2]*Department of Nuclear Engineering, University of California, Berkeley, California 94720, USA*
[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[4]*Department of Physics, McGill University, Montréal, Québec H3A 2T8, Canada*
[5]*Department of Physics, University of Chicago, Chicago, Illinois 60637, USA*
[6]*Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, Michigan 48824, USA*
[7]*Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada*
[8]*Department of Physics and Astronomy, Northwestern University, Evanston, Illinois 60208, USA*

(Received 4 May 2012; published 26 February 2013)

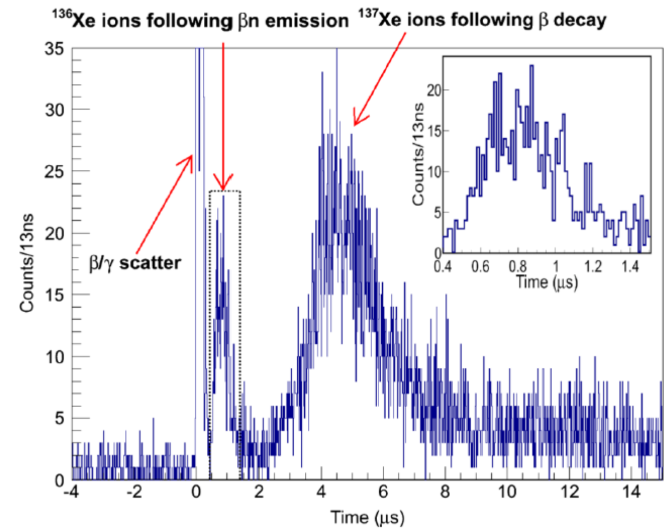
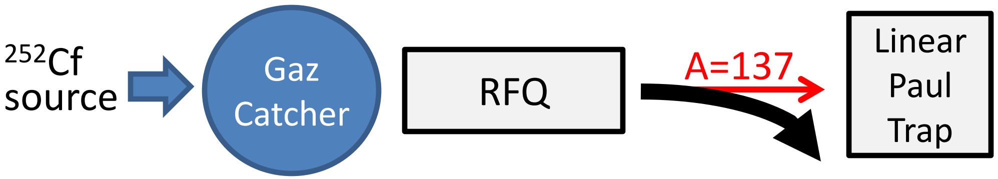


FIG. 2 (color online). Recoil-ion TOF spectrum collected with a 30 ion/s $^{137}I^{+}$ beam. The TOF spectrum of the ^{136}Xe recoil ions from βn emission, highlighted by the dotted box, is shown in the inset.



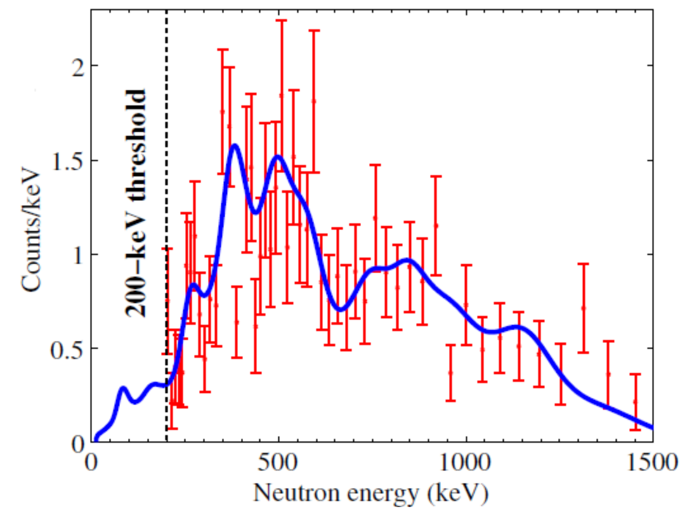
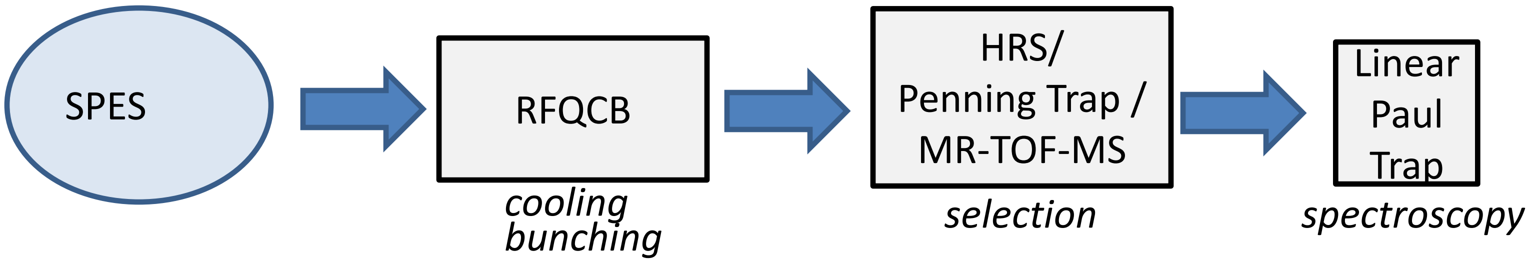


FIG. 3 (color online). Comparison of the βn-energy spectrum for ^{137}I measured here with a known spectrum from Ref. [47]

	present setup	dedicated setup
- total efficiency :	0.05 %	5%
- energy resolution	~ 10 %	3%
- n threshold	200 keV	30 keV

future plans for Caribu

In trap decay spectroscopy @ SPES ?



Synergies DESIR (Spiral1 Upgrade) and SPES (fission fragments)

Day one

- SPIRAL1 light neutron rich beams
- the upgraded version of the LPCTrap (efficiency : ~3%)
- test cases : ^{45}Cl / 10^4 pps ^{46}Cl / 10^2 pps

Mid term

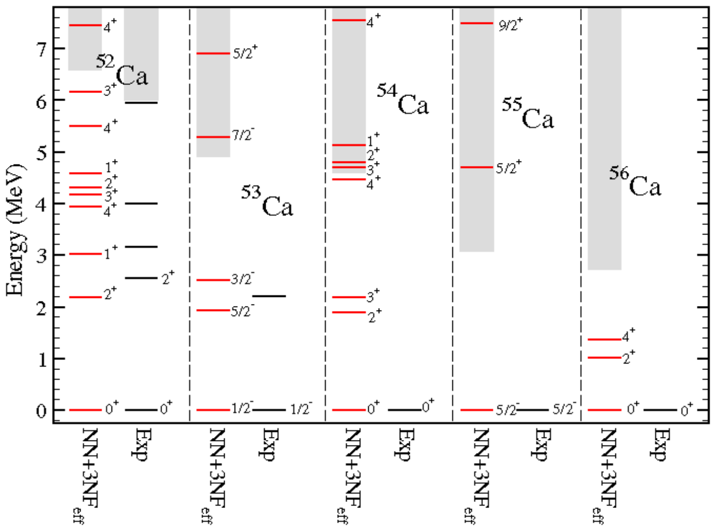
- develop a dedicated setup for DESIR and SPES

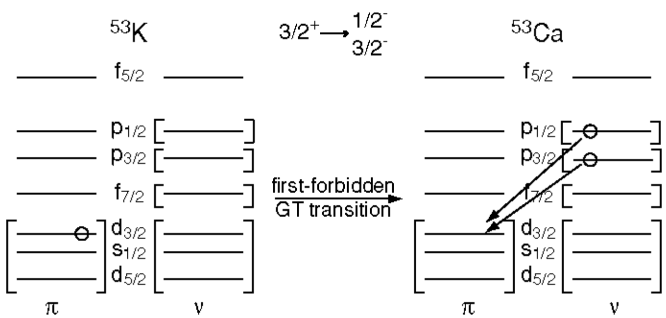
efficiency : ~5%
E resolution :~3%
n-threshold : ~30 keV

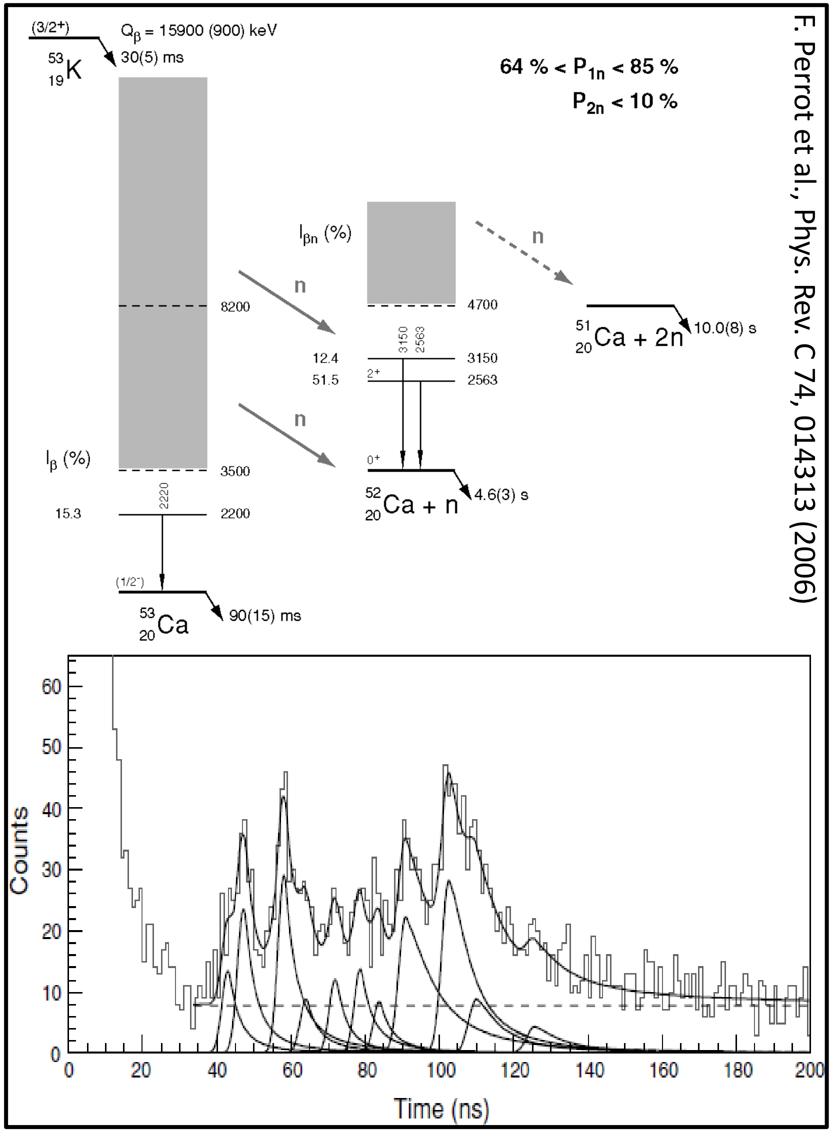
Beta Delayed Neutron Spectroscopy at SPES

Shell structure in n-rich Ca isotopes

Courtesy A. Gottardo







F. Perrot et al., Phys. Rev. C 74, 014313 (2006)

The GT decay should populate the $p_{3/2}$, $p_{1/2}$ proton shells. FF could also populate the $2d_{5/2}$

I heard yesteday that you have to think about possibilities with traps…

and we have a group in Bordeaux working on this subject since now few years… → be happy ☺

today : PIPERADE Project

tomorrow : Trap assisted spectroscopy

→ Mass mesurements @ ALTO using MLLTrap – funding request

→ beta delayed neutron using a Paul trap

PIPERADE requirements

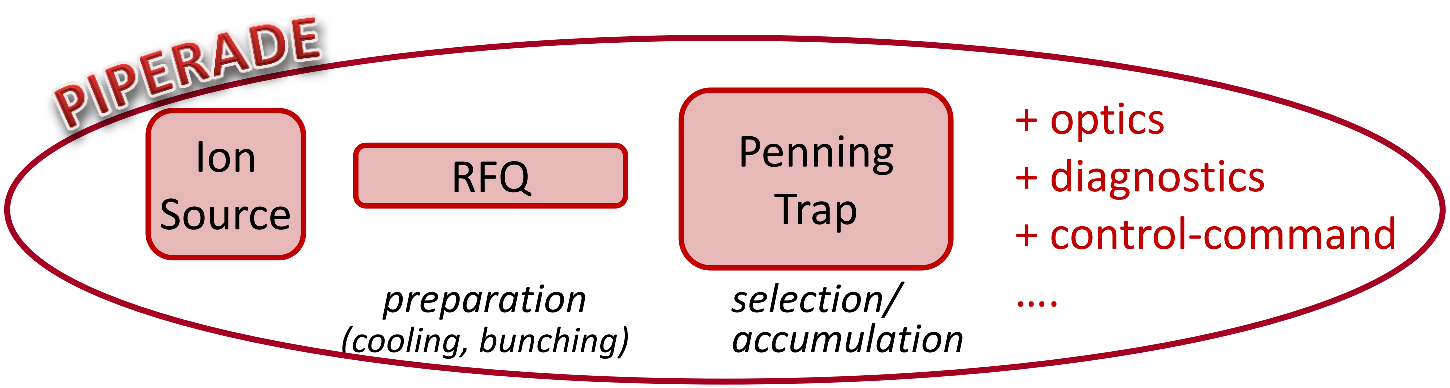
Goal of PIPERADE : deliver **<u>very pure</u>** and **large samples** of exotic nuclei to the DESIR set-ups

- precision measurements
- nuclear structure
- …

↓ **Requirements for the device**

- **Mass resolution > 10^5** (Isobaric cleaning)
- Purify very large samples of ions **(> 10^5 ions/bunch; ~10Hz → > 10^6 ions/s)**
  (Large ratio contamination/ions of interest, high relative intensity also for the molecules)
- **"Fast"** cleaning process (50 – 500 ms)

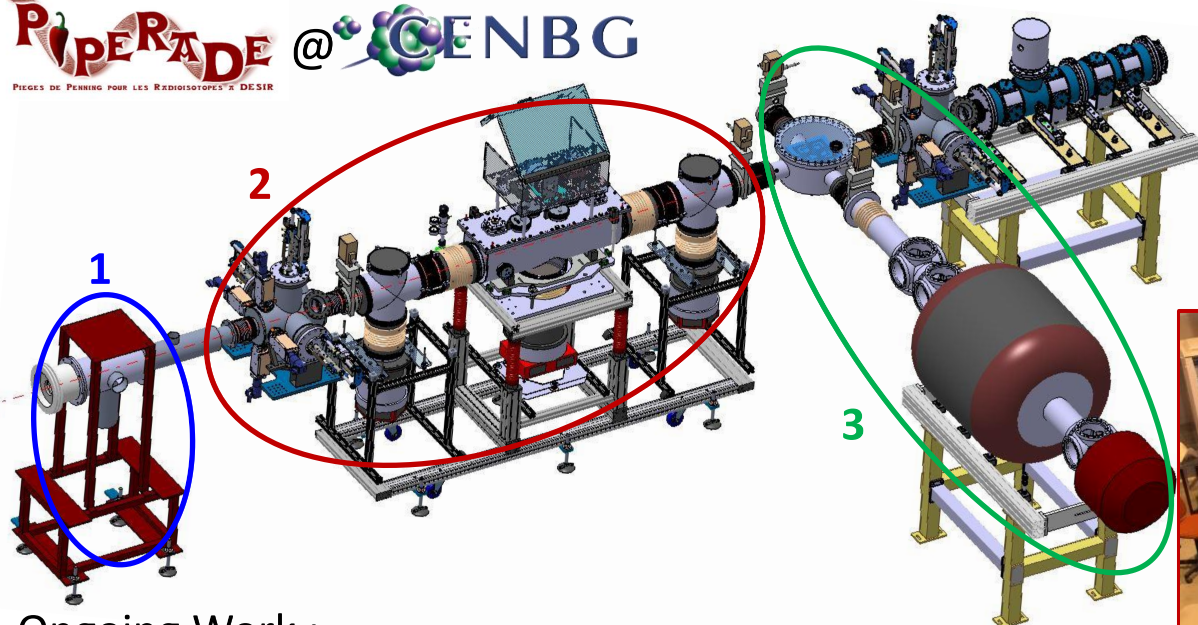
→ **Double Penning trap system** → selection / accumulation

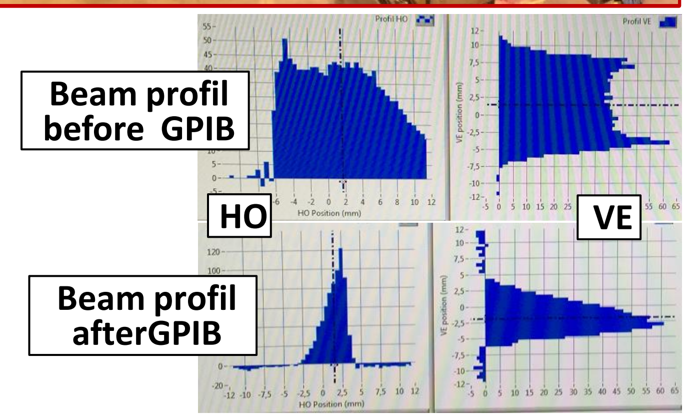


Projet scientifique

PIPERADE @ CENBG

PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR





Ongoing Work :

1- Ion Source : completely new control-command with the DESIR architecture - Working

2- GPIB General Purpose Ion Buncher : operational – On tests

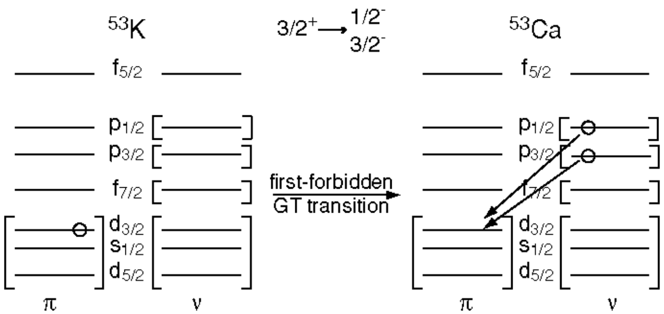
3- 90° switch : DESIR/PIPERADE and S3/LEB ongoing work
Penning Trap : Under contruction@MPIK heidelberg
Magnet : Ordered. Delivery end of 2015

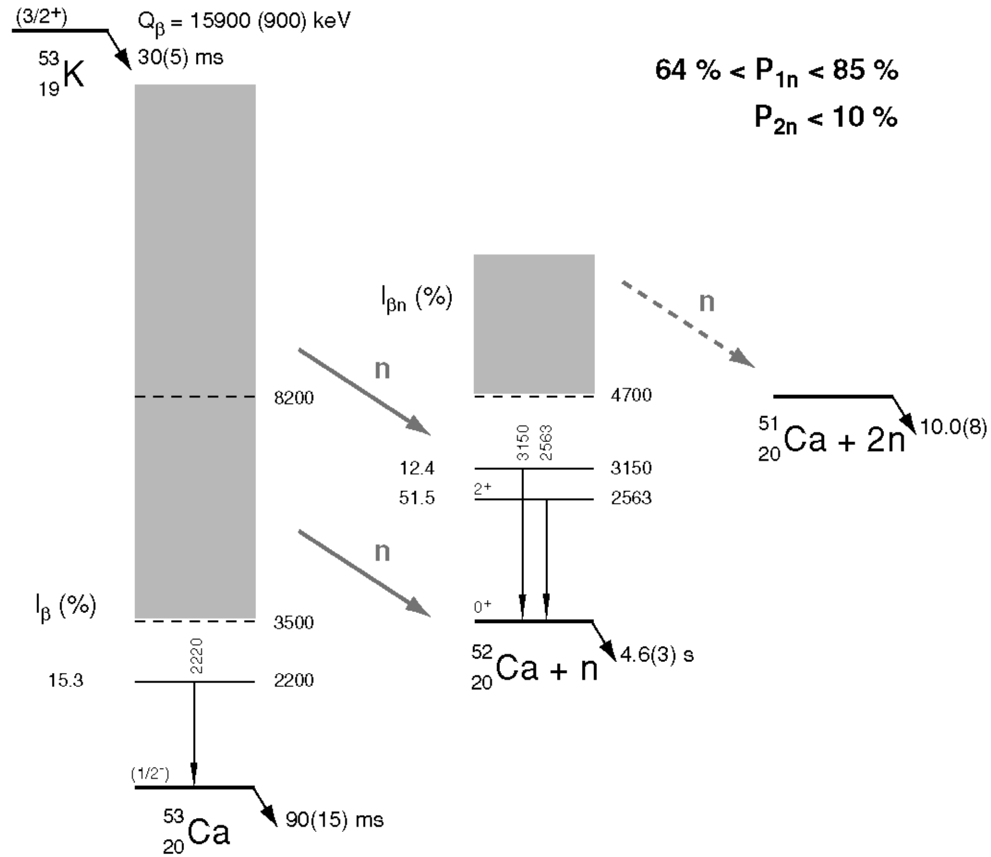
2015 : Tests and qualification of the ensemble "Ion Source + GPIB"
Construction and installation of the 90° switch

2016 : Installation of the magnet and the Penning Trap.
Tests of the full PIPERADE setup.

thank you for your attention

^{53}Ca β-delayed neutron spectroscopy





F. Perrot et al., Phys. Rev. C 74, 014313 (2006)

Not enough statistics to reconstruct the level scheme

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Mass	Q_β/E_n MeV	HI recoil after β-decay (E / TOF 5cm)	HI recoil after n-emission (E / TOF 5cm)
150	10	< 390 eV > 2.2 μs	66 keV 172 ns
	5	< 110 eV > 4.2 μs	33 keV 238 ns
	2	< 20 eV > 10 μs	13 keV 384 ns

Beta Delayed Neutron Spectroscopy… without detecting neutrons ☺

Advantages : no need to detect neutons

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- energy resolution (FWHM) : ~3%
- neutron energy threshold : ~30keV
- Gaussian detector response
- almost background free
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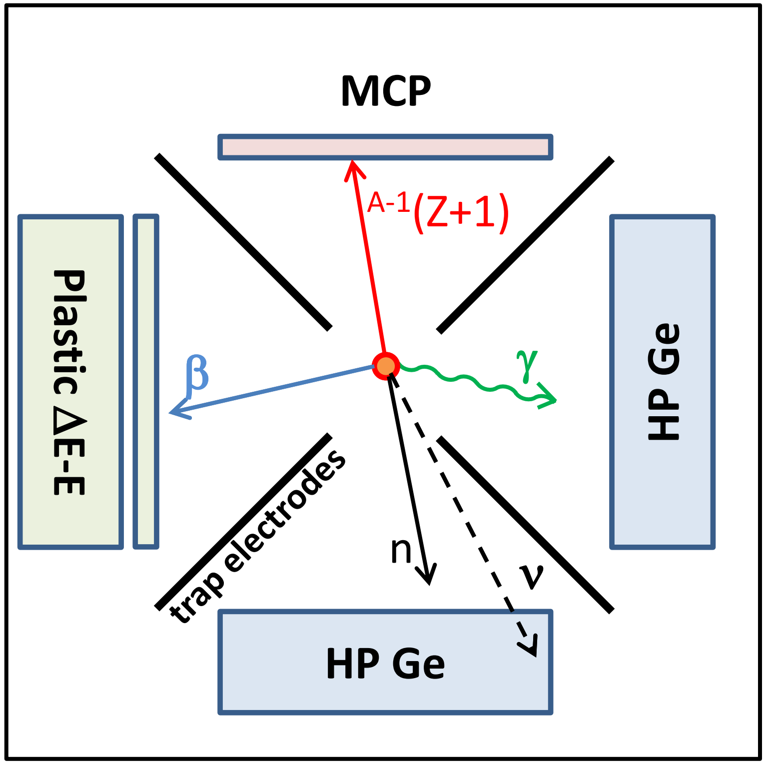
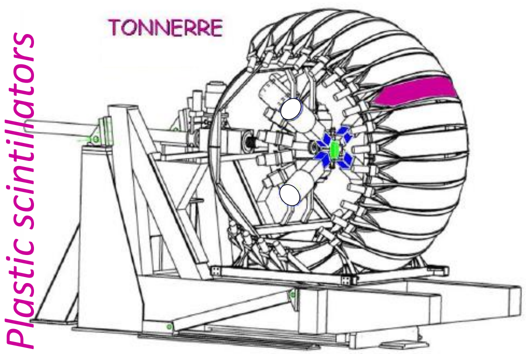
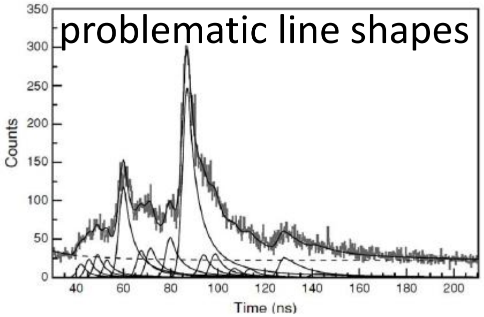
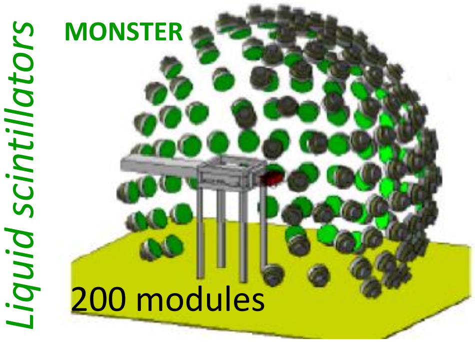
$\quad \hookrightarrow {}^{A-1}(Z+1) + n$





$\varepsilon_{total}(\beta\&n)$: ~15%@1 MeV
resolution : ~10%
n-threshold : ~300 keV
problematic line shapes



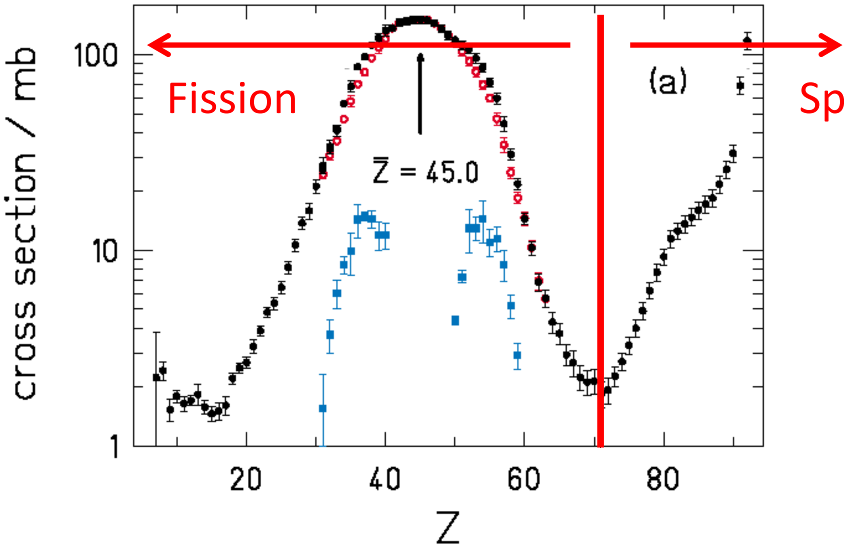


$\varepsilon_{total}(\beta\&n)$: ~5%@1 MeV
resolution : ~5%
n-threshold : ~100 keV

$^{53,54,(55)}K$ β-decay at SPES

Nuclei produced via asymmetric fission -> feasible at SPES?

P. Armbruster et al., Phys .Rev. Lett. 93 (2004) 212701



ISOLDE rates:

^{51}K (365 ms): > 5000 pps

^{53}K(30 ms): 50 pps at least, up to 200 pps

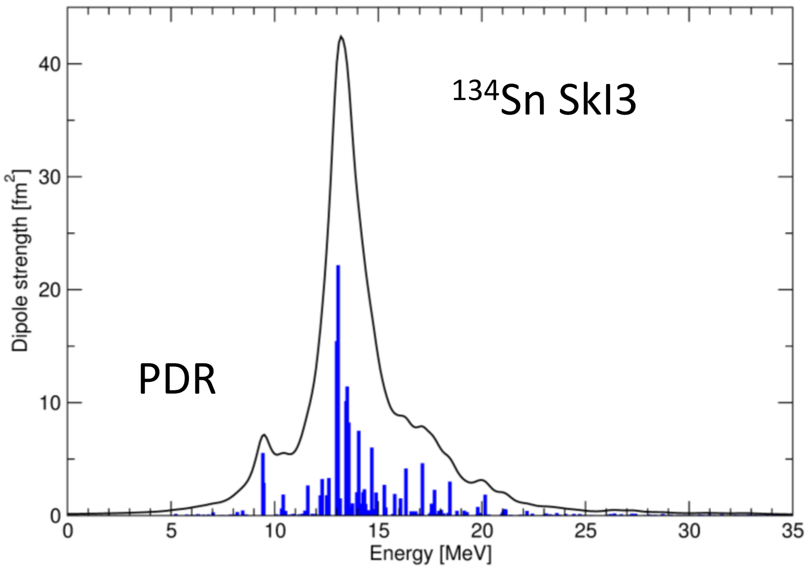
^{54}K(10 ms): some pps (maybe 10 pps) ?

With SPES gain in intensity and extraction time ?

Resonances populated via β decay

The large Q_β-value window (> 12 MeV) allows populating at least the PDR

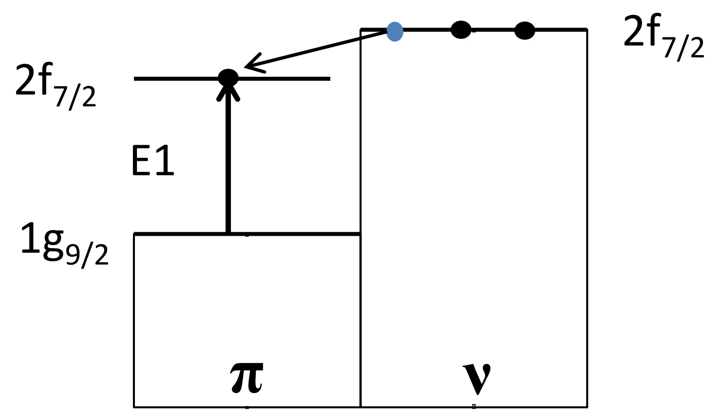
The β decay could populate states which are the PDR on the IAS(R) of the mother nucleus



Example: ^{134}In -> ^{134}Sn (Q_β= 14.7 MeV)

$\nu f_{7/2}$ -> $\pi g_{9/2}$

β decay: $\nu 2f_{7/2}$ -> $\pi 2f_{7/2}$, $\pi 2f_{5/2}$;



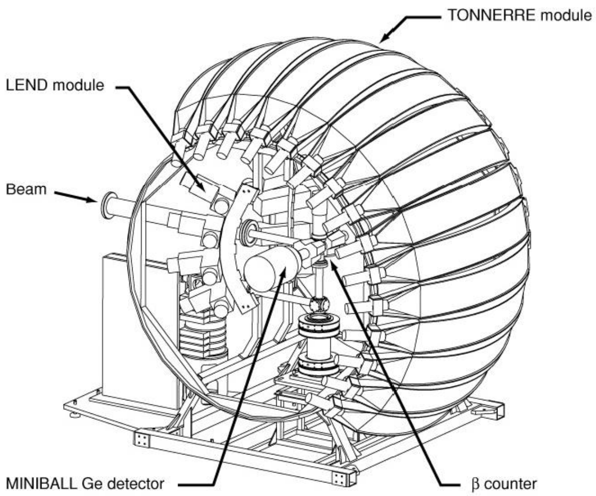
QRPA calculations with the SkI3 interaction: PDR at 10 MeV

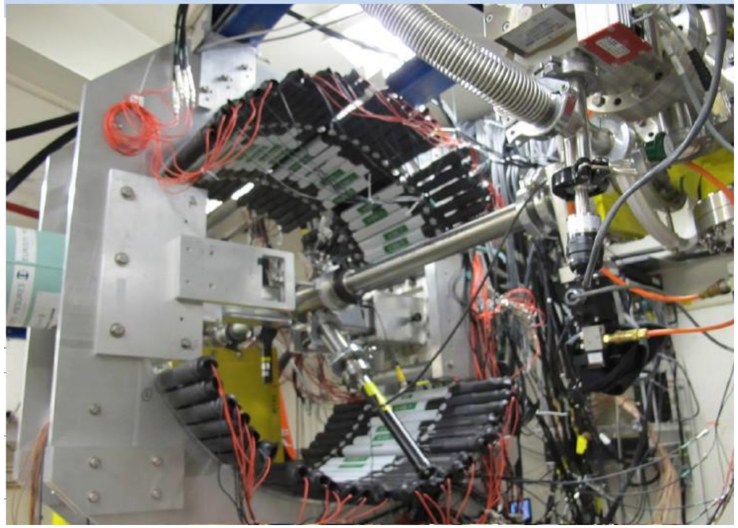
^{133,134}In rates @ ALTO: 1000 pps ; 25 pps (100 times higher at SPES)

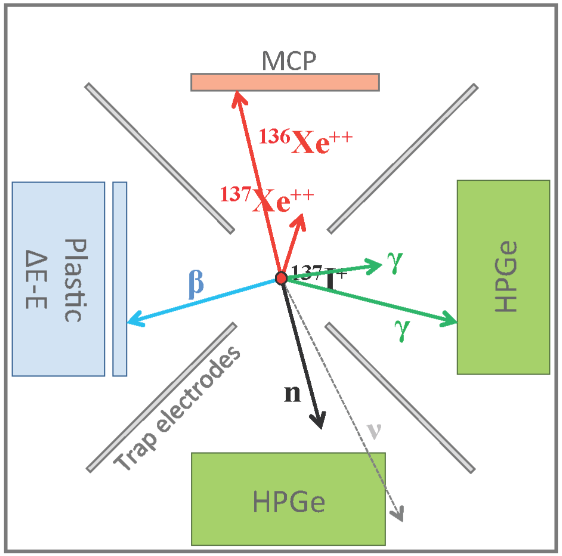
Experimental setup

Tonnere, VANDLE neutron arrays

ε: 12 %; σ: 120 keV (1 MeV)







Ion trap for neutron spectroscopy?

ε: > 60 %; σ: 30 keV (1 MeV)

R.M. Yee et al., Phys. Rev. Lett.110 (2013) 092501

Polarized radioactive beams: spin of states via the neutron angular distribution

Collaboration

A. Gottardo[1], D. Verney[1], M. N. Harakeh[2], G. Colò[3], G. Benzoni[3] , M. Vandebrouck[4], D.Mengoni[5], G. de Angelis[6], F. Azaiez[1], D. Bazzacco[5], S. Bottoni[3], A. Bracco[3], F. Camera[3], F. Crespi[3], M.C. Delattre[1], A. Etilé[7], D. T. Yordanov[1], S. Franchoo[1], C. Gaulard[7], G. Georgiev[7], A. Goasduff[7], Gramegna[6], S. Grévy[8],J. Jaworski[6], P.R. John[5], S. Lenzi[5], S. Leoni[3], J. Ljungvall[7], R. Li[1],S. Lunardi[5], I. Matea[1], T. Marchi[6], V. Modamio[6], A. I. Morales[3], P. Morfouace[1], D. Napoli[6], B. Roussière[1], F. Recchia[5], S. Roccia[7] , I. Stefan[1], D. Testov[1], J.J. Valiente-Dobón[6], A. Vitturi[5] , O. Wieland[3]

[1]*Institut de Physique Nucléaire d'Orsay, F-91406 Orsay, France*
[2]*Kernfysisch Versneller Instituut, University of Groningen, NL-9747 AA Groningen, The Netherlands* [3]*Dipartimento di Fisica, Università di Milano e Istituto Nazionale di Fisica Nucleare, Sezione di Milano, I20100 Milano, Italy*
[4]*GANIL, CEA/DSM-CNRS/IN2P3, F-14076 Caen, France*
[5]*Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35100 Padova, Italy*
[6]*Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*
[7]*CSNSM, UMR 8609, IN2P3-CNRS, Université Paris-Sud 11, F-91405 Orsay Cedex, France*
[8]*CENBG—Université Bordeaux 1—UMR 5797 CNRS/IN2P3, F- 33175 Gradignan, France*

Status of

PIPERADE

PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR

A test bunch of DESIR

CENBG

P. Alfaurt, B. Blank, F. Delalee, L. Daudin, S. El Abbeir, M. Gerbaux, S. Grévy, H. Guérin, L. Serani, B. Thomas

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

P. Ascher, K. Blaum, M. Heck, E. Minaya, S. Naimi, A. de Roubin

LPC Caen

G. Ban, J.- F. Cam, E. Liénard,

GANIL

P. Delahaye, G. Grinyer, J.-C. Thomas

CSNSM

P. Dupré, D. Lunney

IPN ORSAY

L. Perrot

ANR

REGION AQUITAINE

UNIVERSITÉ DE BORDEAUX

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MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Institut de Physique Fondamentale

Fonds Européen de Développement Régional

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- precision measurements
- nuclear structure
- …

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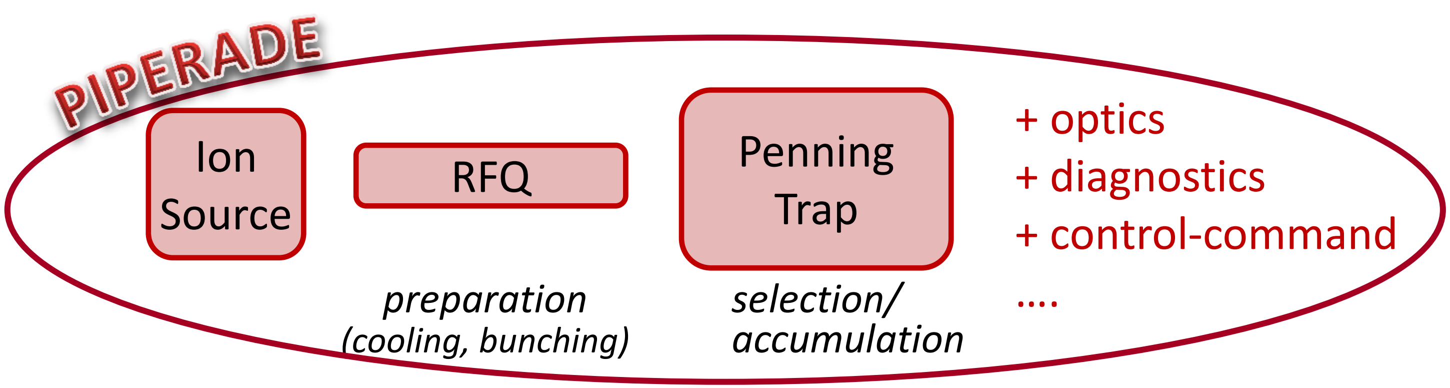
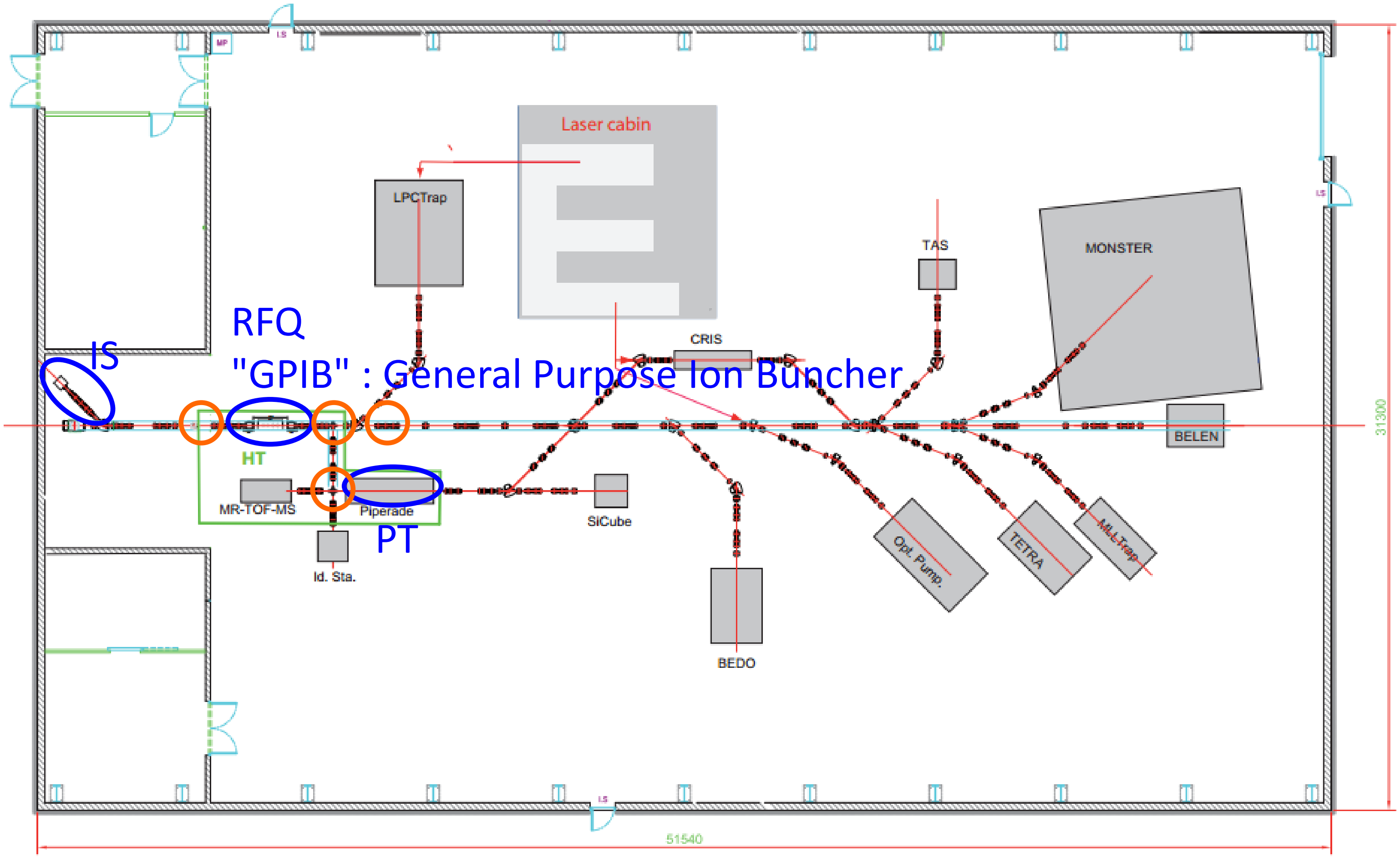


PIPERADE @DESIR

PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR



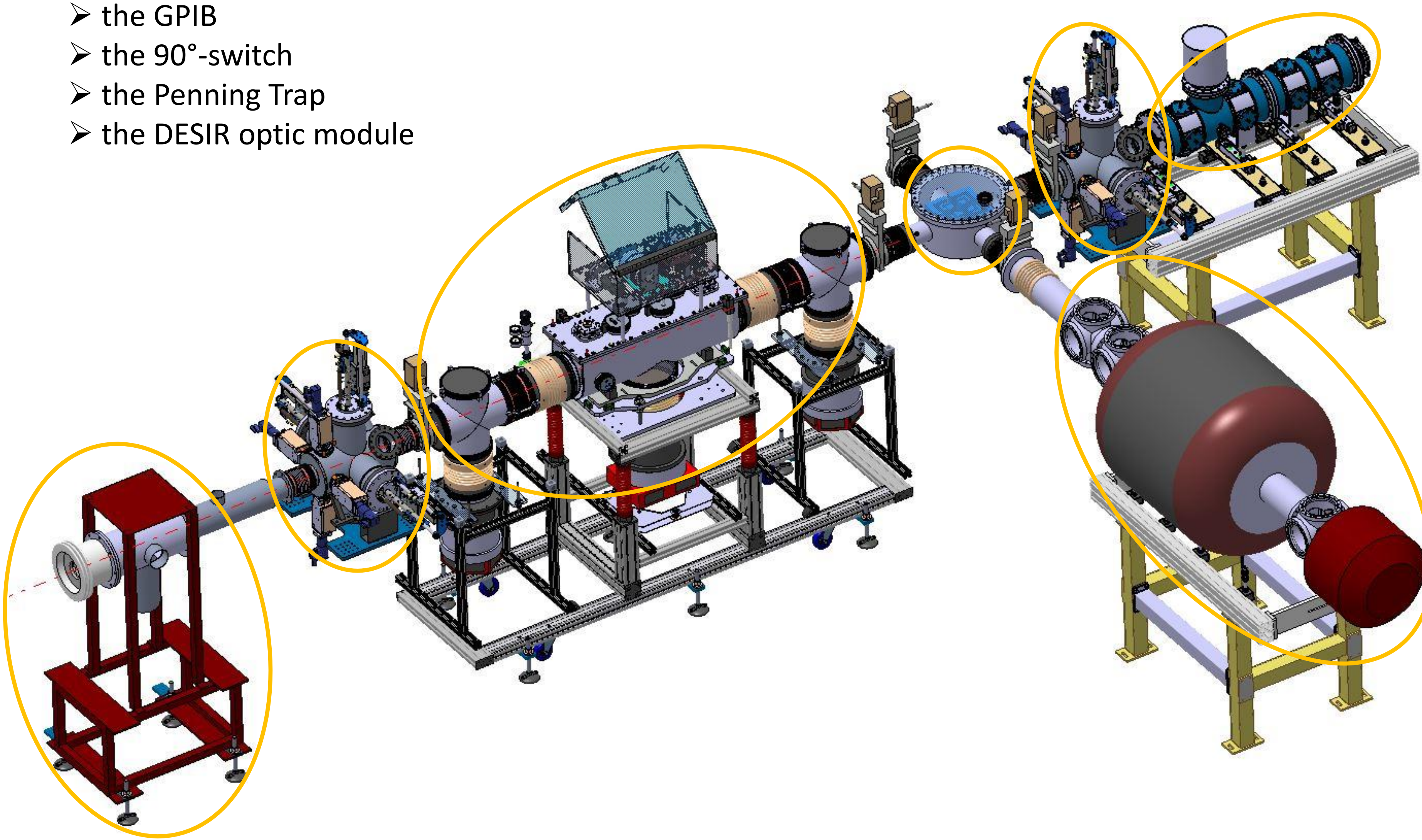
Constraints on PIPERADE @ CENBG

- control command "DESIR-like"
- generic diagnostic boxes
- 90° switch
- test of the DESIR optic module prototype

2015 PIPERADE @ CENBG

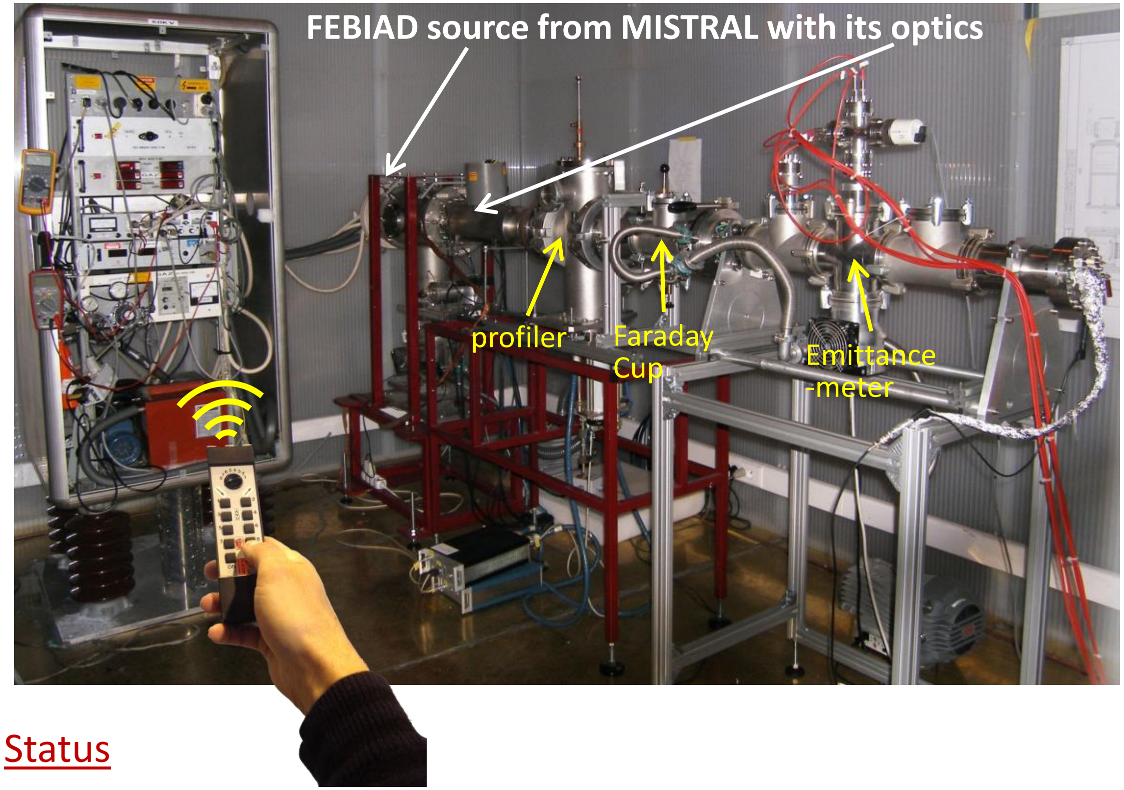
PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR

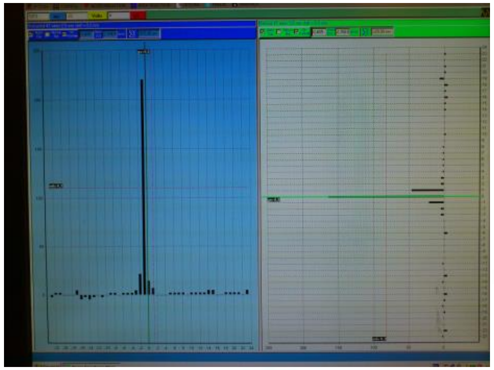
- the ion source
- the diagnostic boxes (X-Y-slits, emittance-meter, profiler, MCP, Si detector, Faraday Cup)
- the GPIB
- the 90°-switch
- the Penning Trap
- the DESIR optic module

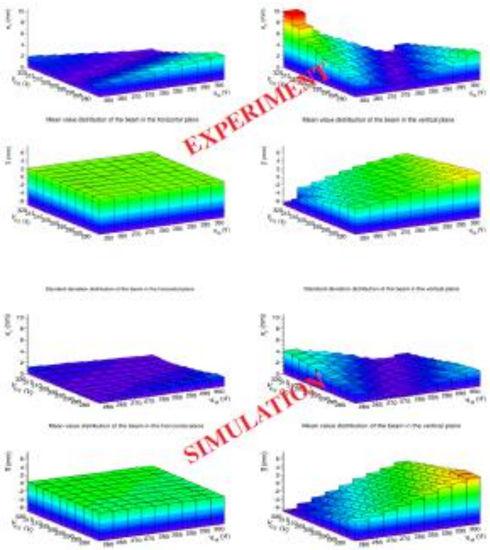


Ion Source

H. Guerin, P.Alfaurt, L. Daudin, M. Gerbaux, S.G - CENBG







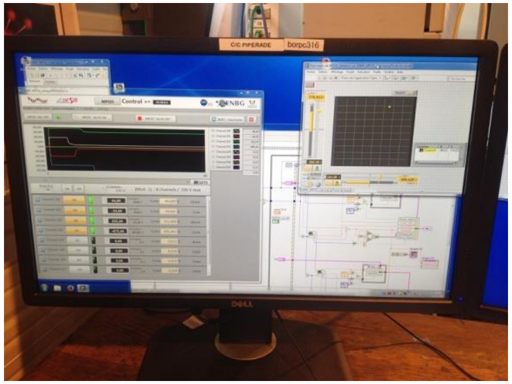
Status

→ Running since march 2013, 25 nA without gaz
→ Caracterization of the optics (comparison with simulations)
→ Emittance measurements

Ongoing

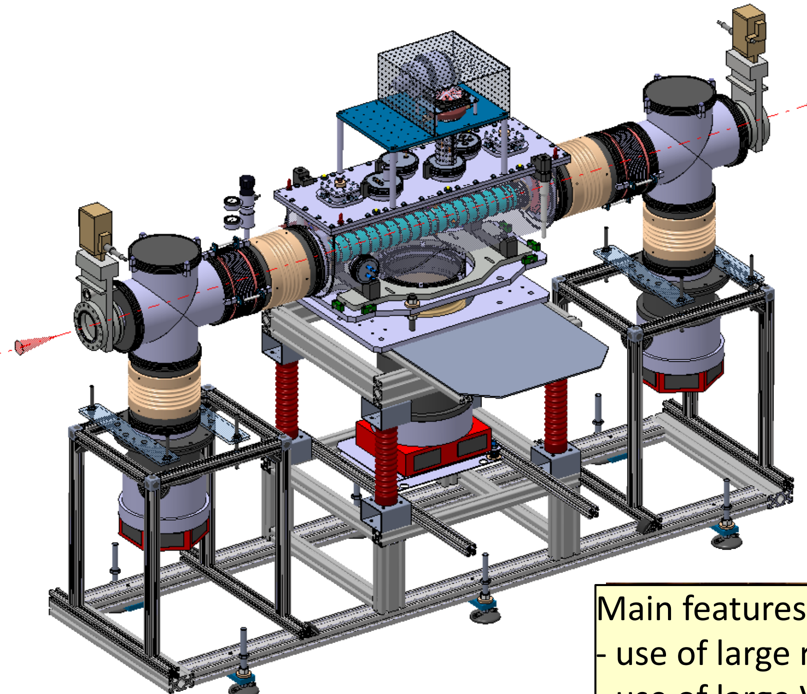
→ Renovation of the control-command
- power supplies (new)
- gaz regulation
- vacuum system
- security

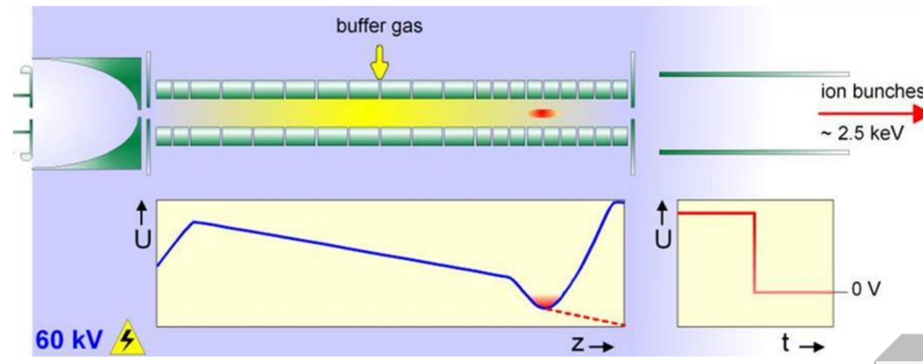
→ beam next week (march 31th)



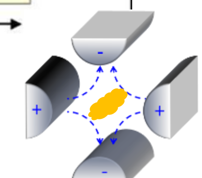
RFQ GPIB

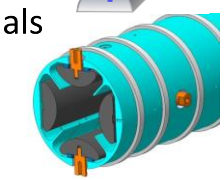
H. Guerin, S. El Abbeir, B. Thomas, L. Daudin, M. Gerbaux, S.G. - CENBG





- ions slowed down by the HV platform
- Ions cooled in the gas
- Radial confinement by RF potential on 4 rods
- Longitudinal confinement and bunching by DC potentials on ring electrodes





Main features :
- use of large r_0 to handle large bunches (less RF heating)
- use of large V_{RF} for better confinement

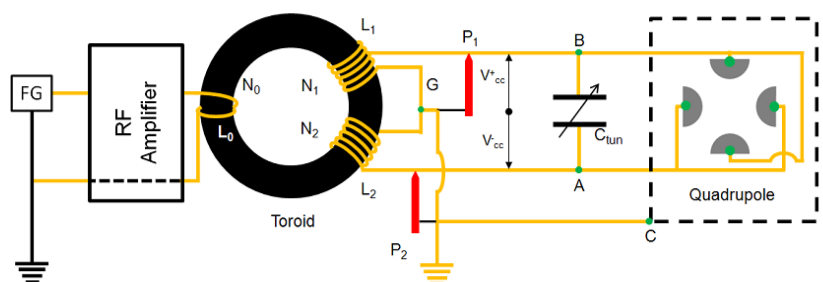
For 10^6 ions/bunch :
- transverse emittance : ~1 π.mm.mrad@60keV
- longitudinal emittance : < 10 eV.μsec
- bunch length : ~800 ns

Status

→ Simulations done
→ Mechanics ready
→ Pumping system ready
→ DC power supplies ready

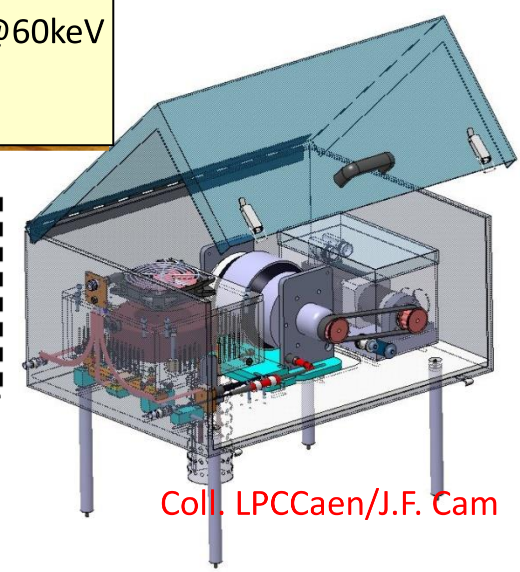
Ongoing developments

→ Control-command (power supplies, timing…)
→ Gaz system
→ RF system



BaLun Circuit

Step-up voltage transformer γ
Symetric voltage (ground equilibrium)
Frequency filter (Q factor)



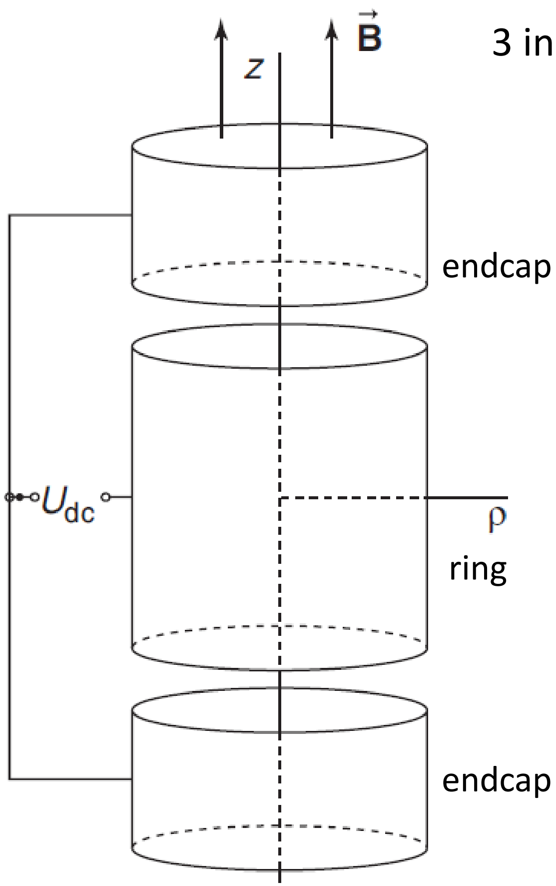
Coll. LPCCaen/J.F. Cam

→ first beam in the GPIB : june 2014

Penning Trap - Principles

Trapping (i.e. confinement in all 3 dimensions) obtained by:

- electrostatic quadrupolar field (axial confinement) $\Phi(z,r) = \frac{U_{dc}}{2d^2}\left(z^2 - \frac{1}{2}r^2\right)$
- homogeneous magnetic field (radial confinement)



3 independent motions at 3 eigenfrequencies

axial motion

$$\omega_z = \sqrt{\frac{qU_{dc}}{md^2}}$$

ω_z ~ 100 kHz

magnetron motion

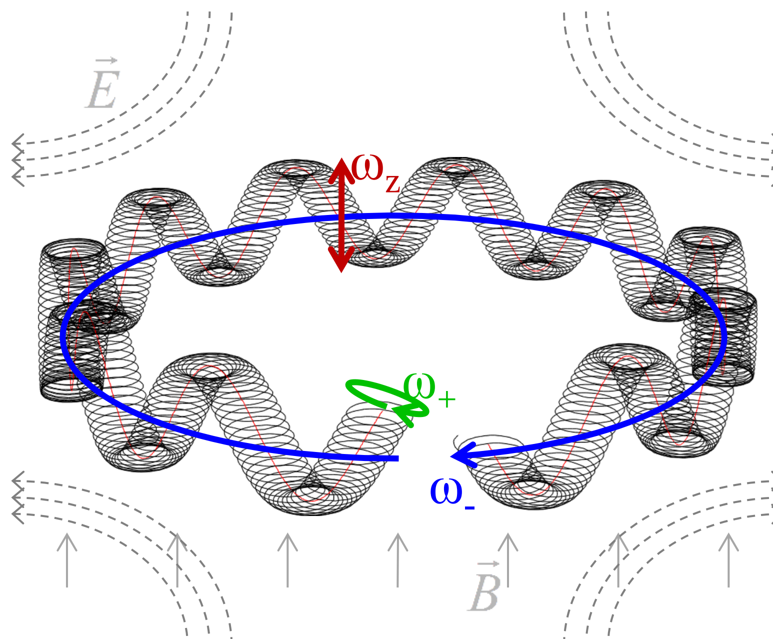
$$\omega_- = \frac{\omega_c}{2} - \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

ω_- ~ kHz

modified cyclotron motion

$$\omega_+ = \frac{\omega_c}{2} + \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

ω_+ ~ 10MHz



Penning Trap - Isobar separation

Sideband buffer gas cooling:

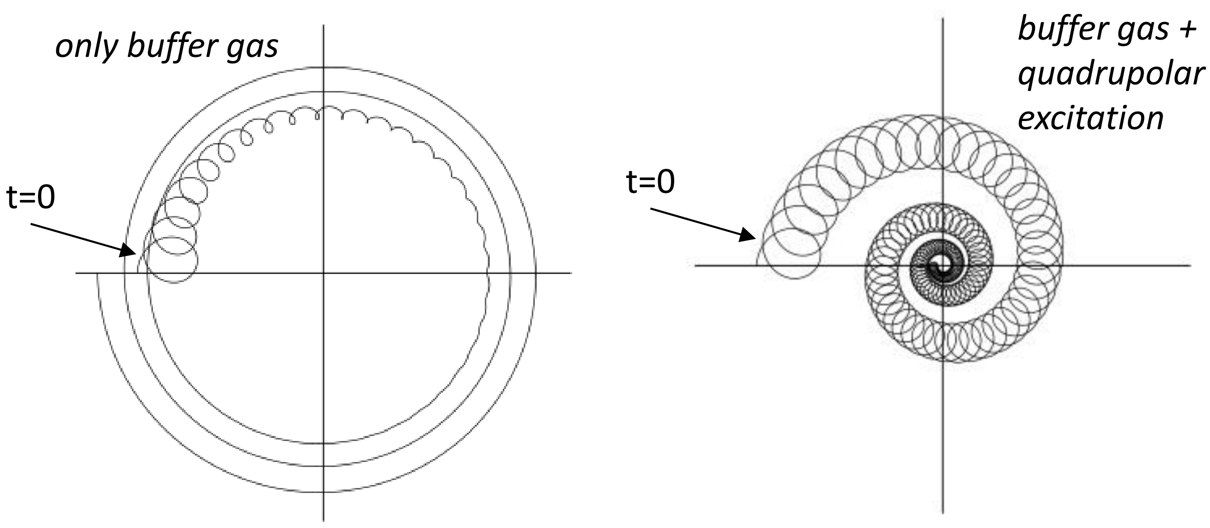
- Dipolar excitation at the magnetron frequency $\omega_- \approx \frac{U_{dc}}{2d^2B}$

(in first order mass independent, all the ions are brought to a higher radius)

- Combining the effect of buffer gas and the use of a quadrupolar excitation at $(\omega_+ + \omega_-)$
  - quadrupolar excitation: coupling the two radial modes
  - buffer gas: cyclotron motion is cooled, magnetron motion increases

-> radii of both motions are cooled

-> mass-selective centering



G. Savard et al, Phy.Lett. A 158, 247-252 (1991)

Penning Trap - Space charge effects

P. Ascher, S. Naimi, A. de Roubin - MPIK, P. Dupré CSNSM

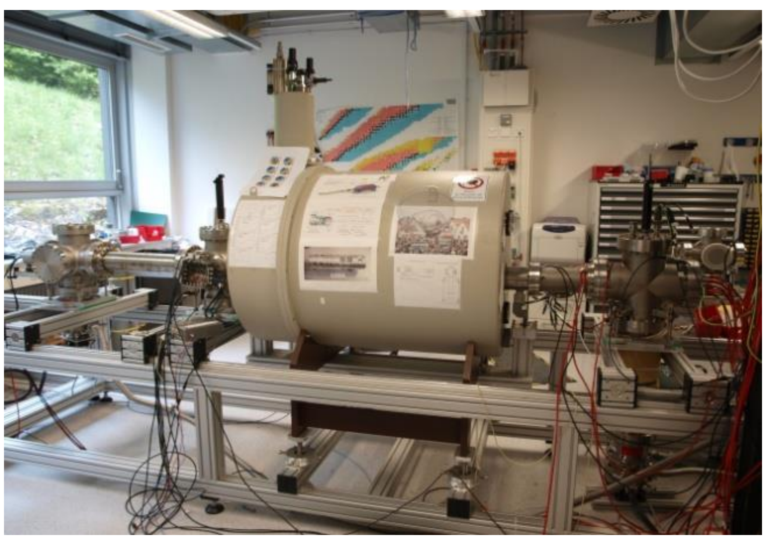
Increasing the number of ions makes the re-centering inefficient

Additional potential created by the cloud itself
→ f-shifts, peak broadening, screening effects

Alternative techniques…

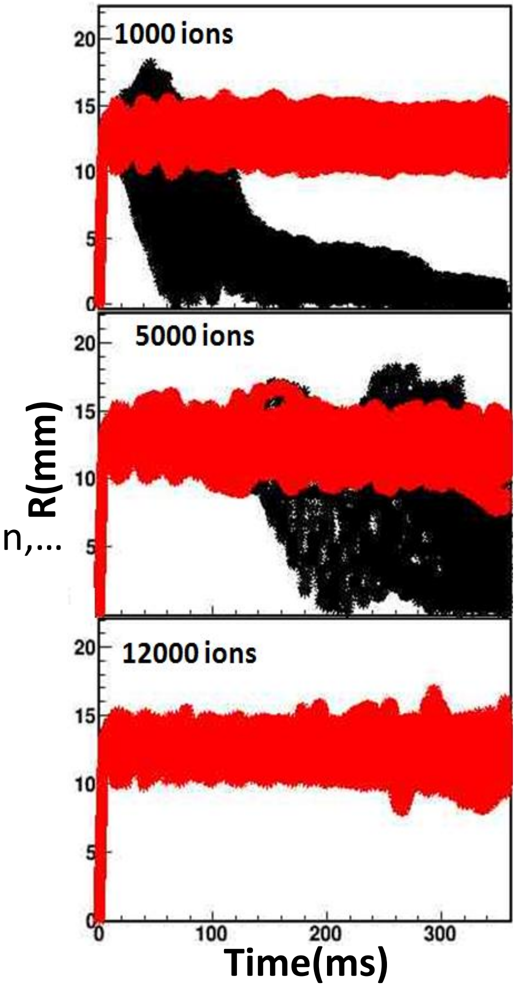
Antisymetric Rotating Wall technique, Phase splitting, … *under study at CSNSM*

Axial coupling, SWIFT technique, SIMCO Excitation,… *under study at MPIK*

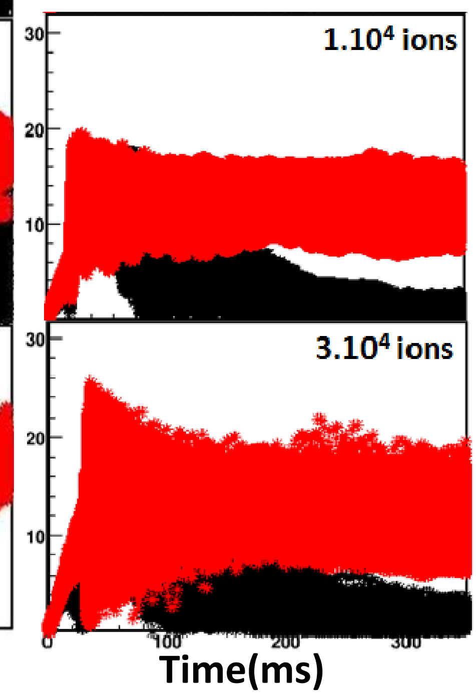


90% ^{136}Te, 10% ^{136}Sb P = 10^{-4} mbar B = 7T

SIMBUCA code, *S. Van Gorp et al., NIM A 638, 192200 (2011)*



With a pre-excitation at ν+ of contaminant



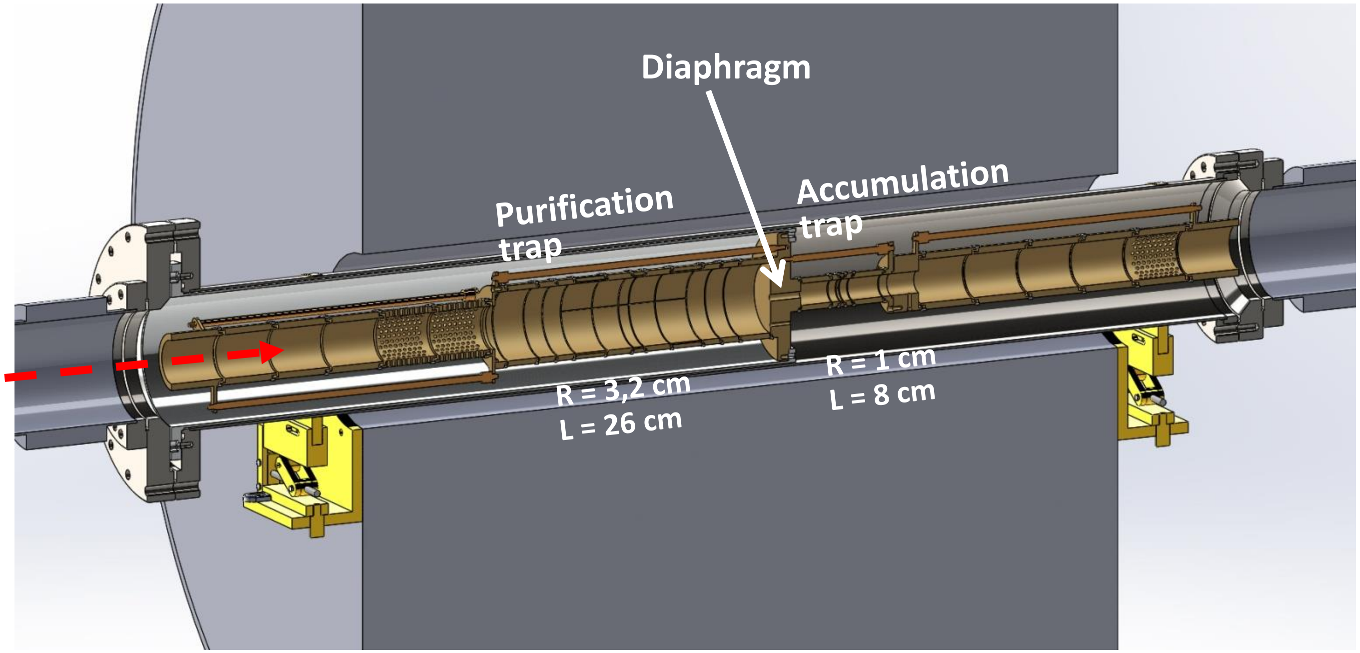
Experimental tests of the methods and investigation of the dependence on the number of ions

Penning Trap - Design Study of the double Trap

S. Naimi, P. Ascher, A. de Roubin, E. Minaya, MPIK

Double Penning trap :

- ➢ Many cycles (purification + storage) before sending large samples to experiments
- ➢ Diaphragm placed between the two traps : pumping barrier and selection of the ions of interest



Status

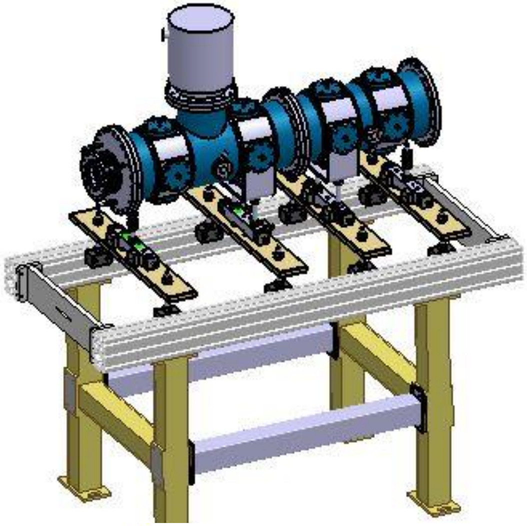
→ Design Study ready - To be built by the MPIK workshop - expected for the end of 2014
→ Call for tenders for the magnet (delivery expected april 2015)

next steps

→ Injection optics
→ Pumping, gaz system…
→ Electronics, diagnostics
  → Tests at MPIK / Transfer to CENBG ?

Other devices

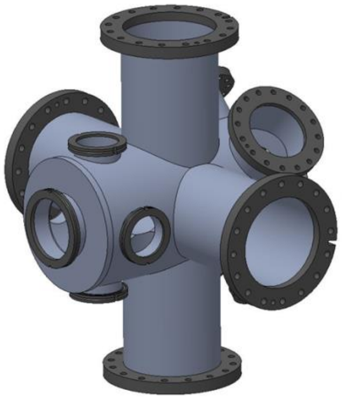
1) DESIR optic module

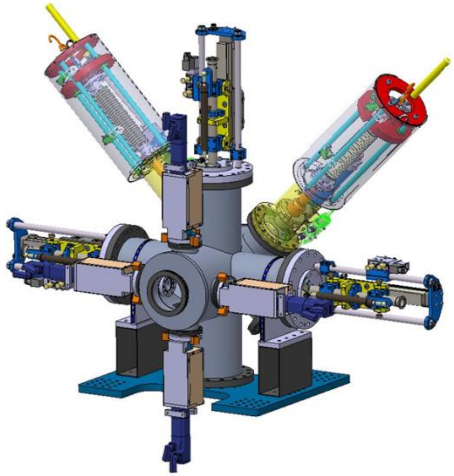


X-Y steerers + Quadrupole triplet

- design @ IPNO (L. Perrot)
- Under construction (SOMINEX)
- Pumping unit under test @ CENBG
- To be delivered @ CENBG : 09/2014

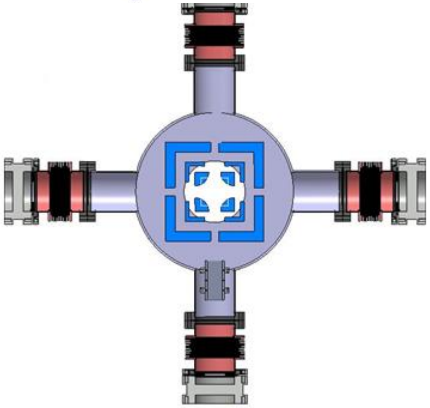
2) Diagnostic boxes





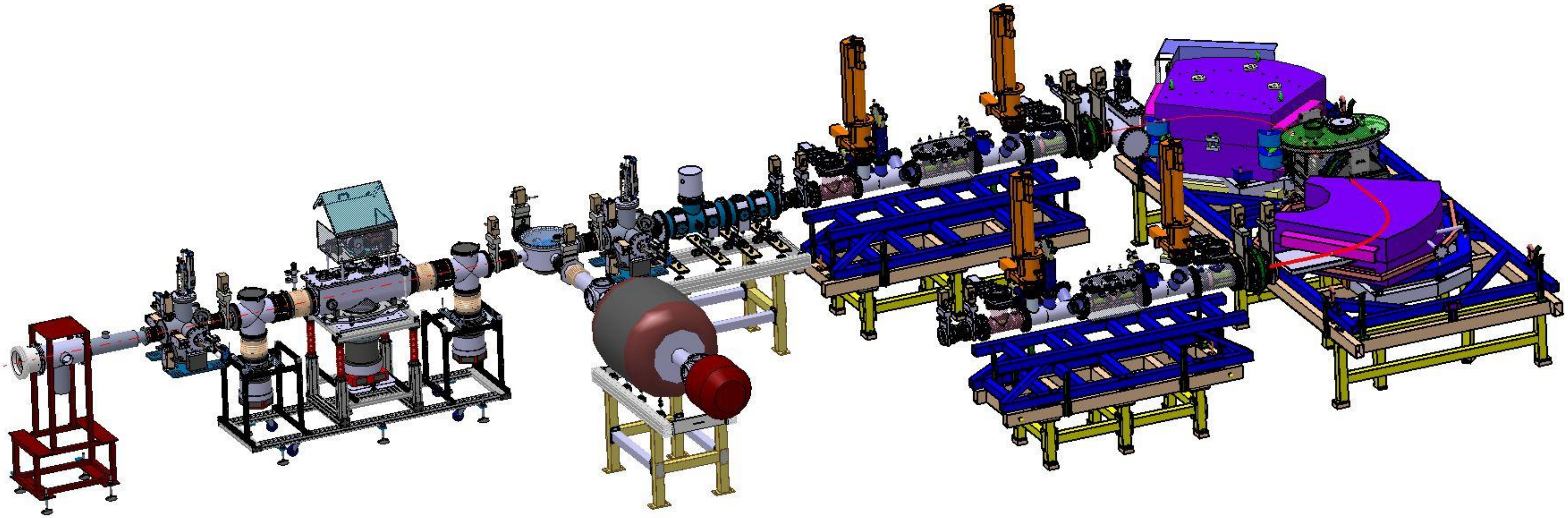
- design @ CENBG
- FEDER Basse Normandie funding @ GANIL (~190 k€)
- call for tenders launched
- expected for the end of 2014

3) 90° switch



- collaboration PIPERADE / S3-LEB
- first design done by P. Delahaye
- simulations for the transmission GPIB - PT under investigations @ CENBG

2017 PIPERADE @ CENBG



thank you for your attention

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