SHIRaC : the Spiral 2 High Intensity Radiofrequency Cooler for the DESIR Facility

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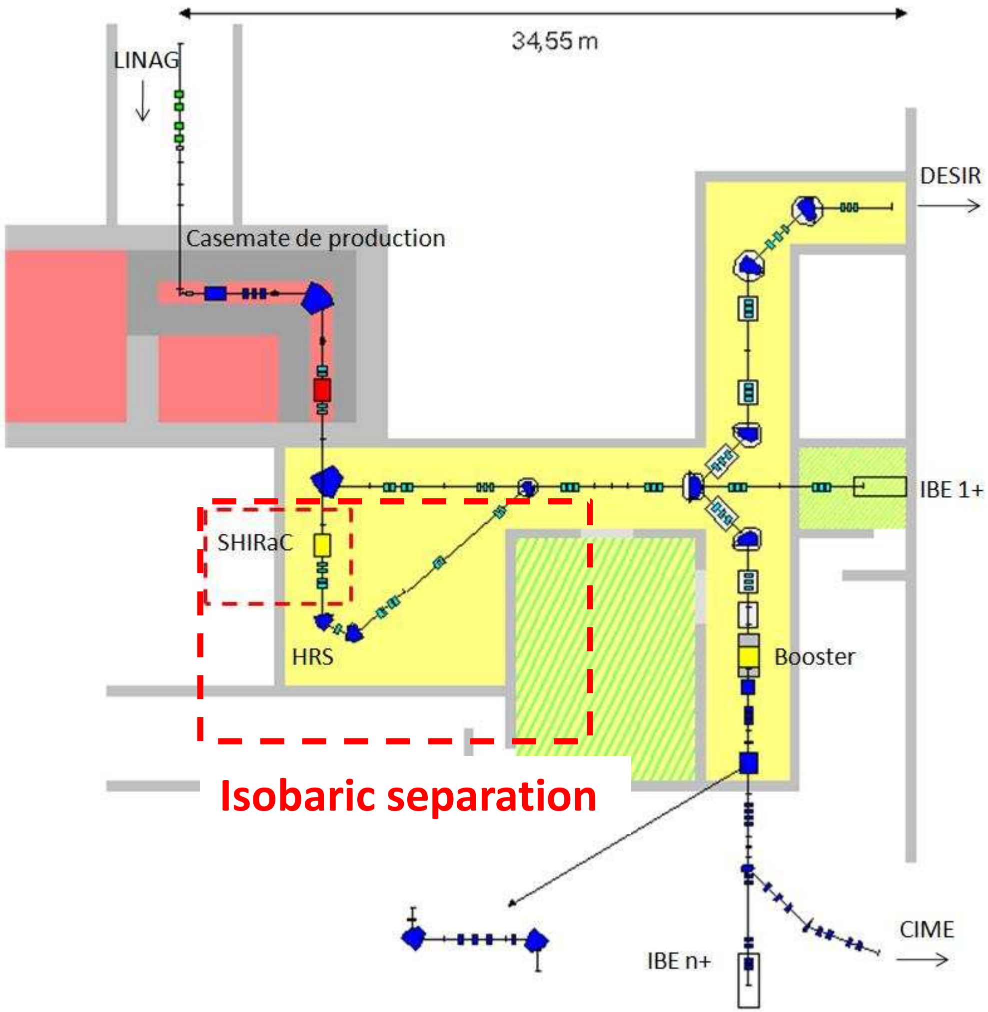
Context

- Development for the DESIR facility.
  http://www.cenbg.in2p3.fr/desir/

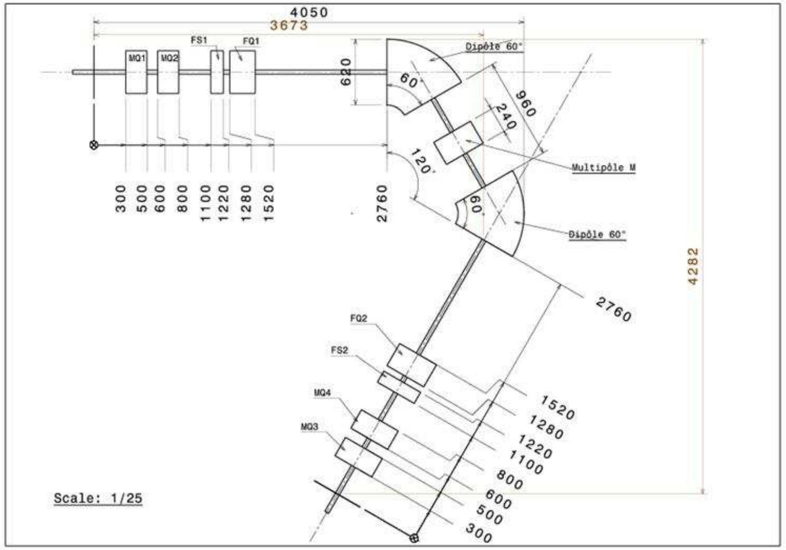
- **S**piral 2 **H**igh **I**ntensity **Ra**diofrequency **C**ooler

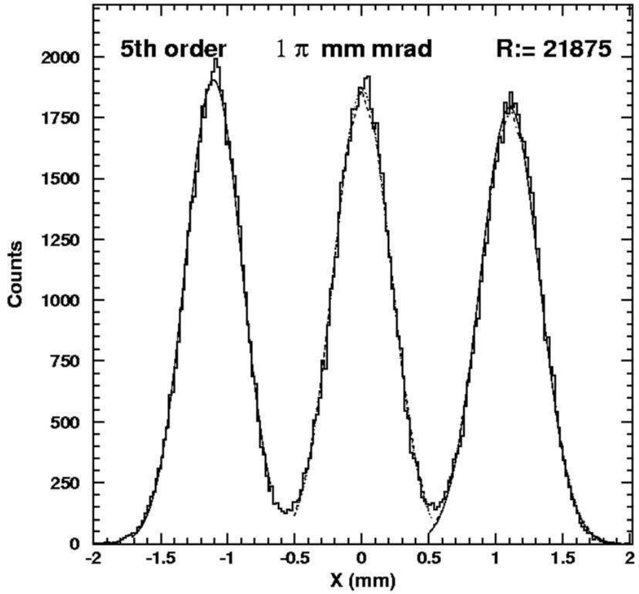
- Goal : Cooling of µA-beams from Spiral2 to low emittance.

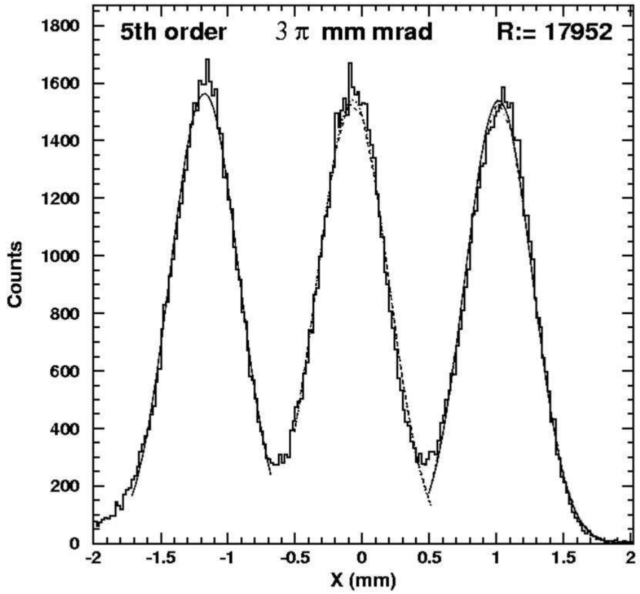


Cooling ≡ Reducing phase space of the beams

HRS mass resolution





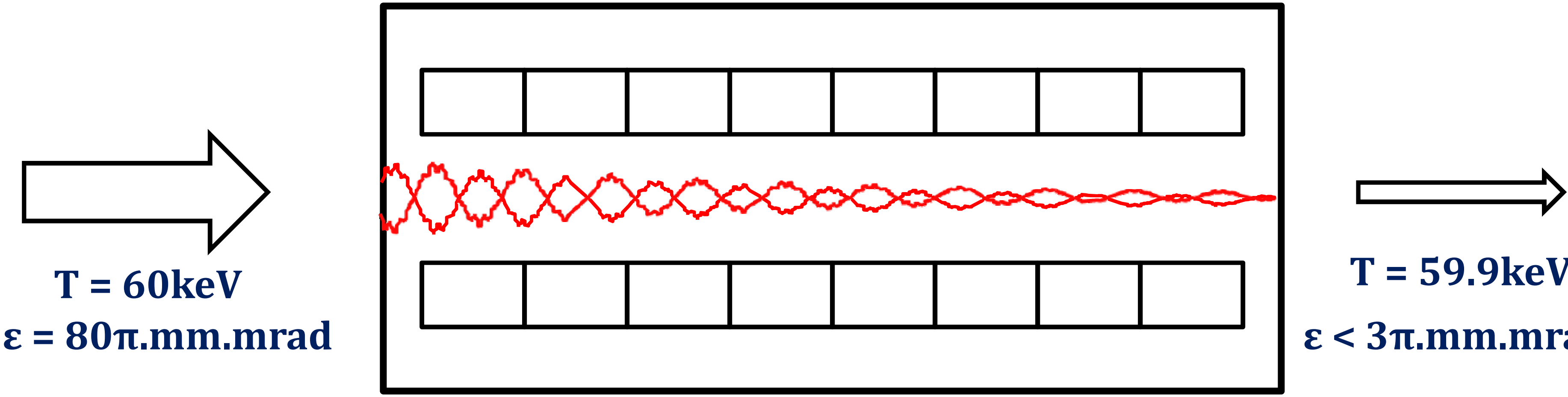


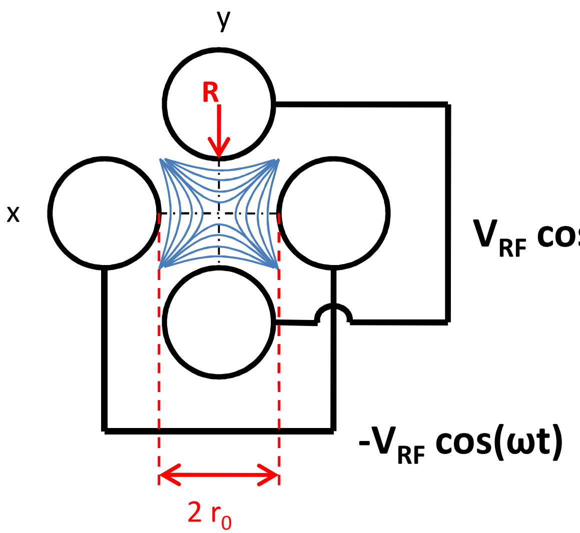
- **T. Kurtukian-Nieto *et al.*, CENBG Bordeaux**
- Mass resolution:

$$\Re = \frac{m}{\Delta m} \leq \frac{D\,\delta a}{\varepsilon}$$

  - δa : angular acceptance of the magnet
  - **ε : beam emittance**

Principle





- Ion cooling by collisions on a light buffer-gas
- Helium : 0.02-0.1 mbar
- T_{ion} ~ 100 eV
- Axial DC potential for guiding and extraction

Specificity

- Main specificity of our device :
  - Between 10 and 100 times higher beams intensities to cool → ~ µA.
  - Space charge ≡ coulombian repulsion between ions.
  - Strong RF fields needed.
    - High RF potential ~ 10kV_{pp} (Present technology ~ 500V_{pp})
    - Low inner radius ~ 3 - 5mm (Present technology ~ 5 – 20 mm)

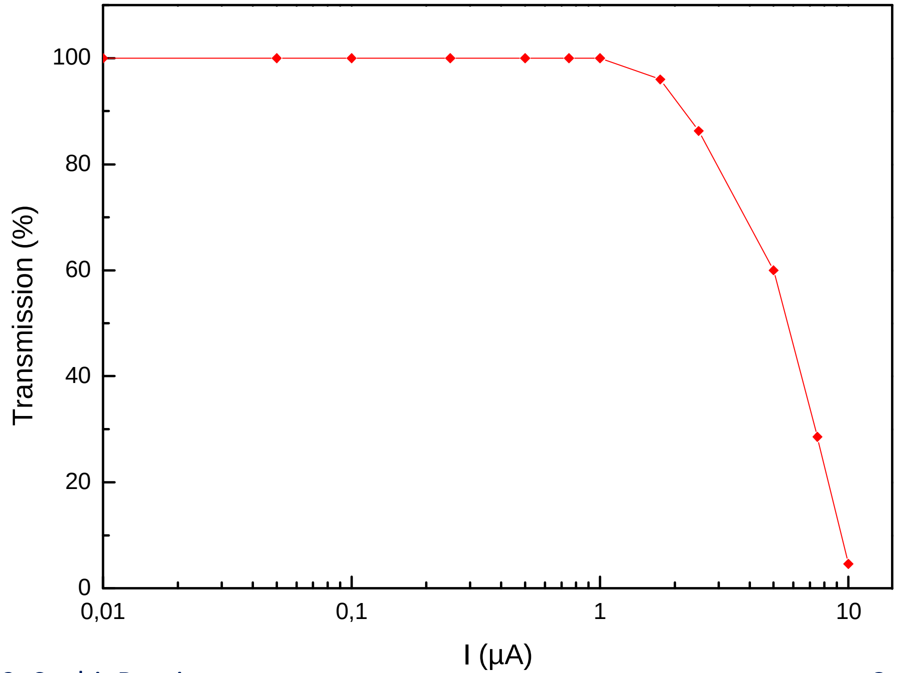
Space charge considerations

- Limitations of the RFQ Cooler (static model) :
  - Dehmelt model : maximum charge density which can be confined

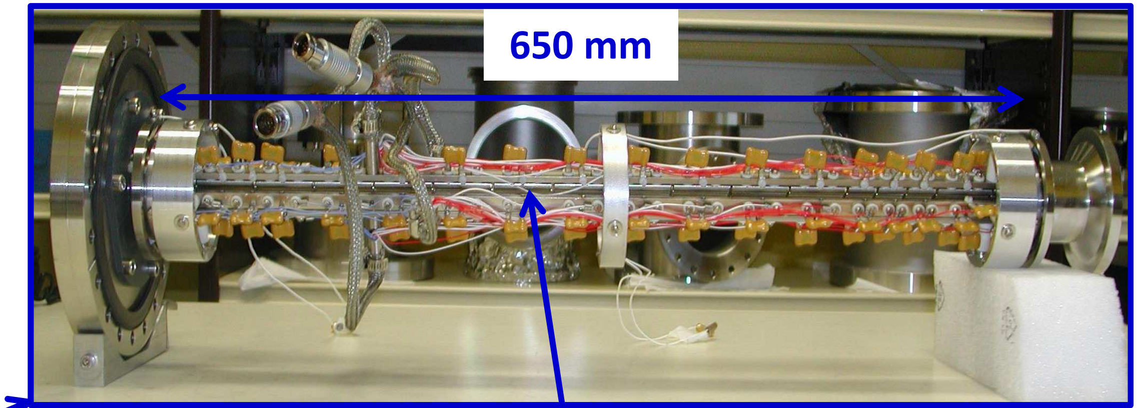
$$\rho_{max} = \frac{2.\varepsilon_0.V_{RF}^2}{m.r_0^2.\omega_{RF}^2} \xrightarrow{\rho_{max} v \propto \frac{I_{max}}{S_{charge}}} I_{max} \propto \frac{V_{RF}}{r_0}$$

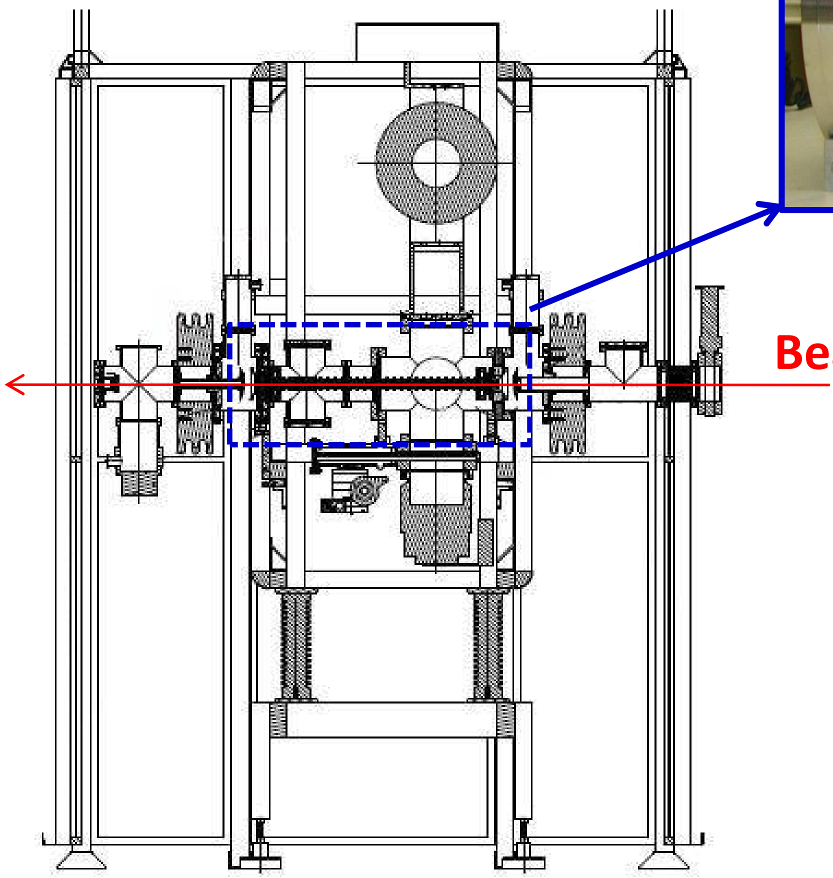
- Calculations :
  - Ion : $^{133}Cs^+$ at 1eV
  - RF : 10kV$_{pp}$ at 5.42MHz
  - r_0 = 5mm

➢ No SC losses up to 1µA



SHIRaC-Prototype 1



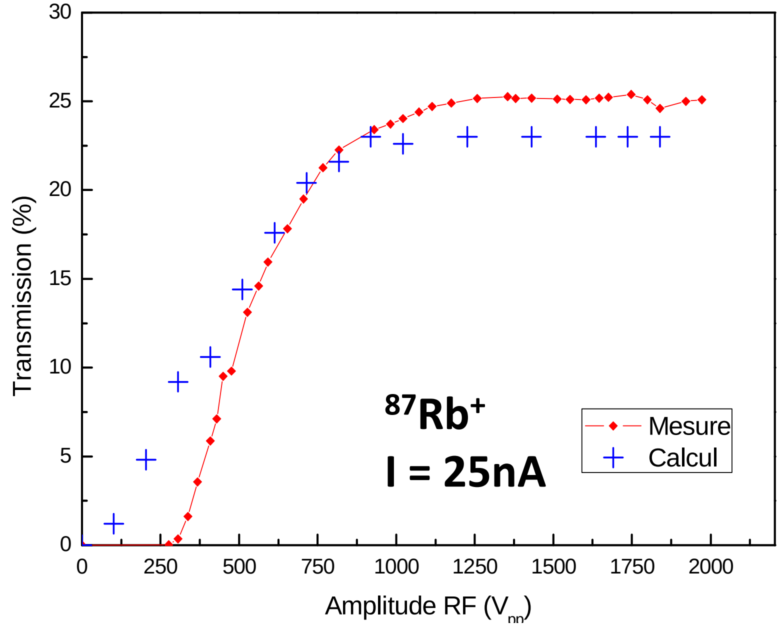


- Transmission only at CSNSM-Orsay
- Deeply modified at LPC-Caen
- RF system :
  - Help from GANIL (M. Di Giacomo)
  - LC-resonant circuit
  - V_{RF} up to $2kV_{pp}$

Transmission efficiency

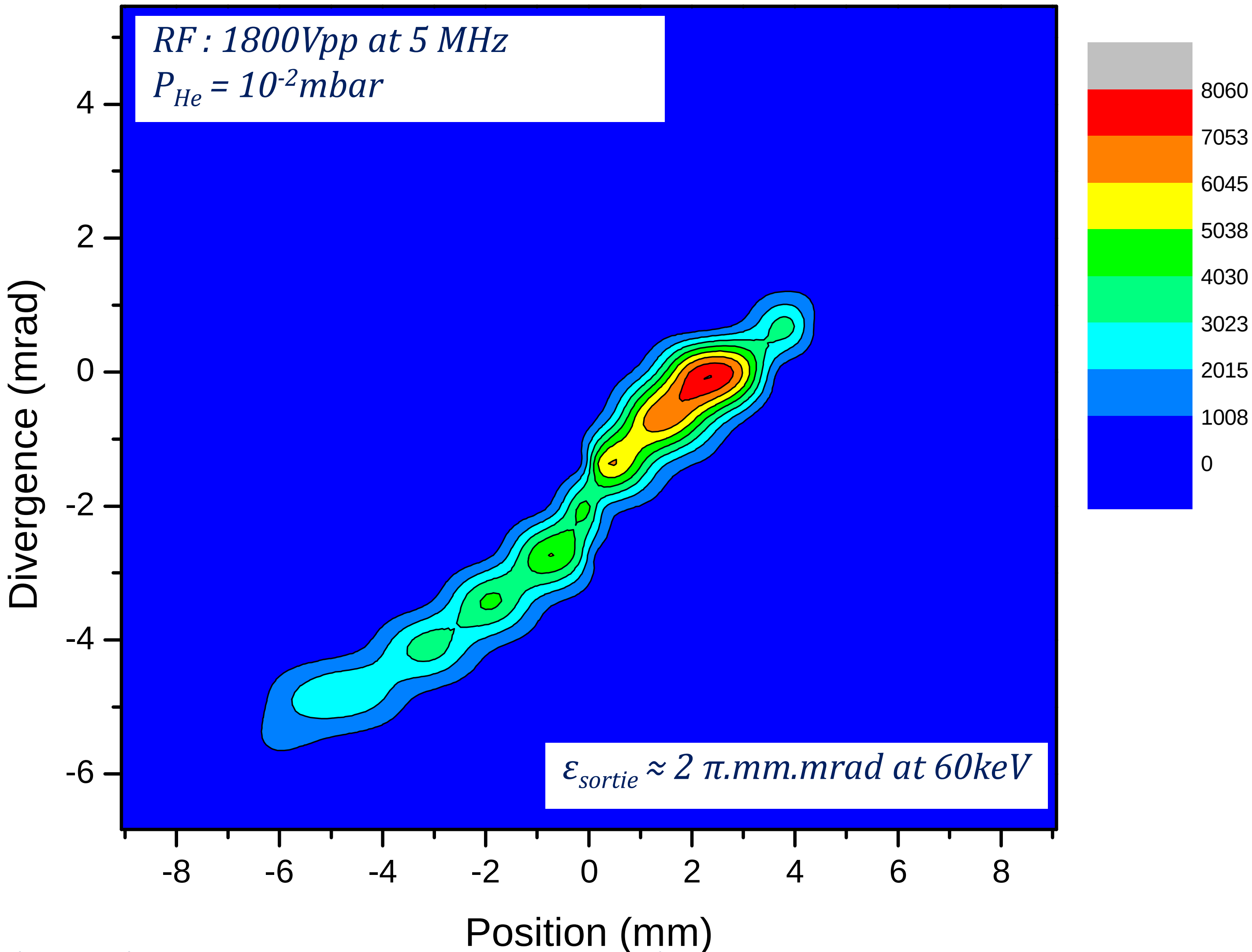
- Operating parameters :
  - Single-charged alkali beams at 3keV and few 10 nA
  - $f_{RF} \approx 5 - 6.3$ MHz
  - P_{He} = few 10^{-2} mbar

- Maximum transmission : 25% for $^{23}Na^{+}$ and $^{87}Rb^{+}$
  - ➢ *Close to required specifications*



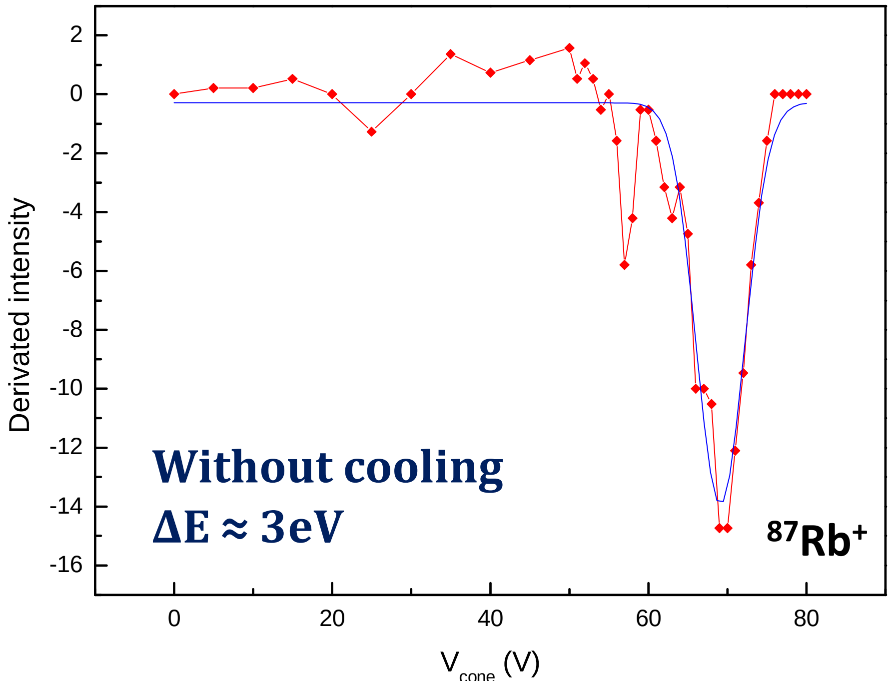
Extracted emittance

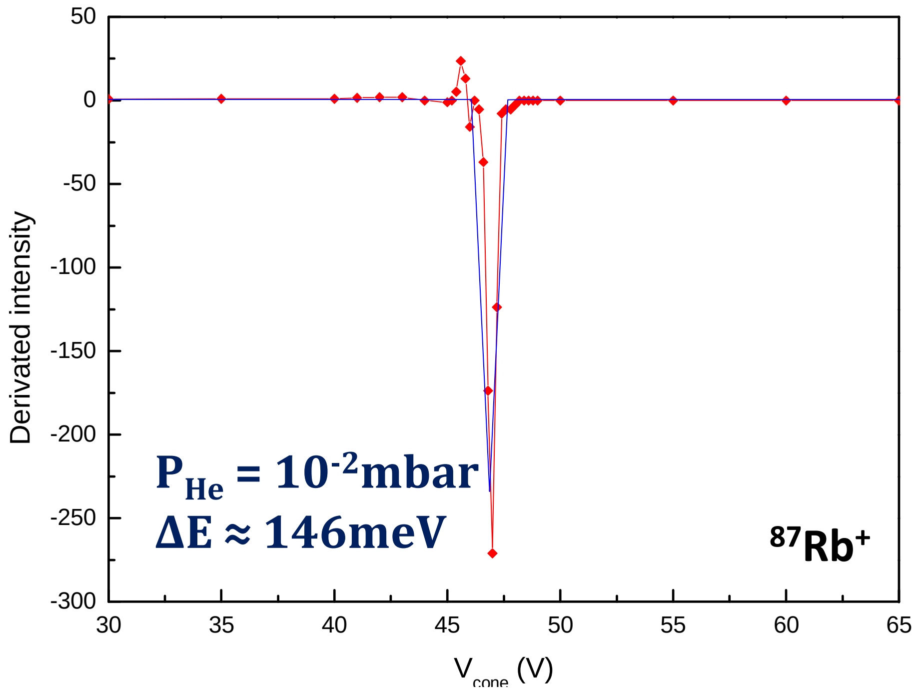
- Study of the emittance reduction at 3keV :



Longitudinal energy spread

- Measurement of the extracted intensity versus DC potential on the last section.
- Energy spread measured before reacceleration





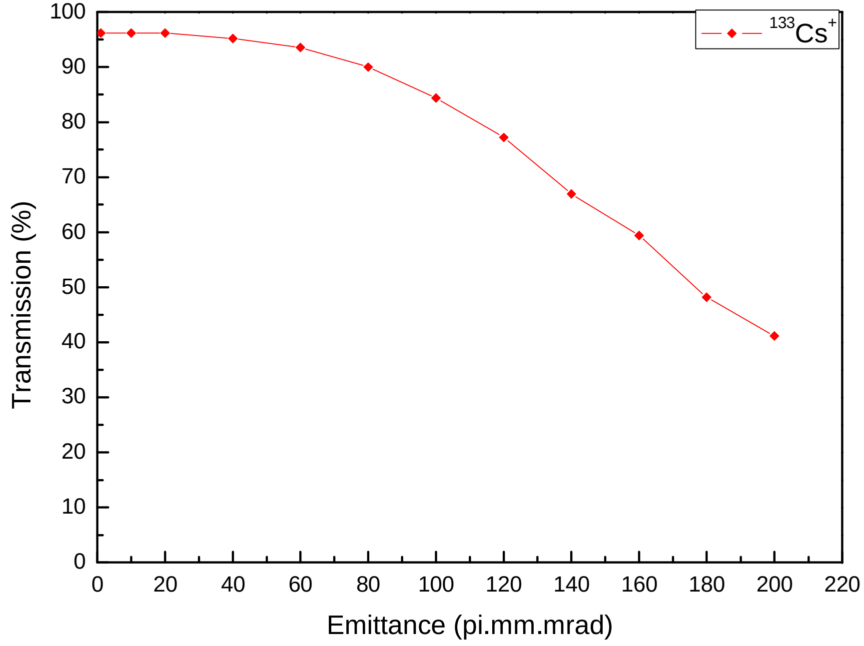
Specifications versus results

- Efficiencies :

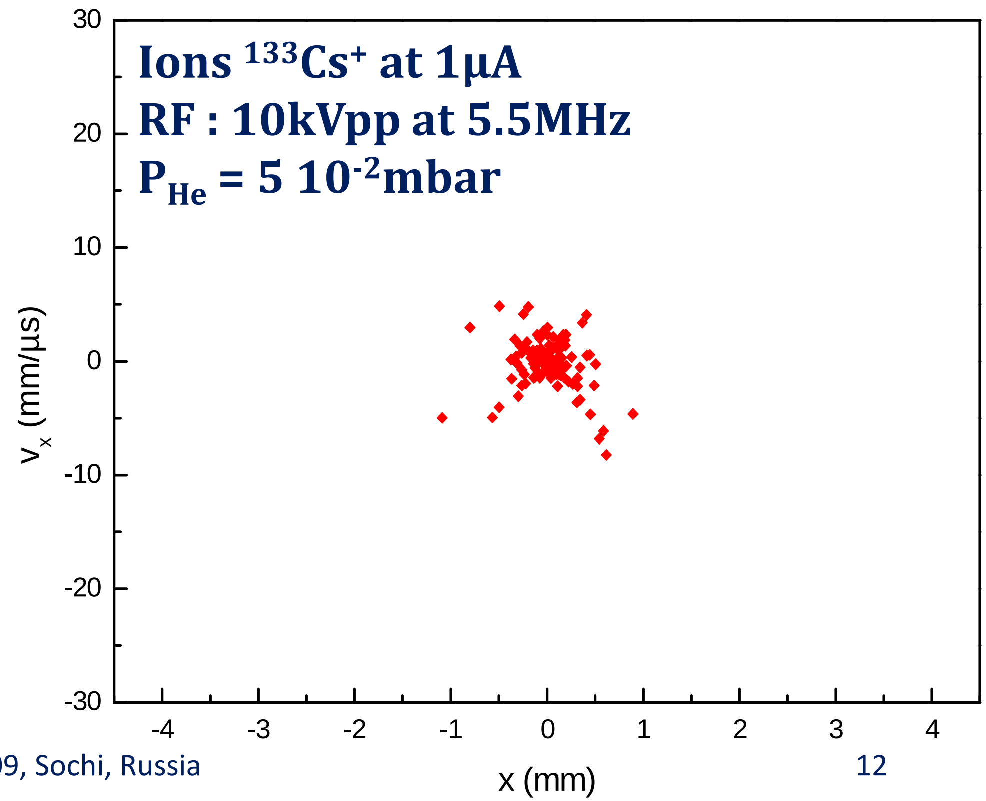
Mass		Specifications	Results
Efficiency	$^{23}Na^{+}$	20 %	25%
	$^{87}Rb^{+}$	60 %	25%
Emittance at 60keV		< 3π.mm.mrad	~ 2π.mm.mrad
Energy spread		≤ 1eV	~ 146meV

- Studies at low intensities (I ~ 25nA)
  - Energy spread and emittance reduction completed
  - Transmission 2-times lower for $^{87}Rb^{+}$
- Beam quality for experimental studies better than Spiral2.
  - Transmission need to be improved
  - Larger inner radius : 3mm → 5mm

SHIRaC-Prototype 2 : Conception

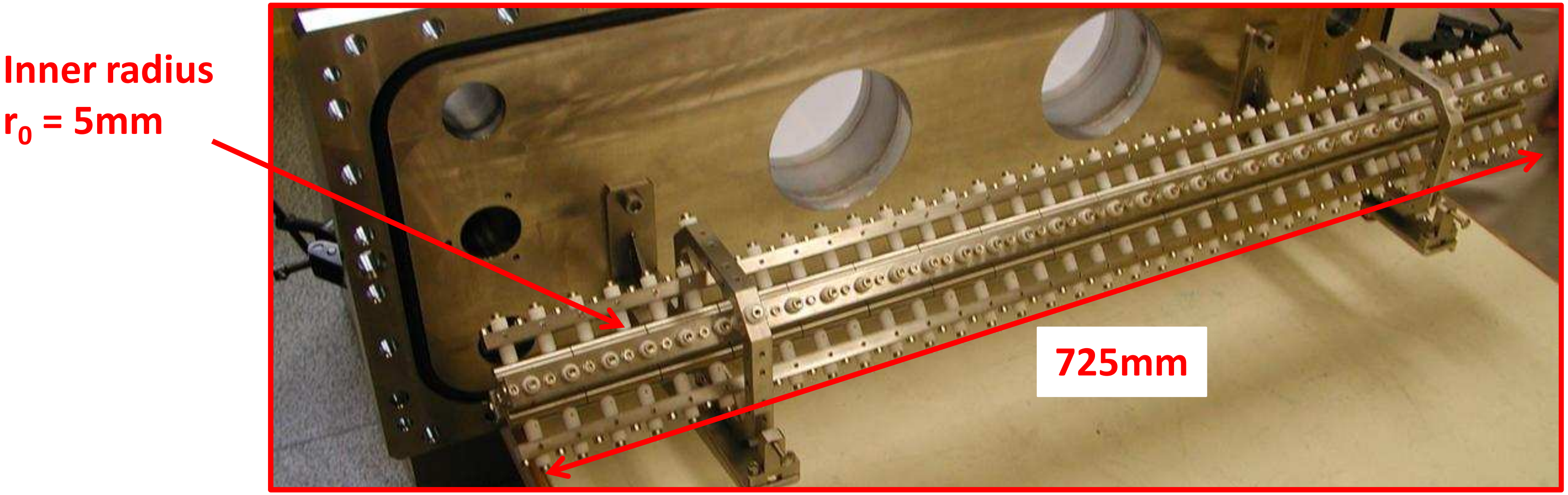


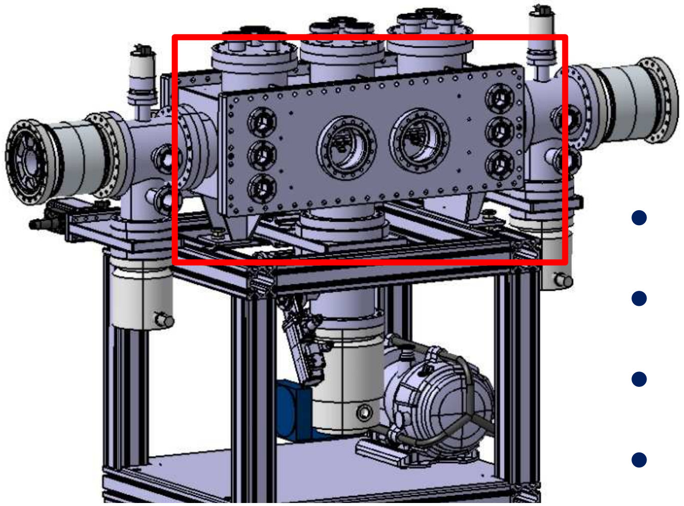
- 5mm-inner radius quadrupole
- Injection electrodes designed for Spiral2 beams



- Efficient injection
  - ➢Acceptance : 80 π.mm.mrad
- Cooling :
  - ε ≈ 2π.mm.mrad at 60keV

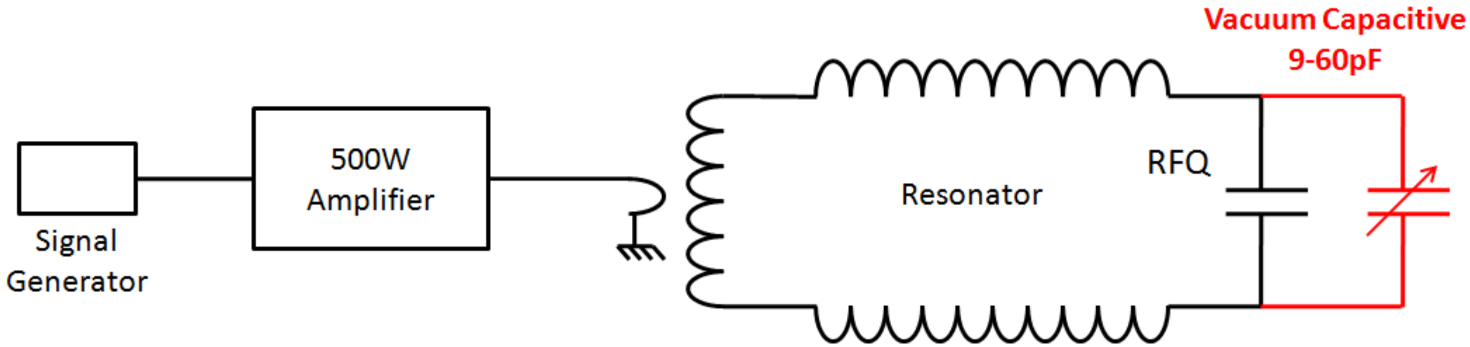
SHIRaC-Prototype 2





- The design of SHIRaC-P2 is completed
- RF system improved : V_{RF} up to $7kV_{pp}$
- Assembly in progress at LPC.
- Tests starts in 2010

SHIRaC-Prototype 2 : Developments

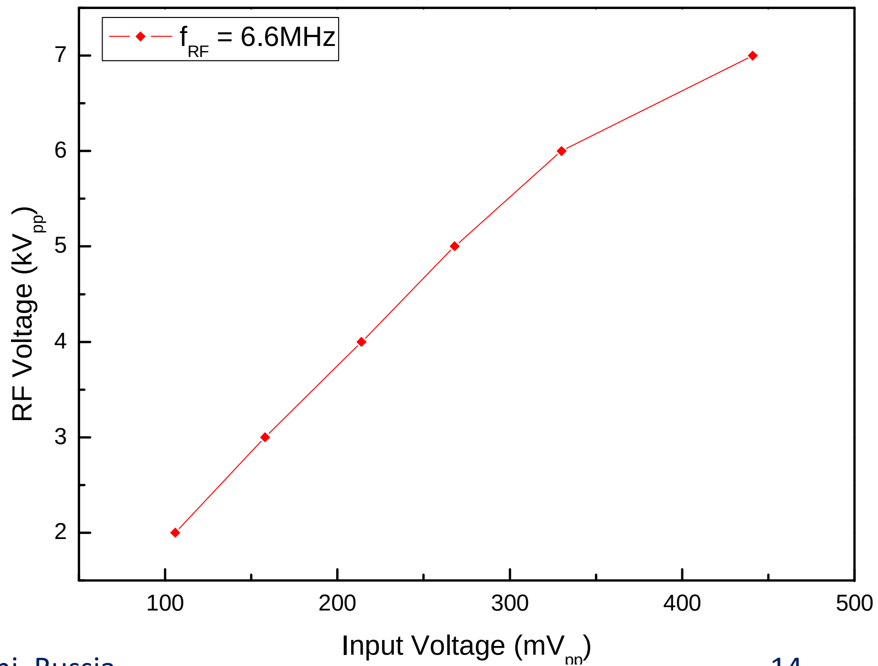


- 500W – Amplifier.
- Vacuum capacitive 9-60pF.
- More suitable assembly.

<u>Results :</u>

➢ $7kV_{pp}$ between 5.9MHz and 7.3MHz.

➢ Limitations due to Electrical Breakdown on our test bench.



Conclusion-outlook

- High intensity Cooler for DESIR
  - Current 10-100 times higher than present technology

- SHIRaC-Prototype 1 :
  - Built at CSNSM-Orsay
  - Developed and studied at LPC-Caen
    - ➢ 25%-transmission for $^{23}Na^{+}$ and $^{87}Rb^{+}$
    - ➢ Emittance ≈ 2π.mm.mrad @ 60keV
    - ➢ Energy spread = 146meV before re-acceleration

- SHIRaC-Prototype 2 :
  - Better transmission expected
  - Mounting currently in progress at LPC-Caen
  - Tests starts in 2010

Thanks for your attention

- LPC-Caen :
  - G. Ban
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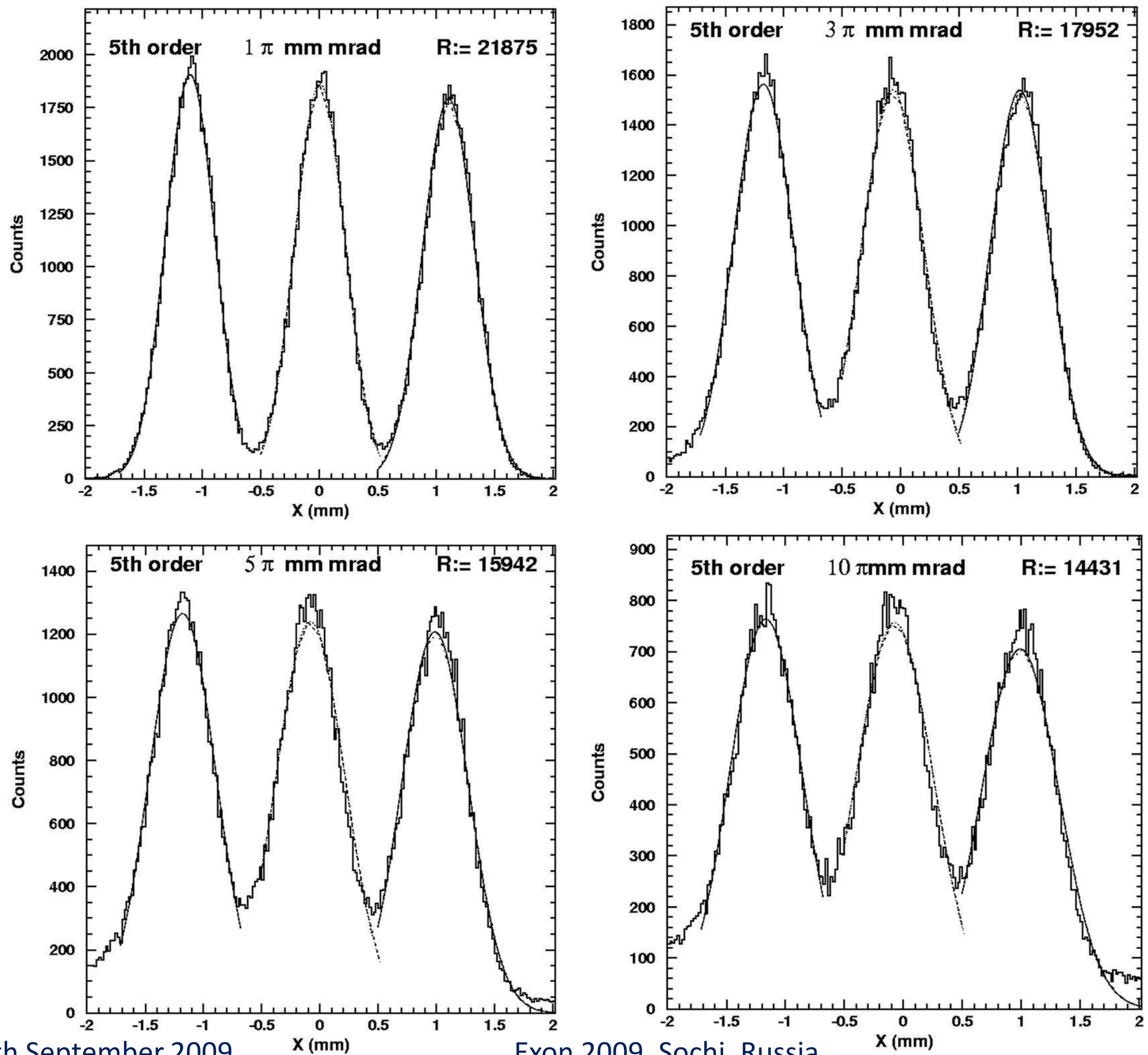
  - H. De Preaumont
  - P. Desrues
  - F. Duval
  - Y. Merrer
  - H. Plard
  - C. Vandamme

- CSNSM-Orsay :
  - S. Cabaret
  - D. Lunney

- Mc Gill university:
  - R.B. Moore

HRS mass resolution versus input emittance

- T. Kurtukian-Nieto's calculations (CENBG-Bordeaux)



Space charge considerations

- Radial force balance equation :
  - E.P. Gilson *et al.*, Phys. Rev. Lett 92, n°15, 155002 (2004)

$$\underbrace{m\omega_0^2 r_{charge}^2 = m.\frac{q^2}{8}.\omega_{RF}^2.r_{charge}^2}_{\text{Confinement term}} = \underbrace{2kT}_{\text{Thermal term}} + \underbrace{\frac{Ie}{4\pi\varepsilon_0 v}}_{\text{Space charge term}}$$

- Beam heating by space charge effect.

  - Ions $^{133}Cs^+$
  - I = 1μA
  - T = 1eV

$$\frac{e}{4\pi\varepsilon_0 v} \approx 7\,meV\,.nA^{-1} \longrightarrow \text{30meV at 60keV and 1μA}$$

Space charge considerations

- Mathieu's equations with space charge.

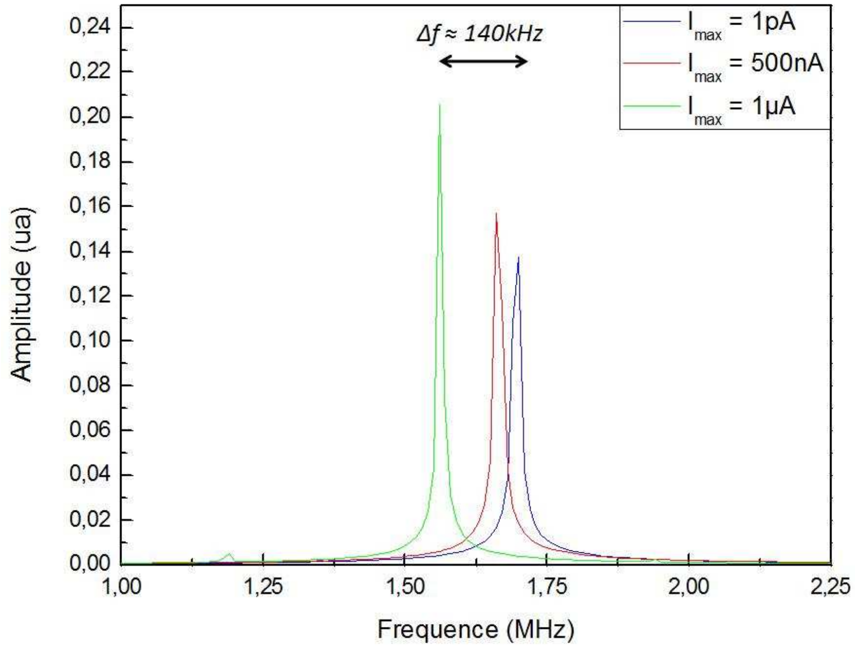
$$\frac{d^2u}{dt^2}+\frac{q_u.\omega_{RF}^{\ 2}}{2}.\cos(\omega_{RF}.t).u=0$$

$$\frac{d^2u}{dt^2}+\frac{q_u.\omega_{RF}^2}{2}.\cos(\omega_{RF}.t).u=-\frac{e}{m}\frac{\partial V_{SC}}{\partial u}$$

- Numerical resolution

- Increase of the ion temperature (macromotion)

- Frequency shift



SHIRaC-Prototype 2 : Developments