**TRIUMF**

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

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# Physics motivation for an electron-driven photo-fission facility at TRIUMF

**mass measurements for nuclear structure and astrophysics**

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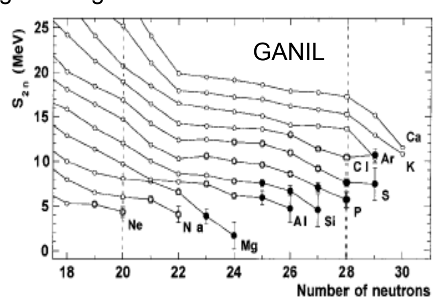
TRIUMF

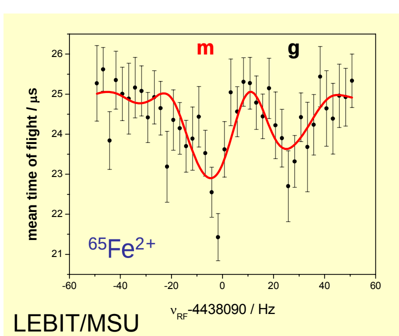
*LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES*

*Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada*

## Mass as indicator for nuclear structure and new phenomena

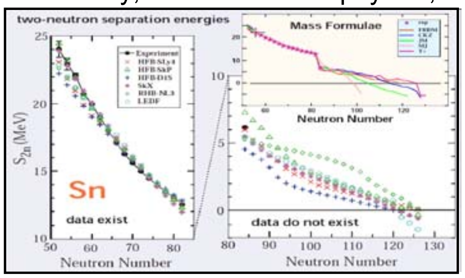
- Masses and separation-energies sensitive tool to uncover structure and unexpected deviations.
- The 'island of inversion' for neutron-rich light nuclei at Na was found (C.Thibault et al.) from mass measurements
- New and better masses confirmed change in Magic Numbers F. Sarazin PRL (2000).
- Isomers in Fe discovered via Penning trap mass measurements (M. Bloch et al. accepted PRL)



## Mass measurements: nuclear structure& theory

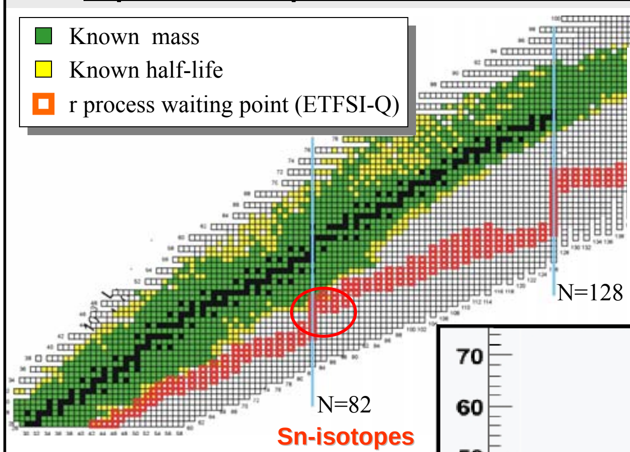
- Nuclear structure at neutron-rich heavy (A=132) hot topic to test theory, for nuclear astrophysics, and nuclear structure.

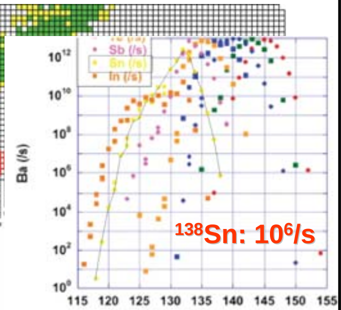


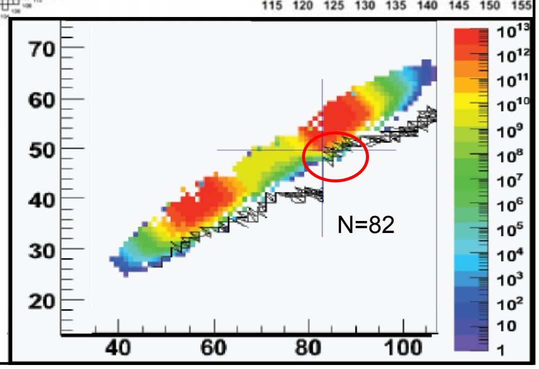

- Nuclear theory needs experimental input to refine the applied models.
- Astrophysics models require reliable data to calculate r-process production path.

- New mass measurements (Dwarschak et al PRL 2008) removed the proposed shell gap at N=84 and restored N=82 as Magic Number.
- This indicated no shell quenching and allows to 'fine-tune' theory, for ex.: HFB-14 (Goriely, Samyn & Pearson)
- BUT: mass measurements difficult, since yields are low and half-lives short (plus beam purity is a problem!)

## r-process path: measurements at ISAC.

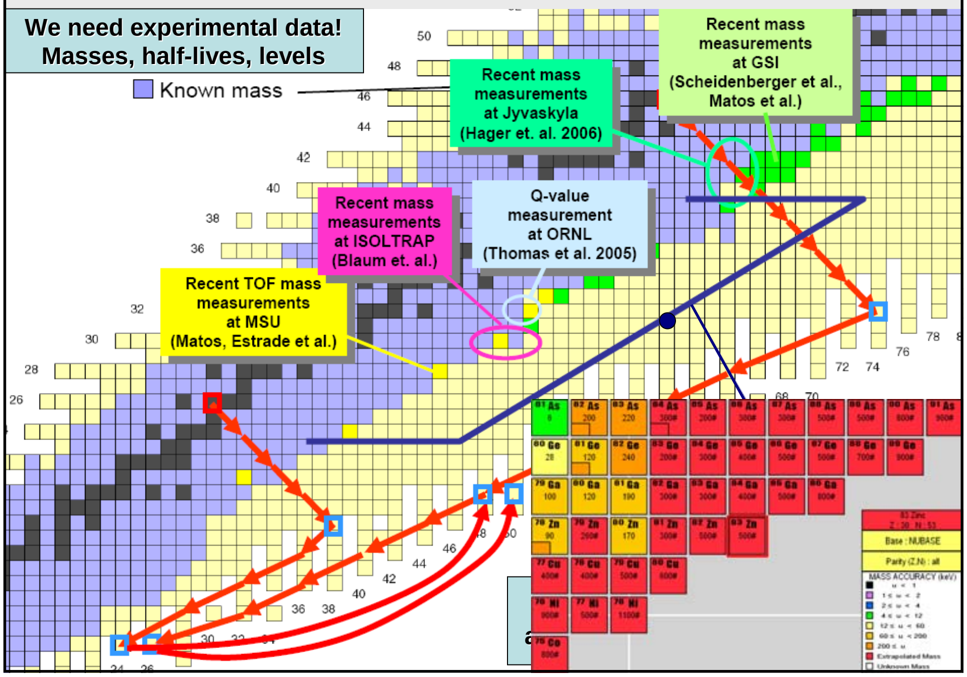


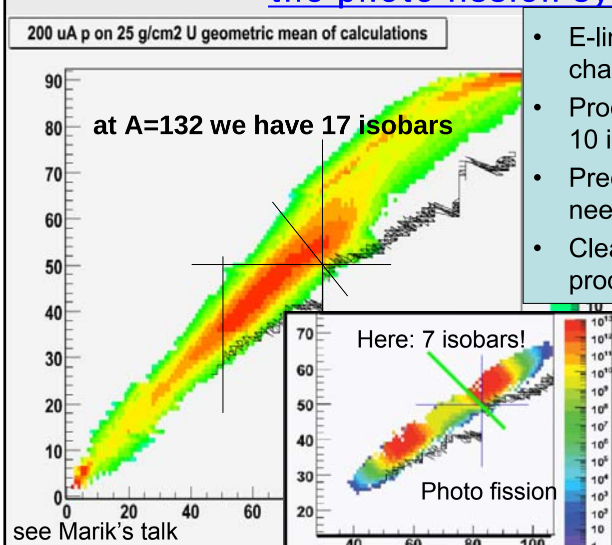




**Pierre's plot shows the reach for r-process nuclei. In the Sn-region we can reach the 'path' and give experimental input for network. Impact to be determined!**

## Crust processes: where could we contribute?




## Production in limited area with the photo fission system



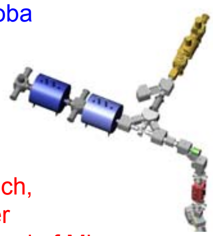

- E-linac provides unique area of chart of isotopes.
- Production sufficient down to 10 isotopes/ second.
- Precise and accurate data needed!
- Cleaner beams due to limited production (isobar suppression).

**Use photo-production and advanced ionisation capabilities (resonant laser) to provide beams in best quality (low emittance) and very clean (low or zero contamination).**

| | | |
|---|---|---|
| ISAC ion beam | RFQ cooler & buncher | EBIT charge breeder |

## TITAN Triumf's Ion Trap for Atomic and Nuclear science

McGill, UBC
U Manitoba
TRIUMF
York
Windsor
Calgary.
MPI-HD
TU Munich,
Muenster
Col. School of Mines,
GANIL
RCNP Osaka



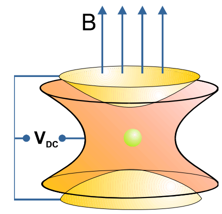
**m/q selection**

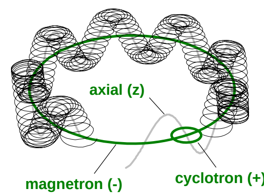
**Cooler Penning trap**

**Precision Penning trap**

**Single ion mass measurements**

- Penning trap mass measurements on isotopes with short half-life $T_{1/2} \approx$ 10 ms and low production yields (≈ 10 ions/s)

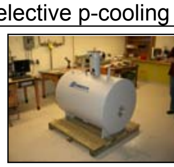


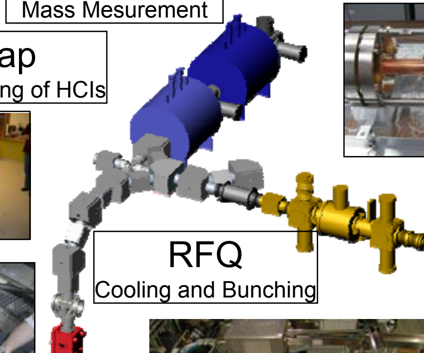




## TITAN system

Penning Trap
Mass Mesurement

Cooler Trap
Mass selective p-cooling of HCIs





RFQ
Cooling and Bunching

EBIT
Charge State Breeding

ISAC Beam

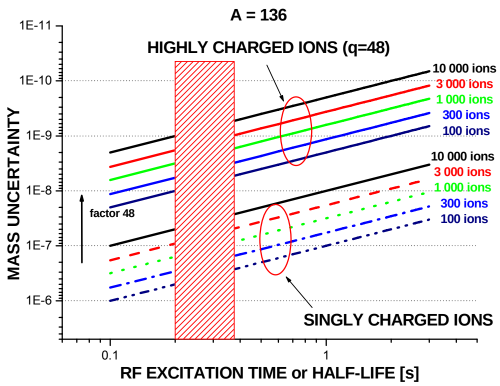
## Mass measurements with TITAN: boost sensitivity with HCI and use extra selectivity

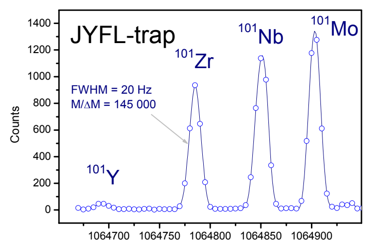
$$\nu_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B \qquad \frac{\delta m}{m} \approx \frac{m}{T_{RF} \cdot q \cdot B \cdot \sqrt{N}}$$

**Example: $^{136}Sn, T_{1/2}$ = 250ms**

**mass not known exp. δm =500 # keV, can we measure it?**

**PROBLEM: low production, short-half-life, isobars!**

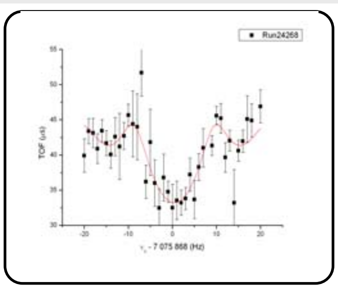


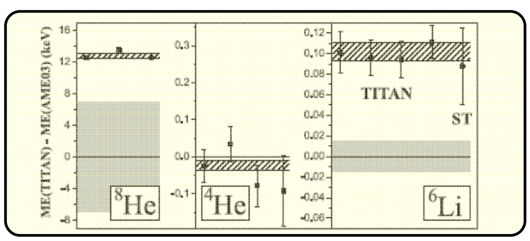



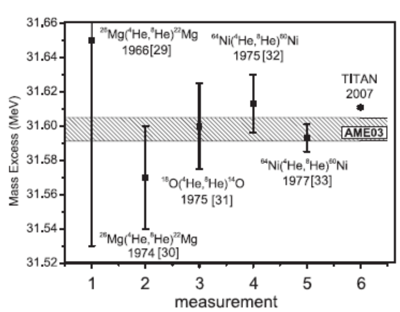

Penning trap system with highly charged ions is very sensitive. We have only one ion in the trap + ability to suppress some isobars.

## TITAN performance: Study of most neutron-rich nucleus: $^{8}He$

**First on-line run of isotopes with $T_{1/2}$ = 119 ms**

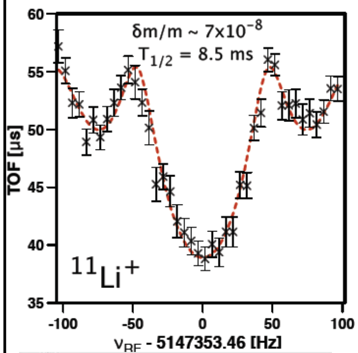


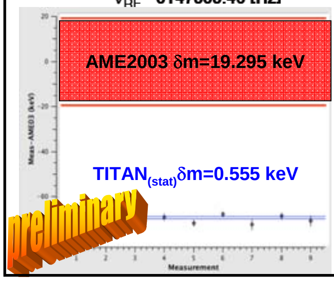


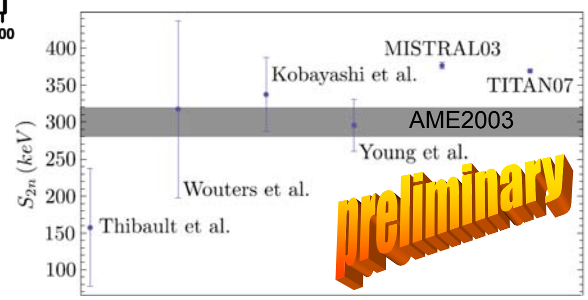

- **Measurements of the mass of $^{8}He$**
- **First direct mass measurement**
- **Can be calculated with ab-initio.**
- **Carried out with 3100/ions sec beam (since then off-line improved by a factor of 10)**
- **Final uncertainty = 330eV.**
- **Submitted to PRL Feb 2008.**
- **Improved mass value of $^{6}Li$ (stable)**

# Penning trap limit: how short can you go?



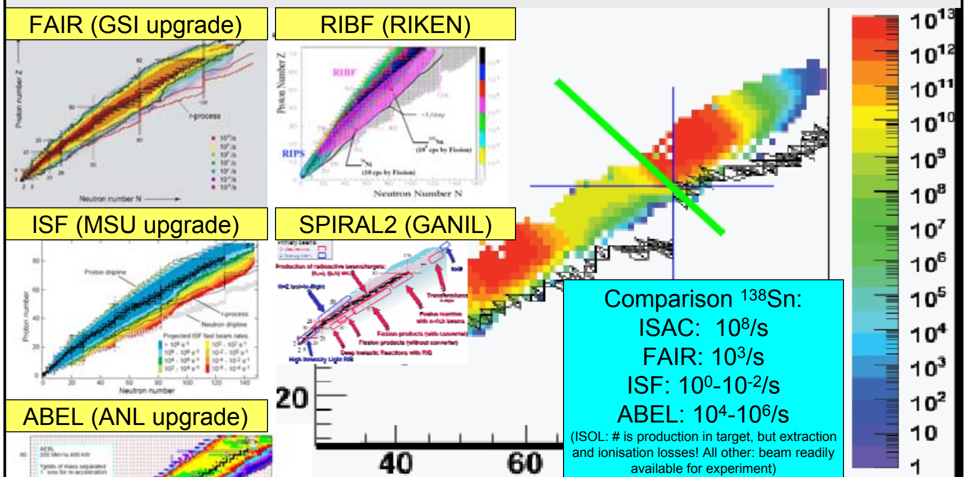

- TITAN direct mass measurement of $^{11}$Li
- Shortest-lived isotope for Penning trap mass measurement!
- Run @ 50 Hz and 20ms excitation
- ISAC yield of 1200 ions/s.
- Limit for half-lives not a problem for photo-fission products!
- Sensitivity presently at ~100 ions/s (can be improved further).

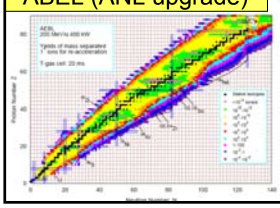



# Conclusion:

- Mass spectrometry is a key field to provide basic and benchmark data, for nuclear structure, for theory, and (where needed) to guide extrapolations into nuclear-astrophysics relevant regions.
- Mass spectroscopy often a discovery tool for new phenomena:
  - Island of Inversion.
  - Restoration of N=82 as Magic Number.
  - Finding of new isomers in unexpected regions.
- What do you need:
  - Sensitivity (single ions), and we can measure at 100 ions/s.
  - Selectivity (isomer suppression via mass selective cooling).
  - Precision and accuracy (proven Penning trap technique).
  - Ability to measure short half-lives ($^{11}$Li…).
- The e-linac will provide unique access to isotopes particularly important for nuclear structure and nuclear astrophysics, and we have world-class experimental facilities to harvest the isotopes. One of them is the TITAN Penning trap mass spectrometer.
- Need to identify key isotopes for network calculations, and evaluate the required mass precision (can vary for ex. for CNO from MeV to 1 keV).

## ISAC photo-fission in comparison

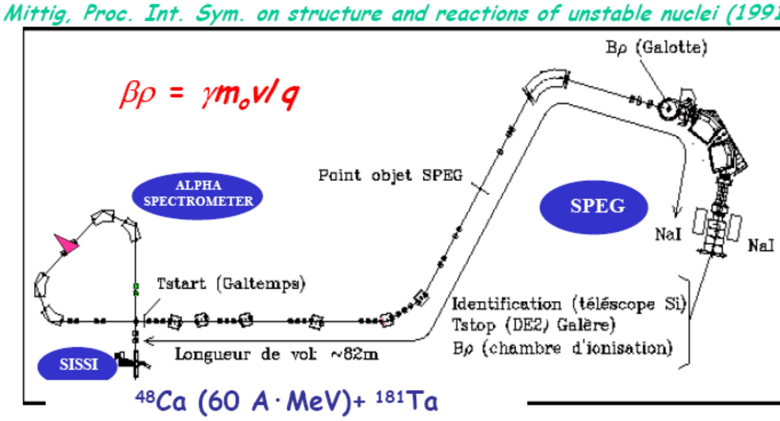


- New facilities have global approach for production, here very localized dedicated effort to boost very neutron rich nuclei.
- Operation planned for in ~5 years after funding (before 2015 pending funding).

## TOF-method (planned for ISF, SPIRAL II)
## Limited precision and accuracy (~500 keV-1 MeV)

*(W.Mittig, Proc. Int. Sym. on structure and reactions of unstable nuclei (1991) 8)*



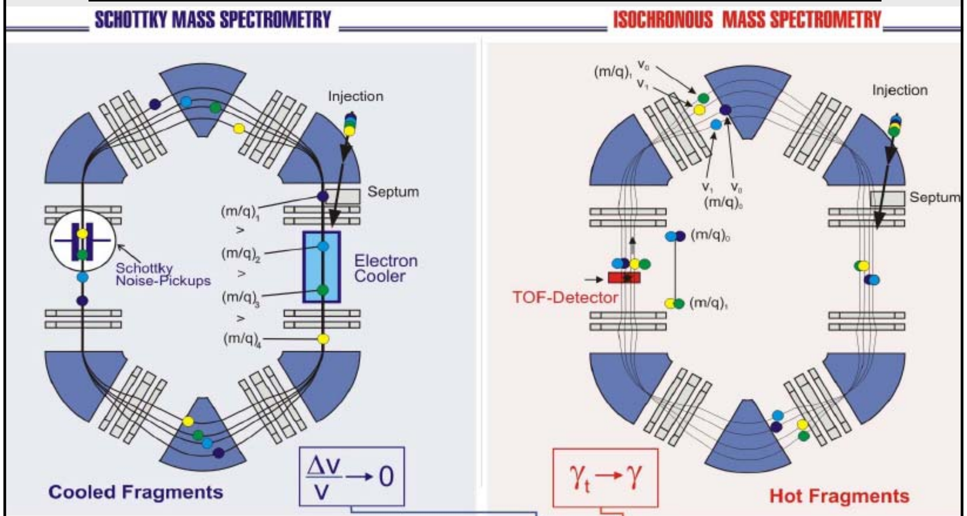

$^{48}$Ca (60 A·MeV)+ $^{181}$Ta

✓Time of flight ≈ 1 μs

✓Mapping of an entire region of the mass surface → Exotic nuclei / Reference nuclei

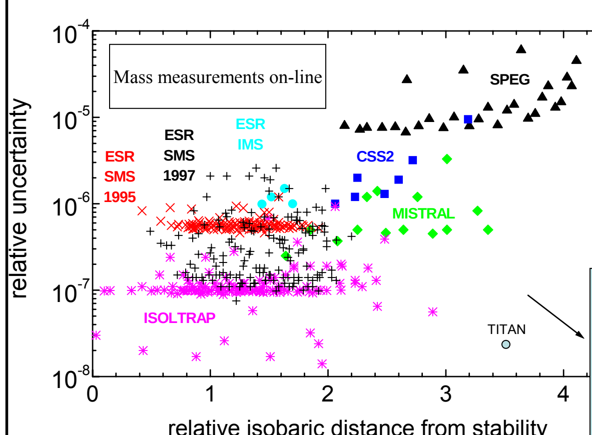
Needs reference masses with high quality in vicinity (like PT)

## TOF-method, multi turns (storage rings, GSI, FAIR, RIKEN) Requires cooling (~1sec & needs reference masses)




$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

## Comparison of techniques:




Time-of-flight spectrometer: fast, but limited resolution. Results in poor extrapolation!

Can work with very low production (>1/mins)

Ion traps: highest precision, but need more flux, and cannot go below few ms!

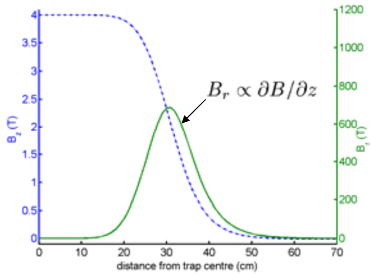
TITAN can provide high quality data for direct measurements or for reference measurements! (no other facility has reach the short half-lives & precision combination!)

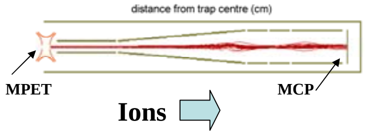
We have unique facility and experiment set-up.

## Mass measurement via time-of-flight (TOF)

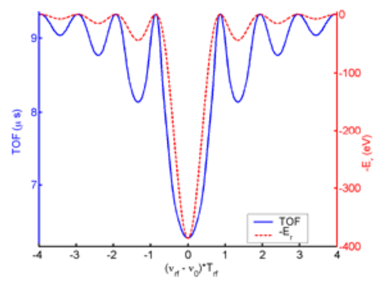
Ions in the trap are

- submitted to an rf-excitation $\omega_{rf}$ of duration $T_{rf}$
- accelerated by the magnetic field gradient: $\vec{F} = -\frac{E_r(\omega_{rf})}{B}\frac{\partial B(z)}{\partial z}\hat{z}$
- stopped by an MCP detector, TOF is recorded




Large $E_r$ = shorter TOF




The mass is found by a scan of $\omega_{rf}$ around the resonance: $\omega_{rf} = \omega_c = \frac{qB}{m}$

System for externally produced ions.