THE ISAC FACILITY AT TRIUMF AND MASS MEASUREMENTS WITH TITAN

Jens Dilling, TRIUMF & UBC, Vancouver

OUTLINE

- The ISAC Facility @ TRIUMF
- Some recent results (also from others!)
- Motivation for mass measurements
- TITAN system
- Conclusions

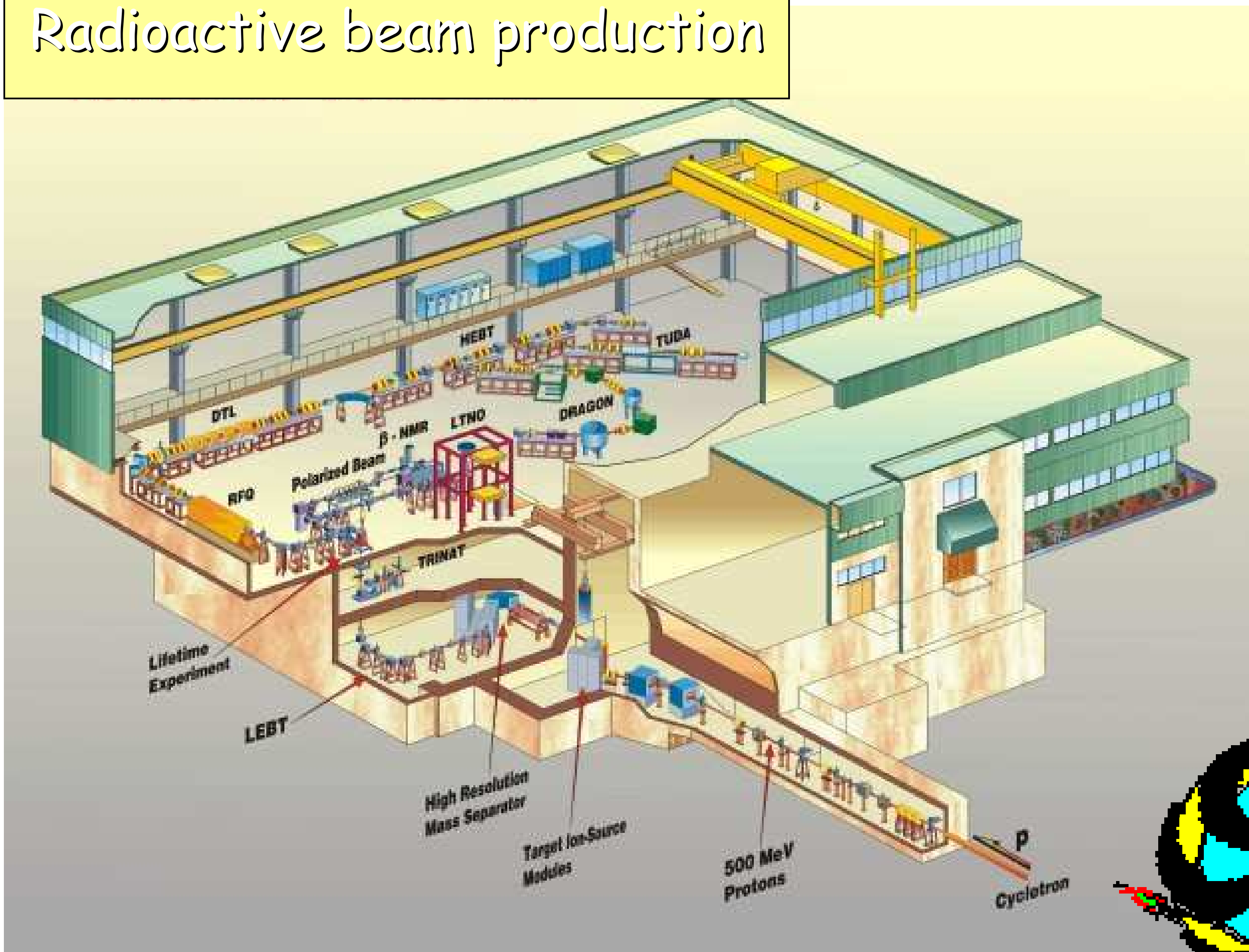
ISOLDE/CERN Seminar March 7 2006

TRIUMF ISAC

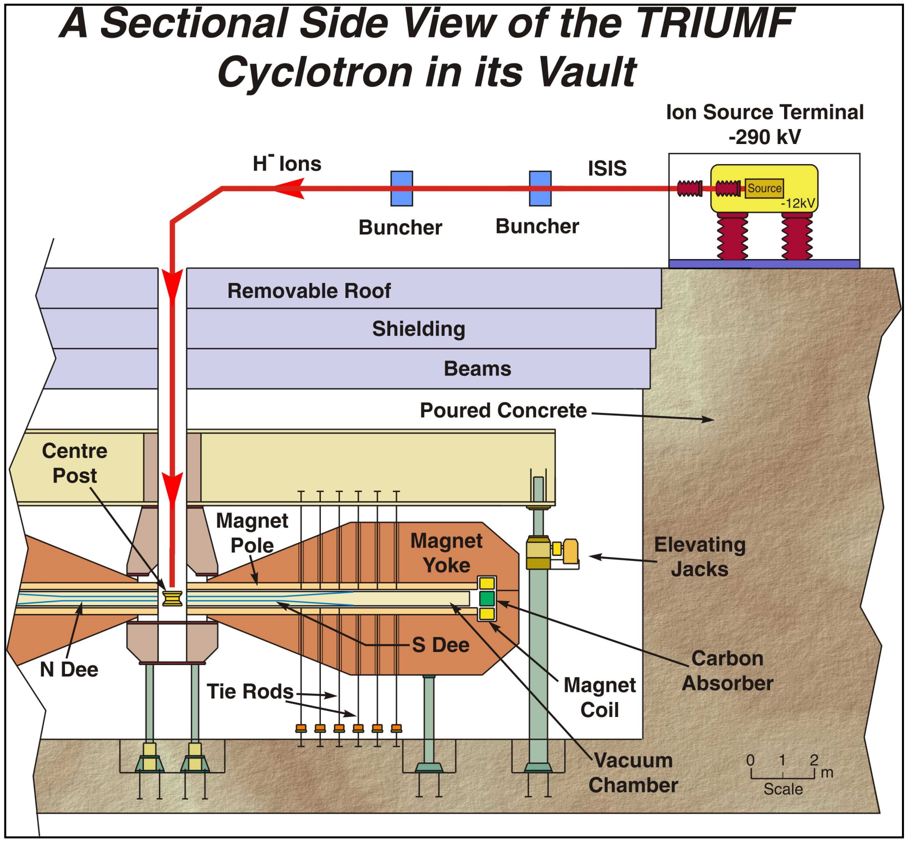
THE UNIVERSITY OF BRITISH COLUMBIA

We need isotopes: ISAC @ TRIUMF

Radioactive beam production

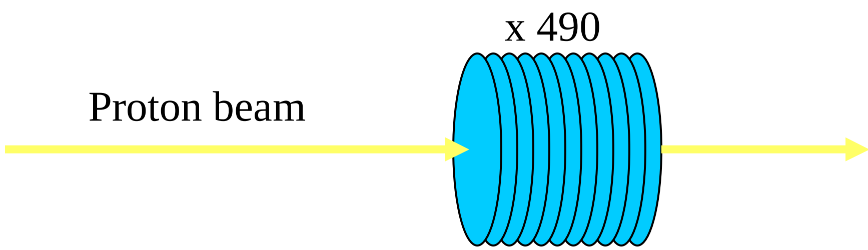


The Core of TRIUMF: The Cyclotron



- **H- ions accelerated by sector-focussing cyclotron.**
- **Up to 520 MeV protons.**
- **Multiple user facility.**
- **Up to 100 μA for ISAC beam line.**
- **Upgrade to 500-600 μA total possible**

Beam production: ISAC Targets



Target materials: Silicon Carbide, Tantalum, Zirconium Carbide, Niobium (Lanthanum Carbide & Uranium Carbide)

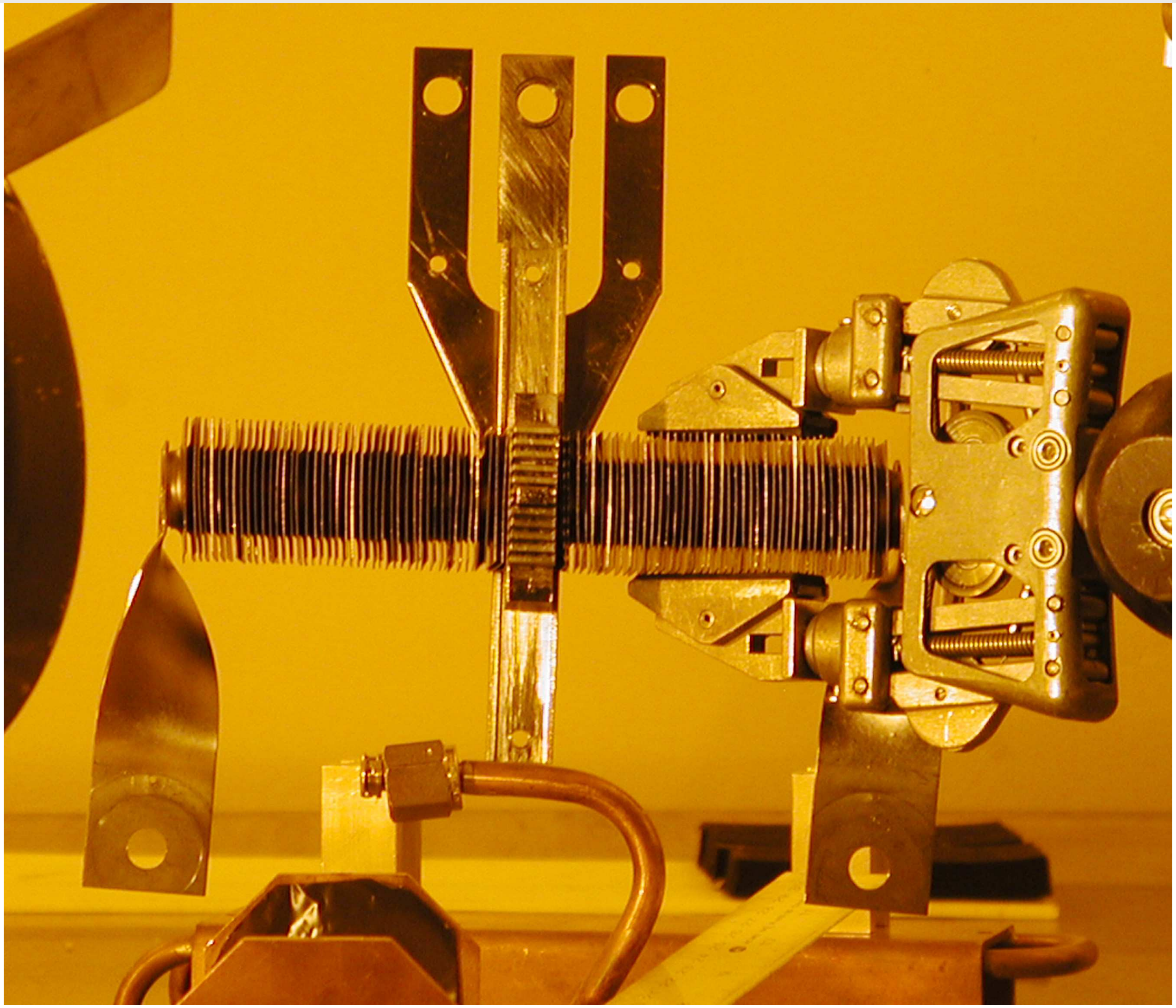
ISAC target assembly

- Up to 100 µA DC-beam @ 500 MeV on target (50 kW !)
- Spallation, fragmentation processes
- Radioactive decay half-life and hot atom chemistry can impede the transport of the gas (limit ~ 10 ms)
- Enhancement of production due to higher p-currents (higher temperature gradients and radiation diffusion enhancement)
- Typical lifetime of target 4-6 weeks
- Actinide target test planned for 2006 (extra license required due to volatile α-emitters)
- Workshop in April 27-29 2006!

ISAC Targets

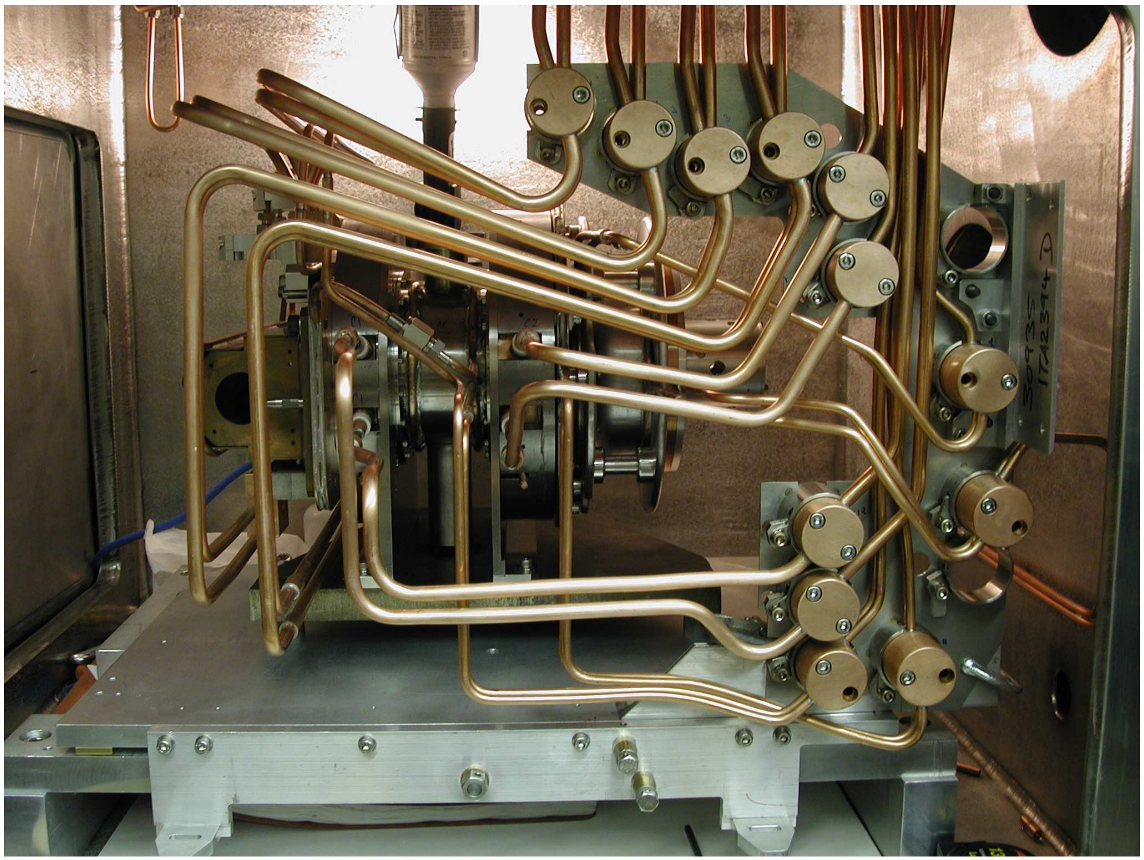
High power target with extra finns for cooling (proton beam stability and focus very critical, difficult to monitor.

New rotating beam system under development (similar to GANIL)



ISAC Target Hall

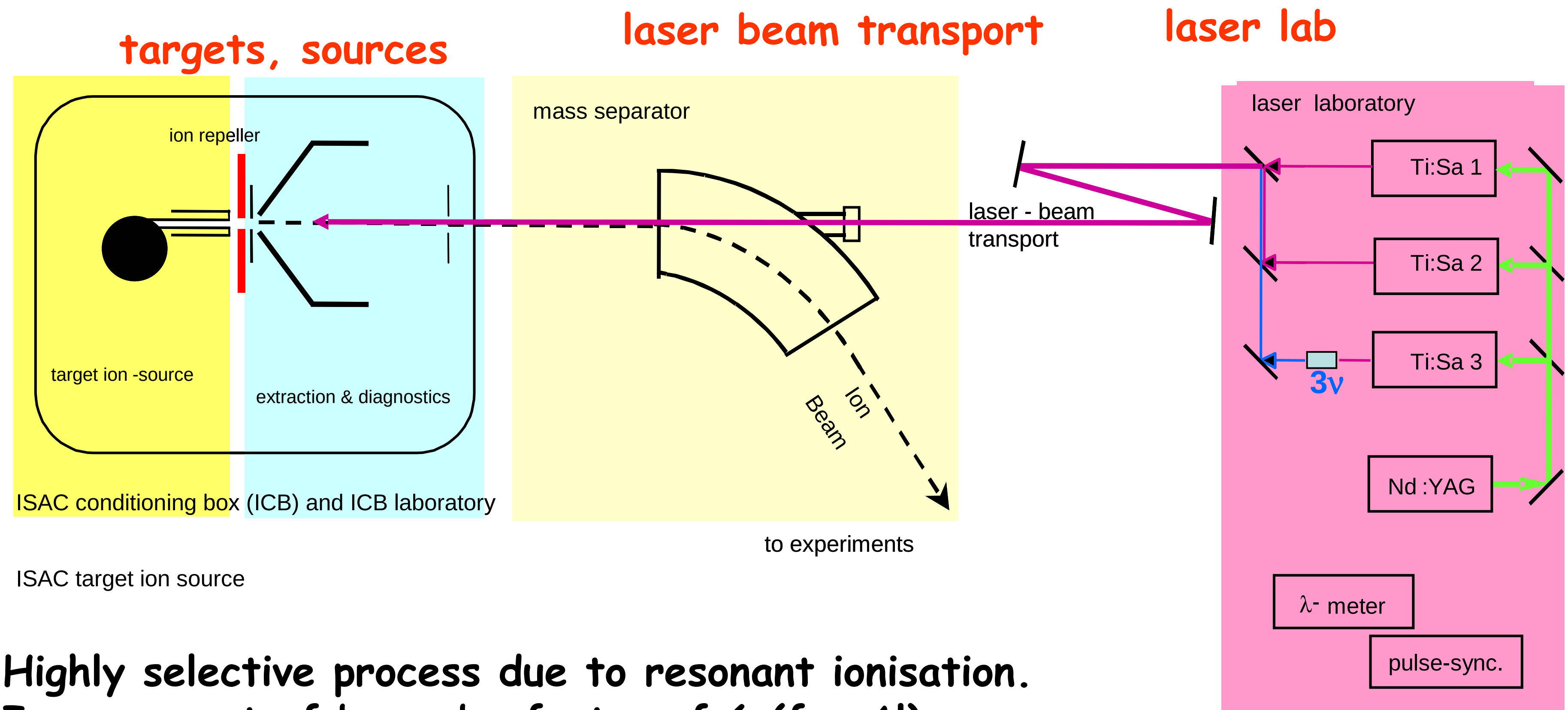
ISAC Ion Sources:



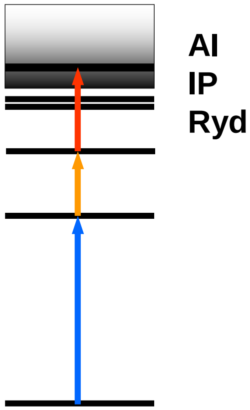
- ECR – Electron Cyclotron Resonance (First experiment on-line (^{18}Ne) with 10^4 ions/s. needs improvements!)
- Surface ion source (standard source for alkali and earth alkali elements) yields ex: **^{11}Li 5*10^4/s, ^{74}Rb 2*10^4/s, ^{21}Na 5*10^9/s, ^{26}Al 6*10^7/s**
- **RELIS (Resonant laser ion source) operational on-line, first experiment ^{62}Ga 5*10^4/s**
- **FEBIAD (off-line tested, to be used for N and noble gazes)**
- **Negative ion source (off-line, to be used for F, Cl…)**

TRIUMF Resonant Ionization Laser Ion Source (TRI LIS)

J. Lassen[1] ,T. Achtzehn[12], P. Bricault[1], M.Dombski[1], J.P. Lavoie[1,3], Ch. Geppert[4], K.D.A Wendt[4]
[1]TRIUMF, [2]TU Darmstadt, [3]U Lavalle, [4]U Mainz

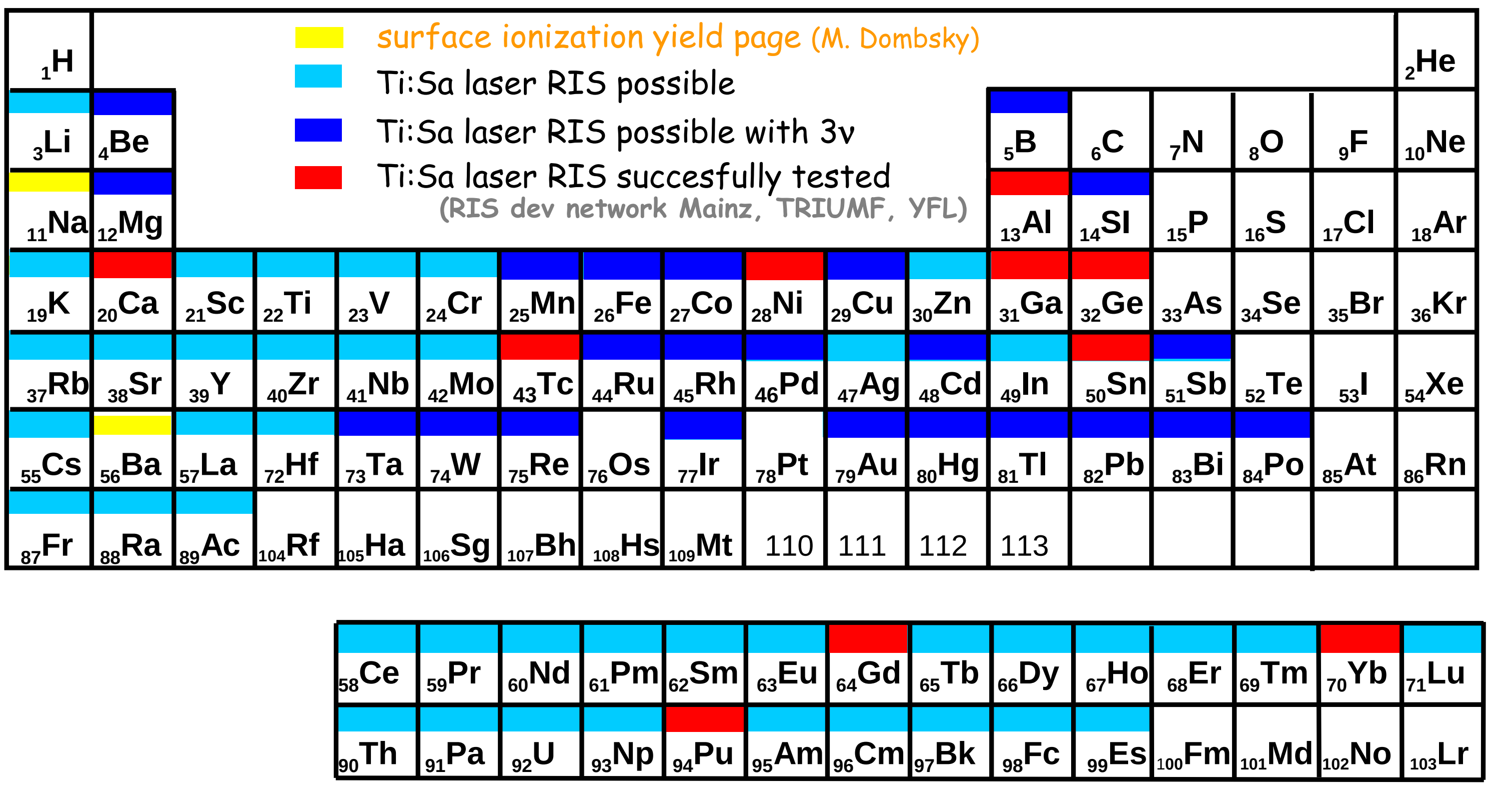


Highly selective process due to resonant ionisation.
Improvement of beam by factor of 6 (for Al),
plus suppression of contamination by factor of 10!

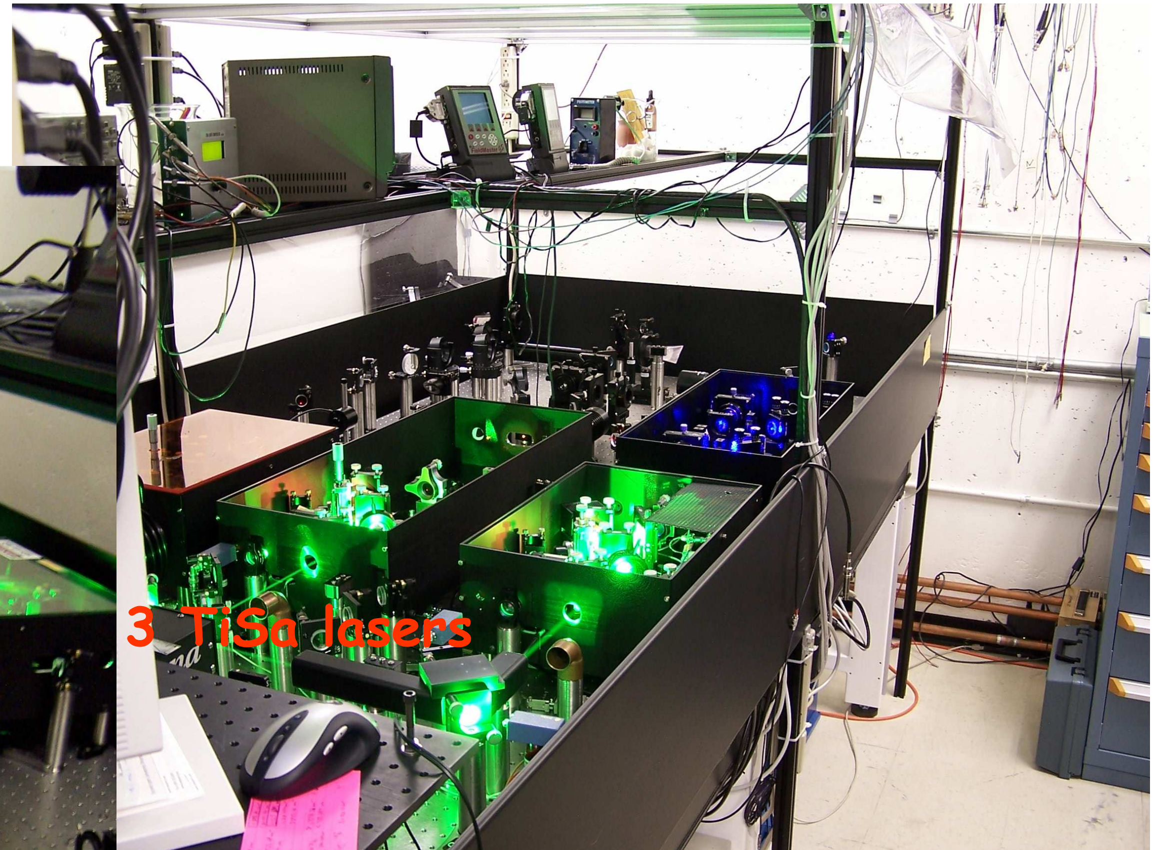


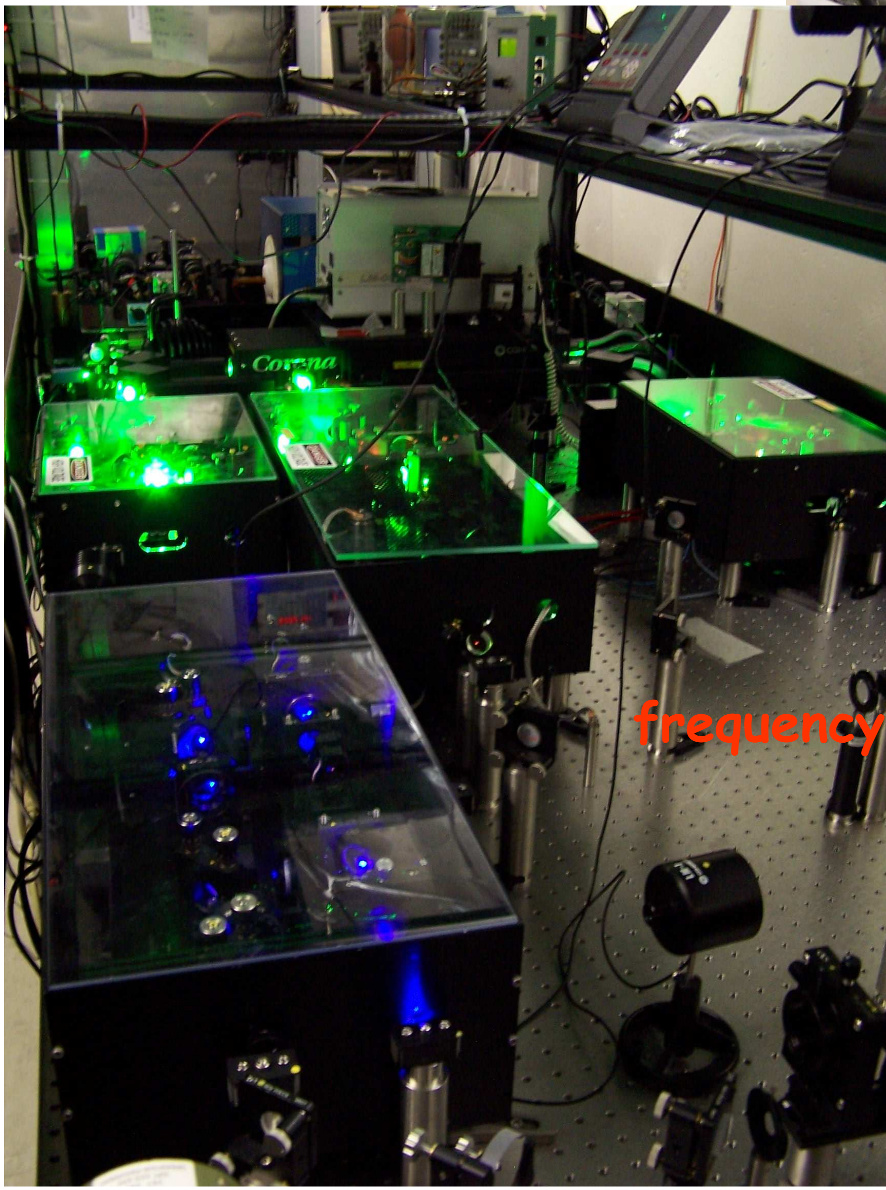
TiSa ν [690nm-930nm], TRIUMF
2ν [350nm-460nm] TRIUMF
3ν [240nm-310nm] TRIUMF & Mainz U

development needed for each new scheme on atomic physics & target chemistry!



TRILIS on-line laser lab



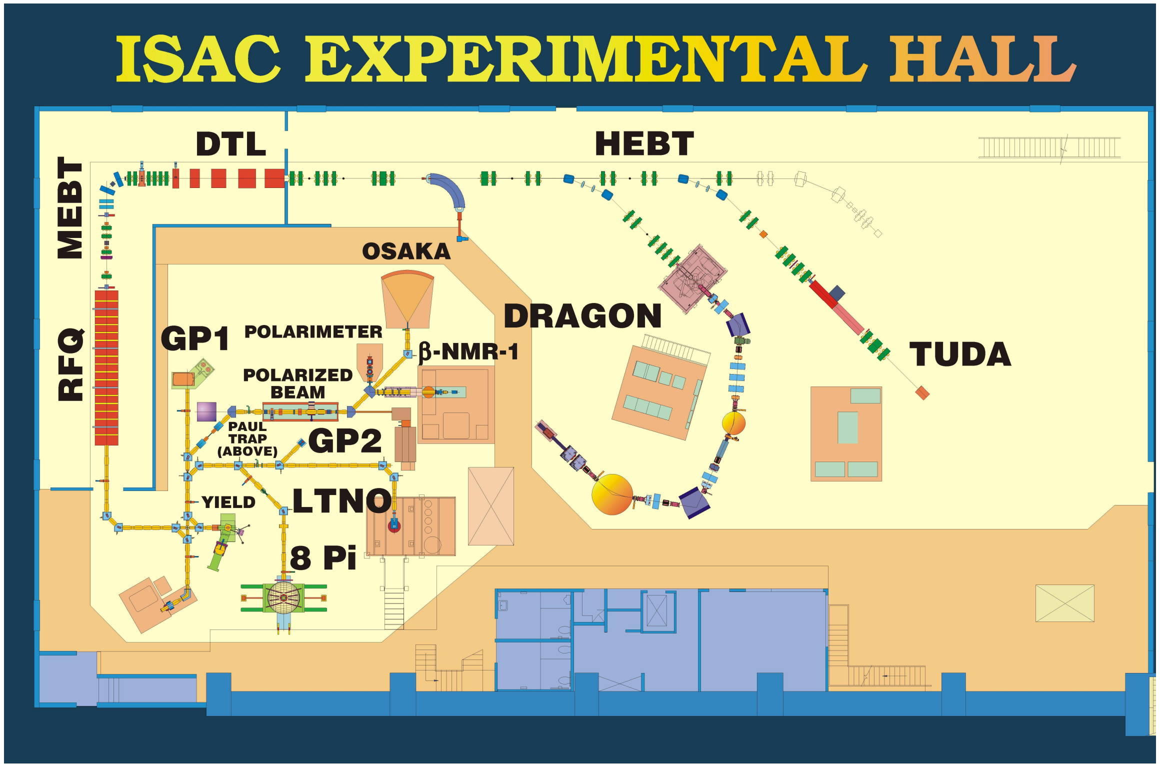


3 TiSa lasers

frequency tripling

reference spots

ISAC beam lines:

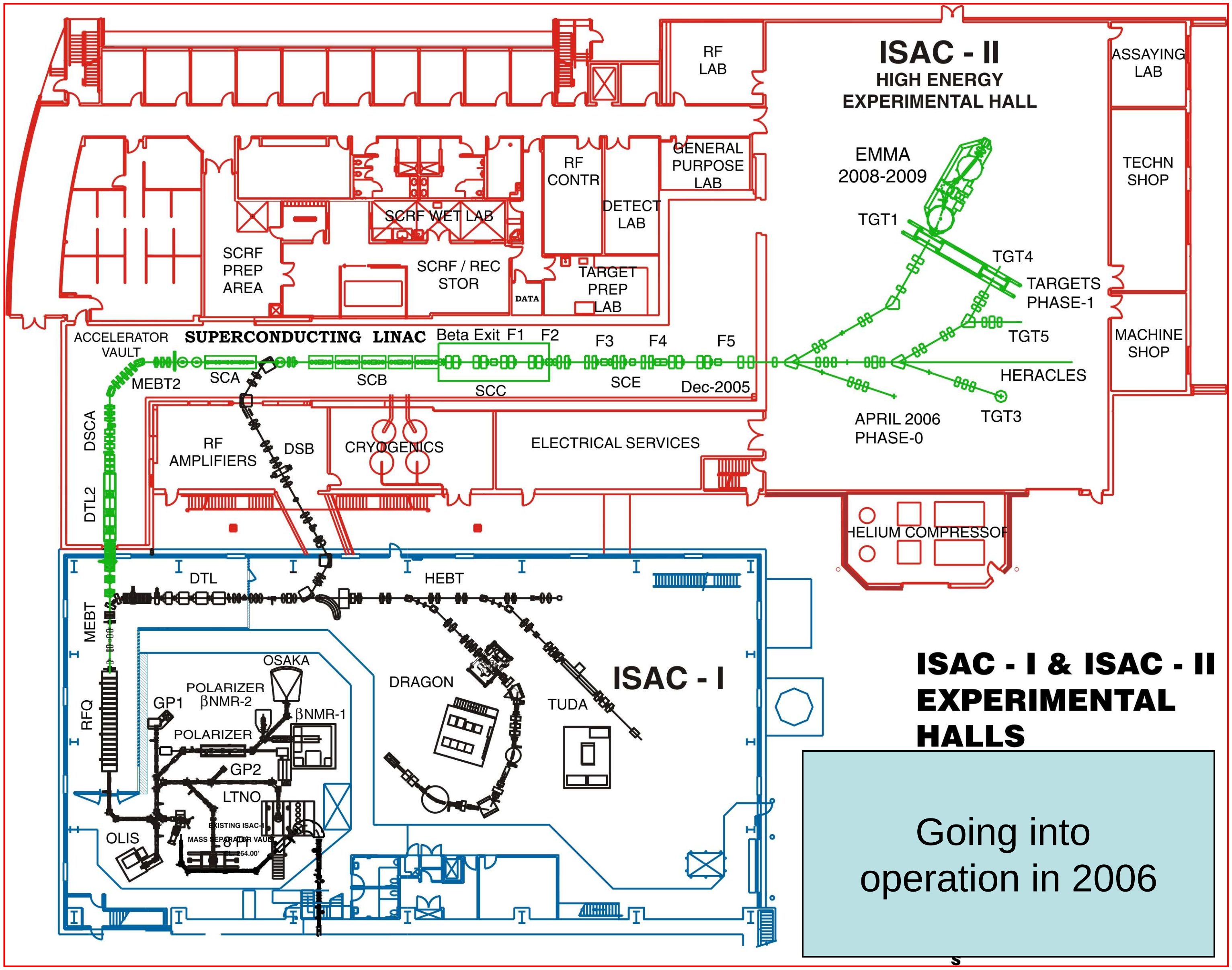


- Beam extracted from Ion source at 30-60 keV separated (R ~ 3000)

- RFQ provides excellent acceleration to 150 keV/u

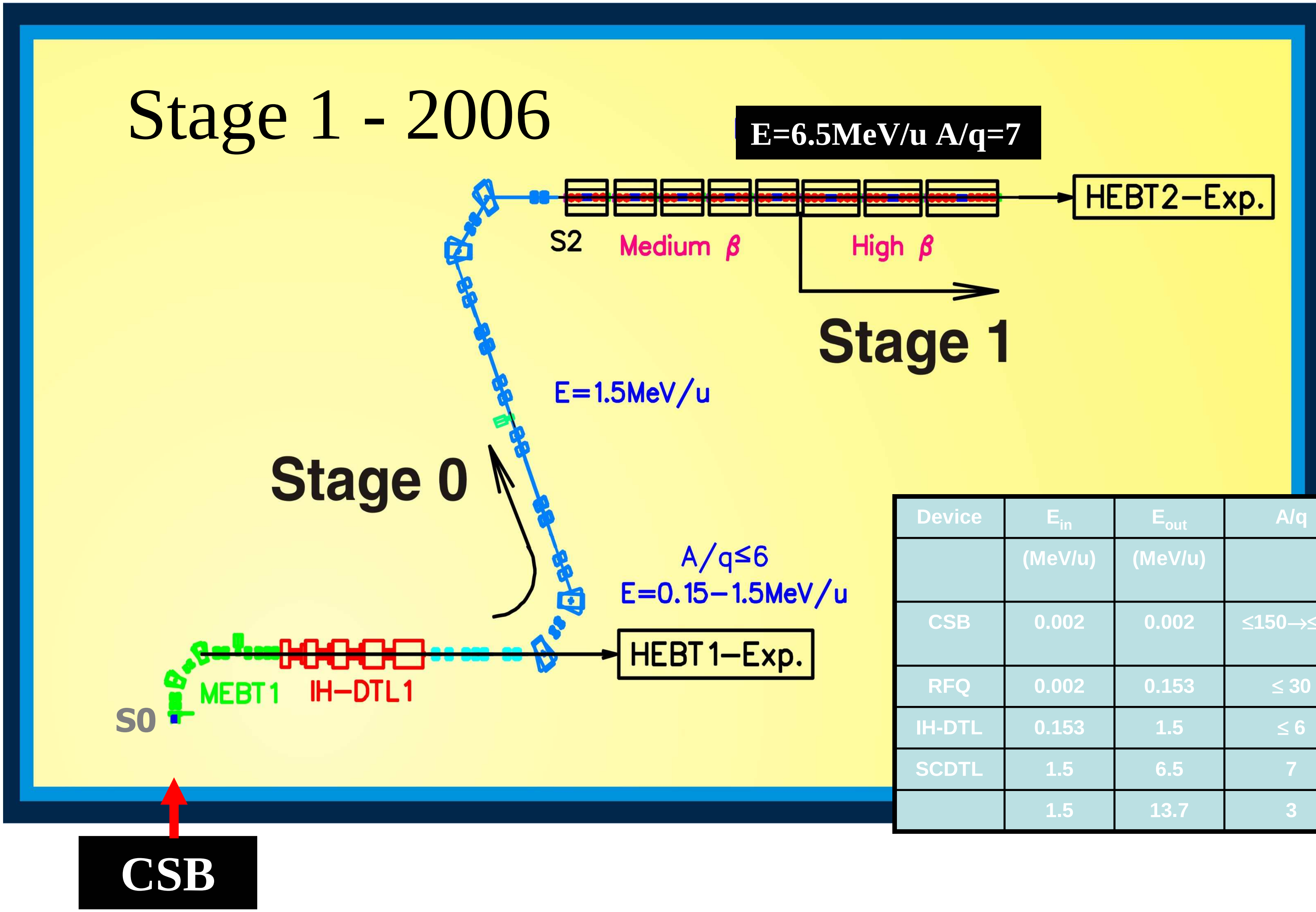
- DTL provides continuously variable acceleration from 150 keV/u to 1.5 MeV/u, perfect to scan astrophysical energy range for explosive burning

ISAC I & II



Going into operation in 2006

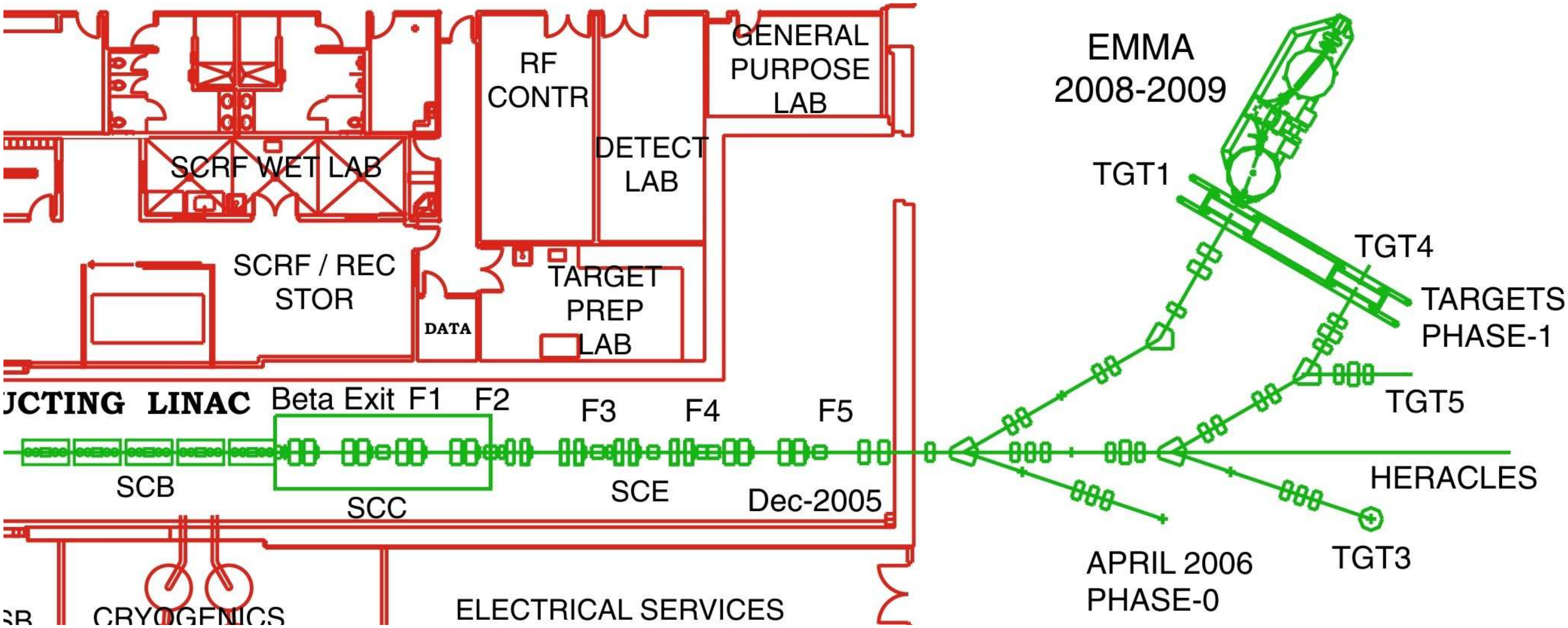
ISAC I & II



Device	E_{in}	E_{out}	A/q	V_{eff}
	(MeV/u)	(MeV/u)		(MV)
CSB	0.002	0.002	≤150→≤30	-
RFQ	0.002	0.153	≤ 30	4.5
IH-DTL	0.153	1.5	≤ 6	7.5
SCDTL	1.5	6.5	7	36.6
	1.5	13.7	3	36.6

ISAC II

- First straight section to experimental hall finished Dec. 2005
- First test beam planned for March 2006
- TIGRESS funded, EMMA applied for with NSERC



ISAC upgrade (a look into the future)

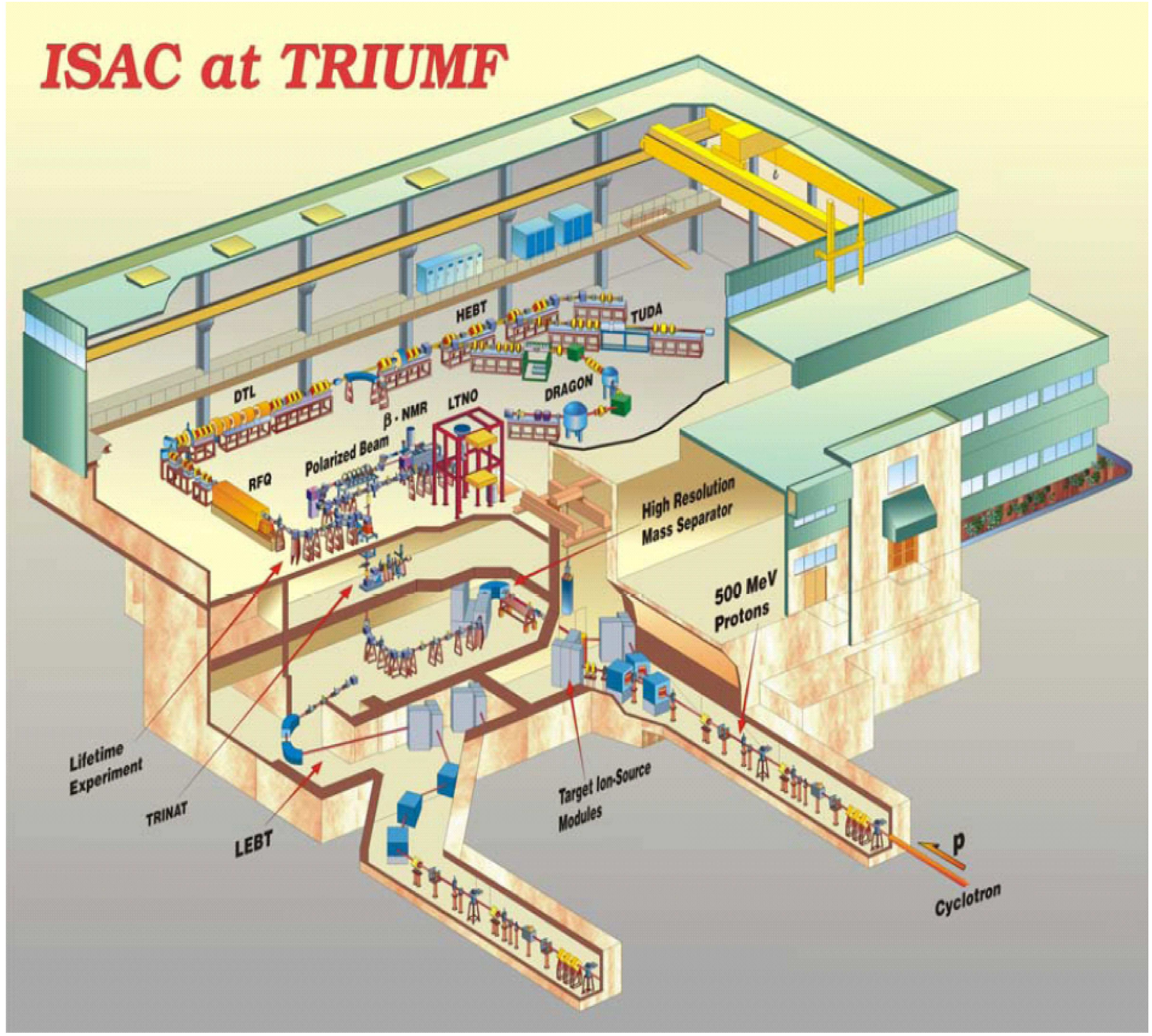
2nd target station:

• 2nd proton beam line with I>>100 μA. (300 μA ?)

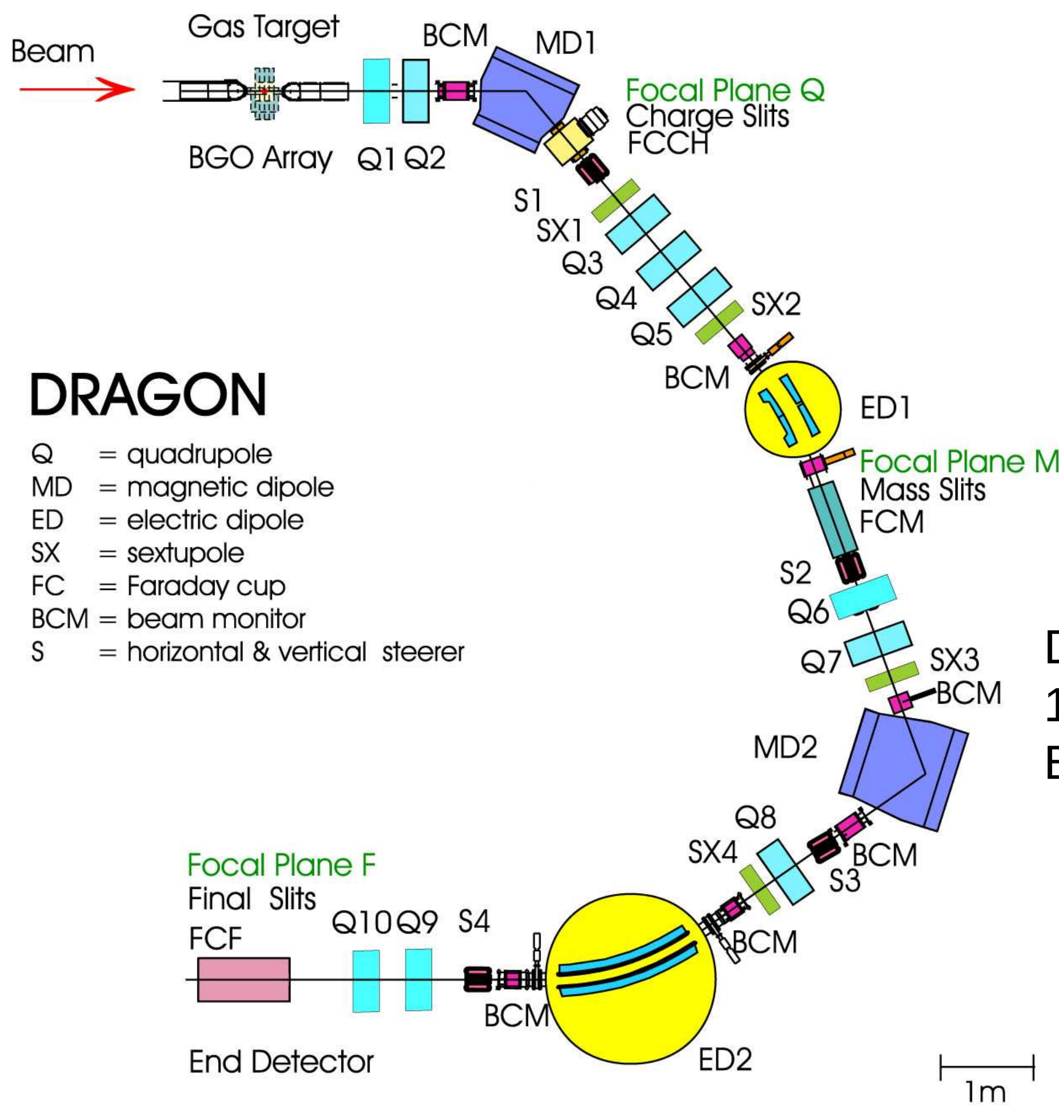
• development work (target & ion source) parallel to beam production

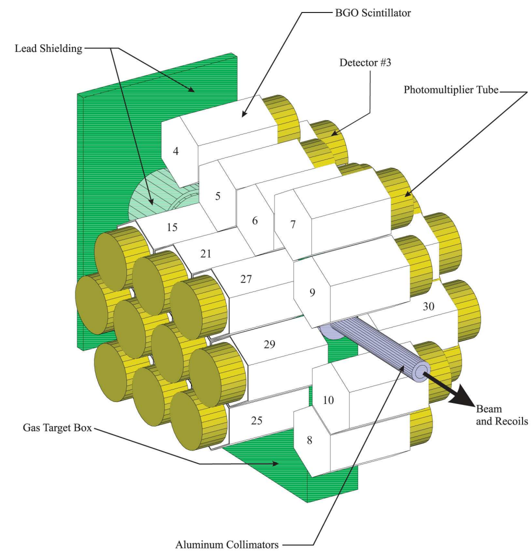
• two RNB in parallel operation, more beam time available!

• CFI application for 2008.



SOME HIGHLIGHTS: Nuclear Astrophysics with DRAGON



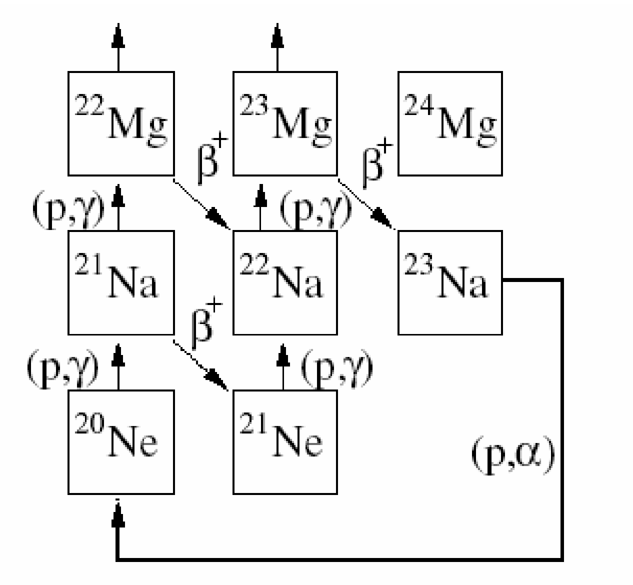


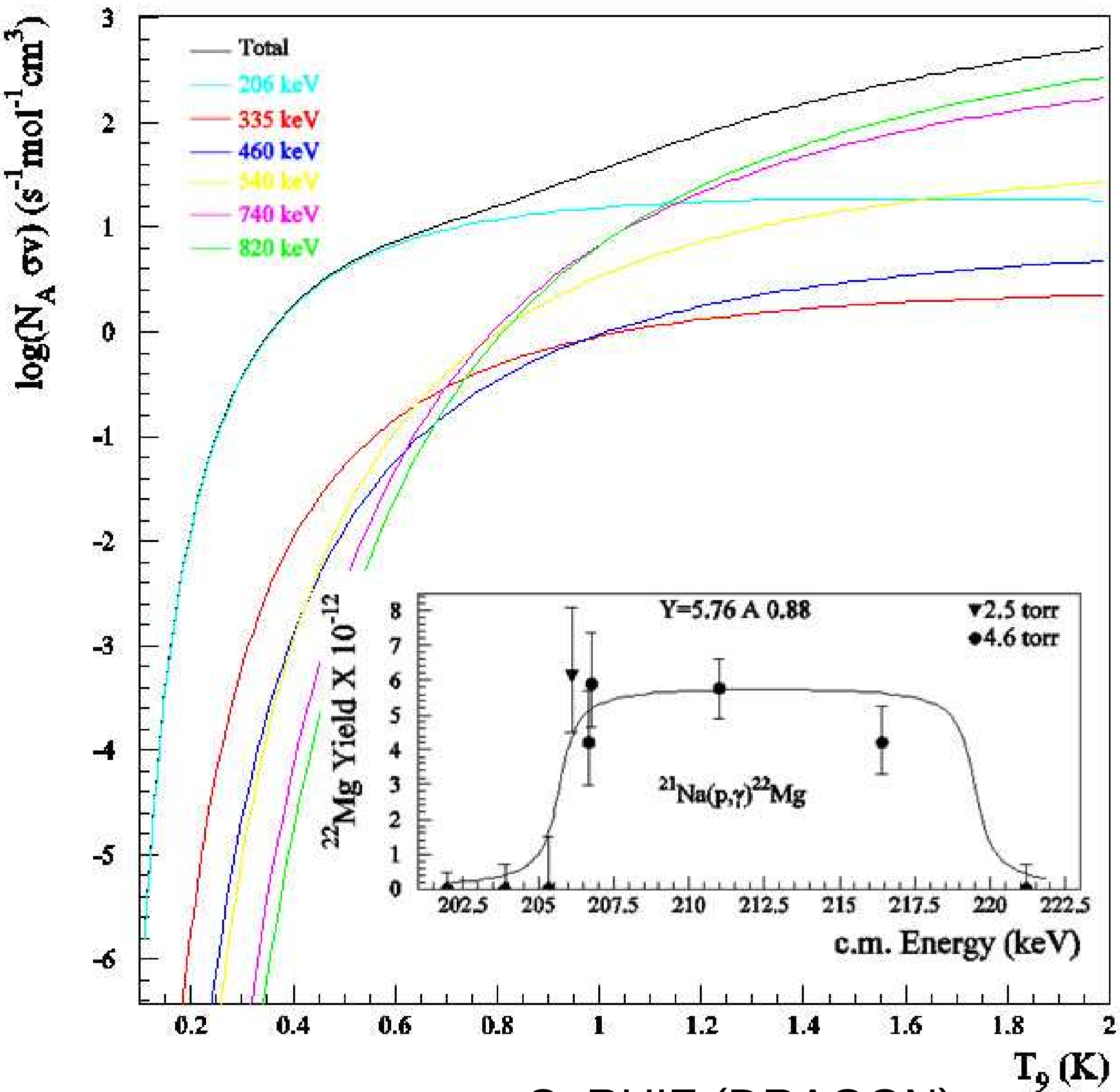
DRAGON operational from
160 keV/u up to 1.6 MeV/u
Beam suppression of 10^{13}

C. RUIZ (DRAGON)

Nuclear astrophysics highlights.

NeNa circle:

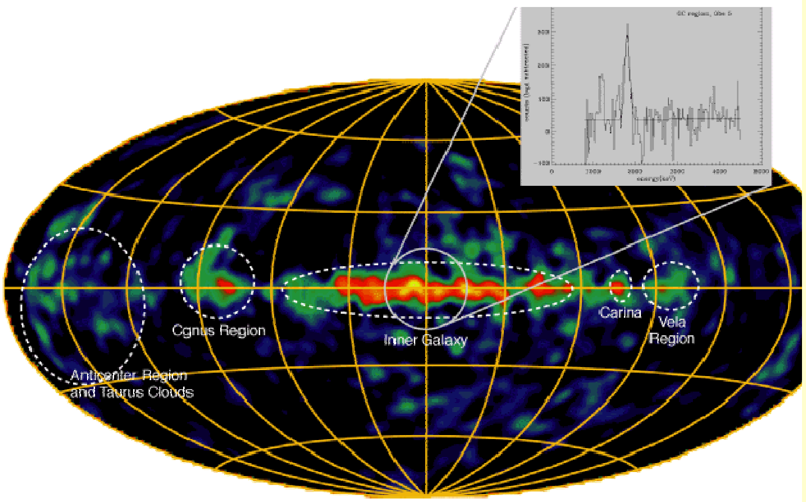


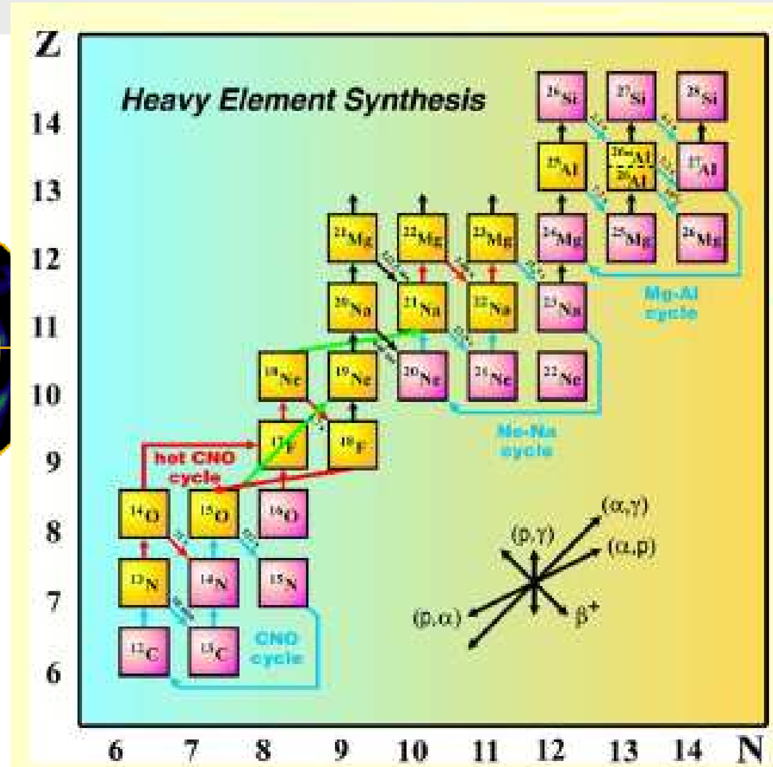


S. Bishop et al. PRL 90(2003) 162

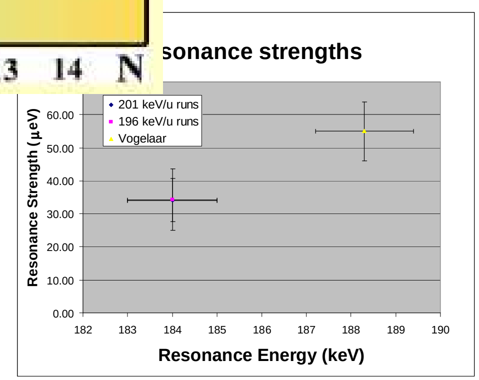
C. RUIZ (DRAGON)

Nuclear astrophysics highlights.





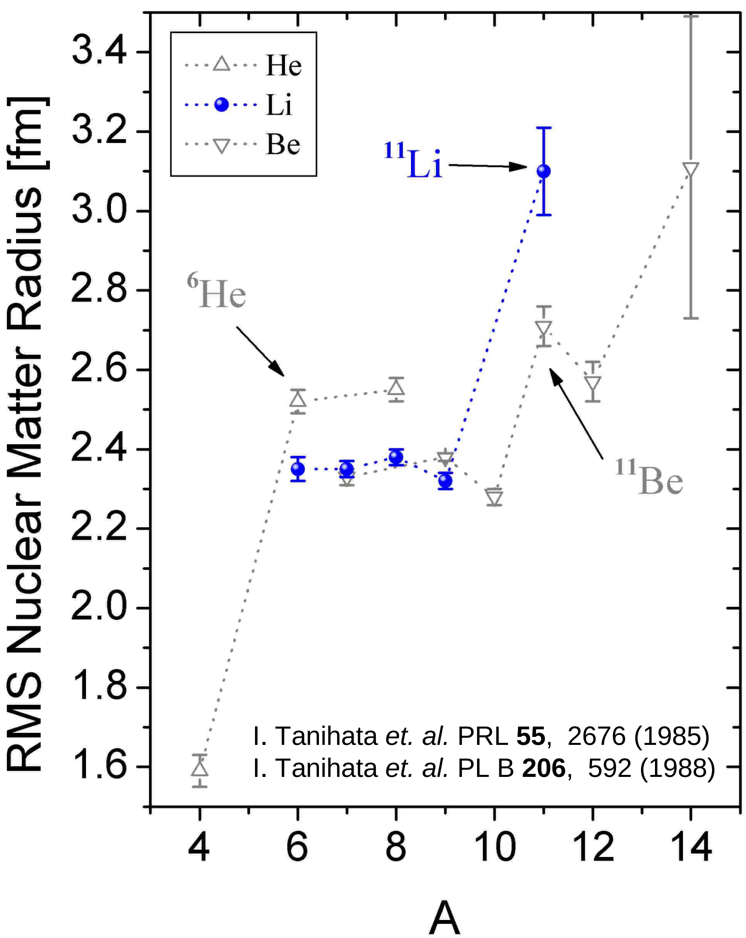
- $\omega\gamma = 34.1 \pm 6.5\ \mu eV$
- $E_R = 184 \pm 1$ keV



- Measured 188 keV resonance in $^{26g}Al(p,\gamma)^{27}Si$
- Beam intensities up to 5 x 10^9 ions/sec
- Measure 1.6 x smaller resonance strength than previously thought
- Results in ~20% slower reaction rate – produces more ^{26}Al in typical Novae
- Further constrain Nova contribution to Galactic ^{26}Al

C. RUIZ (DRAGON)

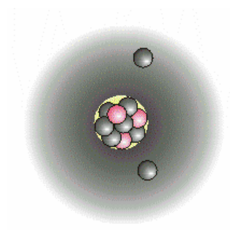
Highlights: Laser spectroscopy



^{6}Li	^{7}Li	^{8}Li	^{9}Li	^{11}Li
∞	∞	838 ms	178 ms	8.6 ms
1	3/2	2	3/2	3/2

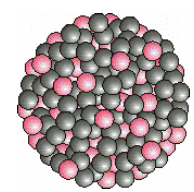
Neutron Halo Nucleus

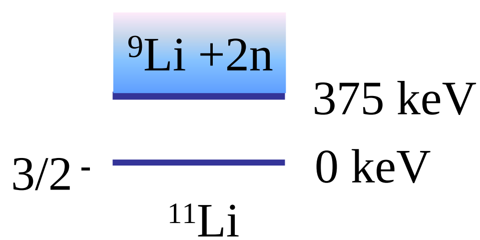
$^{11}\mathrm{Li} = {}^{9}\mathrm{Li} + n + n$



Stable Nucleus

^{208}Pb

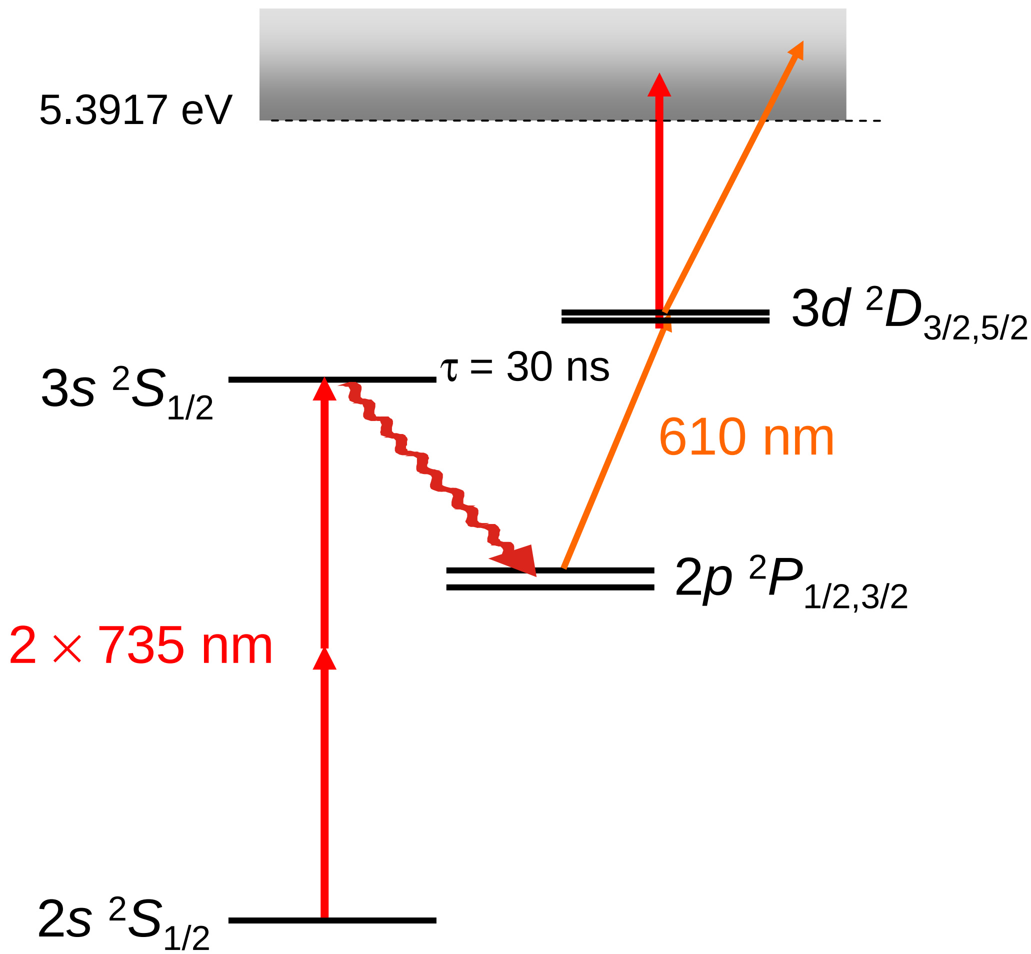




W.Noetershaeuser (GSI)

Resonance Ionization Scheme

"Doubly-Resonant-4-Photon Ionization"



2s – 3s transition

→ Narrow line

2-photon spectroscopy

→ Doppler cancellation

Spontaneous decay

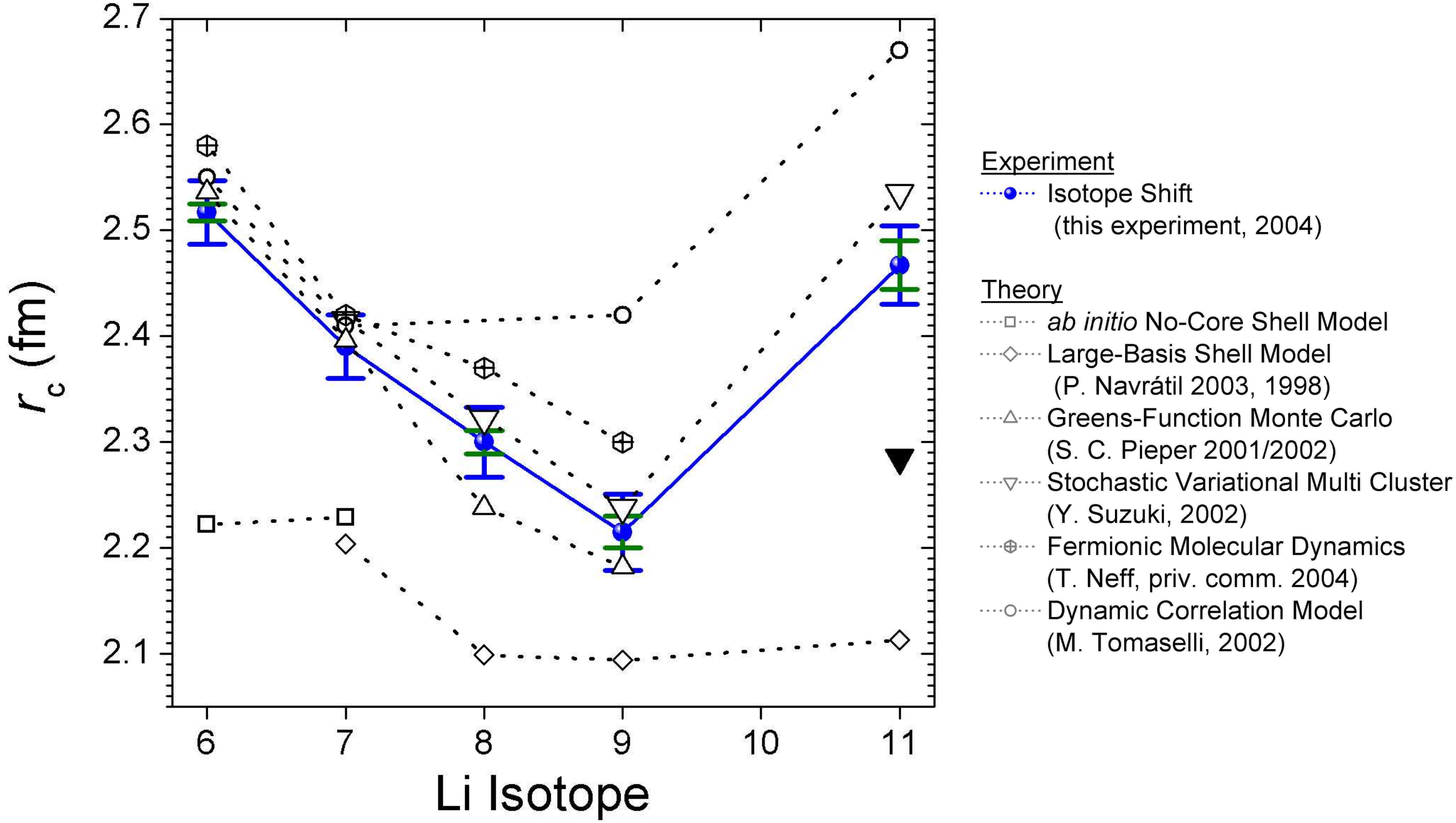
→ Decoupling of precise spectroscopy and efficient ionization

2*p* – 3*d* transition

→ Resonance enhancement for efficient ionization

W.Noetershaeuser (GSI)

Charge Radius

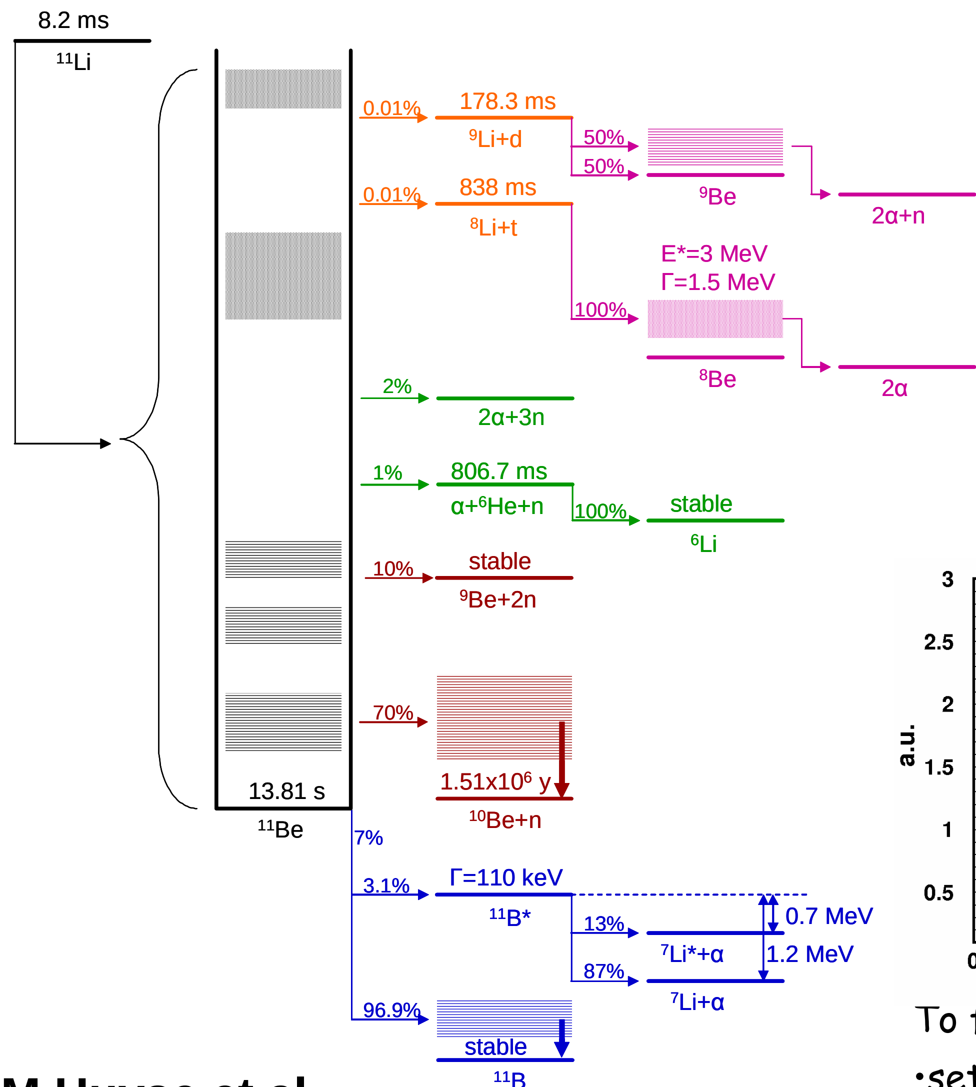


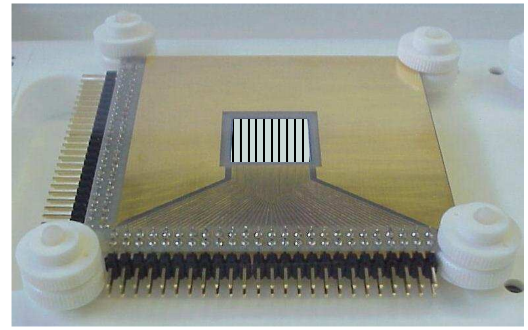
PRL 2006 R. Sanchez et al.

W.Noetershaeuser (GSI)

E1030 – first results

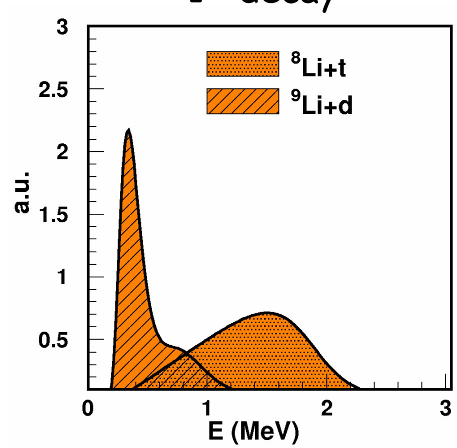
- Measure charged-particle branches of ^{11}Li β-decay (^{9}Li+d, ^{8}Li+t…)



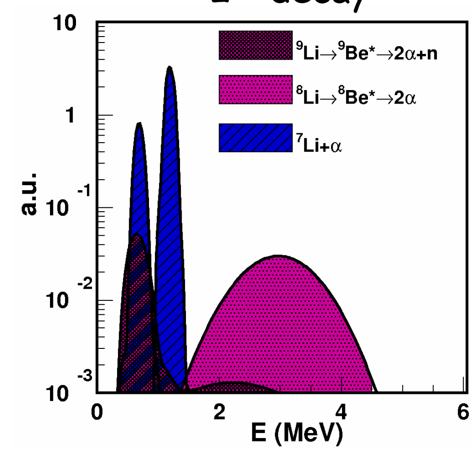


- Implant ^{11}Li in a "pixel" detector
- Follow each single decay and its daughter
- Identify branches by conditions on energy spectra and timing

1st decay



2nd decay

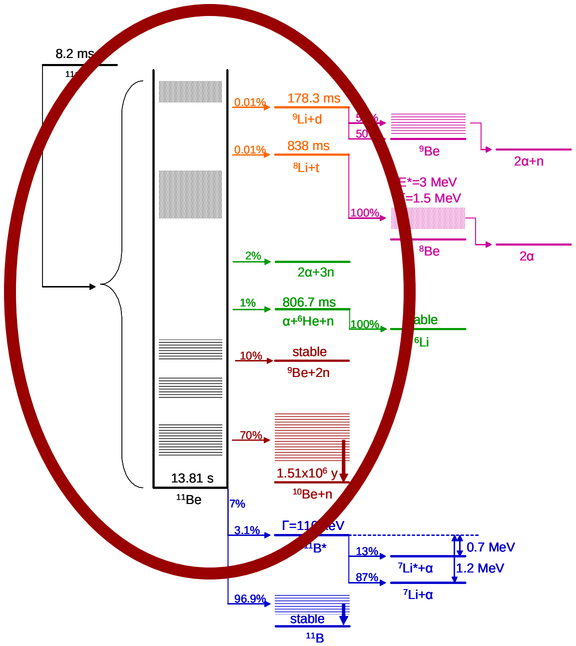


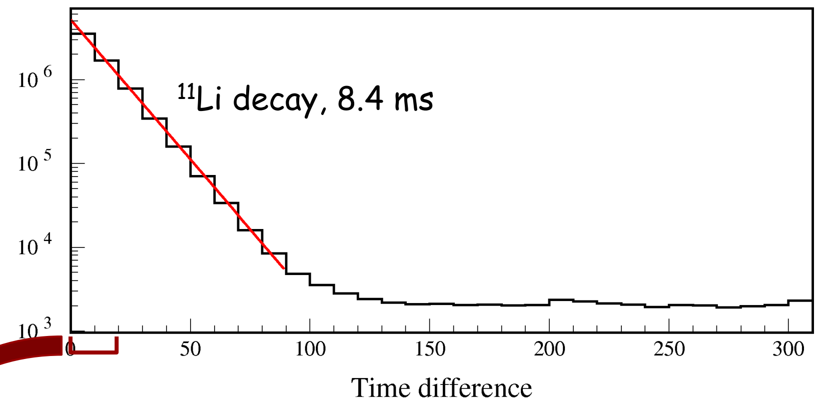
To find evidence of these branches:

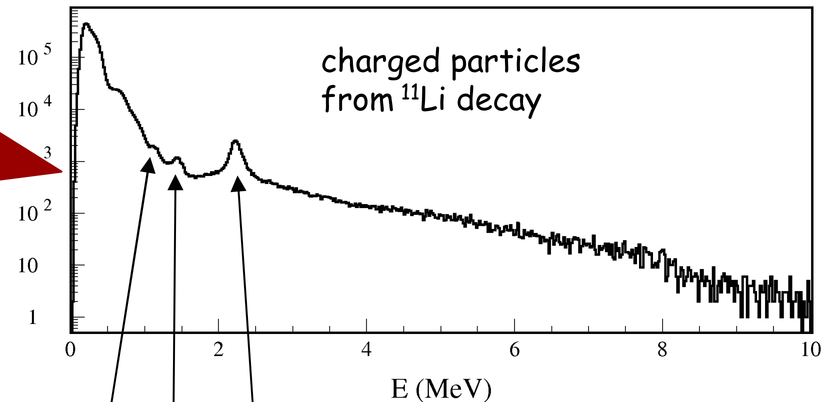
- set energy gates on first decay
- look at time behaviour of features in second decay

M Huyse et al.

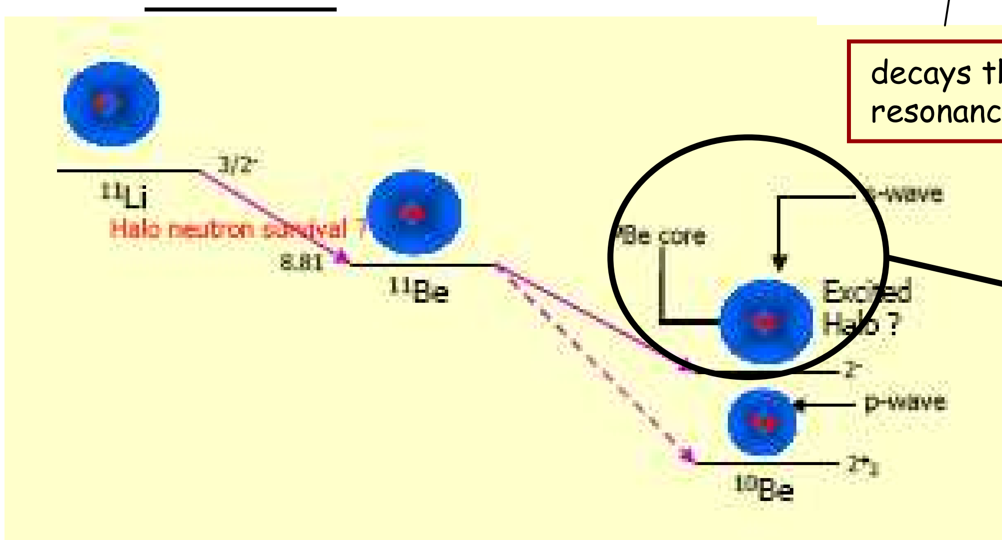
^{11}Li decay





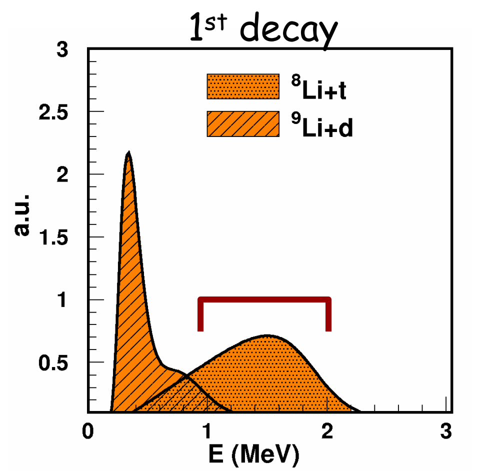


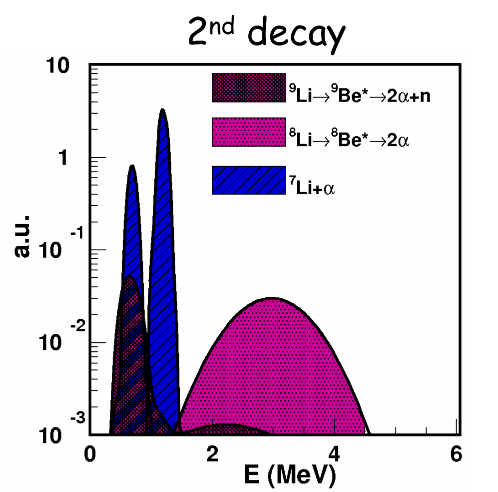
decays through (narrow) resonances in $^{10(9)}$Be

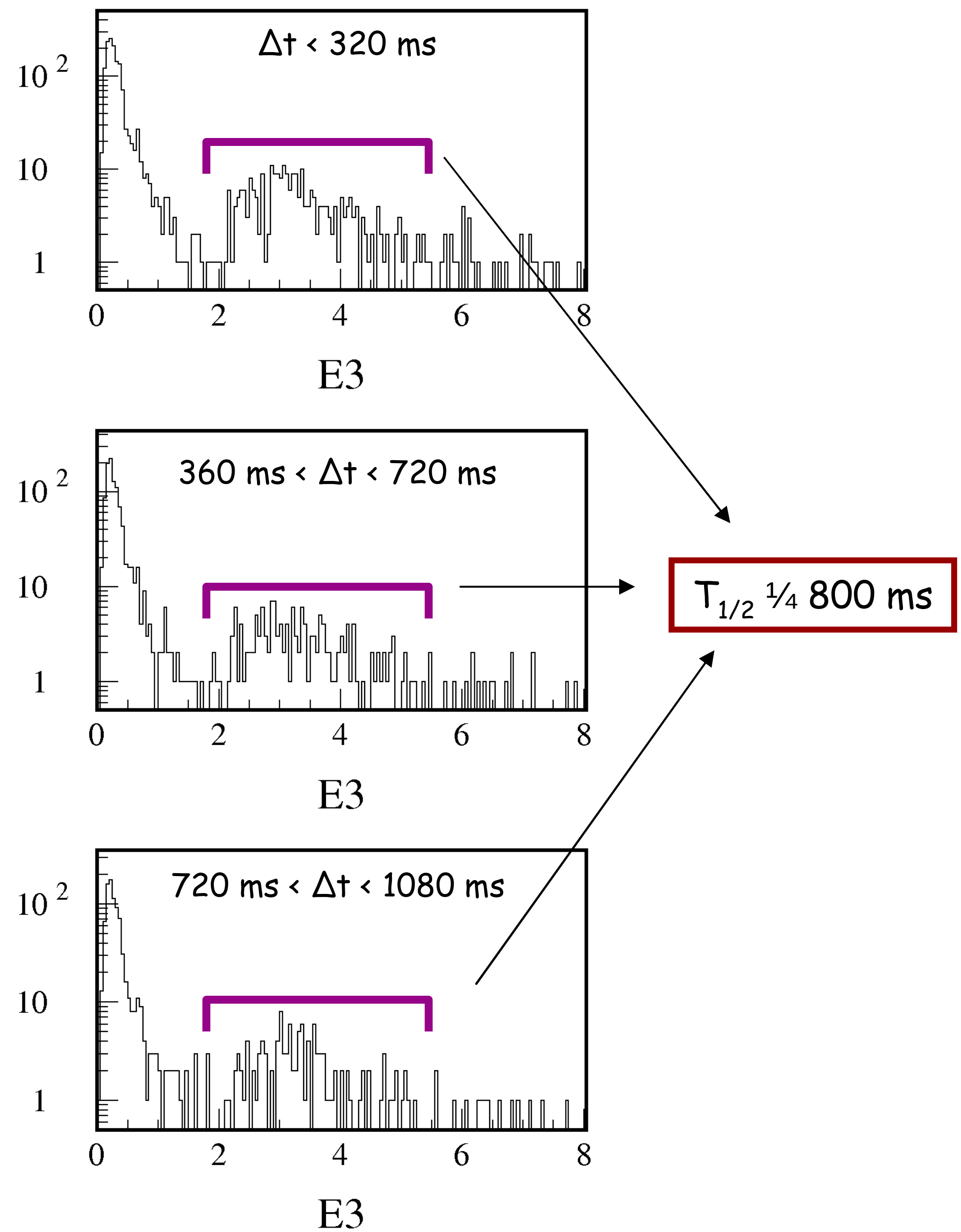


studied with 8π spectrometer
Sarazin et al.
PRC 70 031302 R 2004

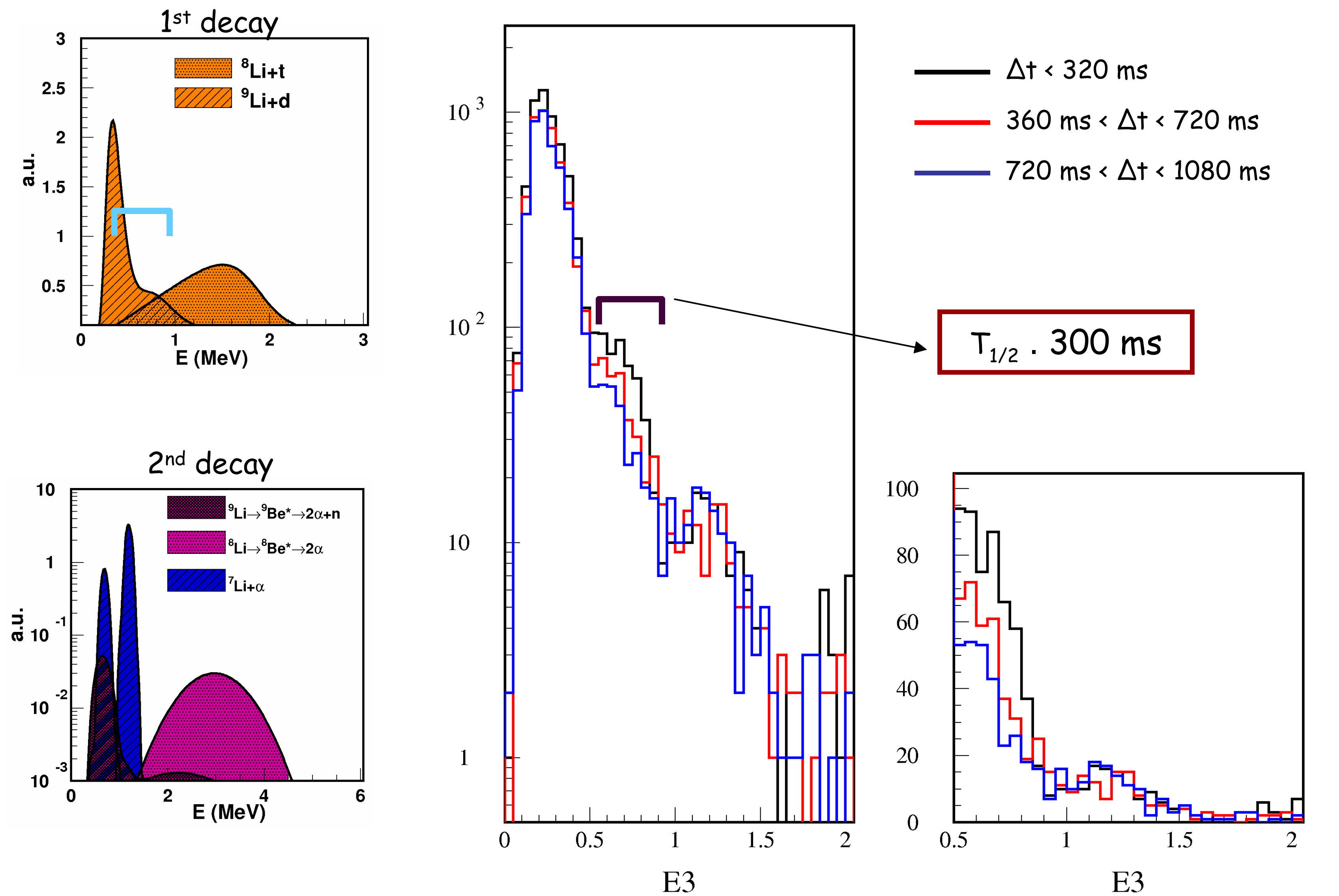
^{11}Li decay – ^{8}Li+t



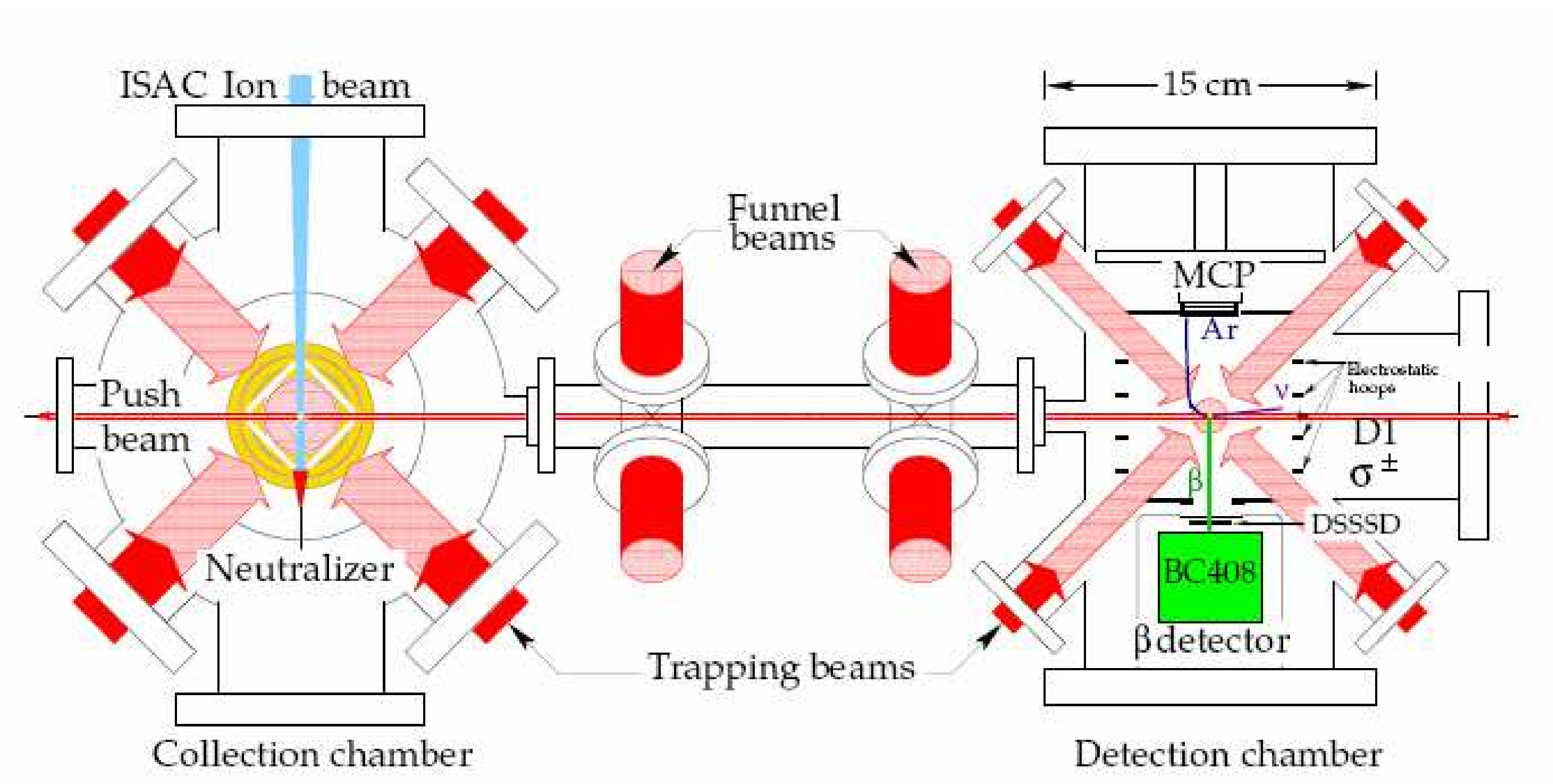




^{11}Li decay – ^{9}Li+d



TRINAT (Weak Interaction Investigations)



^{38m}K $0^+ \rightarrow 0^+$ $\beta - \nu$ correlation

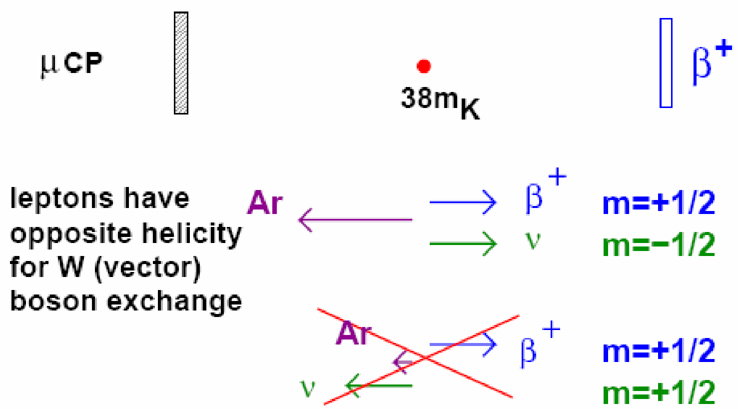
J. Behr et al.

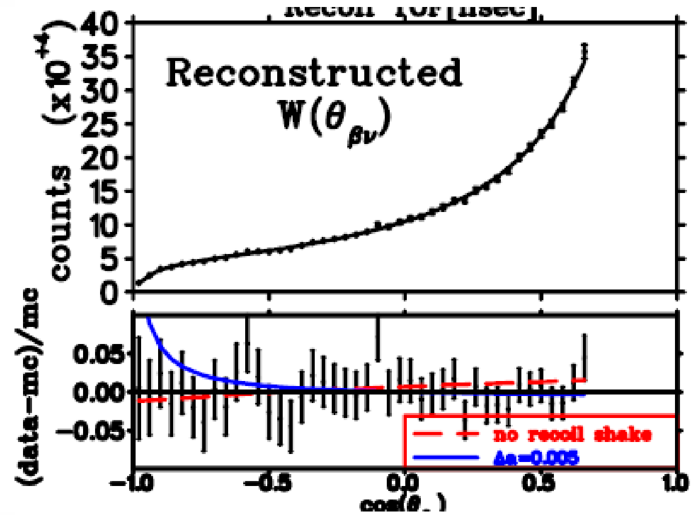
Search for Scalar Interaction, complementary to WHICH program.

TRINAT (Weak Interaction Investigations)

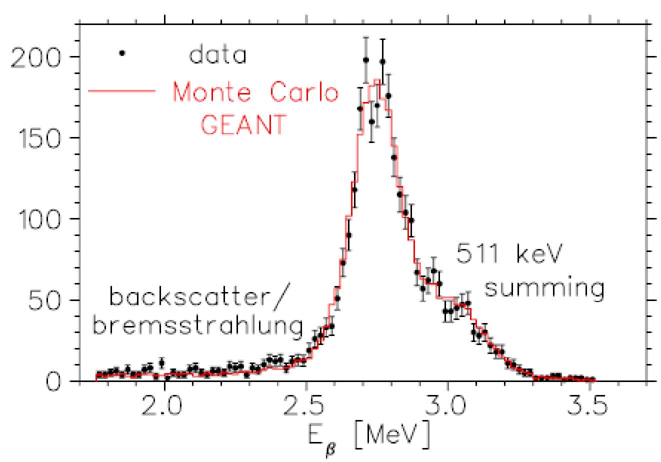
$$W[\theta_{\beta\nu}] = 1 \; + \; b\frac{m}{E} \; + \; a \; \frac{v_\beta}{c} \cos\theta_{\beta\nu}$$

a= +1





For scalar exchange, lepton helicities are same: a= -1

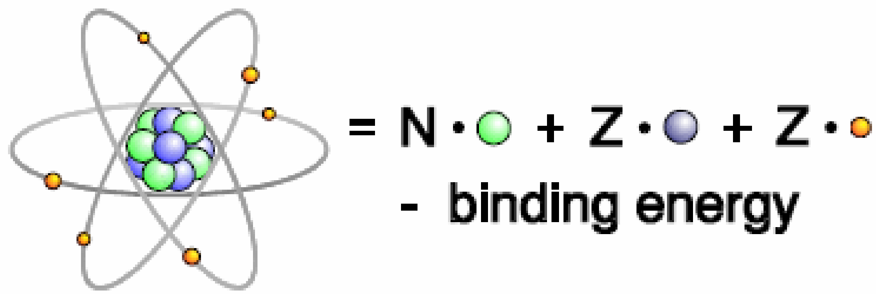


a=0.9981±0.0031(stat)±0.0037(sys)

A. Gorelov et al. PRL (2005)

J. Behr et al.

Mass Measurements: For Nuclear Physics



Fundamental Property
Test of nuclear models and formulas

Limits and Islands
Driplines and Superheavies

Nuclear Structure
Shell closures, pairing, deformation
Halos

Nuclear Astrophysics
r- and rp-process

Reaction and decays
Q-values, boundaries on exotic decays

Fundamental tests
Symmetries
Weak interaction: CVC hypothesis, search for scalar and tensor currents

Unitarity of the Cabbibo, Kobayashi, Maskawa (CKM) Matrix

Weak eigenstates

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Mass eigenstates

V_{ud} (nuclear β-decay) = 0.9740(5)
V_{us} (kaon-decay) = 0.2196(12)
V_{ub} (B meson decay) = 0.0036(5)

⇓

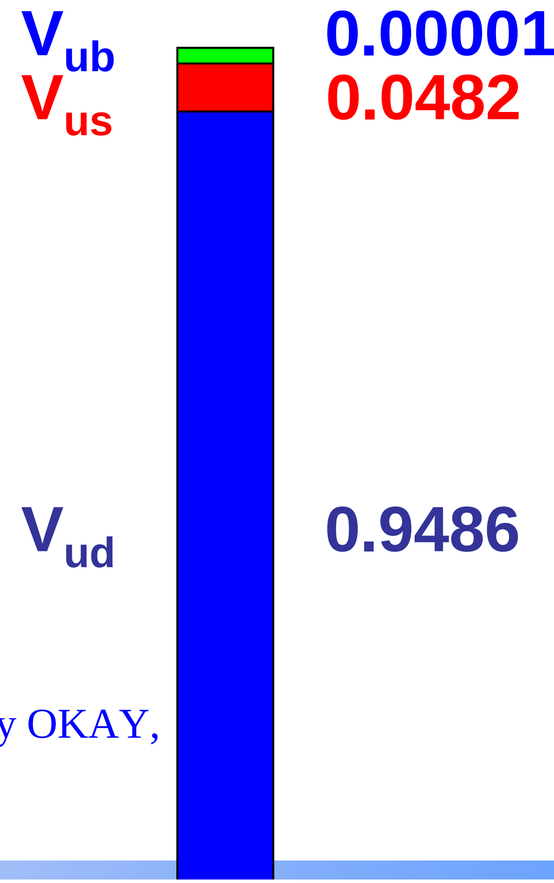
(non-)unitarity of CKM-matrix

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9968 \pm 0.0014$$

i.e. CKM not unitary at the 98% confidence level

(btw: if E865 Brookhaven and E832 Fermilab included-> Unitarity OKAY, if NA48 CERN included-> again 2.4 σ difference).
J.C. Hardy and I.S. Towner PRL 94, 092502 (2005)

Contribution to the unitarity:



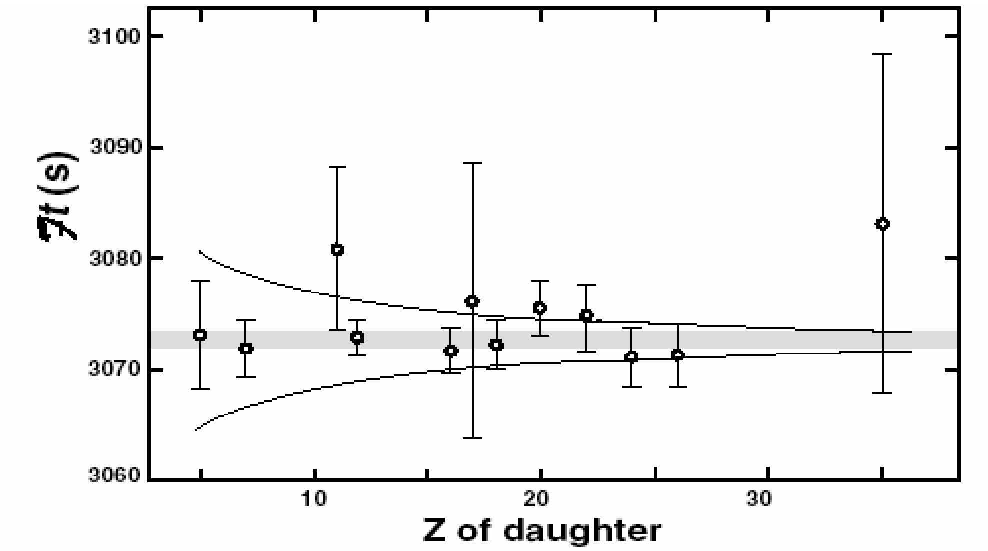
Nuclear β-decay contribution

$$FT \equiv ft(1+\delta_R)(1-\delta_C) = \frac{K}{2G_F^2 V_{ud}{}^2 (1+\Delta_R^V)} = (CVC)\ const.$$

f **is stat. rate function**

t **is partial half - life ($t_{1/2}$ and BR)**

$$K/(\hbar c)^6 = 2\pi^3 \hbar \ln 2/(m_e c^2)^5 = (8120.271 \pm 0.012)\cdot 10^{-10}\, GeV^{-4} s$$



$$FT(average) \equiv ft(1+\delta_R)(1-\delta_C)$$

$$= \frac{K}{2G_F^2(1+\Delta_R)V_{ud}^2} = 3072.2(8)$$

with $\chi^2/\nu = 0.6$

where:

δ_C : Coulomb (isospin) correction

δ_R : nucleus - dependent radiative corrections

Δ_R : nucleus - independent radiative corrections

δ_R : dominant part is QED calc.

considered very reliable!

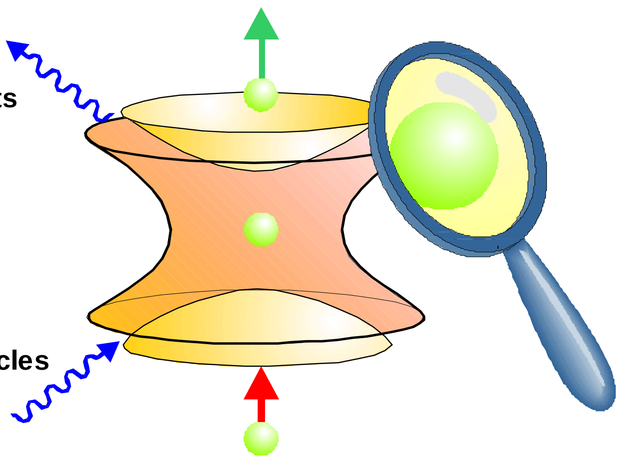
δ_C **: depending on nuclear structure (model dependent)**

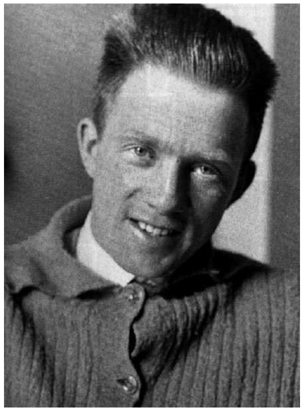
Precision experiments: f. ex.:

^{74}Rb($T_{1/2}$ = 65 ms): δm = ~6 keV

Needed: δm = < 2 keV **δm/m < 1·10^{-8}**

High precision experiments, the tool-box: ion traps





W. Heisenberg

Long-time storage in well-defined fields ⇒

precision measurements of masses and moments

precision decay studies

Confinement and interaction with gas or other charged particles (electrons), laser light, … ⇒

ion manipulation

STORAGE

↓

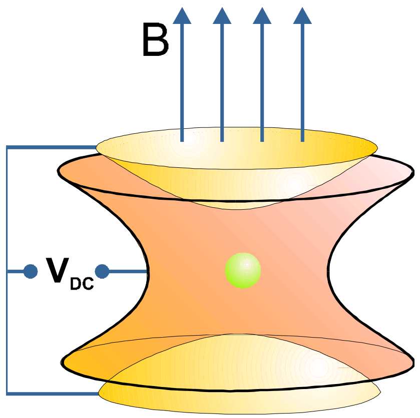
PRECISION

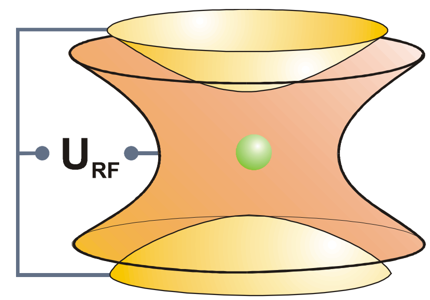
$\Delta t \cdot \Delta E > h / 2\pi$

How do ion traps work?

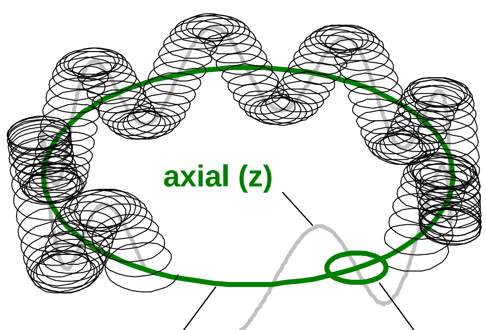
Penning trap:
Static electric quadrupole + magnetic field

Paul trap:
Oscillating electric quadrupole field

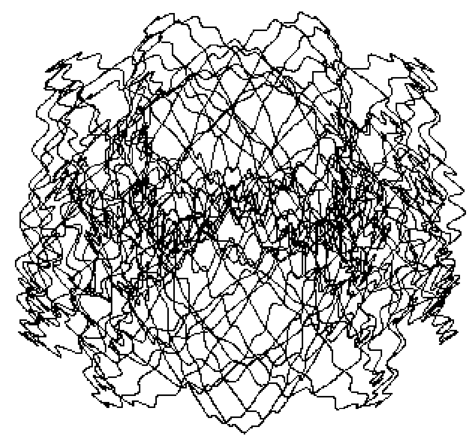




3D confinement



3 harmonic oscillations

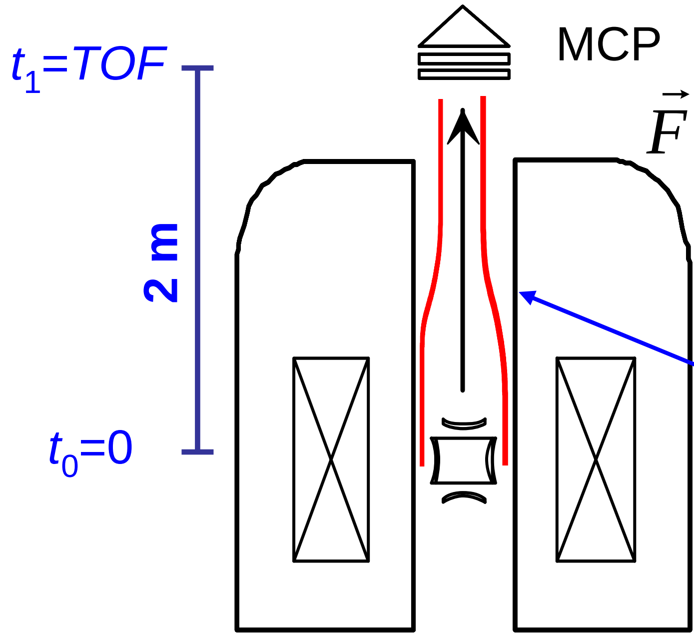


micromotion + macromotion

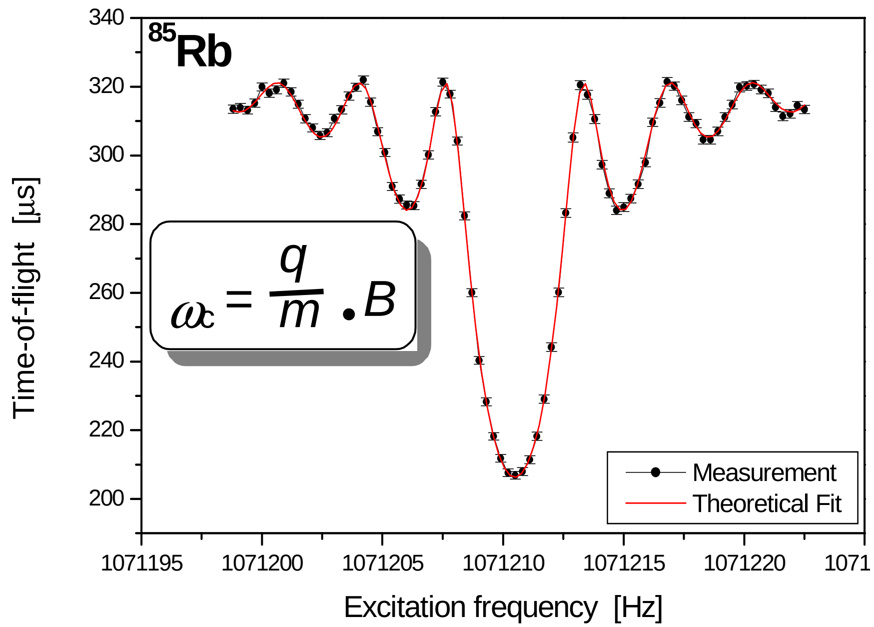
Suited for precision experiments.

Suited for manipulation techniques.

Mass measurement via time-of-flight



$$\vec{F} = \vec{\mu} \cdot \nabla \left|\vec{B}\right|$$



$$\omega_c = \frac{q}{m} \cdot B$$

$$E_{pot} = -\vec{\mu} \cdot \vec{B} \qquad E_{rad} = \mu B$$

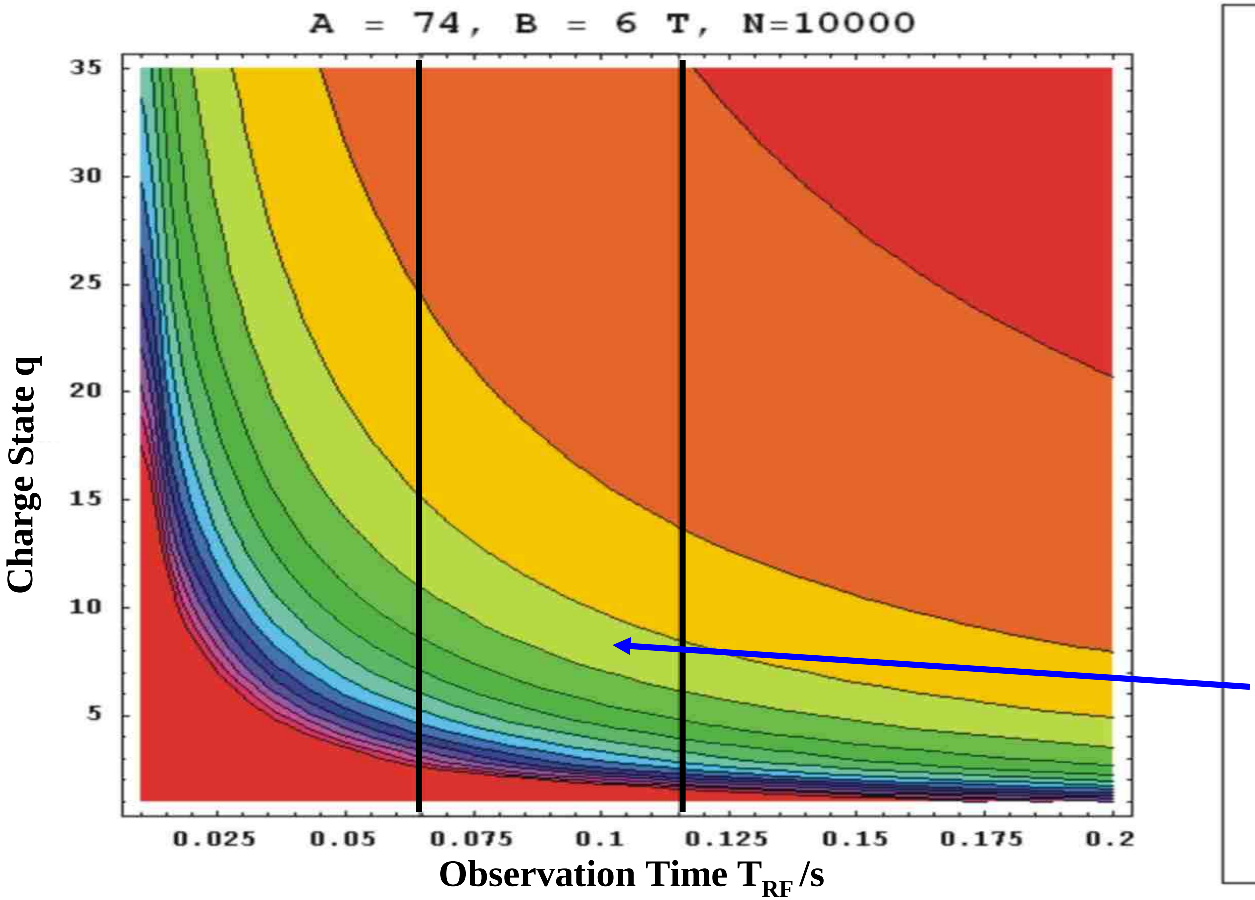
Determine atom mass from frequency ratio with a well known reference

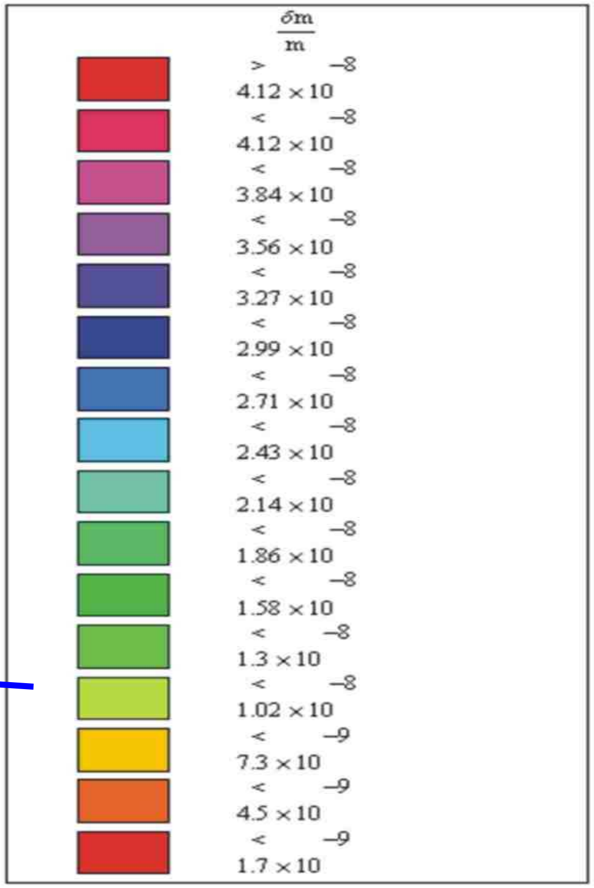
Time-of-flight cyclotron resonance detection → suited for radioactive isotopes

Learned from the master: ISOLTRAP

Accuracy of Penning Trap Mass Measurements

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





W

Use Highly Charged Ions.

TITAN (in a nutshell)

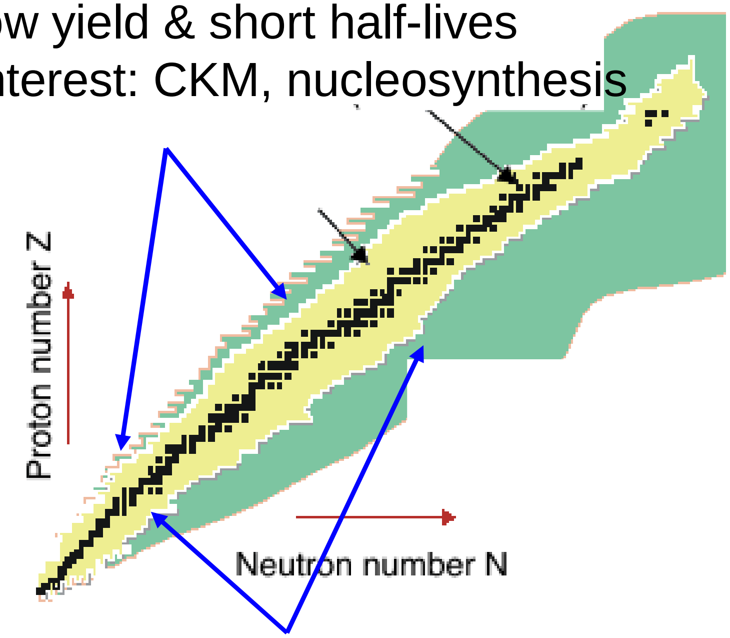
ISAC ion beam → **RFQ cooler & buncher** → **EBIT charge breeder** → **m/q selection** → **Cooler Penning trap** → **Precision Penning trap**

Mass measurements on isotopes with short half-life $T_{1/2}$ 10 ms and low production yields (≈ 100 ions/s) with high precision $\delta m/m \approx 10^{-9}$.

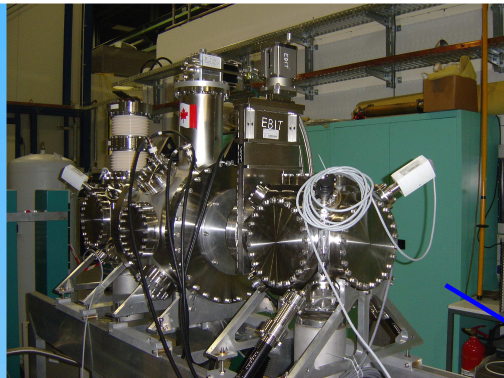
Ideally, uniquely matched to isol-type production mode, fulfill requirements for accuracy.

TITAN started April 2003(NSERC), planned first on-line mass measurements will be in 2006.

low yield & short half-lives
Interest: CKM, nucleosynthesis



Interest: nucleosynthesis, nuclear structure, halo-nuclei

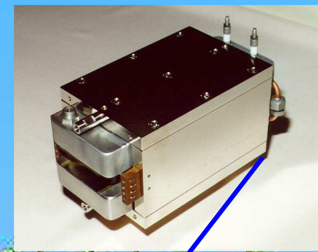


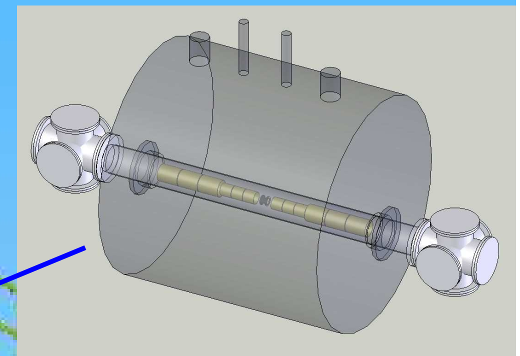
EBIT under testing at MPI-HD.
to TRIUMF March 2006.

Max-Planck-Institut für Kernphysik

McGill

Wien filter
(R=500)

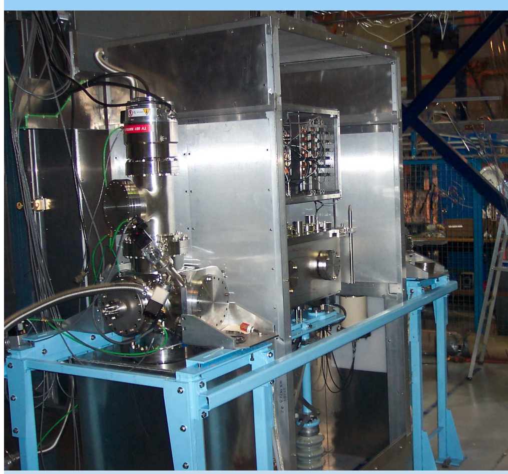




Penning trap magnet
ordered (del. June 2006)

Cooler trap for HCI
(to be built in Manitoba,
CFI grant received)

university of manitoba



RFQ operational on test bench

TITAN platform finished at ISAC

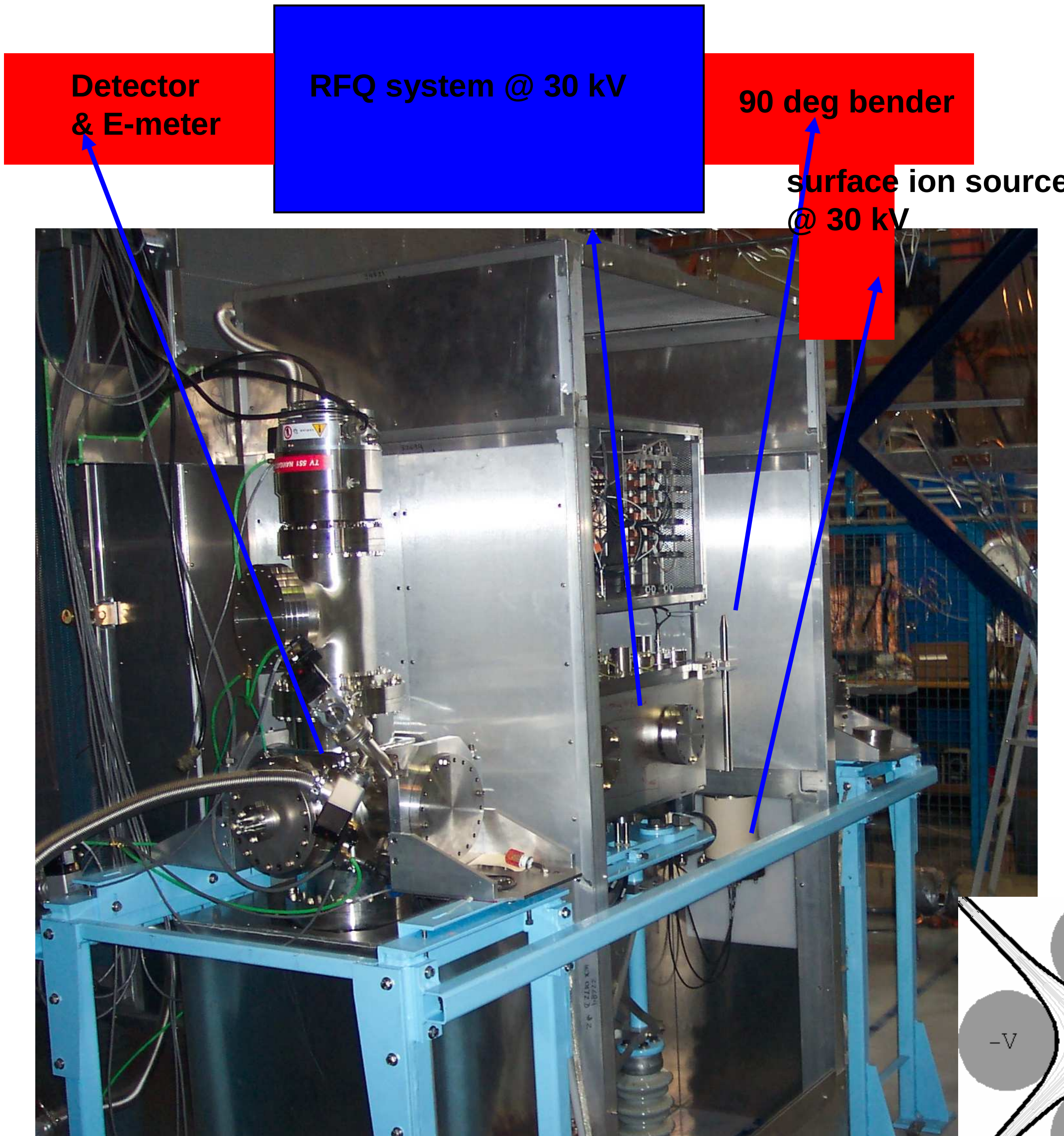
The TITAN system is under construction and will be operational for mass measurements at ISAC/TRIUMF in 2006.

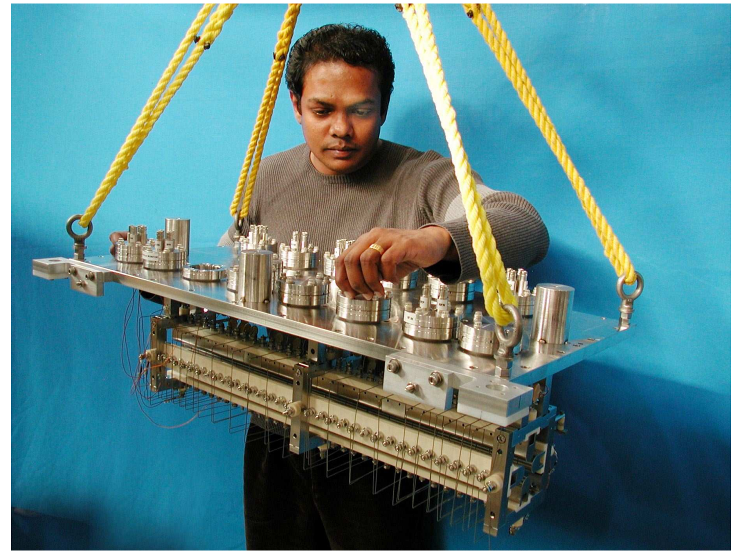
Isotopes with $T_{1/2} \approx 10$ ms

$\delta m/m < 1 \cdot 10^{-8}$

TRIUMF ISAC

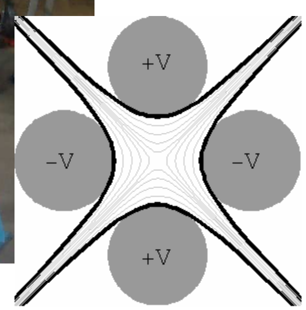
RFQ cooler and buncher (RFCT)

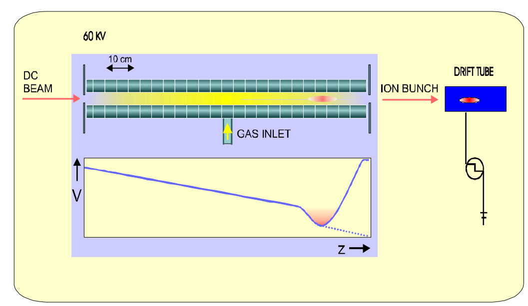




Set-up of test beam line, including High-Voltage Faraday cage. Tested to 60 keV.

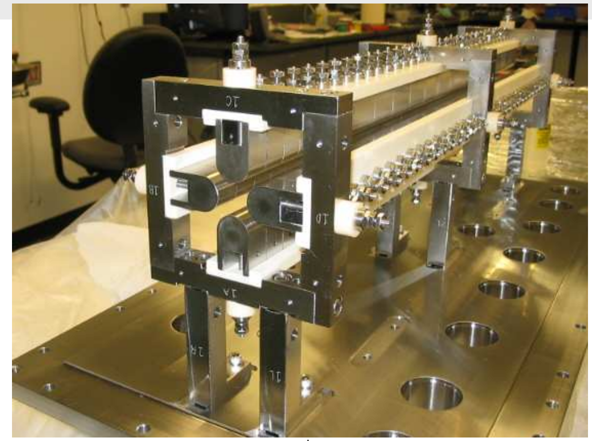
Cooler works in DC and pulsed mode with ε≈60%

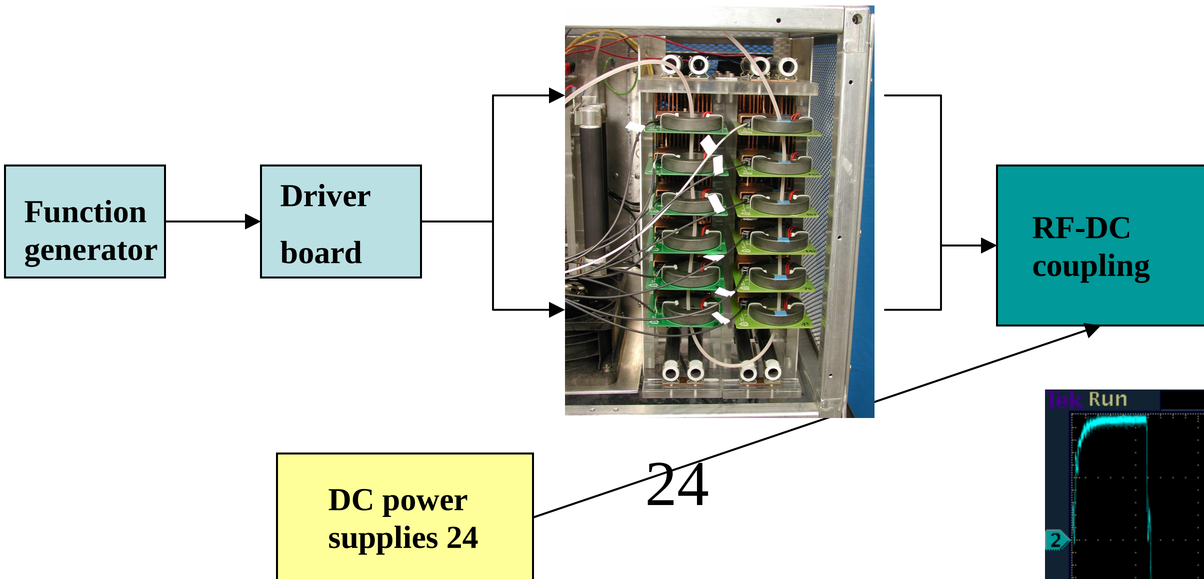




Development of broad-band RF cooler

Driver: based on fast FET-switches developed @ TRIUMF for fast kickers (9 ns @ 1000V) M. Barnes et al.

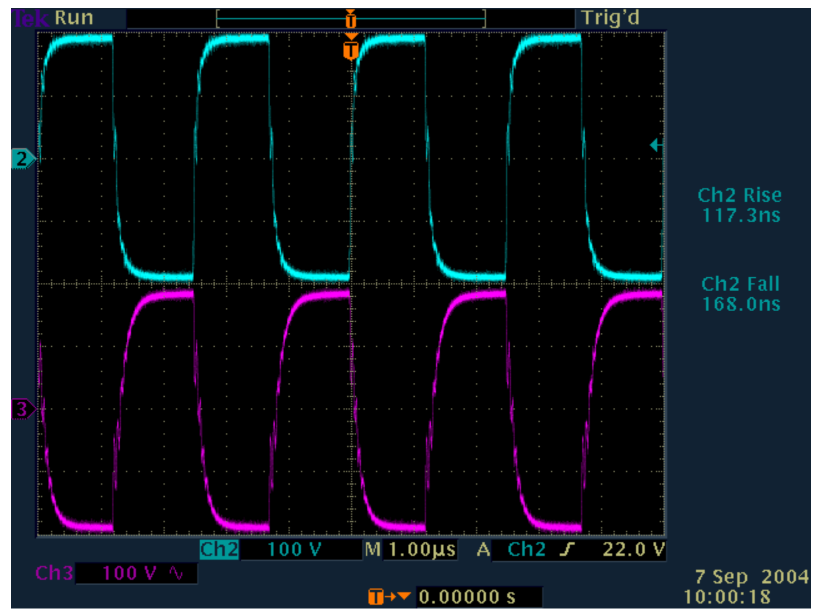




Have reached 650 Vpp @ 400 kHz- 2 MHz.

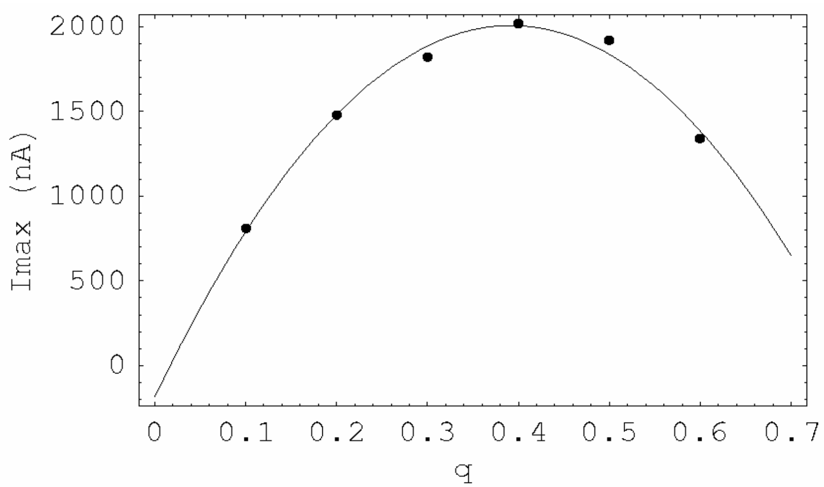
Presently 3*2 switching boards coupled, but can be extended to reach much higher amplitudes.

Limit: heat dissipation in power resistors, temperature of switches.

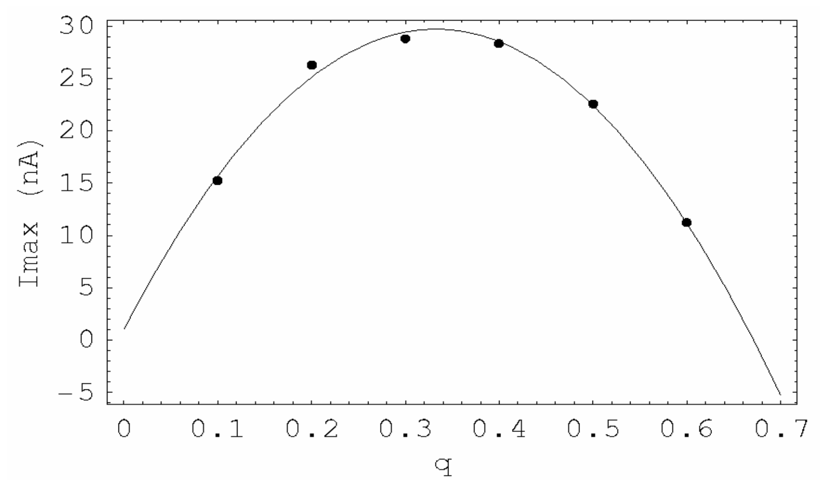


Theoretical space charge limit

Continuous, V_d = 1000 m/s



Bunched, t = 1 ms

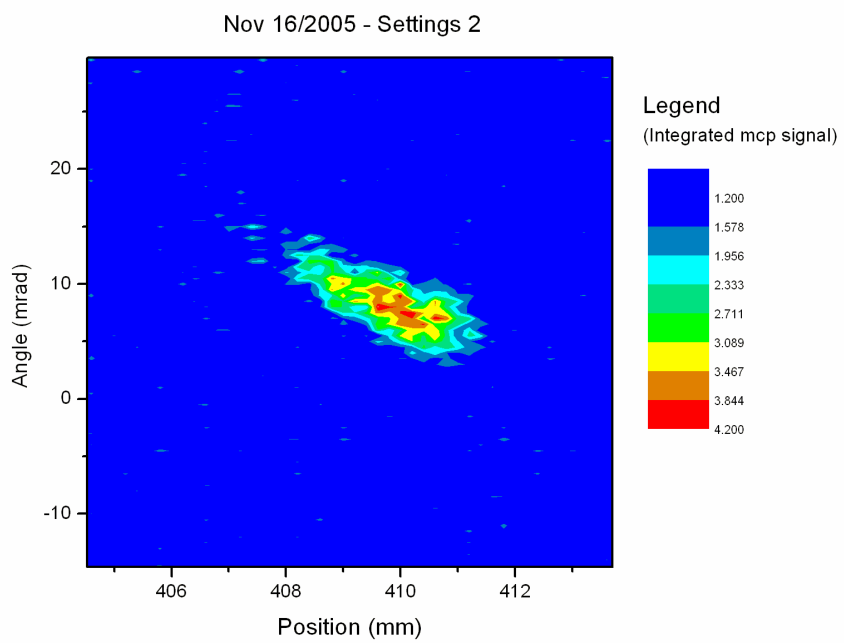


Space charge limit => balance between confining potential (from RF-field, prop. to RF amplitude) and repulsive potential

- In continuous mode $I_{max} \approx 2\ \mu A$, @ q = 0.39. (assume cylinder)
- In bunched mode $I_{max} \approx 30$ nA, @ q = 0.33. (assume sphere)

(Simulations: master thesis M. Smith and in prep. for Int. J. Mass Spec.)

RFQ cooler and buncher (RFCT)



Developed a bunched beam, low current emittance meter.

Emittance measurements to optimize operation by checking beam quality. Cs from test surface source.

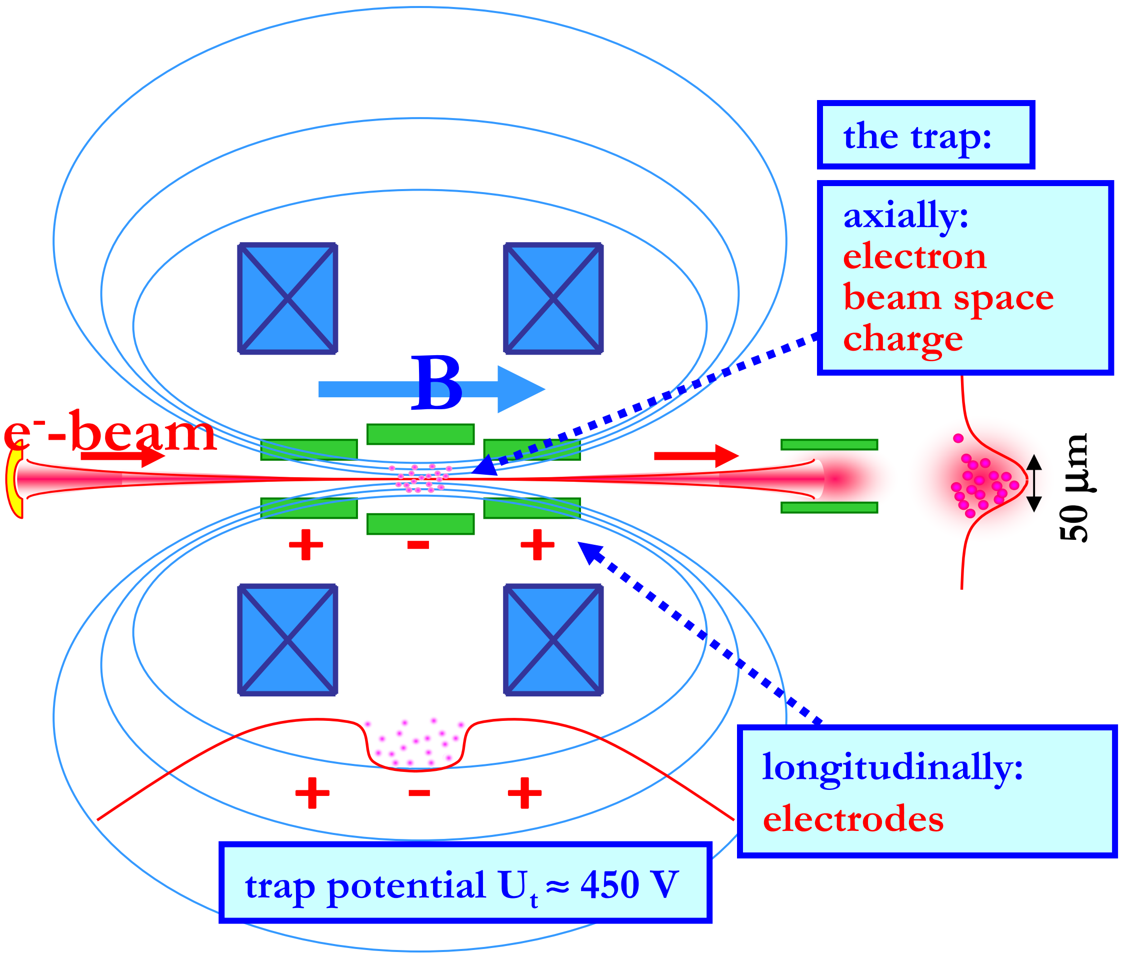
Transversal $\varepsilon_{95\%} = 6.1\ \pi$ mm mrad
He gas: 4.9 mTorr
Cooling Time: 0.01 s
RF: 400V @ 659 kHz
DC Slope: -3V over DCs 1-21 with DC1 = 2V
Trap depth: -30V

Corresponds to an beam quality improvement of a factor of >10.

In agreement with the Monte Carlo simulations for the cooling process and efficiencies.

Finish the efficiency measurements (by pulsed injection of the DC beam) and get ready to move to the ISAC hall. During shut-down Jan-March 2006.

EBIT system for charge breeding



Magnetic field: 6 Tesla

Electron beam energy: up to 80 keV

Electron beam current: 5 A

Beam radius (80% current): ~100 µ m

Central current density: $1.1 \cdot 10^5$ A/cm²

Ionization time (Sn, q: 1→2) 0.16 µ s

Axial oscillation period: 16 µ s

Total electron charges: $8 \cdot 10^{10}$

Build in close collaboration with the MPI for Nuclear Physics in Heidelberg/Germany.

Max-Planck-Institut für Kernphysik

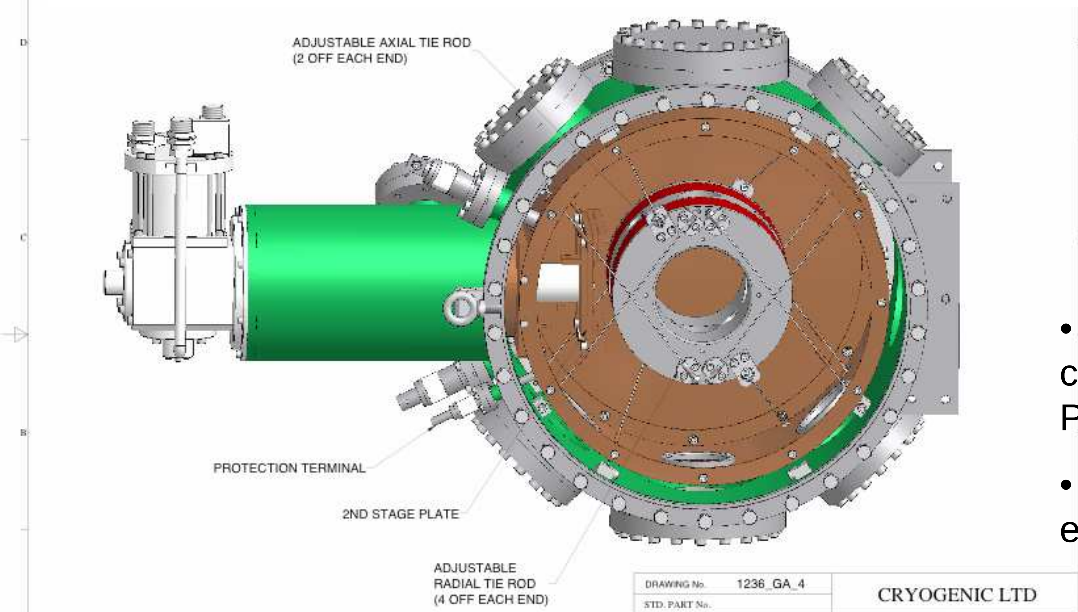
Expected Performance of the TITAN EBIT

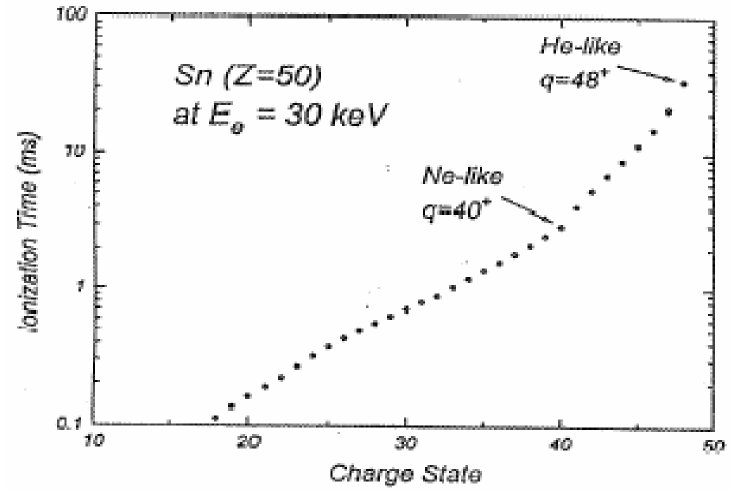
Trapping potential:	**U_e = 450 V @ 5 A**
Ion acceptance:	**ε = >10 π mm mrad @ 3 keV**
Injection efficiency:	**$\eta \approx$ 50 % -100 %**
Ionization time (Sn):	**τ = 3 ms (q = 40+, Ne-like)** **τ = 34 ms (q = 48+, He-like)**
Space charge limit:	**10^9 ions for Sn^{40+}**
Charge state abundance:	**25 ... 90 %**

Charge state Rb	Ion-Time [ms]
27 (Ne-like)	2
35 (He-like)	(50%) 10 (73%) 19
36 (H-like)	50

Cryogen free! Smaller, no preferred orientation.

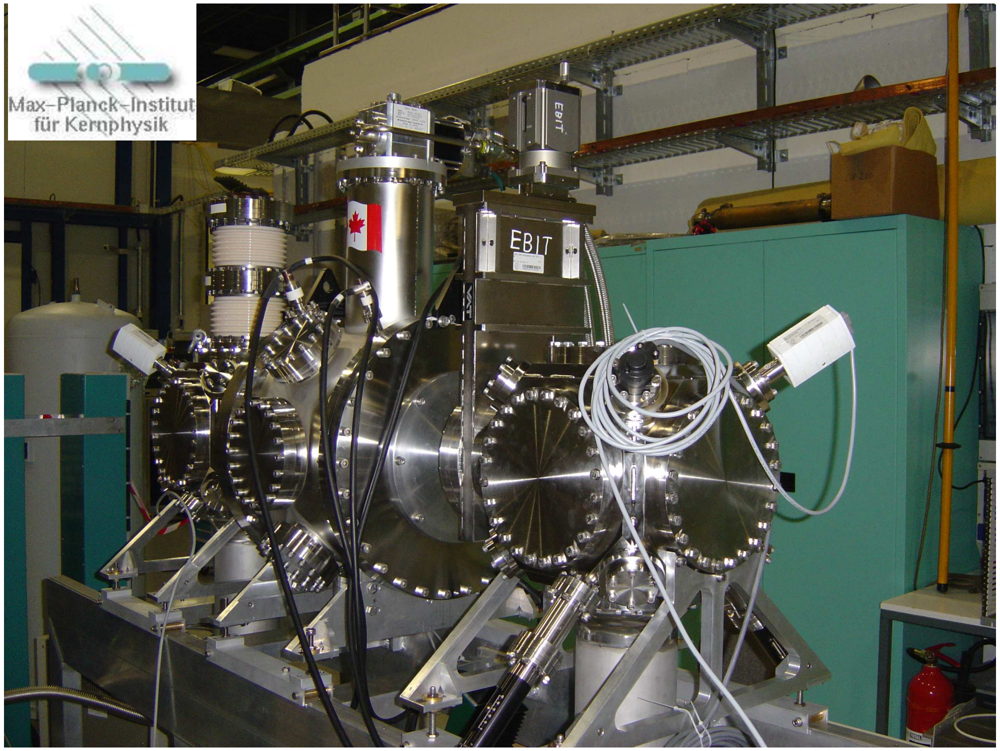
Excellent performance of magnet, vacuum (cryo-cold system)!



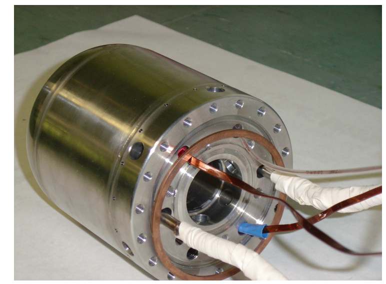


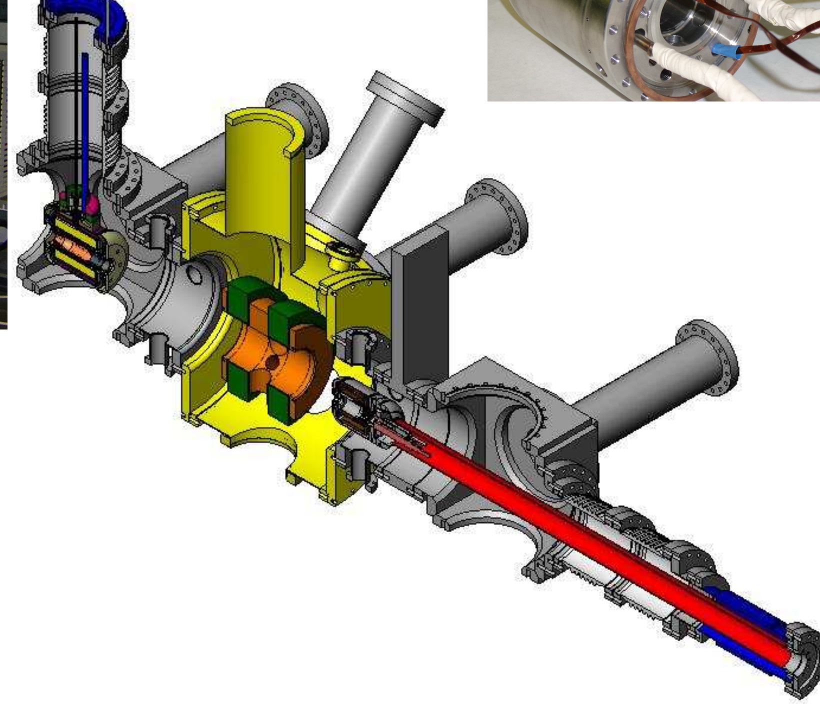
- For charge state distribution: reached 90% in one charge state: for example at Ba^{46+} (Ne-like) PRL 60(1988)1715.
- Manipulation of the distribution by varying the electron-energy and the trapping time.

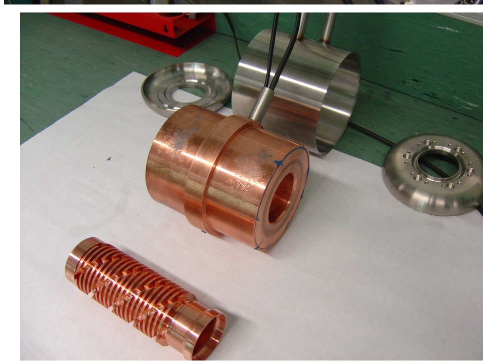
TITAN EBIT @ Heidelberg

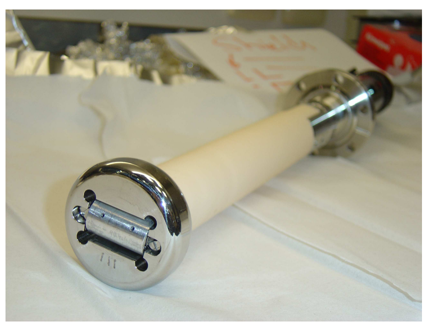


Three different E-guns (0.5A, 1.5A, 5A) assembled, tests underway.





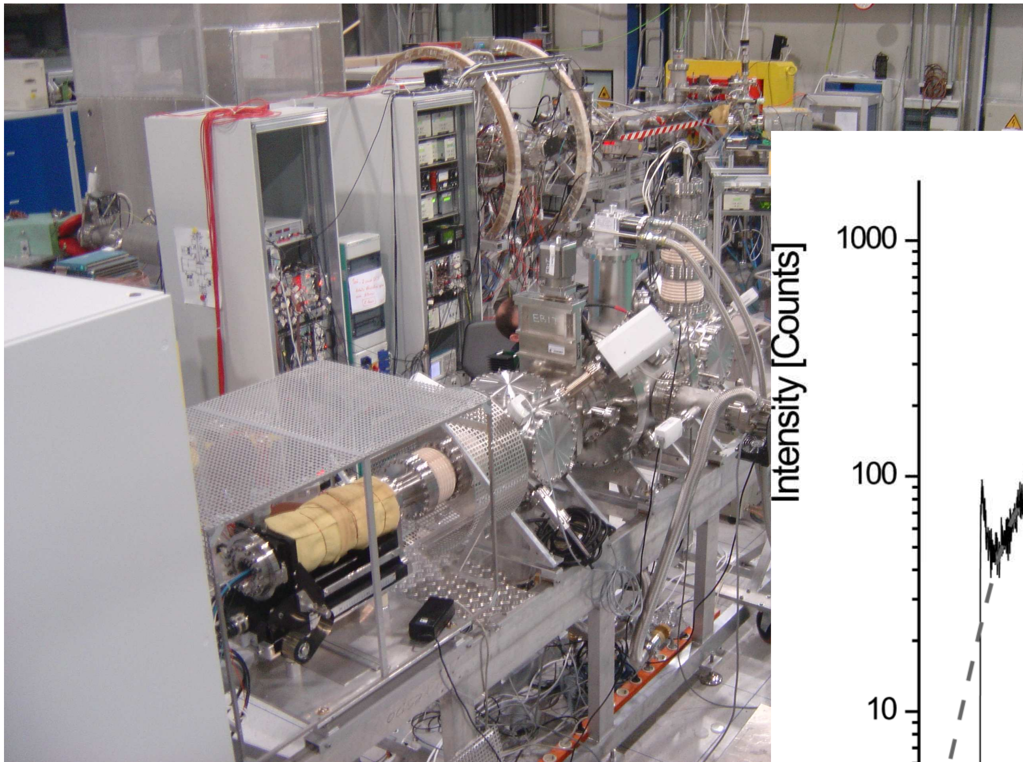




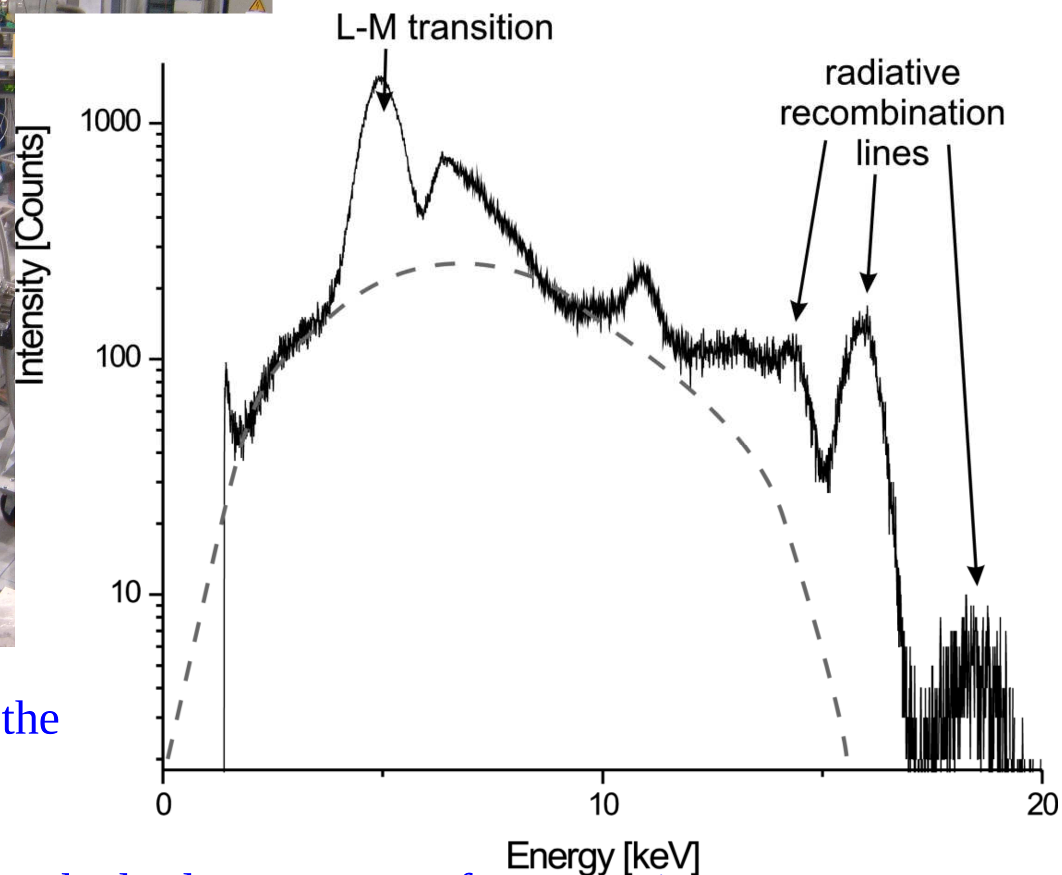
Collector cooling tested up to 5 kW.

G. Sikler et al, European Phys. Journal A 25 (2005) 1.63

TITAN EBIT @ Heidelberg



Fully functional test set-up.



X-ray spectrum of Ba (released from the e-gun cathode).

JUST FINISHED: Injected Kr, and attached selector magnet for extraction tests, Including emittance measurements

Optimization of system with stable ions. Use spectroscopy on-line as diagnosis.

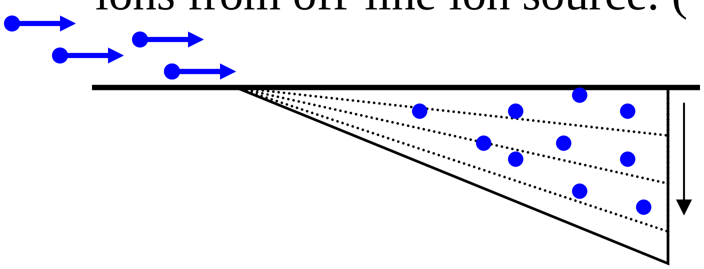
Move system to ISAC Spring 2006

New cooling method for HCI

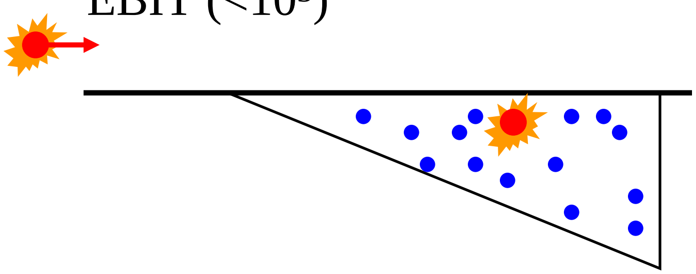
The energy spread and emittance of the ions extracted from EBIT can be large (approx 50eV/q). Need to be cooled before measurement in the Penning trap.

PROPOSAL: cool the HCI with protons or SCI in a special Penning trap

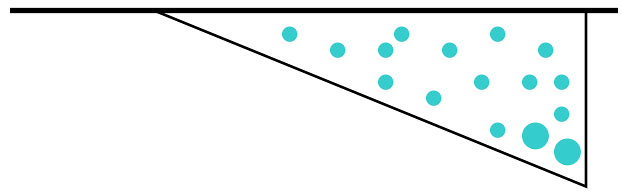
1. Load the cooling trap with “cold” ions from off-line ion source. (~10^7)



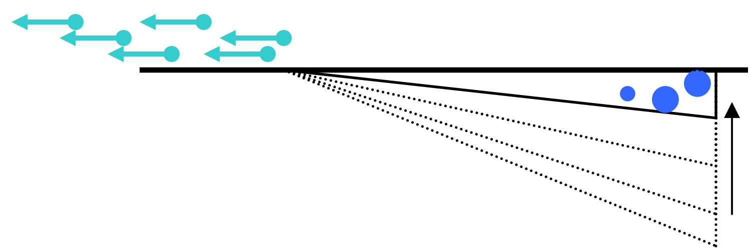
2. Inject the “hot” ions from the EBIT (<10^3)



3. Thermalization



4. Light ion separation/evap. cooling

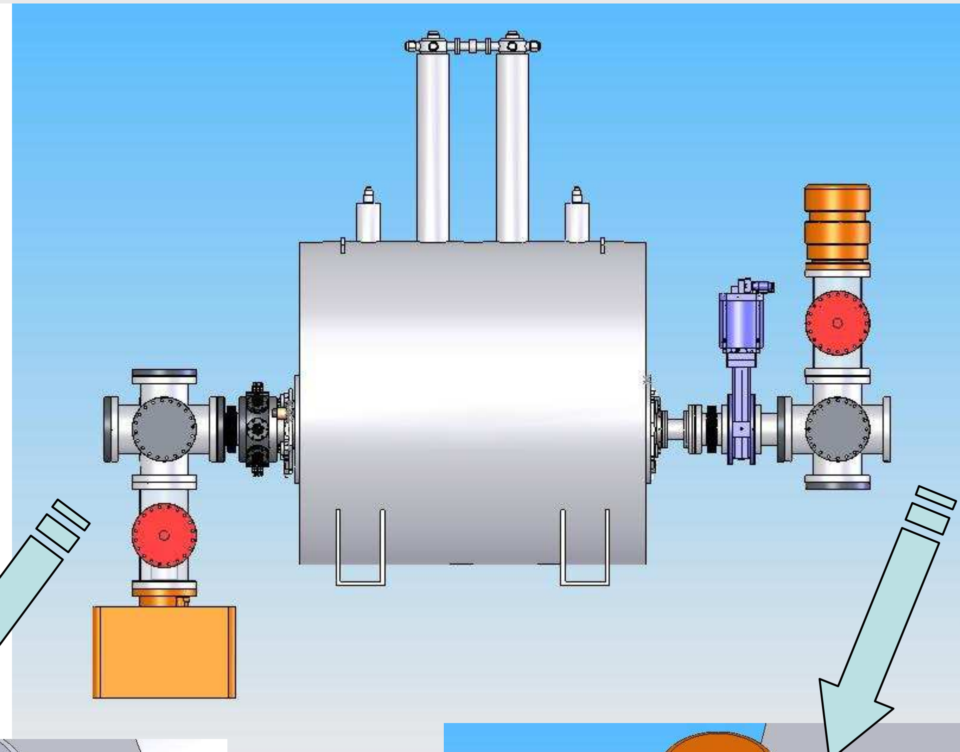


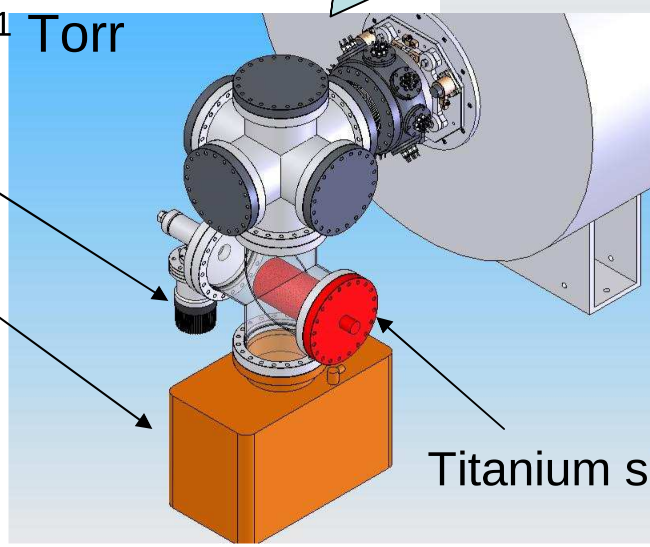
5. Send HCI into the measurement trap via Wien filter

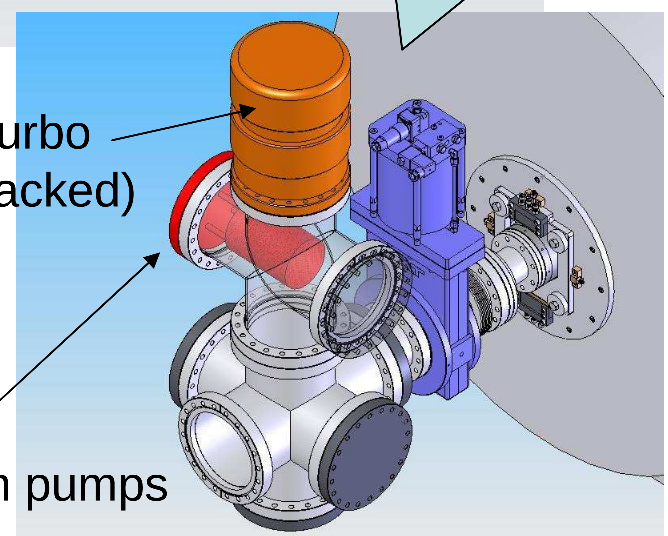
Calculations show that for Kr^{36+} the thermalization time is less than 100ms (factor 20 faster than electron cooling and no recombination losses!)

Penning Trap system

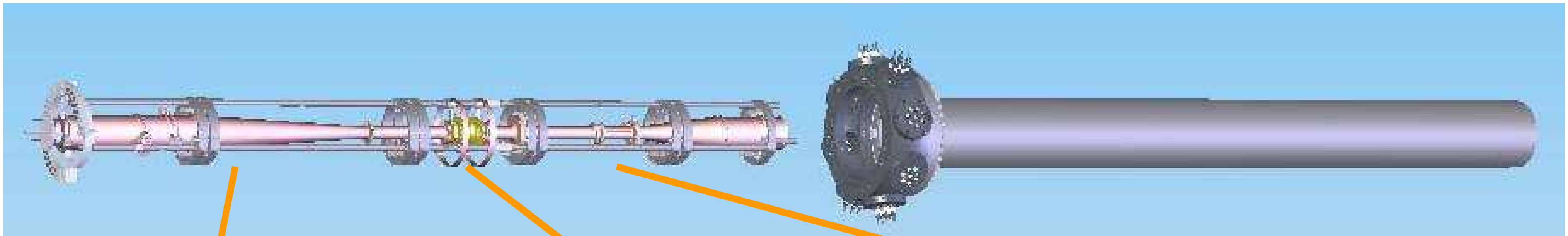
- Custom titanium in-bore vacuum chamber (manufactured)
- Standard stainless steel conflat components (everything received)
- Activated Titanium sublimation pump. P<1x10^{-11} Torr

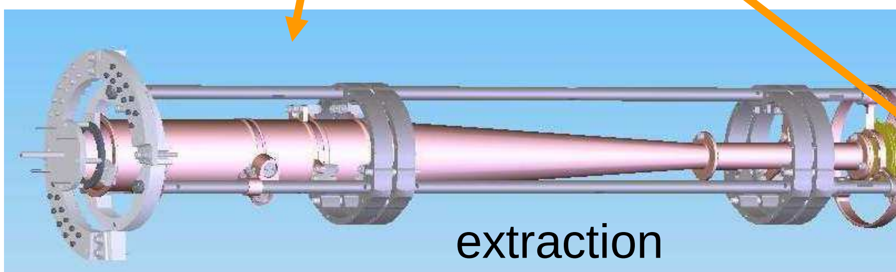


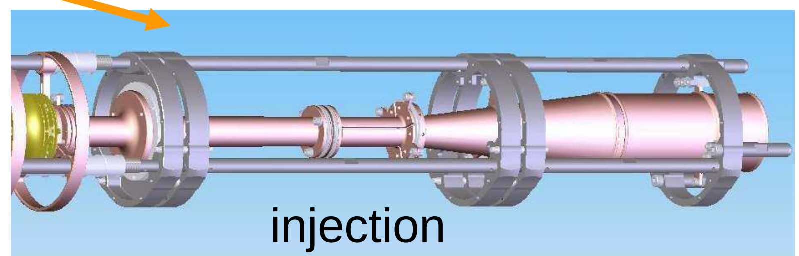




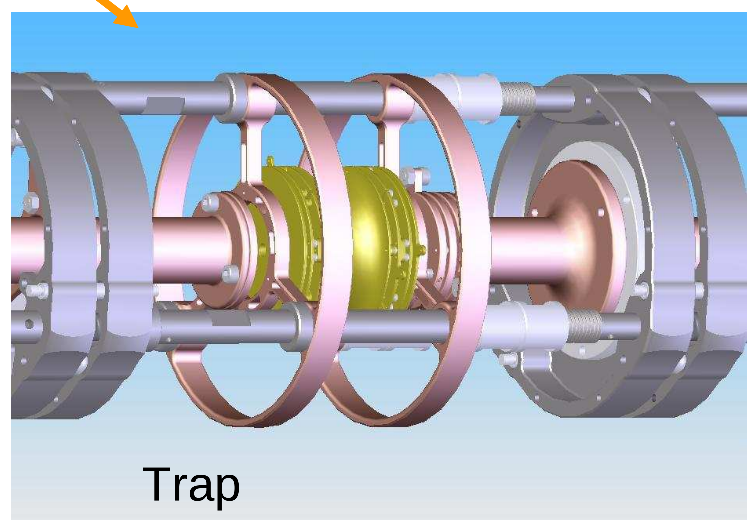
Penning Trap system



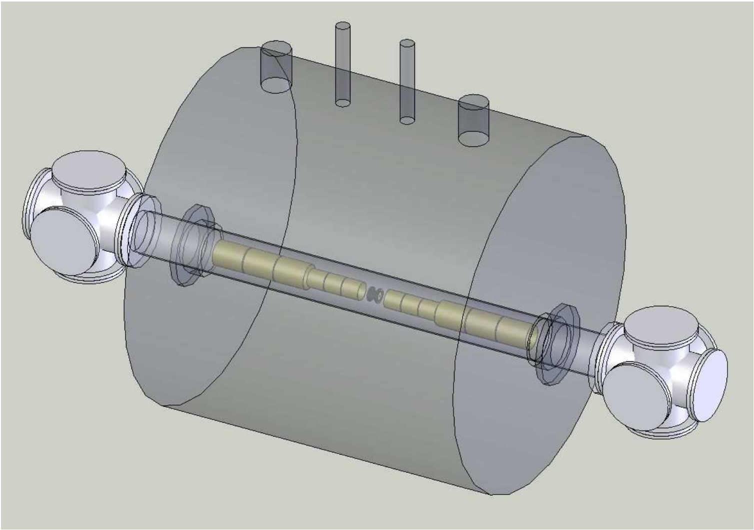




- Titanium, OFHC and ceramic materials
- Design completed, some detailing still needed, ready to being sent for manufacturing,
- Can be done in-house (tests okay)



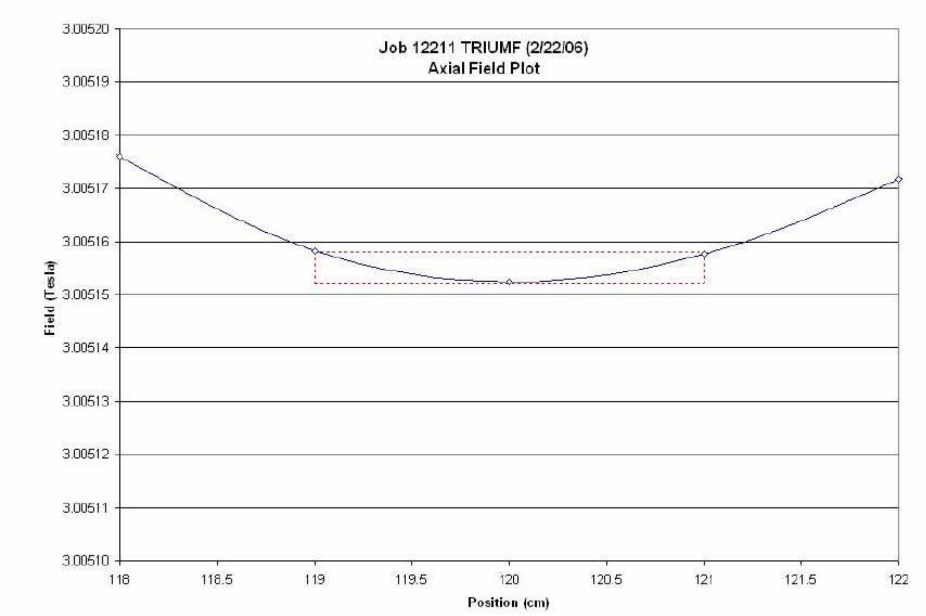
Penning Trap Magnet



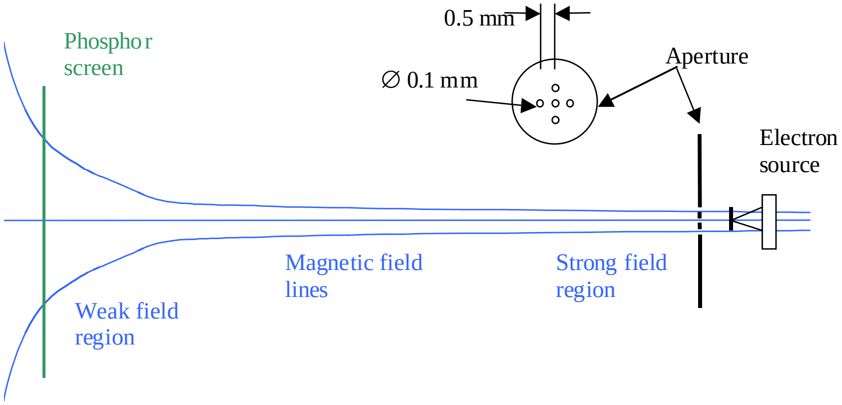
High homogeneity warm-bore magnet

Specs:

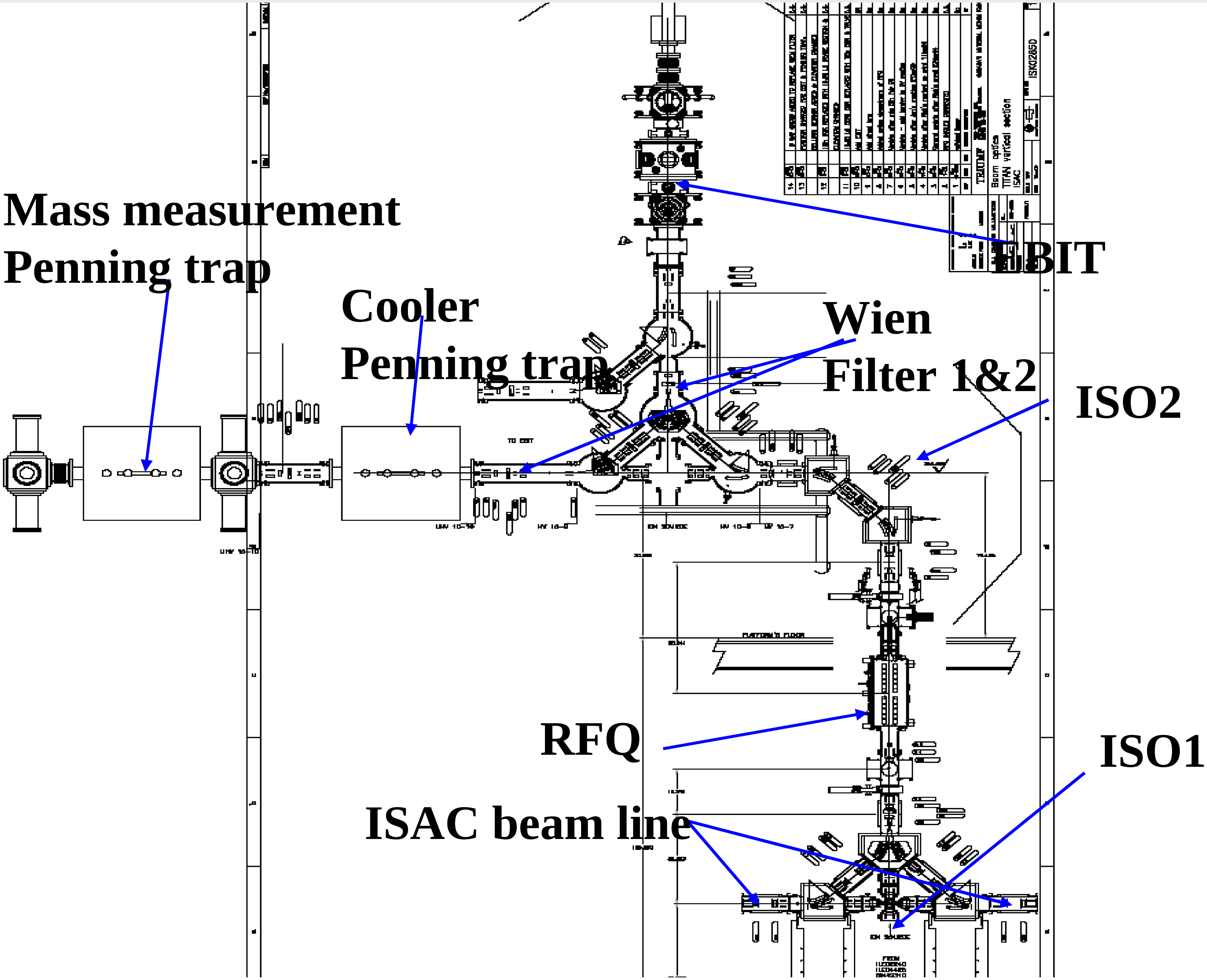
- Field strength 4T
- Bore size 5 inches
- Homogeneity 1 ppm (2cm * 1 cm)
- Long holding time (3 months for LHe)
- First field plot w/o shimming



Alignment procedure:



Transfer beam line



Performance for Mass Measurements

Accuracy:	**up to 10^{-9}**
Cycle time:	**150 ms (7Hz)**
Number of stored ions:	**1 ... 5**

Buncher efficiency (test beanch) :	**> 50%**
EBIT efficiency (Rex-EBIS) **:**	**≈ 50%**
Detection efficiency:	**≈ 50 %**
Beam transfer (ISAC) **:**	**≈ 10 %**
Charge state distribution:	**≈ 50 %**
Overall efficieny:	**≈ 1 %**
Yield for ^{74}Rb (30 μA)	**≈ 12 000/s**
Time required for $\delta m/m < 1 \cdot 10^{-8}$	**≈ 30 min**

(single ion det.; 10 000 ions det / 7 Hz = 1428 s = 23 min)

Summary and Outlook

• ISAC is in a fine operational mode, reached 70μA on target, ion source suite is building up, TRILIS excellent addition. (ACTINIDE WORKSHOP)

•ISAC is an excellent place to do nuclear physics experiments! We are slowly catching up, but still have a lot to learn, help is always welcome!

• ISAC II is coming on-line. Modular system with full energy of 12MeV/u in 2009.

•CSB-ECR system going on-line 2007.

TITAN:

•Components are coming together, installation in experimental hall on-going.

•EBIT operational in Heidelberg, move to ISAC.

•Penning trap construction on-going. Test planned for the spring.

•TITAN can: stable and radioactive beams, dc and bunched, HCI and single charge state. Parallel operation desired.

•FIRST real on-line experiments with TITAN in 2006.

•Additional experiment for branching ratio measurements for $0\nu2\beta$-decay approved.

TITAN collaboration:

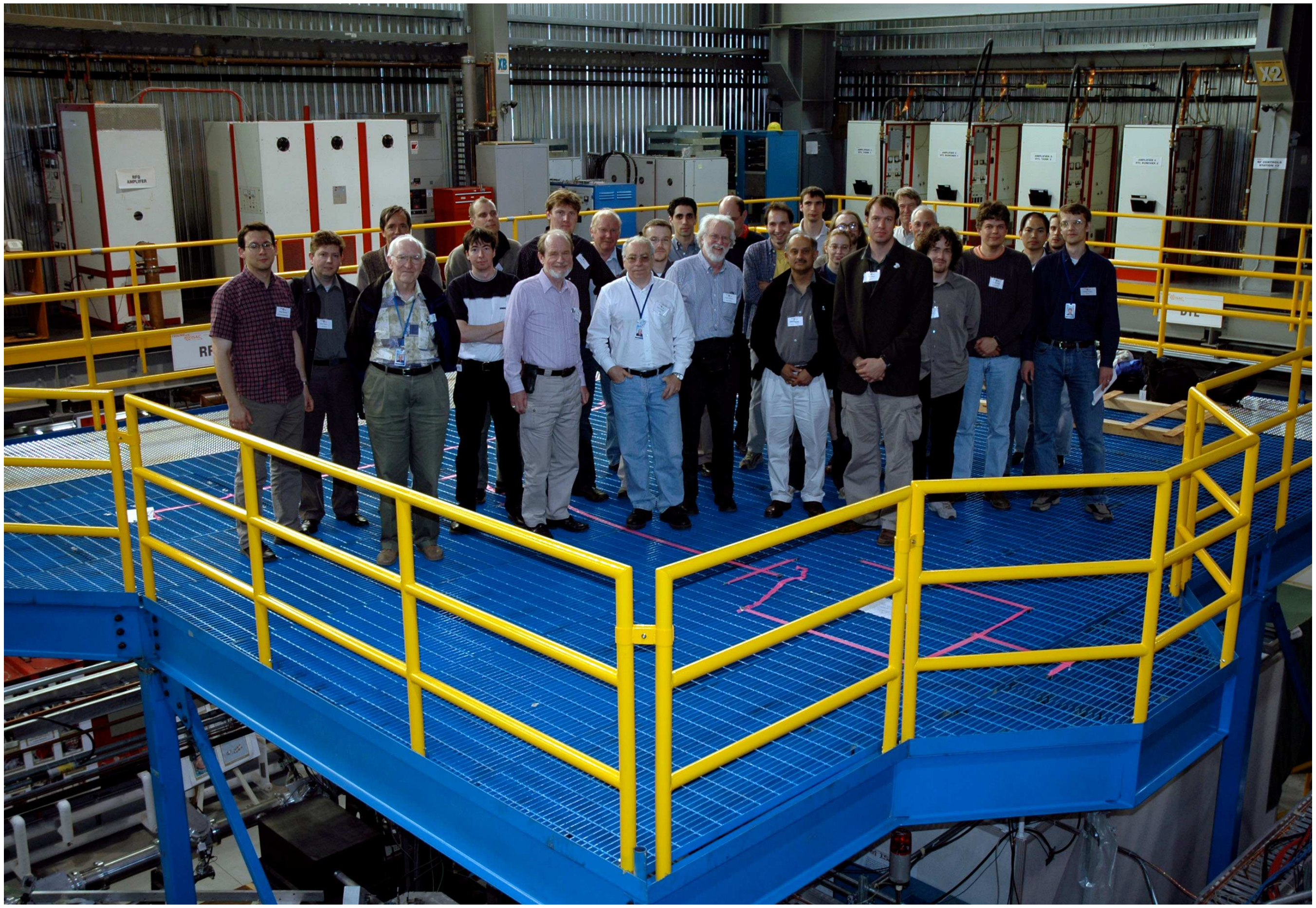
R. Baartman, P. Bricault, F. Buchinger, J. Caggiano, J. Crawford, P. Delheij, G. Drake, G. Gwinner, J. Lee, B. Moore, M Pearson, K. Sharma, R. Thompson, W. Van Weijngaarden J. Crespo, J Ullrich & J Vaz, V. Rijkov, G. Sikler (PDFs),

M. Smith, L. Blomley, M. Brodeur, Z. Ke, M. Froese, C Osborne (students)

TRIUMF
McGill
U Manitoba
York
Windsor
Calgary.
MPI-HD

Thanks to:
C. Ruiz, M. Huyse,
W. Noetershaeuser,
J. Lassen, J Behr.

Thank you
for your attention !



TCP'06

Trapped Charged Particles and Fundamental Physics

September 3 - 8, 2006

Parksville, British Columbia Canada

TCP'06
Parksville, Canada

Topics

Fundamental Interactions and Symmetries
QED Effects
Quantum State Manipulation and Quantum Information
Precision Spectroscopy and Frequency Standards
Storage Ring Physics
Highly Charged Ions in Traps
Traps for Radioactive Isotopes
Plasmas and Collective Behaviour
Anti-Hydrogen

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G. Sprouse (SUNY Stony Brook)
E. Widmann (S.Meyer Institute Vienna)
D. Wineland (NIST Boulder)

Abstract Deadline: May 31, 2006

Local Organizing Committee

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M. Pearson (TRIUMF)
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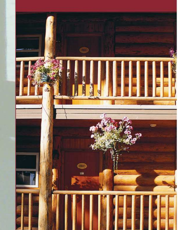

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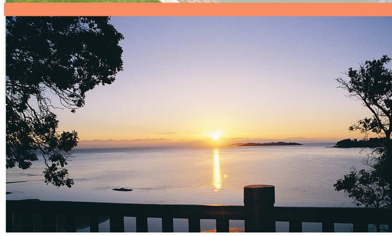

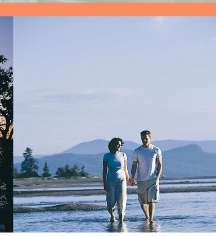

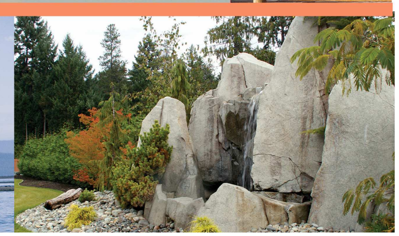

Nuclear β-decay: case by case

Isotope	*Half-live*	*Present _m*	*TITAN _m*	*(Expected)Yield*	*Ion source*
^{26m}Al	**6 s**	**0.06 keV**	**57 eV**	**9□10^{5}**	**TRILIS**
^{38m}K	**923 ms**	**0.4 keV**	**53 eV**	**7□10^{7}**	**Surface**
^{62}Ga	**116 ms**	**28 keV**	**160 eV**	**2□10^{3}**	**TRILIS**
^{62}Zn	**9.1 h**	**10 keV**	**100 eV**	**5□10^{3}**	**TRILIS**
^{66}As	**96 ms**	**200 # keV**	**120 eV**	**1□10^{4}**	**ECR**
^{66}Ge	**2.3 h**	**30 keV**	**170 eV**	**1□10^{4}**	**Febiad**
^{70}Br	**79 ms**	**360 keV**	**196 eV**	**5□10^{5}**	**Febiad**
^{70}Se	**41 min**	**60 keV**	**112 eV**	**1□10^{4}**	**Febiad**
^{74}Rb	**65 ms**	**4 keV**	**285 eV**	**5□10^{3}**	**Surface**
^{10}C	**19.3 s**	**0.4 keV**	**20 eV**	**5□10^{6}**	**ECR**
^{14}O	**70 s**	**0.4 keV**	**22 eV**	**1□10^{5}**	**ECR**
^{26}Si	**2.21 s**	**1 keV**	**52 eV**	**1□10^{3}**	**ECR**
^{30}S	**1.18 s**	**3 keV**	**60 eV**	**1□10^{3}**	**ECR**
^{38}Ca	**439 ms**	**4 keV**	**87 eV**	**2□10^{3}**	**ECR**
^{42}Ti	**200 ms**	**5 keV**	**147 eV**	**1□10^{2}**	**Surface**