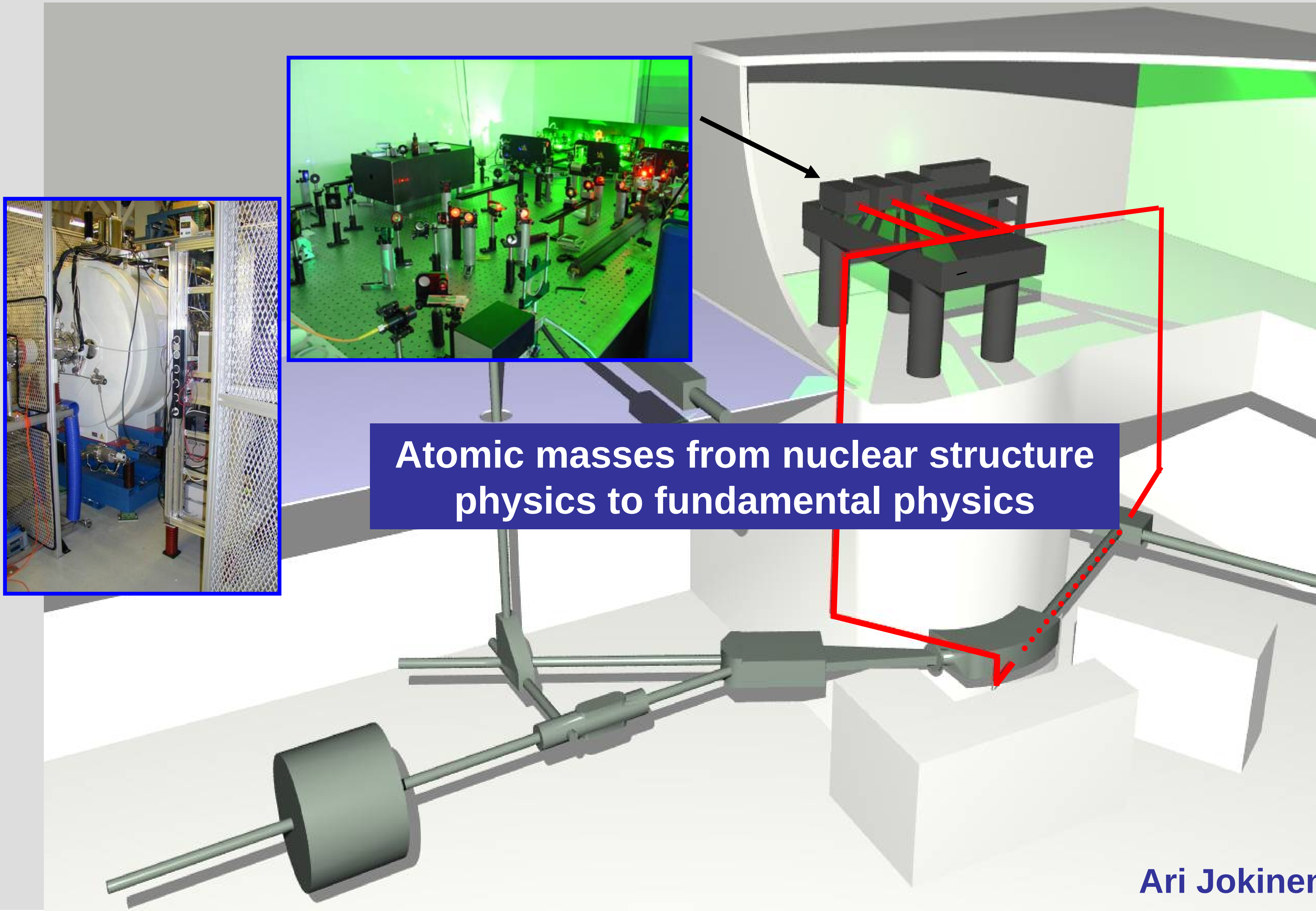
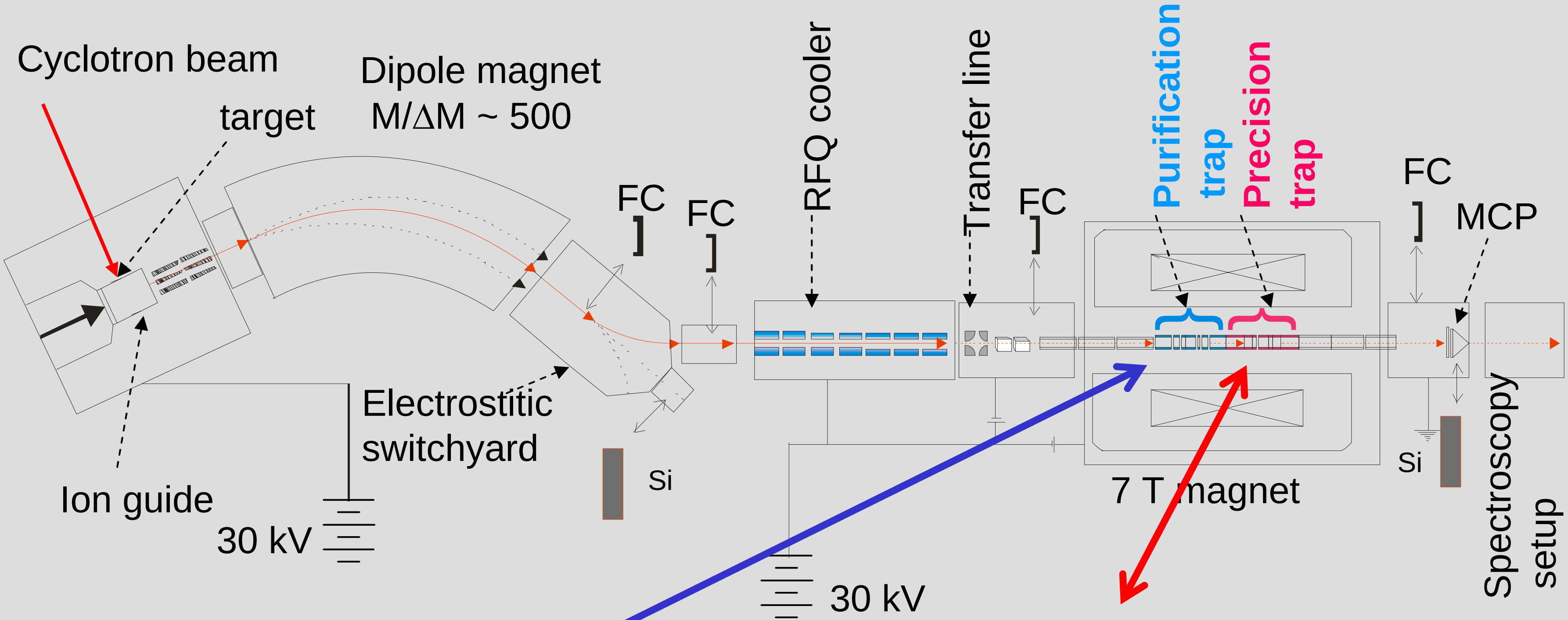
JYFLTRAP at IGISOL

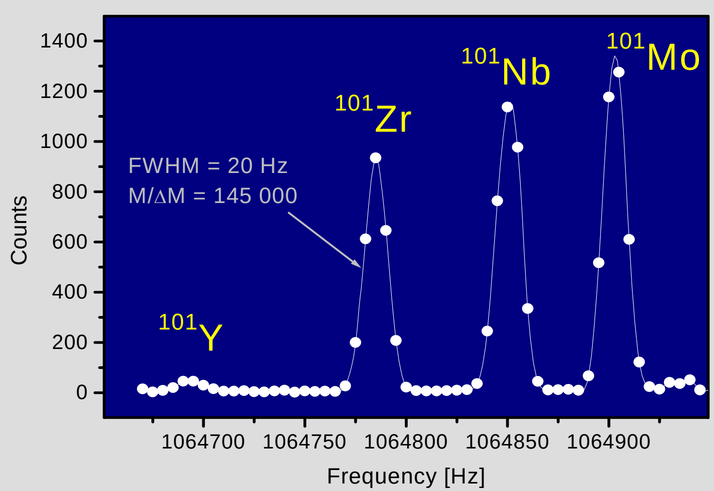


Ari Jokinen

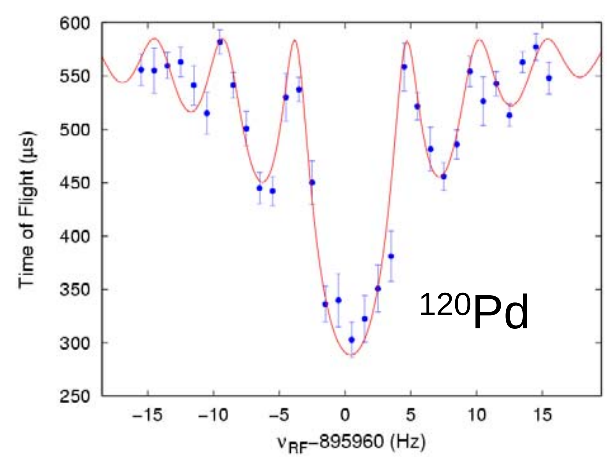
JYFLTRAP setup @ IGISOL



Purification scan



TOF-resonance in Precision trap



Basic equations for mass determination

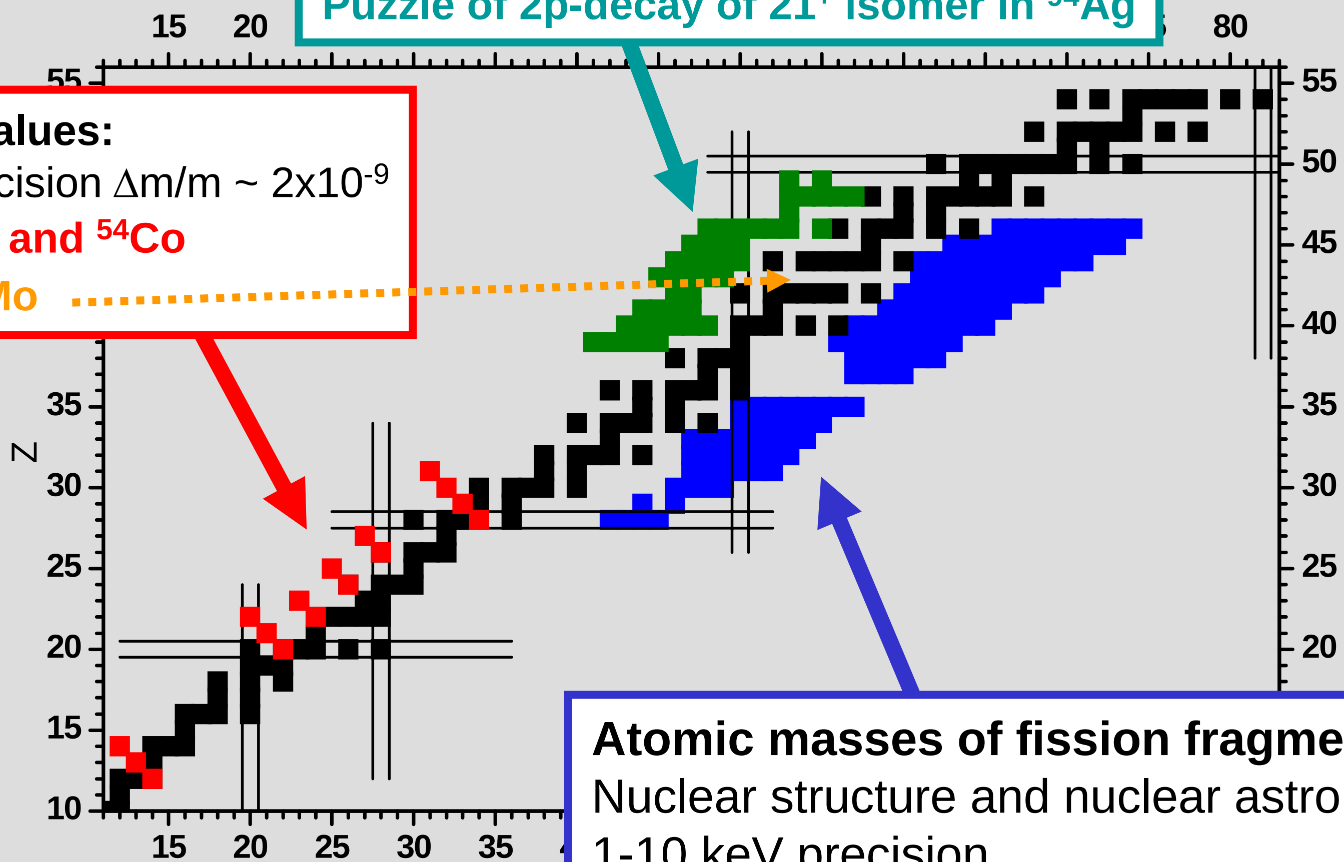
$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

$$\frac{f_{\mathrm{c,ref}}}{f_{\mathrm{c}}} = \frac{m - m_e}{m_{\mathrm{ref}} - m_e}$$

JYFLTRAP program + outline of the talk

N-deficient nuclei below ^{100}Sn:
Nuclear structure and nuclear astrophysics
1-10 keV precision
Puzzle of 2p-decay of 21^+ isomer in ^{94}Ag

Precise Q-values:
Sub-keV precision $\Delta m/m \sim 2 \times 10^{-9}$
Q_{EC} of ^{50}Mn and ^{54}Co
$Q_{0\nu\beta\beta}$ of ^{100}Mo



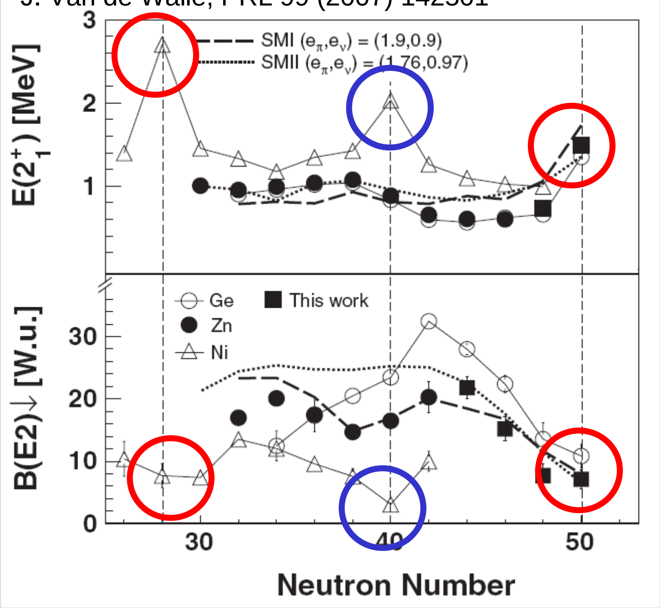
Atomic masses of fission fragments:
Nuclear structure and nuclear astrophysics
1-10 keV precision
N=50 shell gap

A. Jokinen et al., Int. J. Mass Spectr. 251 (2006) 204

N=50 gap in γ-spectroscopy and theory

Z=28,30,32 isotopes,

J. Van de Walle, PRL 99 (2007) 142501

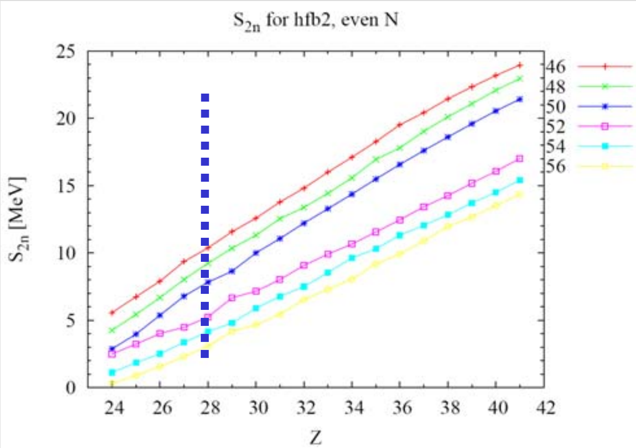


N=28 and N=50 shell gaps
N=40 sub-shell closure

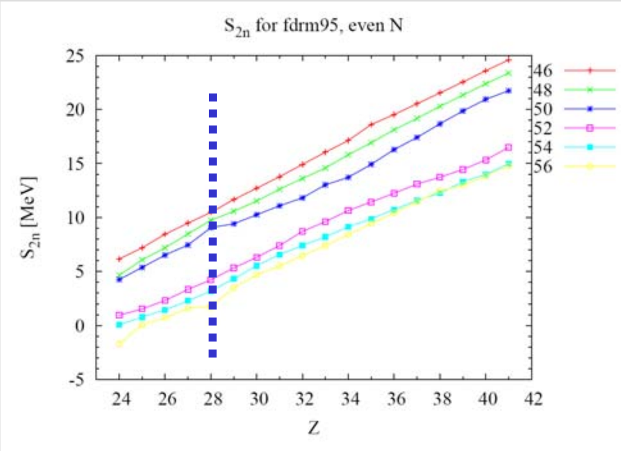
Evolution of N=50 shell gap:
Spectroscopic data with comparison to shell model calculations gives some indications of the evolution of the gap, but quantitative verification is missing.

One possibility is to compare S_{2n} values of even isotones close to N=50 as a function of element number.

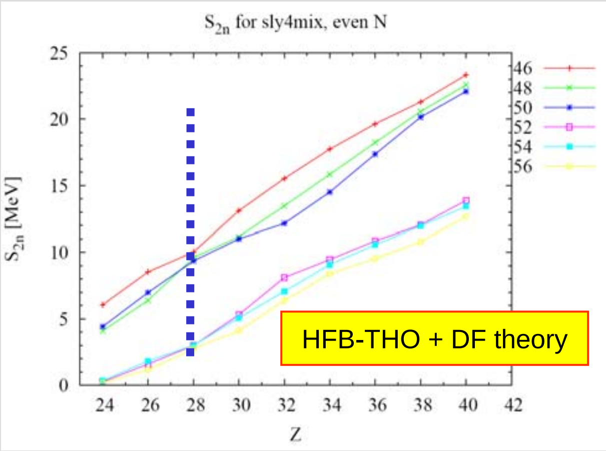
J. Pearson, S. Goriely, NPA 777 (2006) 623



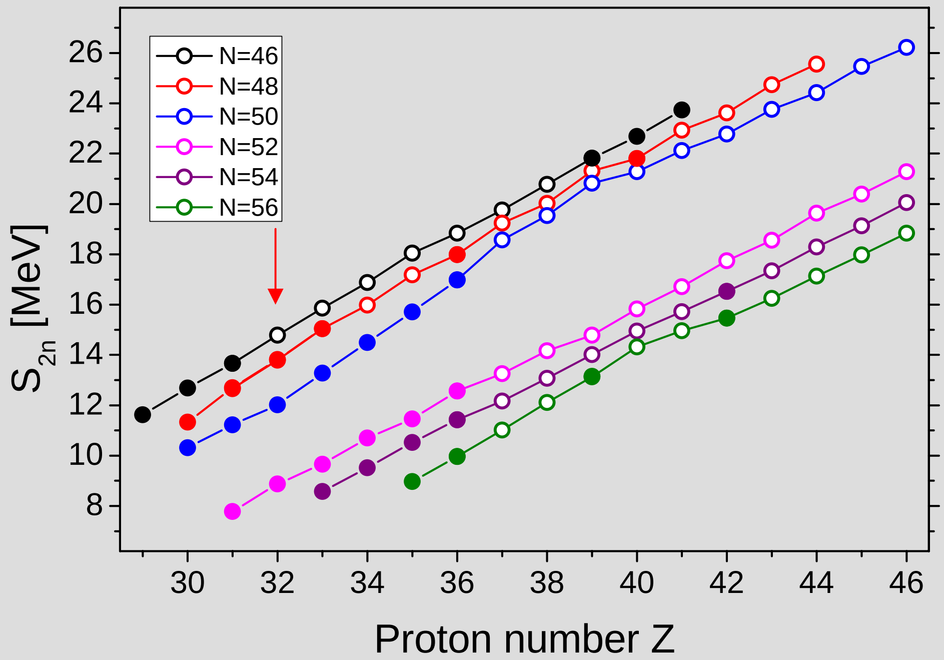
P. Möller et al. ADNDT 59 (1995) 185



M. Stoitsov, et al, PRL **98** (2007)



N=50 gap in γ-spectroscopy and theory



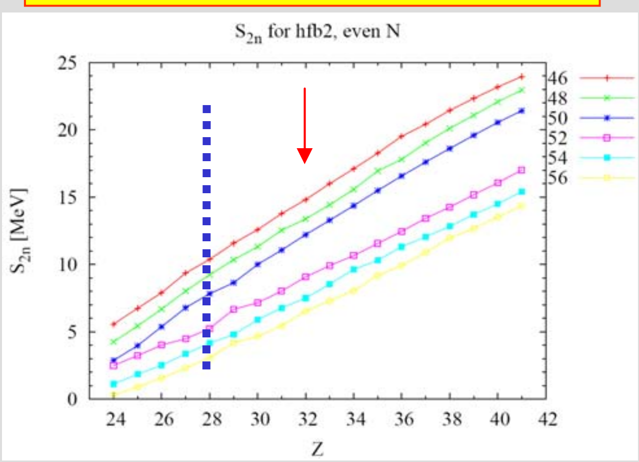
JYFLTRAP-data (solid symbols) + AME2003 (open)

+ Zn-isotope ISOLTRAP, A. Herlert private comm. 2007
+ from JYFLTRAP, Nov. 2007

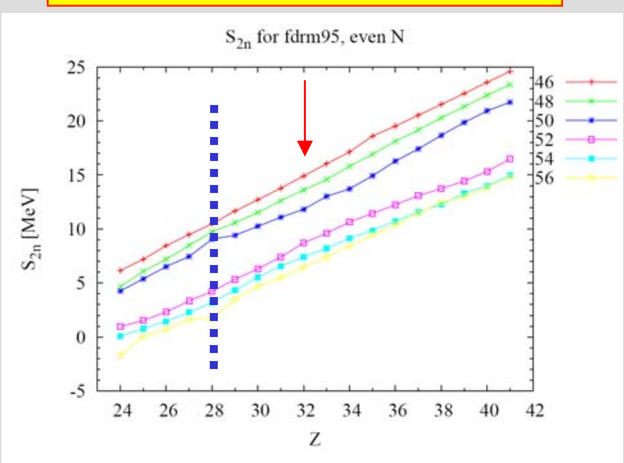
J. Hakala et al. (2008) to be published

Indications of the opening of the gap beyond Z=32 !
Precision binding data of neutron-rich nuclei obtained at Penning trap facilities.

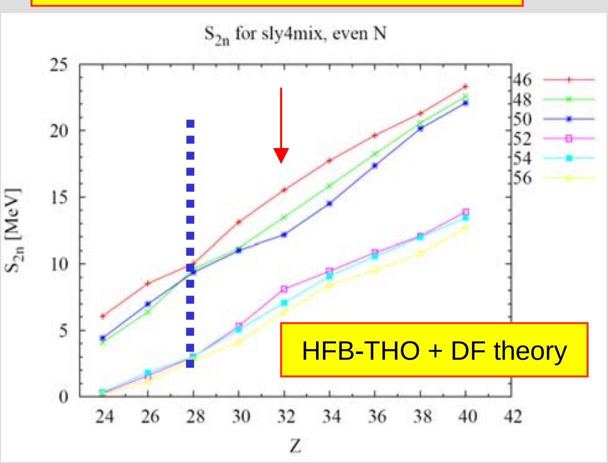
J. Pearson, S. Goriely, NPA 777 (2006) 623



P. Möller et al. ADNDT 59 (1995) 185



M. Stoitsov, et al, PRL **98** (2007)



Physics of superallowed beta decay

Conserved vector current hypothesis:
ft should be constant

$$Ft \equiv ft(1+\delta_R)[1-(\delta_C-\delta_{NS})] = \frac{K}{2G_V^2(1+\Delta_R)}$$

δ_R	radiative correction $f(Z,Q_{EC})$ ~1.5 %
δ_C-δ_{NC}	isospin symmetry breaking correction f(nuclear structure), 0.3-0.7%
Δ_R	nucleus-independent radiative correction f(interactions), ~2.4%

Exp. parameters to be determined:
Beta decay half-life $T_{1/2}$
Beta decay branching ratio I_b
Decay energy Q_{EC}

Single nucleus: determination of $G_V^2(1+\Delta_R)$

Many transitions: Check if Ft is constant
→ Test of the CVC

One can deduce V_{ud} by combining beta decay and muon decay data

$$V_{ud}^2 = \frac{G_V^2}{G_\mu^2}$$

Cabibbo-Kobayashi-Maskawa quark mixing matrix:

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

Unitarity test of CKM-matrix

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

- V_{ud}^2: > 99 % — Superallowed pure Fermi transitions, Neutron decay, Pion beta decay
- V_{us}^2: small — Kaon decay
- V_{ub}^2: very small — B meson decays

^{62}Ga – towards higher Z

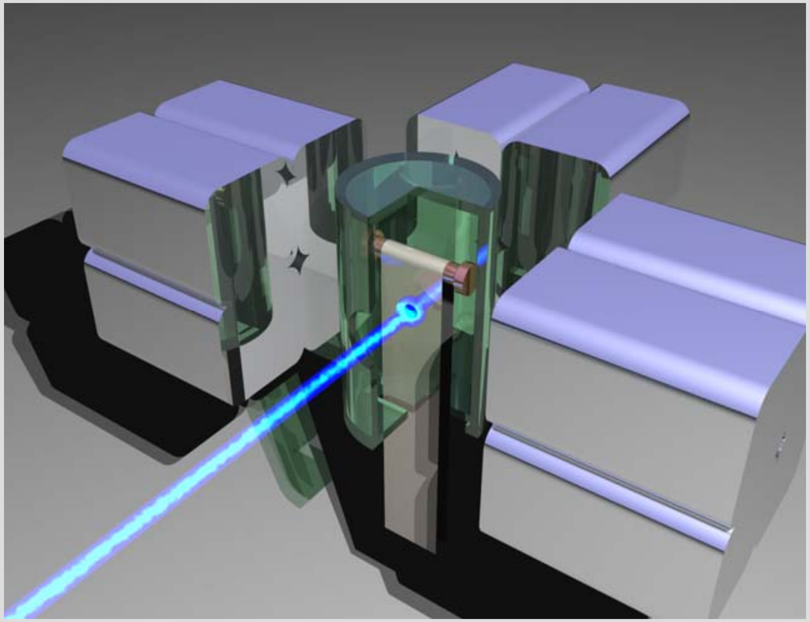
- An impressive progress recently
- Interest for ISOLDE
- Q_{EC}-value = 9181.07(54) keV:
  - JYFLTRAP, T. Eronen et al., PLB 636 (2006) 191
- Half-life = 116.175(38) ms:
  - JYFL; G. Canchel et al., EPJA 23 (2005) 409
  - GANIL; B. Blank et al., PRC 69 (2004) 015502
- Branching ratio 99.861(11) %:
  - TRIUMF; B. Hyland et al., PRL 97 (2006) 102501
  - New data from JYFL; A. Bey et al., (2008) to be published

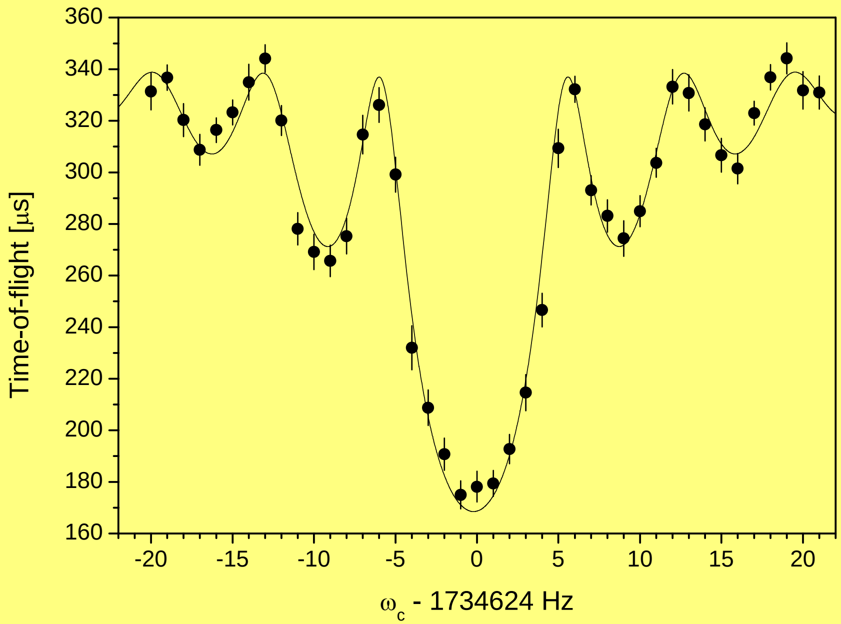
JYFLTRAP:

✓ 48 MeV p-beam on ^{64}Zn-target
✓ 600 ions/s ^{62}Ga, 7x10^5 ions/s ^{62}Zn
✓ Direct comparison between mother and daughter isotopes

$$Q_{EC} = M_p - M_d = \underbrace{\left(\frac{f_d}{f_p} - 1\right)}_{\leq 10^{-3}} M_d \quad \rightarrow \quad \Delta M_d \text{ negligible !}$$

✓ Q_{EC} = 9181.07(54) keV
✓ Rel. mass precision 1.8 x 10^{-8}
✓ Additional check for ^{62}Ni and ^{62}Cu

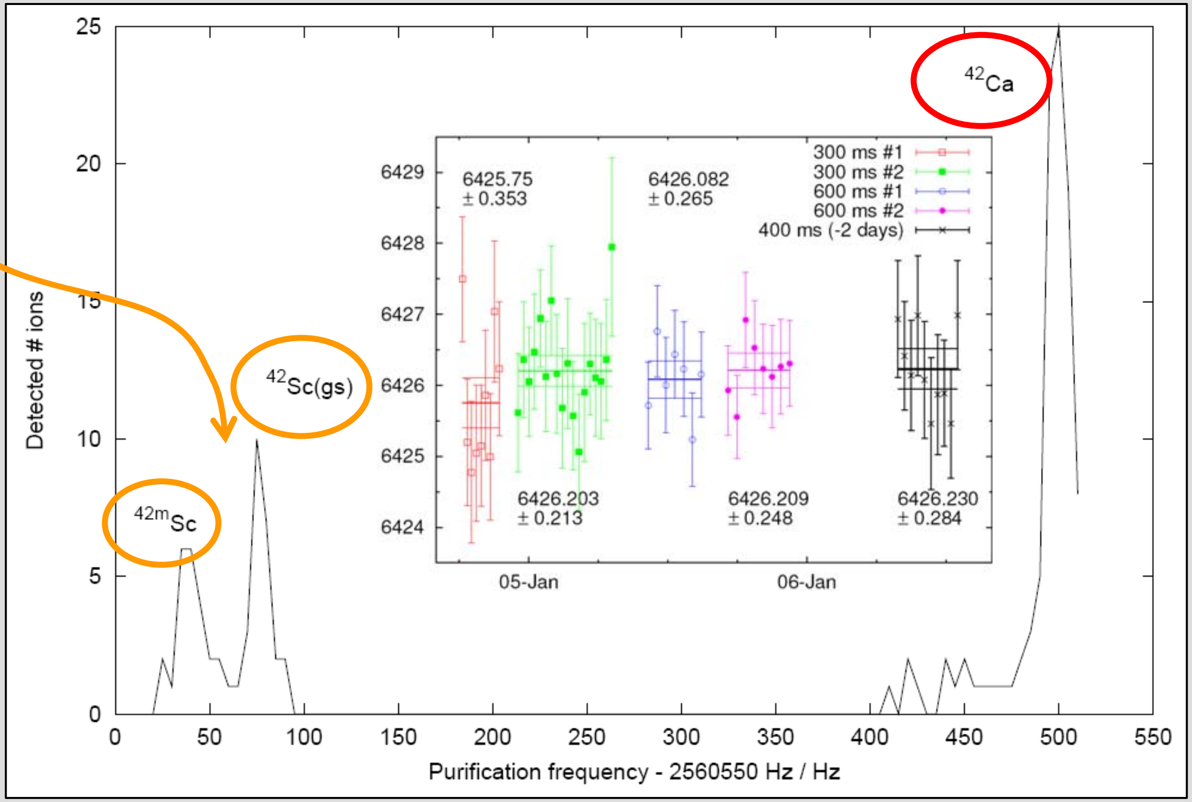




Progress after 2005 survey

- **Critical survey of superallowed beta decay:** J. Hardy and I. Towner, PRC 71 (2005) 055501
- **Q_{EC}(^{46}V) of by 2.19 keV:** G. Savard et al., PRL95 (2005) 102501
- **Penning trap revolution ? (W. Marciano, NUPAC at CERN, Nov-2005)**

- **JYFLTRAP: Q_{EC}(^{46}V) confirmed,** T. Eronen et al. PRL97 (2006) 232501
- **JYFLTRAP: ^{26m}Al and ^{42}Sc remeasured,** T. Eronen et al., PRL 97 (2006) 232501
- **Δ(g.s-isomer) large enough → purification in the first trap, closed triangle measurement, all states during the same run, many tens of pairs of all combinations of states**

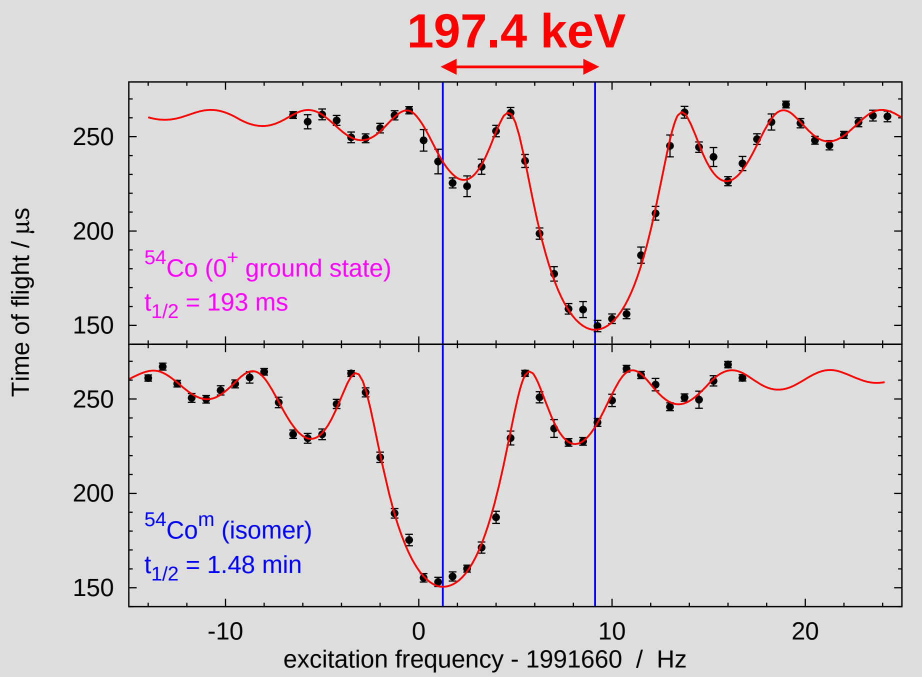


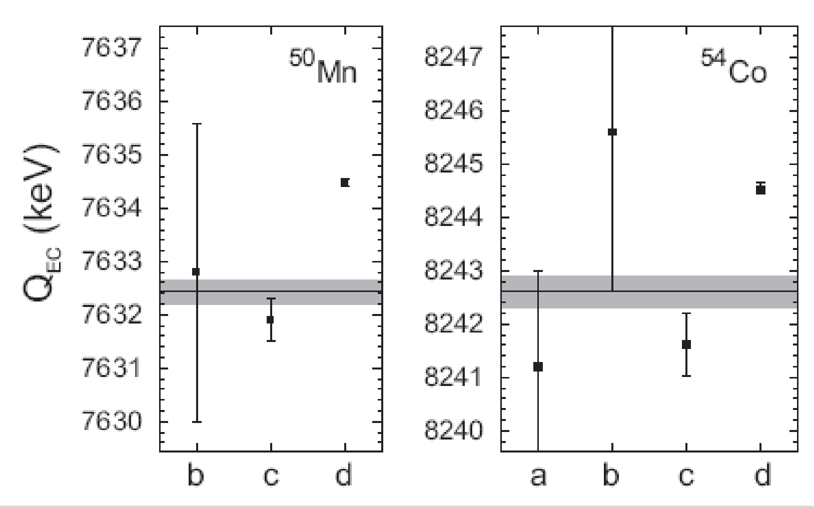
The most recent cases ...

- **New calculations of radiative and isospin-symmetry-breaking corrections** I.S. Towner and J. Hardy, arXiv:0710.3181 and to be published (2008)
- **Shift of ^{46}V, ^{50}Mn and ^{54}Co**
  - **^{46}V anomaly disappeared**
  - **^{50}Mn and ^{54}Co were also shifted down - below the average**
- **^{50}Mn and ^{54}Co became critical tests for the new calculations**
- **^{50}Mn and ^{54}Co at JYFLTRAP**
  - **Proton reactions on enriched ^{50}Cr and ^{54}Fe**
  - **Triangle measurement implying Ramsey-cleaning coupled to Ramsey TOF**
  - **(small Δ(g.s.-isomer) and short half-lives)**
- **Q_{EC}-values slightly higher than given in the latest survey (values dominated by results from H. Vonach et al., NPA278(1977)189)**
- **Same problem persists than observed in case of ^{46}V implying problems with their data-set**

1) New Q-values brings ^{50}Mn and ^{54}Co Ft-values into perfect agreement with an average
2) Strong support for new calc. of corrections
3) Higher value of V_{ud} → unitarity check of CKM closer to 1 → perfect agreement with SM

T. Eronen et al., to be published (2008)





Physics of (neutrinoless) double-beta decay

- **Neutrinos are probably the least understood fundamental particles**
  - **Massless, like photons, but oscillation allows them to be massive**
  - **Majorana or Dirac particles ?**
- **0νββ decay can contribute to these questions (0νββ only possible if neutrinos are Majorana particles !)**
- **Disputable results from Moscow-Heidelberg exp. using ^{76}Ge**
- **Another interesting case ^{100}Mo:**
  - **Rather easy to manufacture**
  - **2νββ matrix elements known**
  - **High Q-value, decay rate of 0νββ scales with Q^5**
- **Two experiments aiming to use ^{100}Mo in search for 0νββ decay:**
  - **MOON**
  - **NEMO-3**
- **Why Q-value:**
  - **A position of the 0νββ signal**
  - **Precision calculations of phase-space integral G and nuclear matrix elements M**

Half-life of 2νββ - decay

$$[T_{1/2}^{2\nu}]^{-1} = G^{2\nu}(M^{2\nu})^2$$

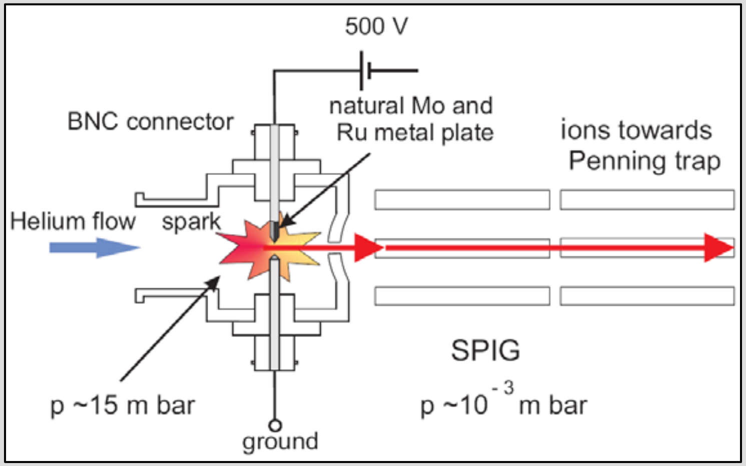
Model benchmarking !

Half-life of 0νββ decay

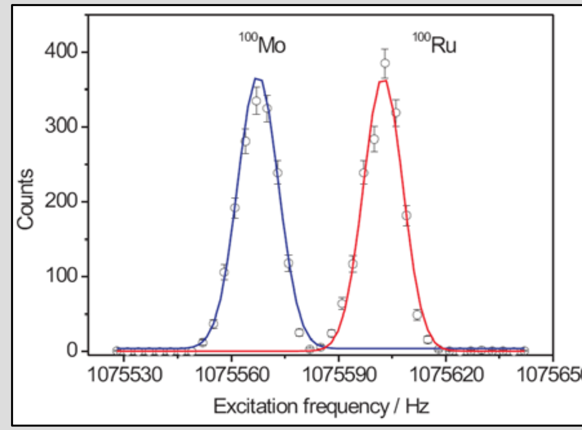
$$[T_{1/2}^{0\nu}]^{-1} = G^{0\nu}(M^{0\nu})^2(\langle m_\nu \rangle / m_e)^2$$

$T_{1/2}$ prediction as function of an effective neutrino mass

Measurement of $Q_{\beta\beta}$ of ^{100}Mo



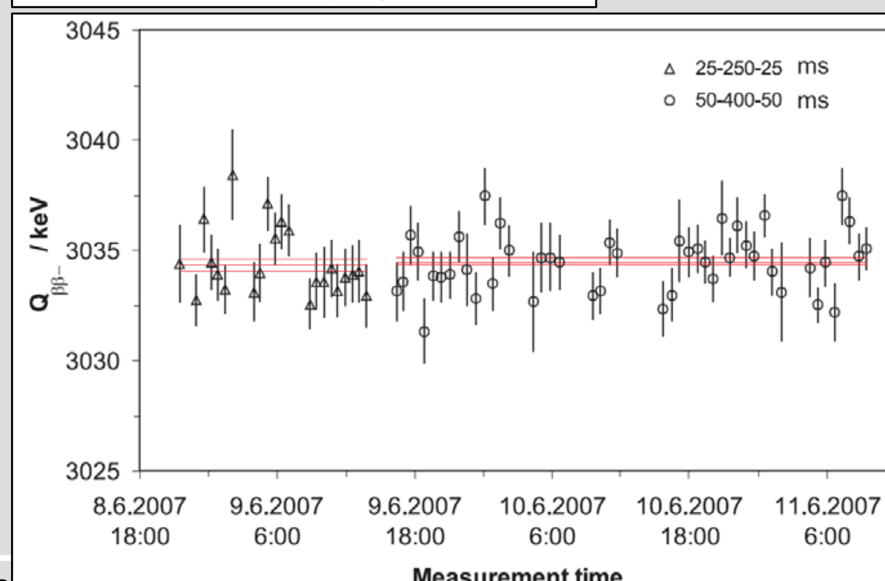
- **Discharge ion source with mixed Ru and Mo electrode**
- **Extraction of stable Mo and Ru isotopes from ion guide**
- **A=100 selection in the dipole magnet**
- **Isotope selection in the purification trap**
- **Sequential measurement of ^{100}Ru and ^{100}Mo**



- **Resonancew frequencies deduced by using conventional both TOF and Ramsey metohod**
- **Numerous frequency ratios between ^{100}Mo and ^{100}Ru were collected by applying two different Ramsey-settings over 2.5 days**
- **$Q_{\beta\beta}$-value was deduced with an uncertainty of 170 eV**
- **Old $Q_{\beta\beta}$-value 3035(6) keV**

- **For consistency check a similar study was performed for the ^{76}Ge and ^{76}Se pair resulting in an agreement within 34 eV compared to SMILETRAP-value.**

G. Douysset et al., PRL 86 (2001) 4259
M. Suhonen et al., J. of Instrum. 2 (2007) 06003



Conclusions on 0νββ-decay

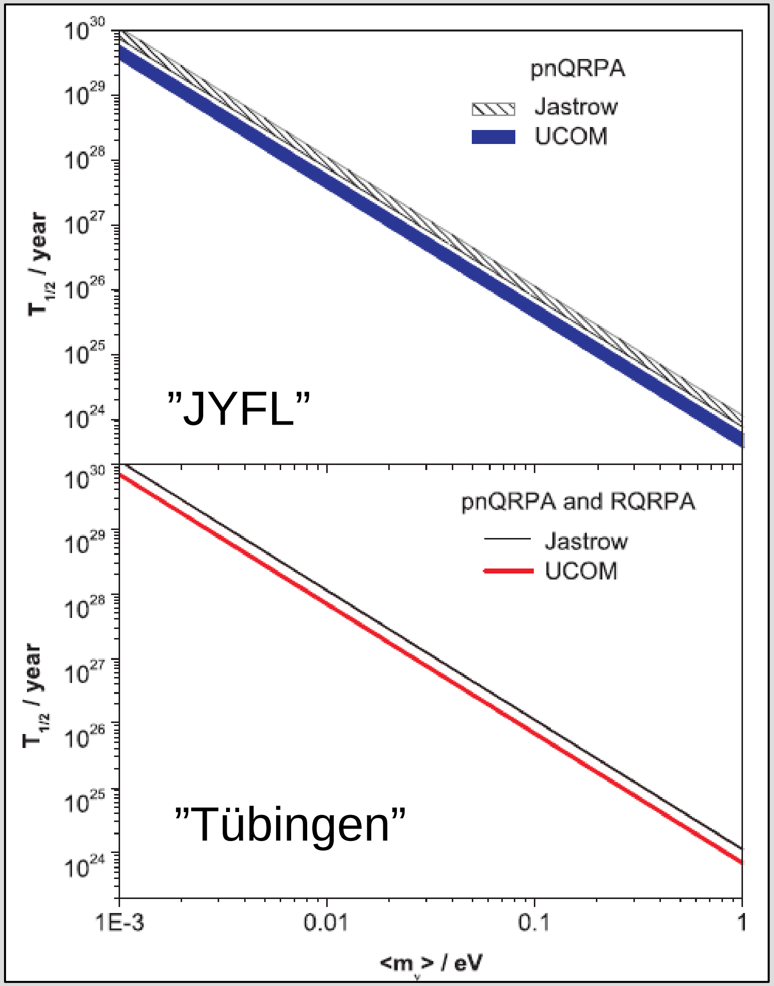
- Half-life of ^{100}Mo 2νββ-decay combined with precise calculation of phase-space integral G
  → determination of experimental matrix element $M^{2\nu}$
- Comparison of exp. and calc. $M^{2\nu}$
  → Deformation do not play a role
  → Model comparison

- Half-life of 0νββ-decay not known, neither an effective mass of neutrinos $<m_\nu>$
  → An estimation of the half-life of 0νββ-decay as a function of the effective neutrino mass

Comparison of pnQRPA from JYFL and an average of pnQRpa from and RQRPA from Tübingen with two approaches for particle-particle interaction

G_A=1.0-1.25

g_{pp}=range required to fit $T_{1/2}(2\nu\beta\beta)$



S. Rahaman et al., to be published (2008)

Decay modes of 21^+ high-spin isomer in ^{94}Ag

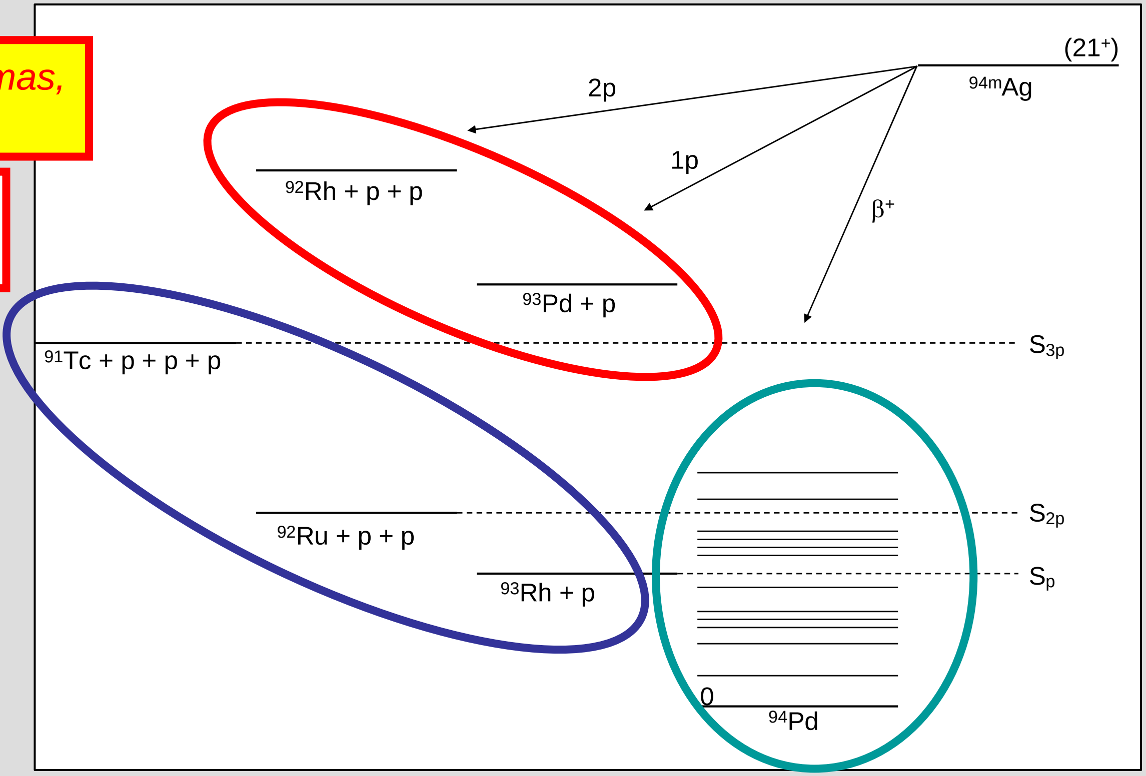
Direct proton decay

Two-proton decay data and related gammas,
*I. Mukha et al., **Nature** 439 (2006) 298*

One-proton decay and related gammas,
I. Mukha et al., PRL 95 (2005) 022501

Beta-delayed proton decay

Beta-delayed protons
I. Mukha et al., PRC 70 (2004) 044311



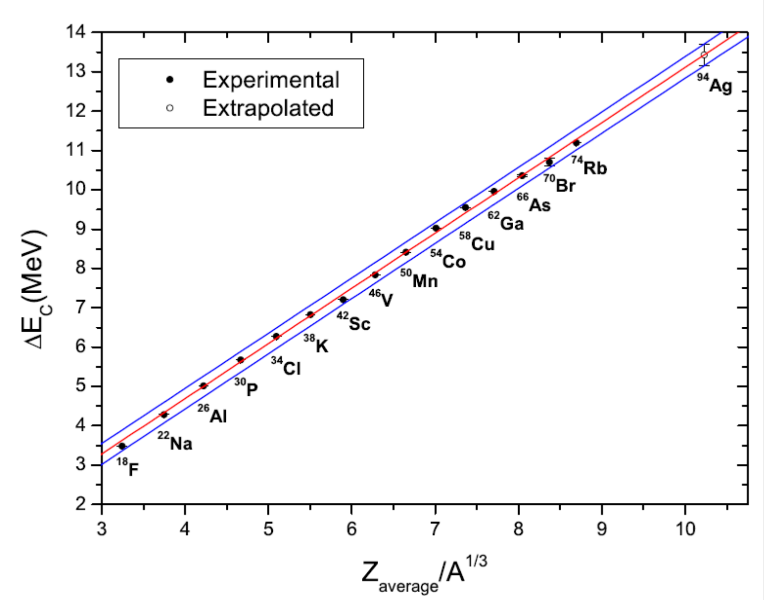
In-beam study of ^{92}Rh levels
O.L. Pechenaya et al., PRC 76, 011304(R) (2007)

Doubts on two-proton decay based on the gamma spectroscopy of ^{92}Rh levels combined with binding information from Atomic Mass Evaluation

Beta decay and related gammas, decay scheme
C. Plettner et al., NPA 733 (2004) 20.

How to solve the problem?

- JYFTRAP: m(^{92}Rh) and m(^{94}Pd)
- Need masses of ^{94}Ag and ^{93}Pd to fix the energy scale
- ^{94}Ag (T_Z=0) from Coulomb displacement energy and ^{94}Pd (← JYFLTRAP)
- ^{93}Pd (Z=46, N=47) from S_{2p} values for N=47 isotones measured at JYFLTRAP



There is a 1.4 MeV discrepancy between 1p and 2p data in terms of excitation energy of 21$^+$ isomer:

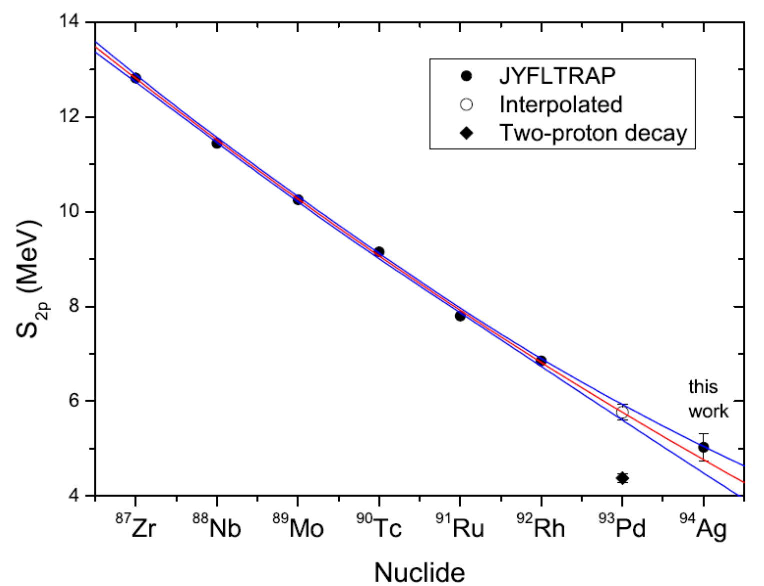
<u>Option 1: 2p-data is right</u>

→ An excitation energy of 21+ isomer is higher than presently anticipated

→ 1p data has some problems, which may be attributed to missing gamma-transitions in ^{93}Pd

<u>Option 2: 1p data is right</u>

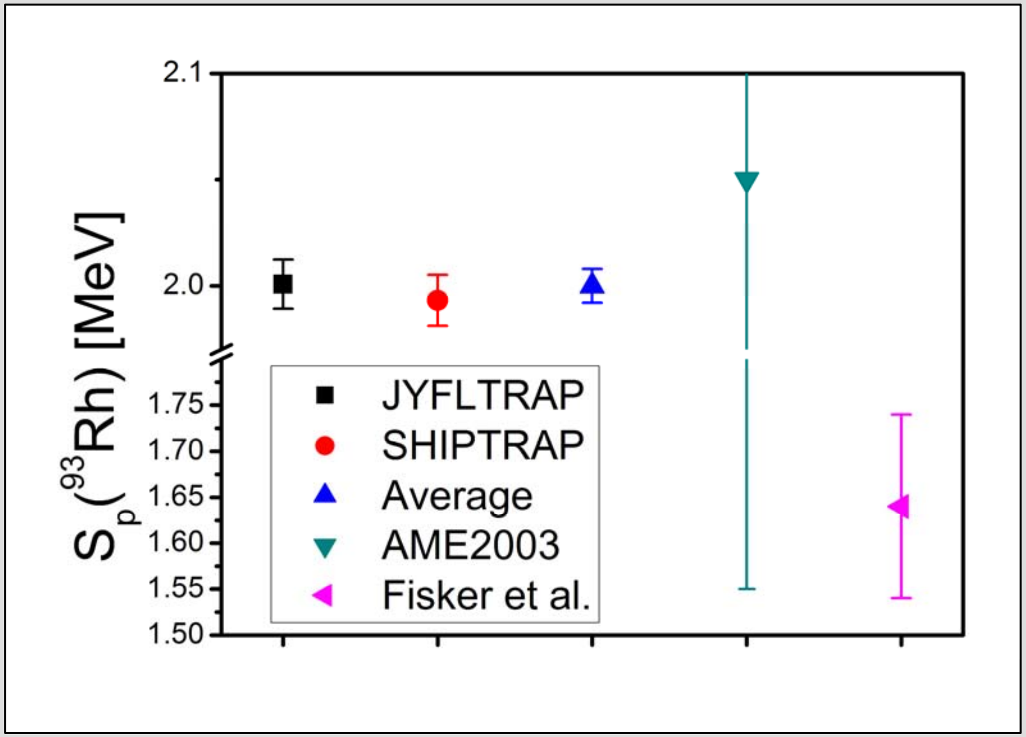
→ 2p-data is … in serious problems

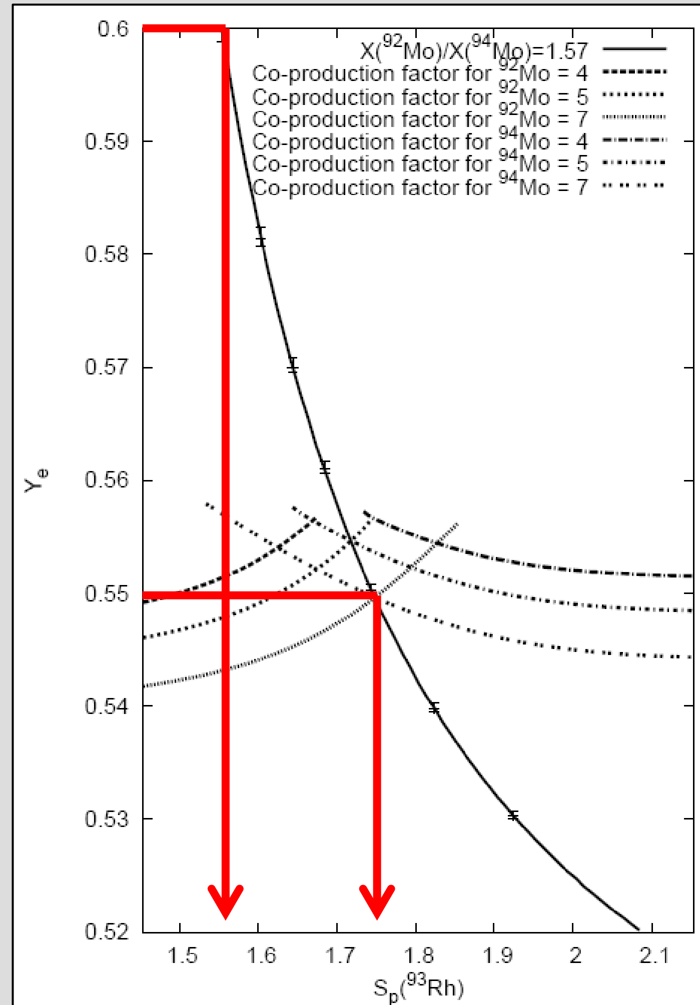


A. Kankainen et al., to be published (2008)

Chance for the νp-process ?

Predicting the proton separation energy of ^{93}Rh from supernova nucleosynthesis,
J. L. Fisker, R. D. Hoffman, J. Pruet, arXiv:0711.1502v1 [astro-ph] 9 Nov 2007



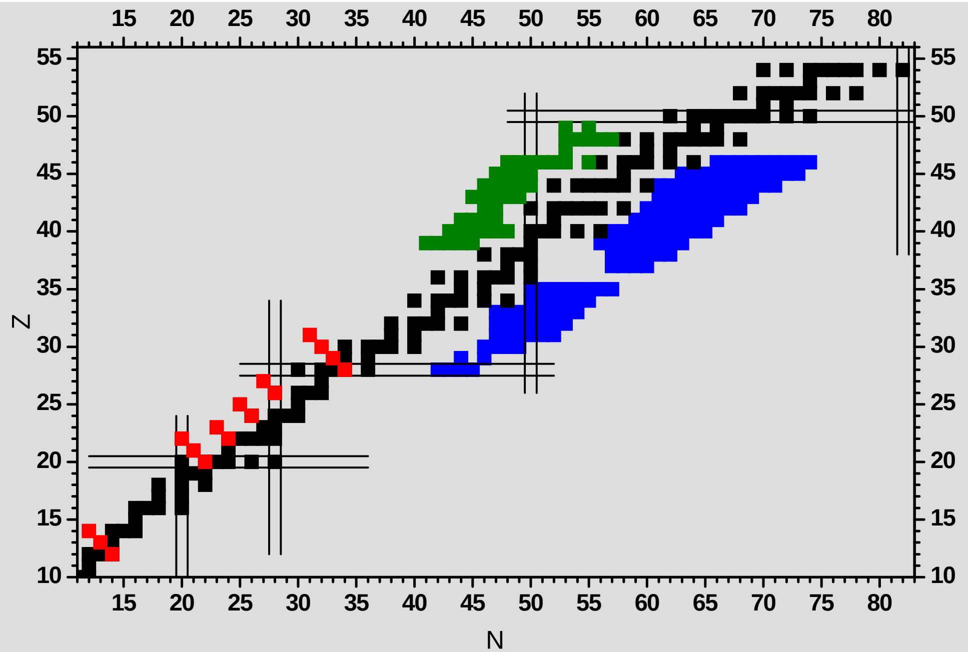


Controversy between J.L. Fisker et al. and PT-data:
Re-check of NA parameters and variables !

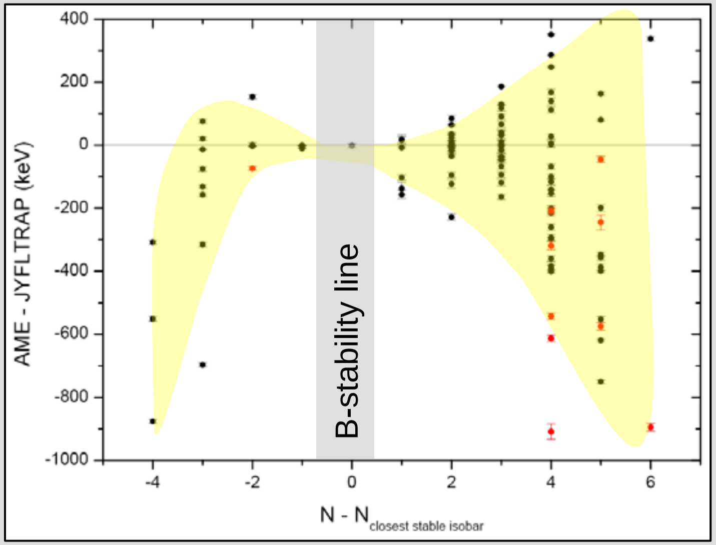
V.-V.Elomaa et al., to be published (2008)

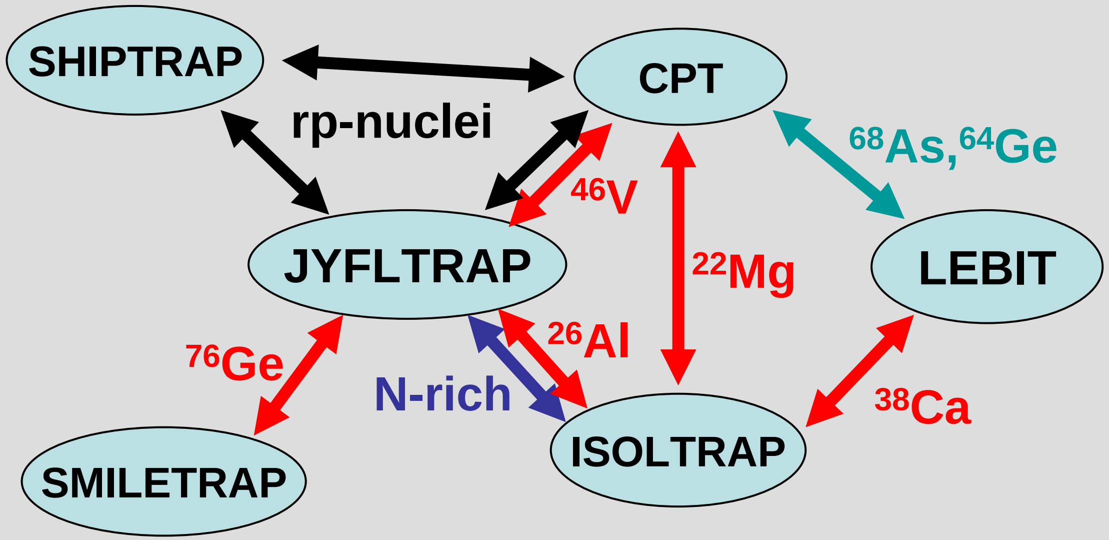
Summary

- Binding data vs. variety of physics topics
- JYFLTRAP program
- Serious deviations compared to AME and old data
- ISOLTRAP, JYFLTRAP, LEBIT, CPT, SHIPTRAP, TITAN, … will change the landscape of mass surface
- Complementary in terms of production, access, trap techniques, etc …
- Healthy competition, internal quality control



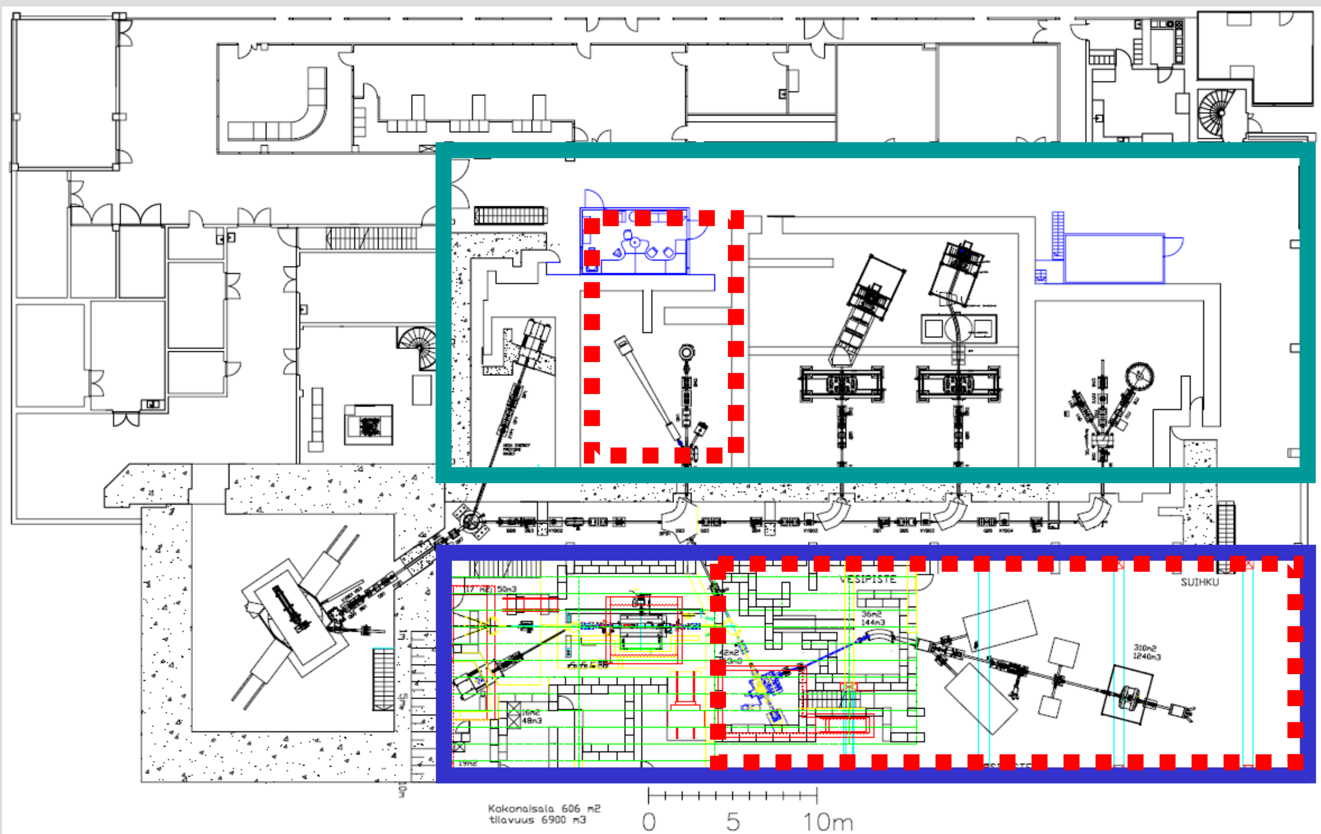
Neutron-deficient nuclei Neutron-rich nuclei





JYFLTRAP outlook

- Data on the half-life of ^{26}Si
- Data on Q_{EC}-values of ^{26}Si and ^{42}Ti
- Check-up of Q_{EC} values of lighter superallowed emitters
- Continuation of the work with nuclear structure and nuclear astrophysics issues
- Continuation of off-line studies for selected cases of double beta decay



Present hall
+ IGISOL area

Extension
+ IGISOL area

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T. Sonoda
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J. Äystö

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Theory: M. Bender, J. Dobaczewski, T. Otsuka, J. Suhonen and + …