Preparation and status of E100: β_b decay of bare $^{205}Tl^{81+}$

FRS/ESR-proposal approved in April 2010

Fritz Bosch for the collaboration:

F. Bosch, C. Brandau, C. Dimopoulou, H. Geissel, S. Hagmann, F. Herfurth, O. Klepper, R. Knöbel, Ch. Kozhuharov, J. Kurcewicz, D. Liesen, S. Litvinov, R. Mann, Ch. Nociforo, F. Nolden, Ch. Scheidenberger, U. Spillmann, M. Steck, Th. Stöhlker, **K. Takahashi**, H. Weick, M. Winkler, D. Winters, GSI Helmholtzzentrum Darmstadt

Z. Djurcic, **W.F. Henning**, Argonne IL

M.K. Pavicevic, I. Anicin, B. Boev, V. Pejovic, University of Belgrade

B. S. Meyer, Clemson University, SC

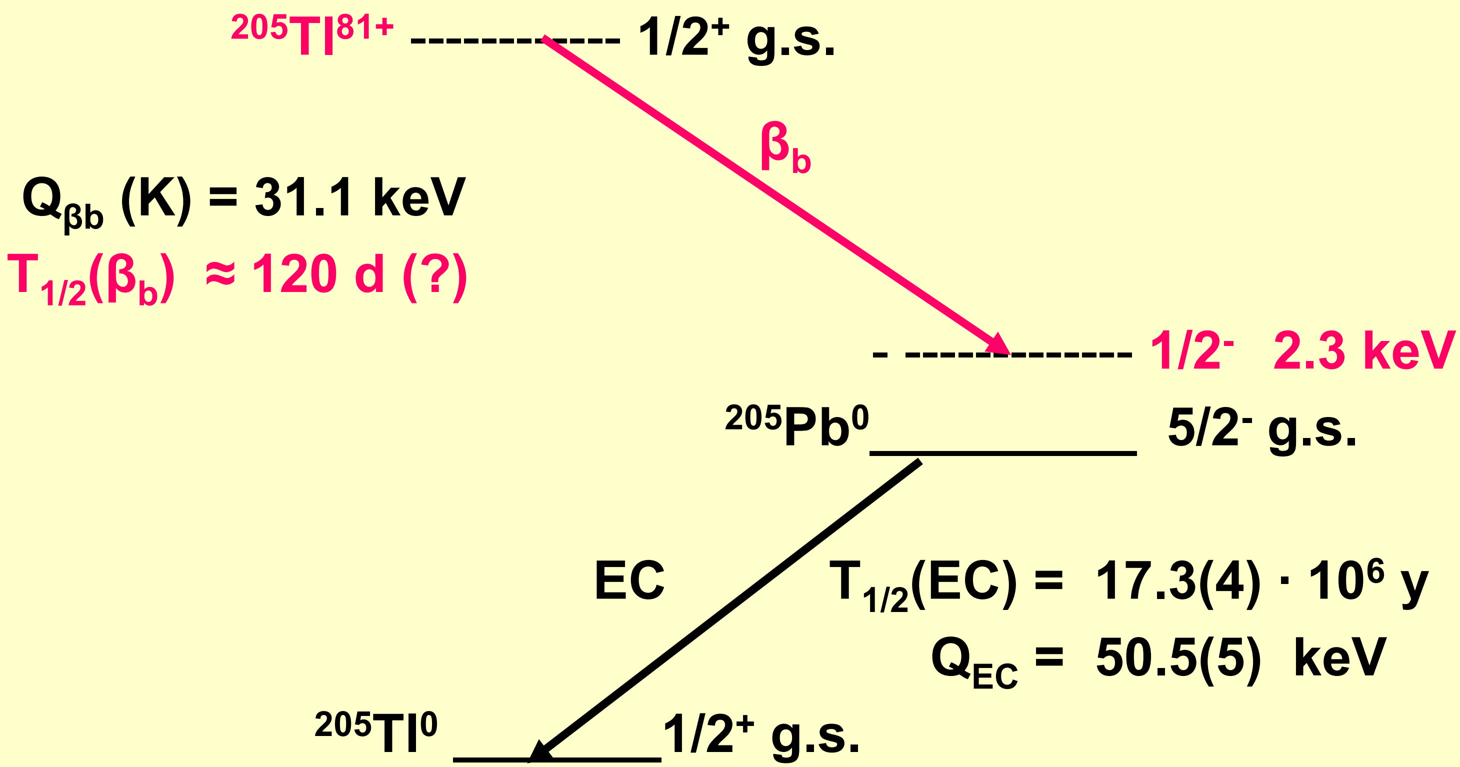
B. Boev, University of Stip, FYRMacedonia

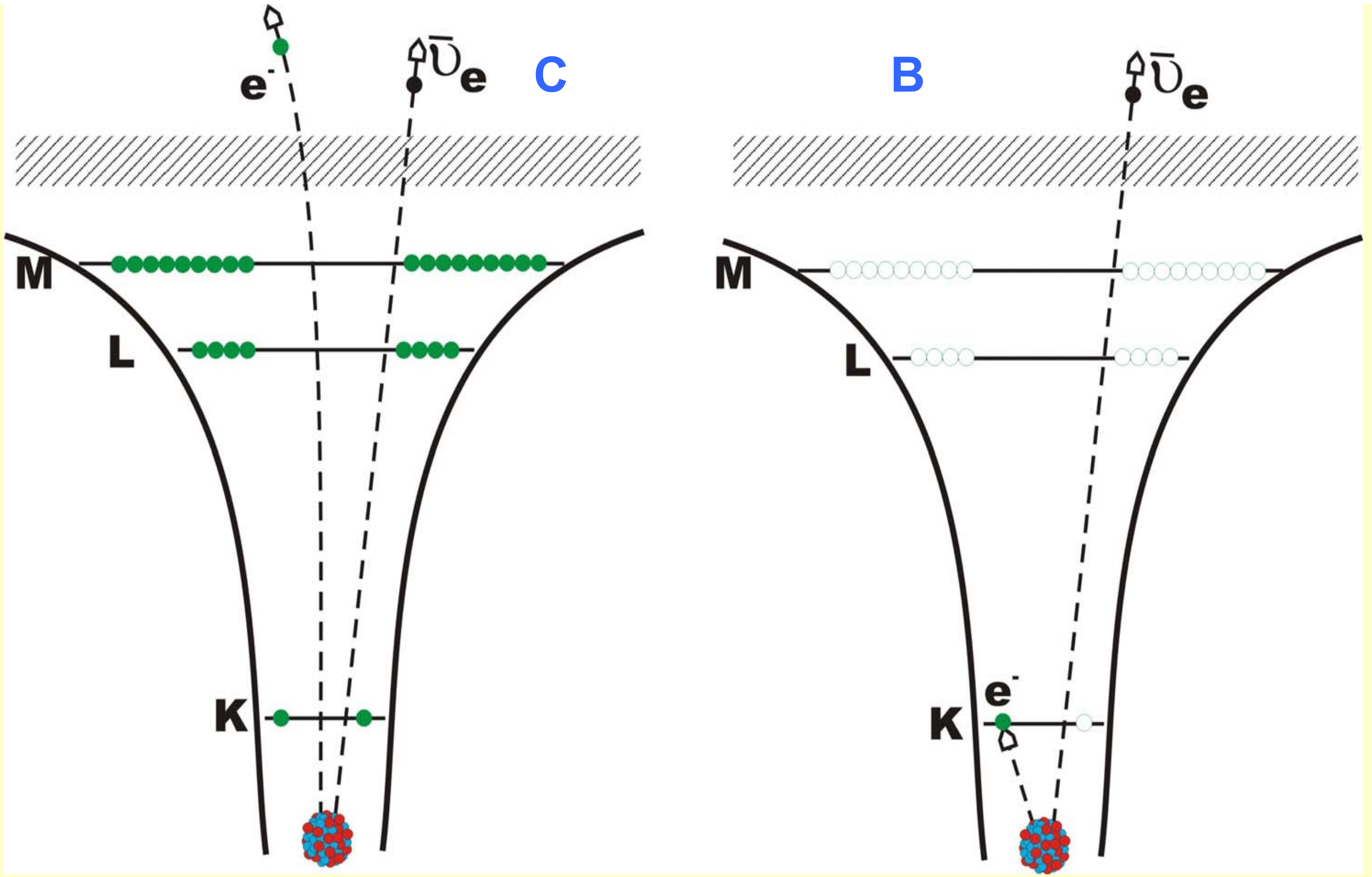
Yu. Litvinov, D. Shubina, N. Winckler, K. Blaum, MPI-K Heidelberg

Th. Faestermann, **P. Kienle**, L. Maier, E. Wefers, E12 TU Munich

G. Amthauer, University of Salzburg

Bound-state β decay (β_b) of $^{205}Tl^{81+}$





$$Q_{\beta b}(\text{bare}) = -\,Q_{EC} \quad - \quad |\Delta B_e| \quad + \quad |E_B(K,L\ldots)|$$

$$Q_{\beta b}(K) = -\,50.5\ \text{keV} \quad - \quad 19.5\ \text{keV} \quad + \quad 101\ \text{keV} = +31\ \text{keV}$$

Physics case 1

^{205}Tl in lorandite ($TlAsS_2$) at the Allchar mine is a **long-time** detector of solar **pp neutrinos** with the lowest threshold of **52.8 keV** (GALLEX ≈ 232 keV):

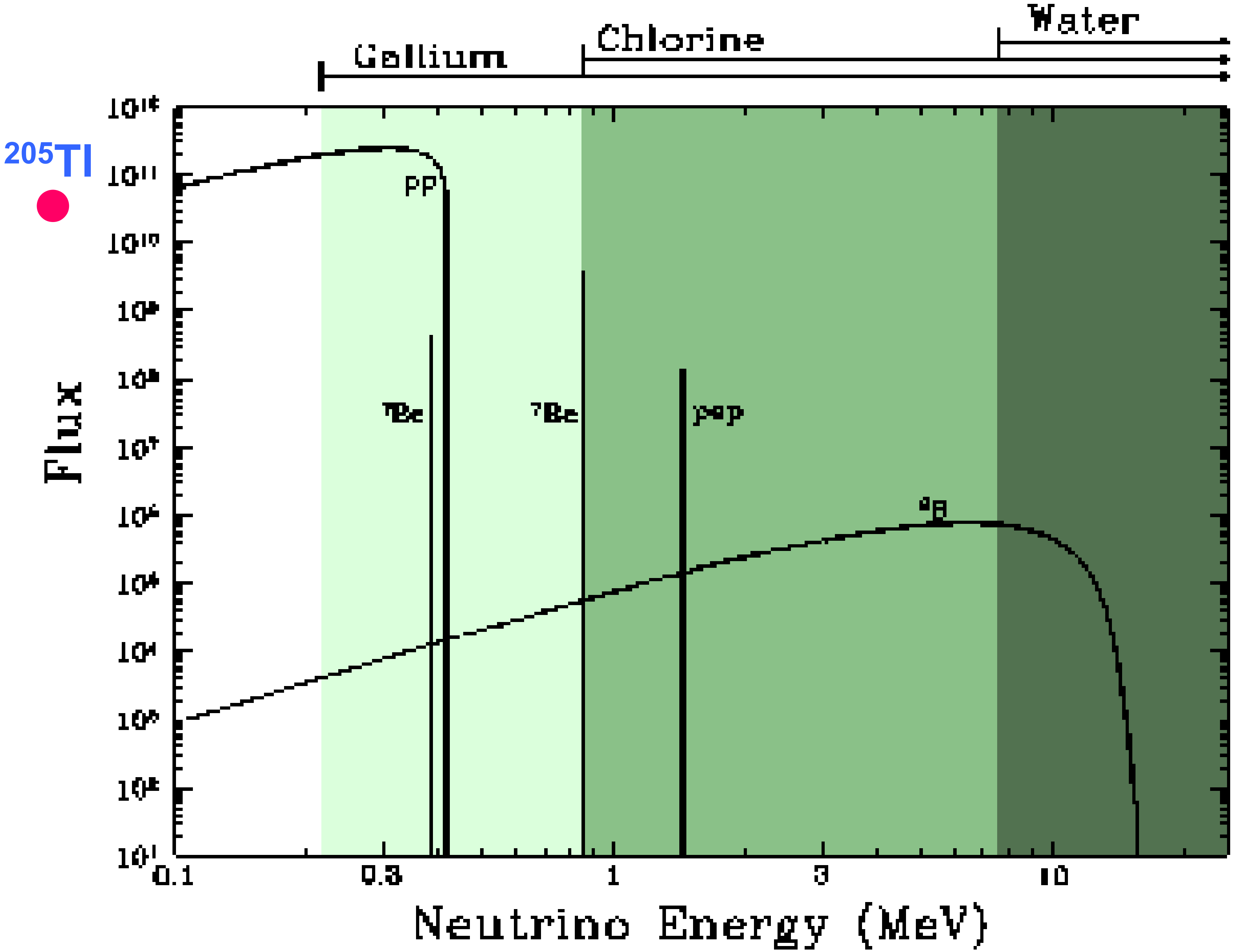
$$^{205}\mathrm{Tl} + \nu_e (E_{\nu e} \geq 53\ \mathrm{keV}) \longrightarrow {}^{205}\mathrm{Pb}^*\ (2.3\ \mathrm{keV}) + e^-\ (>93\%)$$

The ratio ^{205}Pb/^{205}Tl (background-corrected) provides the **product** of the mean solar pp neutrino flux $\Phi_{\nu e}$ and the capture cross section $\sigma_{\nu e}$ within **$4.3 \cdot 10^6$ y** [1]

$$< \Phi_{\nu e} \cdot \sigma_{\nu e} >$$

The β_b **decay-probability** of bare $^{205}Tl^{81+}$ provides the unknown **nuclear matrix element** for the ν_e capture [2]

(M.K. Pavicevic, P. Kienle, W.F. Henning, 1990)



205Tl
Gallium
Chlorine
Water
pp
7Be
7Be
pep
8B
Flux
0.1
0.3
1
3
10
Neutrino Energy (MeV)

Physics case 2

^{205}Pb is the **only purely s-process** "short-lived" (10^7 y) radioactivity (**SLR**) alive in the early solar system

It provides insight on **s-nucleosynthesis** just **after decoupling and prior to the Sun's birth**

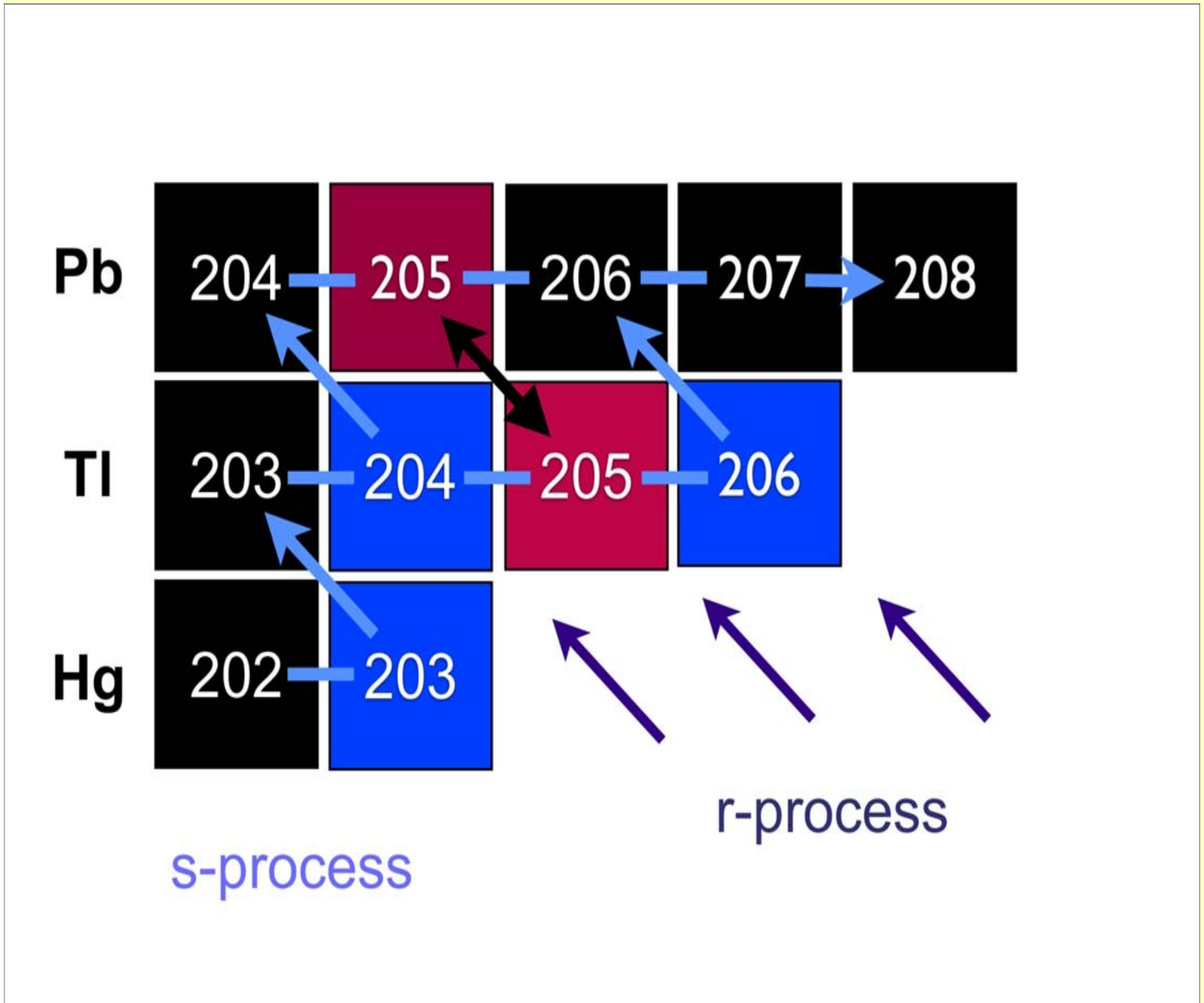
$$N(^{205}Pb)/N(^{204}Pb) = (k+2)\, P(^{205}Pb)/P^{204}Pb) \cdot \tau_{Pb\text{-}205}/T_G$$ [3]

abundances in ISM **s-production rates** **$2 \cdot 10^7$ y/$8 \cdot 10^9$ y**

≈ 10^{-3} (measured) [4] **≈ 1 (assumed)** **≈ $3 \cdot 10^{-3}$**

(K. Takahashi, B.S. Meyer)

^{205}Pb strongly reduced by free EC from 2.3 keV state [5]
→ injection of s-matter from a (AGB) star needed [6]



Sunday, April 18, 2010

Counter-balanced by the β_b decay of highly ionized ^{205}Tl? [7]

→ $\lambda_{\beta b}$ of bare ^{205}Tl provides the mean lifetime of ^{205}Tl in the s-process environment

Why is the old E019 proposal from 1992 **now** feasible?
(We were and still are **not** allowed to accelerate ^{205}Tl)

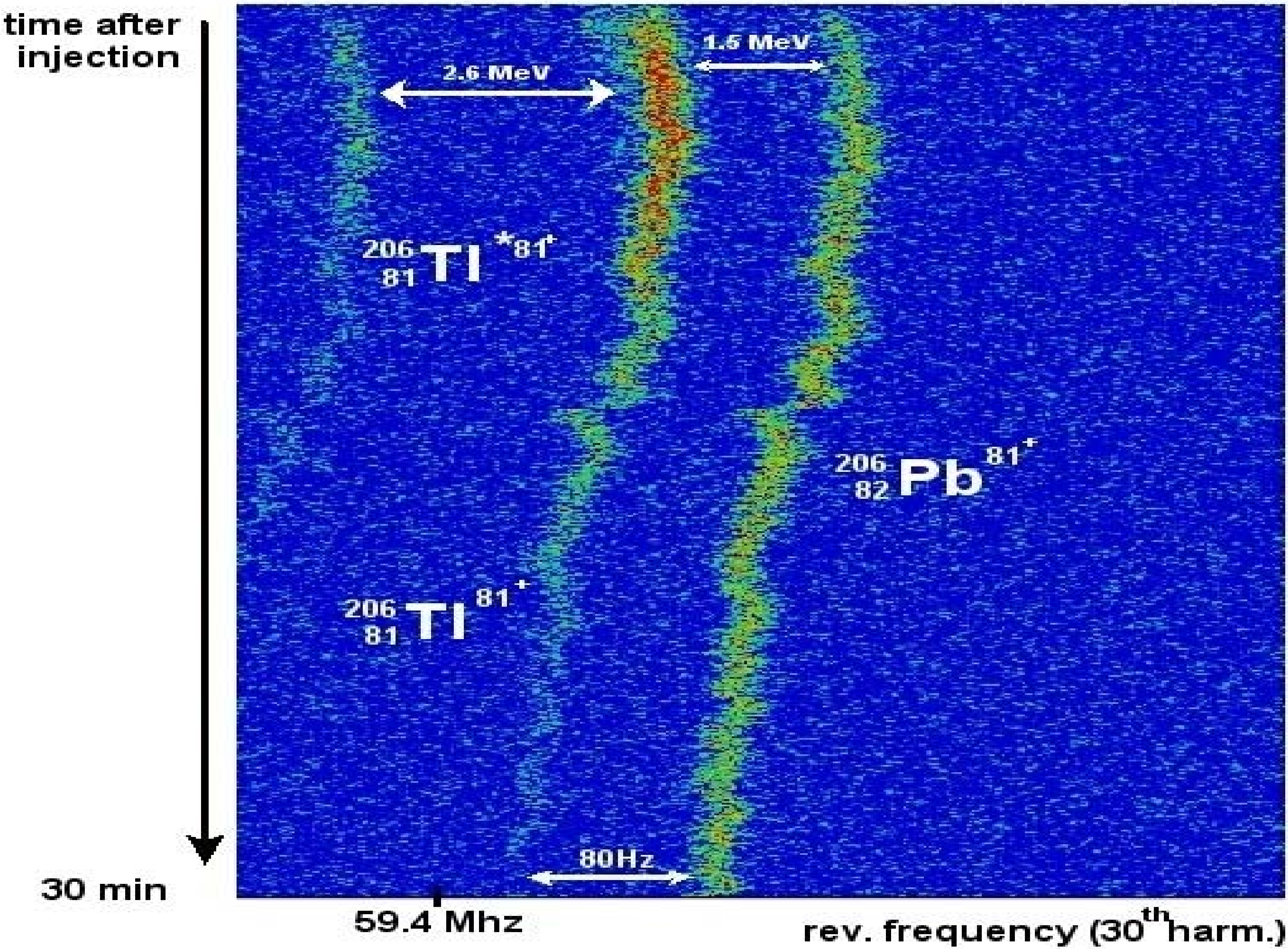
Estimated β_b half-life of bare $^{205}Tl^{81+}$: **120 d** [7] (...1 y...)

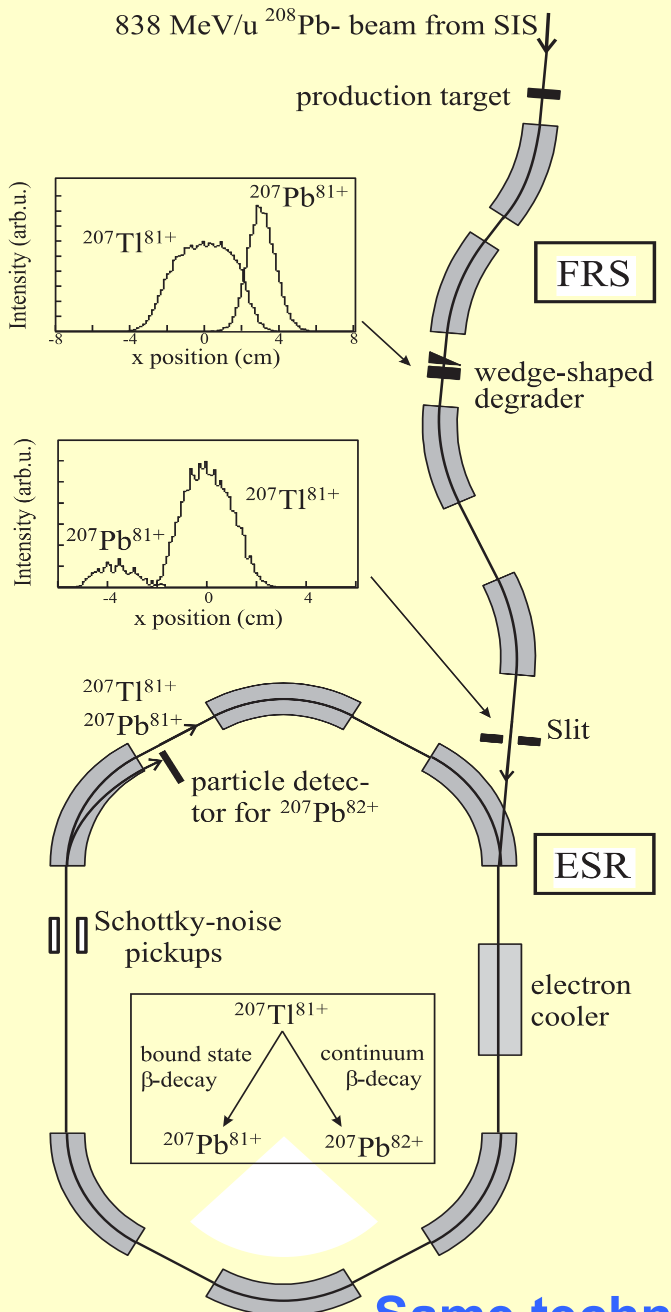
For **30...100 β_b daughters $^{205}Pb^{81+}$ /hour** in the ESR
≈ 2...6 · 10^5 stored and cooled $^{205}Tl^{81+}$ ions needed

1. **Improvements** of ion source, stripping, mult-multi inj. and cooling in SIS yielded **$2 \cdot 10^9$ ^{208}Pb** at FRS (S 312, 2007 [8])

→ **$1 \cdot 10^9$ ^{206}Pb** can be expected at FRS
→ **$1 \cdot 10^5$ $^{205}Tl^{81+}$** in ESR (σ = 17 mb, 3% transmission)

2. Accumulation by **rf-stacking** (bucket transfer) and stochastic cooling (2000, [9])
→ **2...6·10^5 $^{205}Tl^{81+}$ stored and cooled in ESR**


time after injection
30 min
2.6 MeV
1.5 MeV
206 81 Tl *81+
206 81 Tl 81+
206 82 Pb 81+
80Hz
59.4 Mhz
rev. frequency (30th harm.)



1. Inject 10^5 $^{205}Tl^{81+}$/shot from FRS

2. Accumulate in ESR to about $5 \cdot 10^5$

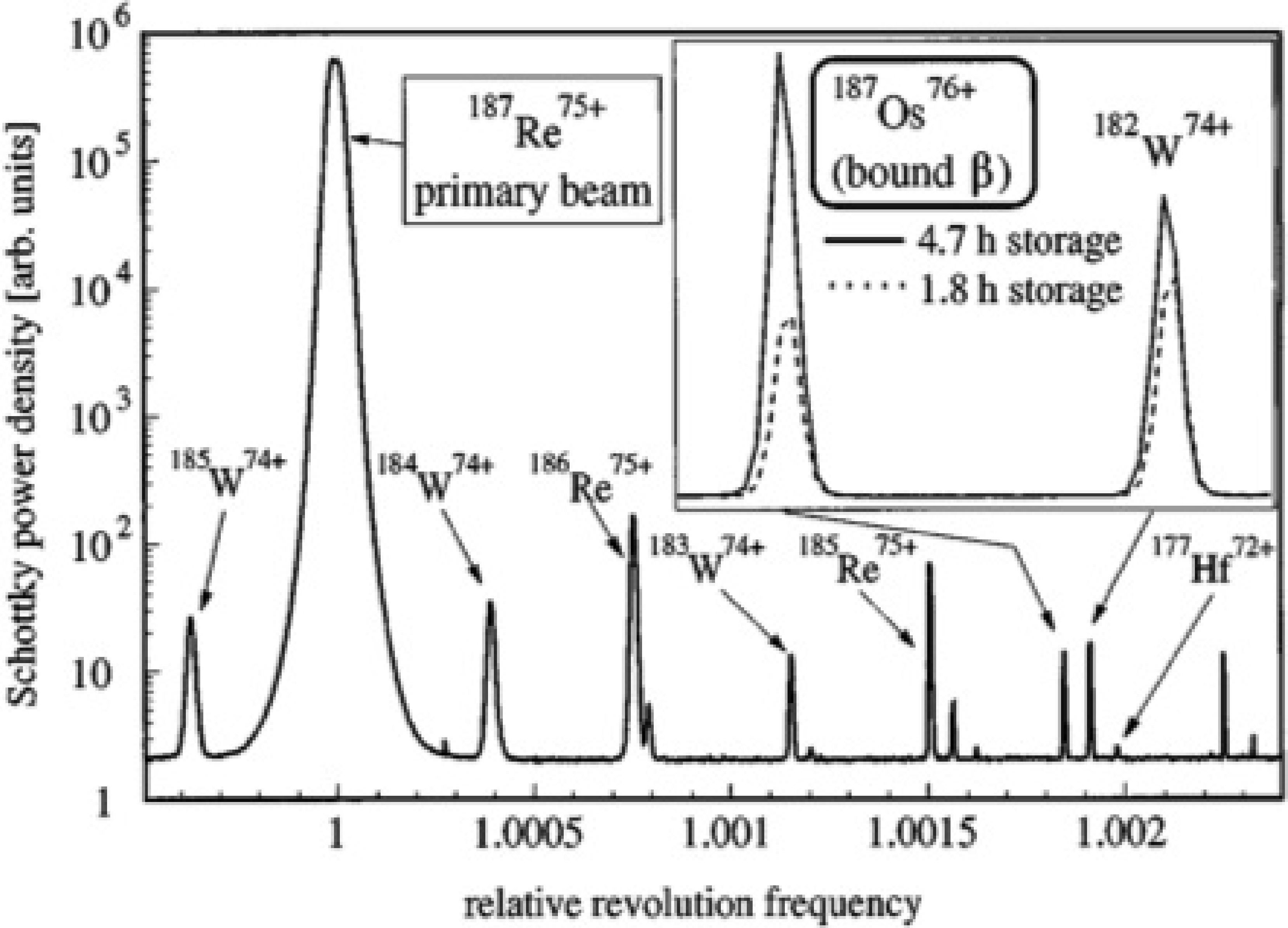
3. Store at different times (few hours)

4. Parent- ($^{205}Tl^{81+}$)- and β_b-daughter ($^{205}Pb^{81+}$)-line not separated in the Schottky spectrum

5. Turn on a gas jet (Argon) for about 2 minutes
   →K electron of $^{205}Pb^{81+}$ stripped-off

6. Get resolved bare $^{205}Pb^{82+}$
   Number measured via Schottky-noise or by means of an in-ring detector

Same technique as applied for ^{163}Dy and ^{187}Re [10,11]



PRL **77**, 5190 (1996) [11]

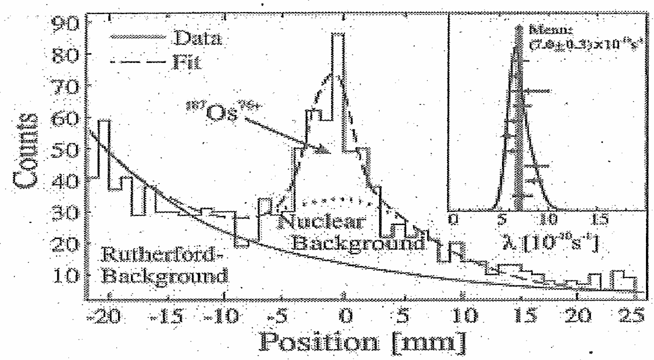


FIG. 3. Position spectrum of ions deflected by the first dipole magnet behind the gas jet target. The narrow peak in the middle of the spectrum is due to $^{187}Os^{76+}$ nuclei from the β_b decay of $^{187}Re^{75+}$. The background from elastic scattering (full drawn) and from nuclear reactions (dotted) has been determined in separate runs. The inset shows the results of ten individual measurements for the decay constant in form of an ideogram, as prescribed in the Review of Particle Properties [15]. The full drawn curve, the sum of Gaussians for each measurement, serves mainly to judge the consistency of the data.

[11] PRL **77** (1996) 5190

Summary: Preparation and status of E100

For ≥ **1 ·10^9 ^{206}Pb ions/extraction in the FRS** (S 312, 2007 [8])

N($^{205}Tl^{81+}$) ≈ 1 · 10^5/injection expected in the ESR

After accumulation by rf-stacking→ **2...6 ·10^5 $^{205}Tl^{81+}$ stored**

→ **After 1 h storage ≈ 30....100 bare $^{205}Pb^{82+}$ (ε = 0.75)**

→ **No enrichment of ^{206}Pb (25%) in a Penning source needed**

8 shifts for tuning of ion source, FRS and ESR,

In-flight fragmentation, multi-injection from FRS

Stoch. cooling and bucket transfer (rf-stacking)

8 shifts to get **2...6 · 10^3 β_b decays** in the ESR

2 shifts for the capture-to-ionization ratio at gas jet

Approved for E100 in April 2010: **18** shifts ("A")

References

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[3] G.R. Huss et al., GCA **73**,4922 (2009)

[4] R.G.A. Baker et al., Earth and Planet. Sci. **291**, 39 (2010)

[5] J.B. Blake and D.N. Schramm, ApJ. **197**, 615 (1975)

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[10] M. Jung et al., PRL **69**, 2164 (1992)

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