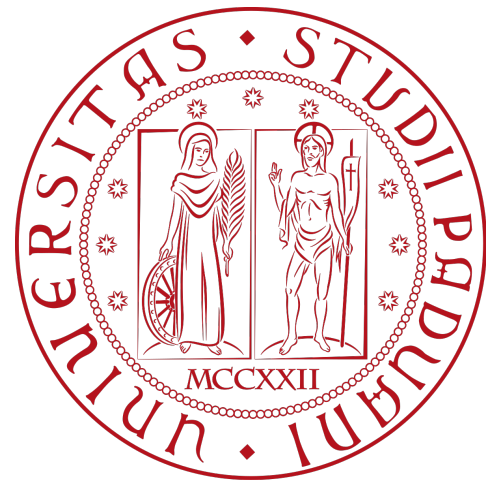


26th AGATA week and Agata Collaboration Council meeting

Report on the AGATA experiment number 23.03 (EXP_024)

Lifetime measurement of the 6.79 MeV state in ^{15}O

*A high-precision Doppler Shift Attenuation Method measurement to constrain
the CNO-cycle bottleneck reaction $^{14}\text{N}(p,\gamma)^{15}\text{O}$*



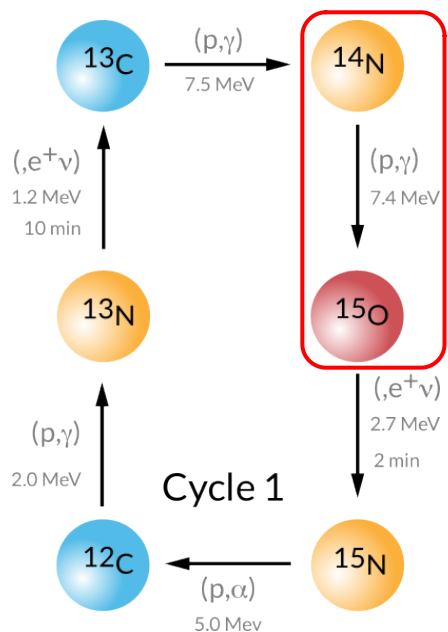
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Speaker: E. Pilotto

HIL Warsaw (Poland) – September 2026

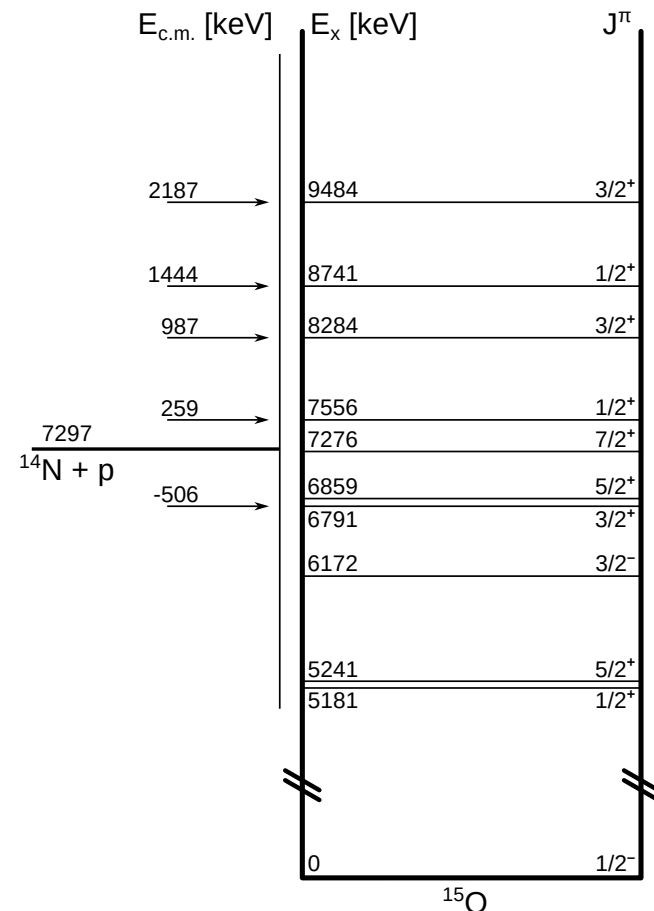
The CNO cycle

CNO-cycle I

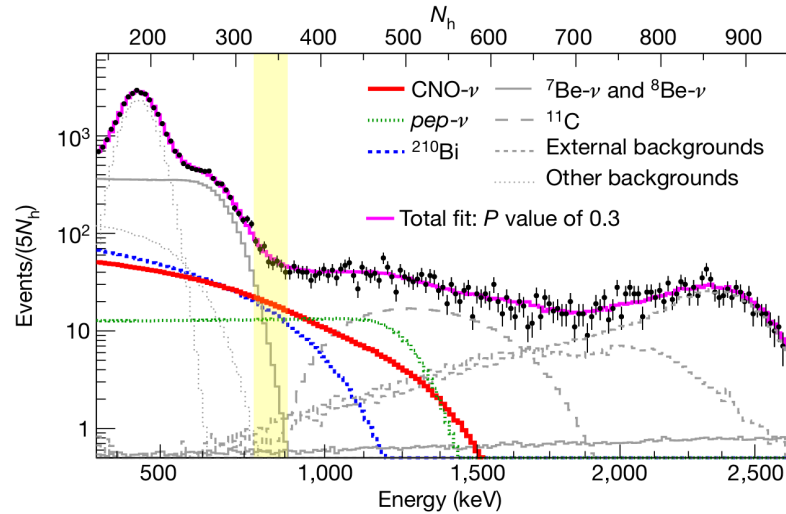


- Main hydrogen-burning mechanism in stars larger than our Sun
- Equilibrium governed by the $^{14}\text{N}(p,\gamma)^{15}\text{O}$ reaction, the slowest of the cycle
- Solar Gamow peak is at 20 – 35 keV, direct measurements stop at 90 keV
- **Sub-threshold resonance** from **6.79 MeV state** in ^{15}O dominates at stellar energies
- **Resonance width** is directly correlated to **lifetime** of the state (**sub-fs range**)

$$\Gamma = \hbar / \tau$$



Solar neutrinos as a probe of metallicity



Borexino collaboration, *Nature* 587 (2020)

$$\Phi \sim \sigma \times N$$

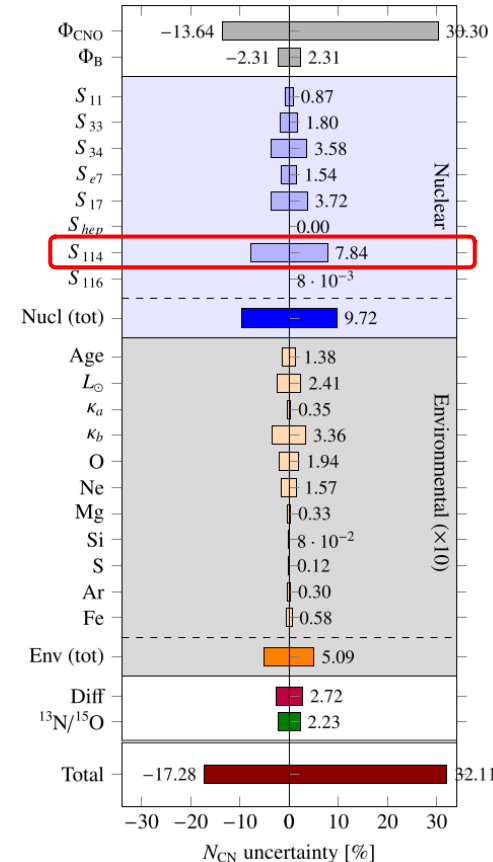
LZ

$Z \sim 0.0137$
spectroscopy

HZ

$Z \sim 0.017$
helioseismology

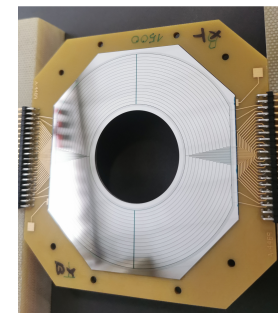
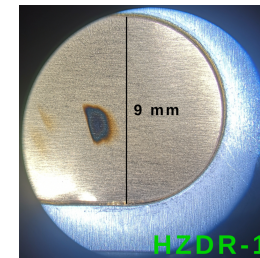
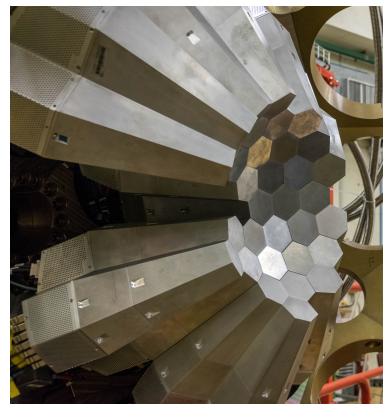
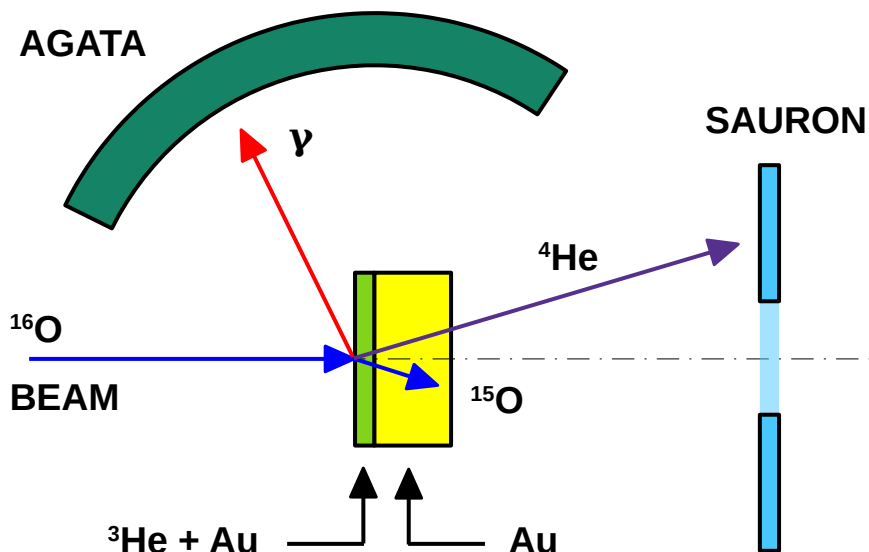
- Borexino isolated the **CNO solar neutrino signal**
- Their measurement favors HZ over LZ hypothesis
- **S_{114} uncertainty** is the **2nd largest contribution** to the error budget, right after statistics
- With the advent of next generation neutrino facilities (JUNO, THEIA, SNO+), **nuclear physics is the limiting factor**



Appel et al, *PRL* 129 (2022)

Setup

- Reaction: ${}^3\text{He}({}^{16}\text{O}, {}^{15}\text{O}){}^4\text{He}$ @ 50 MeV
- **A**dvanced **G**amma **T**racking **A**rray (**AGATA**)
- Annular **DSSD** Si detector
- Composite **implanted** / **sputtered** target
- **D**oppler **S**hift **A**ttenuation **M**ethod (**DSAM**)



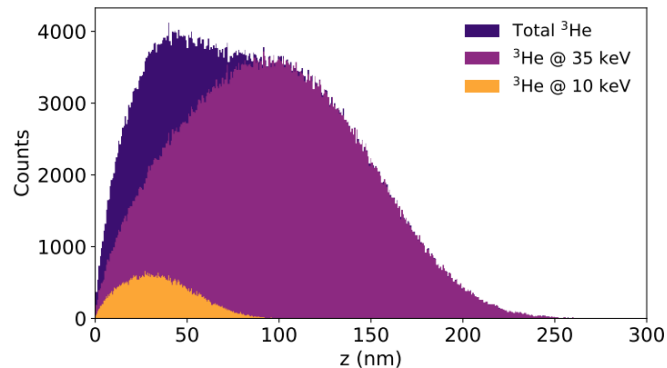
Main features

- Large angular acceptance
- High granularity / angular resolution
- Excellent energy resolution
- Low beam energy $\rightarrow$ minimal background
- Particle identification $\rightarrow$ reaction channel selection

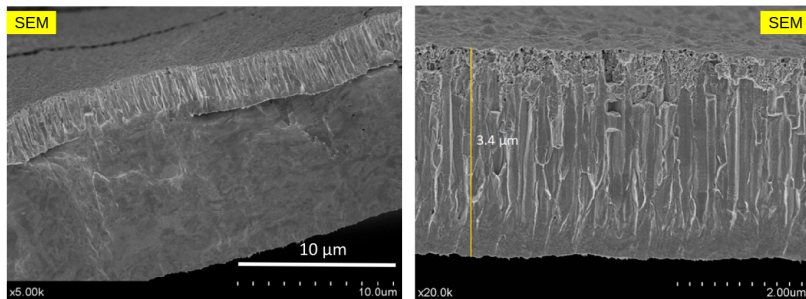
Target Characterization

Pre-irradiation

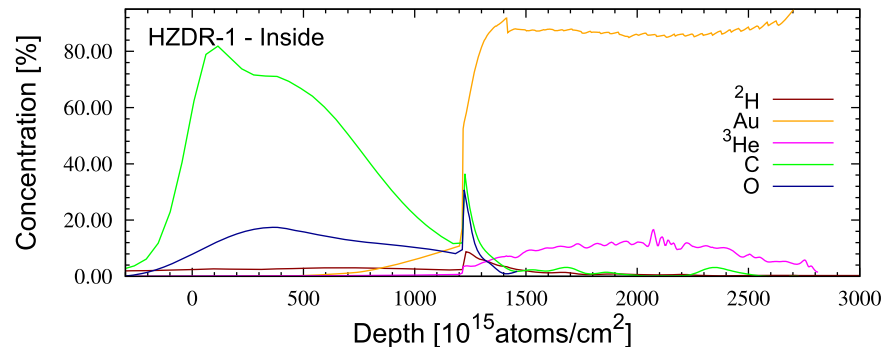
SRIM simulations – implanted targets



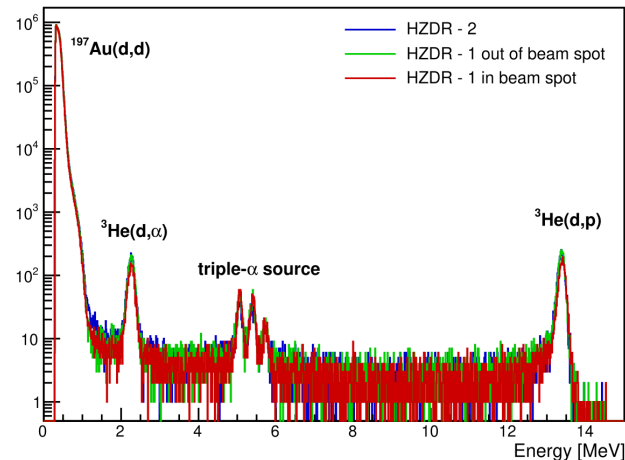
SEM and TEM imaging – sputtered targets



Post-irradiation



ERDA

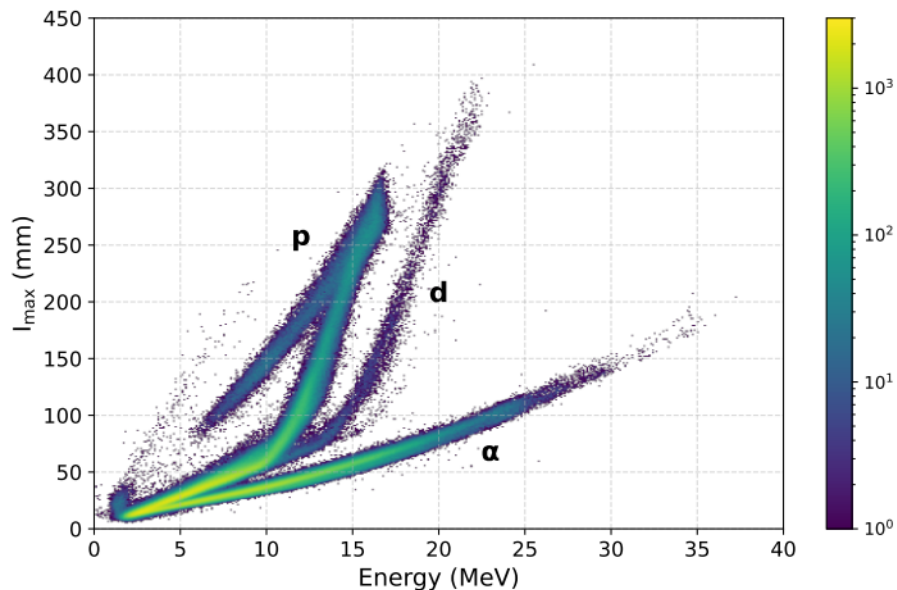


NRA

Fernandez et al, Materials and Design 186 (2020)

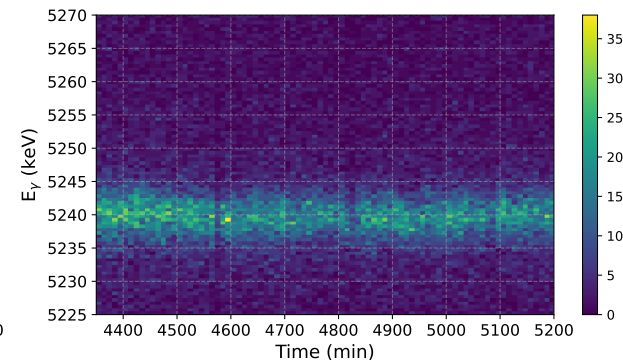
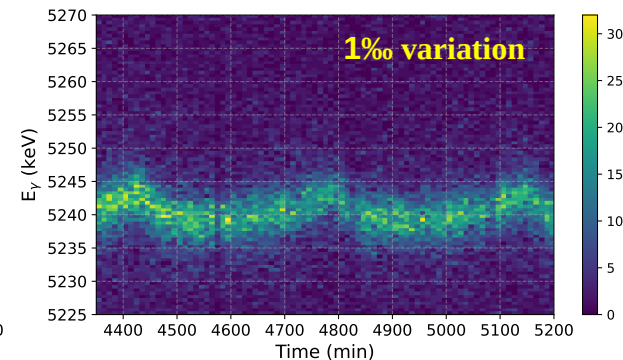
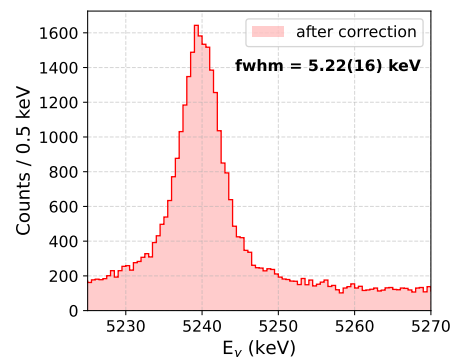
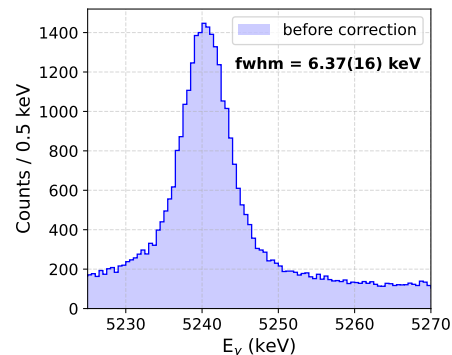
Pilotto et al, EPJA 61:117 (2025)

Sauro – particle identification



$^{15}\text{O}(^3\text{He},p)^{18}\text{F}$
parallel reaction channel
for cross validation

Agata – time evolution correction



+ neutron damage correction algorithm improvement

Differential Recoil Velocity Analysis

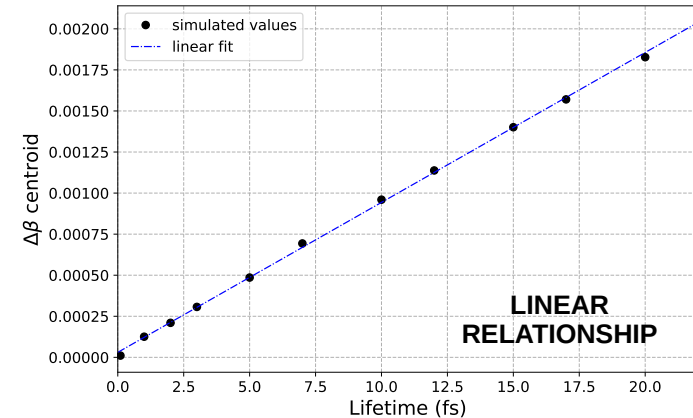
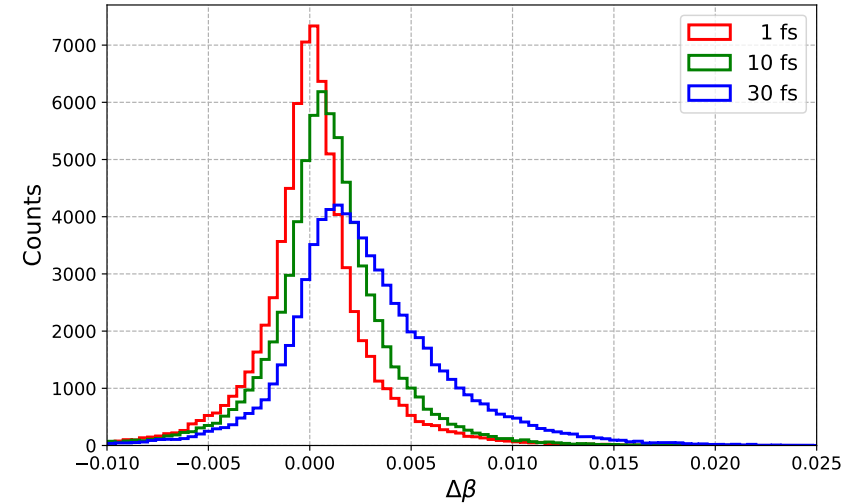
- First introduced in *Fougeres et al, Nature Comm (2022)*
- β_{reac} : kinematic reconstruction + energy loss
- β_{emis} : inversion of Doppler relation

$$R = \frac{E_\gamma}{E_0} = \frac{\sqrt{1 - \beta^2}}{1 - \beta \cos \theta}$$

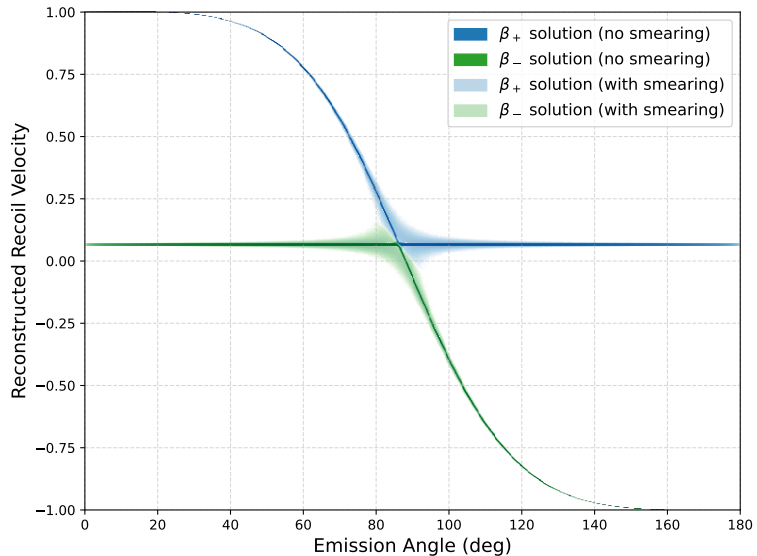
$$\beta_{\pm} = \frac{R^2 \cos \theta \pm \sqrt{1 + R^2 \cos^2 \theta - R^2}}{1 + R^2 \cos^2 \theta}$$

$$\Delta\beta = \beta_{\text{reac}} - \beta_{\text{emis}}$$

**Event by event measurement of
recoil deceleration**



Differential Recoil Velocity Analysis



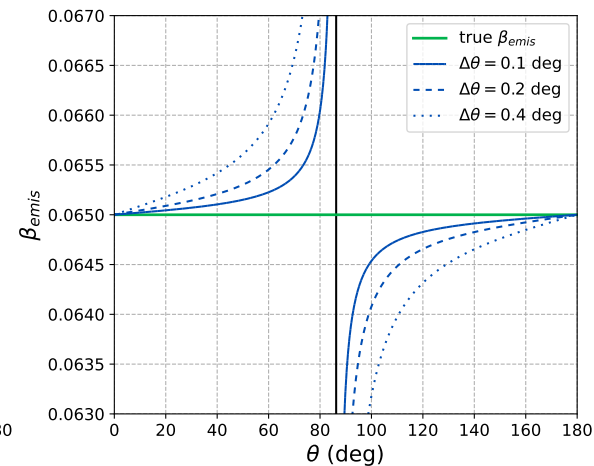
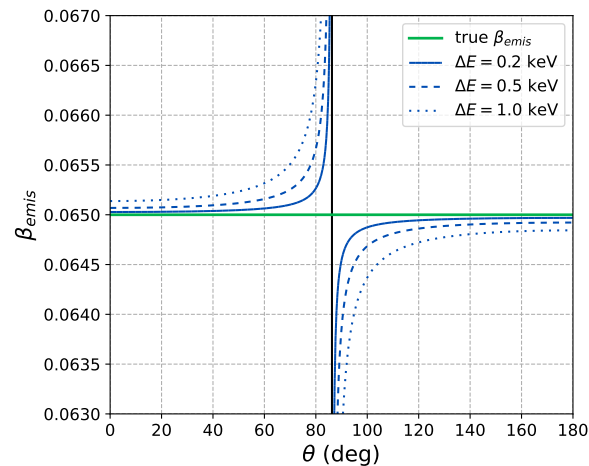
- Relativistic treatment yields two solutions with boundary at

$$\beta = \cos \theta$$

- The **distribution centroid** is independent of both **resolution** and **acceptance**

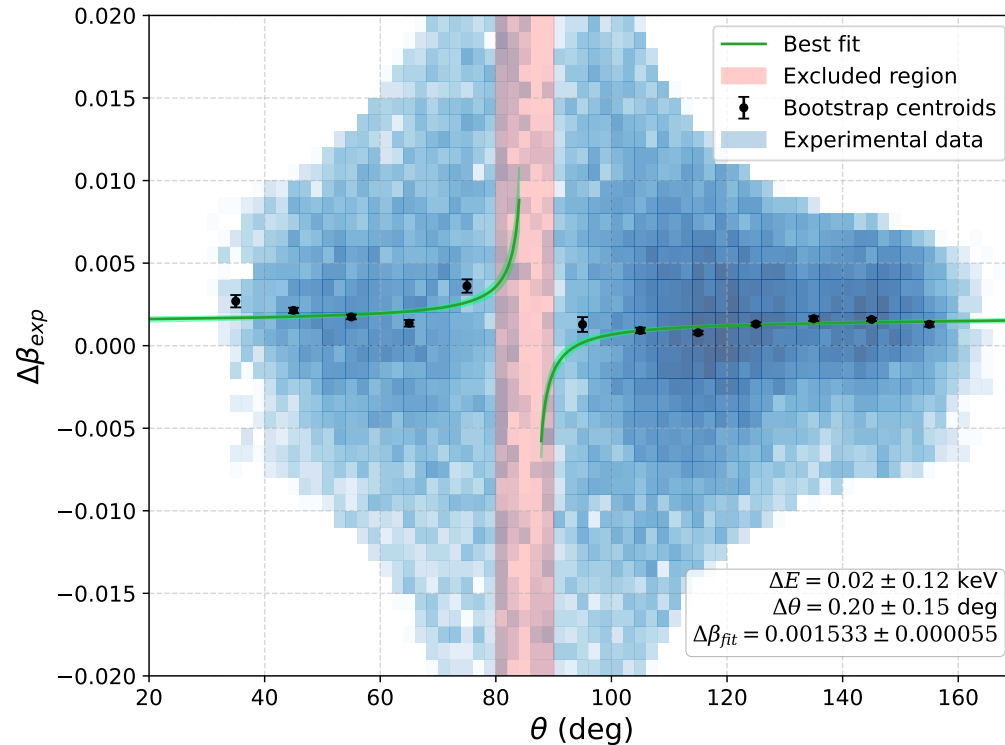
Systematic effects treated as nuisance parameters

- Calibration / literature: ΔE (sensitivity in 0.01 keV range)
- Geometry: $\Delta \theta$ (sensitivity in the 0.1 deg range)
- Correlation degeneracy handled by observing multiple transitions



Systematic effects can be corrected only because of large angular acceptance

Centroid extraction



Projections in 10 deg slices

Low statistics divergence region excluded



For each projection

Centroid fit with bootstrap approach

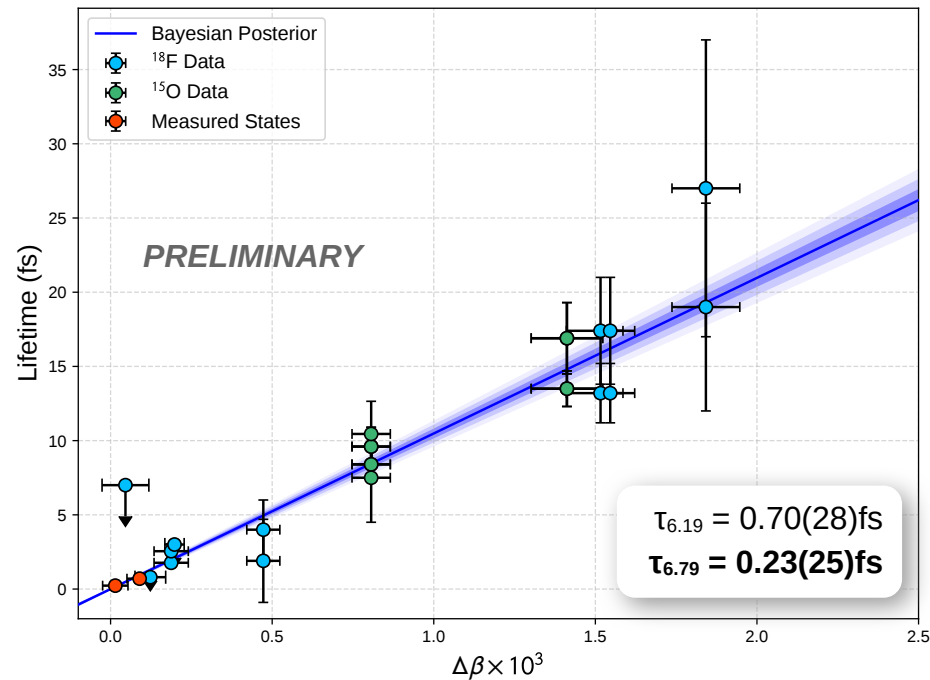
For more accurate uncertainty



Bayesian fit using MCMC algorithm with uninformative priors on $\Delta\beta$, ΔE , $\Delta\theta$

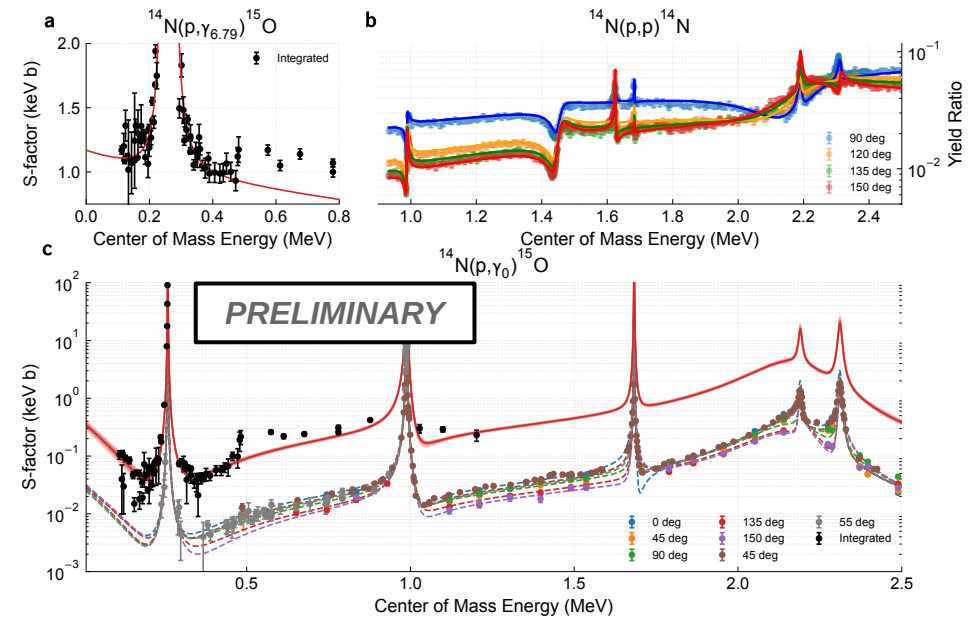
Final lifetime extraction

- **Bayes fit + MCMC algorithm**
- Maximal information: **literature + simulations** priors



R – matrix fit

- Well known model (same as **SFIII** or **Chen et al.**)
- Bayesian fit using **lifetimes** as priors
- Agreement with all datasets



S-factor uncertainty: 8.4% → 3.4%

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Thank you for your attention

