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Neutrinoless Double Beta Decay Experiment

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Science & Technology Facilities Council

erc European Research Council Established by the European Commission

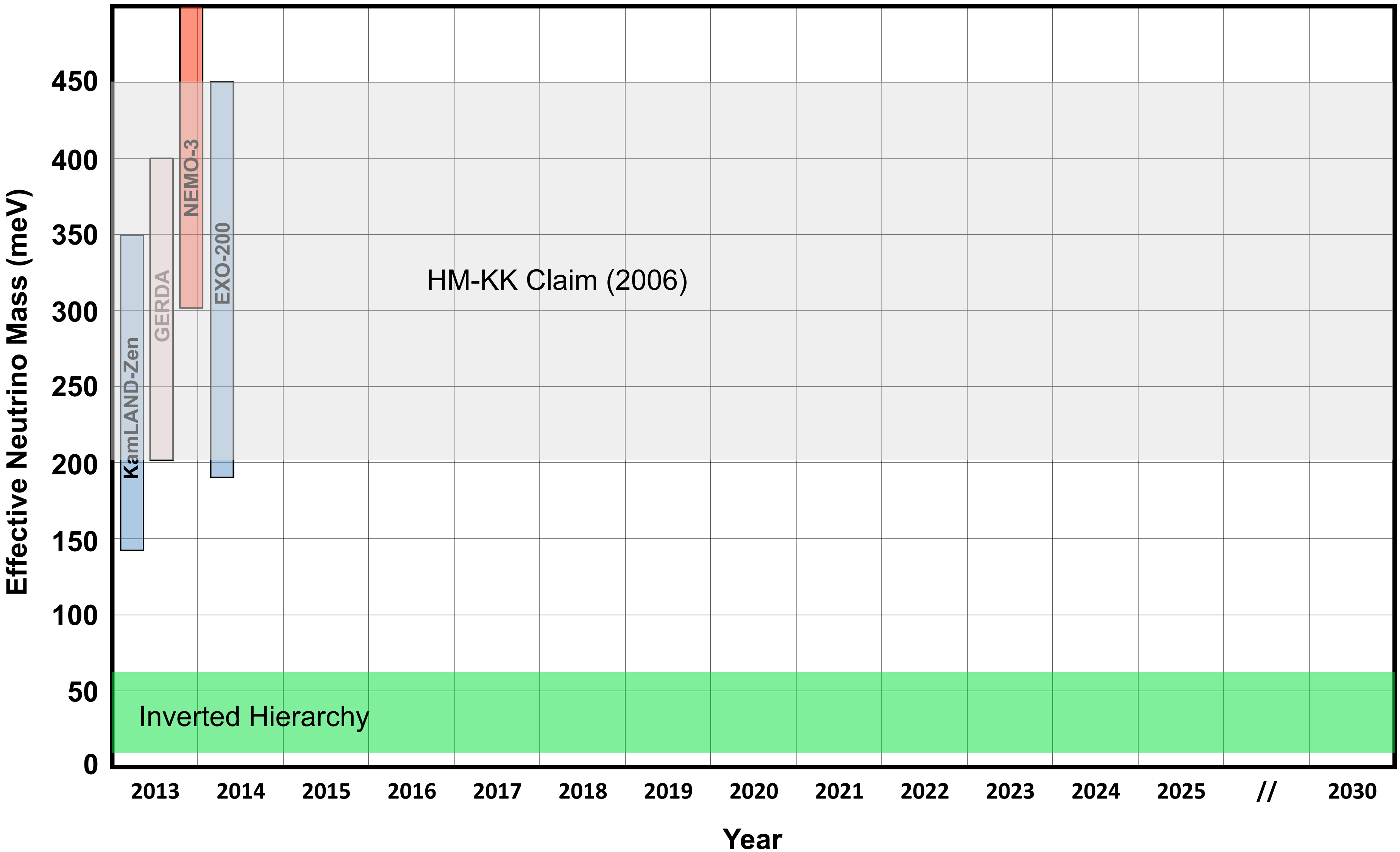
Introduction

- Current results
- How does sensitivity scale?
- SNO+
- Future prospects:
  - The next decade and...
  - Designing experiments sensitive to the non-degenerate normal hierarchy

Double Beta Decay Experiments

- Currently running experiments
  - CANDLES
  - KamLAND-Zen
  - EXO-200
  - GERDA
- Experiments under construction
  - CUORE (currently running COURE-0)
  - Majorana “Demonstrator”
  - NEXT
  - SuperNEMO (NEMO3 recently ran)
  - **SNO+**

Current Results



How does sensitivity scale?

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}|M^{0\nu}|^2\left(\frac{\langle m_\nu\rangle}{m_e}\right)^2$$

- In a background free experiment measurement of the half-life is linear with exposure (mass x time)
- For 0νββ the neutrino mass sensitivity scales as the sqrt of the half-life. **Harder!**
- With significant backgrounds (that scale with exposure) the half-life sensitivity scales as sqrt of exposure, and neutrino mass scales as 4th root!

SNO+

SNO+ Detector

Acrylic vessel (AV)
12 m diameter

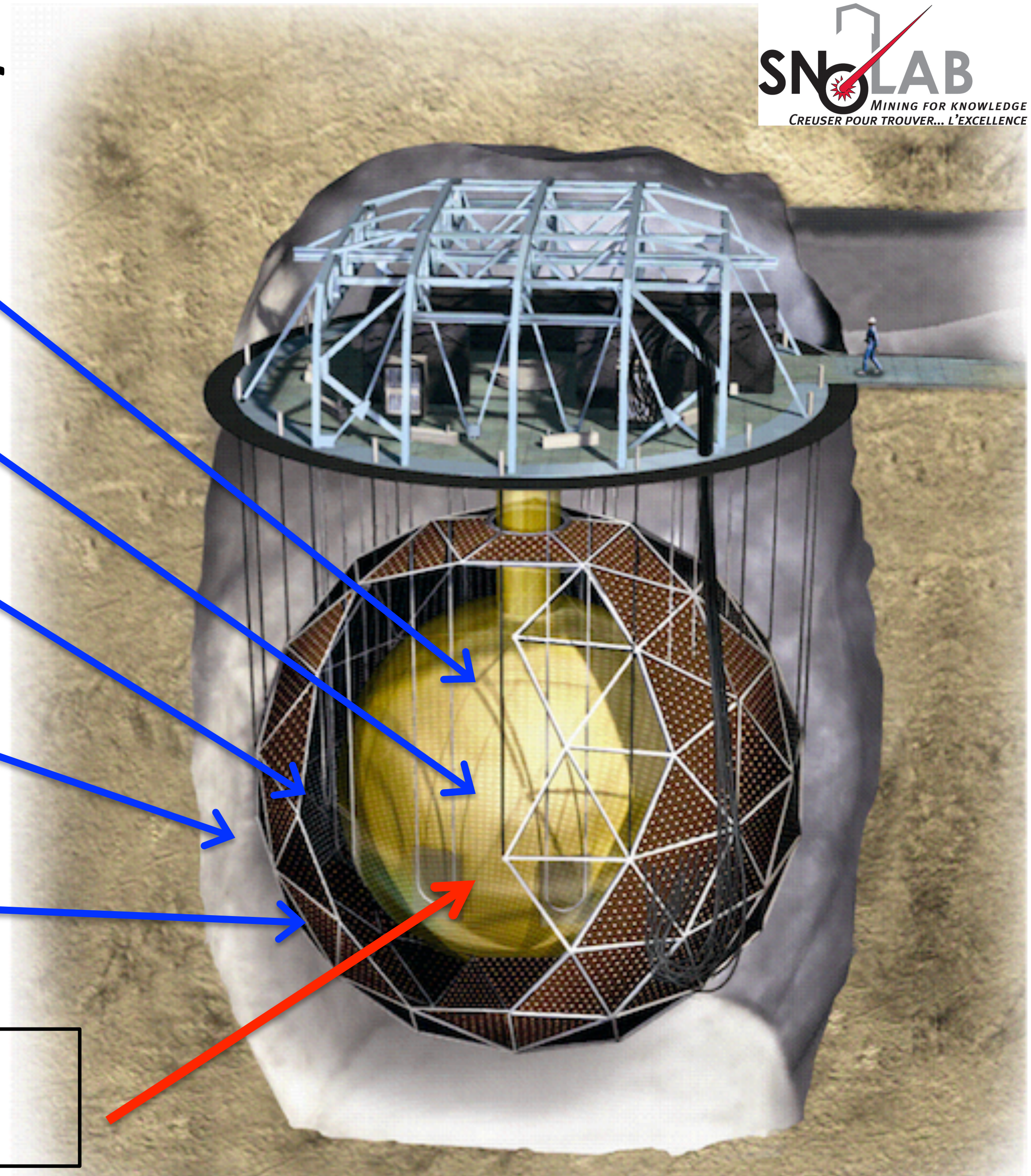
780 tonnes of LAB LS

1700 tonnes H_20
inner shielding

5700 tonnes H_20
outer shielding

~9500 PMTs

O(tonne) 0νββ
element/isotope



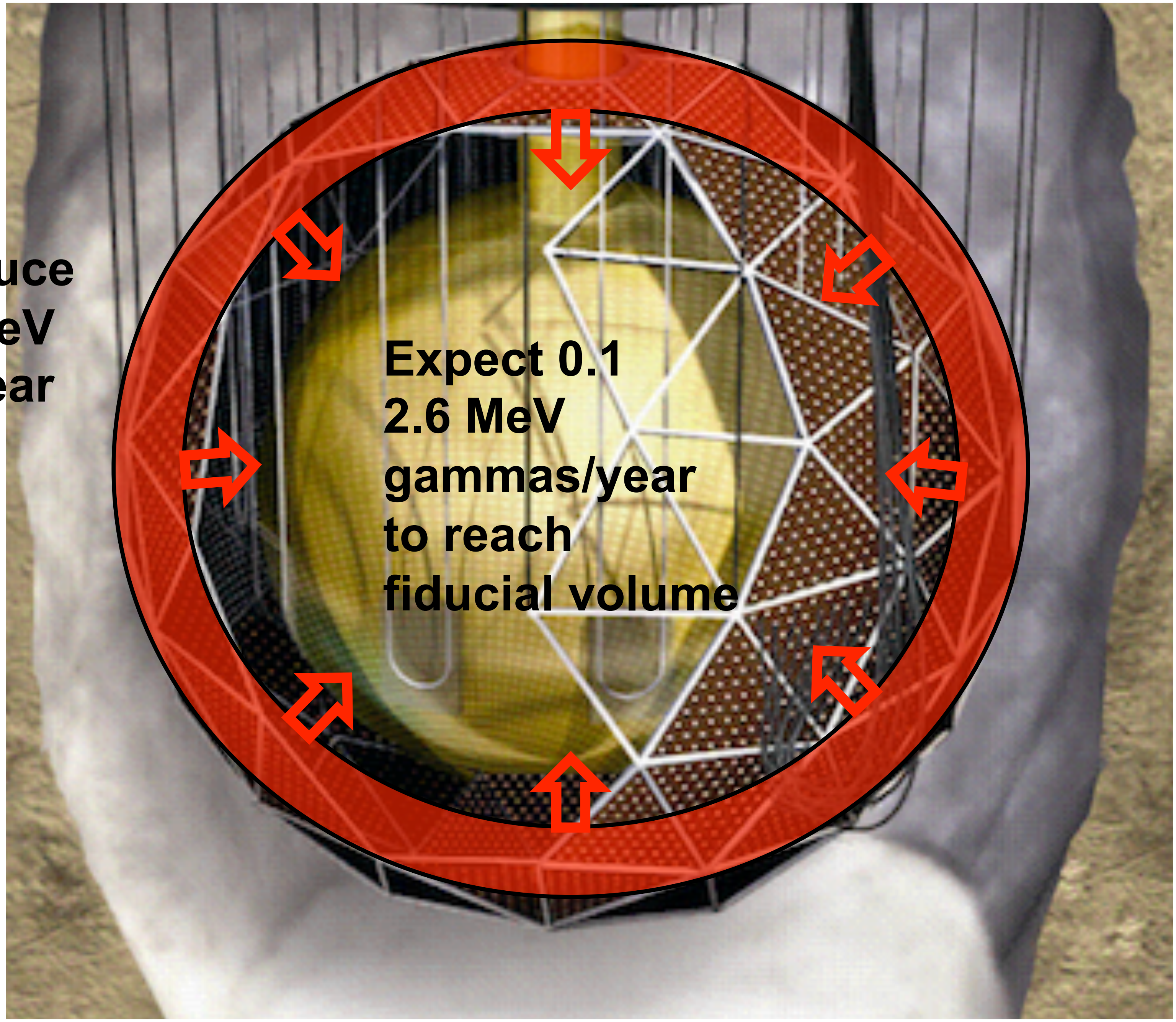
National Geographic

SNO+ Concept

- Load liquid scintillator with 0νββ isotope
  - Trade off energy resolution for higher statistics and lower backgrounds
- Why take this approach?
  - Cost-effective: detector already exists
  - Various isotopes can be used
  - Shielding:
    - Huge external shielding (7400 tonnes H_2O)
    - Self-shielding of scintillator
  - Purification of scintillator by distillation
  - Fast timing to reject Bi-Po backgrounds
  - Flexibility of liquids: loading-level & purification

Effect of shielding

PMTs produce $\sim 10^{11}$ 2.6 MeV gammas/year



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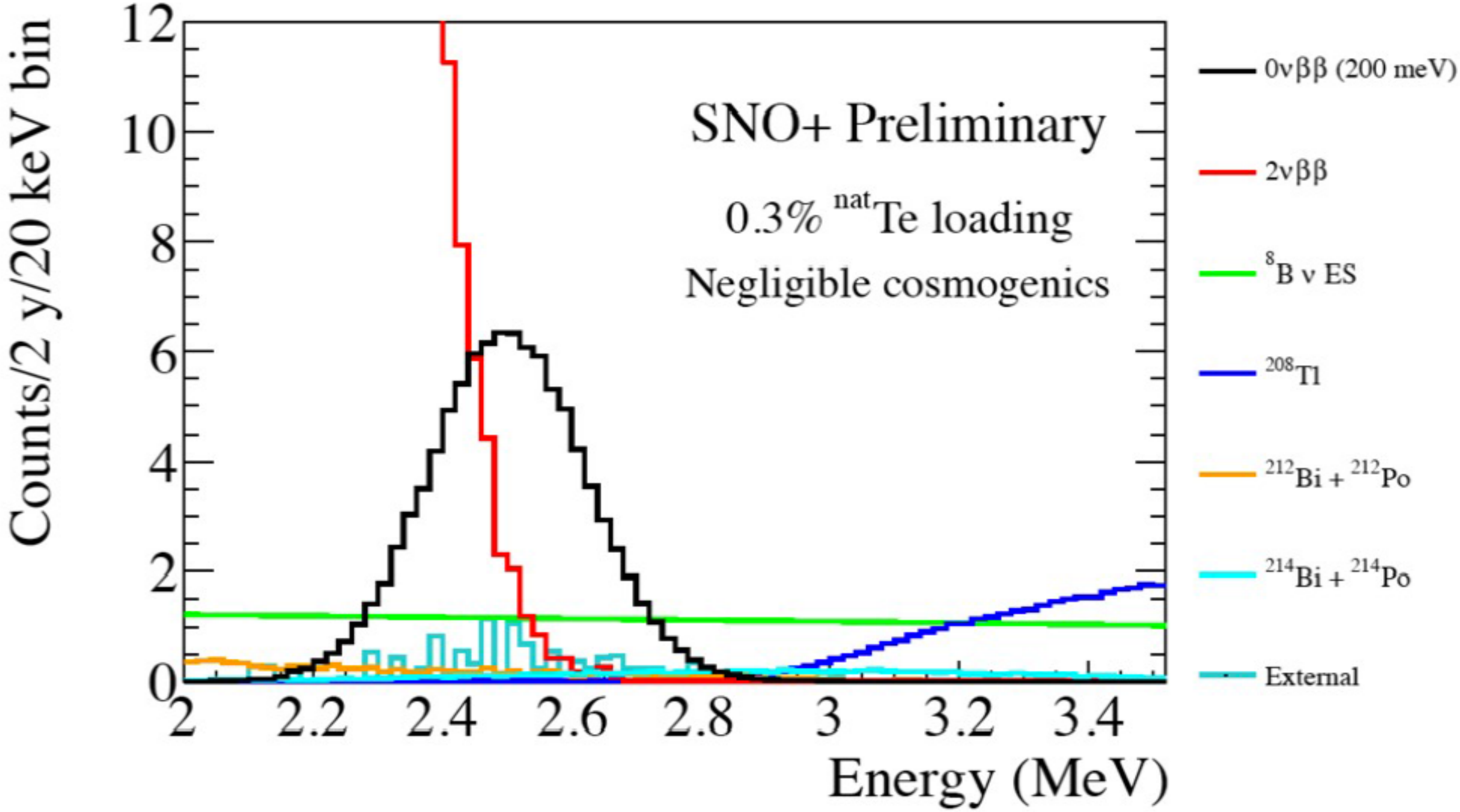
Simulated energy spectrum



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SNO+ Schedule

- Water fill has begun
- Scintillator process system completion: March 2015
- Detector filled with scintillator: September 2015

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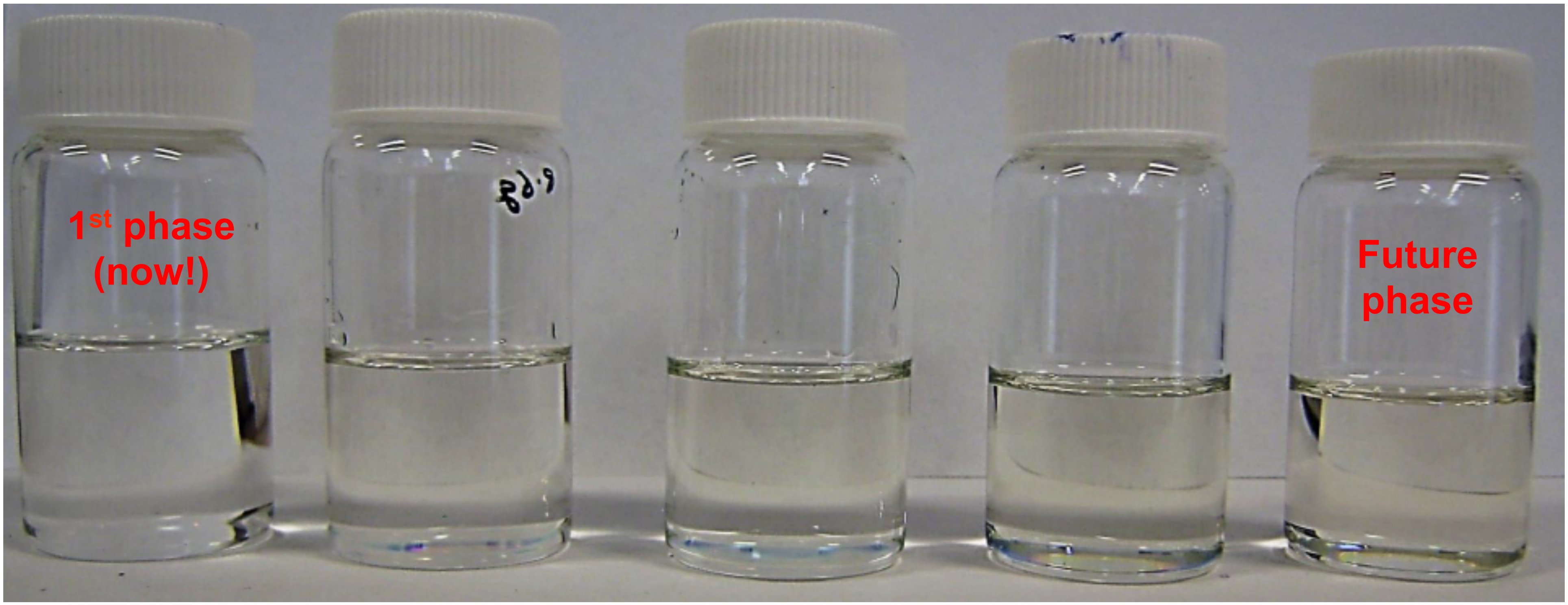
Ongoing R&D towards future SNO+ phases...



0.3% 0.5% 1% 3% 5%

[J. Klein]

SNO+ Scaling

Initial plan is to deploy 0.3% (natural) Te. But…

Scaling works very well in detector like SNO+.

$$\widehat{T_{1/2}^{0\nu\beta\beta}} = \frac{\ln(2)}{n_\sigma}\frac{N_A \cdot a \cdot \eta \cdot \epsilon}{W}\sqrt{\frac{M \cdot t}{b \cdot \delta E}} \cdot f(\delta E)$$

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Dominant SNO+ backgrounds DO NOT scale with Te mass!

$$\widehat{T^{0\nu\beta\beta}_{1/2}} = \frac{N_{isotope} \ln 2}{n_\sigma} \frac{t}{\sqrt{(bM + C)\delta E t}} \cdot f(\delta E)$$

C=^{8}B νs, External γs (AV+PMTs), LAB U,Th
b=2ν, cosmogenics, scintillator cocktail

For $bM_{Te}<C$, $m_{\beta\beta} \sim (M_{Te})^{1/2}$ not $\sim(M_{Te})^{1/4}$!

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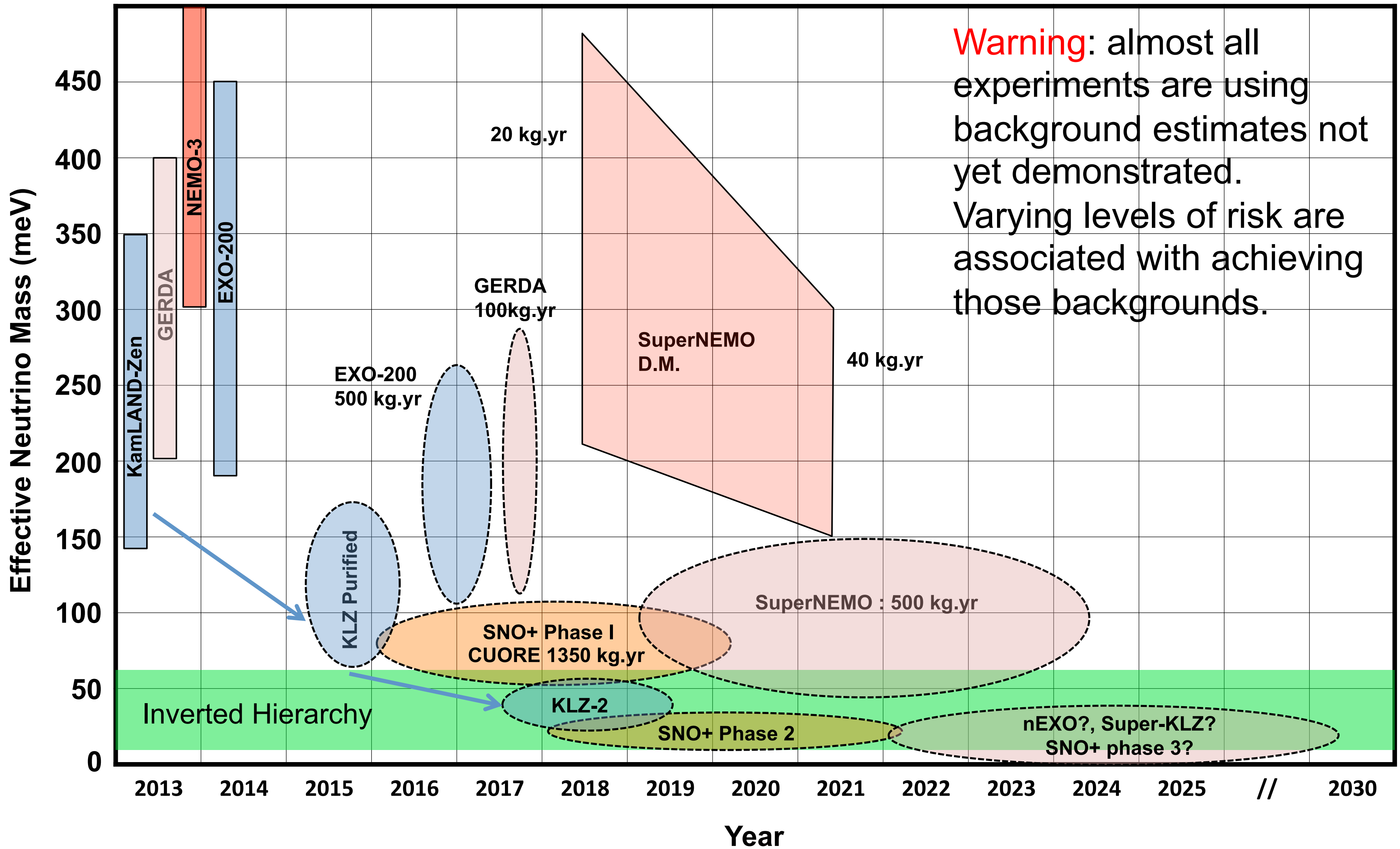
Where is the field heading in the next decade?

Comparing Sensitivities



[Input from D. Waters, S. Biller]

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Designing experiments sensitive to the non-degenerate normal hierarchy

Getting a sense of the landscape

- Make some order of magnitude comparisons
- Consider **quantities** and **costs** of material
  - for **one** $0\nu\beta\beta$ event per **year**
  - for a Majorana neutrino mass of 2.5 meV

- ^{136}Xe is the cheapest isotope to enrich
  - ~$20/g
  - Assume all isotopes could be enriched at this price

S. Biller PRD 87, 071301, (2013)

S. Biller PRD 87, 071301, (2013)

Properties of candidate $0\nu\beta\beta$ isotopes.

Isotope	Q (MeV)	Percent natural abund.	Element cost [5] (\$/kg)	$T^{0\nu}_{1/2}$ for 2.5 meV (10^{29} yrs)	Tons of isotope for 1 ev/yr	Equivalent natural tons	Annual world production [5] (tons)	Natural element cost (\$M)	Enriched at \$20/g (\$M)	$0\nu/2\nu$ rate [2,8] (10^{-8})
^{48}Ca	4.27	0.19 ✗	0.16	2.70	31.1	16380 ✗	2.4×10^8 ✓	2.6	622 ✗	0.016
^{76}Ge	2.04	7.8	1650	3.18	58.2	746	118 ✗	1221	1164 ✗	0.55
^{82}Se	3.00	9.2	174	1.05	20.8	225	2000	39	416 ✗	0.092
^{96}Zr	3.35	2.8	36	0.93	21.4	763	1.4×10^6	27	427 ✗	0.025
^{100}Mo	3.04	9.6	35	0.51	12.2	127	2.5×10^5	4.4	244 ✗	0.014 ✗
^{110}Pd	2.00	11.8	23000 ✗	0.98	26.0	221	207	5078	521 ✗	0.16
^{116}Cd	2.81	7.6	2.8	0.79	22.1	290	2.2×10^4	0.81	441 ✗	0.035
^{124}Sn	2.29	5.6	30	1.38	41.2	736	2.5×10^5	22	825 ✗	0.072
^{130}Te	2.53	34.5 ✓	360	0.75	23.6	68 ✓	$\sim$150	24	471 ✗	0.92 ✓
^{136}Xe	2.46	8.9	1000	1.40	45.7	513	50 ✗	513	914 ✗	1.51 ✓
^{150}Nd	3.37	5.6	42	0.37	13.4	240	$\sim 10^4$	11	269 ✗	0.024

↑

Enrichment at \$20/g is unfeasible for **ALL** isotopes
→ use natural element

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Xe: production levels & cost
Pd: cost
Ge: production levels & cost
Ca: 16 ktonnes impractical?

Enrichment at $20/g is unfeasible for all isotopes
→ use natural element

Te stands out in 0v/2v and mass of natural isotope required

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Conclusions

- After a decade of building the next generation experiments... 1st wave of new results:
  - **$m_{\beta\beta}$ < 150 - 350 meV (90% CL)**
- SNO+: load **tonnes** of ^{130}Te into 780 tons of liq. scint.
- Phased program:
  - 0.3% loading (800 kg ^{130}Te) → 2nd phase ~5%
    - Sensitivity to inverted hierarchy region
  - Future: larger fiducial volume, loading, light level...
- Much more soon to come:
  - KZ-upgrades, CUORE, EXO-200, Gerda, SNO+, SuperNEMO, Majorana demonstrator, NEXT
- Huge windows for discovery opening up
- Stay tuned!

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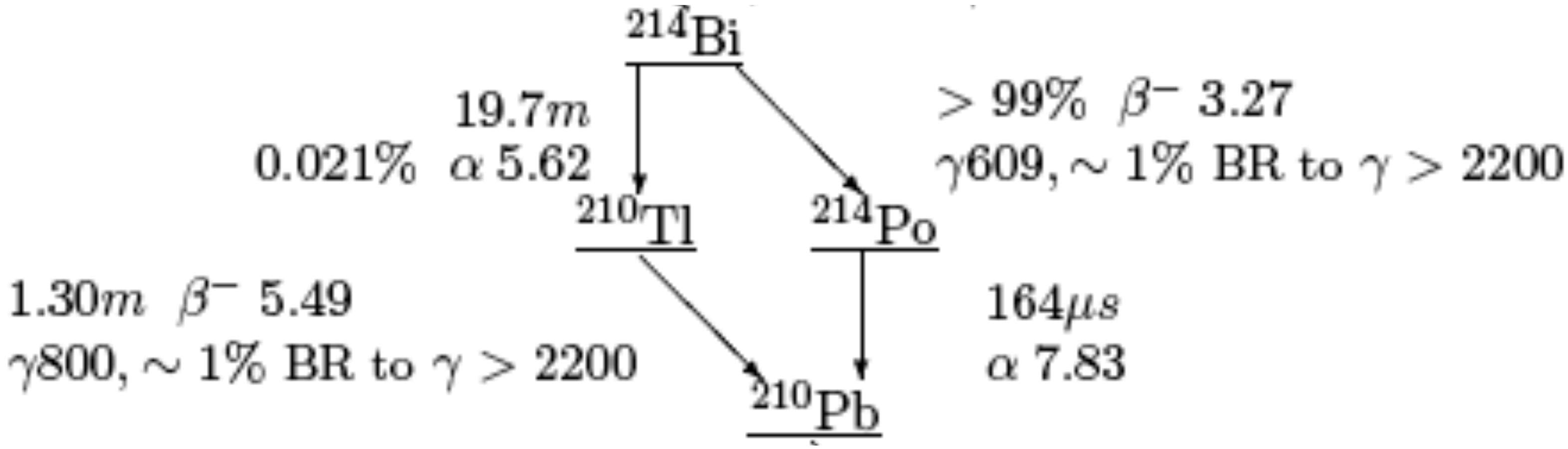
Backup slides

Why switch to ^{130}Te (from ^{150}Nd)?

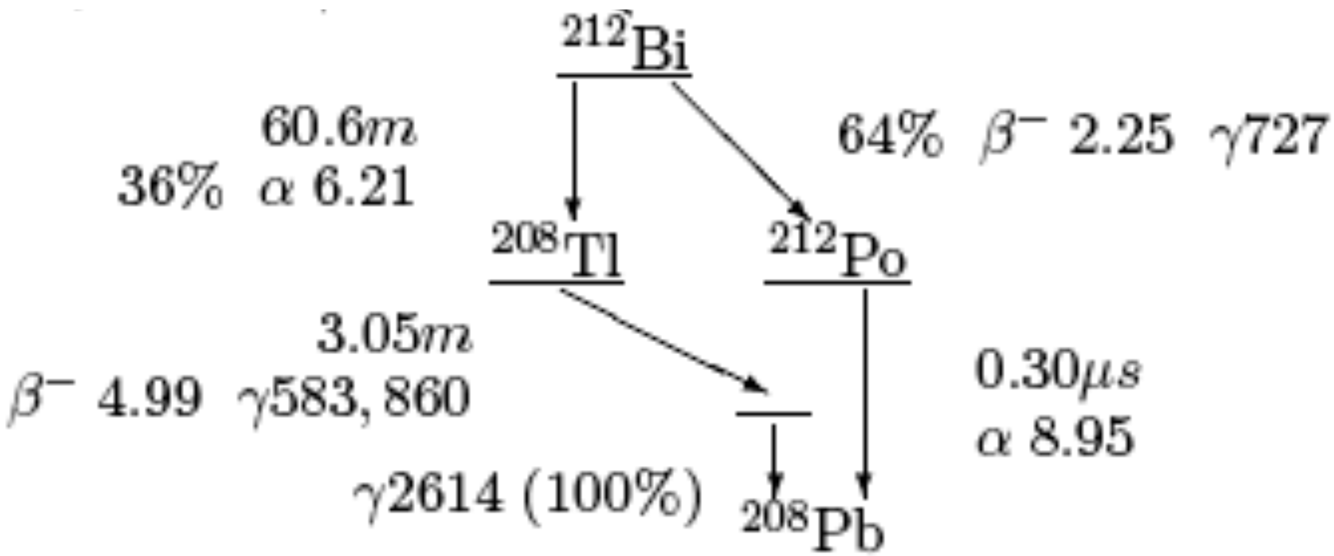
- 34% isotopic abundance
  - 0.3% loading is 810.5 kg of ^{130}Te
- $2\nu\beta\beta$ half-life of 70×10^{19} years
  - Relative $0\nu/2\nu$ rate is ~50 times higher
- Good optical properties
  - Higher loading
- ^{214}Bi tagged down to 10^{-4} level

^{238}U



^{214}Bi
19.7m
0.021% α 5.62
> 99% β^- 3.27
γ609, $\sim$ 1% BR to γ > 2200
^{210}Tl
^{214}Po
1.30m β^- 5.49
γ800, $\sim$ 1% BR to γ > 2200
164μs
α 7.83
^{210}Pb

^{232}Th



^{212}Bi
60.6m
36% α 6.21
64% β^- 2.25 γ727
^{208}Tl
^{212}Po
3.05m
β^- 4.99 γ583, 860
0.30μs
α 8.95
γ2614 (100%)
^{208}Pb