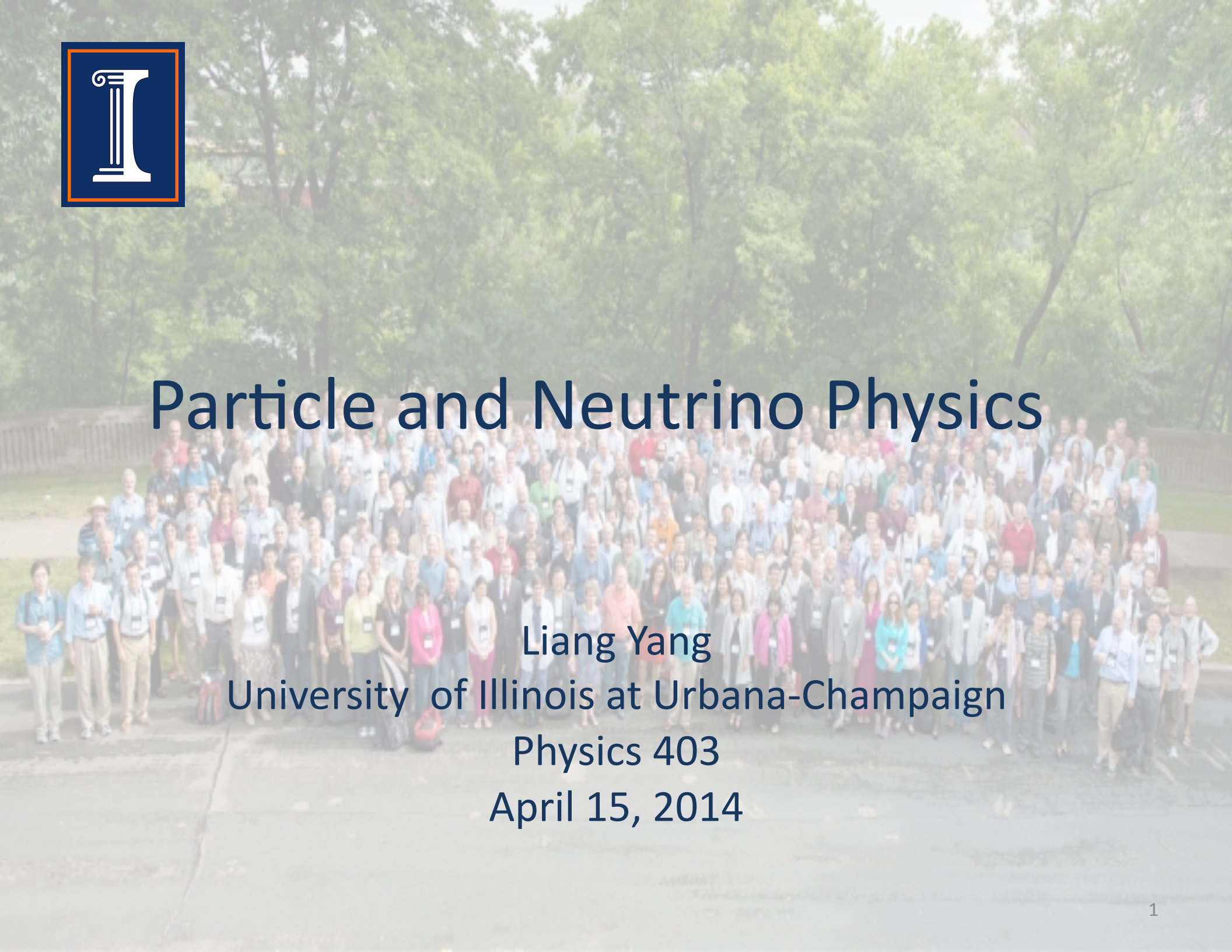


Particle and Neutrino Physics

Liang Yang
University of Illinois at Urbana-Champaign

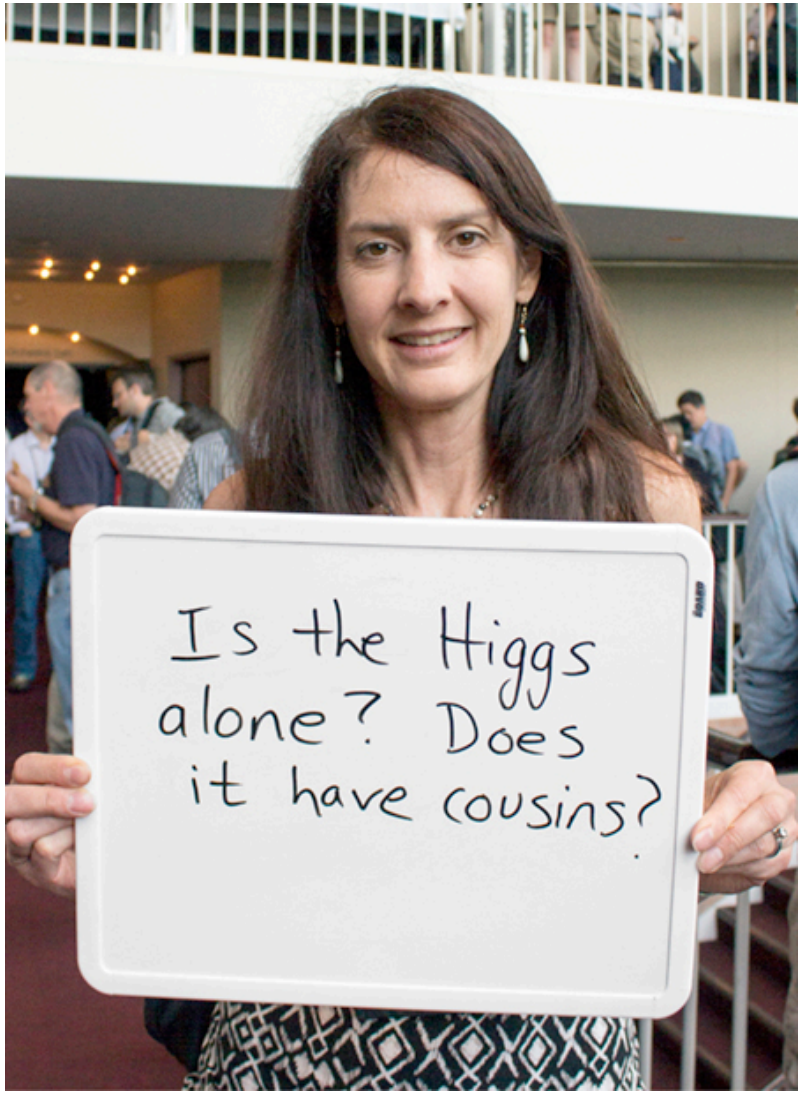
Physics 403

April 15, 2014

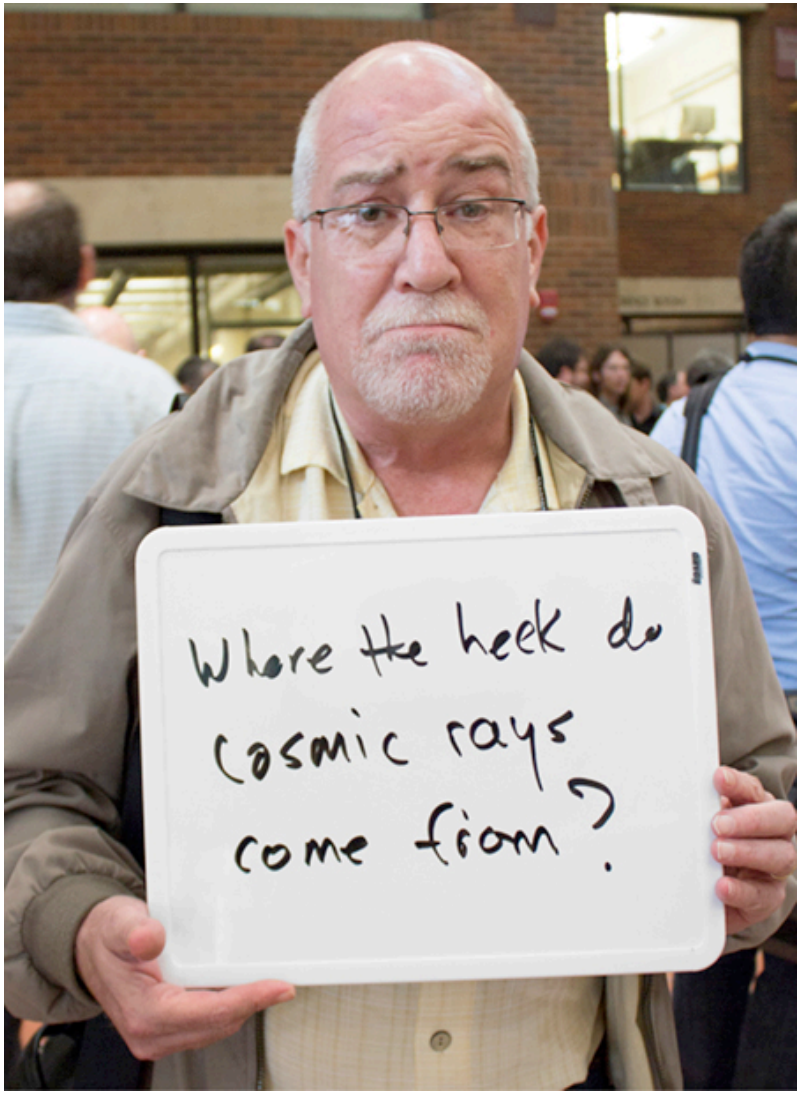
SNOWMASS on the Mississippi

- Community study 2013 for the high energy community
- 10 year plan in the context of twenty year global vision of the field
- P5 (Particle physics project prioritization panel) report expected in May

Open Questions in Particle Physics

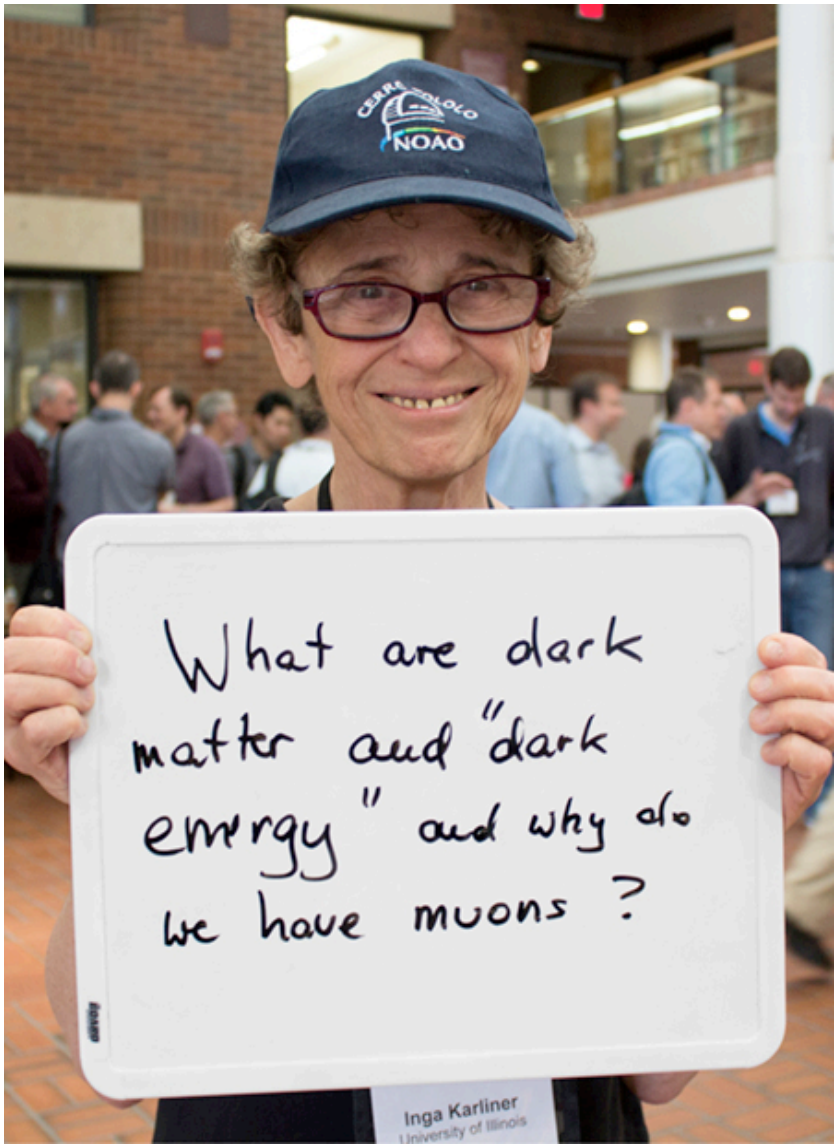


Robin Erbacher
University of California, Davis

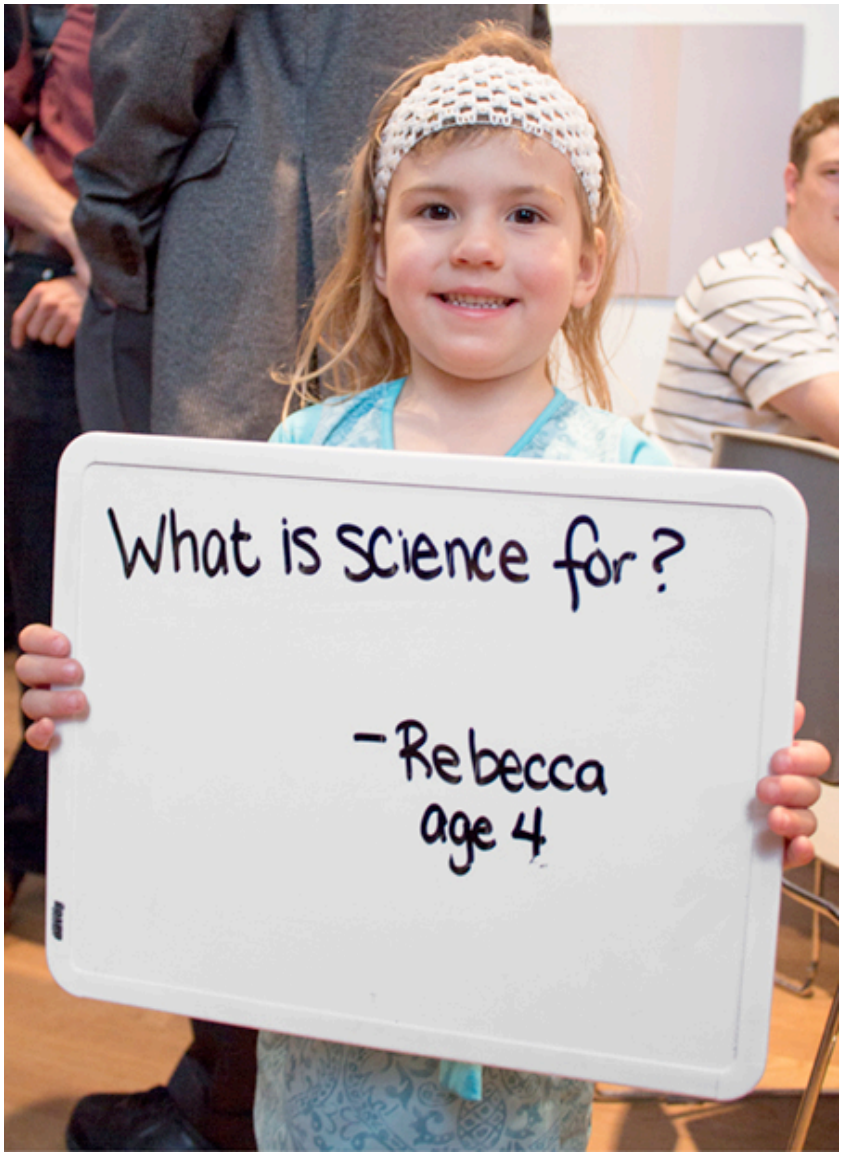


James Matthews
Louisiana State University

Open Questions in Particle Physics



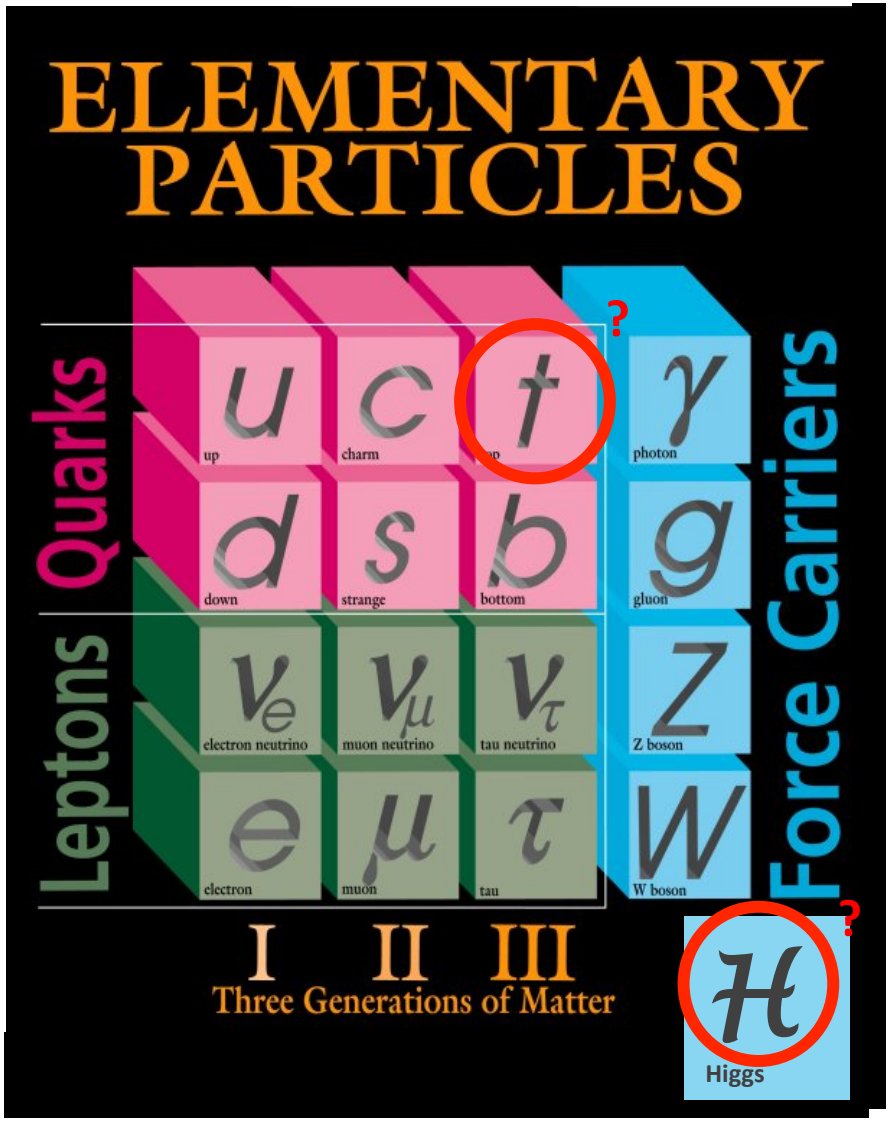
Inga Karliner
University of Illinois, Urbana-Champaign



Rebecca (age 4)

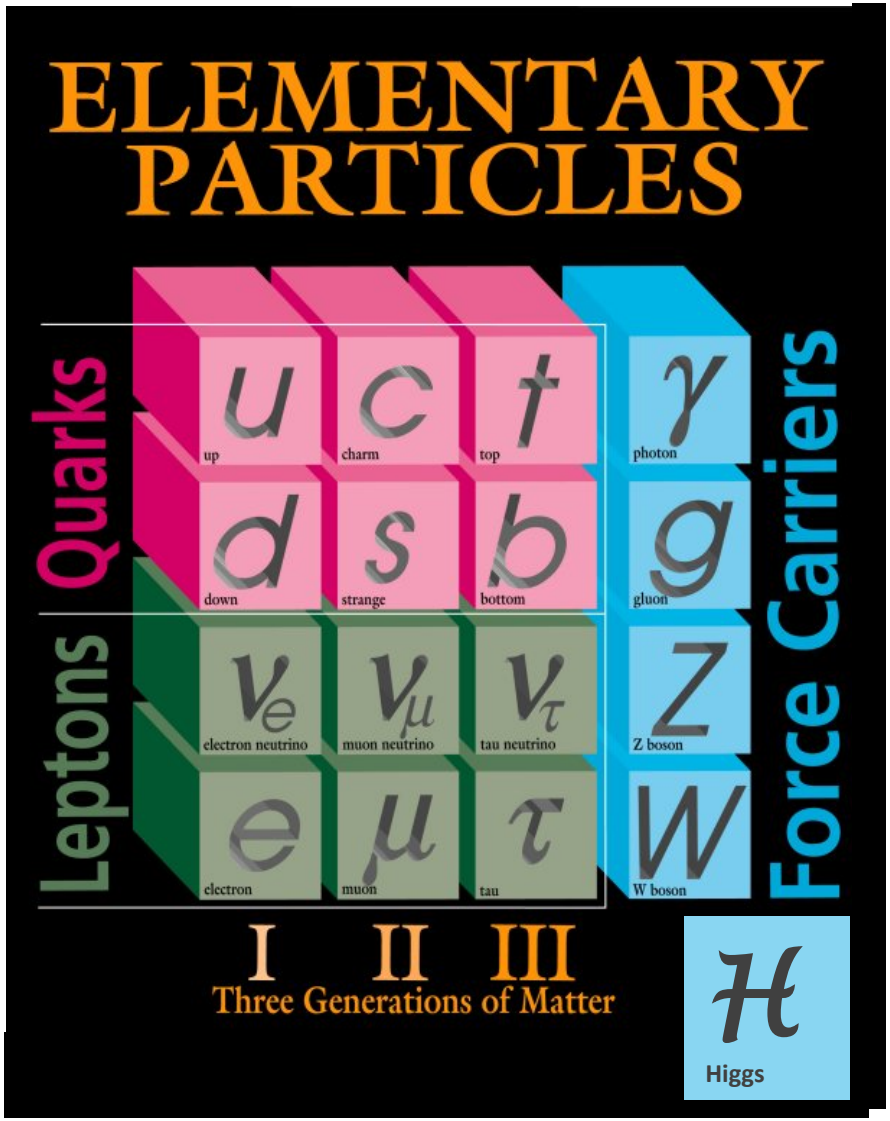
The Standard Model (~1994)

- Neutrinos in the 1994 Standard Model:
  - Three neutrinos with a conserved lepton flavour number.
  - Massless.
  - Strictly Left-handed.



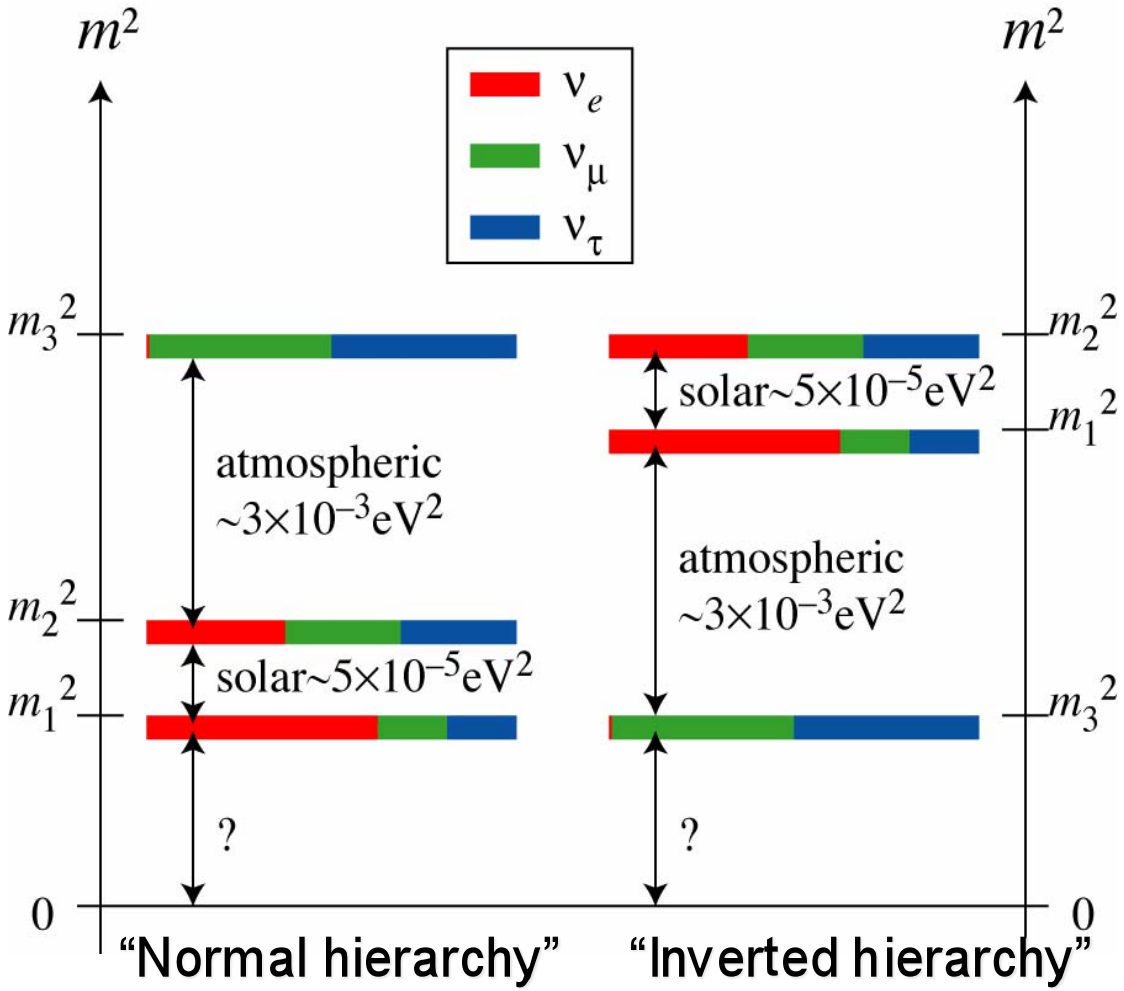
The Standard Model (Now)

- Neutrinos in the 2014 Standard Model:
  - Neutrinos have Mass!
  - Lepton number conservation?
  - Sterile Neutrinos?



Known and Unknown Properties of Neutrinos

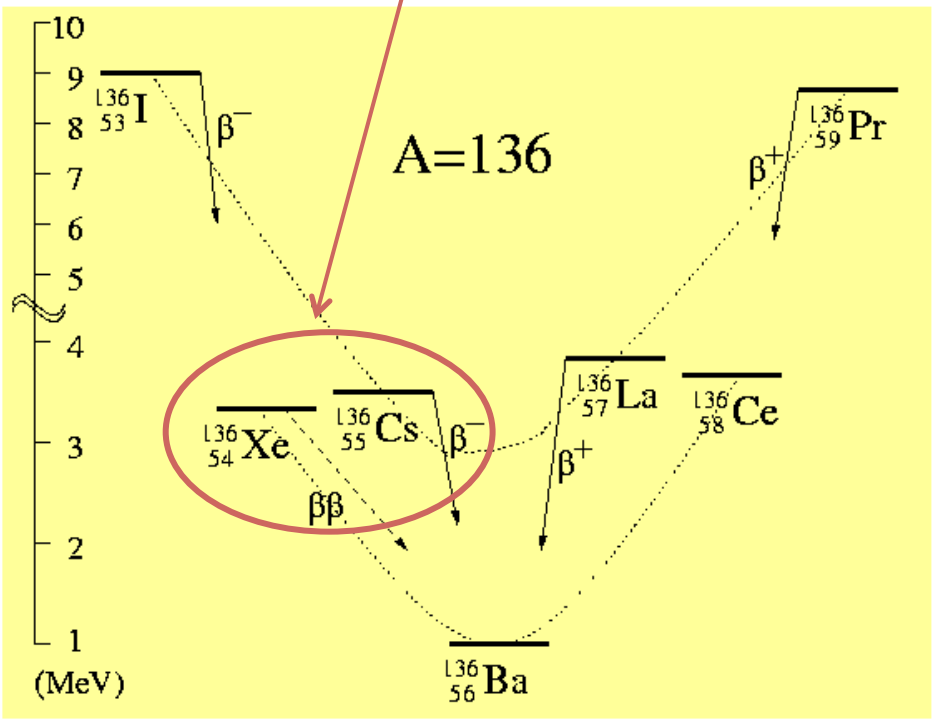
- Majorana particle, (i.e. its own antiparticle)
- Absolute mass scale of neutrinos.
- Mass hierarchy
- CP violation phase



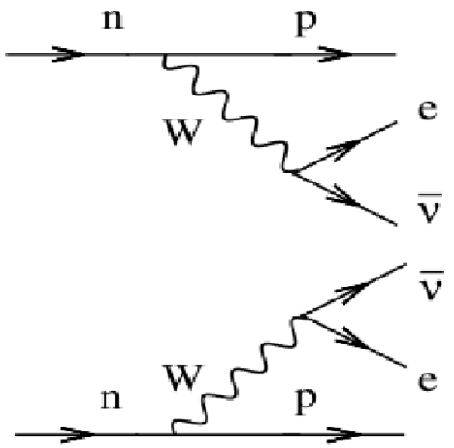
The search for neutrinoless double beta decay can shed light on the first three questions.

Double Beta Decay

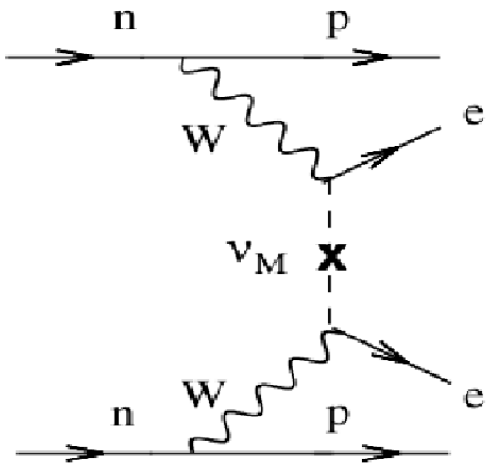
Observable if single beta decay is forbidden



Two neutrino double beta decay



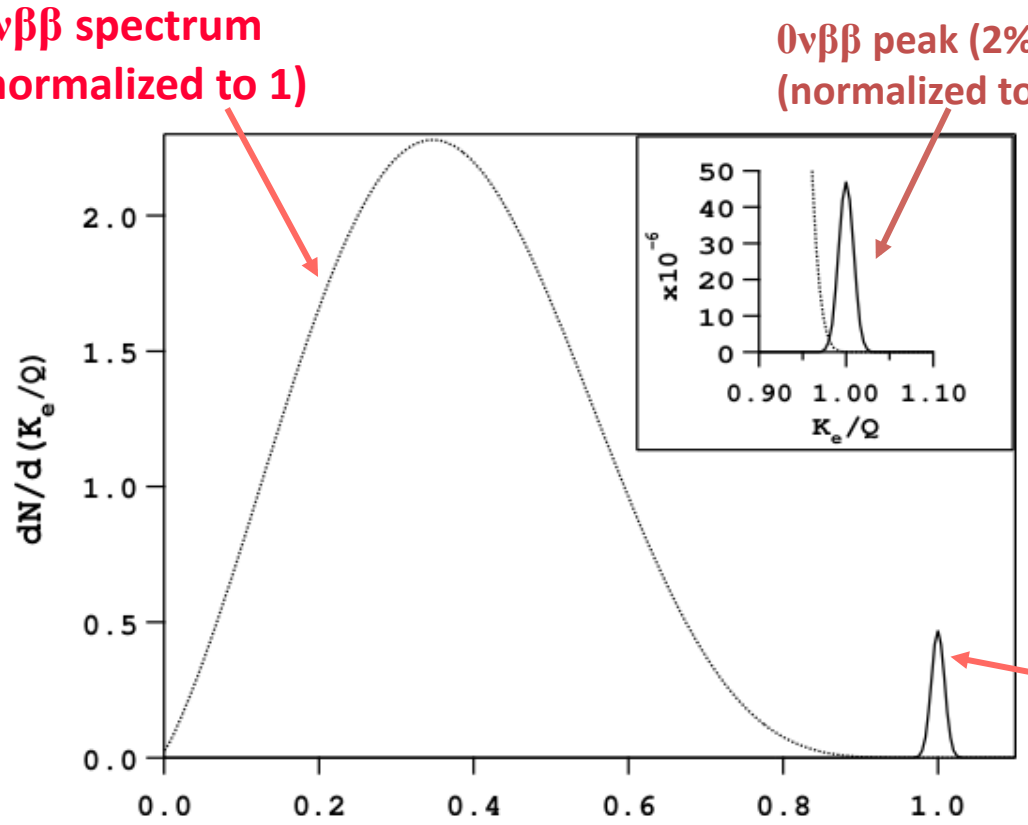
Neutrinoless double beta decay



Observation of $0\nu\beta\beta$:

- Majorana neutrino
- Neutrino mass scale
- Lepton number violation

Double Beta Decay Energy Spectrum



The two peaks can be separated in a detector with good energy resolution

[P. Vogel, arXiv:hep-ph/0611243]

Summed electron energy in units of the kinematic endpoint (Q)

If 0νββ is due to light ν Majorana masses

$$\langle m_\nu \rangle^2 = \left(T_{1/2}^{0\nu\beta\beta}\, G_{0\nu\beta\beta}(E_0, Z)\, \left| M_{0\nu\beta\beta} \right|^2 \right)^{-1}$$

$M_{0\nu\beta\beta}$ Nuclear matrix element

$G_{0\nu\beta\beta}$ Phase space factor

$T_{1/2}^{0\nu\beta\beta}$ Measured half-life

$$\langle m_\nu \rangle = \left| \sum_i U_{ei}^2 m_i\, \varepsilon_i \right|$$

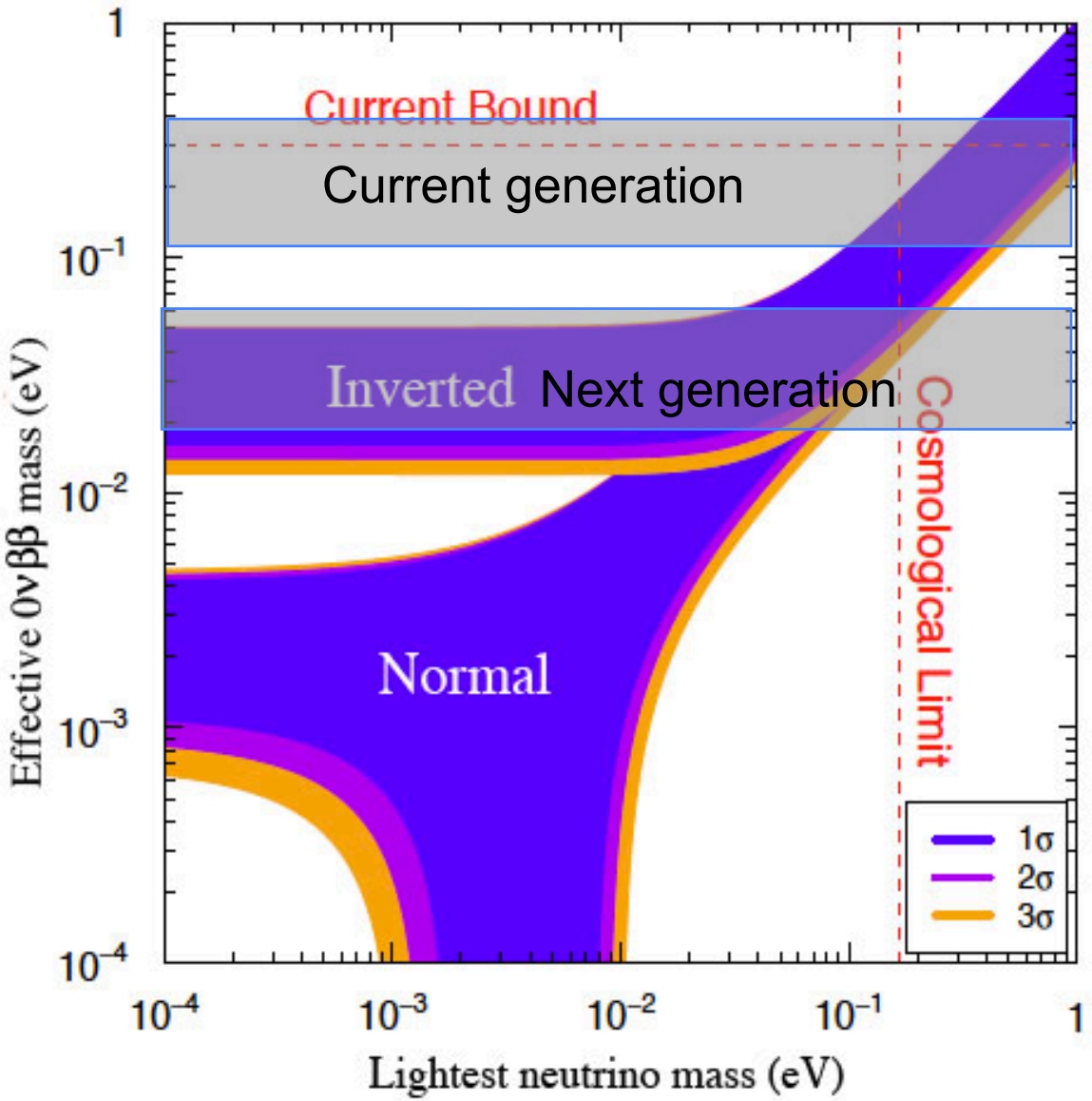
effective Majorana ν mass
($\varepsilon_i = \pm 1$ if CP is conserved)

Experimental Sensitivity to Neutrino Mass

Isotope Mass

10-100 kg

1-10 ton



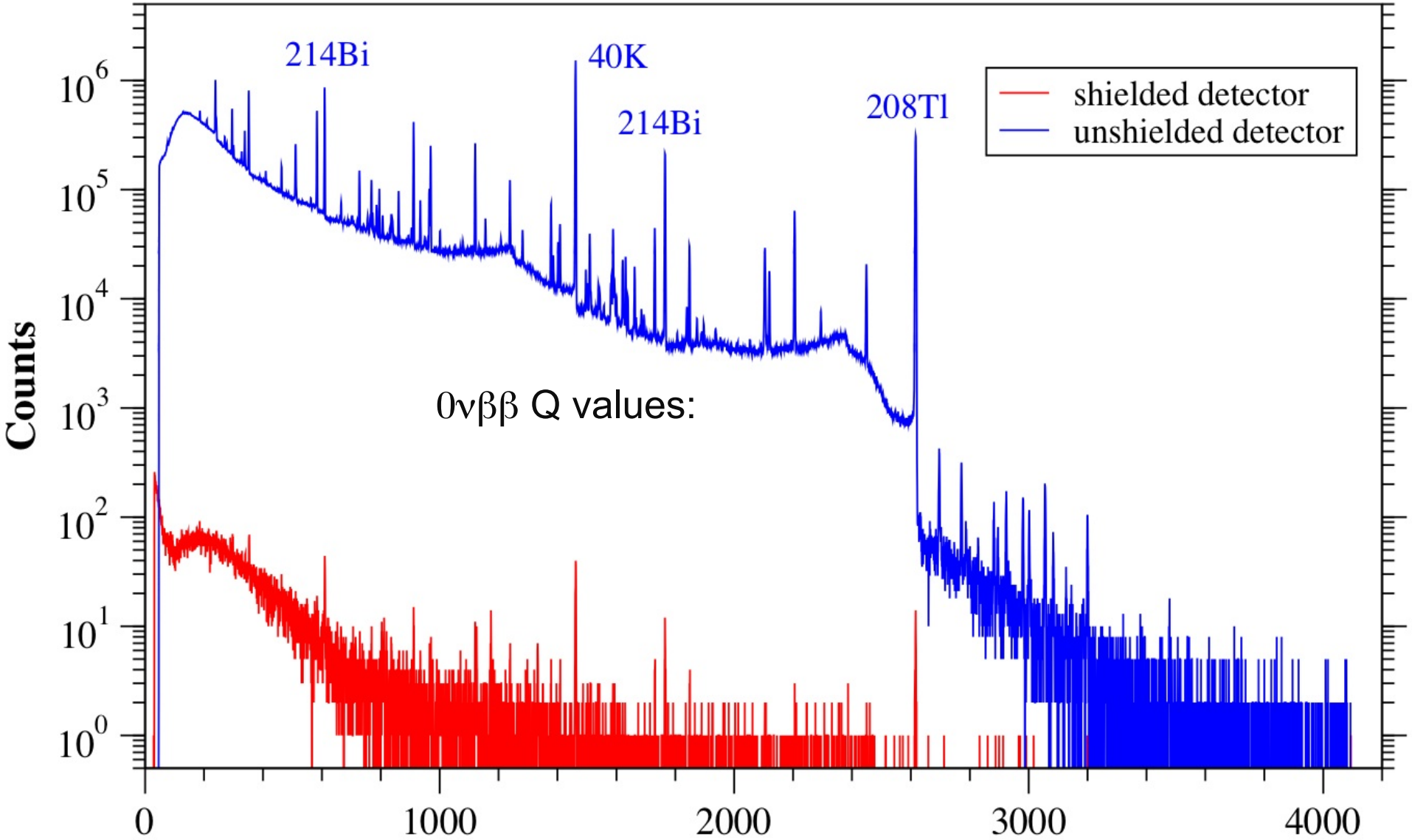
Background

10-100cts/yr/ton

0.1-1cts/yr/ton

arXiv:1203.5250v1

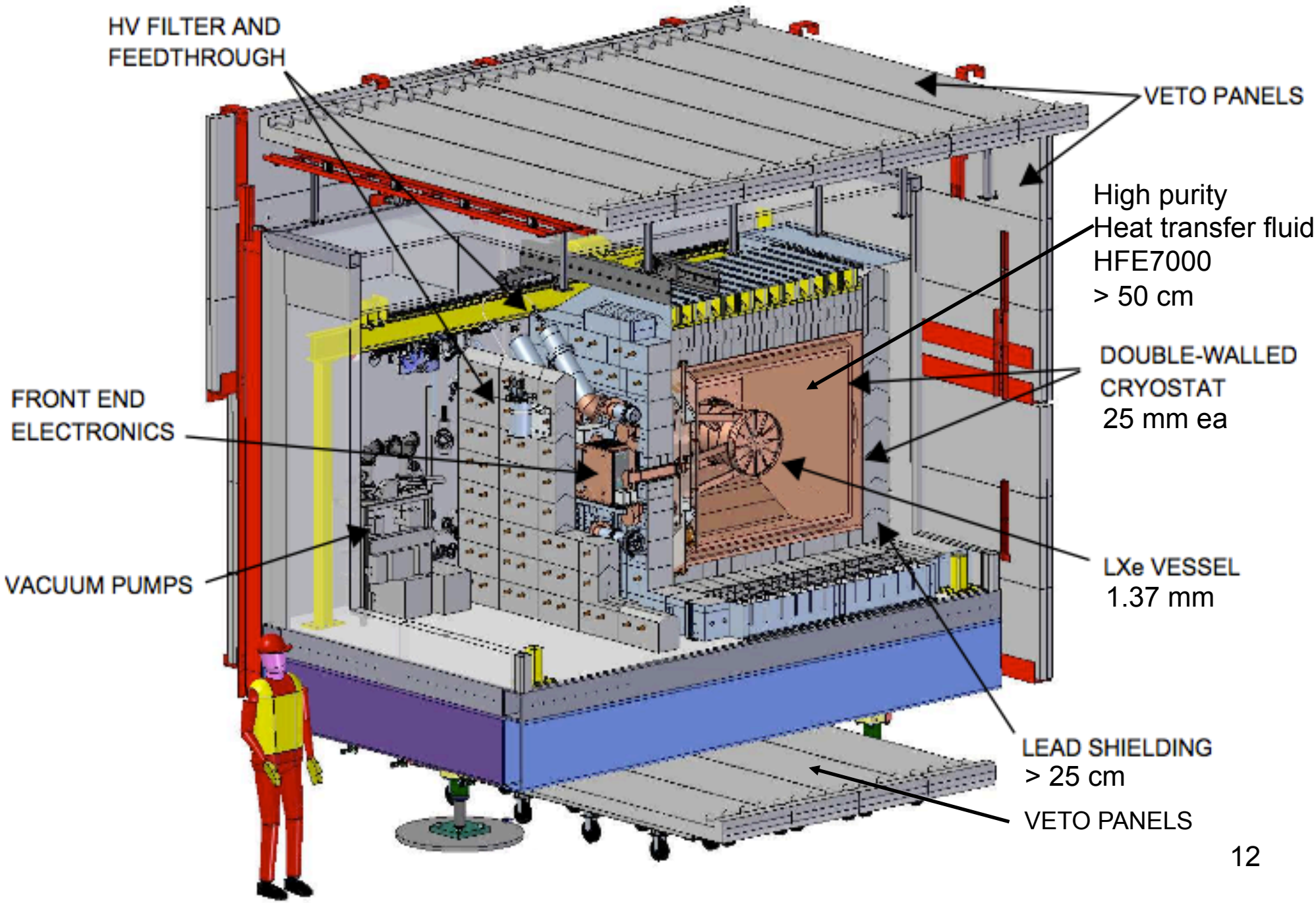
Energy Spectrum of Natural Radioactivity



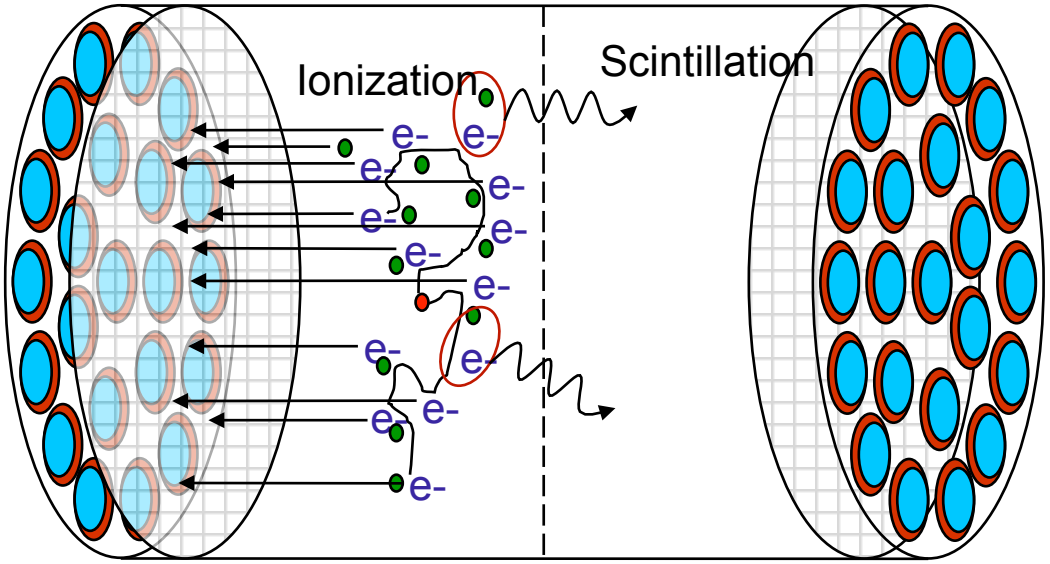
Although ^{40}K decay energy is below most $0\nu\beta\beta$ Q values, gammas from U and Th are big background concerns.

Source: http://npgroup.pd.infn.it/luna/images/background.jpg
C. Hall, SnowMass premeting, 2013

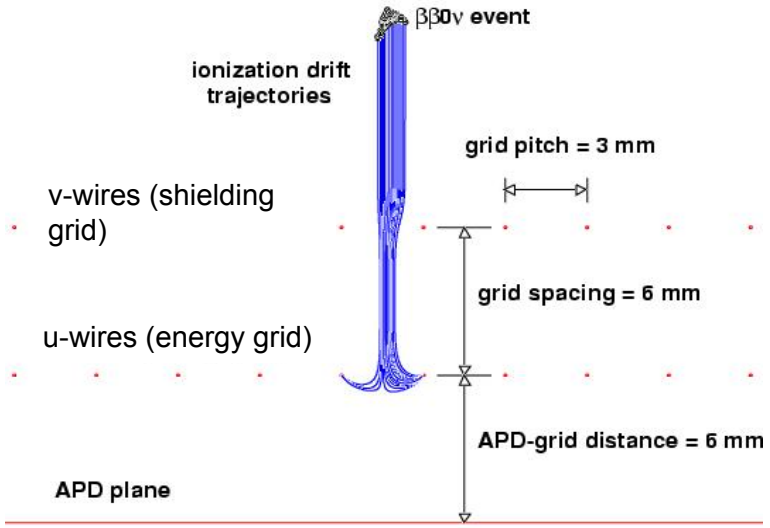
The EXO-200 Detector: Liquid Xenon TPC



EXO-200 Time Projection Chamber (TPC)



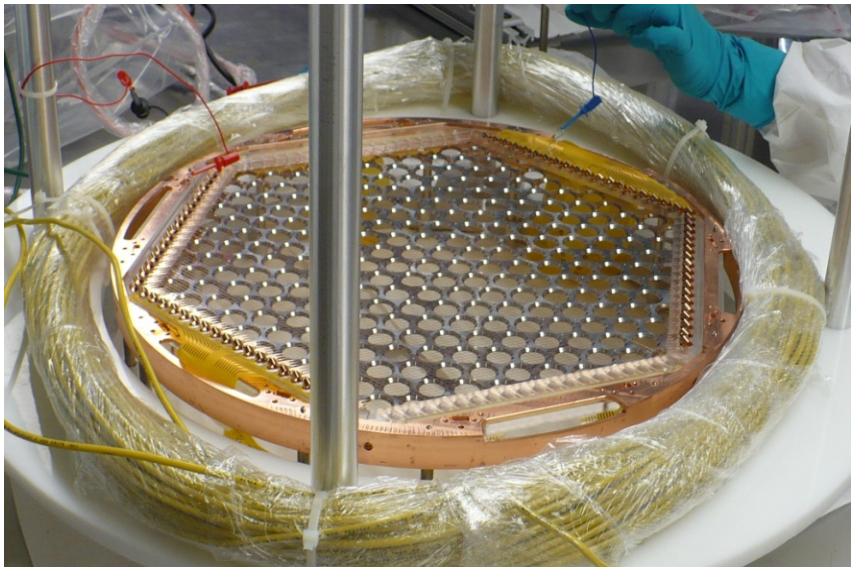
TPC Schematics



Simulation of Charge Drift

- Two TPC modules with common cathode in the middle.
- APD array observes prompt scintillation for drift time measurement.
- V-position given by induction signal on shielding grid.
- U-position and energy given by charge collection grid.

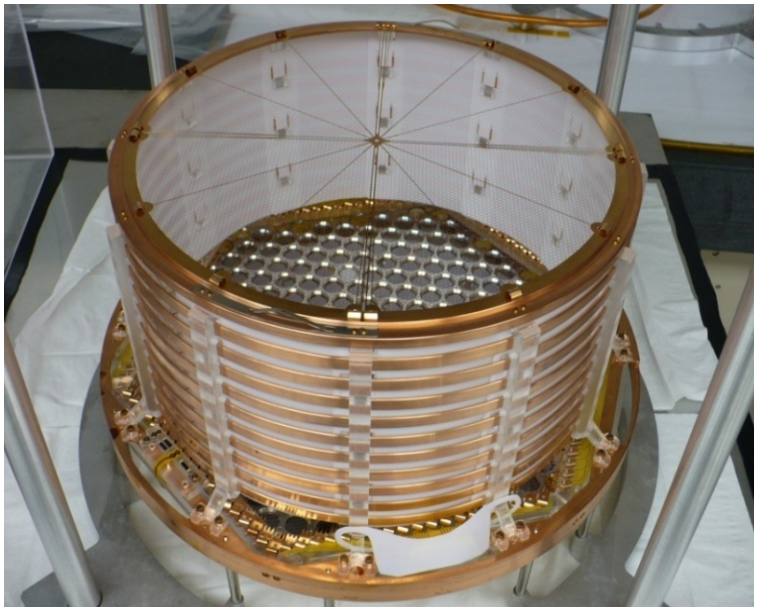
TPC Construction



Measuring wire tension

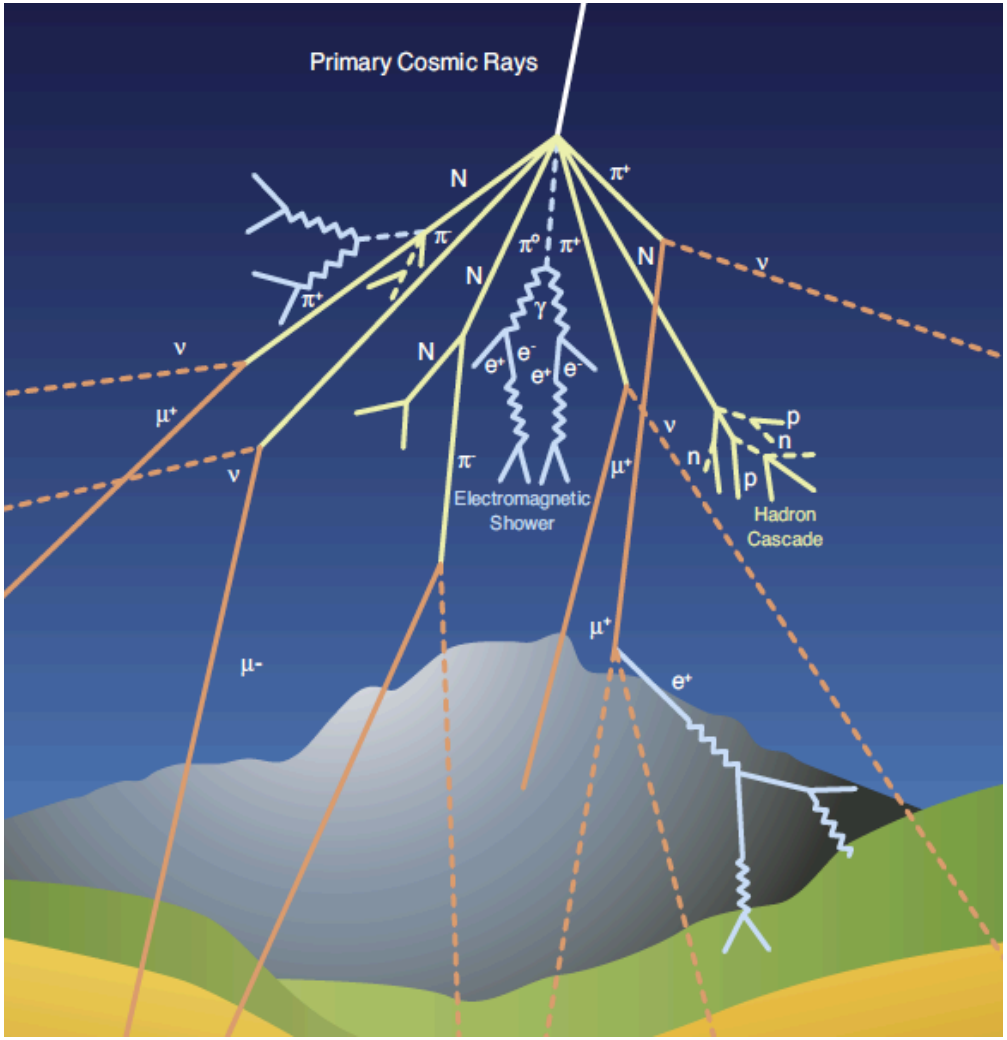
Installing field cages and teflon reflectors

Loading APDs



Completed TPC module

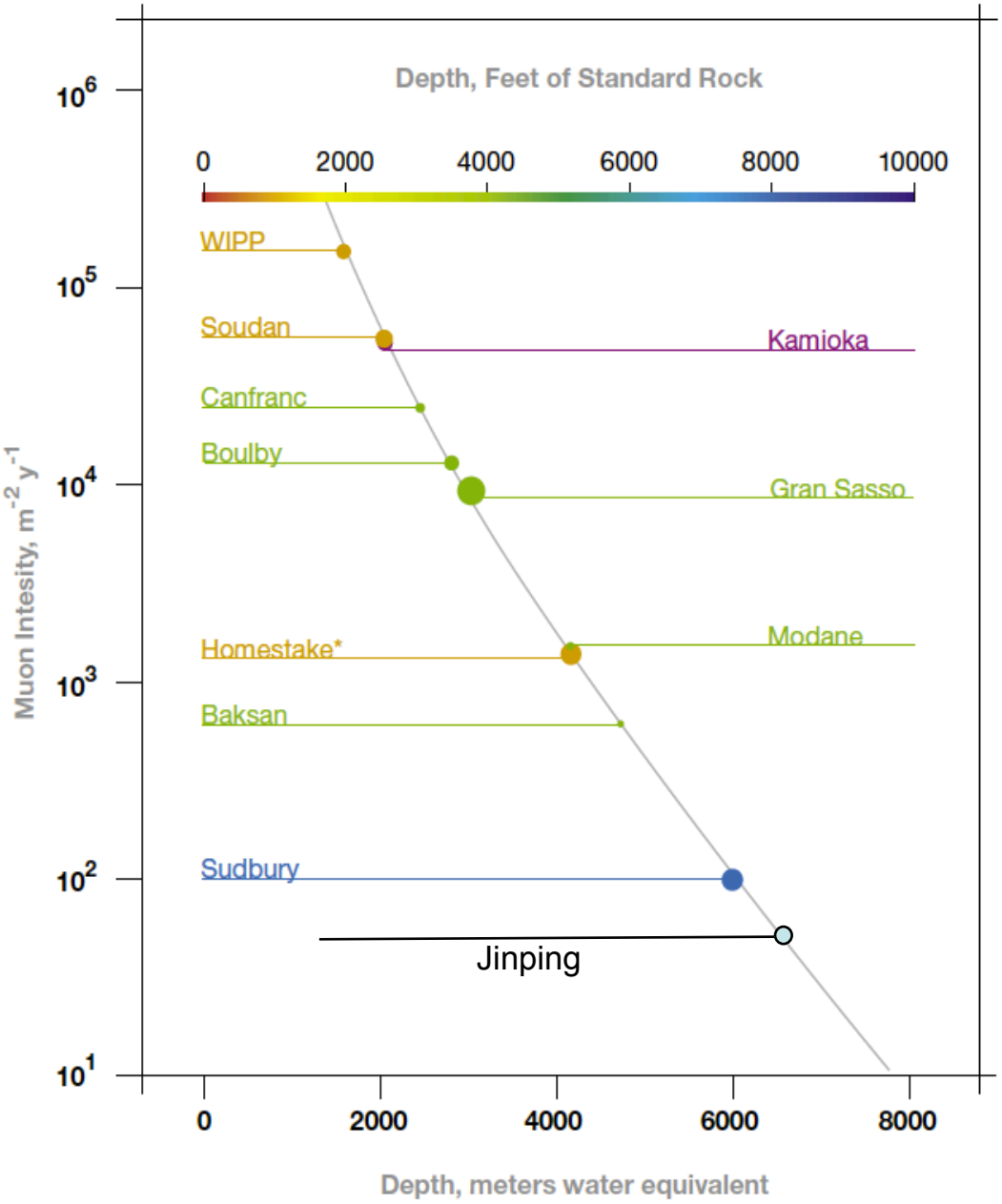
Cosmic Ray Background



Source: CERN

- Cosmic rays striking the upper atmosphere will create a shower of subatomic particles, including energetic muons,
- Cosmic muons can create radioactive isotopes via spallation, neutron activation and other nuclear processes.
- When muon goes through a detector, it can produce radioactive isotopes directly inside the detector.
- Muon can also produce secondary particles in material outside the detector such as fast neutrons, which later interact with the detector material.

Going Underground….

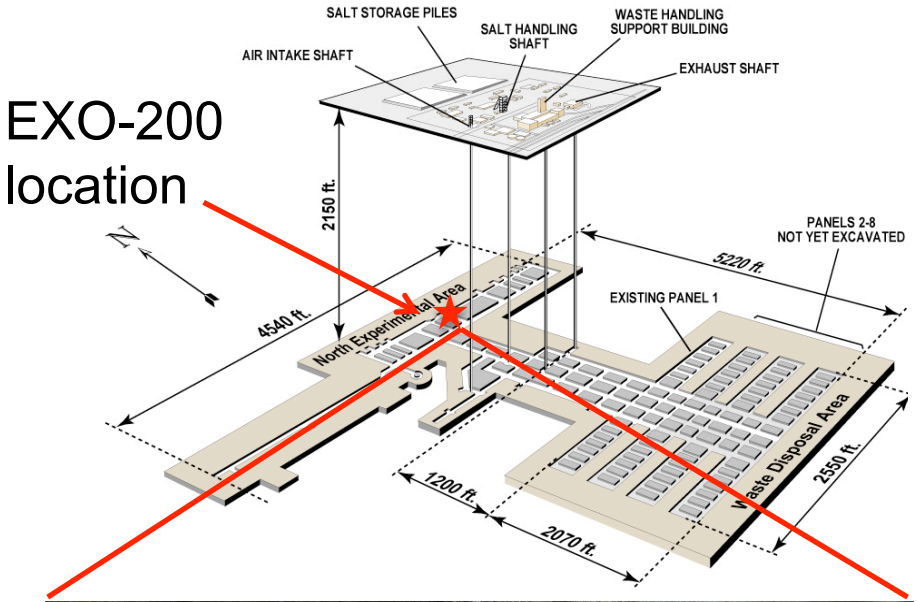


- By going to deeper underground lab, one can effectively shield against cosmic muons.

- At 6600 m.w.e., Jinping lab in Sichuan, China is the deepest underground lab, with a muon flux of ~50/m^2/yr, 9 order of magnitude reduction compared to sea level

- The muon angular and energy distribution depends on the depth, so Monte Carlo simulation is needed to understand the full background from the cosmic ray.

EXO-200 installation site: WIPP



- EXO-200 installed at WIPP (Waste Isolation Pilot Plant), in Carlsbad, NM
- 1600 mwe flat overburden (2150 feet, 650 m)
- U.S. DOE salt mine for low-level radioactive waste storage
- Cleanroom installed on adjustable stands to compensate salt movements.
- Salt "rock" low activity relative to hard-rock mine

$$\Phi_\mu \sim 1.5 \times 10^5\, yr^{-1} m^{-2} sr^{-1}$$

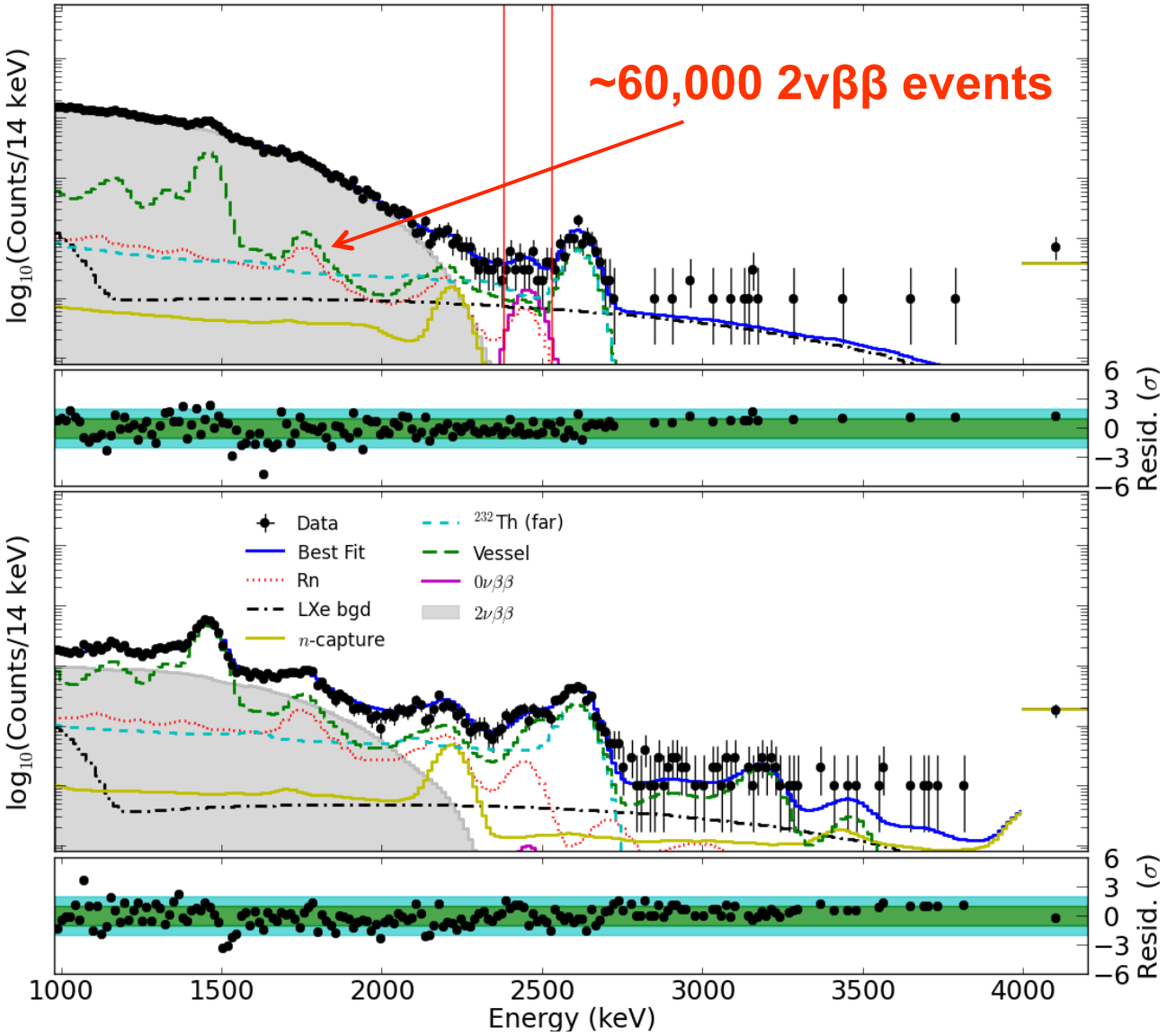
$$U \sim 0.048\, ppm$$

$$Th \sim 0.25\, ppm$$

$$K \sim 480\, ppm$$

Esch et al., arxiv:astro-ph/0408486 (2004)

Recent Result from EXO-200



Simultaneous fit to both energy and standoff distance

$T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25}$ yr (90% C.L.)

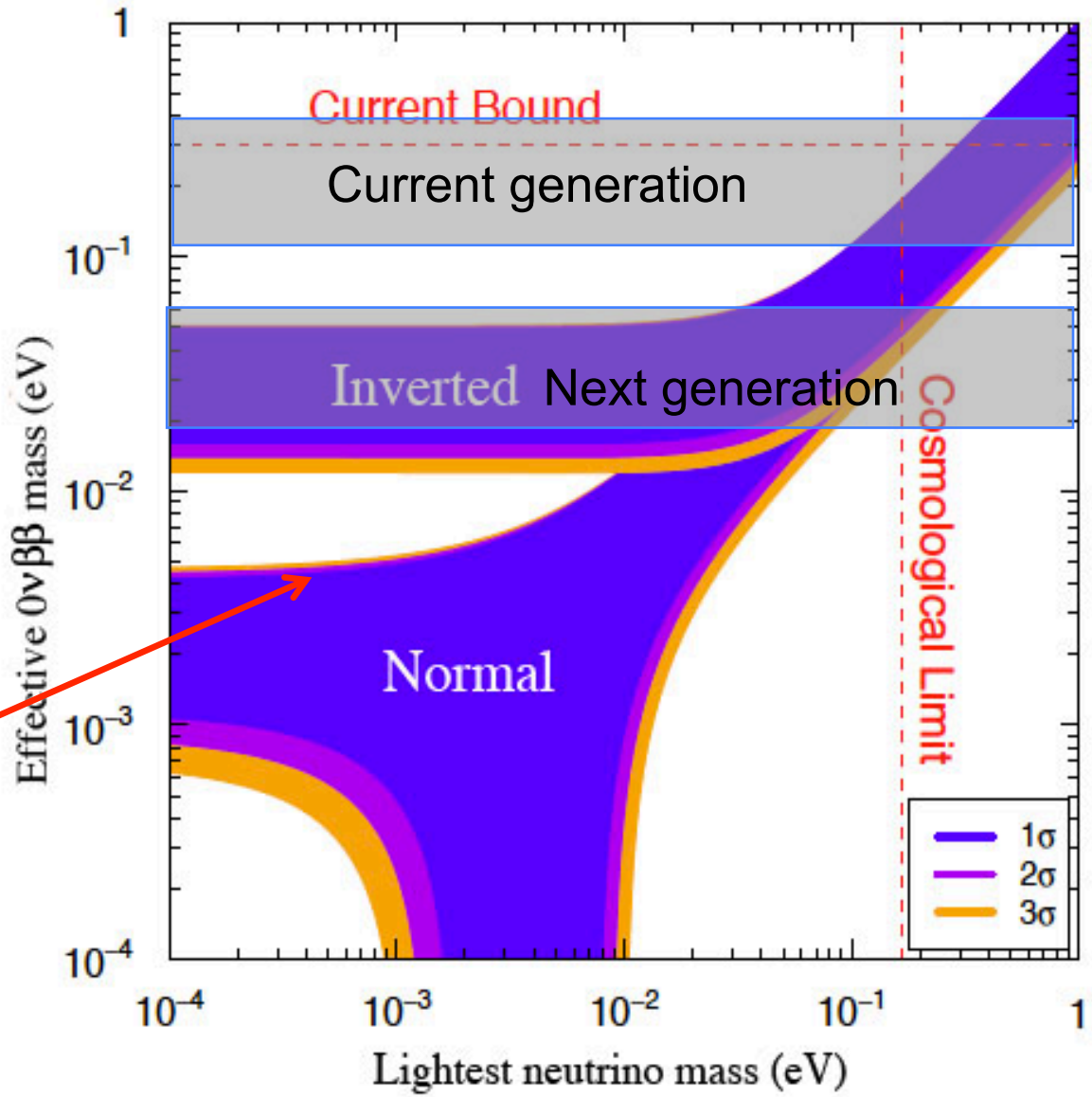
$\langle m_{\beta\beta} \rangle < 190 - 450$ meV (90% C.L.)

Experimental Sensitivity to Neutrino Mass

Isotope Mass

10-100 kg

1-10 ton



Background

10-100cts/yr/ton

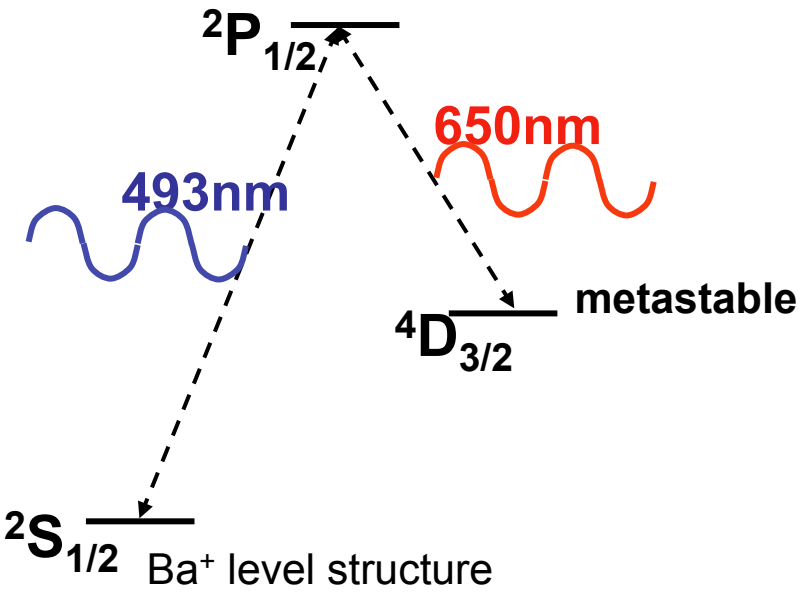
0.1-1cts/yr/ton

Can one probe the Normal Hierarchy region?

Need a background free experiment

arXiv:1203.5250v1

Barium Tagging

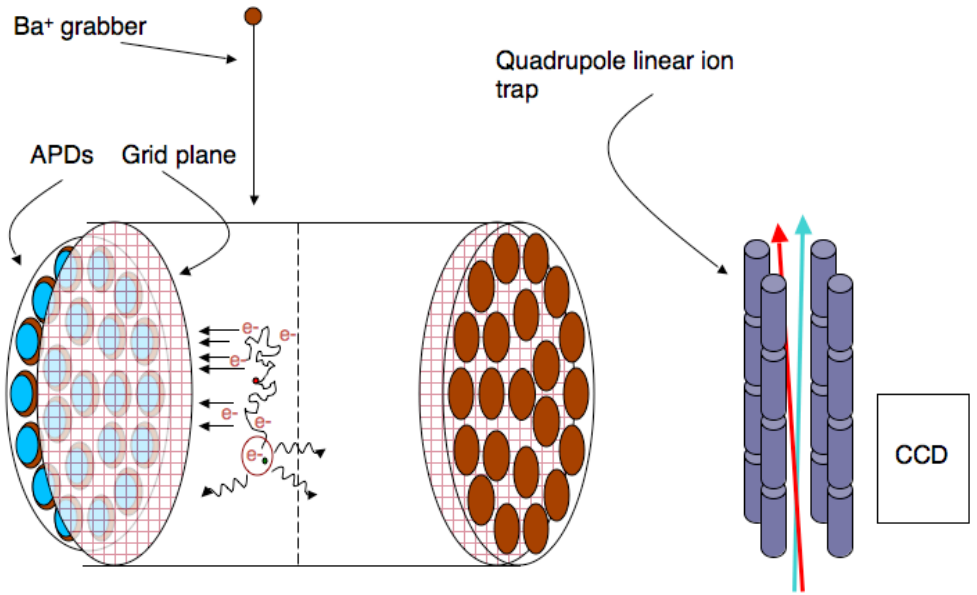


Ba^+ level structure

The ultimate sensitivity of double beta decay experiments are limited by the radioactive background, which one can eliminate by tagging decay daughter nucleus.

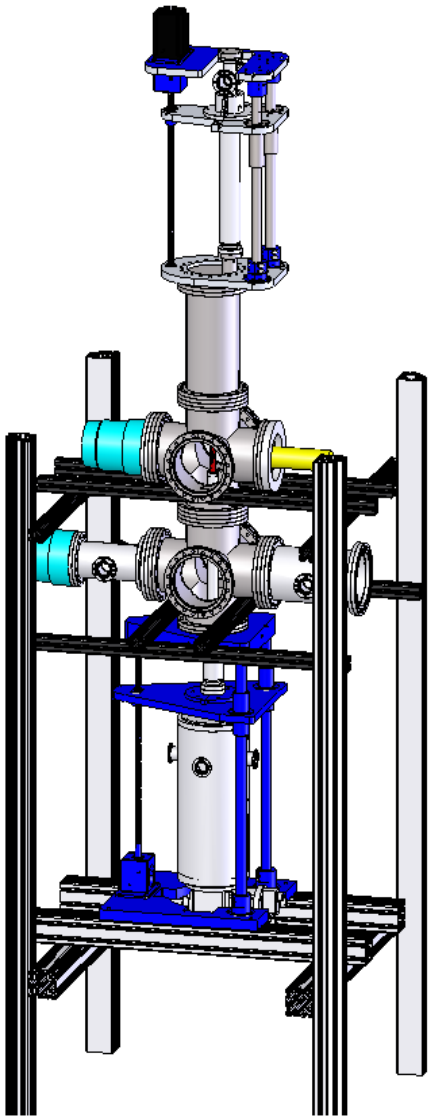
But, can one find and detect a single Ba ion in thousands kilograms of liquid Xenon?

We work on ideas to achieve this difficult task.



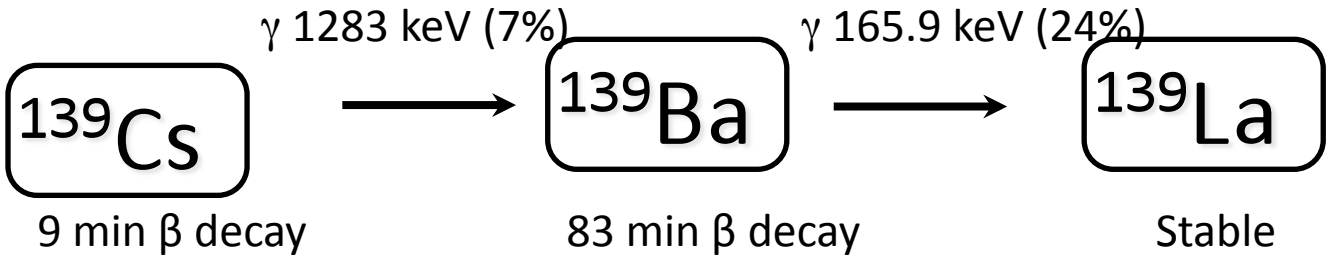
One proposed barium tagging scheme

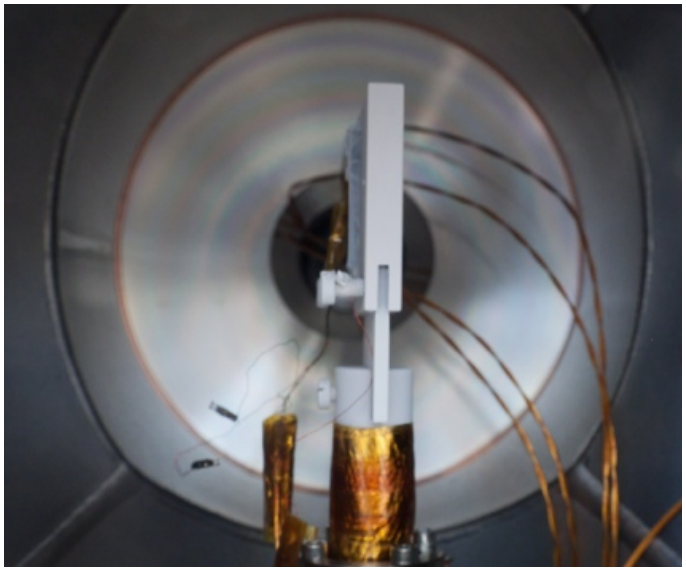
Study Barium Ion Transport



TUM apparatus at Argonne

CARIBU beam at Argonne National Lab can provide nice radioactive beams of Cs-139 or Ba-139





Xe Ice on Electron

- Study neutralization of Ba in Xenon Ice.
- Study of desorption of Ba from surfaces.
- Produce single Ba source in liquid cell to demonstrate efficiency of tagging.

What can Neutrino tell us about the Universe?

- What role did neutrino play in the evolution of the universe? (~ 4% mass of the universe, absolute mass scale? Number of species? … double beta decay experiment, tritium decay experiment, sterile neutrino search…)
- Can neutrino be responsible for the matter and anti-matter asymmetry? (CP violation phase? … long baseline neutrino experiment)
- Neutrino might be the best probe deep into the universe (IceCube…)
- Supernovae neutrinos, relic neutrinos…