LUX: The next stage(s)
Multi-tonne LXe TPC’s
(DM08, Marina del Rey, 21 Feb 08)

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(Supported by US DOE HEP)

see information at

http://particleastro.brown.edu/
http://luxdarkmatter.org

“TELL US SOMETHING WE DON’T KNOW”

- Thanks
  - My thanks to Simon Fiorucci (pd), Luiz de Viveiros (grad), Peter Sorensen (grad), Carlos Hernandez Faham (grad) and David Malling (grad) at Brown
  - Plus input/experience of many of my collaborators incl. Tom Shutt, LUX and XENON10

- Advertisements
  - S4 DUSEL / Dark Matter Working Group Meeting
    - TODAY 6.30 pm / immediately after close of this meeting
      - Tiki Room of Best Western- Jamaica Inn - 250 m along Admiralty Way from this hotel
        - (Food will be available for purchase during meeting)

  - http://dmtools.brown.edu
    - Beta version of new plotter now available. Give it and try and send us feedback

LUX & Related DUSEL R&D Projects

- Xe Purification
  - Gas Recirculation / Heat Exchange incl. latent heat of vaporization ~80% of energy
  - Liquid Recirculation
  - Effect on Electron Drift / Photon Transparency / Radioactivity
- Cryostat Construction
  - Baseline: Copper with Regular stainless flanges (shielded)
  - Low Activity Stainless (Screening programs Borexino/Gerda highlighted availability)
  - Titanium
- Cryostat Cooling
  - Suitable for large masses / safety fall back intrinsic
- Watershield
  - Very effective for γ and n / Suitable for large scale deployments / 2 m water is equiv to >1700 ft in depth* /
- Photodetectors
  - LUX Baseline from R8778 ø2.25” PMT (Hamamatsu).
  - Future - incremental program: Screening / Reduction in component contributions to stainless / quartz PMTs
  - QUPID (see Arisaka Talk) - goal very significant improvements in background (factor >50)
- Electronics .....
- .....

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LUX IS R&D FOR THE MULTI-TONNE DETECTOR

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LUX IS R&D FOR THE MULTI-TONNE DETECTOR

Goal is also to improve sensitivity by x100 vs existing measurements

QUESTIONS

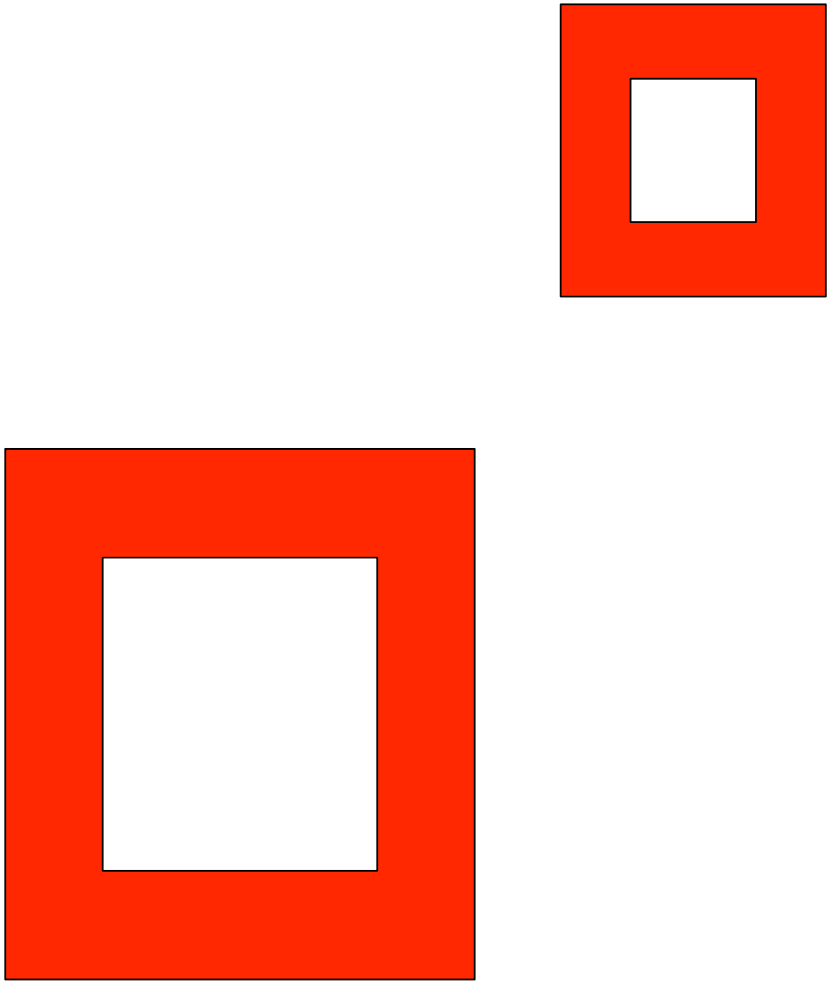
- Surely we need to reduce the level of gamma and neutron backgrounds from cryostat/photodetectors as dark matter sensitivity (and detector scale) increases?

- Intrinsic Radioactivity Backgrounds - these will invalidate self shielding projections?

- Light Collection - how much worse will primary scintillation light collection be as detectors scale?

- We seek zero background and some signal !! in a fiducial volume

- If we want to improve WIMP cross section sensitivity by a factor 10 then we need
  - Background per time per mass to be 0.1x
  - Fiducial Mass to be 10x larger
    - otherwise we will need to count 10x longer (not a good discovery strategy)
  - So total background event # per time over entire detector fiducial is ~ same

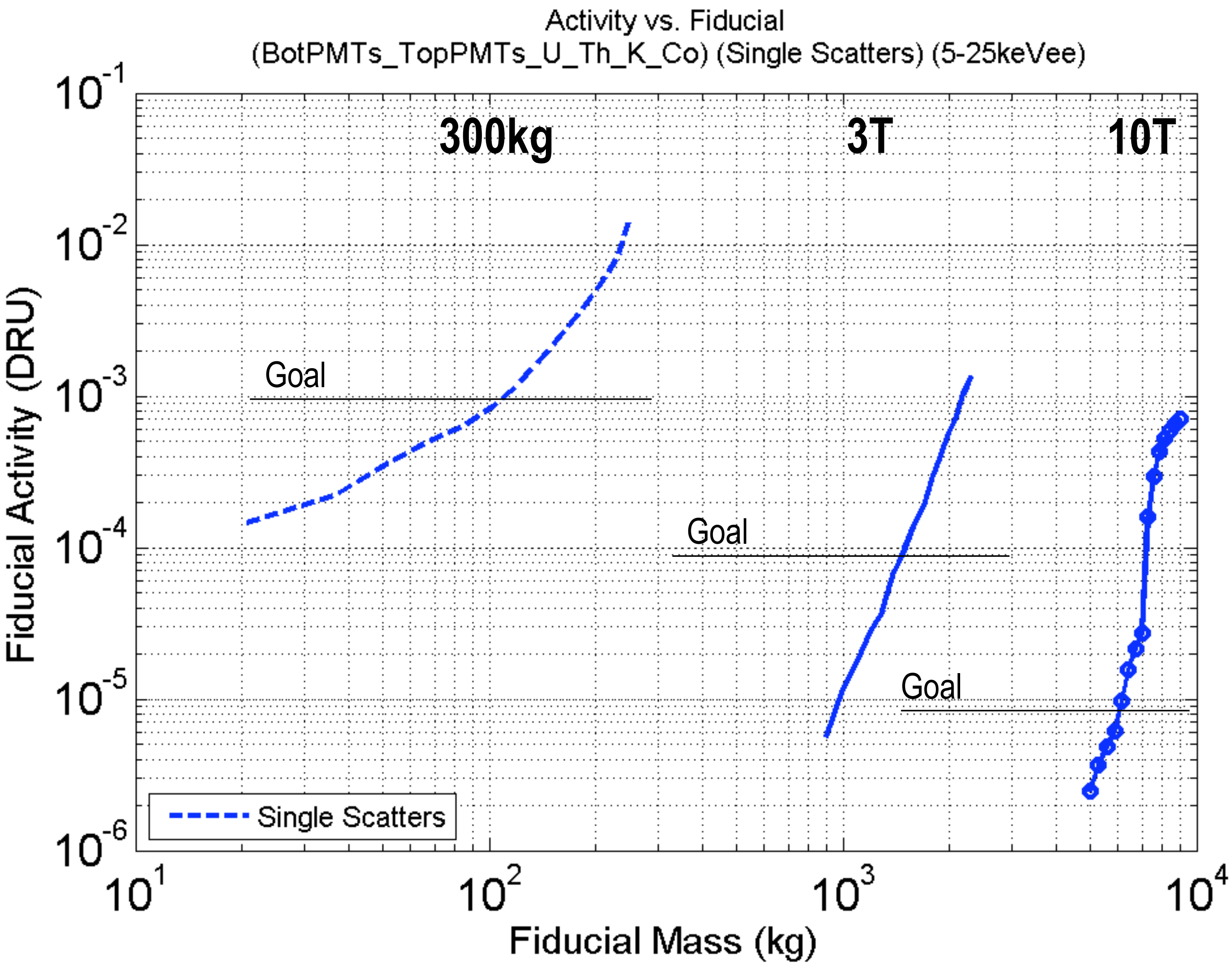


Assumptions in Projections (Baseline)

- Following Monte Carlos use a very conservative (i.e. high) assumptions about external radioactivity at the top and bottom boundary of the Xe target representing location of photodetectors
  - ~20 / 20 / 30 / 10 mBq (U238 / Th232 / K40 / Co60) per 4 sq. inch area
    - e.g. On LUX ø2.2” R8778 screening to date showing all PMTs contribute gamma at <~0.5x this level
  - Gamma (Electron Recoil) Rejection assumed at a flat 99.4%
  - Neutron emission is set at a level of 5 n/year per 4 sq.inch area. This is an upper limit based on pessimistic assumption of distribution of U/Th in lighter A materials with higher (alpha,n) neutron yields. U fission as neutron source is subdominant/vetoed.

- As the size of the detector is scaled from a gross mass of 300 kg (LUX) to 3 tonne to 10 tonnes
  - Let us assume that there is no improvement in the photodetector radioactivity per unit area
    - This is clearly a worst case assumption since we should expect improvement in photodetector radioactivity per unit area, however, it serves as a good reference

Gamma Activity vs. Fiducial Mass



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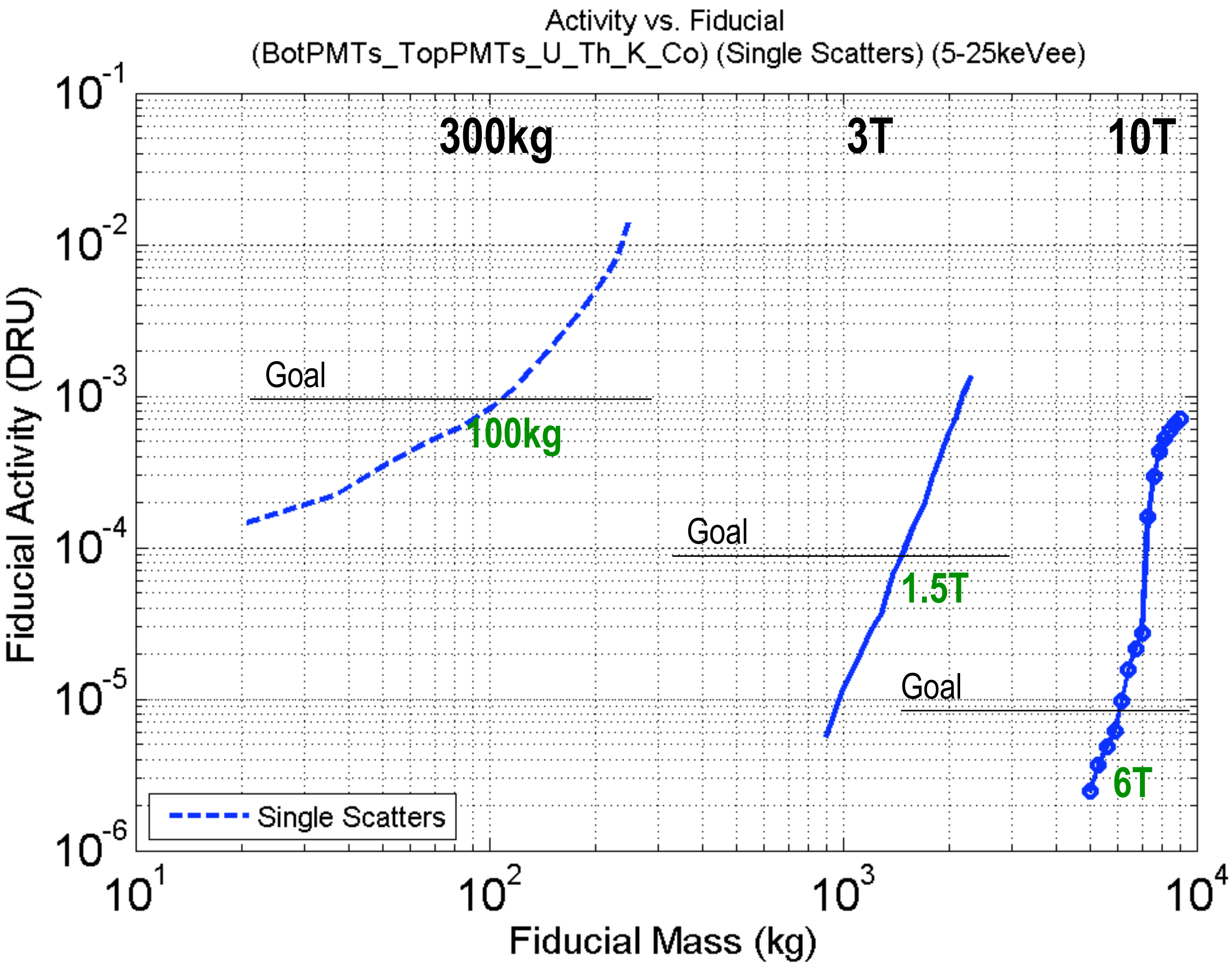
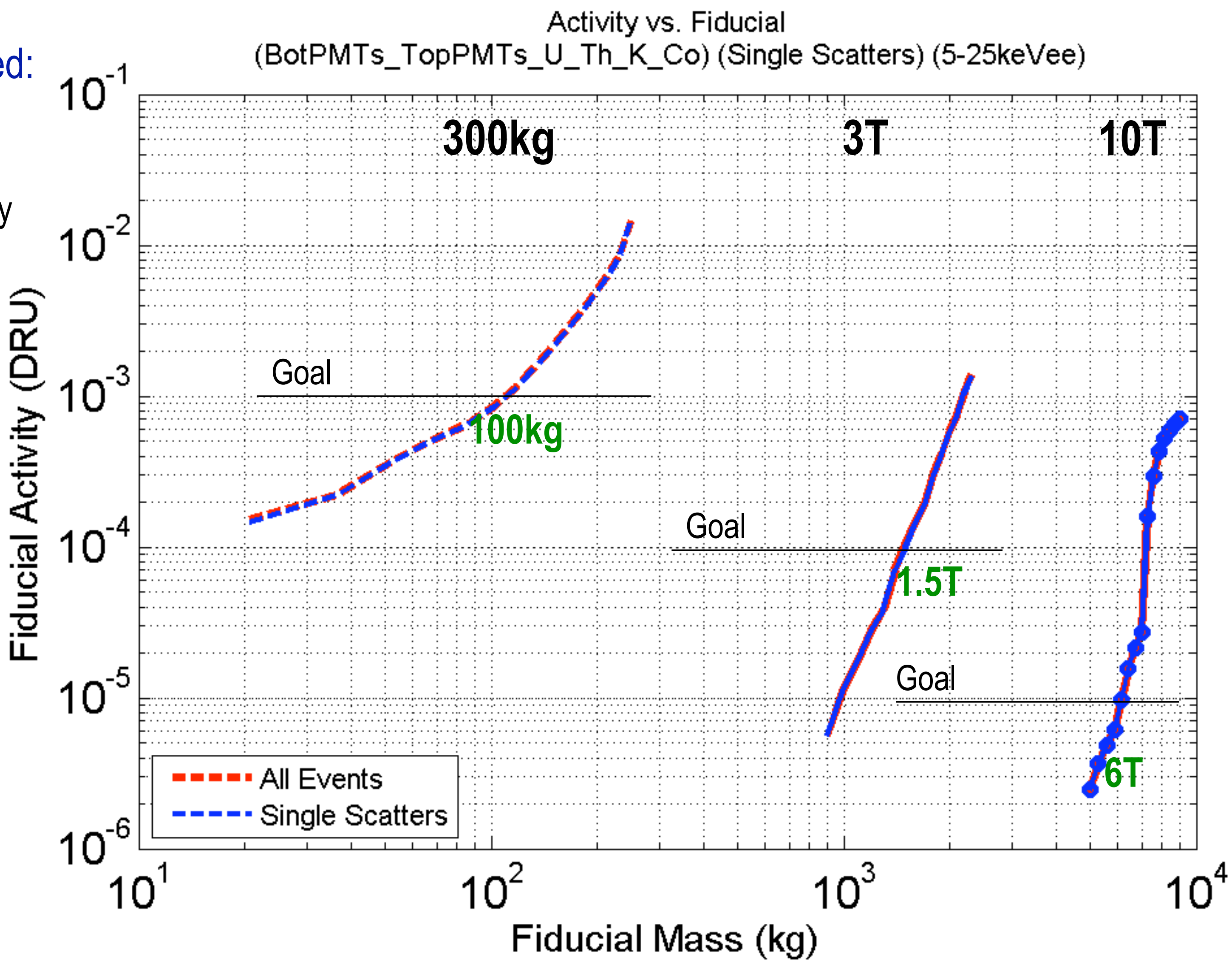


Gamma Activity vs. Fiducial Mass

- For each detector, two lines are plotted:
  - All Fiducial Events (Red)
  - Single Scatters Only (Blue)



Gamma Activity vs. Fiducial Mass

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  - All Fiducial Events (Red)
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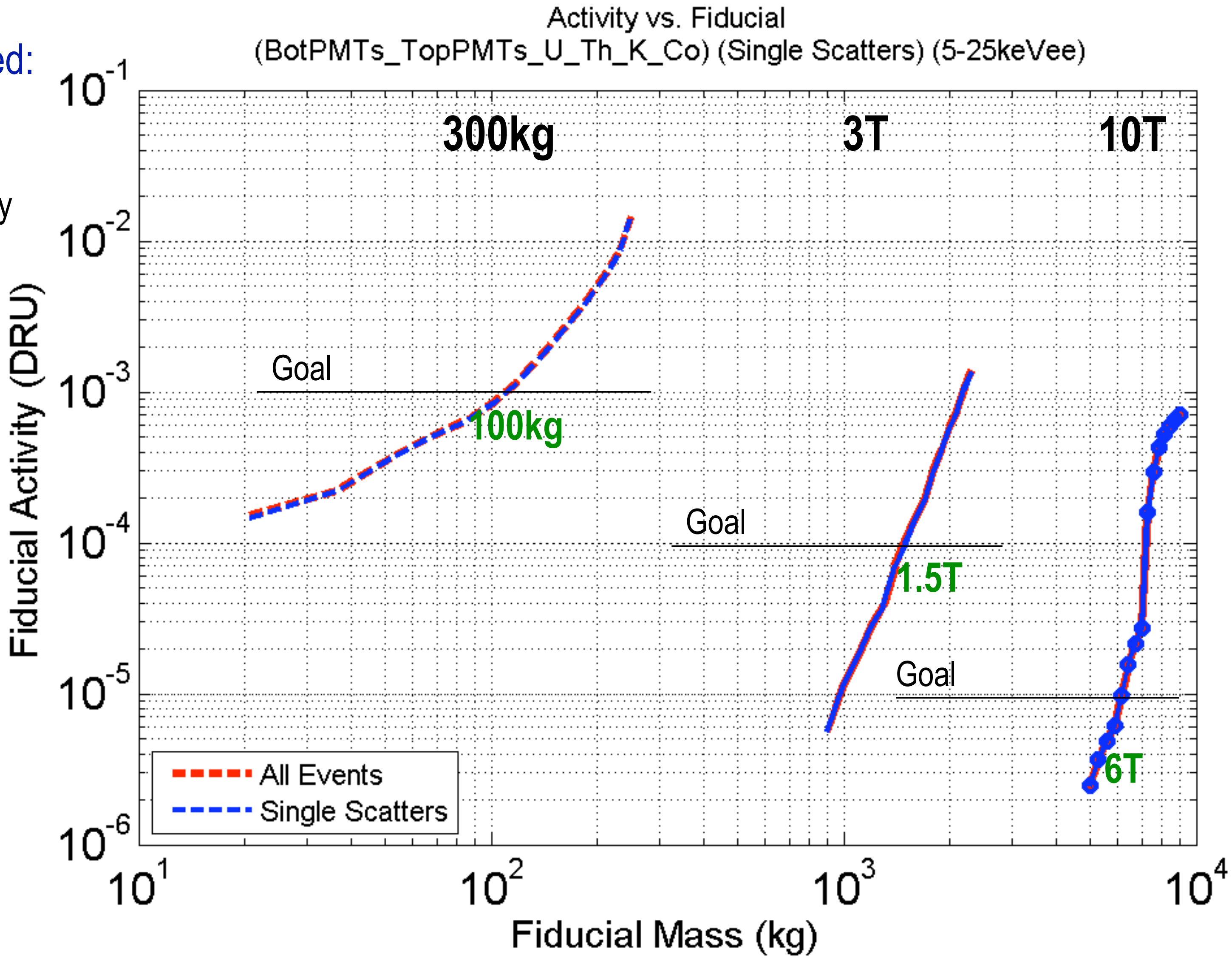
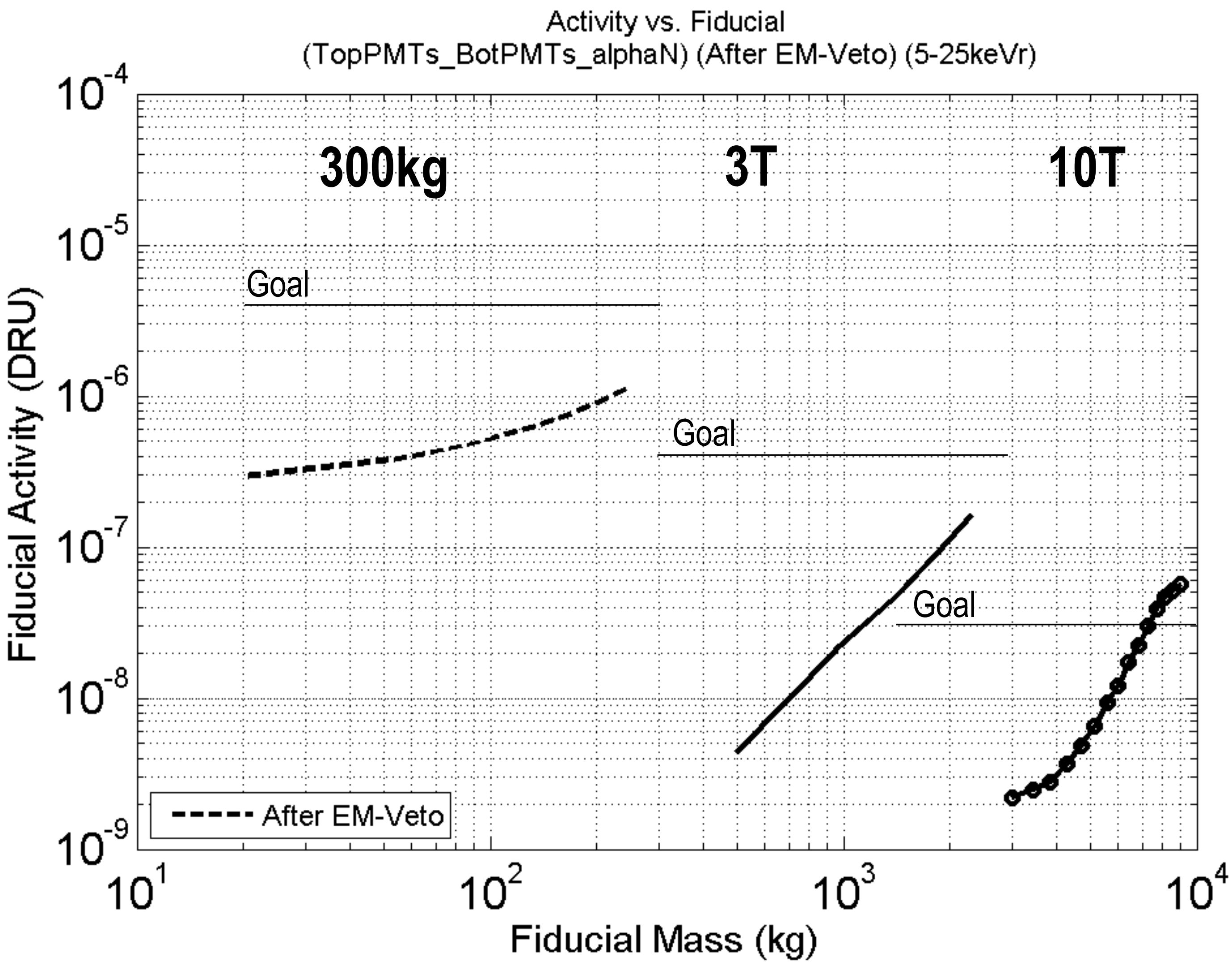
Vast majority of multiple scatters are already vetoed because their total energy is above region of interest for dark matter

Single Phase - XMASS and DEAP/CLEAN can use this as long as fiducialization cuts are good

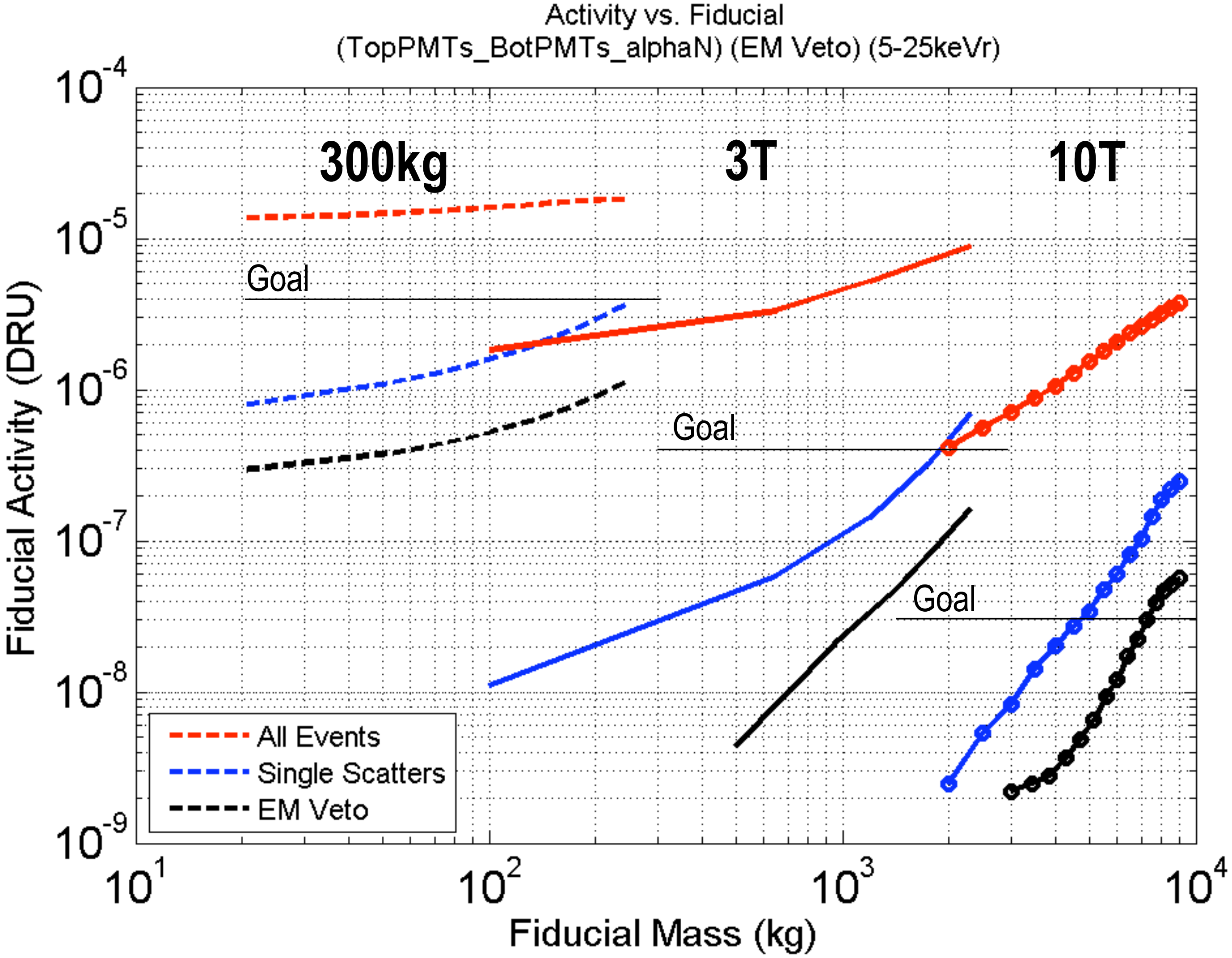


Neutron Activity vs. Fiducial Mass



Neutron Activity vs. Fiducial Mass

- For each detector, three lines are plotted:
  - All Fiducial Events (Red)
  - Single Scatters Only (Blue)
  - Single Scatters, after EM-component Veto (Black)



Neutron Activity vs. Fiducial Mass

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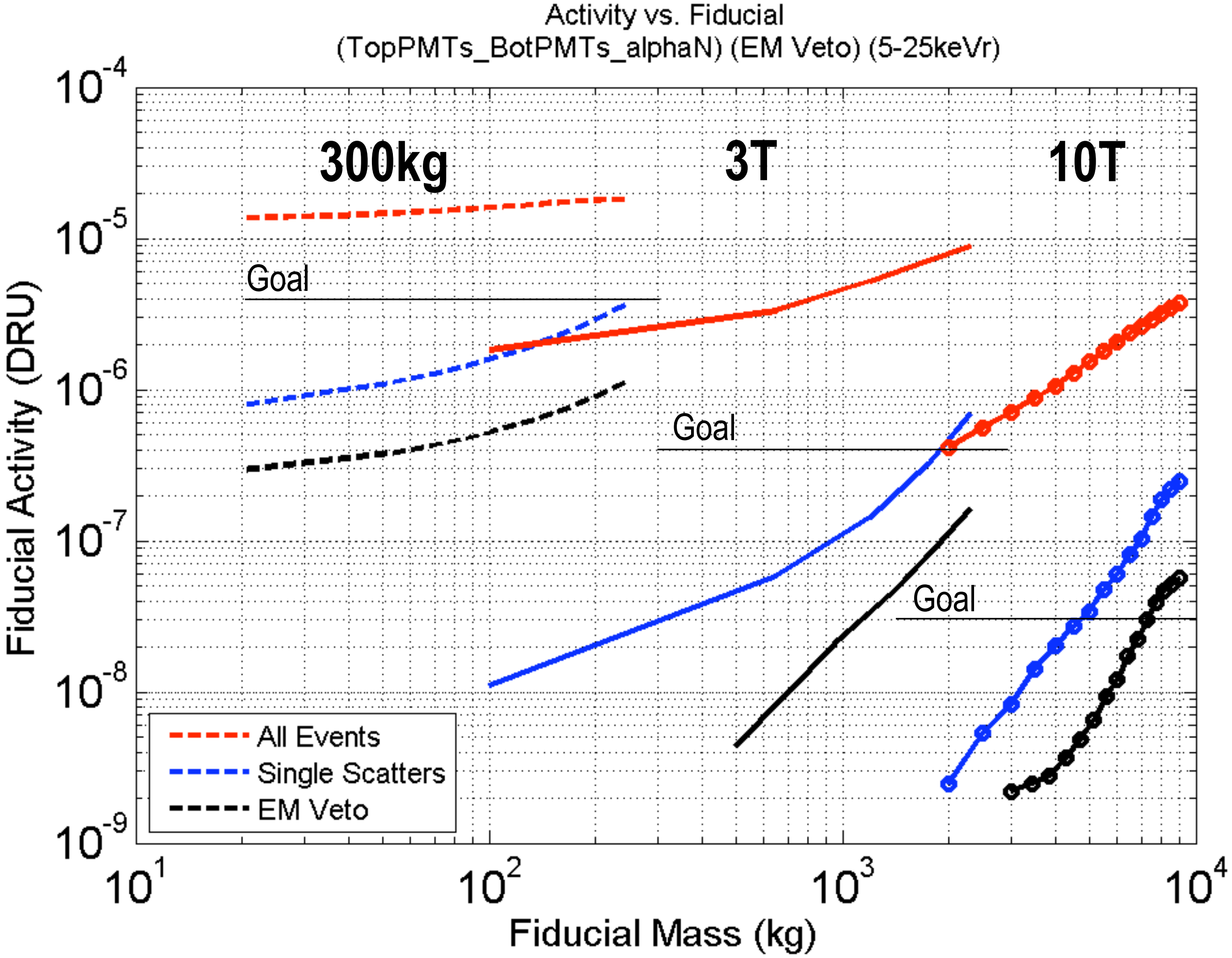
Neutrons reduced by factor 20x using multiple vertex cut

Single Phase - XMASS and DEAP/ CLEAN cannot exploit this well for low energy neutrons, so must work much harder on n activity



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- Intrinsic Radioactivity Backgrounds - these will invalidate self shielding projections?

- Light Collection - how much worse will primary scintillation light collection be as detectors scale?

Possible Intrinsic Activities

- Must Consider Source of Radioactivity that are “inside” LXe
  - ^{85}Kr
  - U/Th/Rn
  - Atmospheric gases
  - Cosmogenic activation of Xe
  - ^{3}H
  - ^{40}K
  - ^{14}C
  - ^{136}Xe $\beta\beta$
  - p-p solar ν
  - Thermal n radiative capture on Xe
- Following assessments assume ER rejection is only 99.5% (conservative)
  - Actual rejection is energy dependent / better
    - Also able apply multiple scatter cut at 1 cm in z, 2 cm in x,y

Start with very traditional concern: ^{85}Kr

- β Q-value = 687 keV
- $\tau_{1/2}$ = 10.76 years
- Natural isotopic abundancy = 2.10^{-11}
- MC: 1 ppm ⇔ ~40 dru flat below 300 keV
- Best current commercial offer: 5 ppb
  - Can be improved by dedicated
- CWRU chromatography method: < 2 ppt
  - Limited by measurement method
- XMASS measurement at ~3 ppt with distillation
- LUX[300kg] ER background goal: 8.10^{-4} dru in 100 kg fid.
  - 5 ppt (1 μBq/kg) → 2.10^{-4} dru
- LUX[3ton] goal → requires ~0.5 ppt (0.1 μBq/kg)

^{238}U / ^{232}Th - chemistry

- U, Th and daughters chemically *incompatible* with Xe.
  - Reactive metals vs inert gas.

- ^{222}Rn, from U chain highly soluble in Xe.
  - ^{220}Rn, from Th much less emanating.
  - Data shows that Rn remain in solution in LXe (see bulk alphas)
    - Does not completely ''Freeze out'' on walls

- Rn daughters likely to remain in liquid for some time.
  - Mostly neutral following decay (Walters, 2003)
    - Not removed by drift field
  - Would probably react with any surface
    - Diffusion quite slow
    - ~45 min to decay to ^{210}Pb. Wall contact may be minimal.
  - ^{210}Pb (22 yr $\tau_{1/2}$) and daughters removed by purification, plate-out.

- This Rn channel presumably only significant source of internal U/Th related impurities.

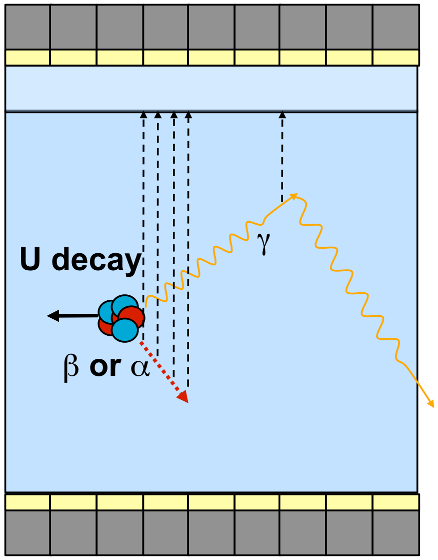
^{238}U / ^{232}Th decay chains

- Origin: emanation from detector components, or plumbing
  - PMTs, capacitors, Teflon walls, metallic supports, pipe joints…
  - XMASS: [U] ~0.2ppt, [Th] < 0.1ppt

XE10 alpha counting:
→ [U] ~ 130 μBq/kg
→ [Th] ~ 8 μBq/kg

- Gamma output
  - MC: 100 μBq/kg → ~0.8(2) mdru for U(Th) in [0-30 keV]
  - BUT: never a « naked γ » in the U/Th chains
    all decays also yield either an α or a β

➔ Gamma background is made irrelevant by XYZ coincidence veto, even for LUX[10t]



^{238}U / ^{232}Th : naked β

- ^{238}U
- ^{234}Th 24d → no naked β
- ^{234}Pa 1min → no naked β
- ^{234}U
- ^{230}Th
- ^{226}Ra 1600y
- ^{222}Rn 3.8d
- ^{218}Po 3min
- ^{214}Pb 27min → 6% 1MeV
- ^{214}Bi 20min → 18% 3.3MeV
- ^{214}Po 160μs
- ^{210}Pb 22.3y → 16% 63keV
- ^{210}Bi 5d → 100% 1.2MeV
- ^{210}Po 140d
- ^{206}Pb

- ^{232}Th
- ^{228}Ra 5.7y → no naked β
- ^{228}Ac 6h → no naked β
- ^{228}Th 2y
- ^{224}Ra 3.6d
- ^{220}Rn 55s
- ^{216}Po 0.15s
- ^{212}Pb 10.6h → 12% 573keV
- ^{212}Bi 1h → 55% 2.25MeV
- ^{212}Po 304ns
- ^{208}Tl 3 min → no naked β
- ^{208}Pb

α decay – β decay – stable

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α decay – β decay – stable

^{238}U / ^{232}Th : naked β

- Naked » β candidates
  - 6 candidates in U/Th chains, all below Rn (previous slide)
  - Consider ^{220}Rn (τ=55s) daughters less of a problem
  - Only one really dangerous: ^{214}Pb → 6% naked β (1 MeV)

- XENON10 result (α counting): ~5 mHz/10 kg ~1.6 mBq

  (~0.2 mBq/kg of Xe)

- LUX[300kg] goal: 0.8 mdru → need < 16 mBq in 300 kg

  (50 μBq/kg of Xe)

- LUX[3ton] goal → need < 16 mBq
  - Background goal 10x lower but fiducial volume 10x larger
  - Dependent on discrimination level achieved

Atmospheric gasses

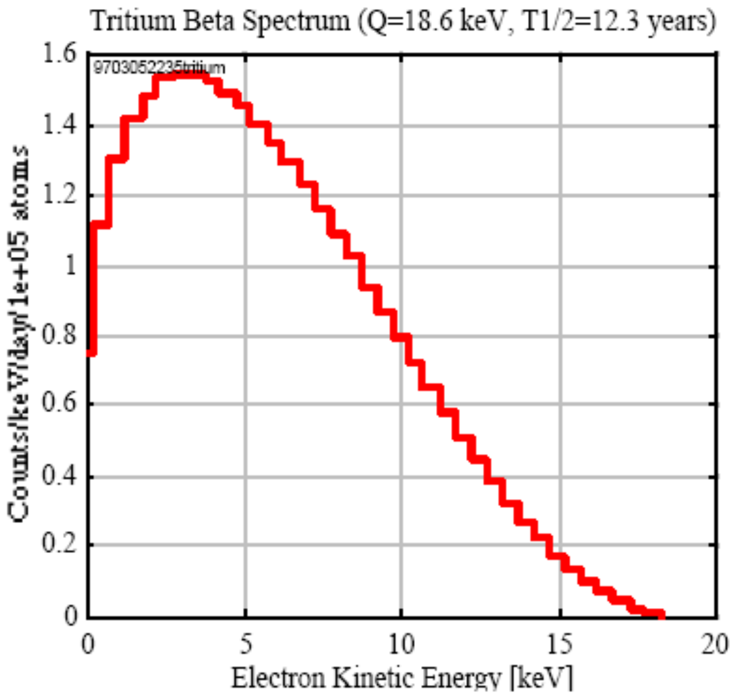
- The most likely chemical contamination
- Present in detector from outgassing, especially from Teflon.
- ^{14}C and ^{3}H are of particular concern.
  - $C0_2$, H_2O, CH_4, many others…
  - Chemically: soluble in LXe.
  - These gasses also a concern for charge and light collection.
- Also Kr, Ar.

^{3}H

- Naked β Q-value = 18.6 keV
- $\tau_{1/2}$ = 12.3 years
- 90 days cosmogenic activation
  →40 mdru at the peak (3600 atoms/kg)
  →Production rate: 40 atoms/day/kg

- LUX[300kg] goal: 2.10^{-4} dru
  - requires < ~20 ^{3}H /kg (35 nBq/kg)
  - ~ 12 hours exposure at sea level
- LUX[3ton] goal ~ 1 hour exposure

- For H from outgassing
  - At surface: [^{3}H] / [^{1}H] ~ 10^{-18}
    → LUX[300kg] requires [H] < 4 ppm



If peak = 1 /keV/day
total area = 10 /day

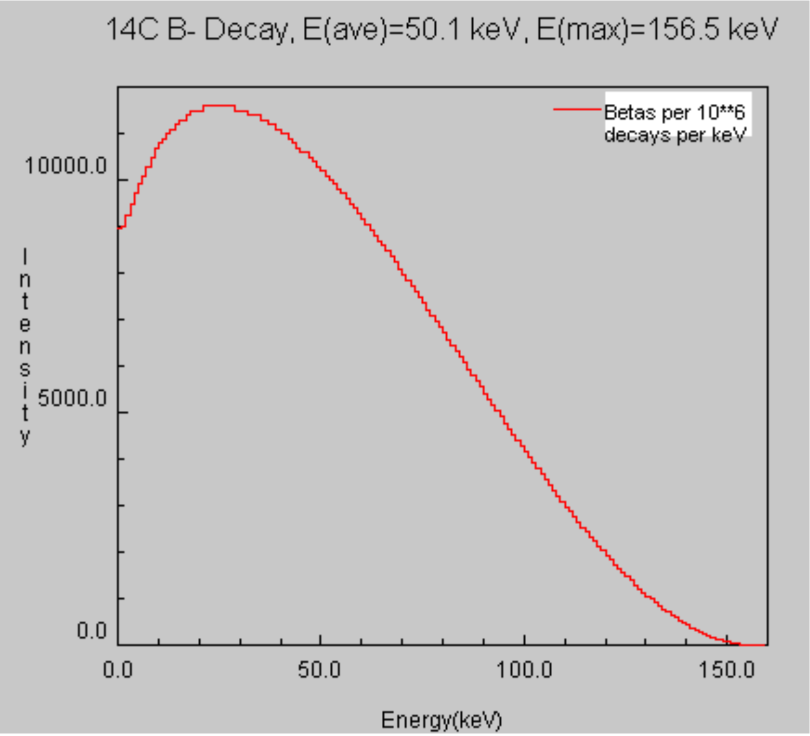
^{14}C

- Naked β 156.5 keV
- $\tau_{1/2}$ = 5730 years
- Isotopic abundance: 1 ppt

[0-100keV]

- [C] = 1 ppb → ~0.01 mdru
- To reach LUX[300kg] goal:
  - →we only need [C] < ~20 ppb
  - →^{14}C activity: ~0.3 μBq/kg
- To reach LUX[3ton] goal:
  - →we need [C] < ~2 ppb

- [!] CH_4 very soluble in Xe (similar polarizability)



Conclusion

- Xe "chemistry" is dull.
  - Almost completely inert, non-polar with weak polarizability
  - Can apply aggressive gettering/distillation/filtering without fear of harming/losing it
    - Most radio impurities are heavy ions, and are chemically incompatible with Xe. Even if present, they will not stay in either gaseous Xe or liquid Xe if they come into contact with other chemicals and/or surface.
  - Getters
    - Getters have been used to reduce electronegative contaminants <0.1 ppb to achieve long electron drift length (>2 m)
    - Getters have also removed molecules absorb scintillation - transparency is also very high
    - The levels of contamination now achieved are similar to those required for radiopurity in multi-tonne LXe experiments
  - Naked betas (not a 2nd vertex to veto with) will be a challenge
    - However, most obvious candidate 214Pb (from 222Rn) is already reduced below level required in XE10 without any specific precautions.
- Intrinsic sources will require continued significant focus of collaborations
  - Have the techniques in hand incl. Rn emanation studies
    - Handling of PTFE in order to remove atmospheric gases
    - The Solar Neutrino experiments appeared to face much greater challenges in bg reduction, yet they proceeded, and won! μBq Rn levels achieved.

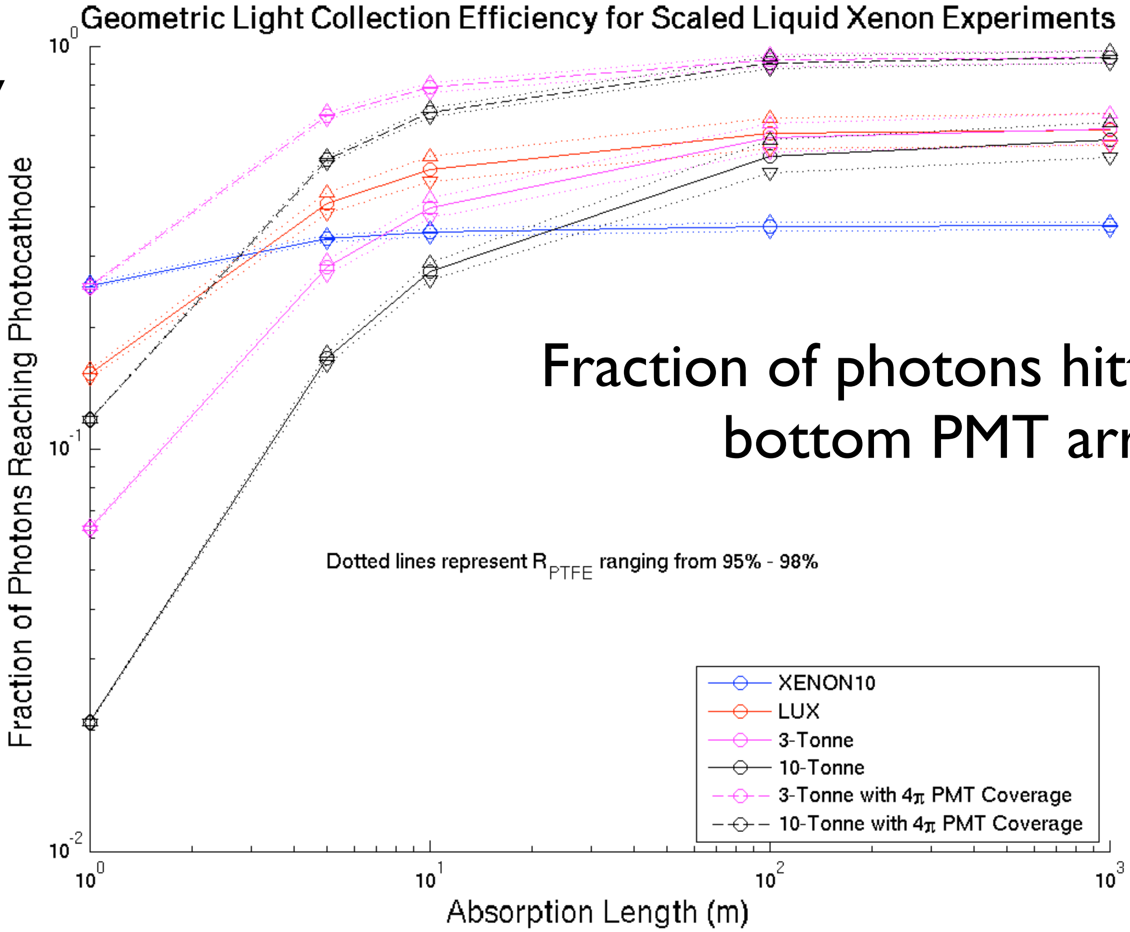
- Surely we need to reduce the level of gamma and neutron backgrounds from cryostat/photodetectors as dark matter sensitivity (and detector scale) increases?

- Intrinsic Radioactivity Backgrounds - these will invalidate self shielding projections?

- Light Collection - how much worse will primary scintillation light collection be as detectors scale?

David Malling, Brown University

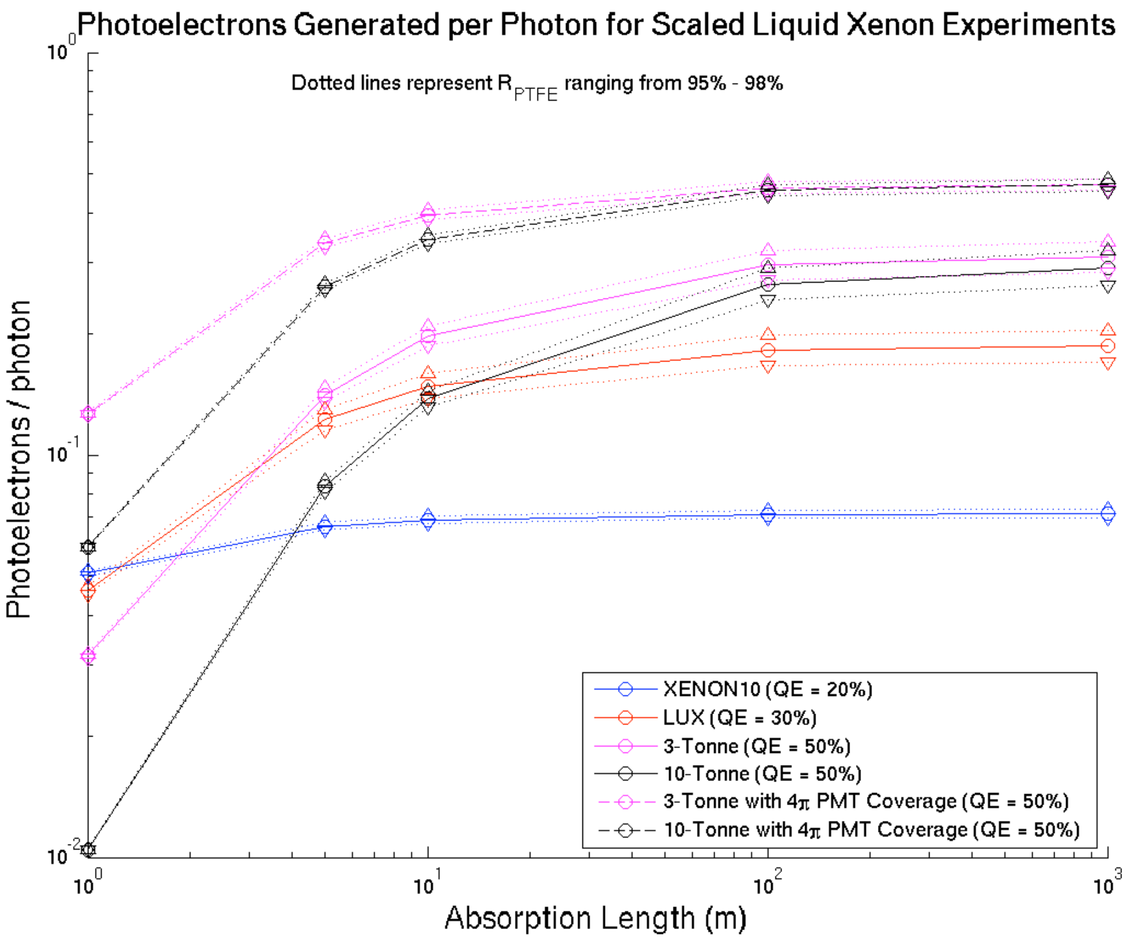
- very similar analyses being done by LUX Collaborators at CWRU & UCLA



Typical variation if model 95-98% Teflon reflection variation

Fraction of photons hitting top or bottom PMT arrays

- XENON10 grids intercept a large fraction of the scintillation photons
  - For isotropic incidence, 95% transparent grid (at 0 angle of incidence) is actually 22% more transparent than the 83% standard XENON10 grid
- LUX grids have greater transparency which allows a much greater light collection efficiency
- Grids are the dominant source of photon absorption at high liquid Xe absorption lengths
- Teflon reflectivity and PMT photocathode coverage, LUX, 3-tonne and 10-tonne detectors surpass XENON10 light collection between 3 and 20 m liquid Xe absorption length



- Enhancements in PMT QE further separates the XENON10 collection efficiency from the larger detectors (50% is probably best in any photodetector that depends on photcathode)
- For any likely liquid Xe absorption length, large Xe detectors promise to outperform XENON10 in light collection efficiency as much as 5x (without 4-pi PMT coverage) or 8x (with 4-pi PMT coverage)

Light Monte Carlo - Summary

- For LXe attenuation length >5 m we will exceed S1 photoelectron statistics obtained in XENON10 with a 10 tonne detector
  - XENON10 grids were less transparent normal incidence (85% vs 93%)
  - QEs of R8520 were lower than is now being achieved. Also CE in short tube is ~70%.
- Data shows
  - Attenuation >1 m (theoretically expected to be very long)
    - MEG (90% CL lower limit) / XENON10 (best fits require infinte , >1 m)
- Theory shows
  - Attenuation due to impurities expected to be km with the level of purity achieved for electron drift requirements / Xe atoms no relevant absorption of 175 nm light from dimers
  - Raleigh scattering has little effect on S1 light collection statistics
    - Strong effect on position reconstruction on S1 alone
- Improved photoelectron statistics on S1 for LXe
  - Some motivation since improvement in S2/S1 based ER discrimination,
    - Although recombination fluctuations are dominant >10 keVr
    - Note also intrinsic discrimination/band separation of ER/NR is best at lowest energies <10 keVr
  - Motivation for 4π
    - Factor 2x in light stats vs end caps + teflon for attenuation lengths > 10 m (more if attenuation length was less)
    - Mainly focused at improving handle on systematics (using S1 hit patterns)
      - This is also very relevant to 39Ar pileup disambiguation

FINAL CONCLUSION

- We are able to present a clear baseline evolution of LXe TPC that will allow us to move from 10^{-45} cm^2 (LUX 300 kg) to 10^{-47} cm^2 (10 tonne)

  - Existing performance for PMT radioactivity/Quantum Efficiency are good enough to make >10 tonne detector viable
    - The PMT activity sets the activity that must be beaten by all other components, so as we improve PMT performance we must also work harder on other components (e.g. cryostat/internal electronics/shielding)

  - However, a reduction in PMT/detector material backgrounds is very well motivated
    - Purity of WIMP signal - reduces any ambiguity of discovery
    - Ability to do 0νββ search

  - Intrinsic Backgrounds
    - High purity of Xe already achieved because of electron/photon transmission requirements
    - Event rejection using multiple hit (TPC) and energy window also provide strong rejection
    - Puts the contamination goals at a level that appear deliverable
    - Collaboration will require programs to characterize slow leak of Rn and atm. gasses from components