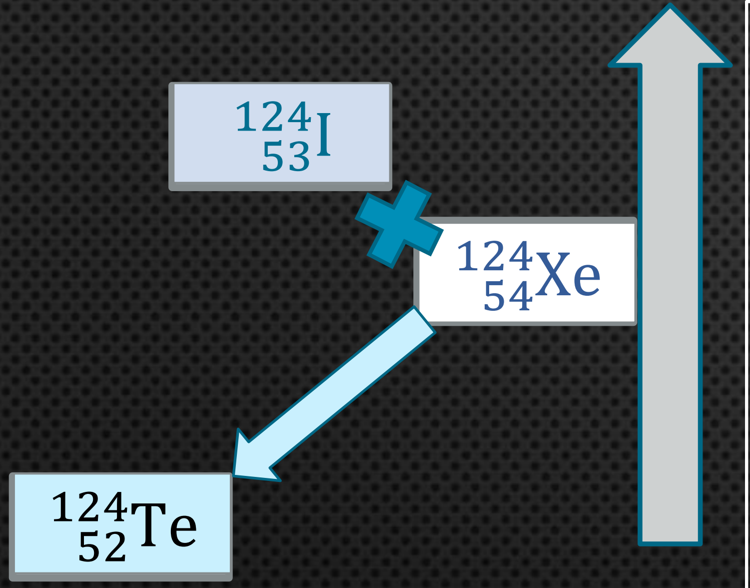
XENON100 & XENON1T

SEARCHING FOR THE TWO-NEUTRINO DOUBLE ELECTRON CAPTURE OF ^{124}XE

ALEXANDER FIEGUTH ON BEHALF OF THE XENON COLLABORATION

TAUP2017

DECAYS OF ^{124}Xe



- Abundance of 0.095 % in natural xenon
- β-decay into ^{124}I energetically forbidden
- Double β-decay into ^{124}Te predicted
- Q-Value of 2856.73(12) keV allows several decay modes

$$^{124}\mathrm{Xe} + 2e^- \rightarrow {}^{124}\mathrm{Te}^* + 2\nu_e \qquad (2\nu\mathrm{DEC})$$

$$^{124}\mathrm{Xe} + e^- \rightarrow {}^{124}\mathrm{Te}^* + e^+ + 2\nu_e \qquad (2\nu\beta^+\mathrm{EC})$$

$$^{124}\mathrm{Xe} \rightarrow {}^{124}\mathrm{Te} + 2e^+ + 2\nu_e \qquad (2\nu 2\beta^+)$$

Processes predicted by Standard Model

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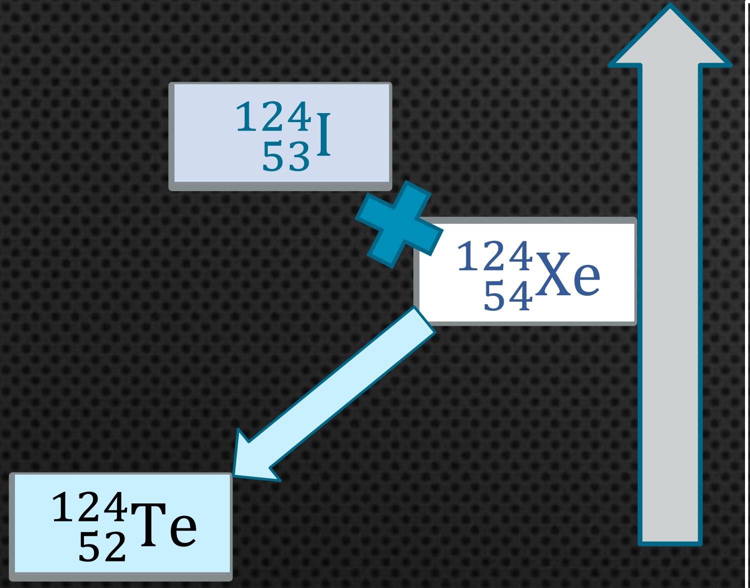

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$^{124}Xe + 2e^- \rightarrow {}^{124}Te^* + 2\nu_e$	$(2\nu DEC)$
$^{124}Xe + e^- \rightarrow {}^{124}Te^* + e^+ + 2\nu_e$	$(2\nu\beta^+ EC)$
$^{124}Xe \rightarrow {}^{124}Te + 2e^+ + 2\nu_e$	$(2\nu 2\beta^+)$

all unobserved in xenon

Processes predicted by Standard Model

Nuclear matrix element (NME)

$$T_{\frac{1}{2}}(2\nu) \sim a_{2\nu} F_{2\nu} |(M_{2\nu})|^2$$

Dimensional factor $\sim yr^{-1}$

Phase-space factor $\sim Q^{\geq 5}$

Depending on NME model

Theoretical half-life predictions	Decay mode
~10^{27} yr	$2\nu 2\beta^+$
$10^{22} - 10^{24}$ yr	$2\nu\beta^+$EC
$10^{21} - 10^{23}$ yr	**2νDEC**

Winter, Rolf G. Phys.Rev. 100 (1955) 142-144
J. Suhonen 2013 *J. Phys. G: Nucl. Part. Phys.* **40** 075102

Xe XENON Dark Matter Project

THE XENON DARK MATTER PROJECT

Dual-phase xenon detectors with extremly low background designed for dark matter search located at Laboratori Nazionali del Gran Sasso (LNGS)

- International collaboration (140 physicists)
- Successfully explores parameter space for potential dark matter particles (WIMPs)
- Different stages with the upcoming XENON1T to become the most sensitive dark matter detector in the world
- **Suitable for other rare event searches**

www.xenon1t.org

XENON100

2011/12

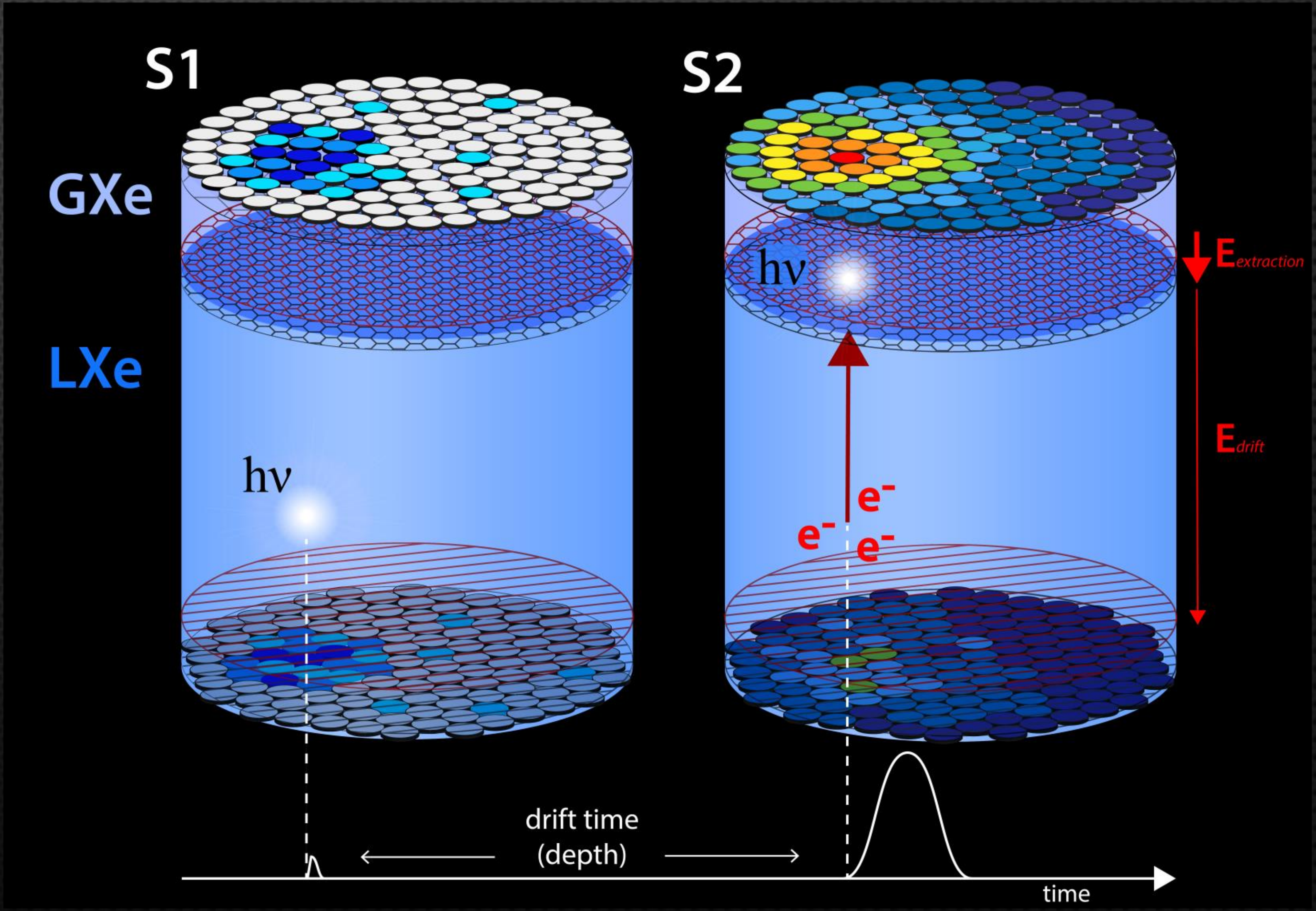
Analysis of 225 live days will be shown in this talk

XENON1T

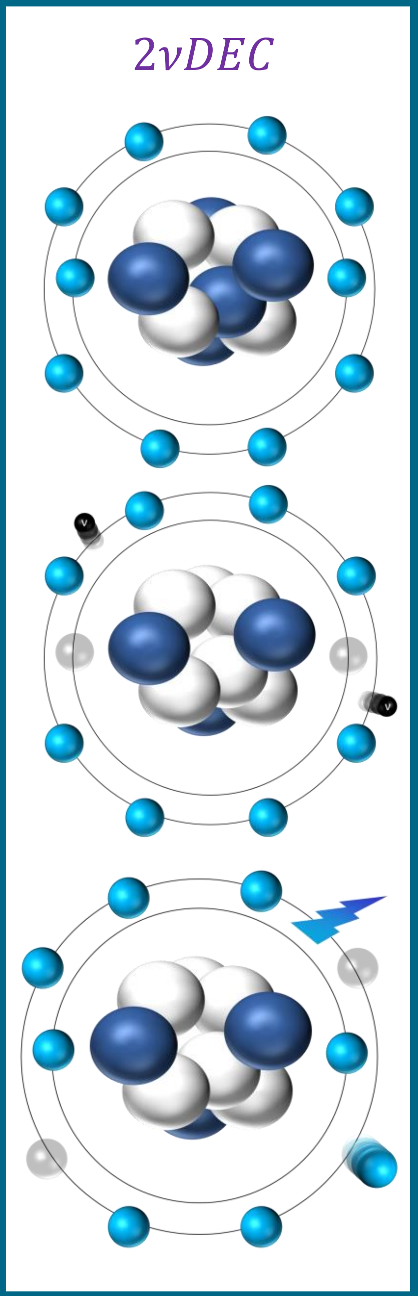
2016 – ongoing

First science run completed and is analyzed. Data taking ongoing.

DETECTION TECHNIQUE - DUAL PHASE XENON TPC



WHY SEARCH FOR DOUBLE ELECTRON CAPTURE WITH THIS DETECTOR?



Expected signal for two K-shell electron capture

64.33 keV

Due to the small range (<0.5 mm) and time difference (~10^{-15} s) the individual X-rays (Auger electrons) cannot be resolved

- Source = Detector
- High self-shielding capacity
- 3D vertex reconstruction allows for selection of a fiducial volume
- Careful screening of materials and active removal of radioactive krypton

Extremely low background experiment with keV-scale optimized sensitivity

Data is for "free" as it is the same as for the dark matter search

Nesterenko, D.A. et al. Phys.Rev. C86 (2012) 044313

ANALYSIS OF XENON100 DATA

In D.-M. Mei, I. Marshall, W.-Z. Wei, and C. Zhang Phys. Rev. C **89**, 014608 a study is carried out by non-collaboration members without insight to the data
→ **Limit was overestimated**

Study on real data!

224.6 live days
Same dataset used for several analyses regarding dark matter

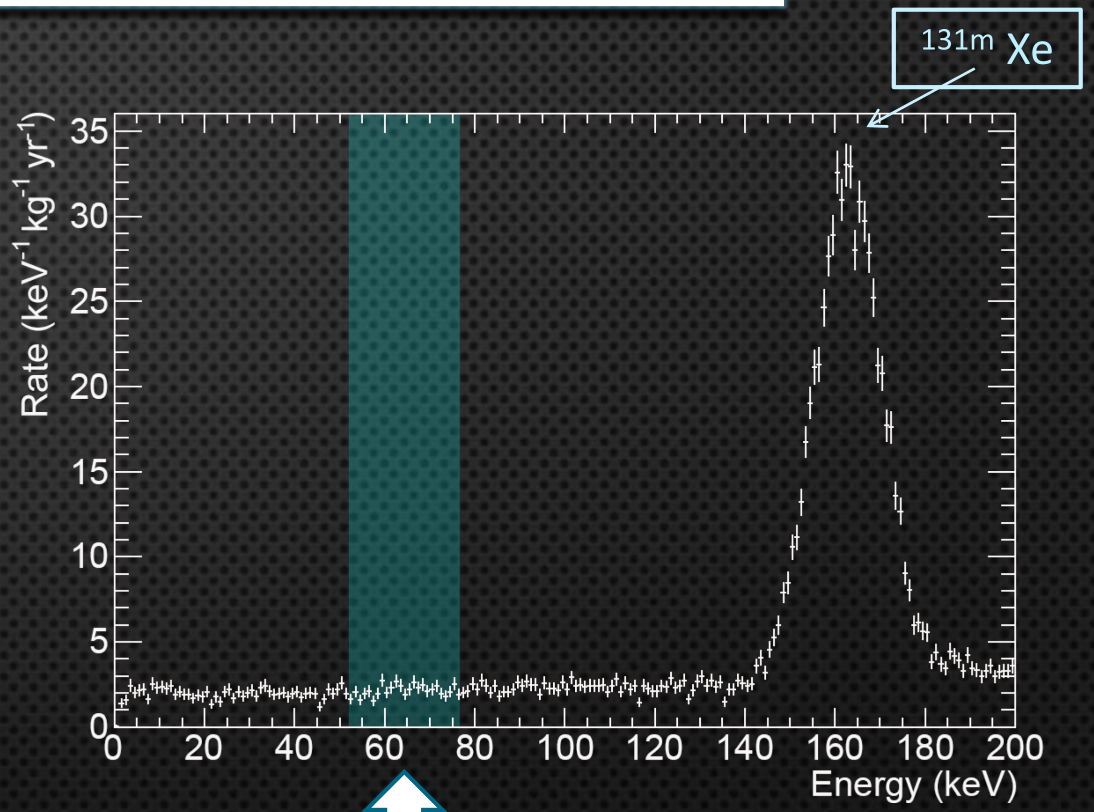
Derive an energy scale based on the combination of the two signals (S1 & S2) using neutron activation lines induced by ^{241}AmBe

Energy resolution of 4.1keV @ 64.33 keV

Select 34 kg fiducial volume, corresponding to 29 g of ^{124}Xe (0.089%)

Apply data quality and selection cuts and estimate their acceptance using ^{232}Th & ^{60}Co calibration sources

Plot it!



Phys.Rev.Lett. 109 (2012) 181301

ANALYSIS OF XENON100 DATA

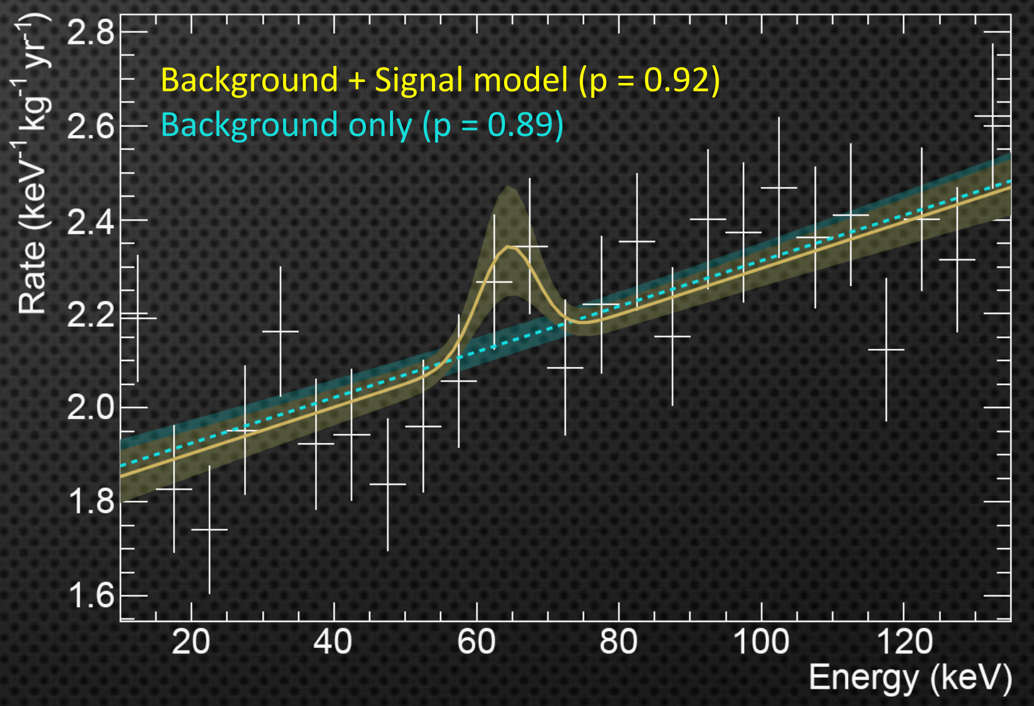
Expected signal: single energy peak at 64.33 keV

Γ: decay rate
η: ^{124}Xe abundance
mt: exposure
N_A: Avogadro´s constant
M_{XE}: molar mass of xenon
σ_{sig}: peak width
μ_{sig}: peak position
f_{bkg}: linear background

Bayesian fit from 10 keV to 135 keV with two models:

Linear background only
Linear background and a Gaussian signal

$$f_{sig} = \frac{\Gamma\, \eta\, \epsilon\, mt\, N_A}{\sqrt{2\pi}\, \sigma_{sig} M_{XE}} \cdot e^{-\frac{(E-\mu_{sig})^2}{2\sigma_{sig}^2}} + f_{bkg}$$



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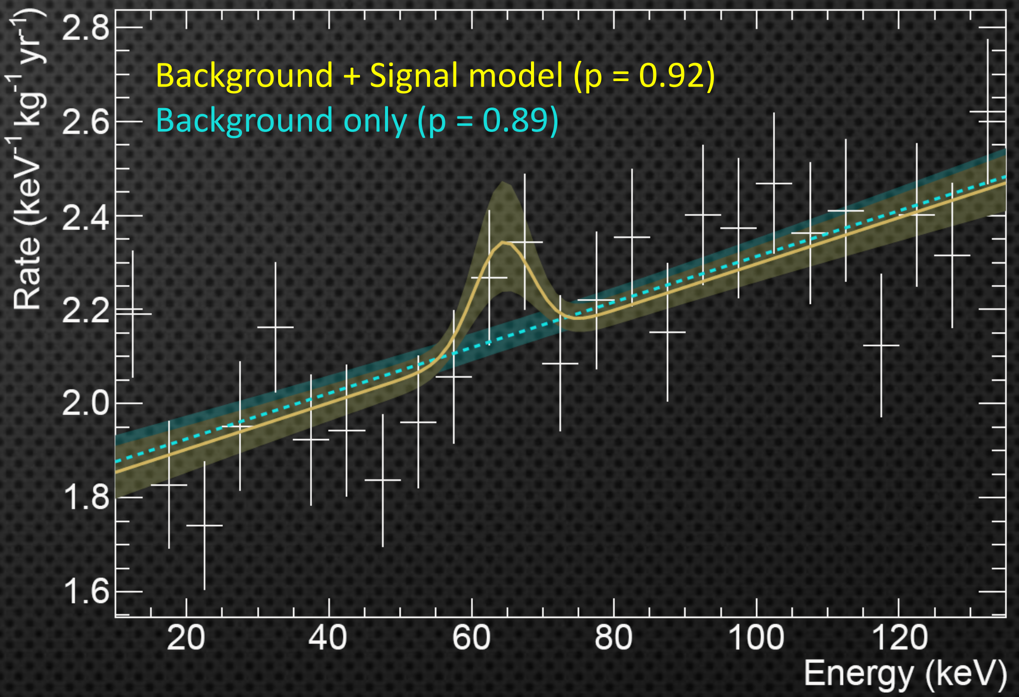

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$$f_{sig} = \frac{\Gamma\,\eta\,\epsilon\,mt\,N_A}{\sqrt{2\pi}\,\sigma_{sig} M_{XE}} \cdot e^{-\frac{(E-\mu_{sig})^2}{2\sigma_{sig}^2}} + f_{bkg}$$

Use knowledge about parameters
Implement systematic uncertainties as Gaussian priors
Evaluate signal significance with Bayes factor (BF)

$$BF = \frac{P(f_{bkg}|\vec{D})}{P(f_{sig}|\vec{D})} = 1.2$$

Favors background only model

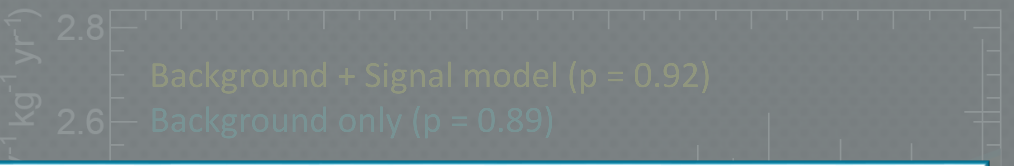
Calculate lower limit on the half-life

A. Caldwell, D. Kollar, and K. Kroninger, Comput. 438 Phys. Commun. 180, 2197 (2009).

ANALYSIS OF XENON100 DATA

Expected signal: single energy peak at

Bayesian fit from 10 keV to 135 keV with two models:



Γ: deca
η: ^{124}Xe
mt: exp
N_A: Avo
M_{XE}: m
σ_{sig}: pe
μ_{sig}: pe
f_{bkg}: lin

Us

Result on the 90% lower credibility limit of the double K-shell electron capture from XENON100 data

$$T_{\frac{1}{2}} > 6.5\ x\ 10^{20}\ yr$$

arXiv:1609.03354
Phys. Rev. C 95, 024605
XENON (Aprile et al.)

Other results on the half-life

XMASS (Abe et al.): $> 4.7 \cdot 10^{21}\ yr$
Gavrilyuk et al. : $> 2.0 \cdot 10^{21}\ yr$

This result supersedes the obtained limit ($> 1.6 \cdot 10^{21} yr$) by Mei et al.

Implement systematical uncertainties as Gaussian priors
Evaluate signal significance with Bayes factor (BF)

$$BF = \frac{P(f_{bkg}|\vec{D})}{P(f_{sig}|\vec{D})} = 1.2$$

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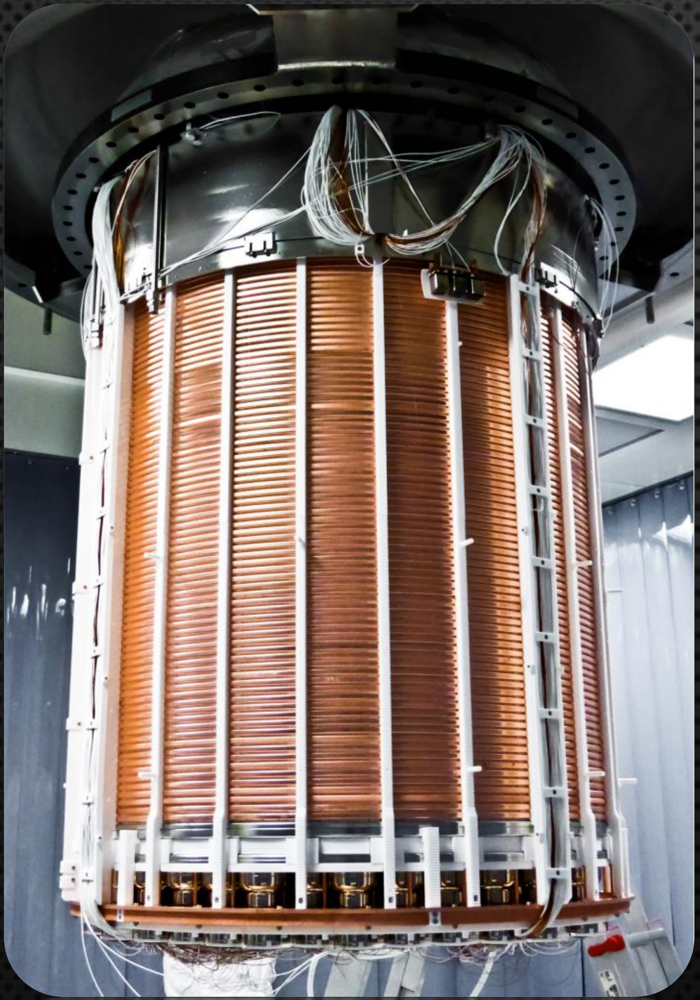
arXiv:1705.06655
(submitted to PRL)

FIRST DATA FROM XENON1T – A PRELIMINARY LOOK



See talk of M. Lindner
on Thursday (9:45 am)

First science run

34.2 live days

1042 kg fiducial volume

~1kg of ^{124}Xe

Lowest ER background of a dark matter experiment achieved to date (region of interest)

Search for the 2vDEC
Prepare analysis for search on final exposure

< 0.11 events per (keV x kg x yr)

UNDERSTANDING YOUR DETECTOR – ENERGY CALIBRATION

$$E_R = W \times \left(\frac{cS1}{g1} + \frac{cS2b}{g2} \right)$$

How much energy is needed
to produce a quantum
(e^- or γ)
13.7 eV

charge

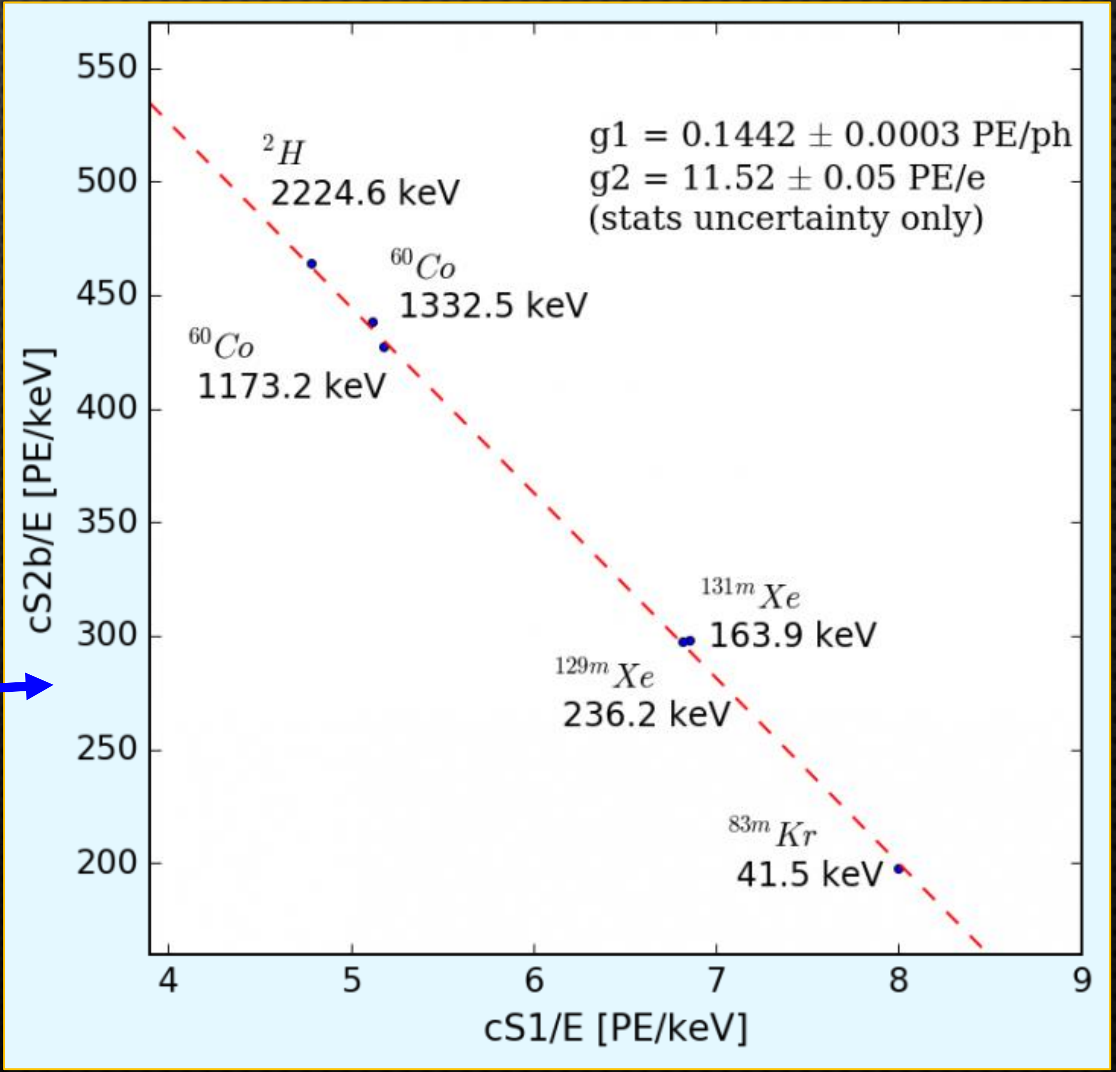
+

light

=

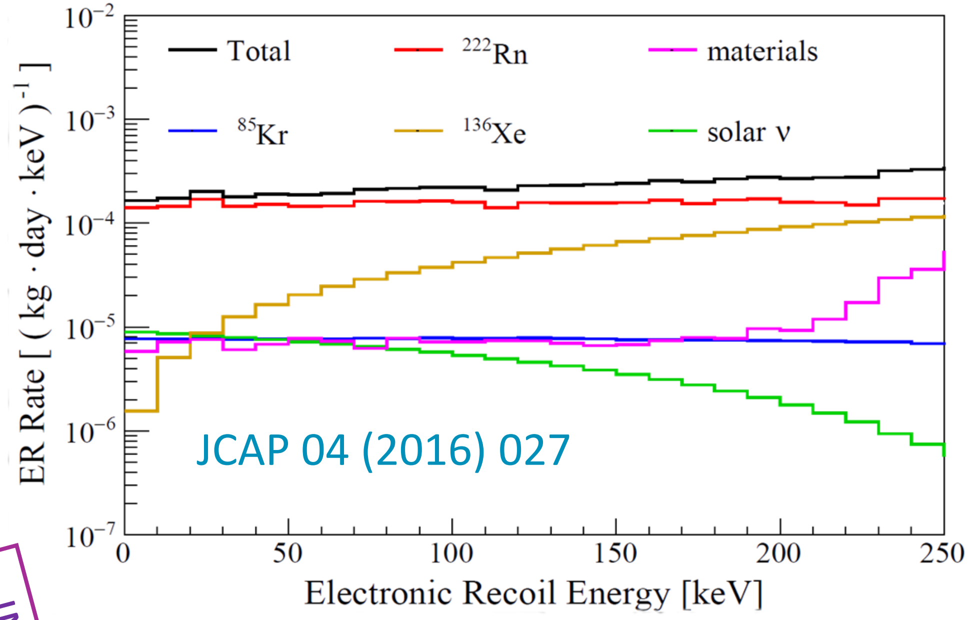
Total quanta

Conserved!



UNDERSTANDING YOUR DETECTOR – BACKGROUNDS

Monte Carlo Simulation (before data taking)



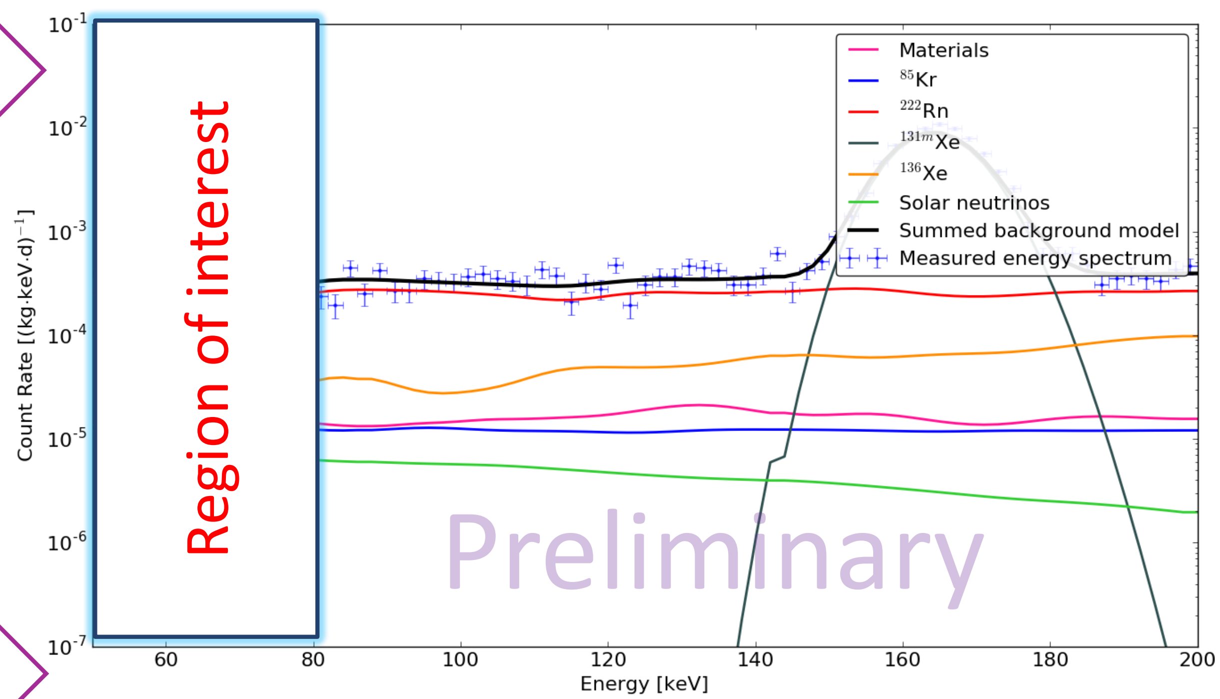
INPUT

70 parameters from radionuclides in different detector components
Internal backgrounds and solar neutrinos
Reduce number of free parameters by grouping and scaling factors

INPUT

Fit

Monte Carlo matched to data via minimization



OUTPUT

Background model for the search for the 2vDEC

SEARCHING FOR THE DECAY - FIT METHOD

Γ: *decay rate*
η: ^{124}Xe *abundance*
mt: *exposure*
N_A: *Avogadro´s constant*
M_{XE}: *molar mass of xenon*
σ_{sig}: *peak width*
μ_{sig}: *peak position*
f_{bkg}: *background model*

$$f_{sig} = \frac{\Gamma\, \eta\, \epsilon\, mt\, N_A}{\sqrt{2\pi}\, \sigma_{sig} M_{XE}} \cdot e^{-\frac{(E-\mu_{sig})^2}{2\sigma_{sig}^2}} + f_{bkg}$$

Check different background models:

- **Flat background**
- **Linear background with slope**
- **Background model interpolated from Monte Carlo Matching**

Do a χ^2 minimization
constrain the fit parameters μ and σ using detector knowledge by adding quadratic penalties on χ^2

Check with classical Feldman & Cousins approach
Signal or set an upper limit on the decay rate
Calculate half-life value or set a lower limit

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$(E-\mu_{sig})^2$

Work in progress – expect results soon

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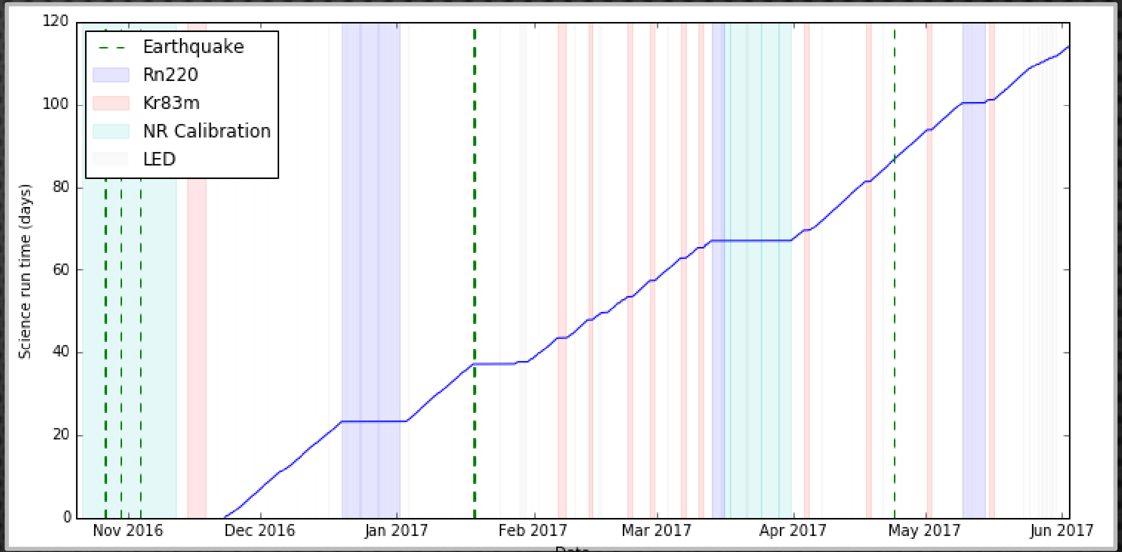
XENON1T – OUTLOOK

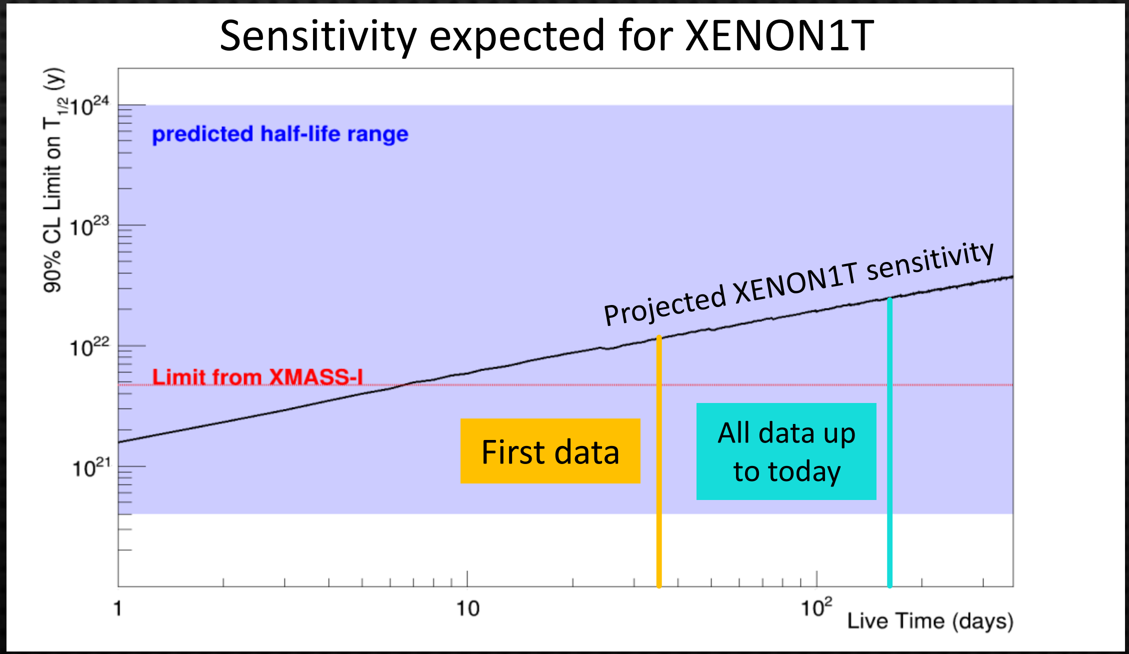
Improve on the data shown

- Investigate MC/Data matching for a refined background model
- Simulate background model and fit to data
- Search in 2-D space to maximize information
- Increase in fiducial volume

Blinded analysis on new data

- Data taking ongoing
  > 100 days recorded
- Better energy resolution due to higher light yield
- Use calibration to design specific ER cuts





Thanks for your Attention

Any questions?

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