Krypton in XENON

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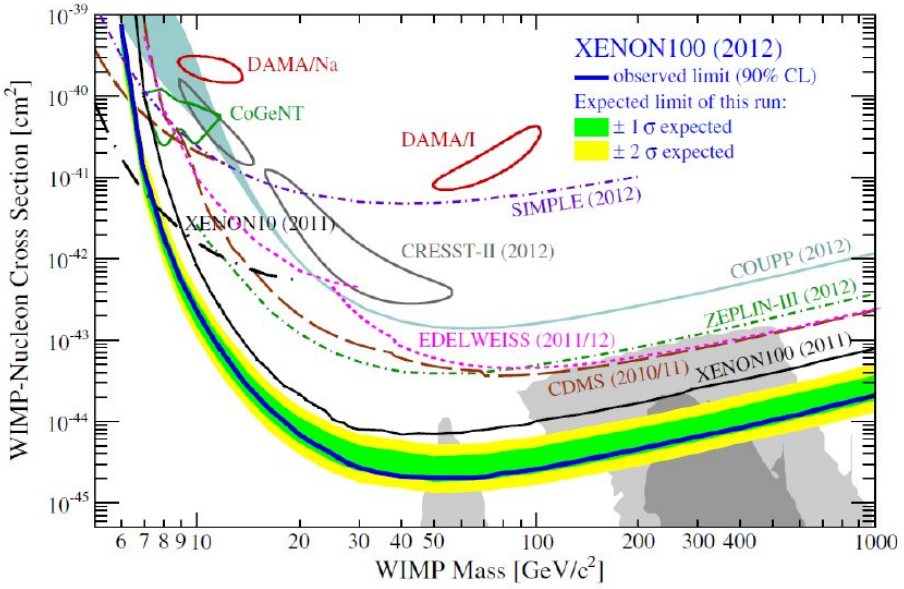
Low Radioactivity Techniques, 2013

XENON100
Dark Matter Search

Columbia Rice UCLA Zürich Coimbra LNGS INFN SJTU Purdue

Bologna Subatech Münster Heidelberg Nikhef Weizmann Mainz Bern



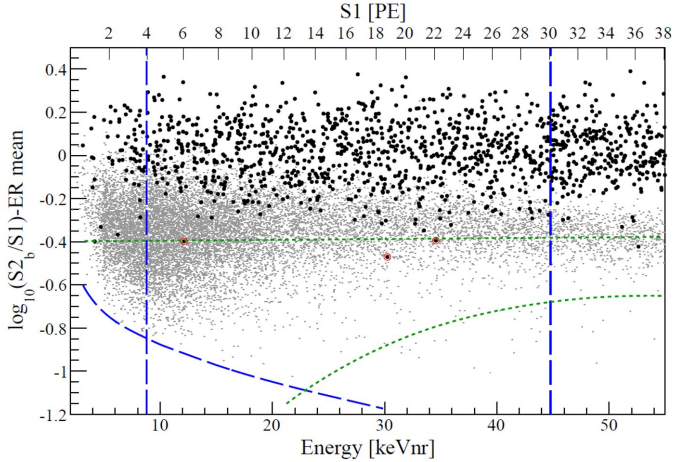
E. Aprile et al. (XENON100), Phys. Rev. Lett. 109, 181301 (2012), arXiv:1207.5988.

XENON100: Effect of ^{85}Kr on Background Level

Krypton Distillation

similar to:
K. Abe et al. (XMASS Collaboration),
Astropart. Phys. 31 290 (2009)

+

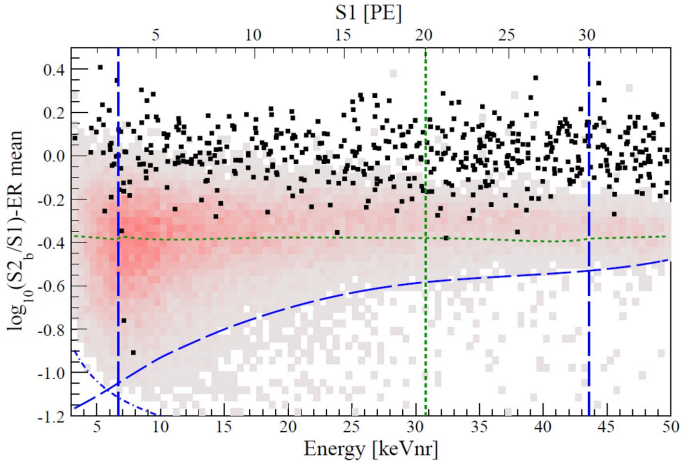


E. Aprile et al. (XENON100), Rhys. Rev. Lett. 107, 131302 (2011)

"100 Live Days"
48kg FV

22 mDRU

=



E. Aprile et al. (XENON100), Phys. Rev. Lett. 109, 181301 (2012)

"225 Live Days"
34kg FV

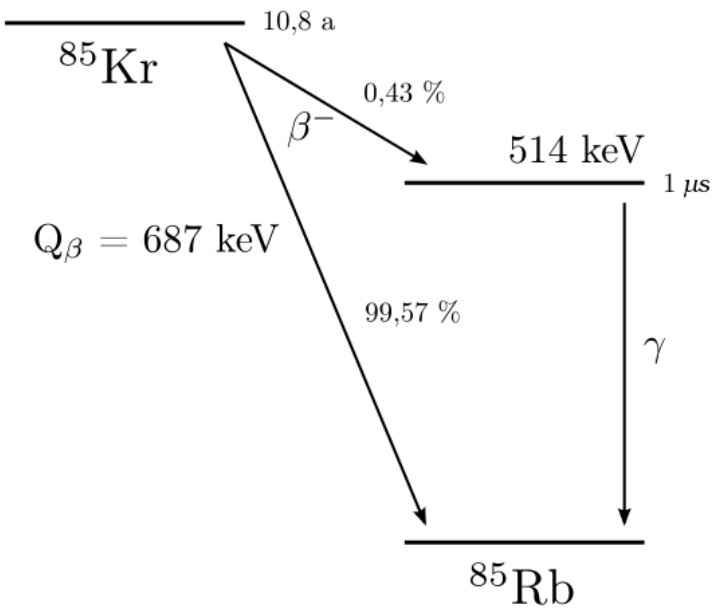
5.3 mDRU

The Need for an Off-Line Analysis Tool

^{85}Kr limits search for Dark Matter

⇒ need to remove ^{85}Kr
- krypton distillation column

⇒ need (off-line) analysis tools
- delayed coincidence
- spectral fit



^{85}Kr decay scheme

Too little ^{85}Kr (for analysis)

1 ppt Kr in Xe:
- about 3200 ^{85}Kr atoms in 35 kg LXe
- about 0.6 ^{85}Kr-decays/day/35 kg LXe

⇒ months of data needed

⇒ make use of known (see next slide) ^{85}Kr/^{nat}Kr ratio

Off-line krypton assay

RGMS (Rare Gas Mass Spectrometer)

Insertion: The ^{85}Kr/^{nat}Kr Ratio

Geophysical Literature

^{85}Kr/^{nat}Kr $\approx 2 \times 10^{-11}$ mol/mol

(X. Du et al., Geophysical Research Letters, 30(20), Oct 2003)

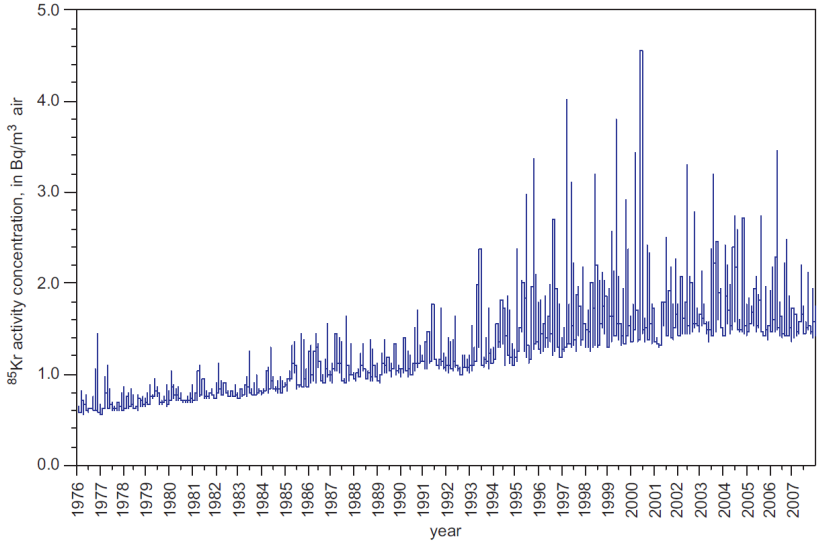
LNGS air sample using miniaturized proportional counters

^{85}Kr in Hall A air sample:

1.3 ± 0.2 mBq/liter (air sample drawn on 1 Oct 2009; S. Lindemann diploma thesis, Heidelberg 2009)

$\Rightarrow 2.1 \pm 0.3 \times 10^{-11}$ mol/mol

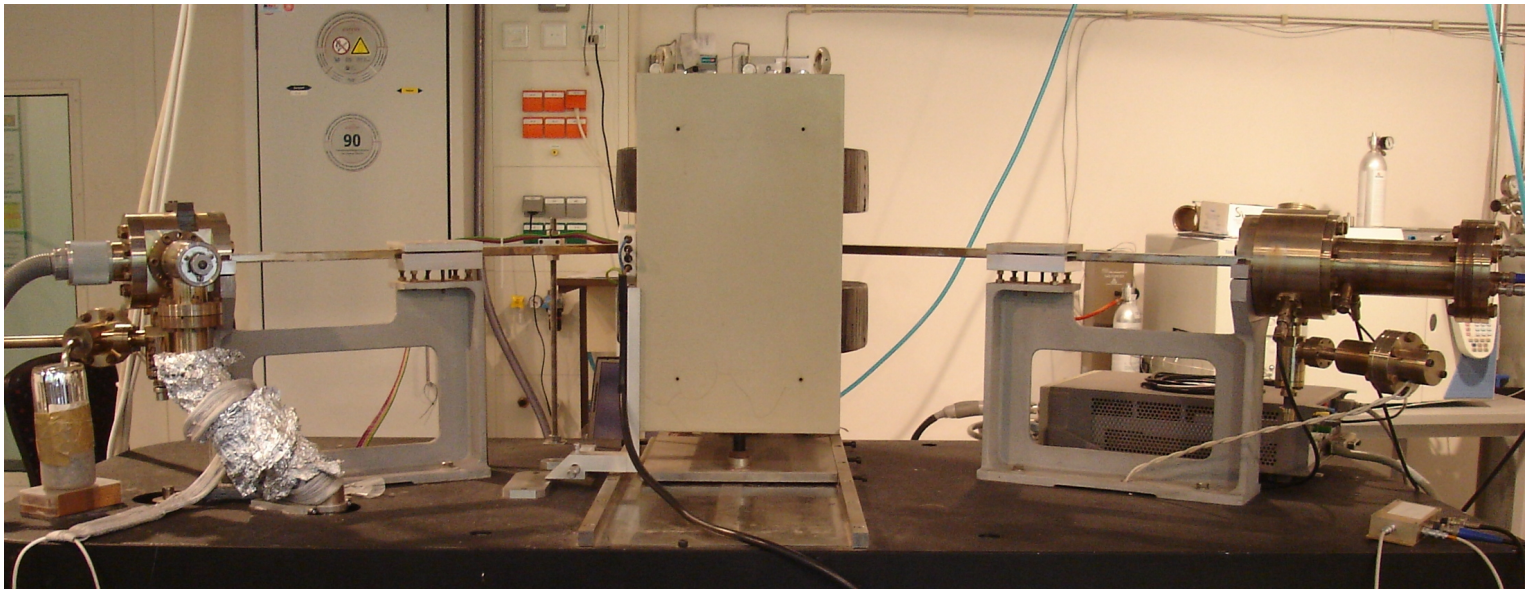
Monitoring in (South-)Germany by BfS



J. Bieringer et al. (Appl. Rad. Isot. 67)

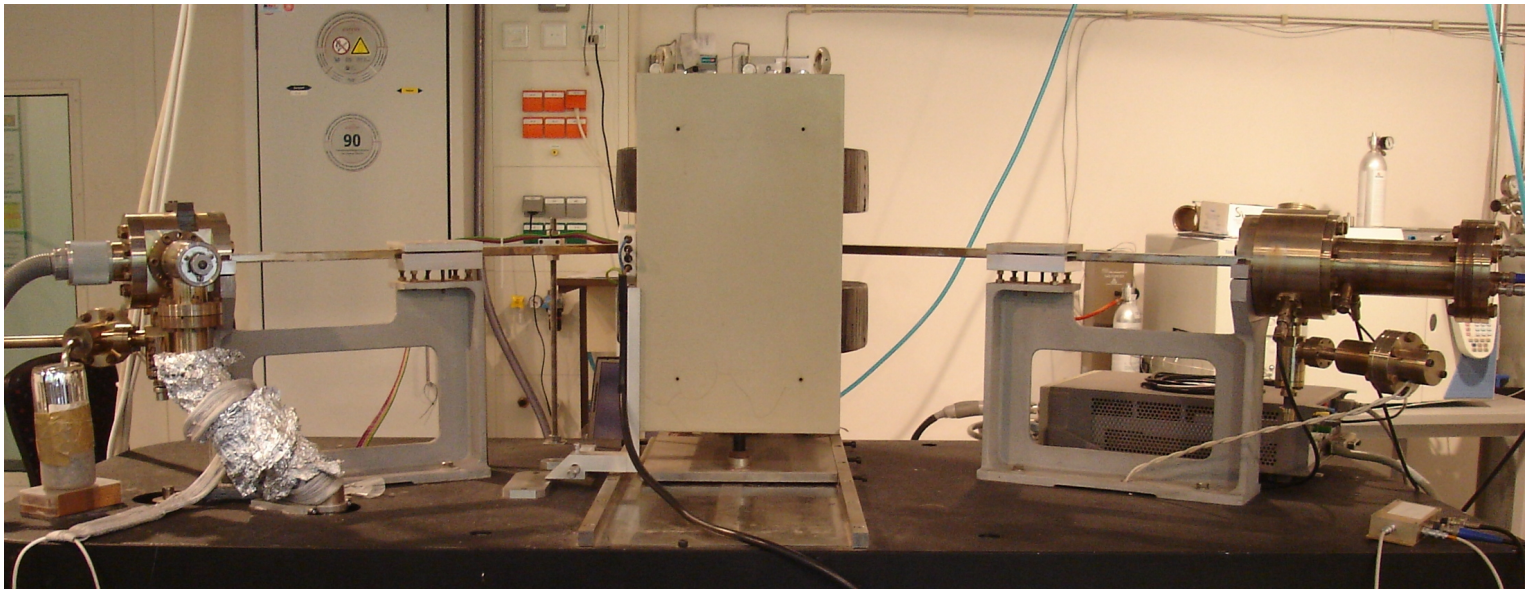
$\Rightarrow$ ^{85}Kr/^{nat}Kr $= 2 - 4 \times 10^{-11}$ mol/mol

Introduction to the RGMS



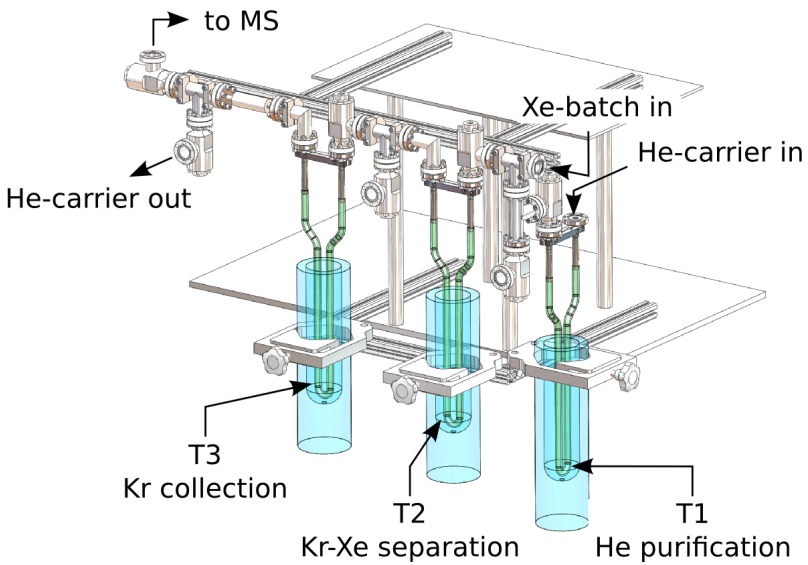
- Only inert gases (RGMS = Rare Gas Mass Spectrometer)
- Pressure < 10^{-6} mbar
- Below 10^{-12} cm^3 (STP) krypton detectable

Introduction to the RGMS



- Only inert gases (RGMS = Rare Gas Mass Spectrometer)
- Pressure < 10^{-6} mbar
- Below 10^{-12} cm^3 (STP) krypton detectable
- 1ppt krypton $\Rightarrow$ 1 cm^3 (STP) xenon needed $\Rightarrow$ pressure $\gg 10^{-6}$ mbar ↯

Introduction to the prepended Cryogenic Gas Chromatograph (pCGC)

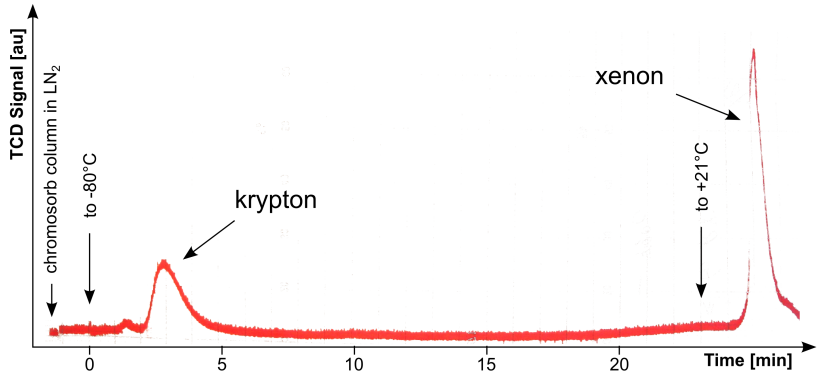


- He matrix gas is cleaned
- Kr stays less time in adsorber than Xe
- Kr atoms are stored; Xe bulk is rejected
- Kr is transfered to MS

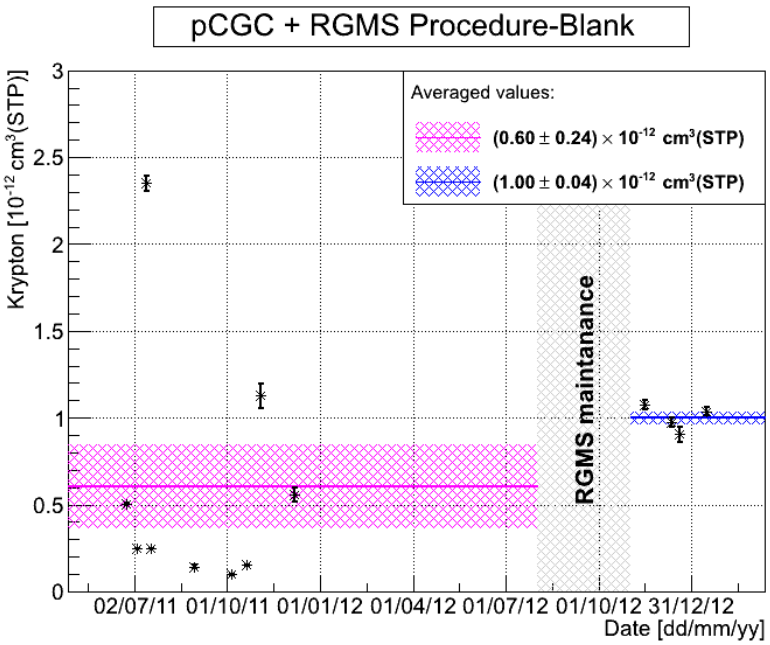
- Cryogenic gas chromatography at $-80\,^{\circ}\mathrm{C}$
- Cutting around 15 min

  $\Rightarrow$ effective rejection of xenon bulk
- Amount of He matrix gas: $\sim 10 - 100\times$ size of Xe sample

Krypton-Xenon separation



RGMS: Procedure Blank and Detection Limit



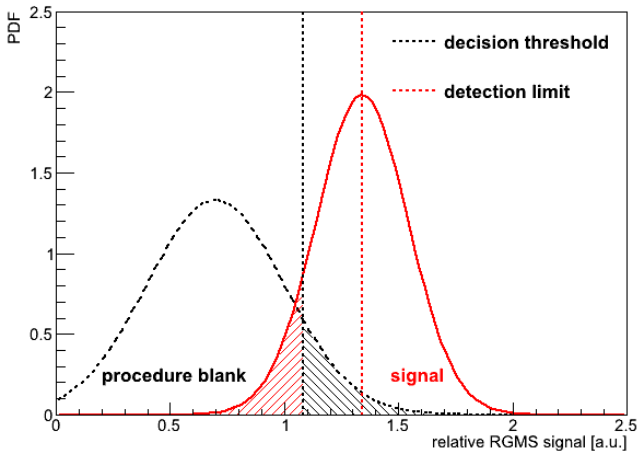
Procedure Blank

- Procedure Blank: 1×10^{-12} ccSTP ^{nat}Kr
- ^{nat}Kr in He matrix gas < 0.1 ppt

Detection Limit (DL)

- Procedure Blank limits absolute amount of ^{nat}Kr detectable
- Maximal size of xenon sample determines RGMS performance

$$\begin{aligned} \mathrm{DL} &= (^{nat}\mathrm{Kr})_{min}/(\mathrm{Xe})_{max} \\ &\approx 1.3 \times 10^{-12}/2\,\mathrm{ccSTP/ccSTP} \\ &= 0.7\,\mathrm{ppt}\,(90\%\mathrm{C.L.}) \end{aligned}$$



Estimation of RGMS Errors

Errors systematically affecting all measurements

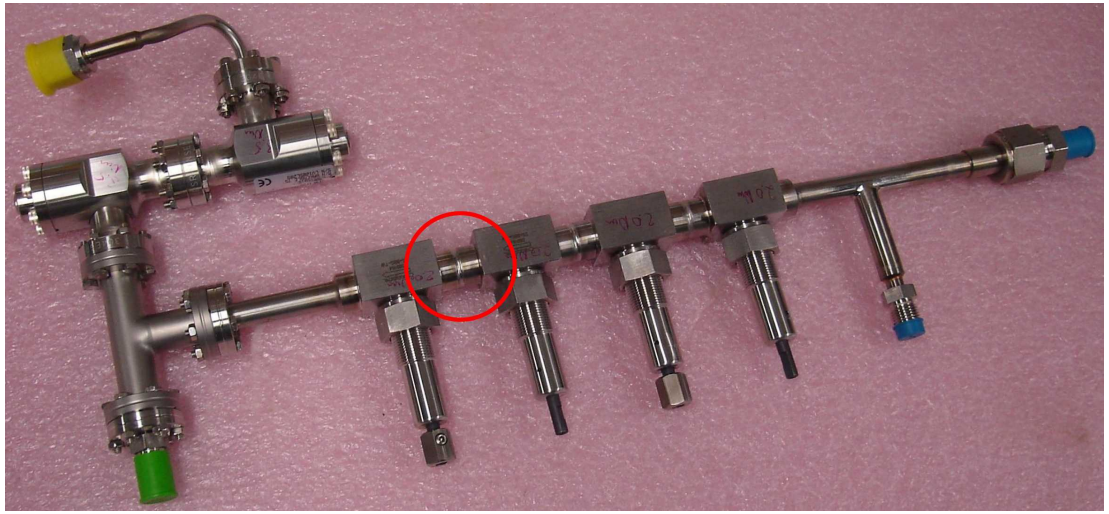
- Absolute calibration of standard (eg1&eg2)
- Xenon sample size determination
  - Size of calibration volume
  - Accuracy of pressure gauge
- Krypton acceptance of chromatographic separation (pCGC)

Errors affecting individual measurements

- Instability of electronics (ion-source, ion-multiplier, . . .) wrt preceding calibration
- Variations in krypton acceptance of pCGC due to manual operation

Total error of RGMS about 20%

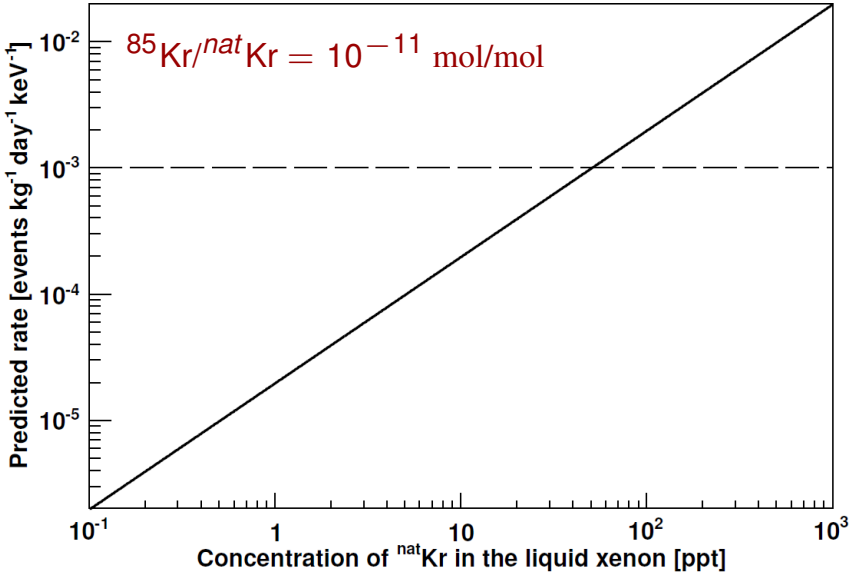
Drawing Xenon Samples for RGMS Measurements



Available sampling containers

- *Xe-pipettes*: 5 - 20 ccSTP samples enclosed in stainless steel, fully metal sealed volumes
- *Xe-bombs*: 1 liter, fully metal sealed (CF16), stainless steel vessels
- Or: connecting xenon gas cylinder directly to RGMS

Conversion ppt → mDRU



see also
M. Selvi's talk
on Friday

E. Aprile et al. (XENON100), Phys. Rev. D 83, 082001 (2011)

DRU (Differential Rate Unit) $\equiv$ cts/(keV$_{ee}$ · kg · day)

Using ^{85}Kr/^{nat}Kr $= 2 \times 10^{-11}$ mol/mol, the conversion to mDRU for XENON100 reads:

$$100\,\text{ppt} \mathrel{\hat{=}} 3.9\,\text{mDRU}$$

Results from RGMS Measurements

XENON100: *100 Live Days* publication

Background fit: $700 \pm 100\,\mathrm{ppt}$ ($^{85}\mathrm{Kr}/^{nat}\mathrm{Kr} = 10^{-11}\,\mathrm{mol/mol}$)

RGMS: $360 \pm 70\,\mathrm{ppt}$

$\Rightarrow$ $14\,\mathrm{mDRU}$ from ^{85}Kr

XENON100: *225 Live Days* publication

Delayed Coincidence analysis: $18 \pm 8\,\mathrm{ppt}$

RGMS: $14 \pm 3\,\mathrm{ppt}$

$\Rightarrow$ $0.6\,\mathrm{mDRU}$ from ^{85}Kr

Performance of XENON100 Distillation Column

RGMS: reduction factor $= 350 \pm 100$ (single pass starting from $2.8 \pm 0.6\,\mathrm{ppb}$)

Right now in the XENON100 detector

Less than $1.3\,\mathrm{ppt}$ (90%C.L.)

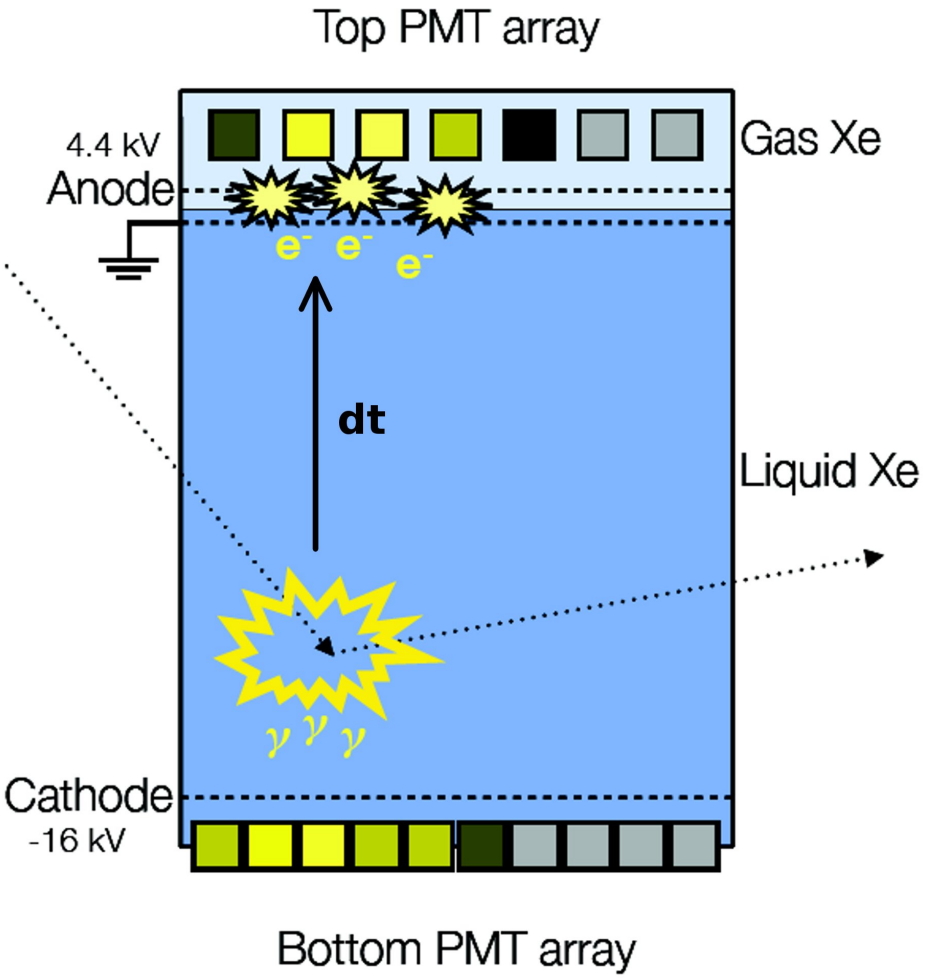
$\Rightarrow$ less than $0.05\,\mathrm{mDRU}$ from ^{85}Kr

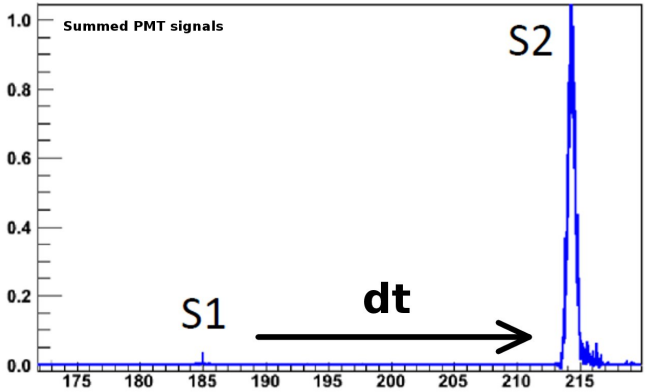
Conclusions

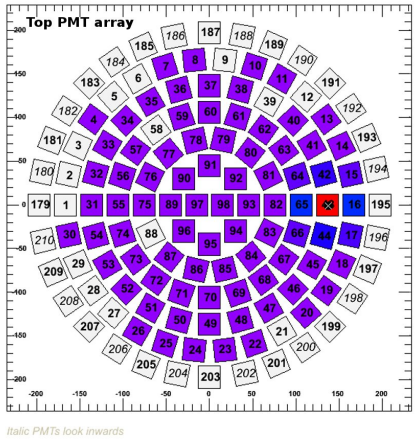
- ^{85}Kr is a potentially dangerous source of background in XENON100 (and XENON1T).
- The RGMS, an off-line krypton in xenon analysis tool, is fully operational with a detection limit below 1 ppt.
- The XENON100 distillation column has proven its capability to degrade krypton to a sub-dominant background.
- XENON100 on-line data-analysis techniques (delayed coincidences and spectral fit) and off-line krypton assay show excellent agreement.
- The achieved krypton level of $< 1.3\,\mathrm{ppt}$ in XENON100 is an important step towards the requirement of $< 0.1\,\mathrm{ppt}$ needed for XENON1T.

Backup Slides

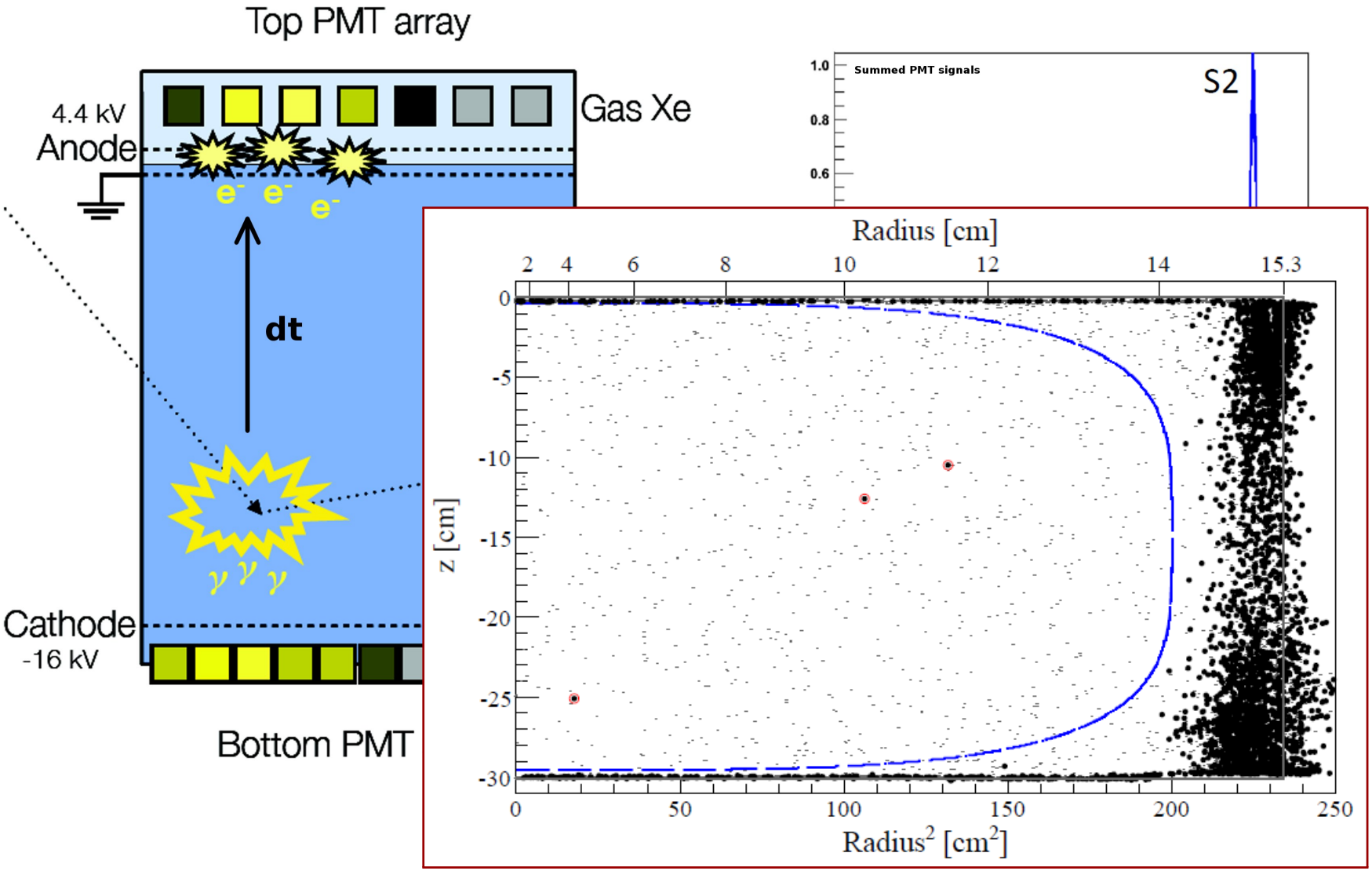
XENON100: 3-dimensional Position Reconstruction



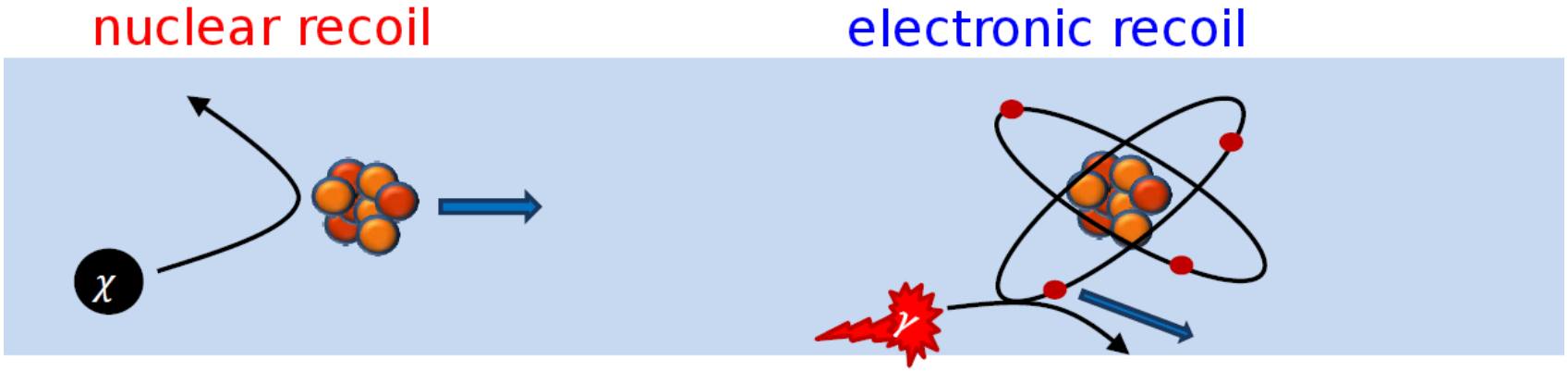


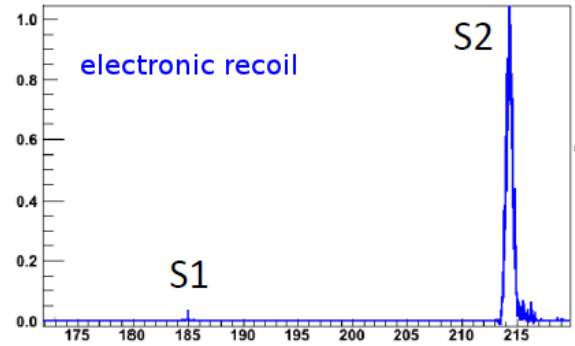


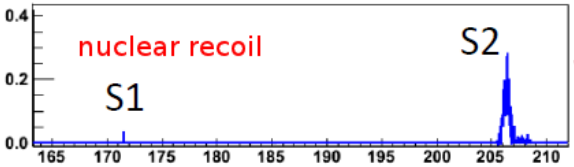
XENON100: 3-dimensional Position Reconstruction

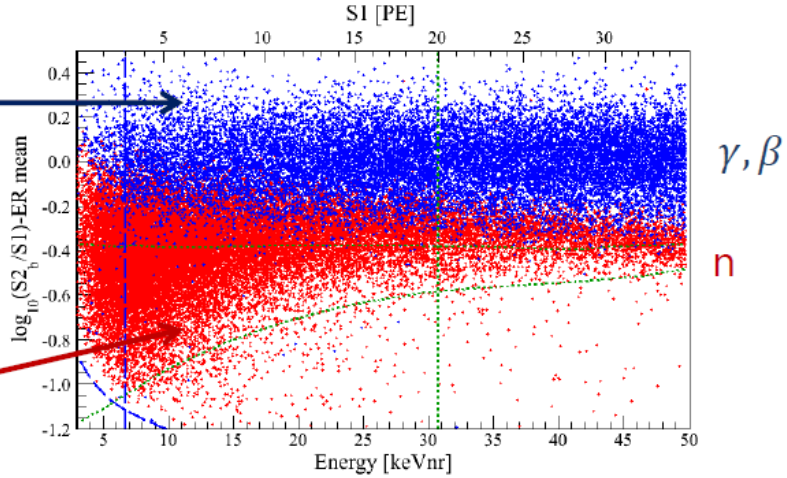


XENON100: Nuclear and Electronic Recoils

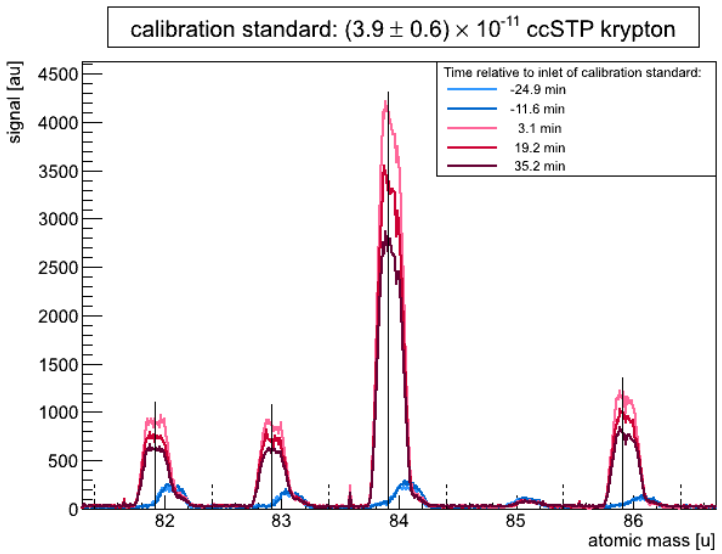








RGMS Calibration



Absolute calibration of eg1&eg2

Commercial calibration gas (helium) with 10 ppm ^{nat}Kr (2% error)

- extract small amount of gas ($\sim$ 0.01 ccSTP): 14% error
- dilute calibration gas (by factor 25 - 200): 2.5% error
- freeze krypton to cold finger, remove helium by pumping: < 2% error

Daily calibration: eg1&eg2

- Permanently installed large gas reservoir
- Pipette off a fixed fraction ($\sim 10^{-5}$) of large gas reservoir
  - 2.2 ± 0.4 ccSTP ^{84}Kr
  - 6.7 ± 1.1 ccSTP ^{86}Kr
- Use before (and after) a measurement to calibrate ion-multiplier response