Background models in the low energy region: TREX-DM and IAXO-D0 setups


Universidad de Zaragoza, Spain
Outline

• The TREX idea: MicroPattern Gaseous Devices for rare event && Low radioactivity techniques
  • Three rare events: double beta decay, low mass wimp or axion experiments
  • TREX-DM and IAXO-D0

• RestSoft: a tool for analysis and simulation → background models
  • Structure
  • RestG4 simulation and input
  • How to continue using restEvents and restProcesses
  • The AnalysisTree for observables, cuts and event selection.

• TREX-DM: a simple analysis and background model
• IAXO-DO: a deeper analysis and background model
• Conclusions
T-REX Project (Rare Event eXperiments)

- Gas TPCs offer high potential for rare event through signal topology.
- Novel readout techniques based on MPGD
  - High granularity readout → Rich topological information
- T-REX to merge MPGDs (=Micromegas) + low background expertise.
- Focused on exploratory R&D and small scale prototyping
What are rare event searches?

**Neutrinoless double beta decay**

- A signal event:
  - 1 two blob track
  - Around Q energy

**WIMPs**

- Q value
- 1 cluster
- Low energy

**Solar Axions**

- 1 X-Ray cluster
- Low energy

_TREX-BB_  
_PANDAX-III_

**TREXDM**

CAST

IAXO

G. Luzón, Low Radioactivity Techniques 2019, 20-23 May, Jaca (Spain)
The IAXO-D0 setup at Zaragoza

IAXO detector prototype
- Ar or Xe+ quencher, 1.4 bar, 3cm drift
- Shielding, material screening

Goals
- Background level: $10^{-7}$-$10^{-8}$ counts keV$^{-1}$ cm$^{-2}$ s$^{-1}$
- Energy threshold: $\sim 0.1$ keV

Micromegas detector
- Same design as CAST XRT-MM detector: excellent performance features
- AGET-based electronics: auto-trigger for every readout channel

6cm x 6cm, 2x 104 strips, 0.475mm width, 0.5mm pitch
A Micromegas TPC for low mass WIMP detection

- ~20 l of pressurized gas at 10 bar (flexible target: ~0.3 kg Ar, ~0.16 kg Ne), 2 volumes, 16.5 cm drift
- Shielding, material screening

**Goals:**

low energy threshold (< 1 keV) and low background level (~1 (keV kg day)$^{-1}$).

NOT focused in directionality → operation at high pressure.

**Microbulk Micromegas readouts:** the largest surface (~25x25 cm$^2$) ever produced with this technology

- AGET-based electronics:
  - auto-trigger for every readout channel
Collaborative software (under Gitlab)

Developed by the group of the Área de Física Nuclear y de Partículas of the Department of “Física Teórica” in the University of Zaragoza, part of the recently created “Centro de Astropartículas y Física de Altas Energías”

Objectives

- Detector design in GDML
- Simulation of particle interactions in materials
- Simulation of physics processes in the detector.
- Storage, visualisation, and data analysis.
- Used in experiment involving axion searches (CAST, IAXO), double beta decay (TREX-BB, PANDAX-III) or Dark Matter (TREX-DM) in the framework of TREX project http://gifna.unizar.es/trex/
- Application to other projects for academic purposes
The REST structure

REST METADATA
Configuration data

REST EXTERNAL
Imported libraries

REST CORE
Main base classes

REST EVENTS
Event data types
- TRestG4Event
- TRestSignalEvent
- TRestHitsEvent
- TRestTrackEvent

REST VIEWERS
Event viewers

REST PROCESSES
Event processes
Analysis processes → Observables

7 libraries

Several scripts

2 programs

REST G4
Launch Geant4 simulation

REST MANAGER
Launch the process and plot task

REST PLOTS
Plots and “cuts” of observables

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GDML Geometry

REST G4

Detailed readout
Input data

Geant4 materials

Input sources
- Particles: gamma, neutron, muon, electron …
- Isotopes (ground or excited level, chains ..)
- Cosmic neutrons
- Cosmic and underground muons
- Cosmic gammas
- Radiactivity neutrons
- Angular distributions
  - Isotrope
  - Flux
  - Histogram

Source origin
- Any GDML volume
- A virtual plane
- A virtual Sphere
- A point

Geant4 Physics List

<physicsList name="G4EmLivermorePhysics"/>
<physicsList name="G4EmPenelopePhysics"/>
<physicsList name="G4EmStandardPhysics_option3"/>
<physicsList name="G4DecayPhysics">
  <option name="ICM" value="true"/>
  <option name="ARM" value="true"/>
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<physicsList name="G4HadronElasticPhysicsHP"/>
<physicsList name="G4IonBinaryCascadePhysics"/>
<physicsList name="G4HadronPhysicsQGSP_BIC_HP"/>
<physicsList name="G4NeutronTrackingCut"/>
<physicsList name="G4EmExtraPhysics"/>
</TRestPhysicsLists>

Sensitive and active volumes

<storage sensitiveVolume="gas">
  <parameter name="energyRange" value="(0,3)" units="MeV"/>
  <activeVolume name="gas" chance="1"/>
  <activeVolume name="Vessel" chance="1"/>
  <activeVolume name="OutLeadShield" chance="1"/>
  <activeVolume name="OutLeadTopShield" chance="1"/>
  <activeVolume name="OutCopperShield" chance="1"/>
  <activeVolume name="OutCopperTopShield" chance="1"/>
</storage>
Radiopurity data

Continuous screening campaign (mostly in Canfranc)

Sample of copper from vessel with same exposure to cosmic rays screened to quantify activation and also possible $^{210}$Pb surface contamination from radon plate-out.

Final silicone connectors from Fujipoly company used in the present set-up analyzed, confirming reduced activity (factor 32 in $^{232}$Th, 3 in $^{226}$Ra) in comparison to first connectors.

And of course, a lot of effort has been devoted to study the radiopurity of MM

See Poster by S. Cebrián
“Radioassay Program for Rare Event experiments using Micromegas”
How to proceed

Let’s continue

Signal observables
- Base line
- Rise time
- Rise slope
- Number of signals
- Signals over threshold

Geant4 observables
- Energy in gas
- Energy in active volumes
- Type of interaction
- Particles involved
- ...

Hit observables
- Energy
- Size
- Shape, symmetry
- Position
- Fiducial volume
- ...

Track observables
- Number of tracks
- Length
- ...

EVENT SELECTION

ANALYSIS

ANALYSIS

ANALYSIS

Readout Information

TRestSignalEvent || TRestG4Event

TRestHitsEvent

TRestTrackEvent

G. Luzón, Low Radioactivity Techniques 2019, 20-23 May, Jaca (Spain)
TREXDM: A “simple” analysis

- Two observables
  - Number of tracks ==1
  - XY fiducial \(\rightarrow\) 2cm far from the walls

![Graph showing energy distribution with cuts in main contributions and a reduction of ~30% -50%.](image-url)
Background rates in 0.2-7 keV$_{ee}$ in c keV$^{-1}$ kg$^{-1}$ d$^{-1}$ (**)

- From primordial/cosmogenic activity in components inside or close to the vessel

<table>
<thead>
<tr>
<th>Component</th>
<th>Argon</th>
<th>Neon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel (primordial)</td>
<td>&lt;0.095</td>
<td>&lt;0.114</td>
</tr>
<tr>
<td>Vessel (cosmogenic)</td>
<td>1.31</td>
<td>1.69</td>
</tr>
<tr>
<td>Copper Boxes (primordial)</td>
<td>&lt;0.020</td>
<td>&lt;0.020</td>
</tr>
<tr>
<td>Copper Boxes (cosmogenic)</td>
<td>0.026</td>
<td>0.029</td>
</tr>
<tr>
<td>Field Cage (PTFE)</td>
<td>&lt;0.036</td>
<td>&lt;0.052</td>
</tr>
<tr>
<td>Field Cage (resistors)</td>
<td>&lt;0.34</td>
<td>&lt;0.48</td>
</tr>
<tr>
<td>Field Cage (kapton-Cu PCB)</td>
<td>&lt;1.12</td>
<td>&lt;1.54</td>
</tr>
<tr>
<td>Field Cage (cable)</td>
<td>&lt;0.027</td>
<td>&lt;0.037</td>
</tr>
<tr>
<td>Cathode (copper)</td>
<td>&lt;3\times10^{-6}</td>
<td>&lt;4\times10^{-6}</td>
</tr>
<tr>
<td>Cathode (PTFE)</td>
<td>&lt;1.0\times10^{-4}</td>
<td>&lt;1.4\times10^{-4}</td>
</tr>
<tr>
<td>Flat Cables</td>
<td>&lt;0.0071</td>
<td>&lt;0.0084</td>
</tr>
<tr>
<td>Connectors</td>
<td>0.083</td>
<td>0.022</td>
</tr>
<tr>
<td>Epoxy</td>
<td>&lt;0.0028</td>
<td>&lt;0.00094</td>
</tr>
<tr>
<td>Mesh Cable</td>
<td>&lt;3.4\times10^{-4}</td>
<td>&lt;1.8\times10^{-4}</td>
</tr>
<tr>
<td>Other PTFE Components</td>
<td>&lt;0.019</td>
<td>&lt;0.027</td>
</tr>
<tr>
<td>Readout Planes</td>
<td>&lt;2.30</td>
<td>&lt;2.68</td>
</tr>
<tr>
<td>Target ($^{39}$Ar)</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Total from internal components</td>
<td>&lt;5.5</td>
<td>&lt;6.6</td>
</tr>
<tr>
<td>Total from quantified internal activity</td>
<td>3.73±0.36</td>
<td>4.20±0.43</td>
</tr>
</tbody>
</table>

68(64)% from activities actually quantified

Cu vessel activated after a few years at sea level:
(0.24±0.05) mBq/kg of $^{60}$Co from dedicated measurement → contribution (24% of the total) could suppressed for a new vessel

1 month exposure, 0.01 mBq/kg → 0.06(0.07) c keV$^{-1}$ kg$^{-1}$ d$^{-1}$ for Ar(Ne), reduction by a factor 22

Low contribution from silicone connectors or PTFE

Measured $^{40}$K in Micromegas, related to kapton etching

$^{39}$Ar activity for underground argon (as DarkSide)
Background model: external contributions

Background rates in 0.2-7 keV$_{ee}$ in counts keV$^{-1}$ kg$^{-1}$ d$^{-1}$ (**)

- From primordial/cosmogenic activity in components outside the vessel and background at the lab

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<td>Cosmic ray 60Co in Cu shielding</td>
<td>0.0250±0.0018</td>
<td>0.0288±0.0070</td>
</tr>
<tr>
<td>222Rn in air</td>
<td>0.1495±0.0024</td>
<td>0.0841±0.0013</td>
</tr>
<tr>
<td>Surface 210Pb on Cu vessel</td>
<td>&lt;5.5×10^{-3}</td>
<td>&lt;6.2×10^{-3}</td>
</tr>
<tr>
<td>Surface 210Pb on Cu shielding</td>
<td>&lt;0.025</td>
<td>&lt;0.034</td>
</tr>
<tr>
<td>Muons (+ muon-induced neutrons)</td>
<td>0.205±0.021</td>
<td>0.336±0.034</td>
</tr>
<tr>
<td>Neutrons at LSC</td>
<td>(2.52±0.22)×10^{-2}</td>
<td>(7.06±0.61)×10^{-2}</td>
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<tr>
<td>Neutrons from 238U fission in Pb</td>
<td>(5.82±0.39)×10^{-5}</td>
<td>(1.09±0.074)×10^{-4}</td>
</tr>
<tr>
<td>Neutrons from 238U fission in Cu</td>
<td>&lt;2.1×10^{-6}</td>
<td>&lt;4.1×10^{-6}</td>
</tr>
<tr>
<td>Radiogenic neutrons</td>
<td>&lt;5.6×10^{-4}</td>
<td>&lt;1.1×10^{-3}</td>
</tr>
<tr>
<td>(Cu, PTFE, steel, polyethylene)</td>
<td>&lt;0.43</td>
<td>&lt;0.56</td>
</tr>
<tr>
<td>Total from external components</td>
<td>0.40±0.02</td>
<td>0.52±0.03</td>
</tr>
<tr>
<td>Total from quantified sources</td>
<td></td>
<td></td>
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Contribution from muons and environmental neutrons under control assuming:
- Neutrons as measured at LSC, with evaporation spectrum and including a 40-cm-thick moderator.
- Measured flux of muons at LSC, considering the energy spectrum and angular distribution from parameterizations corresponding to the depth of Canfranc → muon contribution non-dominant, even without a muon veto, thanks to discrimination methods based on signal topology.

Measured $^{222}$Rn activity of (63±1) Bq/m$^3$ at LSC reduced by a factor 100

(*** up to 16.3 keV$_{nr}$ for Ar, 17.1 keV$_{nr}$ for Ne)
Background model: external contributions

**Background rates** in 0.2-7 keV$_{ee}$ in counts keV$^{-1}$ kg$^{-1}$ d$^{-1}$ (**)

- From primordial/cosmogenic activity in components outside the vessel and background at the lab

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<td>0.52±0.03</td>
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</table>

Radon-induced activity:
<0.32 mBq/cm$^2$ of $^{210}$Pb from a direct germanium measurement on exposed copper

TREX-DM expected background: 1 - 10 c/keV/kg/d

Background assessment for the TREX Dark Matter experiment → sent for publication
https://arxiv.org/abs/1812.04519

(**) up to 16.3 keV$_{nr}$ for Ar, 17.1 keV$_{nr}$ for Ne
IAXO-D0: tracks+ fiducial +topological cuts

x-rays [1-10] keV versus cosmic muons (black lines)

G. Luzón, Low Radioactivity Techniques 2019, 20-23 May, Jaca (Spain)
### Internal contribution results

#### Shielding

<table>
<thead>
<tr>
<th>Isótopo</th>
<th>Actividad (Bq/kg)</th>
<th>Actividad (Bq/m²)</th>
<th>Ar+2% iso Fondo</th>
<th>Errores</th>
<th>Xe+1% iso Fondo</th>
<th>Errores</th>
</tr>
</thead>
<tbody>
<tr>
<td>U238</td>
<td>&lt;3.30×10⁻⁴</td>
<td>&lt;6.07×10⁻⁴</td>
<td>&lt;12.27×10⁻¹0</td>
<td>-</td>
<td>&lt;1.36×10⁻¹0</td>
<td>-</td>
</tr>
<tr>
<td>Th232</td>
<td>&lt;1.00×10⁻⁵</td>
<td>&lt;1.84×10⁻⁴</td>
<td>&lt;8.45×10⁻¹0</td>
<td>-</td>
<td>&lt;7.61×10⁻¹0</td>
<td>-</td>
</tr>
<tr>
<td>K40</td>
<td>&lt;1.20×10⁻⁴</td>
<td>&lt;2.21</td>
<td>&lt;1.85×10⁻¹0</td>
<td>-</td>
<td>&lt;2.42×10⁻¹0</td>
<td>-</td>
</tr>
<tr>
<td>b</td>
<td>136.93 Pb210</td>
<td>80</td>
<td>1.1×10¹⁴</td>
<td>+</td>
<td>5.42×10⁻¹2</td>
<td>+</td>
</tr>
</tbody>
</table>

#### Cu-Chamber

<table>
<thead>
<tr>
<th>Isótopo</th>
<th>Actividad (Bq/kg)</th>
<th>Actividad (Bq/m²)</th>
<th>Ar+2% iso Fondo</th>
<th>Errores</th>
<th>Xe+1% iso Fondo</th>
<th>Errores</th>
</tr>
</thead>
<tbody>
<tr>
<td>U238</td>
<td>&lt;6.20×10⁻⁵</td>
<td>&lt;1.09×10⁻⁴</td>
<td>&lt;1.25×10⁻¹1</td>
<td>-</td>
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<tr>
<td>Th232</td>
<td>&lt;2.00×10⁻⁵</td>
<td>&lt;3.52×10⁻⁵</td>
<td>&lt;5.26×10⁻¹2</td>
<td>-</td>
<td>&lt;1.62×10⁻¹2</td>
<td>-</td>
</tr>
<tr>
<td>K40</td>
<td>~ 0</td>
<td>~</td>
<td>~</td>
<td>-</td>
<td>~</td>
<td>-</td>
</tr>
<tr>
<td>Co60</td>
<td>5.25×10⁻⁴</td>
<td>9.25×10⁻⁴</td>
<td>9.40×10⁻¹0</td>
<td>2.28×10⁻¹1</td>
<td>3.26×10⁻¹0</td>
<td>4.25×10⁻¹1</td>
</tr>
<tr>
<td>U238</td>
<td>&lt;6.20×10⁻⁵</td>
<td>&lt;1.72×10⁻⁴</td>
<td>&lt;7.96×10⁻¹1</td>
<td>-</td>
<td>&lt;1.44×10⁻¹1</td>
<td>-</td>
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<tr>
<td>Th232</td>
<td>&lt;2.00×10⁻⁵</td>
<td>&lt;5.55×10⁻⁵</td>
<td>&lt;2.20×10⁻¹0</td>
<td>-</td>
<td>&lt;1.42×10⁻¹0</td>
<td>-</td>
</tr>
<tr>
<td>K40</td>
<td>~ 0</td>
<td>~</td>
<td>~</td>
<td>-</td>
<td>~</td>
<td>-</td>
</tr>
<tr>
<td>Co60</td>
<td>5.25×10⁻⁴</td>
<td>1.46×10⁻³</td>
<td>4.36×10⁻¹0</td>
<td>8.72×10⁻¹1</td>
<td>6.80×10⁻¹0</td>
<td>1.69×10⁻¹0</td>
</tr>
<tr>
<td>U238</td>
<td>&lt;6.20×10⁻⁵</td>
<td>&lt;1.63×10⁻⁴</td>
<td>&lt;6.18×10⁻¹2</td>
<td>-</td>
<td>&lt;3.89×10⁻¹2</td>
<td>-</td>
</tr>
<tr>
<td>Th232</td>
<td>&lt;2.00×10⁻⁵</td>
<td>&lt;5.04×10⁻⁵</td>
<td>&lt;1.14×10⁻¹1</td>
<td>-</td>
<td>&lt;1.61×10⁻¹1</td>
<td>-</td>
</tr>
<tr>
<td>K40</td>
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<td>~</td>
<td>~</td>
<td>-</td>
<td>~</td>
<td>-</td>
</tr>
<tr>
<td>Co60</td>
<td>4.59×10⁻⁴</td>
<td>3.73×10⁻⁸</td>
<td>1.20×10⁻⁷</td>
<td>2.32×10⁻¹1</td>
<td>3.57×10⁻⁹</td>
<td>3.99×10⁻¹0</td>
</tr>
</tbody>
</table>

#### Pipe

<table>
<thead>
<tr>
<th>Isótopo</th>
<th>Actividad (Bq/kg)</th>
<th>Actividad (Bq/m²)</th>
<th>Ar+2% iso Fondo</th>
<th>Errores</th>
<th>Xe+1% iso Fondo</th>
<th>Errores</th>
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<td>-</td>
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#### Cathode

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</tbody>
</table>

#### Teflon Chamber

<table>
<thead>
<tr>
<th>Isótopo</th>
<th>Actividad (Bq/kg)</th>
<th>Actividad (Bq/m²)</th>
<th>Ar+2% iso Fondo</th>
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<tbody>
<tr>
<td>U238</td>
<td>&lt;6.20×10⁻⁵</td>
<td>&lt;5.04×10⁻⁵</td>
<td>&lt;6.18×10⁻¹2</td>
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<tr>
<td>Th232</td>
<td>&lt;2.00×10⁻⁵</td>
<td>&lt;5.04×10⁻⁵</td>
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<tr>
<td>K40</td>
<td>~ 0</td>
<td>~</td>
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<td>~</td>
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</tr>
<tr>
<td>Co60</td>
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<td>3.73×10⁻⁸</td>
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#### Kapton Readout

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#### Gas

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### 20 muons (0.2 – 328 GeV):
- Energy range: [0,10] keV
- Area: 6.67 cm² (central 2.6x2.6 cm square)
- Time: 12.12h
- 125 mu/m² s

A few $10^{-6}$ counts/keV/ cm²/s

A reduction of more than 4 orders: long tracks crossing the walls

### 25 neutrons (10 MeV – 1 GeV):
- Energy range: [0,10] keV
- Area: 6.67 cm² (central 2.6x2.6 cm square)
- Time: 3.1h
- 50 m/m² s

$< 10^{-6}$ counts/keV/ cm²/s

Reductions around 1 order: tracks distributed in the volume

### 42 high energy neutrons (1-10 GeV):
- Energy range: [0,10] keV
- Area: 6.67 cm² (central 2.6x2.6 cm square)
- Time: 84.9h
- 0.1 n/m² s

$< 10^{-7}$ counts/keV/ cm²/s
Experimental Background level

- Characterization of x-rays with REST observables:
  - 1 track
  - 2 tracks (99% of the total energy)
  - Small, punctual and symmetric energy deposits
  - Centre of the readout (fiducial cut)

- Preliminary background level
  - $1.45 \times 10^{-6}$ counts/(keV · cm² · s)
  → Better x-ray characterization

- Still room to improve
  - Better cuts
  - Less noise
  - Muon vetoes

Central area of the readout: 0.85 x 0.85 cm²
Results

• Background

• Ar+2% iso
  ➢ data from quantified activities $\Rightarrow b = (4.3 \pm 0.9) \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$
  $b_{\text{Ar}_{39}} = (3.9 \pm 0.9) \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$ (~90%)
  ➢ data from upper limit $\Rightarrow b < 1.6 \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$
  ➢ low statistics $^{210}\text{Pb} \Rightarrow b < 6.4 \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$

• Measured level $1.45 \times 10^{-6} \text{ counts/keV/cm}^2/\text{s}$ $\Rightarrow$ Most of it attributed to cosmic muons

• Xenon+1% iso
  ➢ data from quantified activities $\Rightarrow b = (1.1 \pm 0.1) \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$
  ➢ data from upper limit $\Rightarrow b < 4.6 \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$
  ➢ low statistics $^{210}\text{Pb} \Rightarrow b < 6.4 \times 10^{-8} \text{ c/keV/cm}^2/\text{s}$

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Summary and next steps

- Understanding background and signal is compulsory for rare event experiments
- MPGDs offer an access to the rich topology of the events
- Measurements and control of the radiopurity of materials is mandatory
- Software tools as RESTSoft can be modelled and adapted to any purpose for acquisition and simulation, in experiments or in academia
- RESTSoft has been used to build the IAXO-D0 and TREX-DM background models as well as it is currently being used for acquisition and offline analysis

<table>
<thead>
<tr>
<th>TREX-DM</th>
<th>IAXOD0</th>
</tr>
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</table>
| - Neutron calibration  
- Use of topological observables  
- Deeper analysis of current background data in Neon | - Better x-ray characterization (Fe55 calibration)  
- Use signal observables information  
- Measurements with Xenon + Isobutane  
- Deeper study of muons and cosmic neutrons (principal contributions)  
- Xenon + Isobutane model |
Thank you for your attention

• This presentation has used material prepared by S. Cebrian, C. Margalejo and E. Ruiz-Chóliz