The XENON1T Computing Scheme

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CERN

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The XENON1T Collaboration

What are we doing:
Looking for particle Dark Matter with 3.5 tons of liquid xenon in a dual phase time projection chamber (TPC)

A worldwide collaboration:*
• 25 institutes
• 155 members

*Latest count: February 2018

Collaboration Meeting in January 2018 (Florence)
The XENON Dark Matter Experiment (I)

- Full 3D and energy reconstruction!
- Data taking: 24/7 (including calibrations)
- S1 and S2 allow signal discrimination for electronic recoil (ER) and nuclear recoil (NR)
- Data taking rate: ~ 5 Hz
The XENON Dark Matter Experiment (II)

XENON10

- Mass: 25 kg
- Height: 15 cm
- PMTs: 89

XENON100

- Lifetime: 2008-2016
- Mass: 161 kg
- Height: 30 cm
- PMTs: 242

XENON1T

- Lifetime: 2012-2018
- Mass: 3200 kg
- Height: 100 cm
- PMTs: 248

XENONnT

- Lifetime: 2019-20??
- Mass: ~8000 kg
- Height: 144 cm
- PMTs: 476

Continuously improved in sensitivity!

But also improved in:
- Data handling
- Computing
- Analysis
### From XENON100 to XENON1T

<table>
<thead>
<tr>
<th></th>
<th>What we did in XENON100</th>
<th>What we do in XENON1T</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw data storage</strong></td>
<td>Dedicated disk space at the LNGS</td>
<td>Dedicated GRID endpoints at:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• European Grid Interface (EGI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Open Science Grid (OSG)</td>
</tr>
<tr>
<td><strong>Raw data processing</strong></td>
<td>A few reprocessing campaigns at the LNGS</td>
<td>Several reprocessing campaigns on EGI and OSG</td>
</tr>
<tr>
<td><strong>Data analysis</strong></td>
<td>Processed data sets were available at the LNGS:</td>
<td>Center for data analysis at Research Computing Center (RCC) Chicago:</td>
</tr>
<tr>
<td></td>
<td>• For analysis</td>
<td>• Reduced data sets available</td>
</tr>
<tr>
<td></td>
<td>• Download to institutes or analysts computers</td>
<td>• Jupyterhub server for analysts</td>
</tr>
<tr>
<td><strong>GRID usage</strong></td>
<td>Monte Carlo production</td>
<td>Processing, storage and Monte Carlo</td>
</tr>
<tr>
<td><strong>Software &amp; Tools</strong></td>
<td>C++/ROOT</td>
<td>• Python 3</td>
</tr>
<tr>
<td></td>
<td>Homemade tools (e.g. for reprocessing)</td>
<td>• Jupyter notebooks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Homemade tools &amp; Rucio</td>
</tr>
<tr>
<td><strong>Tape storage</strong></td>
<td>LNGS</td>
<td>Center for High Performance Computing (PDC, Stockholm)</td>
</tr>
<tr>
<td><strong>Network</strong></td>
<td></td>
<td>Update to LHCOOne network (ongoing)</td>
</tr>
</tbody>
</table>
The XENON1T Raw Data Overview

<table>
<thead>
<tr>
<th>Source</th>
<th>Kr83m</th>
<th>Rn220</th>
<th>AmBe</th>
<th>LED</th>
<th>Th228</th>
<th>Neutron Generator</th>
<th>DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total size [TB]</td>
<td>40</td>
<td>85</td>
<td>67</td>
<td>30</td>
<td>3</td>
<td>12</td>
<td>332</td>
</tr>
<tr>
<td>Total lengths [h]</td>
<td>791</td>
<td>1141</td>
<td>802</td>
<td>245</td>
<td>13</td>
<td>51</td>
<td>10705</td>
</tr>
</tbody>
</table>

Data sets: 17141
Total time: 13748 hours
Total events: 830 M events
Total size: >571 TB
The XENON1T Data Workflow: Data at Three Stages:

I. Raw data uploaded to Rucio
   - **Tools:** PAX, CAX, RUCIAx
   - **Raw data:** Waveforms

II. Processing on OSG and EGI
   - **Tools:** PAX, CAX, DAG Man
   - **Processed files**
     - Contain reduced information
     - Much smaller
     - No waveforms
     - Re-created when important changes in PAX are made in reprocessing campaigns

III. Second processing on RCC Chicago
   - **Tools:** CAX, HAX
   - **Minitrees**
     - Created from processed files
     - Stored on RCC Chicago for the analyst
     - Contain corrections (e.g. for drift time)
     - Do not need a heavy reprocessing campaign

**Analysts:**
- Work with minitrees mainly
- Can define own minitrees for variables of interest from processed files
- Look at waveforms with a waveform watcher
The XENON1T Data Distribution:

- **DAQ Interprocess Communication @ LNGS**
- **DAQ Web Server @ LNGS**
- **Slow Control (Via DAQ API) @ LNGS**
- **XENON DAQ @ LNGS**
- **Detector Settings Run Information**
- **Data Storage @ LNGS**
- **Tivoli Storage Manager**
- **Tape Backup @ PDC Stockholm**
- **RUCIAx Software connecting XENON Runs DB, Rucio service, and Tape Backup**
- **Run Information for Data Analysis**

**Nodes and Services**
- **FTS @ UChicago**
- **Rucio DB**
- **Rucio Service @ UChicago**
- **Nikhef**
- **CNAF**
- **SURFSara**
- **Weizmann**
- **CCIN2P3**
- **Future Site**
- **XENON Node @ UChicago**
- **OSG dCache @ UChicago**
- **EGI**

**Networks and Interactions**
- **OSG**
- **CAX Software submitting jobs to OSG and EGI triggered by changes to XENON Runs DB**
- **Raw Data**
- **Processed Data**
- **Rucio DB Interactions**
- **Random Selected Element**
- **Jobs**

**Legend**

- **XENON Runs DB Interactions**

**Institutions**
- **Stockholm University**
- **UChicago Research Computing Center**
The XENON1T Data Distribution:

A Rucio server (VM) handles raw data transfers to several Rucio Storage Elements (RSE)

But data handling needs: RUCIAX and Rucio:

- Upload and download raw data
- Uploads run from LNGS only
- Analysts download small junks of raw data
- We “hide” Rucio command line interface from analysts
- Set and change transfer rules for many raw data sets if necessary
- Update the XENON runDB (@LNGS) regularly
- Remove uploaded raw data from LNGS data storage
The XENON1T Data Distribution:

CAX (several tasks):
- Allows to handle several and different tasks on many sites:
  - Job submission at XENON node @UChicago to: OSG, EGI, NSF, Supercomputers (e.g. Comet), and campus clusters (e.g. RCC)
  - Transfers processed data sets via scp to RCC Midway
  - Minor tasks and maintenance tools for XENON runDB
CAX-TSM:
Handles the tape backup with PDC Stockholm
- PDC Stockholm offers 2 PB of tape storage
- Tape server: Tivoli Storage Manager (TSM)
- Upload/download to data storage (@LNGS)
- Update the XENON runDB (@LNGS) once during the upload
The XENON1T Disk Allocation and Requirement

- Data have two copies:
  - US: OSG dCache at UChicago (hold only relevant data)
  - Europa: One of several computing centers
- Tape copy in Stockholm
- Independent from Rucio

- In total: ~2 PB available
- Distributed worldwide
- Connected to computing centers
RUCIAX, CAX, CAX-TSM are

- Part of the same toolbox CAX (Github)
  -> Several experts develop different parts
- Serve different purpose based on “tasks” (CAX) or applications (RUCIAX, CAX-TSM)
- Language: Python 3.x

The Toolbox

We needed to overcome the “language barrier” to talk to Rucio with RUCIAX

Several configurations but:
- Mounted: cmvms at several hosts to provide all our software tools
- Anaconda manages different Python versions
- Offers: CAX, RUCIAX, CAX-TSM, Rucio

For example:
RUCIAX is executed to update XENON runDB locations

Heavy usage of Rucio command line interface (CLI)
The XENON1T Data Acquisition

The XENON runDB (@LNGS) keeps track on meta information:
- Trigger information
- Time stamps
- Source
- Data locations and transfer status
- ...

A web interface allows us to check for:
- Data transfers status (Rucio and non-Rucio)
- Data processing status
Outlook: XENONnT (I):

We expect a larger data amount:
- Higher data taking rate
- More channels (TPC, MuonVeto, NeutronVeto)

~1.5 PB/year raw data in XENONnT

<table>
<thead>
<tr>
<th>Xenon1T</th>
<th>size**</th>
<th>XENONnT</th>
<th>size**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw data</td>
<td>25 GB</td>
<td>Raw data</td>
<td>50 GB</td>
</tr>
<tr>
<td>Processed data</td>
<td>2 GB</td>
<td>Reduced data</td>
<td>Conservative estimate: --&gt; 4x reduction</td>
</tr>
<tr>
<td>Minitrees</td>
<td>22 MB</td>
<td>Processed data</td>
<td>12.5 GB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Processed data</td>
<td>1 GB*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11 MB*</td>
</tr>
</tbody>
</table>

Comments:
- Upload to GRID and tape
- Purge raw data from GRID after successful first level processing
- Keep reduced data in Rucio for reprocessing campaigns
- Keep processed data in Rucio for minitree creation
- Minitrees for the analysts

*Assume Xenon1T reduction
** Example numbers for illustration
Outlook: XENONnT (II):

Update: Software
- Independent tool in Python 2.x to handle:
  - the extended data structure (reduced and processed data in Rucio)
  - RucioAPI instead of CLI
  - the tape storage (CLI for TSM)
- Independent tool for job submission
  - Job submission is adjusted according to reduced and processed data sets
- CAX to handle tasks (similar to XENON1T)

Update: Requirement on data safety (& tape)
- Keep latest raw data in Rucio on dedicated tape storage.
- Move older raw data to PDC/Stockholm
  - Allow quick first level reprocessing if necessary
Summary:

**XENON1T:**
- RUCIA\(\text{X}, \text{CAX-}\text{TSM}, \text{CAX}\) as part of the \text{CAX toolbox} handling several tasks regarding data management and processing
- Allocated disk space at the moment \(\sim 1\) PB
  (multiple copies, 7 RSEs worldwide)

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**XENONnT:**
- Dedicated tools for data management and processing
- The RUCIA\(\text{X}\) successor will be in Python 2.x (access RucioAPI)
- Independent PDC tape storage will be integrated in tape storage handling on dedicated RSEs
- Data processing is extended by another intermediate step:
  “Reduced raw data” \(\rightarrow\) Safe processing time and disk space
- Reduced raw data and processed data will be distributed by Rucio
- \text{PAX, HAX} (and more!) tools of XENON1T will be used again

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**Successful established:**
XENON1T takes still data!

**Schedule:**
“End of the year”
Thank you for your attention!

Stay tuned: XENON1T announces new results soon:
- Twitter: https://twitter.com/xenon1t
- Blog: https://www.xenon1t.org
Backup: An overview on our science runs campaigns (average)

Data sets: 17141
Total time: 13748 hours
Total events: 830 M events
Total size: 571 TB

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<th>Neutron Generator</th>
<th>DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Rate&gt; [Hz]</td>
<td>27.75</td>
<td>44.28</td>
<td>9.37</td>
<td>329</td>
<td>51</td>
<td>24</td>
<td>9.83</td>
</tr>
<tr>
<td>&lt;Event size&gt; [Mb/event]</td>
<td>0.848</td>
<td>0.68</td>
<td>2.55</td>
<td>0.13</td>
<td>2.97</td>
<td>2.65</td>
<td>1.87</td>
</tr>
<tr>
<td>&lt;Events/dataset&gt;</td>
<td>96918</td>
<td>137674</td>
<td>31384</td>
<td>164180</td>
<td>51231</td>
<td>81894</td>
<td>23705</td>
</tr>
<tr>
<td>&lt;Size&gt; [MB]</td>
<td>48806</td>
<td>64381</td>
<td>79305</td>
<td>18435</td>
<td>71748</td>
<td>216126</td>
<td>29685</td>
</tr>
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| Total size [TB]        | 40    | 85    | 67   | 30   | 3     | 12               | 332 |
| Total lengths [h]      | 791   | 1141  | 802  | 245  | 13    | 51               | 10705 |
Backup: Details on Processing:

- Raw data sets are organized in zip files of 100 events each
- DAGMan handles job submissions based on single zip files

Run <run number>
- file_001.zip
- file_002.zip
- file_....zip

Processing: PAX
At our connected computing centers

Run <run number>
- file_001.root
- file_002.root
- file_....root

Merge

File: run_number.root
- CAX moves it to RCC Chicago
- Create minitrees for analyst
Backup: XENON1T at the LNGS