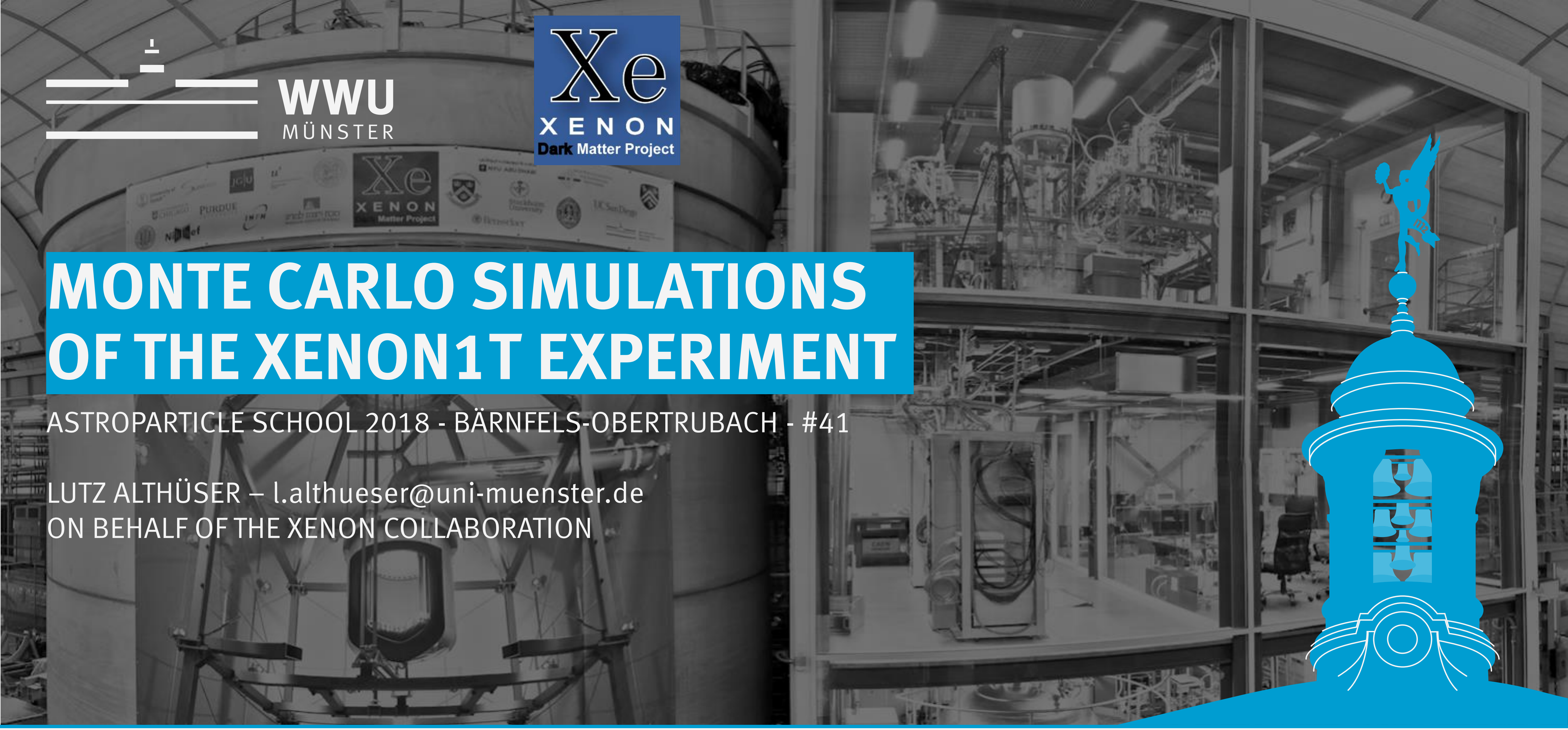


MONTE CARLO SIMULATIONS OF THE XENON1T EXPERIMENT

ASTROPARTICLE SCHOOL 2018 - BÄRNFELS-OBERTRUBACH - #41

LUTZ ALTHÜSER – l.althueser@uni-muenster.de
ON BEHALF OF THE XENON COLLABORATION

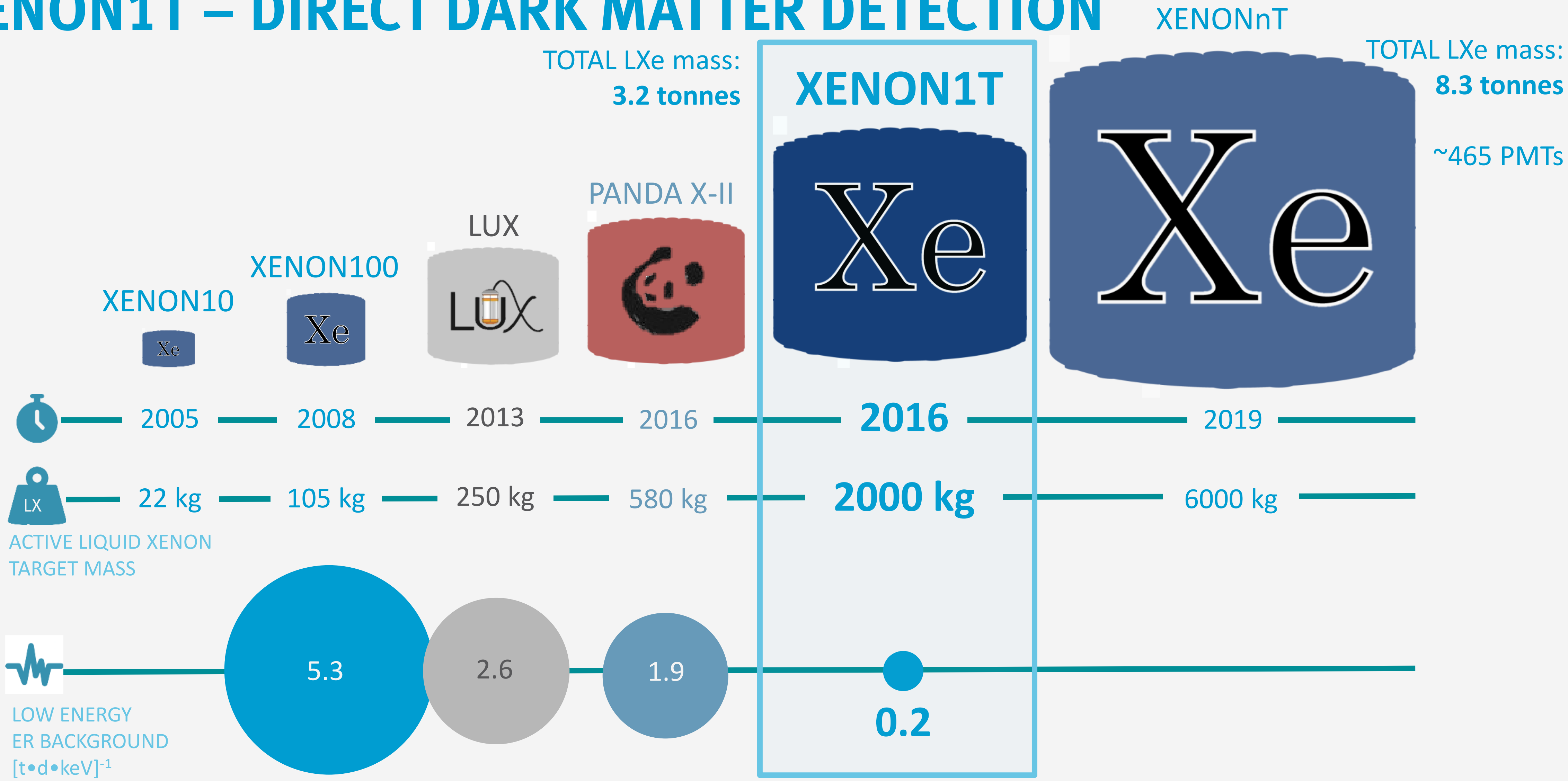
living.knowledge

Institut für Kernphysik
Westfälische Wilhelms-Universität Münster

XENON COLLABORATION

- ~165 SCIENTISTS
- 27 INSTITUTIONS
- 11 COUNTRIES

XENON1T – DIRECT DARK MATTER DETECTION

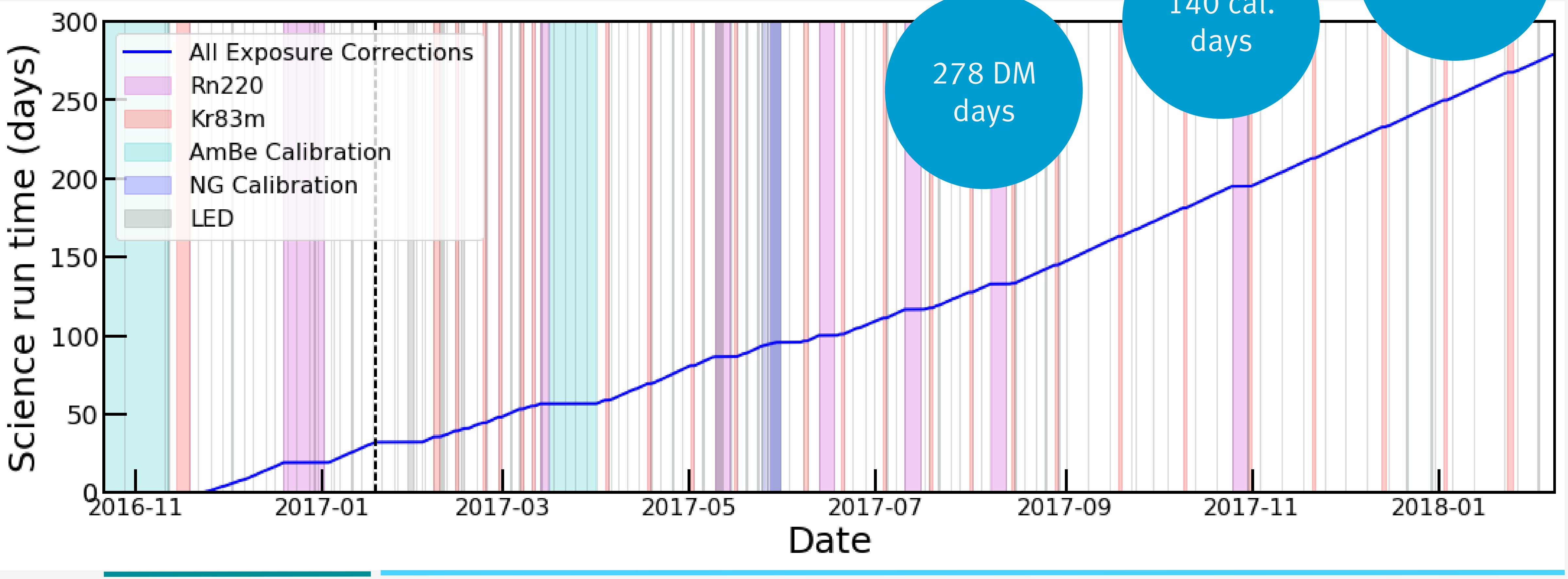


XENON1T – DIRECT DARK MATTER DETECTION

278 DM days

140 cal. days

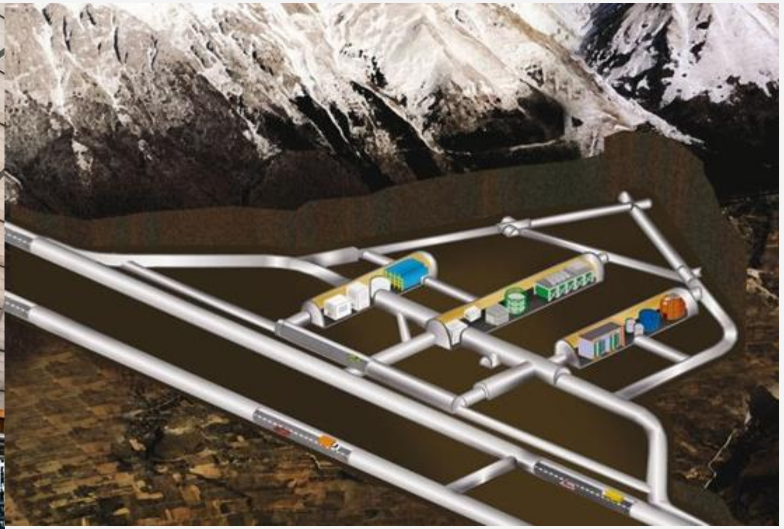
443 live days



SR0 (32 days)

SR1 (246 days)

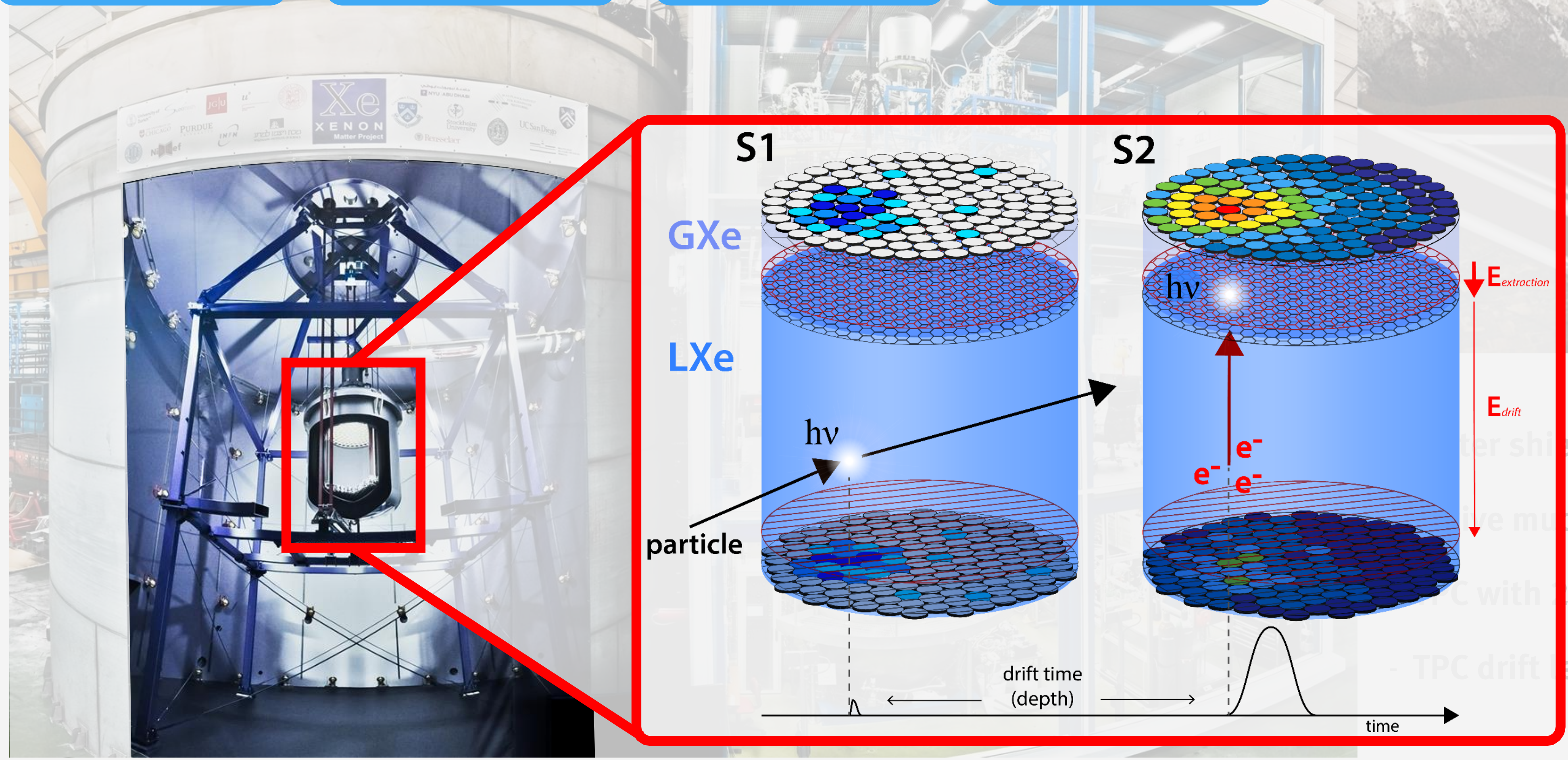
XENON1T – DIRECT DARK MATTER DETECTION

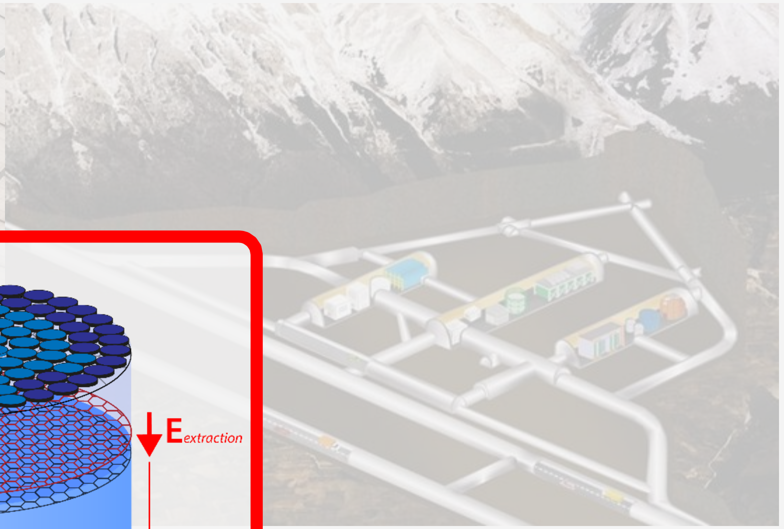


- Water shield (700 t high purity water)
- Active muon shield (84 8-inch PMTs)
- TPC with 2 t LXe (3.2 t total) and 248 3-inch PMTs (127 top / 121 bottom)
- TPC drift length and diameter ~1 m

WORKING PRINCIPLE OF THE TIME PROJECTION CHAMBER (TPC)

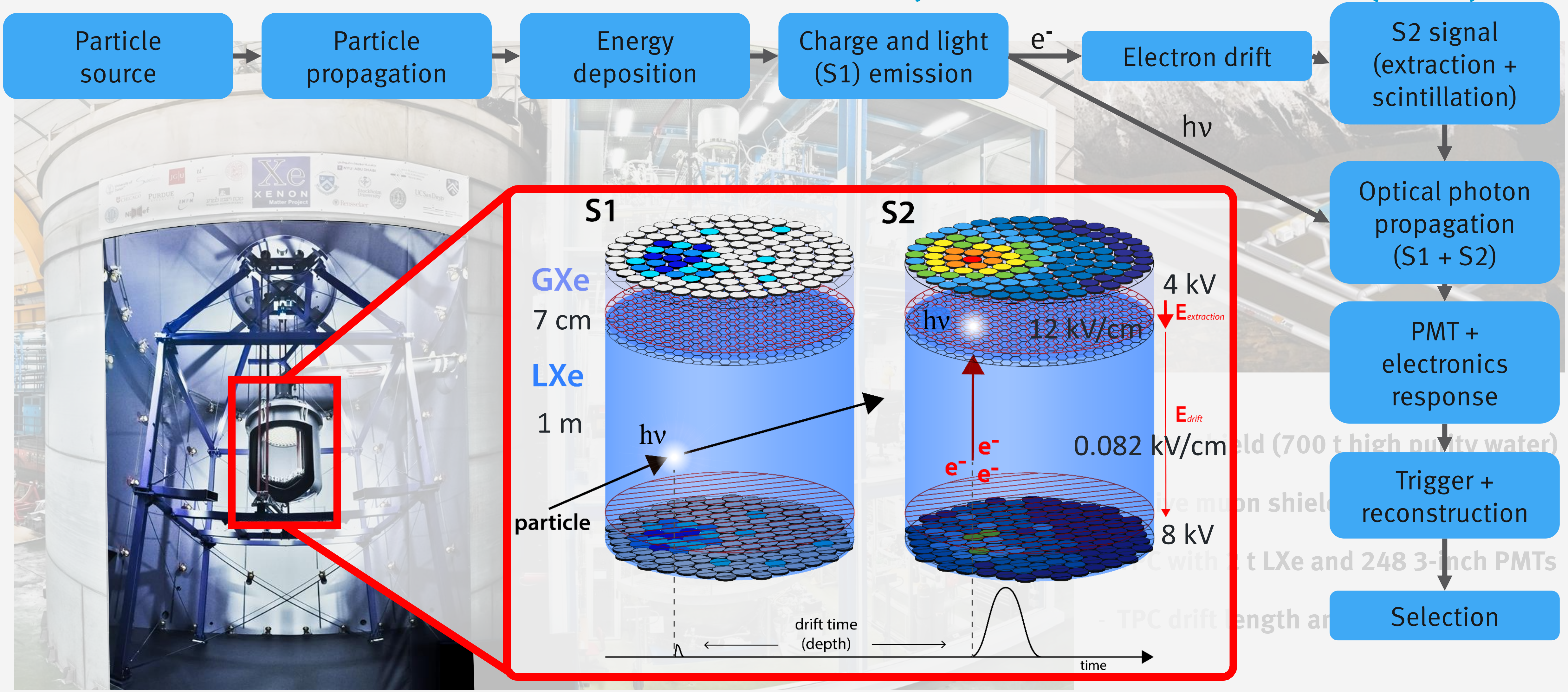
Particle source → Particle propagation → Energy deposition → Charge and light (S1) emission



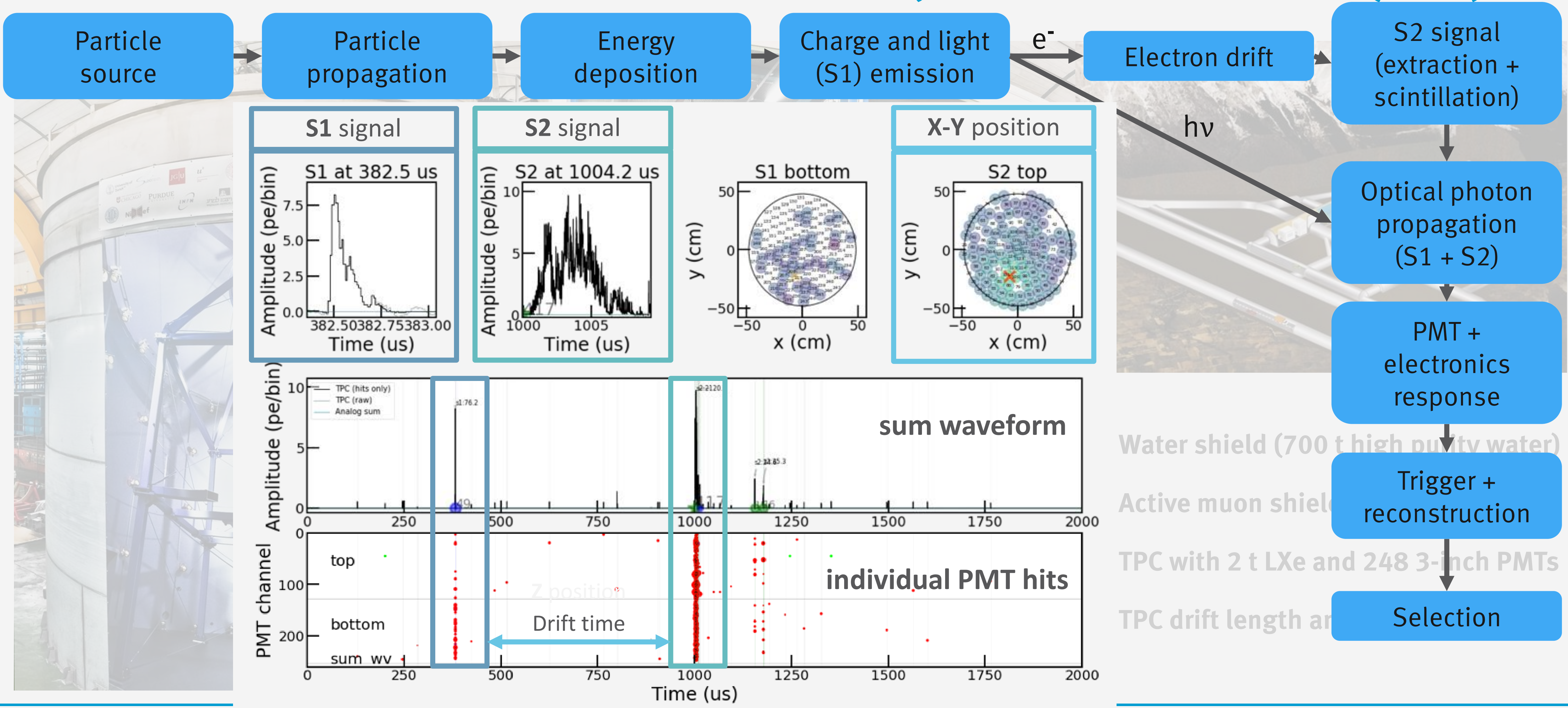


- ...er shield (700 t high purity water)
- ...e muon shield (84 8-inch PMTs)
- ...C with 2 t LXe and 248 3-inch PMTs
- TPC drift length and diameter ~1 m

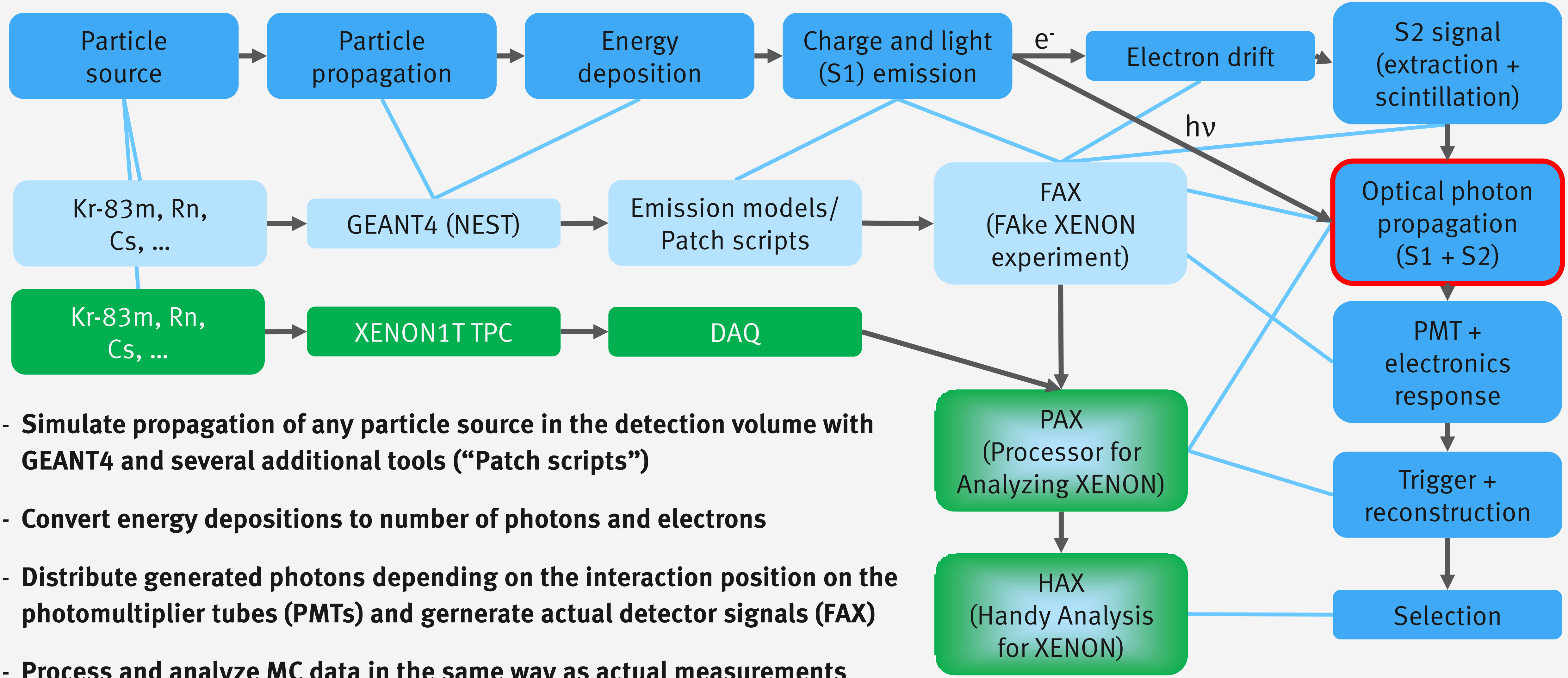
WORKING PRINCIPLE OF THE TIME PROJECTION CHAMBER (TPC)



WORKING PRINCIPLE OF THE TIME PROJECTION CHAMBER (TPC)



INTEGRATION OF THE MONTE CARLO TOOLS



- **Simulate propagation of any particle source in the detection volume with GEANT4 and several additional tools (“Patch scripts”)**
- **Convert energy depositions to number of photons and electrons**
- **Distribute generated photons depending on the interaction position on the photomultiplier tubes (PMTs) and gernerate actual detector signals (FAX)**
- **Process and analyze MC data in the same way as actual measurements**

Optical photon simulations in XENON1T

GEANT4

- Geometry implementation
- Definition of the particle source type
- Simulation of the optical response for S1 or S2
- Simulation of the energy depositions by generated particles

NEST

Noble **E**lement **S**imulation **T**echnique

- Included in GEANT4
- Patch for some GEANT4 radioactive decays (^{83m}Kr, …)
- Generation of electron and photon yields for FAX stage

Optical photon simulations

- Tuning GEANT4 stage with data
- Generation of per-PMT maps

Position reconstruction

- From S2 hit patterns

PAX

Processor for **A**nalyzing **X**enon

- Data processor for simulated and real data
- MC truth data is stored in addition to the regular output

FAX

FAke **X**enon experiment

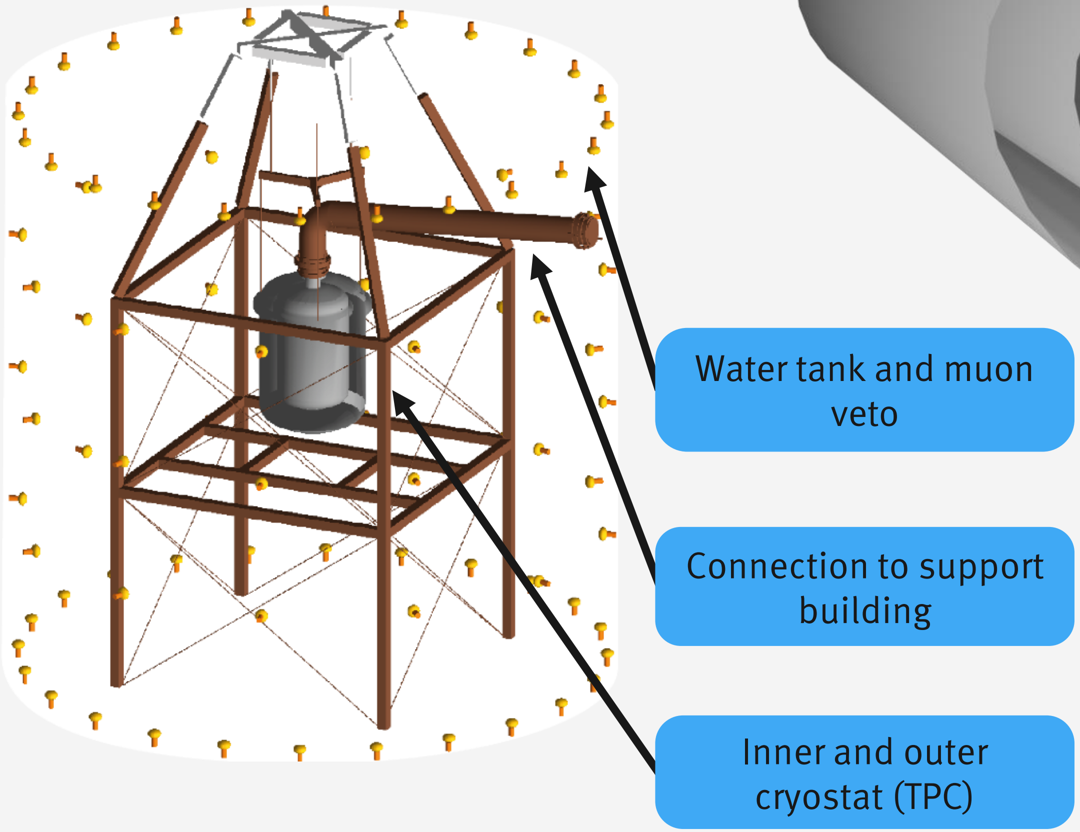
- Determines photon production times (S1, drift electrons and do S2, …) and hit patterns
- Makes ADC waveforms with respect to PMT and digitizer artefacts

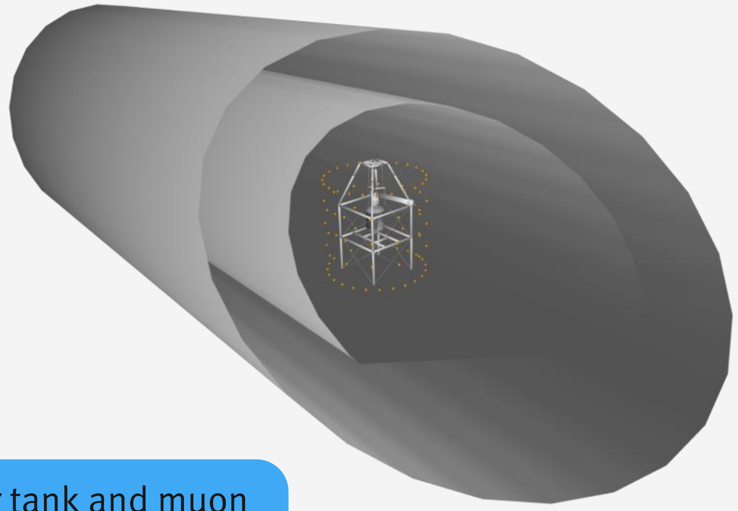
HAX

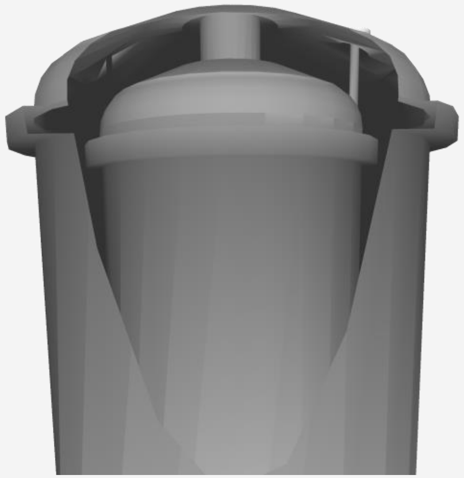
Handy **A**nalysis tools for **X**enon

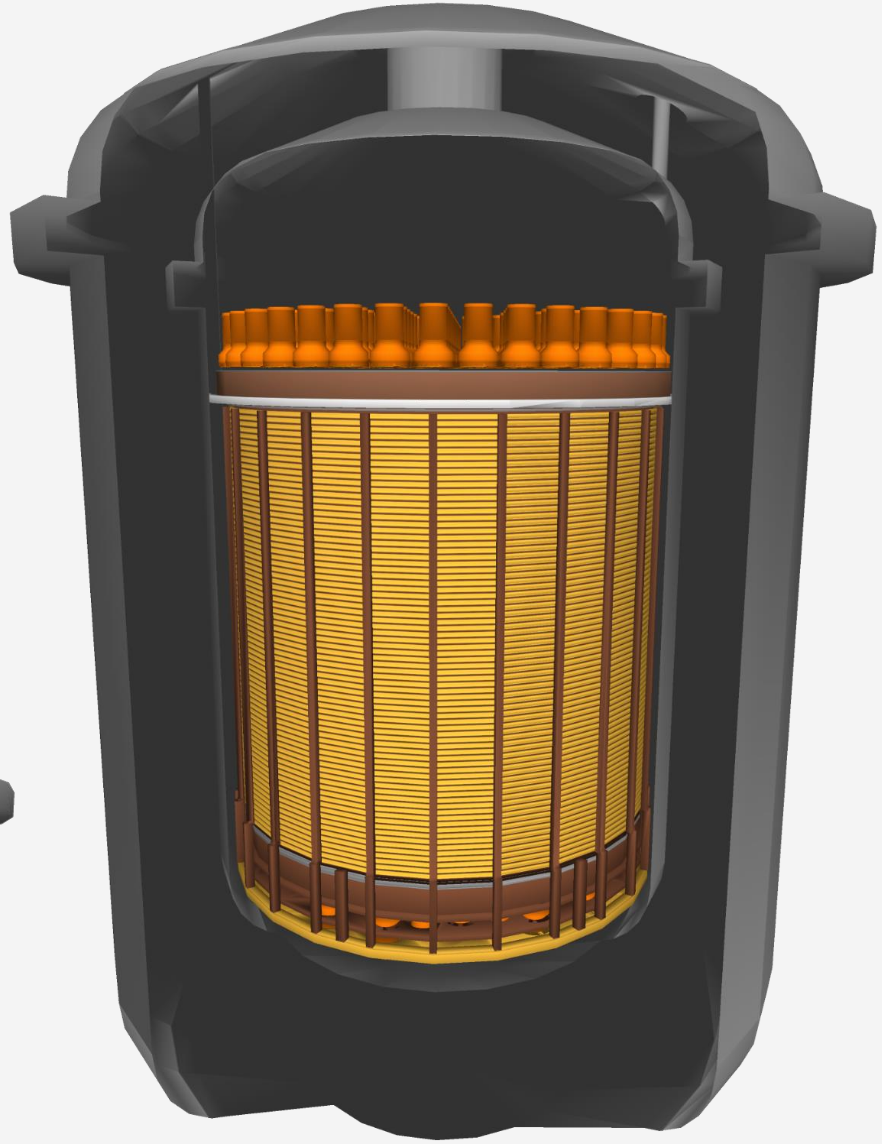
- **Distribution of photons on the PMTs is following per-PMT optical photon simulations with GEANT4**
- **GEANT4 optical simulations parameters (reflectivites, absorption lengths, …) are tuned by fitting MC simulations to Kr-83m measurements**

GEANT4 SIMULATION GEOMETRY

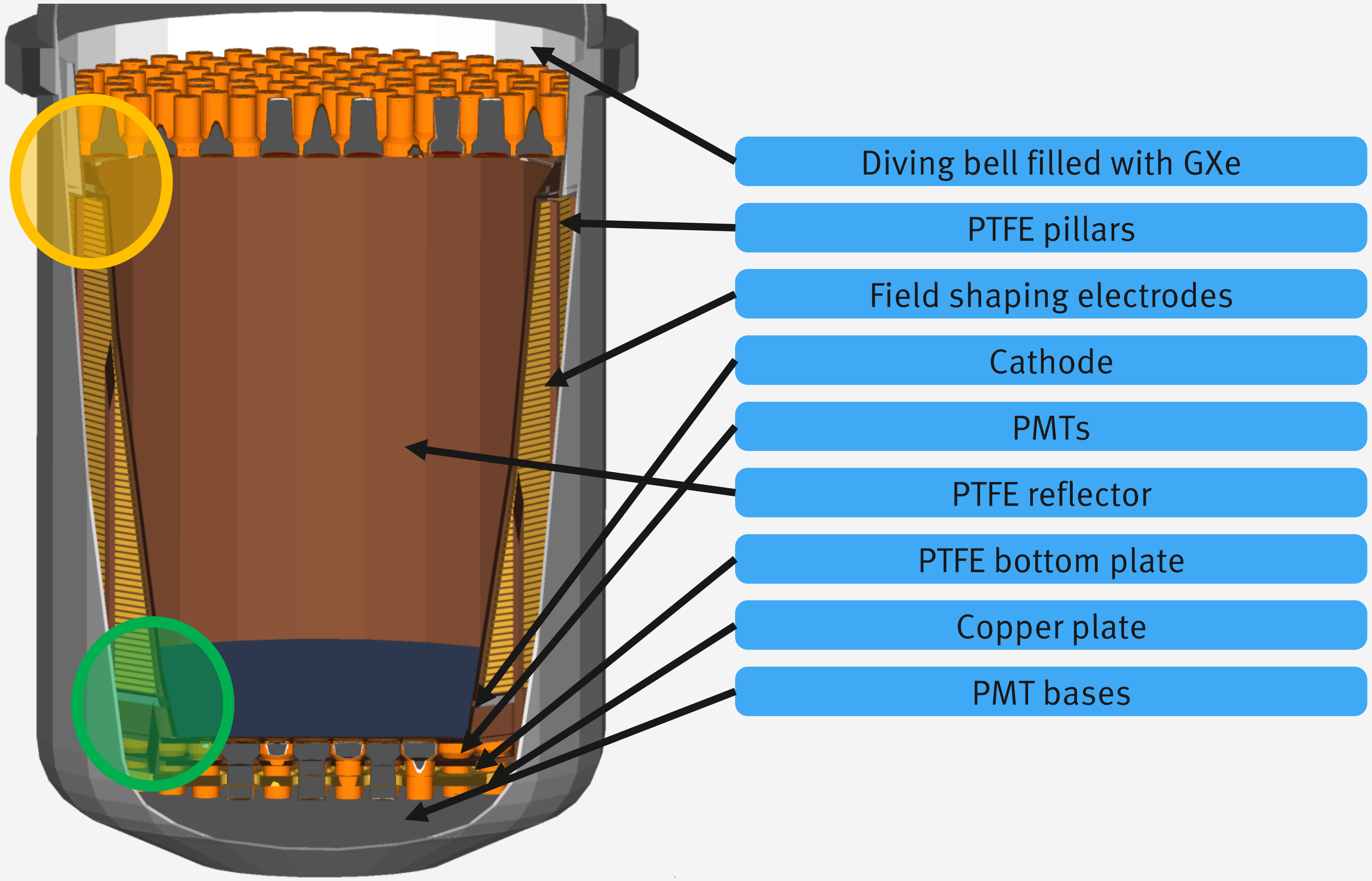


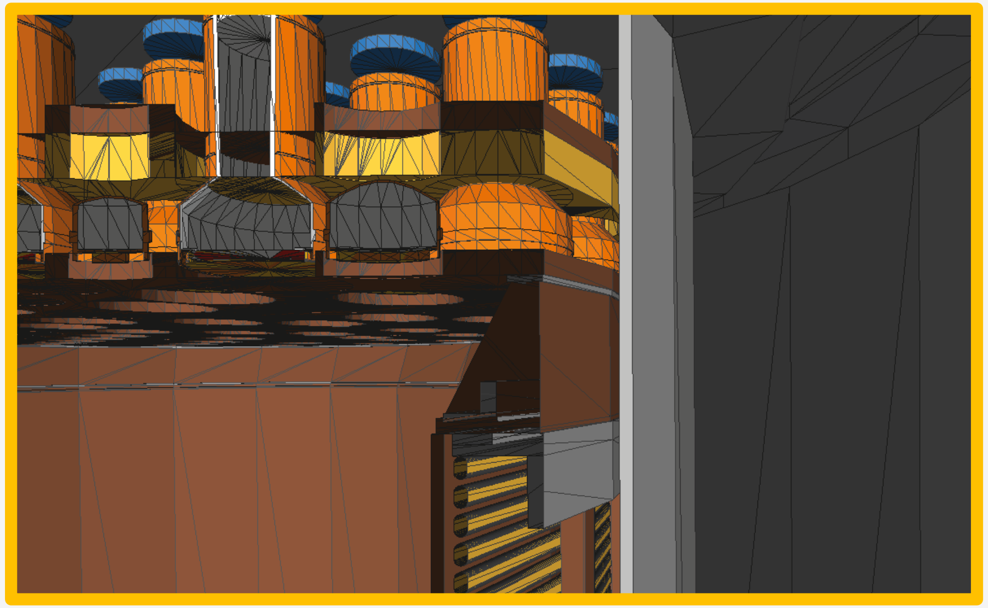




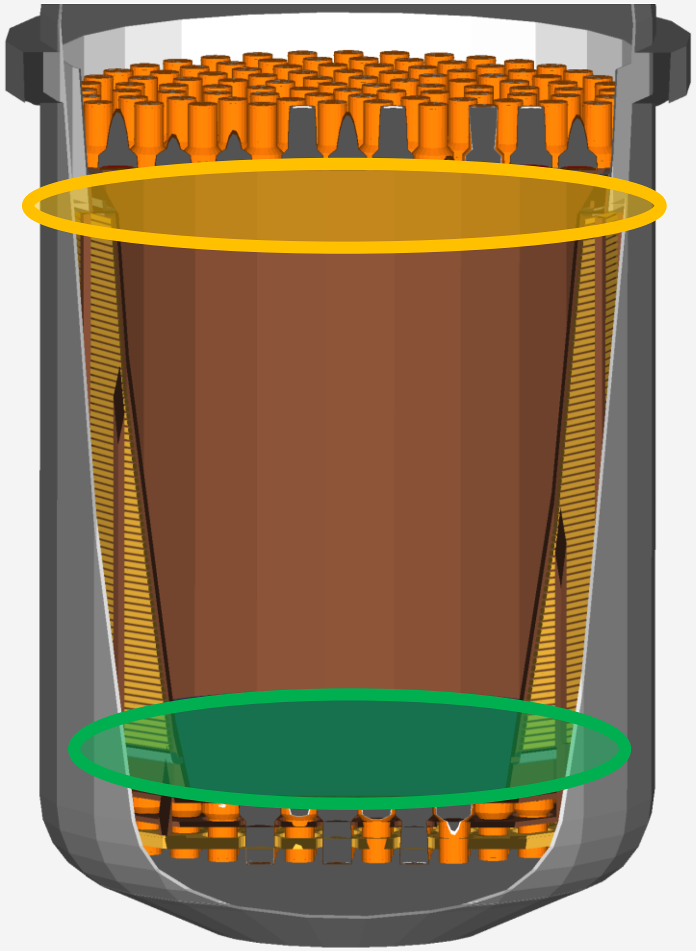


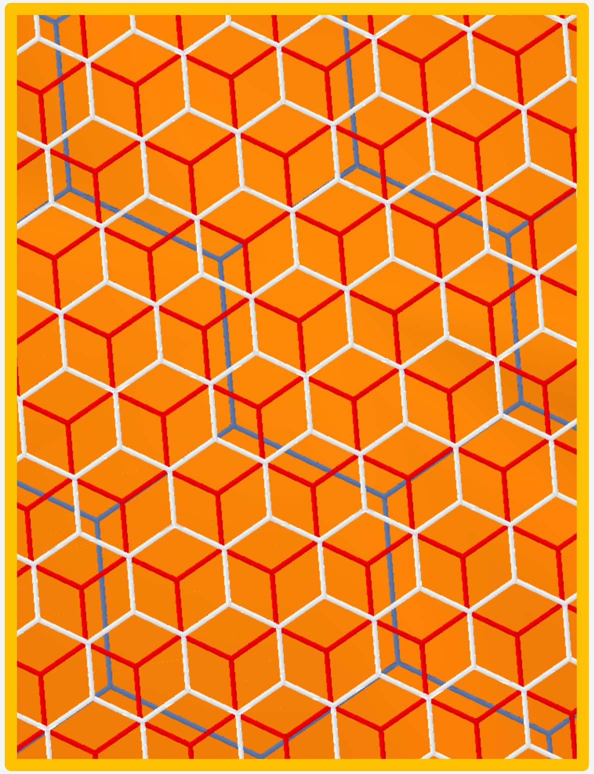
GEANT4 SIMULATION GEOMETRY

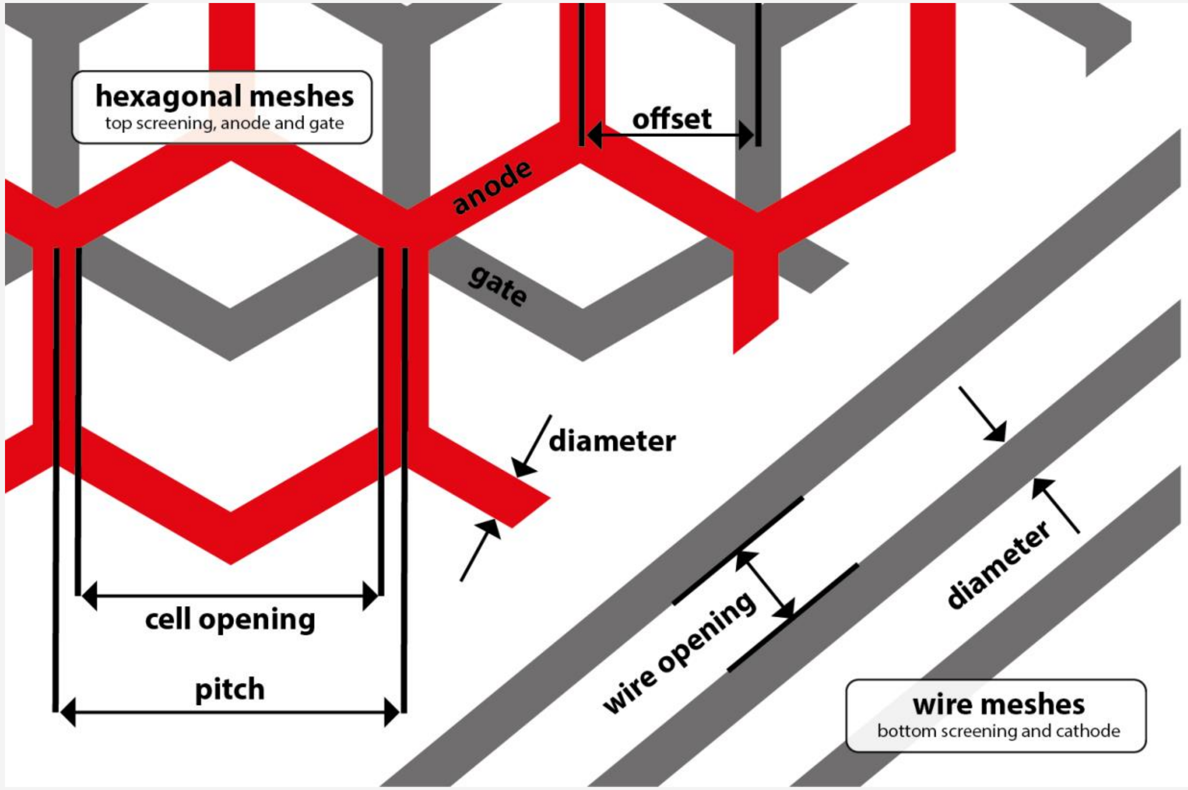




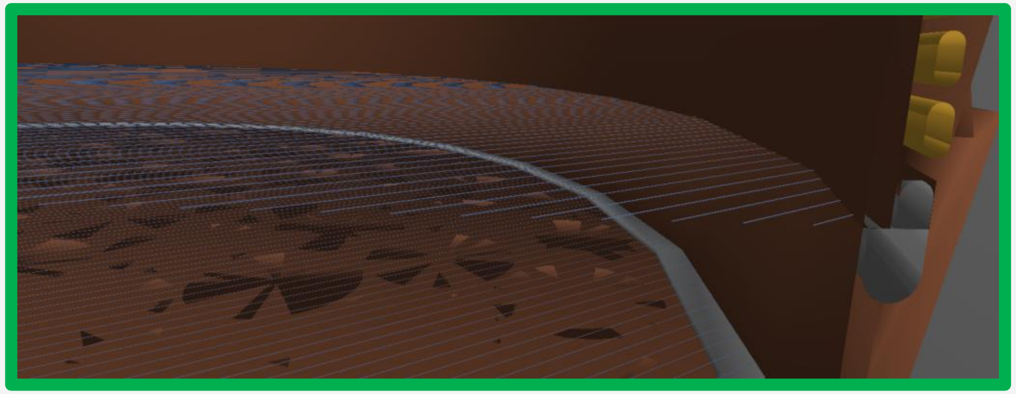
GEANT4 SIMULATION GEOMETRY





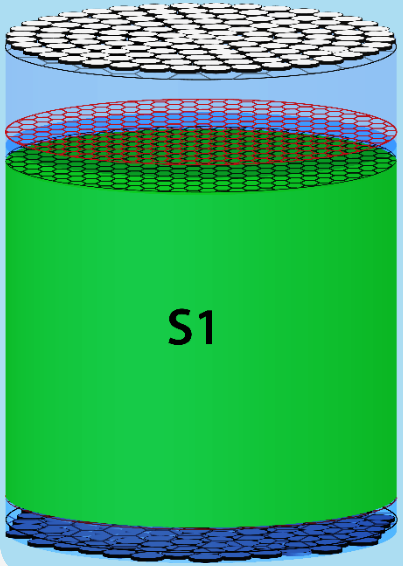


Anode:	3.5 mm	/ 0.178 mm
gate mesh:	3.5 mm	/ 0.127 mm
cathode:	7.75 mm	/ 0.216 mm



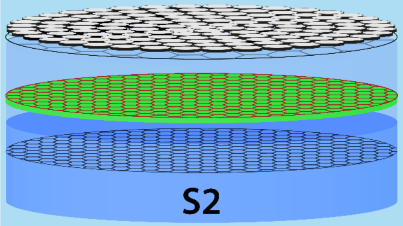
GEANT4 OPTICAL PHOTON PROPAGATION

S1 signals



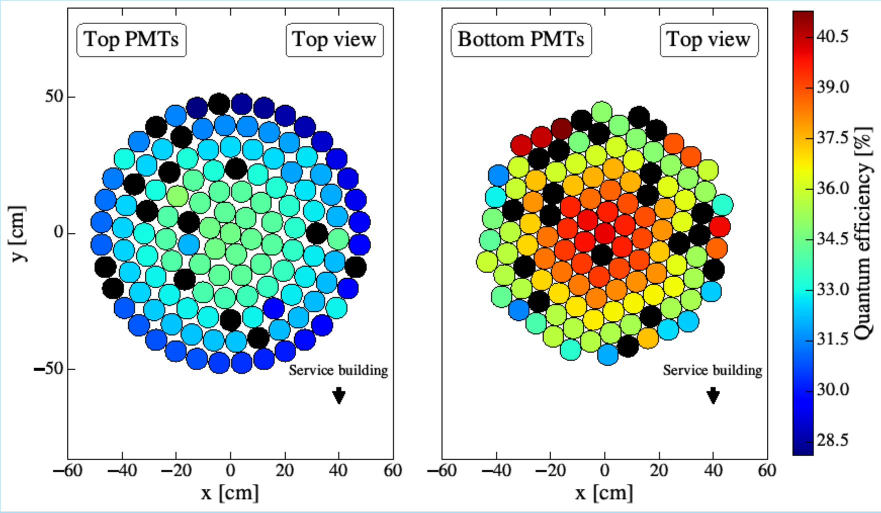
- Whole TPC from cathode to LXe/GXe transition (~100 cm)
- Confined to LXe
- 7eV photons

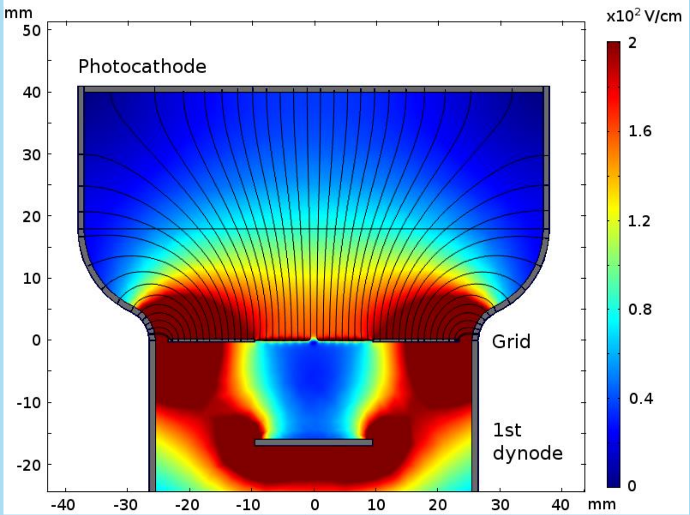
S2 signals



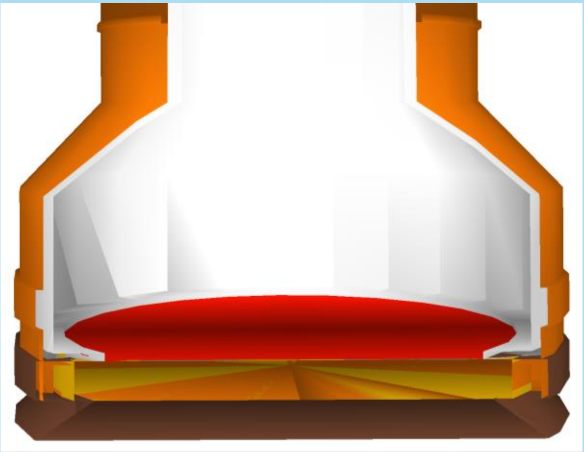
- Thin disc between LXe/GXe transition and Anode (~1 mm)
- Confined to GXe

Optical photon simulation corrections



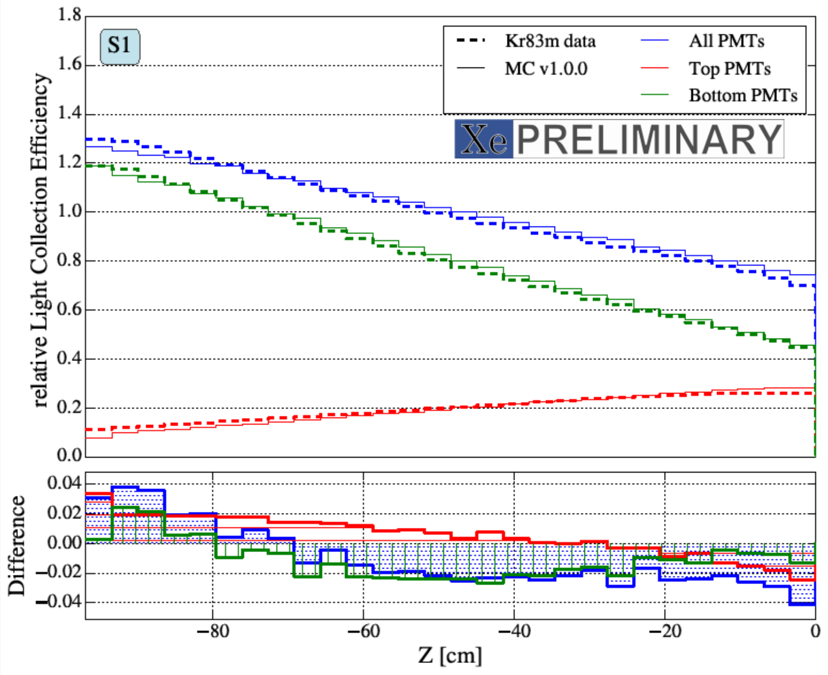


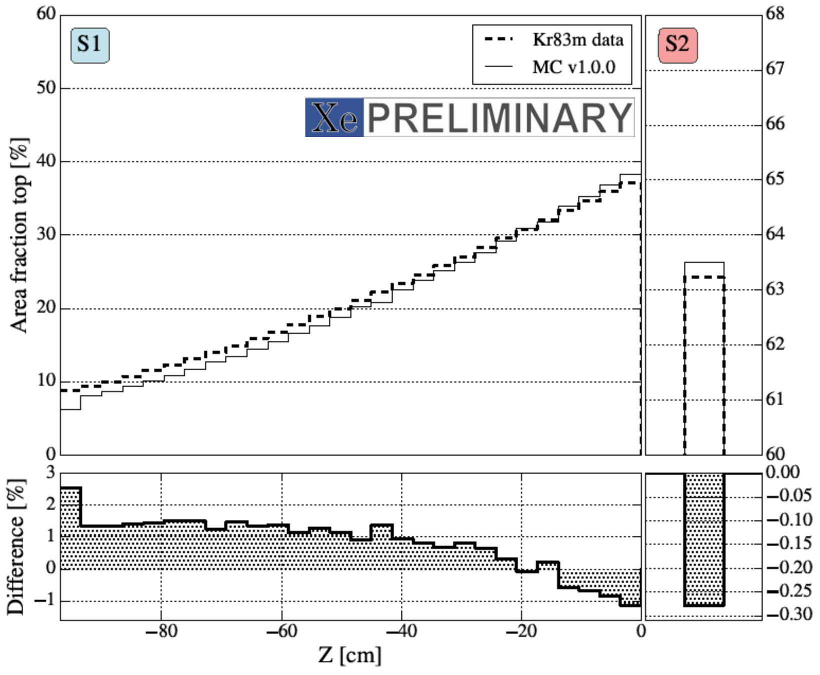
- Exclude PMTs that are not included in the measurements
- Correct by the Quantum Efficiency (# of photons @photocathode) and Collection Efficiency (# electrons @1st dynode) for each PMT



GEANT4 OPTICAL PHOTON PROPAGATION

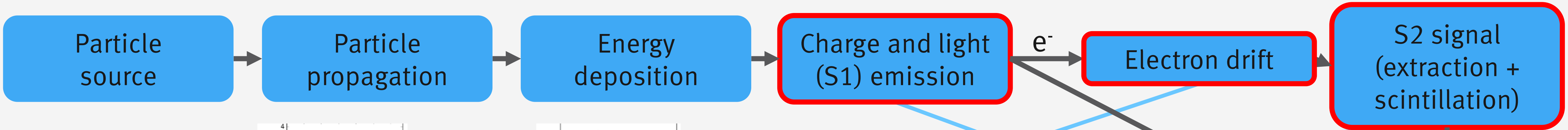
Fitting optical simulations to Kr-83m data

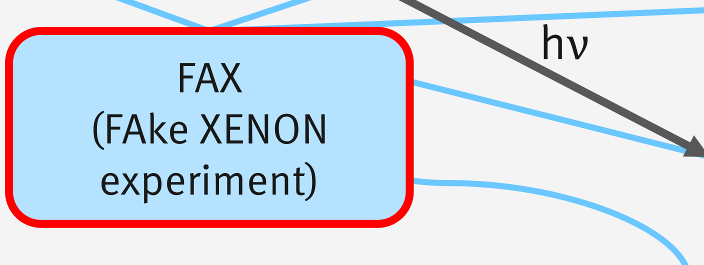


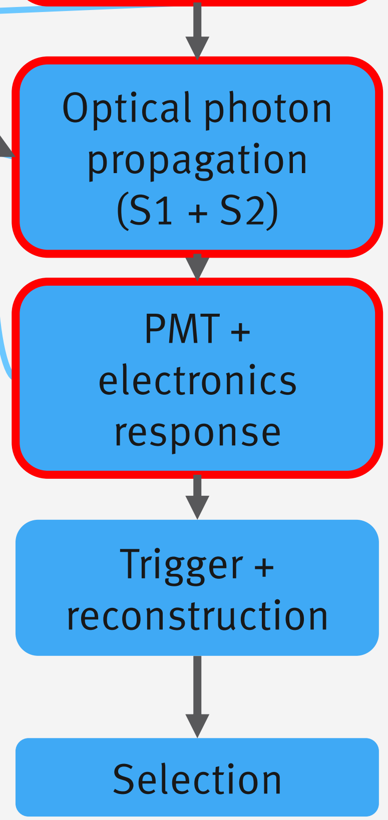


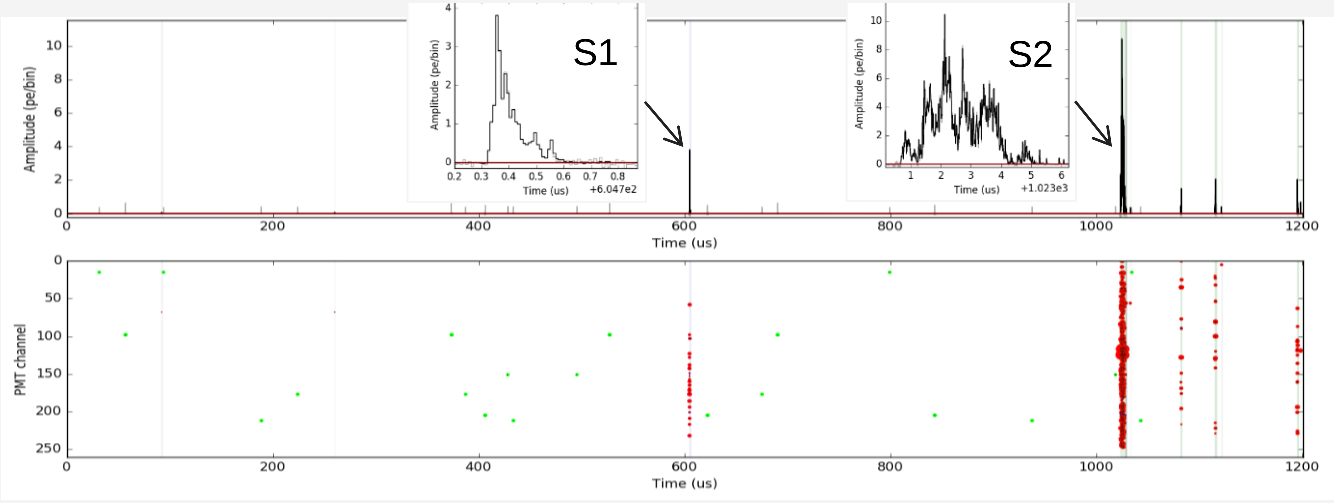
parameter	fitted values
LXe refraction index	1.69
LXe Rayleigh scatter length	30cm
LXe absorption length	5000cm
GXe absorption length	50cm
LXe PTFE reflectivity	99%
GXe PTFE reflectivity	99%
top screening mesh transp.	96.5%
anode transparency	89.8%
gate mesh transparency	92.7%
cathode transparency	97.2%
bottom screening mesh transp.	97.2%

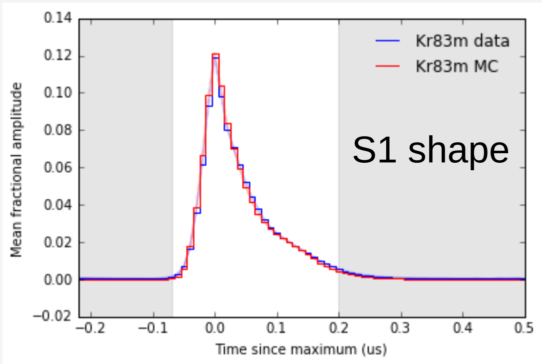
FAKE XENON EXPERIMENT

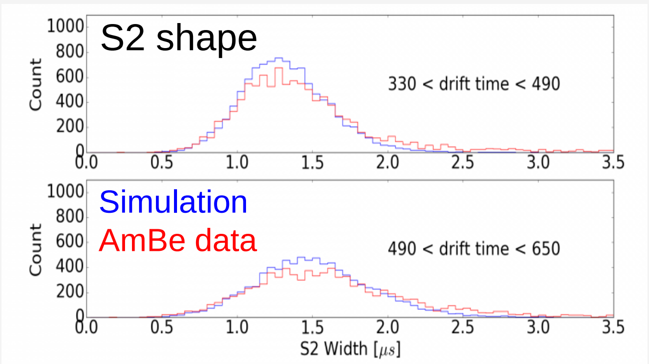








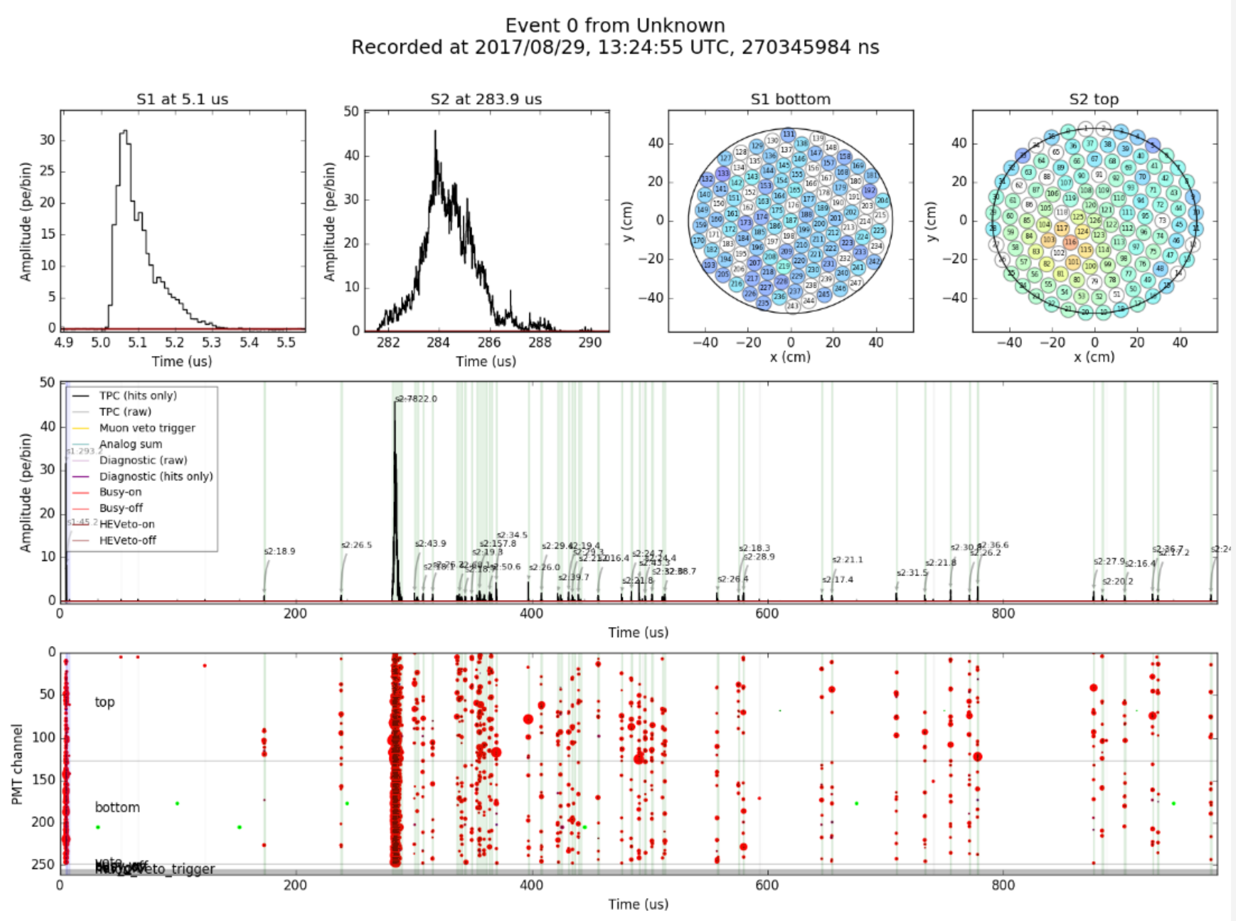


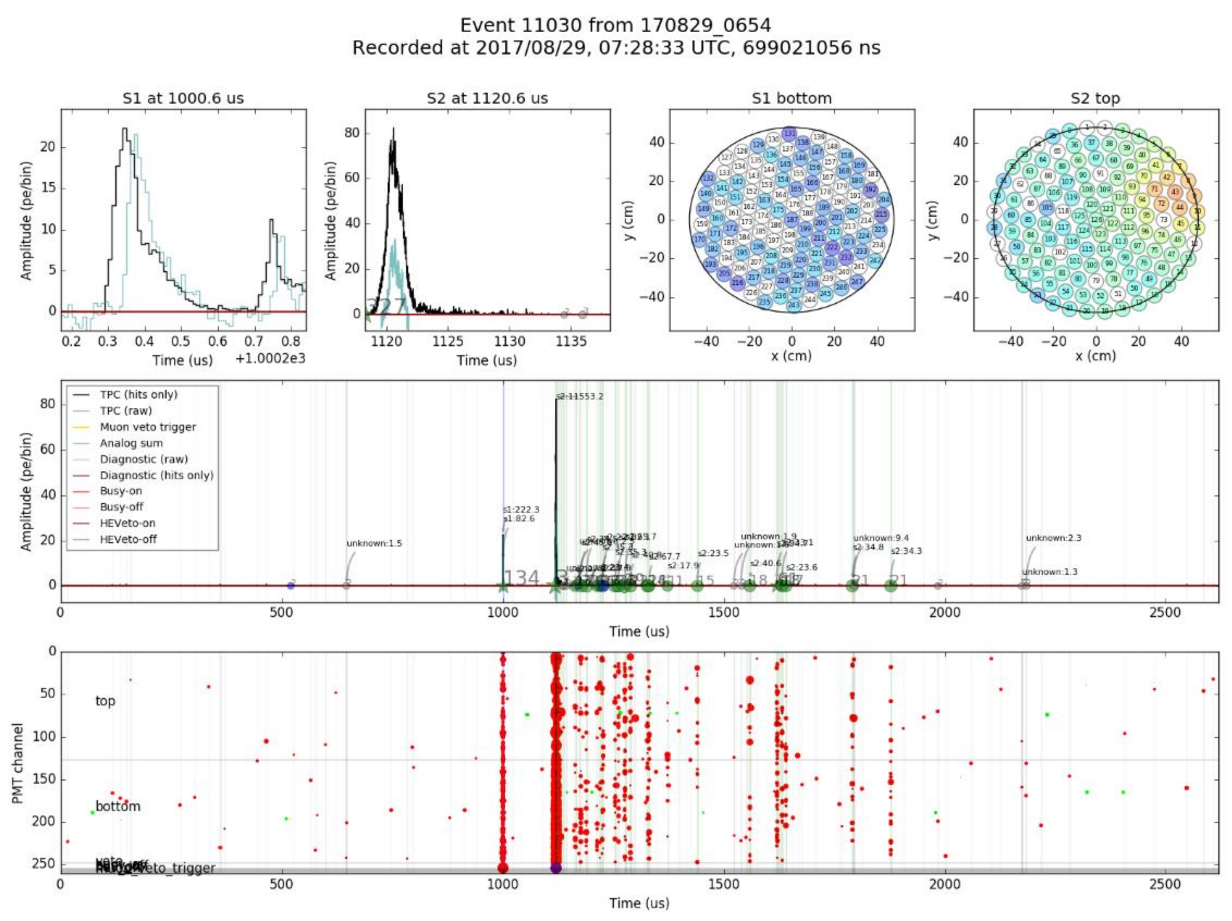


- **Using Geant4 particle tracks**
- **Waveform generation:**
  - Baseline fluctuations
  - Photoionization
  - SPE/DPE shape
  - PMT gains/QE/CE/after-pulses/dark counts/noise/...

COMPARISON OF FAX SIMULATIONS TO KR-83m DATA

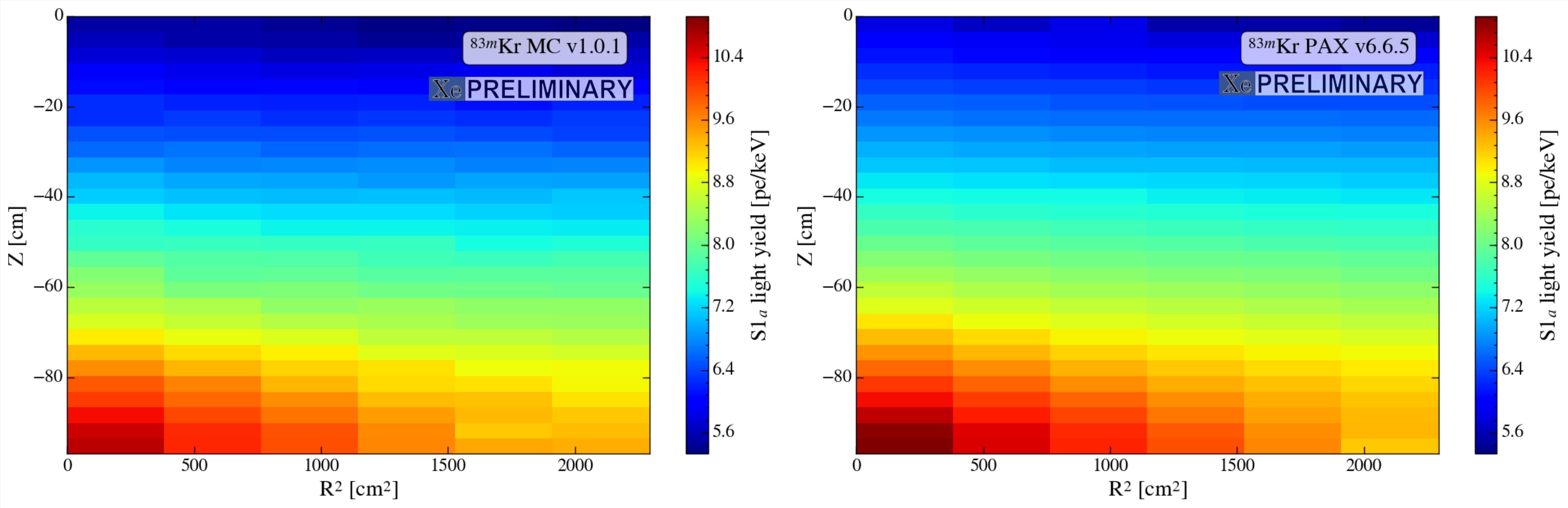
Waveforms observed within PAX



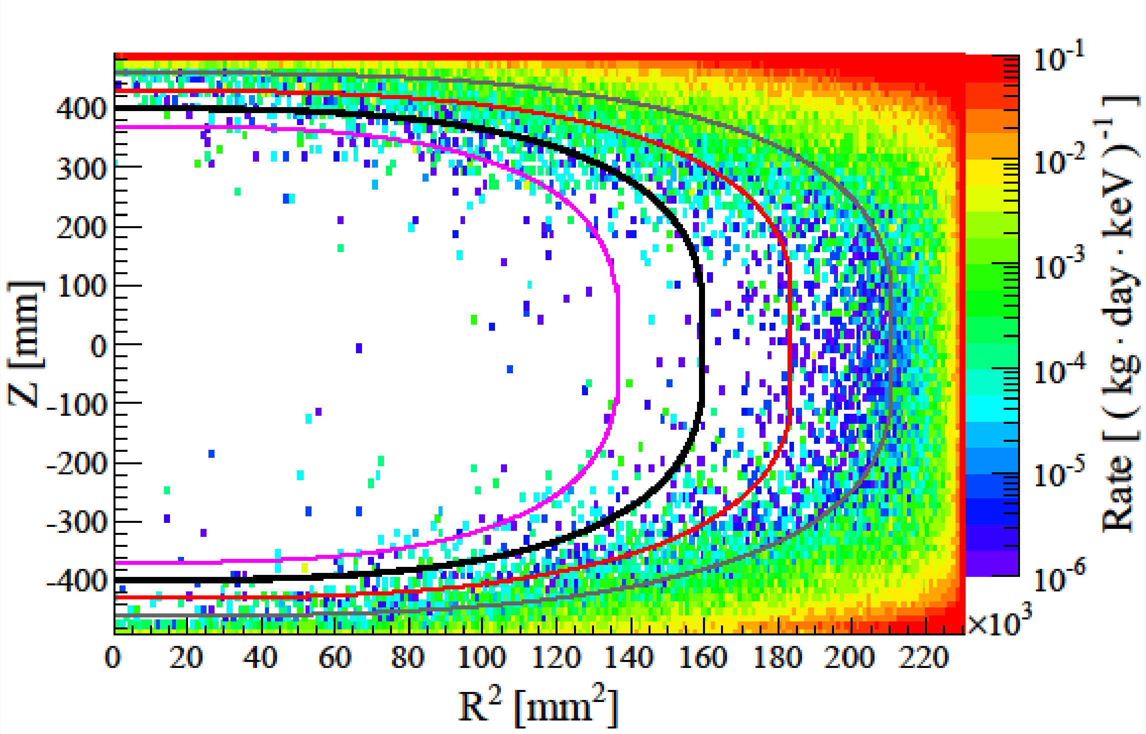


COMPARISON OF FAX SIMULATIONS TO KR-83m DATA

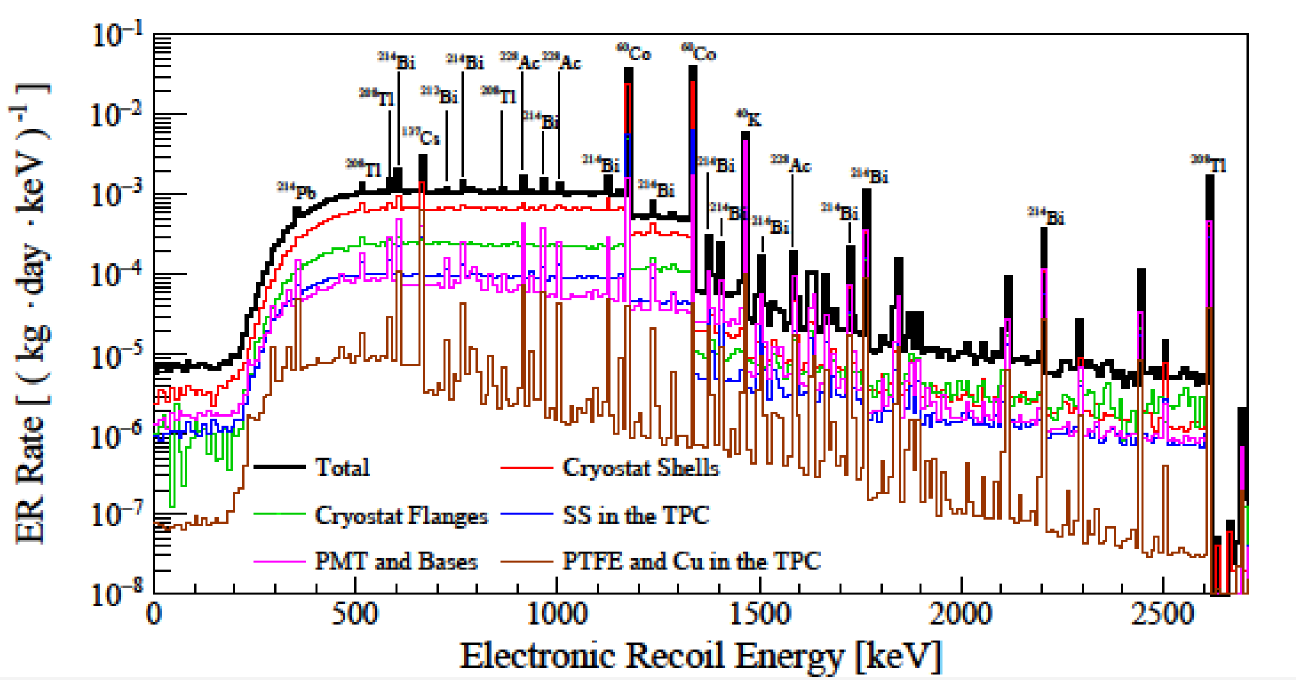
S1 light collection efficiency/light yield



Background simulations

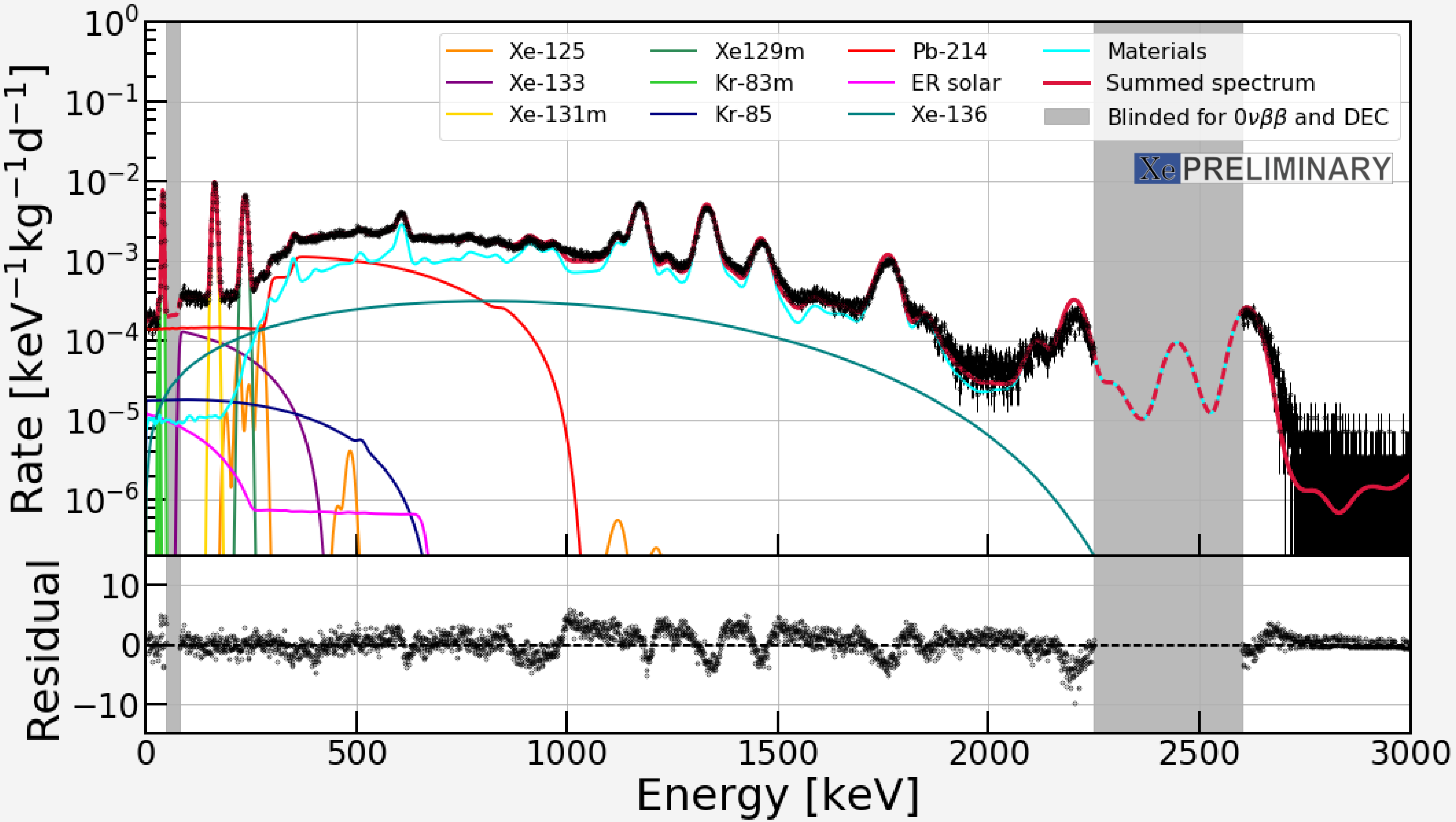


- Material backgrounds from 40K, 60Co, 232Th and 238U chains
- Extensive material screening during construction

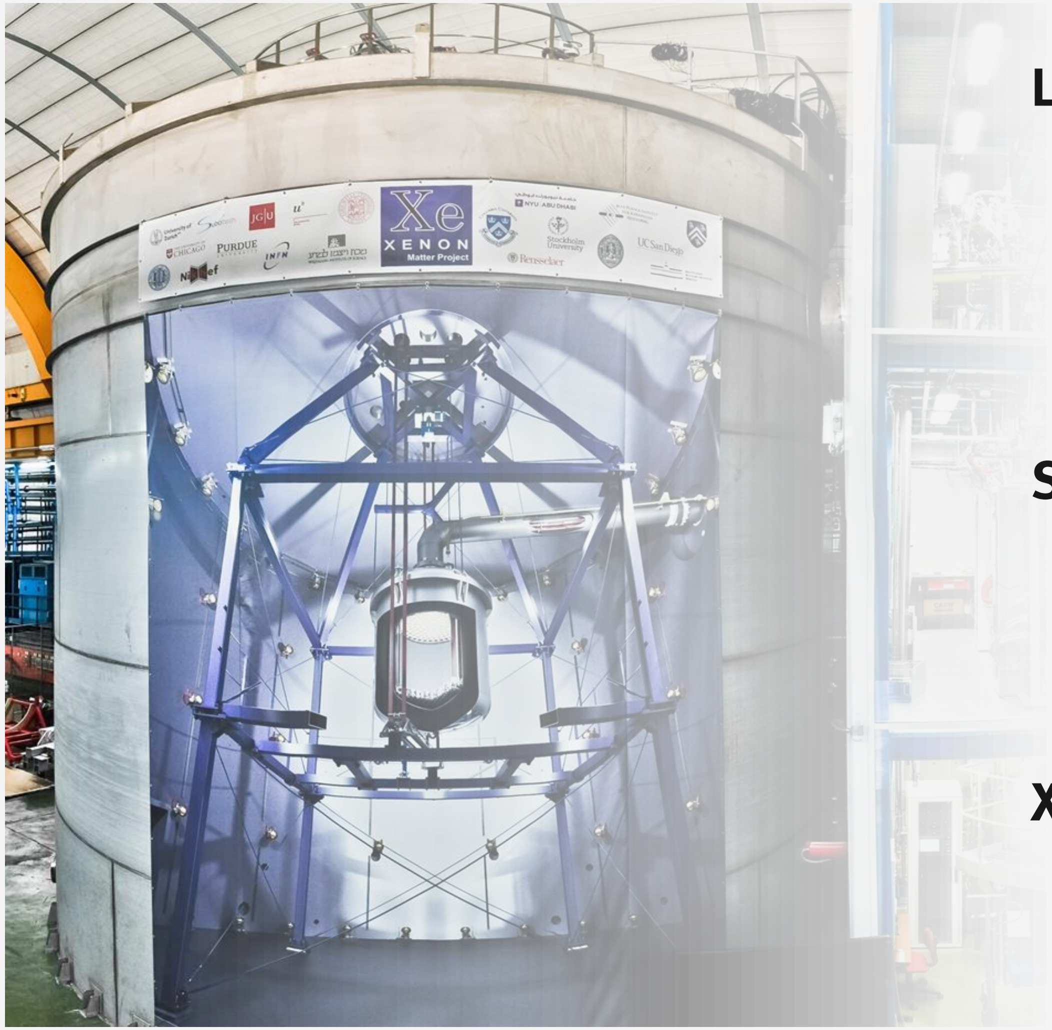


- Position reconstruction allows for fiducialization and self-shielding
- Flat material contribution in ROI

Measured spectrum and simulation



SUMMARY



Light collection efficiency and backgrounds well understood

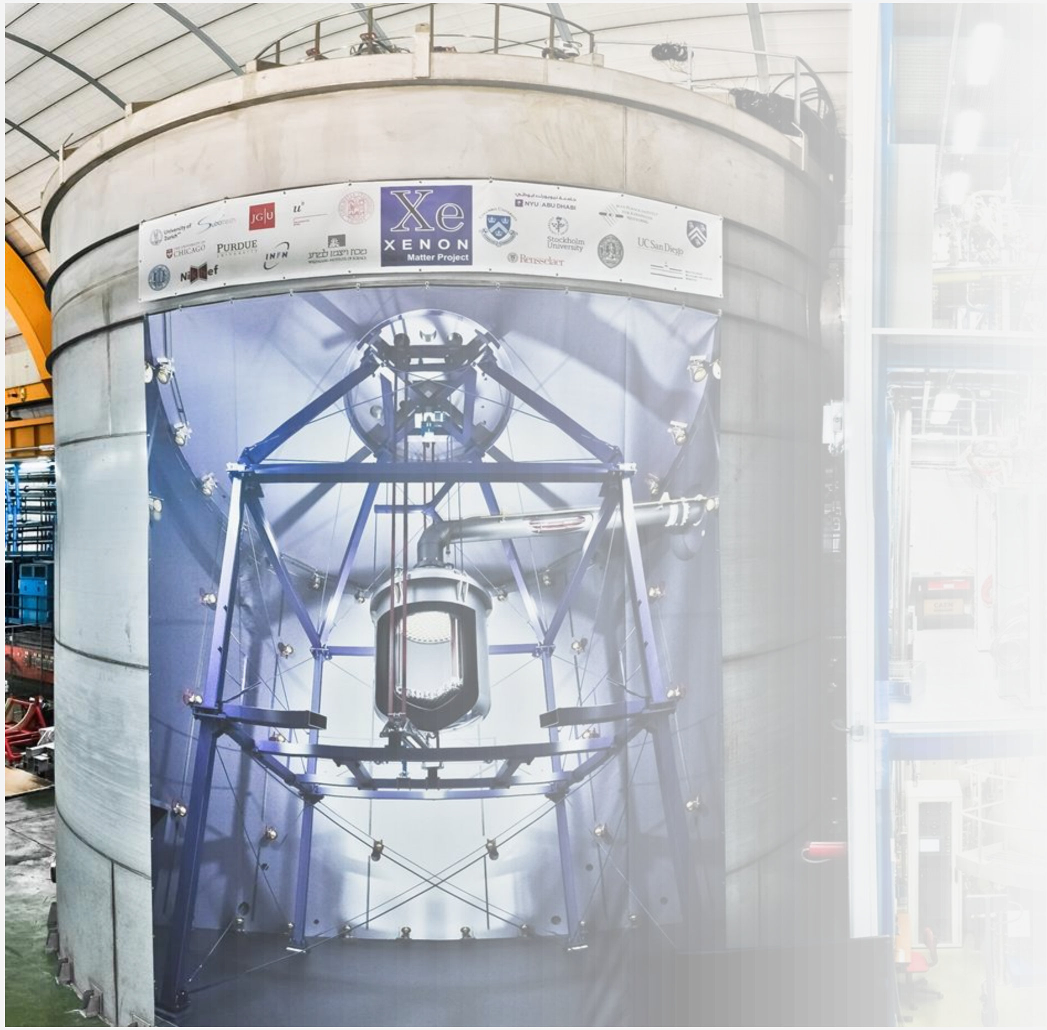
- Direct measurements with Kr-83m calibrations
- Agreement with optical Monte Carlo simulations (Geant4)
- Agreement with measured energy spectrum (official unblinding soon)

Simulations with FAke Xenon experiment

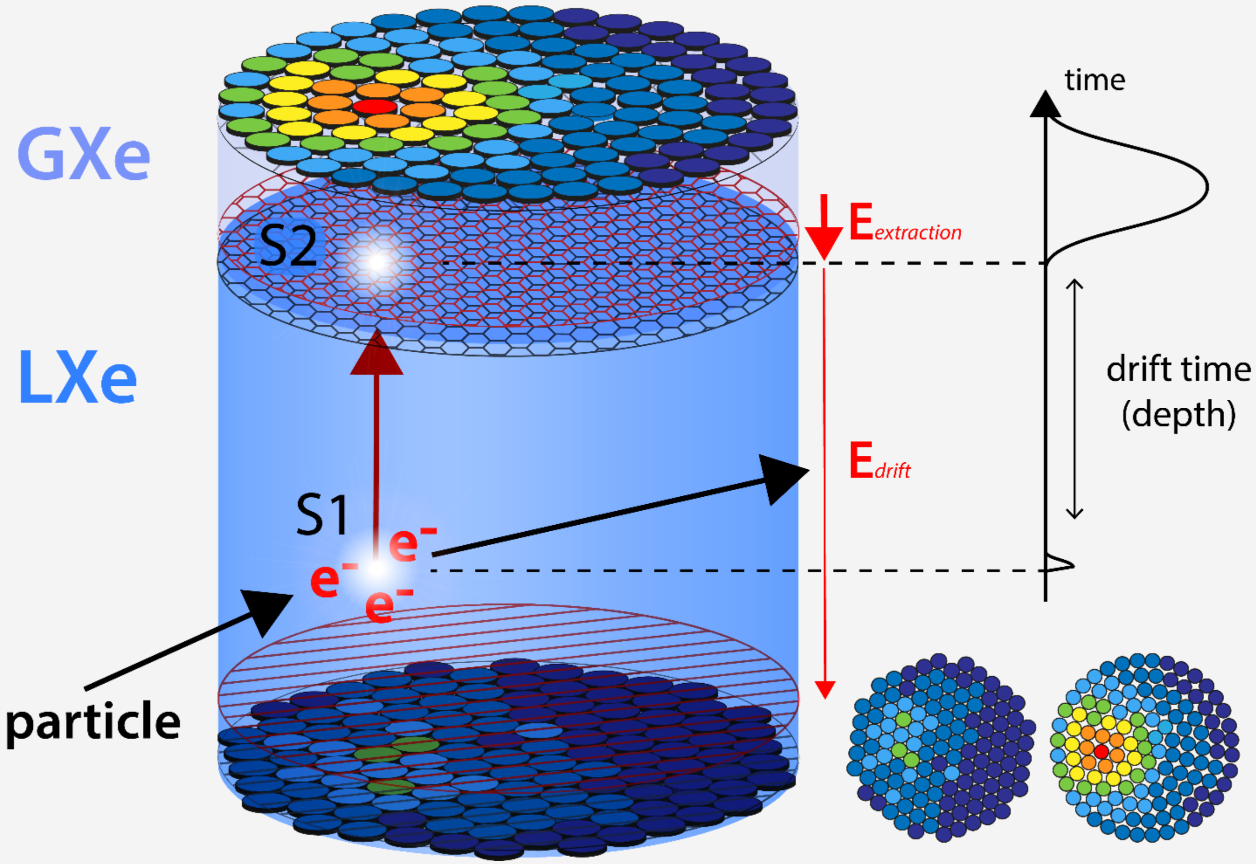
- Same data processing tools (PAX/HAX/LAX)
- Agreement with RAW data from the detector
- Performance testing of data cuts/selections

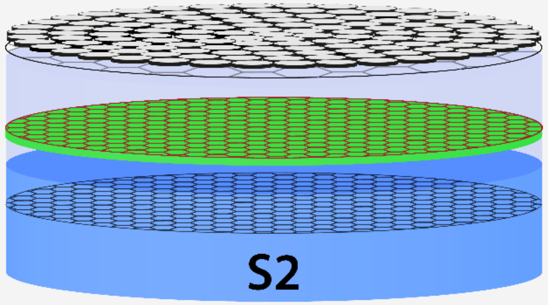
XENONnT coming soon!

- Twitter: @XENON1T
- Blog: **www.xenon1t.org**


Xe
XENON
Matter Project
PURDUE
UC San Diego

COMPARISON OF FAX SIMULATIONS TO KR-83m DATA

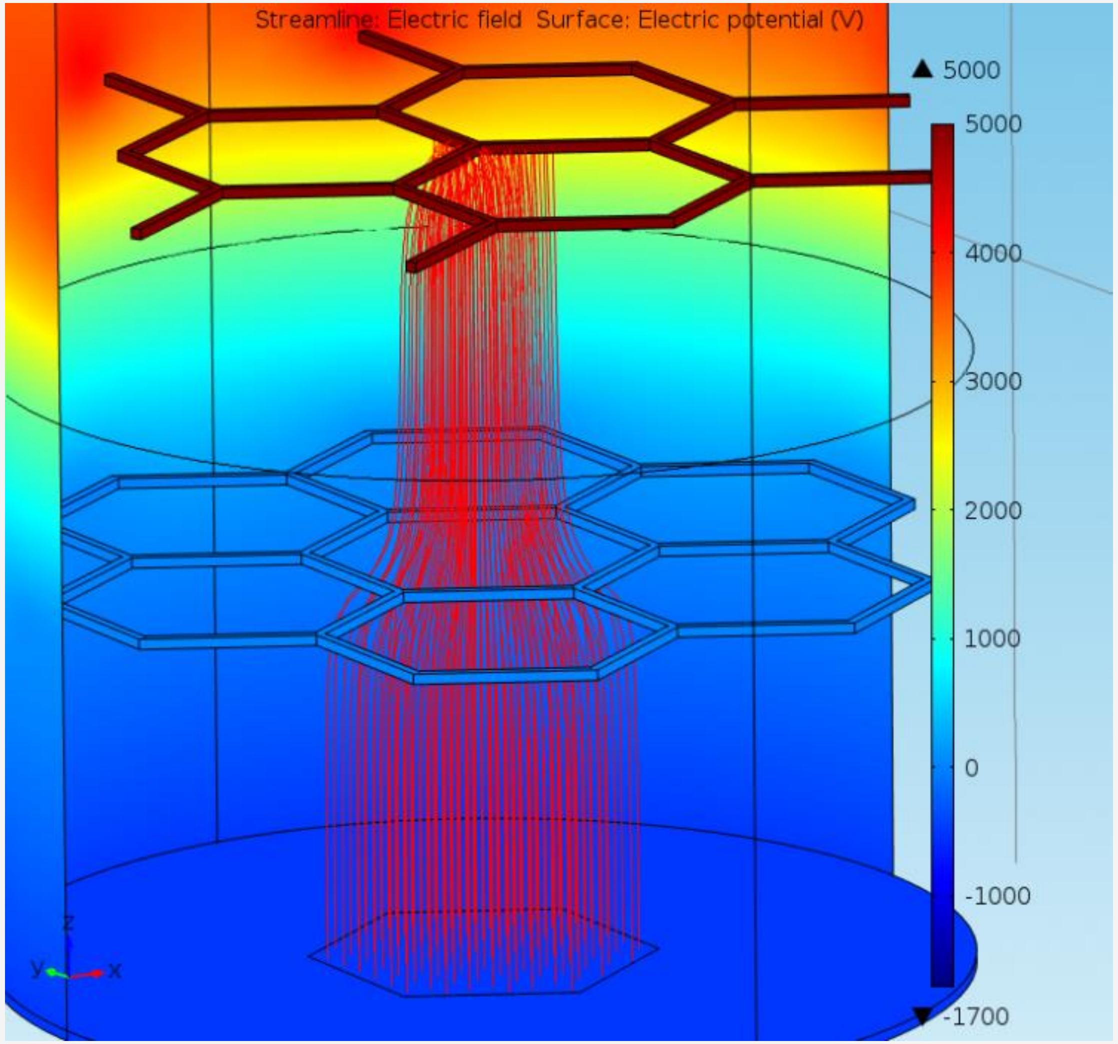




Improved S2 simulation

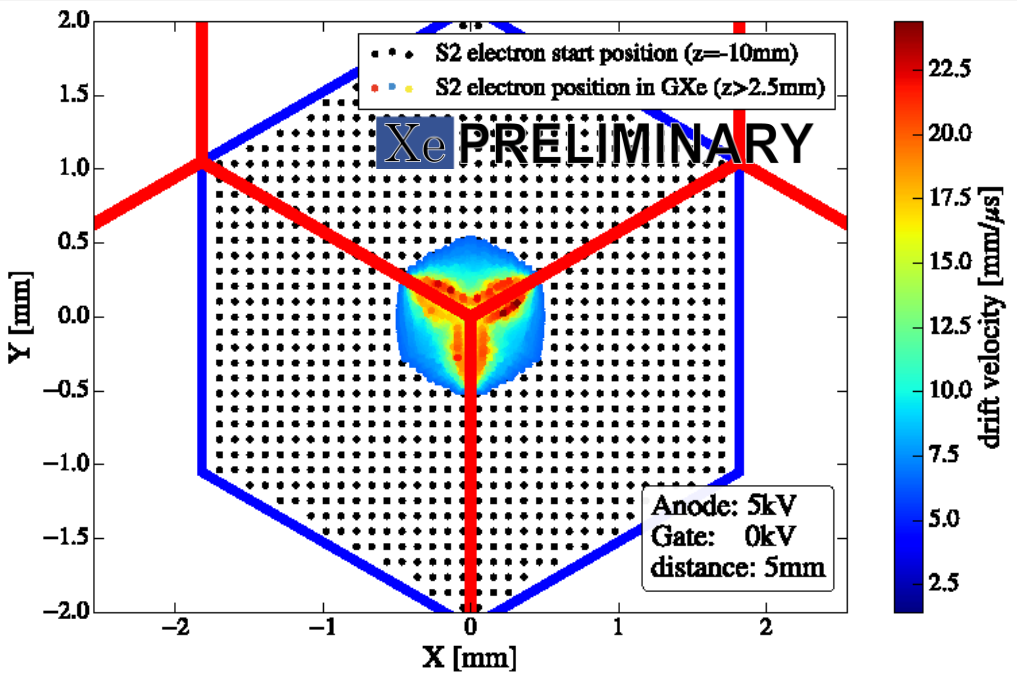
- Implement detailed mesh structure
- Generate photons in a volume defined by electric field simulations
- Generation volume with an actual density distribution

COMPARISON OF FAX SIMULATIONS TO KR-83m DATA



Electric field simulations of S2 electrons

- S2 photons are generated along the path of electrons drifting towards the anode
- Most of the S2 photons are produced close to the anode, resulting in a significantly lower amount of photons in the center of each mesh cell



GEANT4 OPTICAL PHOTON PROPAGATION

Fitting optical simulations to Kr-83m data

parameter	init. asm.	fitted values	fitting range
LXe refraction index	1.63	1.69	1.56 to 1.69
LXe Rayleigh scatter length	30cm	30cm	5cm to 100cm
LXe absorption length	5000cm	5000cm	10cm to 80000cm
GXe absorption length	10000cm	50cm	10cm to 80000cm
LXe PTFE reflectivity	99%	99%	80% to 99%
GXe PTFE reflectivity	99%	99%	80% to 99%
top screening mesh	94.5%	96.5%	fixed
anode	92.9%	89.8%	fixed
gate mesh	92.9%	92.7%	fixed
cathode	96%	97.2%	fixed
bottom screening mesh	94.5%	97.2%	fixed

COMPARISON OF FAX SIMULATIONS TO KR-83m DATA

Particle source → Particle propagation → Energy deposition → Charge and light (S1) emission → e⁻ → Electron drift → S2 signal (extraction + scintillation) → Optical photon propagation (S1 + S2) → PMT + electronics response → Trigger + reconstruction → Selection

XENON1T TPC

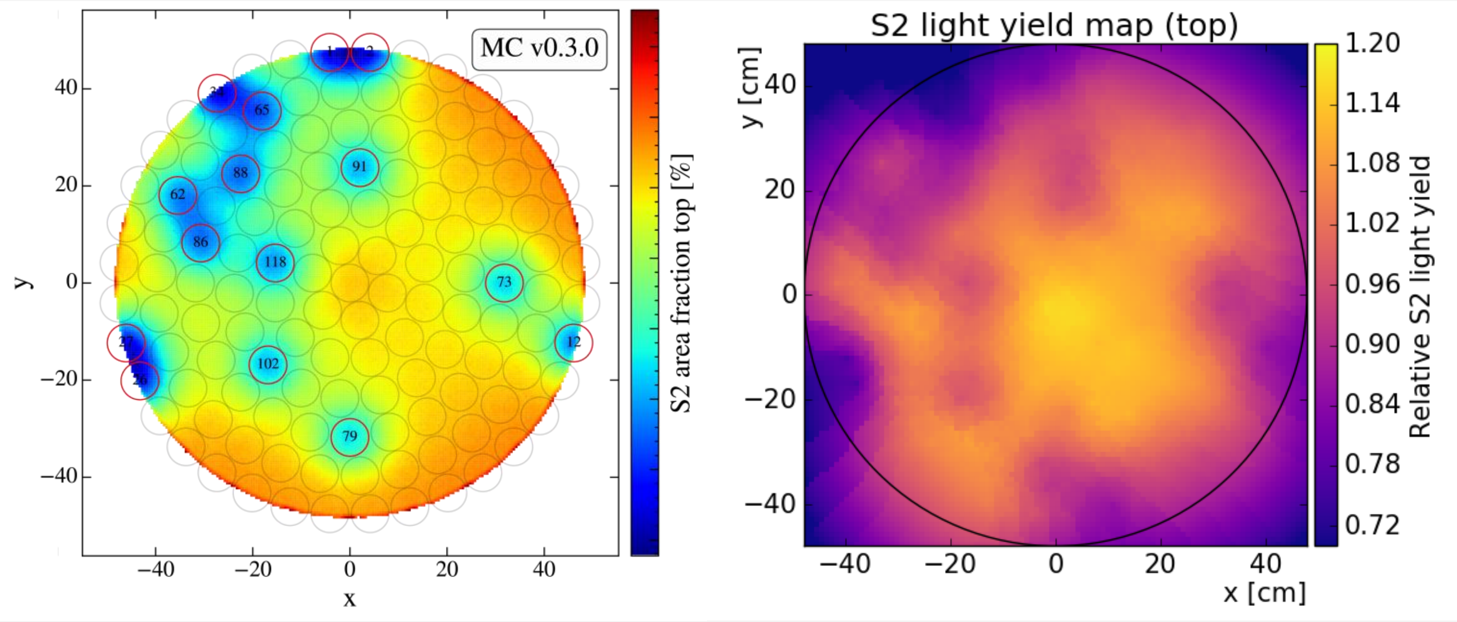
GEANT4 (v4.9.2 + NEST)

FAX (FAke XENON experiment)

PAX (Processor for Analyzing XENON)

HAX (Handy Analysis for XENON)

Including detector dependent corrections



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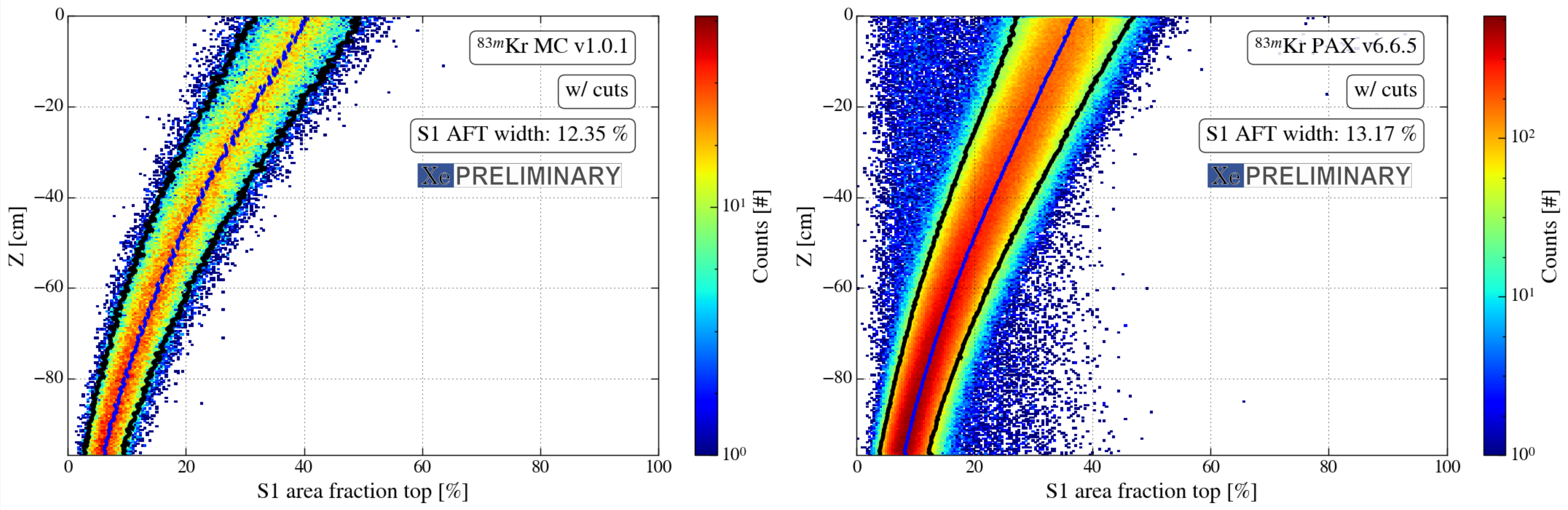

XENONnT