Novel Studies on Neutral Bremsstrahlung in Xenon Optical TPCs

Cristina M.B. Monteiro*

LIBPhys, Physics Department, University of Coimbra, Portugal

on behalf of the NEXT Collaboration

*cristinam@uc.pt

Main authors of the work

University of Coimbra : C. M. B. Monteiro, C. A. O. Henriques, J. M .R Teixeira, J. M. F. dos Santos

University of Santiago de Compostela: Pablo Amedo, D. González-Díaz, A. Saa Hernandez

University of Aveiro: C. D. R. Azevedo

Fermi National Accelerator Laboratory: Adam Para

University of Valencia: J. Martín-Albo

Outline

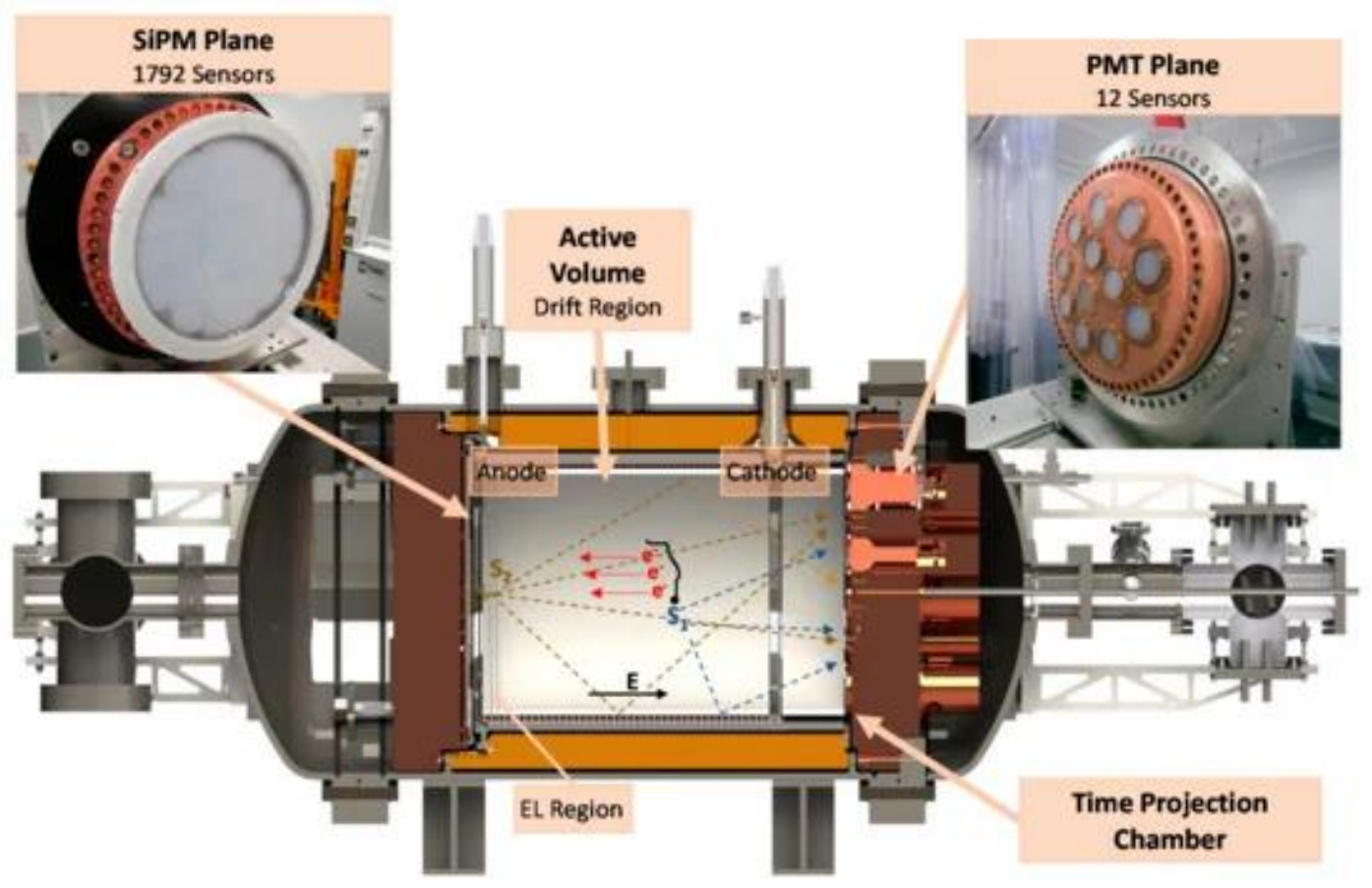
1. The NEXT Experiment and Collaboration
2. Detector NEXT-White(NEW)
3. Electroluminescence in Xenon
4. Neutral Bremsstrahlung
5. NBrS observation in NEXT-NEW
6. NBrS studies in Xe - Dedicated Experimental Setup : the driftless GPSC
7. NBrS studies in Xe - Waveforms
8. NBrS studies in Xe – Results
9. NBrS studies in Xe – Comparison
10. Conclusions

NEXT - the Neutrino Experiment with a Xenon Time projection chamber

- For detailed info on NEXT, see presentations nº 199 and nº 122 in Session: Discussion Panel Neutrino 3 (31/8)
- NEXT aims at searching for neutrinoless double beta decay ($\beta\beta0\nu$) events in xenon gas, enriched at 90% in the isotope ^{136}Xe;
- The noble gas Xe is chosen due to: easy to enrich, purify and scale-up;
- The present detector (NEXT-White (NEW)) is a High-Pressure TPC, at present the largest optical High-pressure Xenon TPC in operation;
- Filled with Xe at 10 bar;
- The chosen ionization signal amplification process is Electroluminescence (EL);
- Excellent Energy Resolution and 2D-Topological capabilities;
- The experiment runs in the Canfranc Underground Laboratory (LSC), Spain, (NEXT-NEW: running successfully since 2016);
- The NEXT Collaboration includes 23 institutions from Spain, Portugal, USA, Israel and Colombia.

Detector NEXT-NEW

For detailed info on NEXT, see presentations nº 199 in Session: Discussion Panel Neutrino 3 (31/8)



- NEXT-NEW detector:
- 5 kg high-pressure Xenon;
- Signal readout comprises 2 planes:
- 1) a plane of photomultipliers (PMTs) for energy measurements (S2, but also S1 for start-of-event);
- 2) a silicon photomultiplier (SiPM) tracking plane for offline topological event analysis and filtering.
- Xenon in a closed system, purified by a hot getter;
- Ionisation signal amplification mechanism: Electroluminescence (EL gap ~ 6 mm);

Electroluminescence in Xenon

- Electroluminescence:

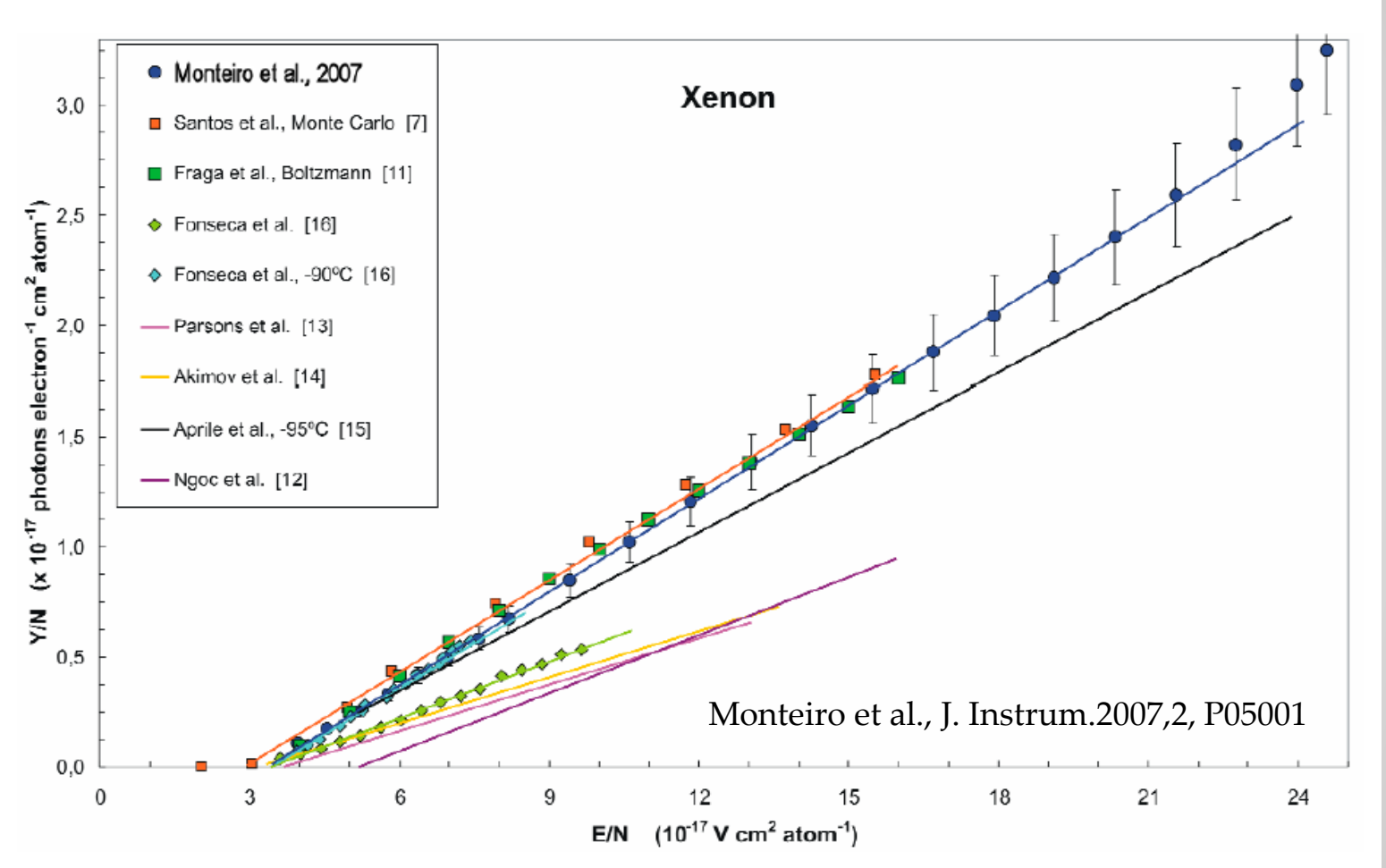
excimer-based secondary scintillation created in a three-body collision of two neutral atoms, Xe, and one excited atom, Xe^*, produced by electron impact:

$$Xe^* + 2Xe \rightarrow Xe_2^* + Xe$$

$$Xe_2^* \rightarrow 2Xe + h\nu$$

One excited atom creates an excited excimer, Xe_2^*, which decays emitting one VUV photon, $h\nu$, mainly in the second continuum (~172 nm for Xe gas), corresponding to transitions of the singlet and triplet bound molecular states, from vibrationally relaxed levels, to the repulsive ground state

- Excitation threshold in Xe : ~ 0.75 kV/cm/bar



Neutral Bremsstrahlung - NBrS

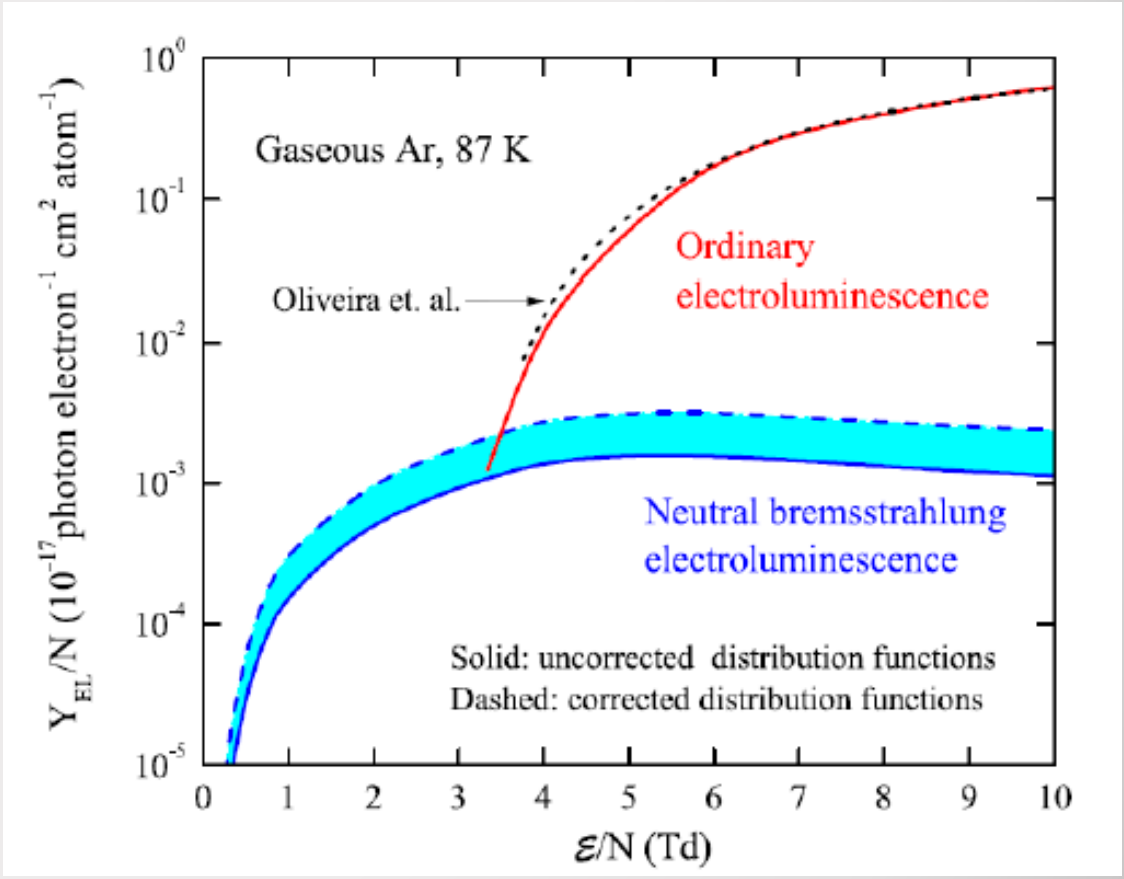
- *A. Buzulutskov et al. Astropart. Phys., 103(2018)29, A. Bondar et al., NIM A 958(2020)162432,* observed a component of non-VUV scintillation above and below the EL threshold in Ar with a continuous spectrum from UV to NIR

NBrS was pointed out as the natural explanation: a concurrent secondary scintillation mechanism based on bremsstrahlung of drifting (slow) electrons scattered on neutral atoms:

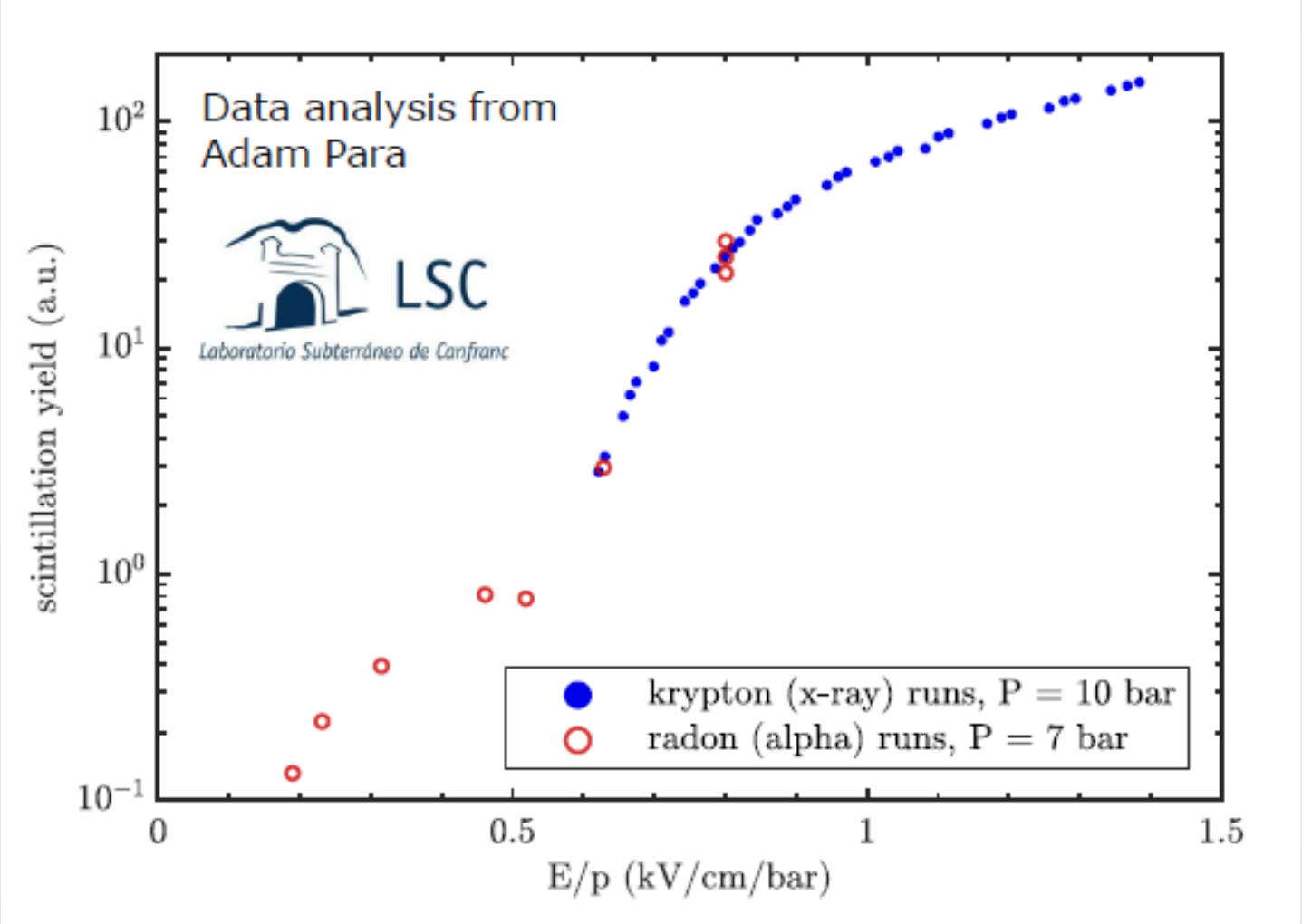
$e^- + Ar \rightarrow e^- + Ar^* + h\nu$ (elastic scattering)

$e^- + Ar \rightarrow e^- + Ar + h\nu$ (inelastic scattering)

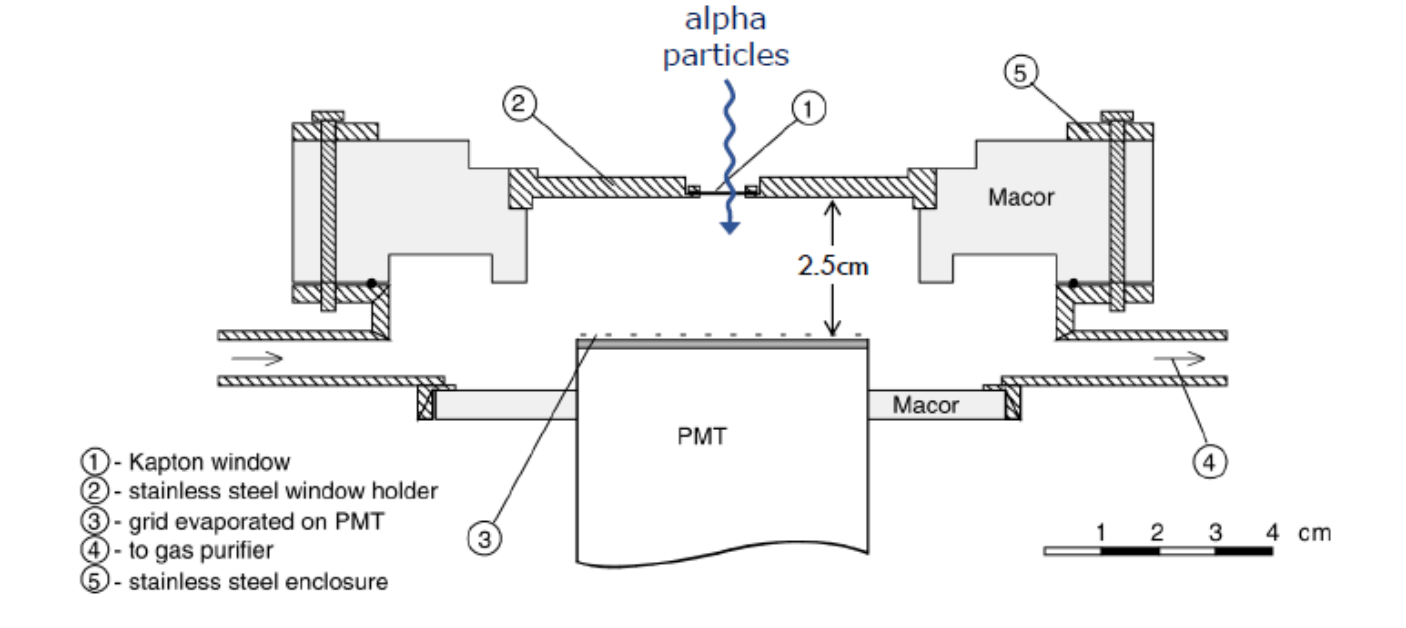
Occurs below the gas excitation threshold as well as above

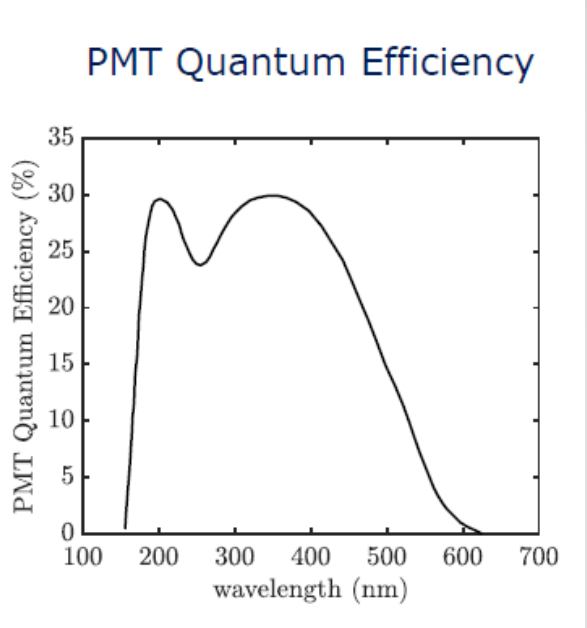


NBrS observation in NEXT-NEW



NBrS studies in Xe: driftless GPSC

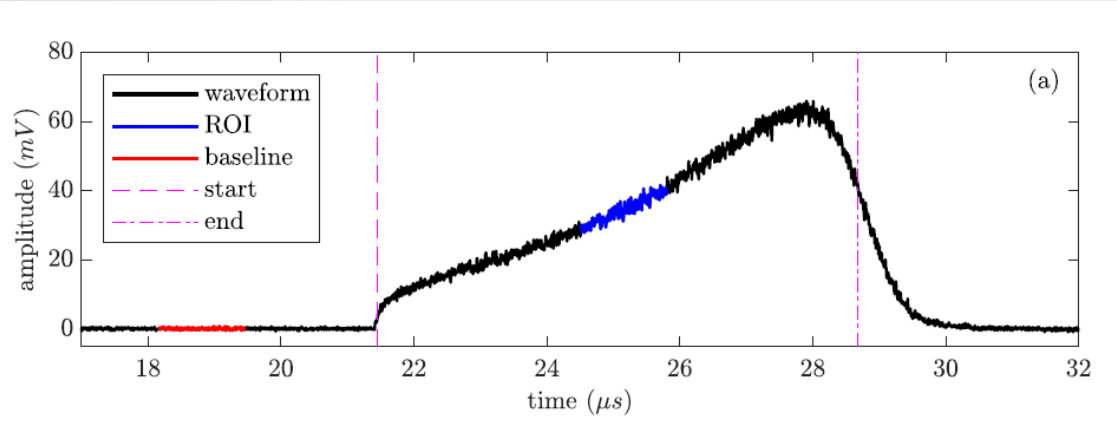




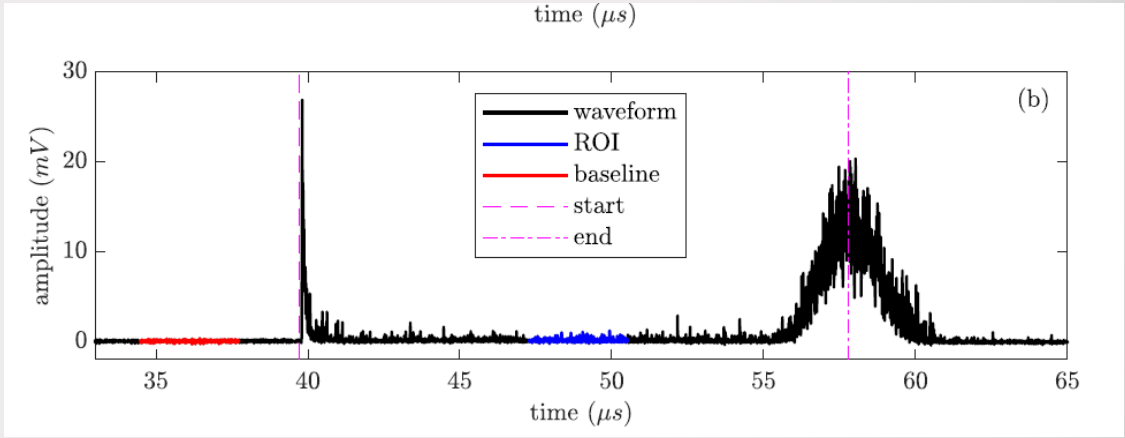
- Dedicated setup: GPSC without drift-region
- 25-mm scintillation gap
- PMT: 52-mm diameter; spectral sensitivity: 155-625 nm
- Gas in a closed circuit, continuously purified by hot getters, SAES st707
- Xenon gas @ 1.24 bar
- Incident radiation: alpha particles from a collimated ^{241}Am source
- Mean energy deposition: 1.7 MeV; mean penetration depth: 2.6 mm

NBrS studies in Xe: waveform analysis

- Oscilloscope (WaveRunner 610Zi from LeCroy) with a sampling of 10 GS/s
- The start and end of the events are represented by vertical lines.
- The regions for determining the EL (blue) and NBrS (blue), and the baseline offset (red), are shown.



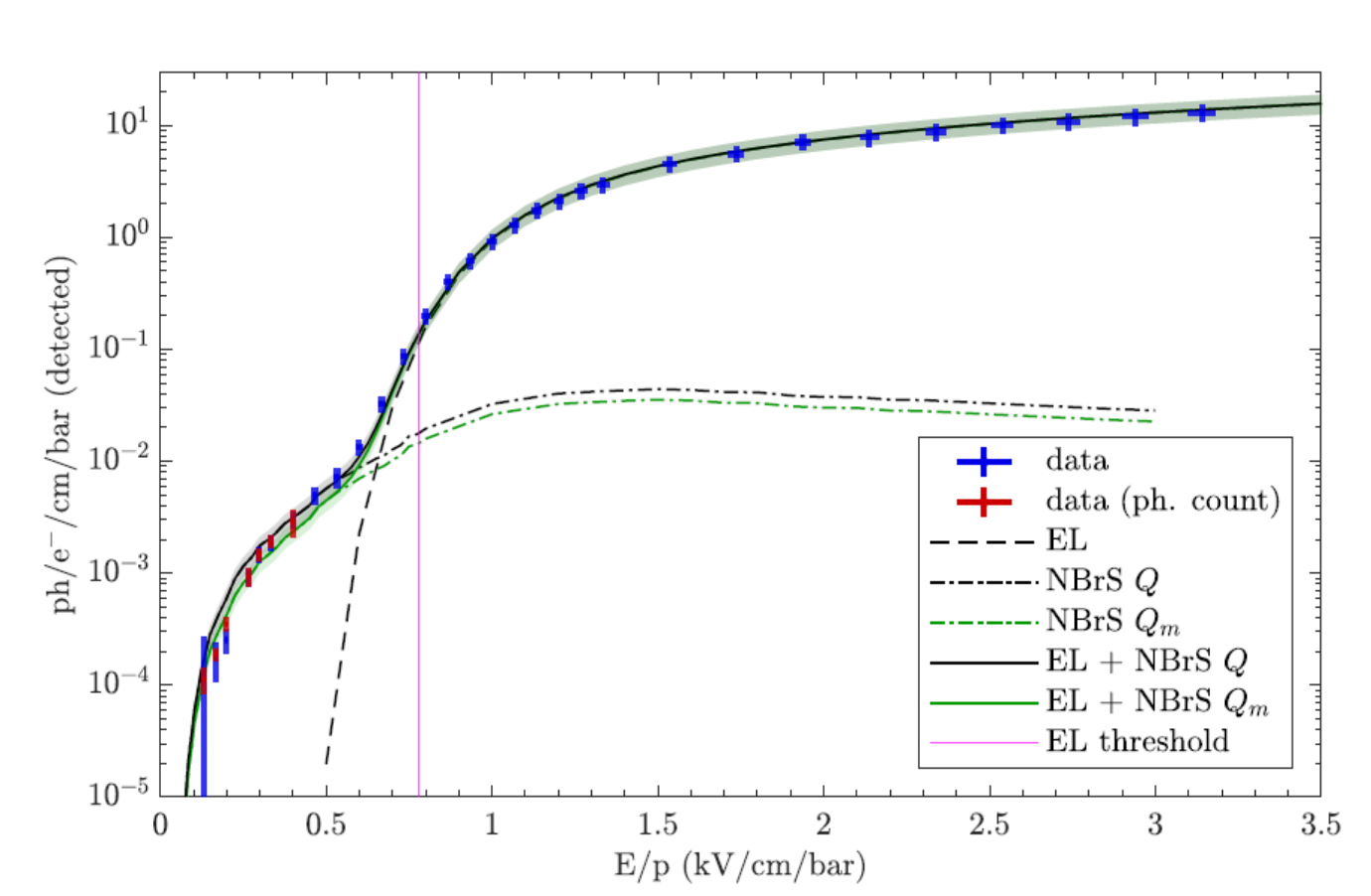
Typical driftless GPSC waveforms for an E/p value above the Xe excitation threshold (1.5 kV/cm/bar)



Driftless GPSC waveforms for an E/p value below the Xe excitation threshold (320 V/cm/bar)

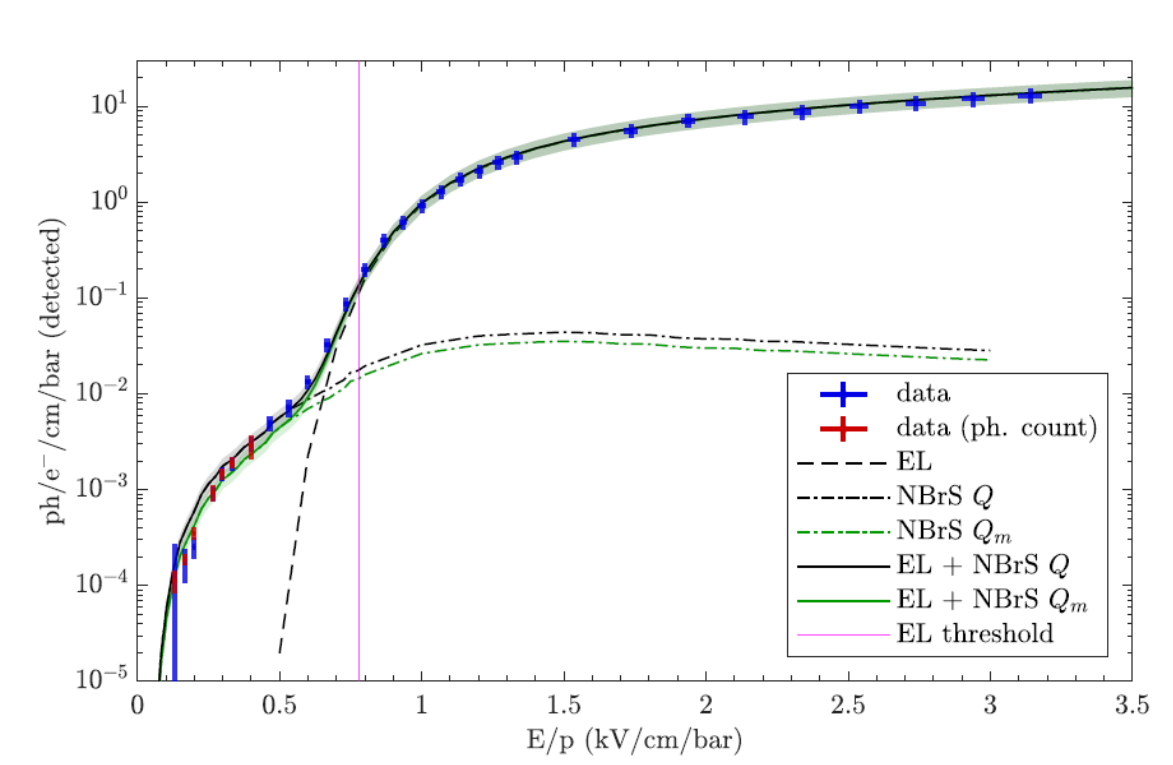
NBrS studies in Xe - Results

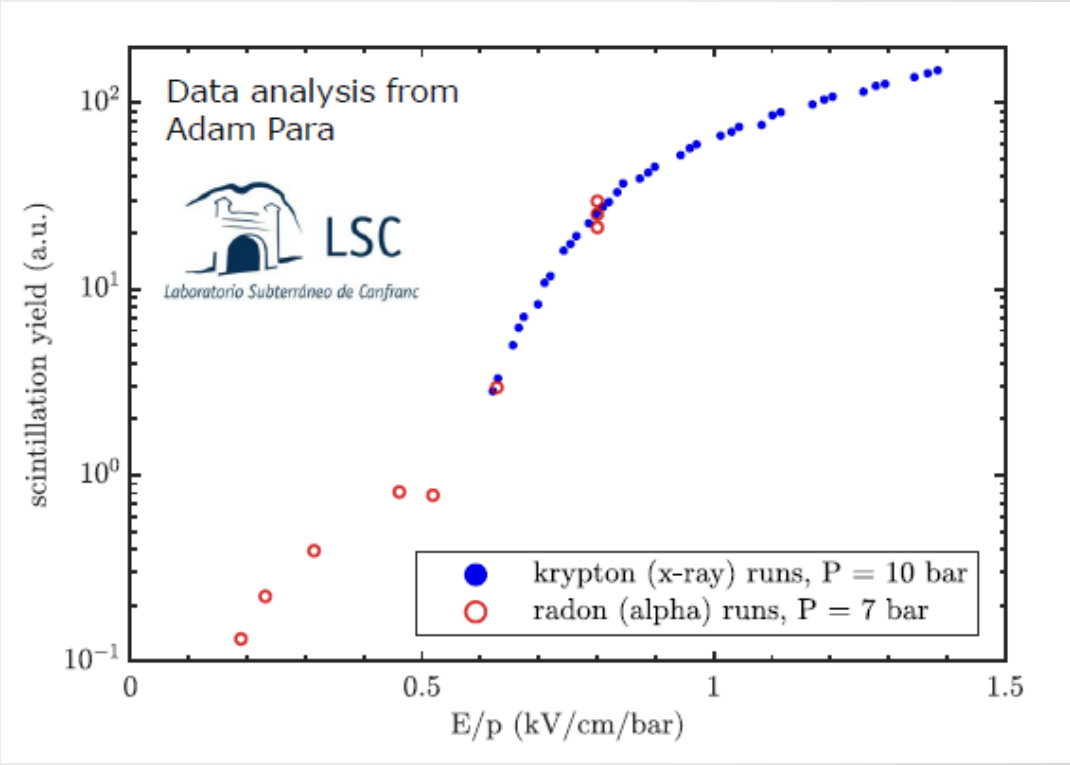
Experimental and simulation results



NBrS studies in Xe - comparison

(Paper submitted for publication with the detailed studies)





Conclusions

- We present unambiguous identification of NBrS scintillation in Xe, supported by a predictive theoretical model:
- We have shown the presence of NBrS in NEXT-White, at present the largest optical HPXe-TPC in operation,
- We studied NBrS in a dedicated setup and implemented a robust theoretical model for NBrS,
- There is a significant photon emission at electric fields well below the EL threshold, detectable with standard photosensors,
- The subthreshold emission is not based on excimer formation , since it is not quenched unlike the ordinary EL emission,
- For EL-fields > 1 kV/cm/bar the NBrS contribution to secondary scintillation is <1%,
- BUT: It will be seen in the TPC buffer regions in the gas phase, between the high voltage electrode and the ground electrodes shielding the PMT planes,
- AND: Relevant in a range of E/p values extending from those applied for secondary scintillation (1kV/cm/bar) to typical drift fields of 100V/cm/bar.
- A clear corollary of our work is that the ample community of neutrino and dark matter experiments based on xenon should not ignore NBrS effects in their experiments.

Acknowledgements

The NEXT Collaboration acknowledges support from the following agencies and institutions: the European Research Council (ERC) under the Advanced Grant 339787-NEXT; the European Union's Framework Programme for Research and Innovation Horizon 2020 (2014{2020) under the Grant Agreements No. 674896, 690575 and 740055; the Ministerio de Economía y Competitividad and the Ministerio de Ciencia, Innovacion y Universidades of Spain under grants FIS2014-53371-C04, RTI2018-095979, the Severo Ochoa Program grants SEV-2014-0398 and CEX2018-000867- S, and the Mara de Maeztu Program MDM-2016- 0692; the Generalitat Valenciana under grants PROMETEO/ 2016/120 and SEJI/2017/011; the Portuguese FCT under project PTDC/FIS-NUC/2525/2014 and under project UIDP/04559/2020 to fund the activities of LIBPhys-UC; the U.S. Department of Energy under contracts No. DE-AC02-06CH11357 (Argonne National Laboratory), DE-AC02- 07CH11359 (Fermi National Accelerator Laboratory), DE-FG02-13ER42020 (Texas A&M) and DE-SC0019223 / DE-SC0019054 (University of Texas at Arlington); and the University of Texas at Arlington (USA). DGD acknowledges Ramon y Cajal program (Spain) under contract number RYC- 2015-18820. JM-A acknowledges support from Fundaci on Bancaria \la Caixa" (ID 100010434), grant code LCF/BQ/PI19/11690012.