Novel approach to Xenon optical TPCs: the presence of Neutral Bremsstrahlung

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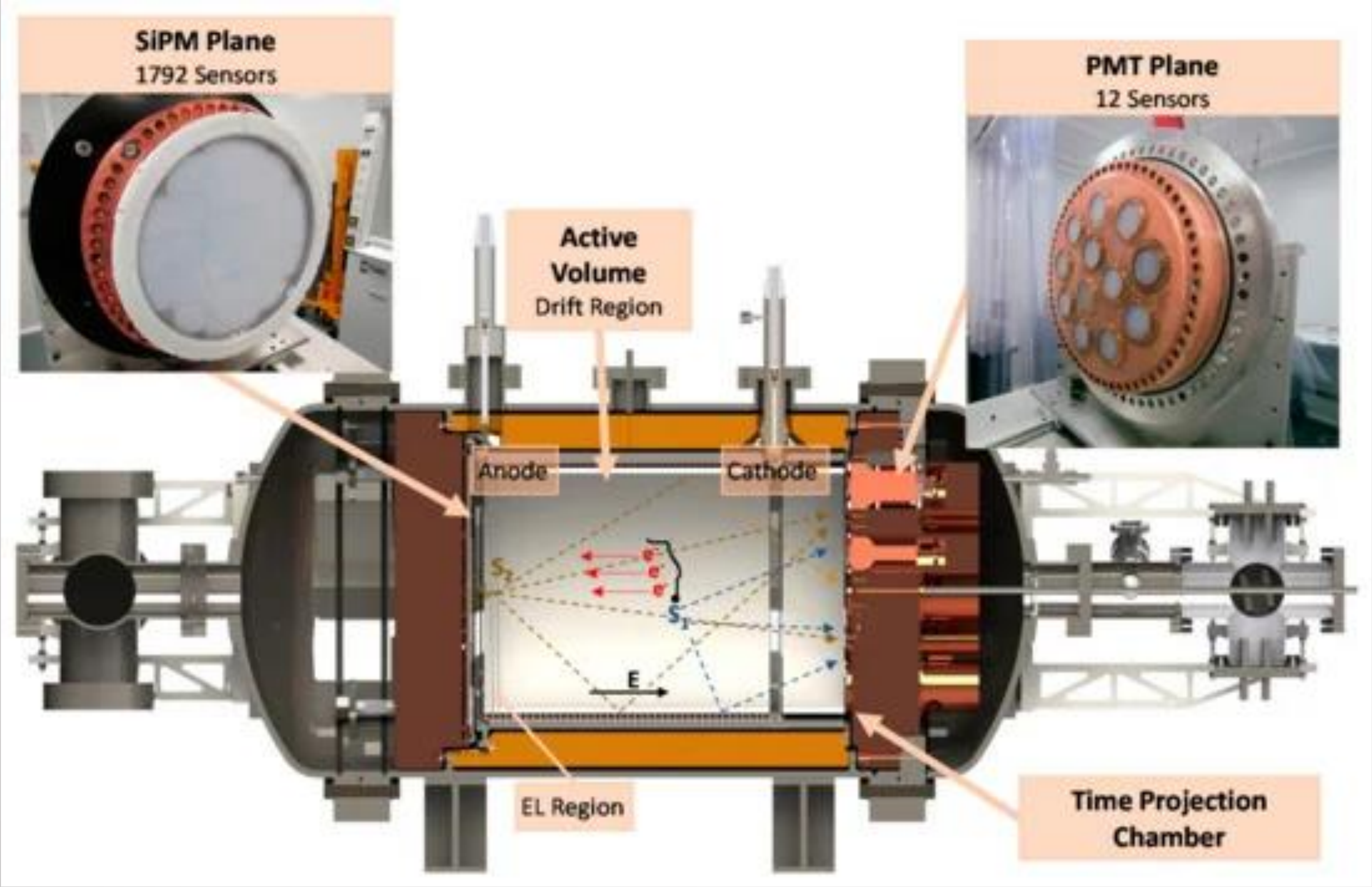
NEXT - the Neutrino Experiment with a Xenon Time projection chamber

- 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 ionisation 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



- 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:

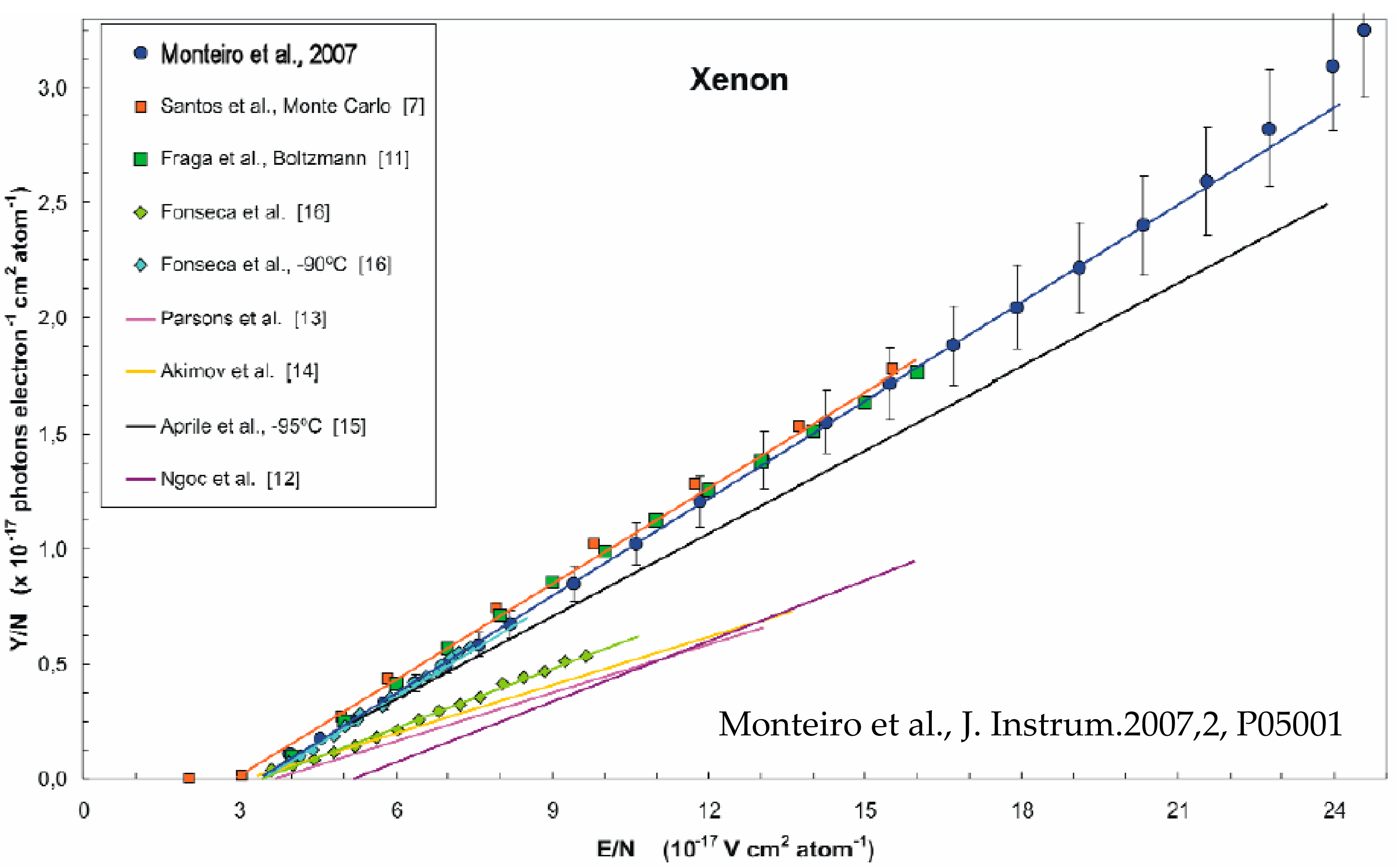
excimer-based secondary scintillation created in a three-body collision of two neutral atoms, Xe, and one excited atom, Xe*, produced by electron impact:

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

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

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



Monteiro et al., J. Instrum.2007,2, P05001

Neutral Bremsstrahlung - NBrS

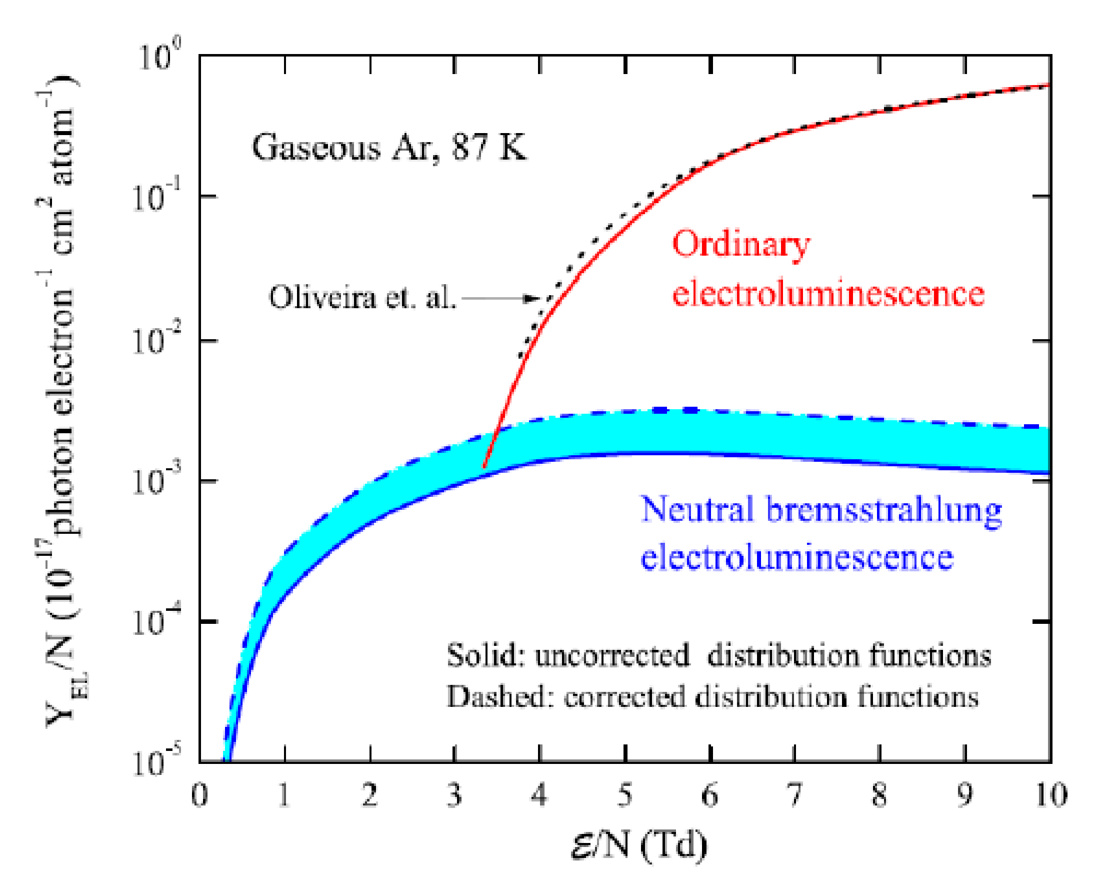
- *A. Buzulutskov et al. Astropart. Phys., 103(2018)29, A. Bondar et al., NIM A 958(2020)162432,* observed a component of non-VUV scintillation above and below the EL threshold in Ar with a continuous spectrum from UV to NIR

NBrS was pointed out as the natural explanation:

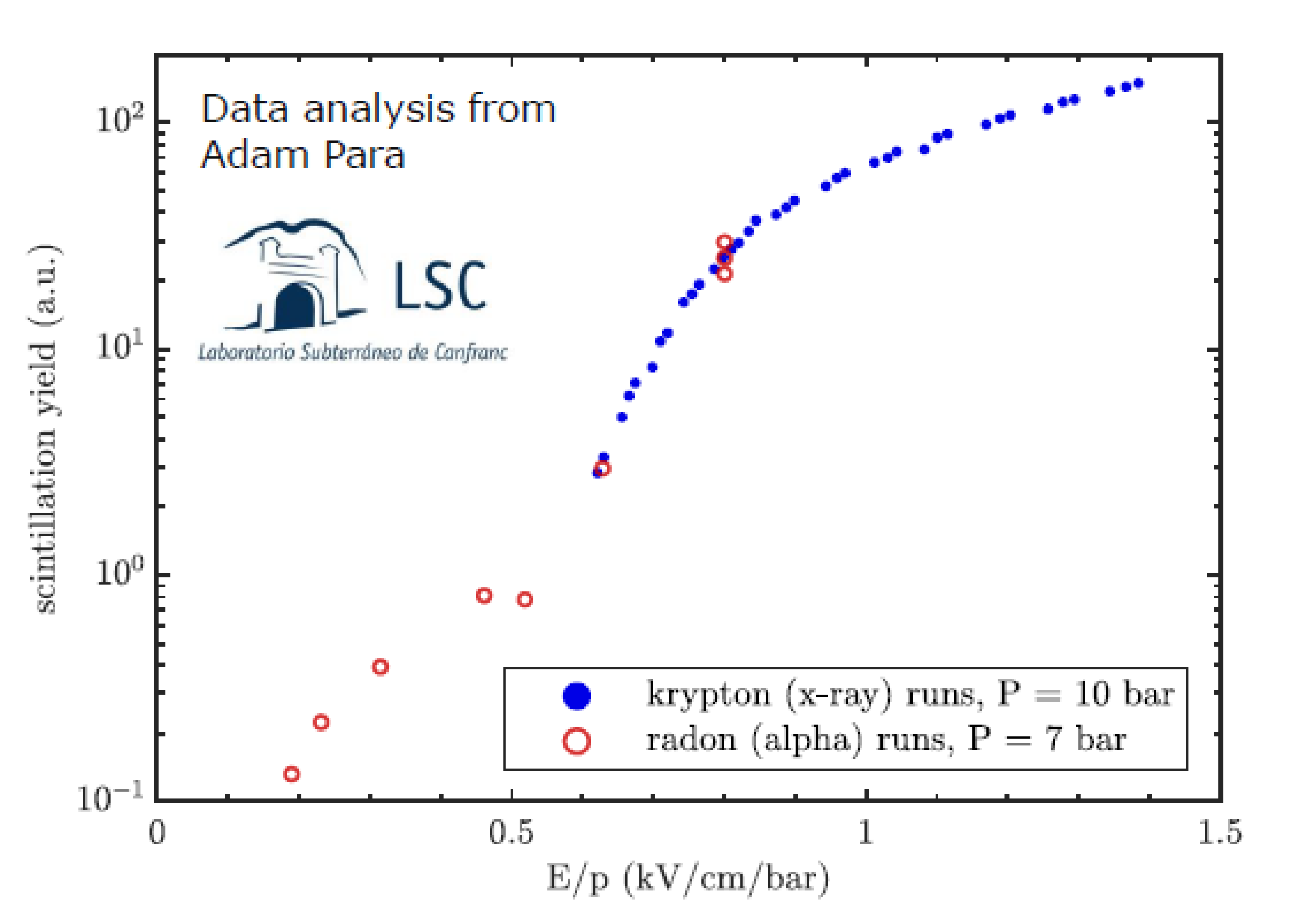
a concurrent secondary scintillation mechanism based on bremsstrahlung of drifting (slow) electrons scattered on neutral atoms:

e- + Ar → e- + Ar* + *hv* (elastic scattering)

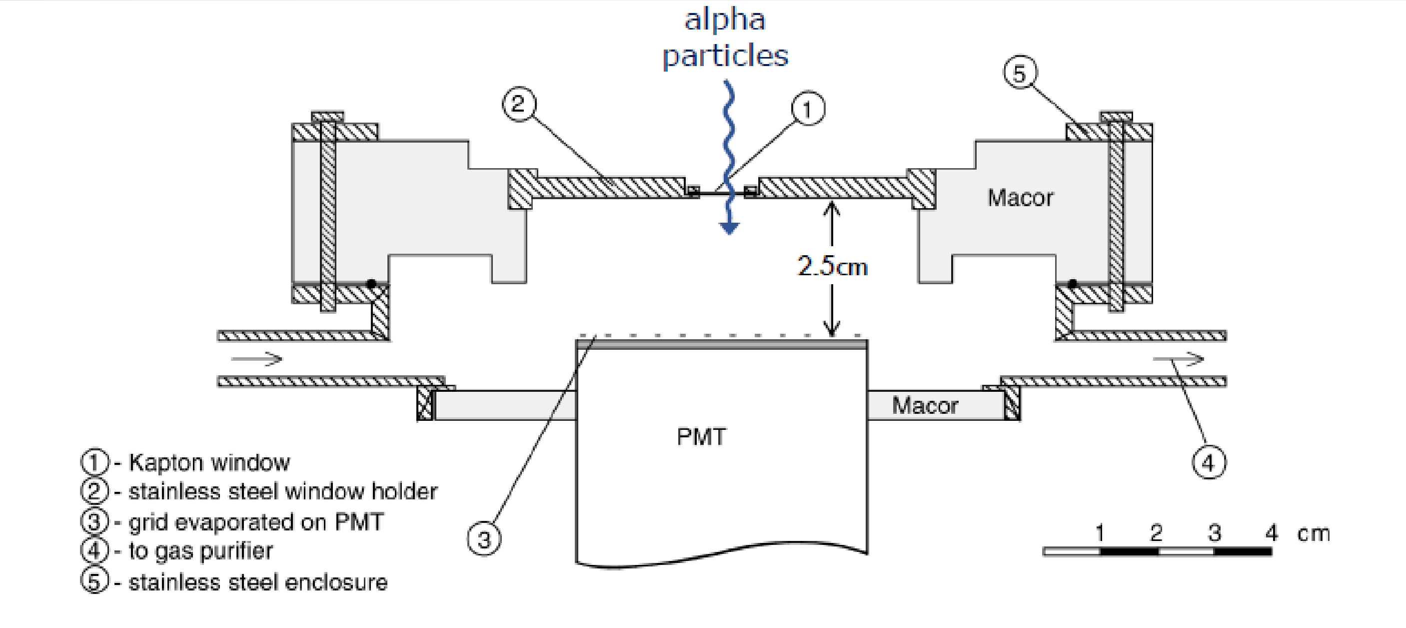
e- + Ar → e- + Ar + *hv* (inelastic scattering)

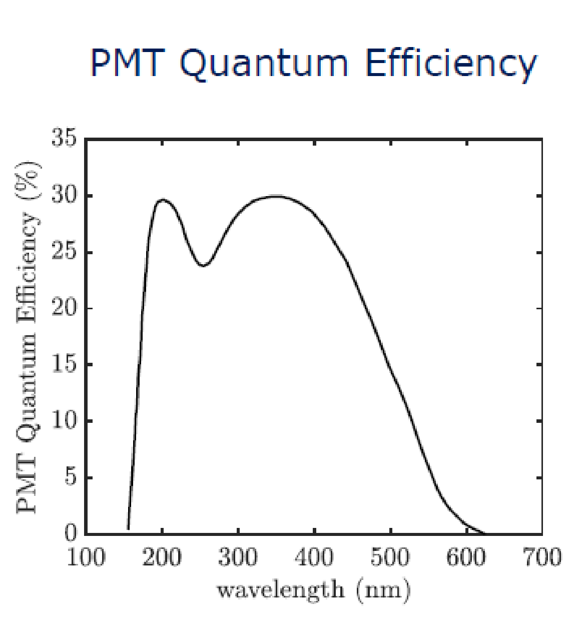


NBrS observation in NEXT-NEW



NBrS studies in Xe: driftless GPSC

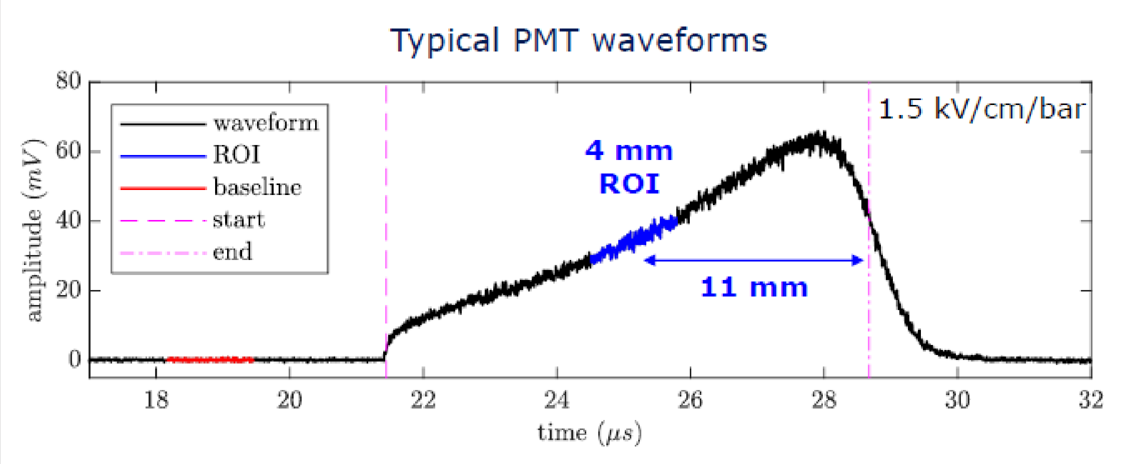




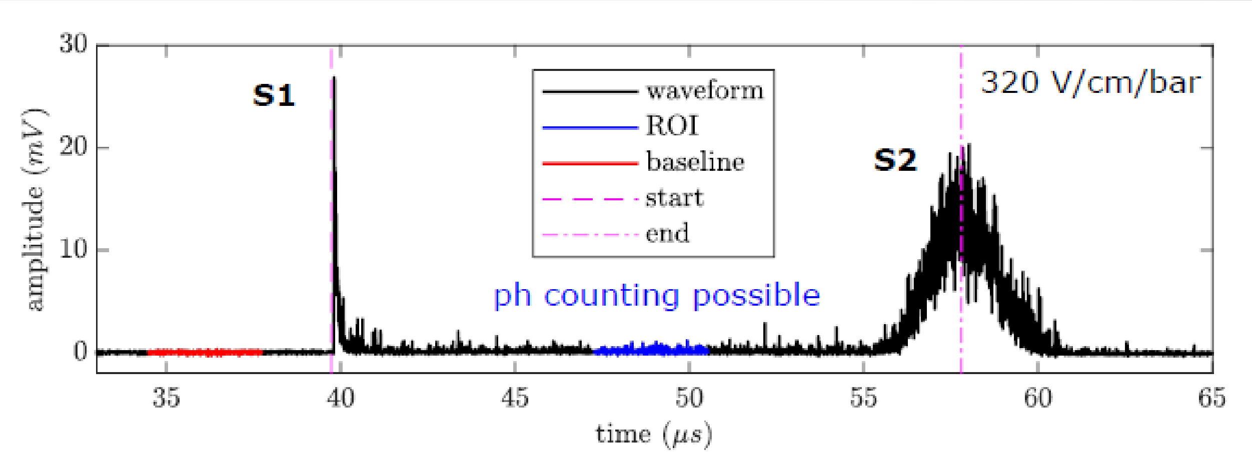
- Dedicated setup: GPSC without drift-region
- 25-mm scintillation gap
- PMT: 52-mm diameter; spectral sensitivity: 155-625 nm
- Gas in a closed circuit, continuously purified by hot getters, SAES st707
- Xenon gas @ 1.24 bar
- Incident radiation: alpha particles from a collimated ^{241}Am source
- Mean 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.
- ROI → photons collected when the electron cloud is 1.3-0.9 cm away from the anode



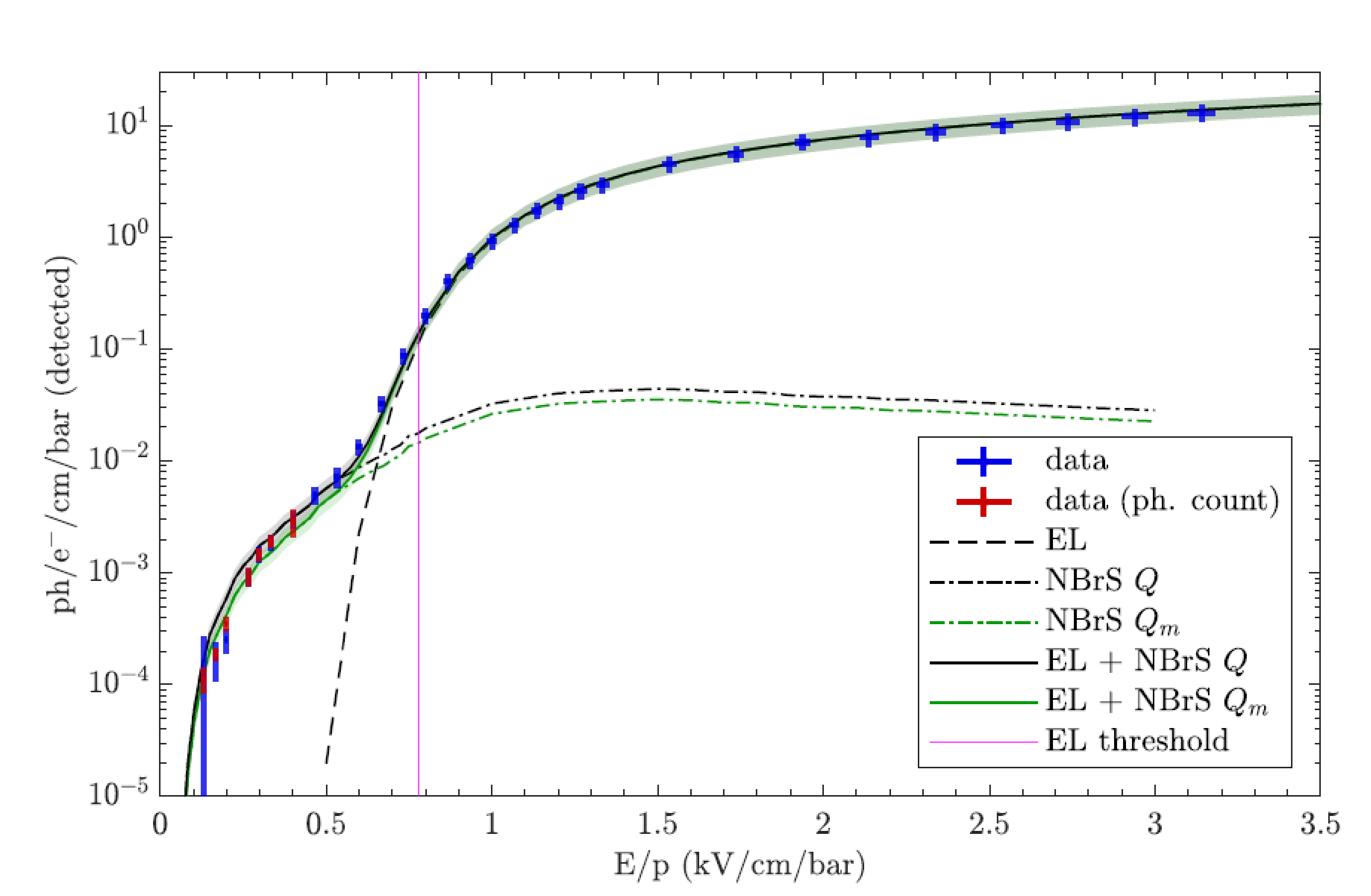
Typical driftless GPSC waveforms for an E/p value above the Xe excitation threshold (1.5 kV/cm/bar)



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

NBrS studies in Xe - Results

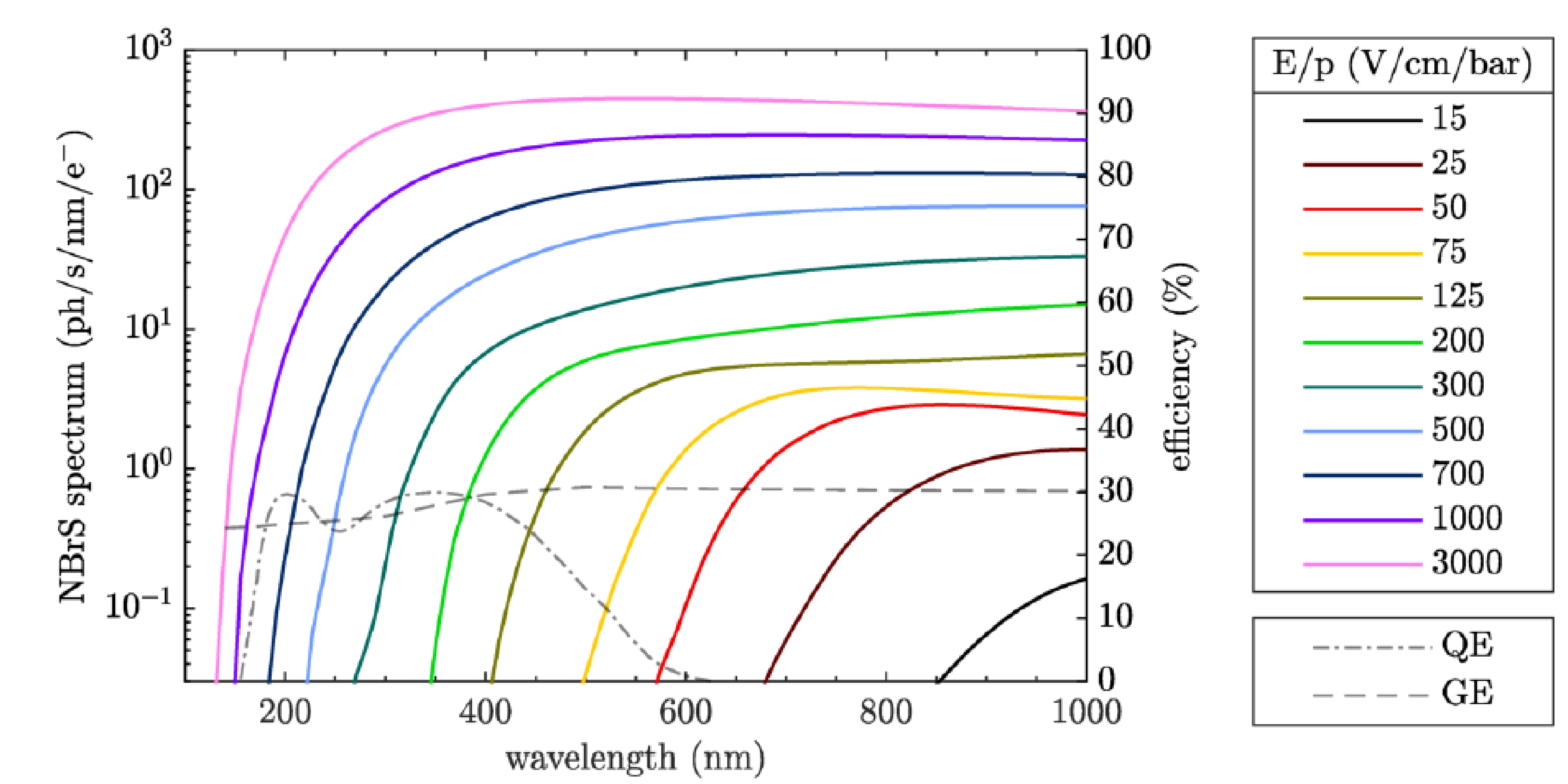
Experimental and simulation results



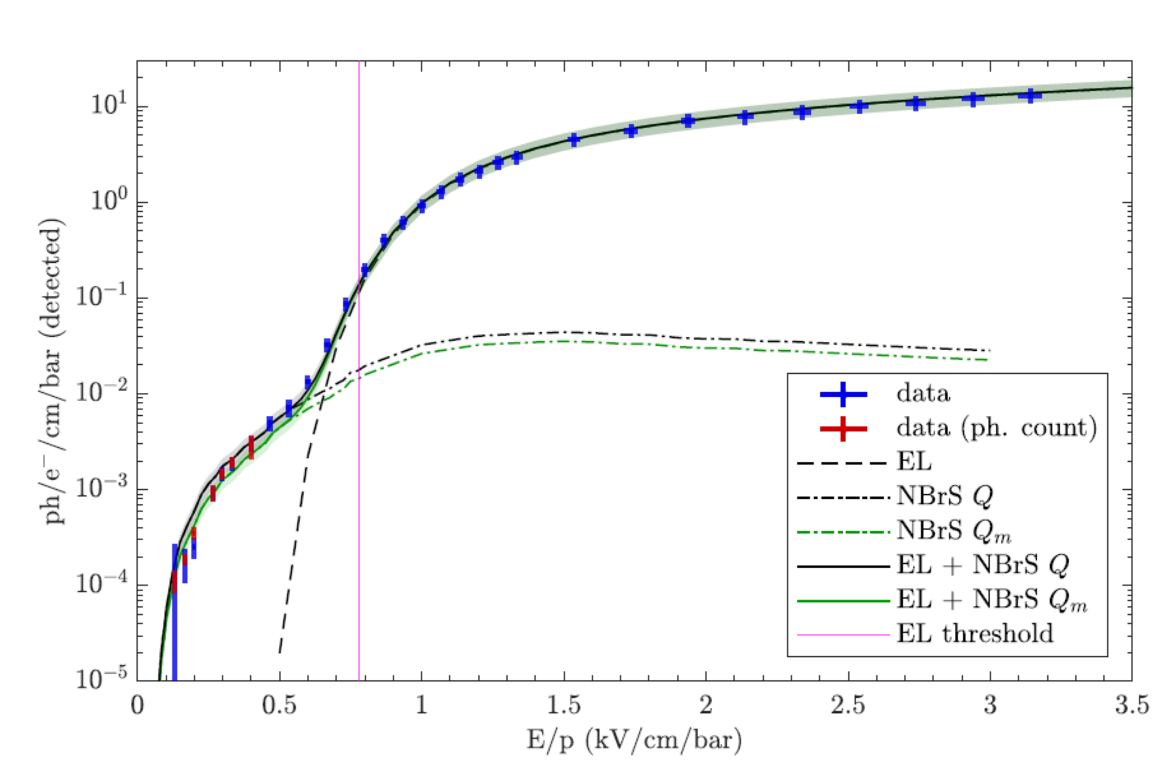
NBrS studies in Xe - Simulation

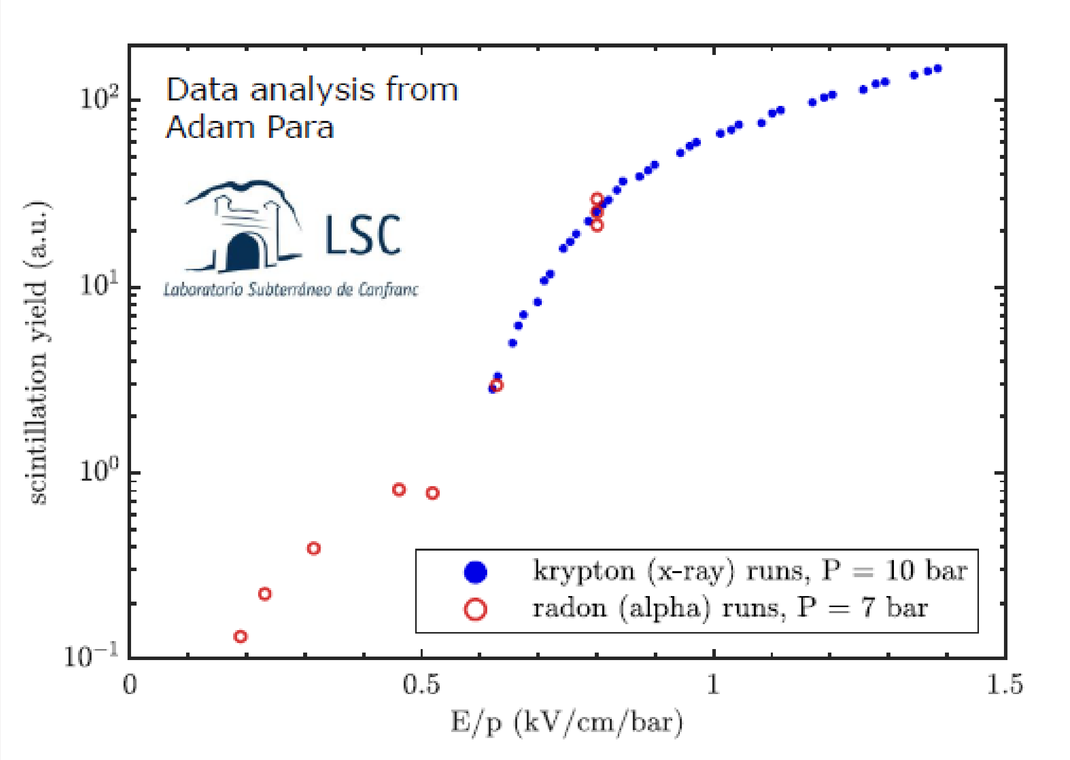
$$Y \equiv \frac{dN_\gamma}{dz} = \frac{1}{v_d}\int_0^\infty \frac{dN_\gamma}{d\nu dt}\frac{1}{v_d} \cdot \int_0^\infty \int_0^\infty N \frac{d\sigma}{d\nu} v(\varepsilon) \frac{dP}{d\varepsilon} d\varepsilon d\nu \quad [ph/cm]$$

$$\frac{d\sigma}{d\nu} = \frac{8}{3}\frac{r_e}{c}\frac{1}{h\nu}\left(\frac{\varepsilon_i - h\nu}{\varepsilon_i}\right)^{1/2} \cdot \left[\varepsilon_i \cdot Q_{(m)}(\varepsilon_i - h\nu) + (\varepsilon_i - h\nu)\cdot Q_{(m)}(\varepsilon_i)\right]$$



NBrS studies in Xe - comparison





Conclusions

- We present unambiguous identification of NBrS scintillation in Xe, supported by a predictive theoretical model:
- We have shown 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 in the range of 150-600 nm at electric fields well below the EL threshold detectable with standard sensors,
- The subthreshold emission is not based on excimer formation , since it is not quenched as 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 and down to the thermal limit (~ E/p = 10 V/cm/bar in pure Xe at room temperature) if using photosensors with sensitivity up to 1000 nm.

Acknowledgements

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