Very-thick transparent GEMs with wavelength-shifting capability for noble element TPCs

Marcin Kuźniak, Diego González-Díaz et al. (see next slide)
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Dark Wave

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Letter

Development of very-thick transparent GEMs with wavelength-shifting capability for noble element TPCs

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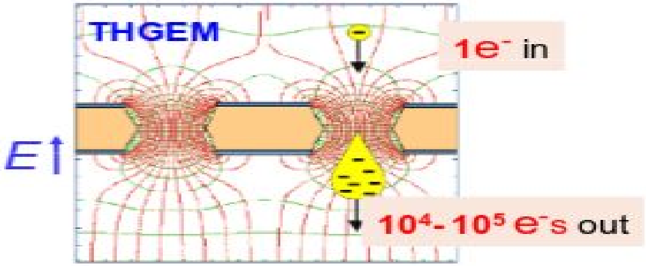
Motivation

- Scale-up of gaseous or dual phase TPCs
  - Needed for dark matter searches, neutrino experiments, …
  - Challenges with stability, uniformity, liquid levelling, overall efficiency
  - VUV conversion or detection over large surface area
- Integrated system for light and charge collection and detection
  - Simplified (optical only) readout
  - Low noise

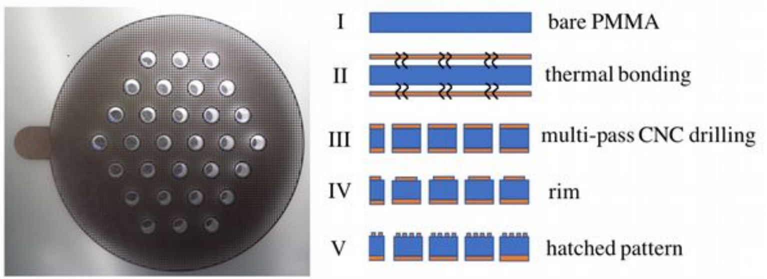
Inspirations

Thick-GEM

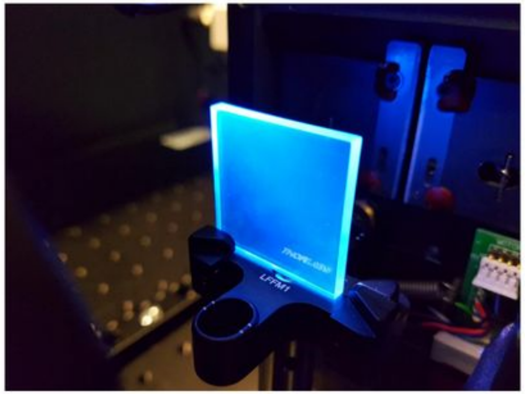


FAT-GEM:
- Metal mesh electrodes partly transparent to visible light
- Optical charge readout via electroluminescence

D. Gonzalez-Diaz et al., J. Phys. Conf. Ser. 1498, 012019 (2020)



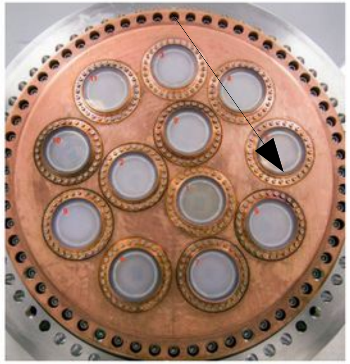
Wavelength shifting and scintillating PEN tiles
(developed for LEGEND, see Louis Manzanillas talk next)



Tile WLS efficiency: ~9%
Y. Abraham et al., arXiv:2103.03232

Y Efremenko et al 2020 J. Phys.: Conf. Ser. 1468 012225

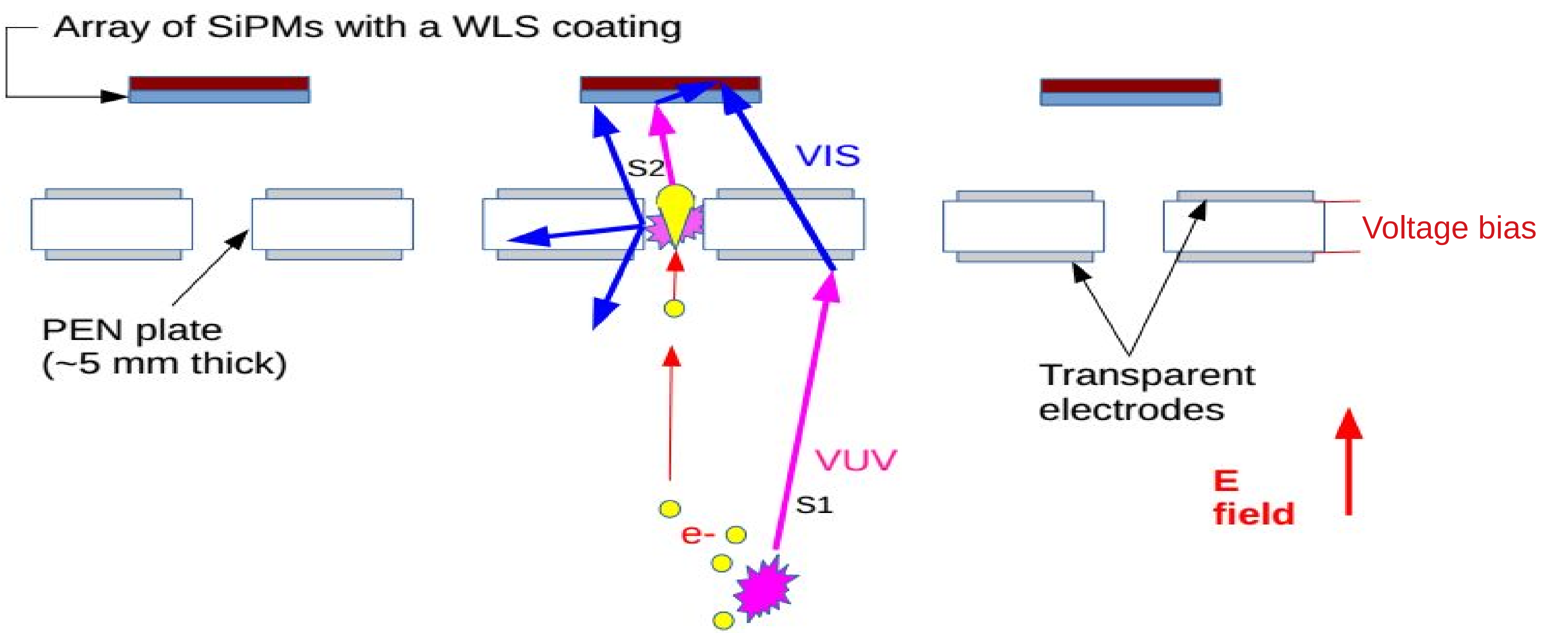
Transparent PEDOT:PSS electrodes
(used for NEXT-White, planned for DarkSide-20k)



F. Monrabal et al 2018 JINST 13 P12010

Concept

- Base plate transparent to visible light and wavelength shifting
  - S2 converted to visible on the spot
- Electrodes transparent to visible and VUV
  - S1 and S2 efficiently collected after conversion to visible
- Detection with an array of blue sensitive photosensors (with optional WLS coating)



Transparent electrode production

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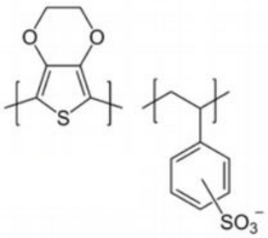
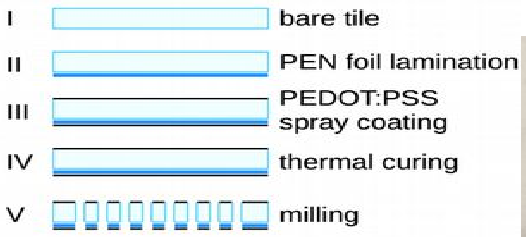
- PEDOT:PSS conductive polymer, deposited from solution
- Many commercial formulations, multiple coating methods
  - Used Clevios F ET (Heraeus)

- Can give very transparent coatings:
  - Substantially diluted
  - Airbrushed
  - Thickness in range of O(10) nm

- Optical properties
  - 95 – 99% transmission (visible)
  - Low refractive index
  - Low haze
  - Tunable conductivity
  - VUV transmission ???





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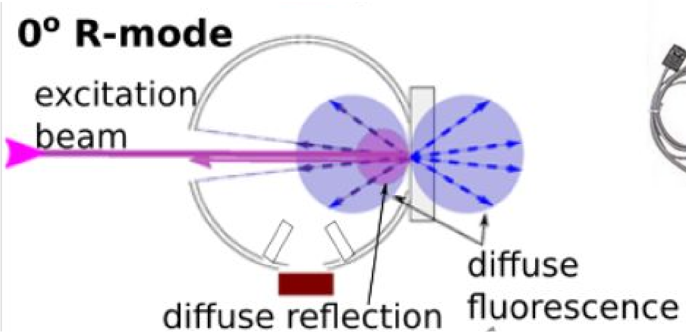
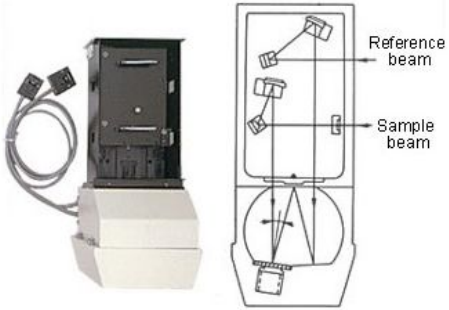
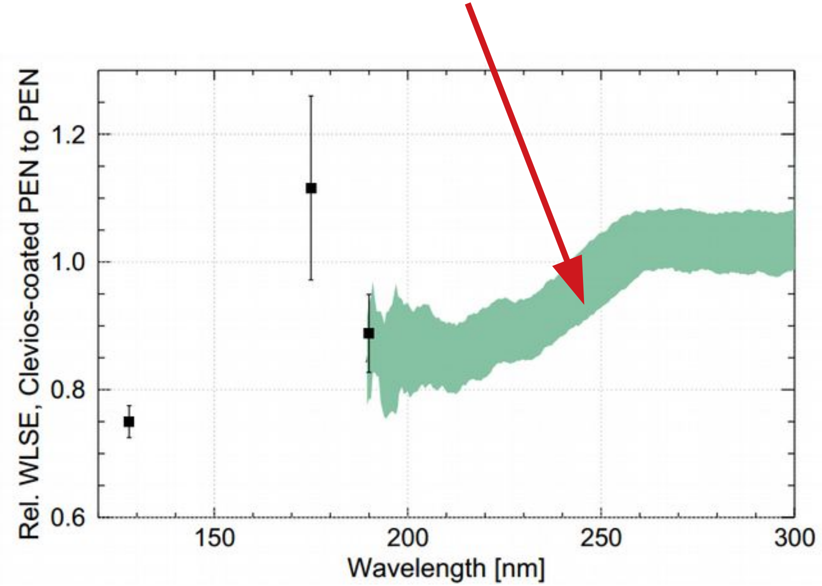
PEDOT:PSS transparency

- Spectrophotometer UV scan with an integrating sphere in a diffuse reflection mode:
  - Good measure of the overall wavelength shifting intensity
  - Robust against angular effects in emission
  - Accessible only down to 190 nm

- Measured PEDOT:PSS coated PEN tile relative to uncoated
  - Error bar from taking probing multiple spots on the samples

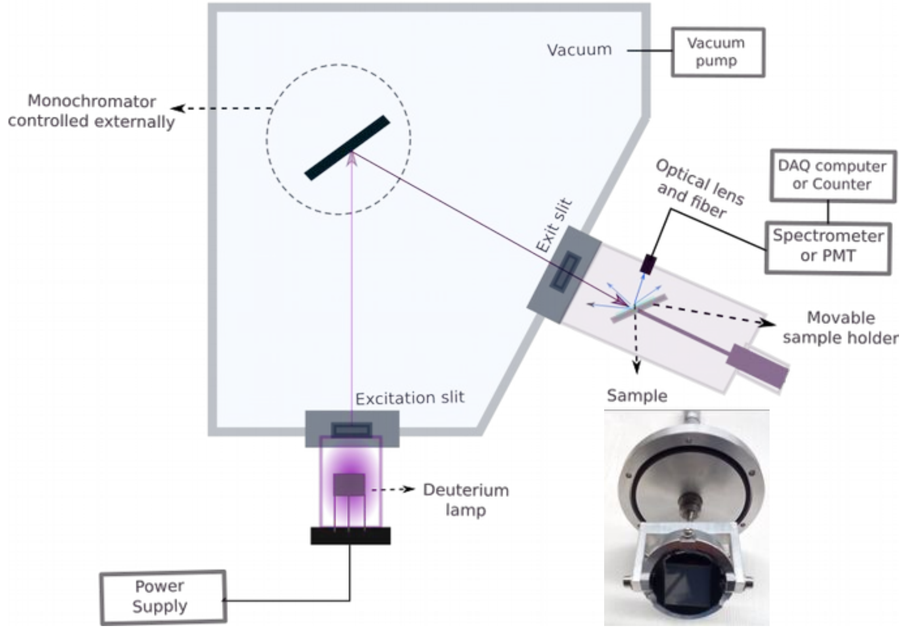


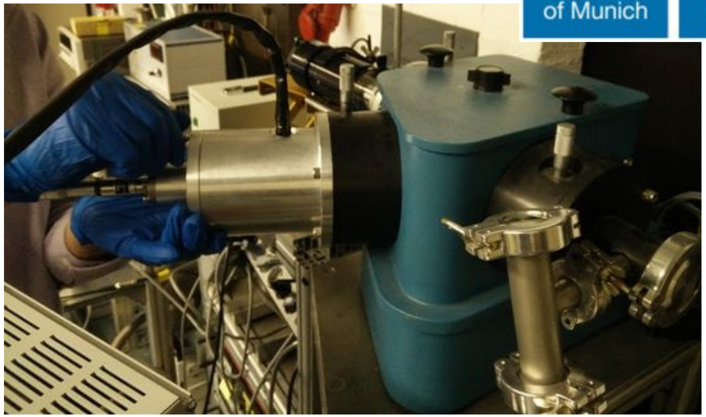


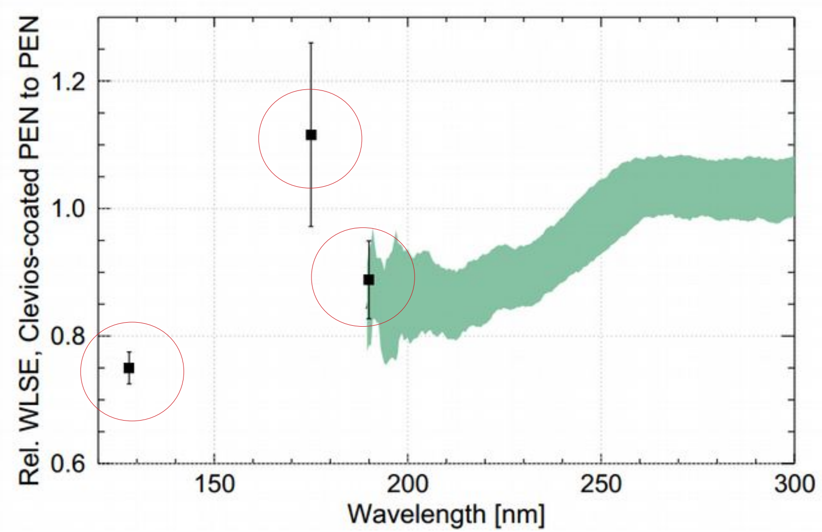


PEDOT:PSS transparency

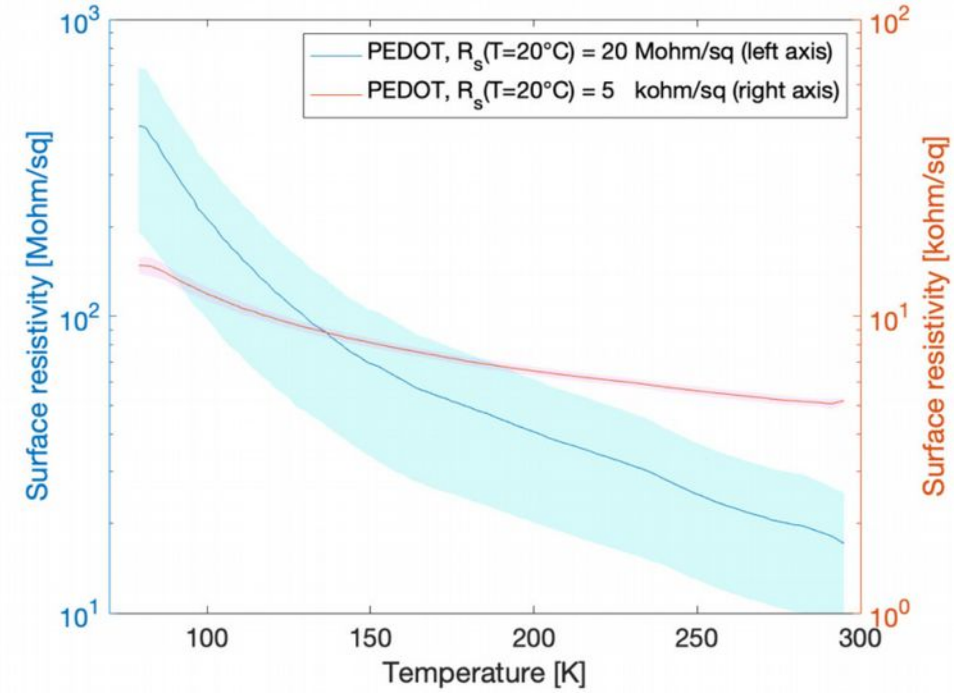
- Fixed angle measurement with a vacuum monochromator below 200 nm
- At 190 nm both methods agree
- At 128 nm WLS efficiency of PEDOT:PSS coated PEN reduced by ~25% (only)
- Possible to better optimize the coatings







PEDOT:PSS resistivity



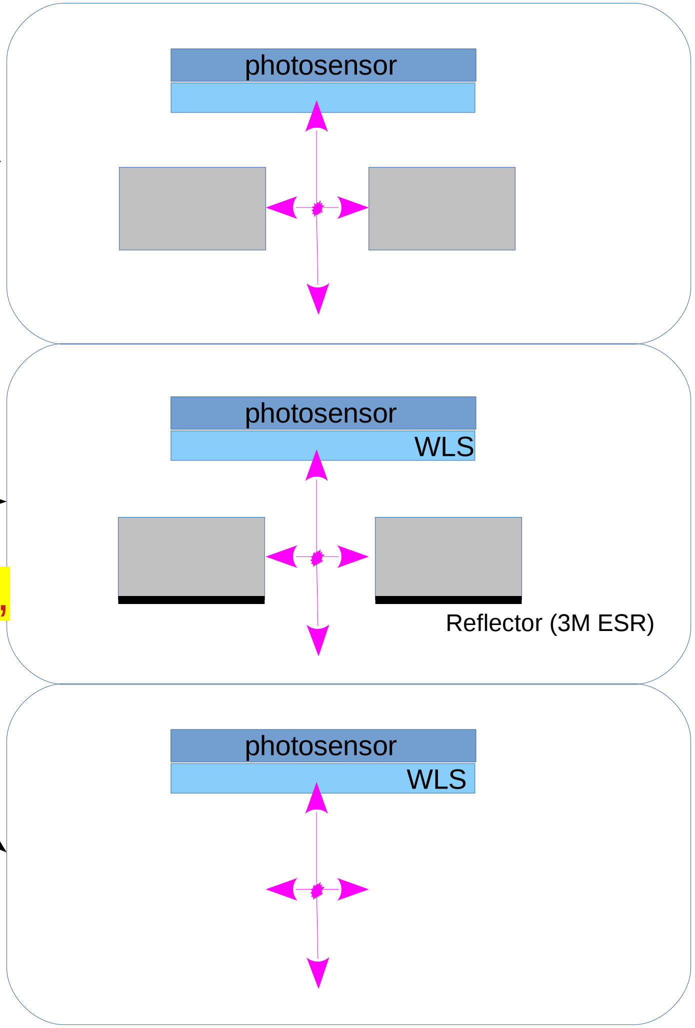
- For spark protection > O(10) MΩ is desired
- Surface resistivity measured as a function of temperature
- Thin coatings satisfy the requirement:
  - At RT: ~20 MΩ/sq.
  - At 77K: ~400 MΩ/sq.

Simulated light collection

	TPC | side	Base mat.: WLSE	PD | side	S1 ε_{vuv}: 1.5% ε_{vis} [%]	S1 f	S2 ε_{vuv}: 10% ε_{vis} [%]	S2 f
a	PEDOT	PMMA:0	PEDOT	0	1	0	1
b	PEDOT	PEN:0.09	PEDOT	1.1(5)	2.5	1.3(5)	1.2
c	PEDOT	PEN:1	PEDOT	12(5)	17	14(5)	4.9
d	PEDOT	PMMA:1	PEDOT	32	44	36	8.1
e	PEDOT Q51	PEN:0.09	PEDOT	4(2)	6.6	1.4(6)	1.2
f	PEDOT Q51	PMMA:0	PEDOT	2.3	4.2	0	1
g	PEDOT ESR	PMMA:1	PEDOT	7.7	11	58	13
h	mesh	PEN:0.09	mesh	0.8(3)	2.1	1.0(3)	1.1
i	mesh	PMMA:1	mesh	19	26	25	6.0
j	mesh	Ar/Xe:0	mesh	0	60	0	4.5

Idealized cases:

No absorption, WLSE=1



WLS tile

Wire mesh TPC-like

- Geant4 model used to simulate S1 and S2 light collection
- For S2 significant enhancement, due to more efficient geometry
- Figure of merit: $f \equiv \dfrac{\varepsilon_{vuv}/2 + \varepsilon_{vis}}{\varepsilon^{(a)}_{vuv}/2}$

Simulated light collection

	TPC side	Base mat.: WLSE	PD side	S1 ε_{vuv}: 1.5% ε_{vis} [%]	S1 f	S2 ε_{vuv}: 10% ε_{vis} [%]	S2 f
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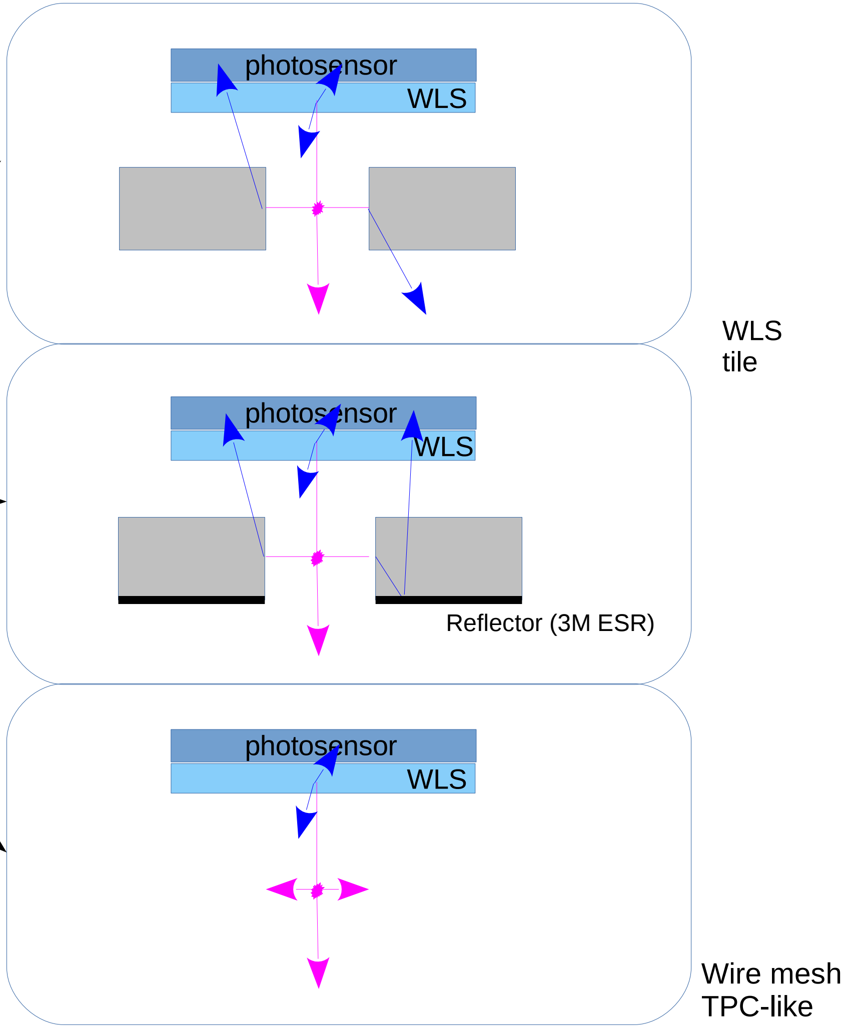
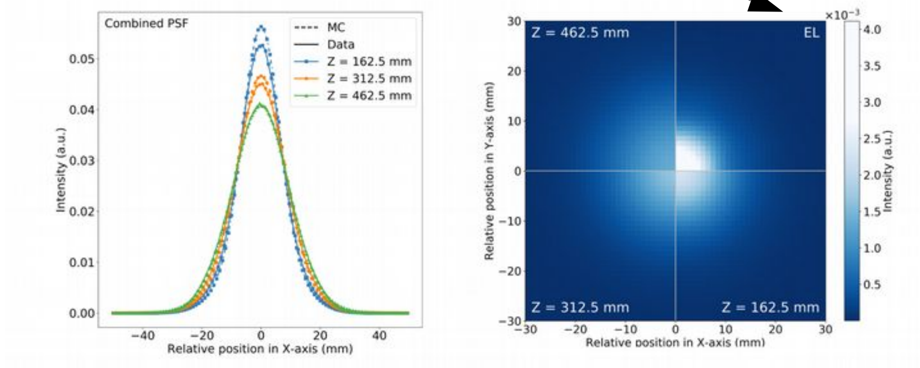


- Geant4 model used to simulate S1 and S2 light collection
- For S2 significant enhancement, due to more efficient geometry
- Figure of merit: $$f \equiv \frac{\varepsilon_{vuv}/2 + \varepsilon_{vis}}{\varepsilon_{vuv}^{(a)}/2}$$

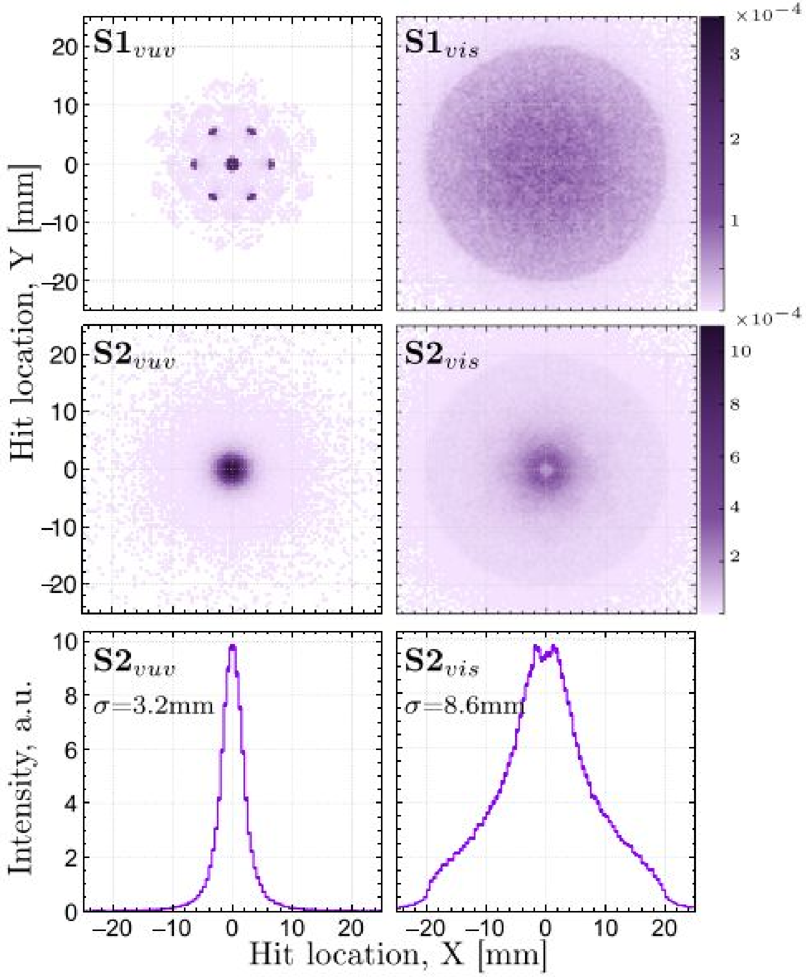
Simulated hit pattern

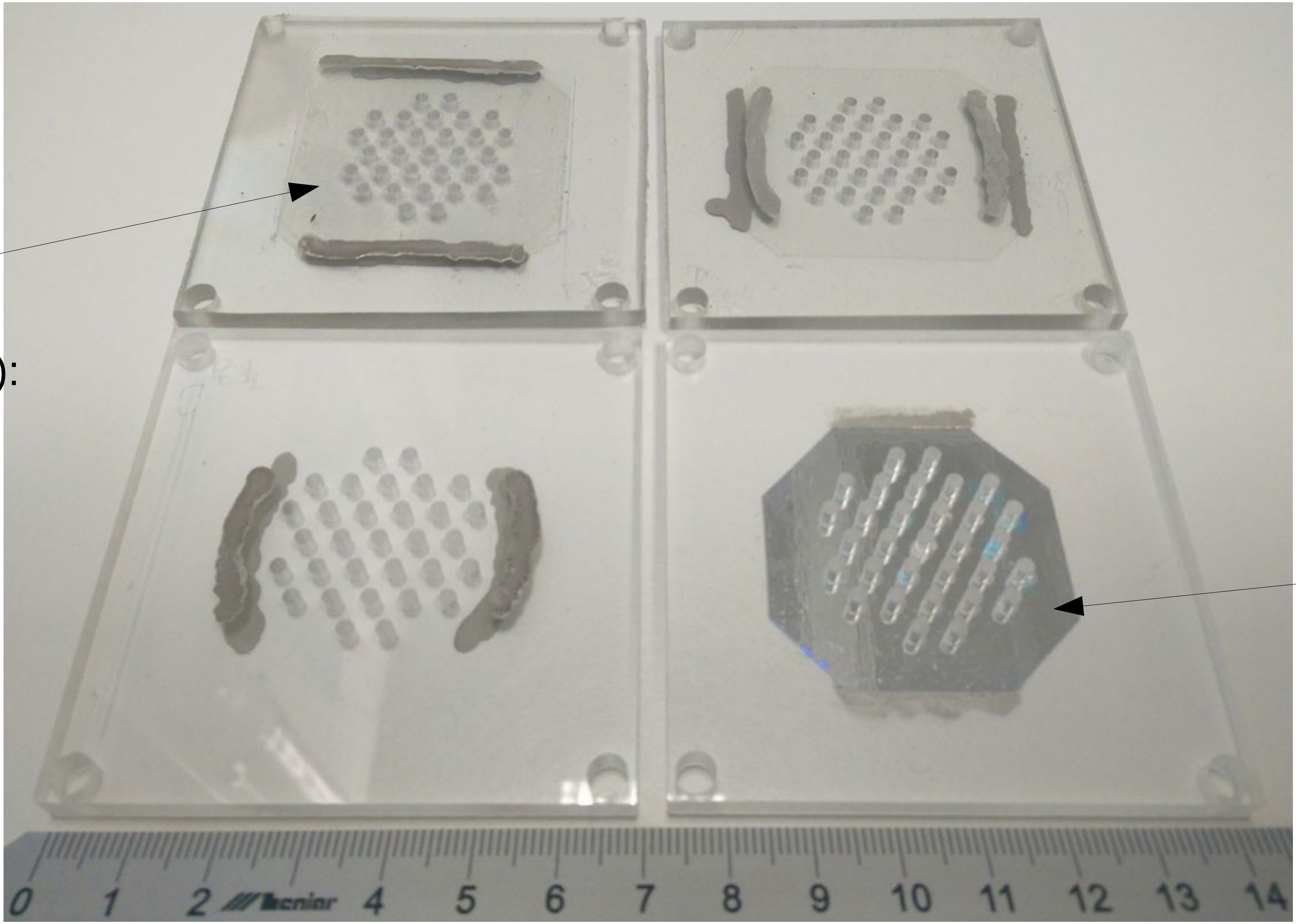
- Illumination pattern from S2 (point spread function, PSF) is well localized
- Good potential for precise position reconstruction
    - Example from NEXT

(See talk by Ander Simón Estévez later today)



- Up to a factor of 2-3 enhancemnt in S2 collection, with no major increase in PSF





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PEN foil
(Teonex Q51):

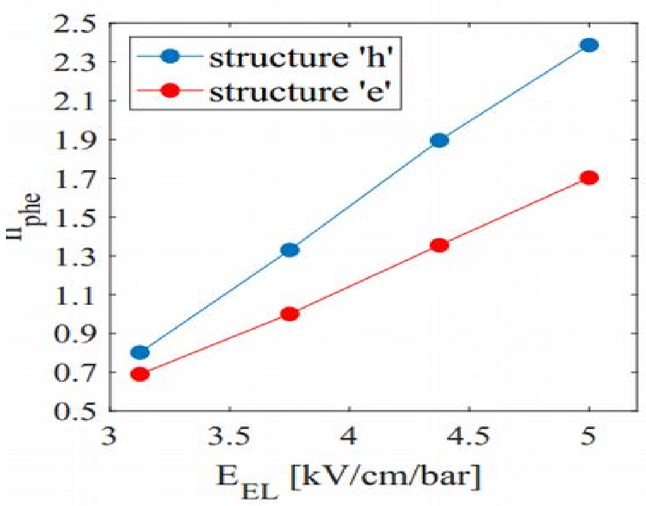
WLSE: 47%

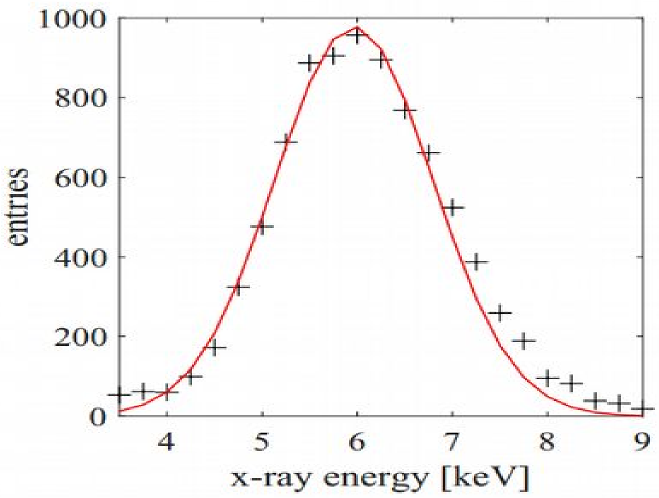
(See
Cenk
Turkoglu
talk next)

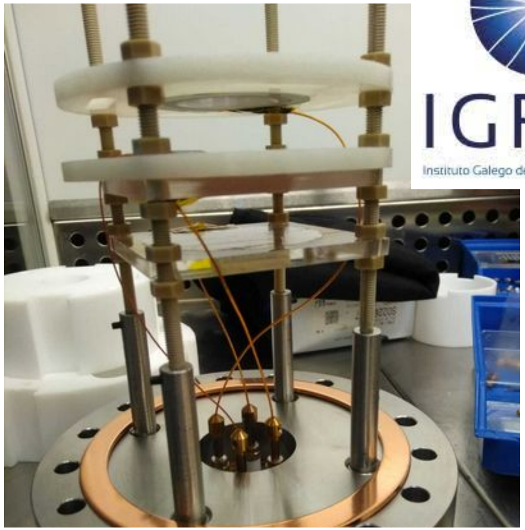
ESR
reflector

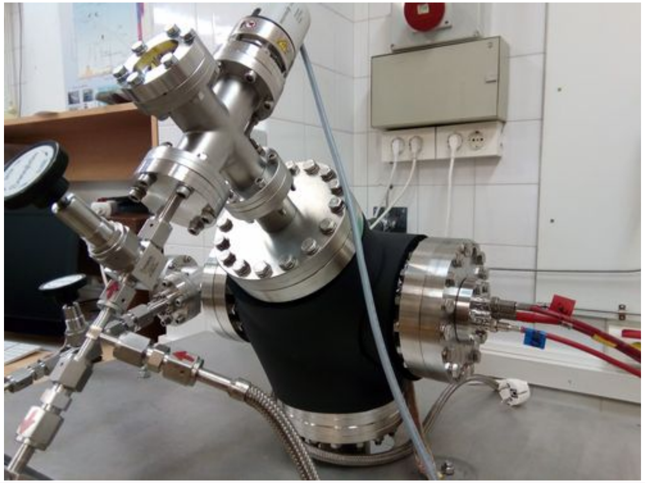
Proof-of-principle tests

- HV stability up to 6kV (in air)
- Collected data @4kV at 2bar Xe
  - 32% FWHM energy resolution
  - Good, stable performance









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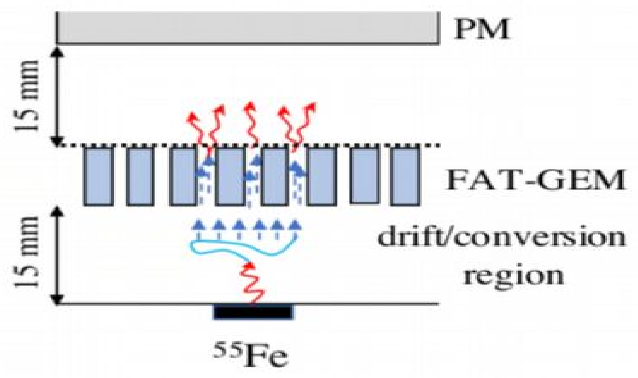
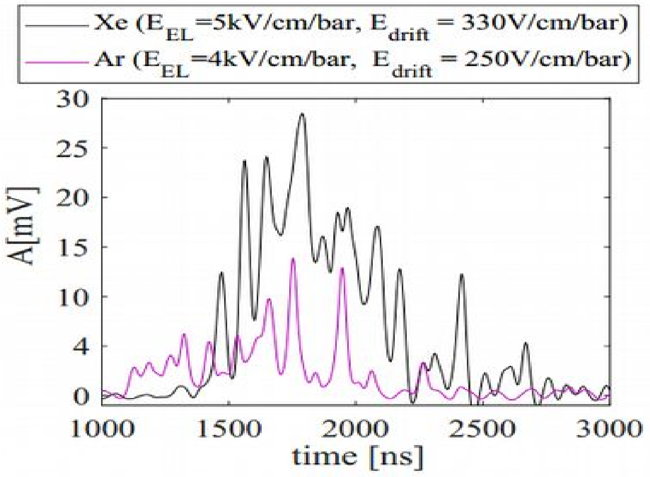
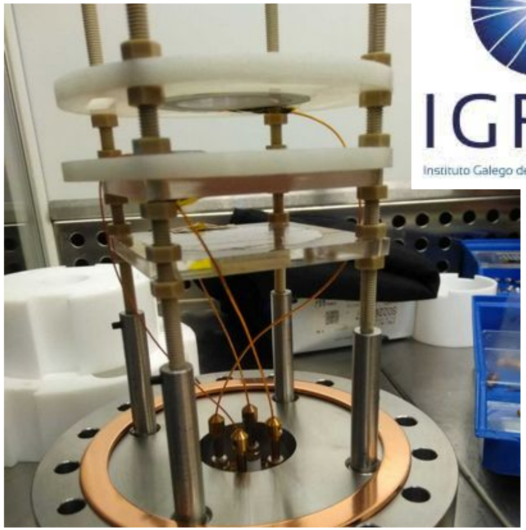
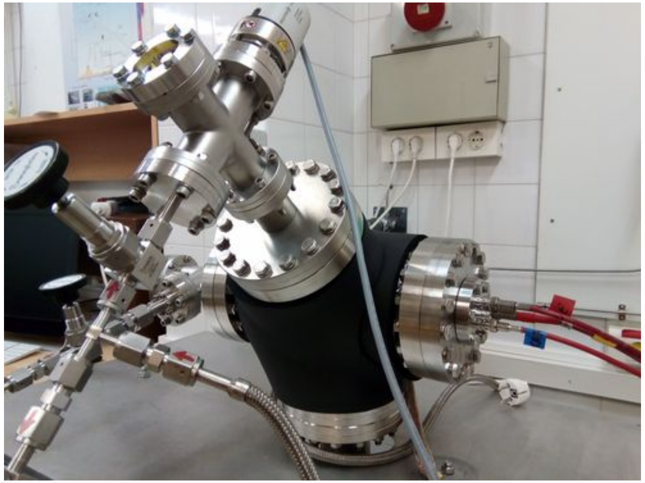
Proof-of-principle tests









- Tested in a gaseous Xe and Ar TPC at IGFAE
- ^{55}Fe 5.9 keV X-ray source
- PMT is blind to Ar scintillation wavelength
  - Clear signal visible in Ar: evidence for WLS!

Summary and outlook

- Main feature of the proposed structures
  - Enhanced S2 collection, with S1 remaining high
  - Easy and scalable production
  - Intrinsic radiopurity
- Proof-of-principle HV tests successful:
  - First light seen, hints of WLS, adequate performance of PEDOT:PSS
- Complete characterization and optimization planned
- Room for improvements:
  - spark immunity of PEDOT:PSS (optimized configurations to be tested soon)
  - WLS efficiency of the tile (will try TPB and commercial WLS plastics)
- Other possible operation modes under consideration:
  - „Floating” on LAr surface, or LHM-like configuration

Backup