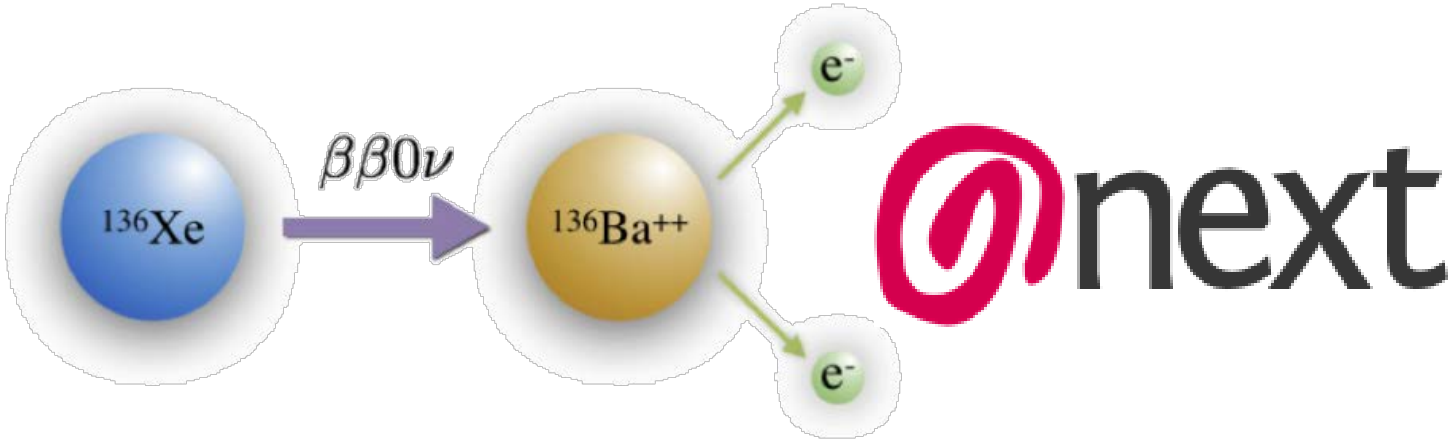
The FBI concept in the context of Ba-tagging for neutrinoless double beta decay events.

Fluorescent **B**icolor **I**ndicator



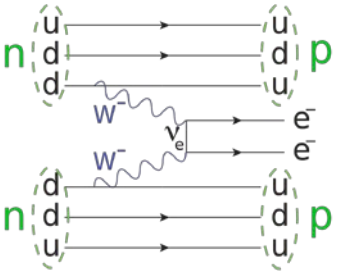
Detecting "tagging" the Ba^{++} signaling a ββ0v process in TPC xenon chambers.

Zoraida Freixa[a,b] on behalf of next

Iván Rivilla,[b,c] Borja Aparicio,[a] Pablo Herrero,[c,d] Celia Rogero,[d] Francesc Monrabal,[b,c] Fernando P. Cossío,[a] Juan José Gómez-Cadenas[b,c]

[a] University of the Basque Country (UPV/EHU), 20018 Donostia, Spain. [b] Ikerbasque, Basque Foundation for Science, 48009 Bilbao, Spain. [c] Donostia International Physics Center (DIPC), 20018 Donostia, Spain. [d] Materials Physics Center CFM (CSIC-UPV/EHU).20018, Donostia, Spain.

How to confirm experimentally if neutrino is a Majorana particle?



$\beta\beta 2\nu$

$^{Z}_{A}X \rightarrow {}^{Z+2}_{A}X + 2\,e^{-} + 2\,\bar{\nu}$

SM-allowed process
Measured in several nuclei

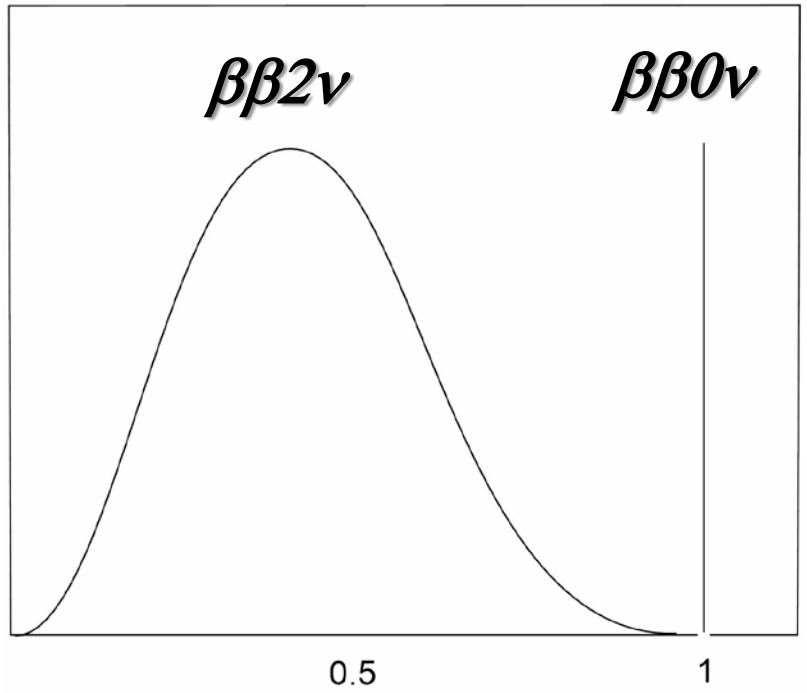
$T^{2\nu}_{1/2} \sim 10^{19} - 10^{21}\ yr$

$\beta\beta 0\nu$

$^{Z}_{A}X \rightarrow {}^{Z+2}_{A}X + 2\,e^{-}$

Lepton number violating process
Requires massive, Majorana neutrinos

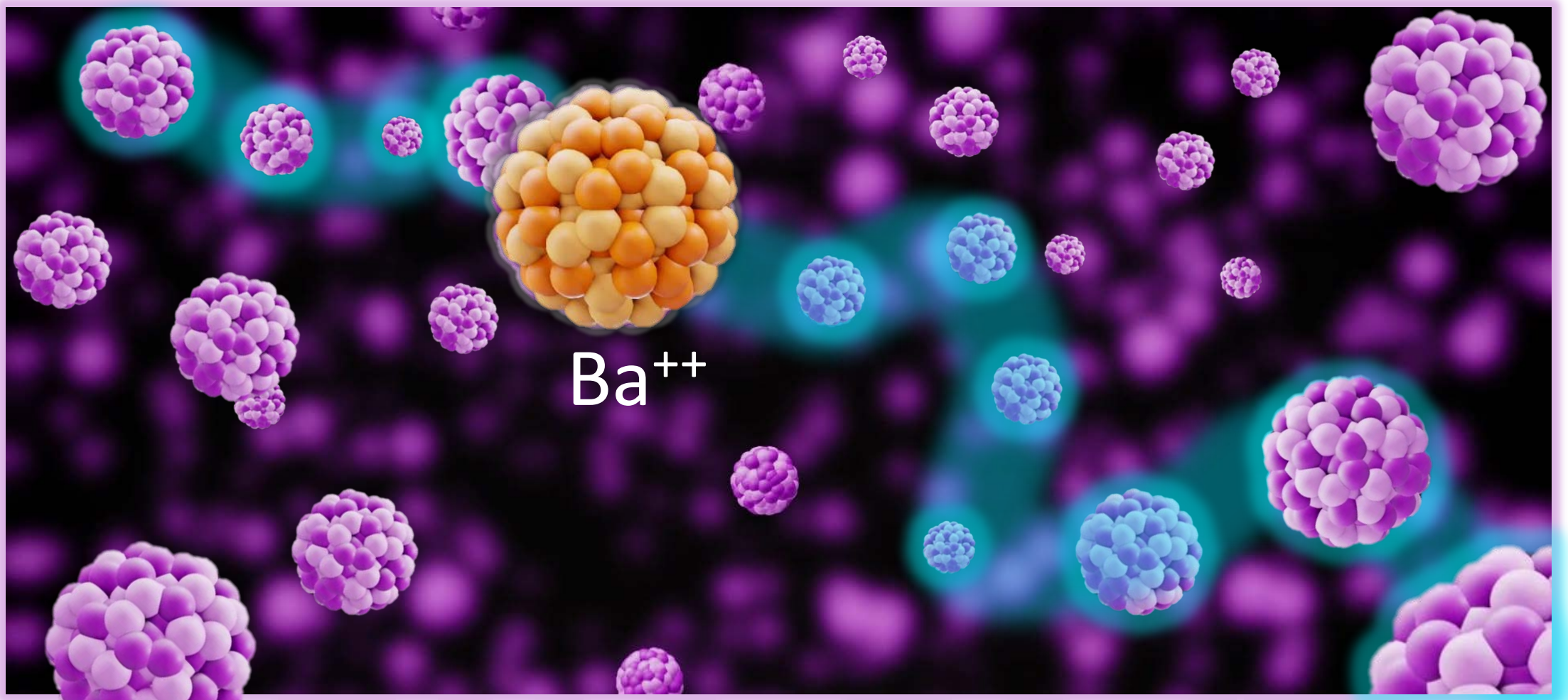
$T^{0\nu}_{1/2} > 10^{26}\ yr$



$(T_{e1} + T_{e2}) / Q_{\beta\beta}$

How to confirm experimentally if neutrino is a Majorana particle?

$\beta\beta0\nu$ in high-pressure ^{136}Xe gas



Detecting “tagging” the Ba^{++} signaling a ββ0v process has been a long sought holy grail of xenon chambers.

How to confirm experimentally if neutrino is a Majorana particle?

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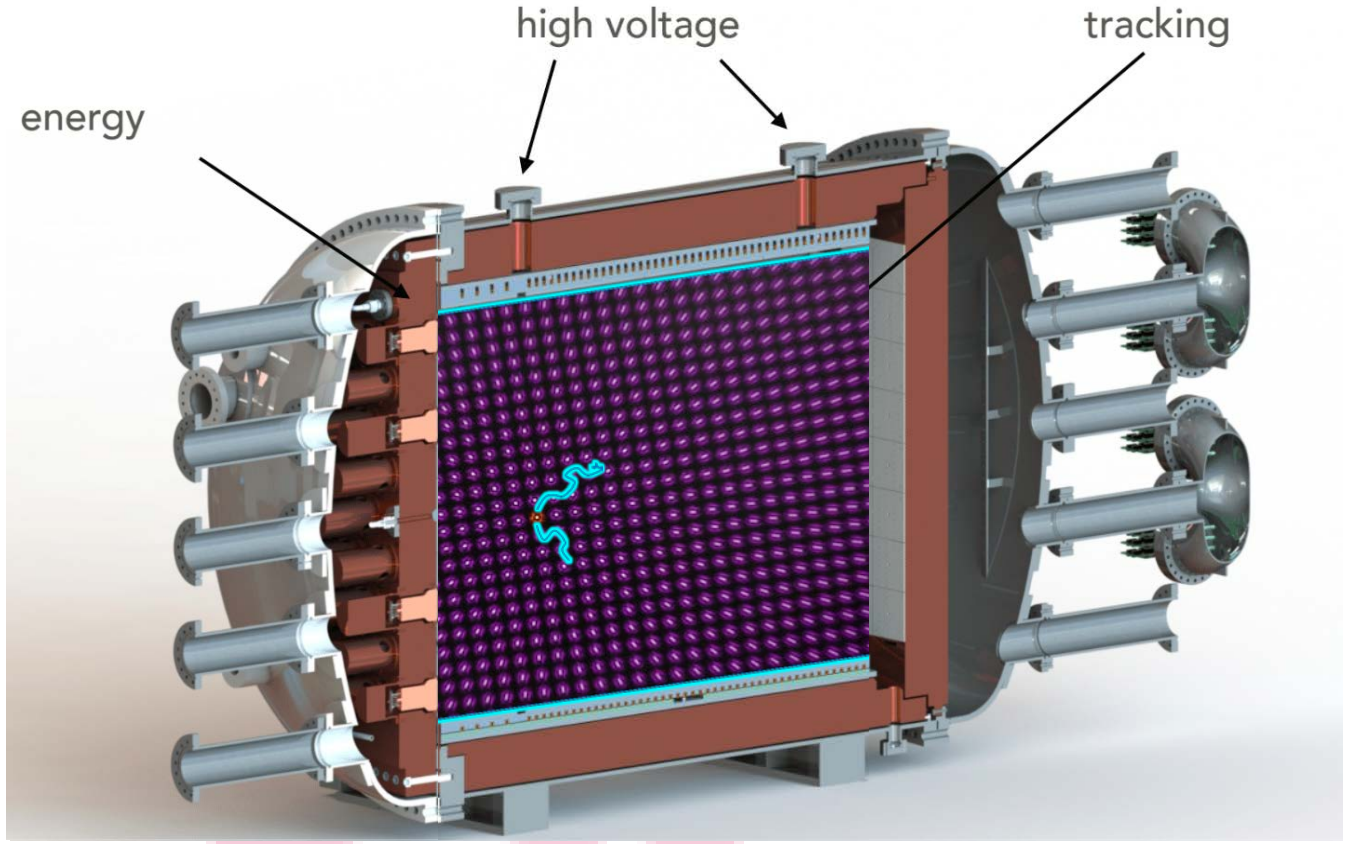
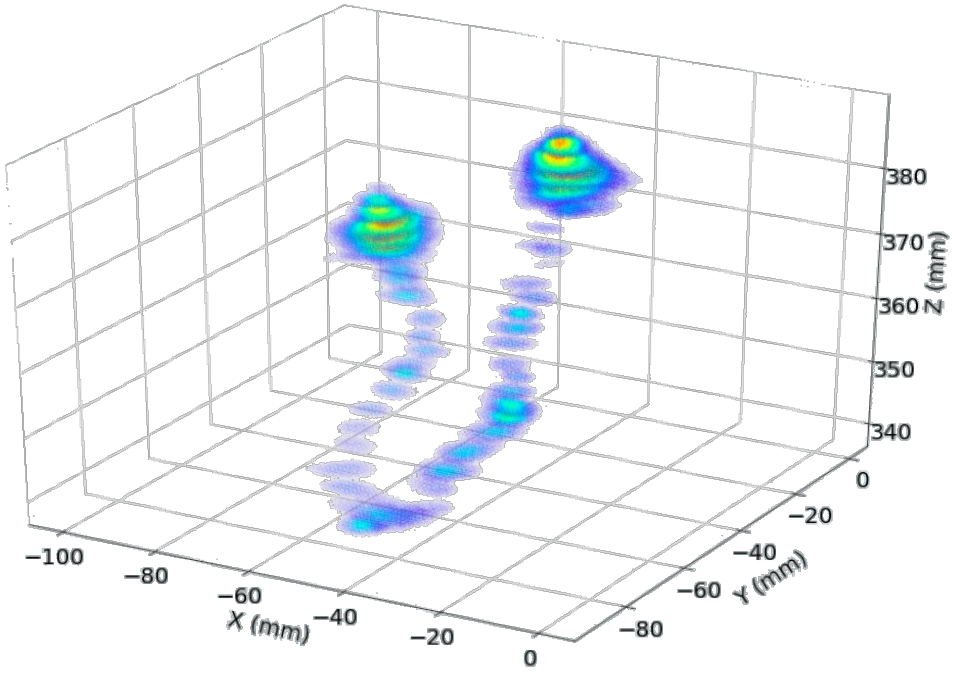




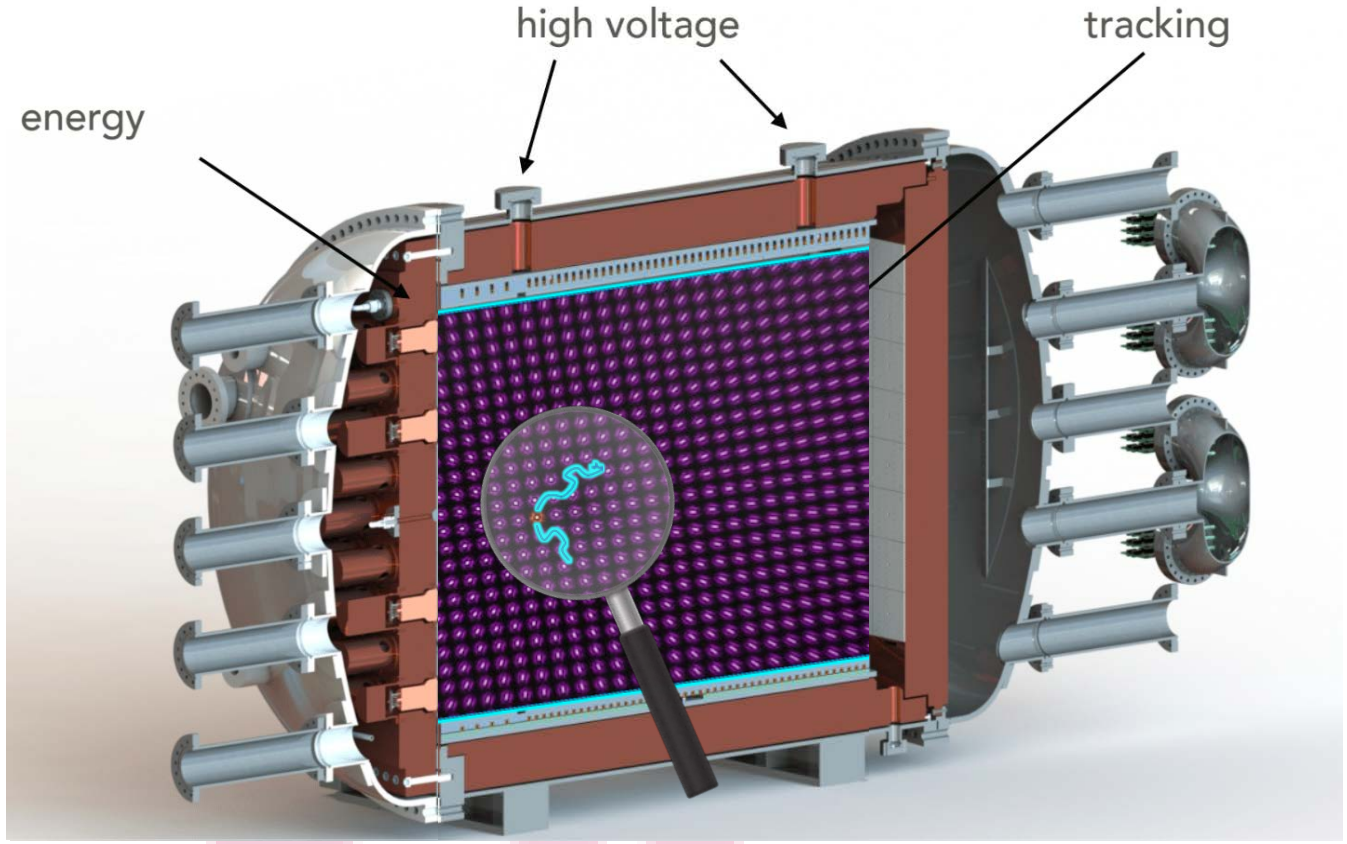
ββ2ν candidate at 2 MeV, showing 2 energy blobs at the extremes.

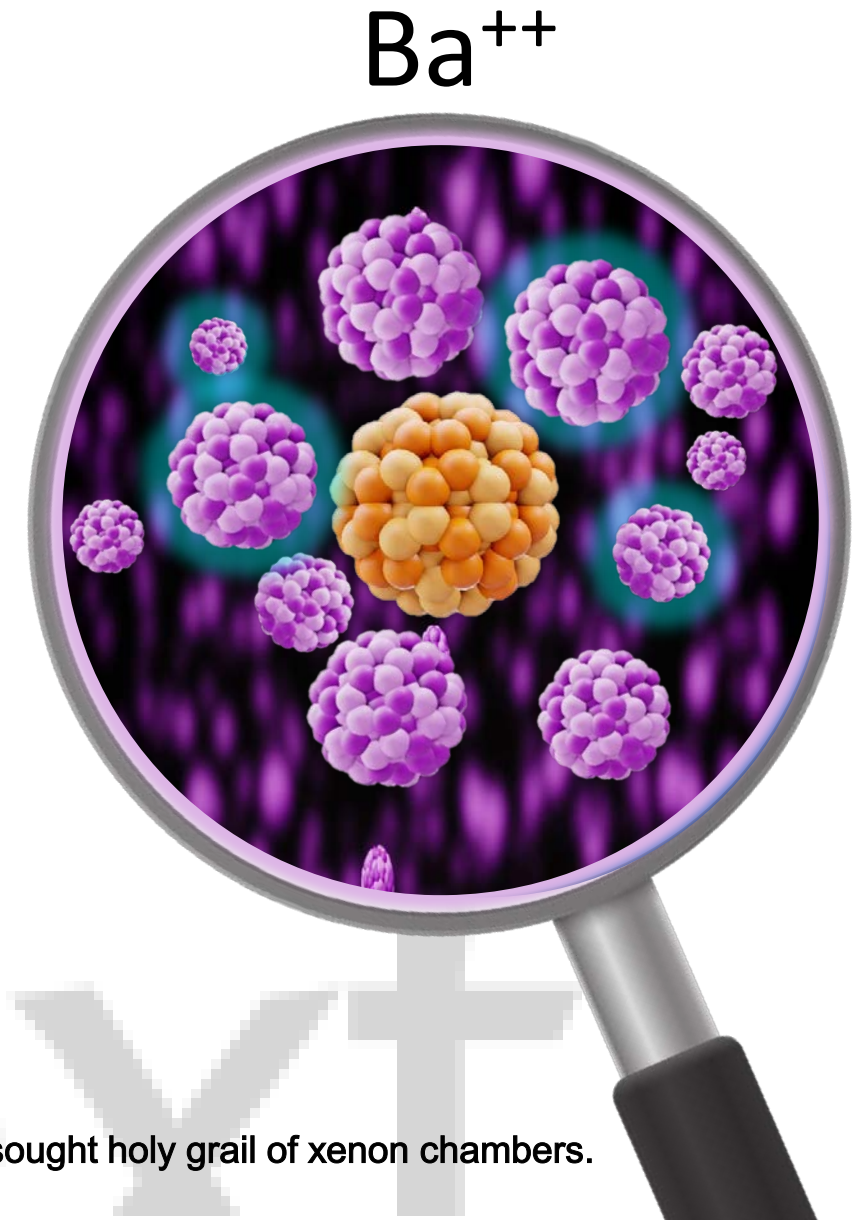
Energy resolution better than 1% FWHM at $Q_{\beta\beta}$.

Detecting "tagging" the Ba^{++} signaling a ββ0ν process has been a long sought holy grail of xenon chambers.

How to confirm experimentally if neutrino is a Majorana particle?

$\beta\beta0\nu$ in high-pressure ^{136}Xe gas

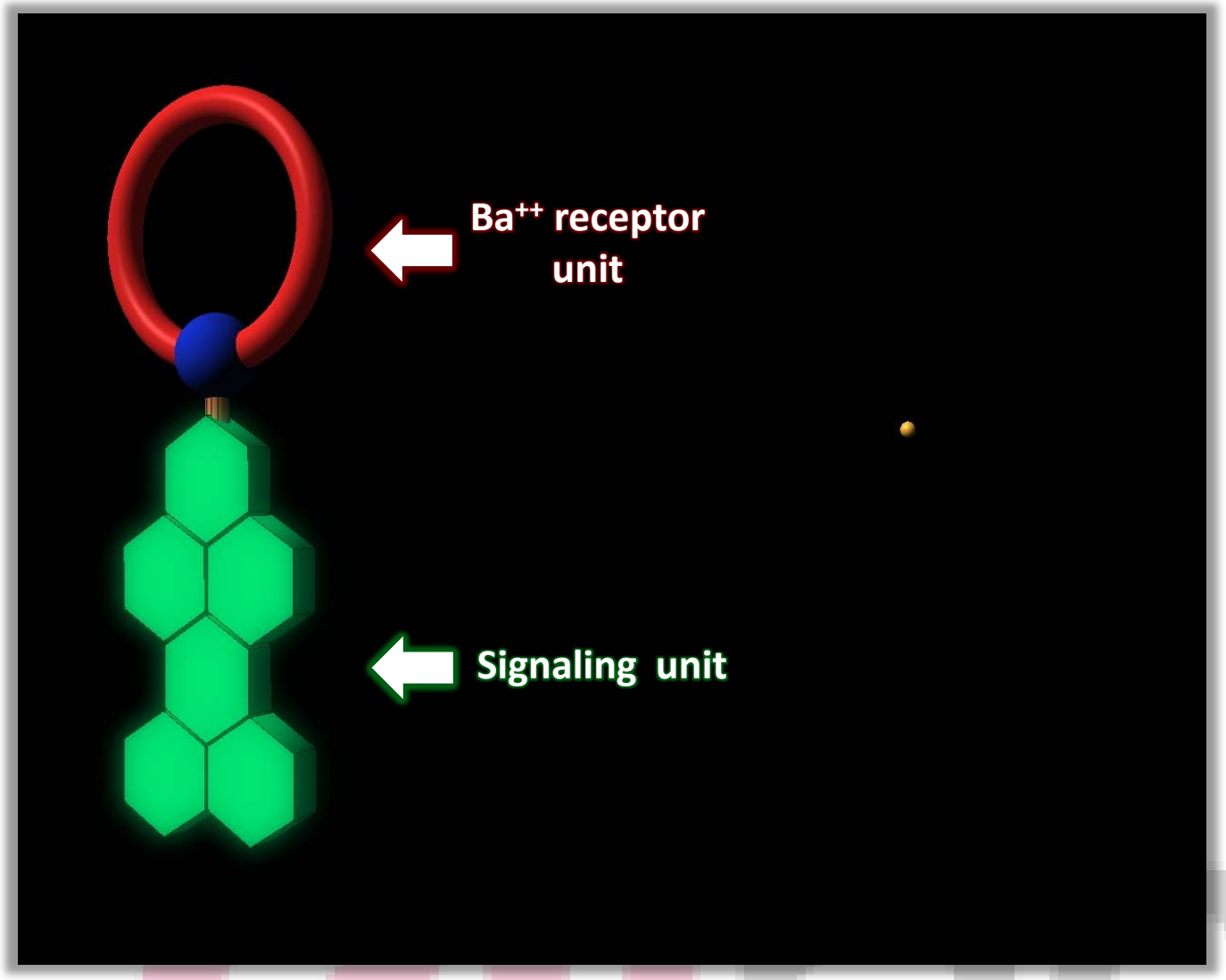


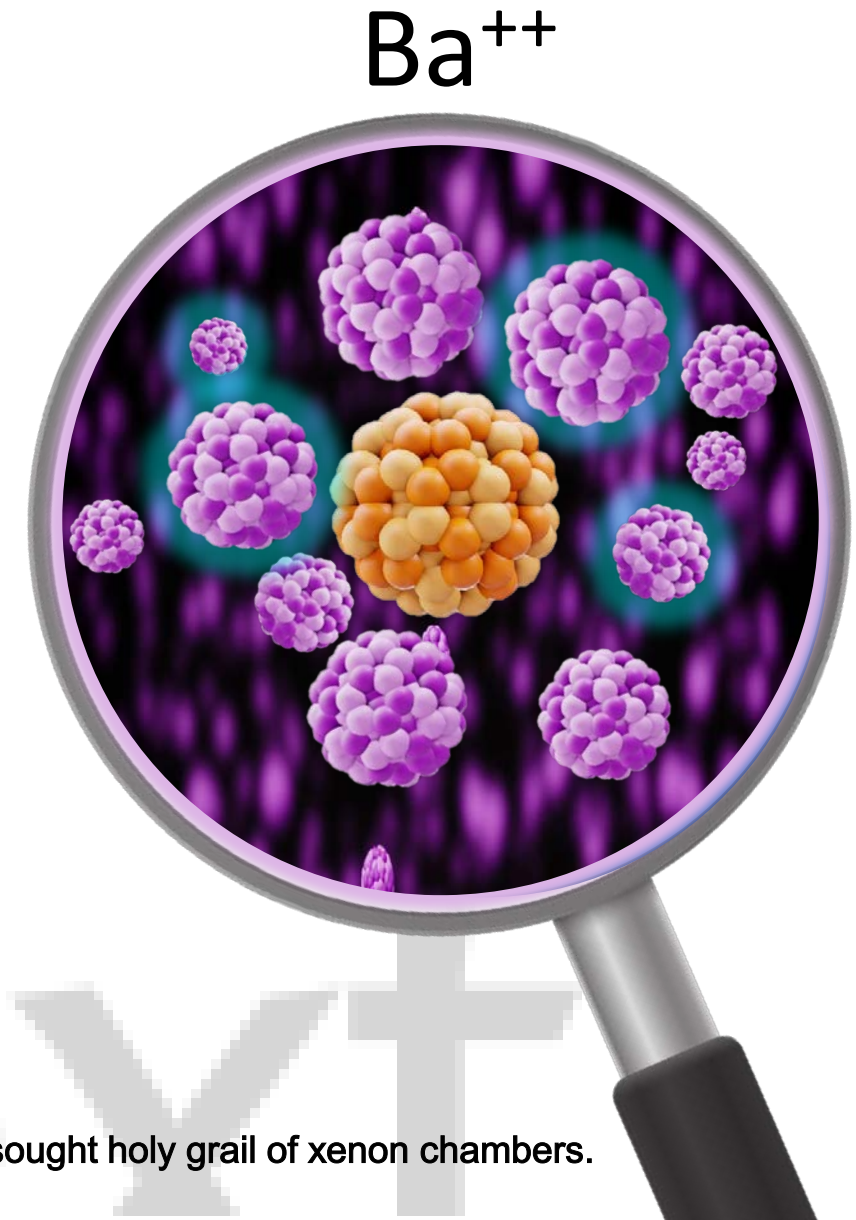


Detecting "tagging" the Ba^{++} signaling a ββ0v process has been a long sought holy grail of xenon chambers.

Idea: Exploit single molecule fluorescent imaging (SMFI) to visualise ("tag") a single Ba^{++} ion as it arrives at the TPC cathode.

D. Nygren , *J.Phys.Conf.Ser.* **2015**, *650(1)*, 012002





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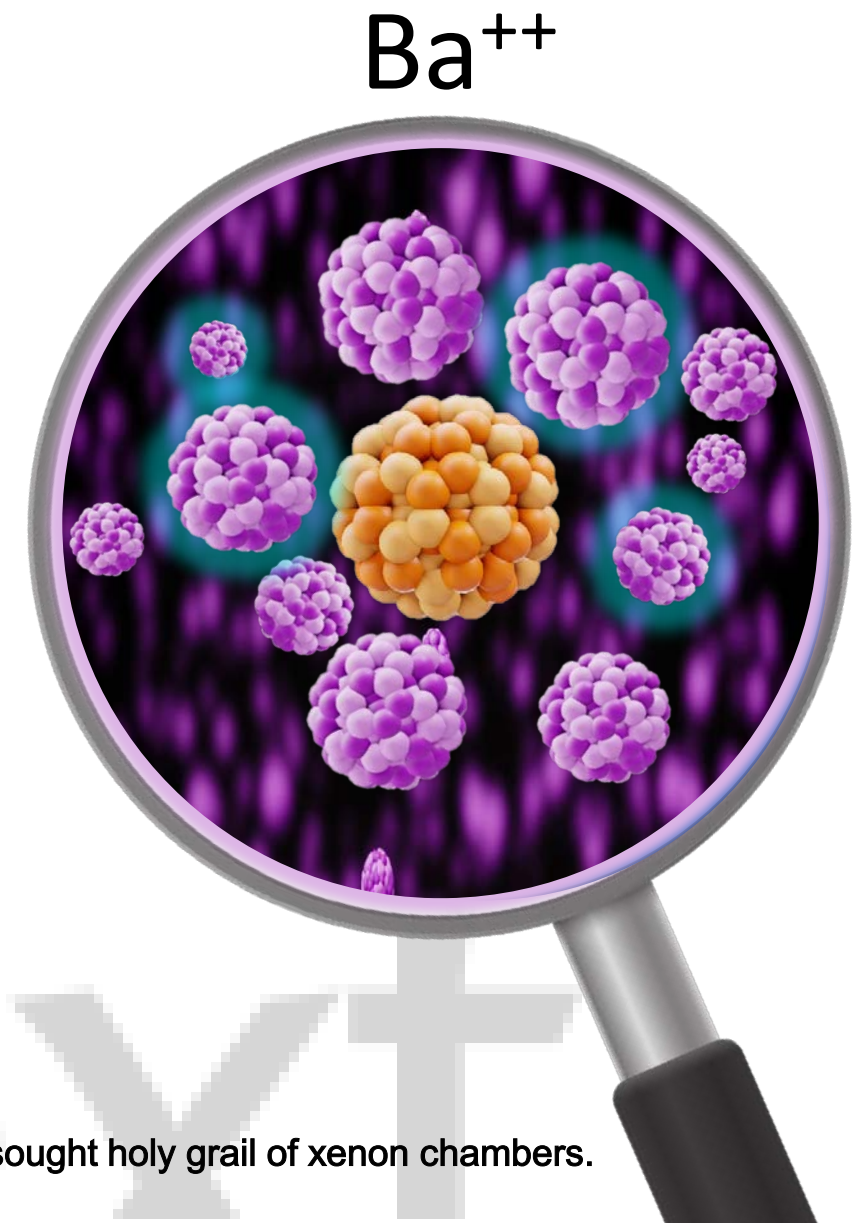
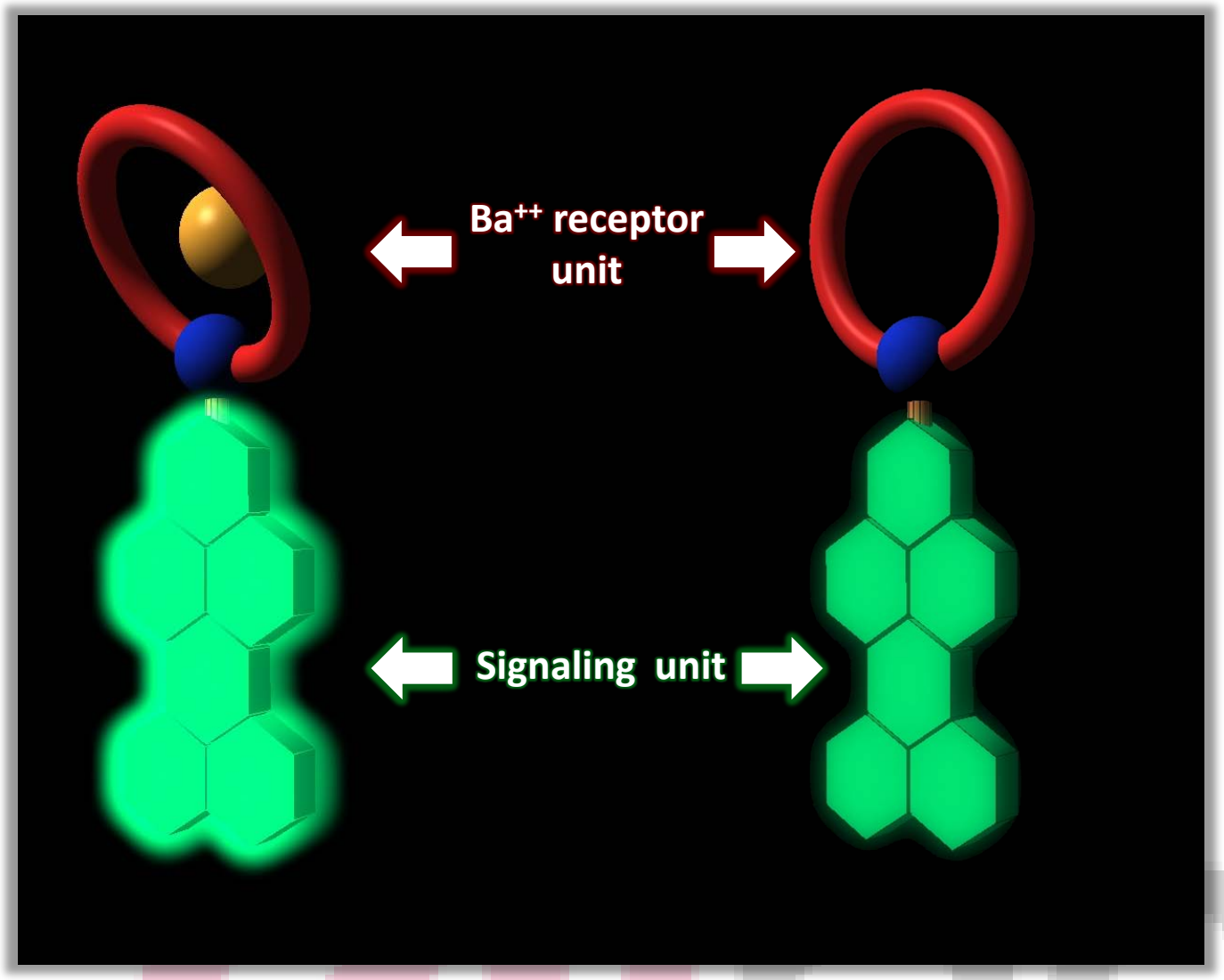
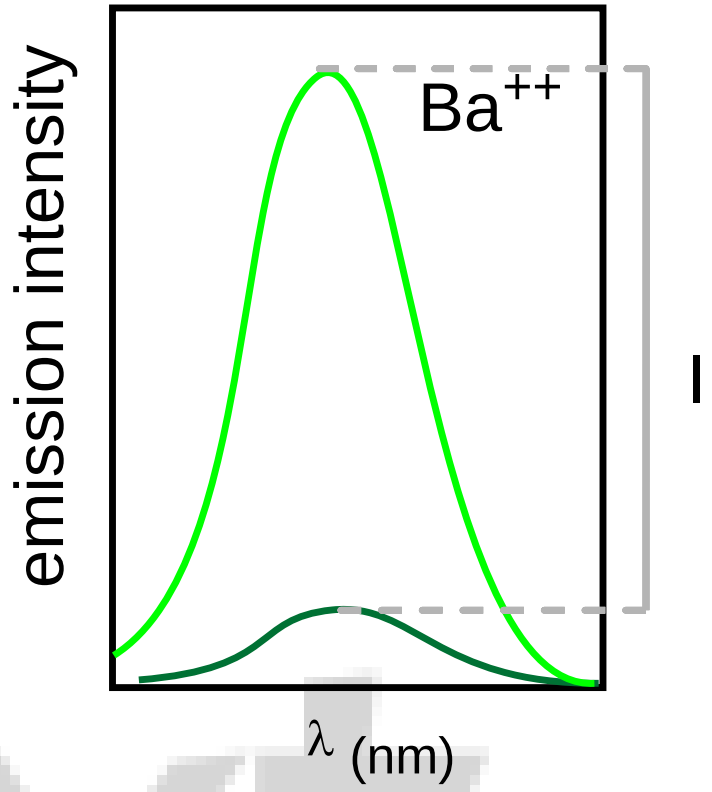


Detecting "tagging" the Ba^{++} signaling a $\beta\beta0\nu$ process has been a long sought holy grail of xenon chambers.

Dry single Ba^{++} ion detection with off-on fluorescence

GodXilla next





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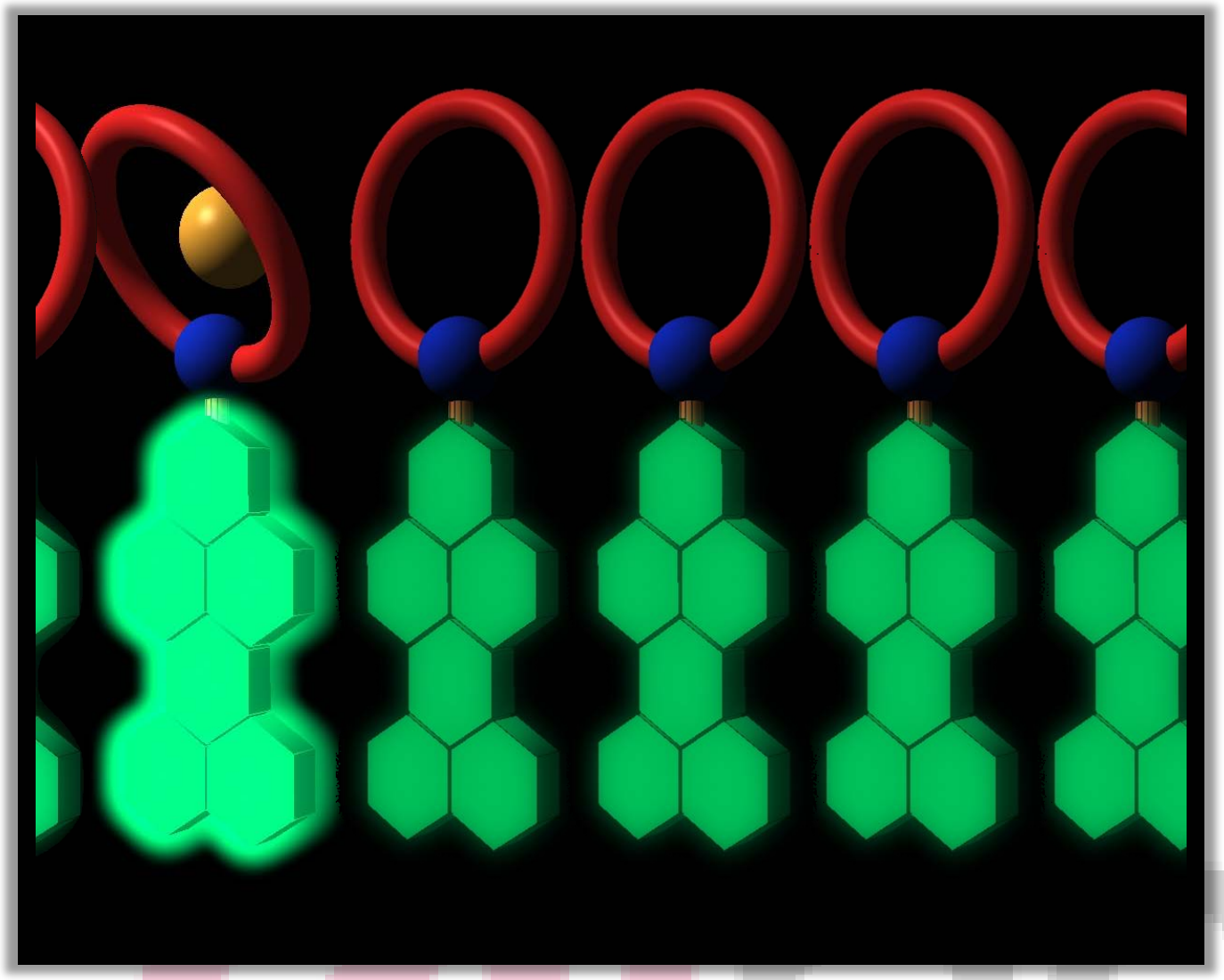

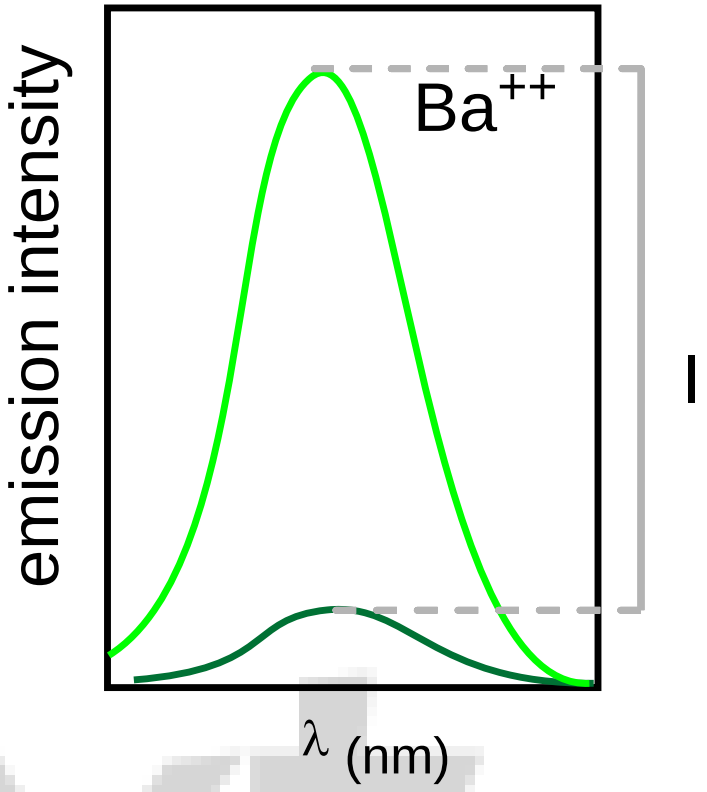

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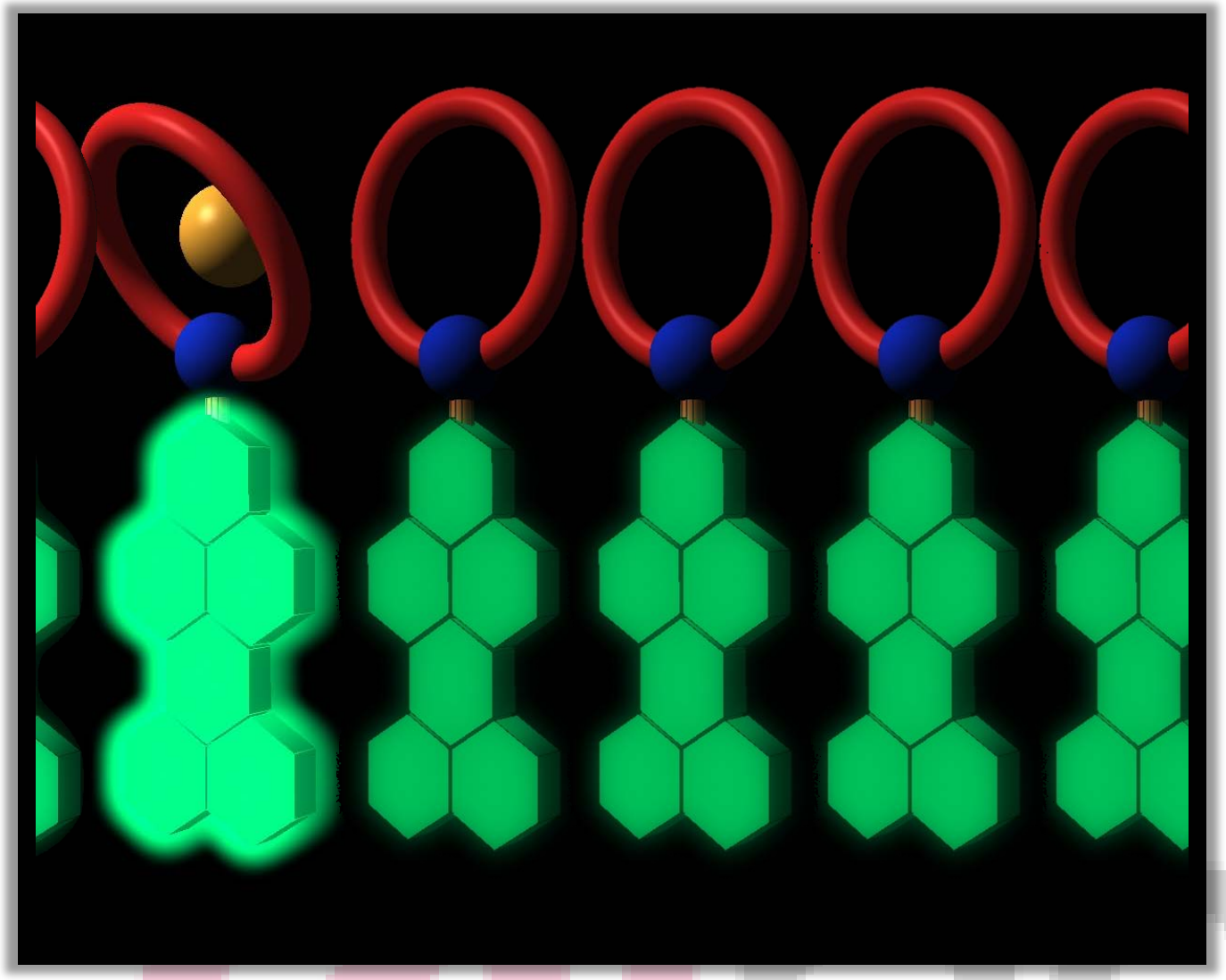
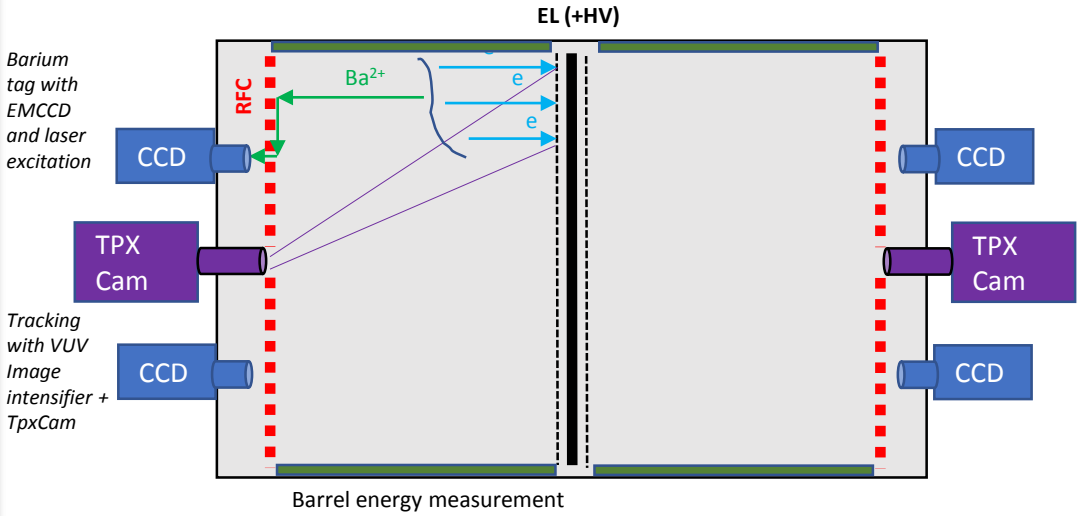


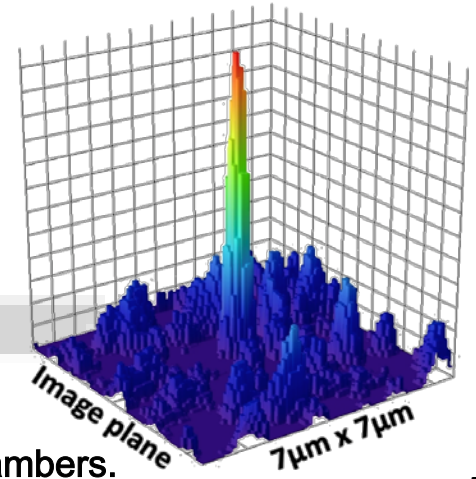
"CRAB" concept with RF carpet concentrators and camera-based topology measurement



Phys. Rev. Lett. **2017**, *120*, 132504.

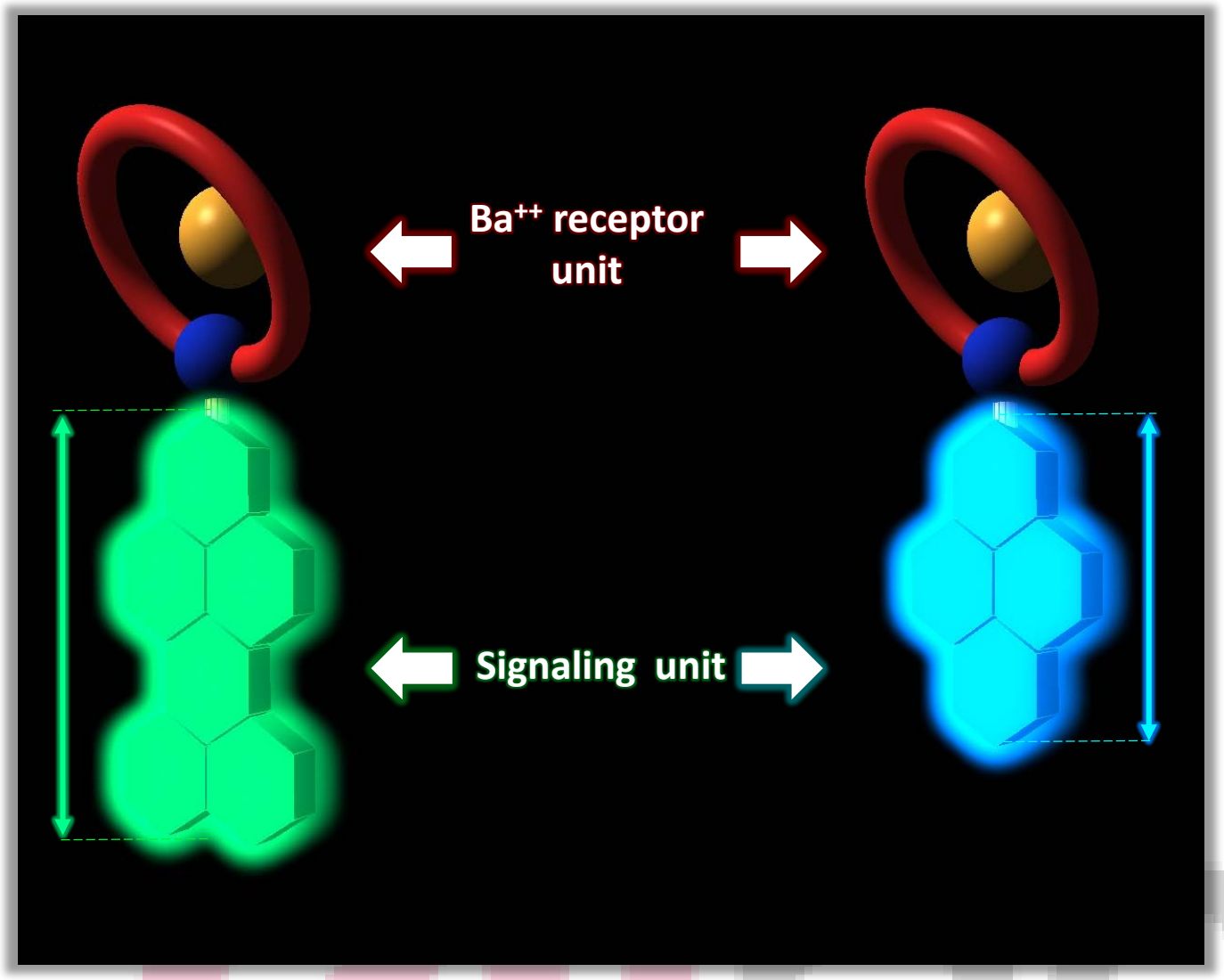
Sci. Rep. **2019**, 9, 15097.

ACS Sens. **2021**, *6(1)*, 192–202



Detecting "tagging" the Ba^{++} signaling a ββ0ν process has been a long sought holy grail of xenon chambers.

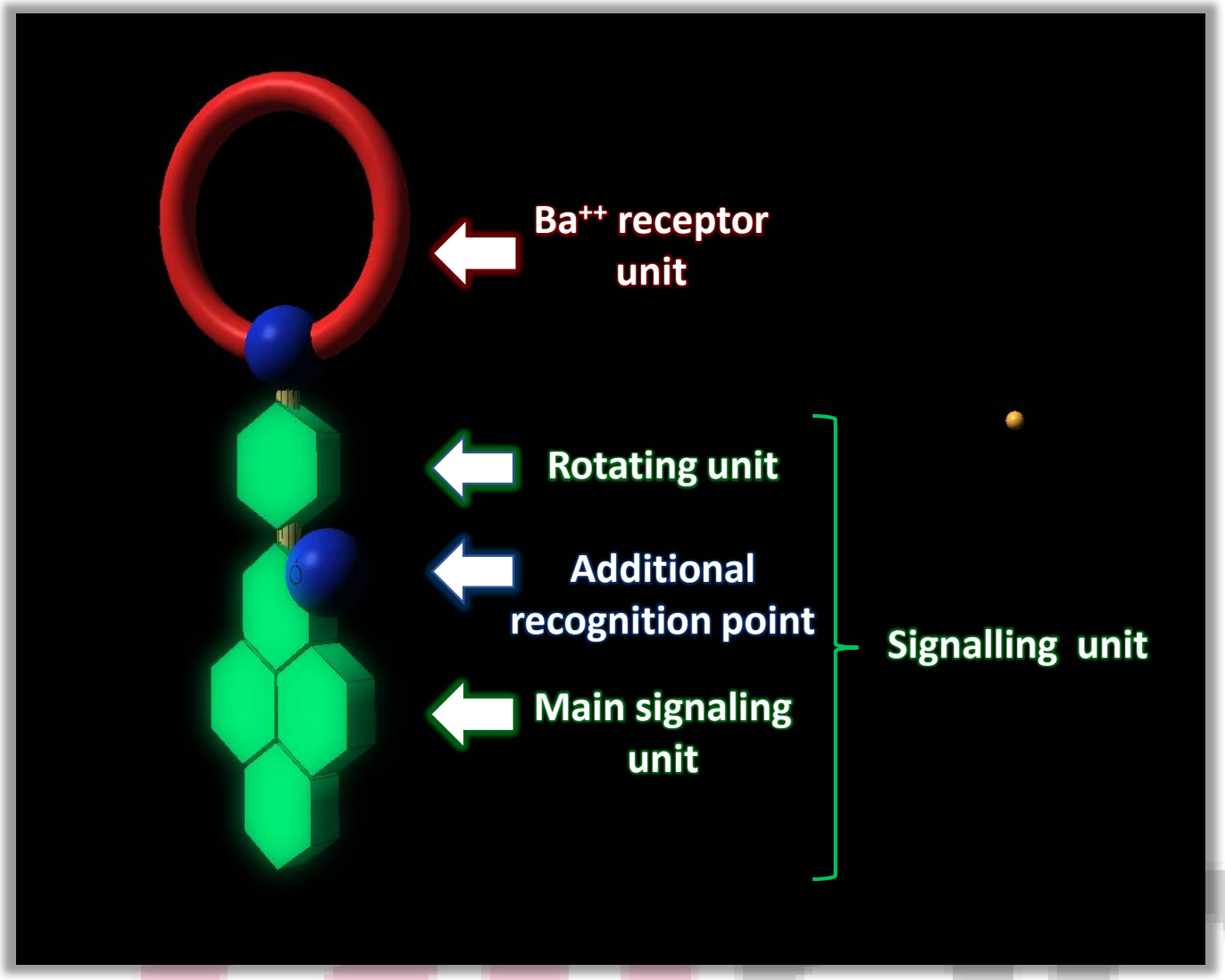
(Barium atOm Light Detector) BOLD next



Fluorescent Bicolour Indicator

BOLD next

FBI concept



"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020****, 583*, 48-54**.**

Fluorescent Bicolour Indicator

BOLD next

FBI concept

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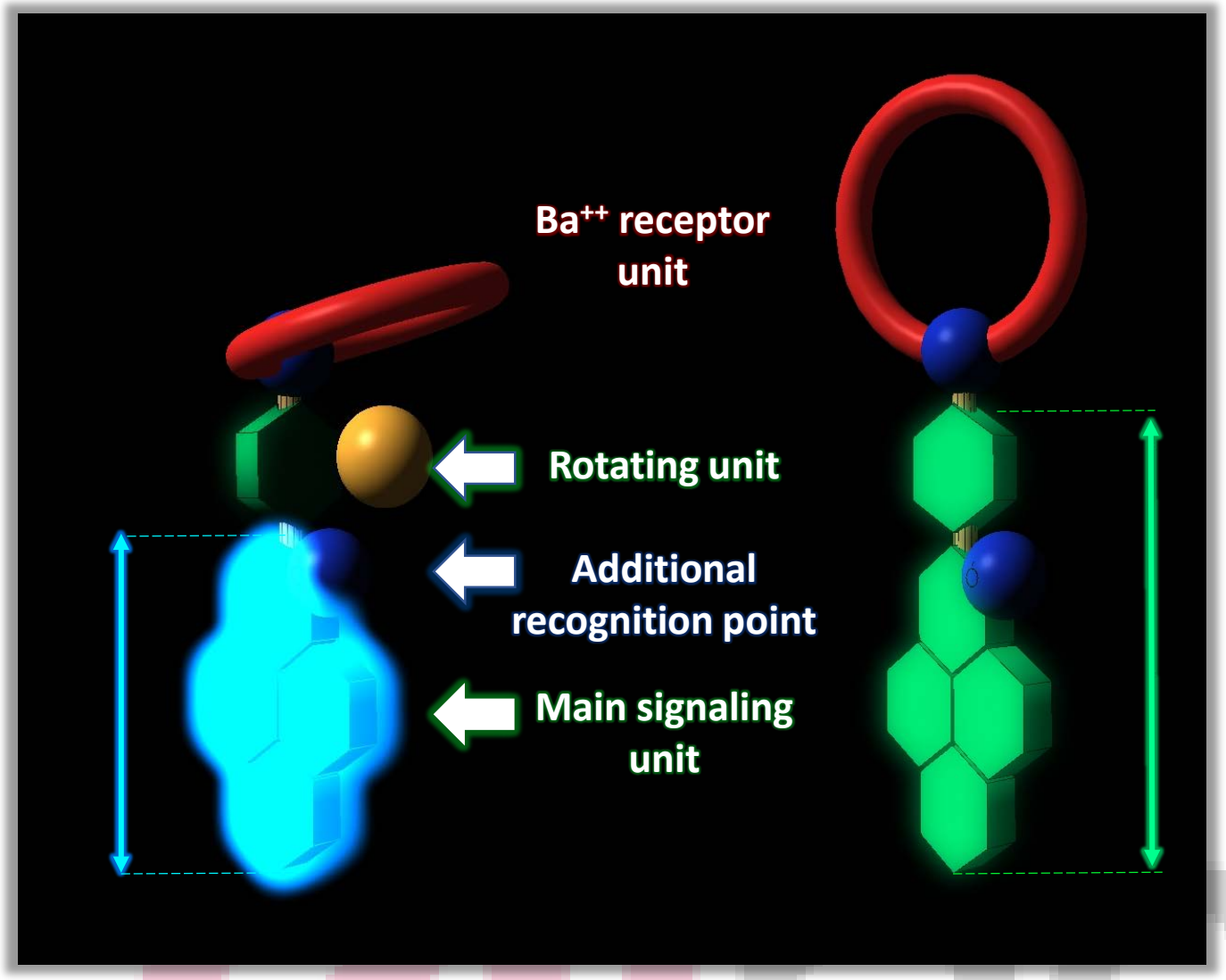
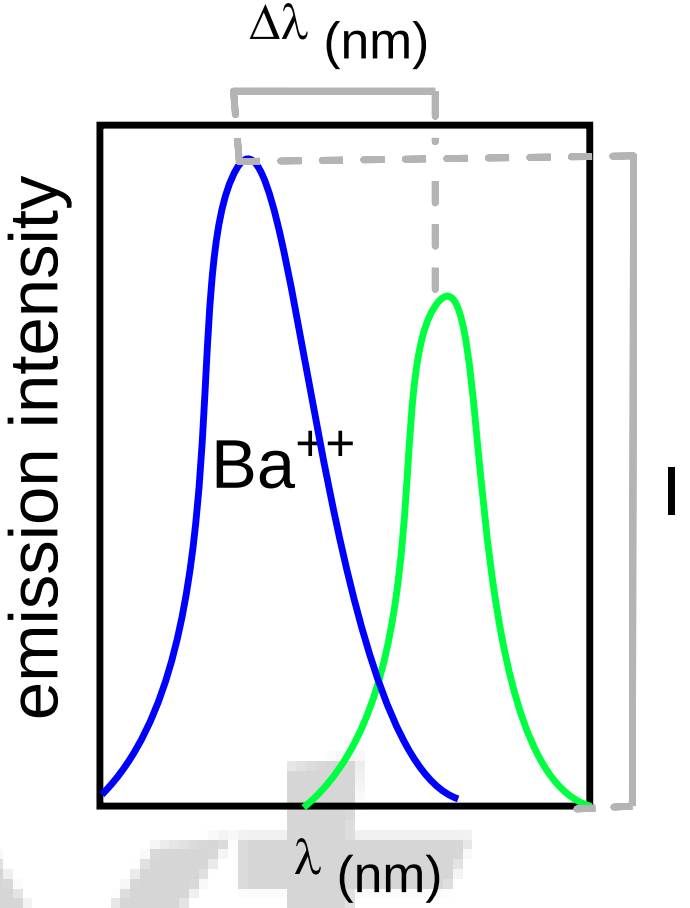
Fluorescent Bicolour Indicator

BOLD next

FBI concept



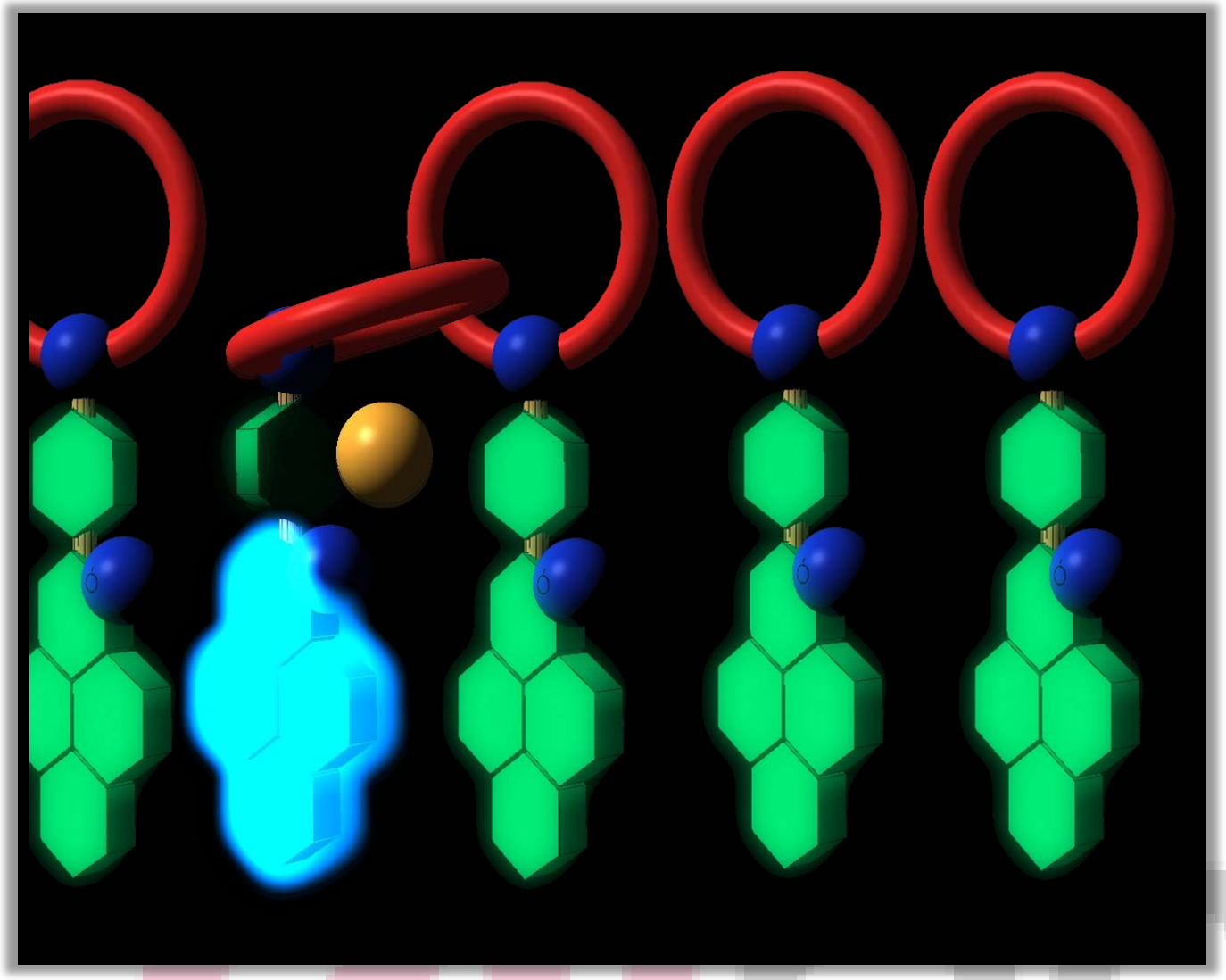


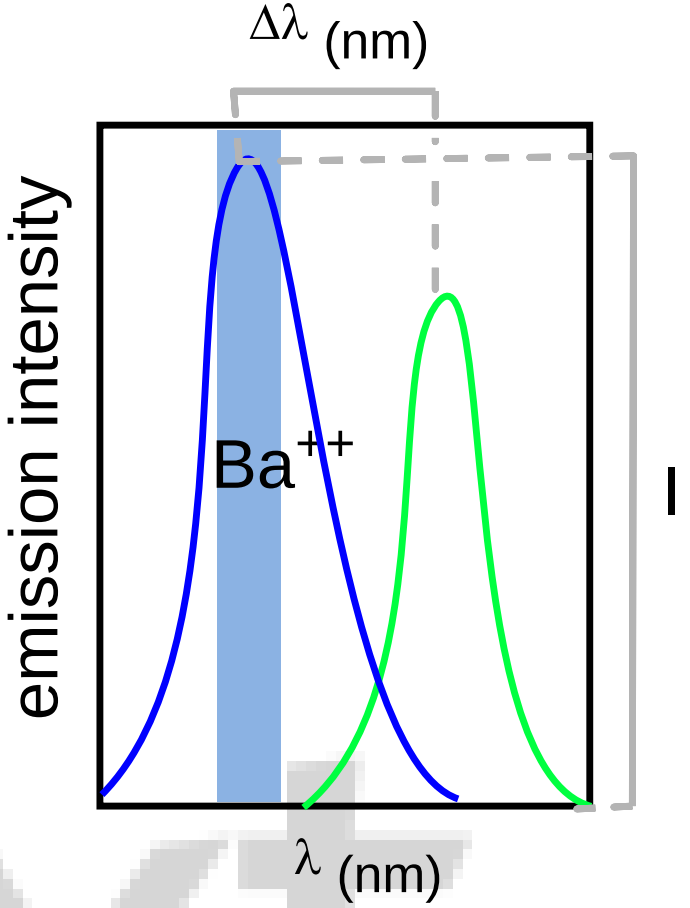
"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020****, 583*, 48-54**.**

Fluorescent Bicolour Indicator

BOLDnext

FBI concept



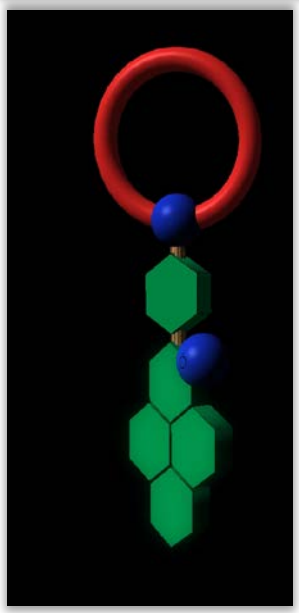


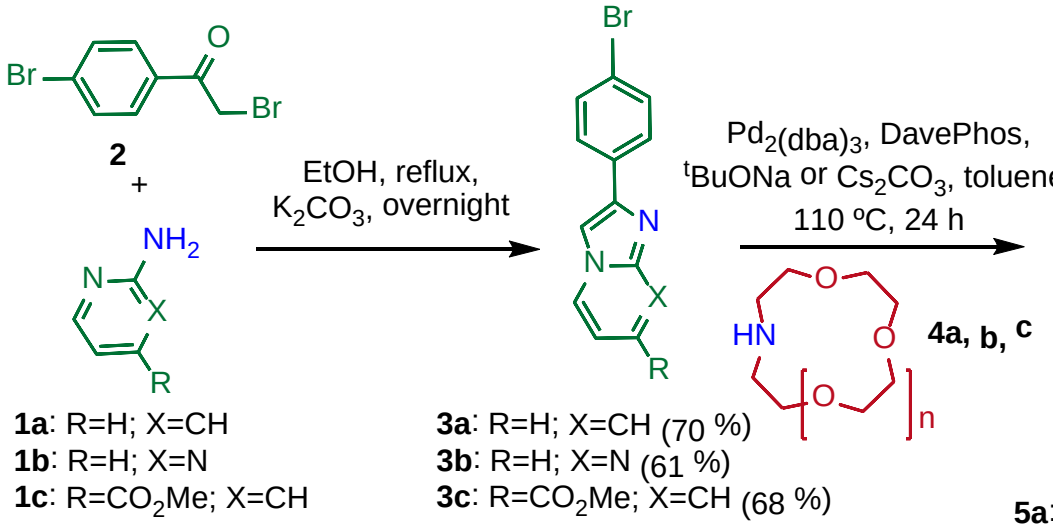
"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020****, 583*, 48-54**.**

Fluorescent Bicolour Indicator

BOLD next

Chemical synthesis of FBI sensors





1a: R=H; X=CH
1b: R=H; X=N
1c: R=CO_2Me; X=CH

3a: R=H; X=CH (70 %)
3b: R=H; X=N (61 %)
3c: R=CO_2Me; X=CH (68 %)

5a: R=H; X=H; n=1 (87 %)
5b: R=H; X=H; n=2 (90 %)
5c: R=H; X=H; n=3 (95 %)
5d: R=H; X=N; n=3 (30 %)
5e: R=CO_2Me; X=H; n=3 (47 %)

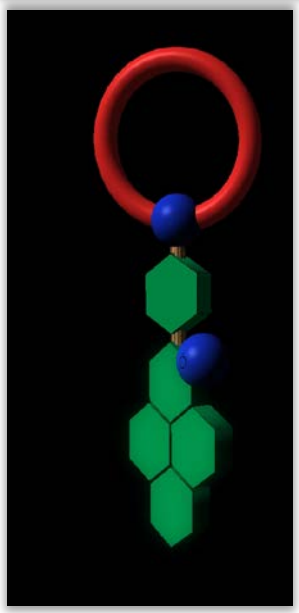
7aa: R=H; X=CH; R'=H; n=1 (40 %)
7ba: R=H; X=CH; R'=H; n=2 (40 %)
7ca: R=H; X=CH; R'=H; n=3 (47 %)
7da: R=H; X=N: R'=H; n=3 (22 %)
7ec: R=CO_2Me; X=CH; R'=H; n=3 (32 %)
7cb: R=H; X=CH; R'=$(CH)_4$; n=3 (38 %)

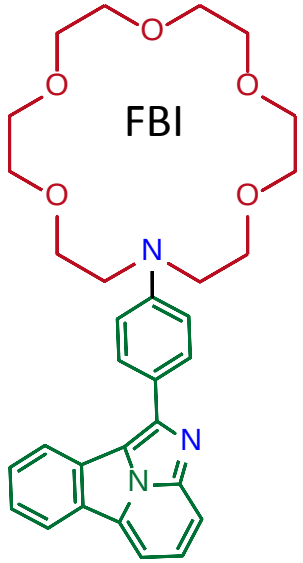
"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020****, 583,* 48-54**.**

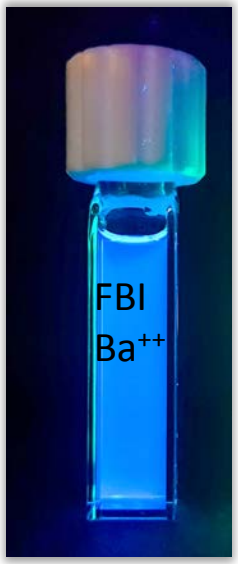
Fluorescent Bicolour Indicator

BOLD next

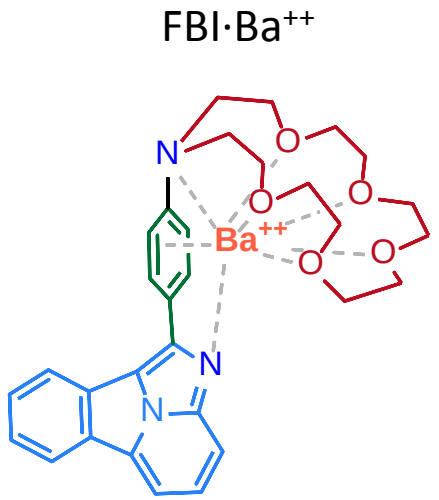
Ba^{++} sensing in solution

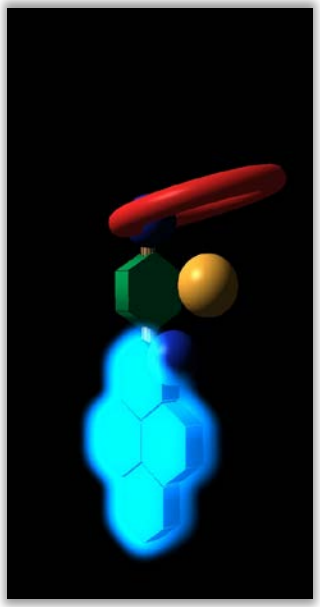


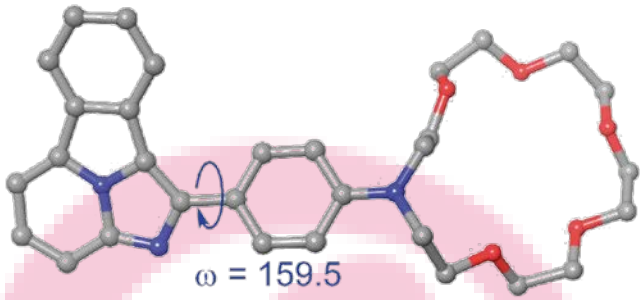


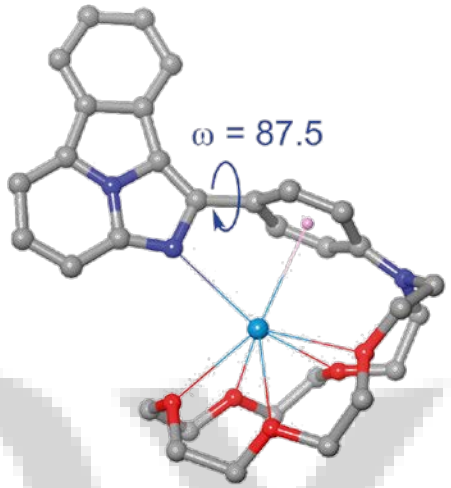


Excitation: 365 nm







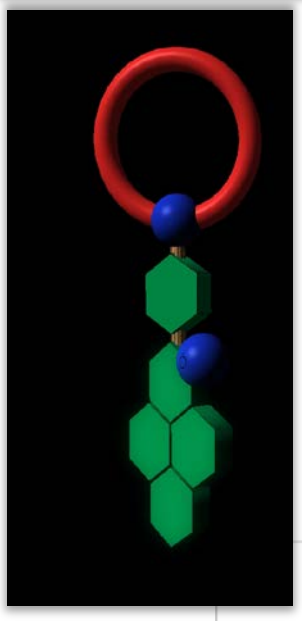


"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020****, 583*, 48-54***.***

Fluorescent Bicolour Indicator

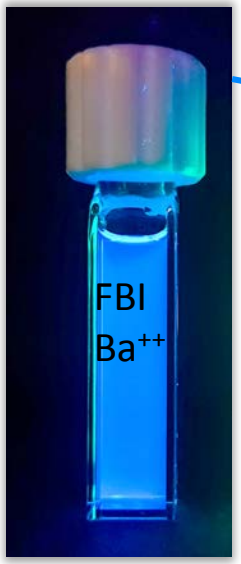
BOLD next

Ba^{++} sensing in solid support



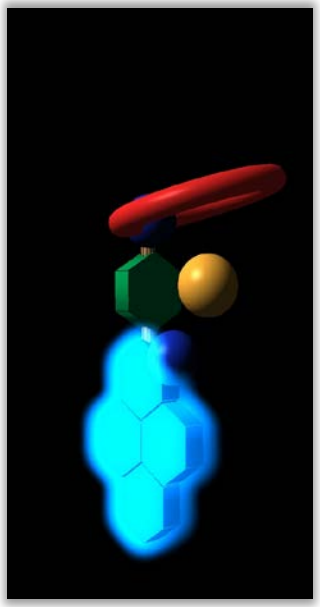
FBI

[FBI] = 2.3 x 10^{-5} mmol/mg of silica

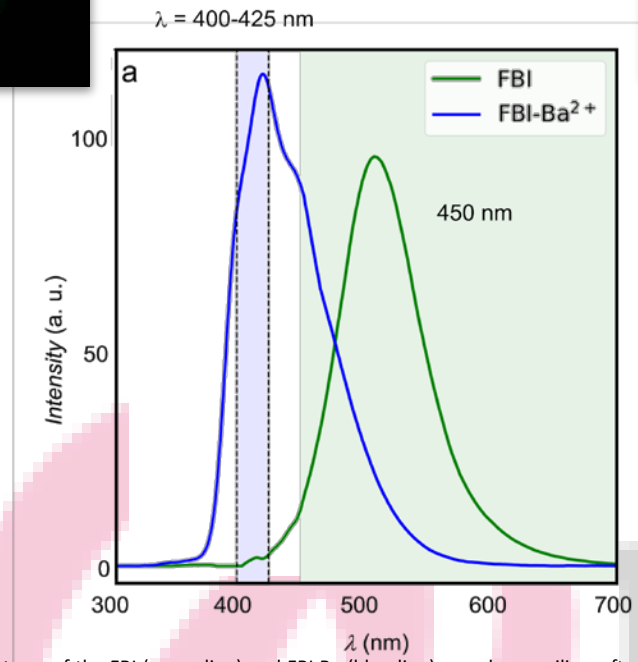


$FBI \cdot Ba^{++}$

[FBI] = 7.4 x 10^{-8} mmol/mg of silica saturated in $Ba(ClO_4)_2$



Excitation: 365 nm



Emission spectrum of the FBI (green line) and FBI·Ba (blue line) samples on silica, after silica subtraction.
The FBI spectrum is scaled by a factor of 310 with respect to the FBI-Ba^{++} spectrum. Excitation at 250 nm.

The FBI mantains its **fluorescent properties in solid phase** (silica gel)

Calculated **discriminaton factor** $FBI \cdot Ba^{++}$ vs FBI = **$(2.5 \pm 0.6) \times 10^4$**

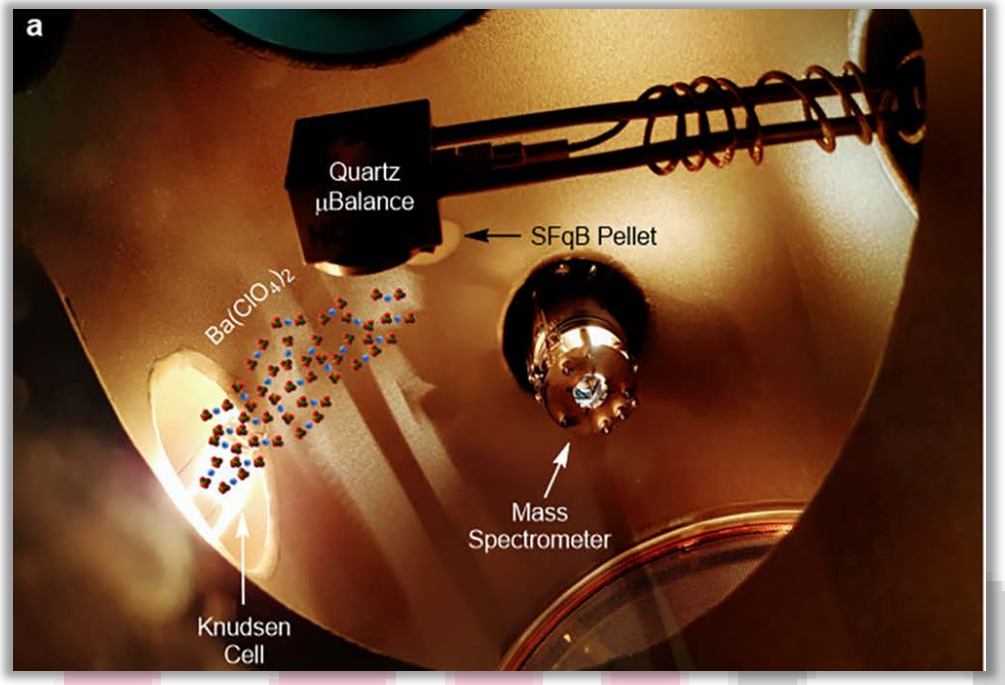
"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020***, *583*, 48-54.

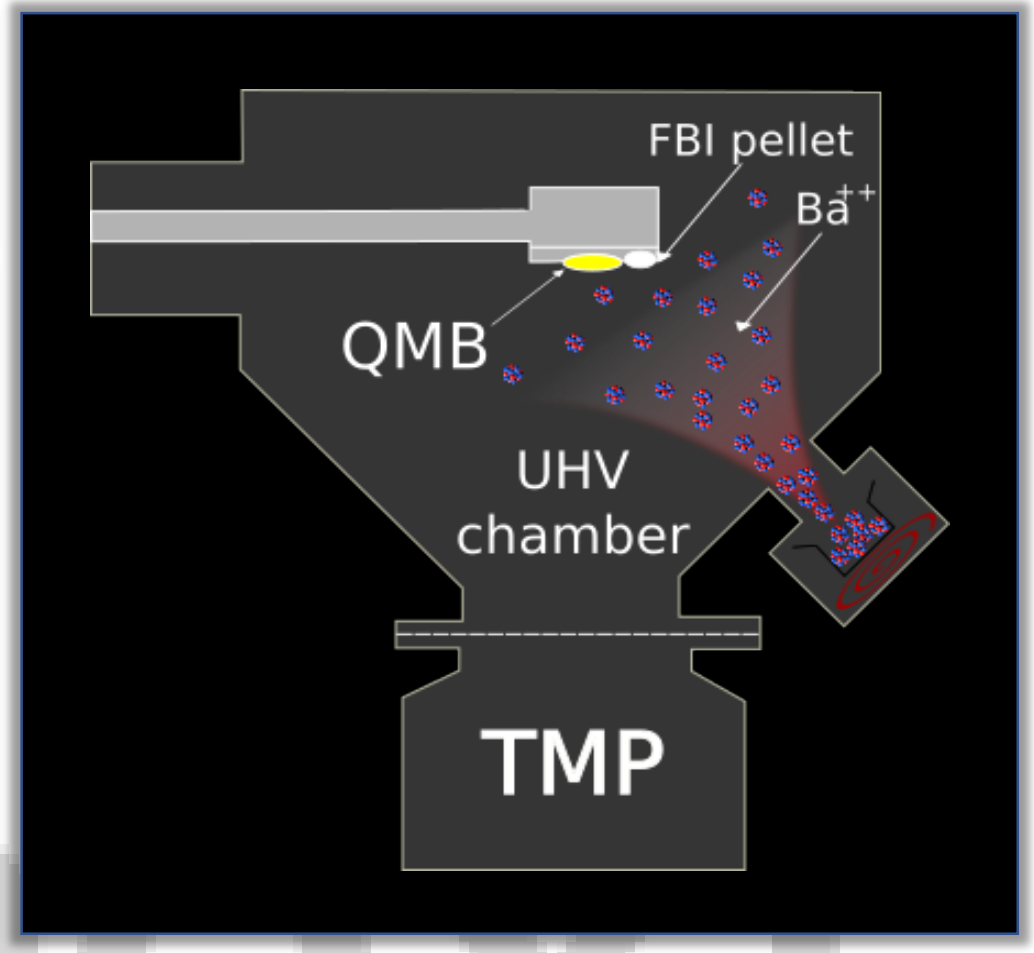
Fluorescent **B**icolour **I**ndicator

BOLD next

Ba^{++} sensing in high-vacuum

FBI deposited
on silica pellet



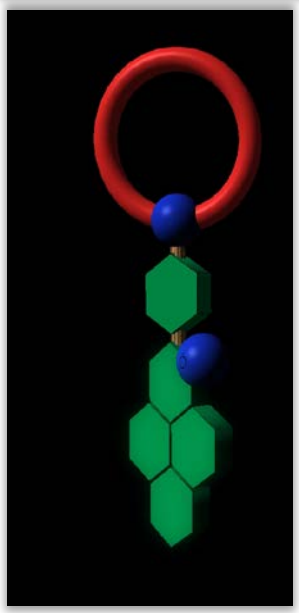


"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020****, 583*, 48-54**.**

Fluorescent Bicolour Indicator

BOLD next

Ba^{++} sensing in high-vacuum



FBI

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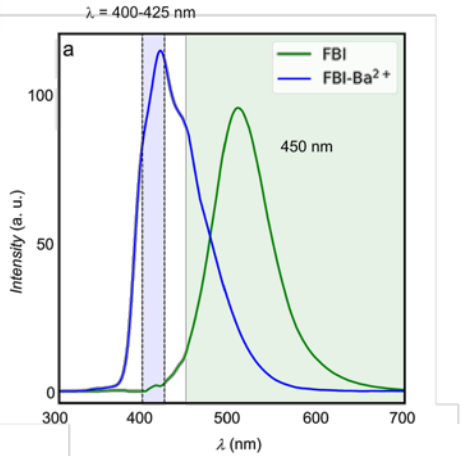
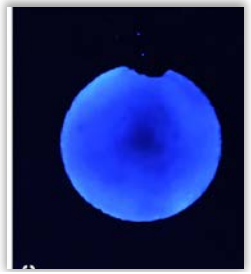
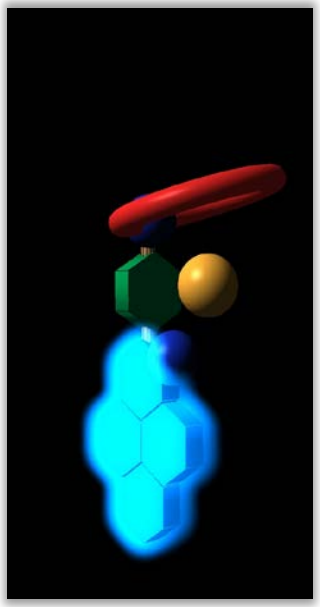
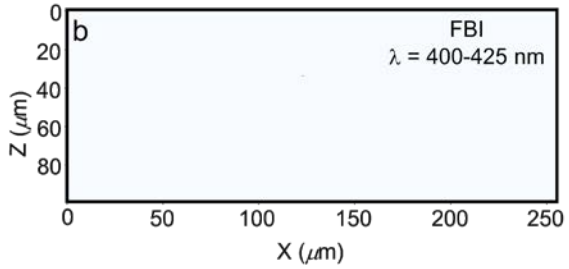


$FBI \cdot Ba^{++}$

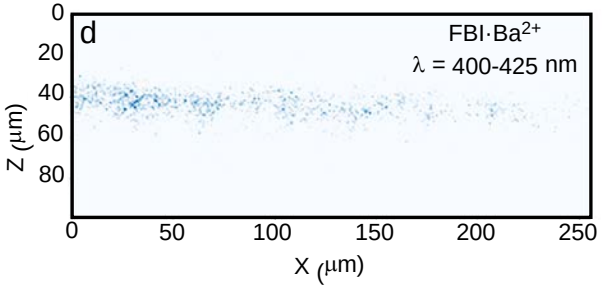
Excitation: 365 nm

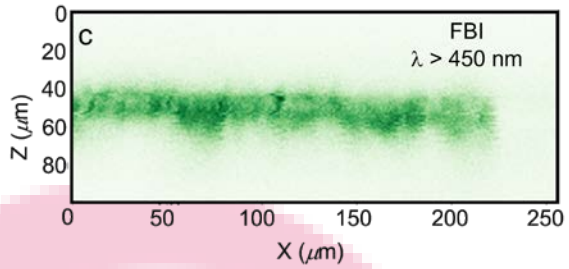




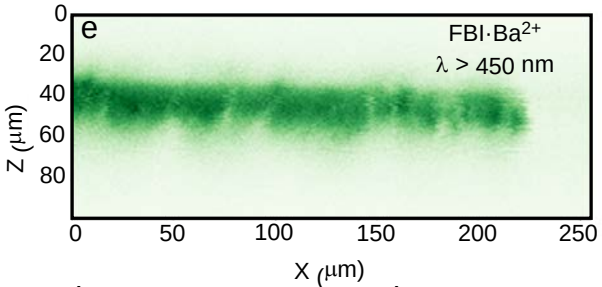


blue filter
λ = 400-425 nm





green filter
λ > 450 nm



2 Photon Absorption Microscopy (excitation at 800 nm)

FBI sensors capture Ba^{++} in dry phase!

DFT-computed Gibbs reaction energies

$FBI + Ba(ClO_4)_2 \longrightarrow FBI \cdot Ba(ClO_4)_2$

ΔG_{rx} = -90 kcal/mol

$FBI + Ba^{++} \cdot 8Xe \longrightarrow FBI \cdot Ba^{++} + 8Xe$

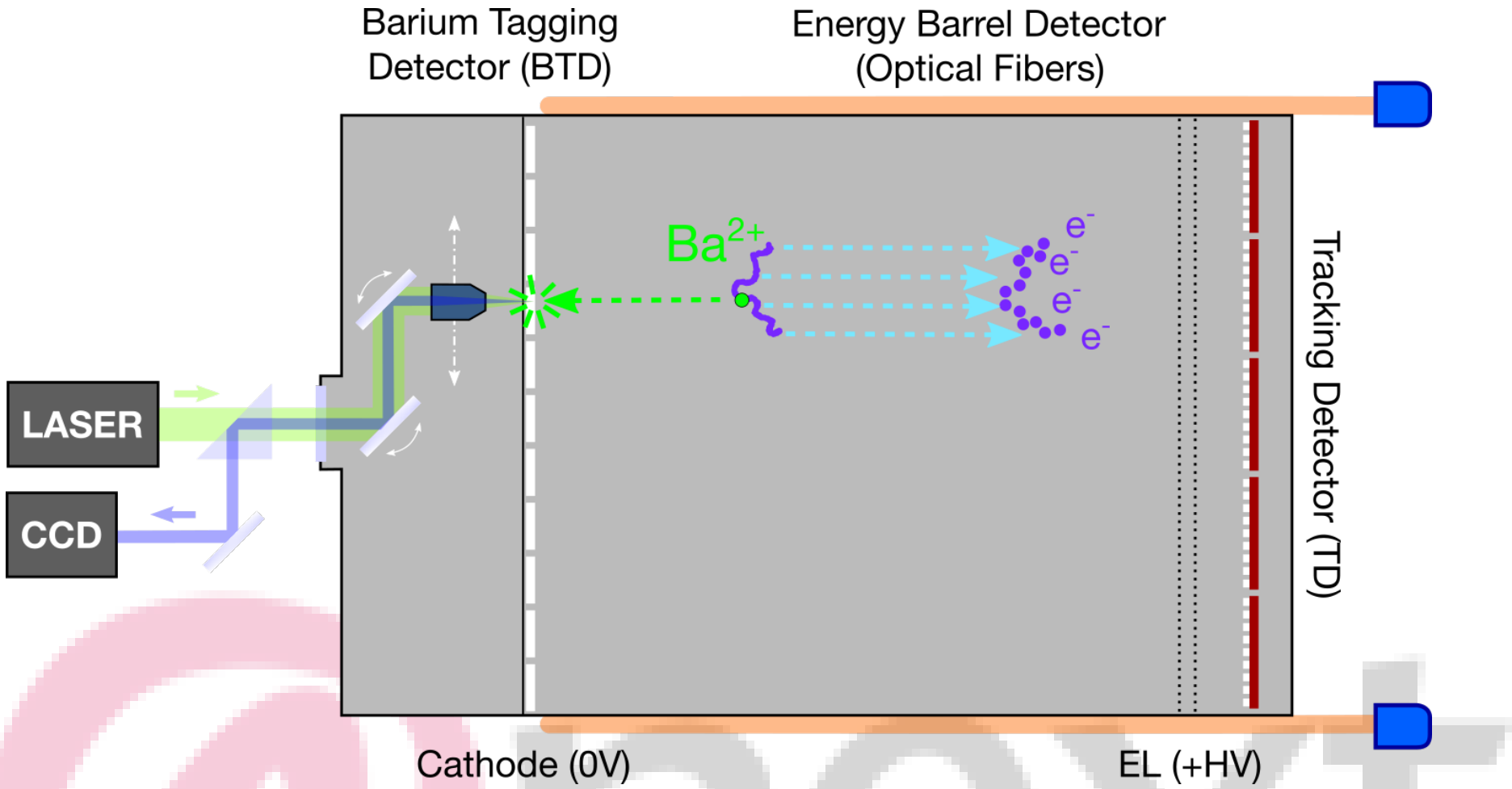
ΔG_{rx} = -195.9 kcal/mol

"Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments", *Nature* ***2020***, *583*, 48-54.

Fluorescent Bicolour Indicator

What's NEXT @BOLDnext?

"BOLD" concept with fully active cathode, SiPM-based tracking and Energy Barrel Detector



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