Detecting reactor antineutrinos with a LAr bubble chamber

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XXXV Annual Meeting DPYC-SMF, May 2021

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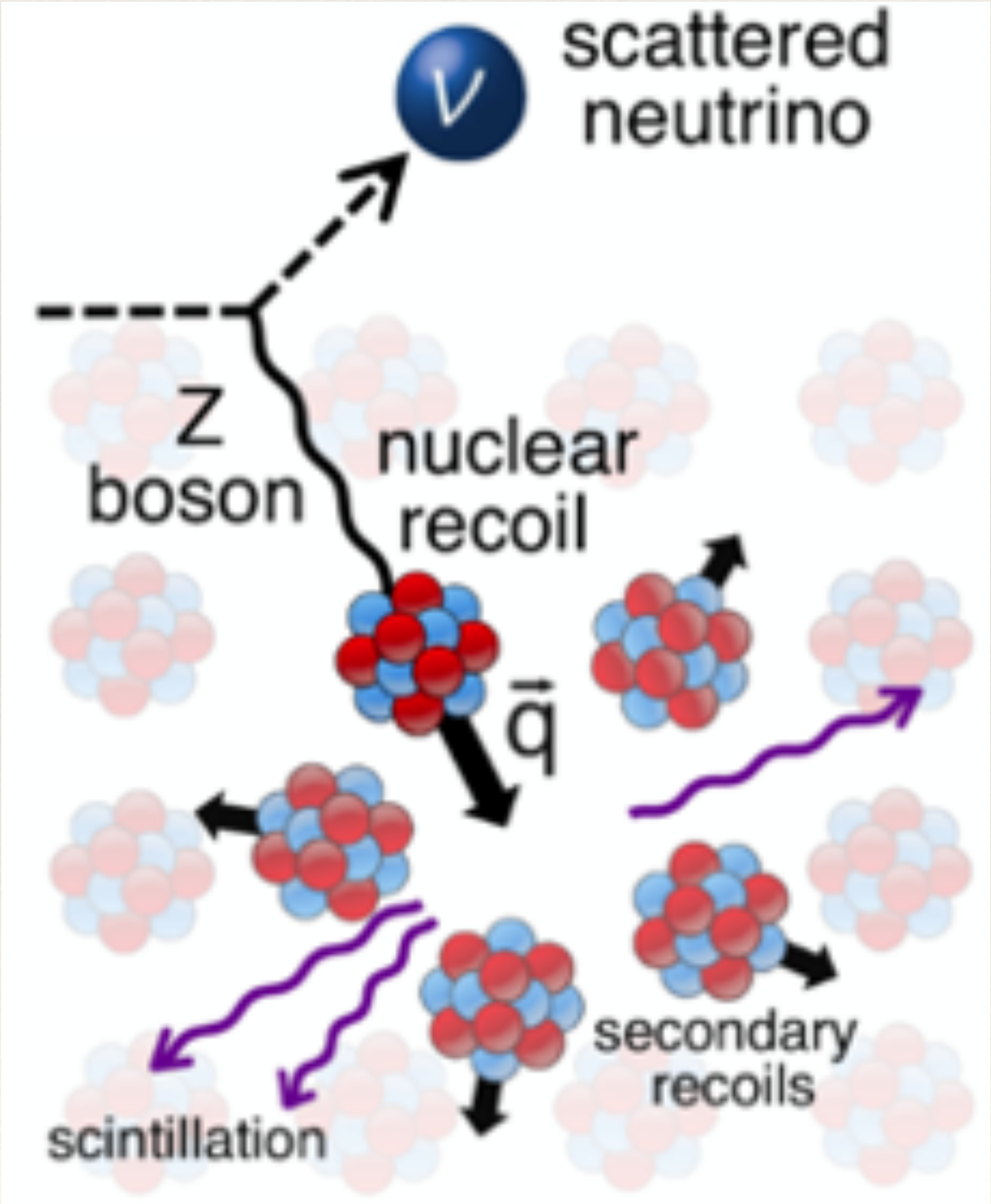
Outline:

- **Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)**
- **CEvNS at nuclear reactors**
- **LAr Scintillating Bubble Chamber**
- **Final Remarks**

Coherent Elastic Neutrino-Nucleus Scattering

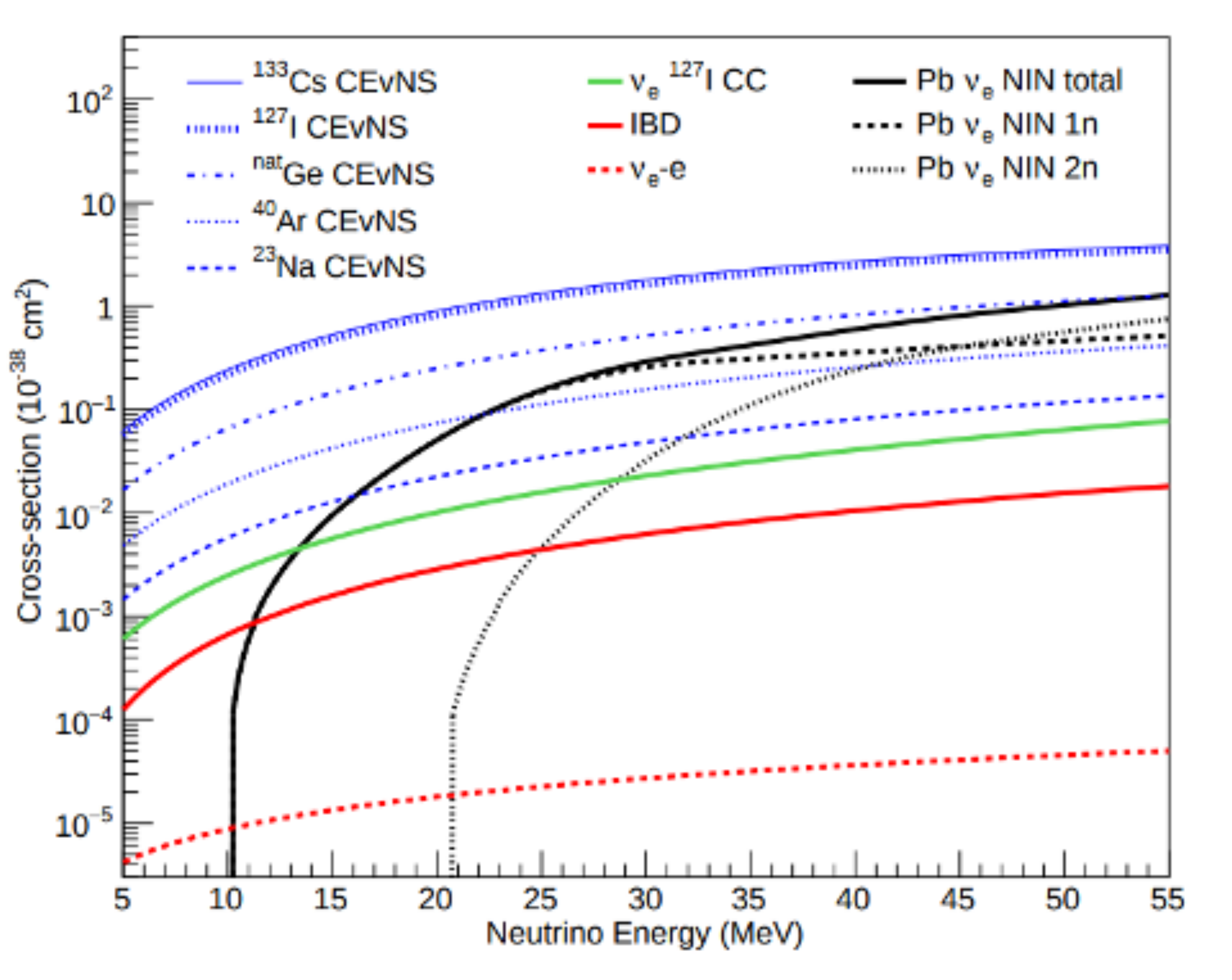
$$E_\nu \leq 50 \text{ MeV}$$



$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right) F^2(q^2)$$

Maximum NR energy: $T_{\max} = \frac{2E_\nu^2}{M_N}$

Coherent Elastic Neutrino-Nucleus Scattering



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COHERENT Collaboration, Science 357,1123 (2017)

Coherent Elastic Neutrino-Nucleus Scattering

Ingredients for CEvNS:

- Intense neutrino flux
- Low-threshold detectors
- Great background discrimination

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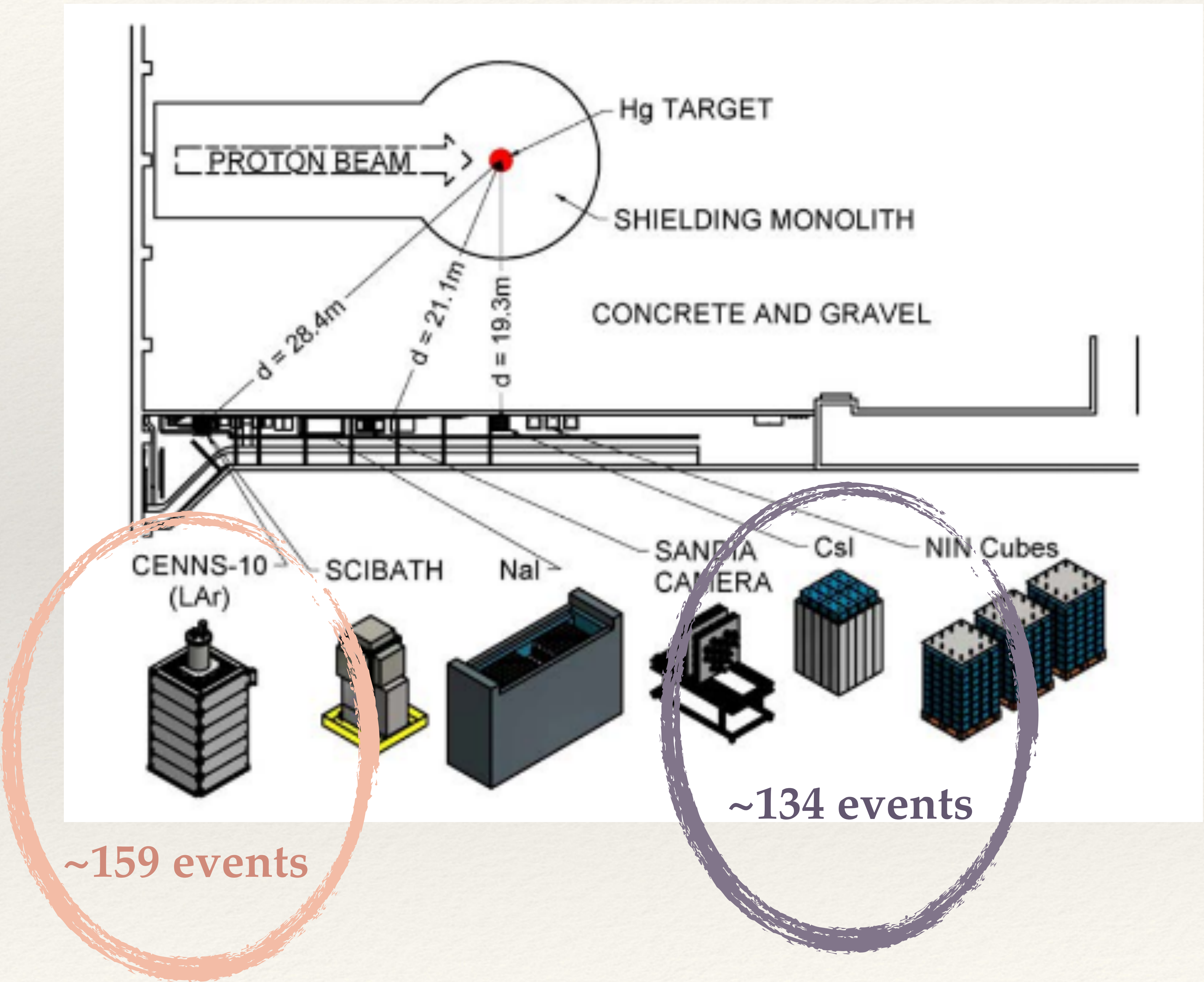


COHERENT Collaboration, Science 357,1123 (2017) & Phys.Rev.Lett. 126 (2021) 1, 012002

Why nuclear reactors?

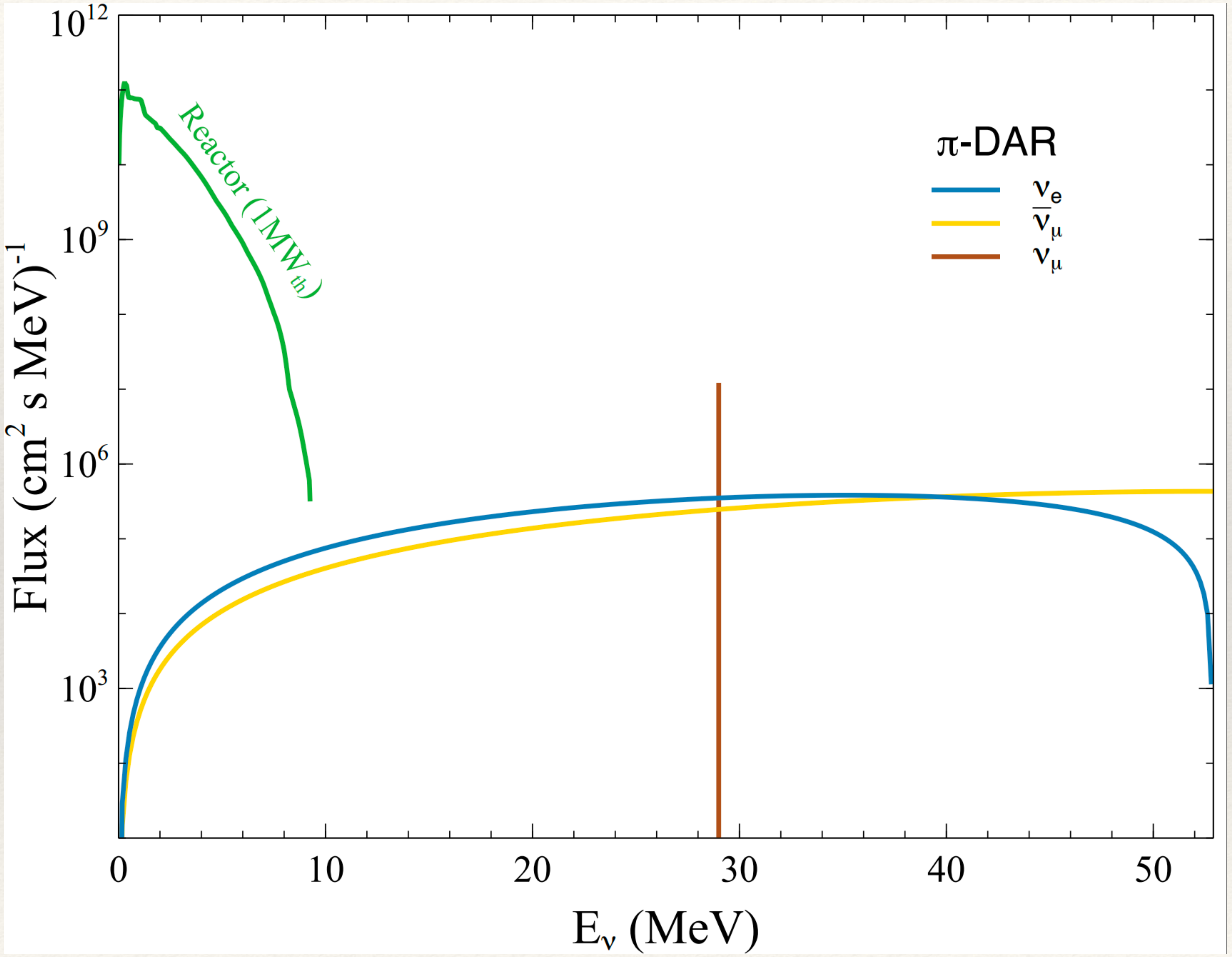
✓Intense antineutrino flux

✓Completely coherent scattering $(E_\nu \leq 10\ \text{MeV})$

✓Only $\bar{\nu}_e$

✓Different channel than SNS:

$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\downarrow$$
$$e^+ + \nu_e + \bar{\nu}_\mu$$



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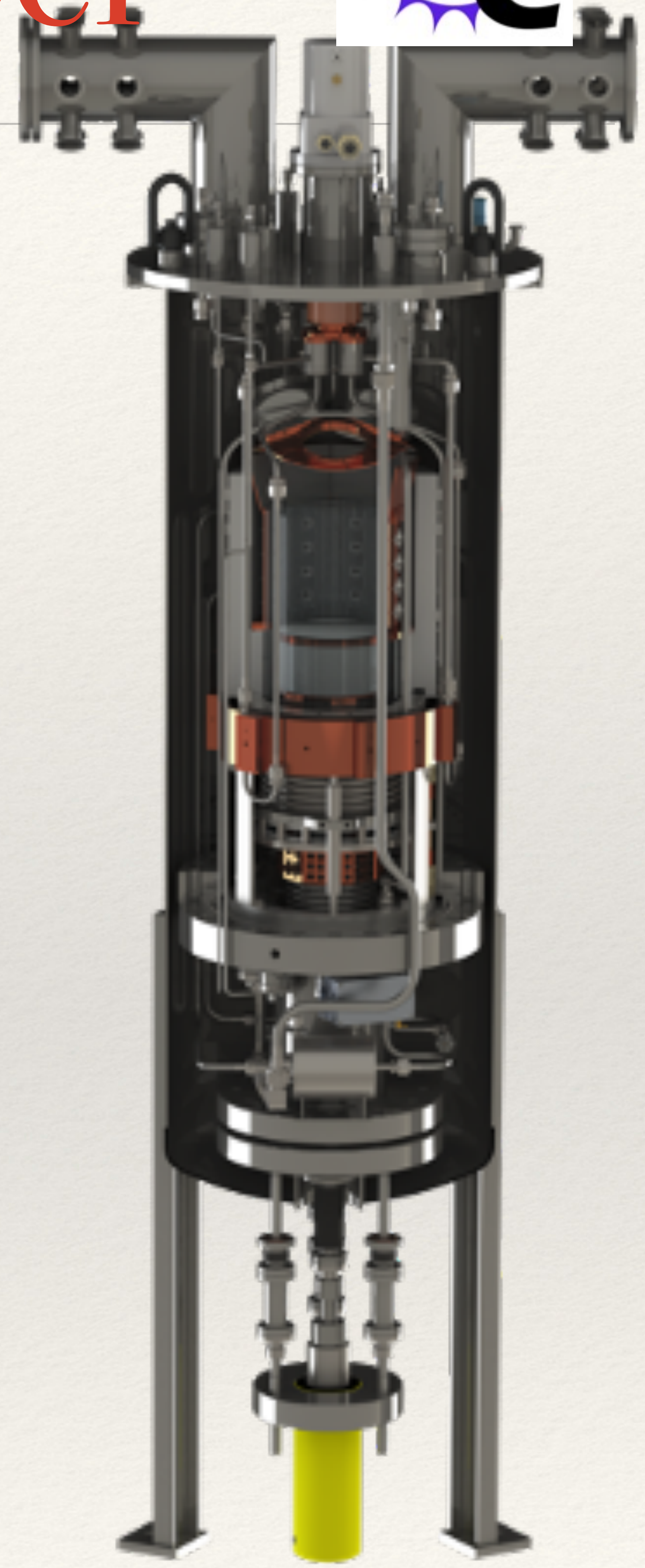
$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

Experiment	Nuclear Reactor	Power [GW]
TEXONO [41]	Kuo-Sheng Nuclear Power Station	2.9
CONUS [37]	Brokdorf	3.9
νGeN [72]	Kalinin Nuclear Power Plant	~ 1
MINER [36]	TRIGA 1	10^{-3}
νCLEUS [38]	FRM2	4
Ricochet [39]	Chooz Nuclear Power Plant	8.54
RED-100 [40]	Kalinin Nuclear Power Plant	~ 1
SBC [73]	ININ (or Laguna Verde)	10^{-3} (2)
CONNIE [74]	Angra 2	3.8
vIOLETA [75]	Atucha II	2
SoLid [76]	BR2	$(0.4, 1) \times 10^{-1}$
NEON [77]	Hanbit Nuclear Power Plant	2.8

Taken from D. Aristizabal-Sierra, V. De Romeri, LJF, D.K. Papoulias, JHEP 03 (2021) 294

Liquid argon scintillating bubble chamber*



Combines features of scintillation detectors and bubble chambers

- Insensitive to electron recoils
- Sub-keV thresholds (~100 eV)
- Single bubble created from nuclear recoils
- Energy resolution for backgrounds above ~5 keV

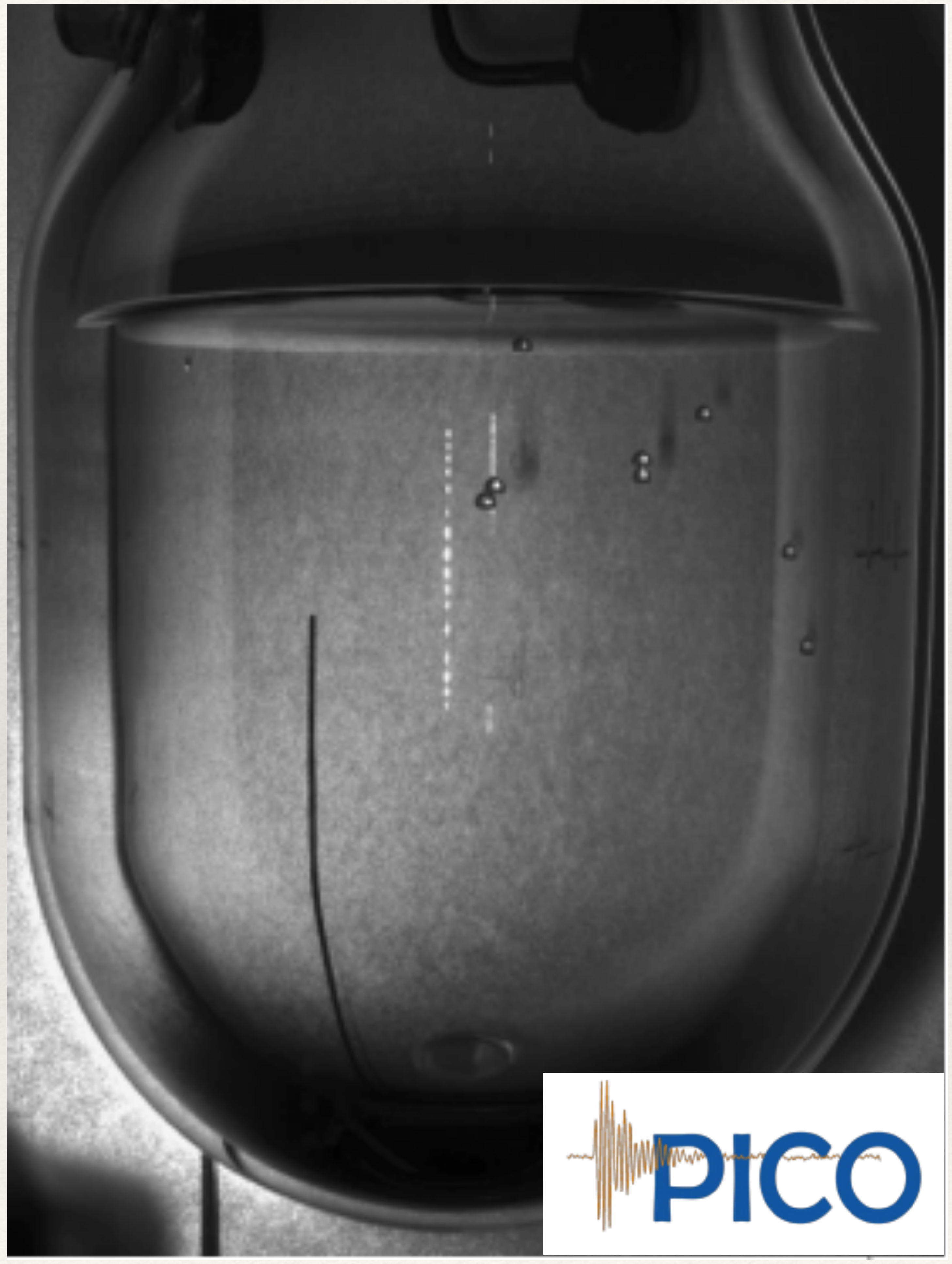
*LJF, E. Peinado, E. Alfonso-Pita, E. Vázquez-Jáuregui, SBC Collaboration (https://journals.aps.org/prd/pdf/10.1103/PhysRevD.103.L091301)

Bubble nucleation

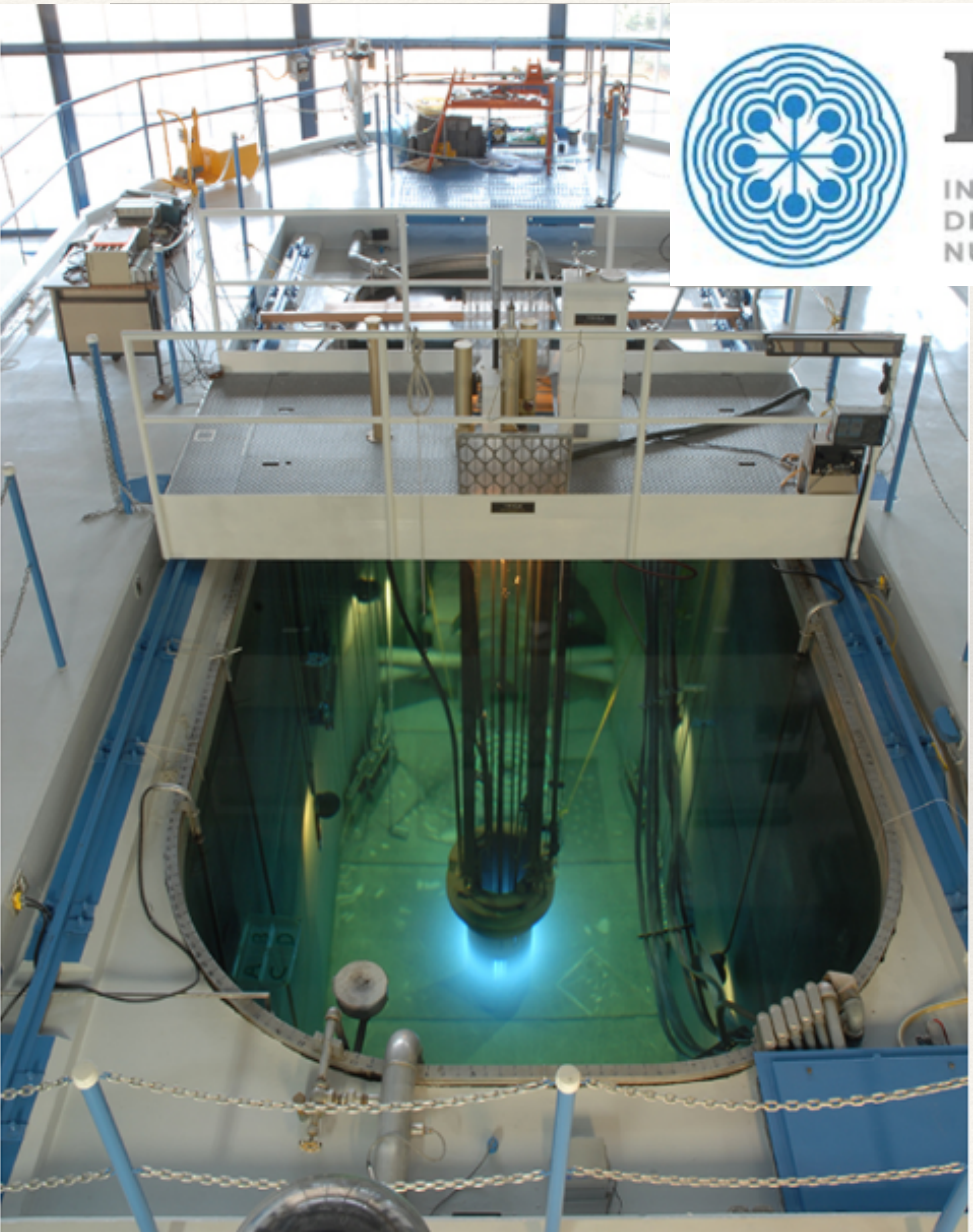
- Superheated fluid
- Energy deposition causes local boiling

  ↓

  Bubble nucleation
- Events detected by cameras, piezo-acoustic sensors, and SiPMs



Proposed reactor locations

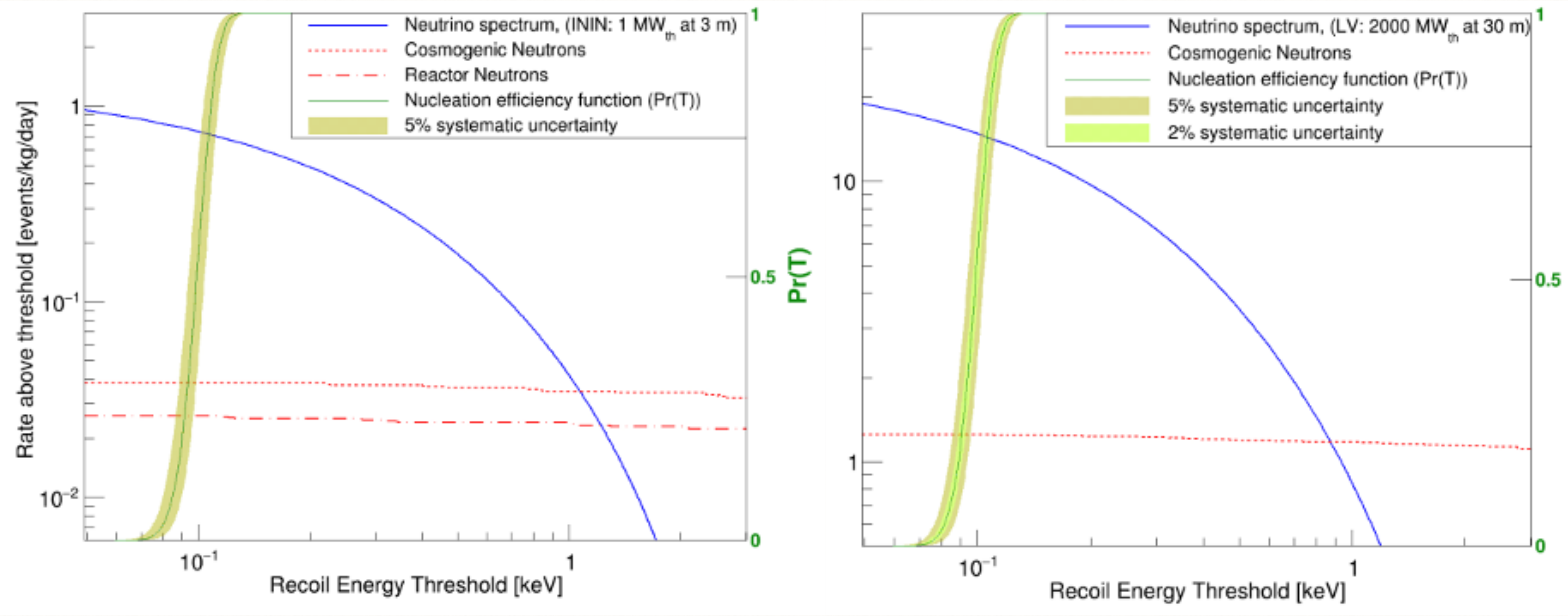


ININ
INSTITUTO NACIONAL DE INVESTIGACIONES NUCLEARES

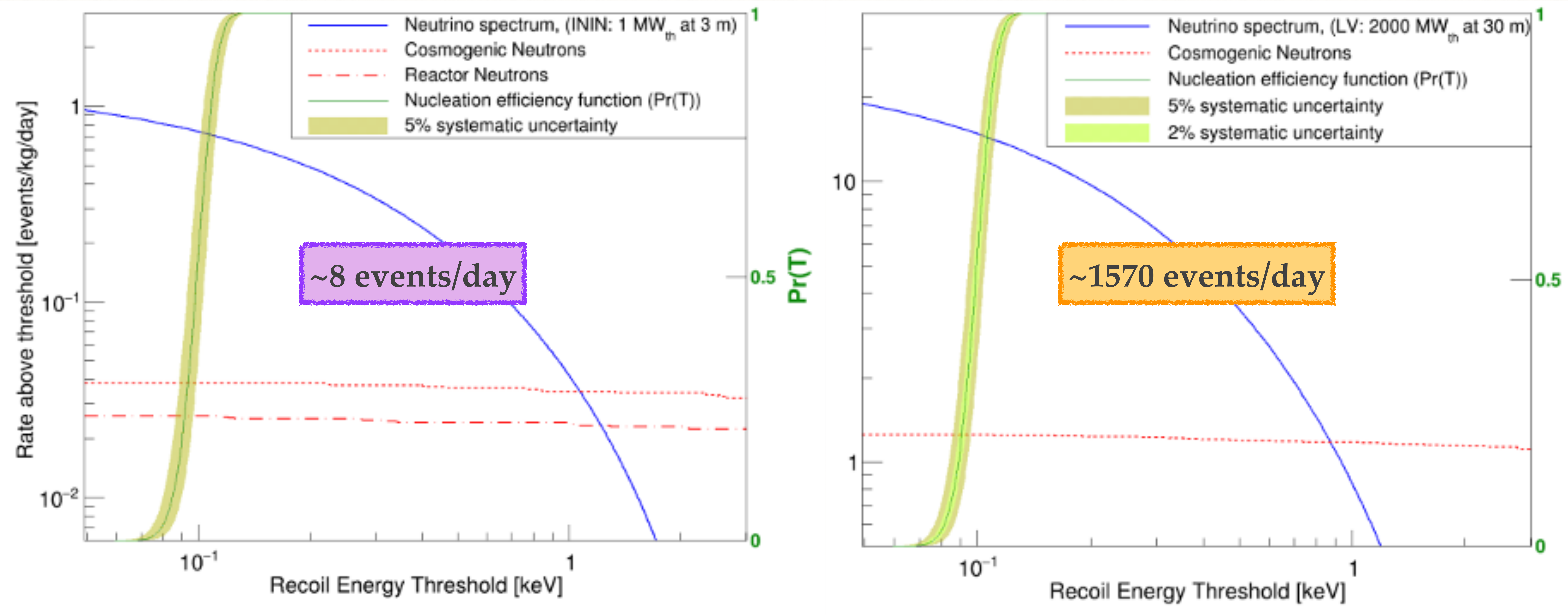
CENTRAL NUCLEAR LAGUNA VERDE

1 MWth	Power	2 GWth
3 - 10 m	Baseline	30 m
10 kg	Target mass	100 kg

Expected detection rates



Expected detection rates



Physics reach

Statistical analysis:

$$\chi^2 = \min_{\alpha,\beta,\gamma} \left[\left(\frac{N_{\text{meas}} - (1+\alpha)N_{\text{th}}(X,\gamma) - (1+\beta)B_{\text{reac}}}{\sigma_{\text{stat}}} \right)^2 + \left(\frac{\alpha}{\sigma_\alpha} \right)^2 + \left(\frac{\beta}{\sigma_\beta} \right)^2 + \left(\frac{\gamma}{\sigma_\gamma} \right)^2 \right], \qquad \sigma_{\text{stat}} = \sqrt{N_{\text{meas}} + (1+R)B_{\text{cosm}}}$$

Physics reach

Nuisance parameters

Fitted variable

$$\chi^2 = \min_{\alpha,\beta,\gamma}\left[\left(\frac{N_{\rm meas} - (1+\alpha)N_{\rm th}(X,\gamma) - (1+\beta)B_{\rm reac}}{\sigma_{\rm stat}}\right)^2 + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 + \left(\frac{\beta}{\sigma_\beta}\right)^2 + \left(\frac{\gamma}{\sigma_\gamma}\right)^2\right],$$

$$\sigma_{\rm stat} = \sqrt{N_{\rm meas} + (1+R)B_{\rm cosm}}$$

α : flux

β : background

γ : threshold

Physics reach

Nuisance parameters

Fitted variable

$$\chi^2 = \min_{\alpha,\beta,\gamma}\left[\left(\frac{N_{\rm meas} - (1+\alpha)N_{\rm th}(X,\gamma) - (1+\beta)B_{\rm reac}}{\sigma_{\rm stat}}\right)^2 + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 + \left(\frac{\beta}{\sigma_\beta}\right)^2 + \left(\frac{\gamma}{\sigma_\gamma}\right)^2\right],$$

$$\sigma_{\rm stat} = \sqrt{N_{\rm meas} + (1+R)B_{\rm cosm}}$$

α : flux

β : background

γ : threshold

ININ → A

Laguna Verde → B

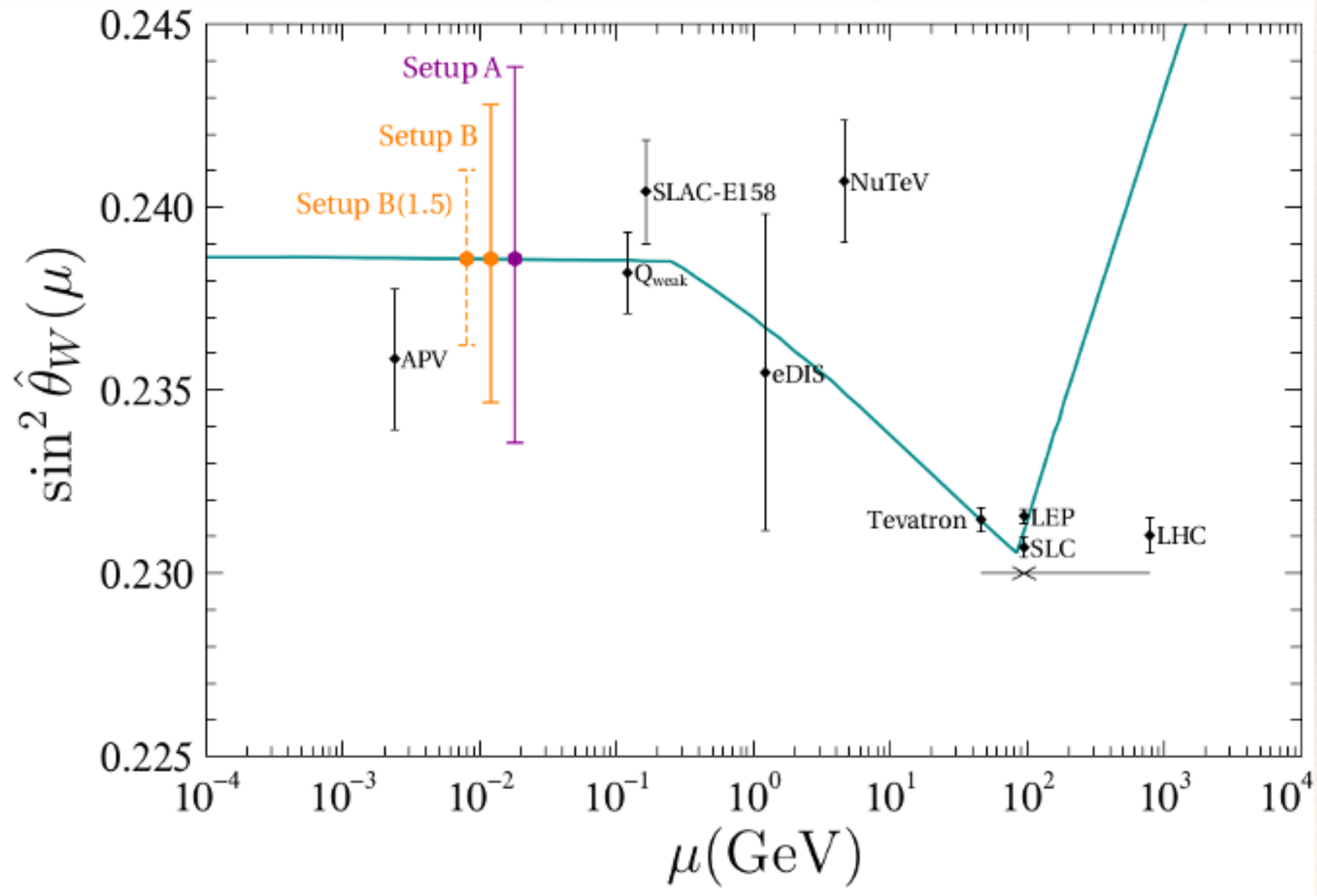
Laguna Verde (best-case scenario) → B(1.5)

Setup	LAr mass (kg)	Power (MW_{th})	Distance (m)	Anti-ν flux uncertainty (%)	Threshold uncertainty (%)
A	10	1	3	2.4	5
B	100	2000	30	2.4	5
B(1.5)	100	2000	30	1.5	2

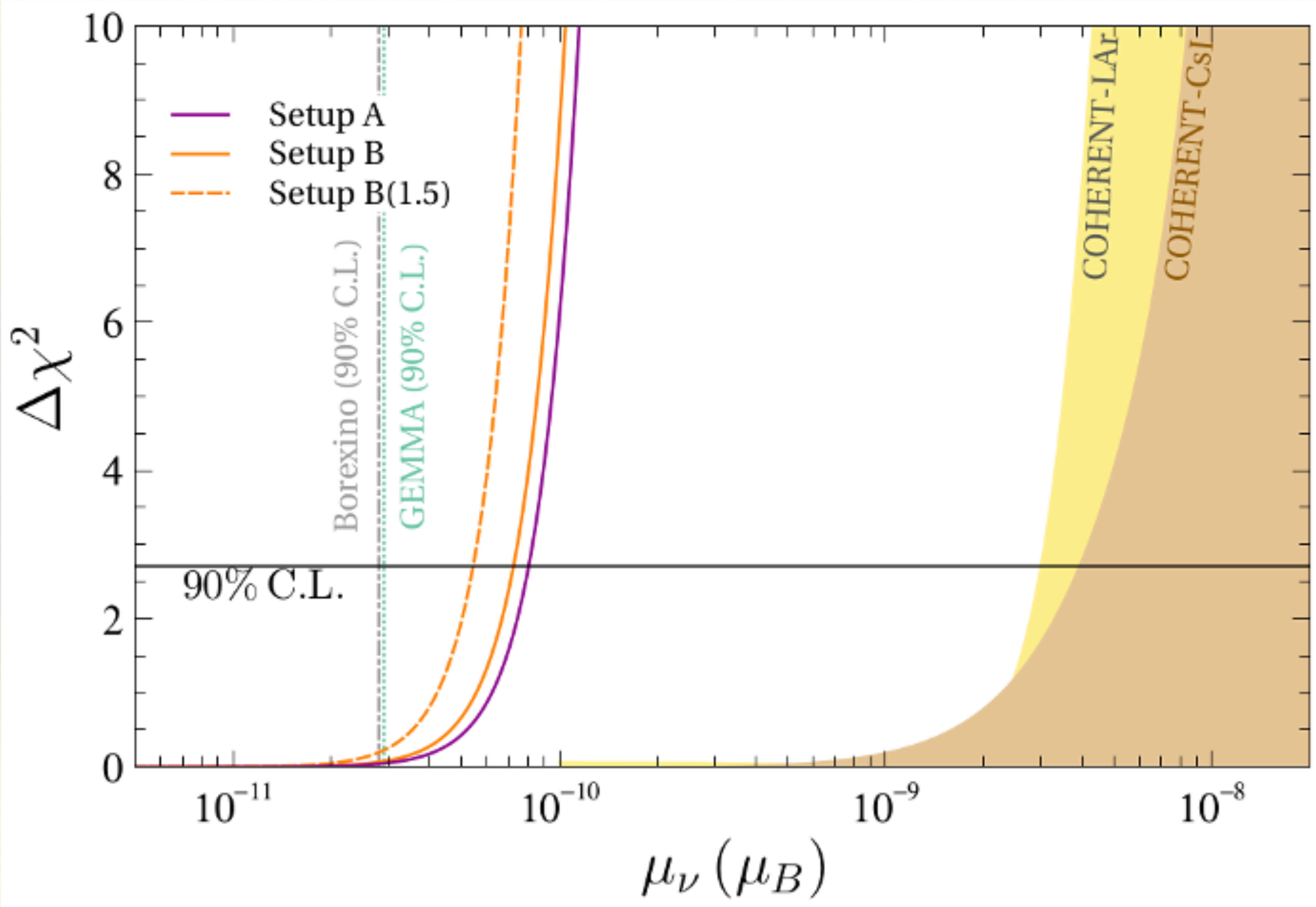
Physics reach: weak mixing angle

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N {Q_w}^2 \left(2 - \frac{M_N T}{E_\nu^2}\right) F^2(q^2),$$

$$Q_w = Z(1/2 - 2\sin^2\theta_W) + N(-1/2)$$



Physics reach: neutrino magnetic moment



$$\left(\frac{d\sigma}{dT}\right)_{\mathrm{SM}} + \left(\frac{d\sigma}{dT}\right)_{\mu_\nu}$$

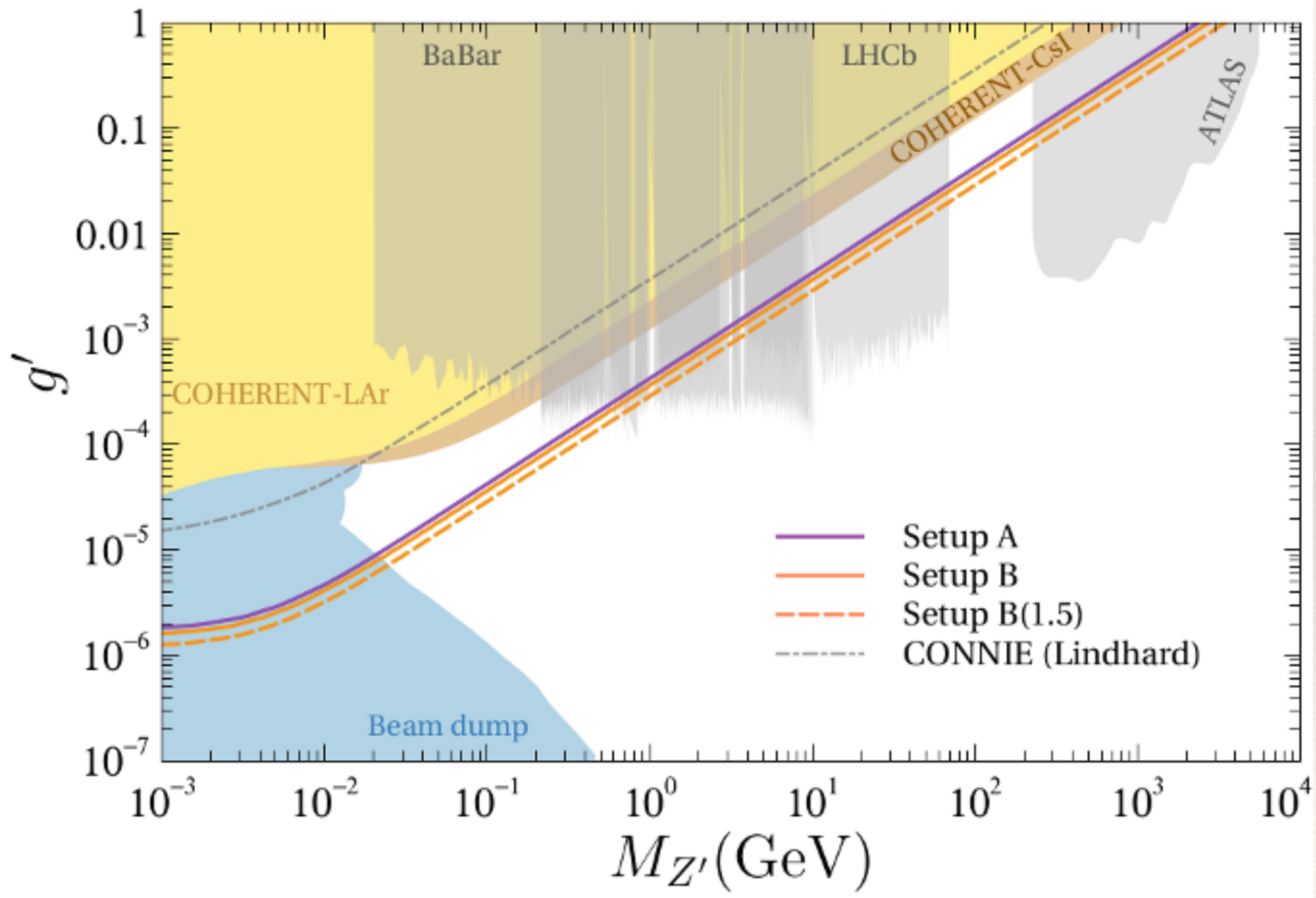
$$\left(\frac{d\sigma}{dT}\right)_{\mu_\nu} = \pi \frac{\alpha_{\mathrm{EM}}^2 Z^2 \mu_\nu^2}{m_e^2}\left(\frac{1}{T} - \frac{1}{E_\nu} + \frac{T}{4E_\nu^2}\right) F^2(q^2)$$

Physics reach: Z’ boson

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N {Q_w}^2 \left(2 - \frac{M_N T}{E_\nu^2}\right) F^2(q^2),$$

$$Q_w = Z(g_p^V + 2\epsilon_{\alpha\alpha}^{uV} + \epsilon_{\alpha\alpha}^{dV}) + N(g_n^V + \epsilon_{\alpha\alpha}^{uV} + 2\epsilon_{\alpha\alpha}^{dV})$$

$$\epsilon_{\alpha\alpha}^{qV} = \frac{g' x_\alpha x_q}{\sqrt{2} G_F (q^2 + M_{Z'}^2)}$$



Final Remarks

LAr Scintillating Bubble Chamber offers:

- High chance of detecting reactor CEvNS
- Opportunity for precision low-energy measurements
- More stringent limit to new physics signals, compared with other CEvNS experiments

Thank you for your attention