tightly linked to **LiquidO**, **AntiMatter-OTech/CLOUD**, and **SuperChooz** team, specially **EDF**

SUPERCHOOZ

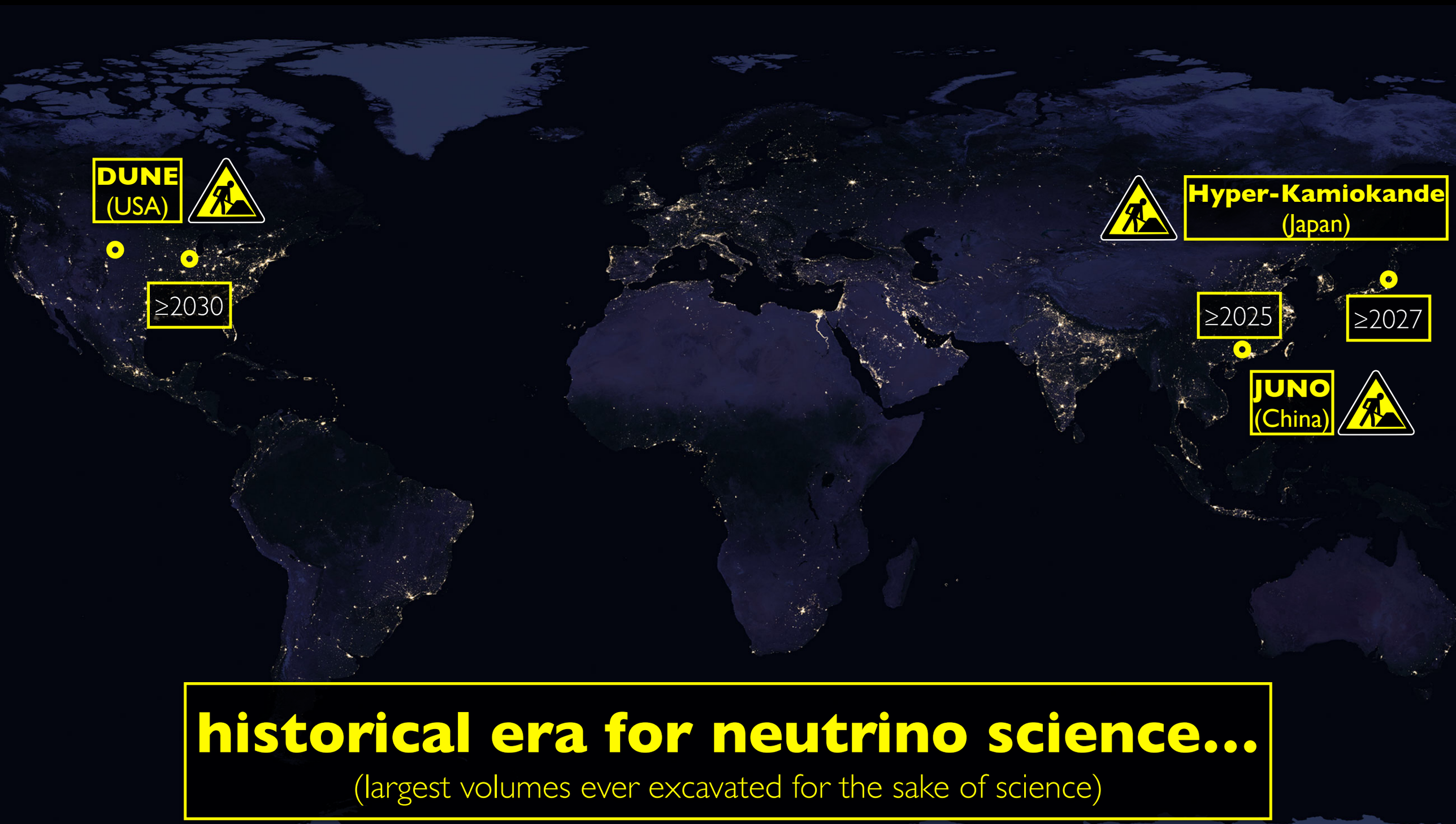
European Innovation Council

Anatael Cabrera

IJCLab (Orsay)

CNRS / Université Paris-Saclay

main **flagship** ν experiments…



historical era for neutrino science…

(largest volumes ever excavated for the sake of science)

status on neutrino oscillation knowledge…

Standard Model(3 families)
[leptons & quarks]
&
PMNS$_{3x3}$(**θ_{12},θ_{23},θ_{13}**)
&
$\pm\Delta m^2$ (**$\pm\Delta m^2_{23}$**) & **$+\delta m^2$** (**$\pm\Delta m^2_{12}$**)

no conclusive sign of any extension so far!!

(inconsistencies vs uncertainties)

must measure all parameters → characterise & test (i.e. over-constrain) ***Standard Model***

	today			**≥2030**		
	best knowledge		global	foreseen	dominant	source
θ_{12}	3.0 %	SK⊕SNO	2.3 %	<1.0%	JUNO	reactor
θ_{23}	5.0 %	NOvA+T2K	2.0 %	**few %?** (octant)	DUNE⊕HK	beam
θ_{13}	1.8 %	DYB+DC+RENO	**1.5 %**	**1.5 %**	DC⊕DYB⊕RENO	reactor
$+\delta m^2$	2.5 %	KamLAND	2.3 %	≲1.0%	JUNO	reactor
$\lvert\Delta m^2\rvert$	3.0 %	T2K+NOvA & DYB	1.3 %	≲1.0%	JUNO⊕DUNE⊕HK	reactor & beam
Mass Ordering	**unknown**	SK et al	NO @ **~3σ**	@5σ	JUNO⊕DUNE⊕HK	reactor⊕beam
CPV	**unknown**	T2K	3/2π @ **≲2σ**	**@5σ?**	DUNE⊕HK⊕ALL	reactor⊕beam
			(**now**)			(reactor-beam)

JUNO⊕DUNE⊕HK will lead precision in the field → **Mass Ordering** & **CPV** **except θ_{13}!**

ORCA⊕PINGU⊕IceCube complementary for Mass Ordering & Δm^2 measurements

main **flagship** ν experiments…

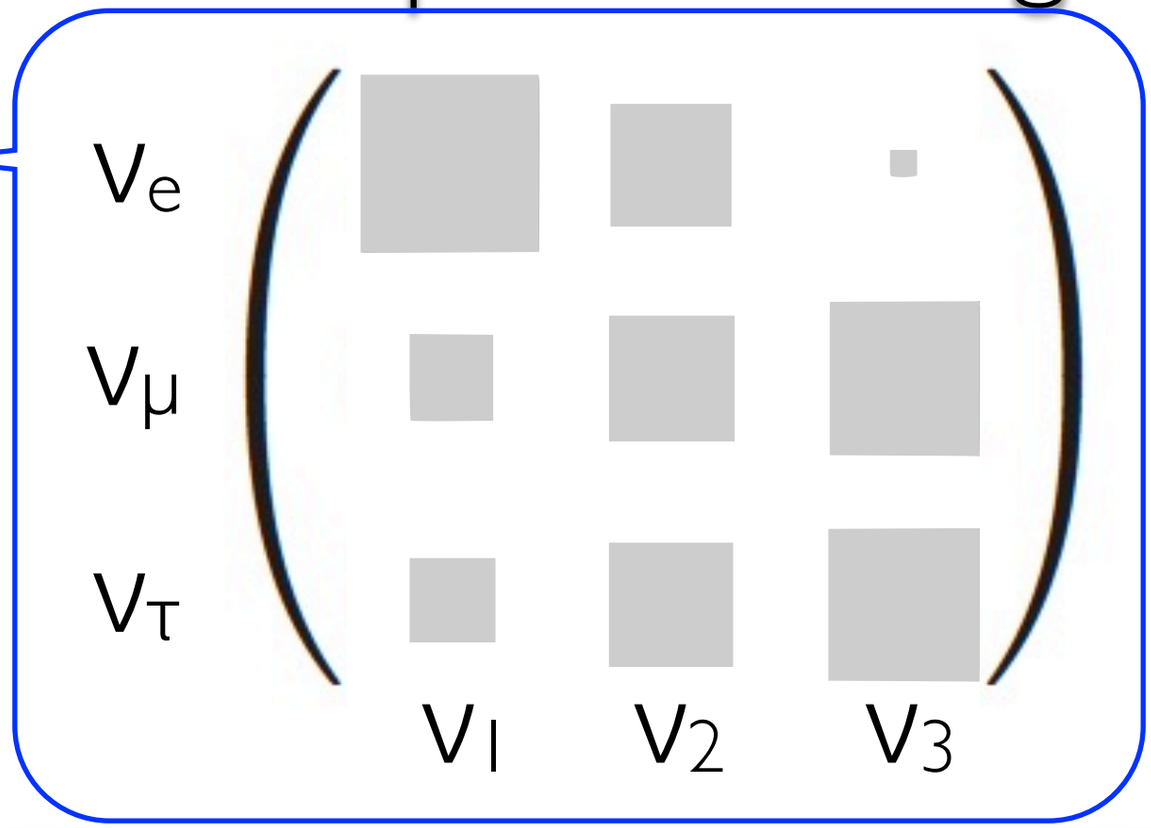
major improvements everywhere, except θ_{13} & maybe θ_{23}**-octant**?

enough?

2 accelerator experiments **HyperK** & **DUNE** → **redundancy**
&
1 reactor experiment **JUNO** → **no cross-check!**

SM's leptonic mixing sector (PMNS)…

$$\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$



consider full matrix structure

(not just composition)

why shape?

- **large mixing** but a **small one**!
- **largest CP-violation** (SM)
- **any symmetry behind? [or Nature's caprice?]**

U_{3x3} unitary?

[assumed!!, not demonstrated]

(BSM) any relation to CKM?

standard (SM) neutrinos oscillations:

- what's the PMNS "telling us"?
  - θ_{13}: smallest but why so small?
  - θ_{23}: largest but octant resolution?
  - θ_{12}: highest ever precision [JUNO]: so what's next?
  - new θ_{ij}? if so, mixing definitions may be biased!

    $\Longrightarrow$ enforced unitarity may be incorrect
- solar pp & CNO: Sun full astrophysics! (^{8}B: tiny fraction)
- synergies: even more out of JUNO+HyperK+DUNE?

  $\Longrightarrow$ crosscheck JUNO? — nobody!

SuperChooz's ***ikigai***...

neutrinos to probe BSM: "discovery territory"

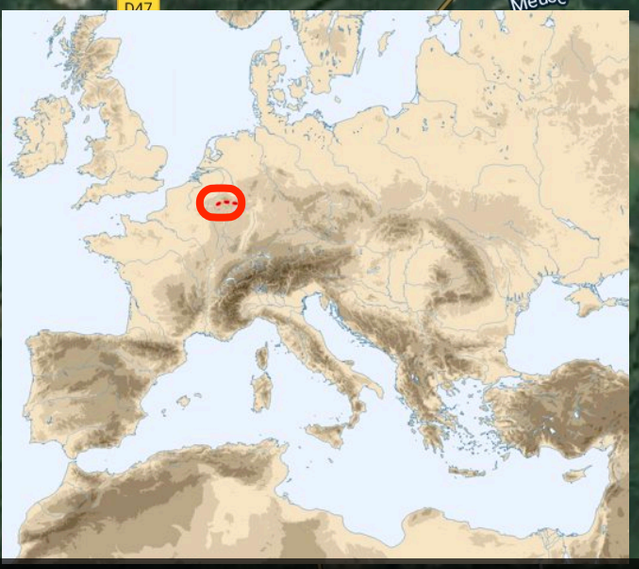
- new neutrino(s), interaction(s) and/or phenomenology?
  - probe unitarity violation/conservation [must: @ $\leq$1%]
  - mapping the solar's "upturn"?
- probe fundamental symmetries — all!
  - probe baryon# violation/conservation?
  - $\Longrightarrow$ proton decay! — all decay mechanism(s)!
- (foresight) link(s) between PMNS and CKM?

SuperChooz's ***ikigai***...

the new opportunity…

in the **middle of central Europe** (between France-Belgium): **Chooz** [meeting point with Germany, Luxembourg, Netherlands]

one of the most powerful **anti-matter generators**



← a "**SK-size opportunity**" here!!

les Ardennes
(France-Belgium)

Europe's most powerful reactor site…

3rd generation of reactor neutrino experiments @ Chooz

the reactor (source)...

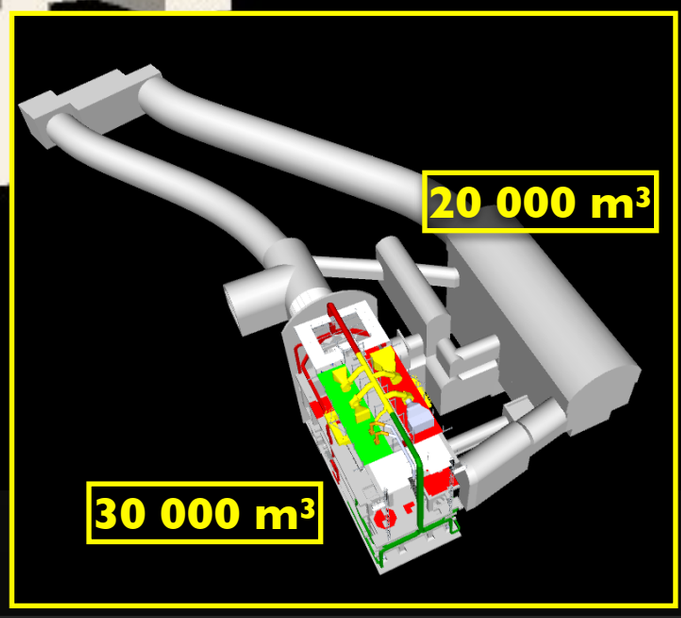
Chooz-B nuclear reactor plant: 2x N4 reactors [4.2GW$_{thermal}$ each]

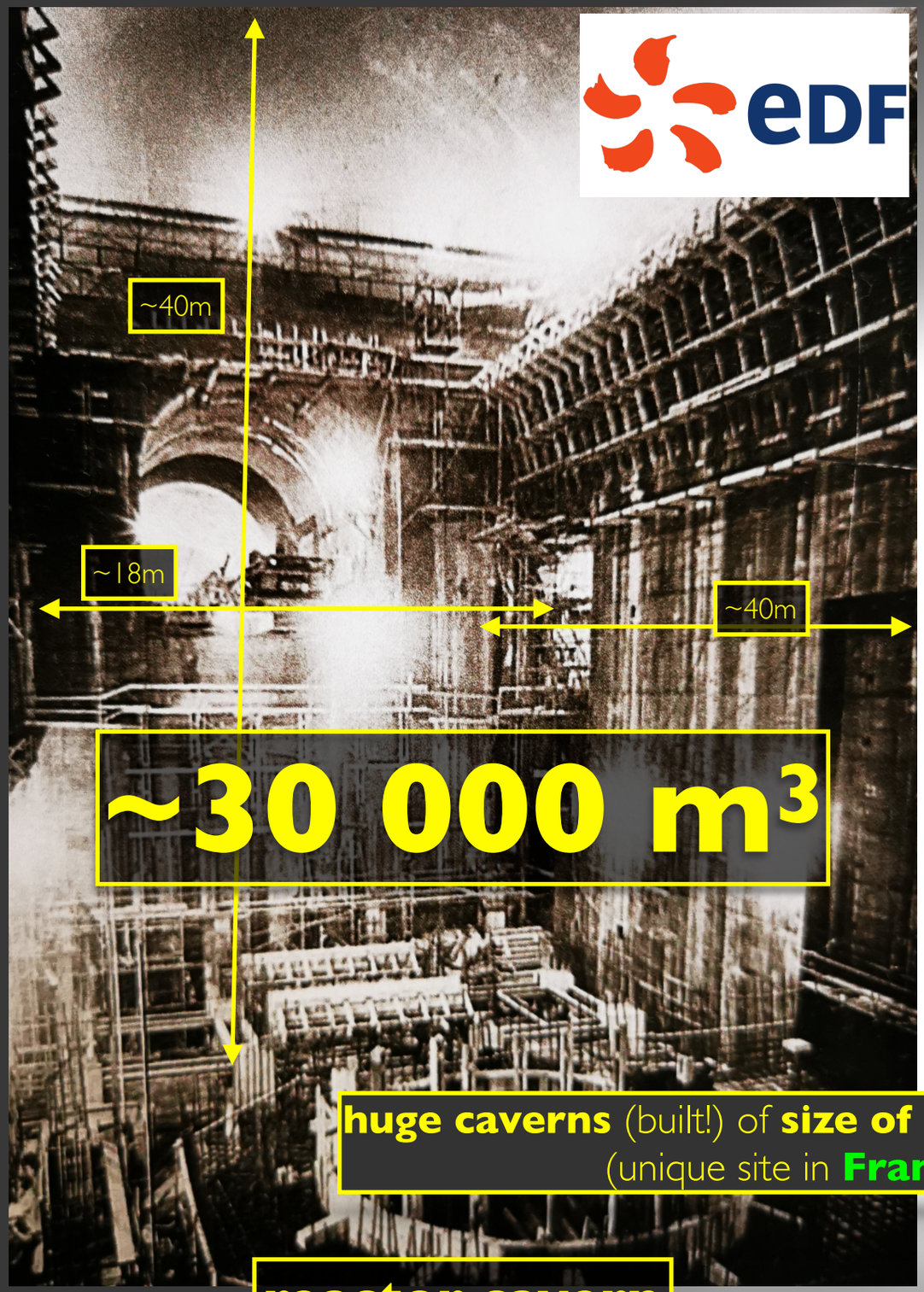
once upon a time, in the 60s…

≤50 000 m³

dismantling

Chooz-A for science?





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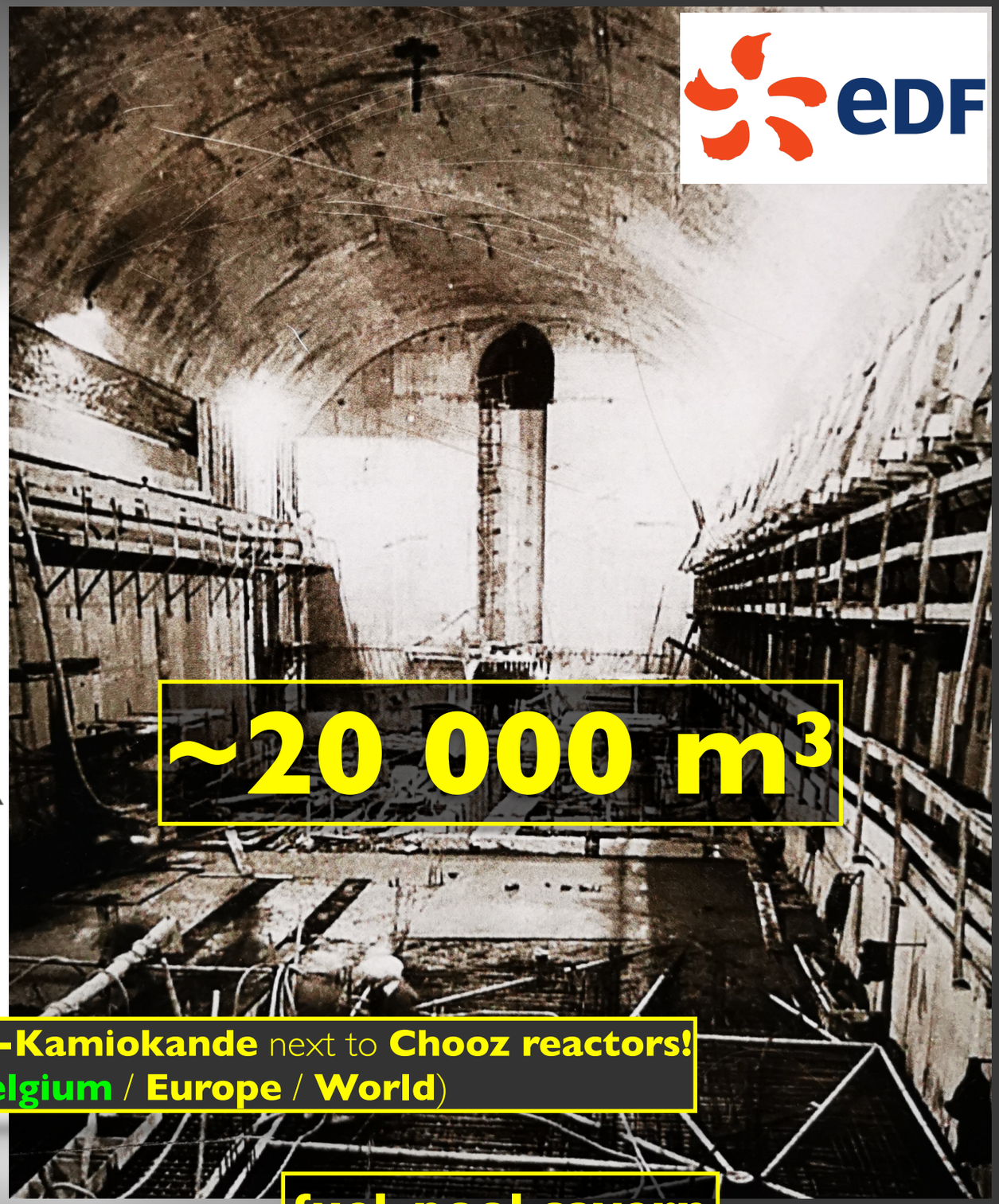


huge caverns (built!) of **size of Super-Kamiokande** next to **Chooz reactors!**
(unique site in **France-Belgium** / **Europe** / **World**)

reactor cavern

fuel-pool cavern

construction caverns [1962-1967]

SuperChooz cavern is built (60's)…

DUNE (USA)

Super Chooz? (Europe)

Hyper-Kamiokande (Japan)

JUNO (China)

historical opportunity!! one of the largest underground laboratories in Europe — built!!

EDF leadership looking forward to SuperChooz

SuperChooz Signature September 2022 — CNRS-EDF

SuperChooz
@Superchooz

We are delighted to announce that the #SuperChooz agreement between @EDFofficiel and @CNRS directions was signed on the 7th Sept 2022 (twitter.com/IN2P3_CNRS/sta…), thus officially starting the so-called “SuperChooz Pathfinder” exploration era.

←follow **SuperChooz** (Tweeter)

SuperChooz Pathfinder starts…

SuperChooz experimental setup…

the Ardennes mountains

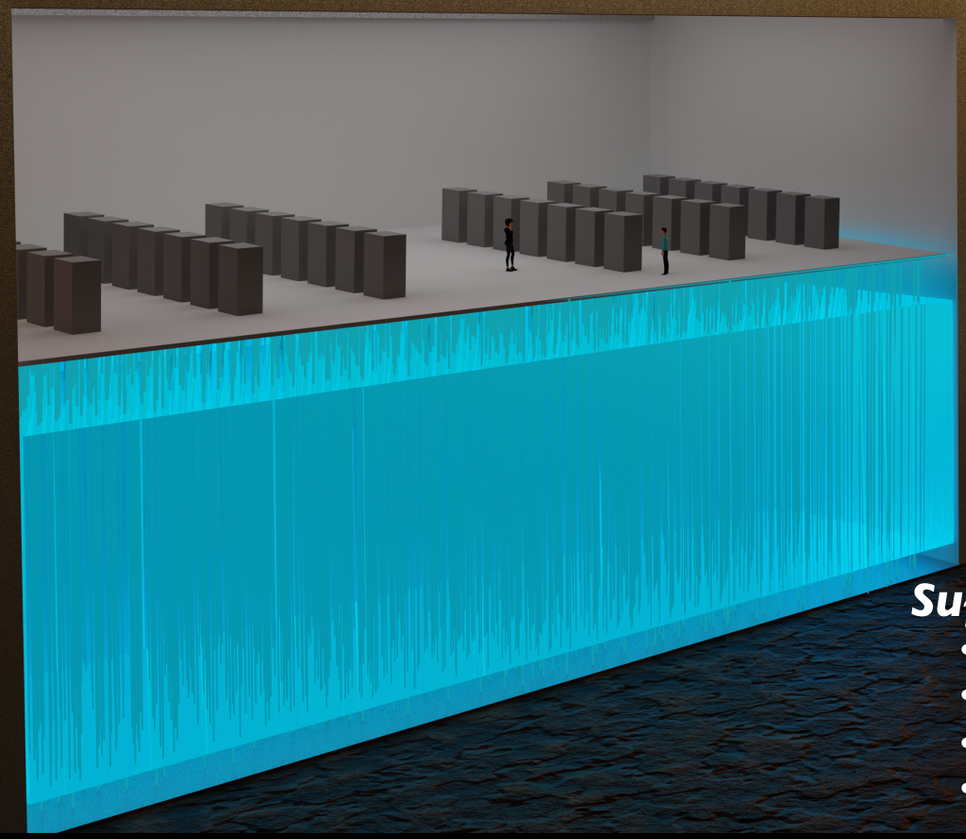
European Innovation Council

UK Research and Innovation

***AntiMatter-OTech** project*
***CLOUD** experiment*

1 Dec 2022

***Chooz-A:** Cavern Reactor Core*



***Chooz-B:** Reactor Cores*

Ultra Near Detectors @ Chooz-B:

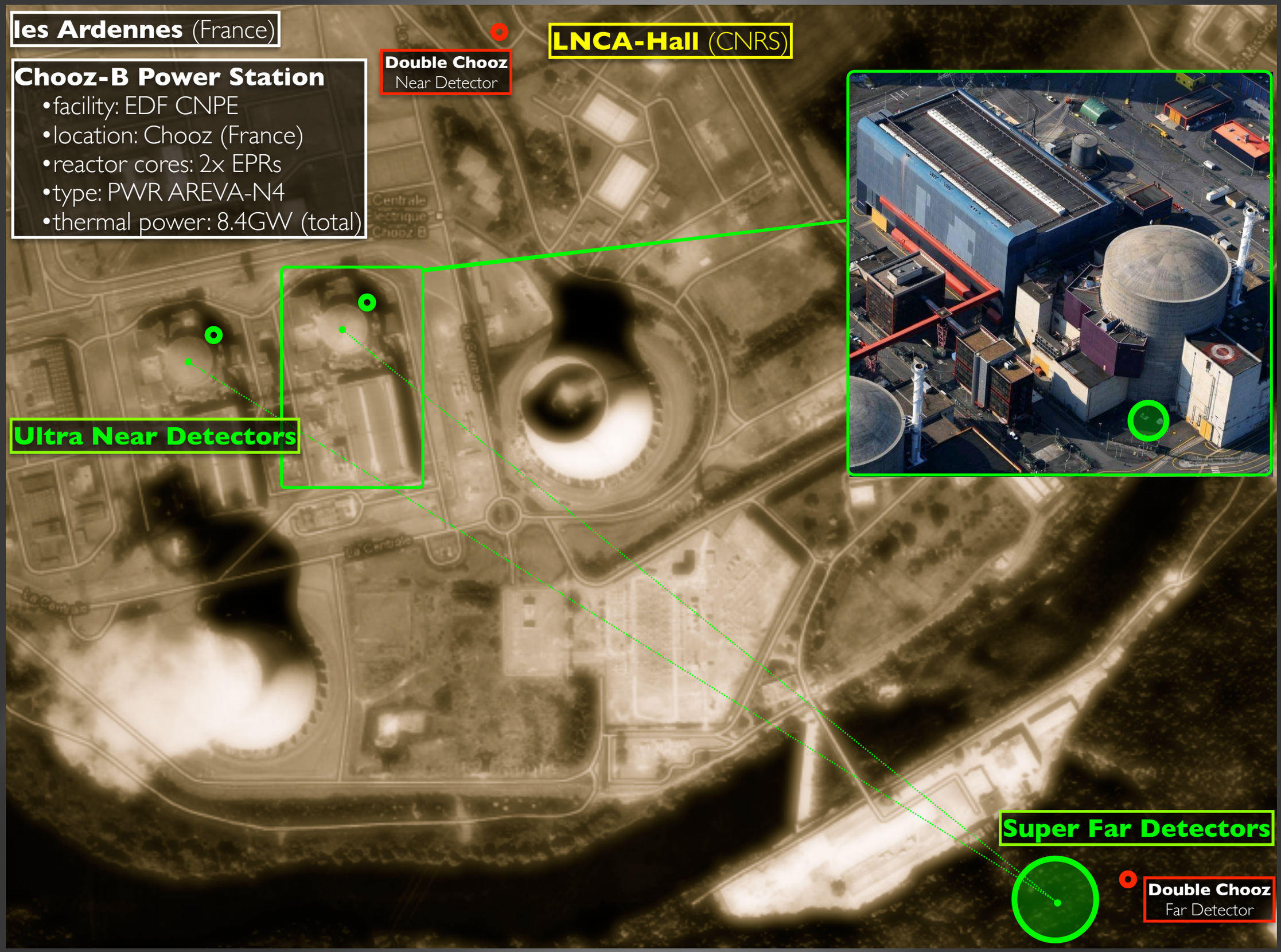
- *LiquidO technology*
- *Mass: ≤5 tons*
- *Overburden: ≤5m*
- *Baseline: ≤30m*

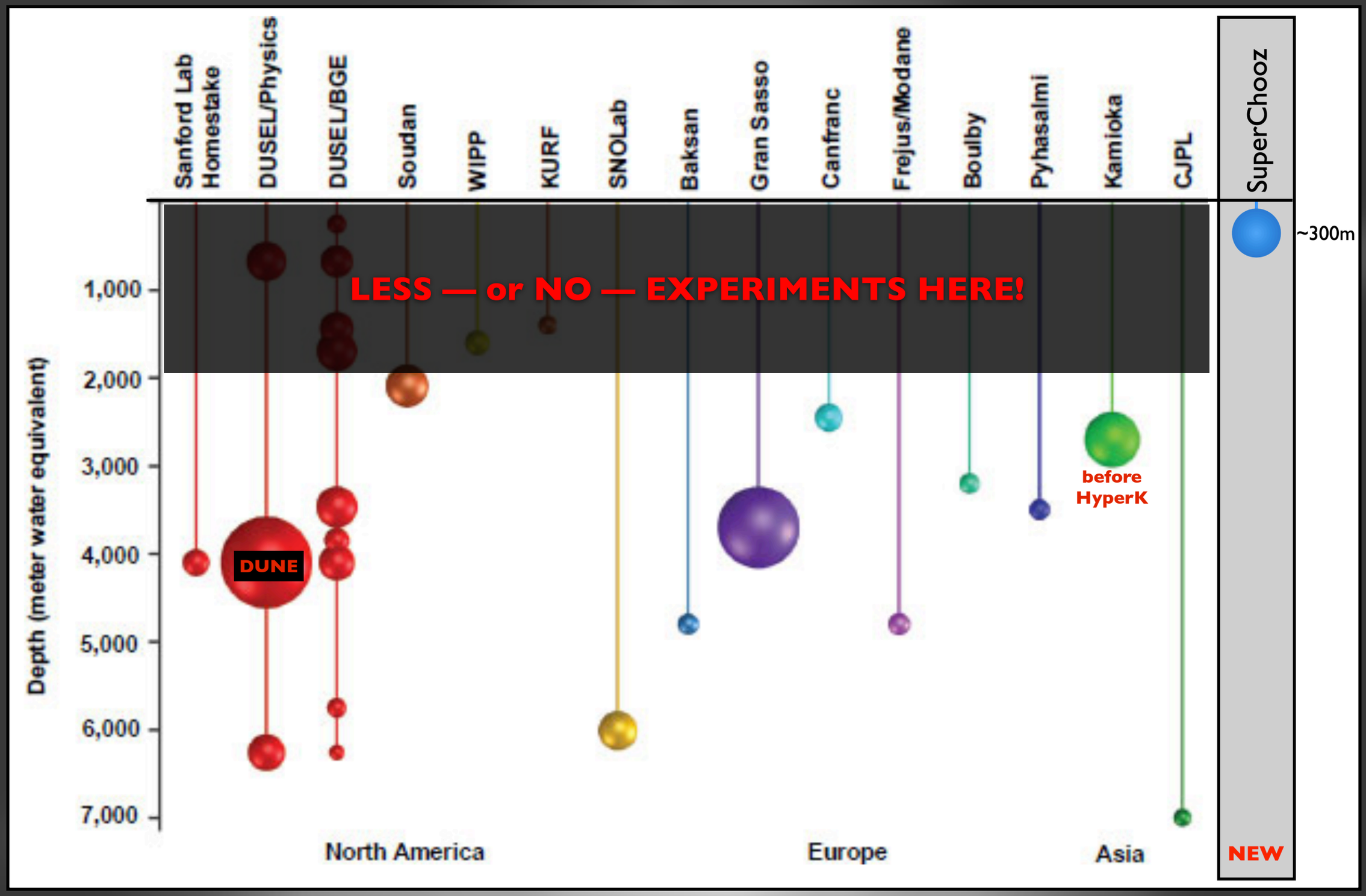
Super Far Detector @ Chooz-A

- *LiquidO technology*
- *Mass: ~10,000 tons*
- *Overburden: ≤100m*
- *Baseline: ~1km*

the Meuse river

SuperChooz → new laboratory facilities — beyond the existing **LNCA** (key support!)





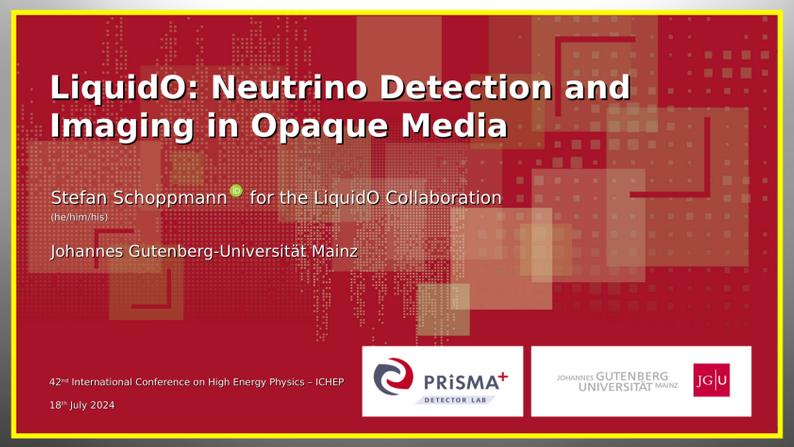
ISSUE!!! overburden <100m rock (or <300 mwe)

world underground volume…

experimental demonstration...

L I Q U I D

new technology — the breakthrough



experimental demonstration...

de facto **SuperChooz's demonstrator** project
(independent project: innovation & physics)

C L O U D

European Innovation Council

UK Research and Innovation

project: "**AntiMatter-OTech**"

first LiquidO-based experiment...

CLOUD = "**C**hooz **L**iquid**O** **U**ltranear **D**etector"

scientific programme…(so far)

SuperChooz rates…

10 years exposure

Antineutrino Reactor (@1.1km):
- $\phi \approx 6$ ν•day^{-1}•ton^{-1} [→**DC-FD**]
- $\phi \approx$ 20M ν•year^{-1} [~**10kton**]
- **$\phi \approx$ 220M ν's** [exposure: 100,000 ton•year]

Neutrinos Sun:
- **$\phi_\odot \approx$ 250,000 ν's** [exposure: 100,000 ton•years]

Antineutrino Reactor (@20m):
- $\phi \approx$ 16k ν•day^{-1}•ton^{-1} [→**DC-ND→CLOUD**]
- $\phi \approx$ 10M ν•year^{-1} [~**2ton**]
- **$\phi \approx$ 100M ν's** [exposure: 20 ton•year]

Neutrinos Sun:
- **$\phi_\odot \lesssim$ 100 ν's** [exposure: 20 ton•years]

Chooz-A: *Cavern Reactor Core*

Chooz-B: *Reactor Cores*

Ultra Near Detectors @ Chooz-B:
- *LiquidO technology*
- *Mass: ≤5 tons*
- *Overburden: ≤5m*
- *Baseline: ≤30m*

Super Far Detector @ Chooz-A
- *LiquidO technology*
- *Mass: ~10,000 tons*
- *Overburden: ≤100m*
- *Baseline: ~1km*

the Meuse river

θ_{13} & $|\Delta m^2|$

(≤1% precision)

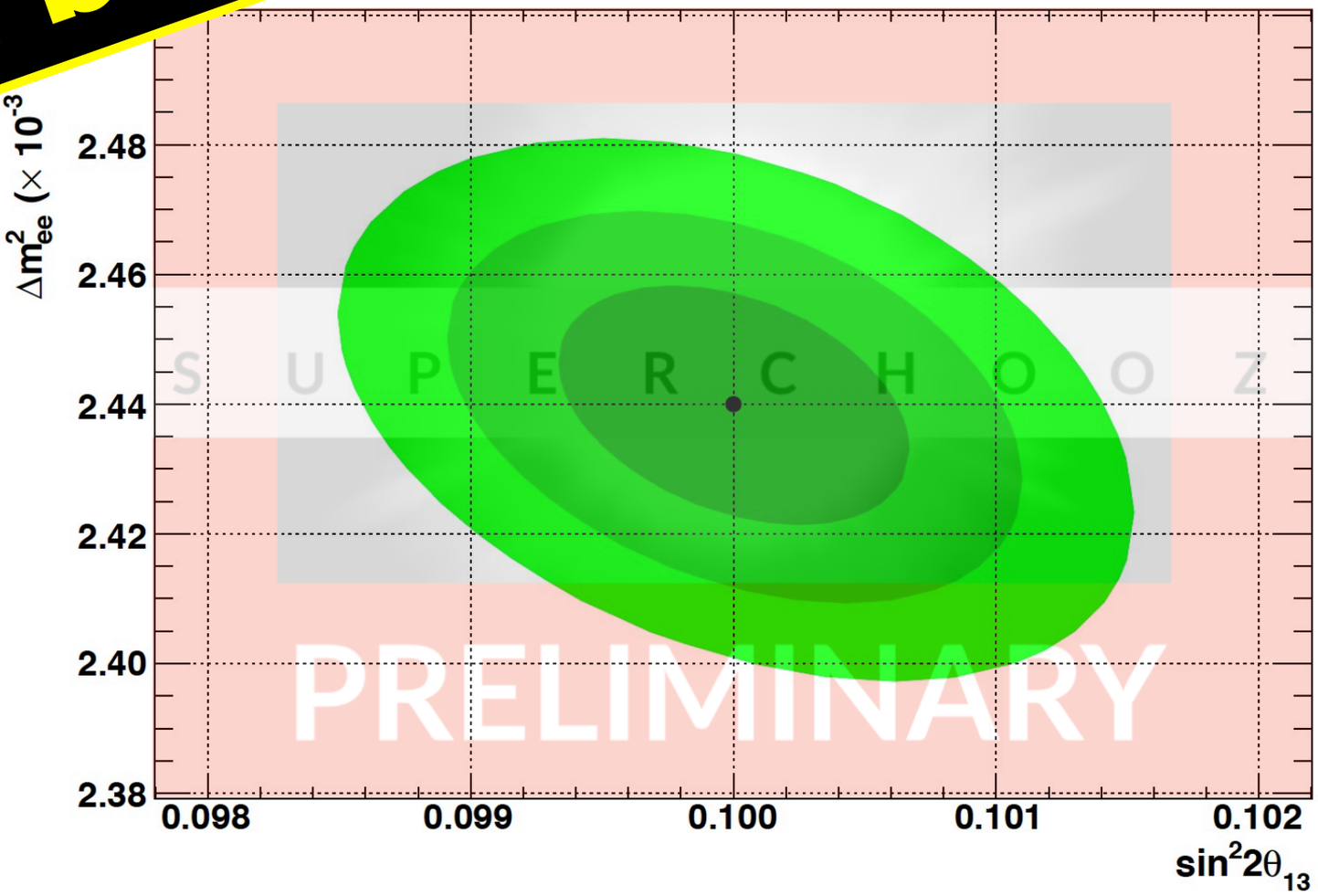
physics I: reactor neutrinos…

overall θ13⊕Δm²(ee) sensitivity…

Input Δm^2_{ee} unc.	Output Δm^2_{ee} unc.	$\sin^2 2\theta_{13}$ unc.
1%	≤0.5%	≤0.5%
Free		

world best

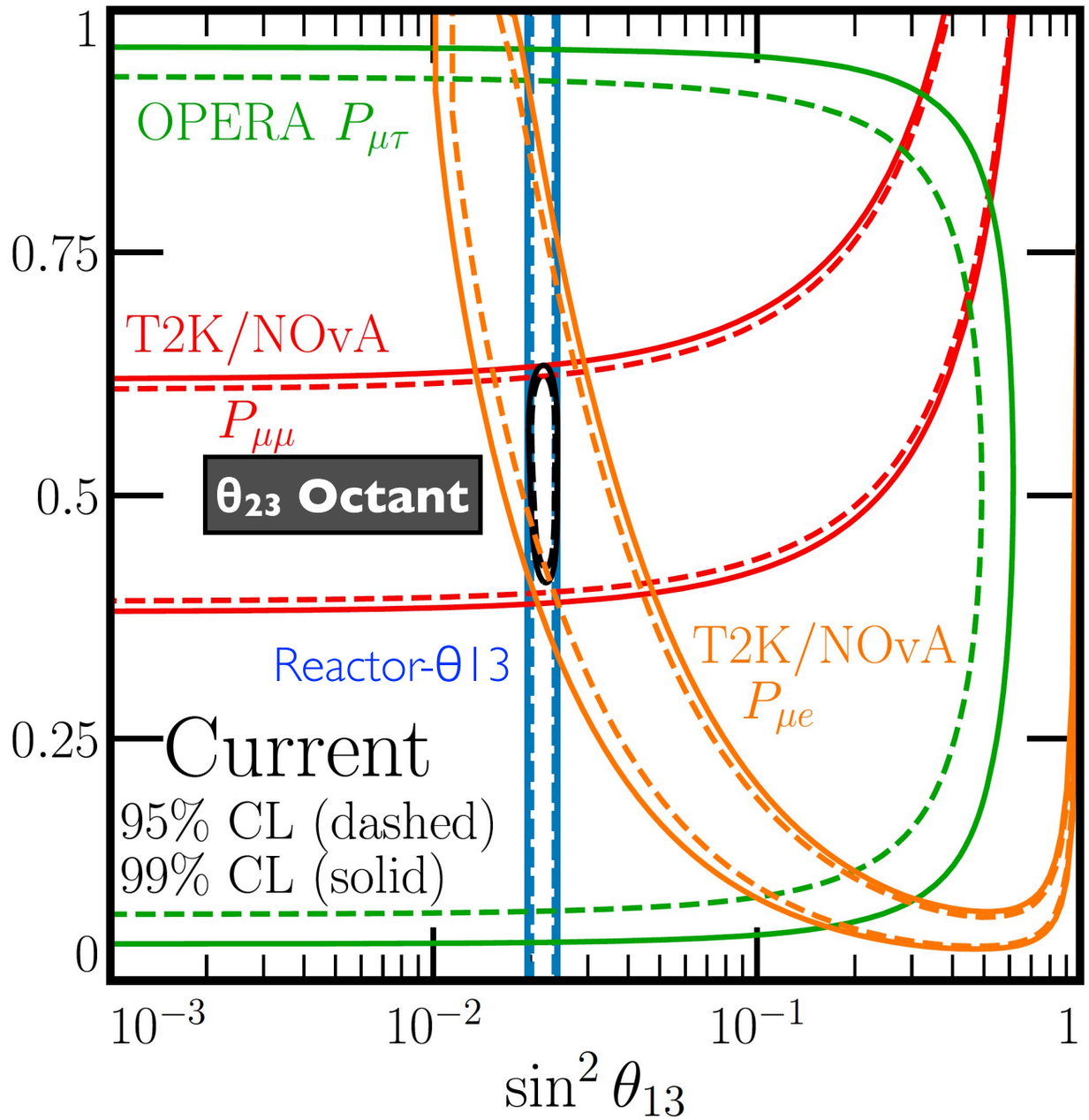
≥3× **≥6×**

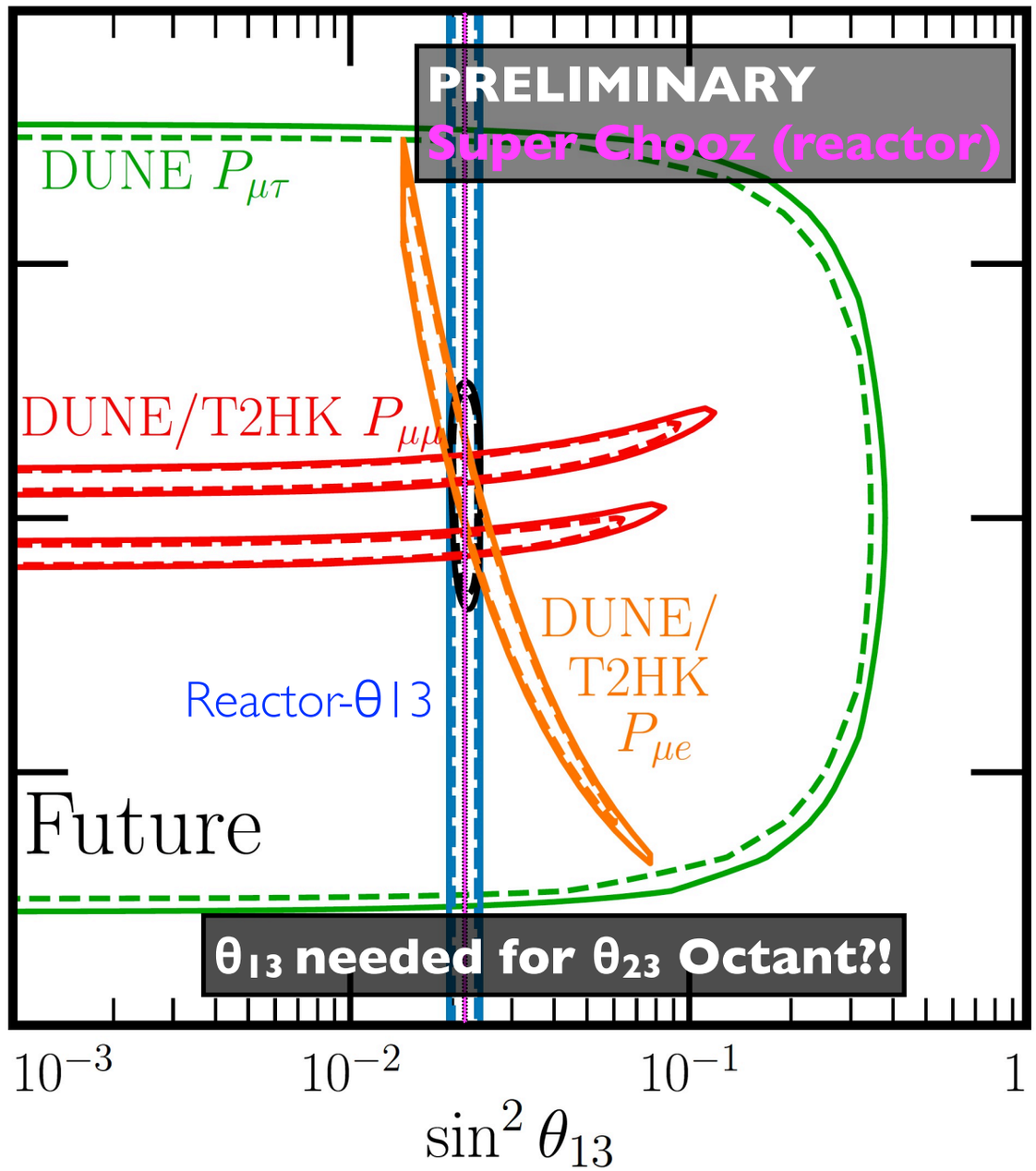


[first time] sub-percent measurement of θ13⊕Δm²(ee)

Super Chooz potential under investigation…

Plot: hacked version from original in ***Ellis, Kelly & Weishi-Li at* arXiv:2008.01088**





synergy: SC θ13 may help — critical?! — to resolve the "θ23 octant" ambiguity

(accelerator) measured the combined effect of θ13⊕θ23 (hard to disentangle)

Super Chooz: the smallest but powerful…

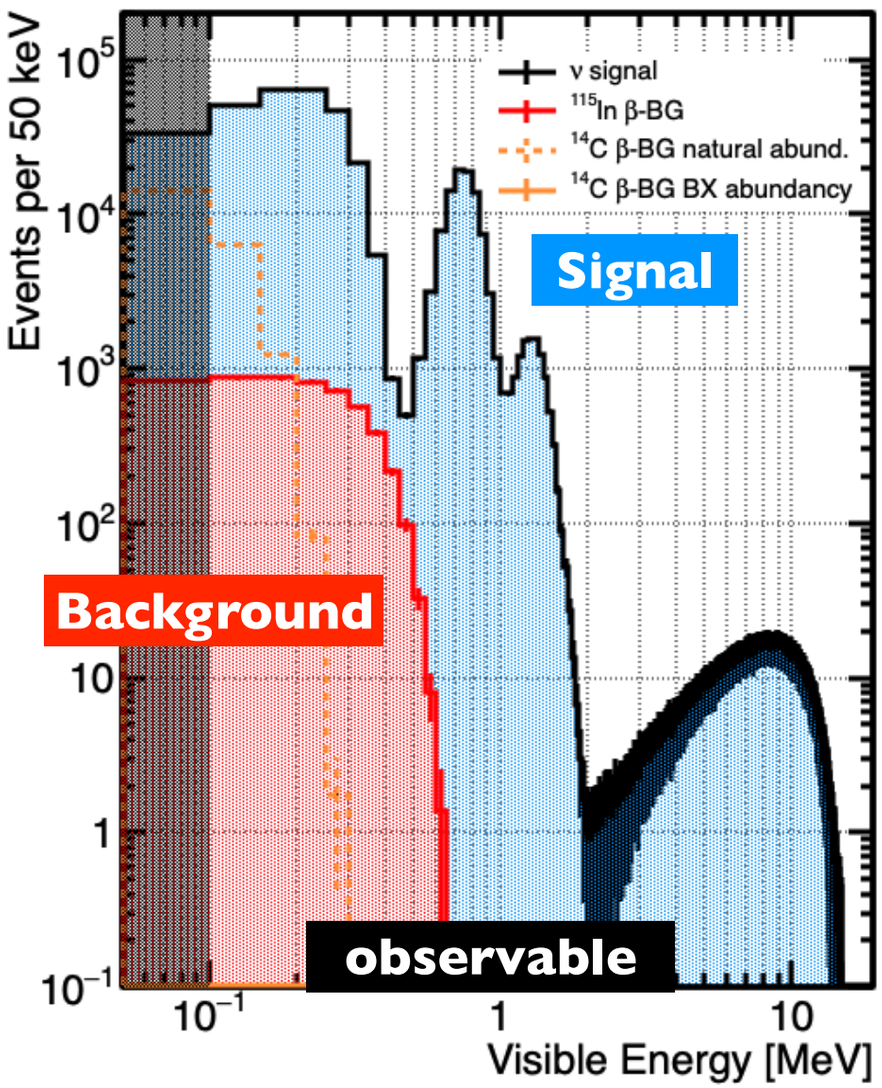
θ_{12} & δm^2

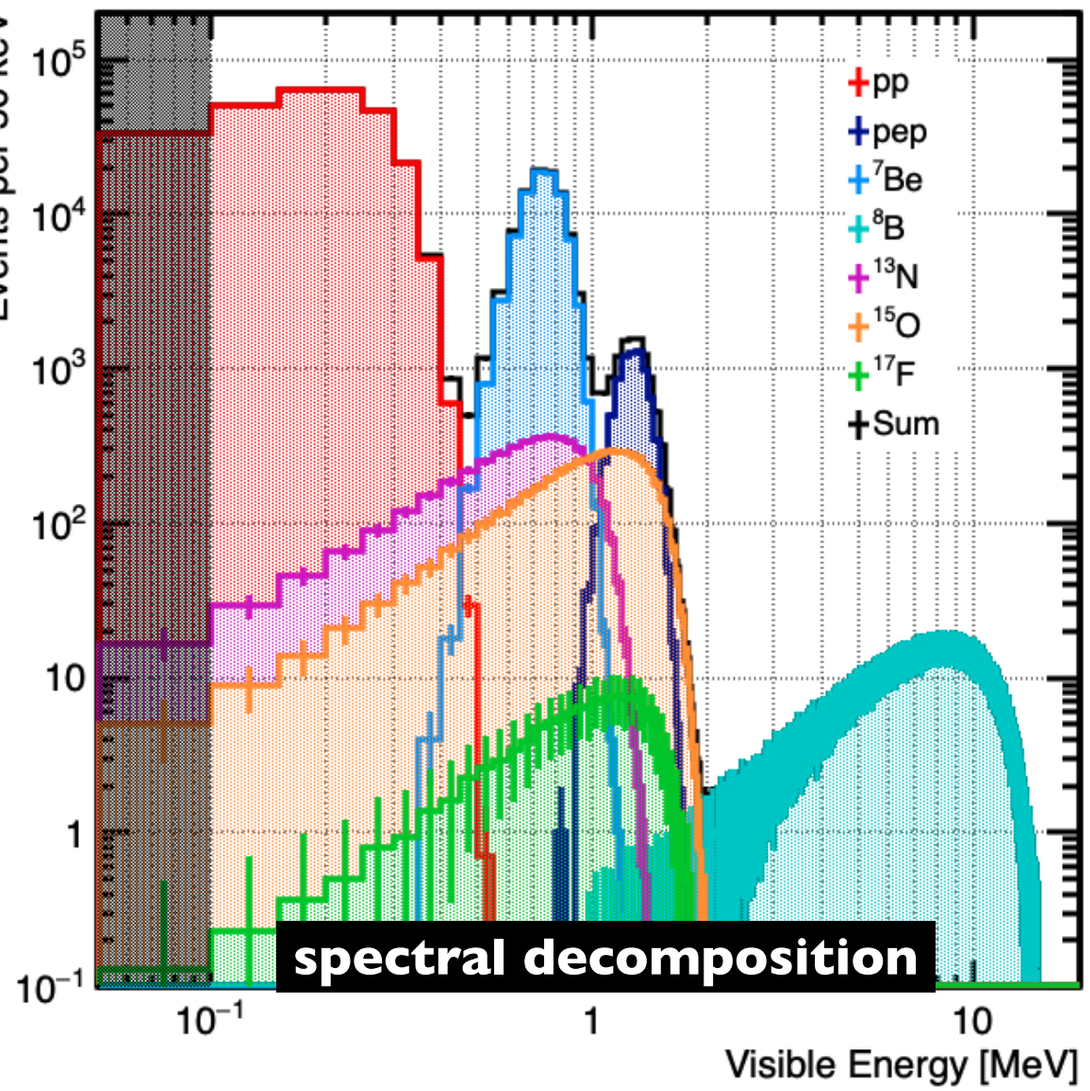
(≤1% precision)

physics II: solar neutrinos

Indium's solar spectra extraction…

energy resolution & threshold considered — no systematics yet



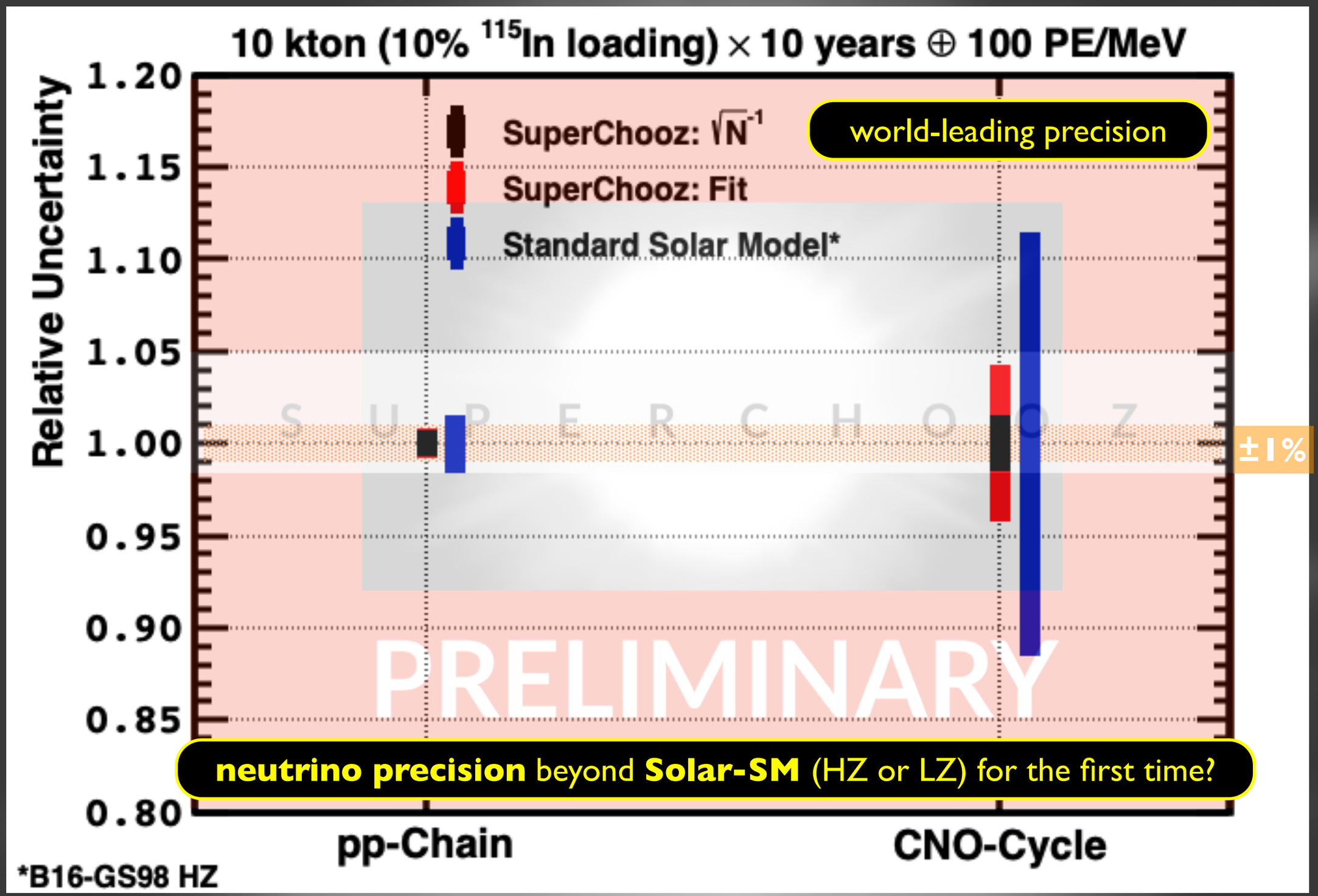


Signal to BG ≥10x

Background-less ≥0.5MeV
[LENS' background model]

Full Spectral Information:

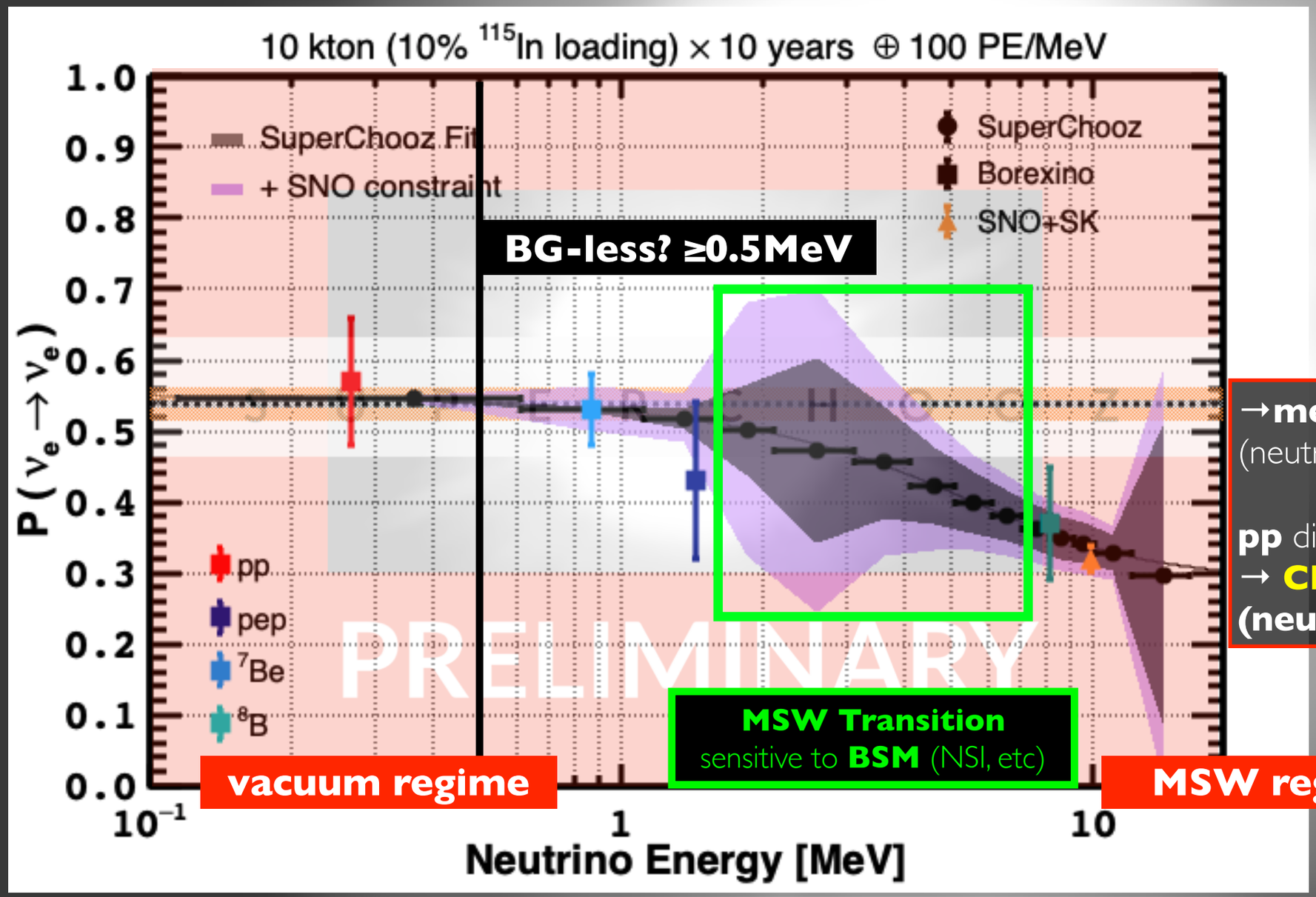
- Neutrino Energy (CC interaction)
- High Statistics: **10%** (In loading) x **10 years**
- Light level: **≥100PE/MeV** (thershold: 0.1MeV)



highest precision solar physics…

neutrino oscillation transition…

In-interaction: neutrino energy scan (impossible for elastics scattering)



today's precision on θ_{12}

→measure θ12 & δm²
(neutrino)

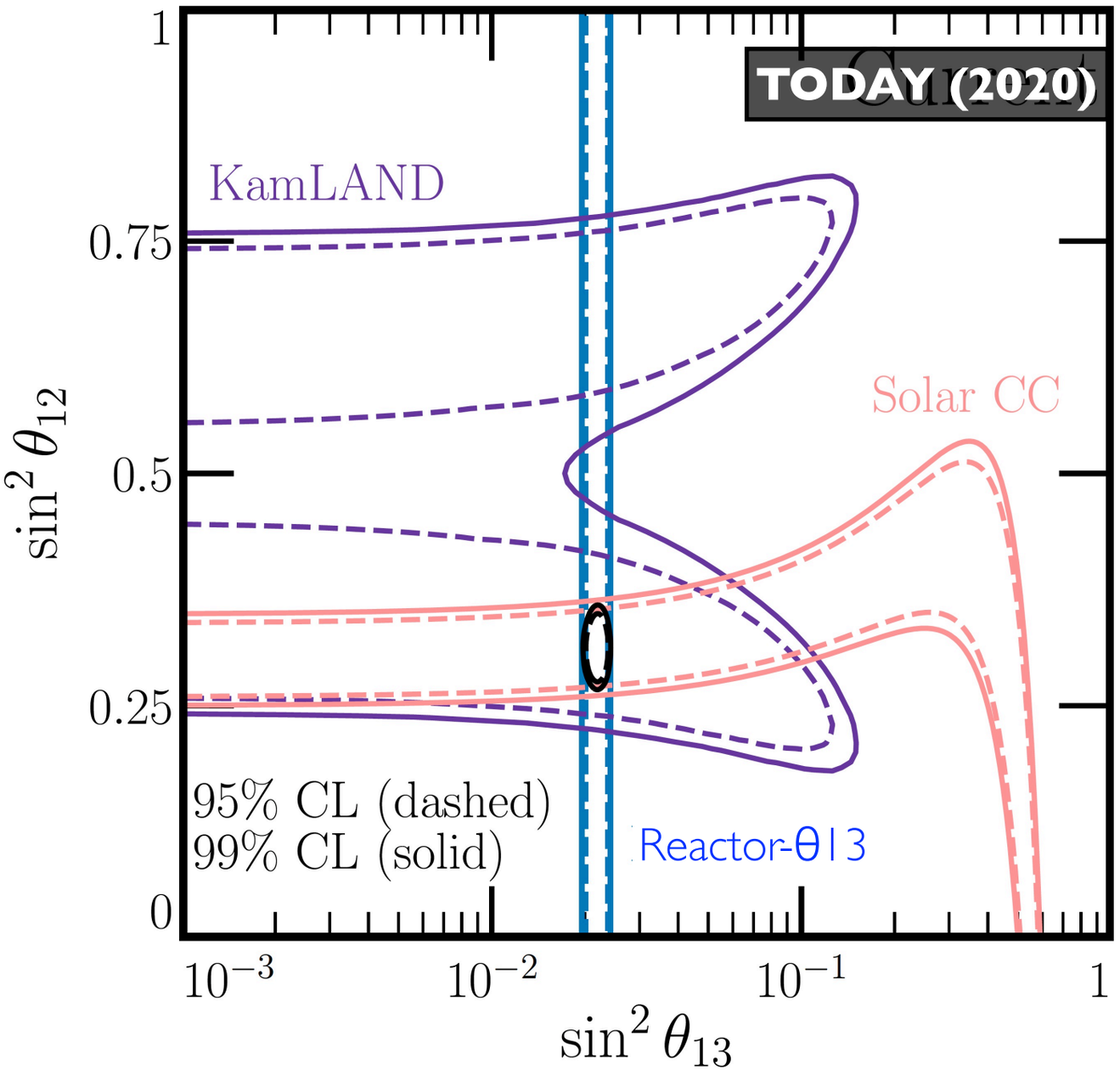
pp direct comparison with **JUNO**[≤0.5%]
→ CPT violation?
(neutrino vs anti-neutrino)

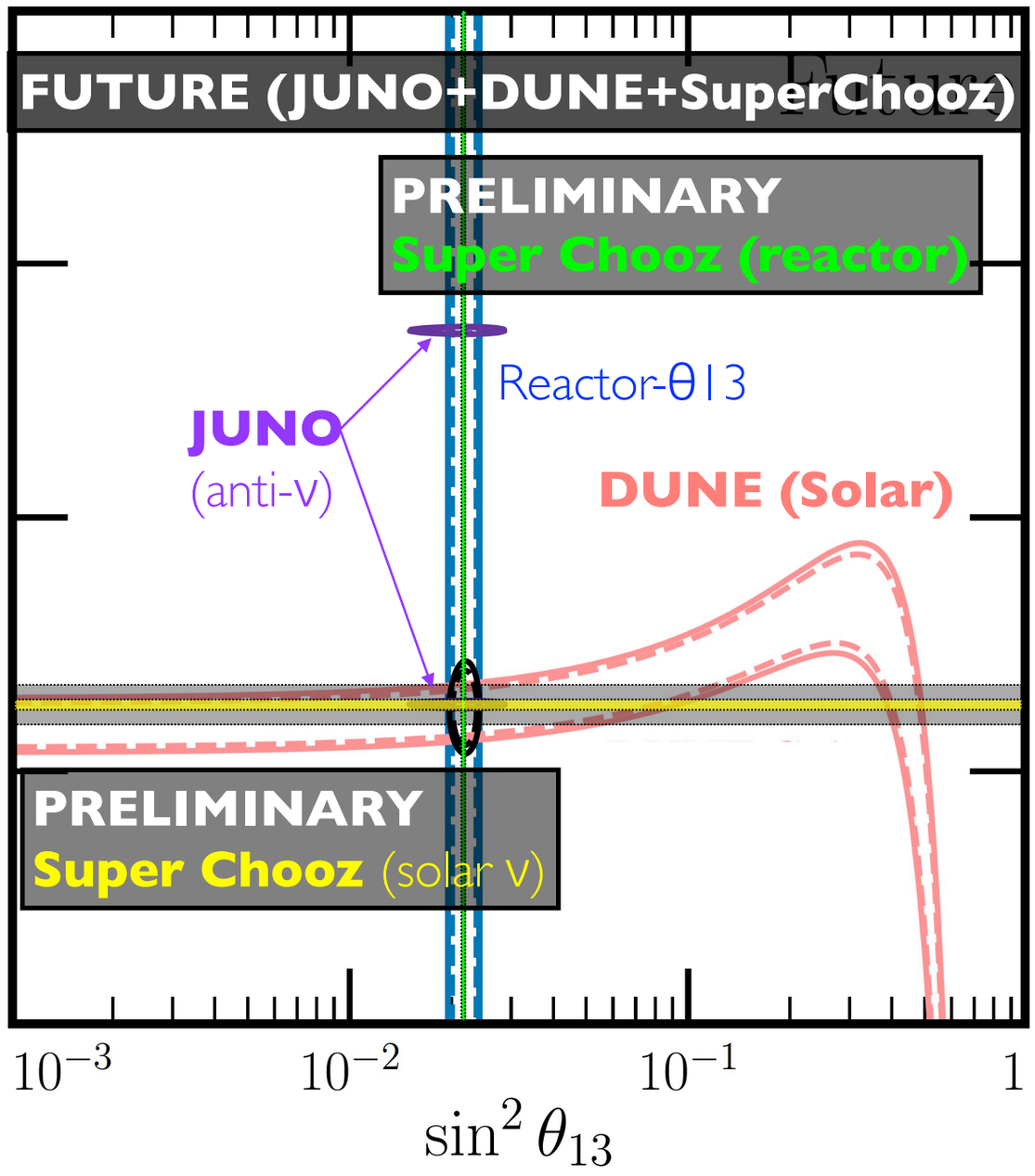
solar neutrinos: longest baseline neutrino with few % precision→ new physics?

use ϕ(SNO-NC) for ^{8}B control [1.5,10] MeV — ultimate limitation?

Super Chooz potential under investigation…

Plot: hacked version from original in ***Ellis, Kelly & Weishi-Li at* arXiv:2008.01088**



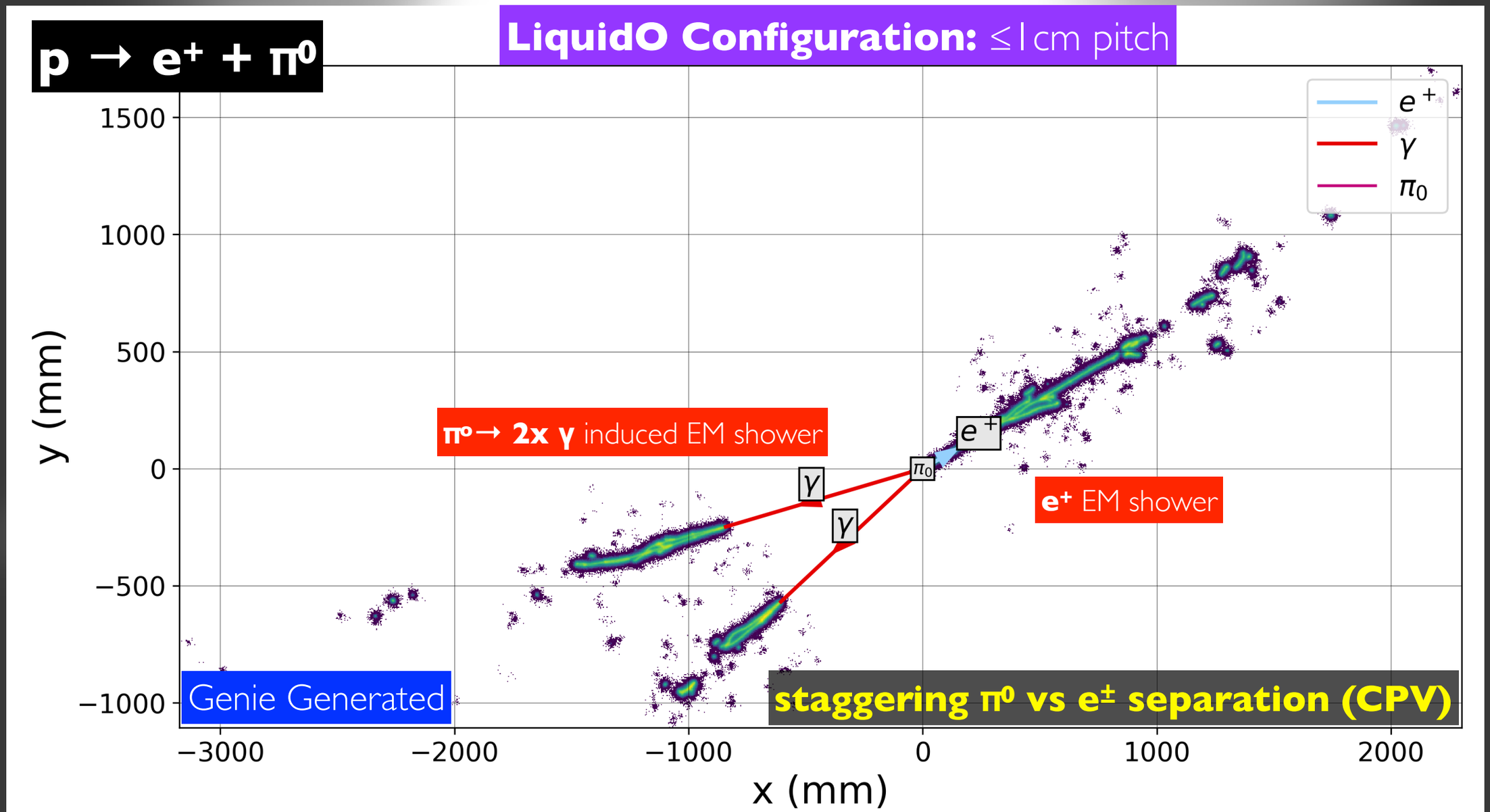


Super Chooz: the smallest but powerful…

discovery channels too…

m(proton)**~1 GeV**

free-H per unit of mass:
water: ~10%
scintillator: up to 20%



main conclusions…

status on neutrino oscillation knowledge…

SuperChooz impact the full ***SM picture*** (3 families) [new synergies]

SuperChooz explore consistency/completeness⟹ **BSM discovery?**

SuperChooz = SC

	today			**≥2030**	
	best knowledge		global	foreseen	dominant	source
θ_{12}	3.0 %	SK⊕SNO	2.3 %	≤0.5%	JUNO⊕**SC**	reactor⊕solar
θ_{23}	5.0 %	NOvA+T2K	2.0 %	**≲1.0%?**	DUNE⊕HK⊕**SC**	beam⊕reactor
θ_{13}	1.8 %	DYB+DC+RENO	1.5 %	**≤0.5%**	**SC**	reactor
$+\delta m^2$	2.5 %	KamLAND	2.3 %	<0.5%	JUNO⊕**SC**	reactor⊕solar
$\lvert\Delta m^2\rvert$	3.0 %	T2K+NOvA & DYB	1.3 %	<0.5%	JUNO⊕DUNE⊕HK⊕**SC**	reactor⊕beam
Mass Ordering	**unknown**	SK et al	NMO @ ≤3σ	@5σ	JUNO⊕DUNE⊕HK	reactor⊕beam
CP	**violation?**	T2K+NOvA	3/2π @ ≤2σ	**@5σ?**	DUNE⊕HK [**SC**]	beam⊕reactor
CPT	**violation?**	—	—	**<1%?**	**SC**	reactor⊕solar
Unitarity	**violation?**	—	—	**<1%?**	**SC**	reactor⊕solar
Baryon#	**violation?**	—	—		JUNO⊕DUNE⊕HK⊕**SC**	

reactor⊕solar main channels of **SC**, but low energy **atmospherics under study…**

thanks to **EDF** teams & support,
LiquidO consortia,
AM-OTech consortia,
CLOUD collaboration,
and **SuperChooz** team.

Дякую…
thanks…
merci…
고맙습니다…
Děkuji
ありがとう…
danke…
obrigado…
спасибі…
grazie…
谢谢…
hvala…
gracias…
شكرا…

SUPERCHOOZ

new potential **flagship neutrino** project based in **Europe** [>2032]**?**
(once **JUNO⊕HyperK⊕DUNE** are **running**)

new detector [**LiquidO**] ⊕ **new site** [Chooz-A] ⊕ **new physics?!**

ICHEP 2024 | PRAGUE

https://liquido.ijclab.in2p3.fr/

anatael@in2p3.fr

HEP-European Physics Society
(July 2019 @ Ghent Belgium)

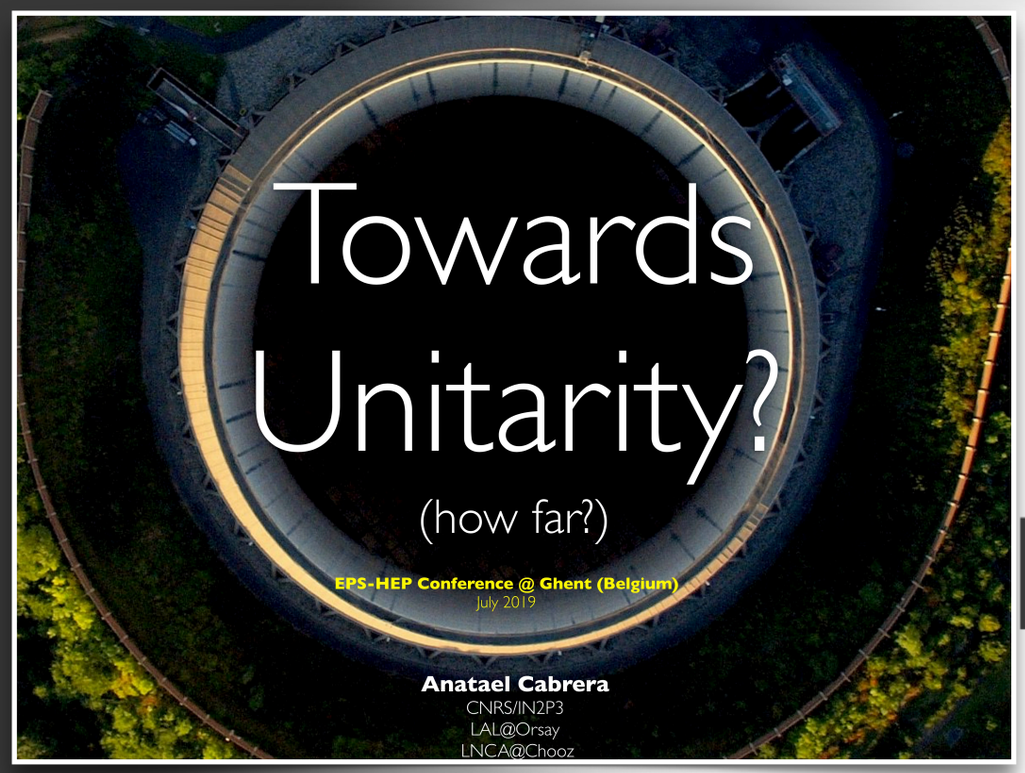
EP Seminar

The SuperChooz Experiment: Unveiling the Opportunity

by Dr Anatael CABRERA (IJCLab - IN2P3/CNRS)

Tuesday 29 Nov 2022, 11:00 → 12:00 Europe/Zurich

222/R-001 (CERN)



https://indico.cern.ch/event/577856/contributions/3421609/

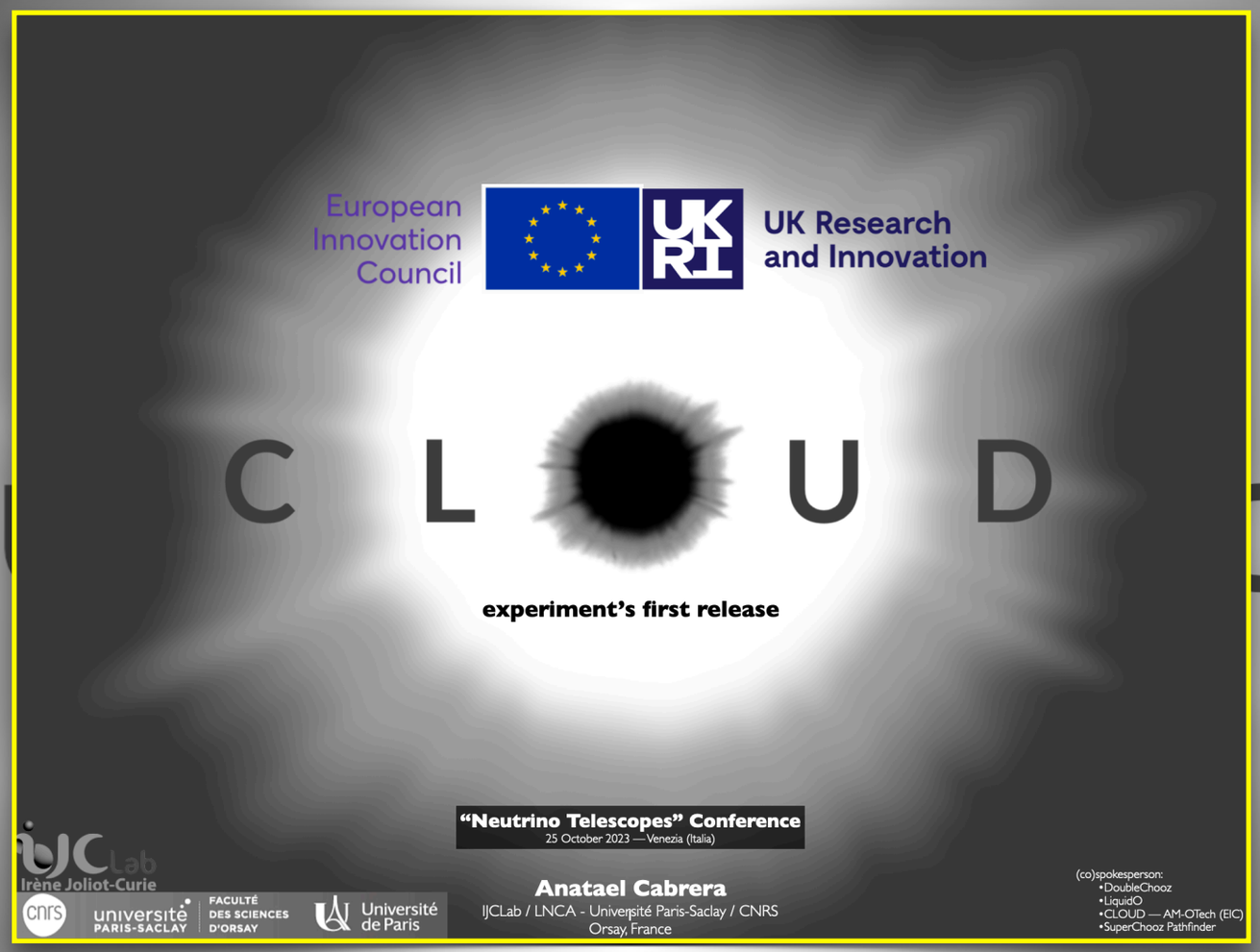
https://zenodo.org/doi/10.5281/zenodo.7504161

https://indico.cern.ch/event/1215214/

LiquidO: https://liquido.ijclab.in2p3.fr/

exploring since 2018…

“Neutrino Telescope” conference — October 2023



https://zenodo.org/doi/10.5281/zenodo.10049845

first release last fall (2023)…