Dark Matter Searches at SNOLAB: looking for WIMPs, heavy or light

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UniversitéLaurentienne

SNOLAB

Outline

- The case for dark matter

- SNOLAB:

The canadian deep underground science laboratory

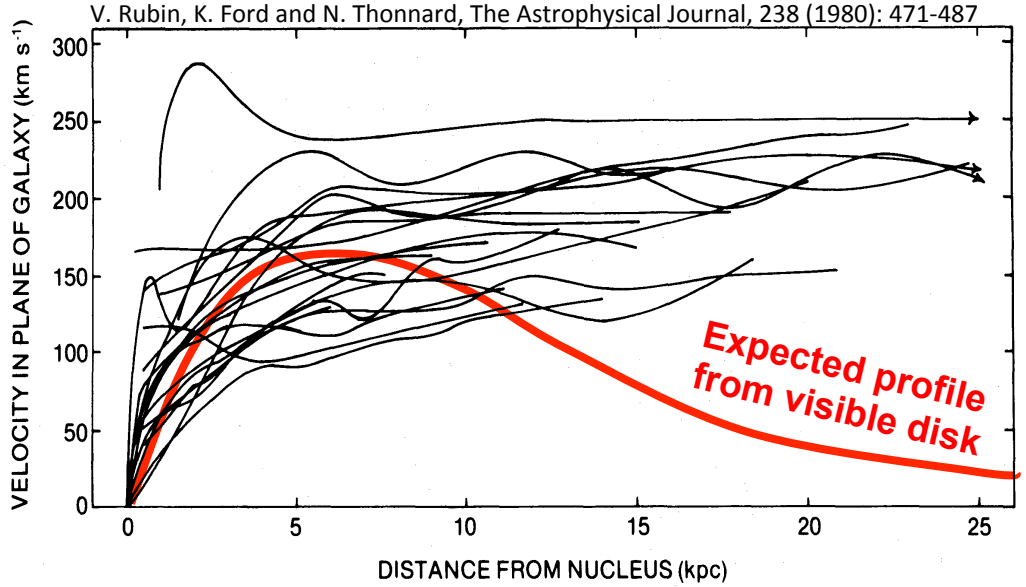
- 2 extremes WIMPs detectors:
  - DEAP3600
  - NEWS-G

Dark matter:
Converging evidences

Dark matter: Converging evidences

Galaxy rotation curves

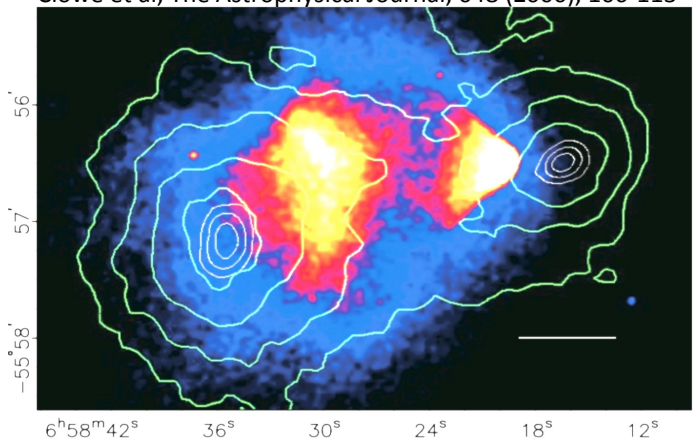
V. Rubin, K. Ford and N. Thonnard, The Astrophysical Journal, 238 (1980): 471-487



Dark matter: Converging evidences

Bullet cluster

Clowe et al, The Astrophysical Journal, 648 (2006), 106-113



Contour: Mass distribution (gravitational lensing)

Color: Hot gases (X-rays)

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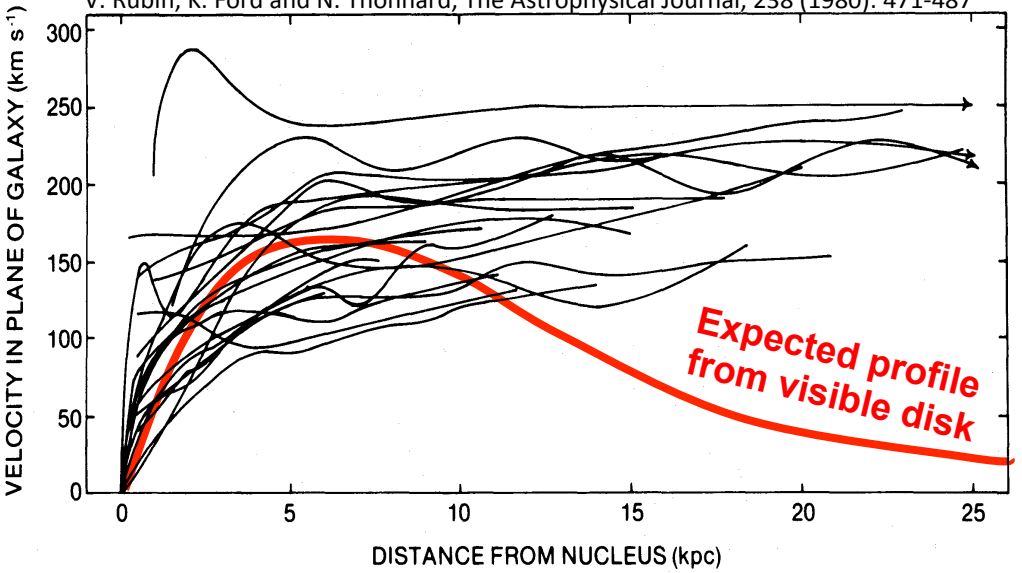

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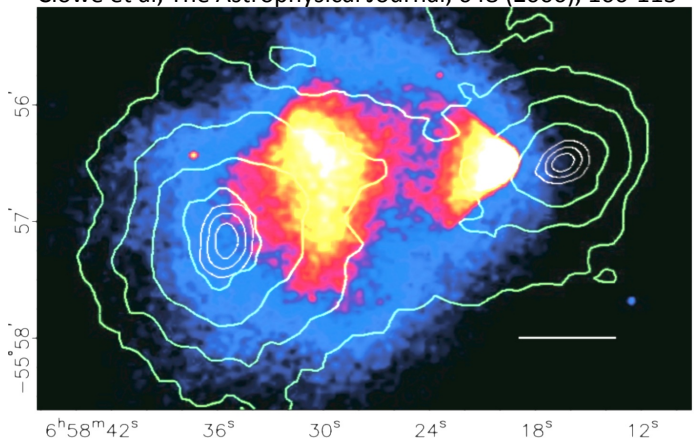

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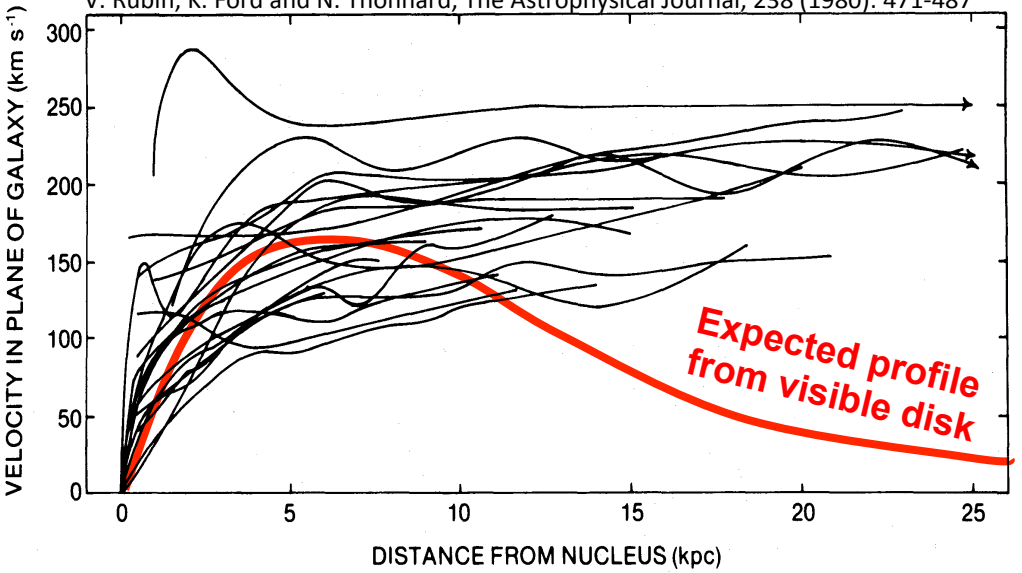
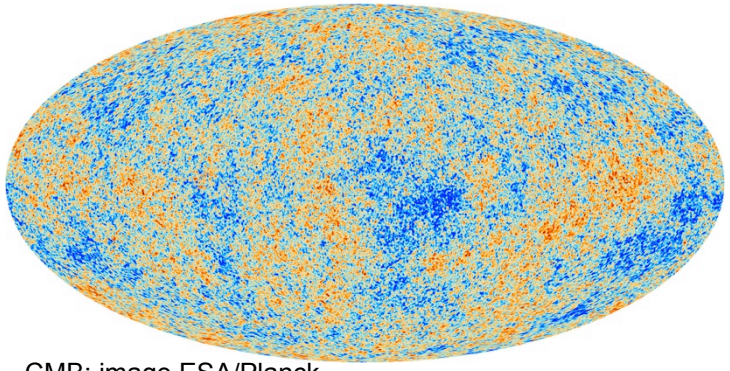


Cosmic Microwave Background



CMB: image ESA/Planck

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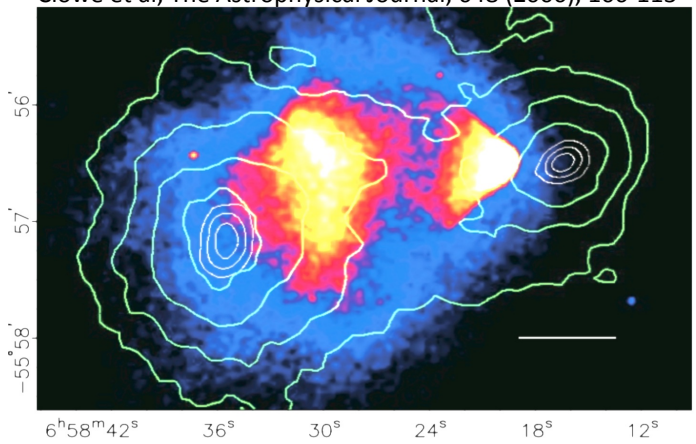

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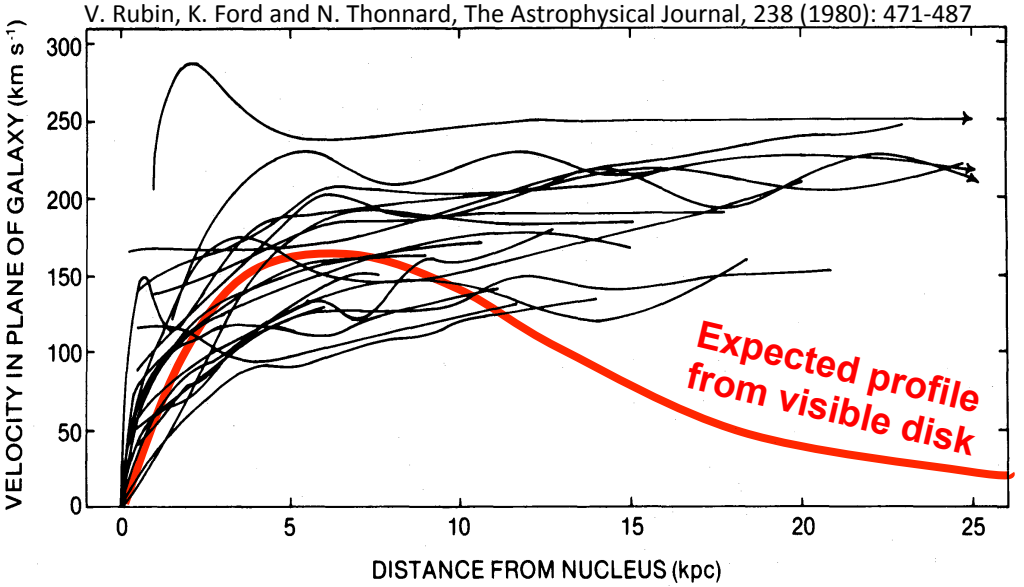

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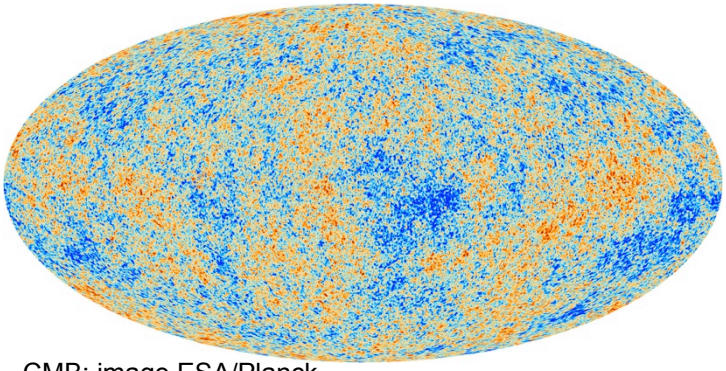

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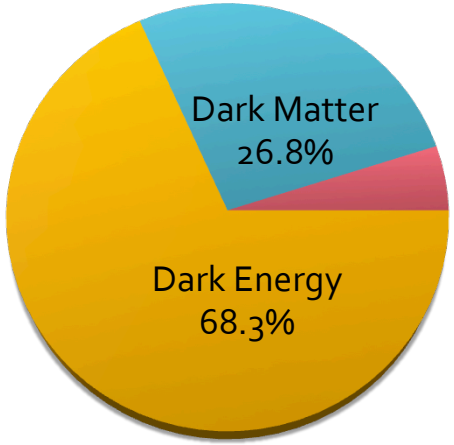

Universe composition (Mass-Energy density)

Many candidates…

- Massive Astrophysical Compact Halo Objects (MACHOS): <16% (surveys)
- Sterile neutrinos
- Axions
- Weakly Interacting Massive Particles (WIMPs)
- …

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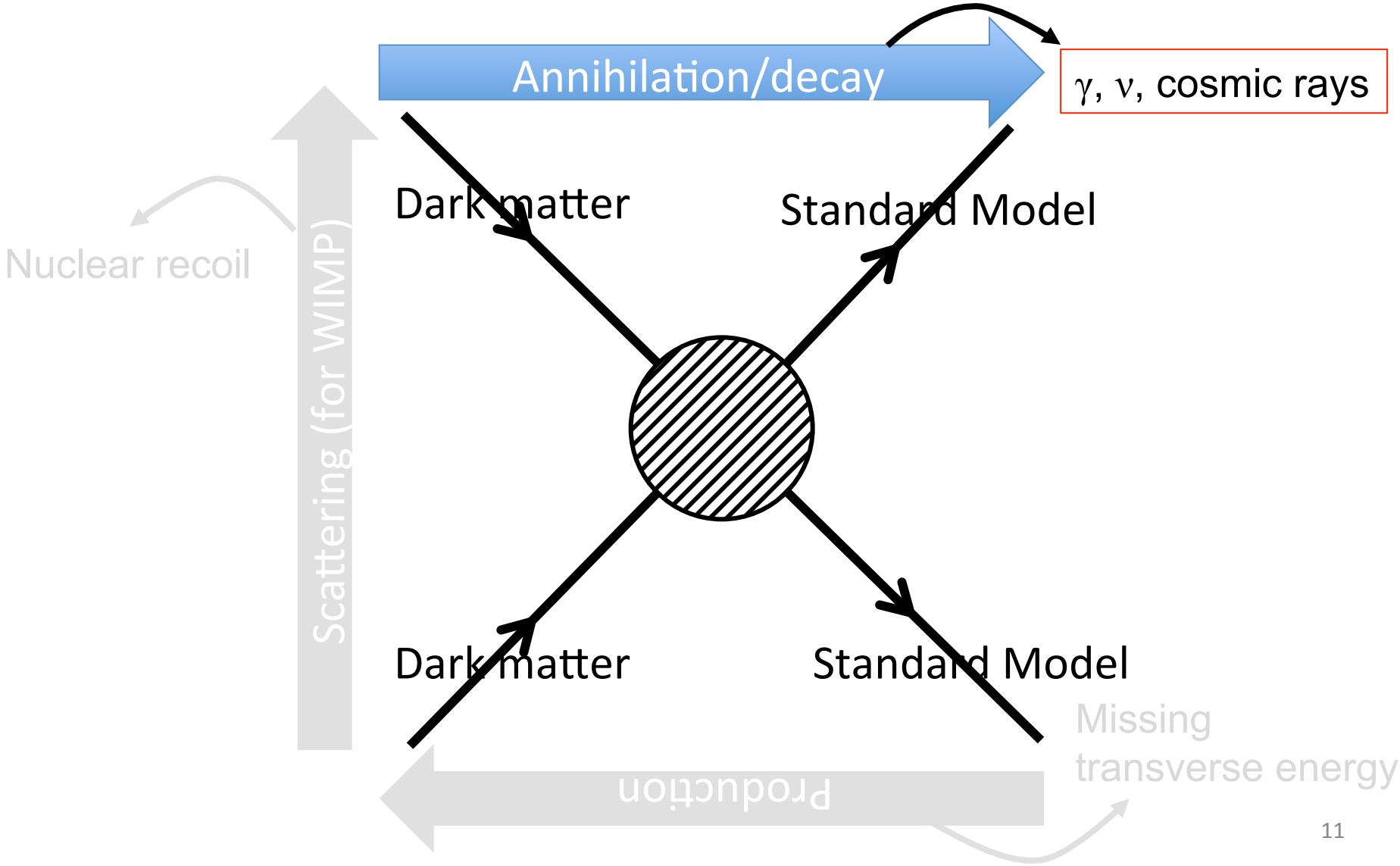
The multiple paths to dark matter



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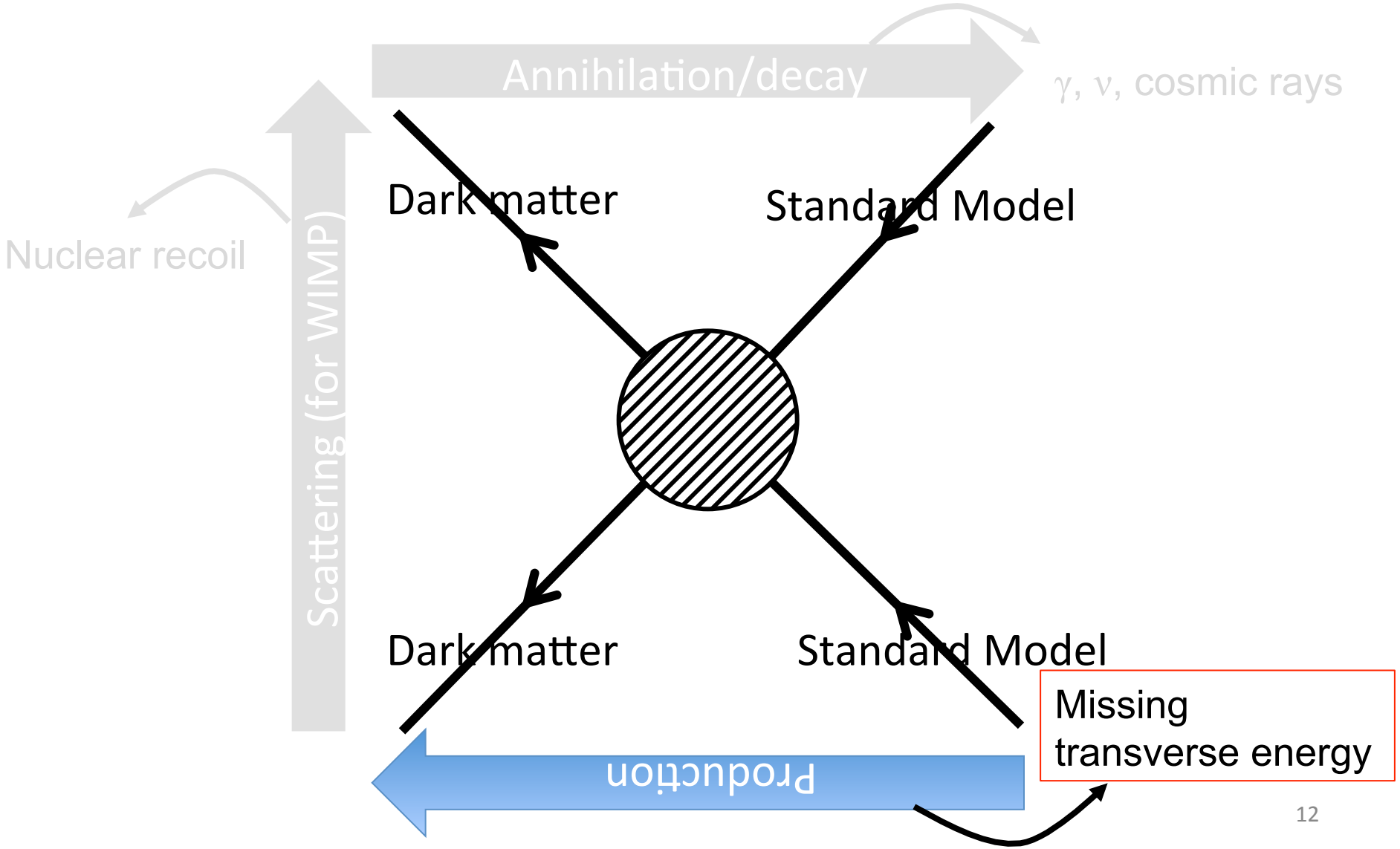

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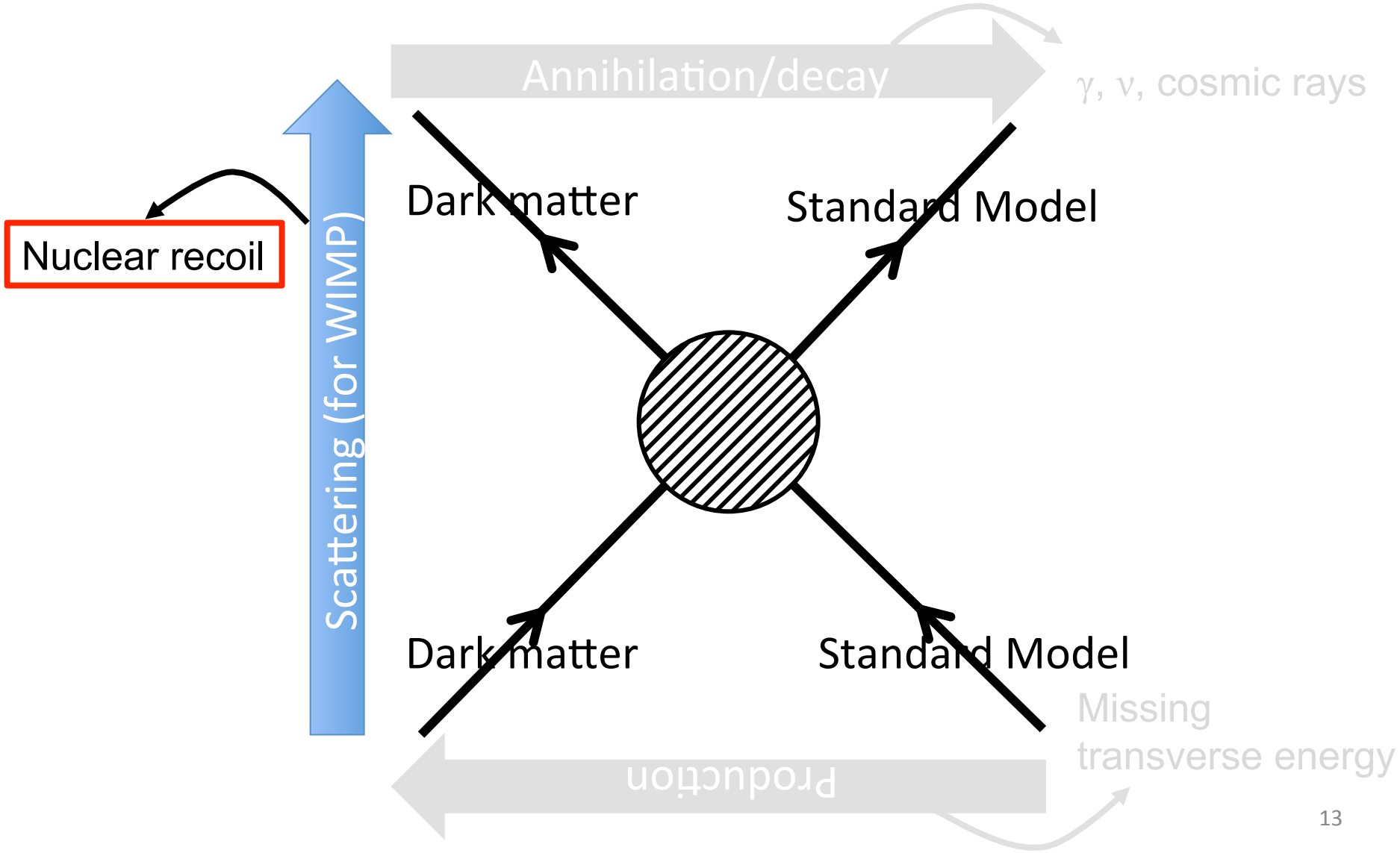
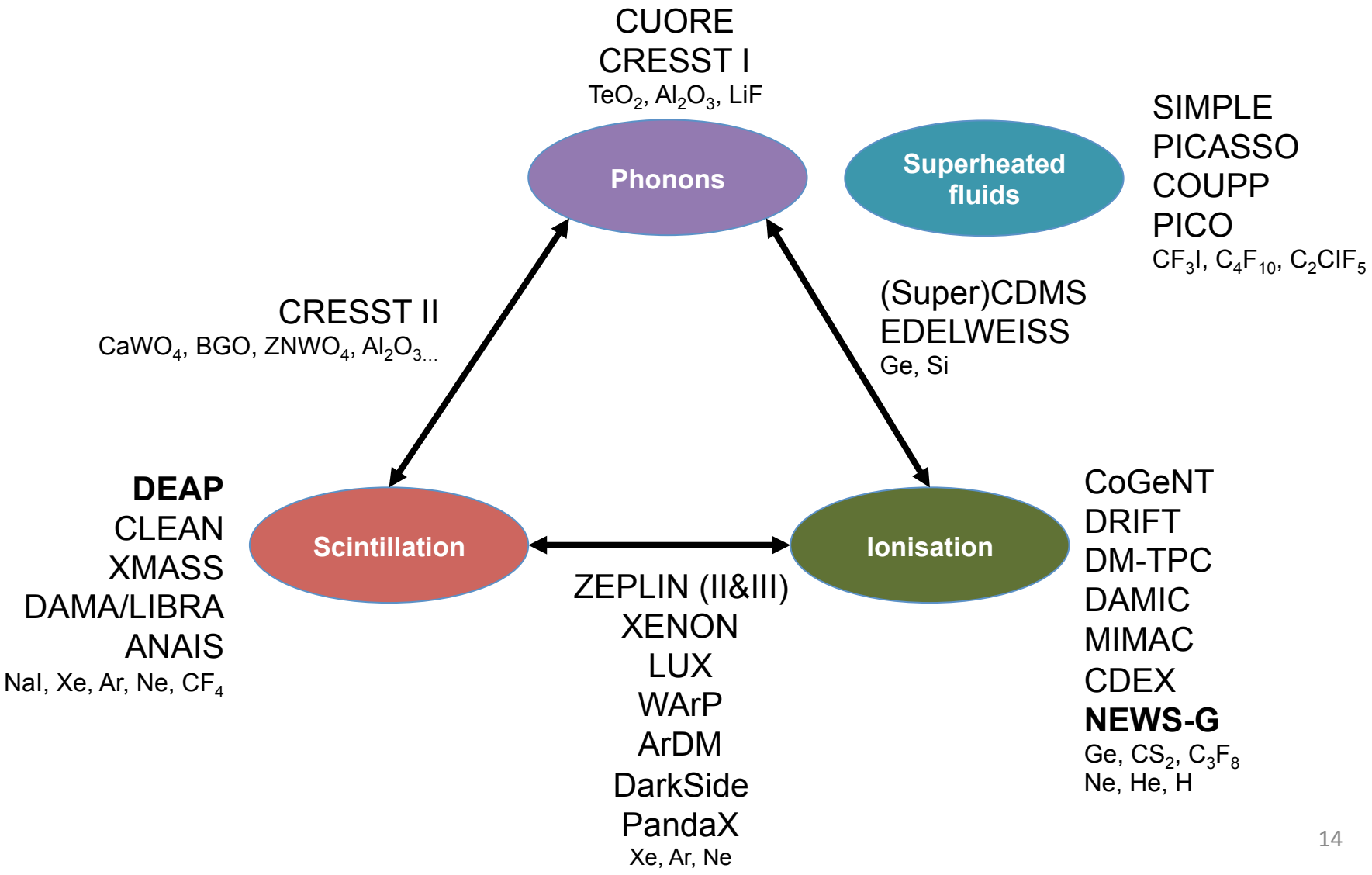
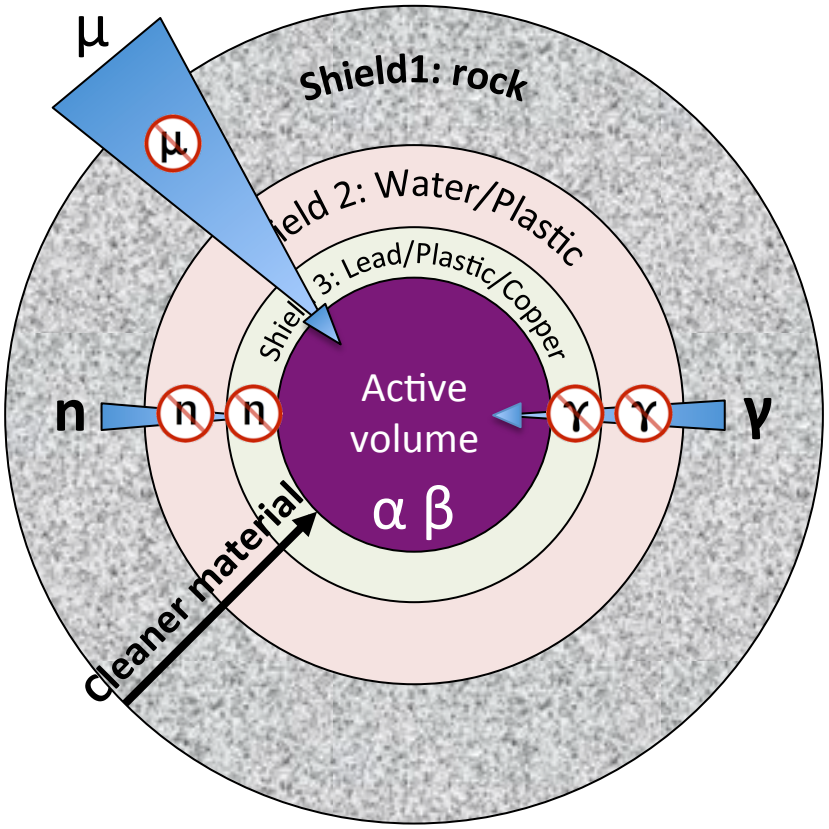


Direct detection techniques



Multiple background suppression strategies

Passive shielding (external Background)

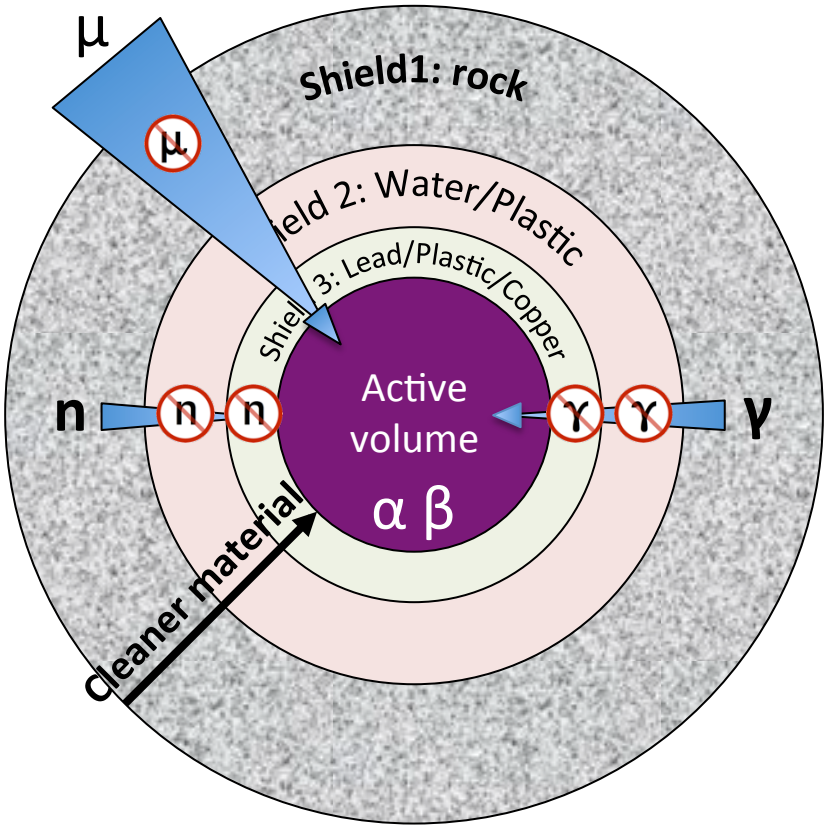


Discrimination (Internal background)

- Active veto
- Energy
- Position
- Pulse shape
- …

Multiple background suppression strategies

Passive shielding (external Background)



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- Position
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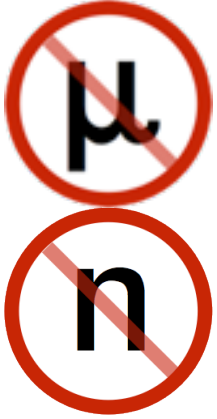
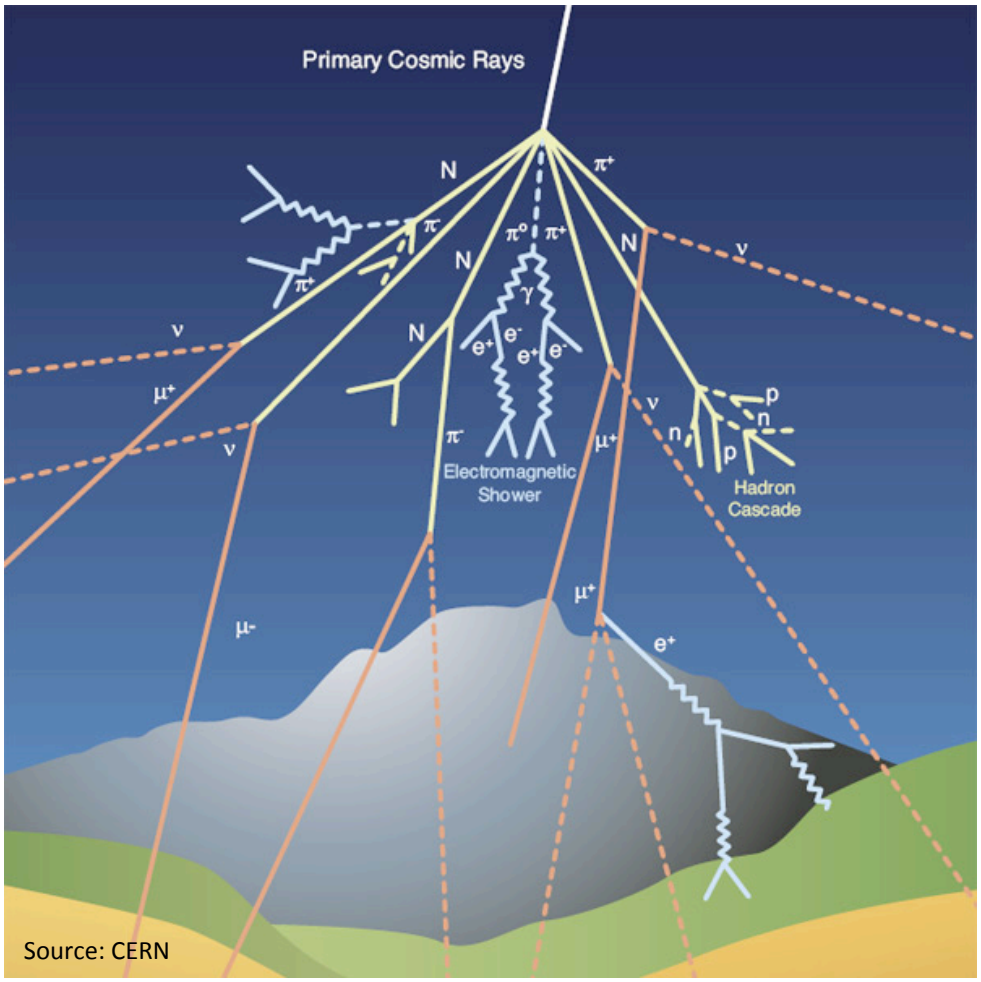
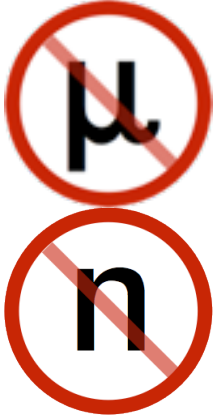
Neutrons mimicking WIMP signal
=> All sources need to be removed or shielded



The cosmic rays problem

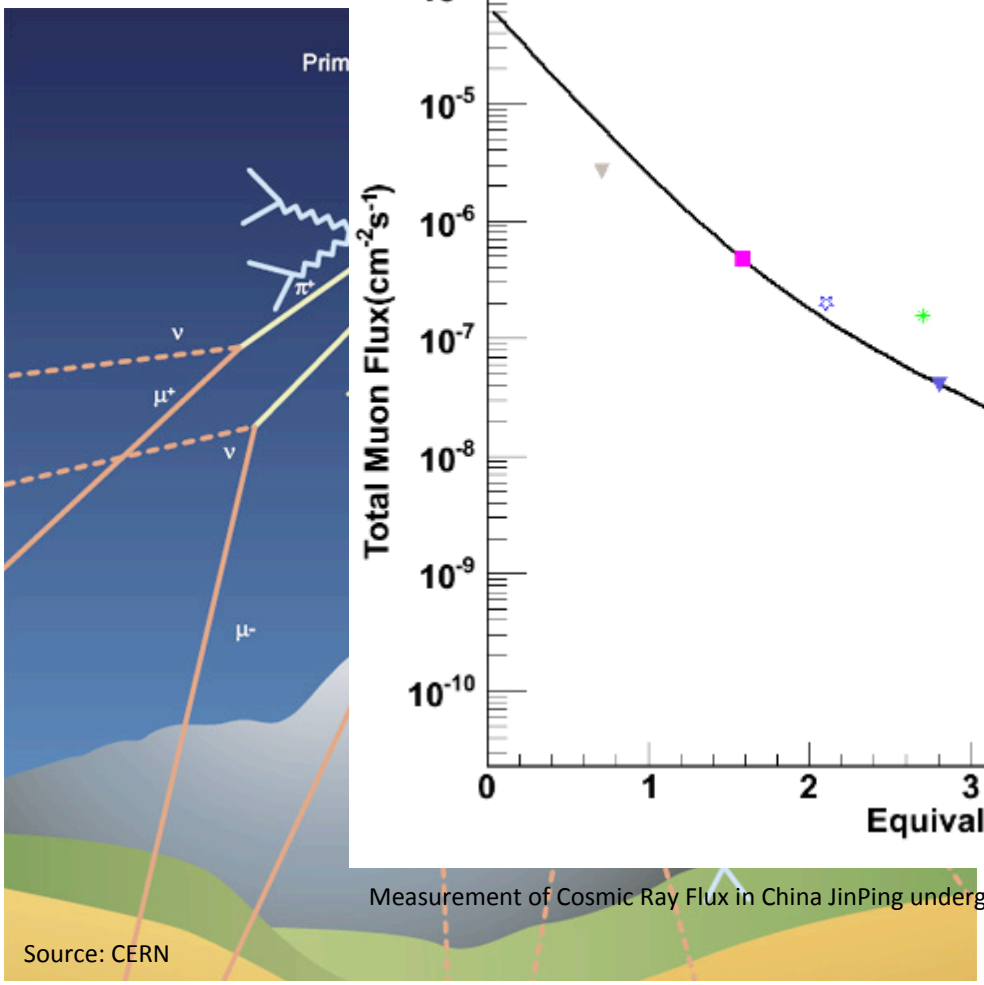


- High energy muons travel deep
- Production of unstable isotopes
- Muon-induced spallation=> neutrons



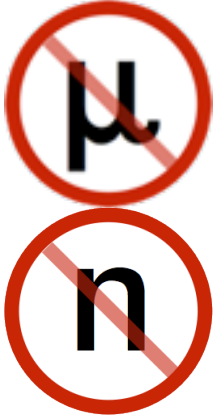
The cosmic rays problem

➔Going deep !



Source: CERN

Measurement of Cosmic Ray Flux in China JinPing underground Laboratory Arxiv:1305.0899



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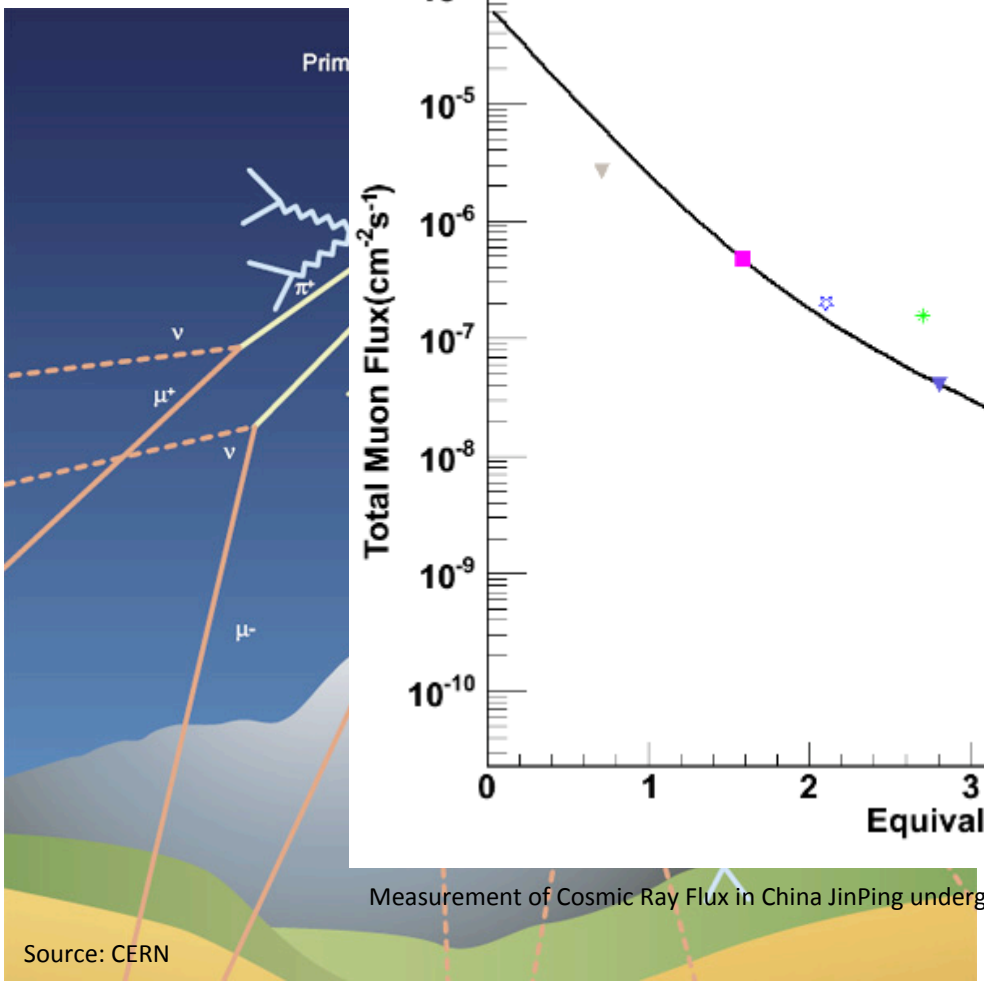

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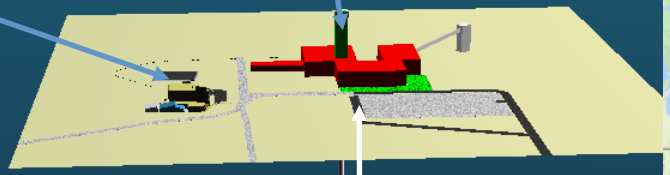
SNOLAB Surface facility

- Offices
- Clean laboratory
- Warehouse
- Machine shop

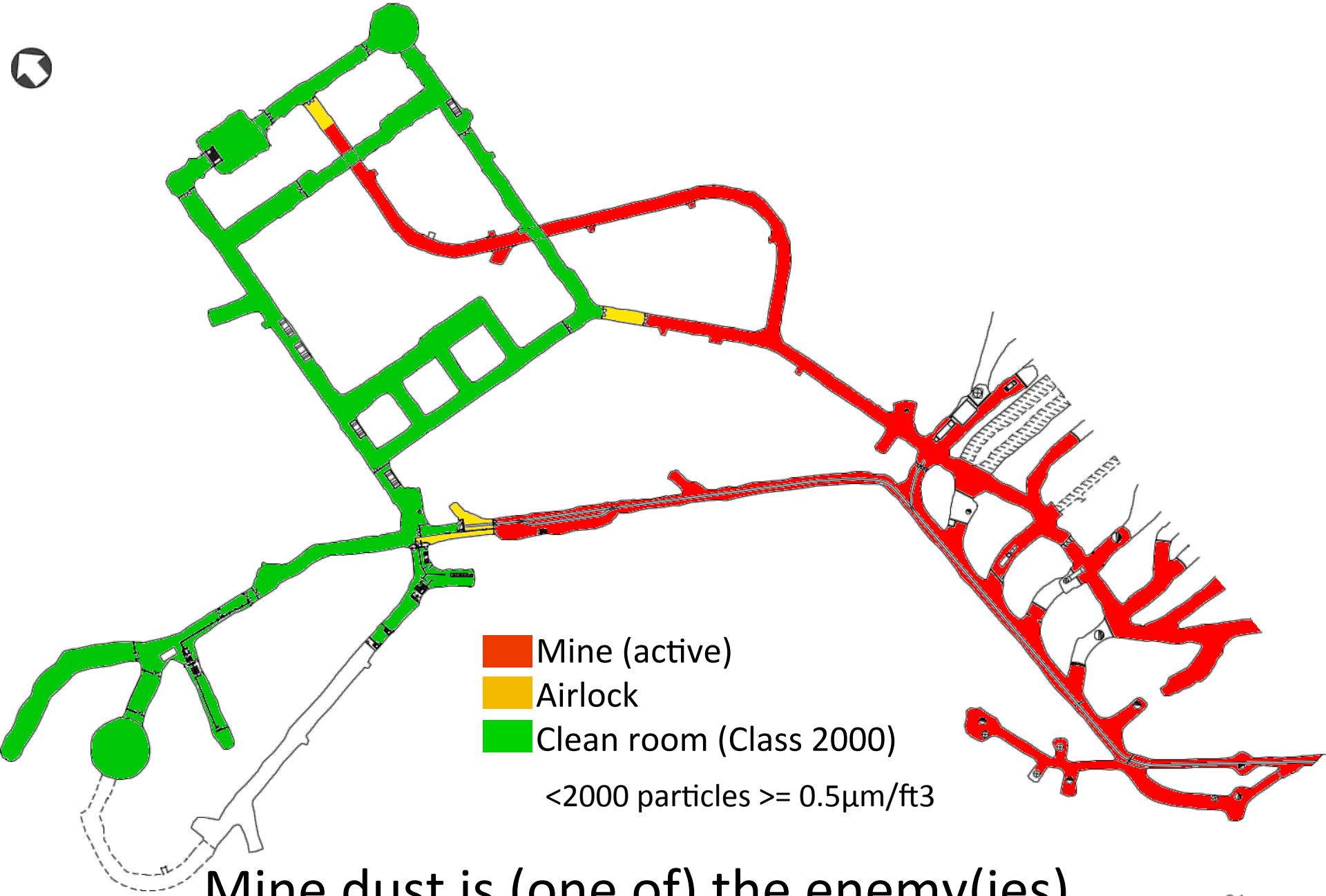
Shaft headframe



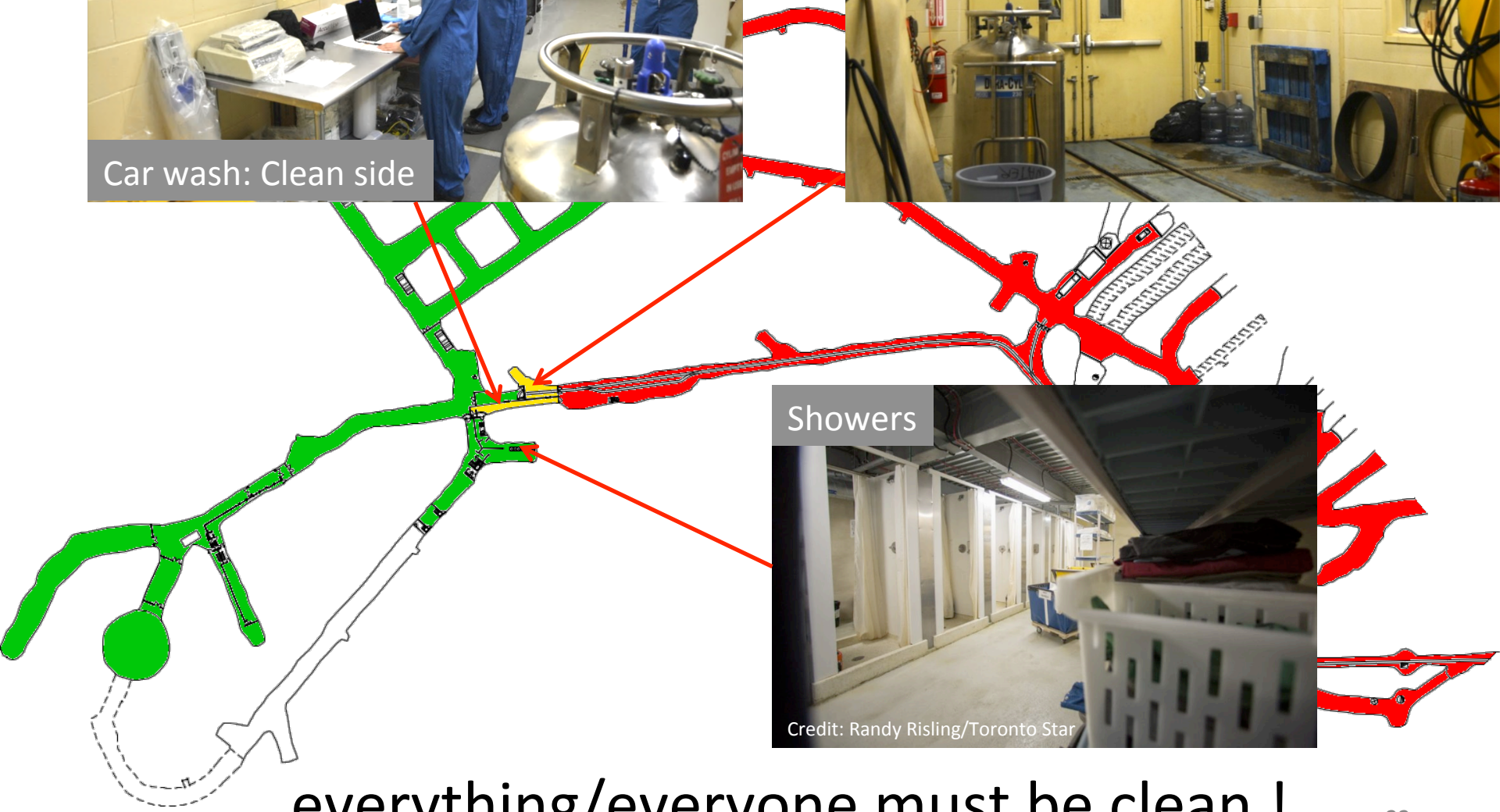
6800 ft
2000 m
6060 m.w.e

SNOLAB
Underground facility

0.27 muon/m^2/day



Mine dust is (one of) the enemy(ies)..

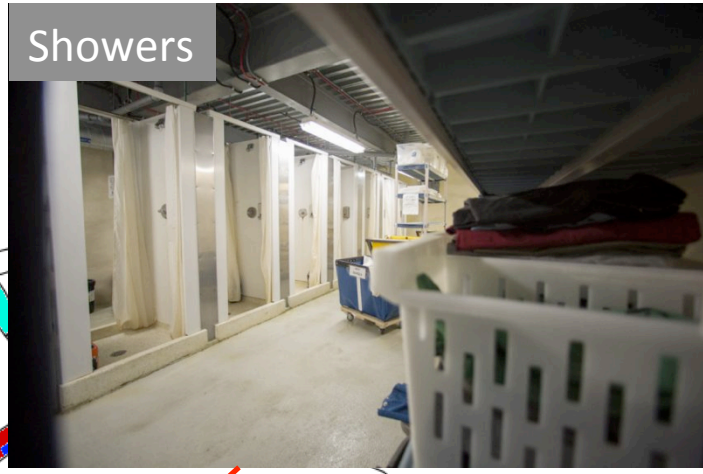


… everything/everyone must be clean !

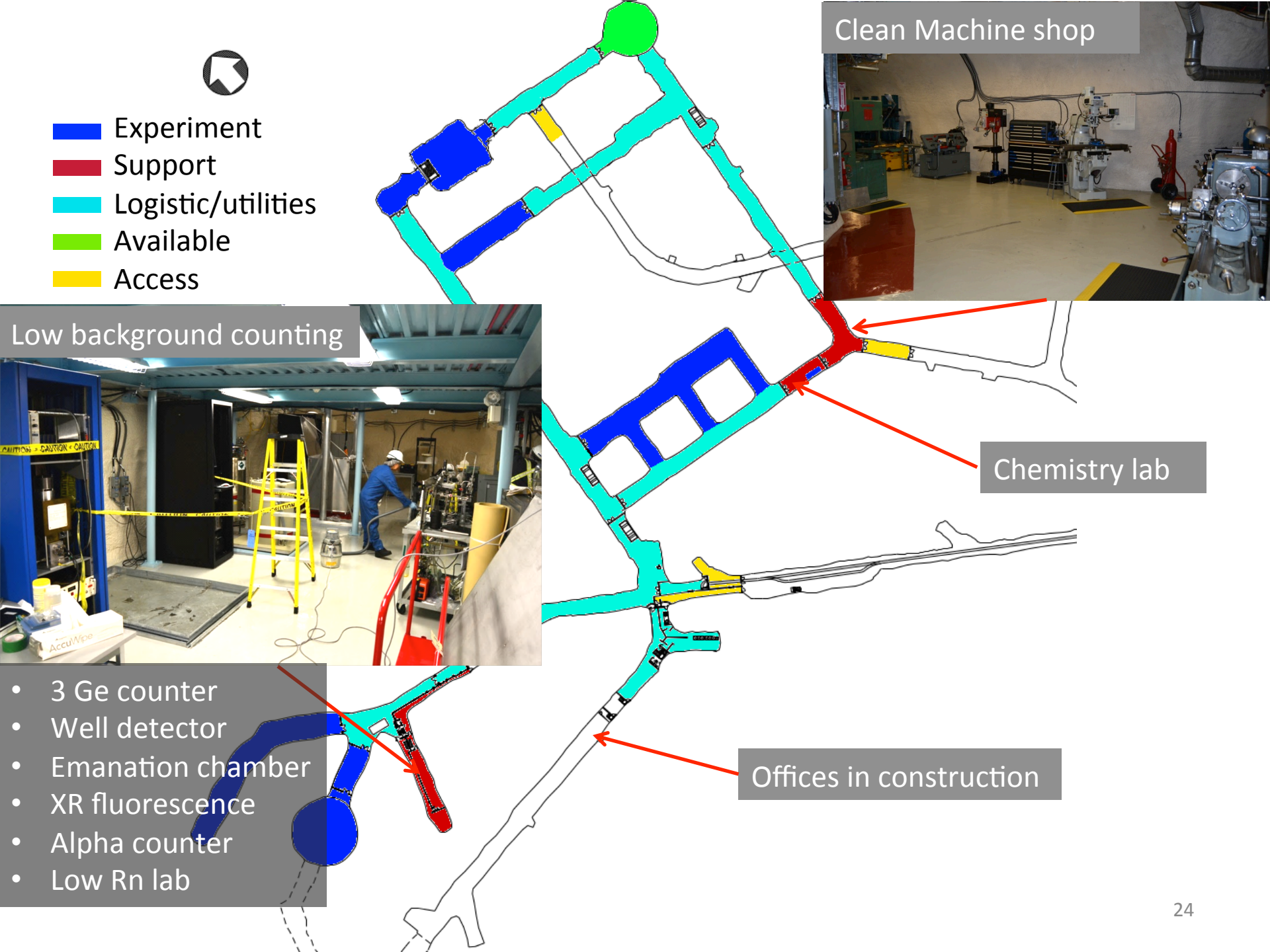
Experiment
Support
Logistic/utilities
Available
Access

Toilets !

Showers



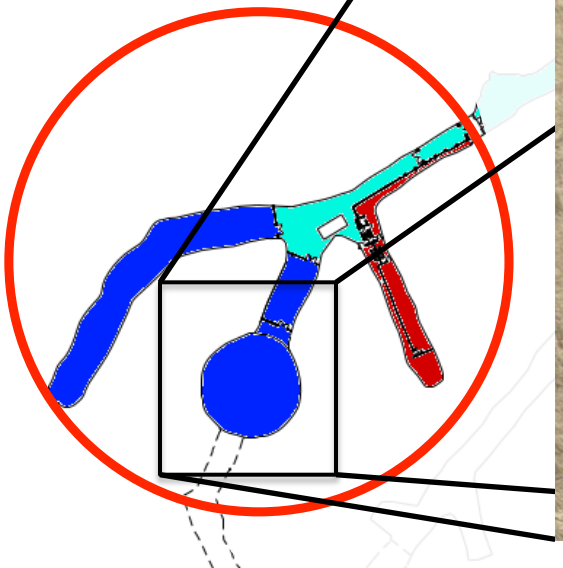
Refuge/lunch room

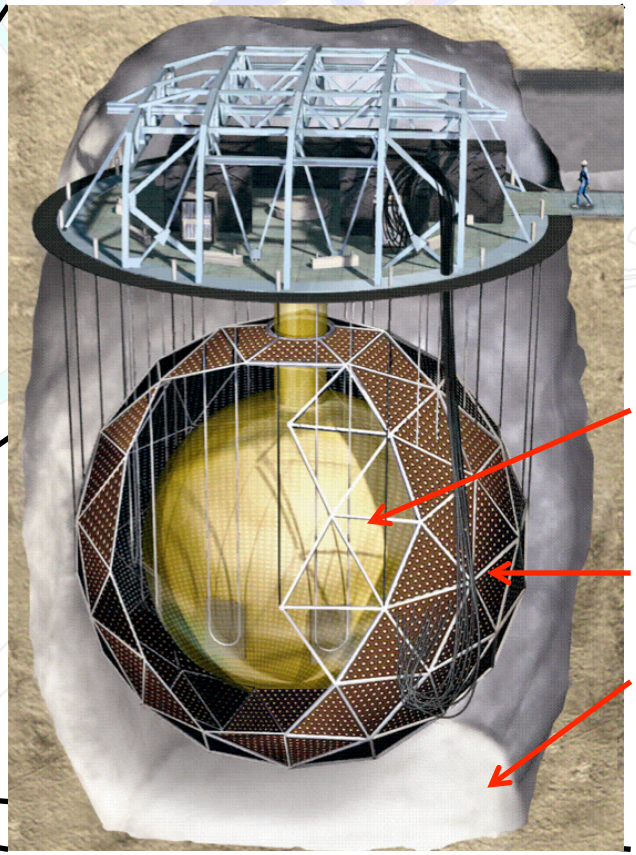

Experiment
Support
Logistic/utilities
Available
Access
Clean Machine shop
Low background counting
Chemistry lab
• 3 Ge counter
• Well detector
• Emanation chamber
• XR fluorescence
• Alpha counter
• Low Rn lab
Offices in construction

The SNO detector

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and **Arthur B. McDonald "for the discovery of neutrino oscillations, which shows that neutrinos have mass"**

http://www.nobelprize.org/nobel_prizes/physics/laureates/2015/





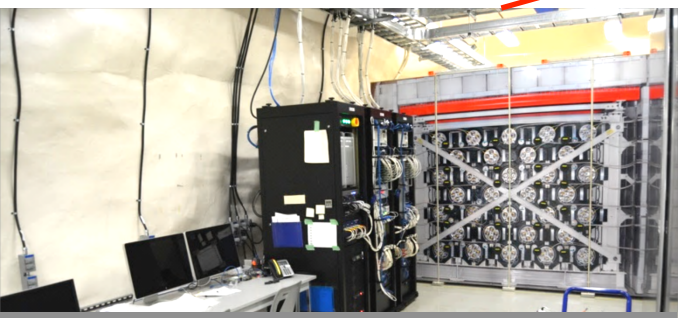
Ø12m Acrylic vessel (heavy water)

~9500 Photomultipliers

Light water (ultra-pure)

Experiment
Support
Logistic/utilities
Available
Access

Next generation 0νββ

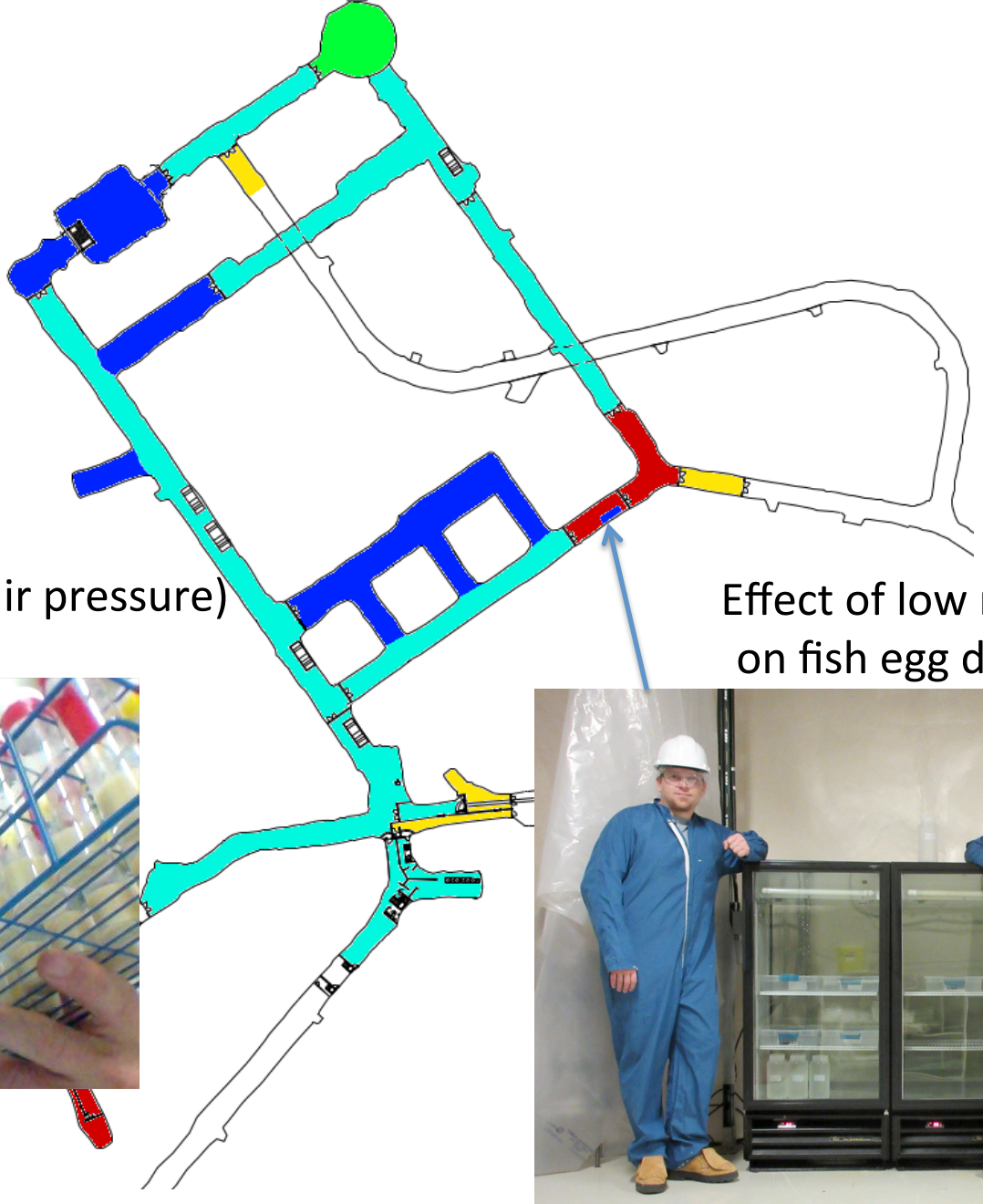


HALO:
Supernova detector

SNO+:
Neutrino-less double β

New neutrinos detectors

Experiment
Support
Logistic/utilities
Available
Access

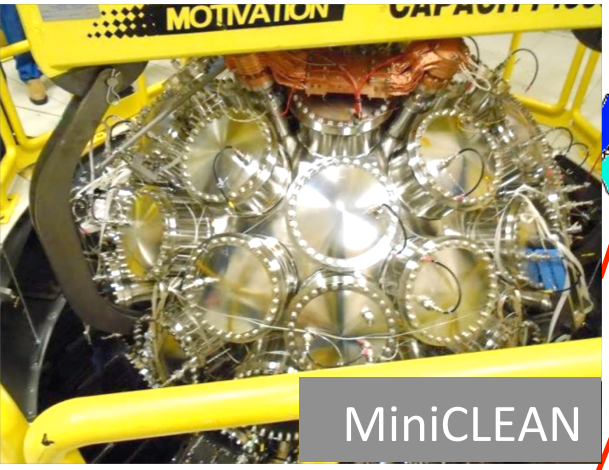


FLAME:
Effect of stress (higher air pressure) on fruits flies

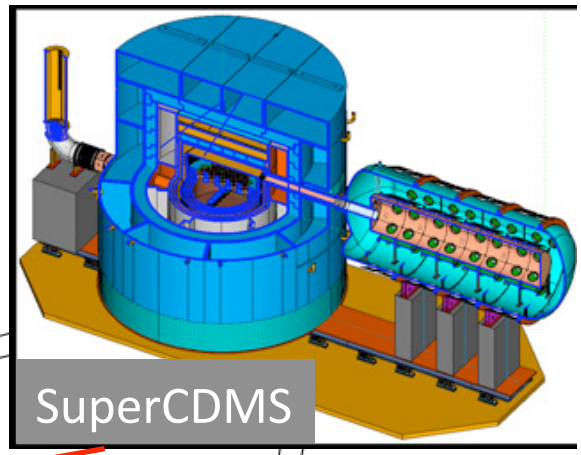
REPAIR:
Effect of low radioactivity on fish egg development

Newcomers: biology

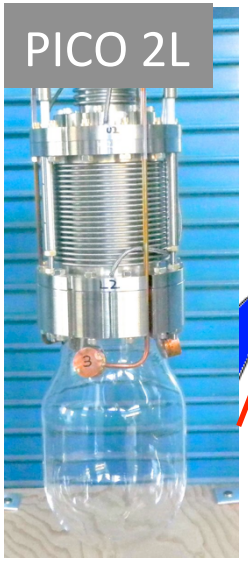
WIMPs: an extensive search



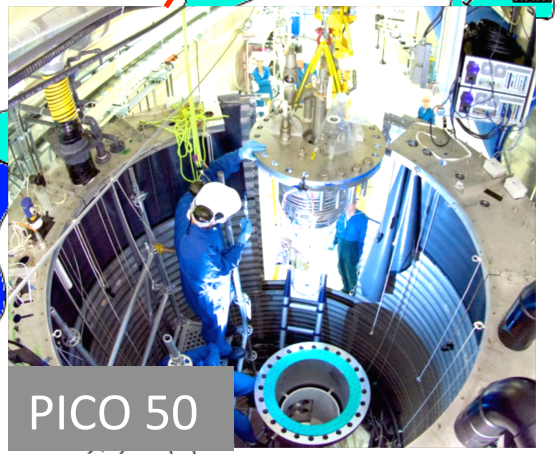
MiniCLEAN



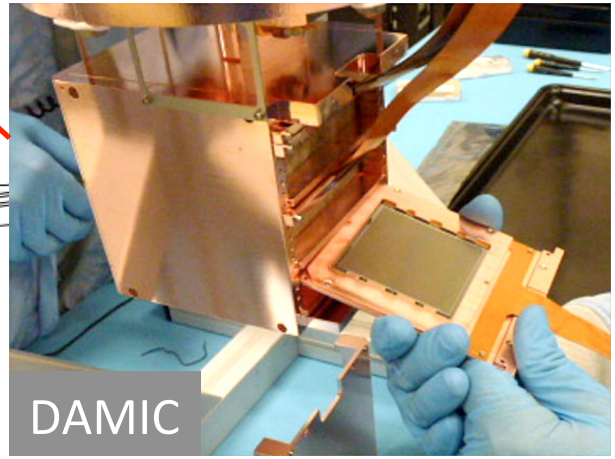
SuperCDMS



PICO 2L



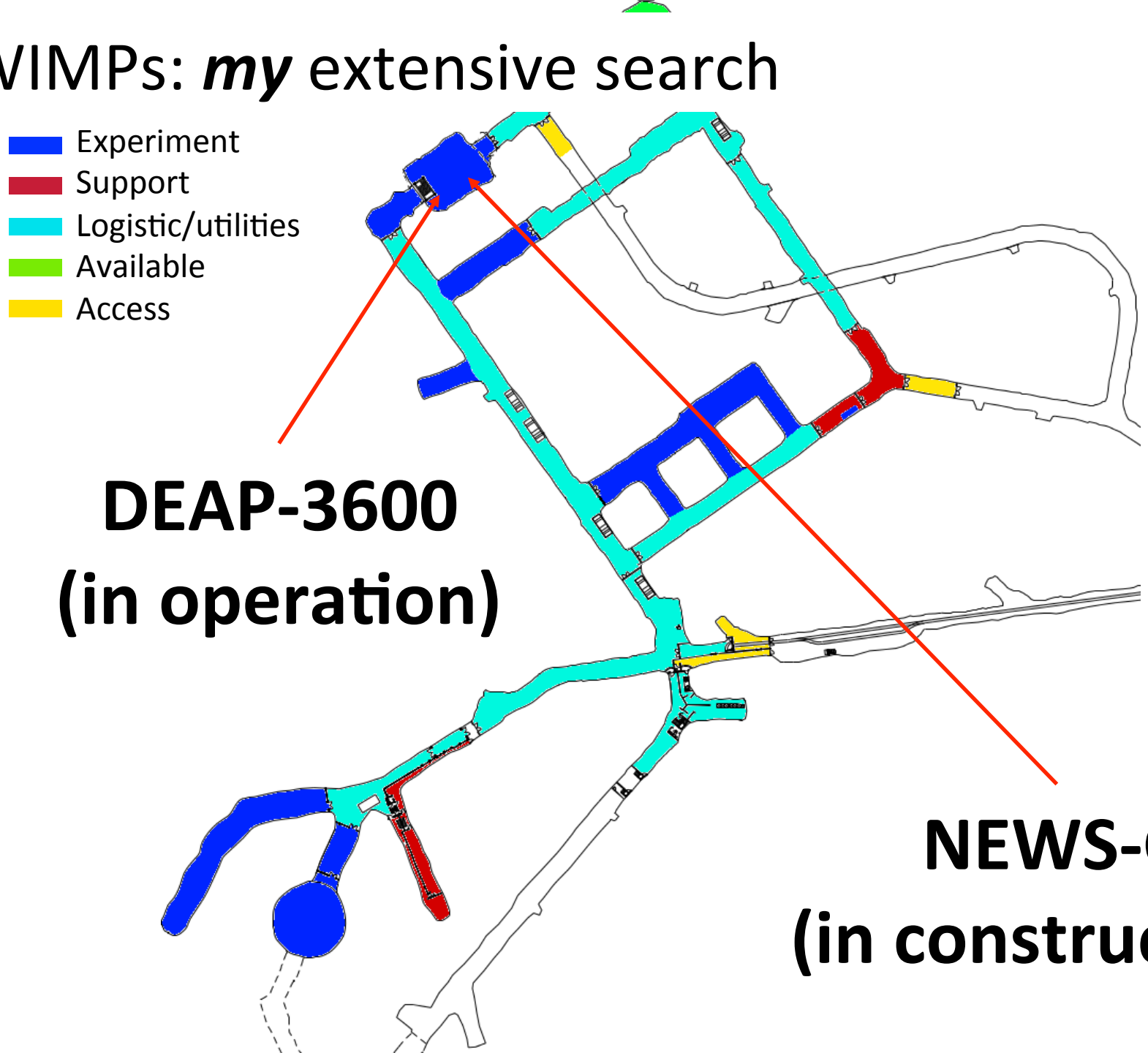
PICO 50



DAMIC

DMTPC (Proj)

WIMPs: ***my*** extensive search



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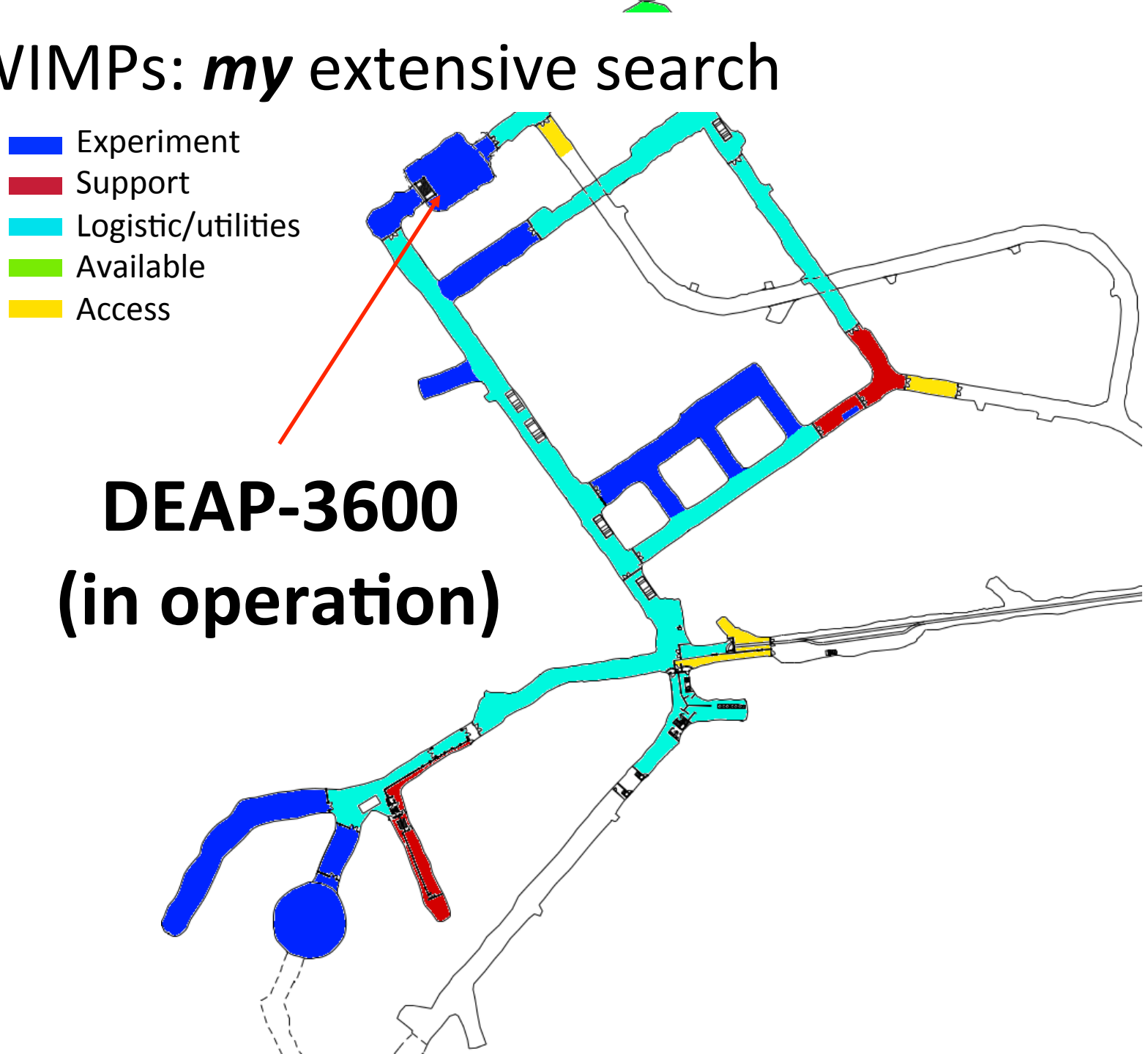
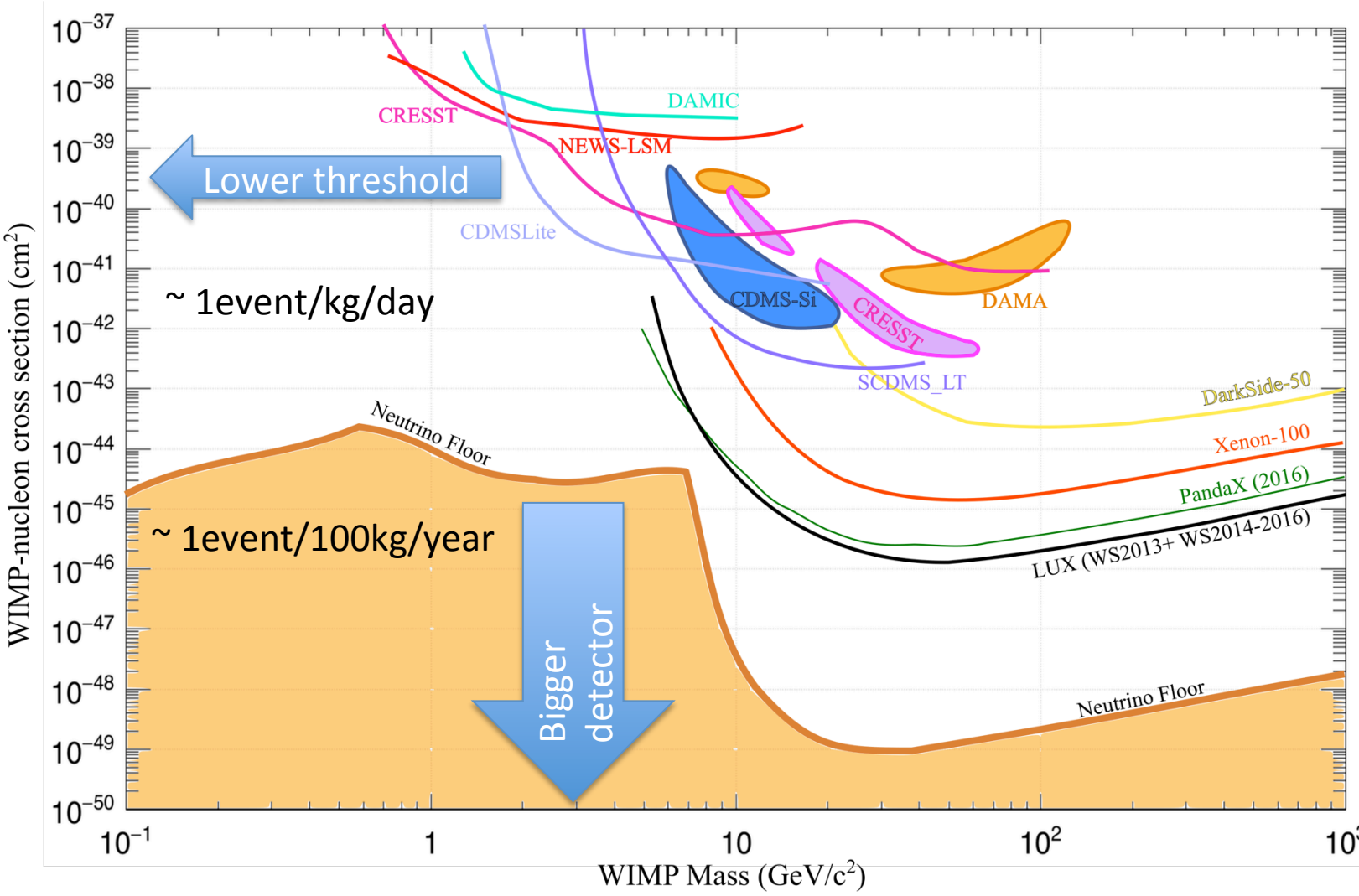


WIMP search (SI), state of the art



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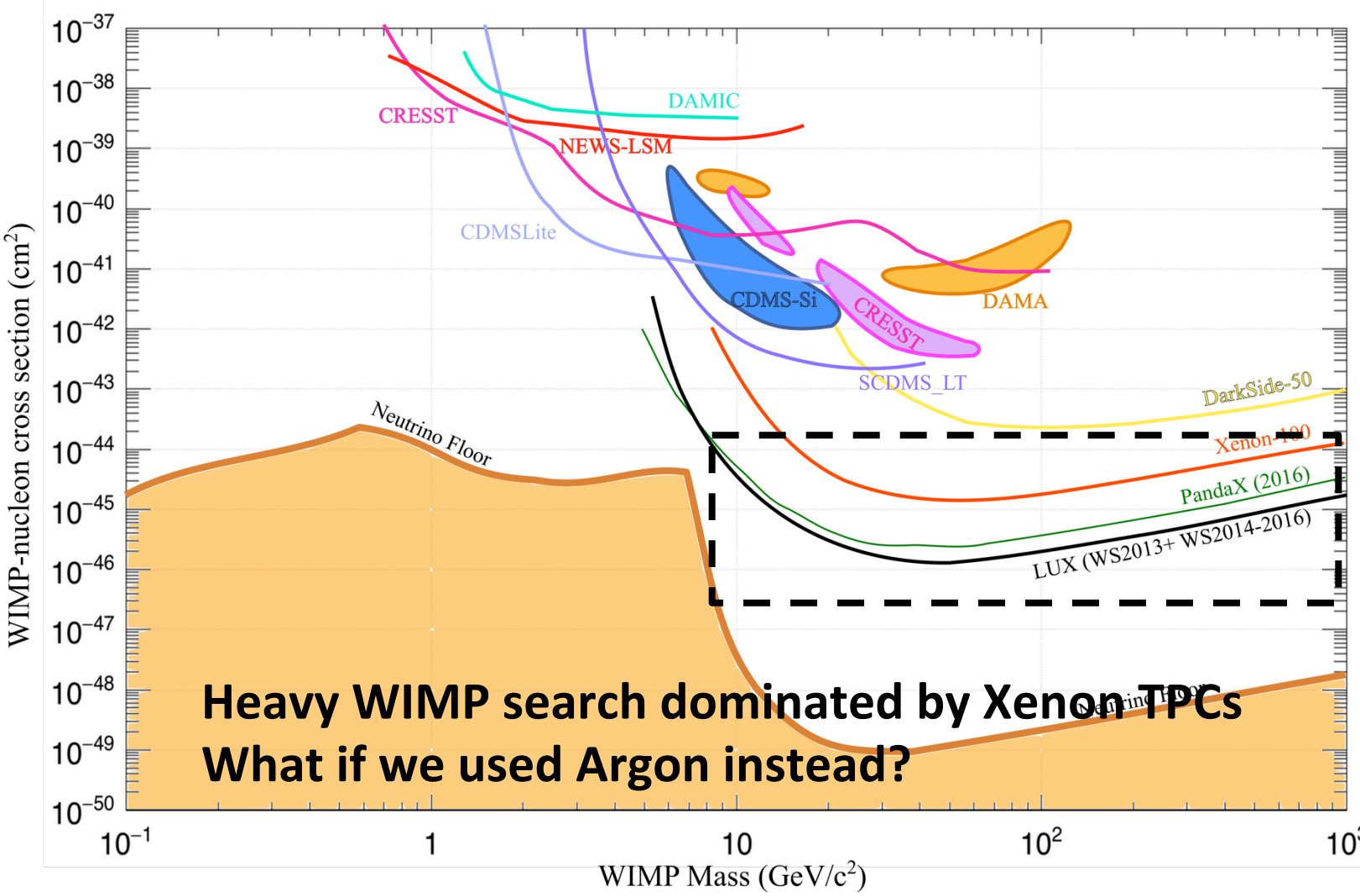
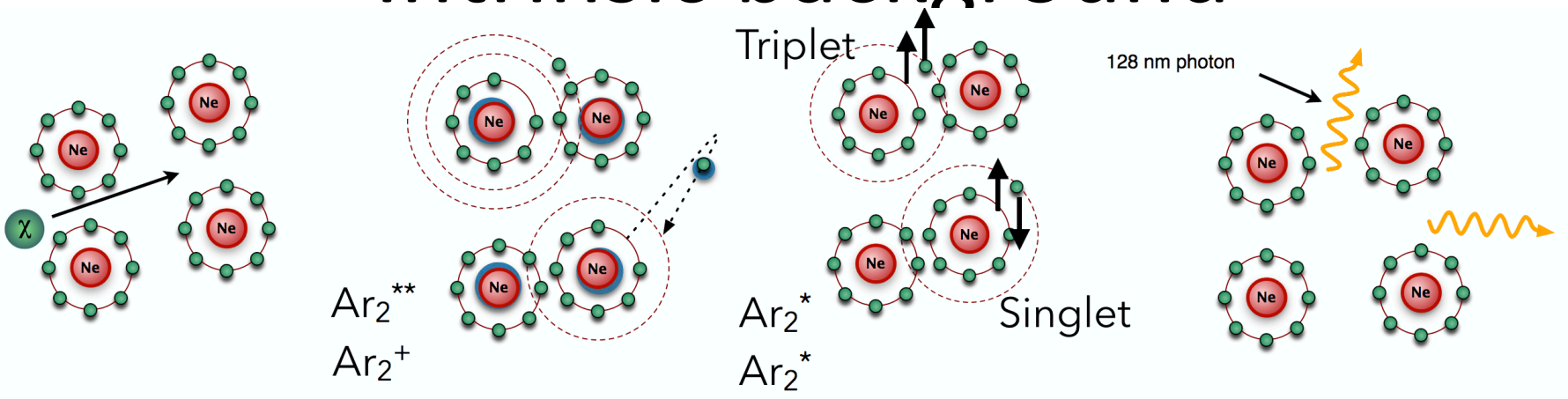


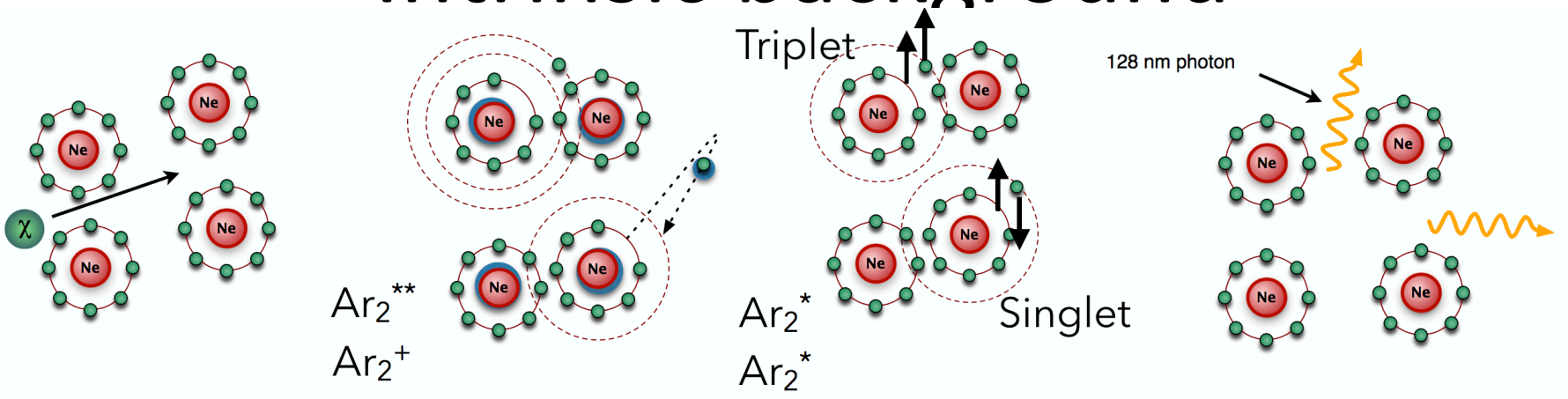
Intrinsic background



Pros:

- Easy to purify
- Transparent to scintillation light
- 40 photons/keV
- Relatively high A
- Favorable form factor (m_χ >1000GeV)

Intrinsic background



Pros:

- Easy to purify
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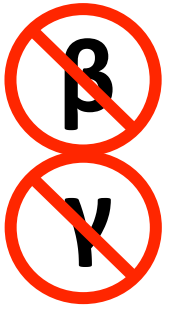
- 40 photons/keV
- Relatively high A
- Favorable form factor (m_χ >1000GeV)

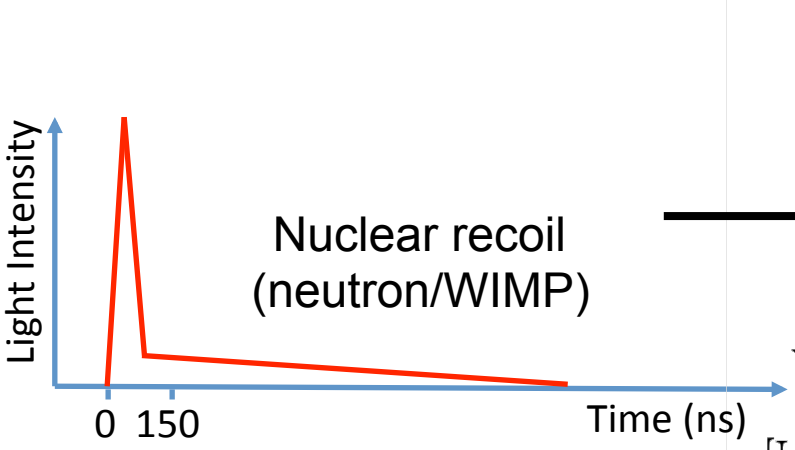
Cons:

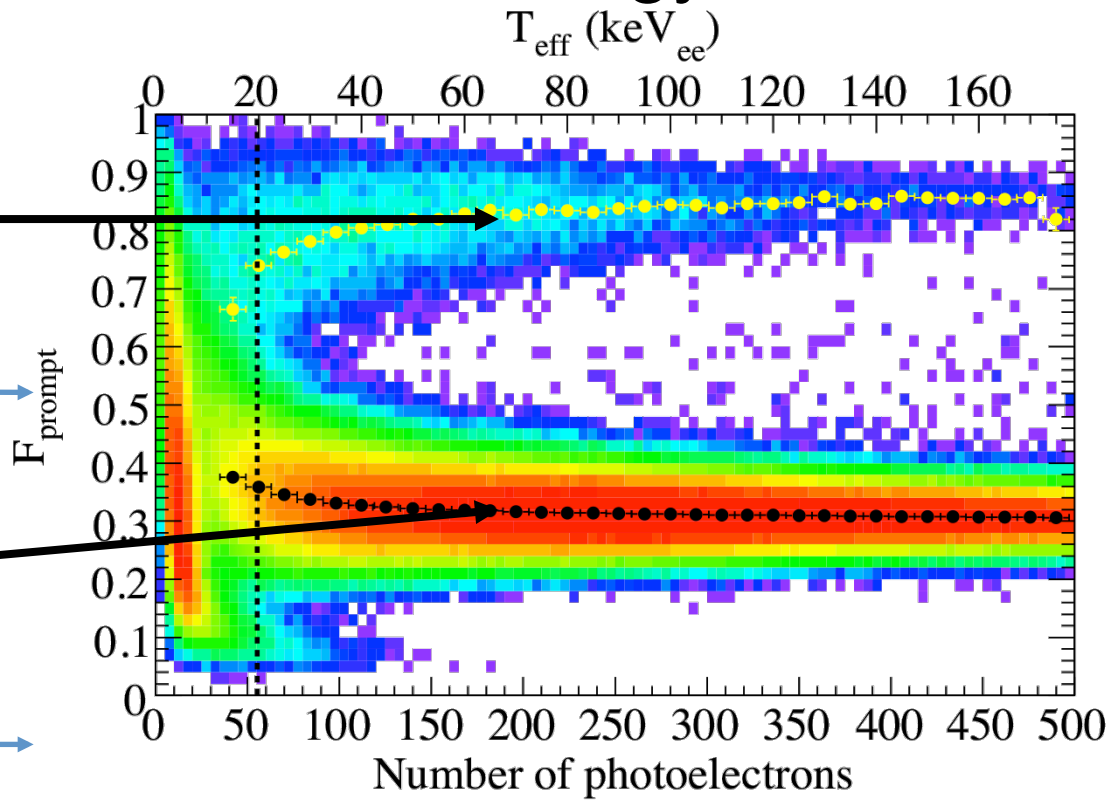
- Need Wavelength Shifter
- Natural Argon: 1Bq/kg ^{39}Ar (β-, 565keV)

Pulse shape discrimination



Scintillation depends on Linear Energy Transfer

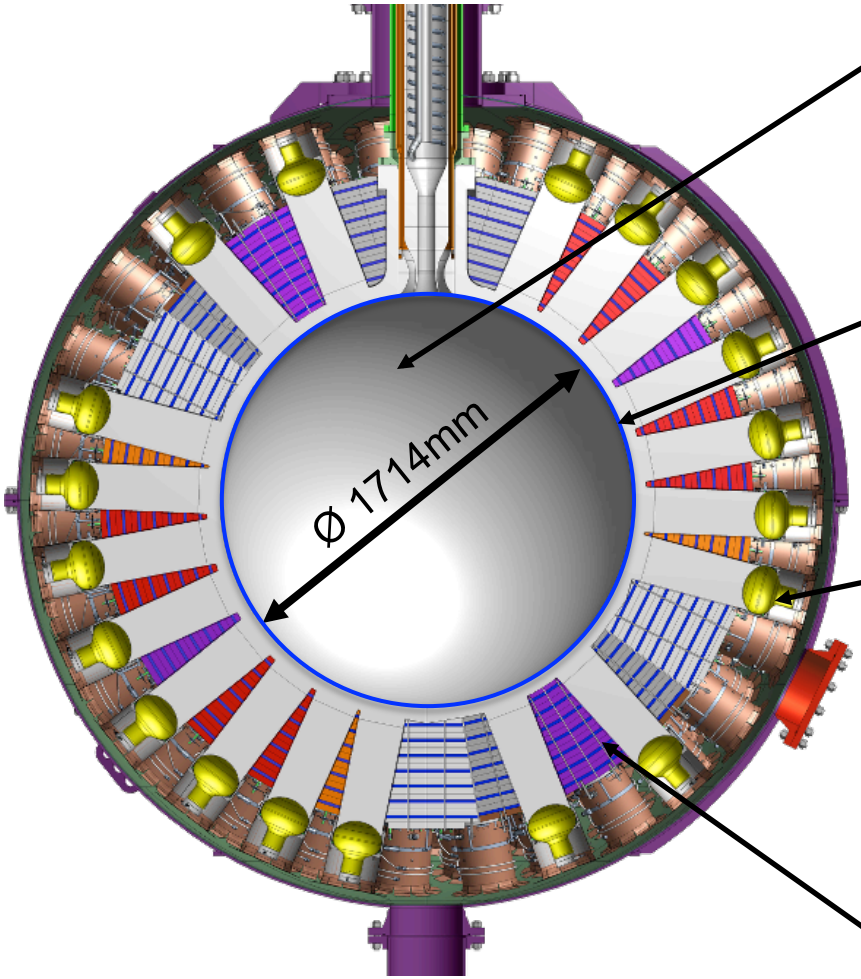




Astroparticle Physics 85, (2016), Pages 1–23

Photo-counting statistic critical !

Single phase, spherical detector

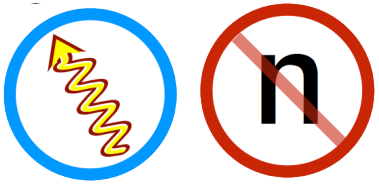


- 3600 kg purified LAr (1000kg fiducial)

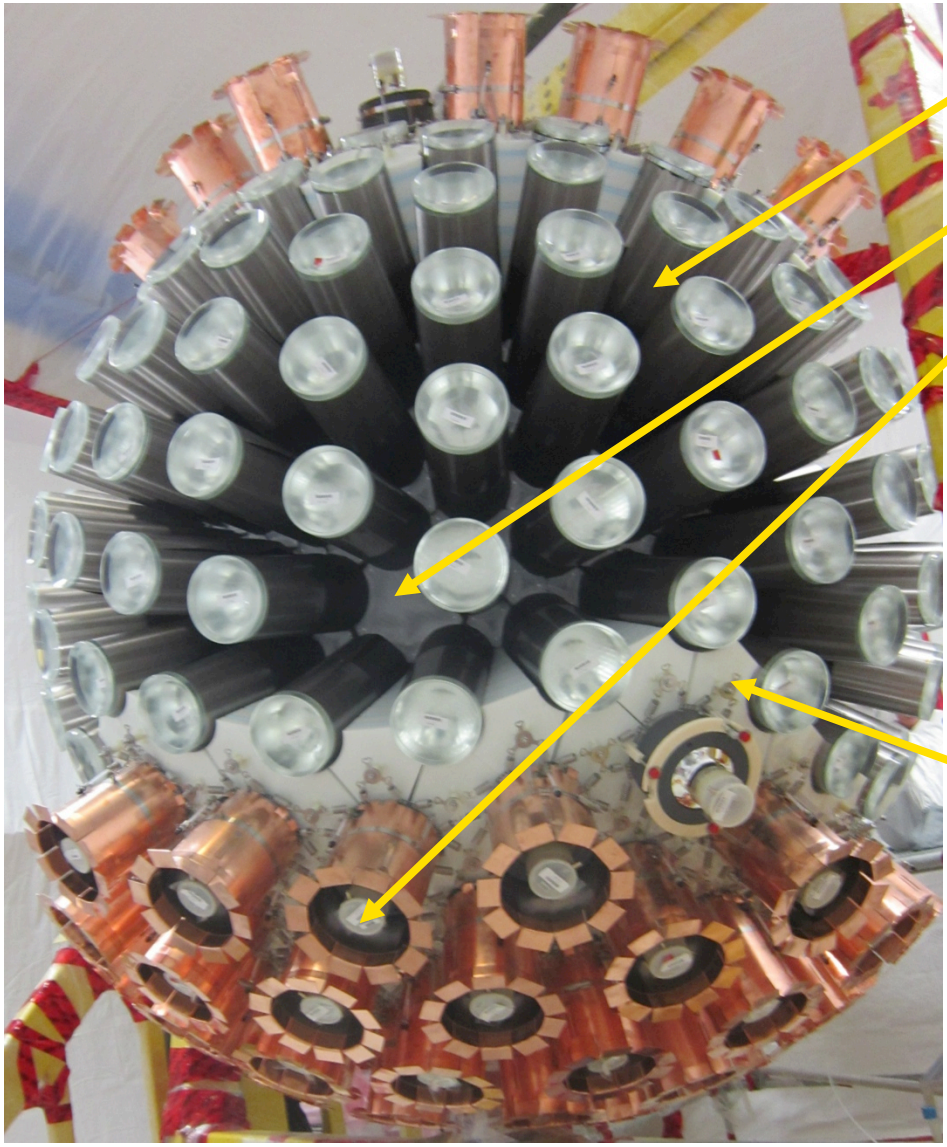
- Wavelength shifter
  - 128nm → 420nm
- Maximum light detector coverage (75%)

- No shadowed area
- 0.5m plastic shield

Acrylic:
DEAP's "secret weapon"

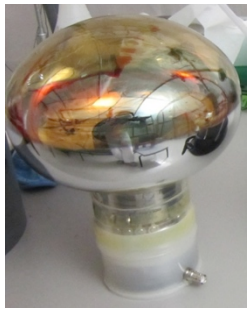


- Part of neutron shield
- Light guides bonded for max light transmission



Maximum light detection:

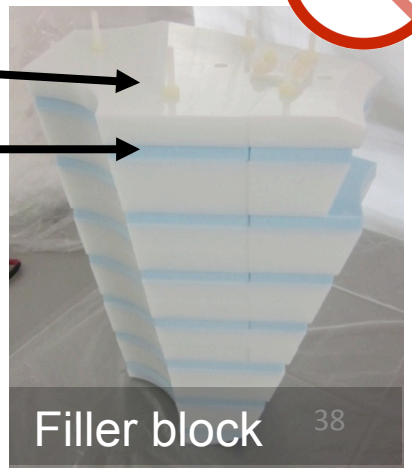
- Specular reflectors
- Diffuse reflectors
- 255x Hamamatsu R5912 HQE (32% QE)

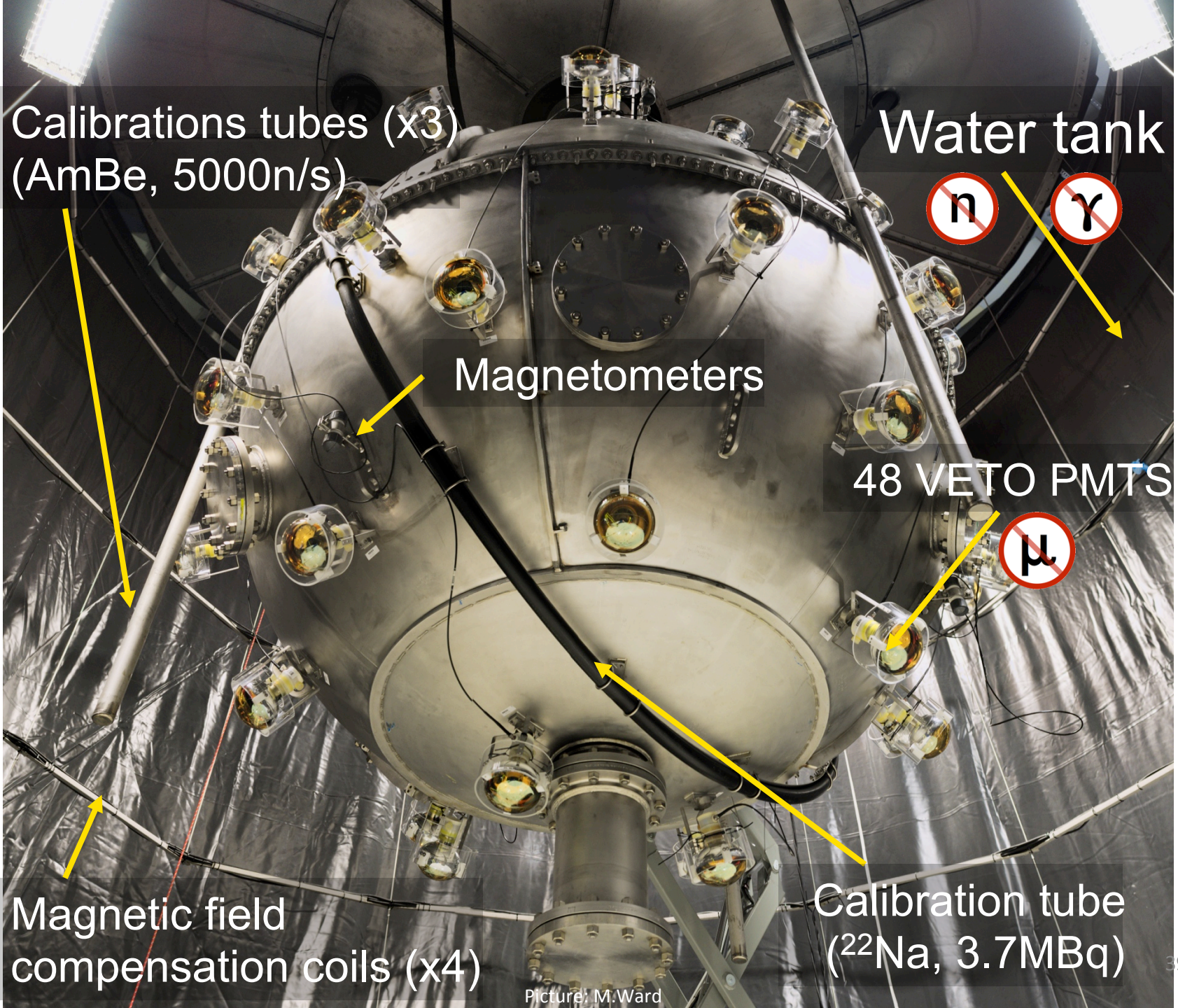


Complete the shield:

Polyethylene

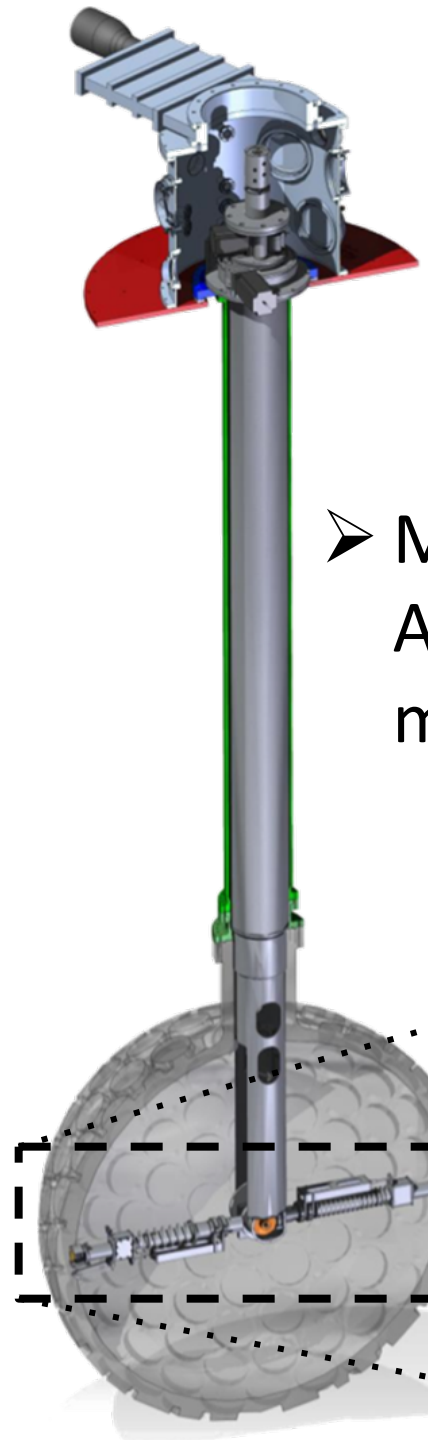
Styrofoam



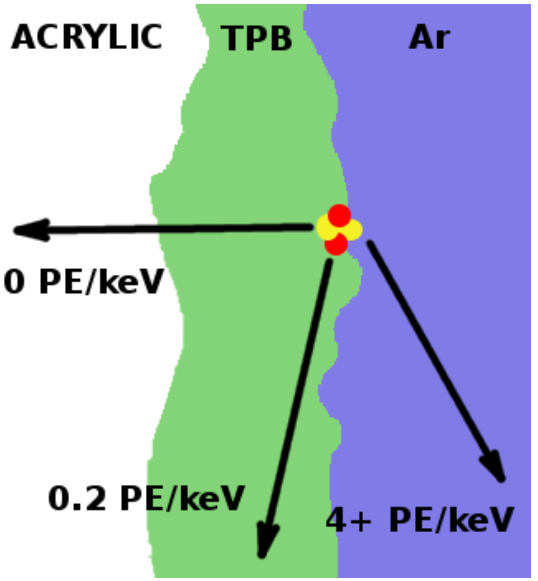


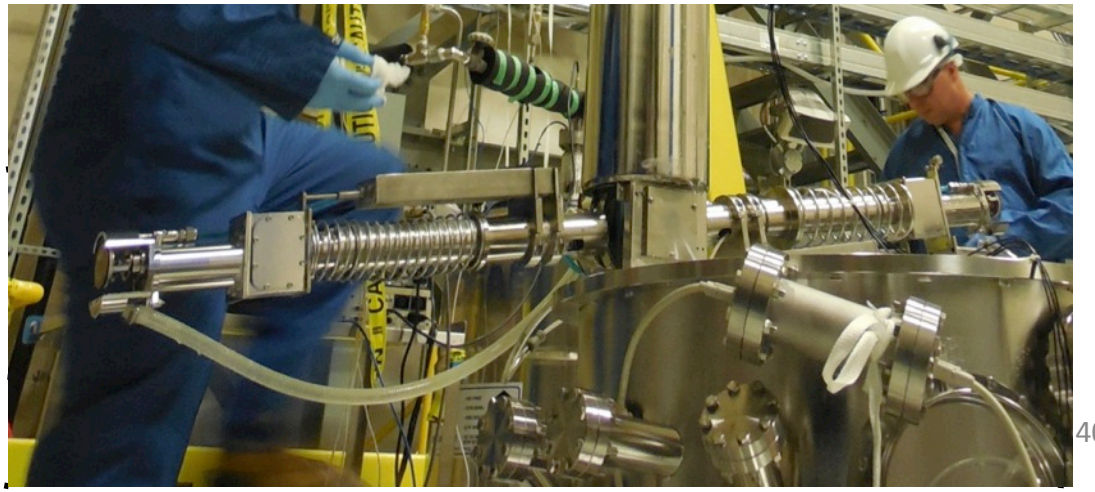
Picture: M.Ward

Removing the surface contamination

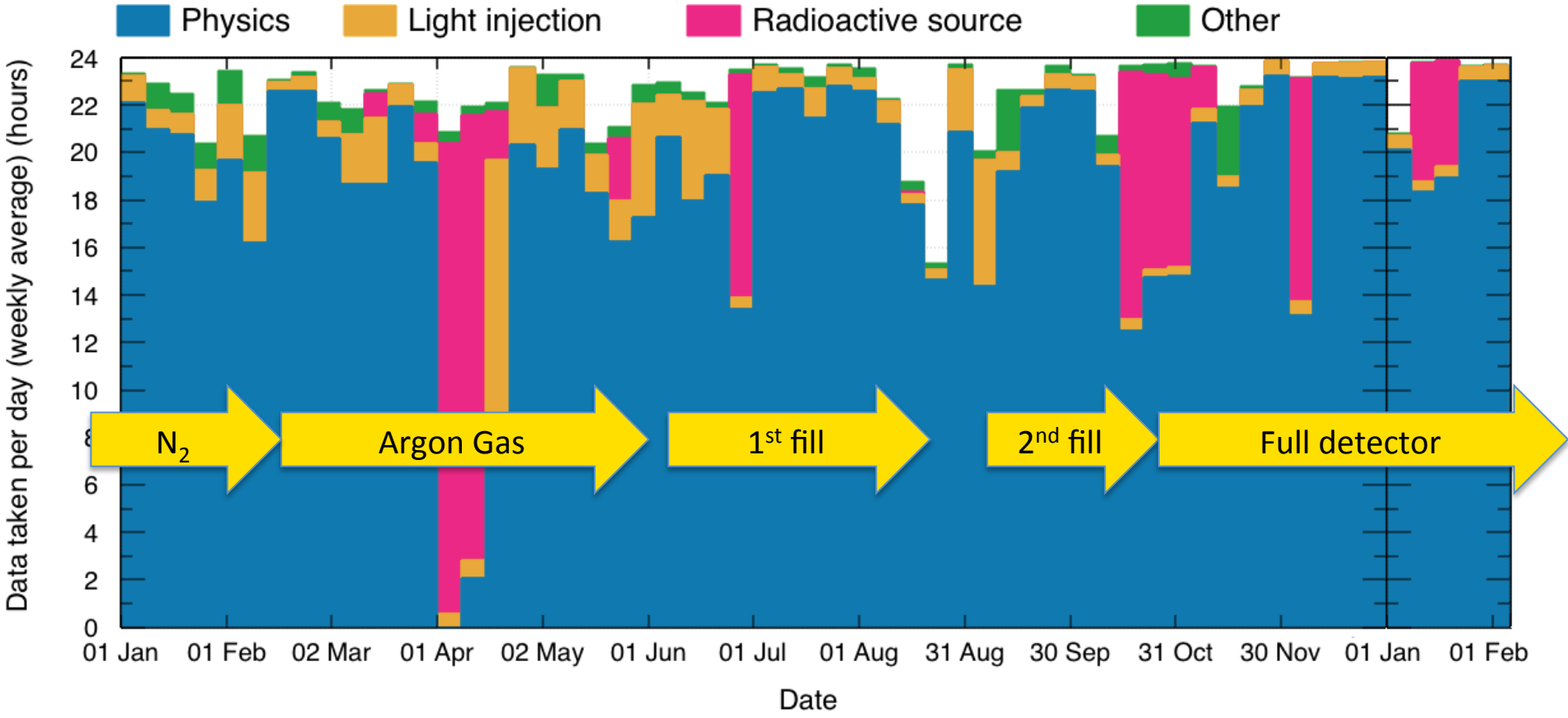


- Mechanical sanding of the AV inside surface (<10 α/ m^2/day)

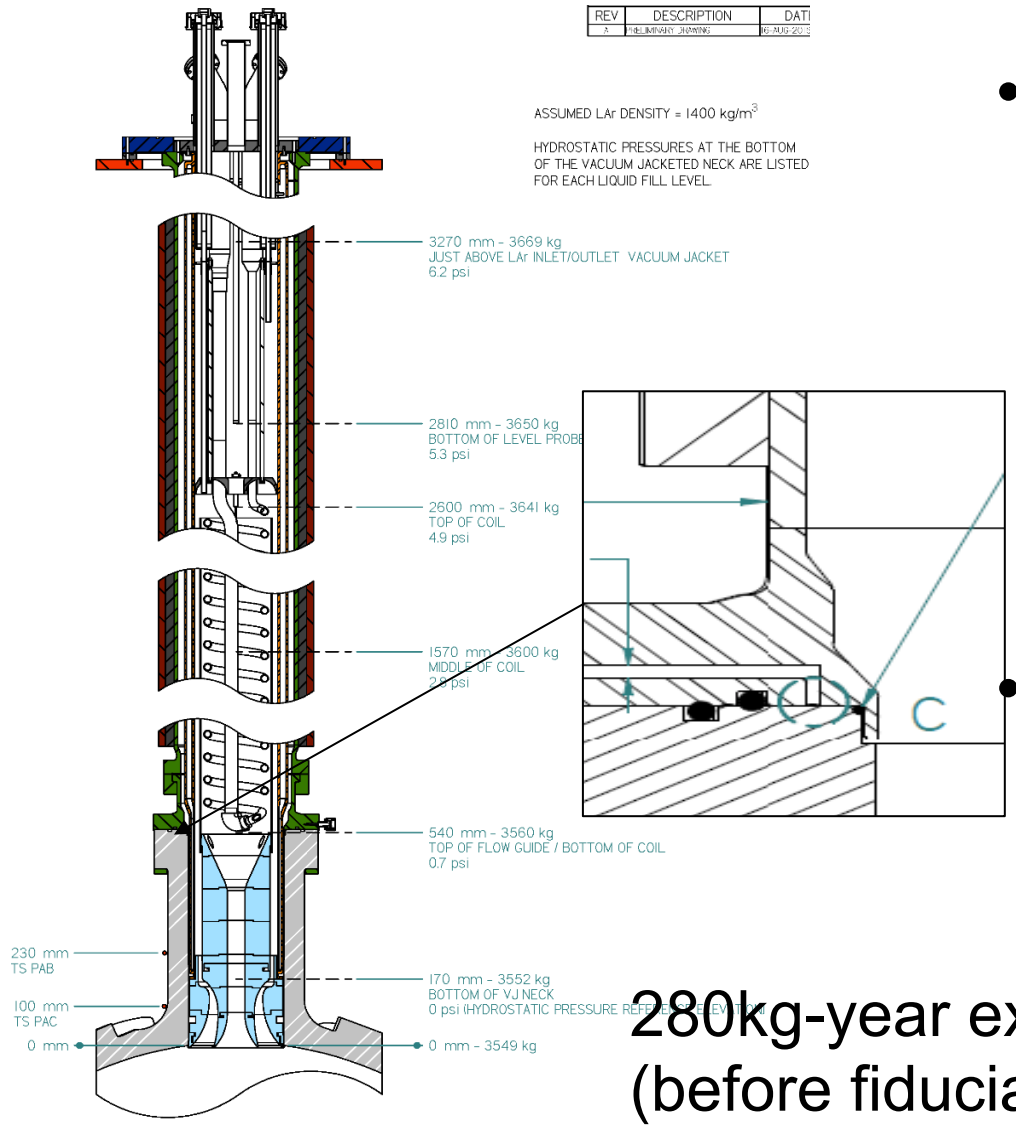




Data taking timeline (2016-2017)



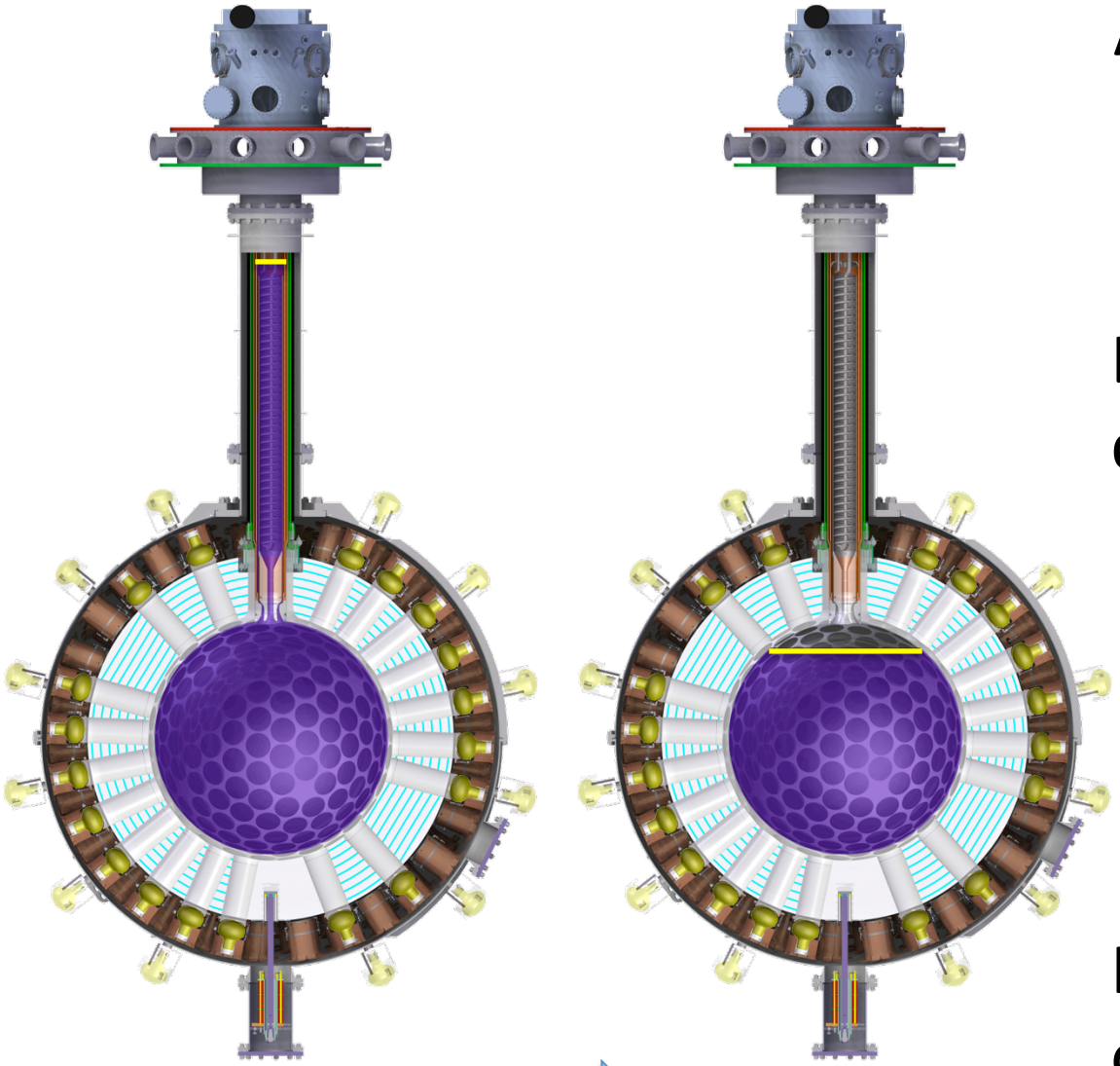
2 fills? Aug 17th incident



- Seal failure at the acrylic – steel interface
  - Seals got too cold
  - Rn scrubbed N_2 leaked into the liquid argon → 100ppm
    - More than the purification system can handle
- Remedy
  - Vent Argon & Refill

280kg-year exposure before incident (before fiducialization and other cuts)

Aftermath of the incident

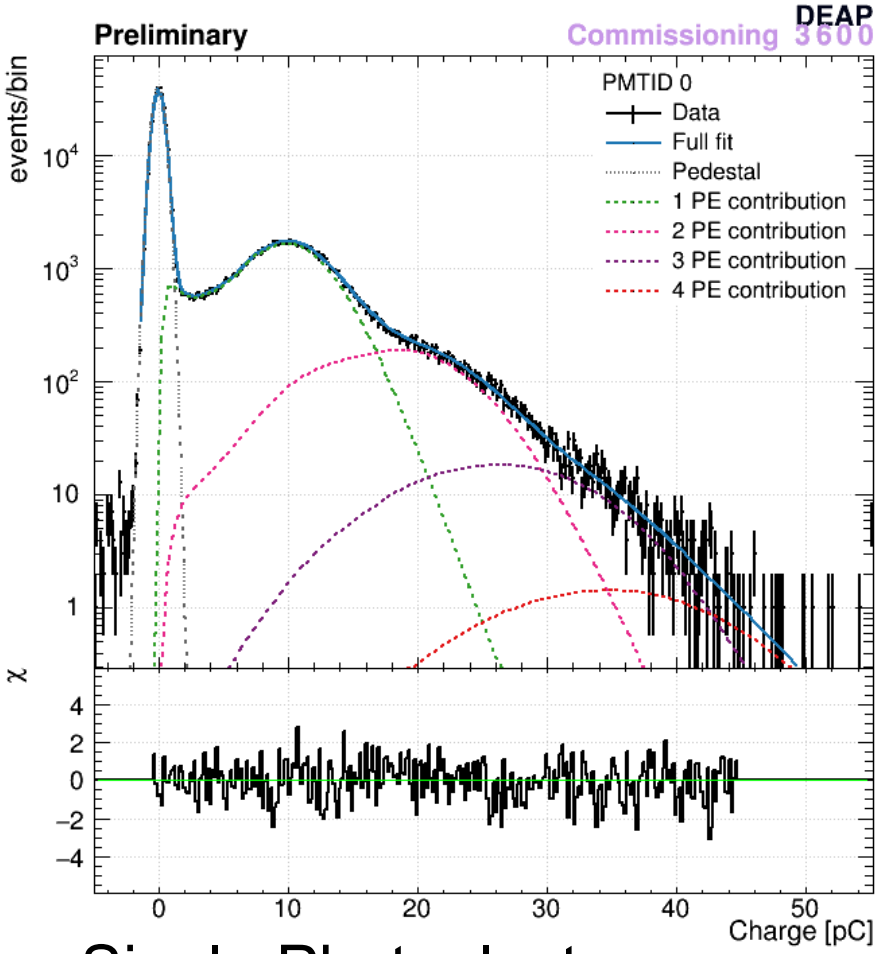


DEAP-3600 → DEAP-3260

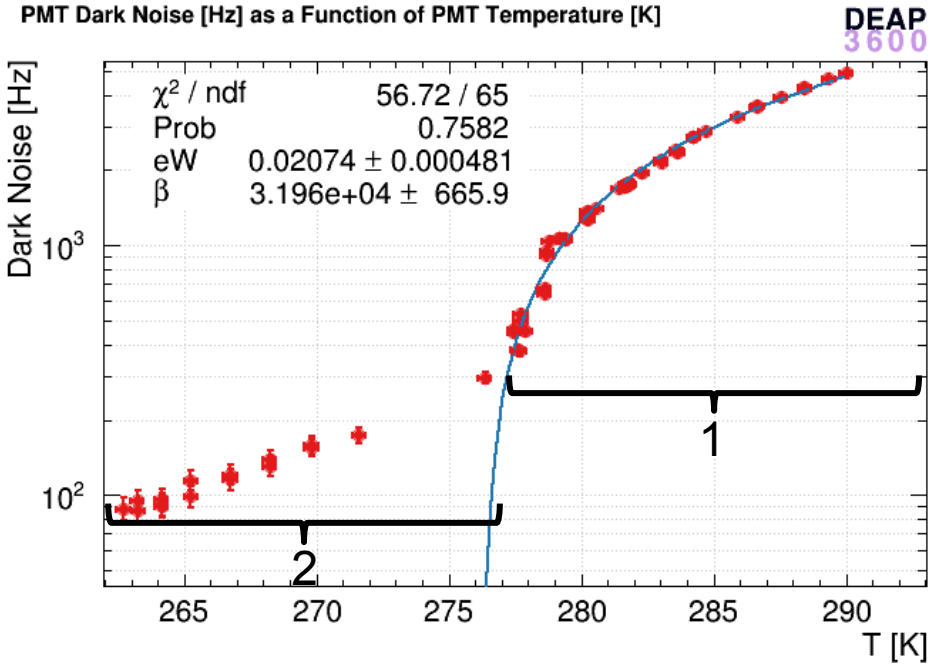
Liquid level set at safe distance from the seal

Impact estimate on operations on-going

PMT understanding: critical



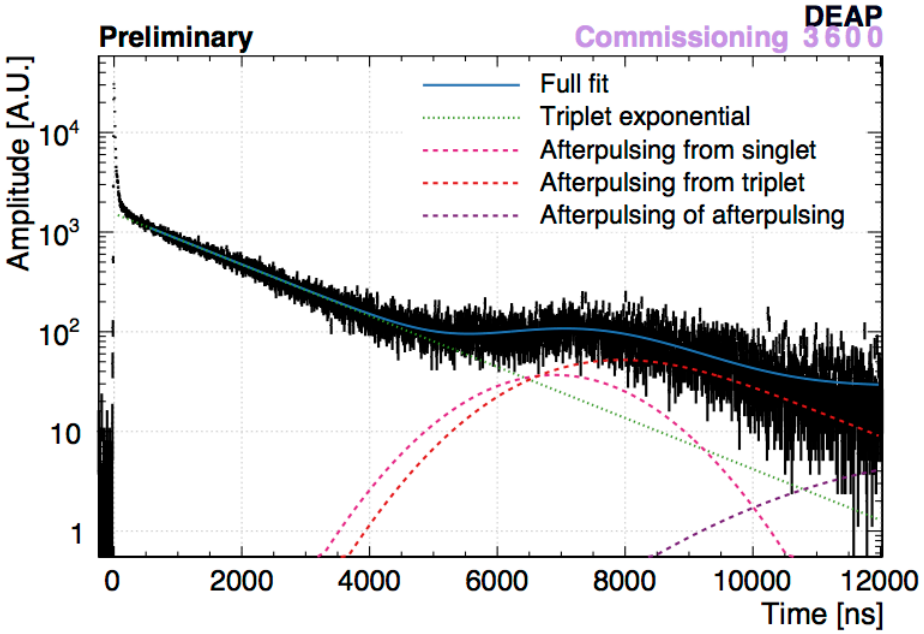
Single Photoelectron charge calibration

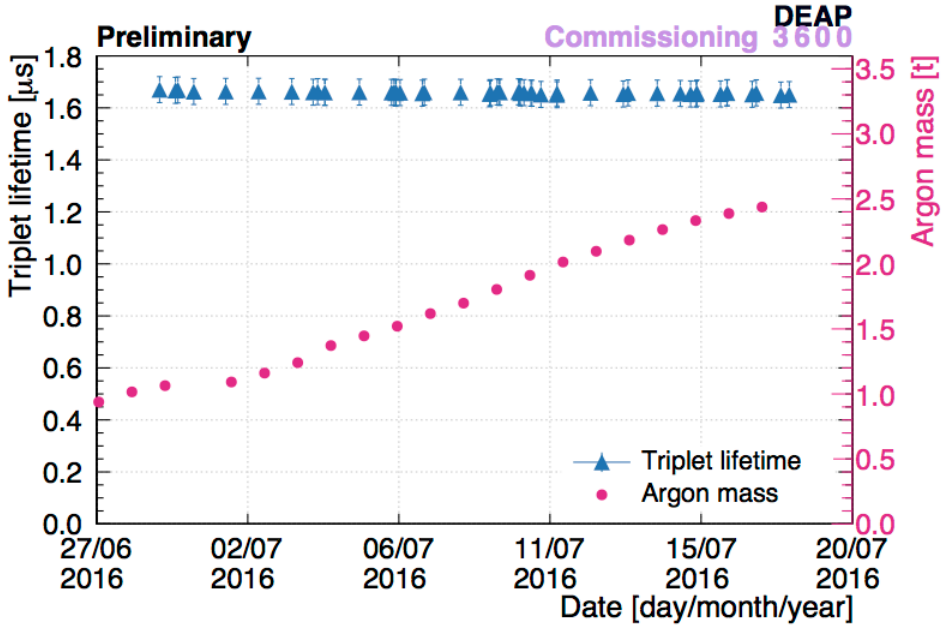


Dark rates when getting cold:

1) Thermionic emission
2) Non-thermionic emission

Argon purity: excellent !



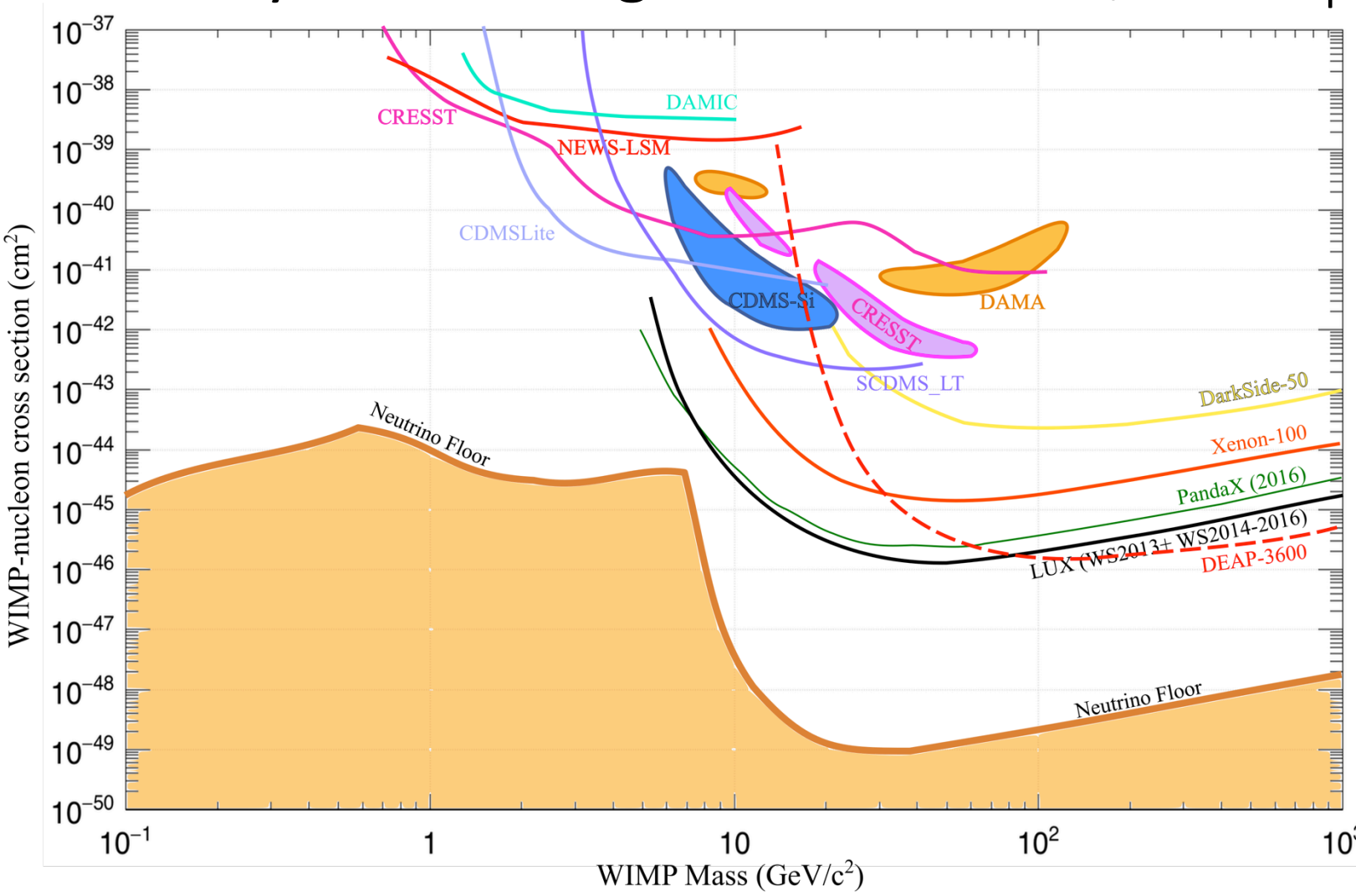


Triplet (long) lifetime comparable to literature

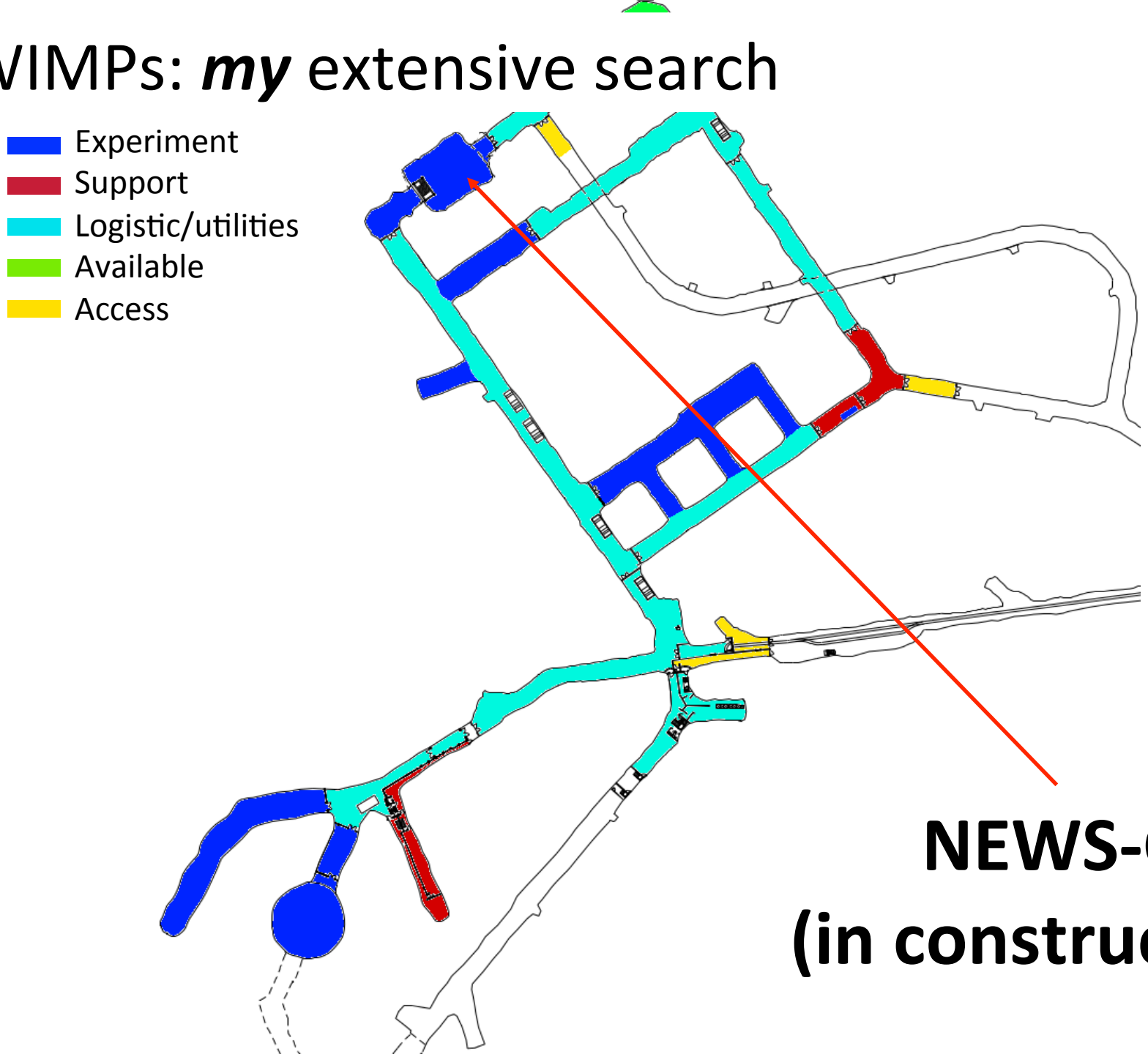
➔ Good argon purity

DEAP-3600 expected sensitivity

3 ton-year of background-free data, 60keV$_r$

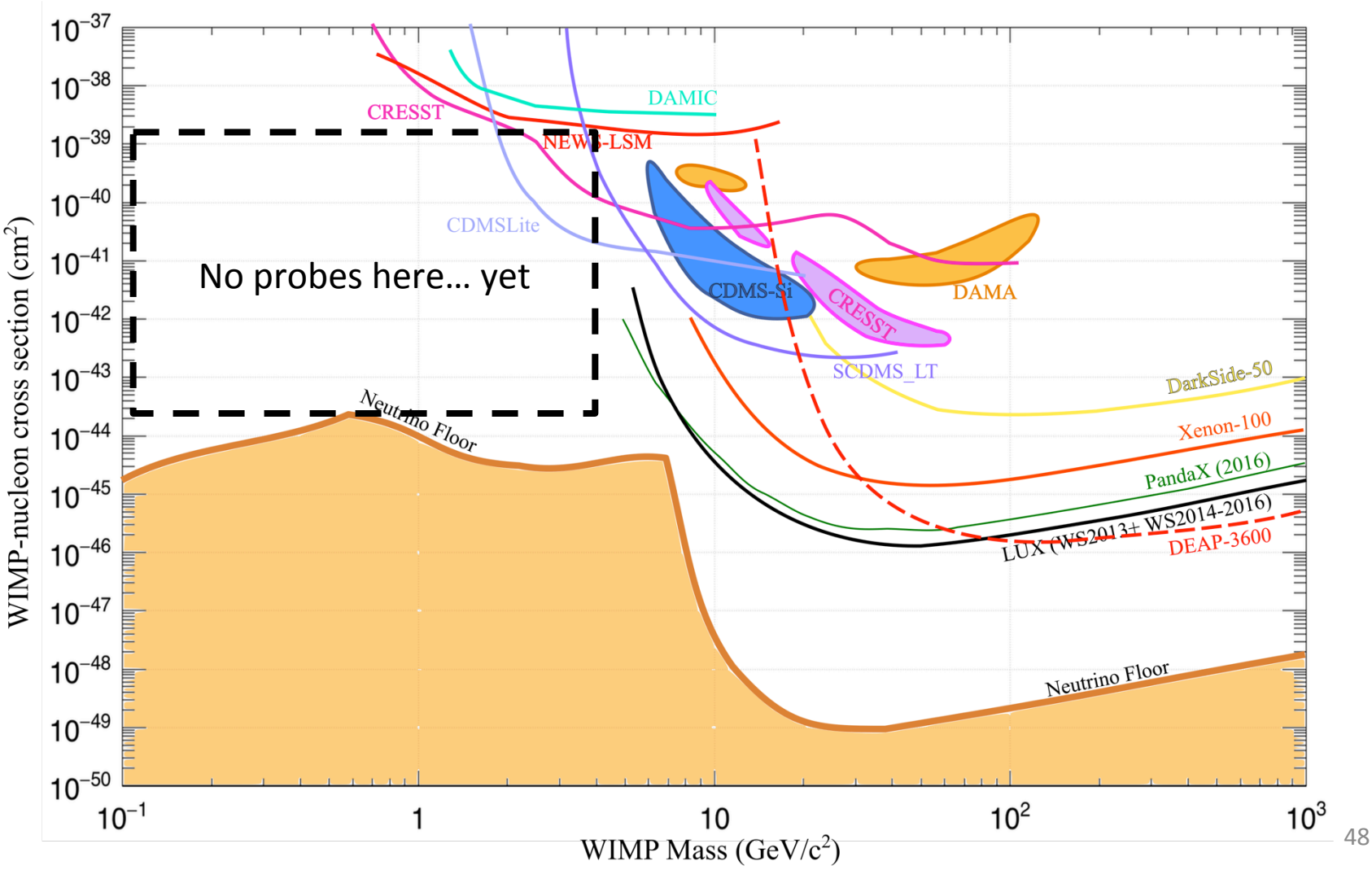


WIMPs: ***my*** extensive search



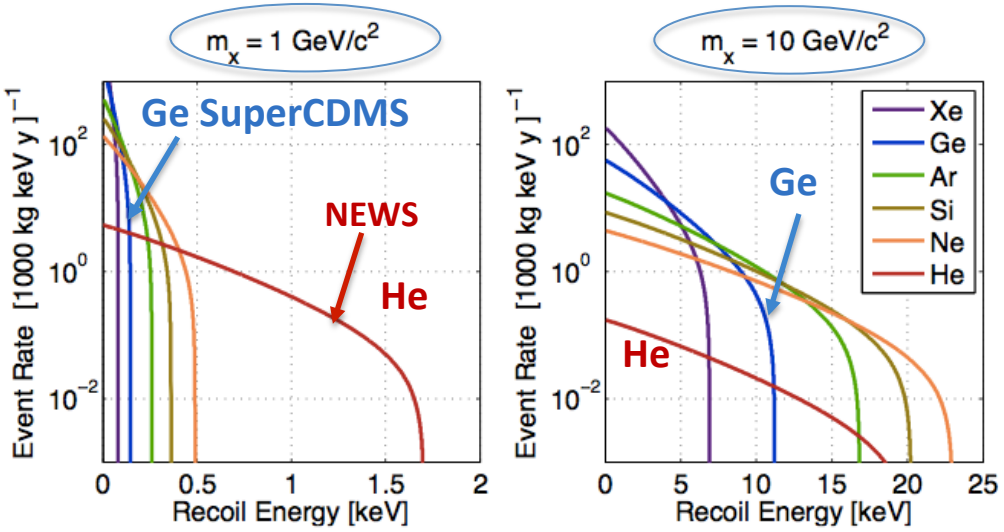
NEWS-G
(in construction)

Nothing yet at high mass?
Let's look for lighter WIMPs



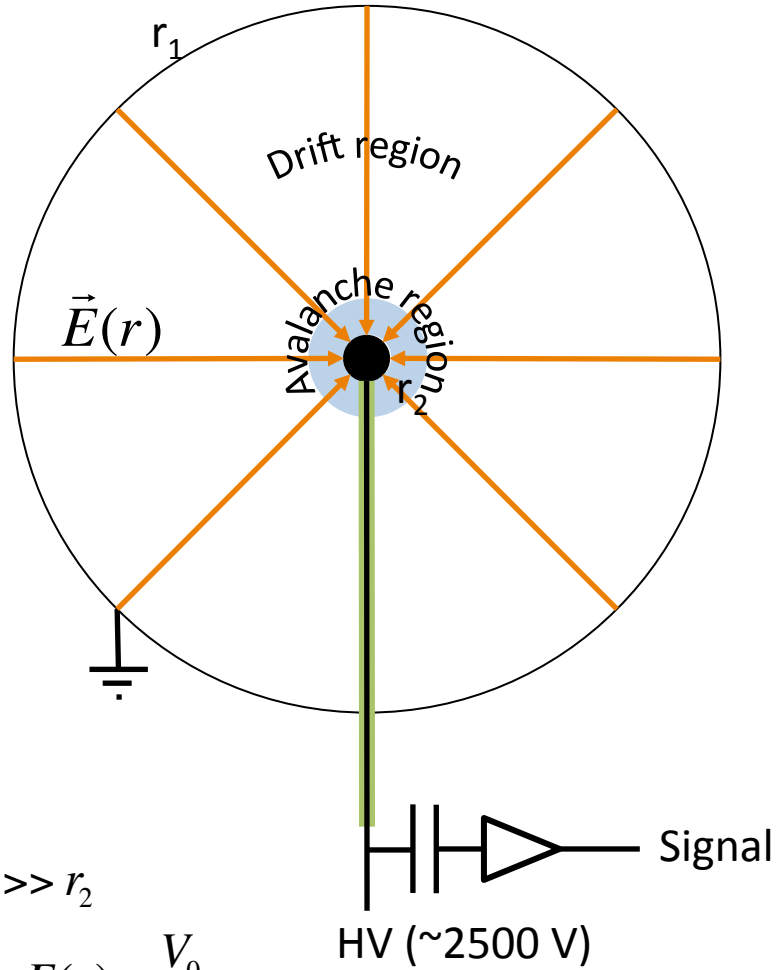
Detection of low mass particle

- Kinematical match
- To detect **flying ping pong balls** is it better to have as **target** :
  - **Curling stone ?**
  - **Ping pong balls ?**
- => use light nuclei to detect light WIMPs
- H, He, Ne lightest among noble gas



Recoil distributions with various targets

New Experiments With Spheres (Gas)



$r_1 >> r_2$

$$\Rightarrow E(r) \approx \frac{V_0}{r^2} \times r_2$$

$$\Rightarrow C \approx 4\pi\varepsilon r_2 \sim 0.1pF$$

- Spherical detector
- Single electrode
- Spherical proportional counter/ TPC
- **Flexible (P, gaz)**

➢ Low threshold ~50 eV_{ee} <u>independent on sphere radius</u>

➢ Large mass / large volume (~30 kg) with single channel

New Experiments With Spheres (Gas)


Saclay: I. Giomataris & G. Charpack


Thessaloniki U.

- 2 old LEP RF cavity Ø130 cm used for test (prototypes)
- **1 low activity Ø60 cm in operation @ Laboratoire Souterrain de Modane**

Illustration of particle identification at MeV energy

Ar/CH_4 + 3g ^3He @ 200 mb SPC 130cm Ø @ LSM

Tracks

α ^{210}Po
5.3 MeV

n capt on ^{3}He
764 keV

Rise time (µs)

PL

Amplitude (AU)

1

2

3

^{222}Rn ^{218}Po ^{214}Po

α ^{210}Po
5.3 MeV
from ^{210}Pb
@ Cu surface
Range = 15 cm

Rate 400 capt/d

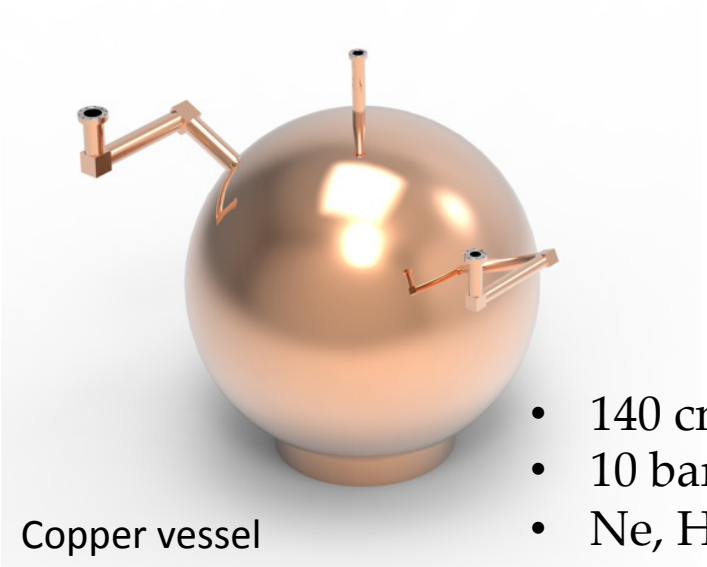
n capt on ^{3}He
=> p + T

Point like

« Volume » alpha

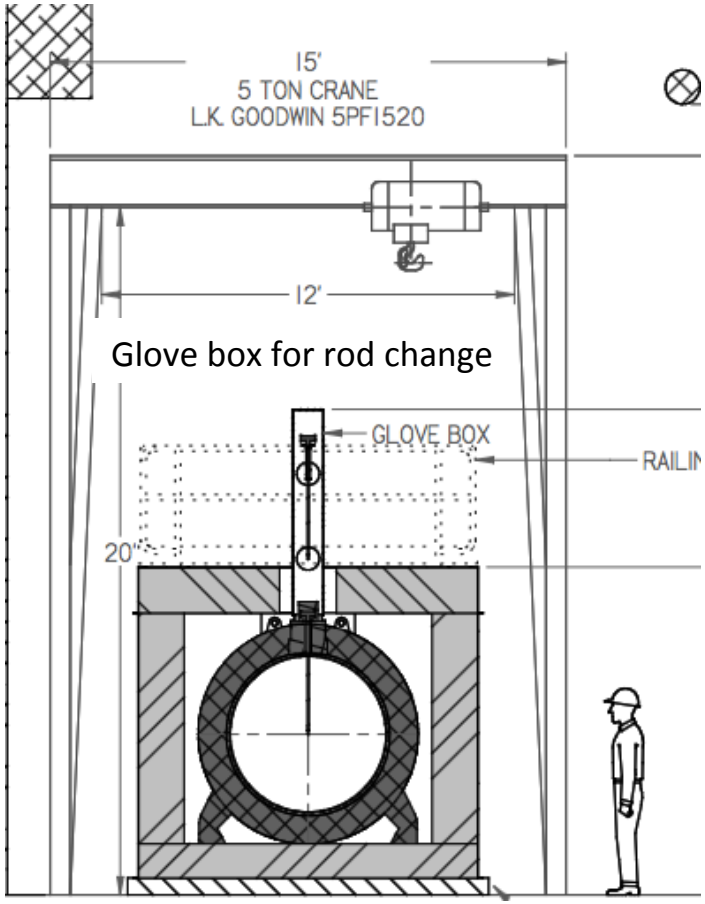
Recoils from fast neutron/dark matter expected here

Implementation at SNOLAB: fall 2017

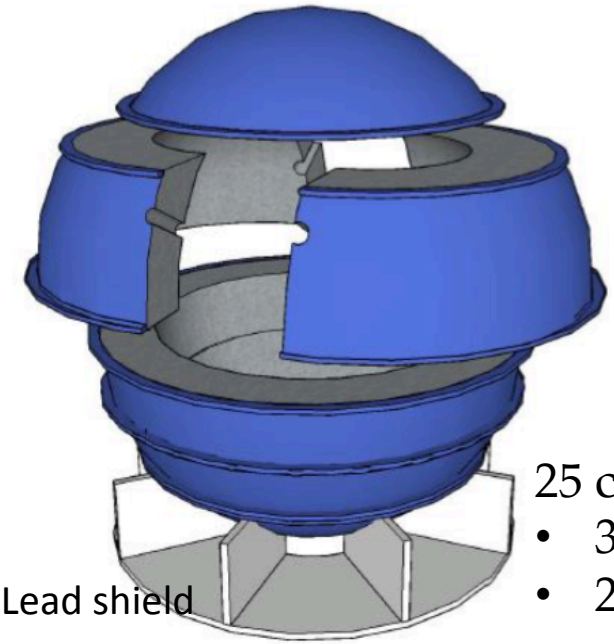


Copper vessel

- 140 cm Ø, 12mm thick
- 10 bars
- Ne, He, CH_4



40 cm Polytethylene
+ Boron sheet



Lead shield

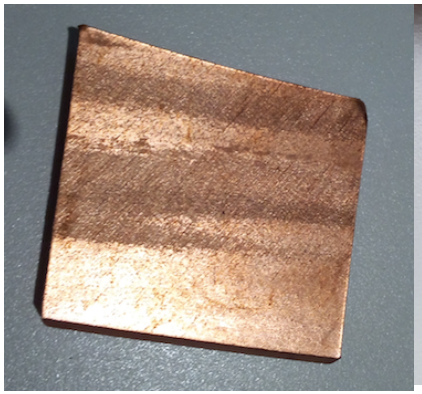
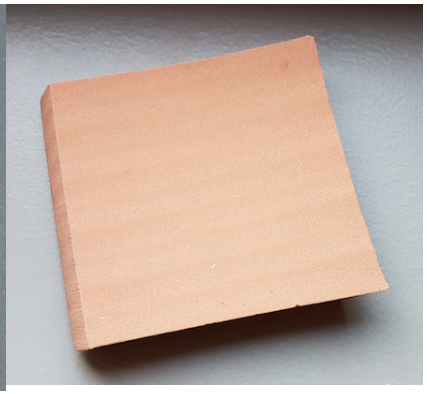
25 cm lead shield:

- 3cm inner: archeological
- 22cm outer: very low activity

Still R&D underway


Copper spinning test

- Sphere fabrication
- Lower activity copper.
- Cleaning with high pressure water

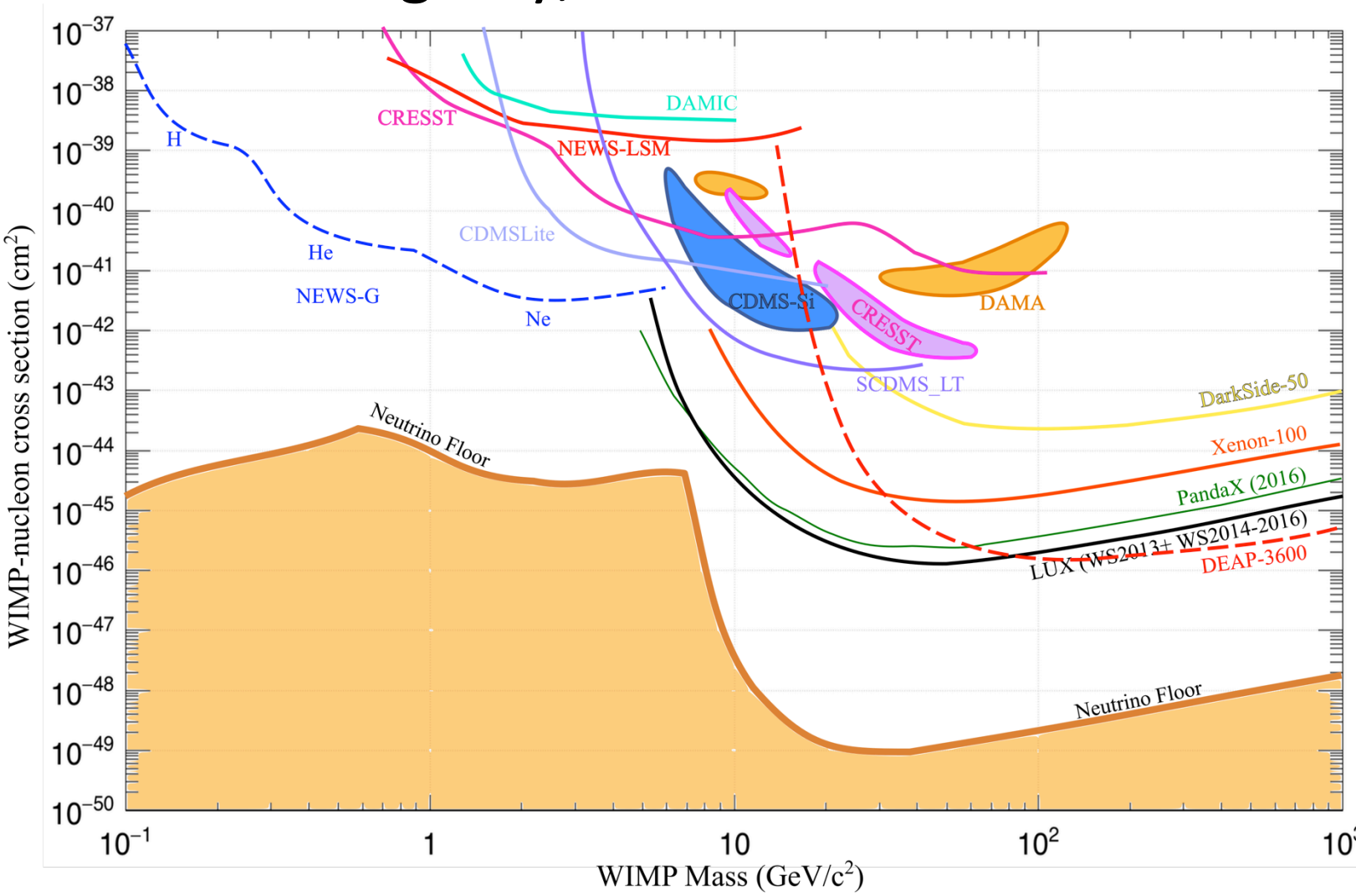




New “achinos” sensors

- Single channels “achinos” for better amplification
- Multi channels sensors

NEWS-G expected sensitivity

100 kg-day, 1 electron threshold



Don't let the bright lights fool you !

The DARK SIDE controls the Universe

Dark Matter holds it together
Dark Energy determines its destiny

Inspired from: http://grimbeorn.blogspot.ca/2012_04_08_archive.html

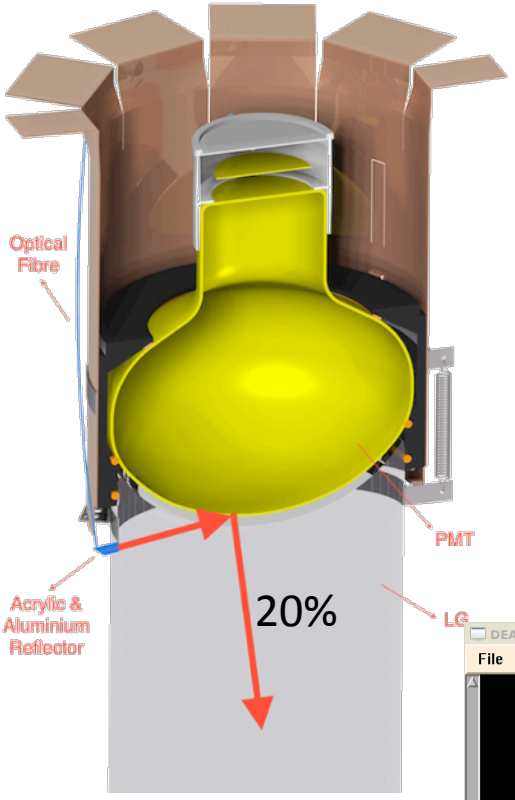
JOIN T SNOLAB IRE

BACKUP SLIDES

Laserball: only calibration light source inserted in the AV

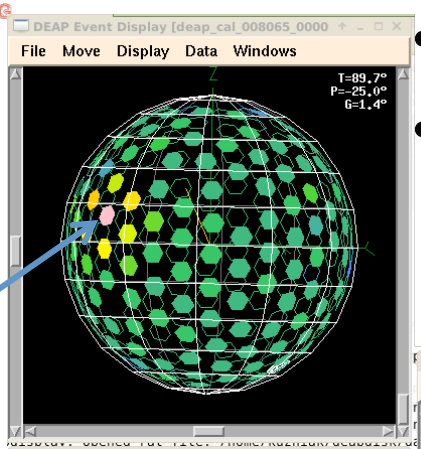
- Fast laser (typ. 58ps):
  - λ: 378 nm, 405 nm or 444 nm
- Before (444nm) and after TPB (378nm)
- PMT+LGs efficiency measurements
  - Known light emission map
- Channel-to-channel timing correction
  - LB at the center, fast laser driver => sub-ns precision

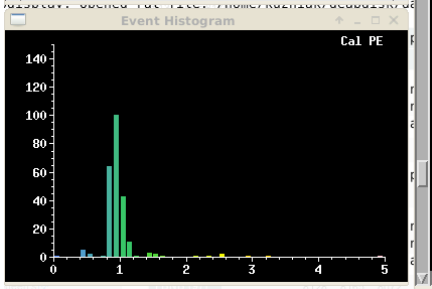
Light injection

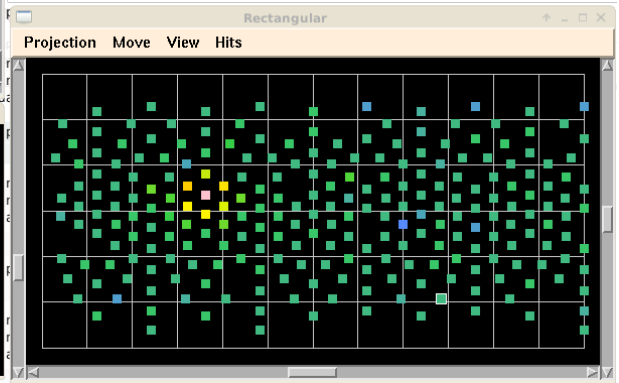


- 20 light guides equipped with optical fibers
  - Pulses (laser-LED): typ. 1ns
  - λ: 425nm
- Single photon-electron calibration
- After pulsing measurement

PMT receiving the light







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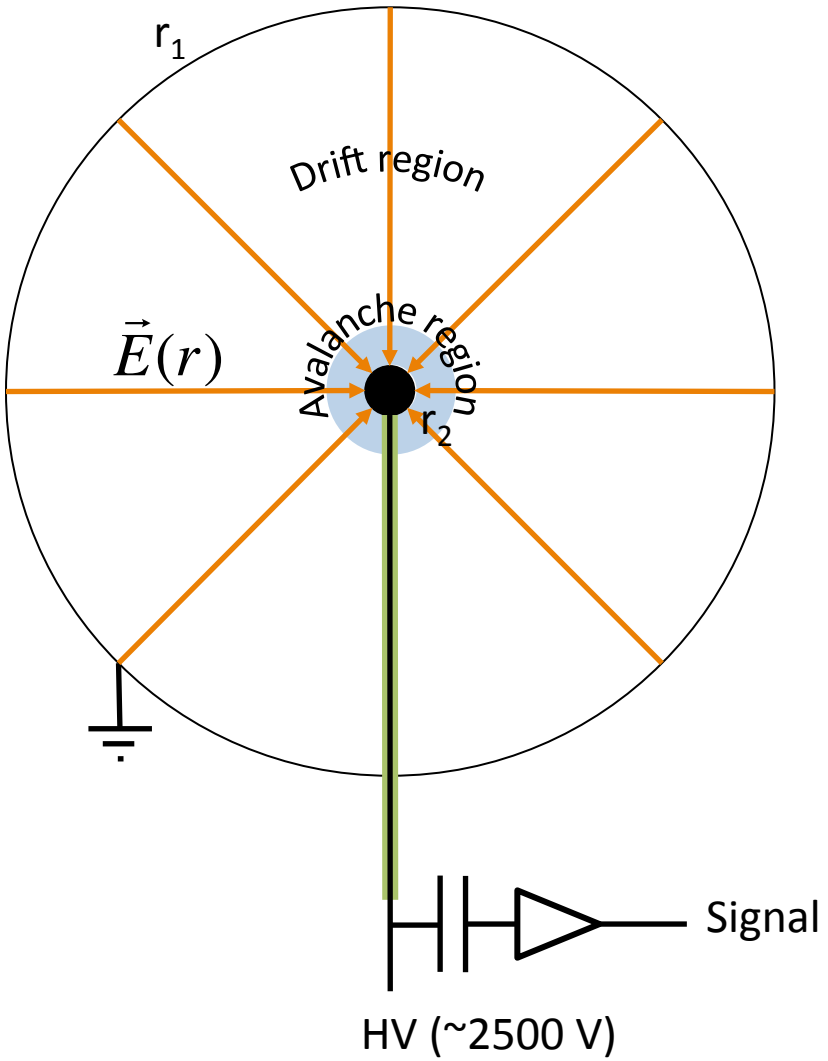

- Spherical detector
- Single electrode

$$1/\rho = 1/r_1 - 1/r_2$$

$$r_1 >> r_2 \Rightarrow \rho \approx r_2$$

$$E(r) \approx \frac{V_0}{r^2} \times r_2$$

$$C \approx 4\pi\varepsilon r_2 \sim 0.1pF$$

➢ Low threshold ~50 eV_{ee} <u>independent on sphere radius</u>

SNOLAB extension