*He recoils in CYGNO 10 L prototype

CYGNO/INITIUM physics case: beyond classical WIMP searches

Elisabetta Baracchini

Gran Sasso Science Institute

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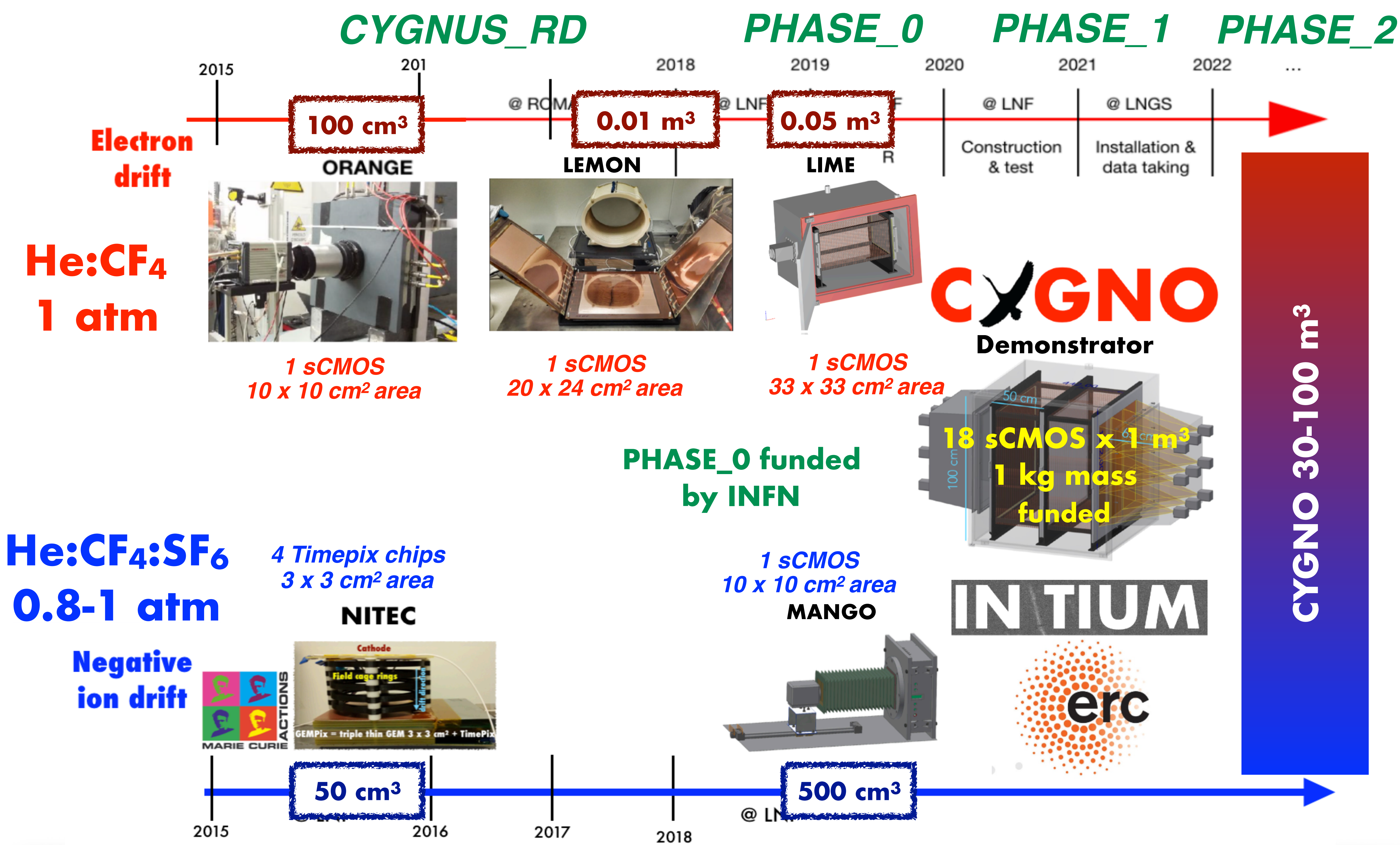
European Research Council

Established by the European Commission

3D optical readout CYGNO roadmap & synergy with negative ion drift INITIUM erc



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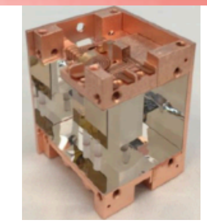
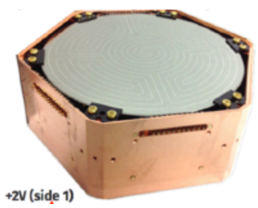
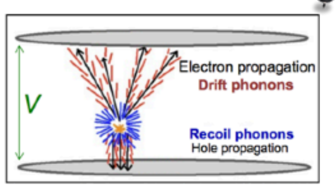
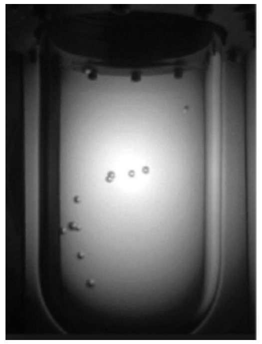
Direct WIMP DM searches overview & context



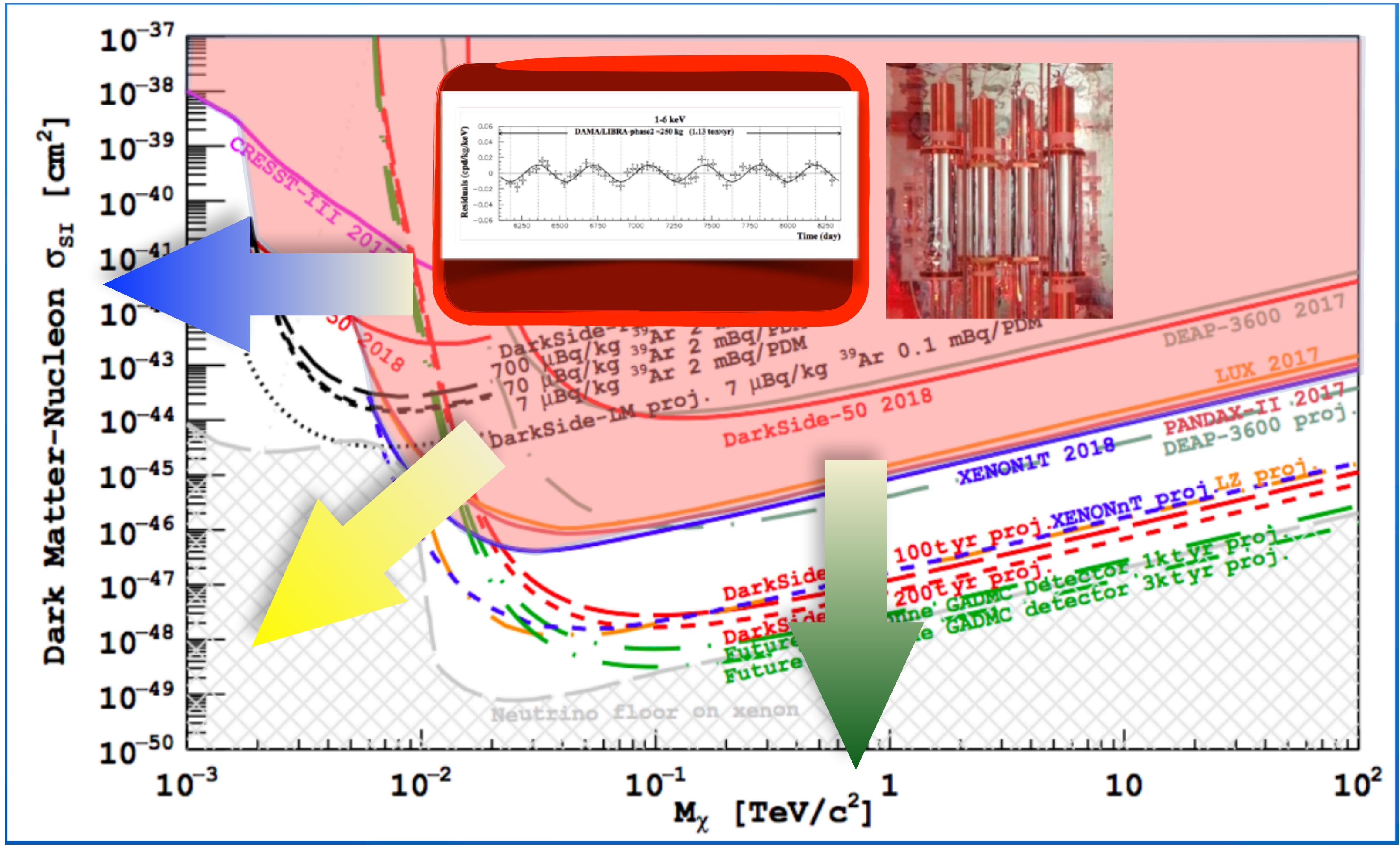




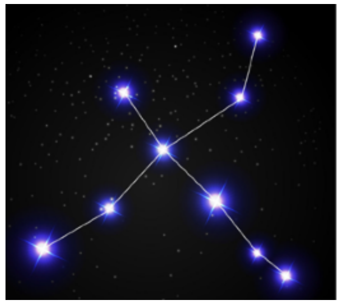
- Small mass detectors with light nuclei
- 0.1-1 kg enough to explore uncharted territories
- 10^4-10^5 rejection @ 10 keV
- Trend to reduce module mass & background discrimination to reach lower threshold

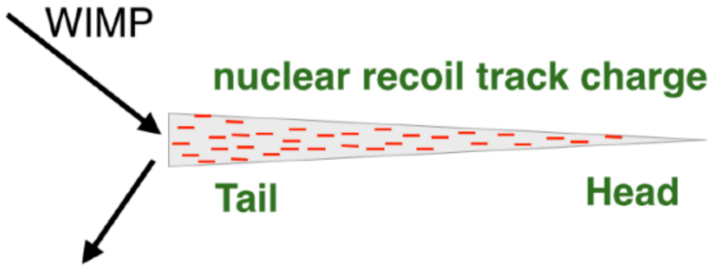


- PICO dominating SD searches
- Insensitive to e/γ by construction (10^{10} rejection @ 3 keV)

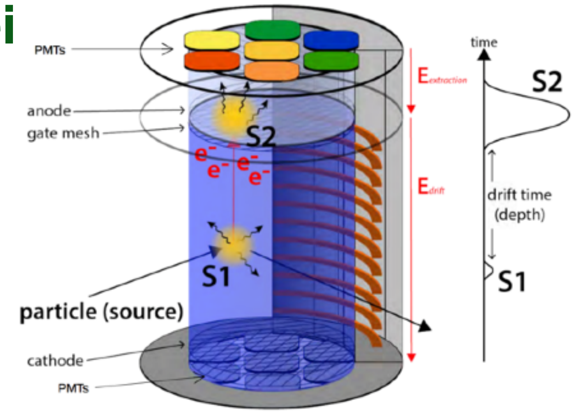


The "third way": directional tracking detectors for both SI and SD





- Ton scale detector with heavy nuclei
- 10^3 (LXe) - 10^{7-10} (LAr) rejection
- Can go to M_{WIMP} <10 GeV only completely giving up background discrimination (S_2 only analyses)
- Eventually, will be dominated by neutral background also at high masses



WIMP searches as from CYGNUS simulations

erc

Simulation parameters

Gas mixture	SF_6	$He:SF_6$	$He:SF_6$	$He:CF_4$
Gas pressure [Torr]	20	740:20	755:5	740:20
W [eV/ion pair]	35.5	38.0	35.6	38.0
Transverse diffusion, σ_T [$\mu m/\sqrt{cm}$]	116.2	78.6	78.6	213.0
Longitudinal diffusion, σ_z [$\mu m/\sqrt{cm}$]	116.2	78.6	78.6	148.0
Drift velocity [mm/μs]	0.140	0.140	140	24.45
Mean avalanche gain	9×10^3	9×10^3	9×10^3	10^6

To be updated with "optical 3D", i.e. CYGNO-like

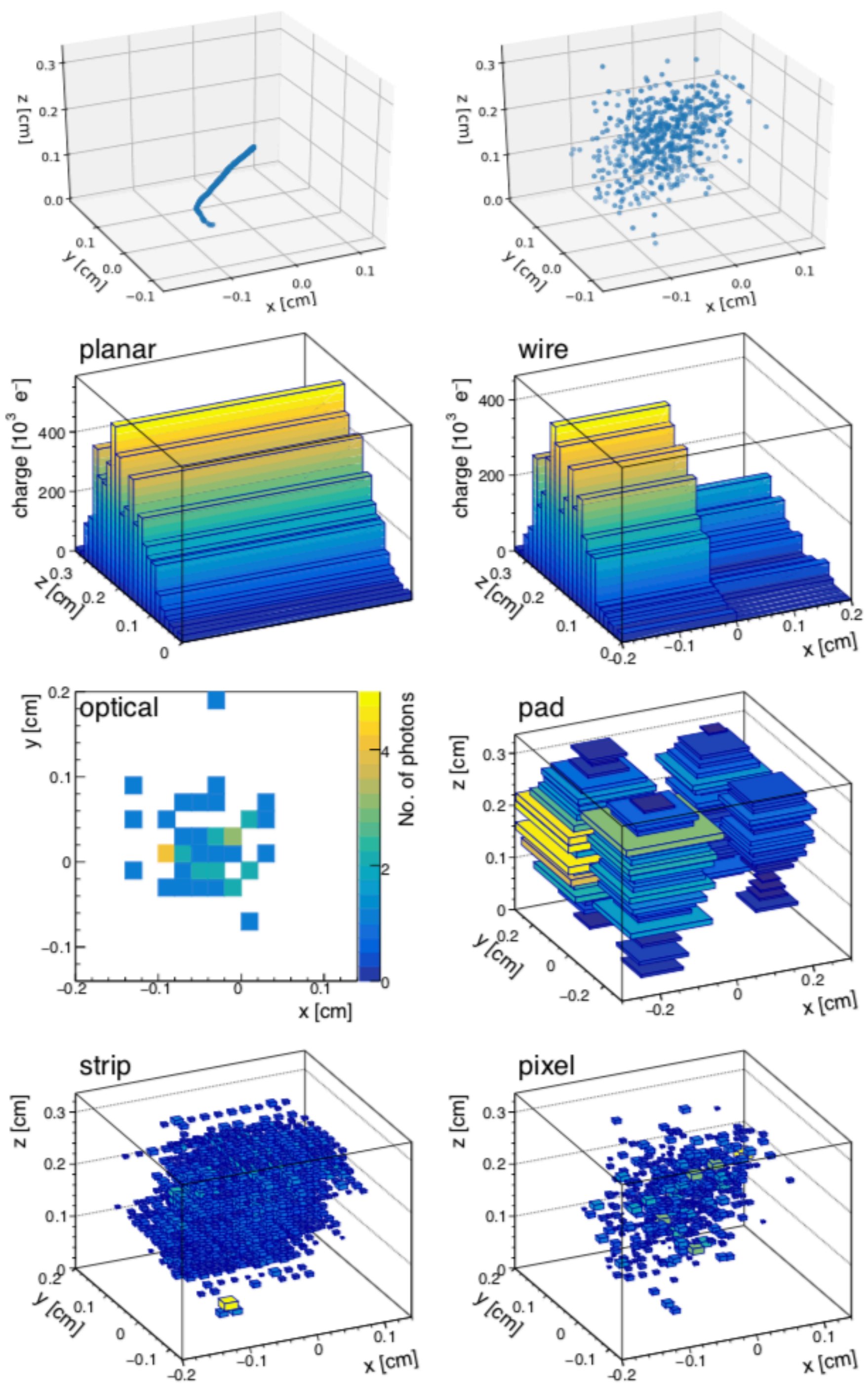
Readout type	Dimensionality	Segmentation ($x \times y$)	Capacitance [pF]	σ_{noise} in 1 μs [e^-]	Threshold/σ_{noise}
planar	1d (z)	10 cm × 10 cm	3000	18000	3.09
wire	2d (yz)	1 m wires, 2 mm pitch	0.25	800	4.11
pad	3d (xyz)	3 mm × 3 mm	0.25	375	4.77
CCD	2d (xy)	200 μm × 200 μm	n/a	20 photons	5.77
strip	3d (xyz)	1 m strips, 200 μm pitch	500	2800	4.61
pixel	3d (xyz)	200 μm × 200 μm	0.012 - 0.200	42	5.77

WIMP searches as from CYGNUS simulations

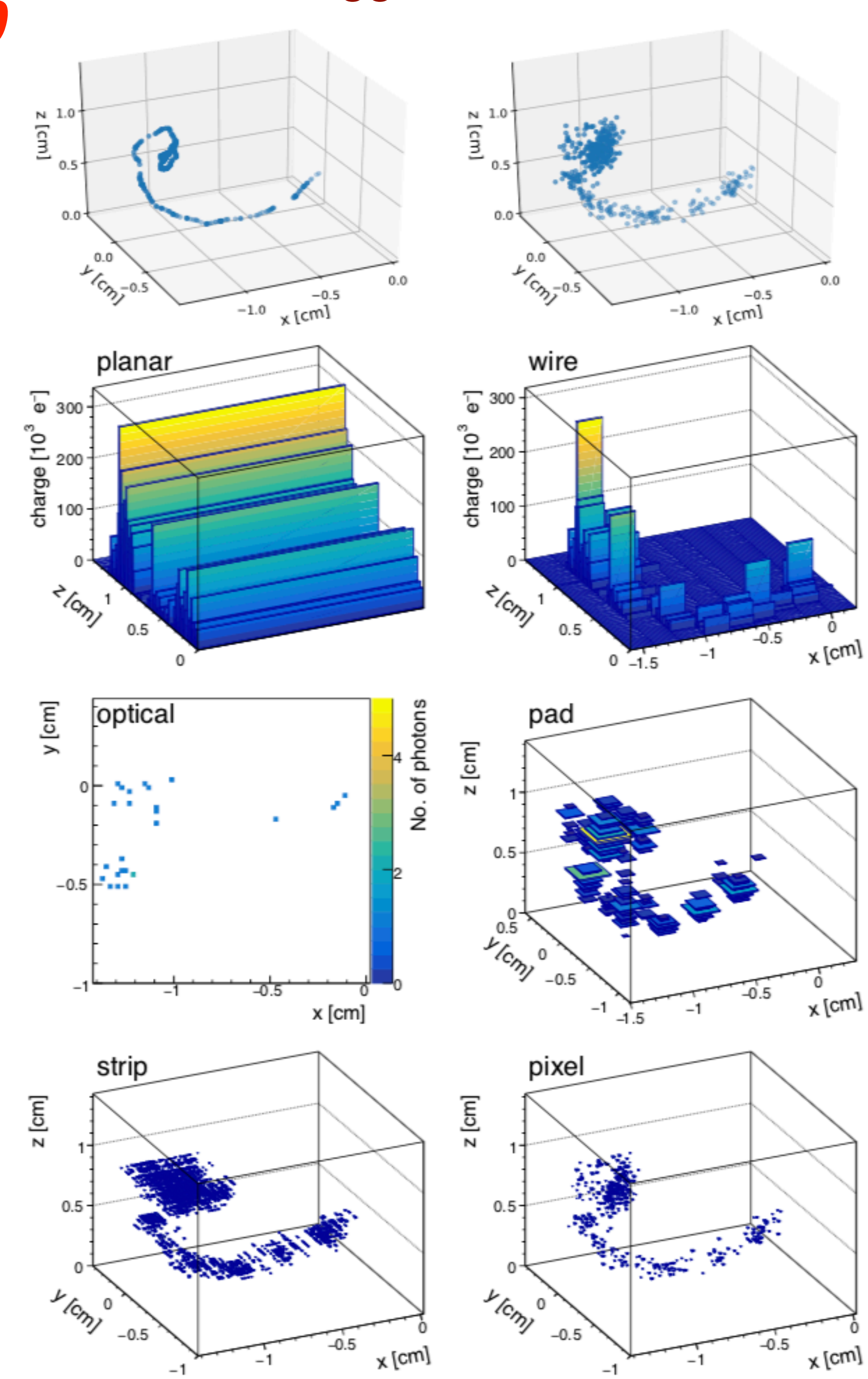
Recoils examples

He:SF$_6$ 740:20

20 keV$_{ee}$ He recoil

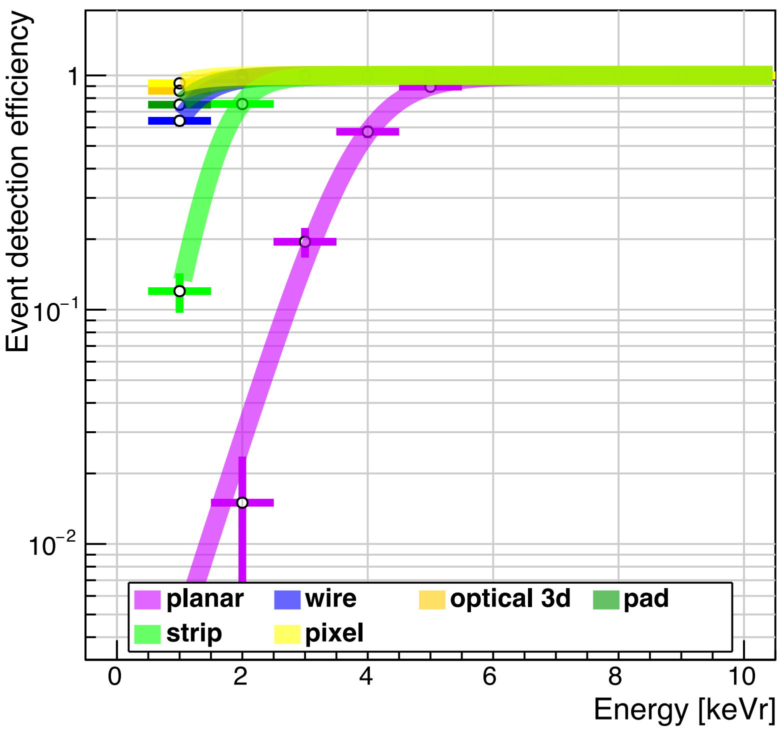


20 keV$_{ee}$ electron recoil



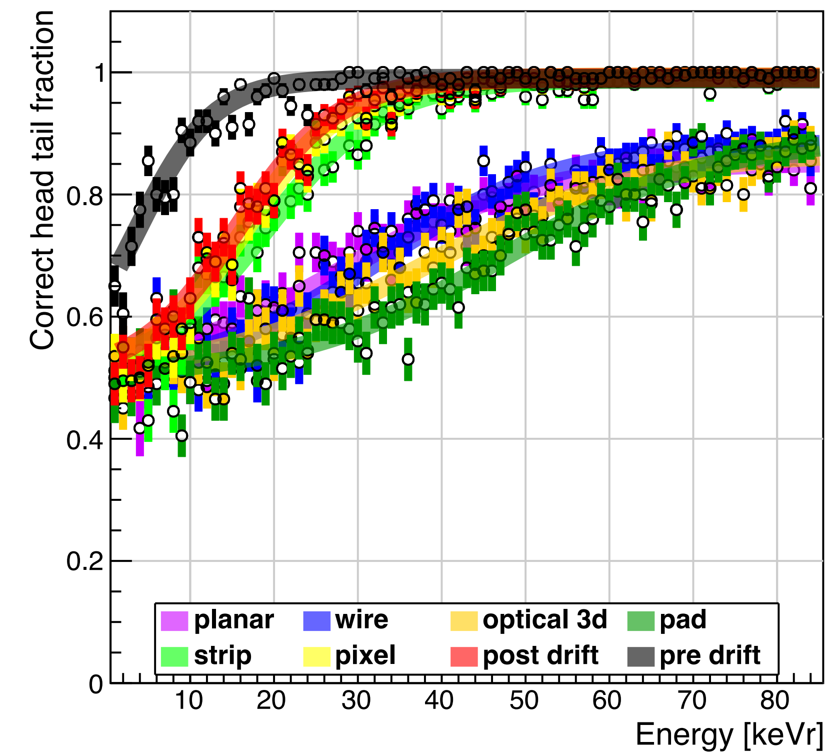
WIMP searches as from CYGNUS simulations

Some readout performances (to be updated with tonight's plots)

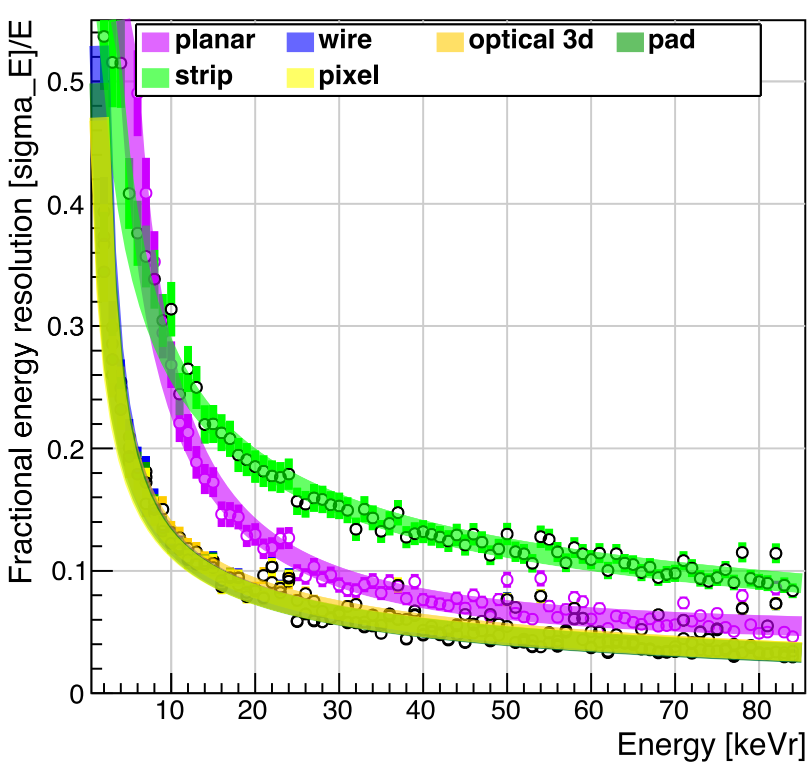


He:SF$_6$ 740:20

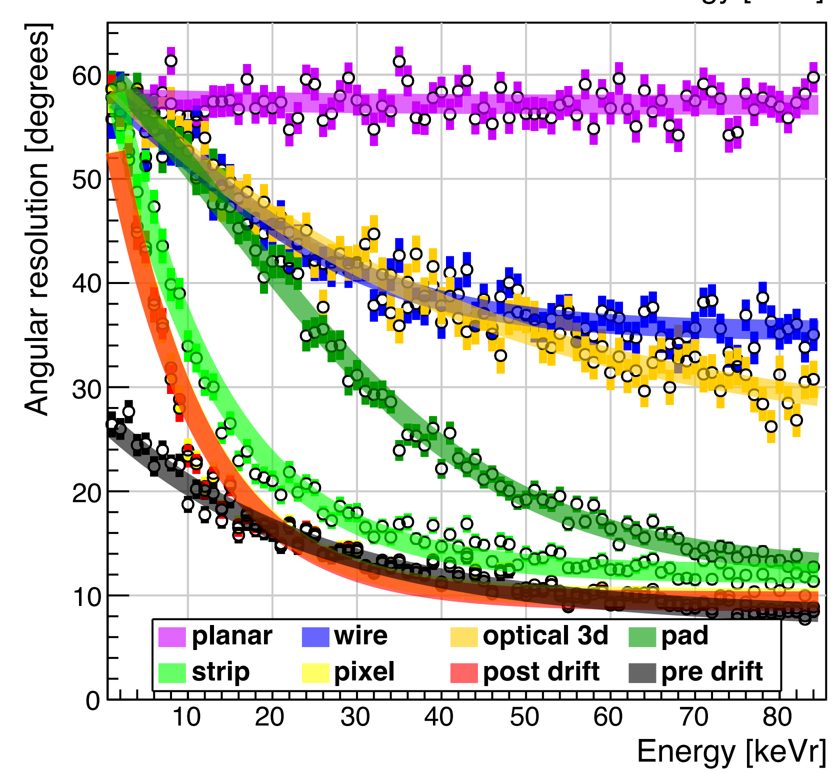
For optical 3D, He:CF$_4$ 740:20 is used



PRELIMINARY



Message: after 3D pixels and strips, optical 3D is the best (due to loss of gain with photons production + 1/r^2)

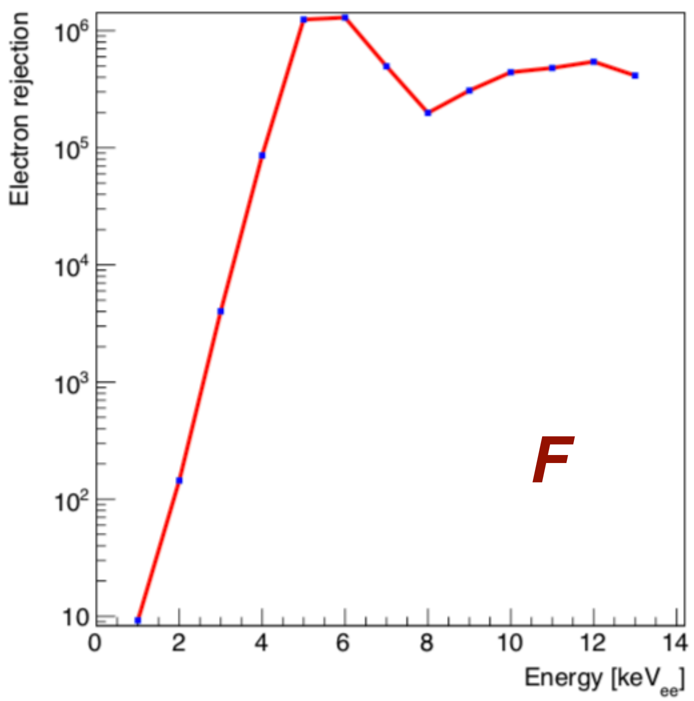


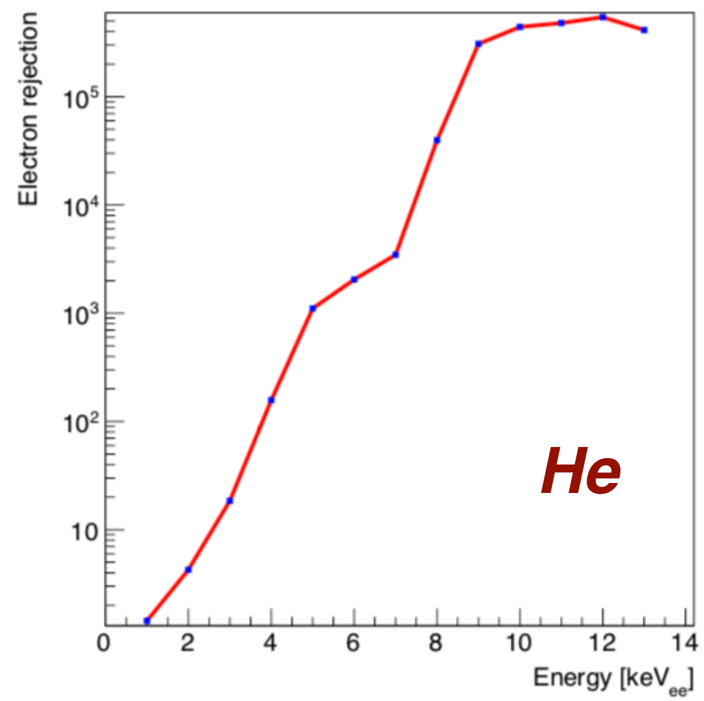
WIMP searches as from CYGNUS simulations

Expected electron rejection factor using only fitted track length vs energy

can be improved

Before drift



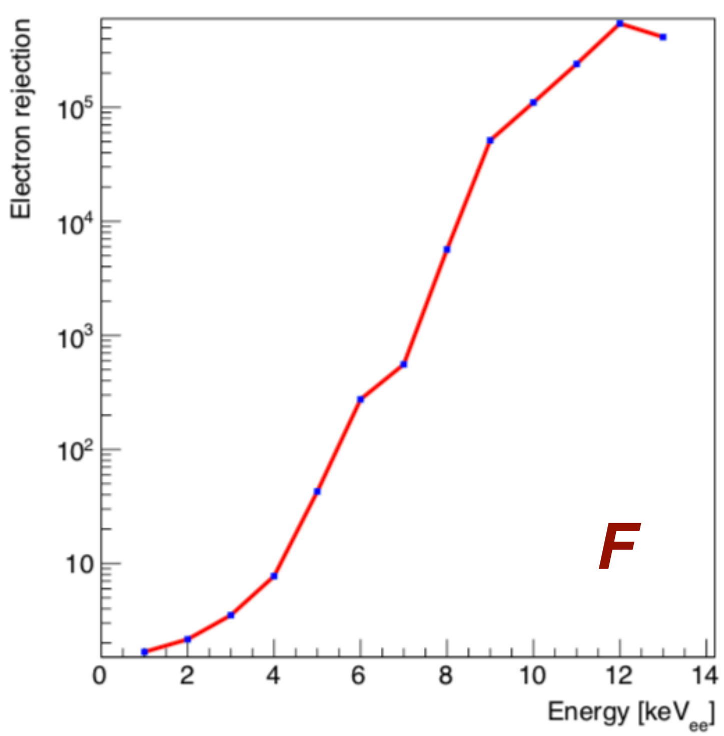


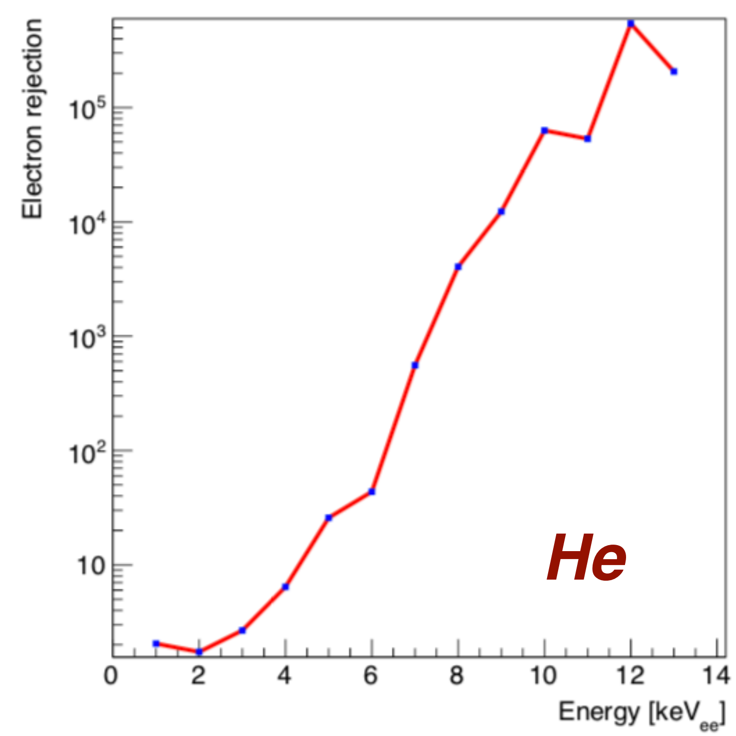
To notice: more difficult to distinguish He than F from e^- at low energies!

He:SF_6 740:20

To much CPU to do this for all readouts

After 25 cm drift



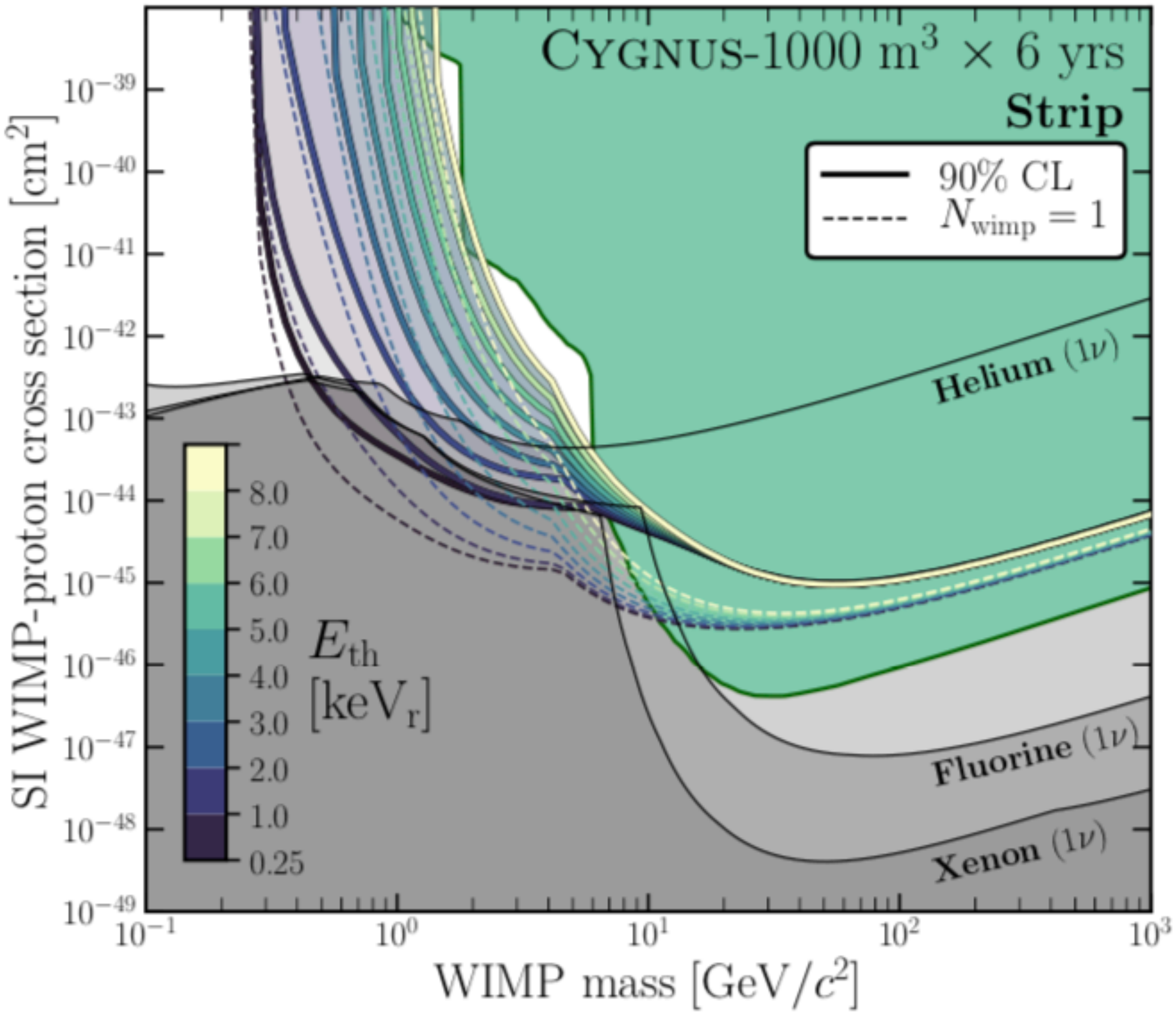


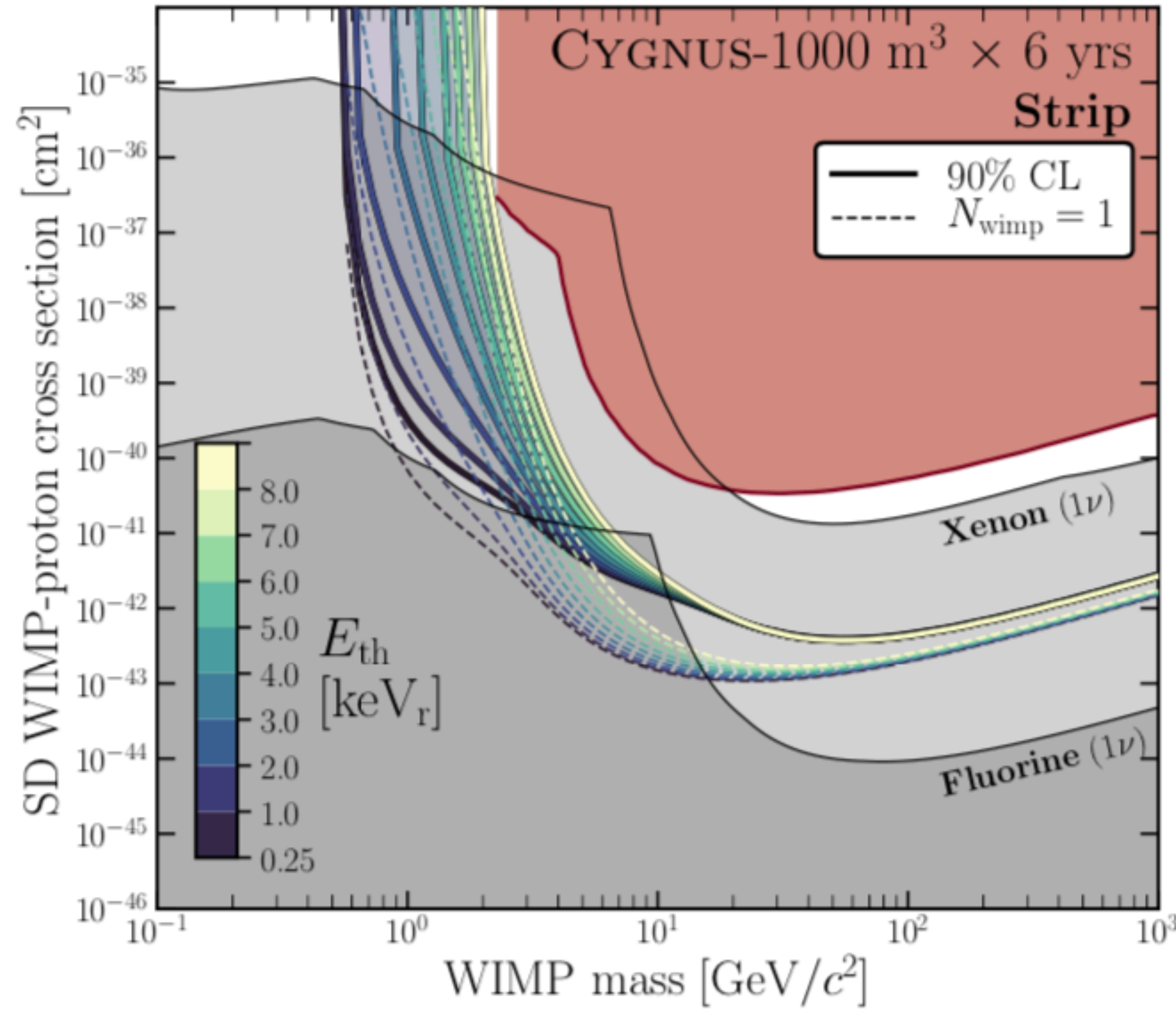
Message: bkg discrimination possible at O(keV$_{ee}$)

WIMP searches as from CYGNUS simulations

Final message of the paper:

need to demonstrate on actual detector rejection performances



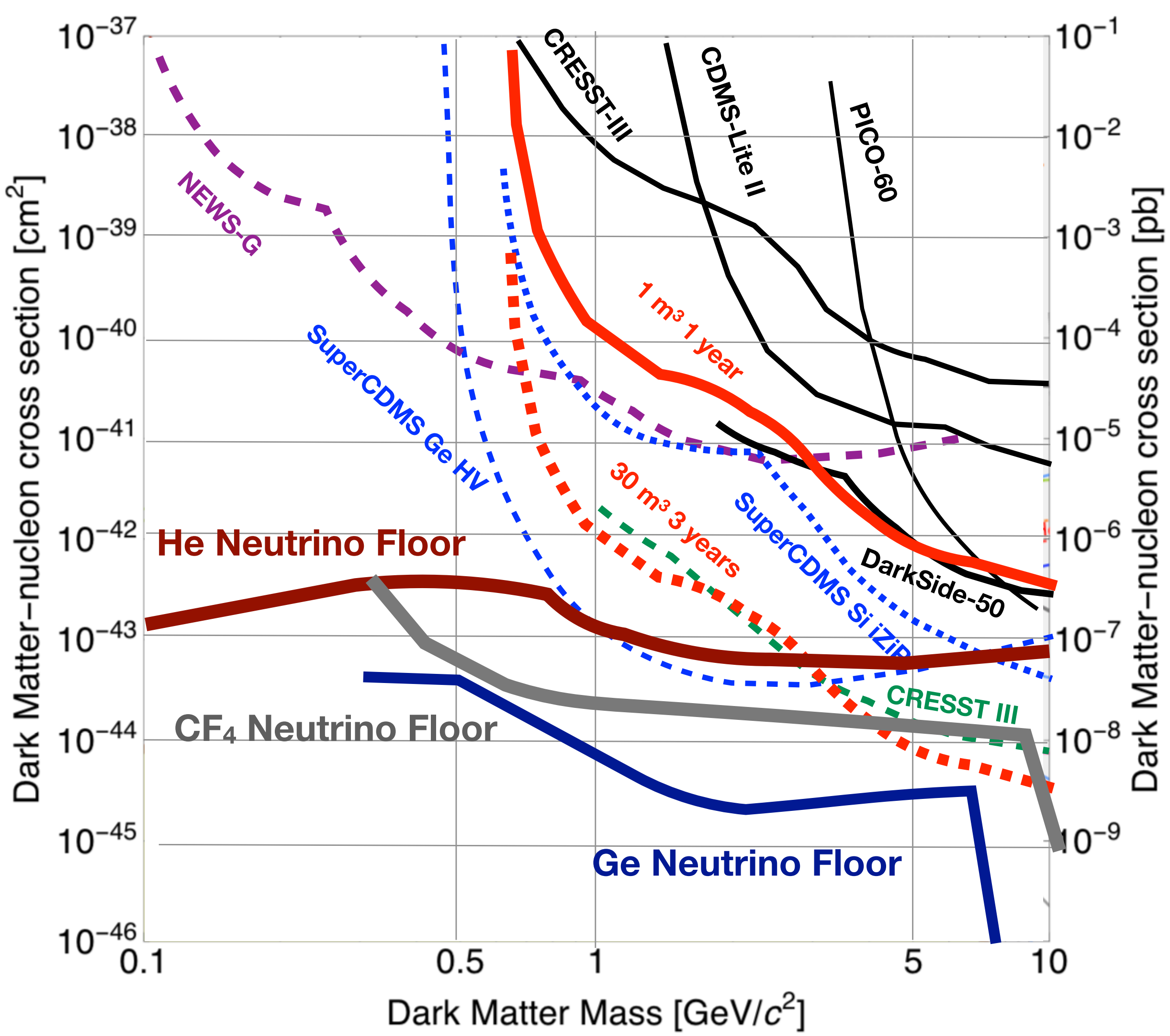


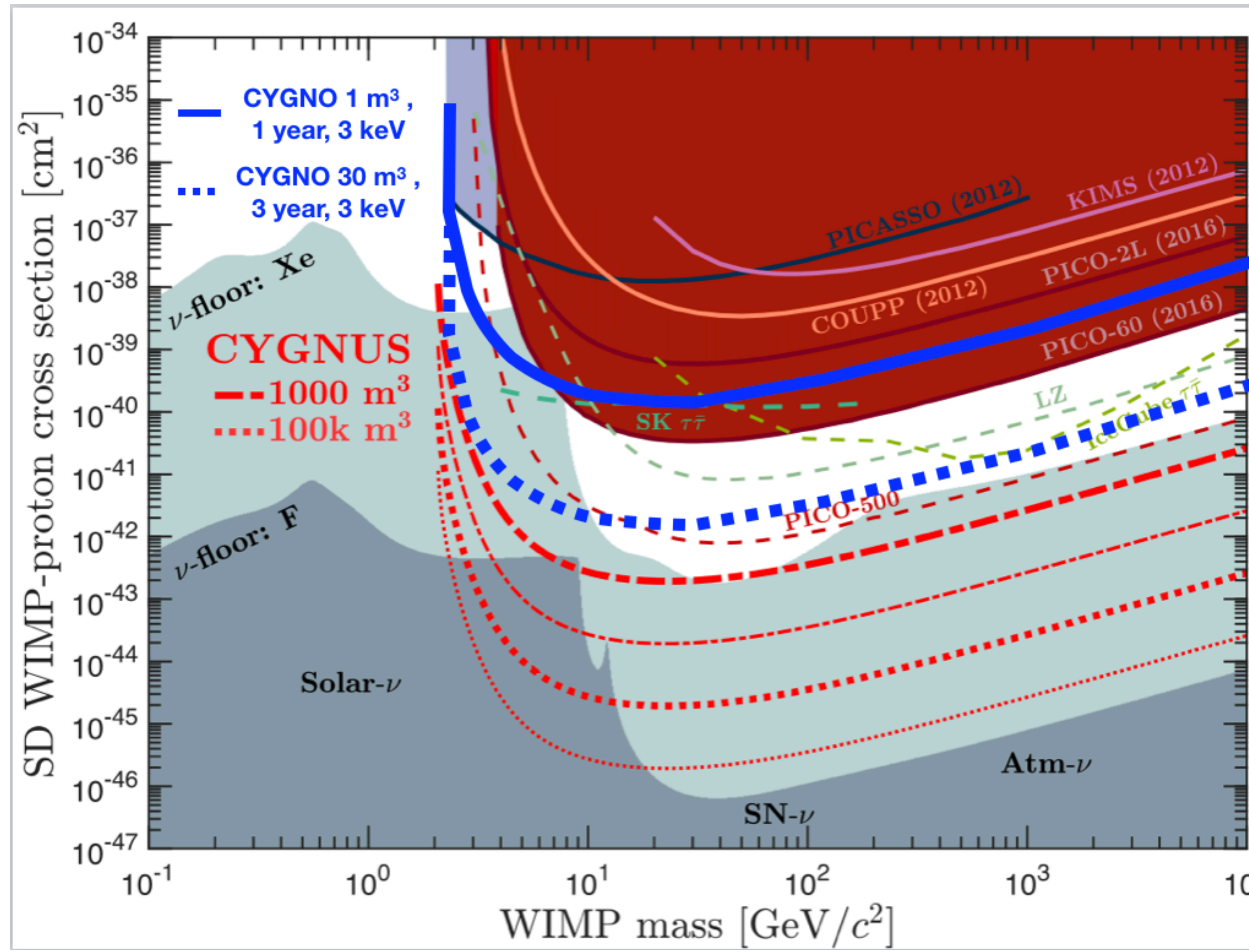
Energy threshold: hard cut is assumed, that can get rid out of all electronic background, i.e. zero electronic background assumed

Neutrino background from coherent scattering on nuclei included

CYGNO prospects sensitivity at low WIMP mass

PHASE-1
PHASE-2
Published limits
Expected limits
PHASE-1
PHASE-2





PRELIMINARY

Zero background assumed

Energy threshold: 1 keV_{nr} on He, 2 keV_{nr} on C and 3 keV_{nr} on F

PRELIMINARY

CYGNUS 1000 m^3 background studies

External background and vessel options

10 x 10 x 10 m^3 with 20 Torr SF_6

Material	Width (cm)	Rock γ recoils (keV^{-1} yr^{-1})	Vessel γ recoils (keV^{-1} yr^{-1})	Total γ recoils (keV^{-1} yr^{-1})	^{238}U limit (mBq kg^{-1})	^{232}Th Limit (mBq kg^{-1})	^{40}K Limit (mBq kg^{-1})
Steel	5	$3.8 \pm 0.3 \times 10^6$	$6.6 \pm 0.6 \times 10^5$	$4.4 \pm 0.4 \times 10^6$	0.003	0.0045	0.08
	10	$6.0 \pm 1.0 \times 10^5$	$7.2 \pm 0.9 \times 10^5$	$1.32 \pm 0.19 \times 10^6$	0.003	0.004	0.06
	20	$2.1 \pm 0.6 \times 10^4$	$7.3 \pm 1.4 \times 10^5$	$7.5 \pm 1.5 \times 10^5$	0.0027	0.0042	0.075
	30	$4.6 \pm 3.0 \times 10^3$	$6.3 \pm 1.5 \times 10^5$	$6.3 \pm 1.5 \times 10^5$	0.003	0.0053	0.053
Titanium	5	$1.0 \pm 0.2 \times 10^7$	$< 2.9 \pm 0.2 \times 10^5$	$< 1.0 \pm 0.2 \times 10^7$	0.003	0.0046	0.06
	10	$3.8 \pm 0.9 \times 10^6$	$< 4.13 \pm 0.36 \times 10^5$	$< 4.2 \pm 0.9 \times 10^6$	0.0022	0.0031	0.05
	20	$6.6 \pm 1.1 \times 10^5$	$< 4.17 \pm 0.53 \times 10^5$	$1.08 \pm 0.16 \times 10^6$	0.002	0.0035	0.041
	30	$< 4.8 \pm 3.1 \times 10^4$	$< 5.11 \pm 0.71 \times 10^5$	$< 5.6 \pm 1.0 \times 10^5$	0.0017	0.0027	0.041
Copper	5	$2.3 \pm 0.2 \times 10^6$	$< 1.57 \pm 0.17 \times 10^4$	$2.3 \pm 0.2 \times 10^6$	0.0057	✓	✓
	10	$4.0 \pm 0.9 \times 10^5$	$< 1.60 \pm 0.24 \times 10^4$	$4.1 \pm 0.9 \times 10^5$	0.0058	✓	✓
	20	$9.5 \pm 4.0 \times 10^3$	$< 1.58 \pm 0.33 \times 10^4$	$< 2.53 \pm 0.73 \times 10^4$	0.0056	✓	✓
	30	$5.1 \pm 3.3 \times 10^2$	$< 1.58 \pm 0.43 \times 10^4$	$< 1.6 \pm 0.5 \times 10^4$	0.0053	✓	✓
Acrylic	5	$2.5 \pm 0.3 \times 10^8$	$3.44 \pm 0.32 \times 10^5$	$2.5 \pm 0.3 \times 10^8$	0.0002	0.0017	0.037
	10	$1.90 \pm 0.19 \times 10^8$	$5.97 \pm 0.57 \times 10^5$	$1.90 \pm 0.19 \times 10^8$	5.7×10^{-4}	9.3×10^{-4}	0.024
	20	$9.7 \pm 1.4 \times 10^7$	$1.14 \pm 0.12 \times 10^6$	$9.8 \pm 1.4 \times 10^7$	3.4×10^{-4}	5.4×10^{-4}	0.011
	30	$4.1 \pm 0.9 \times 10^7$	$1.12 \pm 0.14 \times 10^6$	$4.2 \pm 0.9 \times 10^7$	3.2×10^{-4}	4.9×10^{-4}	0.013

Goal: achieve <= 10^4 gamma/year/keV

Material	Thickness (mm)	Gamma recoil rate (yr^{-1})	Neutron recoil rate (yr^{-1})
Acrylic	30	$3.57 \pm 0.03 \times 10^5$	0.40 ± 0.02
Copper	12	$< 1.50 \pm 0.02 \times 10^4$	$< 0.12 \pm 0.02$
Steel	10	$5.75 \pm 0.08 \times 10^5$	5.6 ± 1.0
Titanium	8	$< 2.21 \pm 0.02 \times 10^5$	$< 4.0 \pm 0.7$
Titanium	6	$< 1.88 \pm 0.02 \times 10^5$	$< 2.4 \pm 0.4$

740:20 He:SF_6

CYGNUS 1000 m^3 background studies

Internal background and readout options

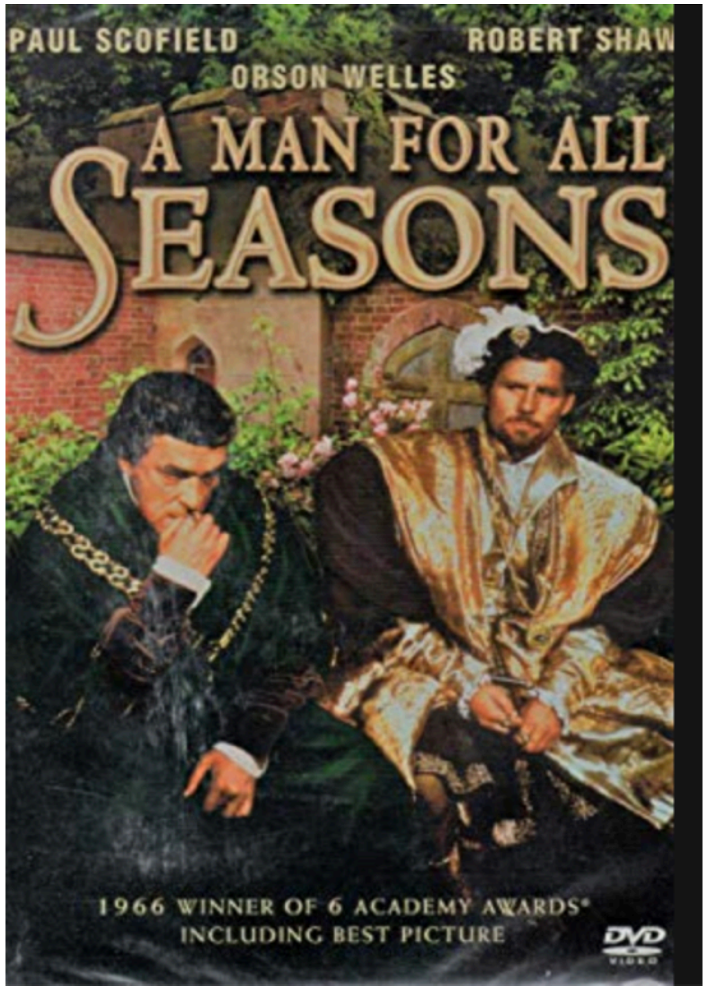
Readout	Material (width)	γ recoils (keV^{-1} yr^{-1})	U limit ($mBq\ kg^{-1}$)	Th limit ($mBq\ kg^{-1}$)	K limit ($mBq\ kg^{-1}$)
THGEM	Acrylic (1 mm)	$3.3\pm0.7\times10^4$	✓	✓	0.54
THGEM	Copper (0.1 mm ×2)	$< 1.5\pm0.3\times10^3$	✓	✓	✓
μ-PIC	Polyimide (1 mm)	$< 1.3\pm0.2\times10^7$	0.12	0.09	0.12
GEM	Kapton (50 microns)	$1.57\pm0.02\times10^5$	✓	✓	3.65
Wires	Steel (50 μm)	1.8 ± 0.3	✓	✓	✓
Wires	Acrylic (2 cm × 1 cm)	$2.4\pm0.1\times10^4$	✓	✓	0.88
Pixel chip	Silicon (400 μm)	$< 2.55\pm0.19\times10^5$	0.26	0.29	0.46
Pixel chip	Copper (3.9 μm)	$< 24\pm2$	✓	✓	✓
Pixel chip	Aluminum (4.5 μm)	$< 937\pm77$	✓	✓	✓
Resistors	Ceramic	$2.5\pm1.3\times10^4$	0.13	✓	✓

Goal: achieve <= 10^4 gamma/year/keV

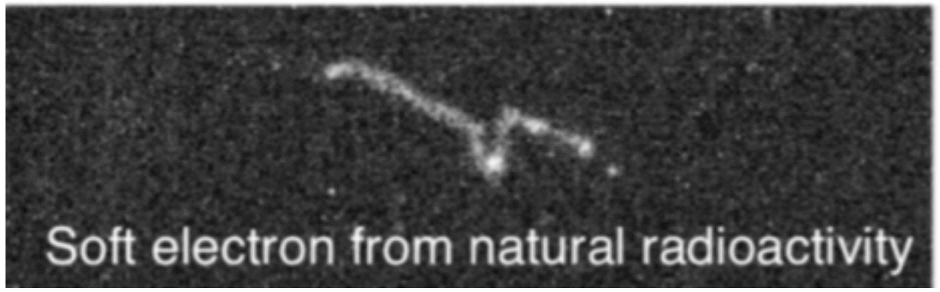
Directionality

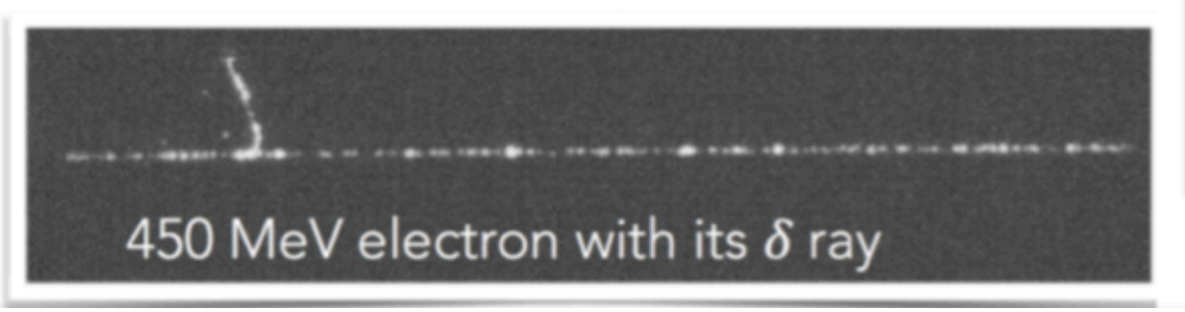
“a tool for all seasons”

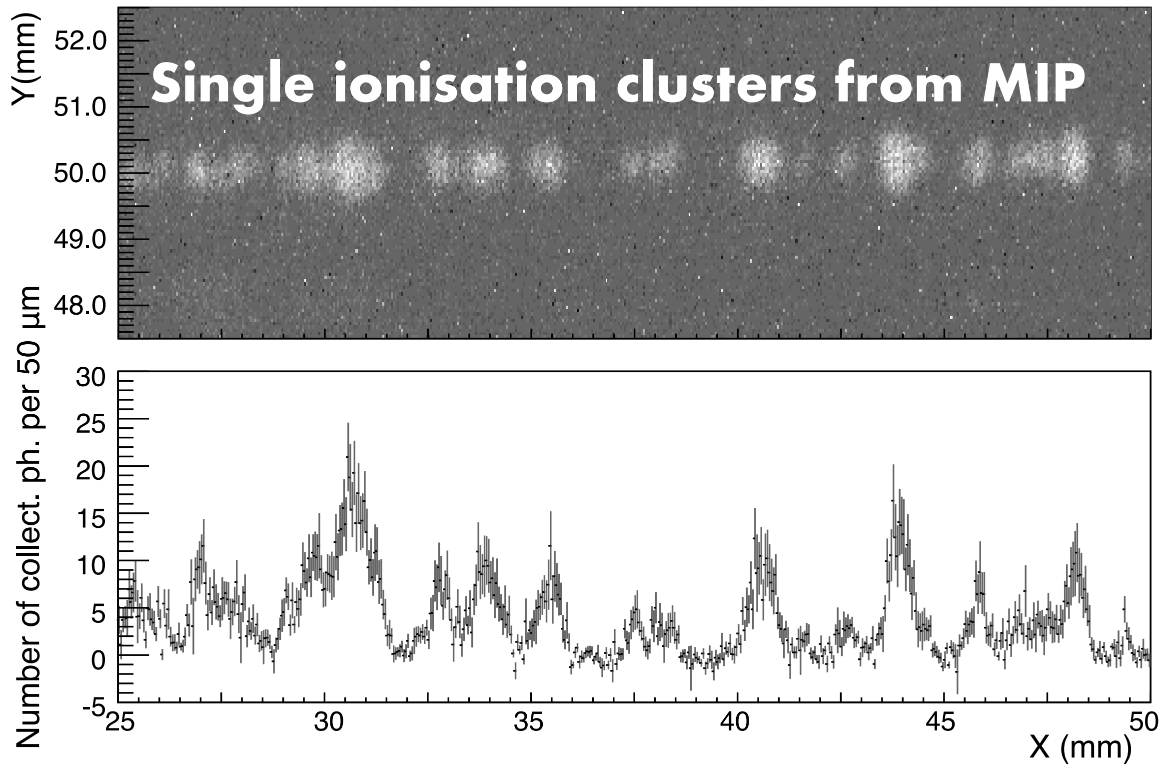
All the directionality features are pertinent to <u>any particle</u> possessing a preferential direction of arrival on Earth and interacting with nuclei OR electrons through a process retain (or correlated to) the particle arrival direction

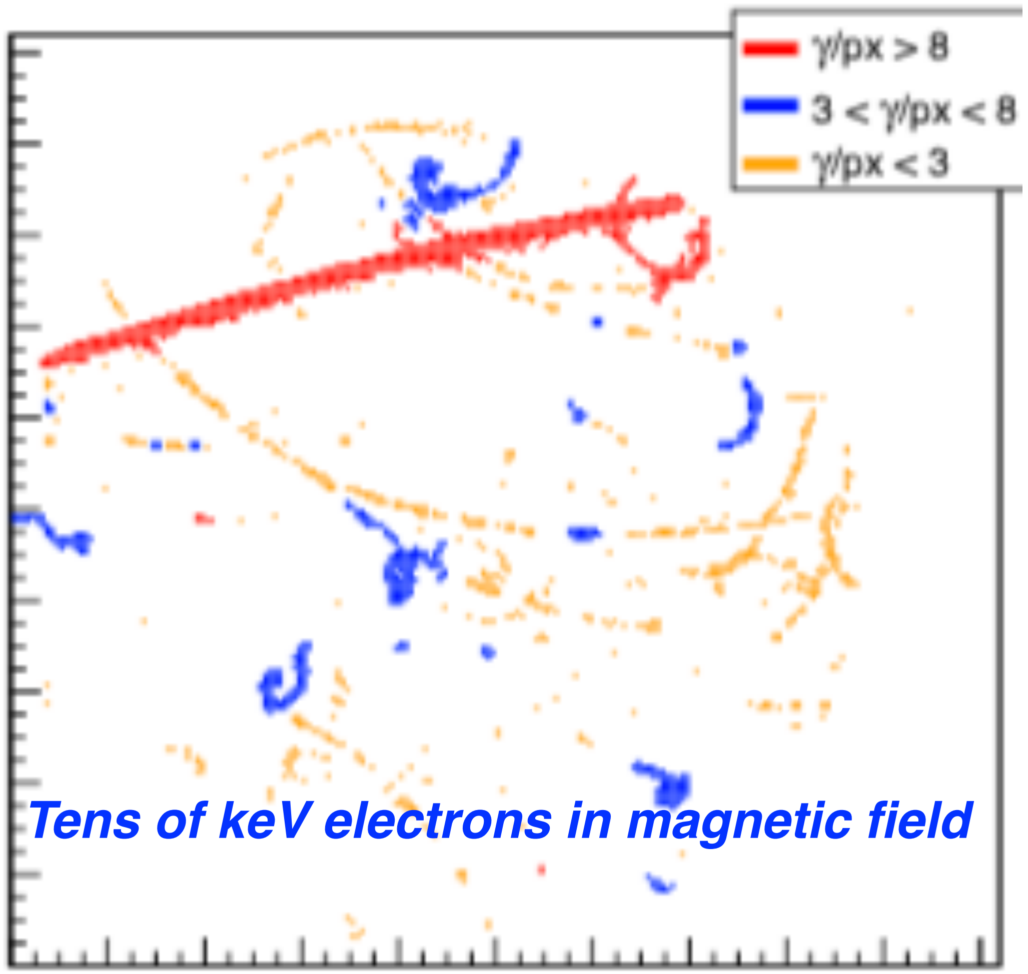


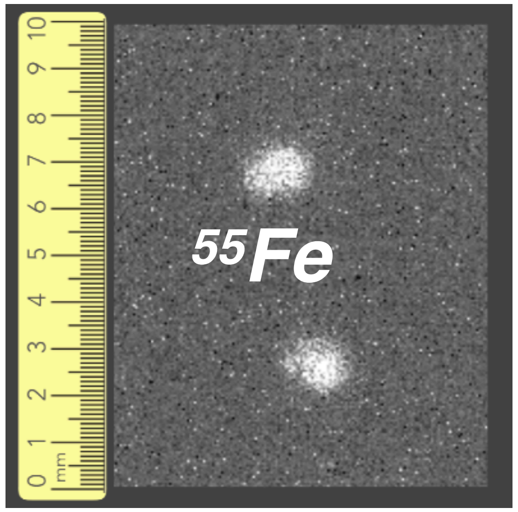
Electron recoil thresholds











Tentative detection threshold: 1-2 ionisation clusters > 100 eV

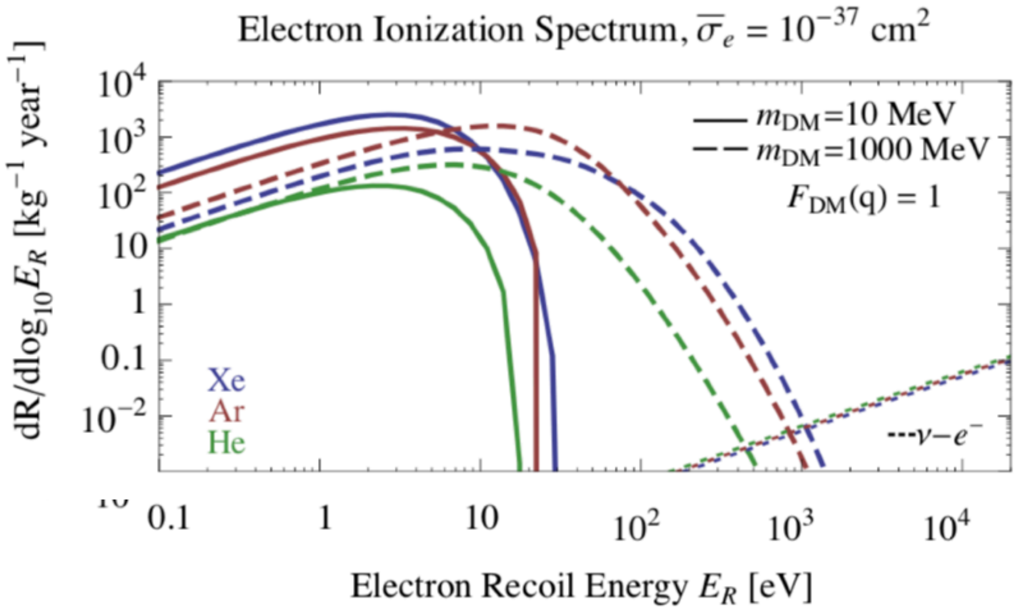
Tentative directional detection threshold: >20-30 keV

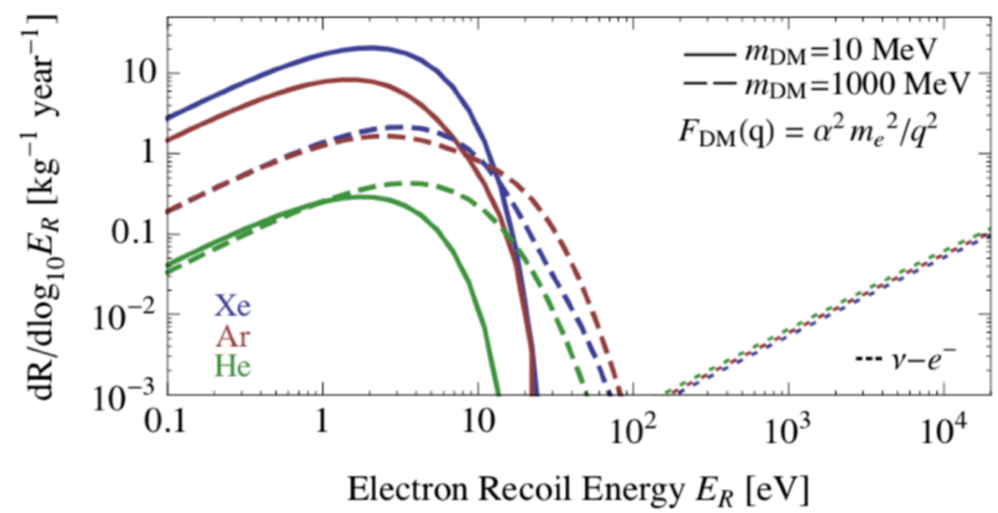
CYGNO/INITIUM beyond WIMP searches: electron recoils from MeV Dark Matter

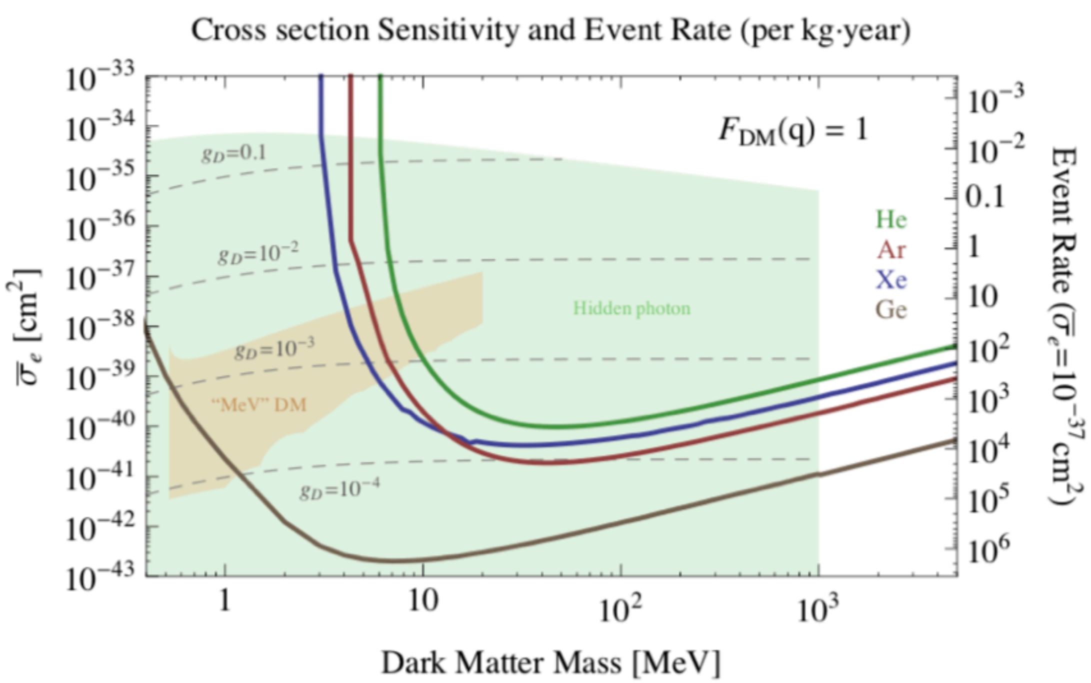
Indicative paper as illustration

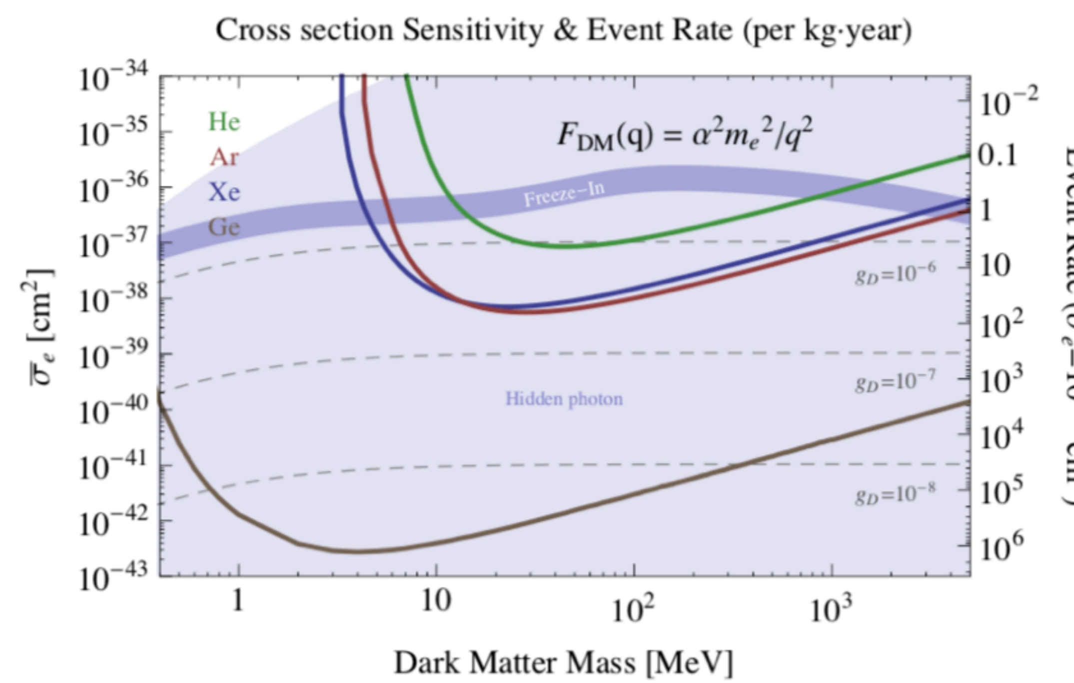
Sub-GeV DM (from arXiv:1108.5383)

$$\frac{dR_{ion}}{d\ln E_R} = N_T \frac{\rho_\chi}{m_\chi} \frac{d\langle \sigma_{ion} v\rangle}{d\ln E_R} = \frac{6.2}{A} \frac{\text{events}}{\text{kg-day}} \left(\frac{\rho_\chi}{0.4 \frac{\text{GeV}}{\text{cm}^3}}\right)\left(\frac{\overline{\sigma}_e}{10^{-40}\text{cm}^2}\right) = \frac{6.2}{A} \frac{\text{events}}{\text{kg-day}} \left(\frac{\rho_\chi}{0.4 \frac{\text{GeV}}{\text{cm}^3}}\right)\left(\frac{\overline{\sigma}_e}{10^{-40}\text{cm}^2}\right)$$







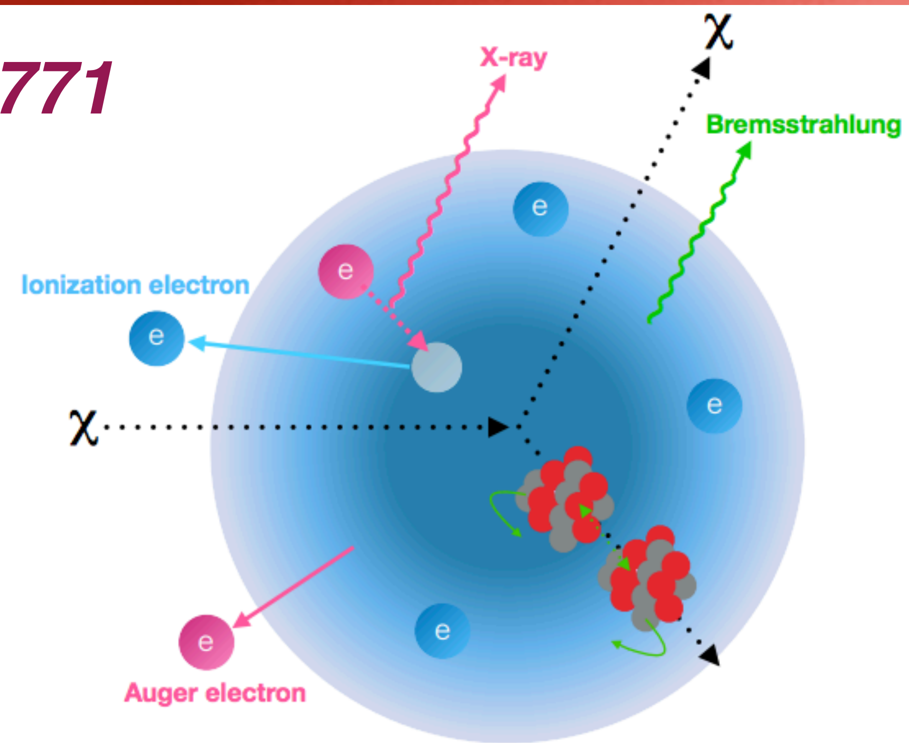


- ***CF_4 has similar number of electrons as Xe :)***
- ***Some sensitivity to 100 MeV for detection without directionality***

Take away message: we are not competitive with XENON & directionality does not help

Migdal effect: a new player in the game

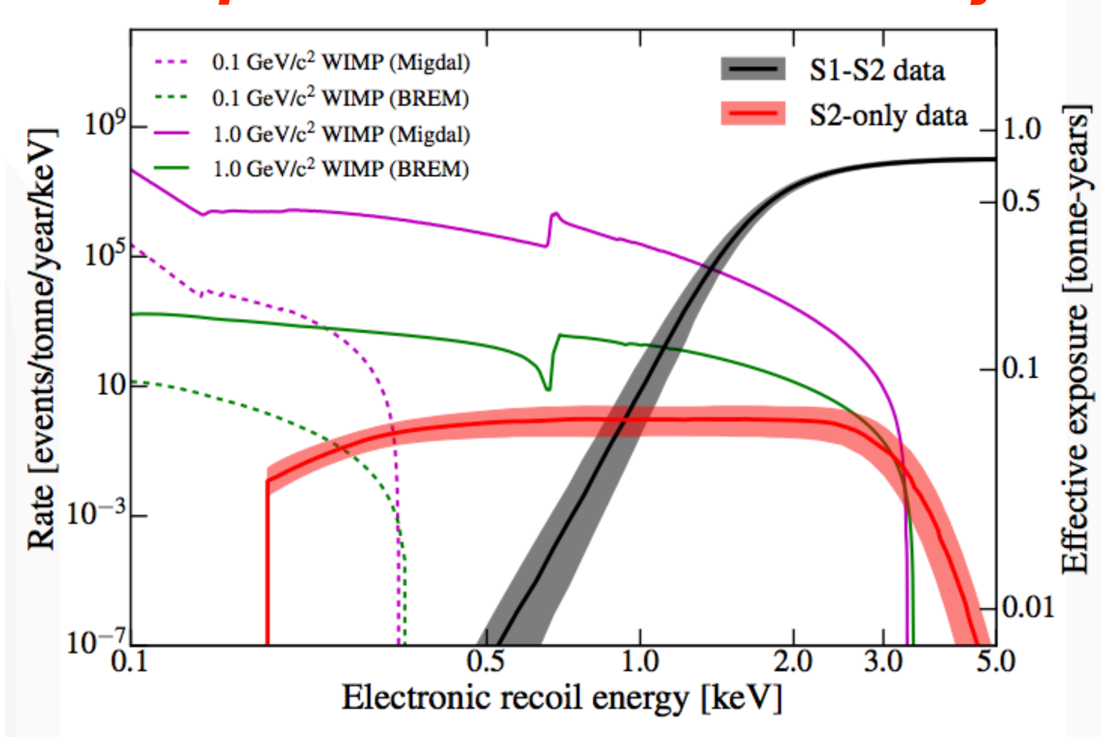
arXiv:1907.12771



Is the ionised electron emitted in the direction opposite w.r.t DM arrival, in order to conserve momentum?

…it seems yes…

Example: XENON 1T analisys

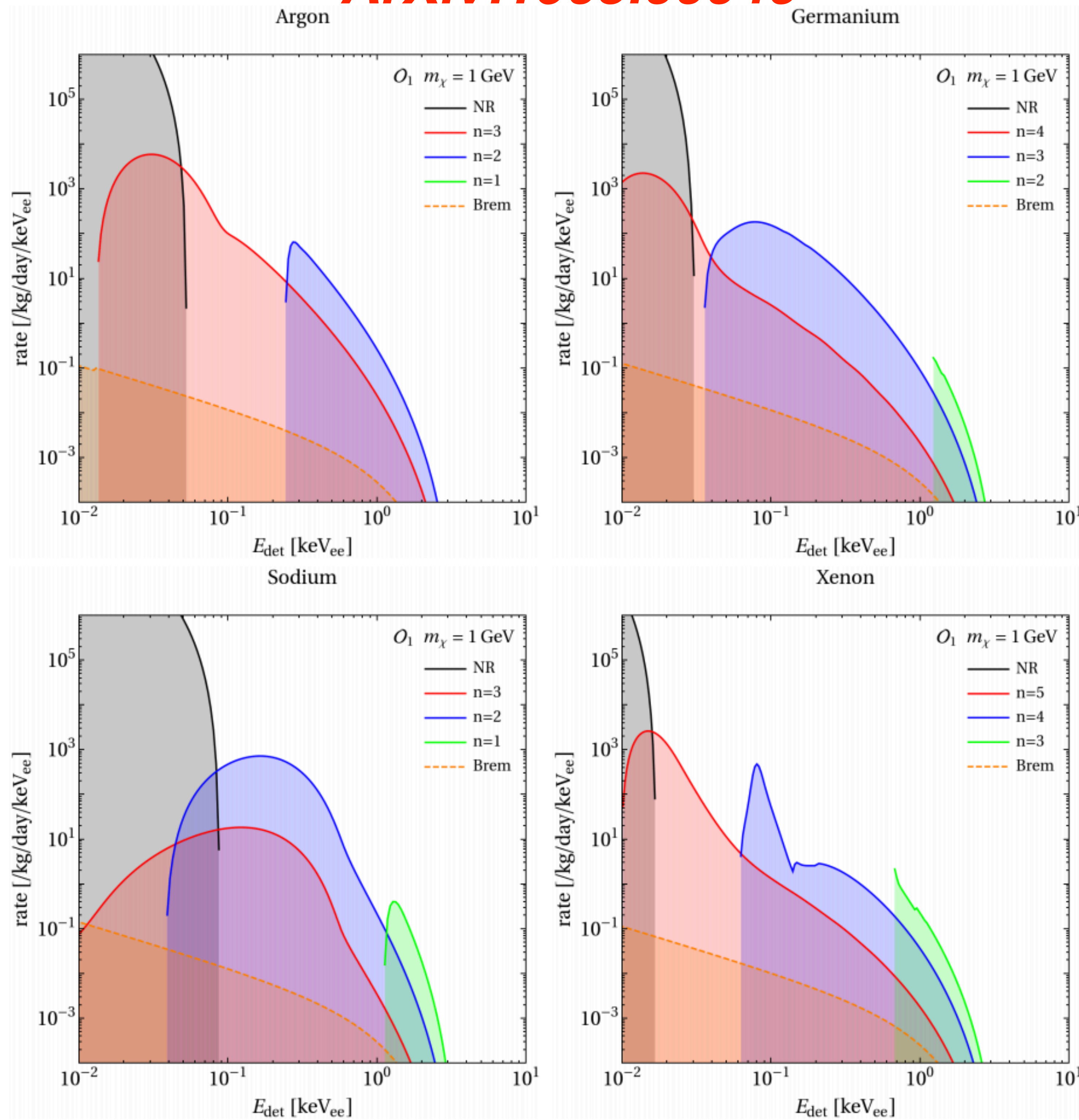


..but electron recoil directionality extremely difficult at < 3 keV…

(would need to significantly lower pressure/density)

Migdal effect: a new player in the game

ArXiv:1905.00046



Migdal effect by 1 GeV DM: C/F similar to Na, He much better!

Single electron ionisation threshold in CYGNO about 50 eV

Take away message: interesting, but we are not competitive with XENON

…nonetheless: Migdal effect has never been experimentally measured

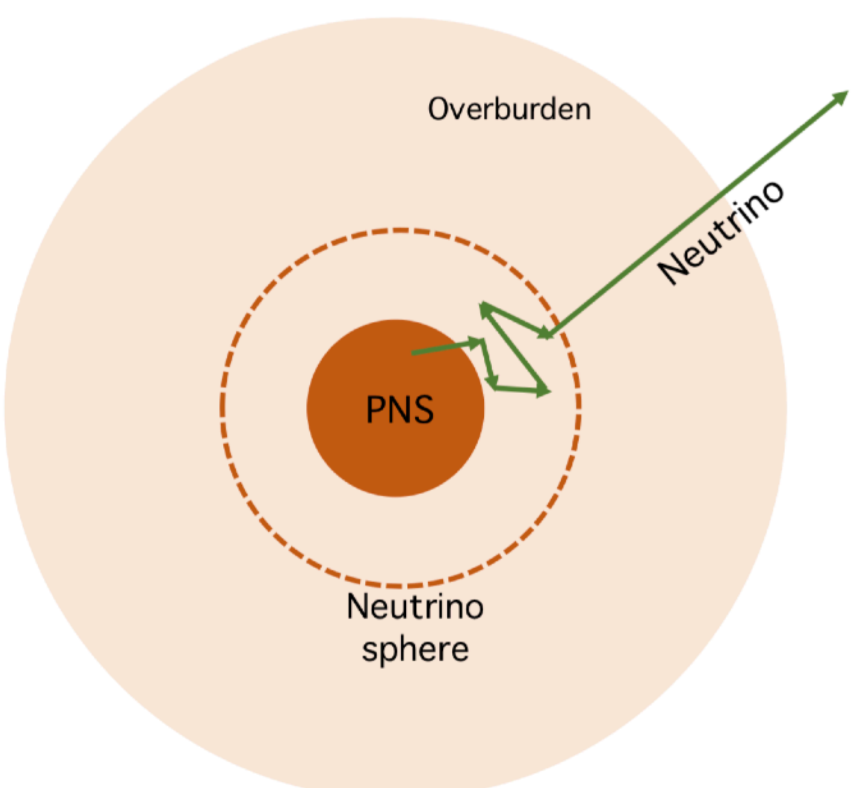
A directional detector could be able to measure it at a neutron beam facility (D. Loomba submitted proposal on this after some discussion)

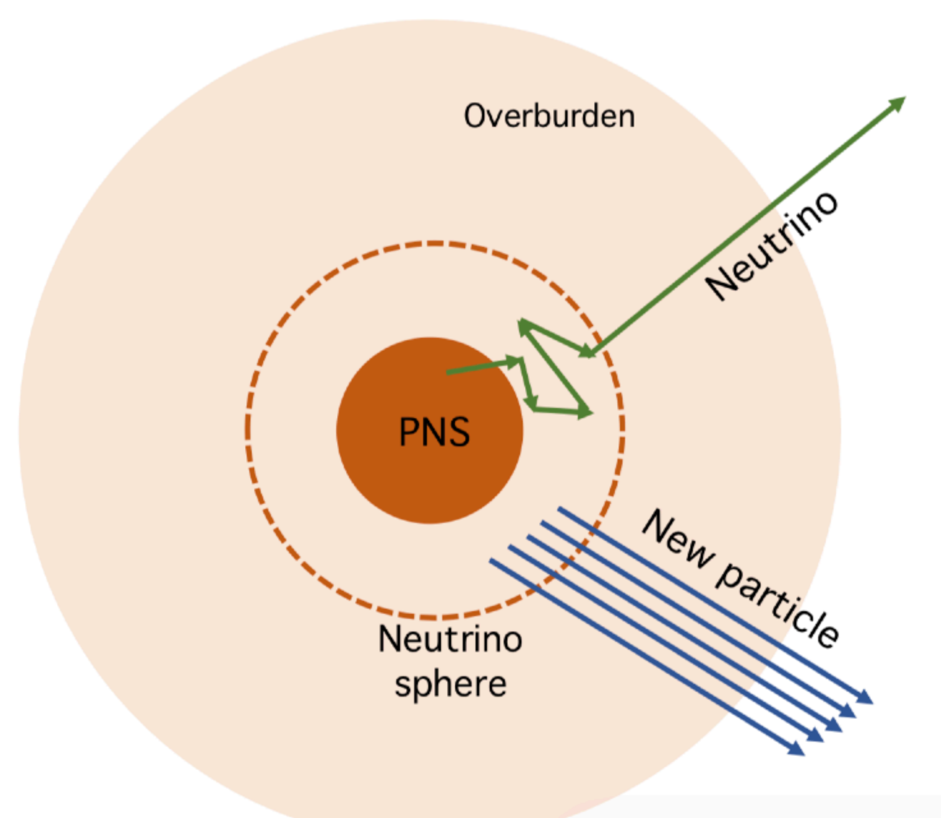
Supernova Dark Matter (SNDM): a case study

Motivation: Supernova (SN) production of MeV-scale particles is large well below the cooling bound

- Core-collapse of massive star releases **>10^{53} erg**
- Protoneutron star (PNS) has temperature ~**30 MeV**
- Neutrinos diffuse inside "neutrino sphere" then free-stream, cooling PNS

- 10-second cooling timescale observed during SN1987a
- **Cooling constraint:** new particle cannot transfer more energy than neutrinos

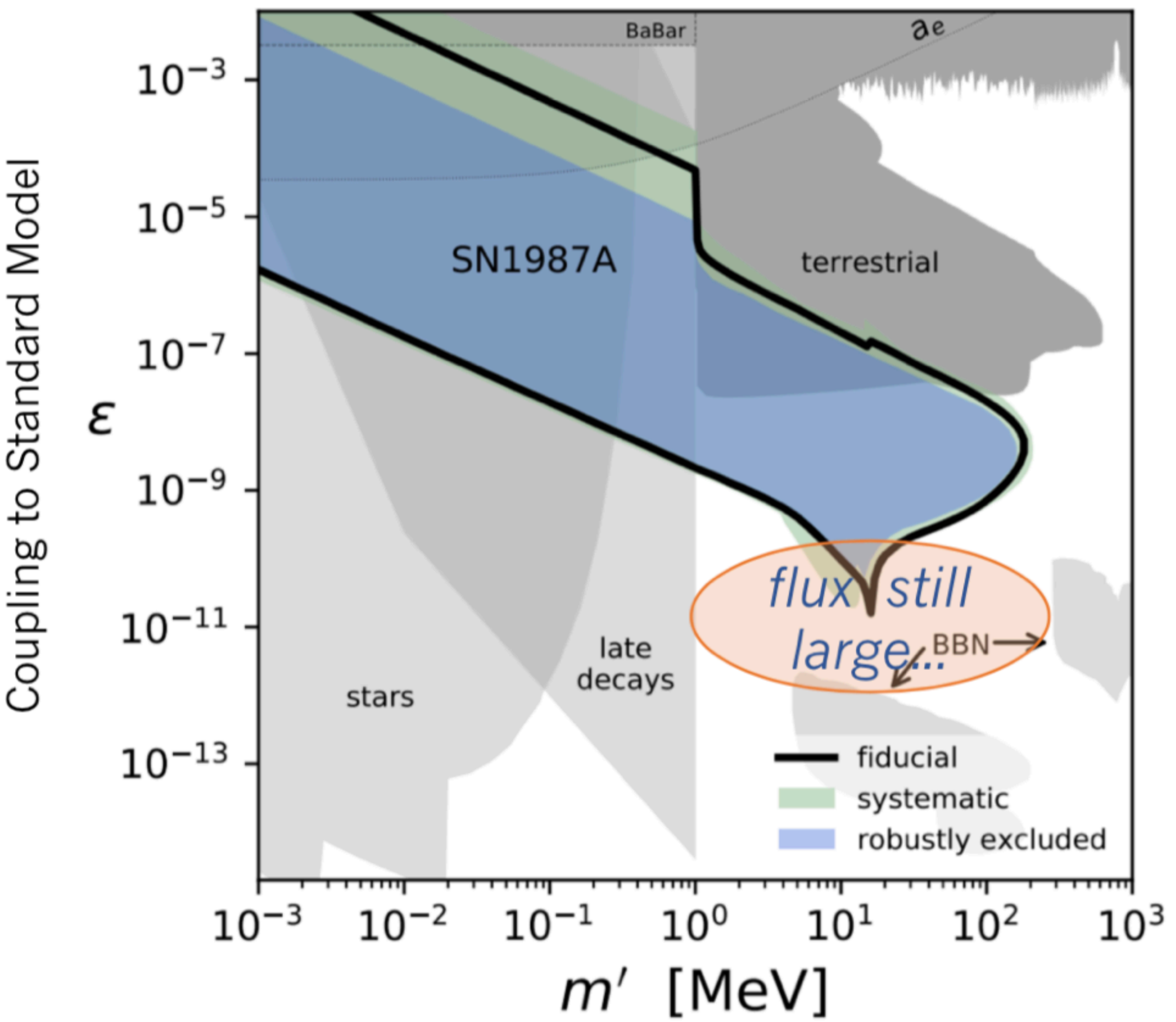




From De Rocco slides

Existing constraints

- Even below cooling limit, flux of MeV-scale particles can still be very large
- True for all models of new physics on MeV scale
- **Direct observation can constrain where cooling bound fails!**



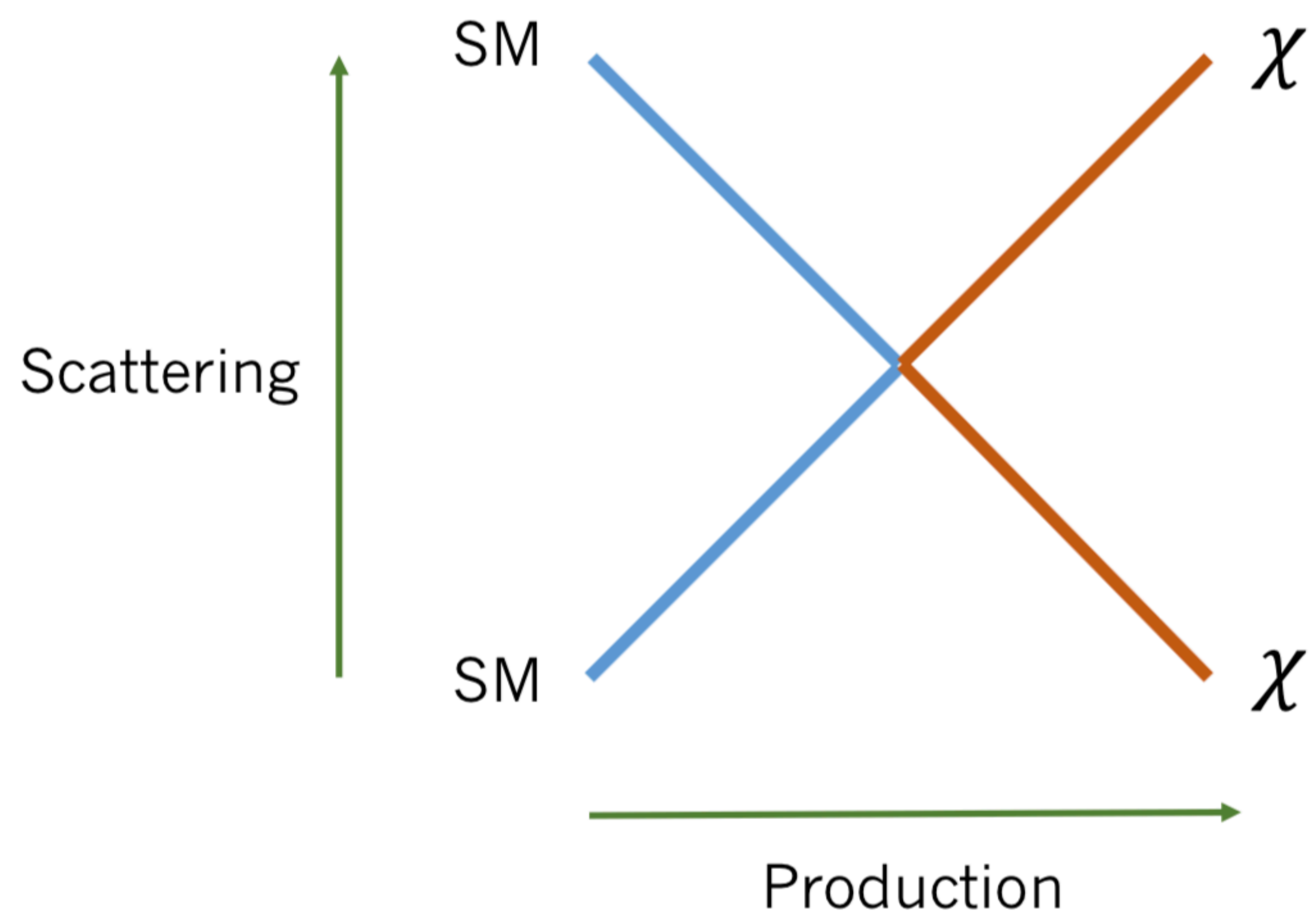
Previous bounds on dark photon. *Chang, Essig, McDermott (2016)*

From De Rocco slides

Proposed model (many others possible)

- Dark sector with stable fermion (χ)
- DM-SM coupling through heavy dark photon (A')

$$\mathcal{L}_{\text{dark}} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon_Y}{2}F'_{\mu\nu}B_{\mu\nu} + \frac{m^2_{A'}}{2}A'_{\mu}A'^{\mu} + \bar{\chi}(i\not{D} - m_{\chi})\chi$$



From De Rocco slides

Diffusive trapping & DM escaping flux

- **At high coupling, particles diffusively trapped by SM scattering**
- Spectrum set by radii at which interactions decouple

Production/annihilation

$$\chi\ \bar{\chi} \longleftrightarrow e^{+}\ e^{-}$$

From De Rocco slides

Diffusive trapping & DM escaping flux

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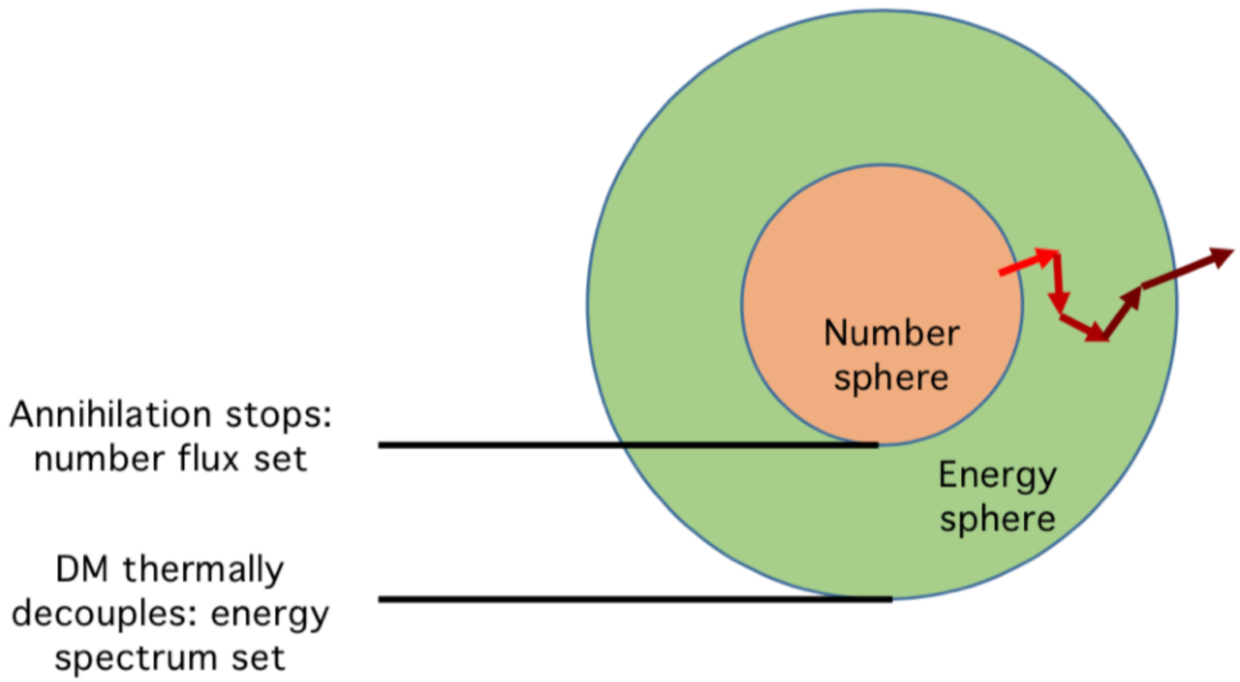
Energy transfer

$$\chi\ e \longrightarrow \chi\ e$$



From De Rocco slides

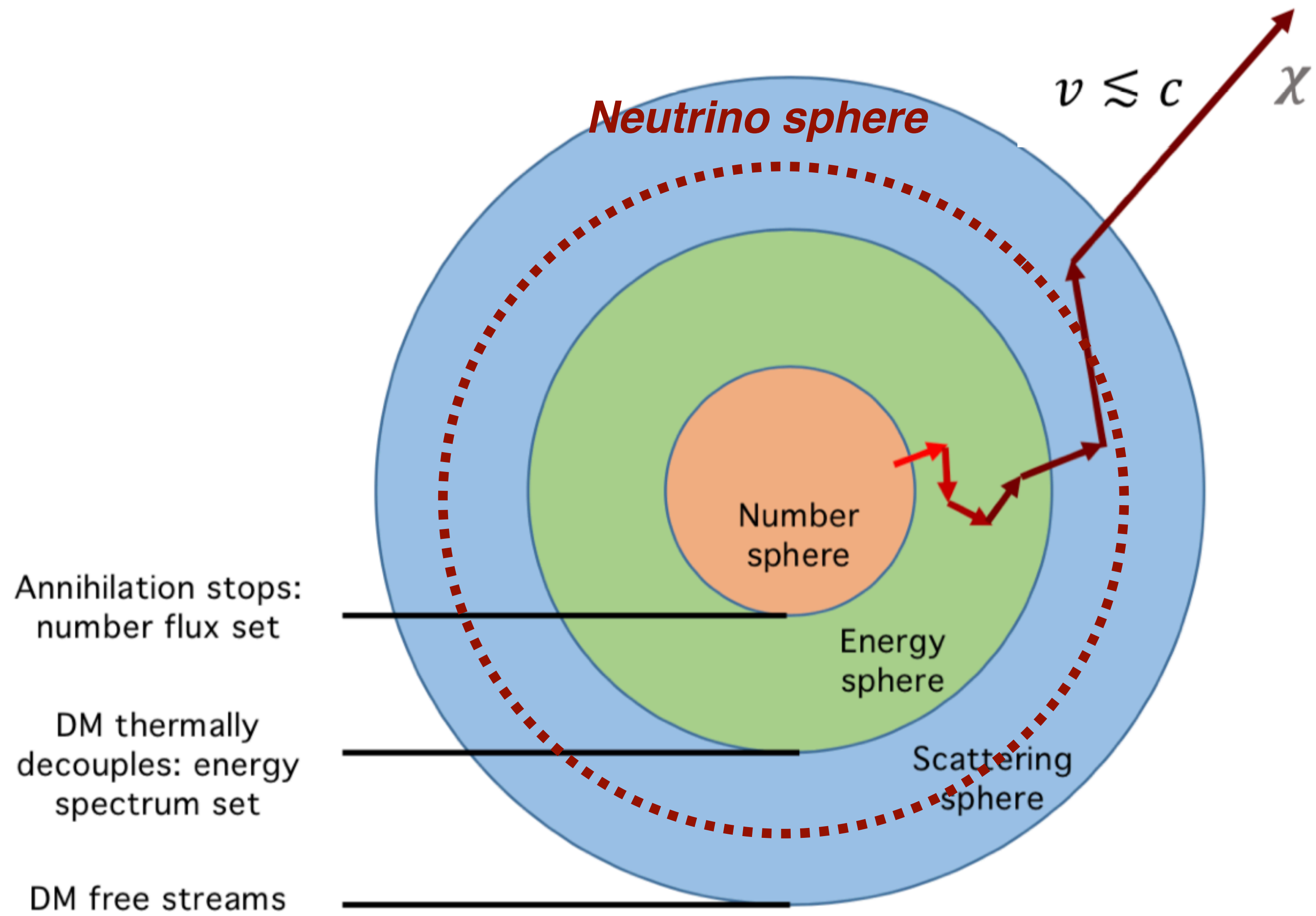
Diffusive trapping & DM escaping flux

- **At high coupling, particles diffusively trapped by SM scattering**
- Spectrum set by radii at which interactions decouple

Production/annihilation
$\chi\,\bar{\chi} \longleftrightarrow e^+\,e^-$

Energy transfer
$\chi\,e \longrightarrow \chi\,e$

Diffusive scattering
$\chi\,p \longrightarrow \chi\,p$



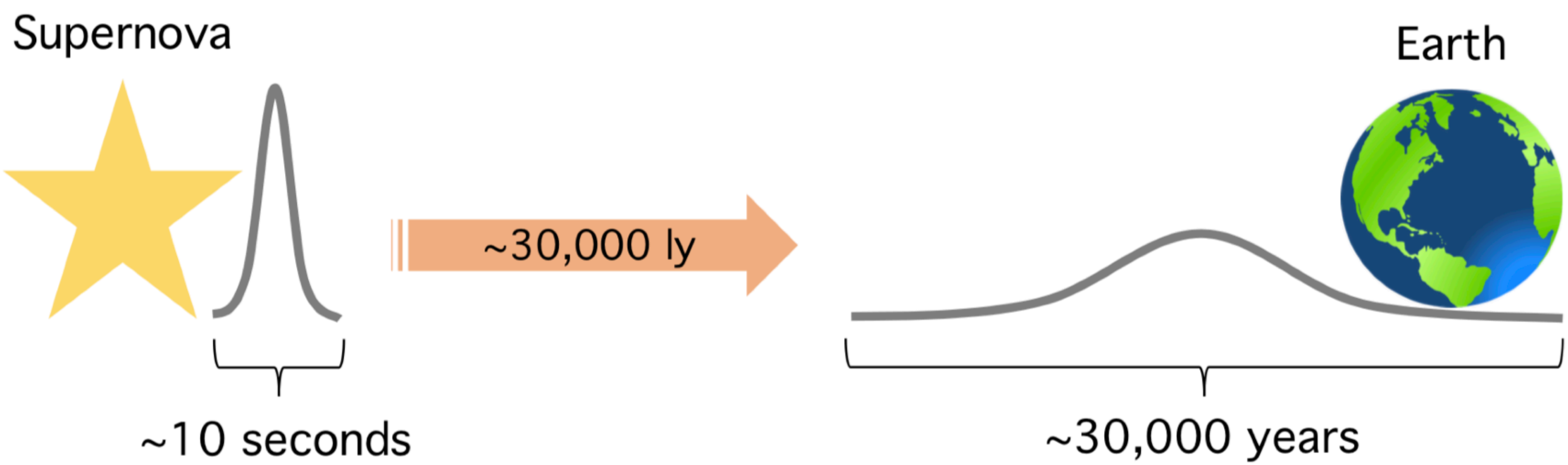
- **Energy transport can still be large**

- Temperature at energy sphere $\lesssim m_\chi$
- **Escaping DM is semirelativistic**

From De Rocco slides

Diffuse galactic flux

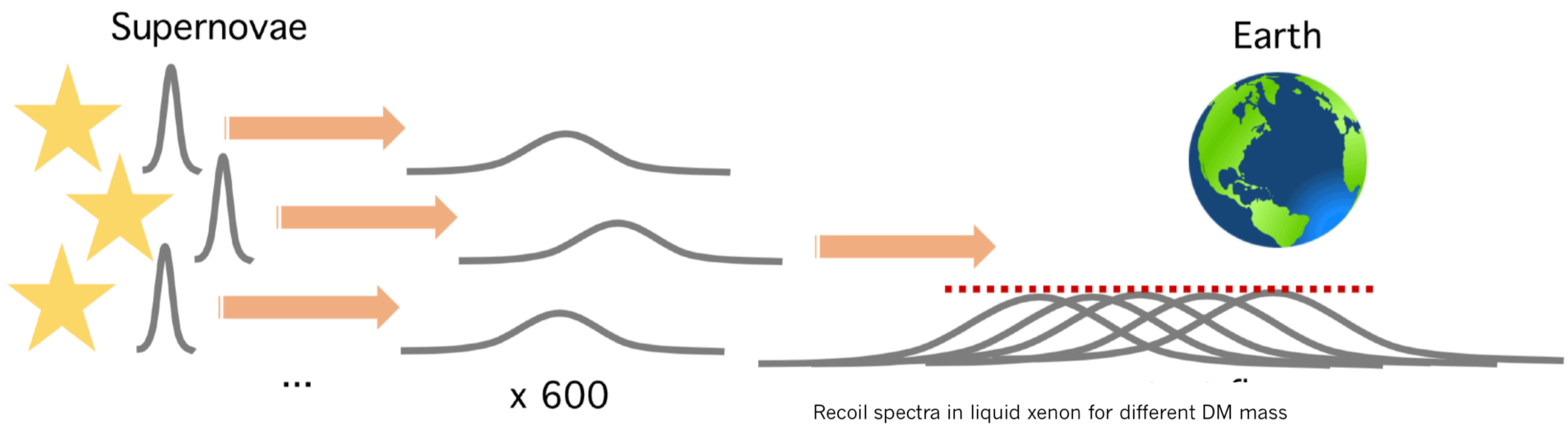
- Dark fermions escape at semirelativistic velocities
- **Arrival times at Earth spread by light travel time**



From De Rocco slides

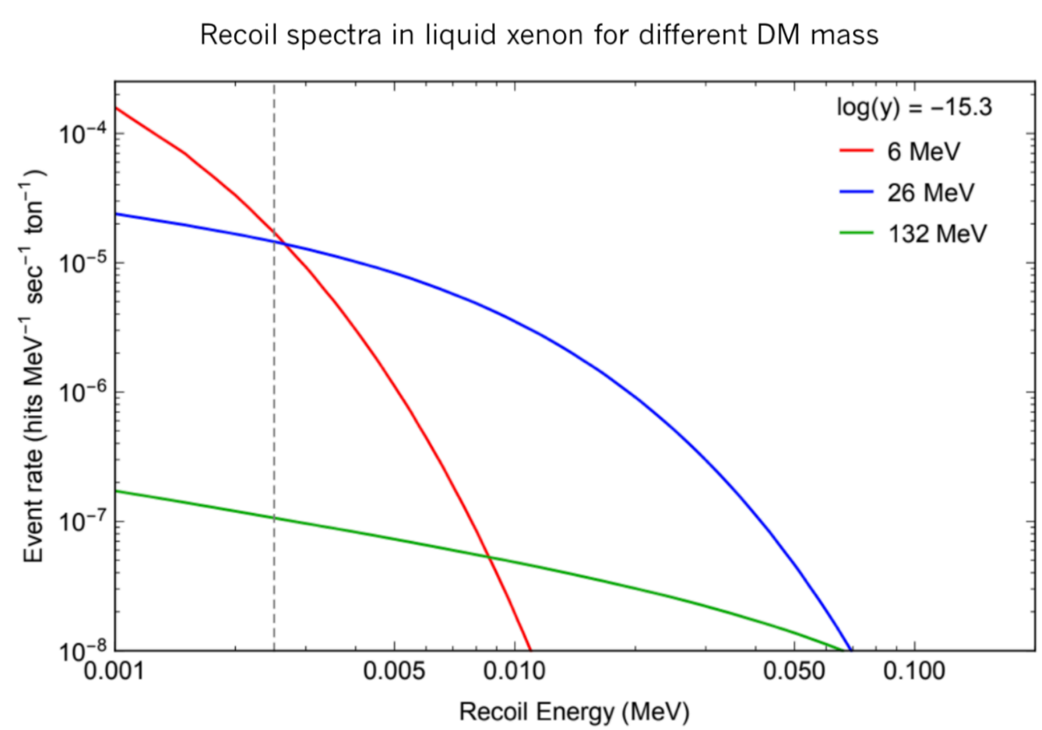
Diffuse galactic flux

- Dark fermions escape at semirelativistic velocities
- Arrival times at Earth spread by light travel time
- **Emissions from several SN overlap to form diffuse flux**



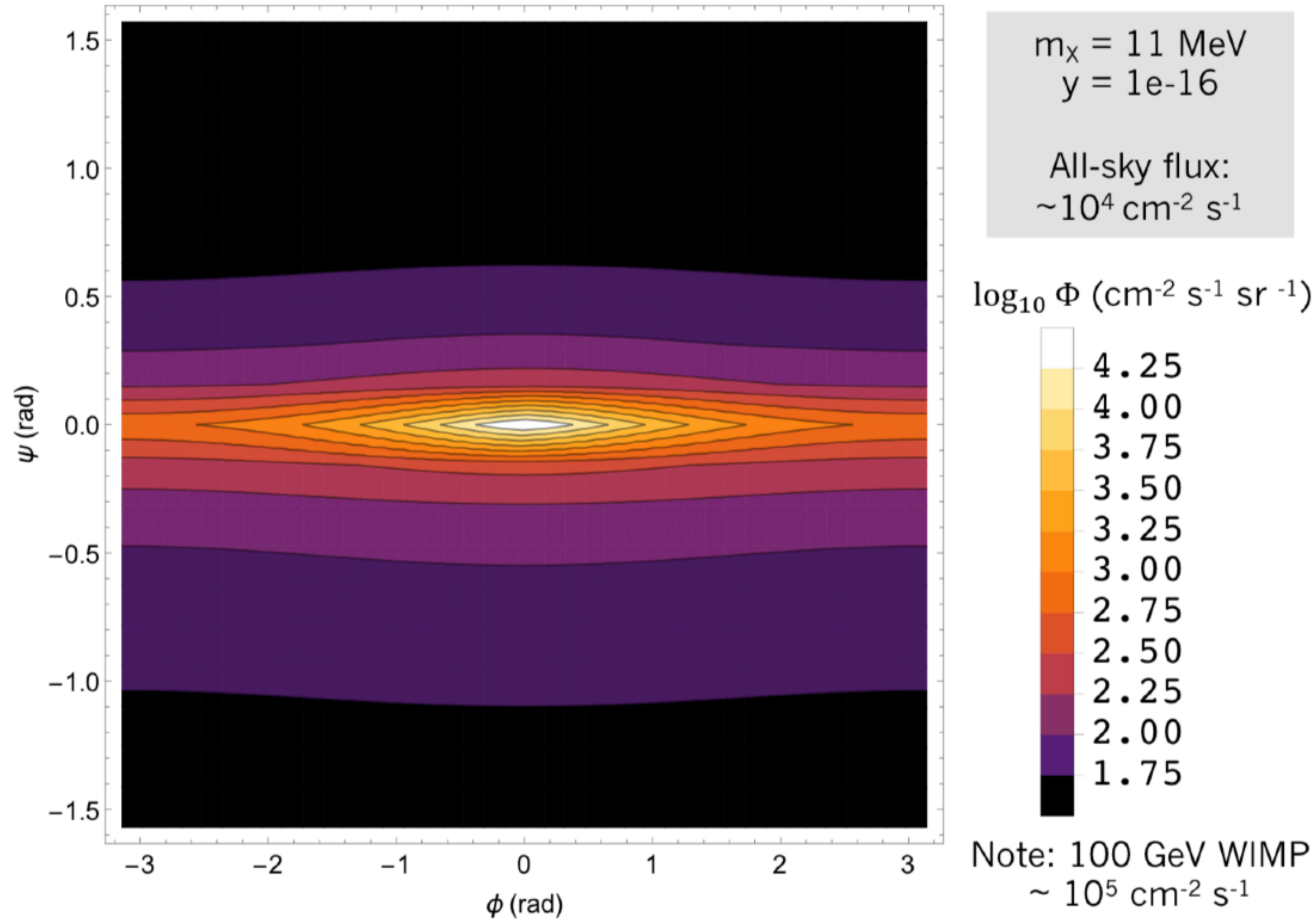
- Recoil spectra of cold WIMPs and hot MeV-scale DM very similar

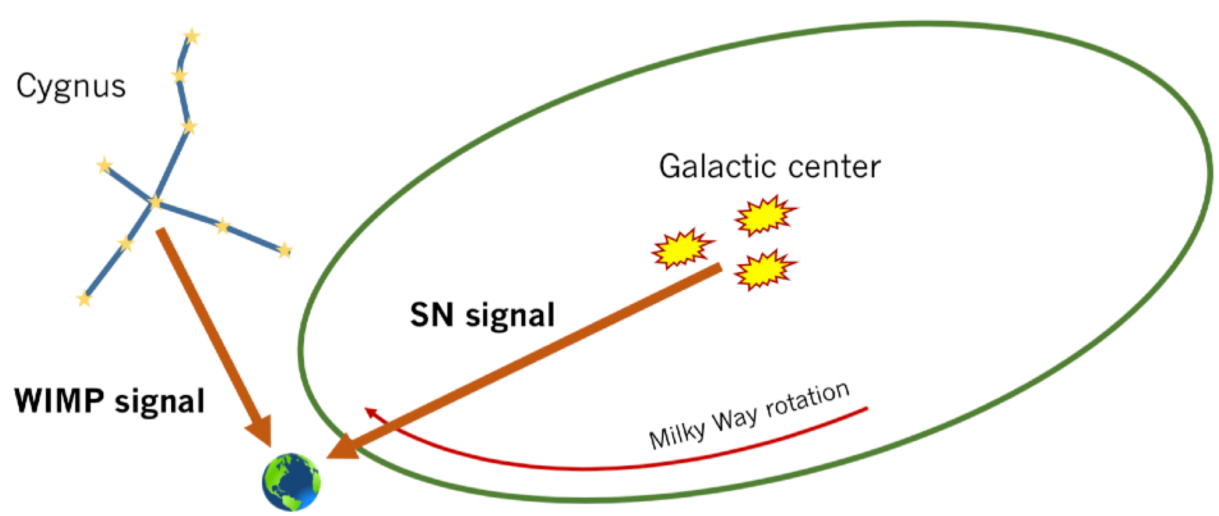
Key point: if XENON sees a couple of events, how can we know if they are WIMP or SNDM?



Directionality saves the day!

- **Diffuse flux strongly peaked towards Galactic center**
- Isotropic intergalactic contribution highly subdominant
- **SN signal is perpendicular to WIMPs!**
- Directional detectors are necessary for discrimination of future signal





See Giorgo's talk for the development of this case study

To be notice: what developed will be very useful for WIMPs & neutrinos sensitivities evaluation as well

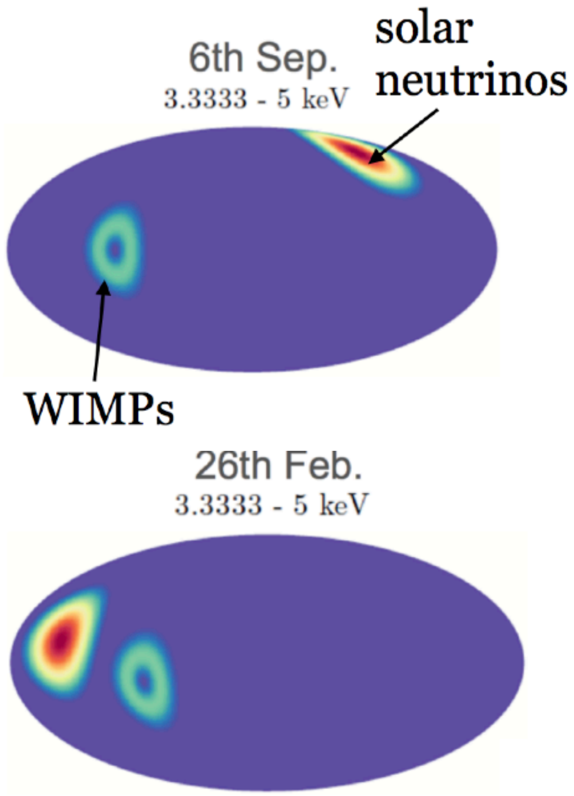
CYGNO/INITIUM beyond WIMP searches: electron recoils from Neutrinos

Directionality as a new window on neutrino physics

erc

Neutrinos: an <u>opportunity</u> for directional DM detectors, rather than an inconvenience

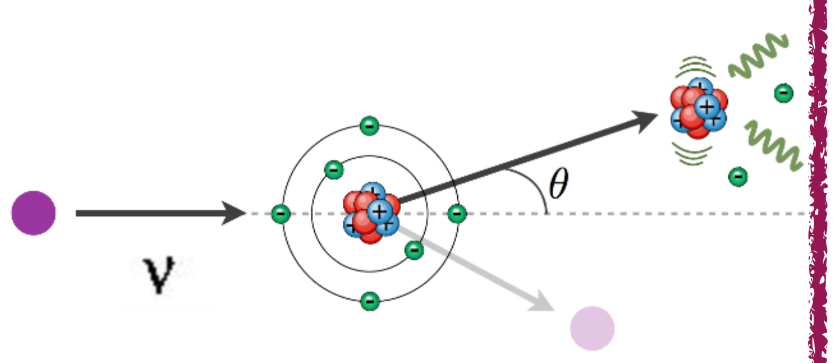
C. O'Hare et al, Phys. Rev. D 92 063518 (2015)



Directionality as a new window on neutrino physics

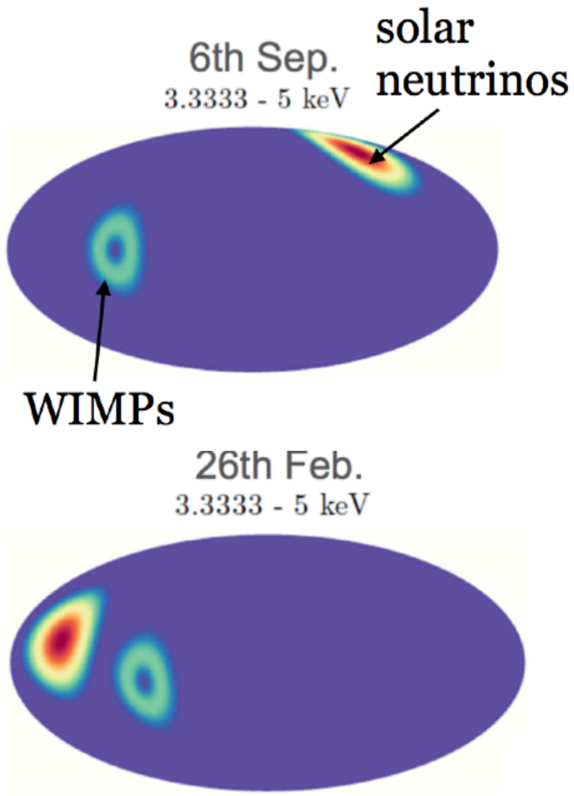
Neutrinos: an opportunity for directional DM detectors, rather than an inconvenience

Coherent Neutrino-Nucleus scattering



NOTE: only a directional DM detector can distinguish from WIMP signal

C. O'Hare et al, Phys. Rev. D 92 063518 (2015)



Message from CYGNUS simulations: need O(ton) detector to see neutrinos through coherent scattering (i.e. not a direct case for CYGNO)

Directionality as a new window on neutrino physics

Neutrinos: an opportunity for directional DM detectors, rather than an inconvenience

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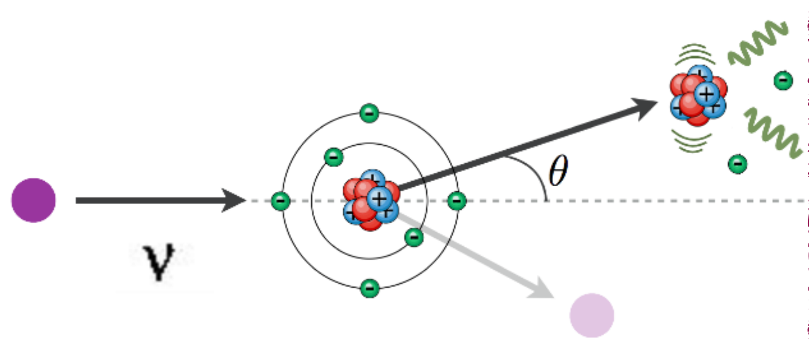

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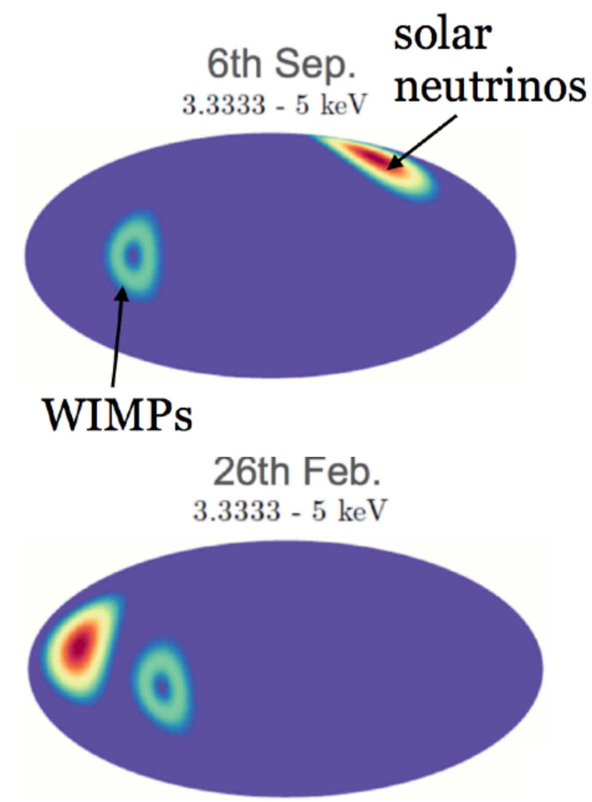
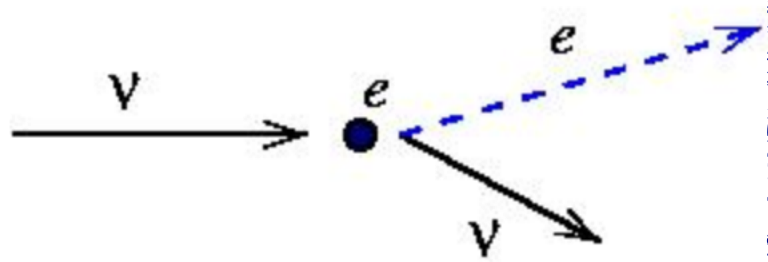


NEW! Physics reach under study

Elastic Neutrino-Electron scattering

with event by event precise neutrino energy measurement



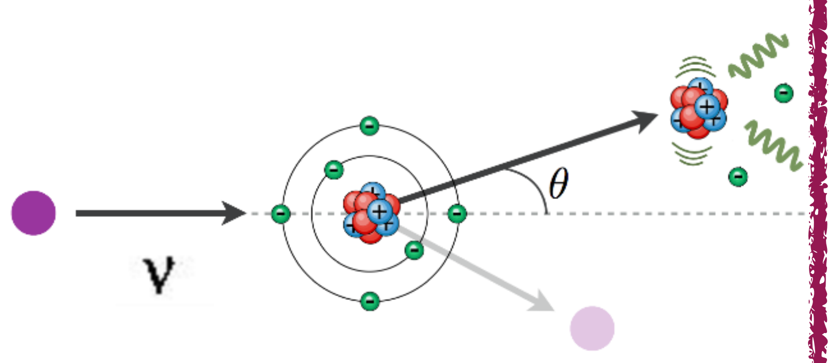
NOTE: only a directional DM detector can distinguish from ER background

Message from back on the envelope evaluations & old published papers: O(50 kg) directional detector can measure neutrinos through elastic scattering using directionality to reject electromagnetic backgrounds (CYGNO PHASE 2 ok!)

Directionality as a new window on neutrino physics

Neutrinos: an opportunity for directional DM detectors, rather than an inconvenience

Coherent Neutrino-Nucleus scattering



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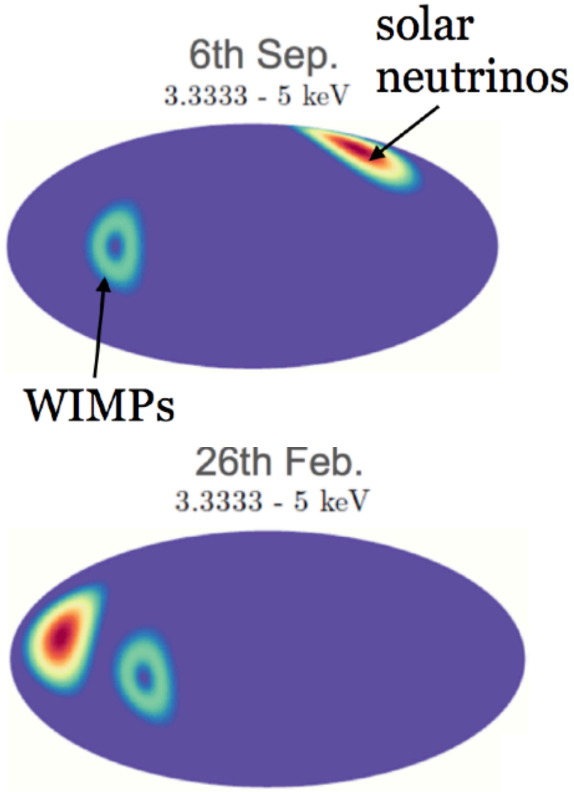

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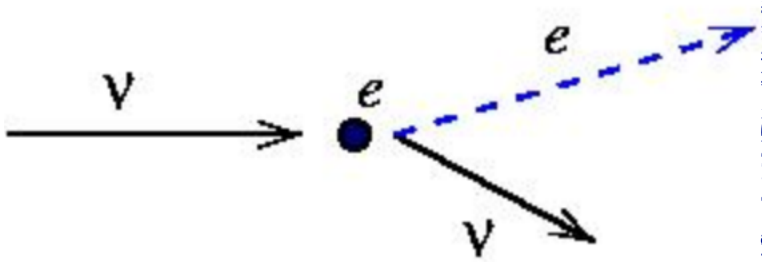


NOTE: only a directional DM detector can distinguish from ER background

A directional DM detector is also a Sun and Supernovae neutrino observatory, with lower energy threshold than solar neutrino experiment based on scintillating liquids

Elastic neutrino - electron scattering with gaseous TPC: revitalising old ideas

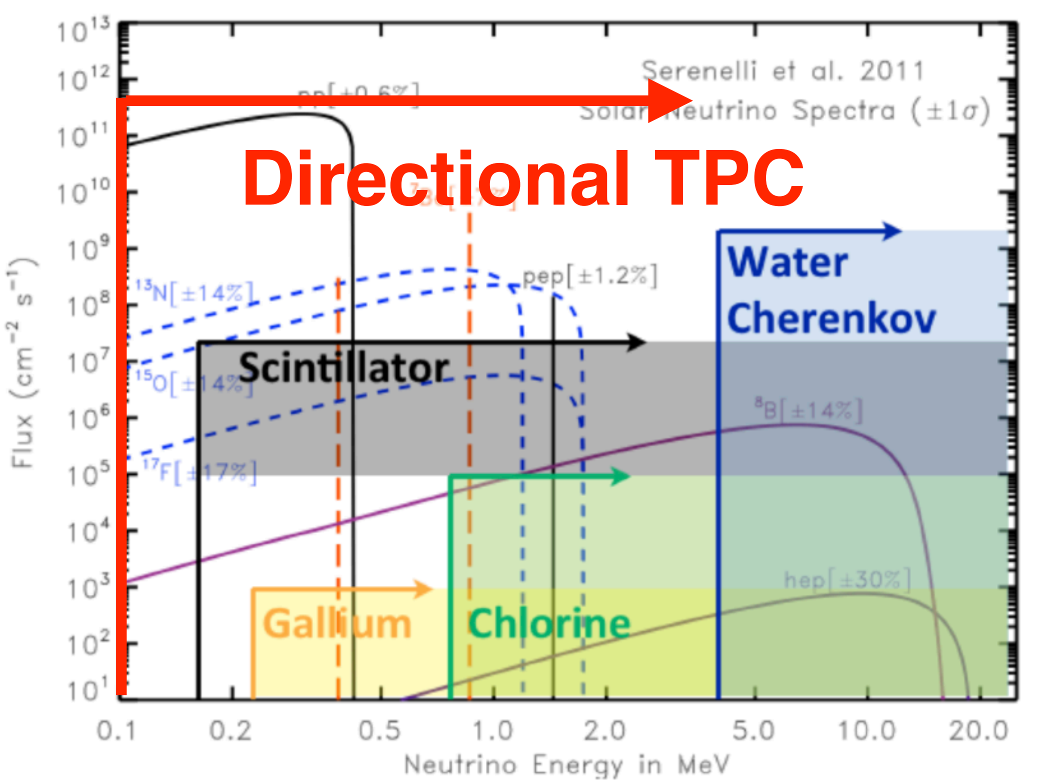
1992 **He**

A HIGH RATE SOLAR NEUTRINO DETECTOR
WITH ENERGY DETERMINATION

J. Séguinot, T. Ypsilantis
Collège de France, IN2P3 - CNRS
et CERN, Genève, Suisse

A. Zichichi
CERN, Genève, Suisse
et INFN-Laboratoire national du Gran Sasso, Italie

1994 HELLAZ: A HIGH RATE SOLAR NEUTRINO DETECTOR WITH NEUTRINO ENERGY DETERMINATION



1996 **CF_4**

A possible gas for solar neutrino spectroscopy

C. Arpesella[a], C. Broggini[b], C. Cattadori[c]
[a] I.N.F.N. Laboratori Nazionali del Gran Sasso, I-67010 Assergi (AQ), Italy
[b] I.N.F.N. Sezione di Padova, via Marzolo 8, I-35131 Padova, Italy
[c] I.N.F.N. Sezione di Milano, via Celoria 16, I-20133 Milano, Italy

Received 25 July 1995; revised 24 October 1995

Tetrafluoromethane appears very attractive for low energy neutrino spectroscopy because it has a high density of 3.7 g ℓ^{-1} (at normal pressure and 15°C temperature), which maximizes the number of target electrons, and it contains low Z nuclei, which minimizes the multiple scattering and allows for the reconstruction of the electron direction.

Typical spatial resolution: 1-2 mm
Energy threshold: 100 keV

The detector has two new outstanding features:
- it can give the spectrum of the low energy neutrinos from the Sun;
- it is sensitive to and it can identify solar neutrinos of different origin: *pp*, ^{7}Be, and, eventually, ^{8}B.

Solar neutrino measurements with directionality

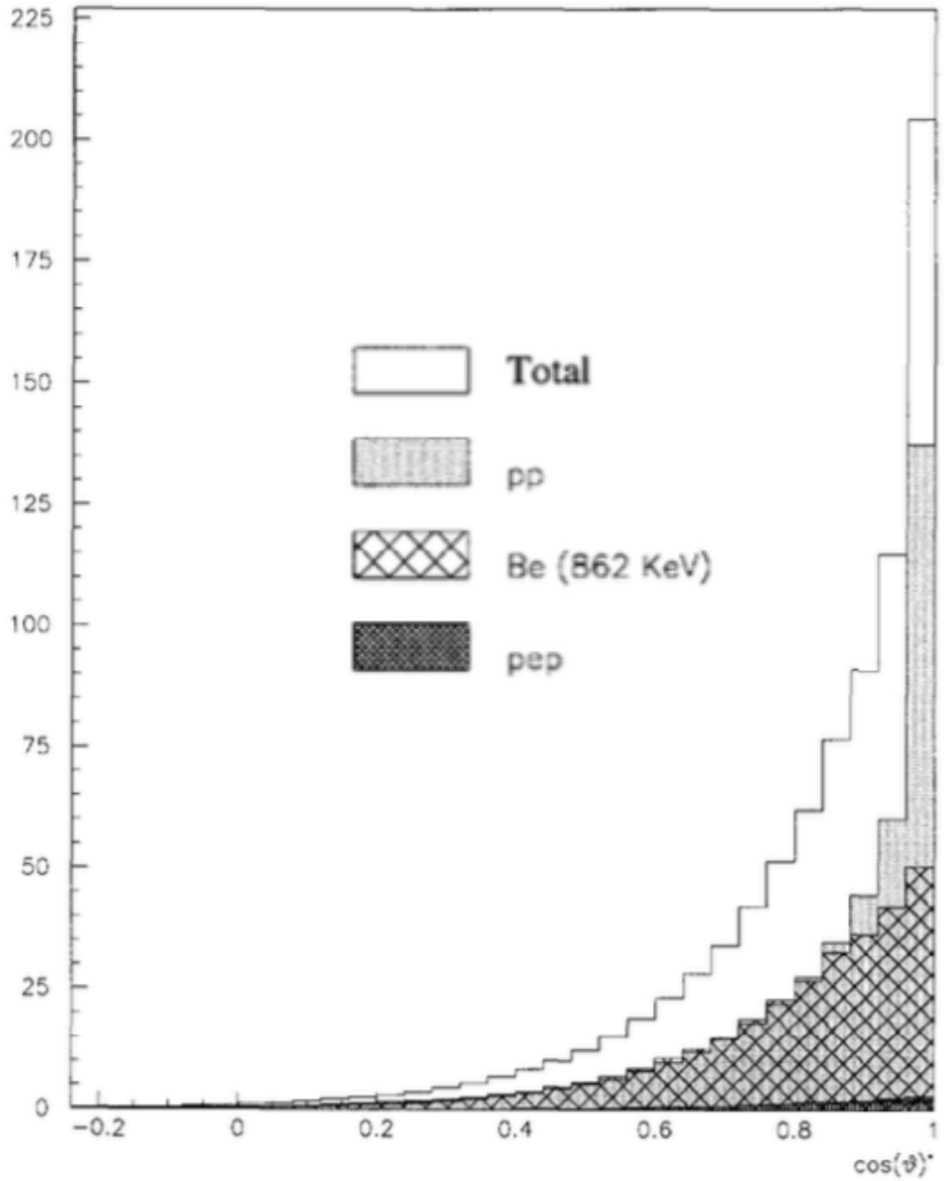


Fig. 4. The events of one year as a function of the reconstructed scattering angle.

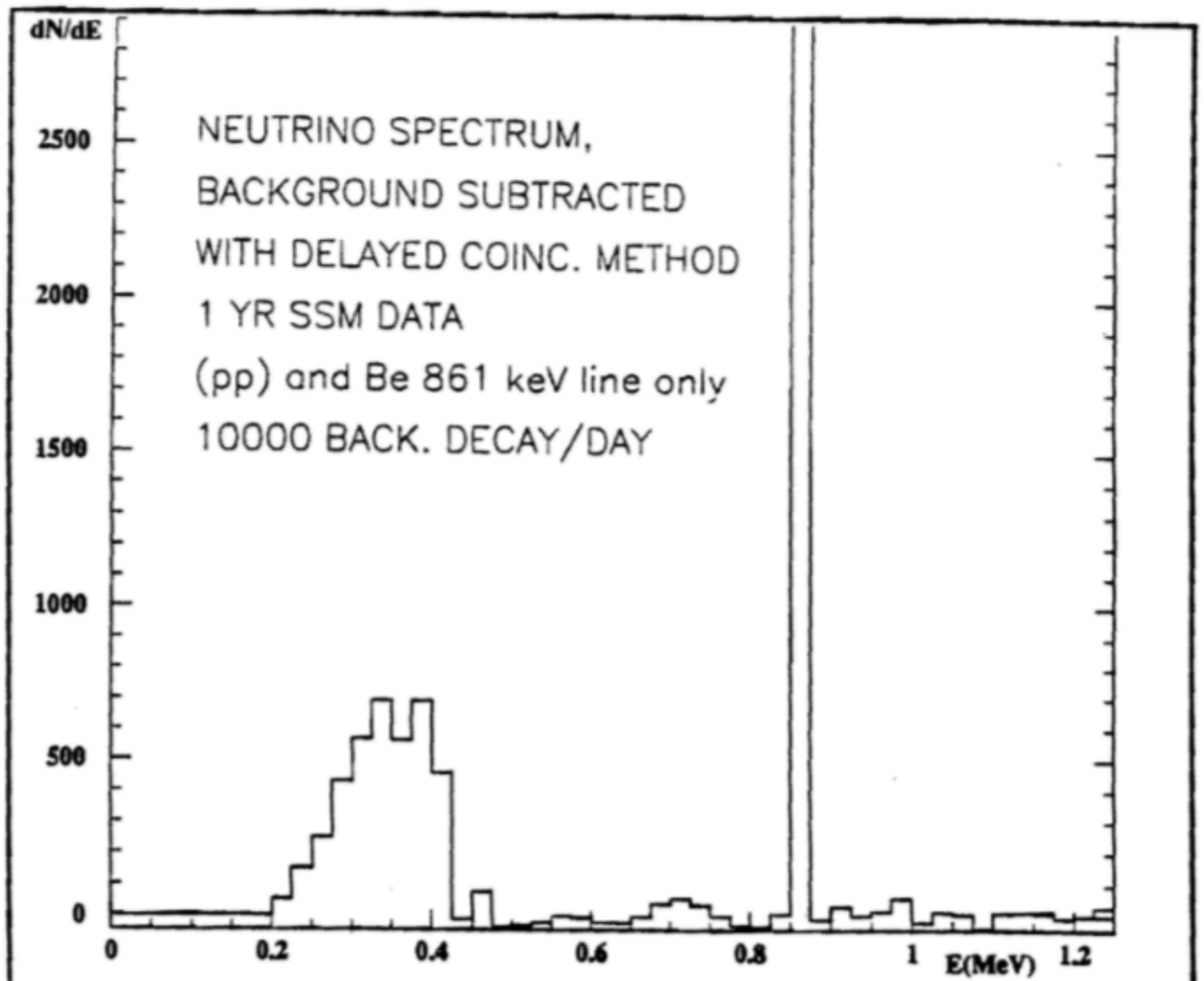
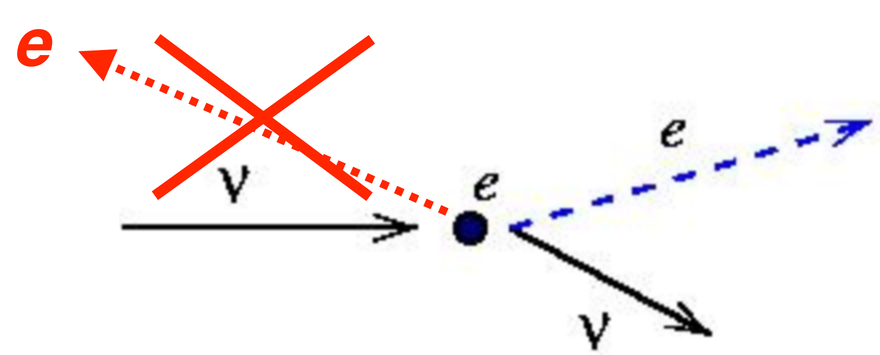


Fig.7. Neutrino spectrum background subtacted with 10^4 γs/d from the TPC cage.

Given the Sun position, recoils in opposite direction are kinematically forbidden



Differently from WIMPs, background can be measured on sidebands data

From HELLAZ paper

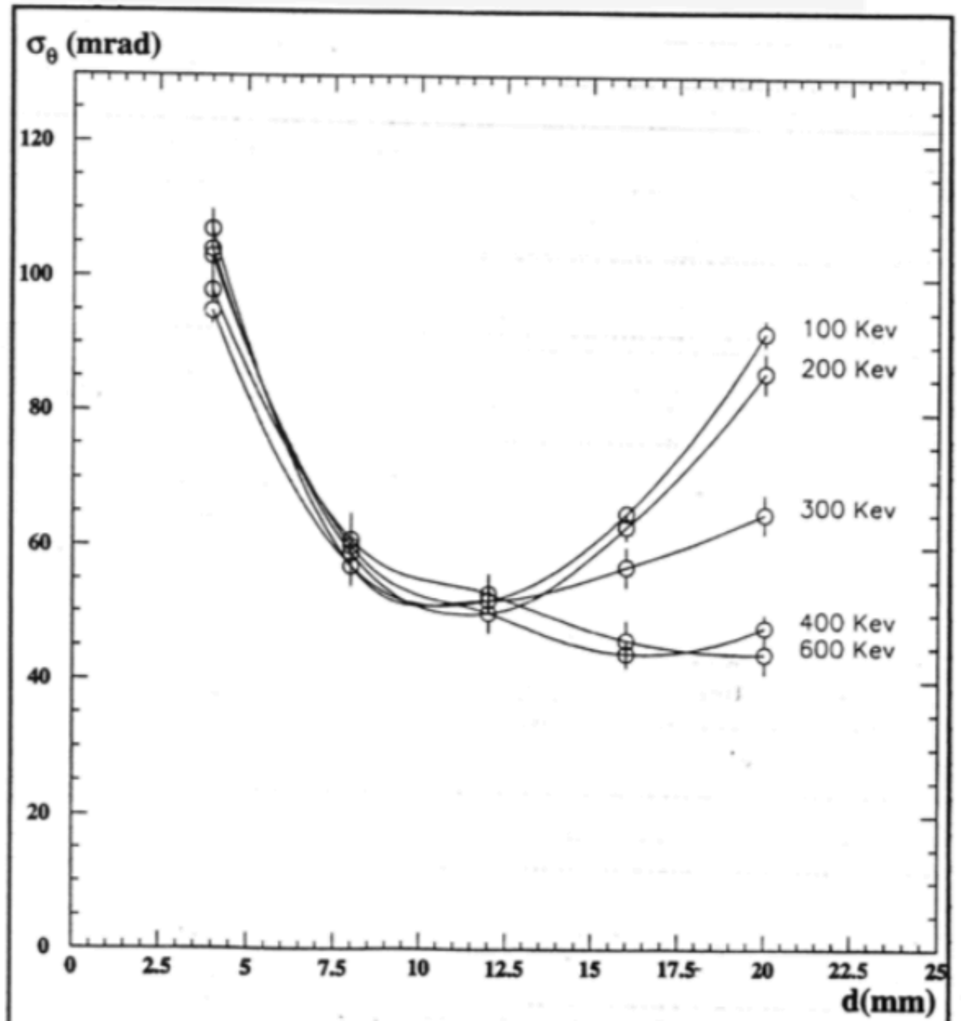


Fig. 11. The recoil electron direction resolution (σ_θ) vs sampled track length (d) for various electron energies and 9 m drift in Helium gas (10 bar, 77° K, $\sigma_d{}^2$=4·10^{-4} cm).

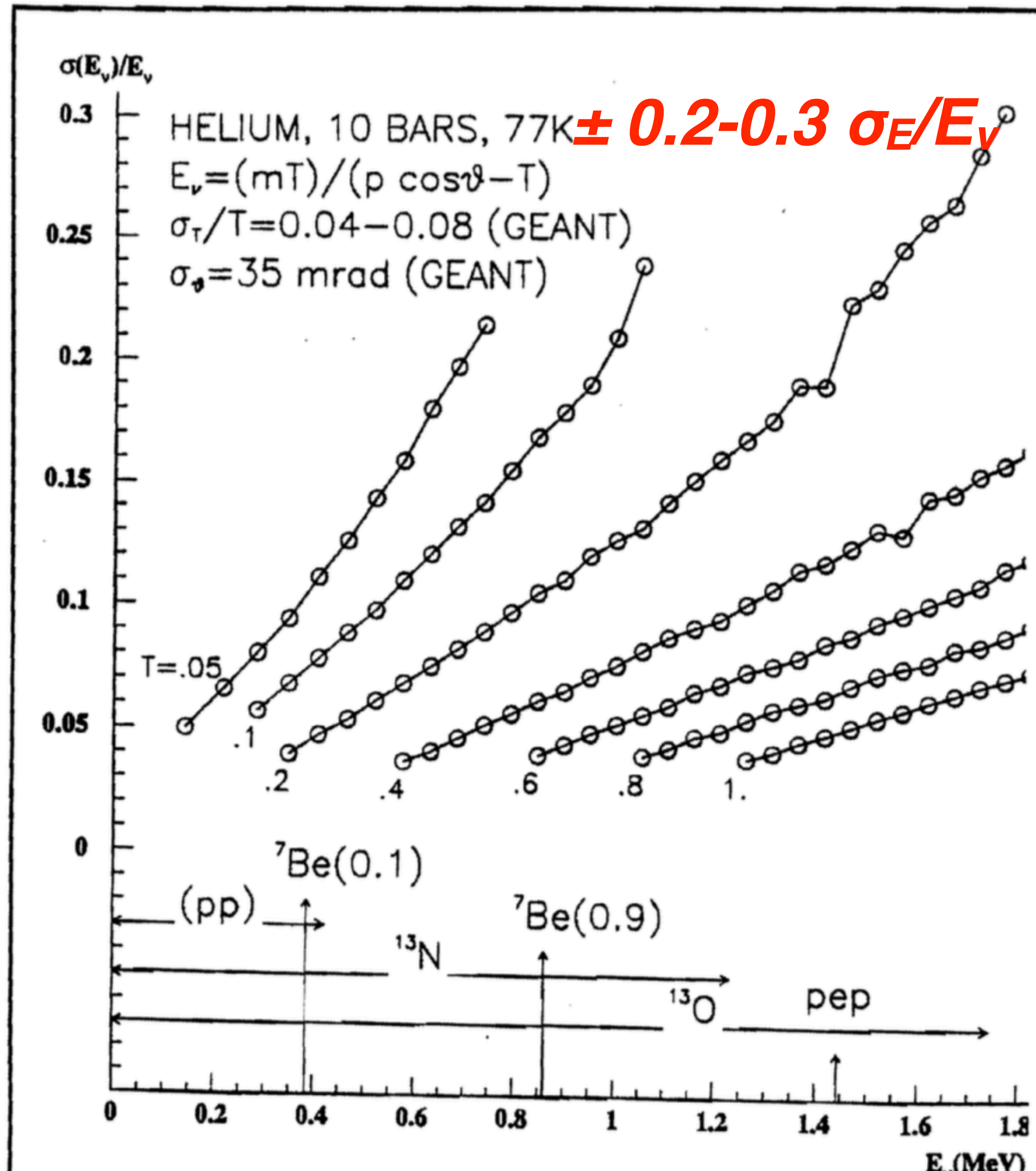


Fig. 11. The neutrino energy resolution vs neutrino energy E_ν for fixed T (MeV).

Because the TPC is filled with low Z, low density gas (He+CH_4, 3.16 mg/cm^3) low energy recoil electrons (T ≥ 100 keV, range ≥ 50 mm) can be detected and electron energy and direction determined (σ_T/T≈3%, σ_θ≈35 mrad). These parameters then determine the neutrino energy with error 2%< $\sigma_{E\nu}/E_\nu$ <4% (at E_ν=300 keV). None of the existant or proposed νe detectors has any significant neutrino energy resolution. BOREXINO will detect electrons with T ≥ 250 keV but cannot determine the electron direction and so E_ν.

shown in Fig. 11 with fixed T contour lines. This shows that resolution $\sigma_{E\nu}/E_\nu$ between 3% to 7% may be obtained in the pp region 220 < E_ν < 420 keV. The resolution σ_T/T is improved to between 2% and 4% if T is measured by electron counting.

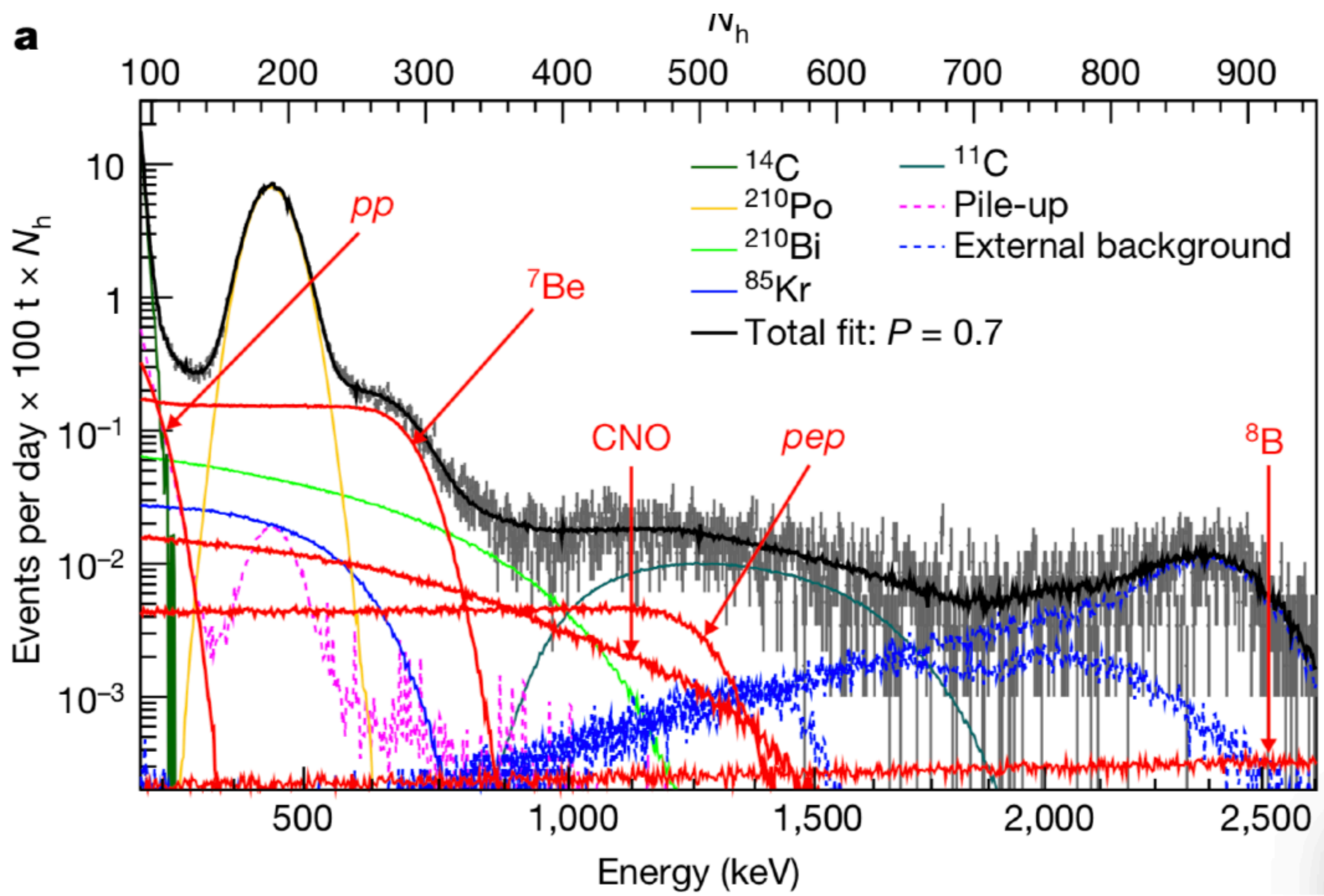
CYGNO as an innovative detector for low energy, precision solar neutrino spectroscopy

Much better neutrino energy resolution than old papers proposed approach

- He:CF4 allows a lot of electron, with a low density gas *Good target/density ratio*
- CYGNO readout approach has O(100) um track resolution *Much better tracking that old papers proposed approach*
- CYGNO can aim at 20 keV DIRECTIONAL threshold for electrons (i.e. 80 keV neutrinos) *Much lower threshold than old papers proposed approach & Borexino*
- CYGNO is sensitive to single ionisation cluster for MeV electrons (i.e. calorimetry)

Question to answer: upper energy threshold.
Obvious: contained track
But: if track not on dE/dx plateau, could measure E through dE/dx?

Borexino Sun neutrino measurement

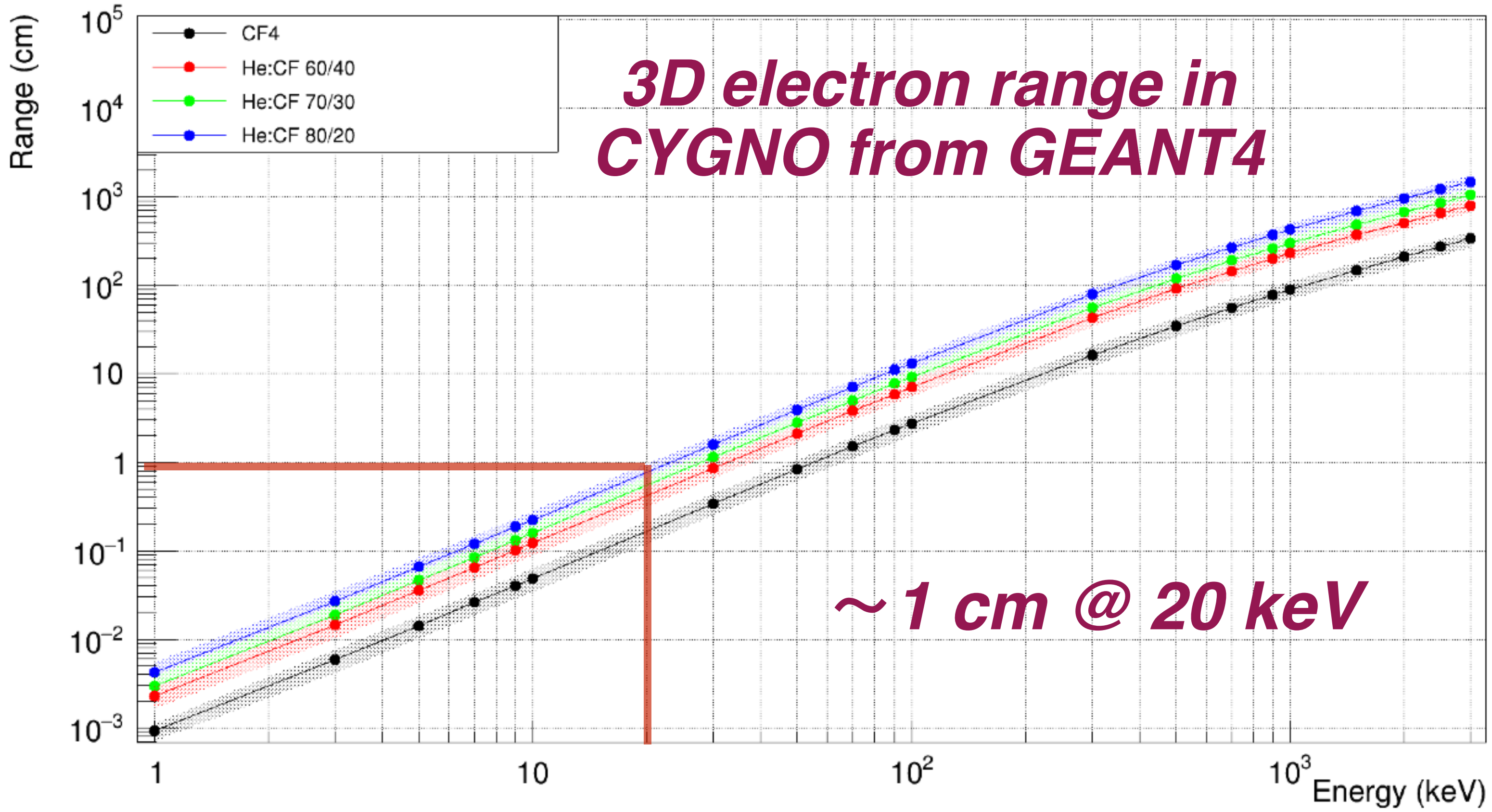


Solar neutrino	Rate (counts per day per 100 t)
pp	$134 \pm 10^{+6}_{-10}$
^{7}Be	$48.3 \pm 1.1^{+0.4}_{-0.7}$
pep (HZ)	$2.43 \pm 0.36^{+0.15}_{-0.22}$
pep (LZ)	$2.65 \pm 0.36^{+0.15}_{-0.24}$
$^{8}B_{HER-I}$	$0.136^{+0.013+0.003}_{-0.013-0.003}$
$^{8}B_{HER-II}$	$0.087^{+0.080+0.005}_{-0.010-0.005}$
$^{8}B_{HER}$	$0.223^{+0.015+0.006}_{-0.016-0.006}$
CNO	<8.1 (95% C.L.)
hep	<0.002 (90% C.L.)

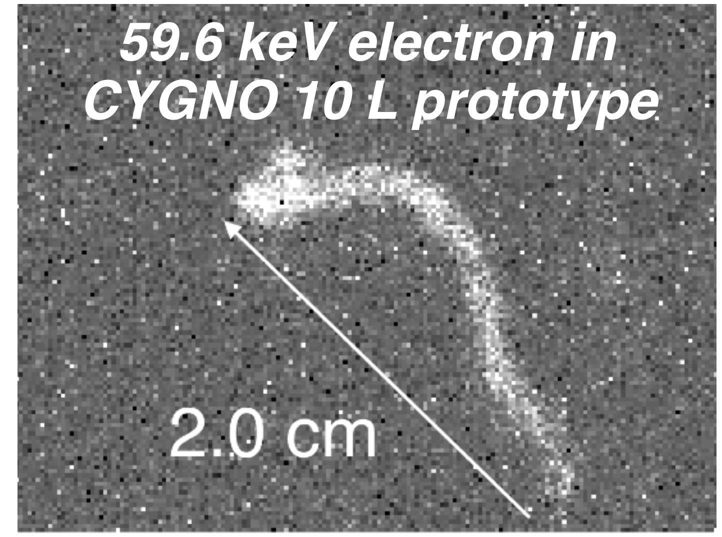
total LER exposure is 1,291.51 days × 71.3 t.

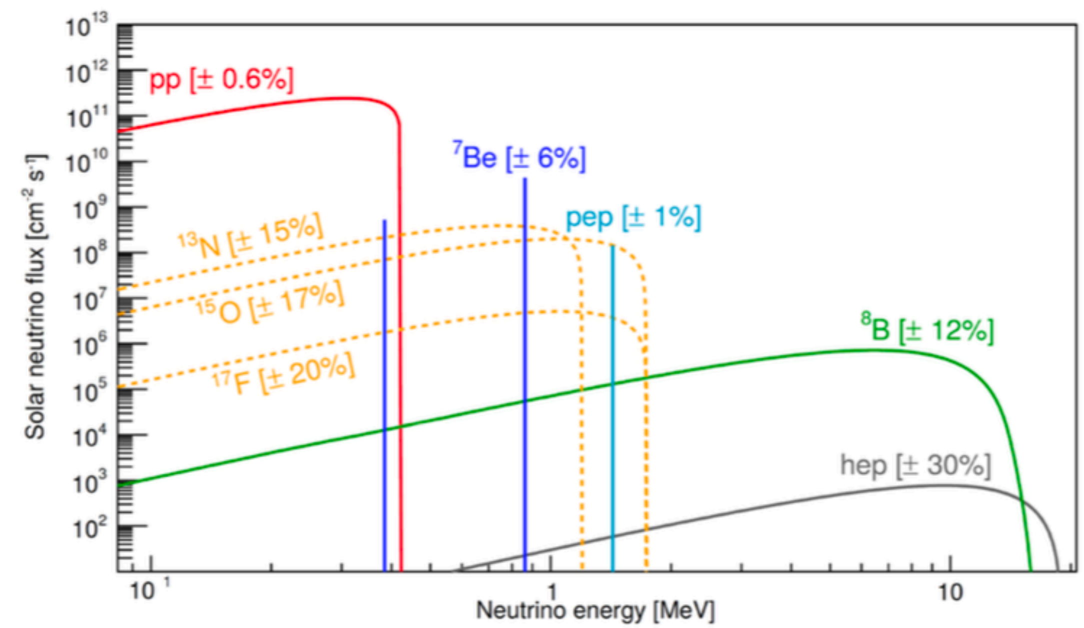
- **CYGNO has O(100) um tracking** — ***Borexino interaction position resolution:12 cm***
- **CYGNO has 20-30 keV DIRECTIONAL threshold** — ***Borexino E_{thr}: 160 keV***
- **CYGNO directionality provides background discrimination**

CYGNO vs HELLAZ



D. Marquez working on electron recoils simulations to estimate performances





HELLAZ: He @ 5 bar, 10 m drift, 1 mm x,y,z strips

	Diffusion	Target density	Electron energy threshold	Expected yield from pp
HELLAZ	0.2 sqrt(cm)	3 kg/m^3	100	0.5-1 m^{-3} y^{-1}
CYGNO	0.01 sqrt(cm)	1-1.5 kg/m^3	10-20	1-2 m^{-3} y^{-1}

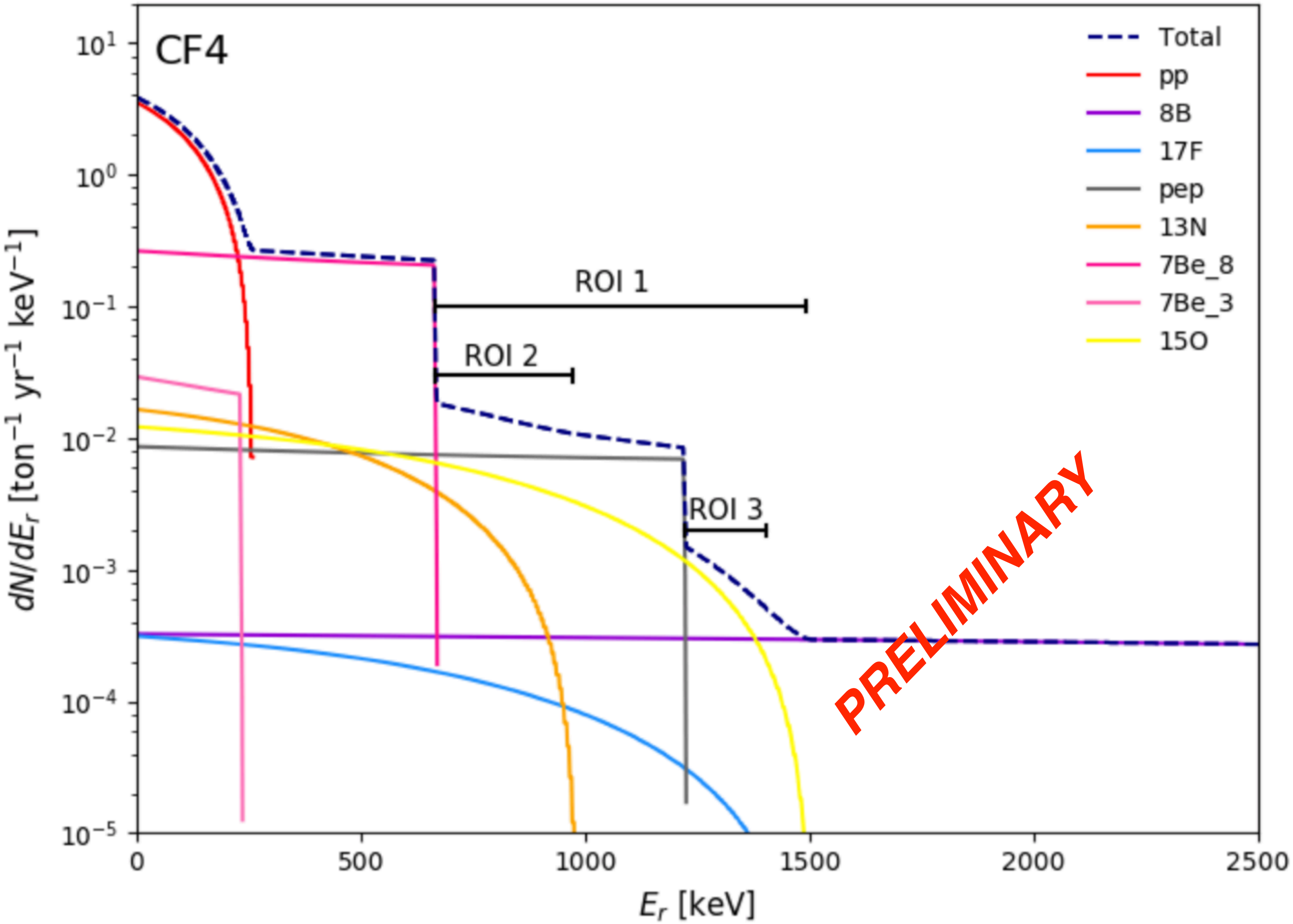
Back of the envelope calculations

CYGNO PHASE-2 can detect order 50 events/year

S. Torelli (new GSSI PhD) is calculating expected number of events from cross section + flux

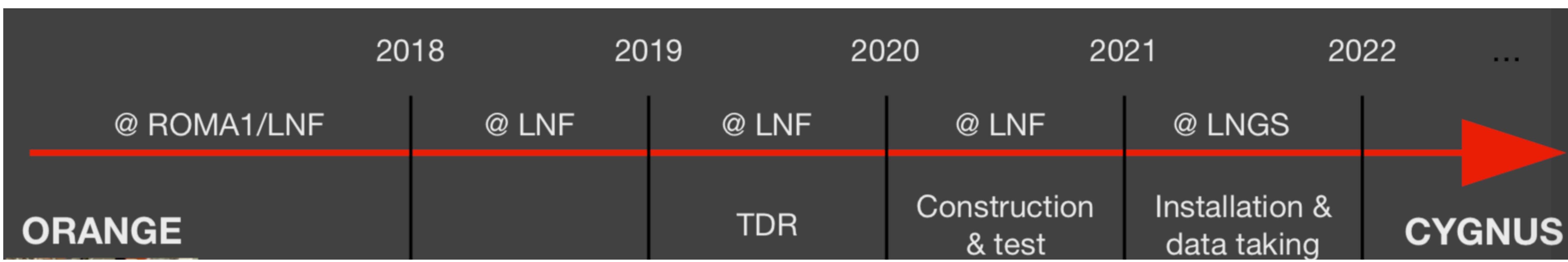
CNO cycle for CYGNUS?

CNO cycle measurement maybe possible with O(ton) detector



Feasibility under study with D. Cerdeno and E. Reid

Stay tuned for (a flock of) CYGNUS birth



https://web.infn.it/cygnus/

Backup slides

Prospects of directional solar neutrino measurements

A great advantage of HELLAZ lies in its capability to identify spectral components of the neutrino flux thus highly constrain the solar models. In particular, the pp spectral shape and intensity is determined by the visible light luminosity hence any observed differences can be uniquely attributed to the neutrino oscillation parameters [4]. This is because the νe elastic cross section is known from the standard model electro-weak theory [5] and doesn't rely on the poorly known nuclear wave-function overlap integrals, needed to determine the inverse β decay cross sections.

The fluxes of the monoenergetic neutrino lines ^{7}Be (862 keV) and p-e-p (1422 keV) can also be measured and their ratio determines the core temperature of the sun [3]. Possibly the shape and width of these lines can be measured thus further constraining the solar models. Because HELLAZ measures neutrino energy, the MSW phase angle is determined hence matter dependent oscillations are observable. Other experiments average over this angle thus are insensitive to these oscillations.

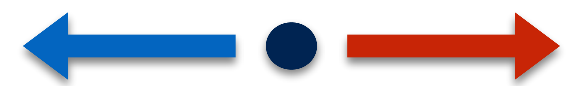
He e CF4 saran simili!

then only ionization fluctuations are important. However, energy loss in He gas is a special case because the dominant energy loss processes are ionization and scintillation with very little energy lost to excitons. For example, a T=100 keV electron in He produces about 2500 electrons and 2000 UV photons ($\tau \leq 2$ ns, $\lambda_{ph} \approx 60$ nm, E_{ph}=21.2 eV) thus accounting for almost all the 100 keV energy. The CH_4 total absorption cross section (30 Mb at 21.2 eV) is about 50% photoionizing thus the He photons will photoionize CH_4 resulting in (photo)electrons being injected into the TPC gas at a point very near the emission point ($l_{abs} \approx 35$ µm), thus an important fraction of the scintillation energy will be recovered. Simple counting of electrons could then give energy resolution $\sigma_T/T = 1/\sqrt{N} \approx 1/\sqrt{3500} = 1.7\%$. The remaining photabsorption cross section gives rise to a H_2^- ion which, by thermal agitation in the applied electric field, may lose its extra electron and add further to the ionization signal. SES-MWCs have already been developed for Cherenkov ring imaging [8] and primary ionization counting [9].

Neutron flux measurement @ LNGS with CYGNO

Environmental neutrons in underground halls are background to all current & future experiments: their precise knowledge is fundamental

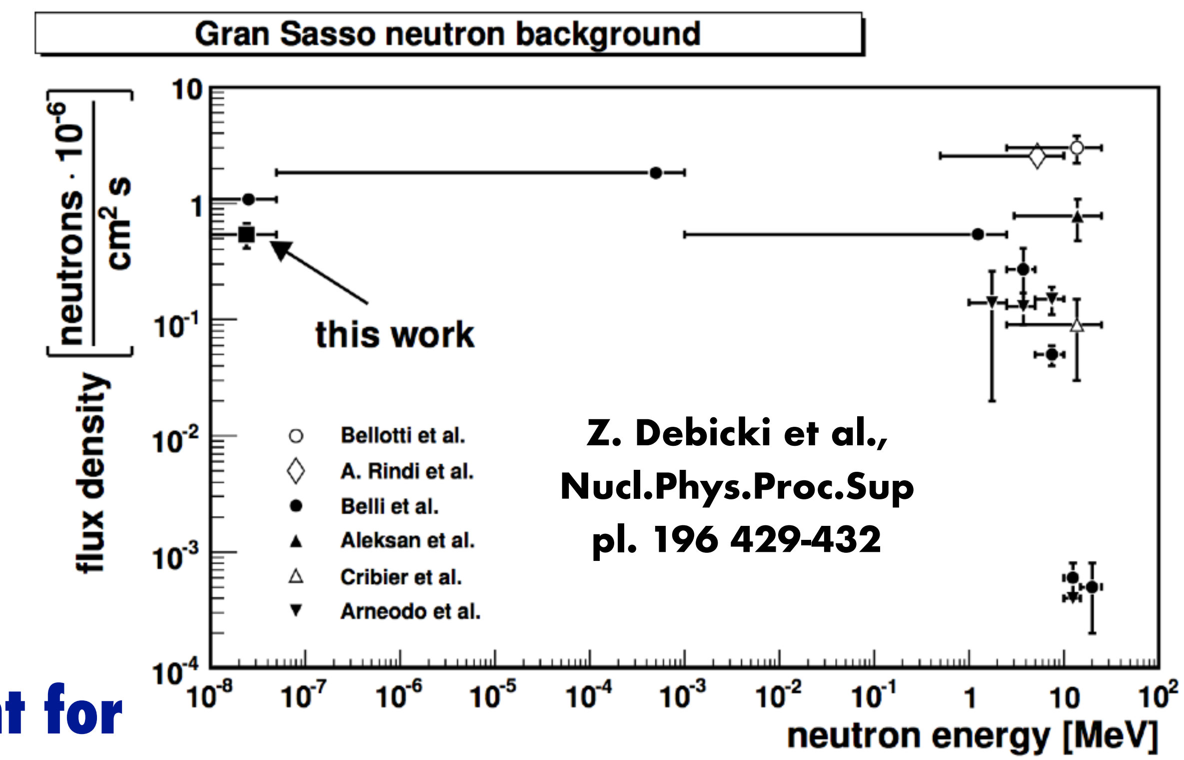
- **Simultaneous sensitivity to thermal and fast neutron flux with $^3He:He:CF_4:SF_6$ at atmospheric pressure**
  - Fast neutron through nuclear recoil
  - Thermal neutron through capture on ^{3}He (0.5% is enough thanks to the large capture cross section).



Proton 573 keV **Tritium 191 keV**

$$n + {}^3He \longrightarrow p + {}^3H + 764keV$$

- **O(10 keV) or lower threshold on fast neutrons**
- **Precise spectral measurement**
- **Directional measurement**
- **Seasonal measurement**
- **Background free measurement**
- **Hall B measurement**
- **Possibility to optimize pressure and gases content for higher yield or lower directional threshold**
- **Demonstrator for DM searches**



5000 detected nuclear recoils induced by fast neutrons/month
5000 detected thermal neutrons through capture/month