FUTURE DIRECT DM SEARCHES: PROSPECTS

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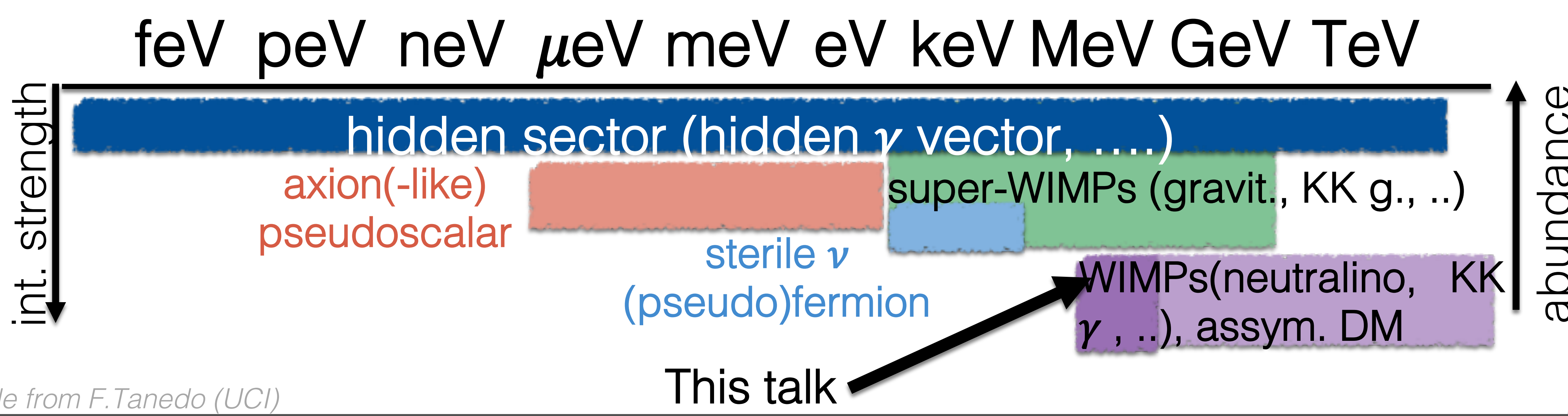
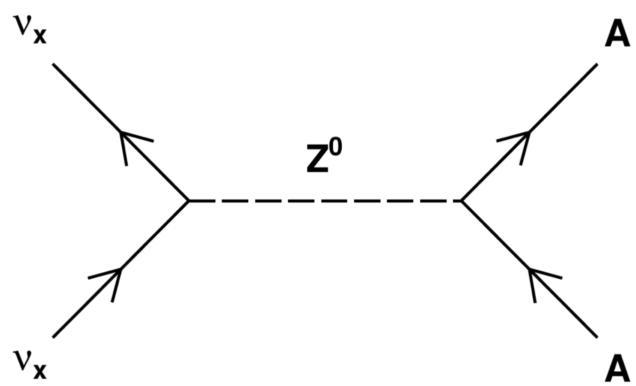
WIN2015, Heidelberg



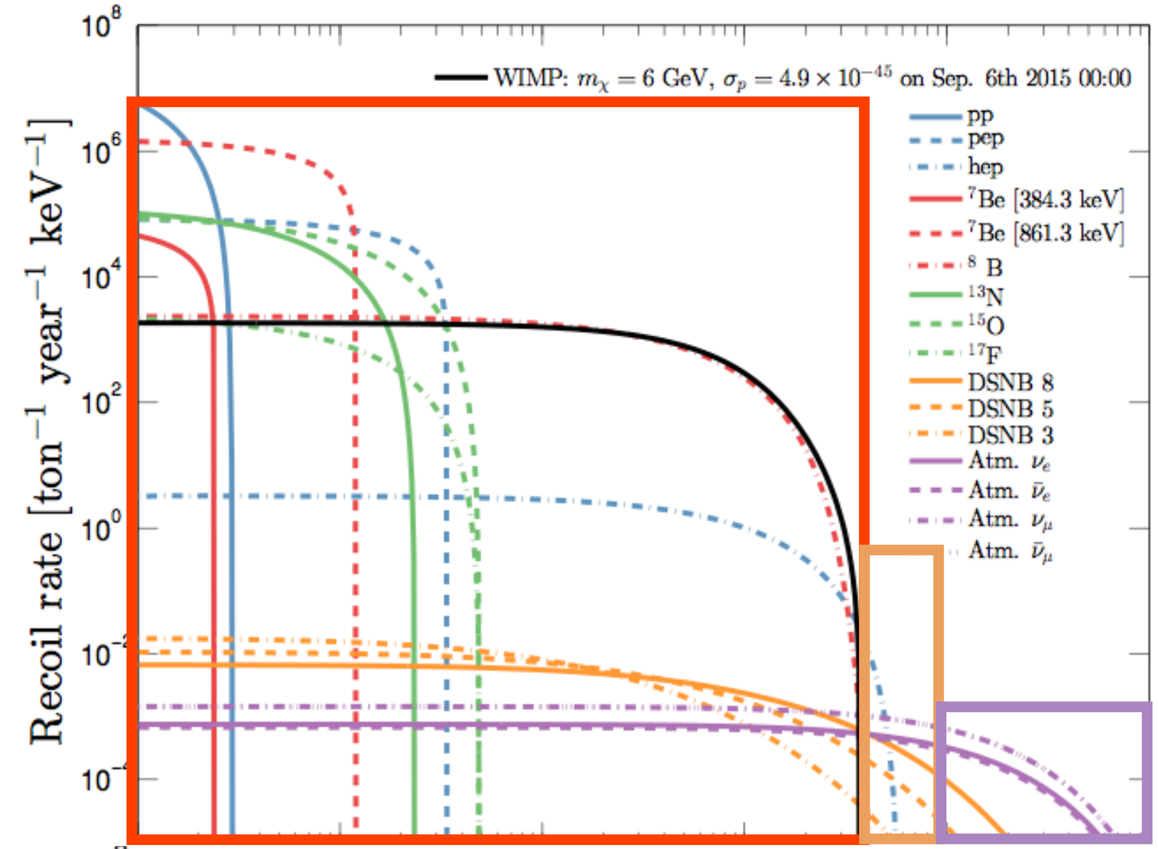
style from F.Tanedo (UCI)

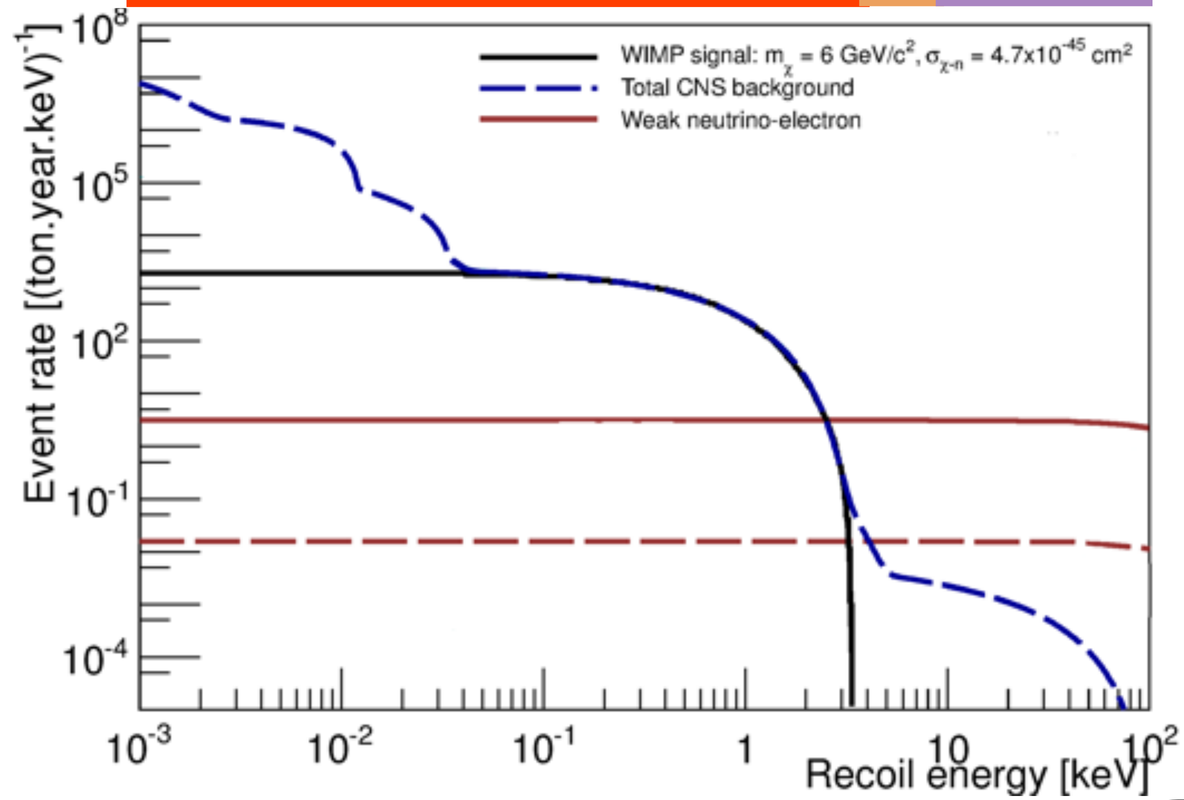
pantic@ucdavis.edu

Neutrinos will become background



Nucleus
Electron





Coherent ν-nucleus scattering affects
1. <10GeV DM@10^{-45}cm^2 via
solar directional modulating νs
2. 10-30GeV DM@10^{-49}cm^2 via
DSN isotropic non-modulating νs
3. >100GeV DM@10^{-49}cm^2 via
atmospheric approx. isotropic non-modulating νs

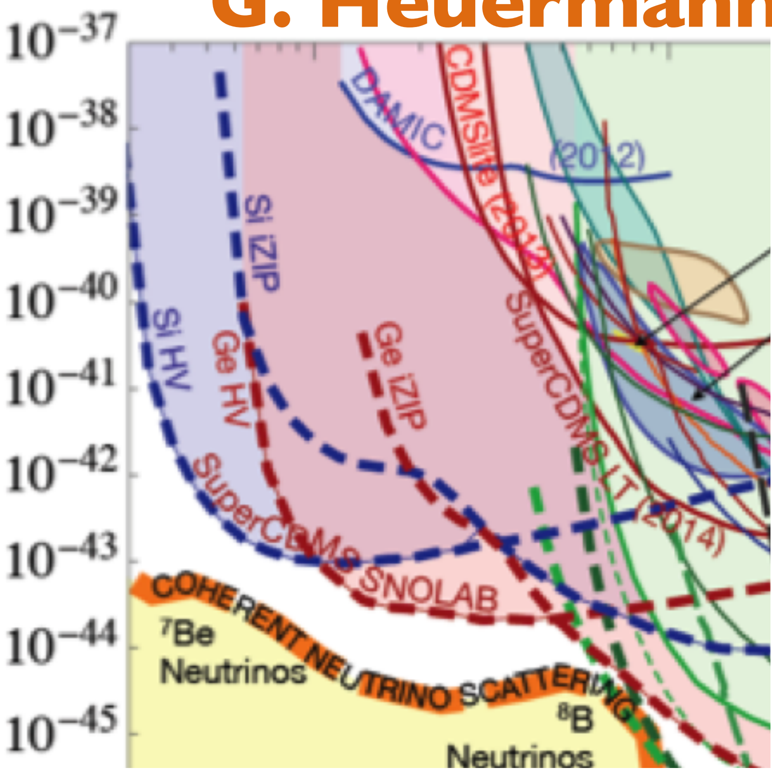
ν-electron scattering effect depends on available rejection power, but expect @10^{-48}cm^2

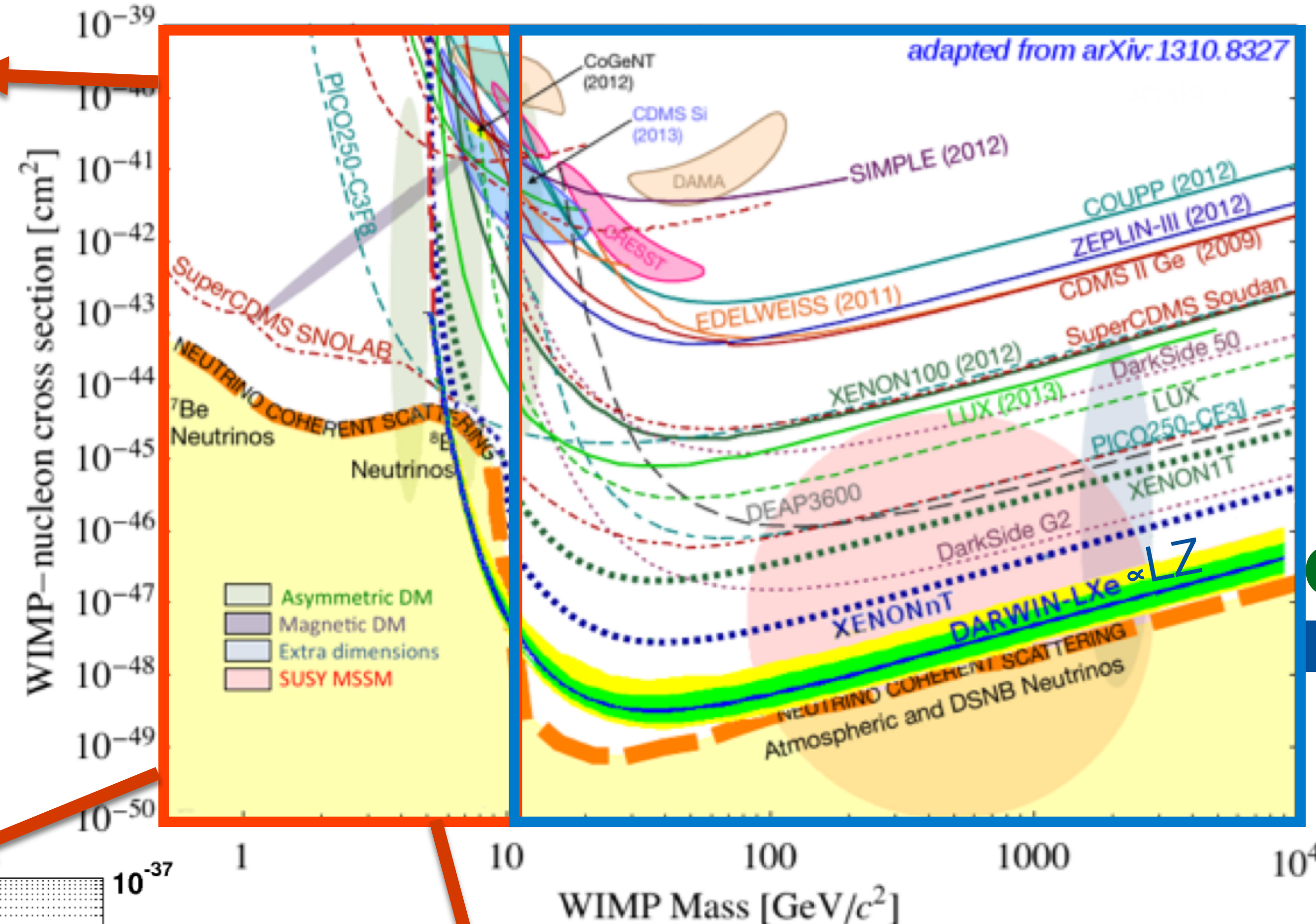
Emilija Pantic (UC Davis) on Future Direct DM at WIN 2015

J. Billard, et all, PRD 89 (2014), O'Hare et al., 1505.0806

Reaching neutrino floor (SI)

G. Heuermann





See talks

J. Maricic

M. Horn

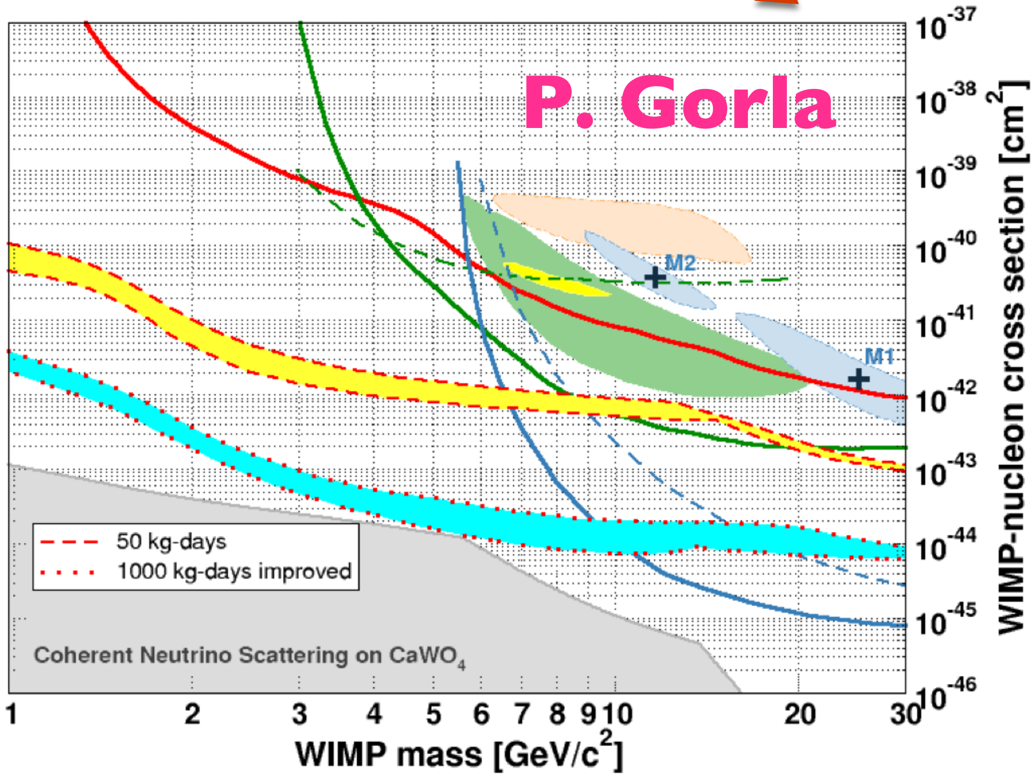
T. Pollman

C. Weinheimer

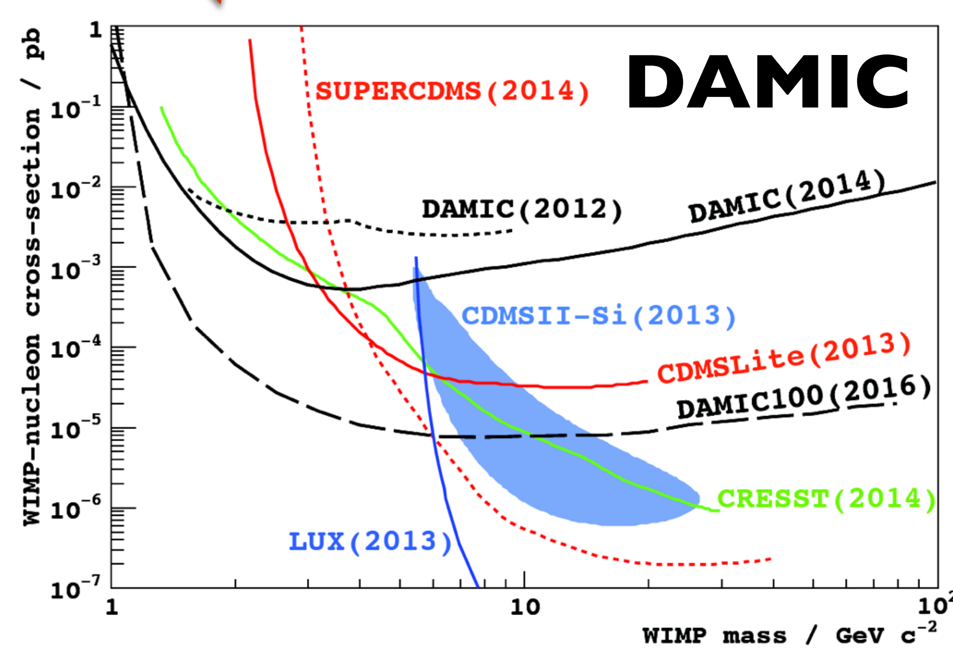
H. Simgen

A. Dobi

P. Gorla



DAMIC



Emilija Pantic (UC Davis) on Future Direct DM at WIN 2015

"Uniform" backgrounds (M_{DM}>10GeV)

C. Weinheimer

PandaX, LUX, XMASS, XE1T, XEnT, LZ, DARWIN, CLEAN, DEAP 3600, DS20T, ARGO

G3	Xe-nat (2-30keV)	UAr (30-200keV)
Kr-nat	(0.03)->0.01ppt	
^{222}Rn ER	4->0.1μBq/kg	<1ppt
^{136}Xe ER	<600 10ty (depletion)	
^{39}Ar ER		3 -> <1 mBq/kg (depletion)
ν ER	<1000 10ty	<2000 10ty
ν NR	<1 10ty ?	<1 10ty ?

Power of rejection with 50% sig. acceptance

orange	10^2-10^3
green	>10^7
light yellow	?

Radon (Kr) reduction major R&D for many experiments

See talks for handling radiogenic, cosmogenic neutrons

Values in the table are requirements for future G3 detectors.
G2 detectors are already under construction or operating.

See:1309.7024, LZ talk at LRT 2015, talks at Beyond 2020 LNGS 2015, 1308.4806,1306.6106, 1407.3981,

Reaching neutrino floor (M_{DM}>10GeV)

G3	*Darwin (LXe)*	*DS20T(LAr)*
Total Mass	*30-50 t*	*30t (upgrade CO+Sardinia)*
"~Bck. free" Exposure	*200ty (rejection, bck)*	*100ty (rejection, bck)*
LY@122keV and E=0	*8->8PE/keV (4π)*	*8-> >10PE/keV ($15m^2$ of $25cm^2$ SiPMs)*
ER Rejection	*99.5-> 99.98% (uniform E)*	*$1.6\ 10^7$->10^9 (LY or depletion)*
HV	*<200kV (100kV ✔)*	*50kV*
Electrodes	*thin wires, >2m in diam. stability, plating*	*thin films, >2m in diam.*
Active veto	*H_20 veto, self veto*	*self veto, Gd-H_20 veto?*

See backgrounds on previous slide

15 to 50% LY increase per unit area over PMT's ✔ dark count, noise for 10cm^2 tiles.✔

1mBq/kg@Sardinia ✔ distillation plant in progress✔

ZEPLIN-III, 99.987%✔

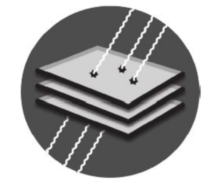
DS proposes ARGO (300t) with 1000ty "background free" for precision neutrino observatory.

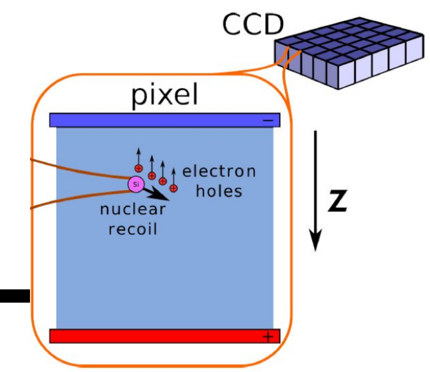
LXe and LAr technology are experiencing different technical difficulties.

See:1309.7024, LZ talk at LRT 2015, talks at Beyond 2020 LNGS 2015, 1308.4806,1306.6106, 1407.3981,

Critical detector parameters(M_{DM}<10GeV)

PandaX XENON Dark Matter Project, LUX, XE1T, XEnT, LZ — Edelweiss, CDMS, CMDSlite, SuperCDMS — CRESST-II, CRESST-III, EURECA — DAMIC





	Xe-nat	Ge (Si)	CaWO4	Si
energy per quanta	*~15eV*	*~3eV*	*~30eV (light)*	*~3eV*
Analysis Threshold (two sig)	*3keVr (2keVr) light yield*	*10keVr (2keVr) charge yield*	*600->100eV*	
internal amplifier	*charge via light*	*charge via phonon*		
Threshold (one sig)	*1-3 e-*	*170-> <15eV$_{ee}$*		*80-140eVee (?)*
Mass	*few tons*	*~10kg*	*1x250->24g (100x24g)*	*~8->100g*

vibrational noise, T_{op}, coupling to the bath, parasitic noise

See: PRL 112, 041302 (2014), talks at WIN2015, CIPANP2015, BeyondWIMPS2015

Critical backgrounds (M_{DM}<10GeV)

	Xe-nat 2phase 22(2-30keV)	Ge/Si	CaWO4	Si (CCD)
Kr-nat ER	0.03->0.01ppt			
isotope ER	^{136}Xe<600 10ty			^{32}S~1ev/keV$_r$ kgd
^{222}Rn/^{210}Pb	4->0.1μBq/kg (ER)	5.6mBq/m^2(Cu) (alpha act)	1-3mBq/kg (alpha act)	<46ev/kgd
"surface" ^{206}Pb NR	?	907-> <20ev/kgy	<12ev/kgy	?
Compton ER (other beta)	<<	10^3->5ev/keVr kgy	10^3 ev/keV kgy	500->0.5 DRUee ^{238}U/^{232}Th<5/15ev/kgd
Activation ER	^{127}Xe,^{46}Sc(Ti)	^{3}H(Ge), many lines	many lines	?
1/2/3 e-	<24/4/1 ->?ev/kgd			
ν ER	<10ev/keVr ty	<10ev/keVr ty	<	?
ν NR	<	<	<	<

rejection | surface cut or veto | wait | light/phonon | delayed image

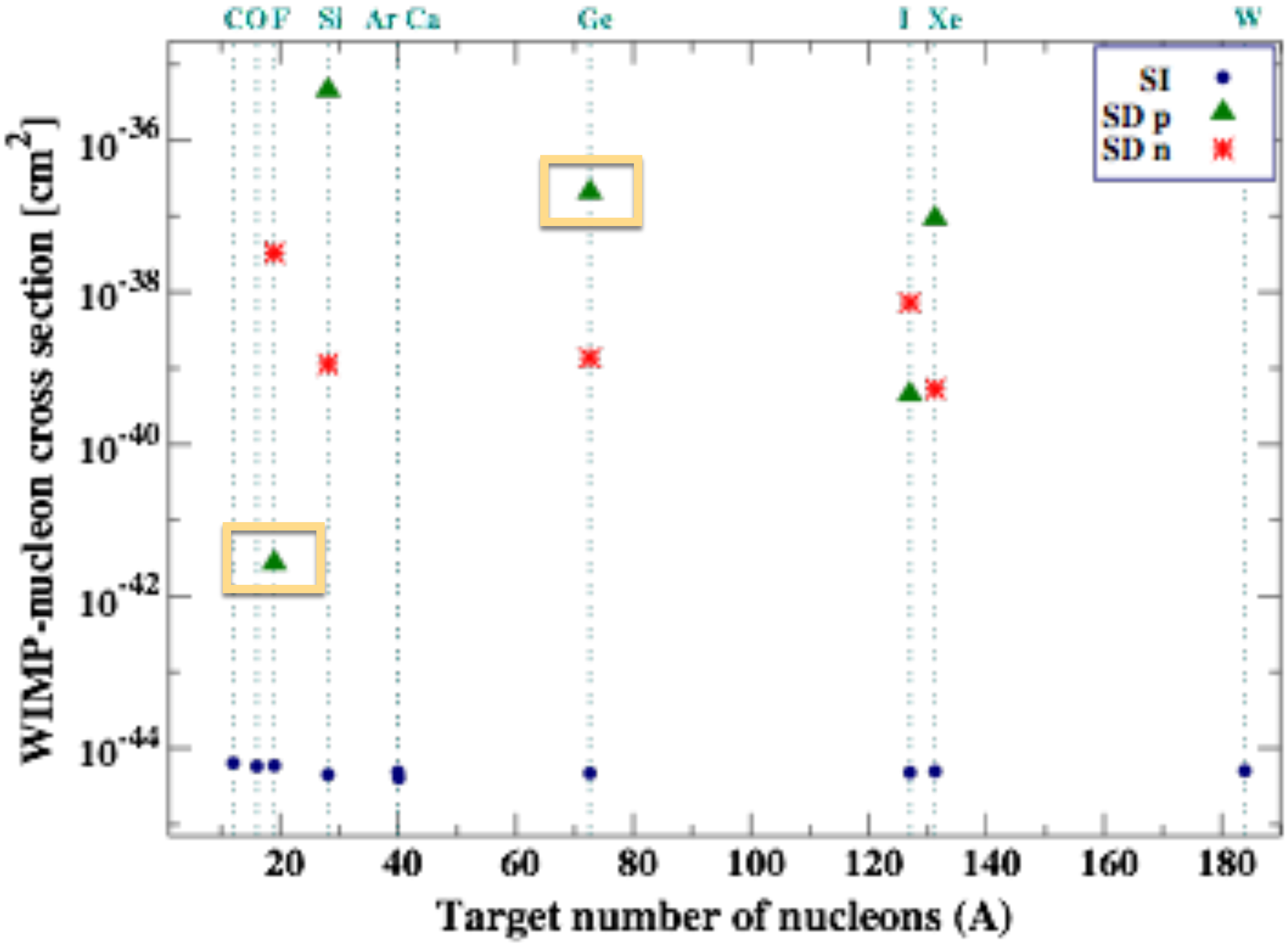
No simple solution for single e-: reduce charge loss to impurities and at gas-liquid boundary; build complex model. Careful large scale detector design and reduced dissolved impurities.

Emilija Pantic (UC Davis) on Future Direct DM at WIN 2015

1309.7024,1308.4806,1306.6106, 1407.3981, J.Phys. G 41 035201, 1407.3176, 1503.08065, 1410.4188

Beyond ν floor: Explore target complementarity

Limitation of DM discovery limit due to CNS:
1. is more relevant for low-mass DM up to G3.
2. can only be moderately improved for SI interactions due to similarity in DM and neutrino signals in the different target nuclei.
3. can be notably improved for SD targets.



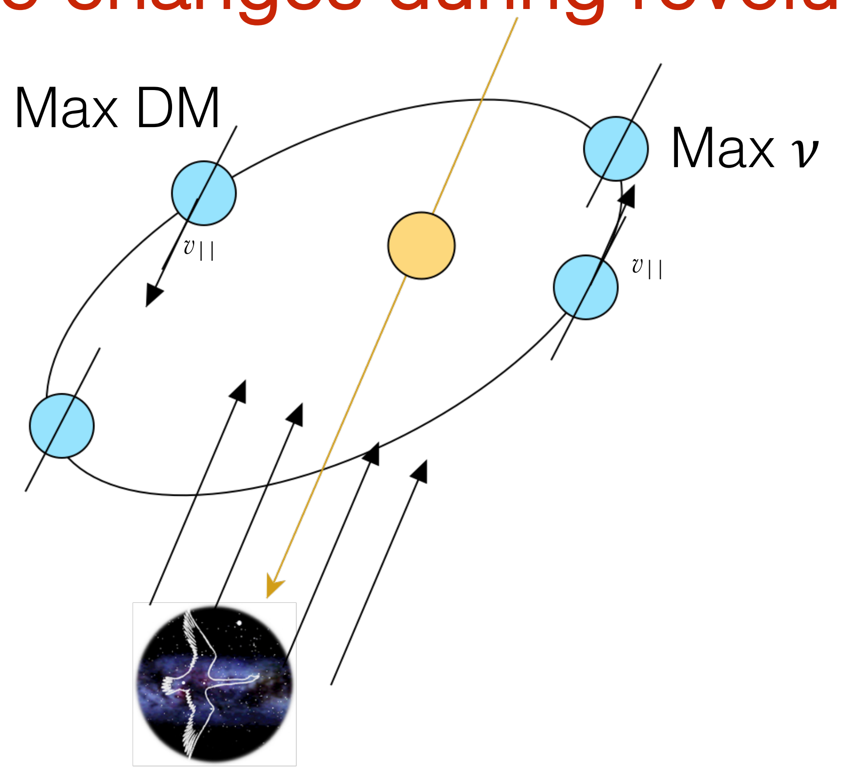
CNS background
under DM only hypothesis
mean reconstructed σ

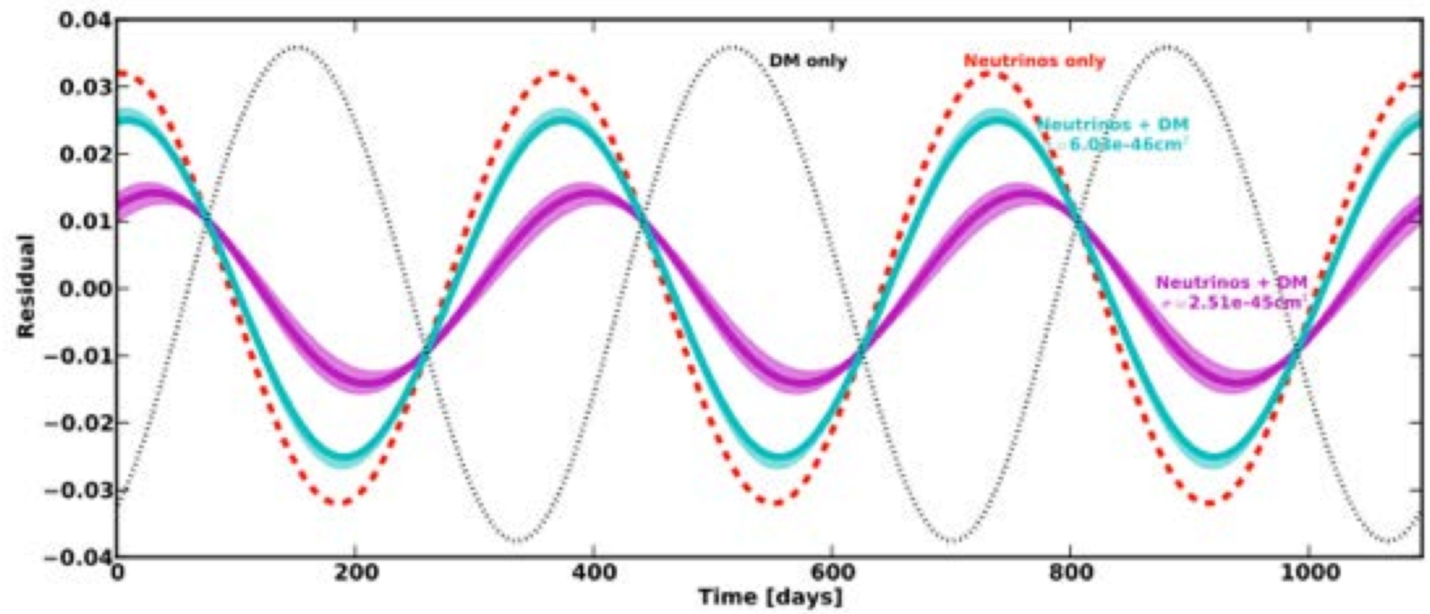
F. Ruppin, et al., PRD 90 (2014)

Beyond ν floor: Explore annual modulation

ygnus around the galactic orbit. We revolve around the Sun and modulate this ra

stance changes during revolution and modulates neutrino flux (~3-5%) with ma



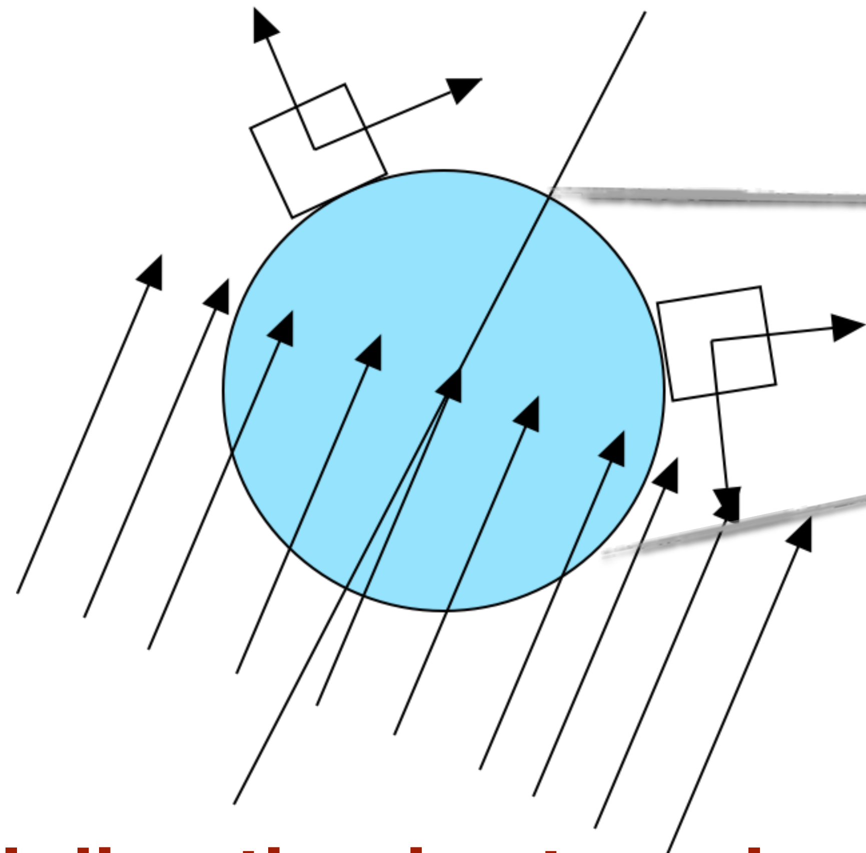


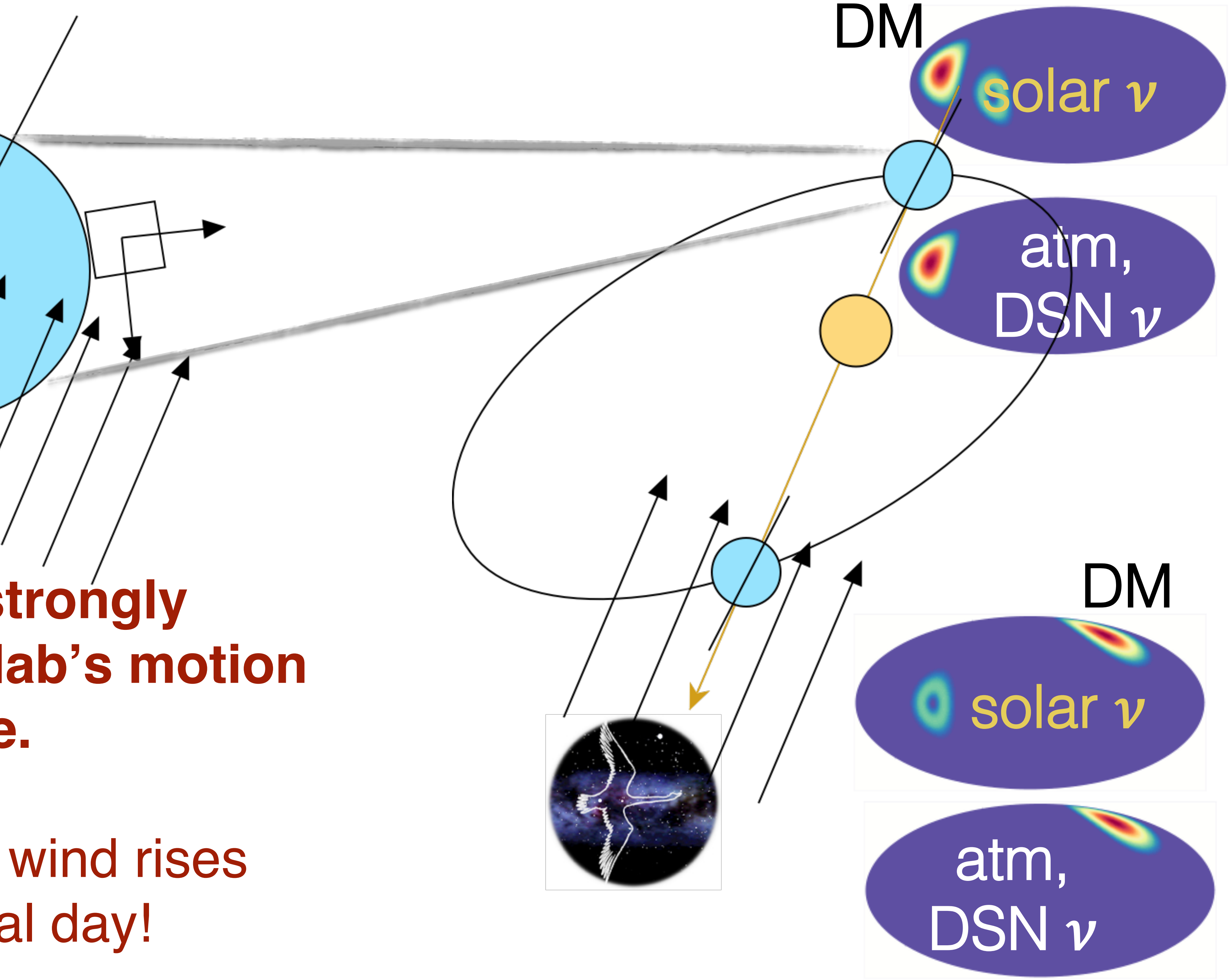
Jonathan Davis, PRL 113, 081302 (2014)

Requires ~1000 of neutrino events to help going beyond ν floor

ect searches and especially modulation-driven searches: DM-ICE17, DM-ICE37

Beyond ν floor: Explore sidereal modulation





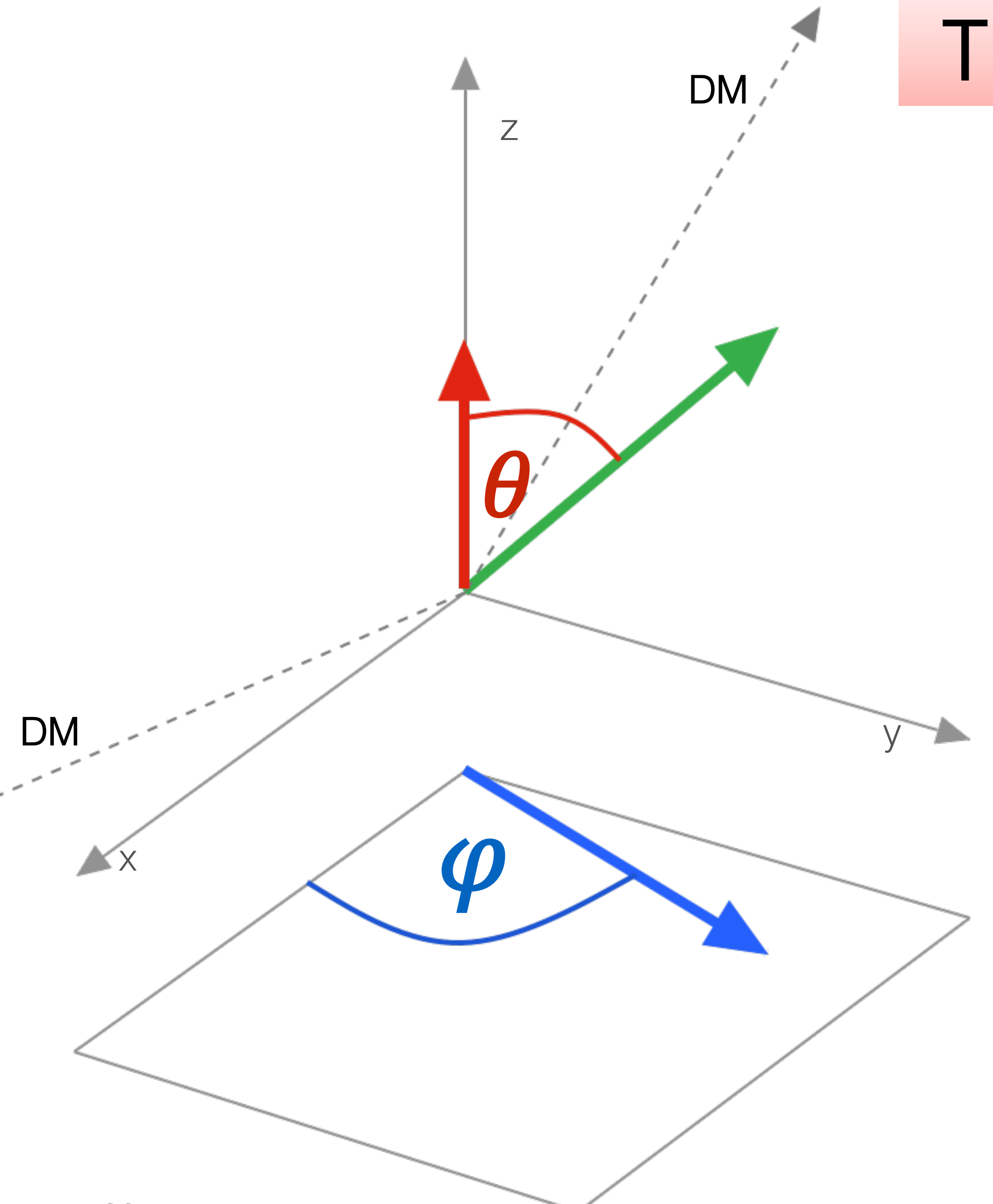
Recoil direction is strongly correlated with the lab's motion in the galactic frame.

"Source" point of DM wind rises and sets each sidereal day!

DM and solar ν recoil distributions can be distinguished as long as the angular resolution is better than 30°.

O'Hare et al., 1505.0806, J.Billard PRD D 91, 023513 (2015), P. Grothaus et al., PRD 2014,

1D, 2D, 3D Directional detectors



Track length for 10keV NR = ~1 mm in gas

- 3d vector (E_R, θ, φ, sense, time)
- 3d axial (E_R, θ, φ, time)

(DRIFT, MIMAC, D[3], NEWAGE)

- 2d vector (E_R, φ, sense, time)
- 2d axial (E_R, φ, time)

(DMTPC)

- 1d vector (E_R, θ, sense, time)
- 1d axial (E_R, θ, time)

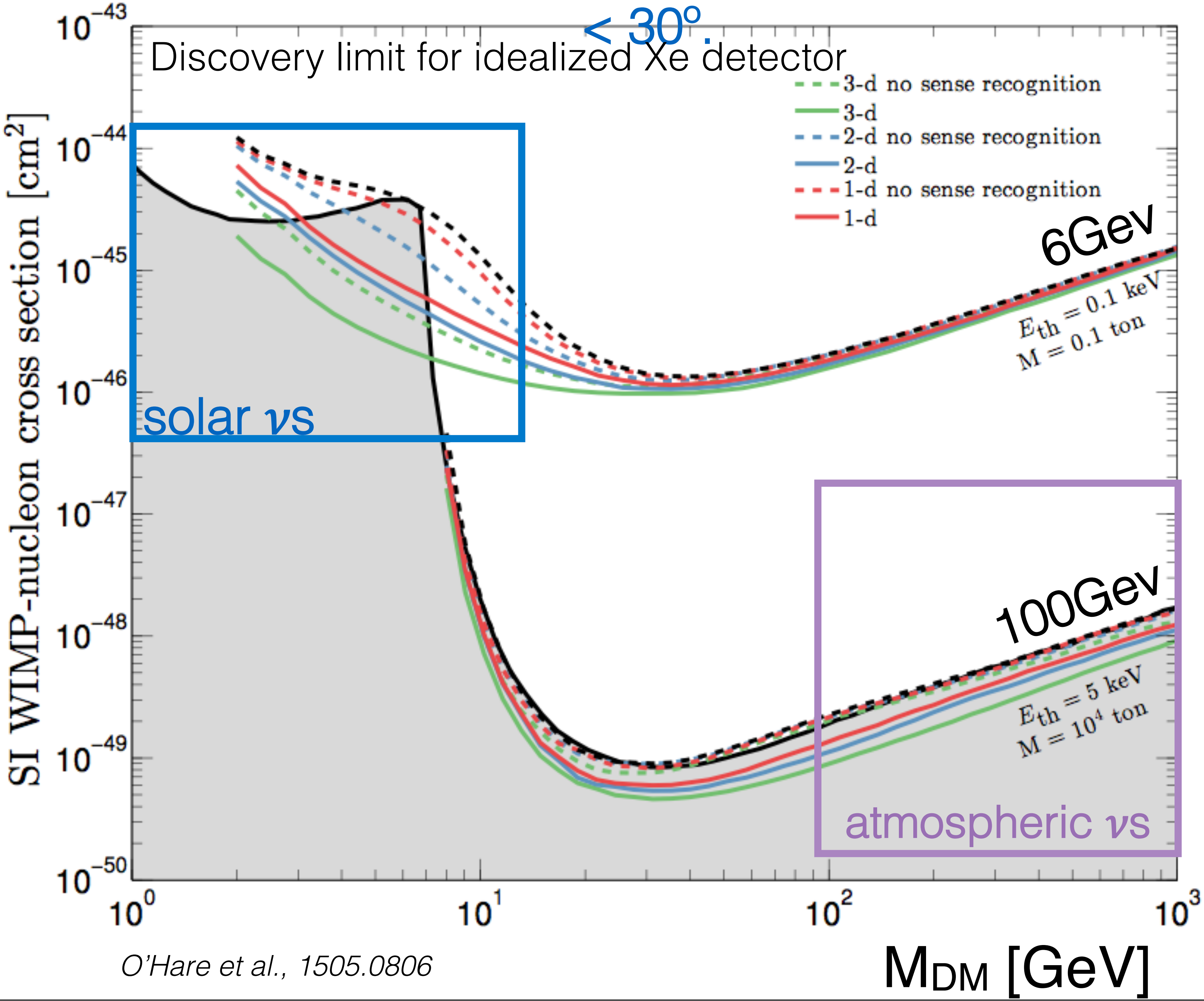
(LAr TPC?)

Difficulties:
Real recoil shows straggling and electron (ion) cloud has diffusion -> limits angular resolution especially at low E_R

Main challenge for gaseous detectors is scalability:
DRIFT (140g) -> Future DRIFT III: 4kg

Directionality comparison

Directional information (w or w/o sense) helps the most for low mass DM if angular resolution < 30º.



O'Hare et al., 1505.0806

Directional information w/o sense does not help too much for high mass DM.

(assumption that atmospheric νs are isotropic)

O'Hare et al., 1505.0806

Summary

1. At least two technologies (LXe and LAr) in the large mass DM region and few technologies (Ge, Si,CaW04 and LXe) in the low mass DM region could reach the neutrino floor.

2. Besides helping constraining DM mass, target complementarity could help with background rejection other than vanilla (SI) interaction.

3. Annual modulation could help both with identifying cosmic neutrino background or DM signal, but only once enough events have been accumulated.

4. Directional information (w or w/o sense of direction) helps the most for the low mass DM but in present detectors we are either missing scalability or directionality.

5. Directional information w/o sense of direction (like columnar recombination) seems not to help a lot for high mass DM.

6. With larger exposures (DM and neutrino signals of a similar size), the discovery potential is dominated by systematic uncertainties in neutrino signals.

7. At very large (beyond G3) exposures with $\#\nu$s > few 1000, one could preform more precise background subtraction and search for DM via deviations in tail of measured distribution.

Choose your DM opponent and be prepared to

feV peV neV μeV meV eV keV MeV GeV TeV





THANK YOU!

listen to a cosmic radio

or receive a punch

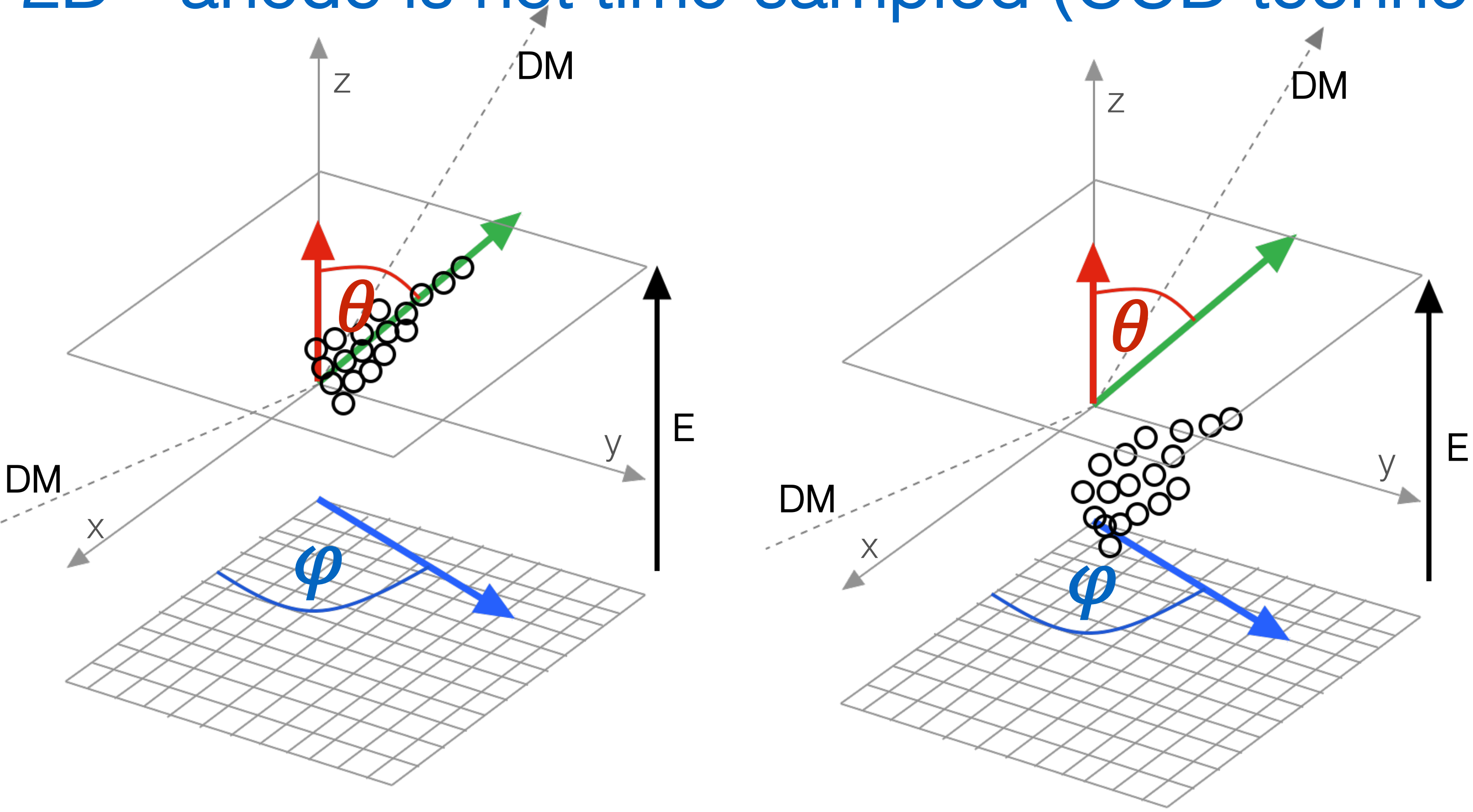


EXTRA SLIDES

Directionality via 2D image (over time)

3D = track is measured by sampling over time the 2D projection of the ionization-induced electron (ion) cloud on a pixelized anode.

2D= anode is not time-sampled (CCD technology)



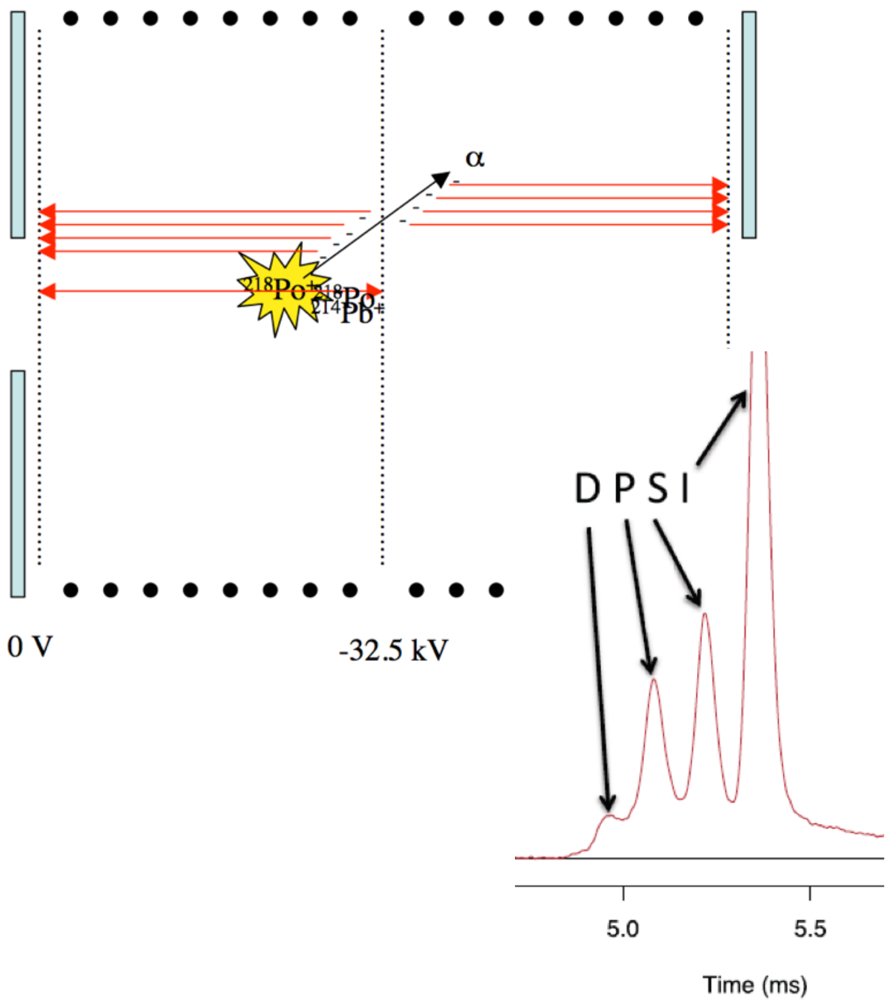
Track length for NR Ơ(10keV) ~1 mm in gas

Direction: Use head tail effect resulting from different dE/dx along the track with threshold ~30-50keV

Difficulties:
Real recoil shows straggling and electron (ion) cloud has diffusion -> limits angular resolution (few detectors demonstrated < 35°)

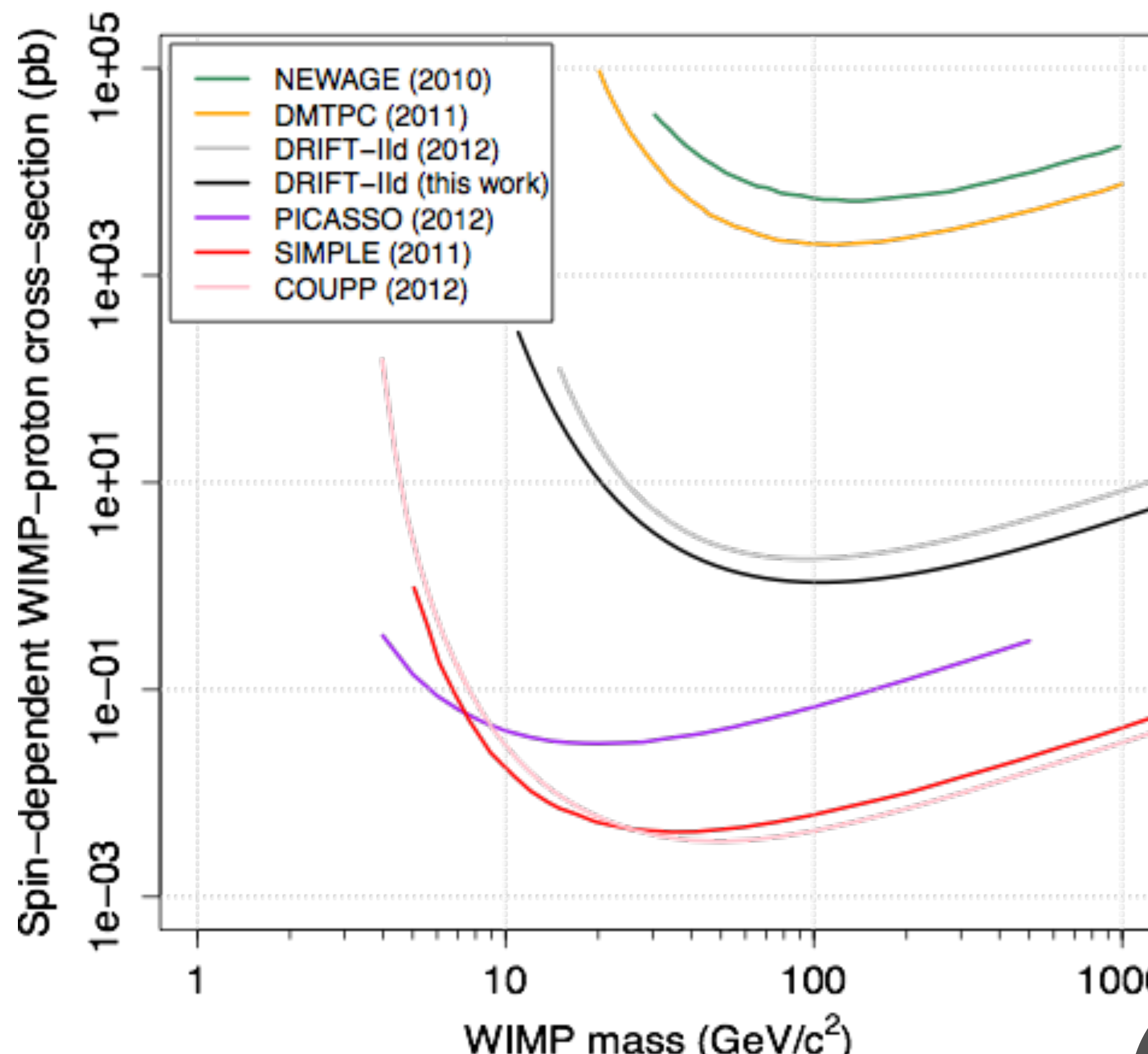
Example: DRIFT - 3D CF_4 multiwire proportional chamber

1m^3 CF_4 +CS_2+0_2 (140g)



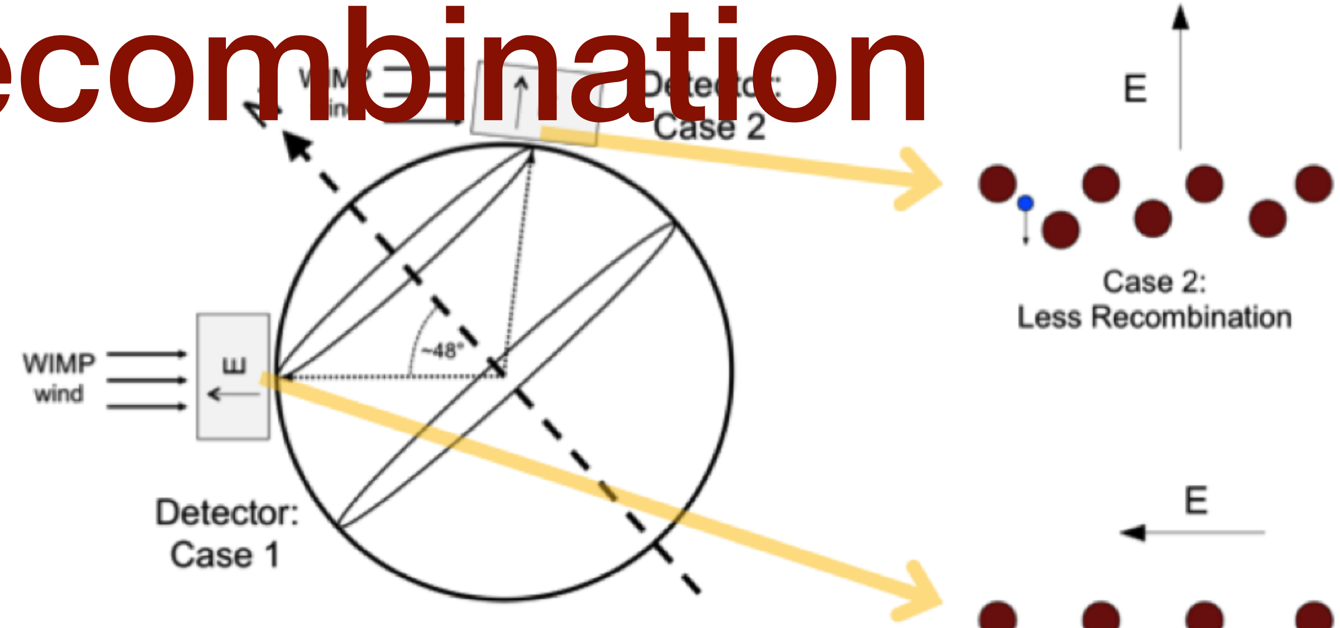
3D vector via charge **(2D xy +drift + Head-Tail)**

Negative ion drift $(CS_2)^-$ for min diffusion.
Particle discrimination based on xy.
Fiducialization using minority peaks
(Rn mitigation)



Main challenge scalability
Future DRIFT III: 4kg target

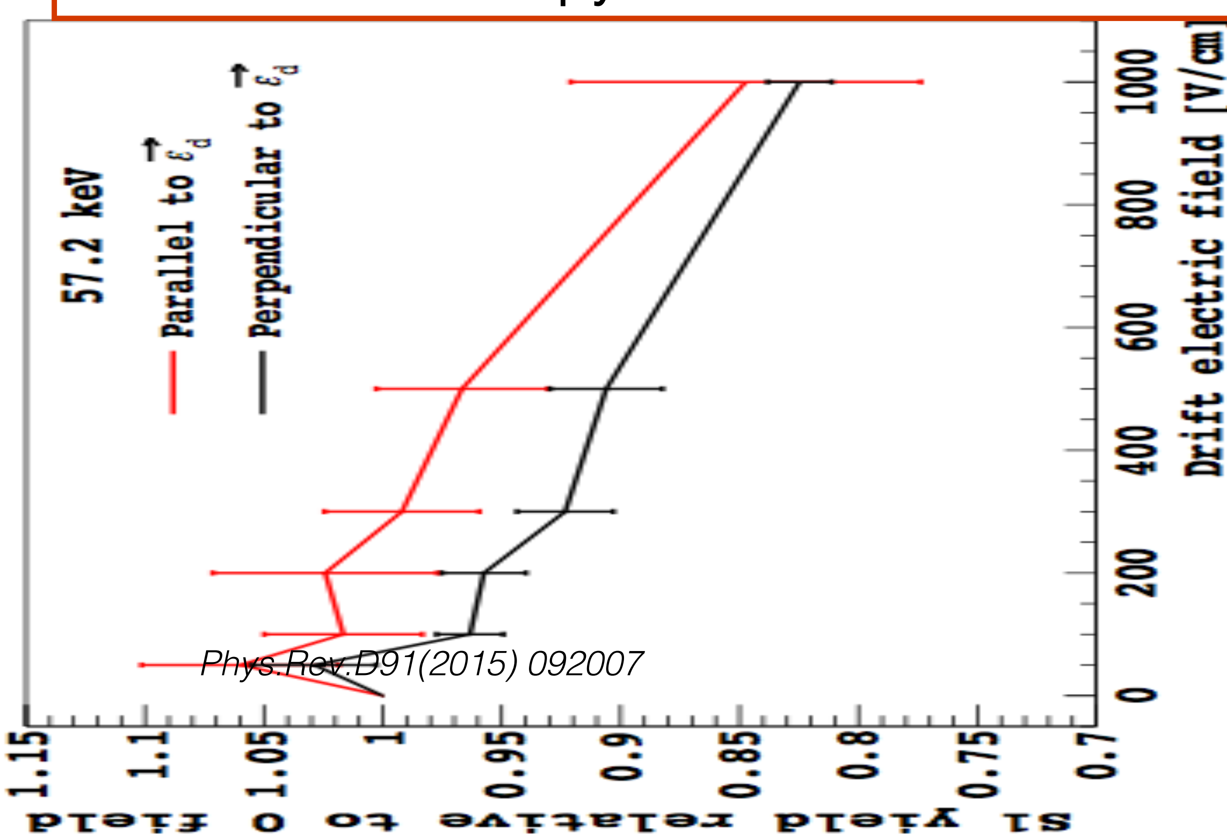
1D Directionality via columnar recombination



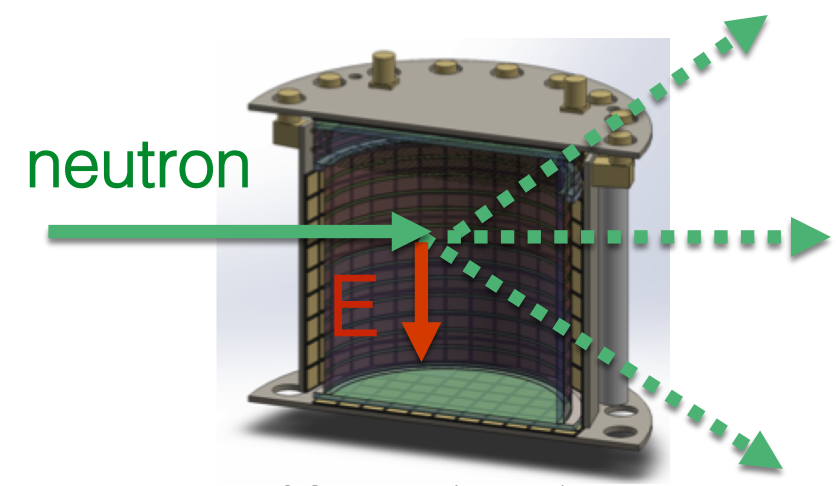
When a nuclear recoil is parallel to the electric field, as in Case 1, there will be more electron-ion recombination since the electron passes more ions as it drifts through the chamber.

Columnar recombination depends on angle between drift field and track direction.
NR range > recombination distance ($E_{threshold}$)
No problem with the scalability, but needs to be confirmed.

Hint for anisotropy of 57.2 keV NR in LAr



1D axial (E_R,θ,time)



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GAP- LAr TPC
4π SiPM coverage
mm spatial resolution

See also: D. Nygren J Conf. Ser 460 (2013)

See also: D. Nygren J Conf. Ser 460 (2013)