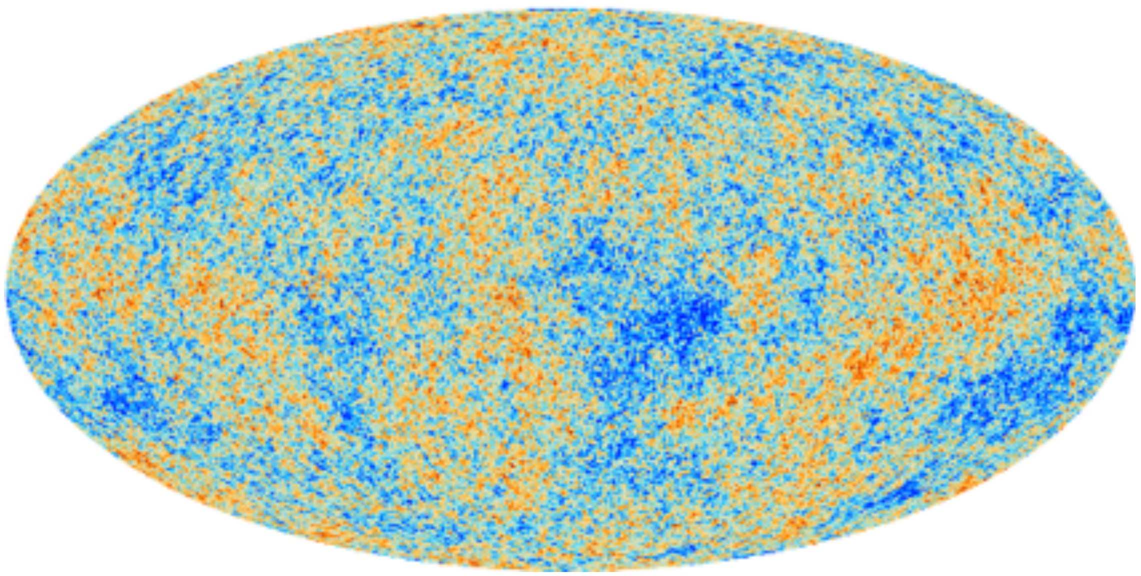
What's up in Dark Matter detection

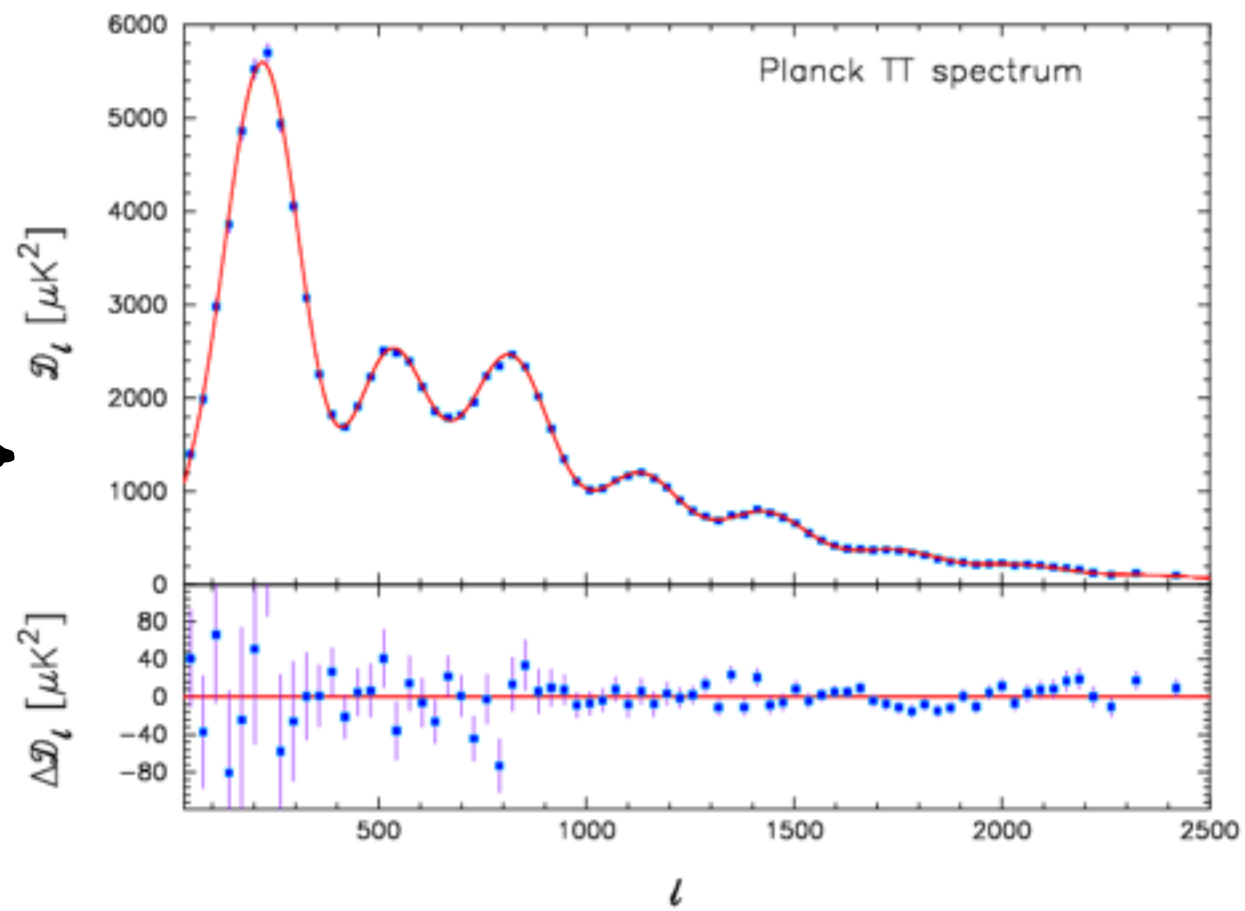
Quentin Riffard

November 28th 2014

How many & Where ?
Universe composition measurement

Planck (LPSC): Large scale DM probe





Precision cosmology (CMB, SN Ia, BAO, …)

Dark energy	$\Omega_\Lambda = 0.686 \pm 0.020$
Non-baryonic matter	$\Omega_{\rm CDM} = 0.2640 \pm 0.0068$
Baryonic matter	$\Omega_{\rm b} = 0.0487 \pm 0.0007$

ΛCDM

Ade *et al.*, Astron.Astrophys. **571** (2014) A16

~ 82% of Universe material content is non-baryonic matter

What is it ?
Dark matter candidates

WIMP (Weakly Interacting Massive Particle)

- Massive: $\mathrm{GeV/c^2} - \mathrm{TeV/c^2}$
- Fermion
- Stable
- No electric charge & No color
- Gravitational & weak interaction

One WIMP candidate from particle physics (SUSY): Neutralino χ

Axions

- Very low mass: $\mu\mathrm{eV/c^2} - \mathrm{meV/c^2}$
- Stable
- No electric charge
- Gravitational + weak and strong interaction (low coupling)

Sterile neutrino

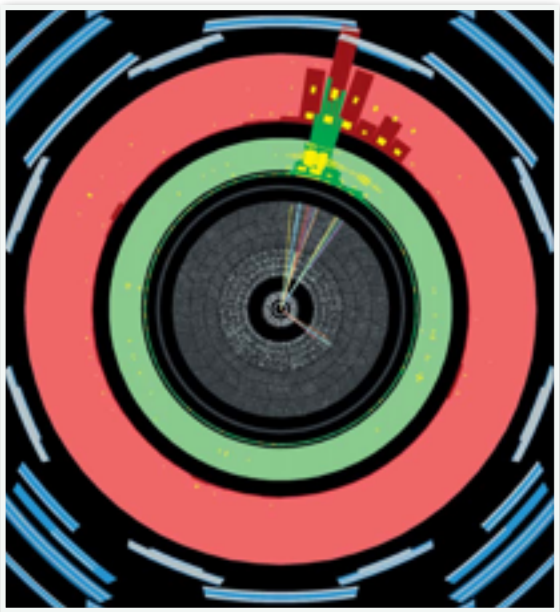
- Low mass: $\mathrm{eV/c^2} - \mathrm{keV/c^2}$
- Stable
- No gauge interaction: Only gravitation

●●●

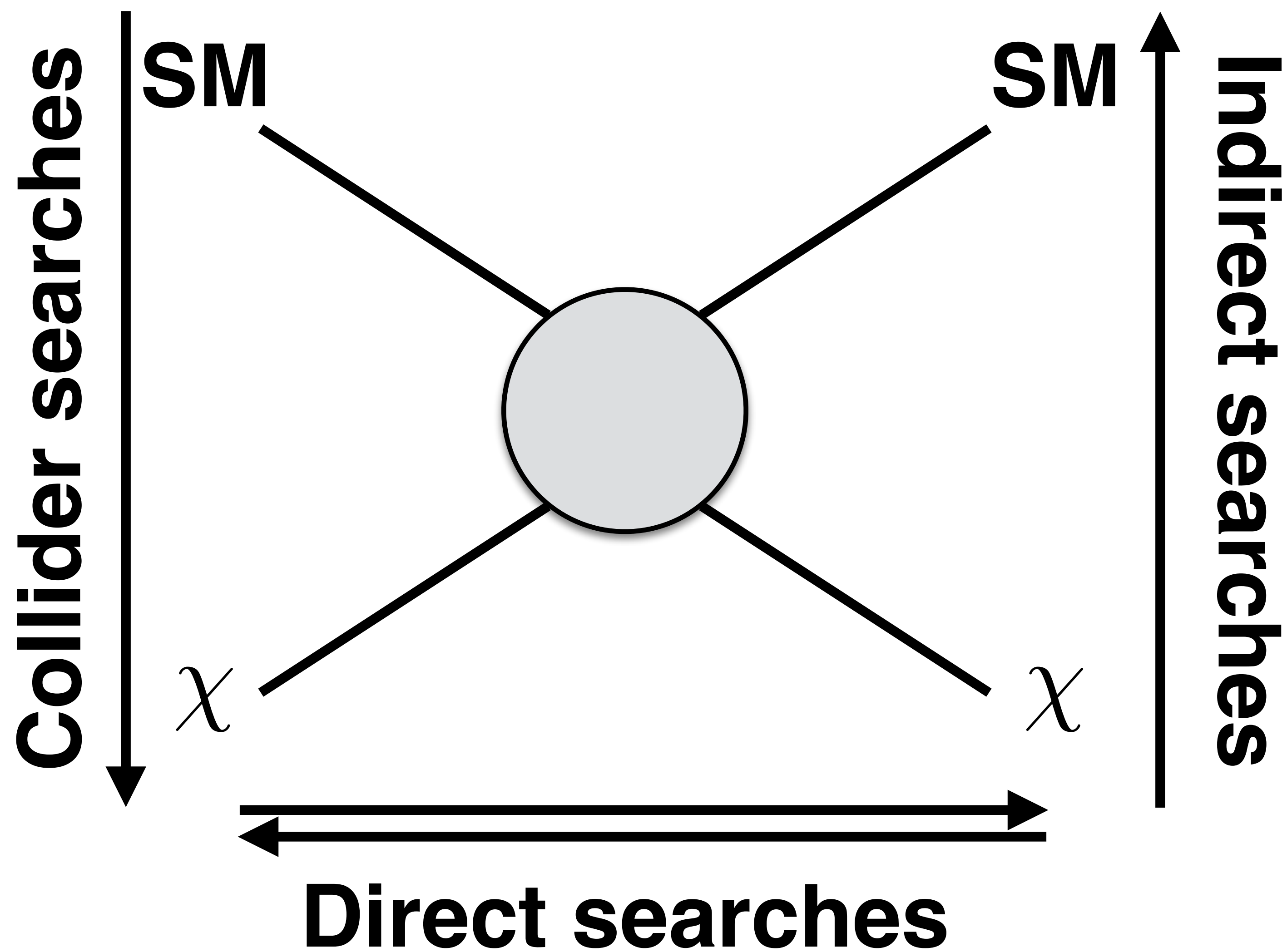
Constrain Dark Matter properties ⟶ **Detection**

Dark Matter interactions

LAPP, LAPTh, LPSC

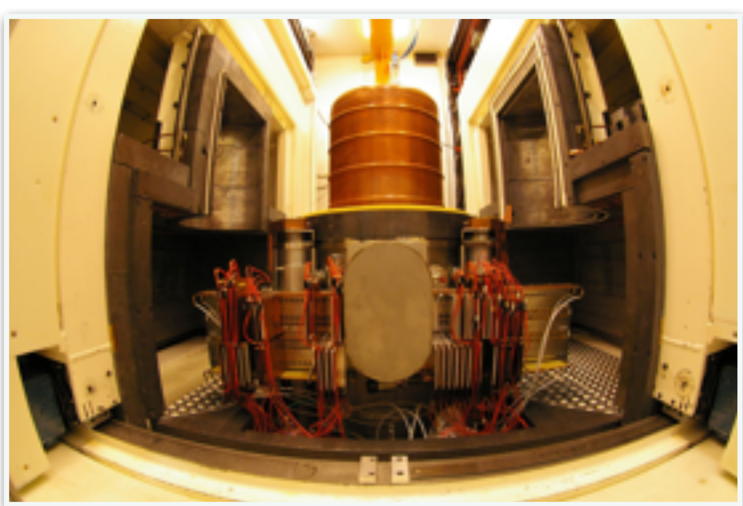


LAPP, LAPTh, LPSC

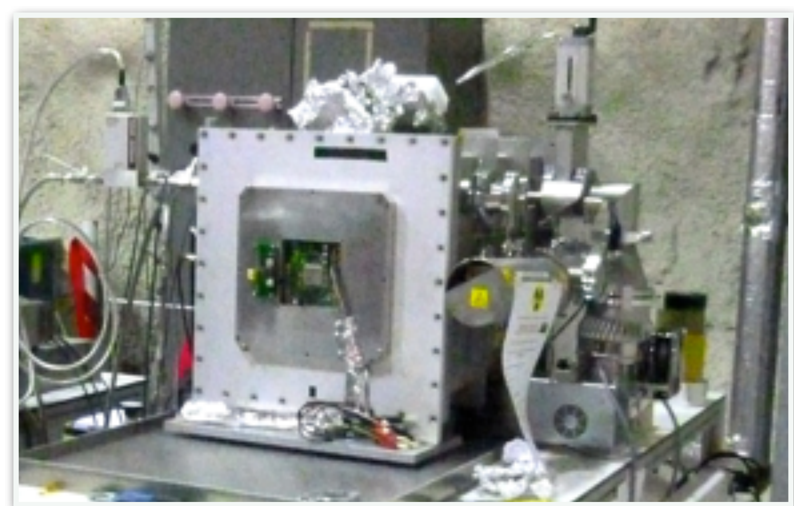


LAPTh, LPSC

LAPP

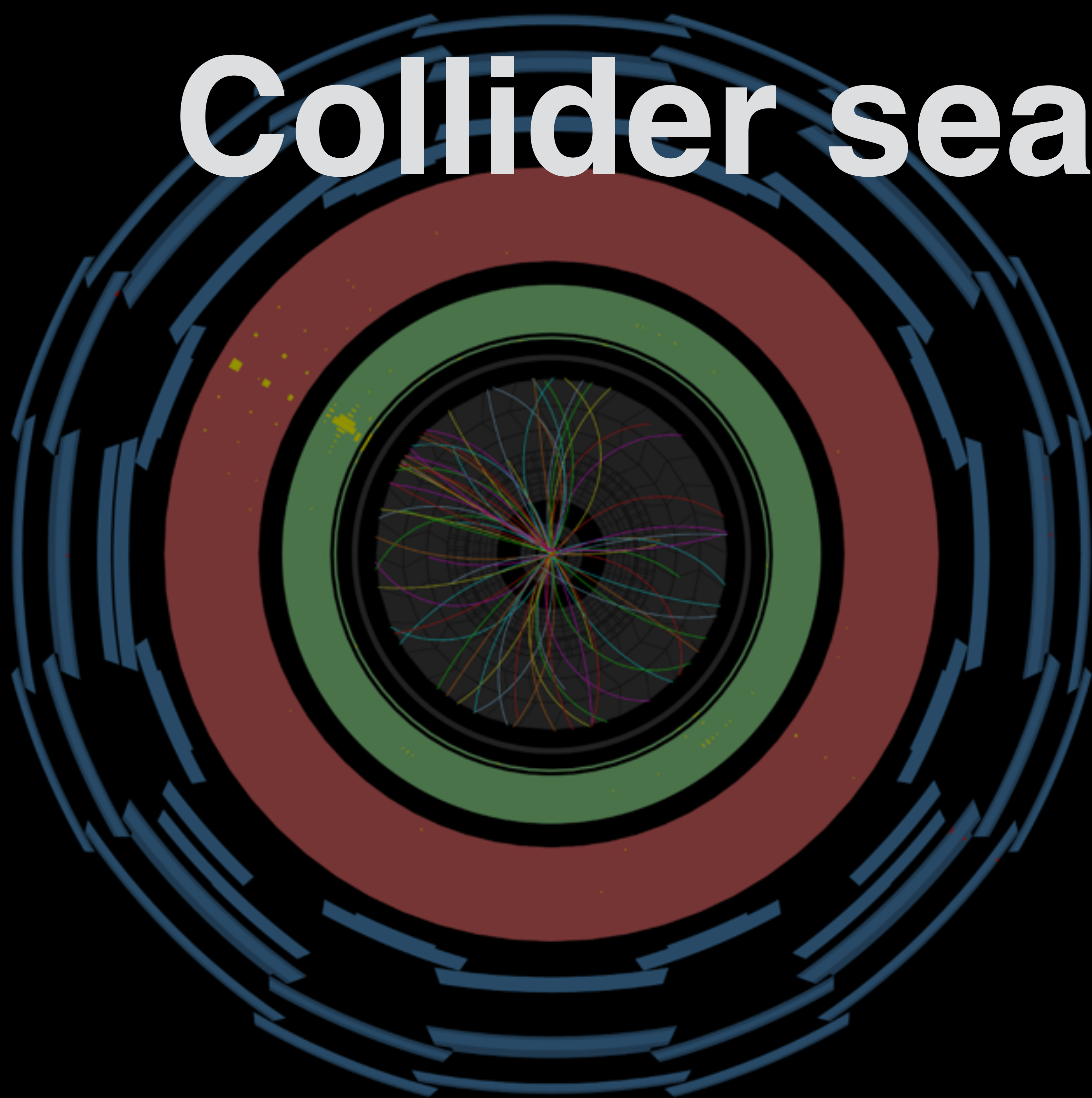


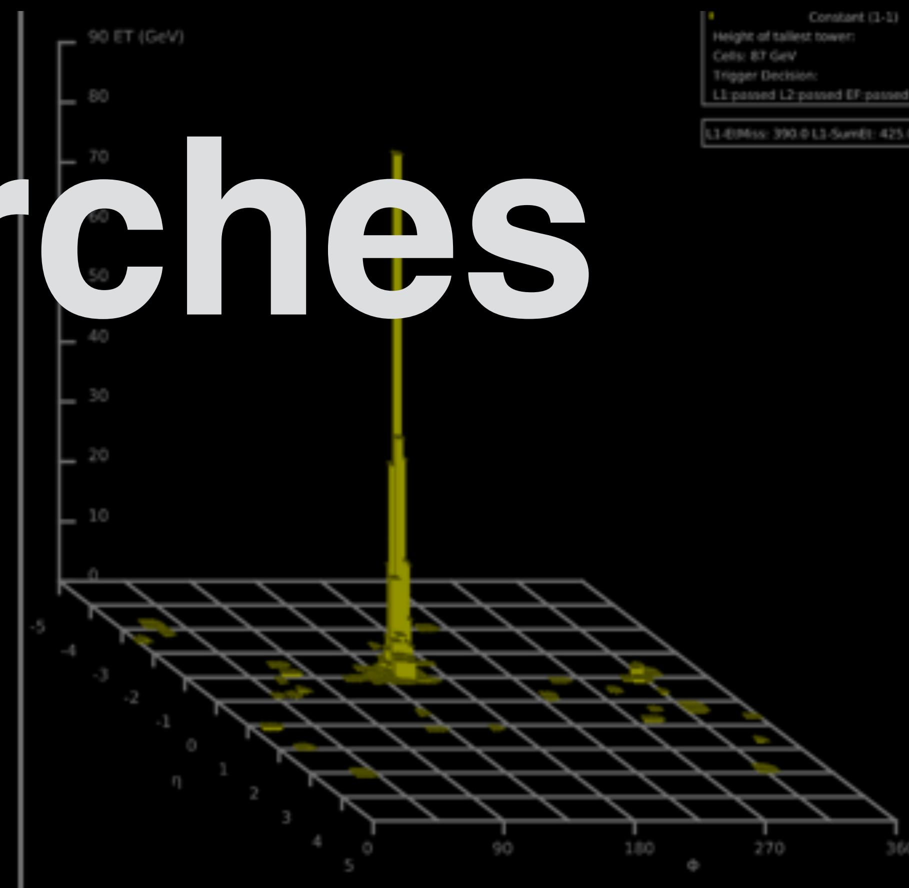
LSM



LSM,LPSC

Collider searches



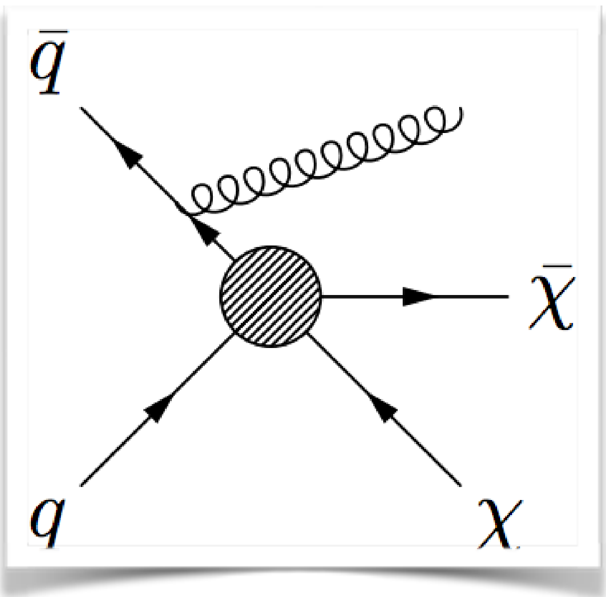


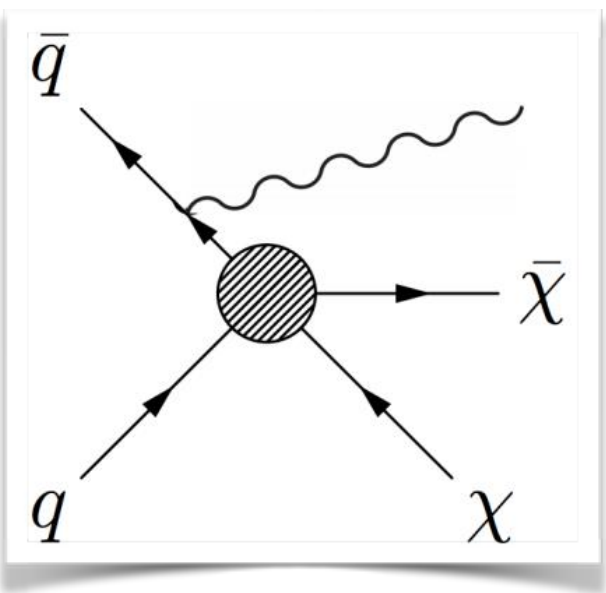
ATLAS EXPERIMENT

Run Number: 180309, Event Number: 36060682

Date: 2011-04-27 02:33:15 CEST

Collider searches: Effective field theories





Effective field theory:
Simplest way to describe interaction between WIMPs and quarks

→ **Effective operator** (examples):

$$\frac{\overline{\chi}\gamma_\mu\chi\bar{q}\gamma^\mu q}{\Lambda^2}$$ vector

$$\frac{\overline{\chi}\gamma_\mu\gamma^5\chi\bar{q}\gamma^\mu\gamma^5 q}{\Lambda^2}$$ axial-vector

O. Buchmueller *et al.*, JHEP **1401** (2014) 025

Suppression scale

$$\Lambda = \frac{m_{\rm med}}{\sqrt{g_q g_\chi}}$$

Mediator mass

couplings to quark

couplings to WIMP

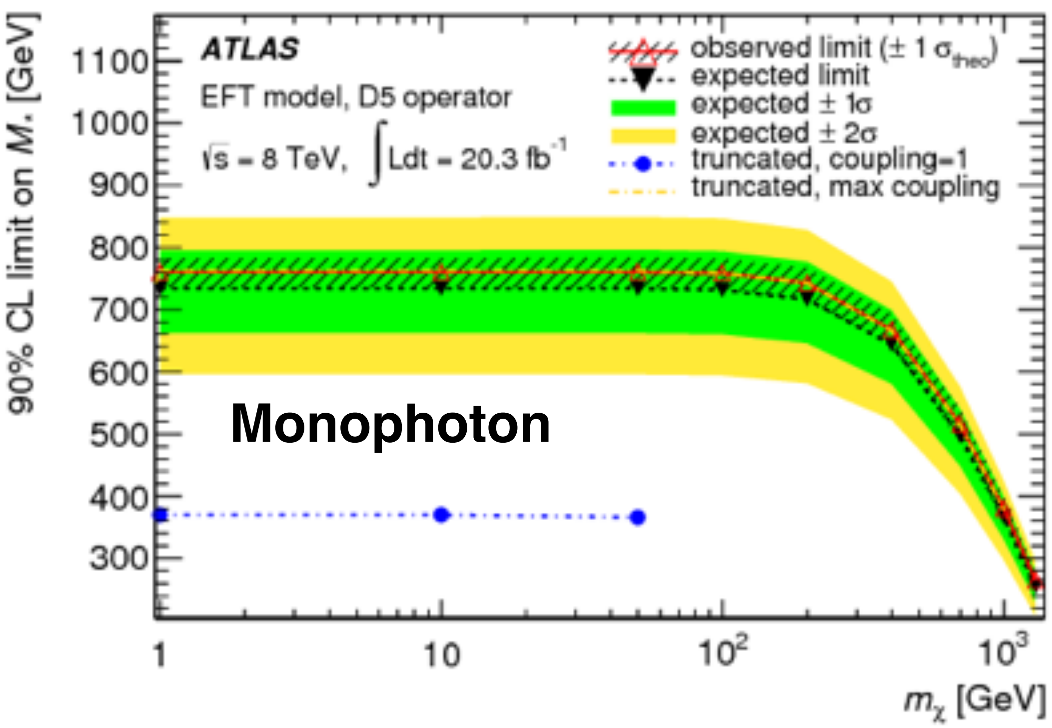
Expected signal in final state: MET + 1 jet/photon

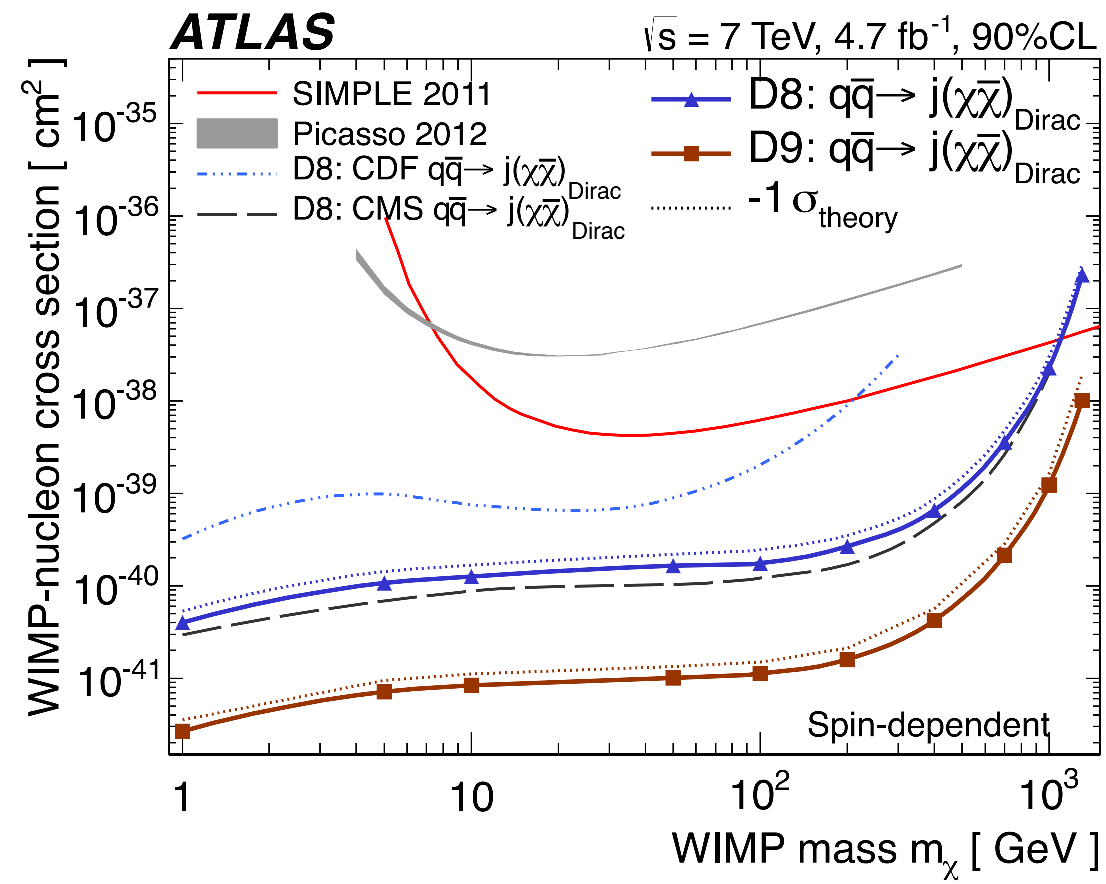
→ **LHC Dark matter searches: constraints on** Λ

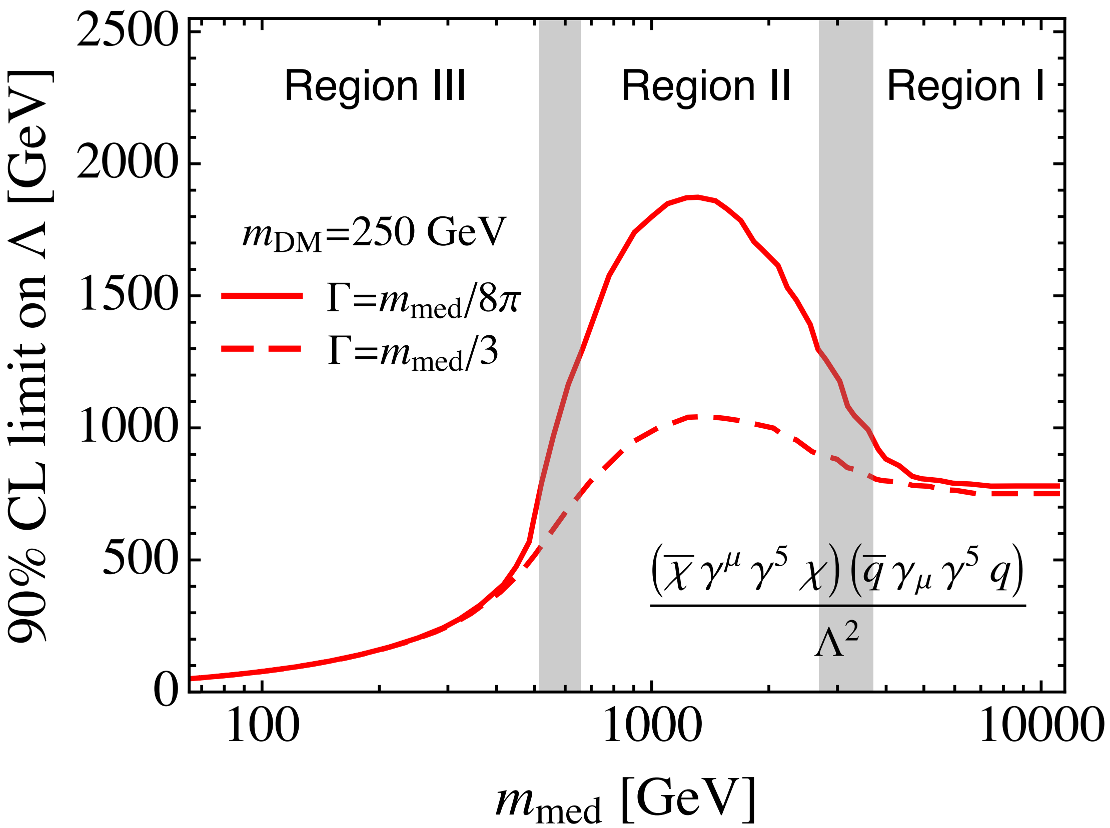
ATLAS Collaboration,JHEP **1304** (2013) 075

Collider searches

In the EFT framework $\Lambda \leftrightarrow (\sigma_p^{SI}, \sigma_p^{SD})$







EFT ⟷ Point-like interaction

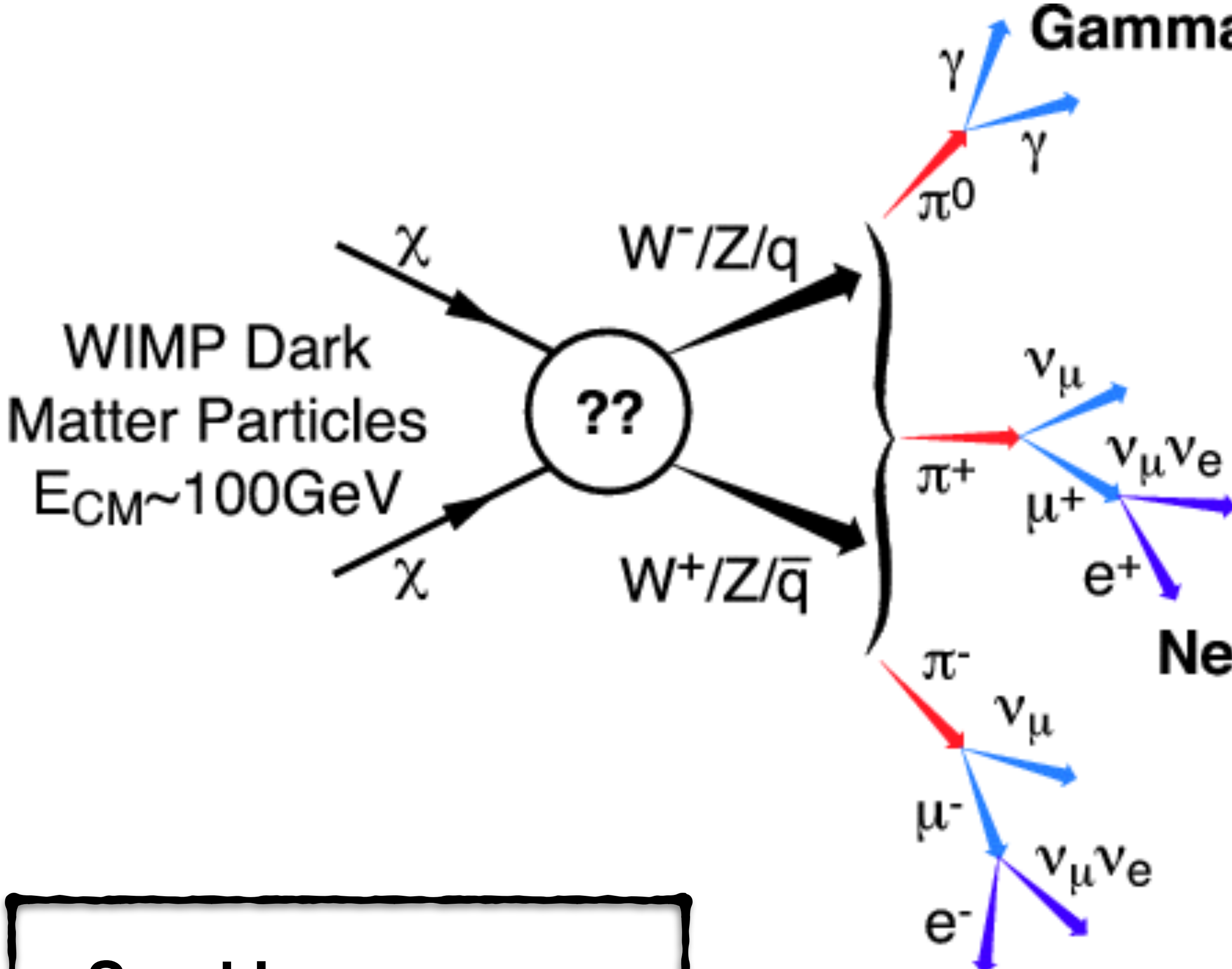
Heavy mediator: $m_{med} > \mathcal{O}(1\,\mathrm{TeV})$

Conclusions:

- Significative constraints on exotic physics
- **No direct correspondance with direct detection (Null transferred momentum)**


Indirect Dark Matter
detection

Indirect Dark Matter detection



Gamma-rays:
- Travel in straight lines
- Spectrum not affected by propagation

→ **H.E.S.S., Fermi-LAT, …**

Neutrinos:
- Travel in straight lines
- Spectrum not affected by propagation
- Hard to detect

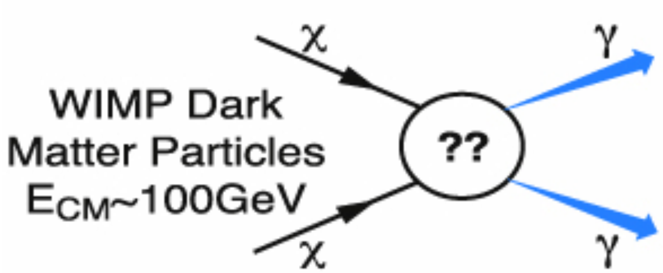
→ **Ice-Cube, Antares**

+ a few $p/\bar{p}$, $d/\bar{d}$

Anti-matter:
- Spectrum strongly affected by propagation
- Isotropic flux

→ **AMS-02 (LAPP, LPSC)**
(Dedicated talk by Li Tao)

Smoking gun



Indirect Dark Matter detection: Gamma-rays

Sources observation:

- Dwarf galaxies
- Galaxy clusters
- Galactic center
- …

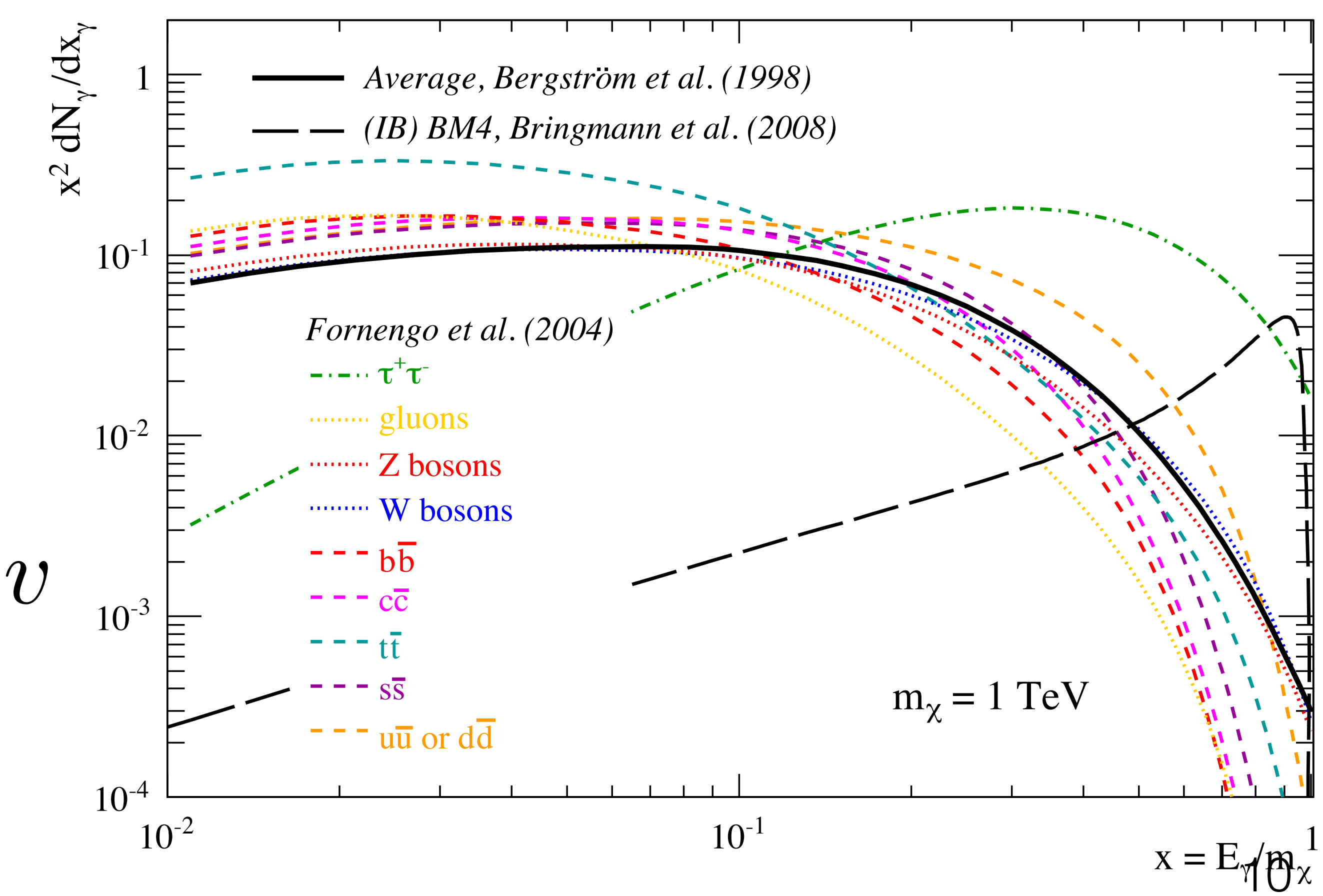
Angular resolution — **DM density**

$$\frac{d\phi}{dE} = \frac{1}{4\pi}\frac{dN}{dE}\frac{\langle\sigma v\rangle}{2m_\chi^2}\int_0^{l_{max}}\int_0^{2\pi}\int_0^{\alpha}\frac{\rho_{DM}^2}{l^2}l^2\sin(\theta)d\theta d\varphi dl$$

Annihilation spectrum

DM velocity distribution

Where: $\langle\sigma v\rangle = \int v\sigma(v)f(\vec{v})d^3v$



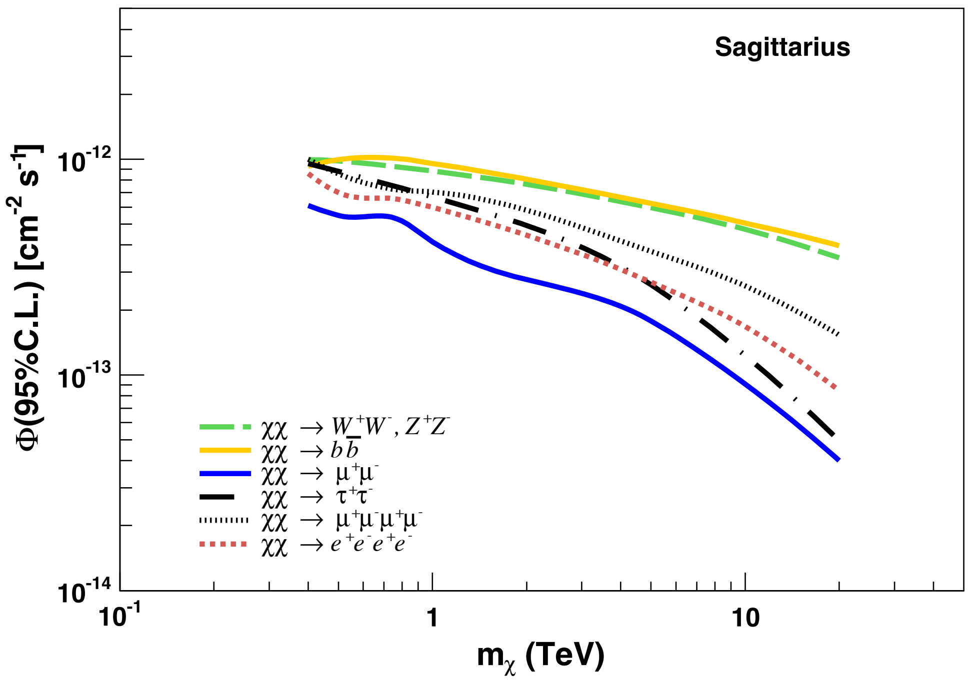
Charbonnier *et al.*, MNRAS **418** (2011) 1526-1556

Indirect Dark Matter detection: Gamma-rays

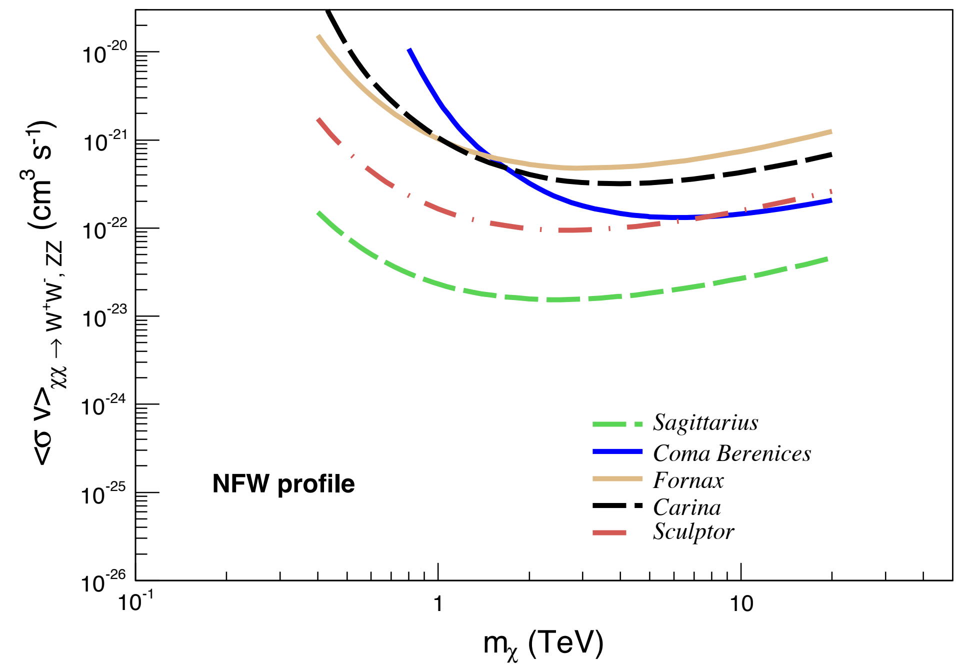
Abramowski *et al*, arXiv:1410.2589

H.E.S.S.-II: Several source observations (Dwarf galaxies)

Gamma flux limits



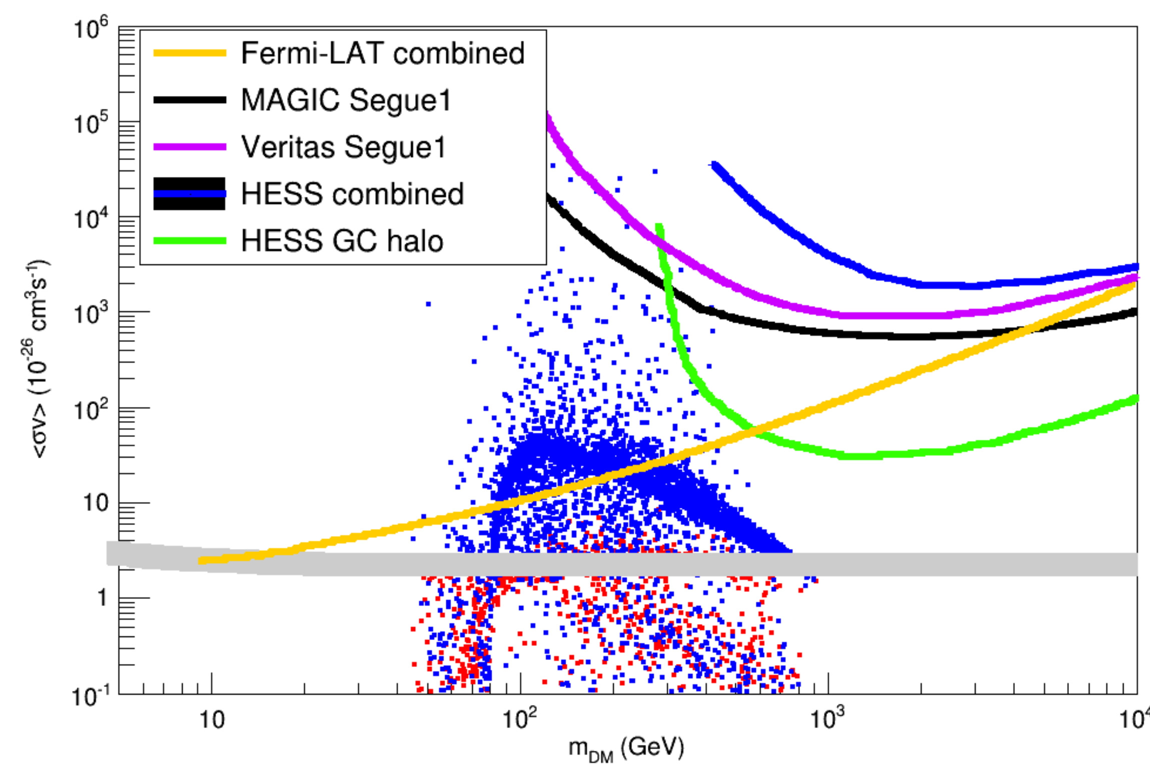
DM annihilation constraints



Conclusions:

- Good way to constrain DM
- Significant constraints on $\langle \sigma v \rangle$
- Limits depend on DM density profile
- Be careful with discovery

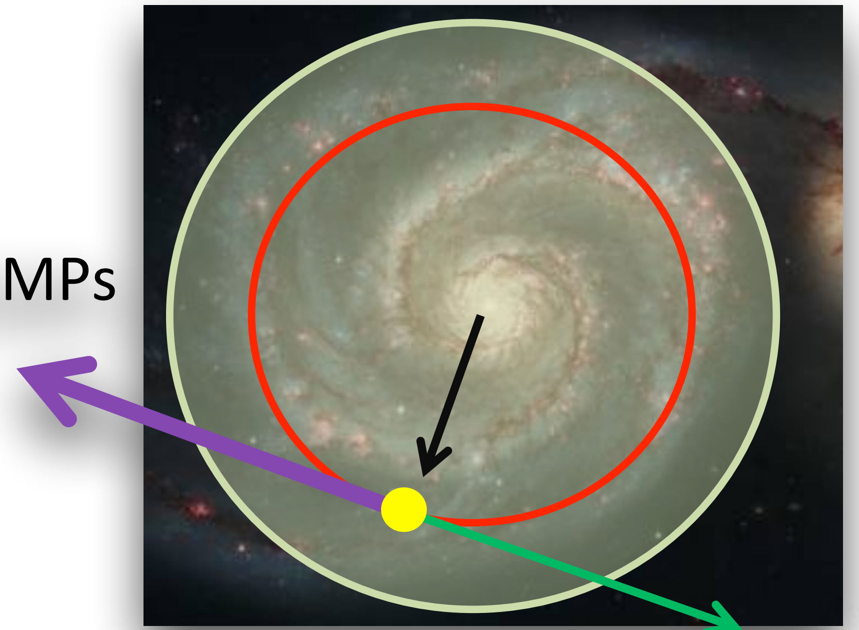
→ **Standard astrophysical sources may be misunderstood**



Conrad, arXiv:1411.1925

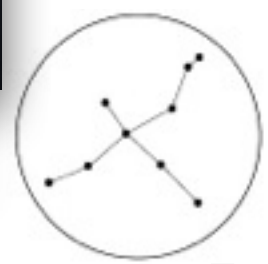
Direct Dark Matter detection

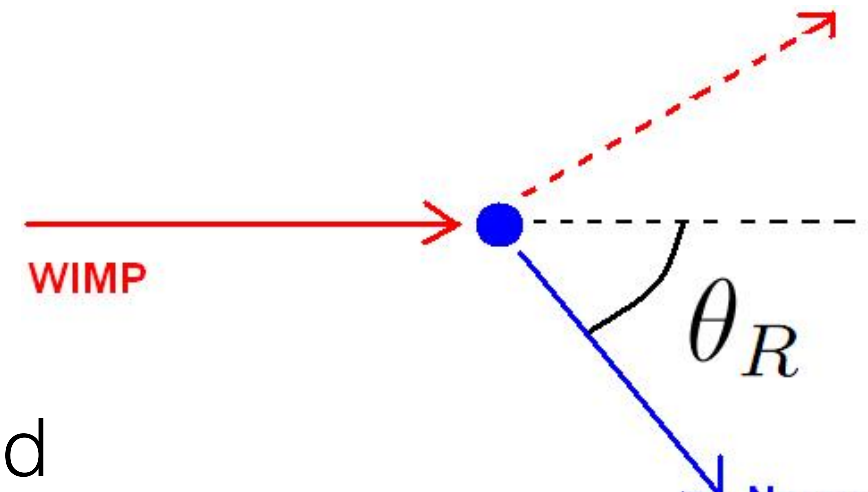
Galactic Dark Matter & direct detection



Dark matter halo:

- Surrounding the Milky Way
- Maxwellian velocity distribution
- Local density: $\rho_0 = 0.3 \pm 0.1\,\mathrm{GeV.c^{-2}.cm^{-3}}$





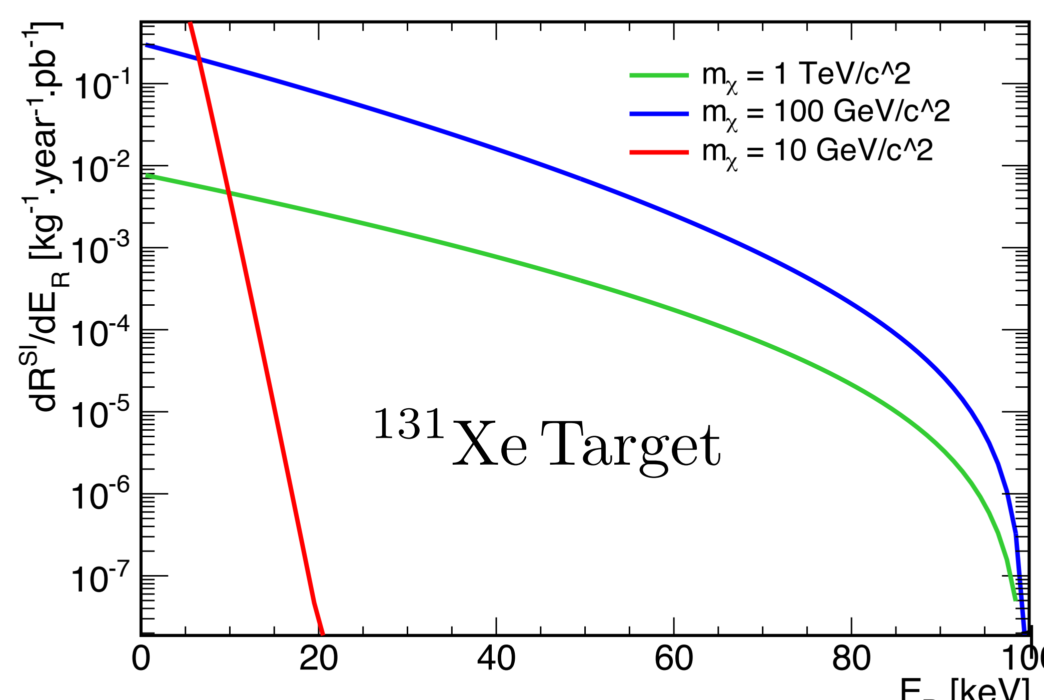
In the laboratory rest frame: Relative WIMP wind

Elastic diffusion on nuclei

→ Nuclear recoil $E_{\mathrm{kin}} = \mathcal{O}(10\,\mathrm{keV})$

Direct detection principle:

Nuclear recoil **energy** measurement



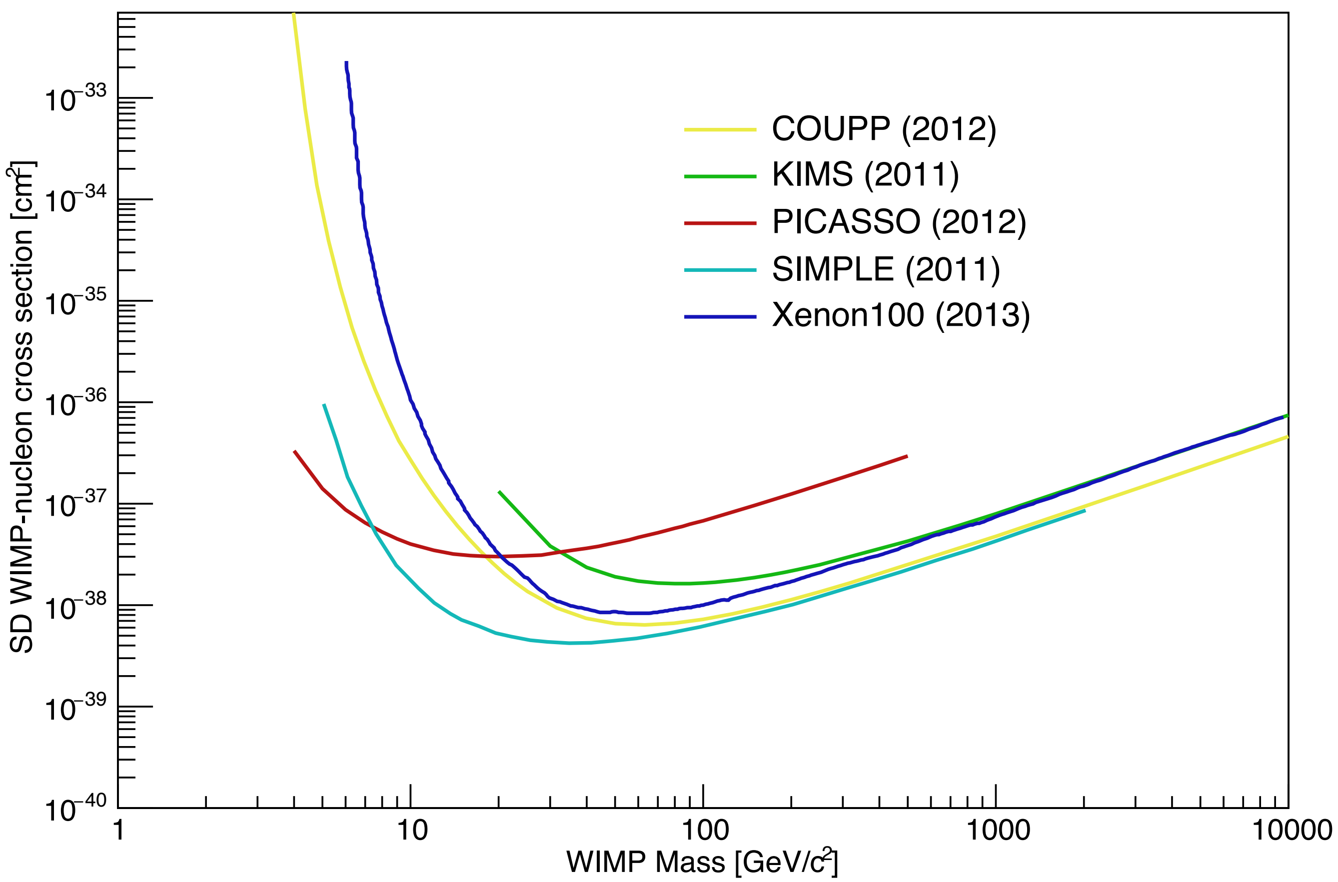
Direct detection: experimental results

DM-Nucleus cross section

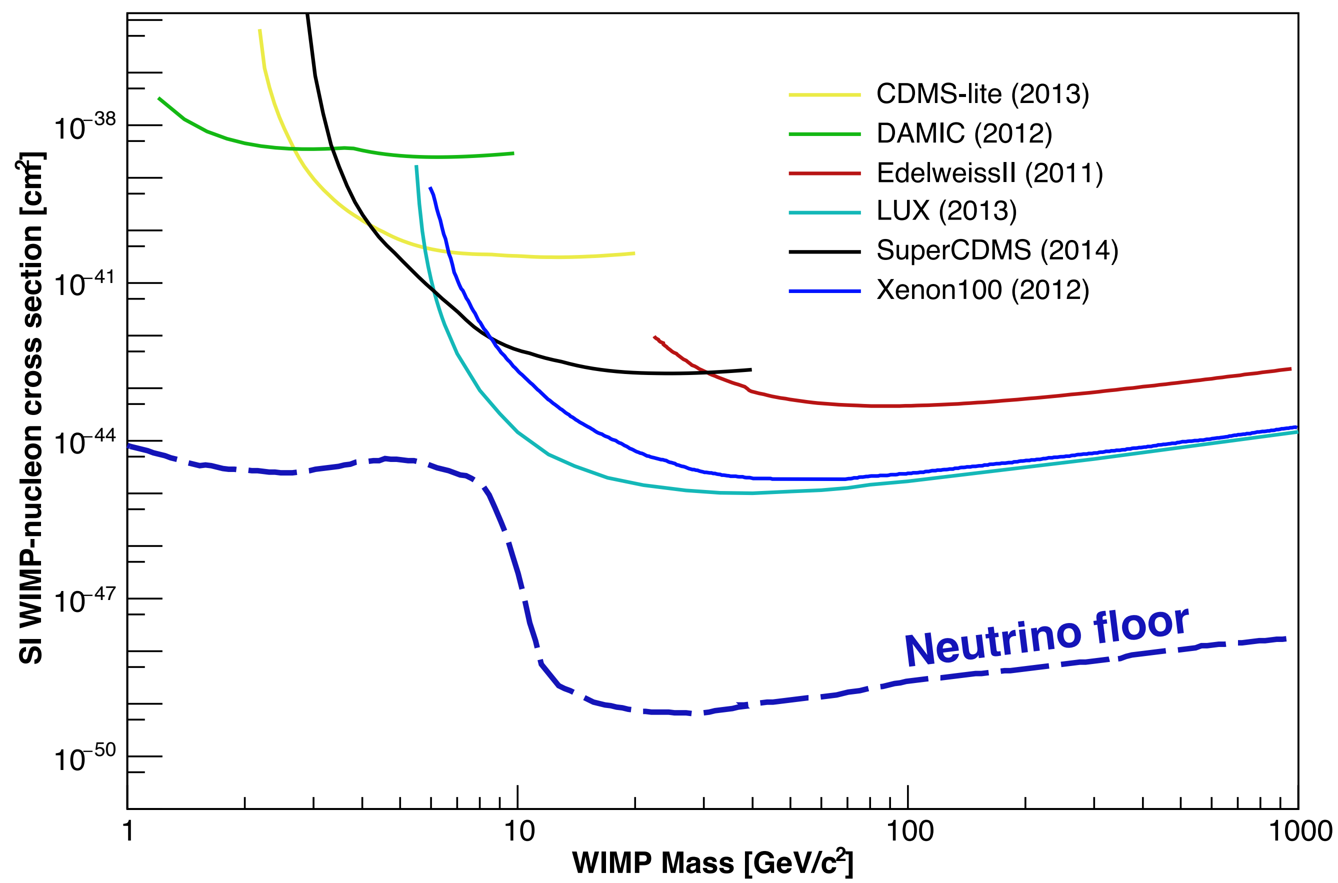
Axial: Spin coupling $\sigma_0^{SD}(^AX) \propto \frac{J+1}{J}\left[a_p \langle S_p \rangle + a_n \langle S_n \rangle\right]^2$

Scalar: Heavy nucleus $\sigma_0^{SI}(^AX) \propto {f_p}^2 A^2$

Axial



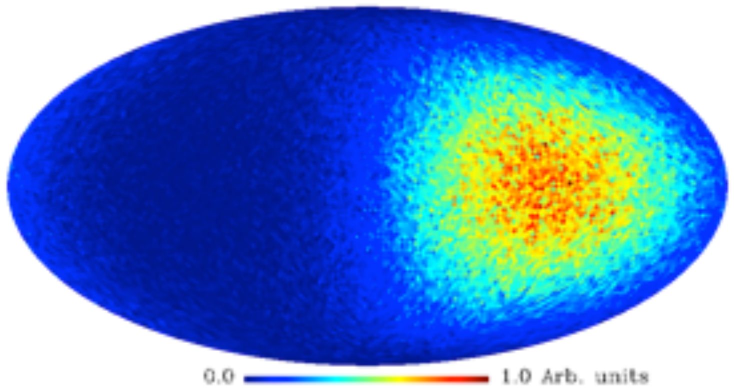
Scalar



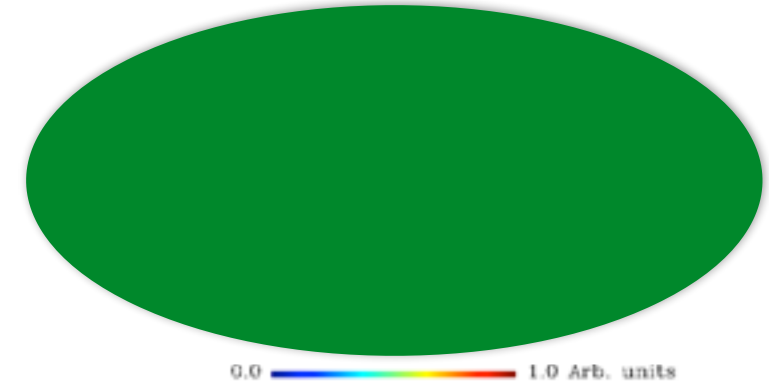
WIMP detection candidate: real WIMP event of Neutron ?

Directional Detection

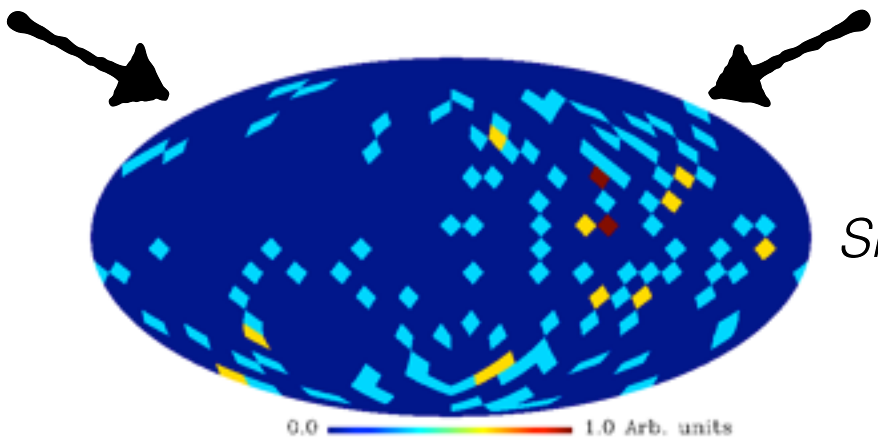
Recoils angular distribution:
Anisotropy



Neutrons angular distribution:
Isotropic



Typical measured recoil angular distribution



Simulation with 100 WIMPs & 100 bkgs

$\mathscr{L}(\ell, b, m_\chi, \lambda)$ Profile likelihood analysis

Billard *et al.*, Phys. Rev. D **85** (2012) 035006

Constraints on WIMP and Halo properties

Directional detection principle:

Measurement of the **energy** and the **track** of the recoils

MCMC Halo & WIMP properties estimation

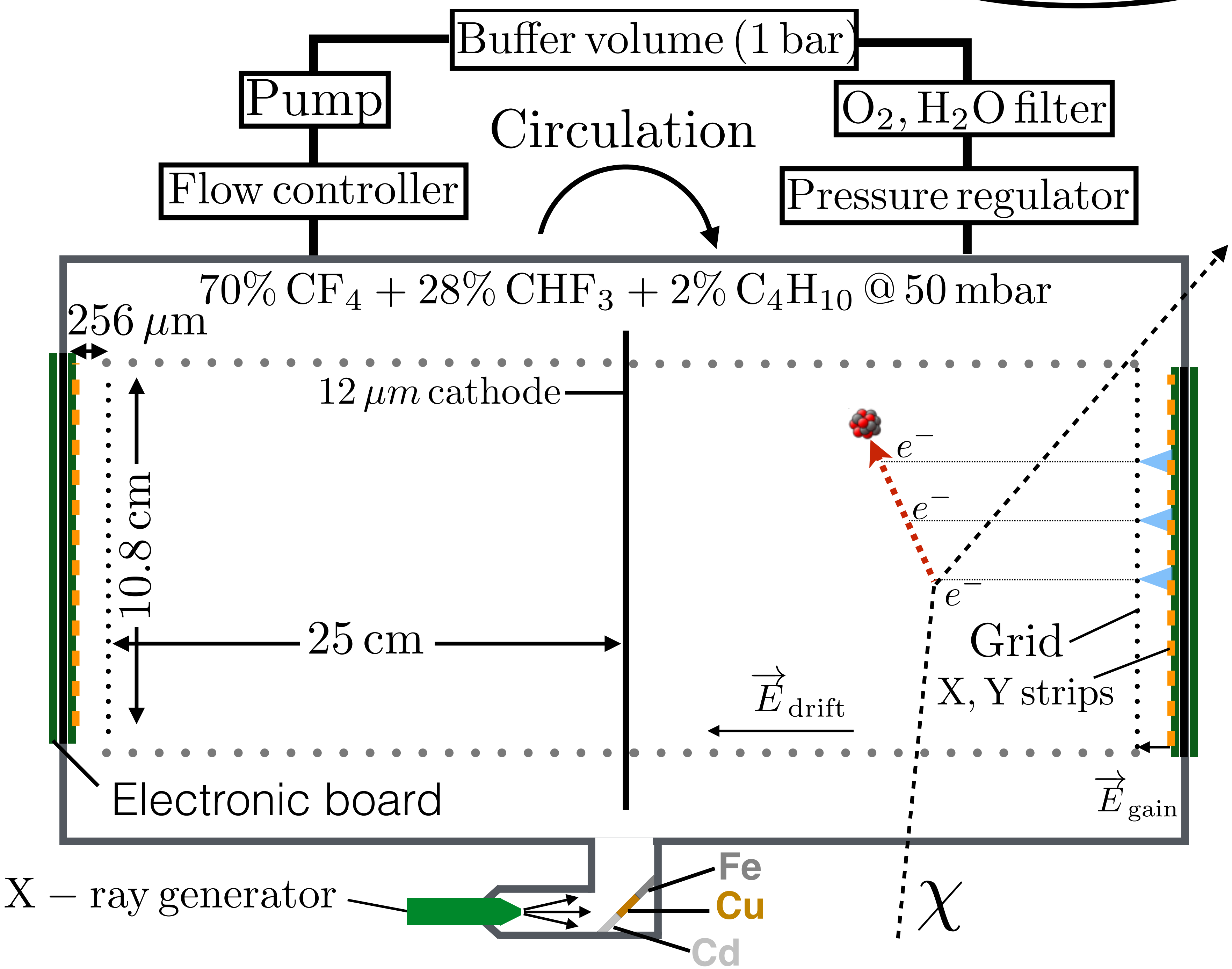
Billard *et al.*, PRD 2011

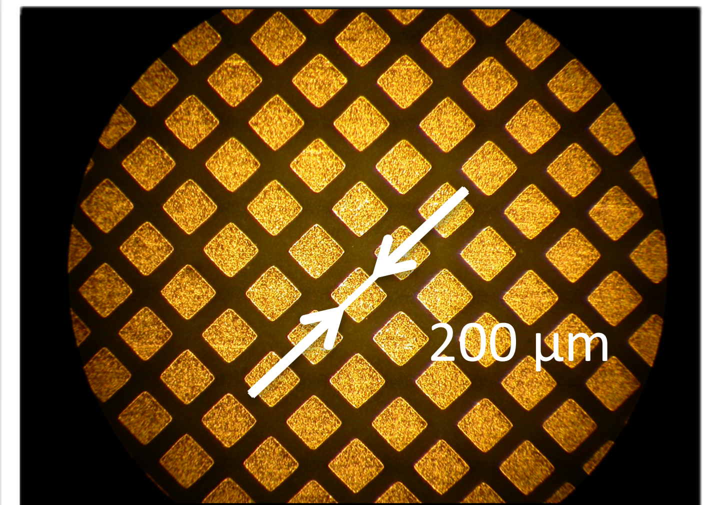
	m_χ (GeV/c^2)	$\log_{10}(\sigma_n$ (pb))	$\ell_\odot$ (°)	$b_\odot$ (°)	σ_x (km.s^{-1})	σ_y (km.s^{-1})	σ_z (km.s^{-1})	β	R_b (kg^{-1}year^{-1})
Input	50	-3	90	0	155	155	155	0	10
Output	$51.8^{+5.6}_{-19.4}$	$-3.01^{+0.05}_{-0.08}$	$92.2^{+2.5}_{-2.5}$	$2.0^{+2.5}_{-2.5}$	158^{+15}_{-17}	164^{+27}_{-26}	145^{+14}_{-17}	$-0.073^{+0.29}_{-0.18}$	10.97 ± 1.2

MIMAC experiment

MIMAC detector: µTPC = TPC + Pixelized Micromegas Fast & self-trigger electronic

Sampling:
512 strips @ 50 MHz
$T_{Sampling} = 20ns$





Micromegas 10x10 cm², designed by IRFU- Saclay (France)

MIMAC Target: ^{19}F
- Light WIMP mass
- Axial coupling

Installed @ LSM since June 2012

3D nuclear recoil tracks from Radon progeny

Detector gas pollution from $^{222}\mathrm{Rn}$ progeny (sources: material)

α **decay:**

Daughter recoil migration to the cathode

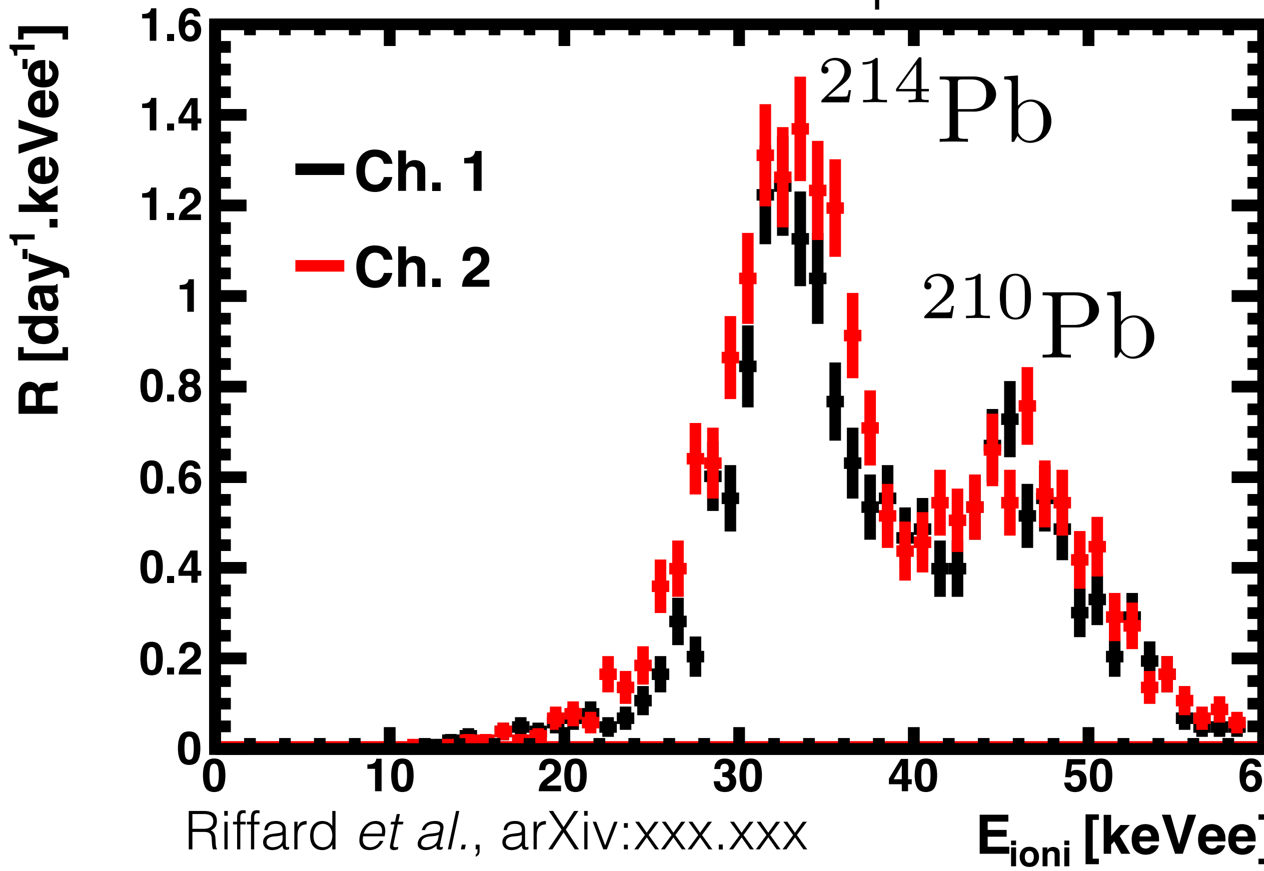
Surface event:

- α-particle: $E_{\alpha}^{kin} \sim 5\,\mathrm{MeV}$ saturation
- daughter: $E_{NR}^{kin} \sim 100\,\mathrm{keV}$ detectable

Parent	Daughter	E_{recoil}^{kin} [keV]	E_{recoil}^{ioni} [keV]
$^{222}\mathrm{Rn}$	$^{218}\mathrm{Po}$	100.8	38.23
$^{218}\mathrm{Po}$	$^{214}\mathrm{Pb}$	112.3	43.90
$^{214}\mathrm{Po}$	$^{210}\mathrm{Pb}$	146.5	58.78

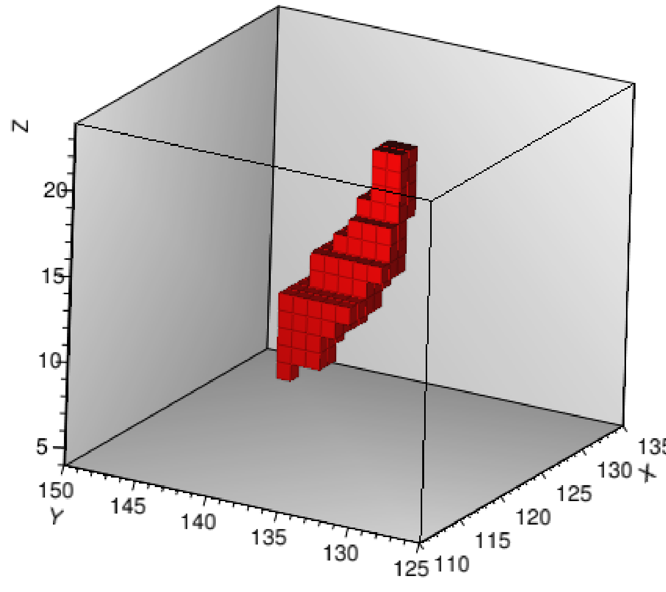
Simulation (SRIM)

Nuclear recoil spectra



Riffard *et al.*, arXiv:xxx.xxx

Mesure:
$$\begin{cases} E_{ioni}(^{214}\mathrm{Pb}) = 32.90 \pm 0.16\,\mathrm{keVee} \\ E_{ioni}(^{210}\mathrm{Pb}) = 45.60 \pm 0.29\,\mathrm{keVee} \end{cases}$$

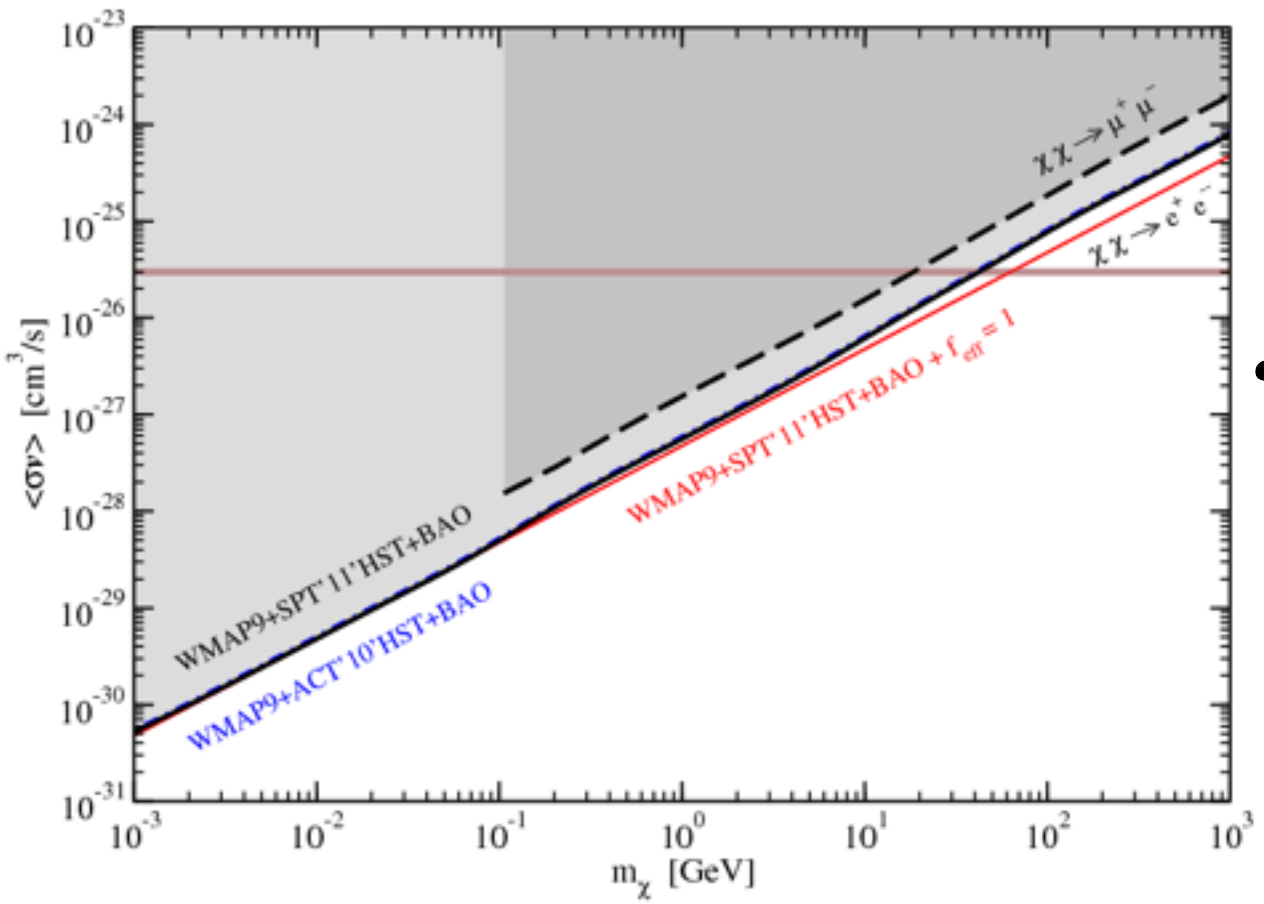


First measurement of 3D nuclear-recoil tracks coming from radon progeny

→ **MIMAC detection strategy validation**

Short term perspectives

CMB constraints on $p_{ann} = \langle \sigma v \rangle / m_\chi$ Dark Matter
(PLANCK, December 1st 2015 @ FERRARA)



→ Update ?

LHC run @ 14 TeV:

- New constraints on exotic physic
- Supersymmetry ?
- Mono-photon/jet limits improvement

Press release from INSU

http://www.insu.cnrs.fr/node/5033

Bienaymé *et al.*, arXiv:1406.6896

Surabondance de matière noire dans le voisinage solaire

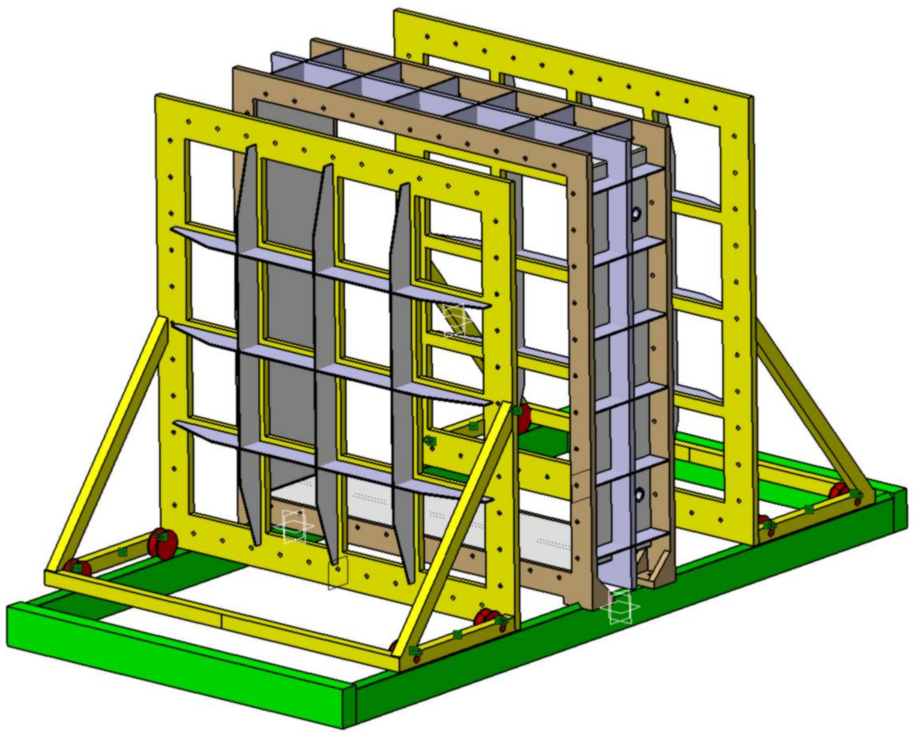
Vendredi, 14 Novembre 2014

Réalisée par une équipe de chercheurs de l'Observatoire Astronomique de Strasbourg (CNRS/Université de Strasbourg) dans le cadre d'une coopération internationale, une étude récente et plus précise du [illegible] le voisinage solaire. Cette étude révèle deux fois plus de matière noire que ce qui était admis jusqu'à présent et devrait encourager les expériences cherchant à détecter directement les particules élémentaires susceptibles de composer cette matière noire.

« devrait encourager les expériences cherchant à détecter directement les particules élémentaires susceptibles de composer cette matière noire. »

Mean term perspectives

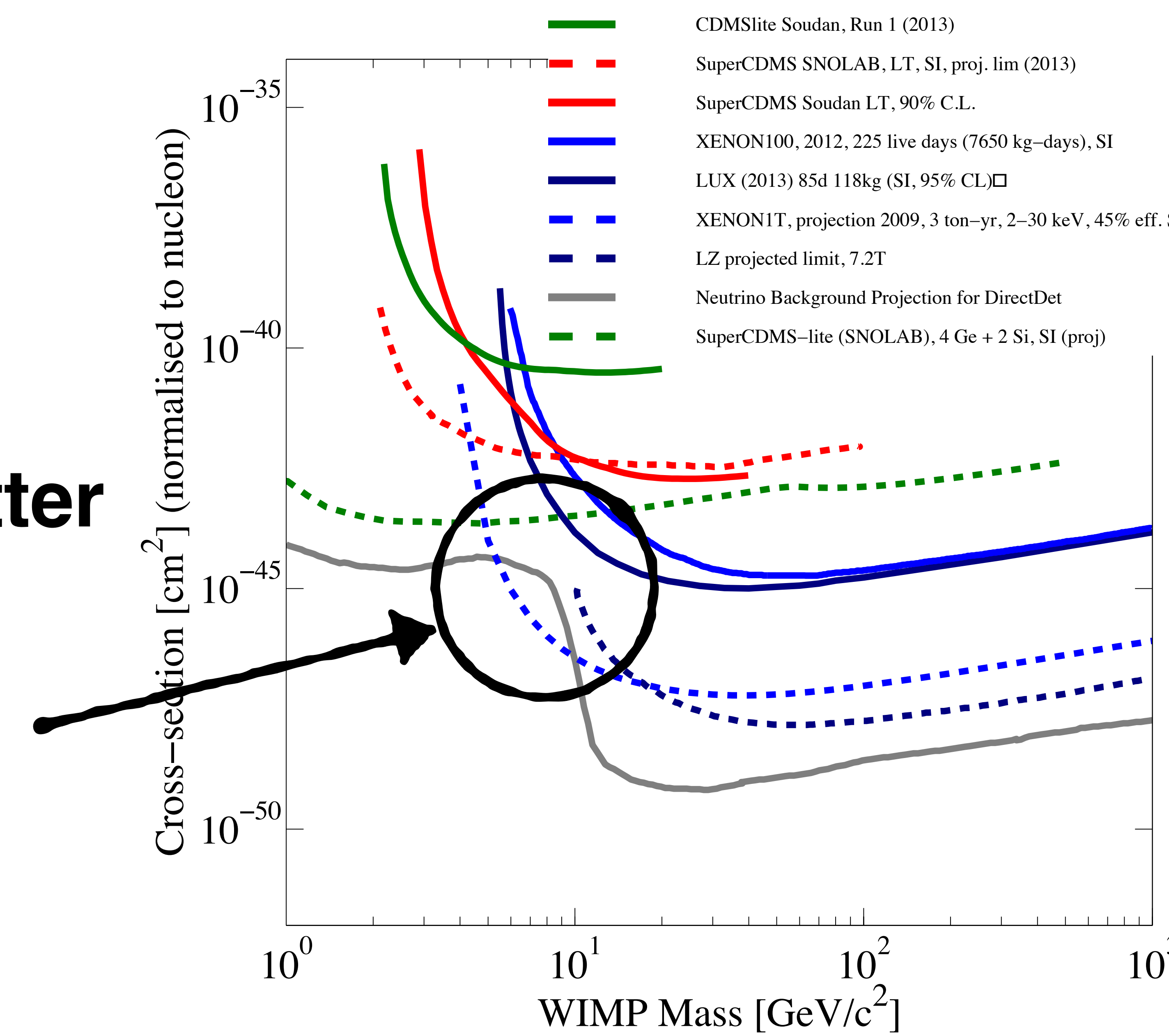
Directional Dark matter demonstrator (m³ scale)



- 16 bi-chamber modules with 35x35 detector
- Competitive with actual project

Ton-scale direct Dark Matter detector

Will reach neutrino floor



Thank you for your attention !