Is the WIMP Paradigm going strong?

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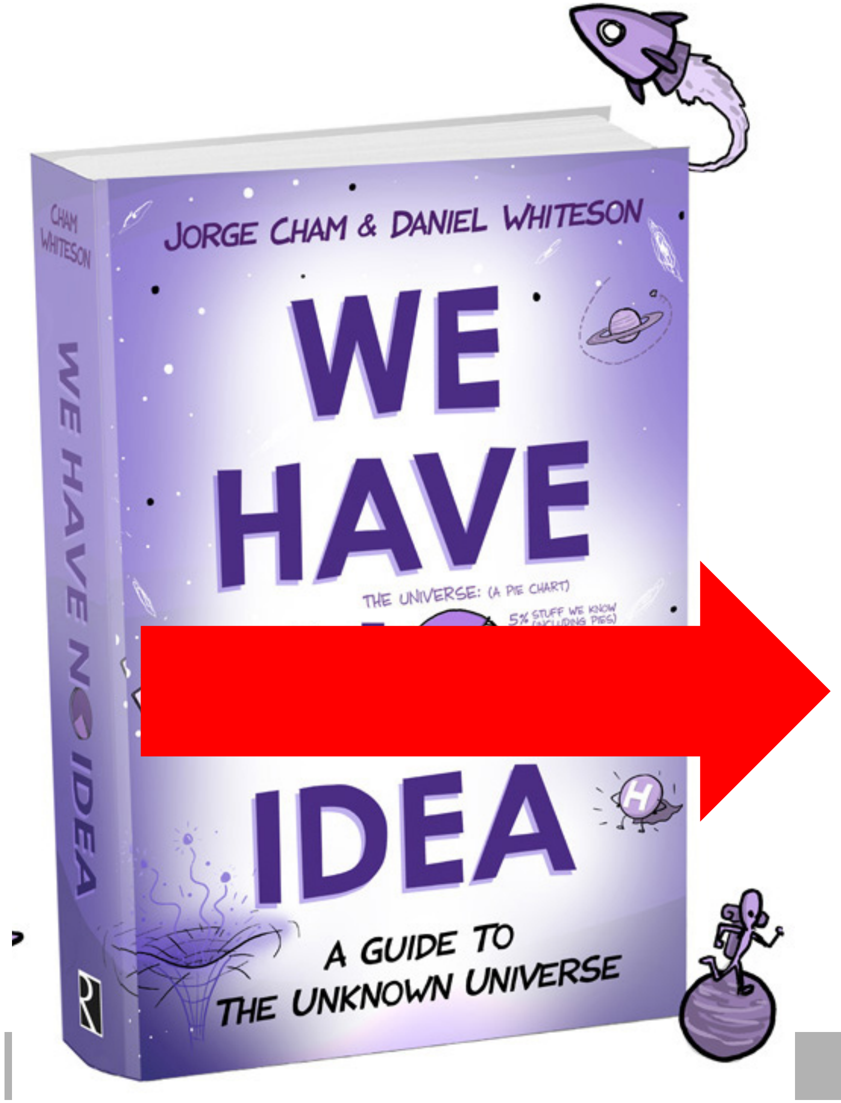
New Scientist, 16 August 2014: *Hinchliffe has asserted that whenever the* ***title of a paper is a question*** *with a yes/no answer,* ***the answer is always no****. This paper demonstrates that Hinchliffe's assertion is false, but only if it is true.*



…but we have many ideas and Nature does not always realize them.
BSM, ν's, DM, DE,…

A long List of Evidences for Dark Matter…

+ Galactic rotation curves
+ Galaxy clusters & GR lensing
+ Bullet Cluster
+ Velocity dispersions of galaxies
+ Cosmic microwave background
+ Sky Surveys and Baryon Acoustic Oscillations
+ Type Ia supernovae distance measurements
+ Big Bang Nucleosynthesis (BBN)
+ Lyman-alpha forest
+ Structure formation
+ …

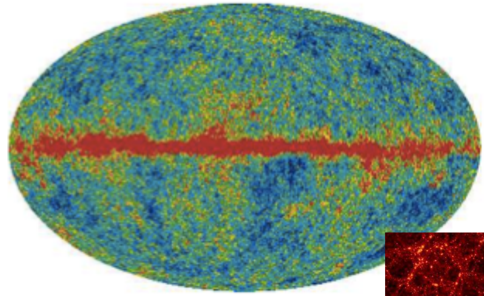
➔ **strong evidence for a large dark sector**

➔ **evidences: GR-dynamic, GR-static, radiation, …**

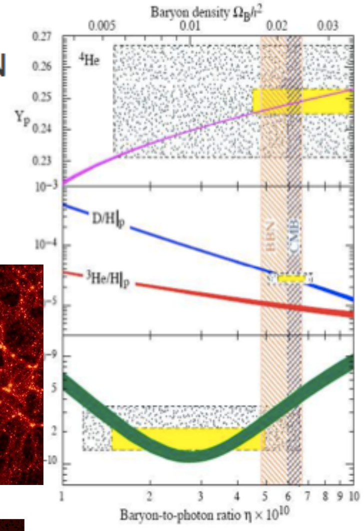
➔ **cannot be explained by ordinary matter**

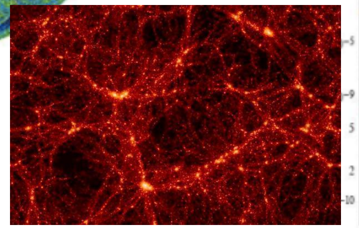
➔ **strong astronomy / cosmology groups in cluster!**

CMB (WMAP)

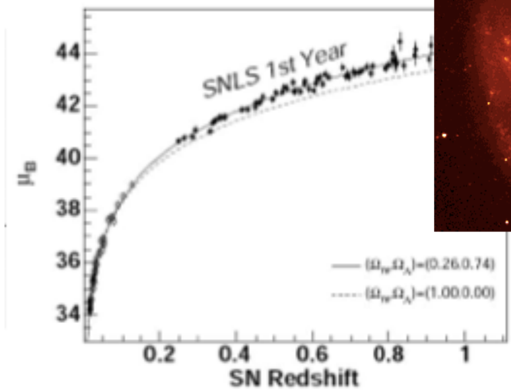


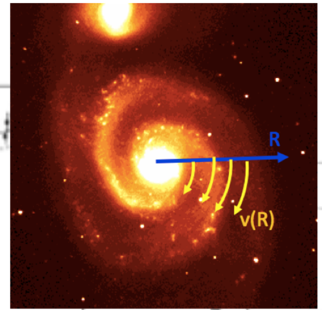
BBN



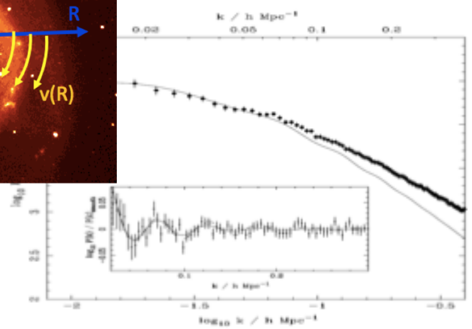


SN 1a

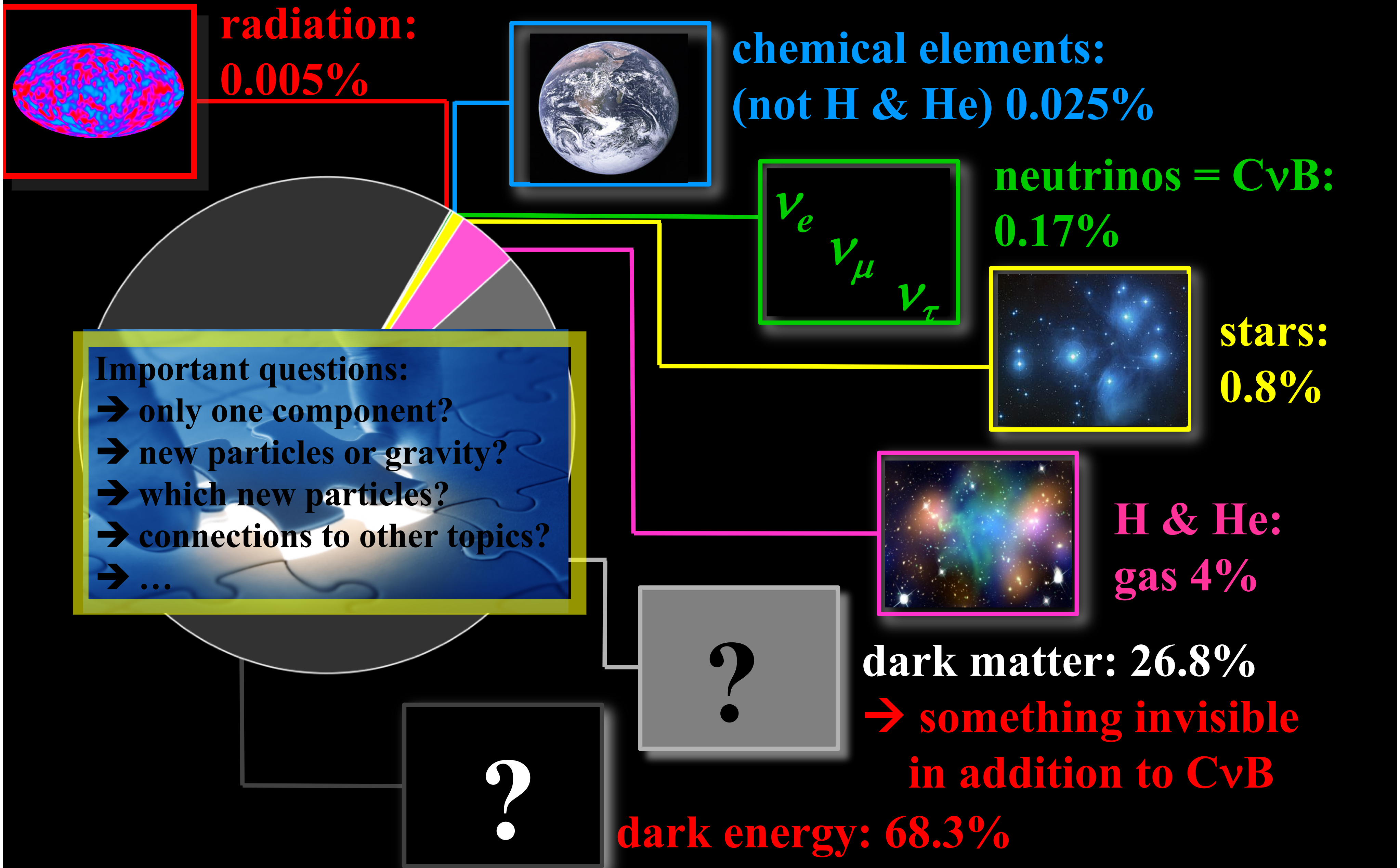




BAO



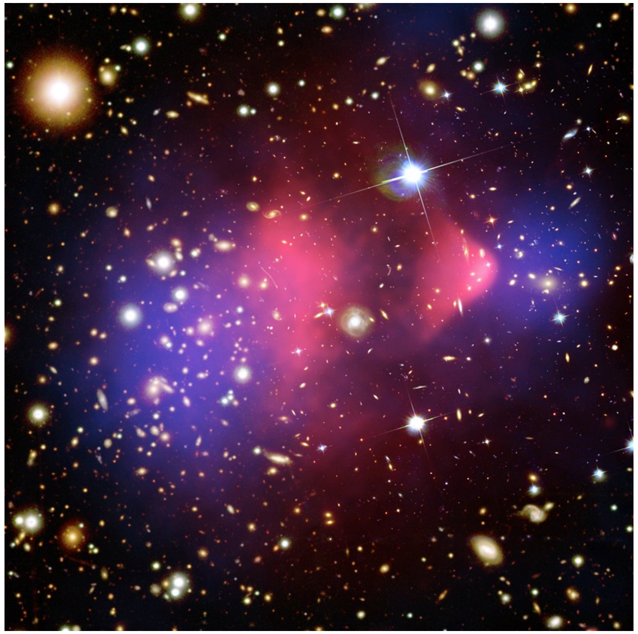
The cosmic Matter Balance



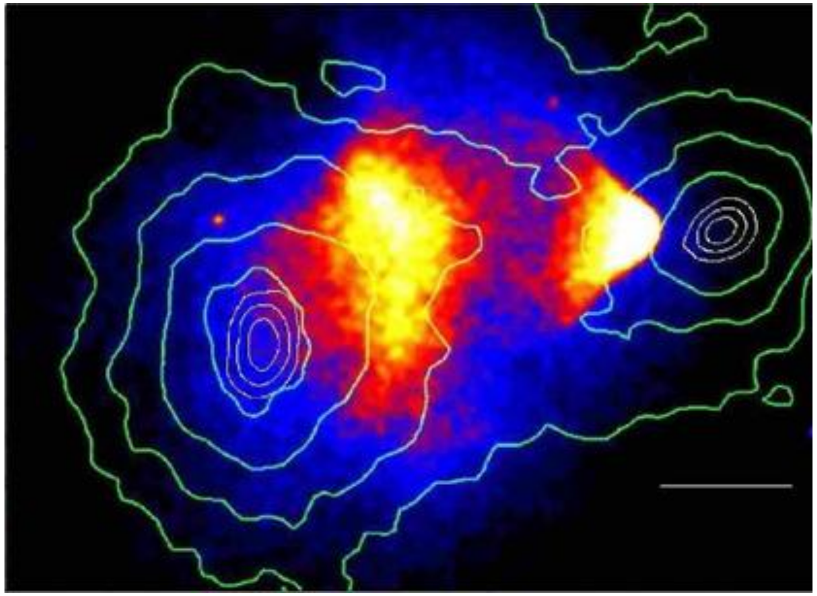
Is it Particles?

- **bullet cluster (1E 0657-56)**
  - colliding galaxy clusters
    = stars, gas, DM ; up to 10^6 km/h
  - x-rays from charged particle interactions
  - Dark Matter just traverses w/o scattering

  ➔ displacement of visible matter
  and GR potential = all matter (~ 8σ)

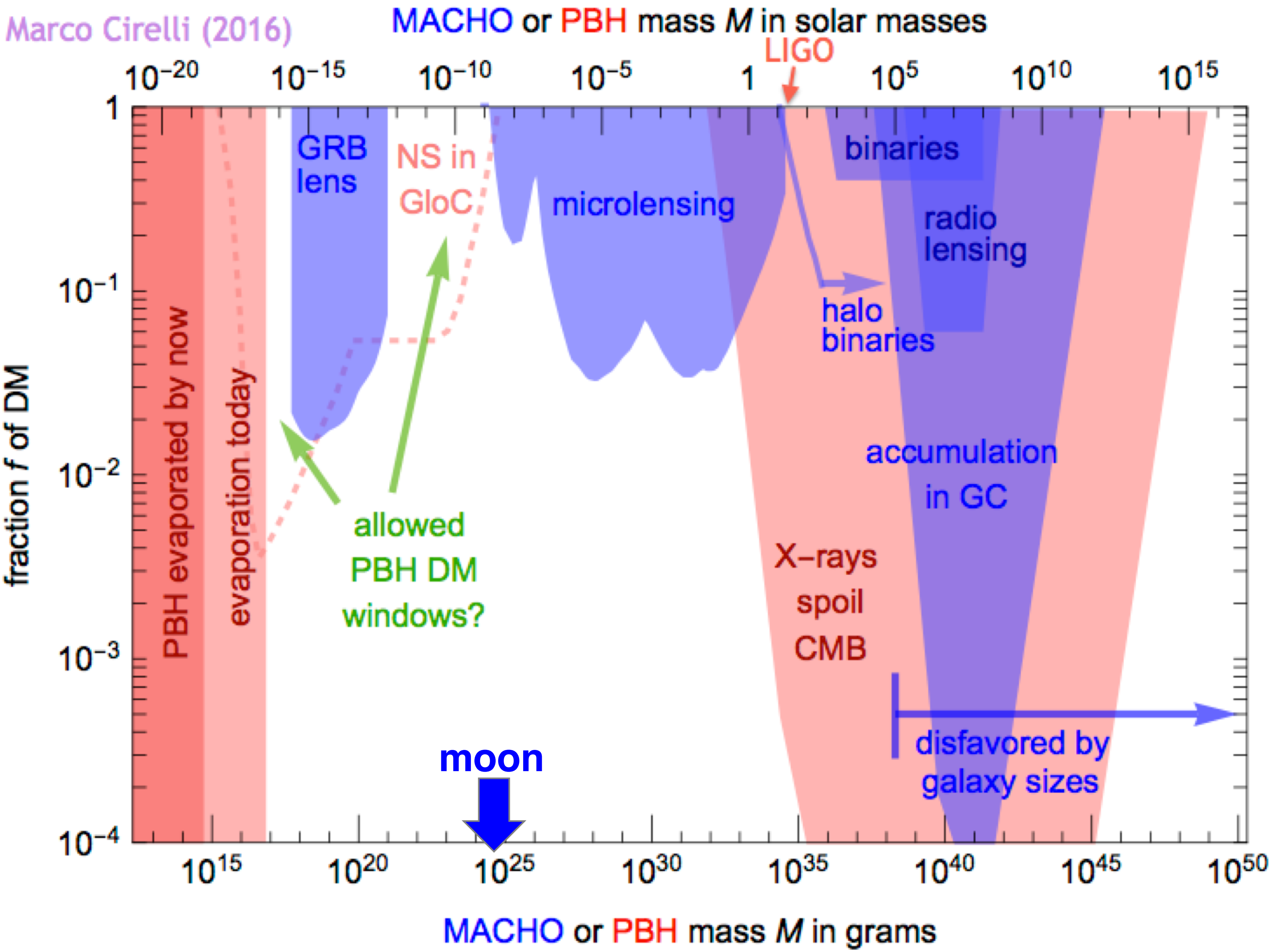


- **Shows that normal particles scatter, but NOT that DM is particles**



- **<u>What is needed:</u>**
  - gravitates ←→ mass
  - non-baryonic
  - SM neutral
  - no or very limited self-interaction
  - no coupling to massive particle
  - stable or long lived

Black Holes as Dark Matter



Competing Dark Matter Directions

Gravity

MOND
a simple one scale modification
→ fails badly

Other
new GR modifications

or

a suitable population (mass, number) of black holes

Particles

BSM physics motivated by SM problems
- WIMPs (neutralinos)
- axions
- sterile ν's
- …

Models with correct abundance
- WIMPs
- dark photons
- ALPs
- other new particles

WIMPs combine both aspects in an attractive way: BSM + abundance

WIMPs seem best motivated: WIMP Miracle

- **WIMPs with masses O(100 GeV)←→ many BSM models ←→ HP**
- **miracle: $\simeq$ correct abundance:**

1) Assume a new (heavy) particle χ is initially in thermal equilibrium:

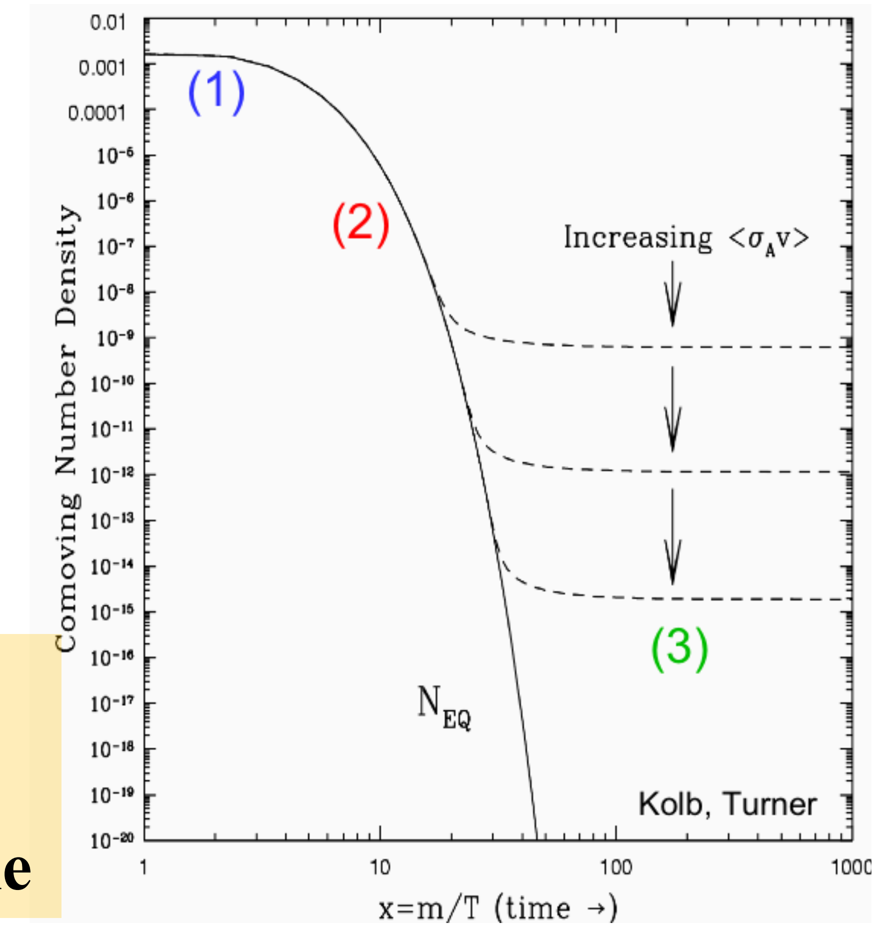
$$\chi\chi \leftrightarrow f f$$

2) Universe cools:

$$\chi\chi \;\substack{\rightarrow \\ \not\leftarrow}\; f f$$

1) "freeze out"

$$\chi\chi \;\substack{\not\rightarrow \\ \not\leftarrow}\; f f$$

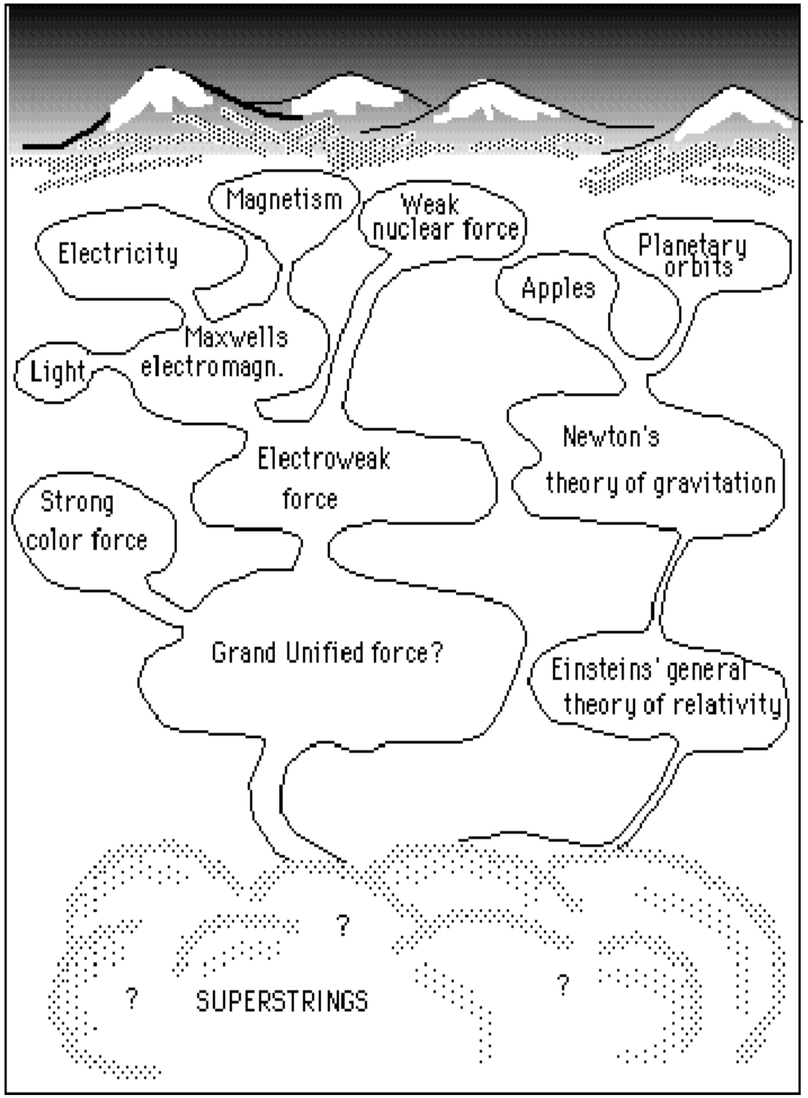


- **amount of DM ~ (x-section)$^{-1}$**
- **natural x-section ~ 1/m^2**
  → correct abundance from EW scale

→ remarkable coincidence: Ω_{DM} ~ 0.2 for m_{WIMP} ~ 500-1000 GeV

→ BSM AND abundance point in the same direction

Reasons to go Beyond the Standard Model



Theoretical:

SM does not exist without cutoff
(triviality, vacuum stability)
Gauge hierarchy problem
Gauge unification, charge quantization
Strong CP problem
Unification with gravity
Global symmetries & GR anomalies
Why: 3 generations, representations, d=4, many parameters (flavour probelm)

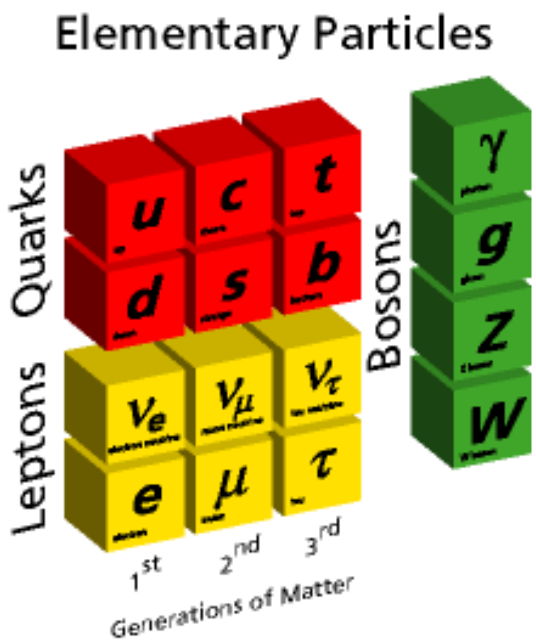
Experimental facts:

- Electro-weak scale << Planck scale
- Gauge couplings almost unify
- Neutrino masses & large mixings
- Flavour: Patterns of masses & mixings
- Baryon asymmetry of the Universe
- Dark Matter
- Inflation
- Dark Energy

Back to the Roots: The Standard Model

→ success of renormalizable local quantum field theories in d=4

QED	→ QCD	→ SM
$U(1)_{em}$	$SU(3)_C$	$SU(3)_C \times SU(2)_L \times U(1)_Y$



Symmetry, renormalizability, no anomalies

→ particle content (representations)

- gauge sector – fixed by gauge group
- scalar sector – must break EW symmetry, $\sim 2_L$
- fermions – anomaly free combinations

- various conceptual ingredients = questions:

- quantum fields
- chiral fermions, anomaly free combinations
- gauge group, d=4, three generations = copies

- many unexplained parameters...

... but it works extremely well and avoids per se many problems...

Extending the SM

ways to extend: more fields, new gauge groups, SUSY, d>4, ...

electrodynamics
relativity — QED
quantum mech.
strong force → QCD
weak decays + Higgs, χ-ral — SM
+ neutrino masses — SM+
+ dark matter … → ?

territory of speculation

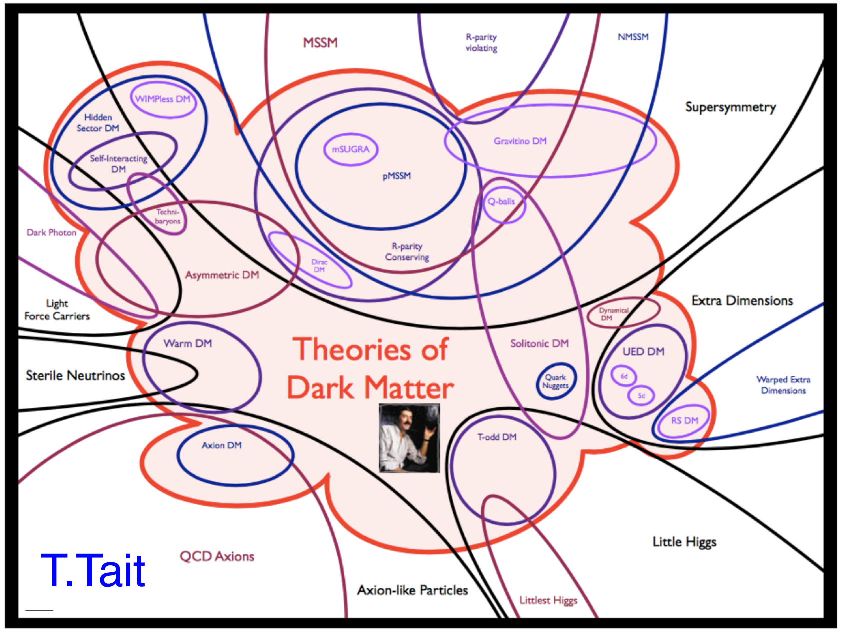
LR? TC? …?
SUSY? GUTs? TOE?
extra dim., …?

gravity — weak scale <<<< M_{planck}

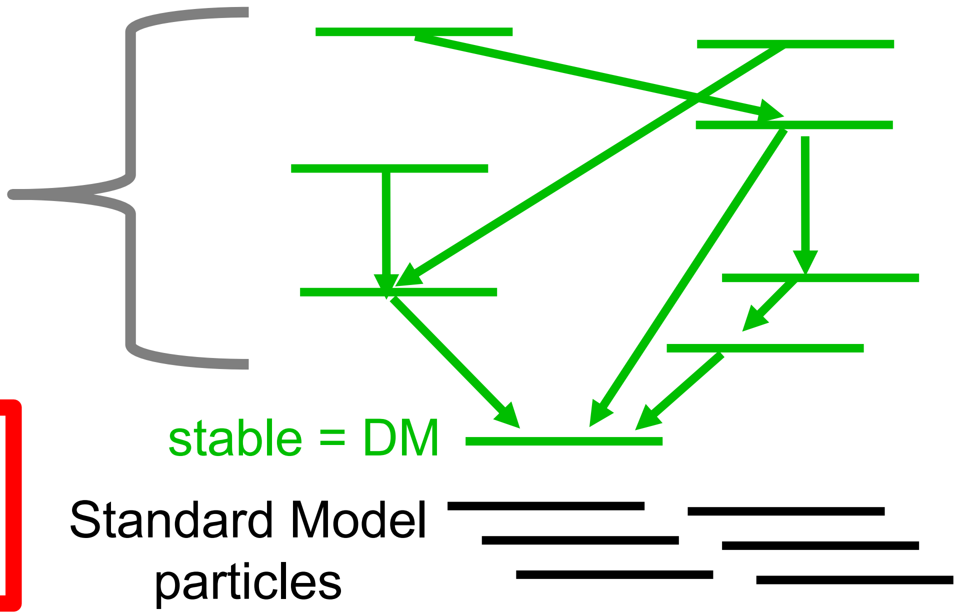
Nevertheless very important lessons:

SM (+neutrino masses) works perfectly
→ triumph of concepts (QFT, symmetries, precision)
☺ Higgs discovered ←→ particle masses
☹ nothing else (so far…) ←→ ☺ quantum structure of SM
→ things may be different than expected: ν' DM,…
→ experimental facts trigger (enforce!) new ideas

DM motivated Extensions have other Consequences



- More particles…
- All existing particles produced in Big Bang and later (decays, …)
- Some particles may be stable
- Very long-lived due to small parameters → natural?
- Effects of unstable states +/-
  ➔ on the early Universe
  ➔ on collider physics

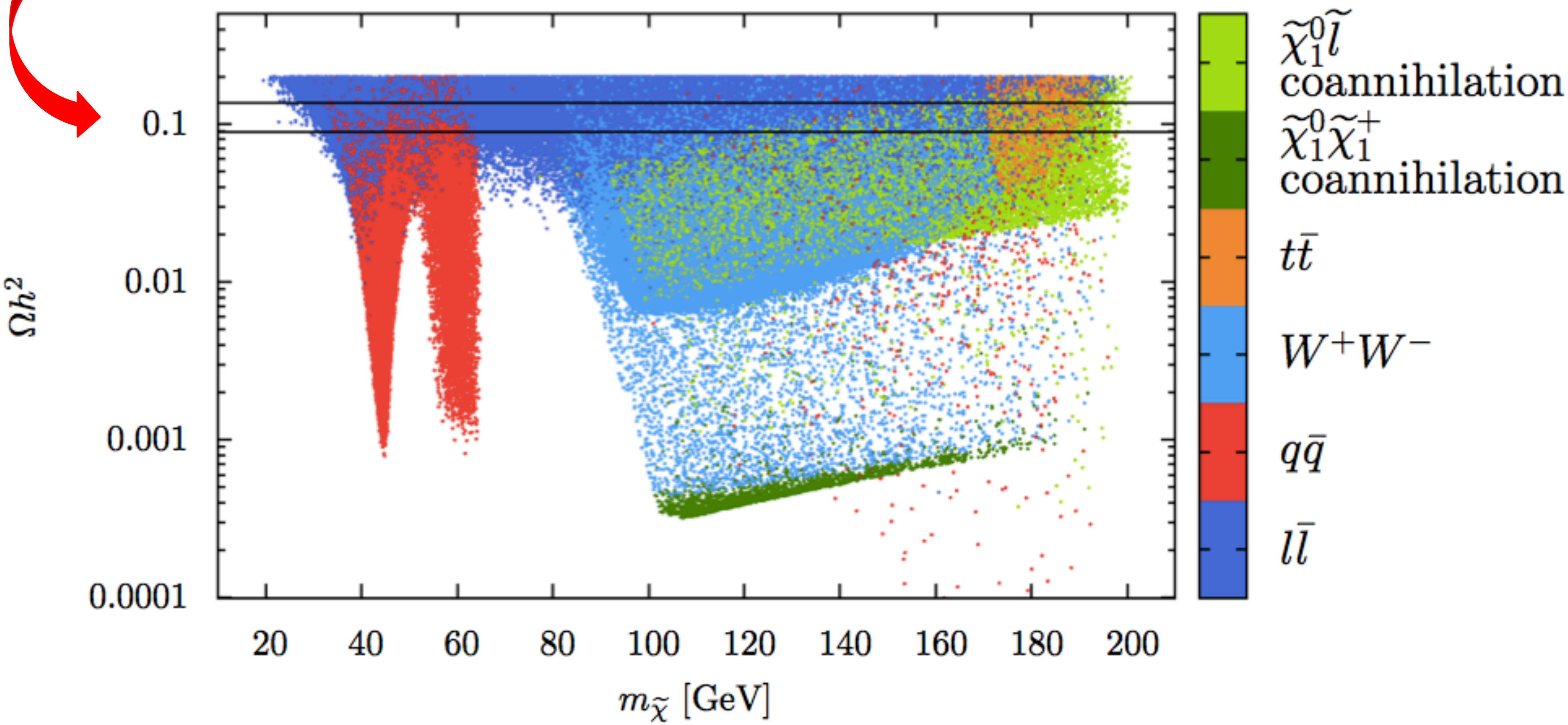


Warning: Your DM model may affect many other known things!

Hierarchy Problem ➔ MSSM ➔ Vanilla WIMP

- **LSP=Neutralino ➔ WIMP miracle ➔ correct abundance**

Scan parameter space for different annihilation channels → Ωh^2
Note: we will not argue for equal probability in parameter space!

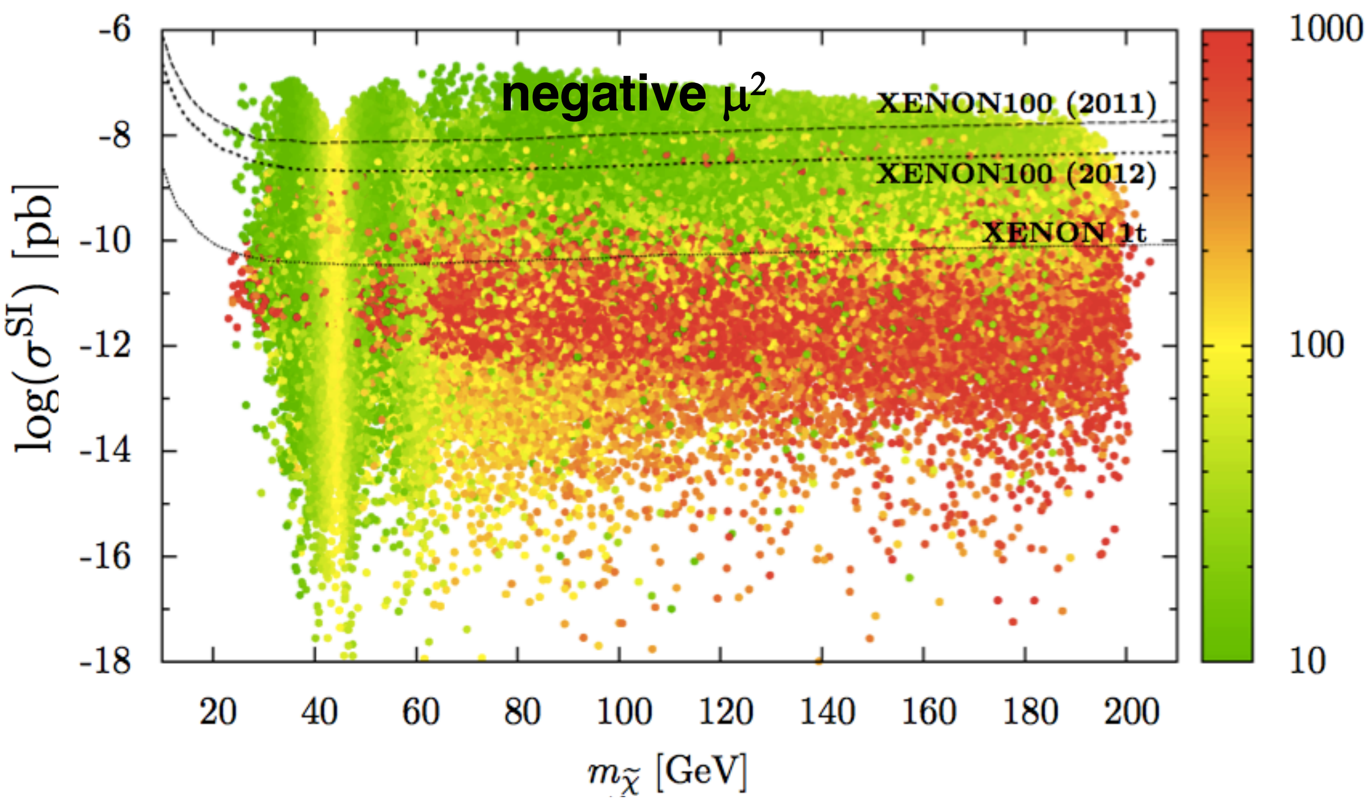


➔ **Select correct range of Ωh^2 ➔ constrains parameter ranges**

How fine-tuned are the paramaters?

- **MSSM neutralino: Level of fine-tuning → Δ_{tot}**

$$\Delta p_i \equiv \left| \frac{p_i}{M_Z^2} \frac{\partial M_Z^2(p_i)}{\partial p_i} \right| = \left| \frac{\partial \ln M_Z^2(p_i)}{\partial \ln p_i} \right| \qquad \Delta_{\text{tot}} \equiv \sqrt{\sum_{p_i=\mu^2, b, m_{H_u}^2, m_{H_d}^2} \{\Delta p_i\}^2}$$



→ XENON100-2010
→ XENON100-2012
→ XENON1T

- XENON100 cuts already into expected space
- XENON1T covers a much larger part

* XENONnT covers most
  ➔ high potential
  ➔ be first!

LMSSM: x-section down

Grothaus, ML, Takanishi: full MSSM, not CMSSM, pMSSM, NMSSM…⇔ WIMP miracle?

Generic WIMP Cros Section

- Quantum mechanics: wavelength $\lambda \sim 1/\text{mass}$

"size = area" of a particle: $\pi\lambda^2 = \pi/m^2$

➔ cross section: area ✖ coupling strength

$\sigma \sim O(0.001\text{-}1.0)^2 \quad g_2^2 \quad \pi/m^2$

model parameters — some weak coupling — area

or tuning, symmetry, …

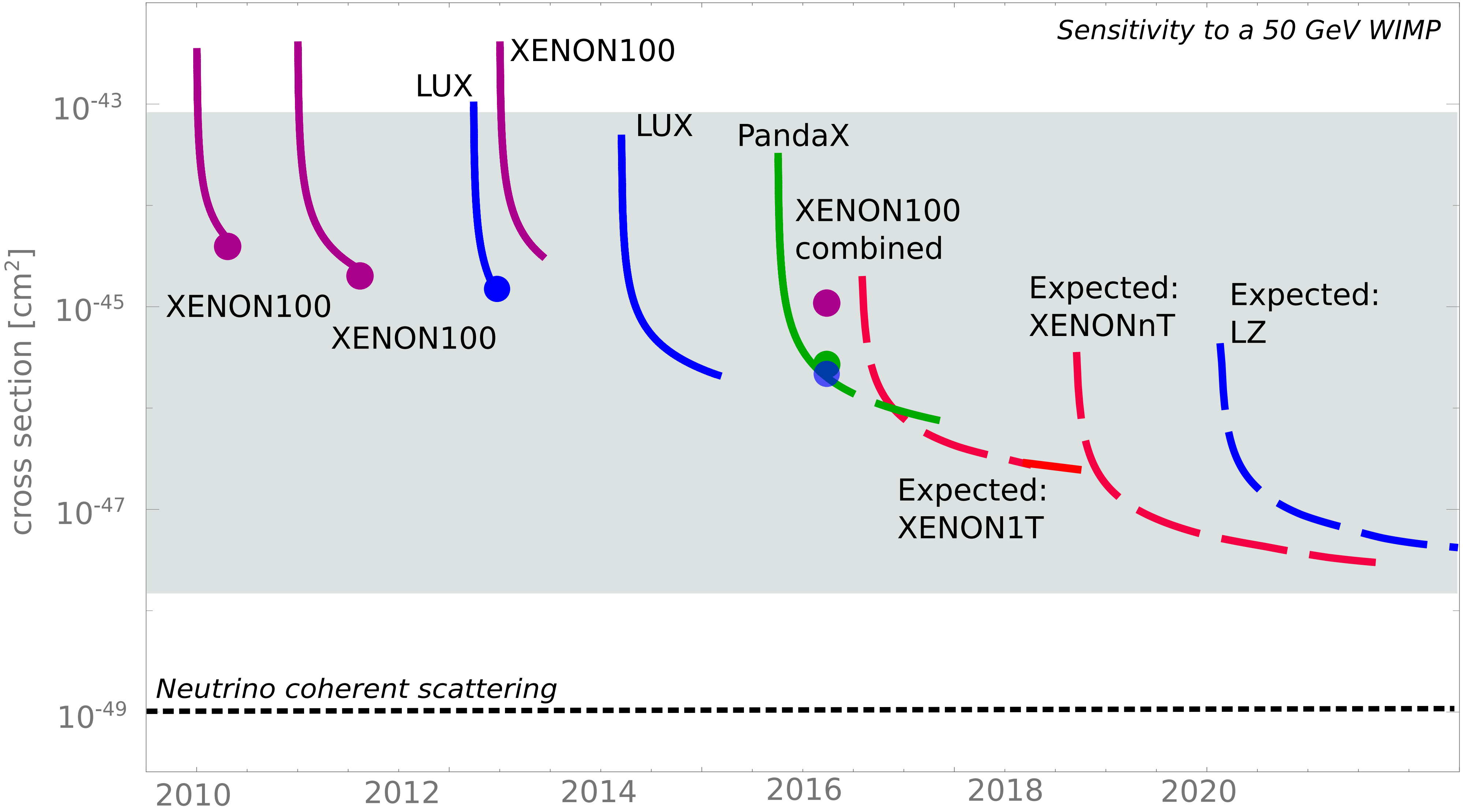
←→ abundance

➔natural range for a 50GeV WIMP: $\sigma \sim 10^{-42} - 10^{-48}\ \text{cm}^2$

known amount of DM ➔~WIMP flux ➔ rate@direct.det.

➔ we know size/sensitivity of a detector which can cover the most interesting natural WIMP space

Compared to Direct WIMP Search Timeline

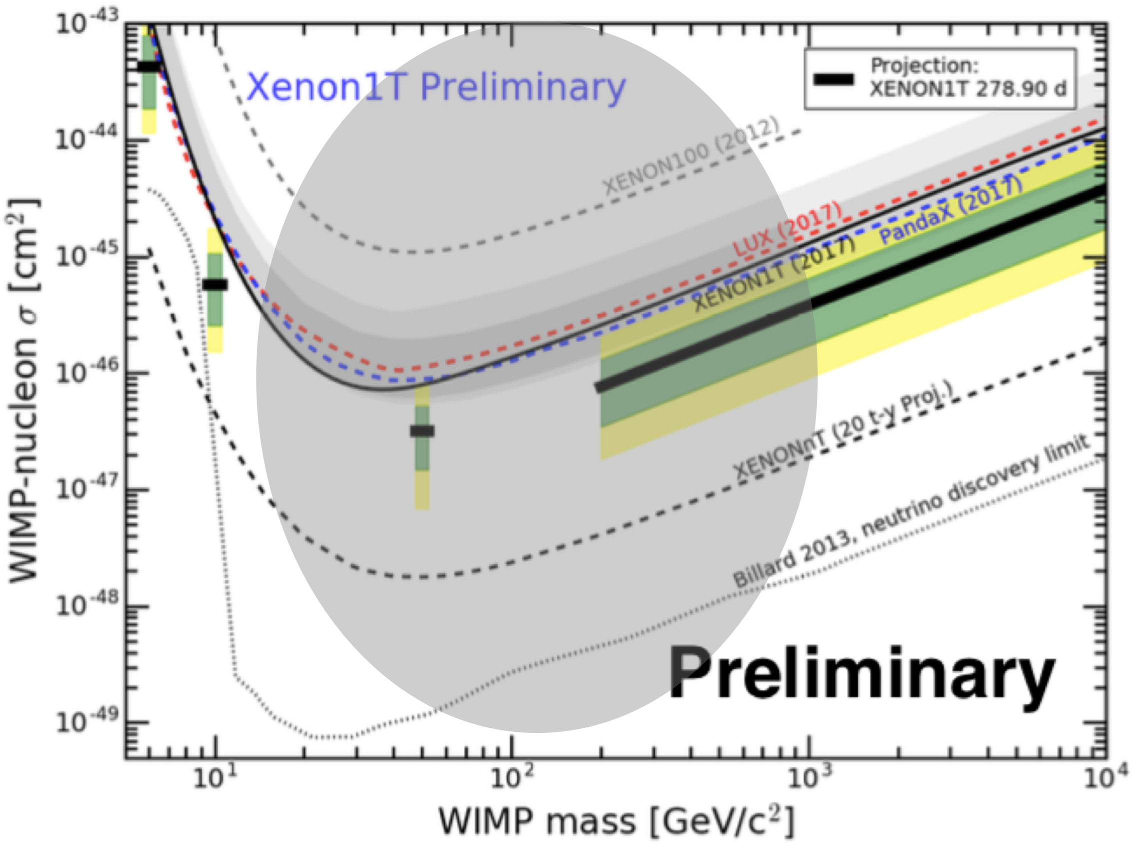


Most of the generic WIMP parameter space will be covered in the next years

Systematically lowering the x-section (symmetry, tuning,…)? ←→ WIMP miracle?

Spin Independent (SI) WIMP Limits

New XENON1T results will come soon…



- Expected sensitivity generated from toy MC at 4 typical WIMPs masses: 6, 10, 50, 200 GeV
- For a 50 GeV WIMP a factor of 3 sensitivity increase compared to SR0
- If WIMP cross-section close to our SR0 limit we expect a signal with 3-sigma significance

Covers more and more of the generic WIMP space…

… but don't forget: it is a log scale ➔ lot's of parameter space left!

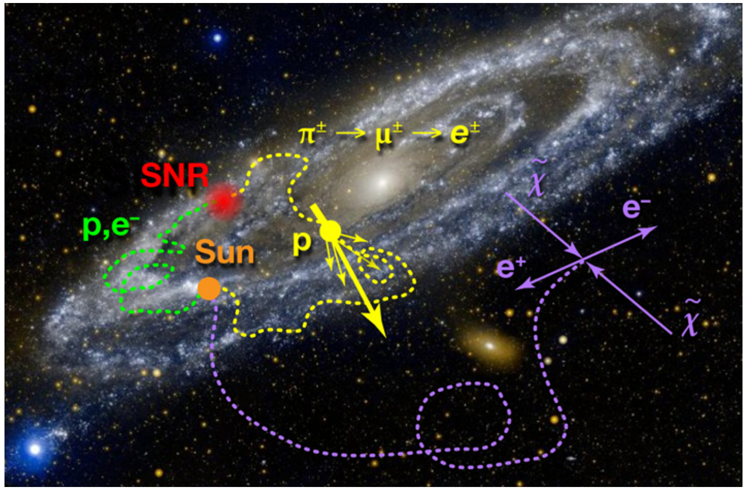
Generic Expectations/Messages

- **WIMPs coupling by weak interactions (g_2 fixed)**
  ➔ x-section systematically (too) high
- **Mixtures of 2_L, 1_L help (MSSM) ➔ ~$(1/2)^2$ or $(1/3)^2$ etc.**
- **Gauge and Higgs portal couplings (g, λ) expected to be O(1) ➔ natural x-section range $\sigma \sim 10^{-42} - 10^{-48}$ cm^2**
- **Smaller x-sections possible:**
  - parameter tuning? tiny Yukawa's? symmetries?
  - AND: how to avoid abundance problems?
- **Models with systematically lower x-section AND correct abundance save the attractiveness of WIMPs**
- **Additional physics case for bigger and more costly experiments helps – just in case!**

Hunting WIMPS in different Ways

known Standard Model (SM) particles interact with WIMPs: assumptions…

indirect detection

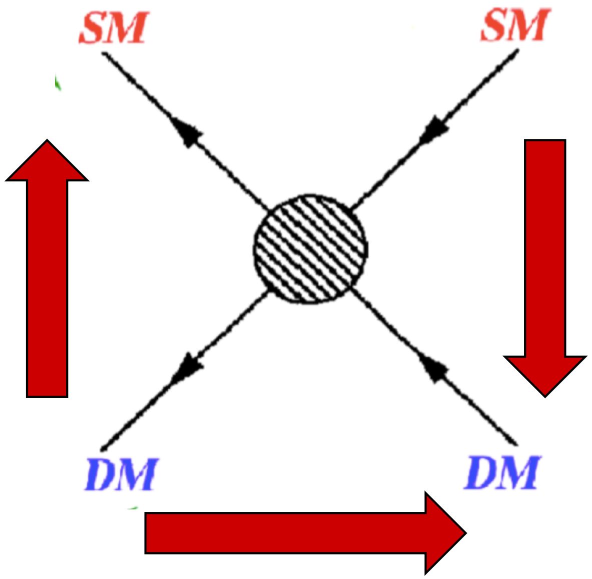


FERMI, PAMELA, AMS, HESS, IceCube, CTA, HAWC…

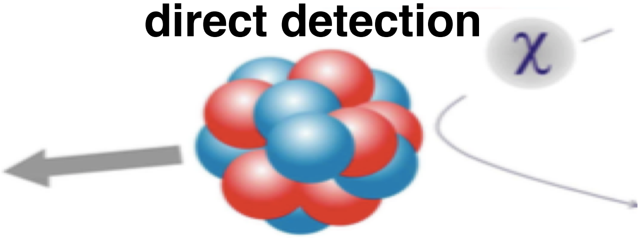
astronnomical uncertainties...

→ is the signal without doubt from DM?

keV lines ↔ atomic physics



direct detection

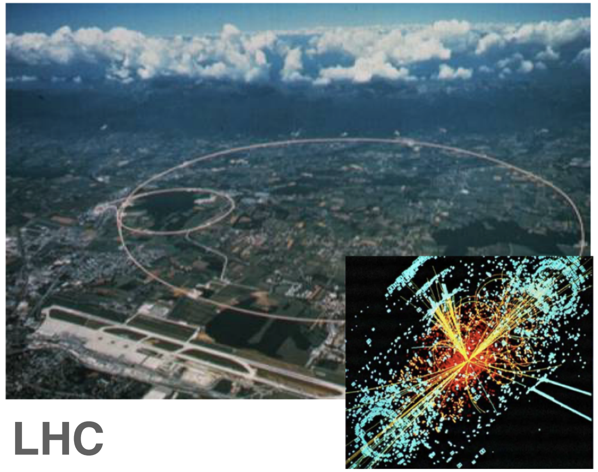


WIMP wind : 220km/s from Cygnus

→ modelling

→ rare event backgrounds

colliders



LHC

may detect new particles, but is it DM (lifetime, abundance)?

So far nothing seen…

→ impact on theory…

→ SUSY → higher scale

→ other SB motivated WIMPs

→ new ideas/candidates

Dark Matter Production at Colliders

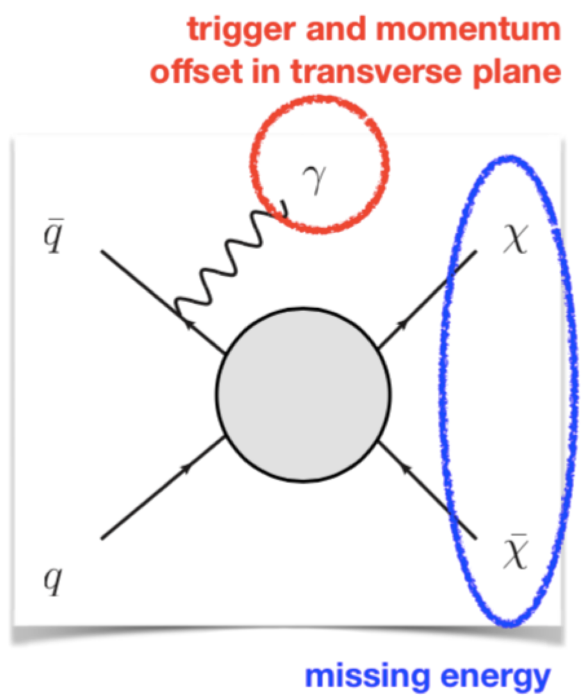
DM particles do not interact via electromagnetic interaction
➔ no DM tracks in a detector

DM particles carry energy & momentum
➔missing energy

two approaches at colliders for DM search:

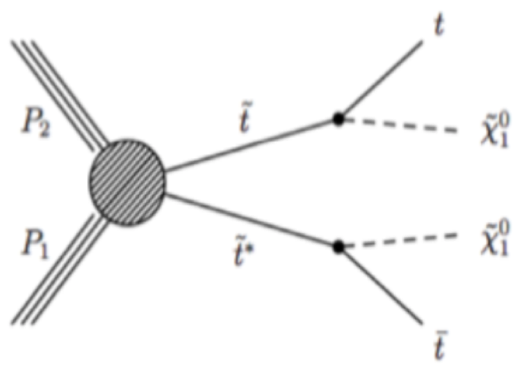
- direct production of DM particles

annihilation of standard model particles into a pair of DM particles



- indirect production of DM particles

search for dedicated decay chains with DM-like particles using a dedicated model (e.g. SUSY)



Drawbacks:

- a signal does not guarantee a long life-time
- unrelated to DM density in the Universe

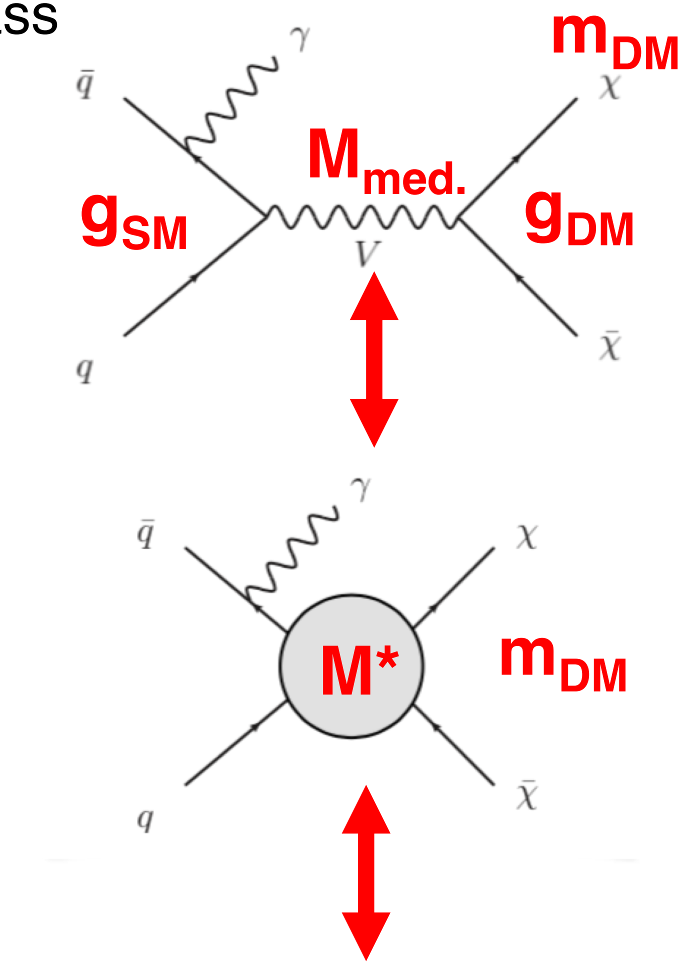
EFT Interpretation

For energy transfer q smaller than the mediator mass
➔ Interaction described by **M*** and **m_{DM}**

type of interaction ➔ different operators
most common:

Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^\mu q$
D9	qq	tensor	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_*^3}\bar{\chi}\chi\alpha_s(G^s_{\mu\nu})^2$

D1, D5, D11 spin independent
D8, D9 spin dependent



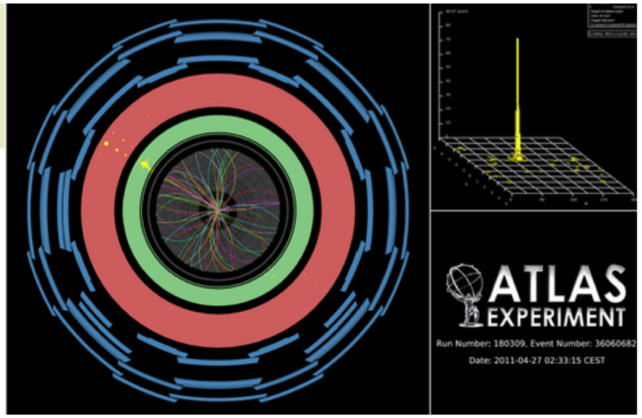
$$\frac{g^2}{(q^2+M^2_{Med.})} \xrightarrow{q^2 \ll M^2_{Med.}} \frac{g^2}{M^2_{Med.}}$$

Mediator induces also SM➔SM processes
➔ LHC sets limits on g^2_{SM}/M^2_{med} (mod. m_{DM})
➔ Unless g_{SM} is tiny TeV-ish limits on $M_{med.}$

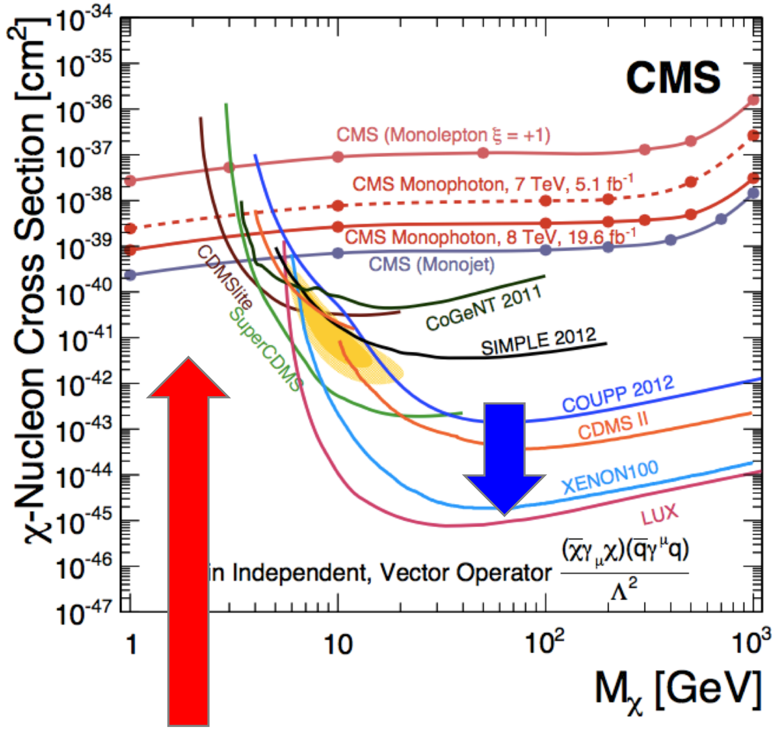
g_{DM} is a free parameter ➔ could be tiny ➔ weaker DM limits *or* full model

Dark Matter at the LHC

- **Generic signature** $pp \rightarrow \not{E}_T + X$



- **Generic kinematics:** weak dependence on WIMP mass for $m_{DM} \ll$ beam energy



light WIMPs
$\mathcal{L}$ ➔ timing

heavy WIMPS
→ direct searches

←→ CRESST-III, SuperCDMS ➔ GeMMC

- **Life is more complex…**
  - many conceivable candidates
  - detection efficiencies, ...

  ➔ EFT or simplified models

  =parametrizion – not always appropriate
  - g_{DM} = assumptions *or* full model +...
- **LHC:**
  - can exclude a DM candidate
  - can establish a candidate
  - does not test if it is DM in Univ.: long lived? abundance?

Results modify Expectations: New Routes…?

Gauge hierarchy problem … ➔ SUSY ➔ ? ➔ conformal

Origin of Flavour ?

Neutrino masses ← keV sterile neutrino

Dark Matter: 1) WIMP

2) other

3) …

lower σ for WIMPs !

…

Hierarchy Problem ←→ new Physics @ Λ

The SM has no hierarchy problem: 4d QFT… → new scales

- Renormalizable QFT with two scalars φ , Φ with masses m, M and a hierarchy **m << M**
- These scalars must interact since $\varphi^+\varphi$ and $\Phi^+\Phi$ are singlets
  → **$\lambda_{mix}(\varphi^+\varphi)(\Phi^+\Phi)$ must exist** in addition to φ^4 and Φ^4 (= portal)
- Quantum corrections ~M^2 drive both masses to the (heavy) scale
  → **vastly different scalar scales are generically unstable**

- **Since SM Higgs exists → problem: embedding with a 2nd scalar**
  - gauge extensions → must be broken…
  - GUTs → must be broken
  - even for SUSY GUTS → doublet-triplet splitting...
  - also for fashinable Higgs-portal scenarios...

Options: no 2nd Higgs –or- some symmetry
SUSY, ... → conformal symmetry

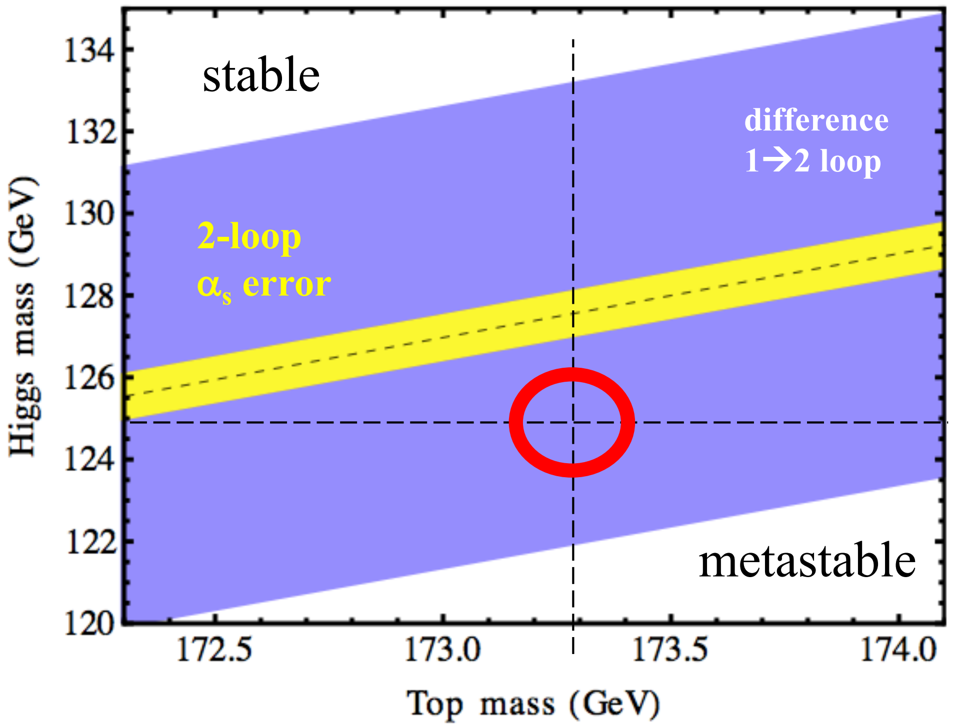
The main Idea

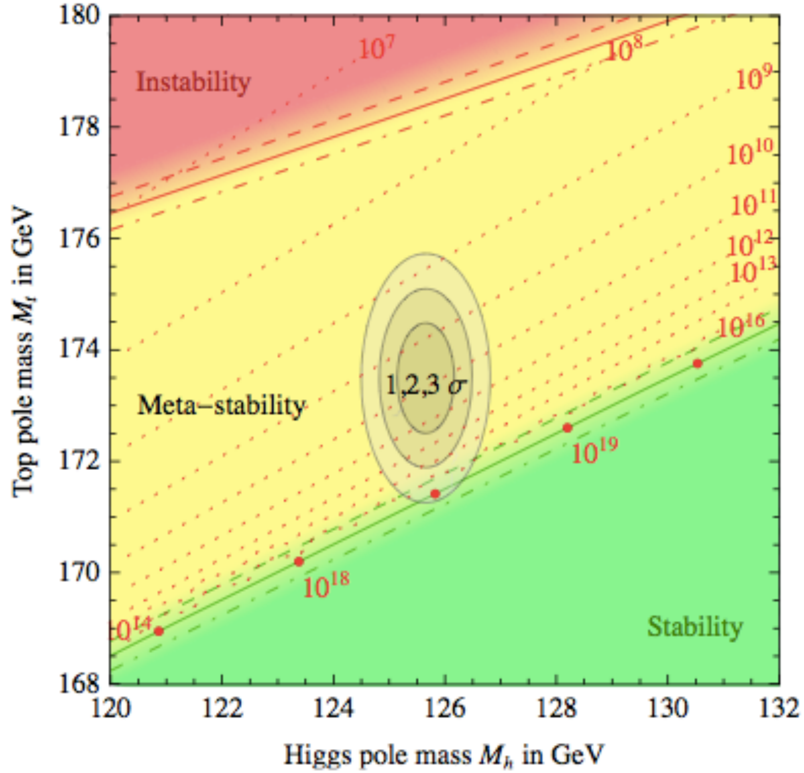
- **Do not introduce two or more fundamental scales**
- **Instead: No fundamental scale**
  → theories with conformal or shift symmetry
- **Dynamical breaking of CS → scale(s)**
- **Non-linear realization of CS:**
  → naïve power counting ($\sim\Lambda^2$) misleading
  → similar to gauge symmetry and vector boson masses

Is anything pointing in that direction?

Is the Higgs Potential at M_{Planck} flat?

Holthausen, ML, Lim (2011) **Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia**





Experimental values point to metastability. Is it fully established?

➔ **we need to include DM, neutrino masses, …? are all errors (EX+TH) fully included?**

➔ **be cautious about claiming that metastability is established**

➔ **May be a very important observation:**

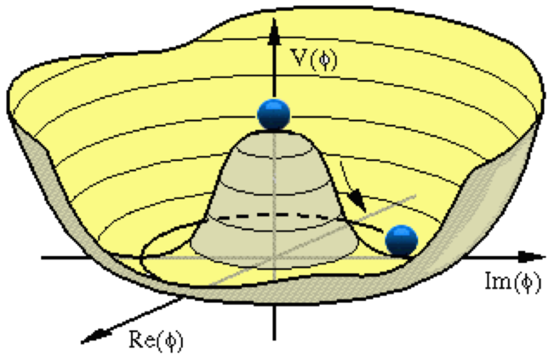
- remarkable relation between weak scale, m_t, couplings and M_{Planck} ←→ precision

- remarkable interplay between gauge, Higgs and top loops (log divergences – not Λ^2)

Is there a Message?

- $\lambda(M_{Planck}) \simeq 0$? ➔ remarkable log cancellations
  M_{planck}, M_{weak}, gauge, Higgs & Yukawa couplings are unrelated

- remember: μ is the only single scale of the SM ➔ special role
  ➔ if in addition $\mu^2 = 0$ ➔ $V(M_{Planck}) \simeq 0$
  ➔ flat Mexican hat (<1%) at the Planck scale!



➔

➔ conformal (or shift) symmetry as solution to the HP

➔ combined conformal & EW symmetry breaking

- conceptual issues
- realizations

Generic Questions

- **Isn't the Planck-scale spoiling things (explicit scale, cut-off, …)?**
  ➔ renormalizable QFTs (SM) don't have cut-offs
  - explicit scales in embeddings act like a cut-off
  - important: no cutoff if the emebedding has no explicit scale

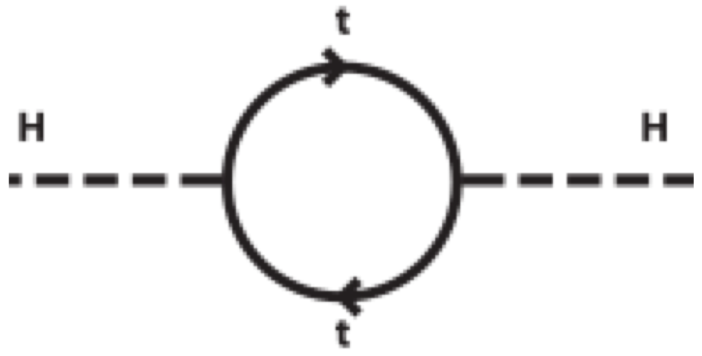
  ➔ non-linear realization of conformal symmetry… ➔ ~conformal gravity…
  ➔ protected by conformal symmetry up to conformal anomaly
  ➔ some mechanism that generates M_{Planck} by dimensional transmutation
  ➔ working assumption: M_{Planck} somehow generated in a conformal setting

- **Are M_{planck} and M_{weak} connected?**
  ➔ maybe …
  ➔ here assumed to be an independently generated scales

- **UV: ultimate solution should be asymptotically safe** ➔ UV-FPs…

- **Conceptual change for scale setting:**
  So far a rollover of scale generation: SM → BSM → GUT → gravity (M_{Planck})
  here: only relative scales – absolute scale is meaningless

Non-linear Realization of Conformal Symmetry



Non-linear realization of conformal symmetry:

➔ protection by conformal symmetry
➔ naïve power counting invalid
➔ similar to vector boson masses
➔ only log sensitivity
↔ conformal anomaly
↔ β-functions

- **Avoids hierarchy problem, even though there is the the conformal anomaly - only logs ↔ β-functions**
- **Dimensional transmutation of conformal theories by log running like in QCD**
  ➔ scalar QCD: scalars can condense and set scales like fermions
  ➔ also for massless scalar QCD: **scale generation; no hierarchy**

Why the minimalistic SM does not work

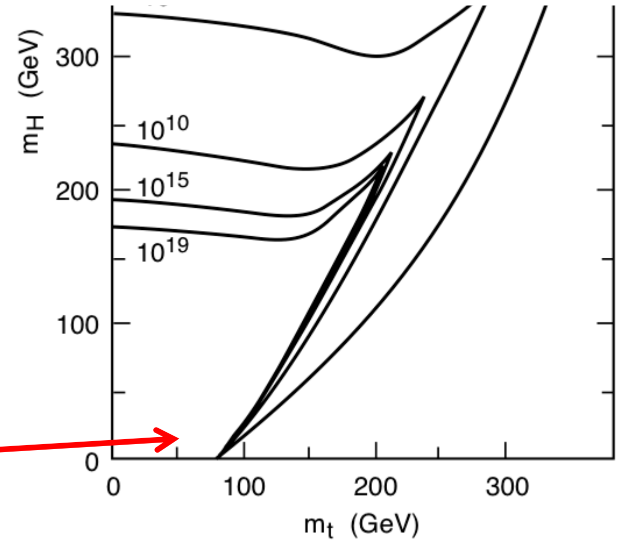
Minimalistic version: → "SM-"

SM + with $\mu = 0$ ←→ CS

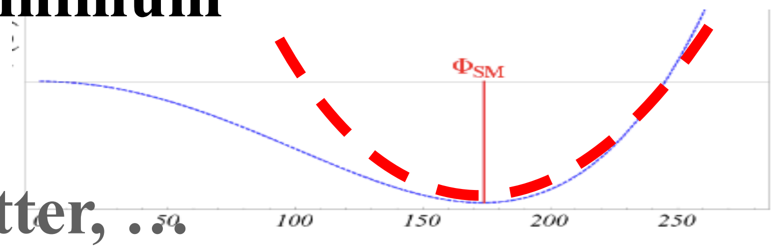
Coleman Weinberg: effective potential

→ CS breaking (dimensional transmutation)

→ induces for $m_t < 79$ GeV
a Higgs mass $m_H = 8.9$ GeV



- **This would conceptually realize the idea, but:**
  Higgs too light and the idea does not work for $m_t > 79$ GeV
- **DSB for weak coupling ←→ CS= phase boundary**
- **Reason for $m_H << v$: V_{eff} flat around minimum**
  ←→ $m_H \sim$ loop factor $\sim 1/16\pi^2$



AND: We need neutrino masses, dark matter, …

Realizing the Idea via Higgs Portals

- SM scalar Φ plus some new scalar φ (or more scalars)
- CS → no scalar mass terms
- the scalar portal $\lambda_{mix}(\varphi^{+}\varphi)(\Phi^{+}\Phi)$ must exist

→ a condensate of $<\varphi^{+}\varphi>$ produces $\lambda_{mix}<\varphi^{+}\varphi>(\Phi^{+}\Phi) = \mu^{2}(\Phi^{+}\Phi)$
→ effective mass term for Φ

- CS anomalous … → breaking → only ln(Λ)

→ implies a TeV-ish condensate for φ to obtain $<\Phi> = 246$ GeV

- Model building possibilities / phenomenological aspects:
  - φ could be an effective field of some hidden sector DSB
  - further particles could exist in hidden sector; e.g. confining…
  - extra hidden U(1) potentially problematic ←→ U(1) mixing
  - avoid Yukawas which couple visible and hidden sector

→ phenomenology safe due to Higgs portal, but there is TeV-ish new physics!

Realizing the Idea: Specific Realizations

SM + extra singlet: Φ, φ

Nicolai, Meissner, Farzinnia, He, Ren, Foot, Kobakhidze, Volkas, …

SM $\otimes$ $SU(N)_H$ with new N-plet in a hidden sector

Ko, Carone, Ramos, Holthausen, Kubo, Lim, ML, Hambye, Strumia , …

SM embedded into larger symmetry (CW-type LR)

Holthausen, ML, M. Schmidt

SM + QCD colored scalar which condenses at TeV scale

Kubo, Lim, ML

SM $\otimes$ $[SU(2)_X \otimes U(1)_X]$

Altmannshofer, Bardeen, Bauer, Carena, Lykken

Since the SM-only version does not work → observable effects:

- Higgs coupling to other scalars (singlet, hidden sector, …)
- dark matter candidates ←→ hidden sectors & Higgs portals
- consequences for neutrino masses

SM ⊗ hidden $SU(3)_H$ Gauge Sector

Holthausen, Kubo, Lim, ML

- hidden $SU(3)_H$:

$$\mathcal{L}_H = -\frac{1}{2}\mathrm{Tr}\; F^2 + \mathrm{Tr}\; \bar{\psi}(i\gamma^\mu D_\mu - yS)\psi$$

gauge fields ; $\psi = 3_H$ with $SU(3)_F$; S = real singlet scalar

- SM coupled by S via a Higgs portal:

$$V_{SM+S} = \lambda_H (H^\dagger H)^2 + \frac{1}{4}\lambda_S S^4 - \frac{1}{2}\lambda_{HS} S^2 (H^\dagger H)$$

- no scalar mass terms
- use similarity to QCD, use NJL approximation, …
- χ–ral symmetry breaking in hidden sector: $SU(3)_L x SU(3)_R$ → $SU(3)_V$ ➔ generation of TeV scale

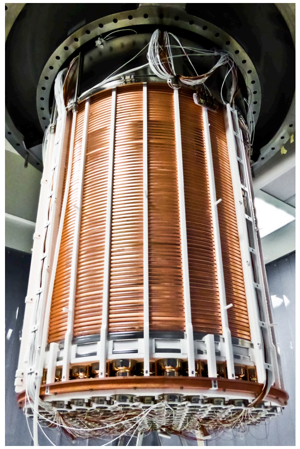
➔ transferred into the SM sector through the singlet S

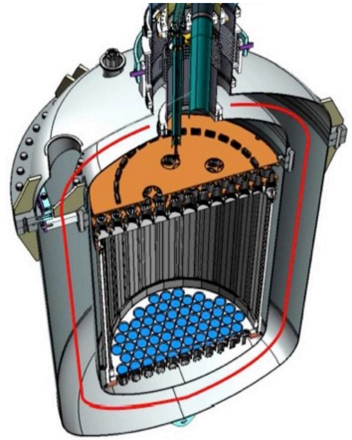
➔ dark pions are PGBs: naturally stable ➔ DM

DARWIN: Towards the ultimate Dark Matter Detector

The current XENON Dark Matter Program

The XENON program at Gran Sasso, Italy (3600 mwe)

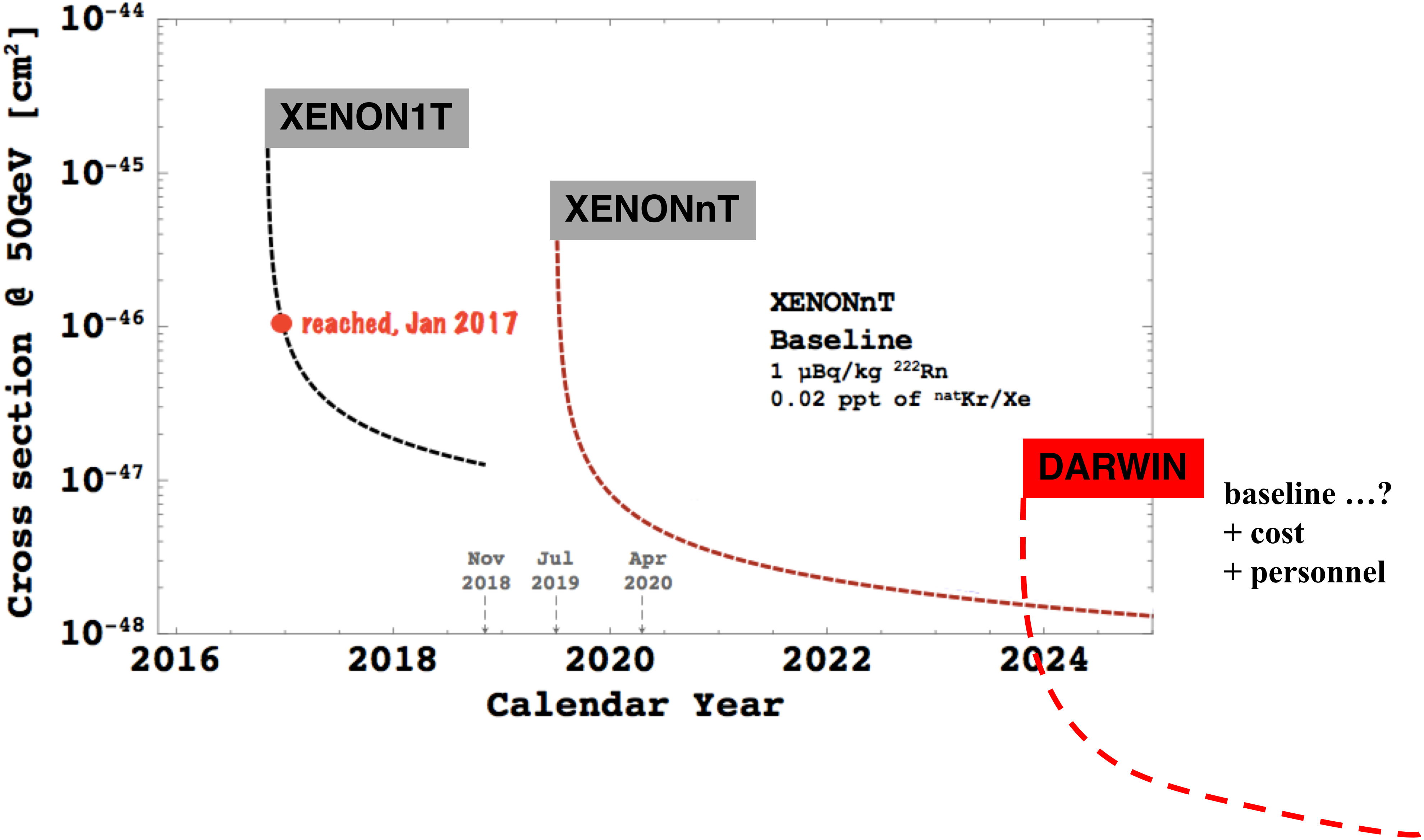




	XENON10	XENON100	XENON1T	XENONnT
Period	**2005-2007**	**2008-2016**	**2012-2018** →	**2019-2023**
Total mass	25 kg	161 kg	3200 kg	~8000 kg
Drift length	15 cm	30 cm	100 cm	150 cm
Status	Completed (2007)	Completed (2016)	Running	Construction
σ_{SI} limit (@50 GeV/c²)	8.8×10^{-44} cm²	1.1×10^{-45} cm²	1.6×10^{-47} cm² (2018)	1.6×10^{-48} cm² (2023)

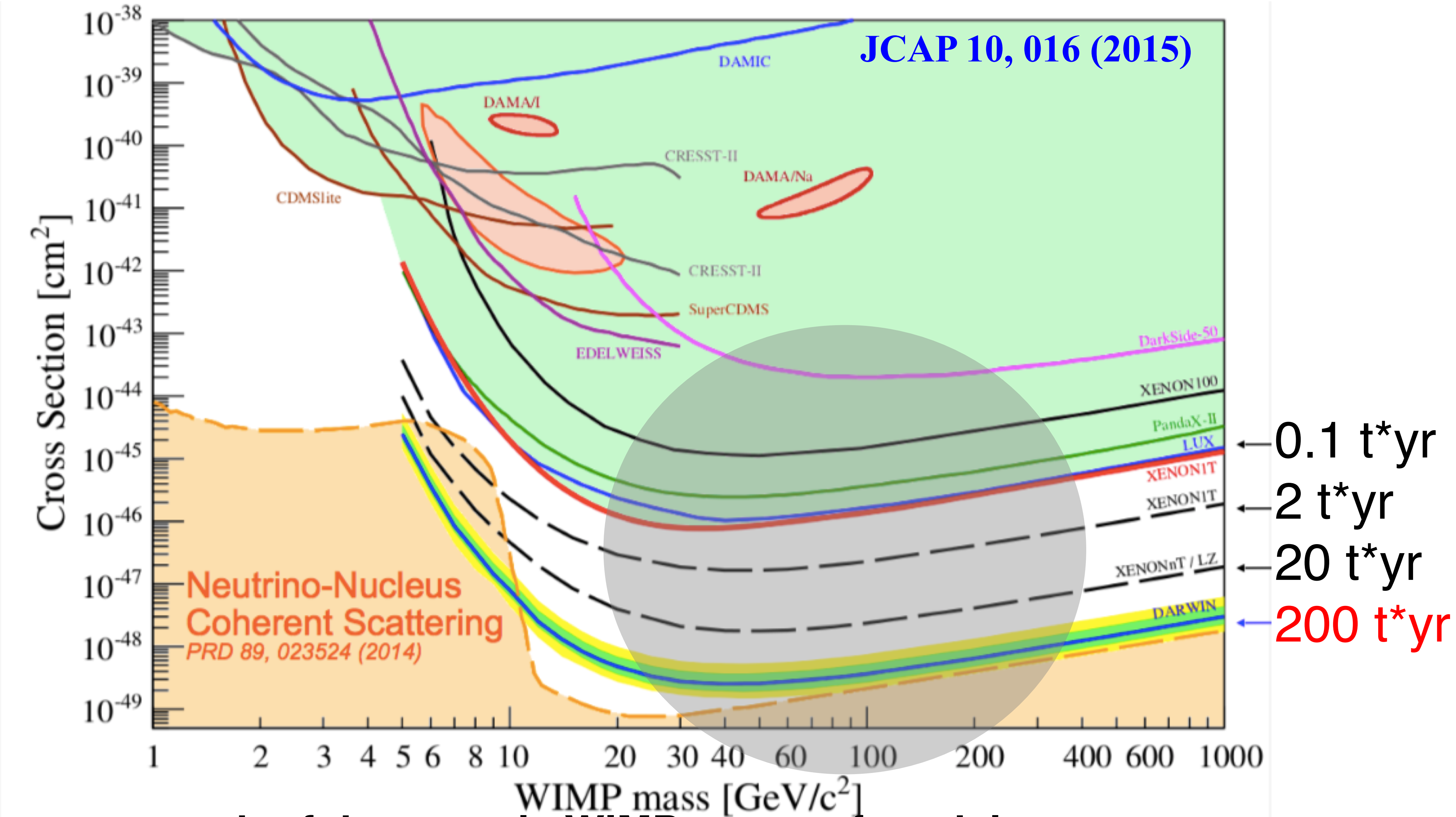
XENONnT being prepared while XENON1T runs → switching gears

Pushing Direct Detection Sensitivity



baseline …?
+ cost
+ personnel

Spin Independent (SI) WIMP Interaction



tests much of the generic WIMP space of models

➔ a declining WIMP case w/o discovery?

➔ solar neutrino signal & CNNS: 200 t*yr

0νββ with ^{136}Xe

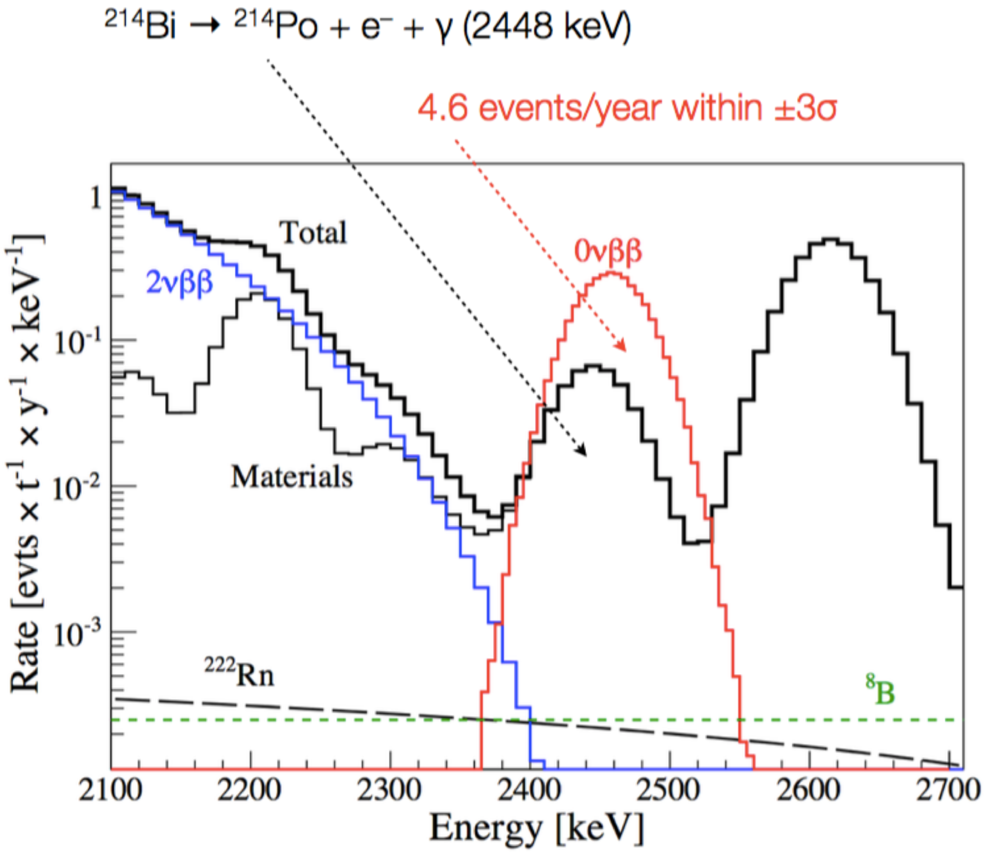
8.9% natural abundance

➔ 3.5 t ^{136}Xe in 40t without enrichment!

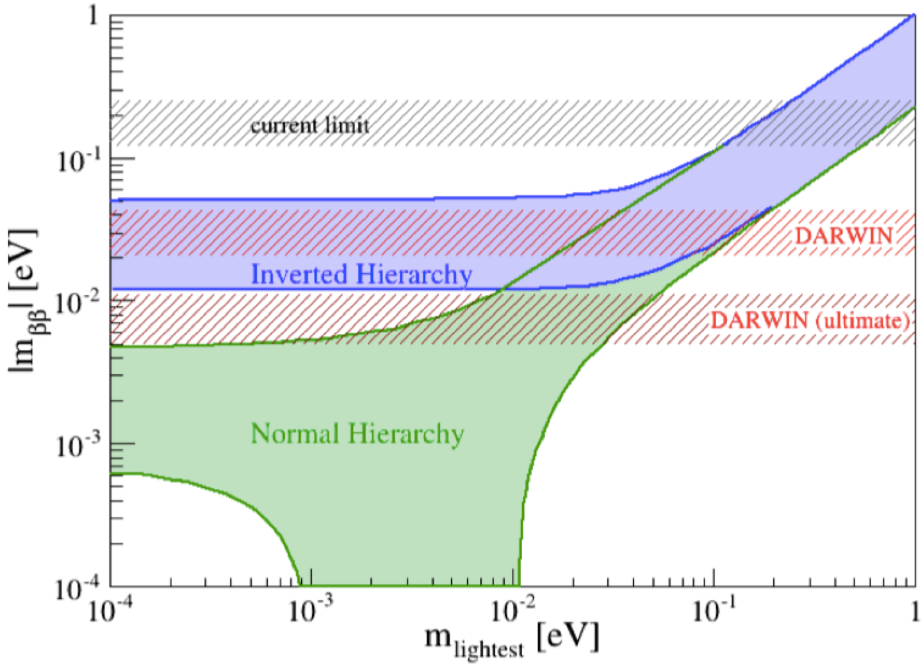
$Q_{\beta\beta}$ = (2458.7 ± 0.6) keV

Assume:

- 6t fiducial
- energy resolution at $Q_{\beta\beta} \simeq 1\%$



JCAP 01, 044 (2014)

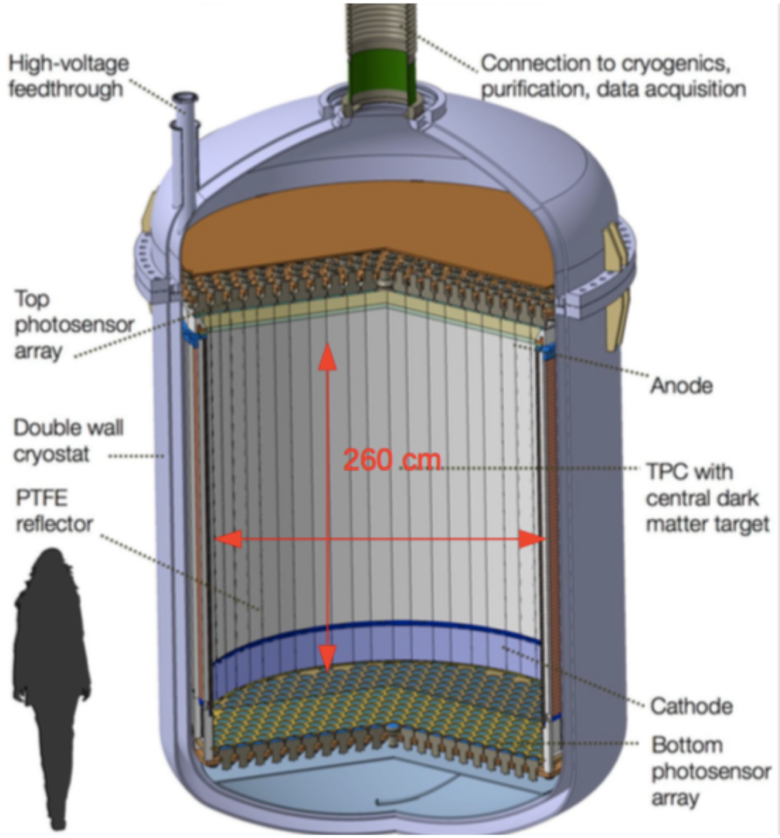


Sensitivity @ 95% CL:

- 30 t*yr → $T_{1/2} > 5.6 \times 10^{26}$ yr
- 140 t*yr → $T_{1/2} > 8.5 \times 10^{27}$ yr

IMPORTANT: DARWIN might become a powerful, cost effective and time-wise competitive 0νββ experiment (no enrichment!)

DARWIN Conceptual Design



JCAP 11, 017 (2016)

DARWIN

www.darwin-observatory.org

- **Baseline: 50t LXE**
- **40t LXe TPC, aim at 200 t*yr**
- **TPC dimension 2.6m x 2.6m**
- ~1800 * 3” PMTs (or ~1000 4” PMTs)
- Low-background cryostat
- PTFE reflector panels
- Copper E-field shaping rings
- Water Cherenkov shield (~14m diameter)
- Liquid scintillator neutron veto under study
- Possible location LNGS
- **aim at sensitivity of a few 10^{-49} cm^2, limited by irreducible ν-backgrounds**
- R&D and initial design now
- **Timescale: after XENONnT**
- **Cost effective:**
  - use existing Xe gas; buy more & re-sell
  - no enrichment (also faster)

The DARWIN Collaboration

France:
- Subatech
- LAL
- LPNHE

Germany:
- University of Münster
- MPIK, Heidelberg
- University of Freiburg
- KIT, Karlsruhe
- University of Mainz
- TU Dresden
- Heidelberg University

Great Britain:
- Imperial College London

Italy:
- INFN, Sezione LNGS
- INFN, Sezione di Bologna

Israel:
- Weizmann Institute of Science

The Netherlands:
- Nikhef, Amsterdam

Portugal:
- University of Coimbra

Sweden:
- Stockholm University

Switzerland:
- University of Zürich

USA:
- Columbia University
- UCLA
- Arizona State University
- Purdue University
- Rice University
- UCSD
- University of Chicago
- Rensselaer Polytechnic Institute

Abu Dhabi:
- New York UniversityAbu Dhabi

- **seed funding**
- **2 approved ERC grants**
- **ExIn application**

Conclusions

- **The WIMP case is still strong**
  - but probably less simple than initially expected
  MSSM neutralino, interaction weaker/different than expected,...
  - may be connected to new ideas in BSM physics
- **Good discovery potential for on-going experiments:**
  - direct detection experiments ➔ new XENON1T results soon…
  - LHC
  - indirect detection
- **Next-to-next generation direct detection experiments**
  - bigger, higher costs, larger collaborations, time, …
  - other science topics: 0nbb, solar n's, SN, coherent scattering,…
- **Change of strategy once DM is observed…**