SWAPS 2014

Concluding remarks

Strategy Workshop on AstroParticle in Switzerland 2014

A lot has changed in the last two years!

time seems to have accelerated:

Higgs Boson and LHC 7/8 TeV results.
θ_{13}
Planck results
...
...
...

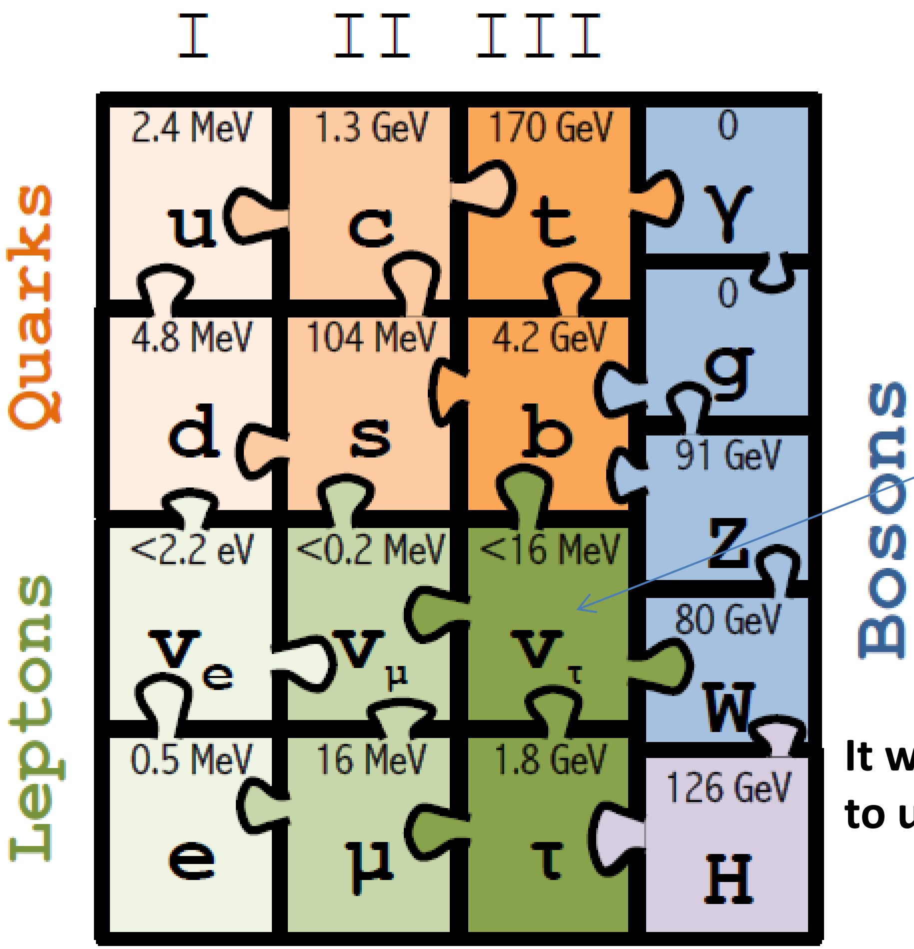
Not a comprehensive summary. apologies to Friday afternoon speakers.

1997-2012 **Higgs boson mass cornered** (LEP H, M_Z etc +Tevatron m_t , M_W)

2012 **Higgs Boson discovered (LHC)**

2013 **Englert and Higgs get Nobel Prize**

and nothing else so far....

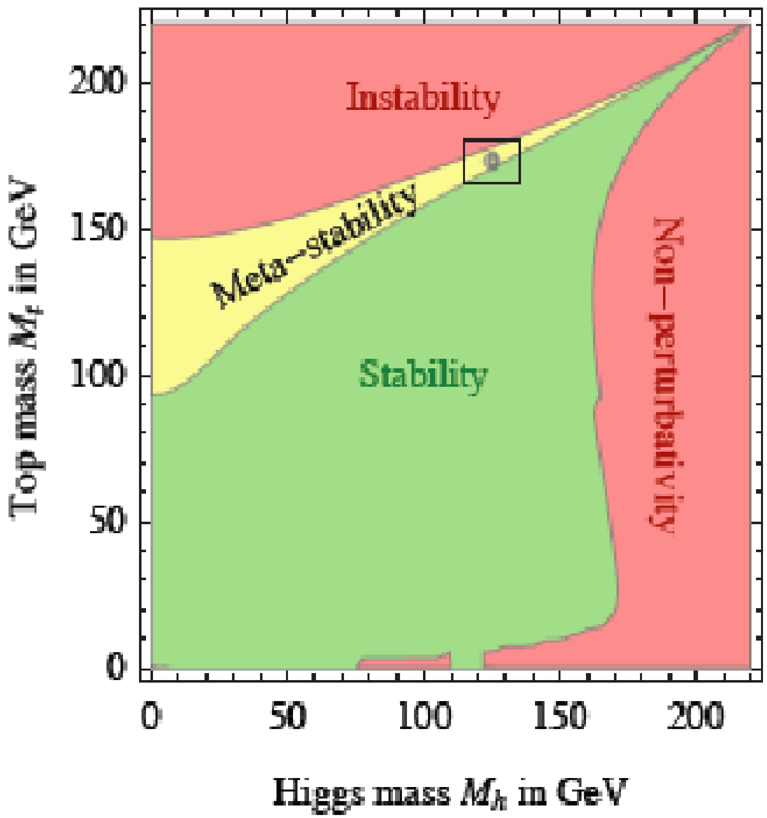


(c) Sfyrla

Nb Lisa Randall has (correctly) ν_1, ν_2, ν_3 in her book: Knocking on Heavens Door

It will take some time for HEP community to understand/accept fully the consequences.

«The Standard Model is complete» **???**



Is it the end?

Both top quark and Higgs boson were found where expected by EW radiative corrections.
➔ strict constraints on new weakly Intereacting particles (also from FCNC, LFV, etc...)

Asymptotic safety of gravity and the Higgs boson mass

Mikhail Shaposhnikov

Institut de Théorie des Phénomènes Physiques, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

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12 January 2010

Abstract

There are indications that gravity is asymptotically safe. The Standard Model (SM) plus gravity could be valid up to arbitrarily high energies. Supposing that this is indeed the case and assuming that there are no intermediate energy scales between the Fermi and Planck scales we address the question of whether the mass of the Higgs boson m_H can be predicted. For a positive gravity induced anomalous dimension $A_\lambda > 0$ the running of the quartic scalar self interaction λ at scales beyond the Planck mass is determined by a fixed point at zero. This results in $m_H = m_{\rm min} = 126$ GeV, with only a few GeV uncertainty. This prediction is independent of the details of the short distance running and holds for a wide class of extensions of the SM as well. For $A_\lambda < 0$ one finds m_H in the interval $m_{\rm min} < m_H < m_{\rm max} \simeq 174$ GeV, now sensitive to A_λ and other properties of the short distance running. The case $A_\lambda > 0$ is favored by explicit computations existing in the literature.

arXiv:0912.0208v2 [hep-th] 12 Jan 2010

Is it the end?

Certainly not!

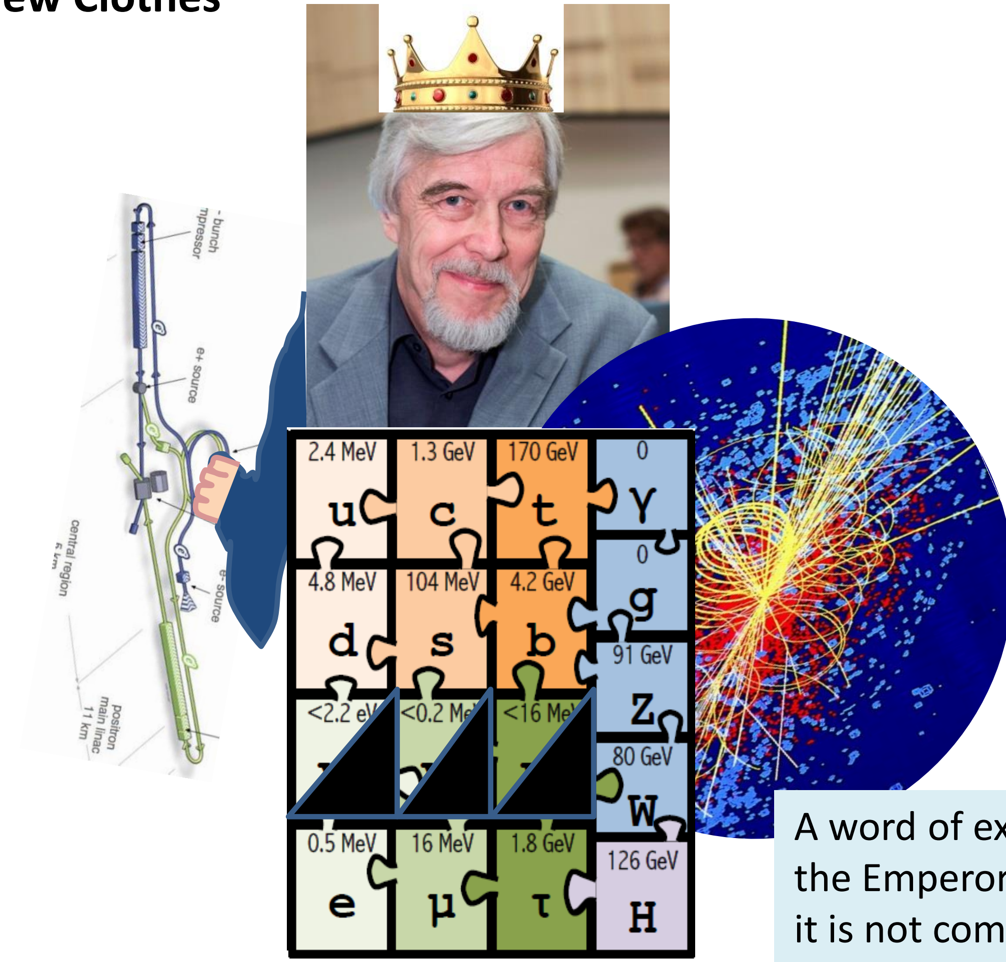
-- Dark matter

-- Baryon Asymmetry in Universe

-- Neutrino masses

are experimental proofs that there is more to understand.

The Emperor’s New Clothes



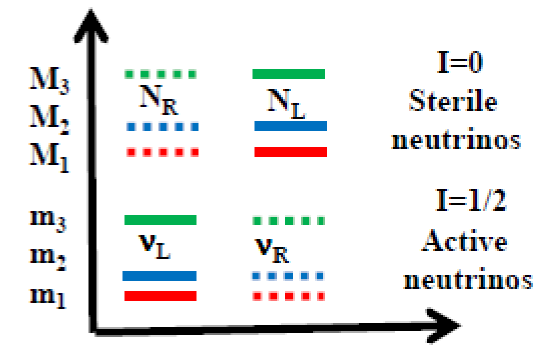
We know only of the left-handed neutrinos.
Where are the right-handed neutrinos?

Andersen:
...made of the finest fabric which is invisible to anyone who is unfit for his position or "hopelessly stupid"... (Wikipedia)

A word of explanation:
the Emperor is the Standard Model, but it is not complete without the understanding of the (nearly unavoidable) right handed /sterile neutrinos. These are invisible to the presently discussed colliders, which are essentially unfit or hopeless for this purpose. What maybe is seen through the right handed neutrinos ‘cloth’ is ***dark matter***.

Neutrinos : the New Physics there is… and a lot of it!

forgive the confusion between fields and particle notations

SM	Dirac mass term only ≡ «Yukawa»	Majorana mass term only	Dirac AND Majorana mass terms
ν_L $\bar{\nu}_R$ I= ½ ½	ν_L ν_R $\bar{\nu}_R$ $\bar{\nu}_L$ ½ 0 ½ 0	ν_L ‘ $\bar{\nu}_R$ ‘ ½ ½	
X 3 Families	X 3 Families	X 3 Families	
6 massless states **wrong**	3 masses 12 states 3 active neutrinos 3 active antinu’s **6 sterile neutrinos…** 3 mixing angles 1 CP violating phase **$0\nu\beta\beta = 0$**	3 masses 6 active states **No steriles** 3 mixing angles 3 CP violating phases **$0\nu\beta\beta \neq 0$**	6 masses (Majorana) 12 states 6 active states **6 sterile neutrinos…** More mixing angles and CPV phases **$0\nu\beta\beta \neq 0$** (different than pure Majorana case if m_N<100 MeV) ➔ Leptogenesis and Dark matter

Mass hierarchies are all unknown except $m_1 < m_2$

Preferred scenario has both Dirac and Majorana terms …

… many physics possibilities and experimental challenges

DARK MATTER

looking for dark matter implies some concept of what one is looking for :

Two typical pictures (but dark matter could be formed of a cocktail)

«Almost sterile» neutrino
Minimal extension to SM
The lightest of the right-handed neutrinos

Very constrained model (0.5 - 100 keV if sterile neutrino is to be all dark matter)

Produced and detected through mixing with active neutrinos which is very small
$N_1 \rightarrow \nu_1\ \gamma$ ($E_\gamma = m_{N1}/2$) (10^{24} years!)

not accessible to colliders etc...
there can be more singlets (N2, N3)

Supersymetry-like (χ) (WIMP)

lightest supersymmetric particle

Produce through a mediator or cascade

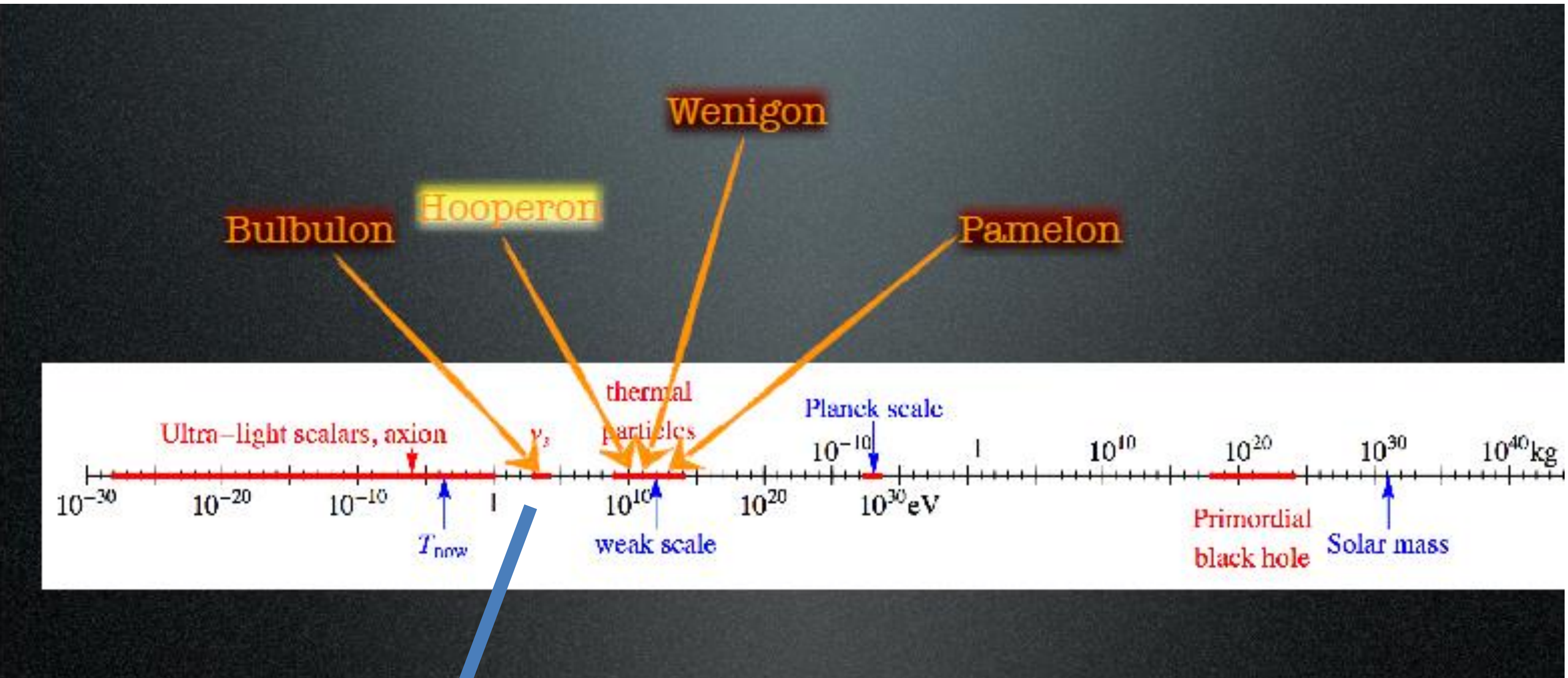
related but not identical to LHC searches

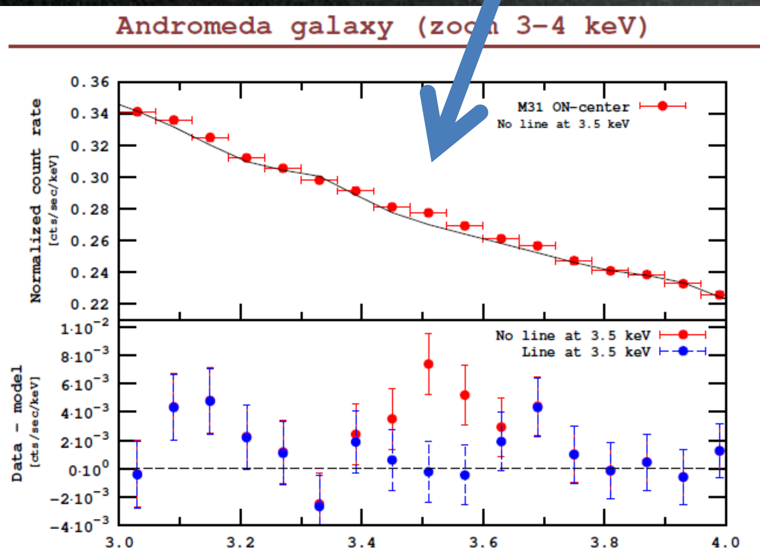
Parametrized in terms of cross-section

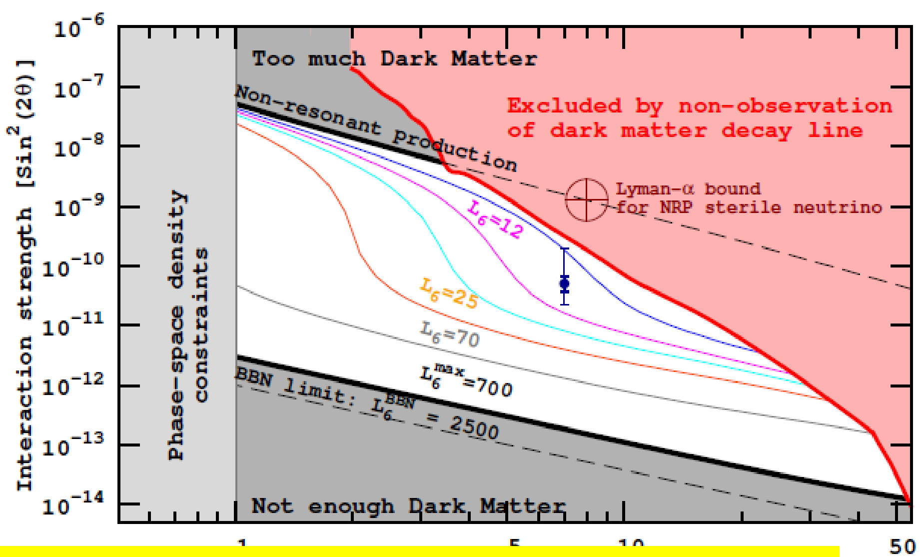
Limited by neutrino inter. background

Observation: decay co-annihilation or interaction

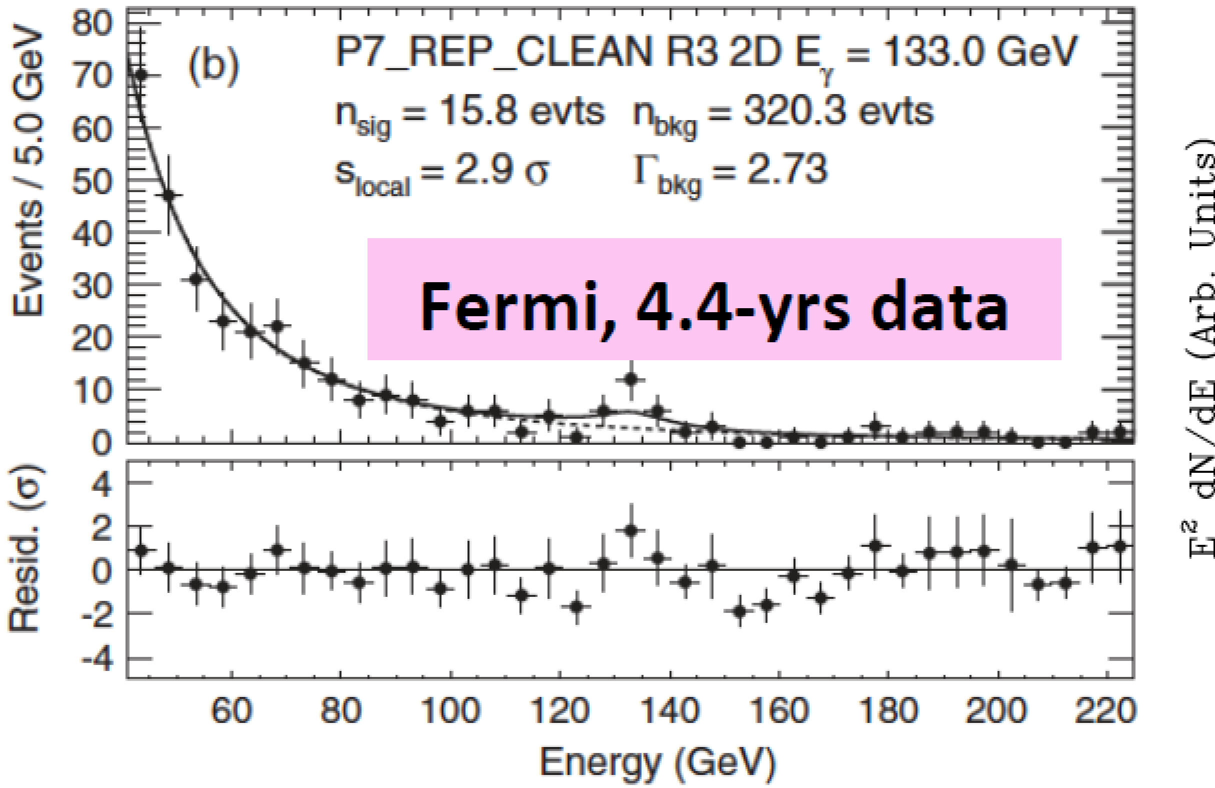
Comment: NOT the eV «sterile neutrino» of the LSND effect.
but lightest of three 'almost sterile neutrinos'







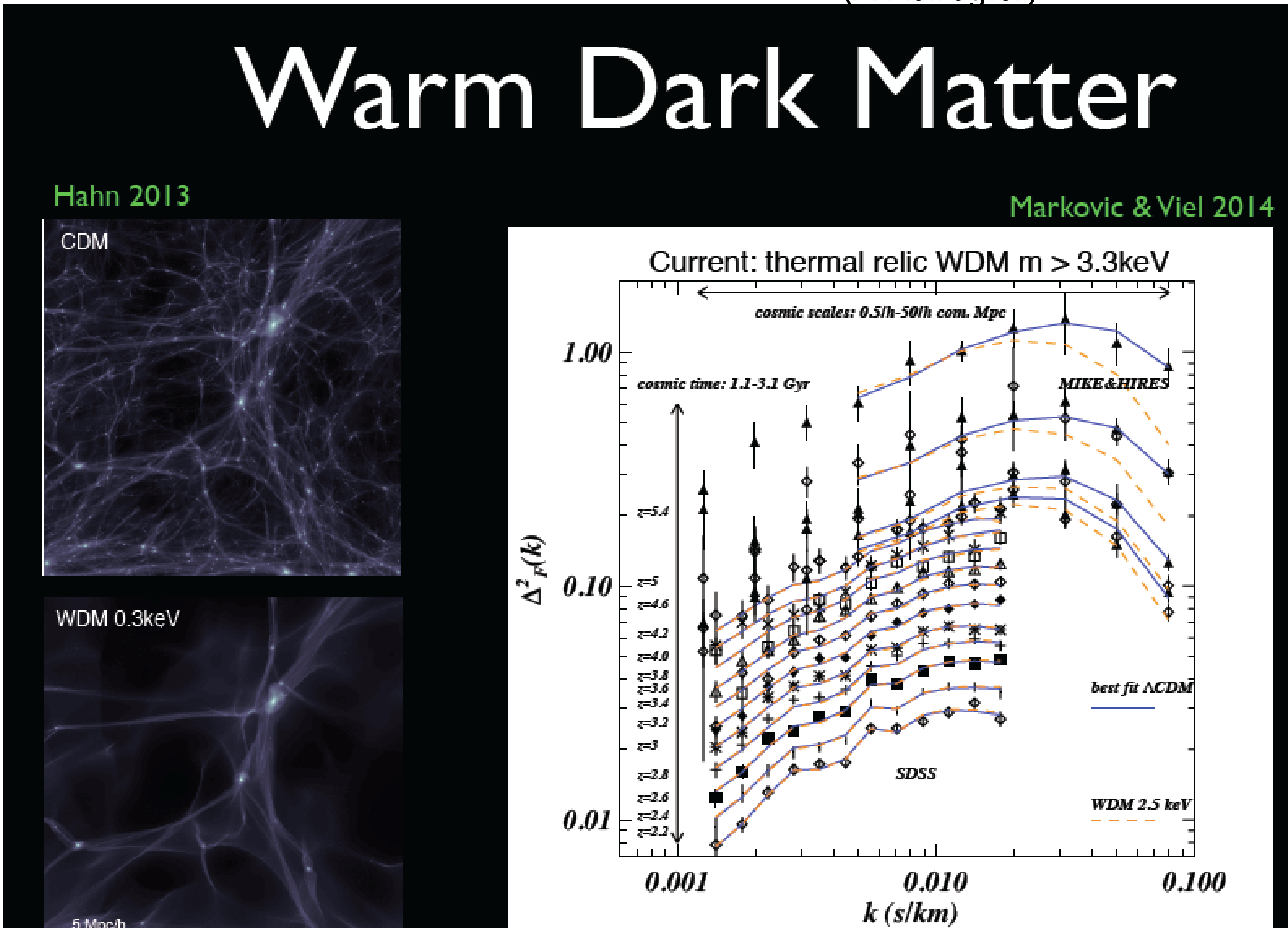
Weak signal and many bins. Needs con/in/firmation. Astro-h etc.. in next few years

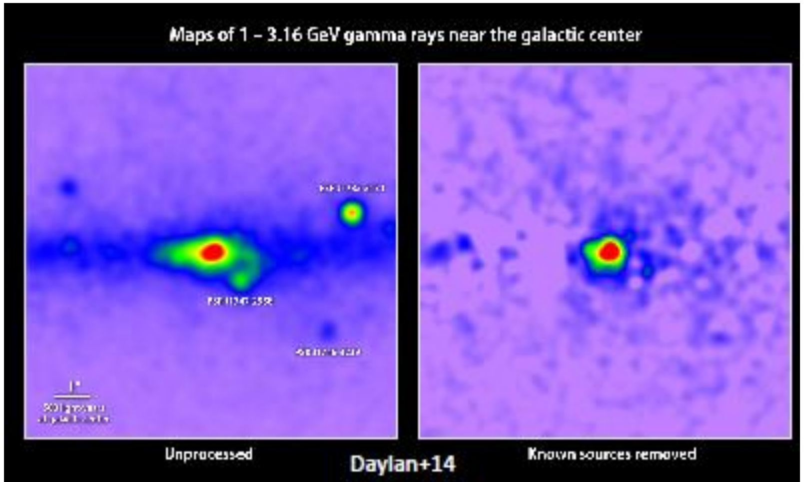


Example of search for annihilation photons
and of ~3σ effect -- expect many of those.

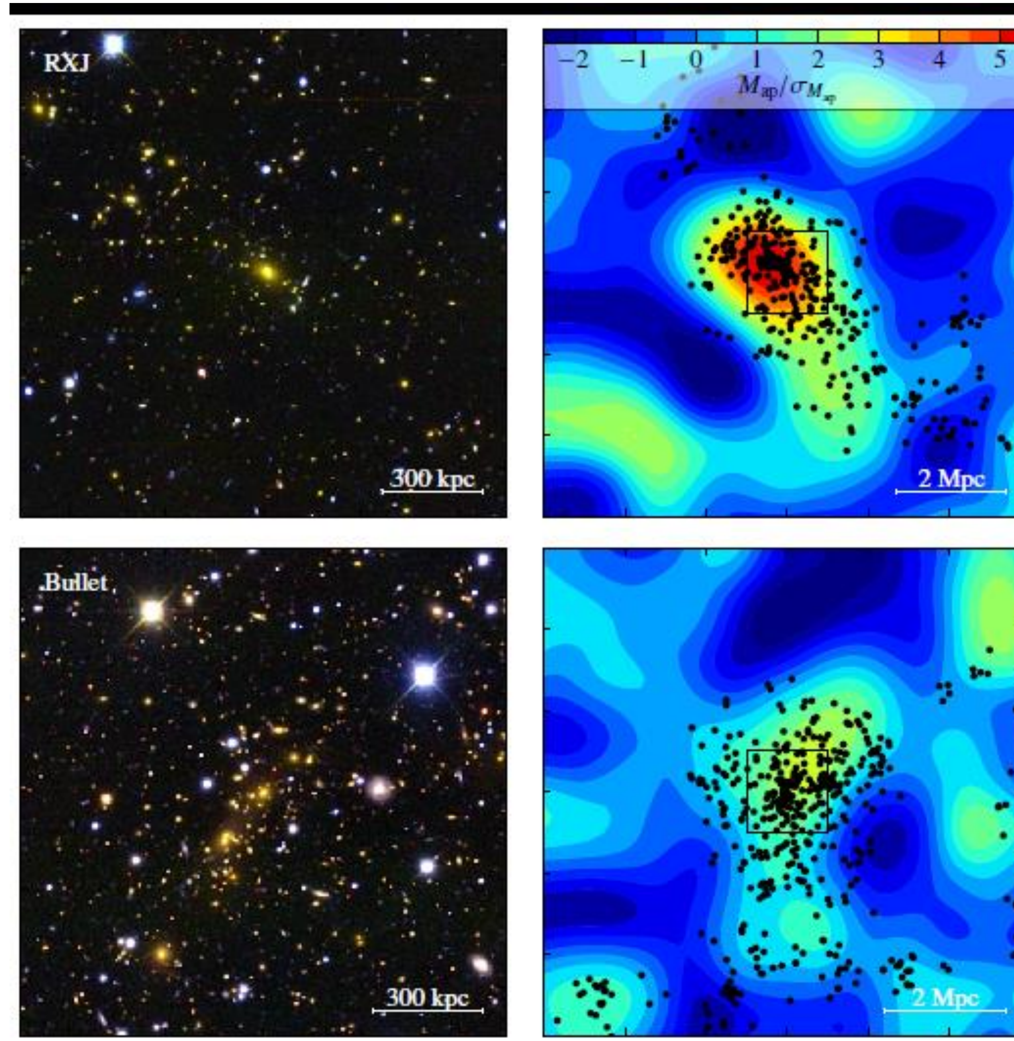
7 keV neutrino ? may die/live soon

at large z deviation from WDM thermal relic impose WDM > 3.5 keV from Lyman α (A Refregier)





If the excess at the Galactic center has a dark matter origin, then it will be confirmed by *Fermi* observations of dwarf spheroidals within the next 4 years



the LSND neutrino «anomalies»

Experiment	What do they measure?	Estimate of significance
Nuclear reactors (ILL, Bugey, Gösgen...)	A small deficit in the $\bar{\nu}_e$ flux from ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu fission.	2.5σ? 1101.2755 1309.4146
Galium detectors (SAGE and GALLEX)	A small deficit in the ν_e-flux from ^{51}Cr and ^{37}Ar decay.	3.0σ 1006.3244
Short baseline oscillation experiments (LSND and MiniBooNE)	$\bar{\nu}_\mu - \bar{\nu}_e$ and $\nu_\mu - \nu_e$ oscillations.	$3.8\sigma + 0\sigma + 3.0\sigma$ (1007.1150 + ...)

Borrowed from Thomas Tram

NB1: no $\bar{\nu}_\mu - \bar{\nu}_e$ and $\nu_\mu - \nu_e$ oscillations have been observed !
(could be photons + these are no-near-detector experiments)

➔ **NEED A GOOD, two detector experiment, with electron-photon separation! ➔ Microboone + DLAR1**

NB2. too light for a DM candidate

The uncomfortable sterile neutrino (LSND)?

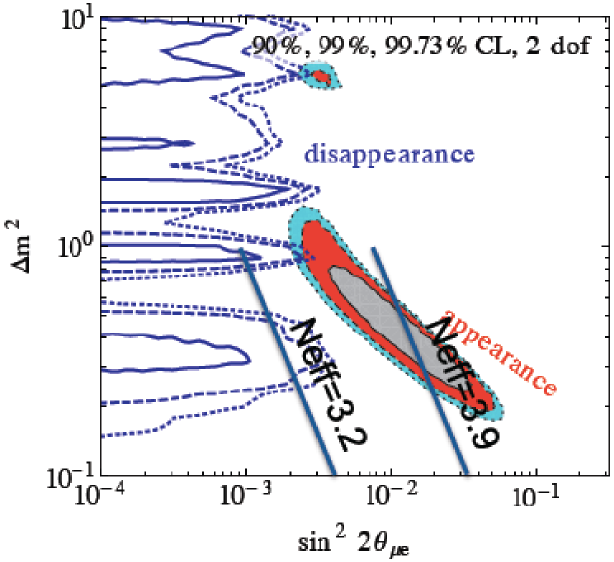
1 eV still DIFFICULT but 0.5 eV neutrino fully thermalized… mass < 1 eV and N_{eff} = 3.8 not strongly excluded by data.

Tension from particle physics and cosmology experiments, NEW EXPERIMENTS such as **SHIP** and lots of new data from COSMOLOGY (verification of BICEP2 from Planck combined with BOSS BAO at different redshifts, cosmic shear surveys such as DES, LSST, Euclid). Tomography techniques at many red shorts effect of massive relics will leave no ambiguity + 21 cm such as SKA

Light sterile neutrinos

Motivations: anomalies in short-baseline neutrino oscillation experiments

3+1 analysis in
Kopp et al. 2013



Appearance: LSND, MiniBoone, NOMAD, KARMEN, ICARUS, E776

Disappearance: reactor, Gallium, MiniBoone, CDHS, Minos, KARMEN

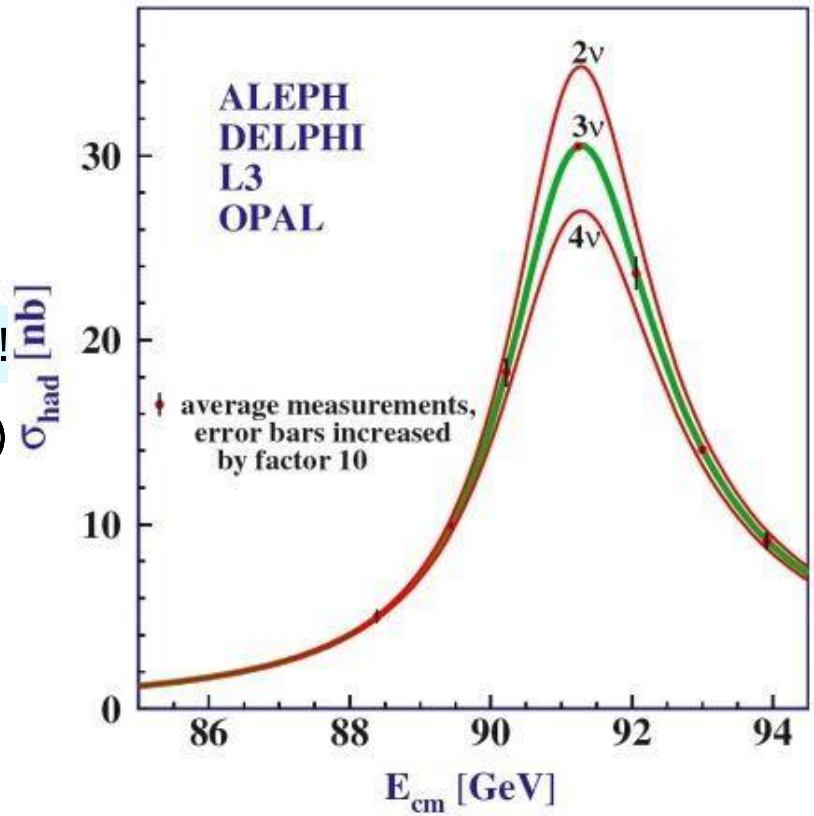
At the end of LEP:

Phys.Rept.427:257-454,2006

N_ν = 2.984 ±0.008

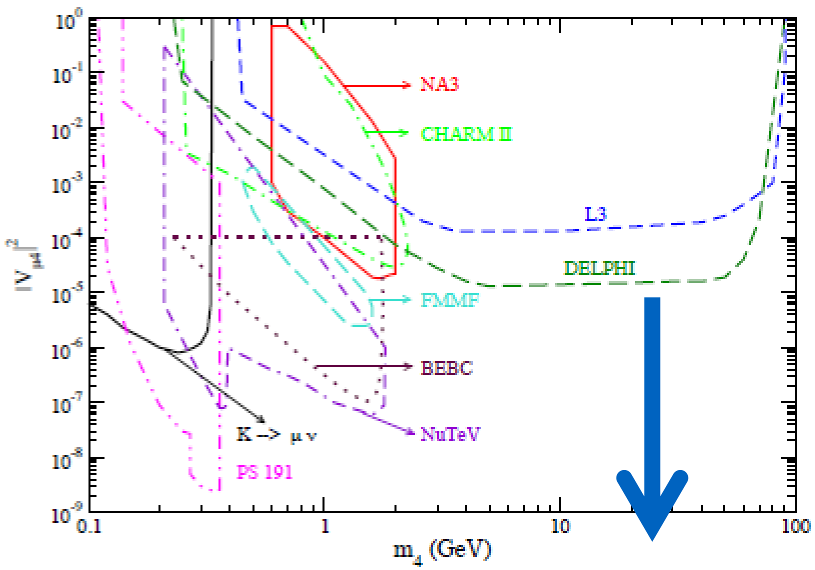
Test of the unitarity of the PMNS matrix

- 2 σ :^) !!



can be revisited at a Z factory (FCC-ee/TLEP)

-- from invisible width
-- from direct search for decays



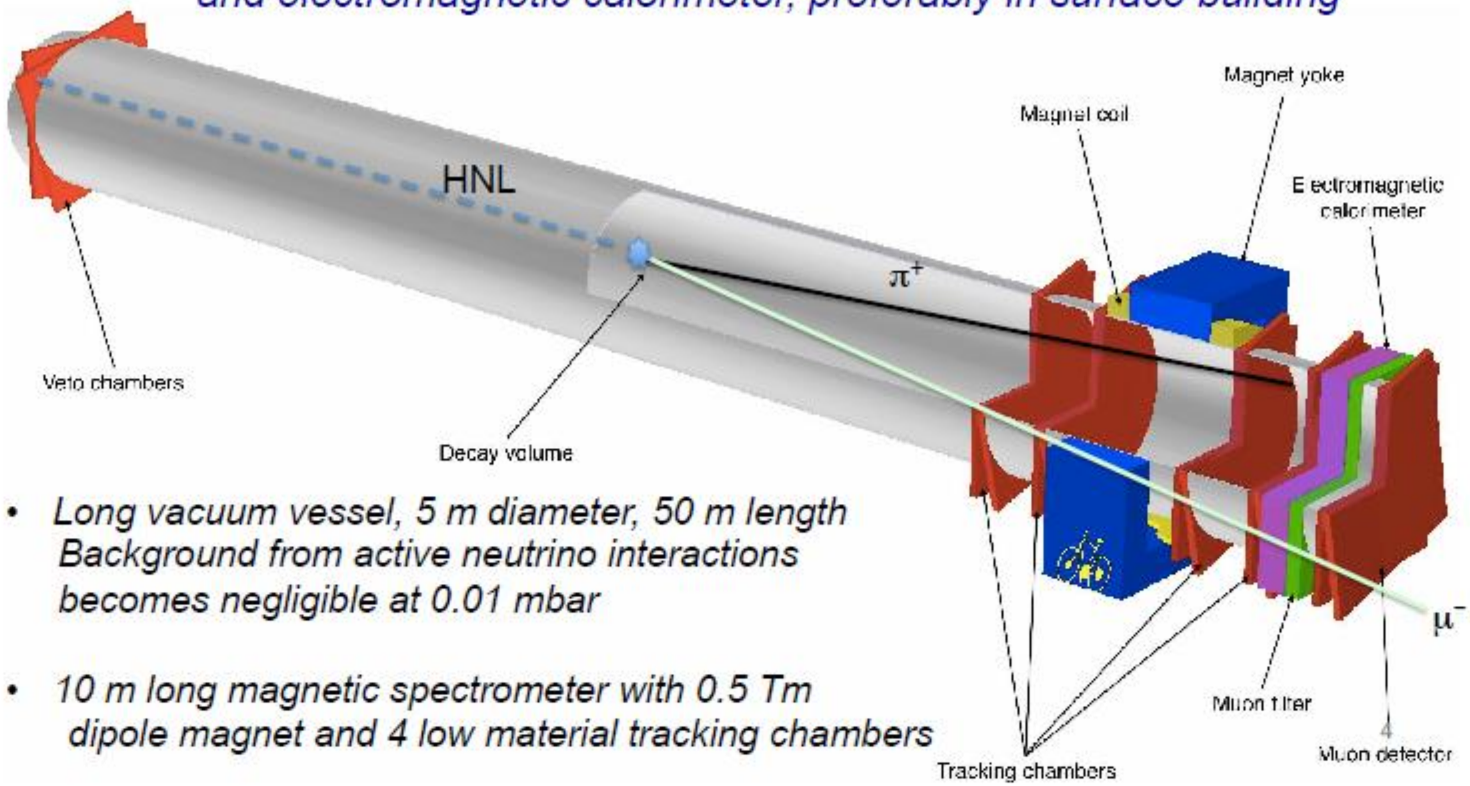
From arXiv:0901.3589, Atre et al

Detector concept

(based on existing technologies)

- *Reconstruction of the HNL decays in the final states: $\mu^-\pi^+$, $\mu^-\rho^+$ & $e^-\pi^+$*

→ *Requires long decay volume, magnetic spectrometer, muon detector and electromagnetic calorimeter, preferably in surface building*



- *Long vacuum vessel, 5 m diameter, 50 m length Background from active neutrino interactions becomes negligible at 0.01 mbar*

- *10 m long magnetic spectrometer with 0.5 Tm dipole magnet and 4 low material tracking chambers*

The neutrino task is very vast !

-- Fully confirm the light neutrino mixing process:
CP violation, mass hierarchy
Long baseline neutrino experiments

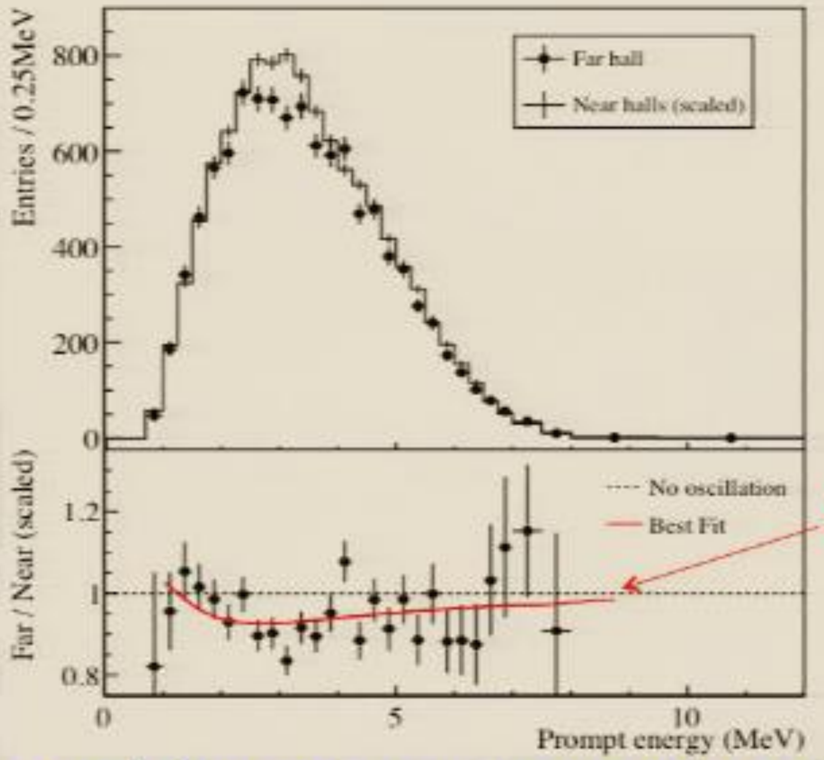
-- explore the nature of the missing degrees of freedom
∃? Majorana mass term **($0\nu\beta\beta$)**
∃? Heavy 'almost sterile neutrinos'
short baseline ν expts, SHIP, FCC-ee etc..

And the situation is very open/uncertain!

08 Mar 2012

Hot news from China!

Far vs. Near Comparison : Spectrum



$\sin^2 2\theta_{13} = 0.092$

Spectral distortion consistent with oscillation.

$\sin^2 2\theta_{13} = 0.092 \pm 0.016\ (\mathrm{stat}) \pm 0.005\ (\mathrm{syst})$

$\sin^2 2\theta_{13} = 0$ excluded at 5.2σ

consequences of large theta_13.

Superbeam (Water Cherenkov vs Liquid Argon) vs betabeam / neutrino factory

-1- golden channel signal $\nu_\mu \rightarrow \nu_e$ is large (5%)

➔ **backgrounds are not so important (water OK)**

➔ **signal can be seen and CP violation measured at conventional superbeam.**

-2- CP asymmetry is small (~0.2 x sinδ) for first maximum

➔ **Systematics from detection (efficiency x cross-sections) become dominant**

(to demonstrate «better than 5%» on ν_e / ν_μ is not trivial)

=> ICFA panel : need comprehensive program to tackle systematic errors.

Among best possibilities: muon storage ring nustorm for cross-section and calibration with Liquid Argon or Water Cherenkov detector (as the case maybe).

Not in P5, US wont do it.

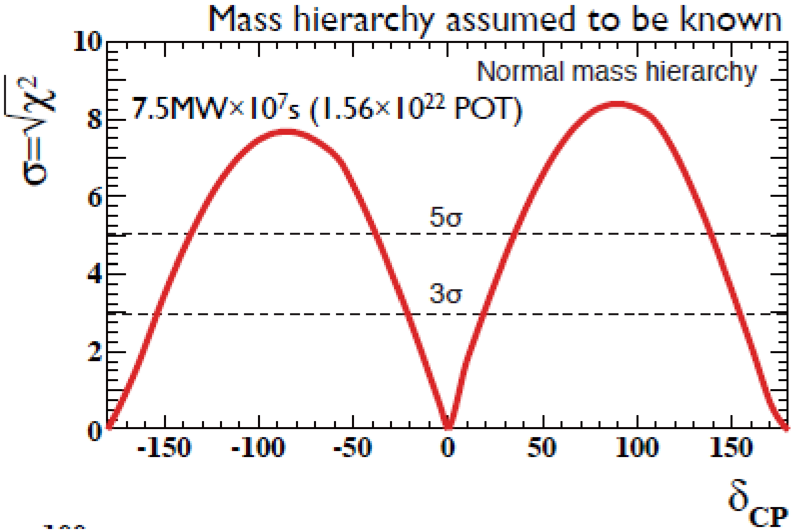
My personnal opinion: this could be a fantastic contribution from CERN.

HYPERK (WC, 300km optimized off-axis narrow band)

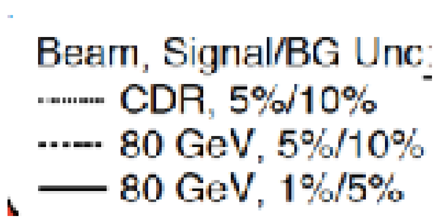
Uncertainty on the expected number of events at Hyper-K (%)

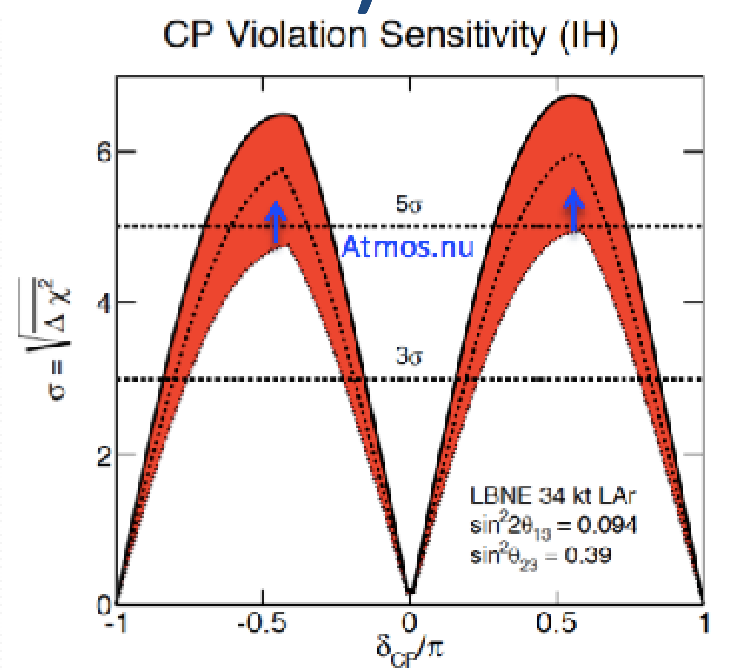
	ν mode		anti-ν mode		(T2K 2014)	
	νe	νμ	νe	νμ	νe	νμ
Flux&ND	3.0	2.8	5.6	4.2	3.1	2.7
XSEC model	1.2	1.5	2.0	1.4	4.7	5.0
Far Det. +FSI	0.7	1.0	1.7	1.1	3.7	5.0
Total	3.3	3.3	6.2	4.5	6.8	7.6

New near detector to reduce systematics!



LBNE (Larg, 1300km Optimized Wide Band)





Also to consider:
timing, political situation,
astroparticle and proton decay capabilities.

Complementarity

-1- HyperK is the natural continuation to T2K

We have invested in NA61, and in the near detectors of T2K
It is the most sensitive proposal for the observation of CP violation in neutrino oscillations and for a large part of underground physics
(proton decay, atmospheric, solar and supernovae neutrinos)
.... and the most straight-forward technology

-2- it is not complete however and there is a physics case for a complementary experiment that would determine unambiguously the value of δ_{CP} and the mass hierarchy, complete the observations of oscillations involving tau leptons and matter effects ➔ {LBNO; LBNE} .
This requires a more sensitive technology (Liq. Argon) , in need of R&D and experience (and probably a longer time scale)

The path is not unique and includes focused R&D **(WA105)** and application + experience on running experiments **(microboone)**

A few good words

Swiss Proverb: If you are in a hurry, go slow

Swiss bankers proverb: if you dont have enough money to do things right...
... we may lend you (with interest) money to do them twice.

Neutrinos, a few possible «to do's»

-- do the most of T2K, NA61, Microboone, WA105, etc....

-- strongly continue search for neutrinoless double beta decay
Progress is vry hard, but unless one is unlucky , quite likely ultimate success
Can demonstrate the existence of Majorana mass term, but can also fail in few blind regions.

-- set-up SWISS participation in HYPERK (We all want to do it , UNIGE working on it
.... but precise contribution of 'swiss groups' to be better defined)

-- contribute to definition of LBNF
P5 → neutrino summit at Fermilab 21-22 July 2014
investigate nuSTORM need/possibilities

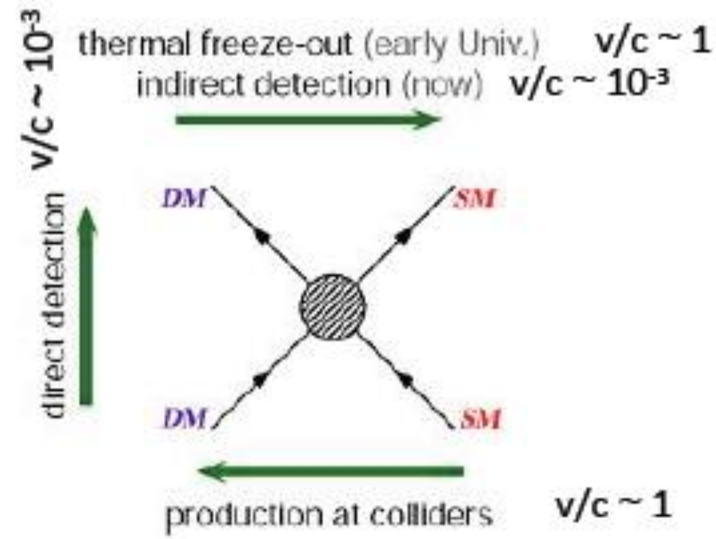
-- remeasure hadroproduction at 8.9 GeV/c in SHINE/NA61 for microBooNE cross-sections
imporve over HARP. replica target.

-- investigate Swiss participation in SHIP proposal

«χ» Dark Matter: 3 strategies important!

In Switzerland we have, aside from LHC, …

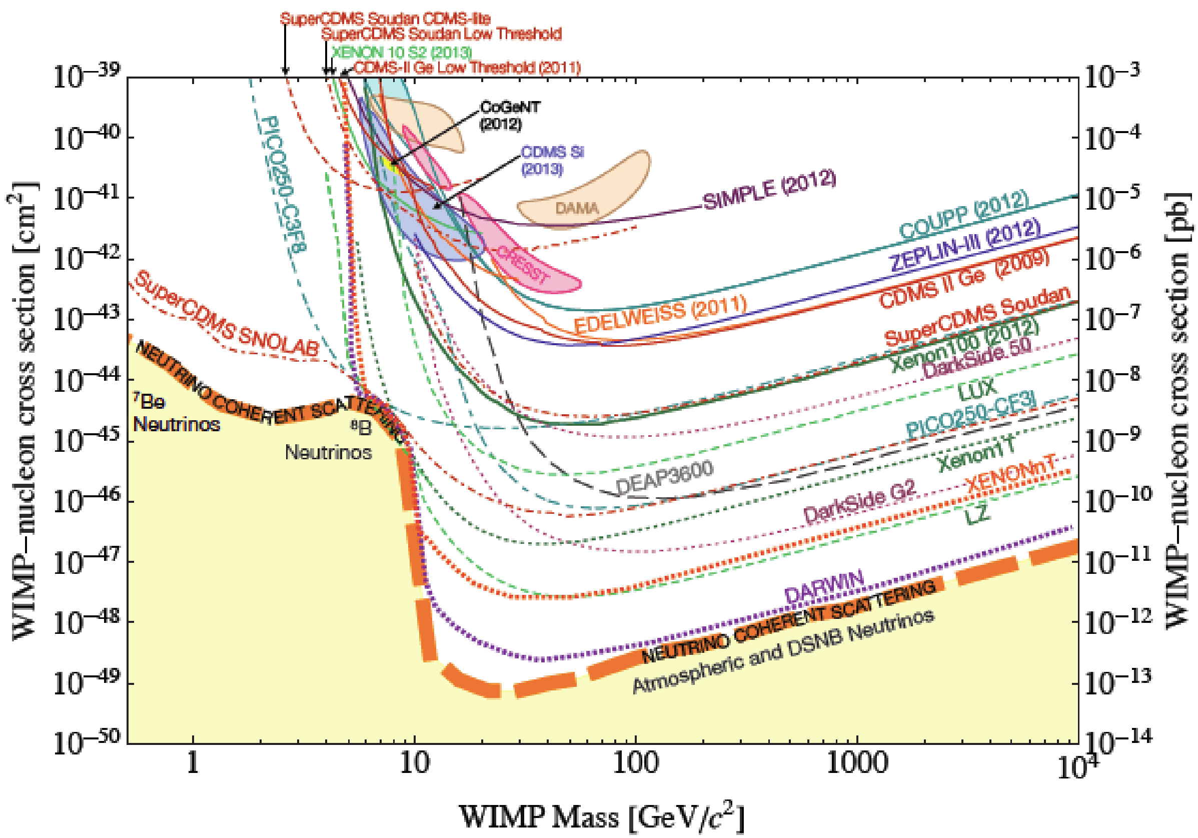
Strong Direct Detection (DD) program:
LXe consolidated strategy will reach NDB limit
ArDM **ready to start** but high E_R, a fundamental precursor of WA105.
GO, DAMIC GO!!
New in CH: Search for highly ionizing particles



Strong Indirect Detection program: IceCube, CTA, space programs (annihilation)
Let's not forget cosmology: LSST,
Where are the astronomers at this meeting?

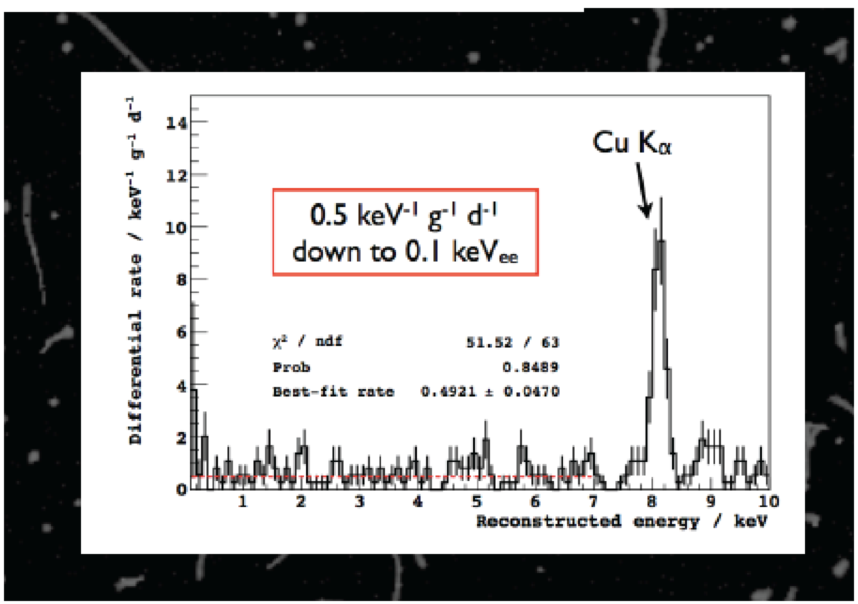
A succesful program to cover up to NSB: Darwin

DARWIN can probe the experimentally available parameter space for WIMPs (m > 10 GeV/c²)

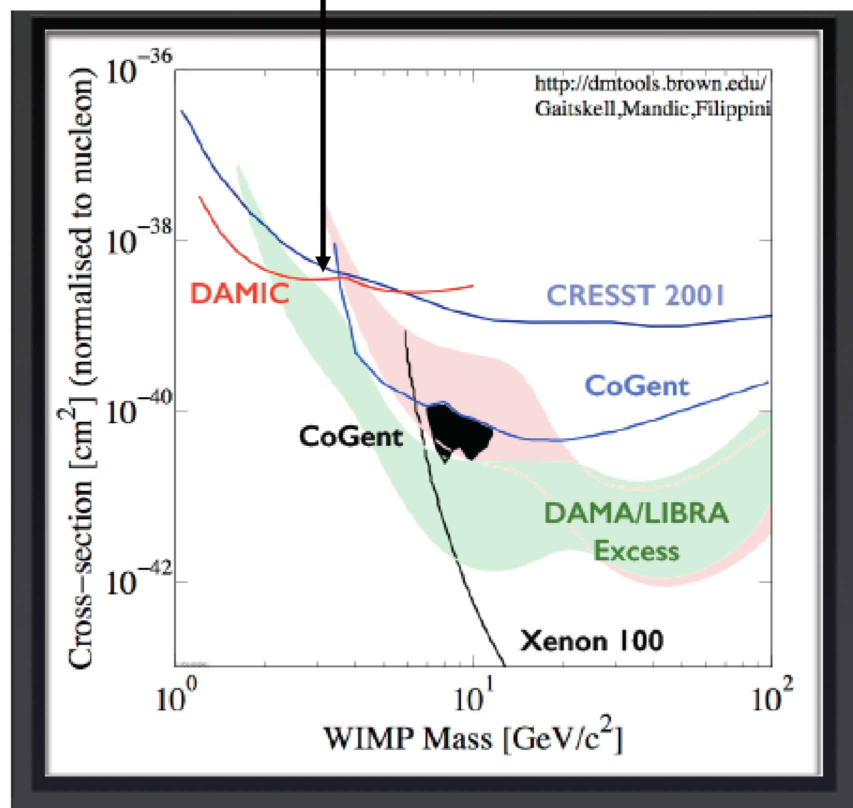


PID with CCDs

understood ^{238}U
contamination in frame



potential to reach low energies
careful calibrations
background understanding

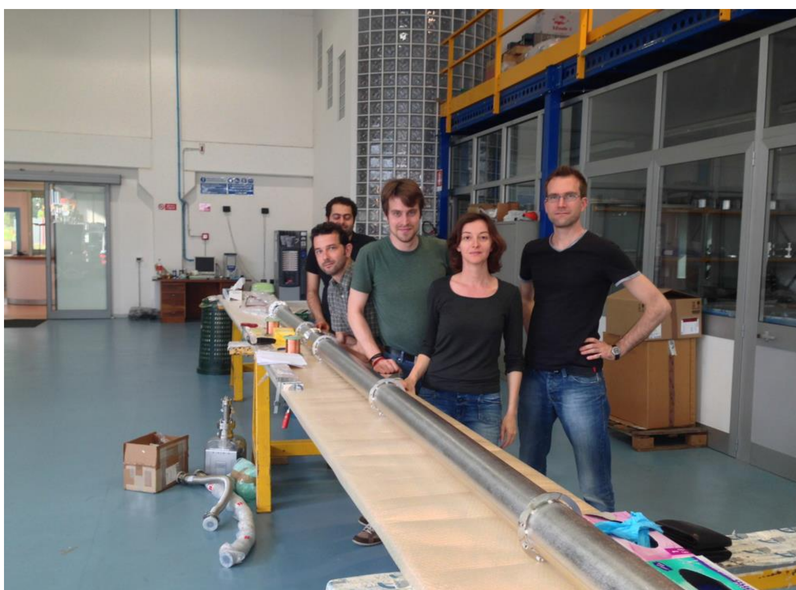


There is remarkable convergence in the technology of cryogenic liquids

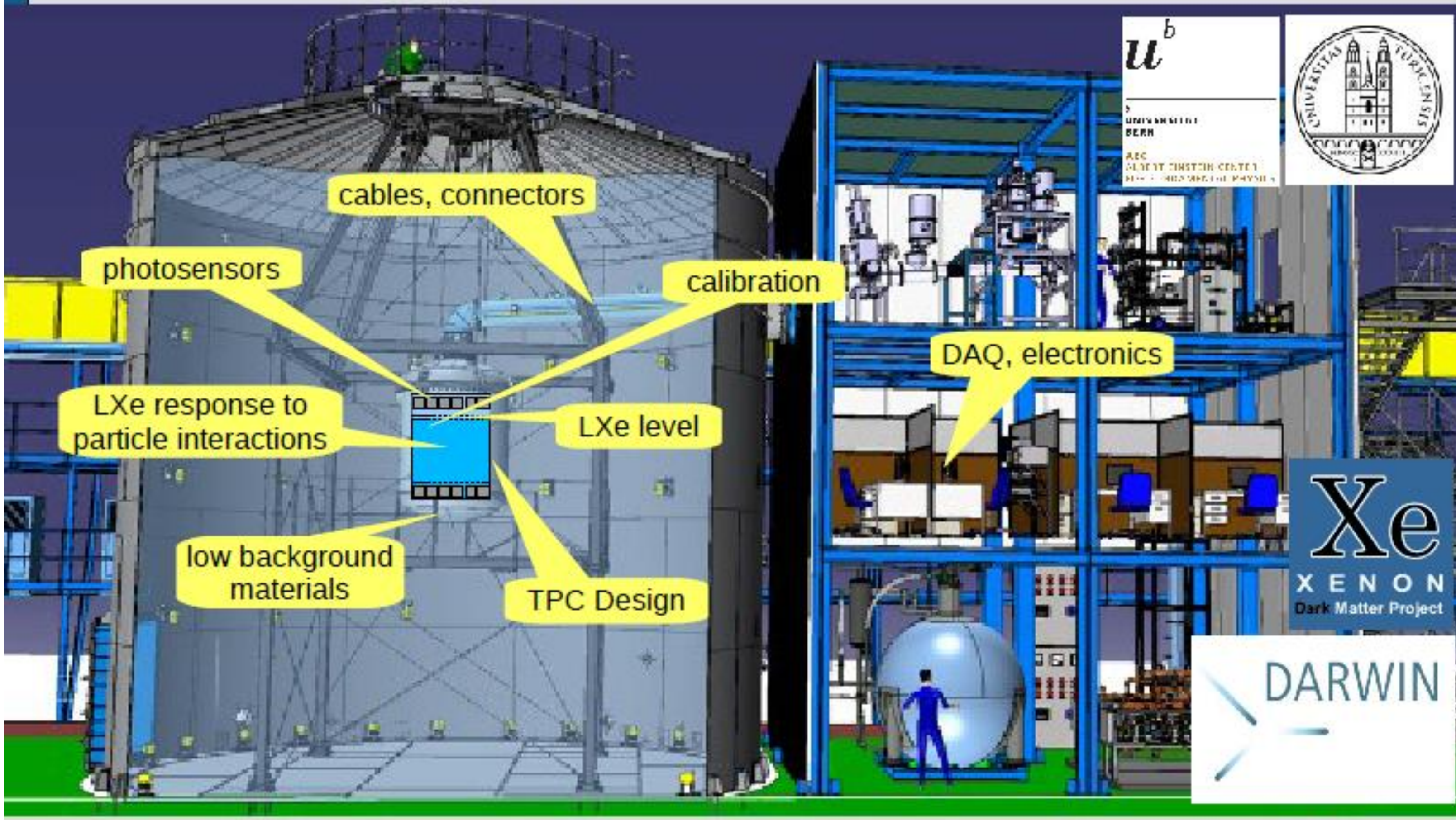
DM, $0\nu\beta\beta$, LArg neutrino detectors.

An amazing assembly of competence in Switzerland.

Legitimate question : are we doing the most of the synergy?
Is action needed to improve? (I frankly do not know the answer)



Summary: R&D on LXe in Switzerland



Questions for discussion

<u>in all fields</u>

-- are we doing the right things and adapting to changes appropriately?

-- if we are following different paths,

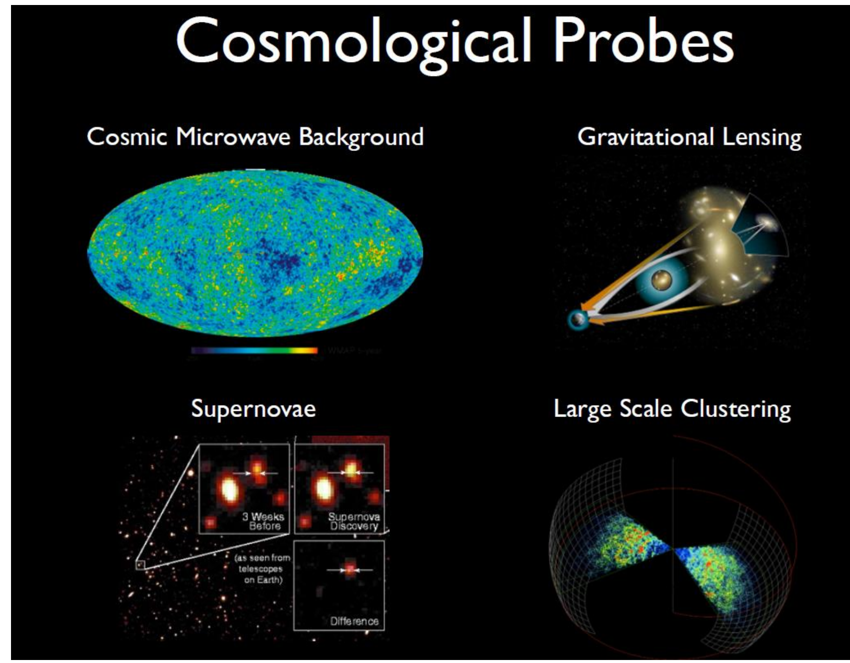
-- are we making sure that all benefits from difference are exploited?

--

COSMOLOGY, NEUTRINOS, DARK MATTER

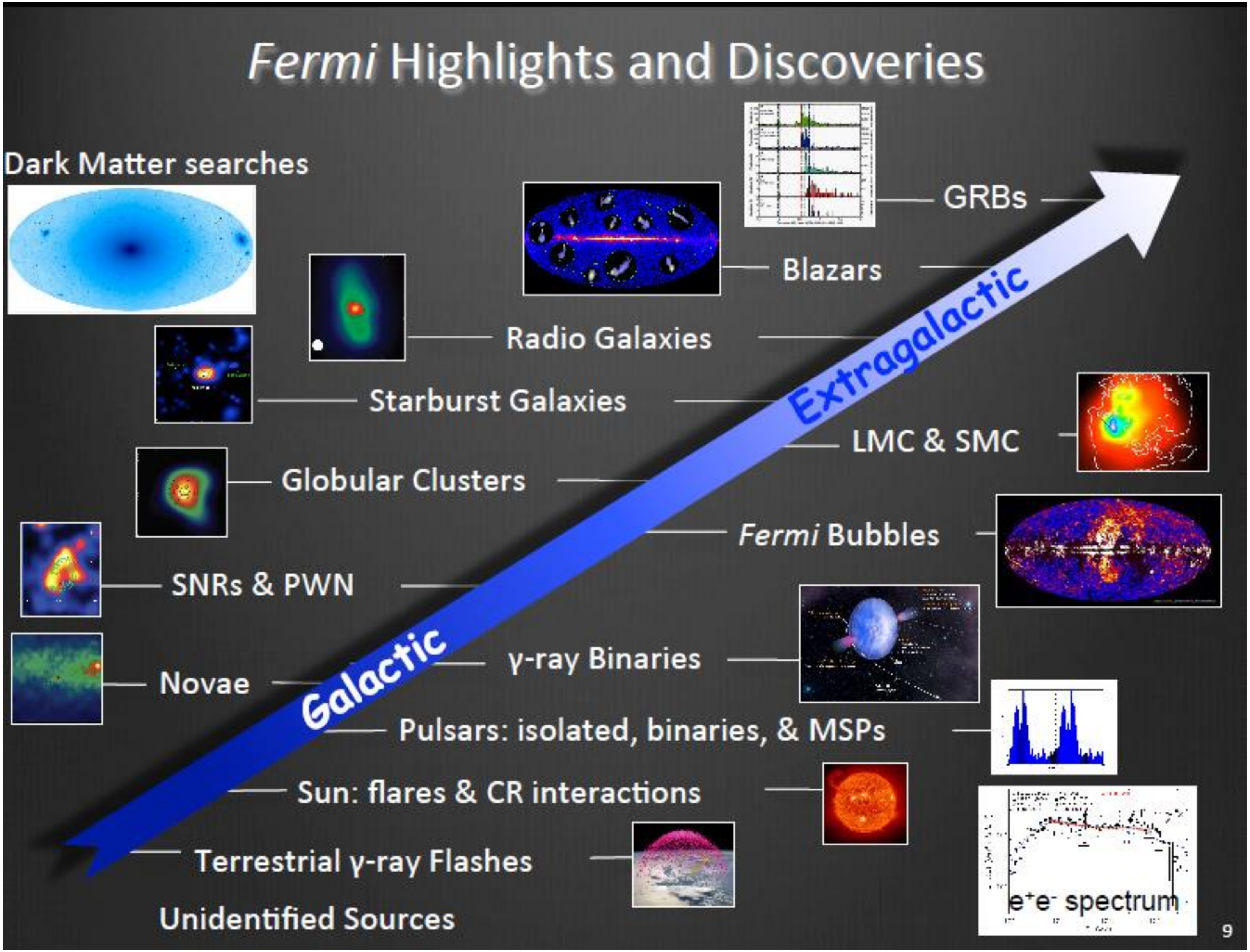
It is amazing to see so much convergence between astrophysical , cosmological and particle physics questions.

	ePlanck+BOSS $\xi(s)$	ePlanck+BOSS $\xi_{\Delta\mu}(s)$	ePlanck + BOSS $\xi_{\Delta\mu}(s)$ +BAO+SN
The ΛCDM model			
h	$0.6824^{+0.0072}_{-0.0072}$	0.6863 ± 0.0075	0.6899 ± 0.0070
$100\Omega_{\rm m}$	$30.22^{+0.94}_{-0.96}$	$29.71^{+0.97}_{-0.96}$	29.24 ± 0.86
Constant dark energy equation of state			
$w_{\rm DE}$	$-1.31^{+0.21}_{-0.16}$	-1.051 ± 0.076	-1.024 ± 0.052
$100\Omega_{\rm m}$	$24.9^{+3.4}_{-2.6}$	28.8 ± 1.6	29.3 ± 1.1
Time-dependent dark energy equation of state			
w_0	$-1.29^{+0.48}_{-0.46}$	$-0.83^{+0.38}_{-0.34}$	-0.95 ± 0.14
w_a	$-0.0^{+1.0}_{-1.1}$	$-0.61^{+0.89}_{-0.96}$	-0.29 ± 0.47
$100\Omega_{\rm m}$	$25.2^{+5.7}_{-6.6}$	$30.9^{+4.1}_{-3.6}$	29.5 ± 1.3
Non-flat models			
$100\Omega_k$	0.07 ± 0.31	0.10 ± 0.29	0.15 ± 0.29
$100\Omega_{\rm m}$	30.18 ± 0.96	$29.60^{+0.99}_{-0.97}$	29.11 ± 0.91
Curvature and dark energy			
$w_{\rm DE}$	$-1.53^{+0.24}_{-0.28}$	-1.05 ± 0.11	$-1.009^{+0.062}_{-0.060}$
$100\Omega_k$	$-0.38^{+0.24}_{-0.28}$	0.02 ± 0.43	-0.14 ± 0.33
$100\Omega_{\rm m}$	$22.0^{+3.2}_{-4.9}$	28.9 ± 2.0	29.4 ± 1.2
Massive neutrinos			
$\sum m_\nu$	< 0.23 eV (95% CL)	< 0.24 eV (95% CL)	< 0.23 eV (95% CL)
f_ν	< 0.017 (95% CL)	< 0.019 (95% CL)	< 0.017 (95% CL)
Massive neutrinos and dark energy			
$\sum m_\nu$	< 0.49 eV (95% CL)	< 0.47 eV (95% CL)	< 0.33 eV (95% CL)
$w_{\rm DE}$	$-1.49^{+0.24}_{-0.30}$	-1.13 ± 0.12	-1.046 ± 0.063
Additional relativistic degrees of freedom			
$N_{\rm eff}$	3.35 ± 0.27	3.31 ± 0.27	3.30 ± 0.27
$100\Omega_{\rm m}$	29.7 ± 1.0	29.2 ± 1.1	29.1 ± 1.0
Deviations from general relativity			
γ	-	0.69 ± 0.15	0.69 ± 0.15
$100\Omega_{\rm m}$	-	$29.76^{+0.93}_{-0.90}$	29.62 ± 0.89
Dark energy and modified gravity			
γ	-	0.88 ± 0.22	0.75 ± 0.17
$w_{\rm DE}$	-	-1.15 ± 0.11	-1.055 ± 0.057



-- Likely to accelerate in coming years

-- Particle physics needs to tackle particle physics questions so that cosmology can concentrate on cosmological questions!


Fermi Highlights and Discoveries
Dark Matter searches
GRBs
Blazars
Radio Galaxies
Starburst Galaxies
Extragalactic
LMC & SMC
Globular Clusters
Fermi Bubbles
SNRs & PWN
γ-ray Binaries
Novae
Galactic
Pulsars: isolated, binaries, & MSPs
Sun: flares & CR interactions
Terrestrial γ-ray Flashes
e+e- spectrum
Unidentified Sources
9

OUTLOOK

The last few years have seen many new and exciting findings.

While it may appear that the Particles Standard Model is complete, more discoveries are necessary if one is to explain Dark Matter, the Baryon Asymmetry and the neutrino masses etc.

It is intriguing to note the importance of unknown neutrino physics in this context.

It is not clear at which scale (at which mass and which couplings) these discoveries will take place.

There are very definite measurements to do (mass hierarchy, leptonic CPV, $0\nu\beta\beta$ etc.) but a broad exploration (such as provided by astrophysical experiments) is both fascinating and may lead us to the solutions of these grand mysteries.


MERCI TERESA!