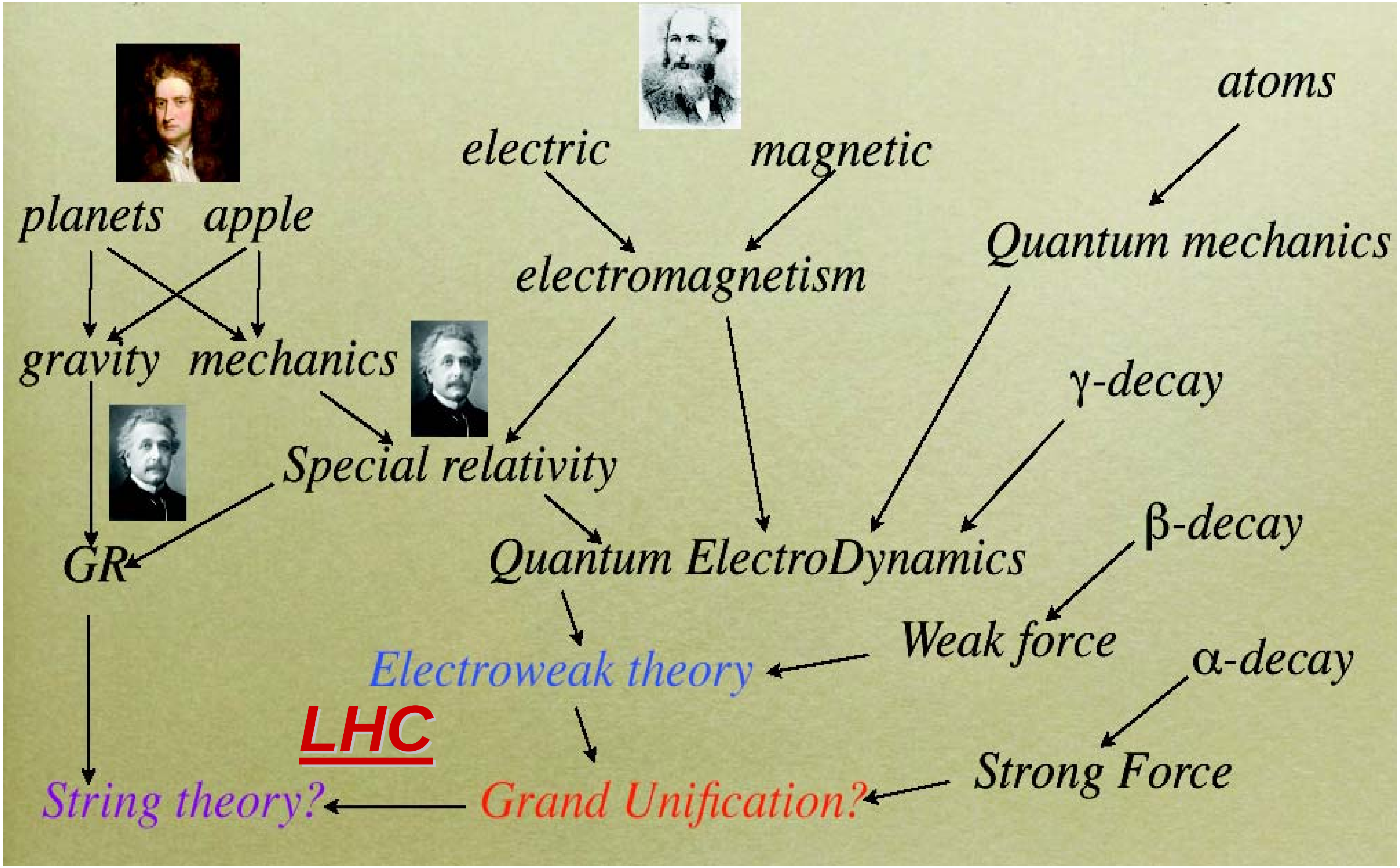
FUNDAMENTAL PHYSICS ROADMAP WORKSHOP,
ESTEC, Noordwijk, JAN. 21, 2010

WHAT CAN WE LEARN ABOUT FUNDAMENTAL PHYSICS FROM ASTROPARTICLE PHYSICS?

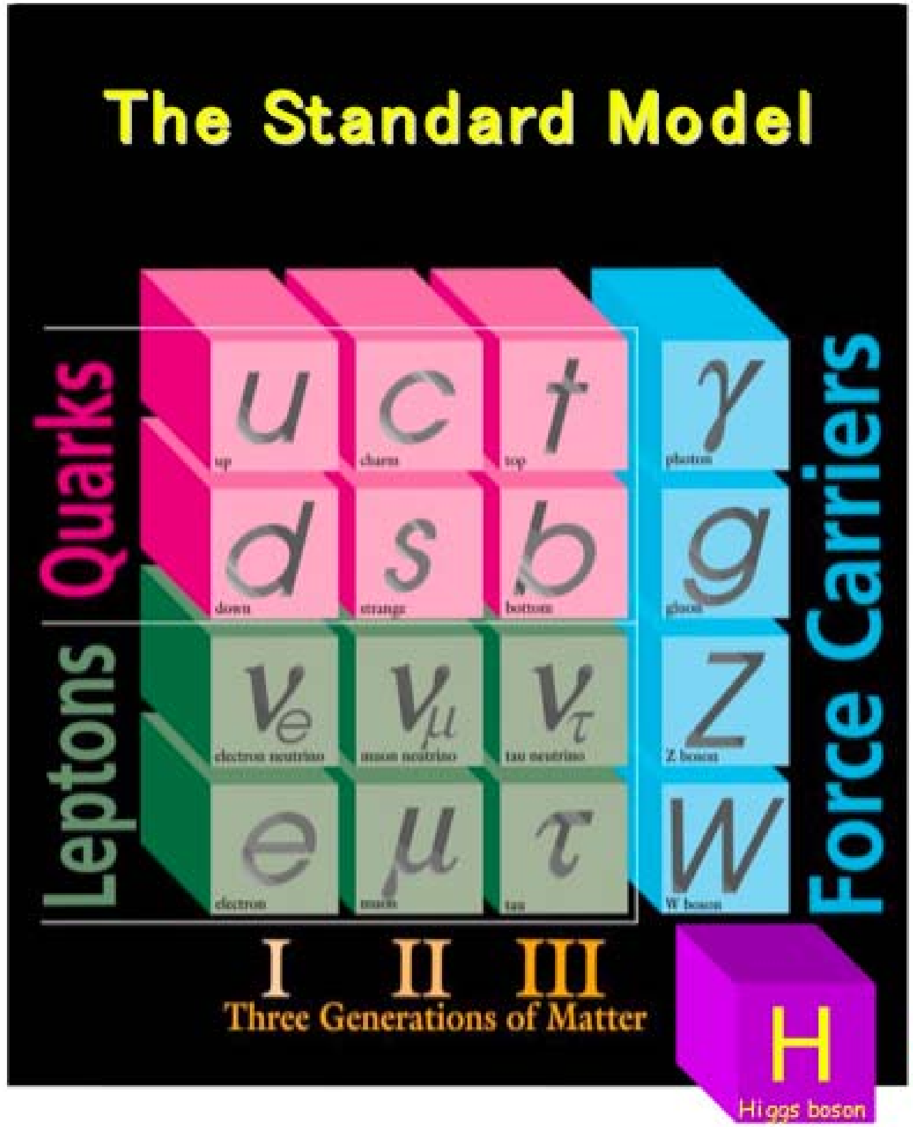
Antonio Masiero
Univ. of Padova
and
INFN, Padova

UNIFICATION OF FUNDAMENTAL INTERACTIONS

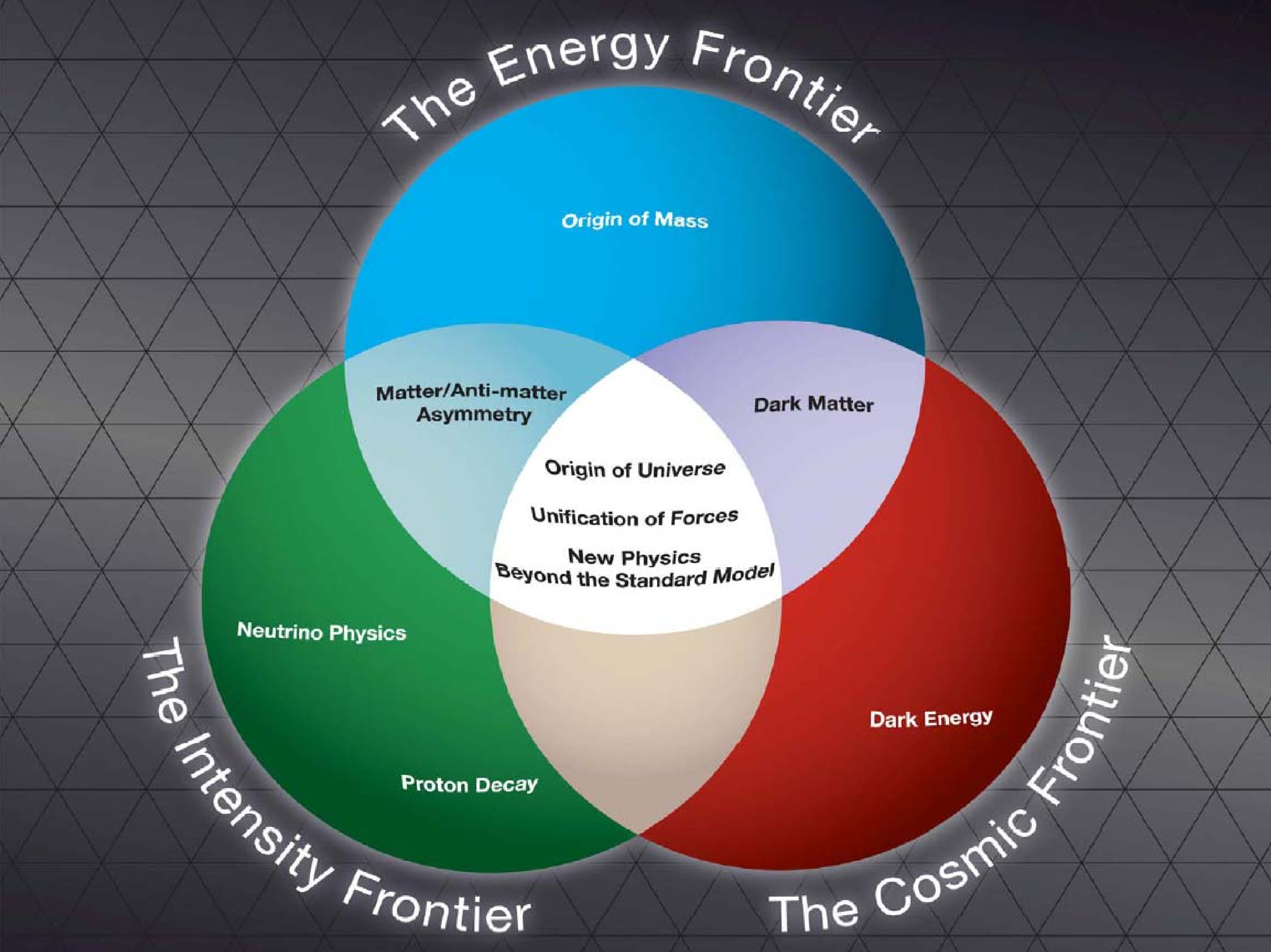


Gravity

?


The Standard Model
Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Leptons
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
e
electron
μ
muon
τ
tau
Force Carriers
γ
photon
g
gluon
Z
Z boson
W
W boson
I II III
Three Generations of Matter
H
Higgs boson

?


The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Proton Decay
Dark Energy
The Intensity Frontier
The Cosmic Frontier

MICRO

PARTICLE PHYSICS

GWS STANDARD MODEL

MACRO

COSMOLOGY

HOT BIG BANG
STANDARD MODEL

HAPPY MARRIAGE
Ex: NUCLEOSYNTHESIS

BUT ALSO

POINTS OF
FRICTION

-COSMIC MATTER-ANTIMATTER ASYMMETRY

-INFLATION

- DARK MATTER + DARK ENERGY

“OBSERVATIONAL” EVIDENCE FOR NEW PHYSICS BEYOND THE **(PARTICLE PHYSICS)** STANDARD MODEL

SM FAILS TO GIVE RISE TO A SUITABLE COSMIC MATTER-ANTIMATTER ASYMMETRY

:

- **NOT ENOUGH CP VIOLATION IN THE SM**

  NEED FOR ***NEW SOURCES OF CPV IN ADDITION TO THE PHASE PRESENT IN THE CKM MIXING MATRIX***

- FOR M_{HIGGS} > 80 GeV THE ELW. PHASE TRANSITION OF THE SM IS A SMOOTH CROSSOVER

NEED *NEW PHYSICS BEYOND SM*. IN PARTICULAR, FASCINATING POSSIBILITY: THE ENTIRE MATTER IN THE UNIVERSE ORIGINATES FROM THE SAME MECHANISM RESPONSIBLE FOR THE EXTREME SMALLNESS OF NEUTRINO MASSES

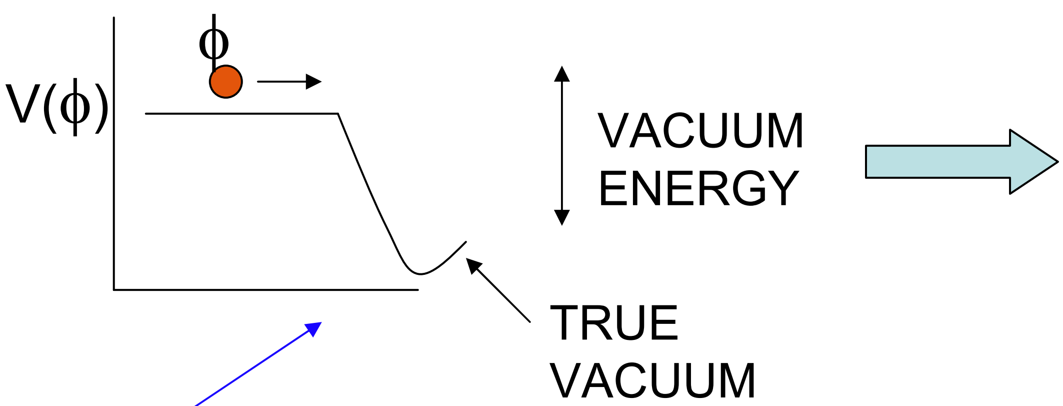
INFLATION

SEVERE COSMOGICAL PROBLEMS

- **CAUSALITY** (isotropy of CMBR)
- **FLATNESS** (Ω close to 1 today)
- **AGE OF THE UNIV.**
- **PRIMORDIAL MONOPOLES**

COMMON SOLUTION FOR THESE PROBLEMS

VERY FAST (EXPONENTIAL) EXPANSION IN THE UNIV.



Ω dominated by vacuum en.

NO WAY TO GET AN "INFLATIONARY SCALAR POTENTIAL" IN THE STANDARD MODEL

NO ROOM IN THE PARTICLE PHYSICS STANDARD MODEL FOR INFLATION !

$V=\mu^2\,\phi^2 + \lambda\phi^4 \longrightarrow$ no inflation

Need to extend the SM scalar potential

Ex: GUT’s, SUSY GUT’s,…

ENERGY SCALE OF “INFLATIONARY PHYSICS”:

LIKELY TO BE $\gg M_W$

DIFFICULT BUT NOT IMPOSSIBLE TO OBTAIN ELECTROWEAK INFLATION IN SM EXTENSIONS

For some inflationary models → large amount of primordial gravitational waves

Present “Observational” Evidence for New Physics

- **NEUTRINO MASSES**
- **DARK MATTER**
- **MATTER-ANTIMATTER ASYMMETRY**
- **INFLATION**

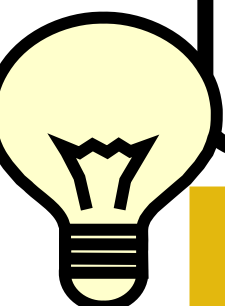
The Energy Scale from the “Observational” New Physics

neutrino masses

dark matter

baryogenesis

inflation



NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

The Energy Scale from the “Theoretical” New Physics

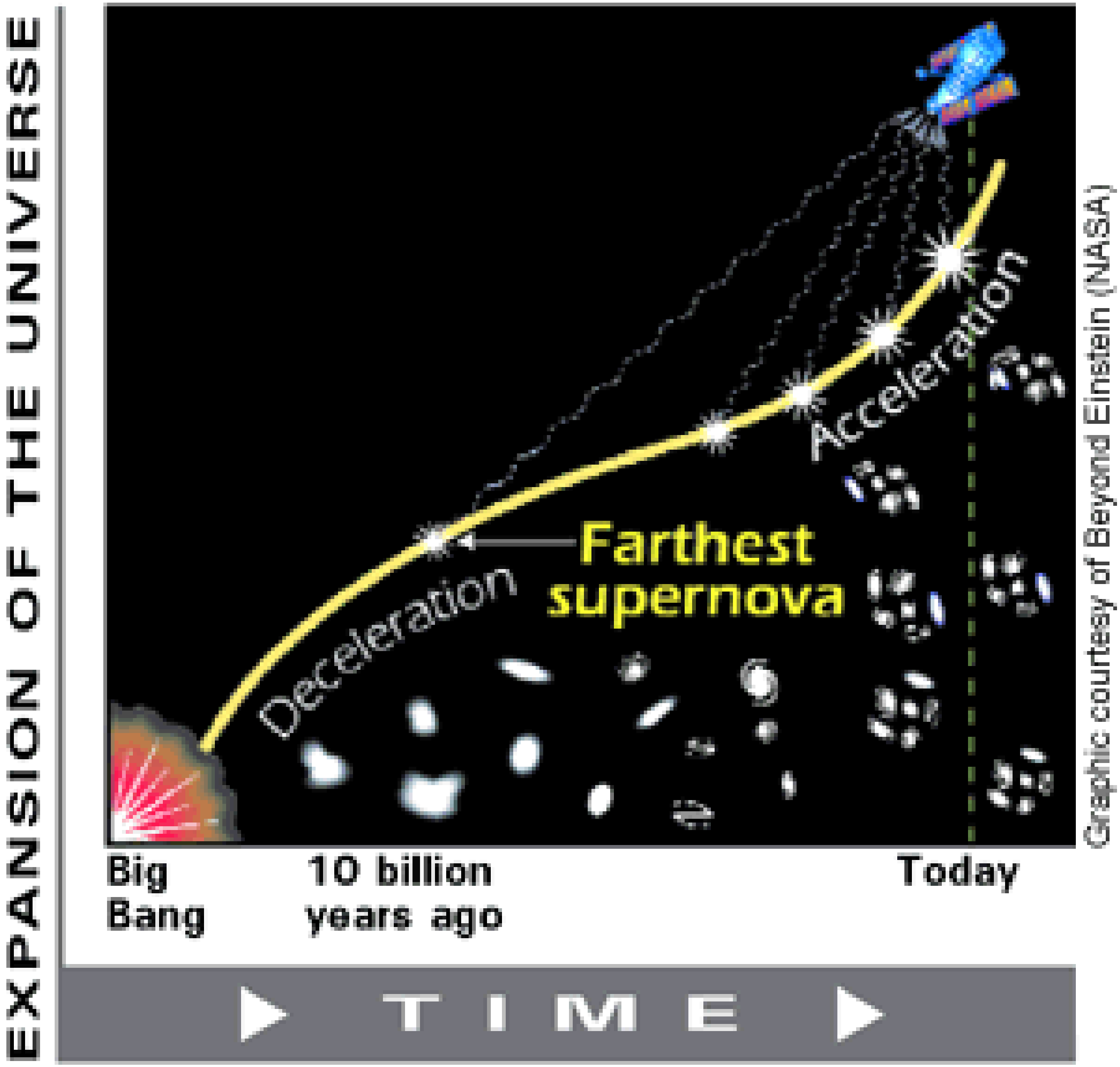
☆ ☆ ☆ Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale +

☆ CORRECT GRAND UNIFICATION “CALLS” FOR NEW PARTICLES AT THE ELW. SCALE

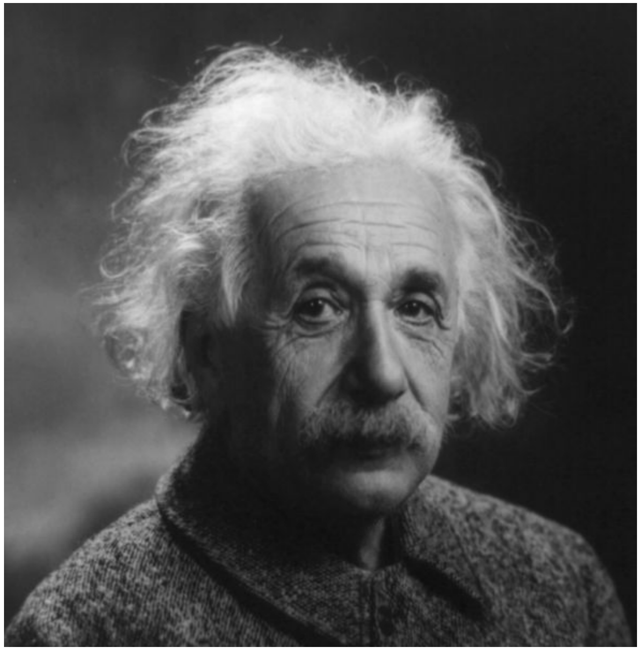
On the Energetic Budget of the Universe

- *Stars and galaxies are only ~0.5%*
- *Neutrinos are ~0.1–1.5%*
- *Rest of ordinary matter*
  (electrons, protons & neutrons) are 4.4%
- *Dark Matter 23%*
- *Dark Energy 73%*
- *Anti-Matter 0%*
- *Higgs Bose-Einstein condensate*
  ~10^{62}%??

Courtesy of H. Murayama



EXPANSION OF THE UNIVERSE
Farthest supernova
Deceleration
Acceleration
Big Bang
10 billion years ago
Today
TIME
Graphic courtesy of Beyond Einstein (NASA)



Albert Einstein (1879-1955)

1916. №. 7.

ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

1. *Die Grundlage der allgemeinen Relativitätstheorie;* *von A. Einstein.*

Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als „Relativitätstheorie ich im folgenden zu Relativitätstheorie' Verallgemeinerung leichtert durch die theorie durch Mir matiker zuerst die

Equazione del Campo di Gravitazione

$$R_{ik} - \frac{1}{2} g_{ij} R + \Lambda g_{jk} = \frac{8\pi G}{c^4} T_{jk}$$

Costante Cosmologica

IS THE COSMOLOGICAL CONSTANT THE SOURCE OF THE DARK ENERGY OG THE UNIVERSE AND THE CAUSE OF ITS ACCELERATED EXPANSION?

DM → NEW PHYSICS BEYOND THE (PARTICLE PHYSICS) SM - if Newton is right at scales>size of the Solar System

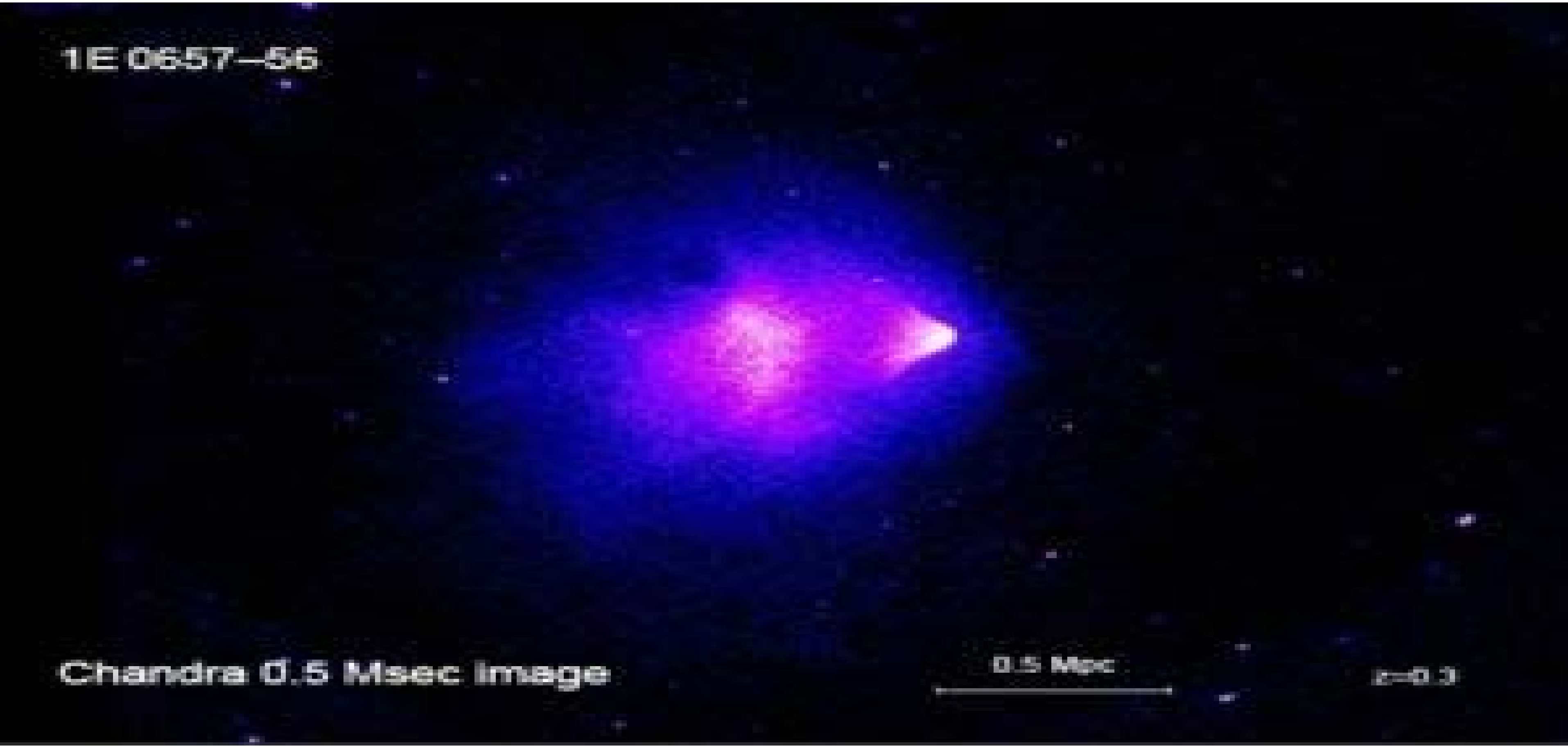
- $\Omega_{DM} = 0.233 \pm 0.013$ *
- $\Omega_{baryons} = 0.0462 \pm 0.0015$ **

*from CMB (5 yrs. of WMAP) + Type I Supernovae + Baryon Acoustic Oscillations (BAO)

**CMB + TypeI SN + BAO in agreement with Nucleosynthesis (BBN)

The **BULLET CLUSTER**: **two colliding clusters of galaxies**

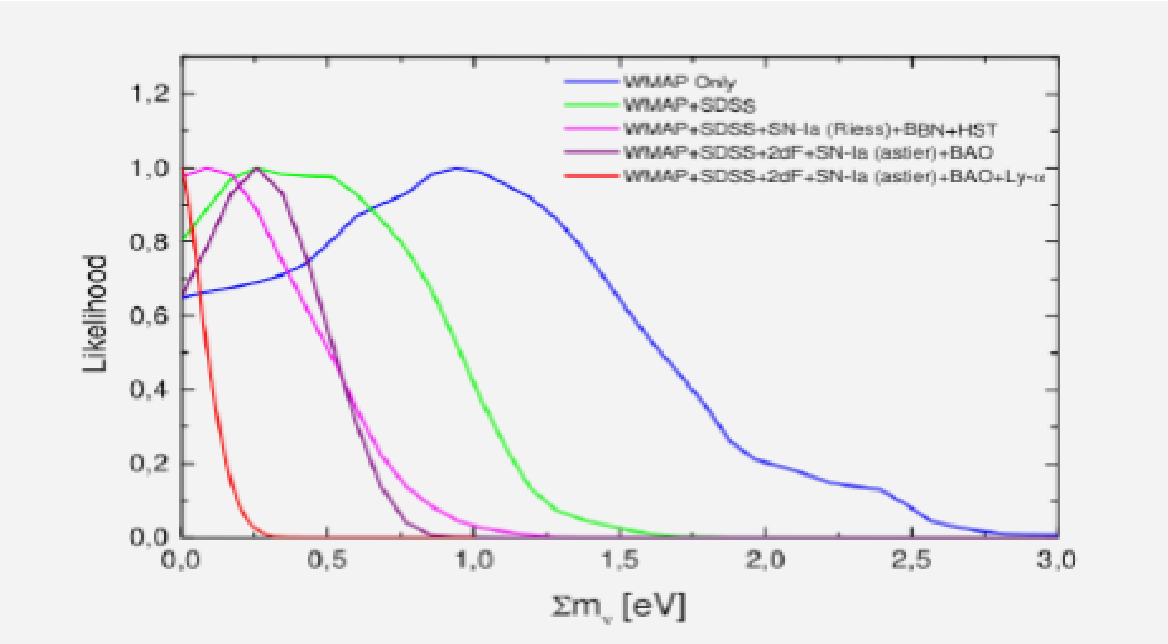
Stars, galaxies and putative DM behave differently during collision, allowing for them to be studied separately. In **MOND** the lensing is expected to follow the baryonic matter, i.e. the X-ray gas. However the lensing is strongest in two separated regions near the visible galaxies → **most of the mass in the cluster pair is in the form of collisionless DM**



DM: the most impressive evidence at the "quantitative" and "qualitative" levels of **New Physics beyond SM**

- QUANTITATIVE: Taking into account the latest WMAP data which in combination with LSS data provide stringent bounds on Ω_{DM} and Ω_B $\longrightarrow$ **EVIDENCE FOR NON-BARYONIC DM AT MORE THAN 10 STANDARD DEVIATIONS!! THE SM DOES NOT PROVIDE ANY CANDIDATE FOR SUCH NON-BARYONIC DM**

- QUALITATIVE: it is NOT enough to provide a mass to neutrinos to obtain a valid DM candidate; LSS formation requires DM to be COLD $\longrightarrow$ **NEW PARTICLES NOT INCLUDED IN THE SPECTRUM OF THE FUNDAMENTAL BUILDING BLOCKS OF THE SM !**



Cosmological Bounds on the sum of the masses of the 3 neutrinos from increasingly rich samples of data sets

Case	Cosmological data set	Σ bound (2σ)
1	WMAP	< 2.3 eV
2	WMAP + SDSS	< 1.2 eV
3	WMAP + SDSS + SN_{Riess} + HST + BBN	< 0.78 eV
4	CMB + LSS + SN_{Astier}	< 0.75 eV
5	CMB + LSS + SN_{Astier} + BAO	< 0.58 eV
6	CMB + LSS + SN_{Astier} + Ly-α	< 0.21 eV
7	CMB + LSS + SN_{Astier} + BAO + Ly-α	< 0.17 eV

Fogli et al., Phys. Rev. D 75, 053001 (2007)

***THE DM ROAD TO NEW PHYSICS BEYOND THE SM*:**

IS **DM** A PARTICLE OF THE ***NEW PHYSICS AT THE ELECTROWEAK ENERGY SCALE*** **?**

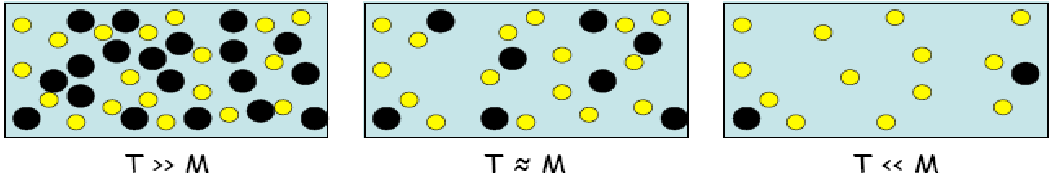
THE "*WIMP MIRACLE*"

Bergstrom

Table 1. Properties of various Dark Matter Candidates

Type	Particle Spin	Approximate Mass Scale
Axion	0	μeV-meV
Inert Higgs Doublet	0	50 GeV
Sterile Neutrino	1/2	keV
Neutralino	1/2	10 GeV - 10 TeV
Kaluza-Klein UED	1	TeV

Many possibilities for DM candidates, but WIMPs are really special: peculiar coincidence between particle physics and cosmology parameters to provide a VIABLE DM CANDIDATE AT THE ELW. SCALE



WIMPS (Weakly Interacting Massive Particles)

#χ exp(-mχ/T$_\chi$)

#χ does not change any more

#χ~#γ m_χ

$T_{decoupl.}$ typically ~ m_χ /20

Ω_χ depends on particle physics ($\sigma_{annih.}^{\chi}$) and "cosmological" quantities (H, T_0, …

$$\Omega_\chi h^2 \simeq \frac{10^{-3}}{\underbrace{\langle(\sigma_{annih.}) V \chi\rangle}_{\sim \alpha^2 / M^2_\chi} \ \mathrm{TeV}^2}$$

From $T^0 M_{Planck}$

COSMO – PARTICLE CONSPIRACY

$\Omega\chi h^2$ in the range 10^{-2} -10^{-1} to be cosmologically interesting (for DM)

$m\chi \sim 10^2 - 10^3$ GeV (weak interaction) $\Omega\chi h^2 \sim 10^{-2}$ -10^{-1} !!!

THERMAL RELICS (WIMP in thermodyn.equilibrium with the plasma until $T_{decoupl}$)

STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) **ENLARGEMENT OF THE SM**	(x^{μ}, θ)	(x^{μ}, j^{i})	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) **SELECTION RULE**	**R-PARITY LSP**	**KK-PARITY LKP**	**T-PARITY LTP**
→ **DISCRETE SYMM.**	Neutralino spin 1/2	spin1	spin0
→ **STABLE NEW PART.**	↓	↓	↓
3) FIND REGION (S) PARAM. SPACE WHERE THE “L” NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV *	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

* But abandoning gaugino-masss unif. → Possible to have m_{LSP} down to 7 GeV

Bottino, Donato, Fornengo, Scopel

SUSY & DM : a successful marriage

- Supersymmetrizing the SM does not lead necessarily to a stable SUSY particle to be a DM candidate.
- However, the mere SUSY version of the SM is known to lead to a too fast p-decay. Hence, necessarily, the SUSY version of the SM has to be **supplemented with some additional (ad hoc?) symmetry to prevent the p-decay catastrophe.**
- Certainly the simplest and maybe also the most attractive solution is **to impose the discrete R-parity** symmetry
- MSSM + R PARITY $\longrightarrow$ LIGHTEST SUSY PARTICLE (LSP) IS STABLE .
- The LSP can constitute an interesting DM candidate in several interesting realizations of the MSSM (i.e., with different SUSY breaking mechanisms including gravity, gaugino, gauge, anomaly mediations, and in various regions of the parameter space).

DM ⟺ THE ORIGIN OF THE SUSY BREAKING

HIDDEN SECTOR SUSY BREAKING AT SCALE $\sqrt{F}$

DM NEUTRALINO

$F = M_W M_{Pl}$

GRAVITY

$M_{gravitino}$ $\sim F/M_{Pl} \sim$

$(10^2 - 10^3)$ GeV

MESSENGERS

DM GRAVITINO

$F = (10^5 - 10^6)$ GeV

GAUGE INTERACTIONS

$M_{gravitino}$ $\sim F/M_{Pl} \sim$

$(10^2 - 10^3)$ eV

OBSERVABLE SECTOR

SM + superpartners

MSSM : minimal content of superfields

HUMAN PRODUCTION OF WIMPs

WIMPS HYPOTHESIS

DM made of particles with mass 10Gev - 1Tev

ELW scale

With WEAK INTERACT.

LHC, ILC may PRODUCE WIMPS

WIMPS escape the detector

→ MISSING ENERGY SIGNATURE

POSSIBILITY TO CREATE OURSELVES IN OUR ACCELERATORS THOSE DM PARTICLES WHICH ARE PART OF THE RELICS OF THE PRIMORDIAL PLASMA AND CONSTITUTE 1/4 OF THE WHOLE ENERGY IN THE UNIVERSE

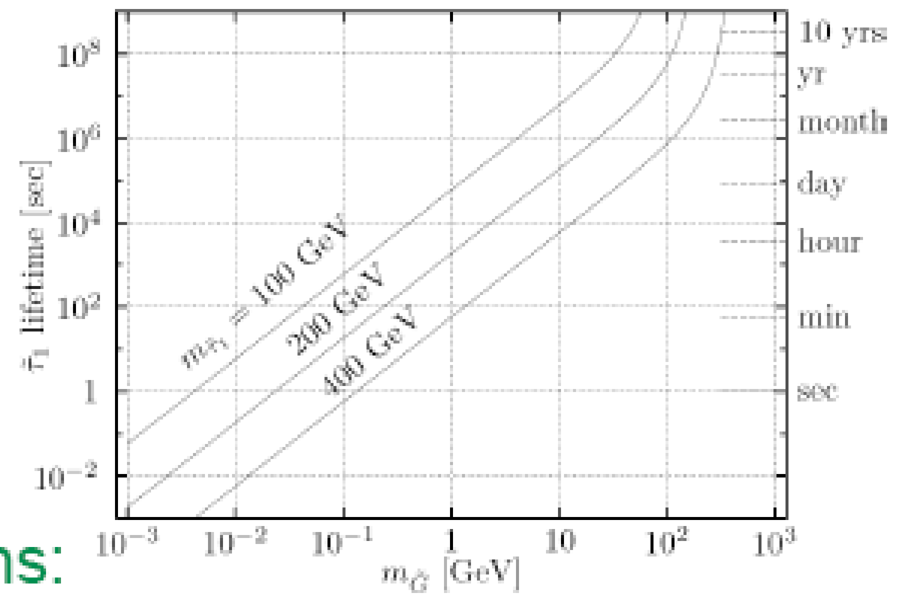
Collider experiments do not distinguish between stable ($\tau > 10^{17}$ s) and long-lived ($\tau > 10^{-7}$ s) particle

$$P' \to P \;\Rightarrow\; \Omega_{P'} = \frac{m_{P'}}{m_P}\Omega_P$$

Gravitino

Long-lived charged particle at the LHC ($\tilde{\tau} \to \tau \tilde{G}$)

Hamaguchi-Kuno-Nakaya-Nojiri; Feng-Smith; Ellis-Raklev-Øye; Hamaguchi-Nojiri-de Roeck



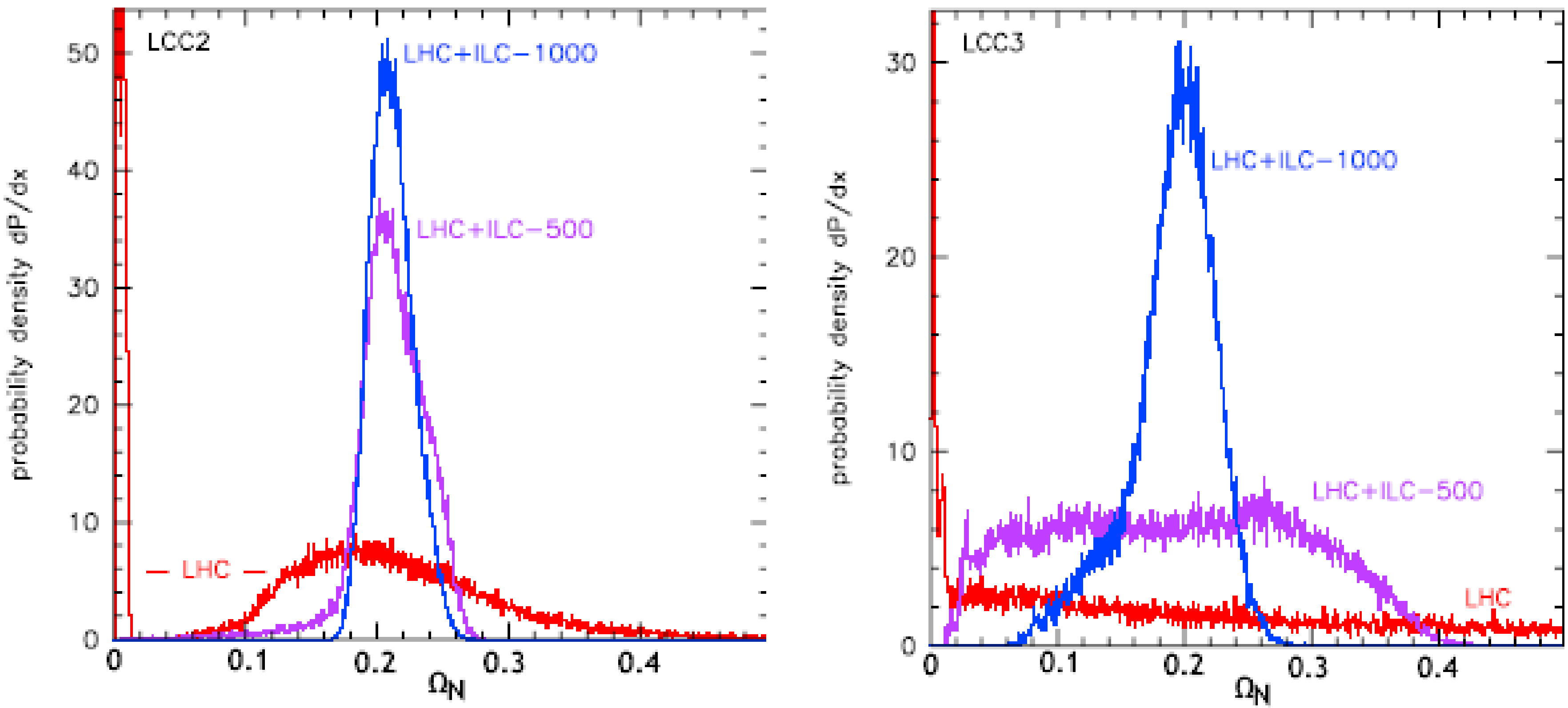
Distinctive ToF and energy loss signatures

"Stoppers" in ATLAS/CMS caverns:

- Measure position and time of stopped $\tilde{\tau}$; time and energy of τ
- Reconstruct susy scale and gravitational coupling

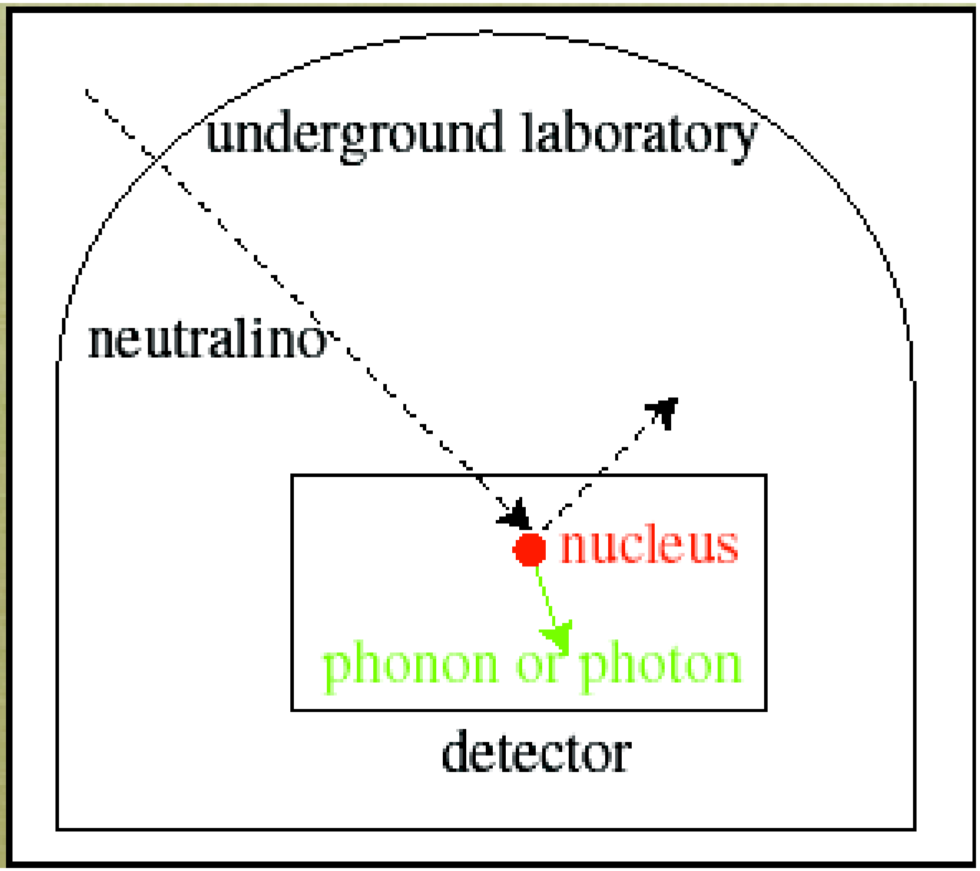
G. GIUDICE

PREDICTION OF Ω DM FROM LHC AND ILC FOR TWO DIFFERENT SUSY PARAMETER SETS

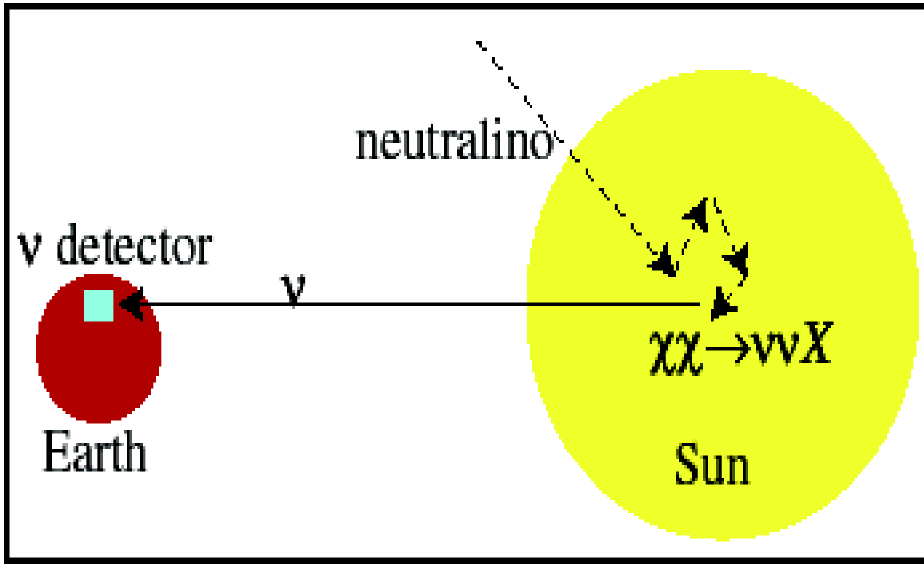


BALTZ, BATTAGLIA, PESKIN, WIZANSKY

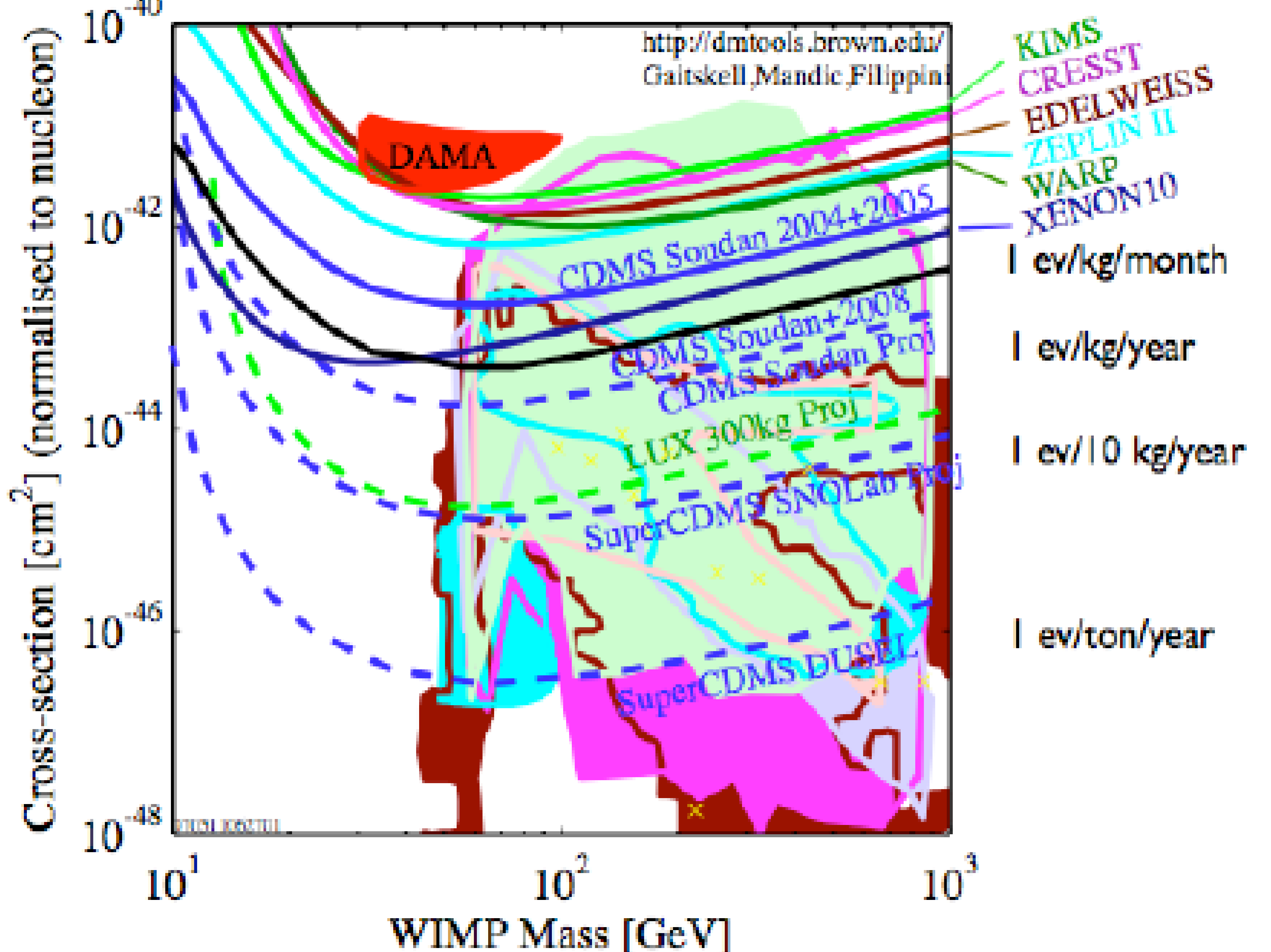
HUNTING FOR DARK MATTER



DIRECT DM SEARCHES



INDIRECT DM SEARCHES



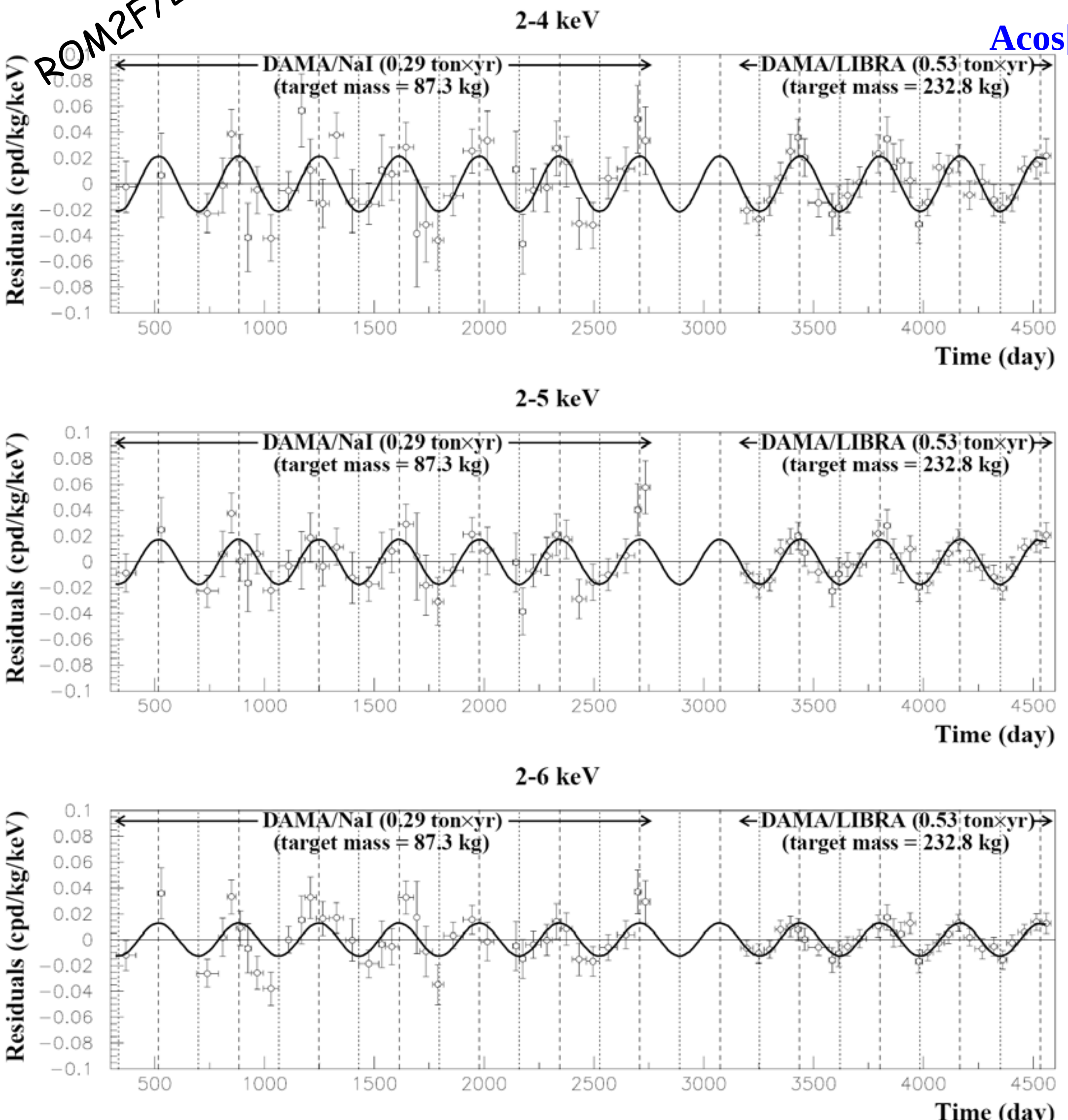
http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
DAMA
KIMS
CRESST
EDELWEISS
ZEPLIN II
WARP
XENON10
CDMS Soudan 2004+2005
CDMS Soudan+2008
CDMS Soudan Proj
LUX 300kg Proj
SuperCDMS SNOLab Proj
SuperCDMS DUSEL
1 ev/kg/month
1 ev/kg/year
1 ev/10 kg/year
1 ev/ton/year
Cross-section [cm^2] (normalised to nucleon)
WIMP Mass [GeV]
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^{1}
10^{2}
10^{3}

Model Independent Annual Modulation Result

DAMA/NaI (7 years) + DAMA/LIBRA (4 years) Total exposure: 300555 kg×day = 0.82 ton×yr

ROM2F/2008/07

experimental single-hit residuals rate vs time and energy



Acos[ω(t-t_0)] ; continuous lines: t_0 = 152.5 d, T = 1.00 y

2-4 keV

A=(0.0215±0.0026) cpd/kg/keV

χ^2/dof = 51.9/66 **8.3 σ C.L.**

Absence of modulation? No

χ^2/dof=117.7/67 ⇒ P(A=0) = 1.3×10^{-4}

2-5 keV

A=(0.0176±0.0020) cpd/kg/keV

χ^2/dof = 39.6/66 **8.8 σ C.L.**

Absence of modulation? No

χ^2/dof=116.1/67 ⇒ P(A=0) = 1.9×10^{-4}

2-6 keV

A=(0.0129±0.0016) cpd/kg/keV

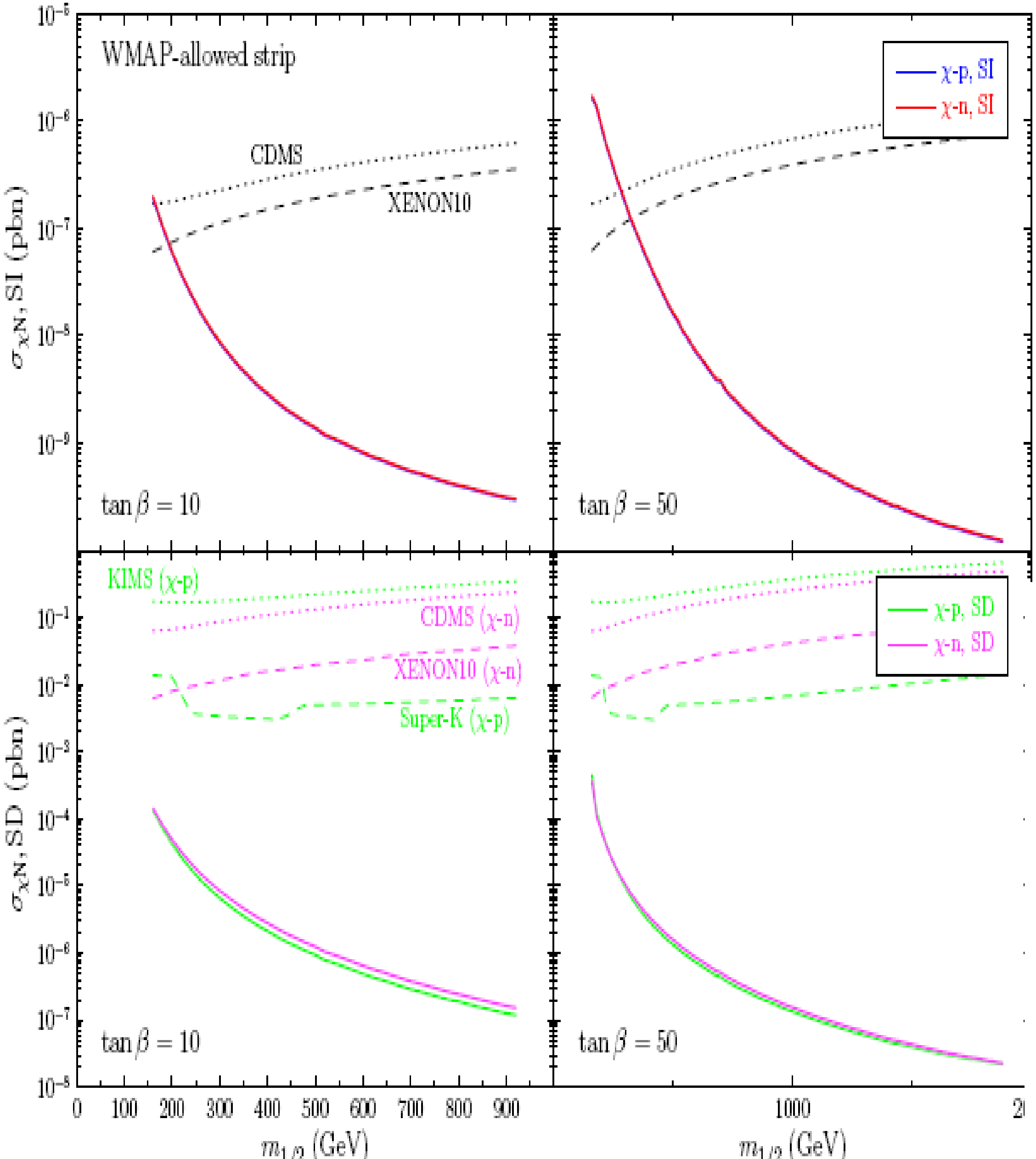
χ^2/dof = 54.3/66 **8.2 σ C.L.**

Absence of modulation? No

χ^2/dof=116.4/67 ⇒ P(A=0) = 1.8×10^{-4}

The data favor the presence of a modulated behavior with proper features at 8.2σ C.L.

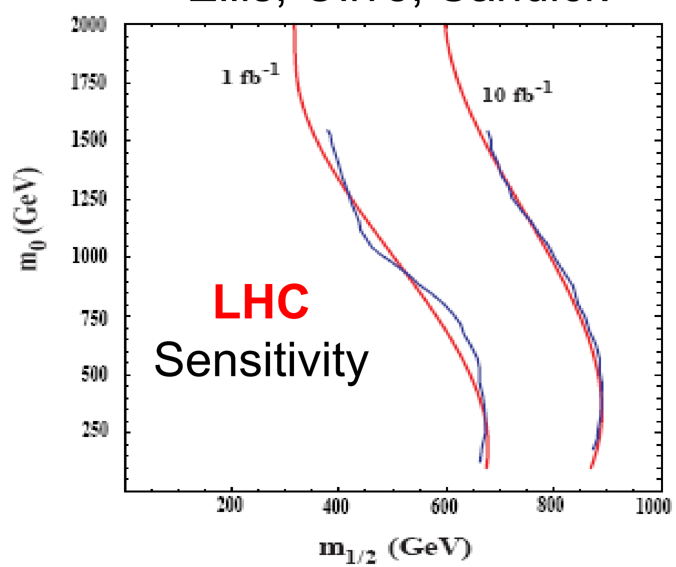
Neutralino-nucleon scattering cross sections along the WMAP-allowed coannihilation strip for tanbeta=10 and coannihilation/funnel strip for tanbeta=50 using the hadronic parameters

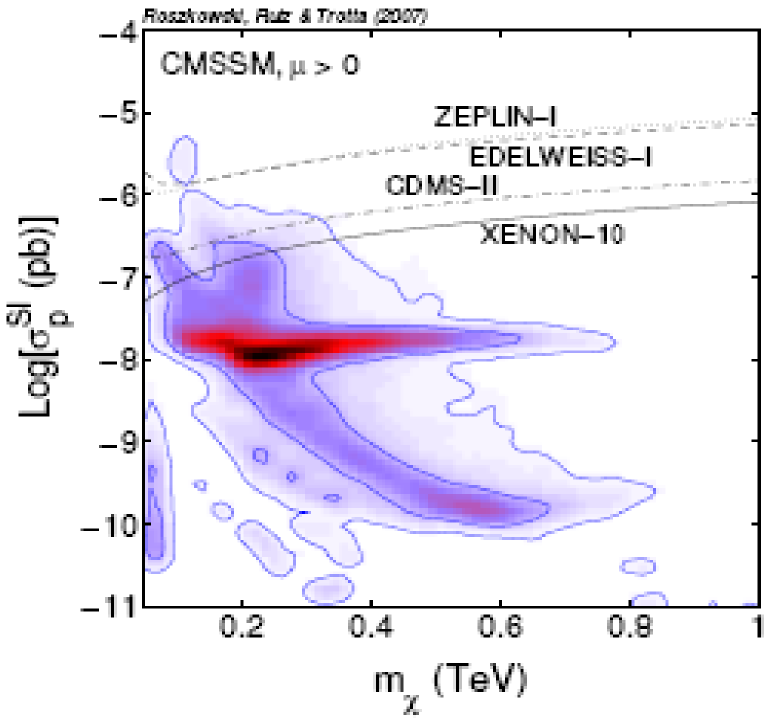


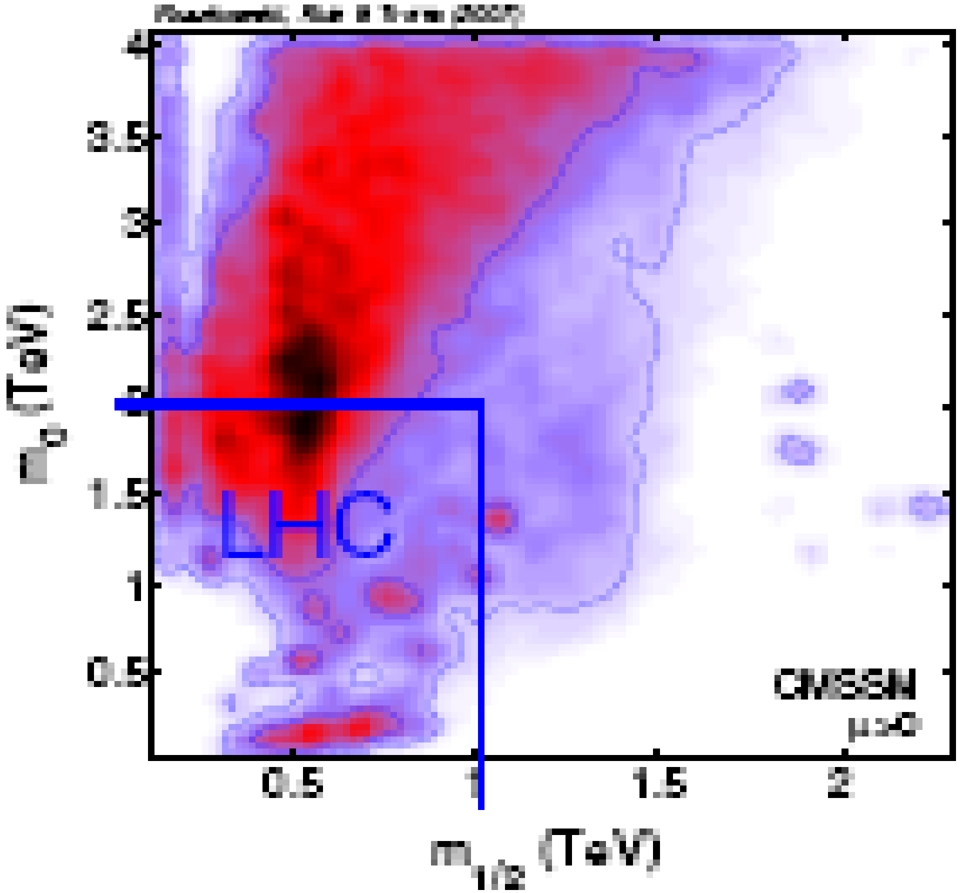
ELLIS. OLIVE. SAVAGE

m_u/m_d	0.553	$\pm$	0.043
m_d	5	$\pm$	2 MeV
m_s/m_d	18.9	$\pm$	0.8
m_c	1.25	$\pm$	0.09 GeV
m_b	4.20	$\pm$	0.07 GeV
m_t	171.4	$\pm$	2.1 GeV
σ_0	36	$\pm$	7 MeV
$\Sigma_{\pi N}$	64	$\pm$	8 MeV
$a_3^{(p)}$	1.2695	$\pm$	0.0029
$a_8^{(p)}$	0.585	$\pm$	0.025
$\Delta_s^{(p)}$	-0.09	$\pm$	0.03

Ellis, Olive, Sandick







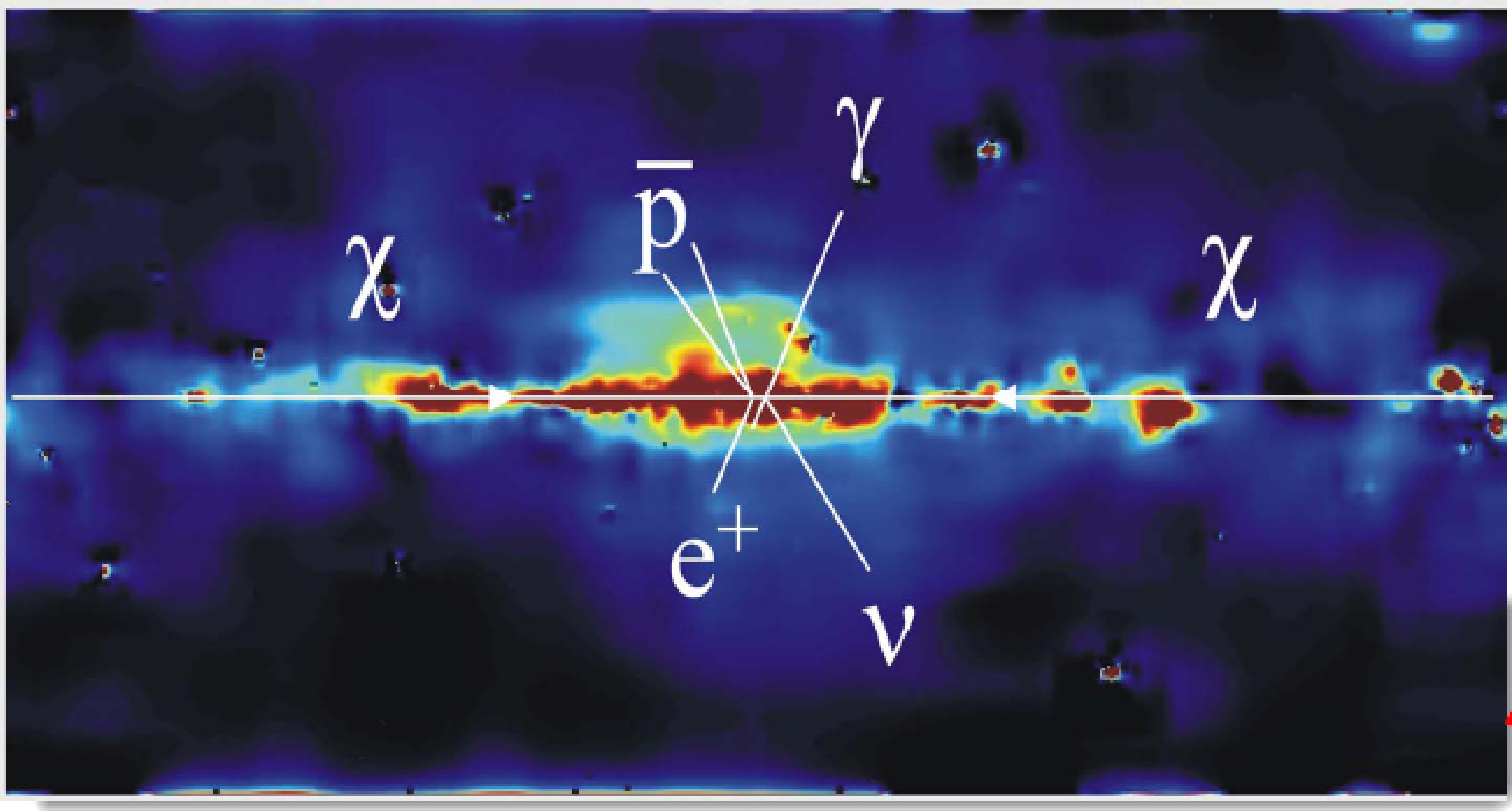
ultimately: "1 tonne" detectors:

$\sigma_p^{SI} \lesssim 10^{-10}$ pb

will cover all 68% region

DM INDIRECT DETECTION

- WIMP-WIMP annihilation in the galactic halos may be detected through production of γ, neutrinos, anti-matter.



?

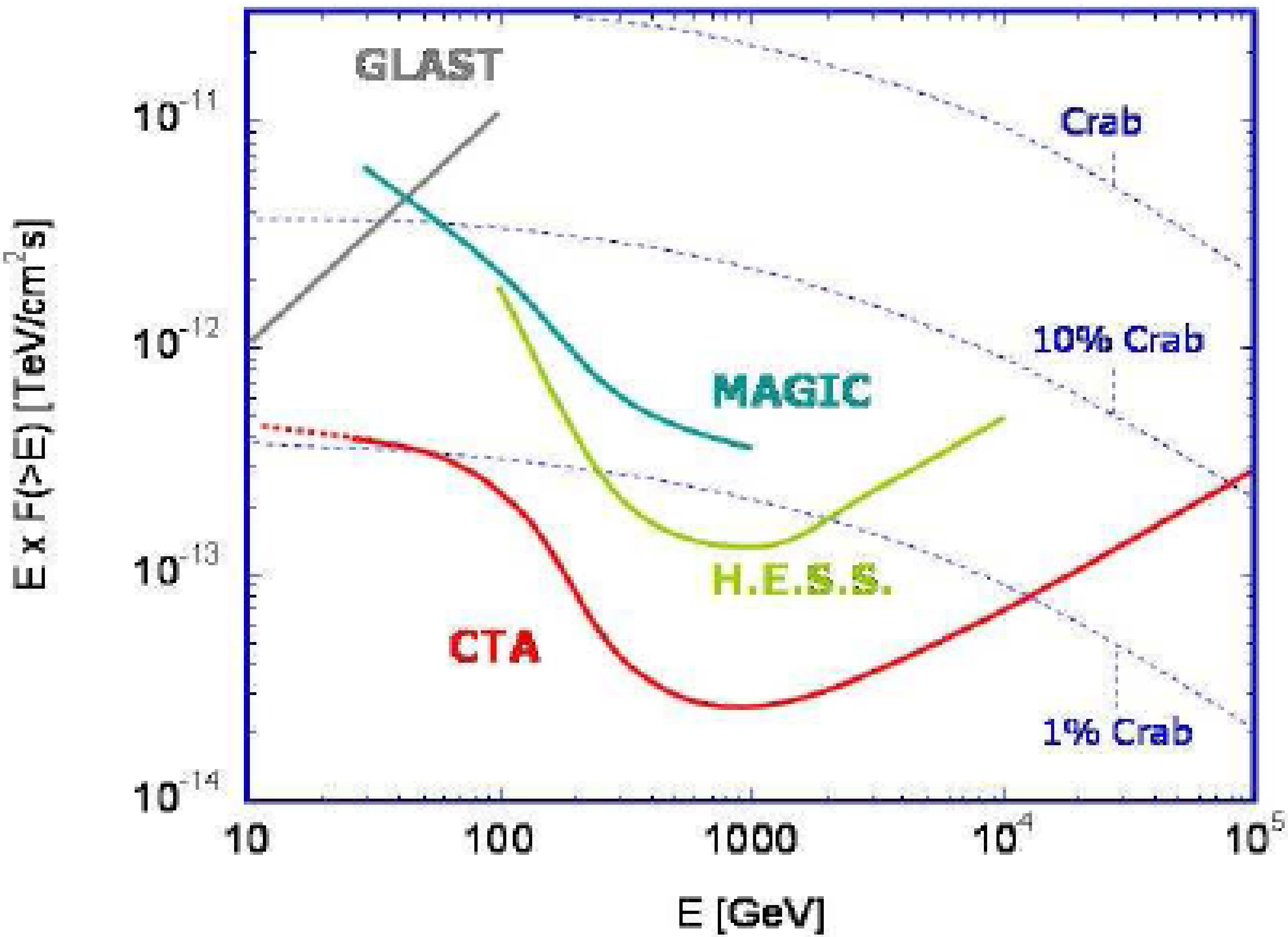
INDIRECT SEARCHES OF DM

- **WIMPs collected inside celestial bodies** (Earth, Sun): their annihilations produce energetic neutrinos
- **WIMPs in the DM halo**: WIMP annihilations can take place (in particular, their rate can be enhanced with there exists a CLUMPY distribution of DM as computer simulations of the DM distribution in the galaxies seem to suggest. From the WIMP annihilation:

-- **energetic neutrinos** (under-ice, under-water exps Amanda, Antares, Nemo, Nestor, …)

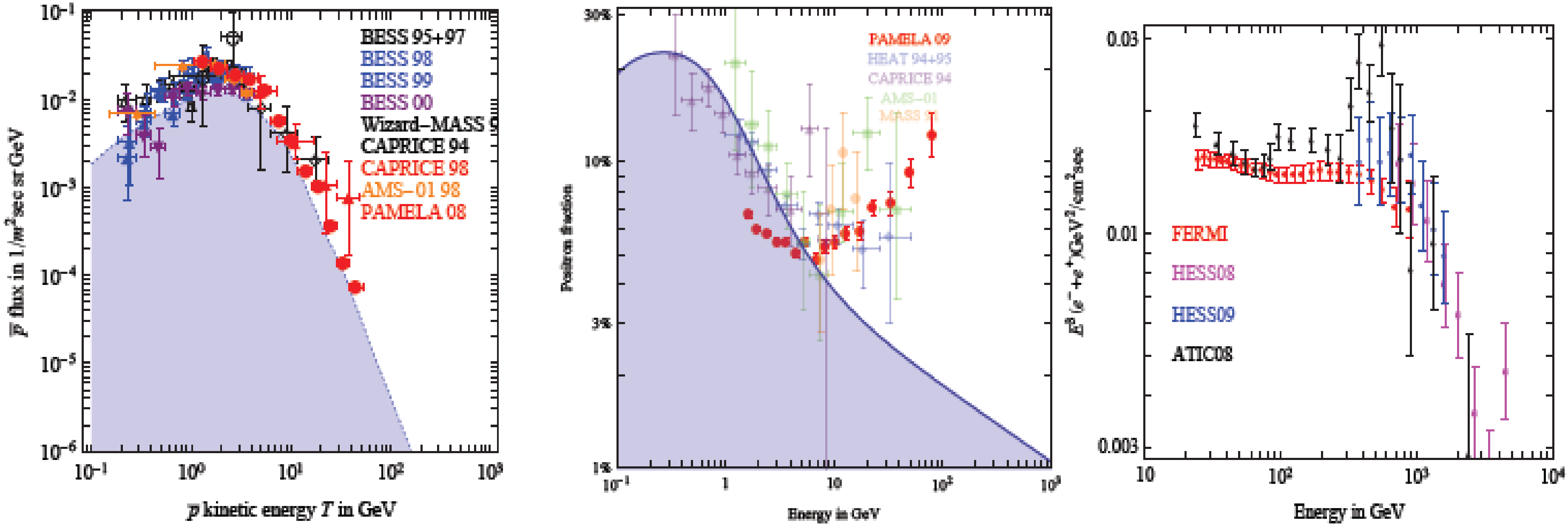
--photons in tens of GeV range (gamma astronomy on ground Magic, Hess, … or in space Agile, Glast…)

--antimatter: look for an excess of antimatter w.r.t. what is expected in cosmic rays (space exps. Pamela, AMS, …)



GLAST
Crab
10% Crab
1% Crab
MAGIC
H.E.S.S.
CTA
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10
100
1000
10^4
10^5
E [GeV]
E x F(>E) [TeV/cm^{2}s]

PAMELA, FERMI/ATIC, HESS



$\bar{p}$: consistent with bck

e^+/e^-: excess

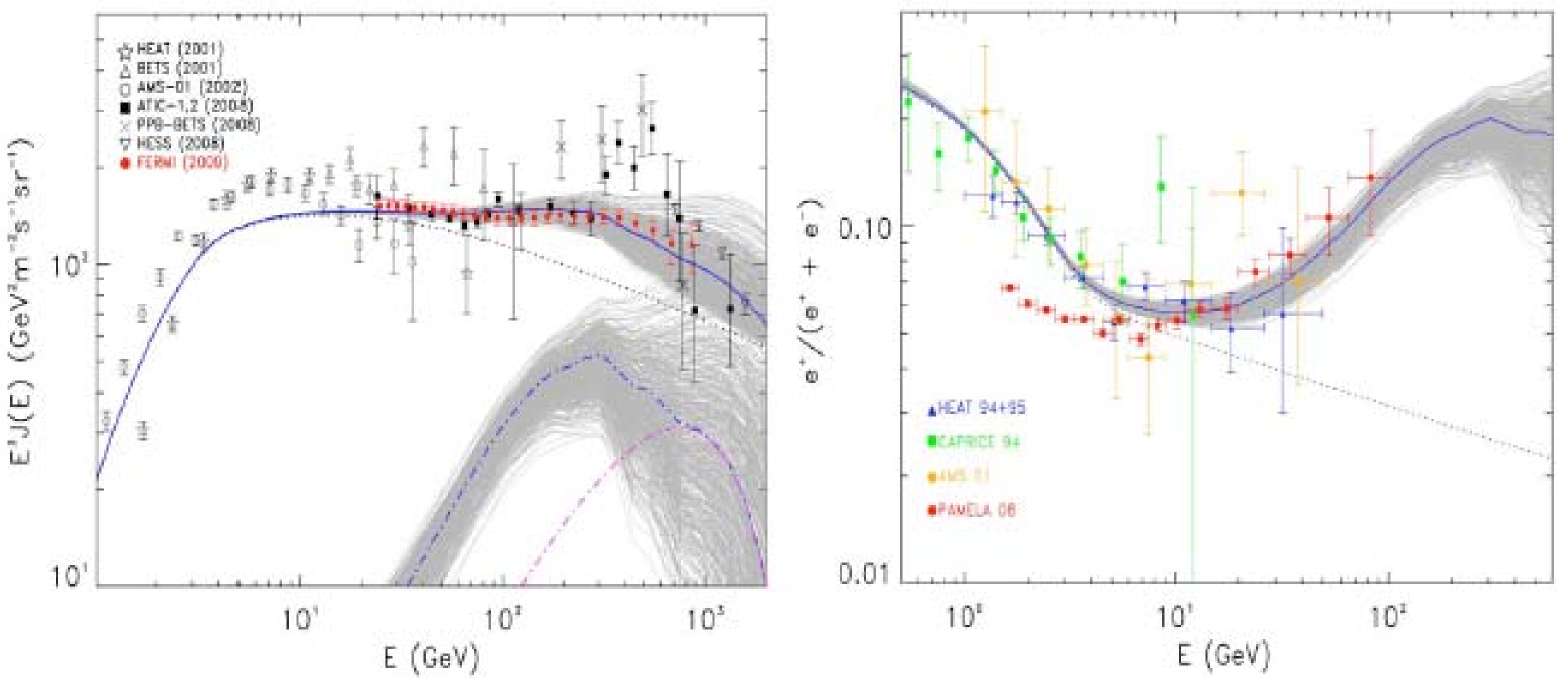
$e^- + e^+$: feature?

Strumia

EPS09

PAMELA excess: October 2008, stimulated enormous theoretical activity; note: statistical errors only! Fermi: feature observed by ATIC not confirmed

Pulsars: Fermi & PAMELA

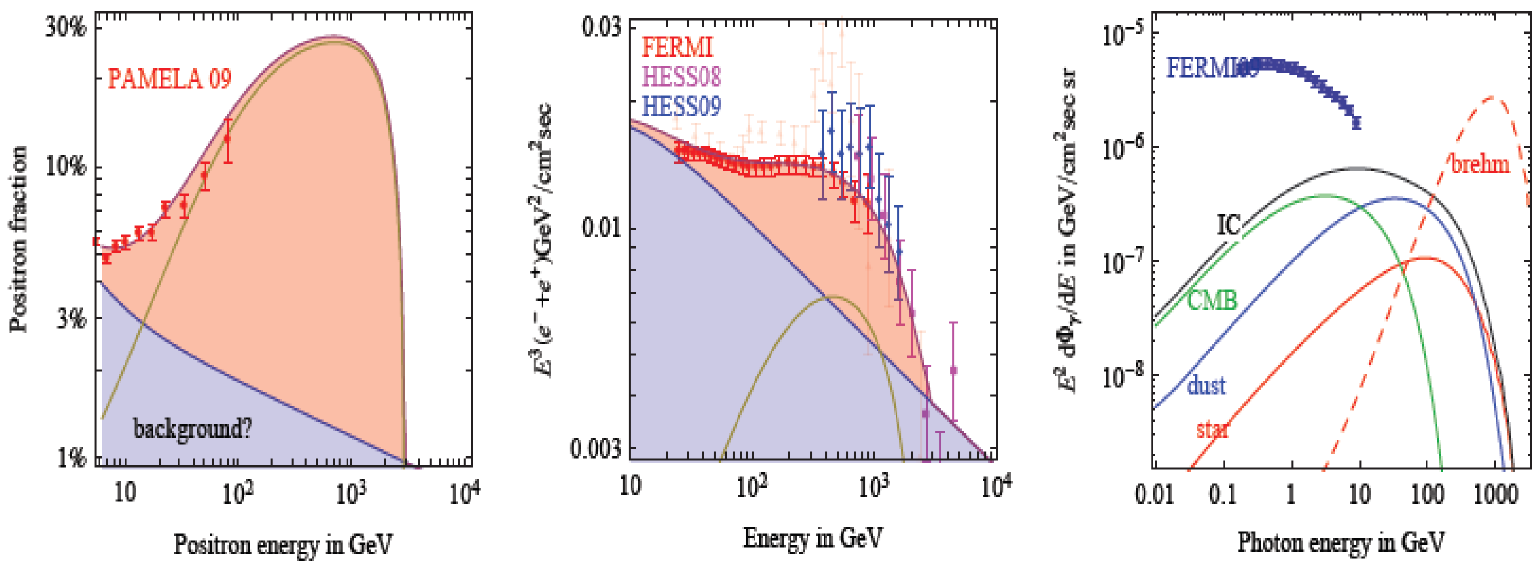


pulsar parameters “randomly” varied!

Grasso et al

Standard Dark Matter best fit

DM with $M = 3.$ TeV that annihilates into $\tau^+\tau^-$ with $\sigma v = 1.9 \times 10^{-22}$ cm^3/s



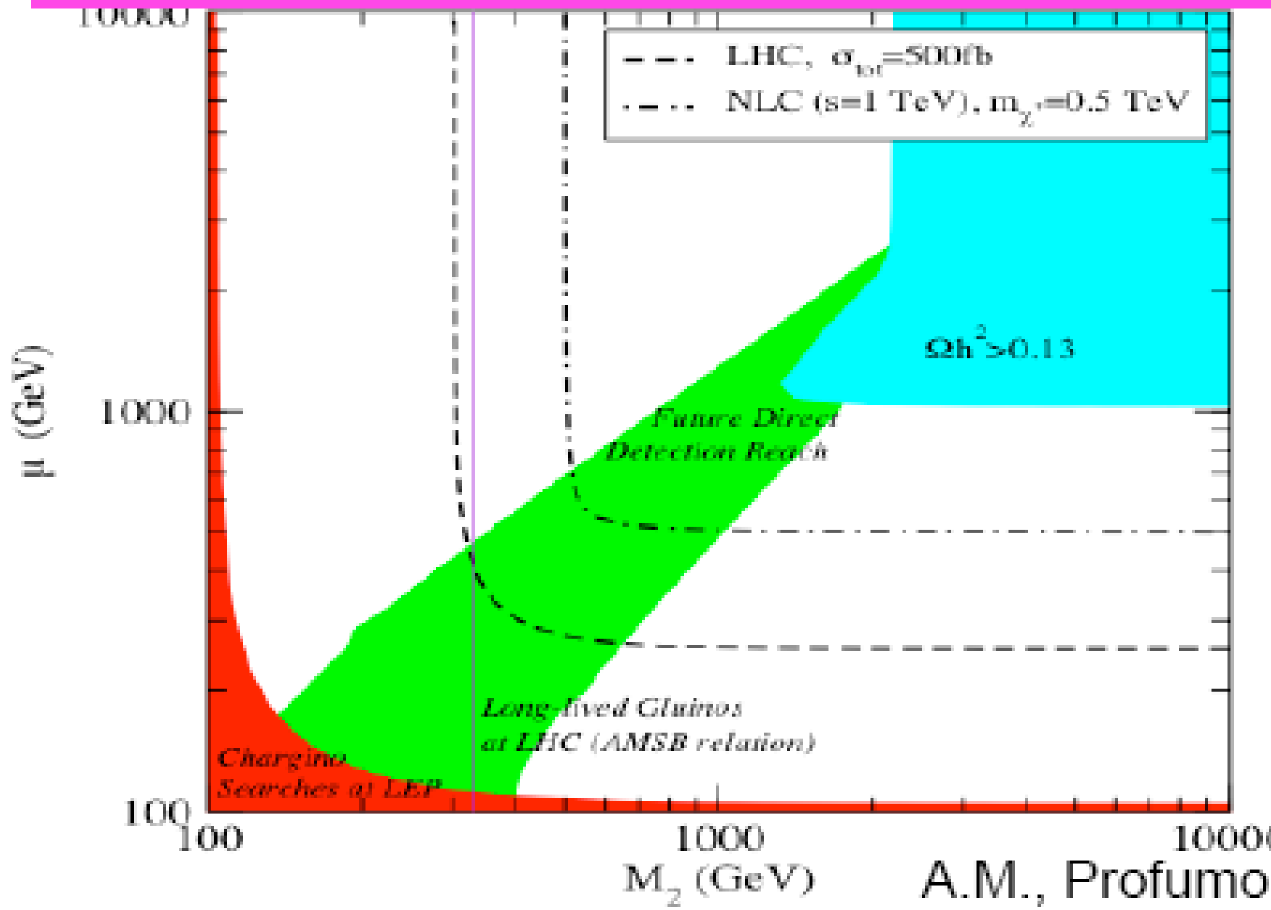
(Inverse Compton depends only on the $e^{\pm}$ spectrum)

Strumia

EPS09

Watch boost factor! DM particles too heavy for SUSY to be relevant for LHC

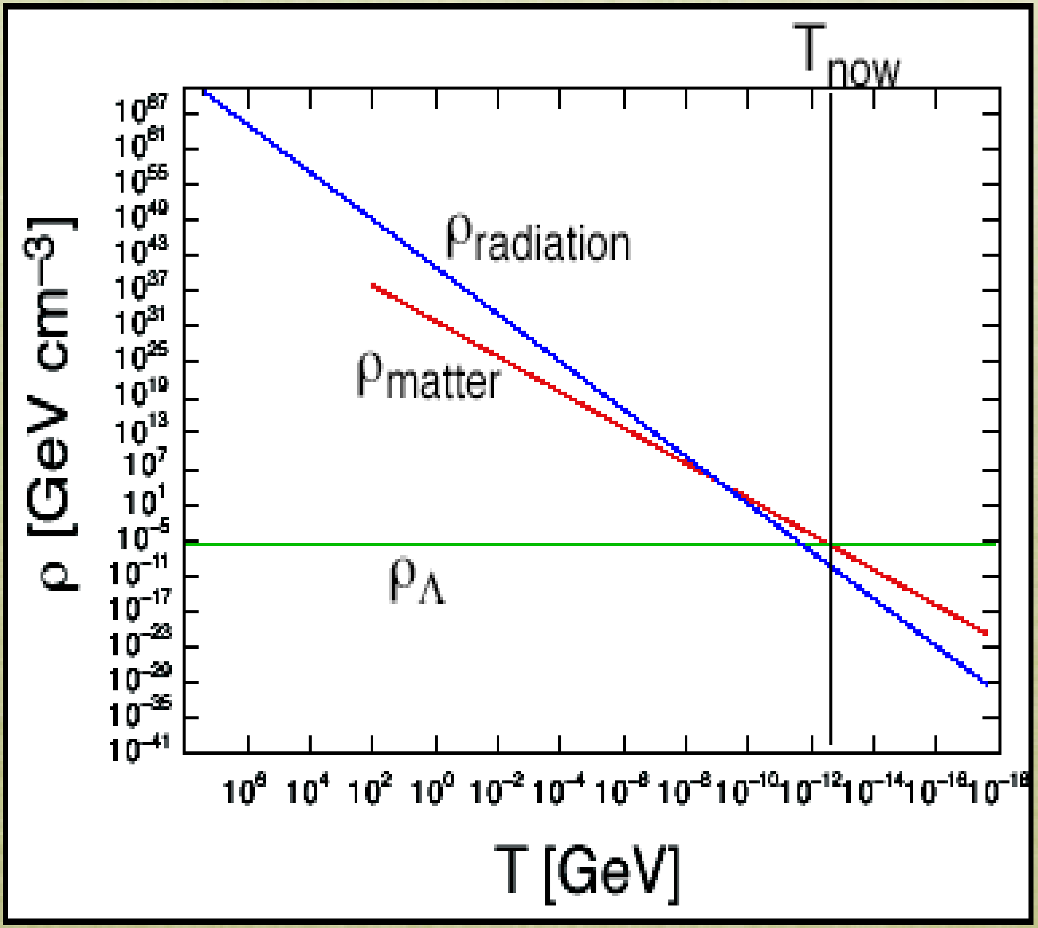
LHC, ILC, DM SEARCHES SENSITIVITIES



A.M., Profumo, Ullio

THE “WHY NOW” PROBLEM

- *Why do we see matter and cosmological constant almost equal in amount?*
- *“Why Now” problem*
- *Actually a triple coincidence problem including the radiation*
- *If there is a deep reason for $\rho_\Lambda \sim ((\mathrm{TeV})^2/M_{Pl})^4$, coincidence natural*



Arkani-Hamed, Hall, Kolda, HM

DM ⟷ DE

DO THEY "KNOW" EACH OTHER?

- DIRECT INTERACTION ϕ (quintessence) WITH DARK MATTER

DANGER:
ϕ Very LIGHT
$m_\phi \sim H_0^{-1} \sim 10^{-33}$ eV

→ Threat of violation of the equivalence principle constancy of the fundamental "constants",…

- **INFLUENCE OF ϕ ON THE NATURE AND THE ABUNDANCE OF CDM**

Modifications of the standard picture of
WIMPs FREEZE - OUT

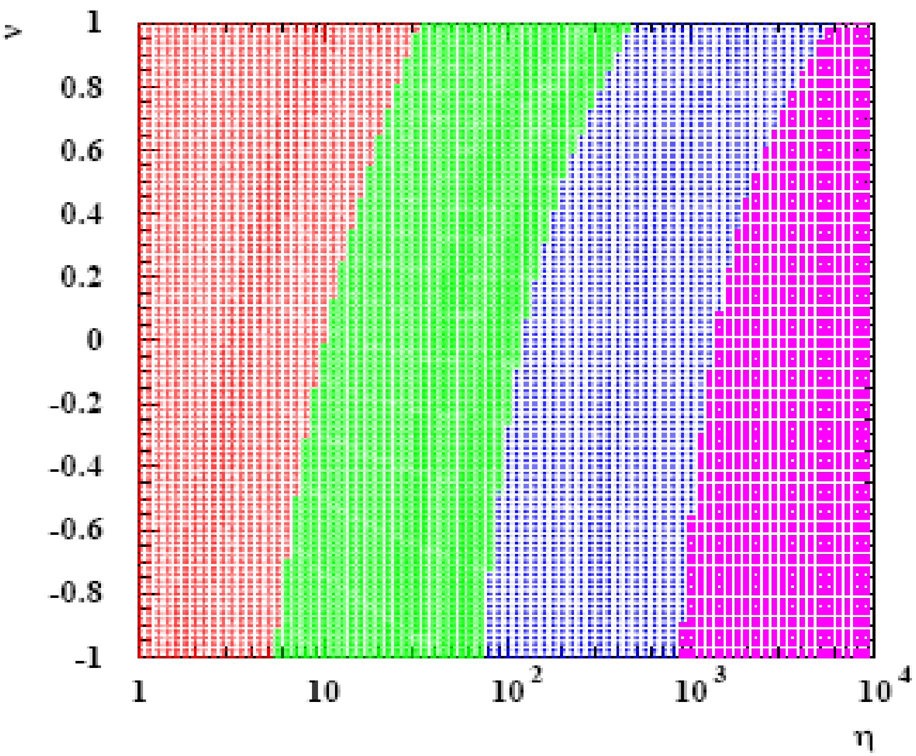
CDM CANDIDATES

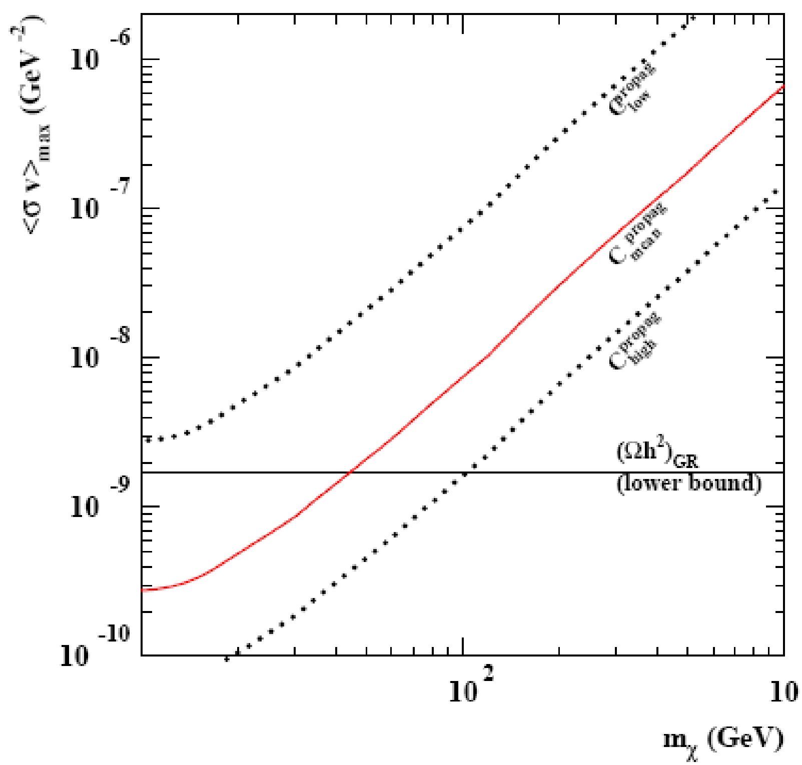
CATENA, FORNENGO, A.M., PIETRONI, SCHELKE

$$H = A(T)H_{\rm std} \qquad \text{at early times}$$

$$H = H_{\rm std} \qquad \text{at later times}$$

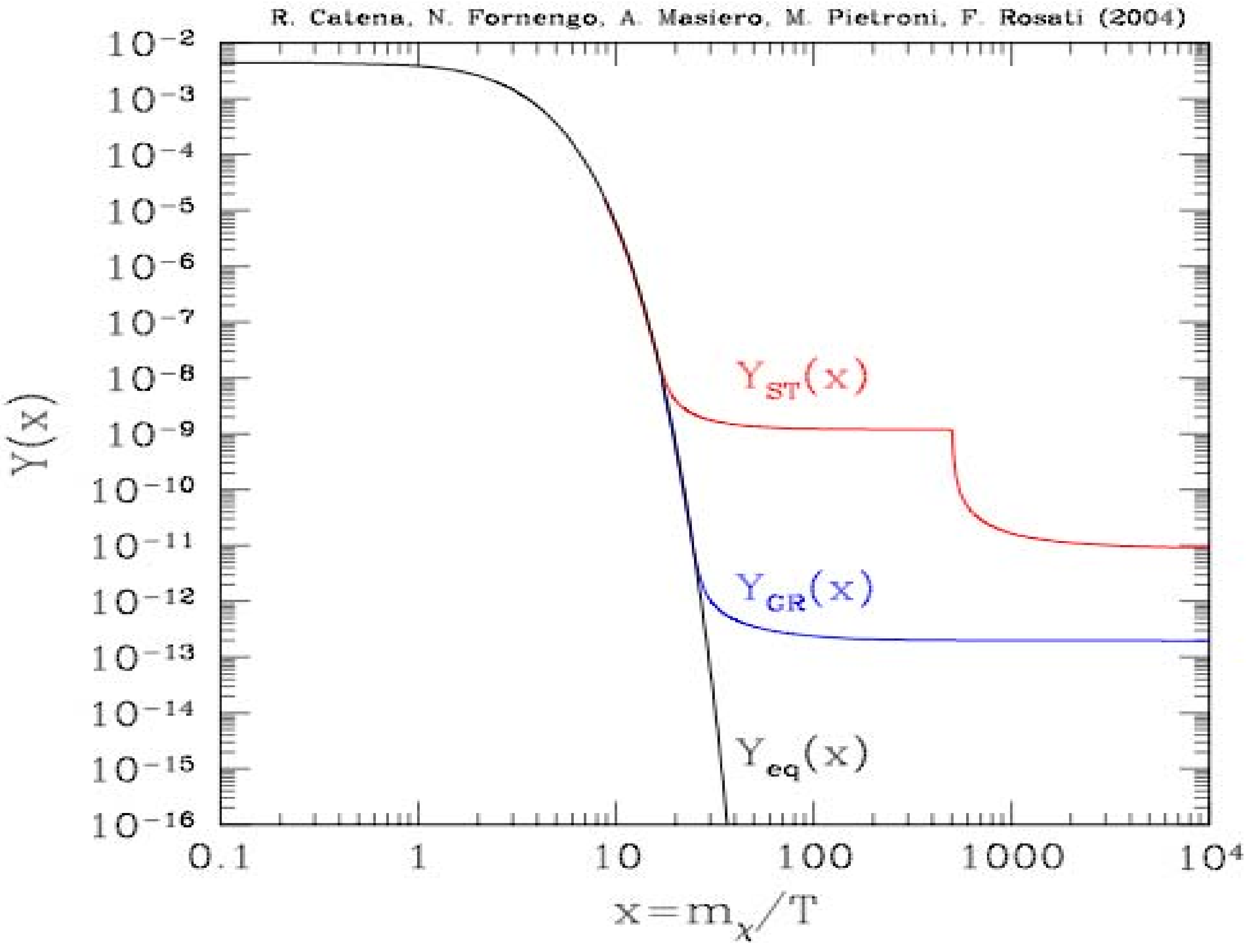
$$A(T) = 1 + \eta \left(\frac{T}{T_{\rm f}}\right)^{\nu} \tanh\left(\frac{T - T_{\rm re}}{T_{\rm re}}\right)$$





SCHELKE, CATENA, FORNENGO, A.M., PIETRONI

NEUTRALINO RELIC ABUNDANCE IN GR AND S-T THEORIES OF GRAVITY




S. Katsanevas
ASPERA
THE MAGNIFICENT SEVEN
ET
AUGER
North
CTA
KM3
1 ton
DM
1 ton
NM
Megaton
scale
NNN
Common with
Astrophysics
ASTRONET
Common with
Particle Physics
CERN SG

MICRO

STANDARD MODEL of PARTICLE PHYSICS

G-W-S MODEL

MACRO

MODELLO STANDARD of COSMOLOGY

HOT BIG BANG

HAPPY MARRIAGE

EX: **NUCLEOSYNTHESIS**

BUT ALSO

FRICTION POINTS

DARK MATTER AND DARK ENERGY

LHC → AN EXCEPTIONAL WINDOW TO EXPLORE THE UNIVERSE AND ITS ORIGIN, BUT…

TEVATRON → LHC → I L C

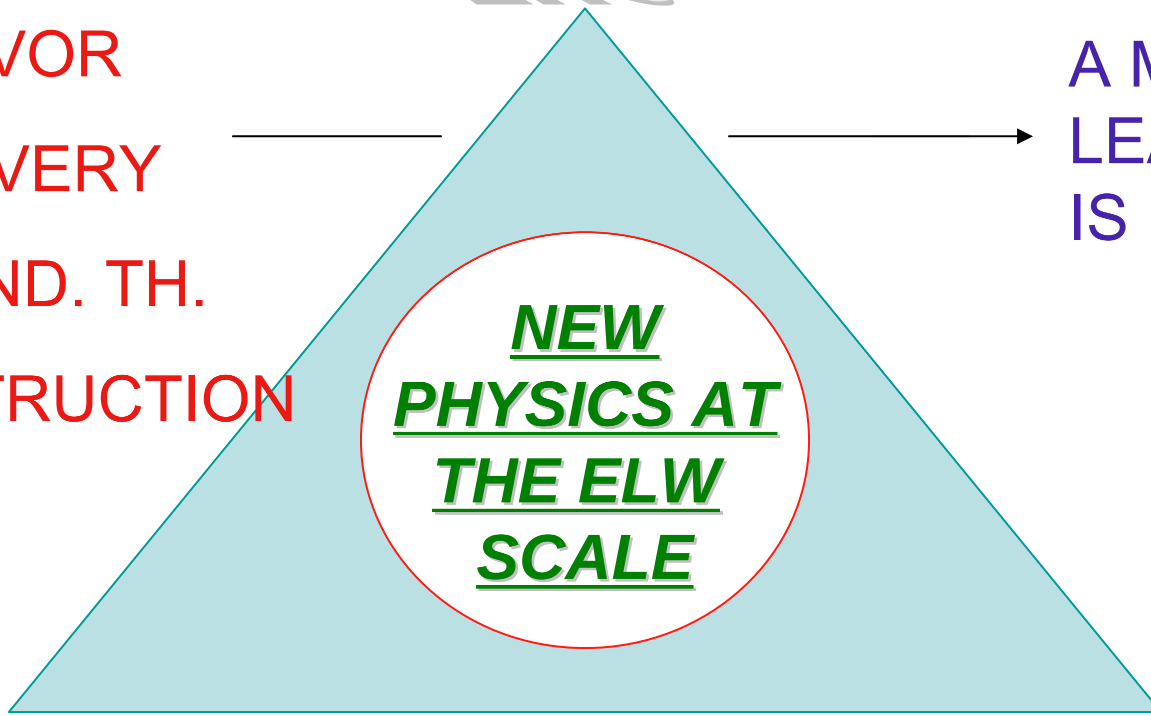
DM - FLAVOR

for DISCOVERY

and/or FUND. TH.

RECONSTRUCTION

A MAJOR
LEAP AHEAD
IS NEEDED



DARK MATTER

$m_\chi\ n_\chi\ \sigma_\chi \ldots$

DARK ENERGY

LINKED TO COSMOLOGICAL EVOLUTION

LEPTOGENESIS

GW   **INFLATION**

"LOW ENERGY"

PRECISION PHYSICS

FCNC, CP $\neq$, (g-2), $(\beta\beta)_{0\nu\nu}$

LFV

NEUTRINO PHYSICS

BACK-UP SLIDES

EVIDENCE FOR DM

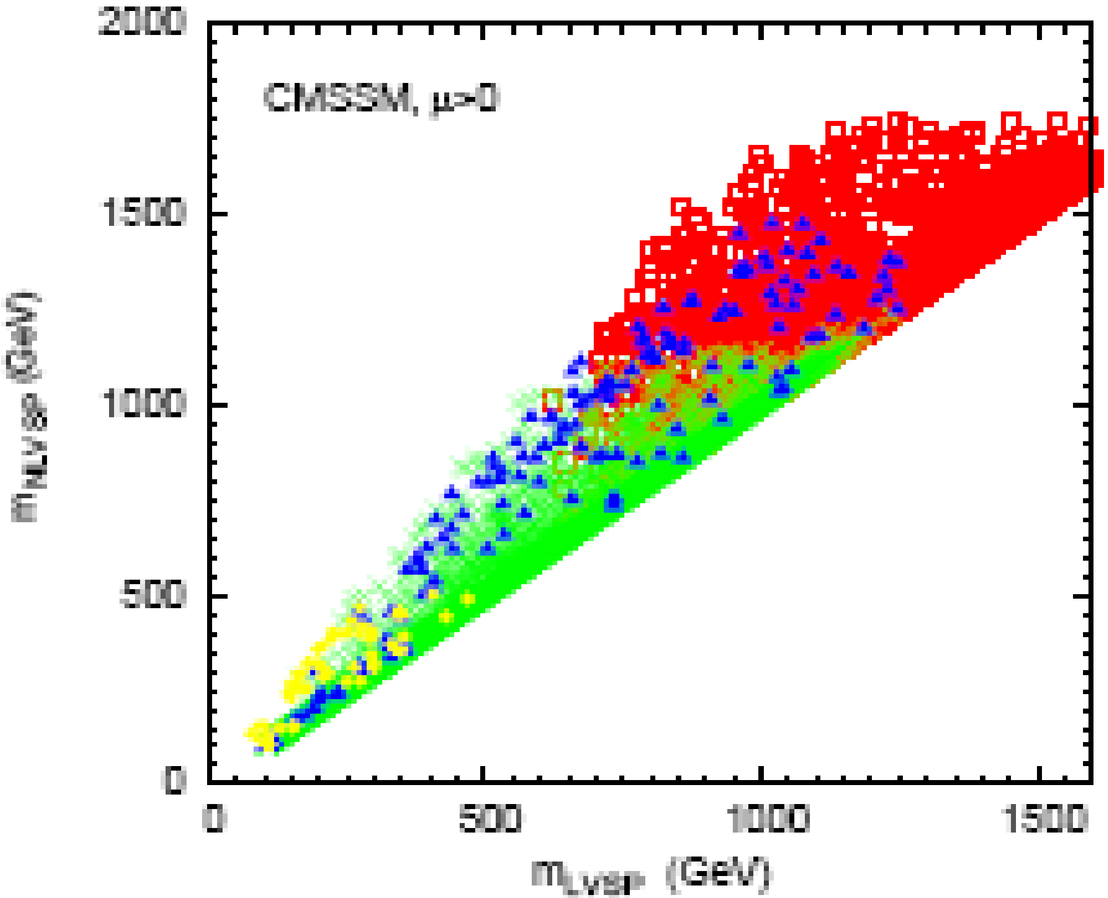
Various astrophysical sources have confirmed the existence of Dark Matter (DM)

- Binding of Galaxies in Clusters (F. Zwicky, 1933)
- Rotation curves of Galaxies (V.C. Rubin and W.K. Ford, 1970)
- Bindings of hot gases in clusters
- Gravitational Lensing observations
- Large Scale Stucture simulations
- High z - Supernovae
- Observations of colliding clusters of Galaxies

The most direct and accurate evidence comes from WMAP by measuring arisotropies of the CMB power spectrum

$\sim 73\%$ DarkEnergy, $\sim 23\%$ DarkMatter, 4% Baryons

PROSPECTS FOR DISCOVERING THE CMSSM AT THE LHC IN LIGHT OF WMAP



RED: FULL SAMPLE OF CMMS MODELS

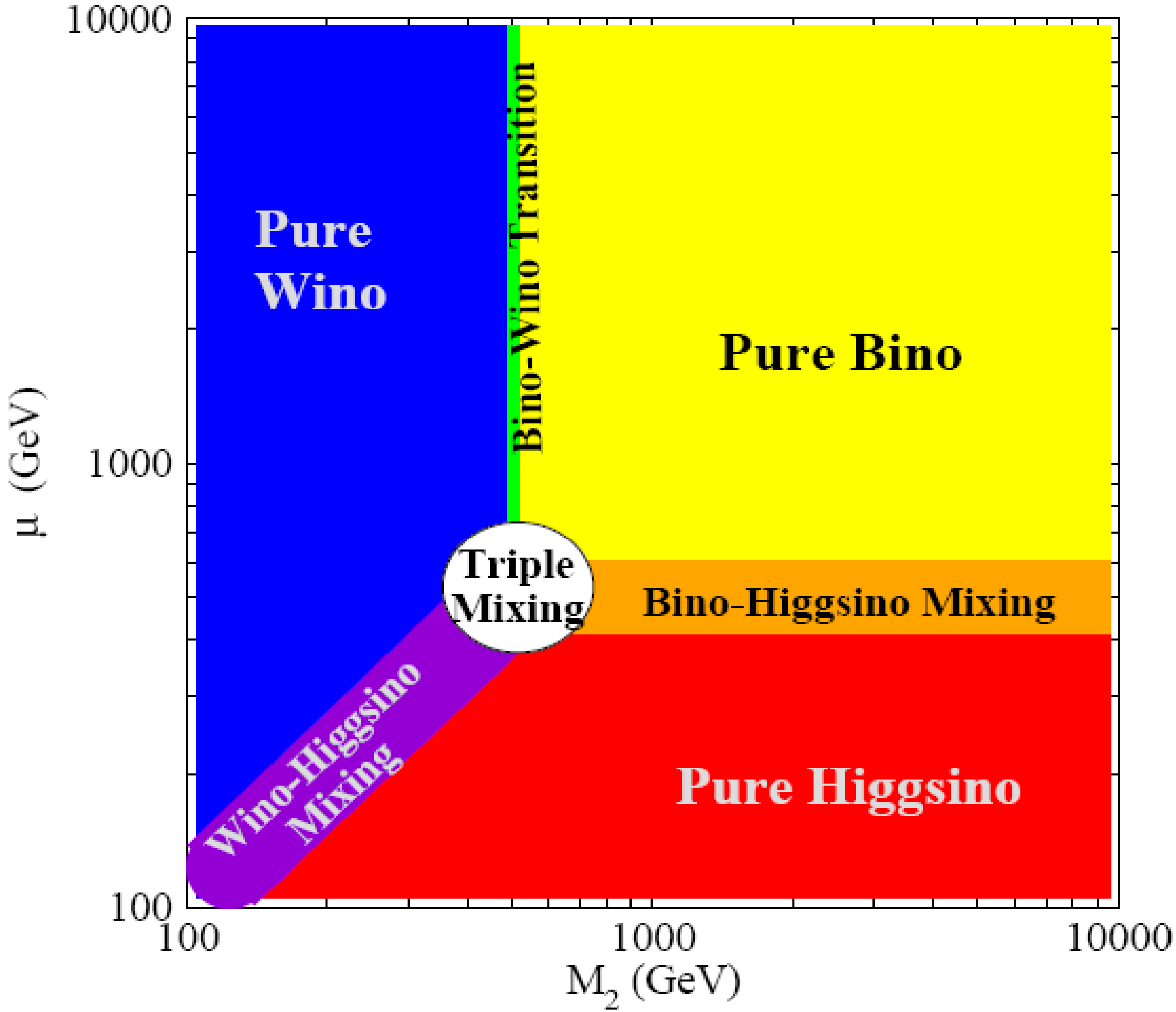
BLUE: POINTS COMPATIBLE WITH WMAP

GREEN: POINTS ACCESSIBLE TO LHC

YELLOW: POINTS ACCESSIBLE TO PRESENT DIRECT DM SEARCHES

Ellis et al.

A.M., PROFUMO, ULLIO



WHY TO GO BEYOND THE SM

"OBSERVATIONAL" REASONS

- HIGH ENERGY PHYSICS

NO (but $A_{FB}^{Z \rightarrow bb}$……)

- FCNC, CP$\neq$

NO (but $b \rightarrow s q\bar{q}$ penguin …)

- HIGH PRECISION LOW-EN.

NO (but $(g-2)_\mu$ …)

- **NEUTRINO PHYSICS**

YES $m_\nu \neq 0$, $\theta_\nu \neq 0$

- **COSMO - PARTICLE PHYSICS**

YES (DM, ΔB_{cosm}, INFLAT., DE)

THEORETICAL REASONS

- INTRINSIC INCONSISTENCY OF SM AS QFT

NO (spont. broken gauge theory without anomalies)

- NO ANSWER TO QUESTIONS THAT "WE" CONSIDER "FUNDAMENTAL" QUESTIONS TO BE ANSWERED BY "FUNDAMENTAL" THEORY

YES **(hierarchy, unification, flavor)**

THEORETICAL REASONS TO GO BEYOND THE SM

- ***FLAVOR PUZZLE*** → **RATIONALE FOR FERMION MASSES AND MIXINGS**

- ***UNIFICATION PROBLEM*** → **NO REAL UNIF. OF ELW.+STRONG INTERACTIONS +GRAVITY LEFT OUT OF THE GAME**

- ***HIERARCHY PROBLEM(S)*** → **ULTRAVIOLET COMPLETION OF THE SM TO (NATURALLY) STABILIZE THE ELW. BREAKING SCALE + TUNING OF THE COSMOLOGICAL CONSTANT**

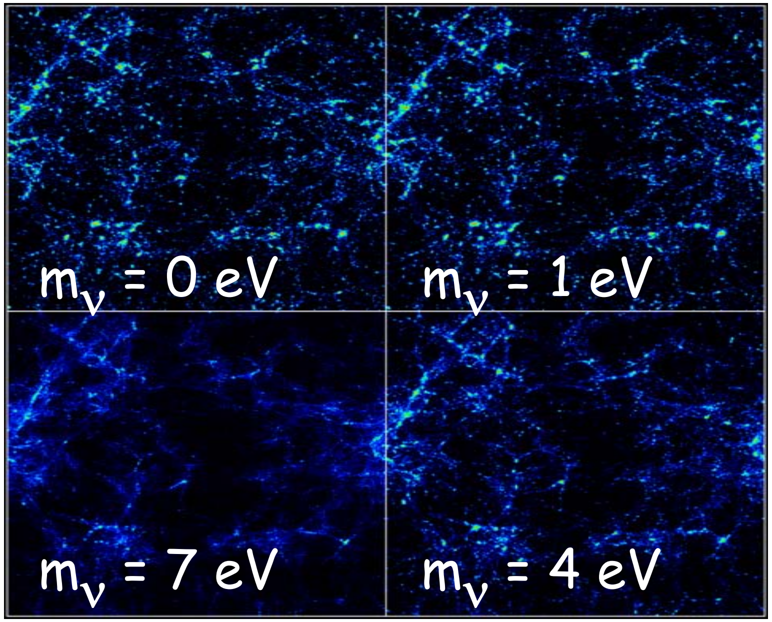
THE RISE AND FALL OF NEUTRINOS AS DARK MATTER

- Massive neutrinos: only candidates in the SM to account for DM. From here the “prejudice” of neutrinos of a few eV to correctly account for DM

- Neutrinos decouple at ~1 MeV ; being their mass<<decoupling temperature, neutrinos remain relativistic for a long time. Being very fast, they smooth out any possible growth of density fluctuation forbidding the formation of proto-structures.

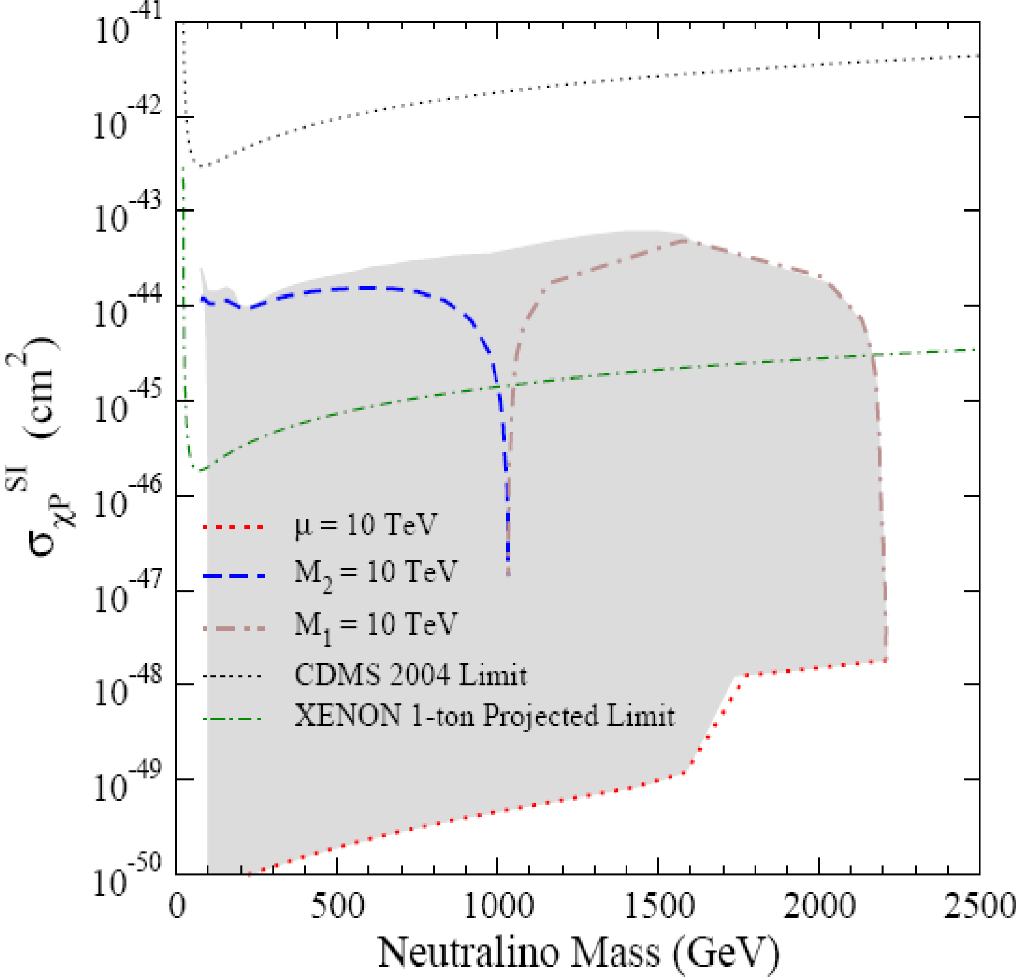
- The “weight” of neutrinos in the DM budget is severely limited by the observations disfavoring scenarios where first superlarge structures arise and then galaxies originate from their fragmentation

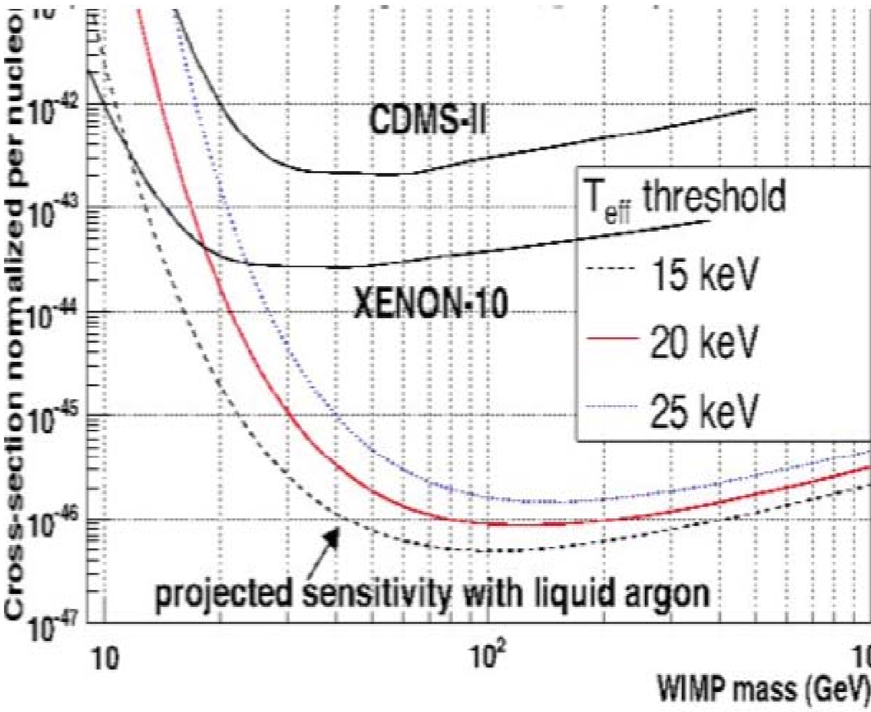
LSS PATTERN AND NEUTRINO MASSES



(E..g., Ma 1996)

SPIN - INDEPENDENT NEUTRALINO - PROTON CROSS SECTION FOR ONE OF THE SUSY PARAM. FIXED AT 10 TEV

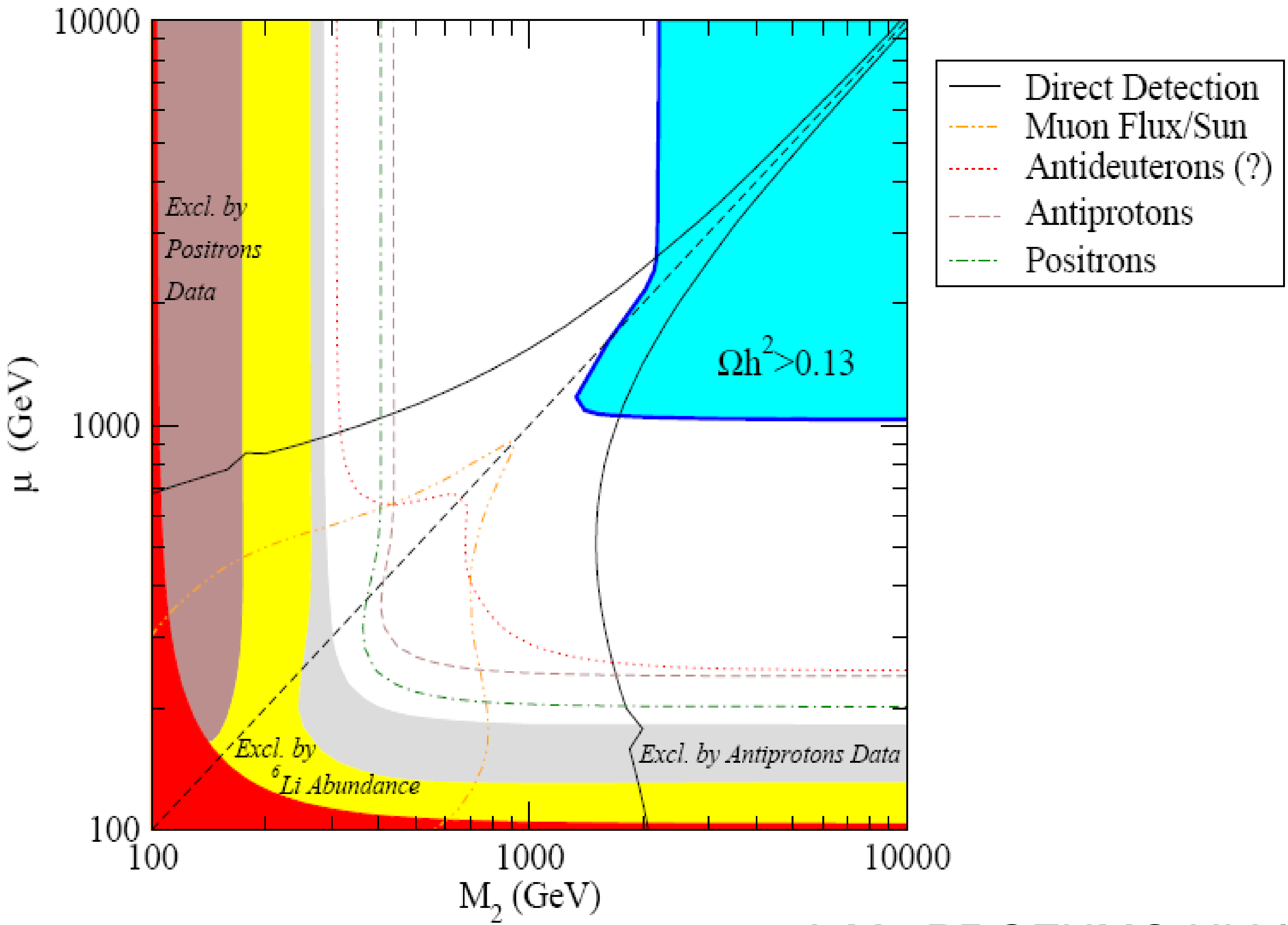




PROFUMO, A.M., ULLIO

Some final thoughts

- Very solid evidence of (a large amount of) **NON-BARYONIC COLD DM**
- In the **SM NO CANDIDATE FOR COLD DM** (ordinary neutrinos are hot DM; indeed, the best limit on neutrino masses comes from cosmology!)
- **WIMPS**: (very) appealing **COSMO (HBB SM) – PARTICLE (GWS SM) "conspiracy" in providing the (quantitatively and qualitatively) right DM**
- WIMPS can be part of the **NEW PHYSICS at the ELW** scale (link ultraviolet completion of the SM – DM constituents)
- Possibility of a **joint cosmo – and particle – exploration of the TeV New Physics**
- **If WIMP is the DM: complementary hunting for TeV New Physics at LHC and in DIRECT and INDIRECT searches of DM**



A.M., PROFUMO,ULLIO

LHC and "LOW-ENERGY" NEW PHYSICS

- **LHC discovers NP**: difficult, if not impossible, to "reconstruct" the fundamental theory lying behind those signals of NP;

- **LHC does not see any signal of NP**: still a NP related to the stabilization of the elw. scale may be present, but with particles whose masses are in the multi-TeV range.

THE G-W-S STANDARD MODEL