

SCINEGHE 09, ASSISI, SEPT. 7 – 9, 2009

***DM* and
*NEW PHYSICS***

Antonio Masiero
Univ. of Padova
and
INFN, Padova

DM and NEW PHYSICS

- Are we sure that ***DM is a manifestation of New Physics beyond the Particle Physics SM?***
- If yes, how likely is it that such ***New Physics sits at the Electroweak Scale*** (hence being visible at the LHC)
- Could DM be related to ***New Physics beyond the SM of Cosmology ?***
- DM to be detected through direct and indirect DM searches and at the LHC? Wishful thinking or realistic ***potential synergy between accelerator and astroparticle physics?***

DM → New Physics beyond the SM
(caveat: validity of the gravitational law)

- $\Omega_{\text{DM}} = 0.233 \pm 0.013$ *

- $\Omega_{\text{barioni}} = 0.0462 \pm 0.0015$ **

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

- **CMB + Type I SN + BAO in agreement with the Nucleosynthesis (BBN)

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

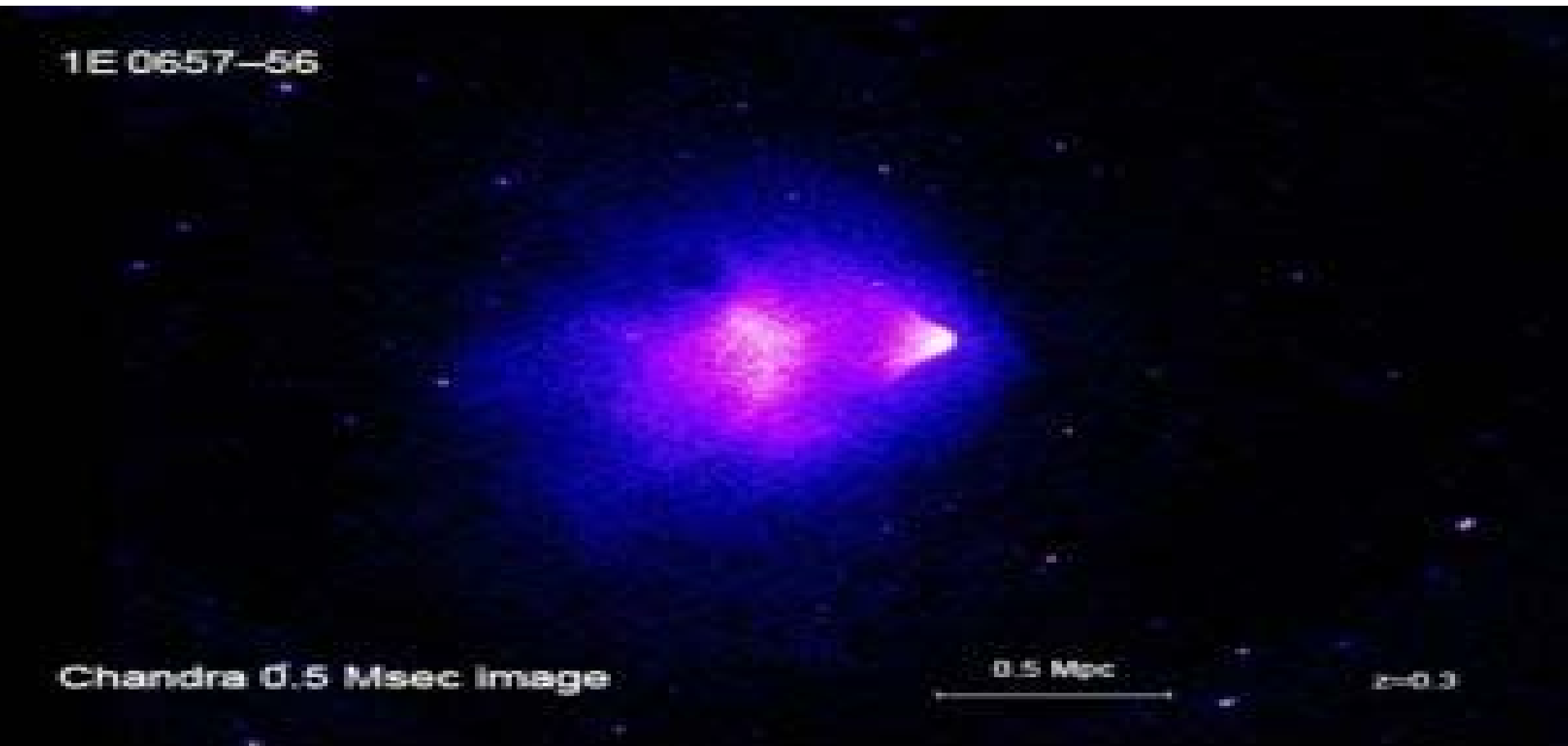
Stars, galaxies and putative DM behave differently during collision, allowing for them to be studied separately. In **MOND** the lensing is expected to follow the baryonic matter, i.e. the X-ray gas. However the lensing is strongest in two separated regions near the visible galaxies → **most of the mass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

1E 0657-56

Chandra 0.5 Msec image



0.5 Mpc

$z=0.3$



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}  **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  **NEW PARTICLES NOT INCLUDED IN THE SPECTRUM OF THE FUNDAMENTAL BUILDING BLOCKS OF THE SM !**

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**

... but the “**WIMP MIRACLE**”
as a bridge between
DM and New Physics at the TeV Scale

Table 1. Properties of various Dark Matter Candidates

Bergstrom

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 DM candidates, but only for WIMPs peculiar
COSMO-PARTICLE COINCIDENCE pointing in a
NATURAL way to **DM related to TeV New Physics**

STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

1) ENLARGEMENT OF THE SM

SUSY
(χ^μ, θ)

EXTRA DIM.
(χ^μ, j_i)

LITTLE HIGGS.
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

SEARCHING FOR WIMPs

WIMPS HYPOTHESIS

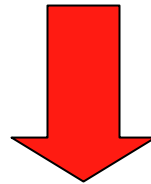
DM made of particles with mass 10Gev - 1Tev

ELW scale

With WEAK INTERACT.

LHC, ILC may PRODUCE WIMPS

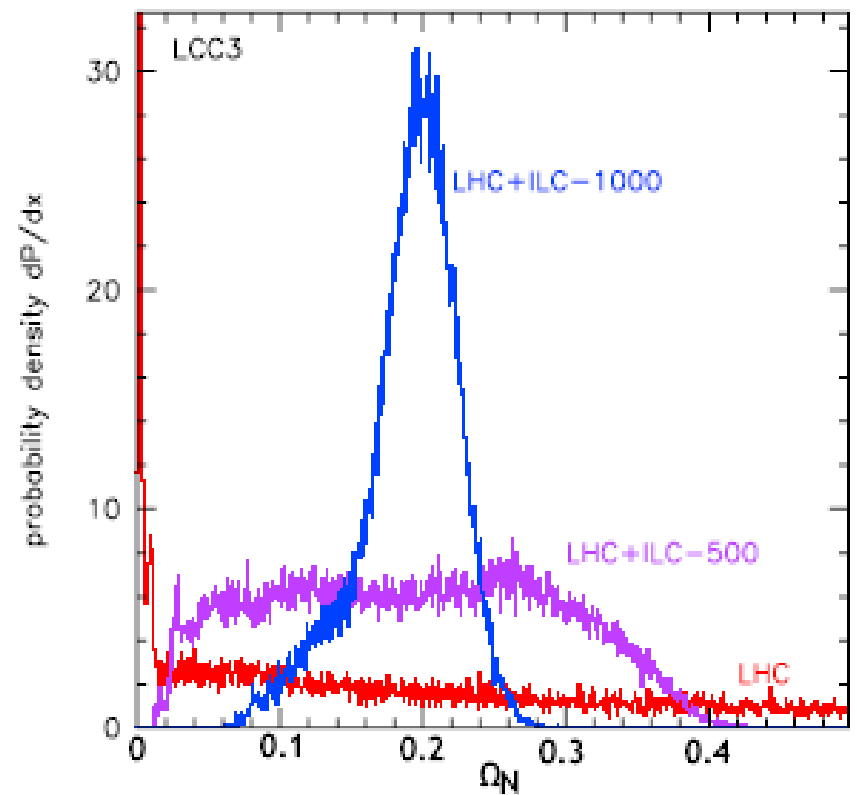
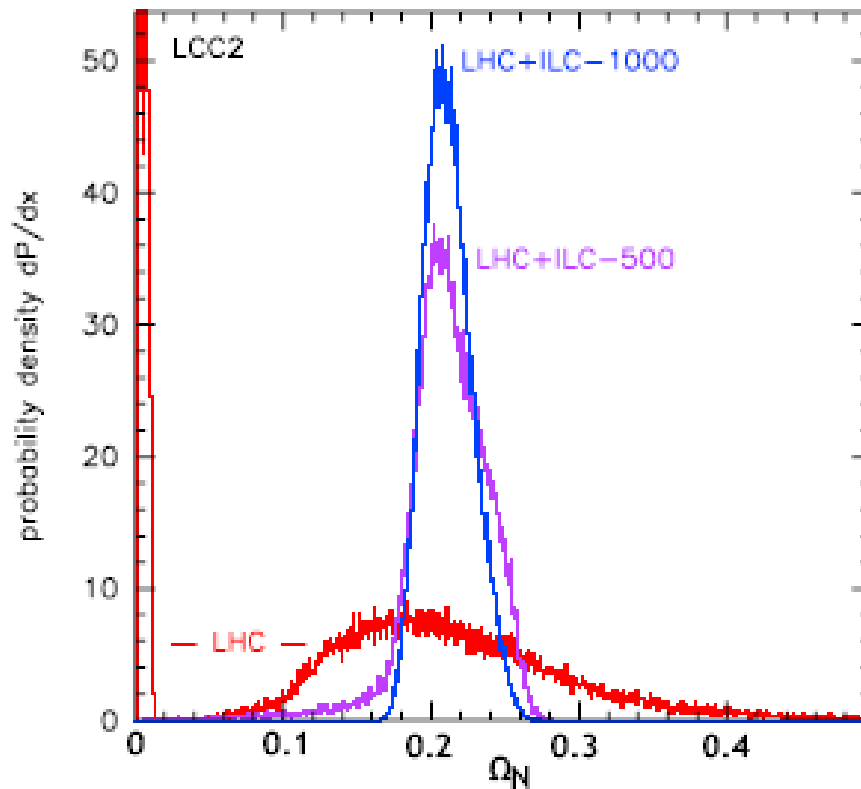
WIMPS escape the detector
→ MISSING ENERGY SIGNATURE



FROM “KNOWN” COSM. ABUNDANCE OF WIMPs →
PREDICTION FOR WIMP PRODUCTION AT COLLIDERS WITHOUT
SPECIFYING THE PART. PHYSICS MODEL OF WIMPs

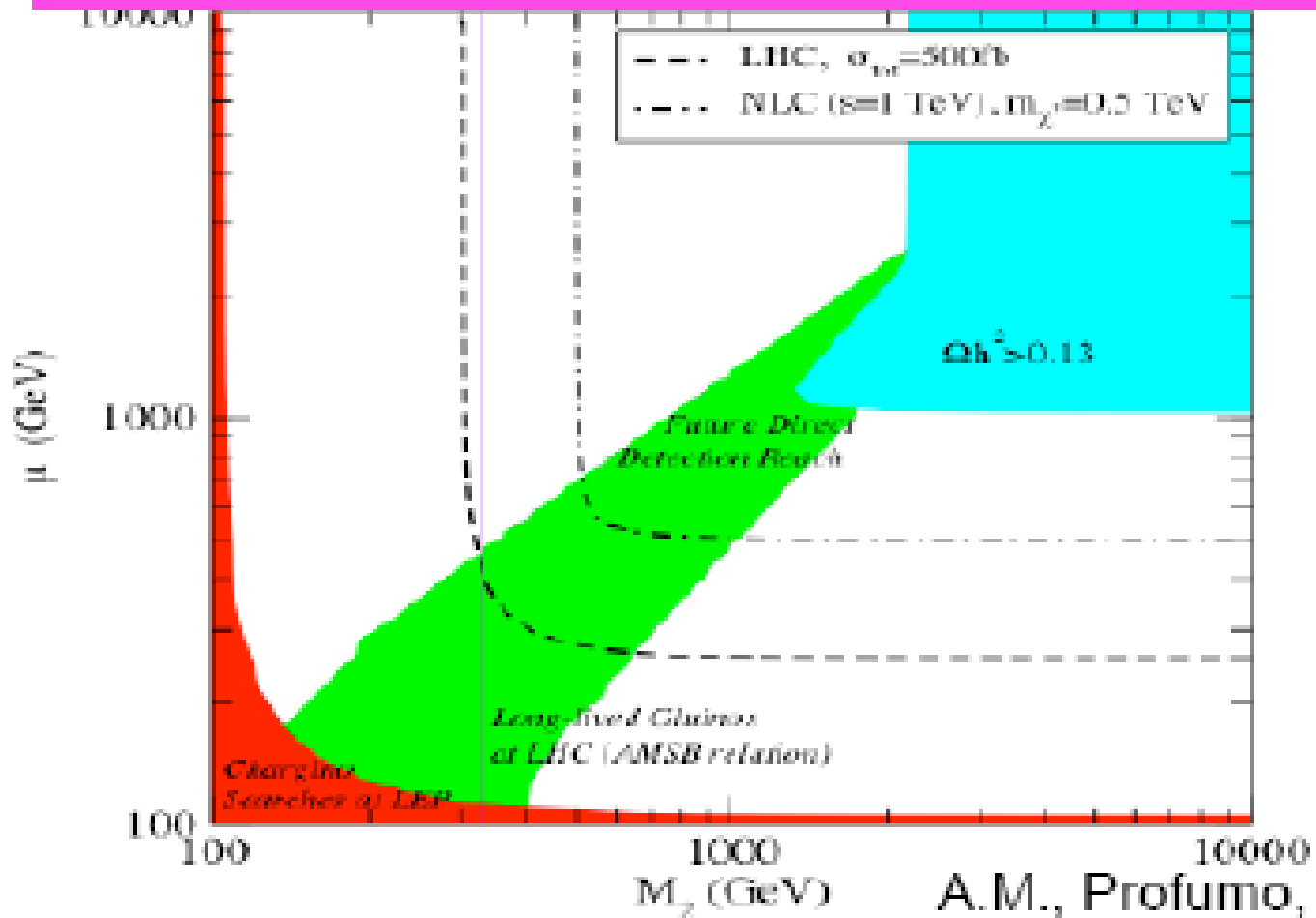
BIRKEDAL, MATCHEV, PERELSTEIN ,
FENG,SU, TAKAYAMA

PREDICTION OF Ω_{DM} FROM LHC AND ILC FOR TWO DIFFERENT SUSY PARAMETER SETS

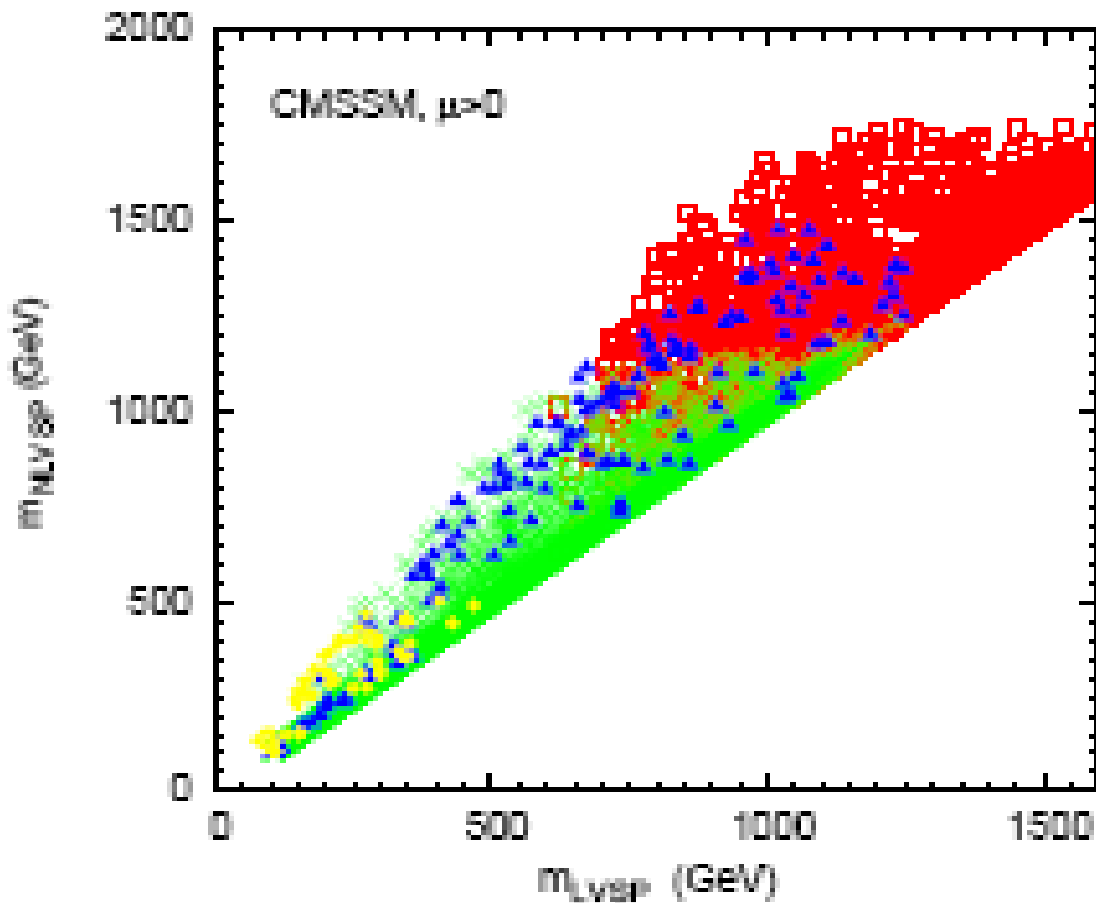


BALTZ, BATTAGLIA, PESKIN, WIZANSKY

LHC, ILC, DM SEARCHES SENSITIVITIES



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

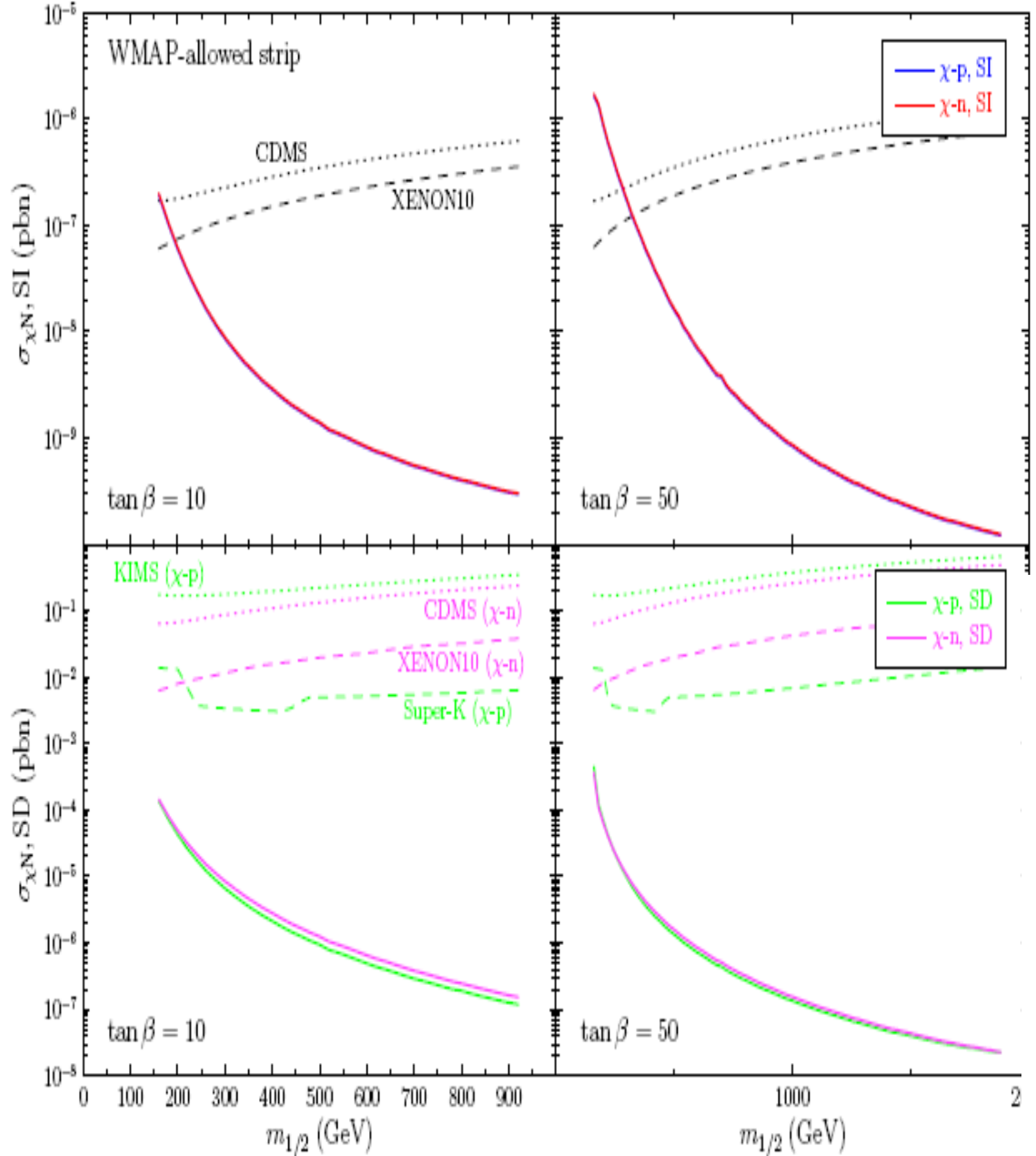


- RED:** FULL SAMPLE OF CMSS MODELS
- BLUE:** POINTS COMPATIBLE WITH WMAP
- GREEN:** POINTS ACCESSIBLE TO LHC
- YELLOW:** POINTS ACCESSIBLE TO PRESENT DIRECT DM SEARCHES

Ellis et al.

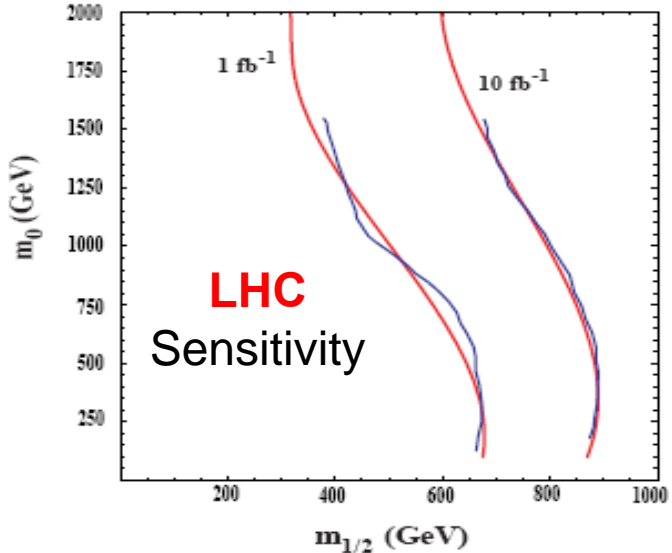
Neutralino-nucleon scattering cross sections along the WMAP-allowed coannihilation strip for $\tan\beta=10$ and **coannihilation/funnel strip** for $\tan\beta=50$ using the hadronic parameters

ELLIS. OLIVE. SAVAGE 



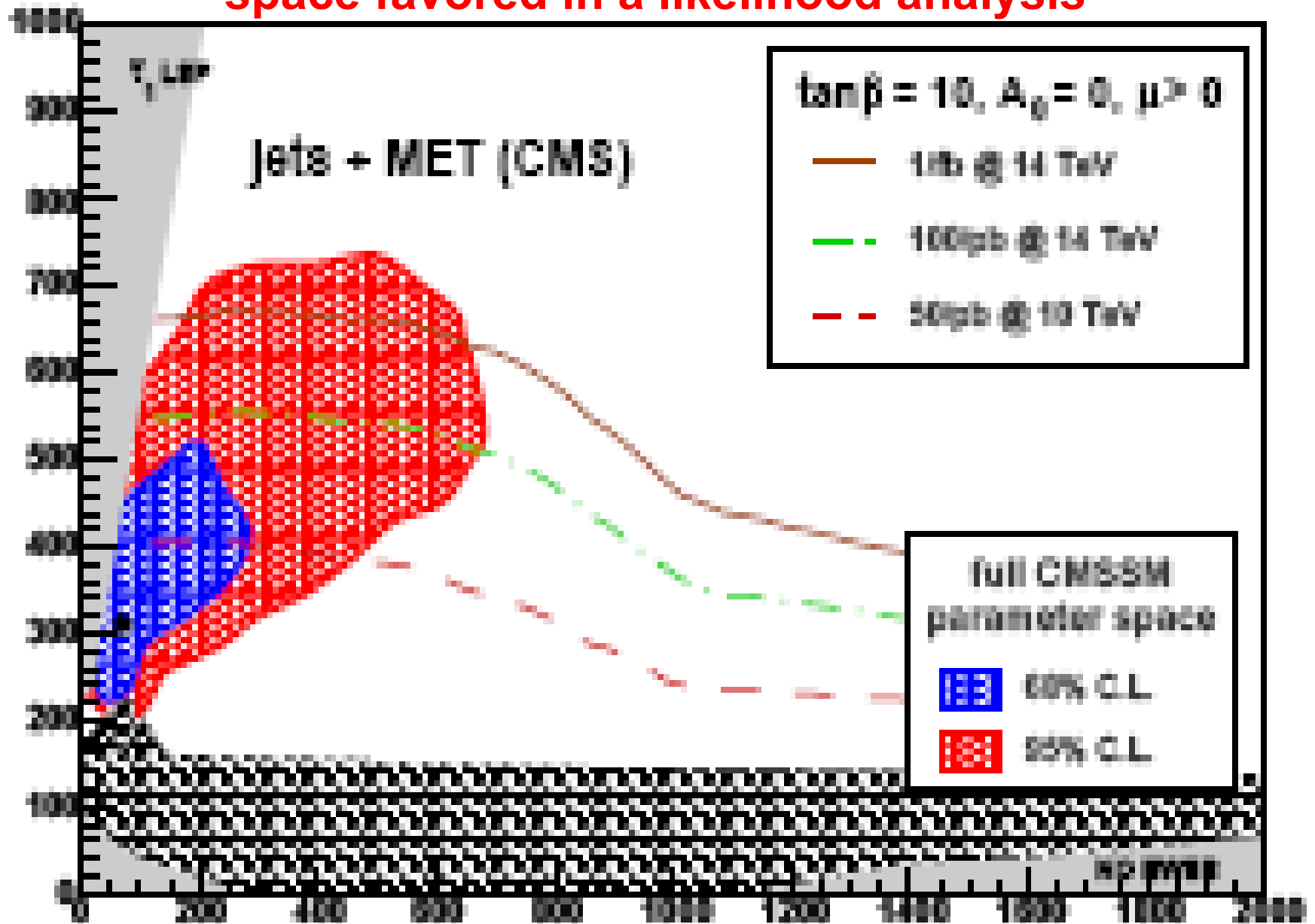
m_u/m_d	0.553 ± 0.043
m_d	5 ± 2 MeV
m_s/m_d	18.9 ± 0.8
m_c	1.25 ± 0.09 GeV
m_b	4.20 ± 0.07 GeV
m_t	171.4 ± 2.1 GeV
σ_0	36 ± 7 MeV
$\Sigma_{\pi N}$	64 ± 8 MeV
$a_3^{(p)}$	1.2695 ± 0.0029
$a_8^{(p)}$	0.585 ± 0.025
$\Delta_8^{(p)}$	-0.09 ± 0.03

Ellis, Olive, Sandick

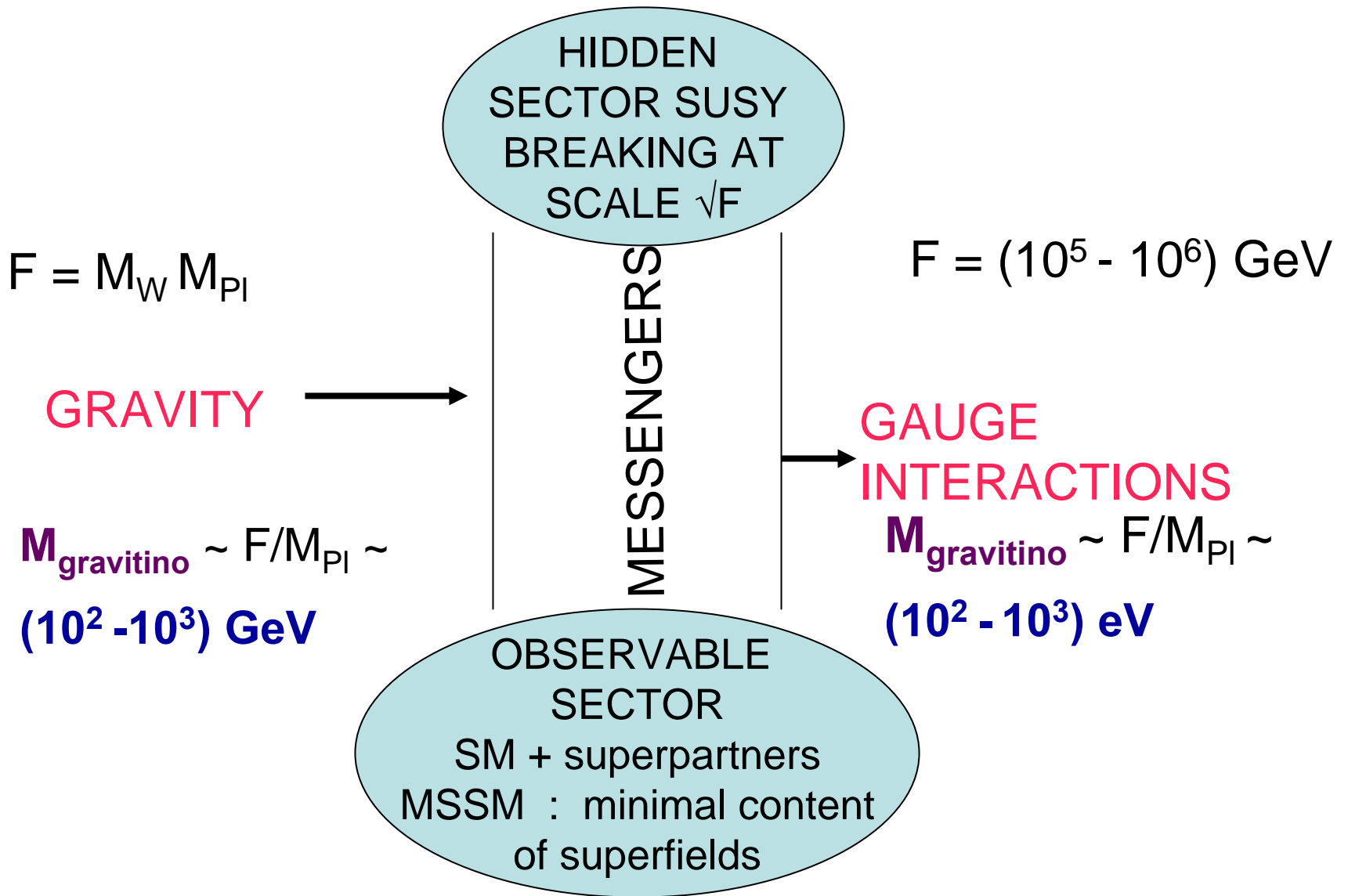


CMSSM: Regions of the param.

space favored in a likelihood analysis



WHICH SUSY



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

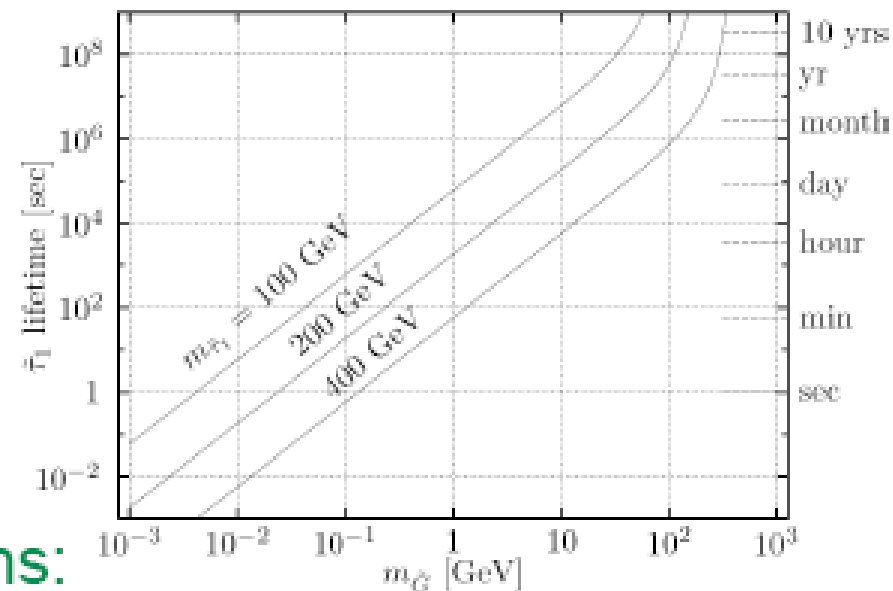
$$P' \rightarrow P \Rightarrow \Omega_{P'} = \frac{m_{P'}}{m_P} \Omega_P$$

Gravitino

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

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

Distinctive ToF and
energy loss signatures

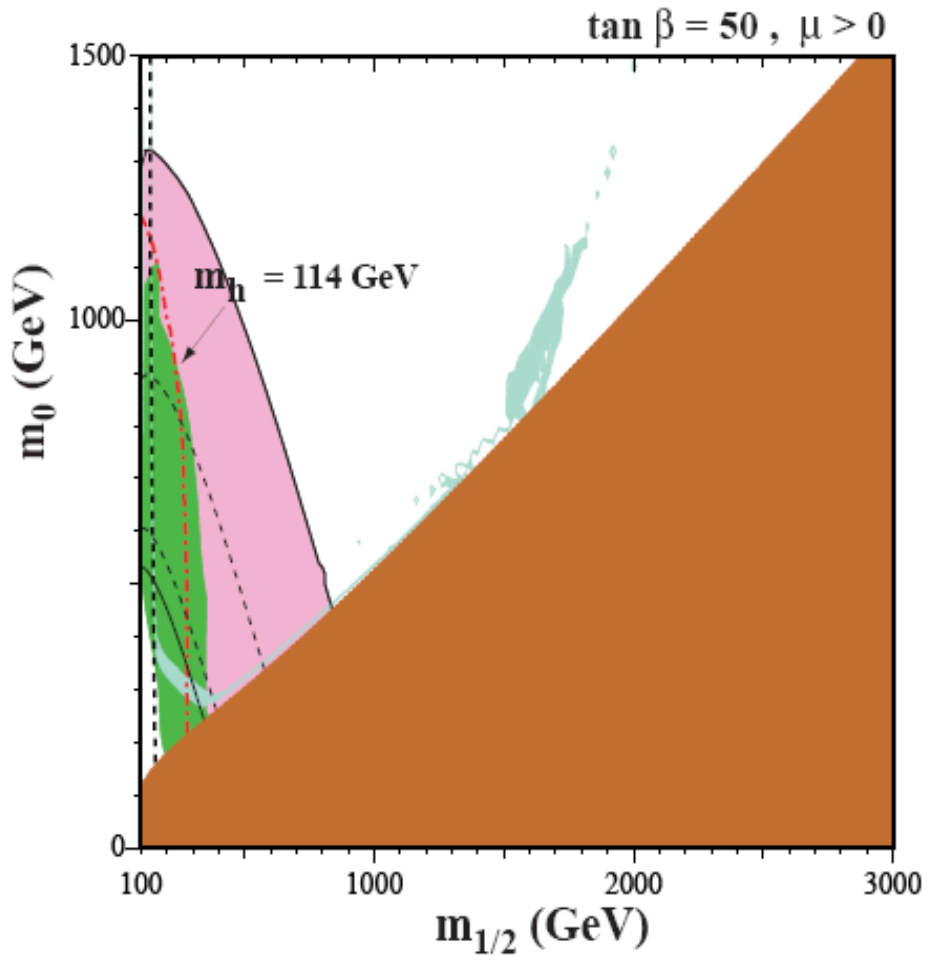
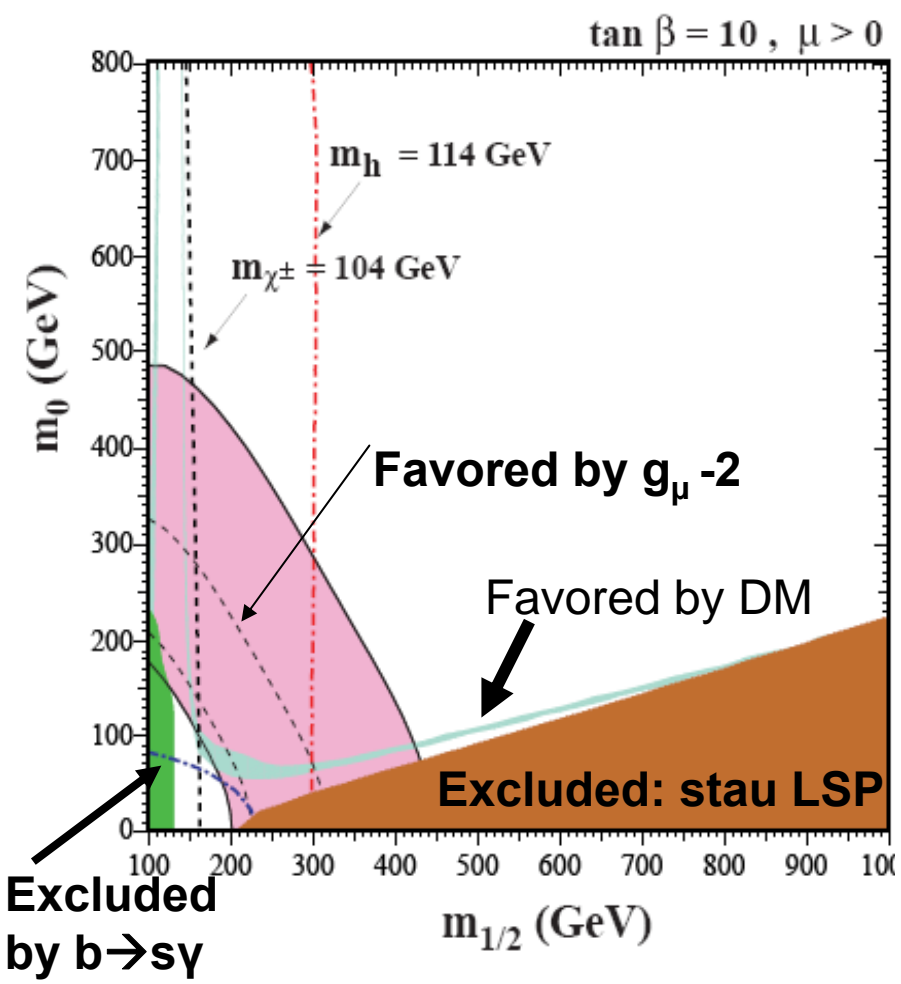


“Stoppers” in ATLAS/CMS caverns:

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

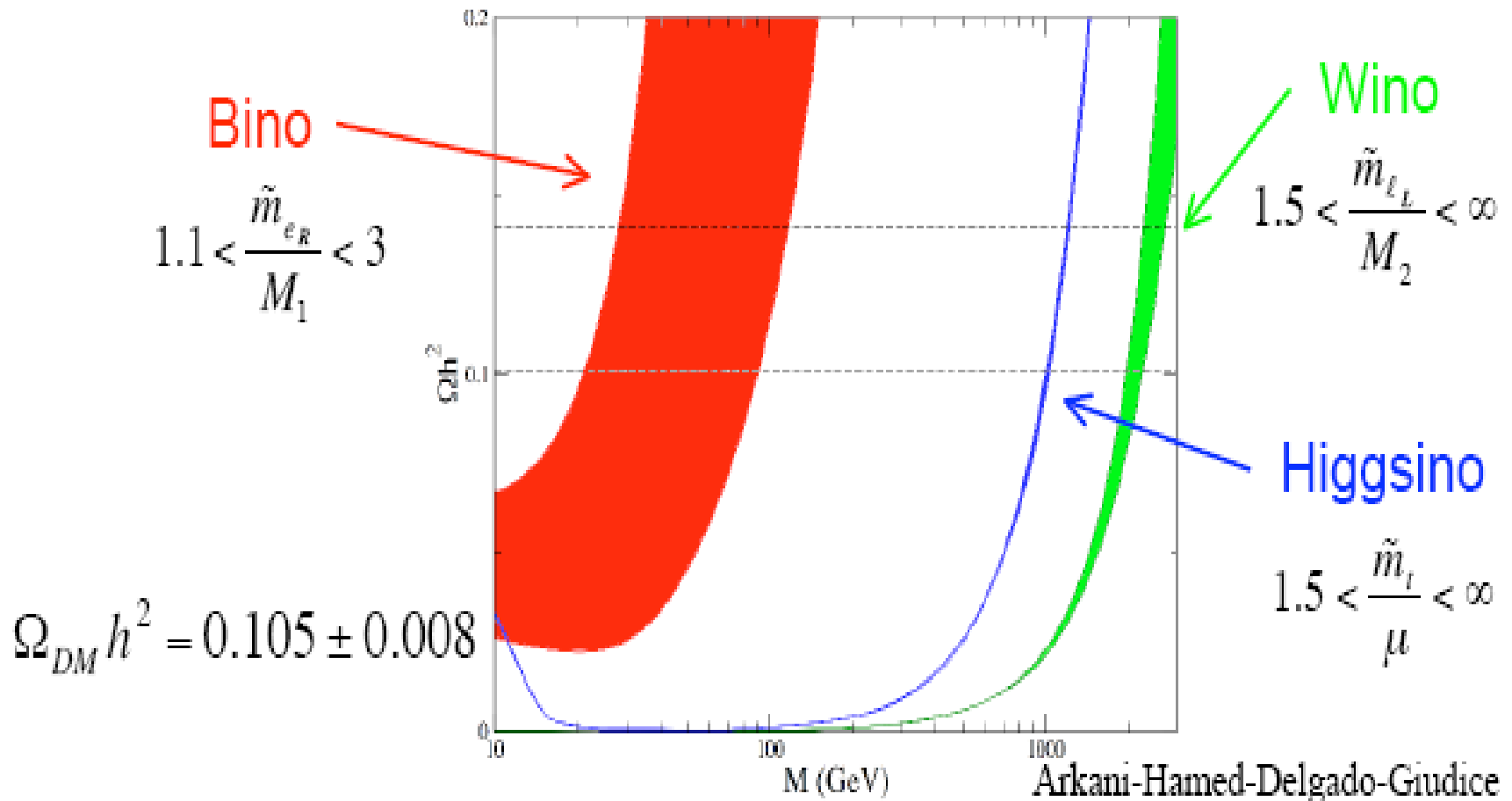
G. GIUDICE

NEUTRALINO LSP IN THE **CONSTRAINED MSSSM**: A VERY SPECIAL SELECTION IN THE PARAMETER SPACE?



Ellis, Olive, Santoso, Spanos

After LEP: tuning of the SUSY param.
at the % level to correctly reproduce
the DM abundance: NEED FOR A
“WELL-TEMPERED” NEUTRALINO



MICRO

PARTICLE PHYSICS

GWS STANDARD MODEL

MACRO

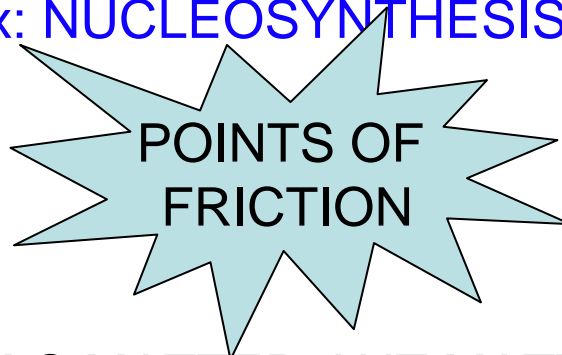
COSMOLOGY

HOT BIG BANG STANDARD MODEL

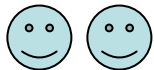


HAPPY MARRIAGE
Ex: NUCLEOSYNTHESIS

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

DM and **NON-STANDARD COSMOLOGIES** **BEFORE NUCLEOSYNTHESIS**

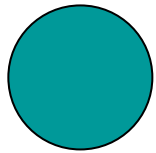
- **NEUTRALINO RELIC DENSITY MAY DIFFER FROM ITS STANDARD VALUE**, i.e. the value it gets when the expansion rate of the Universe is what is expected in Standard Cosmology (EX.: **SCALAR-TENSOR THEORIES OF GRAVITY, KINATION, EXTRA-DIM. RANDALL-SUNDRUM TYPE II MODEL, ETC.**)
- **WIMPS MAY BE “COLDER”**, i.e. they may have smaller typical velocities and, hence, they may lead to smaller masses for the first structures which form **GELMINI, GONDOLO**

LARGER WIMP ANNIHILATION CROSS-SECTION IN NON-STANDARD COSMOLOGIES

- Having a Universe expansion rate at the WIMP freeze-out larger than in Standard Cosmology → possible to provide a DM adequate WIMP population even in the presence of a larger annihilation cross-section (Catena, Fornengo, A.M., Pietroni)
- Possible application to increase the present DM annihilation rate to account for the PAMELA results in the DM interpretation (instead of other mechanisms like the Sommerfeld effect or a nearby resonance)



DO THEY "KNOW" EACH OTHER?



DIRECT INTERACTION ϕ (quintessence) WITH DARK MATTER

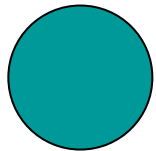


DANGER:

ϕ Very LIGHT

$m\phi \sim H_0^{-1} \sim 10^{-33} \text{ eV}$

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



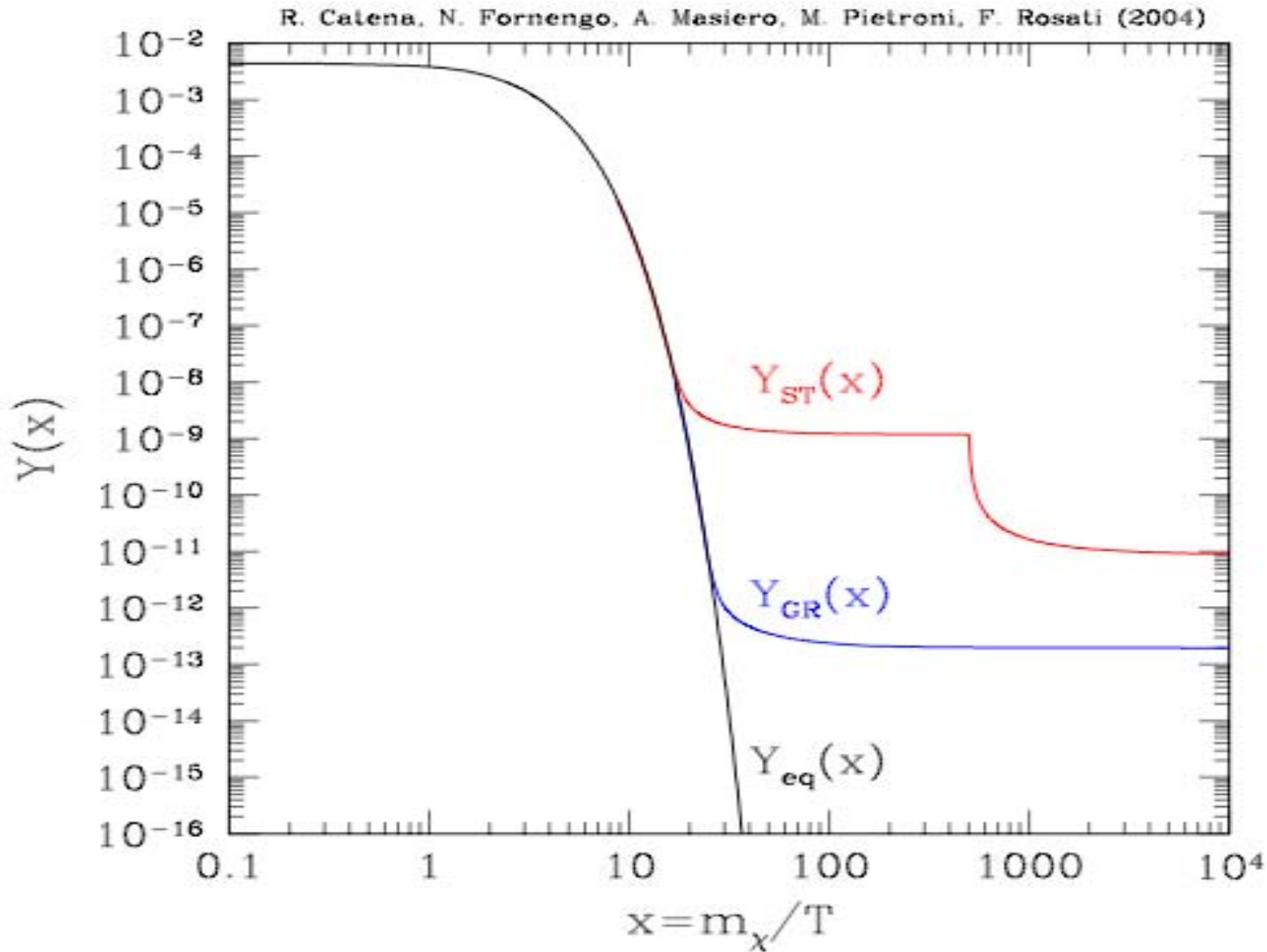
INFLUENCE OF ϕ ON THE NATURE AND THE ABUNDANCE OF CDM

Modifications of the standard picture of
WIMPs FREEZE - OUT

CDM CANDIDATES

CATENA, FORNENGO, A.M.,
PIETRONI, SHELCKE

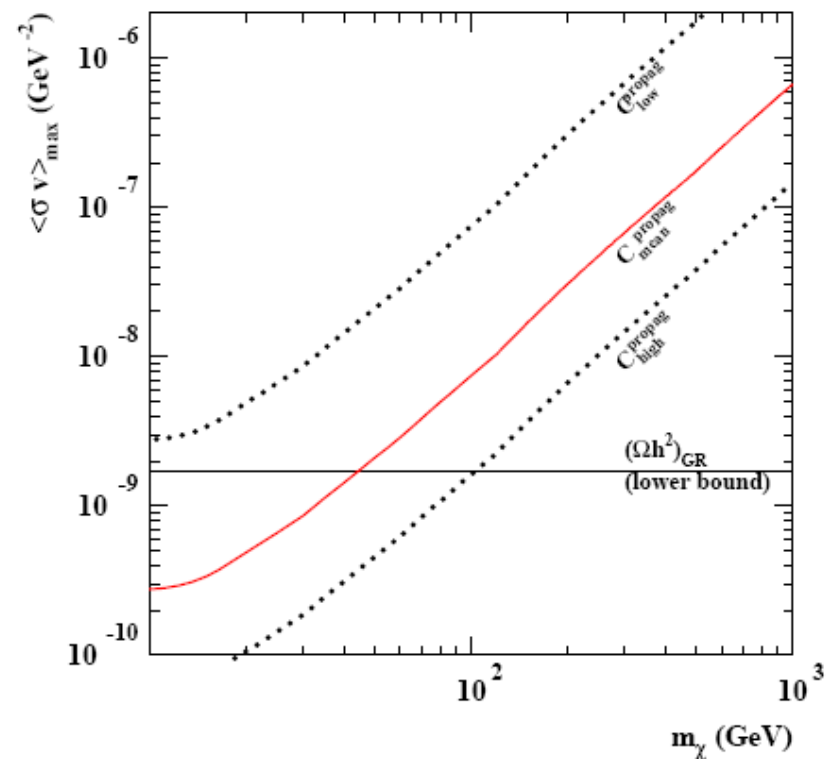
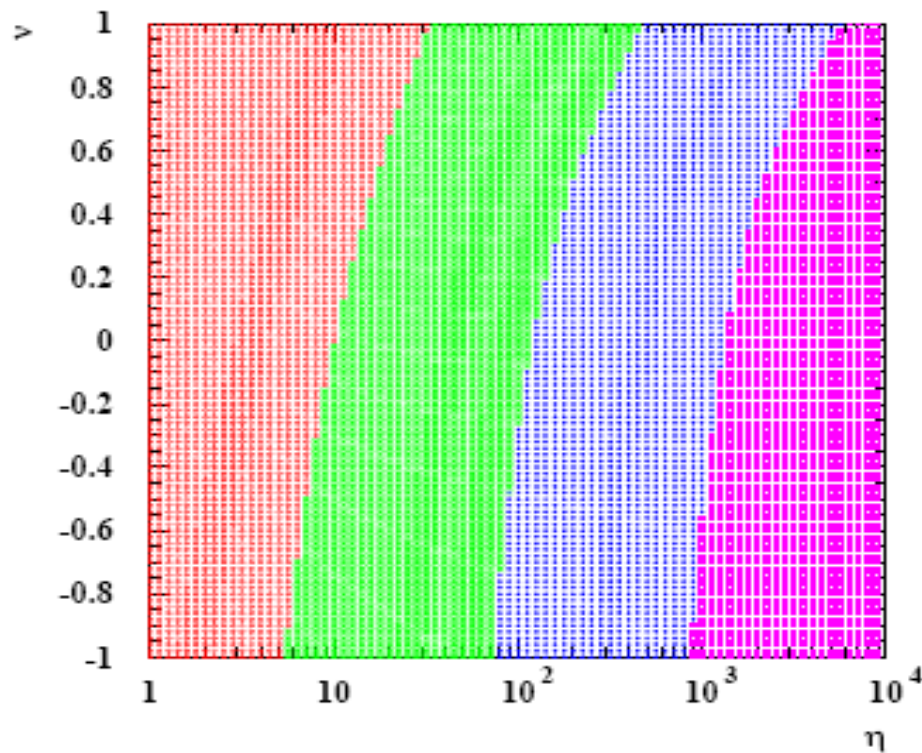
NEUTRALINO RELIC ABUNDANCE IN GR AND S-T THEORIES OF GRAVITY



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

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

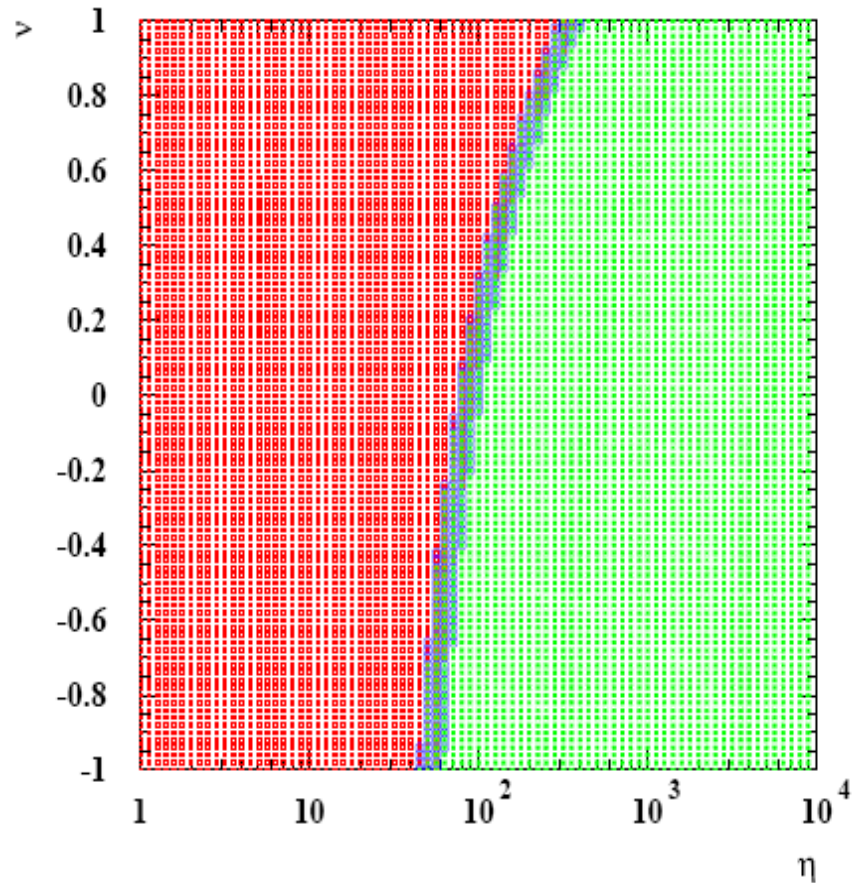
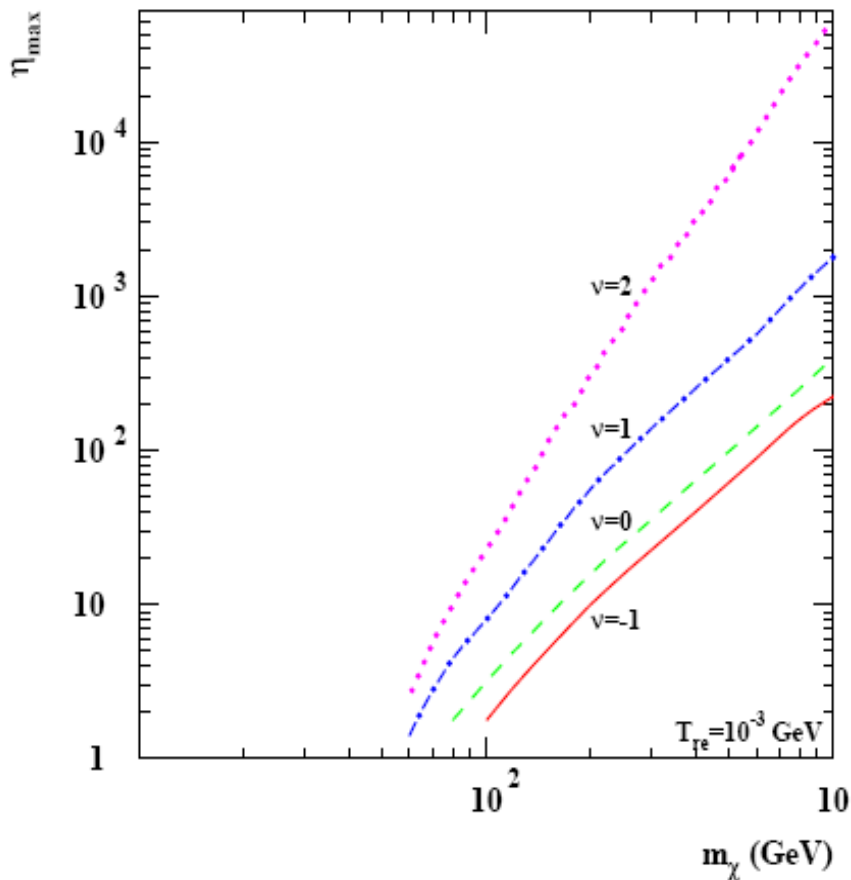
$$A(T) = 1 + \eta \left(\frac{T}{T_f} \right)^\nu \tanh \left(\frac{T - T_{\text{re}}}{T_{\text{re}}} \right)$$



SHELKE, CATENA, FORNENGO, A.M., PIETRONI

CONSTRAINTS ON THE ENHANCEMENT OF THE UNIV.EXPANSION RATE FROM THE LIMITS ON THE ANTIPROTON ABUNDANCE

SCFMP



DM and NEW PHYSICS

- Are we sure that ***DM is a manifestation of New Physics beyond the Particle Physics SM?*** **YES**
- If yes, how likely is it that such **DM New Physics sits at the Electroweak Scale** (hence being visible at the LHC)? **LIKELY BUT NOT COMPELLING** (because of the “ **WIMP miracle**”)
- Could DM be related to ***New Physics beyond the SM of Cosmology ?*** **POSSIBLE BUT STILL NOT REQUIRED** (***DM accounted for by purely NEW PHYSICS beyond the PARTICLE SM***)
- DM to be detected through direct and indirect DM searches and at the LHC? Wishful thinking or realistic ***potential synergy between accelerator and astroparticle physics?*** **Moderate optimism for the latter option if DM is related to New Physics at the TeV scale** (**WIMP option**)

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

Dark Energy

Proton Decay

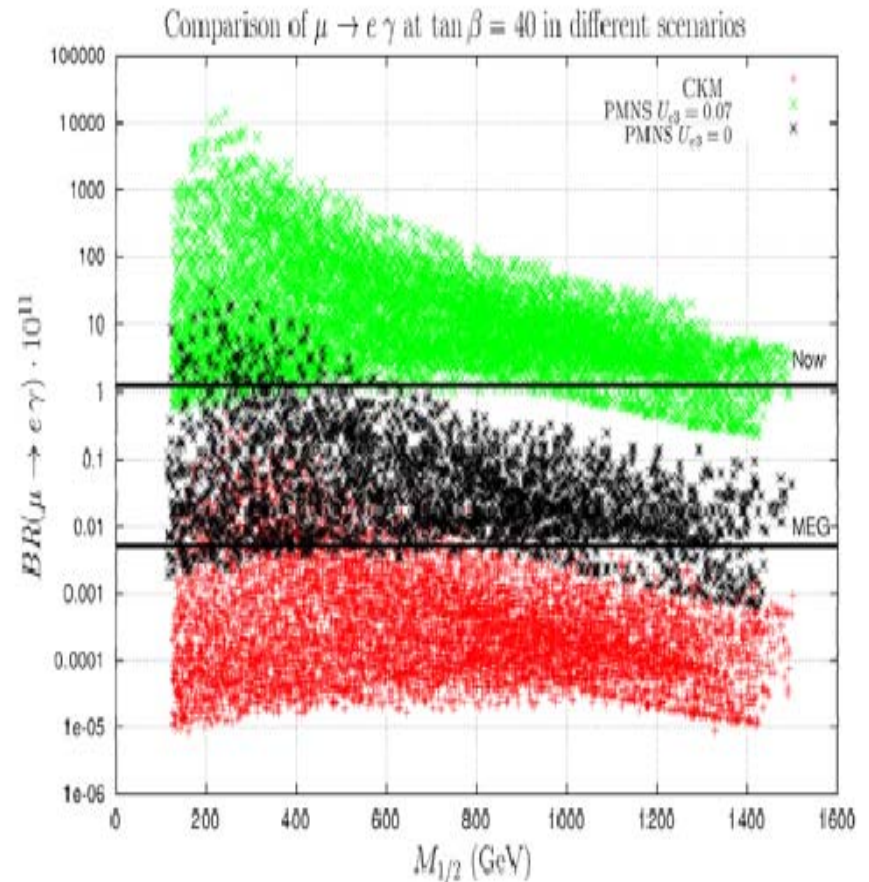
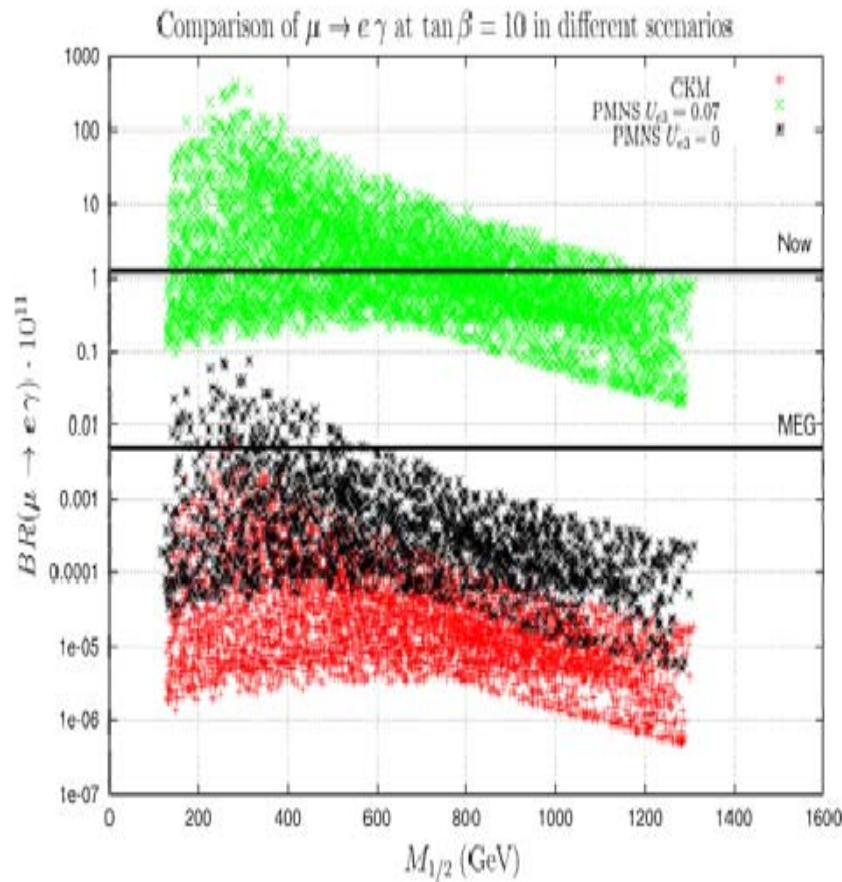
The Intensity Frontier

The Cosmic Frontier



$\mu \rightarrow e\gamma$ in SUSYGUT: past and future

$\mu \rightarrow e\gamma$ in the $U_{e3} = 0$ PMNS case



Calibbi, Faccia, A.M., Vempati

ON THE LHC – DM –FCNC COOPERATION **TO CORNER TeV NEW PHYSICS**

- The traditional competition between direct and indirect (DM,FCNC, CPV) searches to establish who is going to see the new physics first is no longer the priority, rather
- **COMPLEMENTARITY** between direct and indirect searches for New Physics is the key-word
- **Twofold meaning of such complementarity:**
 - i) **synergy in “reconstructing” the “fundamental theory” staying behind the signatures of NP;**
 - ii) **coverage of complementary areas of the NP parameter space (ex.: multi-TeV SUSY physics)**

SLOW “DECOUPLING” of NEW PHYSICS EFFECTS in DM and FCNC SEARCHES w.r.t. the DIRECT ACCELERATOR SEARCHES.