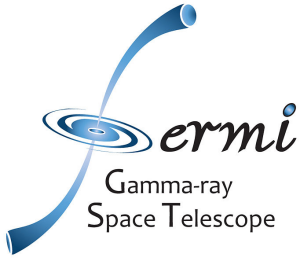


Stefano Profumo

UC Santa Cruz

Santa Cruz Institute for Particle Physics

Affiliated Member, Fermi Collaboration

Quantum-Cosmos Interface: Dark Matter & Baryogenesis

UCSC - Physics 205

Monday March 3, 2014

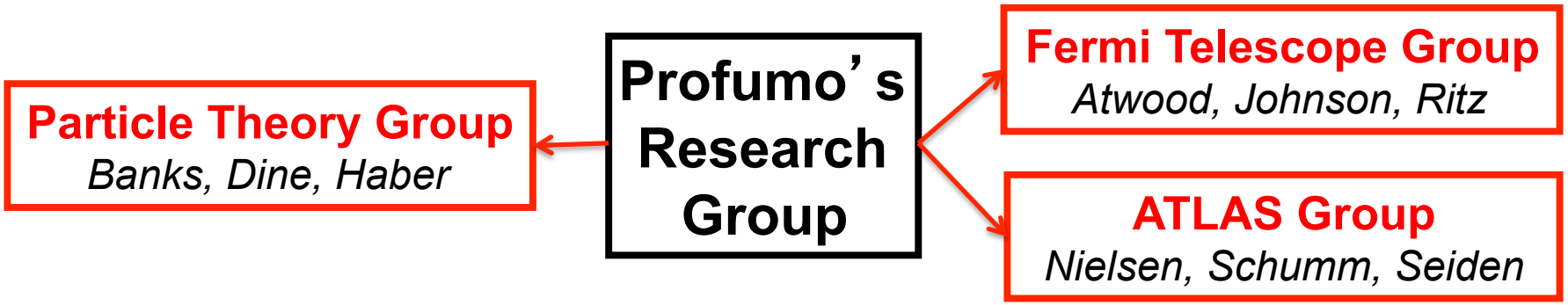
- ✓ PhD **Theoretical Particle Physics** (2004)
  International School for Advanced Studies (SISSA-ISAS), Trieste, Italy

- ✓ Postdoc, FSU and California Institute of Technology (2005-2007)
  Theoretical Astrophysics and Particle Physics

- ✓ Joined **UCSC Physics** Faculty (Assistant Professor, 2007-2011, Associate Professor, July 2011-)

- ✓ Research funded by Department of Energy (Outstanding Junior Investigator Award), National Science Foundation, NASA

- ✓ **SCIPP Deputy Director** for **Theory** (July 2011-)

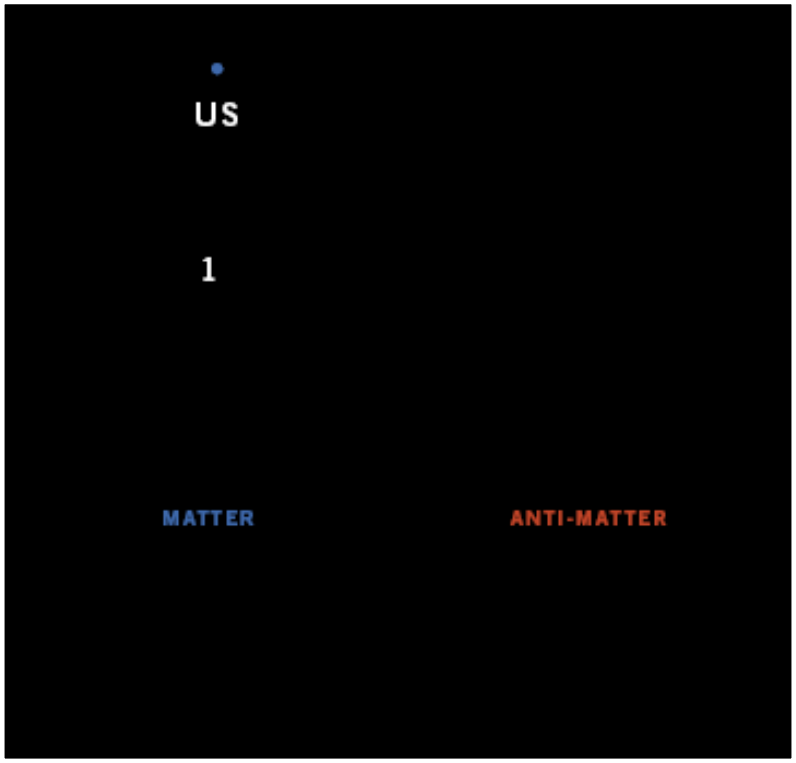


Postdocs
- Draper
- Queiroz
- Shepherd
- Gonzalez

Graduate Students
- Linden*
- Wainwright**
- Kozaczuk***
- Cornell — Stephenson-Haskins (w/Dine)
- Carlson — Storm (with Jeltema)
- Coogan — Manning (with Seiden)

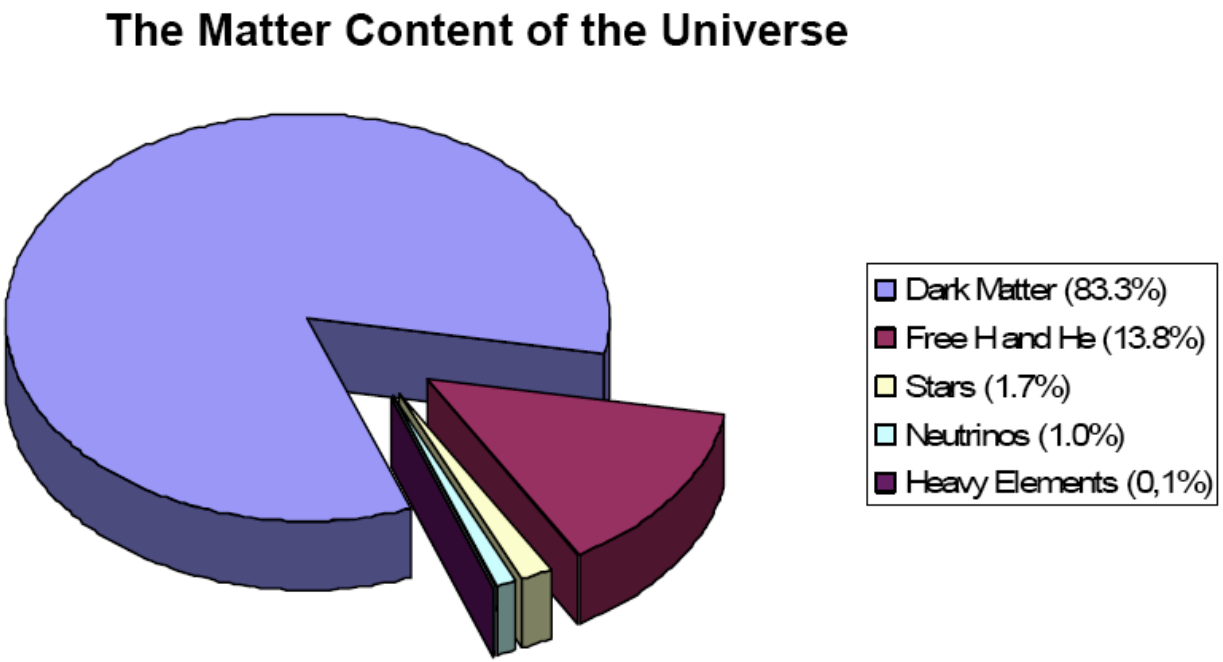
Undergraduate Students
- Dugger (SFSU) Gray (Texas), Stopnitzky (HI)

* *graduated in 2013, NASA Einstein Fellow at U Chicago*
** *graduated in 2013, postdoc at UCSC*
*** *graduated in 2013, postdoc at TRIUMF*

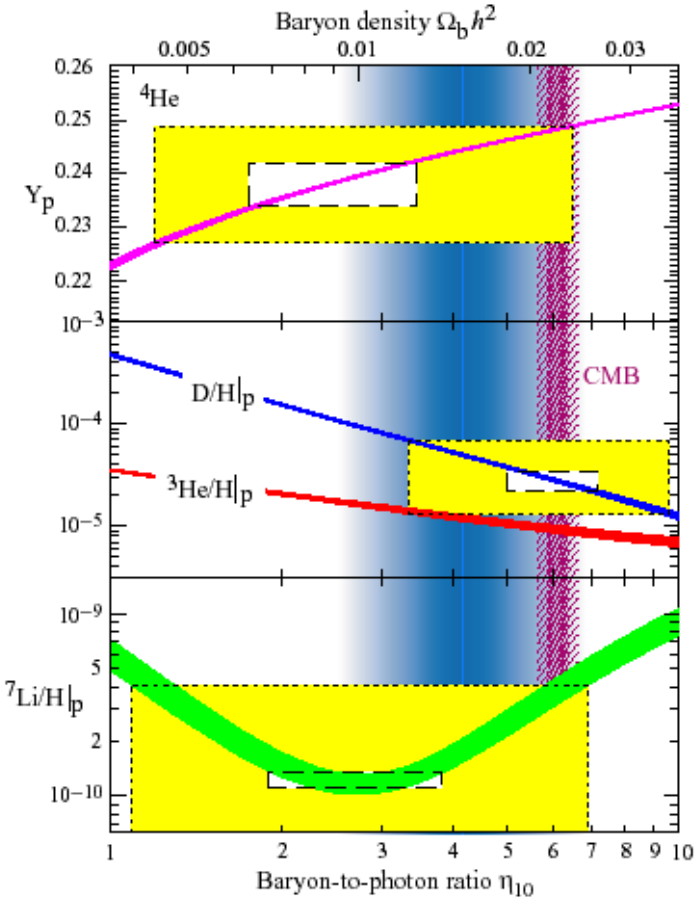


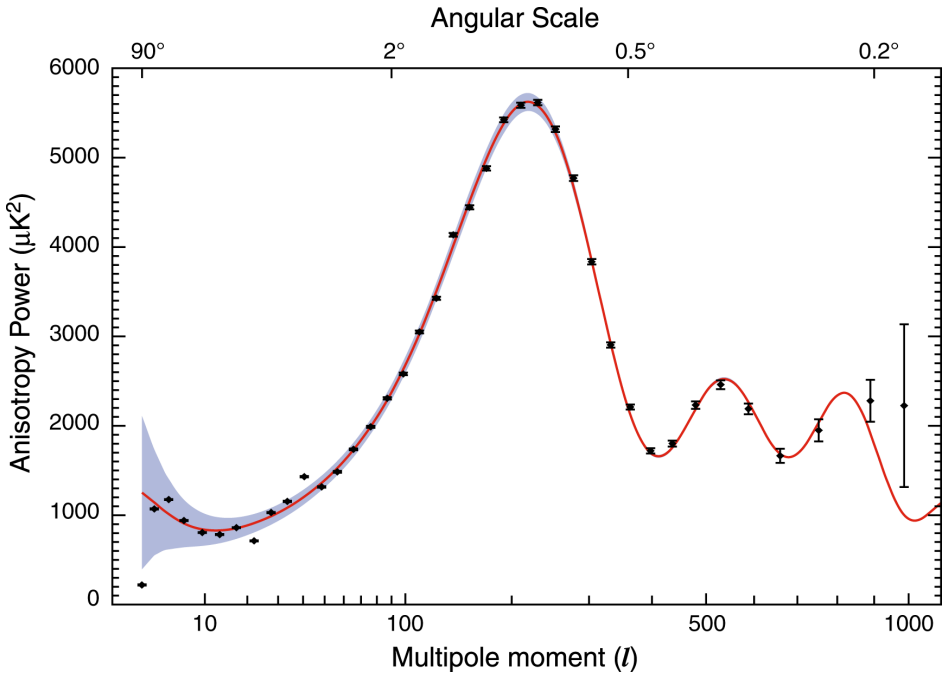
1. What is the origin of the tiny excess of matter over anti-matter?

2. What is the fundamental particle physics nature of Dark Matter?



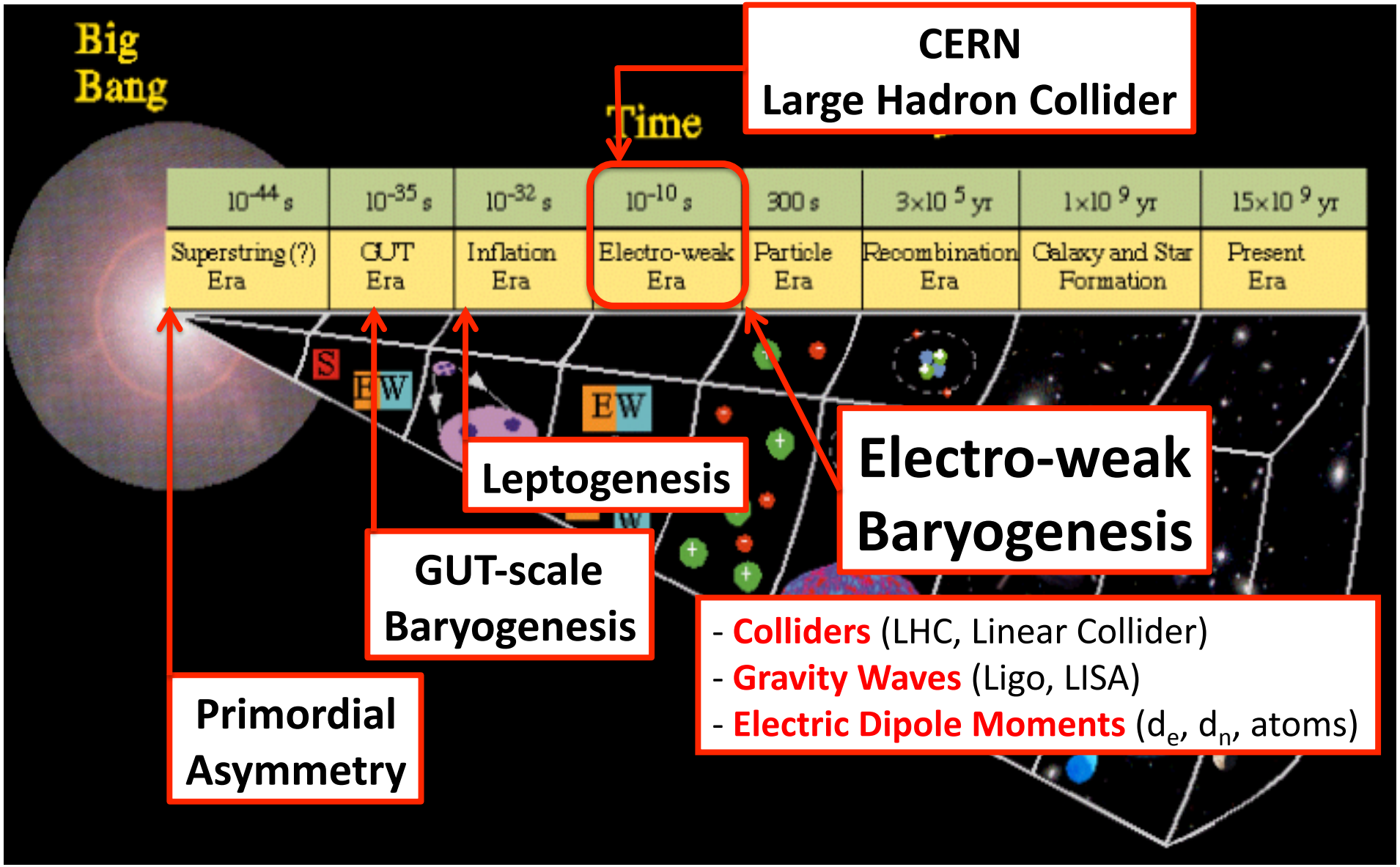
The Matter-Antimatter (Baryon) Asymmetry



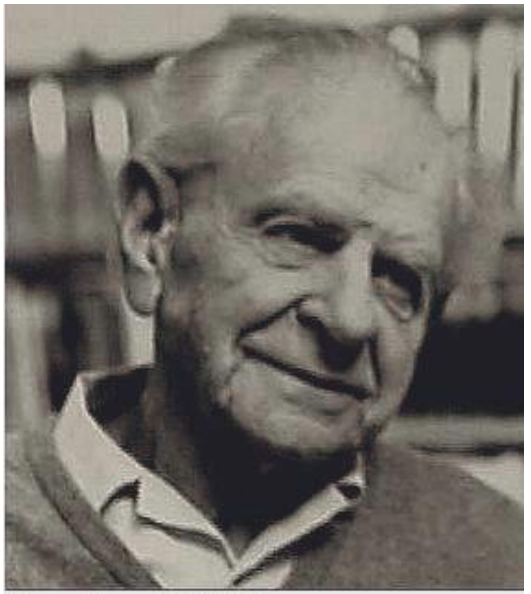


$$\frac{n_{Baryons} - n_{Antibaryons}}{n_{\gamma}} \approx 10^{-10}$$

No "Standard Model" of Baryogenesis!



"In so far as a scientific statement
speaks about reality,
it must be falsifiable:
And in so far as it is not falsifiable
it does not speak about reality"



Sir Karl Popper (1902-1994)

Karl Popper, "*Logik der Forschung*" (1934)
"*The Logic of Scientific Discovery*"

(Supersymmetric) Electro-Weak Baryogenesis: a falsifiable theory

Ingredients of Baryogenesis

(1) ***B***aryon Number violation

If B is conserved, the present BAU can only reflect asymmetric initial conditions

(2) ***C*** and ***CP*** violation

In the absence of a "preference" for matter or antimatter, B-noncoserving interactions will produce baryon and antibaryon excesses at the same rate: no net baryogenesis

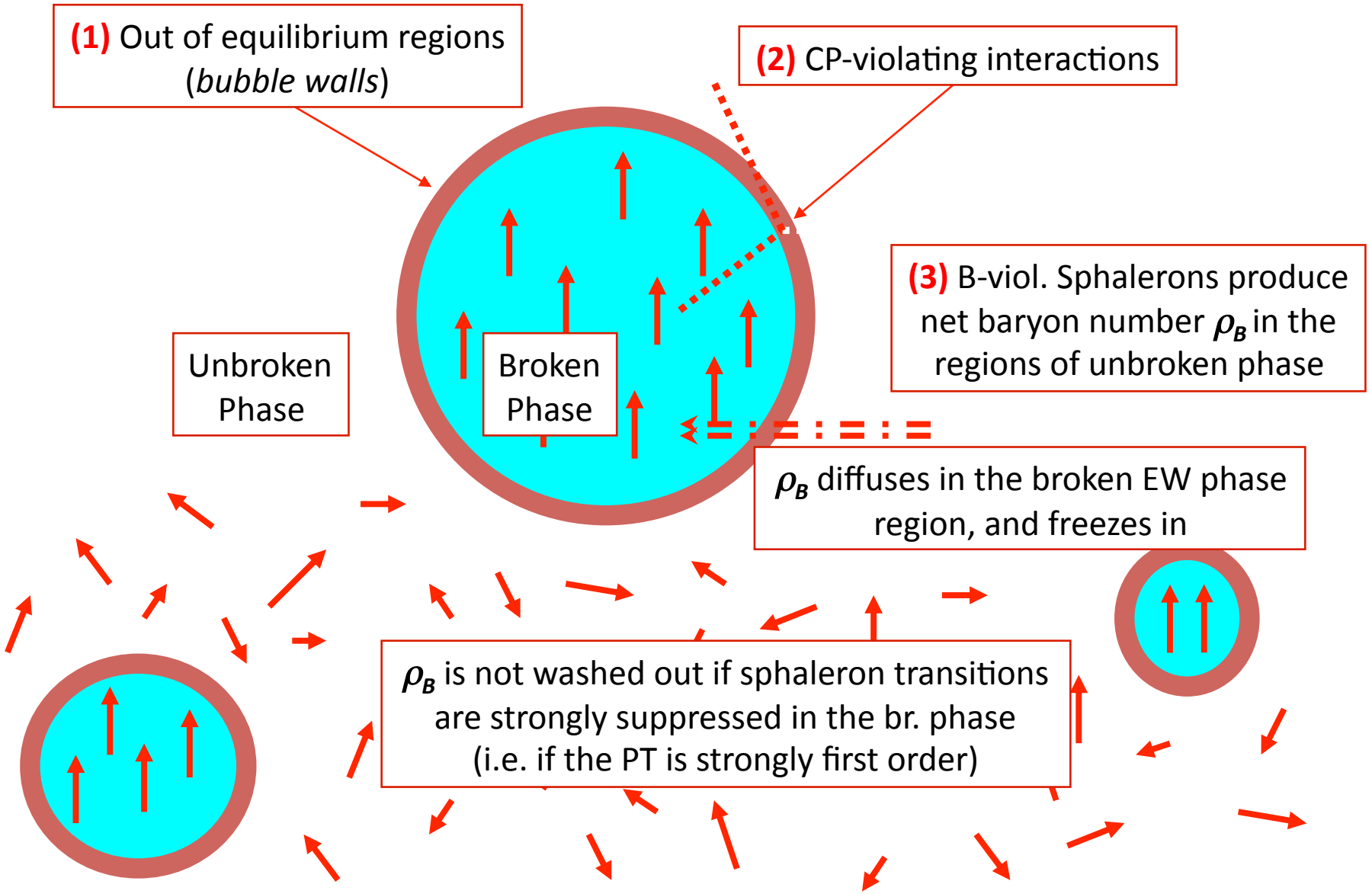
(3) **Out of Equilibrium** conditions

In chemical equilibrium the entropy is maximal when the chemical potential associated with all nonconserved quantum numbers vanishes

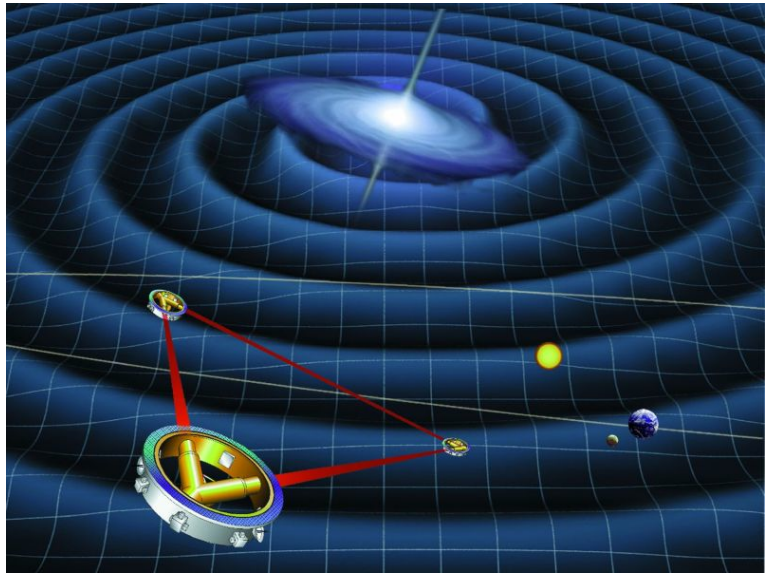
"Sakharov conditions"(*)

(*)A.D.Sakharov, JETP Letters **5**, 24 (1967)

Electro-Weak Baryogenesis

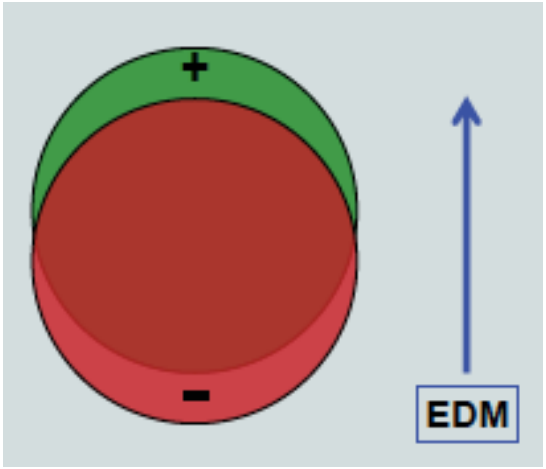


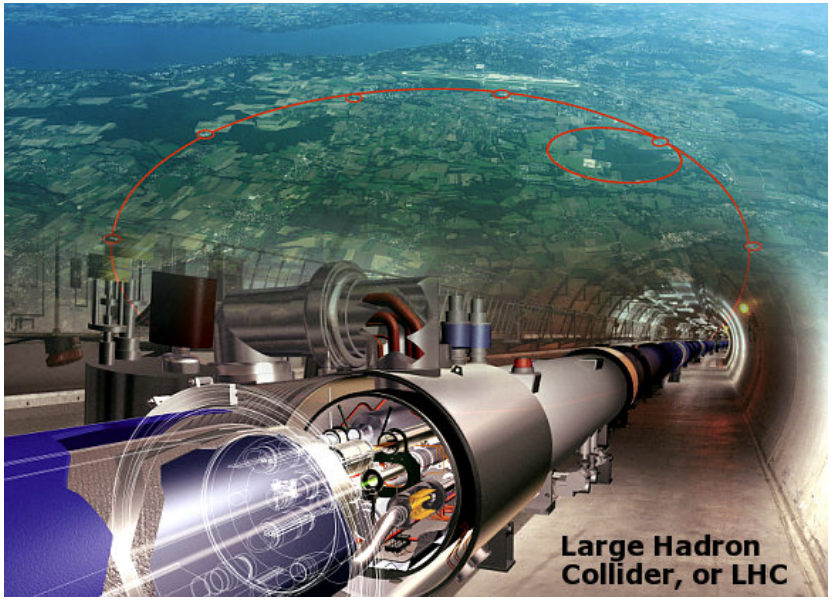
Experimental Tests of Electro-Weak Baryogenesis



Gravity Waves from
Bubble Collisions

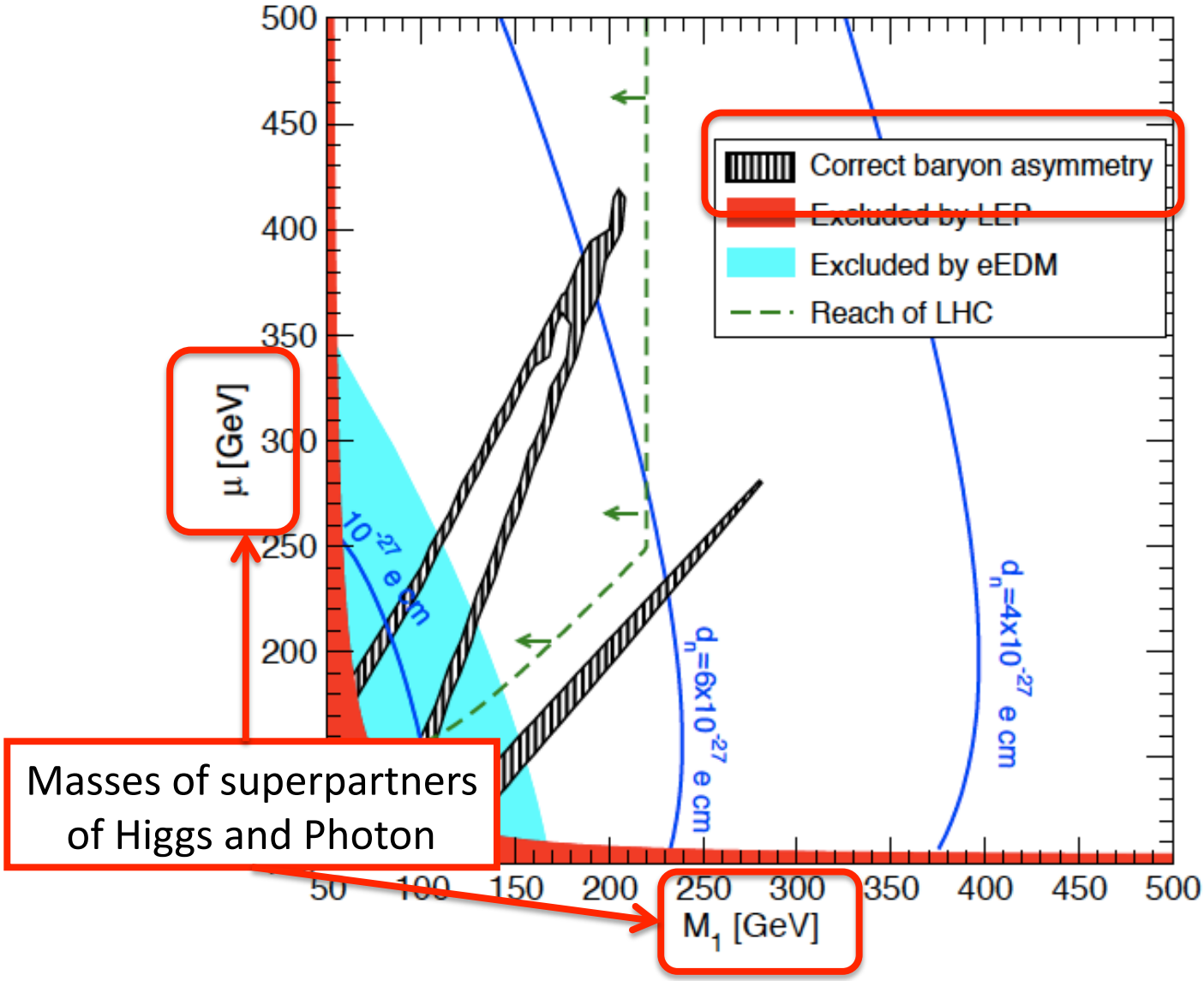
Large
Electric
Dipole
Moments
from CP
violation





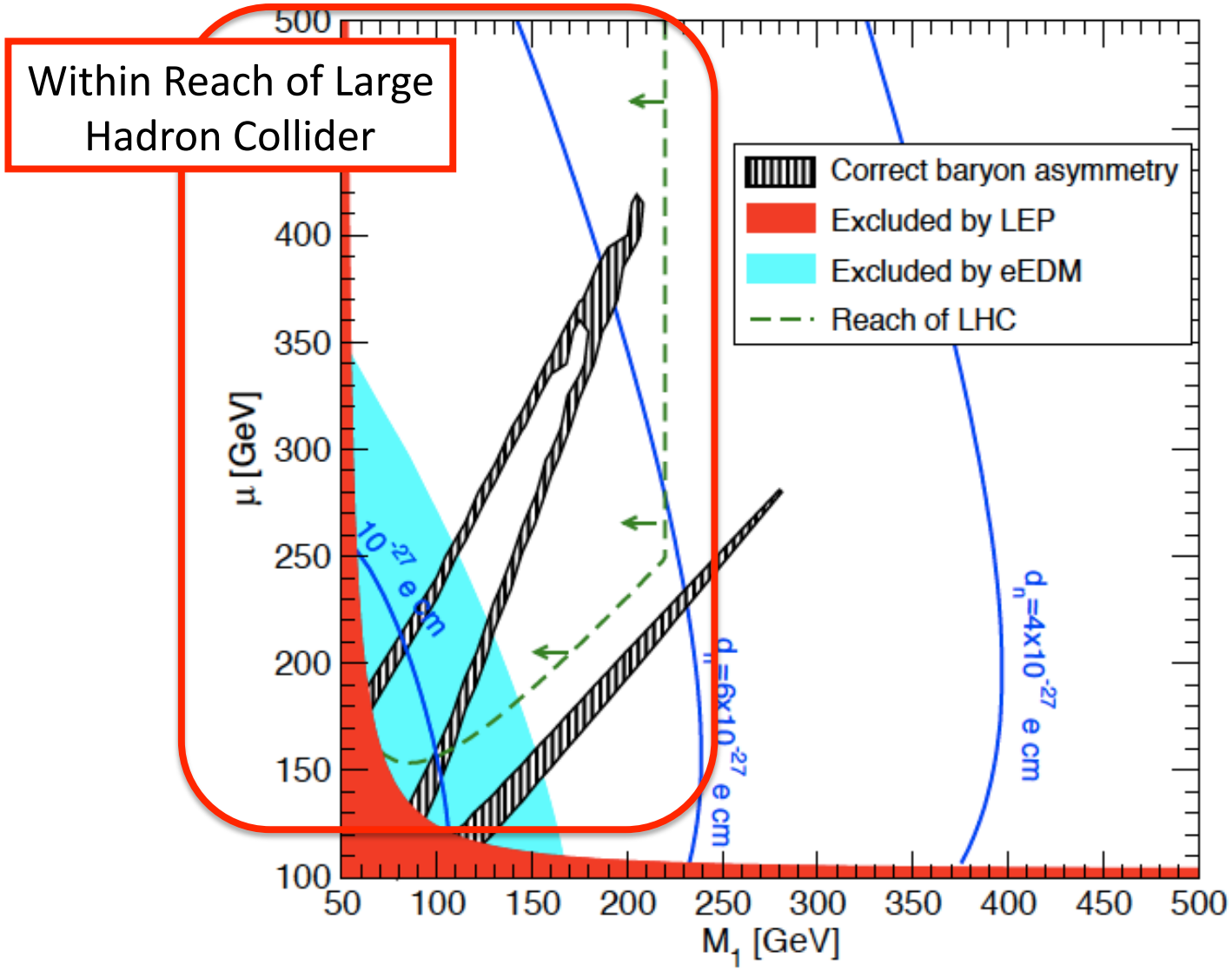
Light superpartners, distinctive
phenomenology at LHC

Electro-Weak Baryogenesis



Cirigliano, Profumo and Ramsey-Musolf, JHEP 2009; DoE NP Long Range Plan

Electro-Weak Baryogenesis



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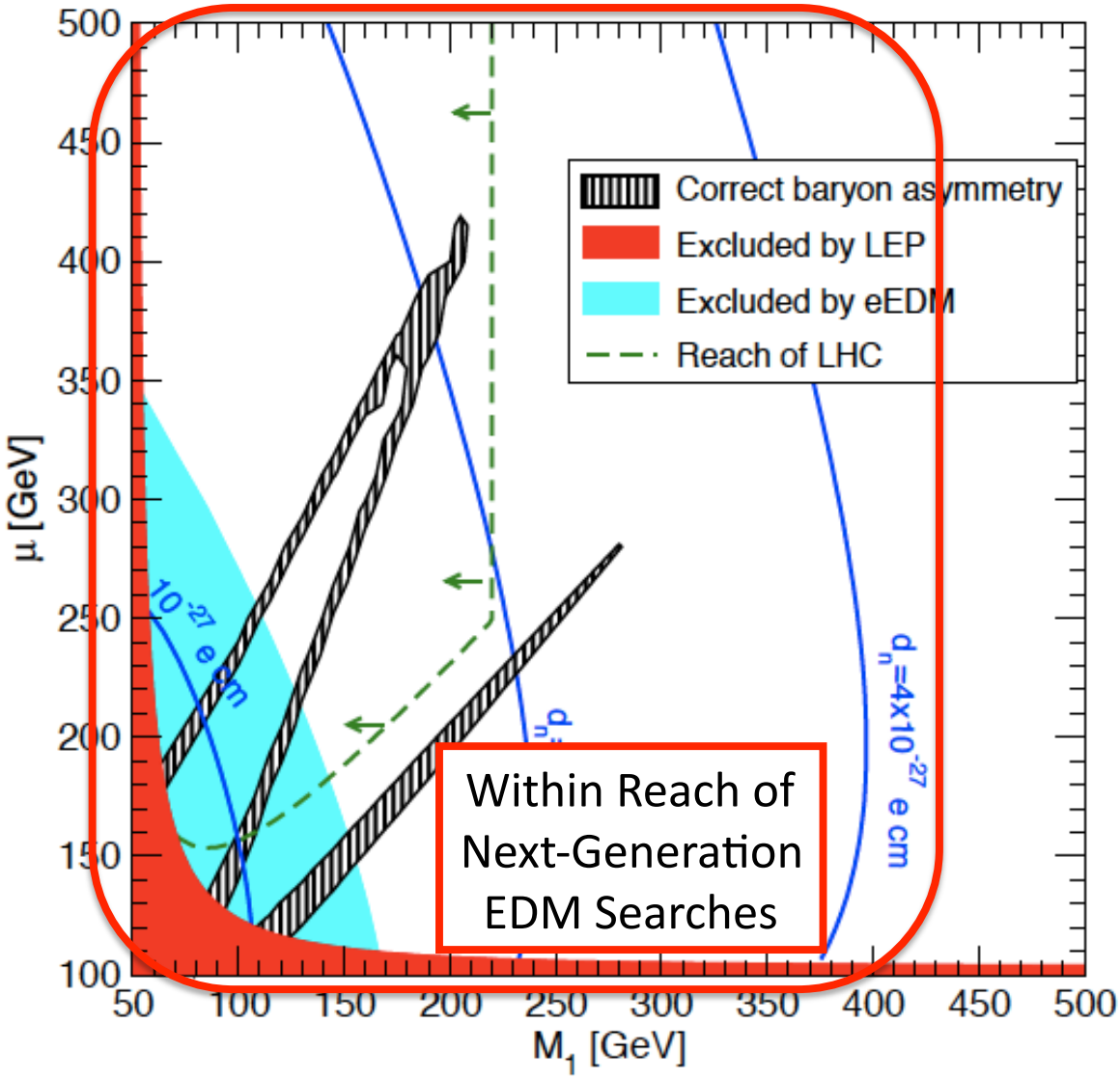
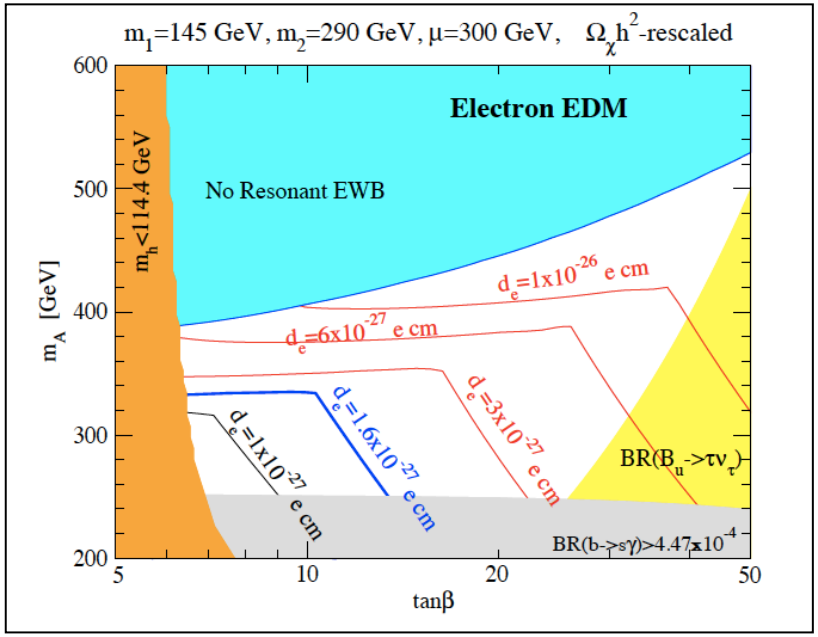


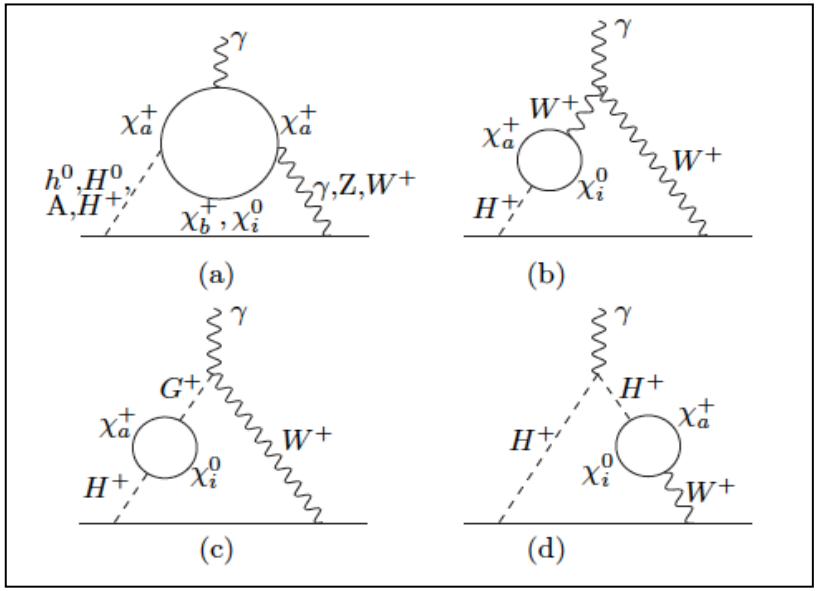
Cirigliano, Profumo and Ramsey-Musolf, JHEP 2009; DoE NP Long Range Plan

Electro-Weak Baryogenesis: Recent Progress

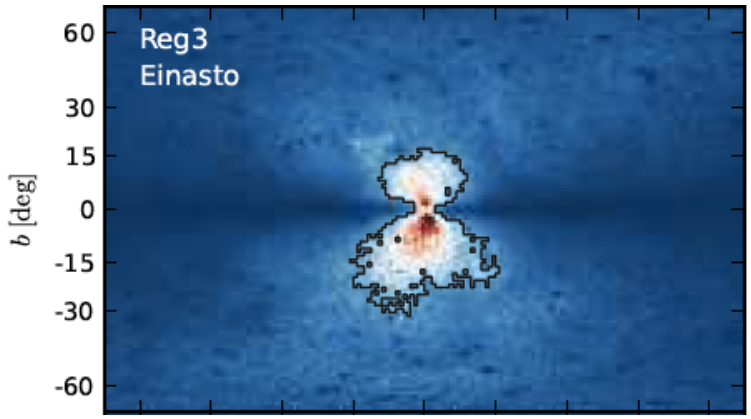
- Comprehensive Phenomenological Analysis of MSSM Electro-weak Baryogenesis

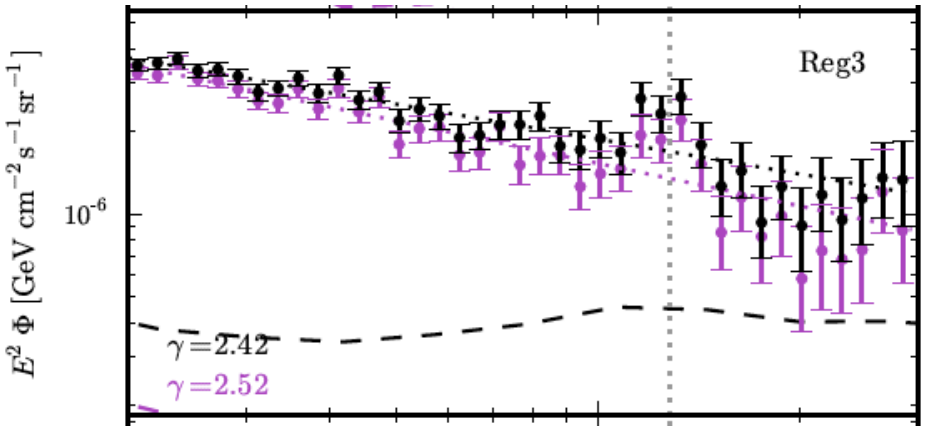


- Complete calculation of electro-weak 2-loop EDM amplitudes
  + publicly available interface to numerical codes (2LEDM)



A model that does everything





- **Line** with right cross section
- Suppressed GR **continuum**
- Right **Higgs** mass
- Right Thermal **Relic Density**

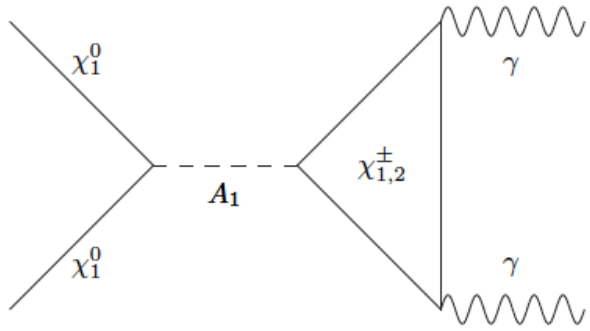
- Successful **EW Baryogenesis**
- Strongly first order **EWPT**
- OK with direct detection
- OK with SUSY searches
- OK with EDM searches

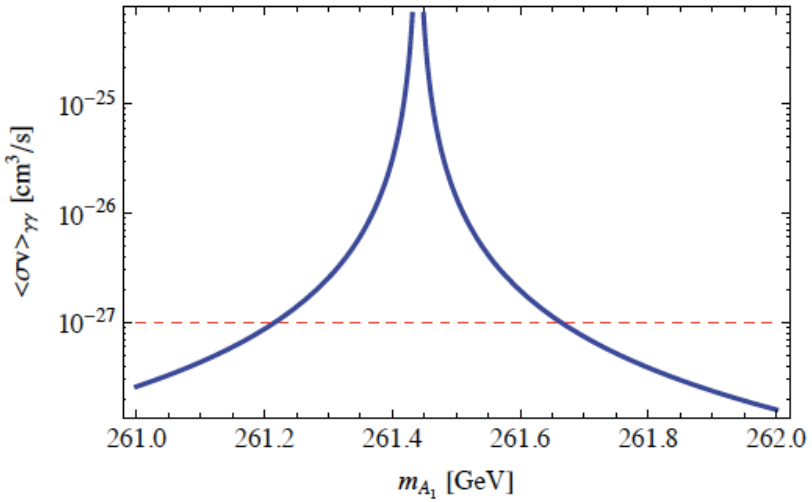
Weniger, 2012; Kozaczuk, Profumo and Wainwright 2013

A model that does everything

$$W = W_{\rm MSSM}|_{\mu=0} + \lambda \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3}\widehat{S}^3,$$

$$-\mathcal{L}^{soft} = -\mathcal{L}^{soft}_{\rm MSSM} + m_S^2\,|S|^2 + \left(\lambda A_\lambda S H_u H_d + \frac{1}{3}\kappa A_\kappa S^3\right) + \text{h.c.}$$





Kozaczuk, Profumo and Wainwright, 2013

A model that does everything…
…across all "three frontiers"!

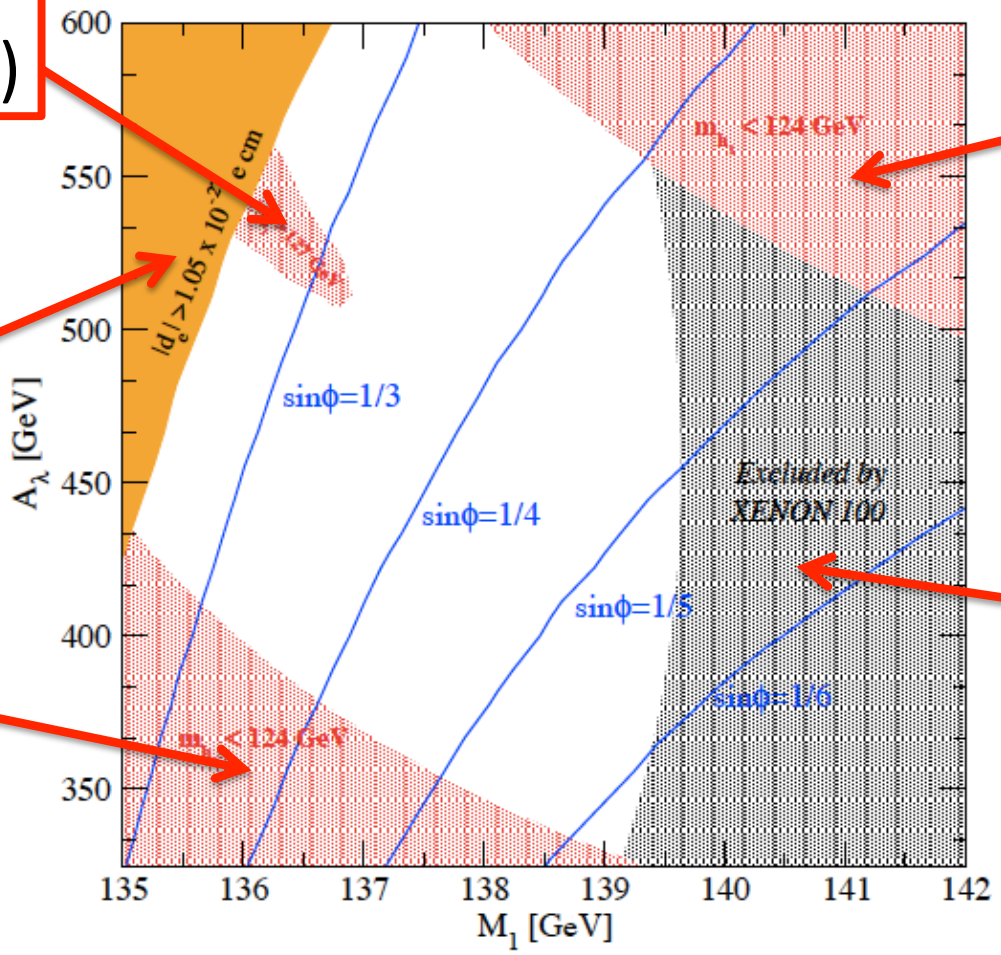
Higgs (too much)

Death by EDM

Higgs

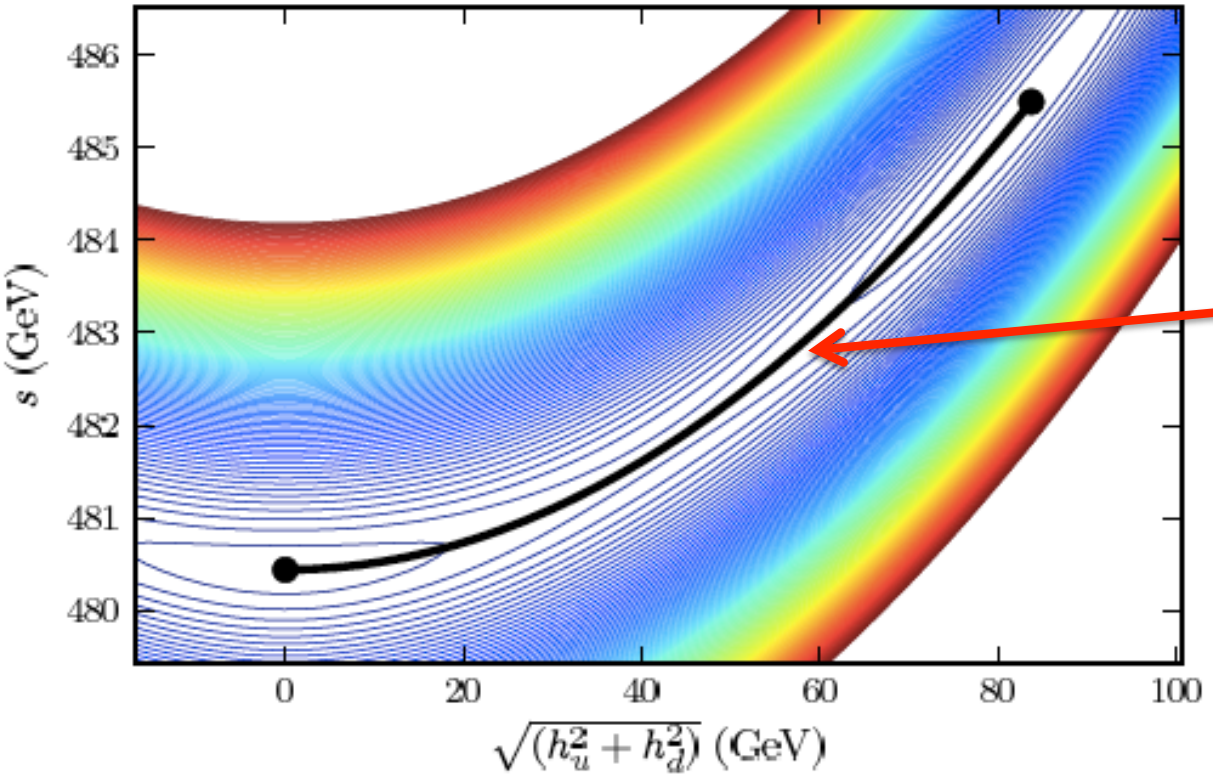
Death by Direct Detection

Higgs



Kozaczuk, Profumo and Wainwright, 2013

A model that does everything

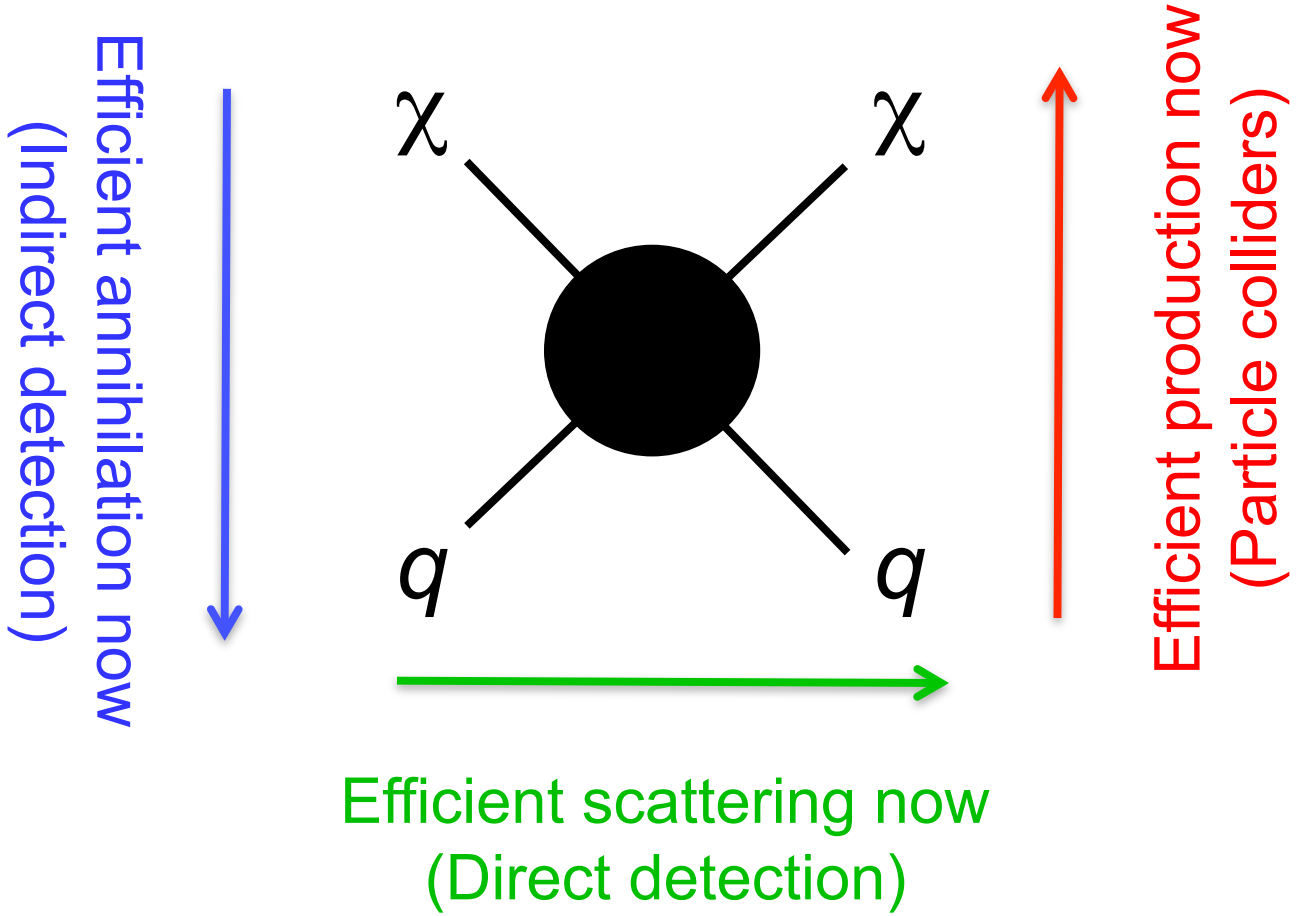


Tunneling Direction in field space

Effective potential at critical temperature
(all NMSSM degrees of freedom included!)
CosmoTransitions

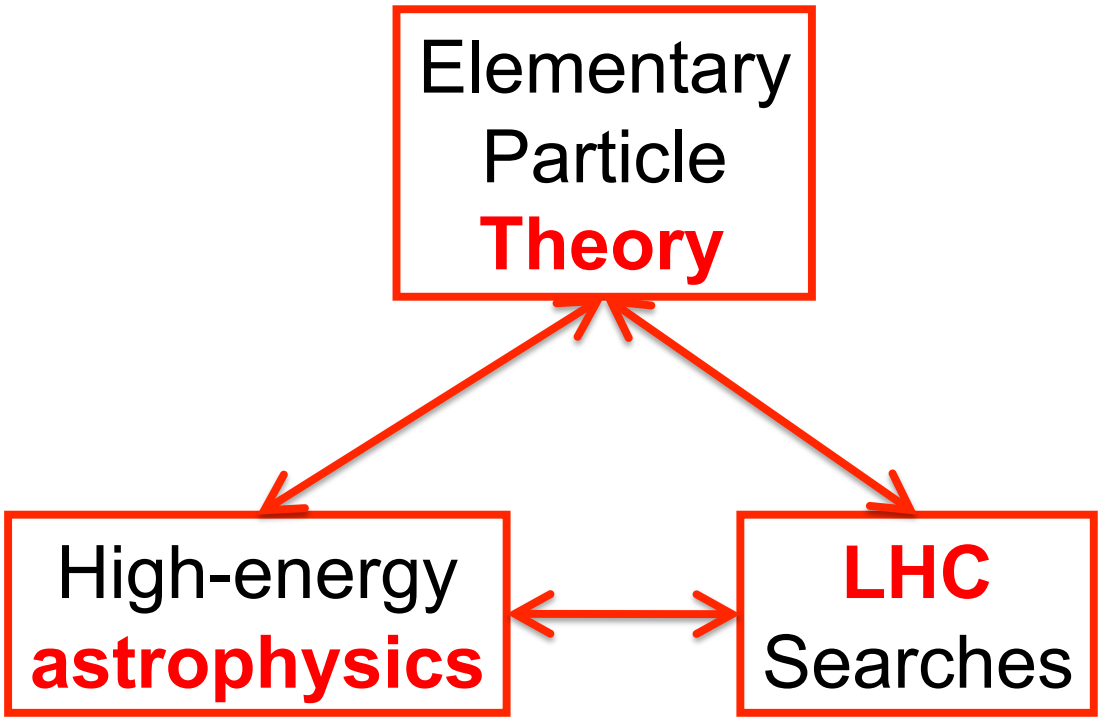
Kozaczuk, Profumo and ***Wainwright****, 2013*

Particle Dark Matter: a multi-pronged approach in a Time of Discovery



Slide Concept: J. Feng

Particle Dark Matter:
a comprehensive approach
for a cross-disciplinary science

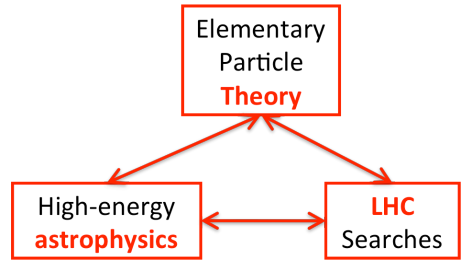


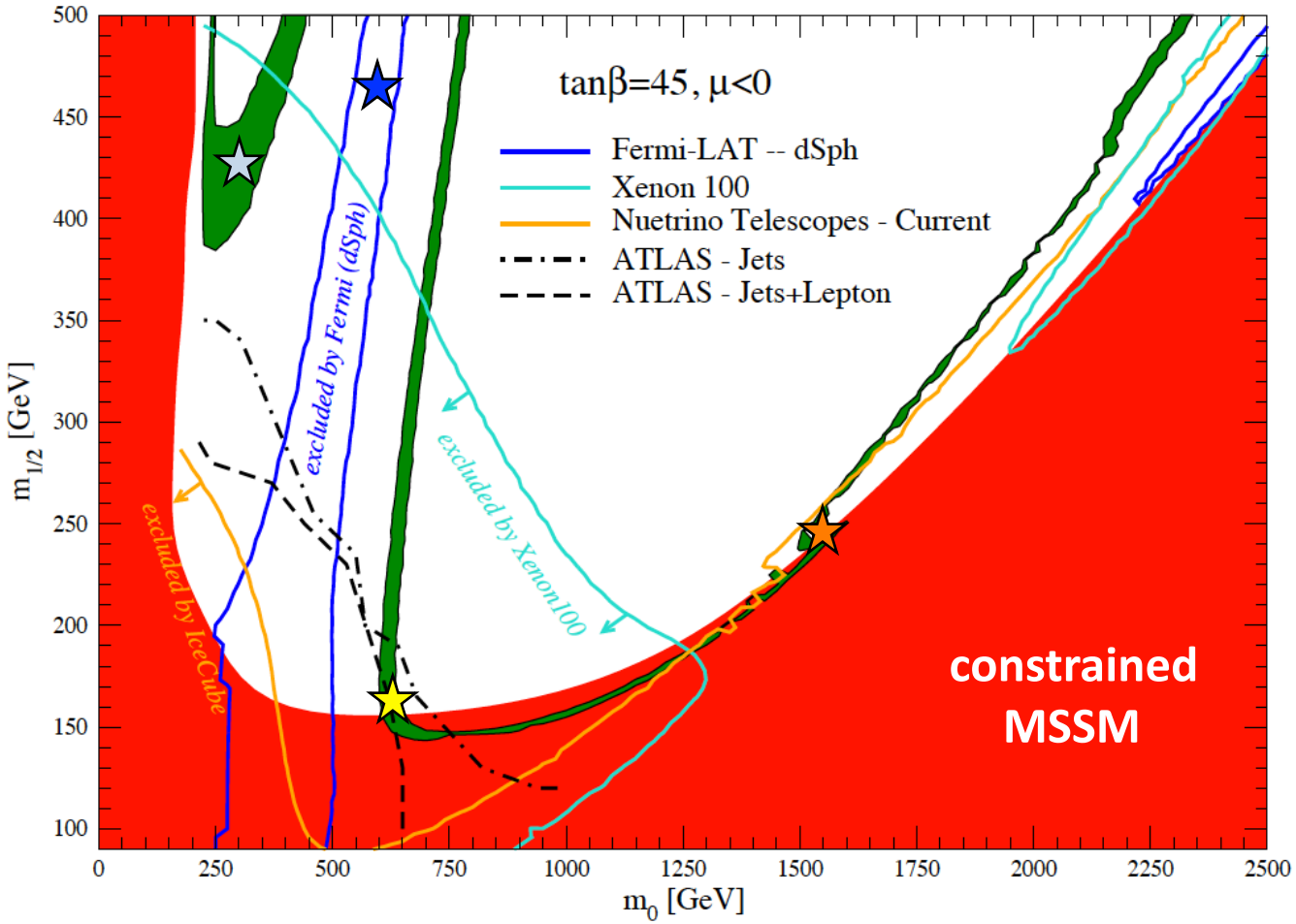
★LHC is probing cosmologically interesting regions

★Only probed by Direct Detection

★Only probed by Neutrino Telescopes

★Only probed by Gamma-Ray Telescopes





*Profumo, arXiv 1105.5162, Phys. Rev. D **84**, 015008 (2011)

Dark Matter in Minimal Universal Extra Dimensions with a Stable Vacuum and the "Right" Higgs

Jonathan M. Cornell,[1,2,3,*] Stefano Profumo,[1,2,†] and William Shepherd[1,2,‡]

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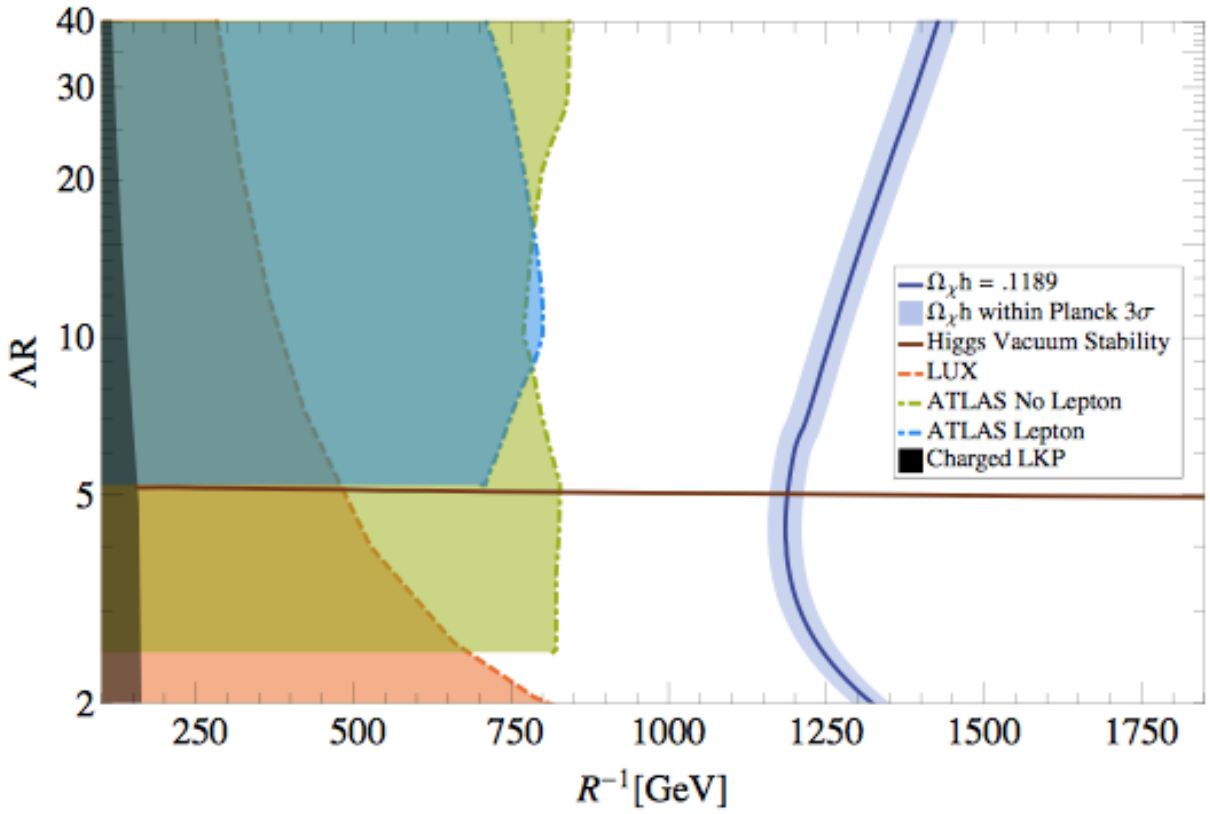

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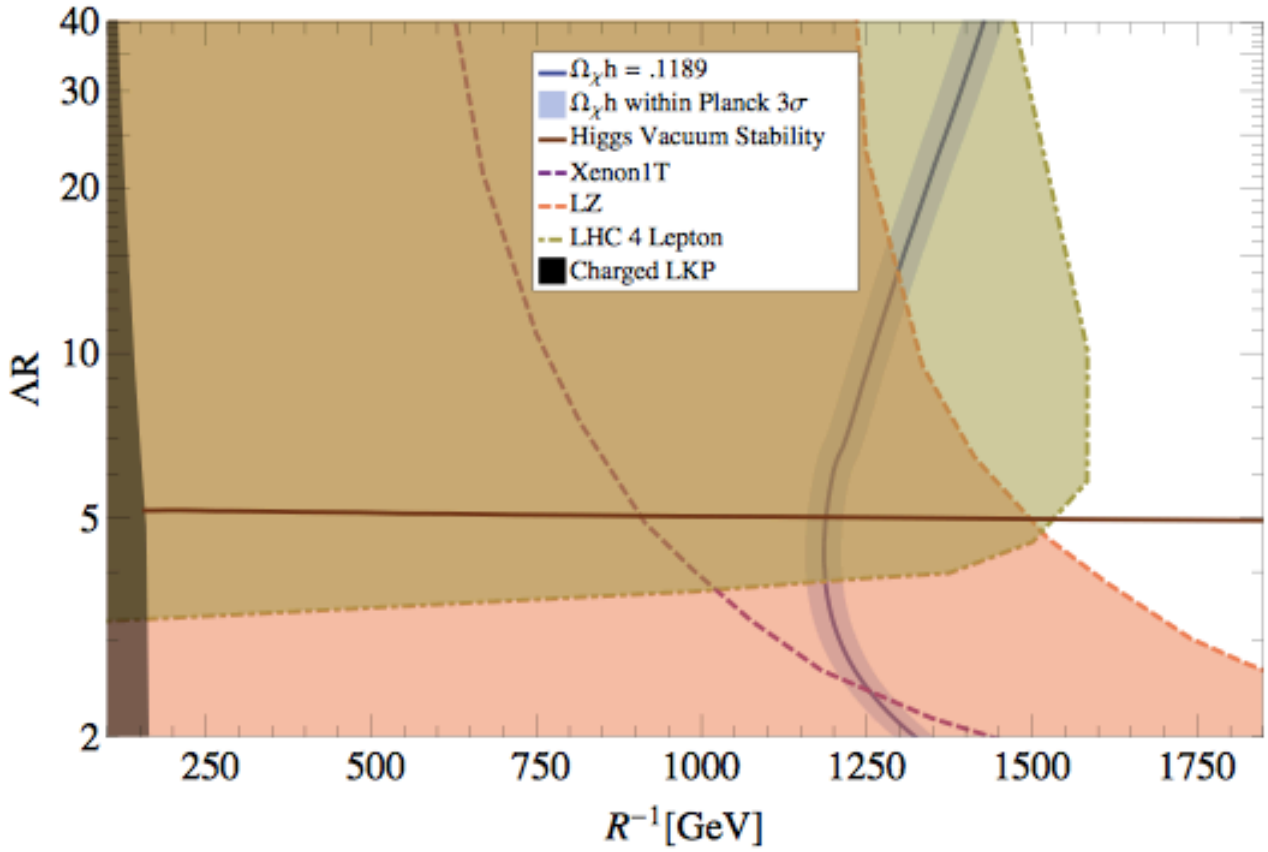
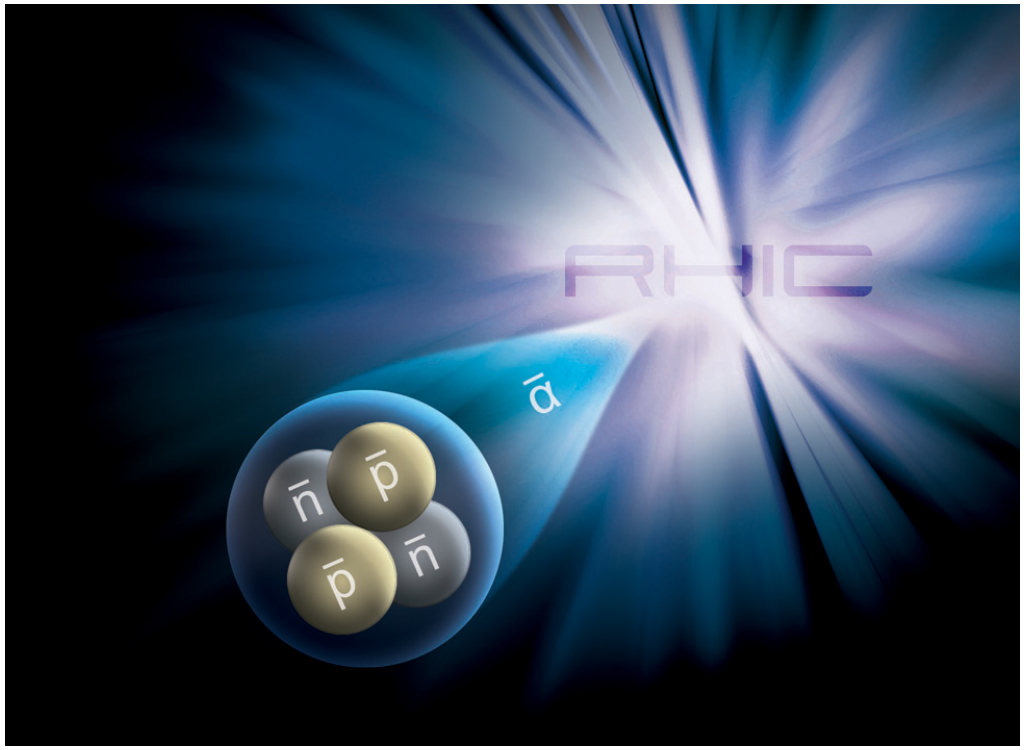


Antihelium from Dark Matter

Eric Carlson,[1,2] Adam Coogan,[1,2,*] Tim Linden,[1,2,3,4,†] Stefano Profumo,[1,2,‡] Alejandro Ibarra,[5,§] and Sebastian Wild[5,¶]

[1] *Department of Physics, University of California, 1156 High St., Santa Cruz, CA 95064, USA*
[2] *Santa Cruz Institute for Particle Physics, Santa Cruz, CA 95064, USA*[**]
[3] *Department of Physics, University of Chicago, Chicago, IL 60637*
[4] *Kavli Institute for Cosmological Physics, Chicago, IL 60637*
[5] *Physik-Department T30d, Technische Universität München, James-Franck-Straße, 85748 Garching, Germany*

(Dated: January 14, 2014)



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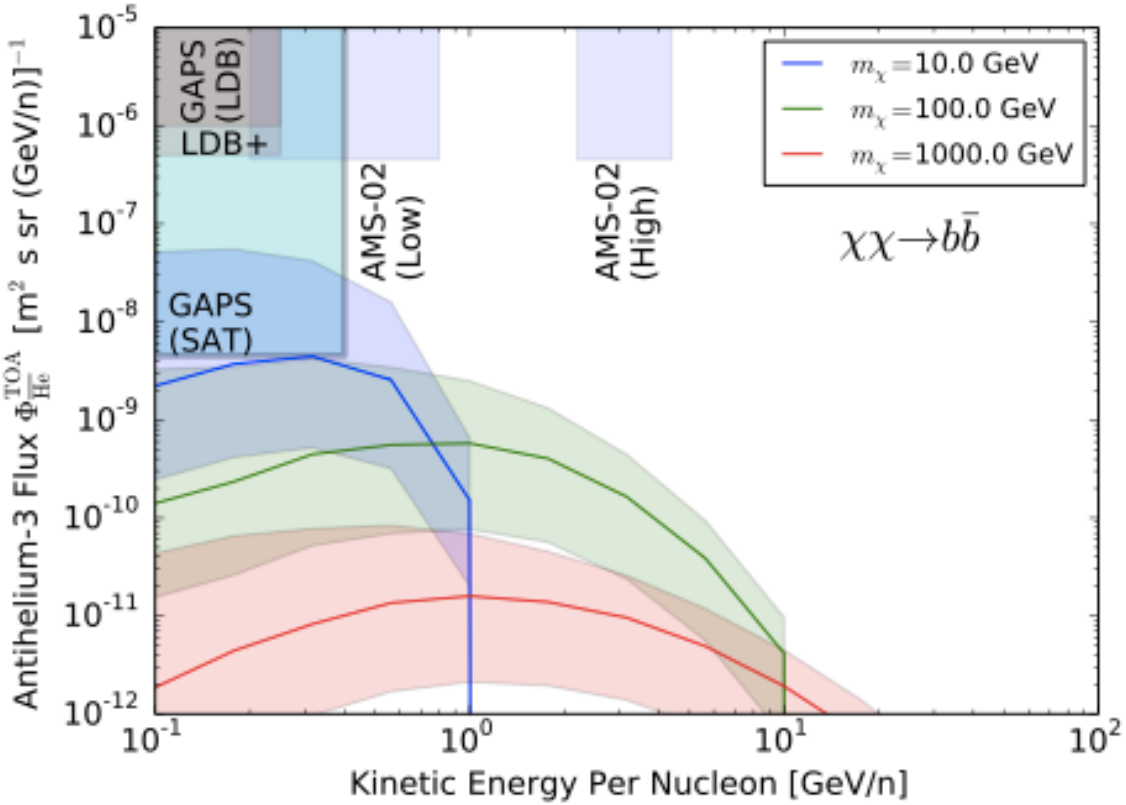
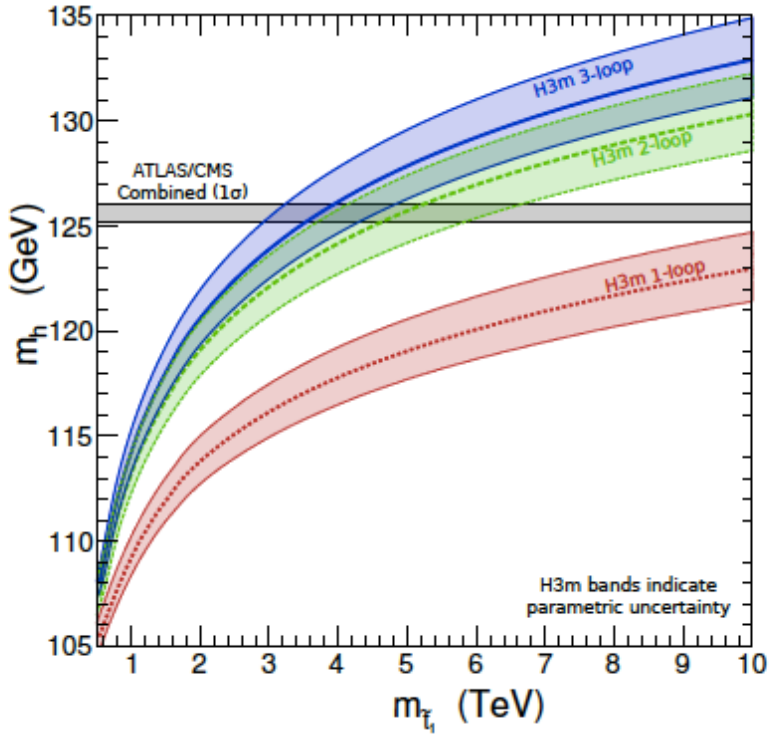
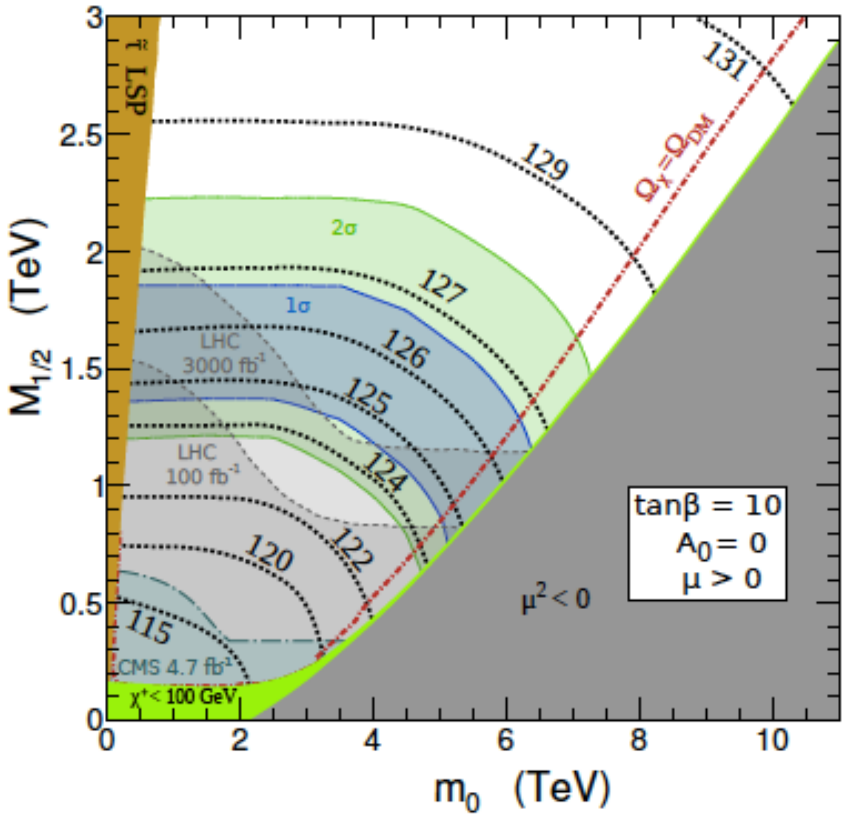


Three-Loop Corrections to the Higgs Boson Mass and Implications for Supersymmetry at the LHC

Jonathan L. Feng,[1] Philipp Kant,[2] Stefano Profumo,[3,4] and David Sanford[5]

[1] *Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA*
[2] *Humboldt-Universität zu Berlin, 12489 Berlin, Germany*
[3] *Department of Physics, University of California, 1156 High Street, Santa Cruz, CA 95064, USA*
[4] *Santa Cruz Institute for Particle Physics, Santa Cruz, CA 95064, USA*
[5] *California Institute of Technology, Pasadena, CA 91125, USA*





Gravitational Waves from Gamma-Ray Pulsar Glitches

Elan Stopnitzky[1, 2, *] and Stefano Profumo[2, 3, †]

[1] *Department of Physics, University of Hawaii at Manoa, 2505 Correa Rd., Honolulu, HI 96822, USA*

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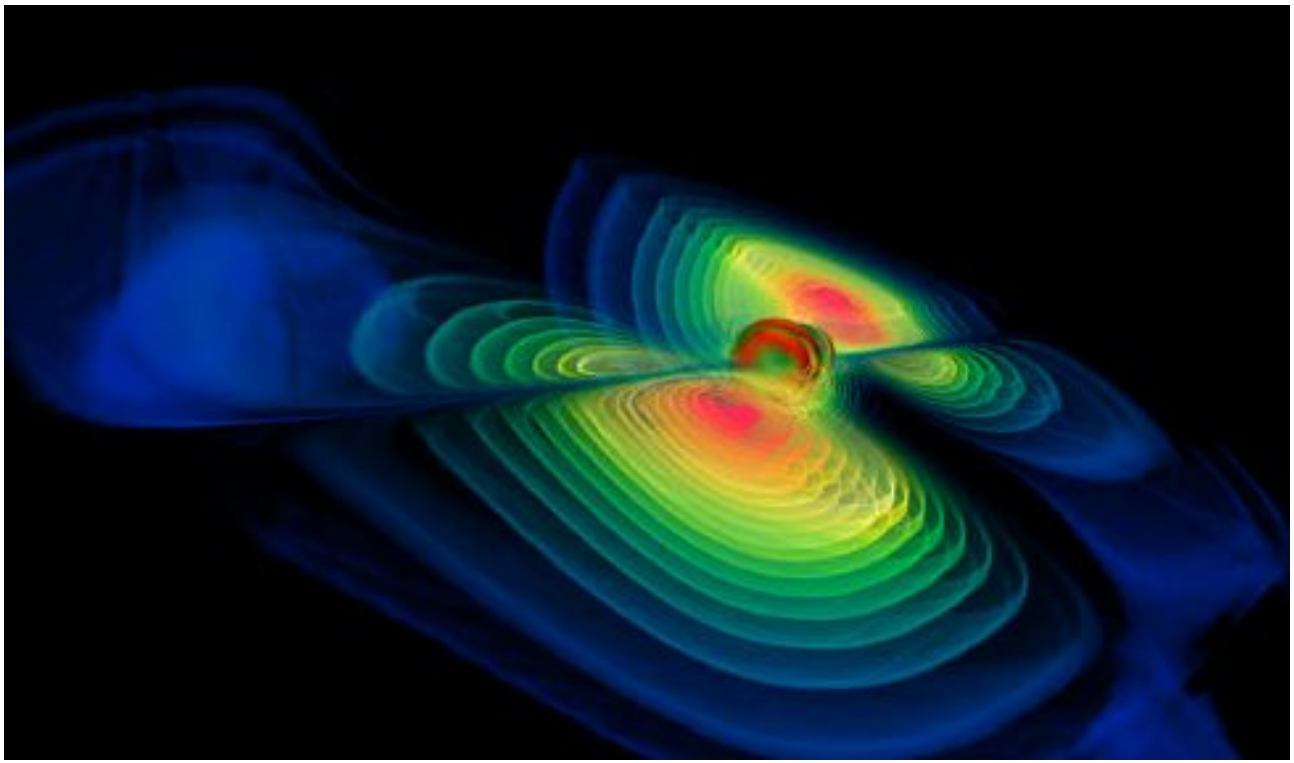

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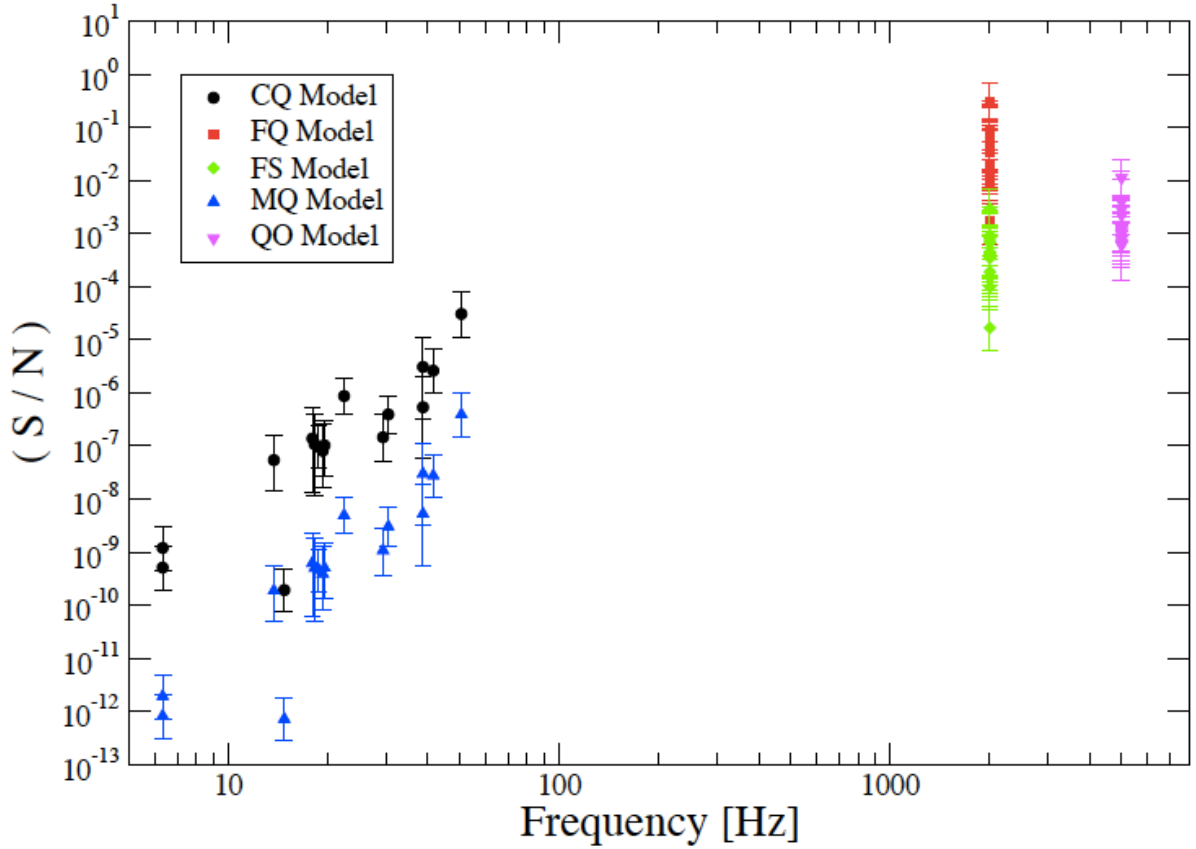
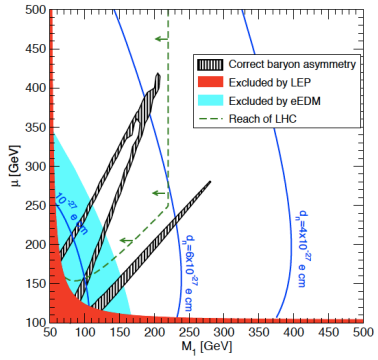


Summary

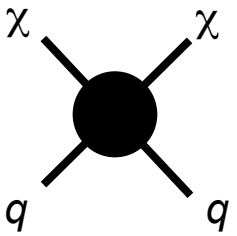
Testable theories for

the **origin of matter**

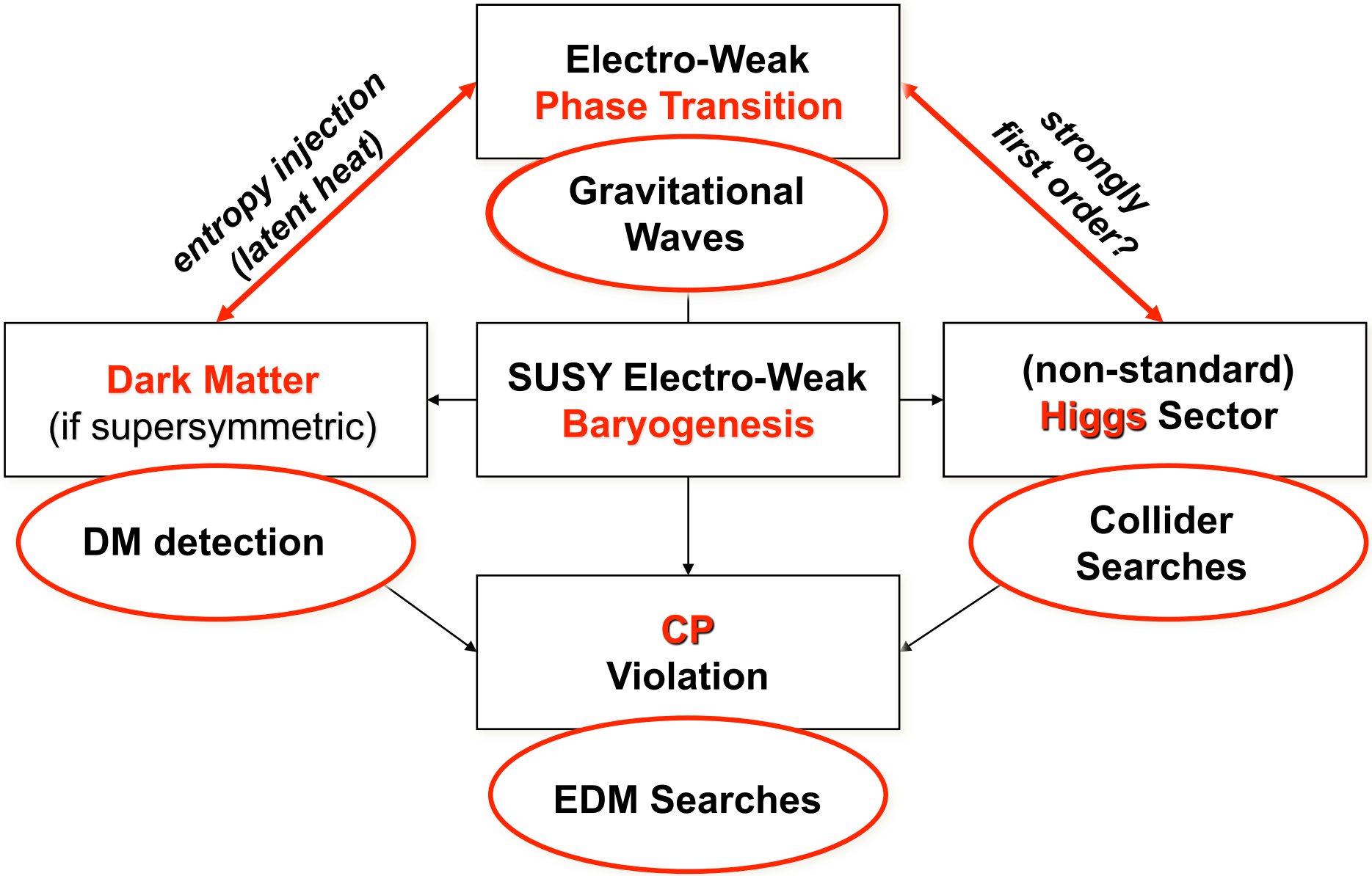


A **cross-disciplinary approach**

in the hunt for **dark matter**



Electro-Weak Baryogenesis: Probes



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"Sakharov conditions"(*)

(*)A.D.Sakharov, JETP Letters **5**, 24 (1967)

Electro-Weak Baryogenesis

The Electro-Weak Phase Transition fulfills all

3 Sakharov requirements[(*)] (**Electro-weak Baryogenesis**)

[(*)]V.A.Kuzmin, V.A.Rubakov and M.E.Shaposhnikov, Phys.Lett. **B197**, 49 (1989)

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✓ ***B*** violation: Weak **Sphaleron** Transitions

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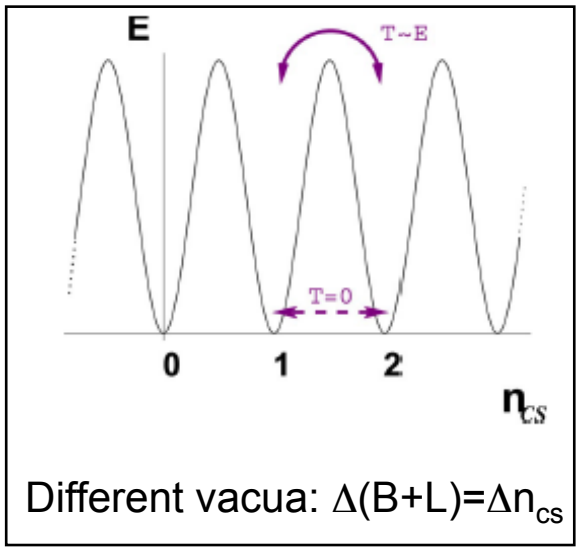

Different vacua: $\Delta(B+L)=\Delta n_{cs}$

- *Classically, baryonic and leptonic currents are **conserved** in the EW theory*
- *Quantum corrections produce **anomalous transitions** between non-degenerate SU(2) field configurations vacua that **violate B+L** (but preserve B-L)*
- ***B-violation** rate is **unsuppressed** at **$T>T_c$**, and is **exp**onentially suppressed at **$T<T_c$***

$$\Gamma_{sph} \propto \alpha_W T^4$$

$$\Gamma_{sph} \propto \exp[-E_{sph}(T)/T]$$

$$E_{sph}(T) \propto \langle\phi\rangle(T)$$

(*)V.A.Kuzmin, V.A.Rubakov and M.E.Shaposhnikov, Phys.Lett. **B197**, 49 (1989)

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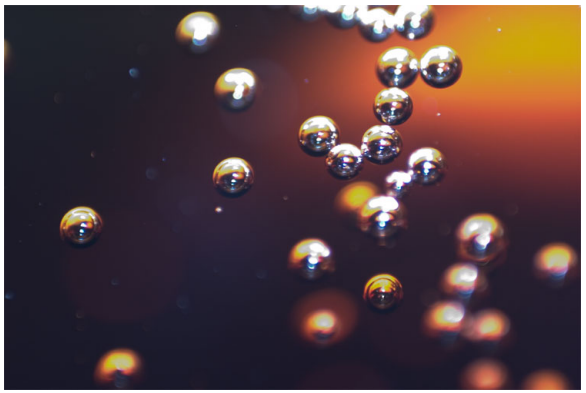

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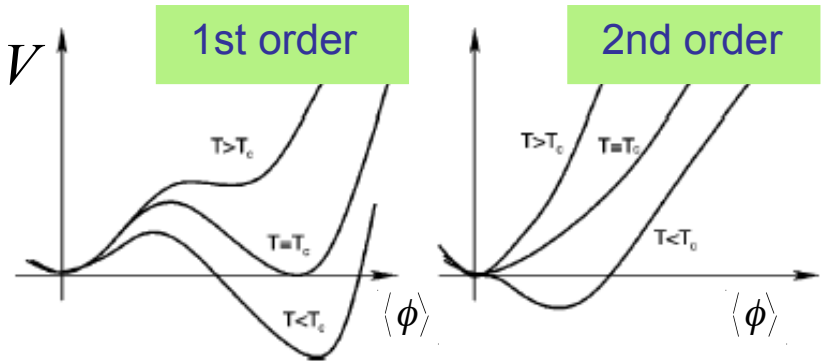

- *If the EWPT is first order (cubic term!), it proceeds through Bubble nucleation*
- *The (expanding) Bubble Walls are out of thermal equilibrium*

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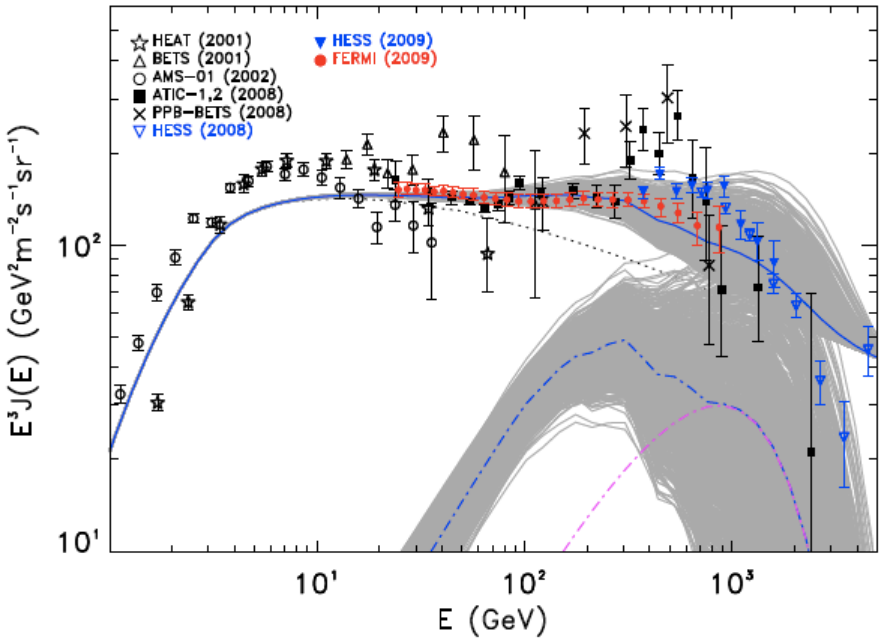
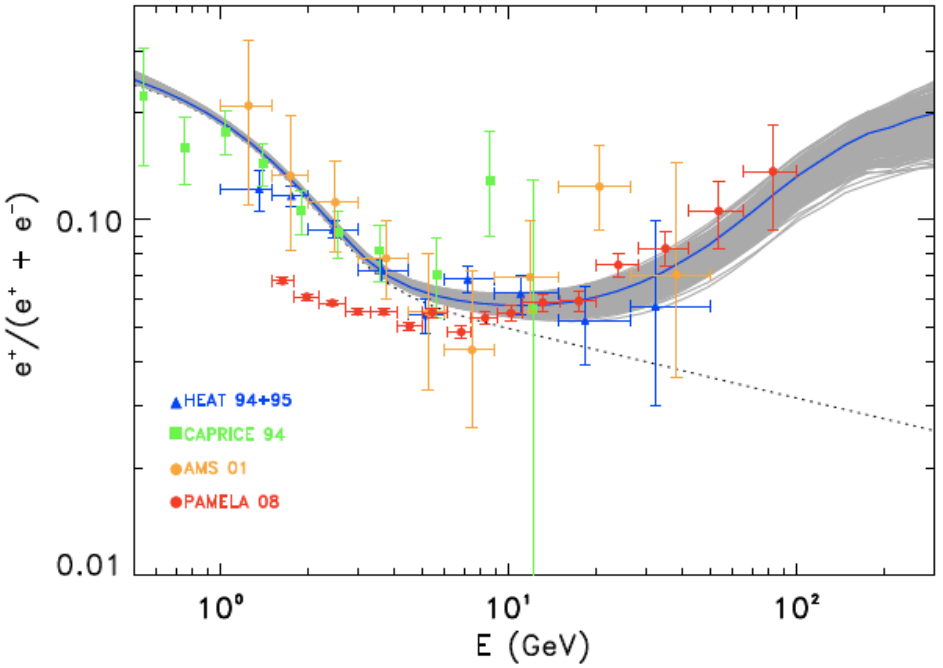
Particle Dark Matter: Indirect Detection and Theory

- **Cosmic Rays**

- Interpretation of Fermi electron/positron data (1)
- Fermi pulsars vs excess positrons (2)
- Dark Matter vs excess positrons (3,4,5)





(1) Grasso, Profumo, Strong et al, Astropart.Phys. 2009
(2) Gendelev, Profumo and Dormody, JCAP 2010
(3) Jeltema and Profumo, JCAP 2009

(4) Brun, Delahayie, Diemand, Profumo, PRD 2009
(5) Cyr-Racine, Profumo and Sigurdson, PRD 2009

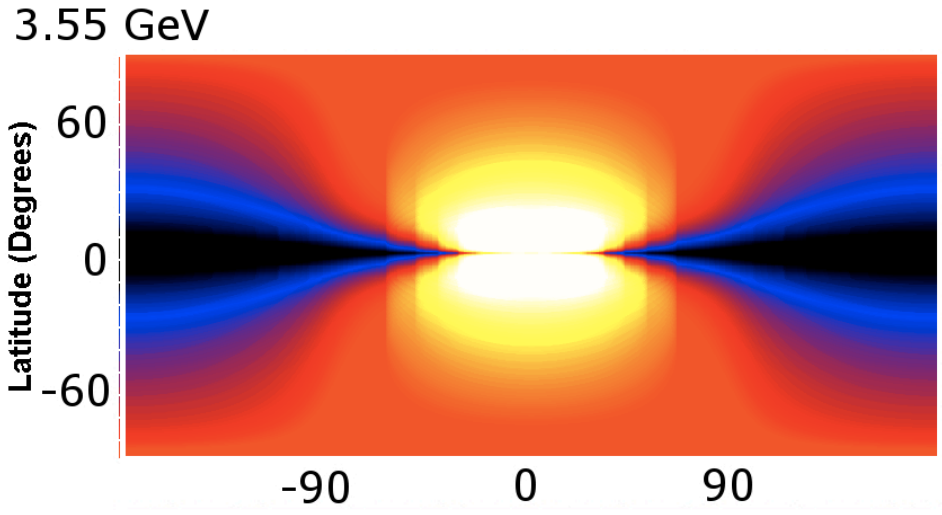
Particle Dark Matter: Indirect Detection and Theory

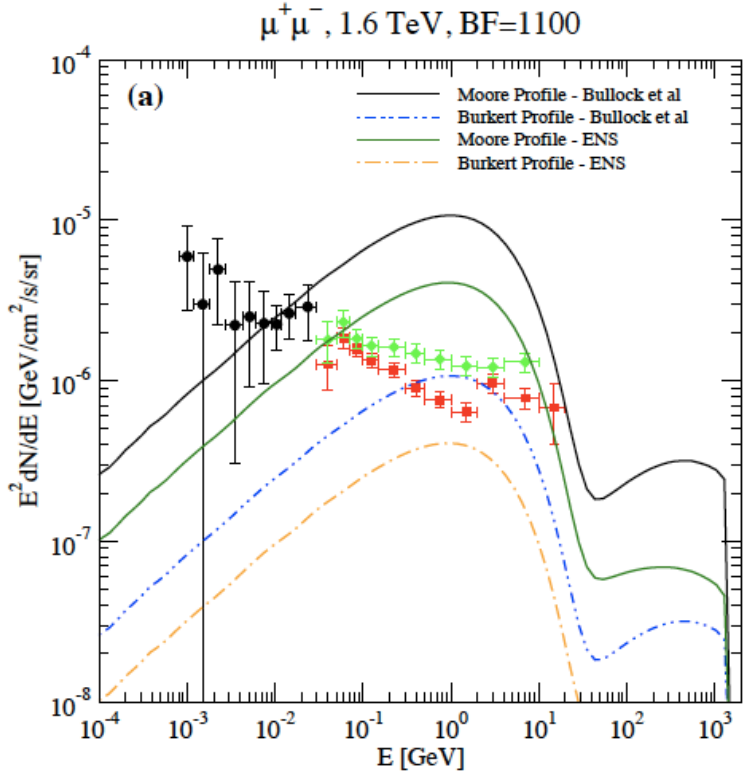
- **Diffuse Emissions**

  - WMAP Haze with consistent CR models (1)
  - A Fermi haze? Systematic effects (2)
  - Extragalactic Inverse Compton (3)

- **Theory/Multi-disciplinary**

  - Multi-component Dark Matter models: direct, indirect and collider searches (4)





(1) Linden, Profumo and Anderson, PRD 2010 sub.
(2) Linden and Profumo, Astroph. J. Lett. 2010
(3) Jeltema and Profumo, JCAP 2009
(4) Profumo, Sigurdson and Ubaldi, PRD 2009