The CP Nature of the Higgs Boson: Introduction

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AMHERST CENTER FOR FUNDAMENTAL INTERACTIONS

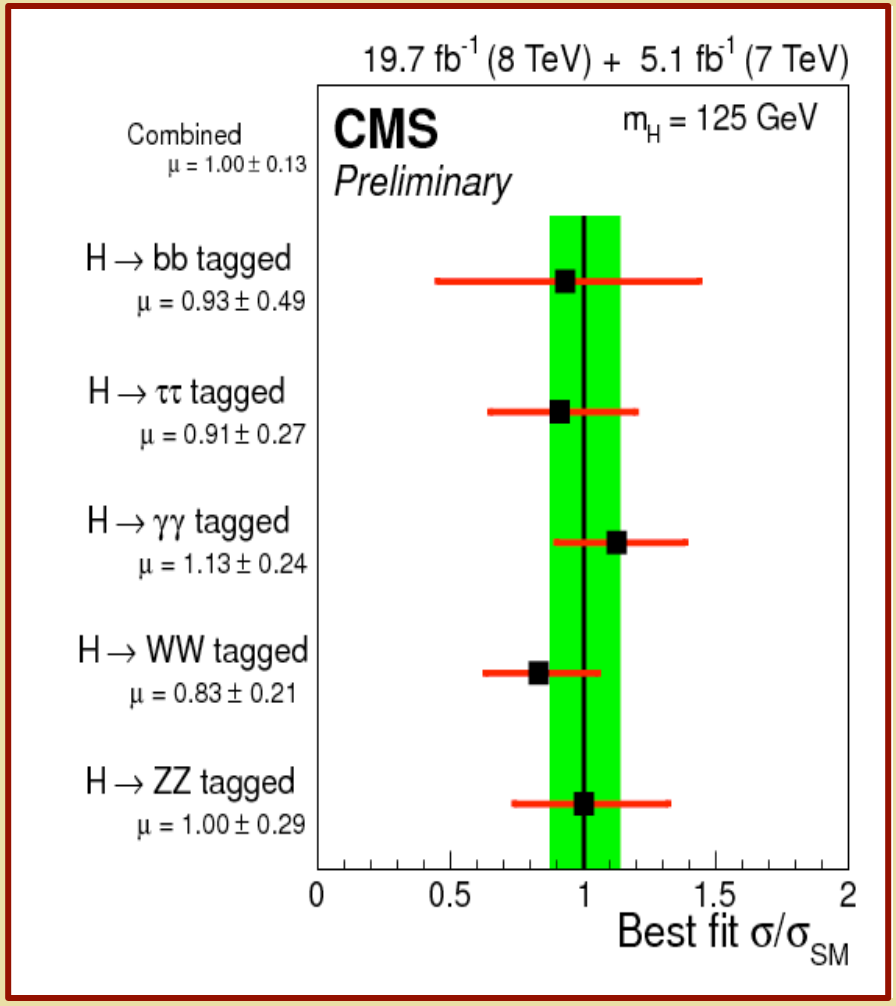
Physics at the interface: Energy, Intensity, and Cosmic frontiers

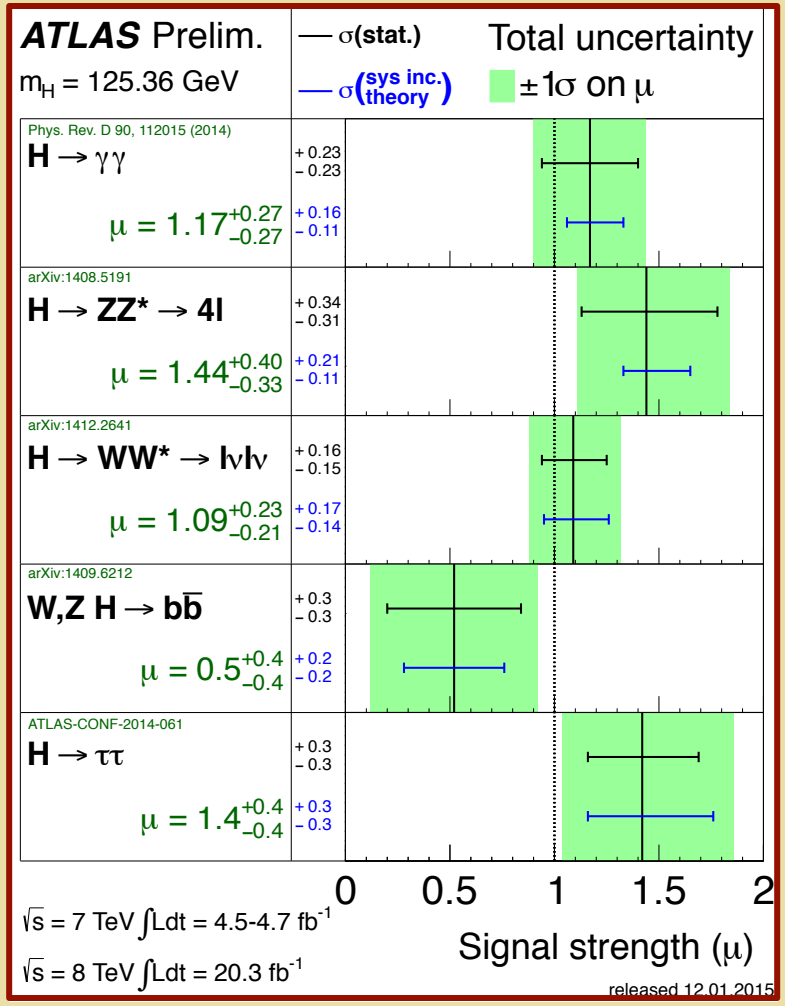
University of Massachusetts Amherst

http://www.physics.umass.edu/acfi/

ACFI Workshop May 2015

BEH-like Boson Observation





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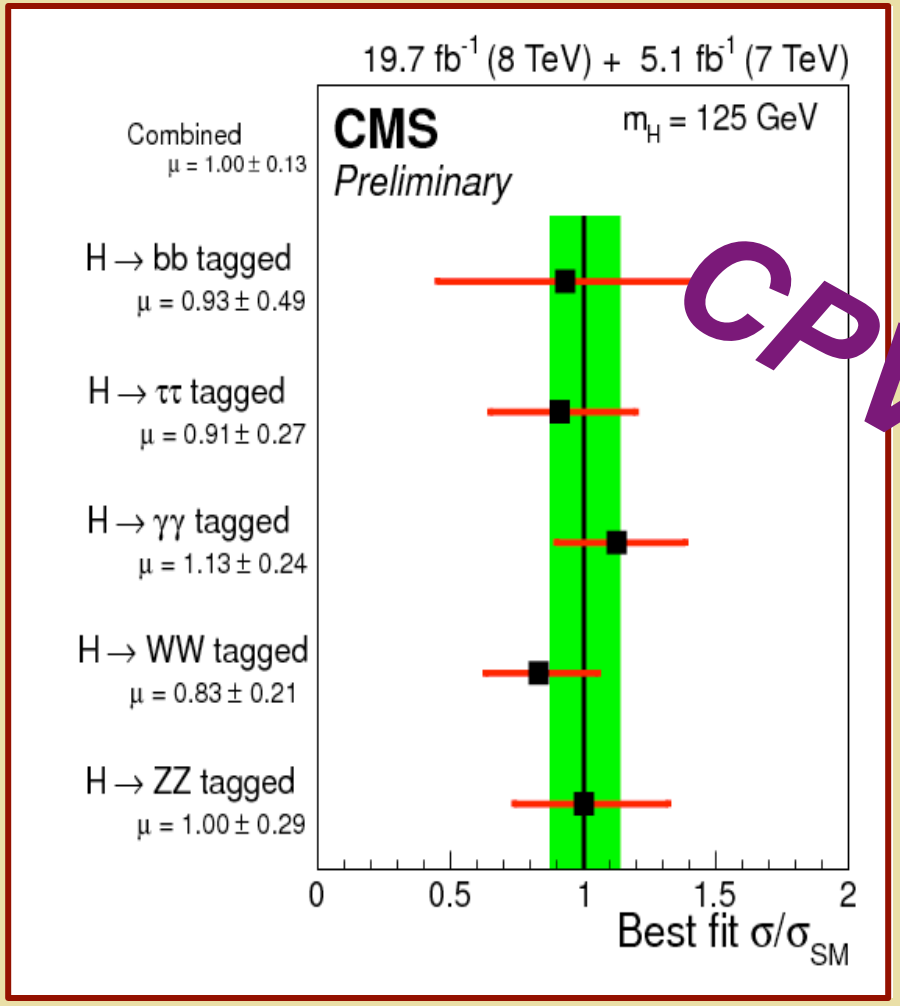
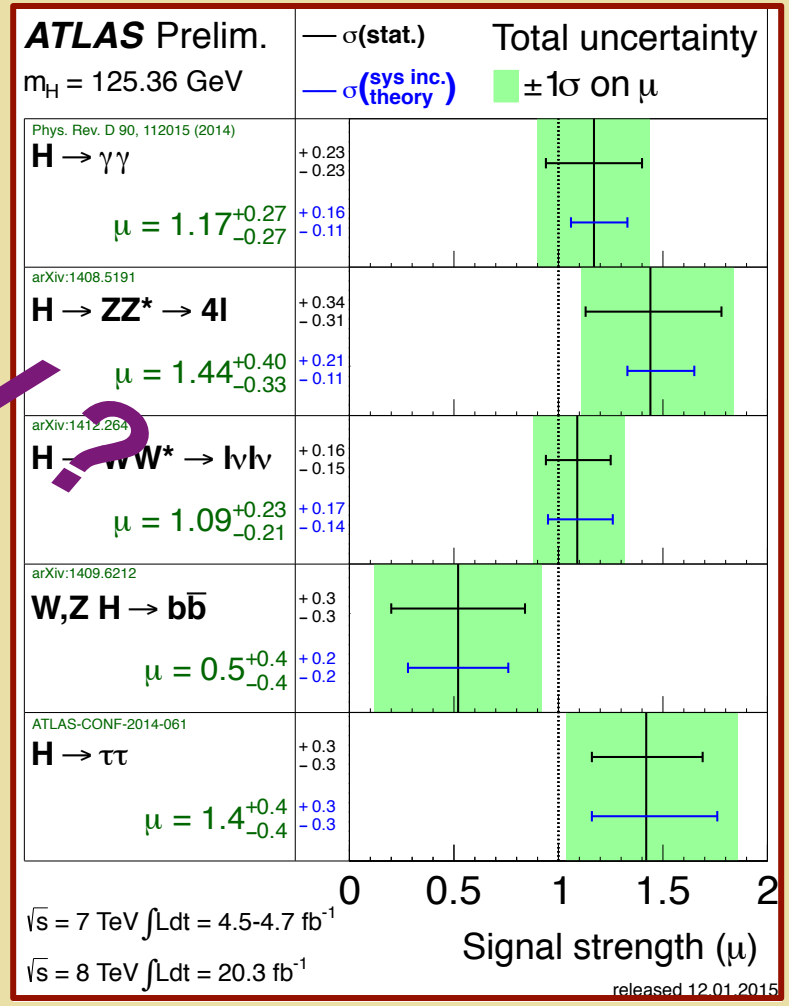


CPV?



Questions for this Workshop

- *What are the sources of CPV in extended Higgs sectors?*
- *What are the implications of Higgs sector CPV for determinations of Higgs properties?*
- *What are the cosmological implications of Higgs sector CPV*
- *What are the potential future collider probes of Higgs sector CPV?*
- *What are the "low energy" constraints (present and future) ?*

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Sources of Higgs Sector CPV

CPV & 2HDM: Type I & II

$\lambda_{6,7}$ = 0 for simplicity

$$
\begin{aligned}
V &= \frac{\lambda_1}{2}(\phi_1^\dagger\phi_1)^2 + \frac{\lambda_2}{2}(\phi_2^\dagger\phi_2)^2 + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) + \frac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right] \\
&\quad -\frac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\}.
\end{aligned}
$$

$$
\begin{aligned}
\delta_1 &= \text{Arg}\left[\lambda_5^*(m_{12}^2)^2\right] , \\
\delta_2 &= \text{Arg}\left[\lambda_5^*(m_{12}^2)v_1v_2^*\right]
\end{aligned}
$$

EWSB →

$$
\delta_2 \approx \frac{1 - \left|\frac{\lambda_5 v_1 v_2}{m_{12}^2}\right|}{1 - 2\left|\frac{\lambda_5 v_1 v_2}{m_{12}^2}\right|}\delta_1
$$

What other extended Higgs sector CPV scenarios ?

Inoue, R-M, Zhang: 1403.4257

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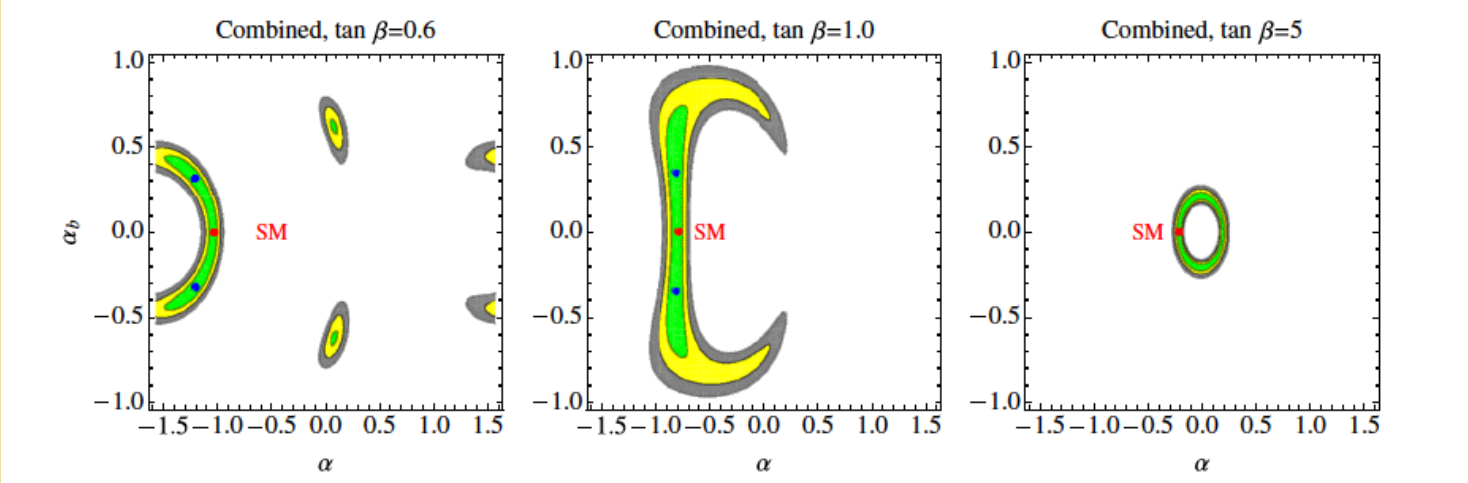
Implications for Higgs Properties

CPV & 2HDM: Type I & II

$\lambda_{6,7}$ = 0 for simplicity

$$V = \frac{\lambda_1}{2}(\phi_1^\dagger\phi_1)^2 + \frac{\lambda_2}{2}(\phi_2^\dagger\phi_2)^2 + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) + \frac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right]$$
$$-\frac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\}.$$



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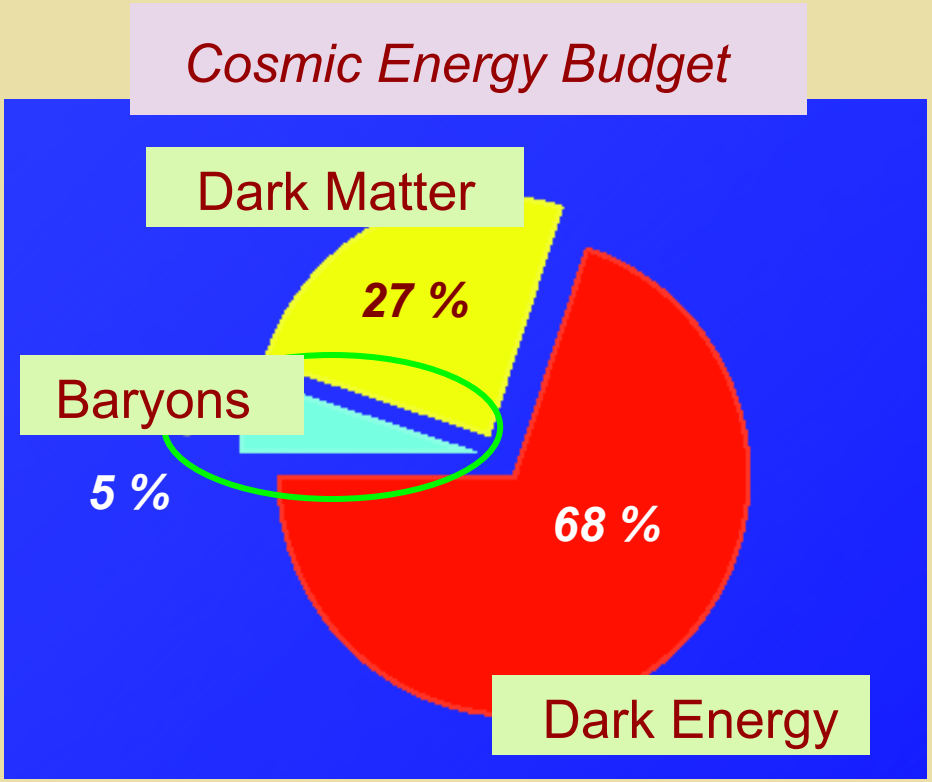
Cosmological Implications



Baryon asymmetry requires new sources of CPV

Ingredients for Baryogenesis

	Standard Model	*BSM*
• *B violation (sphalerons)*	✔	✔
• *C & CP violation*	✖	✔
• *Out-of-equilibrium or CPT violation*	✖	✔

Ingredients for Baryogenesis

Scenarios: leptogenesis, EW baryogenesis, Afflek-Dine, asymmetric DM, cold baryogenesis, post-sphaleron baryogenesis…

	Standard Model	*BSM*
• *B violation (sphalerons)*	✔	✔
• *C & CP violation*	✖	✔
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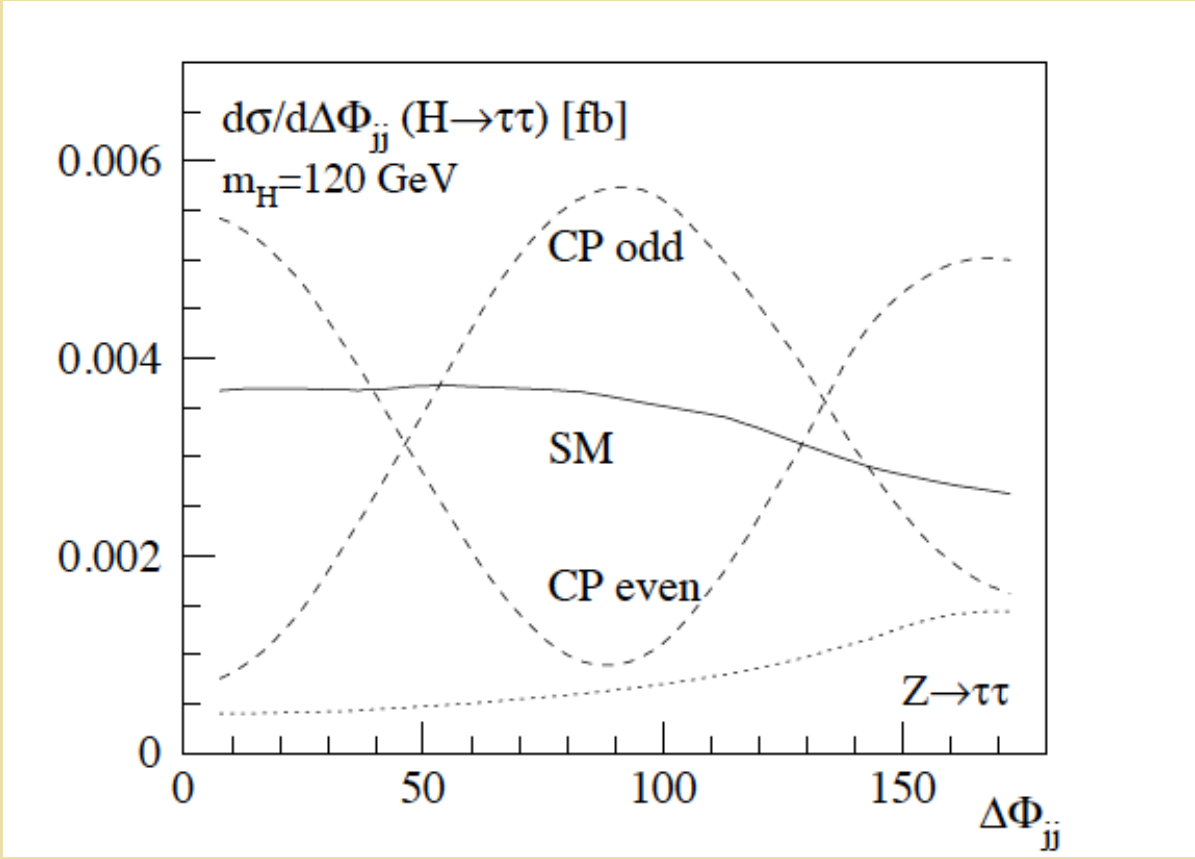
Collider Probes



WBF: dijet azimuthal distribution

Plehn, Rainwater, Zeppenfeld, hep-ph/0105325

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Low Energy Probes: EDMs

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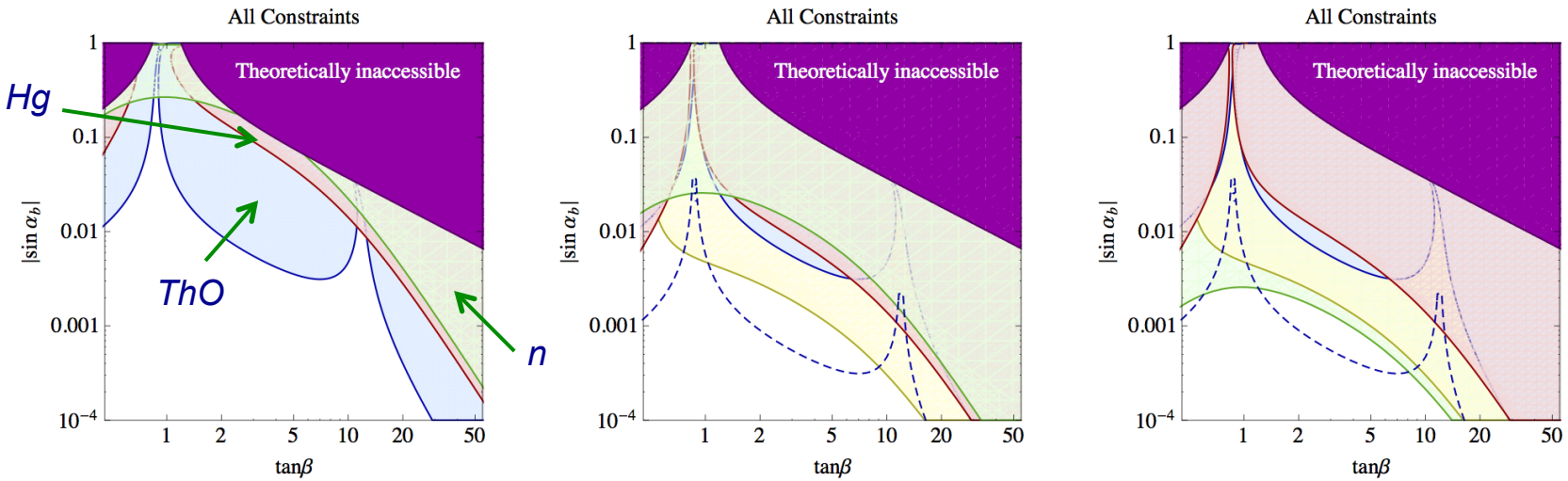
CPV & 2HDM: Type II illustration

$\Lambda_{6,7}$ = 0 for simplicity



Present

sin α_b : CPV scalar mixing

Future:

d_n x 0.1

d_A(Hg) x 0.1

d_{ThO} x 0.1

d_A(Ra)

Future:

d_n x 0.01

d_A(Hg) x 0.1

d_{ThO} x 0.1

d_A(Ra)

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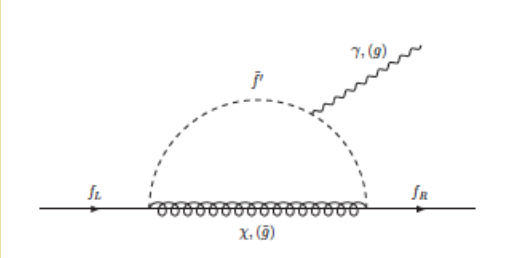
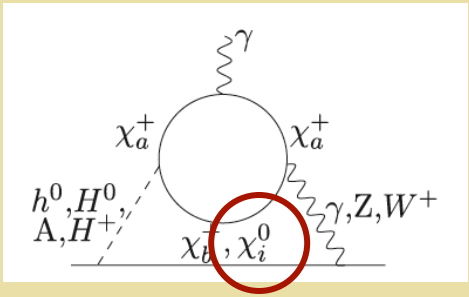
Putting it all together

EDM Probes: EWB Implications

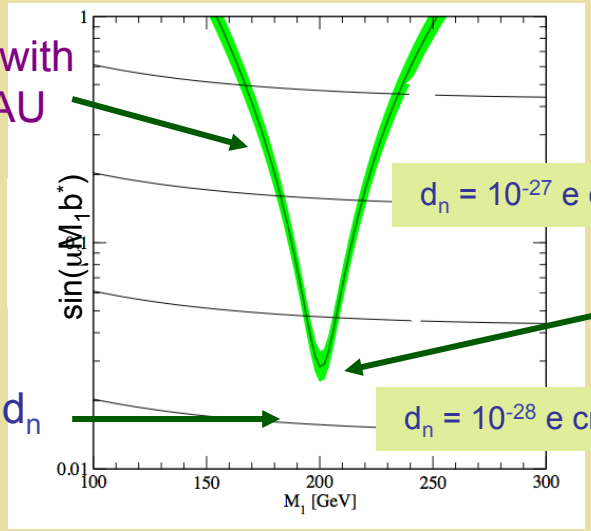


Heavy sfermions: LHC consistent & suppress 1-loop EDMs



Sub-TeV EW-inos: LHC & EWB - viable but non-universal phases

Compatible with observed BAU



Compressed spectrum (stealthy SUSY)

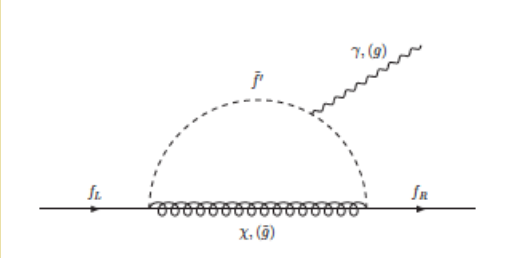
Next gen d_n

Li, Profumo, RM '09-' 10

Viable EWB & CPV:

- *EDMs are 2-loop*
- *CPV is flavor non-diag*

EDM Probes: EWB Implications



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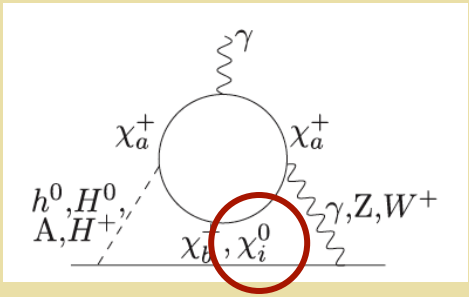

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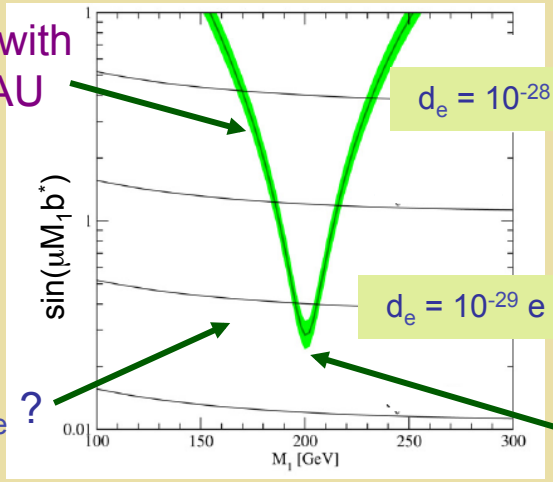

Next gen d_e ?

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Higgs Portal CPV

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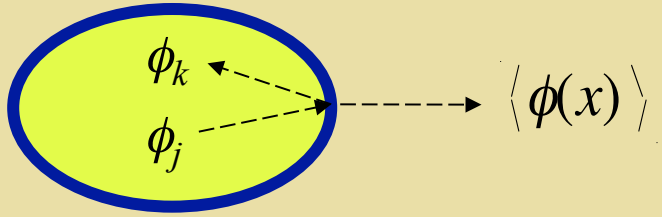

Scalar asym $\rightarrow$ n_L via Yukawa int