Light Neutralino in the MSSM

Alexandre Arbey

Université Lyon 1 & CERN

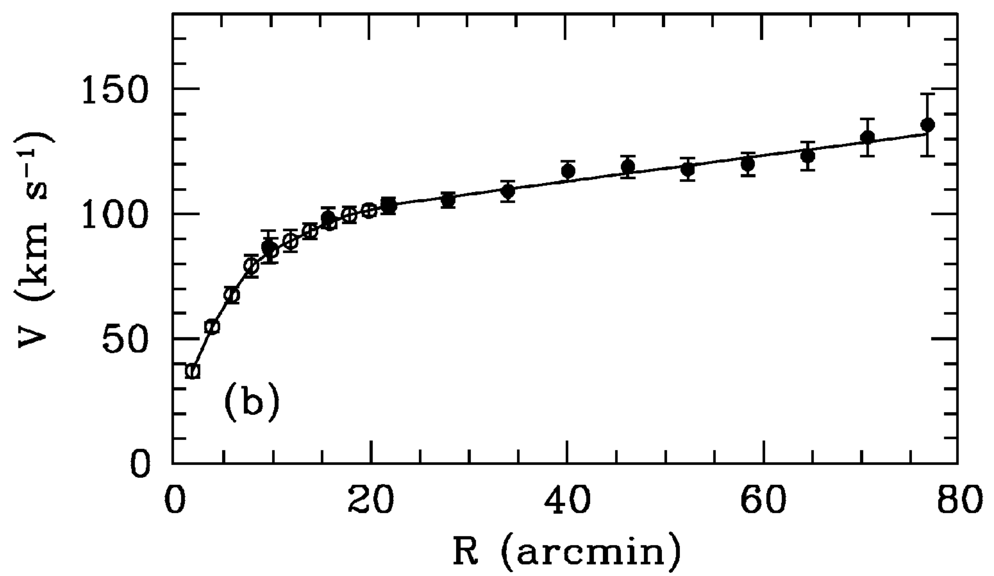
In collaboration with M. Battaglia and F. Mahmoudi

with the help of A. de Roeck and K.K. Li

Evidences for Dark Matter

Dark matter in galaxies...

as can be deduced for example from the rotation curves of spiral galaxies



$$\rho_{\text{deduced}} \propto r^{-2} \quad \gg \quad \rho_{\text{visible}} \propto \exp(-r/r_0)$$

Evidences for Dark Matter

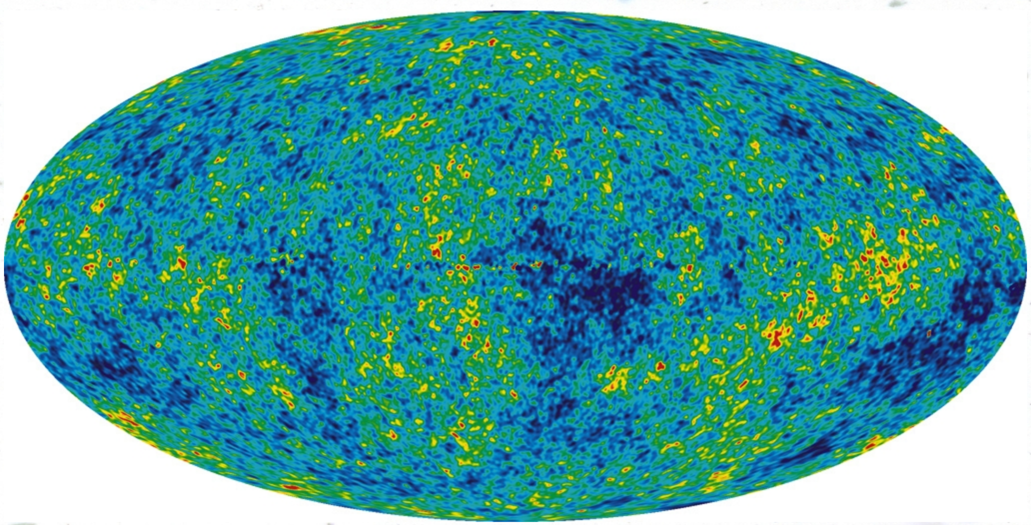
Dark matter in galaxy clusters...

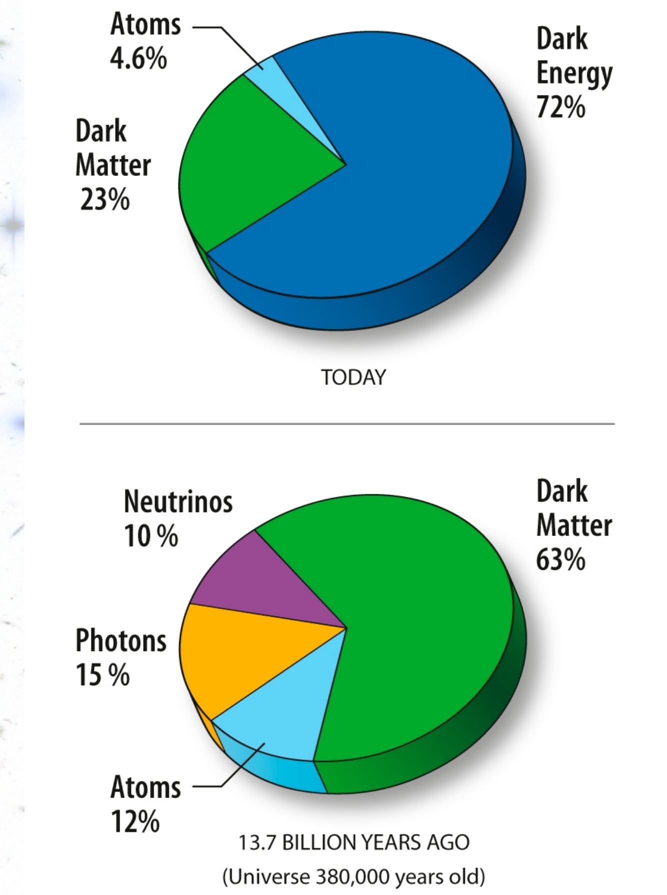
as can be seen for example in the Bullet Cluster through gravitational lensing

Evidences for Dark Matter

Dark matter from cosmological evolution...

e.g. as measured by WMAP





Evidences for Dark Matter

Indirect observations of Dark Matter!

↓

What is the nature of Dark Matter?

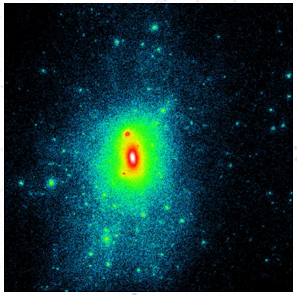
Evidences for Dark Matter

Indirect observations of Dark Matter!

Nature of Dark Matter?

Weakly Interacting Massive Particles (WIMPs)
Good cosmological behaviour and good galaxy formation
Clumpiness problems? (clumps formation, cuspy core, ...)

MSSM with R-parity conservation
Attractive Standard Model extension
Large mass stable particles



The MSSM provides a solution to the dark matter problem!

Candidate dark matter particle : lightest SUSY particle (LSP)
- stau, stop, ... → charged particles, would have been detected
- gluino → coloured particle, would have somehow been detected
- sneutrino → interacts too much with W, too easily detectable
- neutralino → THE usual MSSM candidate
- gravitino → other possible candidate, but difficult to catch...

Neutralino dark matter

Relic density

The relic density of neutralino is determined by solving the system of equations:

Neutralino dark matter

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- Friedmann equation, which describes the evolution of the expansion of the Universe

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- Boltzmann equation, which describes the evolution of the density number of SUSY particles n

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{\rm eff} v \rangle (n^2 - n_{\rm eq}^2)$$

where $\langle \sigma v \rangle$ is the thermally-averaged annihilation cross-section of every SUSY particles into SM particles

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The obtained relic density can then be compared to the observed (by WMAP) dark matter density:

$$0.088 < \Omega_{DM} h^2 < 0.123$$

Neutralino dark matter

Relic density

The MSSM is an excellent model for relic density since large regions of its parameter space satisfy this constraint!!!

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Dark Matter Direct Detection: Generalities

Underground experiments quite similar to neutrino detectors

Need huge amounts of specific crystals / liquids / gases aimed to interact with dark matter particles

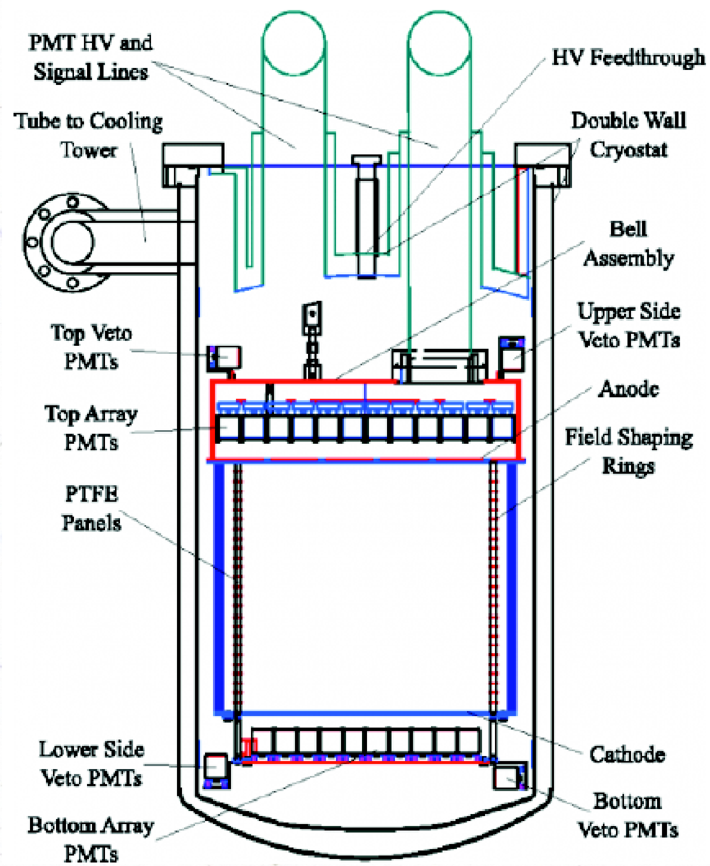
If a DM particle interact with atoms in this detector, the recoil energy is detected and recorded

Many different experiments in the world:

- DAMA
- CoGeNT
- XENON100
- CRESST
- CDMS
- EDELWEISS
- …

They use various technologies and have very different sensibilities

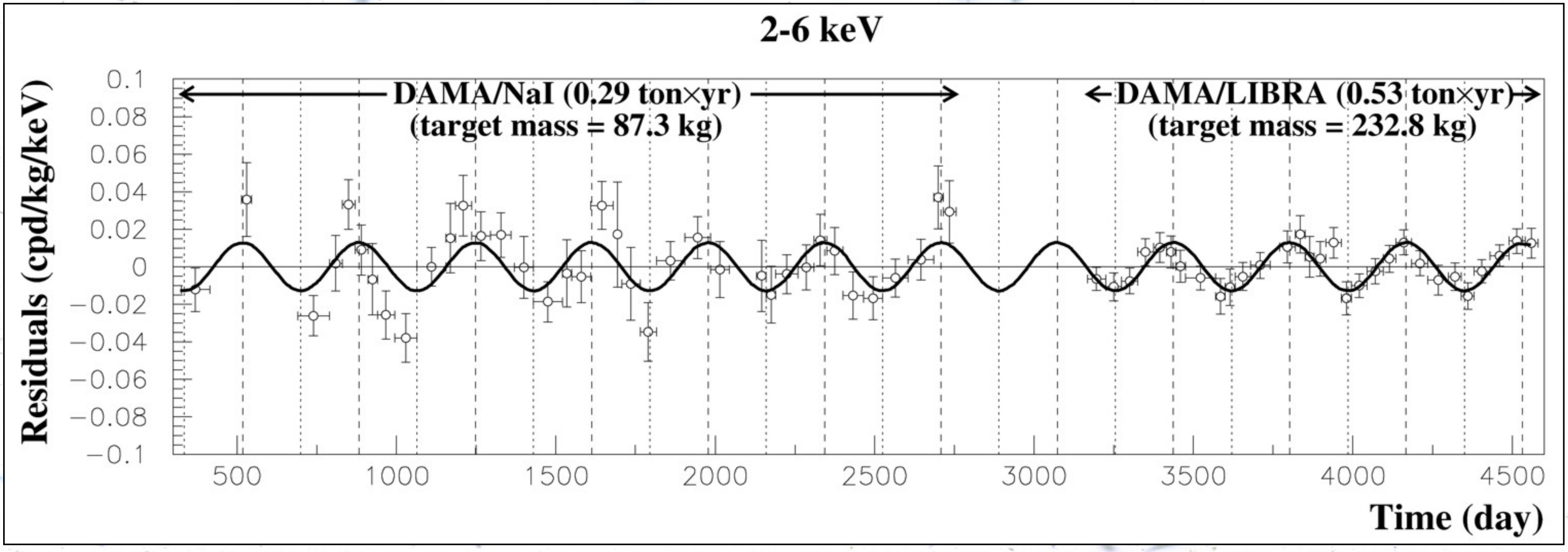
XENON 100 detector



DAMA/LIBRA: Evidence for WIMP Detection?

DAMA/LIBRA experiment in Gran Sasso (Italy) observes an annual modulation at around 9σ statistical CL

Detector stability?
Background stability?
Evidence of Dark Matter?



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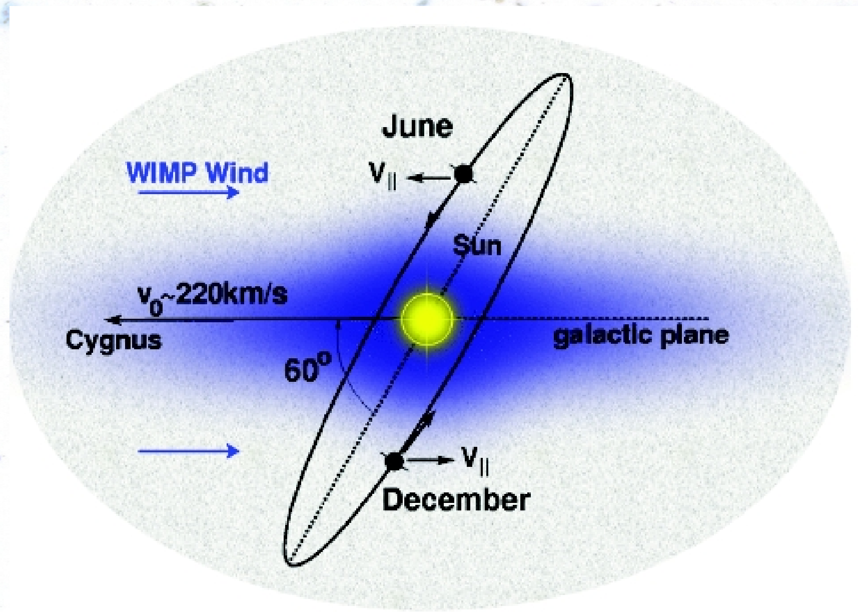

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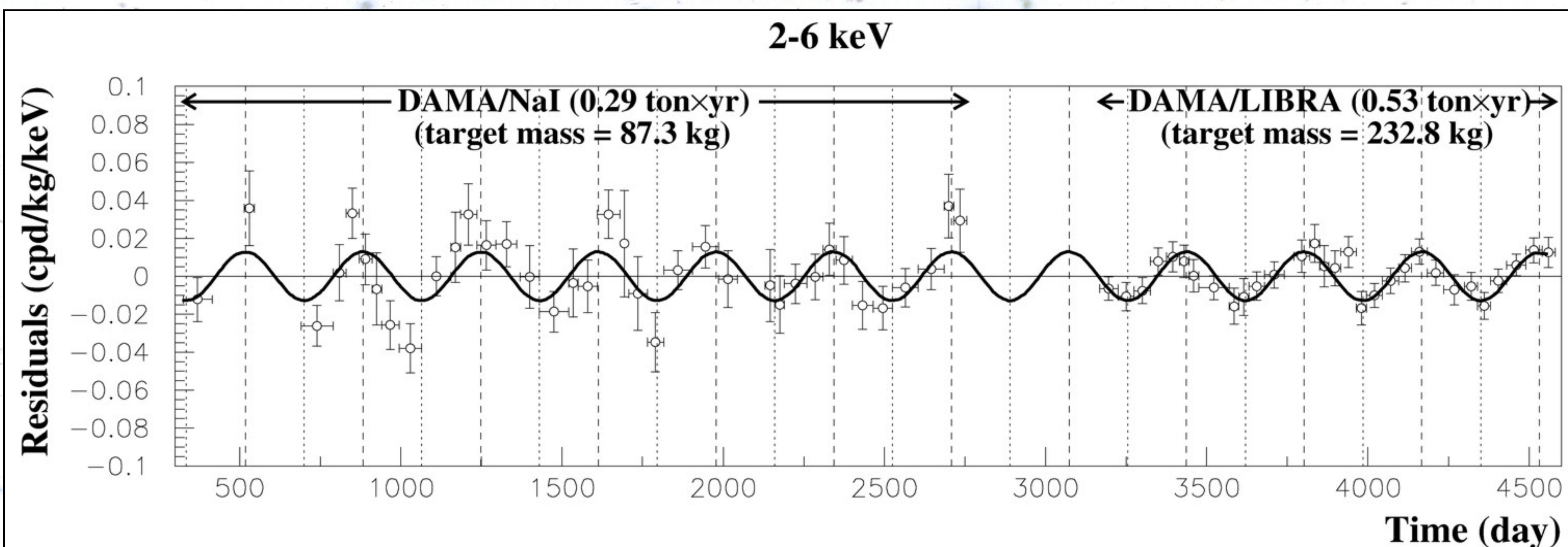
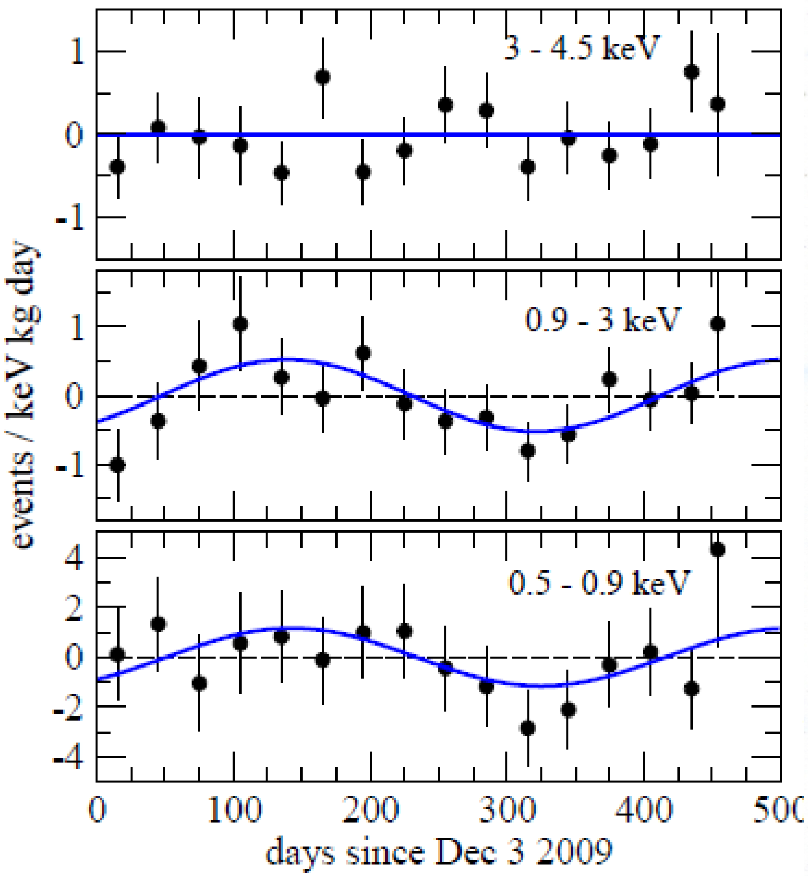


CoGeNT: Evidence for WIMP Detection?

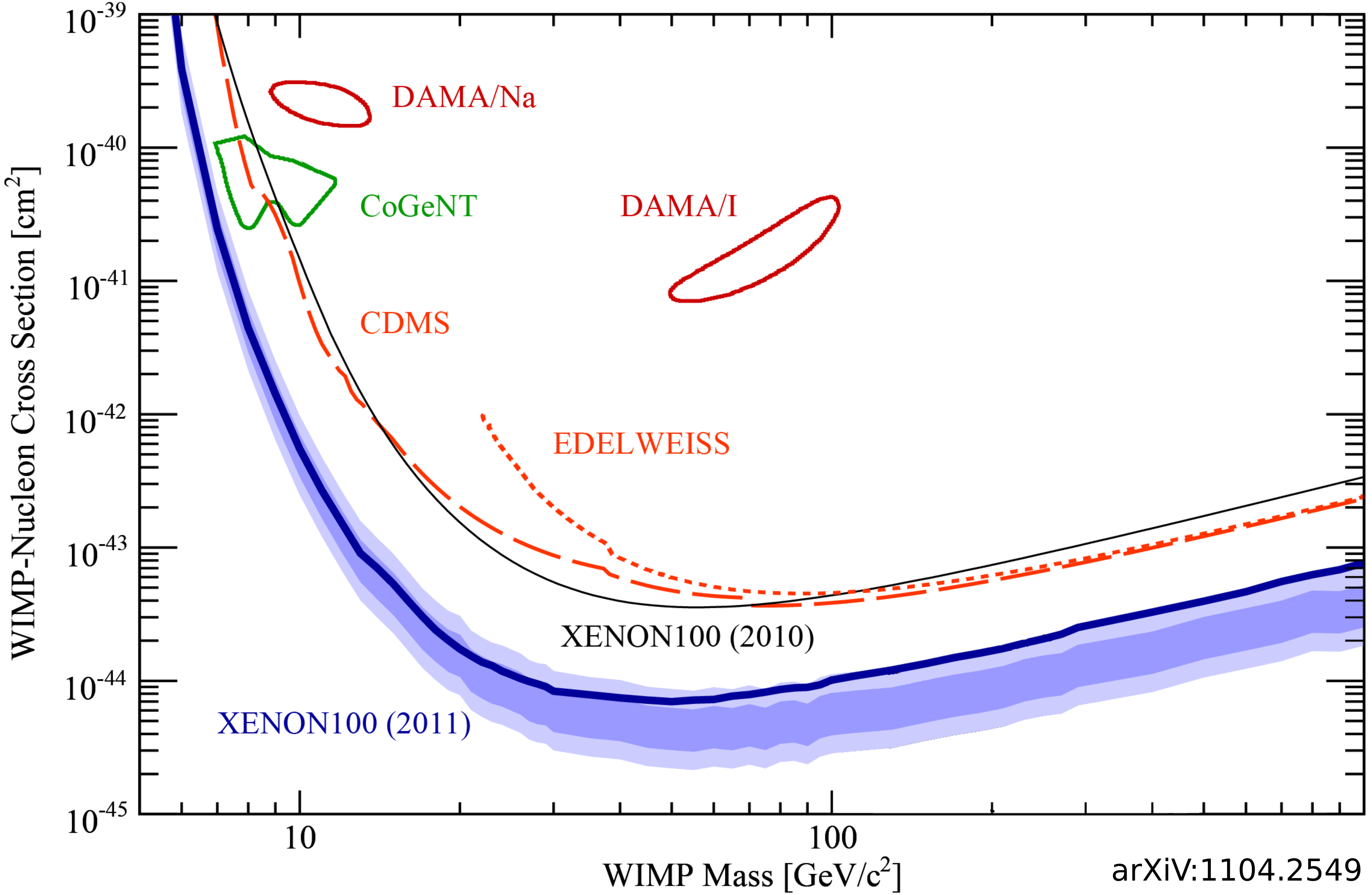


CoGeNT experiment in Soudan (USA) also observes an annual modulation at around 3σ statistical CL

Detector stability?
Background stability?
Evidence of Dark Matter?

However, this modulation is not completely consistent with DAMA results...

Status of direct detection



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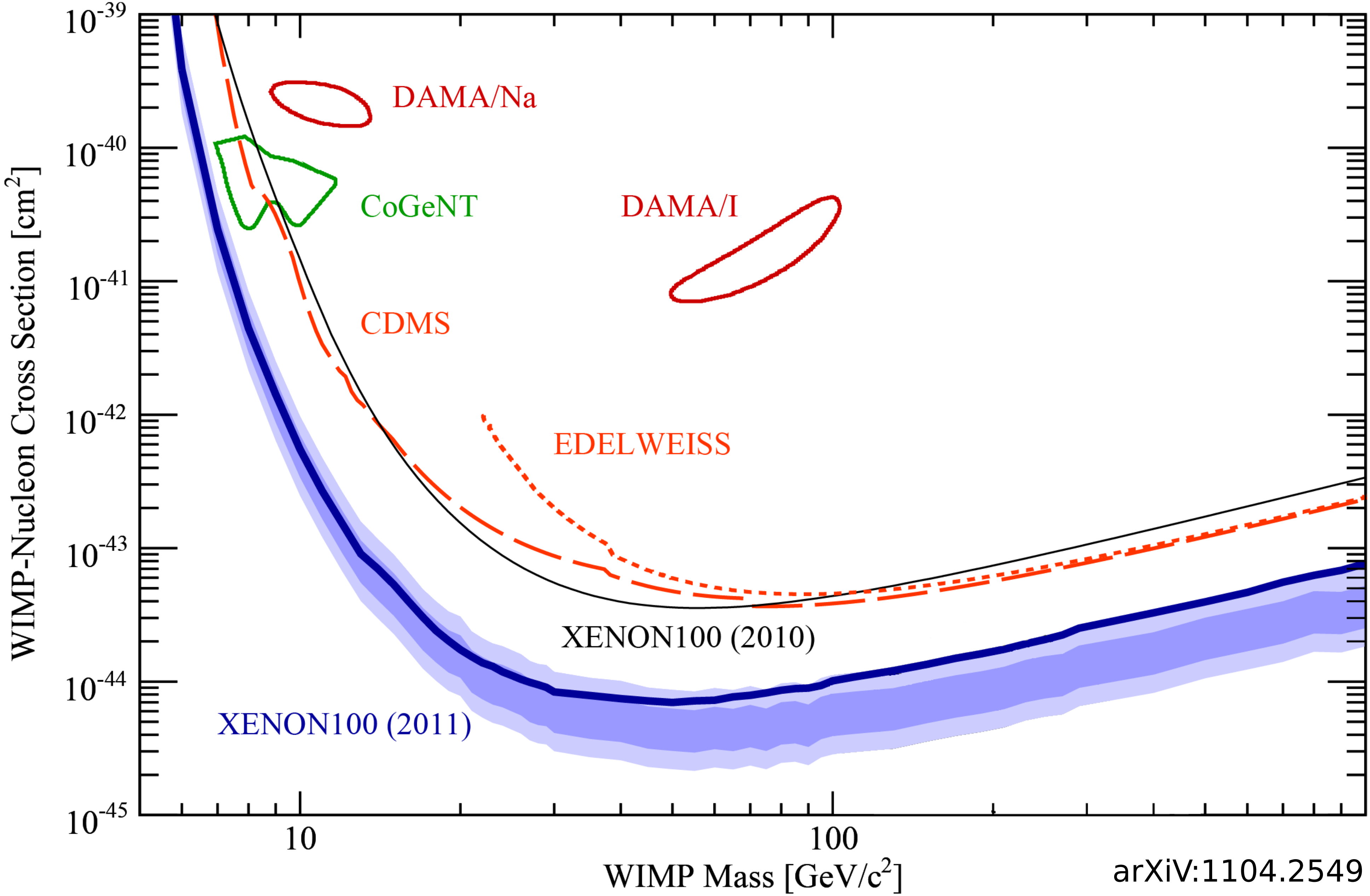
Status of direct detection



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The constrained MSSM scenarios provide no candidate compatible with DAMA, CoGeNT and XENON data

The pMSSM Parameter Space with Light Neutralino Dark Matter

We study scenarios with light neutralino and large neutralino-proton scattering cross-section in pMSSM corresponding to region highlighted by DAMA and CoGeNT results

Dedicated 20M point scan in the pMSSM with 19 parameters

Constraints from DAMA / CoGeNT / XENON:

$$m_{\chi_1^0} < 20 \text{ GeV and } \sigma_{\chi p} > 10^{-6} \text{ pb}$$

Parameter	Range
$\tan\beta$	[1, 60]
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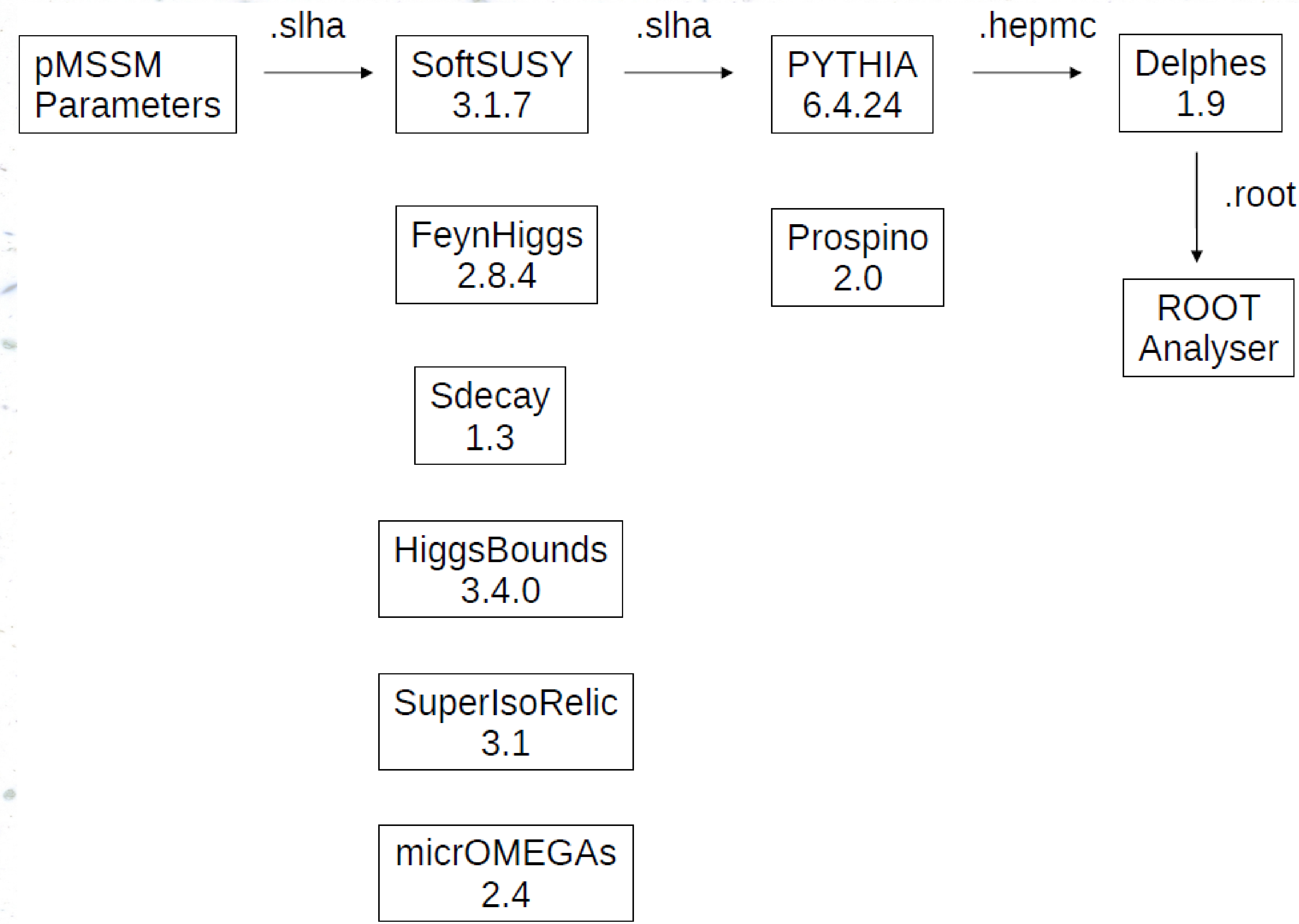
Software and Tools



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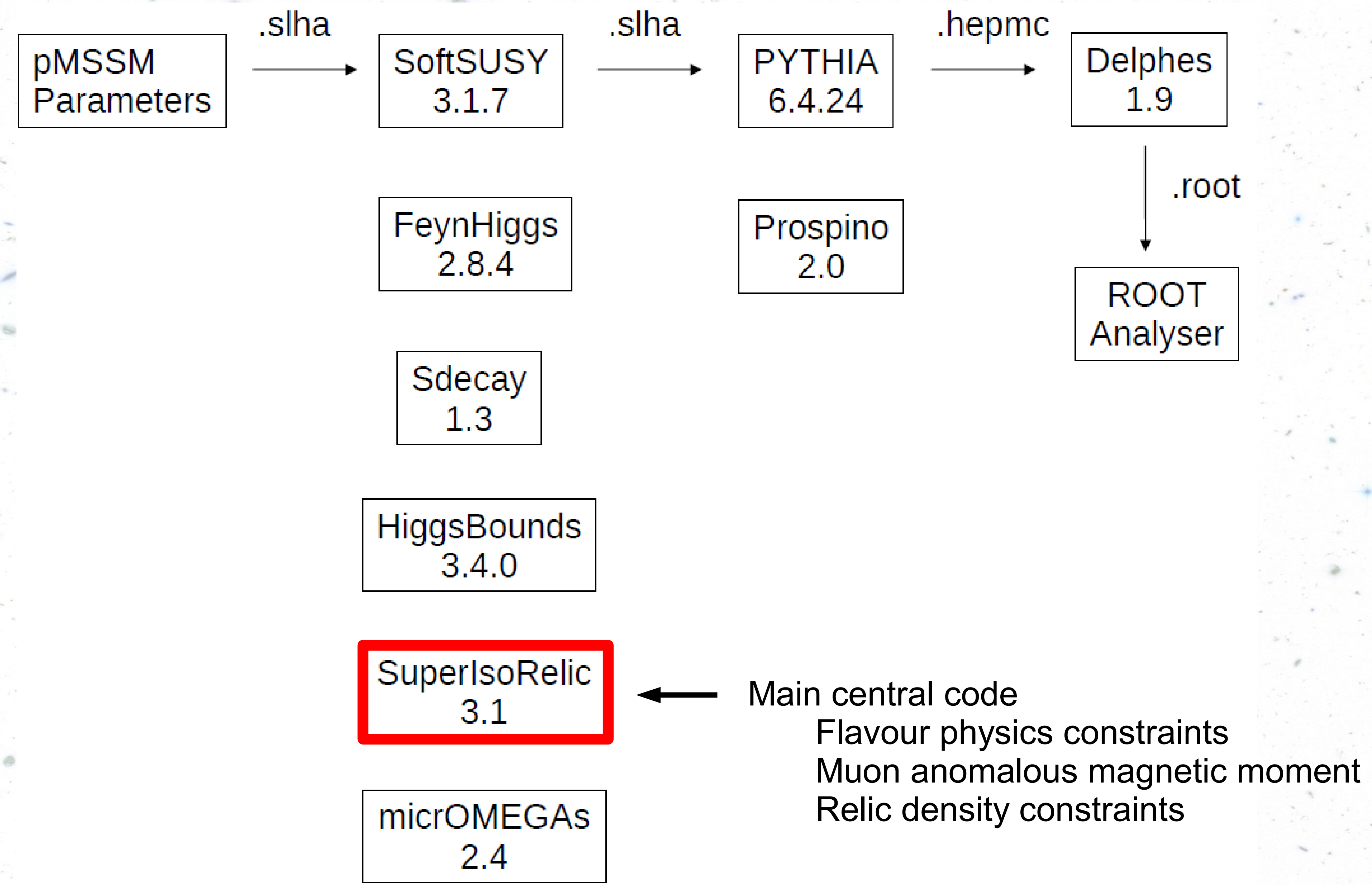

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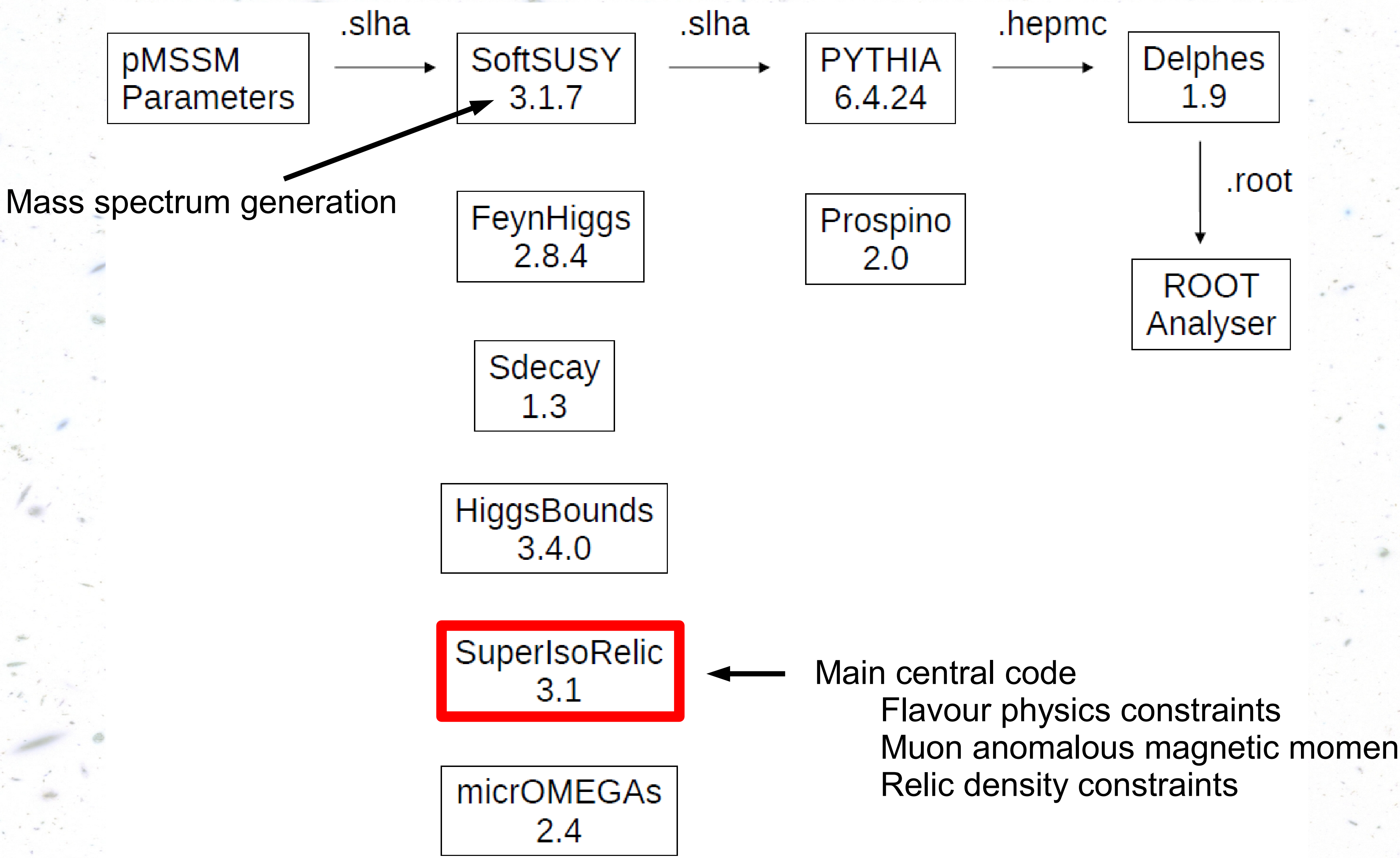

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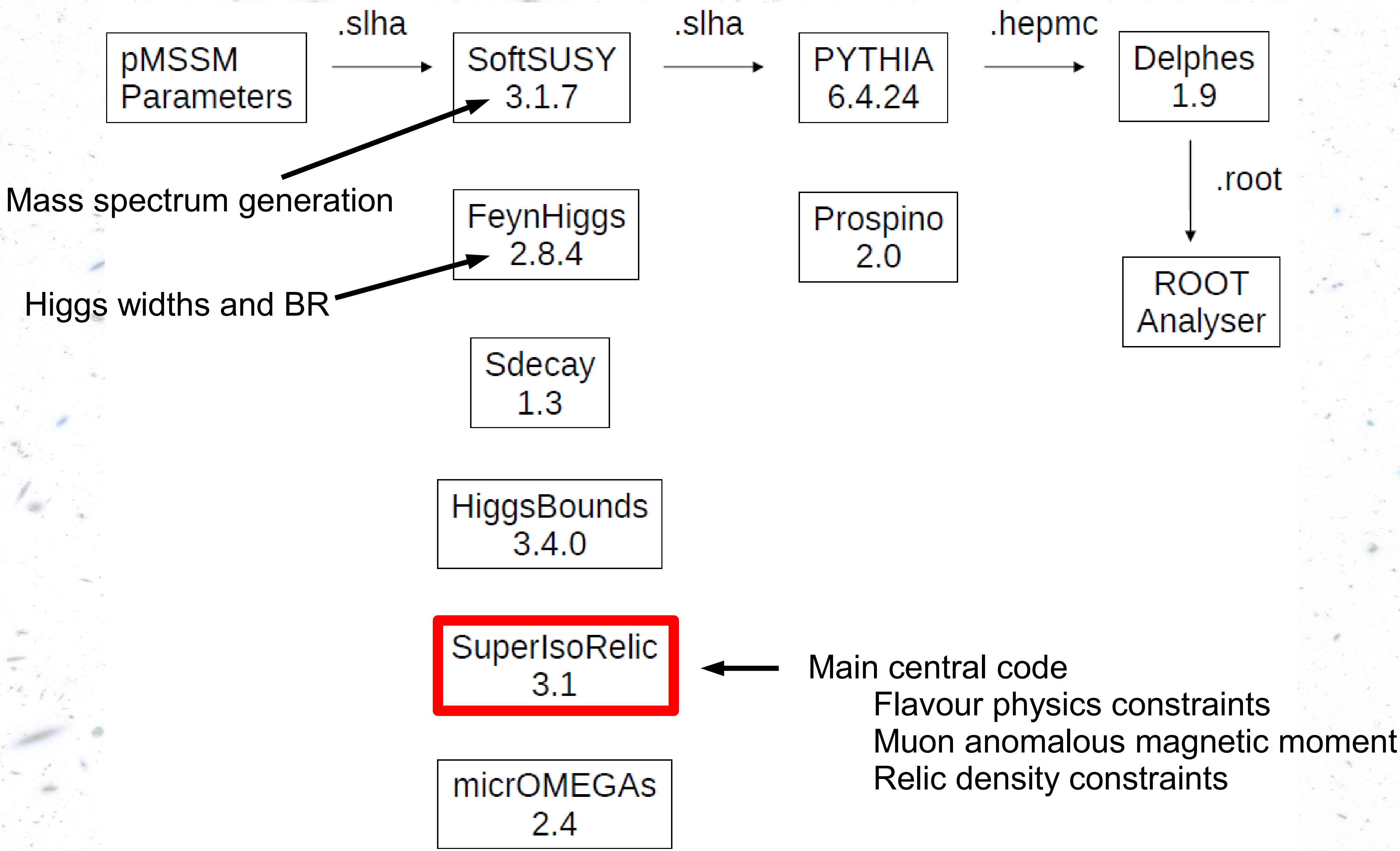

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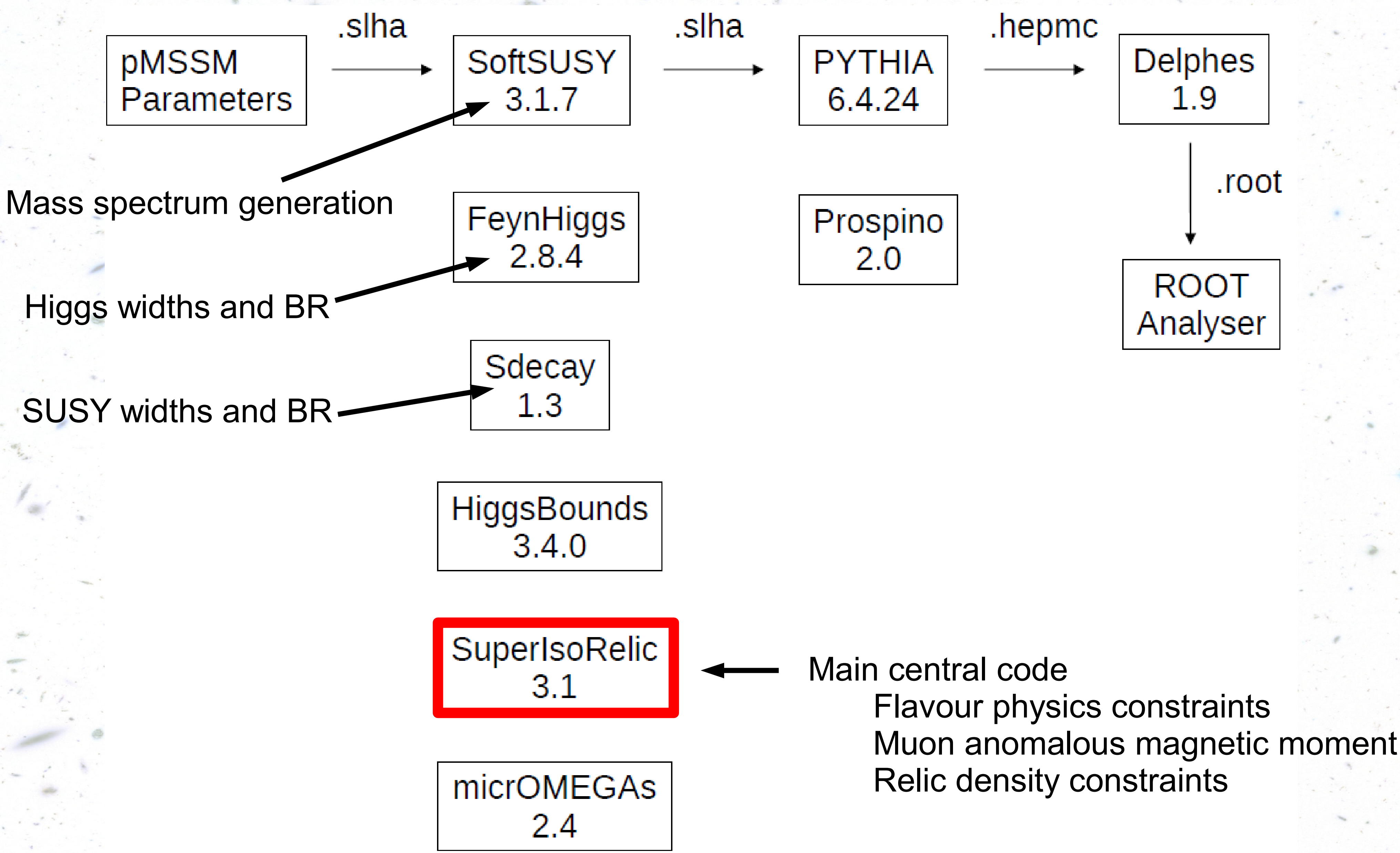

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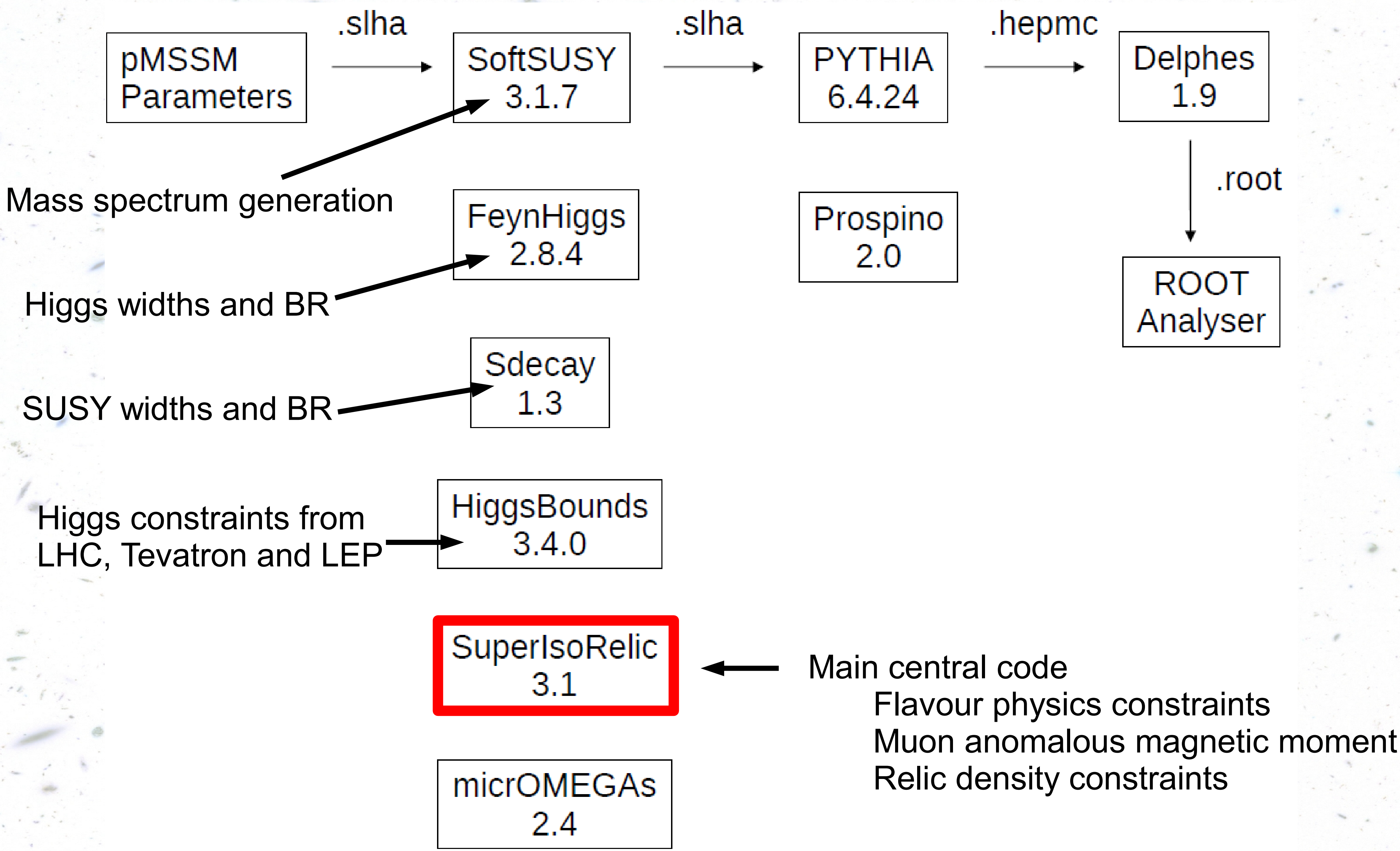

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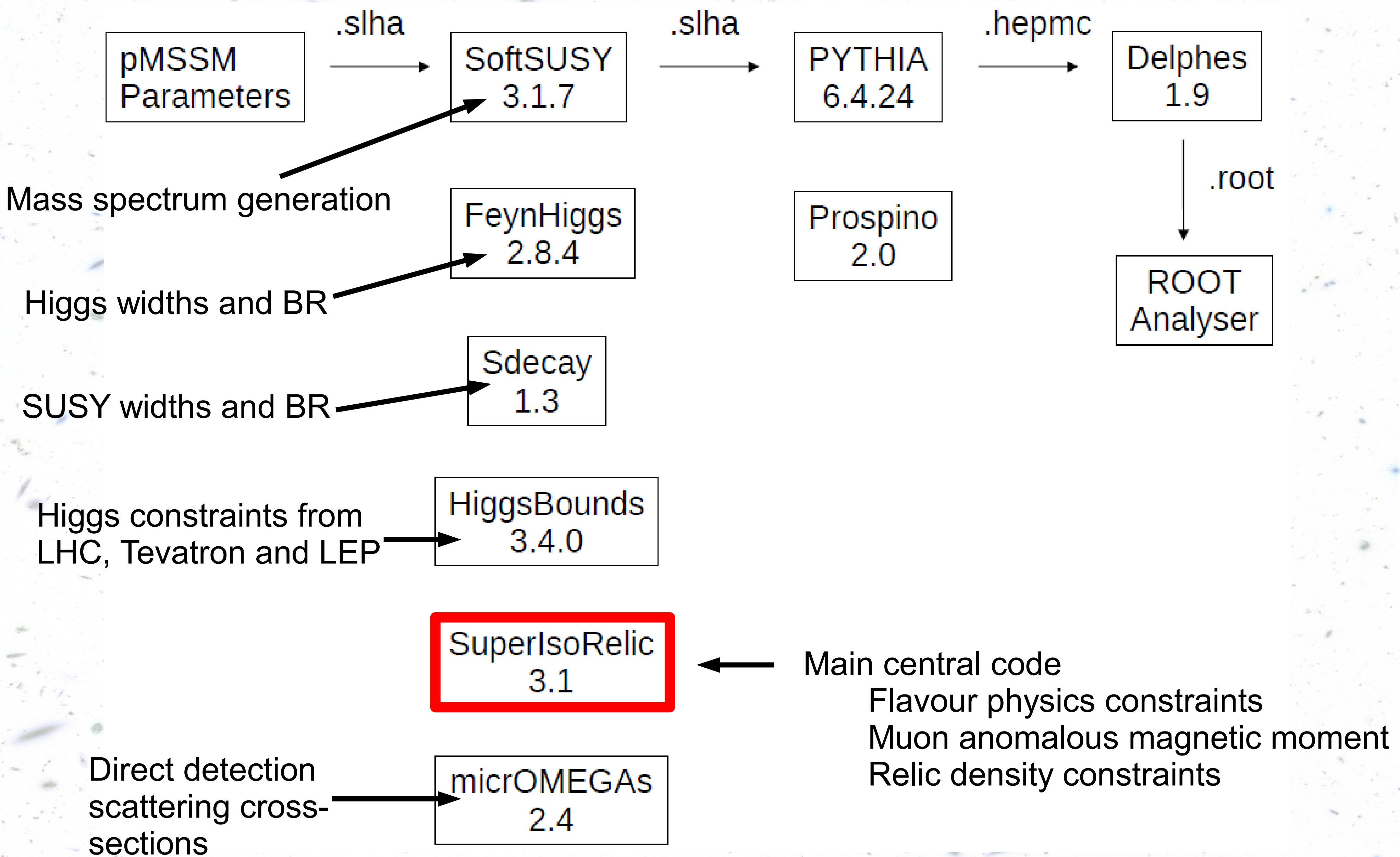

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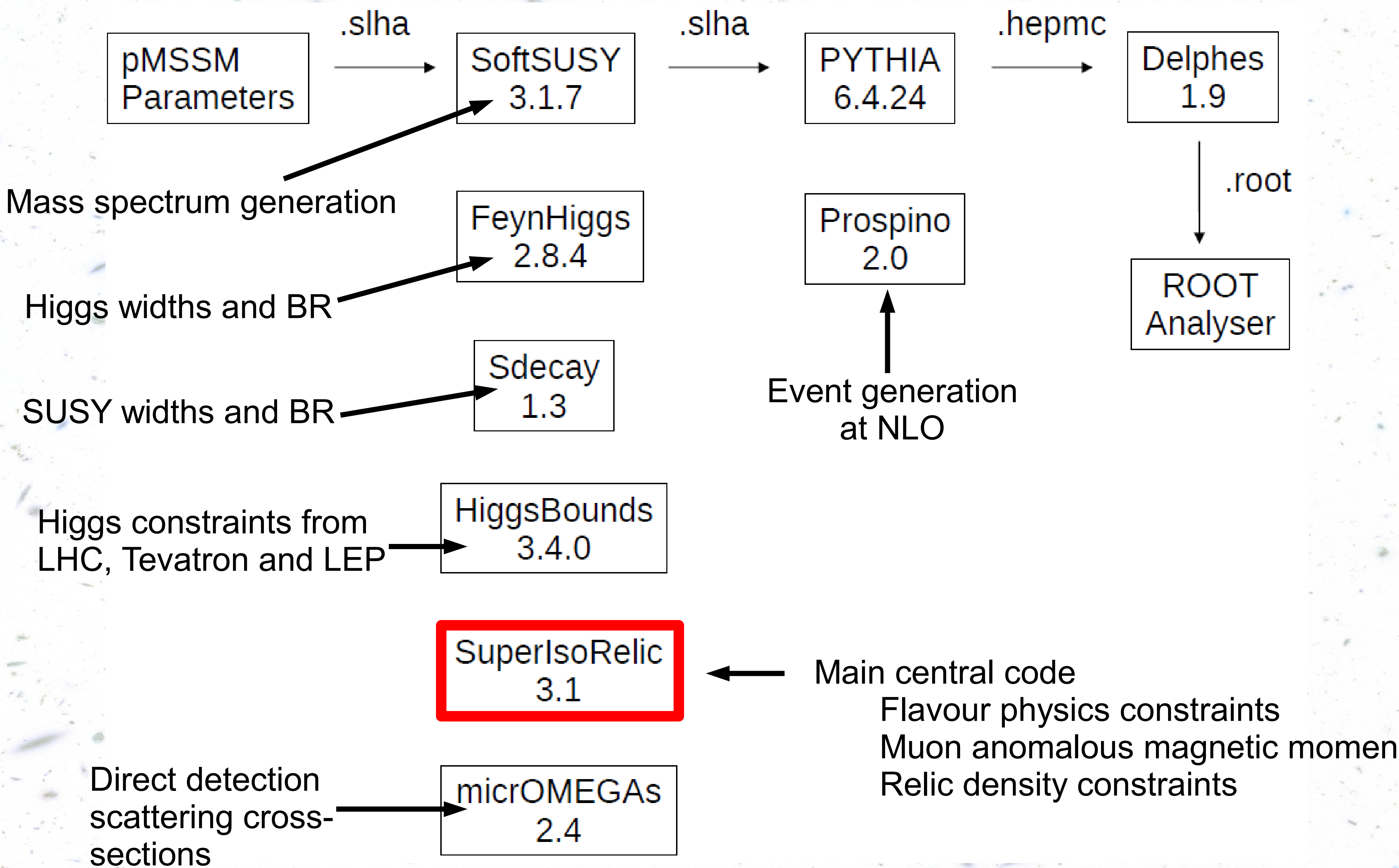

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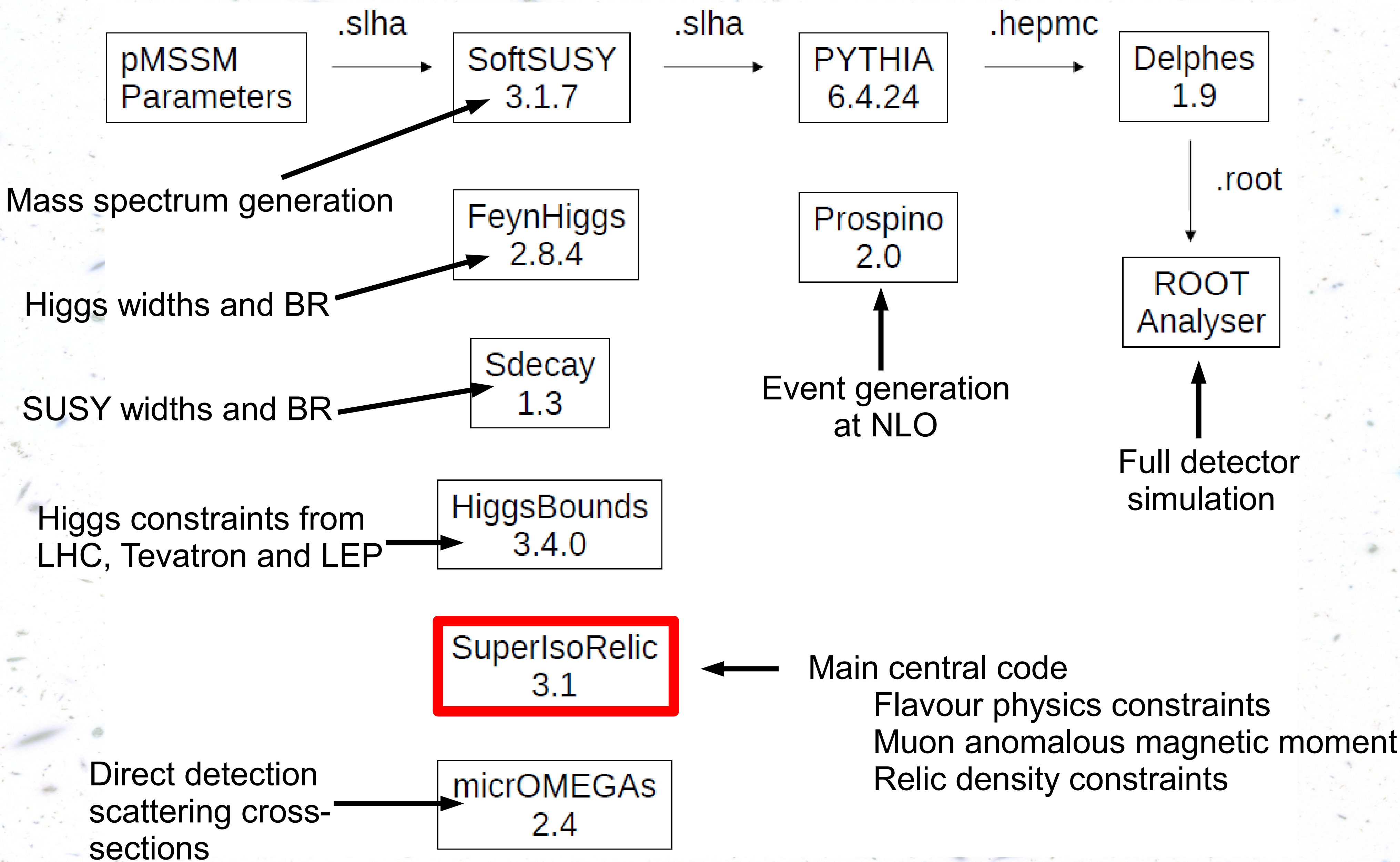

Constraints

Flavour physics

$$2.16\times10^{-4} < \mathrm{BR}(B\to X_s\gamma) < 4.93\times10^{-4}$$

$$\longrightarrow \quad \mathrm{BR}(B_s\to\mu^+\mu^-) < 1.08\times10^{-8}$$

$$0.56 < \frac{\mathrm{BR}(B\to\tau\nu)}{\mathrm{BR}_{SM}(B\to\tau\nu)} < 2.70\,,$$

$$4.7\times10^{-2} < \mathrm{BR}(D_s\to\tau\nu) < 6.1\times10^{-2}\,,$$

$$2.9\times10^{-3} < \mathrm{BR}(B\to D^0\tau\nu) < 14.2\times10^{-3}\,,$$

$$0.985 < \mathrm{R}_{\ell 23}(K\to\mu\nu) < 1.013\,.$$

Muon anomalous magnetic moment

$$-2.4\times10^{-9} < \delta a_\mu < 4.5\times10^{-9}$$

\+ Relic density constraint

\+ Higgs mass limits from LEP, Tevatron and LHC

Mass Limits from LEP and Tevatron

Particle	Limits	Conditions
χ_1^0		
χ_2^0	62.4	$\tan\beta < 40$
χ_3^0	99.9	$\tan\beta < 40$
χ_4^0	116	$\tan\beta < 40$
$\chi_1^\pm$	94	$\tan\beta < 40,\ m_{\chi_1^\pm} - m_{\chi_1^0} > 5$ GeV
$\tilde{e}_R$	73	
$\tilde{e}_L$	107	
$\tilde{\tau}_1$	81.9	$m_{\tilde{\tau}_1} - m_{\chi_1^0} > 15$ GeV
$\tilde{u}_R$	100	$m_{\tilde{u}_R} - m_{\chi_1^0} > 10$ GeV
$\tilde{u}_L$	100	$m_{\tilde{u}_L} - m_{\chi_1^0} > 10$ GeV
$\tilde{t}_1$	95.7	$m_{\tilde{t}_1} - m_{\chi_1^0} > 10$ GeV
$\tilde{d}_R$	100	$m_{\tilde{d}_R} - m_{\chi_1^0} > 10$ GeV
$\tilde{d}_L$	100	$m_{\tilde{d}_L} - m_{\chi_1^0} > 10$ GeV
$\tilde{b}_1$	248	$m_{\chi_1^0} < 70$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	220	$m_{\chi_1^0} < 80$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	210	$m_{\chi_1^0} < 100$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	200	$m_{\chi_1^0} < 105$ GeV, $m_{\tilde{b}_1} - m_{\chi_1^0} > 30$ GeV
	100	$m_{\tilde{b}_1} - m_{\chi_1^0} > 5$ GeV
$\tilde{g}$	195	

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Constraints from DAMA / CoGeNT / XENON:

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→ 58k accepted points
→ 20k accepted after mass limit cuts
→ 1k accepted after flavour cuts
→ 140 accepted after relic density cut

Parameter	Range
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M_A	[50,2000]
M_1	[-120, 120]
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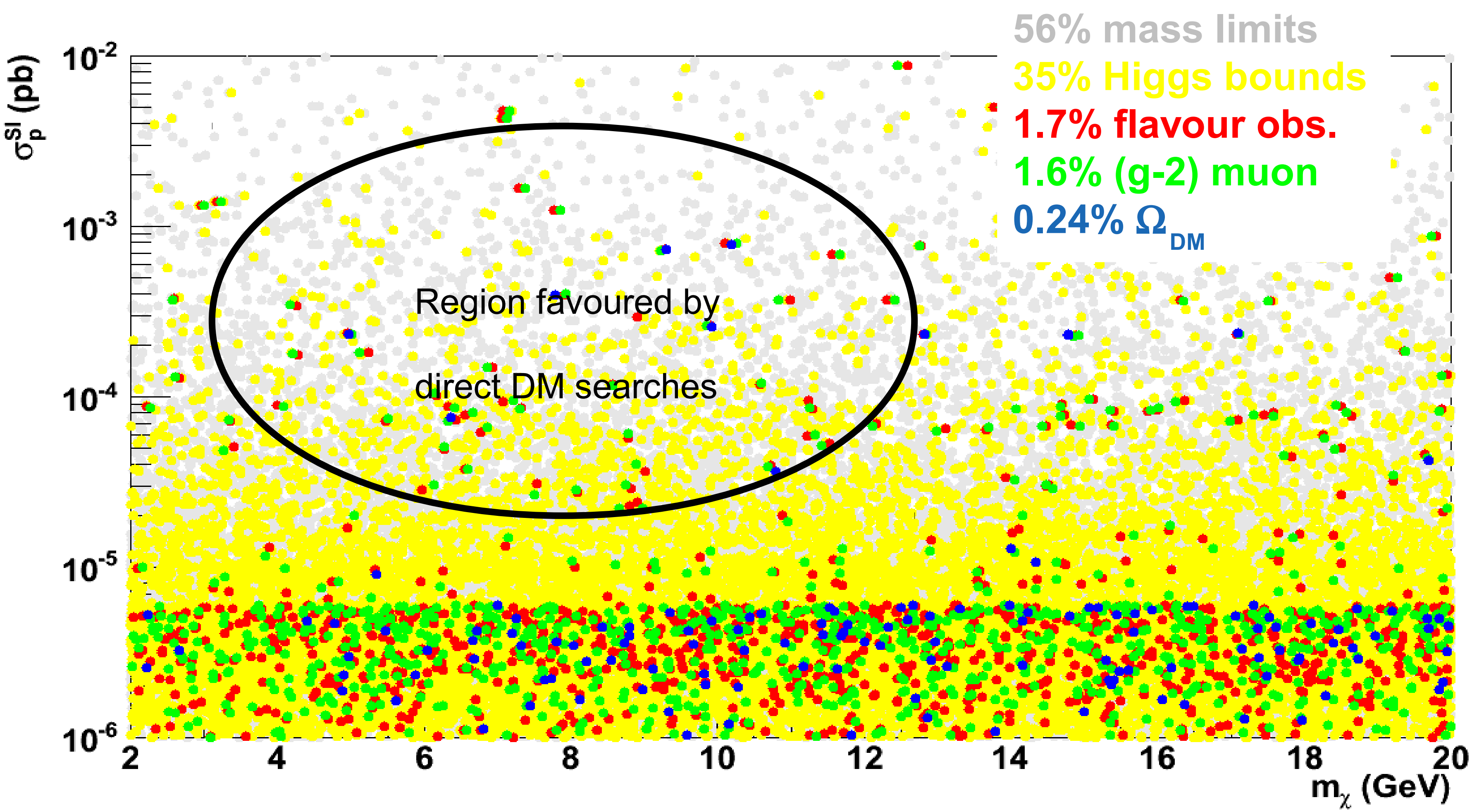
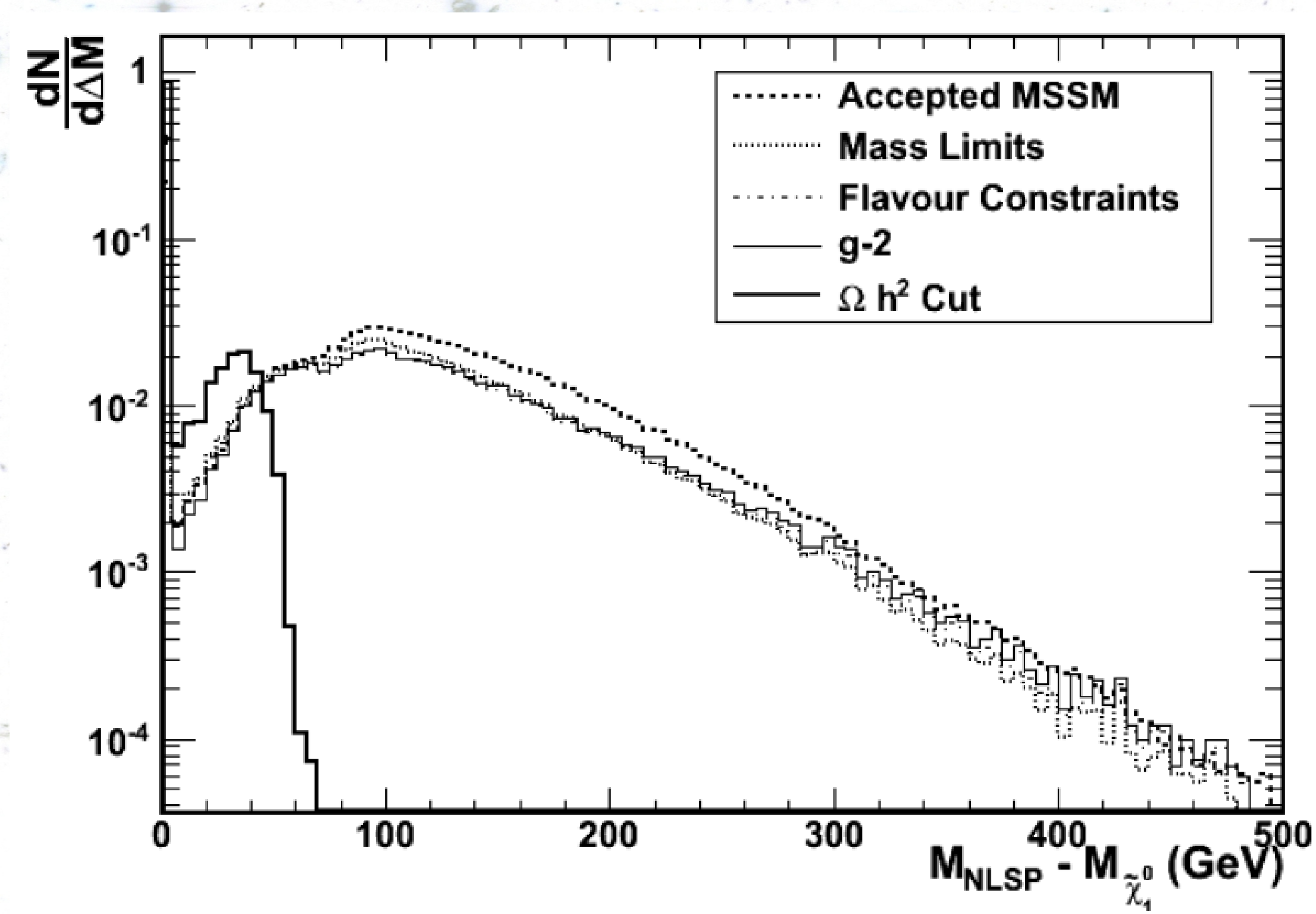
The pMSSM Parameter Space with Light Neutralino Dark Matter

χ-p Cross Section vs. χ Mass from Low Mass pMSSM Scans



Preliminary results

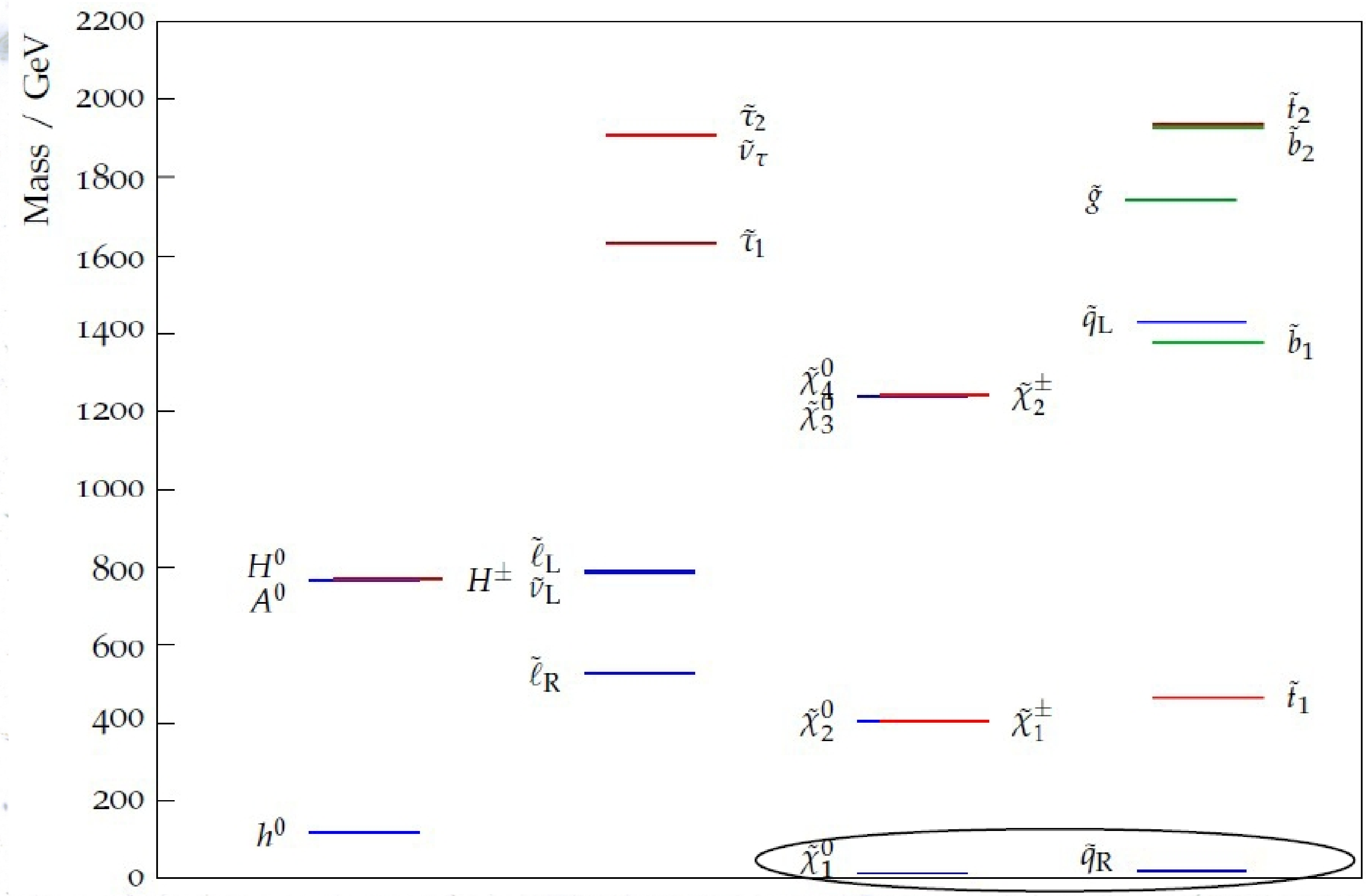


The relic density and direct detection constraints require NLSP almost degenerate with light neutralino 1: this implies characteristic spectra with light gauginos or squarks

Preliminary results

Two classes of spectra:

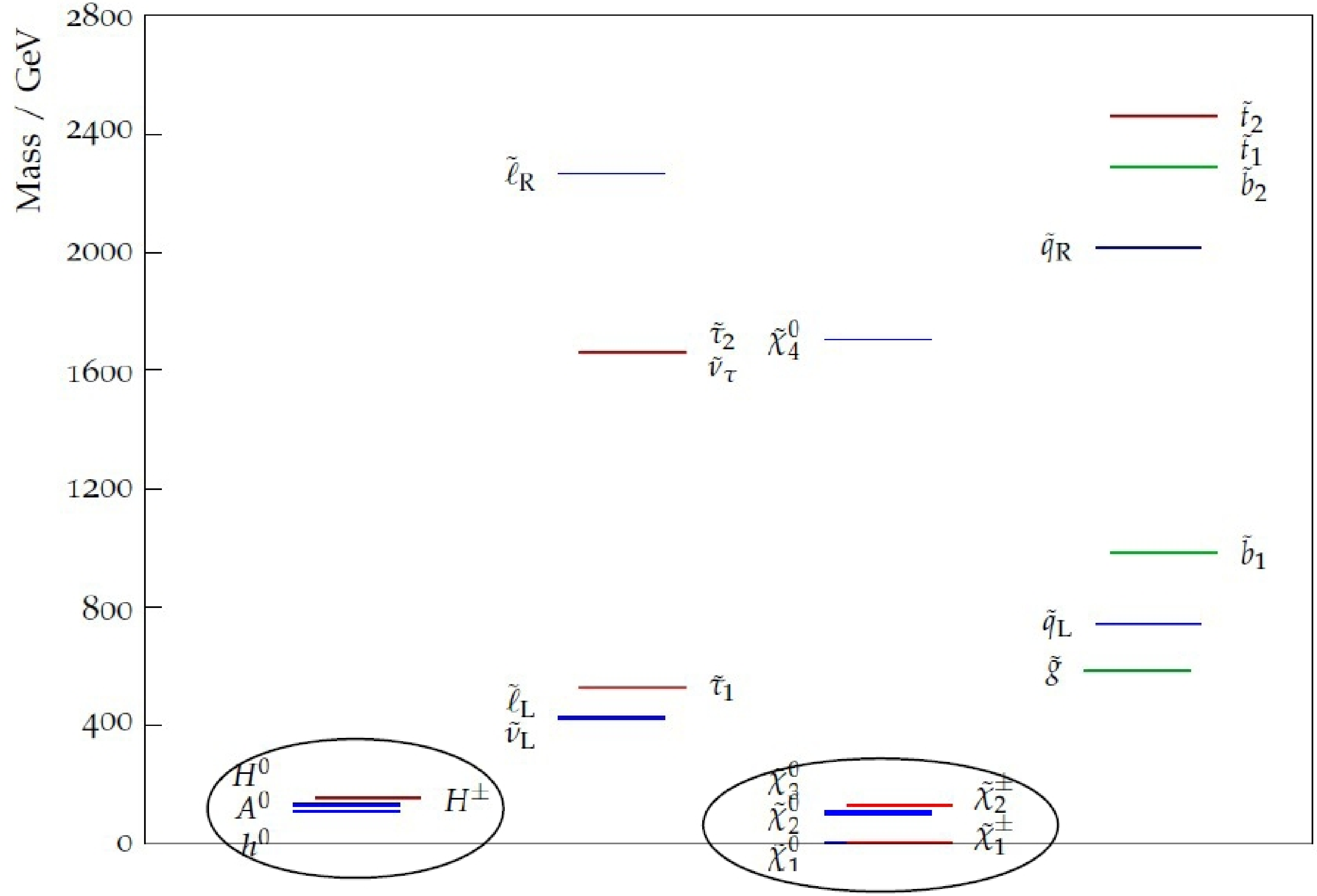
1) One squark degenerate with the LSP, relatively heavy other squarks and neutralinos



Preliminary results

Two classes of spectra:

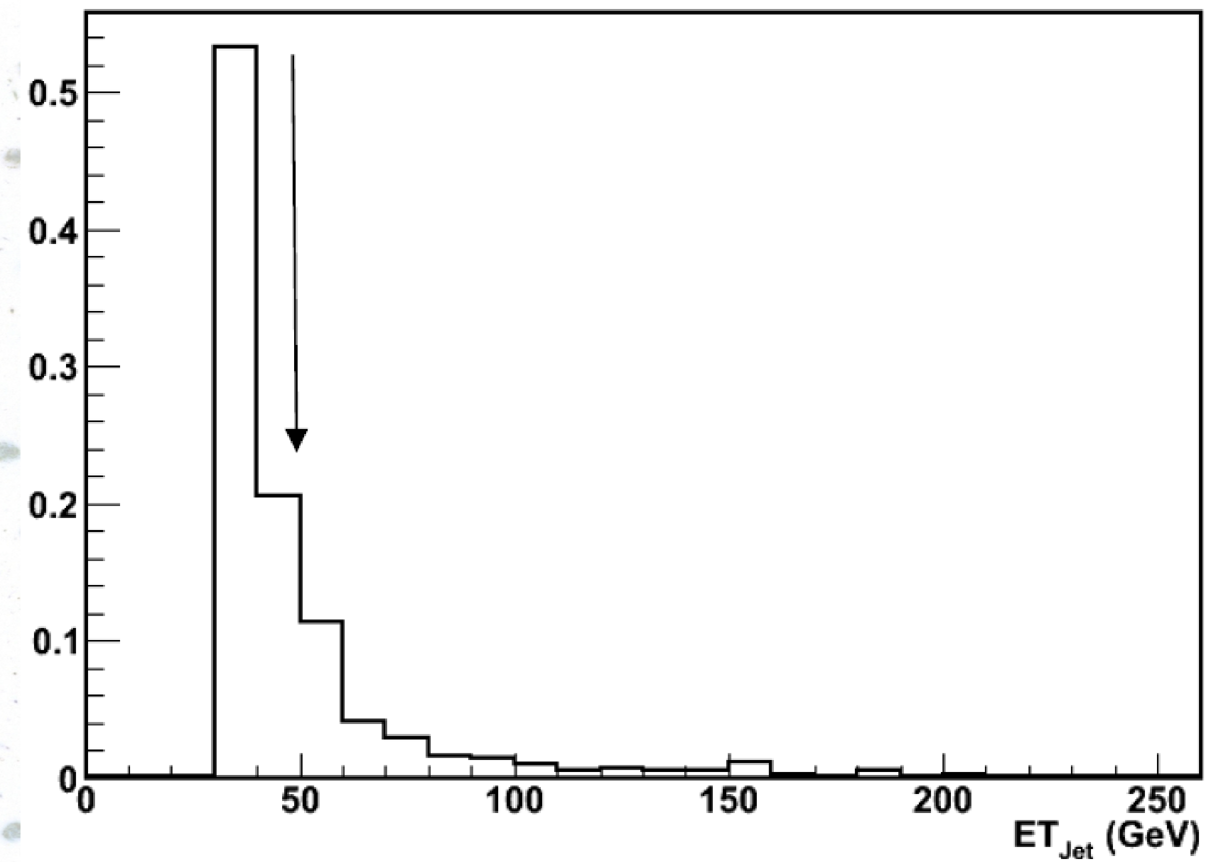
2) Chargino 1 degenerate with the LSP, compressed gaugino spectrum and light Higgs bosons



Preliminary results

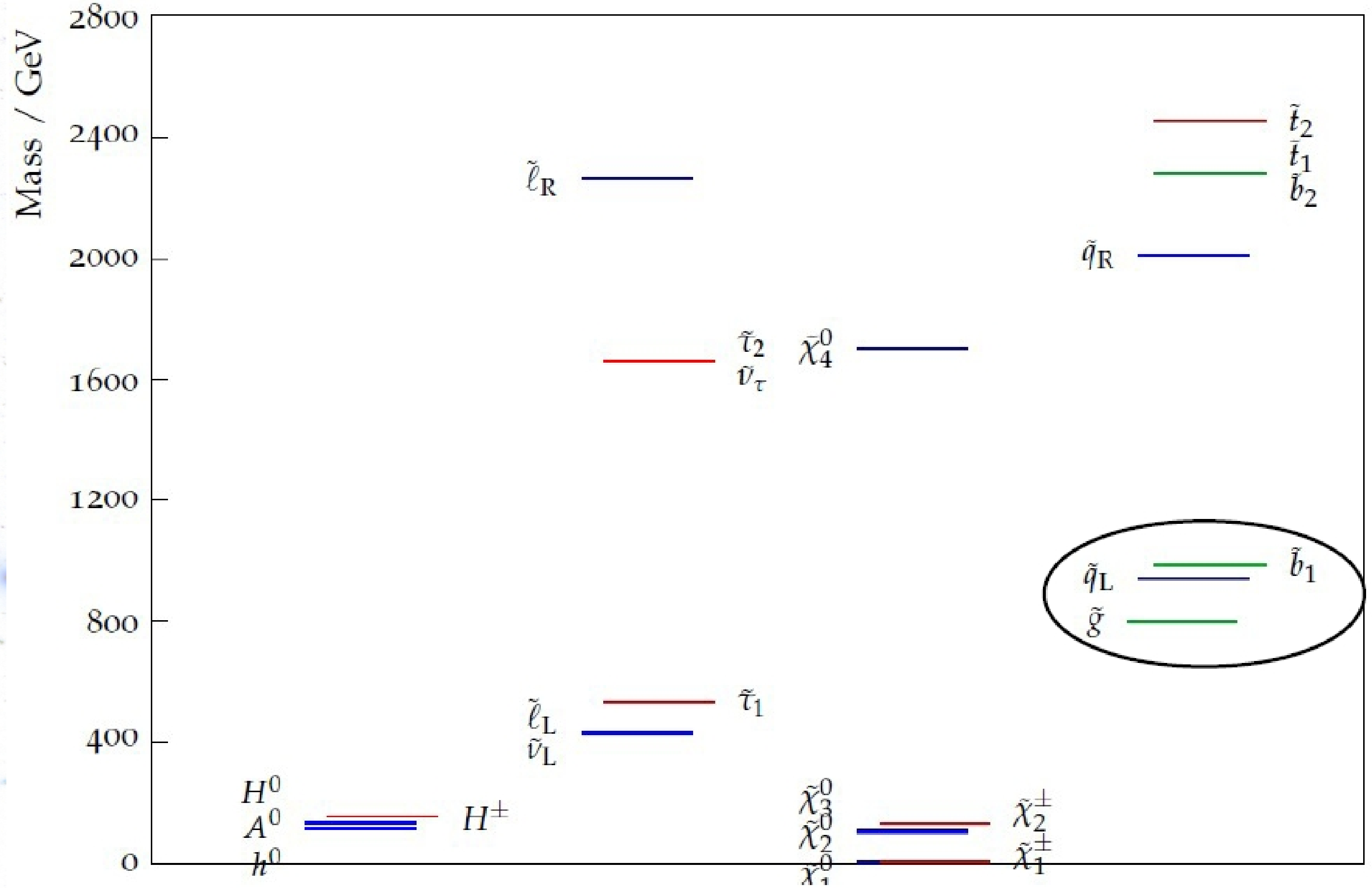
Spectra of type 1) have typically large inclusive SUSY cross sections but soft jet p_T spectrum in hadronic channel, soft MET and no/small signal in leptonic channels.

→ can escape detection



Preliminary results

Spectra of type 2) may have squarks and gluino beyond current sensitivity: Study allowed and explorable region with increasing gluino and squark masses



Conclusion

Dedicated scan searching for light neutralino points compatible with DAMA/CoGeNT/XENON data

Two classes of spectra identified, all characterised by the chargino or a squark degenerate with the LSP, yielding large SUSY inclusive cross sections but small p_T jets and small MET

Detectability of these spectra at CMS under investigation

Plan to increase statistics x5, study additional models (Gravitino DM, NMSSM)