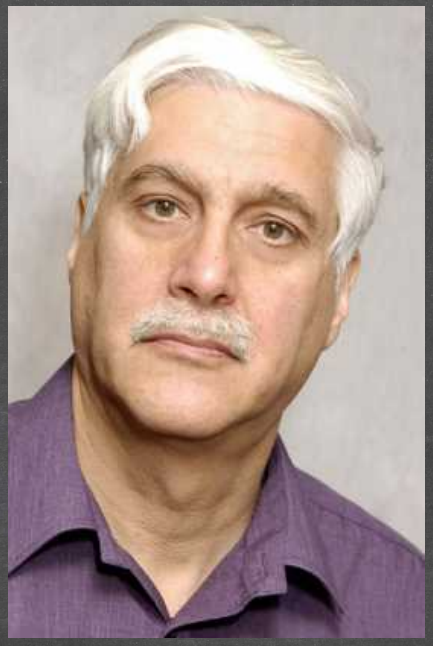
BSM Collider Phenomenology @SHEP

Elena Accomando



Douglas Ross (FRS)

Stefano Moretti

Alexander (Sasha) Belyaev

Why BSM?

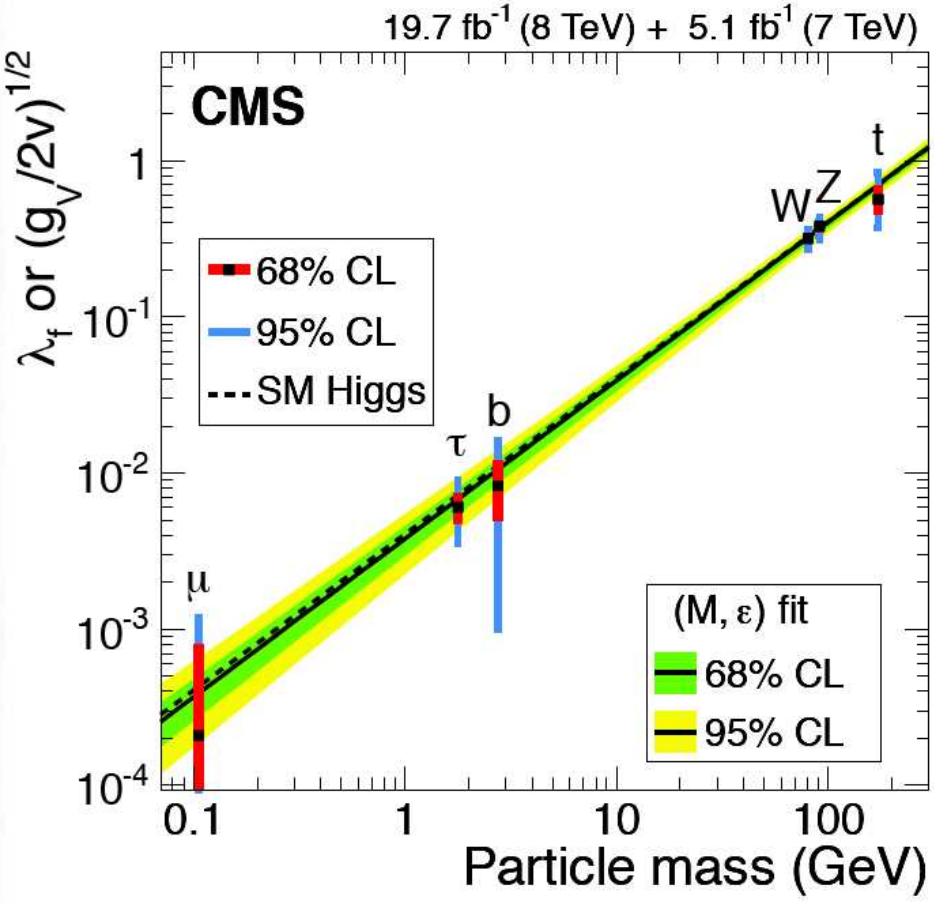
The the Standard Model is very successful from collider point of view

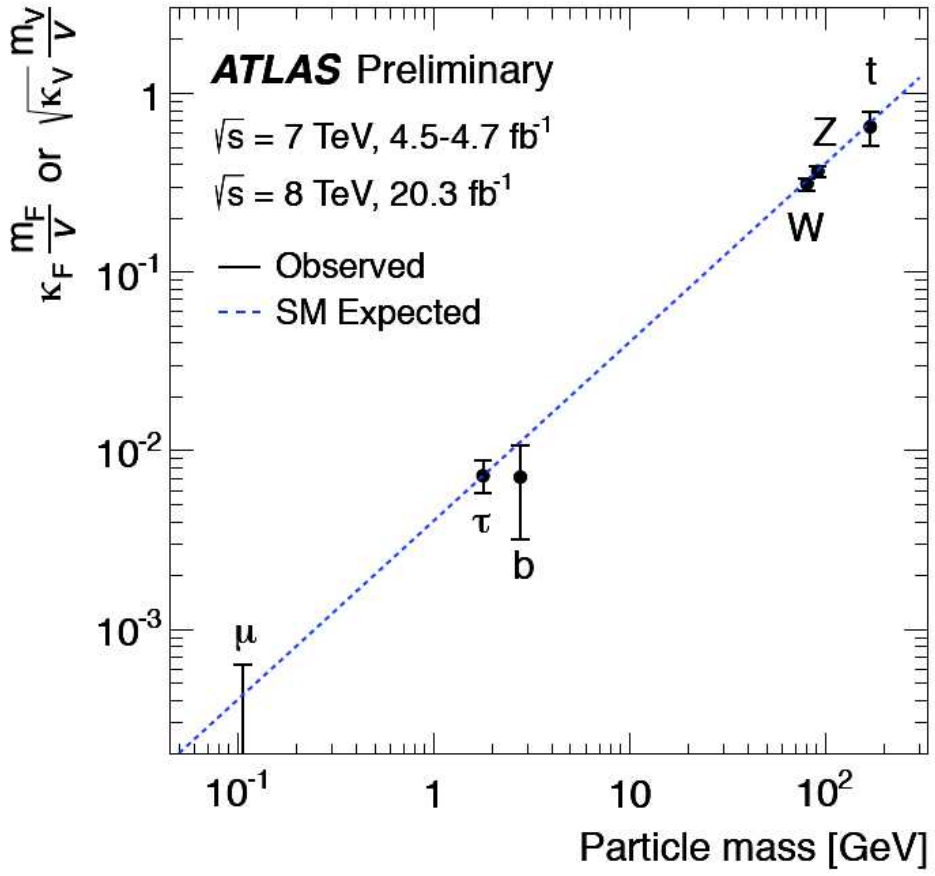
λ = Yukawa coupling for fermions
√g/2v = couplings for W/Z bosons

EPJ C75 (2015) 5, 212

For the first time, non-universal, mass-dependent couplings observed

ATLAS-CONF-2015-007

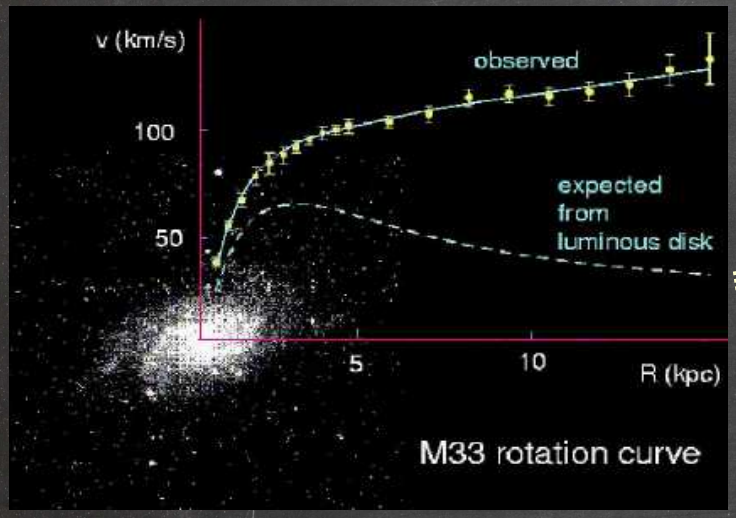




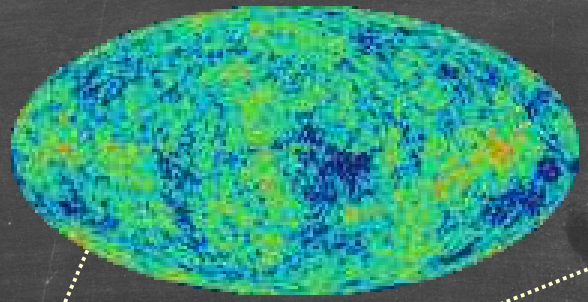
But at a bigger scale SM is empirically incomplete

- the presence of non-baryonic, cold dark matter: DM is neutral, stable, colourless, non-baryonic and massive (cold or warm). Neutrinos are too light, make instead hot DM

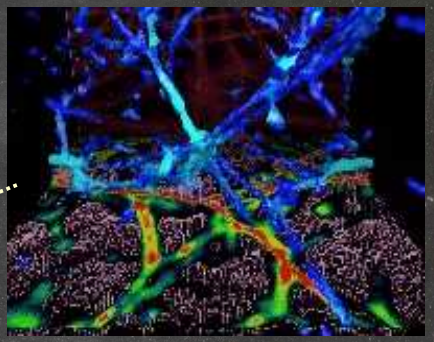
Galactic rotation curves



CMB: WMAP and PLANCK

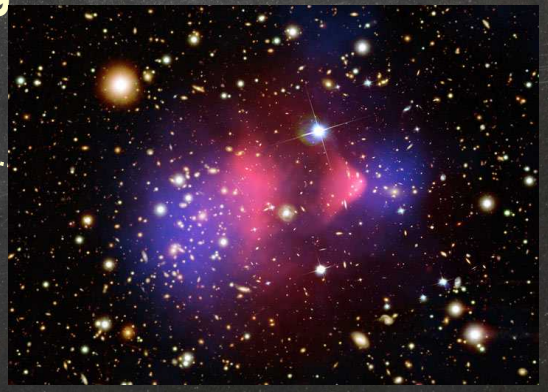


Large Scale Structures



Gravitational lensing

Bullet cluster



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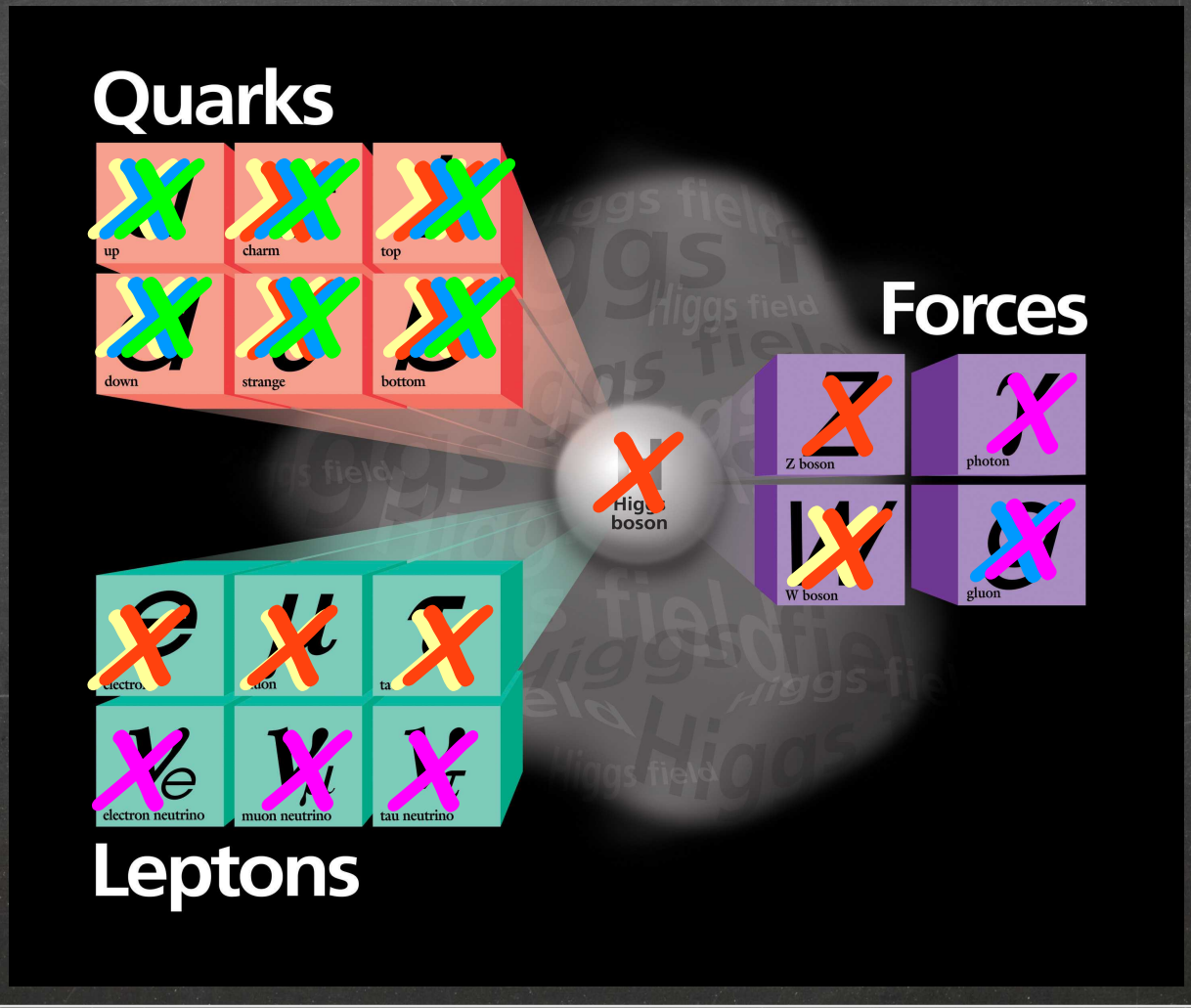
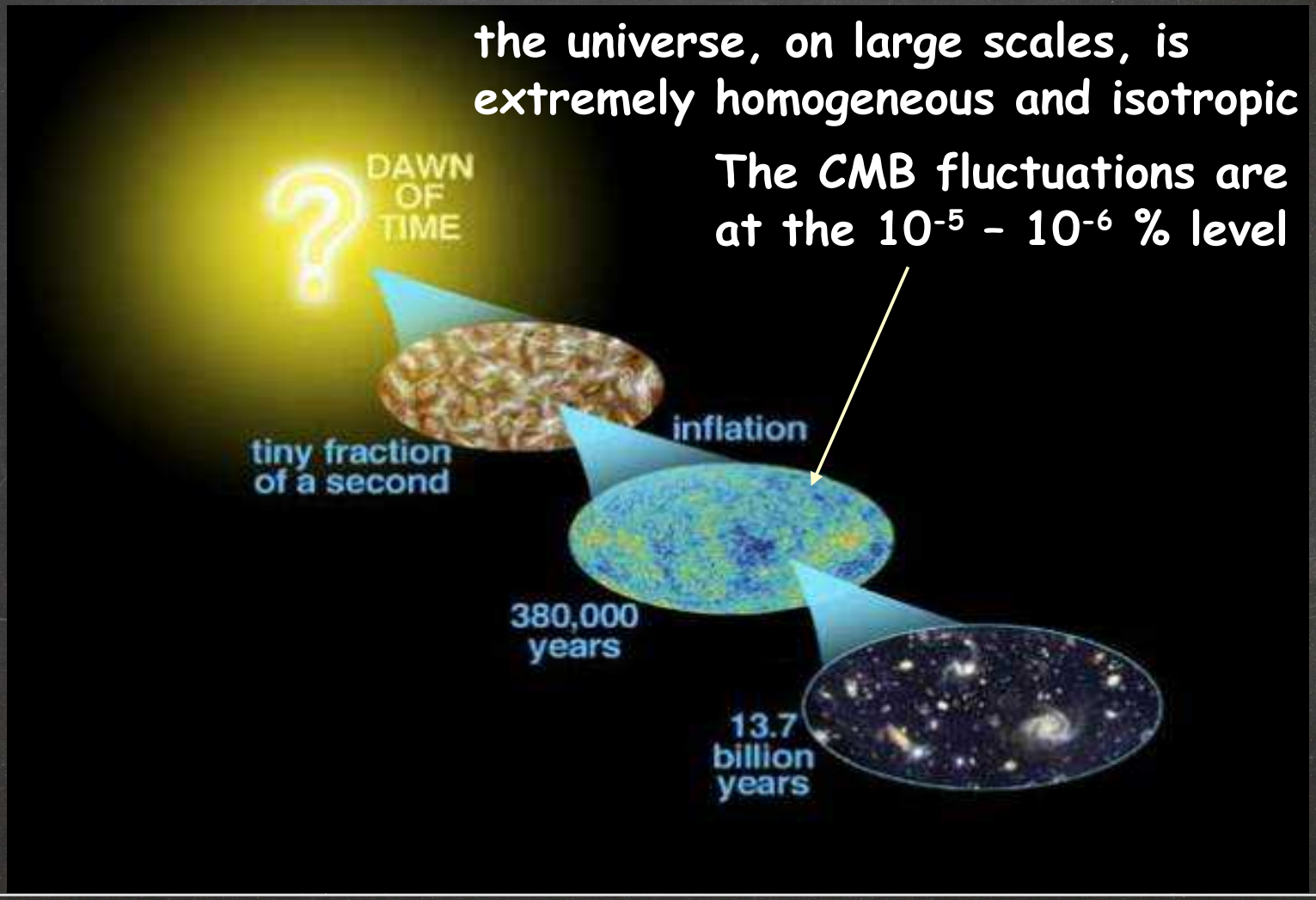


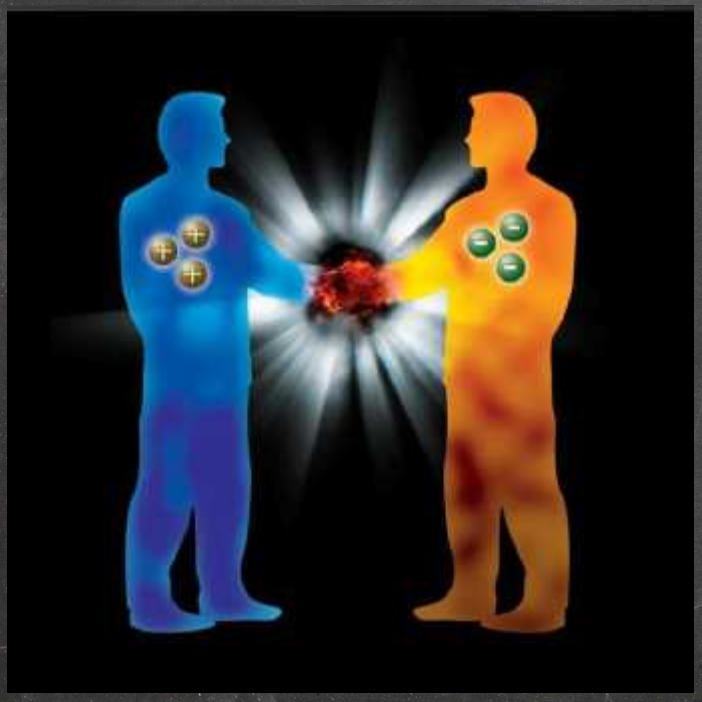
But at a bigger scale SM is empirically incomplete

- the presence of scale-invariant, Gaussian, and apparently acausal density perturbations: consistent with a period of inflation at early times. Higgs filed by itself can not provide inflation.



But at a bigger scale SM is empirically incomplete

- the observed abundance of matter over anti-matter: note, moreover, that inflation would destroy any asymmetry imposed as an initial condition.



The amount of CP violation in the SM which could lead to baryon-antibaryon asymmetry is too small (would provide BAU orders of magnitude below the observed one)

$$\frac{n_B}{n_\gamma} = (6.1^{+0.3}_{-0.2}) \times 10^{-10}$$

Empirical problems of the SM stated above have been established beyond reasonable doubt.

Higgs Boson Discovery has completed the puzzle of the Standard model ...

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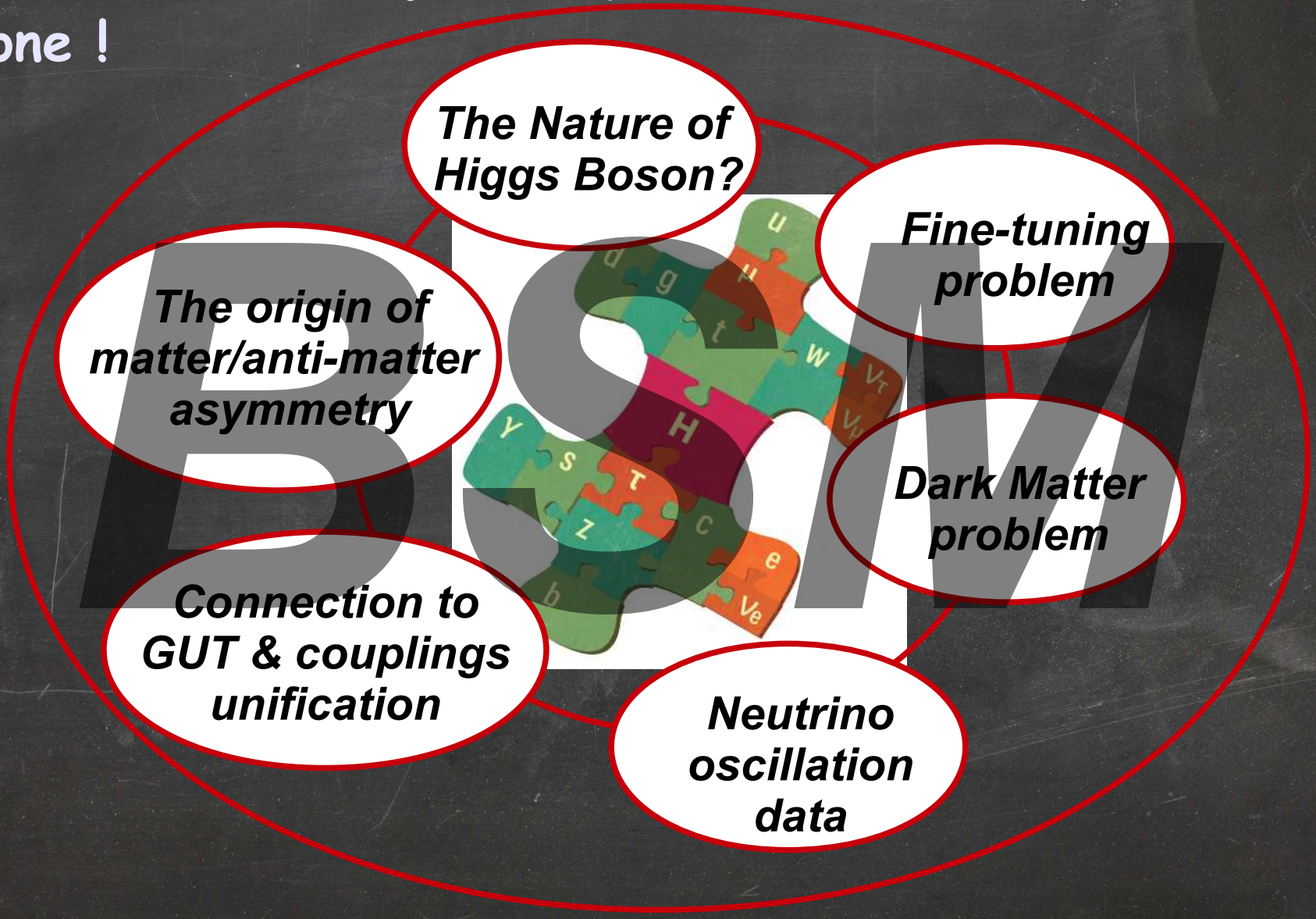
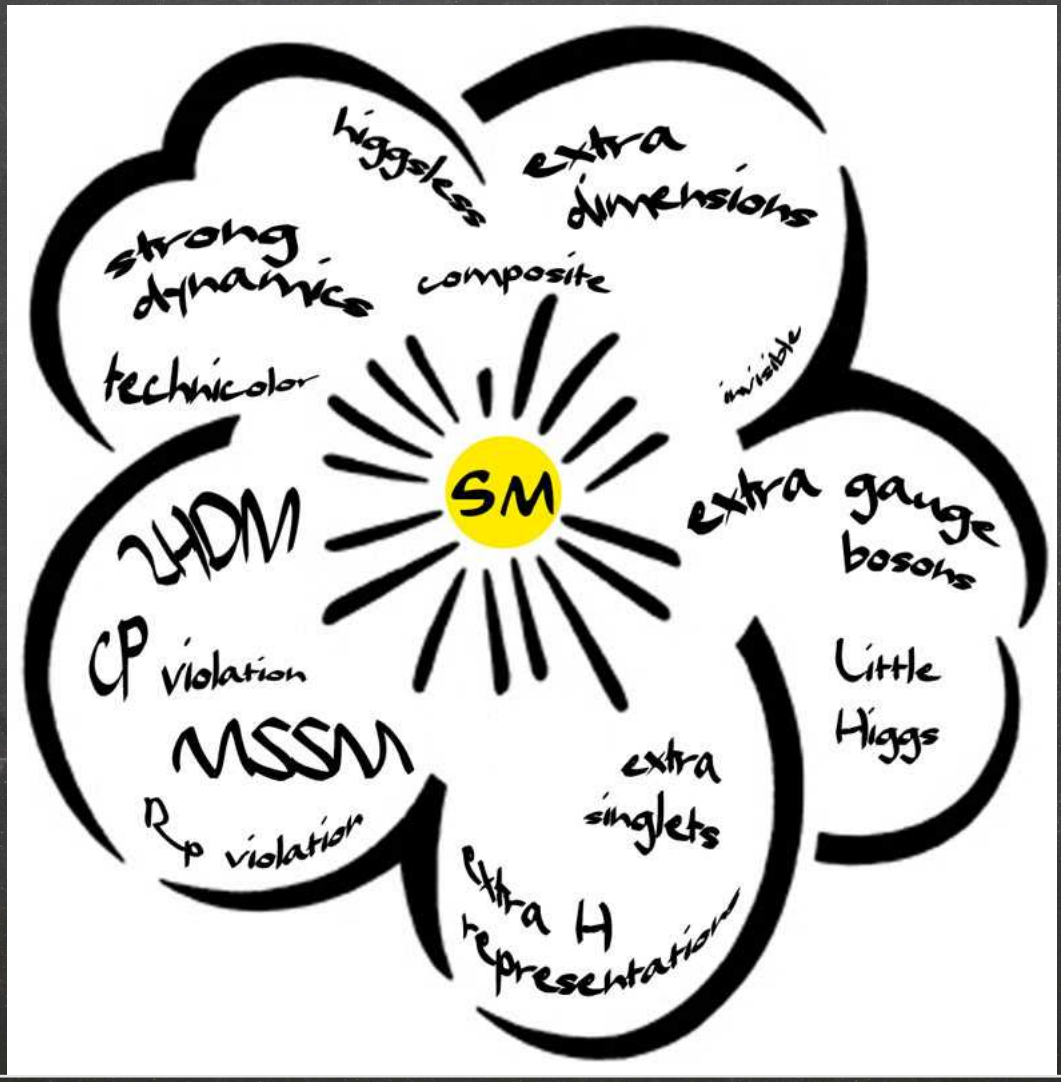
But the SM itself is just a piece of a bigger puzzle – BSM one !



Beyond the Higgs discovery

- Higgs properties are amazingly consistent with all main compelling underlying theories (except higgsless ones!) Some parameter space of BSM theories was eventually excluded.



CPNSH workshop
CERN 2006-009

Beyond the Higgs discovery

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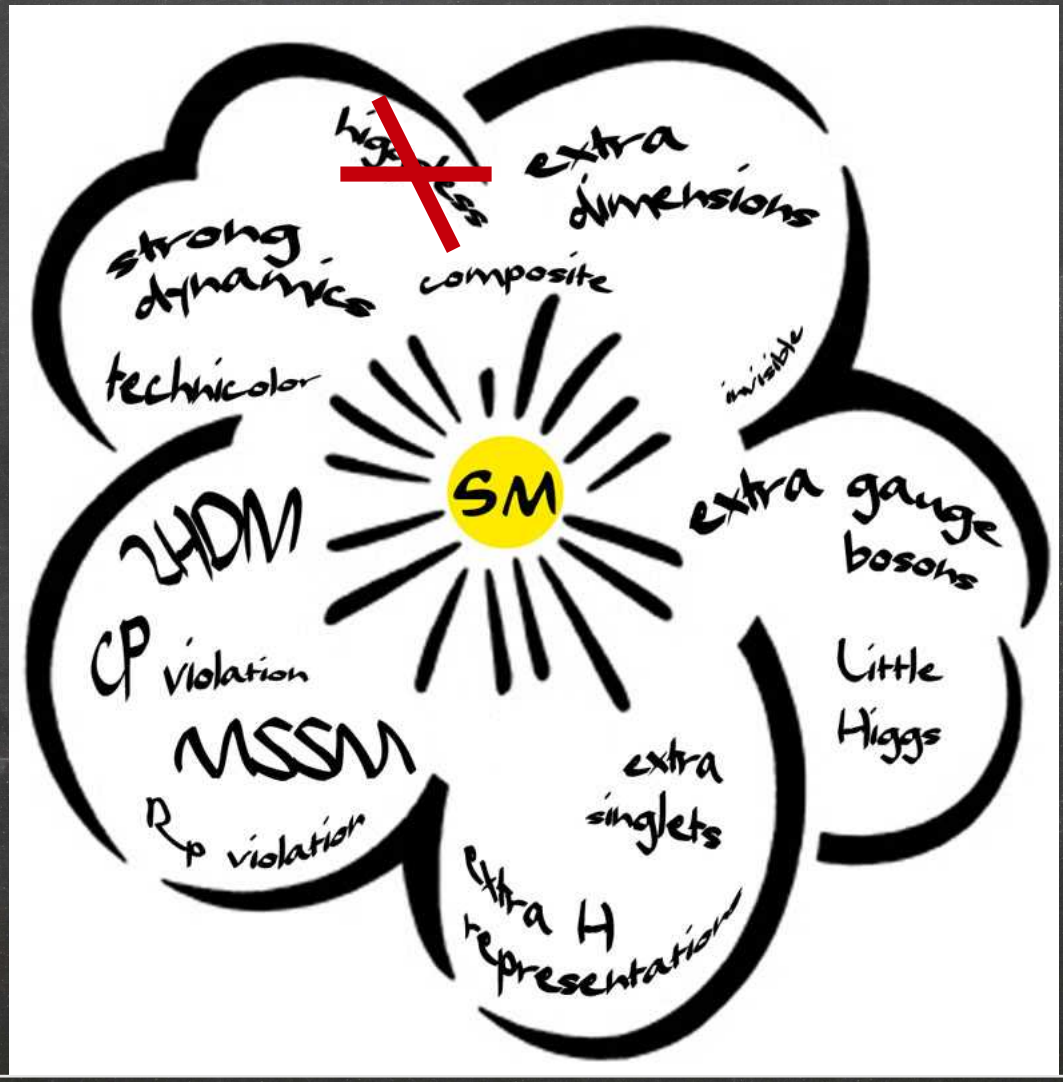

Present Status

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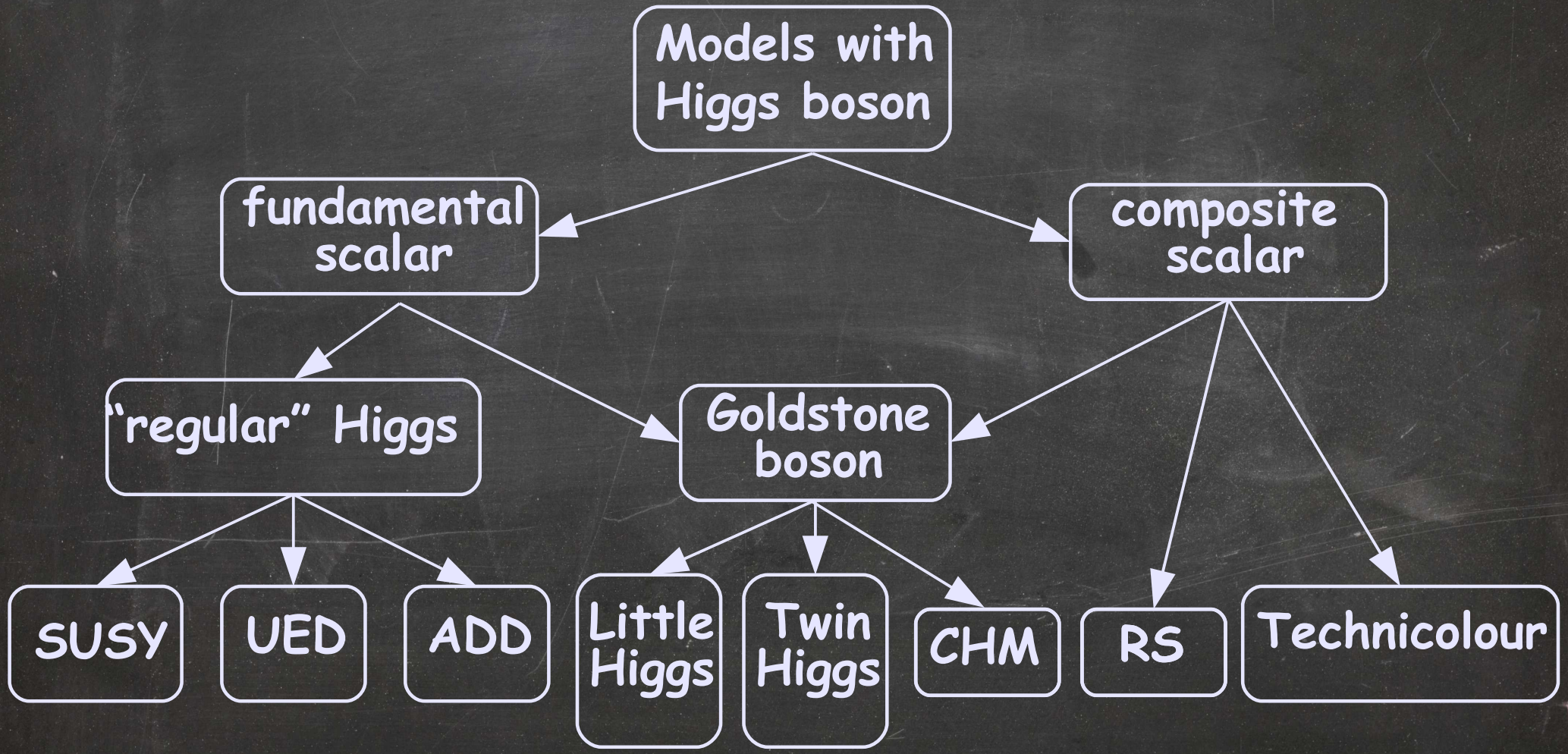


What do we know about Dark Matter?

Spin ?

Mass ?

Stable

Yes ?

No ?

symmetry behind stability ?

Couplings

gravity V

Weak ?

Higgs ?

Quarks/gluons ?

Leptons ?

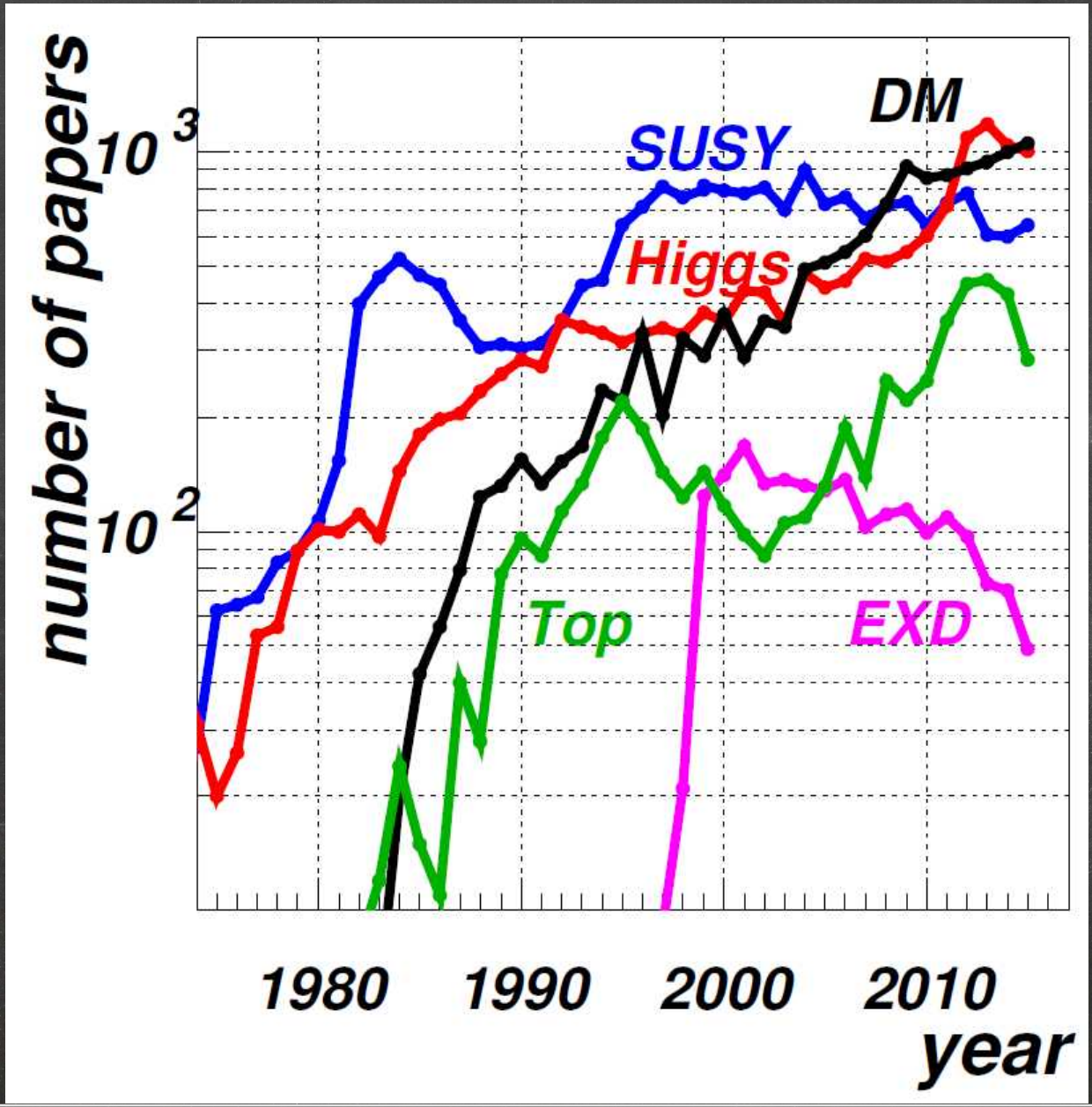
New sector ?

Thermal relic

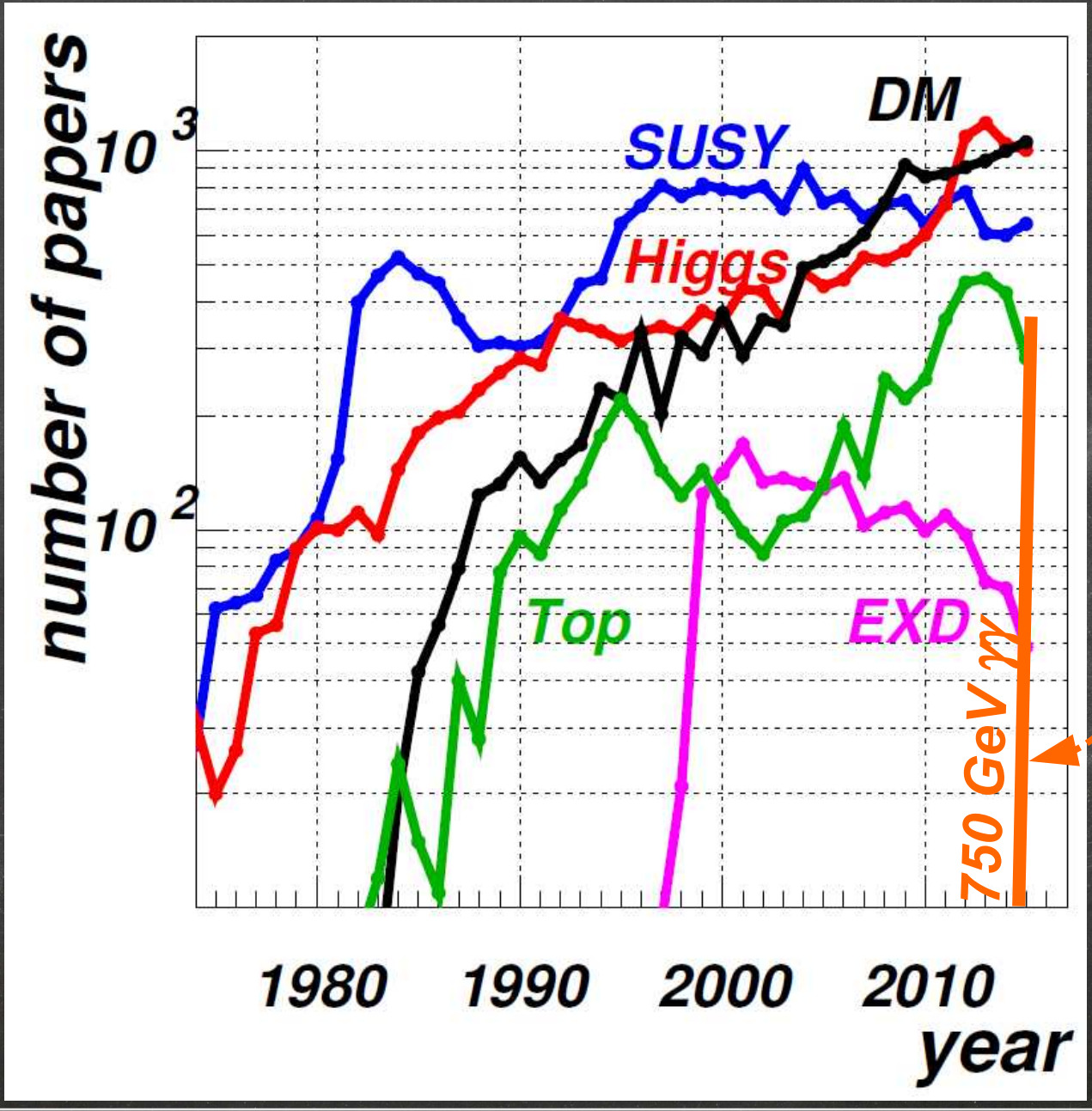
Yes ?

No ?

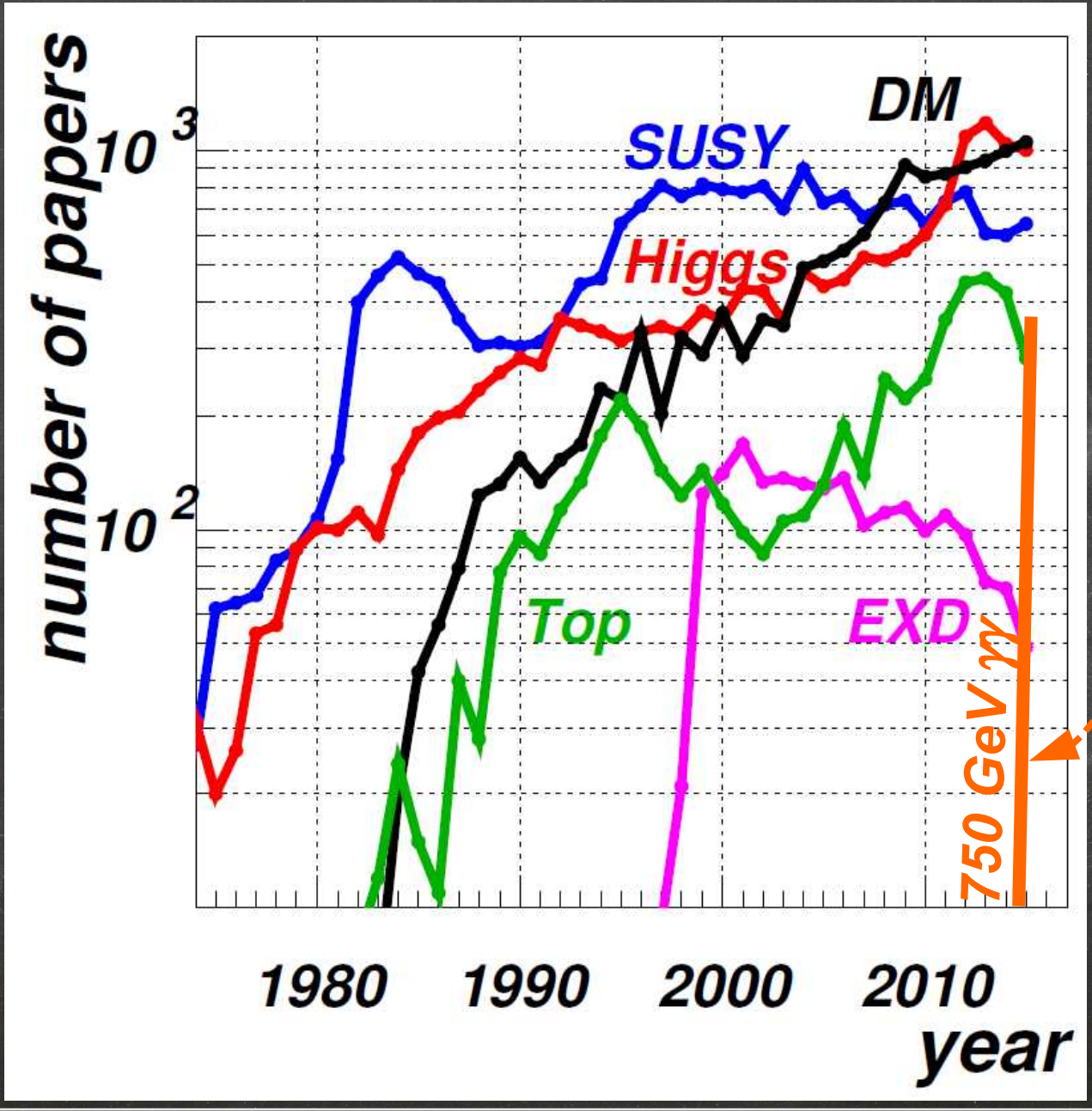
Popular trends and sources of inspiration



another source of inspiration?!



gone … :-(


number of papers
10^3
10^2
SUSY
DM
Higgs
Top
EXD
750 GeV γγ
1980
1990
2000
2010
year

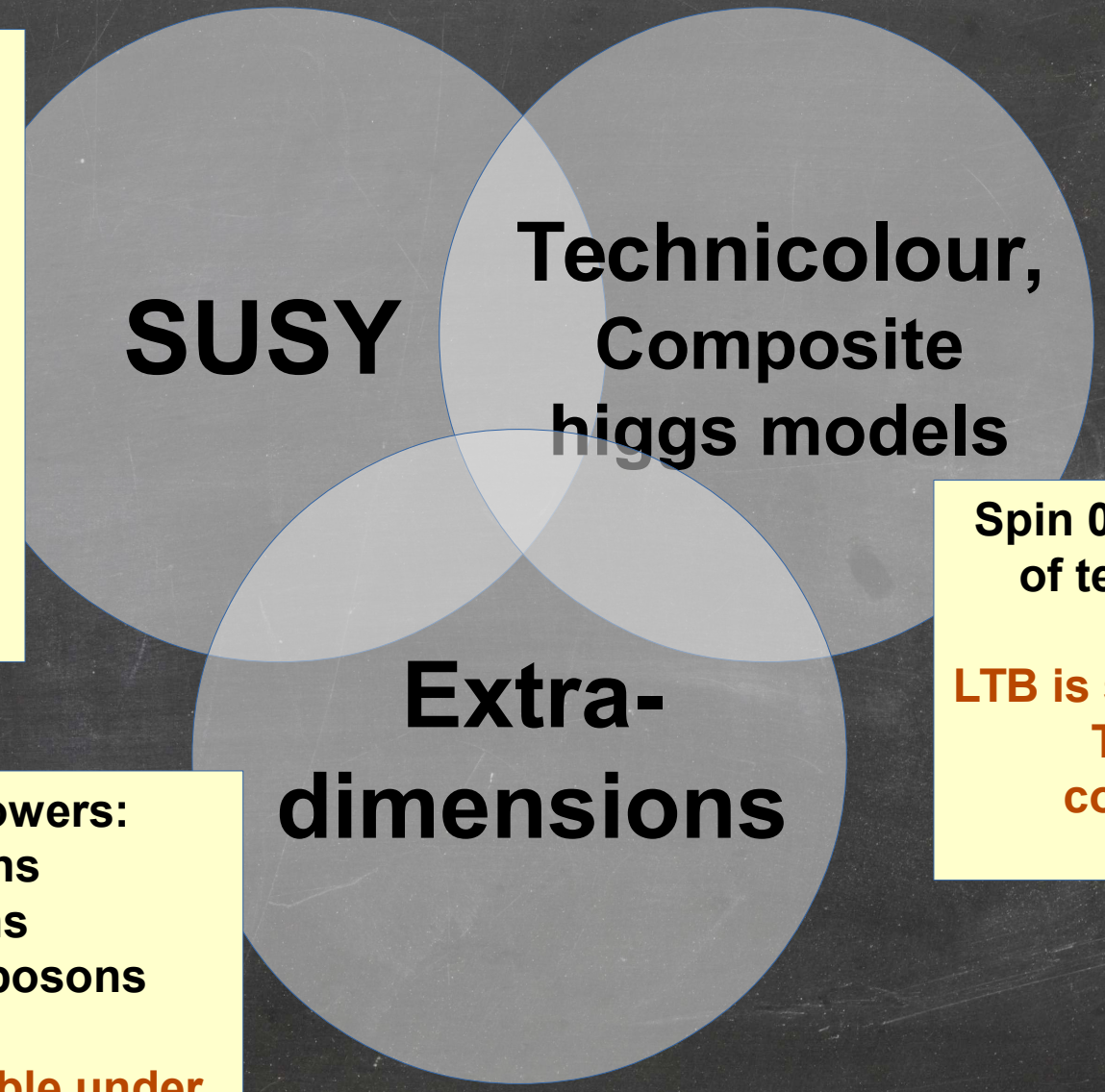
Theories and particles

SUSY partners

New gauge bosons (USSM, E6SSM)

Exotics – diquarks, LQ (E6SSM)

LSP is stable under the R-parity



Spin 0,1 bound states of techni-quarks:

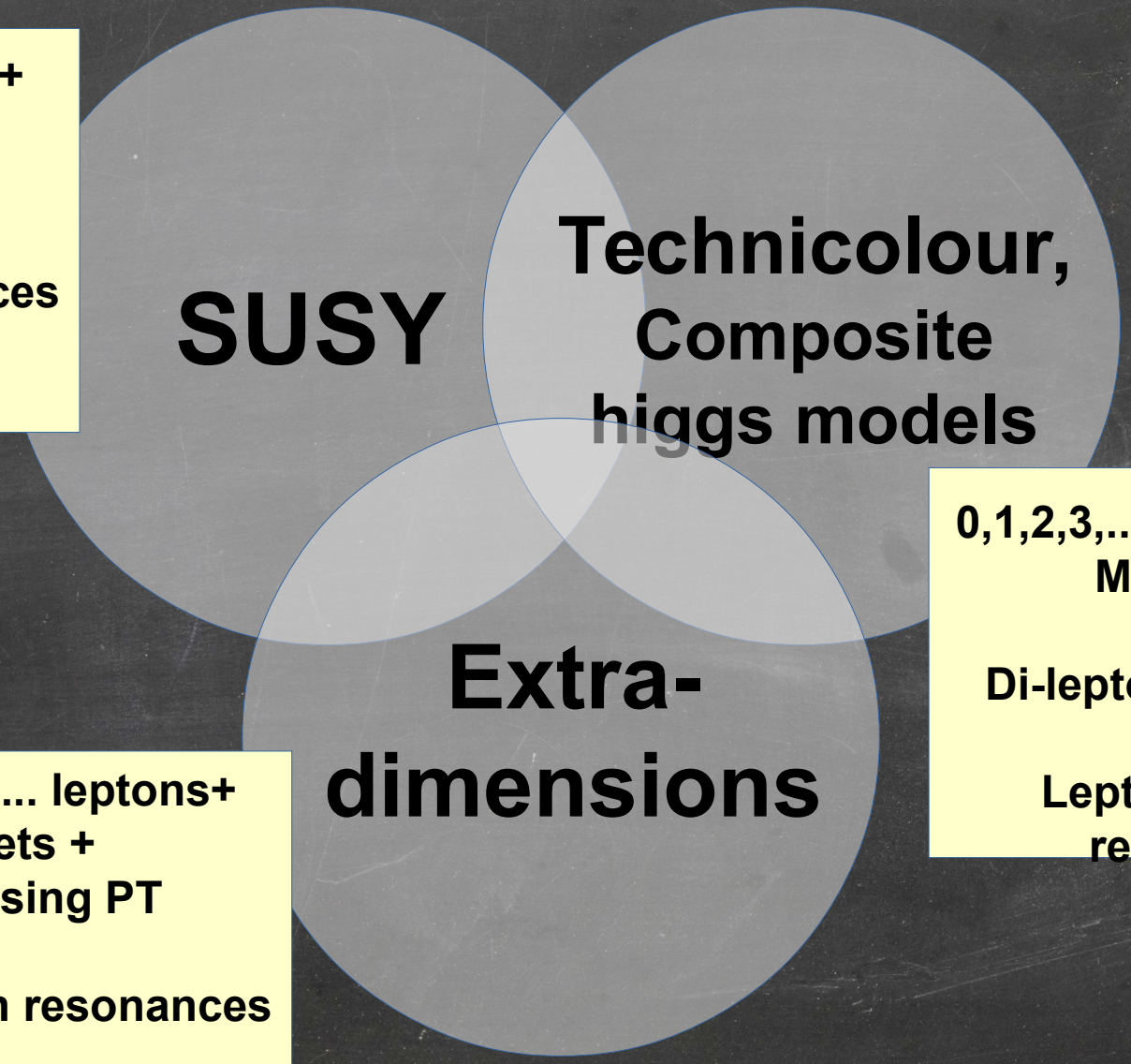
LTB is stable under the TB number conservation

KK – towers:
KK-gravitons
KK-fermions
KK-gauge bosons

LKP is stable under the KK-parity (UED)

Theories and new particles are different

Theories and signatures



0,1,2,3,... leptons+ jets + Missing PT

Di-lepton resonances

Same-sign leptons

0,1,2,3,... leptons+ jets + Missing PT

Di-lepton resonances

Lepton-neutrino resonances

0,1,2,3,... leptons+ jets + Missing PT

Di-lepton resonances

Same-sign leptons

But the new signatures are very similar!

The main problem is to decode an underlying theory from the complicated set of signatures: down->top

SUSY | UED | ADD | Little Higgs | Technicolour | CHM | RS

top->down
Easy

Tons of Signatures

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top->down Easy

down->top Very difficult

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Tons of Signatures

HEPMDB
High Energy Physics Model Data Base

https://hepmdb.soton.ac.uk/

What does our collider-pheno group do?

- Using both top-down and down-top approach to be ready to identify underlying theories from LHC signals
- Using power of **N**ew interactions between **Ex**perimentalists and **T**heorists – **NExT** !
  - Interaction within SHEP: BSM (King, Di Bari), AdS/CFT (Evans), …
  - Interaction between NExT links: RAL, SOTON, RHUL, SUSSEX, QMUL, Bristol, Brunel
  - NExT PhD school and joint NExT PhD students – real theory-experiment connection
  - All faculty members of collider-pheno group have CMS association or full CMS membership
  - Collaboration with CERN via SOTON grants – SOTON-Sao Paulo

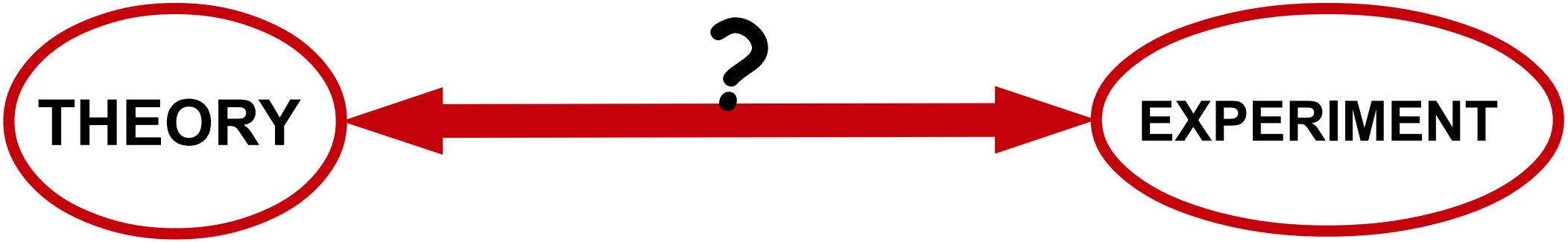
NExT PhD students intake 2015 as an example

NExT PhD Students and Projects

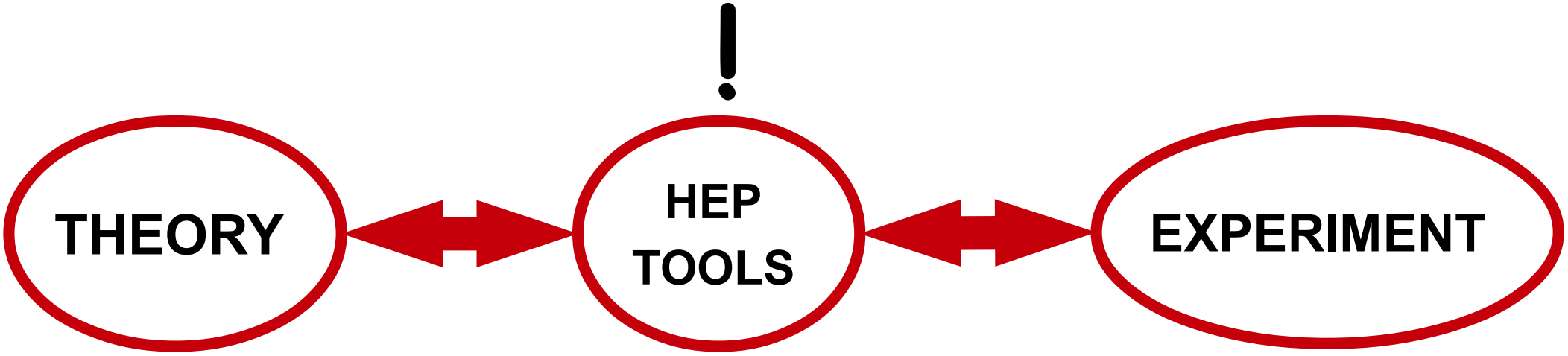
Start Date	Lead Institution	Project	Supervisors	Affiliation/Student
Oct 2015	Southampton	BSM Higgs searches in b-jet final states	S Moretti/C Shepherd-Themistocleous	RAL/Lucy Upton
Oct 2015	QMUL & Southampton	SM tests and BSM searches in final states with b-quarks and tau leptons at the LHC	J Hays/E Accomando	Joint/David Englert
Oct 2015	Bristol & Southampton	SUSY searches at CMS	H Flaecher/S Moretti/C Shepherd-Themistocleous	Joint & RAL/Alex Titterton

What does our collider-pheno group do?

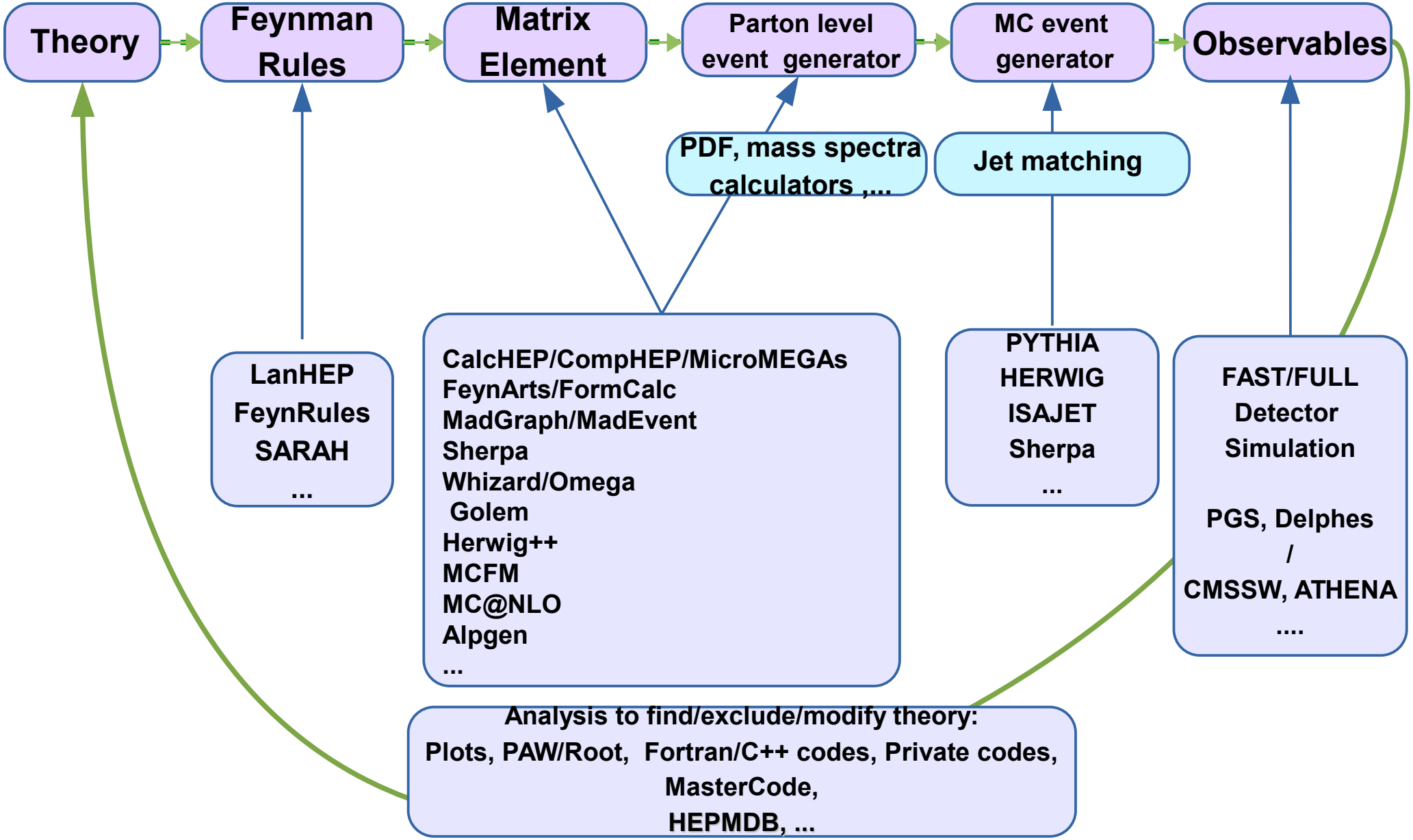
- Models under study:
  - Better understanding of SM – higher order corrections
  - SUSY and its extensions
  - Models with the extended Higgs Sector
  - Extra-dimensions
  - Technicolor and Composite Higgs models:
    - vector and scalar resonances
    - Vector-like quarks
  - Generic models with vector and scalar resonances
  - Generic models with Dark Matter


THEORY
?
EXPERIMENT

Tools are crucial for THEORY - EXPERIMENT connection



Tools are crucial for THEORY - EXPERIMENT connection

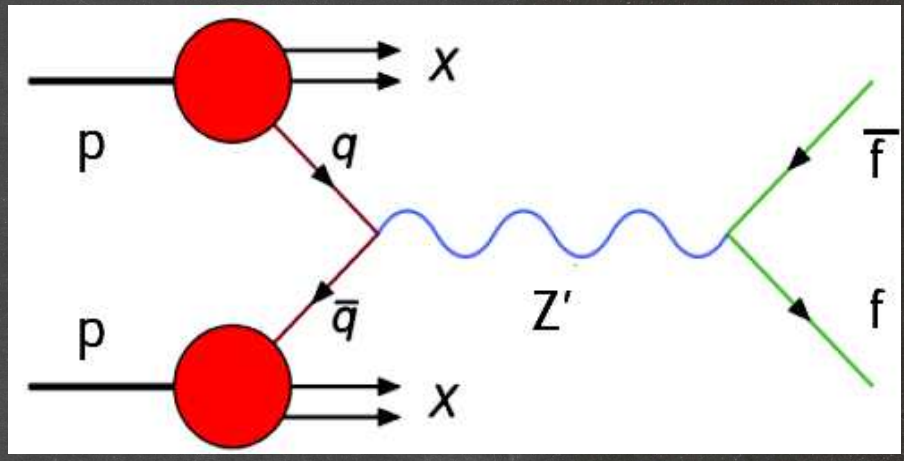


What does our collider-pheno group do?

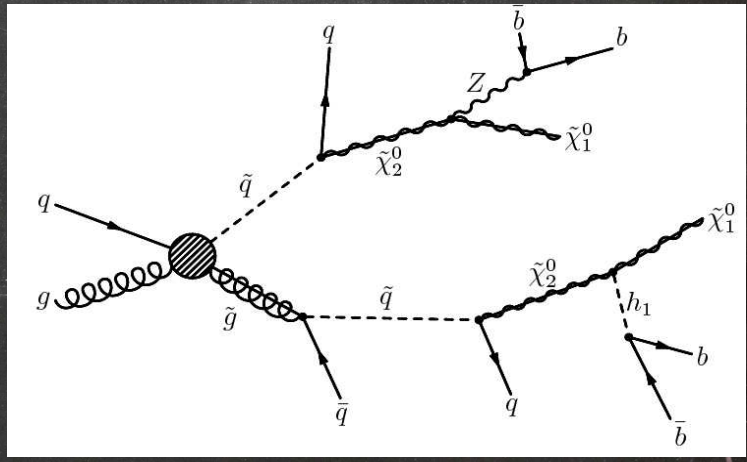
- Development of Tools
  - HERWIG
  - CalcHEP
  - HEPMDB
- Royal-Society grant & SOTON Jubileecollaboraiton&visitors
  - Alexander Pukhov - CalcHEP&micrOMEGAs
  - Andrei Semenov - LanHEP

Results from our group

- Z' at the LHC
  - Parameterisation
  - Forward-backward asymmetry
  - B-L models
  - Composite Higgs models and Technicolor
  - Interference with BG
  - Related CMS papers

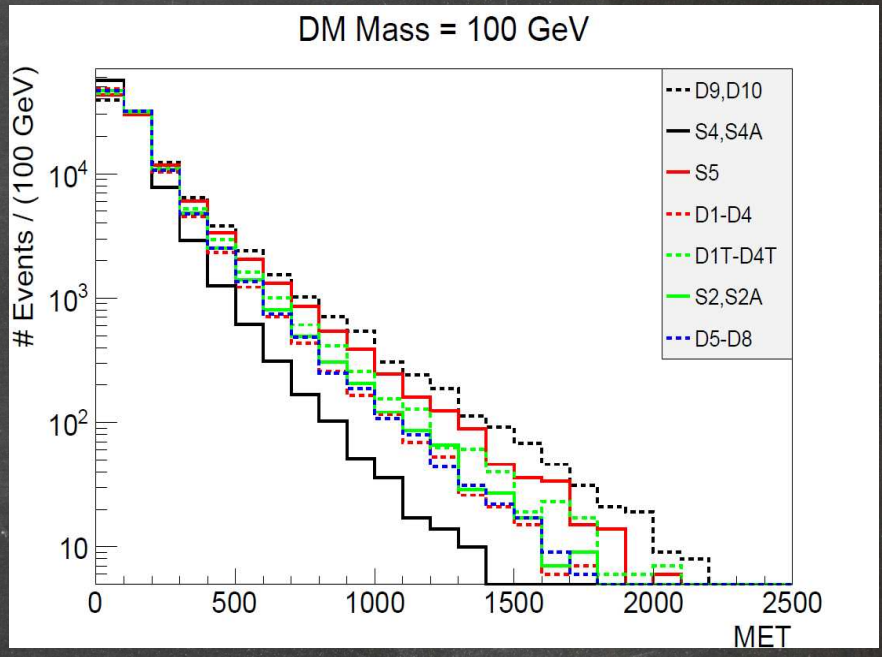


- SUSY and its extensions
  - MSSM, NMSSM, E6SSM
  - New signatures
  - Signatures form Higgses from the Extended SUSY sector



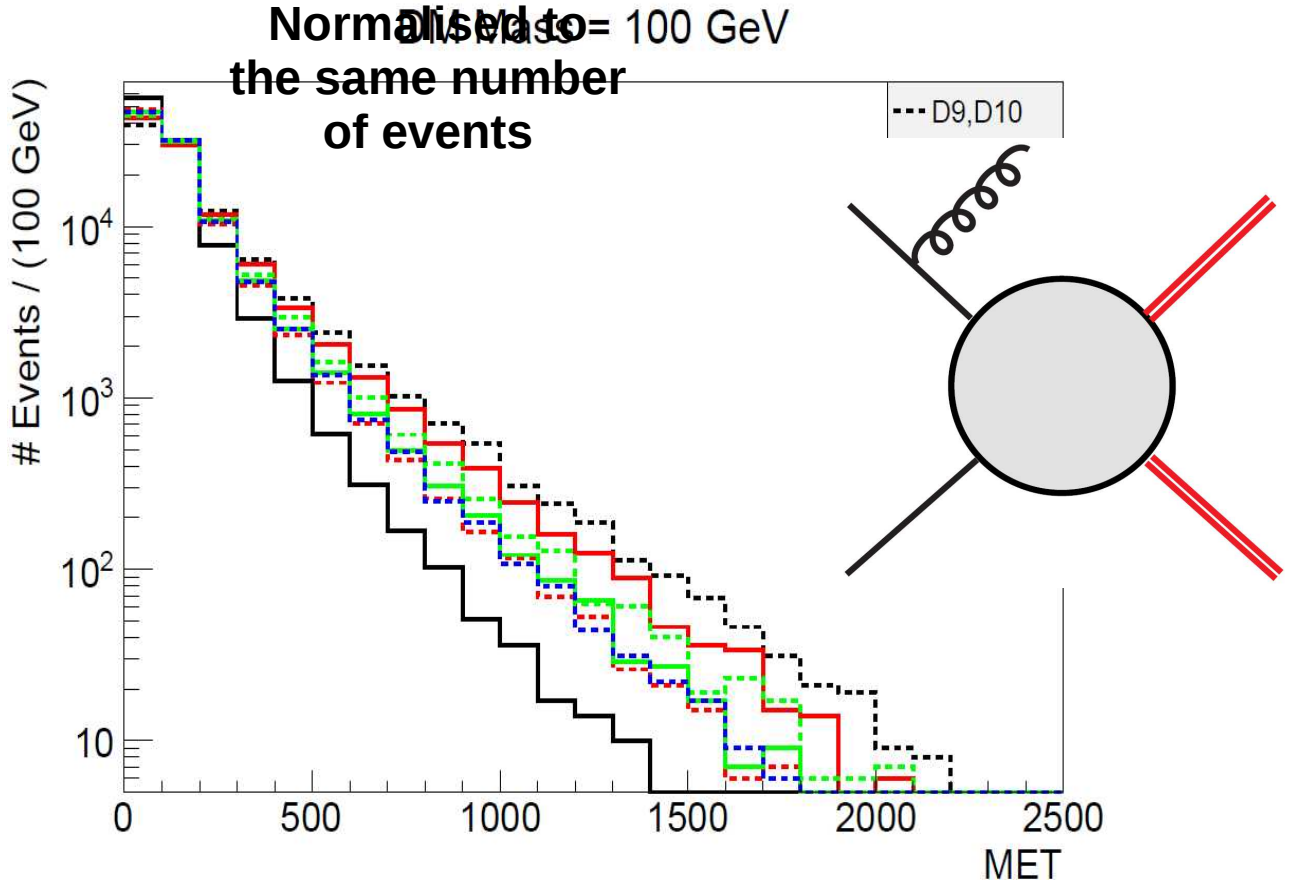
Results from our group

- Dark Matter
  - Characterisation of the spin



- Models with the extended Higgs sector
  - I2HDM
  - 2HDM
  - 3HDM

MET distributions for Contact interactions



Missing Transverse Momentum