Upgrading the CMS detector for new physics

- *Physics search: The search for the lightest Susy*
- *State of the art tool for searches: Machine Learning*
- *Detector upgrade: The CTT-PS sub-detector of CMS*

CMS collaboration, LIP - Lisbon

SUperSYmmetry:

What is it

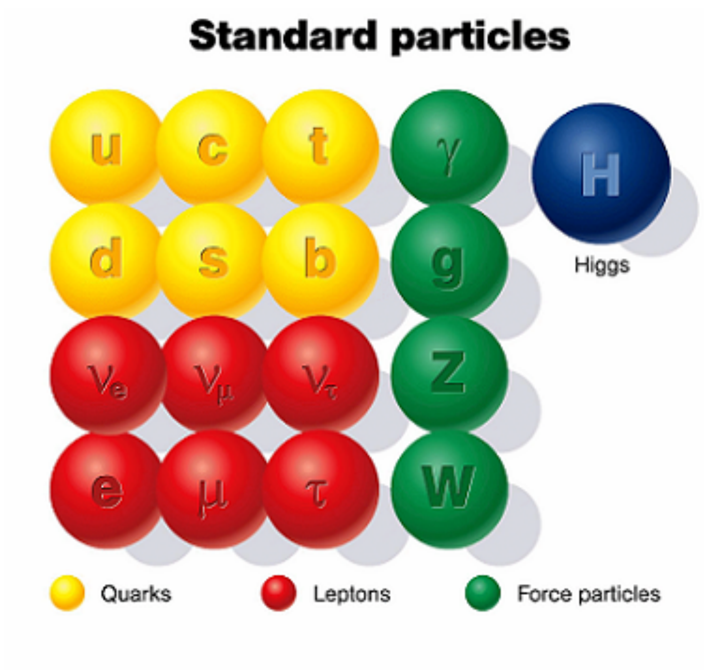
How do we search for it

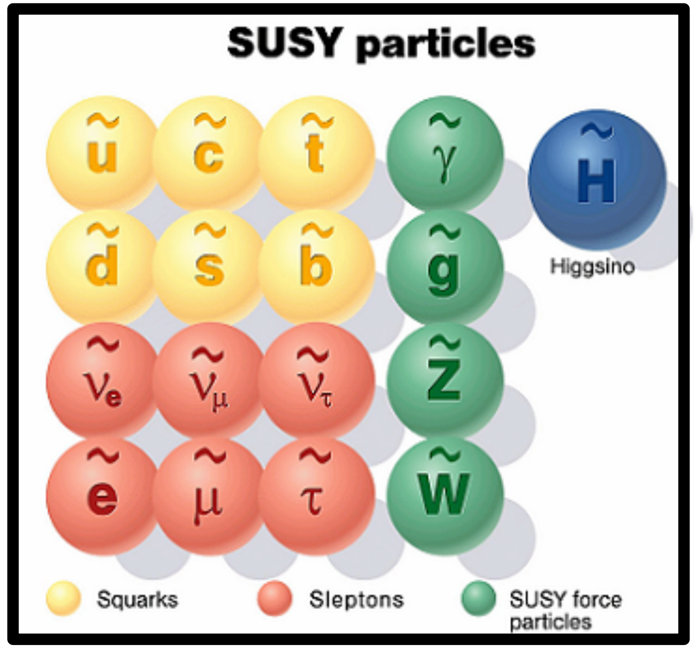
...how do we work

Dr. Pedrame Bargassa

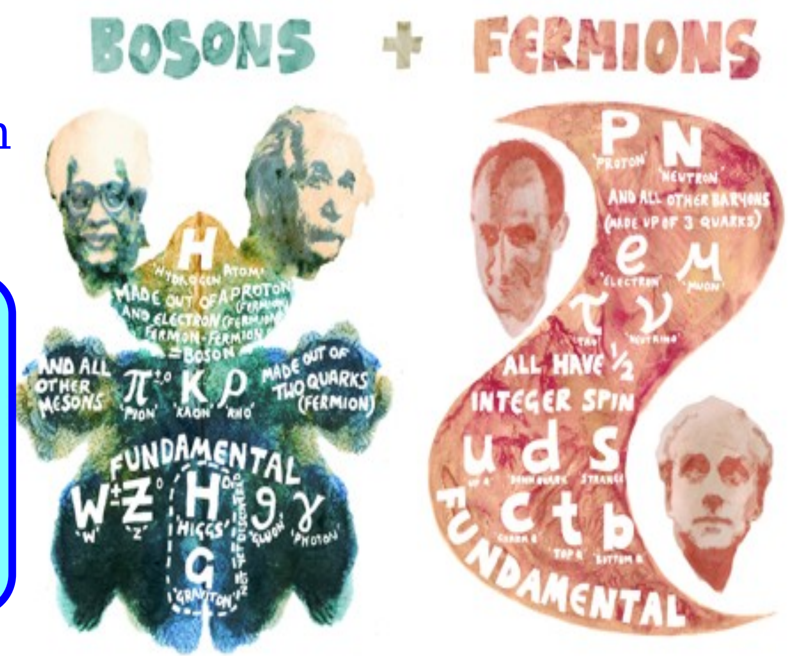
CMS collaboration, LIP - Lisbon

SUperSYmmetry: What it is





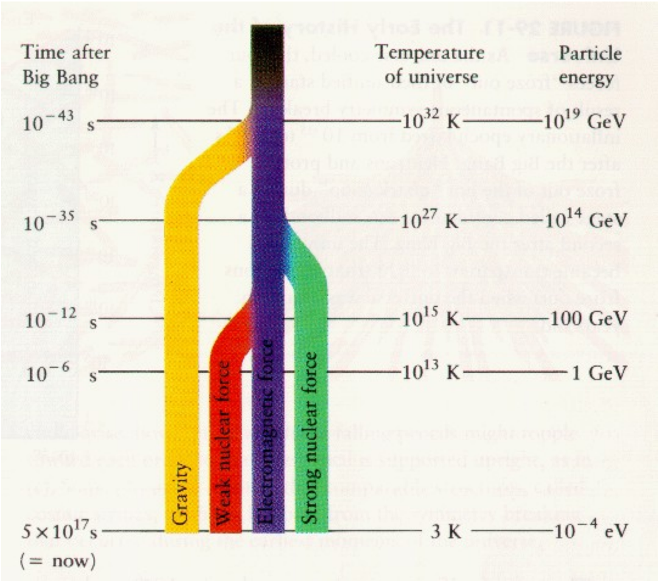
Matter fields could also exist in bosonic form
Force carriers also exist in fermionic form



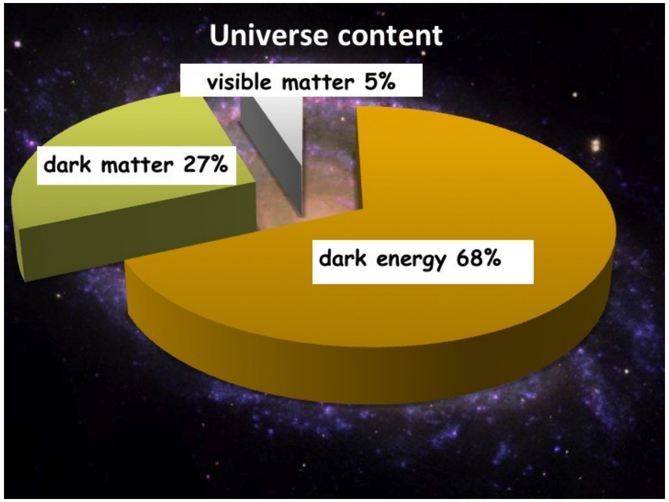
SUSY:
Simple spin symmetrization
between what we know of matter
& force carrier fields/particles

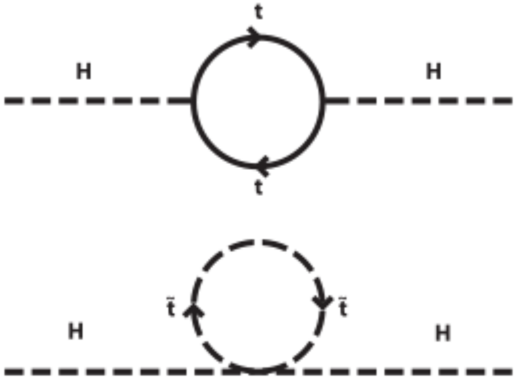
SUSY: Why it is worth searching for

- *Elegantly unifies Electro-magnetic, weak & strong nuclear interactions*



- *Has natural candidates for the Cold Dark Matter*





- *(by definition) Solves the quadratic divergence in the mass of the (lightest ?) Higgs boson*

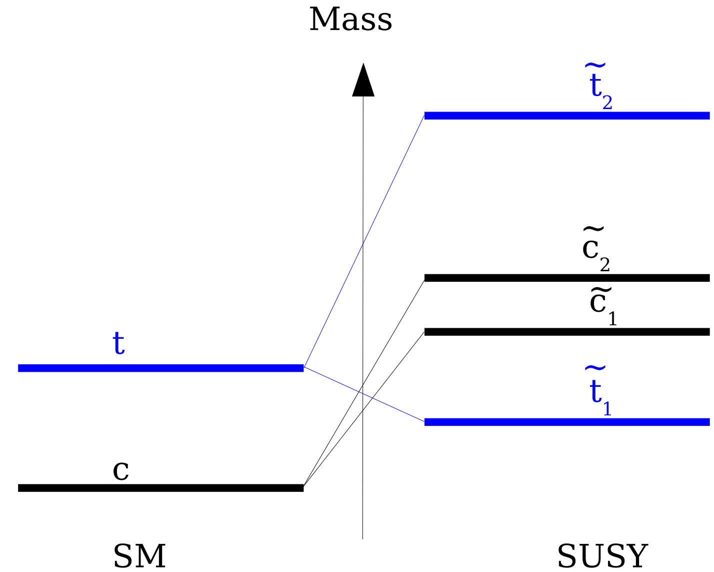
SUSY search: One of our best bets

Mass difference of squarks:

Proportional to $M_Q = M_t$:

Strong mixing in the stops $\tilde{t}_{1,2}$ sector

$\tilde{t}_1$ might be the lightest squark



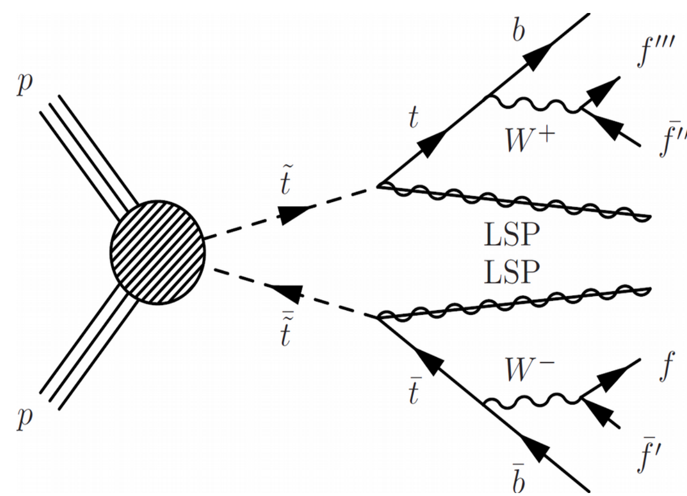
Data on Cold Dark Matter:

$\mathbf{\Omega_{CDM} h^2 = 0.11 \pm 0.01}$ **@ 95% CL** (WMAP)

Gives preference to

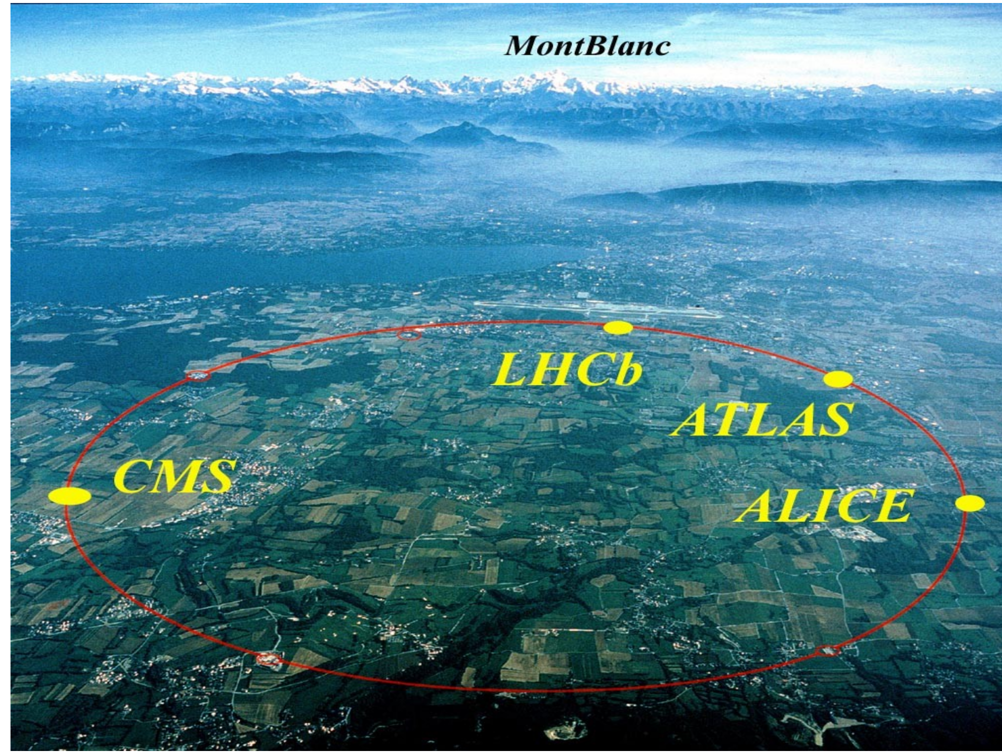
$\Delta m = M(\tilde{t}_1) - M(\tilde{\chi}^0_1) \leq 50\ \mathrm{GeV}/c^2$

Gives preference to 4-body decays

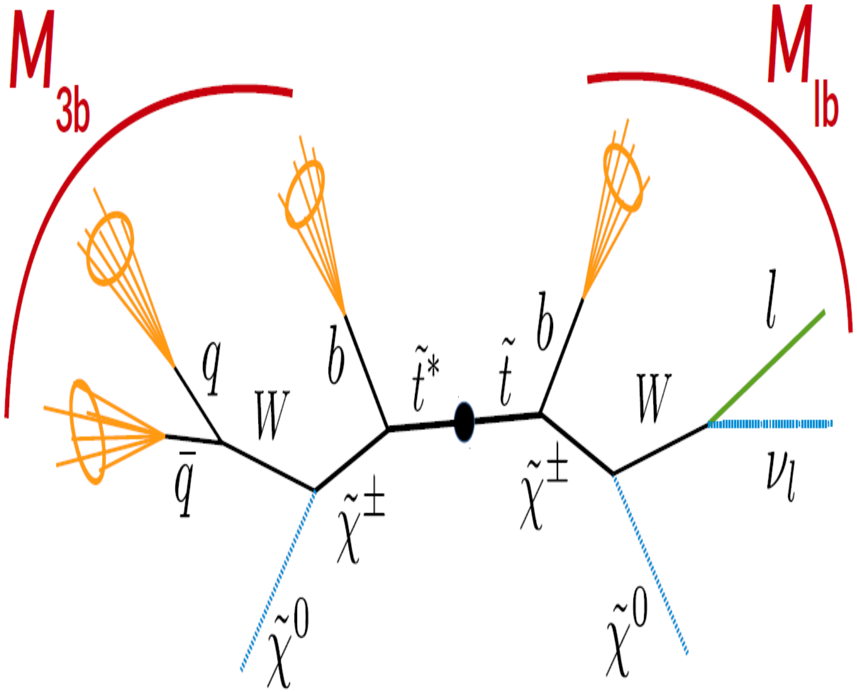


SUSY: How do-we search for it

- **Collide** protons: Produce higher mass particles



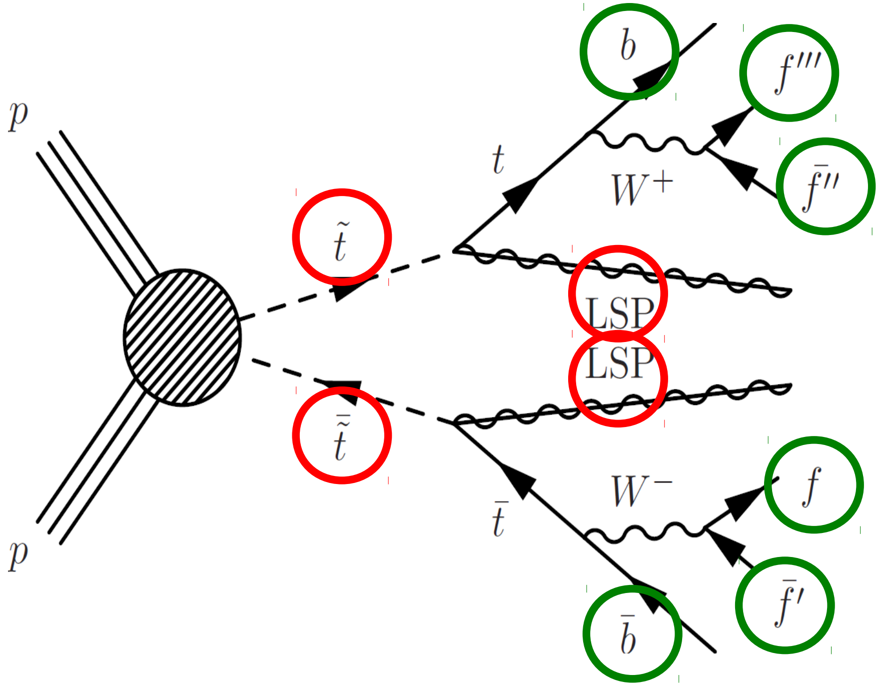
- **Sign** wanted events



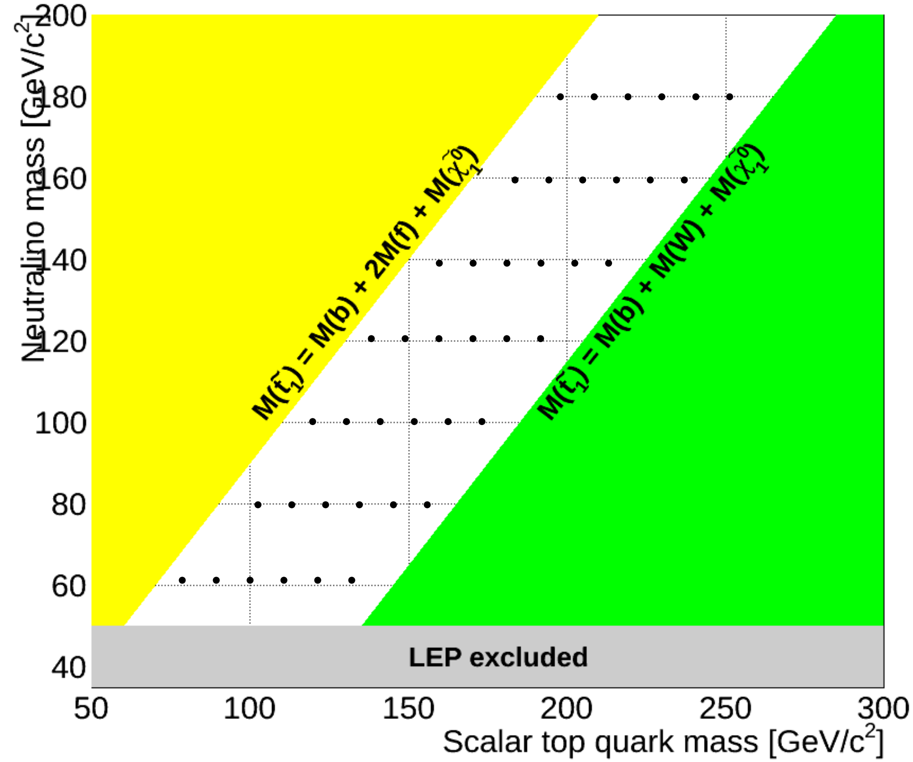
- Here, we are looking for events with **4 jets**, **1 lepton** & **missing energy**
- **Careful !** SM does imitate this **signature** while not being Susy...

- **Each measurable quantity in this event might be a precious source of information, i.e. disentangle between Signal & Background**

SUSY search: Example of a challenge



- **SM particles**: We
  - Know them
  - Measure them in the detector
- **SUSY particles**: We don't know them ! i.e. we don't know their mass → **Affects all the kinematics of the reconstructed events...**

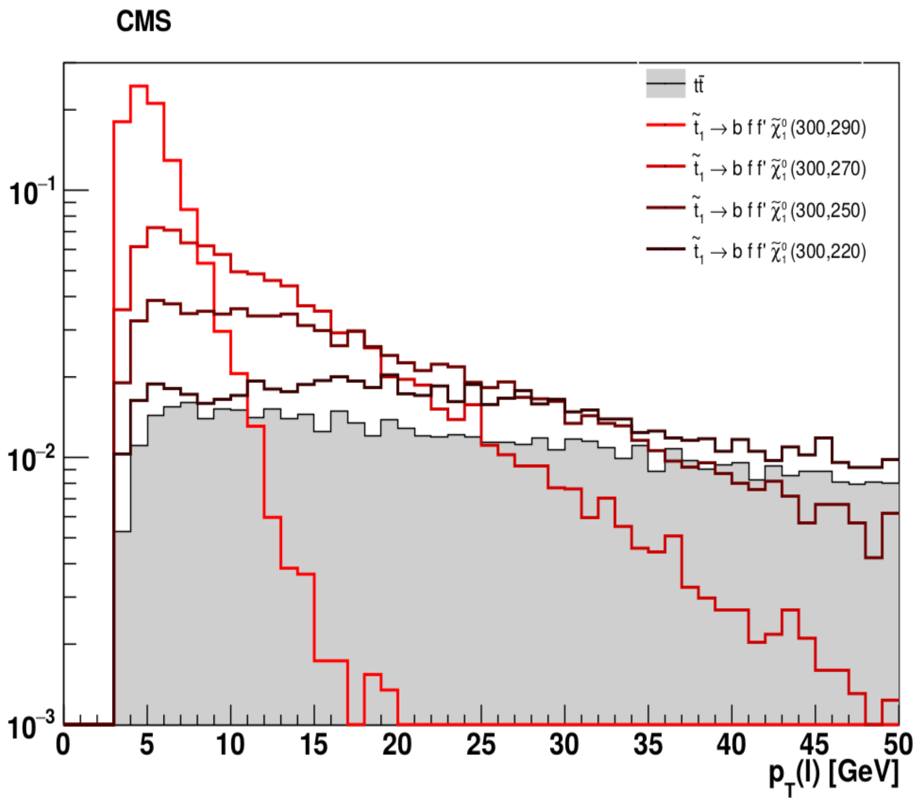


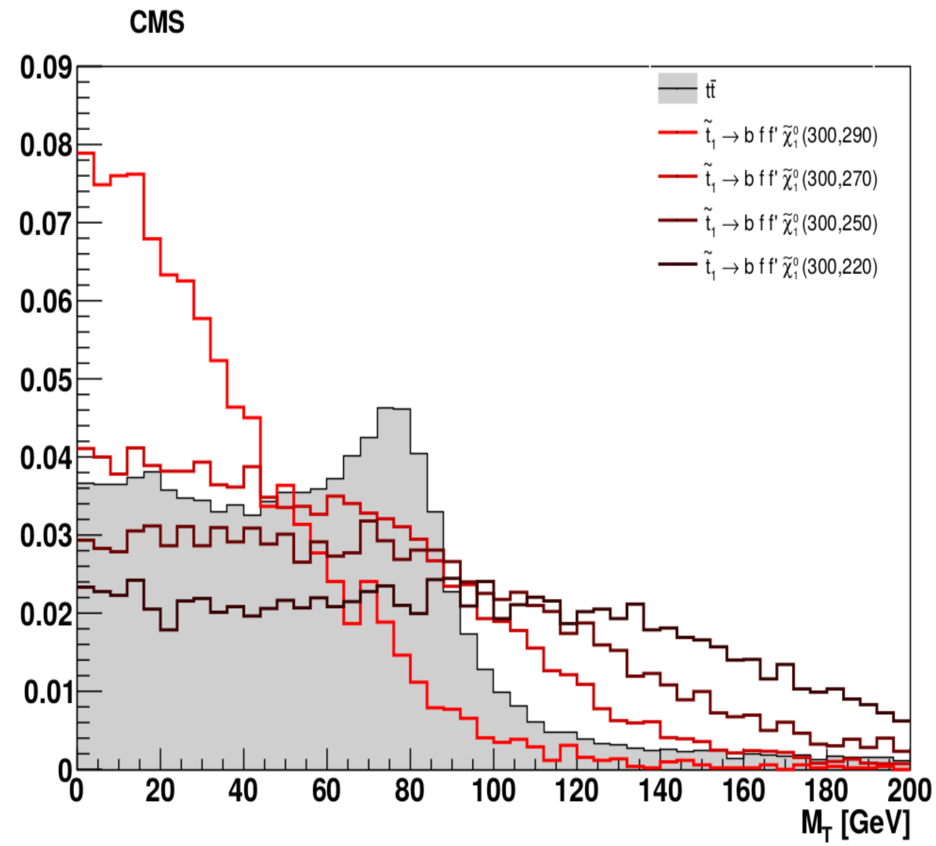
- We have to consider all mass possibilities for the 2 unknowns of this search:

  Scan through the mass plane & search for all kinematic signatures of the same signal

How do-we search for it

- **Characterize** signal versus background events in any possible measurable



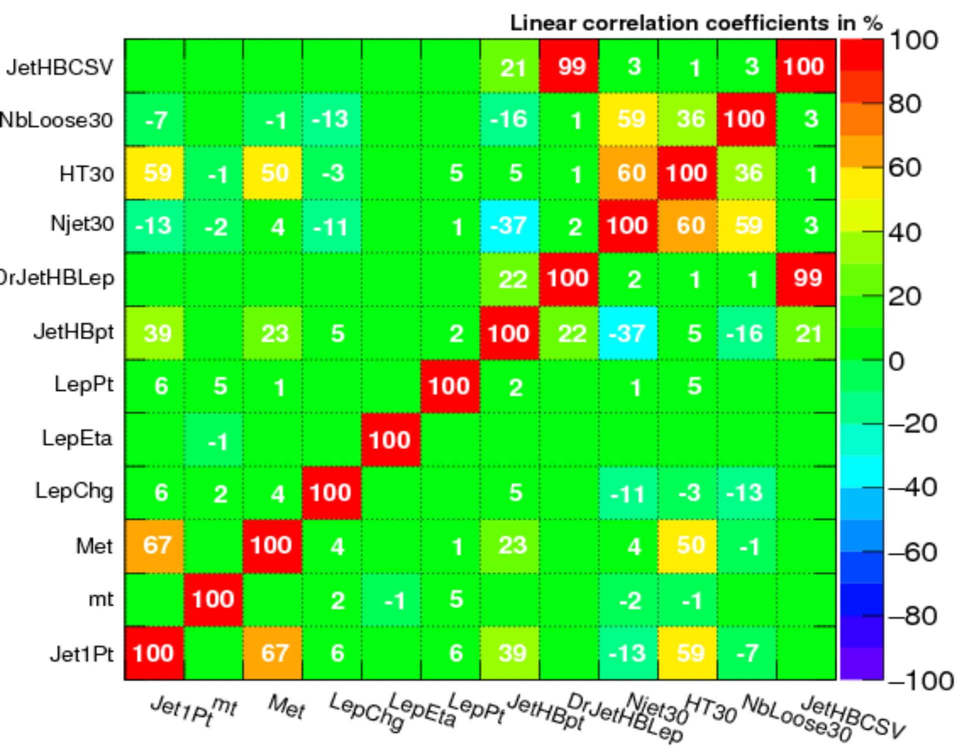


Some 21 other discriminating variables…

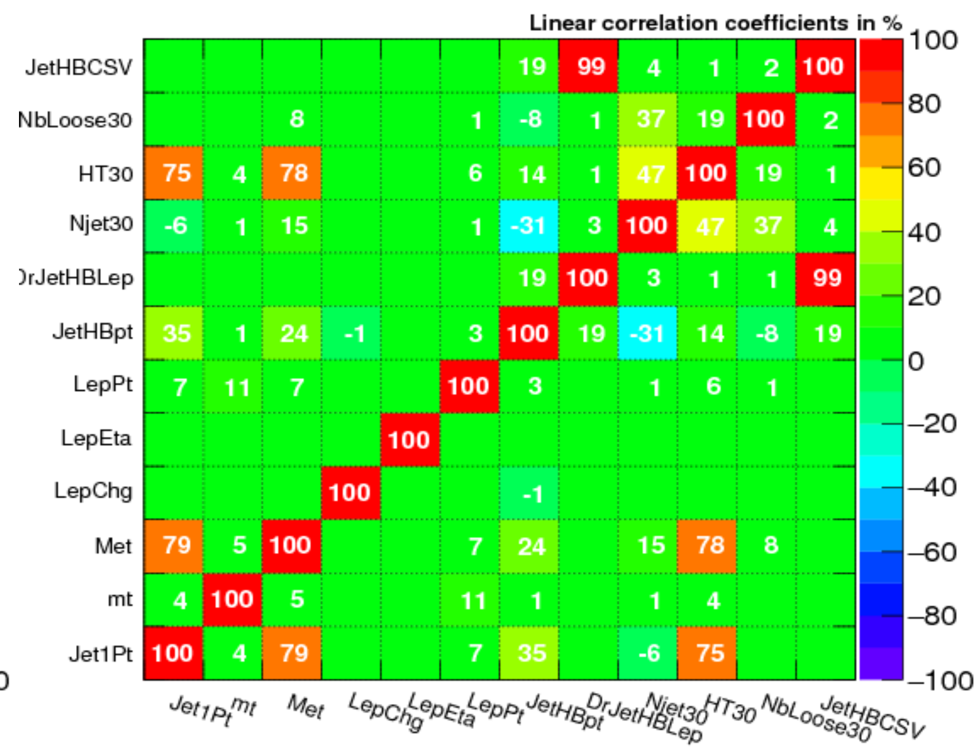
How do we search for it: Multi-Variate Analysis tool

- **Be smart** in separating Signal from Background: Feed our best knowledge to a <u>**Multi-Variate Analysis**</u> tool, which combines the separation capacity of all variables:
  - Not only in 1 dimensional space...
  - ...but also in 2 dimensional : **Makes use of the differences of correlation btween S & B**

Correlation Matrix (background)



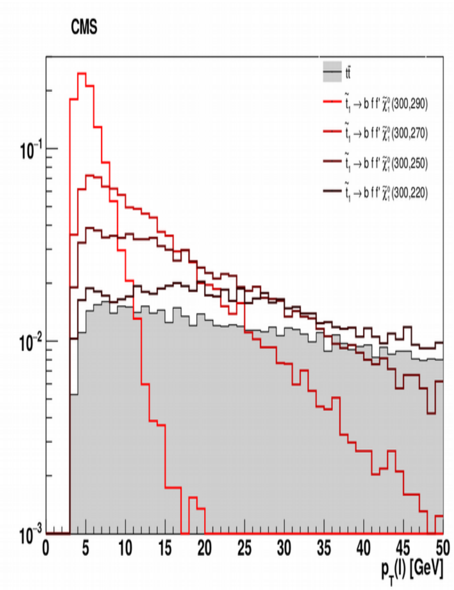
Correlation Matrix (signal)

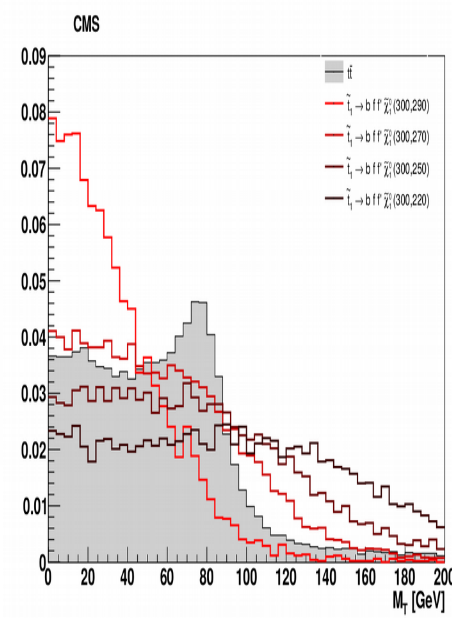


How do we search for it: MVA tool

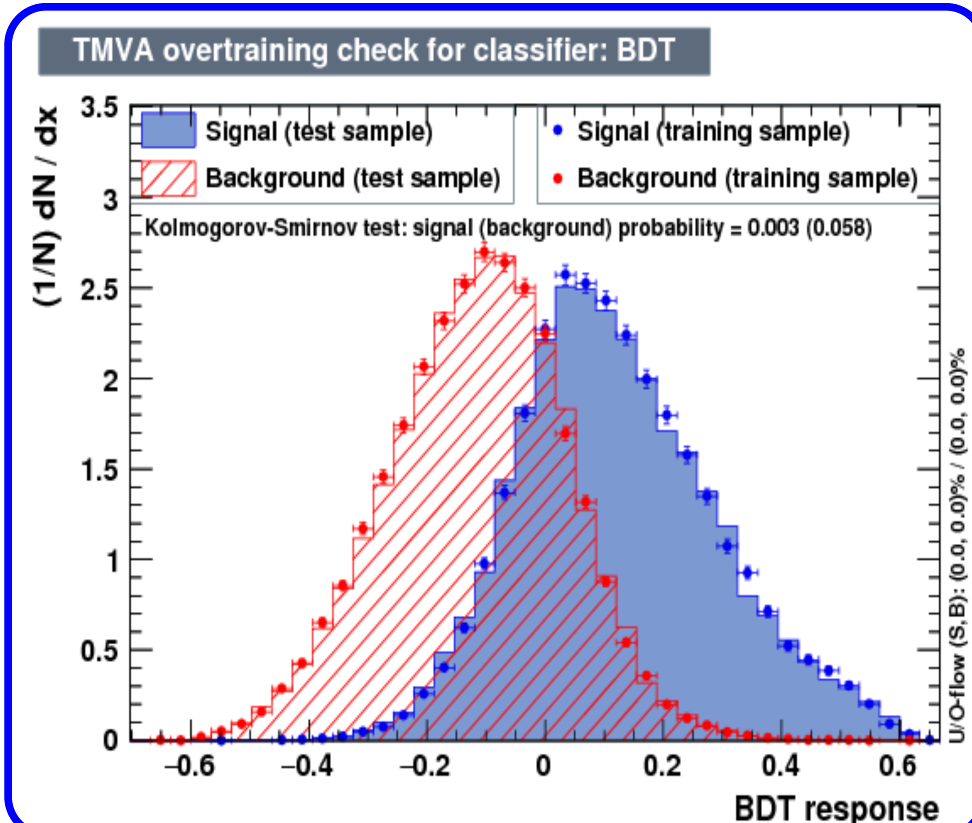
- **Be smart** in separating signal from background: Feed your best knowledge of these to a Multi-Variate Analysis tool, which combines the separation capacity of all single variables
  - Now compare the separation capacity between :-)

Here...





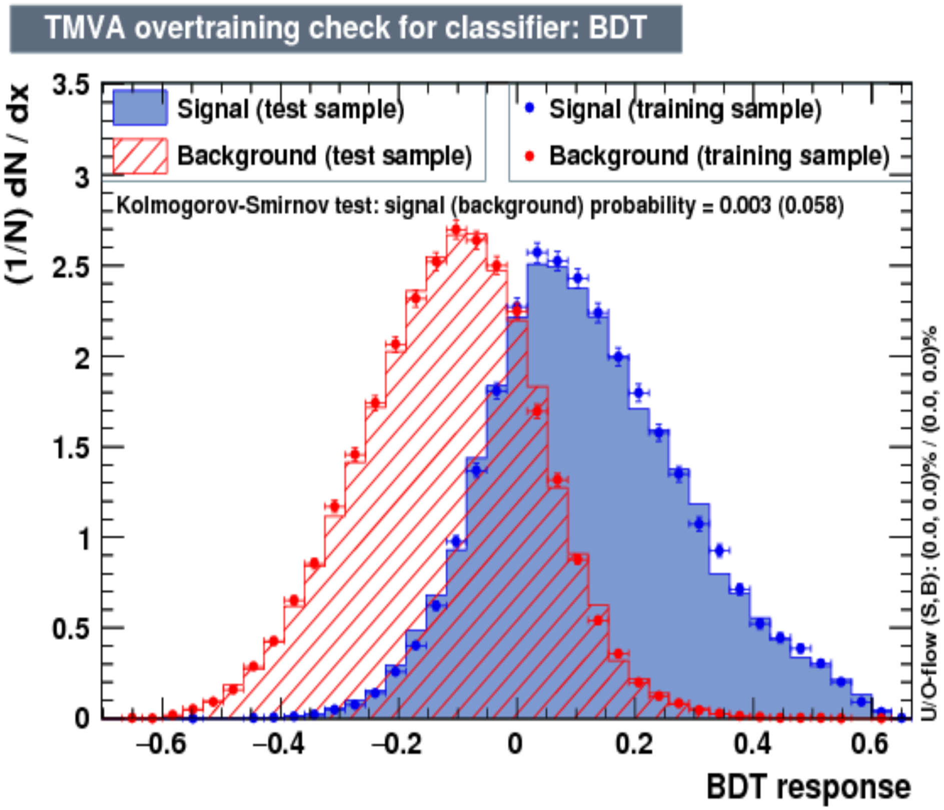
...and here: All the discriminating power of the MVA tool in 1 variable !

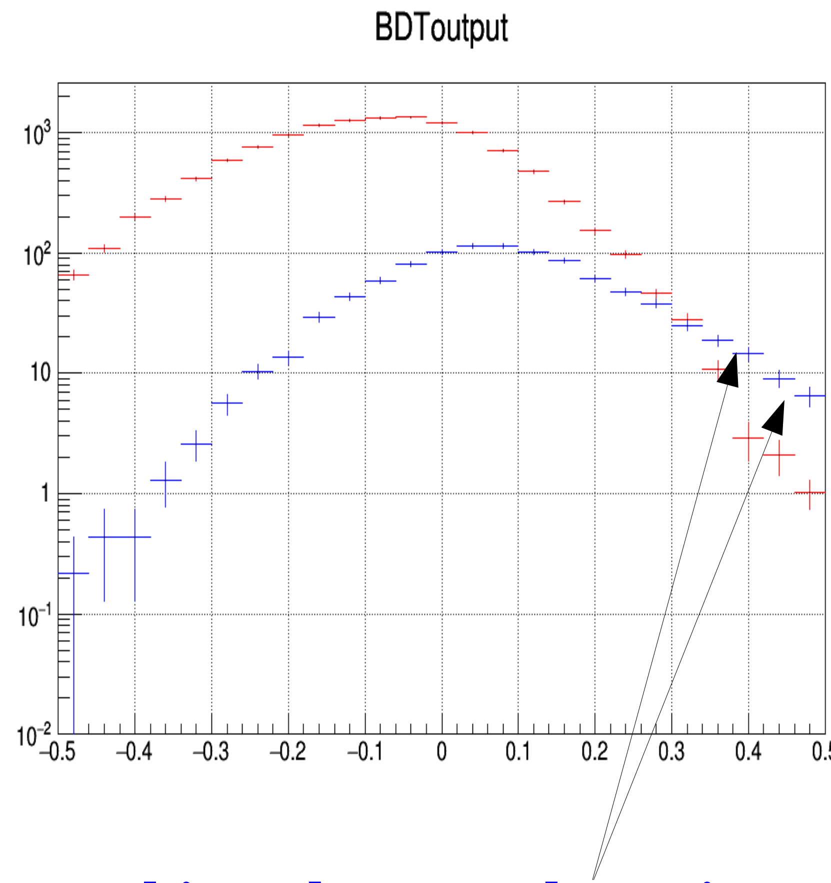


How do we search for it: MVA tool

- We have to be realistic: Account for:
  - Abundance of production of SM background & our possible signal
  - Reconstruction efficiencies
  - Detector effects...

Here is the real picture ;-)





If something shows up here, in Data: Discovery !

How do-we work: Tools / Methods / Environment

- **Code**: You will be using & contributing to code being used by O(10^3) physicists:

  Highly prized in HEP, but also in industry, financing

- **Statistical analysis**

  Essential in HEP, highly prized in financing

- **Data analysis**: Your capacity to understand data & find 1 interesting event out of O(10^4,10^6)

  @ this level, you should be good for a job in HEP, in industry or banks

- **Working in team**:
  - Large collaboration: ~2500 people
    - Physics groups / sub-groups: 10 / 200 people
  - LIP: Students helped by senior researchers & post-doctoral fellows
- **"Can I bring something as student ?"**
  - Yes: 2 summer students of 2nd-3rd year helped us improve the selection power of our MVA tool !
- Dedicated courses to help our students in (all) these aspects: http://www.idpasc.lip.pt/LIP/events/2016_lhc_physics/
- **Contact me: bargassa@cern.ch**

Applications of Machine Learning to particle physics

Giles Strong

LIP Mini-school of particle physics, Oeiras- 07/01/18

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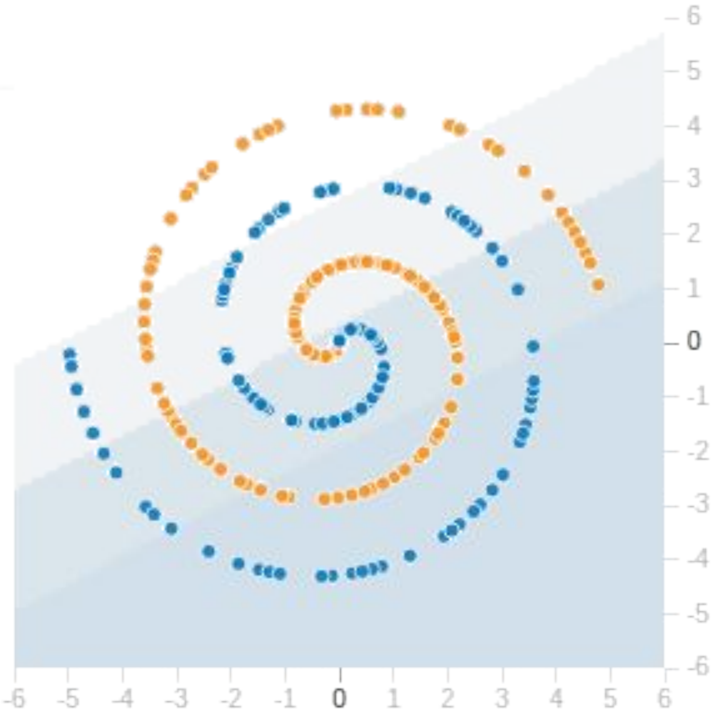
amva4newphysics.wordpress.com

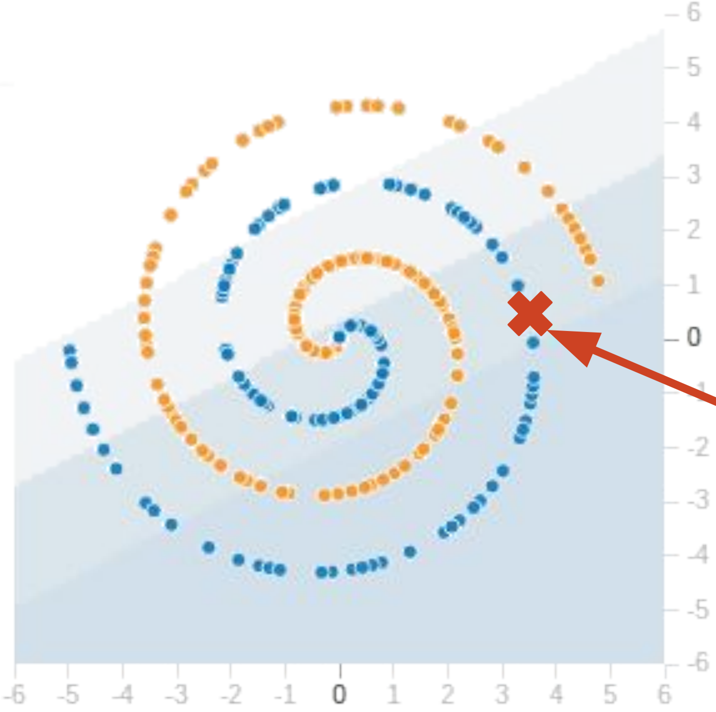
What is machine learning?

What is machine learning?

Automated model building

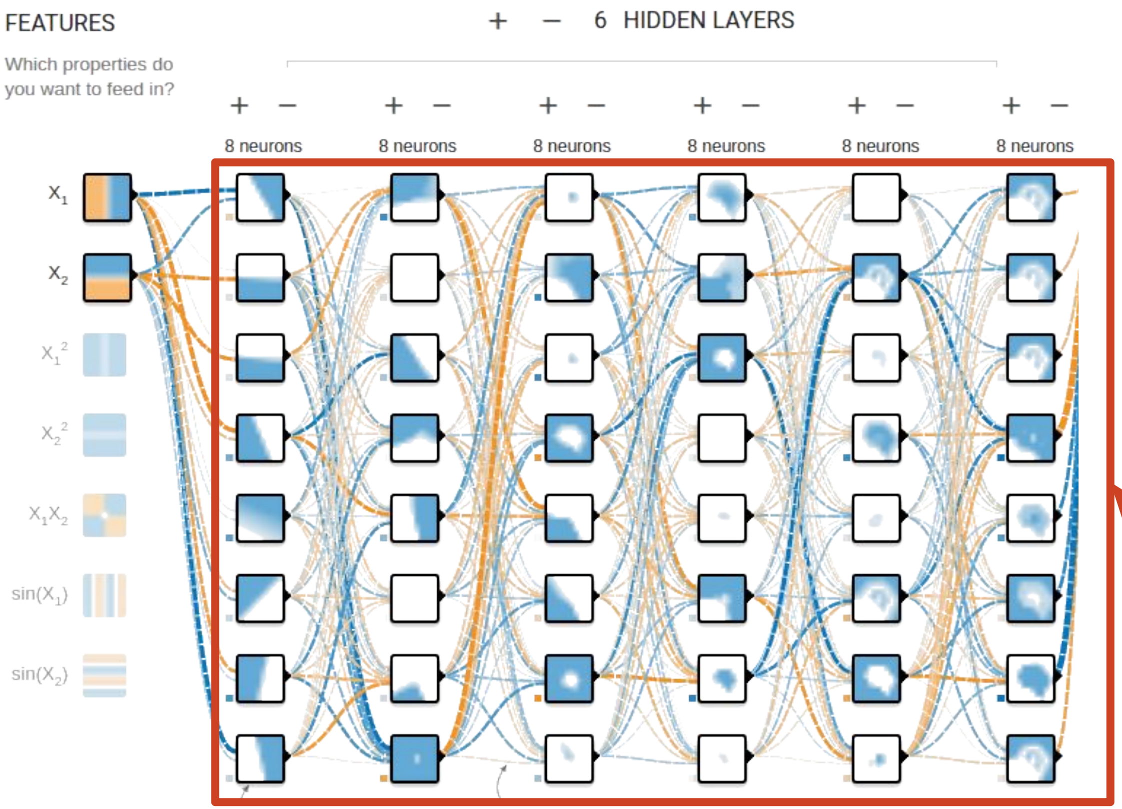


6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6

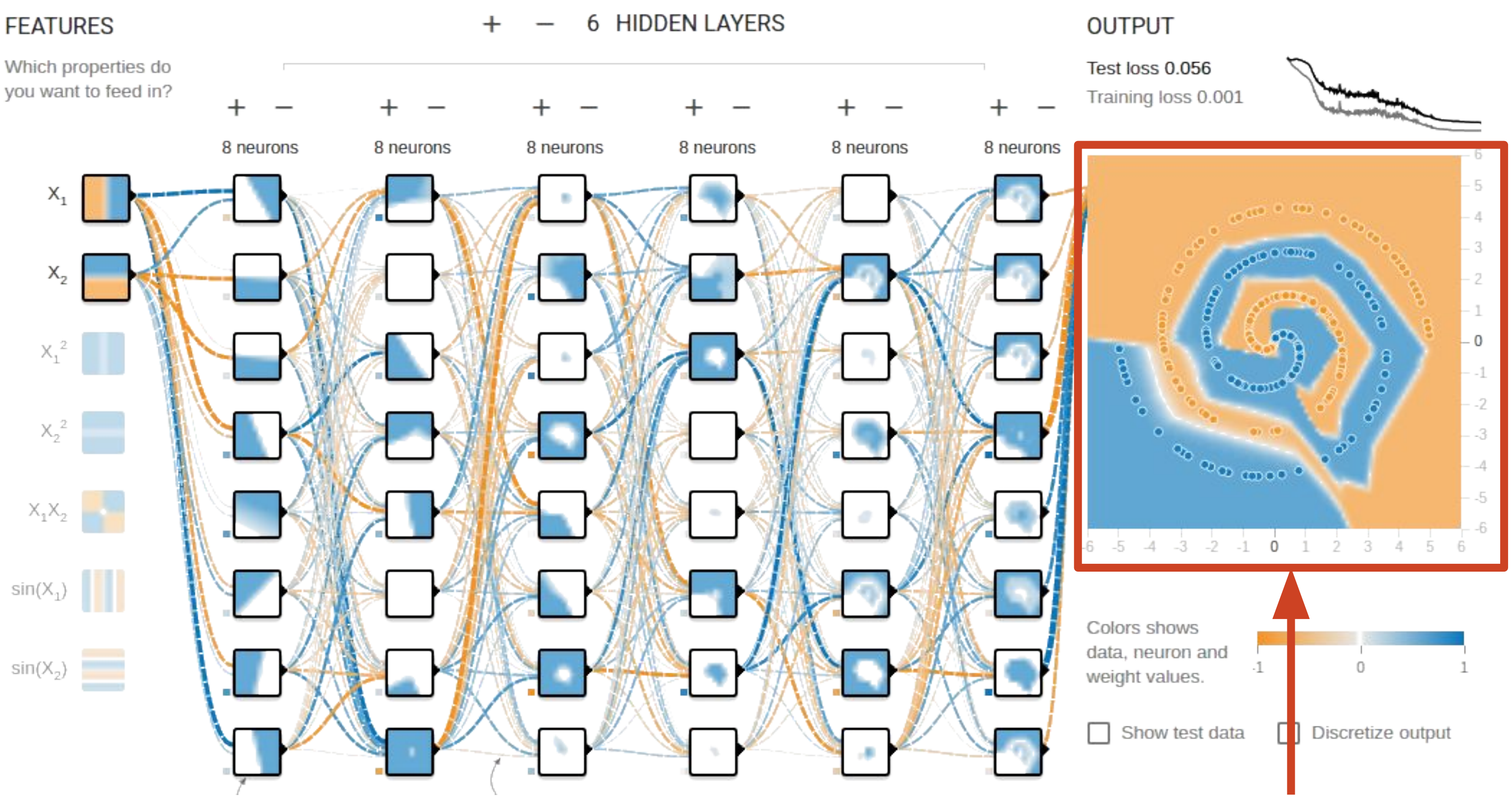


Is a point here blue or orange?

Low-level information - X and Y coordinates



Flexible system to learn map between inputs and target function:
X, Y -> blue/orange



Train on example data

Simple example → High-energy physics

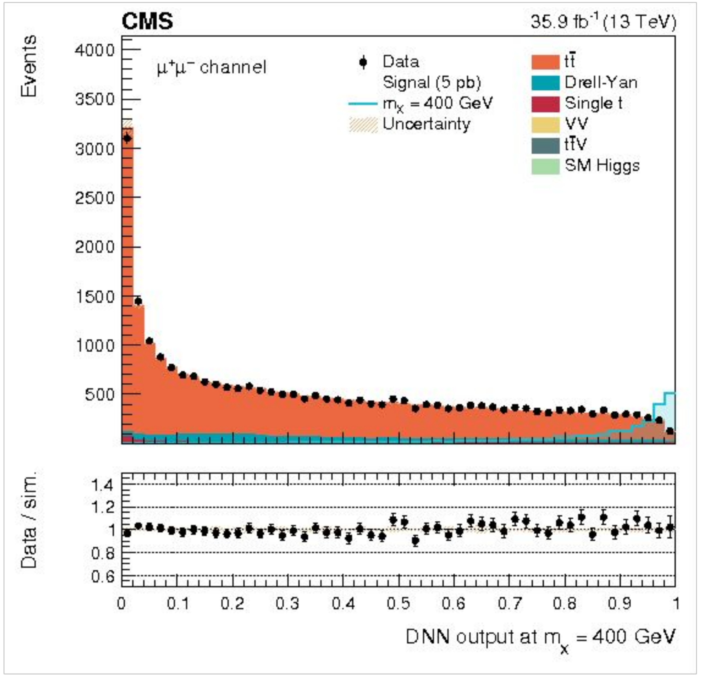
Simple example → High-energy physics

Data and desired outputs are more complex

Underlying principle is the same

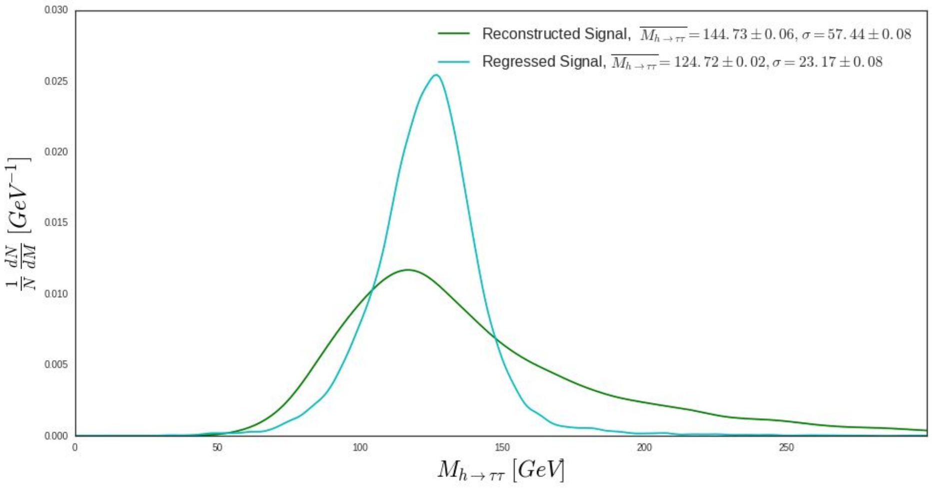
Event classification

- Search for rare processes by predicting what process occurs in a particle collision
- E.g. Di-Higgs production - [1708.04188]



Mass regression

- Predict the mass of a decayed particle from knowledge of its decay products
- E.g. Higgs to tau tau - [AMVA4NP:WP1-D1]()



Reduce systematic uncertainties

- Use *adversarial training* to build classifiers which are immune to unknown model parameters
- Helps improve inference of other model parameters, e.g. cross-section of a particular process
- E.g. Learning to Pivot with Adversarial Networks and Adversarial learning to eliminate systematic errors: a case study in High Energy Physics

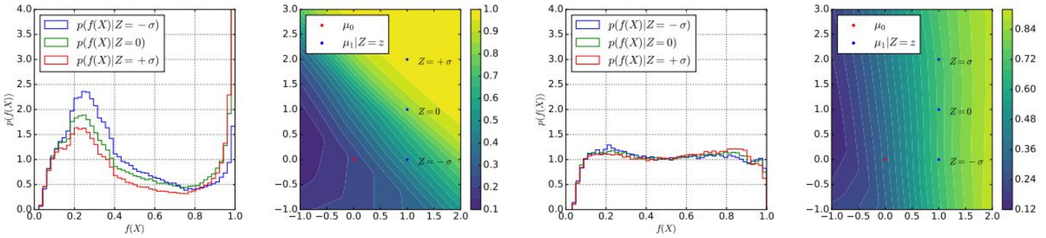


Figure 2: Toy example. (Left) Conditional probability densities of the decision scores at $Z = -\sigma, 0, \sigma$ without adversarial training. The resulting densities are dependent on the continuous parameter Z, indicating that f is not pivotal. (Middle left) The associated decision surface, highlighting the fact that samples are easier to classify for values of Z above σ, hence explaining the dependency. (Middle right) Conditional probability densities of the decision scores at $Z = -\sigma, 0, \sigma$ when f is built with adversarial training. The resulting densities are now almost identical to each other, indicating only a small dependency on Z. (Right) The associated decision surface, illustrating how adversarial training bends the decision function vertically to erase the dependency on Z.

Jet physics

- Use convolutional and recurrent networks to classify jets according to origin process: DeepJet
- Recluster event using QCD-aware recursive networks to provide jet embeddings: QCD-Aware Recursive Neural Networks for Jet Physics

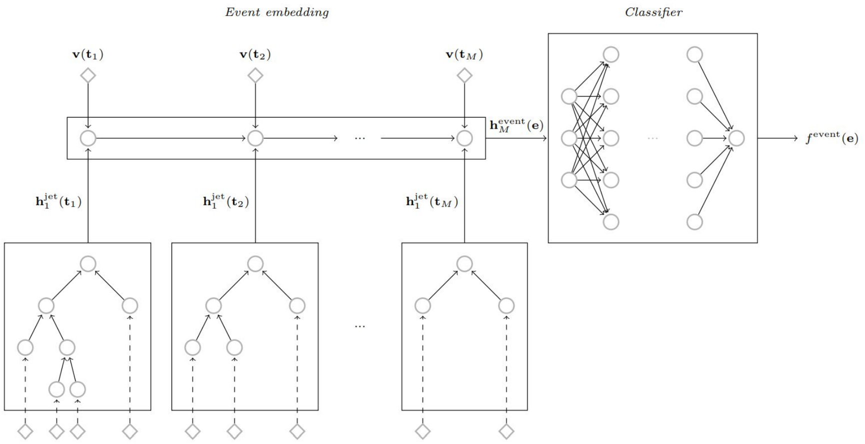


FIG. 2. QCD-motivated event embedding for classification. The embedding of an event is computed by feeding the sequence of pairs $(\mathbf{v}(\mathbf{t}_j), \mathbf{h}_1^{\text{jet}}(\mathbf{t}_j))$ over the jets it is made of, where $\mathbf{v}(\mathbf{t}_j)$ is the unprocessed 4-momentum of the jet $\mathbf{t}_j$ and $\mathbf{h}_1^{\text{jet}}(\mathbf{t}_j)$ is its embedding. The resulting event-level embedding $\mathbf{h}_M^{\text{event}}(\mathbf{e})$ is chained to a subsequent classifier, as illustrated in the right part of the figure.

Many possible applications

Jet tagging

Particle ID

Event classification

Event triggering

Kinematic regression

Simulation

Detector design

Inference

Further reading

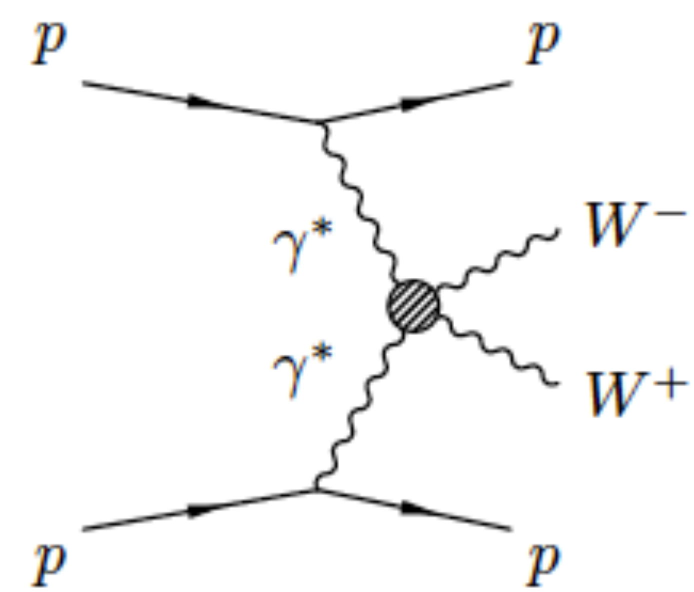
- Play in browser: Tensorflow playground, gradient boosting playground
- Seminars and lectures: MLHEP-17, Karpathy, Hastie, HEP repository
- My resources: NN summary posts, example classifier

The forward detector of CMS

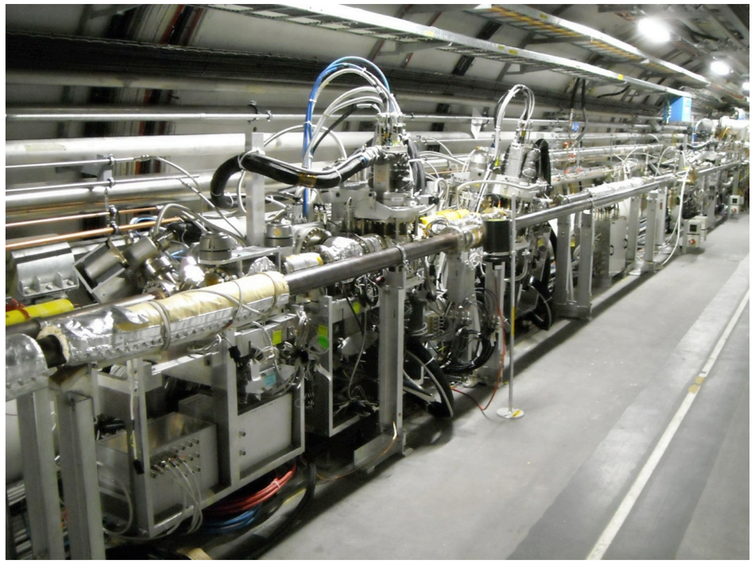
C. da Cruz e Silva

LIP, Lisbon, Portugal

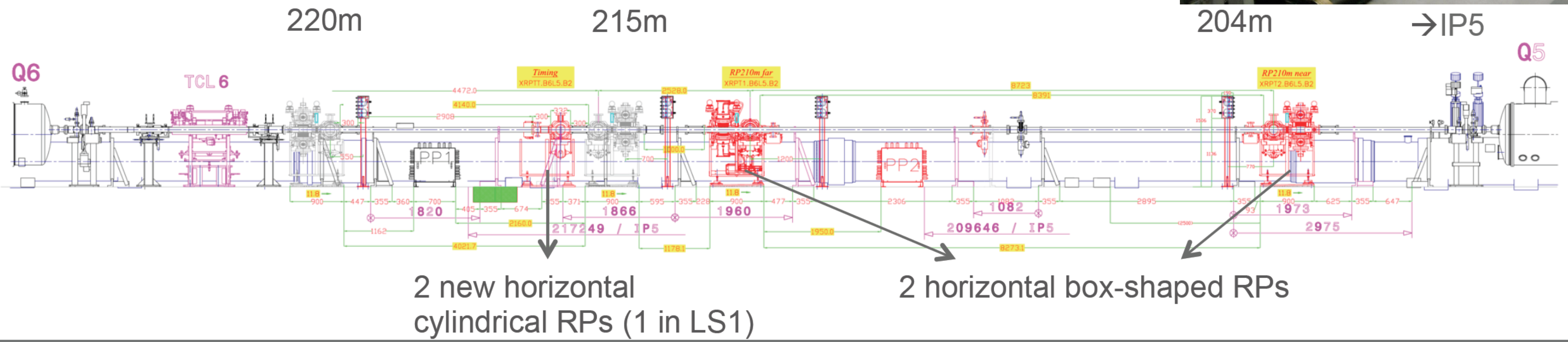
07/02/2018



- Focuses on a special-class of interactions at the LHC
  - Use the LHC as a photon/gluon collider
  - The forward protons are scattered at small angles

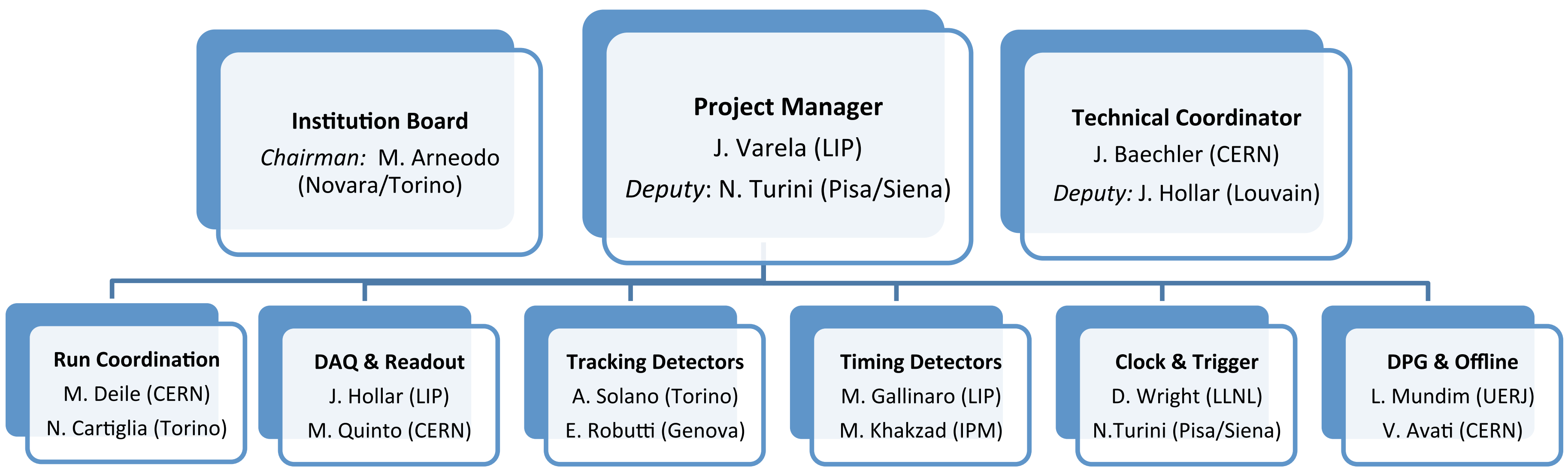


- Use LHC magnets as a proton spectrometer:
  - Need detectors very close to the beamline:
    ~3-4 mm



CT–PPS Status

- CT-PPS has been in operation since 2016
- Results with 2016 data have been published, proving that such a detector can successfully operate in high luminosity conditions
- LIP has had a strong involvement in CT-PPS:

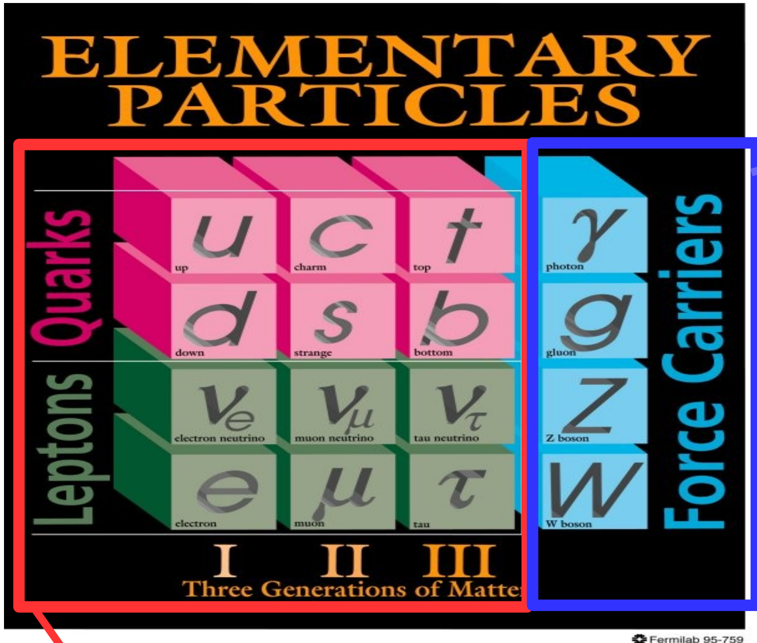


Research Opportunities

- CT-PPS is a new detector:
  - Still under active development: This year (2018) an old sub-detector is being replaced for a different type of detector
  - Trigger systems under active development
- Physics analysis:
  - Initial state has well defined quantum numbers → strong constraints on the properties of the final state
  - Study quartic gauge interactions ($\gamma\gamma \rightarrow WW$), searching for deviations from the SM
- CT-PPS operates very close to the beam:
  - Devices have to sustain high doses of radiation → Using new detector systems
  - Some detectors currently used in CT-PPS are being considered for the upgrades for HL-LHC in CMS → CT-PPS provides the opportunity to acquire experience in these new systems

Backup

Particles… Interactions… wait a minute…



BOSONS force carriers spin = 0, 1, 2, …

Unified Electroweak spin = 1		
Name	Mass GeV/c²	Electric charge
γ photon	0	0
W⁻	80.39	−1
W⁺ W bosons	80.39	+1
Z⁰ Z boson	91.188	0

Strong (color) spin = 1		
Name	Mass GeV/c²	Electric charge
g gluon	0	0

Higgs Boson spin = 0		
Name	Mass GeV/c²	Electric charge
H Higgs	126	0

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, …

Leptons spin = 1/2		
Flavor	Mass GeV/c²	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c²	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

Why would matter exist only in fermionic, and force carriers exist only in bosonic form in the universe ?

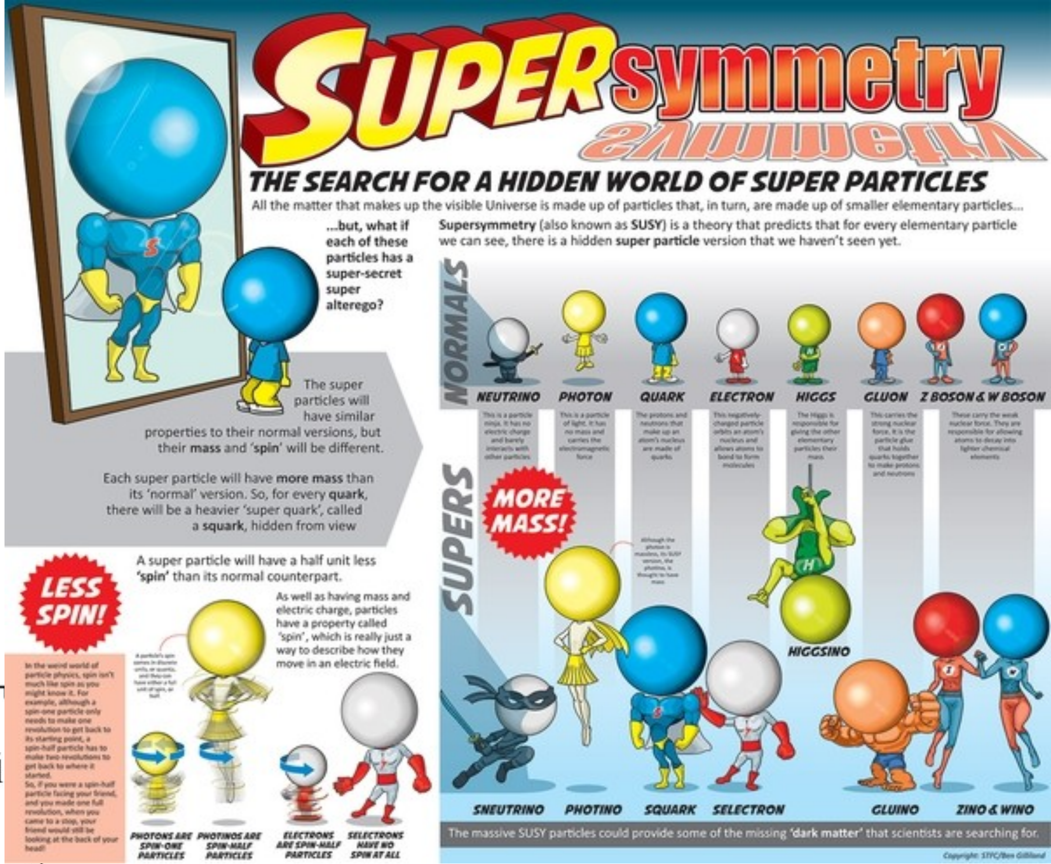
Is this a “happens to be” ? Or there is a hidden symmetry behind this ?

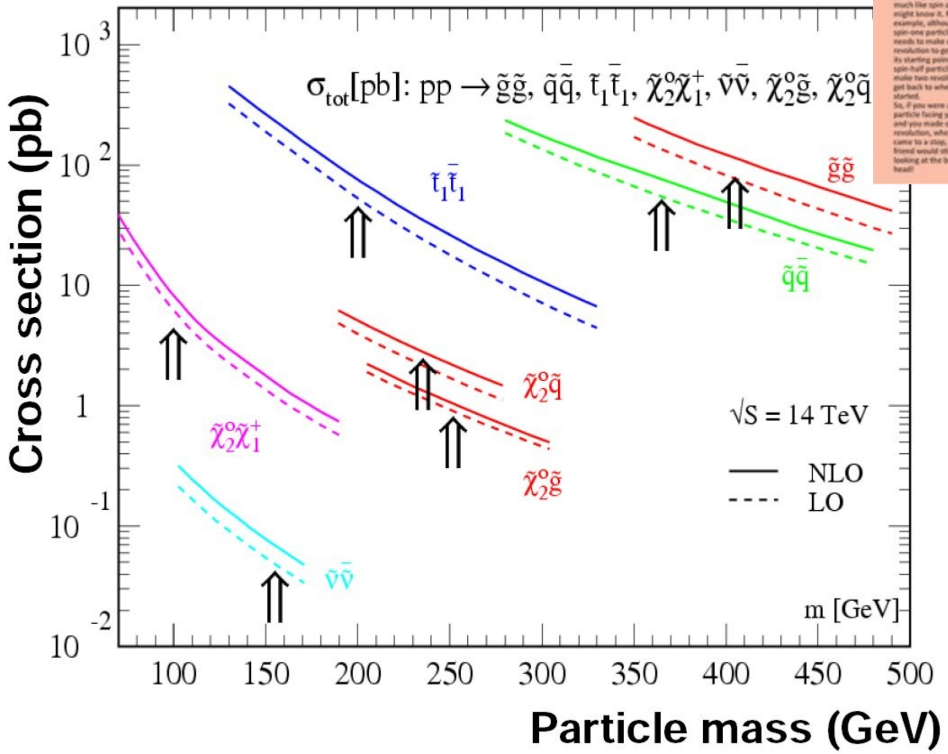
Let's symmetrize things between matter & interaction fields…

sParticles are special:

<u>If</u> SUSY exists, it's a broken symmetry:

- Physical sParticles are mixtures of Susy particles
- They exist @ higher masses



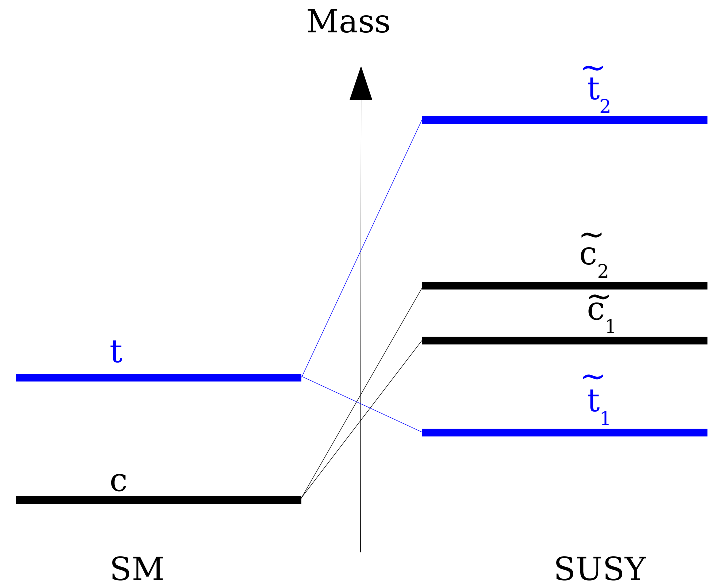


Among all sParticles:
Which one is our best bet ?

Introduction: Motivations for production & decay

Up squarks

$$M^2_{\tilde t} = \begin{pmatrix} \tilde M_Q^2 + M_T^2 + M_Z^2\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\cos 2\beta & M_T(A_T + \mu\cot\beta) \\ M_T(A_T + \mu\cot\beta) & \tilde M_U^2 + M_T^2 + \frac{2}{3}M_Z^2 \sin^2\theta_W \cos 2\beta \end{pmatrix}$$



Mass difference of quark superpartners proportional to $M_Q = M_t$:

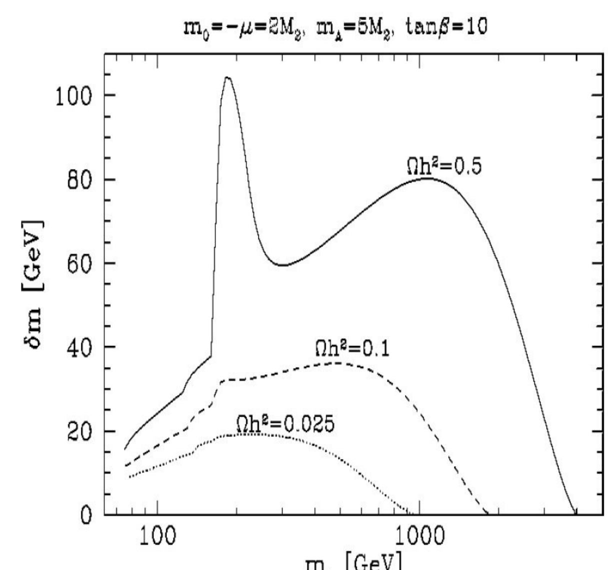
Strong mixing in the stops $t_{1,2}$ sector ?

t_1 might be the lightest squark

$\Delta m = M(t_1) - M(\chi^0_1) \leq 50$ GeV/c^2 :

Compatible with $\mathbf{\Omega_{CDM} h^2 = 0.11 \pm 0.01}$ **@ 95% CL** (WMAP)

Kinematically closes 3- & most of 2-body decays

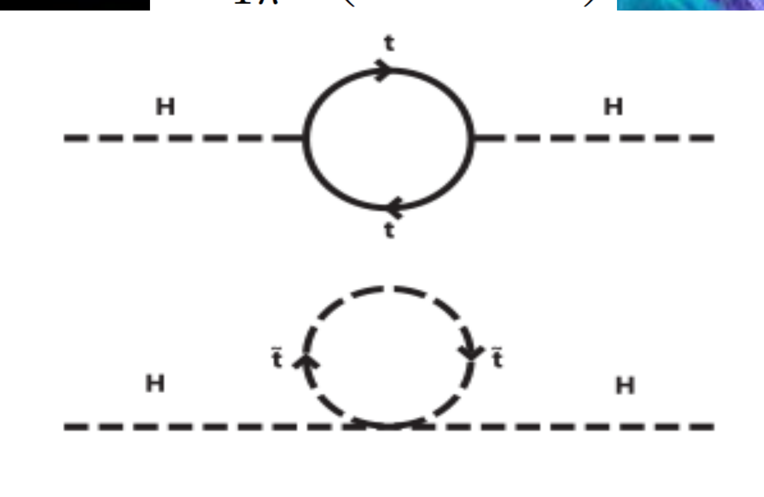


Boehm et al., PRD 62, 35012

SUSY

- **Higgs field introduces huge divergences in the mass of all known SM particles**
- But: Are we mass-instable ? Fortunately not ;-)
  - There has to be another theory which stabilizes masses

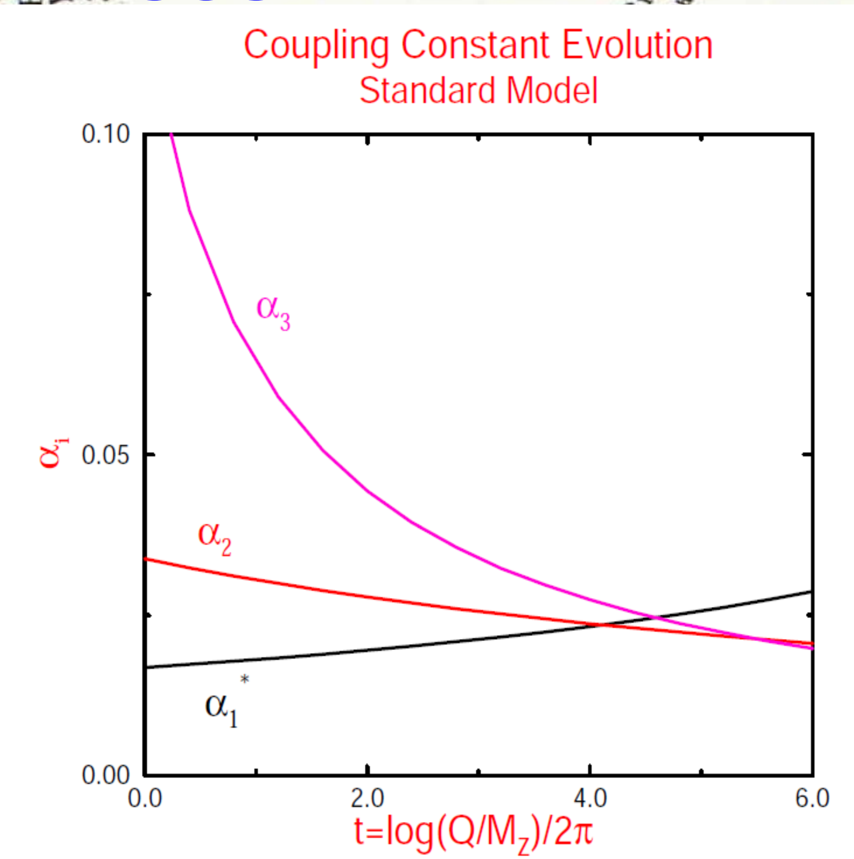
$$+\frac{g_F^2}{4\pi^2}\left(\Lambda^2+m_F^2\right)$$



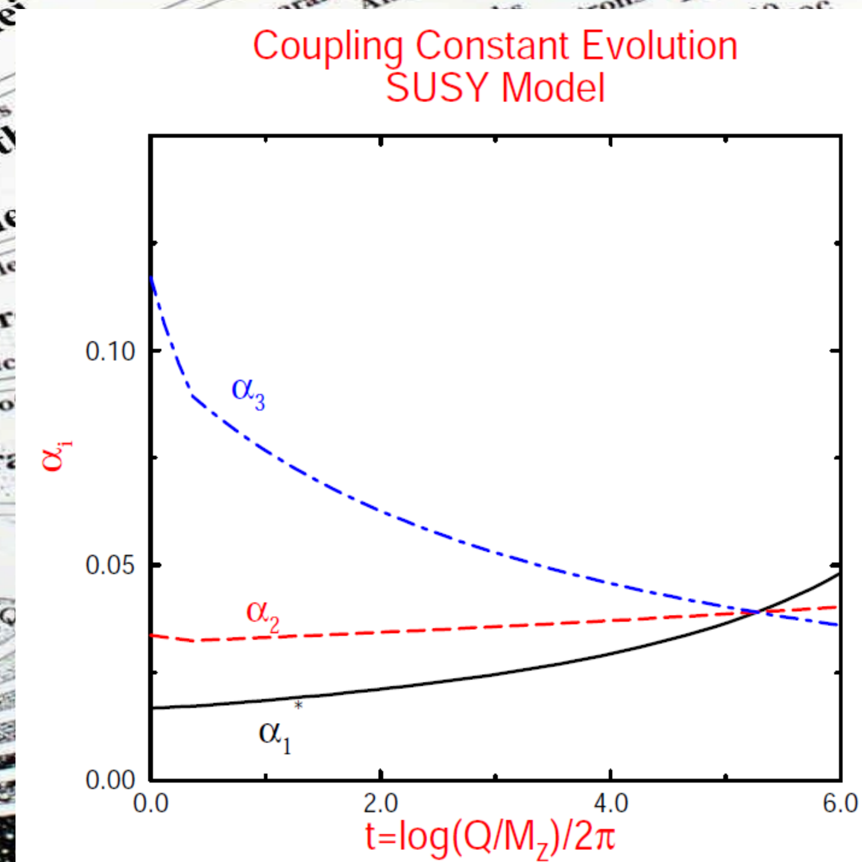
$$-\frac{g_S^2}{4\pi^2}\left(\Lambda^2+m_S^2\right)$$

- **SUSY cures the divergences of the SM <u>by definition</u>: Associates a scalar partner (-) to each SM fermion (+)**

SUSY



- **Unifies the different interactions… quite elegantly**



SUSY

- **Has natural candidate(s) for the Cold Dark Matter**
  - Sneutrino: Susy partner of the neutrino ν
  - Neutralino: Mixture of partners of neutral SM bosons
  - …