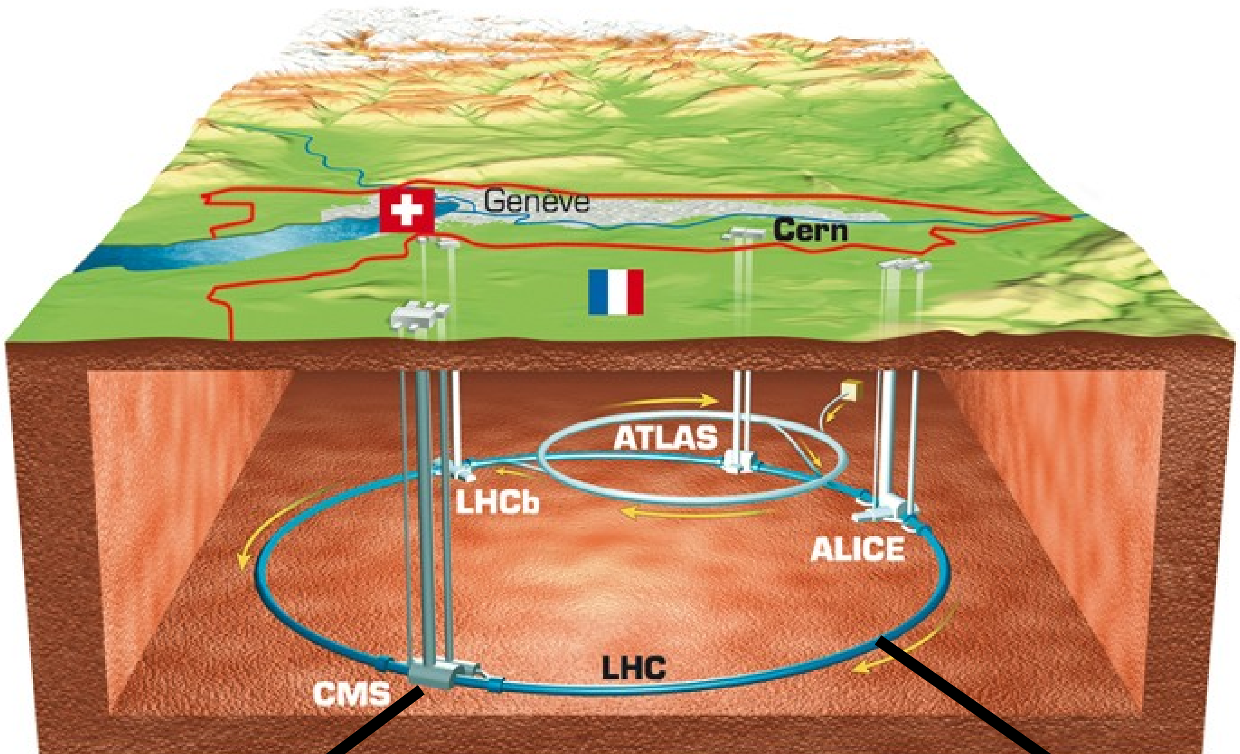
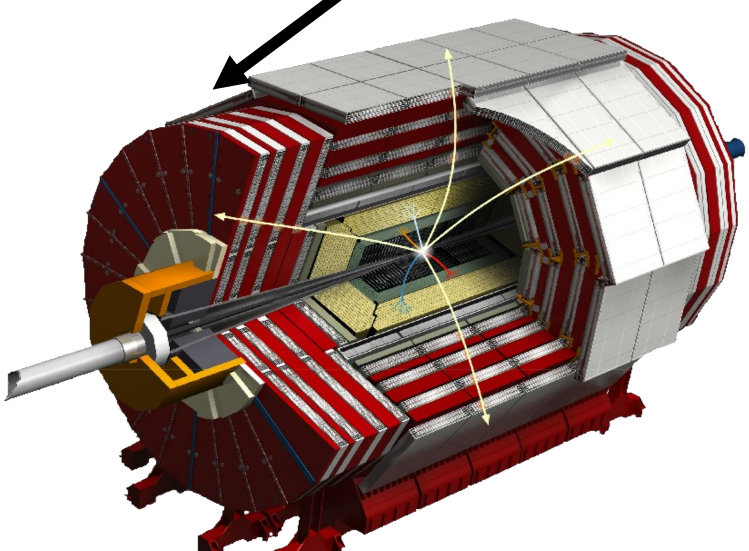
CMS collaboration

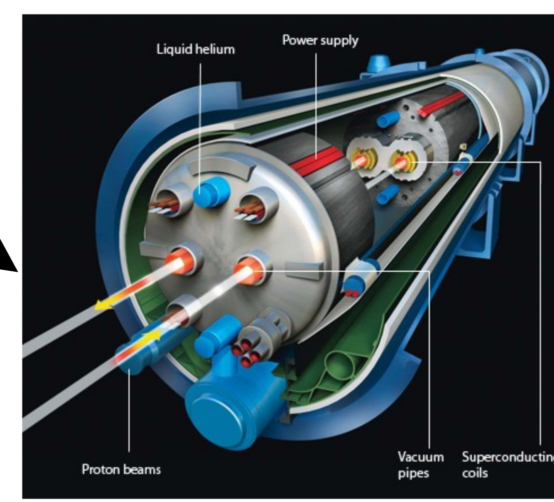
Large Hadron Collider



pp collisions
$\sqrt{s}$ = 2.2 TeV (2009)
7 TeV (2010)
=> world record !
8 TeV (2012)
13 TeV (2015)

High energy frontier





LHC - Run II : new data to come

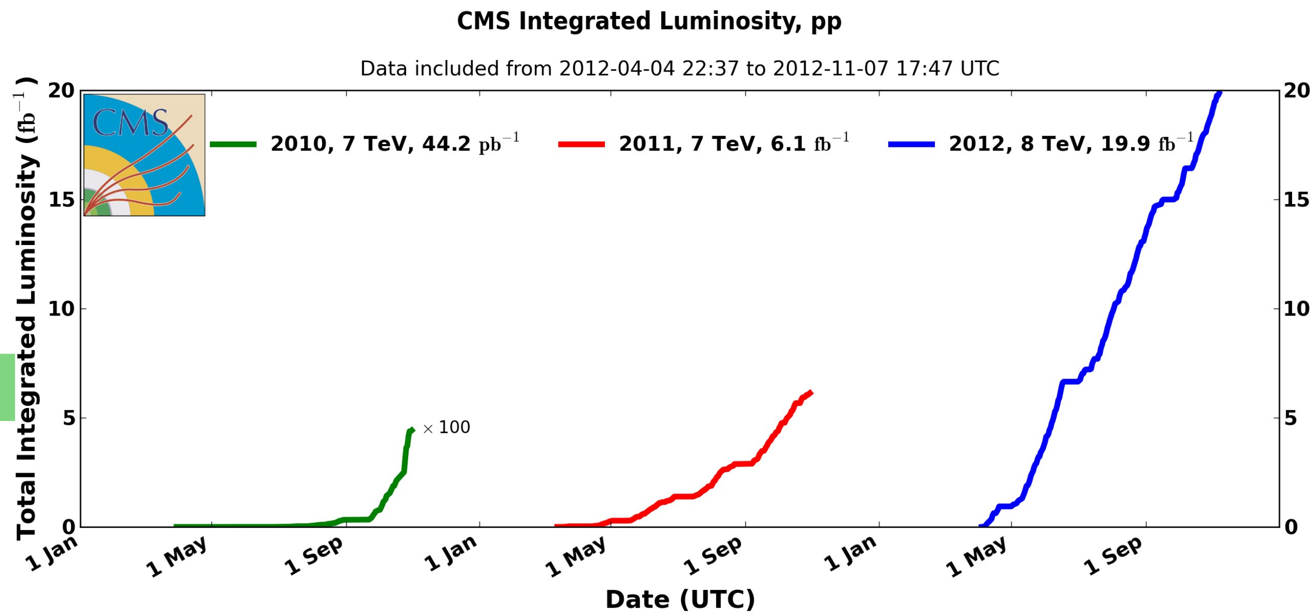
Luminosity

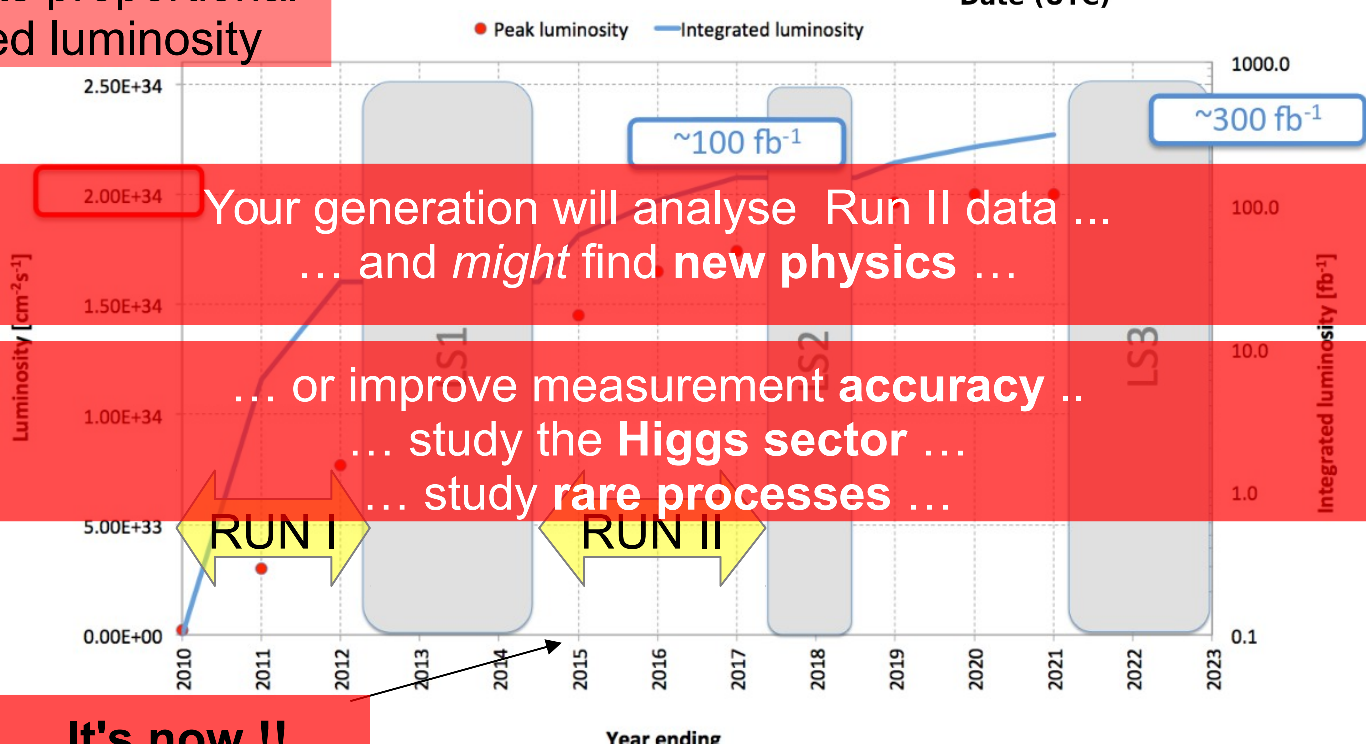
$$L = \frac{N^2 k_p f}{4\pi\sigma_x \sigma_y}$$

- Proton/bunch
- Nof bunches
- Frequency
- Beam resolution

$$N^{sig} = \sigma^{sig} \int L dt$$

Number of events proportional to the integrated luminosity



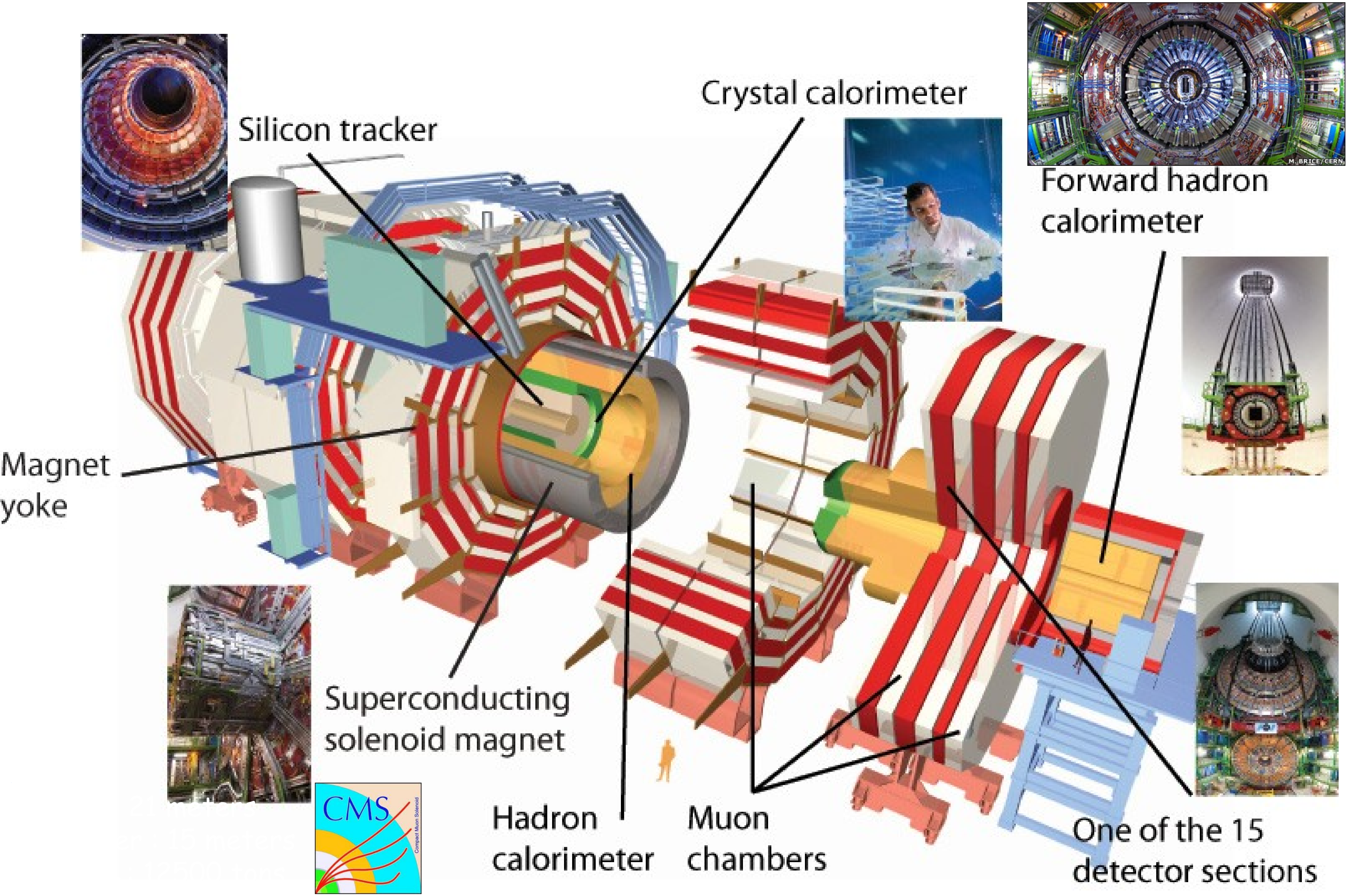


Your generation will analyse Run II data ...
… and *might* find **new physics** …

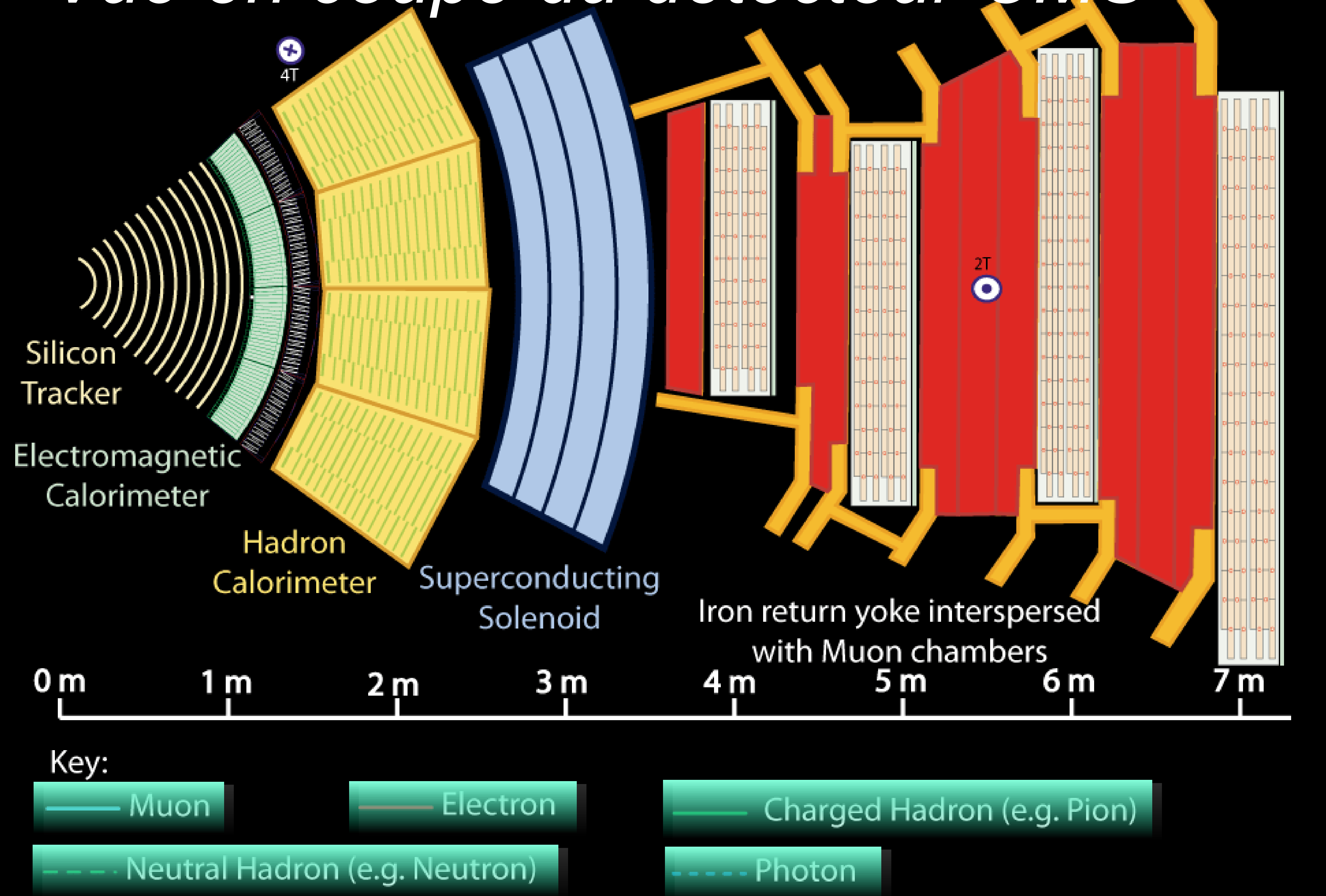
… or improve measurement **accuracy** ..
… study the **Higgs sector** …
… study **rare processes** …

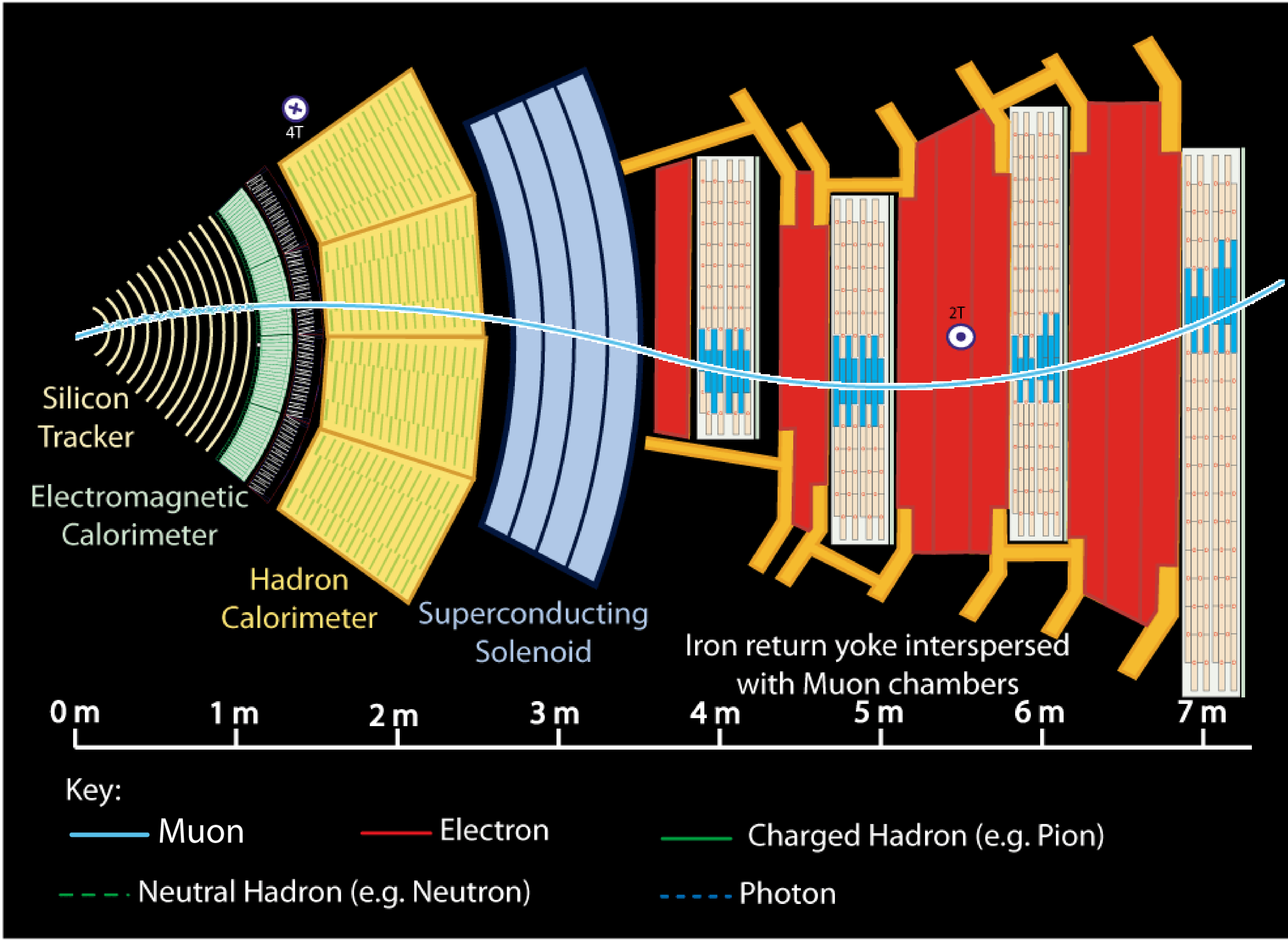
It's now !!

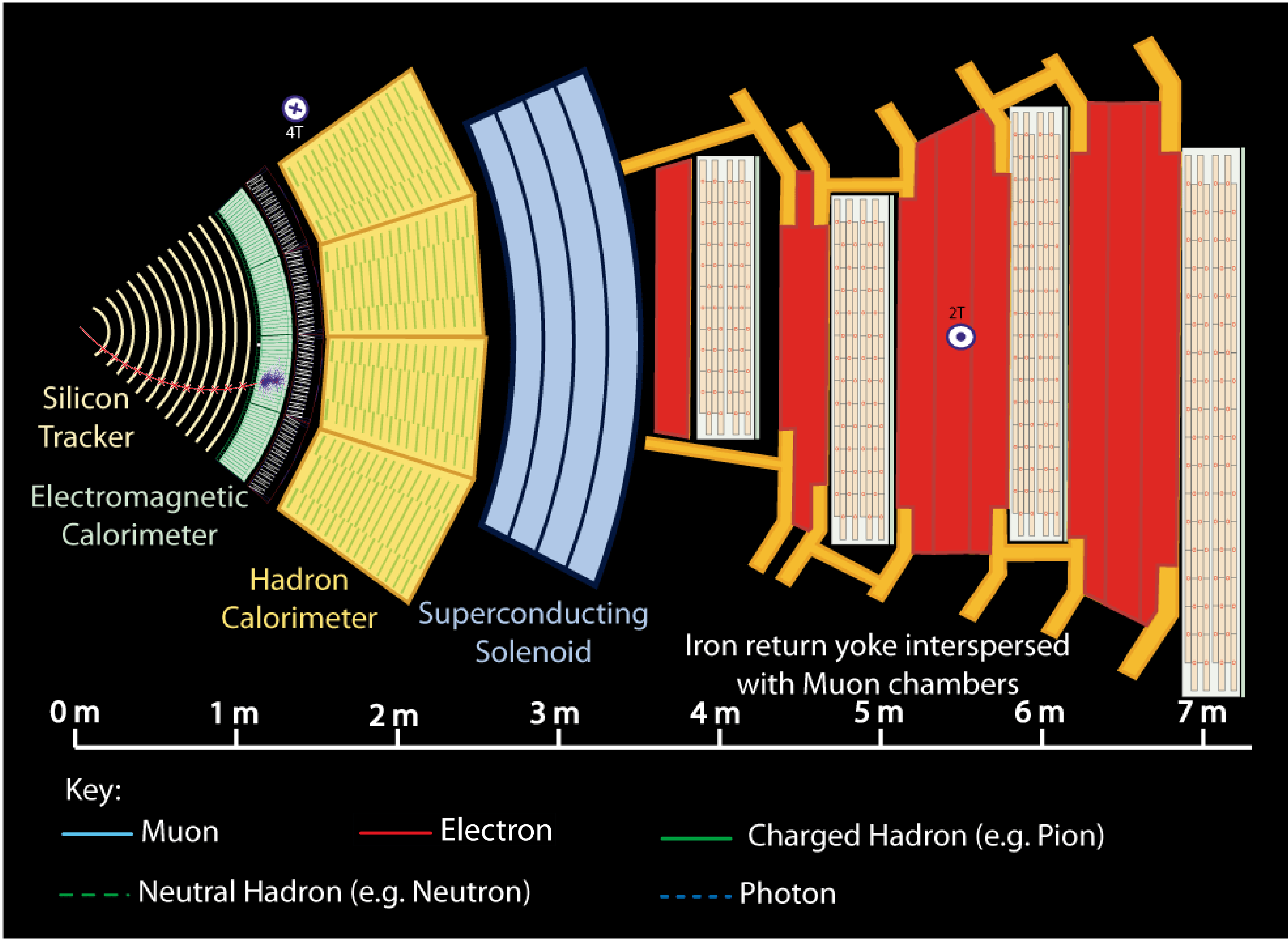
CMS detector



Vue en coupe du detecteur CMS




4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon



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2T
Silicon Tracker
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Key:
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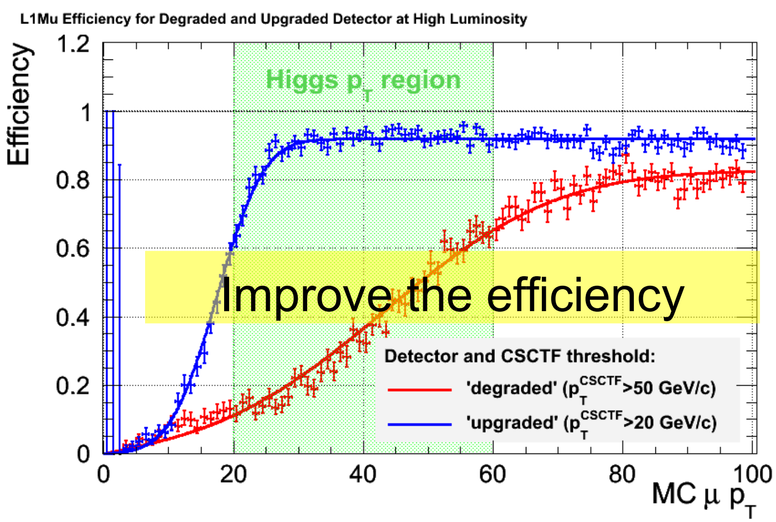
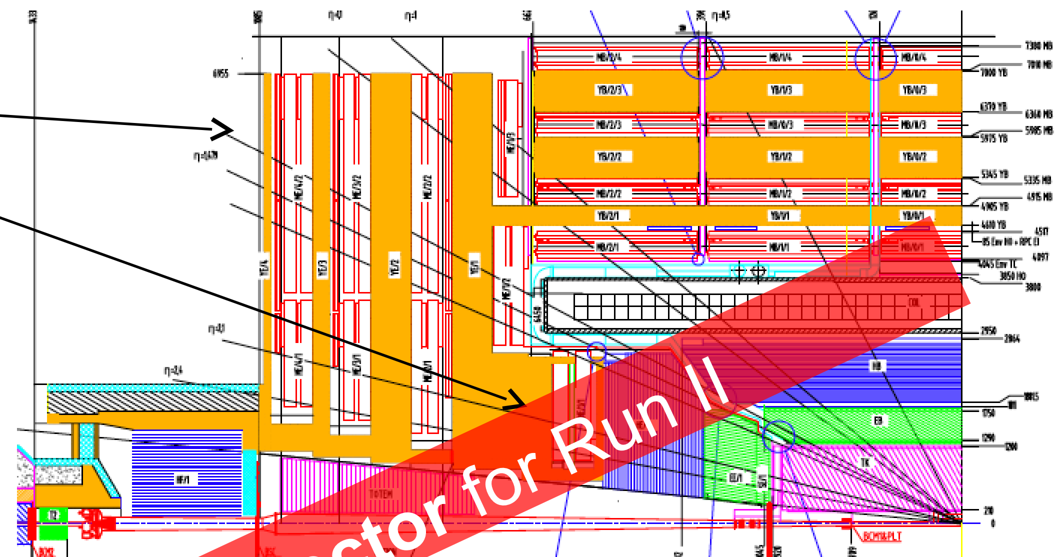
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon

CMS upgrade during LS1

Muon System:

- Complete coverage
- Improve read-out granularity

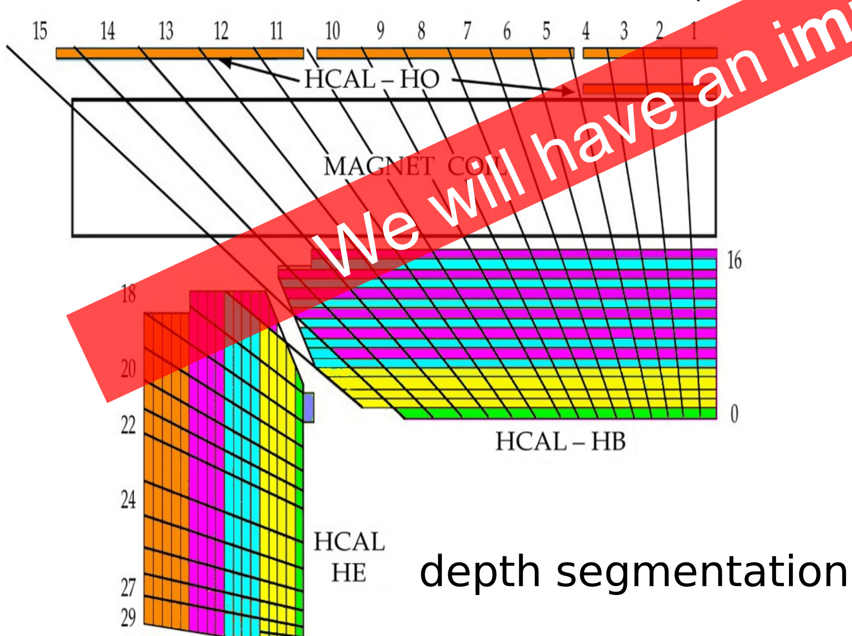




We will have an improved detector for Run II

HCAL:

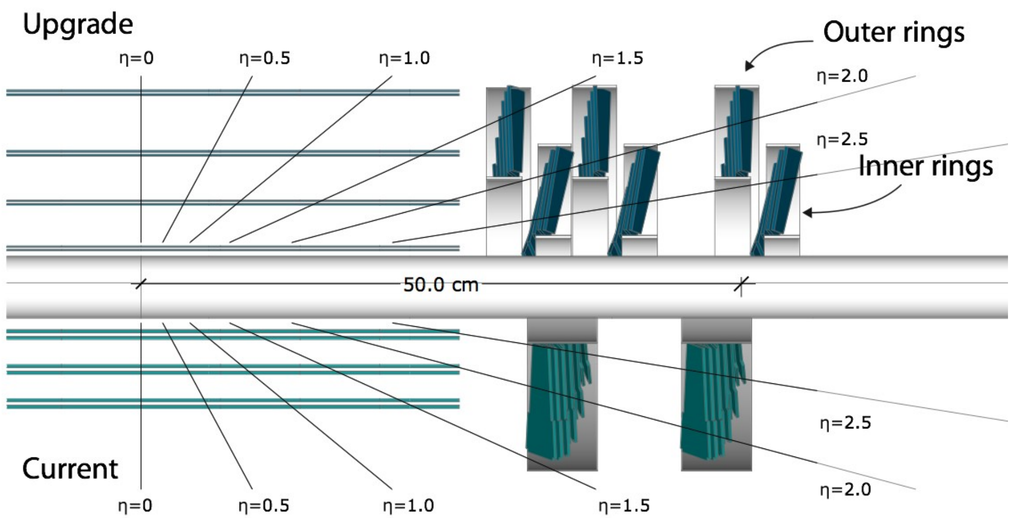
- Replace faulty detectors/electronics by brand new
- Improve bkg rejection using timing in new Front-End electronics
- Higher granularity allows depth segmentation to access the longitudinal show development

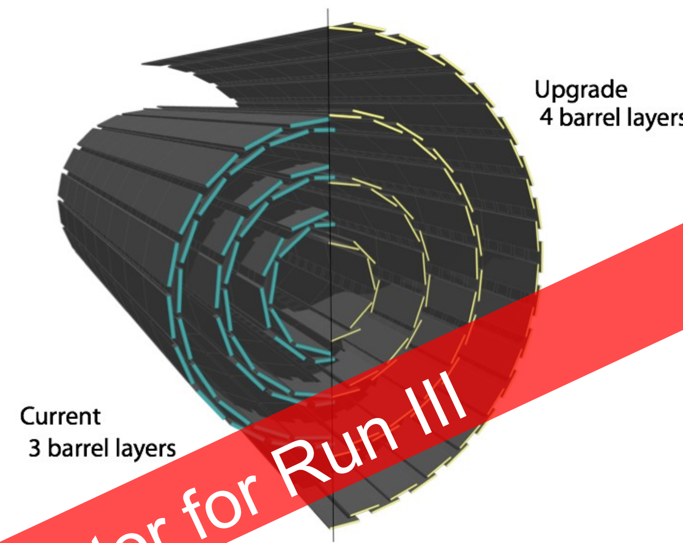


depth segmentation

Improve calibration
Mitigate PU effect
Improve isolation

CMS upgrade during Phase I





New pixel detector

- 4 layers/3 disks (extend range from lower radius: 3 cm)
- New readout chip (tolerate rate up to PU 100)
- Less material (CO_2 cooling, new cabling and powering scheme)
- Similar technology as current detector (sensors, FE chip)
  - Will survive 500 fb^{-1} (250fb^{-1} for first layer)

…and even a better detector for Run III

Reduce photon conversion
Higher efficiency
Lower fake rate
Improve b-tagging

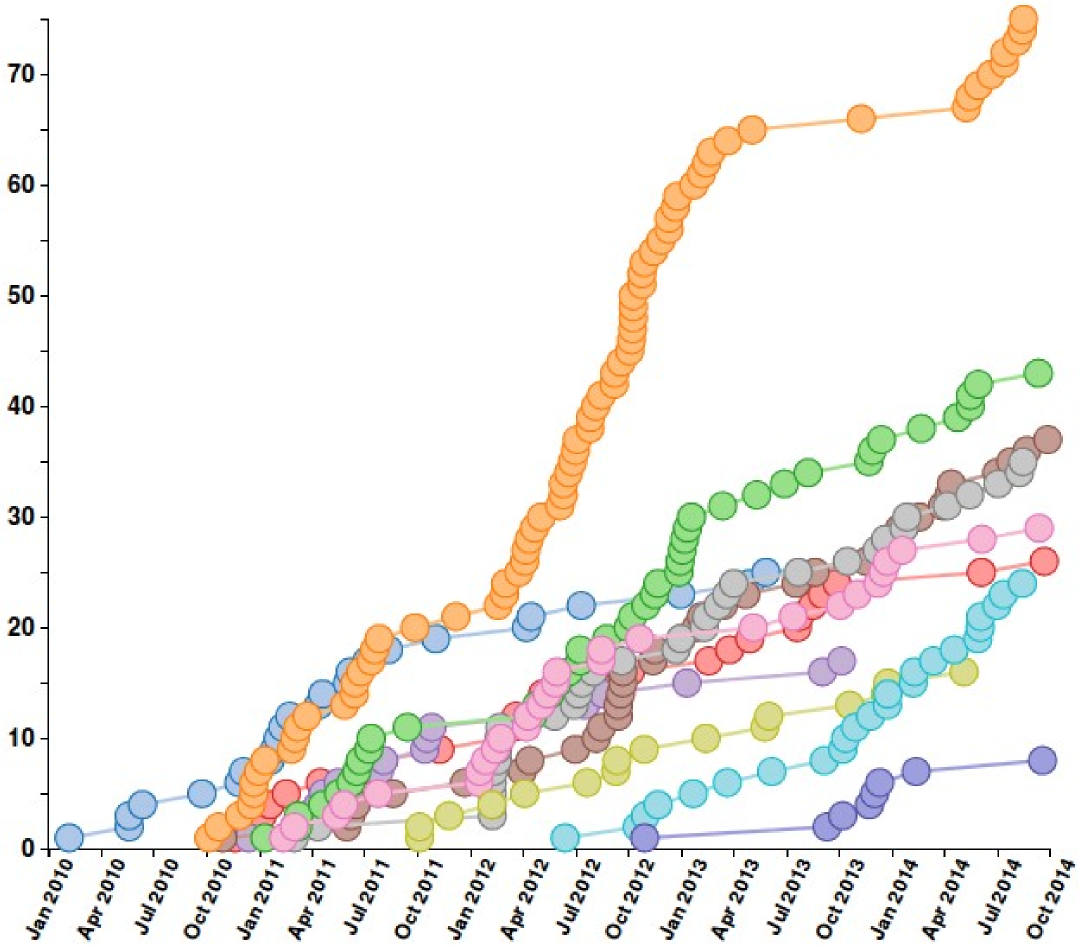
IPHC is involved
in the Back-End
And DAQ developments

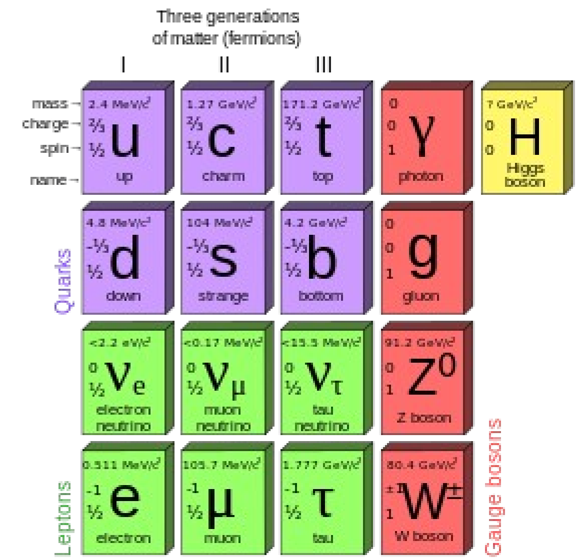
CMS Physics during Run I

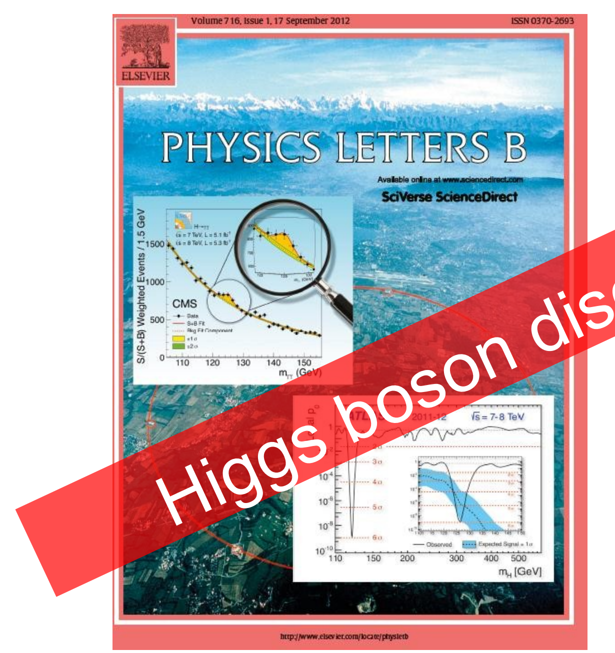
Involvement of CMS@IPHC

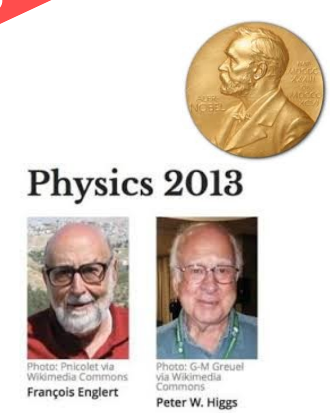
Show all | Total | QCD | Exotica Searches | **Supersymmetry** | B Physics | Electroweak
Top Physics | Heavy Ion | **Higgs** | Forward Physics | Standard Model | Beyond the SM: B2G

335 papers submitted as of 2014-09-26





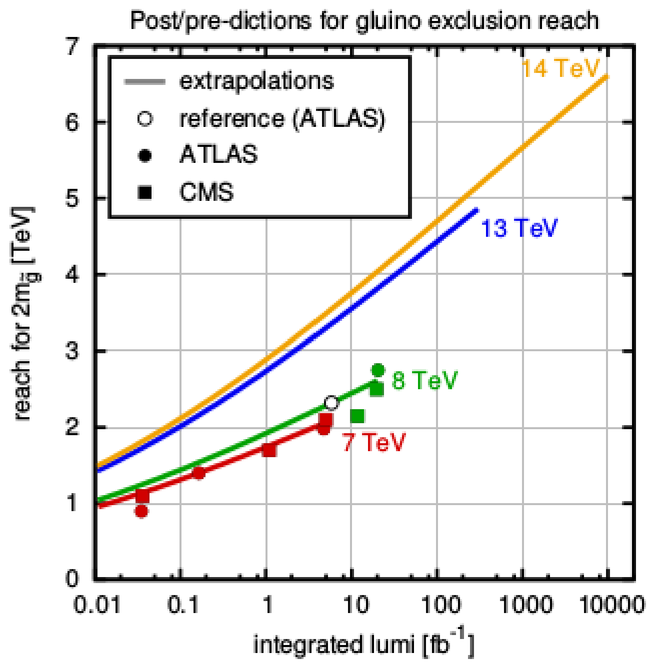


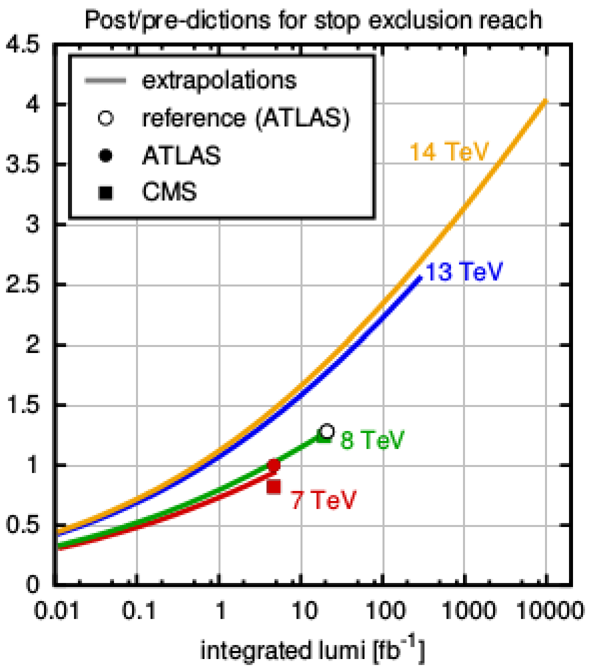


CMS Physics during Run II

Many improvements are expected thanks to:

- Higher **energy** **> x1.5 energy**
- Higher **luminosity** **> x10 data**
- Better **detectors**
- Improved **algorithms**





Impact of the energy & luminosity on the searches

Improvement measurement accuracy
Study rare processes
BSM searches: higher masses/scales

CMS @ IPHC : the Team

L'équipe CMS en octobre 2014

Christophe Goetzmann

Pierre Van Hove

Thibaut Schmitt

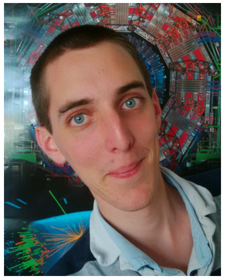
Jeremy Andrea

Daniel Bloch

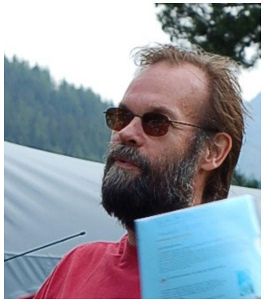
Caroline Collard

Jean-Charles Fontaine

Xavier Coubez



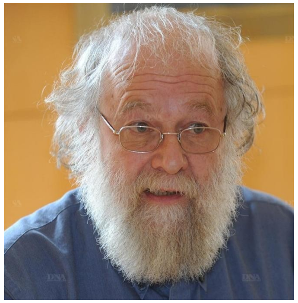
Ulrich Goerlach



Kirill Skovpen

Camille Beluffi

Jean-Marie Brom

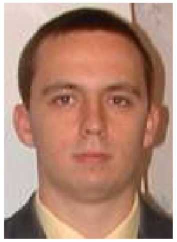


Denis Gelé

Anne-Catherine Lebihan

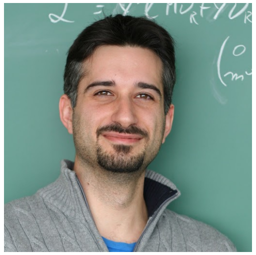
Eric Chabert

Eric Conte



Benjamin Fuks

Lorenzo Basso



Adam Alloul

Michael Buttignol

Laurent Gross

Jean-Laurent Agram

Alexandre Aubin

CMS @ IPHC: Physics searches

top quark

- Top pair cross-section
- b-tagging efficiency
measurement using tt

Boosted techniques (H,top, ...)

Higg quark

- Search for ttH

- Search for new physics
- In tt spin polarization
- Single top FCNC
- Seach for monotop
(top+ invisble)

tH (FCNC)

Higgs sector in N-MSSM

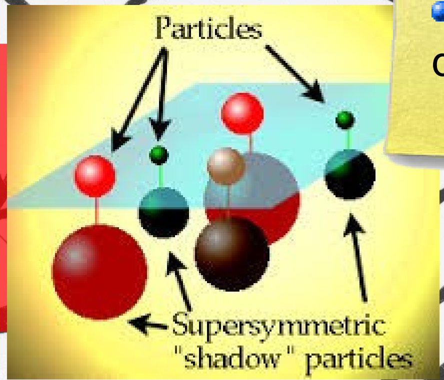
- Search for stop pair
production

Stop pair production (M_T)

- RVP neutralinos with eμ
displaced vertices

Beyond the Standard Model

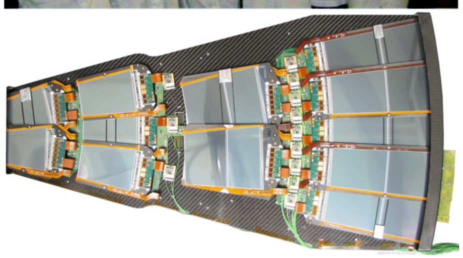
Supersymmetry



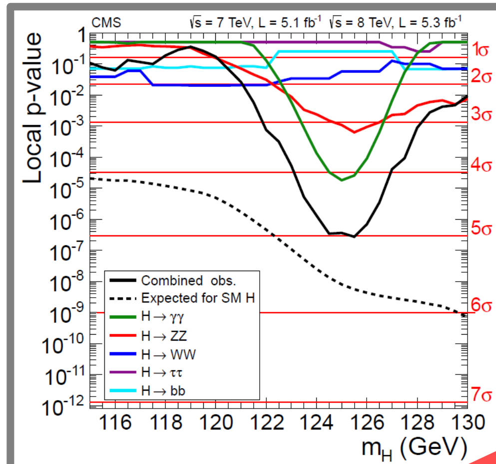
Diversity of skills

Everything will not be covered during the M2 traineeship !

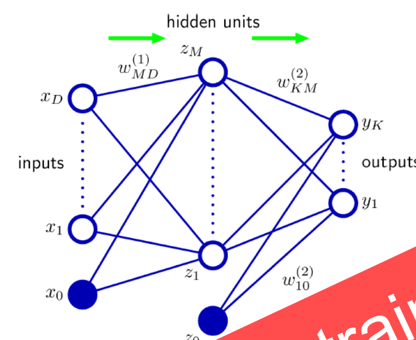
instrumentation



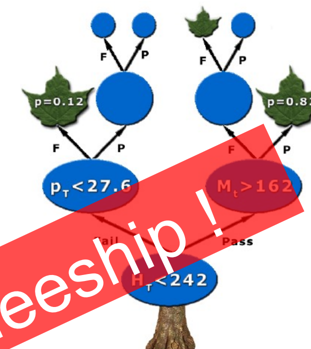
Statistical treatment



algorithms

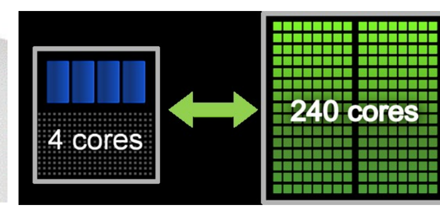


Neural Network



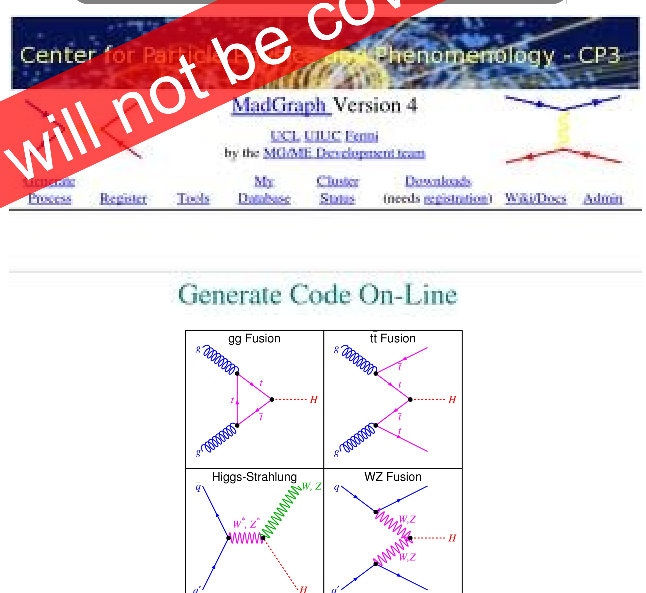
Boosted Decision Tree

Computing

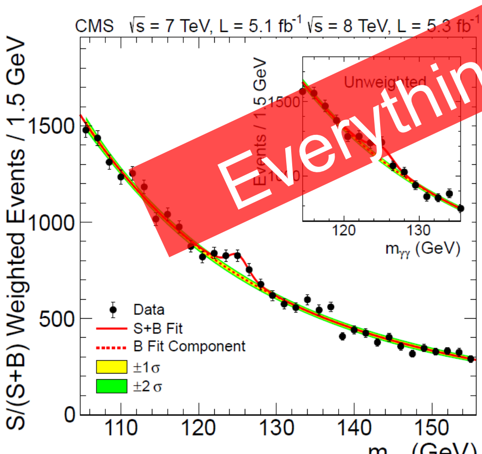


Grid

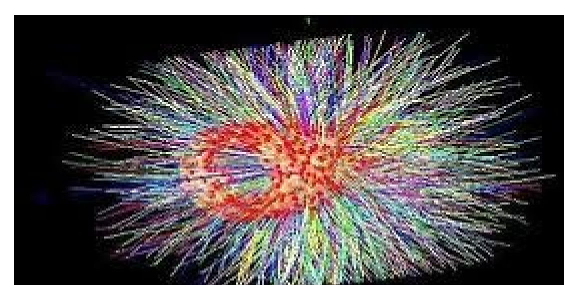
Phenomenology



Physics analysis



Simulation



Search for **stop**
at CMS
with M_T
observable

Possibility to pursue
with a PhD thesis

SuperSymmetry
and the **Higgs**
bosons(s):
The Next to
Minimal Super
Symmetric Model
(N-MSSM)

Possibility to pursue
with a PhD thesis

Search for **tH**
FCNC at CMS:
Analysis overview

Performance
study of
Boosted
techniques
In MadAnalysis 5

Search for **stop**
at CMS
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SuperSymmetry
and the **Higgs**
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The Next to
Minimal Super
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(N-MSSM)

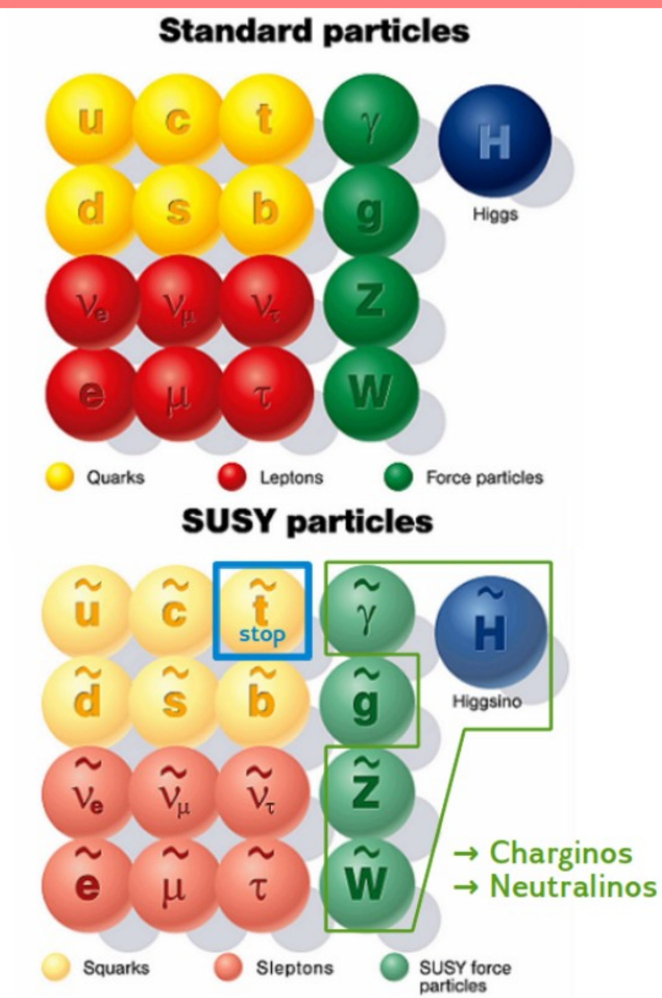
Search for **tH**
FCNC at CMS:
Analysis overview

Performance
study of
Boosted
techniques
In MadAnalysis 5

SuperSymmetry (SUSY) in a nutshell

BSM models ...

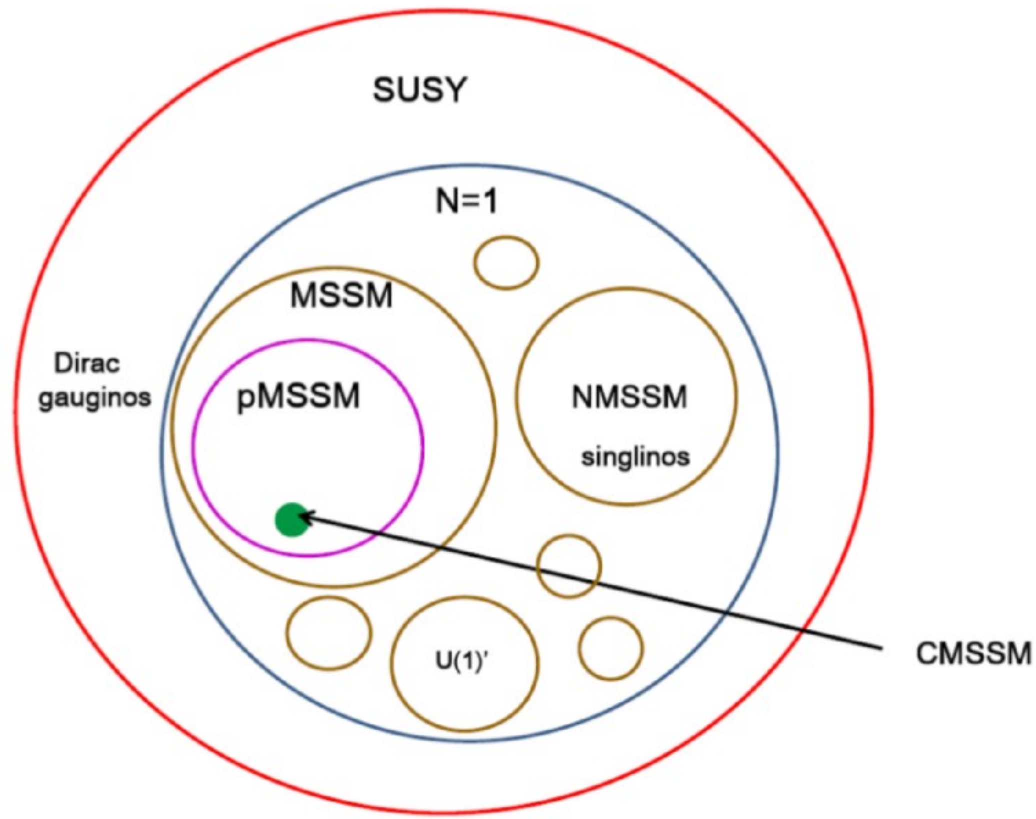
- Add symmetry
- Add matter content
- Add gauge sector
- Extend Higgs sector
- Add extra-dimensions
- ...



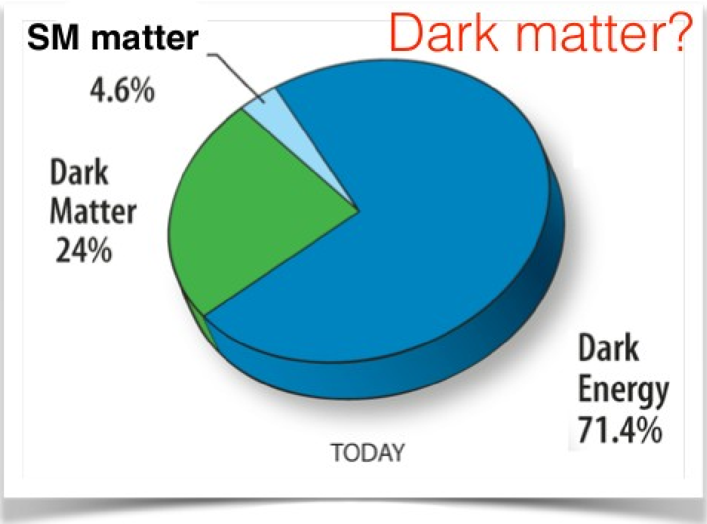
Good features of SUSY:

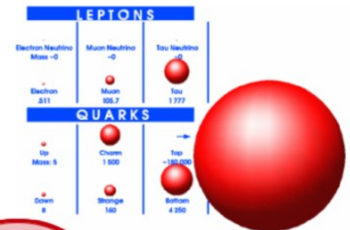
- Propose a candidate for Dark Matter
- Solve the hierarchy problem
- Unification of the couplings at high energy

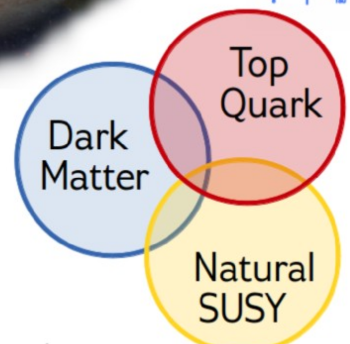
- It's a generic concept (add a boson/fermion symmetry).
- There are many SUSY models.
- Number of parameters range from 5 (more constrained) to > 100

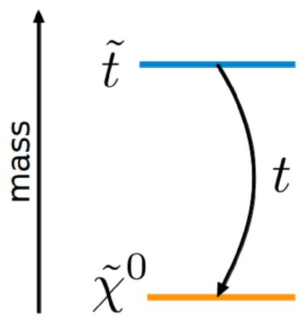


Searching for scalar top (stop)

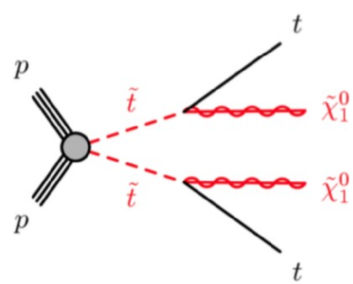


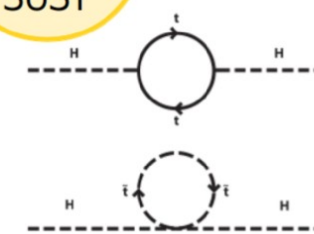


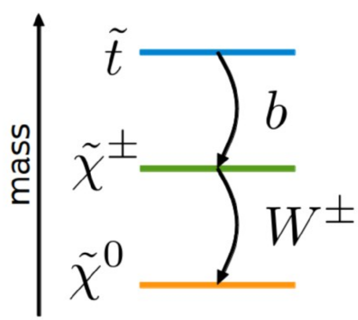




$\boxed{\tilde{t} \to t\tilde{\chi}^0}$

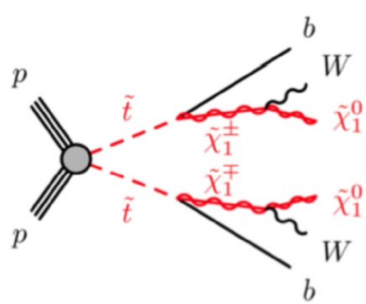






$\boxed{\tilde{t} \to b\tilde{\chi}^{\pm}}$

$x = \{0.25, 0.50, 0.75\}$

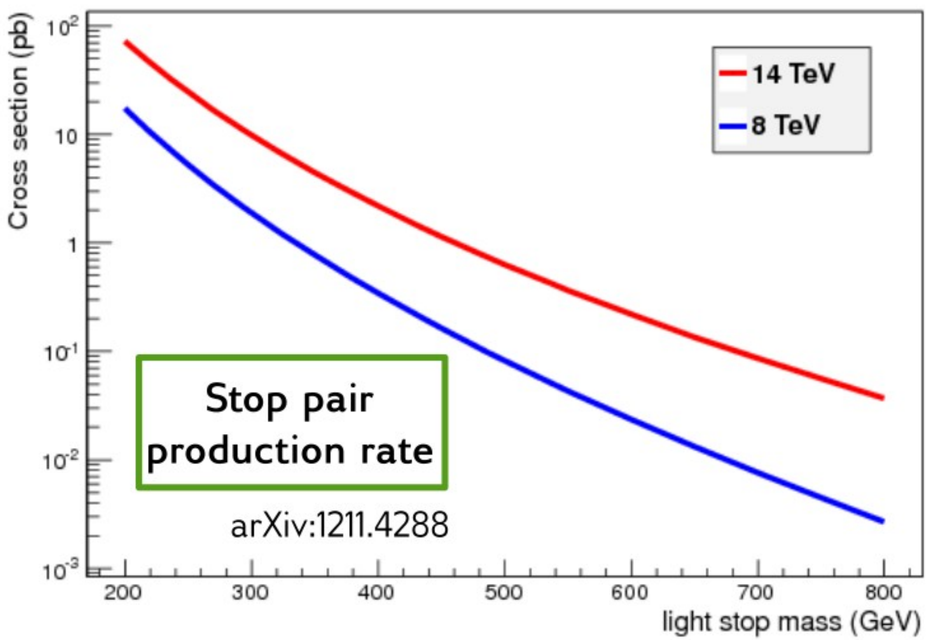


Search for stop at the TeV scale

1-lepton channel

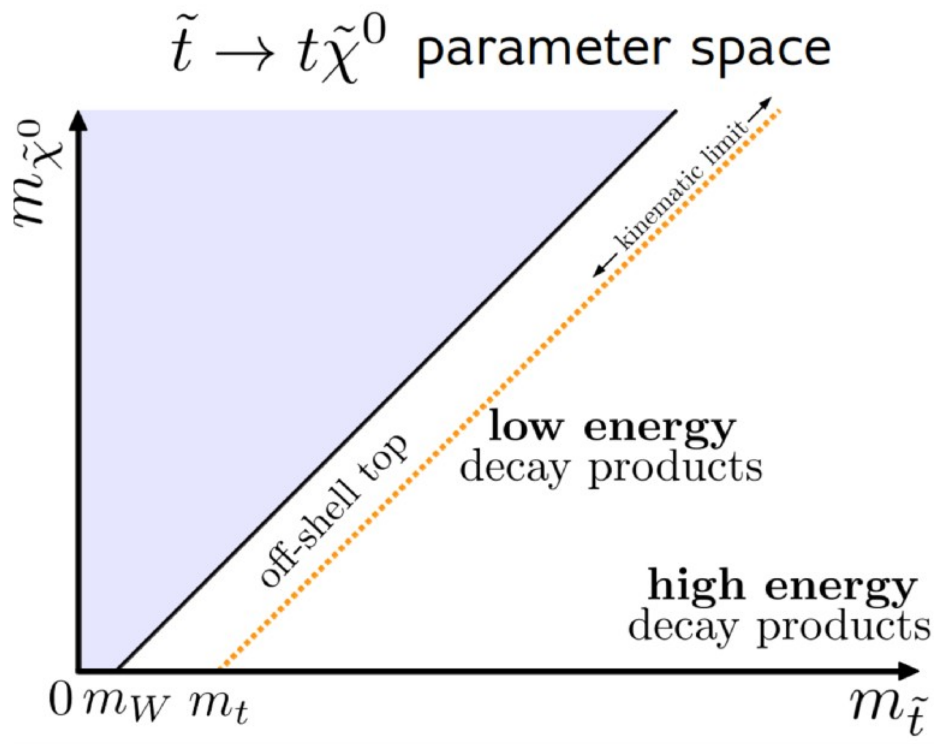
1st $W \to q\bar{q}$ 2nd $W \to \ell\nu_\ell$

Searching for scalar top (stop)



Drives the number of expected signal events

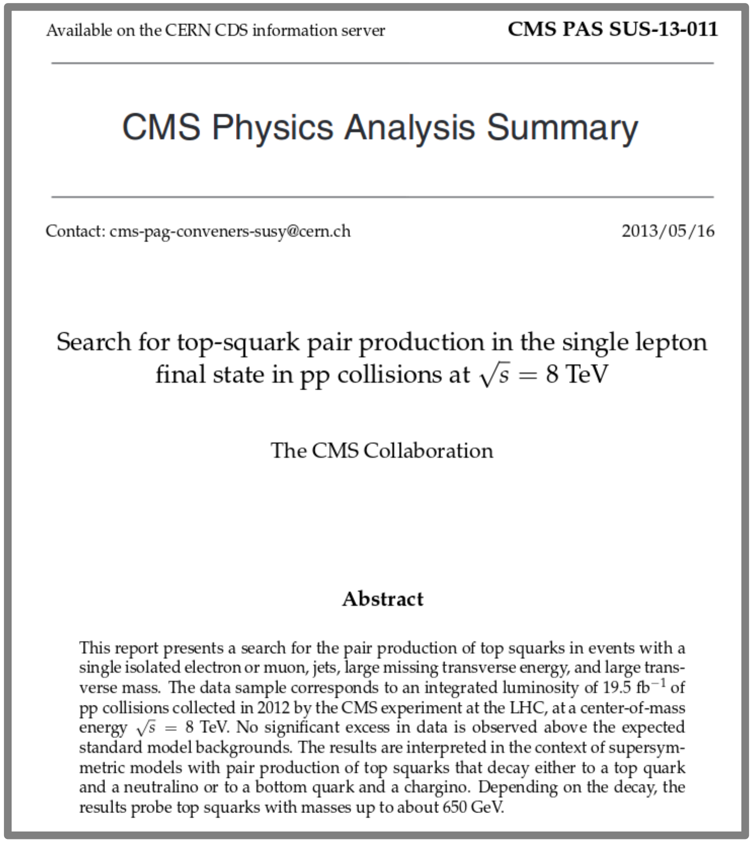
Simplified models
Depends on mass spectra and branching ratio



$$\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}^0}$$

Kinematics depends on the mass differences between the stop and the neutralino

Current results


Available on the CERN CDS information server — CMS PAS SUS-13-011

CMS Physics Analysis Summary

Contact: cms-pag-conveners-susy@cern.ch — 2013/05/16

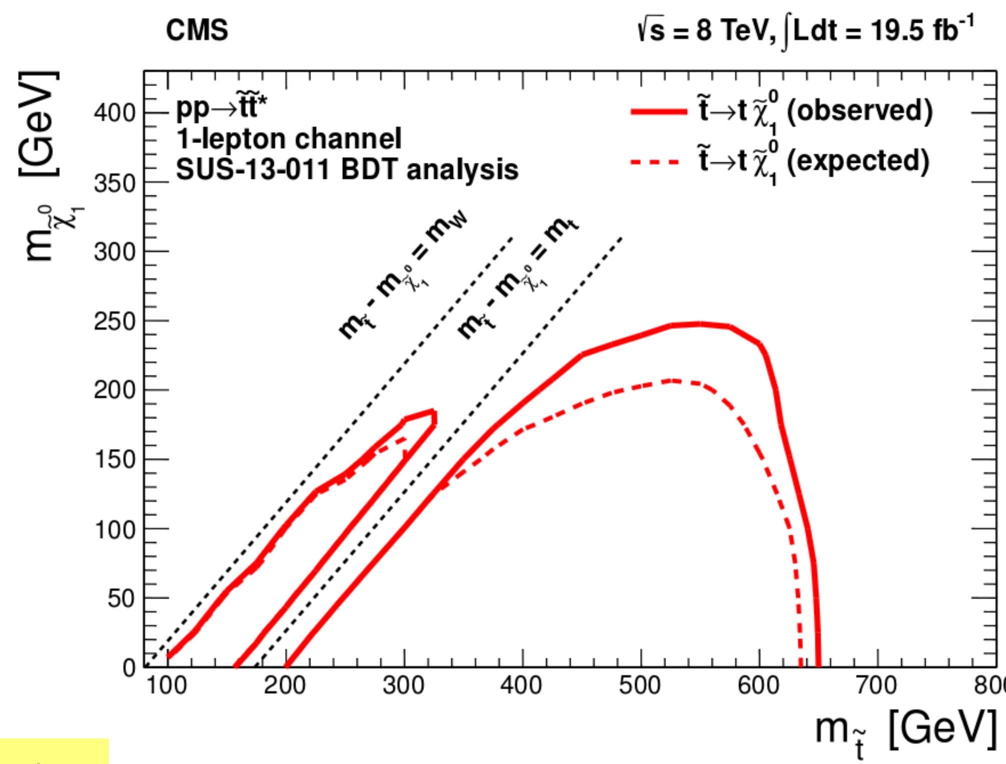
Search for top-squark pair production in the single lepton final state in pp collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration

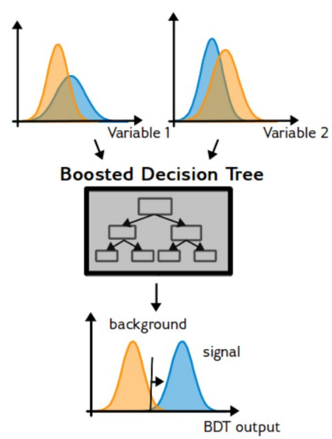
Abstract

This report presents a search for the pair production of top squarks in events with a single isolated electron or muon, jets, large missing transverse energy, and large transverse mass. The data sample corresponds to an integrated luminosity of 19.5 fb^{-1} of pp collisions collected in 2012 by the CMS experiment at the LHC, at a center-of-mass energy $\sqrt{s} = 8$ TeV. No significant excess in data is observed above the expected standard model backgrounds. The results are interpreted in the context of supersymmetric models with pair production of top squarks that decay either to a top quark and a neutralino or to a bottom quark and a chargino. Depending on the decay, the results probe top squarks with masses up to about 650 GeV.

No excess found so far during Run I ...



Boosted Decision Tree



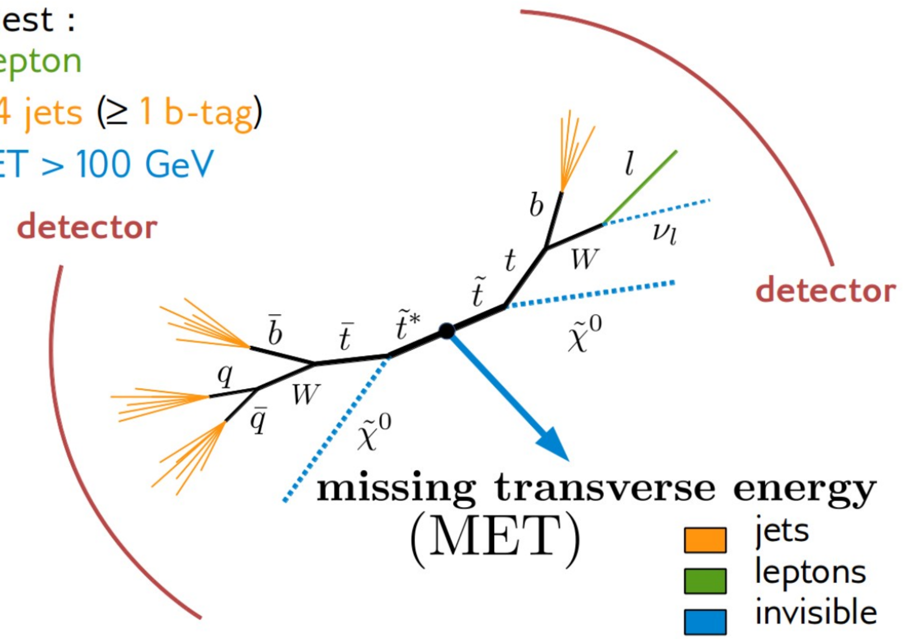
Use MVA method (BDT)
To improve sensitivity

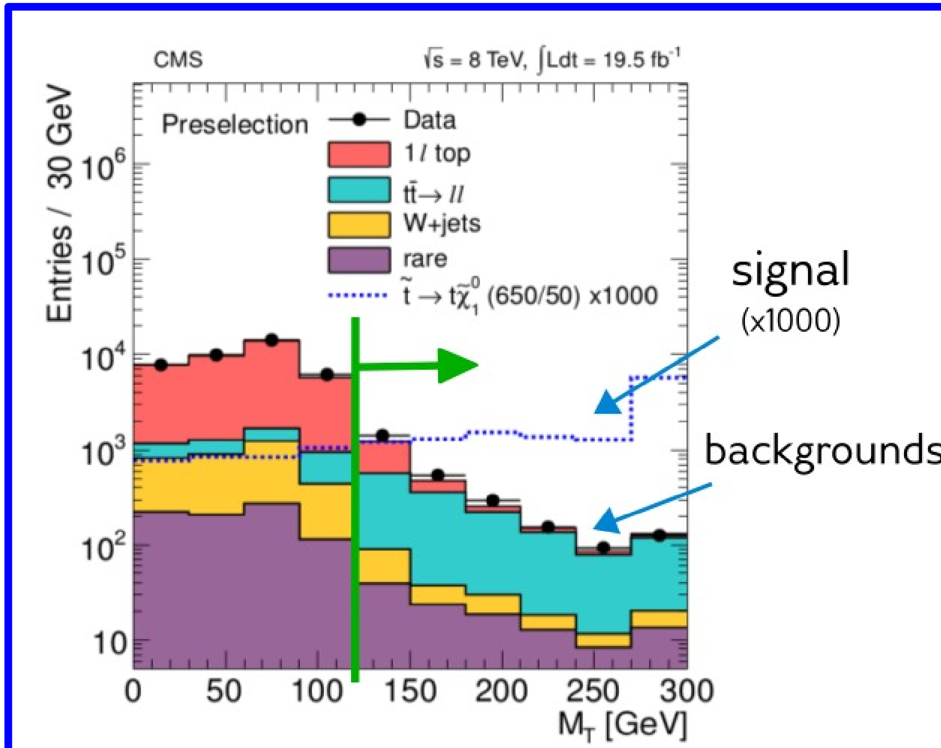
We set limits on parameters

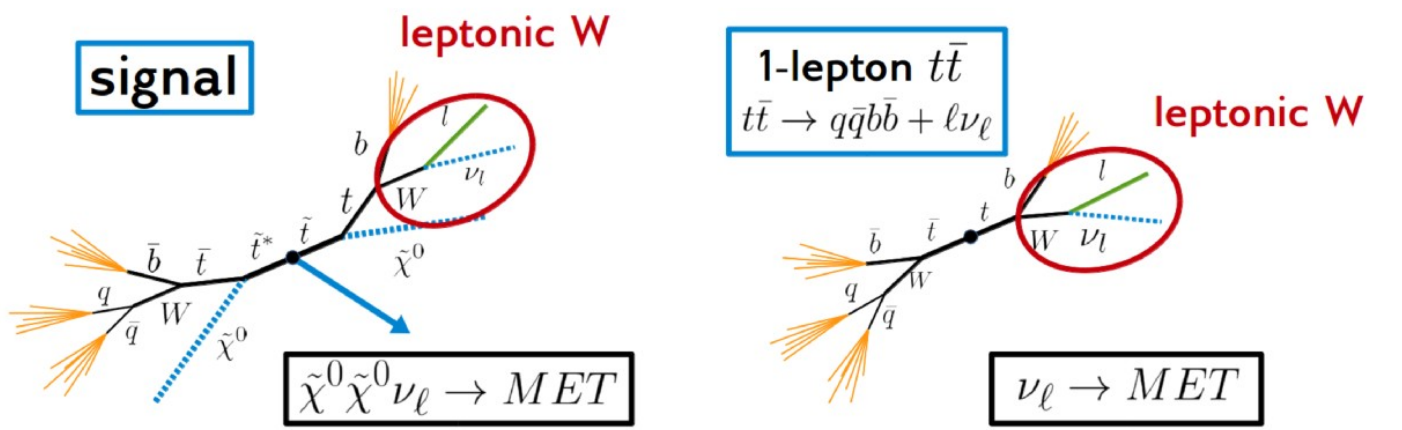
Experimental signature - M_T observable

$$pp \to \tilde{t}\tilde{t}^* \to bbWW + \tilde{\chi}^0\tilde{\chi}^0 \to \ell + qqbb + \nu_\ell\tilde{\chi}^0\tilde{\chi}^0$$

Request :
- 1 lepton
- ≥ 4 jets (≥ 1 b-tag)
- MET > 100 GeV



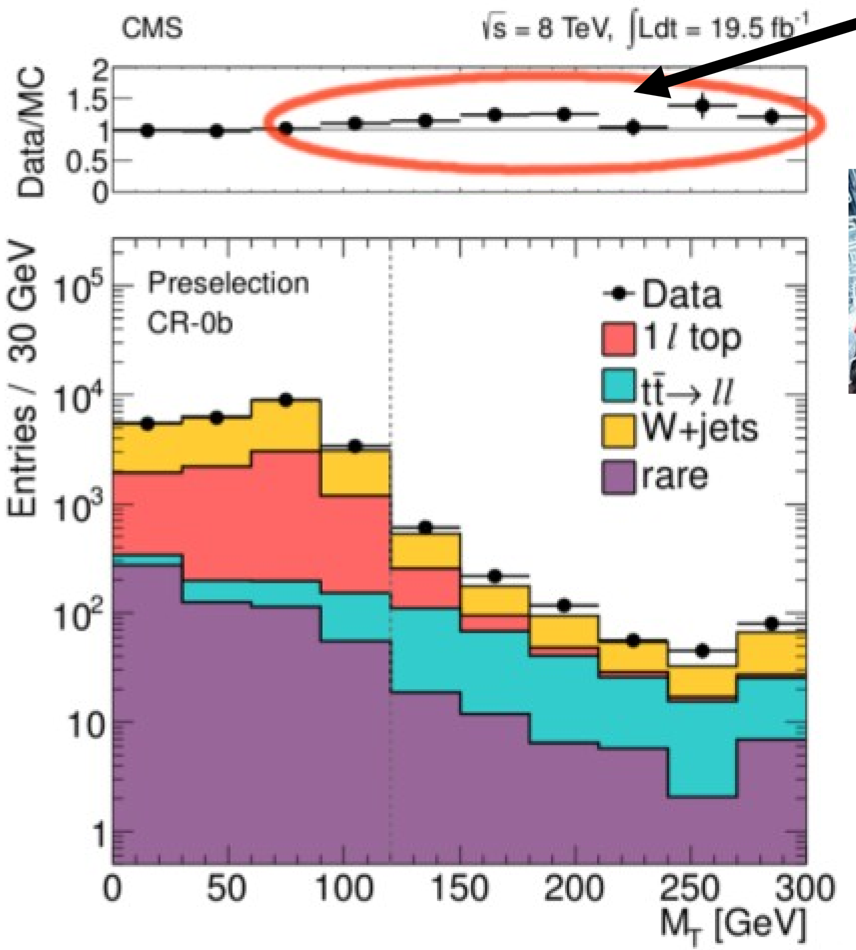




$W_{leptonic}$ = lepton + neutrino mass(W) ~ 80 GeV

The M_T variable
- $M_T = mass_{\text{transv.}}(\ell + MET)$
- exploit the leptonic W to discriminate signal and background

Understanding M_T tail in data



- Use "regions" in data to control *backgrounds*
- Signal is not expected to appear there
- M_T observable is not correctly modeled
- **No explanation provided so far …**
- Simulations are corrected with had-hock scale factors

Goal of the traineeship:

Study possible explanation(s) for the observed disagreement
… and if possible find the correct one(s)

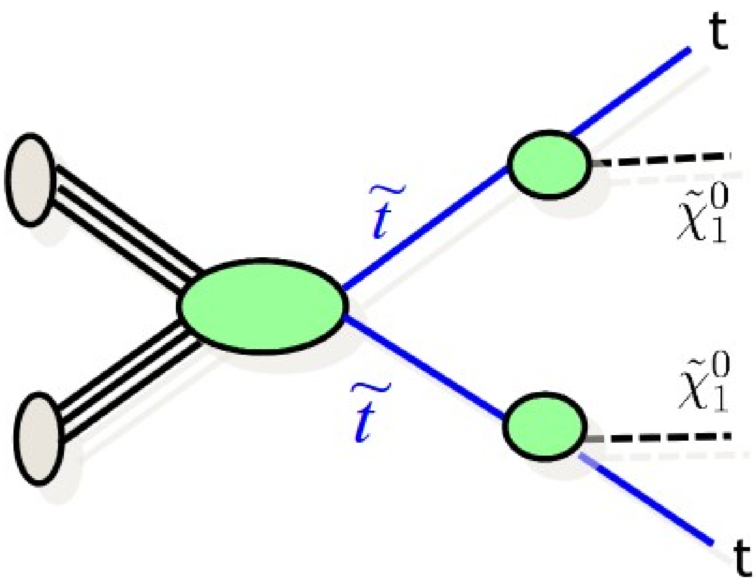
The candidate will analyze CMS Run I data.

The results might be very important for stop searches during Run II

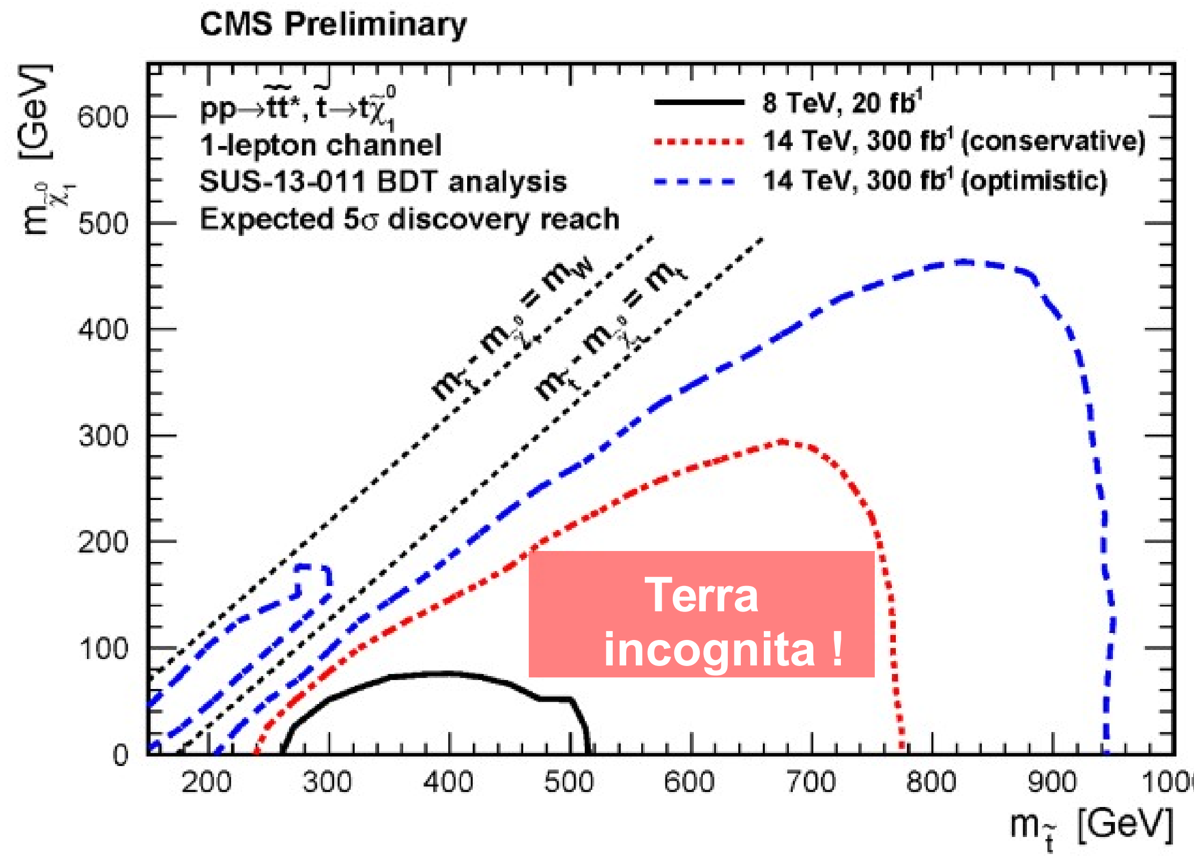
Possibilities to be explored:

- Detector simulation (jet energy resolution, ..)
- Effect of pile-up
- Jet multiplicity modeling
- Heavy flavor modeling of W+jets
- Modeling of rare processes (tt+Z/W)

PhD thesis



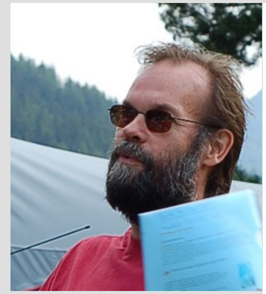
Search in final state with ℓ + jets + MET



Search for direct stop pair production with Run II data

- Adapt the analysis to the new reconstruction features
- Adapt the analysis to higher luminosity (more stat.)
- Study the impact of pile-up
- Deeper understanding of rare background (ttZ,...)
- Exploit boosted techniques relevant at high masses
- Possibility to explore cross decay channels

Search for **stop** at CMS with M_T observable



SuperSymmetry and the **Higgs bosons**(s): The Next to Minimal Super Symmetric Model (N-MSSM)

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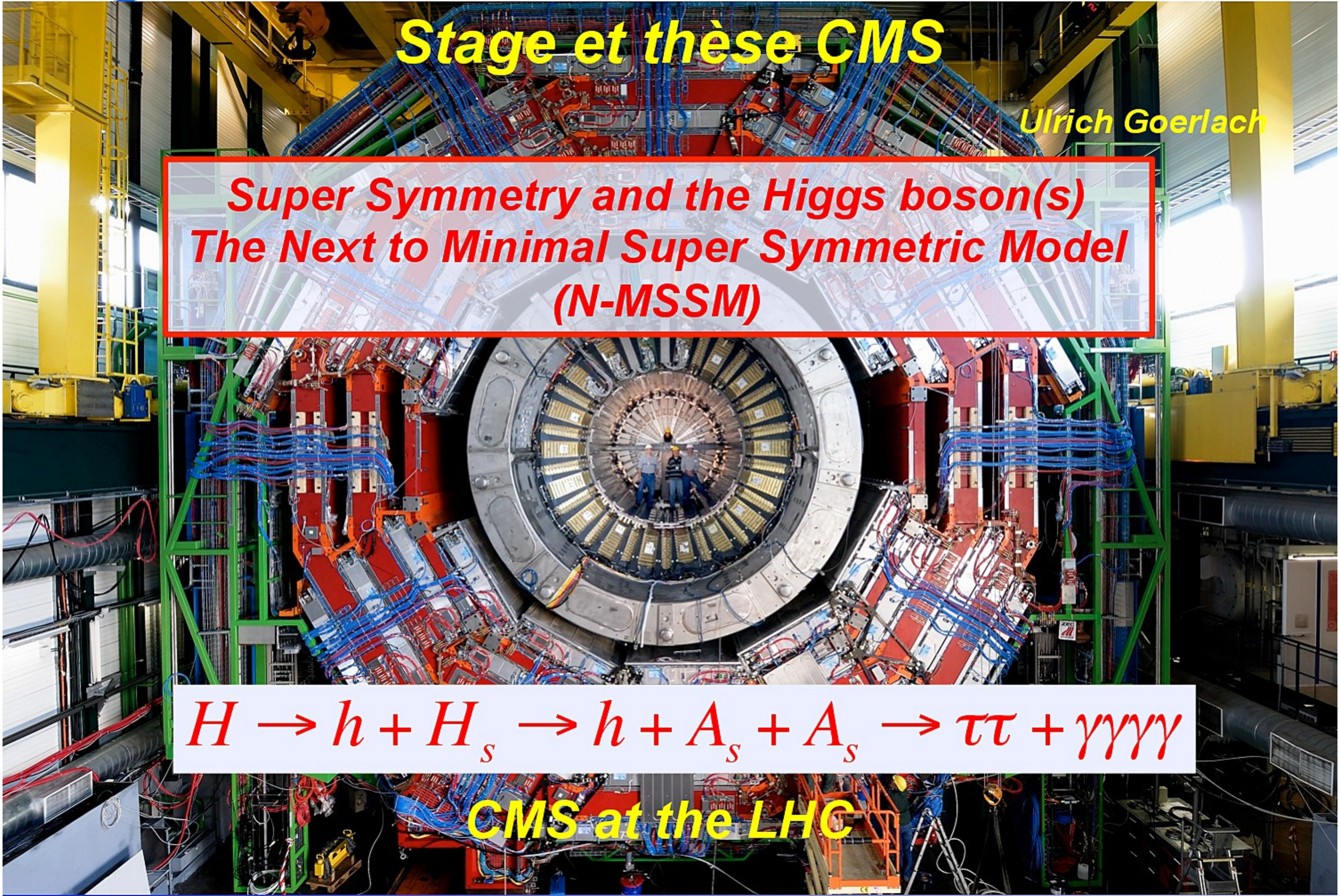

Stage et thèse CMS
Ulrich Goerlach
Super Symmetry and the Higgs boson(s)
The Next to Minimal Super Symmetric Model
(N-MSSM)
$H \rightarrow h + H_s \rightarrow h + A_s + A_s \rightarrow \tau\tau + \gamma\gamma\gamma\gamma$
CMS at the LHC

Super Symmetry and the Higgs boson

- Super symmetry postulates a Super partner for each particle of the Standard model
- Fermions (lepton and quark) ←→ s-boson (slepton and squark)
- Boson (gamma, W, Z, gluons) ←→ sfermion (photino, Wino, Bino, gluino)

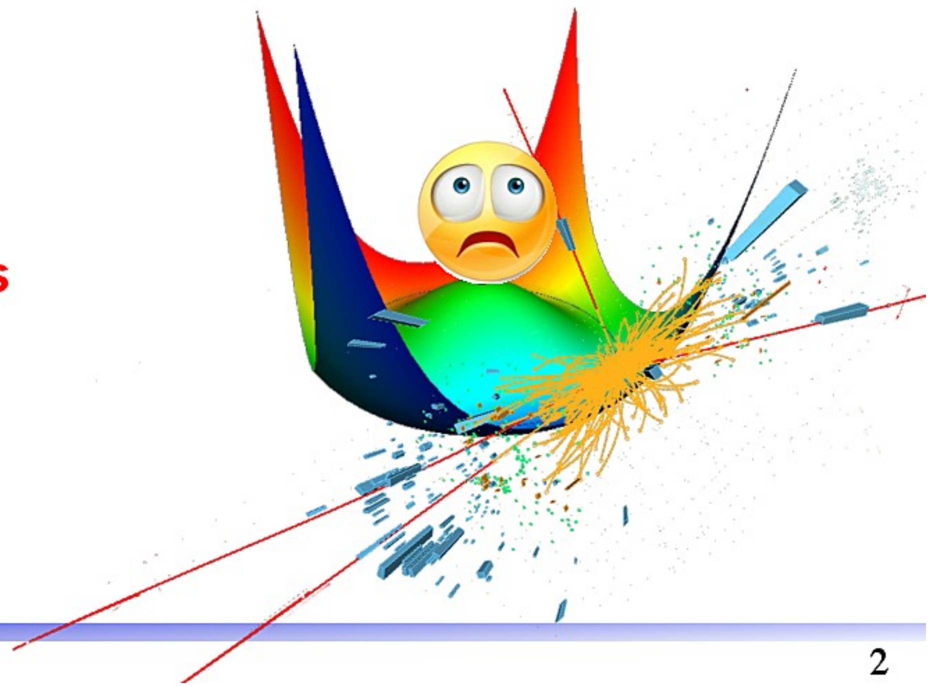
$$Q|\text{Boson, spin } J\rangle = |\text{Fermion, spin } J + \tfrac{1}{2}\rangle$$

$$Q|\text{Fermion, spin } J\rangle = |\text{Boson, spin } J - \tfrac{1}{2}\rangle$$

- Super symmetry is a "broken" symmetry ➔ look for heavy new sparticles
- Nothing found so far !!!!!

- LHC-RUN 2015:

  Look for sparticles with even higher mass



Supermultiplets

- ## Chiral Supermultiplet

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\tilde{u}_L \;\; \tilde{d}_L)$	$(u_L \;\; d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
(×3 families)	$\bar{u}$	$\tilde{u}^*_R$	$u^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\bar{d}$	$\tilde{d}^*_R$	$d^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons	L	$(\tilde{\nu} \;\; \tilde{e}_L)$	$(\nu \;\; e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
(×3 families)	$\bar{e}$	$\tilde{e}^*_R$	$e^\dagger_R$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H^+_u \;\; H^0_u)$	$(\tilde{H}^+_u \;\; \tilde{H}^0_u)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H^0_d \;\; H^-_d)$	$(\tilde{H}^0_d \;\; \tilde{H}^-_d)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

H_d and H_u needed to give masses to down- and up-type fermions

Vector Supermultiplet

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\tilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\widetilde{W}^\pm \;\; \widetilde{W}^0$	$W^\pm \;\; W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\tilde{B}^0$	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

SUSY Primer, S.P. Martin hep-ph/9709356

Super Symmetry and the Higgs sector

- Super symmetry postulates a Super partner for each particle of the Standard model
- <u>Look at the modified Higgs sector :</u>
- SM: Higgs field is a complex $SU(2)_L$ doublet
- choose minimum ➔ one scalar Higgs field
- gives mass to bosons and fermions (Yukawa)
- simplest implementation

- SUSY: need at least two Higgs doublets
- more Higgs bosons, Higgs –Higgs coupling
- MSSM 2 scalars, 1 pseudo scalars neutral and two charged Higgs
- N-MSSM : 3 scalars, 2 pseudo scalars neutral and two charged Higgs

	Names	Spin	P_R	Mass Eigenstates	Gauge Eigenstates
MSSM	Higgs bosons	0	+1	$h^0\ H^0\ A^0\ H^\pm$	$H_u^0\ H_d^0\ H_u^+\ H_d^-$
N-MSSM				$H_1, H_2, H_3\ A_1,\ A_2\ H^+,\ H^-$	$H_u^0\ H_u^+\ H_d^0\ H_d^-\quad S$

The Higgs Mechanism

- **Standard Model:** $\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$ $SU(2)$ doublet, $\phi^+, \phi^0 \in \mathbb{C}$; $\phi^+ = \frac{1}{\sqrt{2}}(\phi_1 + i\phi_2)$ $\quad \phi^0 = \frac{1}{\sqrt{2}}(\phi_3 + i\phi_4)$

  Spontaneous symmetry breaking in $SU(2)$ space. We can chose (local gauge invariance)

  $$\phi_0 = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_0 \end{pmatrix}; \phi_1 = \phi_2 = \phi_4 = 0; \quad \phi(x) = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_0 + H(x) \end{pmatrix}; \ \phi_C(x) = \frac{-1}{\sqrt{2}}\begin{pmatrix} v_0 + H(x) \\ 0 \end{pmatrix}$$

  Yukawa coupling of ϕ and ϕ_C gives mass to down-type and up-type quarks, respectively

- **SUSY:**

$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$; $H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$; two Isopsin doublet fields to give mass to L, R fermions and their SUSY partners $\quad$ $N-MSSM$ add. scalar field S

Coupling of Higgs superfields, Superpotential $W = ... + \mu\, H_u \cdot H_u$ μ free parameter, to be "fine" tuned

N-MSSM, add scalar field S, $W = ... + \lambda\, S \cdot H_u \cdot H_u$; μ replaced by vacuum expectation value of S

$MSSM$: Simplest Higgs field
h, H $\ $ *scalars*
A *pseudo scalar*
H^+, H^- charged

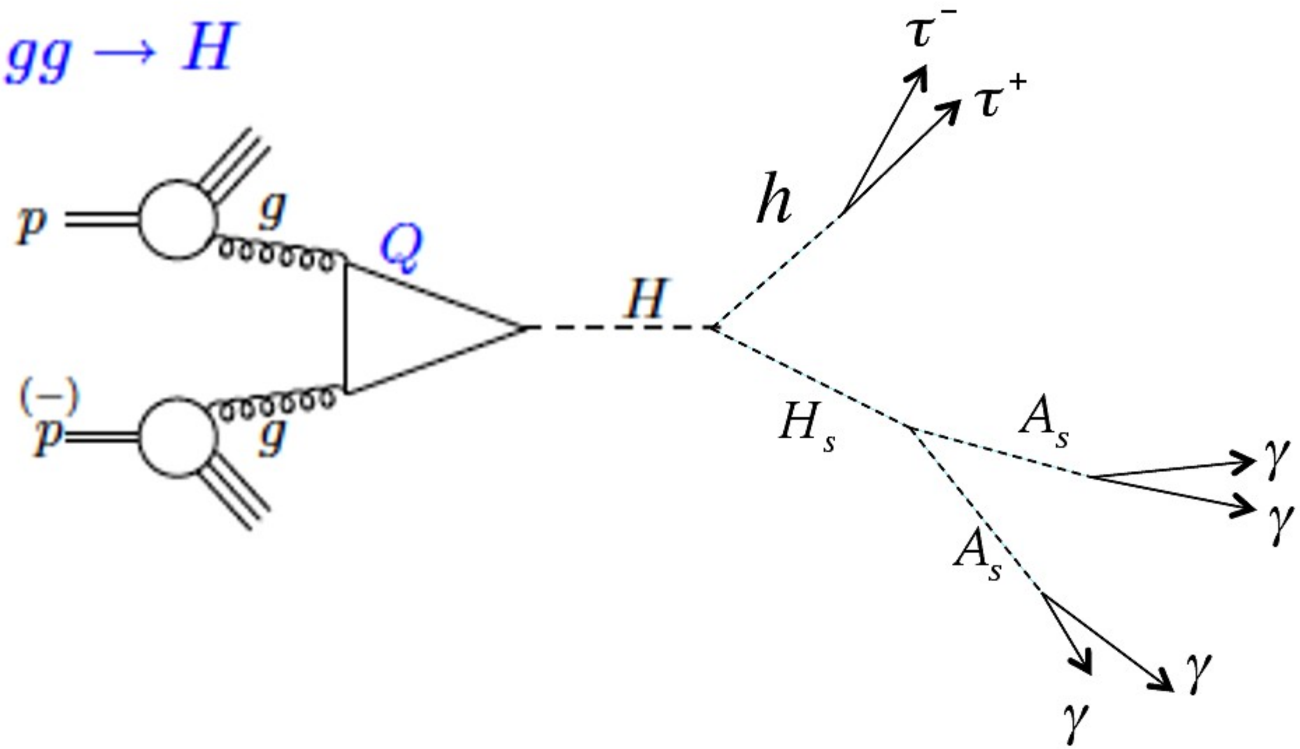
$\xrightarrow{N-MSSM}$

Next to simplest Higgs field
H_1, H_2, H_3 *scalars*
A_1, A_2 *pseudo scalar*
H^+, H^- charged

} new and complex Higgs sector

- Gluon Fusion

$pp \rightarrow gg \rightarrow H$



- New search strategies and challenges !!!
- How to reconstruct and to analyse these complex events?
- Topic of stage and PhD thesis!

Benchmark $H_1 = h$ and $\tan\beta$ small

B.1 (Point ID Poi2a)	Scenario		
M_h, M_{H_s}, M_H	124.6 GeV	181.7 GeV	322.6 GeV
M_{A_s}, M_A	72.5 GeV	311.7 GeV	
$\lvert S_{H_2 h_s}\rvert^2, \lvert P_{A_1 a_s}\rvert^2$	0.90	1	

$\mathrm{BR}(A_s \to \gamma\gamma) = 0.84\,,\quad \mathrm{BR}(H_s \to A_s A_s) = 0.97\,,\quad \mathrm{BR}(H \to h H_s) = 0.51$

$\sigma(ggH_s)\mathrm{BR}(H_s \to A_s A_s \to b\bar{b} + b\bar{b})$	5.87 fb
$\sigma(ggH_s)\mathrm{BR}(H_s \to A_s A_s \to \gamma\gamma + b\bar{b})$	67.33 fb
$\sigma(ggH_s)\mathrm{BR}(H_s \to A_s A_s \to \gamma\gamma + \gamma\gamma)$	193.22 fb

$\sigma(ggH)\mathrm{BR}(H \to hH_s \to h + A_s A_s \to bb + 4\gamma)$	712.47 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to h + A_s A_s \to \gamma\gamma + 4b)$	248.02 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to h + A_s A_s \to \tau\tau + 4\gamma)$	74.60 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to h + A_s A_s \to \gamma\gamma + 4\tau)$	2.47 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to h + A_s A_s \to 6\gamma)$	2.69 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to h + A_s A_s \to \tau\tau + \gamma\gamma + b\bar{b})$	49.55 fb

M.Mühlleitner arXiv:1408.1120v1 [hep-ph]

Stage (4 months)

“Phenomenological” study in preparation of thesis

- Introduction to SUSY and N-MSSM
- Use programs NMSSMtools and NMSSMcalc to calculate mass spectra and branching ratios of some benchmark points. M.Mühlleitner arXiv:1408.1120v1 [hep-ph]
- Cooperation with KIT (Prof. M. Mühlleitner tbc)
- Analyse ntuples (Root) from simulated data with Madgraph and Mad_analysis
- Identify the challenges of the analysis
- Estimate the feasibility of different search strategy

PhD thesis

- Conclude on the choice for one or two search channels for a new non-SM Higgs boson on the base of the work during the “stage” and coordinating with the CMS Higgs analysis groups
- Apply and further develop the analysis for different search channels to find a non-SM Higgs boson in the data of the next LHC run at 13 TeV
- Either discovery
  - Characterisation of new particle
  - MSSM or N-MSSM or ??

- Place a limit or rule out SUSY-models

Search for **stop** at CMS with M_T observable

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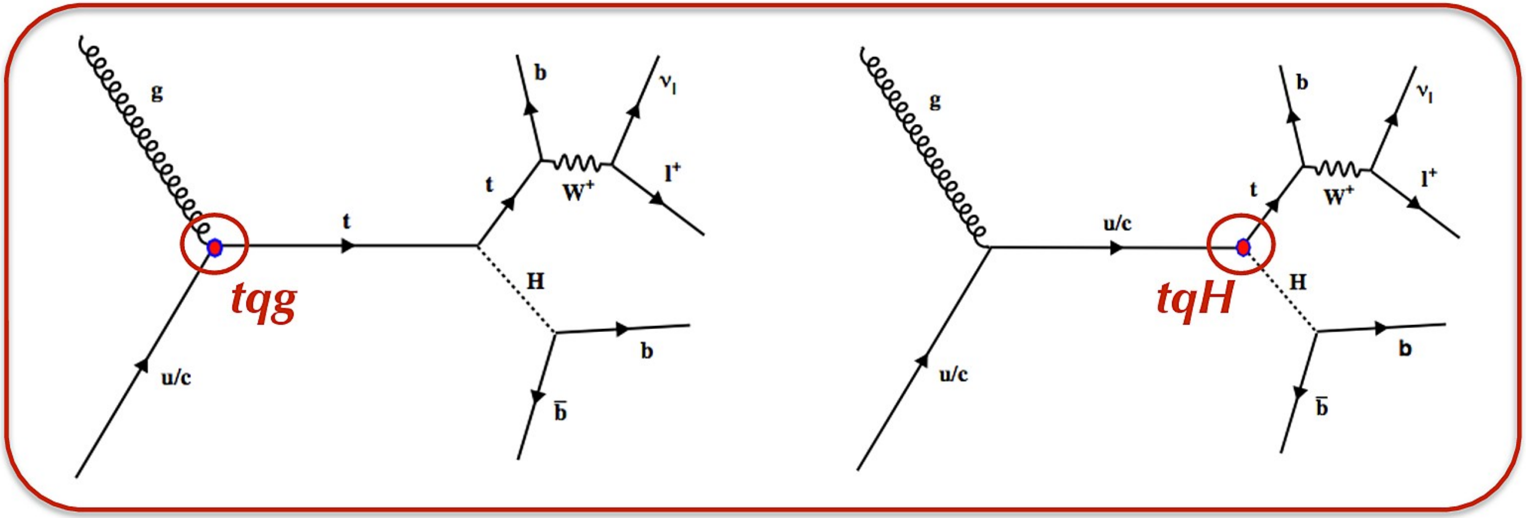
Search for tH FCNC at CMS: Analysis overview

Stage M2: "***Search for associated production of Higgs boson with single top via FCNC at CMS***"

Responsable de stage: Kirill.Skovpen@iphc.cnrs.fr

Phenomenology: http://arxiv.org/pdf/1402.3073v1.pdf



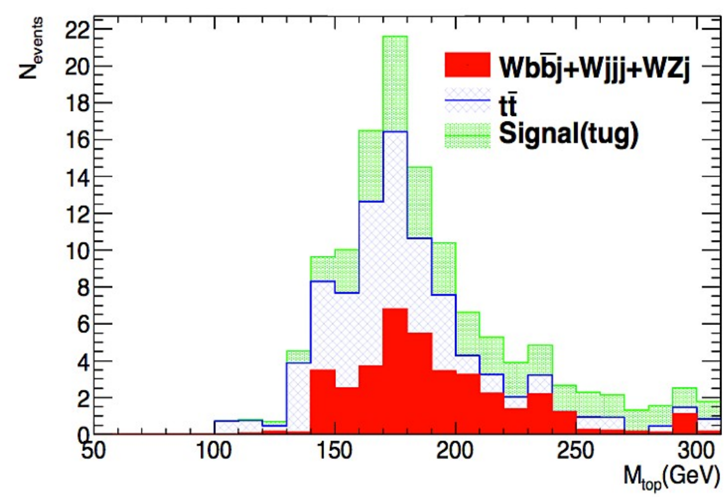
Several studies possible:

- tH(H→bb) (***proposed for the stage***)
- tH(H→WW)
- tH(H→ZZ)
- tH(H→$\tau\tau$)

Analysis motivation and overview:

- Processes of fermion flavor transitions with charge conservation (FCNC) are **forbidden** at tree level in the Standard Model (SM)
- The analysis aims at probing single top quark and Higgs boson production via tqg and tqH anomalous couplings
- Observation of such process would mean **the existence of new physics** beyond the SM !
- This process has not been yet looked for with experimental data at the LHC !

Expected distribution for top quark mass using Monte Carlo (MC) simulated events corresponding to 10/fb at 14 TeV at the LHC:



Search for tH FCNC at CMS: Description of stage

General information:

- The analysis focuses on MC study using events reconstructed in the CMS detector at 13 TeV
- The study of channel with tH(H→bb) is proposed for this stage
- The analysis will be carried out at IPHC in close collaboration with single top and Higgs analysis groups at CERN

Main tasks will include:

- Study of kinematic properties in generation of signal and background events
- Definition of baseline selection criteria
- Study of discrimination variables for background suppression

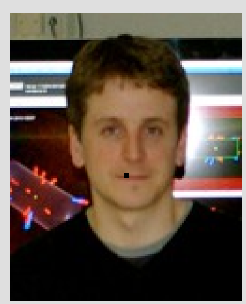
Tools to be used for analysis:

- CMS software based on C++ and python
- CERN ROOT toolkit
- MC event generation software
- Multivariate analysis techniques

Search for **stop** at CMS with M_T observable

SuperSymmetry and the **Higgs bosons**(s): The Next to Minimal Super Symmetric Model (N-MSSM)

Search for **tH** FCNC at CMS: Analysis overview



Performance study of **Boosted techniques** In MadAnalysis 5

Performances study of boosted techniques in MadAnalysis 5

People involved:
- Lorenzo Basso (ANR Postdoc)
- Jeremy Andrea (Chargé de Recherche)

Language: English

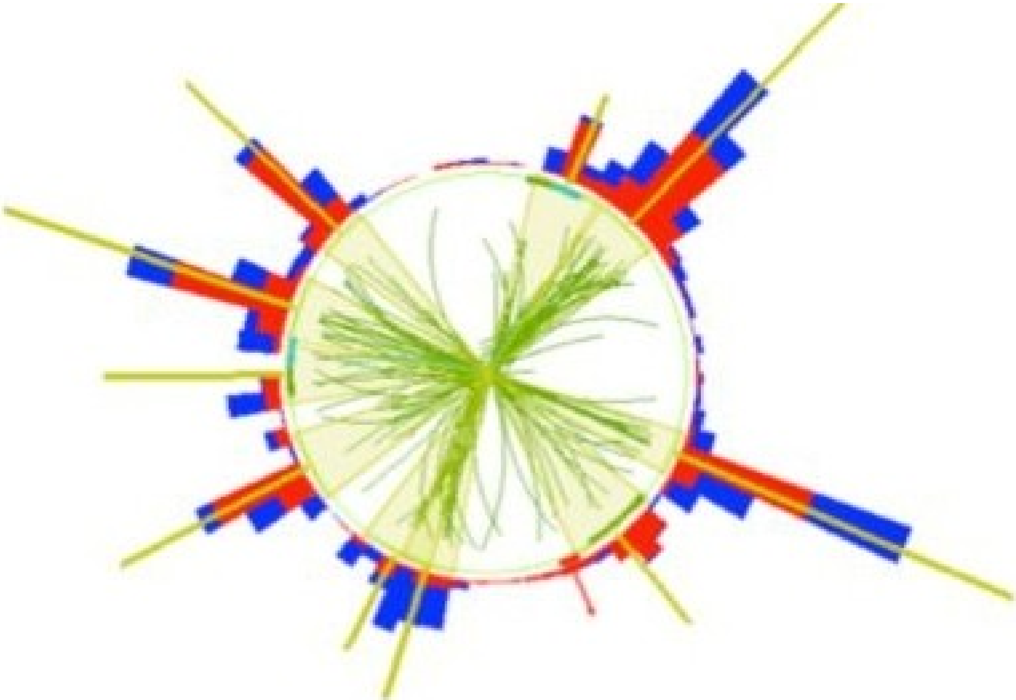
Skills: C++ programming

Not (necessarily) followed by Doctorate Thesis

How does a typical event at LHC look like: ...messy!

MadAnalysis 5 is a simplified tool to analyse *simulated* events.

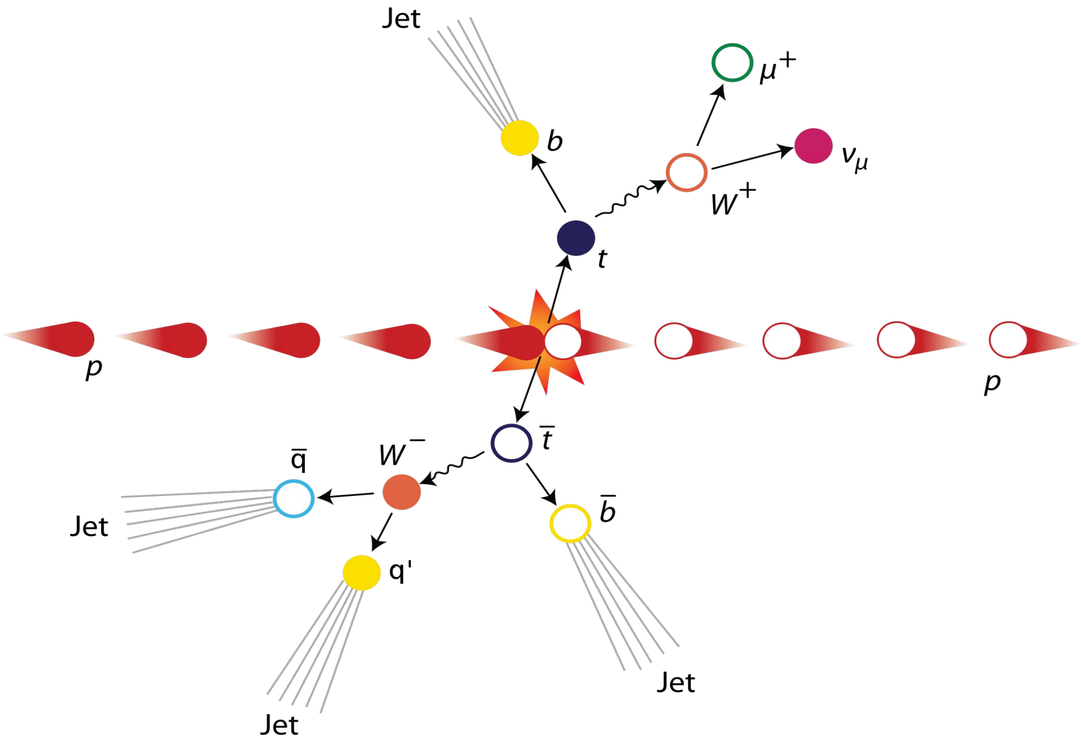
We run simulations to prepare real data analyses.



Example: top quark decay

Here are shown the typical top-quark decays channels:

- b-quark + 1 charged lepton and a neutrino
- b-quark + 2 other (light) quarks



What do we detect and how?

Charged leptons: easy and clean, they are seen as individual (isolated) objects

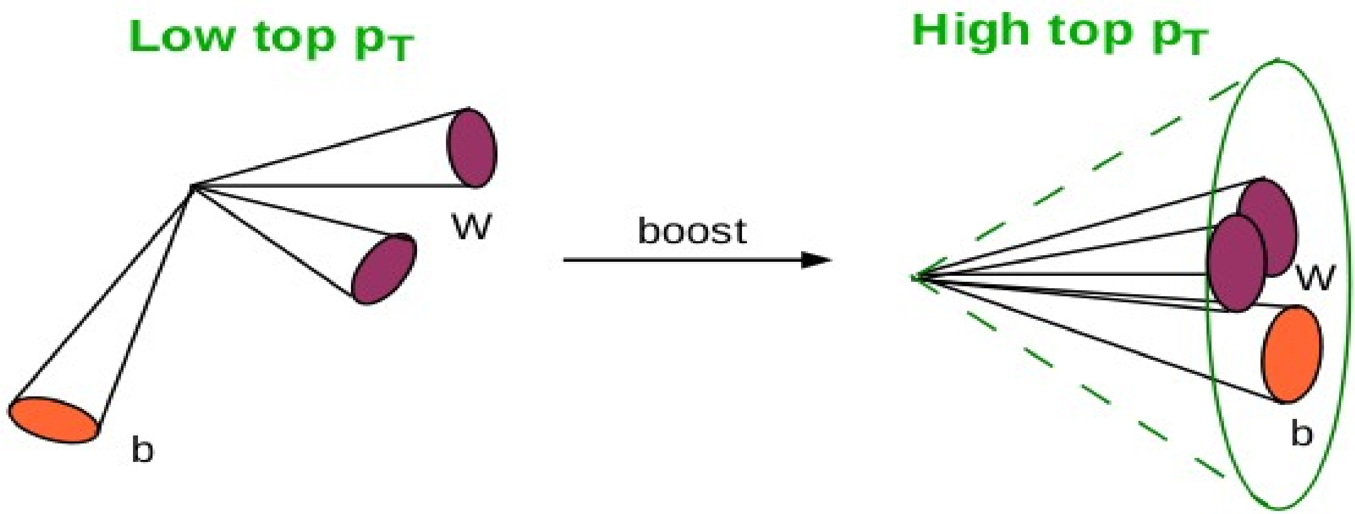
Neutrinos? No, we don't see them, but we know that they are there because something is missing (momentum has to be conserved)

(Light) quarks: they are never alone, what we see is a "spray" of objects, the **JETS!**

The classical analysis require all the above mention particles to be *isolated*, which means to appear as distincted/separated objects

Why "Boosted" ?

From 2015, LHC will increase its energy. We expect to produce new particles never seen so far → must be very heavy...
If they decay into tops, these will have a lot of energy → "boosted"!



- The kinematics (the way the event appear at the detector) is changed, now the decay products are too close to each other to be *seen* as different, even if they *are* different.

- Now the 3 independent pieces are not isolated, but form a "fat" jet.
- Recent (sophisticated) algorithms have been devised and proven to be effective to recognise the important pieces (substructures)
- These are the **BOOSTED TECHNIQUES** (ça va sans dire)

The M2 project

MadAnalysis 5 is a versatile platform to study simulated events.

Boosted techniques are getting more and more common.
They are developed by experts and exist in stand-alone packages.

The project consists in several steps:

- Understand the algorithms and how the work
- Study of the performances of the boosted algorithms (efficiency, rejection power)

  Physics case: application of the suitable routines to well-known cases

  Higgs → bb ("2-prong"), top → bjj ("3-prong")

  → compare to existing literature and optimisation of performances
- Comparison of the routines with respect to traditional algorithms
- Study of brand new signal ("4-prong"), new to the literature: a new heavy particle that decay into a top-quark and a b-quark, all merged into the same fat jet. Boosted algorithm may be the only way to probe its existence!