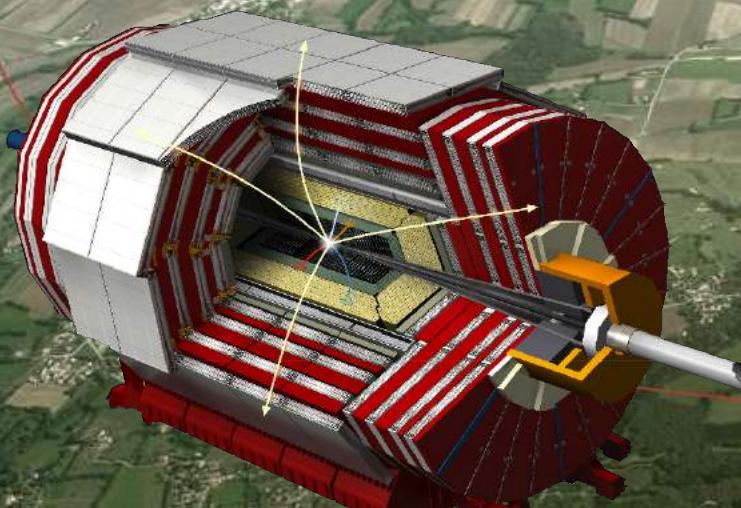


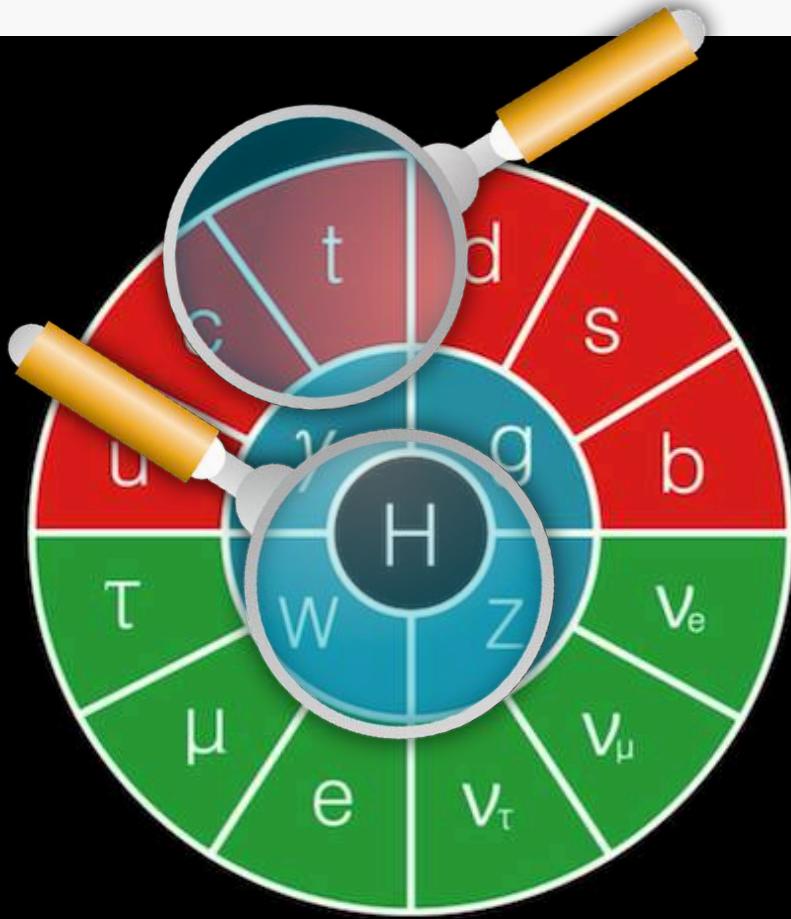
The CMS experiment

**Compact
Muon
Solenoid**



Most of the slides are extracted from the SHARE presentation given by X. Coubez

Standard Model



LHC is a unique tool to directly probe the EW sector, the EW symmetry breaking mechanism and study the heaviest quark (top physics) ...

<u>FERMIONS</u>		<u>BOSONS</u>	
MATTER		FORCE CARRIERS	
■ QUARKS		■ GAUGE BOSONS	
■ LEPTONS		□ HIGGS BOSON	

... and also search for new phenomena !!!

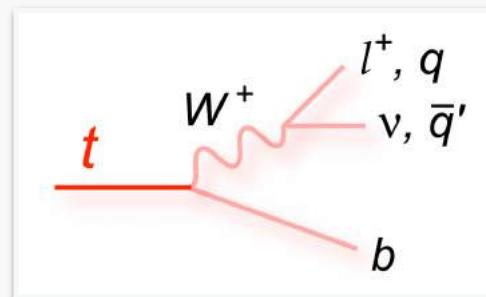
PARTICLES OF THE STANDARD MODEL

Top and Higgs physics

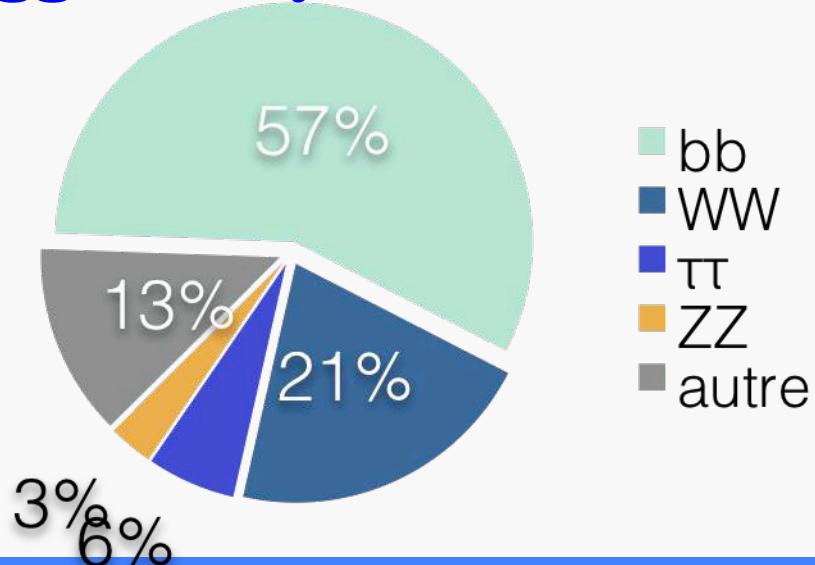
Top quark

- Heaviest particle
- Decay before hadronizing

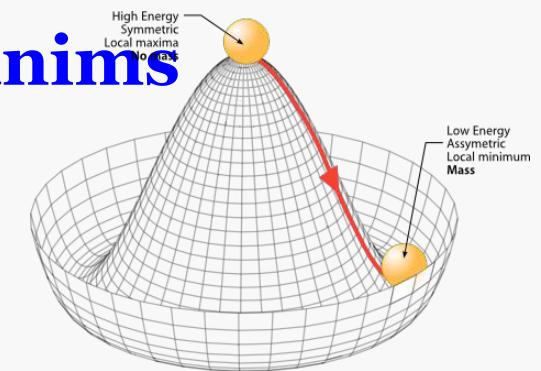
top : 173.3 GeV
W: 80.4 GeV
(Z: 91.2 GeV)
b: 4.2 GeV



Higgs decays (125 GeV)

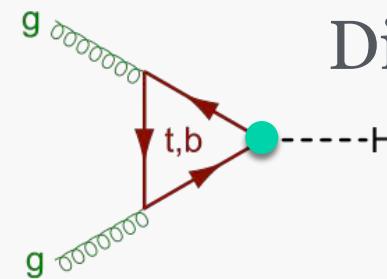


Higgs mechanisms



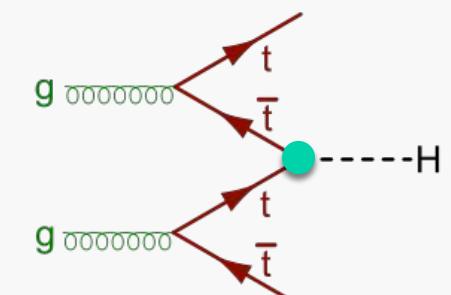
Theory in 1964
Discovery in 2012
EW symmetry breaking
mechanism

Yukawa coupling: top-Higgs

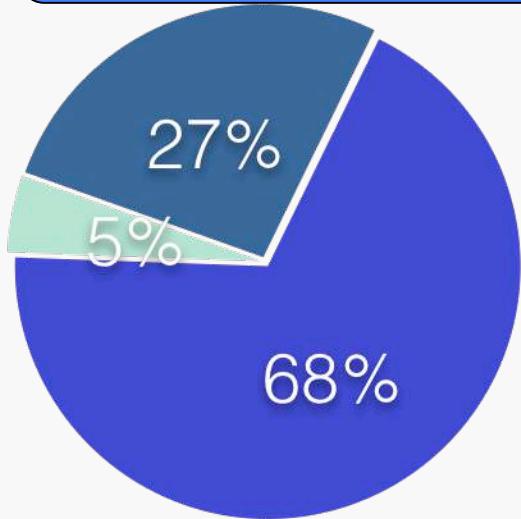


Direct measurement

Indirect measurement



Beyond the Standard Model



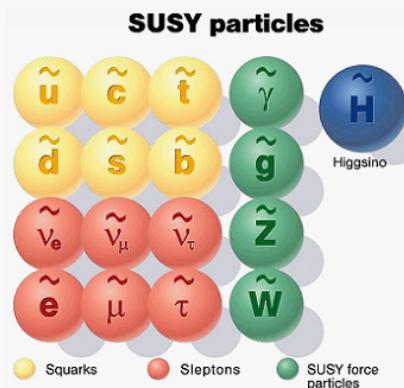
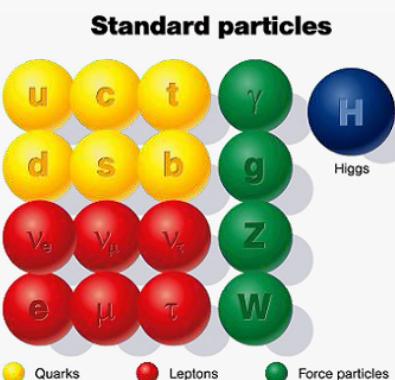
- Ordinary Matter
- Dark Matter
- Dark Energy

Experimental problems

Neutrino masses
Dark matter & energy
Matter/anti-matter asymmetry
...

Theoretical problems

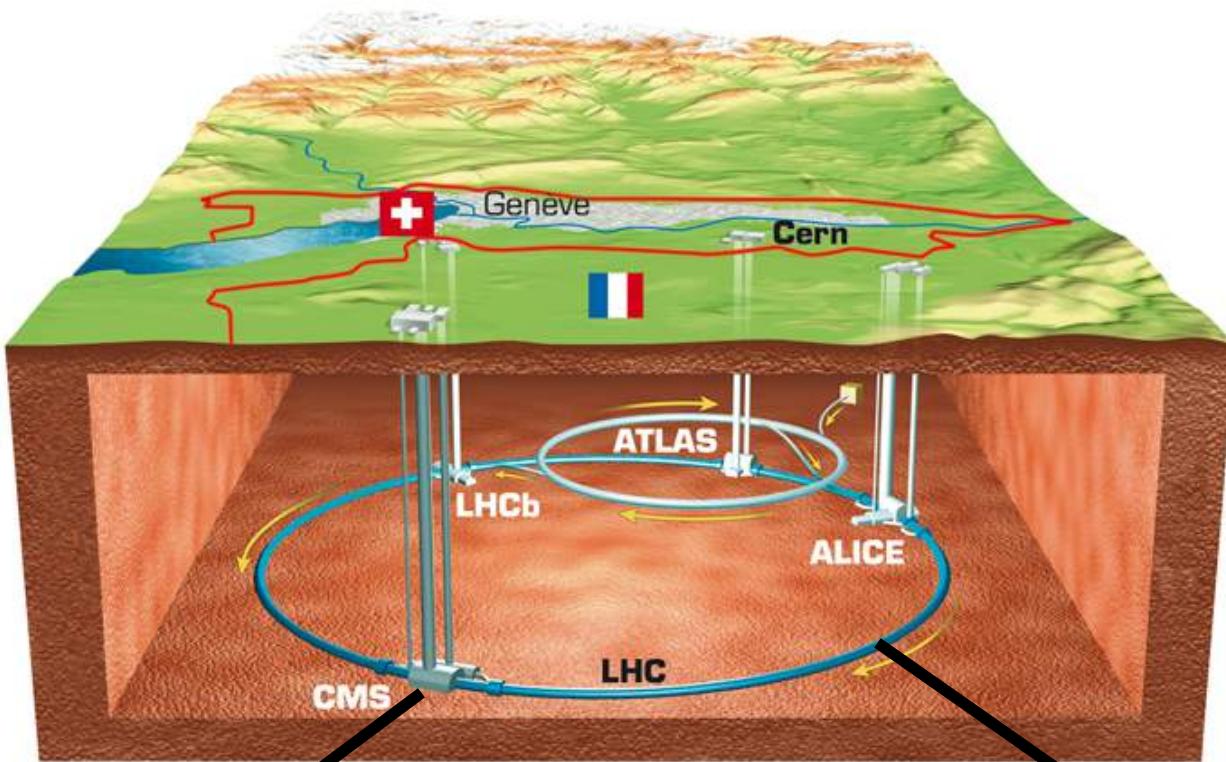
Origin of Higgs potential, hierarchy problem
Unification of the interactions (GUT)
Scales of particle masses ...



Beyond the standard models

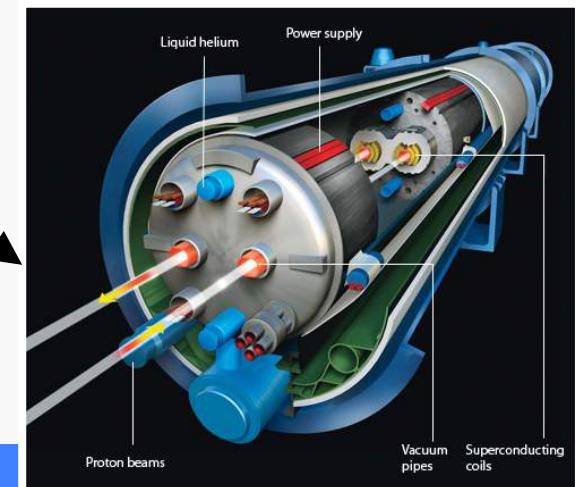
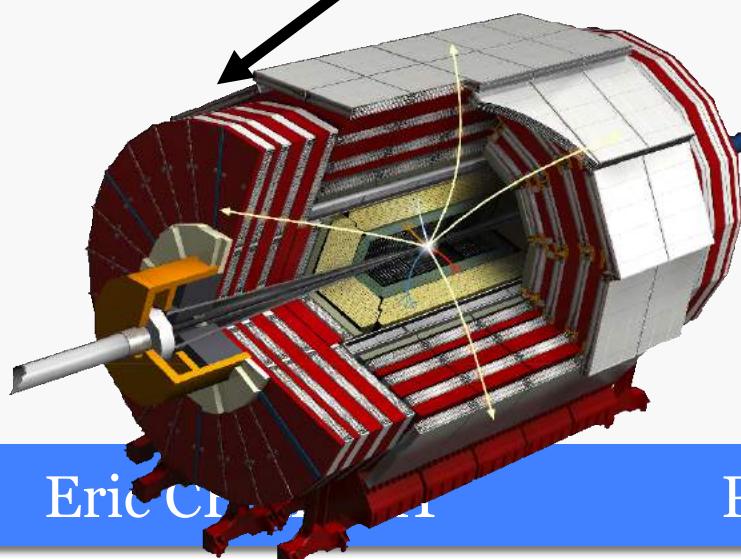
Supersymmetry
Extra-dimensions
Compositeness
Leptoquarks
...

Large Hadron Collider



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

High energy frontier



Large Hadron Collider

Run I 2009-2012

7 - 8 TeV

~ 25 fb^{-1} (recorded by CMS)

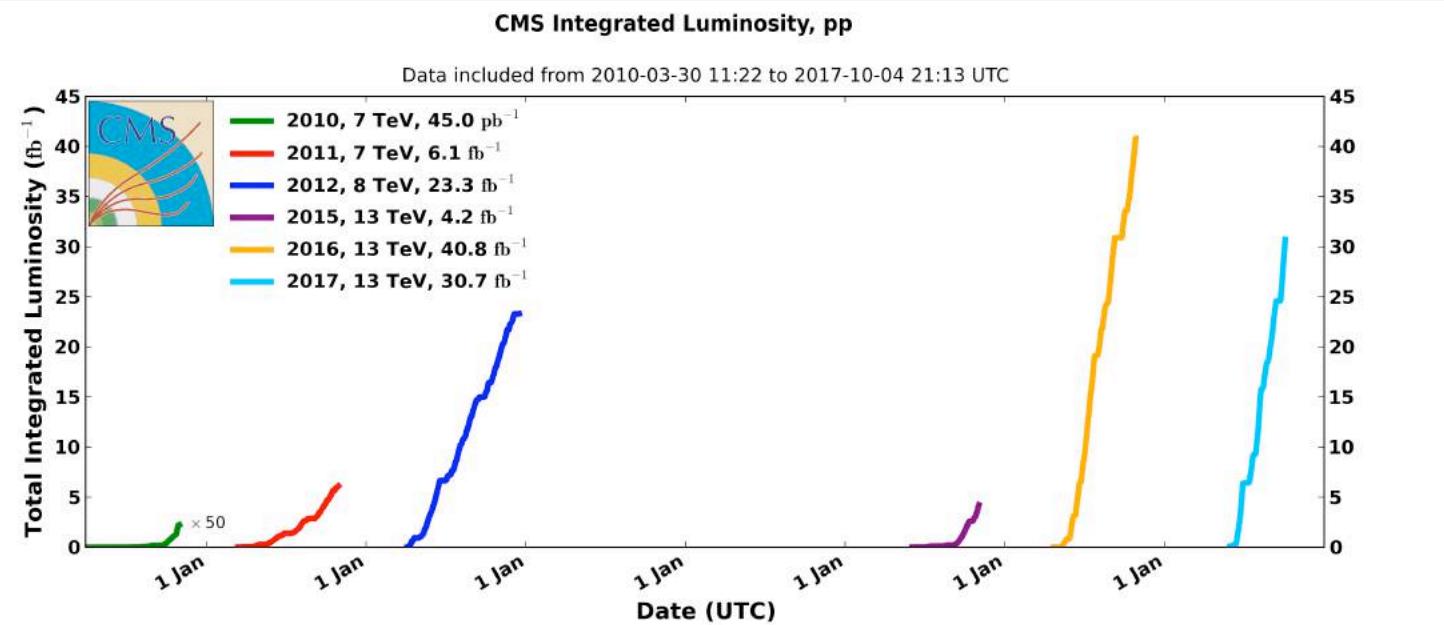
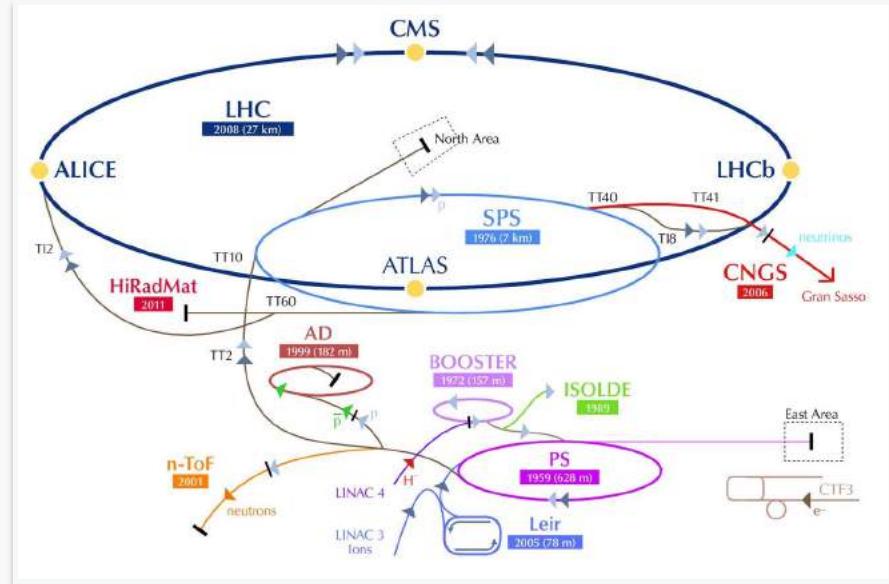
⚠ Discovery of Higgs boson

Run II 2015-2018 (ongoing)

13 TeV

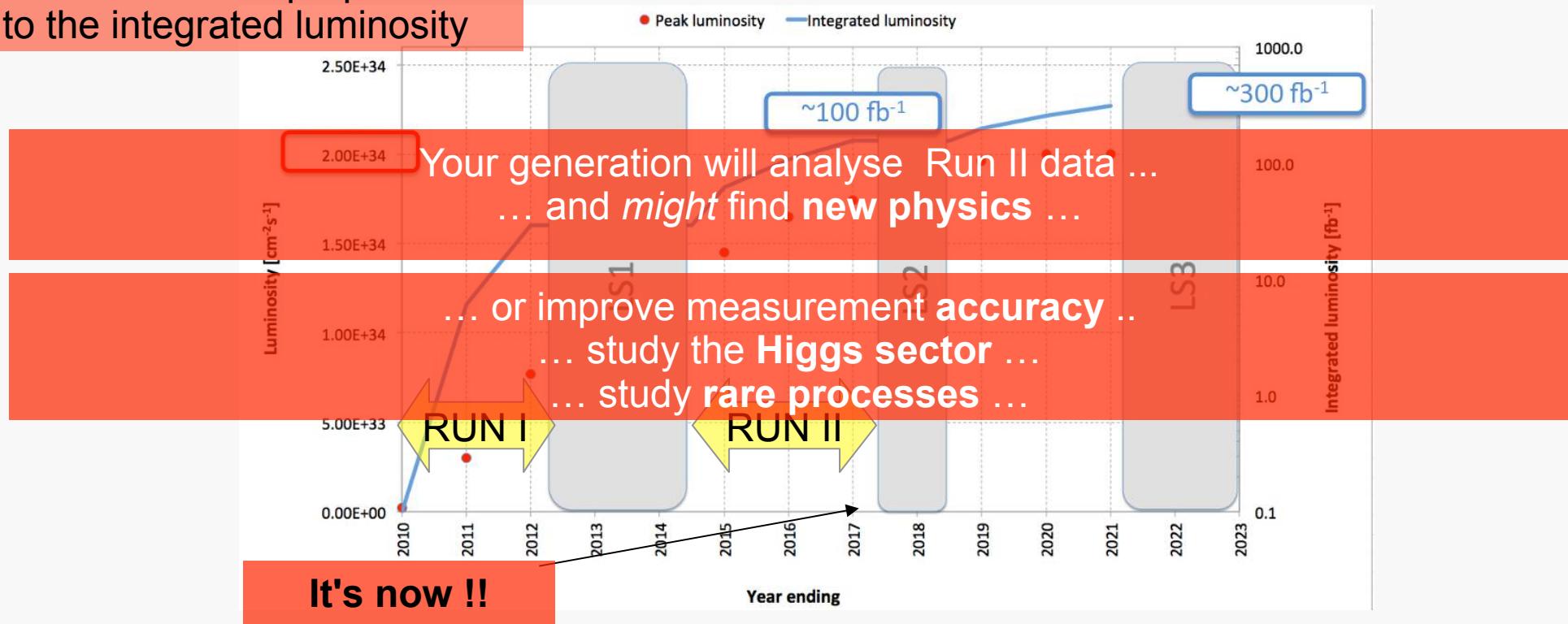
~ 70 fb^{-1} (recorded by CMS)

Discovery of ... ?



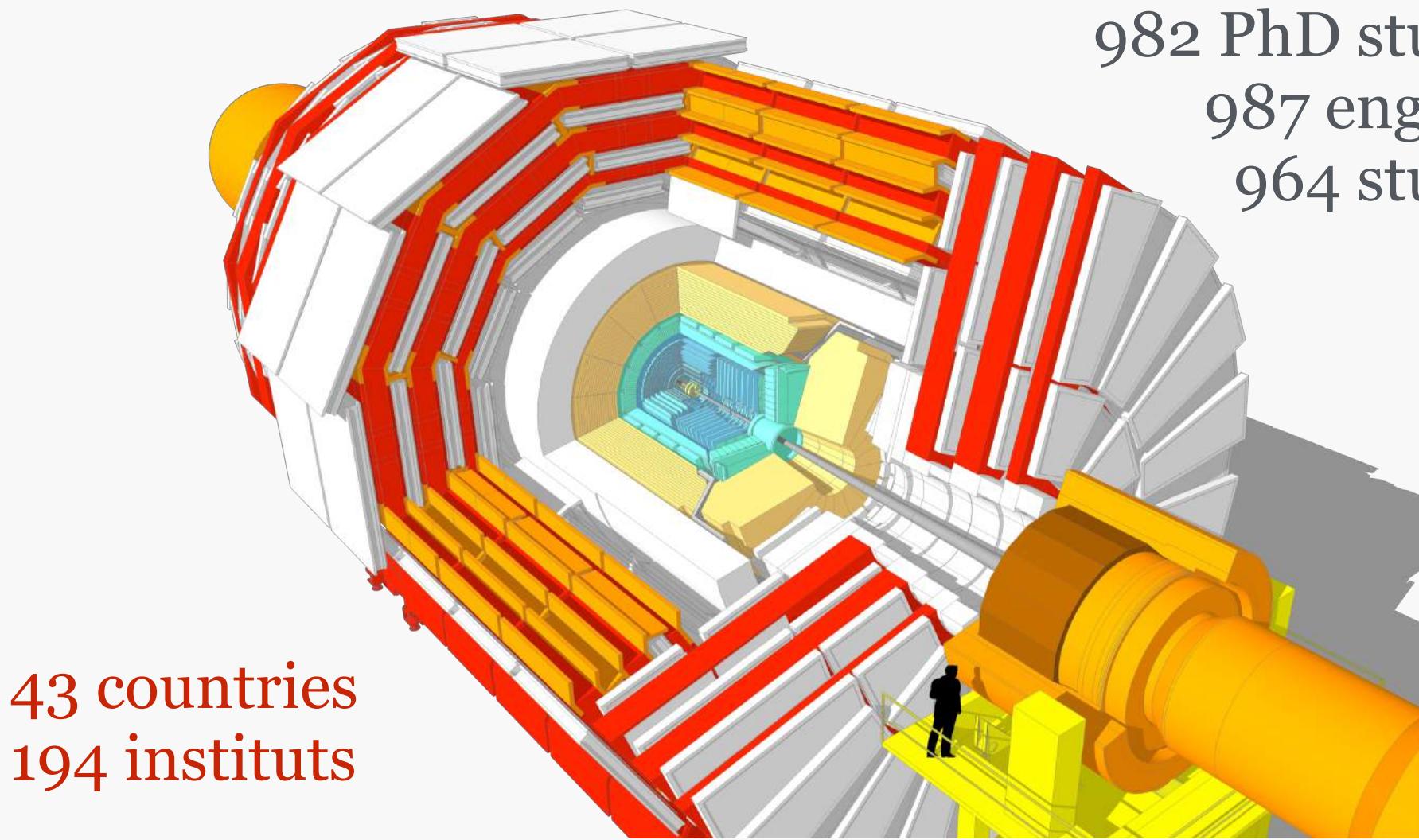
Run II: new data to analyze ...

Number of events proportional
to the integrated luminosity



and the future to be prepared ...

CMS Collaboration



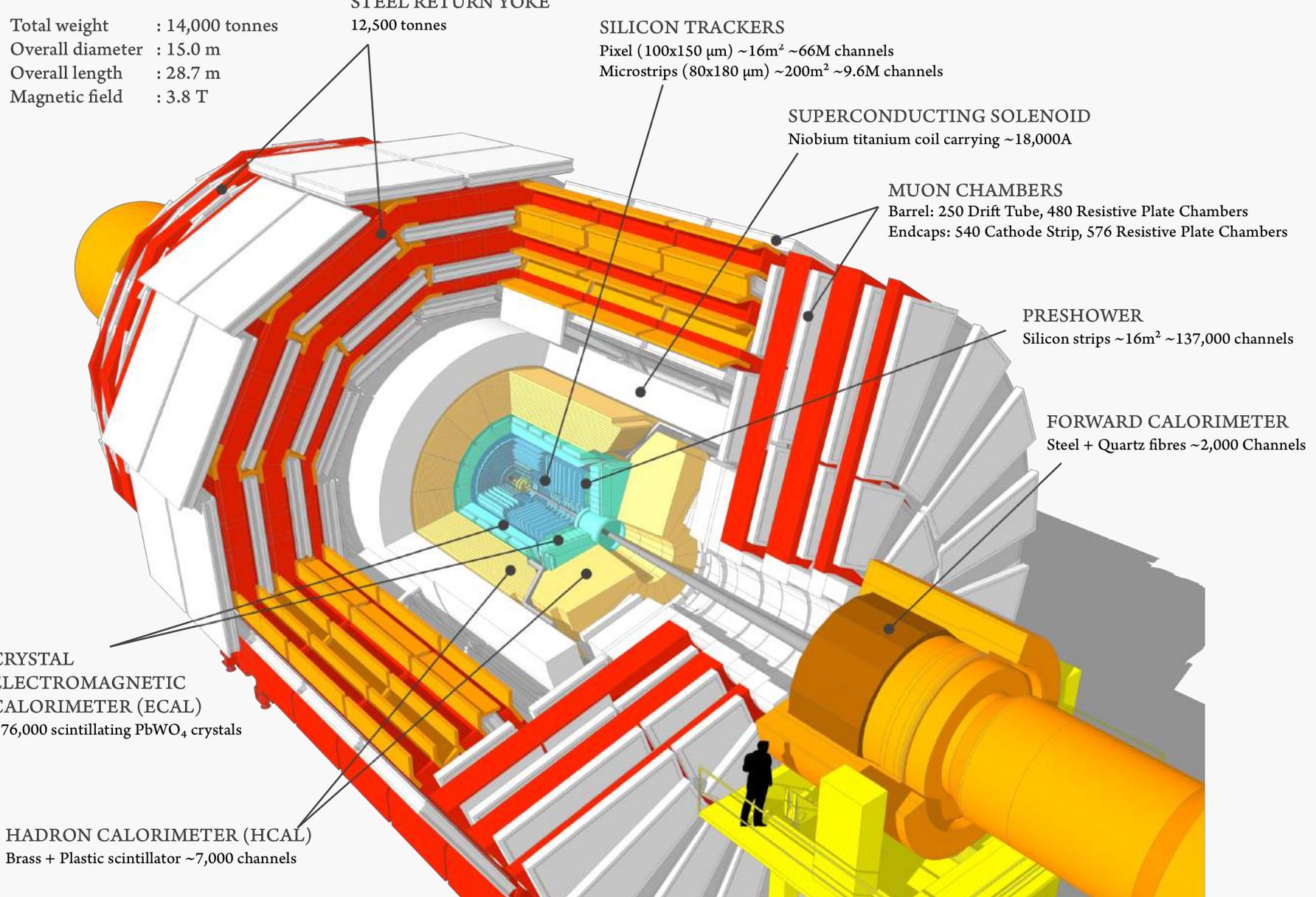
43 countries
194 instituts

4800 collaborators:
1956 physicists
982 PhD students
987 engineers
964 students

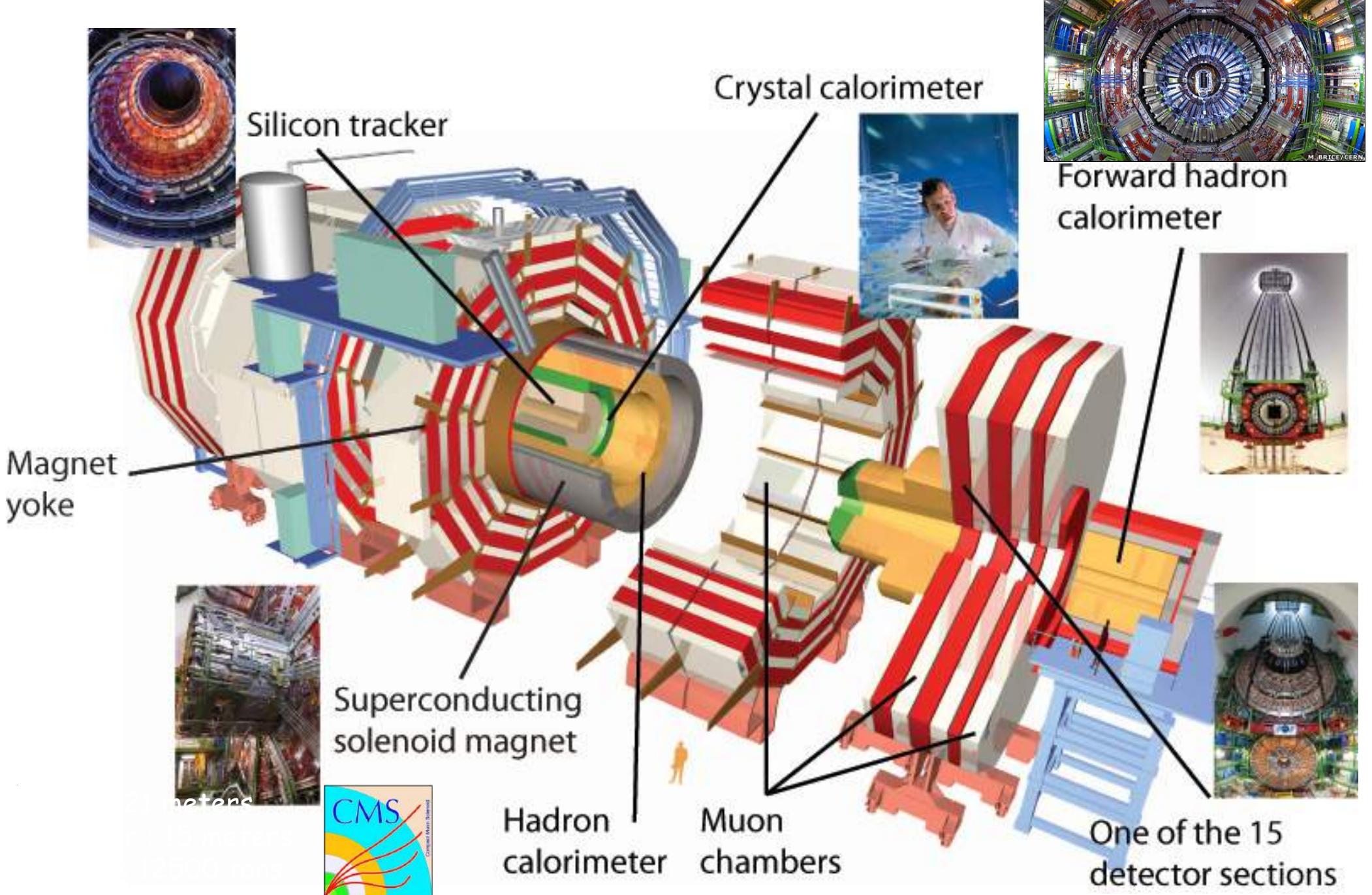
CMS detector

CMS DETECTOR

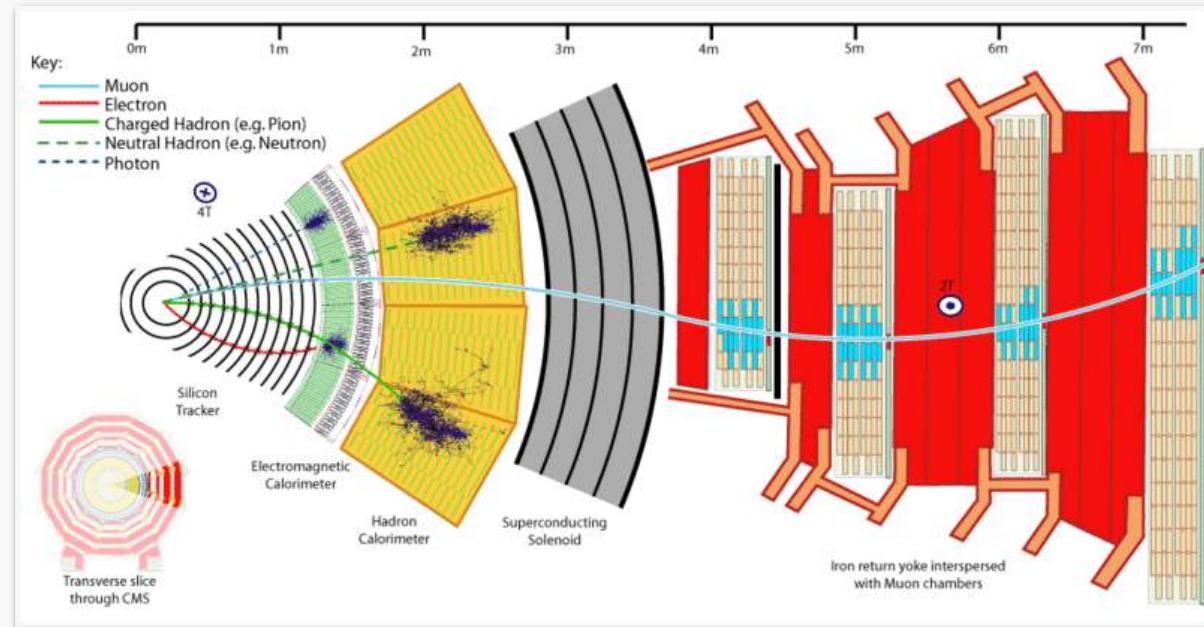
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T



CMS detector

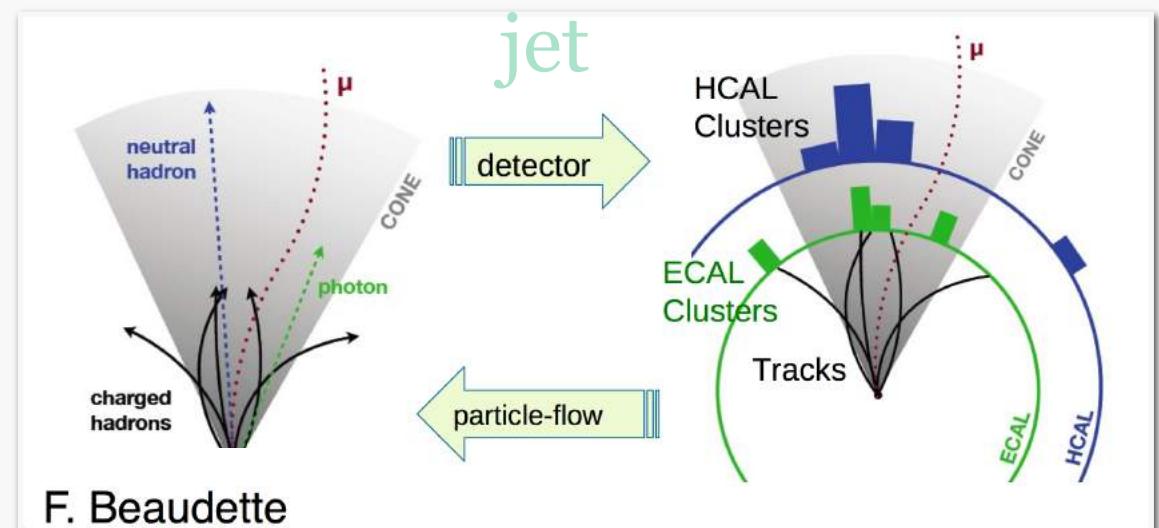


From detection to particle reconstruction

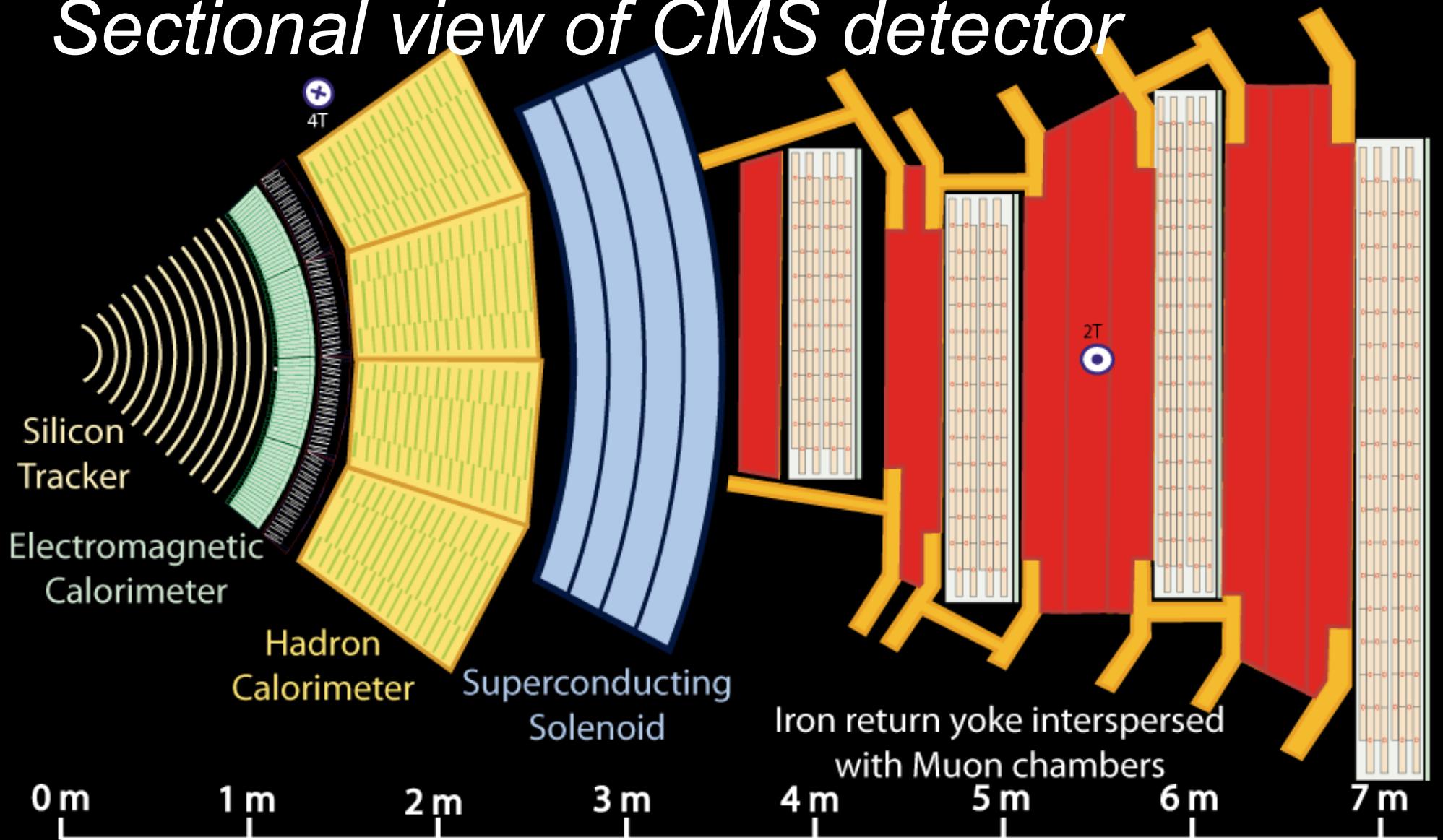


Particle reconstruction

- tracking
- calorimetry
- Particle flow
- Transverse missing *energy*



Sectional view of CMS detector



Key:

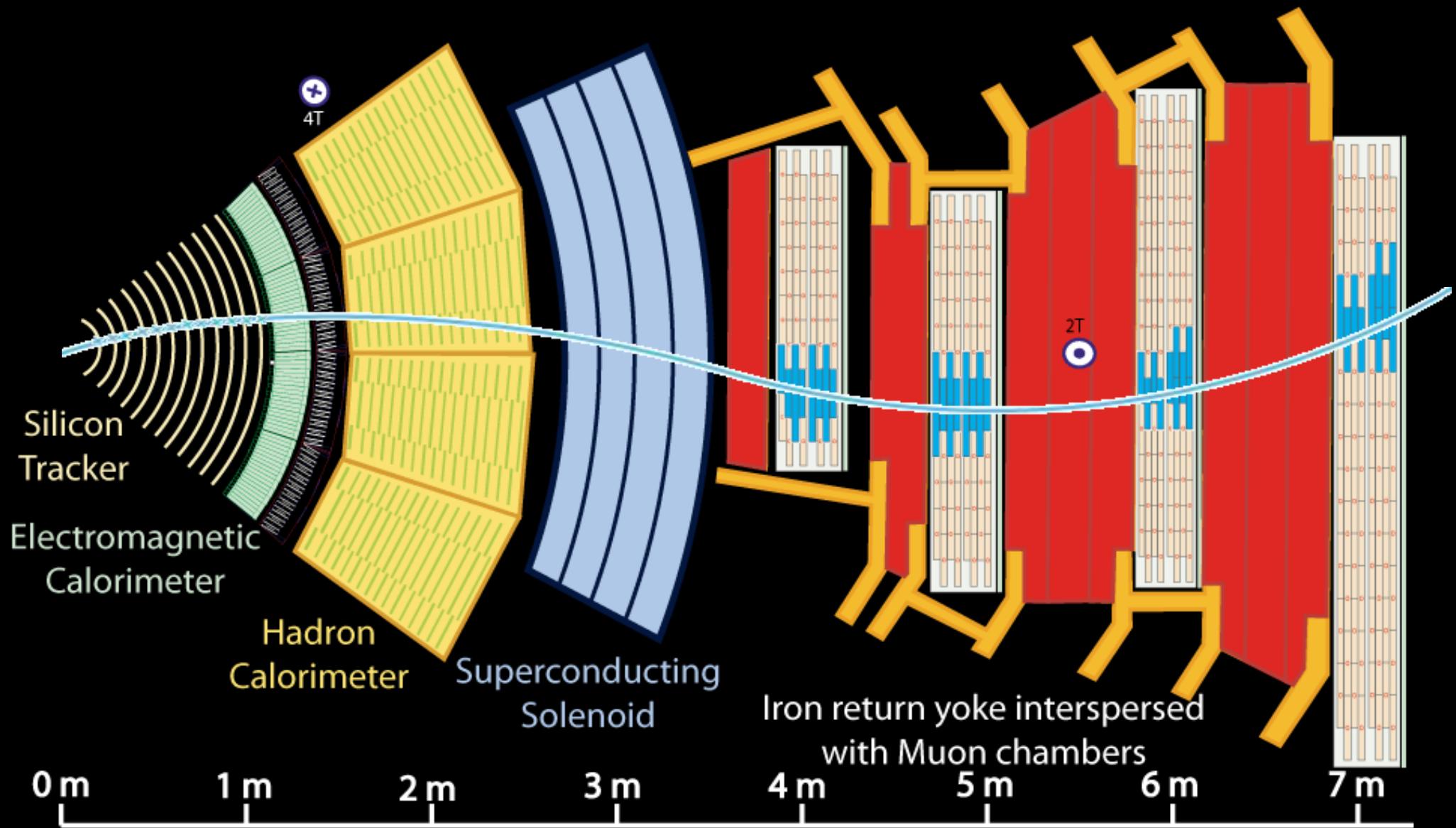
— Muon

— Electron

— Charged Hadron (e.g. Pion)

- - - Neutral Hadron (e.g. Neutron)

----- Photon



Key:

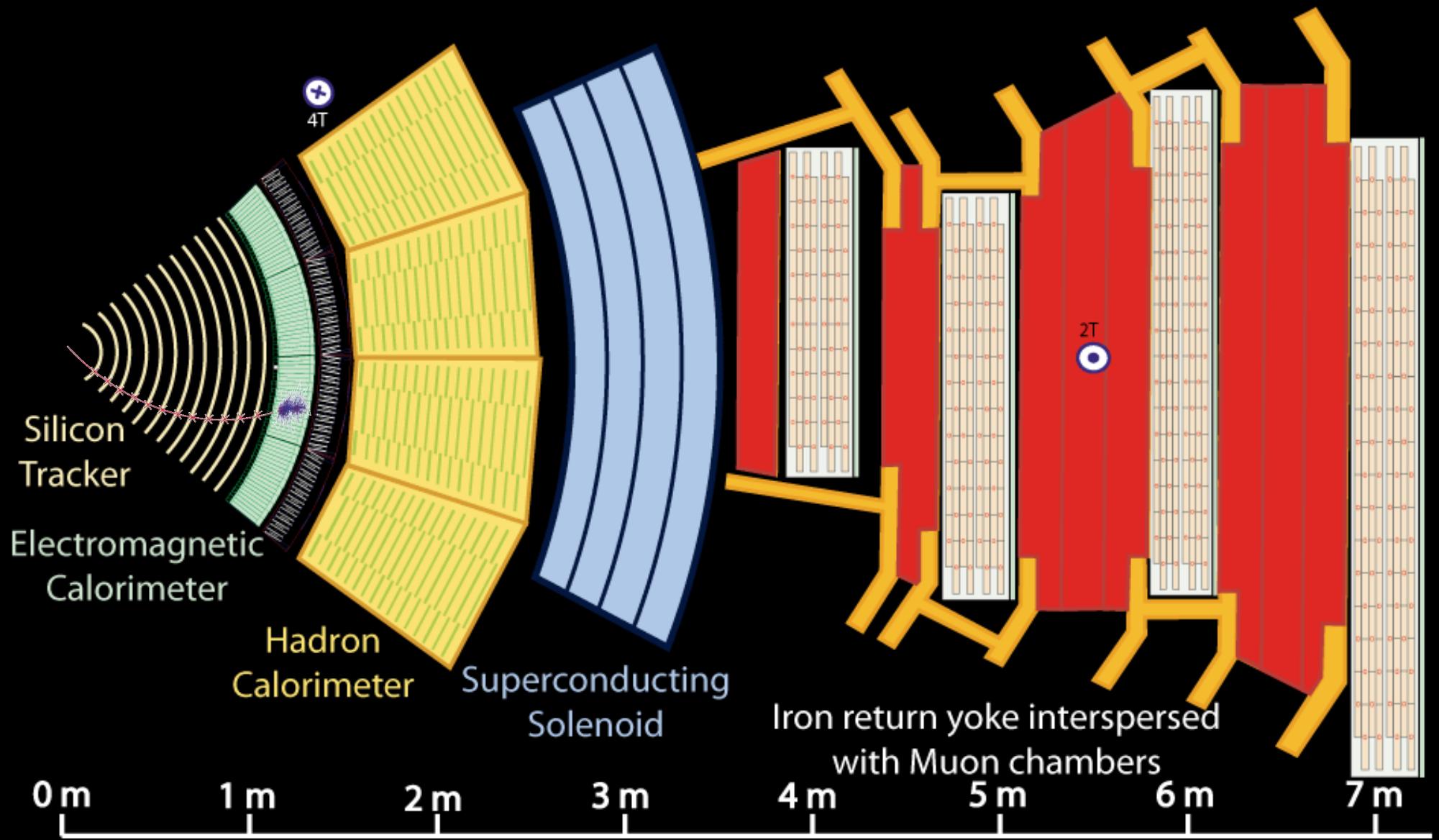
Muon

Electron

Charged Hadron (e.g. Pion)

Neutral Hadron (e.g. Neutron)

Photon



Key:

— Muon

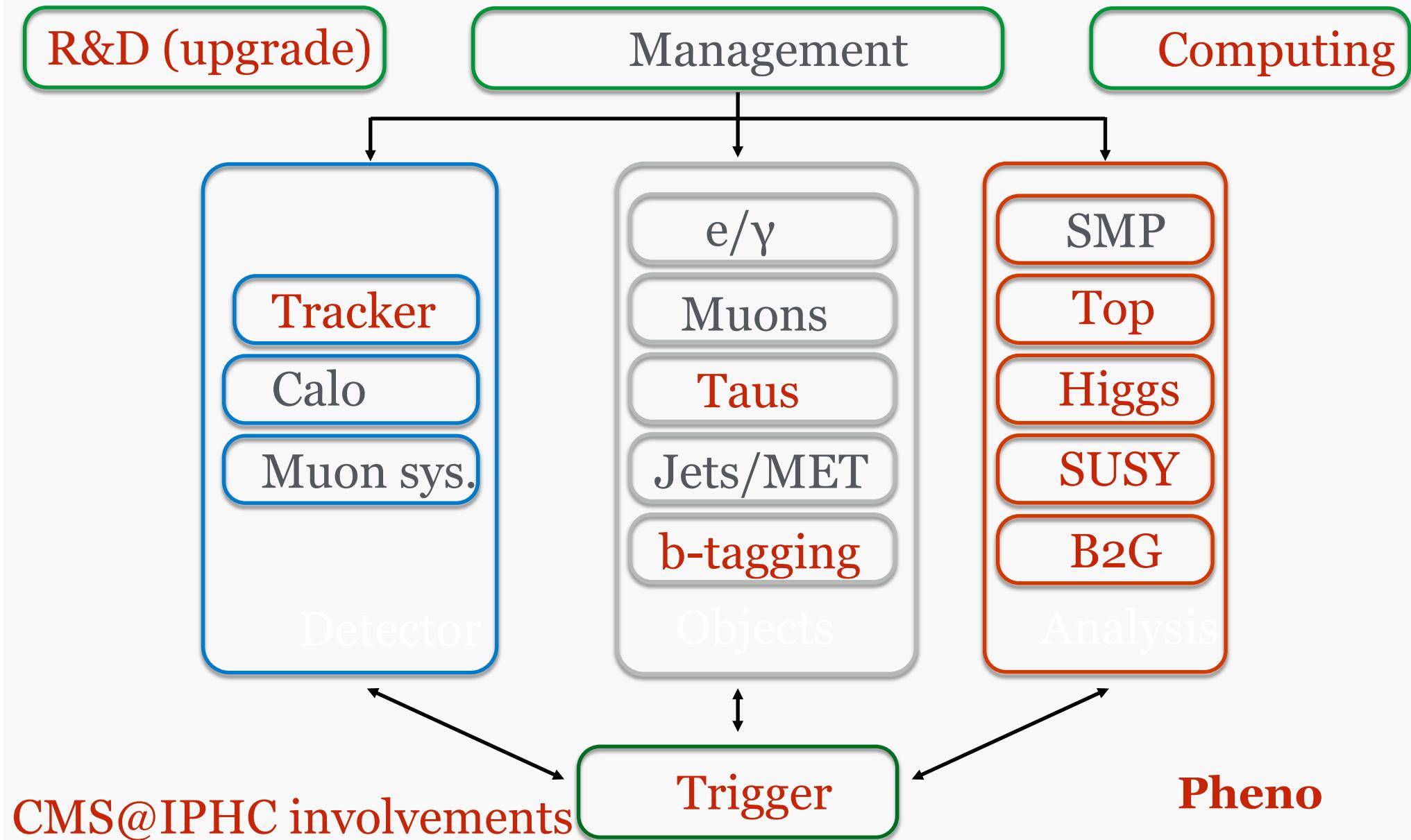
— Electron

— Charged Hadron (e.g. Pion)

- - - Neutral Hadron (e.g. Neutron)

----- Photon

CMS organigram and interplay btw groups



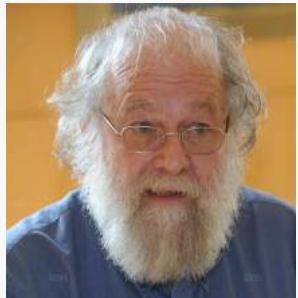
CMS team @IPHC



Daniel Bloch



Caroline Collard



Jean-Marie Brom



Pierre Van Hove



Denis Gelé



Jeremy Andrea



Anne-Catherine Lebihan



Eric Chabert



Ulrich Goerlach



Jean-Charles Fontaine



Jean-Laurent Agram



Jean-Eric Conte



Vladimir Cherepanov



Guillaume Bourgatte



Marketa Jansona



Nicolas Tonon

Upgrade DAQ Gross, Ltracker CMS

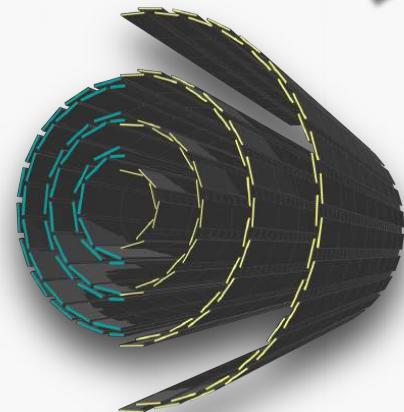
Laurent aurent Charles, Christian Bonnin, Jérôme Hosselet, Damien Tromson

Grille de calcul (et cloud) IPHC

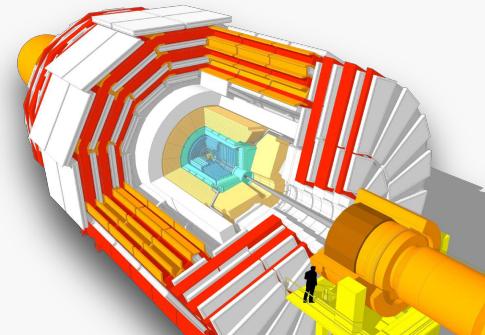
Yannick Patois, Jérôme Pansanel, Eric Kieffer, Emmanuel Medernach, Nicolas Rudolf, Christoph Helfer, Sébastien Geiger, Vincent Legoll

12 physicists, 1 Post-doc, 3 PhD students

upgrades



detector

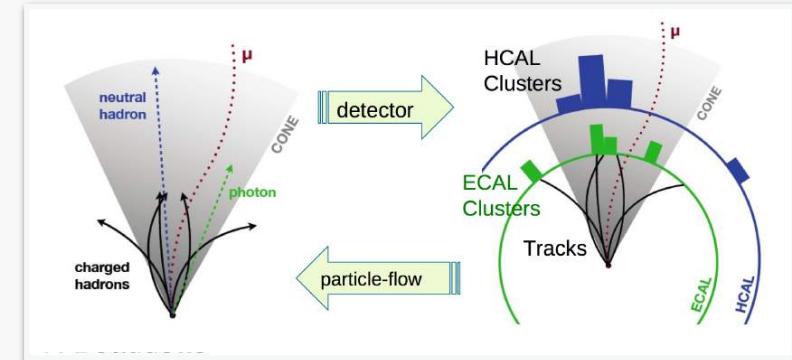
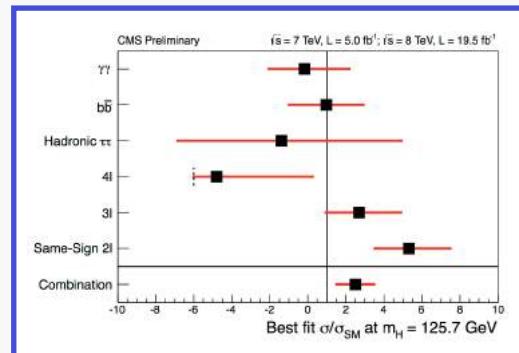


Data taking



Pheno
Analyses

reconstruction



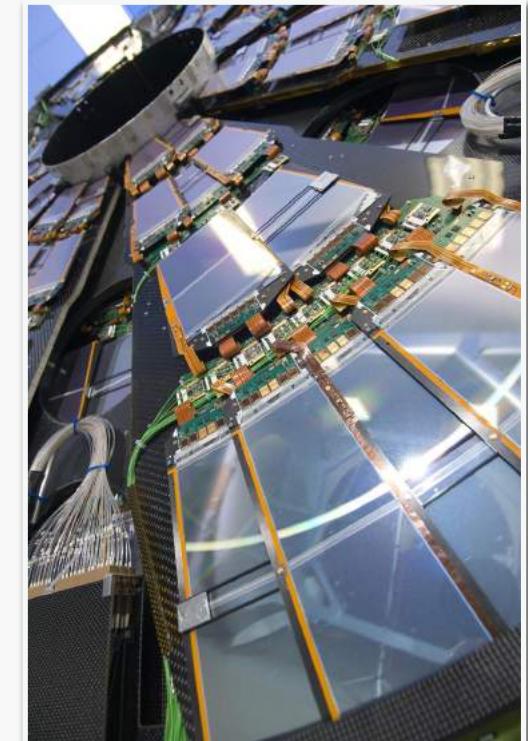
Tracker

Historical involvement of IPHC

→ participation to the construction

- Data-taking (shifts)
- Study of performances and monitoring
 - Efficiency
 - Ageing studies

Responsibility for local reco & calibration
of the strip tracker

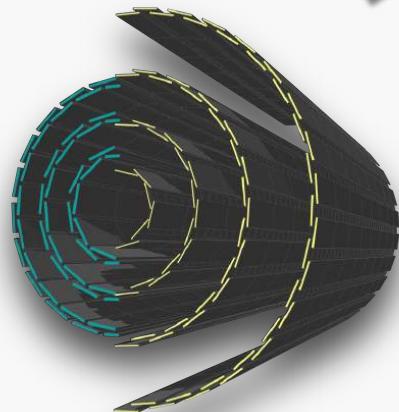


Participation to the upgrades



detector

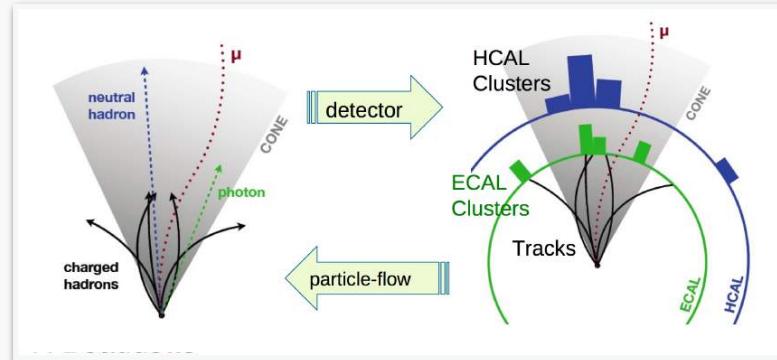
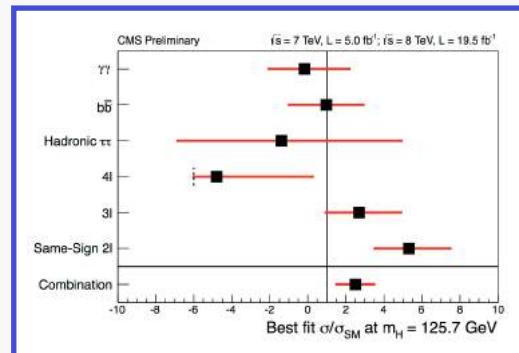
upgrades



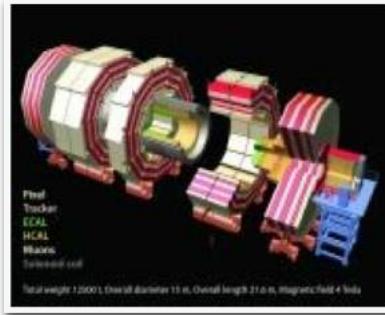
Pheno
Analyses



reconstruction



Trigger system



L1 \downarrow 40 MHz



HLT \downarrow 100 kHz



\downarrow 1 kHz

hardware

software

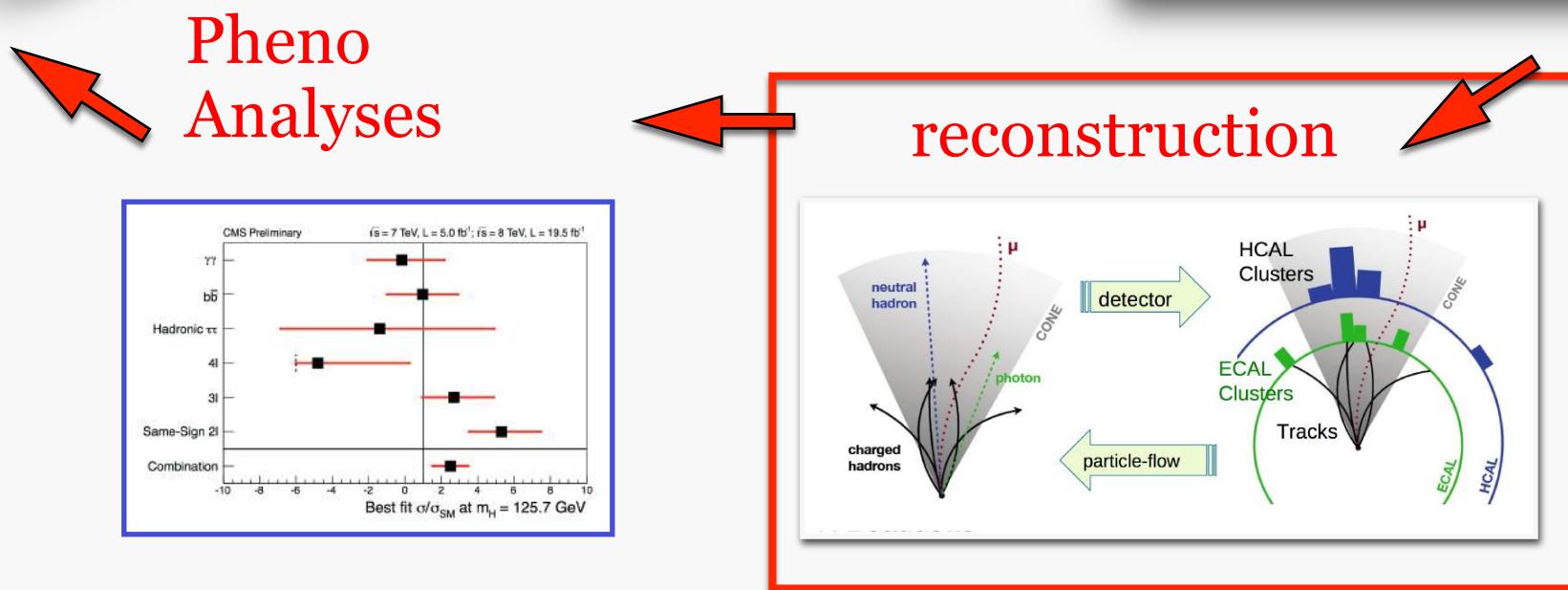
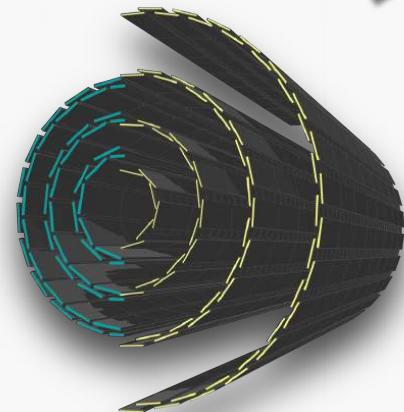
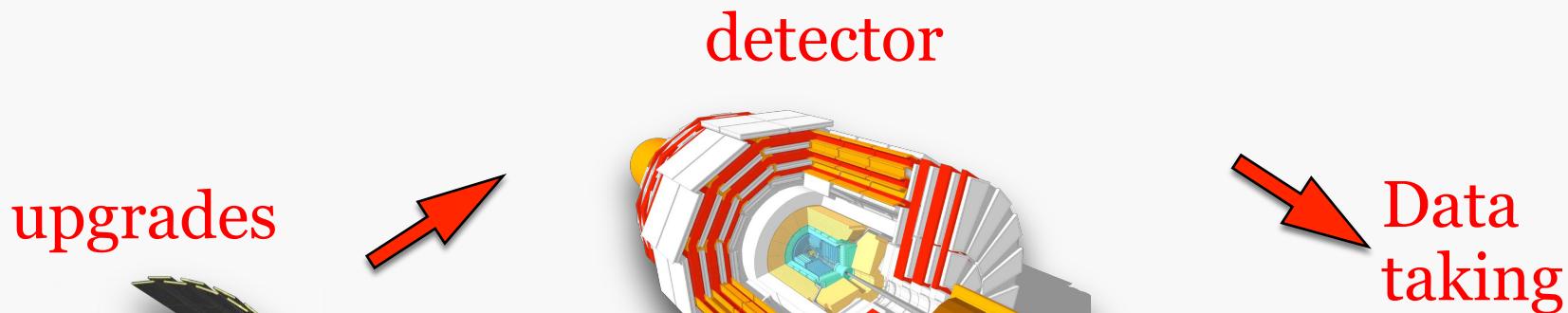


Goal:

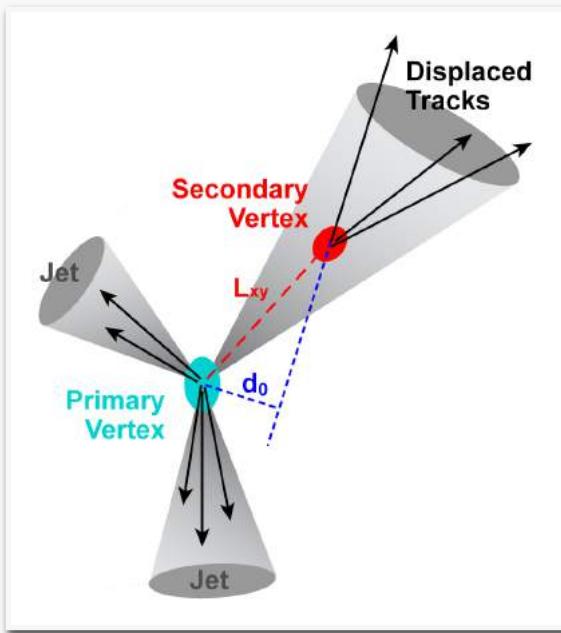
Select the 1000 most interesting events among 40 000 000 produced during collisions

Involvement @ IPHC:

Work on b-tagging algorithms working @ HLT

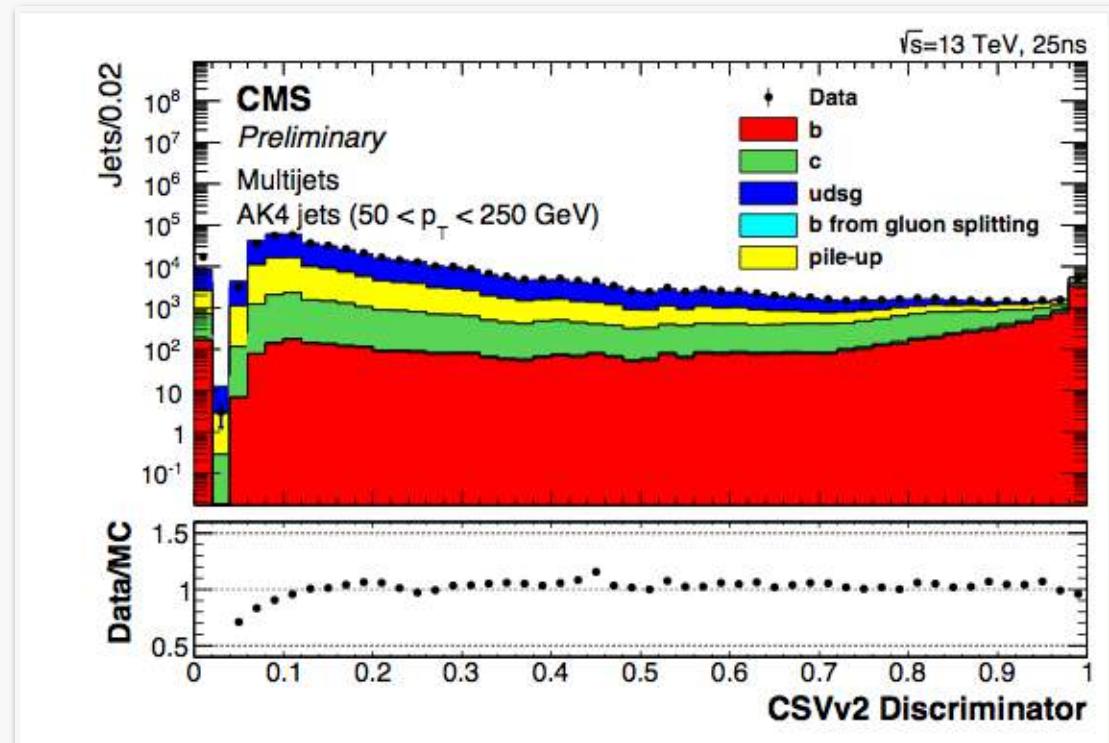


B-tagging



Properties of b-jets

- High mass (5 GeV)
- Long lifetime(1.5 ps)
- High γ_{CT} (qq mm)
- High track multiplicity (~5)
- Possible leptonic decays ($b \rightarrow \mu X$ 20%)



Expertise of IPHC

- B-tagging @ HLC
- Commissioning
- Calibration of discriminant
- Performance measurements
- Preparation for upgrade

Tau-id

Decay mode	Meson resonance	$\mathcal{B} [\%]$
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \rightarrow h^- \nu_\tau$		11.5
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		3.2
All modes containing hadrons		64.8

sine die

Reconstruction of hadronic tau decays

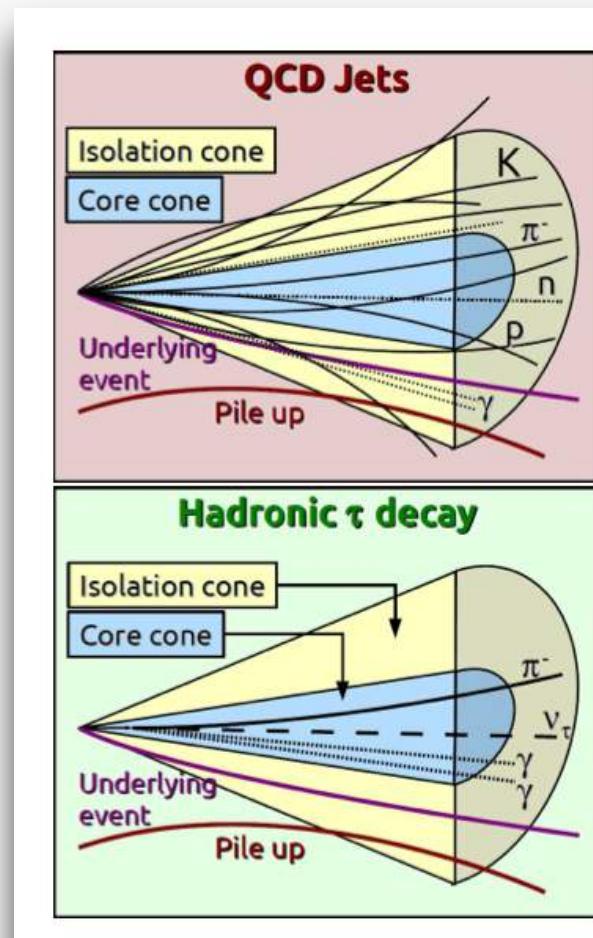
- Low track multiplicity
- Reconstruction of intermediate resonances

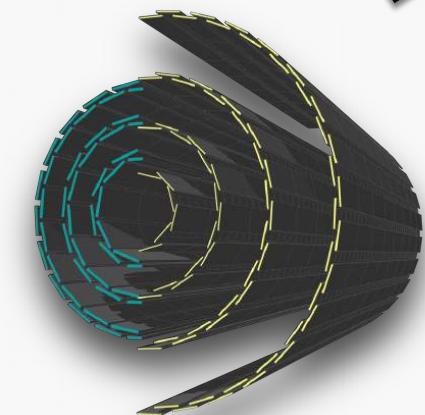
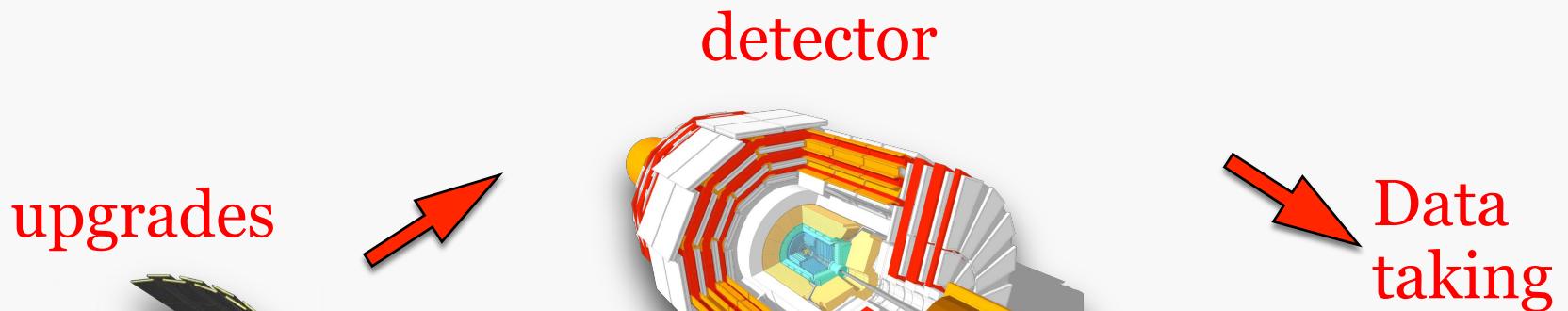
Expertise of IPHC

- Discrimination against anti-electrons
- polarization

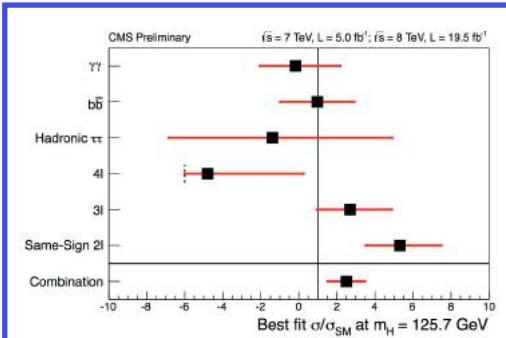
Properties of taus

- Heaviest lepton (1.7 GeV)
- Mainly decays in hadrons

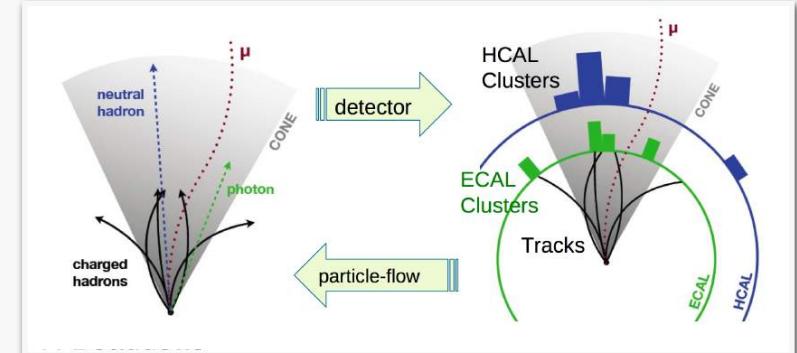




Pheno Analyses



reconstruction



Physics analyses @ IPHC



top quark

- Top pair cross-section
- b-tagging efficiency measurement using $t\bar{t}$
- Study of tZq processes



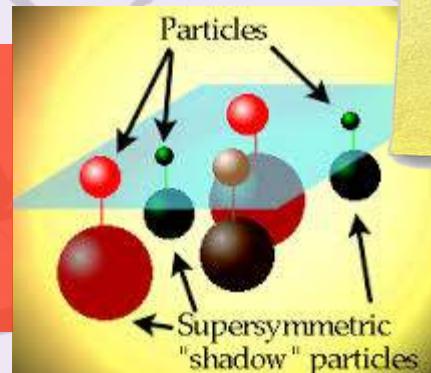
Higgs boson

- In $t\bar{t}$ spin polarization
- Single top FCNC
- Search for monotop (top+ invisible)

- Search for $t\bar{t}H$
- CPV in $H \rightarrow \tau\tau$

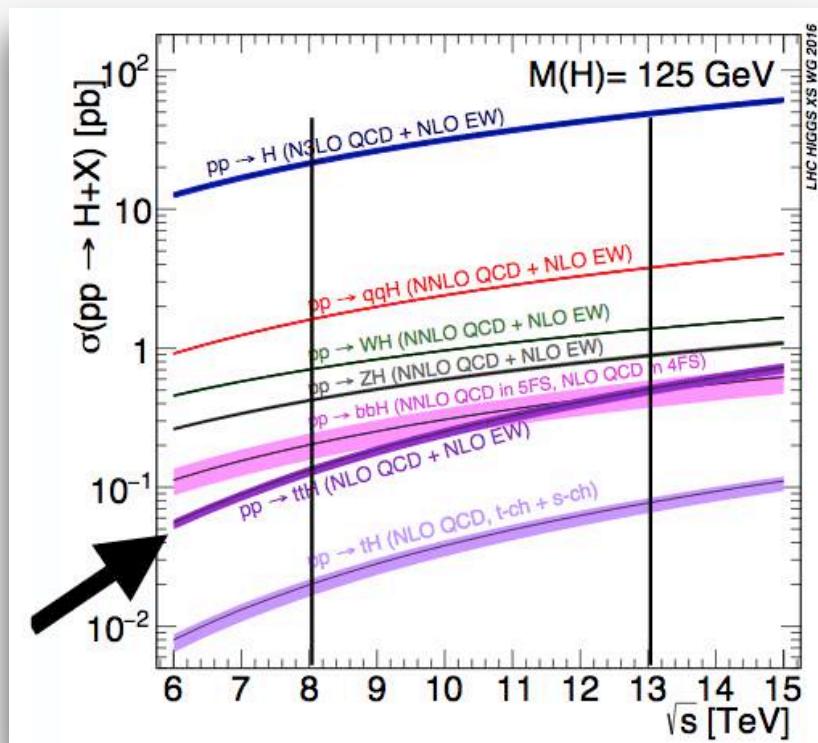
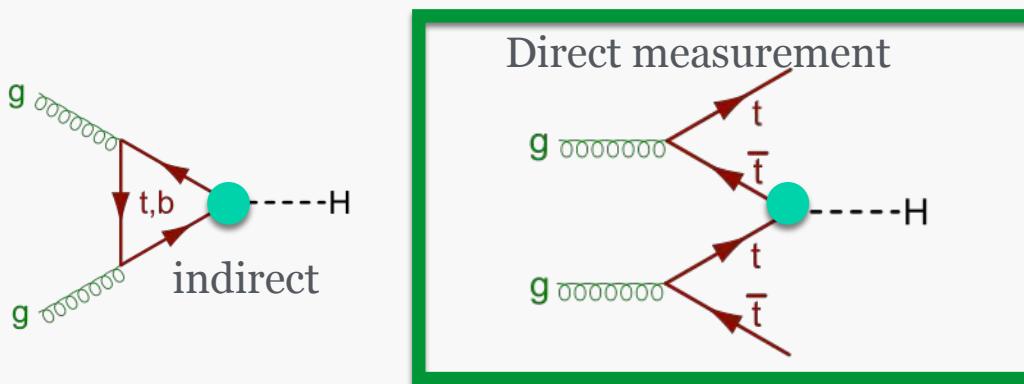
Beyond the Standard Model

Supersymmetry

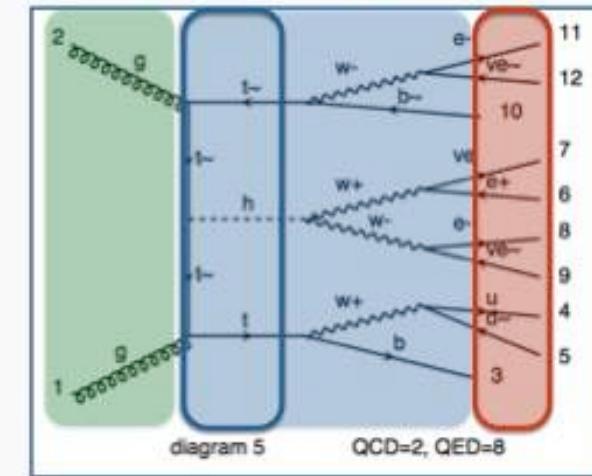


- Search for stop/sbottom pair production

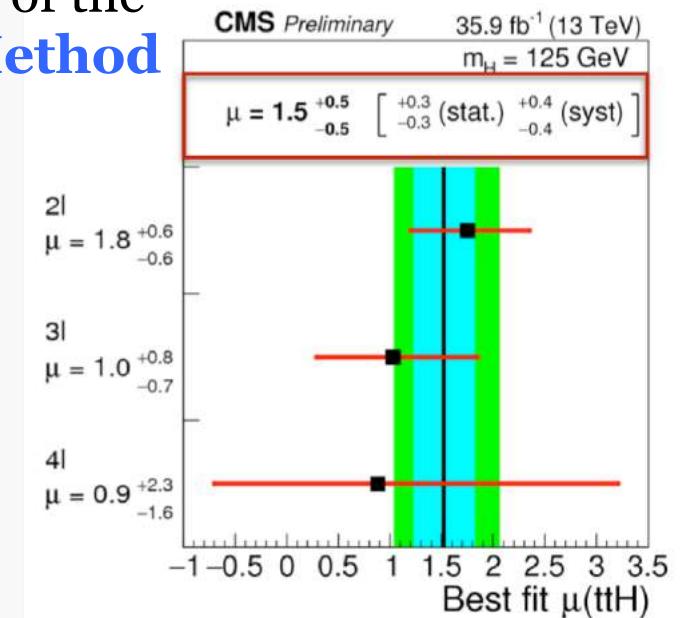
ttH: top yukawa coupling



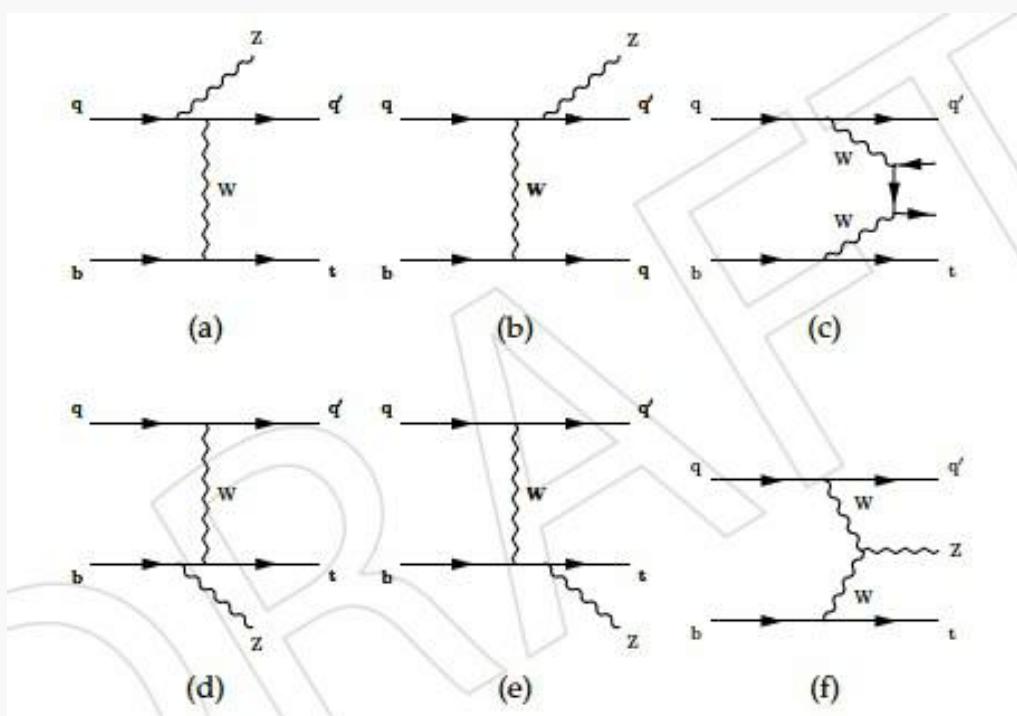
First observation of this process with a significance of 3.3



Measurement in the leptonic channels performed @ IPHC with the use of the **Matrix Element Method**

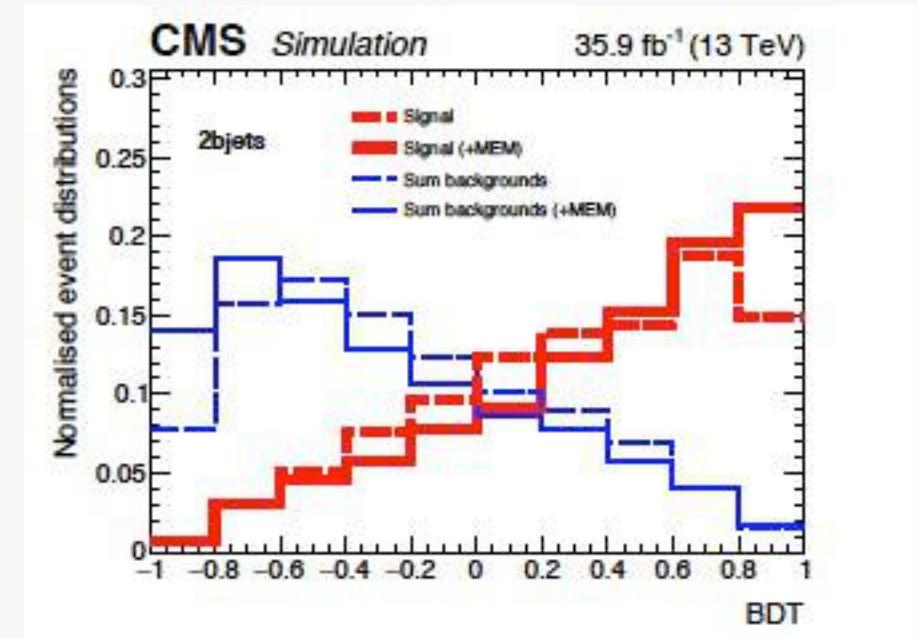


Top quark physics: rare processes



tZq

- Processes predicted by SM
- Cross-section enhanced by some BSM models

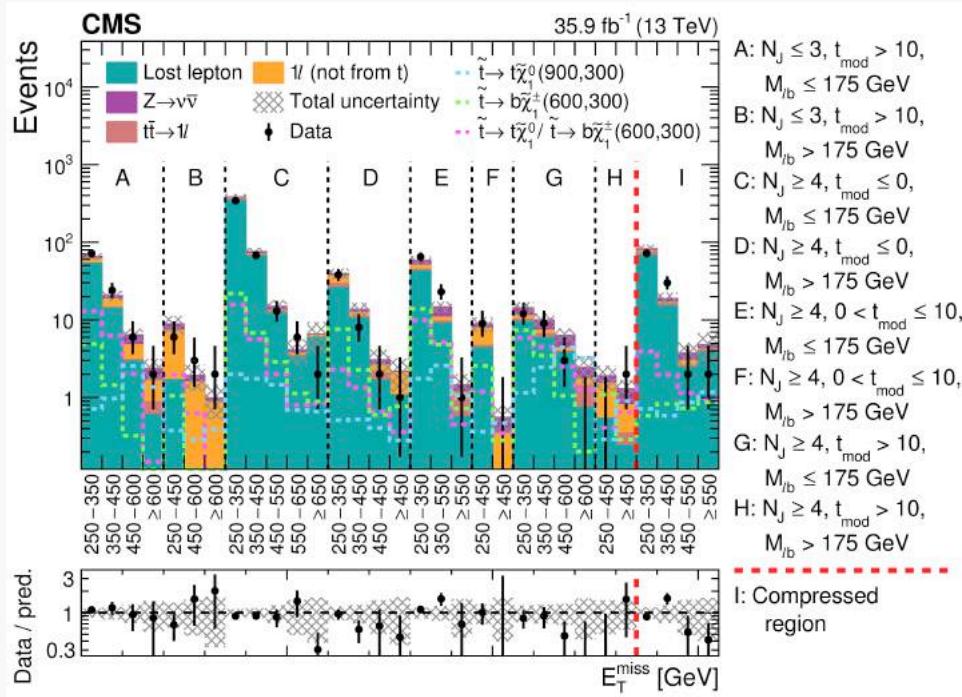


Involvement of IPHC

→ Participation/Responsibility of the analyses since run I

First observation of this process with a significance of 3.7

Supersymmetric searches: stop

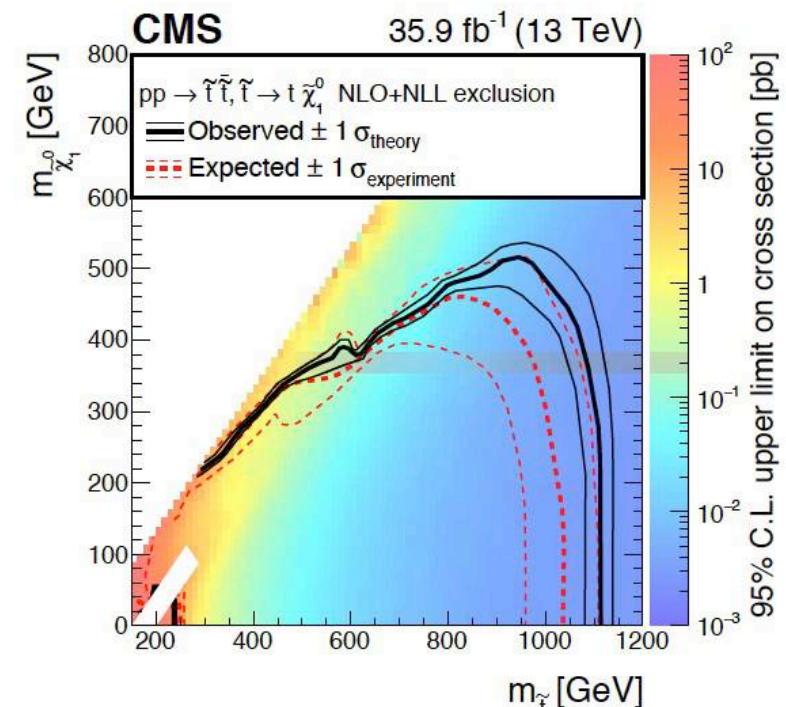
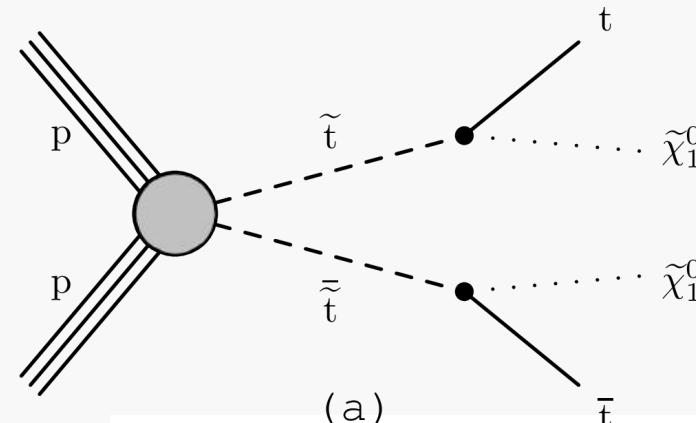


Main signal characteristic:

High MET signifying the presence of neutralinos
 → Derived quantities

Involvement of IPHC

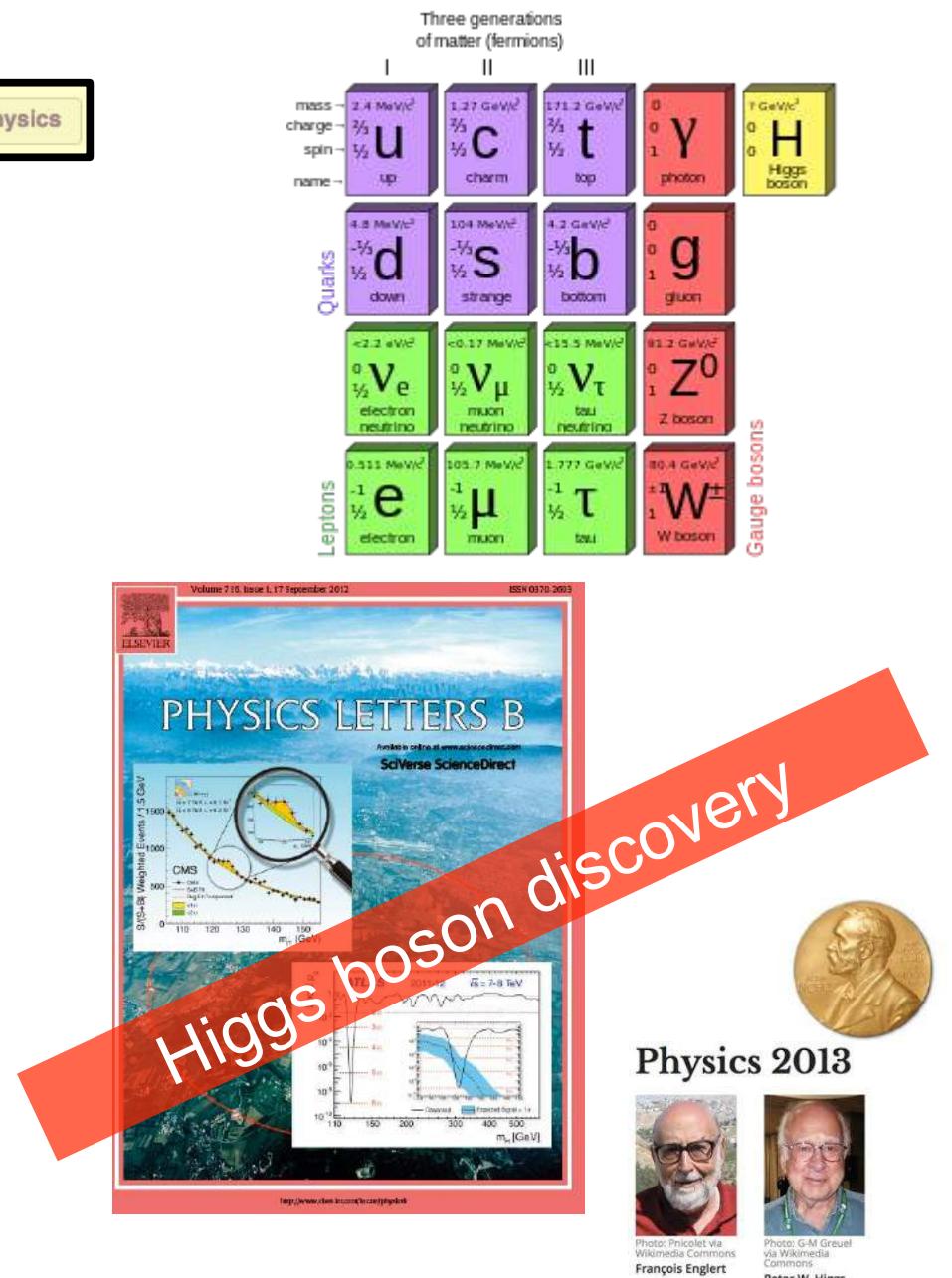
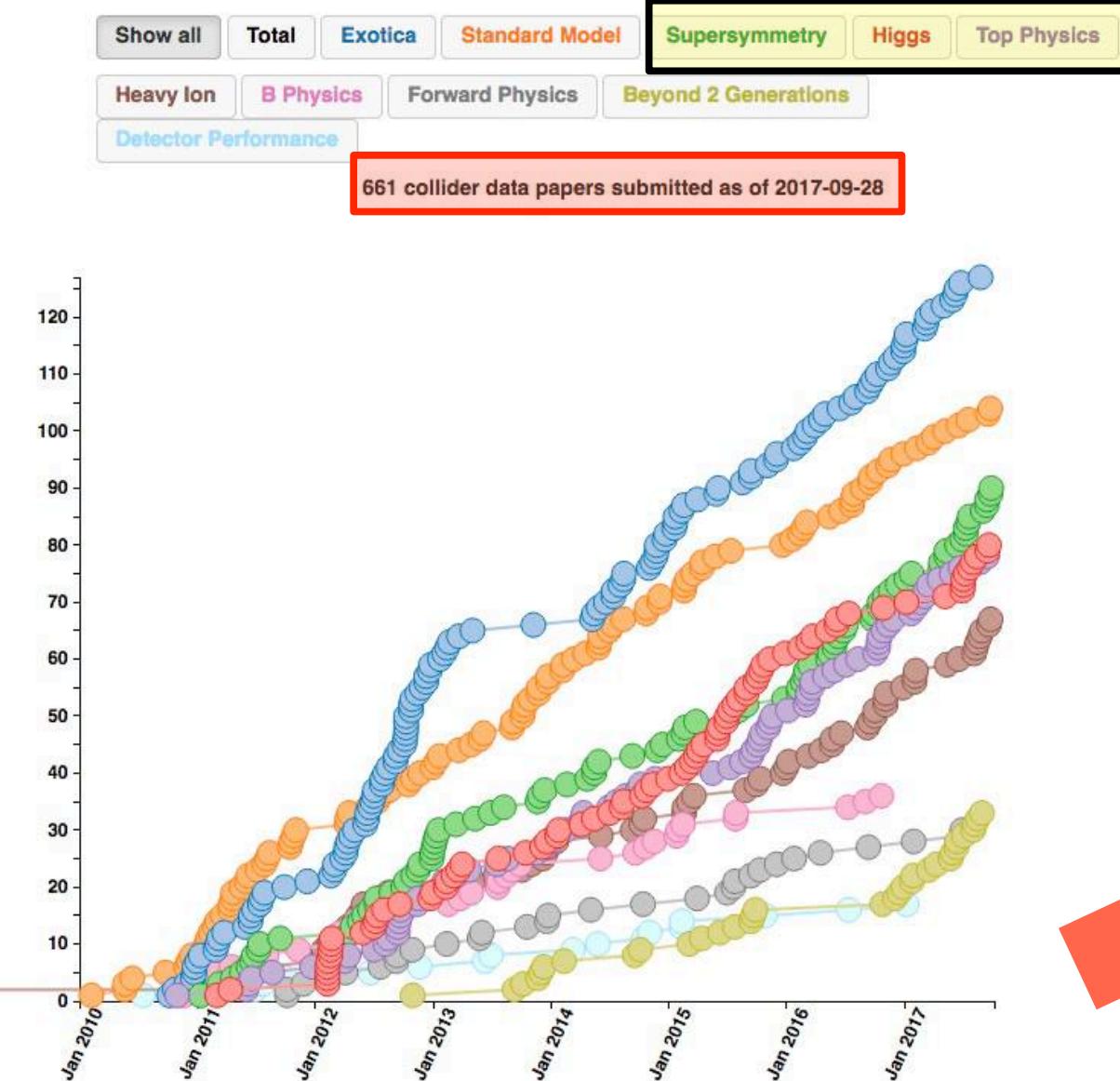
→ Participation/Responsibility
 of the analyses since run I



Limits entering into the constraining the naturalness territory ...

Physics papers & results

Involvement of CMS@IPHC



Physics analyses @ IPHC



top quark

1st observation of tZq: 3.7 σ



Higgs boson

1st observation of ttH: 3.3 σ

Beyond the
Standard Model

Supersymmetry

No discovery but
extension of the limits for
stop mass > 1 TeV

Phenomology

Expertise logiciel

FeynRules,
MadGraph_MC@NLO,
Pythia,
Delphes

Collaboration internationale
~ 100 analyses publiées
~ 20 analyses ATLAS/CMS réimplémentées

Framework d'analyse
MA5 (MADANALYSIS 5)
depuis 2012



Développement

1^{ère} publi MA5,
CPC 184 (2013) 222-256
192 citations

1^{ère} école internationale
MadAnalysis 5
en Corée (2017)

Etudes phénoménologiques

Model building

$$\mathcal{L}_{int} = -W_a F^a - W^{*a} F_a^\dagger - \frac{1}{2} W_{ab} \psi^a \cdot \psi^b - \frac{1}{2} W^{*ab} \bar{\psi}_a \cdot \bar{\psi}_b$$

Phénoménologie



Physique expérimentale

- Etude de sensibilité**
Recherche de FCNC dans le secteur du top (Z, g, γ, H)
Recherche de la signature monotop)
Recherche de vector-like quarks
- Réinterprétation de résultats**
Contraintes sur un modèle top - matière noire

Publi Monotop hadronique

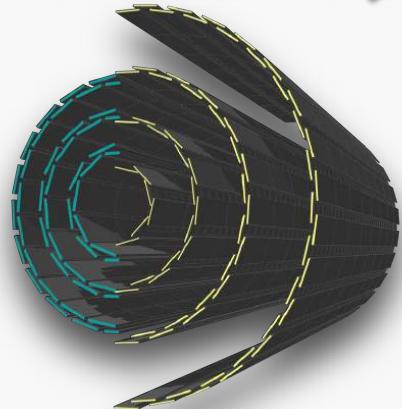
PhysRevD 84 074025

51 citations

15 publications
depuis 2012

detector

upgrades

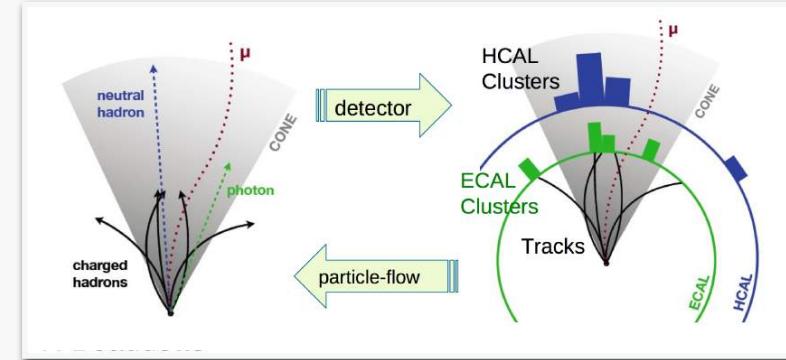
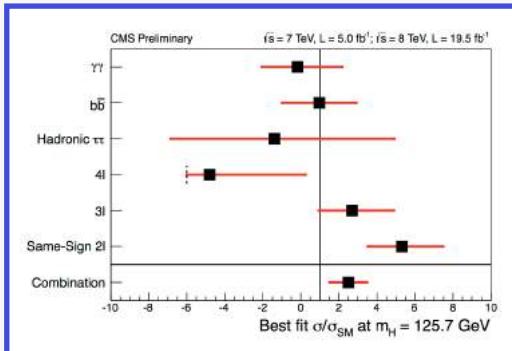


Data taking

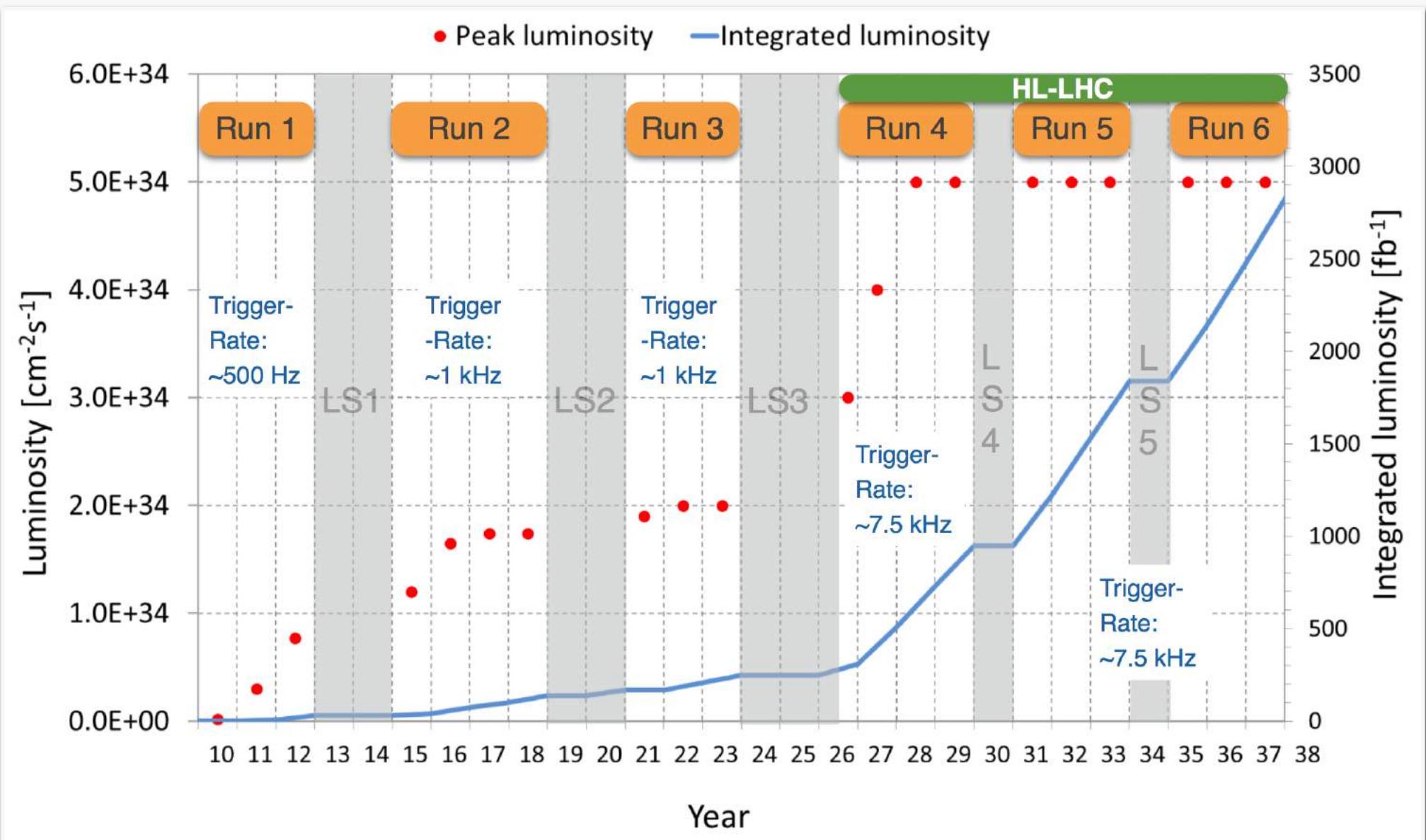


Pheno
Analyses

reconstruction



LHC schedule



Pixels – Phase I

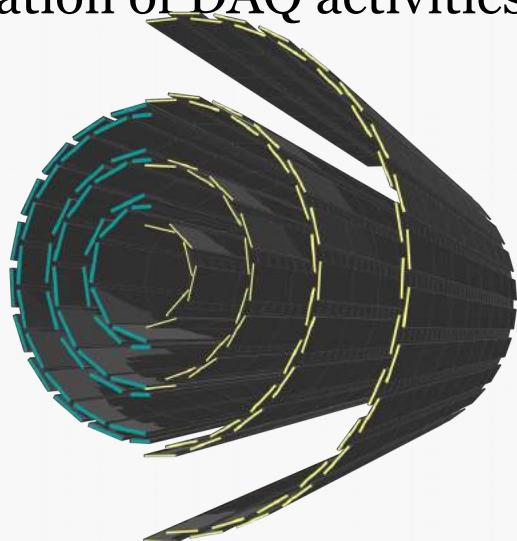
Extended technical stop (2016-2017)
→ replacement of the pixel detector

- New readout
 - Excellent efficiency even at high luminosity
 - Faster
- 3 → 4 layers (materiel budget divided by 2)
- Better resolution

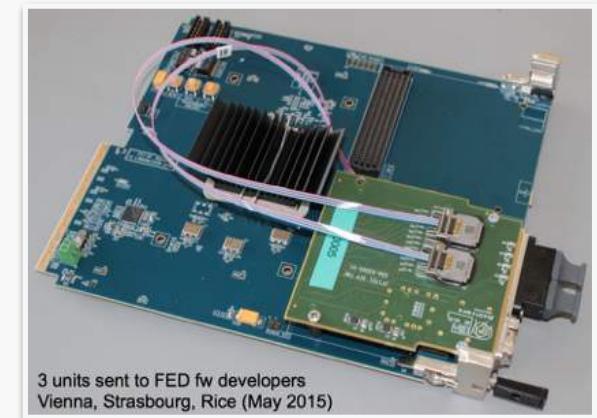
Responsibility of IPHC

- Data Acquisition (DAQ) based on newer electronic cards (μ TCA)
- Coordination of DAQ activities for Phase I @ CERN

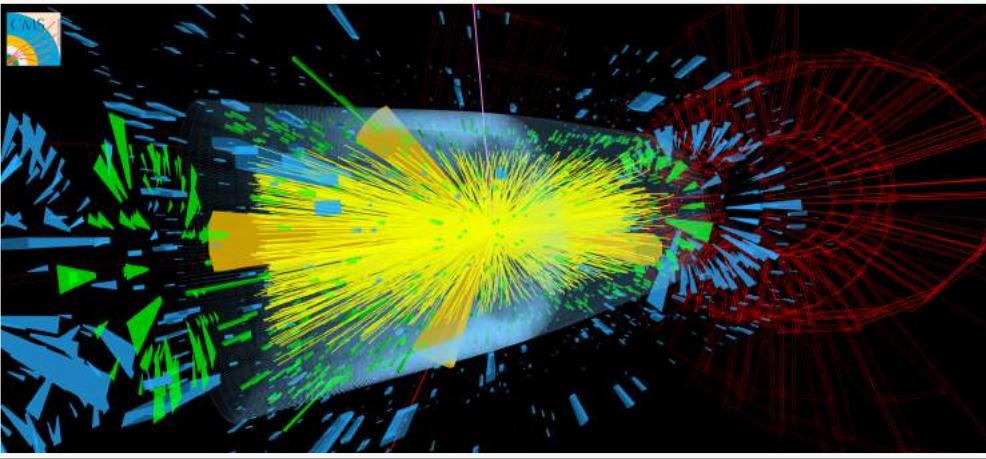
Former
pixel



New pixel



Tracker – Phase II

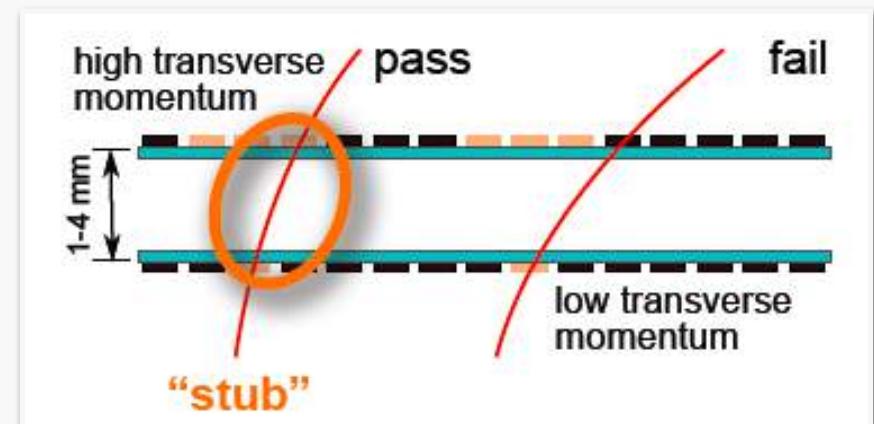


Replacement of the whole tracker

- Increase radiation hardness
- Extend angular coverage
- Able to work with a PU of 200
- Including in the L1 trigger

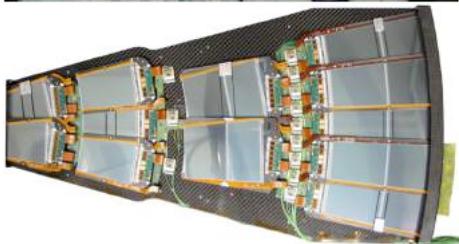
Expertise of IPHC

- Working on DAQ system based on μ TCA cards
- Test of electronic chains
- Responsible for DAQ during beam tests where prototypes are tested/characterized

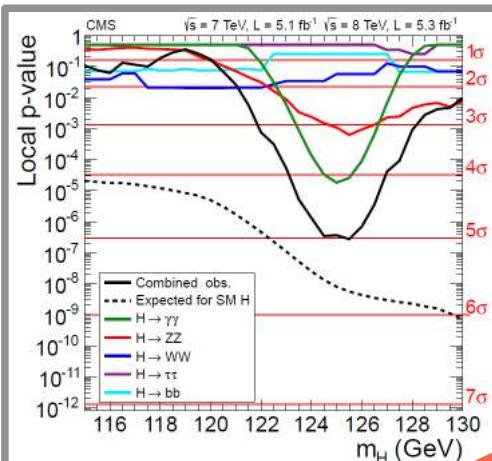


Diversity of skills

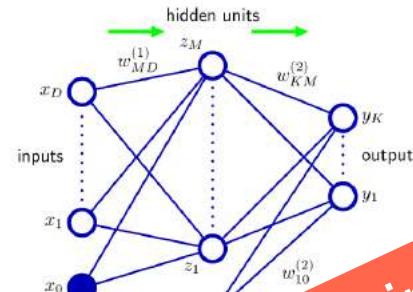
instrumentation



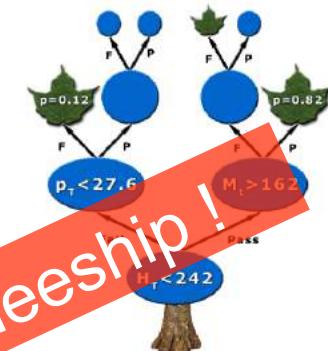
Statistical treatment



algorithms

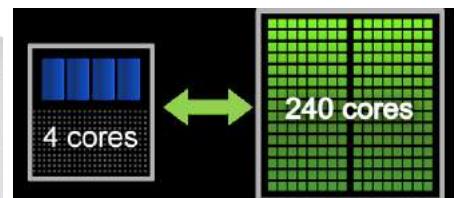


Neural Network



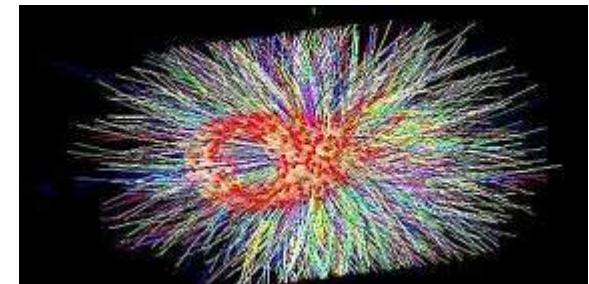
Boosted Decision Tree

Computing

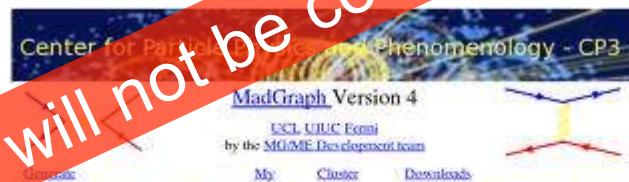
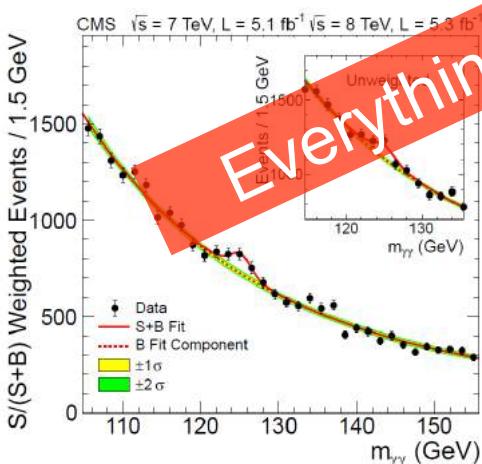


Grid

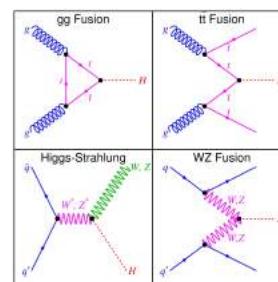
Simulation



Physics analysis



Generate Code On-Line



Everything will not be covered during the M2 traineeship !

Internships

Supersymmetry:
Search for **stop**
at run II with CMS



C. Collard | E. Chabert

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Caroline.Collard@iphc.cnrs.fr

Aspects **formels** et
phénoménologiques de la
SUSY : des principes de
construction aux prédictions
pour les collisionneurs



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Tau polarisation @
LHC
Detector & DAQ
tests for upgrade



U. Goerlach | V. Cherepanov

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vladimir.cherepanov@iphc.cnrs.fr

présentation le 26/10

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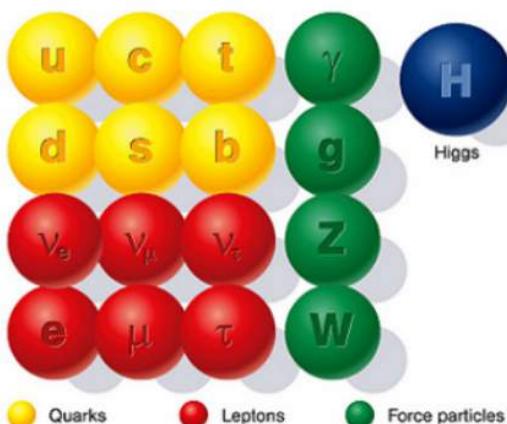
présentation le 26/10

SuperSymmetry (SUSY) in a nutshell

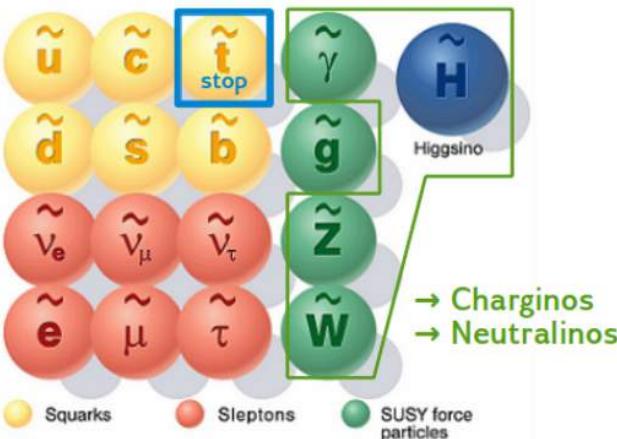
BSM models ...

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

Standard particles



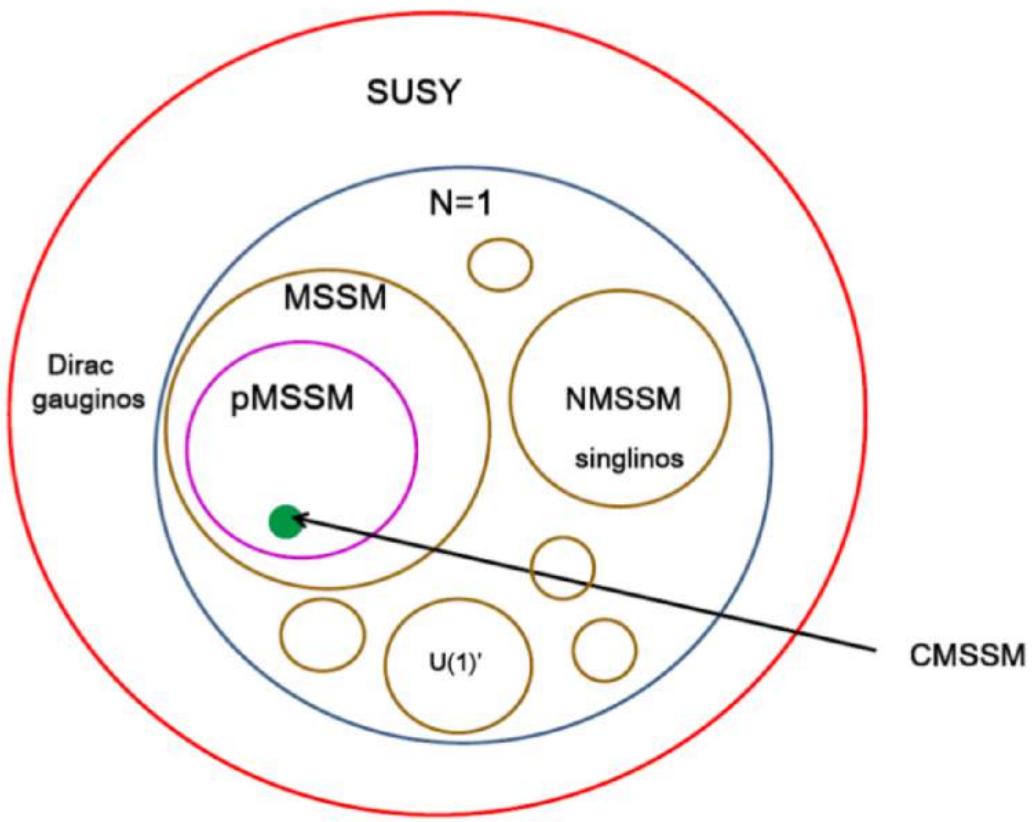
SUSY particles



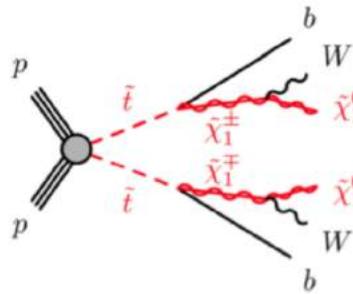
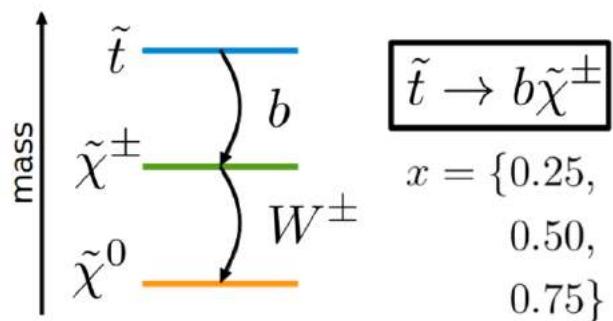
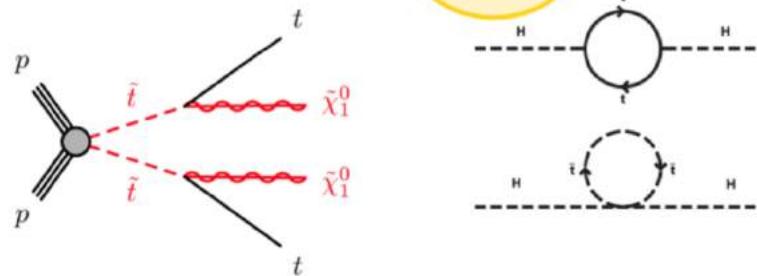
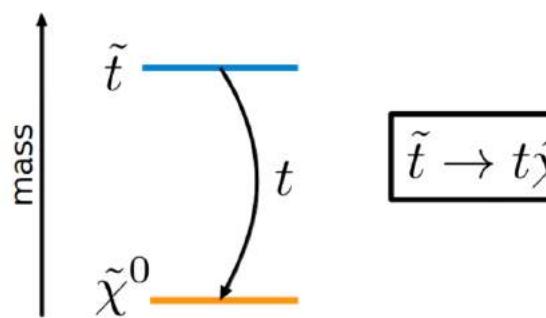
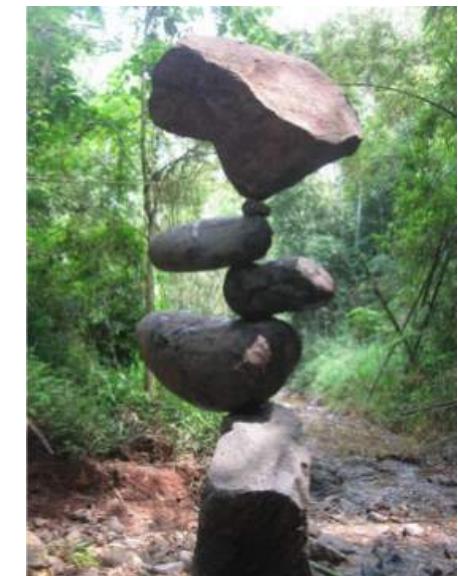
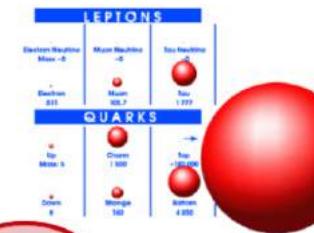
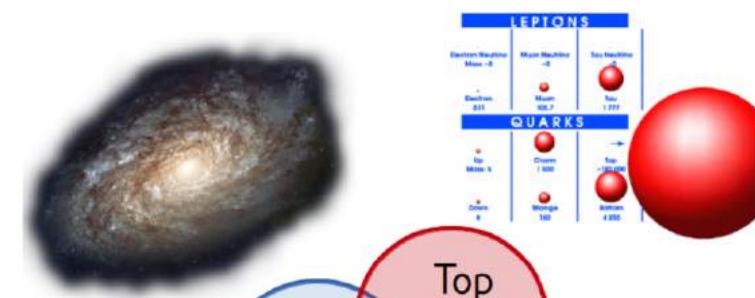
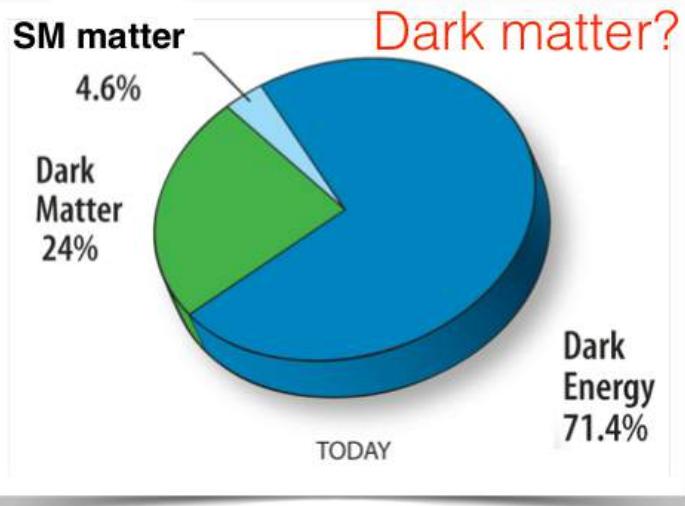
Good features of SUSY:

- 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



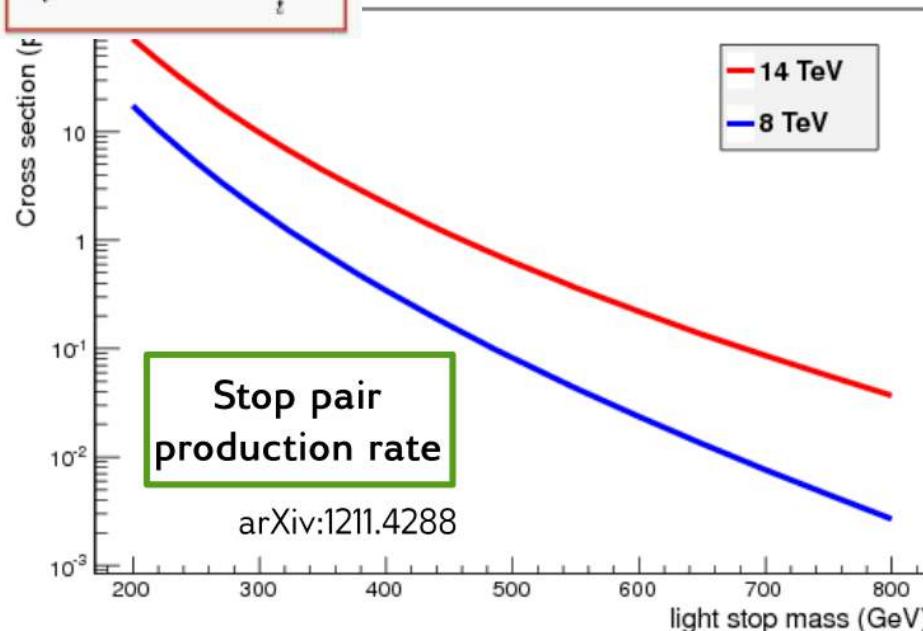
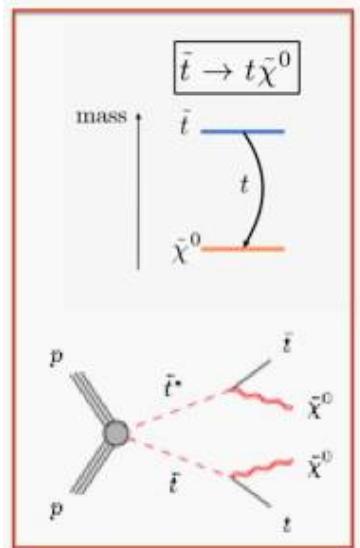
Search for a scalar top (stop)



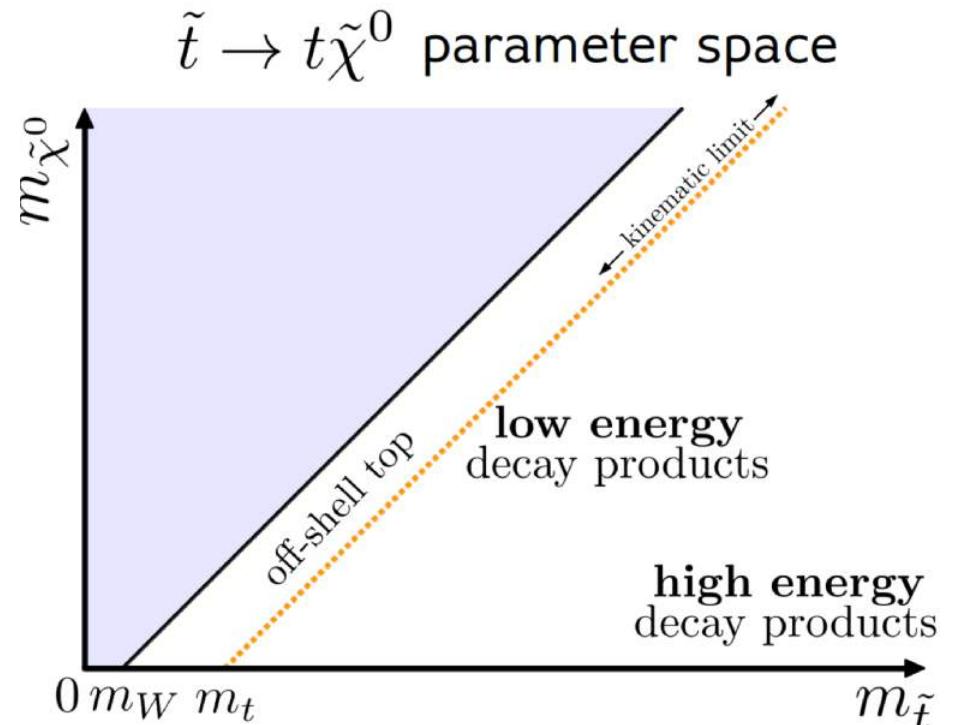
Search for stop at the TeV scale

1-lepton channel
 1st $W \rightarrow q\bar{q}$ 2nd $W \rightarrow \ell\nu_\ell$

Search for a scalar top (stop)



- Simplified models → free parameters are masses
- Depends on mass spectra and branching ratio

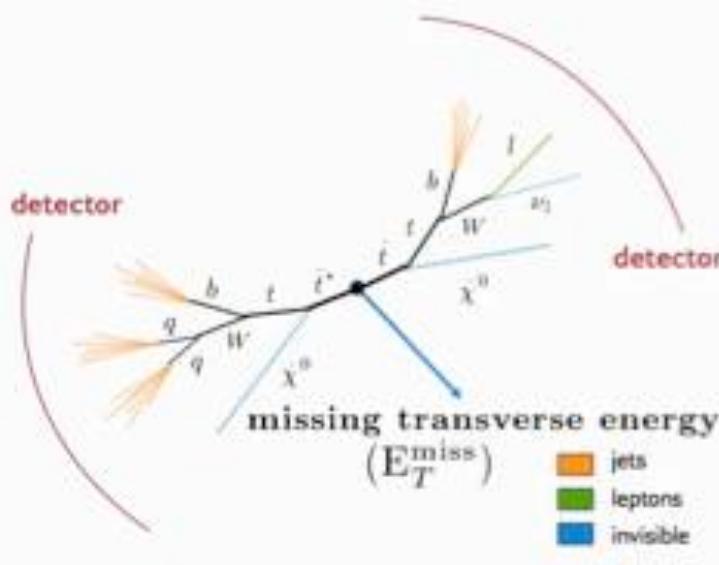


$$\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}^0}$$

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

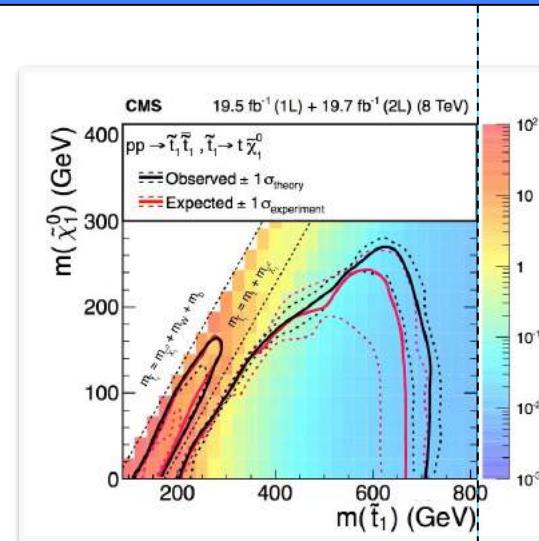
Drives the number of expected signal events

Search for a scalar top (stop)

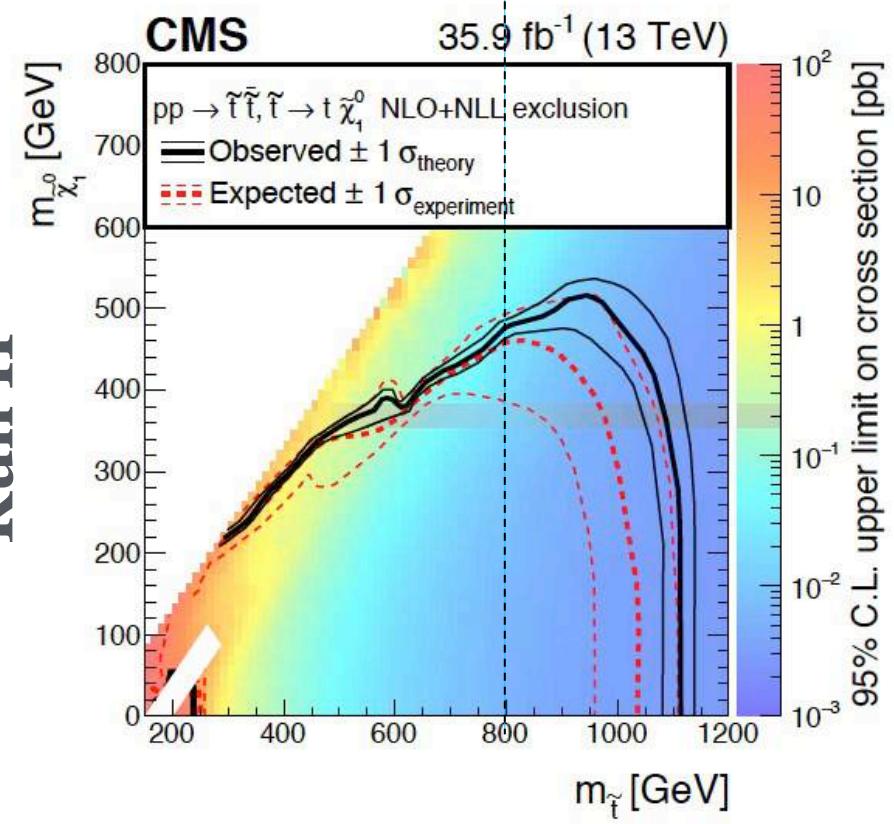


- Event selection
 - Study several variables
 - Event reconstruction
- Event categorization
 - Optimization
- Background estimation
- Systematics uncertainties
- Hypotheses tests
 - discovery ?
 - Limits / interpretations

Run I

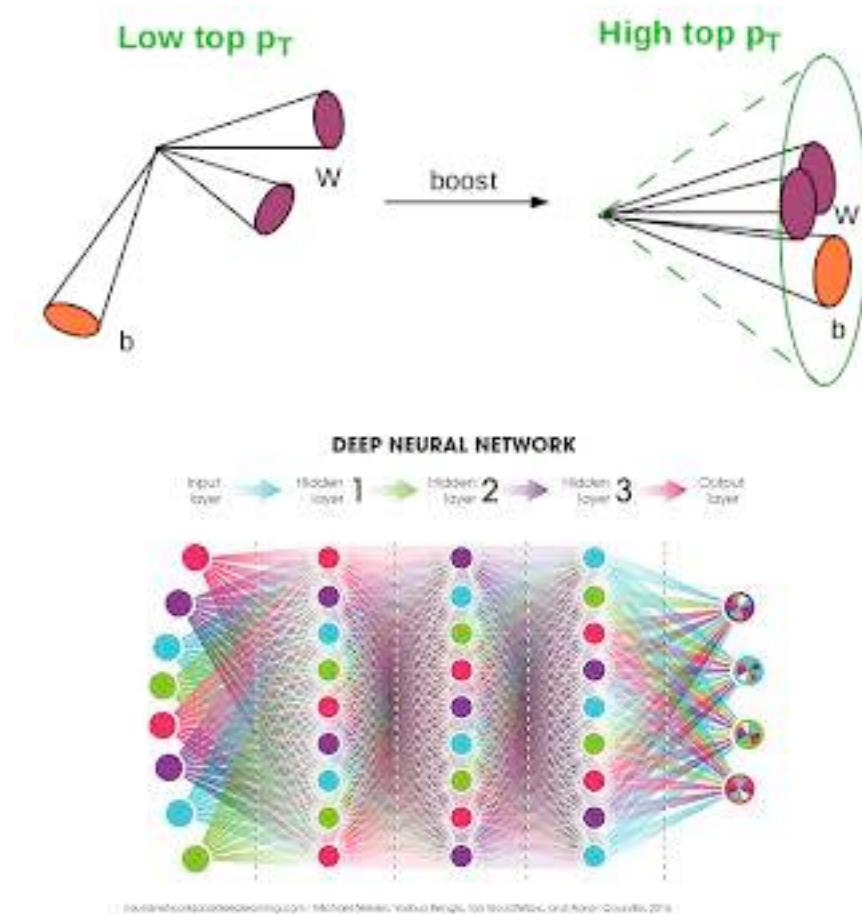


Run II



How to extend our searches ?

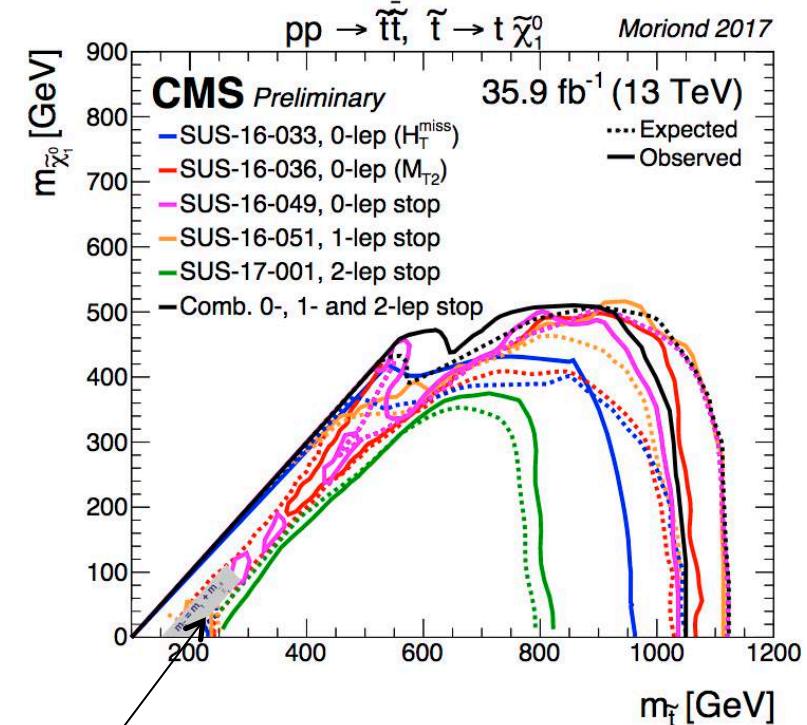
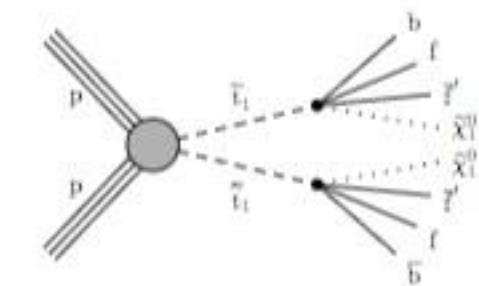
- “Classical” searches refined
 - Boosted object tagging
 - Usage of advanced machine learning techniques
 - Better control of the systematics
 - ...
- Dedicated searches for compressed spectra
- New channels:
 - Decays with taus
 - Production not per pair
 - Asymmetric decays
- Longer decay chains
- R-Parity violation ...
- Extended SUSY models
 - Extended higgs sector
 - Hidden sector
 - ...



Davidson et al., arXiv:hep-ph/1902.05946v1 [hep-ph], 100 pages, 100 figures, 2019

How to extend our searches ?

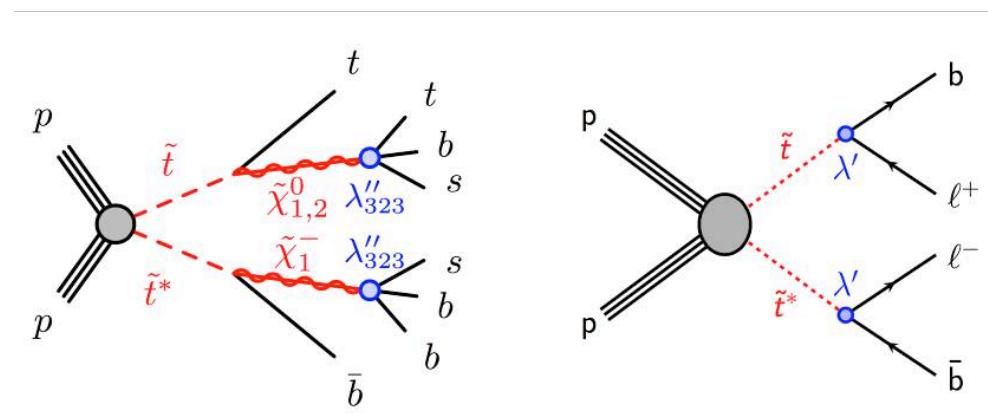
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Holes ...

How to extend our searches ?

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 - Boosted object tagging
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 - Better control of the systematics
 - ...
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Supersymmetry:
Search for **stop**
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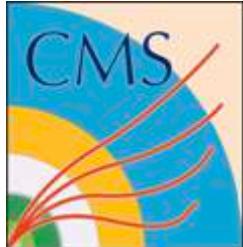
Tau polarisation @
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présentation le 26/10



Helicity measurement of tau-leptons, the key to fundamental parameters of the SM and BSM physics

Guillaume Bourgatte, Vladimir Cherepanov, Ulrich Goerlach, Anne-Catherine Lebihan

- Most precise measurement of tau polarisation
- Measurement of effective weak mixing angle in the decay of $Z^0 \rightarrow \tau \tau$
- Weak vector and axial vector couplings of tau leptons (Neutral Currents)
- Transverse and longitudinal spin correlations in $Z^0 \rightarrow \tau \tau$
- Ultimate goal is to measure possible CP violation in Higgs $\rightarrow \tau \tau$ decays

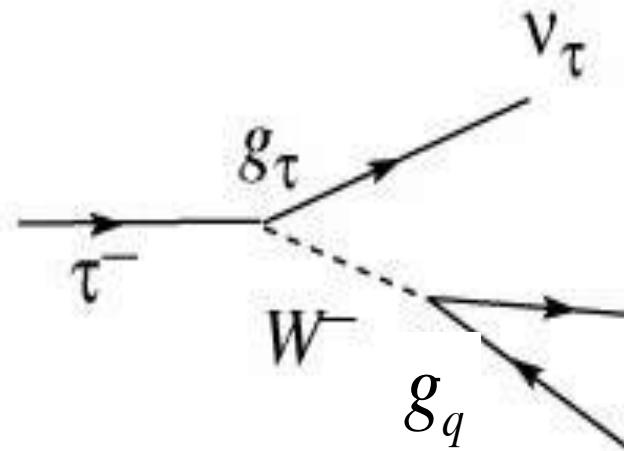
Neutral bosons mix \Rightarrow Physical bosons

$$\begin{pmatrix} Z^0 \\ \gamma \end{pmatrix} = \begin{pmatrix} \cos \theta_W & -\sin \theta_W \\ \sin \theta_W & \cos \theta_W \end{pmatrix} \begin{pmatrix} W^0 \\ B^0 \end{pmatrix}$$

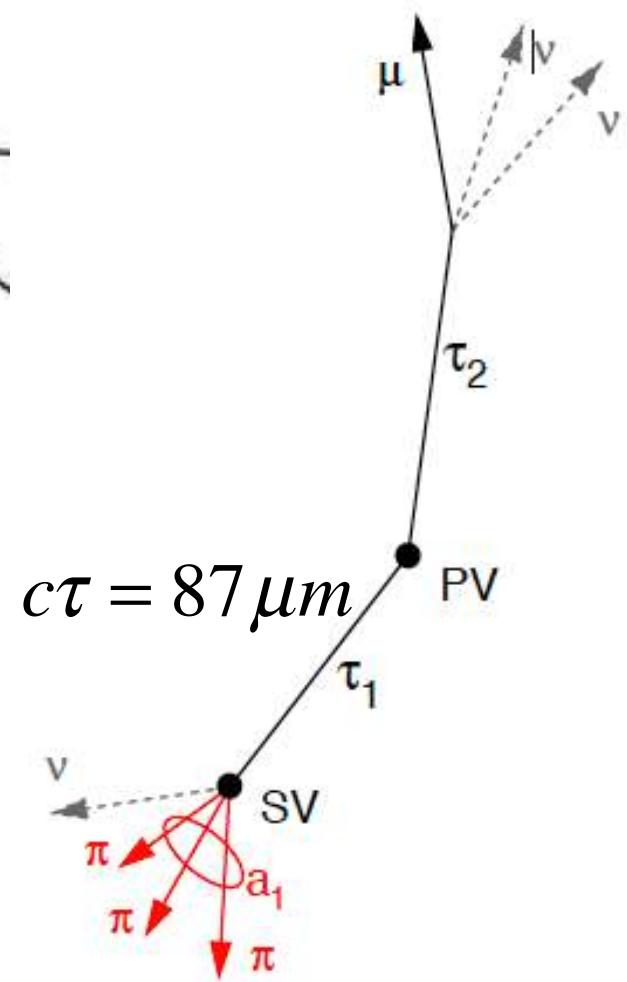
$$\frac{G_F}{\sqrt{2}} = \frac{\pi \alpha}{2 \sin^2 \theta_W M_W^2}$$

at the High Luminosity LHC

Tau hadronic decays



Neutrinos are not measured

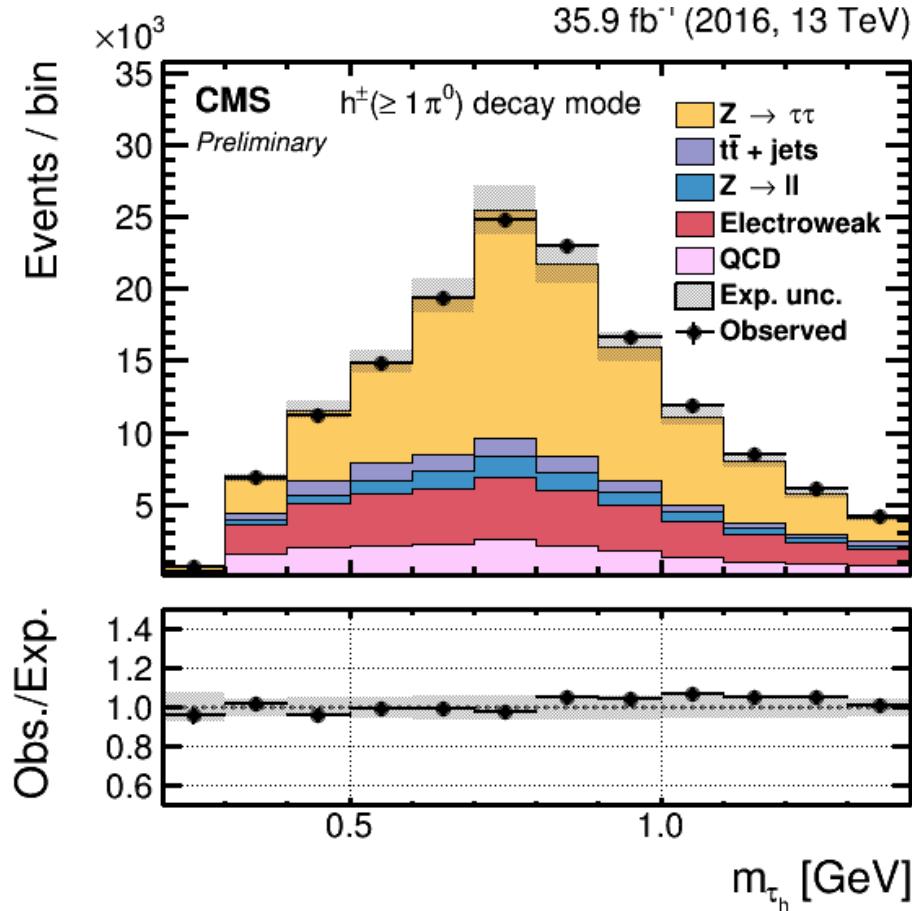


Decay mode	Meson resonance	$\mathcal{B} [\%]$
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \rightarrow h^- \nu_\tau$		11.5
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		3.2
All modes containing hadrons		64.8

Hadronic tau decays, reconstructed

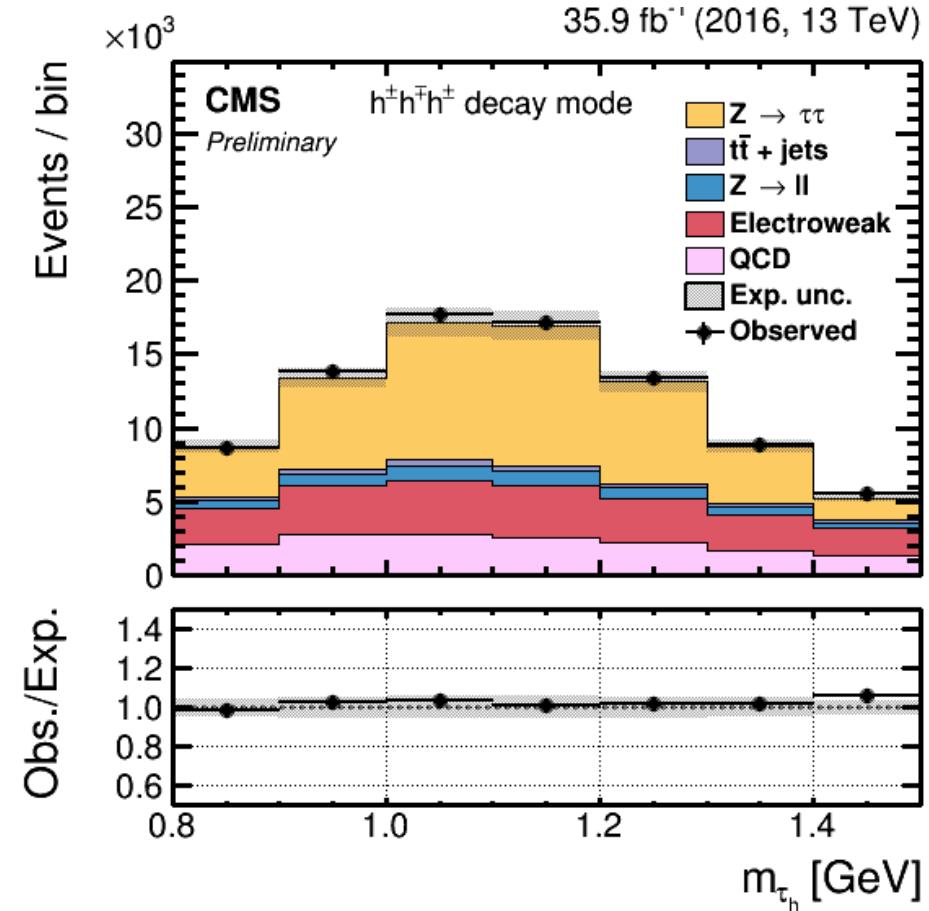
Mass of $\rho = 770$ MeV

One prong plus π^0 $\tau \rightarrow \rho \nu \rightarrow \pi^0 \pi^\pm \nu$

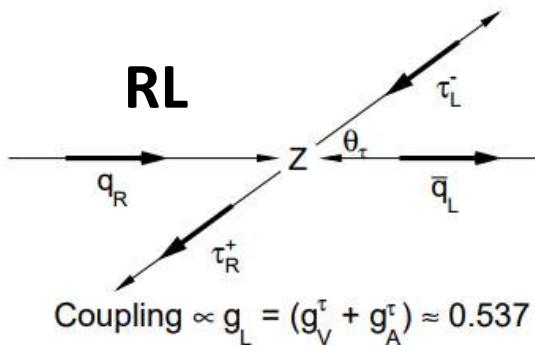
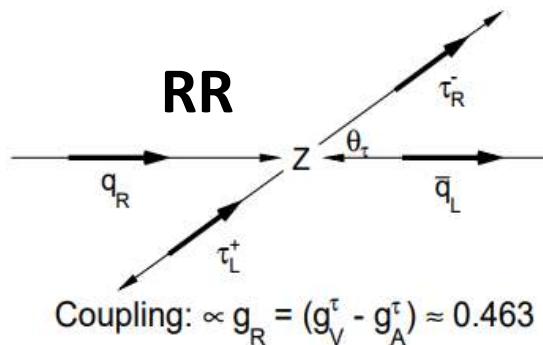


Mass of $a_1 = 1230$ MeV

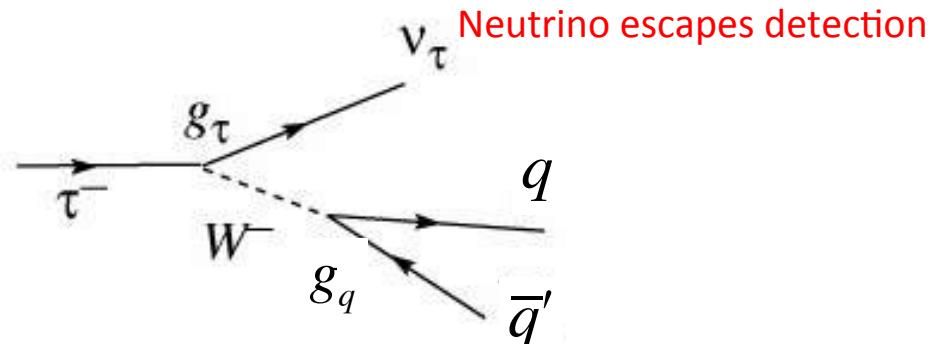
$\tau \rightarrow a_1 \nu \rightarrow \pi^\pm \pi^\mp \pi^\pm \nu$ three prongs



Tau polarisation in Z^0 decays:



The spin state of tau lepton can be extracted from angular distribution of the decay products



- τ^- are preferably with helicity -1
- Polarization asymmetry: $A_{pol} = \frac{1}{\sigma} [\sigma(h_\tau = +1) - \sigma(h_\tau = -1)]$

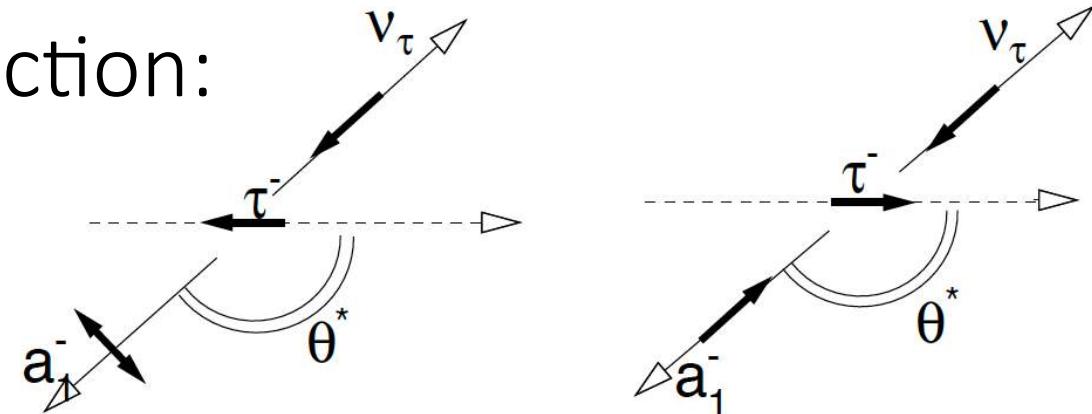
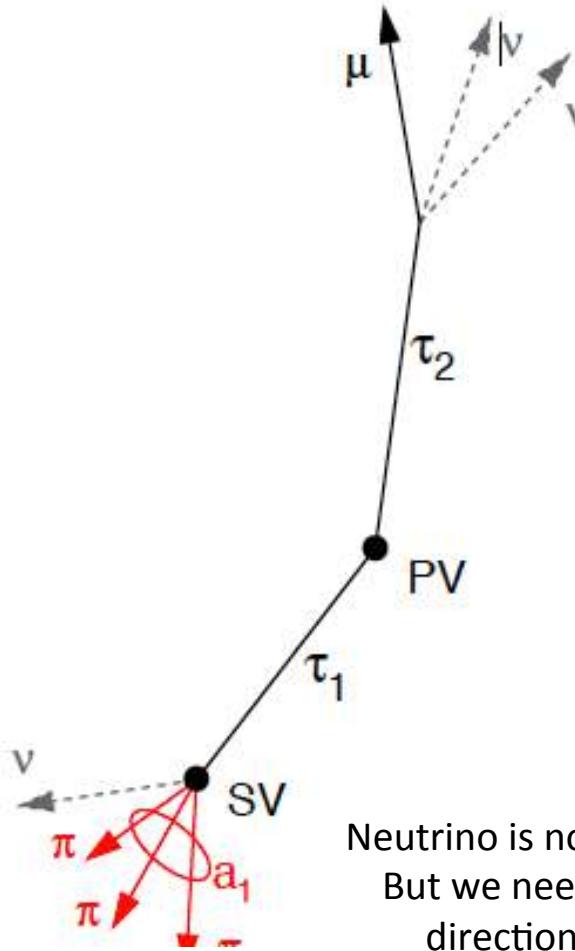
$$\text{At the } Z\text{-pole } |A_{pol}| \approx 2 \frac{g_V^\tau}{g_A^\tau}$$

$$= -\frac{2v_\tau a_\tau}{v_\tau^2 + a_\tau^2} \approx -2 + 8 \sin^2 \theta_W.$$

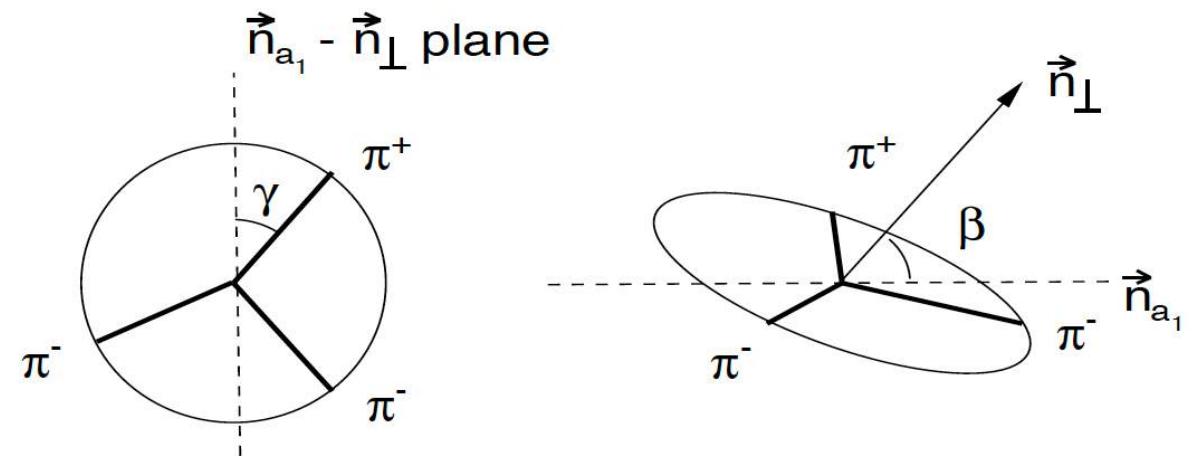
Table 2.2: Couplings for $Z \rightarrow f\bar{f}$ in Standard Model (with $\sin^2 \theta_W = 0.231$)

f	Q_f	v_f	a_f	g_R	g_L
ν_e, ν_μ, ν_τ	0	$\frac{1}{2}$	$+\frac{1}{2}$	0	1
e^-, μ^-, τ^-	-1	$-\frac{1}{2} + 2 \sin^2 \theta_W \approx -0.037$	$-\frac{1}{2}$	0.463	-0.537
u, c, t	$+\frac{2}{3}$	$\frac{1}{2} - \frac{4}{3} \sin^2 \theta_W \approx 0.191$	$+\frac{1}{2}$	-0.309	0.691
d, s, b	$-\frac{1}{3}$	$-\frac{1}{2} + \frac{2}{3} \sin^2 \theta_W \approx -0.345$	$-\frac{1}{2}$	0.155	-0.845

Tau polarisation reconstruction:

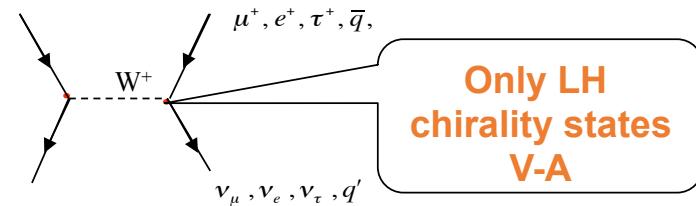
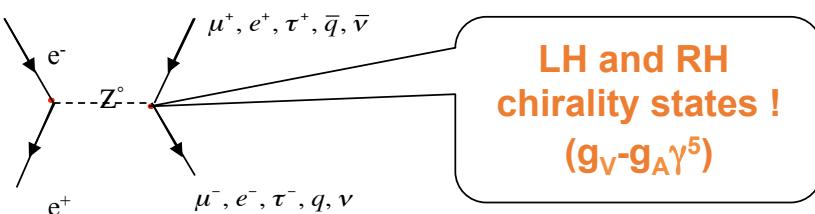


Spin configurations for the decay $\tau^- \rightarrow a_1^- \nu_\tau$ in the τ^- rest frame:



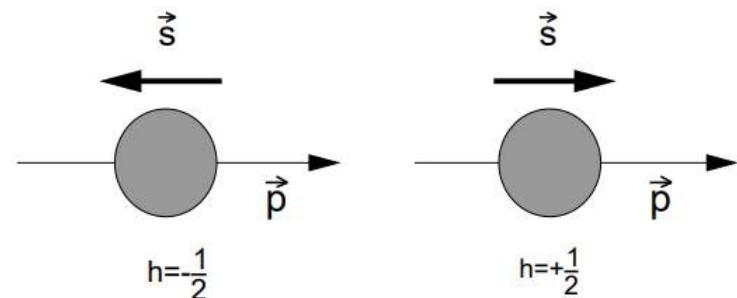
Spin analyzers for $a_1^- \rightarrow 3\pi$ decay in a_1^- rest frame:

- γ describes the relative pions orientation within its plane
- β is the angle between laboratory and the 3π plane



$Z^0 \rightarrow \tau \tau \diamondsuit$ hadrons or leptons and hadrons

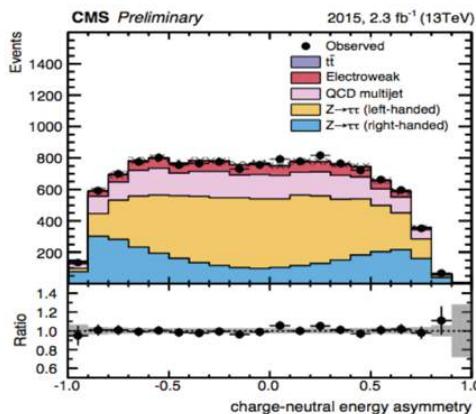
- Combining the information from all CMS sub-detectors allows to fully reconstruct the di-tau system including escaped neutrinos!
- Find « optimal » variables to determine how many taus are produced in negative and positive helicity state



$H^0, Z^0 \rightarrow \tau \tau$

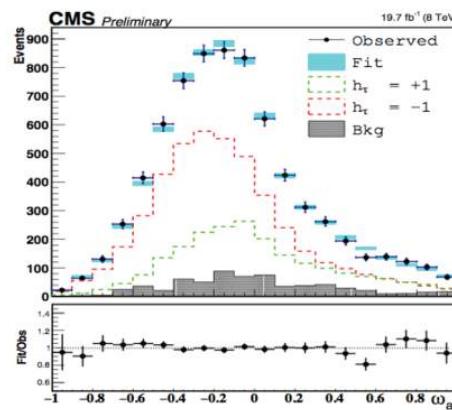
- Many possibilities have to be analysed and tested with data
- Needs a good understanding of the physics
- A high precision can be achieved analysing and combining together various tau decay channels

$\tau \rightarrow \rho \nu \rightarrow \pi^0 \pi^\pm \nu$



$$\cos \psi^* \sim [E(\pi^\pm) - E(\pi^0)]/[E(\pi^\pm) + E(\pi^0)]$$

$\tau \rightarrow a_1 \nu \rightarrow \pi^\pm \pi^\mp \pi^\pm \nu$

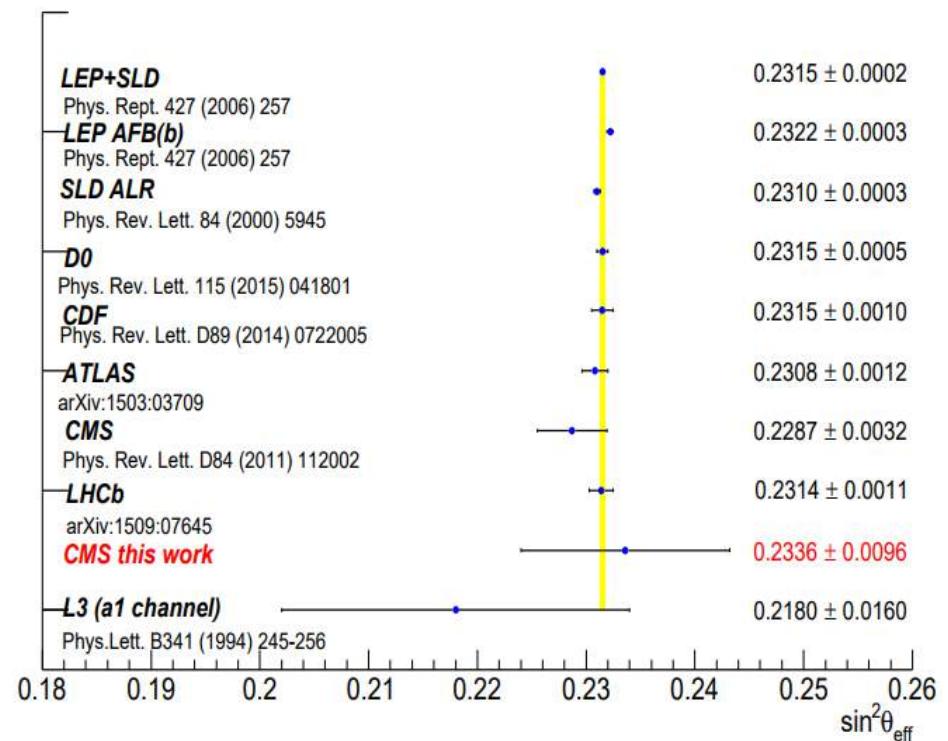


$$\omega_{a_1}(\cos \theta^*, \gamma, \beta, \alpha)$$

DP_2016_060

Examples of two variables, which could be used.
Others in development ...

Effective weak mixing angle measured in 8 TeV LHC data

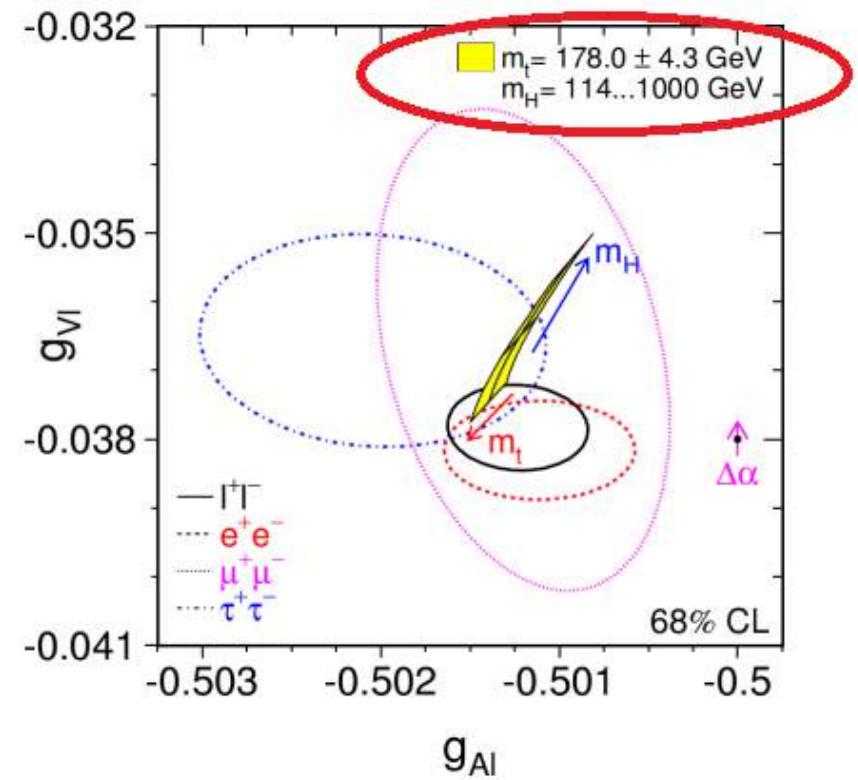


Why high-precision measurements?

Direct searches at LHC do not show
a big success so far ...
(= no new particles)

Small loop effects of New Physics
can be visible in very precisely measured
parameters

A striking example from LEP, the masses
of top quark and Higgs boson were
predicted long ago of the actual discovery!



PhD Thesis:

**Measurement of Electroweak Parameters in the Decay of $Z^0 \rightarrow \tau\tau$ and
the Upgrade of the CMS Detector for very High Luminosity**

Directeur de thèse : ULRICH GOERLACH,

CO-ENCADRANT : VLADIMIR CHEREPANOV

« stages »:

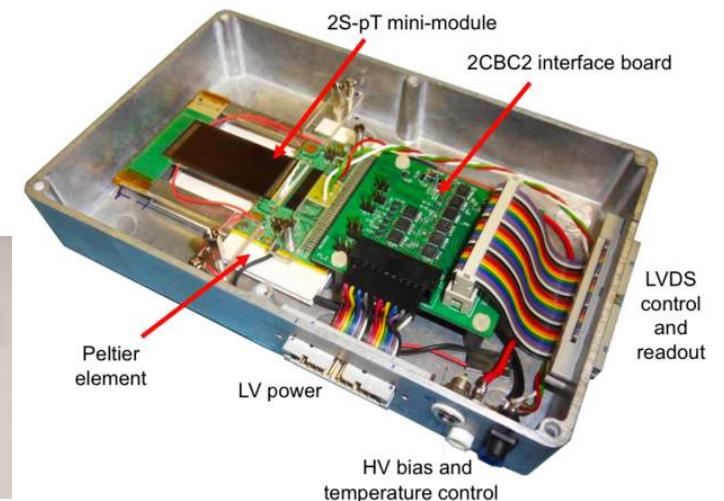
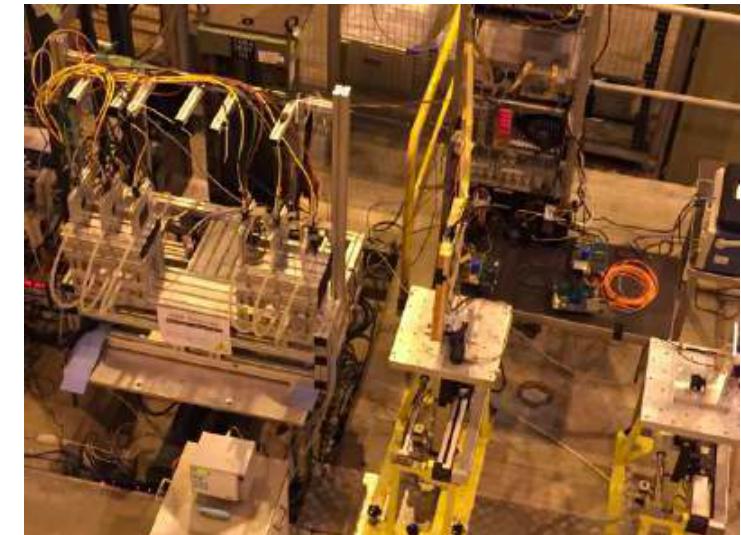
- Tau-polarisation at the LHC
- Detector and DAQ tests for the Upgrade of the CMS Detector

CO-ENCADRANTS : VLADIMIR CHEREPANOV, ULRICH GOERLACH

Detector and DAQ tests for the Upgrade of the CMS

- Detector and DAQ tests
- Existing test bench
- At the moment being rebuilt with new Scintillators and PMs

- Work with ^{90}Sr source and cosmics
- Test beam, if scheduled (?)
- Goal: understanding of DAQ and detectors
- Hardware competences for future employment



Internships

Supersymmetry:
Search for **stop**
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présentation le 26/10