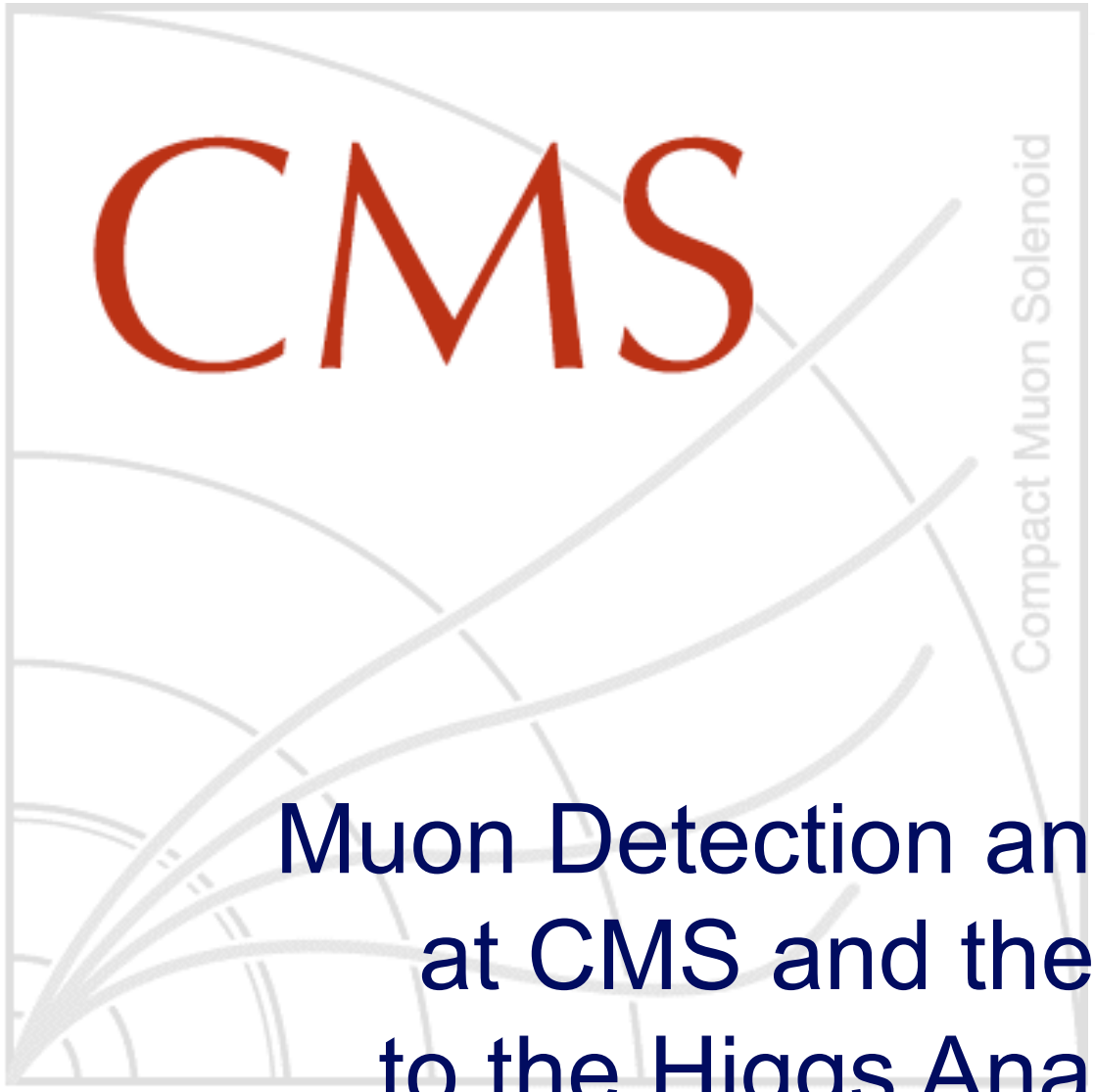


Muon Detection and Reconstruction at CMS and their contribution to the Higgs Analysis Searches

Giorgia Mila

INTRODUCTION

My research activity: devoted to the **CMS experiment**
aimed to the analysis of the **Higgs discovery *golden channel***
(which forseens four muons in the final state)

2007

muon detection in the CMS Drift Tubes
- detector performance investigation
- on-line Data Quality Monitoring

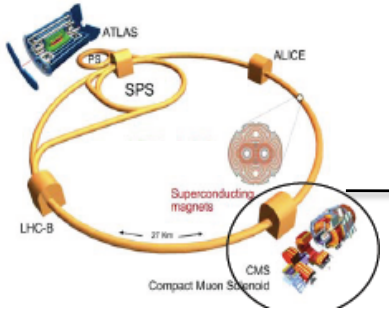
2008

reconstruction of the muon track inside the whole CMS detector
- study of different tracking algorithms
- off-line Data Quality Monitoring

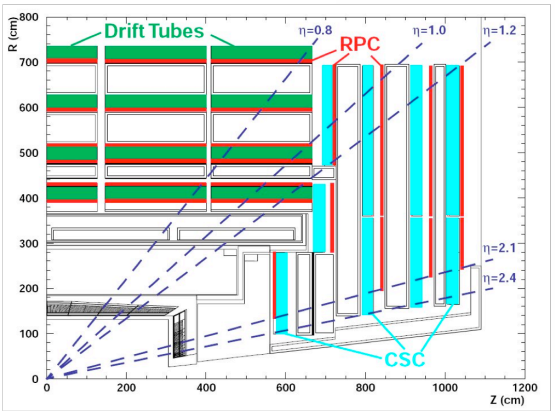
2009

H→ZZ→4μ discovery potential analysis
- final state kinematic signature
- background rejection and computation from data

The CMS Detector

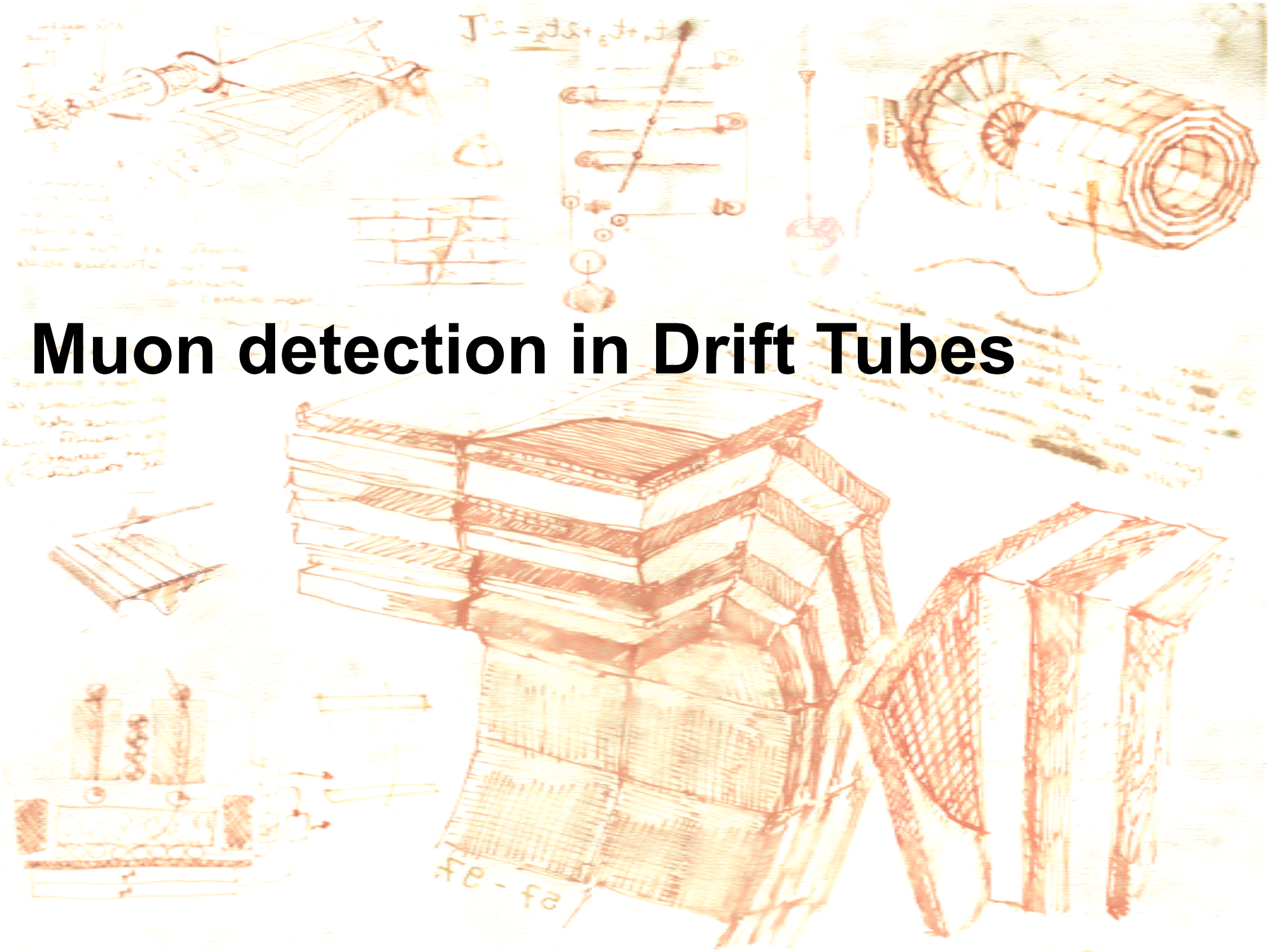


inner part:
- tracking system
- elm, hadronic calorimeters
- superconducting magnet



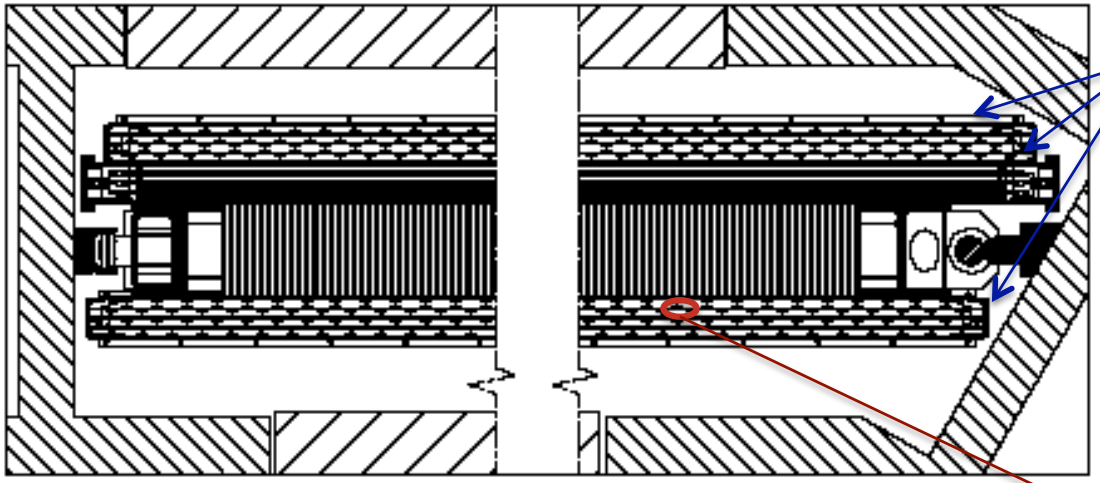
outer part: muon spectrometer
- DT, RPC detectors in the barrel
- CSC, RPC detectors in the endcaps

Muon detection in Drift Tubes

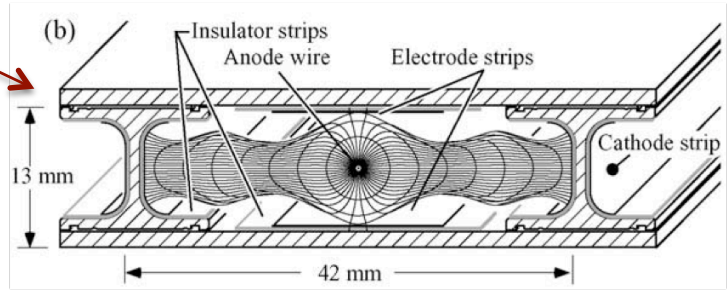


Drift Tube Detectors

The Drift Tubes (DT) are detectors designed for the measurement of the three-dimensional position and direction of muons in the CMS spectrometer



3 SuperLayers (SL) [2ϕ SLs, 1θ SL]
4 Layers (L) per SL



- ✓ distance from wire computed through the drift time
- ✓ ambiguity left-right solved by the pattern recognition
- ✓ each DT chamber provides:
  - three 2D segments, combining 4 cell drift times
  - one 3D segment, matching the ϕ and θ segments

Drift Tube Assembly and Quality Check

Construction of the outermost DT chambers: Torino (Sette Comuni laboratory).

→ **Development of the software** used to test the chamber quality with cosmic muons.

In particular :

- Optimisation of the pattern recognition for the segment reconstruction
- Analysis of the internal alignment between the SLs

→ **Participation to the DT final assembly phase**

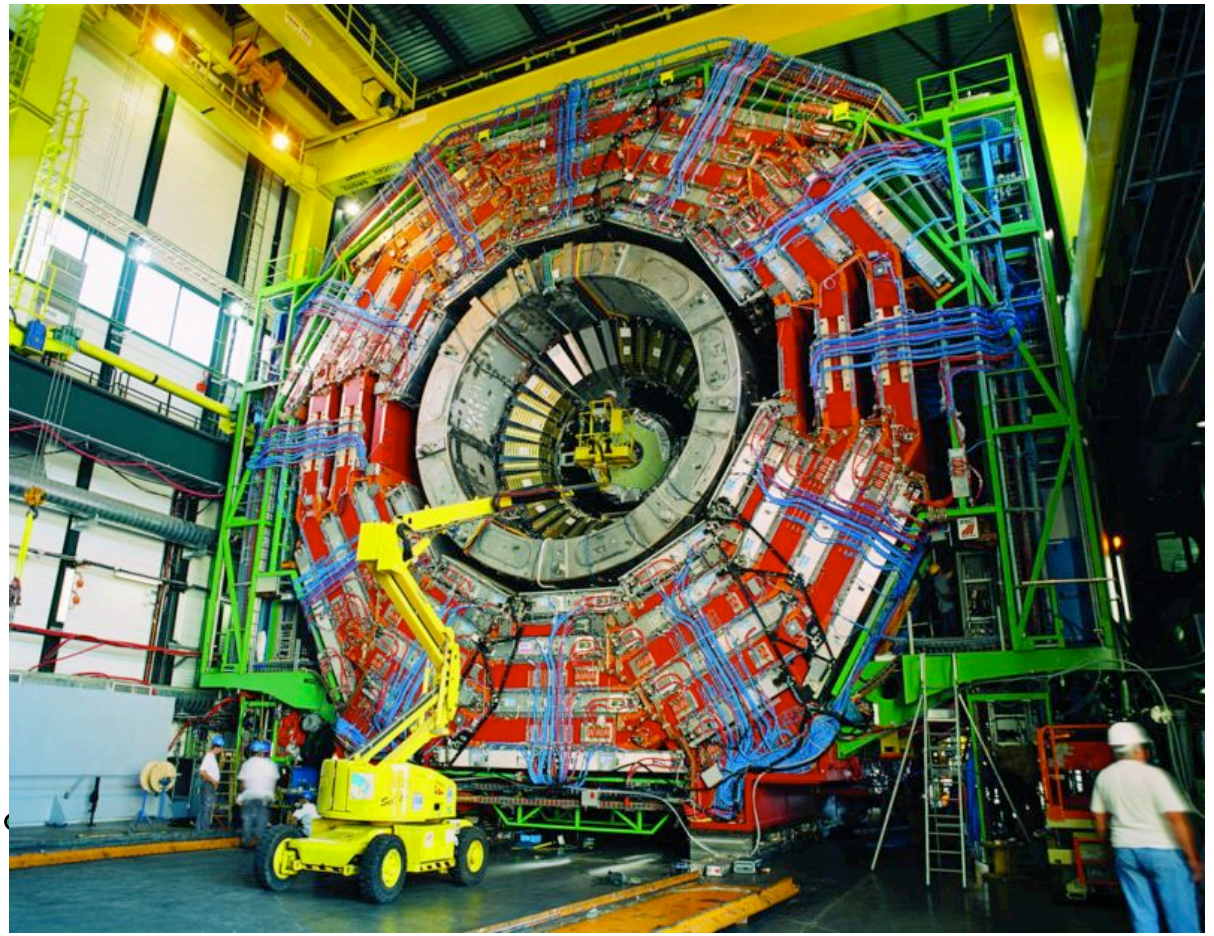
Drift Tube Installation and First Commissioning

DT installation inside the CMS detector on the surface of the CMS experimental site.
Begin of the DT commissioning in situ (voltage distribution, gas mixture, cable connections)

→ **First DT performance studies** with cosmic data using the official CMS software.

Main parameters:

- Drift time distribution
- Cell occupancy
- Segment quality and resolution
- Cell and chamber efficiency
- Internal alignment



The CMS Commissioning with Cosmic Data

2006

Aug: **M**agnet **T**est/**C**osmic **C**hallenge

global data taking with a fraction of each CMS subdetector with magnetic field on

2007

Lowering into cavern: Underground global runs

increasing fraction of CMS integrated

2008

May-Aug: Weekly "global runs"
+ Cosmic Runs At Zero Tesla (**CRUZET**)

Entire CMS integrated; 300 M events, B off

Sep: First beams

Beam splash events; beam halo

Oct: Cosmic Run at Four Tesla (**CRAFT**)

Run 24/7 for extended period

270M events, full detector, nominal B field

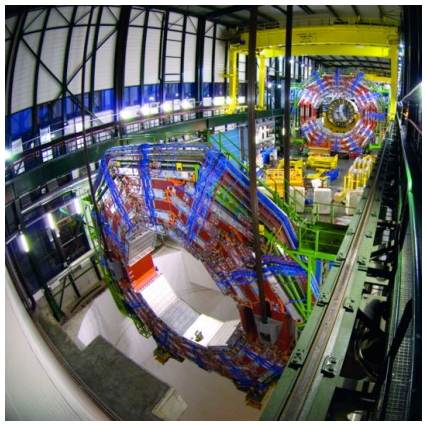
2009

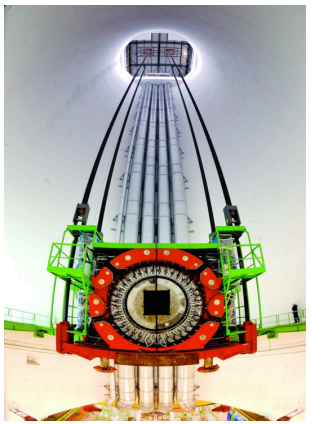
Aug: **CRAFT 09**

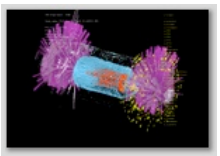
300M events

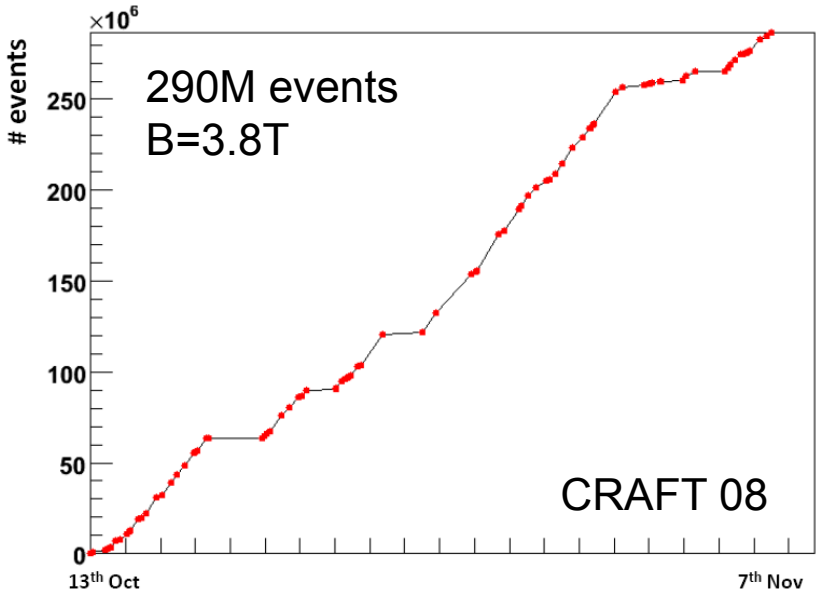
Nov-Dec: Circulating beams

Beam halo, collision events









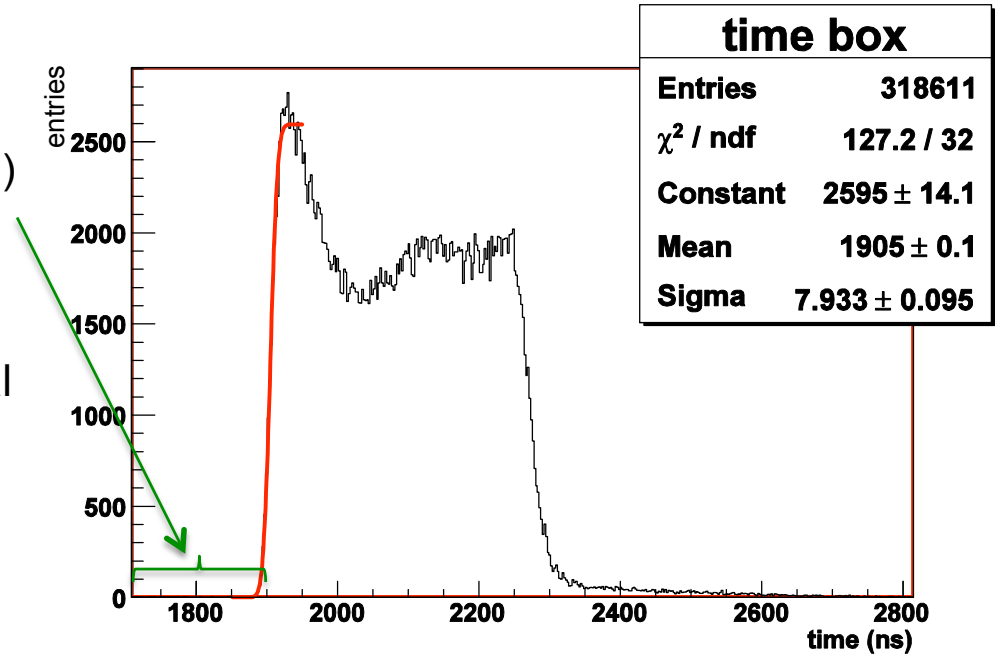
Drift Tube Calibration

Drift Tube cells make a time measurement when a muon pass through them.

To determine the effective point of the muon passage and reconstruct its trajectory (assumed the drift velocity known) it's crucial to **synchronise** all the cell measurements

Pedestal of the drift time distribution (tTrig) [due to delays on the read-out trigger chain]

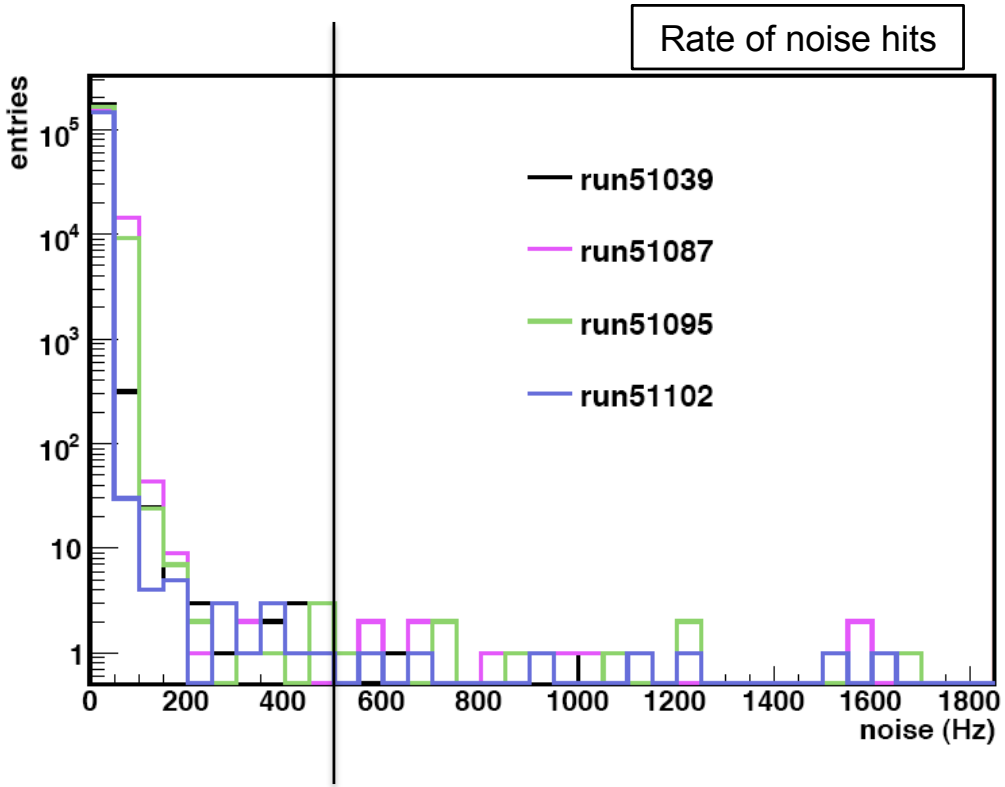
Fit to the rising edge of the drift time distribution is performed using the integral of a gaussian function (red line)



To ensure the quality of this fit it's necessary to monitor the **electronic noise**

Drift Tube Noise Studies

Noise threshold cut : N>500Hz



CRAFT commissioning

# of noisy cells < 0.1%

Noise geometrical distribution

noisy cells concentrated in:

- external part of layers
- innermost DT chambers

Noise behaviour

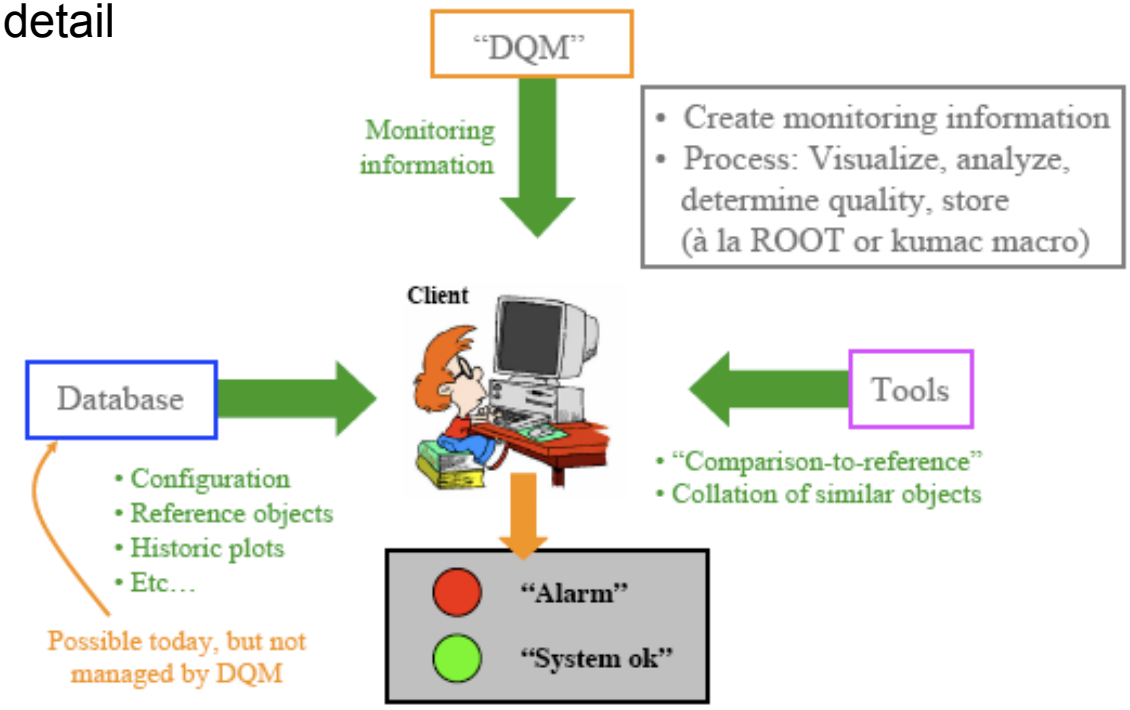
- constant in time
- grows exponentially with decreasing readout signal threshold
- not correlated with:
  - magnetic field
  - presence of other sub-detectors in the data acquisition

Data Quality Monitoring

The aim is to control and display the detector status and data quality
It was tested and used during the commissioning data taking

- based on online and/or offline analysis of events and detector parameters
- provides graphical detector synoptic view :

  - list of histograms (and results of the associated quality tests)
  - colours (which represent the results of quality test)
  - navigation at different depth of detail



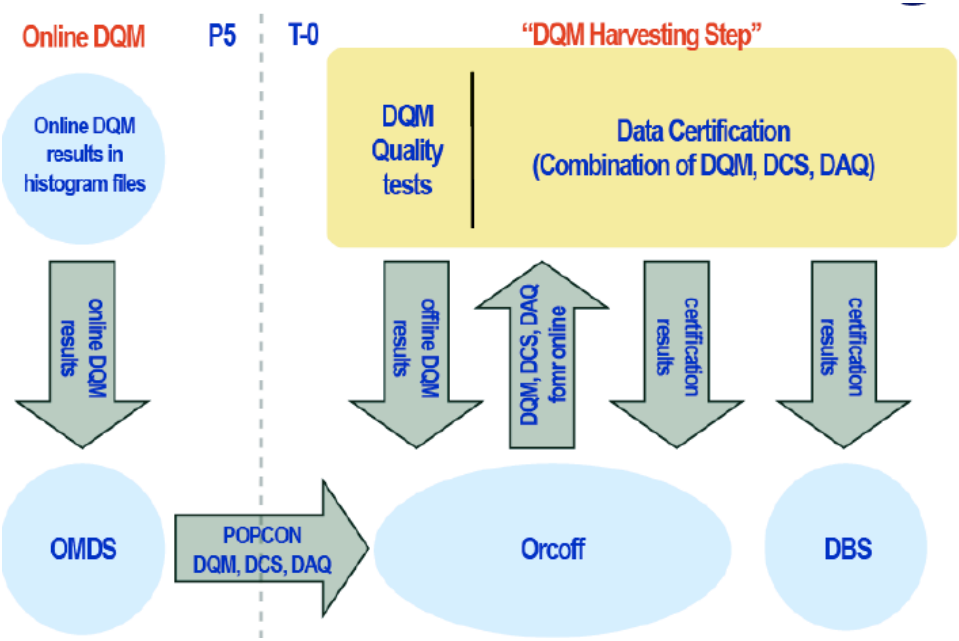
Online / Offline DQM

DQMOnline:

- runs over a percentage of the raw data
- delay of few seconds with respect to the data taking
- prompt feedback on the detector performance

DQMOffline:

- runs after the data reprocessing and has access to the full data sample using the most updated calibration constants
- delay of 1 day respect to the data taking
- prompt feedback on the calibration constants and on the quality of the reconstruction
- certify the data for analysis usage

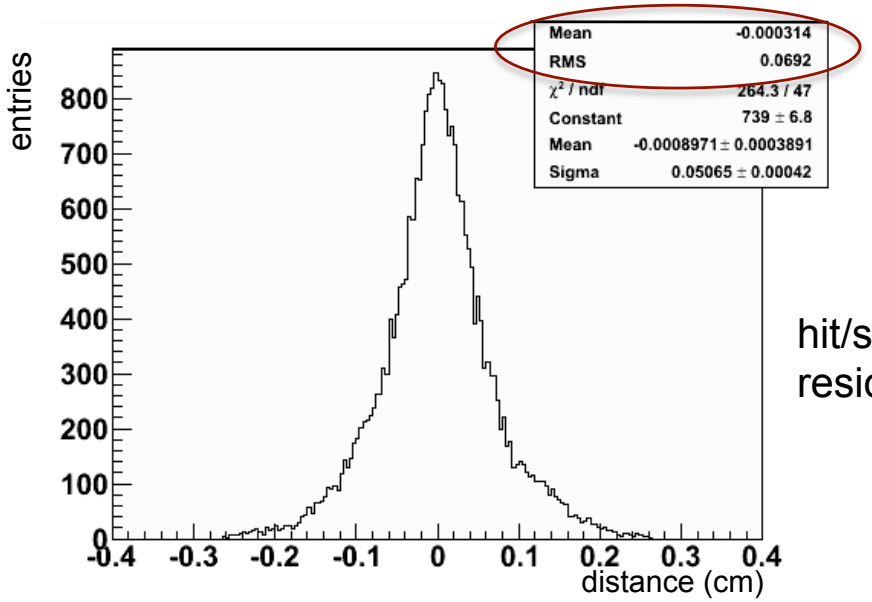


Online Monitoring of the DT Performance

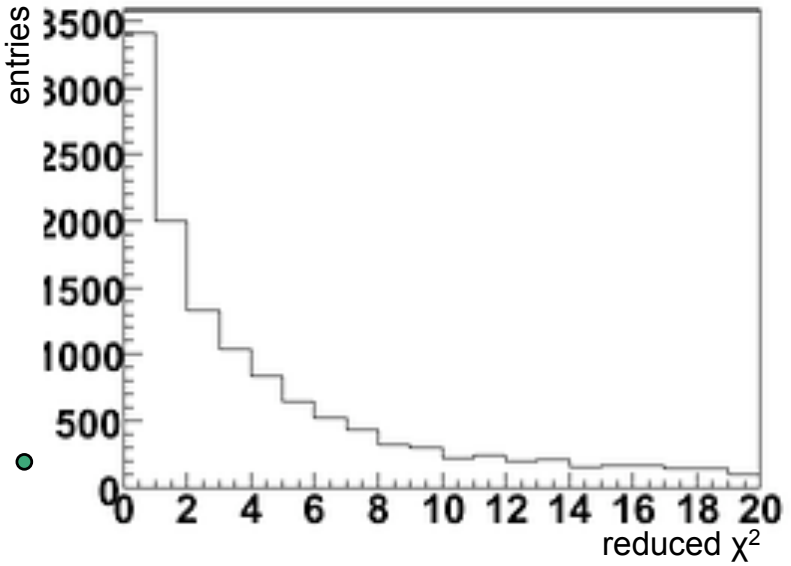
The DT online DQM monitors these main parameters :

- Data integrity
- Drift time distributions
- Hit occupancy
- Segment quality
- Local trigger
- Electronic test pulses
- Noise status

Ex. →



hit/segment residuals

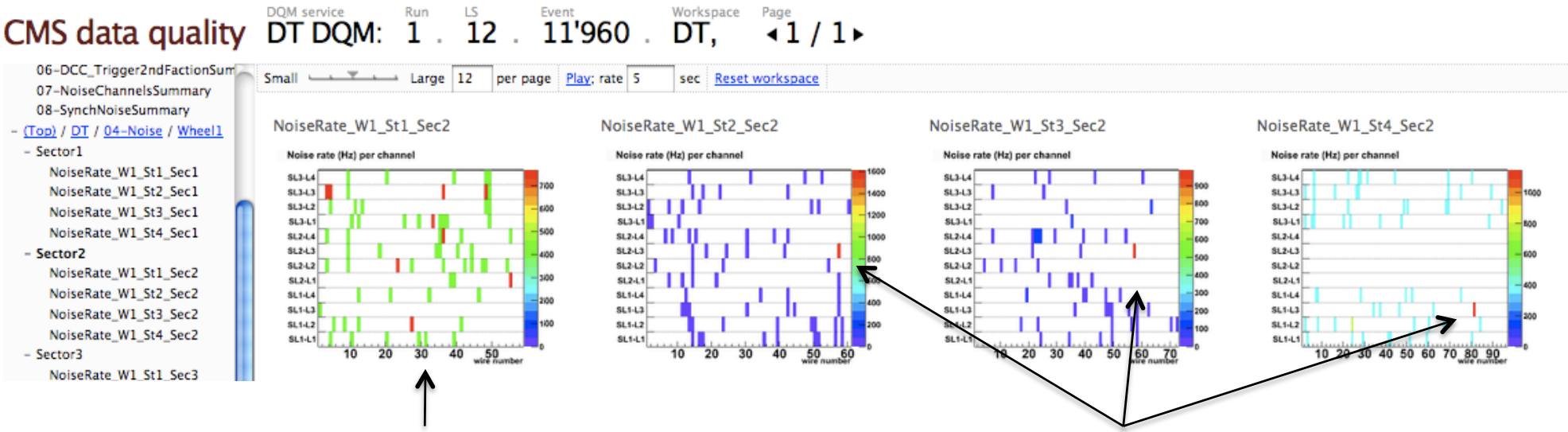


segment reduced χ^2

Online Monitoring of the DT Electronic Noise

DQM functionality:

- ✓ find noisy cells at different levels of granularity
- ✓ results summarized in 2D histograms

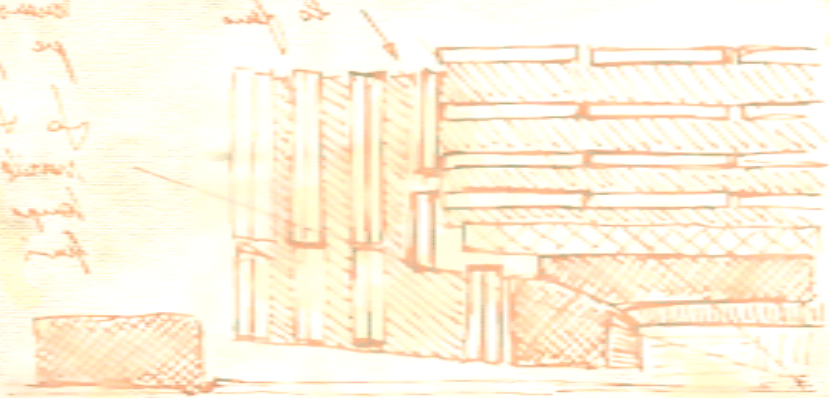


more noise on station 1

noisy cells positioned within the last 10 cells

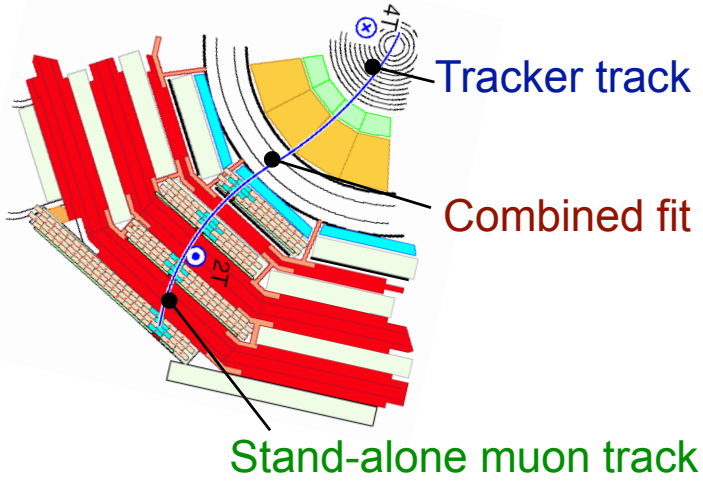
Note: noise detailed studies confirmed by the DQM prompt analysis tool

Muon reconstruction in the whole CMS detector



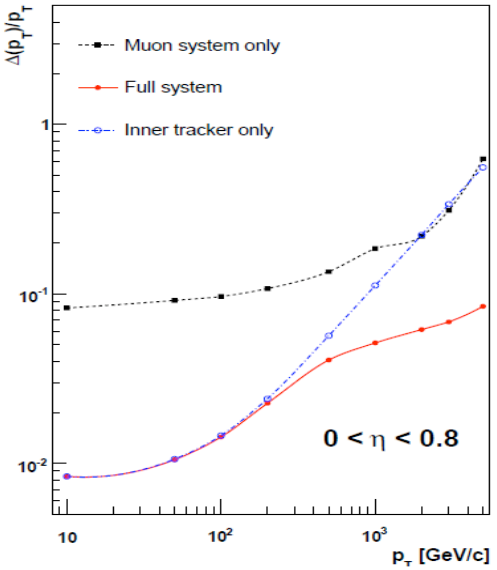
Muon Reconstruction

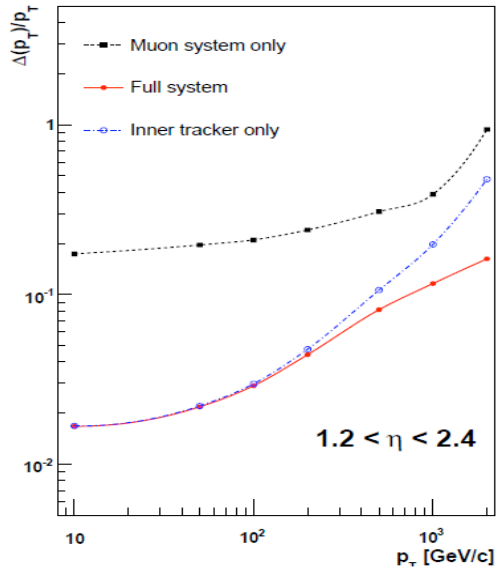
- StandAlone Muons (DT, CSC, RPC):
  - low background
  - low resolution at low p_T (multiple scattering)
  - important contribution to the resolution at high p_T



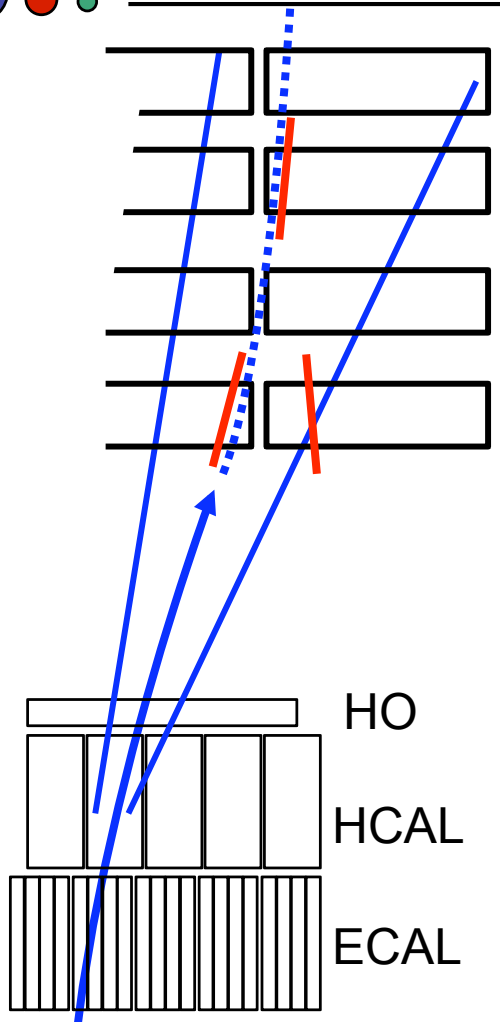
- Tracker Muons:
  - high background (hadrons, electrons)
  - very good resolution p_T< 100 GeV/c

- Global Muons (matching):
  - purity from Standalone
  - Tracker resolution





The Reconstructed Muon Collection



- Track fits
  - StandAlone muon track
  - Tracker track + matched information
  - Global track + TeV muon refits (using only first muon station)
- Muon identification variables
  - Matched muon chambers + segments
  - Deposited energy in ECAL, HCAL, HO
- Muon arrival time and velocity
- Isolation information

A muon object is mainly a track
but it contains also other information
↓ **DQMOffline**

✓ check the algorithm which has generated it
✓ monitor all the tracking objects (seeds, track parameters)
✓ consider all the additional information not directly associated to the fit procedure

Muon DQM Offline Certification

I've implemented a framework which provides the full monitoring and validation chain, from the histograms production to the final certification of the μ collection

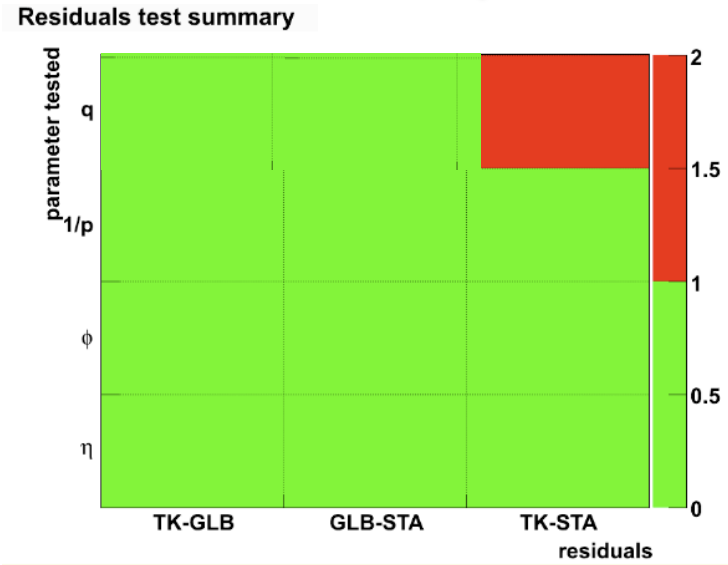
→ List of plots concerning the muon parameters
[coming from all the different CMS subdetectors]

→ Automatic tests to the relevant quantities
[thresholds tuning, dependence from the data sample]

→ Few summary plots with the results ("quality flag") of the tests
[to have an immediate view of the reconstruction status]

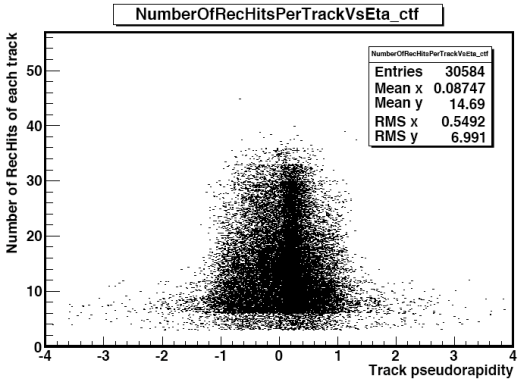
→ Final sentence of the muon reconstruction status
[matching of all the quality flags, complex metrics]

Ex.

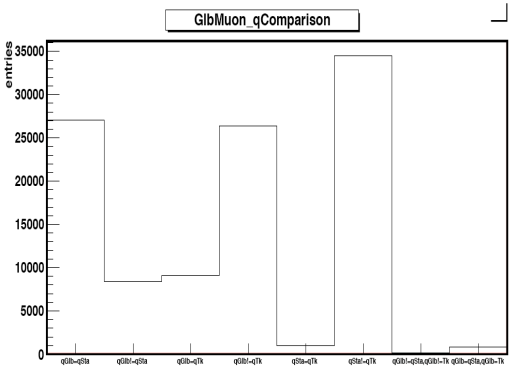


Muon Parameters (1)

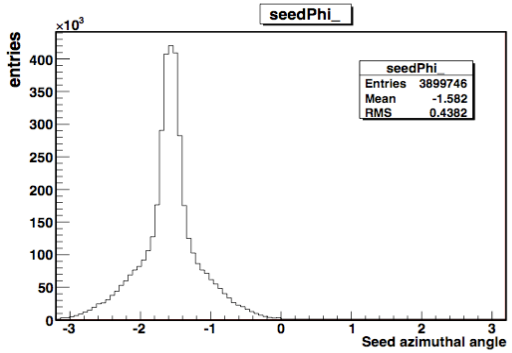
- Track variables
  - track quality (χ^2, number of RecHits ...) [and dependence of (η, Φ, ϑ)]
  - distance to beamline [and dependence of (η, Φ, ϑ)]
  - momentum: components + errors



- Comparison among the different Glb muon part (Glb/Sta_Glb/Tk_Glb)
  - charge comparison
  - residuals on η, $1/p_t$, 1/p, Φ, q/p, q/p_t, ϑ and their correlations

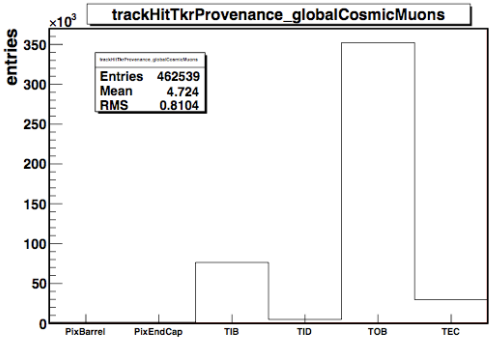


- Track seeds
  - direction, number of RecHits, momentum [and dependence of (η, Φ, ϑ)]

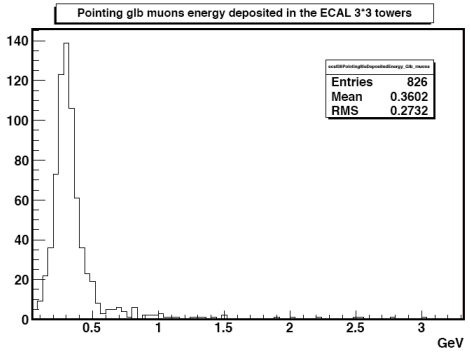


Muon Parameters (2)

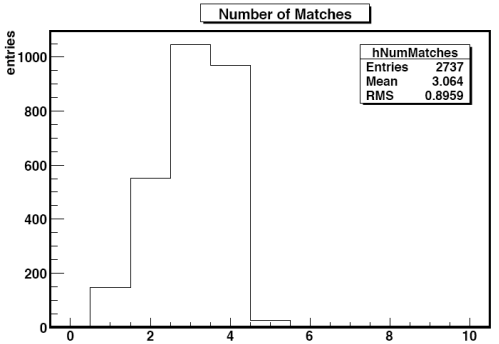
- Track hits
  - provenance
  - percentage notUsed/Used



- Muon energy deposits (single cells, 3×3 towers)
  - ecal, hcal, h0
  - barrel, endcap

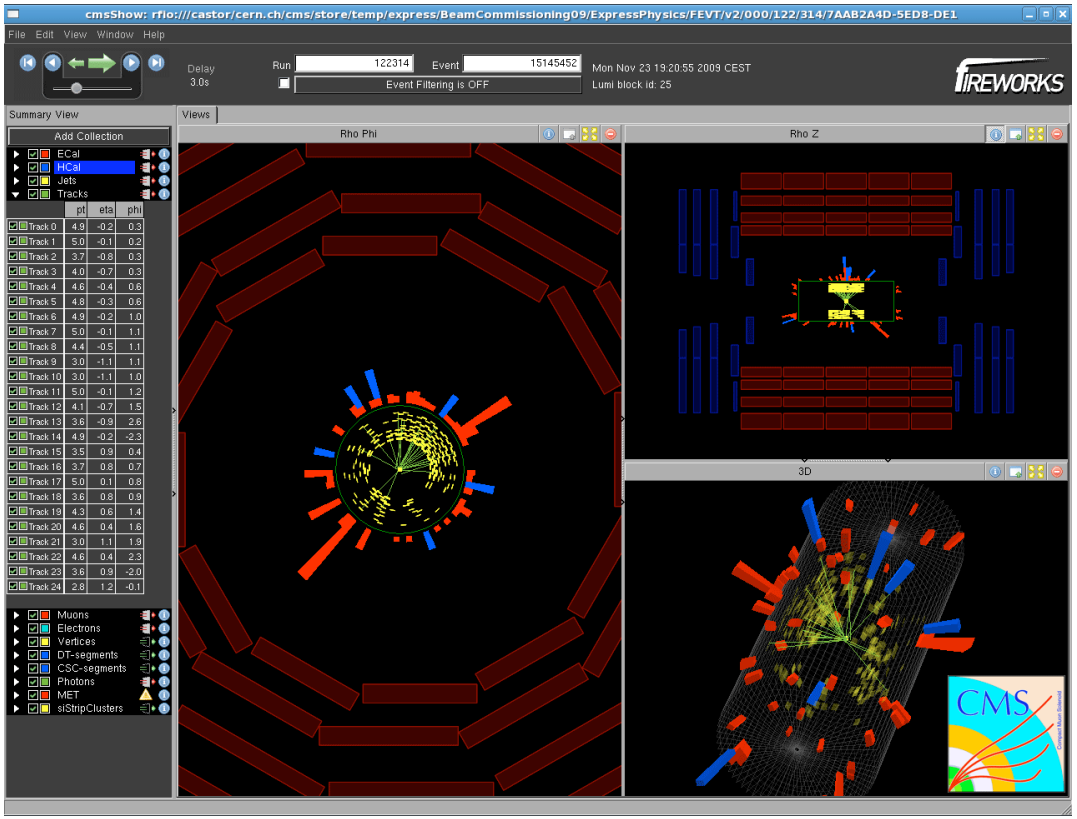


- Muon identification quantities
  - # of chambers with matching segm
  - residuals between segm/track + errors



From Cosmics To Circulating Beams

On 23th November 2009, the LHC generated its first proton-proton collisions

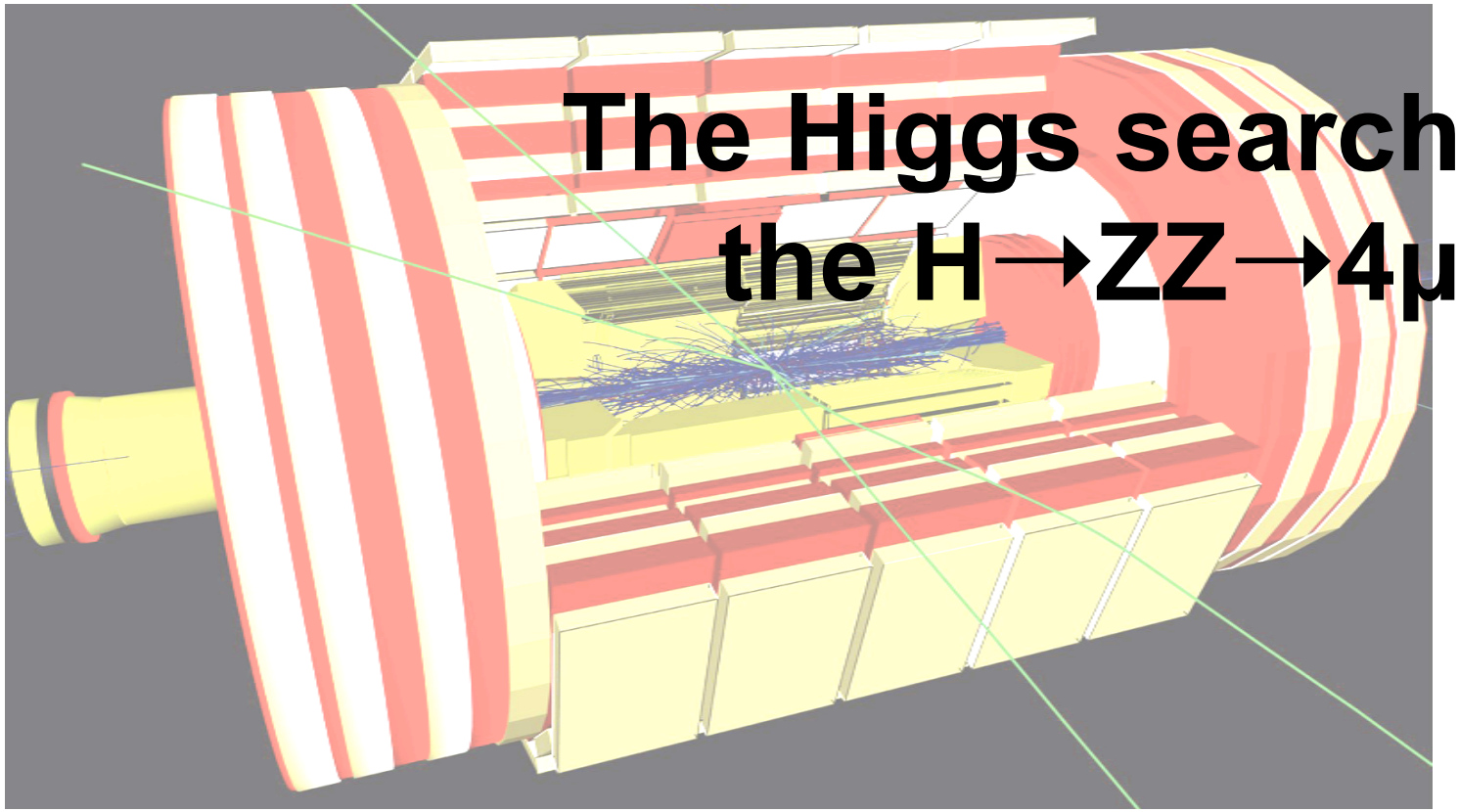


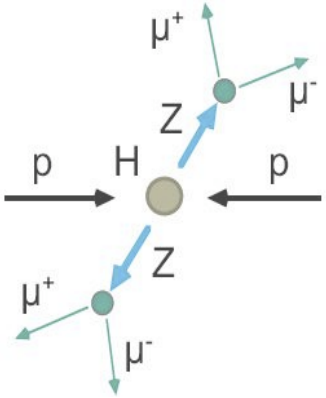
Thanks to the commissioning phase

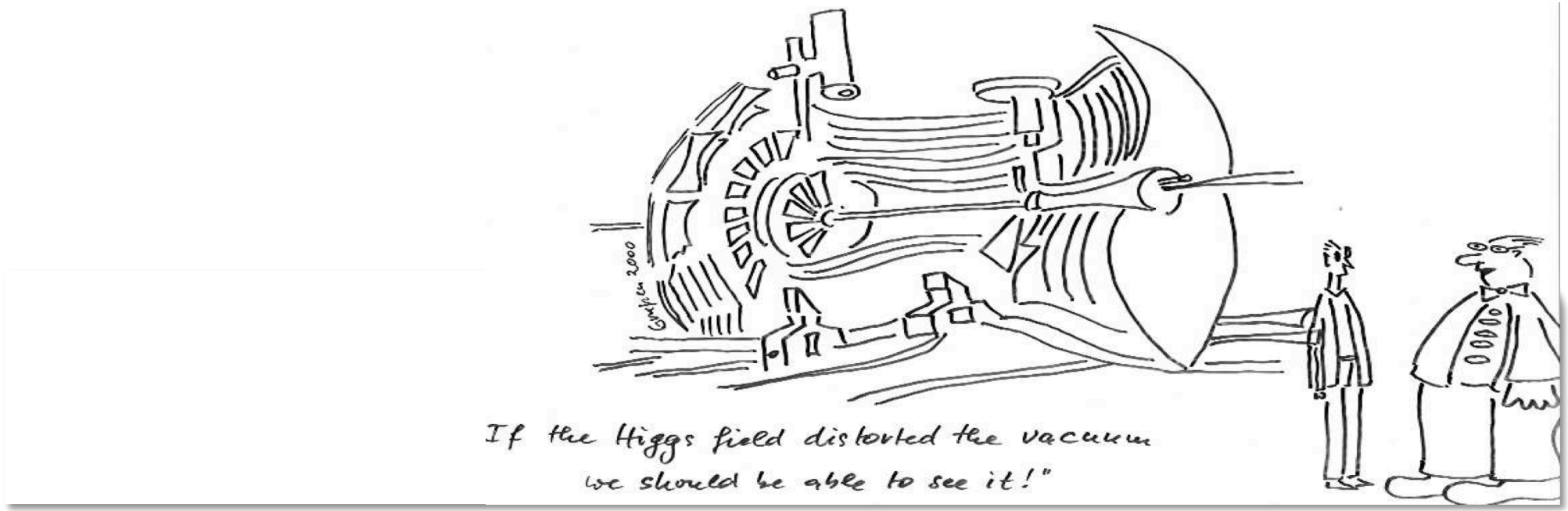
[- studies on the detector response and performance
- exercises on the calibration and alignment procedures
- discovery and fix of unexpected problems
- development and test of the Data Quality Monitoring tools]

CMS was ready to analyse nearly "on-the-fly" the first collision events

The Higgs search through the H→ZZ→4μ channel







Analysis Main Concepts

- ✓ Analysis strategy to spotlight the discovery potential of the H→ZZ→4μ process in the context of the start-up conditions:
  [lumi = $2*10^{33}$ $cm^{-2}s^{-1}$ || $\sqrt{s}$ = 10 TeV || 1 fb^{-1} of collected data]

- ✓ Investigation of the sensitivity for the observation of a Higgs boson with an hypothesis mass in the range from 115 GeV/c^2 to 350 GeV/c^2.

- ✓ Study conceived inside a more general analysis on the H→ZZ→4l channels combined signature.

- ✓ Separation between Higgs signal and its main backgrounds performed using a sequential set of kinematics cuts .

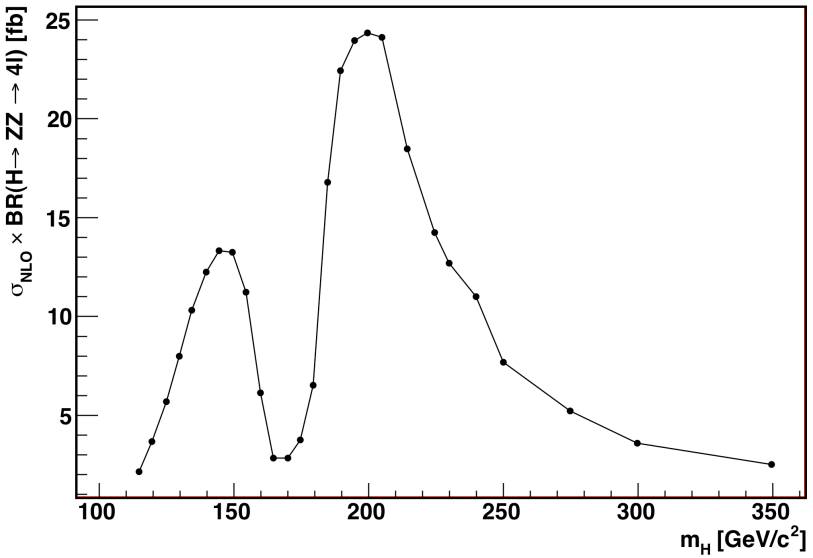
Monte Carlo Data Simulation

Monte Carlo production of the relevant physics processes:

Process	Monte Carlo	σ_{NLO} BR
$H \rightarrow ZZ \rightarrow 4l$	PYTHIA	2-25 fb
$t\bar{t} \rightarrow 2Wb\bar{b}$	MadGraph	281 pb
$Zb\bar{b} \rightarrow 4l$	MadGraph	56 pb
$ZZ \rightarrow 4l$	MadGraph	0.189 pb

Higgs mass dependence

[Plus additional bkg samples to mimic "real" data streams from CMS: variety of Electroweak and QCD processes, e.g. Z+jets and W+jets]



Preliminary Event Selection Steps (1)

Trigger selection:

- rely on the presence of one or two high p_T leptons with different threshold depending on the lepton isolation

HLT path	HLT threshold [GeV]
Single Isolated e	15
Single Relaxed e	18
Double Isolated e	(10,10)
Double Relaxed e	(12,12)
Single Isolated μ	11
Single Relaxed μ	16
Double Relaxed μ	(3,3)
Double Isolated $e, , \mu$	(8 , 7)
Double Relaxed e, μ	(10 , 10)

Event skimming:

- goal: reduce the sample size in order to preserve a manageable data volume

- at least two leptons with p_T>10GeV/c
- one additional lepton with p_T>5GeV/c

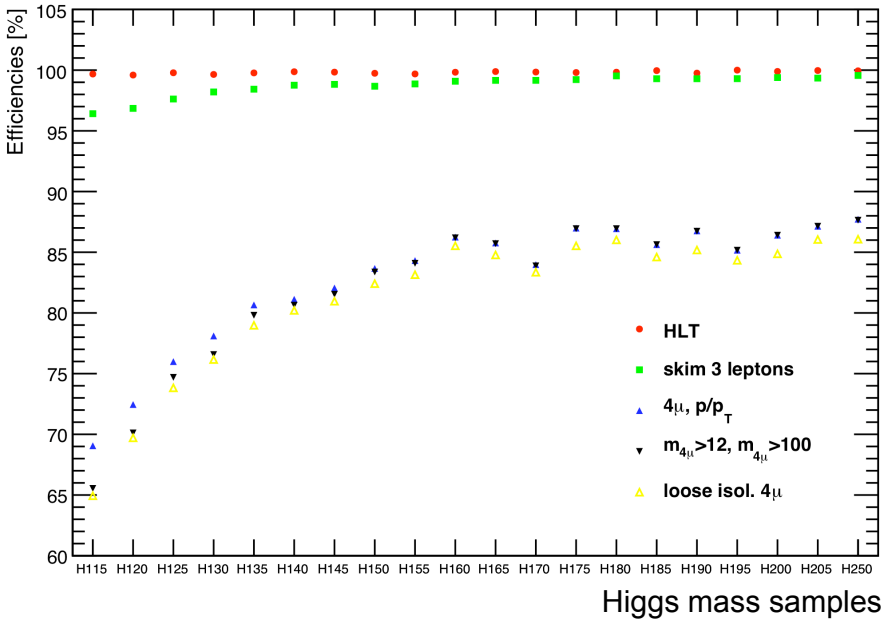
Pre-selection:

- goal: eliminate fake events, in particular from QCD

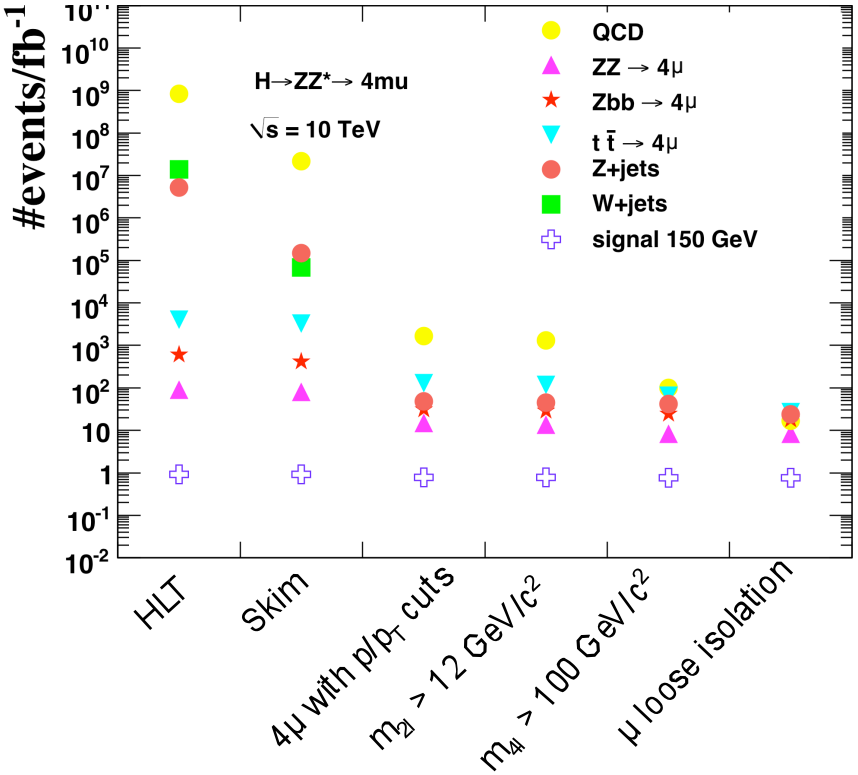
- at least two $\mu^+\mu^-$ pairs of identified muons with p_T>5GeV/c (barrel) or P^μ>9 (endcap) and $|\eta^\mu|$<2.4
- at least two $m_{\mu^+\mu^-}$>12 GeV/c^2
- at least one $m_{\mu^+\mu^-}$>100 GeV/c^2
- at least 4 isolated μ

Preliminary Event Selection Steps (2)

Signal efficiency



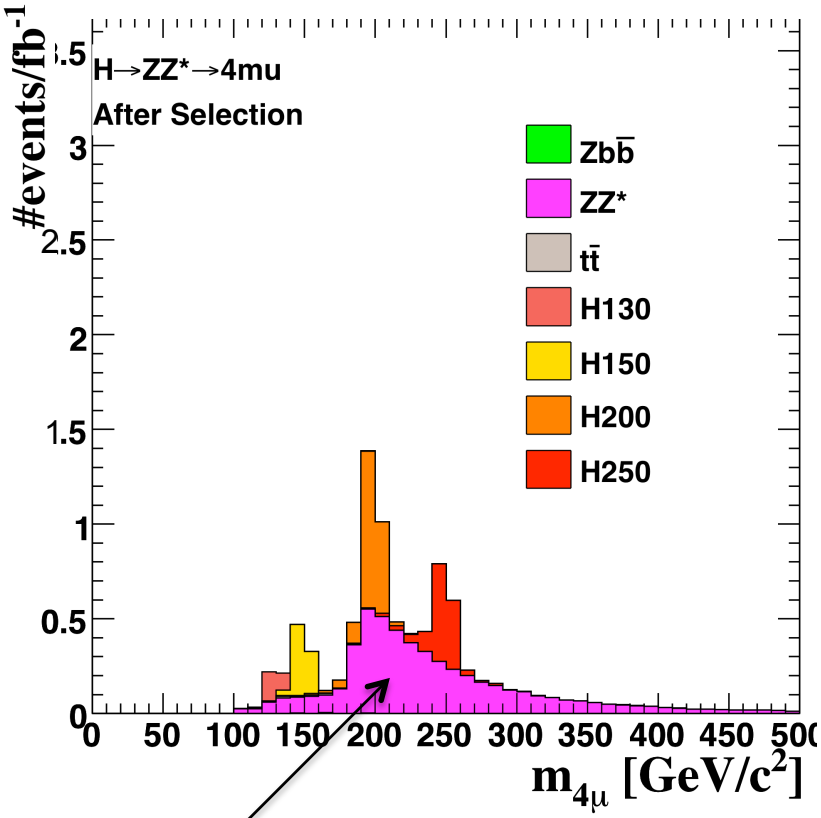
Expected events



Final Selection Cuts

Results for the H→ZZ→4μ channel

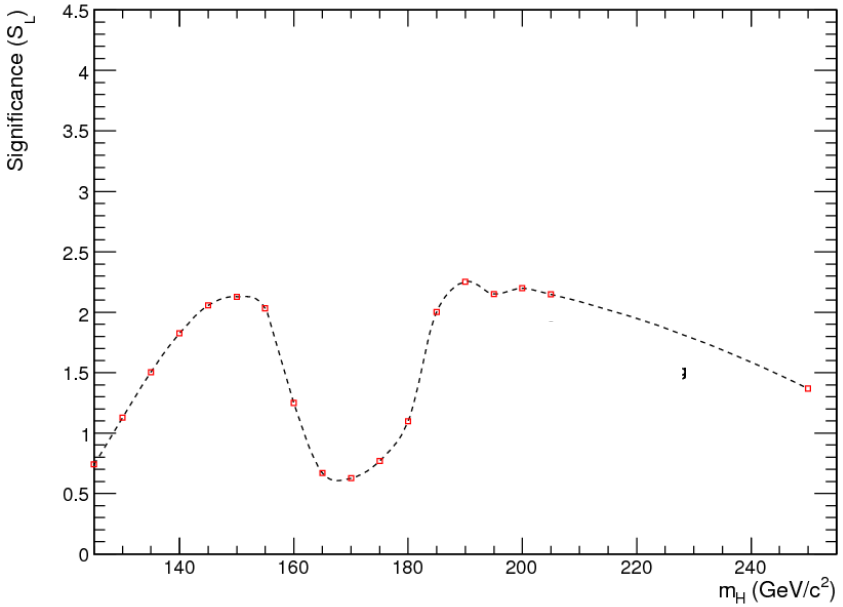
μ Isolation	$Iso_3 + Iso_4 < 30$ $Iso_3 + Iso_4 < 1.5\ p_{T,3} - 15$ $Iso_3 + Iso_4 < 2\ p_{T,4} - 10$
μ Impact Point	$IP_4 < 5$ & $IP_3 < 4$
μ Transverse momentum	$p_{T,min} > 5$ GeV/c
M_Z	[50 GeV/c^2 , 100 GeV/c^2]
M_{Z^*}	[20 GeV/c^2 , 100 GeV/c^2]



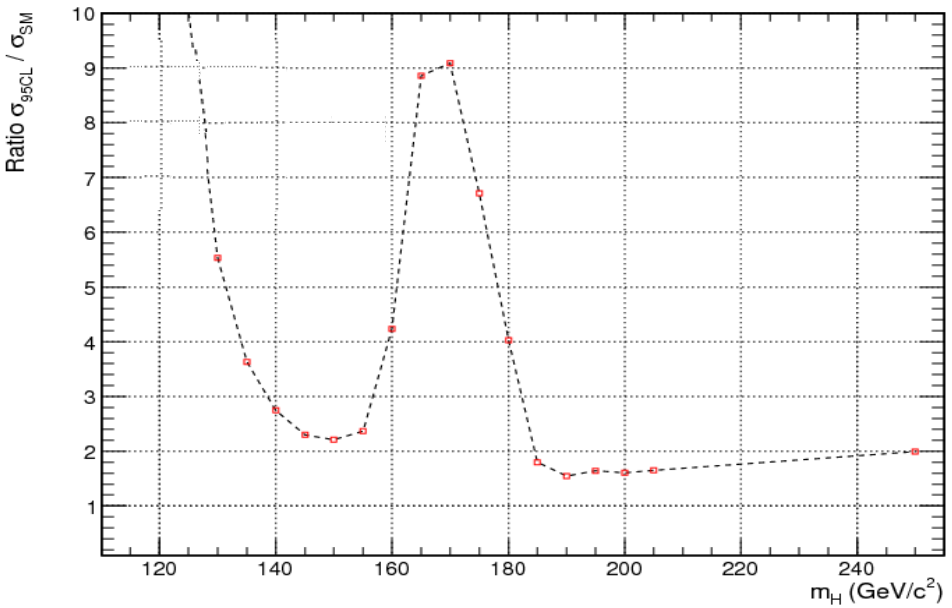
dedicated analysis to measure this background from data

Combined Results

Combined results for the H→ZZ→4l channels



significance of signal vs bkg



95% exclusion limit

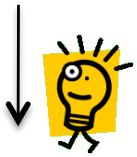
[in terms of a ratio of an excluded cross section to the Higgs boson cross section]

Probability for the background to fluctuate to a number of events ≥ the observed N_{s+b}, converted in an equivalent number of one-sided standard error of a Gaussian distribution

Measurement of the ZZ background from data (1)

It starts from the H → ZZ → 4l analysis cuts and discrimination variables.
[the ZZ process has the same kinematics of the H → ZZ → 4l final state]

One additional requirement is applied to the $Z,Z^{(*)}$ masses which have to be both on-shell [in the range 80-100 GeV/c^2 and 70-110 GeV/c^2 , respectively]



- simpler kinematics cuts
- unification of all the H → ZZ → 4l event selection criteria

to be used with the few statistics available with the first data holding the more refined cuts by a greater integrated luminosity

Measurement of the ZZ background from data (2)

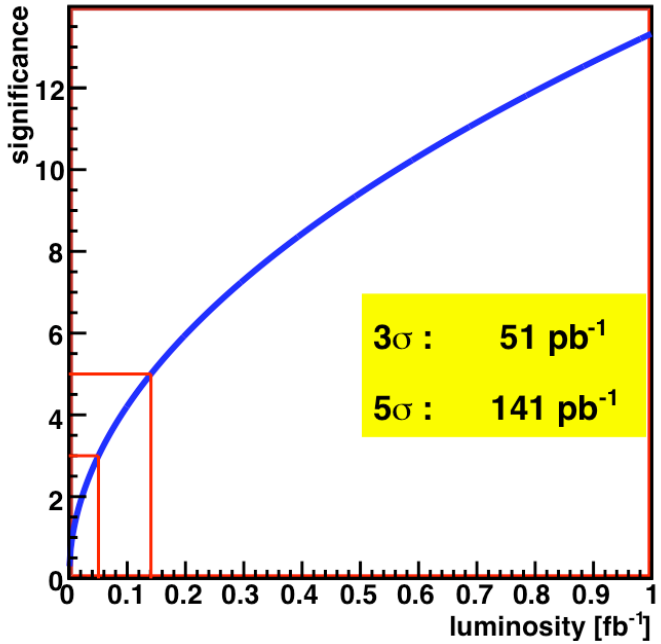
Isolation and impact point (4μ channel):

variable	H→ZZ→4μ cuts	new cuts
μ Isolation	$Iso_3+Iso_4 < 30$ $(Iso_3+Iso_4) < 1.5\ p_{T,3} - 15$ $(Iso_3+Iso_4) < 2\ p_{T,4} - 10$	$Iso_4 < 13$ $Iso_4 < 0.37\ p_{T,3} - 3.7$ $Iso_4 < 1.5\ p_{T,4} - 7.5$
μ Impact Point	$IP_4 < 5$ & $IP_3 < 4$	$IP_4 < 5$

Results (with all the 4l channels combined together)

- need of only 141 pb^{-1} of integrated luminosity to re-discovery the ZZ process

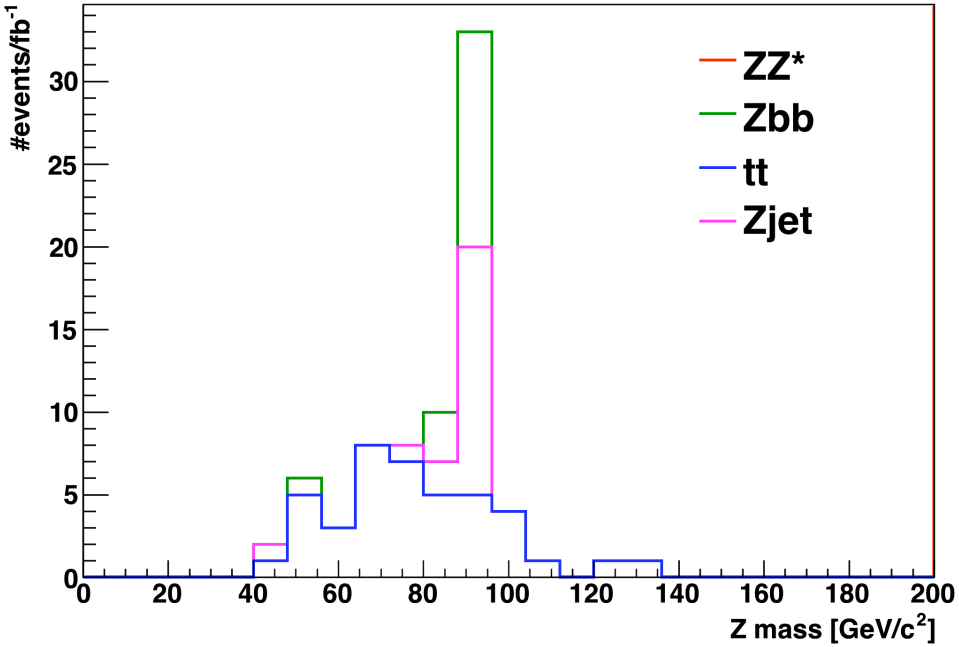
- same significance obtained using the more refined analysis selection



Measurement of the Zbb background from data (1)

- Kinematic region:
  - H → ZZ → 4l and ZZ → 4l are completely suppressed
  - Zbb → 4l, Z+jets, tt → 2Wbb are still present
- Z+jets: assumed to be separable from Zbb with other methods
- Z mass parameter: separates the Zbb and Z+jets (under the peak) from tt

Expected events with 1 fb^{-1} of data:

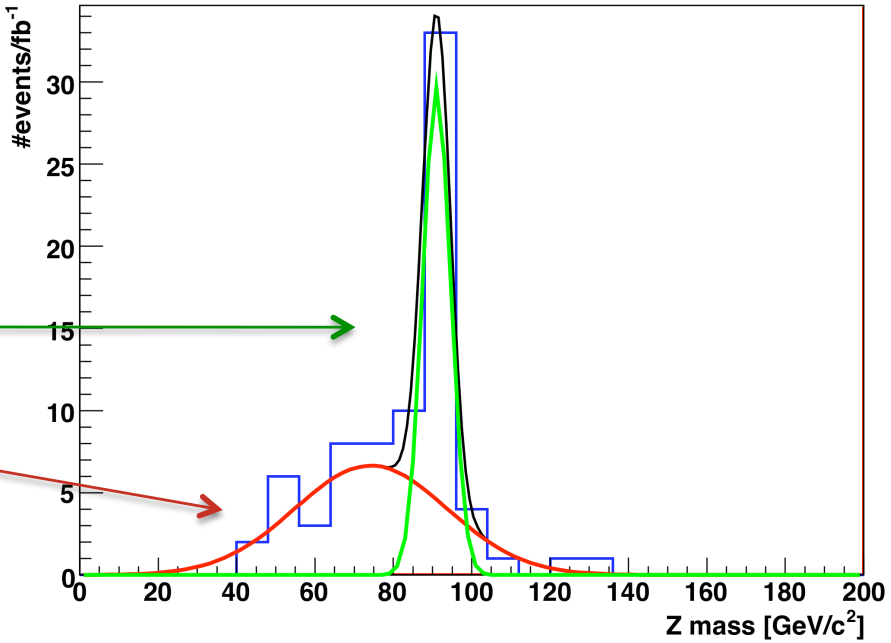


Zbb analysis: pseudo-experiment with 1 fb^{-1} of data (2)

Fit (black line) with two gaussian functions:

Expected events:

- Zbb+Z+jets = 34 ± 30%
- tt = 43 ± 30%



Systematics computation takes into account:

- ✓ comparison between the pseudo-experiment and the MC attended events
- ✓ Poissonian variations of the initial number of events
- ✓ statistical fluctuations in further pseudo-experiments with the same amount of data

Conclusions

- Detector performance and calibration investigation of the CMS Drift Tubes in different time windows and working condition.

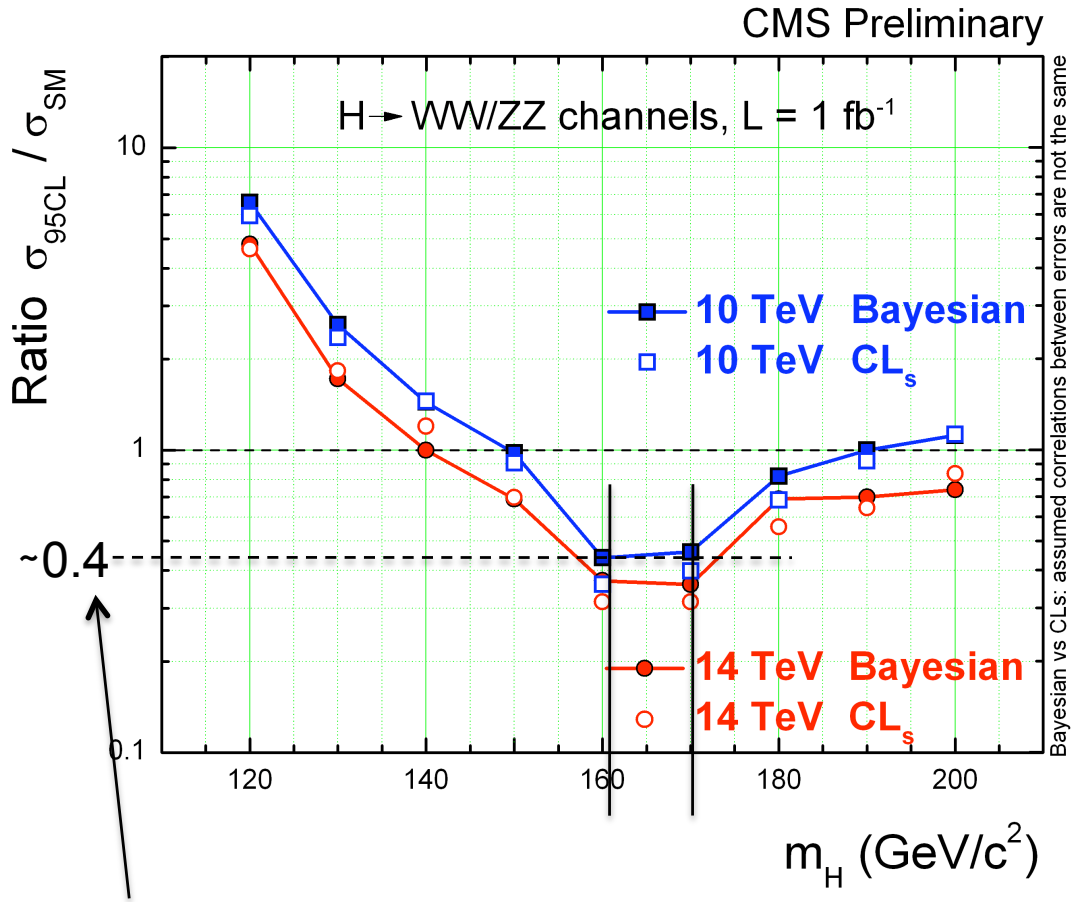
- Study of different techniques of particle track reconstruction not only in single DT detectors but also in the complex CMS environment where many different information have to be weighted and matched together.

- Implementation of a dedicated software for Data Quality Monitoring and Certification of both the DT performance and the muon reconstruction quality.

- Analysis of the H→ZZ→4μ discovery potential . Studies performed on signal kinematics signature, background rejection (through a sequential set of cuts) and computation from data.

BACKUP SLIDES

Higgs sensitivity @ 10 TeV



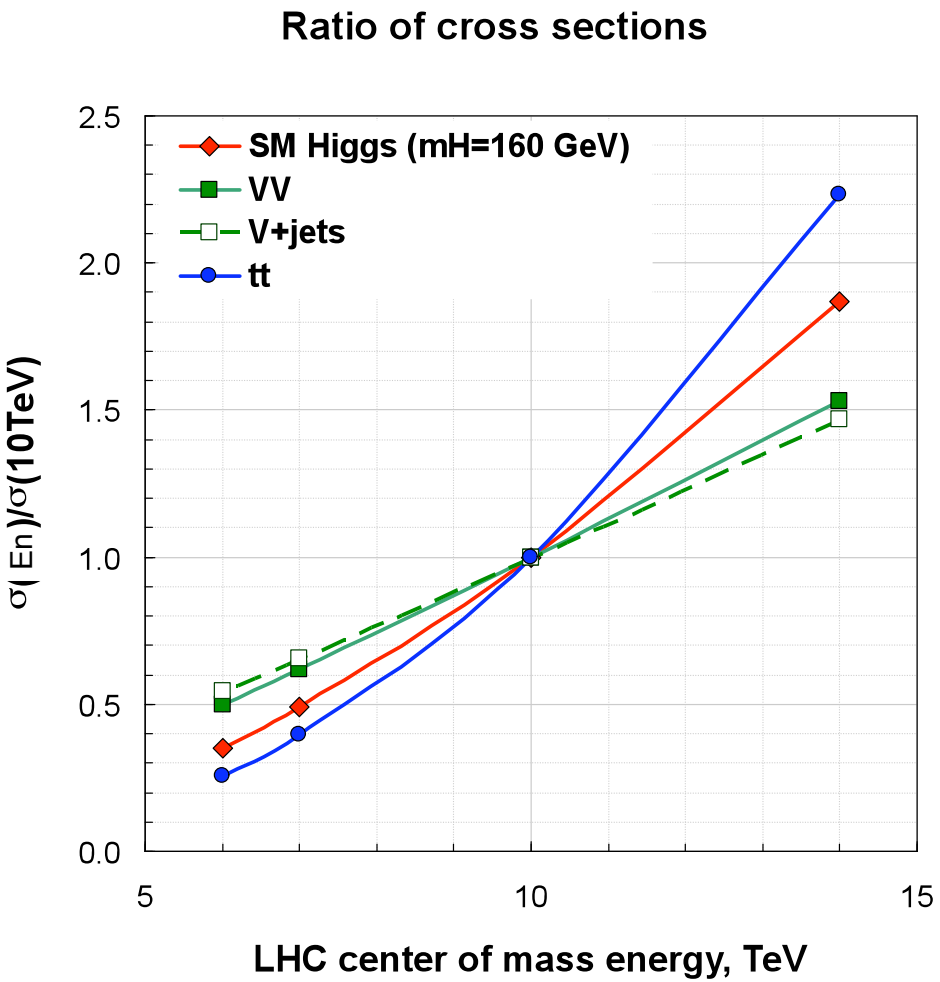
95% exclusion limit in terms of a ratio of an excluded cross section to the Standard Higgs boson cross section

Two different approaches, Bayesian and CL_S, give consistent results

The relative difference in the ration *r* for 14 and 10 TeV p-p collision energies is a factor 1.5
→ at 10 TeV needed twice the luminosity to have a comparable sensitivity of 14 TeV

By simple statistic interpolation:
Needed only 200 pb^{-1} to exclude the Higgs boson in the 160-170 GeV/c^2 mass range

Higgs sensitivity @ 7 TeV



Due to variation of the Higgs and its backgrounds cross sections :

(10 TeV) : (7 TeV) = 2.5

Increasing factor of luminosity needed