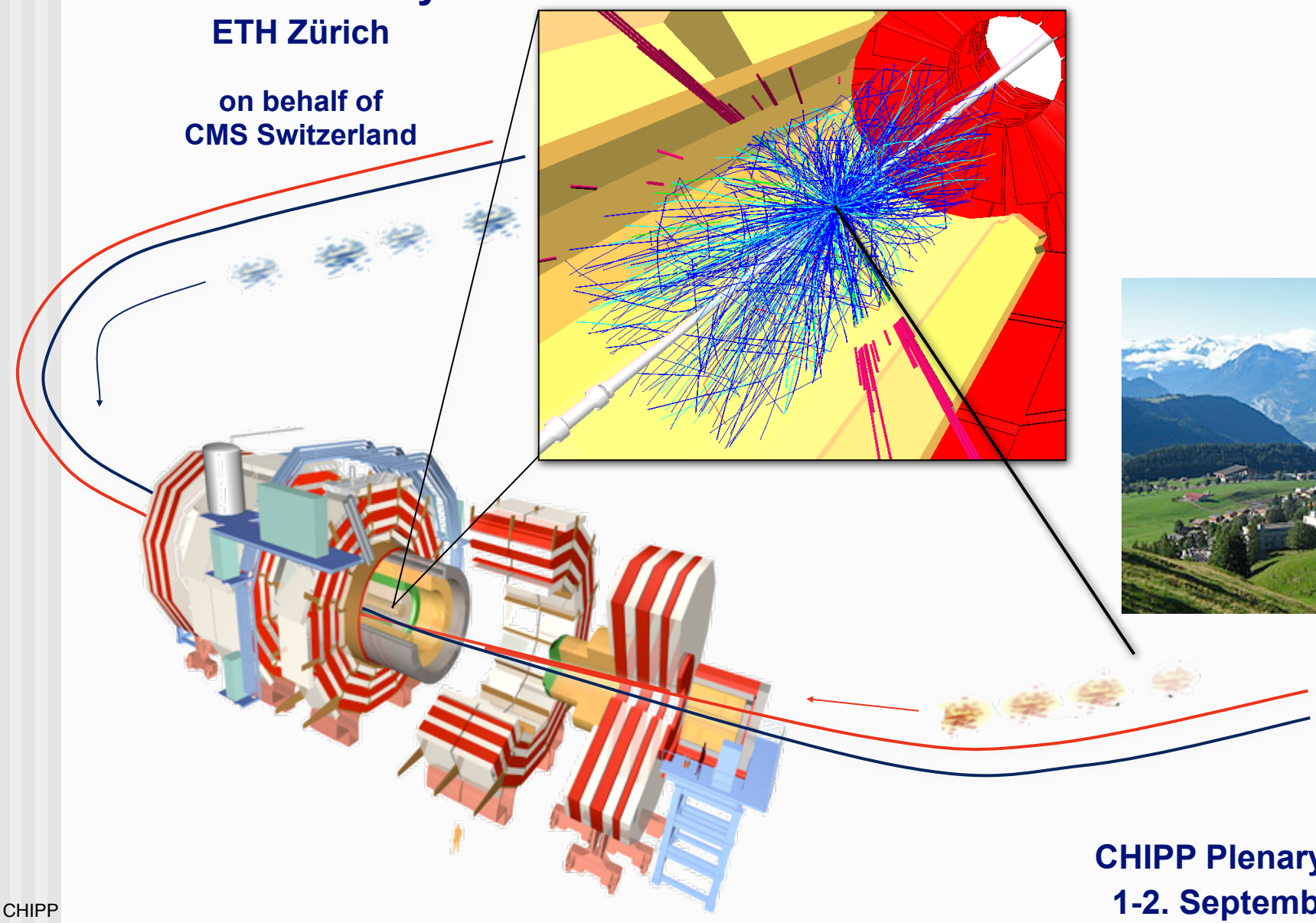
CMS Physics Status Report

Rainer Wallny

ETH Zürich

on behalf of
CMS Switzerland



CHIPP Plenary Leysin,
1-2. September 2011

Outline

- Switzerland and CMS
  - involved groups and roles within CMS
- CMS detector operations and performance
- Recent summer conference “score card”
  - Lepton Photon 2011 and EPS 2011
- Selected Physics results
  - Personal selection of most recent results
  - Biased towards analyses with Swiss contributions
- Conclusions

The Swiss CMS community

ETH Institute for Particle Physics

ETH Zurich

B.Casal, N.Chanon, G.Dissertori, M.Dittmar, M.Donegà, C.Grab, W.Lustermann, P.Martinez Ruiz Del Arbol, F.Moortgat, F.Nessi-Tedaldi, L.Pape, F.Pauss, A.Rizzi, F.Ronga, L.Sala, A.Starodumov, M.Takahashi, A.Thea, K.Theofilatos, D.Treille, R.Wallny, J.Weng

P.Bortignon, M.-A.Buchmann, L.Bäni, J.Eugster, P.Milenovic, P.Nef, C.Nägeli(*), M.Rossini, A.Sanchez, B.Stieger, C.Urscheler, M.Weber, H.Weber, L.Wehrli

D.Da Silva Di Calafiori, L.Djambazov, M.Dröge, G.Faber, C.Haller, O.Holme, U.Horisberger, U.Röser, H.Von Gunten, S.Zelepoukine

(*) also PSI

PSI Villigen

W.Bertl, K.Deiters, W.Erdmann, R.Horisberger, Q. Ingram, H.Kaestli, D.Kotlinski, U.Langenegger, T.Rohe

F.Meier, J.Sibille

D.Feichtinger, F.Martinelli, B.Meier, S.Streuli

University of Zurich

E.Aguilo, C.Amsler, V.Chiochia, S.De Visscher, P.Otiougova, C.Regenfus, P.Robmann, A.Schmidt, H.Snoek, J.Storey

C.Favaro, R.Ivova, B.Millan, M.Verzetti

J.Rochet, S.Steiner

41 Physicists
20 PhD students
16 Engineers/ Technicians
77 Total

Swiss "Hats" in CMS

ETH Institute for Particle Physics

- Physics leadership roles:
  - Deputy Physics coordinator: G. Dissertori [ETH]
  - B-physics convenor: V. Chiochia [UZH]
  - B-physics inclusive convenor :W. Erdmann [PSI]
  - SUSY leptonic searches: F. Ronga [ETH] → F. Moortgat [ETH]
  - jetMET: F. Moortgat [ETH]
  - E/gamma: P. Meridiani [ETH]
  - b-tagging and vertexing: A. Rizzi [ETH] → A. Schmidt [UZH]

- Roles in Management, Detector/Hardware and Upgrade :
  - Swiss Regional Representative of the CMS Management Board: Q. Ingram [PSI]
  - Chairman of the Pixel Upgrade Management Board: R. Horisberger [PSI]
  - Chairmain of the ECAL Institution Board: Q. Ingram [PSI]
  - Barrel Pixel Upgrade Coordinator: W. Erdmann [PSI]
  - Deputy tracker project manager: V. Chiochia [UZH]

Swiss “Hats” in CMS

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Günther

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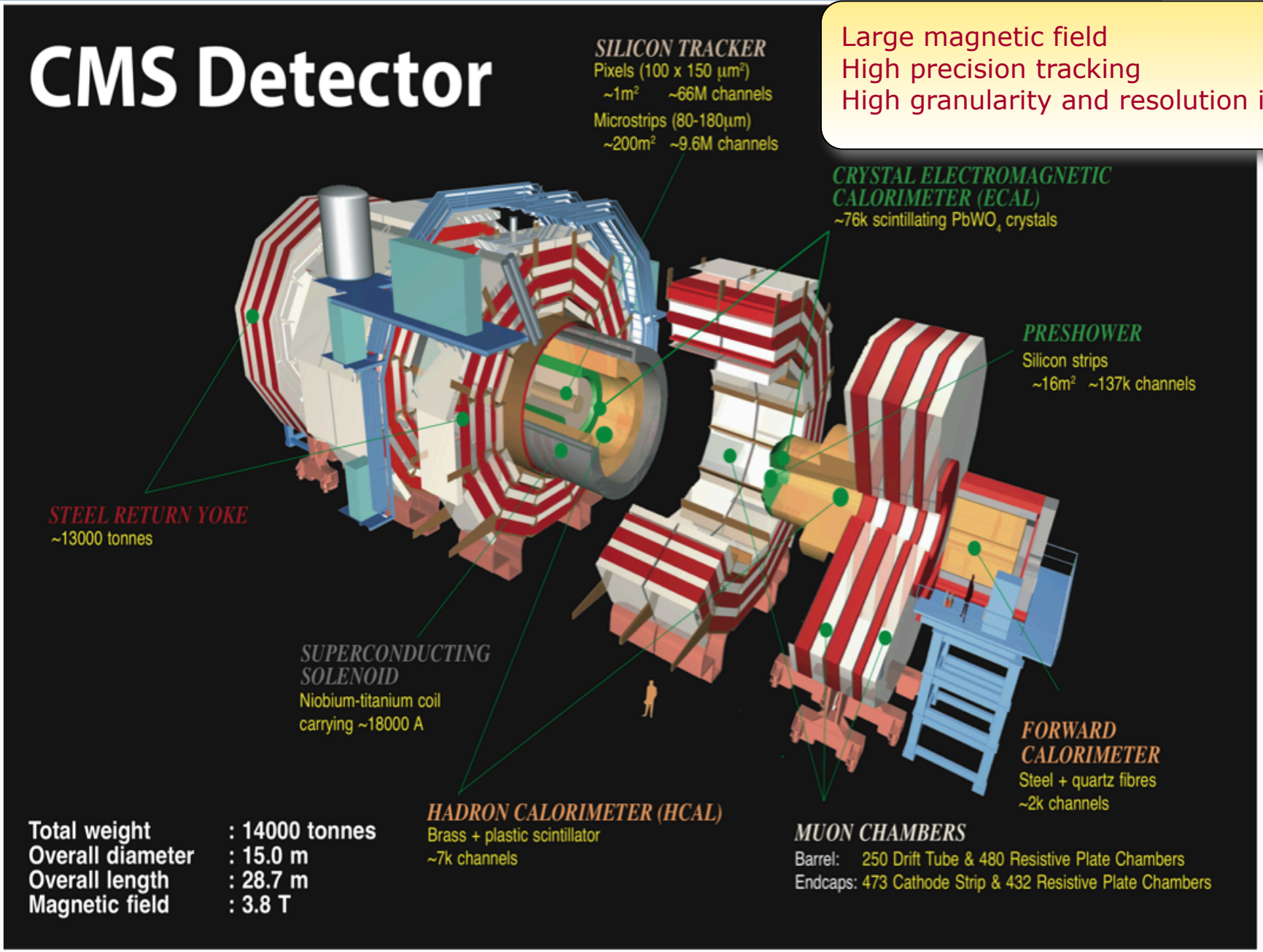
The CMS Detector

ETH Institute for Particle Physics



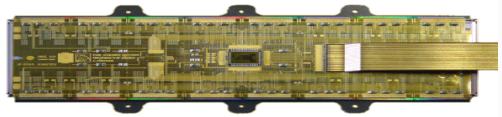
Large magnetic field
High precision tracking
High granularity and resolution in ECAL

CMS Phase 1 Upgrade (2017)

ETH Institute for Particle Physics

BPIX upgrade

- 4 layers (1216 modules, 1.6x current BPIX)
- CO2 cooling
- reduced dead material
- digital readout chip (PSI)



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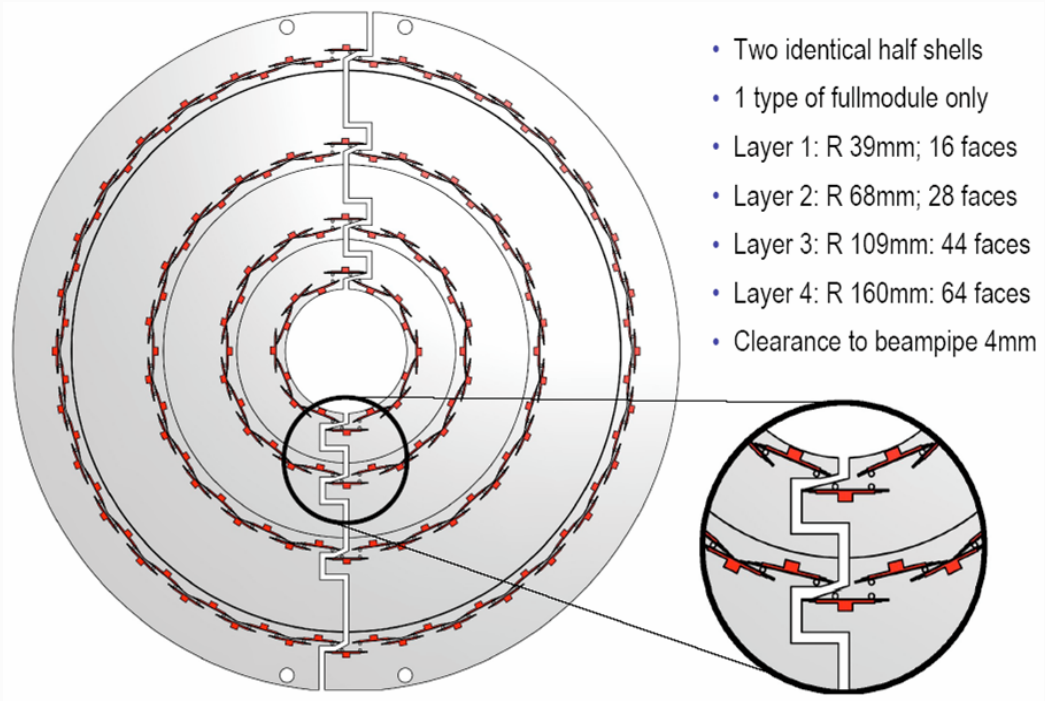
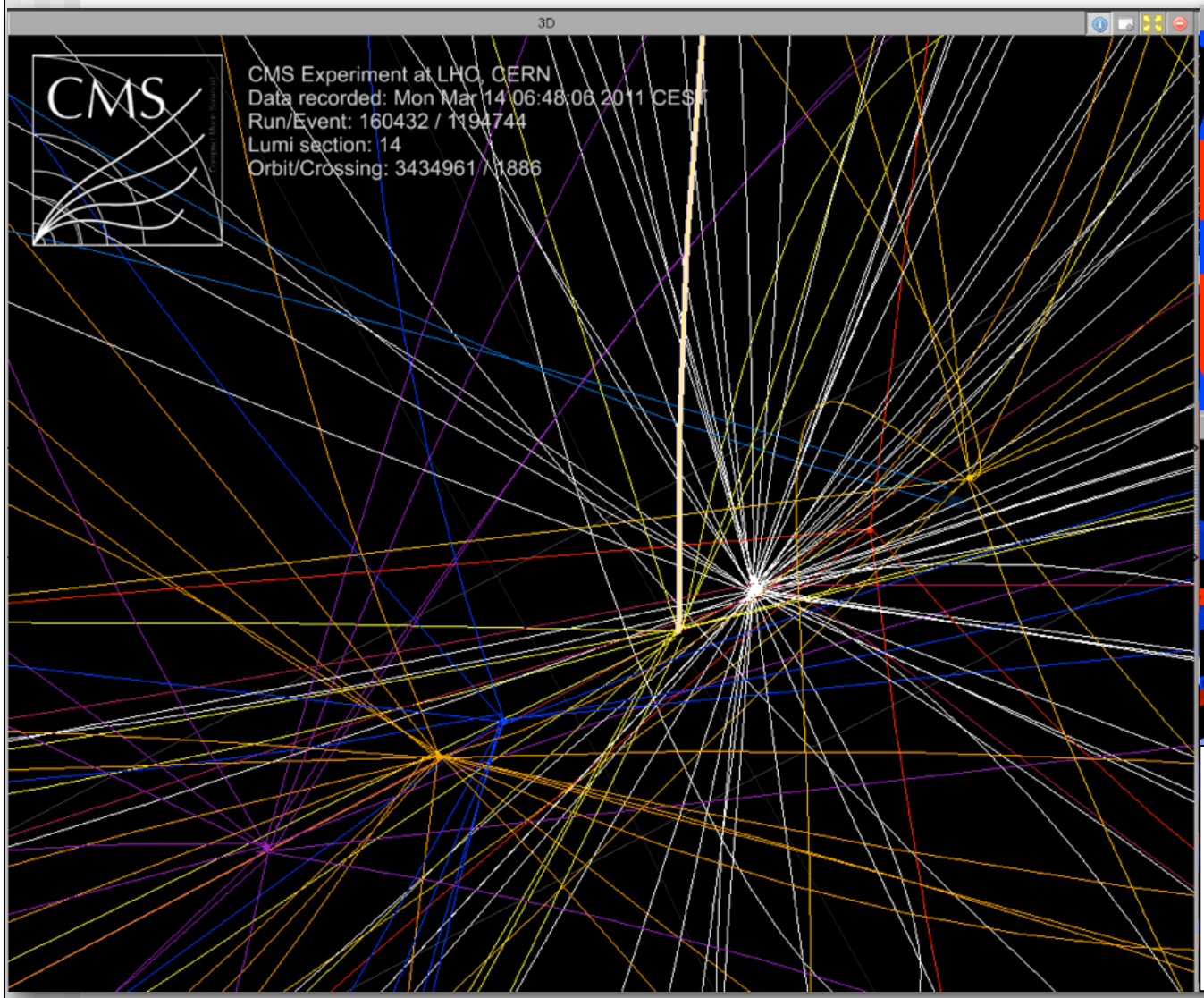


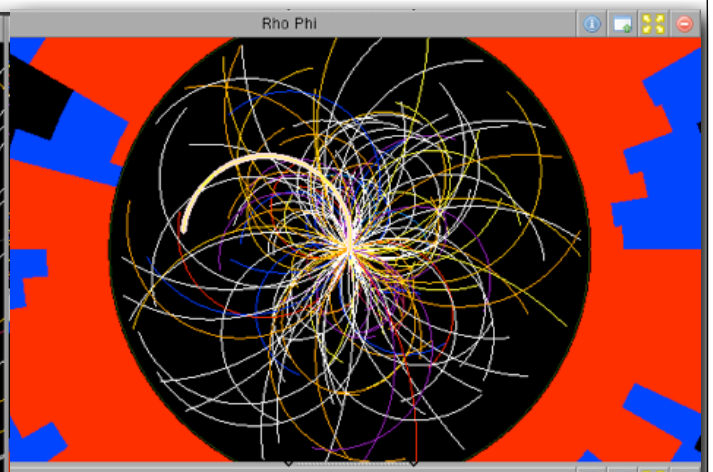
CH consortium

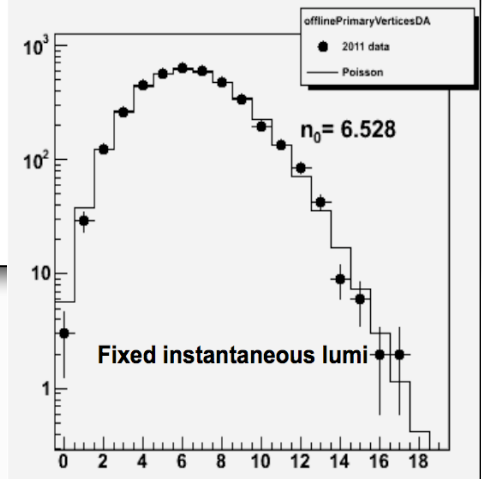
- build innermost two layers (30%)
- production at PSI
- module testing at ETH
- supply tube construction by UZH
- develop new module testing procedures

New data, new challenges

ETH Institute for Particle Physics







current peak lumi 2.4×10^{33} $cm^{-2}s^{-1}$ →up to ~15 pile-up events

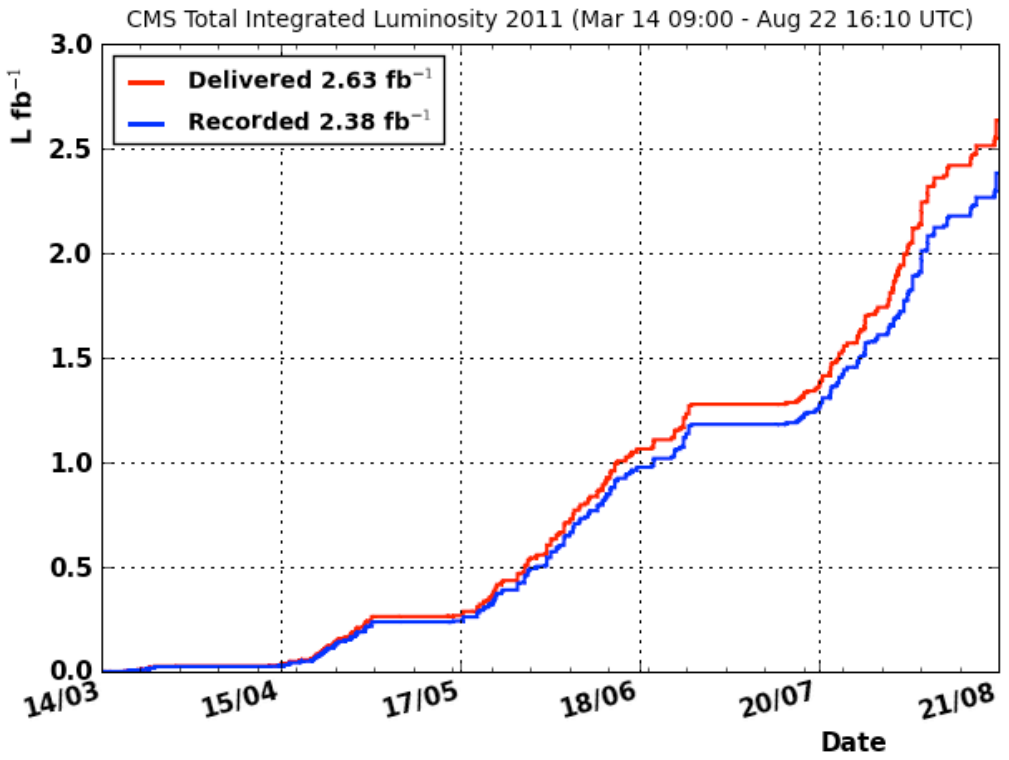
Mitigation on all fronts: Trigger, Reconstruction, Analysis, Computing

CMS Detector Operation

ETH Institute for Particle Physics

ETH/ UZH/PSI

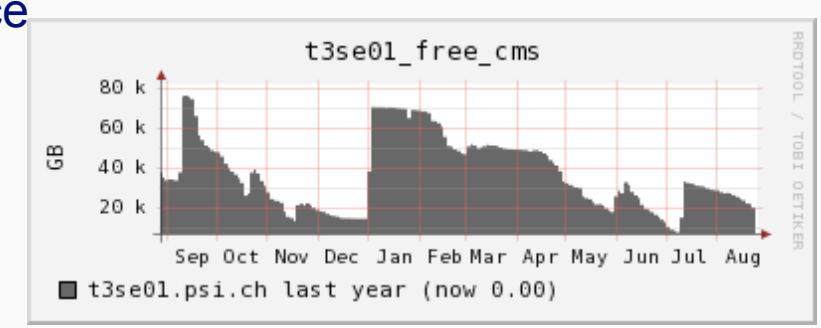
- **2.6 fb^{-1}** delivered by LHC and **2.4 fb^{-1}** recorded by CMS
- Overall data taking efficiency ~90%.
  - Average fraction of operational channels per subsystem >98.5%
  - Currently certified data for physics: Golden 2.1 fb^{-1} (81%), Muon 2.2 fb^{-1} (87%).
- We carry our share in detector operations
  - Run Field Managers
  - Shift leader and central shifters (DCS, DAQ, DQM, Trigger)
  - Detector on-call experts (DOCs)
  - higher-level detector experts
- Also:
  - Data quality monitoring
  - Detector calibrations
  - offline reconstruction
  - ….

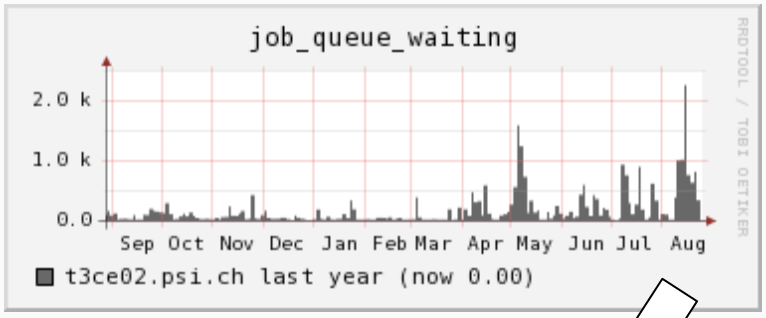


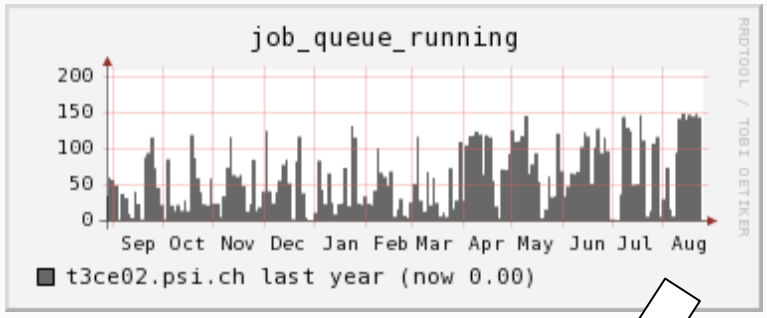
Tools: Computing

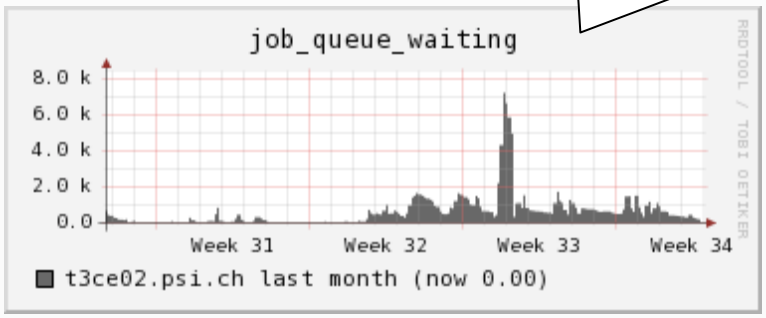
- All Swiss CMS groups finance and share a common TIER3 which is heavily used
- located at PSI (infrastructural support by PSI IT)
- 3271 HS06 CPUs with 253 TB disk space
- next upgrade envisioned soon
  - commensurate with surge in LHC data and 2012 running

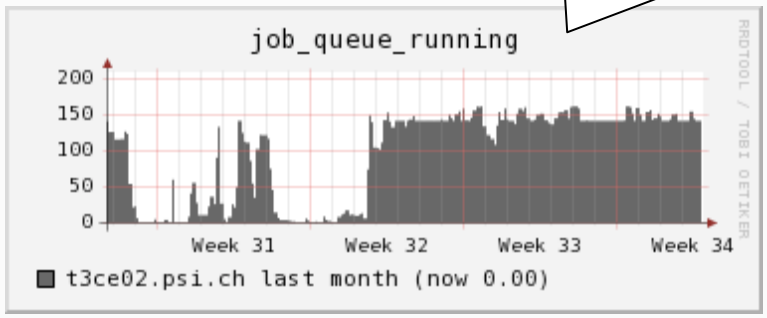
PSI
UZH
ETH









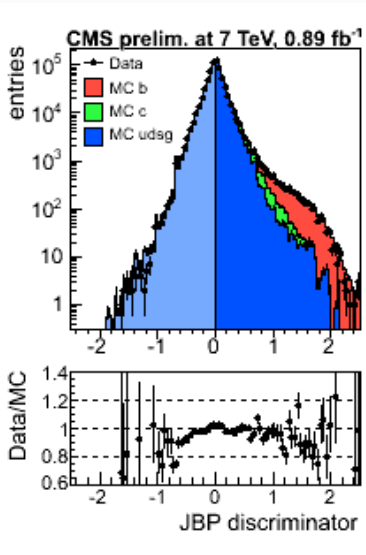


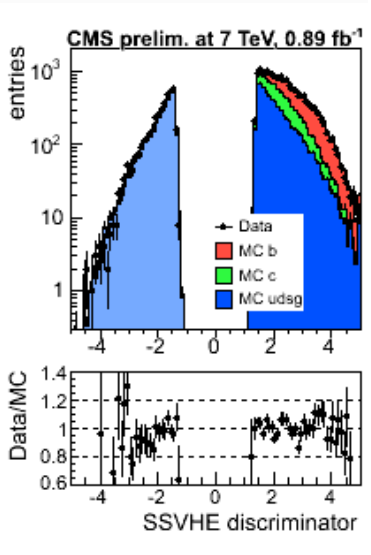
Tools: B-tagging performance

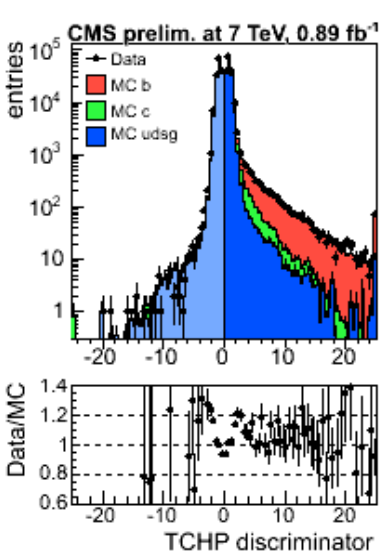
ETH Institute for Particle Physics

UZH/ ETH

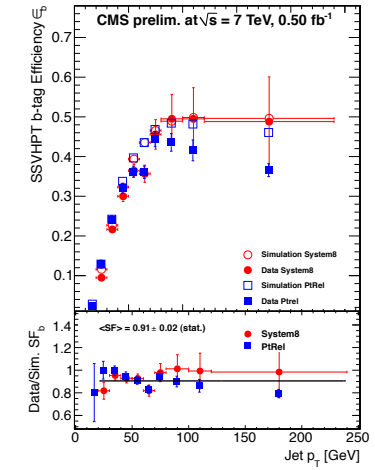
- Several algorithms at several working points available for tagging b-quarks
  - Jet Probability (JPL)
  - Secondary Vertex (SSV)
  - Track Counting (TC)







- Complementary b-tagging tools for physics analyses
  - large range of efficiency and purity
  - well described by Monte Carlo simulation



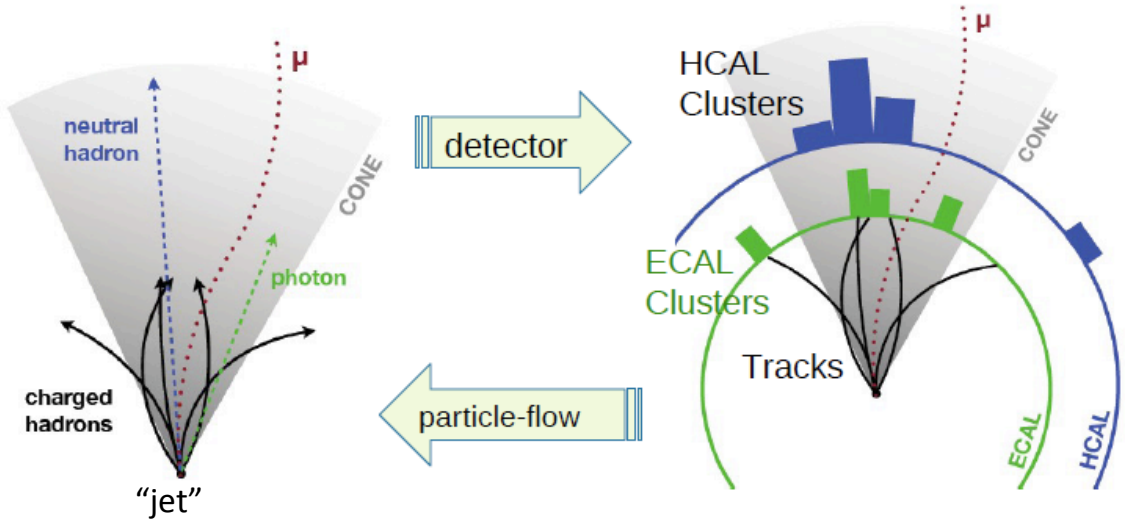
BTV-11-001

Tools: Particle Flow

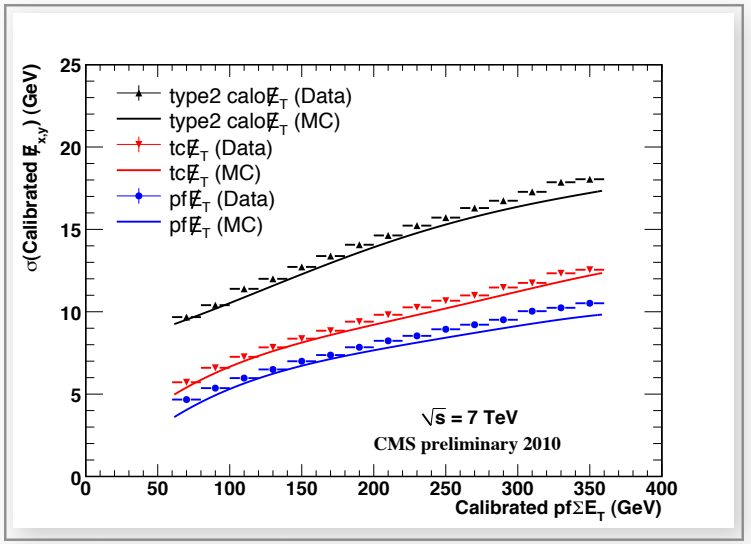
ETH Institute for Particle Physics

UZH/ ETH

- Particle flow combines information from all sub-detectors for a nearly complete event "interpretation"
  - capitalize on superior tracking capabilities and fine ECAL granularity
  - offset limitations in hadron calorimetry (inside coil)

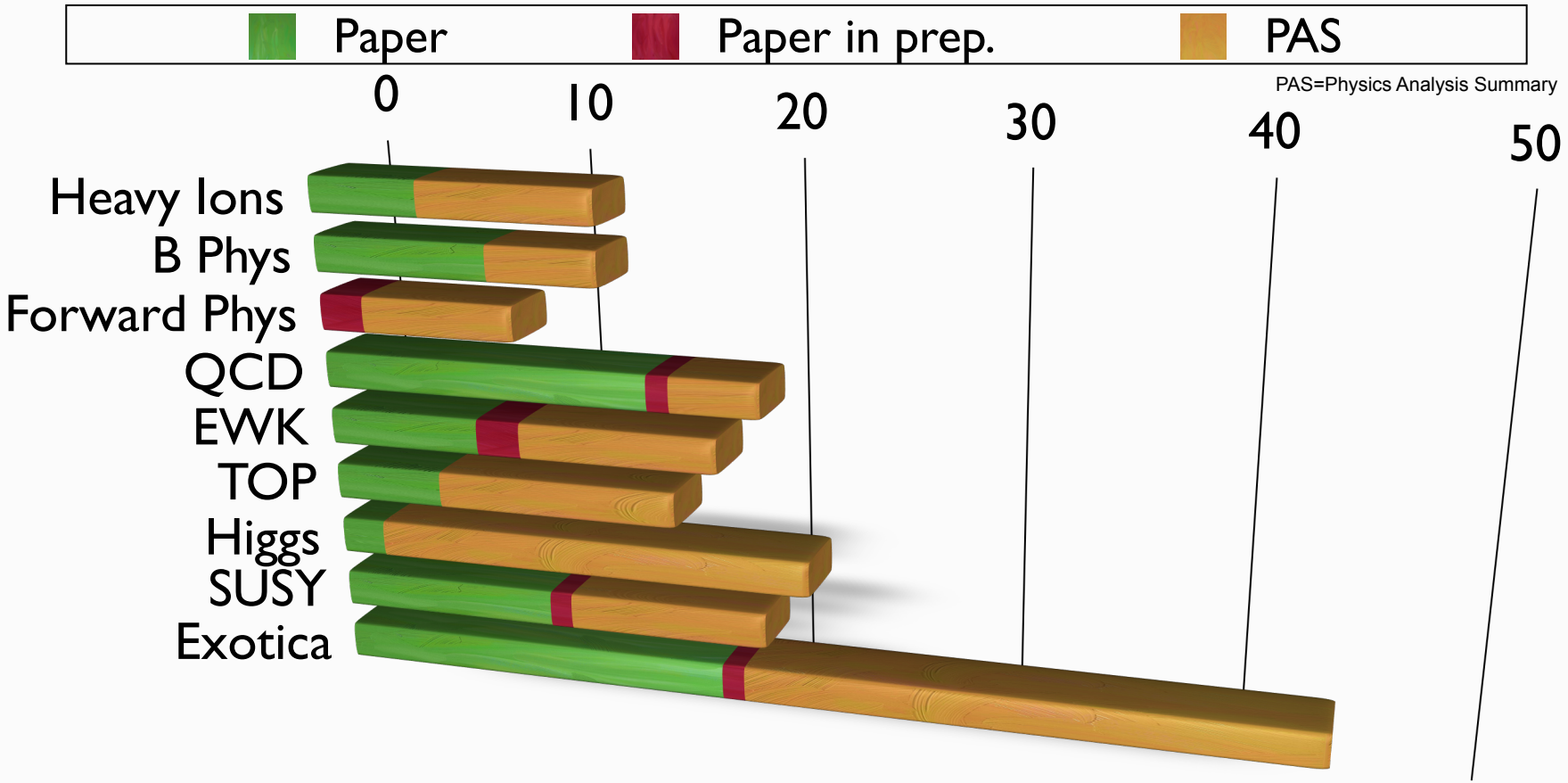


- significant performance improvements in object reconstruction
  - also adds robustness against pile-up



- State of the analysis art in CMS:
  - widely used in Swiss-led analyses
  - substantial Swiss contributions to further development

List of physics analyses so far



166 CMS public physics analyses @ 7 TeV so far
(68 physics journal publications + 98 preliminary results (PAS))
for Summer'11: 38 public results for EPS 2011
24 public results for Lepton Photon 2011

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

ETH Institute for Particle Physics

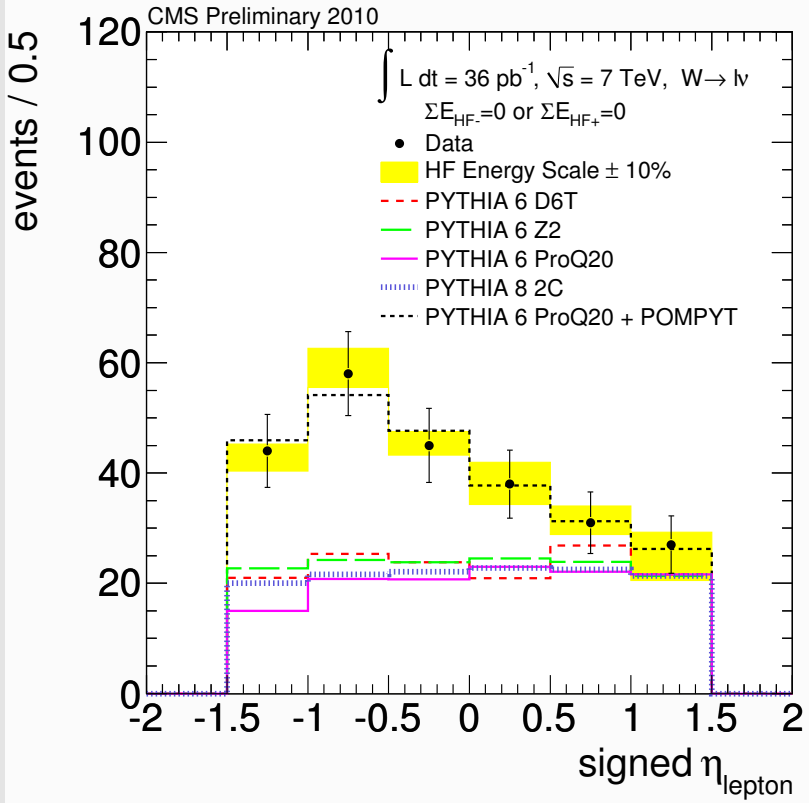
QCD/Diffraction

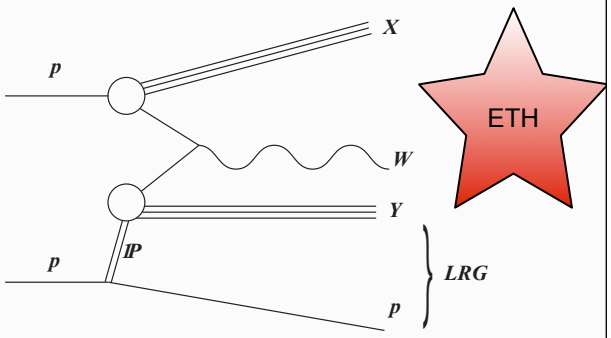
Diffractive W(Z) Production

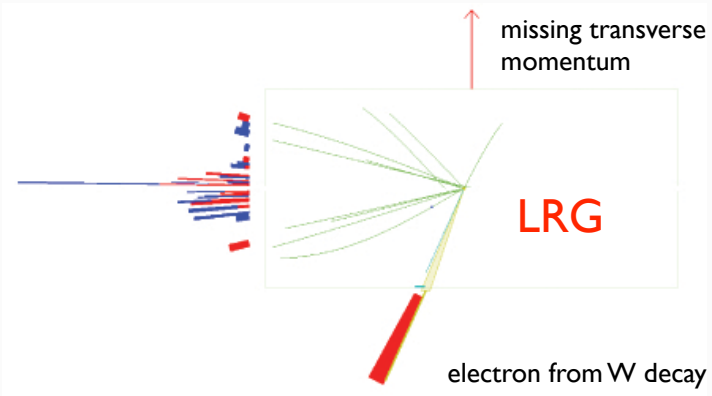
ETH Institute for Particle Physics

Observation of W(Z) production with a large rapidity gap

- no energy deposition in forward calorimeter







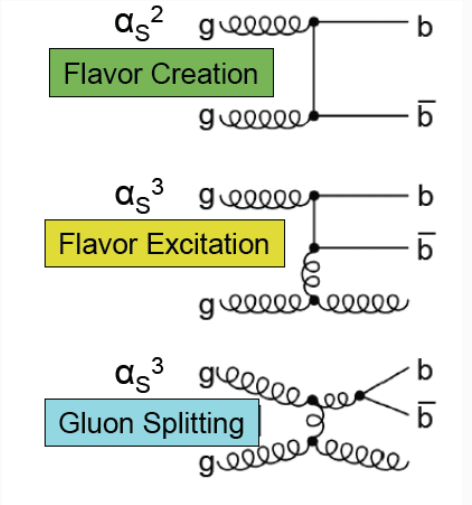
- sensitive variable: signed η_{lepton}
  - side of the gap determines sign
  - lepton predominantly opposite to gap
  - determine diffractive component via likelihood fit (~ 50%)

FWD-10-008 **close to journal submission**

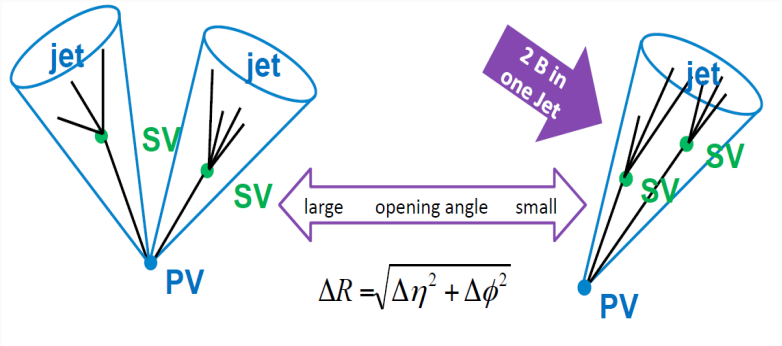
$b\bar{b}$ Angular Correlations

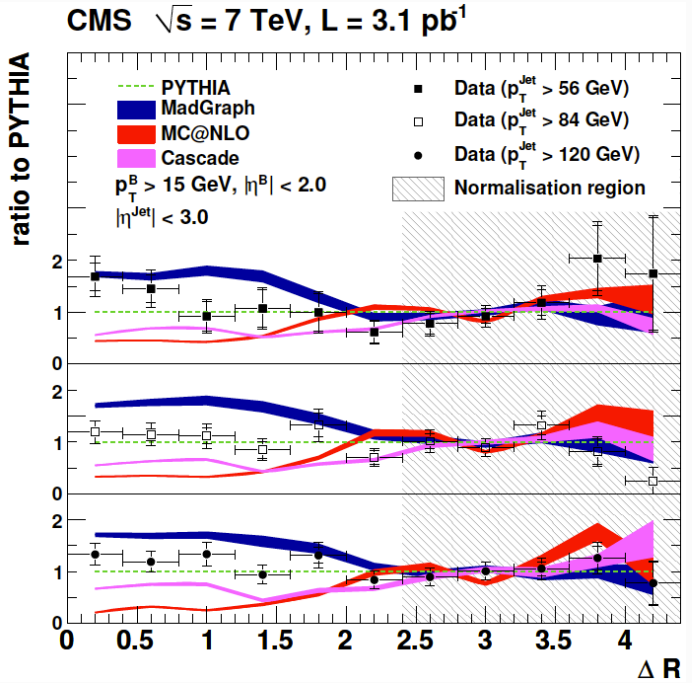
ETH Institute for Particle Physics

- Angular distance $\Delta R=\sqrt{\Delta\eta^2 +\Delta\Phi^2}$ between b- und b-quarks sensitive to different production mechanisms
  - Gluon splitting at low ΔR
  - Flavor creation at high ΔR
- Developed dedicated inclusive vertex-finder to resolve vertices at low ΔR
  - unique analysis tool



ETH/ UZH





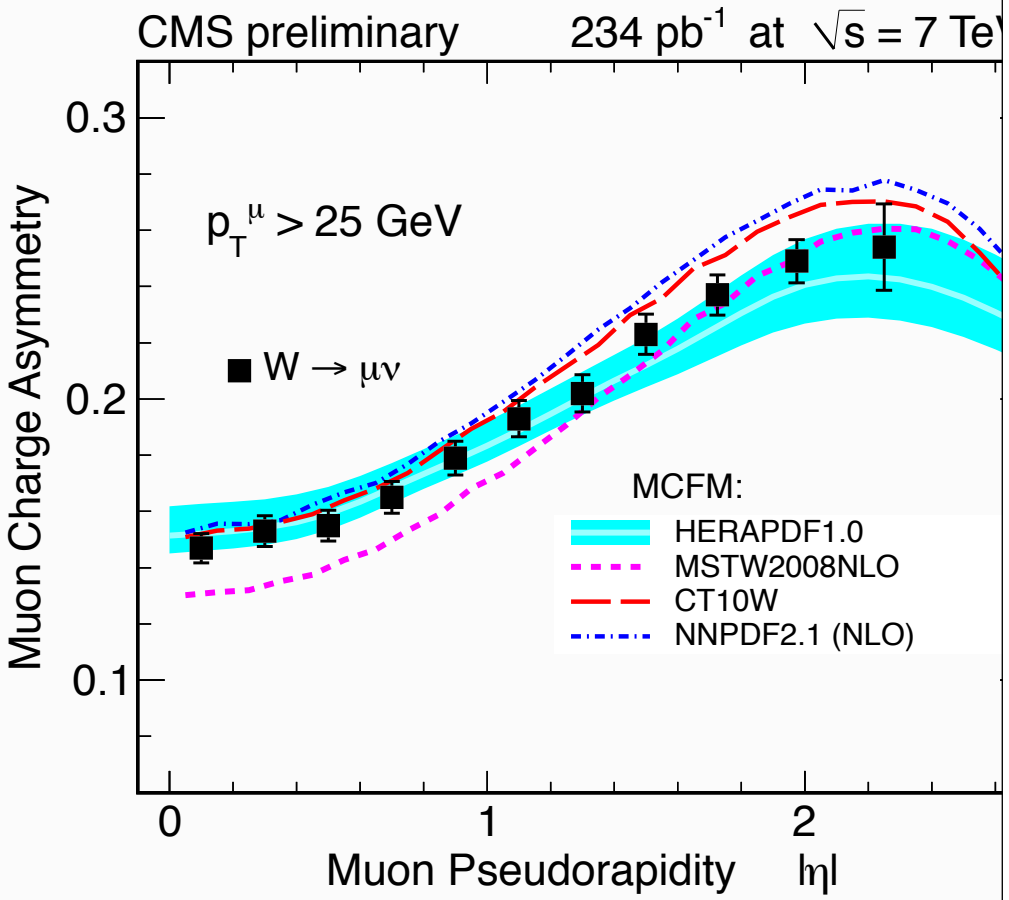
- General pQCD prescription confirmed, but none of the LO and NLO models describe the data well

BPH-10-010 JHEP 1103(2011) 136 arXiv:1102.3194v2

TOP & EWK

Muon Charge Asymmetry

- In proton proton collisions, ($u\bar{d} \rightarrow$) W^+ is more abundantly produced than W^-
  - Rapidity distribution sensitive to parton distribution functions (pdf)
    - u/d, sea quarks
  - Some tension in LHC predictions by different pdf sets
  - Some tension between CDF and D0 W- and lepton charge asymmetries
- New CMS measurement with improved uncertainties
  - Input in global pdf fits

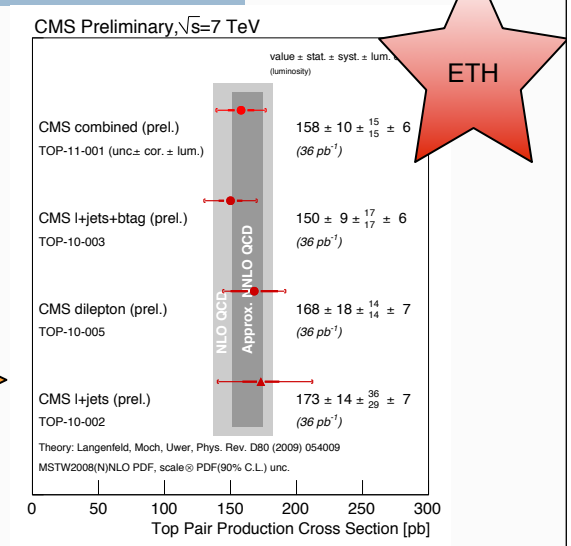


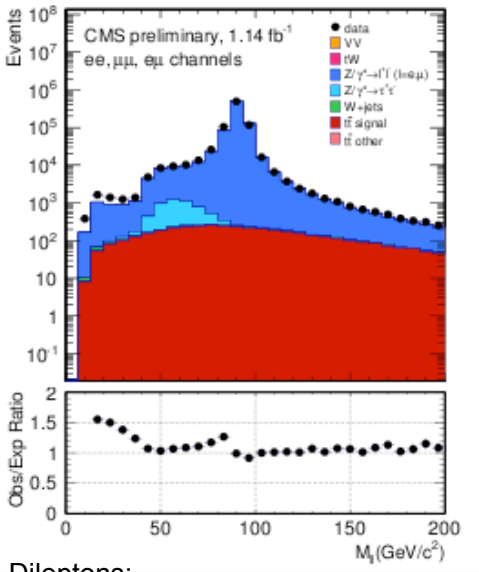
EWK-11-005

Top Pair Production Cross Section

ETH Institute for Particle Physics

- New cross section measurements for LP2011
  - new all hadronic measurement
  - update on dilepton and new lepton-tau measurement
  - measurements start to be systematically dominated
- Improved precision for CMS combination

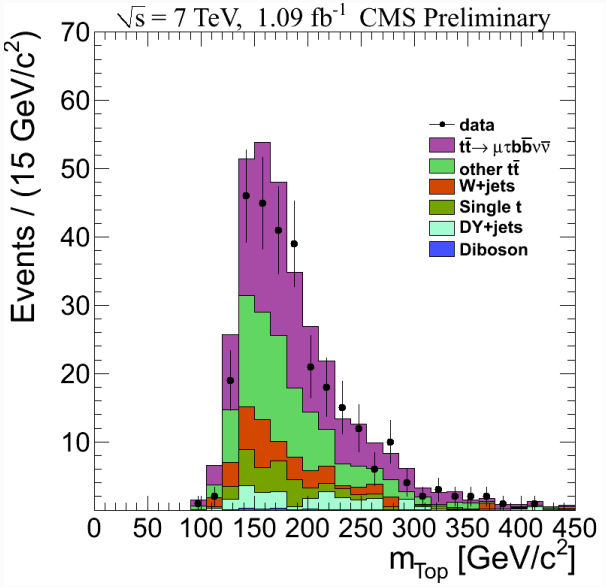




Dileptons:

169.9 ± 3.9(stat.) ± 16.3(syst.) ± 7.6(lumi.) pb

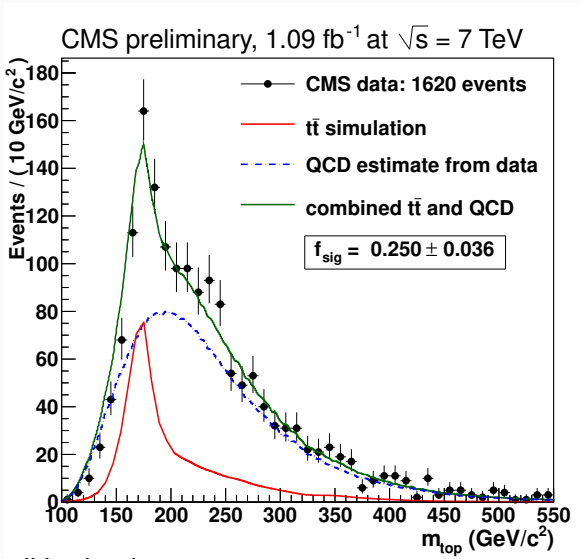
TOP-11-005



Lepton-tau:

148.7 ± 23.6(stat.) ± 26.0 (syst.) ± 8.9 (lumi.) pb

TOP-11-006



all hadronic:

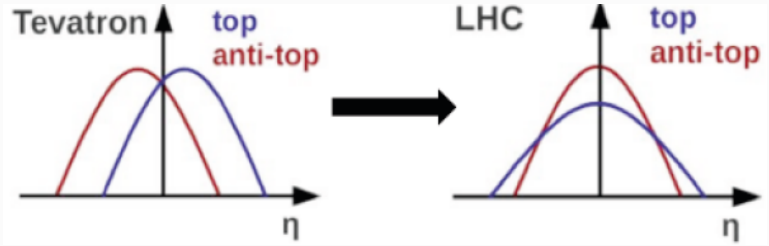
136.0 ± 20.0(stat.) ± 40.0 (syst.) ± 8.0 (lumi.) pb

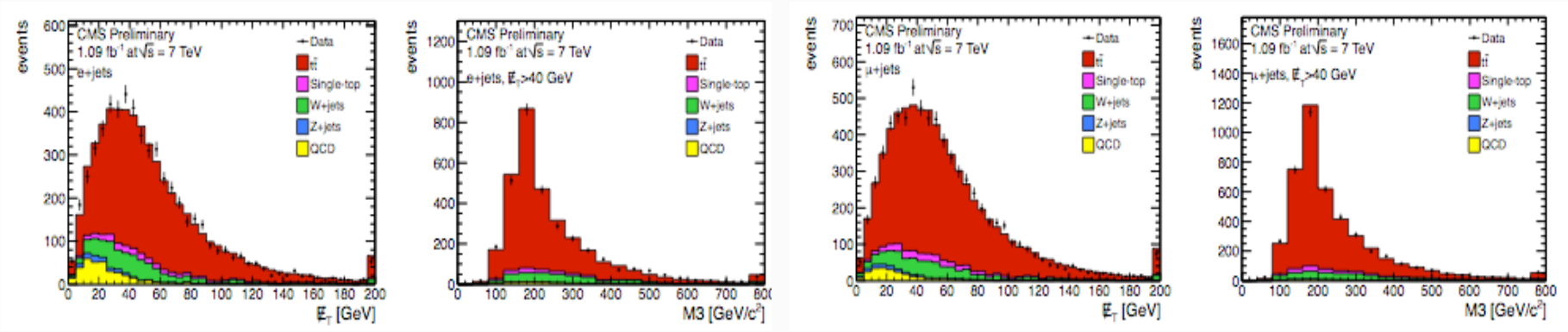
TOP-11-007

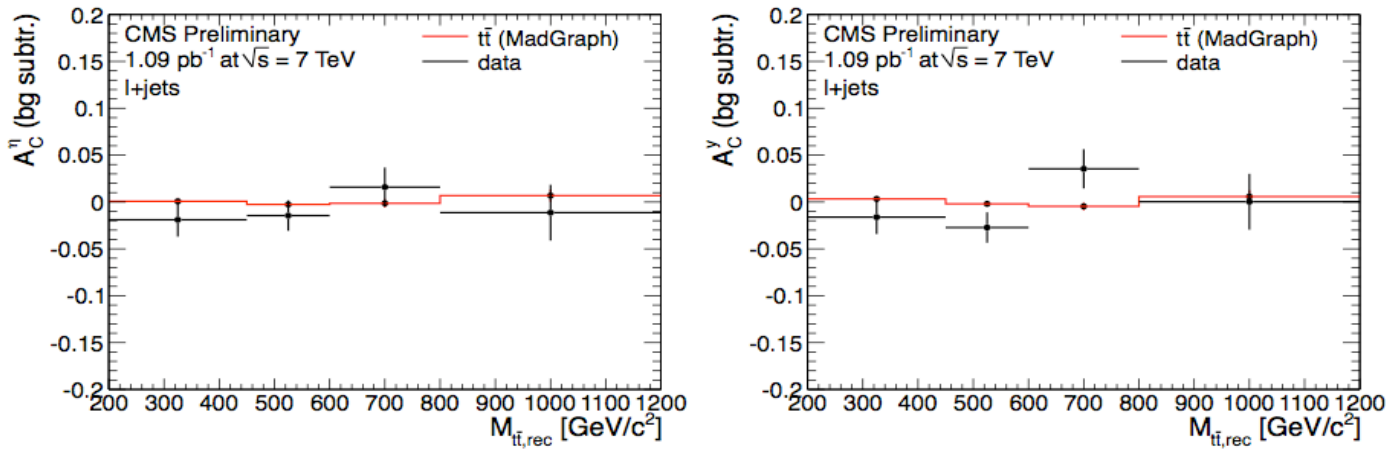
Top Charge Asymmetry

ETH Institute for Particle Physics

- CDF has reported some ~3σ deviation in A_{tt} in proton-antiproton collisions
- At LHC, a small charge asymmetry is predicted in proton-proton collision due to parton distributions/ kinematics (A~0.013 ± 0.001@ 7 TeV)







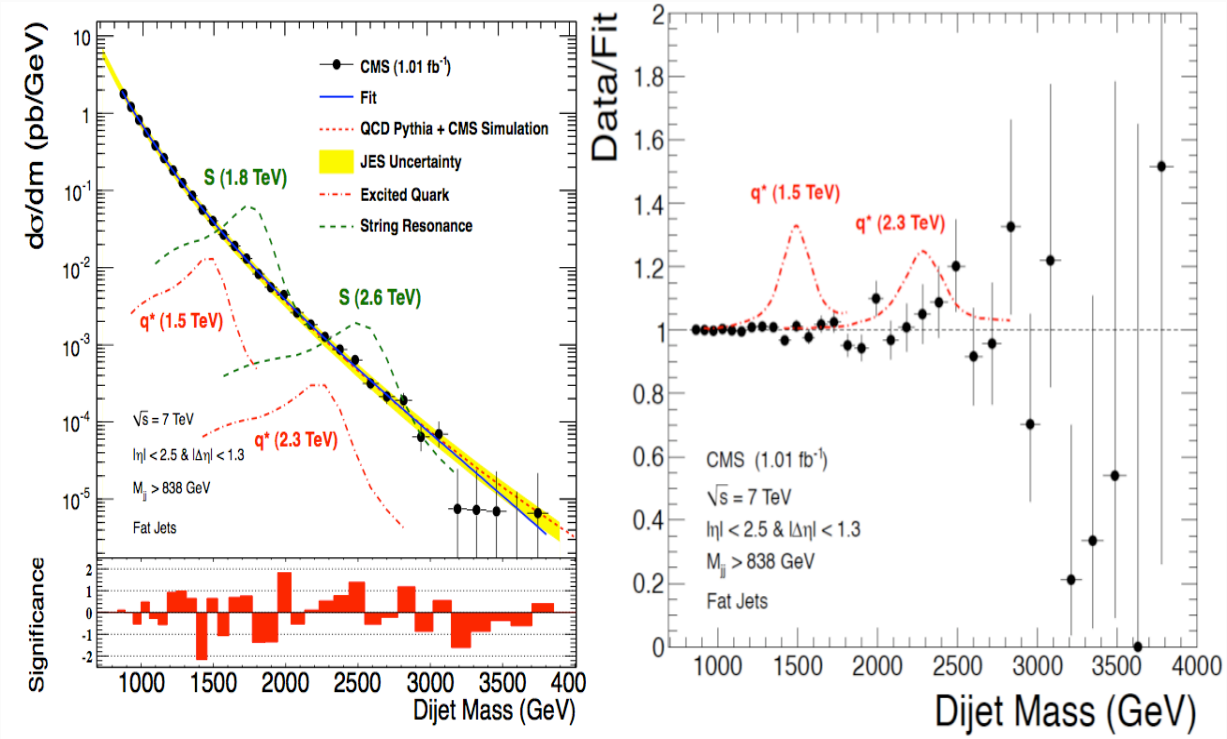
- No significant deviation seen from theoretical prediction

TOP-11-014

EXOTICS

Search for Dijet-Resonances

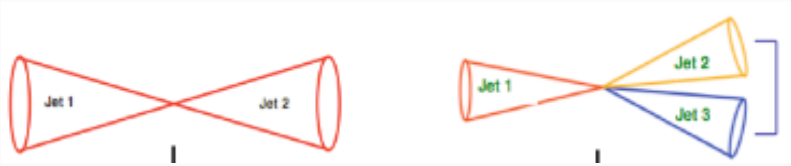
- Search for resonant production of new particle decaying into two jets

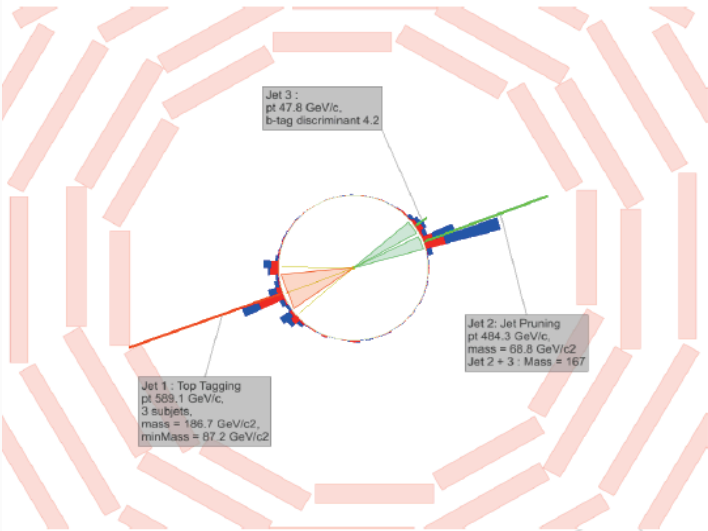


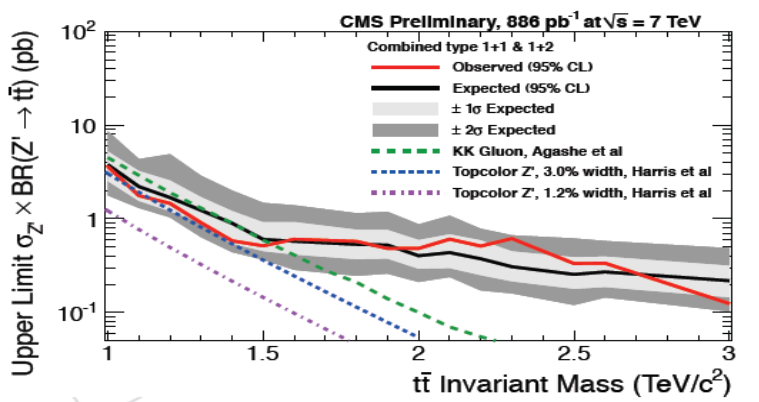
- Can exclude at 95%CL new particles predicted in several models
  - excited quarks with M(q*)<2.49 TeV
  - string resonances with mass M(S)<4.00TeV ..
- First paper on 2011 data
  - CERN-PH-EP/2011-119 2011/07/24 *Submitted to Physics Letters B*

Z'→ tt̄ search

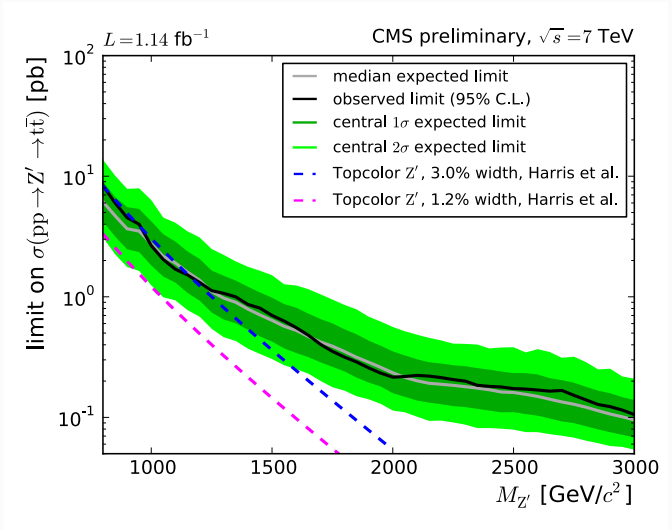
- Search in the all hadronic decay μ + jets and channel
  - top quarks are boosted for high Z' mass
  - jets merge
  - Use 'fat jet' algorithm and apply jet pruning to find sub-jets







EXO-11-006



EXO-11-055

- probing region of $M_{Z'}$ ~ 1 TeV

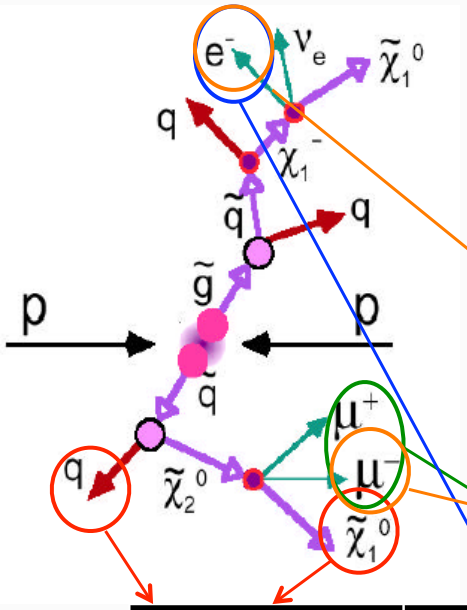
ETH Institute for Particle Physics

SUSY

The CMS SUSY Strategy

ETH Institute for Particle Physics

- **Focus on signatures (topologies)**, use different approaches/observables
- Established many different **data-driven techniques** to derive backgrounds
- Different trigger paths (all hadronic HT-based, leptonic)
- Not necessarily optimized for best excl. limits, but sharpened tools for discovery!
- **Interplay of methods provides stringent cross check**



All hadronic	1-lepton	OS 2-lepton	SS 2-lepton	≥ 3-lepton
Jets + MET	Single lepton + jets + MET	Opposite-sign di-lepton + MET	Same sign di-lepton + jets + MET	Multi-lepton

Large SM backgrounds **Low**

sensitivity to strongly produced SUSY

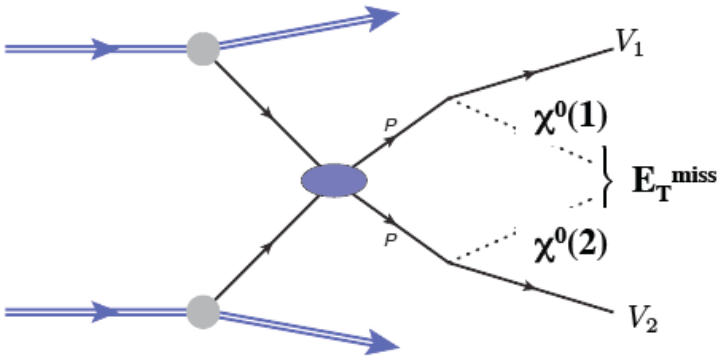
Hadronic Search with MT_2

ETH Institute for Particle Physics

ETH

- M_{T2} is a generalization of the transverse mass M_T in case of two decay chains with each an unobserved particles.

$$M_{T2} = \min_{p_T^{\chi(1)} + p_T^{\chi(2)} = p_T^{\text{miss}}} \left[\max\left(m_T^{(1)}, m_T^{(2)} \right) \right]$$



  - $M_{T2} \approx$ MET for symmetric systems, $p_T^{(1)} \approx p^{T(2)}$
  - M_{T2} = 0 GeV for back-to-back systems
  - more robust against jet mis-measurements than MET

SUS-11-005

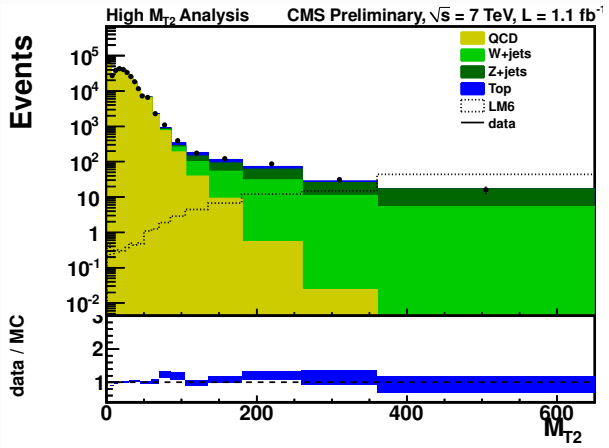
- Sensitive to mass scale
  - here used as a discovery variable

- No excess observed

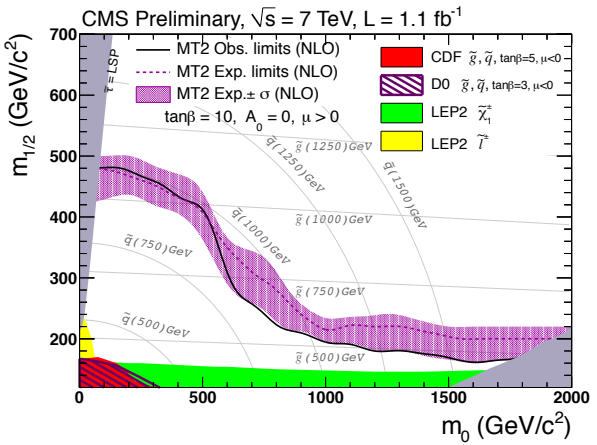
Model independent limit on σ × BR at 95% confidence level

Process	σ× BR (pb)	
	observed limit	expected limit
High M_{T2} analysis	0.010	0.011
Low M_{T2} analysis	0.020	0.014

≥ 3jets, signal: $M_{T2} > 400$ GeV



Exclusion plot in cMSSM plane



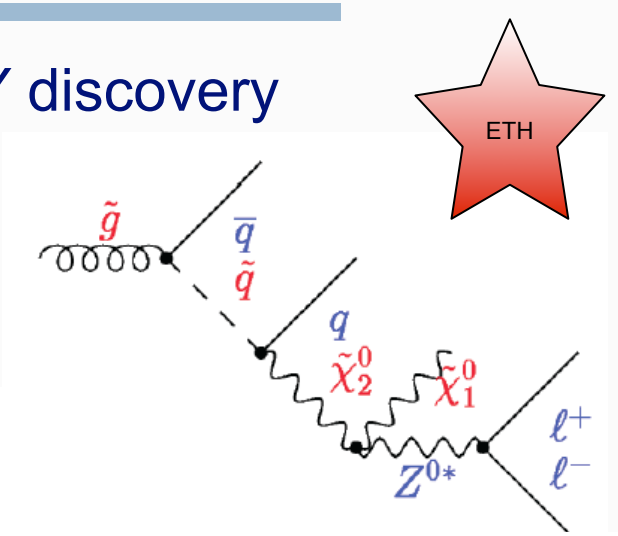
Opposite Sign Dileptons: JZB

ETH Institute for Particle Physics

- A discriminator (developed by ETH) for SUSY discovery with Z-bosons:

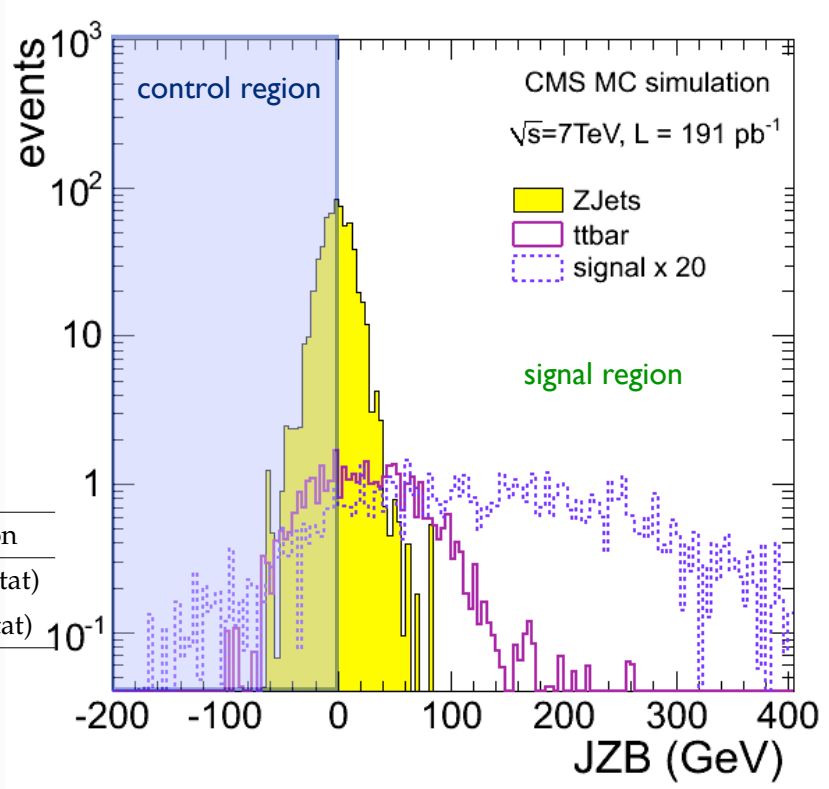
$$JZB = |\sum_{jets} \vec{p}_T| - |\vec{p}_T^{\,Z}|$$

  - major backgrounds Z + jets with artificial MET
  - top dilepton decays with accidental lepton invariant mass in Z-window



- Data driven background prediction
  - from negative JZB tail

- No excess observed



Region	Observed events	Background prediction	MC expectation
$JZB > 50$ GeV	20	$24 \pm 6(\text{stat}) \pm 1.4(\text{peak})^{+1.2}_{-2.4}(\text{sys})$	16.0 ± 1.2 (MC stat)
$JZB > 100$ GeV	6	$8 \pm 4(\text{stat}) \pm 0.1(\text{peak})^{+0.4}_{-0.8}(\text{sys})$	3.6 ± 0.4 (MC stat)

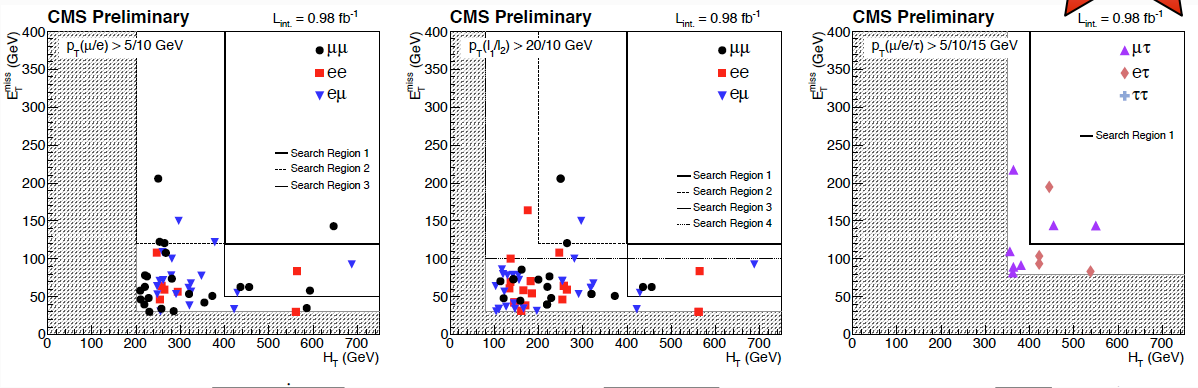
SUS-11-012

Same Sign Dilepton Search

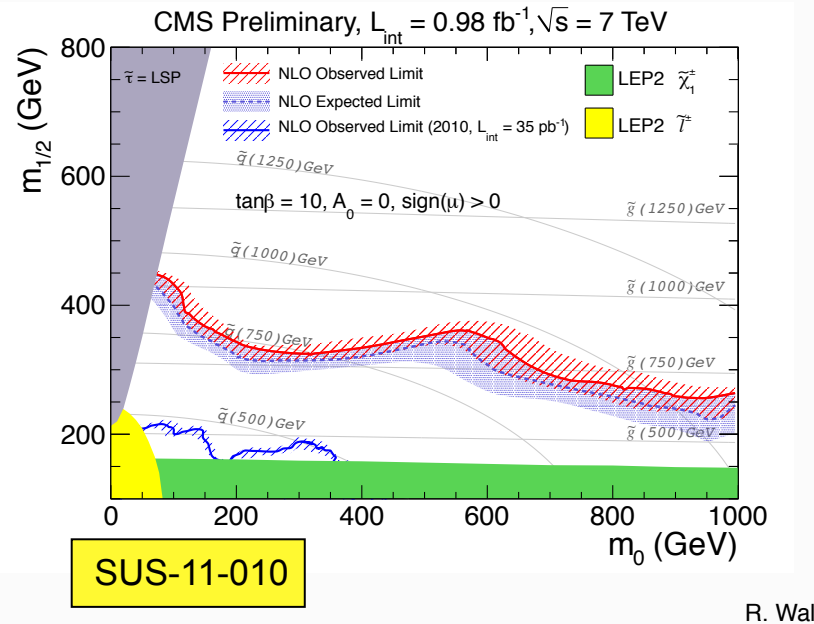
ETH Institute for Particle Physics

- Same sign lepton signature strongly suppressed in SM
  - background mainly from fake leptons and mis-reconstruction
- Three searches:
  - inclusive dileptons (e,μ)
  - high p_T dileptons (e,μ)
  - final state with τ_{had} (e/μ,τ)
- No excess observed.

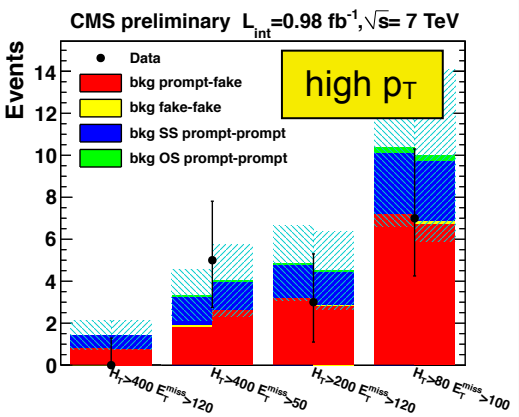
ETH

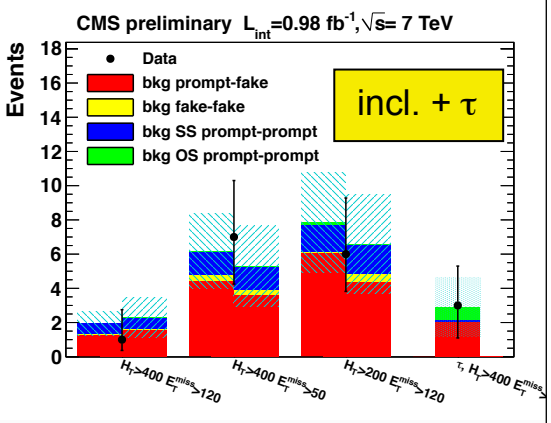


inclusive | high p_T | τ



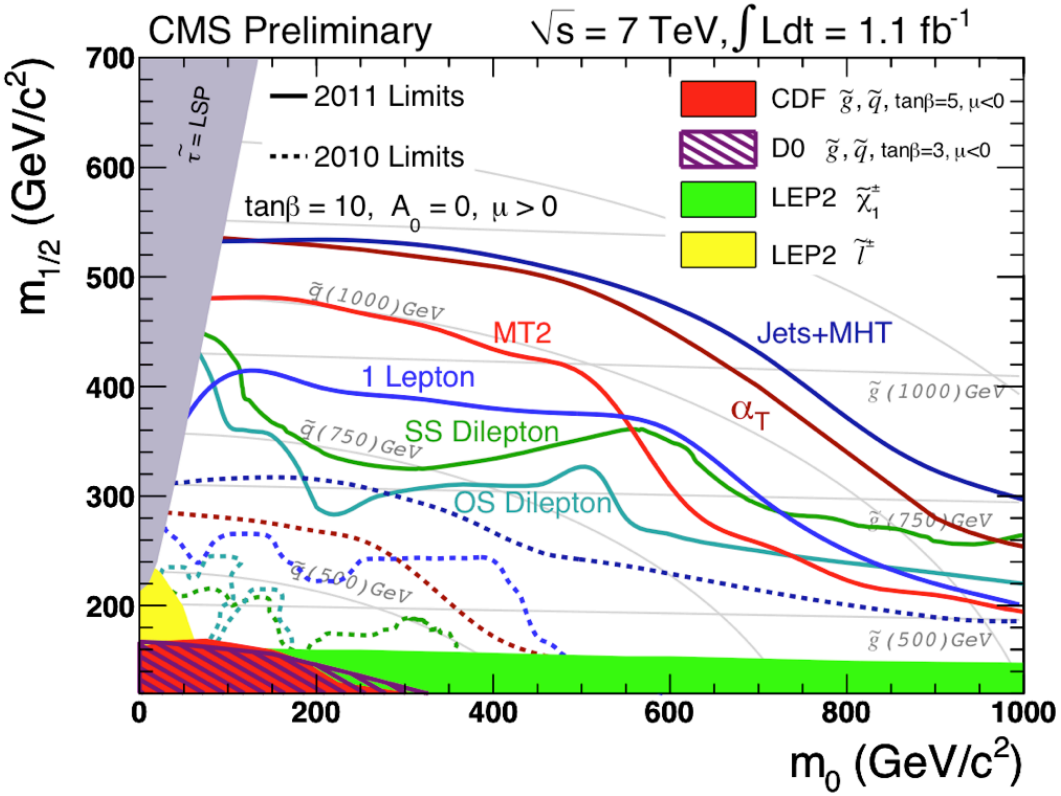
SUS-11-010

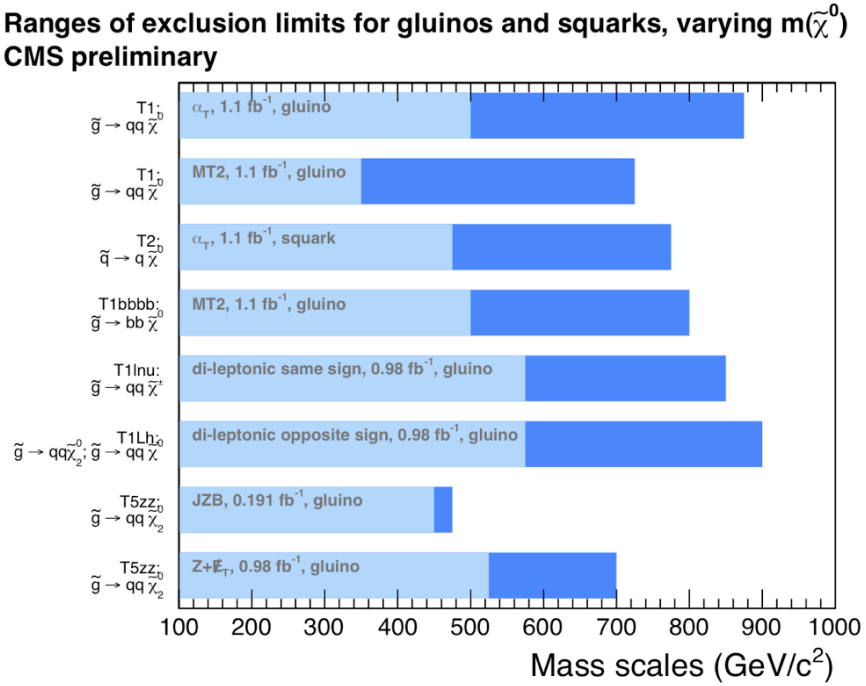




cMSSM & Simplified Models

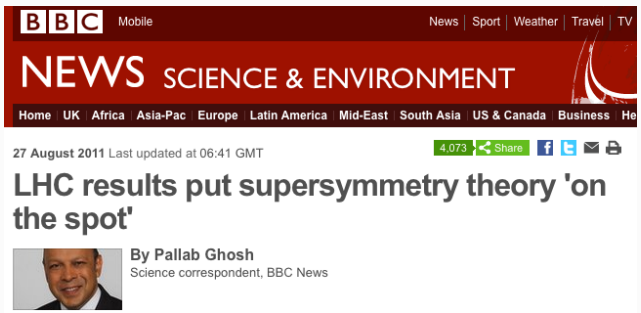
- Significant progress in probing cMSSM parameter space between 2010-11
- Simplified models: Simple theory mapped on main final state topologies
- Several methods confirm and complement each other





- BBC: "Air is getting thin for SUSY" ? Caveat: Only very 'simple-minded' SUSY.

http://www.bbc.co.uk/news/science-environment-14680570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27 August 2011 Last updated at 06:41 GMT

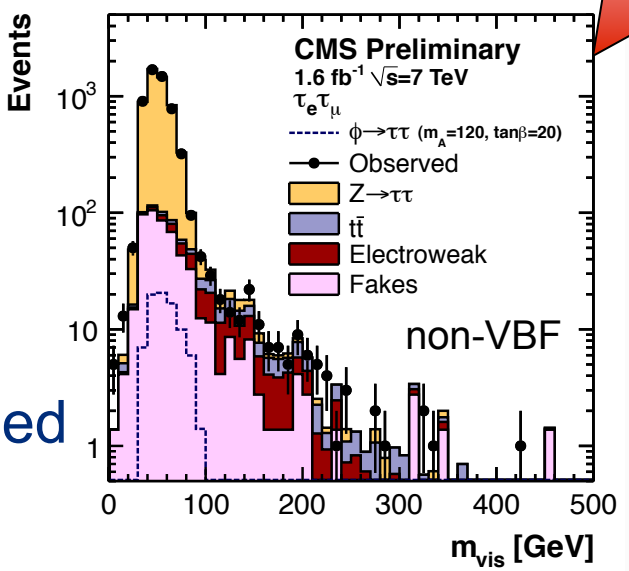
4,073 Share

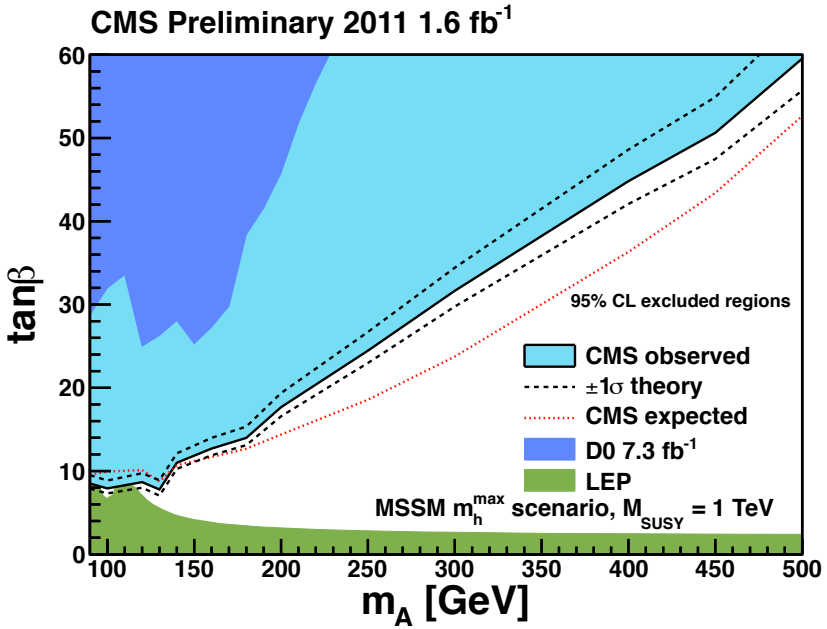
LHC results put supersymmetry theory 'on the spot'

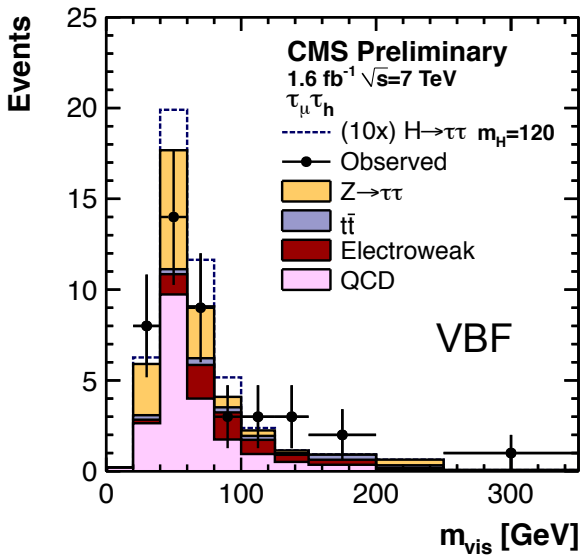
By Pallab Ghosh
Science correspondent, BBC News

MSSM Higgs →τ⁺τ⁻

- Decay of MSSM Higgs boson(s) into τ's enhanced in high tanβ scenarios
- τ -Identification challenging
  - particle flow ideal tool
- Search uses both lepton and hadronic τ-decays
- SM H →τ⁺τ⁻ produced via VBF also included





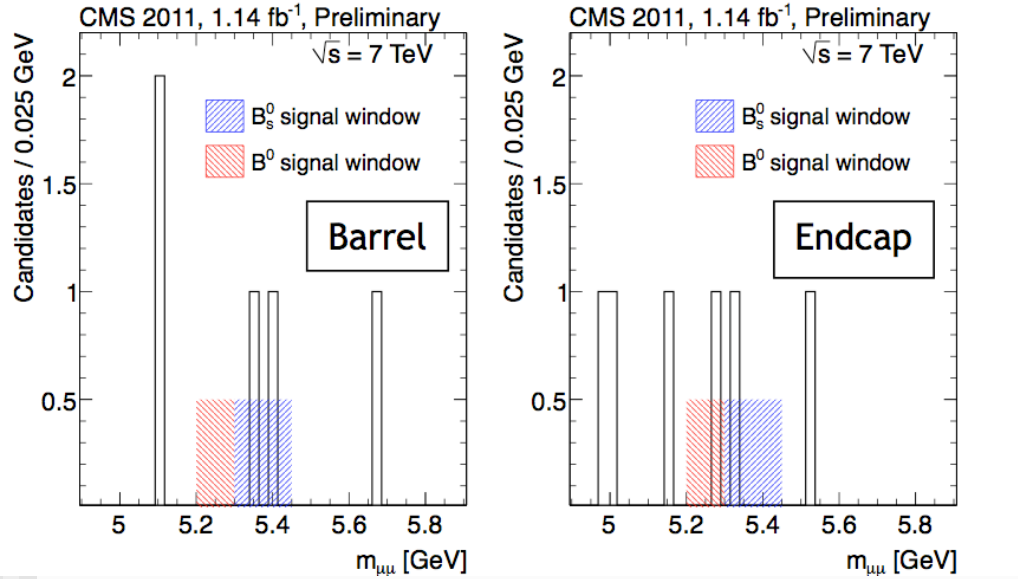


HIG-11-020

$B_s \rightarrow \mu^+\mu^-$

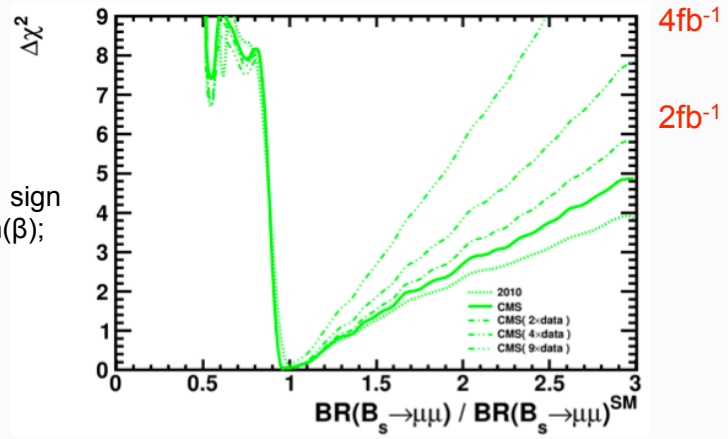
- Indirect sensitivity to new physics (MSSM:BR$\propto(\tan\beta)^6$ → sensitivity to extended Higgs boson sectors → additional constraints on parameter region).

SM: $B_s \rightarrow \mu^+\mu^- = (3.2\pm0.2)\times10^{-9}$; $B_d \rightarrow \mu^+\mu^- = (1.0\pm0.1)\times10^{-10}$



Impact on new models
arXiv:1106.2529

CMSSM
Unified masses
4 parameters, 1 sign
m_0, $m_{1/2}$, A_0, tan(β);
sign(μ)



- Events observed in the unblinded windows consistent with background plus SM expectations.

$B_s \rightarrow \mu^+\mu^- < 1.9\times10^{-8}$ (95% CL)

$B_d \rightarrow \mu^+\mu^- < 4.6\times10^{-9}$ (95% CL)

BPH-11-002 **[arXiv:1107.5834], submitted to PRL**

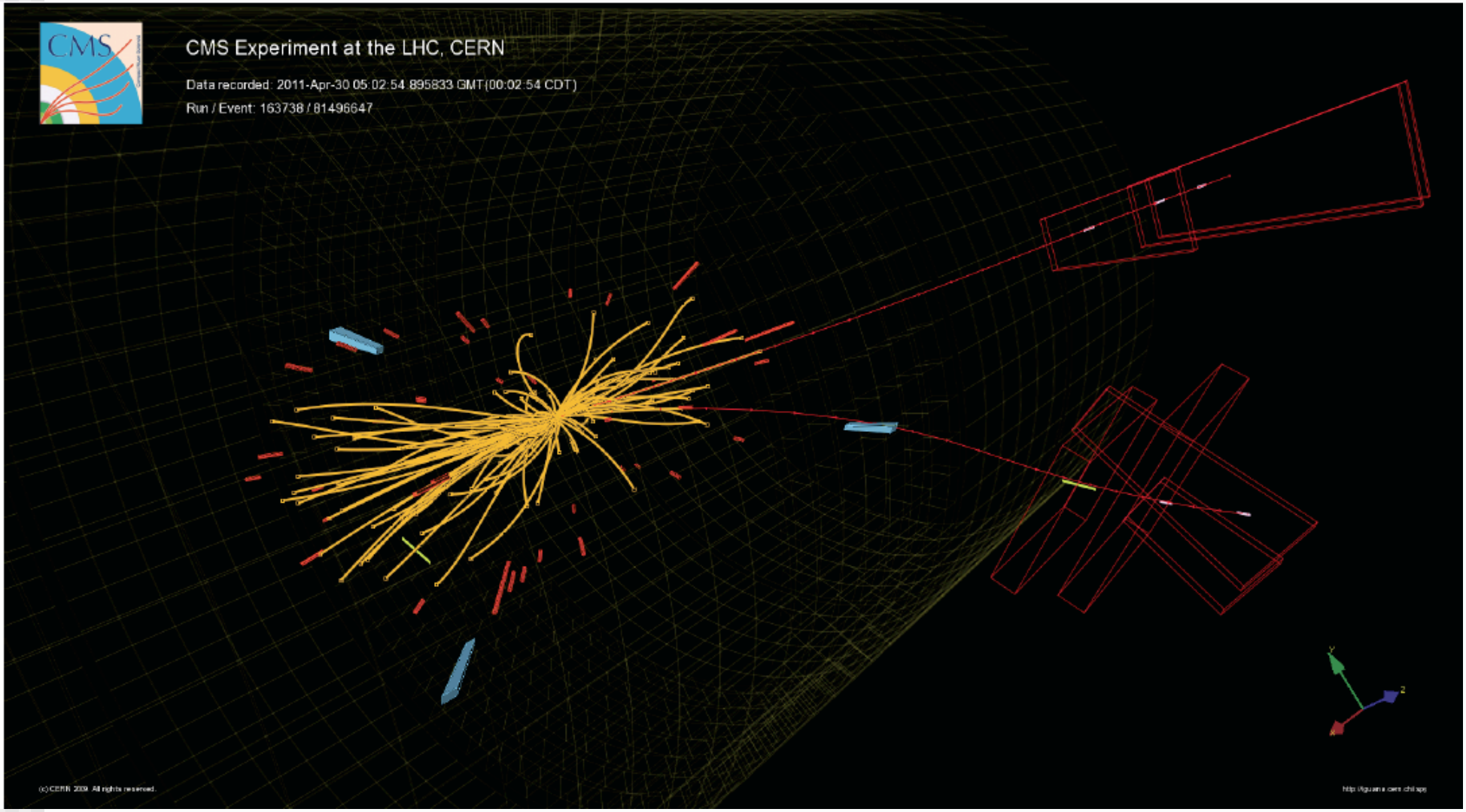
- Combination with LHCb :

$B_s \rightarrow \mu^+\mu^- < 1.1\times10^{-8}$ (95% CL)

BPH-11-019 LHCb-conf 2011-47

$B_s \rightarrow \mu^+\mu^-$ Candidate Event

ETH Institute for Particle Physics



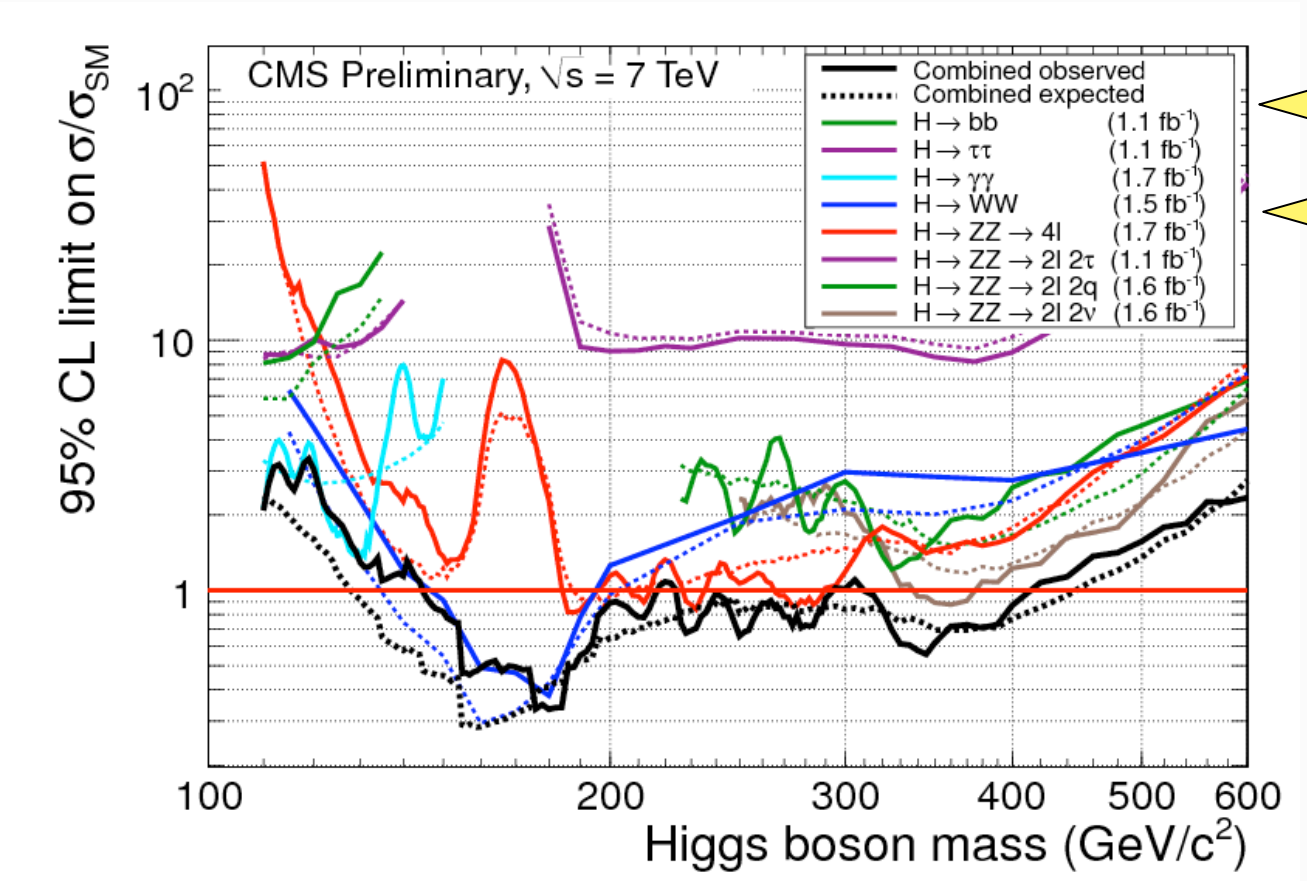
ETH Institute for Particle Physics

HIGGS

Search for the SM Higgs Boson

ETH Institute for Particle Physics

- Express results as 95% upper limit C.L. on the signal strength modifier $\mu = \sigma/\sigma_{SM}$

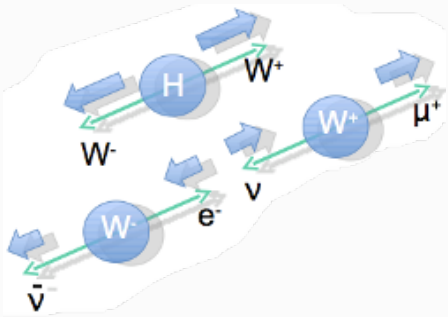


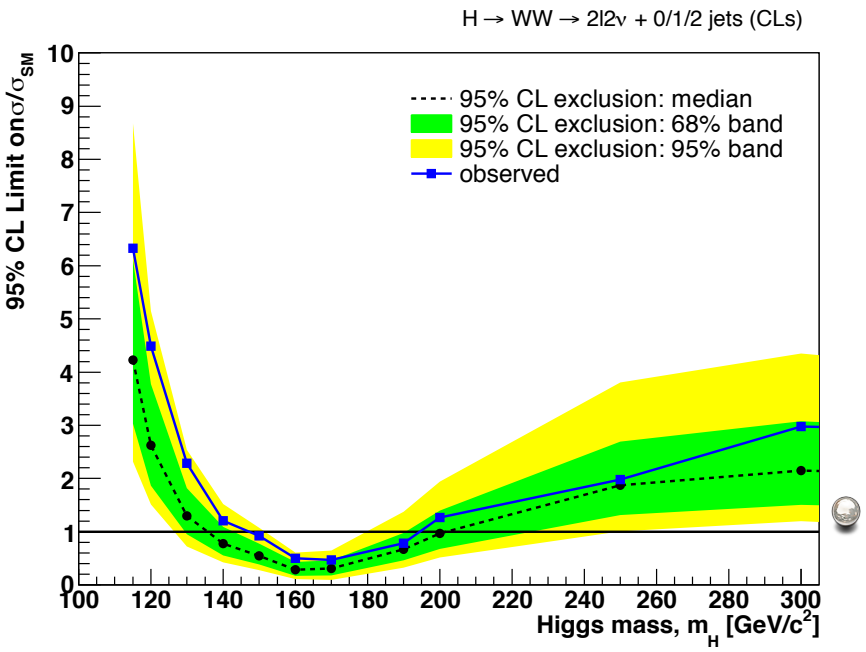
ETH/ UZH

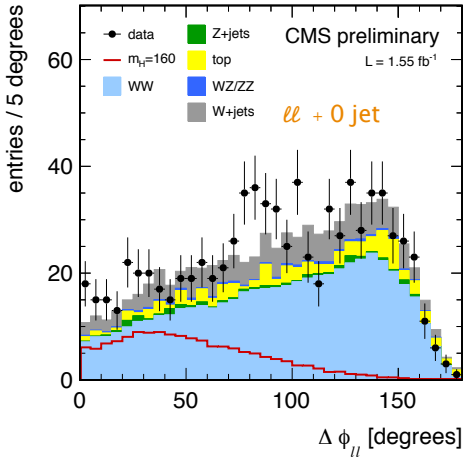
- Combine 8 major results in one limit result
  - 4 channels with significant Swiss contributions

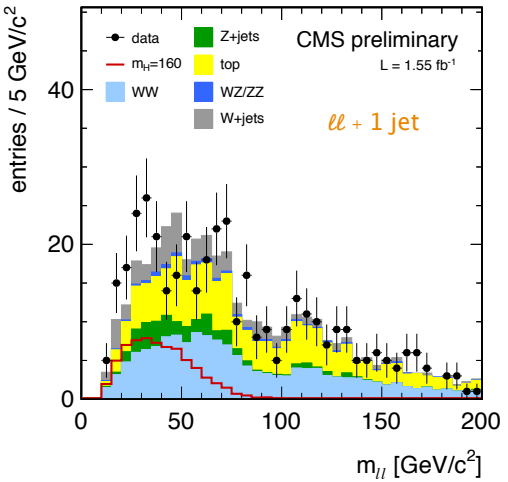
H→ WW→2l2ν

- The “workhorse” channel - good sensitivity around intermediate mass range
  - but low mass resolution ±30 GeV
- signal features distinct small opening angle/low inv. mass of the lepton system
  - cut-based or MVA analysis
- Main challenge: control WW and Drell-Yan background with high pile-up as well as top (≥ 1 jet)







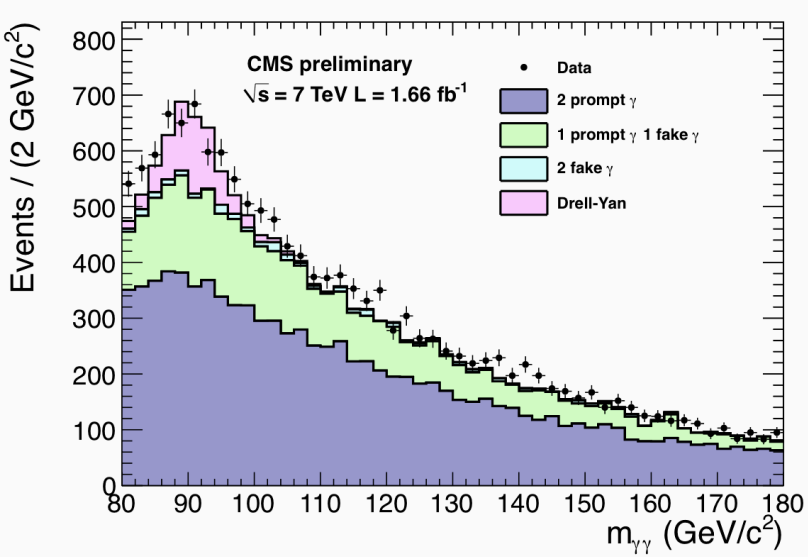


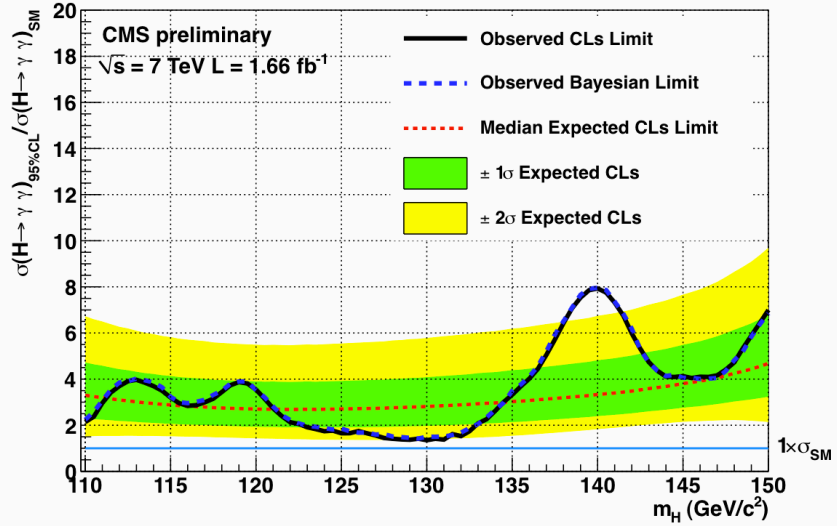
Excludes m_H range of 147-194 GeV at 95% C.L.

HIG-11-014

H→ γγ

- Mainstay analysis in the low mass region of m_H=110-150 GeV
  - low sensitivity, high mass resolution (1-2 GeV but to be improved)
  - tiny signal on steeply falling spectrum
- Background model from fit to data
  - Analysis is performed in 8 distinct categories (barrel/endcap, converted/unconverted photon, Higgs pT<40 GeV or pt>40 GeV)
- Main challenges:
  - vertexing with PU, calibrations
  - transparency corrections for ECAL crystals



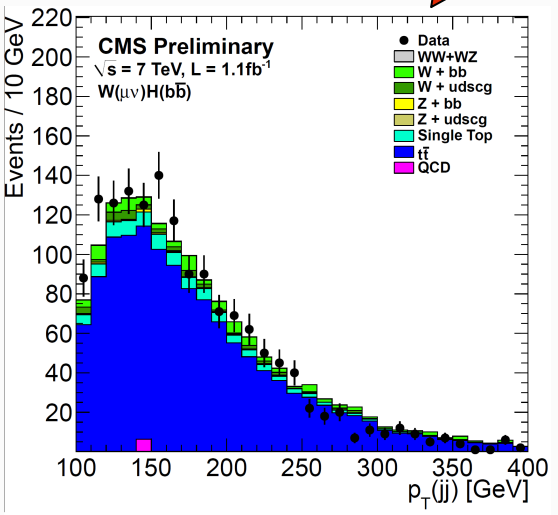


- Exclusion limits:
  - 2.7- 4.7 x SM expected
  - 1.3- 8 x SM observed

HIG-11-021

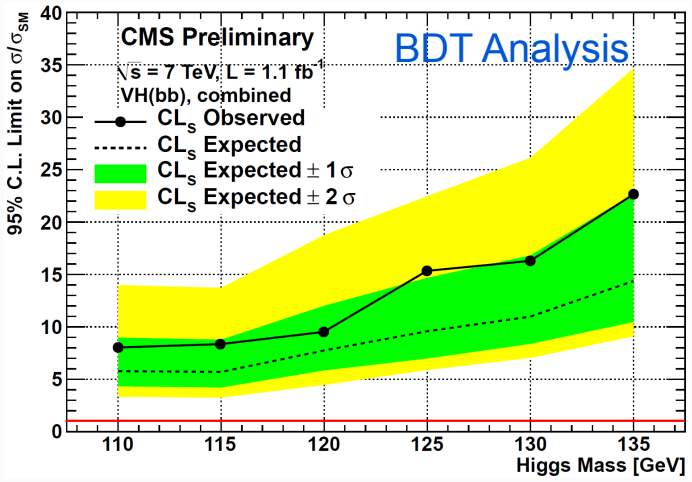
H→ bb̄

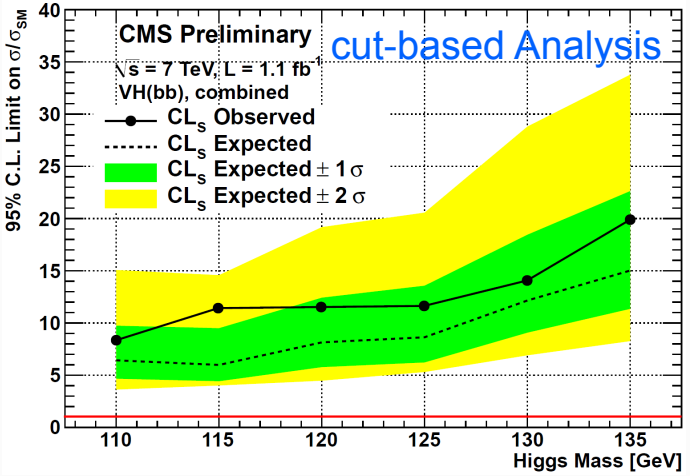
- Associated production WH/ZH provides alternate channel to access the low mass Higgs region
  - prime channel at the Tevatron
- previously considered too difficult at LHC due to overwhelming background
  - Boost requirement on H (and recoiling vector boson) improves S/B
  - Using 10% of the signal for P_T^{jj}> 150 Ge
  - verify background model in 3 control regions (V + heavy and light flavor dominated and tt dominated)



HIG-11-012

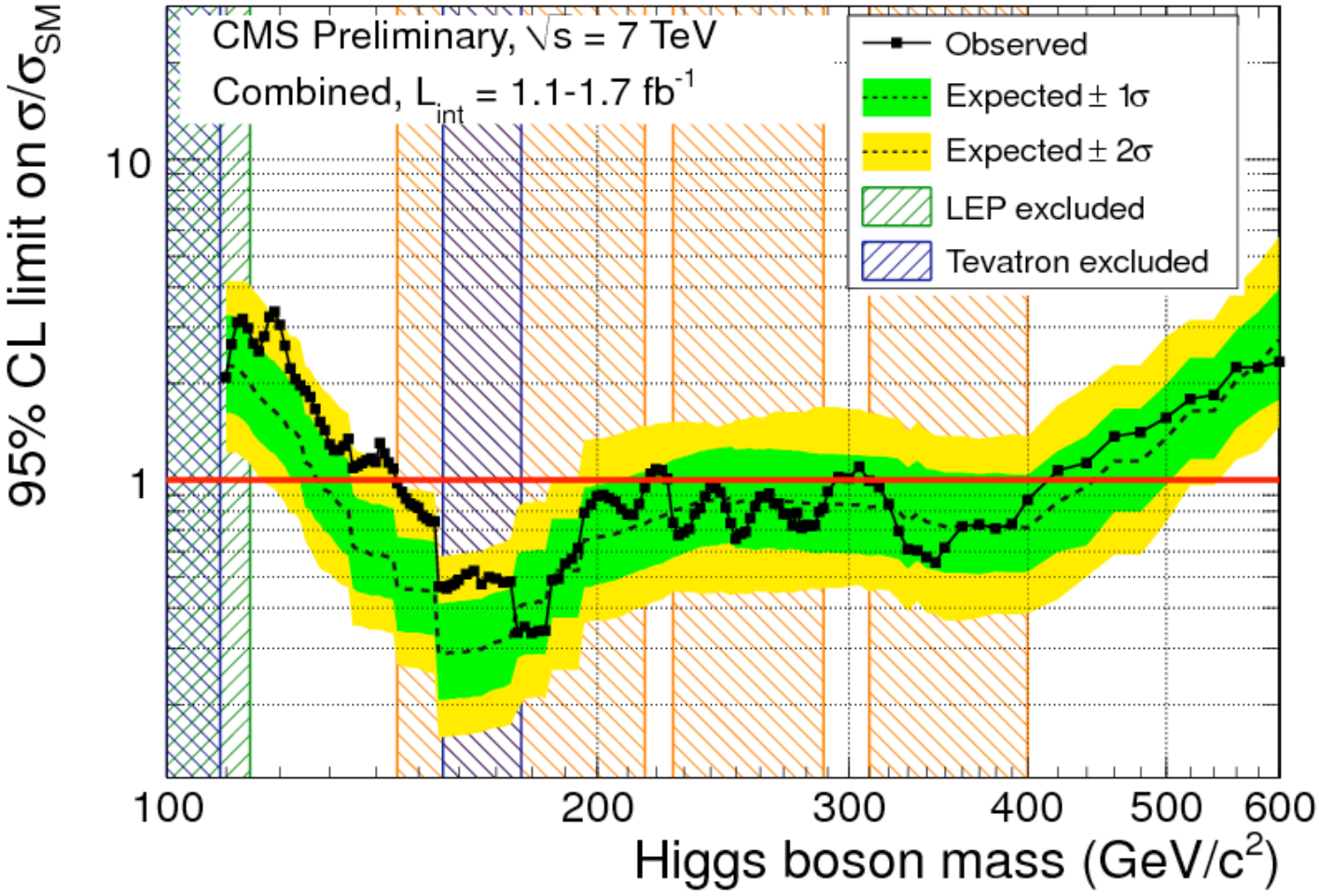
- Cut based and boosted decision tree analysis
  - expected limits 5-15 x SM, observed 7-20 x SM





Higgs Combination

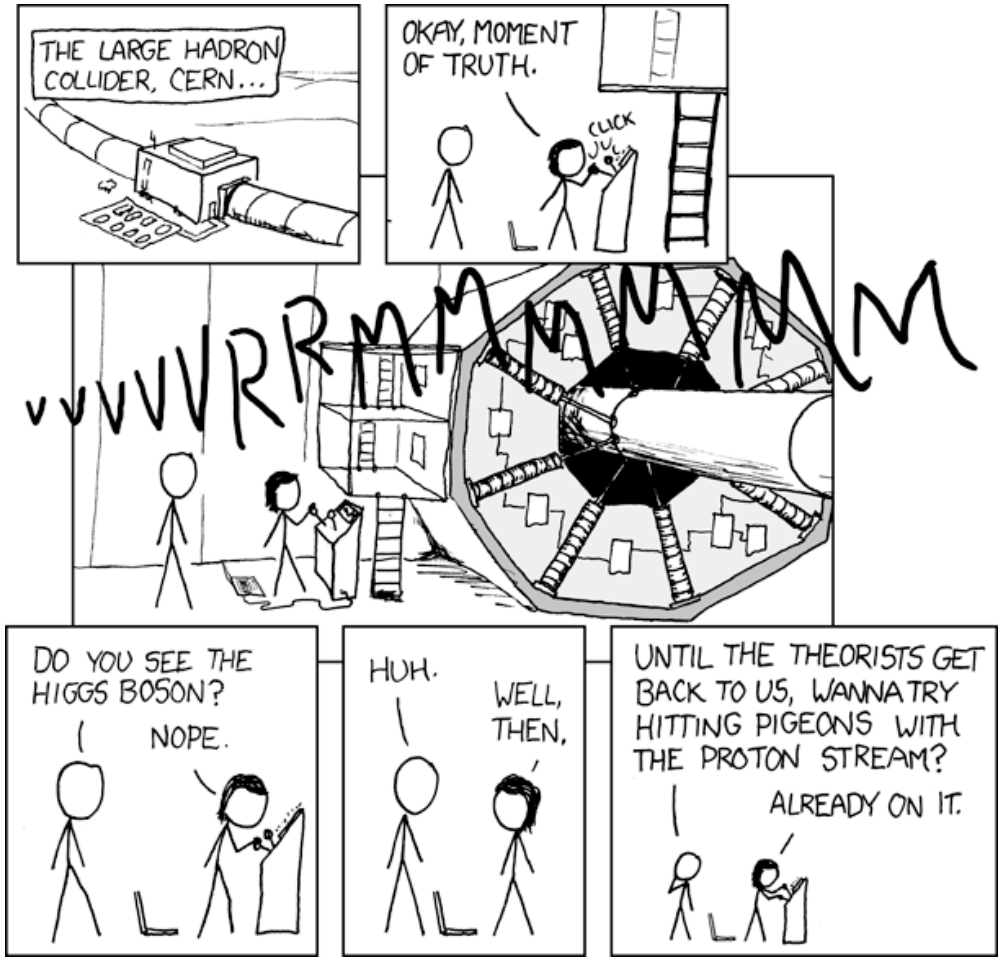
- The combined 95% C.L. upper limits on the signal strength modifier $\mu = \sigma/\sigma_{SM}$, as a function of the SM Higgs boson mass in the range 110-600 GeV/c² :



HIG-11-022

- The largest excursion of the observed data has a p-value of about 1% (~2.3σ)
- This becomes p=40% after correction for the “look elsewhere effect”

Conclusions



Conclusions

- CMS and LHC have entered the fb^{-1} era @ 7 TeV
  - plethora of data produces many exciting physics results - ~2.4 fb^{-1} on tape!
  - higher pile-up is a challenge but so far can be mitigated
- CMS starts to probe TeV scale of New Physics and is closing in on the Higgs boson
  - "Simple" SUSY (e.g. cMSSM) is becoming squeezed
  - Exclusion of Higgs boson masses at high masses
  - Some interesting structure below m_H~ 150 GeV
- Several SM measurements approach precision domain
  - probing the Standard Model further
- Swiss scientists are strong members of CMS
  - leading several flagship analyses
  - several "Swiss only" analyses
  - substantial contributions to online and offline operations
  - several leadership positions within CMS management

ETH Institute for Particle Physics

Backup

ETH Institute for Particle Physics

HIGGS

Combination of all Higgs channels - details

Method used: modified frequentist construction (CLs)

Likelihood used to build the test statistics: $\mathcal{L}(data\,|\,\mu,\theta) = \text{Poisson}\,(\,data\,|\,\mu\cdot s(\theta)+b(\theta)\,)\cdot p(\tilde{\theta}|\theta)$

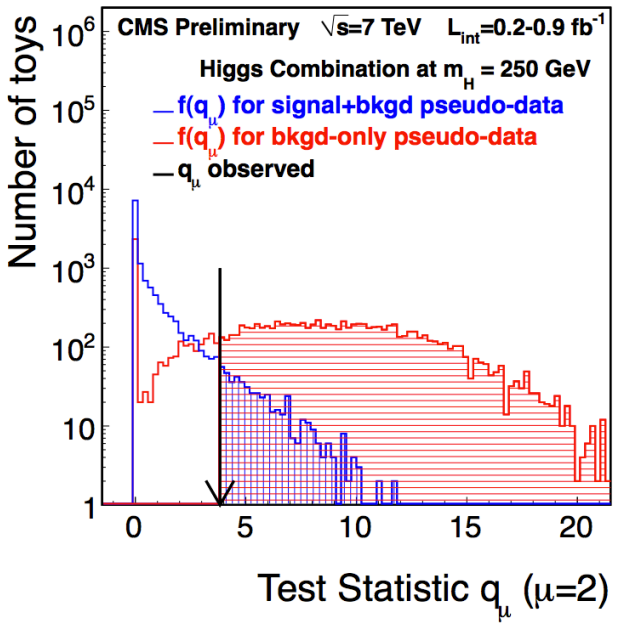
μ = signal strength modifier
s(θ) = signal model
b(θ) = background model

Systematic uncertainties enter as nuisance parameters θ

(241(146) nuisance parameters at low(high) mass)

Test statistics $q_\mu = -2\ln\dfrac{\mathcal{L}(\text{data}|\mu,\hat{\theta}_\mu)}{\mathcal{L}(\text{data}|\hat{\mu},\hat{\theta})}$

μ fixed; $\hat{\theta}_\mu$ $\hat{\theta}$ floating.



CLs steps:

- Find $\hat{\theta}_\mu^{obs}$ $\hat{\theta}_0^{obs}$ maximizing the likelihood on data
- Generate toy Monte Carlo pseudo-data to construct the test statistic pdf's assuming a signal (strength μ) and background-only (μ = 0) and using $\hat{\theta}_\mu^{obs}$ $\hat{\theta}_0^{obs}$

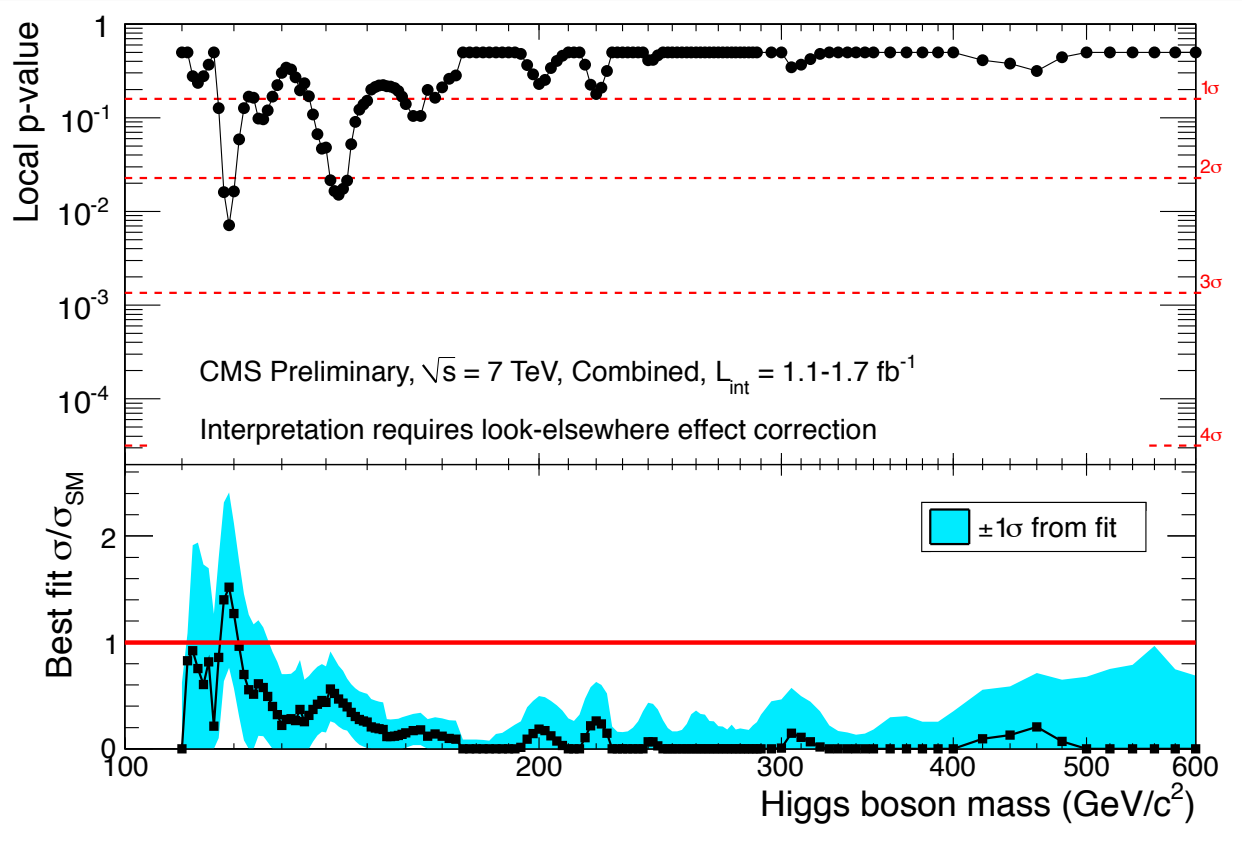
CPU consuming

$$CL_s(\mu) = \frac{P\left(q_\mu \geq q_\mu^{obs}\,|\,\mu s(\hat{\theta}_\mu^{obs})+b(\hat{\theta}_\mu^{obs})\right)}{P\left(q_\mu \geq q_\mu^{obs}\,|\,b(\hat{\theta}_0^{obs})\right)}$$

If the CLs ≤ α for μ =1
⇒ the Standard Model is excluded at (1-α) confidence level

Look-elsewhere-effect corrected following E. Gross et al. The European Physical Journal C - Particles and Fields 70 (2010) 525–530.

p-value (with no LEE)



HIG-11-022