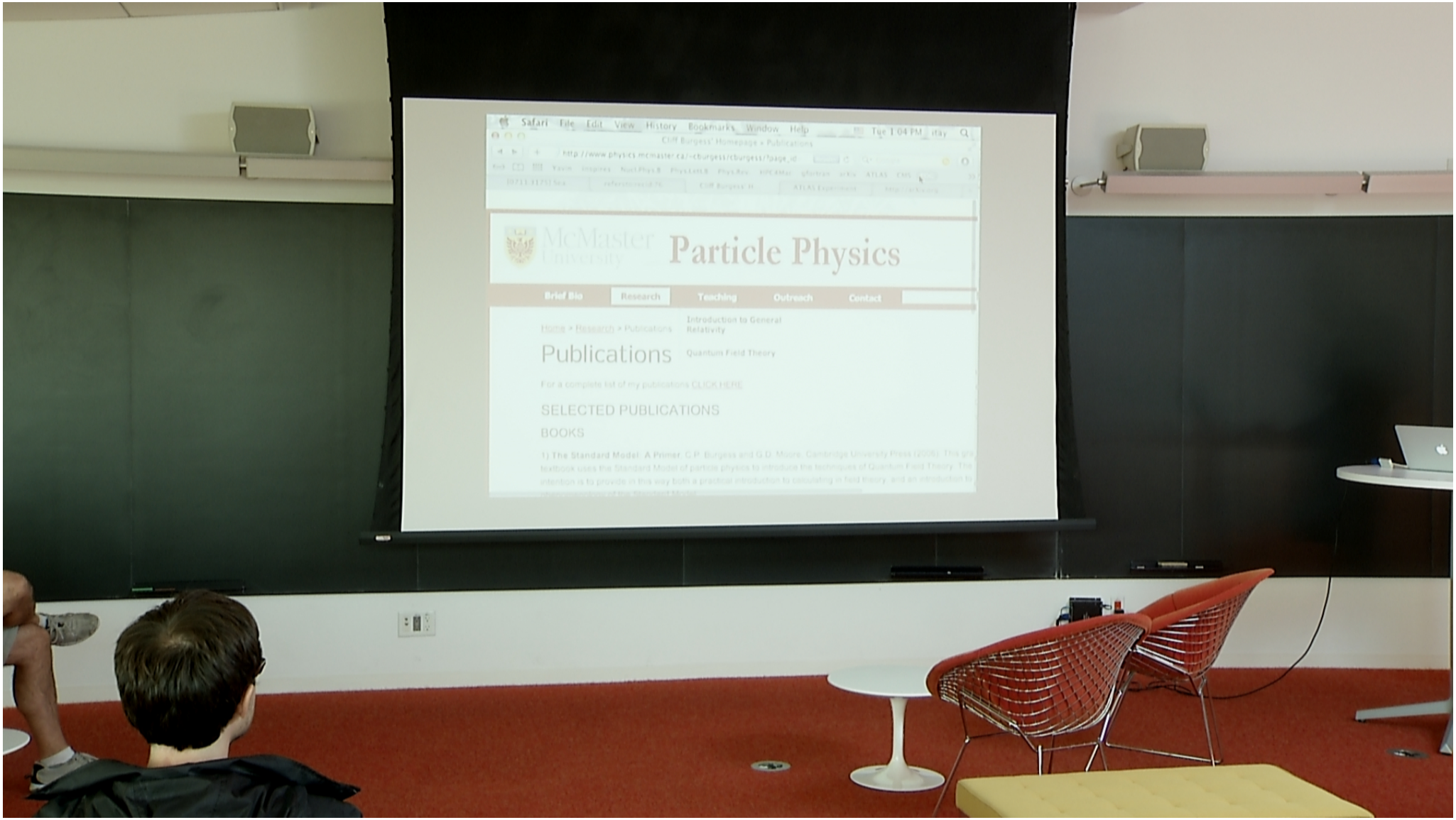
Title: TBA

Date: Jul 10, 2012 01:00 PM

URL: http://pirsa.org/12070011

Abstract: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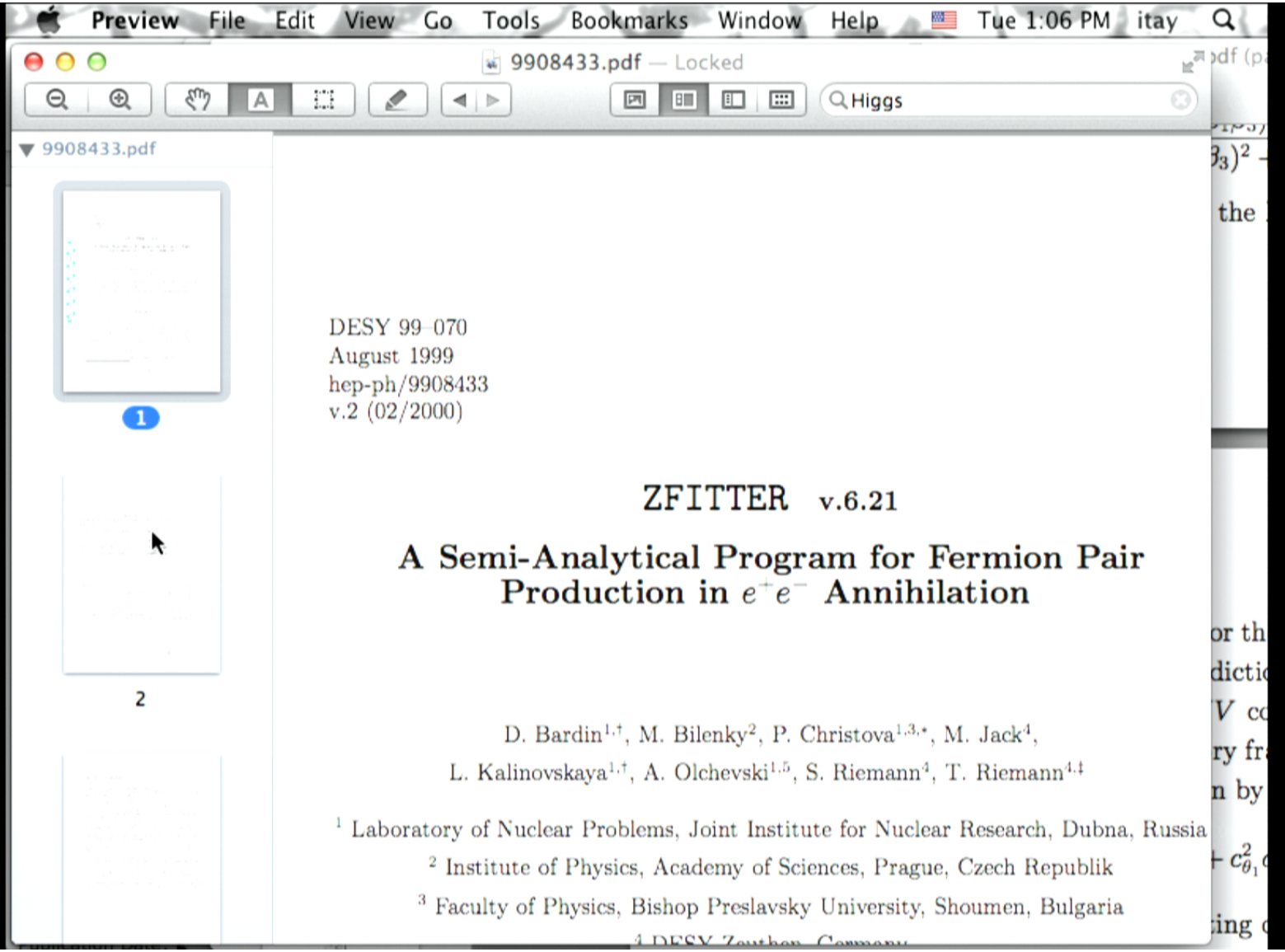
Tue 1:04 PM itay
Cliff Burgess' Homepage » Publications
http://www.physics.mcmaster.ca/~cburgess/cburgess/?page_id
McMaster University
Particle Physics
Brief Bio
Research
Teaching
Outreach
Contact
Home » Research » Publications
Publications
Introduction to General Relativity
Quantum Field Theory
For a complete list of my publications CLICK HERE
SELECTED PUBLICATIONS
BOOKS
1) The Standard Model: A Primer, C.P. Burgess and G.D. Moore, Cambridge University Press (2006).


Preview File Edit View Go Tools Bookmarks Window Help Tue 1:06 PM itay
9908433.pdf — Locked
Higgs
9908433.pdf
1
2
DESY 99–070
August 1999
hep-ph/9908433
v.2 (02/2000)
ZFITTER v.6.21
A Semi-Analytical Program for Fermion Pair Production in e^+e^- Annihilation
D. Bardin[1,†], M. Bilenky[2], P. Christova[1,3,*], M. Jack[4],
L. Kalinovskaya[1,†], A. Olchevski[1,5], S. Riemann[4], T. Riemann[4,‡]
[1] Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, Dubna, Russia
[2] Institute of Physics, Academy of Sciences, Prague, Czech Republik
[3] Faculty of Physics, Bishop Preslavsky University, Shoumen, Bulgaria

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Higgs

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153

154

155

Here and below the following abbreviations are used:

$$c_W^2 = \frac{M_W^2}{M_Z^2}, \tag{A.3.7}$$

$$s_W^2 = 1 - c_W^2, \tag{A.3.8}$$

$$r_W = \frac{M_H^2}{M_W^2}, \tag{A.3.9}$$

$$r_Z = \frac{M_H^2}{M_Z^2}, \tag{A.3.10}$$

$$R_W = \frac{M_W^2}{s}, \tag{A.3.11}$$

$$R_Z = \frac{M_Z^2}{s}. \tag{A.3.12}$$

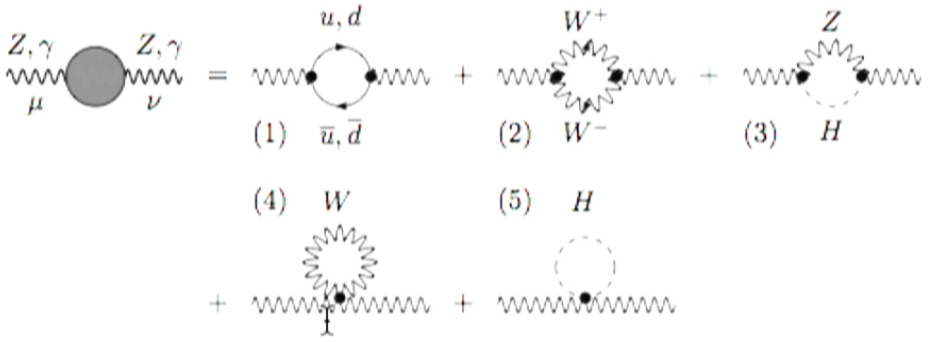
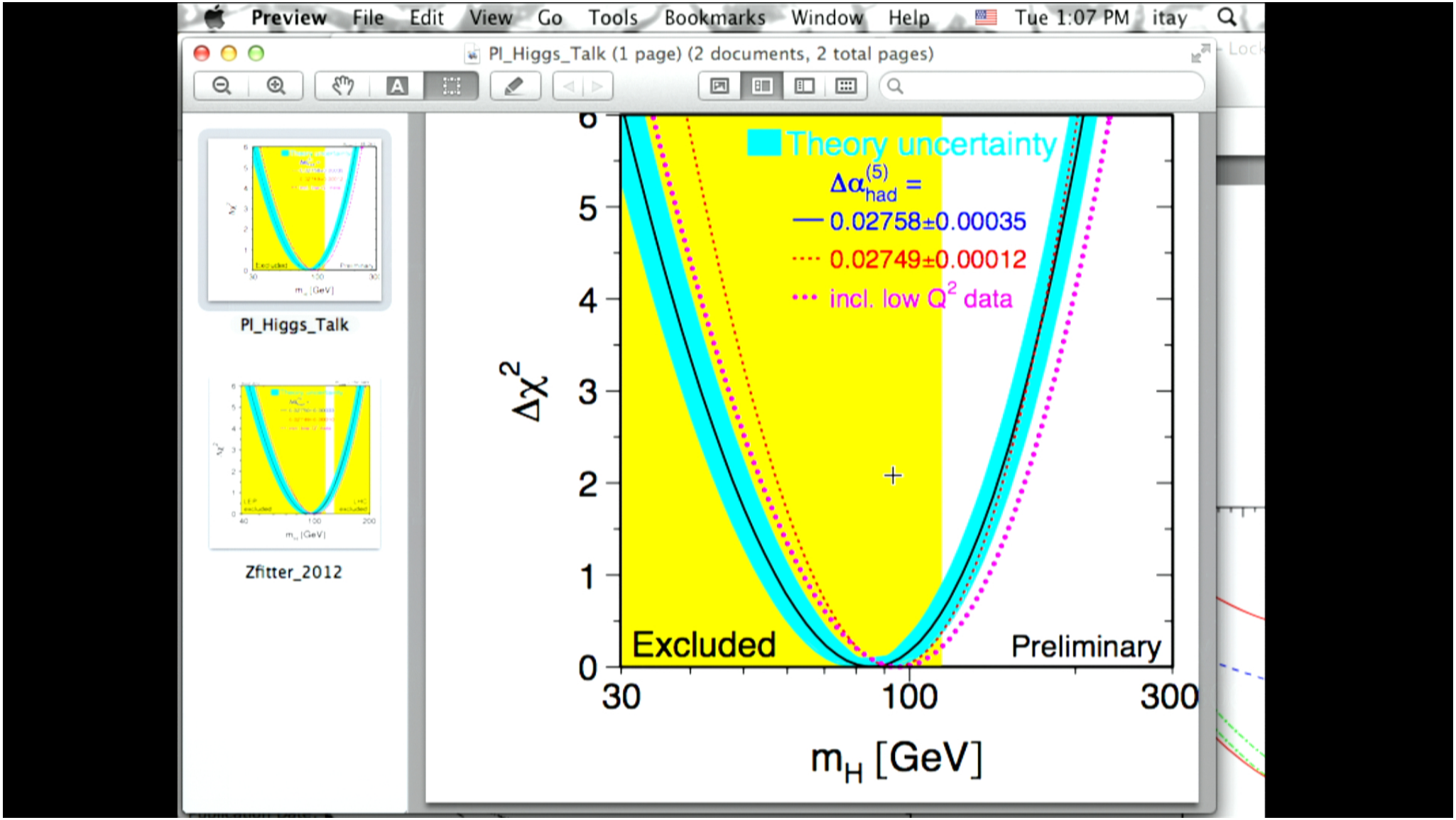


Figure A.1. *Photon and Z-boson self-energies and the Z–γ transition*

In the unitary gauge both $\Sigma_{\gamma\gamma}^{\rm bos}$ and $\Sigma_{Z\gamma}^{\rm bos}$ may be expressed in terms of one function,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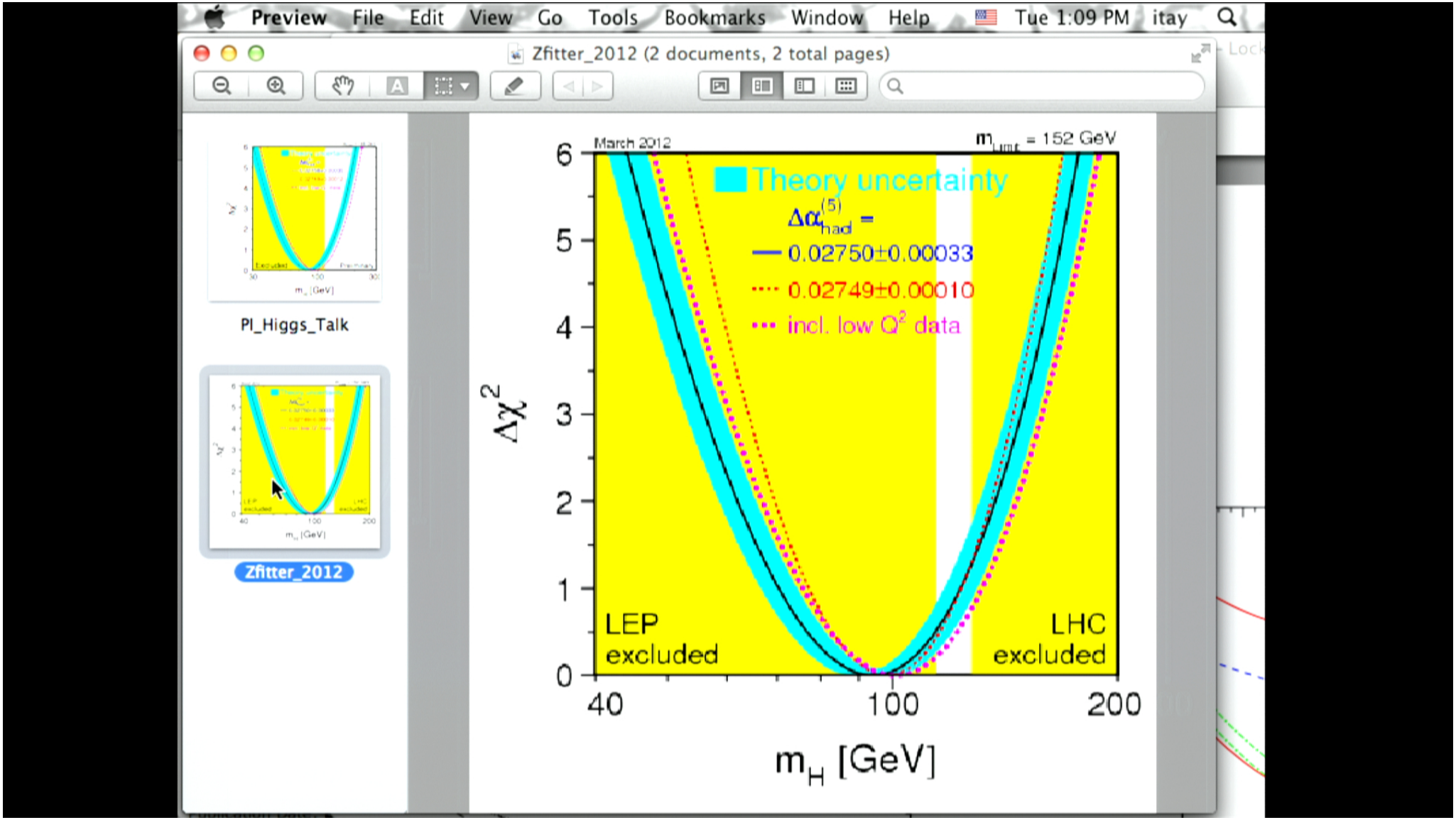
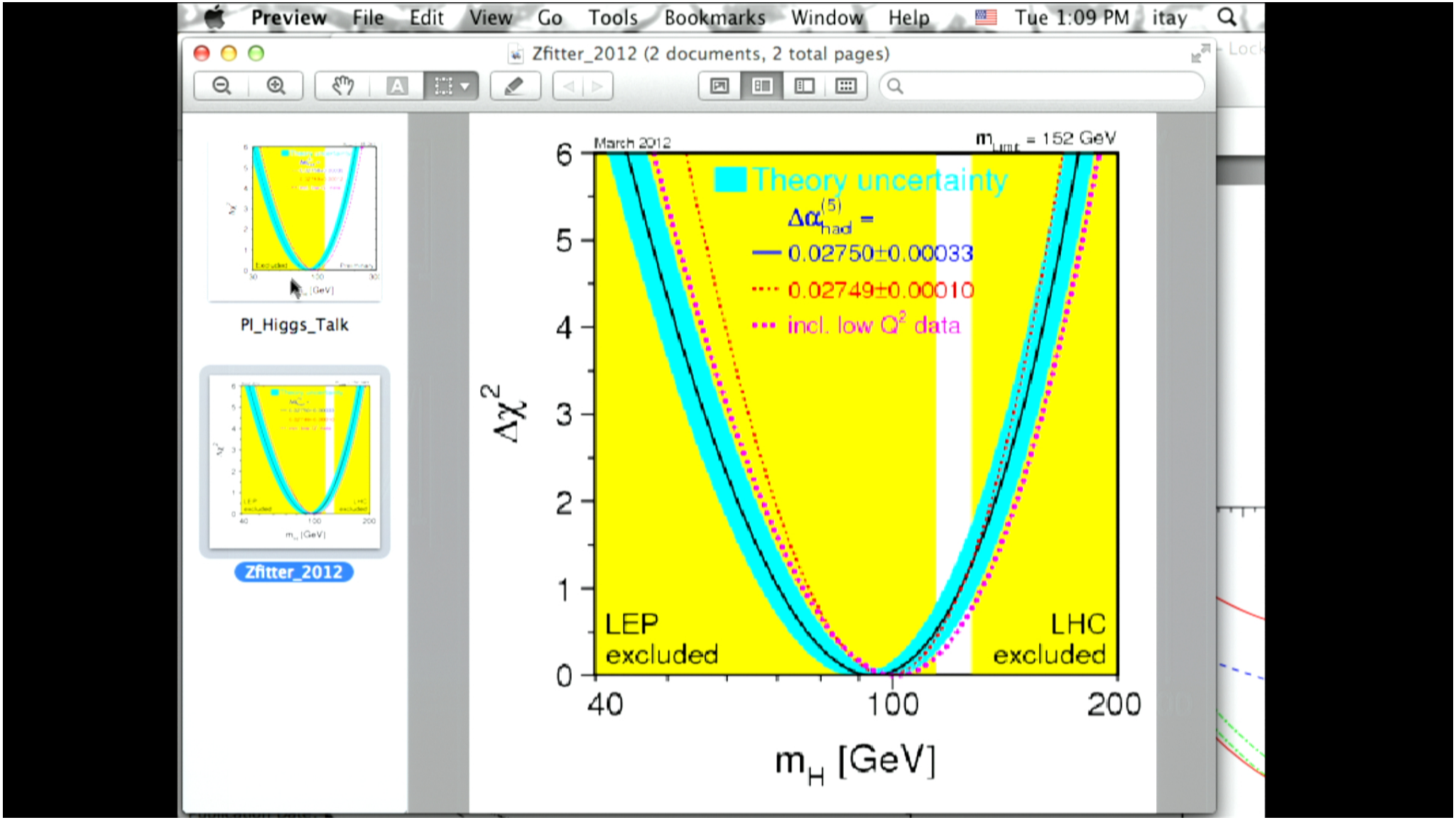
PI_Higgs_Talk (1 page) (2 documents, 2 total pages)
PI_Higgs_Talk
Zfitter_2012
Theory uncertainty
$\Delta\alpha^{(5)}_{had}$ =
0.02758±0.00035
0.02749±0.00012
incl. low Q^2 data
$\Delta\chi^2$
Excluded
Preliminary
m_H [GeV]


Preview File Edit View Go Tools Bookmarks Window Help Tue 1:09 PM itay
Zfitter_2012 (2 documents, 2 total pages)
PI_Higgs_Talk
Zfitter_2012
March 2012
m_{Limit} = 152 GeV
Theory uncertainty
$\Delta\alpha^{(5)}_{had}$ =
0.02750±0.00033
0.02749±0.00010
incl. low Q^2 data
LEP excluded
LHC excluded
$\Delta\chi^2$
m_H [GeV]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Zfitter_2012 (2 documents, 2 total pages)
PI_Higgs_Talk
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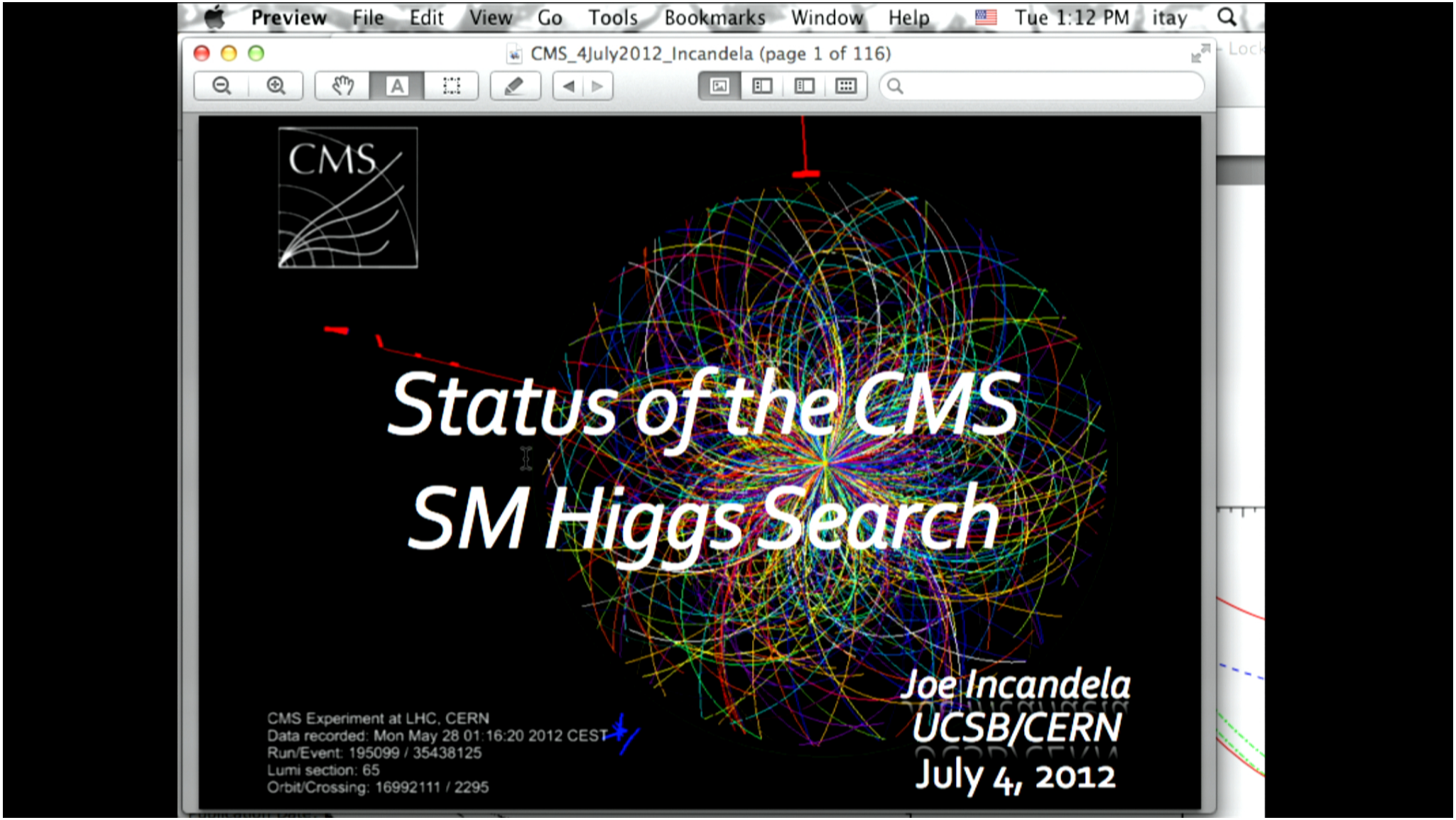
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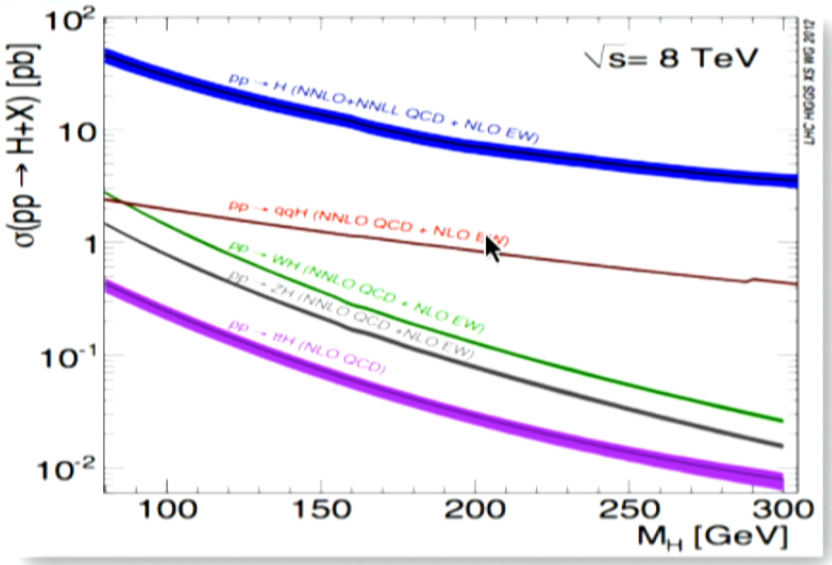
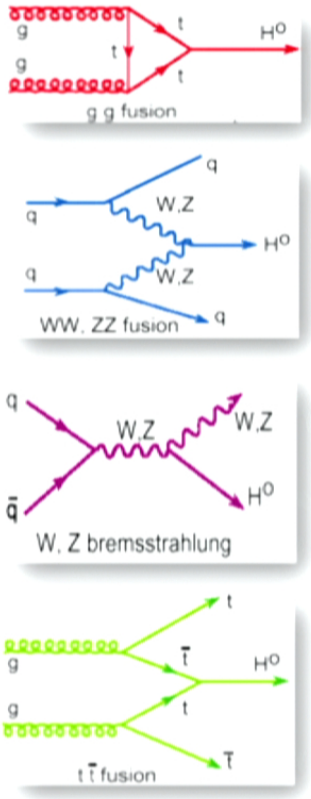
CMS_4July2012_Incandela (page 1 of 116)
CMS
Status of the CMS
SM Higgs Search
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295
Joe Incandela
UCSB/CERN
July 4, 2012

Higgs boson production





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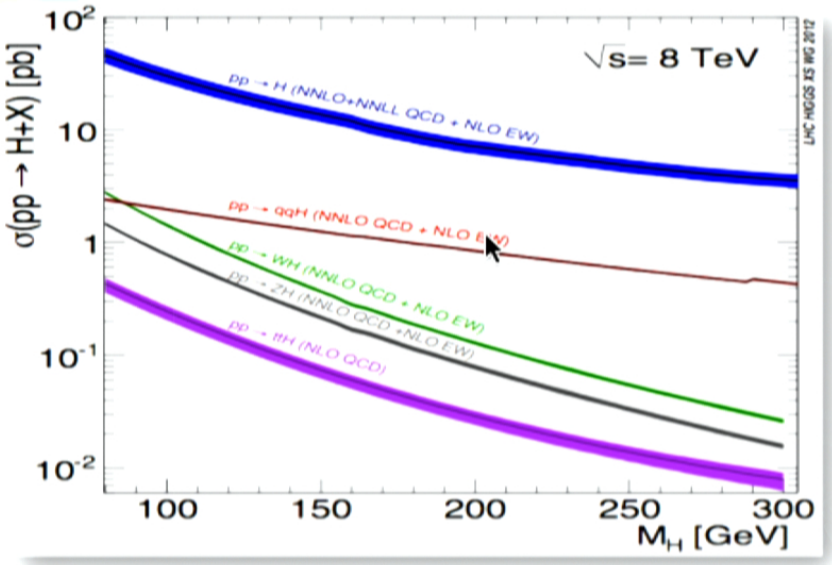
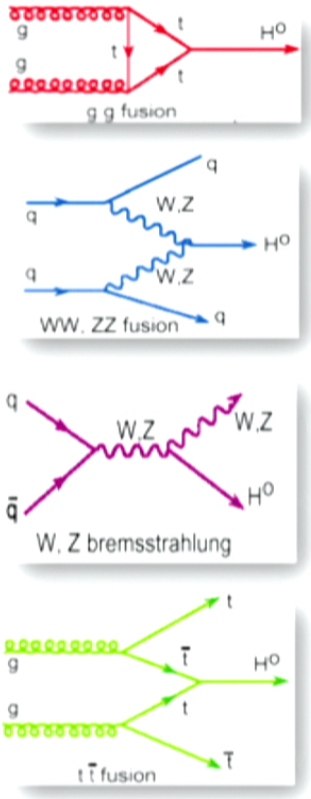
  - gg VBF VH ttH
  - Latter 3 have smaller cross sections but better S/B in many cases

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

11

Higgs boson production





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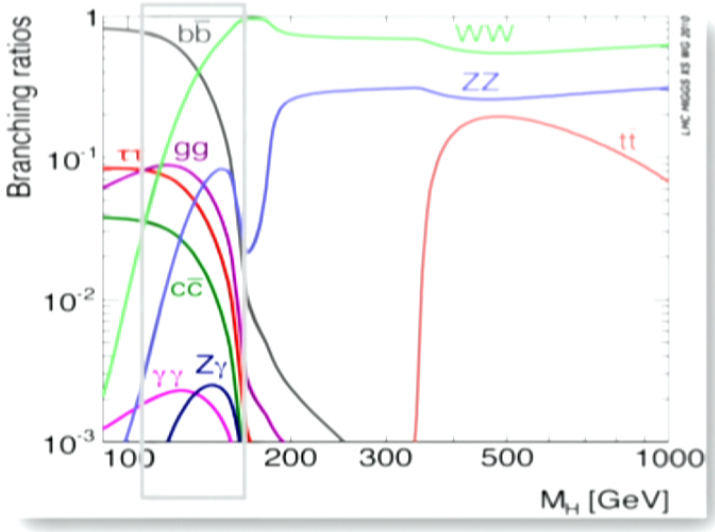
Higgs boson decays

5 decay modes exploited

- High mass: WW, ZZ
- Low mass: bb, ττ, WW, ZZ, γγ
- Low mass region is very rich but also very challenging:
  main decay modes (bb, ττ) are hard to identify in the huge background
- Very good mass resolution (1%): H→γγ and H→ZZ→4l



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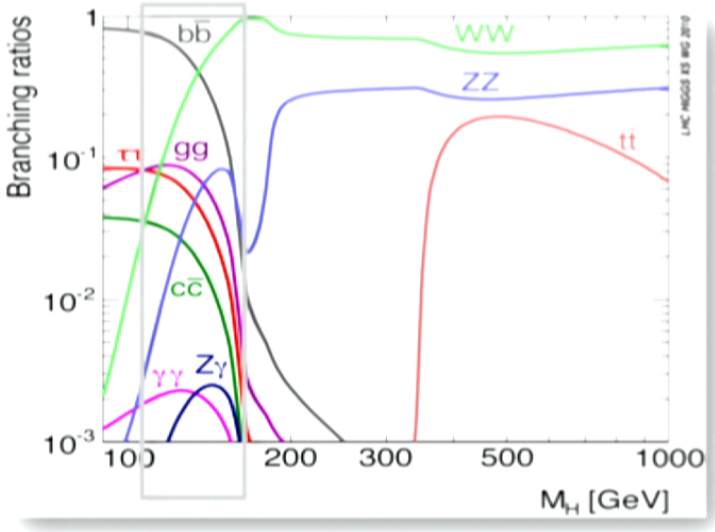
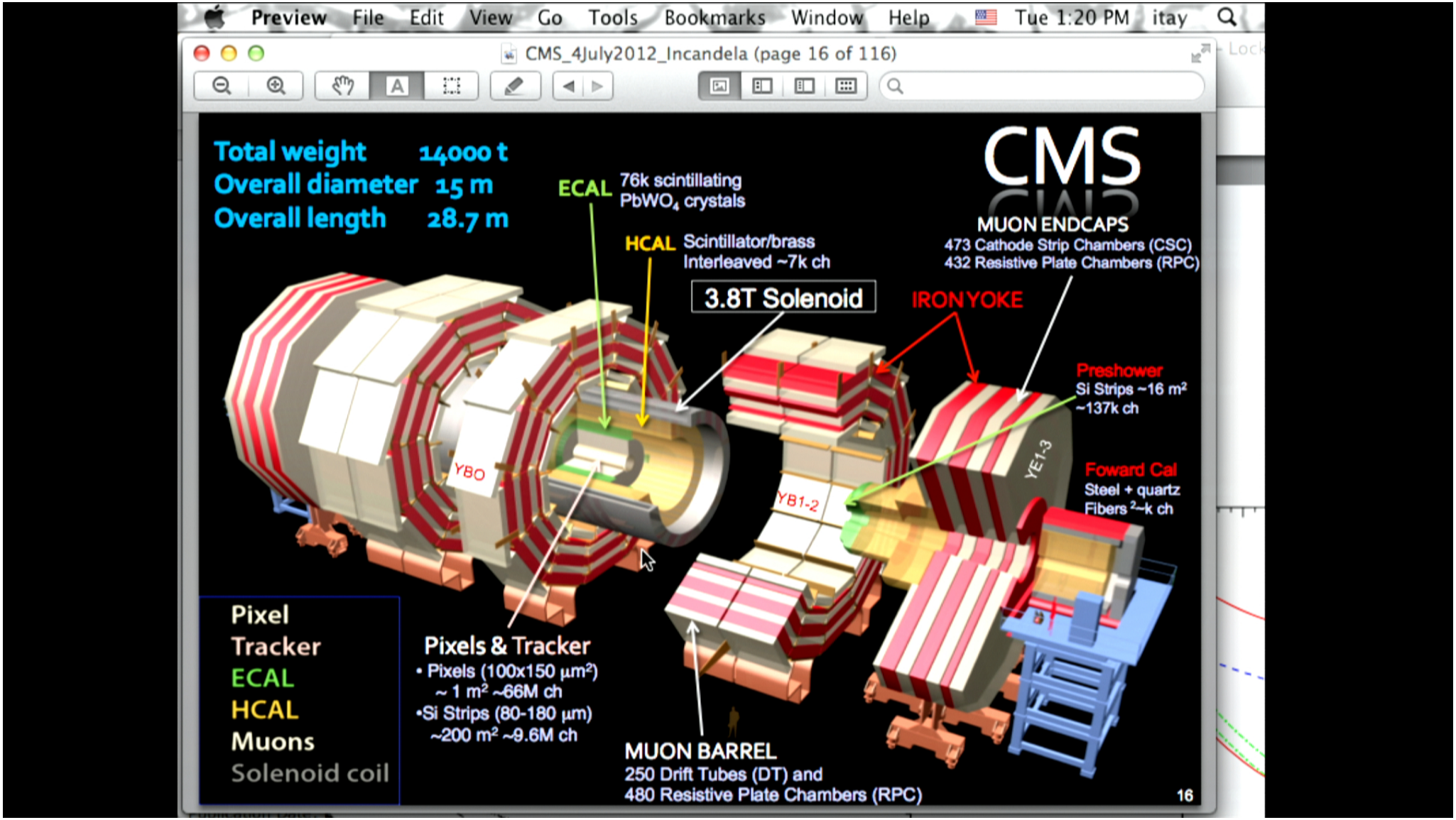
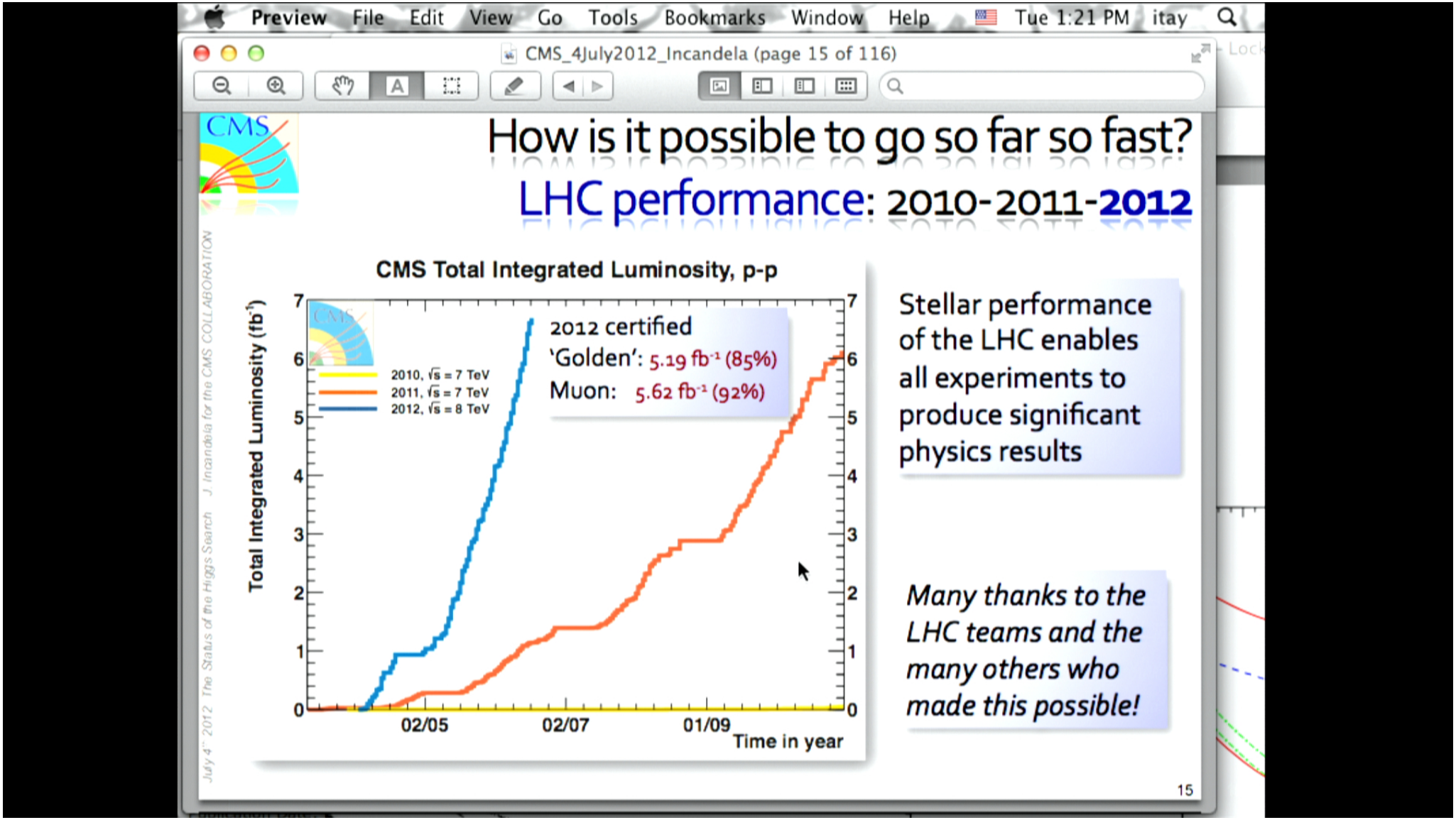
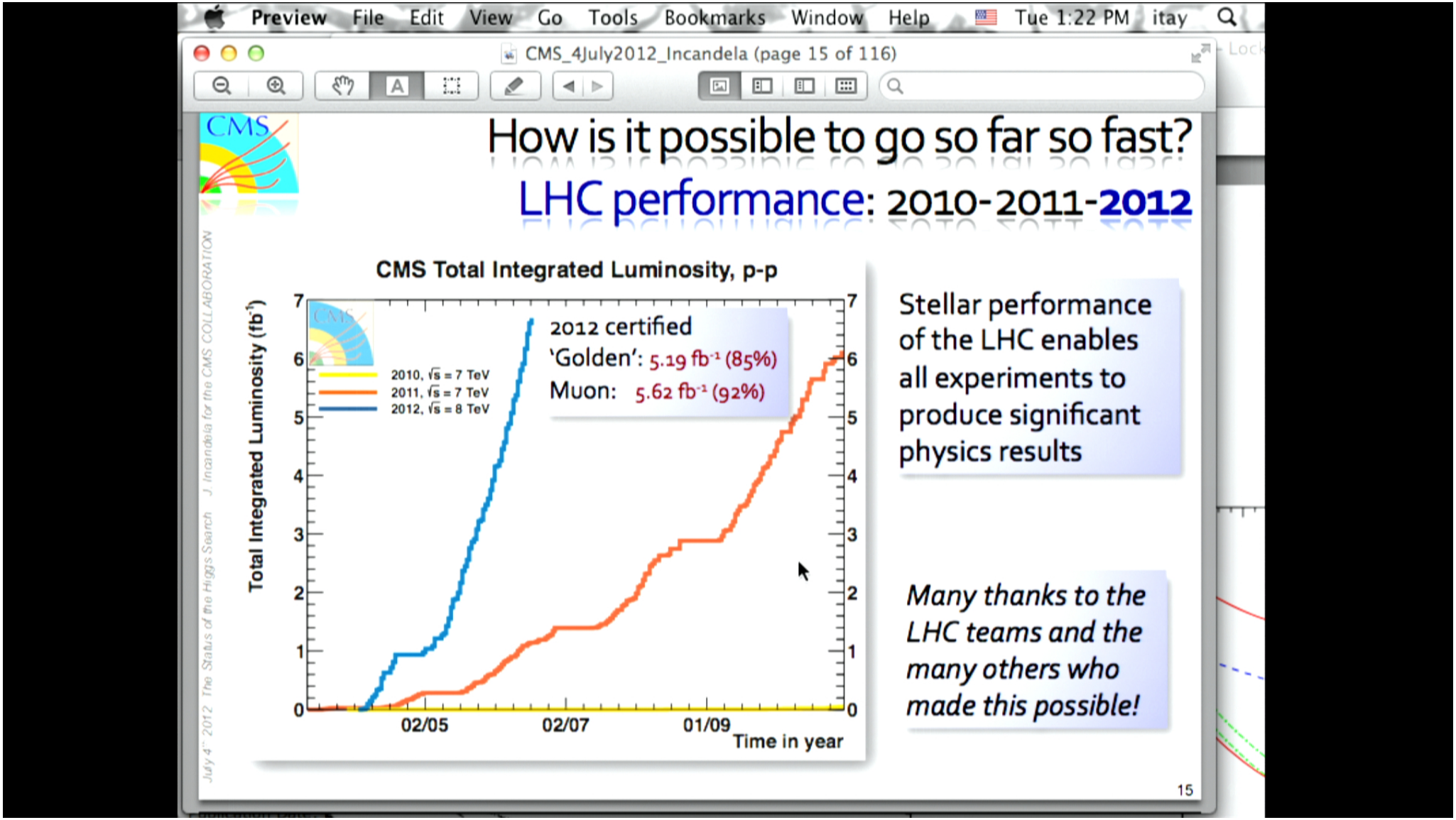



z
z


Preview File Edit View Go Tools Bookmarks Window Help Tue 1:20 PM itay
CMS_4July2012_Incandela (page 16 of 116)
Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m
CMS
ECAL 76k scintillating PbWO4 crystals
HCAL Scintillator/brass Interleaved ~7k ch
3.8T Solenoid
IRON YOKE
MUON ENDCAPS
473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)
Preshower
Si Strips ~16 m²
~137k ch
Foward Cal
Steel + quartz
Fibers ²~k ch
YB0
YB1-2
YE1-3
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm²)
~ 1 m² ~66M ch
•Si Strips (80-180 μm)
~200 m² ~9.6M ch
MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)
16


Preview File Edit View Go Tools Bookmarks Window Help Tue 1:21 PM itay
CMS_4July2012_Incandela (page 15 of 116)
How is it possible to go so far so fast?
LHC performance: 2010-2011-2012
CMS Total Integrated Luminosity, p-p
Total Integrated Luminosity (fb⁻¹)
2010, √s = 7 TeV
2011, √s = 7 TeV
2012, √s = 8 TeV
2012 certified
'Golden': 5.19 fb⁻¹ (85%)
Muon: 5.62 fb⁻¹ (92%)
02/05
02/07
01/09
Time in year
Stellar performance of the LHC enables all experiments to produce significant physics results
Many thanks to the LHC teams and the many others who made this possible!
July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION
15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CMS_4July2012_Incandela (page 15 of 116)
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LHC performance: 2010-2011-2012
CMS Total Integrated Luminosity, p-p
Total Integrated Luminosity (fb⁻¹)
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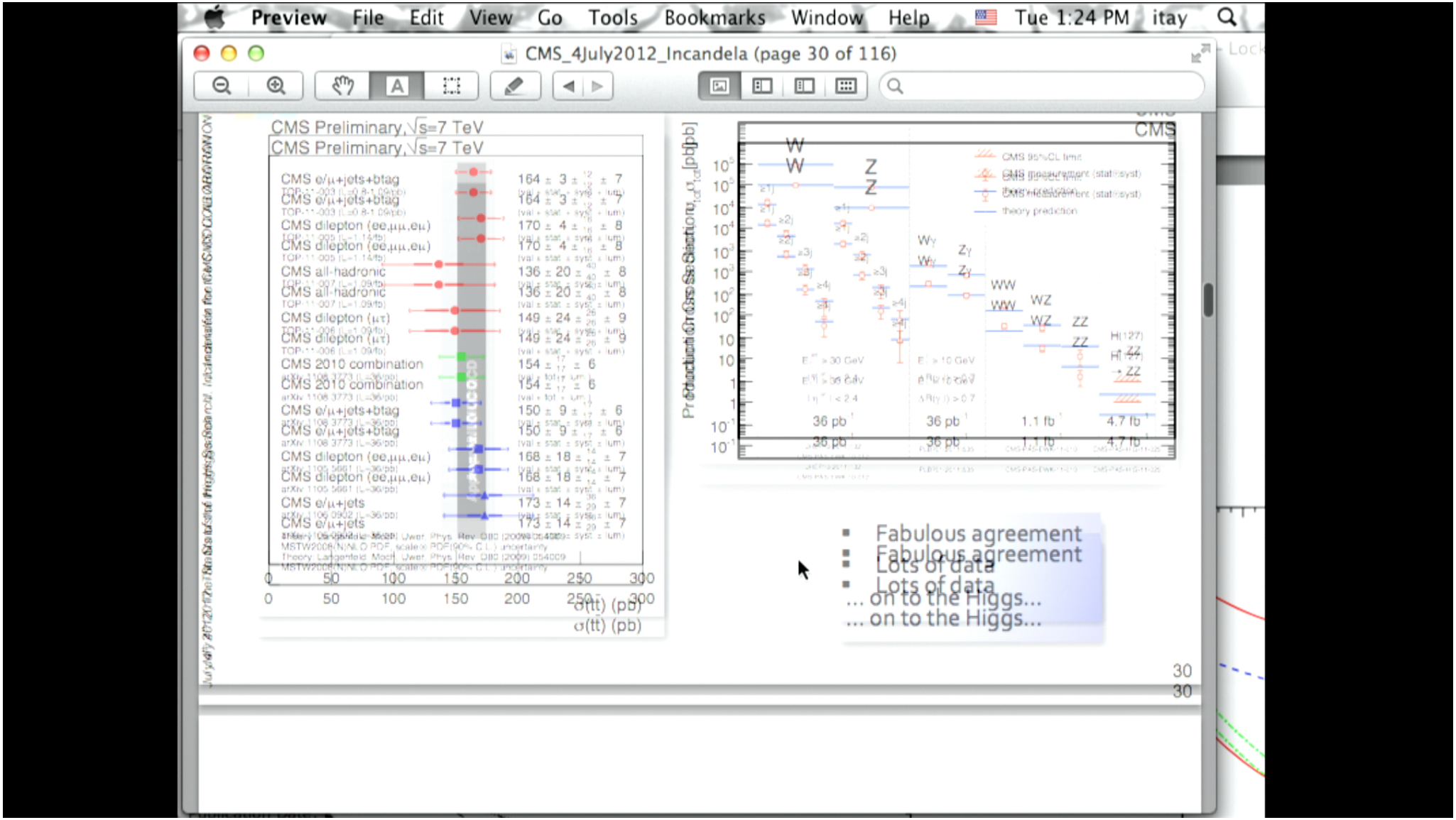
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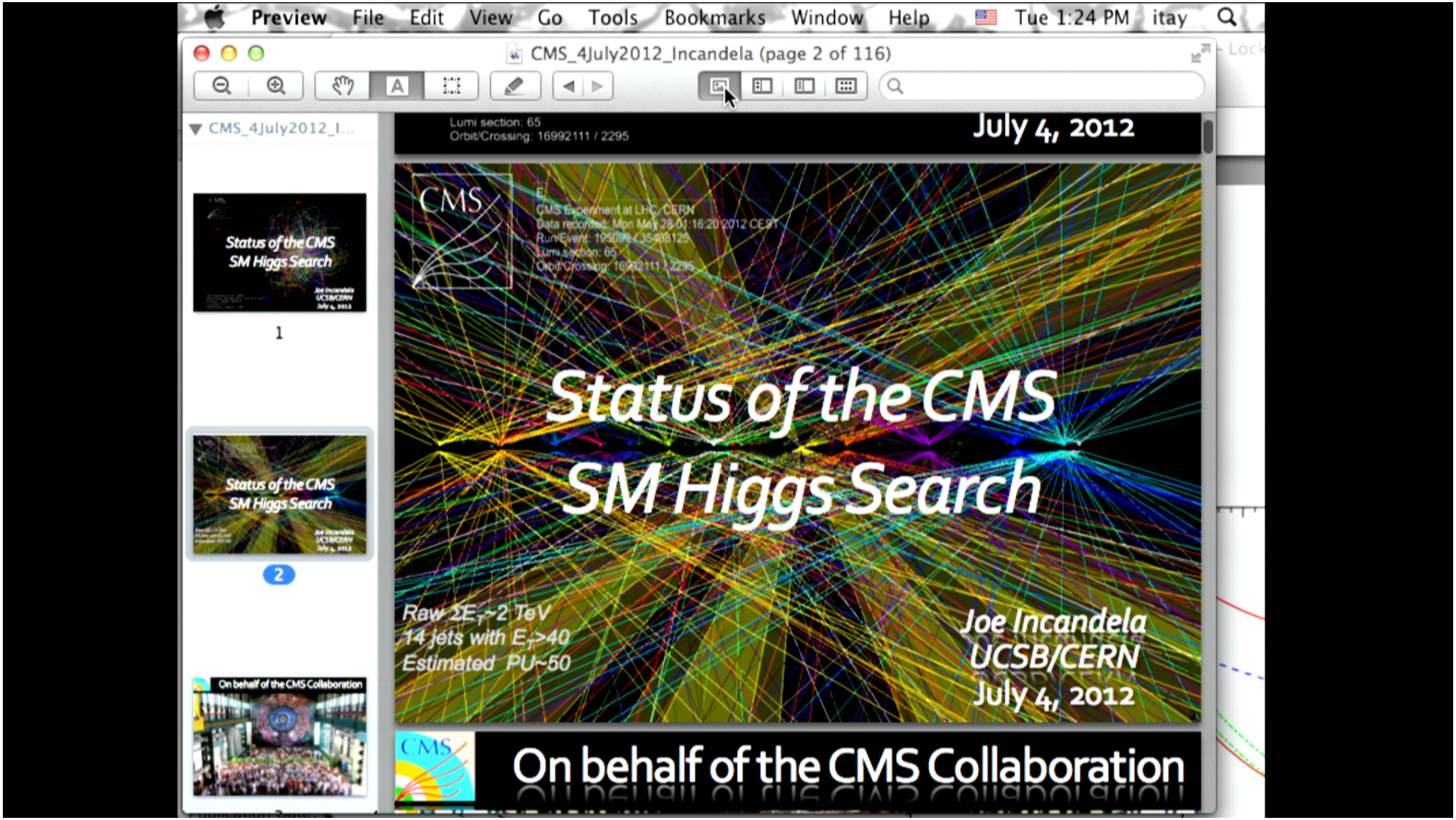
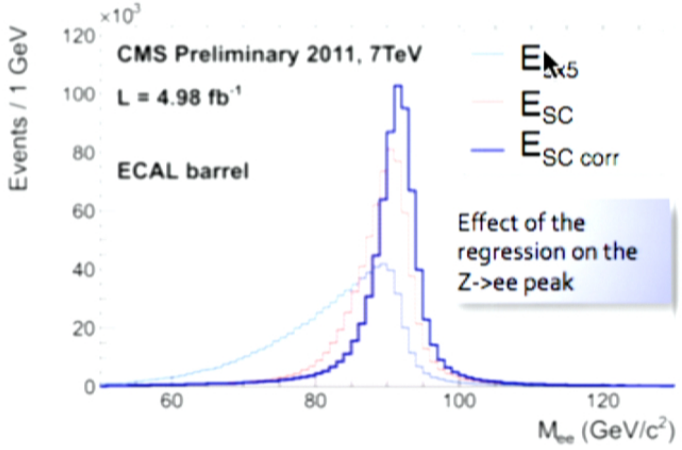
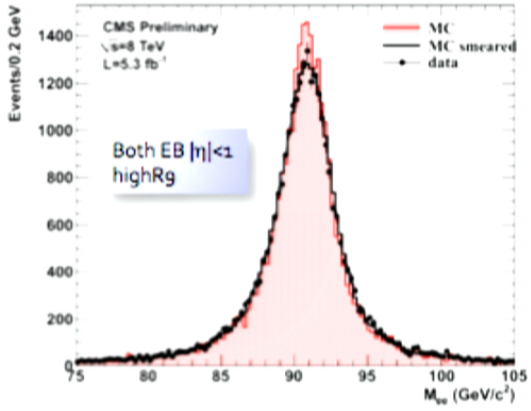
CMS_4July2012_Incandela (page 30 of 116)
CMS Preliminary, √s=7 TeV
CMS e/μ+jets+btag
CMS dilepton (ee,μμ,eμ)
CMS all-hadronic
CMS dilepton (μτ)
CMS 2010 combination
CMS e/μ+jets
σ(tt) (pb)
CMS
W W
Z Z
Wγ
Zγ
WW
WZ
ZZ
H(127)
CMS 95%CL limit
CMS measurement (stat⊕syst)
theory prediction
36 pb⁻¹
1.1 fb⁻¹
4.7 fb⁻¹
Fabulous agreement
Fabulous agreement
Lots of data
Lots of data
... on to the Higgs...
... on to the Higgs...
30
30


Preview File Edit View Go Tools Bookmarks Window Help Tue 1:24 PM itay
CMS_4July2012_Incandela (page 2 of 116)
CMS_4July2012_I...
Lumi section: 65
Orbit/Crossing: 16992111 / 2295
July 4, 2012
Status of the CMS SM Higgs Search
1
2
Status of the CMS SM Higgs Search
Raw ΣE_T~2 TeV
14 jets with E_T>40
Estimated PU~50
Joe Incandela
UCSB/CERN
July 4, 2012
On behalf of the CMS Collaboration
On behalf of the CMS Collaboration

Photon Energy Scale and Resolution

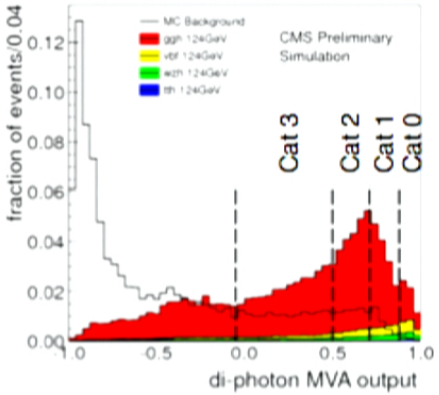
- ECAL cluster energies corrected using a MC trained multivariate regression
  - Improves resolution and restores flat response of energy scale versus pileup
    - Inputs: Raw cluster energies and positions, lateral and longitudinal shower shape variables, local shower positions w.r.t. crystal geometry, pileup estimators
- Regression also used to provide a per photon energy resolution estimate
- To measure the Energy Scale and resolution: use $Z \rightarrow e^+e^-$

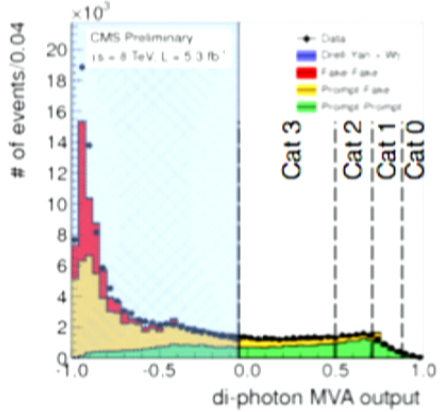




Diphoton MVA

- Diphoton MVA trained on signal and background MC with input variables largely independent of $m_{\gamma\gamma}$
  - Kinematics: p_T and η of each photon, and $\cos\Delta\phi$ between the 2 photons
  - Photon ID MVA output for each photon
  - per-event mass resolution and vertex probability
- Encode all relevant information on signal vs background discrimination (aside from $m_{\gamma\gamma}$ itself) into a single di-photon MVA output to first order independent of $m_{\gamma\gamma}$



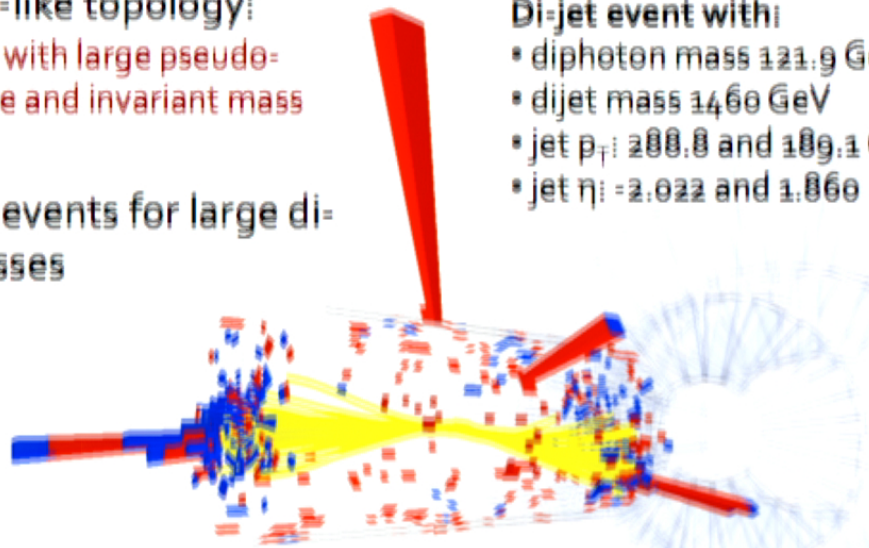


- Residual data-MC disagreement
  - For BG only make analysis sub-optimal
  - For signal would cause some category migration included in the systematic errors

Di-jet Tagging

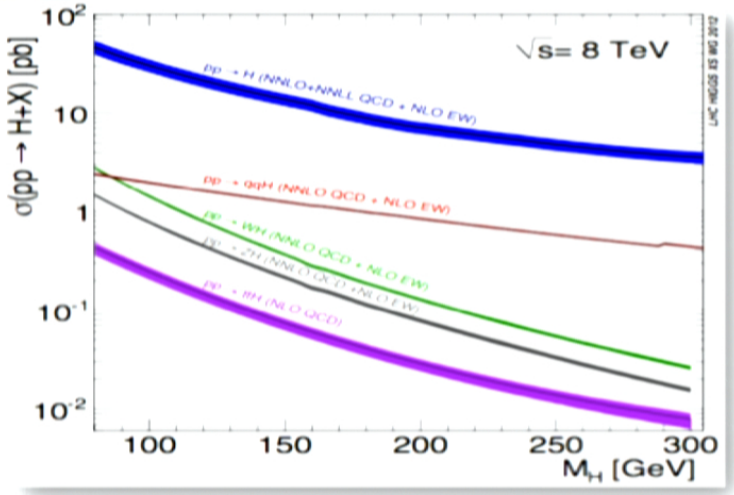
- Exclusive selection of di-photon events with VBF-like topology:
  - Two high pT jets with large pseudo-rapidity difference and invariant mass
- High S/B
- ≈80%-pure VBF events for large di-jet invariant masses

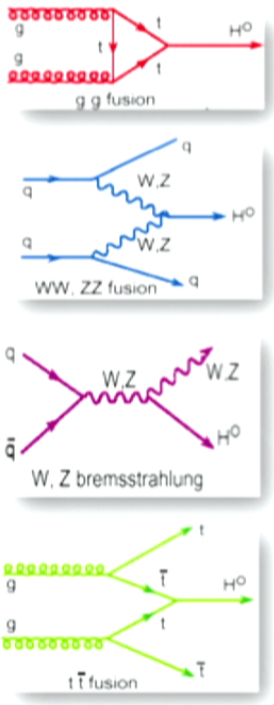
Di-jet event with:
- diphoton mass 121.9 GeV
- dijet mass 1460 GeV
- jet p_T: 288.8 and 189.1 GeV
- jet η: -2.022 and 1.860



CMS Experiment at LHC, CERN
Data recorded: Mon Sep 26 20:18:07 2011 CEST
Run/Event: 177201 / 625786854
Lumi section: 450

Higgs boson production





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July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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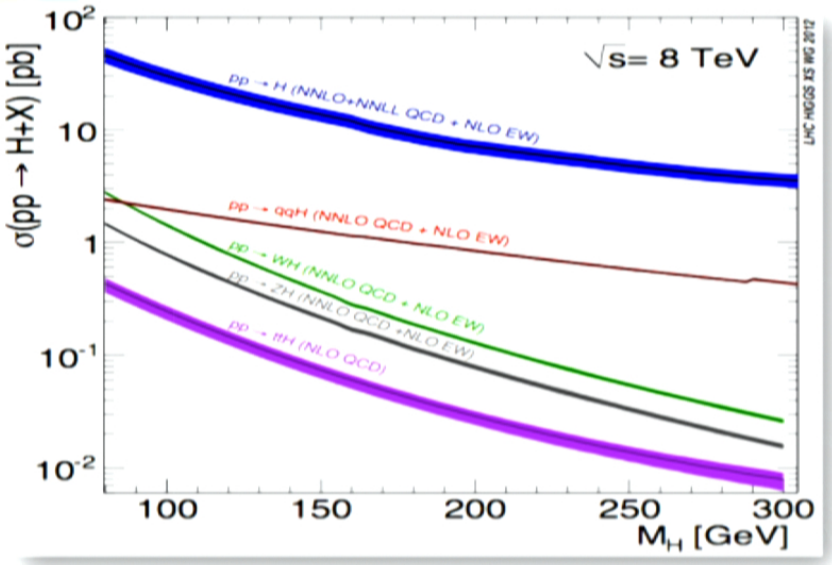
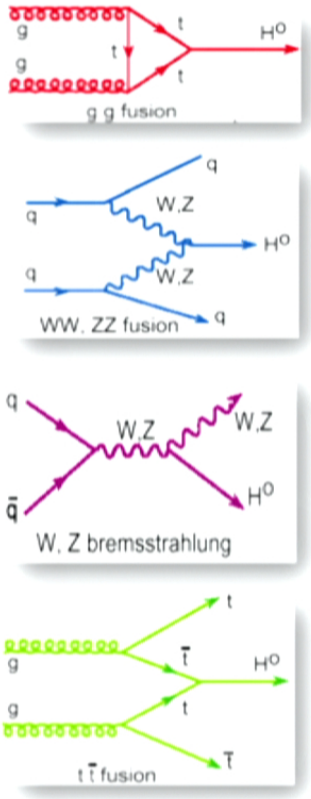
Higgs boson decays

Higgs boson production





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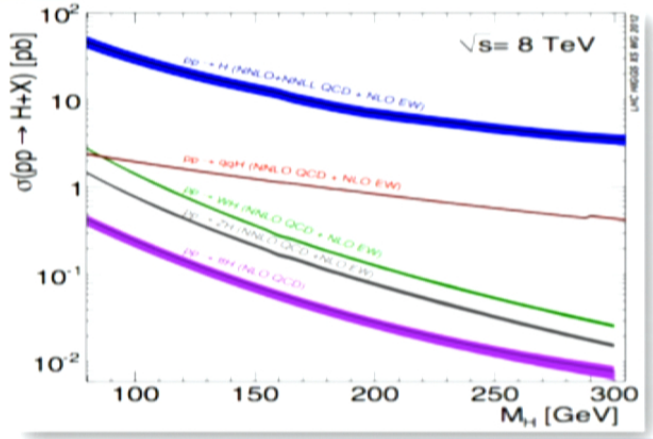

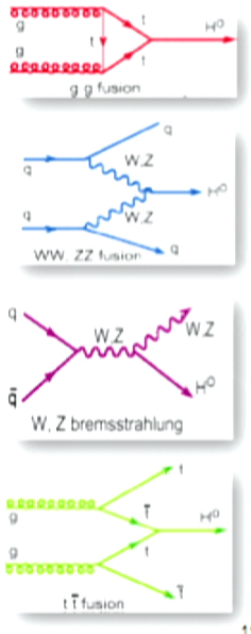

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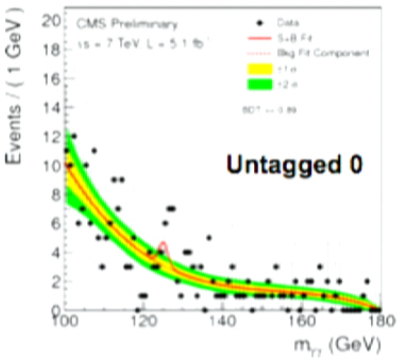
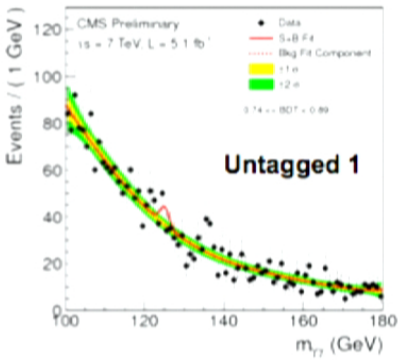
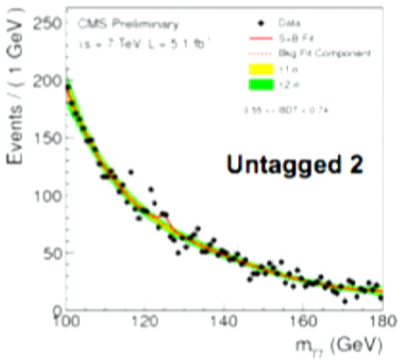
Higgs boson decays

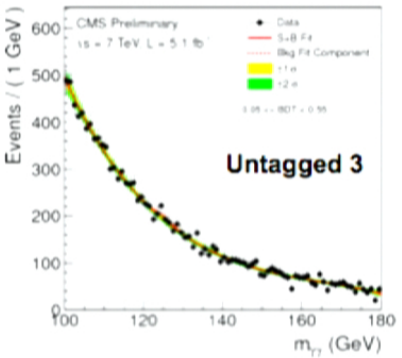
5 decay modes exploited

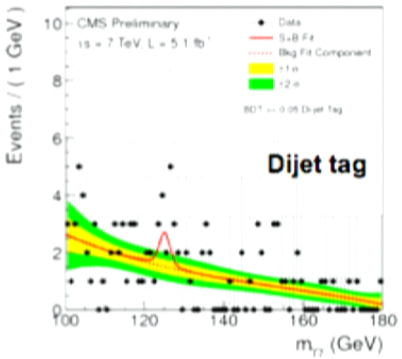
7 TeV Mass Distribution in Categories











- Background model is entirely from data.
- Fit to mass distribution in each category with polynomial functions (3rd to 5th degree)
  - keep bias below 20% of fit error.
  - causes some loss of performance due to number of parameters in fit function.

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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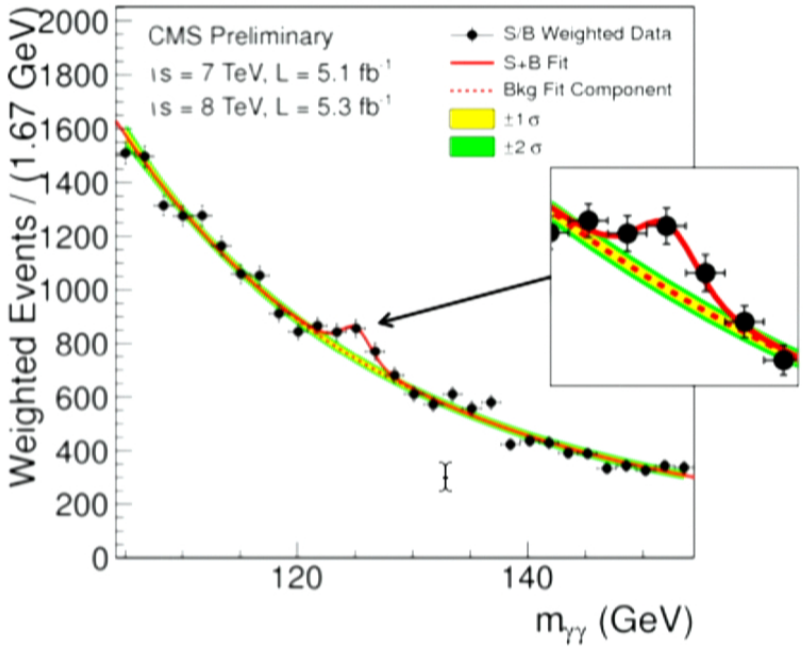
S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval



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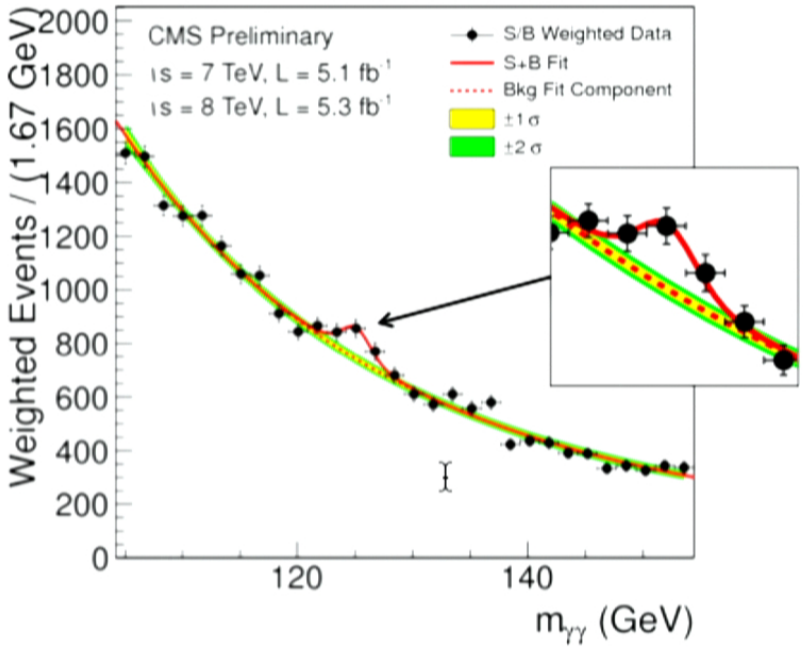
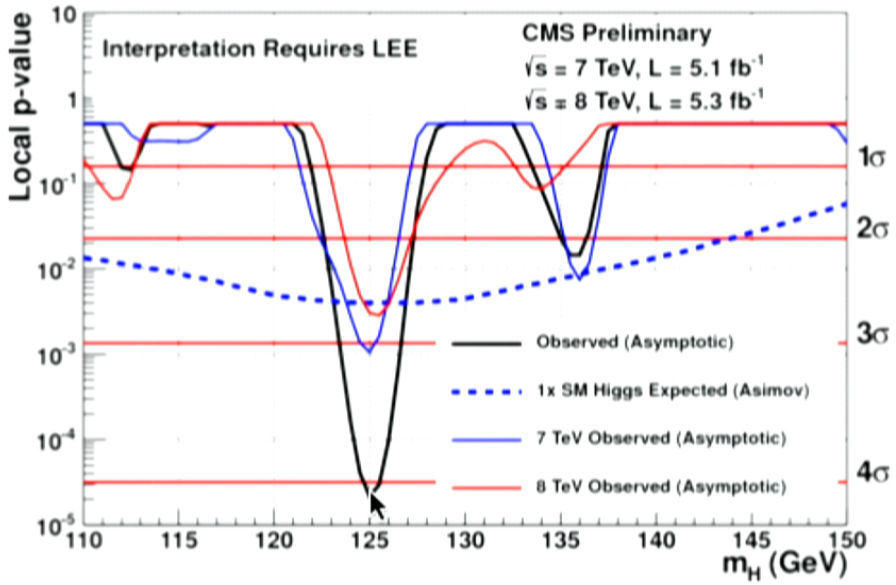
CMS_4July2012_Incandela (page 43 of 116)

S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
  - B is integral of background model over a constant signal fraction interval



P-Values



- Minimum local p-value at 125 GeV with a local significance of 4.1 σ
- Similar excess in 2011 and 2012
- Independent cross check analyses give similar results
- Global significance in the full search range (110-150 GeV) 3.2 σ

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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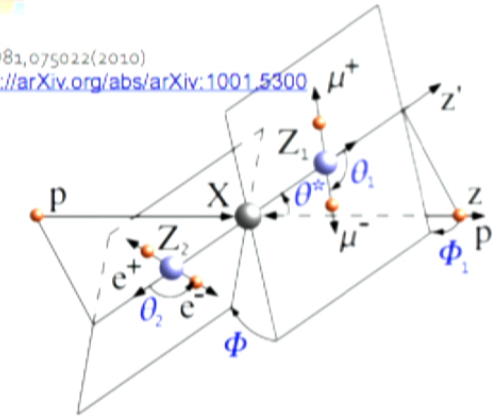
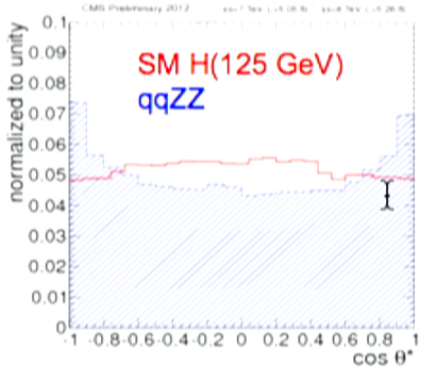
MELA

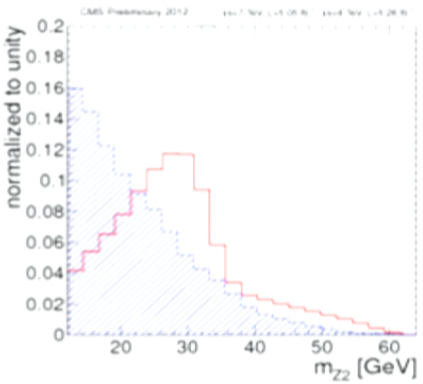
PRD81,075022(2010)
http://arXiv.org/abs/arXiv:1001.5300

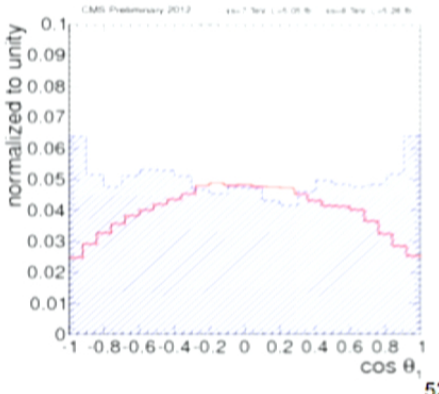


Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$







J. Incandela for the CMS COLLABORATION
July 4th 2012 The Status of the Higgs Search

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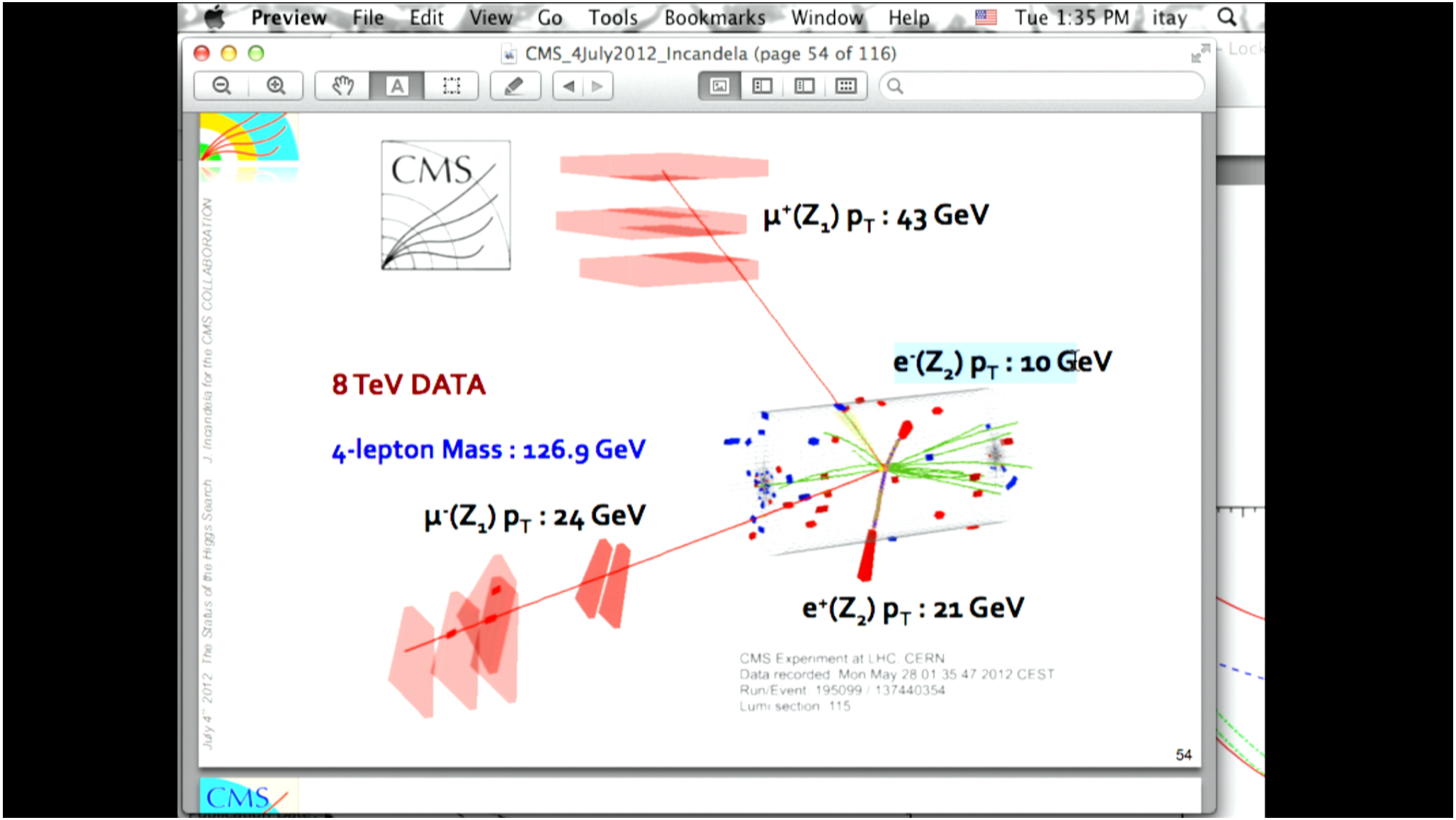
CMS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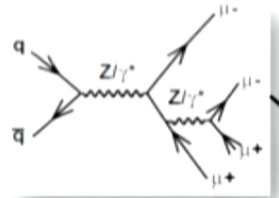
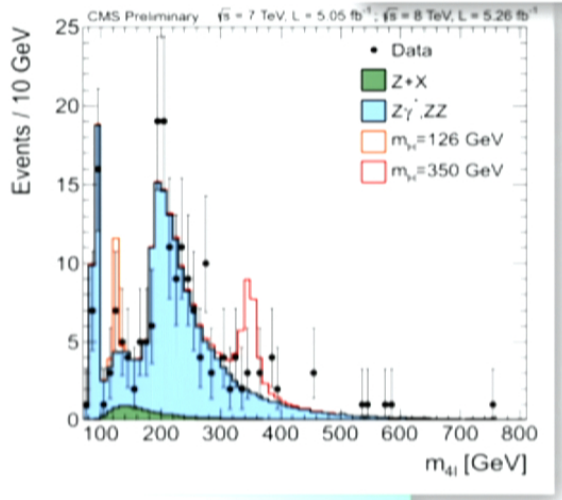
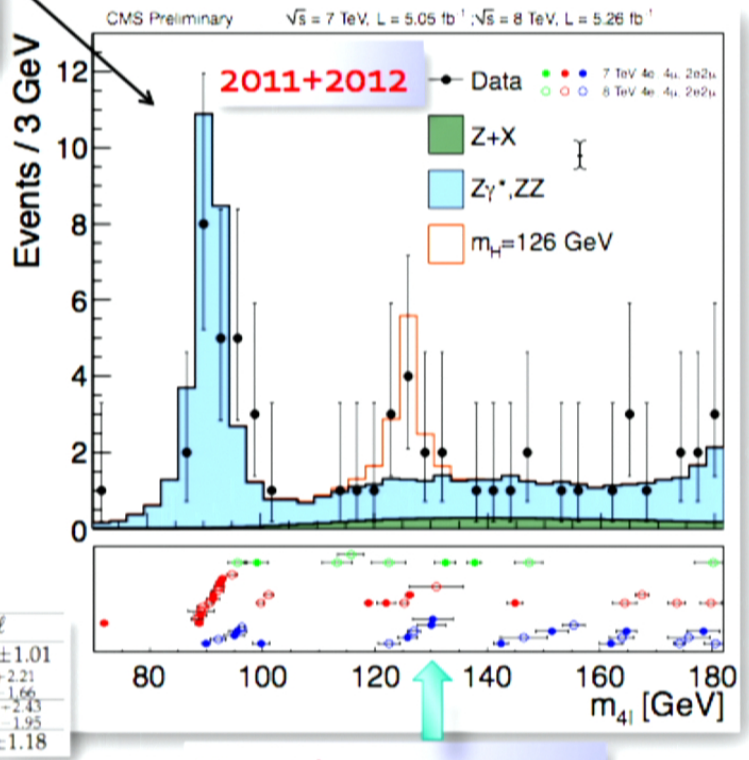
CMS_4July2012_Incandela (page 54 of 116)
CMS
$\mu^+(Z_1)\ p_T$: 43 GeV
$e^-(Z_2)\ p_T$: 10 GeV
8 TeV DATA
4-lepton Mass : 126.9 GeV
$\mu^-(Z_1)\ p_T$: 24 GeV
$e^+(Z_2)\ p_T$: 21 GeV
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115
July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION
54
CMS

Results: m(4l) spectrum







Yields for m(4l)=110..160 GeV

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.65 ±0.31	5.65 ±0.59	7.17 ±0.76	15.48 ±1.01
Z+X	$1.20^{+1.08}_{-0.78}$	$0.92^{+0.65}_{-0.55}$	$2.29^{+1.81}_{-1.36}$	$4.41^{+2.21}_{-1.66}$
All backgrounds	$3.85^{+1.12}_{-0.84}$	$6.58^{+0.88}_{-0.81}$	$9.46^{+1.96}_{-1.56}$	$19.88^{+2.43}_{-1.95}$
m_H = 126 GeV	1.51 ±0.48	2.99 ±0.60	3.81 ±0.89	8.31 ±1.18

164 events expected in [100, 800 GeV]

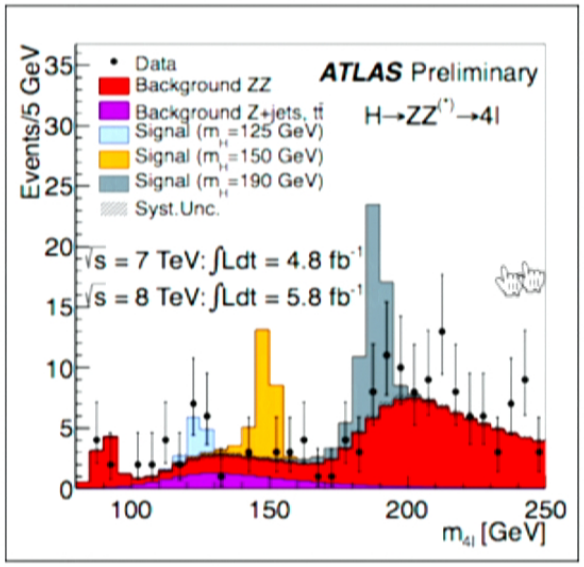
Event-by-event errors

of these properties match the predictions: the fact that it is seen in the predicted channels and at a mass favoured by other, indirect measurements. In the weeks and months ahead, ATLAS will better measure these properties, enabling a clearer picture to emerge about whether this particle is the Higgs Boson, or the first of a larger family of such particles, or something else entirely.

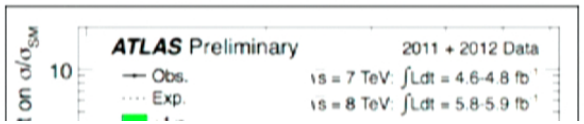
The 2012 data set comes from proton collisions with an increased centre of mass energy of 8 TeV and includes more data (collected in only three months) than was collected in all of 2011. This rapid accumulation of data was possible thanks to the outstanding efforts of the LHC accelerator group. The data set presented at the seminar comes from approximately one quadrillion (million billion) proton collisions.

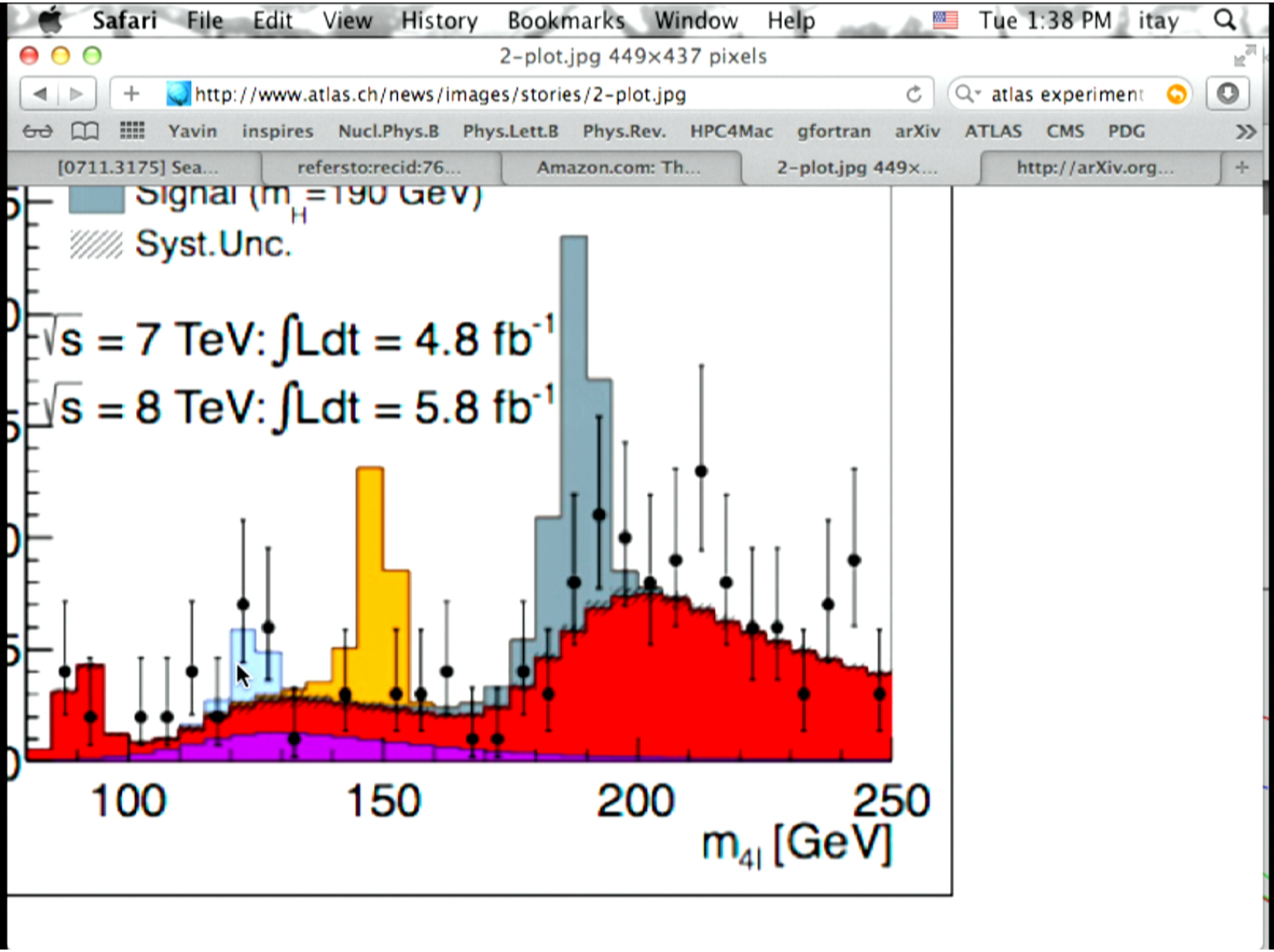
The ATLAS detector has performed remarkably well, even under the more difficult beam conditions of 2012, and has, with nearly full efficiency, collected high quality data for this search. Powerful computing provided by the worldwide LHC Computing Grid was essential for the reconstruction and analysis of the data.

The LHC is expected to provide ATLAS with double the data again by the end of the 2012, before the beginning of a long shutdown to upgrade the accelerator. When the machine starts up again toward the end of 2014, it will operate at nearly twice its current energy. The new



Mass distribution for the four-lepton channel. The search with the purest expected signal is done by examining events with two Z bosons that have decayed to pairs of electrons or muons. In the region from 120 to 130 GeV, 13 events are seen where only 5.3 were expected. The complete analysis concludes that the probability of such an excess would be three times in ten thousand if there were no new particle.

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http://www.atlas.ch/news/images/stories/2-plot.jpg
atlas experiment
Yavin inspires Nucl.Phys.B Phys.Lett.B Phys.Rev. HPC4Mac gfortran arXiv ATLAS CMS PDG
[0711.3175] Sea...
refersto:recid:76...
Amazon.com: Th...
2-plot.jpg 449×...
http://arXiv.org...
Signal (m_H =190 GeV)
Syst.Unc.
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.8 fb^{-1}
100
150
200
250
m_{4l} [GeV]

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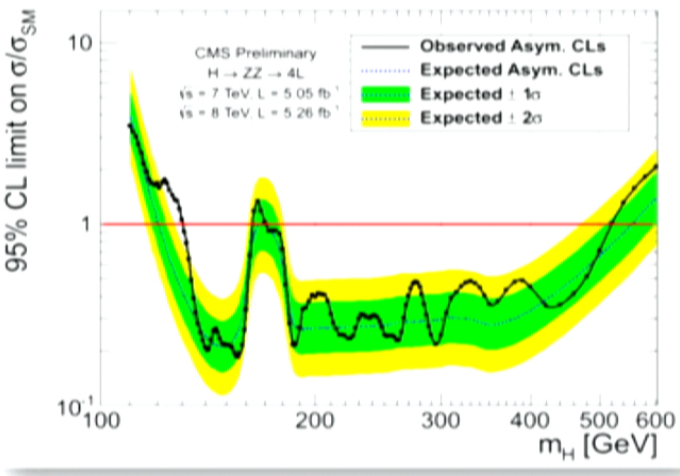
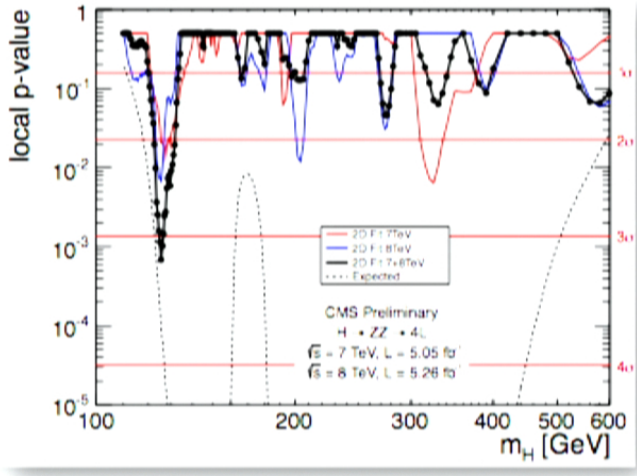
CMS_4July2012_Incandela (page 62 of 116)

Limits and p-values





Expected exclusion at 95% CL :
121-550 GeV
Observed exclusion at 95% CL :
131-162 GeV and 172-530 GeV

Expected significance at 125.5 GeV :
3.8 σ
Observed significance at 125.5 GeV:
3.2 σ

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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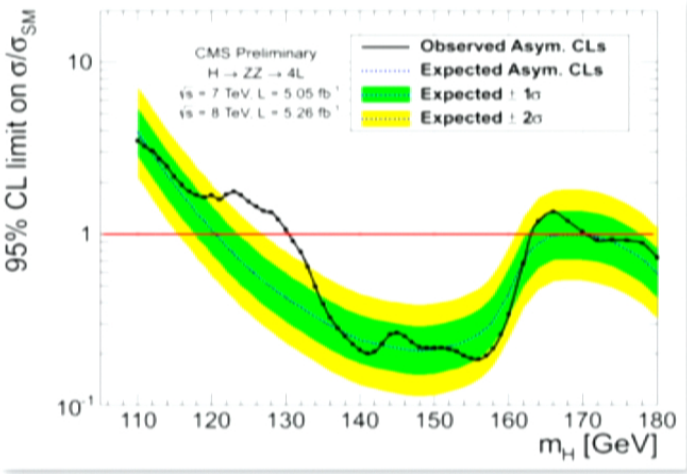
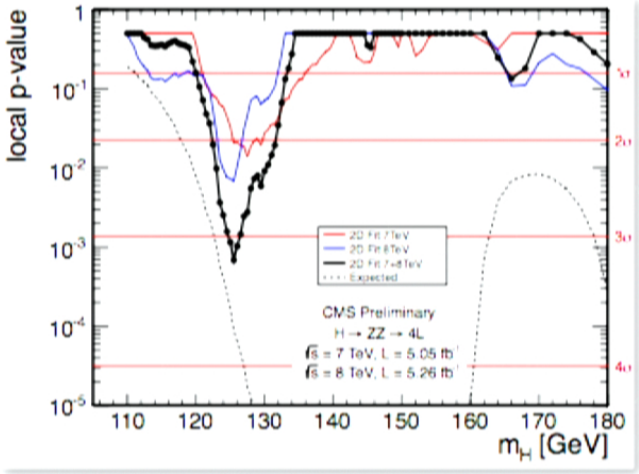
CMS_4July2012_Incandela (page 63 of 116)

Limits and p-values





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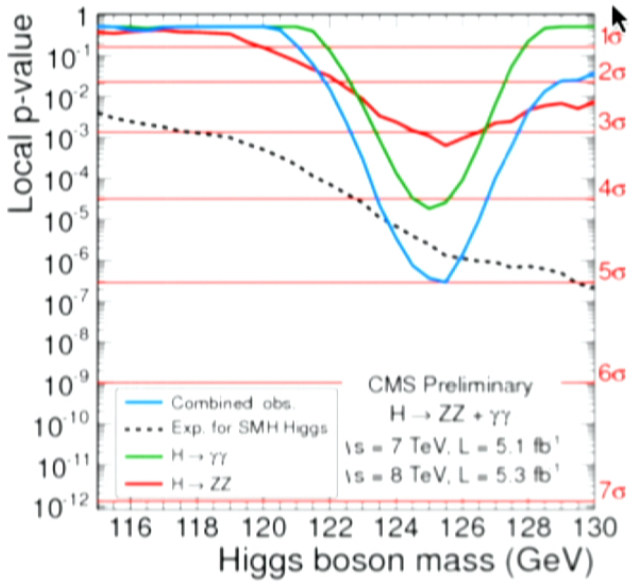
July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

Characterization of excess near 125 GeV



- high sensitivity, high mass resolution channels: γγ+4l
  - γγ: 4.1 σ excess
  - 4 leptons: 3.2 σ excess
  - near the same mass 125 GeV
- comb. significance: **5.0 σ**
- expected significance for SM Higgs: **4.7 σ**

July 4, 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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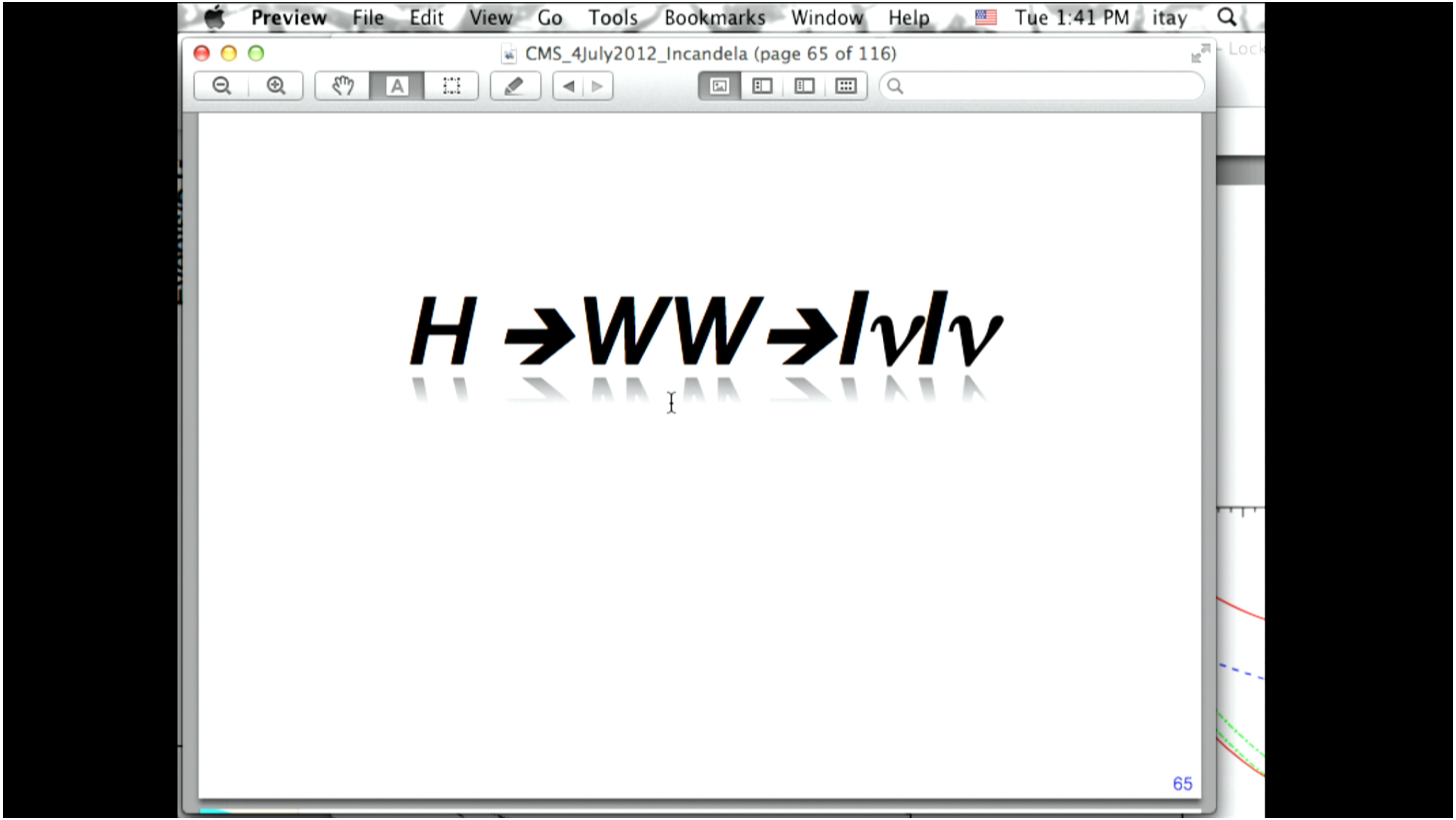
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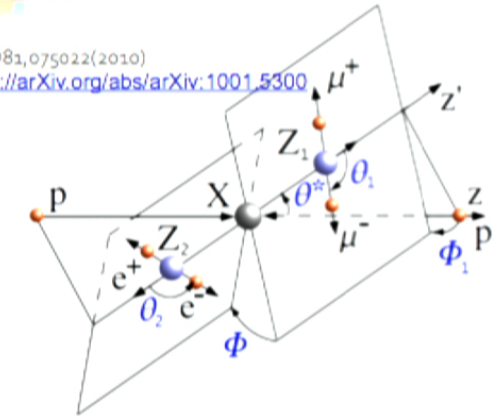
CMS_4July2012_Incandela (page 65 of 116)
H →WW→lνlν
65

m_{4l} [GeV] m_{4l} [GeV]

51

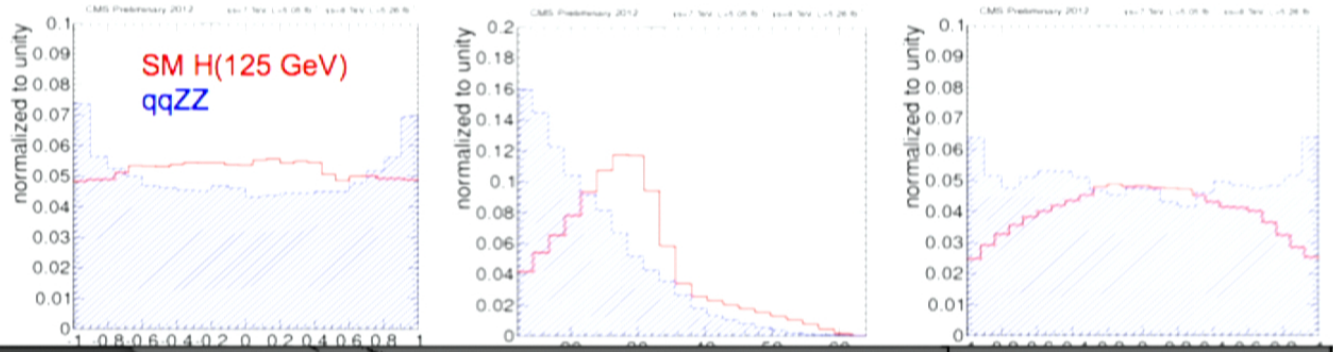
MELA

PRD81,075022(2010)
http://arXiv.org/abs/arXiv:1001.5300



Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4l})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4l})}\right]^{-1}$$



J. Incandela for the CMS COLLABORATION
4th July 2012 The Status of the Higgs Search

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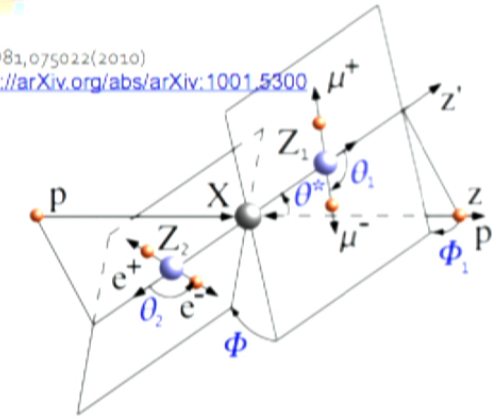
m_{4l} [GeV] m_{4l} [GeV]

51

CMS

MELA

PRD81,075022(2010)
http://arXiv.org/abs/arXiv:1001.5300



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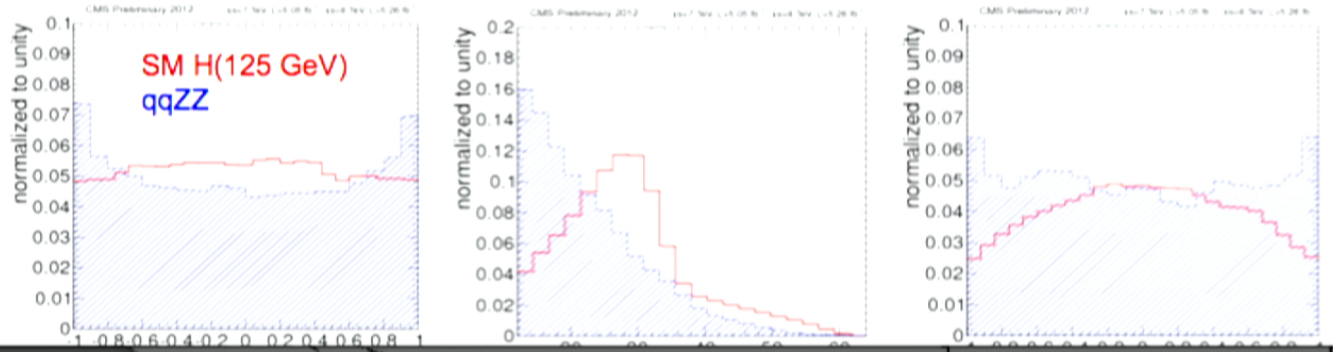

J. Incandela for the CMS COLLABORATION
4th July 2012 The Status of the Higgs Search

MELA

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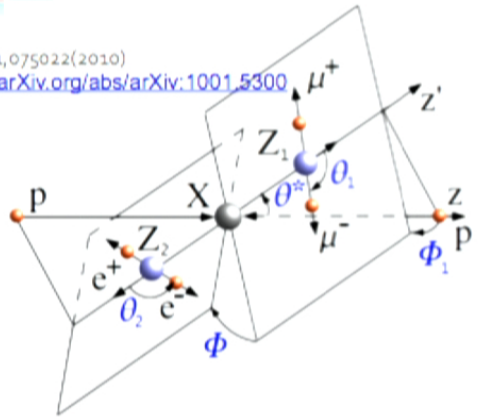

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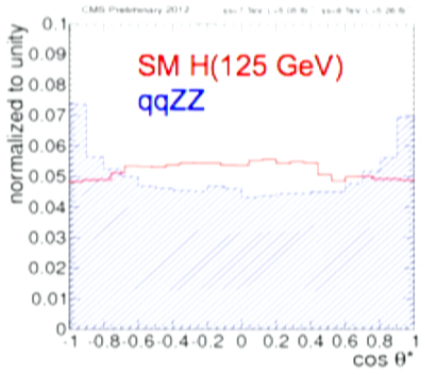

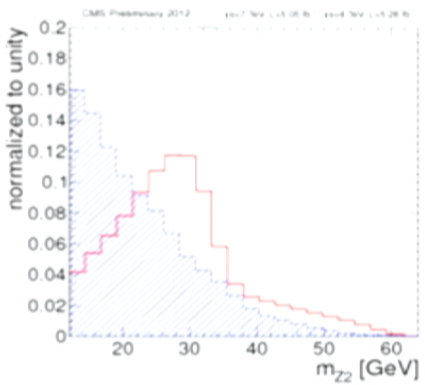

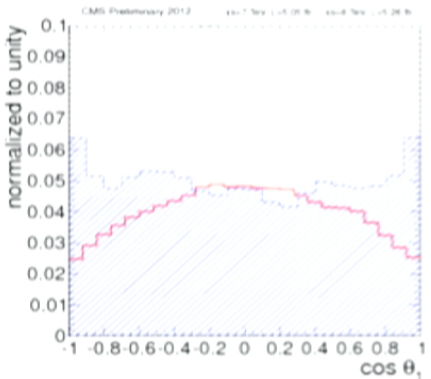

July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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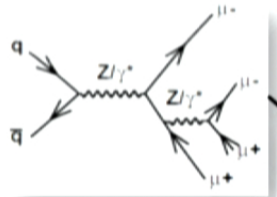
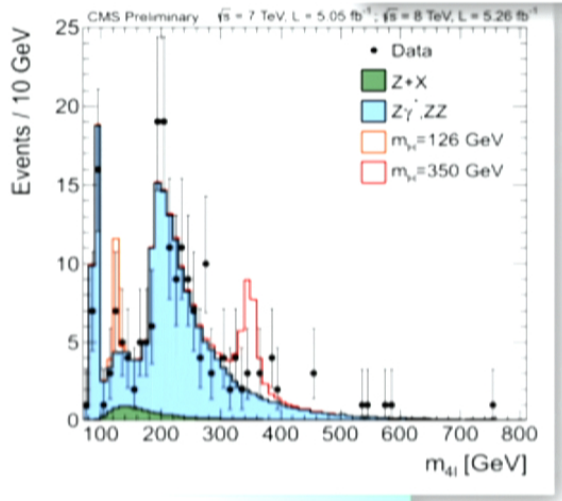
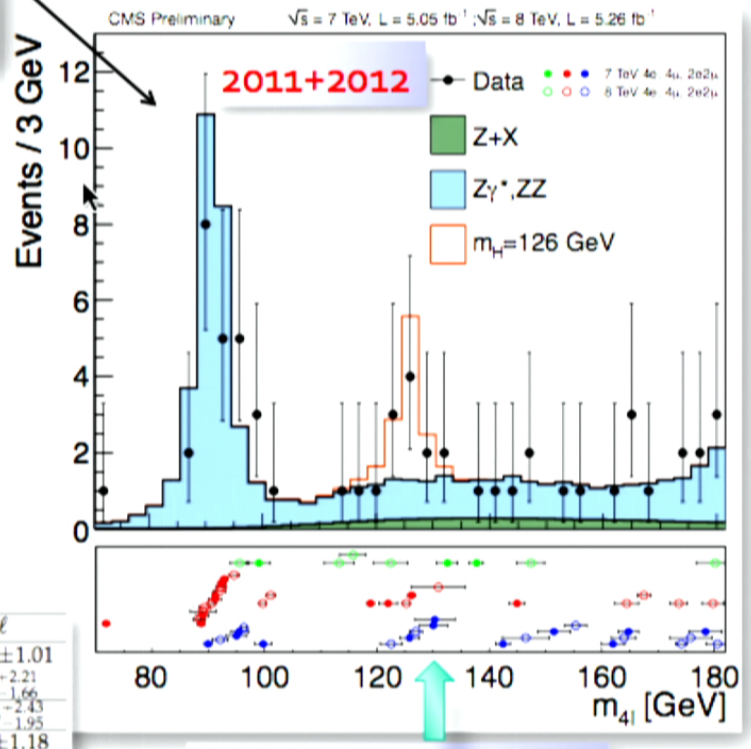
Results: m(4l) spectrum







Yields for m(4l)=110..160 GeV

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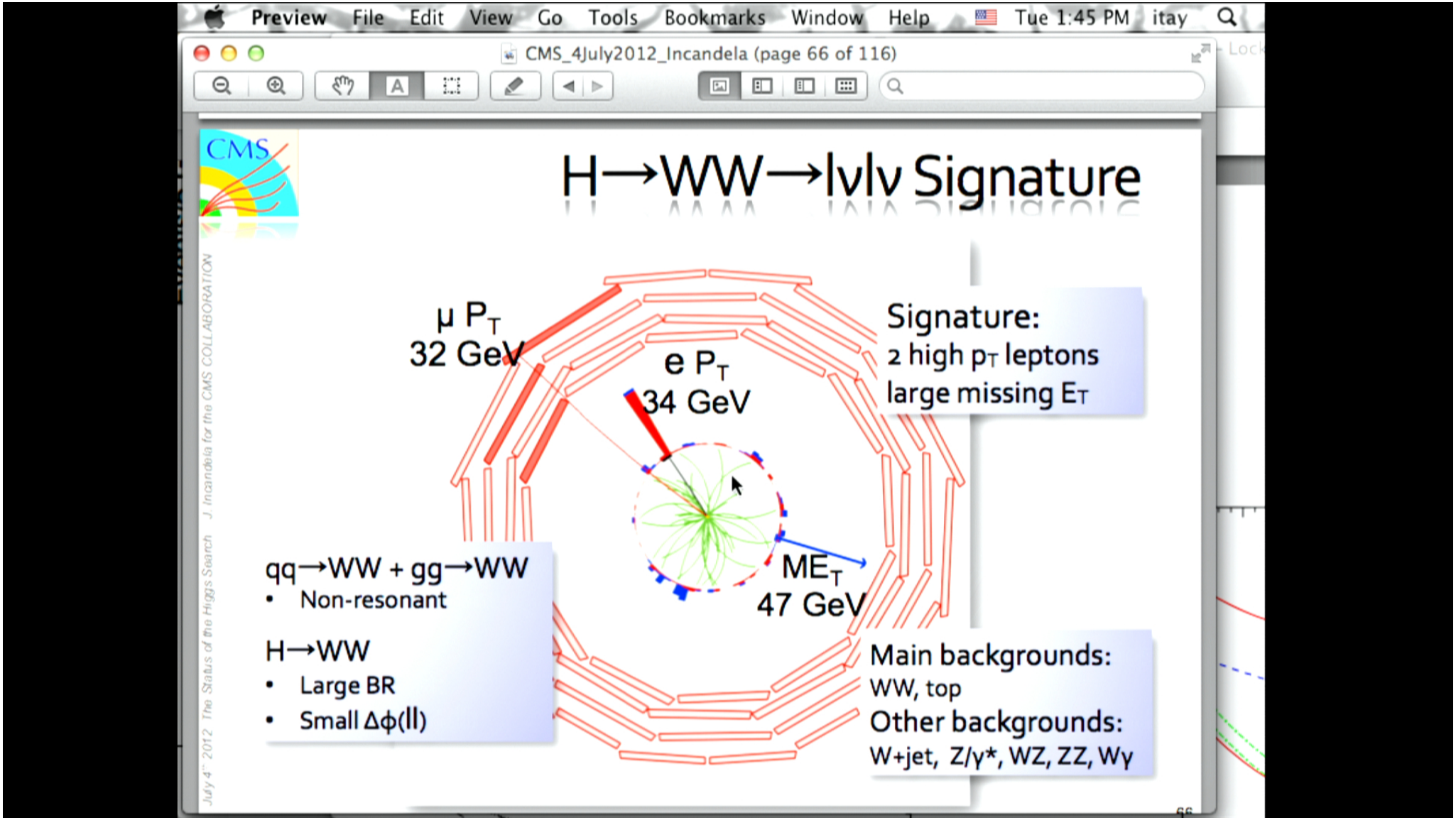
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CMS_4July2012_Incandela (page 66 of 116)
H→WW→lνlν Signature
μ P_T
32 GeV
e P_T
34 GeV
ME_T
47 GeV
Signature:
2 high p_T leptons
large missing E_T
qq→WW + gg→WW
• Non-resonant
H→WW
• Large BR
• Small Δφ(ll)
Main backgrounds:
WW, top
Other backgrounds:
W+jet, Z/γ*, WZ, ZZ, Wγ
J Incandela for the CMS COLLABORATION
The Status of the Higgs Search
July 4th 2012
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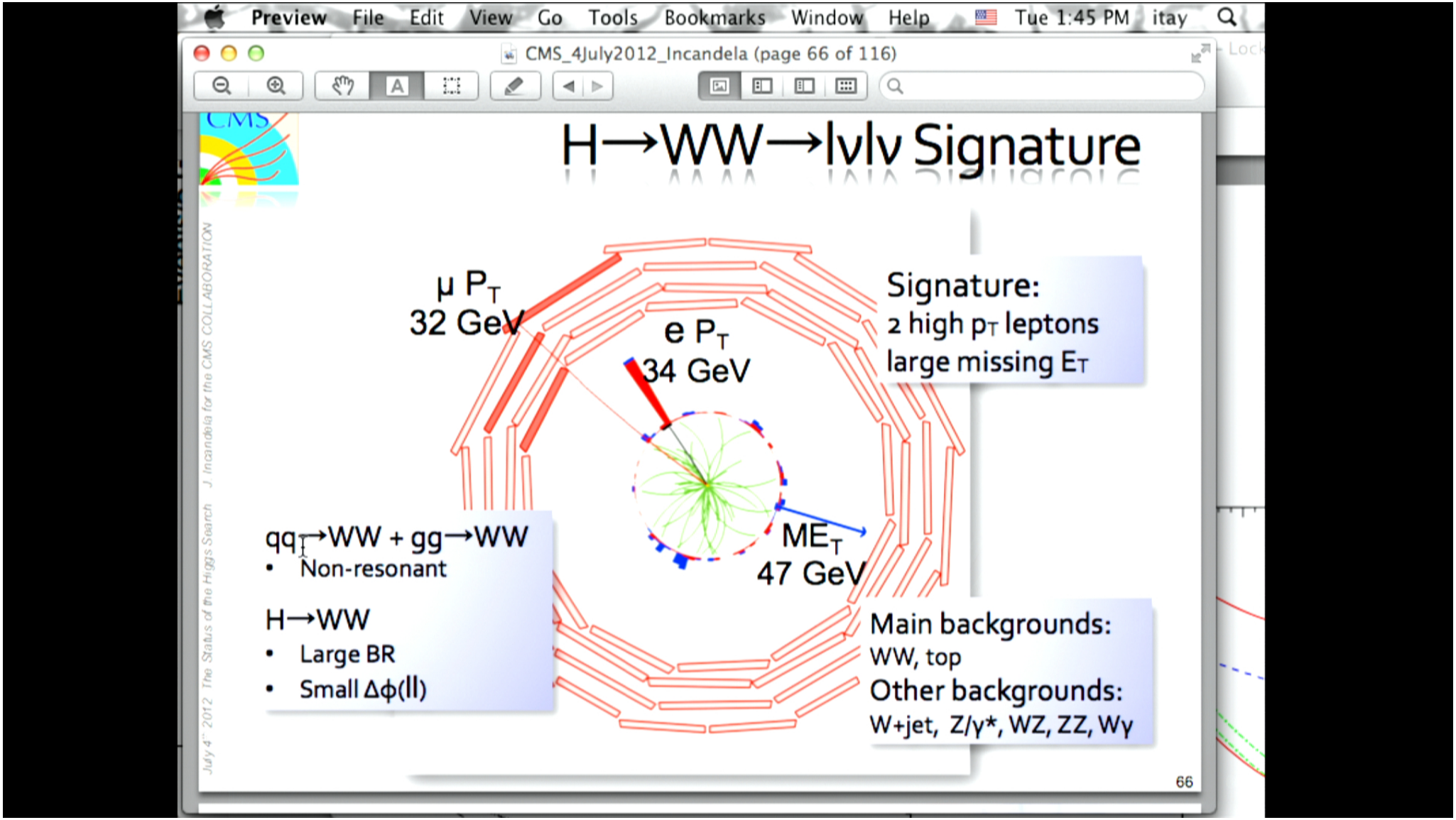
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CMS_4July2012_Incandela (page 66 of 116)
H→WW→lνlν Signature
μ P_T
32 GeV
e P_T
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Signature:
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Main backgrounds:
WW, top
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July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION
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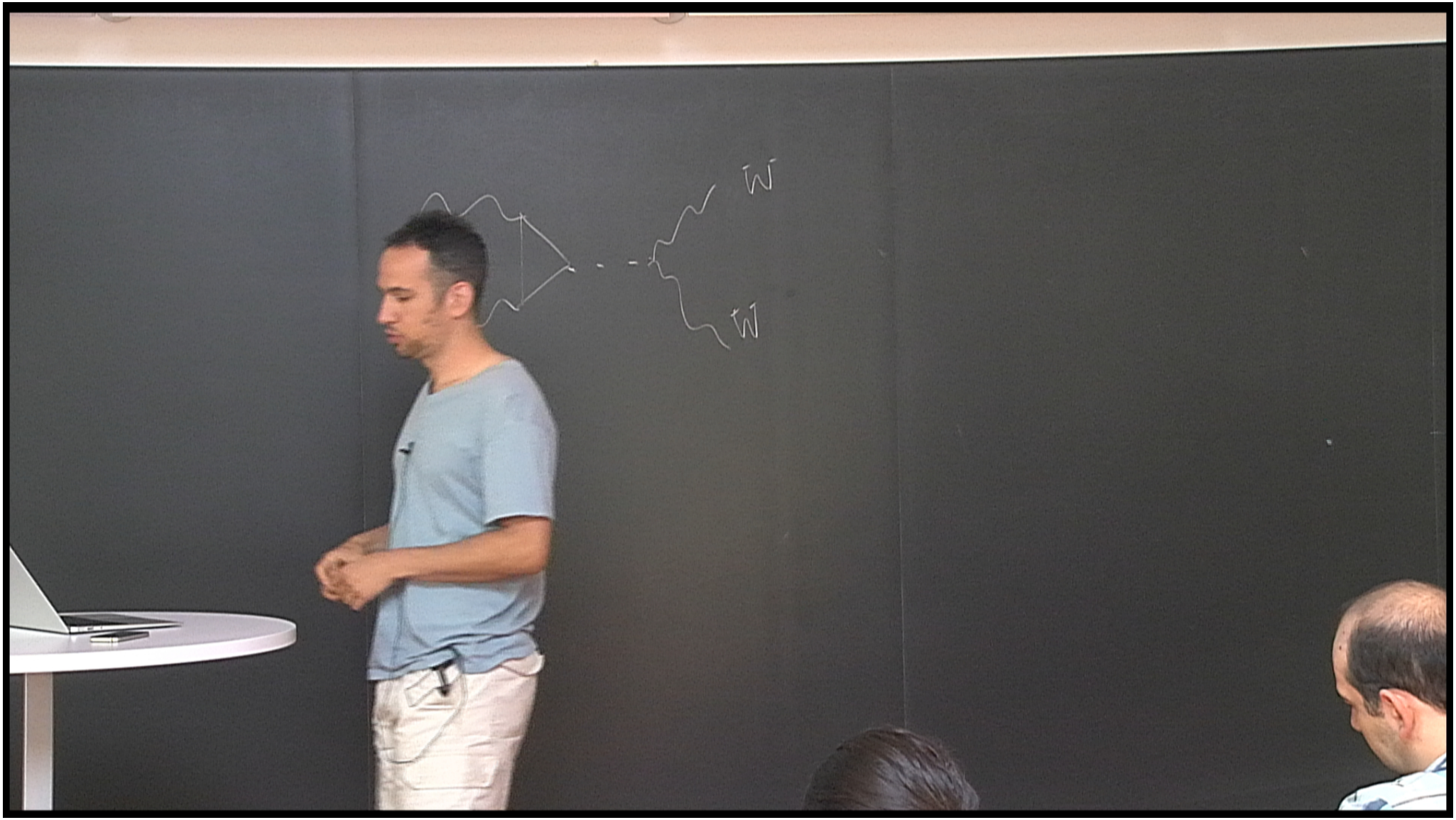
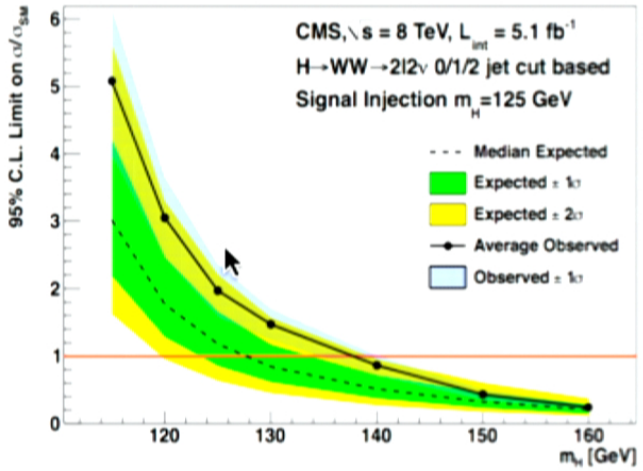
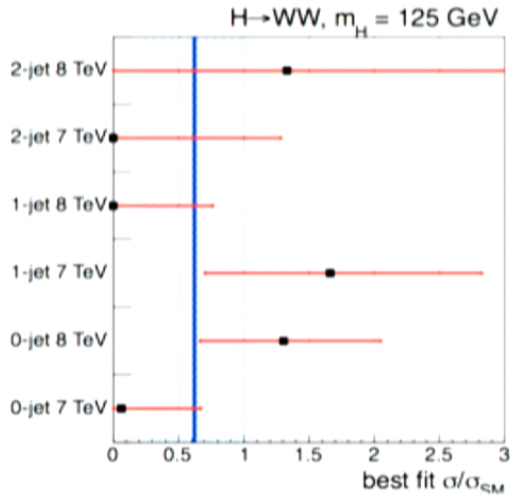

W
W

8 TeV – injected SM Higgs signal





- Signal injection using prediction at 5.1/fb 8 TeV
  - Average background prediction
  - Signal injection for m_H = 125 GeV with toys

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CMS_4July2012_Incandela (page 74 of 116)

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VH →Vbb, V→lν, ll, νν

VH →Vbb, V→lν, ll, νν

- Characteristics and importance
  - By far, largest BR for m_H<130 GeV
  - Key piece of the observation puzzle
  - Tests specific production & decay couplings
- But σ_{bb}(QCD) ~ 10^7 σxBR(H-> bb)!
  - Search in associated production with W or Z

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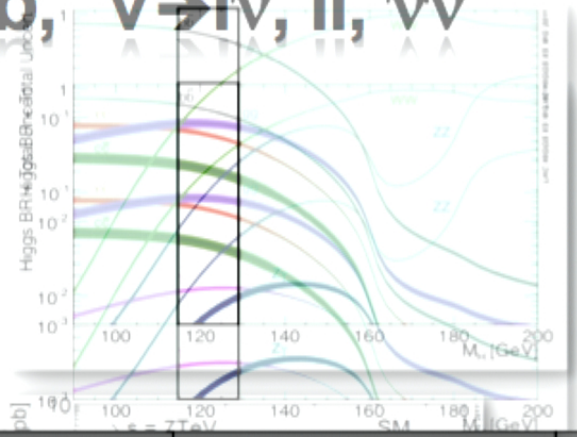
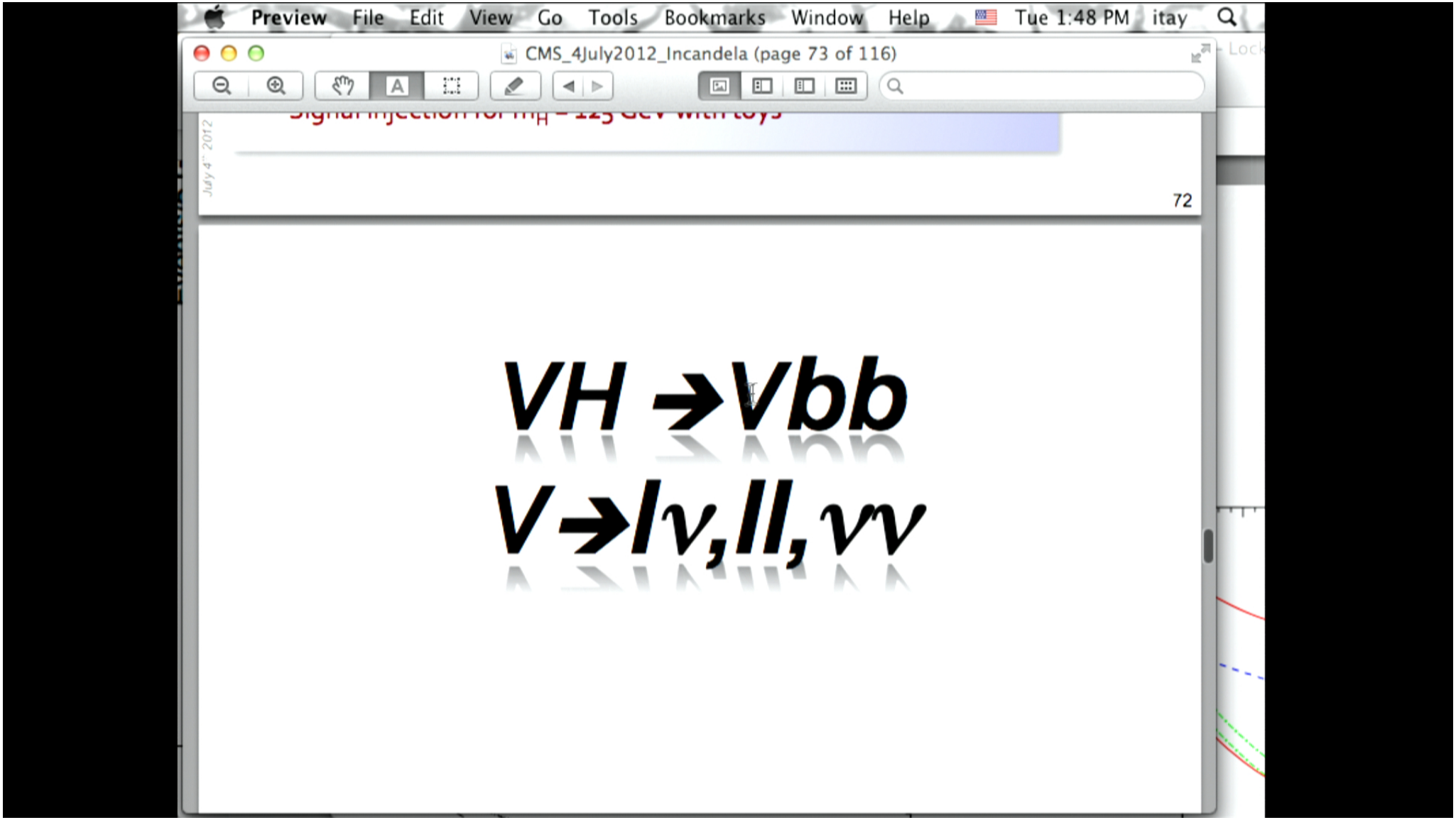
  - By far, largest BR for m_H<130 GeV
  - Key piece of the observation puzzle
  - Tests specific production & decay couplings
- But σ_{bb}(QCD) ~ 10^7 σxBR(H-> bb)!

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VH →Vbb
V→lν,ll,νν

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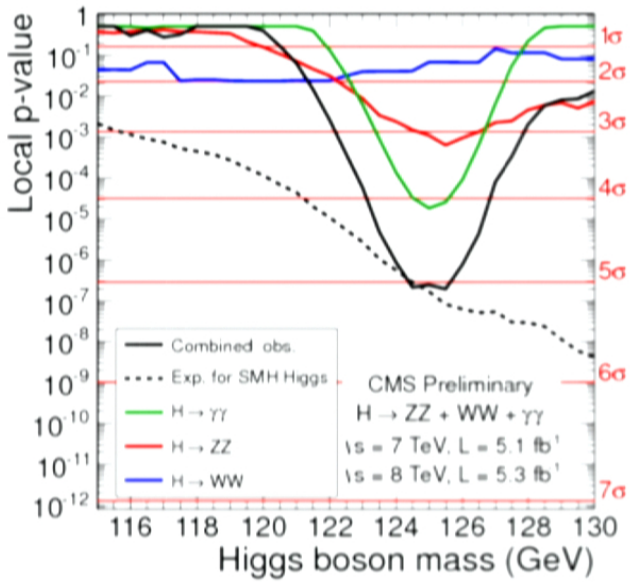
Characterization of excess near 125 GeV

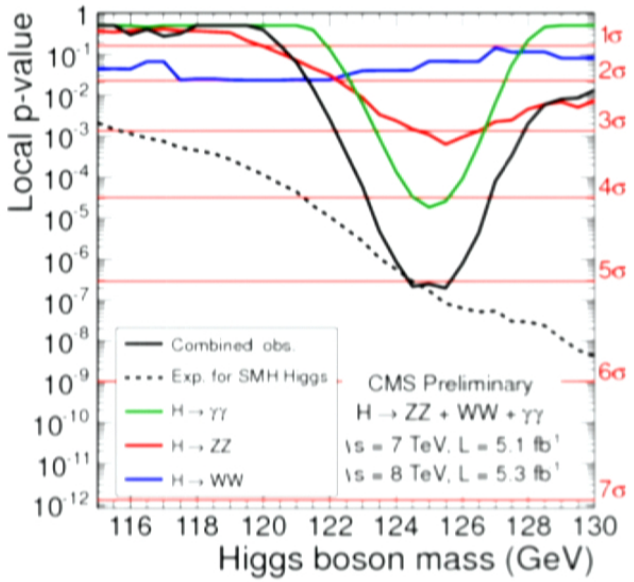


adding high sensitivity, but low mass resolution WW

comb. significance: 5.1 σ

expected significance for SM Higgs: 5.2 σ

Characterization of excess near 125 GeV



adding high sensitivity, but low mass resolution WW

comb. significance: 5.1 σ

expected significance for SM Higgs: 5.2 σ

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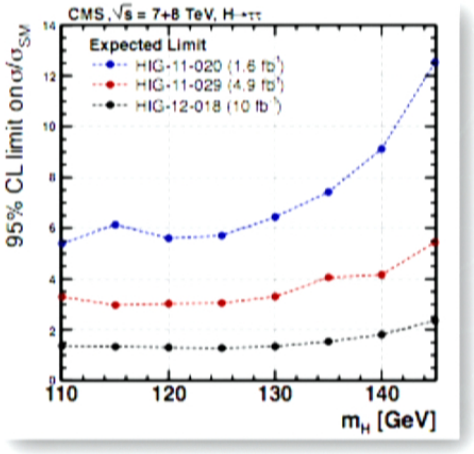
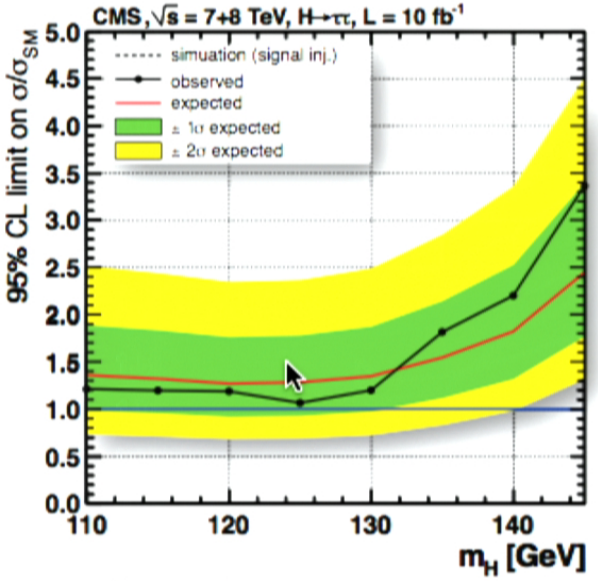
Results for H→ττ





- ~2x improvement in sensitivity in 2011 data alone
  - => 70% improvement in sensitivity on the same data
  - 40% improvement with the additional luminosity
- No significant departure from SM background-only expectation
  - Observed limit of 1.06 x SM at m_H = 125 GeV

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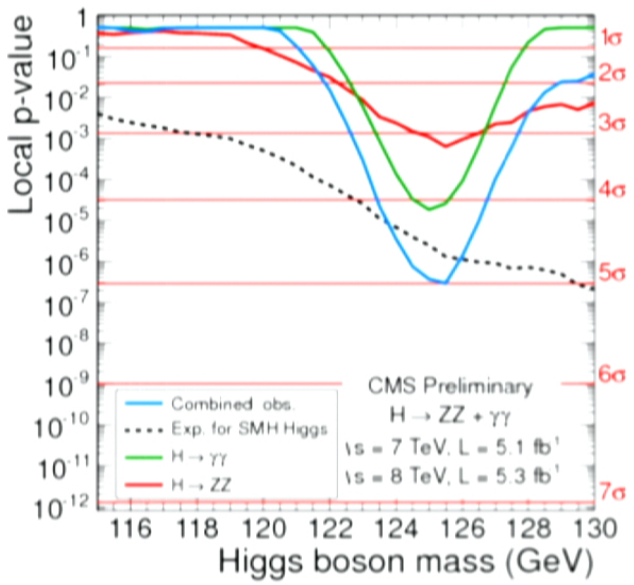

- high sensitivity, high mass resolution channels: γγ+4l
  - γγ: 4.1 σ excess
  - 4 leptons: 3.2 σ excess
  - near the same mass 125 GeV
- comb. significance: **5.0 σ**
- expected significance for SM Higgs: **4.7 σ**

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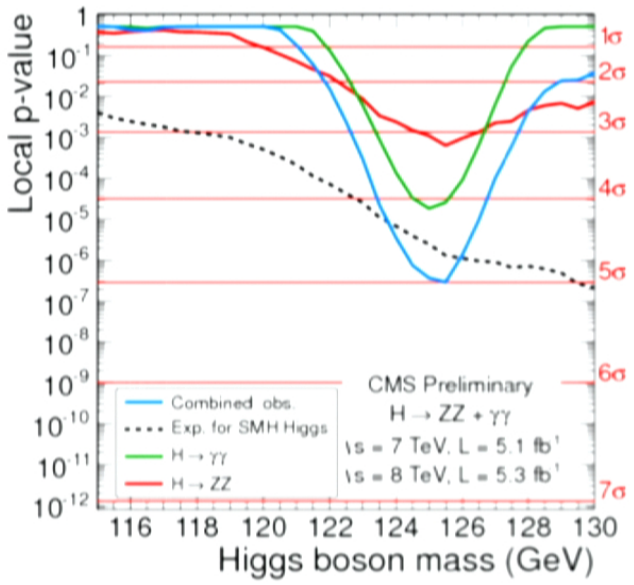
CMS Characterization of excess near 125 GeV

Characterization of excess near 125 GeV



- high sensitivity, high mass resolution channels: γγ+4l
  - γγ: 4.1 σ excess
  - 4 leptons: 3.2 σ excess
  - near the same mass 125 GeV
- comb. significance: **5.0 σ**
- expected significance for SM Higgs: **4.7 σ**

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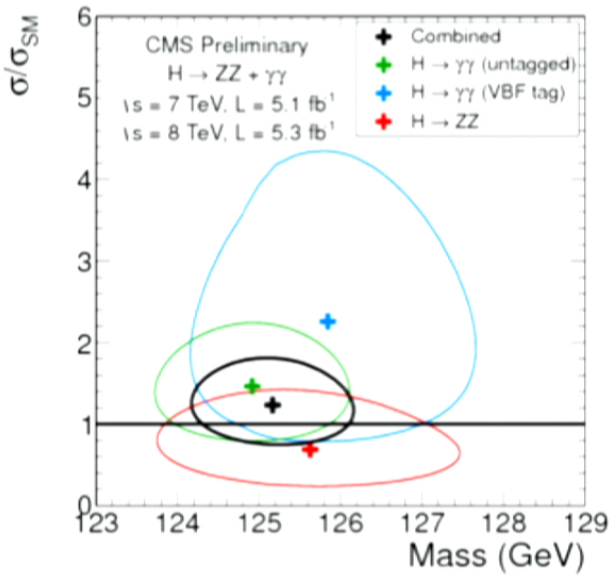
Characterization of the excess: mass



- Likelihood scan for mass and signal strength in three high mass resolution channels
- results are self-consistent and can be combined

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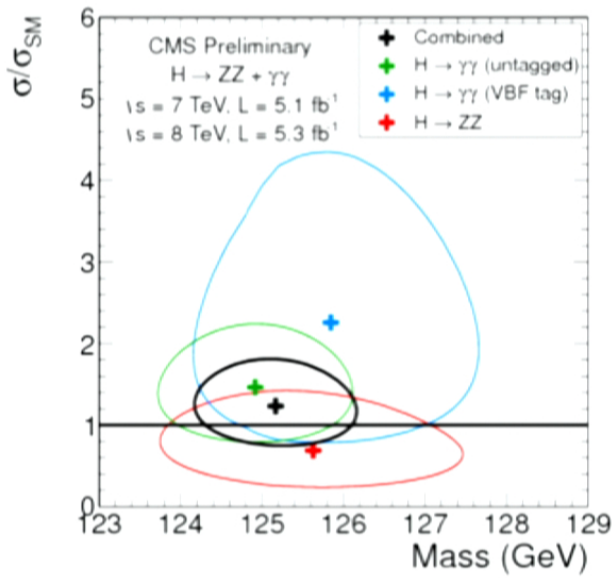
Characterization of the excess: mass



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July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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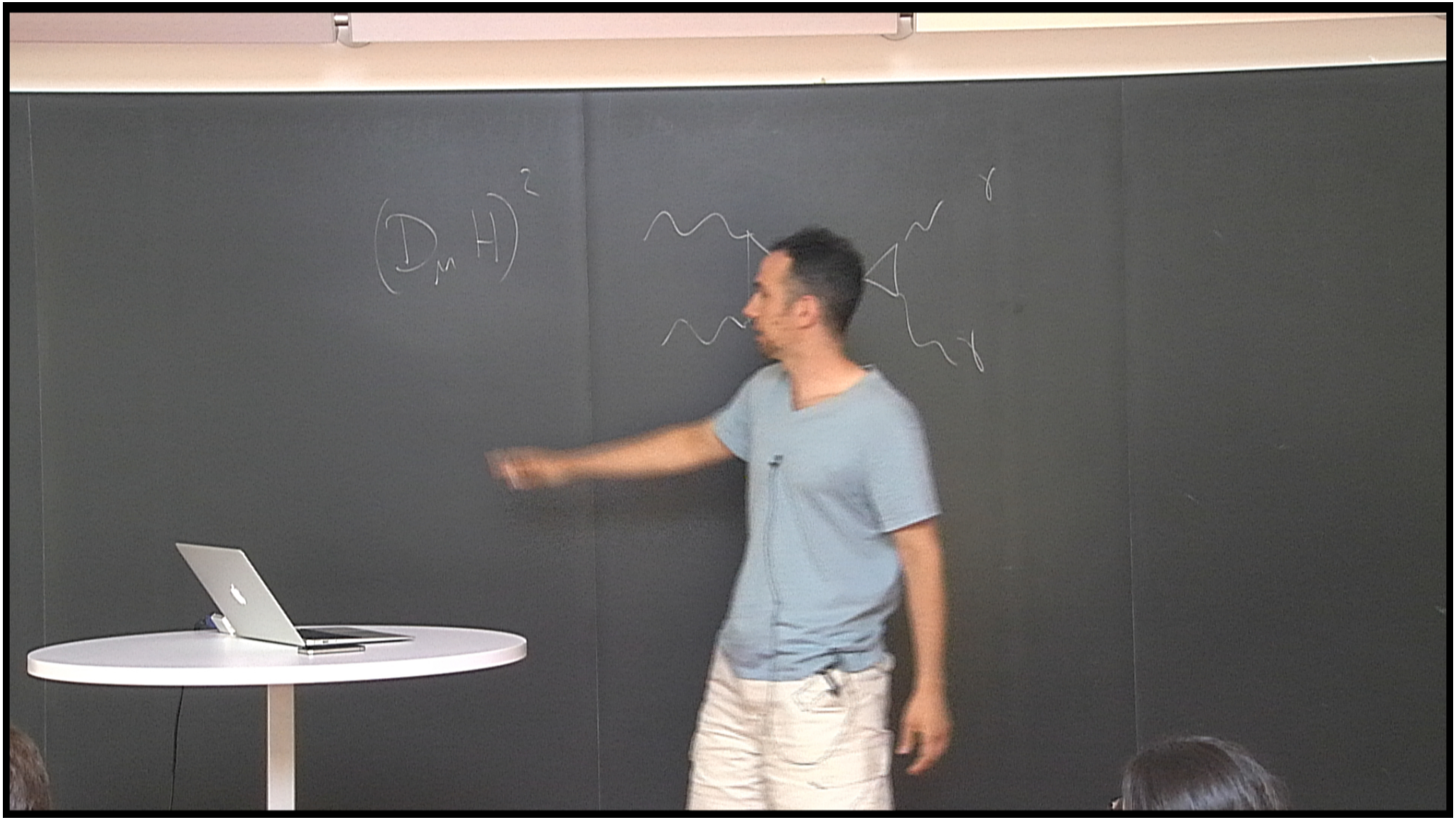
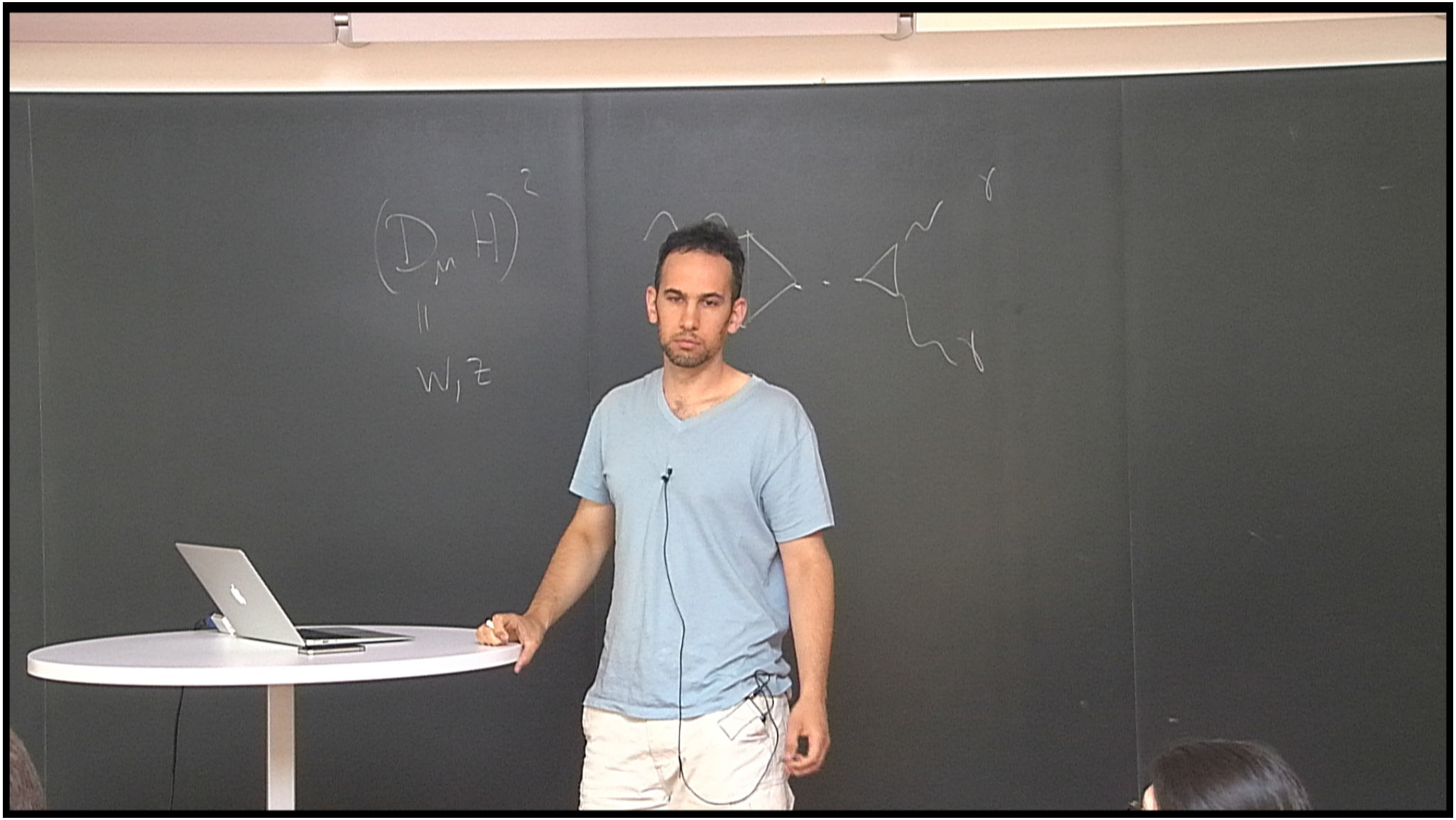
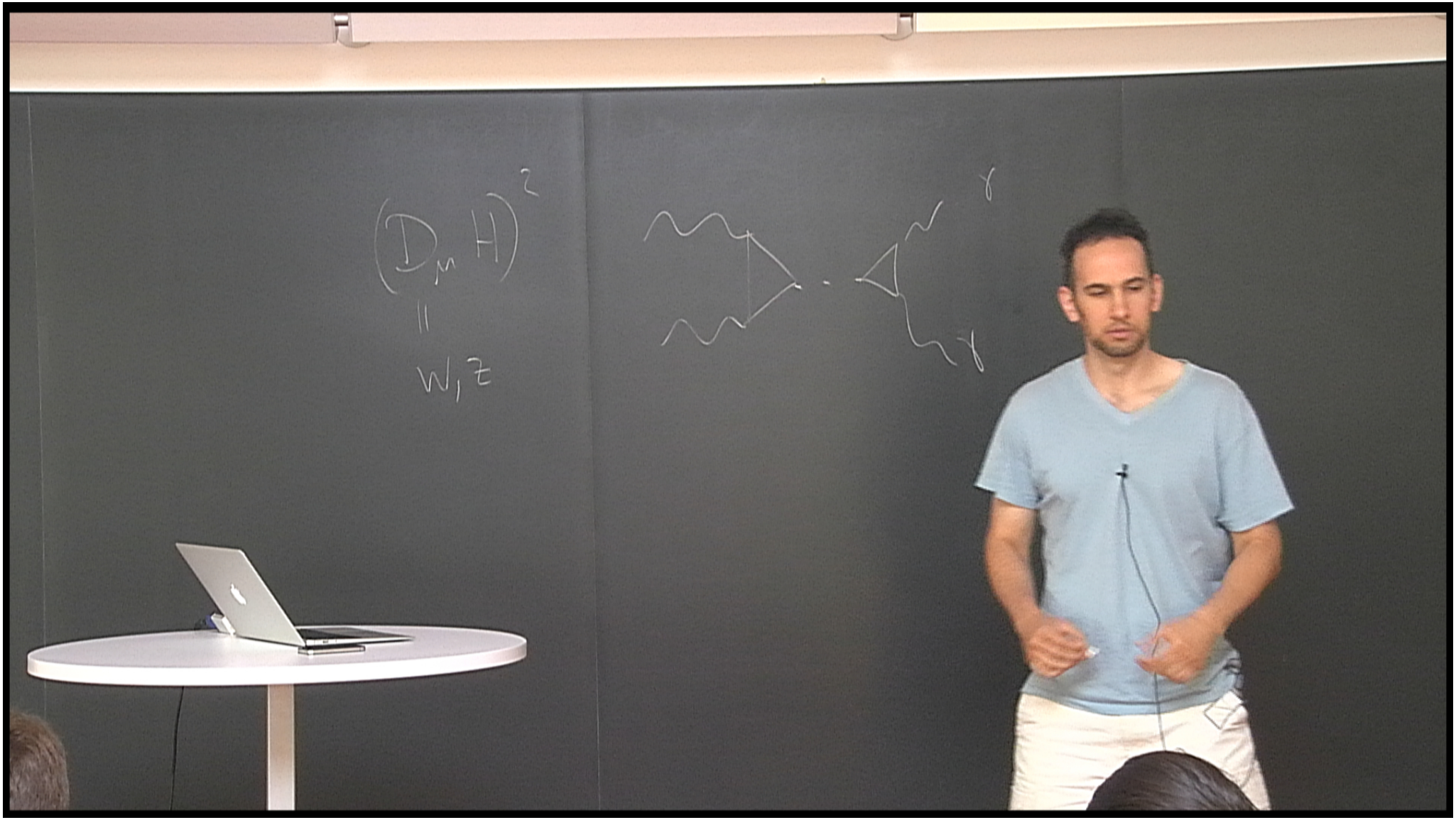
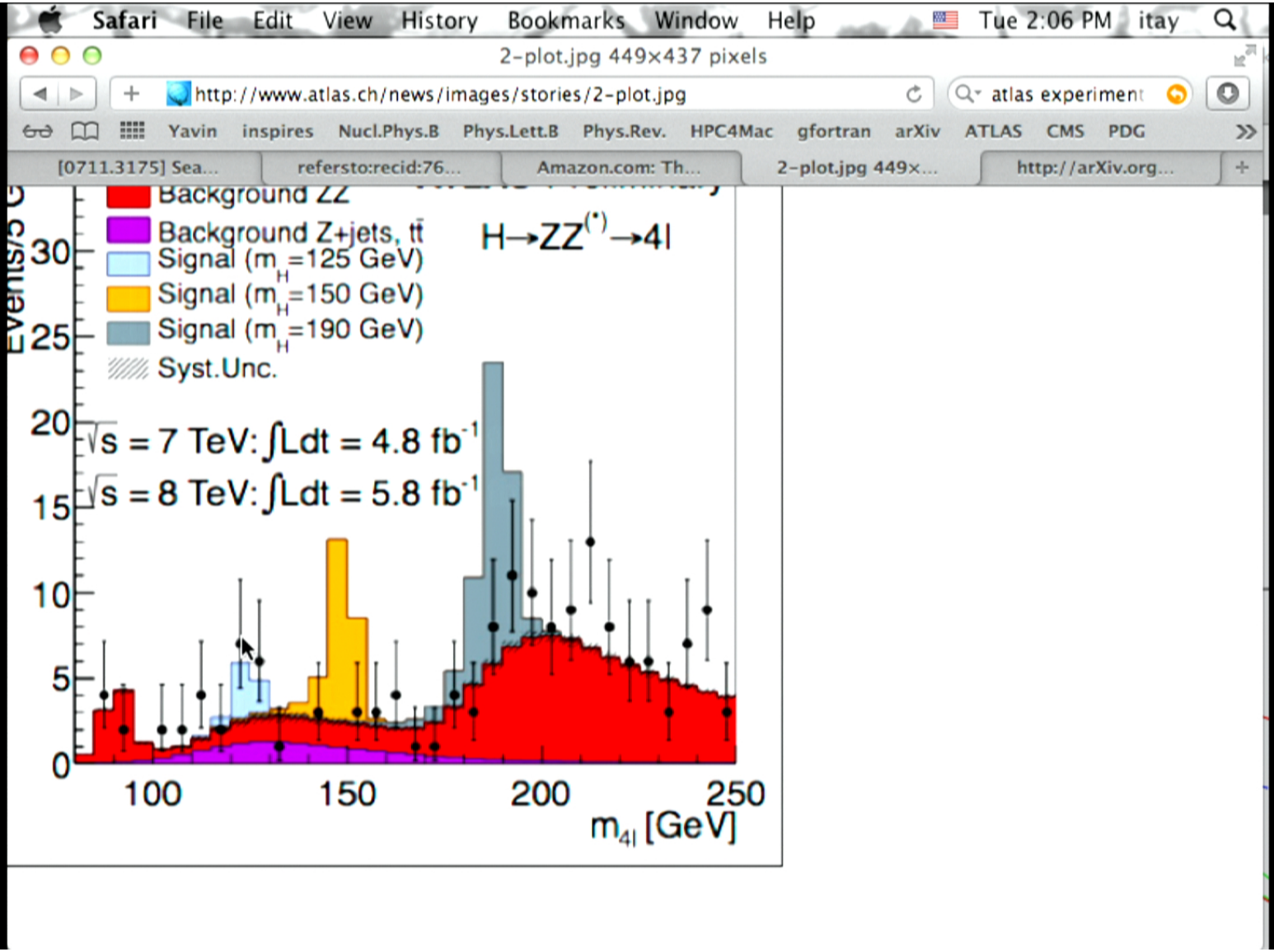

$(D_M H)^2$
γ
γ


$(D_\mu H)^2$
W, Z
γ
γ


$(D_\mu H)^2$
=
W, Z
γ
γ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http://arXiv.org...
Background ZZ
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
H→ZZ^(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb^-1
√s = 8 TeV: ∫Ldt = 5.8 fb^-1
Events/5
0
5
10
15
20
25
30
100
150
200
250
m_4l [GeV]

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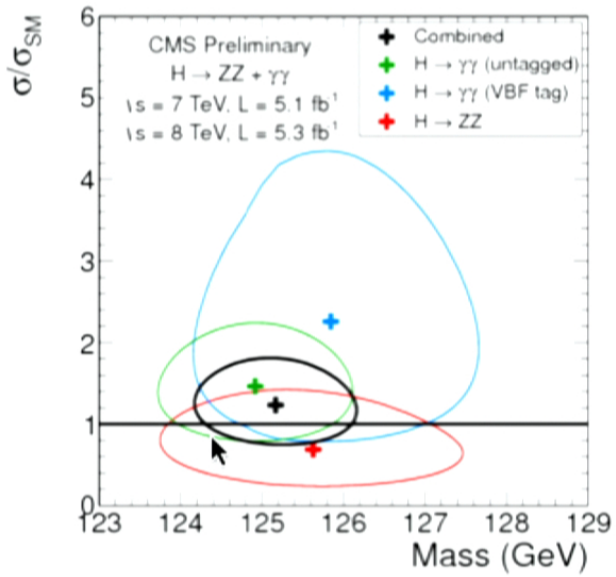
Characterization of the excess: mass



- Likelihood scan for mass and signal strength in three high mass resolution channels
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July 4th 2012 The Status of the Higgs Search J. Incandela for the CMS COLLABORATION

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