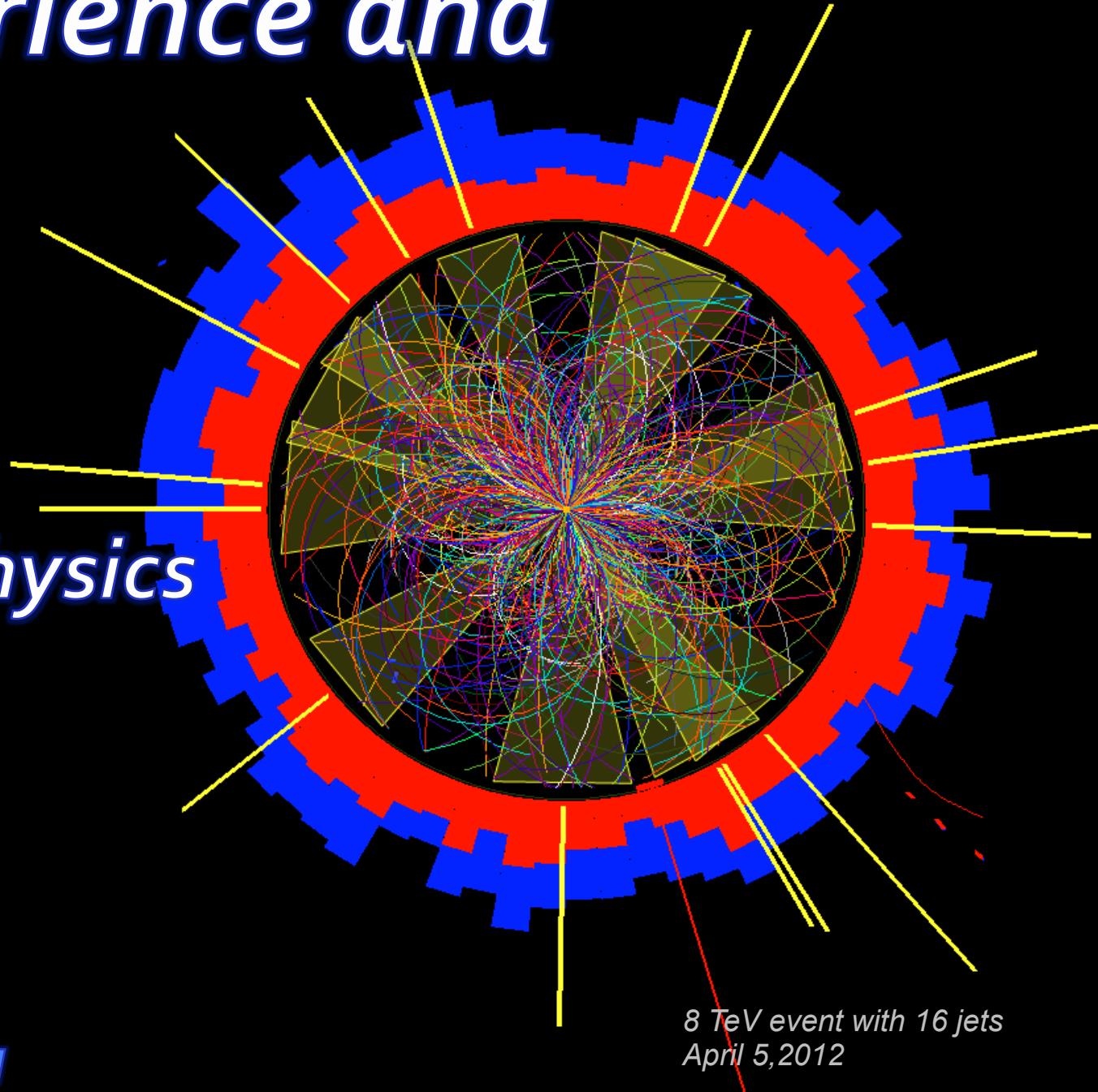


LHC Experience and Prospects

*Computing in
High Energy Physics
2012*

*May 21, 2012
New York City*

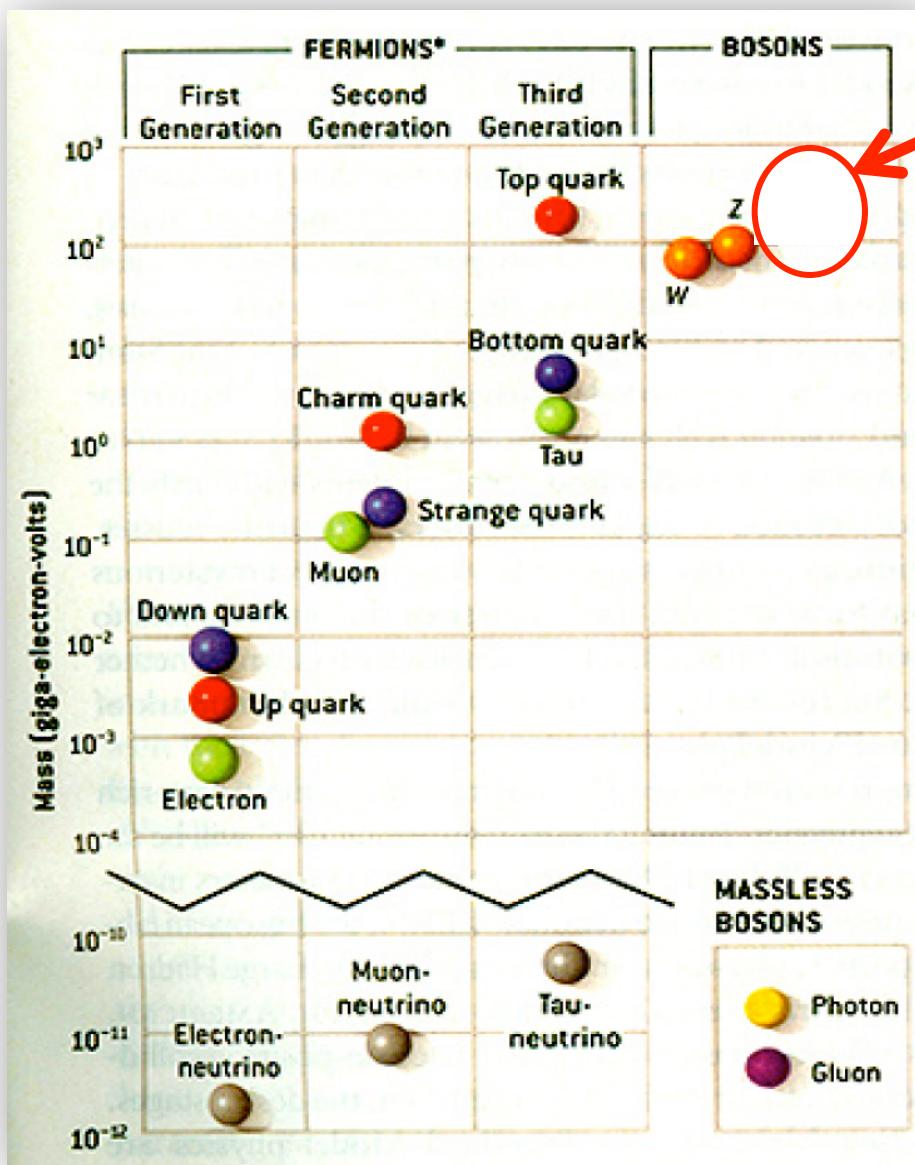
*Joe Incandela
UC Santa Barbara/CERN*



*8 TeV event with 16 jets
April 5, 2012*

The Standard Model

1 Missing piece: Higgs



	Measurement	Fit	$ O^{meas} - O^{fit} /\sigma^{meas}$
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768	0
m_Z [GeV]	91.1875 ± 0.0021	91.1874	1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	0
σ_{had}^0 [nb]	41.540 ± 0.037	41.479	1.7
R_I	20.767 ± 0.025	20.742	1
$A_{fb}^{0,I}$	0.01714 ± 0.00095	0.01645	0.9
$A(P)$	0.1465 ± 0.0032	0.1481	0.5
Confirmed to below 1 % uncertainty by 100's of precision measurements			
A_c	0.670 ± 0.027	0.668	0
A_I (SLD)	0.1513 ± 0.0021	0.1481	1.7
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	0.9
m_W [GeV]	80.399 ± 0.023	80.379	1
Γ_W [GeV]	2.085 ± 0.042	2.092	0
m_t [GeV]	173.3 ± 1.1	173.4	0

July 2010

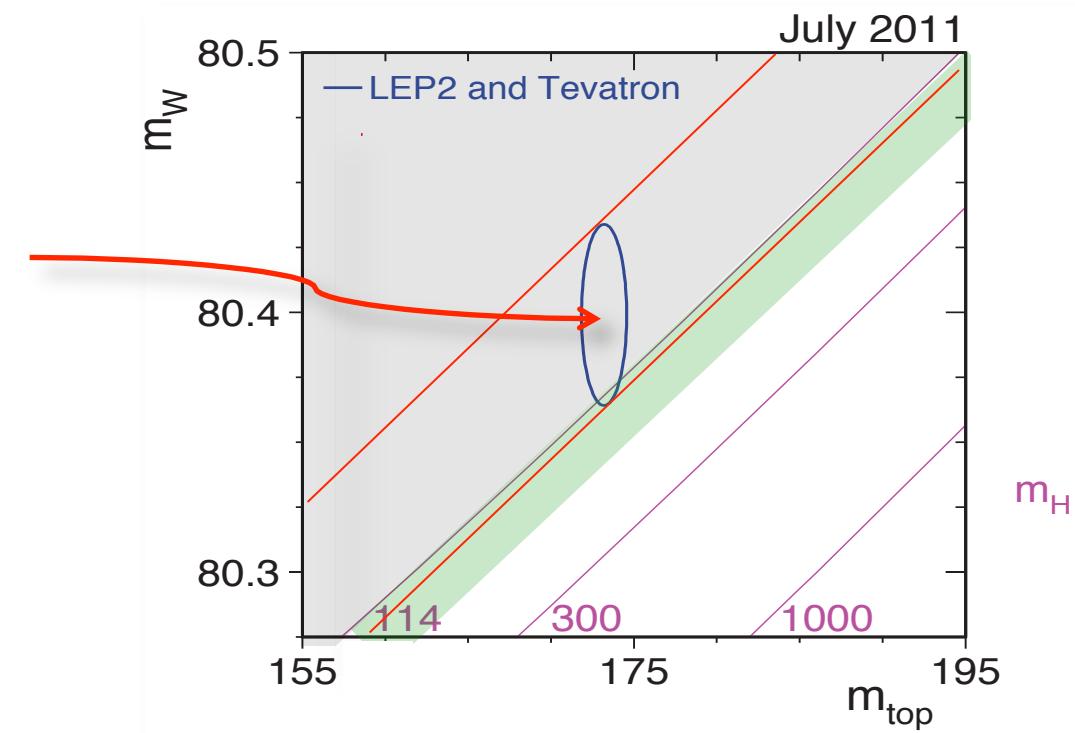
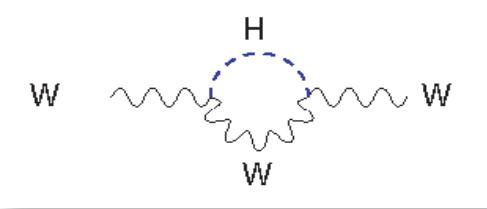
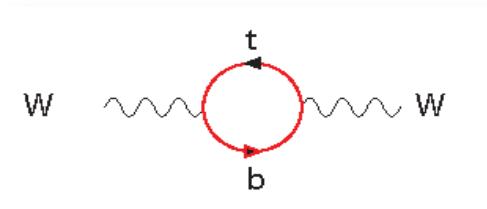
Where we stood last summer

- July 2011

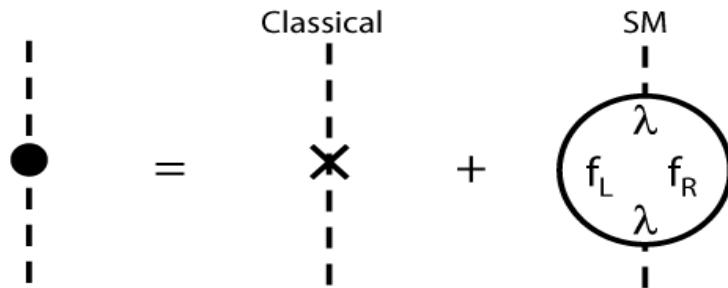
- $M_t = 173.2 \pm 0.9 \text{ GeV}$
- $M_W = 80.399 \pm 0.023 \text{ GeV}$

$$\Rightarrow M_H = 89^{+35}_{-26} \text{ GeV (68\% CL)}$$

- Between the red diagonals



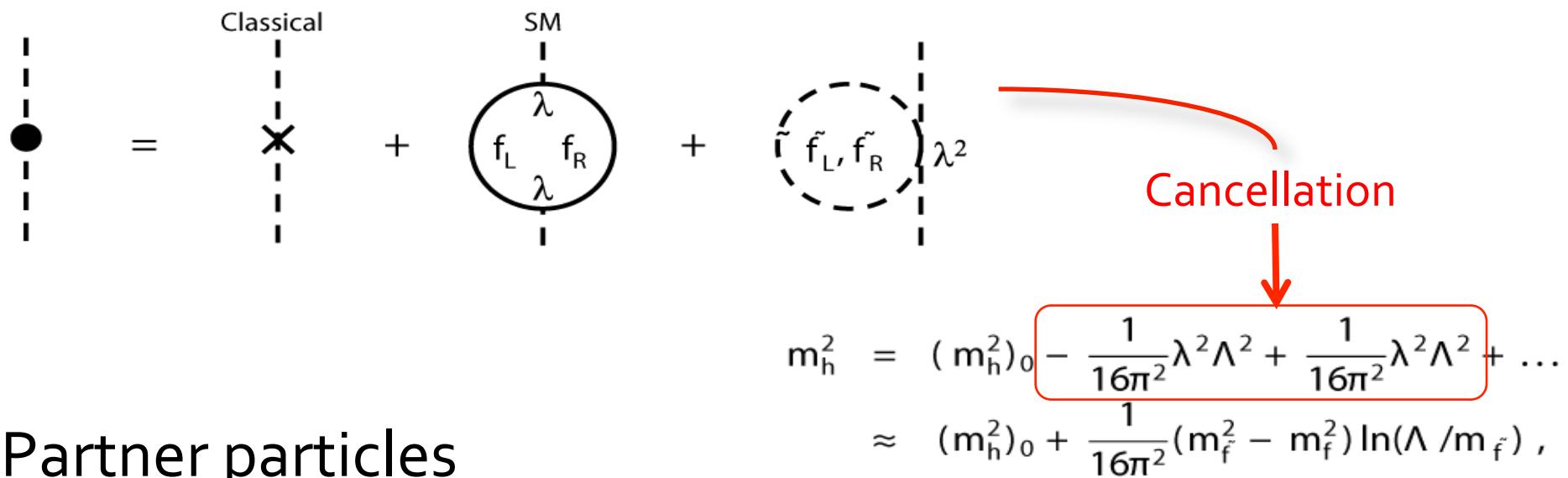
- $M_H < 185 \text{ GeV (95\% CL)}$
 - But we don't assume it's not above 185 without a direct search...



$$m_h^2 = (m_h^2)_0 - \frac{1}{16\pi^2} \lambda^2 \Lambda^2 .$$

↗

- The Higgs mass:
 - SM particles affect the Higgs mass. Corrections are huge
 - Λ could be 10^{19} times the mass of the proton (Planck scale)
 - A.K.A. The Hierarchy problem



- Partner particles
 - Need same couplings λ
 - Partners (especially 3rd generation) with not too big masses
- A much smaller term is all that's left
 - It too becomes large if the new partners are very very heavy
- SUSY is the most appealing source of partners

The Dark Side

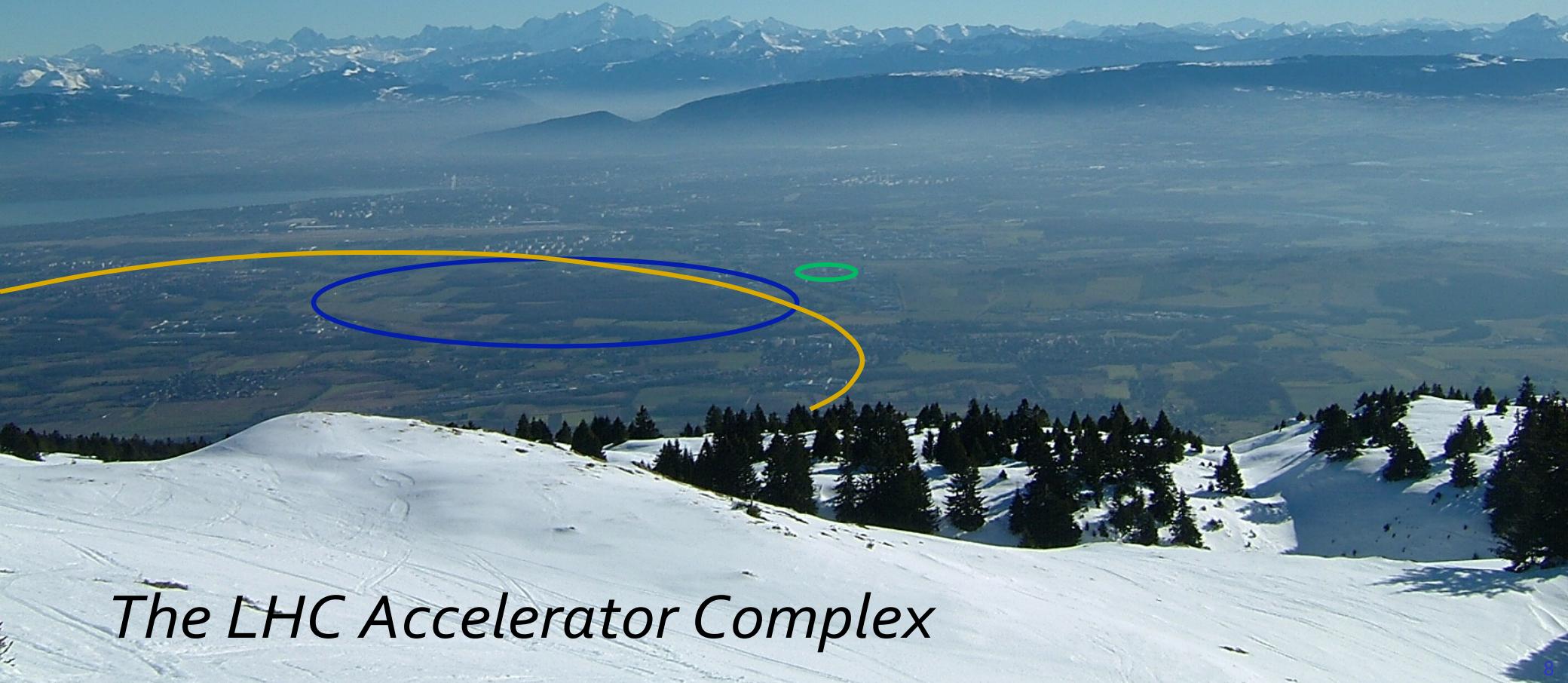
LUG DARK SIDE

- We now know that only ~5% of the energy in the universe is ordinary matter (remember $E=mc^2$).
- 25% is dark matter
 - SUSY theories can happily predict this amount
- There are other possibilities but SUSY is a favorite
 - Provides great dark matter candidates
 - (e.g. Neutralino or Gravitino)
 - Leads to remarkable unification of field strengths
 - And it fixes the Higgs mass problem



Or maybe not ...

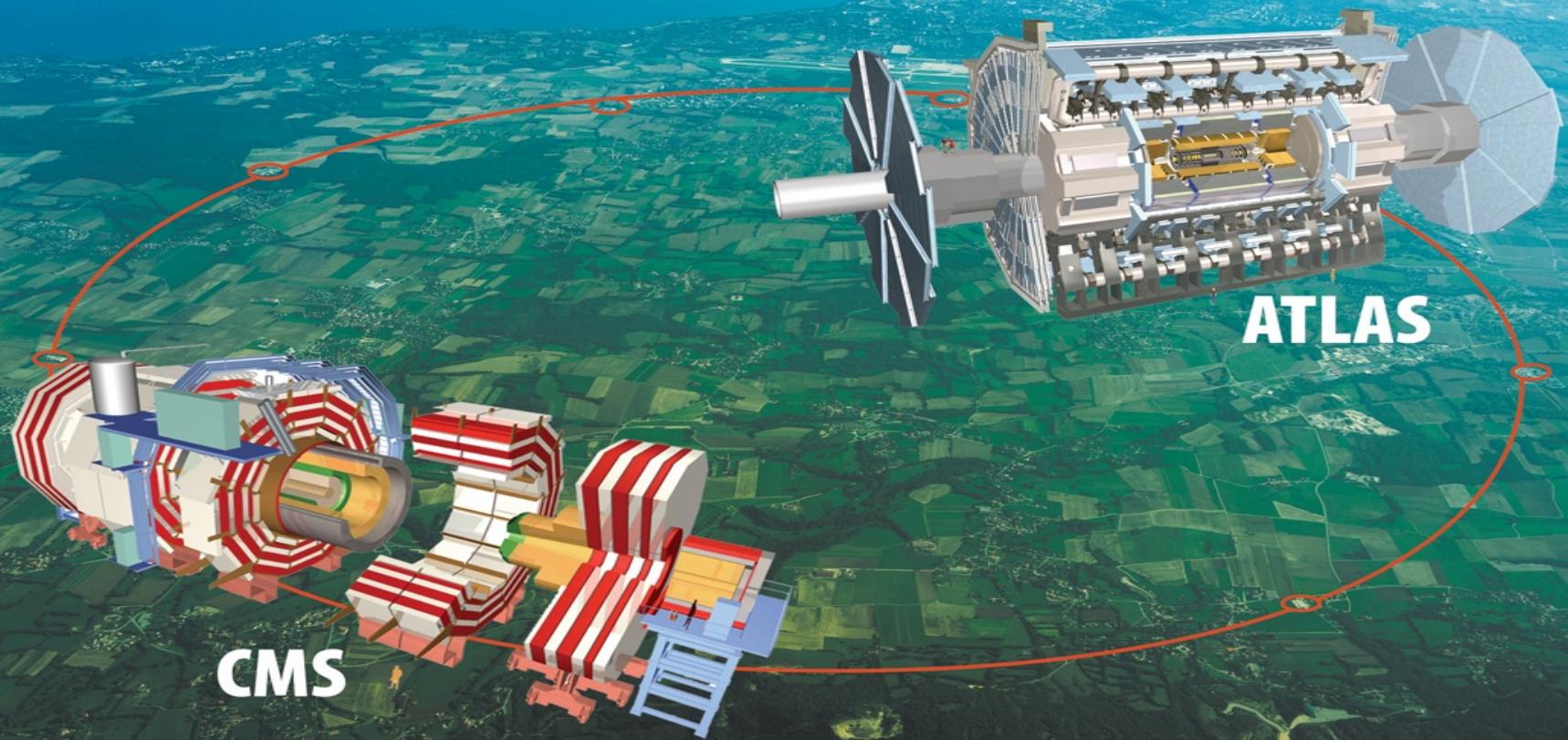
- The absence of any hint of SUSY at LEP, the Tevatron, or LHC accelerators (so far) coupled with results from cosmology and astrophysics experiments, has motivated alternative models.
- These are characterized by new particles (like SUSY) or new spatial dimensions
 - Little Higgs (with T Parity)
 - Universal extra dimensions (with KK parity)
 - Strong dynamics
 - Extra dimensions (large or warped)
 - Hidden Valleys
 - Split SUSY
 - ...
- If you don't exactly know what you're looking for, a **Large Hadron Collider (LHC)** is the great tool to use!



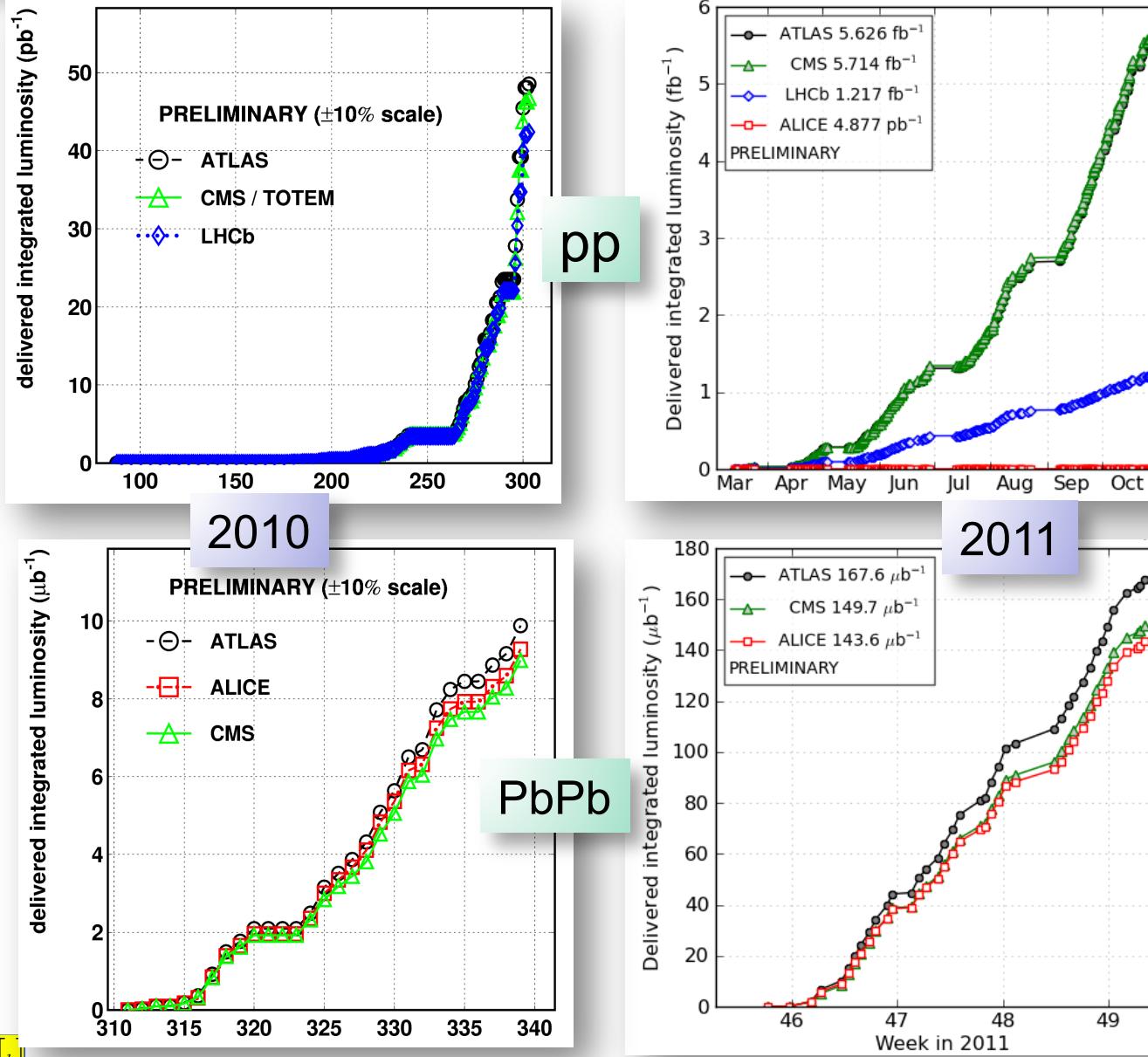
Specialized



General purpose



Incredible performance! Both pp and Pb-Pb

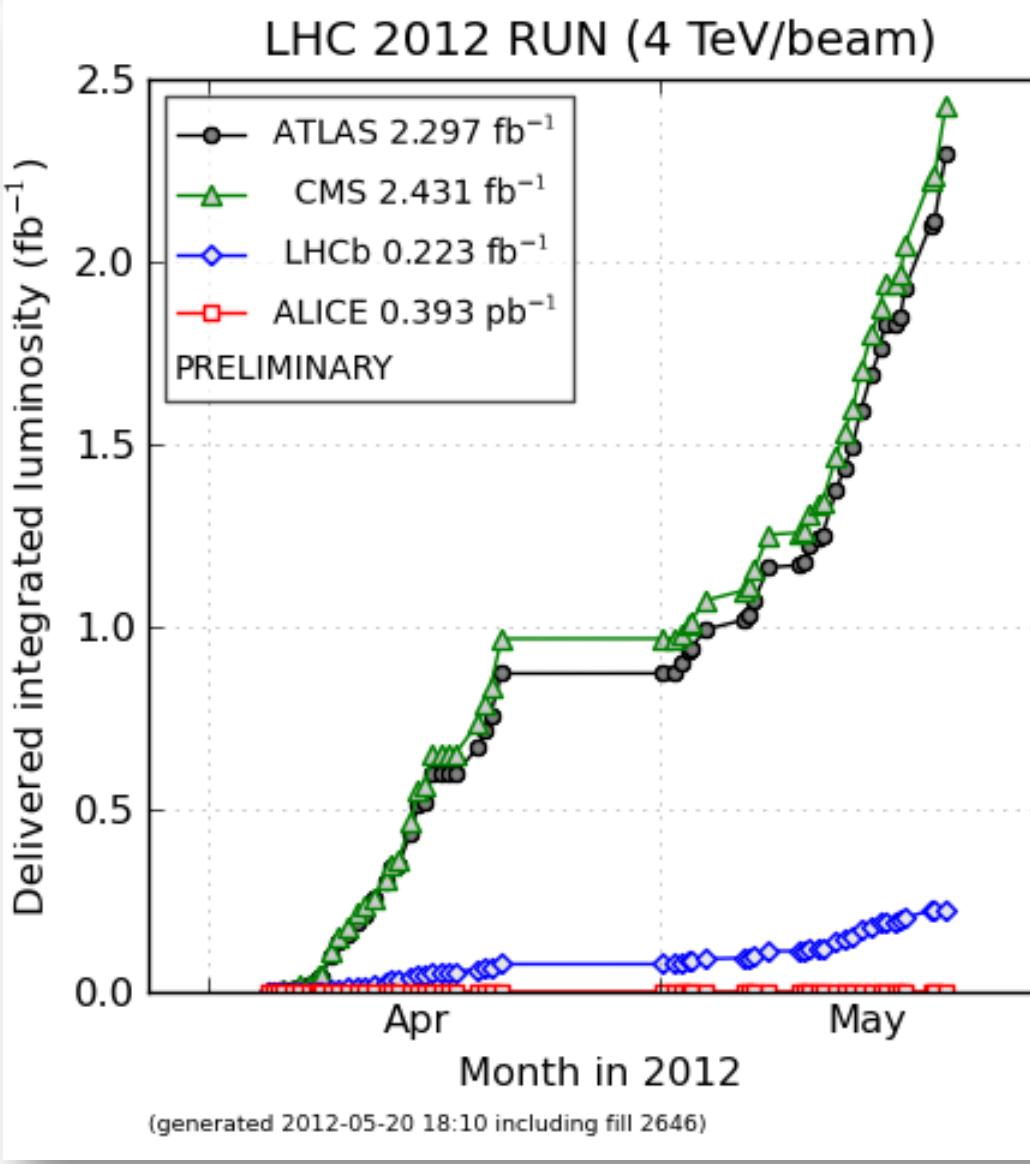


Stellar performance
of the LHC enabled
all experiments to
produce significant
physics results in
the first 3 years of
operation

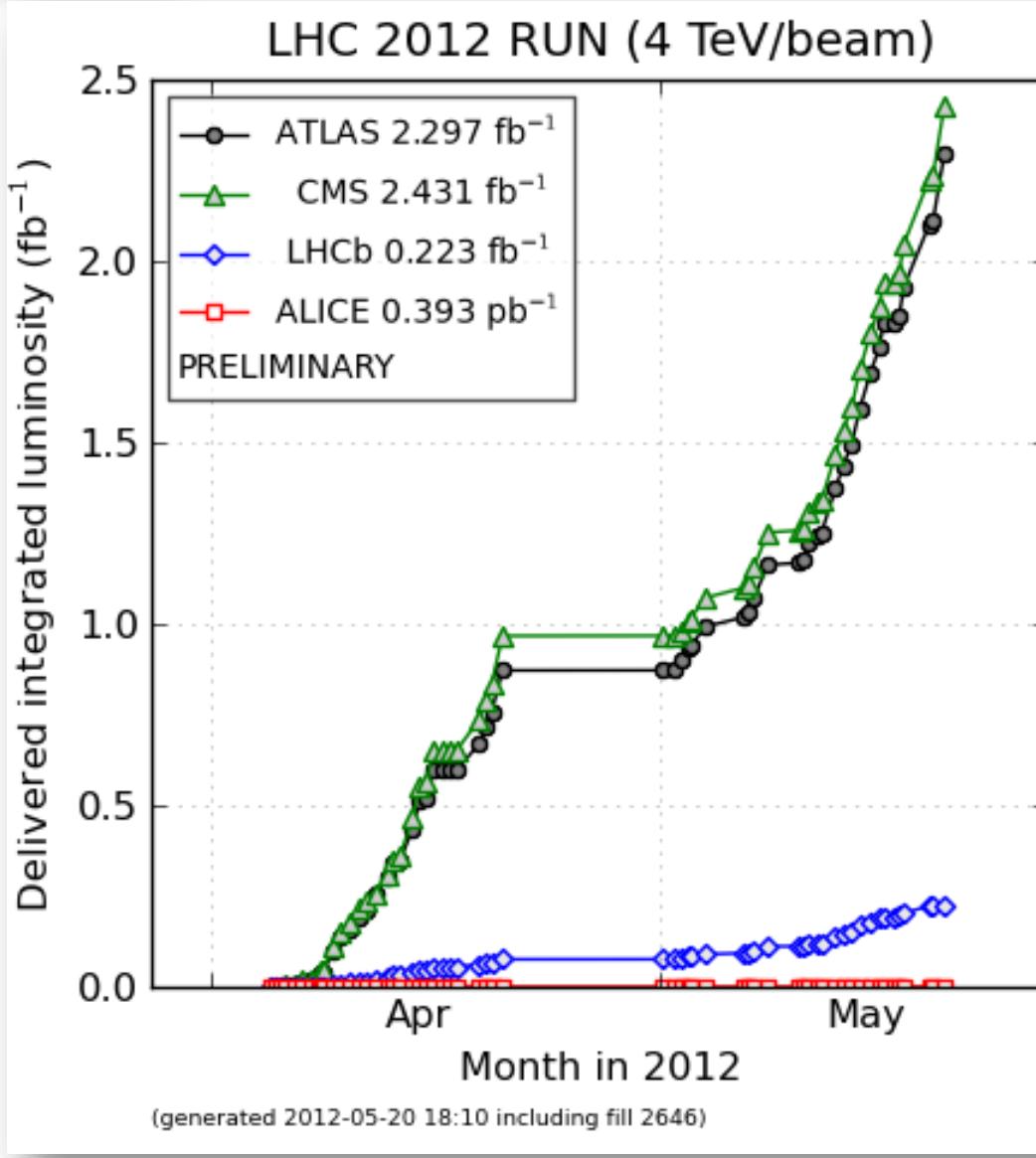
Performance in 2012

Having gained confidence in 2011 operations:

The LHC has increased energy to 4 TeV beams, tighter collimation and $\beta^*=0.6$ to allow much higher instantaneous luminosity L and much more $\int L dt$
 (More on this later...)



Performance in 2012



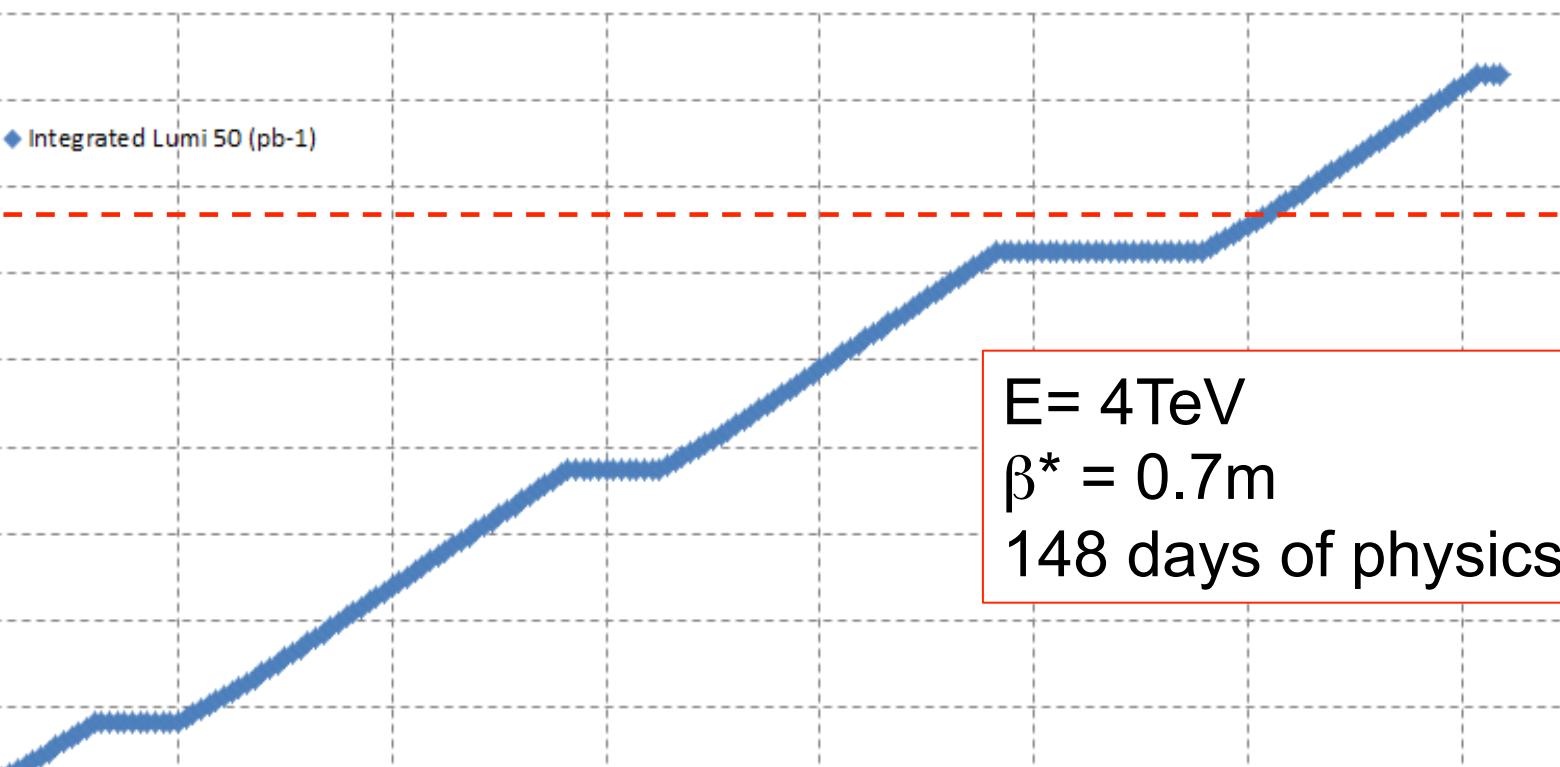
Having gained confidence

**And it continues to perform
extraordinarily well!**

*Many thanks to Steve and all
the incredibly talented staff
involved!*

Up to now we've shown
instantaneous luminosity L
and much more $\int L dt$
(More on this later...)

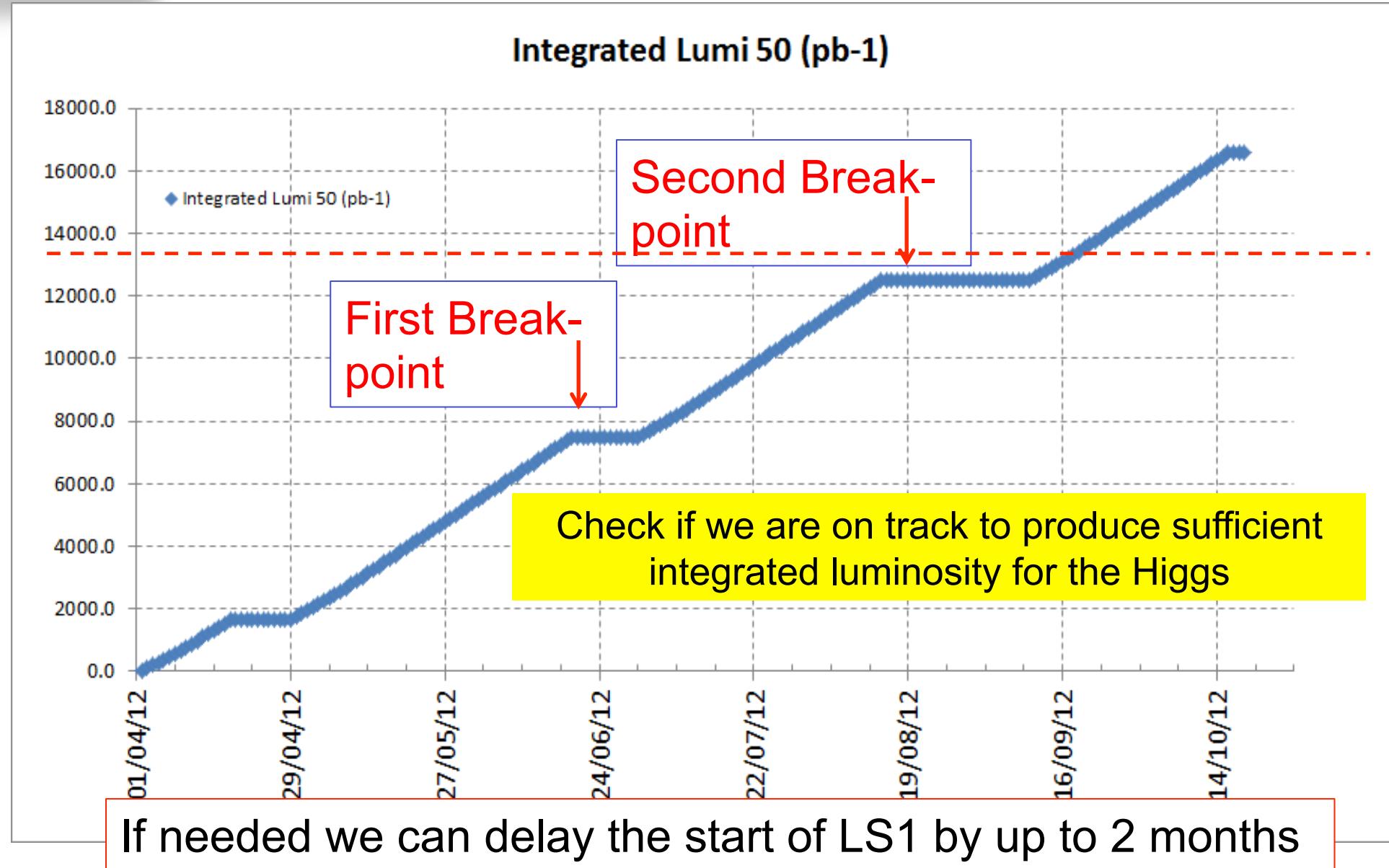
Integrated Lumi 50 (pb-1)



Reasonable to expect that the luminosity estimate is fairly conservative ($\beta^*=0.6$ m may be possible, many other improvements, etc.)

From Steve Myers

We envisage 2 break-points

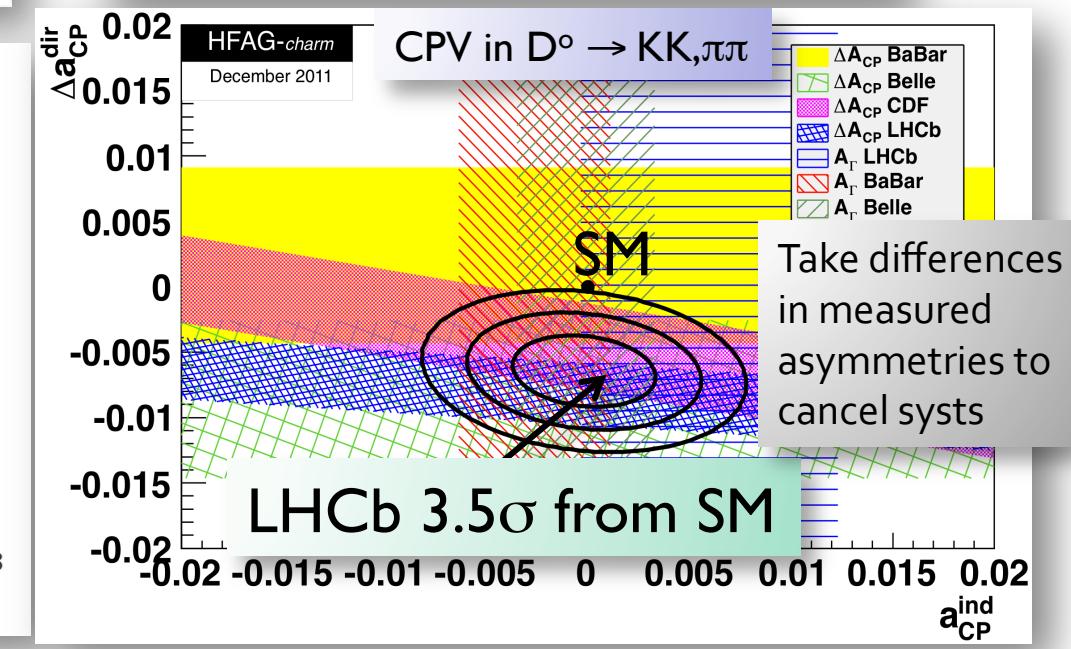
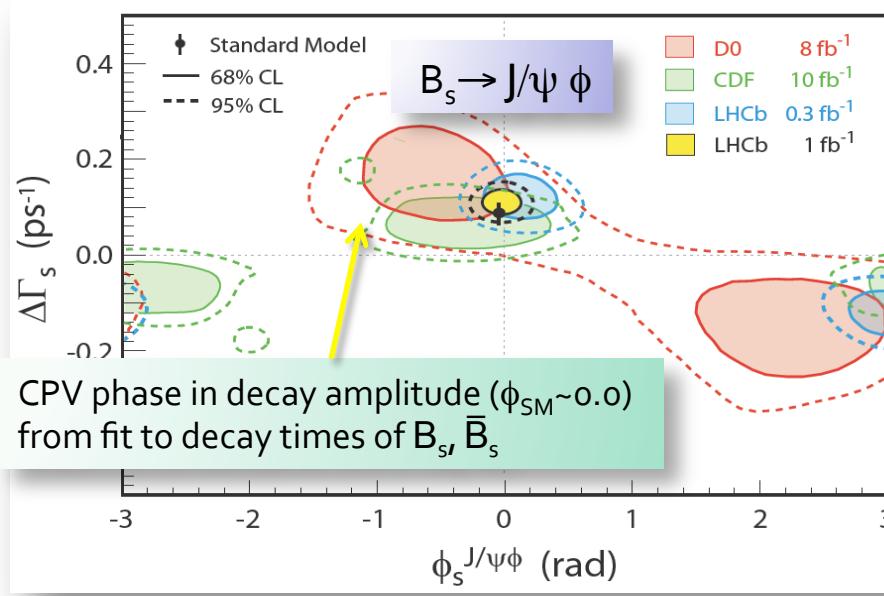
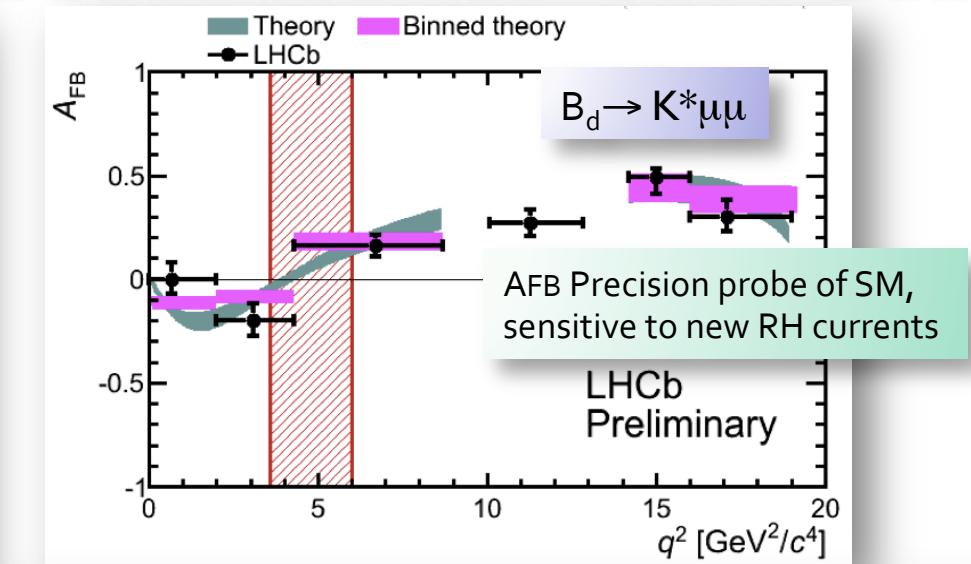
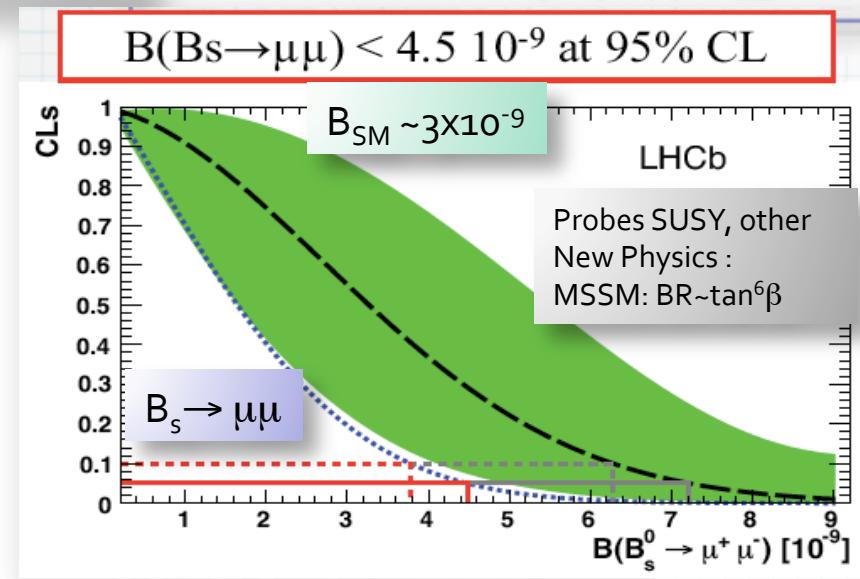


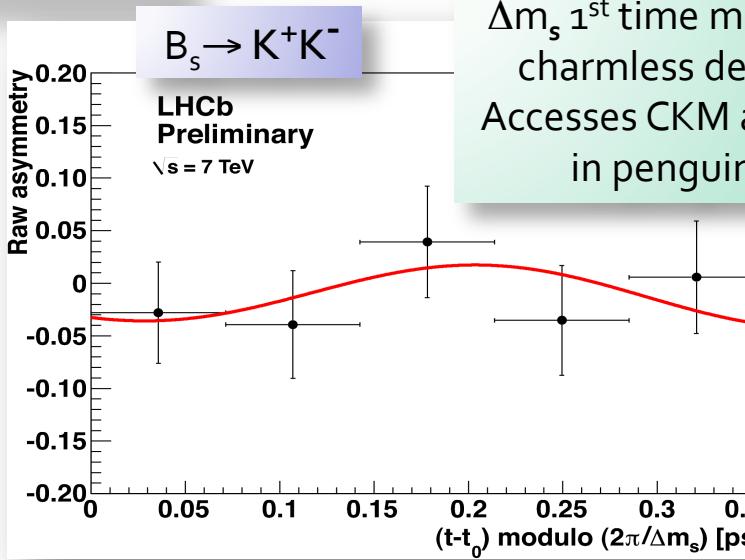
From Steve Myers



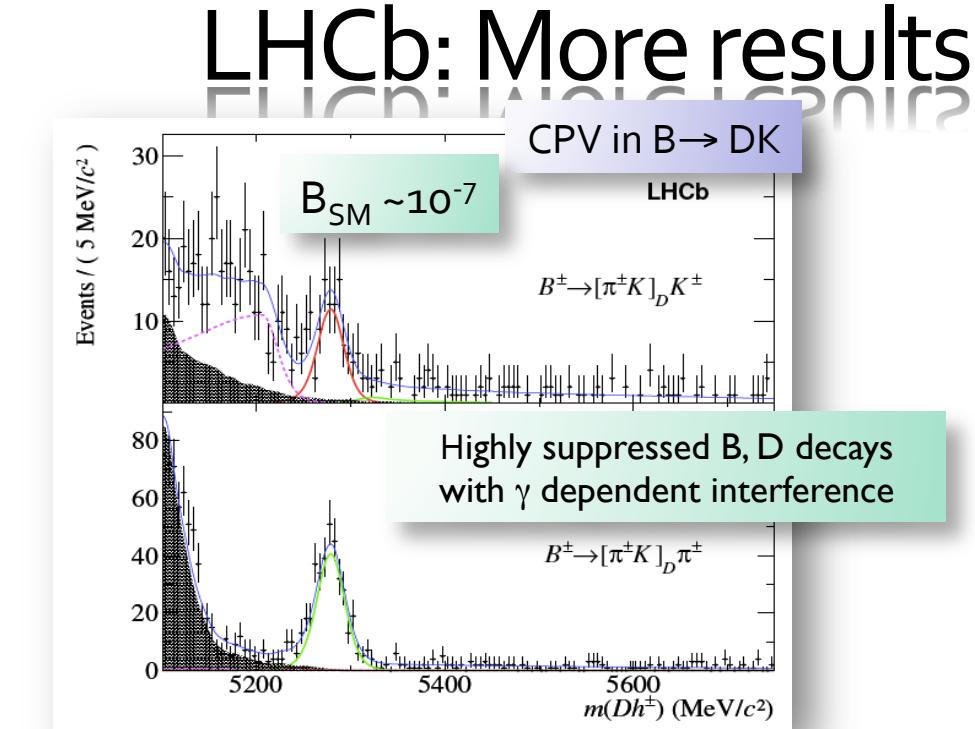
- *Probing the heavy flavor sector*
 - *To understand CP violation*
 - *Find indirect evidence of new physics*
 - *To discover new particles*
 - *To observe the rarest decays*

LHCb: Recent results, 2011 data



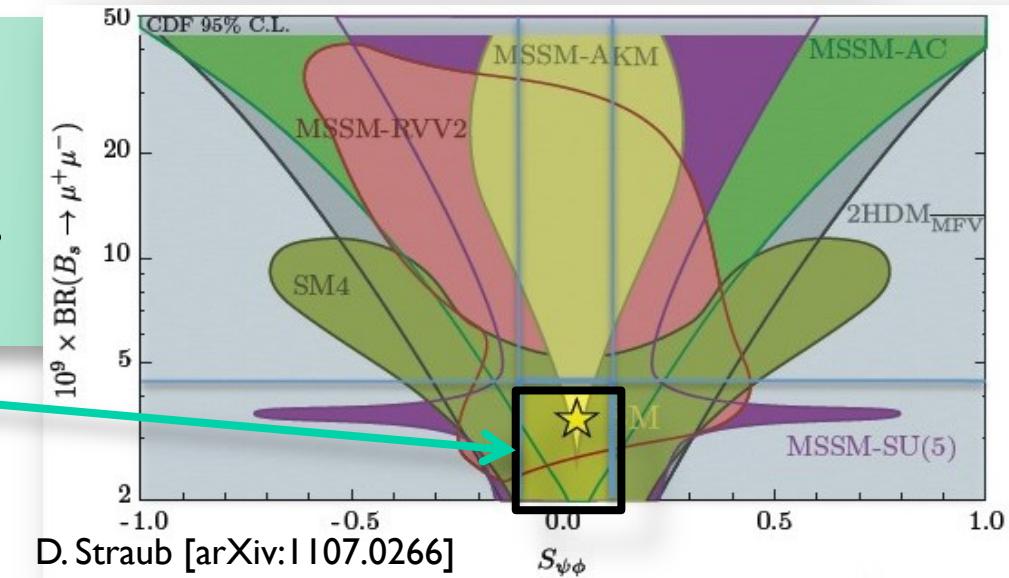


Δm_s 1st time meas. in charmless decays
Accesses CKM angle γ in penguins



- LHCb measurements constrain many SUSY models particularly at high $\tan \beta$.
 - Complementary to direct searches by ATLAS and CMS

Allowed region from $B_s \rightarrow \mu\mu$ and ϕ_s

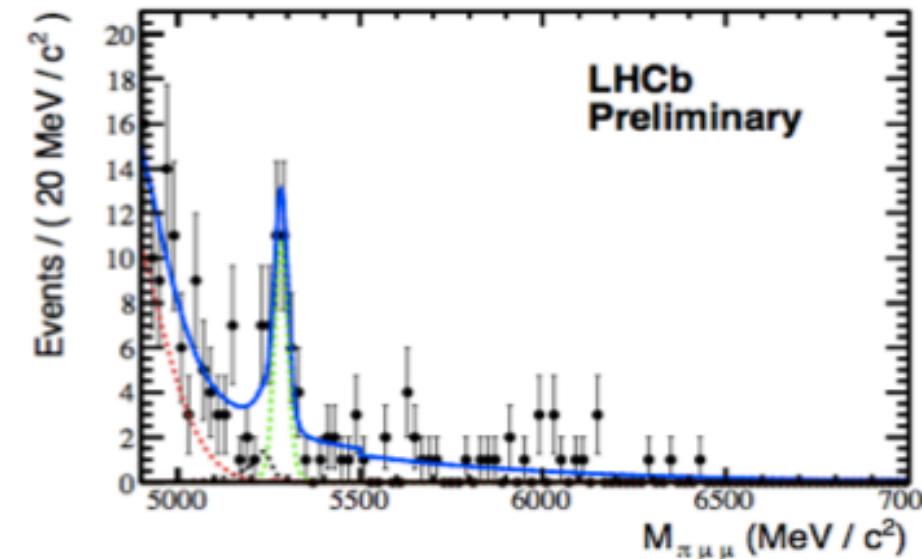


New particles discovered at LHC: LHCb

First observation of $B^+ \rightarrow \pi^+ \mu^+ \mu^-$

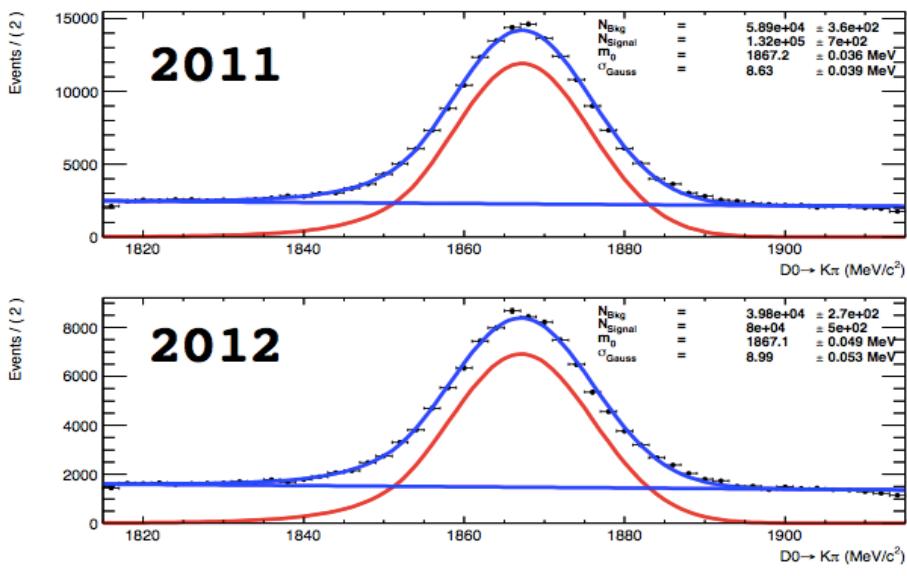
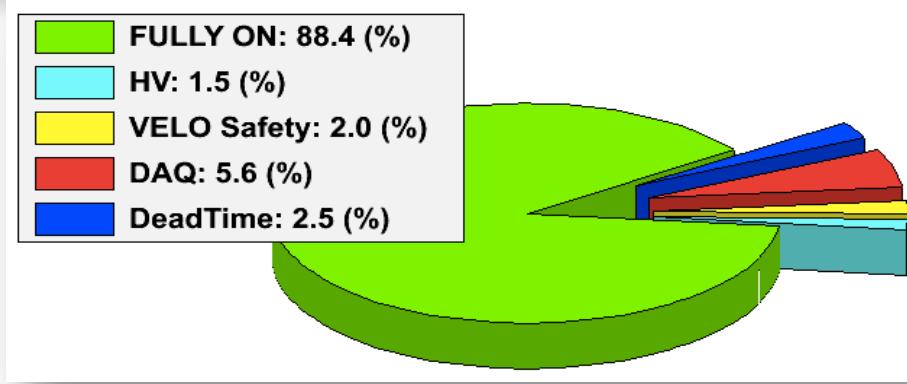
LHCb-CONF-2012-006

- This is the first observation of a $b \rightarrow d\ell\ell$ transition
- LHCb(1.0 fb^{-1}) : $B^+ \rightarrow \pi^+ \mu^+ \mu^-$: $25.3^{+6.7}_{-6.4}$ signal events
 - 5.2σ excess above background
- The measurement is consistent with the SM prediction

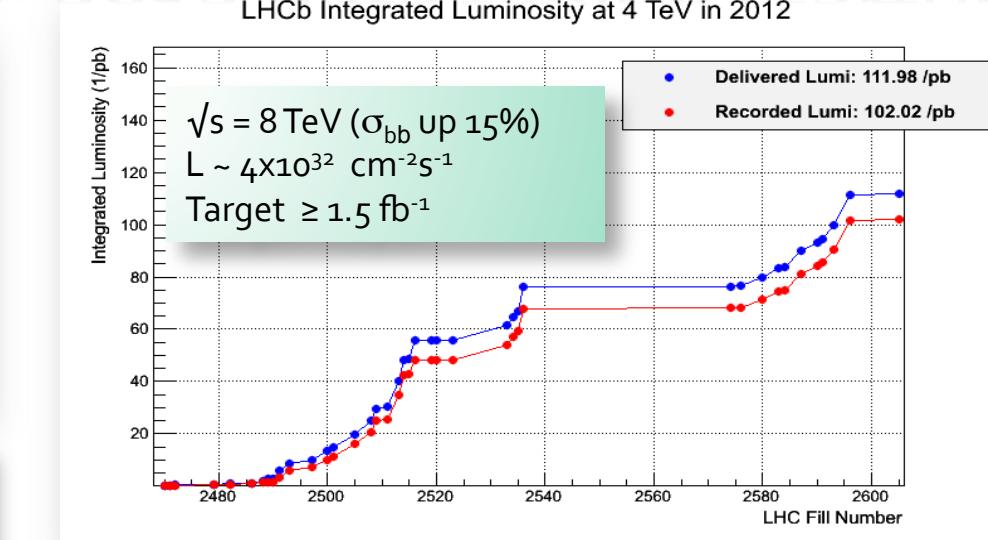


- $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (2.4 \pm 0.6(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-8}$ [preliminary]
- The rarest B decay ever observed

LHCb: 2012 data taking startup



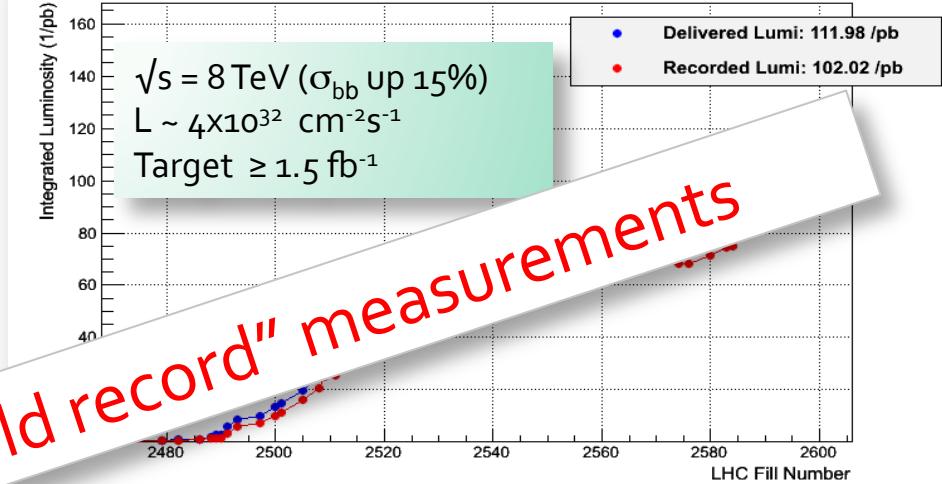
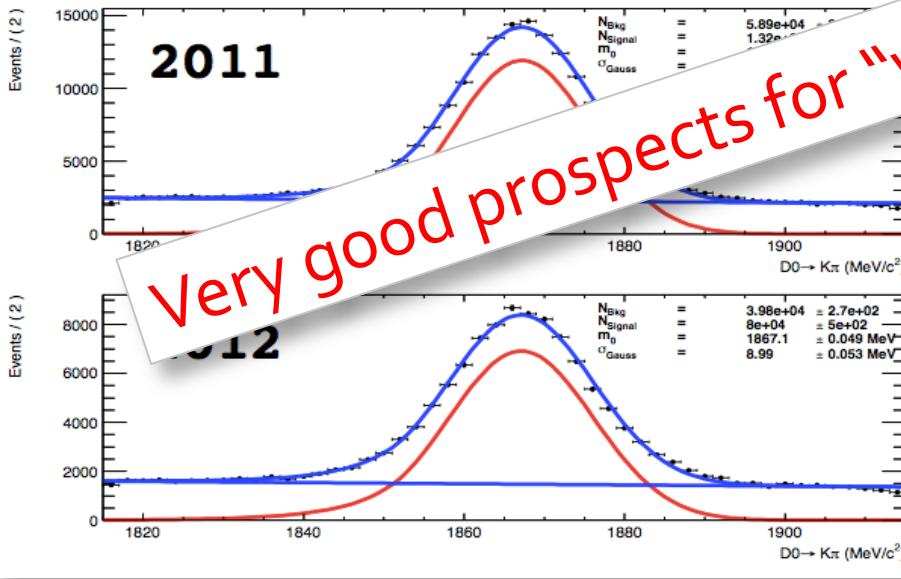
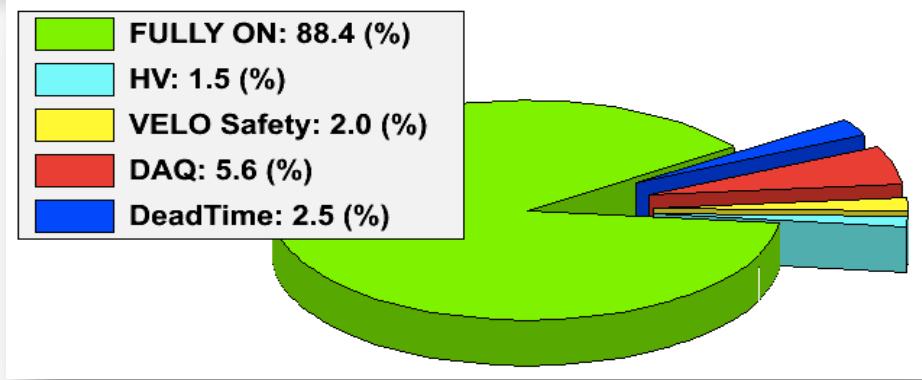
HLT-online reconstructed $D^0 \rightarrow 2\text{-body}$: same S/B, increased yield (amount under study)



- Data-taking ~90% efficiency
 - Successful test vertical collision scheme
 - Symmetric with magnet swaps (25 ns)
 - Test HLT deferred trigger
- Better S/B at 8 TeV + improved HLT + more CPU → +20-30% mainly had. Decays

LHCb: 2012 data taking startup

LHCb Integrated Luminosity at 4 TeV in 2012



- Data-taking ~90% efficiency
 - Successful test vertical collision scheme
 - Symmetric with magnet swaps (25 ns)
 - Test HLT deferred trigger
- Better S/B at 8 TeV + improved HLT + more CPU → +20-30% mainly had. Decays

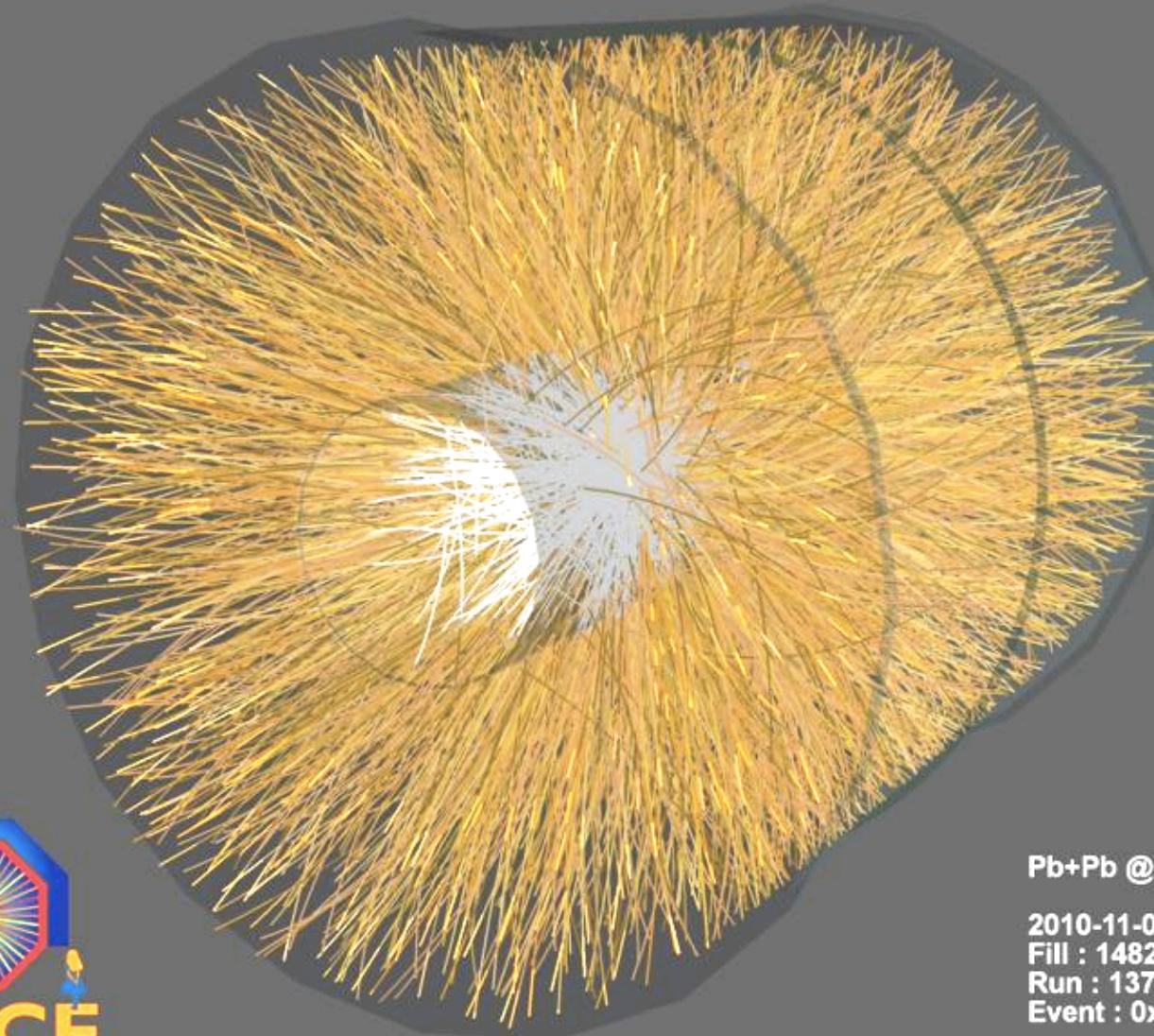
HLT-online reconstructed $D^0 \rightarrow 2\text{-body}$: same S/B, increased yield (amount under study)



- *Probing the early state of the Universe: Quark Gluon Plasma*
 - *Elliptic Flow*
 - *Hadron suppression*
 - *Dissolved/Recombined Charmonium*
 - ...

Pb-Pb event in ALICE

J. Incandela CERN/UCSB



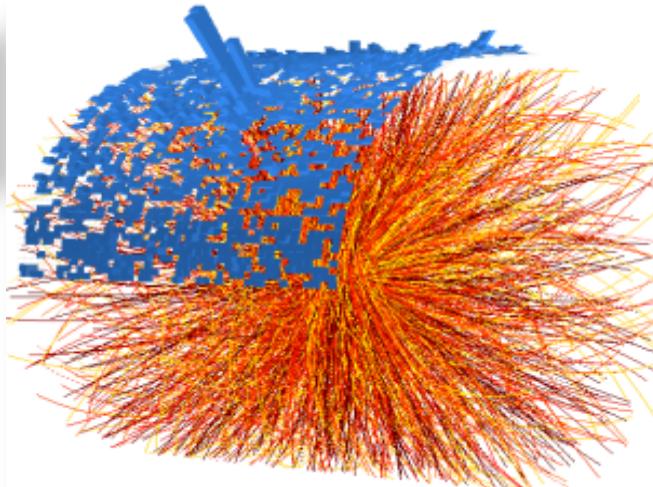
Pb+Pb @ $\text{sqrt}(s) = 2.76 \text{ ATeV}$

2010-11-08 11:30:46

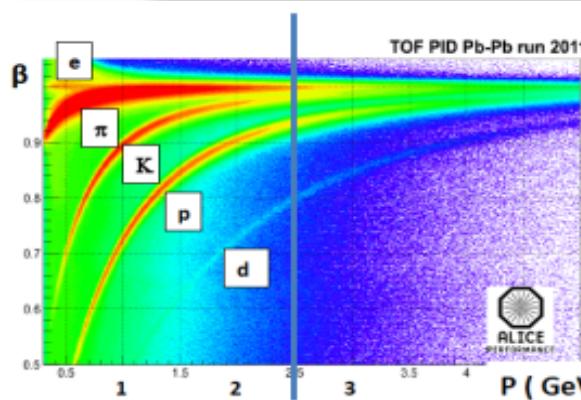
Fill : 1482

Run : 137124

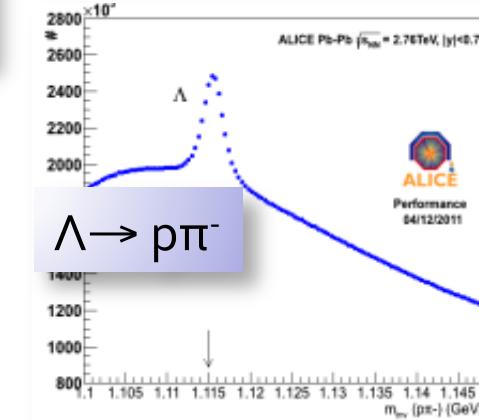
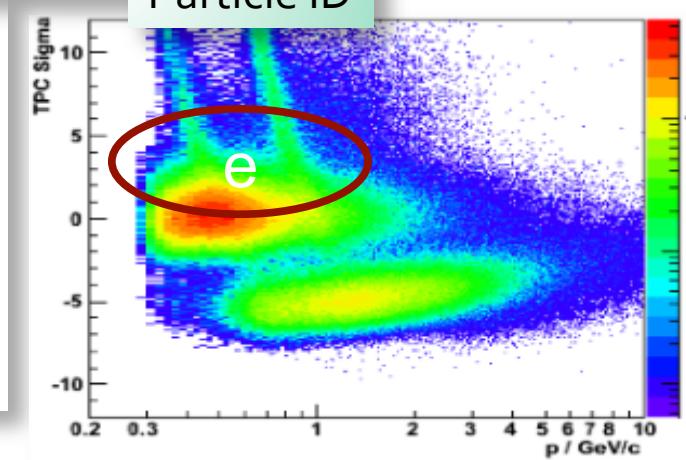
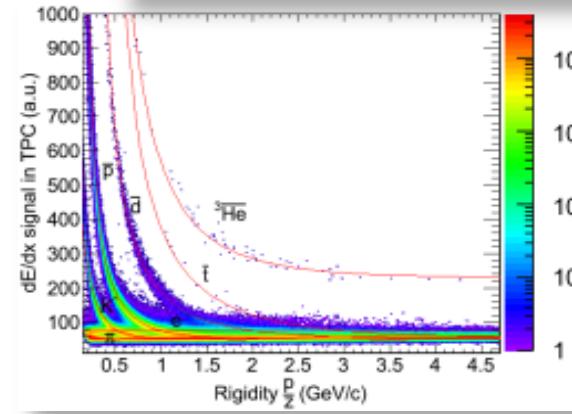
Event : 0x00000000D3BBE693



Additional EM Calorimetry

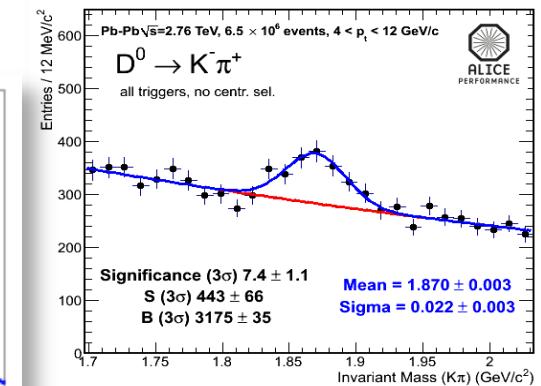


Particle ID

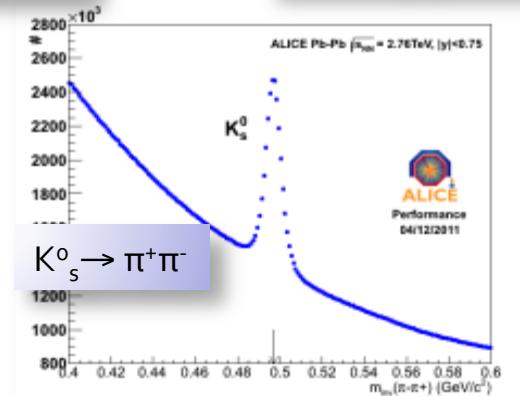


Additional EM Calorimetry

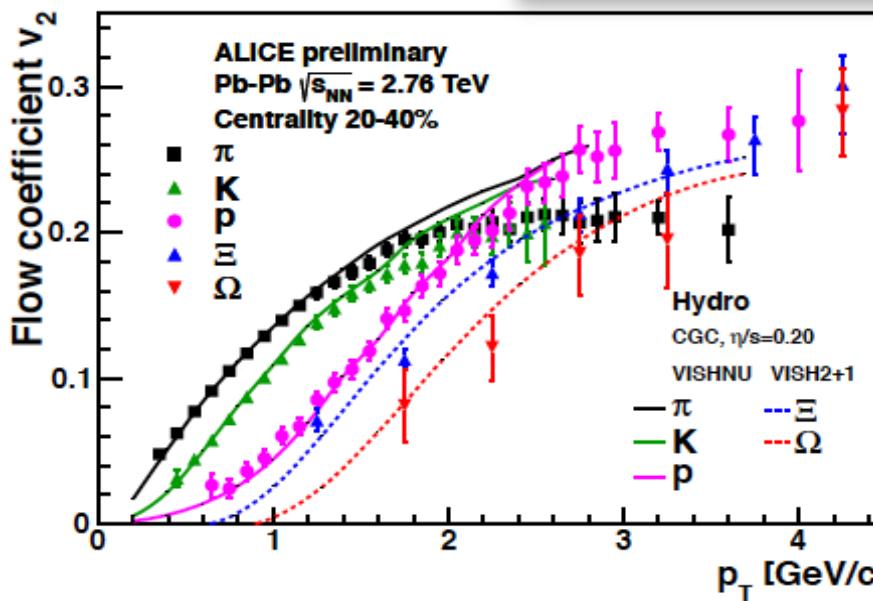
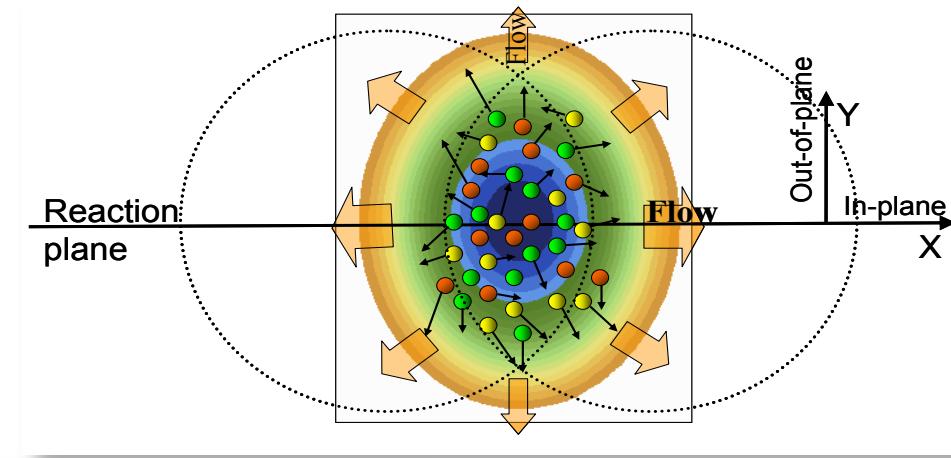
ALICE in 2011



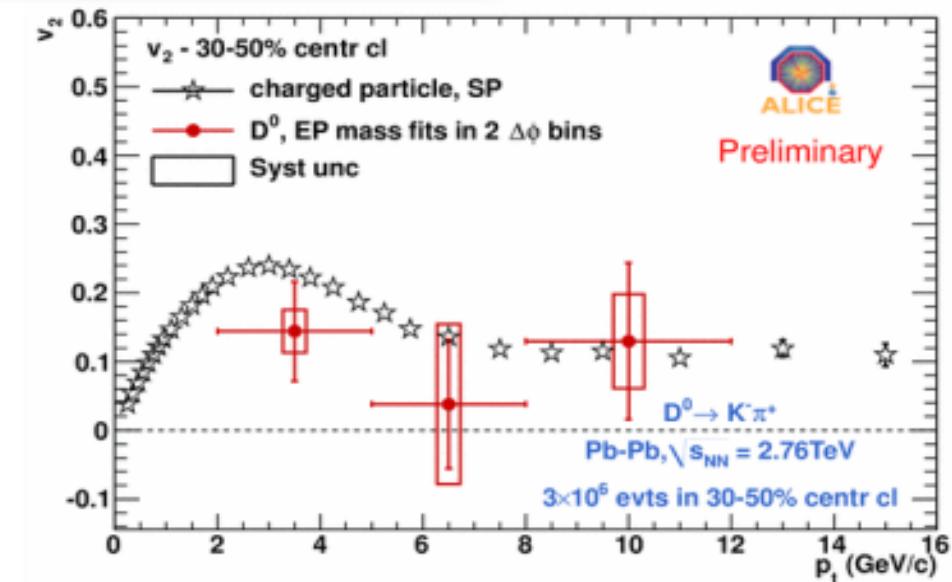
Low p_T tracking



ALICE Selected PbPb results: Flow

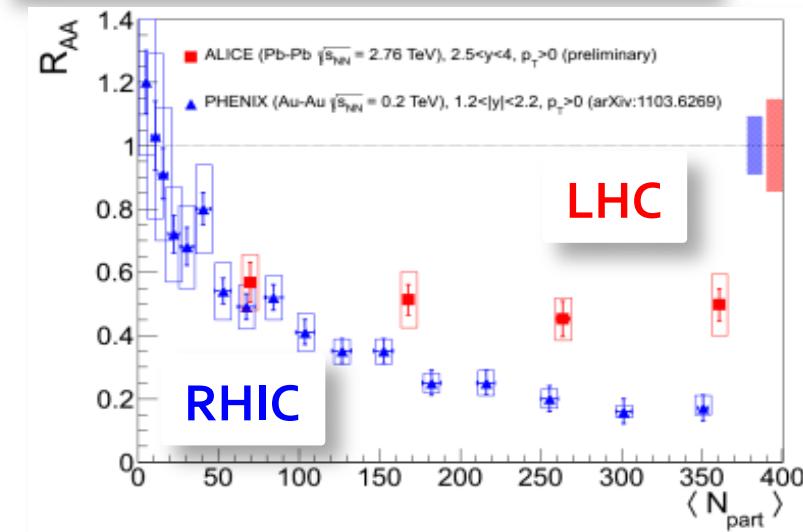
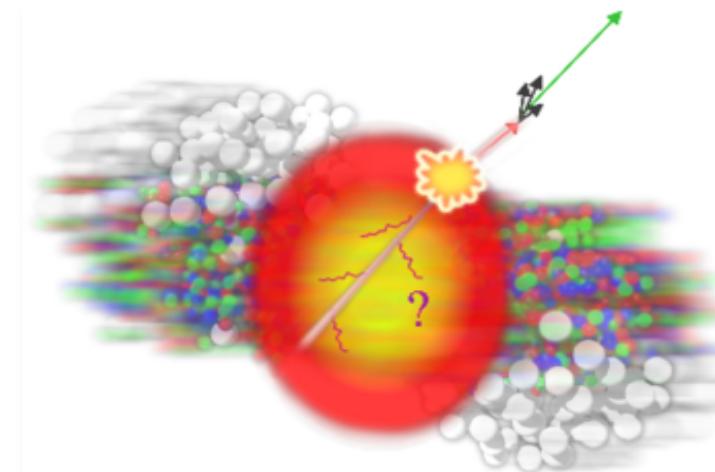
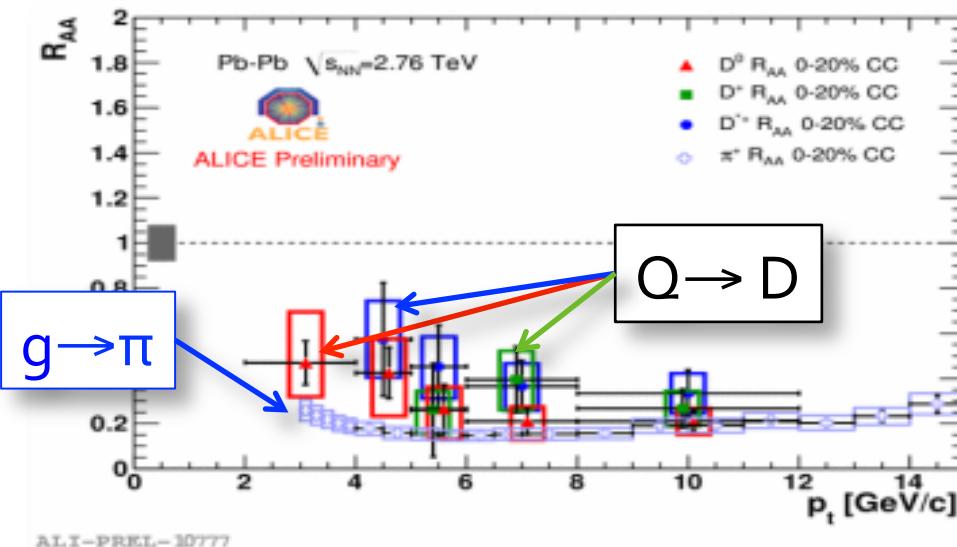


QGP explosive expansion generates
 u,d,s mass ordering of elliptic flow



Charm flows as well:
 c quark thermalization in QGP

ALICE Selected PbPb results: Nucl. Mod. Factor R_{AA}



QGP tomography with high p_T partons:

$$E_{\text{loss}}^g > E_{\text{loss}}^q > E_{\text{loss}}^Q ?$$

- pQCD dictates that gluons will lose more energy than quarks in the QGP
 - *For heavy quarks, there's an additional kinematic factor (dead cone effect), which suppresses gluon emission*

- Interaction of Quarkonia with QGP
 - J/ψ less suppressed in denser QGP
 - Recombination ?

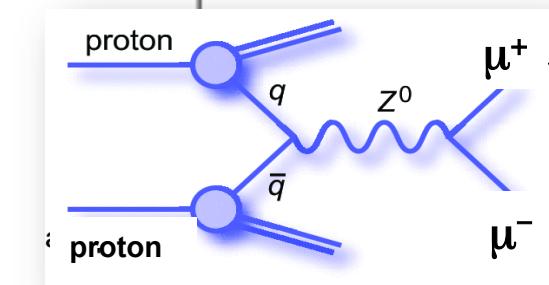
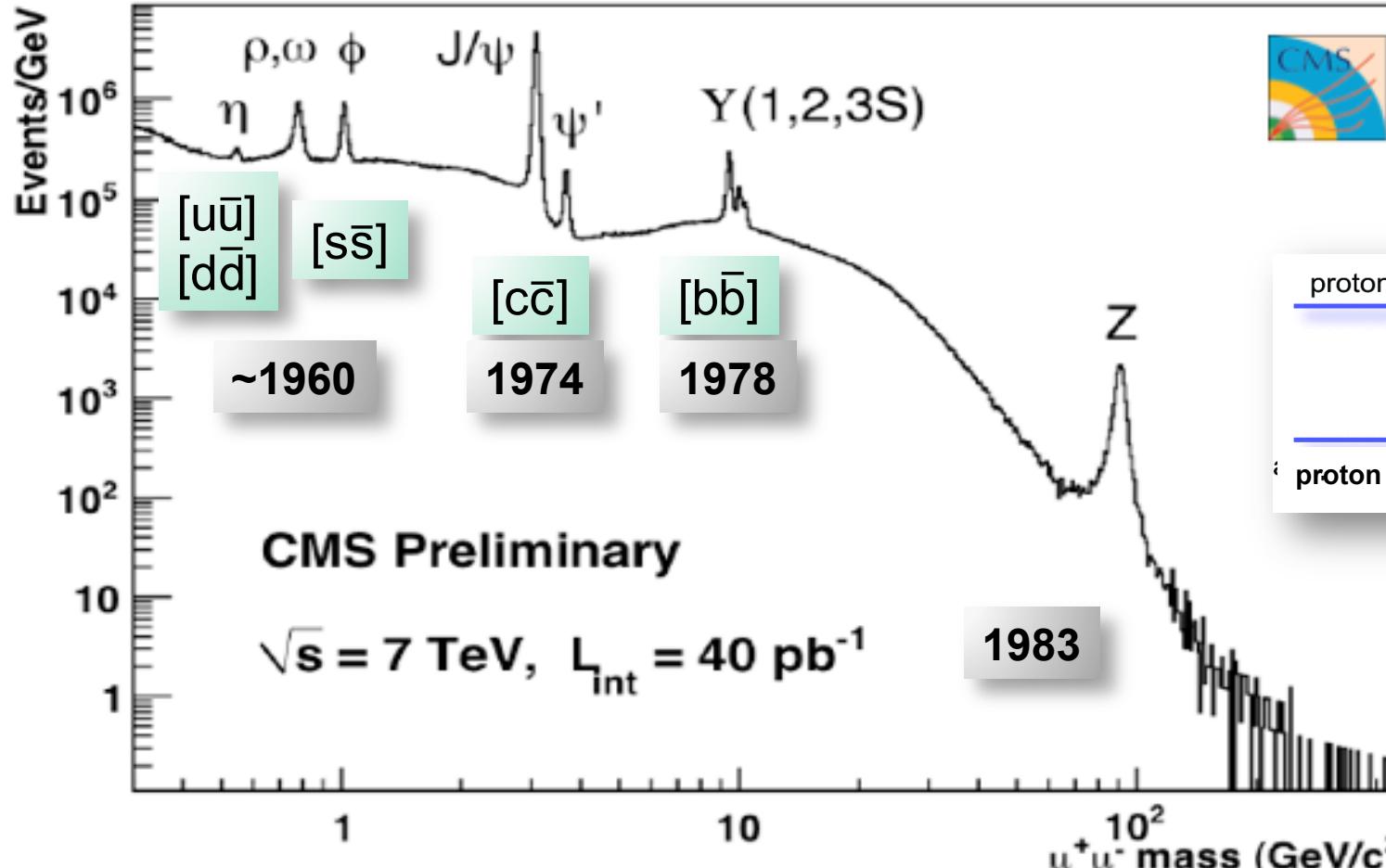


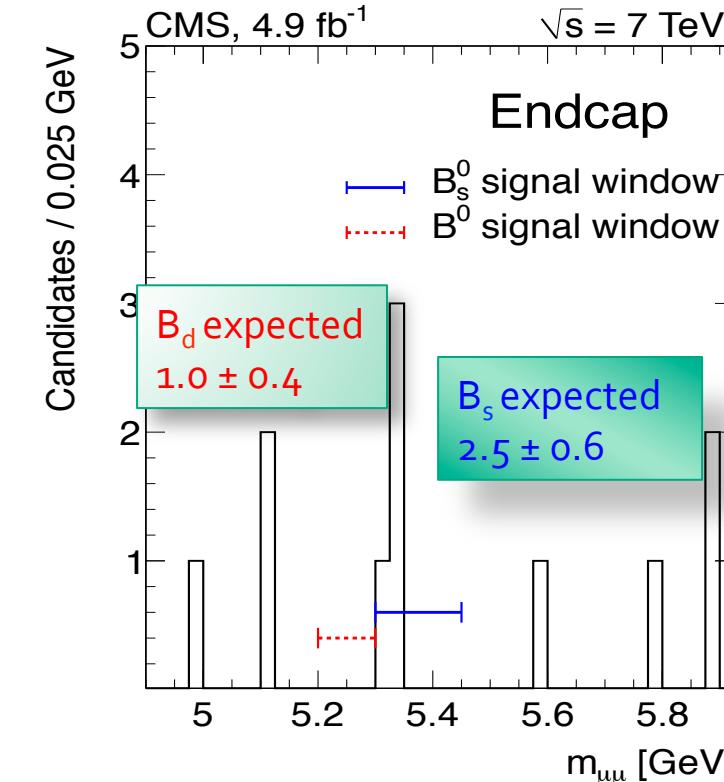
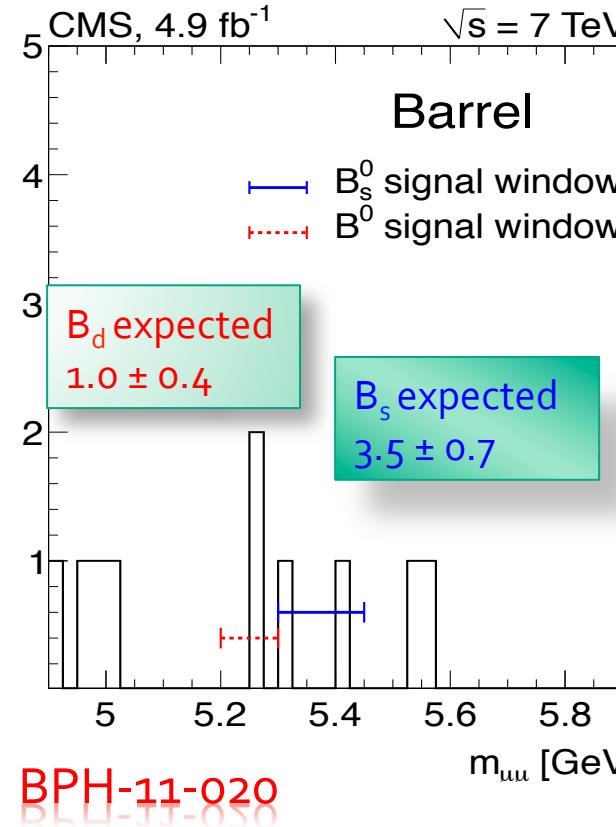
ALICE: Goals for 2012

- pp @ 8 TeV 5 pb⁻¹ baseline MB sample at new \sqrt{s}
 - High multiplicity trigger: Charm in high multiplicity events
 - *Jets (EMCAL) and photons (EMCAL/PHOS)*
 - *Electrons: High p_T with TRD, HF@high p_T, electrons for quarkonia*
- pPb/Pbp @ 4 TeV 30 nb⁻¹
 - Separation of initial and final state effects in PbPb
 - Measurements: parton saturation & shadowing
 - *Heavy flavor, Quarkonia, Jet rates, Direct photons, Dell-Yan cross sections*

ATLAS & CMS

Re-discovery of the Standard Model





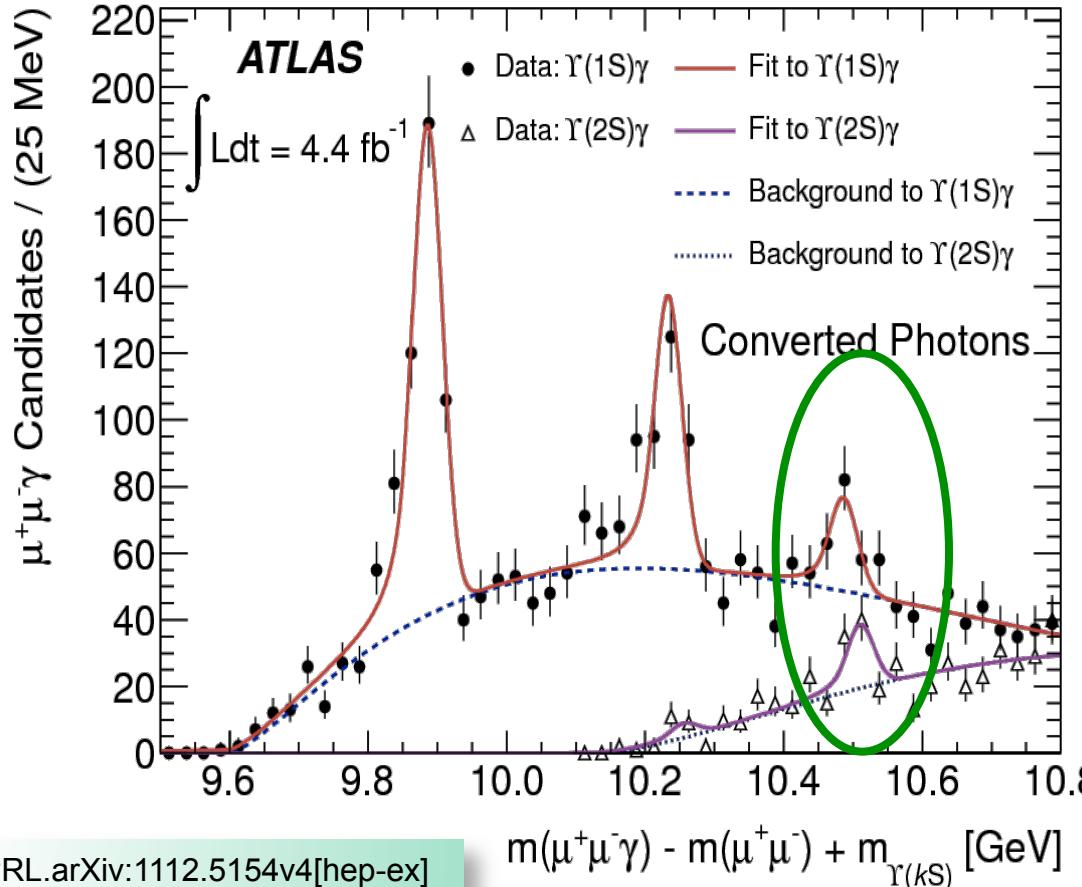
$B_{d/s} \rightarrow \mu\mu$

From 1.5B events on tape

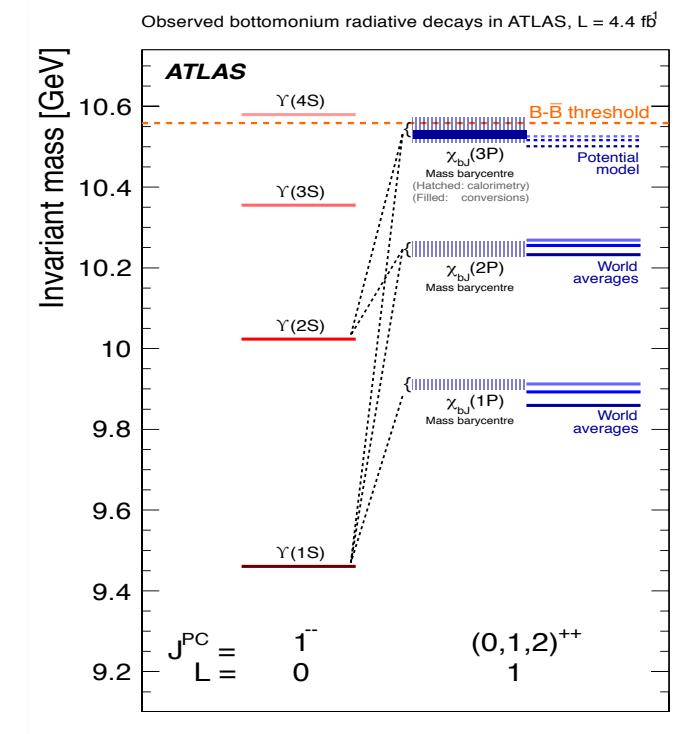
	CDF	CMS	Atlas	LHCb	SM
Luminosity (fb^{-1})	10	4.9	2.4	1.1	
$\text{Br}(B_d \rightarrow \mu^+\mu^-)$ 95% CL ($\times 10^{-9}$)	4.6	1.8		1.03	0.10 ± 0.01
$\text{Br}(B_s \rightarrow \mu^+\mu^-)$ 95% CL ($\times 10^{-9}$)	31	7.7	22	4.5	3.2 ± 0.2

New particles discovered at LHC: ATLAS

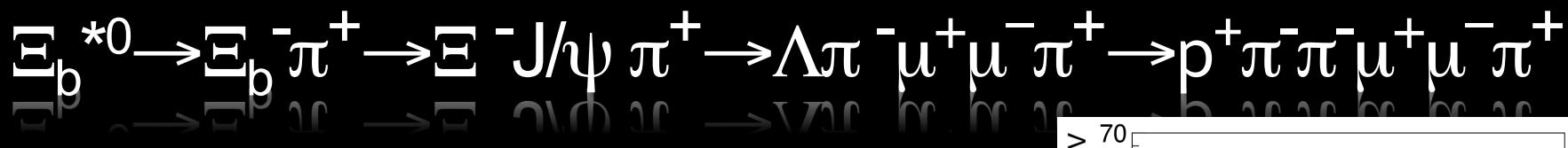
$X_b(3P) \rightarrow \gamma(1s,2s) \gamma$



$$m [X_b(3P)] = 10.530 \pm 0.005 \text{ (stat)} \pm 0.009 \text{ (syst)} \text{ GeV}$$



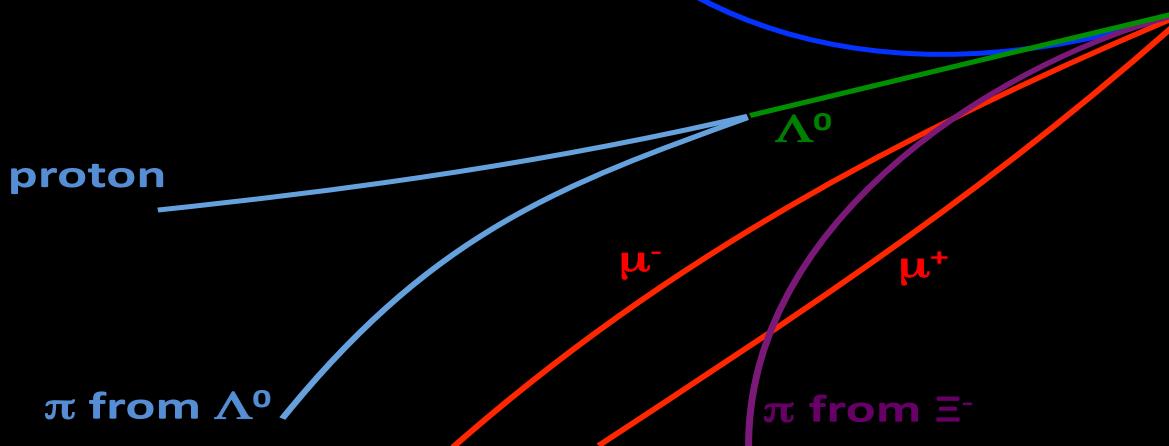
$X_b(nP) \rightarrow \gamma(1s,2s) \gamma \rightarrow \mu\mu\gamma$
 $X_b(1P) m = 9.9 \text{ GeV}$ and $X_b(2P)$
 $m = 10.2 \text{ GeV}$ states clearly visible
 New structure at 10.5 GeV $\rightarrow X_b(3P)$
 Confirmed with $\gamma(2s)$ data and with
 un-converted photons
 Significance $> 6 \sigma$
 As theoretically predicted



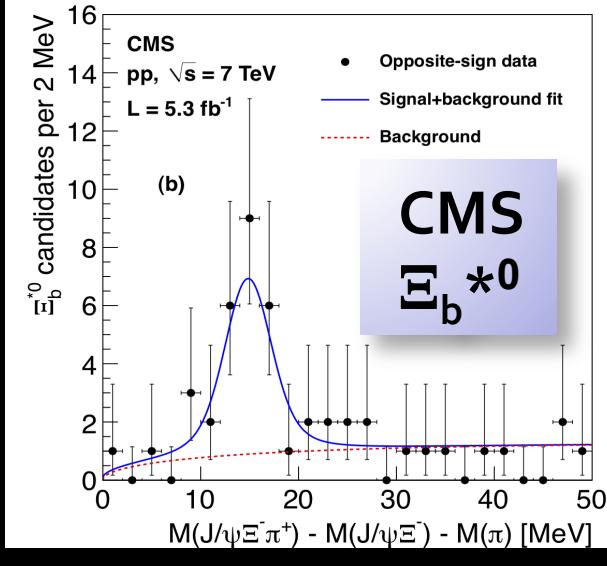
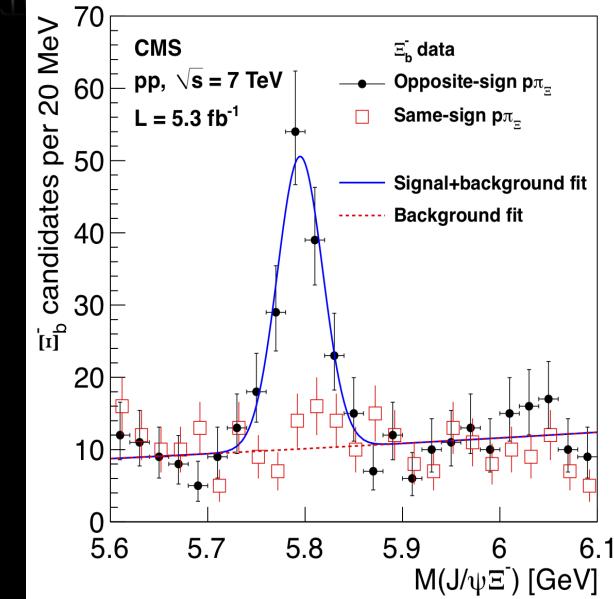
arXiv:1204.5955

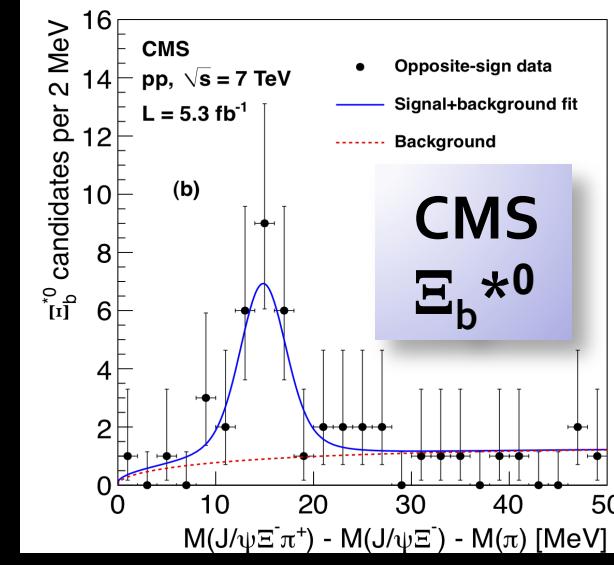
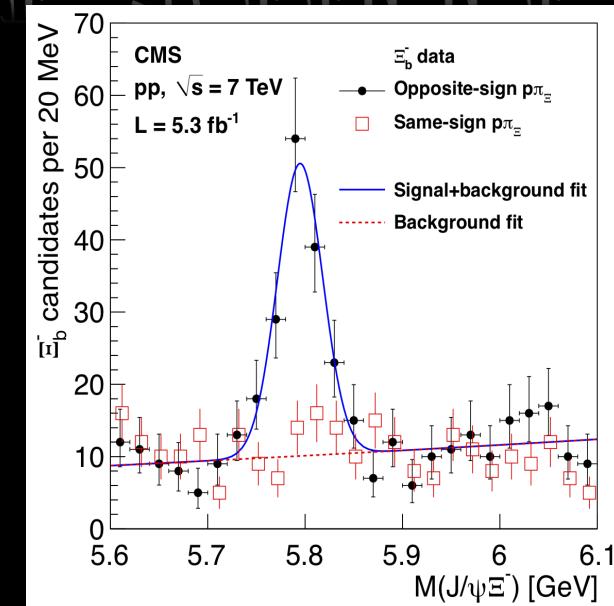
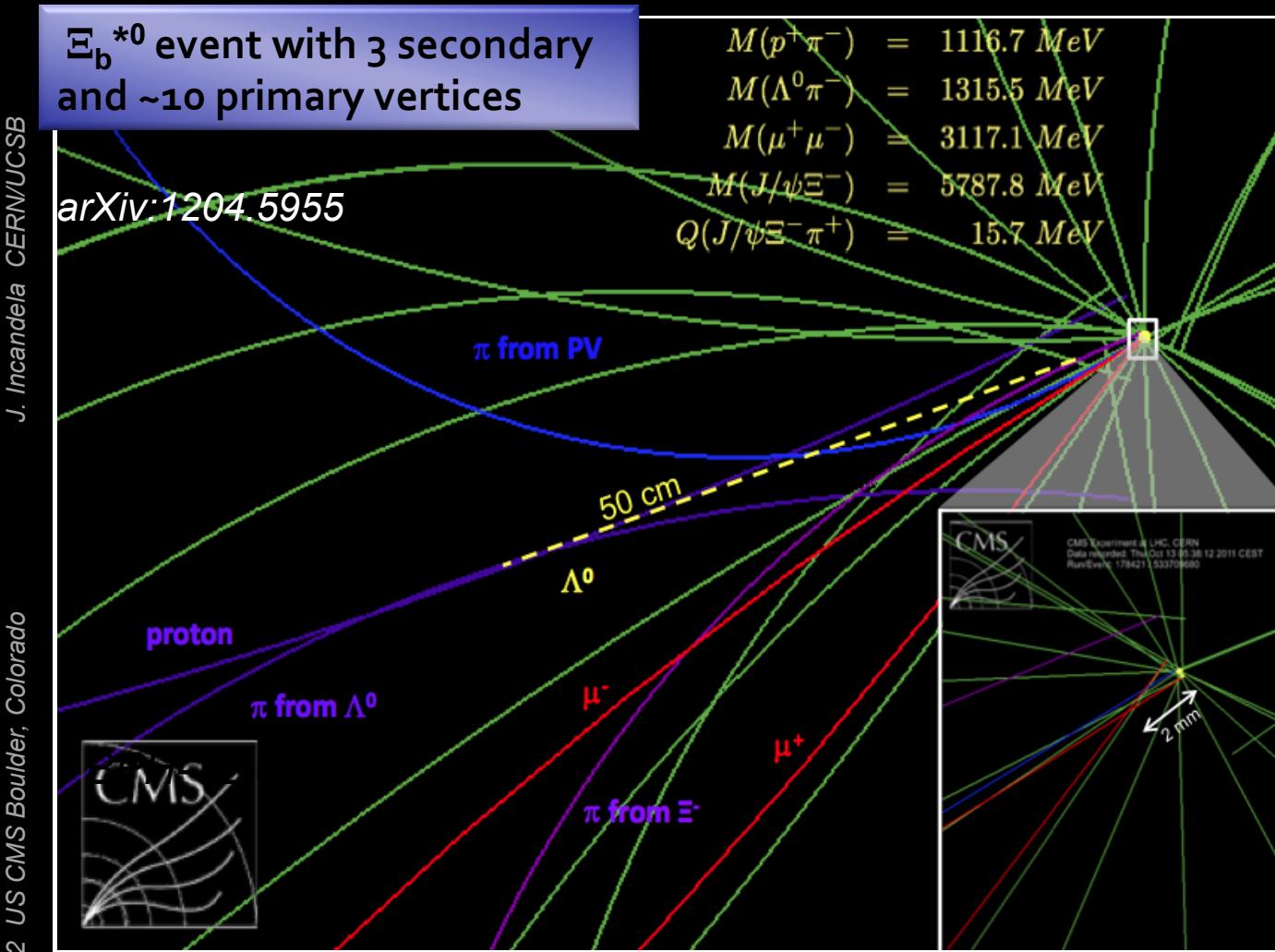
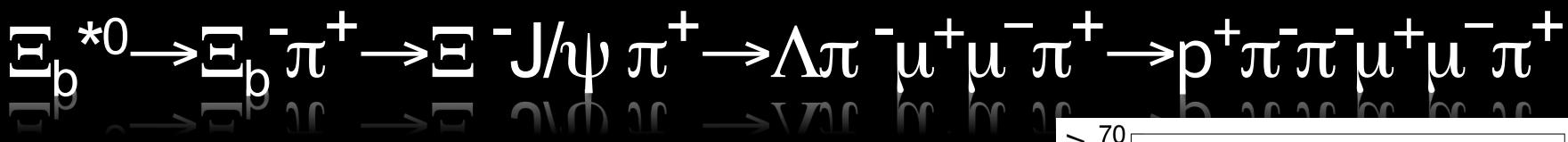
π from PV

$$\begin{aligned}
 M(p^+ \pi^-) &= 1116.7 \text{ MeV} \\
 M(\Lambda^0 \pi^-) &= 1315.5 \text{ MeV} \\
 M(\mu^+ \mu^-) &= 3117.1 \text{ MeV} \\
 M(J/\psi \Xi^-) &= 5787.8 \text{ MeV} \\
 Q(J/\psi \Xi^- \pi^+) &= 15.7 \text{ MeV}
 \end{aligned}$$



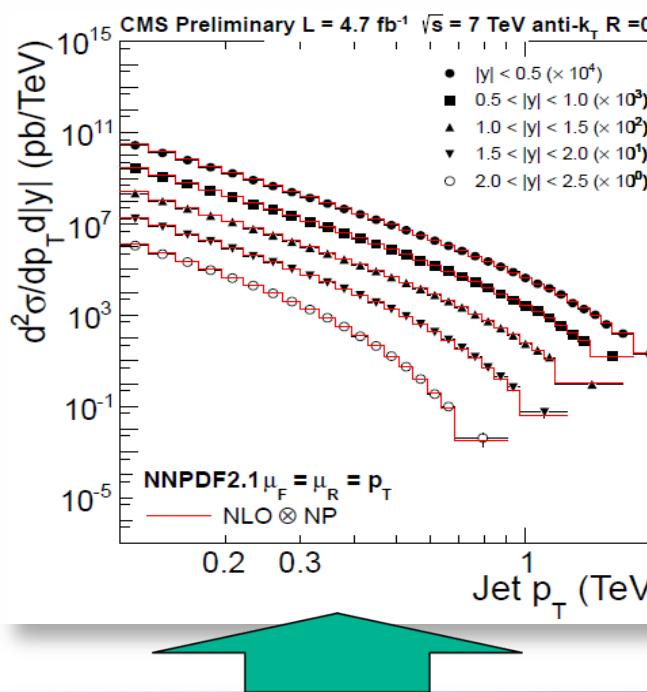
New particles discovered at LHC: CMS



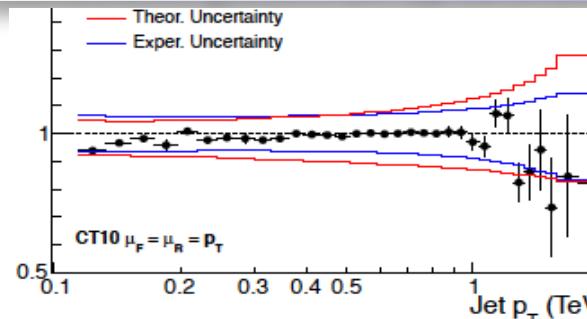


New particles discovered at LHC: CMS

Standard Model: Precision Jets, W, and γ^*/Z



Inclusive jet and dijets. 2-4% JES.
Constrains gluon PDF up to $x=0.6$

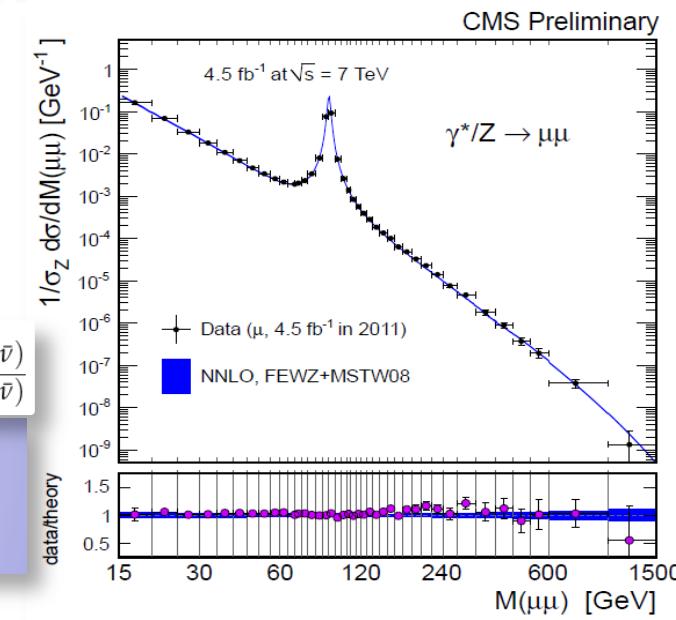


CMS-PAS-QCD-11-004

CMS-PAS-SMP-12-001

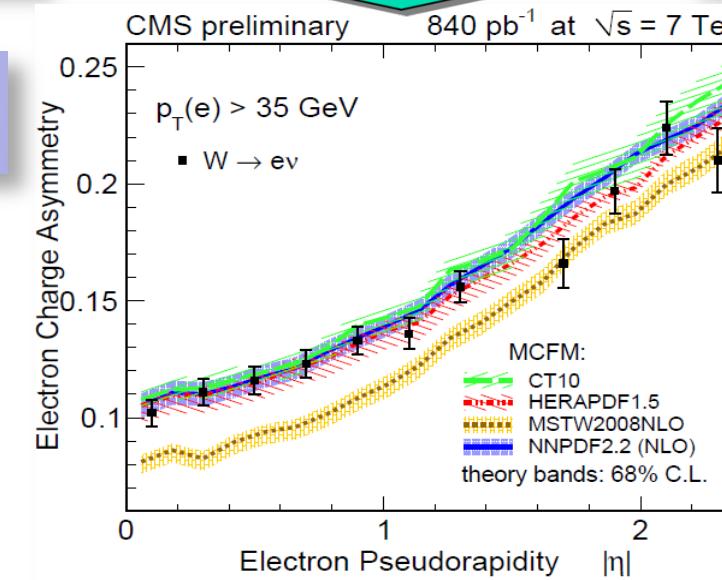
$$A(\eta) = \frac{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) - d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) + d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}$$

W electron charge asymmetry
measured to 0.5-1% per bin of 0.1
in $\Delta\eta$. Constrains u/d PDF ratio



Differential Drell-Yan
cross section: 2.5M $\mu\mu$
pairs tests NNLO PDFs
and cross sections

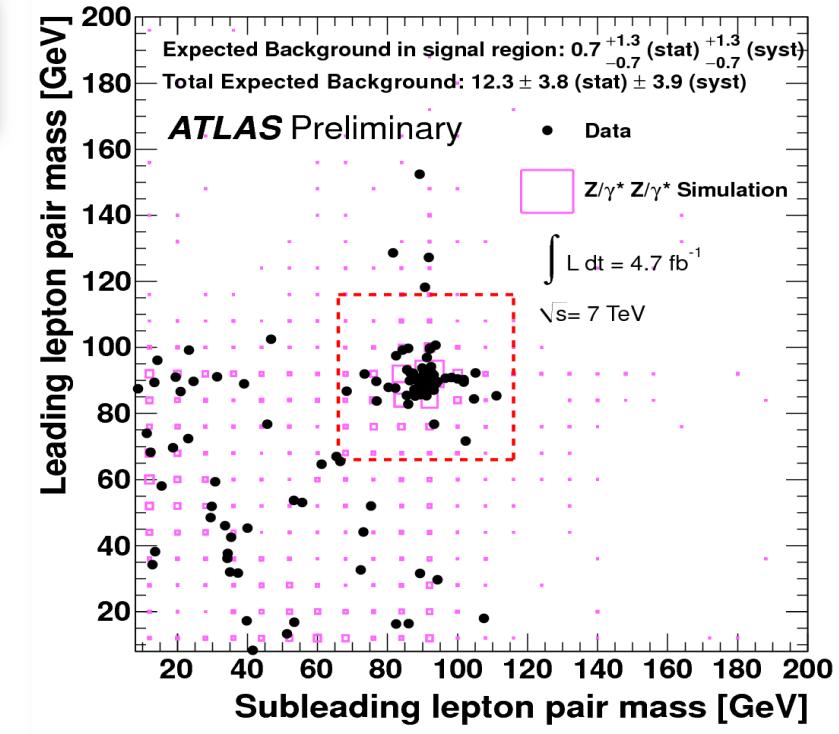
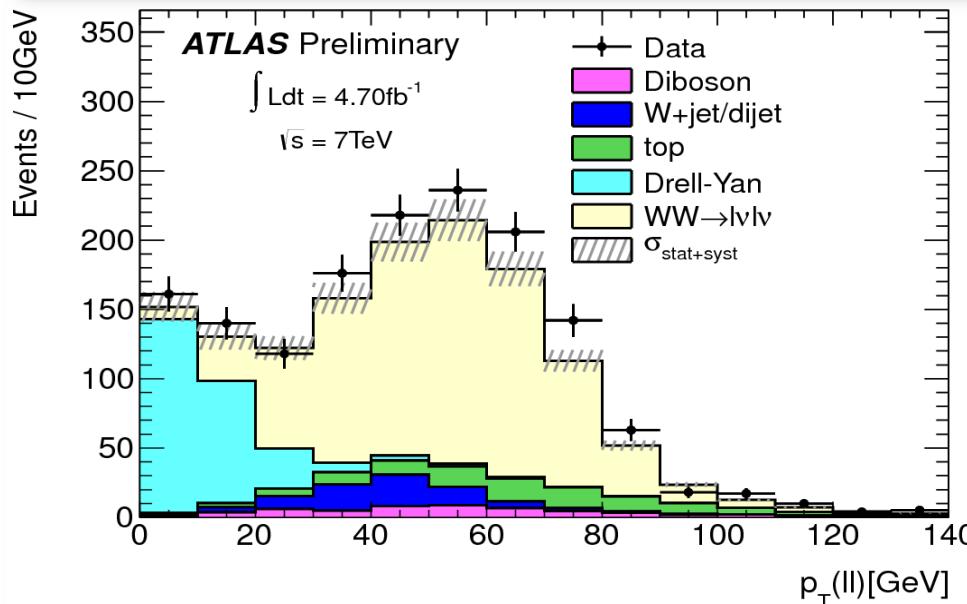
CMS-PAS-EWK-11-007



Electroweak di-boson production

Process	Final state	Measured total cross-section	Theory (NLO)
WW	l ⁺ l ⁻ l ⁺ l ⁻	$\sigma_{W^+W^-}^{tot} = 53.4 \pm 2.1(\text{stat}) \pm 4.5(\text{syst}) \pm 2.1(\text{lumi}) \text{ pb}$	$45.1 \pm 2.8 \text{ pb}$
ZZ	4l	$\sigma_{ZZ}^{tot} = 7.2^{+1.1}_{-0.9} \text{ (stat)}^{+0.4}_{-0.3} \text{ (syst)} \pm 0.3 \text{ (lumi) pb}$	$6.5^{+0.3}_{-0.2} \text{ pb}$
ZZ	llvv	$\sigma_{ZZ}^{tot} = 5.4^{+1.3}_{-1.2} \text{ (stat.)}^{+1.4}_{-1.0} \text{ (syst.)} \pm 0.2 \text{ (lumi.) pb}$	$6.5^{+0.3}_{-0.2} \text{ pb}$

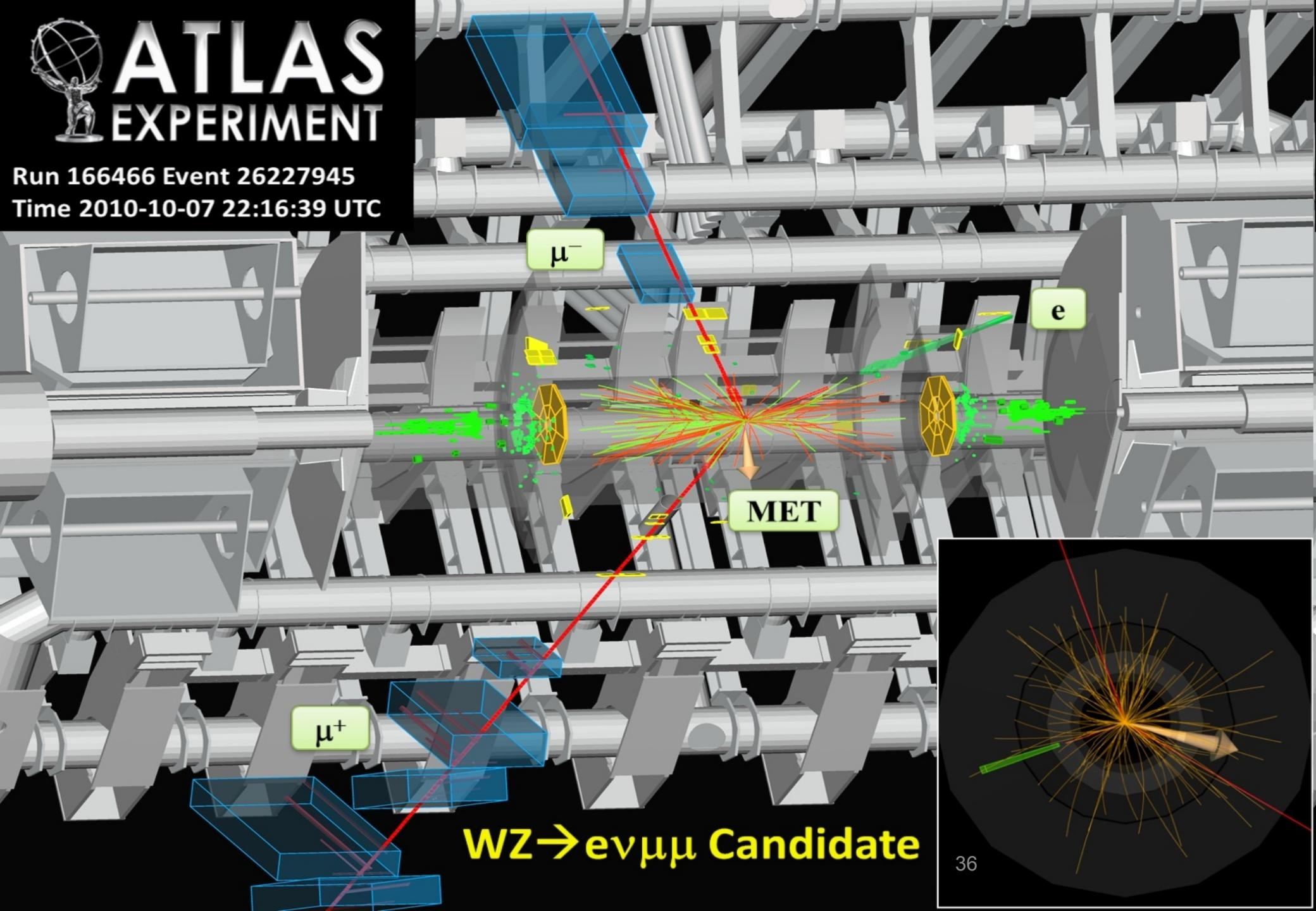
- Backgrounds to Higgs searches
- Access triple gauge couplings, New Physics





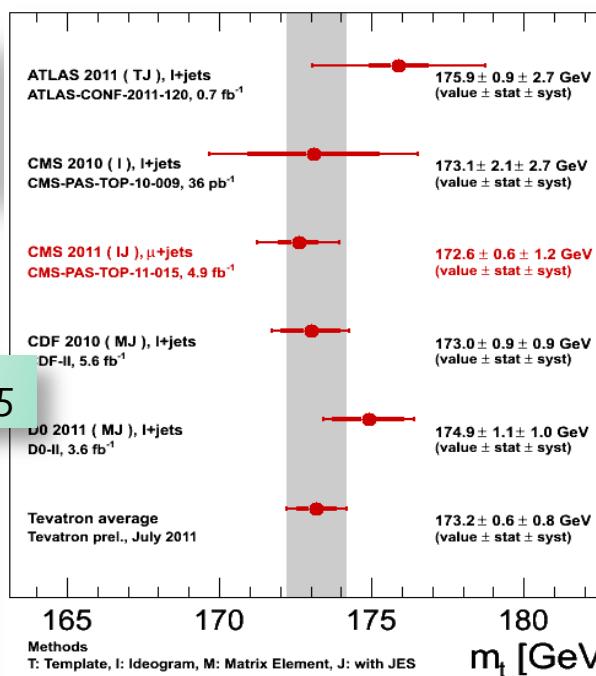
ATLAS EXPERIMENT

Run 166466 Event 26227945
Time 2010-10-07 22:16:39 UTC

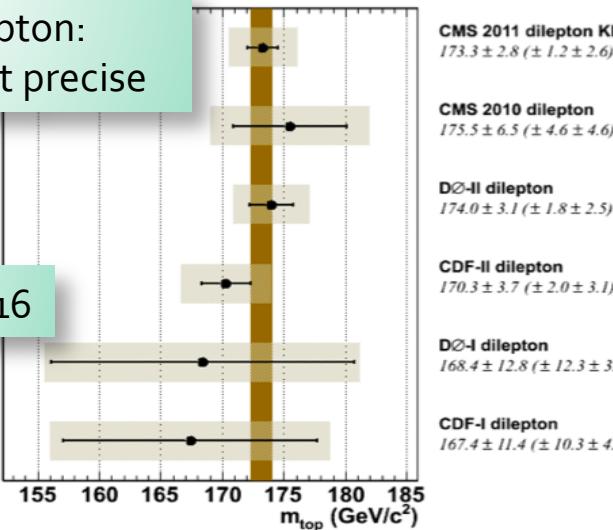




TOP-11-015

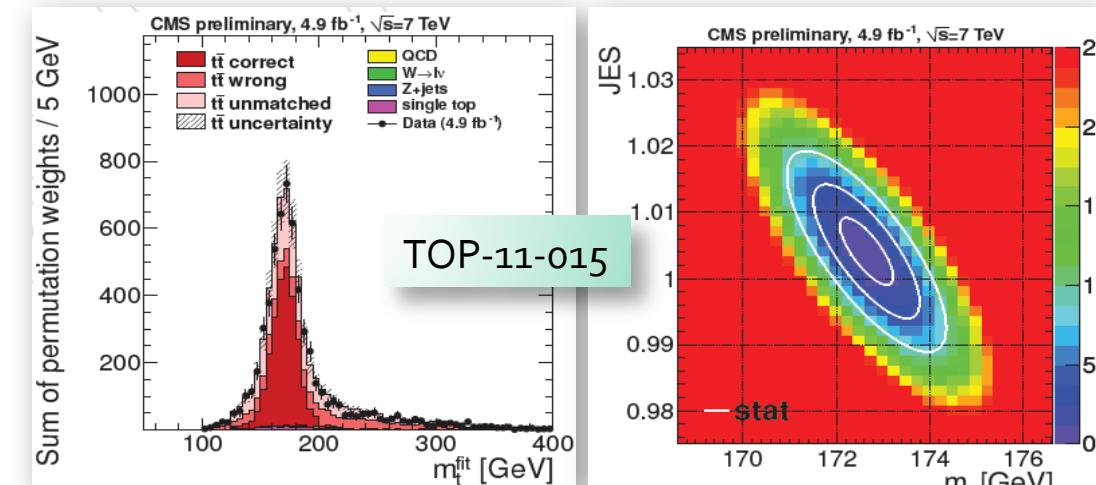
Dilepton:
most precise

TOP-11-016



Top mass

CMS average : $172.6 \pm 0.4 \pm 1.2 \text{ GeV}$
Tevatron average: $173.2 \pm 0.6 \pm 0.8 \text{ GeV}$

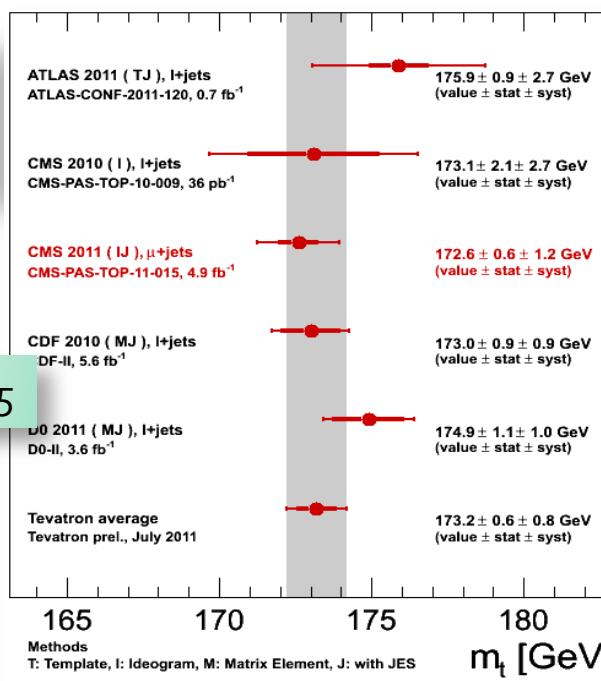
CMS μ +Jets analysis

$$m_t = 172.64 \pm 0.57 \text{ (stat+JES)} \pm 1.18 \text{ (syst)} \text{ GeV}$$

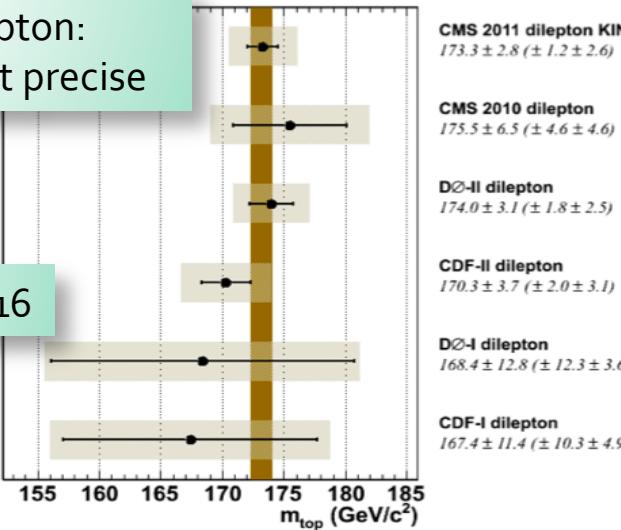
$$\text{JES} = 1.004 \pm 0.005 \text{ (stat)} \pm 0.012 \text{ (syst)}$$



TOP-11-015

Dilepton:
most precise

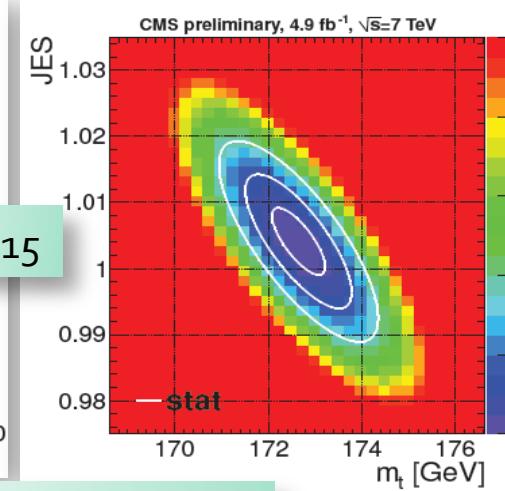
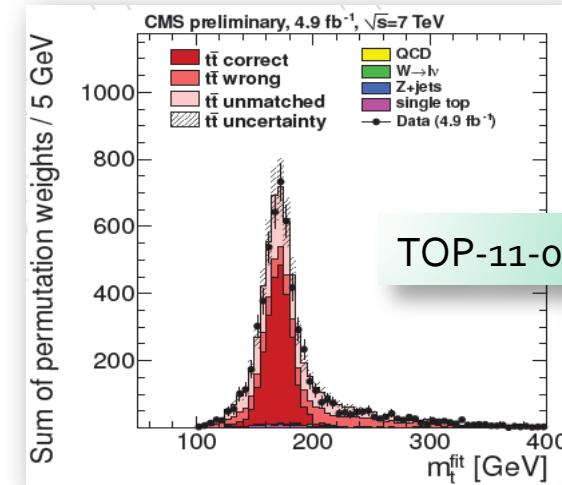
TOP-11-016



After applying the calibration, we obtain a top quark mass from 44660 events of $m_t = 172.6 \pm 0.2 \text{ (stat)} \pm 1.8 \text{ (syst)} \text{ GeV}$ which confirms the result obtained in the main analysis.

Top mass

CMS average : $172.6 \pm 0.4 \pm 1.2 \text{ GeV}$
Tevatron average: $173.2 \pm 0.6 \pm 0.8 \text{ GeV}$

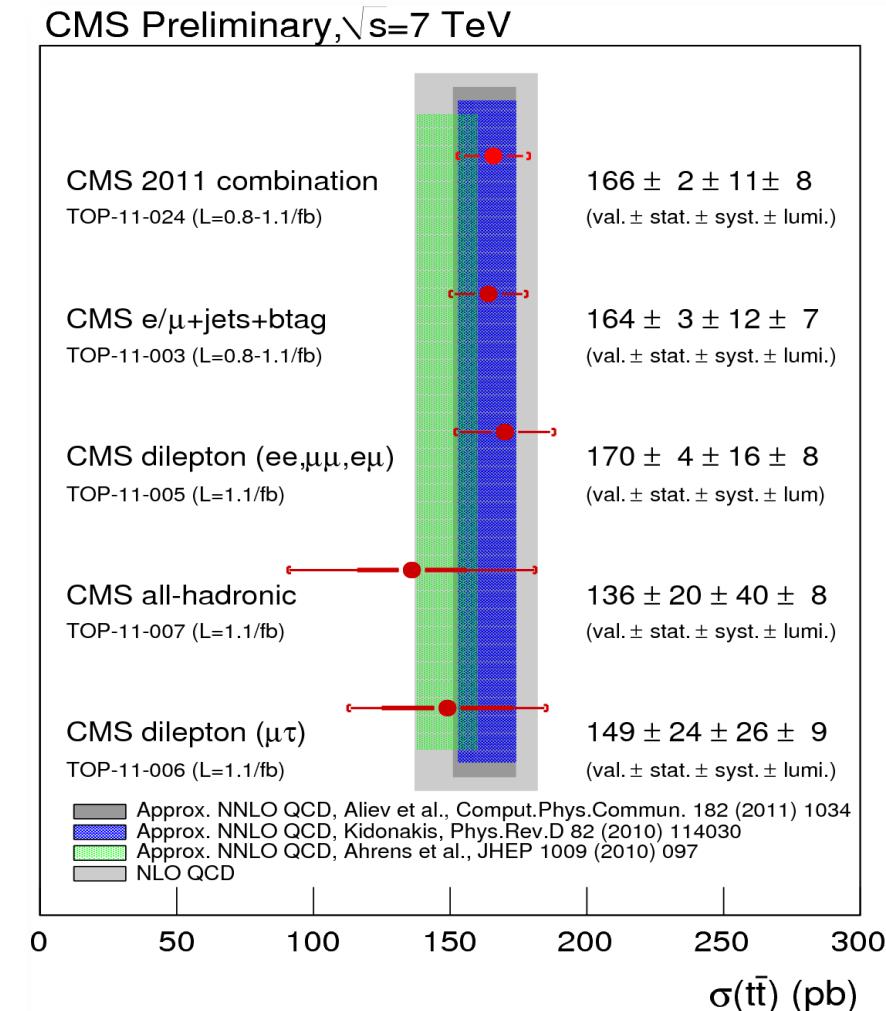
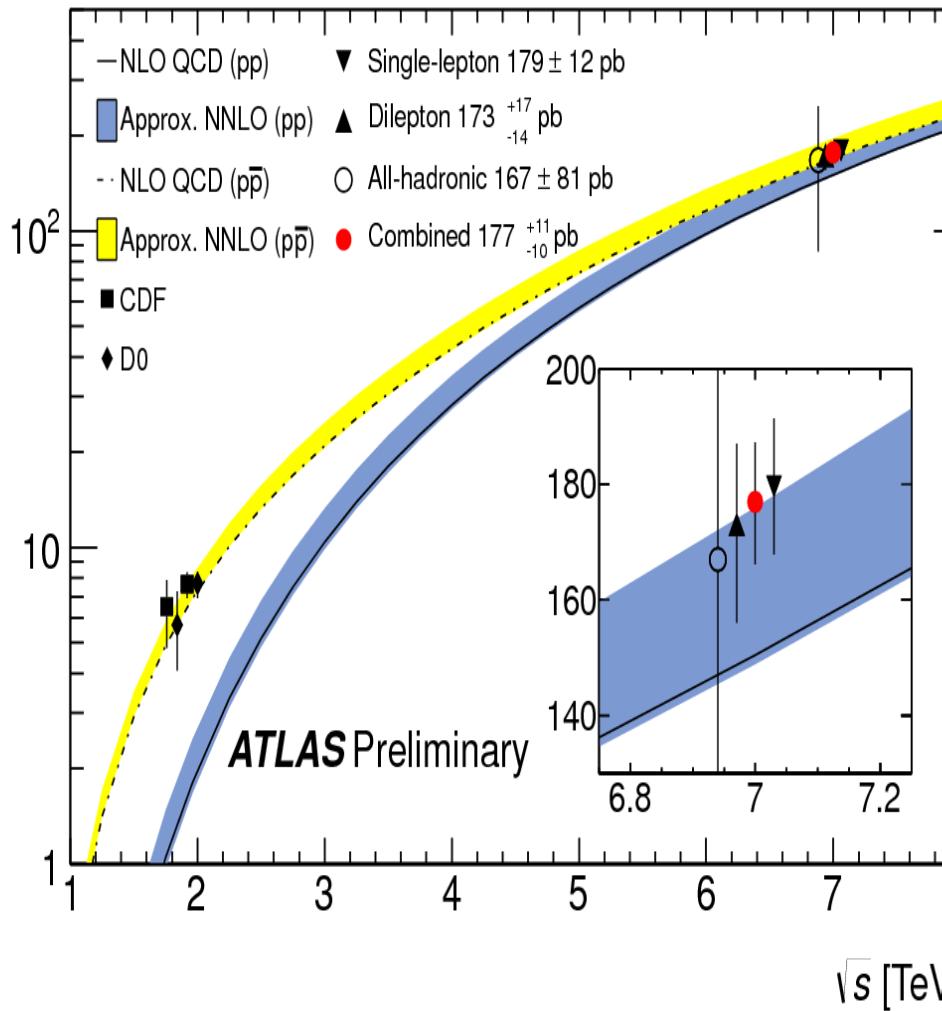
CMS μ +Jets analysis

$$m_t = 172.64 \pm 0.57 \text{ (stat+JES)} \pm 1.18 \text{ (syst)} \text{ GeV}$$

$$\text{JES} = 1.004 \pm 0.005 \text{ (stat)} \pm 0.012 \text{ (syst)}$$

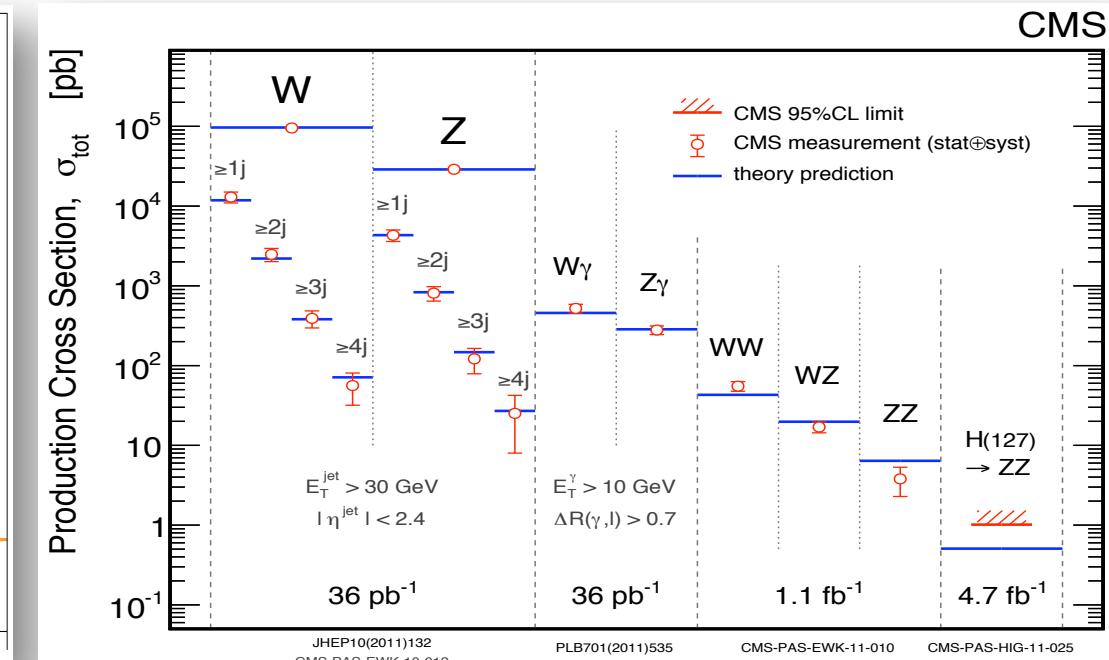
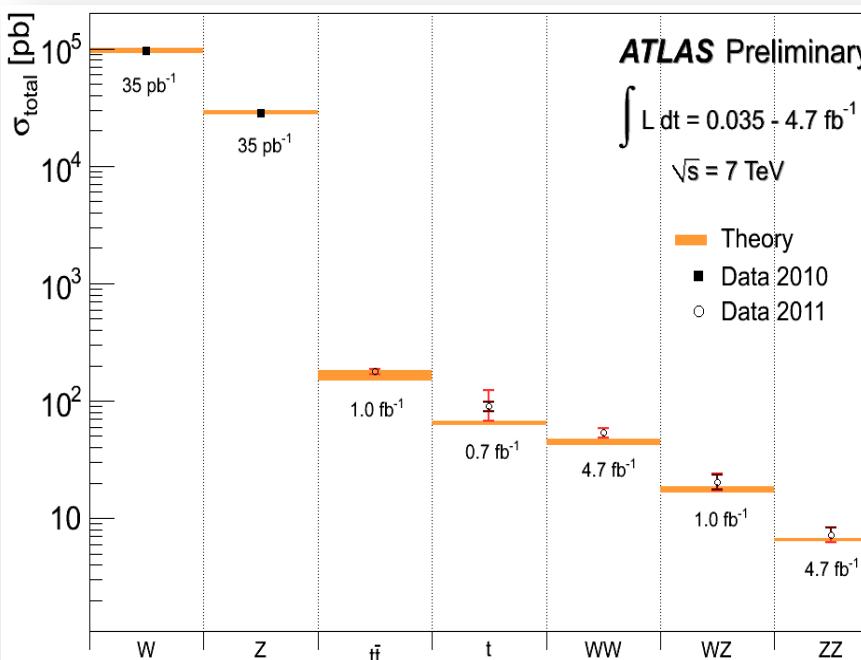
Cross-check: 44660 events

ATLAS-CONF-2012-024



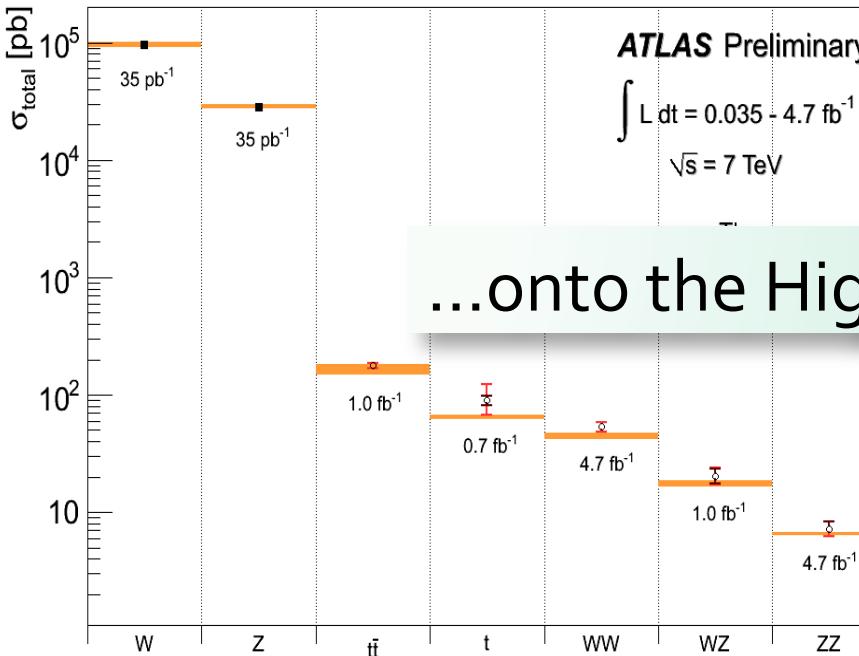
CMS-TOP-11-024

SM Cross Section Measurements

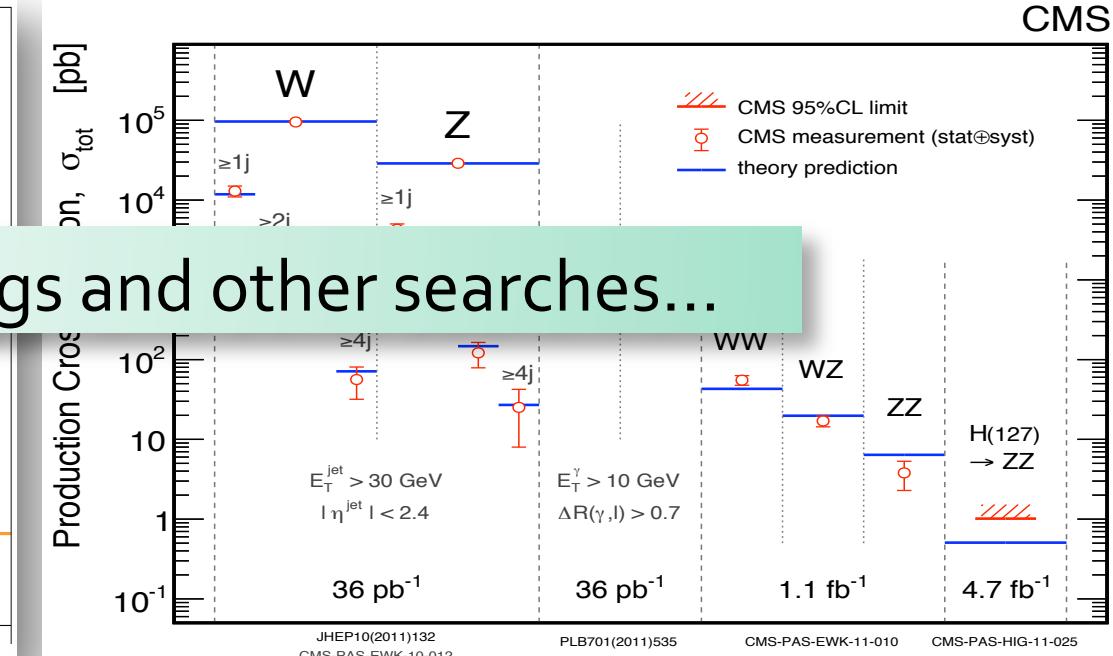


- As $\int L dt$ grows and more rare processes become accessible
 - use them to confirm our understanding of the SM
 - to validate detector/physics simulation, objects reconstruction, event selections and analysis techniques

SM Cross Section Measurements

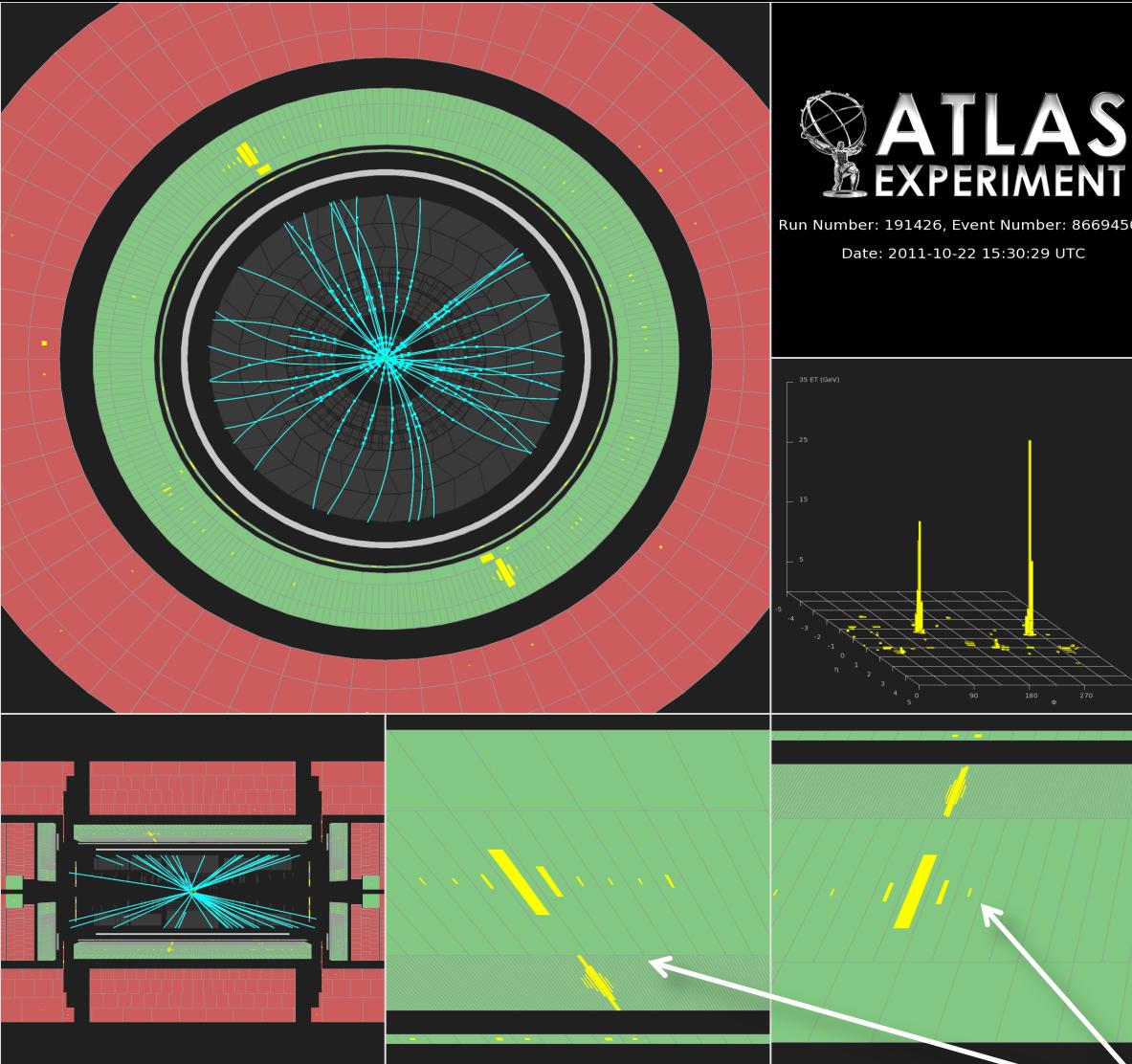


...onto the Higgs and other searches...

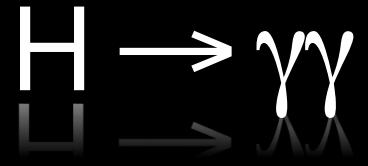


- As $\int L dt$ grows and more rare processes become accessible
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Higgs Searches



$\sigma \sim 40 \text{ fb}$

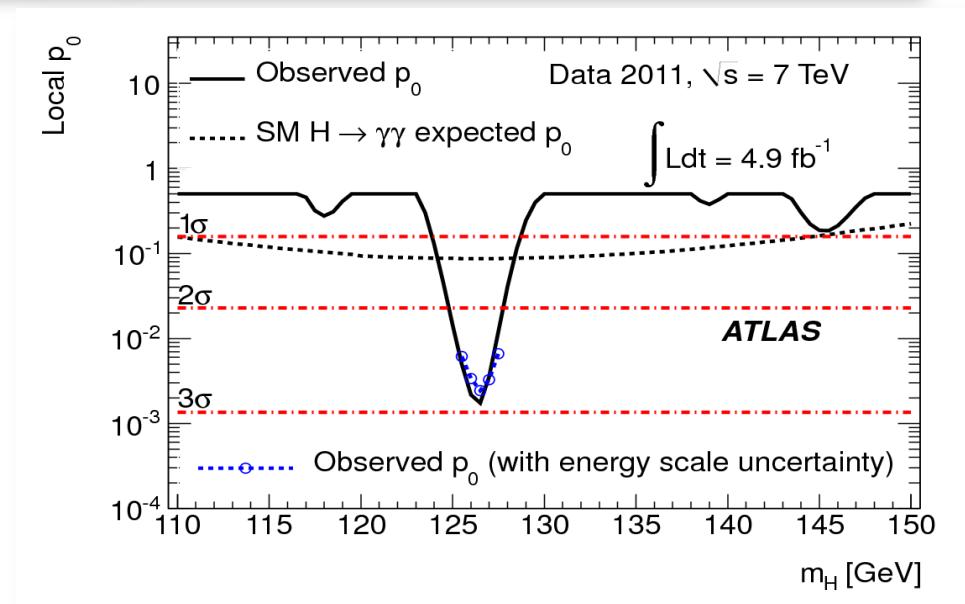
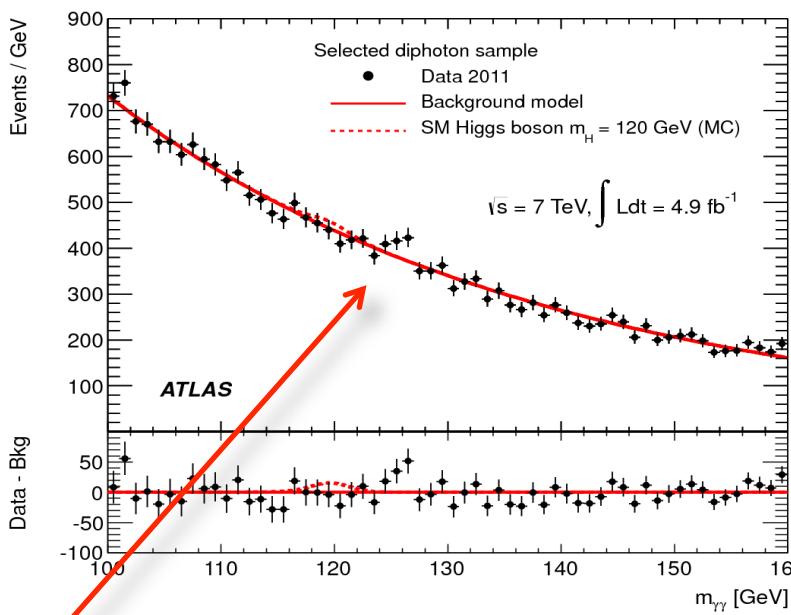


- The challenges
 - Very large backgrounds
 - Two real and/or fake γ 's
 - Real γ 's radiated off quarks
 - Neutral pion decaying to collimated pair of γ 's
 - Look for small excess at one mass from $H \rightarrow \gamma\gamma$
 - Need excellent γ energy resolution
 - You have to know the point of decay of the Higgs to about 1 cm.

ATLAS uses several ECAL layers to point back

Fit observed $\gamma\gamma$ mass distribution with signal + background model:

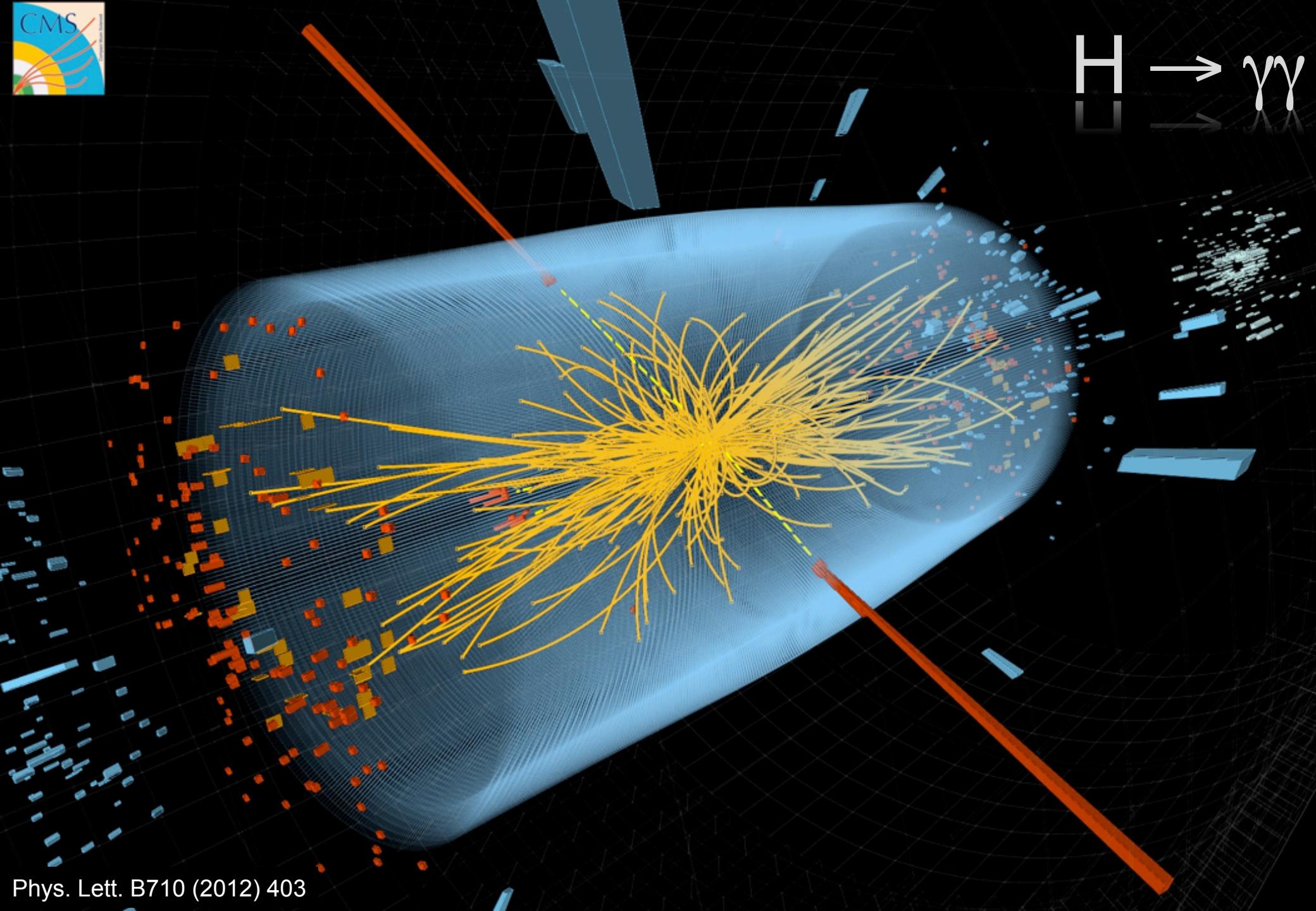
- Exponential spectrum for background;
- Crystal-ball function to describe the signal



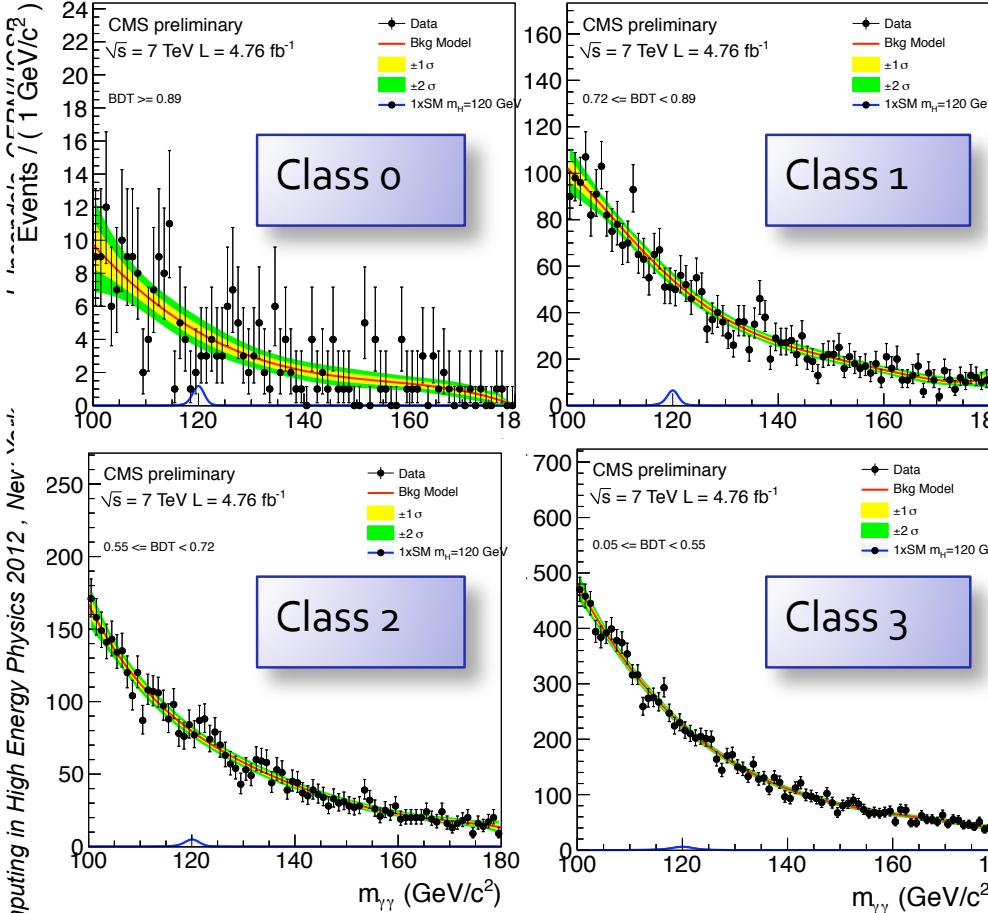
! Observed exclusion:
113-115 GeV
134.5-136 GeV

Phys. Rev. Lett. 108, 111803 (2012)

Excess at 126.5 GeV with a significance of
2.8 σ – local
1.5 σ – global (110-150 GeV)

$H \rightarrow \gamma\gamma$ 

CMS Update 2: $H \rightarrow \gamma\gamma$ with MVA

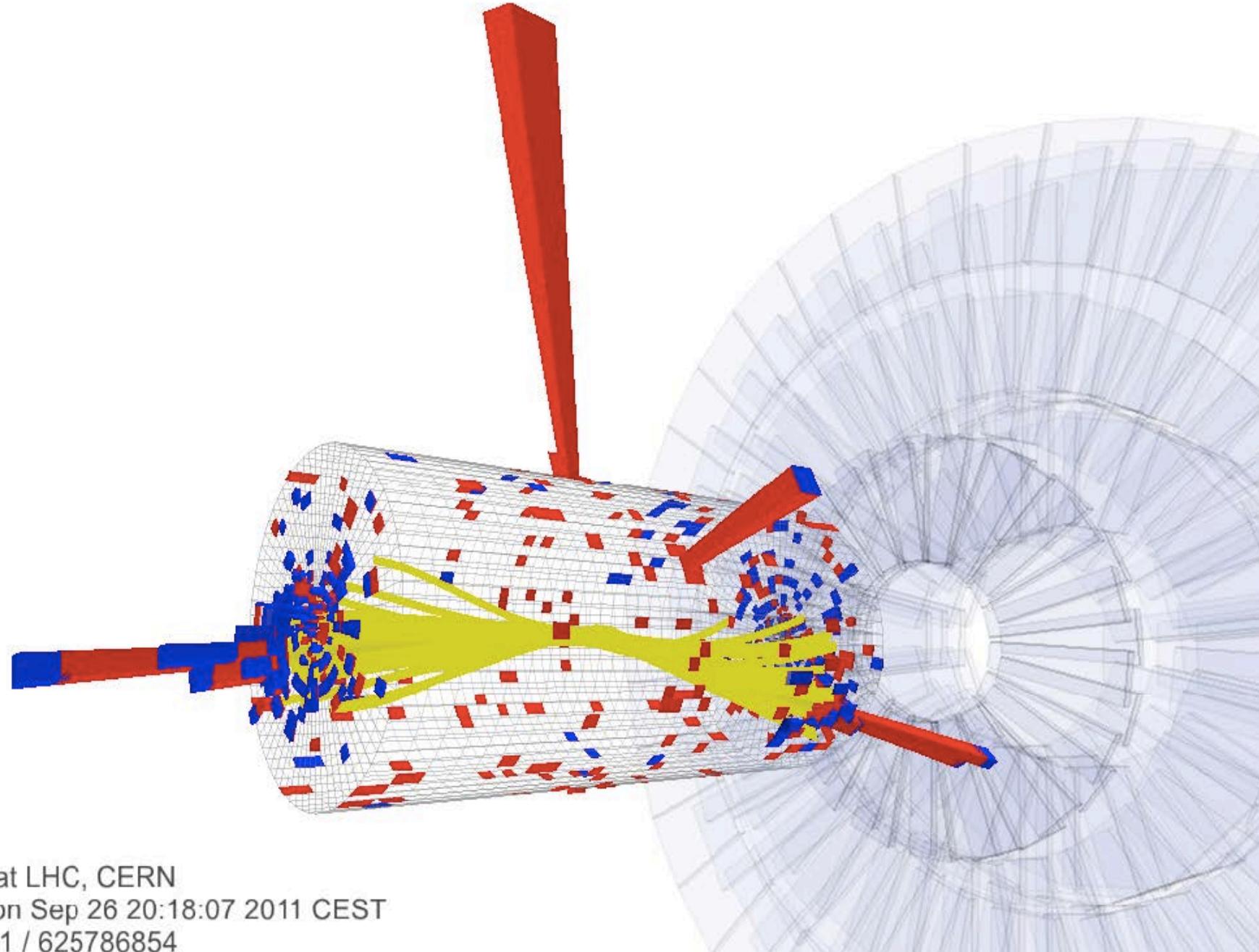
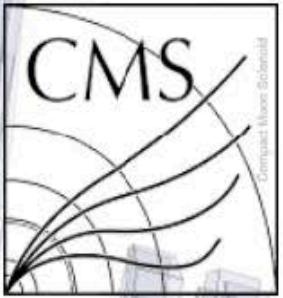


- Train MVA on Monte Carlo
 - Use variables independent of M_H
 - Categorize on MVA output
 - 4 classes: MVA cut values optimized against expected limit using MC background
 - 5th VBF Dijet class (loose cut MVA)
- Results

- Best class (class 0)
 - Almost exclusively $p_{\gamma\gamma}^{\text{T}} > 40 \text{ GeV}$
- Second best class (class 1)
 - Predominantly unconverted γ 's

	0	1	2	3	Dijet tag
SM signal expected	3.4 (4.4%)	19.3 (25.0%)	18.7 (24.2%)	33.0 (42.8%)	2.8 (3.6%)
Data (events/GeV)	4.5 (1.2%)	55.1 (14.8%)	81.3 (21.8%)	229.1 (61.6%)	2.1 (0.6%)
σ_{eff} (GeV)	1.18	1.25	1.64	2.47	1.65
FWHM/2.35 (GeV)	1.09	1.09	1.43	2.08	1.32

Events/GeV = no. of events in a bin of $\pm 10 \text{ GeV}$, centered at 120 GeV , divided by 20 GeV .
Resolutions: 120 GeV Higgs



CMS Experiment at LHC, CERN

Data recorded: Mon Sep 26 20:18:07 2011 CEST

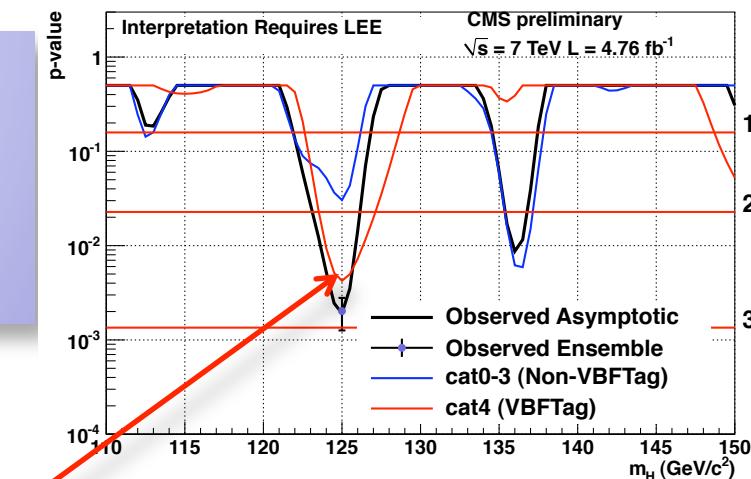
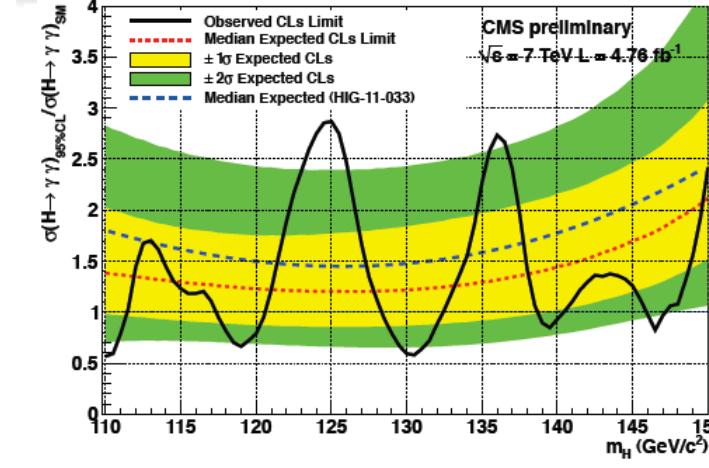
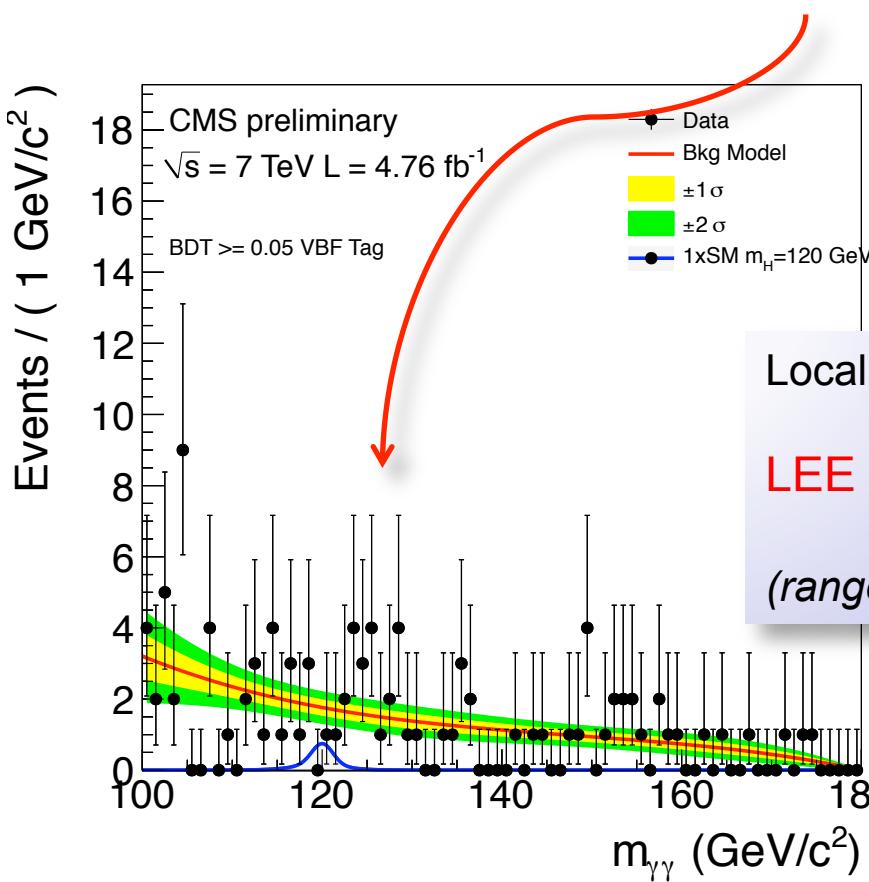
Run/Event: 177201 / 625786854

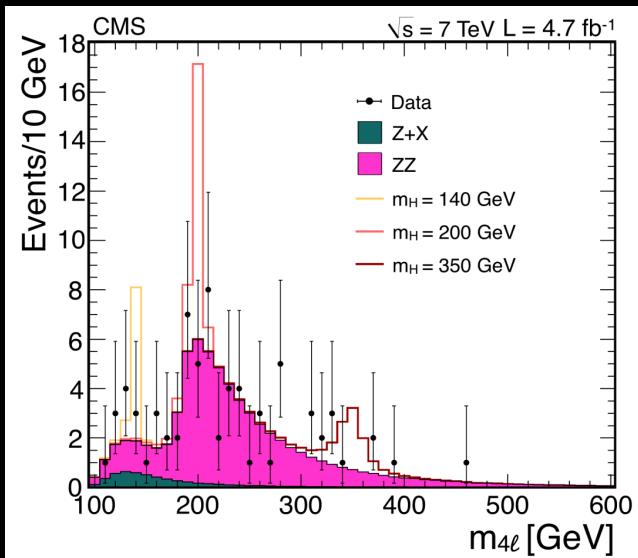
Lumi section: 450

See talks by R. Yoshida, W. Quayle

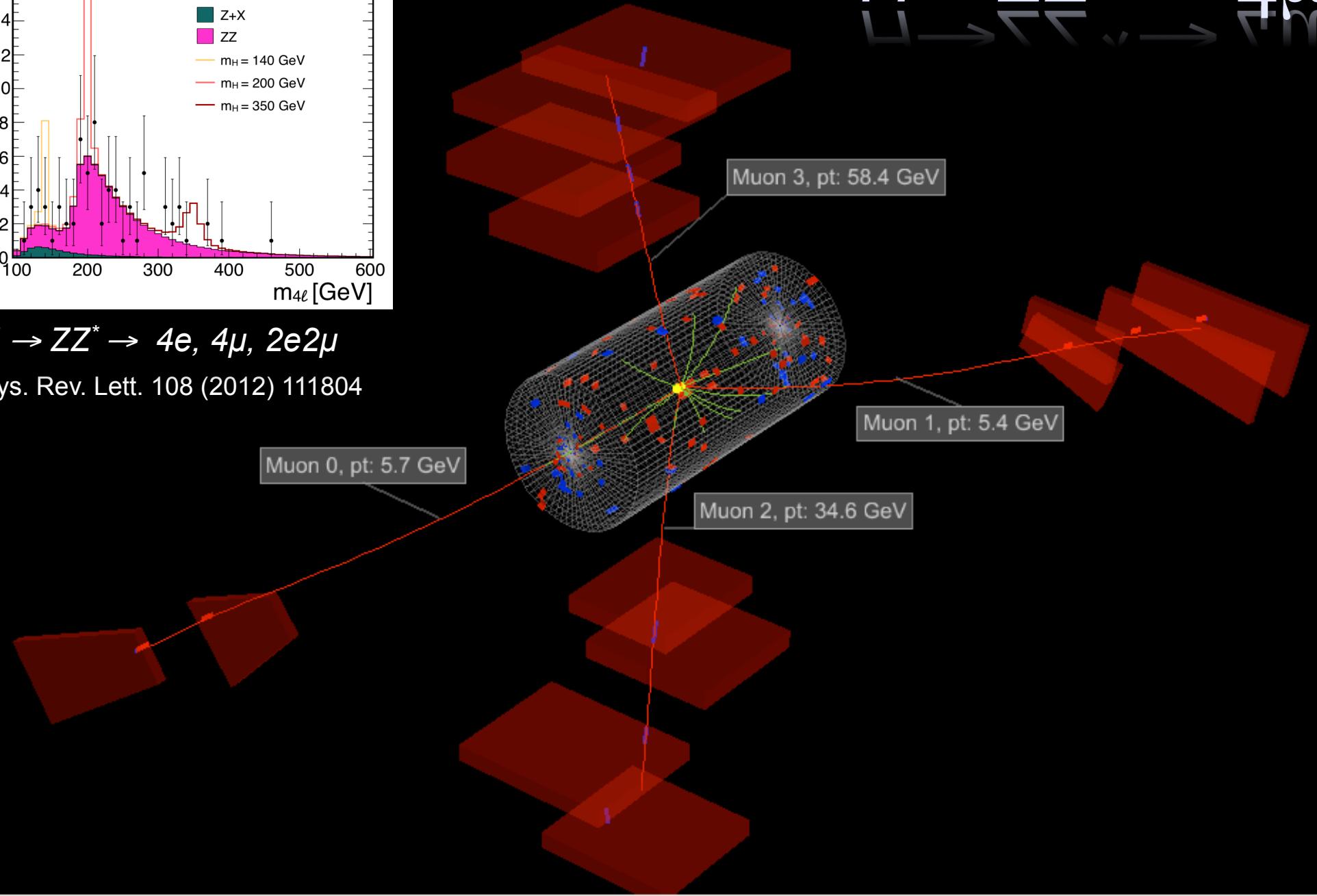
CMS Update 2: $H \rightarrow \gamma\gamma$ using MVA

- MVA's for vertex ID, γ and $\gamma\gamma$ ID
- VBF again split off separately
 - Dominates in vicinity of 124-125 GeV**




 $H \rightarrow ZZ^* \rightarrow 4\mu$
 $H \rightarrow ZZ^* \rightarrow 4e, 4\mu, 2e2\mu$

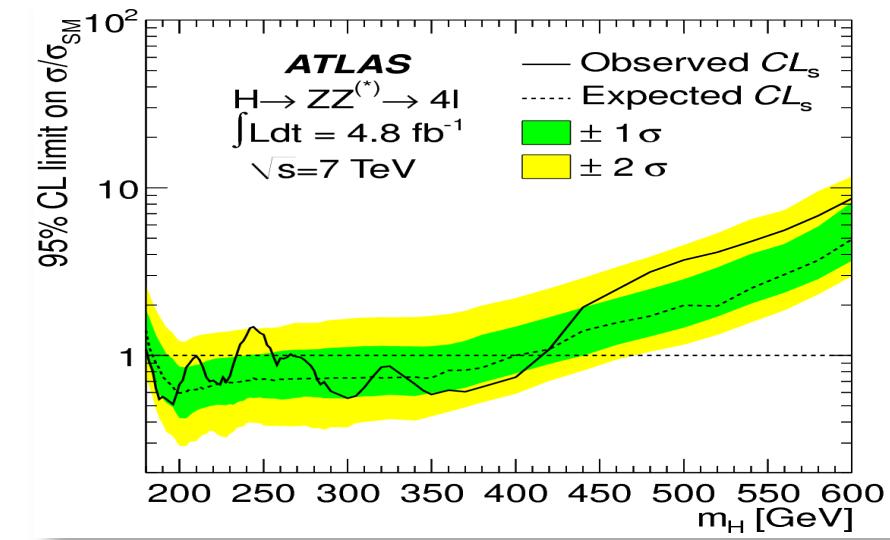
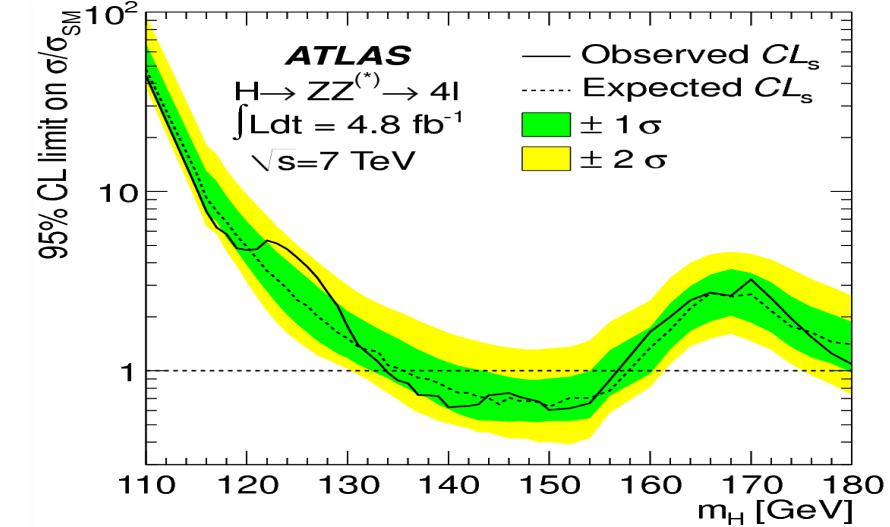
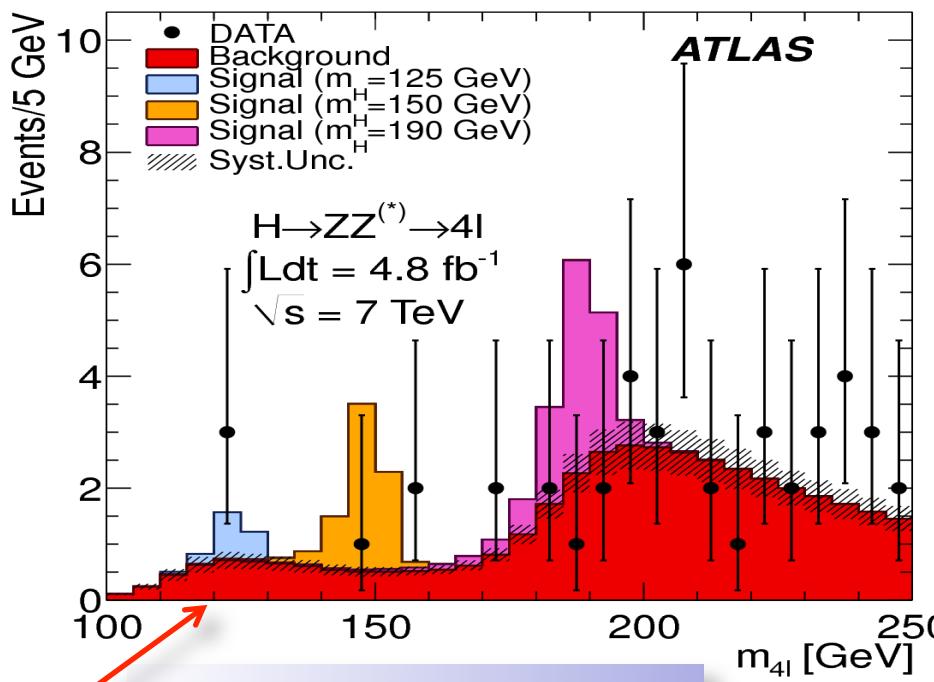
Phys. Rev. Lett. 108 (2012) 111804

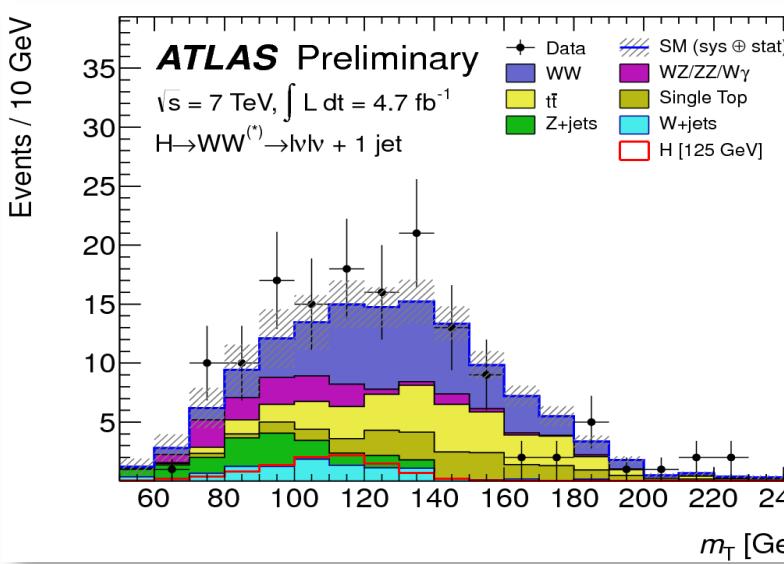
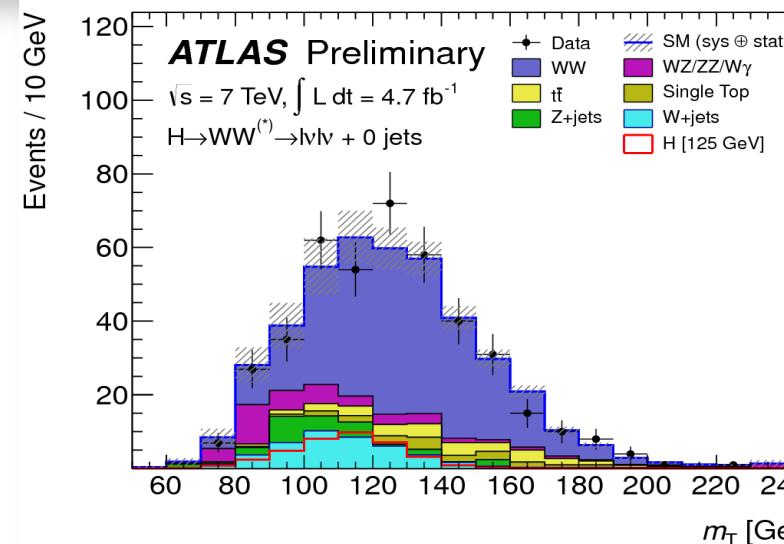


ATLAS: $H \rightarrow ZZ \rightarrow 4l \rightarrow 4e, 4\mu, 2e2\mu$

Event yield (full search range)

	4e	2e2 μ	4 μ
Background	13.4 ± 2.0	29.7 ± 4.5	18.6 ± 2.8
Signal (130 GeV)	0.43 ± 0.08	1.22 ± 0.21	1.00 ± 0.17
Data	17	30	24

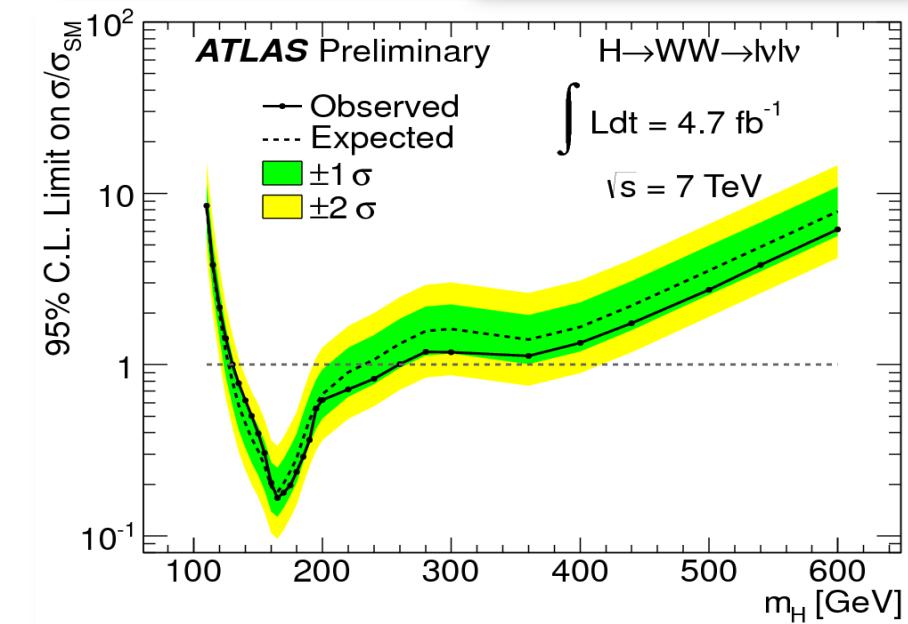




ATLAS: $H \rightarrow WW \rightarrow l\bar{l}l\bar{l}$

Fit the transverse mass distribution
to improve the sensitivity

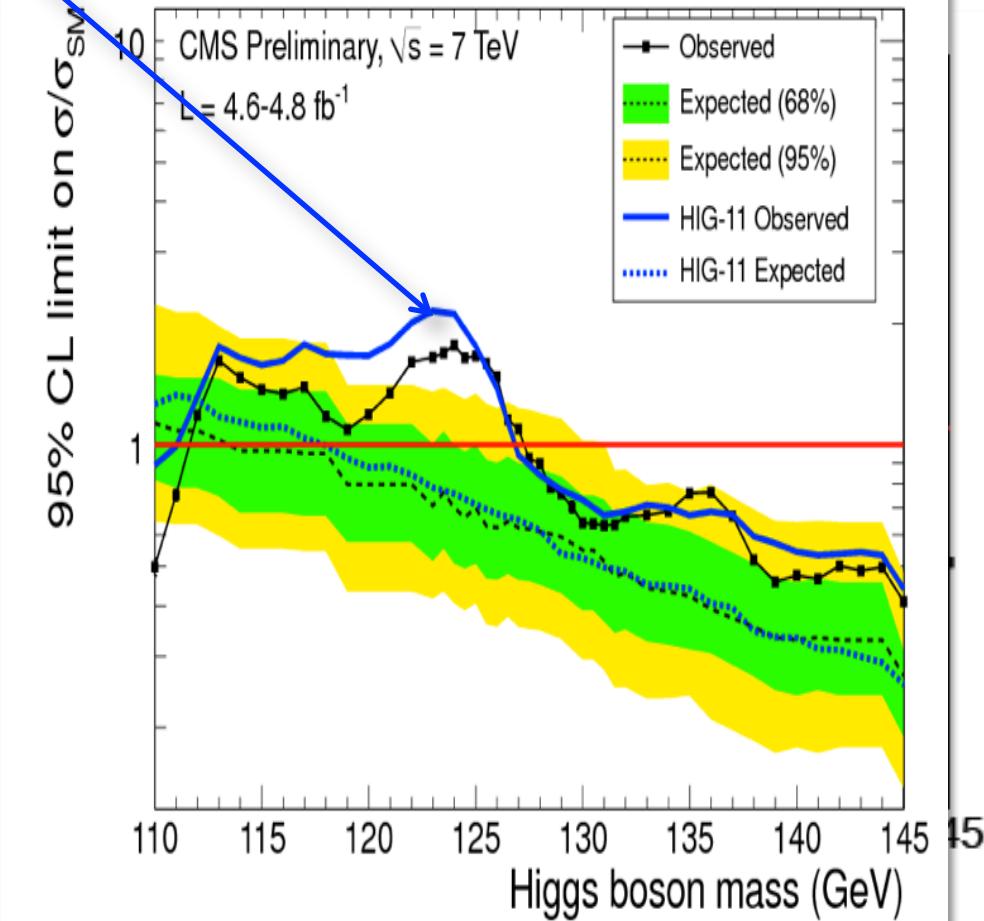
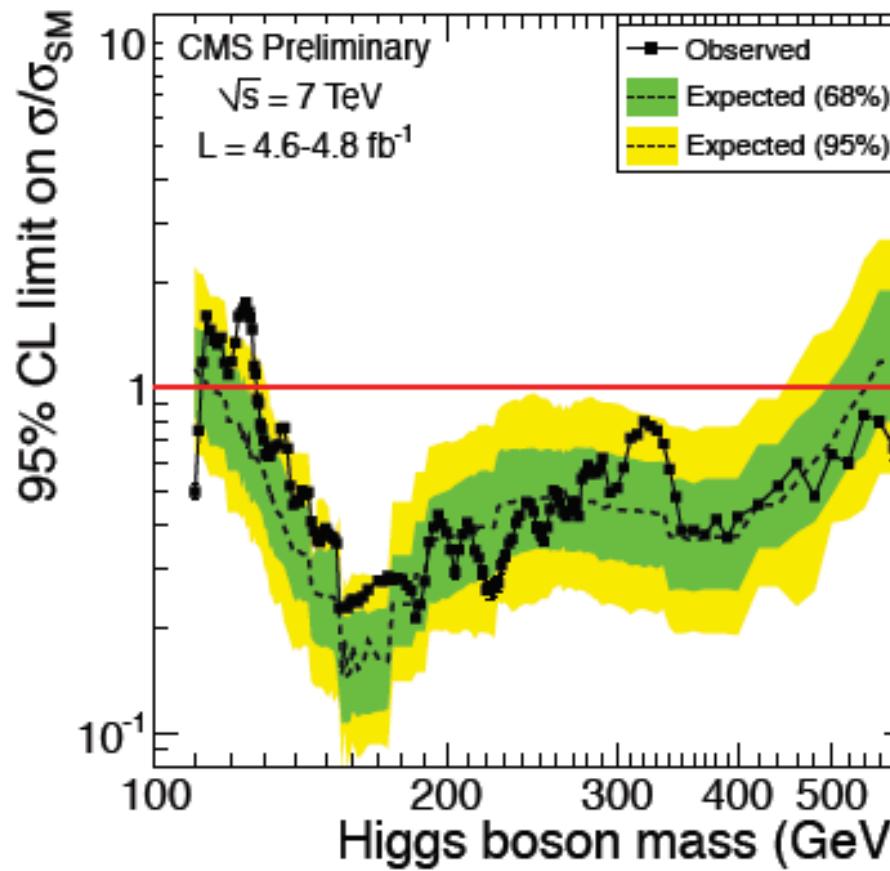
[ATLAS-CONF-2012-012](#)



Observed Exclusion: 130-260 GeV
 (expected: 127-234 GeV)

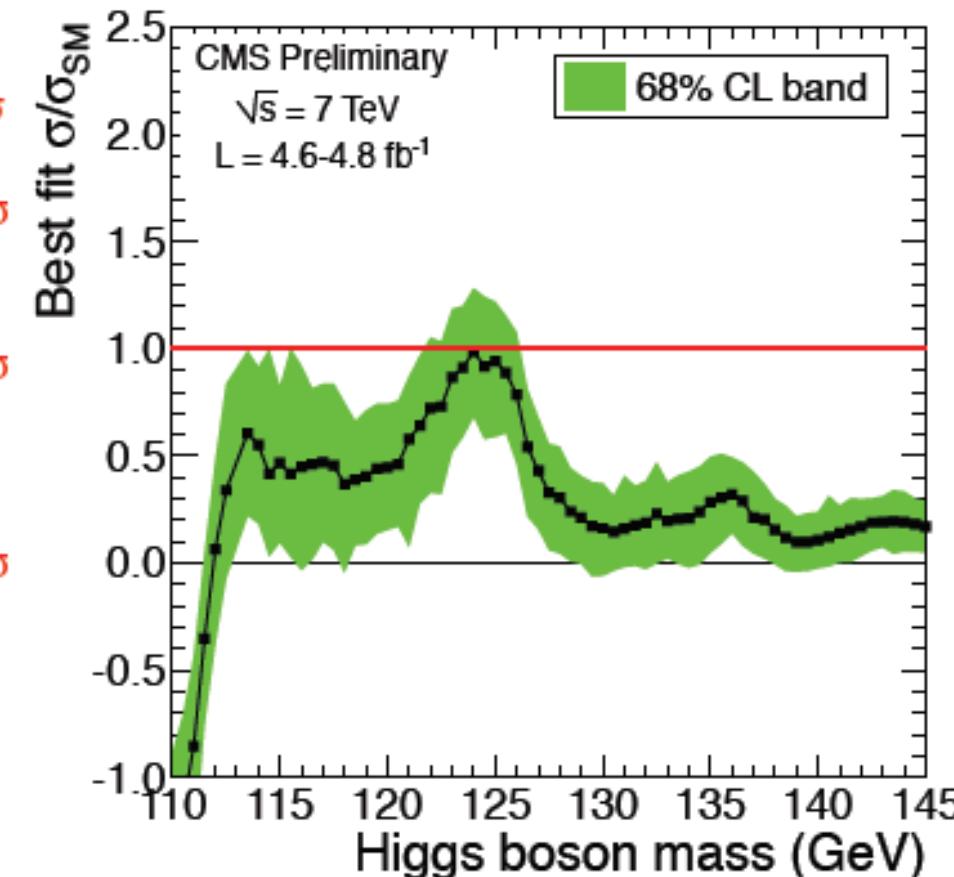
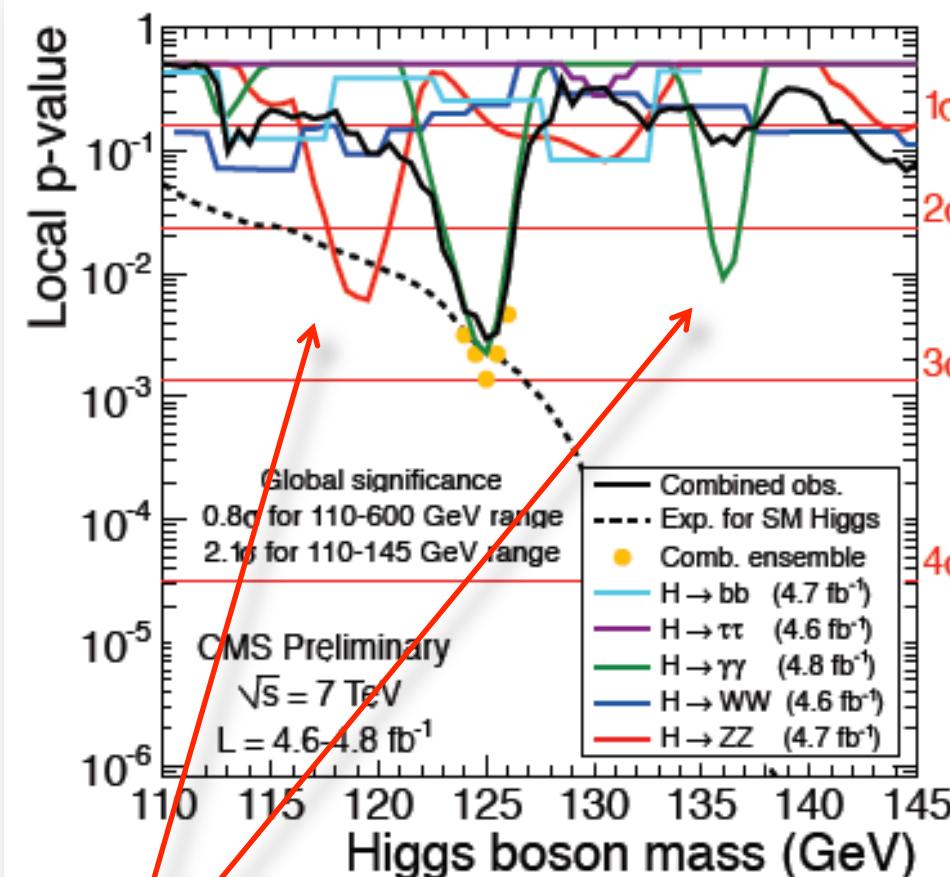
Published

CMS Combination



Expected exclusion 114.5 - 543 GeV
 Observed exclusion 127.5 - 600 GeV

CMS Combination: p-vals, SM consistency

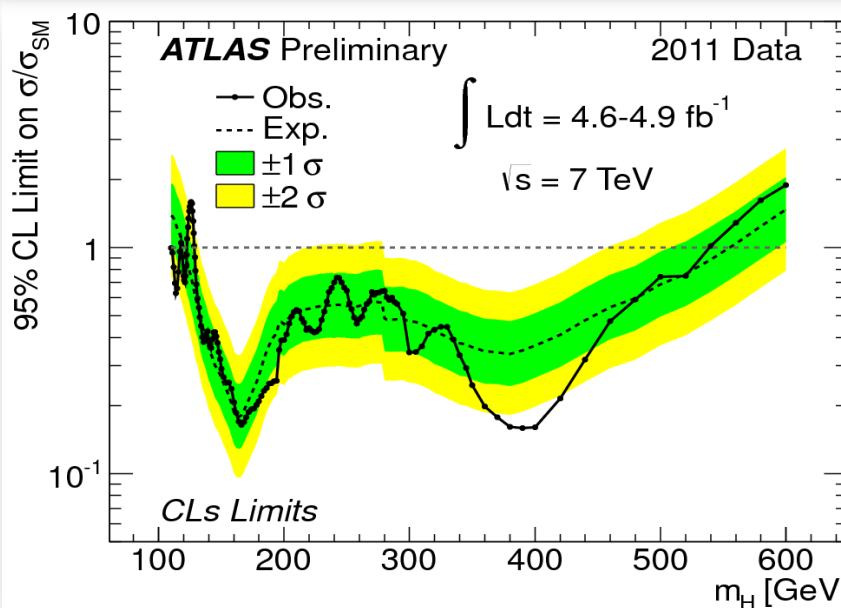


Local p-value 2.8σ
Global p value 0.8σ (110-600 GeV)
Global p-value 2.1σ (110-145 GeV)

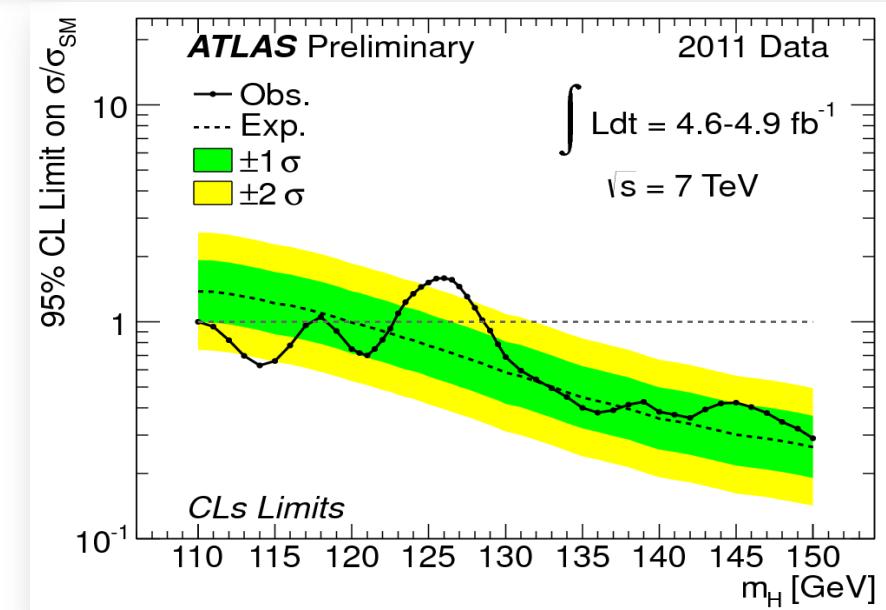
Exclusion info

95% CL: 110-117.5, 118.5-122.5, 129-539 Obs)

95% CL: 120-555 GeV (Exp)

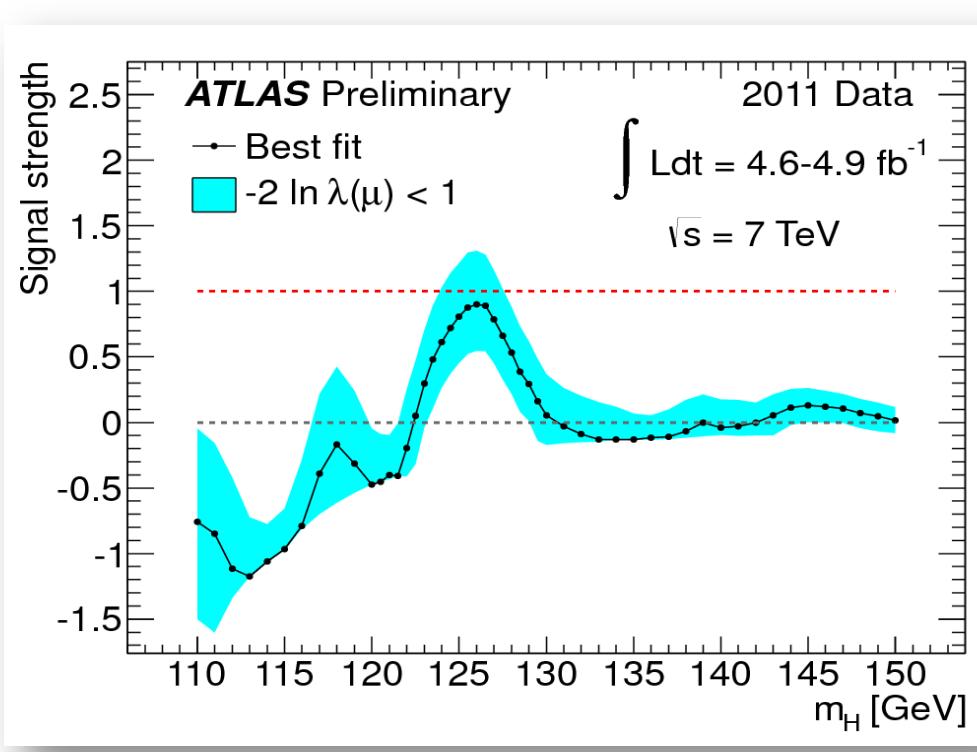


Excluded at 99% CL:
130-486 GeV (Obs)

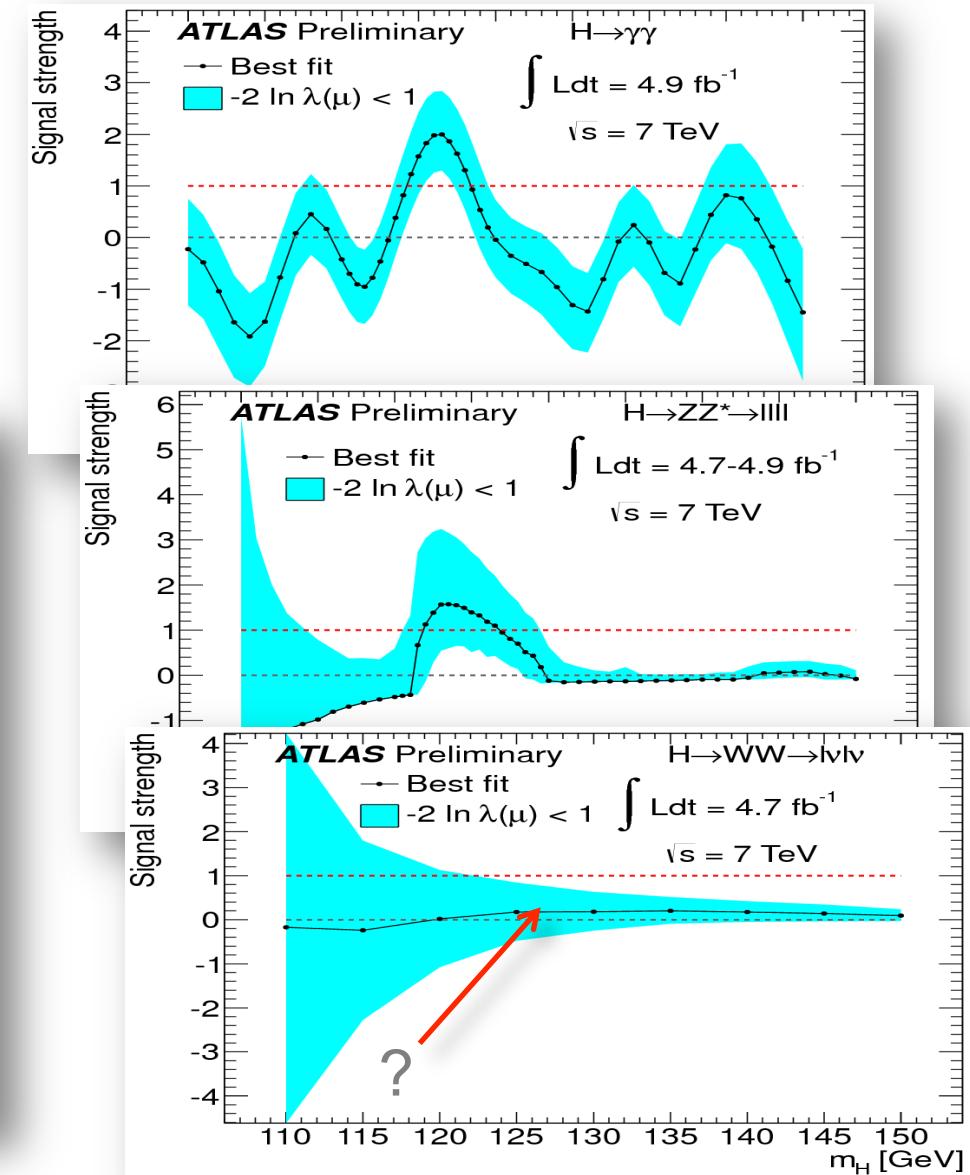


Not excluded:
117.5-118.5, 122.5-129,>539 GeV

The combined signal rate is consistent with the Standard Model expectation of a 126 GeV Higgs boson.



ATLAS 'Signal' Strength

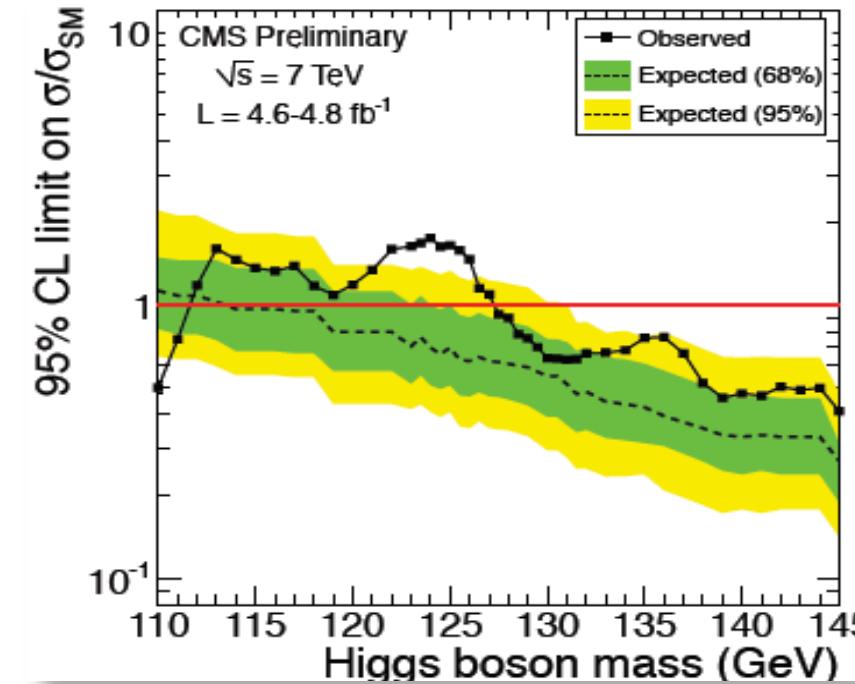
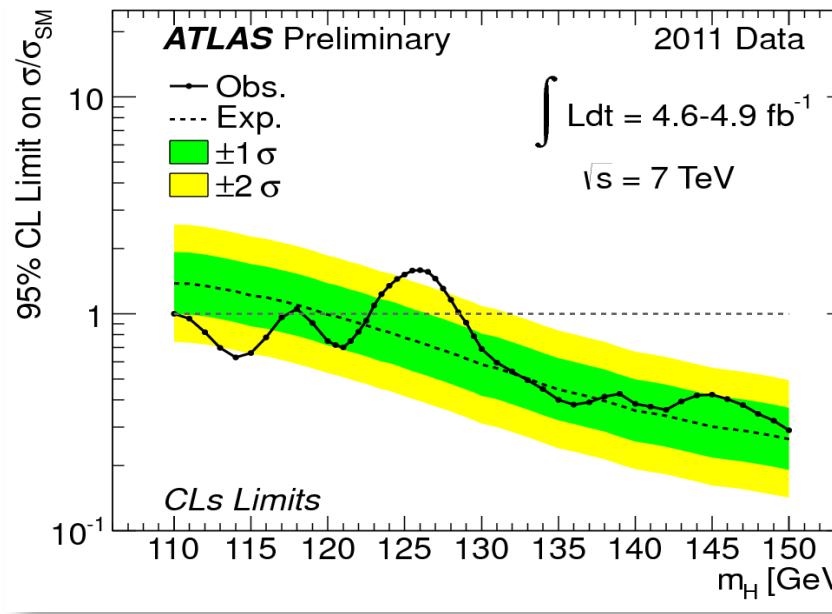


Overview of the 125 GeV region

- Results are not so consistent
 - Tevatron
 - $b\bar{b}$: CDF yes, DØ no
 - WW: CDF no, DØ yes
 - LHC
 - $gg \rightarrow H \rightarrow \gamma\gamma$: CMS not much, ATLAS YES
 - $VV \rightarrow H \rightarrow \gamma\gamma + 2 \text{ jets}$: CMS yes, ATLAS not much
 - $ZZ^{(*)}$: ATLAS YES, CMS yes
 - $WW^{(*)}$: ATLAS no, CMS a bit
- Or perhaps this is how the Higgs discovery begins
 - First sightings are lucky upward fluctuations...

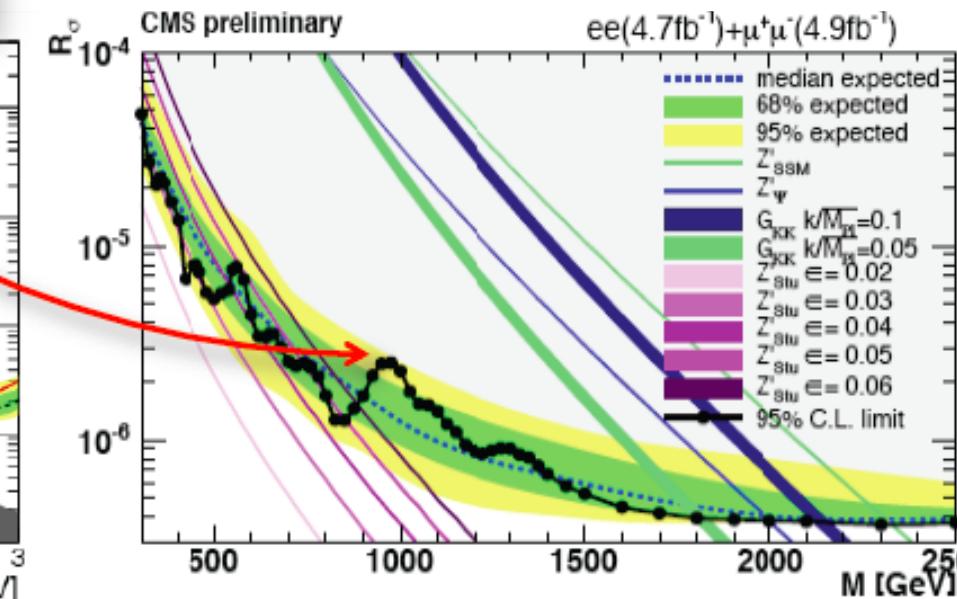
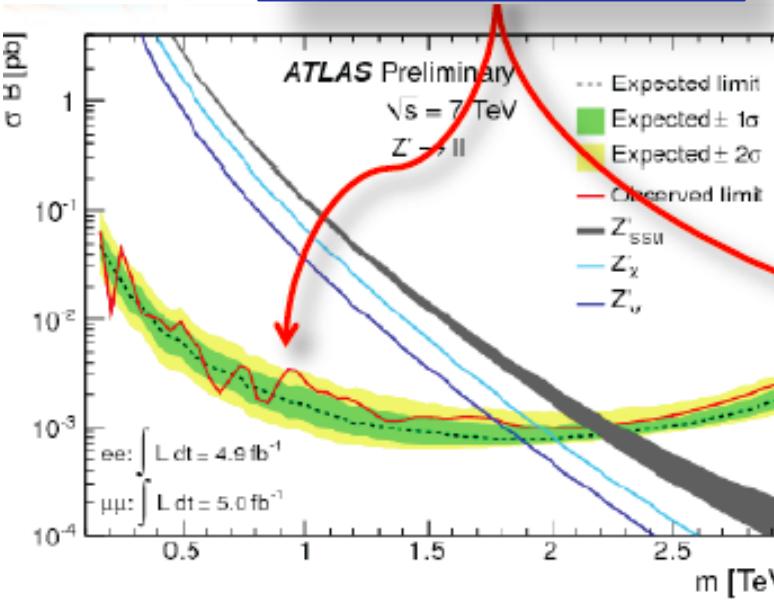
We need data!

- Obviously we need (a lot) more data
 - We're sitting in a very vulnerable position
- Coincidental small excesses at 125 GeV ...
 - We tend to believe something is there because we expect it to be there (given that it's not anywhere else).



- Hopefully we'll also see something in other searches
 - Up to now, it has been surprisingly quiet...

$Z' \rightarrow ll$ search

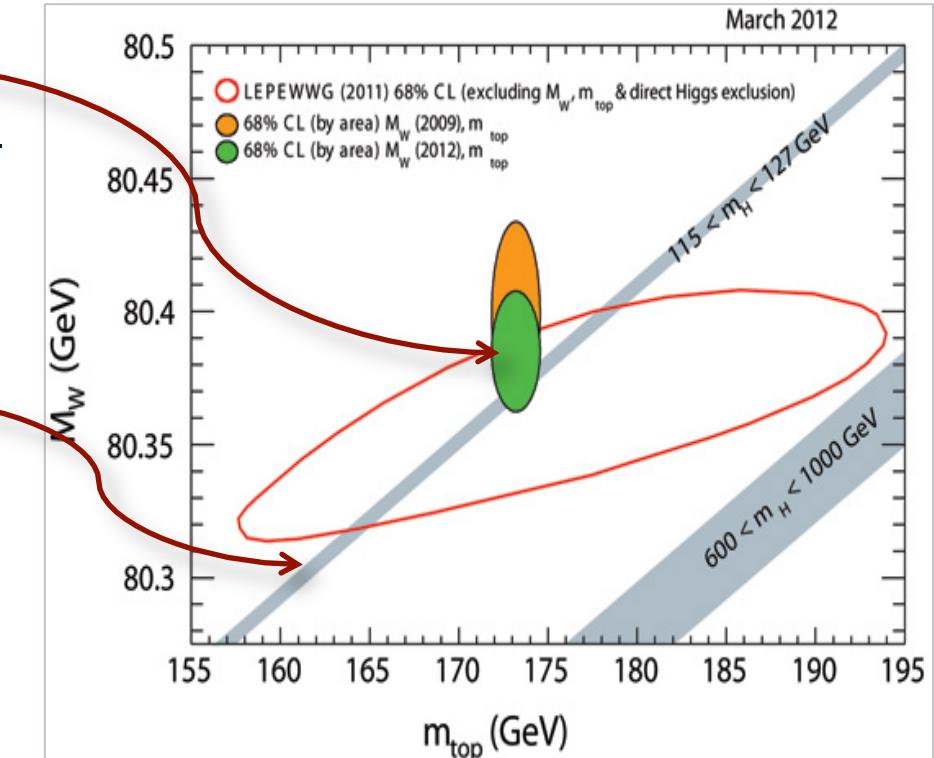
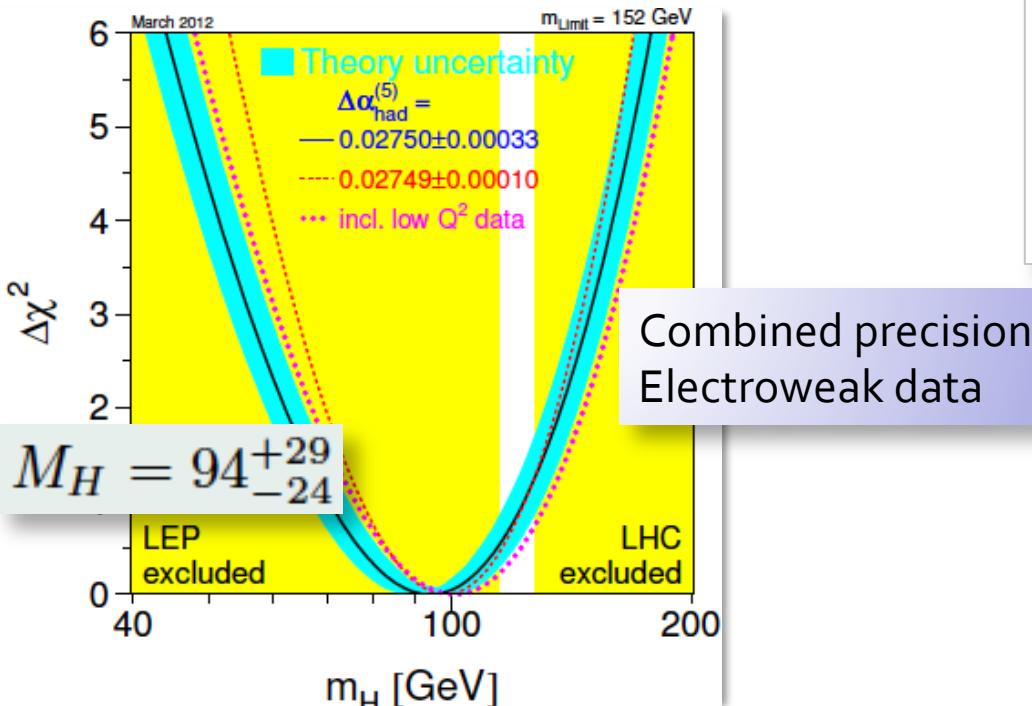


SM Higgs in perspective

1. M_{top} vs. M_W

- Tevatron M_W Tours de Force!!
- $m_W = 80385 \pm 15$ MeV (World Ave – Mar 2012)
- Shifts for SM Higgs expectation

2. Colliders leave little space

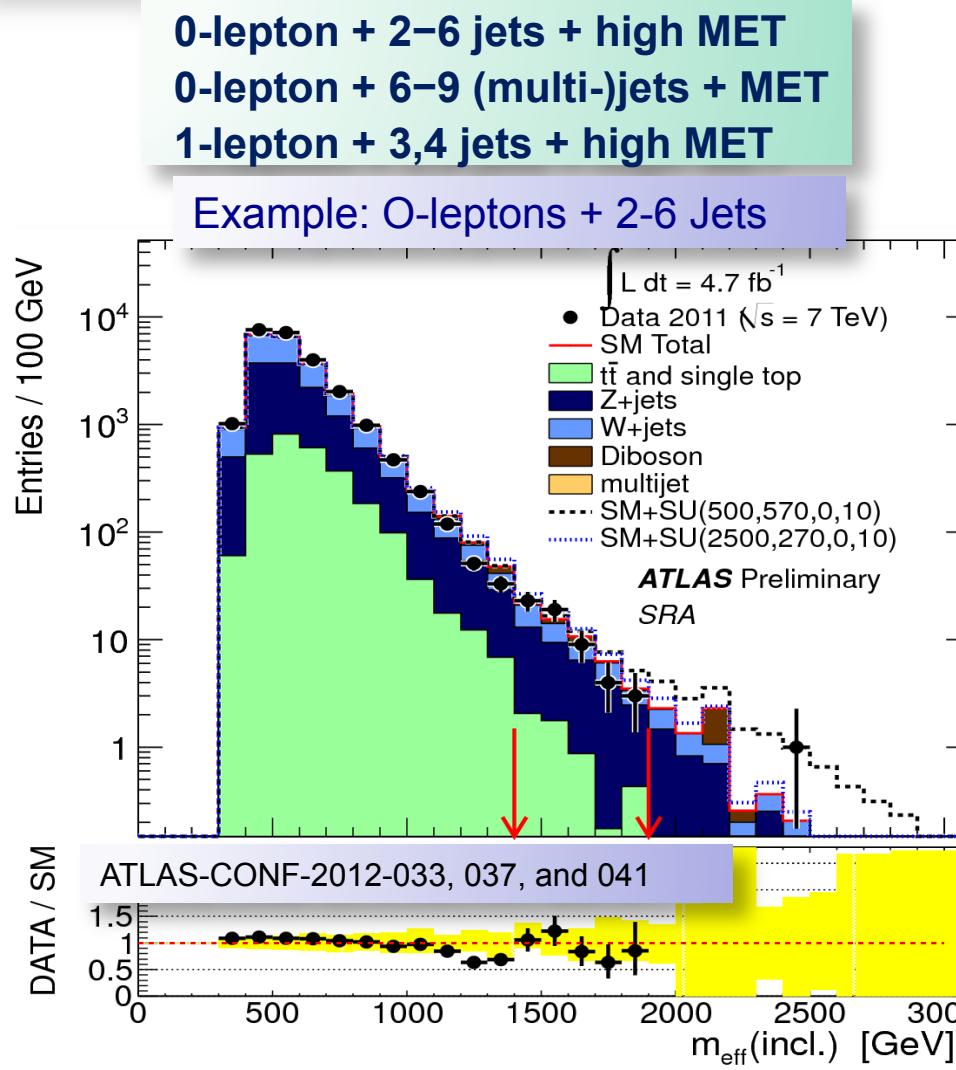


This is the main story of the past year

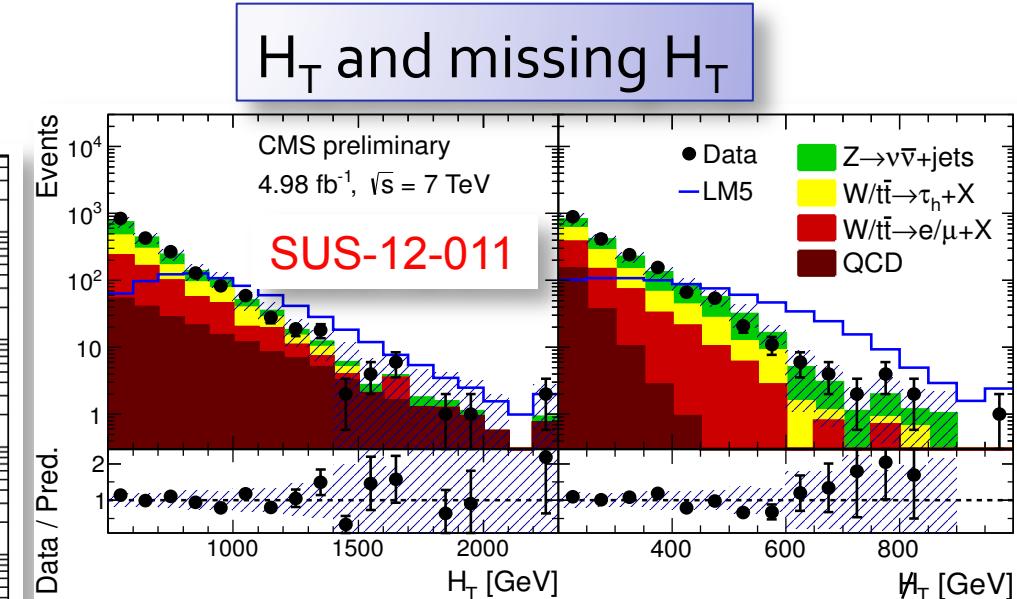
We eliminated >450 GeV of the mass range.

Supersymmetry





Signal region



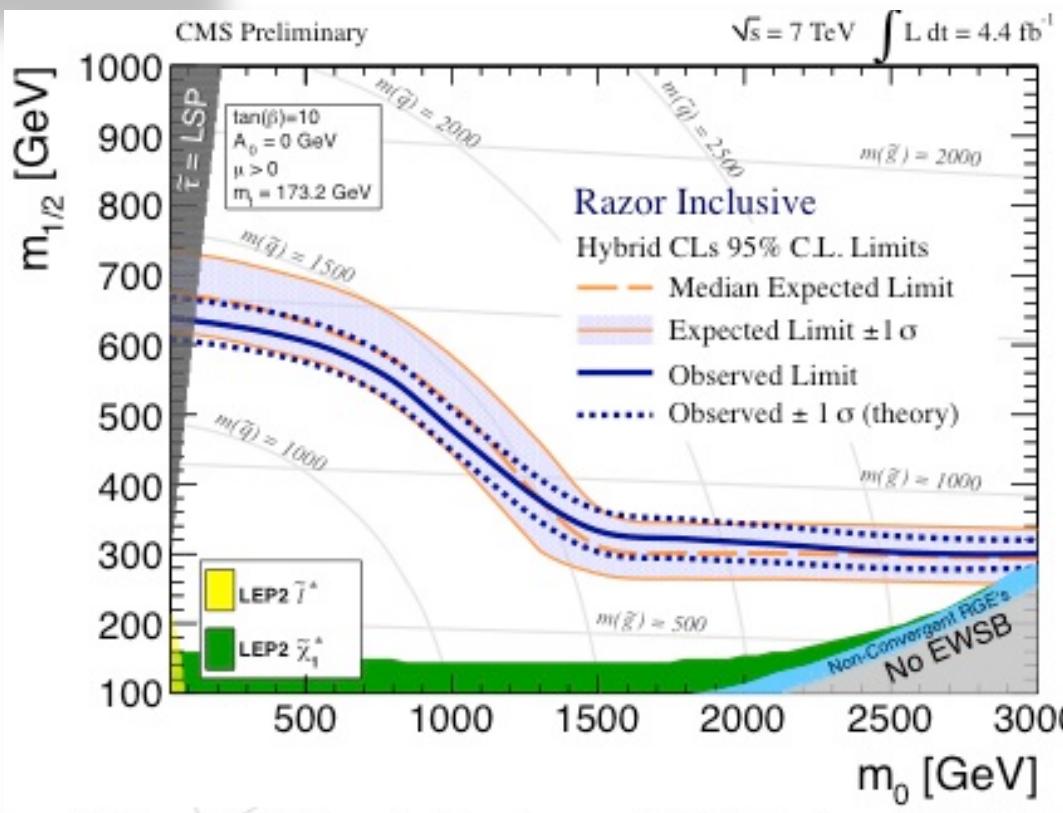
Many all hadronic searches

- with and without b-tags.

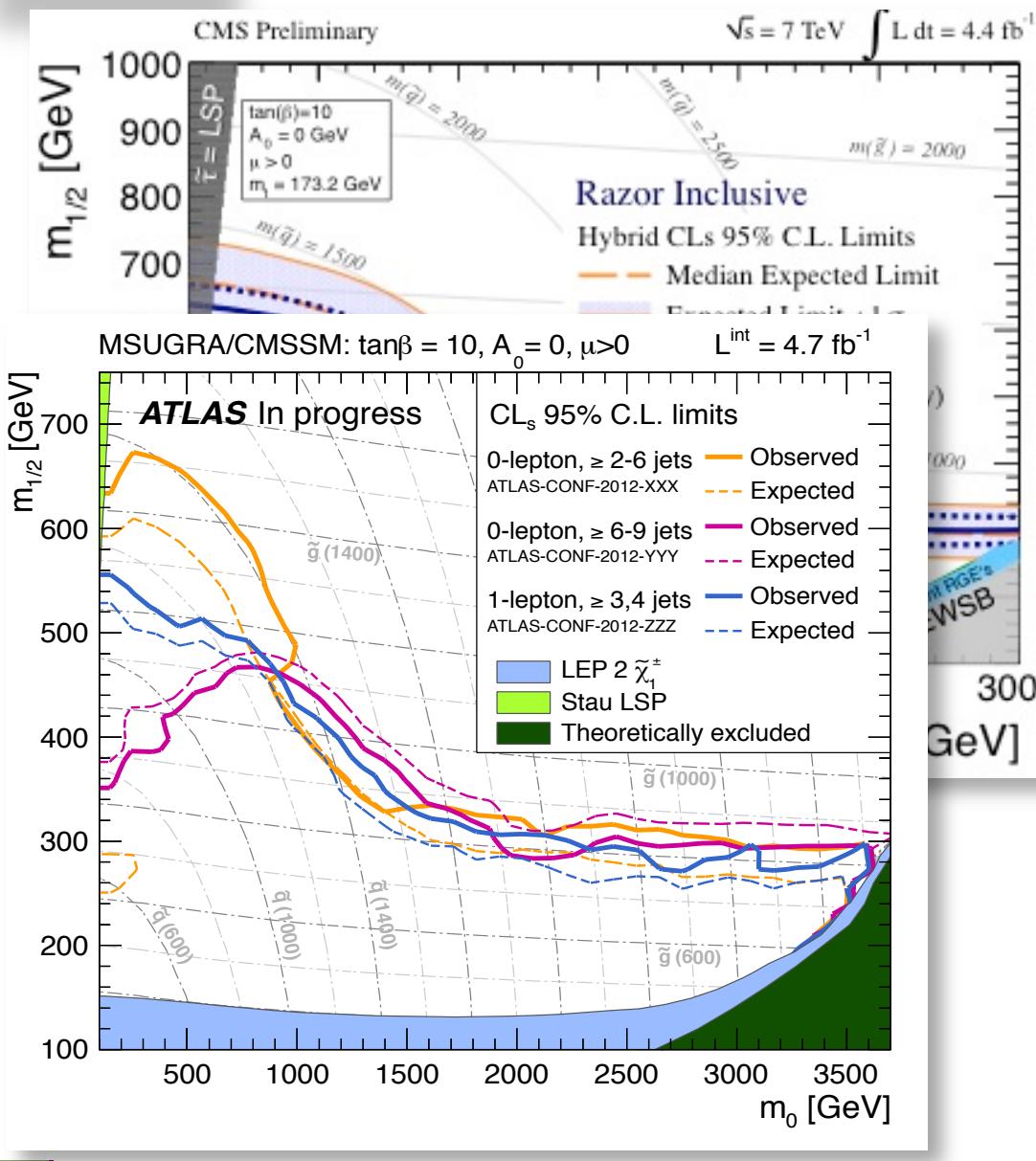
Also searches completed with

- 1, 2, ≥ 3 leptons
- 1 and 2 photons

SUSY getting squeezed



- Simple SUSY models are under pressure
 - e.g. mSUGRA: $\tan\beta=10$, $A_0=0$, $\mu>0$
 - Limits ~ 1400 GeV for squarks and gluinos
- But SUSY is not dead
 - A Higgs discovery will mark the true start of the hierarchy problem
 - A 115-130 GeV Higgs is “tailor made” for SUSY
- “Natural” SUSY models are still plentiful
 - More complicated (and interesting)
 - More difficult searches for which it is hard to even get the data on tape!



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ATLAS SUSY Searches* - 95% CL Lower Limits (Status: March 2012)

Inclusive searches

MSUGRA/CMSSM : 0-lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-033]	1.40 TeV	$\tilde{q} = \tilde{g}$ mass	$\int L dt = (0.03 - 4.7) \text{ fb}^{-1}$
MSUGRA/CMSSM : 1-lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-041]	1.20 TeV	$\tilde{q} = \tilde{g}$ mass	$\sqrt{s} = 7 \text{ TeV}$
MSUGRA/CMSSM : multijets + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-037]	850 GeV	\tilde{g} mass (large m_0)	
Pheno model : 0-lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-033]	1.38 TeV	\tilde{q} mass ($m(\tilde{g}) < 2 \text{ TeV}$, light $\tilde{\chi}_1^0$)	ATLAS
Pheno model : 0-lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-033]	940 GeV	\tilde{g} mass ($m(\tilde{g}) < 2 \text{ TeV}$, light $\tilde{\chi}_1^0$)	Preliminary
Gluino med. $\tilde{\chi}^\pm$ ($\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^\pm$) : 1-lep + j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-041]	900 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 200 \text{ GeV}$, $m(\tilde{\chi}^\pm) = \frac{1}{2}(m(\tilde{\chi}_1^0) + m(\tilde{g}))$)	
GMSB : 2-lep OS _{SF} + $E_{T,\text{miss}}$	$L=1.0 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2011-156]	810 GeV	\tilde{g} mass ($\tan\beta < 35$)	
GMSB : 1-t + j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-005]	920 GeV	\tilde{g} mass ($\tan\beta > 20$)	
GMSB : 2-t + j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-002]	990 GeV	\tilde{g} mass ($\tan\beta > 20$)	
GGM : $\gamma\gamma + E_{T,\text{miss}}$	$L=1.1 \text{ fb}^{-1}$ (2011) [1111.4116]	805 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) > 50 \text{ GeV}$)	
Gluino med. \tilde{b} ($\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$) : 0-lep + b-j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-003]	900 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)	
Gluino med. \tilde{t} ($\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$) : 1-lep + b-j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-003]	710 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 150 \text{ GeV}$)	
Gluino med. \tilde{t} ($\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$) : 2-lep (SS) + j's + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-004]	650 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 210 \text{ GeV}$)	
Gluino med. \tilde{t} ($\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$) : multi-j's + $E_{T,\text{miss}}$	$L=4.7 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-037]	830 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 200 \text{ GeV}$)	
Direct $\tilde{b}\tilde{b}$ ($\tilde{b} \rightarrow b\tilde{\chi}_1^0$) : 2 b-jets + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [1112.3832]	390 GeV	\tilde{b} mass ($m(\tilde{\chi}_1^0) < 60 \text{ GeV}$)	
Direct $\tilde{t}\tilde{t}$ (GMSB) : $Z \rightarrow ll$ + b-jet + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-036]	310 GeV	\tilde{t} mass ($115 < m(\tilde{\chi}_1^0) < 230 \text{ GeV}$)	
Direct gaugino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow 3l\tilde{\chi}_1^0$) : 2-lep SS + $E_{T,\text{miss}}$	$L=1.0 \text{ fb}^{-1}$ (2011) [1110.6189]	170 GeV	$\tilde{\chi}_1^{\pm}$ mass ($(m(\tilde{\chi}_1^0) < 40 \text{ GeV}, \tilde{\chi}_1^0, m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0), m(\tilde{l}, \tilde{v}) = \frac{1}{2}(m(\tilde{\chi}_1^0) + m(\tilde{\chi}_2^0)))$)	
Direct gaugino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow 3l\tilde{\chi}_1^0$) : 3-lep + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-023]	250 GeV	$\tilde{\chi}_1^{\pm}$ mass ($m(\tilde{\chi}_1^0) < 170 \text{ GeV}$, and as above)	
AMSB : long-lived $\tilde{\chi}_1^{\pm}$	$L=4.7 \text{ fb}^{-1}$ (2011) [CF-2012-034]	118 GeV	$\tilde{\chi}_1^{\pm}$ mass ($1 < \tau(\tilde{\chi}_1^{\pm}) < 2 \text{ ns}$, 90 GeV limit in [0.2,90] ns)	
Stable massive particles (SMP) : R-hadrons	$L=34 \text{ pb}^{-1}$ (2010) [1103.1984]	562 GeV	\tilde{g} mass	
SMP : R-hadrons	$L=34 \text{ pb}^{-1}$ (2010) [1103.1984]	294 GeV	\tilde{b} mass	
SMP : R-hadrons	$L=34 \text{ pb}^{-1}$ (2010) [1103.1984]	309 GeV	\tilde{t} mass	
SMP : R-hadrons (Pixel det. only)	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-022]	810 GeV	\tilde{g} mass	
GMSB : stable \tilde{t}	$L=37 \text{ pb}^{-1}$ (2010) [1106.4495]	136 GeV	\tilde{t} mass	
RPV : high-mass $e\mu$	$L=1.1 \text{ fb}^{-1}$ (2011) [1109.3089]	1.32 TeV	\tilde{e}_τ mass ($\lambda'_{311}=0.10, \lambda'_{312}=0.05$)	
Bilinear RPV : 1-lep + j's + $E_{T,\text{miss}}$	$L=1.0 \text{ fb}^{-1}$ (2011) [1109.6606]	760 GeV	$\tilde{q} = \tilde{g}$ mass ($c\tau_{LSP} < 15 \text{ mm}$)	
MSUGRA/CMSSM - BC1 RPV : 4-lepton + $E_{T,\text{miss}}$	$L=2.1 \text{ fb}^{-1}$ (2011) [ATLAS-CONF-2012-035]	1.77 TeV	\tilde{g} mass	
Hypercolour scalar gluons : 4 jets, $m_{ij} \approx m_{kl}$	$L=34 \text{ pb}^{-1}$ (2010) [1110.2693]	185 GeV	s gluon mass (excl: $m_{sg} < 100 \text{ GeV}$, $m_{sg} = 140 \pm 3 \text{ GeV}$)	

Similar tables
for CMS

 10^{-1}
 1
 64
 10

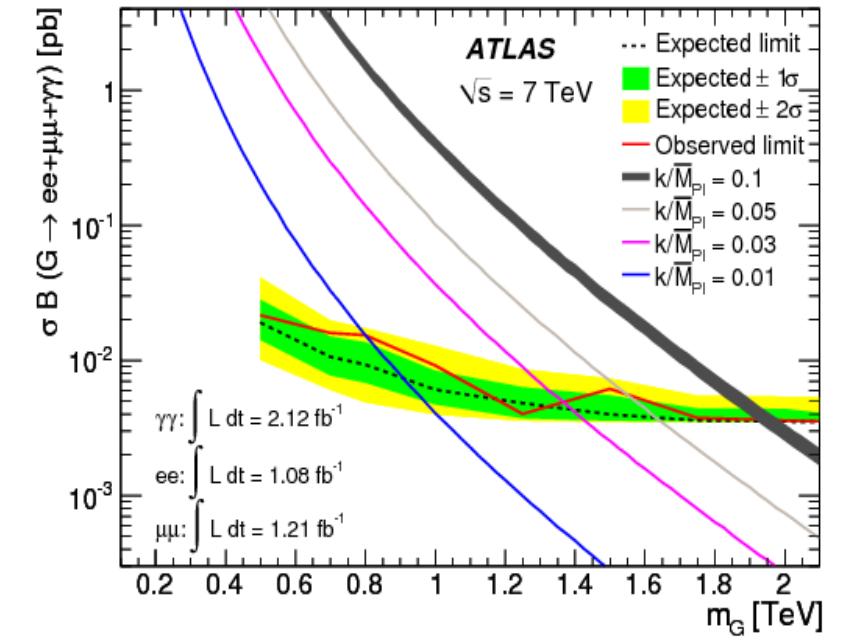
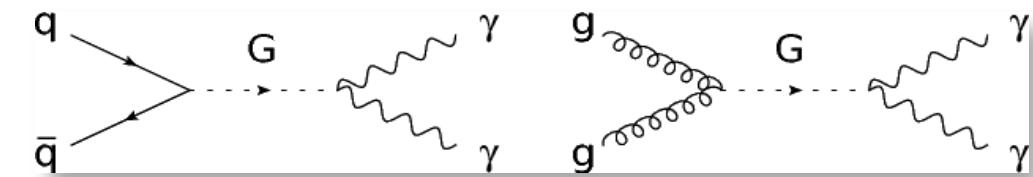
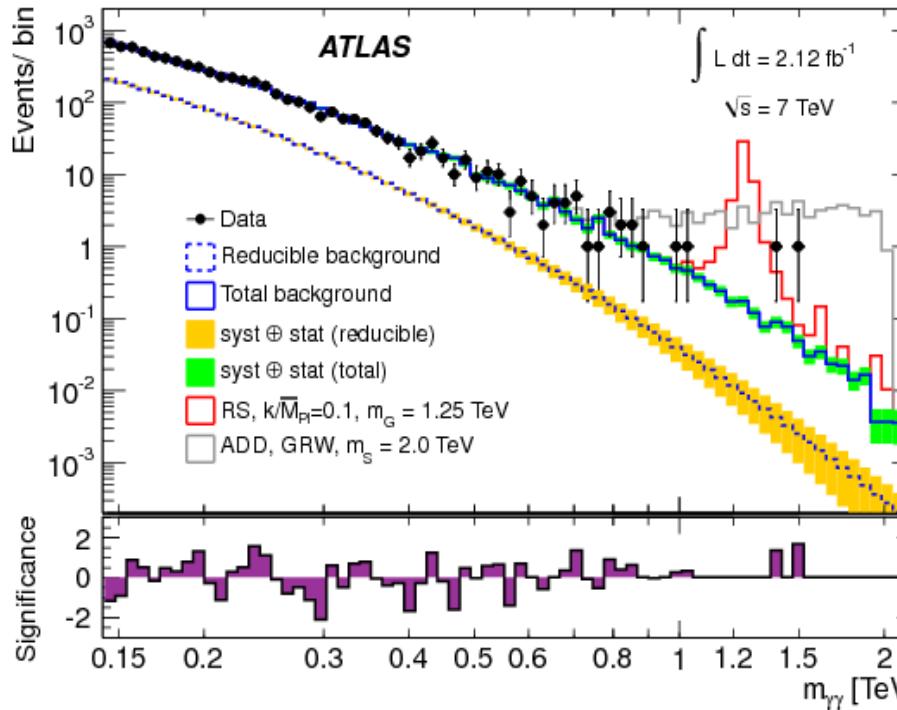
Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena shown

Exotica
EXOTICG

New particles decaying into $\gamma\gamma$

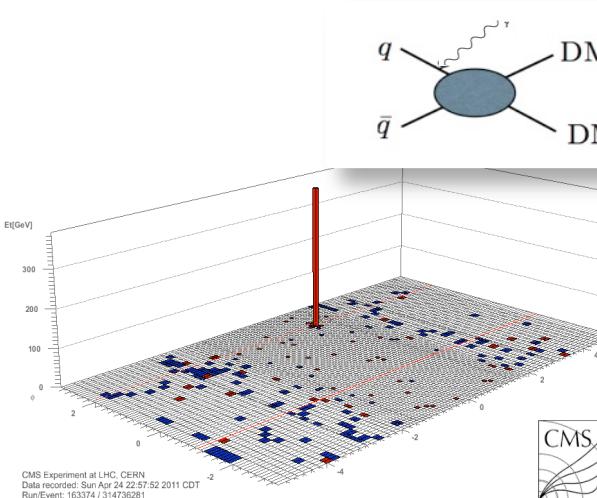
**Search for extra dimension signals:
Kaluza-Klein Gravitons in Randall-Sundrum and Arkani-Hamed, Dimopoulos and Dvali models**



Accepted by Phys. Lett. B
arXiv:1112.2194v1[hep-ex]

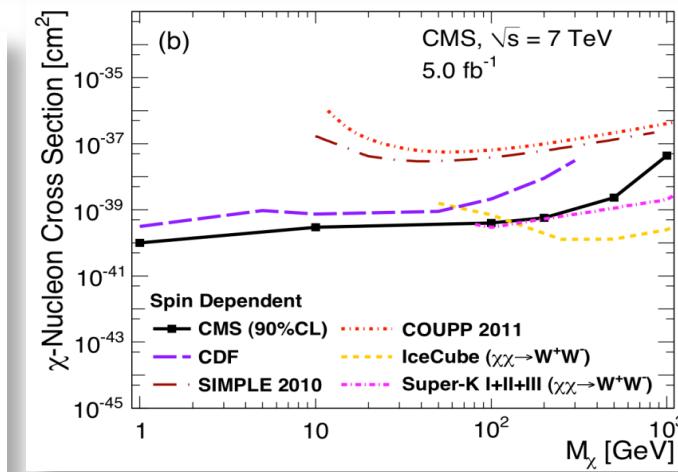
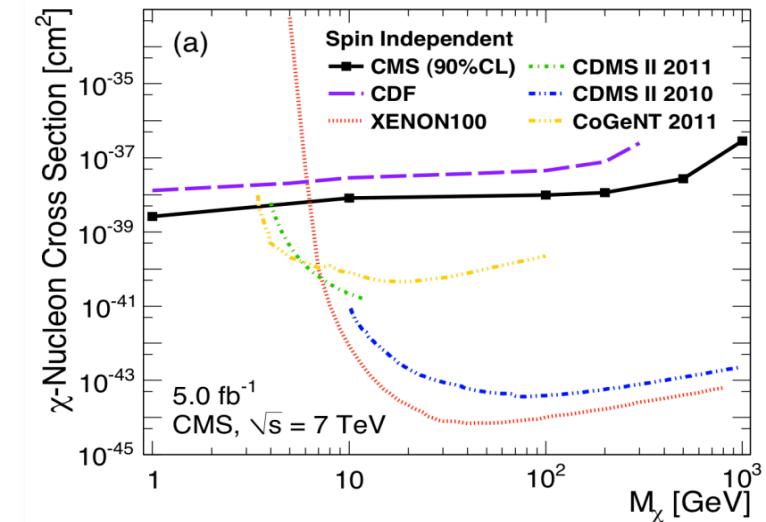
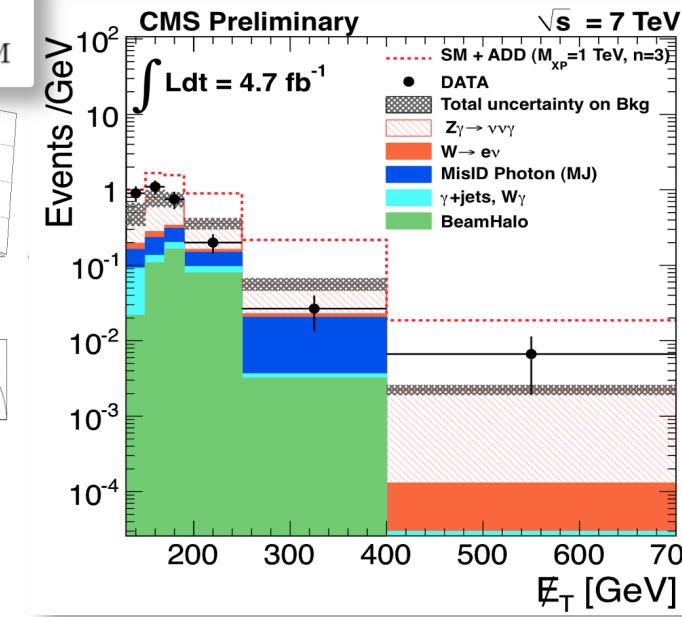
CMS Search for Dark Matter

- Pair-produced DM particles via monojets & monophotons (ISR)
 - Look for “nothing” plus a single radiated photon or jet
 - Probing the same effective operators as in direct detection
 - High sensitivity to **spin-dependent couplings**
 - Extends direct detection below 5 GeV
 - Interpret also in ADD LED, set limits on Planck Scale vs. EDs*



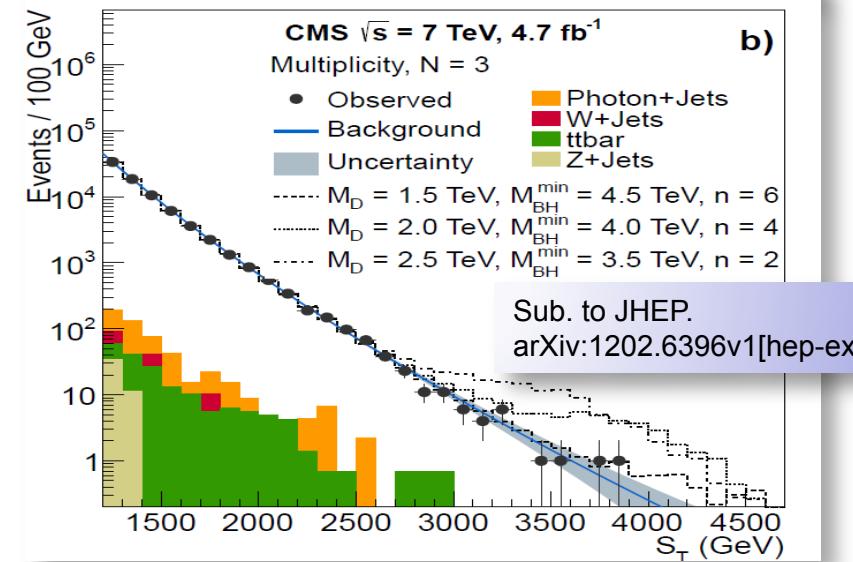
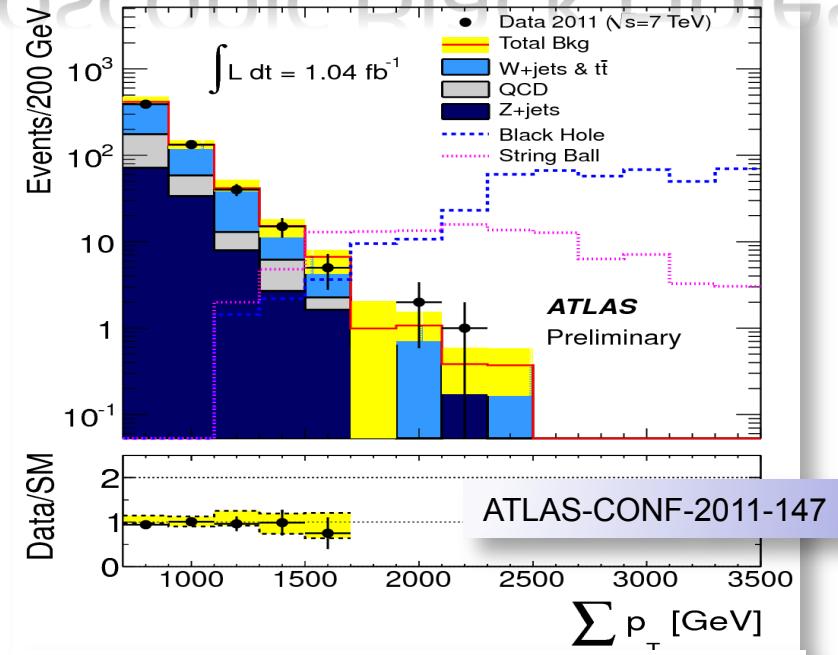
EXO-11-096

EXO-11-059





Microscopic Black Holes

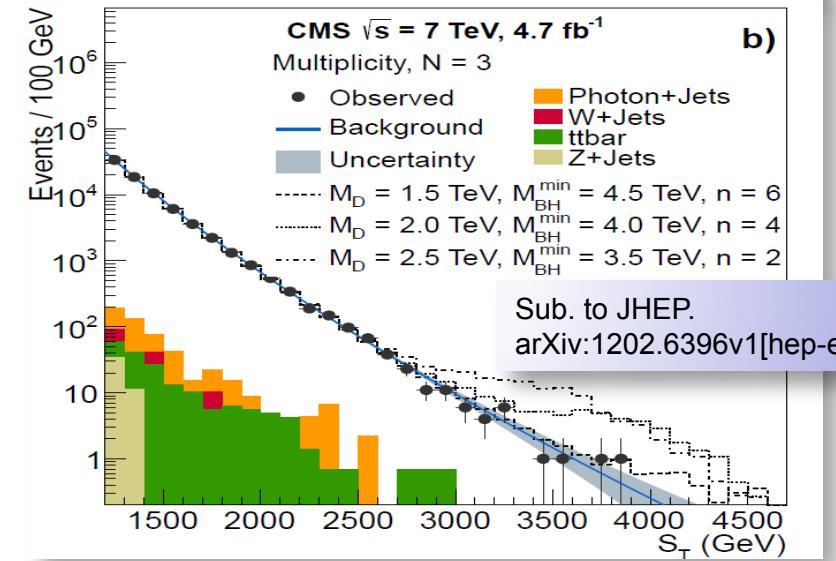
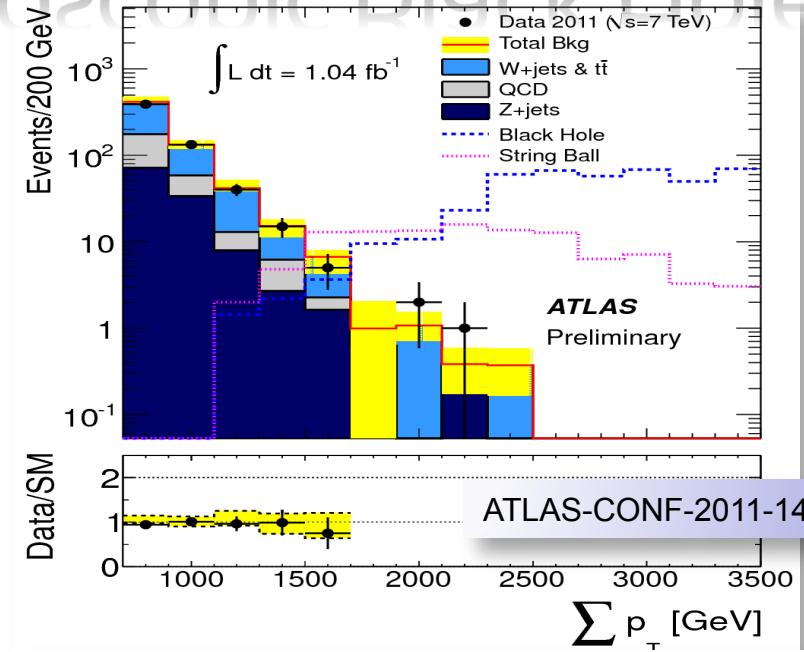


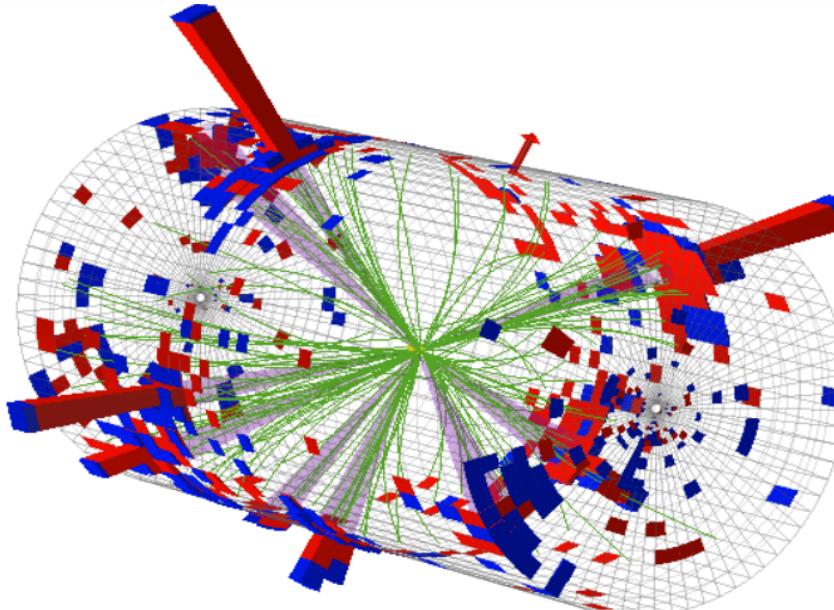
Decay into all objects democratically weighted by degrees of freedom

ΣP_T : scalar sum of the E_T of the N objects in the event

Examples: (ATLAS) at least one electron or muon and two or more jets, (CMS) any three objects

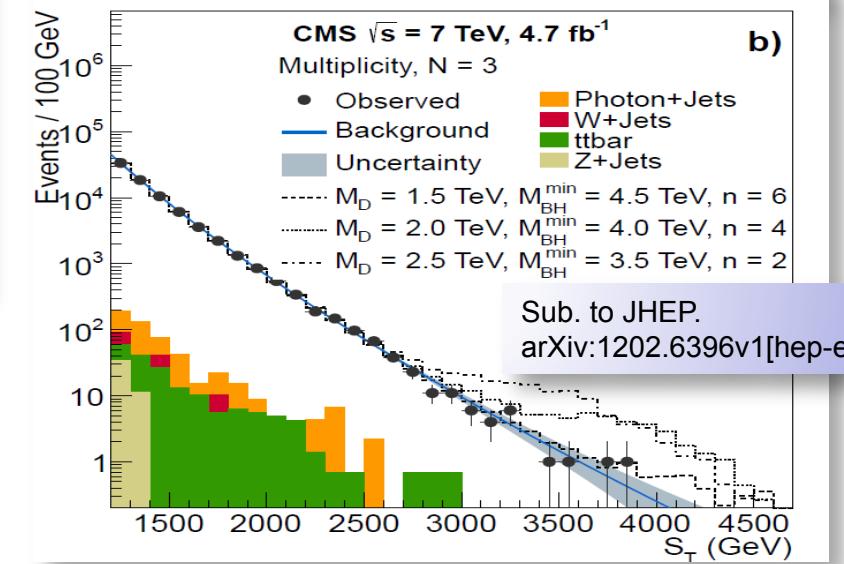
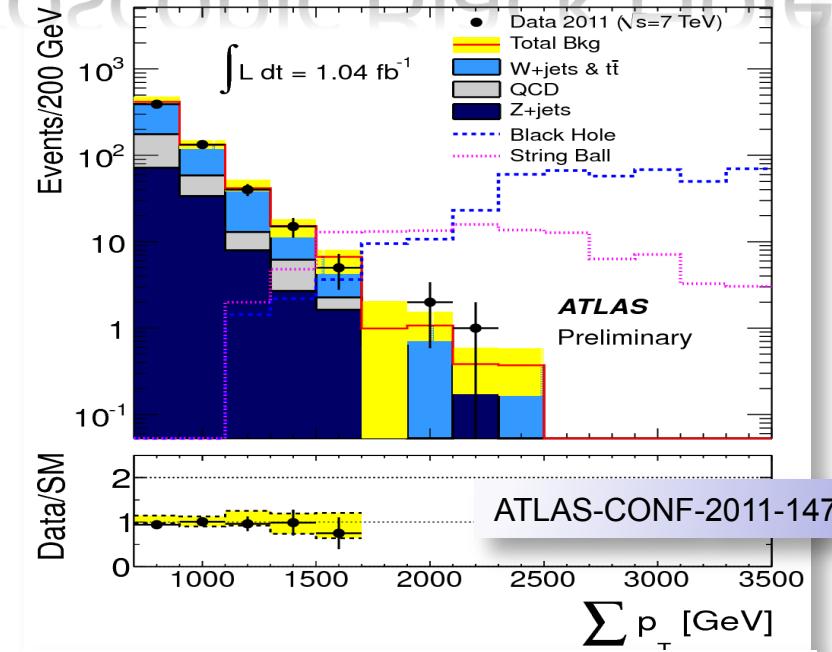
Microscopic Black Holes





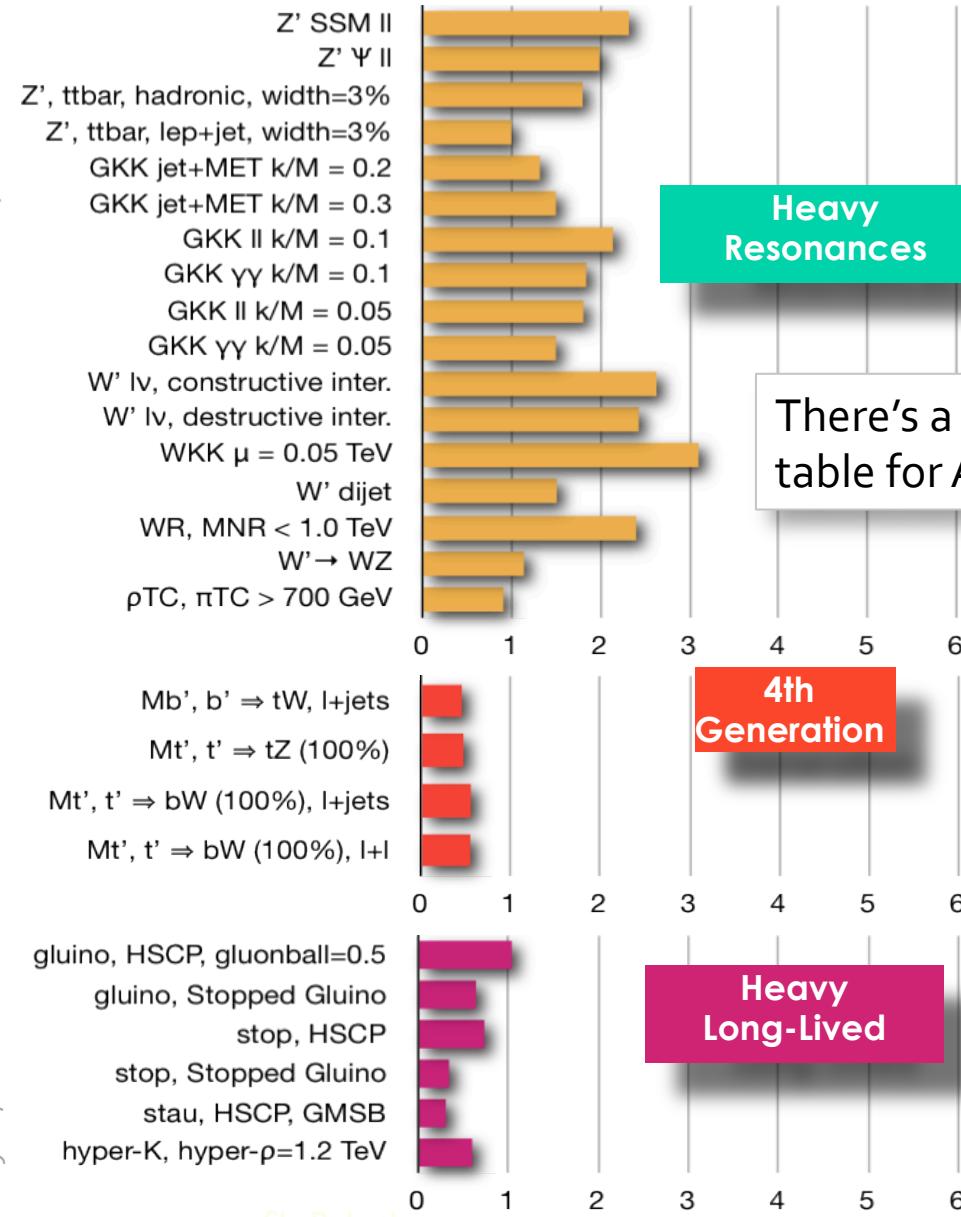
A candidate event in CMS with
9 jets and $S_T = 2.6$ TeV

Microscopic Black Holes

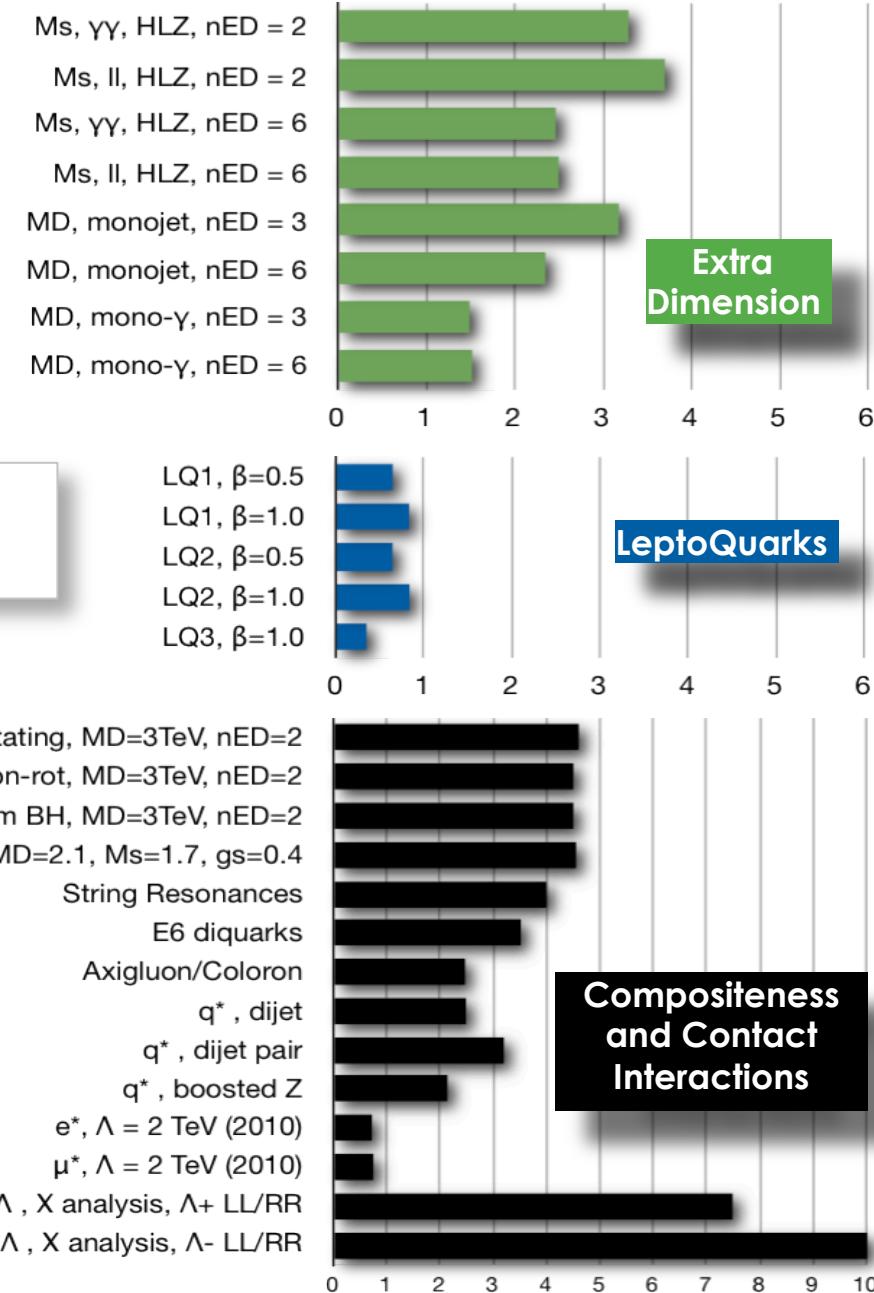


CMS Searches 2011

95%CL Exclusion Limits



There's a similar table for ATLAS



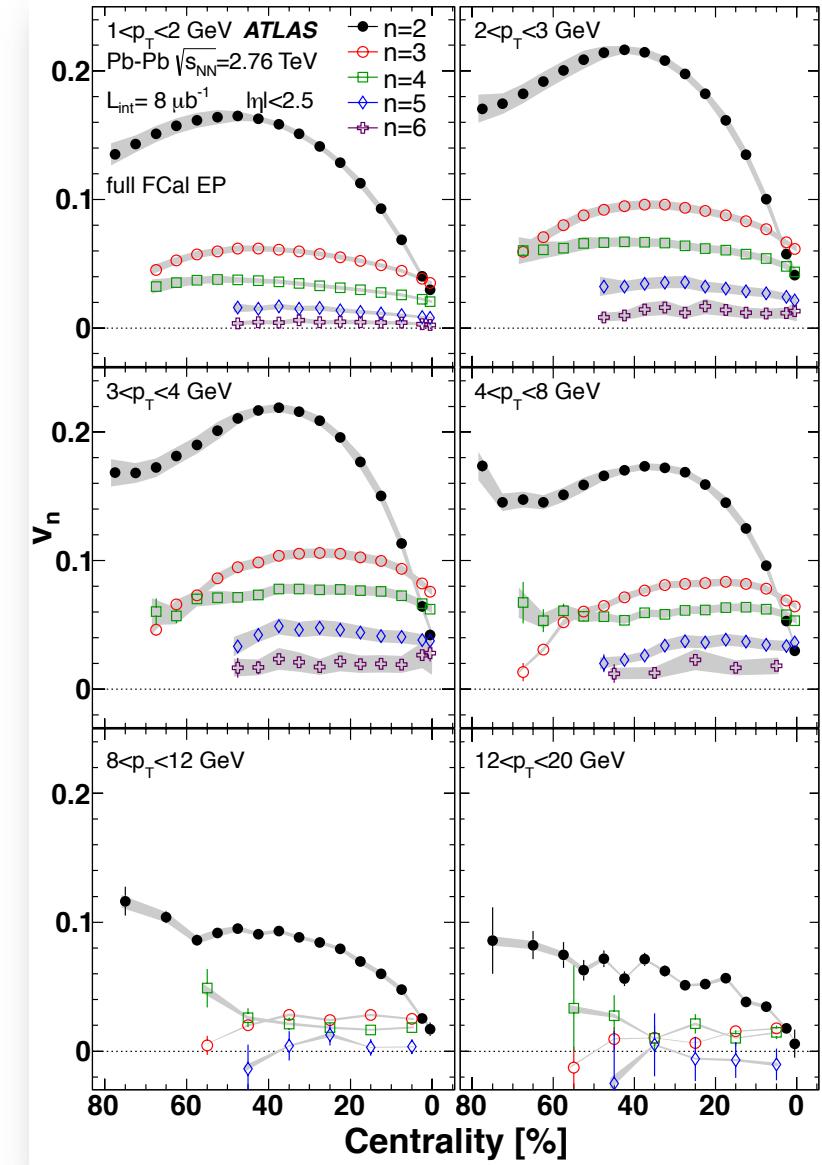
Heavy ions

Heavy ions

- Azimuthal Anisotropy
 - Fourier coefficients v_n vs. centrality for six p_T ranges
 - *From the full FCal event plane method.*
 - *The shaded bands indicate systematic uncertainties*

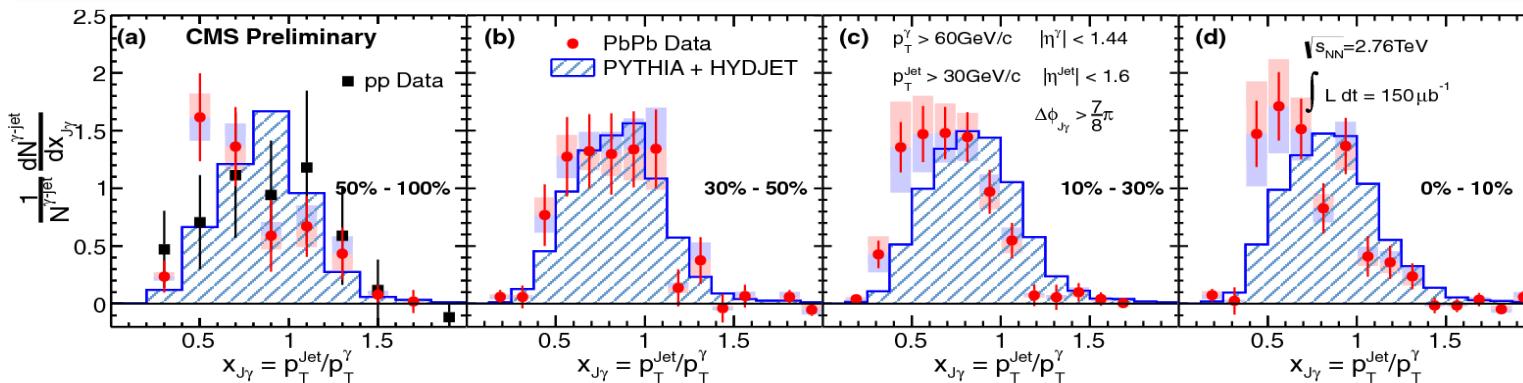
arXiv:1203.3087

ATLAS: Pb-Pb elliptic flow

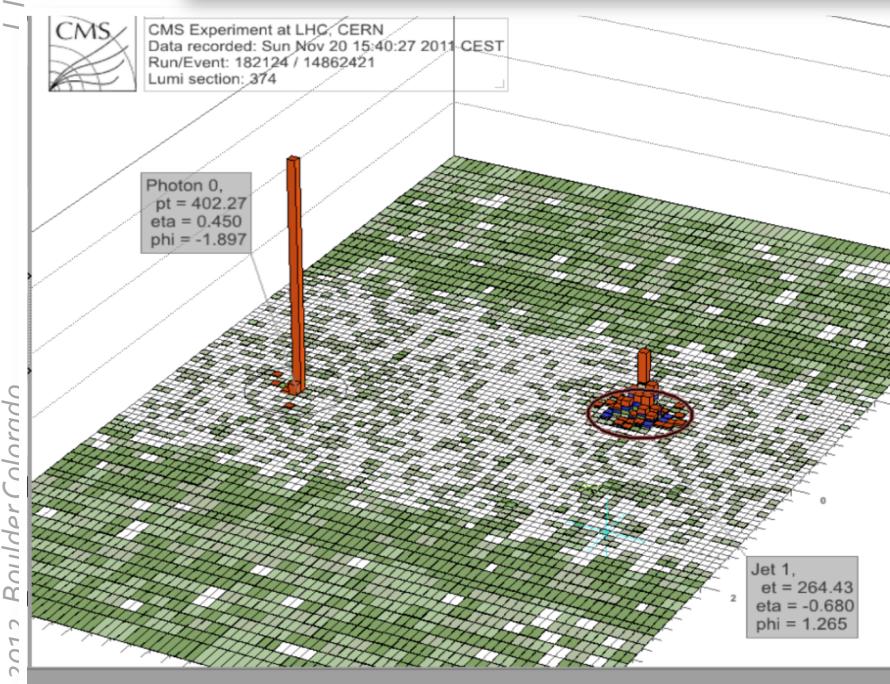


2011 Dataset

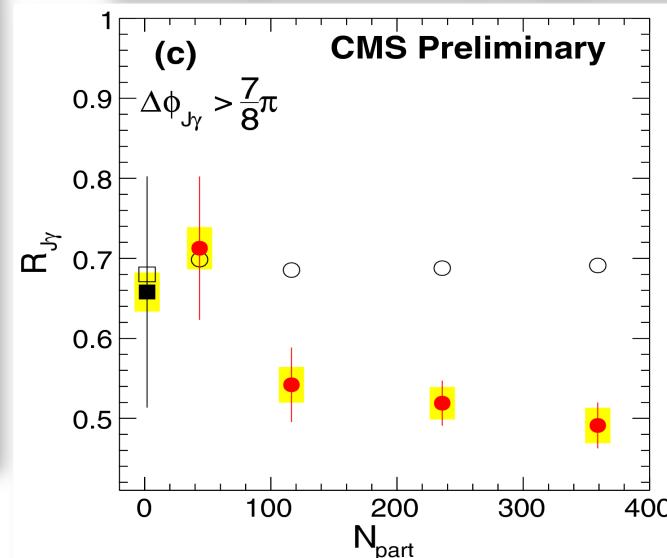
$\gamma + \text{jet}$ p_T balance in PbPb: HIN-11-010



Full 2011 dataset:
Direct measure of
parton energy
loss in QGP using
 $x_{J\gamma}$ and $R_{J\gamma}$



- Transverse momentum ratio:
 $x_{J\gamma} = p_T^{\text{jet}}/p_T^\gamma$ vs centrality (N_{part})
- Fraction γ with associated jets:
 $R_{J\gamma}$ vs centrality (N_{part})

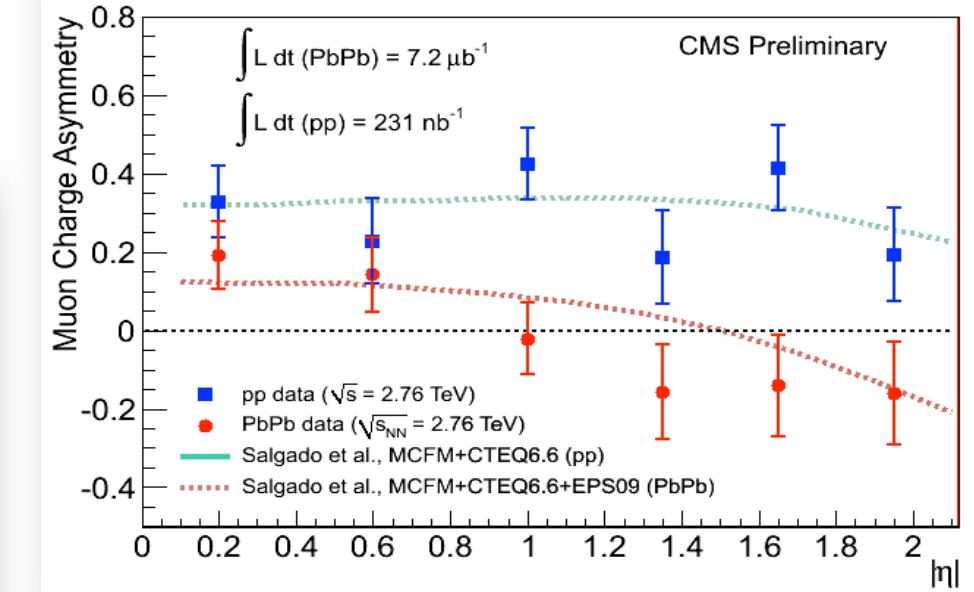
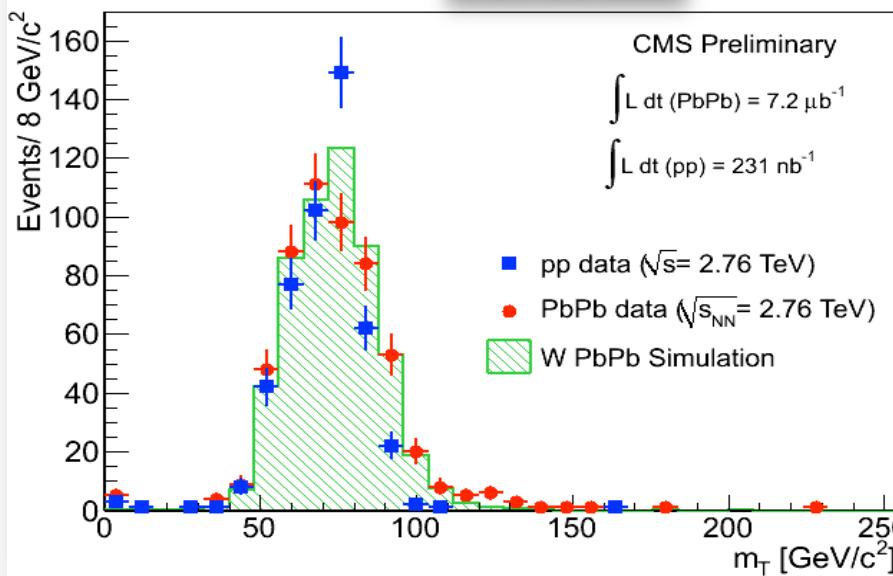


- $R_{J\gamma}$ in central PbPb collisions is well below PYTHIA + HYDJET
 - Large fraction shifted to $p_T < 30$

CMS: PbPb W Production

- Consistent with the SM
 - Taking into account nucleon content of colliding nuclei

HIN-11-008

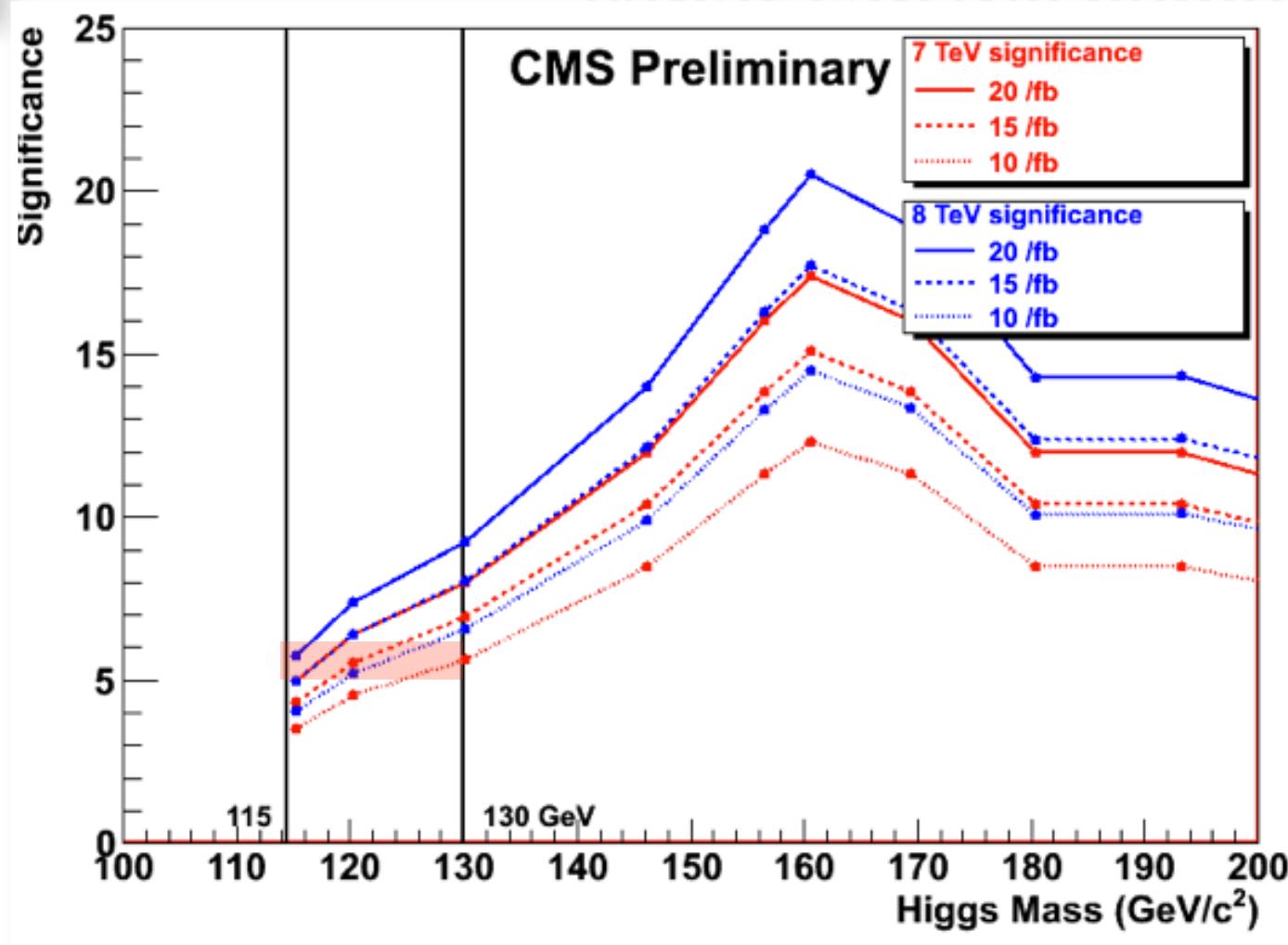


The 2012 Run

I $\mu\epsilon \Sigma \tau \Sigma$ know

*A big year for the LHC (and
HEP in general)*

What can we expect in 2012?



We should be able to find the SM Higgs or kill it...

At $5.3 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$, heading to $7 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$ and beyond (?)

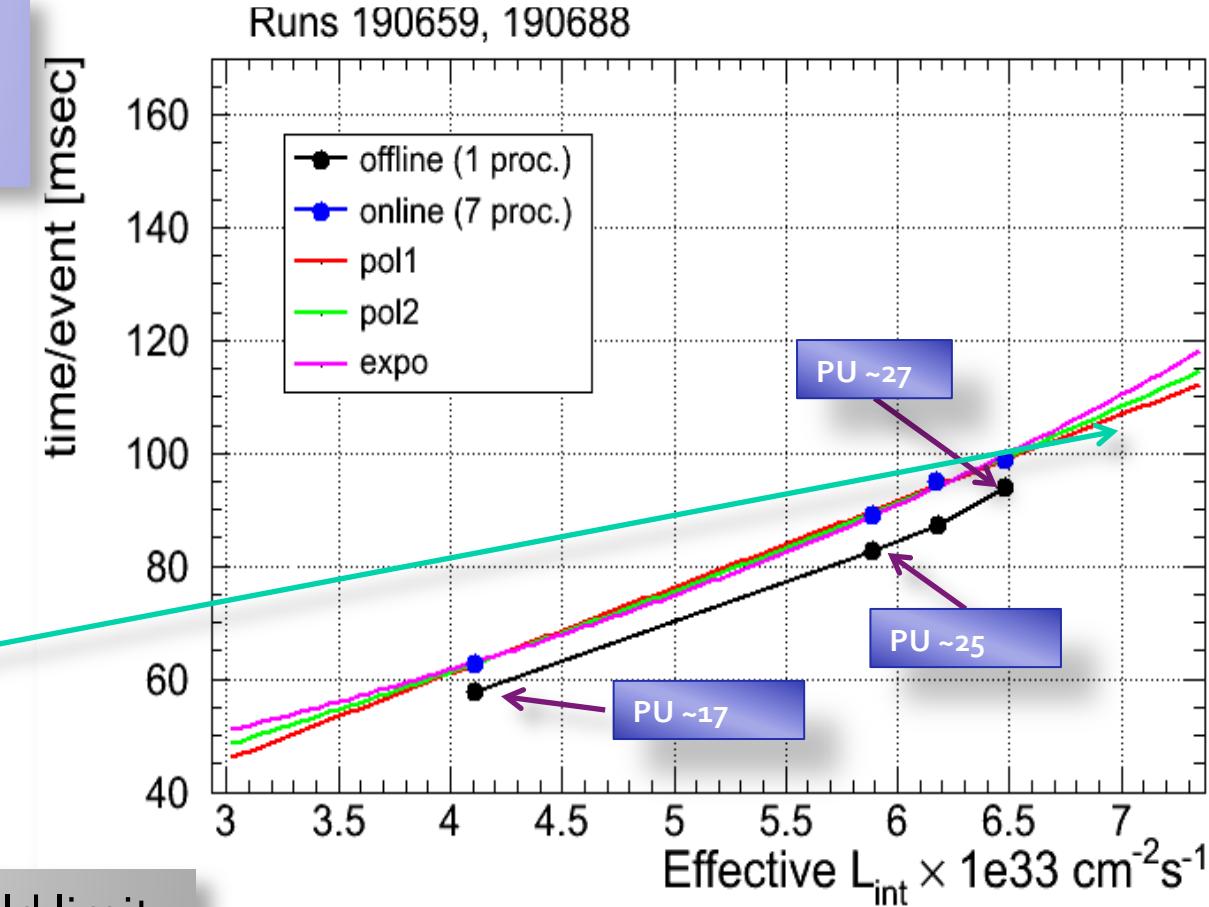
CMS HLT

Peak rate: $\sim 500 \text{ Hz}$ @ $5 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$

Average : $\sim 385 \text{ Hz}$

Prepared for
 $7 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
PU~30

$\sim 100 \text{ ms}$ per event near is our old limit.
Upgraded HLT farm in early May as
have other experiments.
Limit now around 170-180 ms

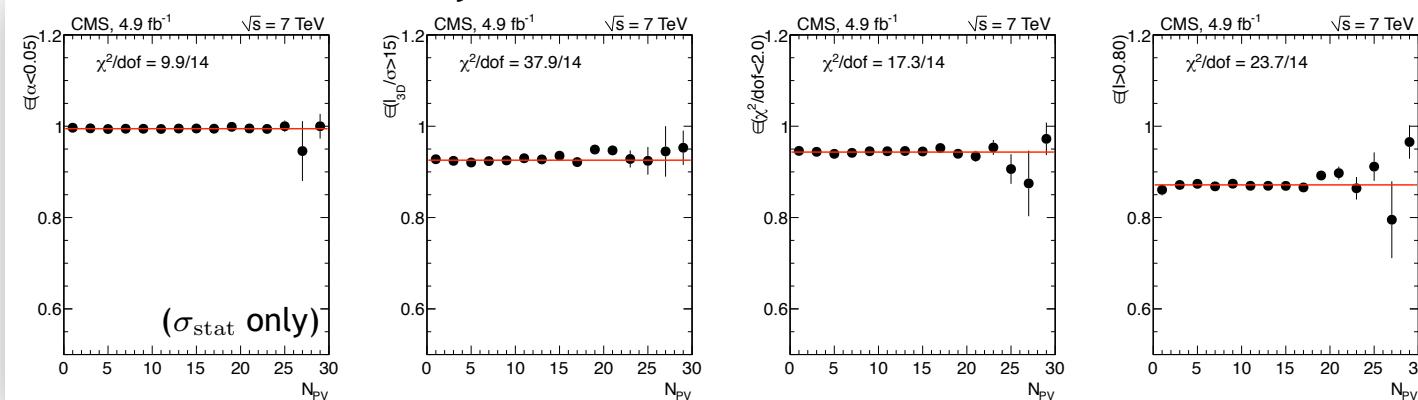


Pileup Studies for Physics

- CMS Studied $\langle \text{PU} \rangle \sim 25$
- No optimizations as of yet. Just re-run 2011 analyses
 - Impact on low mass Higgs
 - $H \rightarrow \gamma\gamma$ sees about 15% equivalent lumi loss
 - Worse (much) for $H \rightarrow \tau\tau, WW$
- No significant impact on precision top physics
- No significant impact on $B_{d/s} \rightarrow \mu\mu$

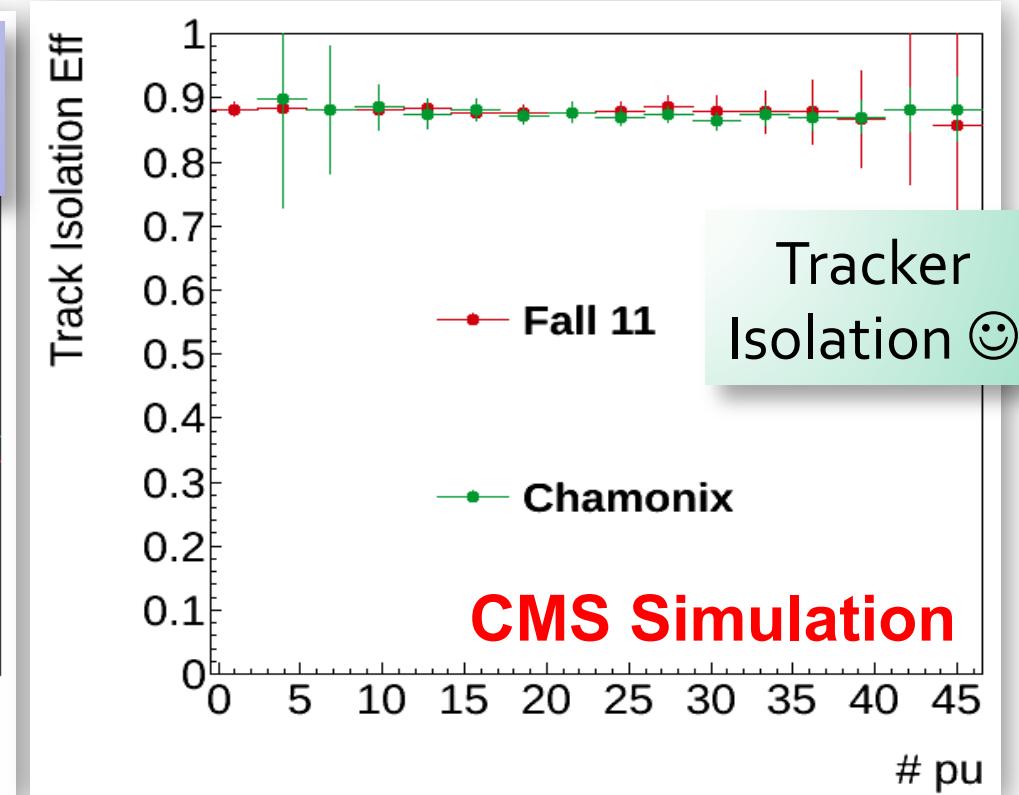
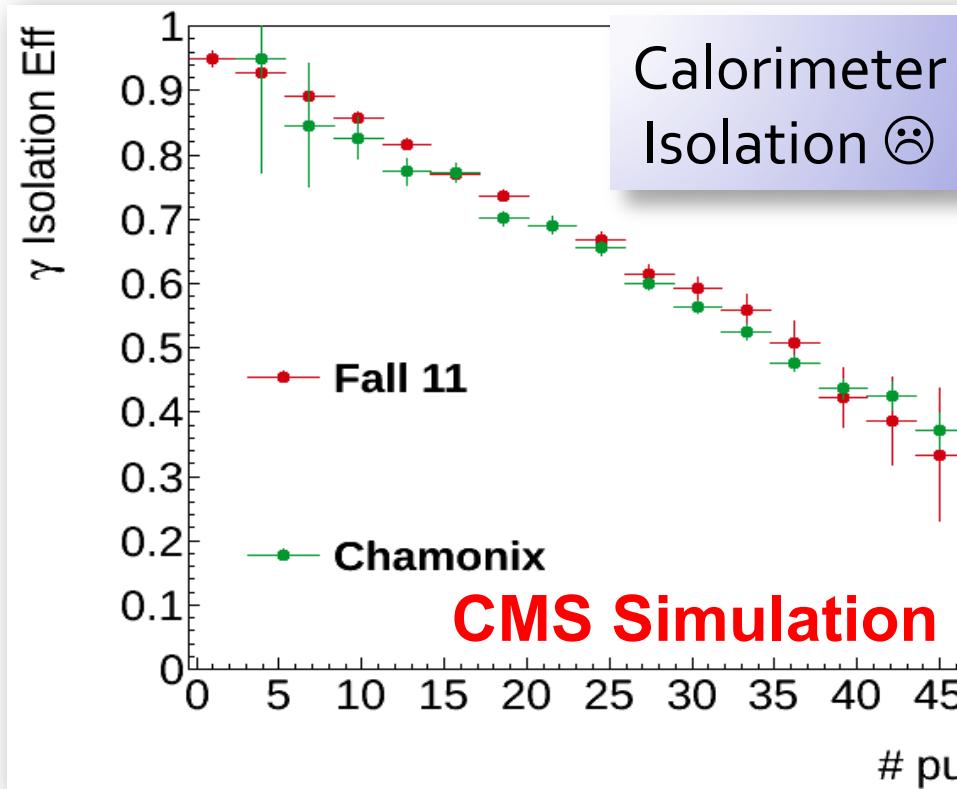
Pileup independence: $B^\pm \rightarrow J/\psi K^\pm$ PUBLIC

- Measure efficiency of all selection criteria in data vs N_{PV}



High-PU Effect on γ Isolation

- Photon isolation efficiency (5% relative isolation cut)
- No effect on track isolation (same 5% relative isolation cut)



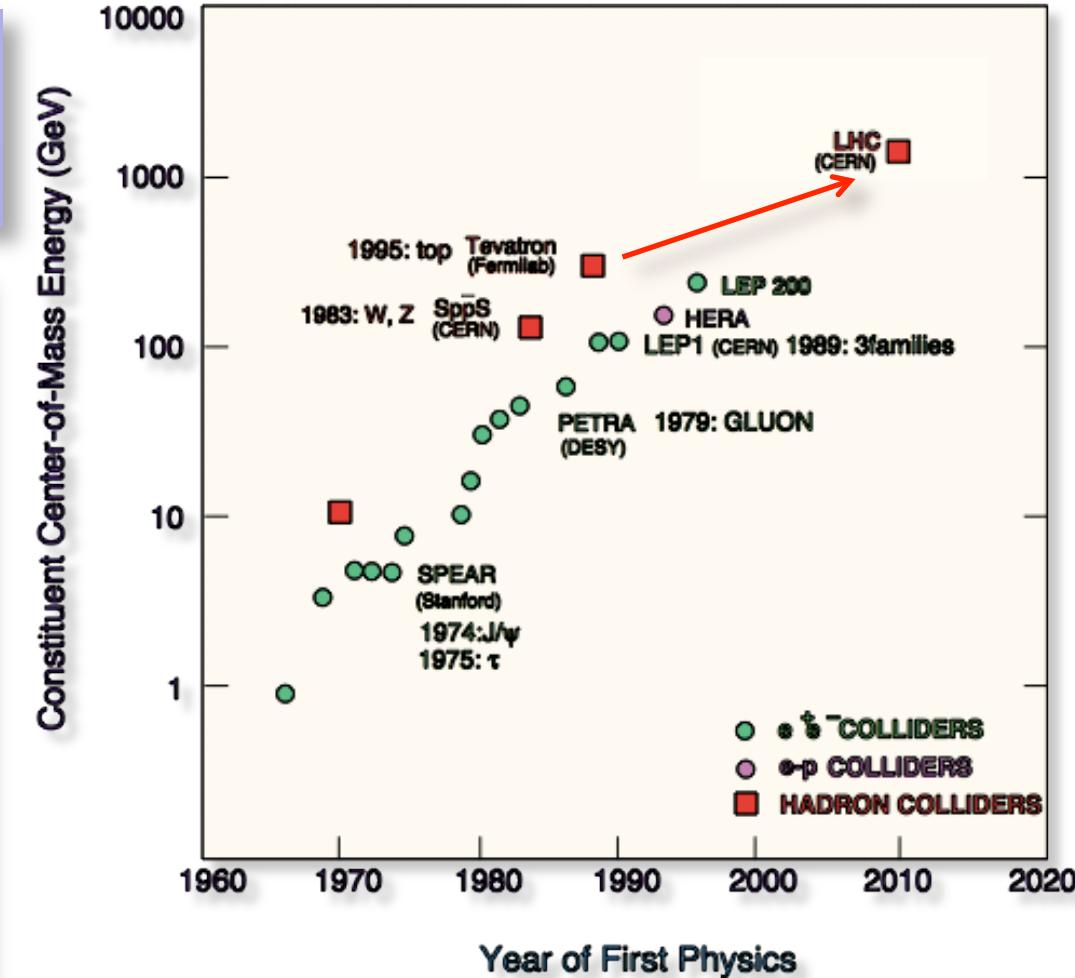


Computing challenges

- Tevatron a few years into Run2 vs LHC on year 3

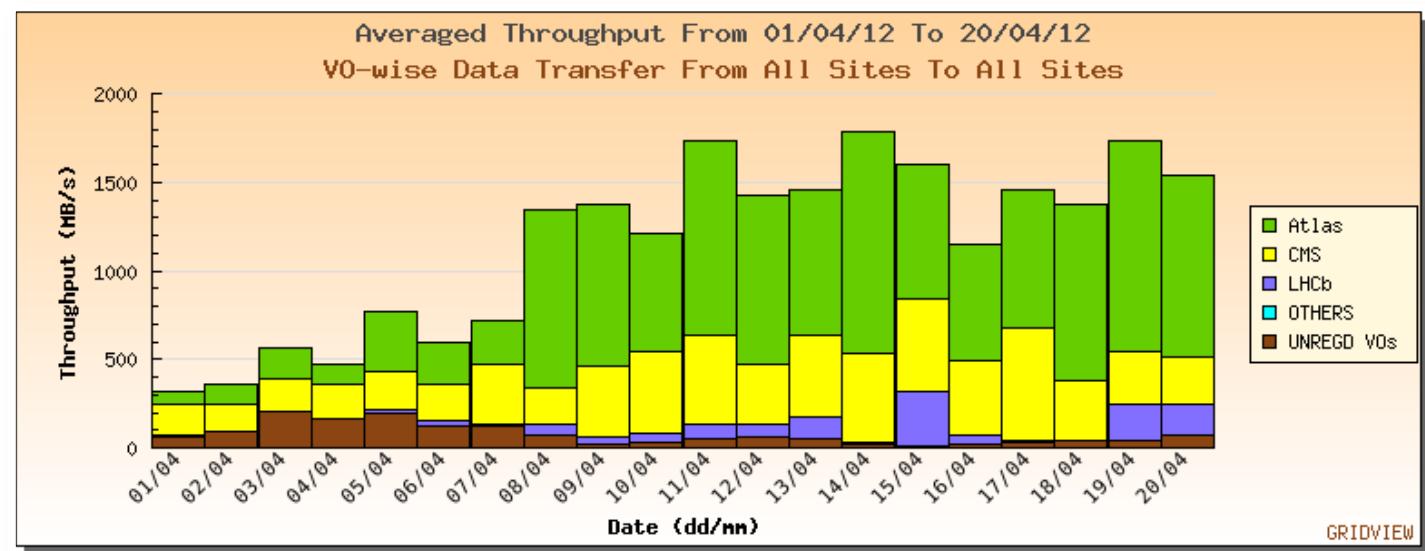
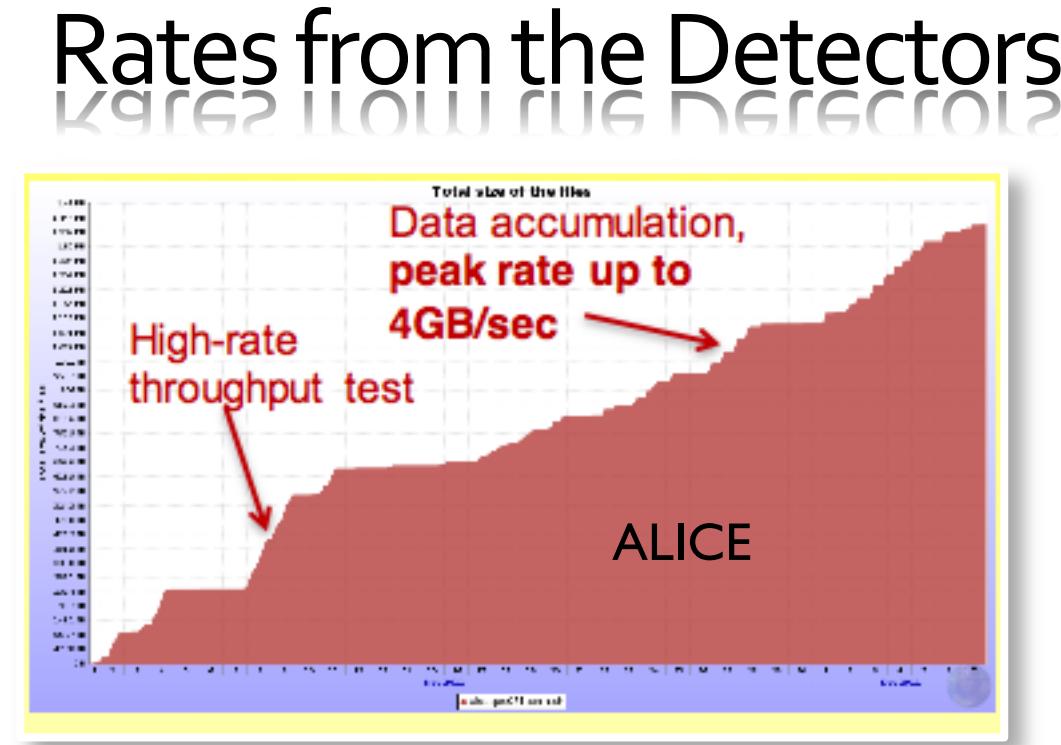
	Tevatron	LHC
Trigger	50Hz	ATLAS 500 Hz CMS 400 Hz LHCb 2 kHz
RAW Size	150kB	ATLAS 0.6 MB CMS 0.5 MB
RECO Size	150kB	ATLAS 1.1 MB CMS 1 MB
Reco Time	~1-2 seconds (CPU of day)	~10 seconds

The Scale of the Problem



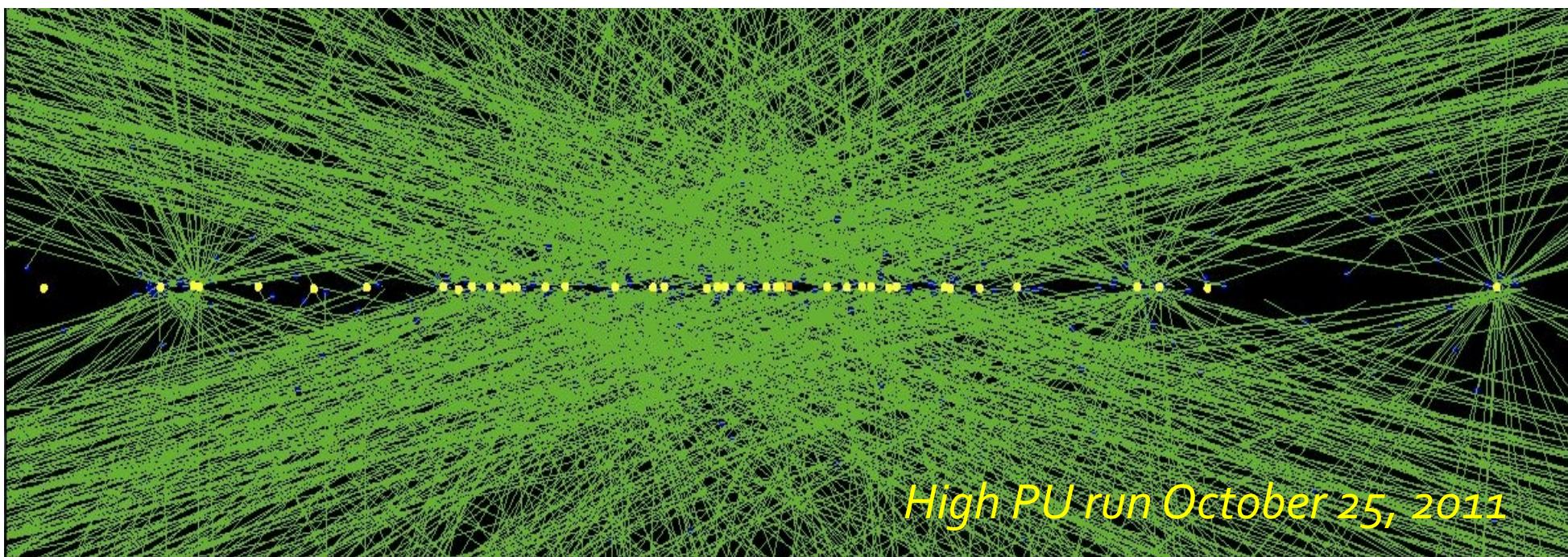
Roughly a factor of 10 in the relevant quantities

- CMS and ATLAS detectors read out at 10's of TB/sec
 - Selective triggers get this down to 0.5 – 1 GB/sec
- Larger events in ALICE lead to even bigger numbers



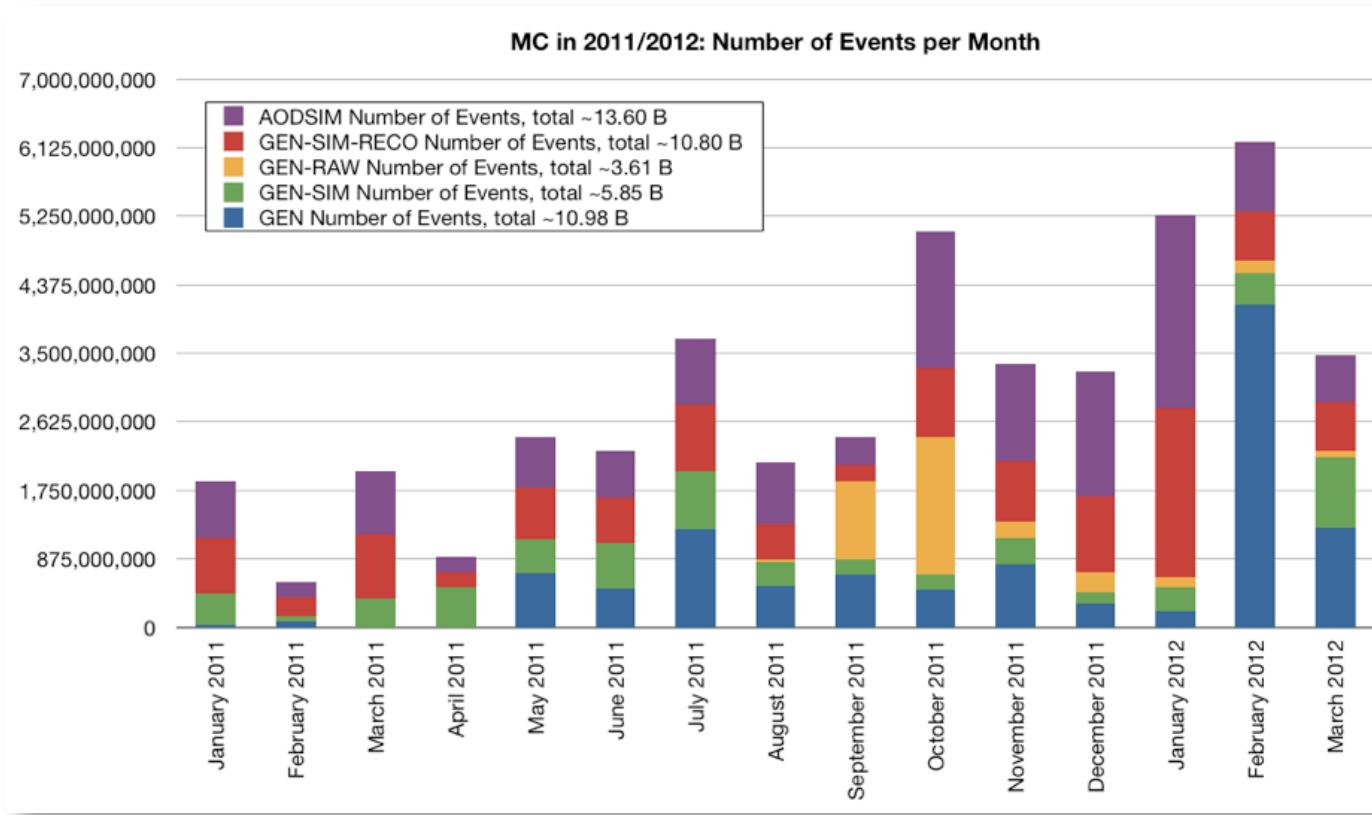
Reprocessing & Reconstruction Challenges

- High profile analyses like $H \rightarrow \gamma\gamma$ require a precise detector calibration
 - In 2011 every CMS event was reconstructed 3 times on average (as planned)
 - In 2012 the events look more like this



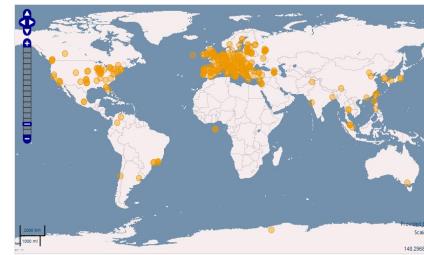
Simulation Challenges⁸⁵

- LHC experiments produce up to 3 times as many simulated events as real data events
- This is higher than in previous hadron colliders



The Challenge of Distributed Analysis

- Must make a complicated distributed system accessible to a lot of people – A global computing system at your fingertips



→ bsub

- A lot of things need to go right for this to work

Local Environment Packaged

Choice of site(s) with the desired data files or resources

Success submission through site grid interface

Arrival at Batch farm

Authenticate User and VO

Find local environment

Discovery and open local data file or remote file

Communicate job status and write results somewhere

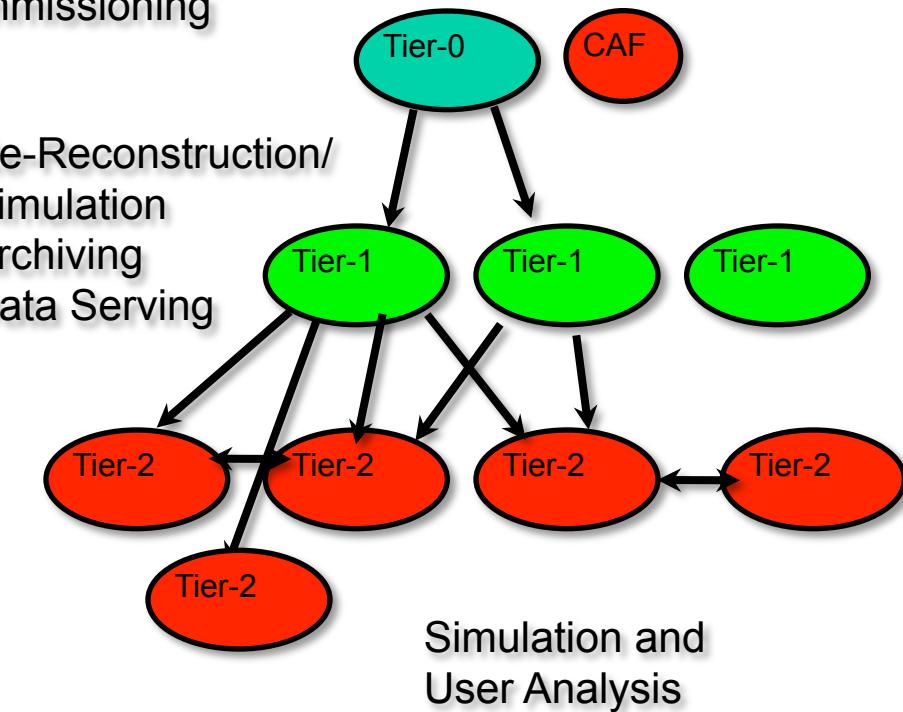
- Efficiency of completion, user experience, debugging and tracking are still being improved

*How do they (you know
who you are) do it?*

- Distributed computing environments very early
 - Grid concepts evolved and matured at the same time
 - Many concepts were motivated by the desire to make use of resources at the home institutes

Computing Architecture

Prompt Reconstruction
Storage
Commissioning



Workflows were carried out at the expected location basically from the first day. A major LHC success story.

Distributed Computing was commissioned with the detectors



Scale of Resources

- Computing has grown exponentially in capacity

	CMS CERN Resources 2011	CDF CAF Resources 2011
Disk	5000TB	500TB
Tape	21PB	6PB
CPU Cores	5500	~1000 (?)

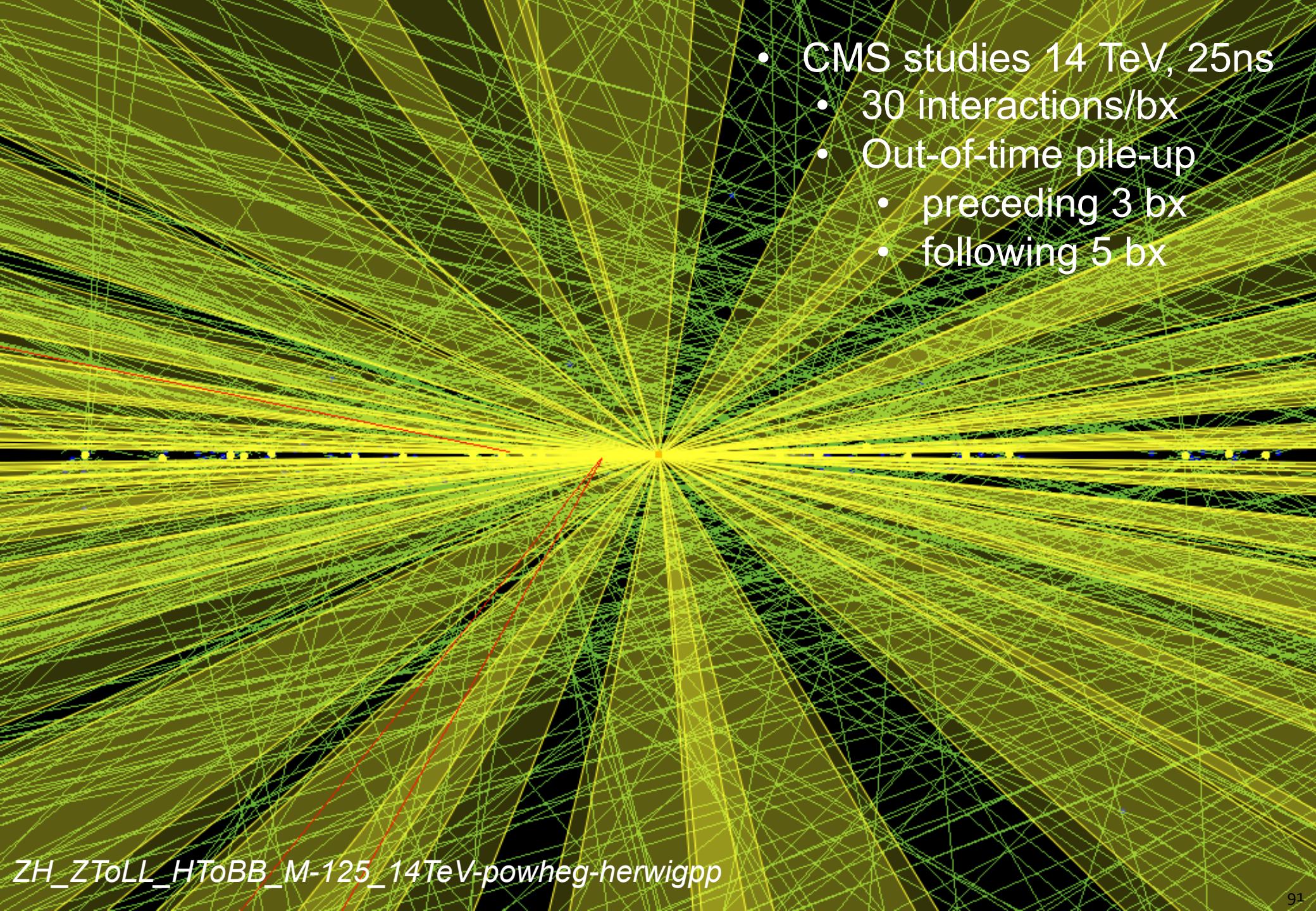
- The LHC experiments have 3-4 times more processing capacity *away* from CERN than at CERN
 - Tevatron had about 1 times
- Experiments have > 10x more capacity



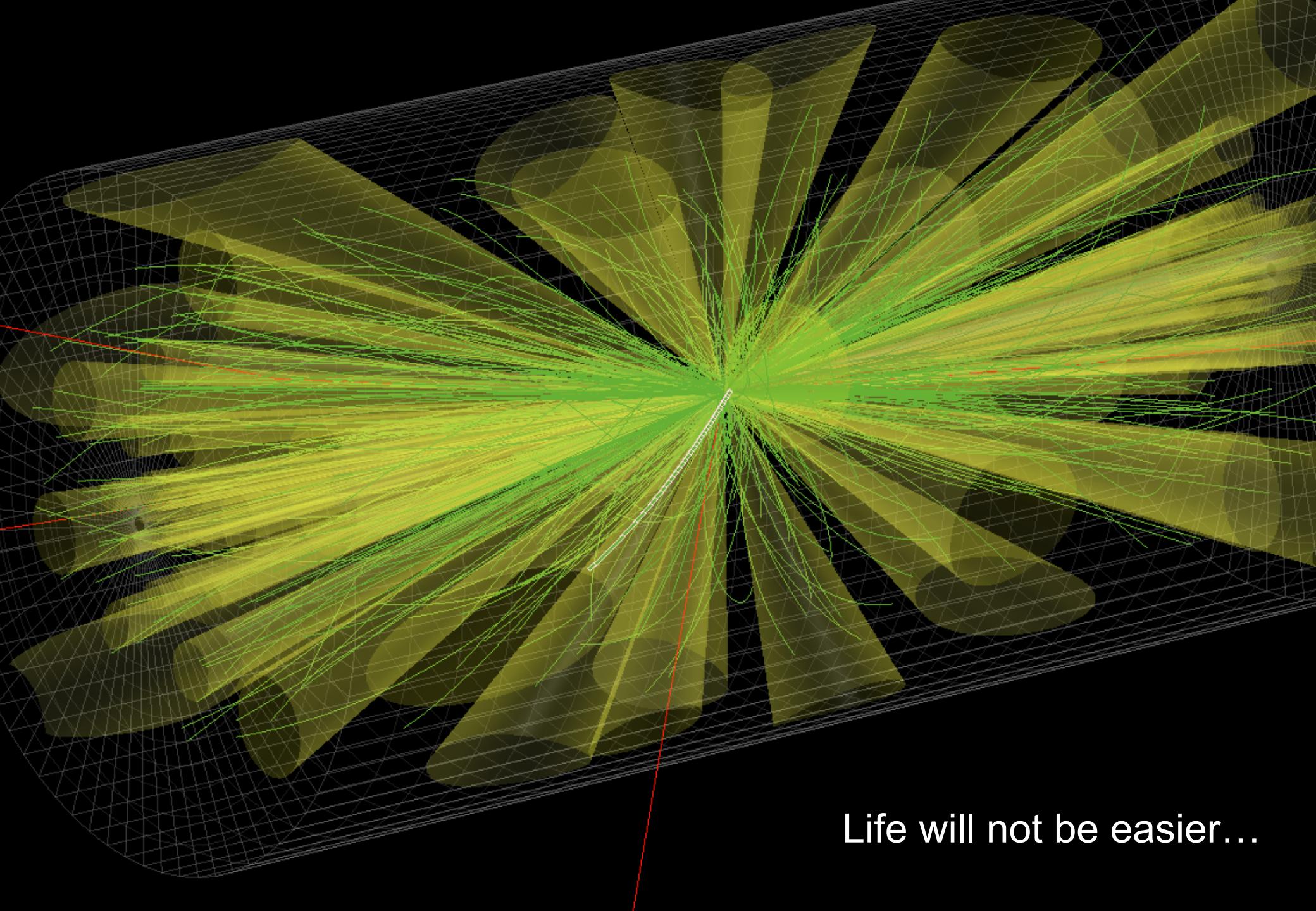
But don't relax, the upgrades are coming ...

- LHC Experiments are moving toward more and more data collected each successive year
 - Each run will have 3x the $\int Ldt$ of the previous run
 - With 3-year runs the 1st year of every new run will approximately match the discovery potential of the previously collected data
- Detectors are becoming more granular
 - More channels and more precision
- More complexity
 - Computing challenges get more interesting every year

- CMS studies 14 TeV, 25ns
- 30 interactions/bx
- Out-of-time pile-up
 - preceding 3 bx
 - following 5 bx



ZH_ZToLL_HToBB_M-125_14TeV-powheg-herwigpp



Life will not be easier...

- Lots of 2011 full dataset results and publications underway
- LHC experiments are gearing up for ICHEP and year end
- The SM Higgs story will likely be completed this year
- Searches for new physics continue to expand into more difficult areas and have some new reach with $\sqrt{s}=8 \text{ TeV}$
- It's amazing how well it all works, despite the immense challenges!



Conclusion

- Computing is the final step in a long journey to realizing the full physics potential of the LHC
- Many many thanks to the LHC computing and software groups
 - None of this is possible without you!



The year of the Dragon...



Stay Tuned

<http://aliweb.cern.ch/>

<http://atlas.ch/>

<http://cms.web.cern.ch/>

<http://lhcb.web.cern.ch/lhcb/>

<http://totem.web.cern.ch/Totem/>