LHC Higgs Cross section recommendations and Search for MSSM Higgs bosons in the $\tau\tau \to e\mu + 4\nu$ final state with ATLAS

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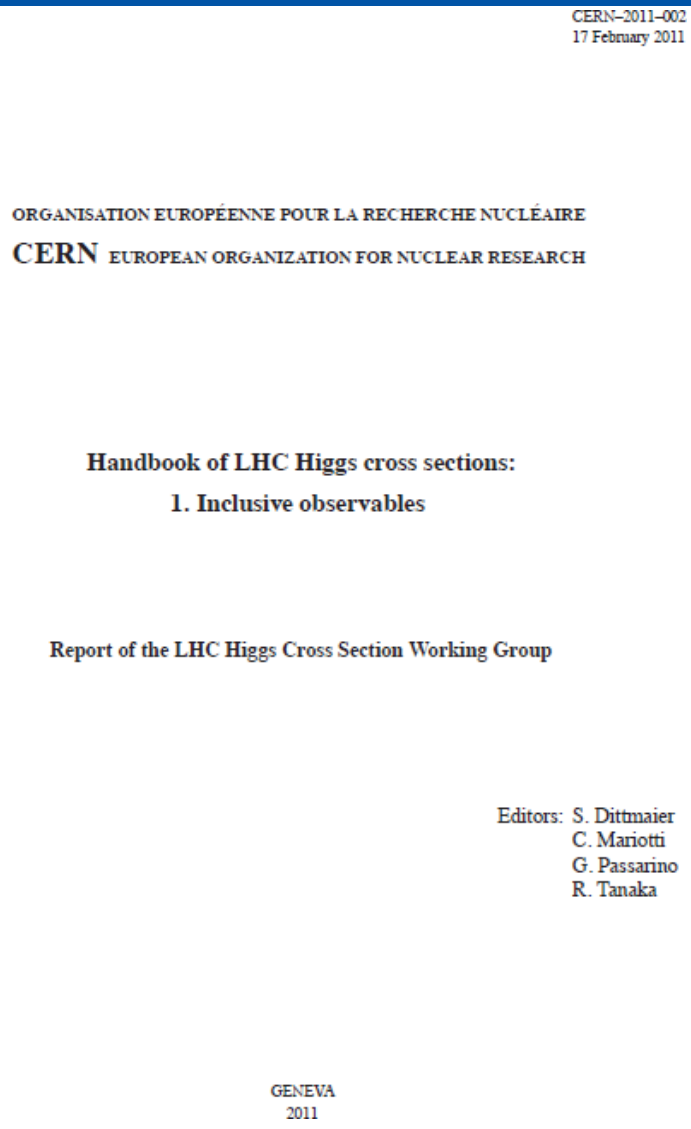
Physics on the TeV-scale at the Large Hadron Collider
FSP 101 ATLAS

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Cross Section Recommendations

LHC Higgs Cross Section WG

- Theorists and experimentalists working together on giving recommended cross sections and recipes for uncertainties to the community
- First Yellow Report on inclusive cross sections published this year: CERN-2011-002
- Currently working on Yellow Report 2 $\Rightarrow$ differential distributions


CERN–2011–002
17 February 2011

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
1. Inclusive observables

Report of the LHC Higgs Cross Section Working Group

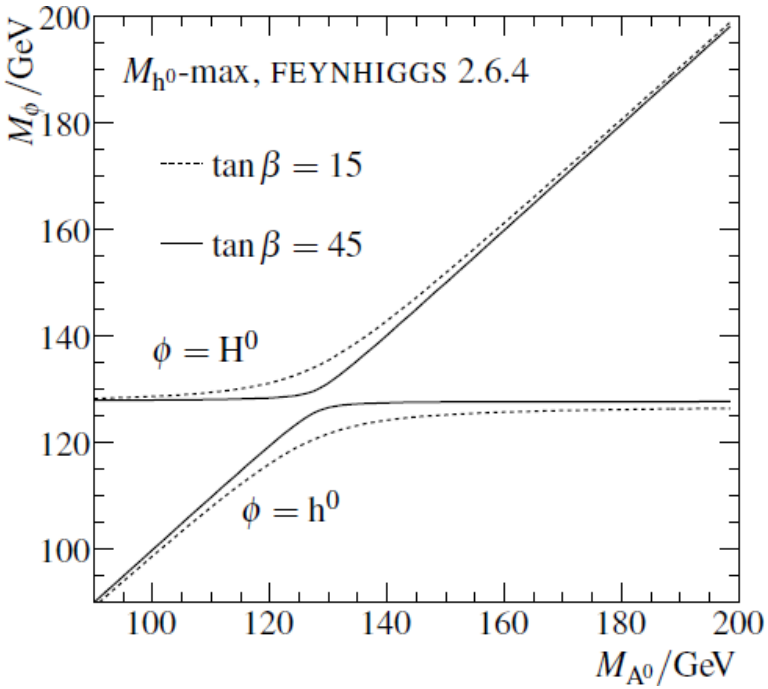
Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

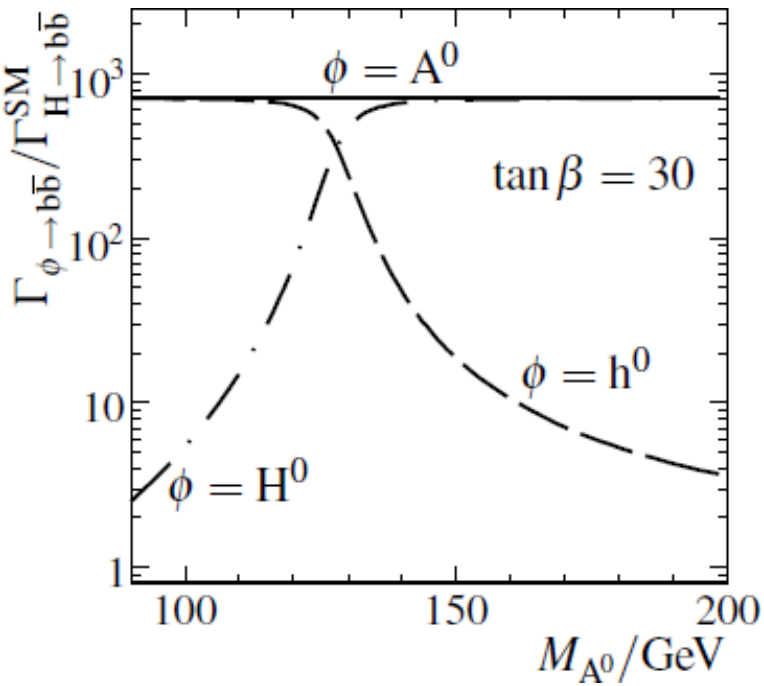
GENEVA
2011

- https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections
- This talk: short overview on cross sections for neutral MSSM Higgs bosons, see also this twiki page: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/MSSMNeutral

The Minimal Supersymmetric Standard Model (MSSM): Higgs-Sector in a Nutshell

- 2 Higgs doublets $\Rightarrow$ 5 physical Higgs bosons: $h, H, A, H^{\pm}$
- Tree level: completely fixed by $M_A, \tan\beta$ (ratio of the two VEVs)
- higher orders: 105 additional parameters $\Rightarrow$ reduce to 5 parameters
- fix these in benchmark scenarios, e.g. MHMAX

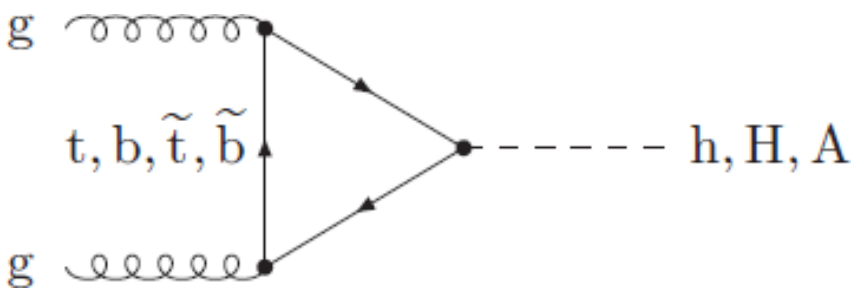




- always h or H mass degenerate with A
- mass degenerate Higgs bosons have enhanced couplings to down-type fermions $\Rightarrow$ changed production cross sections!

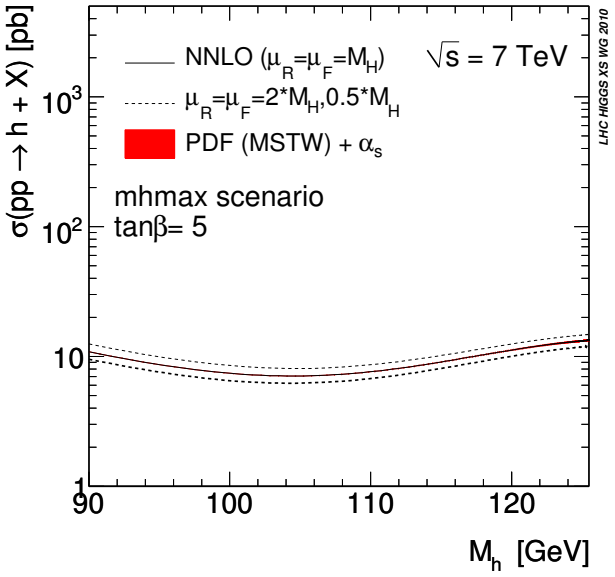
Gluon-Gluon-Fusion for MSSM Higgs Bosons

- bottom-loop also important for high $\tan\beta$
- squark-loops important if squarks are light (not the case in MHMAX)



$$\sigma^{MSSM}(gg \to \phi) = \left(\frac{g_t^{MSSM}}{g_t^{SM}}\right)^2 \sigma_{tt}(gg \to \phi) + \left(\frac{g_b^{MSSM}}{g_b^{SM}}\right)^2 \sigma_{bb}(gg \to \phi) + \frac{g_t^{MSSM}}{g_t^{SM}} \frac{g_b^{MSSM}}{g_b^{SM}} \sigma_{tb}(gg \to \phi),$$

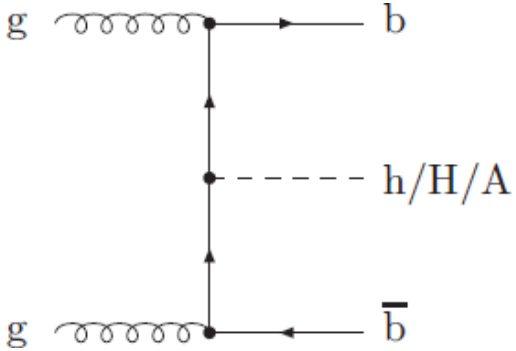
- NLO contribution to $\sigma_{tt}, \sigma_{tb}, \sigma_b$: HIGLU, with complete quark mass dependence
- NNLO contribution on top for σ_{tt} from ggh@NNLO (infinite top mass), numerically small for high $\tan\beta$
- masses and couplings from FeynHiggs



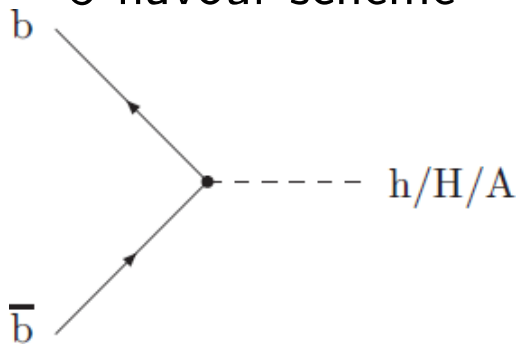
b-Quark-Associated Production for MSSM Higgs Bosons

- high $\tan\beta \Rightarrow$ b-associated production important!
- use SM-like cross section and rescale to MSSM (very good approximation)
- two calculational approaches:

4-flavour scheme



5-flavour scheme



- retain complete b kinematics
- potentially large collinear logs
- available in NLO QCD

- resum large logs into b-PDF
- zero p_{T} at LO
- available in NNLO QCD

- should agree if calculated at sufficiently high order of perturbation theory

- but at finite order still differences, especially for high masses
- Which cross section to use?

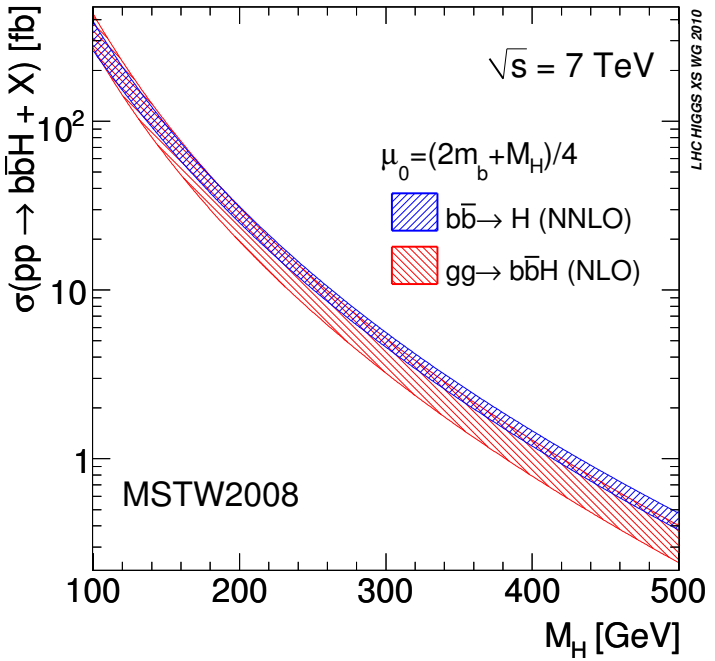
Santander Matching

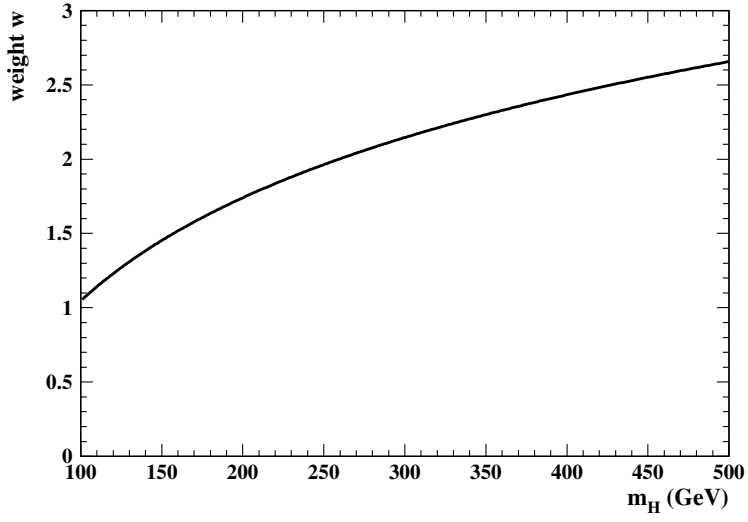
- Harlander, Krämer, Schumacher (CERN-PH-TH/2011-134)
- heuristic reweighting

$$\sigma^{\text{matched}} = \frac{\sigma^{4\text{FS}} + w \cdot \sigma^{5\text{FS}}}{1 + w}$$

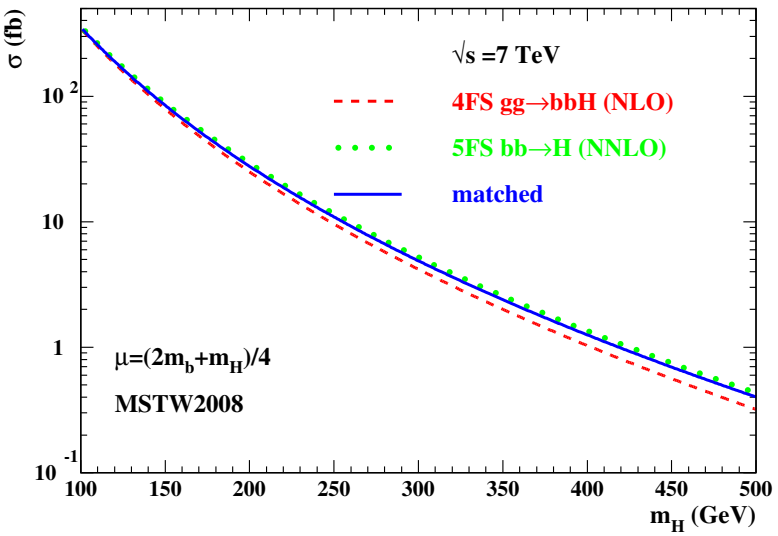
$$w = \ln \frac{m_H}{m_b} - 2$$

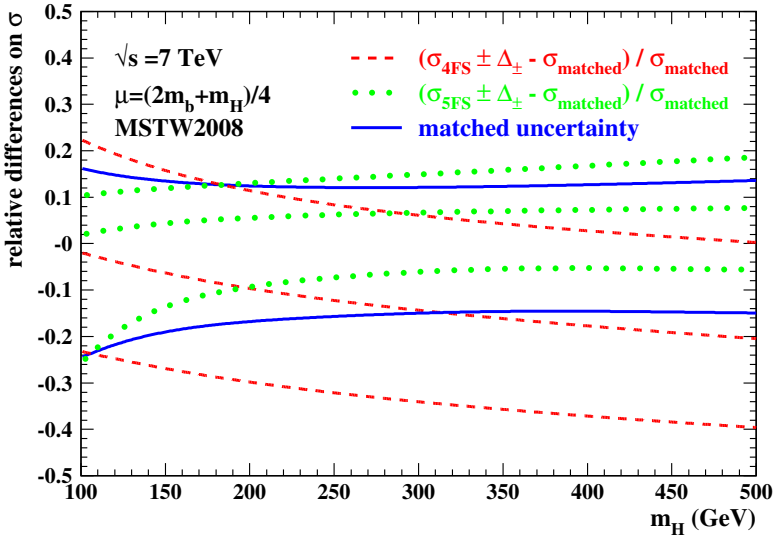
- low masses: equally 4 and 5FS
- very high masses: 5FS dominant





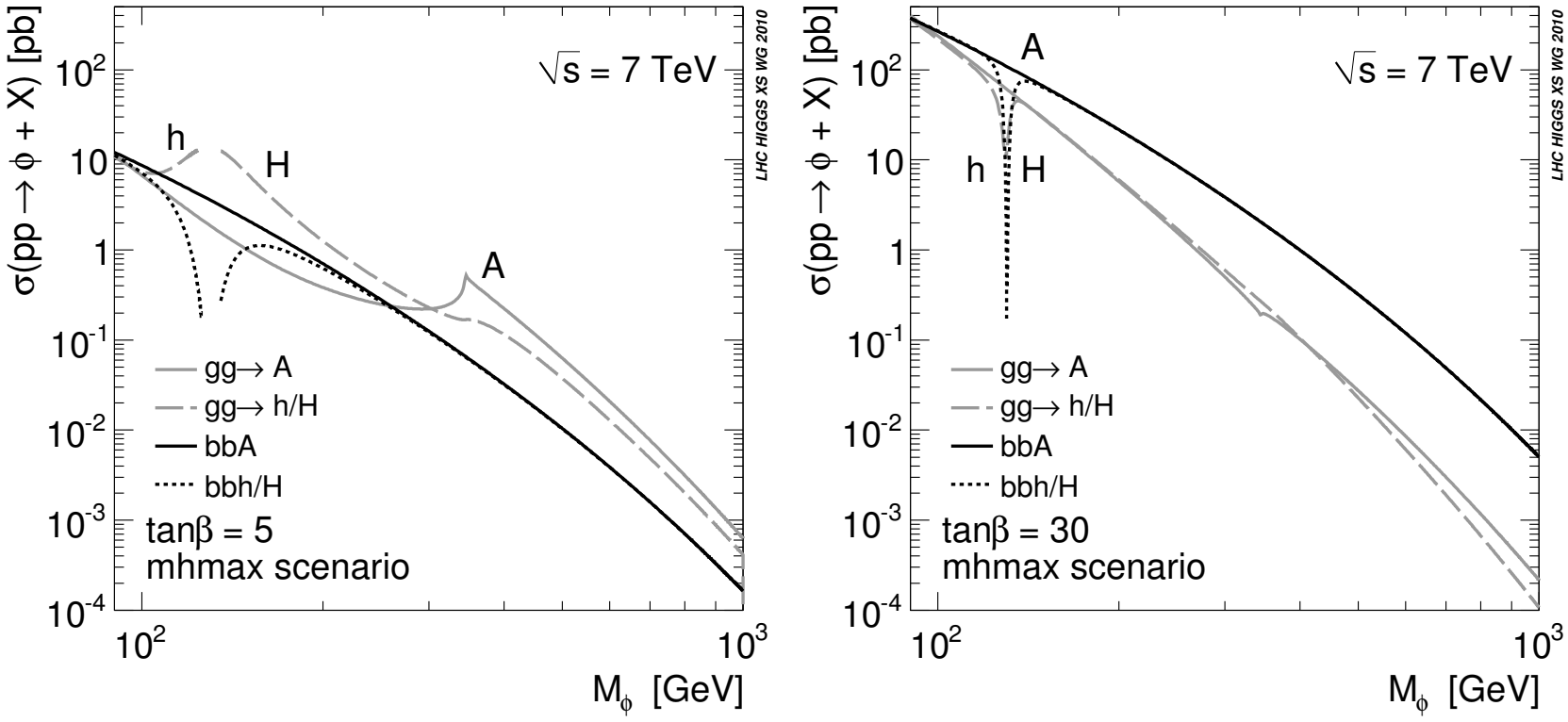
- agreed between experiments and theorists to use this for now!





- linear weighting/addition of scale and PDF uncertainties
- very close to each other for low masses, high masses dominated by 5FS, as expected/constructed

Overall Picture



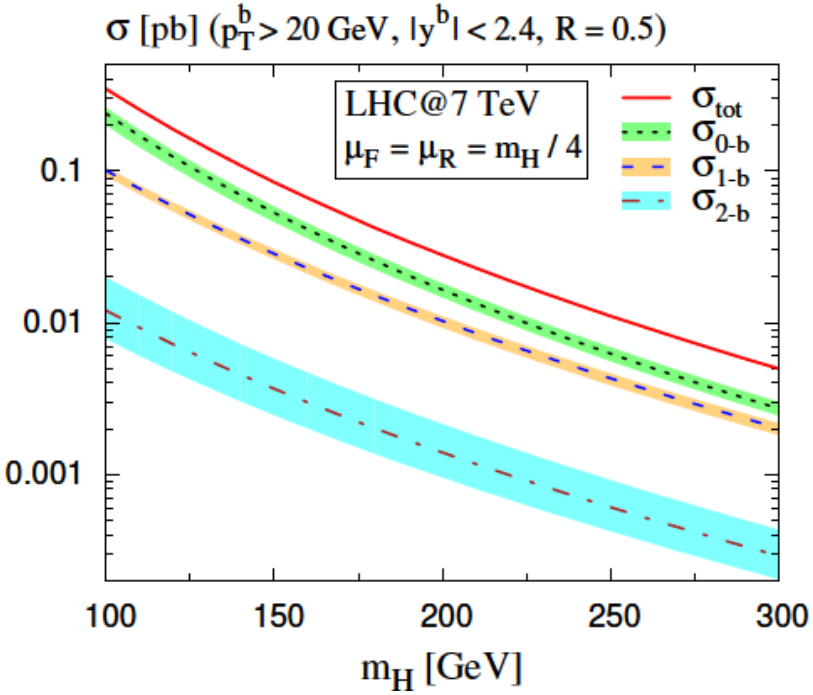
- Inclusive cross sections for these two production channels available from TWIKI
- simple accessor tool (based on ROOT) to simply plug-in to any analysis
- available for: MHMAX, MHMAX variants with different μ and for the no-mixing scenario

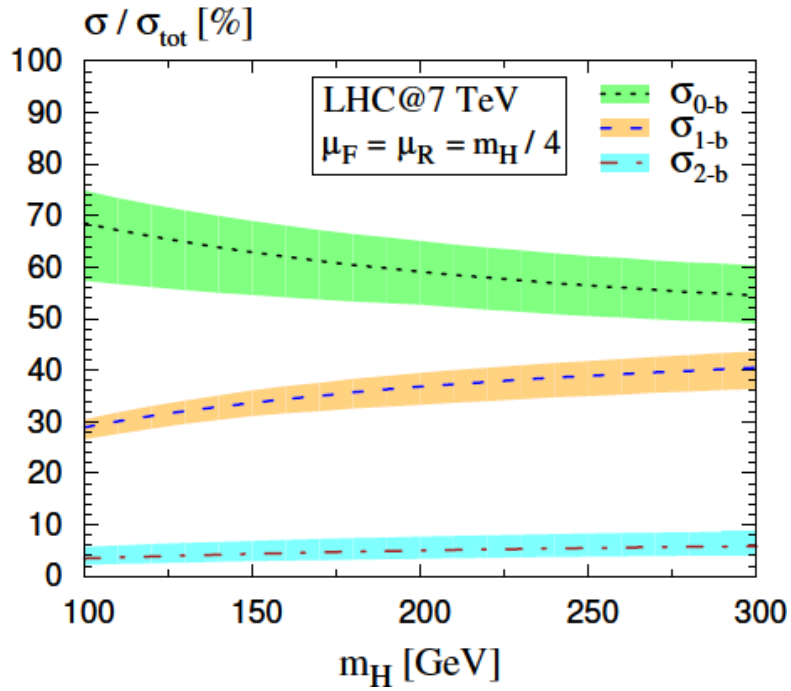
Future Updates: Differential Distributions

- currently working on Yellow Report 2: Differential Distributions
- should be available for Xmas
- studies on Higgs-p_{T}, b-jet p_{T}, ...
- here only one preview based on arXiv:1111.2182 [hep-ph]

Preview on Differential Distributions: Higgs + 1 Jet

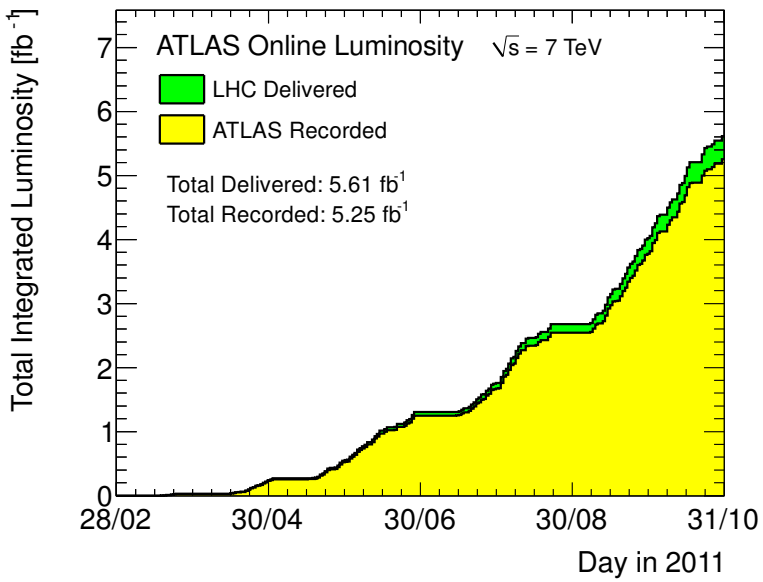
- "Jet-veto in bottom-quark induced Higgs production at next-to-next-to-leading order" (R. Harlander and M. Wiesemann, arXiv:1111.2182 [hep-ph])
- Calculation of $H + n$ jet ($n = 0$ and $n \geq 1$) and $H + nb$ jet ($n = 0, 1, 2$)
- very useful for present and upcoming analyses which will separate into at least one b-tagged jet, at least one non-b-tagged jet and exactly zero jets





Search for $h/H/A \to \tau\tau$ with ATLAS

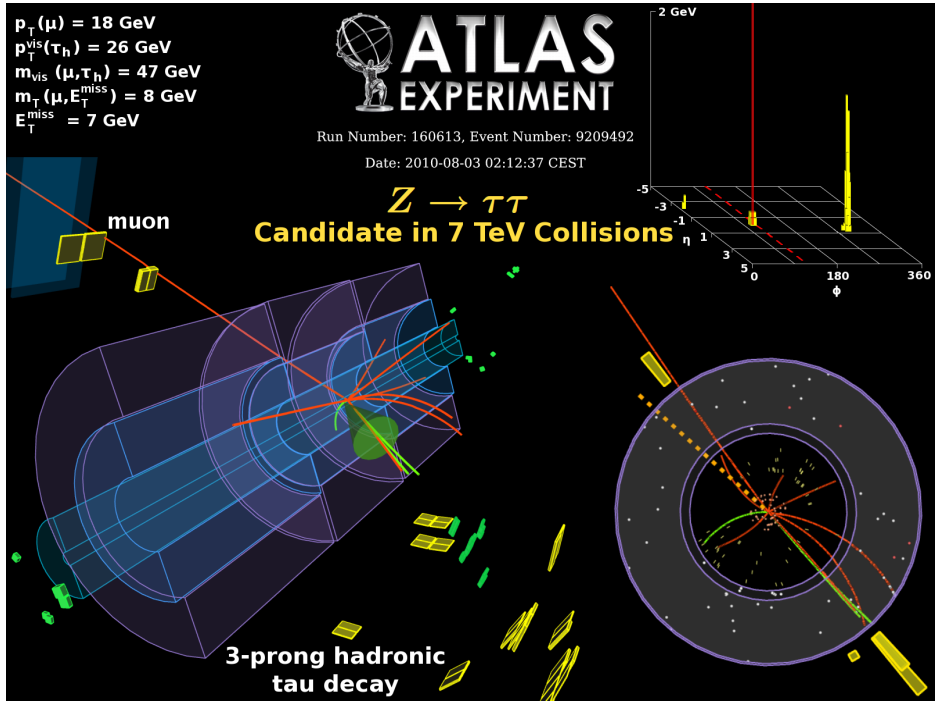
- concentrating on $\tau\tau \to e\mu + 4\nu$ final state
- analysis of other final states ($\ell\tau_{had}$, $\tau_{had}\tau_{had}$) shown in talk by Thomas Schwindt
- ATLAS-CONF-2011-132 – based on $\approx 1.1\,\mathrm{fb}^{-1}$ of data



- rest of 2011 data being analyzed at the moment
- Analysis of 2010 data ($\approx 35\,\mathrm{pb}^{-1}$) published in Phys. Lett. B705 (2011) 174-192, not shown here, but very similar analysis

Motivation

- MSSM @ high $\tan\beta$:
- dominant decay to $b\bar{b}$: fully hadronic final state, very difficult
- $BR(A/h)$ or $BR(A/H) \to \tau\tau \approx 10\%$, but easier signature
- $\tau_{had}\tau_{had}$: largest BR, but also fully hadronic
- $\tau_{had} + e$ or $\tau_{had} + \mu$: easier to trigger, cleaner sample
- $\ell\ell$ cleanest final state, but smallest BR
- also can reach down to lower p_{T} with electrons and muons $\Rightarrow$ expected to be more relevant at low Higgs boson masses



Signature

- ATLAS searches for MSSM Higgs bosons so far: fully inclusive in jet multiplicity, b-tagging not utilized yet
- this talk: only $e\mu$ final state
  - 1 isolated electron, 1 isolated muon and rather small $E_{\mathrm{T}}^{\mathrm{miss}}$

Backgrounds

- $Z \to \tau\tau \to e\mu + 4\nu$: irreducible (shapes after presel. taken from data)
- $t\bar{t} \to WWb\bar{b} \to e\mu + 2\nu + b\bar{b}$: harder leptons, higher $E_{\mathrm{T}}^{\mathrm{miss}}$ (MC@NLO)
- Single-top (AcerMC/MC@NLO)
- Diboson production (MC@NLO)
- QCD: estimated from data

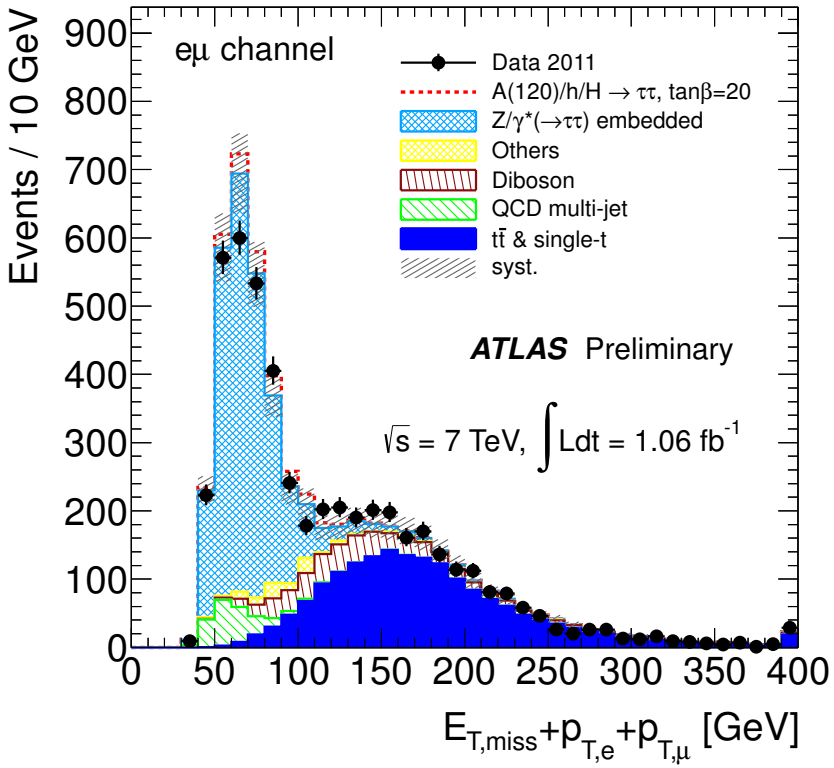
Signal process	$\sigma \times$ BR [pb]
$b\bar{b}A/H/h(\to \tau\tau)$, $m_A = 120$ GeV	7.62/0.69/7.3
$gg \to A/H/h(\to \tau\tau)$, $m_A = 120$ GeV	4.93/2.21/4.1
$b\bar{b}A/H/h(\to \tau\tau)$, $m_A = 200$ GeV	0.49/0.49/0.02
$gg \to A/H/h(\to \tau\tau)$, $m_A = 200$ GeV	0.13/0.16/0.46
$b\bar{b}A/H/h(\to \tau\tau)$, $m_A = 300$ GeV	0.02/0.03/0.002
$gg \to A/H/h(\to \tau\tau)$, $m_A = 300$ GeV	0.003/0.005/0.11
Background process	σ [pb]
$W \to \ell$ ($\ell = e, \mu, \tau$)	10.5×10^3
$Z/\gamma^* \to \ell^+\ell^-$ ($m_{\ell\ell} > 10$ GeV)	4.96×10^3
$t\bar{t}$	165
Single-top (t-, s- and Wt-channels)	58.7, 3.9, 13.1
Di-boson (WW, WZ and ZZ)	46.2, 18.0, 5.6

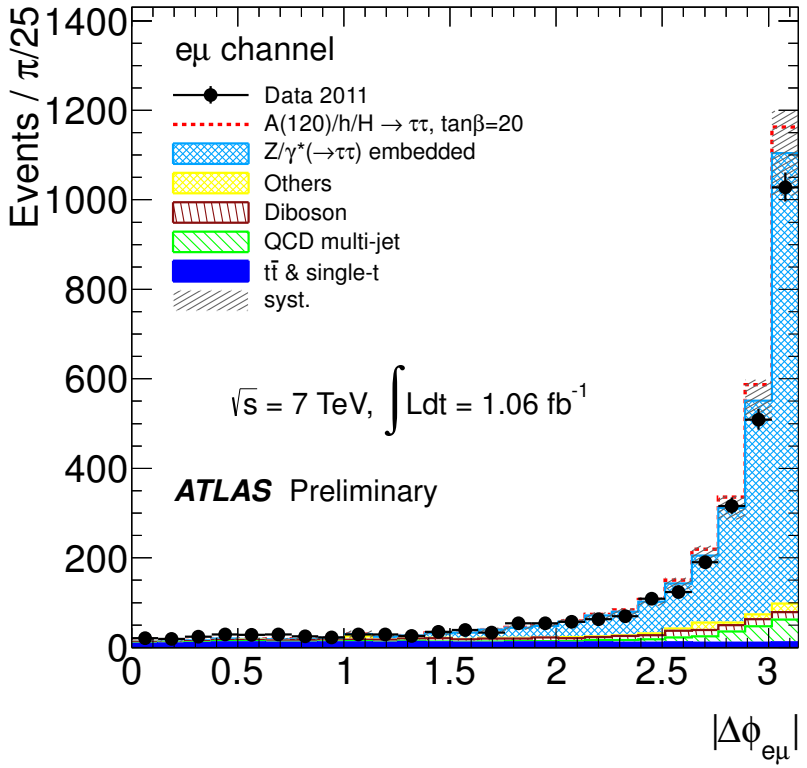
Preselection

- either:
  - single-electron trigger (e20), $p_{\mathrm{T}}^{e} > 22$ GeV, $p_{\mathrm{T}}^{\mu} > 10$ GeV
  - single-muon trigger (mu18), $p_{\mathrm{T}}^{e} > 15$ GeV, $p_{\mathrm{T}}^{\mu} > 20$ GeV
- exactly one isolated electron and one isolated muon
- calorimetric and tracking based isolation requirements
- opposite electric charge
- further topological cuts

- example signal in the following: $m_A = 120$ GeV, $\tan\beta = 20$

Selection Variables





- $p_{\mathrm{T}}^{e} + p_{\mathrm{T}}^{\mu} + E_{\mathrm{T}}^{\mathrm{miss}} < 120$ GeV
- mainly against $t\bar{t}$ and dibosons

- $\Delta\phi_{e\mu} > 2.0$
- mainly against $t\bar{t}$ and dibosons

- Background composition after topological selection:

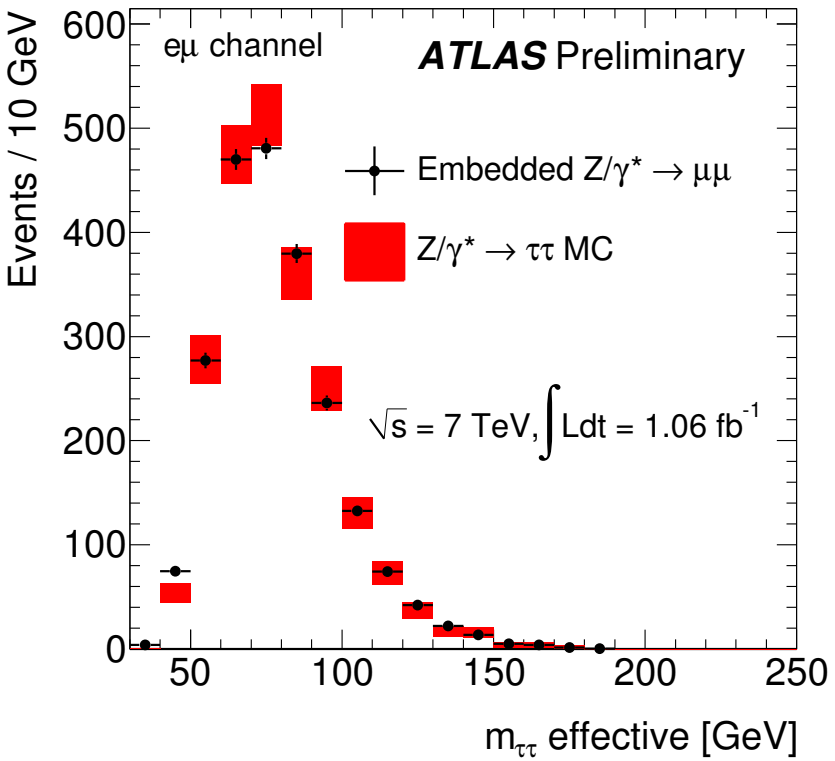
	Data	Total MC bkg (w/o QCD)	W+jets	Di-boson	$t\bar{t}$+ single-top	$Z/\gamma^* \to ee, \mu\mu$	$Z/\gamma^* \to \tau^+\tau^-$	A/H/h signal
$e\mu$	2472	2496±27	30±15	109±5	100±2	40±4	2217±22	155±6

Estimation of $Z \to \tau\tau$ background shape

Embedding

- more details in talk by Thomas Schwindt
- select $Z \to \mu\mu$ in data
- replace muons by τ's
- simulate τ-decays and detector response to τ decay products
- merge back with remaining data event
- pile-up and UE effects thus mostly estimated from data
- normalization done to $Z \to \tau\tau$ MC after preselection cuts

- shape of final mass variable (details later)



QCD background estimate

- ABCD method

	isolated	anti-isolated
$q_e = -q_\mu$	A	C
$q_e = q_\mu$	B	D

- assume $A/B = C/D$ (uncorrelated variables), shapes taken from region C
- $n_A = r_{C/D} \times n_B$, $r_{C/D} = 2.00 \pm 0.03(stat.) \pm 0.39(syst.)$
- $n_A^{QCD} = 120 \pm 20(stat.) \pm 23(syst.)$

Systematics

	Di-boson	$t\bar{t}$+Single-top	$Z \to \tau\tau$	Signal
$\sigma_{inclusive}$	$\pm 7\%$	$\pm 10\%$	$\pm 5\%$	$\pm 14\%$
e efficiency	$\pm 4\%$	$\pm 3\%$	$\pm 5\%$	$\pm 5\%$
μ efficiency	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$
energy scales and resolution	$\pm 2\%$	$\pm 6\%$	$\pm 1\%$	$\pm 1\%$
Luminosity		$\pm 3.7\%$		
Total	$\pm 10\%$	$\pm 13\%$	$\pm 9\%$	$\pm 16\%$

Final Discriminating Variable: Effective Mass

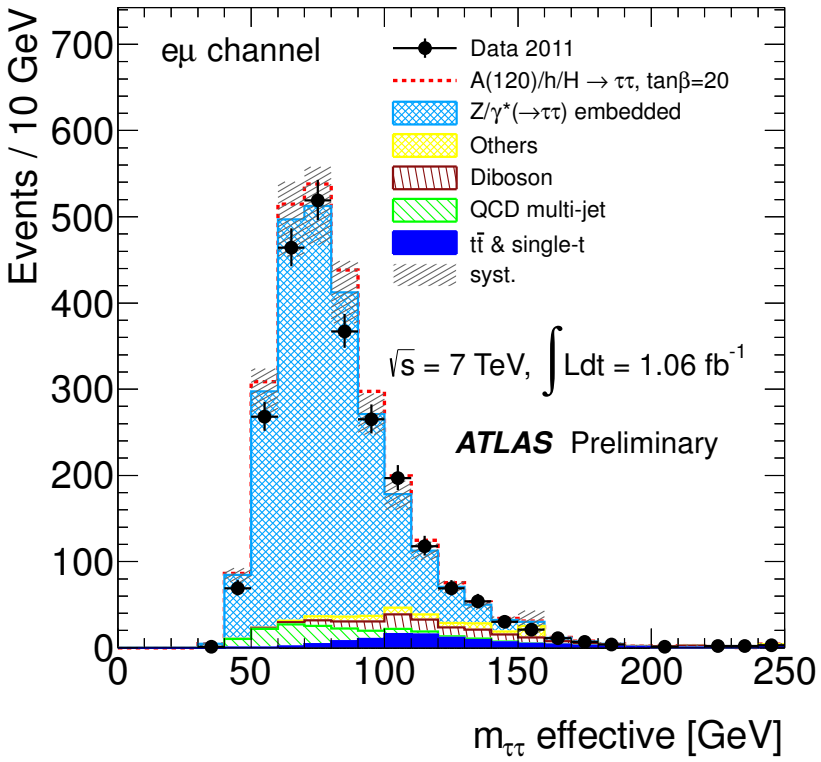
Effective mass

- collinear mass not promising for inclusive analysis (back-to-back topology)
- used instead the "effective" mass:

$$m_{\text{eff}}^2 = (p_e + p_\mu + p_{E_{\text{T}}^{\text{miss}}})^2$$

with

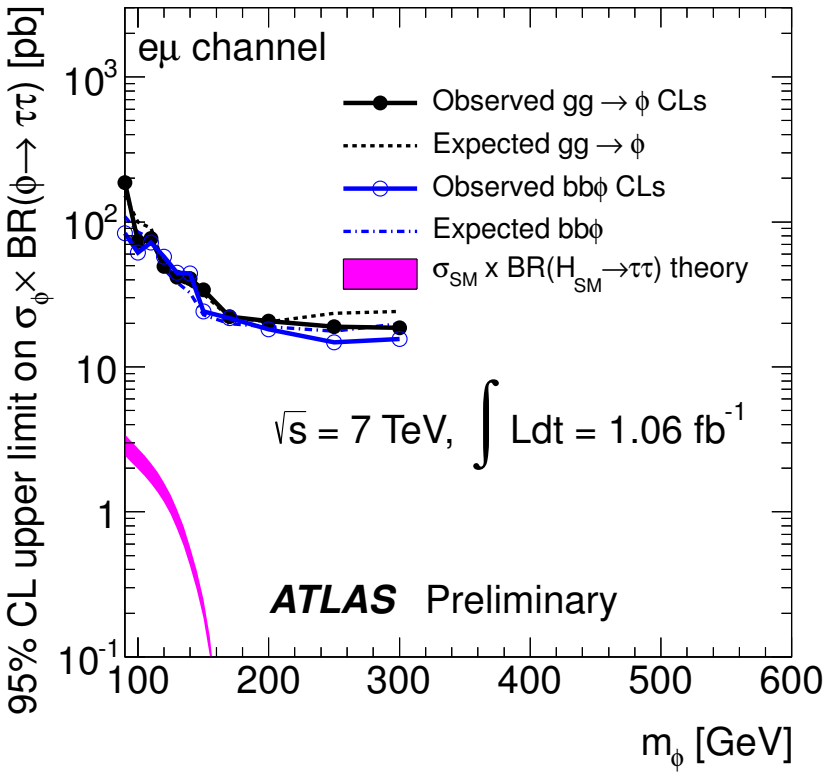
$$p_{E_{\text{T}}^{\text{miss}}} = (E_{\text{x}}^{\text{miss}}, E_{\text{y}}^{\text{miss}}, 0, E_{\text{T}}^{\text{miss}})$$



Observed 2472 events, expect 2600 ± 200 from background

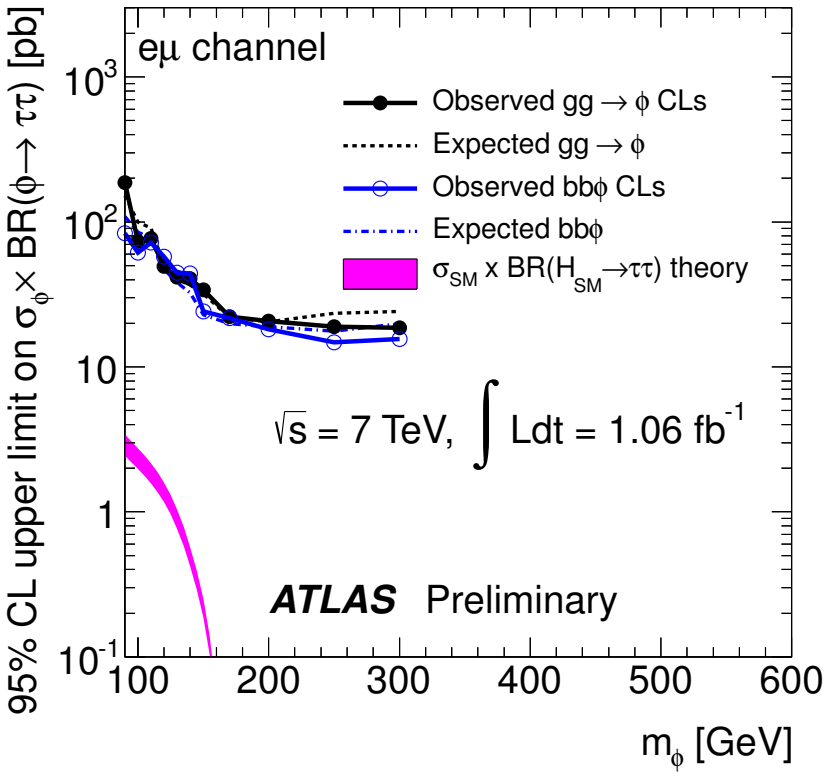
- No excess seen $\Rightarrow$ set limits!
- use mass shape information in limit setting
- Profile-Likelihood test statistic, CL_s for hypothesis test

Limit on $\sigma \times BR$



- assume 100% ggF or b-associated production and only one narrow resonance
- can be used to test arbitrary models (see talk by O. Brein on HiggsBounds)

Limit on $\sigma \times BR$



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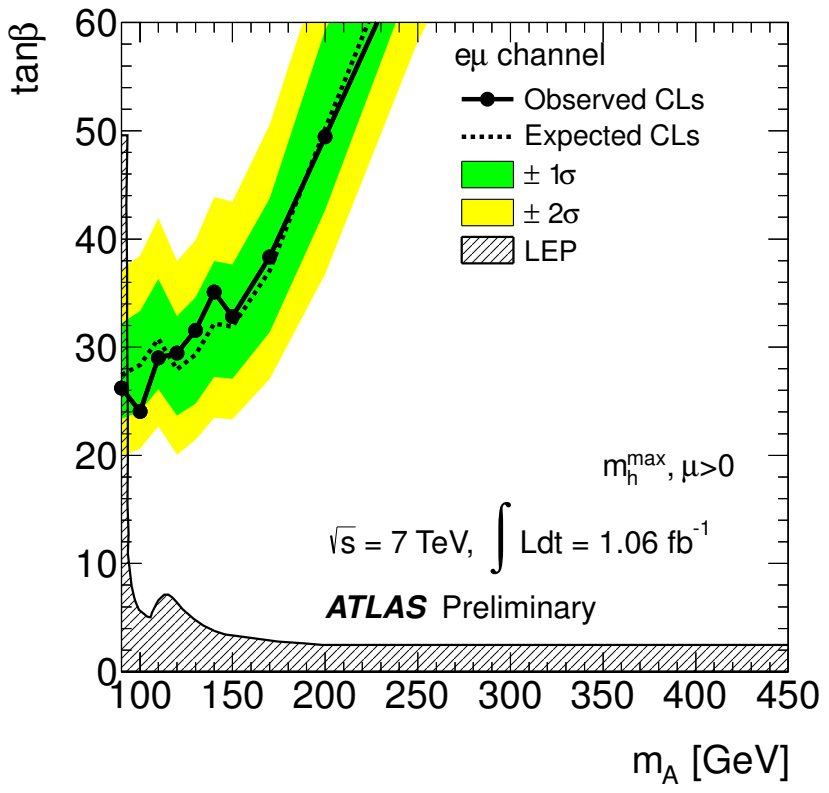
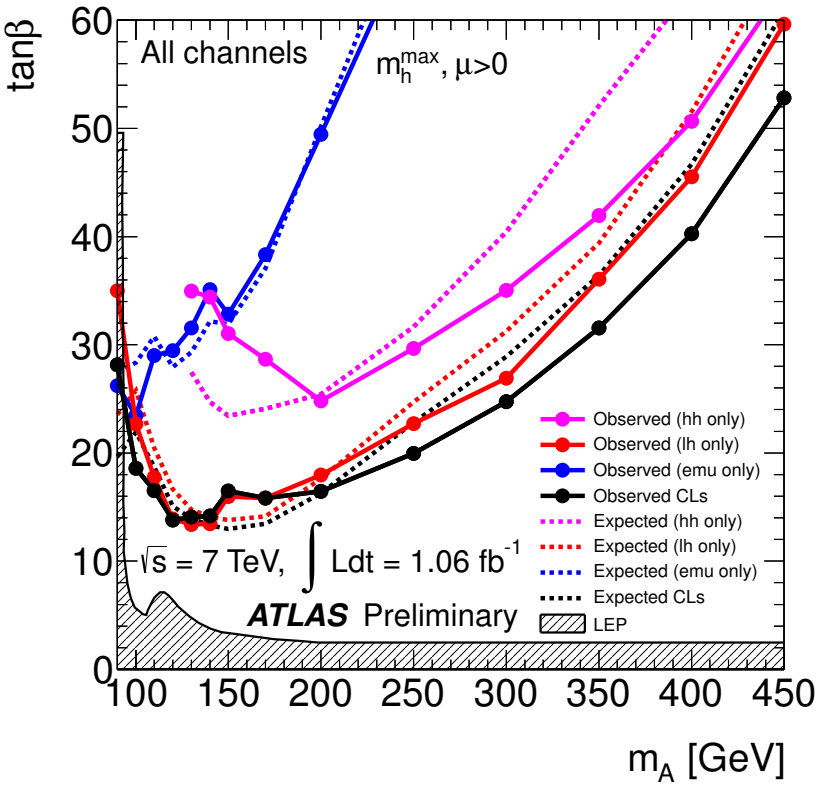
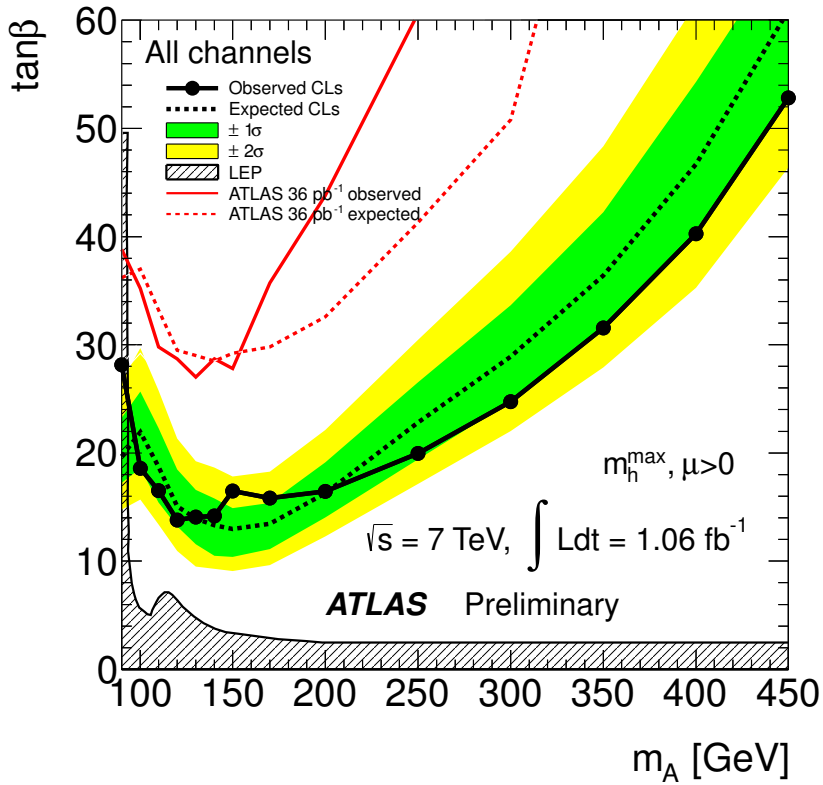
Limit in $(m_A, \tan\beta)$ plane



- assumes specific MSSM scenario (here: MHMAX)
- fixes relative contributions of ggF and b-associated production

Combination with other Decay CHannels





- $e\mu$ channel contributes most for low masses
- higher masses dominated by $\ell\tau_{had}$ channel, $\tau_{had}\tau_{had}$ significant for high masses
- Limits with 2010 dataset completely superseeded

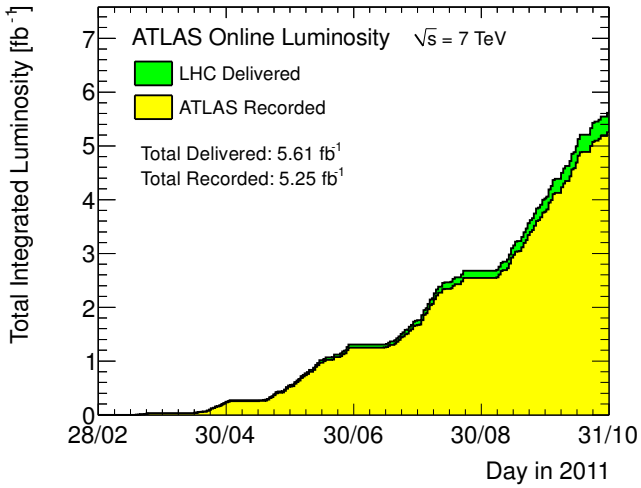
Summary

LHC Higgs cross section working group recommendations

- YR1: inclusive cross sections
- YR2: differential distributions – coming soon
- being used by ATLAS and CMS – common parameters and cross sections for both experiments

Search for neutral MSSM Higgs bosons in the $\tau\tau$ final state

- based on $1.1\,\mathrm{fb}^{-1}$ (about $4\times$ more on tape)
- no excess seen $\Rightarrow$ placed limits
- large parts of MSSM parameter excluded
- future: more exclusive analyses (b-tagging), better use of mass reconstruction techniques



- more results to come soon!