Various MC Tools
(for the Higgs search)

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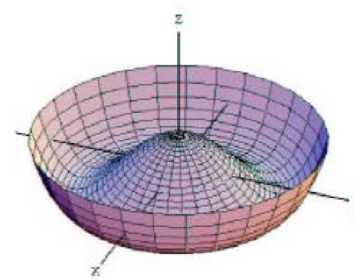

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  - H->WW
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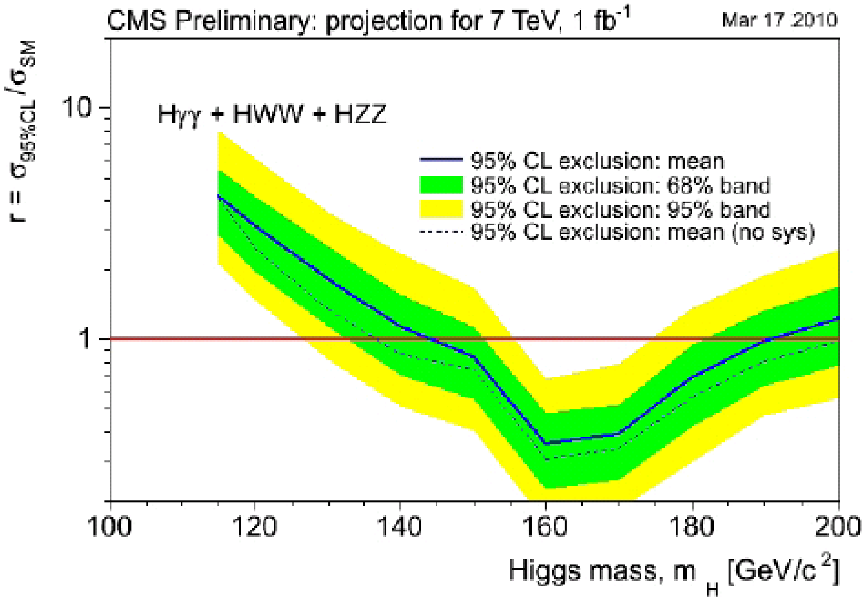
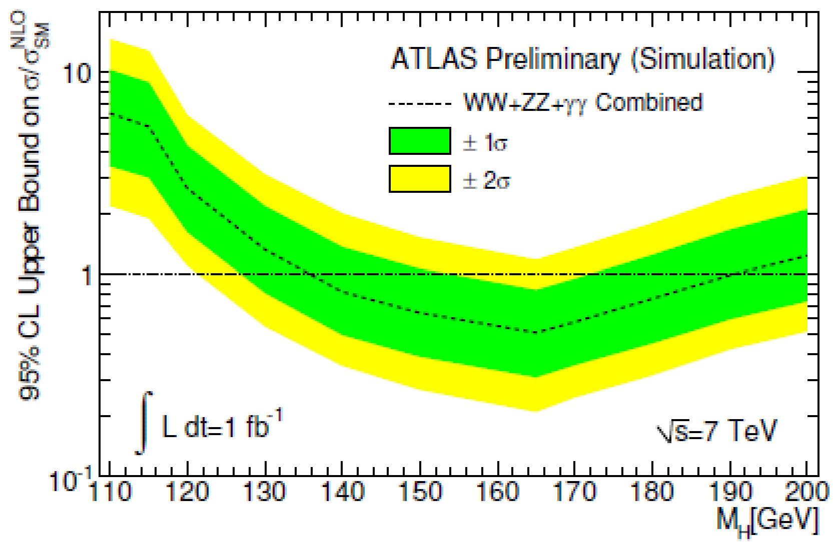
Introduction





- Data of $1fb^{-1}$ at 7TeV is still for the exclusion of SM Higgs.
- We are learning many things from data for the Higgs discovery.
- Our experiences (but needed more and more and still with large statistical uncertainties) with the 7TeV data so far shows that MC simulation and prediction is not so bad even at √s=7TeV.
(I'm working at ATLAS for the Higgs search. One of users of MC tools.)

In this talk, let's focus on MC tools used in the SM Higgs search.

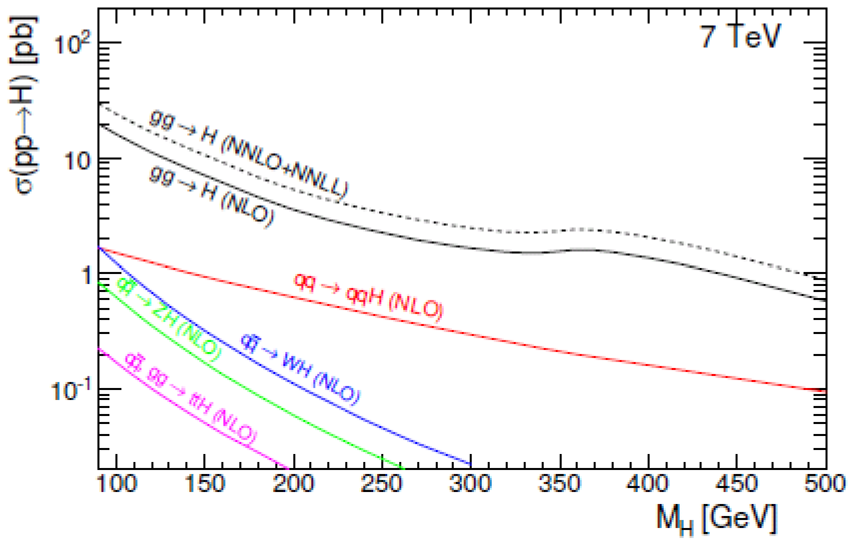
MC Tools

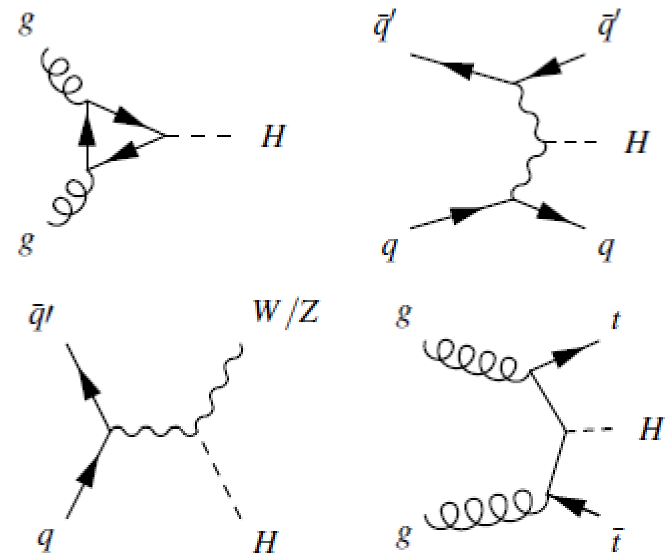
- There are two kinds of MC tools
  - Event generation (generators)
    - Inputs to detector simulations.
    - LO or NLO event generators are available in the market.
      - Many LO event generators;
        - » Pythia, Herwig, Alpgen, Sherpa, MadGraph, AcerMC, CompHep, CalcHep …
      - There are a few NLO event generators;
        - » MC@NLO, Powheg, …
  - Calculation of physics variables (calculators)
    - (differential) cross-section, branching ratio, …
    - NLO or higher order corrections have been achieved.
      - NNLO calculation is available.
    - Events/distributions produced with MC simulation are reweighted with outputs from these calculators. For example;
      - Signal events by Pythia but we use NNLO x-sec and NLO BR to evaluate exclusion limits.
      - $\gamma\gamma$+jets by Alpgen but reweighted with ResBos/Diphox.

(+ a kind of "framework" like Rivet etc but not mentioned in this talk.)

Higgs Signal Production Tools

- Production process : gluon-fusion, VBF, WH/ZH, ttH and bbH





Process	Event generators used in ATLAS/CMS/CDF/D0
Gluon-fusion	Pythia, MC@NLO
VBF	Pythia, Herwig, Sherpa
WH/ZH	Pythia, Herwig, Sherpa
ttH	Pythia
bbH for MSSM	Pythia, Sherpa

LO MC to NLO MC

- We use mainly LO event generators to produce Higgs signal except for gluon-fusion production with MC@NLO.
- NLO MC generators are available for most of signal processes.

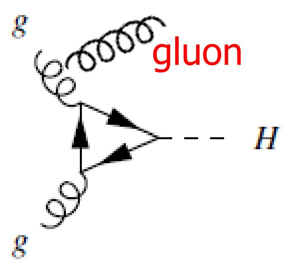
Process	NLO event generators
Gluon-fusion	MC@NLO, Powheg
VBF	Powheg
WH/ZH	MC@NLO, Powheg
ttH	Not yet but will be implemented soon.
bbH	After ttH? (urgent for MSSM?)

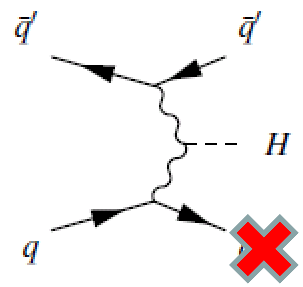
  - ATLAS and CMS (will) start to use Powheg.

Why NLO MC? -> NEXT two pages

Signal MC

- Exclusive analysis with the number of jets is performed because two dominant signal production processes (gluon-fusion and VBF) have different event topologies.
  - 0 jet analysis for gluon-fusion
  - 2 jets analysis for VBF
  - 1 jet analysis for both;
    - Gluon-fusion + additional 1 jet
    - VBF with mis-reconstruction of 1 jet or out-of-acceptance





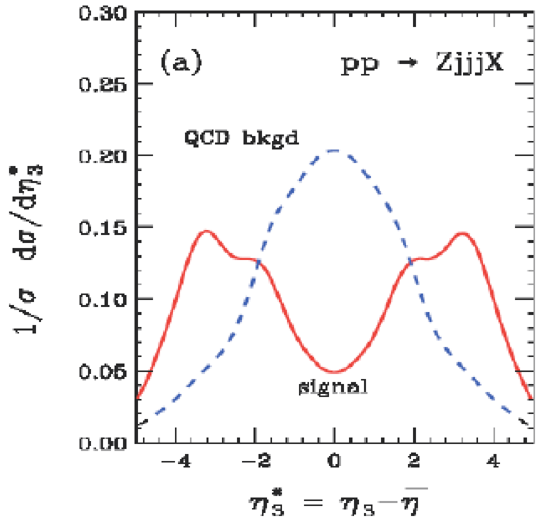
-> Description of additional one jet in gluon-fusion is important.
-> <u>NLO MC of gluon-fusion is required.</u>

(Higgs pT description is also better. This variable can be one of discrimination parameters.)

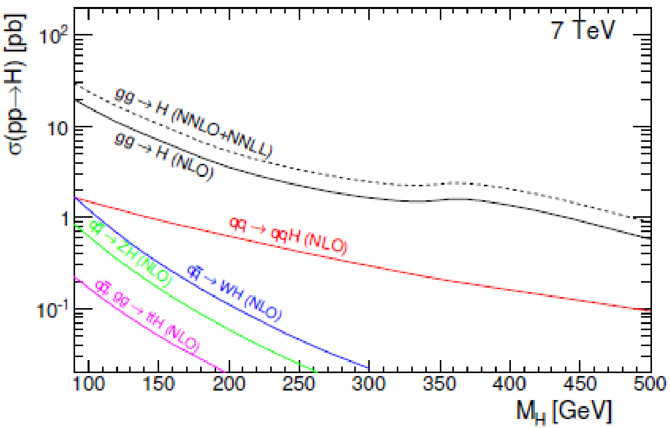
- Pythia and MC@NLO has been used so far.
- Powheg will be tested and used soon.
  - Only "positive weight" events -> We can avoid careless mistakes.

Signal MC

- "Central jet veto" is applied in VBF/2jets analysis.
  - Description of the 3rd jet in VBF is important.
    -> NLO MC of VBF is also required.
  - Pythia and Herwig have been used so far.
  - Powheg can be used.
    - VBF structure (a dip in η distribution) and 3jet should be checked.



- WH(ZH) have contributions to VBF/2jets analysis in low mass region.
  - We'll use looser conditions of VBF selection than our MC VBF studies in 2010/2011.
    - These channels could pass, for example, a looser Δη cut etc.
  - Pythia and Herwig have been used for "VH".
  - Sherpa can generate events with "VBF+VH".
  - Powheg can be also used for these channels.



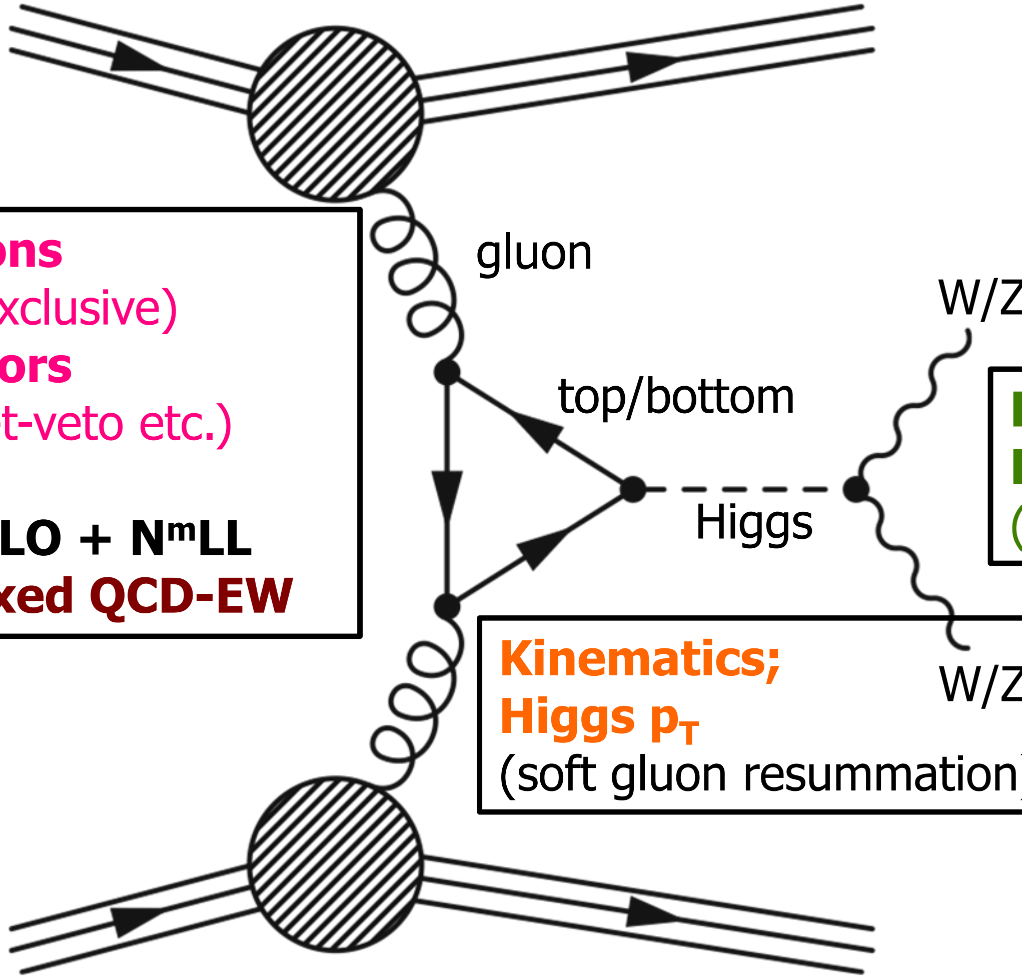
"Powheg" could be a baseline generator for the Higgs signal processes.

Higgs Signal Prediction

4 categories
- Cross sections
- Branching ratio
- PDF
- Kinematics

Higgs Cross Sections
(inclusive/exclusive)
Differential K-factors
(effect of jet-veto etc.)

QCD correction $N^kLO + N^mLL$
EW correction, Mixed QCD-EW



Higgs decay
Branching ratios
(QCD/EW corr.)

Kinematics;
Higgs p_T
(soft gluon resummation)

PDF+α_s uncertainties
Renormalization/Factorization scale dependence

What tools are available now? -> NEXT page

Tools

Cross Section

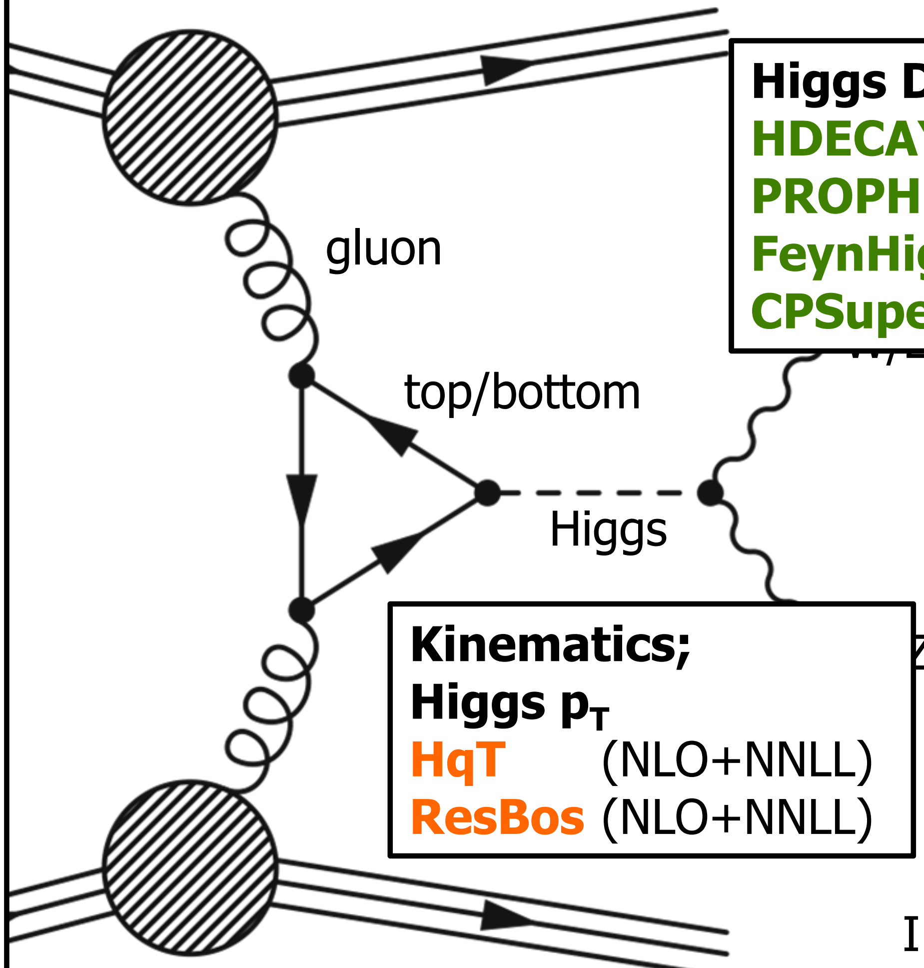
ggF
HIGLU (NLO QCD+EW)
HPro (NLO QCD)
FEHiPro (NNLO QCD+EW)
HNNLO (NNLO QCD)
ggh@NNLO (NNLO QCD)

VBF
VV2H (NLO QCD)
VBFNLO (NLO QCD)
HAWK (NLO QCD+EW)
VBF@NLO (NNLO QCD)

WH/ZH
V2HV (NLO)
… (NNLO)

ttH
HQQ (QCD LO)

bbH
bbH@NNLO (NNLO)



Higgs Decay
HDECAY (NLO)
PROPHECY4f (NLO)
FeynHiggs,
CPSuperH

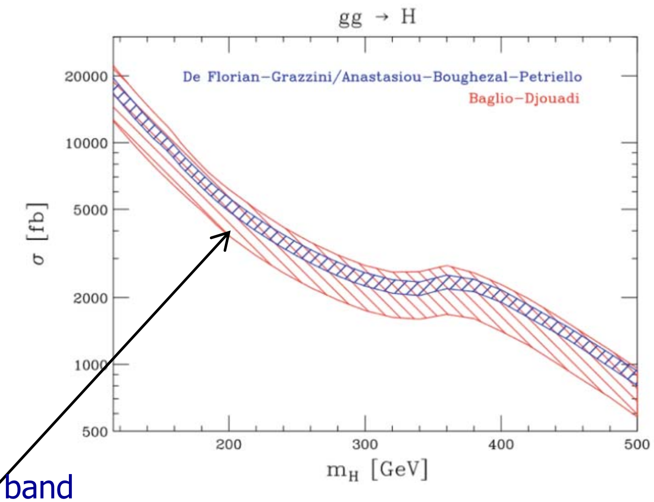
Kinematics;
Higgs p_T
HqT (NLO+NNLL)
ResBos (NLO+NNLL)

PDF: MSTW, CTEQ, NNPDF, etc.

I miss some of (new) tools …sorry.

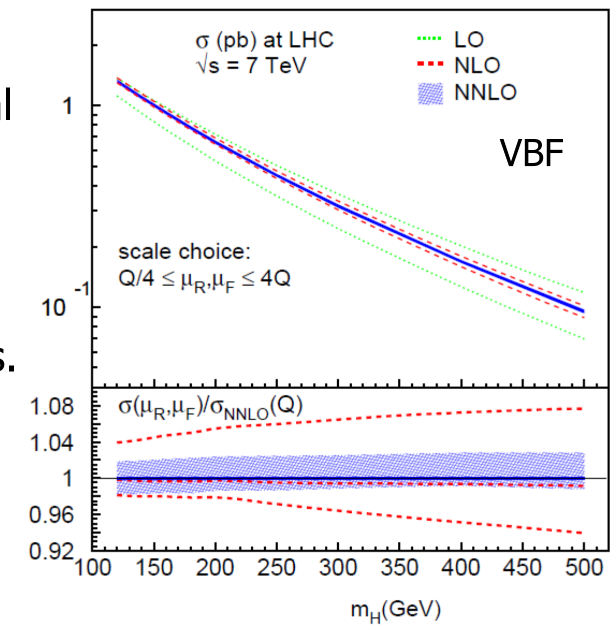
Cross section tools

- Gluon-fusion process
  - QCD NNLO+NNLL calculation is available from 3 groups.
    - De Florian and Grazzini
    - Anastasiou, Boughezal and Petriello
    - Baglio and Djouadi
  - NNLO contribution is still large ~10%.
    - We need one more? a few %?
  - Scale uncertainty ~ 7-8 %, PDF+α_s uncertainty ~ 3-4 % -> ~10% in total



Blue band

- VBF process
  - HAWK : QCD NLO calculation is ready including s-channel and interference between s/t/u-channels.
  - VBF@NNLO : QCD NNLO calculation is available.
    - NNLO contribution is small <1%
    - Scale uncertainty is small ~2%

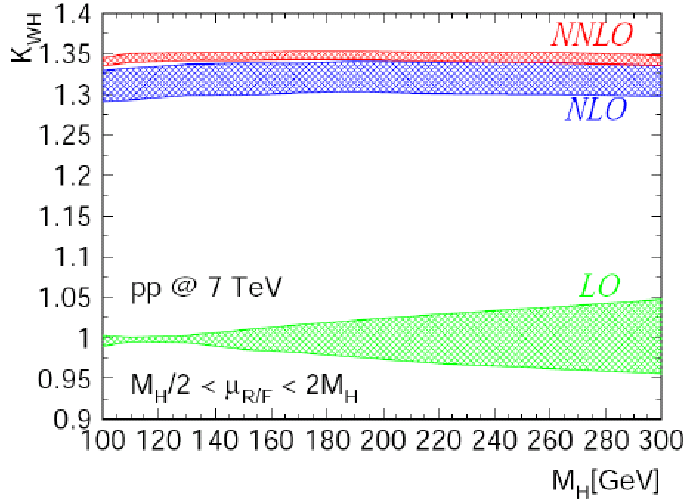


Bolzoni, Maltoni, S.M., Zaro '10

Cross section tools

- WH and ZH process
  - WH -> QCD NNLO calculation is ready.
  - NNLO contribution ~ 4%.

$\sqrt{s}$ = 7 TeV R.Harlander



- ttH process
  - NLO calculation is ready.
  - NLO contribution is small. A few% at m_H=120GeV

PAUL SCHERRER INSTITUT PSI MSTW2008 small K-factors! M. Spira

M_H [GeV]	LO [fb]	NLO [fb]	scale [%]	α_s [%]	PDF [%]
90	213.17(9)	224.8(3)	[−9.8%,+4.3%]	[−0.3%,+0.4%]	[−3.5%,+3.4%]
95	186.11(8)	195.6(2)	[−9.9%,+4.2%]	[−0.4%,+0.4%]	[−3.6%,+2.7%]
100	162.70(7)	170.4(2)	[−9.6%,+4.1%]	[−0.4%,+0.4%]	[−3.2%,+3.0%]
105	143.06(6)	149.0(2)	[−9.7%,+4.1%]	[−0.3%,+0.2%]	[−3.6%,+3.0%]
110	126.06(6)	130.8(2)	[−9.7%,+3.7%]	[−0.4%,+0.2%]	[−3.6%,+2.6%]
115	111.38(5)	115.0(1)	[−9.5%,+3.6%]	[−0.5%,+0.4%]	[−3.4%,+3.0%]
120	98.66(4)	101.4(1)	[−9.4%,+3.4%]	[−0.4%,+0.3%]	[−3.1%,+3.2%]
125	87.66(4)	89.8(1)	[−9.6%,+3.5%]	[−0.3%,+0.3%]	[−3.3%,+3.1%]

$\sqrt{s}$=7TeV

BR tools

- NLO calculation by HDECAY and PROPHECY4f

Theoretical uncertainties from missing higher orders in PROPHECY4f

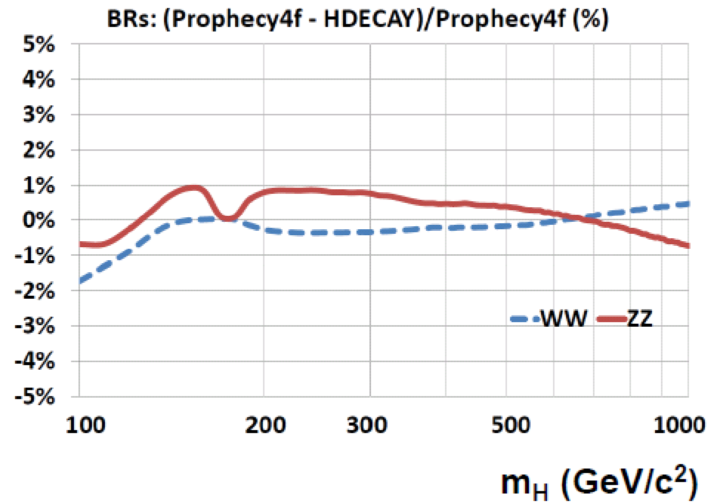
partial width	QCD	electroweak	total
$\mathrm{H} \to \mathrm{bb/cc}$	~ 0.1–0.2%	~ 1–2% for $M_\mathrm{H} \lesssim 135\,\mathrm{GeV}$	~ 1–2%
$\mathrm{H} \to \tau\tau$		~ 1–2% for $M_\mathrm{H} \lesssim 135\,\mathrm{GeV}$	~ 1–2%
$\mathrm{H} \to \mathrm{tt}$	$\lesssim 5\%$ [a]	$\sim 2\%$ for $M_\mathrm{H} < 500\,\mathrm{GeV}$	$\sim 5\%$
		$\sim 0.1(\frac{M_\mathrm{H}}{1\,\mathrm{TeV}})^4$ for $M_\mathrm{H} > 500\,\mathrm{GeV}$	~ 5–10%
$\mathrm{H} \to \mathrm{gg}$	$\sim 10\%$ [b]	$\sim 1\%$	$\sim 10\%$
$\mathrm{H} \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$\mathrm{H} \to \mathrm{WW/ZZ}$		$\sim 0.5\%$ for $M_\mathrm{H} < 500\,\mathrm{GeV}$	$\sim 0.5\%$
$\to 4f$		$\sim 0.17(\frac{M_\mathrm{H}}{1\,\mathrm{TeV}})^4$ for $M_\mathrm{H} > 500\,\mathrm{GeV}$	~ 0.5–15%

$M_\mathrm{H} > 500\,\mathrm{GeV}$: higher-order heavy-Higgs corrections dominate error

[a] mass effects only at NLO
[b] only NNLO included in HDECAY

Ansgar Denner

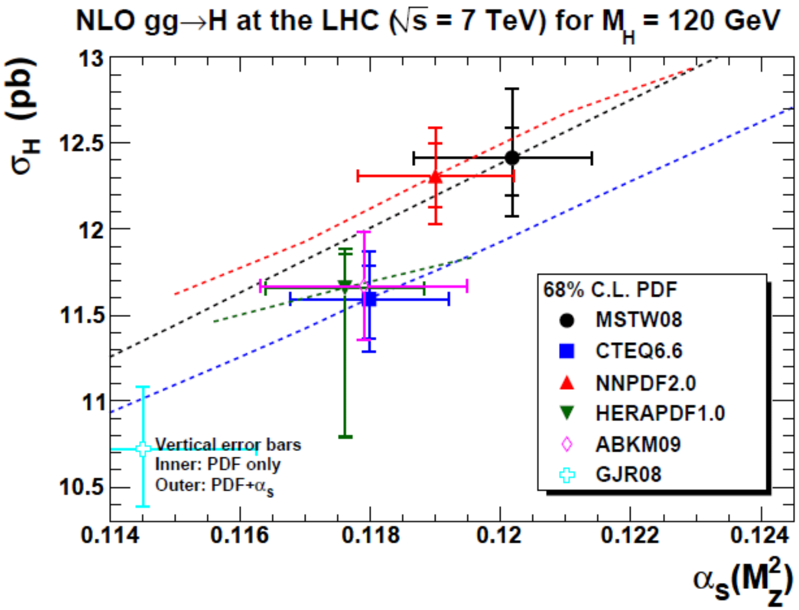
Ivica Puljak

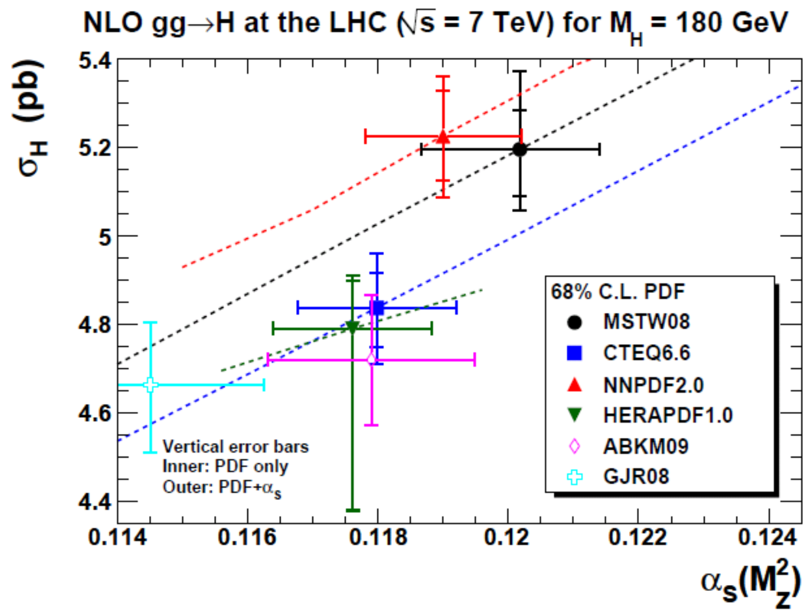


- WW/ZZ, $\gamma\gamma$, $\tau\tau$, bb is 0.5-2% in m_H<500GeV.
- Good agreement between HDECAY and PROPHECY4f ~1% level
  - ~2% in a low mass region.

PDF tools

Graeme Watt





- NLO gluon-fusion x-sec as a function of α_s for m_H=120 and 180GeV
- Fitted α_s value is agreed within ~2%. (MSTW <-> CTEQ)
  - The best α_s value depends on PDF.
- PDF only and PDF with α_s uncertainty ~ 4%.
- Higgs gluon-fusion x-sec with MSTW and CTEQ is agreed within ~8%.
  - Depend on the choice of α_s value.

LHC Higgs x-sec WG was setup with ATLAS/CMS/Theory groups.

They will define common parameters for the Higgs search at LHC.

BG estimation

- Experimentalists want to estimate BG from data itself as much as possible.
  - BG in a signal region is estimated from control regions in data.
- There are two (or more) categories
  - BG estimation could be done with almost no MC help.
    - Process : QCD, W+jets, OS=SS contribution, … (~ fake BG)
    - Methods are checked by alternative methods based on data or MC.
    - A (dominant) uncertainty comes from data statistics in control regions.
      - No uncertainty from MC if we don't use MC helps.
    - Basically, even if our MC simulation does not describe the data well, we can estimate our BG properly.
  - BG estimation with MC helps
    - Process : Z+jets, ttbar, SM WW/ZZ, … (~ not fake BG)
      - It is difficult to extract them from data due to small x-sec and contamination of other BG processes.
    - Ratios and/or shapes are obtained from MC but their normalization is determined by data. (We can reduce systematic uncertainties.)
    - Better description of data in our MC simulation is required.
    - Uncertainties from MC prediction/simulation become systematic uncertainties.
      - Scale and PDF uncertainties

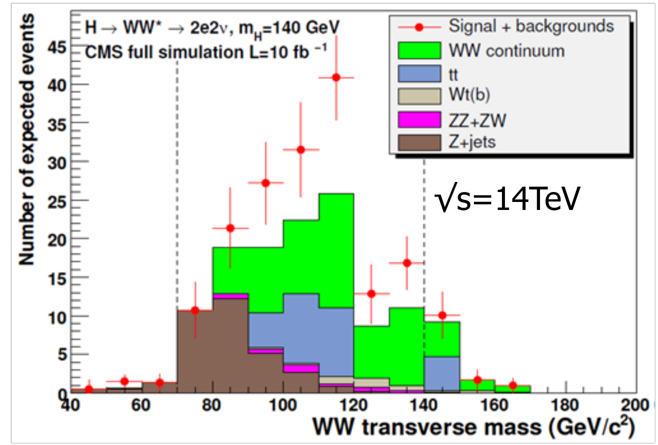
In the reality, it is impossible to estimate all the BGs with only the former technique.

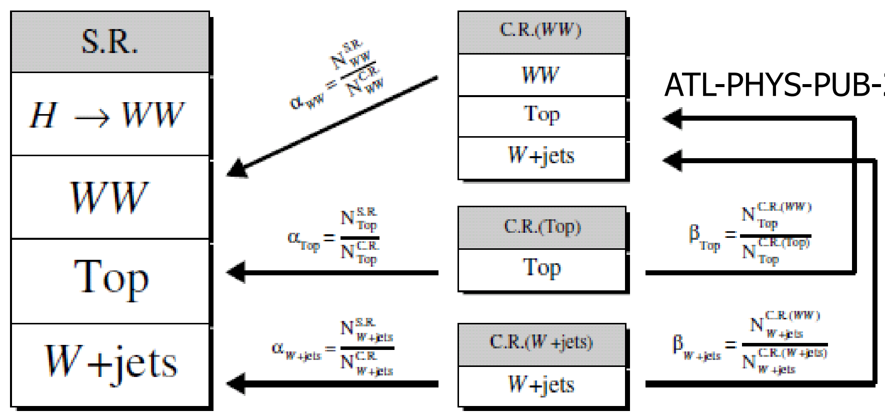
As example,

H->WW->lνlν

- No mass peak is observed in this channel.
  -> BG estimation is very important.
  - BG shapes are obtained from MC.
    - Shape uncertainties should be evaluated.
  - Normalization: numbers of BG events in a signal region are estimated from control regions (data) with some fractions (MC). -> Bottom fig (ATLAS)
    - All the fractions obtained from MC have uncertainties.

  -> MC generators are used to obtain these parameters.





ATL-PHYS-PUB-2010-005

-> Q: What type of generators are required?
A: It depends on <u>"event topology and event selection to suppress BG", that is, there is no unique answer, which can be used for all the physics.</u>
The choice of generators should be done physics-by-physics.

BG MC generators for Higgs search

- What event topology has to be generated well, for example in case of H->WW->lνlν?
  - "2 leptons" is not good enough because we veto events by using an additional jet.

  -> We need "2 leptons" plus a good description of the additional jet.
    - "up to 1jet" should be descried properly!

- Our requirement/request on "(new) event generators" is
  - Such jet(s) should be generated by ME event generators or NLO generators.
    - PS is OK but we want to avoid to use PS for the description of jets used in our event selection. (this is not the case for additional jet of NLO generators.)
    - This is our motivation to use ME generators in our analysis.
      - ME-PS matching should be performed to avoid double counting.
    - We need to check kinematics distributions between data and MC.

- We'll review generators used in SM H->WW, γγ, ZZ and tautau analysis from this viewpoint.

BG MC for H->WW->lνlν

- Requirement from “event topology+event selection”
  - 2lepton+up to 1jet for 0jet analysis
  - 2lepton+up to 2jets for 1jet analysis
  - 2lepton+up to 3jets for 2jet(VBF) analysis.

Process	Generator	OK? (from my view)
qq/qg->WW	MC@NLO	0jet analysis
qq/qg->WW	Pythia	△
qq/qg->WW+jets	Alpgen/MadGraph/Sherpa/…	0/1/2jet analysis
gg BOX WW	gg2WW	△-> “+1jet” possible??
W	Pythia	△
W	MC@NLO	△
W+jets	Alpgen/MadGraph/Sherpa/…	0/1/2jet analysis
ttbar	MC@NLO	0/1/2jet analysis
ttbar+jets	Alpgen/MadGraph/Sherpa/…	0/1/2jet analysis

Note1: gg BOX contribution is small ~ 3% of qq/qg->WW.
Note2: we need W+up to 2jets for W sample because one of jets has to be a fake lepton.

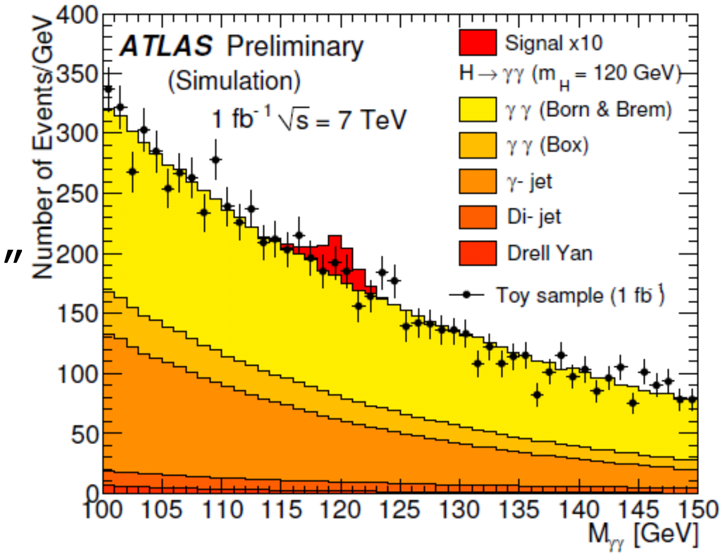
BG MC for H->WW->$l\nu l\nu$

Process	Generator	OK? (from my view)
Single top (t-ch)	MC@NLO	0/1/2jet analysis
Single top (s-ch)	MC@NLO	0/1jet analysis
Single top (Wt)	MC@NLO	0/1jet analysis

Single top is less important than ttbar(~160pb) but x-sec of t-channel is ~60pb, so we cannot ignore it. (LHC, 7TeV)
For 2jet analysis, ME generators with ME-PS matching could be used.
(CDF use MadGraph but w/o ME-PS matching(?))

The choice of baseline of ME generator depends on experiment.
- Alpgen at CDF/D0
- Alpgen and Sherpa at ATLAS
- MadGraph at CMS
(All the generators are used for cross-checks.)

BG MC for H->γγ



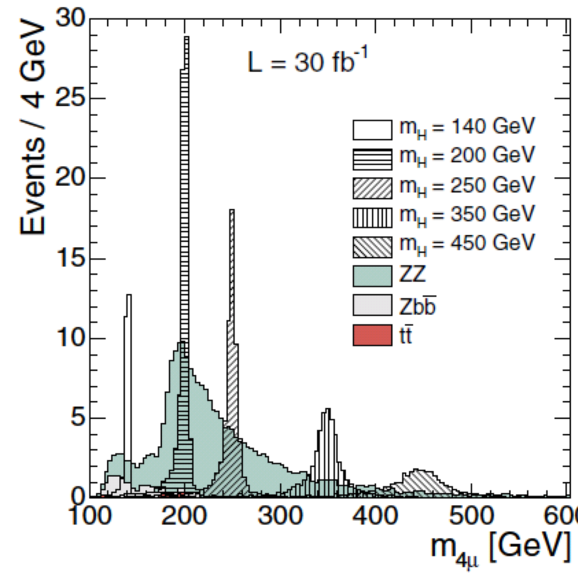
- Requirement from "event topology+event selection"
  - 2 photons for inclusive analysis (this is different from H->WW!)
  - 2 photons+up to 2jets for 1jet analysis
  - 2 photons+up to 3jets for 2jet(VBF) analysis

Process	Generator	OK? (from my view)
γγ	Pythia	inclusive analysis
γγ+jets	Alpgen/MadGraph/Sherpa…	0/1/2jet analysis
EW γγ+jets	MadGraph/Sherpa…	1/2jet analysis
γ+jet	Pythia	inclusive analysis
γ+jets	Alpgen/MadGraph/Sherpa/…	0/1/2jet analysis
dijets	Pythia	inclusive analysis
Multi-jets	Alpgen/MadGraph/Sherpa/…	0/1/2jet analysis

Other important topic is fragmentation.
We'll measure fake rates (jet->photon) but if possible, we want to describe it well in MC simulation.

BG MC for H->ZZ->4l

- Requirement from "event topology+event selection"
  - 4leptons! (very simple like 2photons)
  - Exclusive studies are not so active.
    On the other hand, 2l2q, 2l2b, 2l2ν etc studies are active.



Process	Generator	OK? (from my view)
qq/qg->ZZ	Pythia, Herwig	Yes
gg BOX ZZ	gg2ZZ	Yes
Zbb	AcerMC/Comphep/…	Yes
Zbb+jets	Alpgen/MadGraph/Sherpa/…	Yes
ttbar	MC@NLO	Yes

BG MC for (VBF) H->$\tau\tau$

- Requirement from "event topology+event selection"
  - 2leptons(ll/lh/hh)+up to 3jets
    - Since we apply CJV, the 3rd jet is important.

Process	Generator	OK? (from my view)
QCD Z+jets	Alpgen/MadGraph/Sherpa/…	Yes
EW Z->$\tau\tau$+jets	MadGraph/Sherpa…	Yes
W+jets	Alpgen/MadGraph/Sherpa/…	Yes
ttbar	MC@NLO	Yes

For MSSM bbA search,

Process	Generator	OK? (from my view)
Zbb+jets	Alpgen/MadGraph/Sherpa/…	Yes

- Need to take care of double-counting between Z+jets and Zbb+jets. (this is the case for W+jets.)

Summary

"Signal MC tools" is ready for the Higgs hunting at LHC!!!

- Signal acceptance can be evaluated with NLO MC generators.
  - ATLAS and CMS will start to use Powheg.
- Higgs x-sec and BR prediction can be performed with NNLO/NLO precision.
  - Also, some kinematics can be reweighted.

BG (SM processes) event generators used in our analysis are also OK.

- ME generators with ME-PS matching are widely used for the Higgs search studies.
- Actually they are being tested with the real data now.
- We need more data to see kinematics of W/Z+jets and also ttbar and hope that all the generators used in our analysis will pass the real test. (probably not so easy…)

Backup

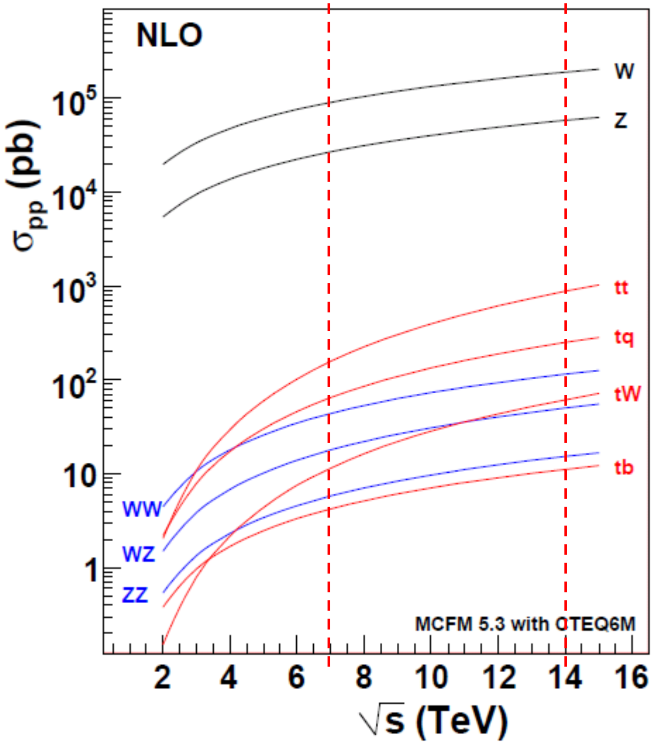
Materials

- WS of the LHC Higgs x-sec WG at CERN
  - 5 and 6 July, 2010
  - http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=92082
- MC4LHC readiness
  - 29 March – 1 April, 2010
  - http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=74601
- ATLAS
  - Expected performance of the ATLAS experiment : detector, trigger and physics
    - http://cdsweb.cern.ch/record/1125884
  - https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults
- CMS
  - CMS Physics Technical Design Report, Volume II: Physics Performance
    - http://iopscience.iop.org/0954-3899/34/6/S01/
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
- CDF and D0
  - http://tevnphwg.fnal.gov/results/SM_Higgs_Fall_09/

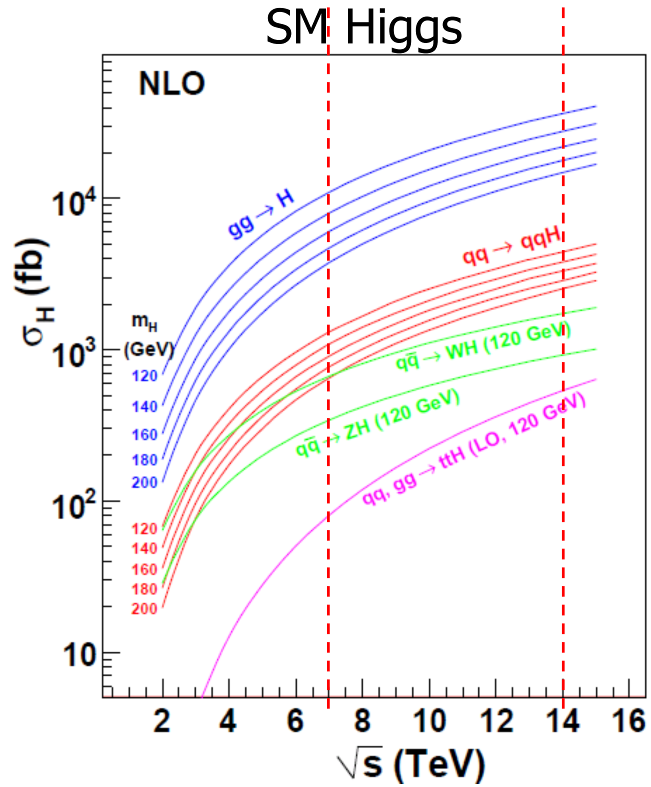
Many thanks!

"√s=14TeV to 7TeV"

Known SM process



SM Higgs

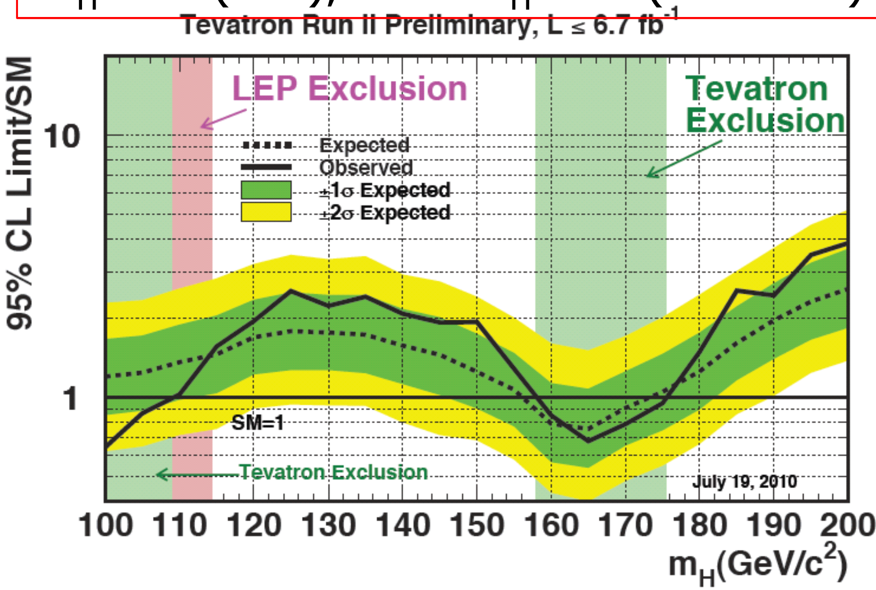


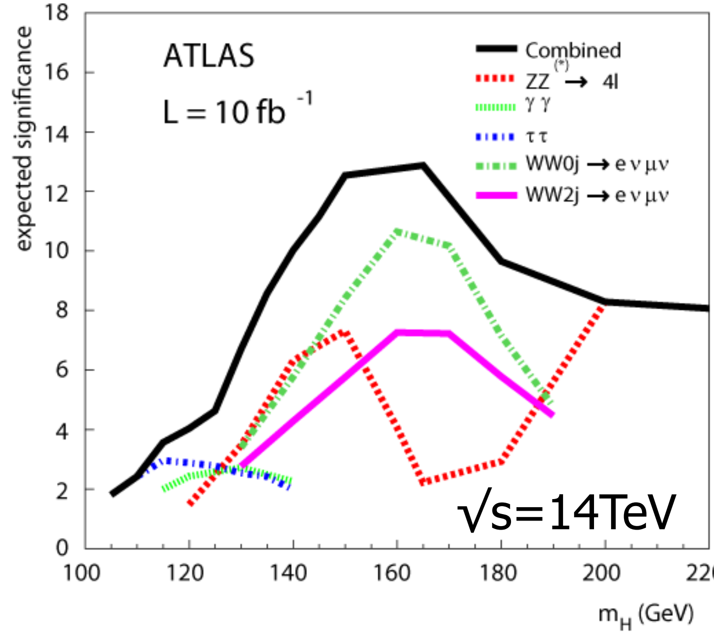
Process	7/14TeV	7/10TeV
ttbar	**0.18**	0.40
W	0.48	0.68
Z	0.46	0.67
WW	0.38	0.60

Process	7/14TeV	7/10TeV
ggF (120)	0.30	0.53
ggF (160)	0.27	0.50
VBF (120)	0.30	0.52
VBF (160)	0.27	0.50

Higgs Hunting

m_H<114(LEP), 158<m_H<175(Tevatron)



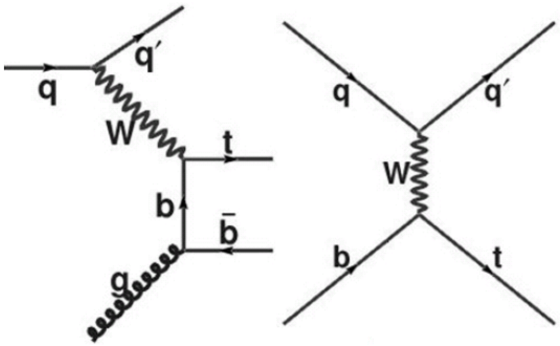


The right plot is 14TeV result, that is, prospect after the long shutdown of LHC (2012).

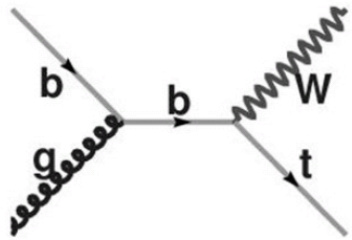
H->WW->lνlν	130-190GeV
H->ZZ->4l	130-160, >180GeV
H->γγ	120-140GeV
H->ττ	110-140GeV

A low mass Higgs can be discovered with $10fb^{-1}$ at √s=14TeV.
-> "Summer in 2014" or "Winter in 2015"

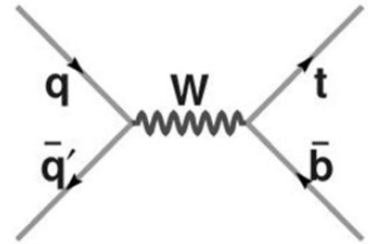
Single top



~60pb
(t-channel)



~13pb
(Wt)



~4pb
(s-channel)

LHC(7TeV)