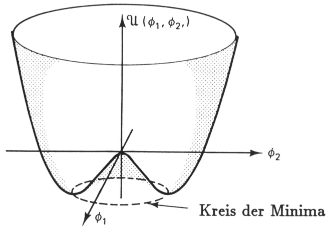
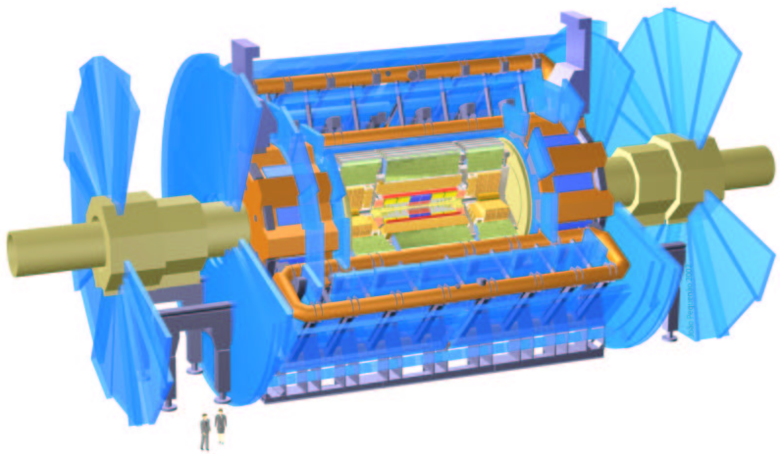
Tools for Higgs in ATLAS

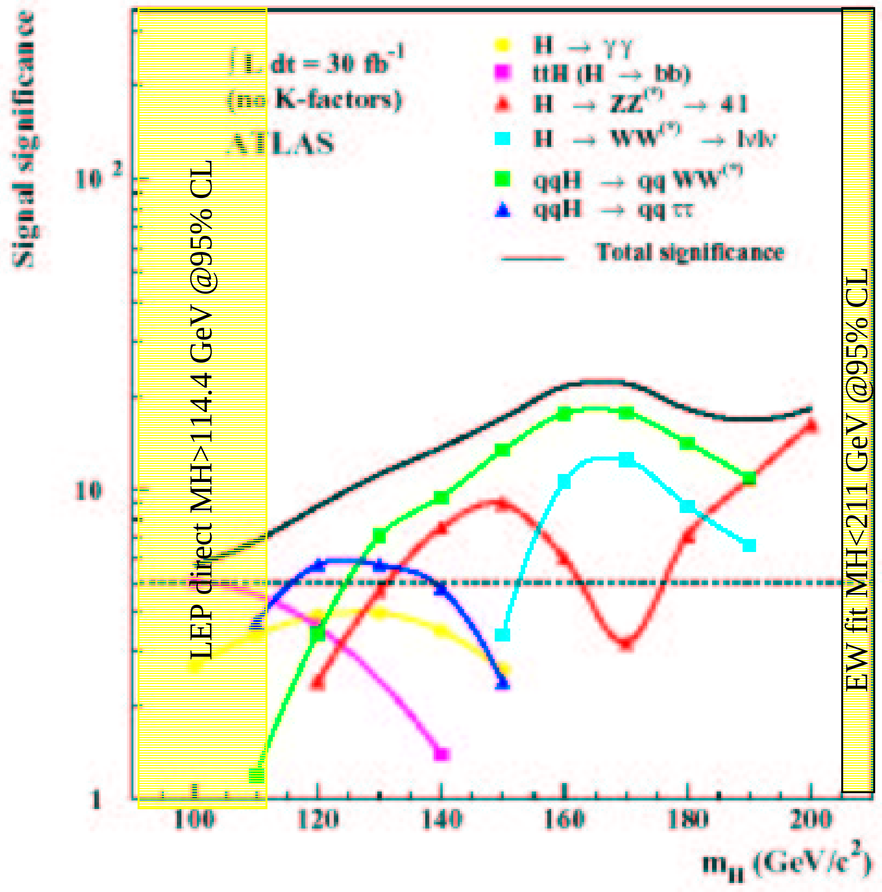
- **Revealing the physical mechanism that is responsible for the breaking of electroweak symmetry is one of the key problems in particle physics"**
- **A new collider, such as the LHC must have the potential to detect this particle, should it exist.**
- **To establish the Higgs mechanism:**
  1. **Discovery (OK)**
  2. **Parameter measurements (OK)**
  3. **Demonstration of Higgs boson self-coupling (potential) (??!)**





Outline:
- -> status of discovery potential
- -> which tools have been used
- -> present issues for few analyses

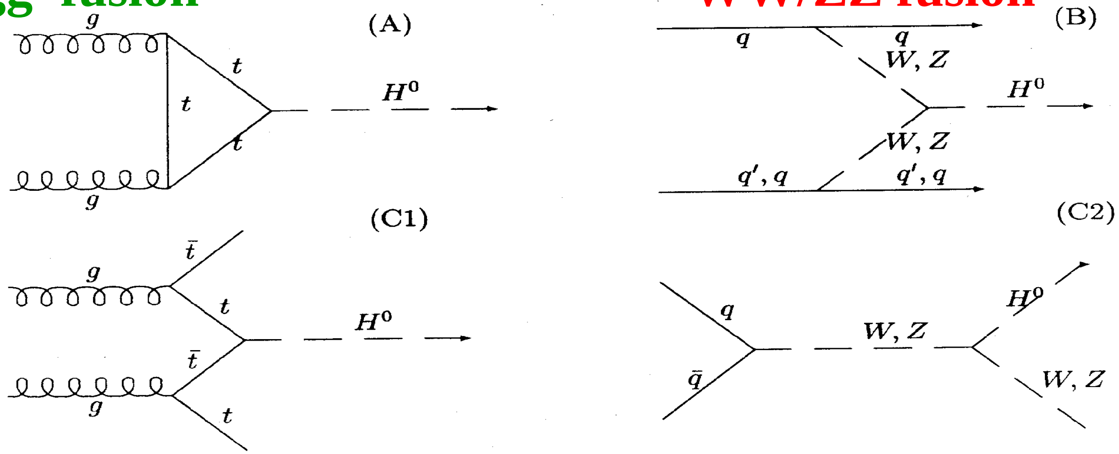
Prospects for Standard Model Higgs searches



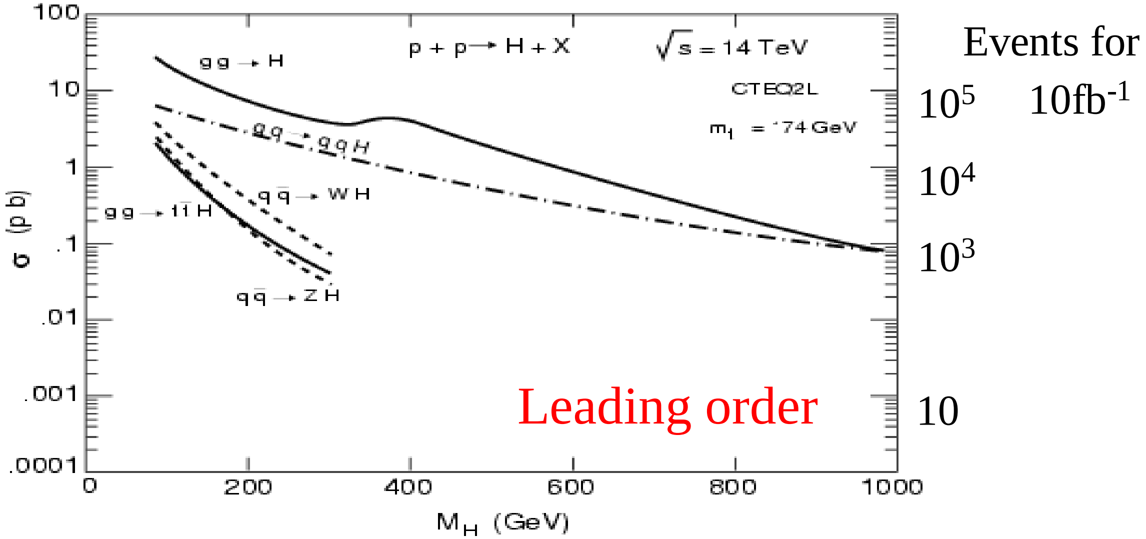
- Discovery potential well understood:
  - -> several complementary channels
  - -> some channels with very exclusive topologies (large bgd. suppression).
- Potential for coupling measurements already with $30 fb^{-1}$.
- Studied already prospects for mass, width (direct and indirect), CP, spin measurements.
- Detector performance is crucial: b-tag, ℓ/γ E-resolution, γ/j separation, E_T^{miss} resolution, forward jet tags, central jet-veto, τ-reconstruction

SM Higgs production

gg fusion **WW/ZZ fusion**



associated $t\bar{t}H$ **associated WH, ZH**



Direct:

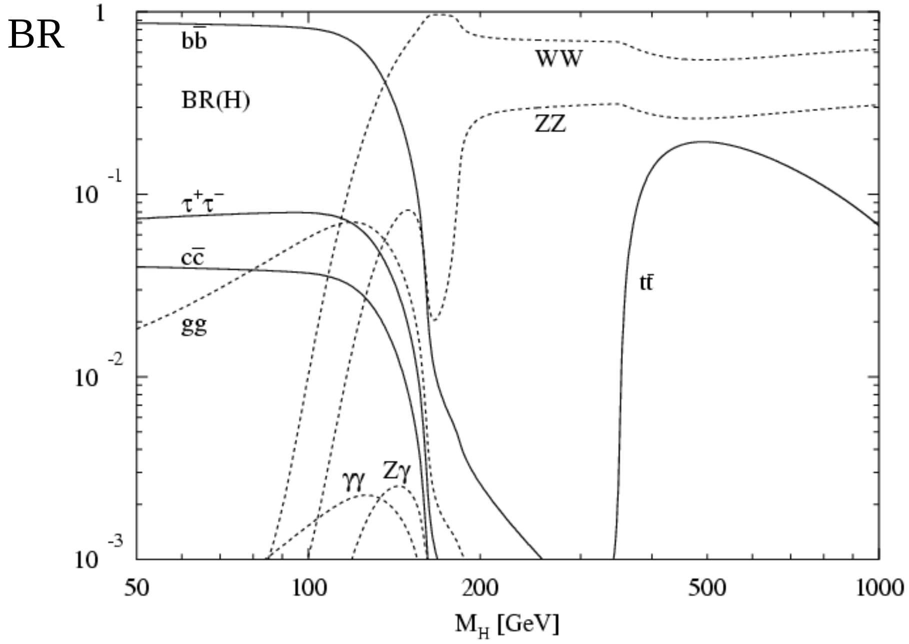
-> gg fusion dominant
-> VBFusion 20% of gg at 120 GeV
2 jets @ large η

Associated:

-> 1-10% of gg
isolated lepton from W decay
reconstruct top-quarks

Having available four production mechanisms is the key for measurements of Higgs boson parameters

Main discovery channels



Large QCD backgrounds:

σ ($H \to bb$) ≈ 20 pb;
(direct production, m_H =120 GeV)
σ (bb) ≈ 500 μb

→ no hope to trigger / extract fully hadronic final states

→ look for final states with ℓ, γ (ℓ = e,μ)

$m_H < 2\, m_Z$:

$t\bar{t}H \to \ell b\bar{b} + X, \quad H \to \gamma\gamma,$

$H \to ZZ^* \to 4\ell, \quad H \to WW^{(*)} \to \ell\nu\ell\nu$

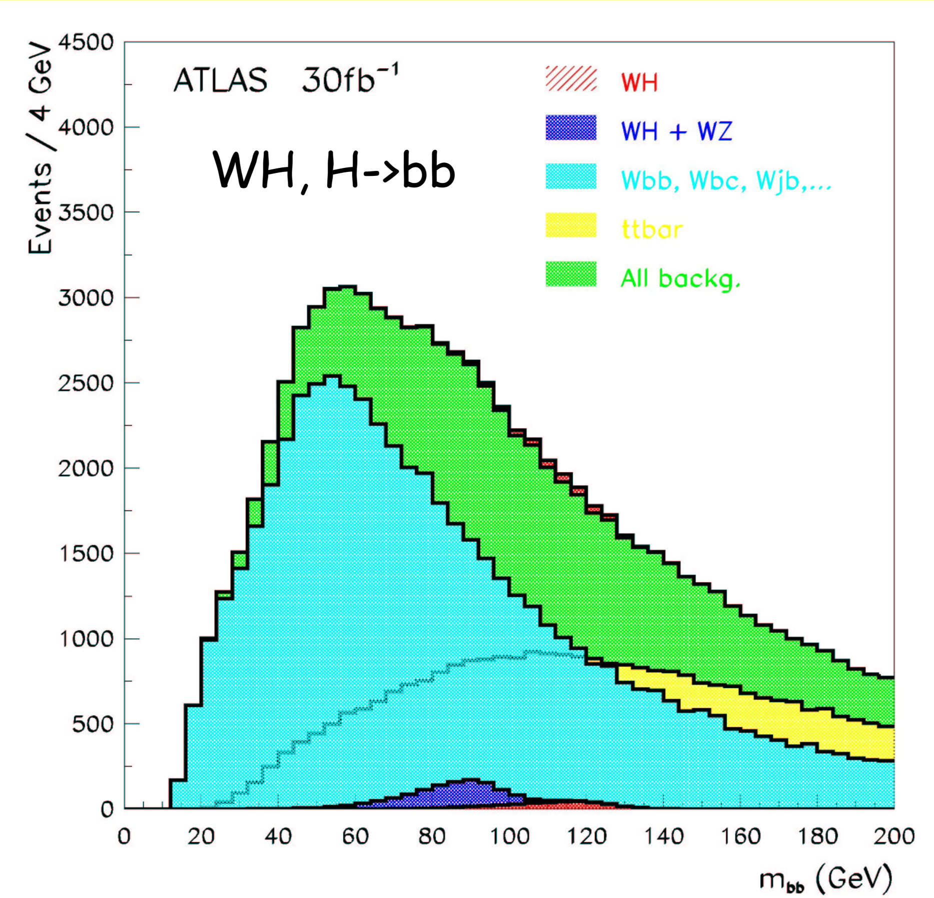
$qqH \to qqWW^{(*)} \; (\to \ell\nu\ell\nu)$
$qqH \to qq\tau\tau \; (\to \ell\nu\ell\nu, h\nu\ell\nu)$

$m_H > 2\, m_Z$:

$H \to ZZ \to 4\ell$
$qqH \to ZZ \to \ell\ell\, \nu\nu$
$qqH \to ZZ \to \ell\ell\, jj$ — $m_H > 300$ GeV
$qqH \to WW \to \ell\nu jj$ — forward jet tag

We have not forgotten about WH, H->bb

(comment by R. Harlander last Tuesday)



m_{bb} (GeV)

-> For several years benchmark channel to optimise detector performance for b-tag

-> By today we have more performant alternatives in the same mass range (100-120 GeV)

-> Sensitivity rather weak and very difficult to control bgd. shape

Signal	250
Bgd:	
WZ, Z->bb	220
Wbb	2000
Wbj,Wjj	4200
tt->WbWb	3700
tb,tbq	740
Total bgd	10820
Red/irred	0.65
S/B	2.3%

MSSM Higgs boson production and decays

Two Higgs doublets: 5 Higgs particles **H, h, A**
H^+, H^-

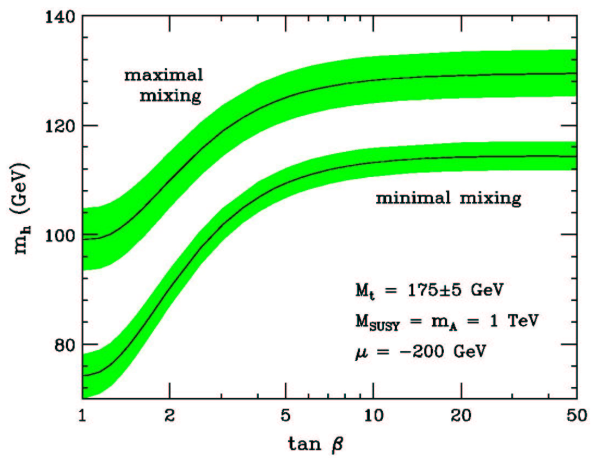
determined by two parameters: m_A, $\tan\beta$

Fixed mass relations at tree level,
(Higgs self coupling in MSSM fixed by gauge couplings)

Important radiative corrections !!
(tree level relations are significantly modified)

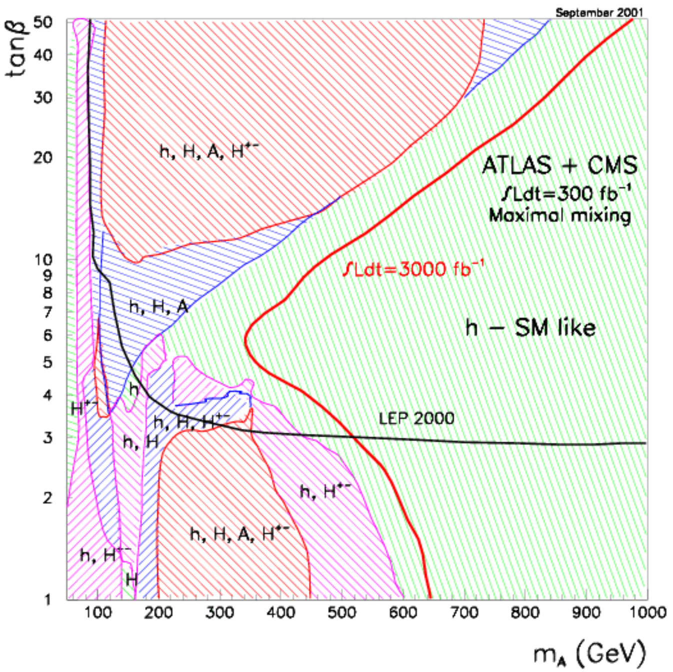
For large mA the h boson is SM like (decoupling limit)

upper limit for the light Higgs mass



-> $h \to \gamma\gamma$, $tth \to bb$, $H \to ZZ^{(*)} \to 4l$ as in Standard Model
-> HWW, HZZ strongly suppressed with $\tan\beta$,
VBF production absent for A-boson
-> A/Hbb, $A/H\tau\tau$, $A/H\mu\mu$ enhanced with $\tan\beta$
-> typical of MSSM: $A/H \to \tau\tau, \mu\mu$; $H^+ \to \tau\nu$, tb
-> if SUSY accessible Higgs $\to$ SUSY particles or SUSY cascade $\to$ Higgs

Status: MSSM Higgs sector



- Discovery potential well understood with assumption of heavy SUSY particles.
- Several overlapping channels, studies exended to m_A=1 TeV range.
- Only limited studies for SUSY-> Higgs or Higgs -> SUSY scenarios.
- Some channels at low tanβ excluded by LEP2, but still interesting in eg. 2 HDM
- Some understanding of the tanβ and mass measurements (heavy H/A, H^{+-}).
- NO dedicated studies on couplings yet.
- NO dedicated studies on the capability to disentangle MSSM and SM scenarios (in case only h-boson seen) yet.

NO exotic scenarios:
they do not provide exotic signature... but eg. available example of H^+ in extra dimentions, A/H->$\tau\mu$

Tools for signal

Even generation: PYTHIA (improved ISR/FSR) + TAUOLA, PHOTOS
HERWIG (for charged Higgs analyses)

Scan for SM model: HIGLU, QQH, VVH (LO!),
HDECAY

Scan for the MSSM model: HIGLU, QQH, VVH (LO!)
HDECAY,FEYNHIGGS,SUBH

For some comparison studies: ResBOS

Issues:

-> Production mechnisms for Yukawa coupling sensitive processes bbH/bbA

-> Charged Higgs in the transition region (tt->H^+bWb vers gb->tH^+)

-> We will measure Higgs mass with precision ~ 0.1% for light h->$\gamma\gamma$, will theoretical calculations provide similar (better) precision of predictions for the MSSM (SUGRA, ... other) models?

Tools for backgrounds

For event generation (4-momenta):

-> „Complete" Monte Carlo generators: hard process, ISR/FSR, hadronisation decays => PYTHIA, HERWIG

-> Matrix-element Monte Carlo generators: hard process only (+ direct interface to PY/HW or LesHouches accord.) => AcerMC, COMPHEP, MadCUP....

-> TAUOLA, PHOTOS

For some comparison studies:

-> „Distribution provider": only certain inclusive distributions available => MCFM,.... (for NLO vers LO studies)

By now, generation of the LARGE number of processes is available at the Born level.

But we need to control REDUCIBLE bgds. also -> Parton Shower Monte Carlo.

But we need to control well TRANSITION region, between „soft" and „hard" ranges of the phase-space -> Parton Shower Monte Carlo versus ME matching. (For most Higgs physics relevant jets with pT = 20-50 GeV)

Backgrounds

Universal: W+(b)jets, Z+(b)jets, tt+(b)jets

More specific: WW, ZZ, $\gamma\gamma$, ttW, ttZ, ttWW, tttt
WW+jets, ZZ+jets,
electroweak WW+jets, ZZ +jets,
electroweak ttbb,……

Exclusive selections:

-> lepton multiplicity and angular correlations (spin correlations), inv. mass
-> total energy balance (off-shell decays)
-> jet multiplicity and angular separation
-> jet presence or absence in defined regions of phase-space (forward, central)
-> identification of heavy flavour jets, tau-leptons is an important tool

Rich spectrum of analyses planned.
Analyses will be very exclusive!

Monte Carlo TOOLS: consistency problem

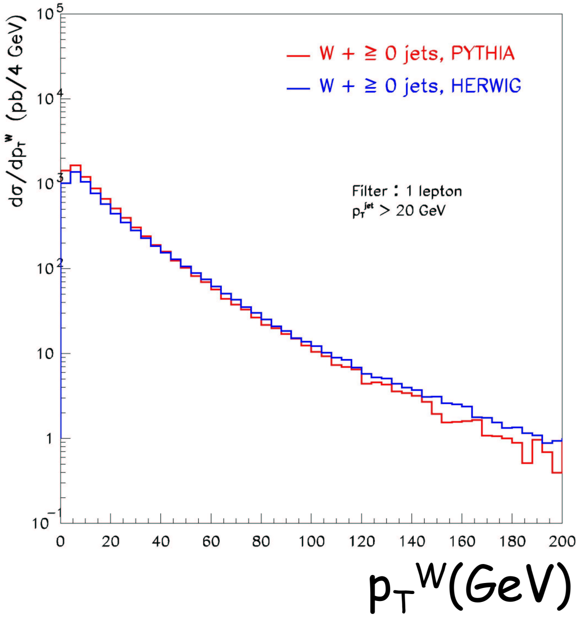
One often faces the problem of the lack of consistency between predictions from different generators for the same process:

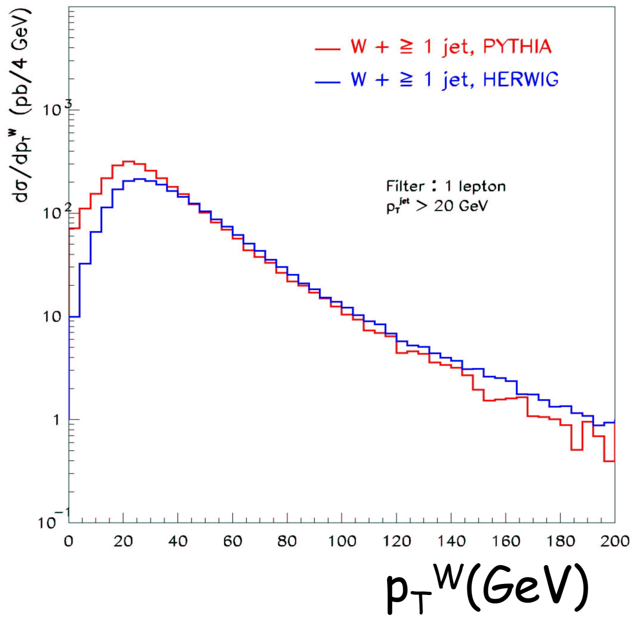
- used definition for α_{QCD}...(1L, 2L), running or fixed
- factorisation/renormalisation scale
- modeling of the parton shower/hadronisation/decays
- fraction of heavy flavour jets, angular correlations
- finite width effects, off-shell decays

We are not always well aware of the size of the theoretical error which should be assigned to a given prediction.

below just few examples.......

Present problems of exclusive analyses.....



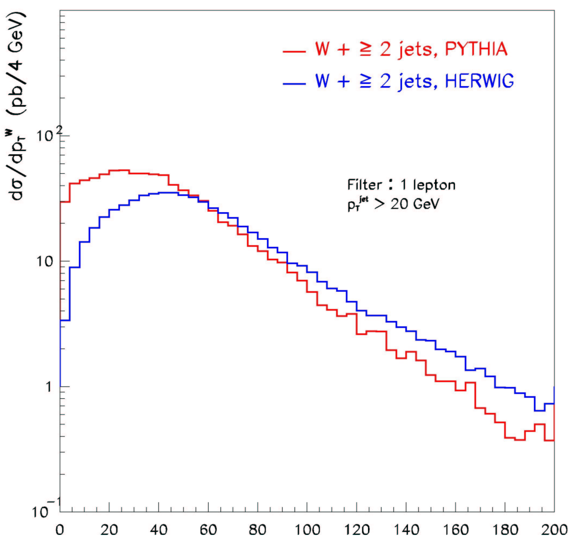


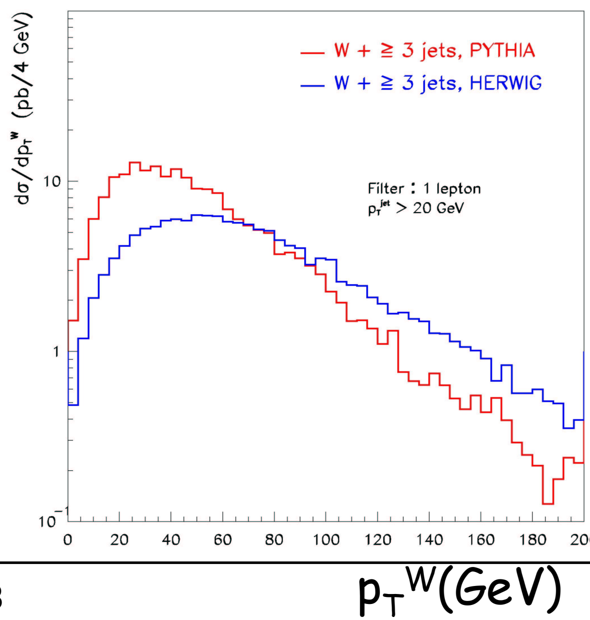
default

— PYTHIA

— HERWIG

p_T^W spectrum in events with multi-jets





⇒ source of discrepancy is different model for QCD ISR/FSR

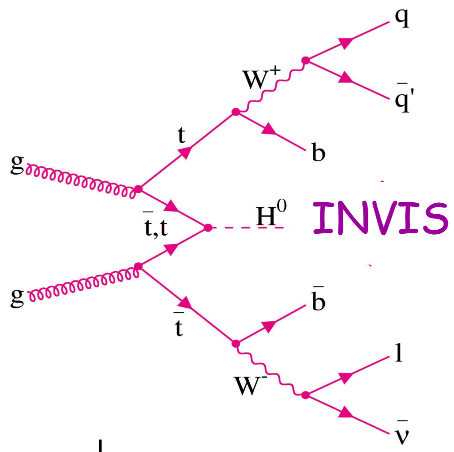
⇒ could it be tuned?

⇒ shouldn it be tuned?

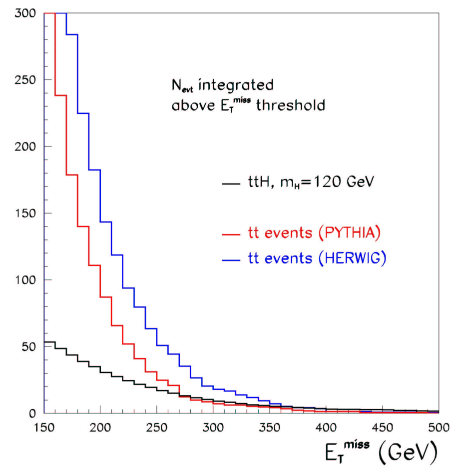
Present problems of exclusive analyses....

<u>Example1: ttH, H->inv.</u>

reconstruct both top's accompanied by large ETmiss. After selection dominant bgd. originates from ttjj t->Wb->τνb with „fake" W->jj reconstructed.



observe(?) excess in the E_T^{miss} distribution, S/B ~ 1/3



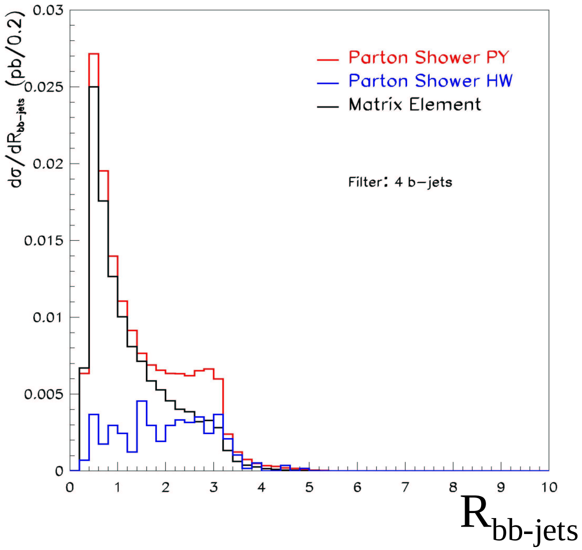
Selection	PYTHIA	HERWIG
Trigger lepton	$2.2\ 10^{-1}$	$2.2\ 10^{-1}$
2 b-jets + 2 jets	$4.9\ 10^{-2}$	$5.2\ 10^{-2}$
reco t->jjb	$2.4\ 10^{-2}$	$2.6\ 10^{-2}$
$m_T^{lep-ETmiss}$>120 GeV	$4.1\ 10^{-4}$	$5.2\ 10^{-4}$
$E_T$miss > 150 GeV	$2.0\ 10^{-5}$	$3.2\ 10^{-5}$

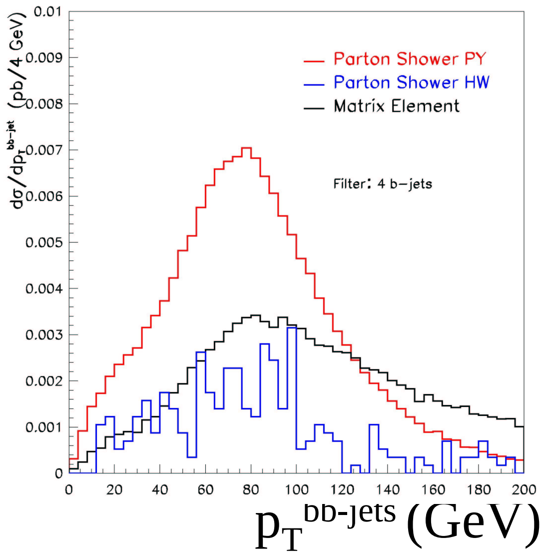
difference mostly caused by fraction of fake W->jj being reconstucted =>

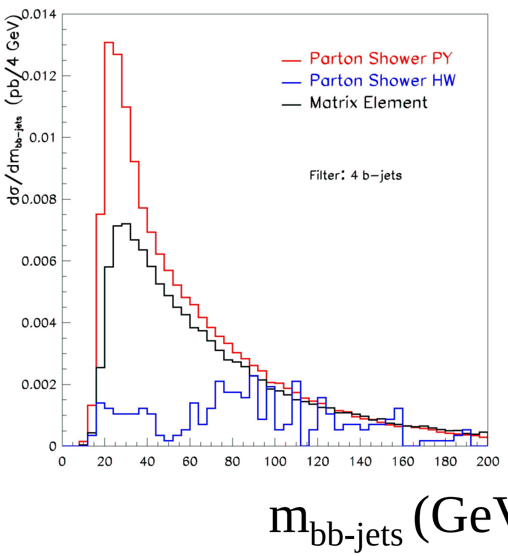
TH precision on topology ?? ~ 10 α_{QCD} ??
Possible causes: different ISR/FSR model, spin correlations (in Herwig but not in PYTHIA),....

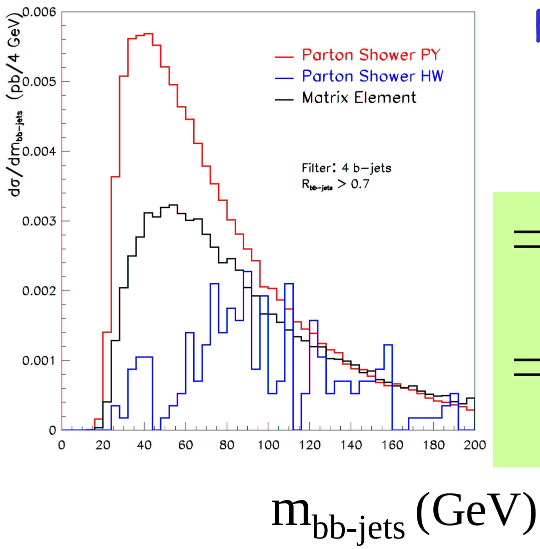
⇒ understand possible source of discrepancy
⇒ provide firm estimate of theoretical uncertainty

Present problems of exclusive analyses....







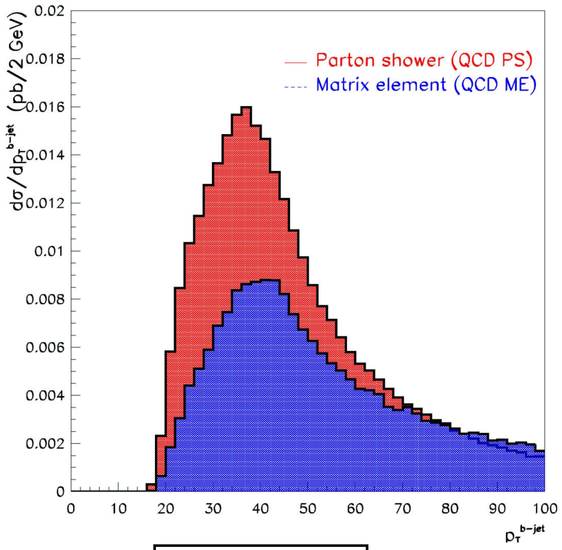


Example2:
irreducible ttbb backgd. to ttH
comparison of the differential distributions for b-jets not originating from top-quark decays.

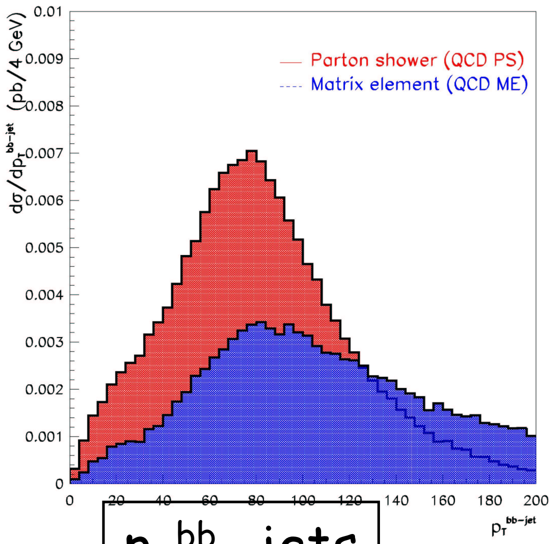
black: ME calculations (AcerMC)
red: PYTHIA
blue: HERWIG

⇒ understand what is missing in HERWIG
⇒ improve consistency between different approaches

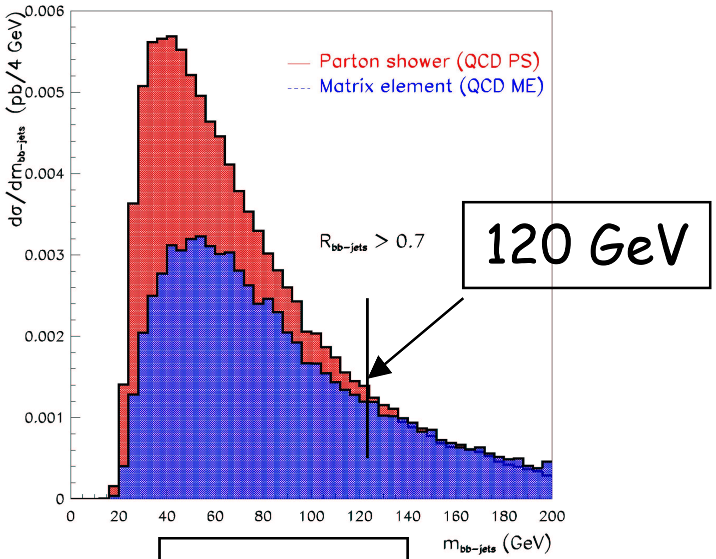
Present problems of exclusive analyses....



p_T^{b}-jet



p_T^{bb} -jets



m_{bb}-jets

Example2: irreducible ttbb backgd. to ttH

Parton-showr predictions for heavy-flavour jets above ME predictions.

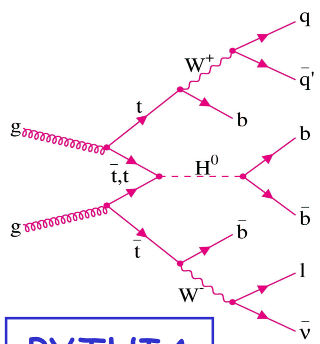
This observation holds for other processes in moderate pTjet.

red: PYTHIA Parton Shower
blue: AcerMC matrix-element

⇒ in analysis require $p_T$jet > 30 GeV
⇒ improve understanding of consistency and reliability between approaches

Present problems of exclusive analyses.....

Example3: reducible backgd from ttjj to ttH, H->bb



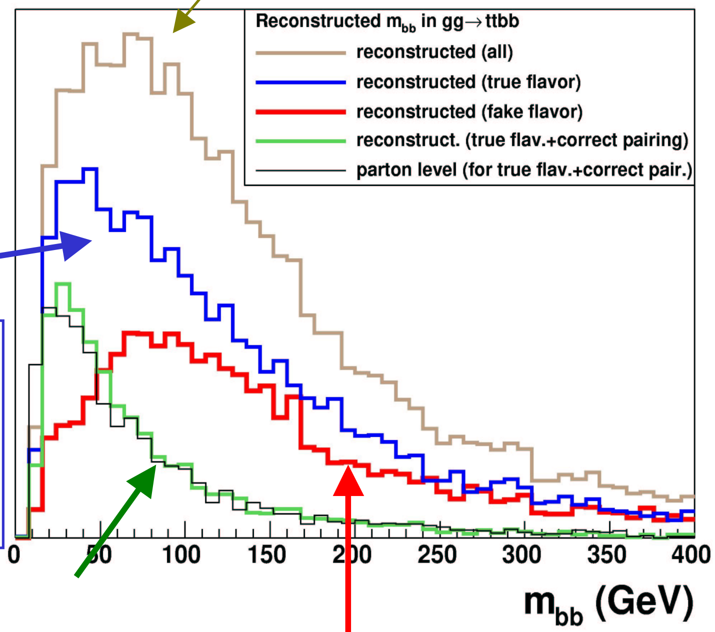
PYTHIA

All true bb, so also contrib. from g->bb splitting in the ISR/FSR and/or combin.

AcerMC

only true bb from ME and not originating from top-quarks: very good agreement between shape from ME partons and reconstructed jets

Total bgd



PYTHIA

Any other bc,jb,jc combination identified as bb

1. ME heavy-flavour partons might contribute only 20% - 60% of total bgd (see eg. 4b in QCD jets)

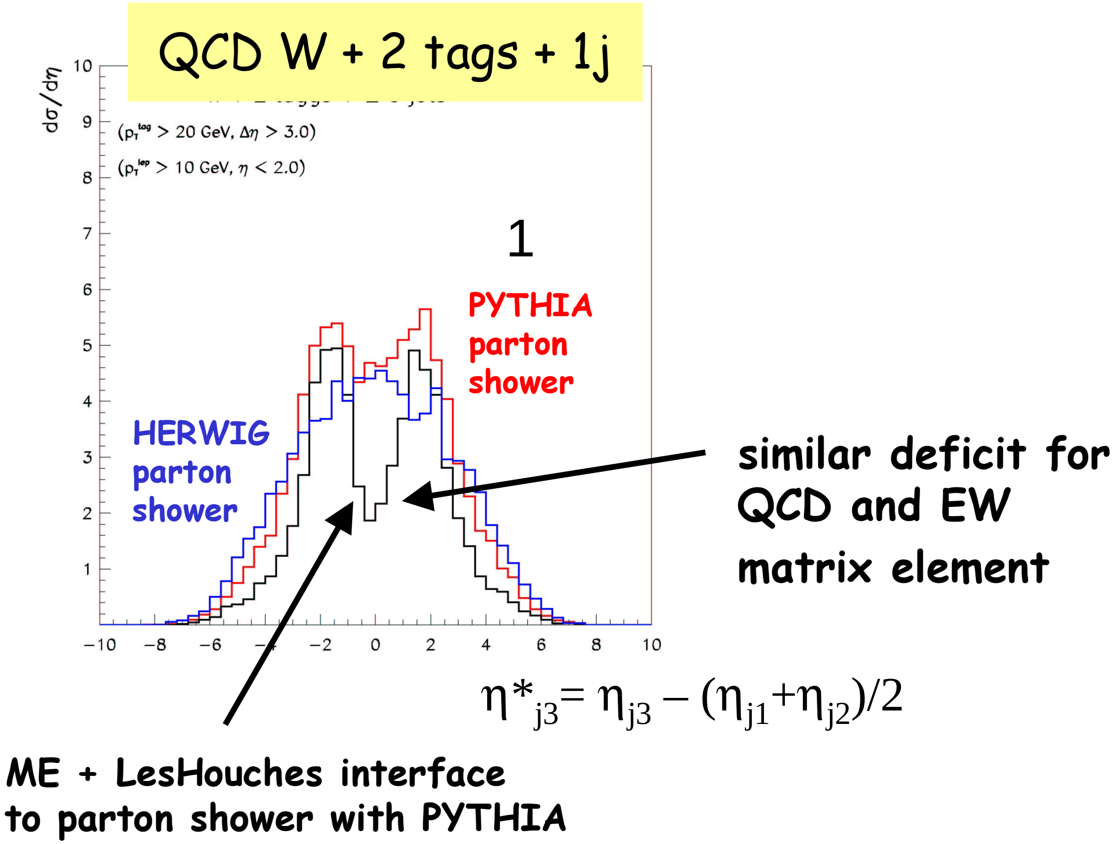
2. Notice difference in shape of different components

Full fledged event generator should contain:

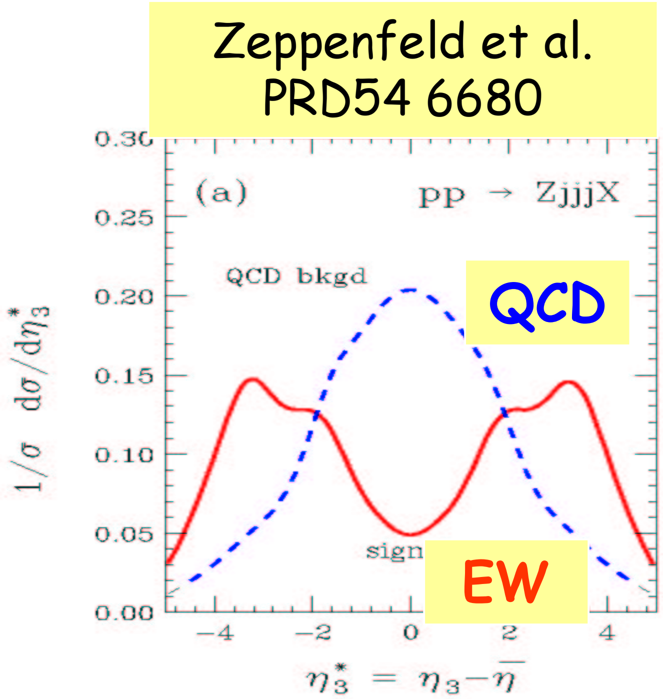
⇒ consistent ME/PS model for ttbb

⇒ <u>and</u> the same for reducible ttjj (j=g,u,d,s,c)

How well works LesHouches accord



$\eta^*_{j3} = \eta_{j3} - (\eta_{j1} + \eta_{j2})/2$



Existing problem with ME events interfaced by LesHouches accord:

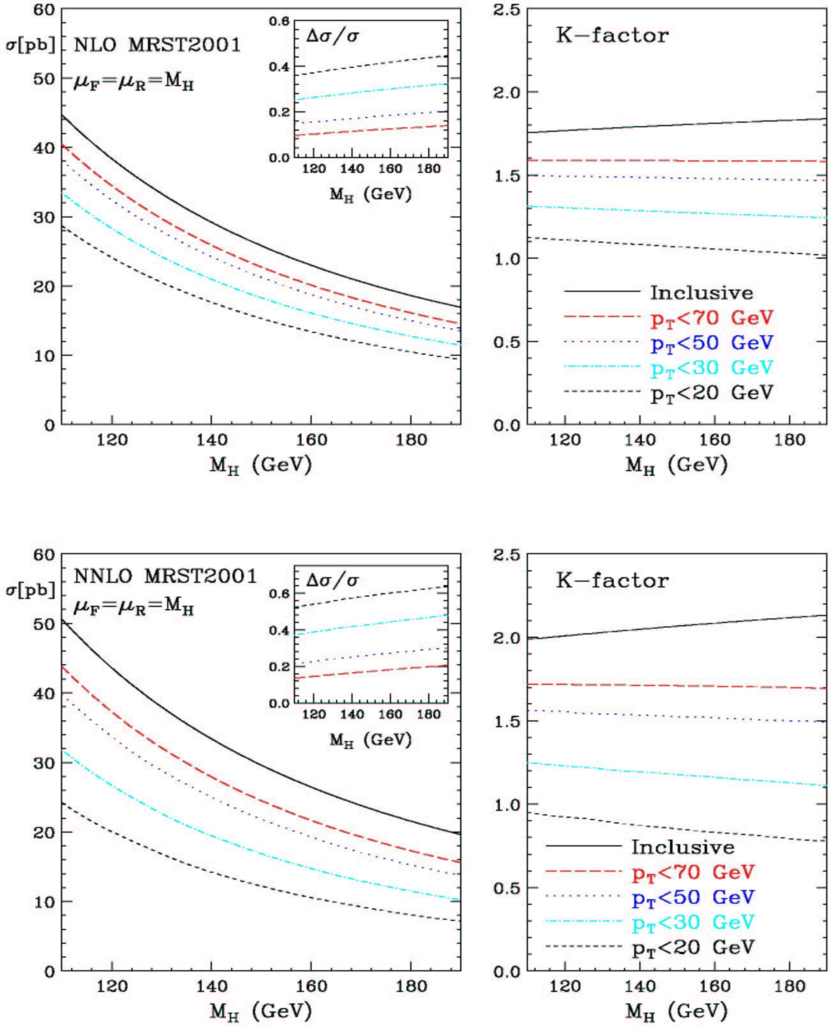
-> not enough central radiation between colour objets

-> some features of generators not implemented for external processes (eg. improved PS in Pythia, spin correlations in Herwig)

NLO, NNLO calculations for gg->H

S. Catani et al., hep-ph/0206052

K-factor with jet-veto



gg-> H->γγ almost inclusive selection

gg->H->WW*->lνlν tight jet-veto to reject tt background.

Inclusive xsection

⇒K-factor ~ 1.7 for NLO
~ 2.1 for NNLO

Applying jet-veto implies „loss" in the xsection. The dominant part of QCD corrections is due to soft collinear radiation.

With veto p_T^{jet} >20 GeV

⇒K-factor ~ 1.1 for NLO
~ 0.9 for NNLO

Full fledged NNLO Monte Carlo will probably be needed (most difficult part will be background not signal).

NLO, NNLO issues....

Example: bbH, bbA Yukawa production in MSSM.

NNLO calculations (Harlander, Kilgore,hep-ph/0304035):
- up to two-loops: bb->H
- up to one-loop: bb->Hg, gb->Hq
- at tree level: bb->Hgg, bb->Hqq, bb->Hbb, gb-Hgb, bb->Hbb, bq->Hbq, gg->Hbb,qq->Hbb

[fb] for tanβ=1

m_H	120 GeV	300 GeV	800 GeV
σ_{LO}	480	22	3.4
σ_{NLO}	690	30	4.1
σ_{NNLO}	720	30	4.4
	+ 50%	+35%	+30%

What are the sources/sizes of theoretical uncertainties on those predictions:
μ_R, μ_F, PDF's, $m_b(Q^2)$, resummation,.... ??

ongoing discussion on VFS versus FFS approaches

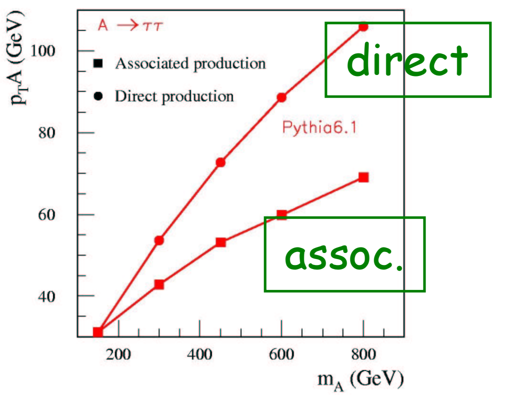
Available for event generation:
- bb->H lowest order + improved PS
- bb->Hg, gb->Hq + simple PS
- gg->bbH, qq->bbH + simple PS

In fact to observability contributes as well process not included in above calculations:
direct gg->H (mediated also by b-quark loop)

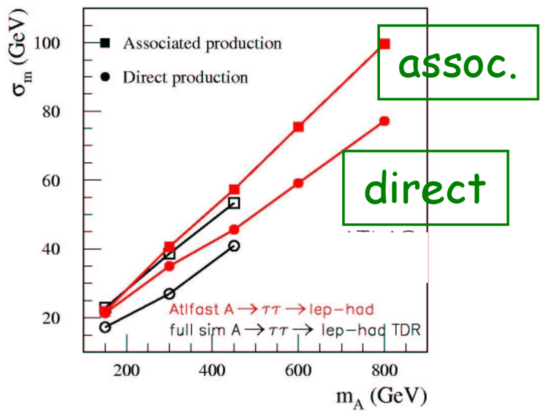
Is it a problem that „only" calculations are available?
=> Yes, because analysis is very exclusive

NLO, NNLO issues....

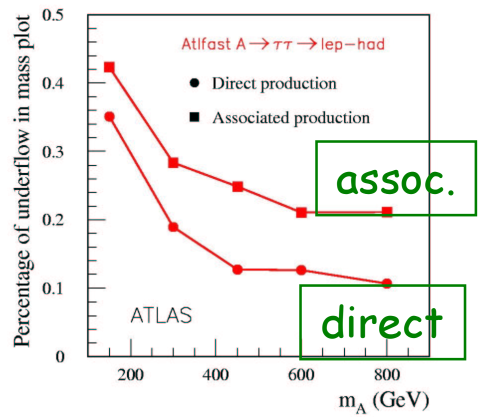
Higgs transverse momenta



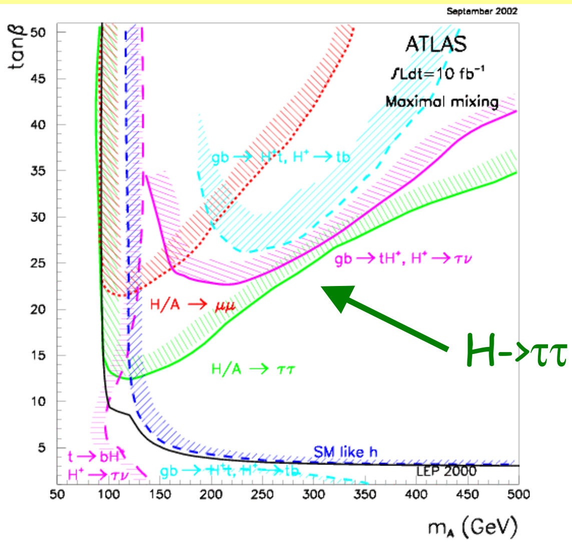
H->ττ mass resolution



Fraction of events for which H->ττ cannot be reconstructed



5s discovery contour in MSSM



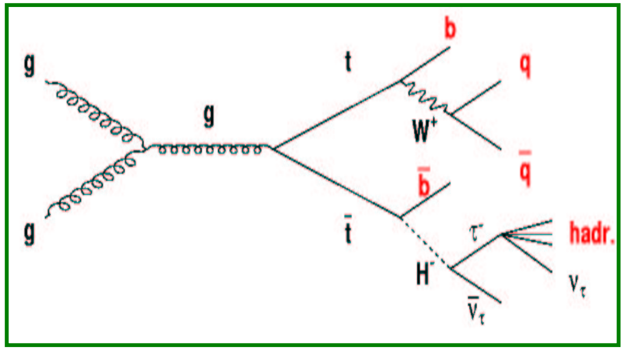
<u>direct</u>: gg->H
<u>associated</u>: gg,qq -> bbH

reconstruction effic. & accept. differs by factor 2

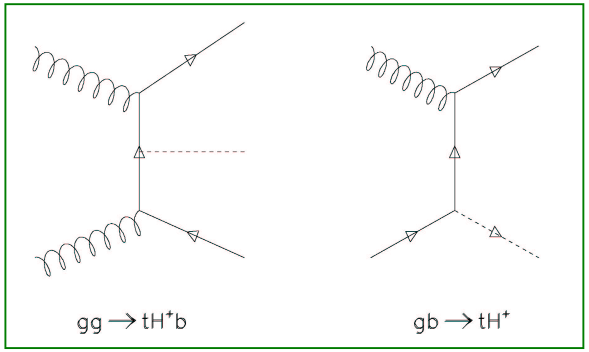
a) reco efficiency + resolution for A/H->ττ reconstruction depends (factor 100%) on event topology (p_T^H plays main role)
b) single b-jet or b-jet veto required (p_T^{jet} ~ 20 GeV , a rather soft cut for LHC), combine statistically evidence for either sample.
c) dominant bgds: tt, incl. Z, incl. W

Charged $H^{+-} \to \tau\nu$

for low masses

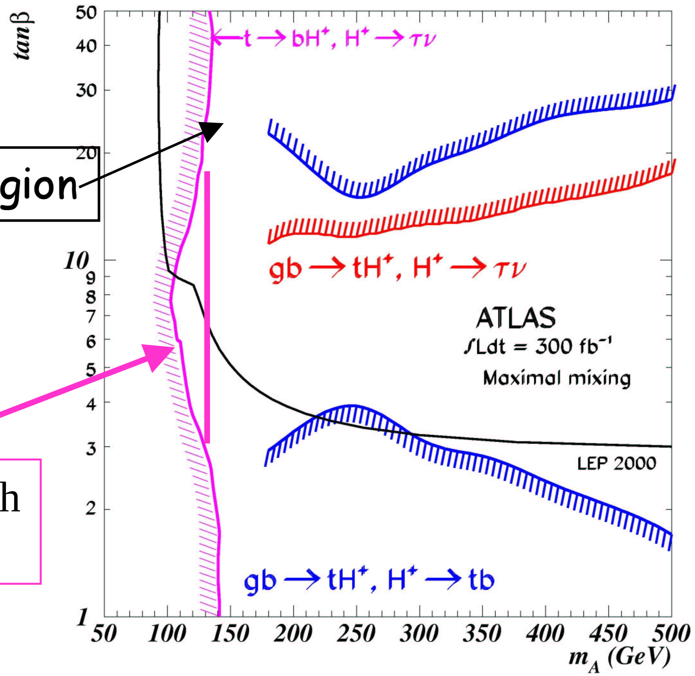


for higher masses

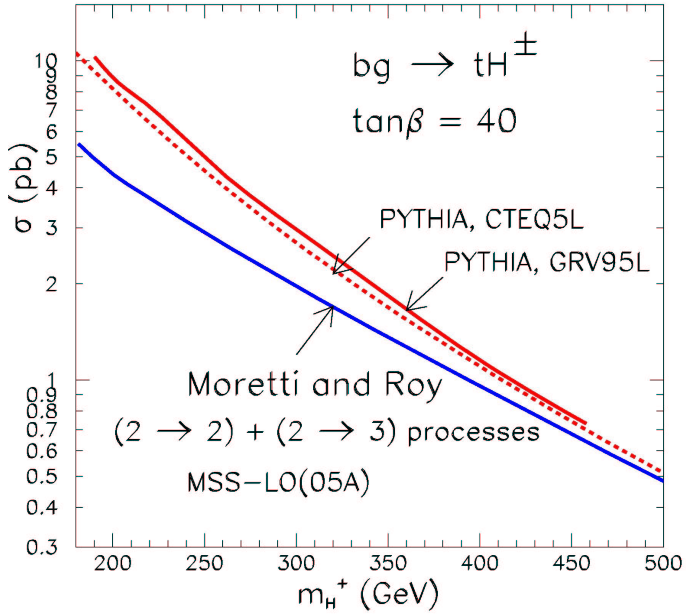


5σ discovery contours

transition region



extended with new analysis



we don't have Monte Carlo (only patches)
for generating events in the transition region

$(2 \to 2) = gb \to tH^+$
$(2 \to 3) = gg \to tbH^+$

Conclusions

EVENT GENERATORS are mandatory to fully explore the potential of the detector and machine and the complexity of the planned analysis.

There have been an enormous progress over the last twenty years in the availability of NLO, NNLO calculations („integrated over full phase-space") and matrix-element tree-level event generators.

It is however rather clear that, given the experimental goals fixed order and /or „cut-off" dependent generators will often not be sufficient. (It was already the case for LEP analyses).

For Higgs physics mandatory very good understanding of reducible and irreducible bgds. This can be only achieved with better understanding of the parton-shower type versus matrix element type predictions: will MC@NLO be the solution for it?

We would like that as results of this workshop <u>we have clear plan</u> for achieving theoretical precision better by factor 10(!?) with respect to what we have now!