VBF SM Higgs boson searches with ATLAS

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on behalf of the ATLAS collaboration

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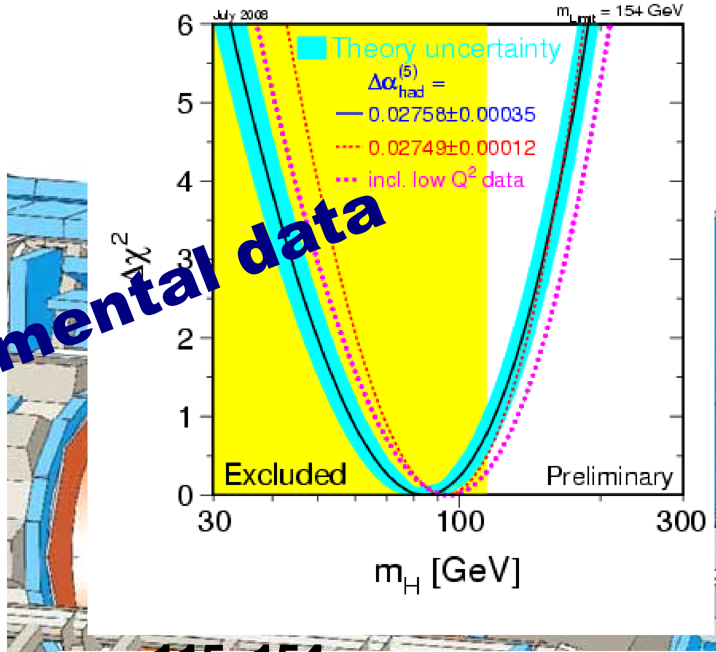
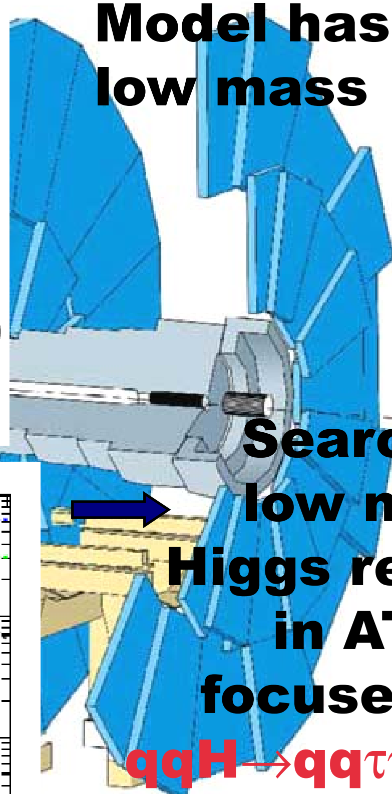
Experimental data

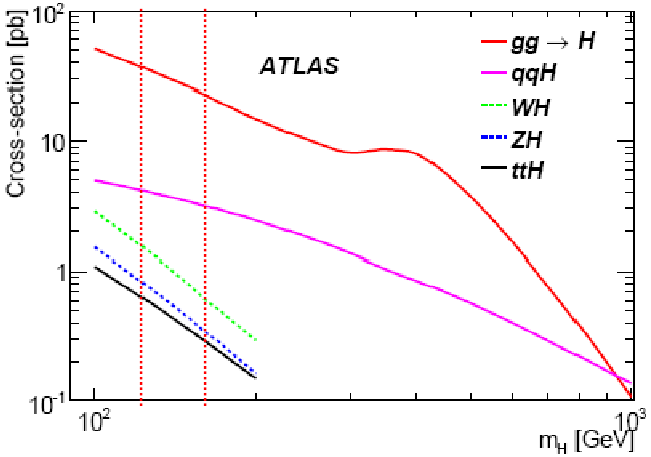


Higgs boson in Standard Model has low mass

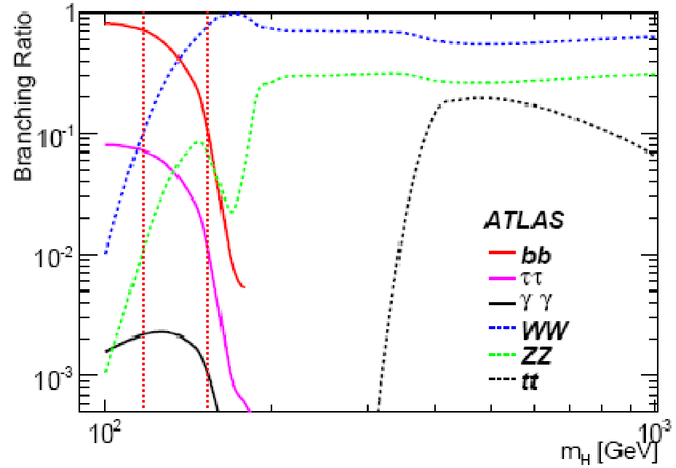


Search in low mass Higgs region in ATLAS focuses on qqH→qqττ,WW or gg→H→γγ

115 -154



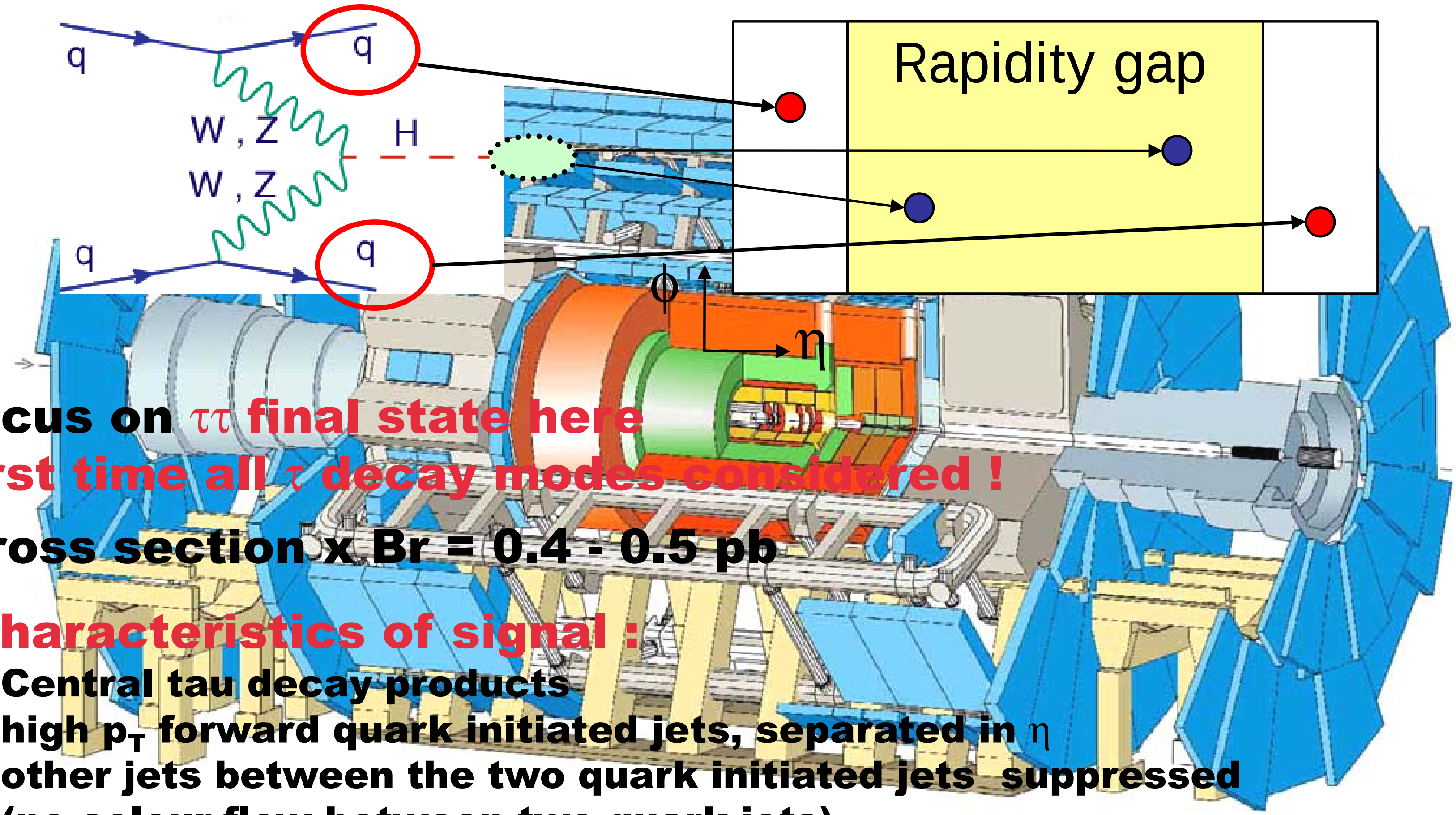
115 -154



Following results on SM Higgs discovery reach in VBF channel obtained with :

> full GEANT4 simulation with realistic detector geometry and misalignment / distortion effects , large statistics (Computing System Commissioning)
> Detailed trigger simulation (including lvl1 firmware trigger)
> most recent reconstruction and identification methods
> LO/NLO ME generators (Alpgen, Sherpa, MC @ NLO) matched to PS generators (Herwig) for backgrounds
> All tau decay final states combinations considered

VBF SM Higgs boson production



focus on ττ final state here

First time all τ decay modes considered !

Cross section x Br = 0.4 - 0.5 pb

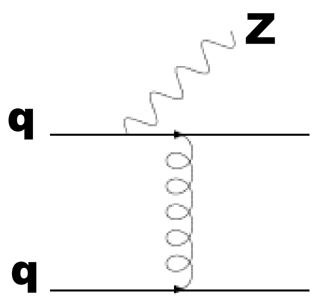
Characteristics of signal :

+ Central tau decay products
+ high p_T forward quark initiated jets, separated in η
+ other jets between the two quark initiated jets suppressed (no colour flow between two quark jets)
+ missing energy in the transverse plane (due to taus)

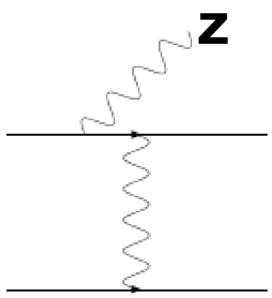
Main backgrounds

Z+jets : 2 taus and q jets as in signal
Handle : different kinematic

tt : 2 taus as in signal, but no q,g jets
Handle : different kinematic and jet flavour



QCD Zjj



EW Zjj

g,

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g,

q

q

jet

g,

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g,

W+jets : 1 tau and q(g) jets as in signal.
Handle : different kinematic and tau identification

s boson s
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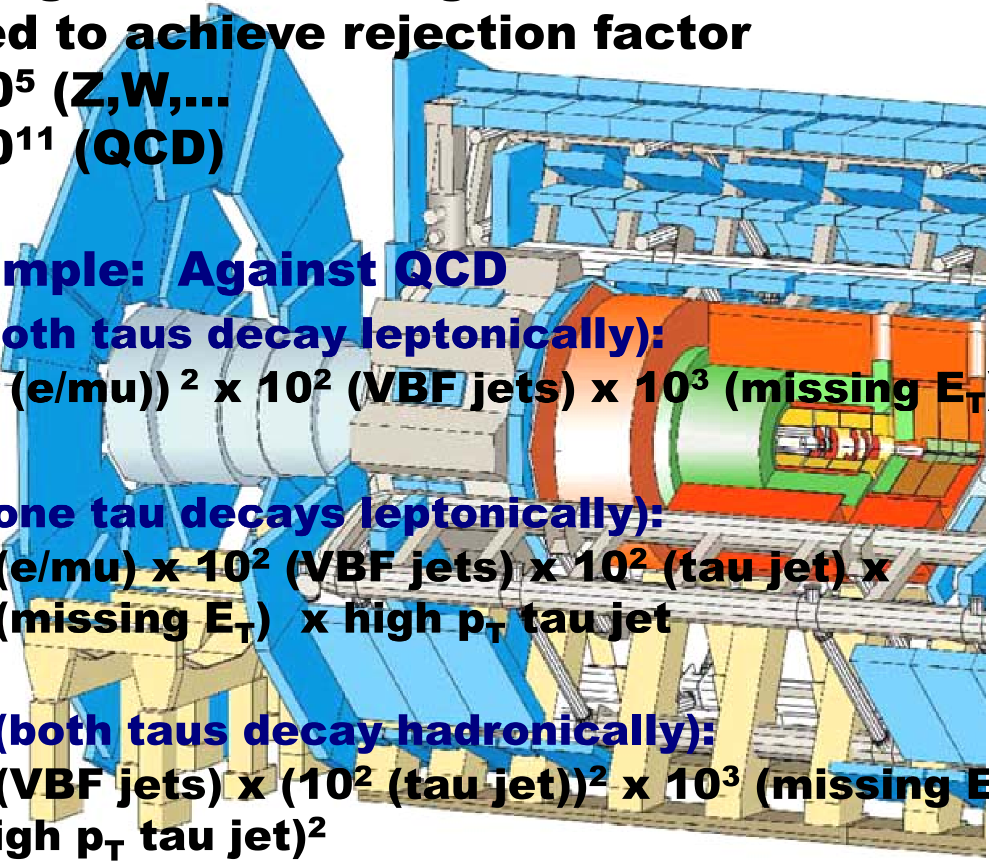
Pure QCD : all q,g initiated jets, no real taus
Handle : different kinematic (missing ET), tau identification

Analysis Strategy



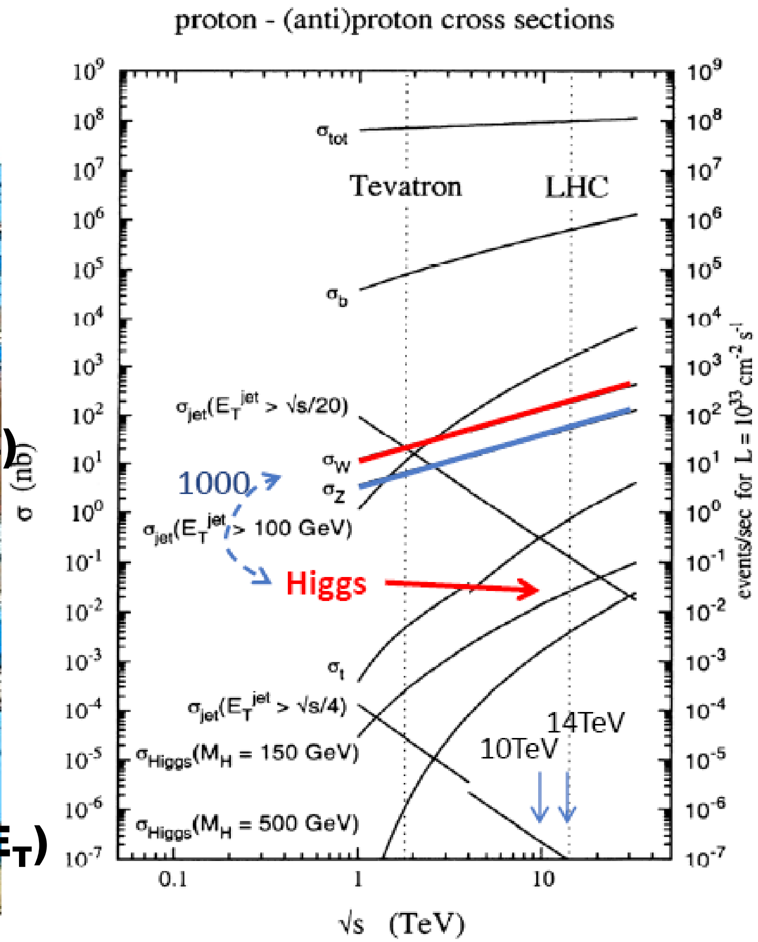
Backgrounds are large.
Need to achieve rejection factor
> 10^5 (Z,W,...
> 10^{11} (QCD)

Example: Against QCD

ll (both taus decay leptonically):
$(10^3$ (e/mu)$)^2$ x 10^2 (VBF jets) x 10^3 (missing E_T)

lh (one tau decays leptonically):
10^3 (e/mu) x 10^2 (VBF jets) x 10^2 (tau jet) x 10^3 (missing E_T) x high p_T tau jet

hh (both taus decay hadronically):
10^2 (VBF jets) x $(10^2$ (tau jet)$)^2$ x 10^3 (missing E_T) x (high p_T tau jet$)^2$



Tau lepton decays & identification

- **Leptonic decay mode**

35 %

$\tau \rightarrow \nu_\tau + \nu_e + e$ **(17.4%)**

$\tau \rightarrow \nu_\tau + \nu_\mu + \mu$ **(17.8%)**

Tau identification=
Electron/muon identification
(ε=80/90%, rejection q(g) jet ~ 0.1%)

- **Hadronic decay mode**

77 %

1 prong

$\tau \rightarrow \nu_\tau + \pi^\pm$ **(11.0%)**

$\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0$ **(25.4%)**

$\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0$ **(10.8%)**

$\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0 + \pi^0$ **(1.4%)**

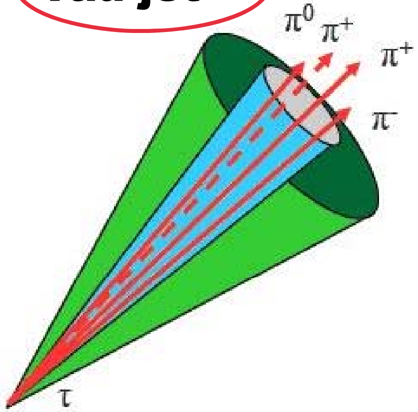
$\tau \rightarrow \nu_\tau + K^\pm + n\pi^0$ **(1.6%)**

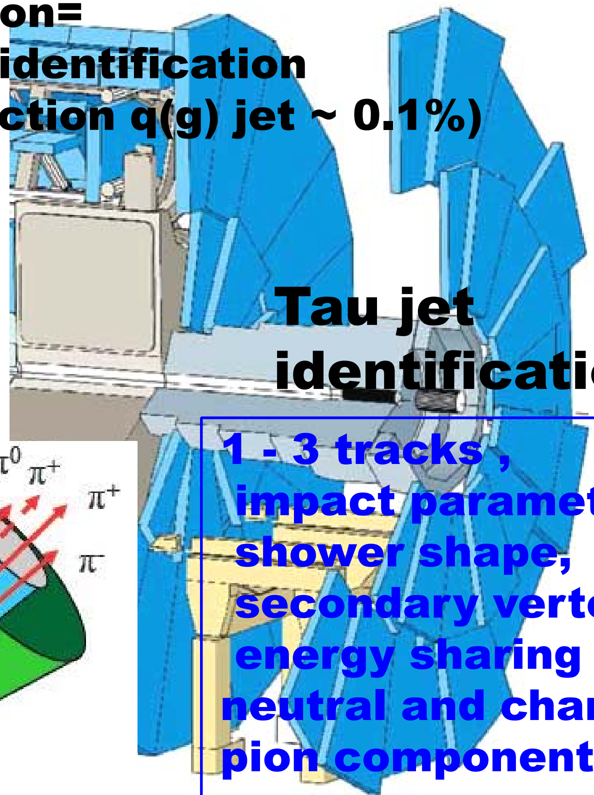
3 prong

$\tau \rightarrow \nu_\tau + 3\,\pi^\pm + n\pi^0$ **(15.2%)**

23 %

Tau jet





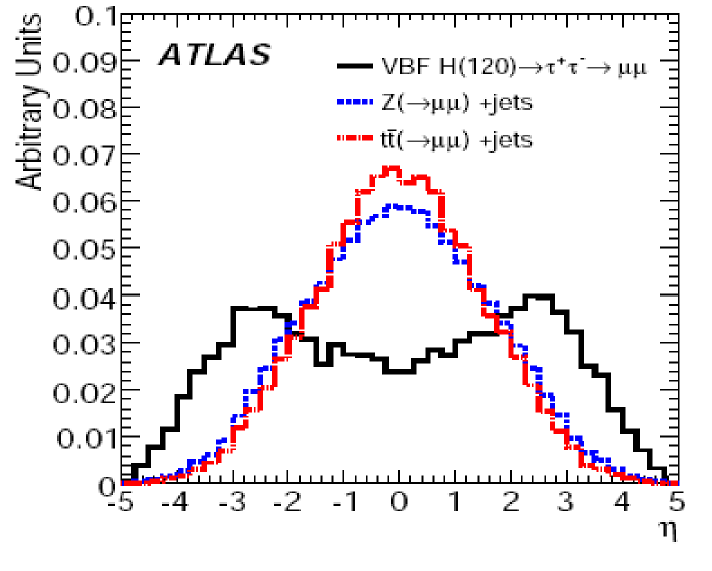
Tau jet identification

1 - 3 tracks ,
impact parameter,
shower shape,
secondary vertex,
energy sharing of neutral and charged pion component

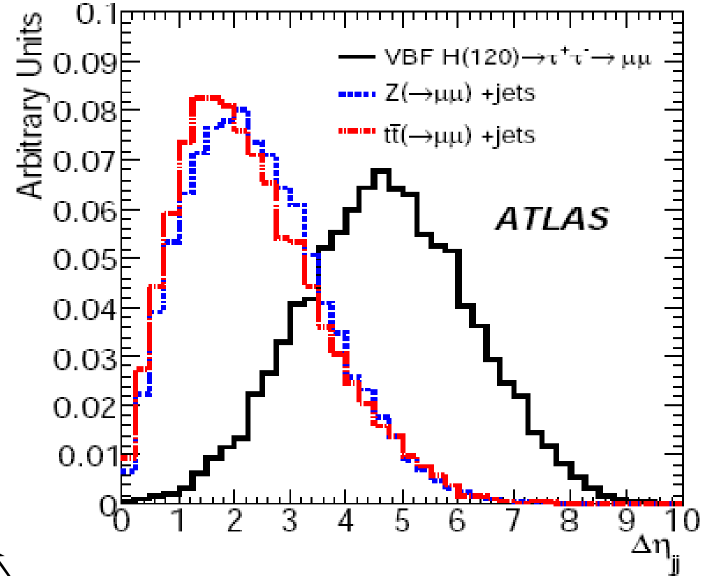
ε=50%, rejection q(g) ~ 1%

Rapidity gap in VBF processes

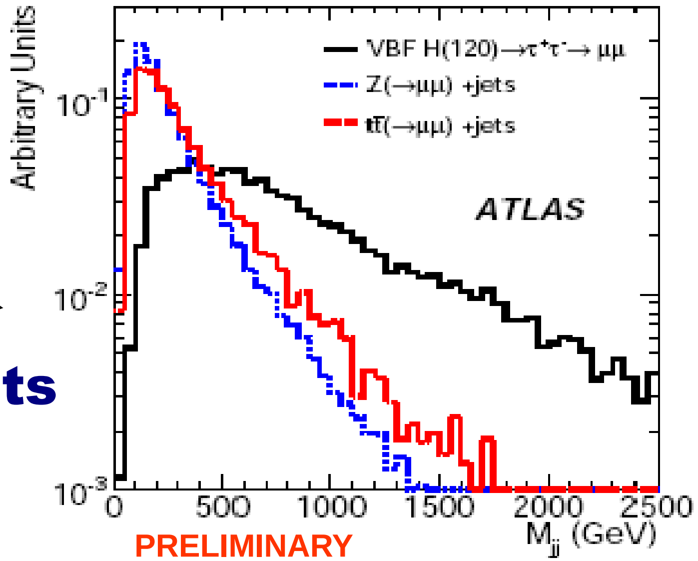
PRELIMINARY



PRELIMINARY



- Find central taus
- Look for first and second highest pT jet in the event



PRELIMINARY

High pT forward jets

Trigger and signal selection&yield

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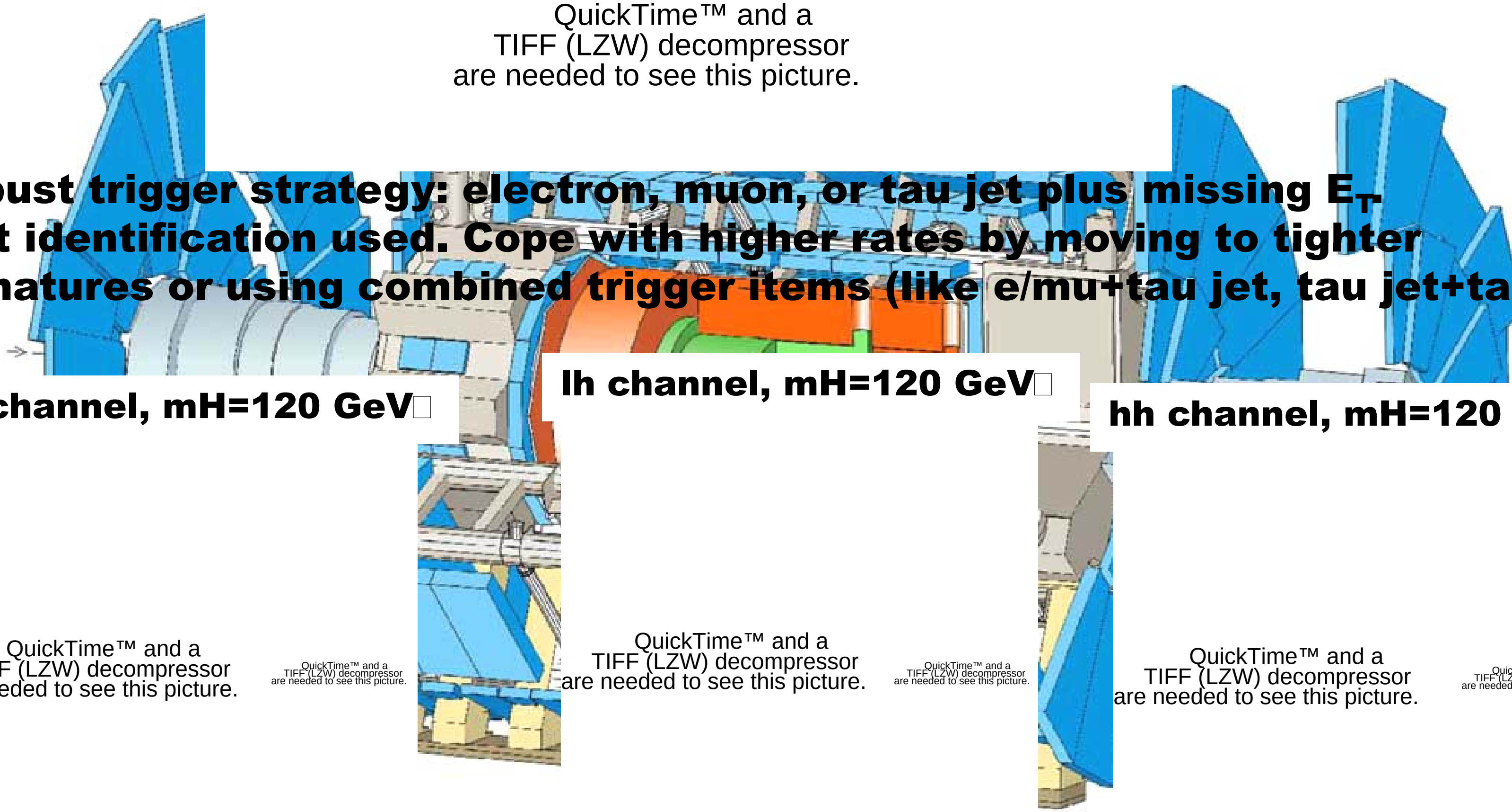

Robust trigger strategy: electron, muon, or tau jet plus missing E_T.
Soft identification used. Cope with higher rates by moving to tighter signatures or using combined trigger items (like e/mu+tau jet, tau jet+tau jet)

ll channel, mH=120 GeV

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lh channel, mH=120 GeV

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hh channel, mH=120 GeV

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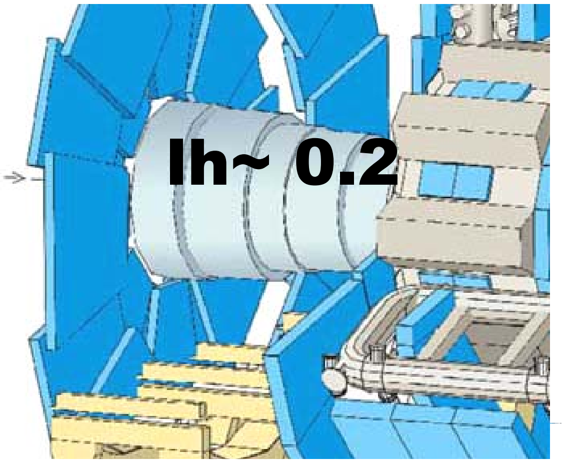
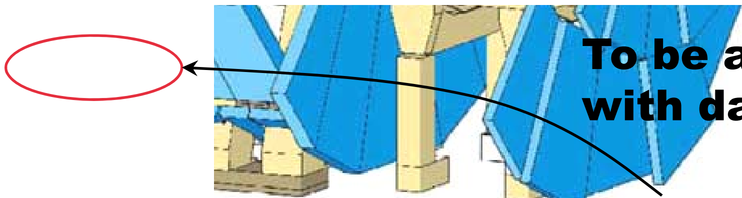
Backgrounds yields

ll ~ 0.5



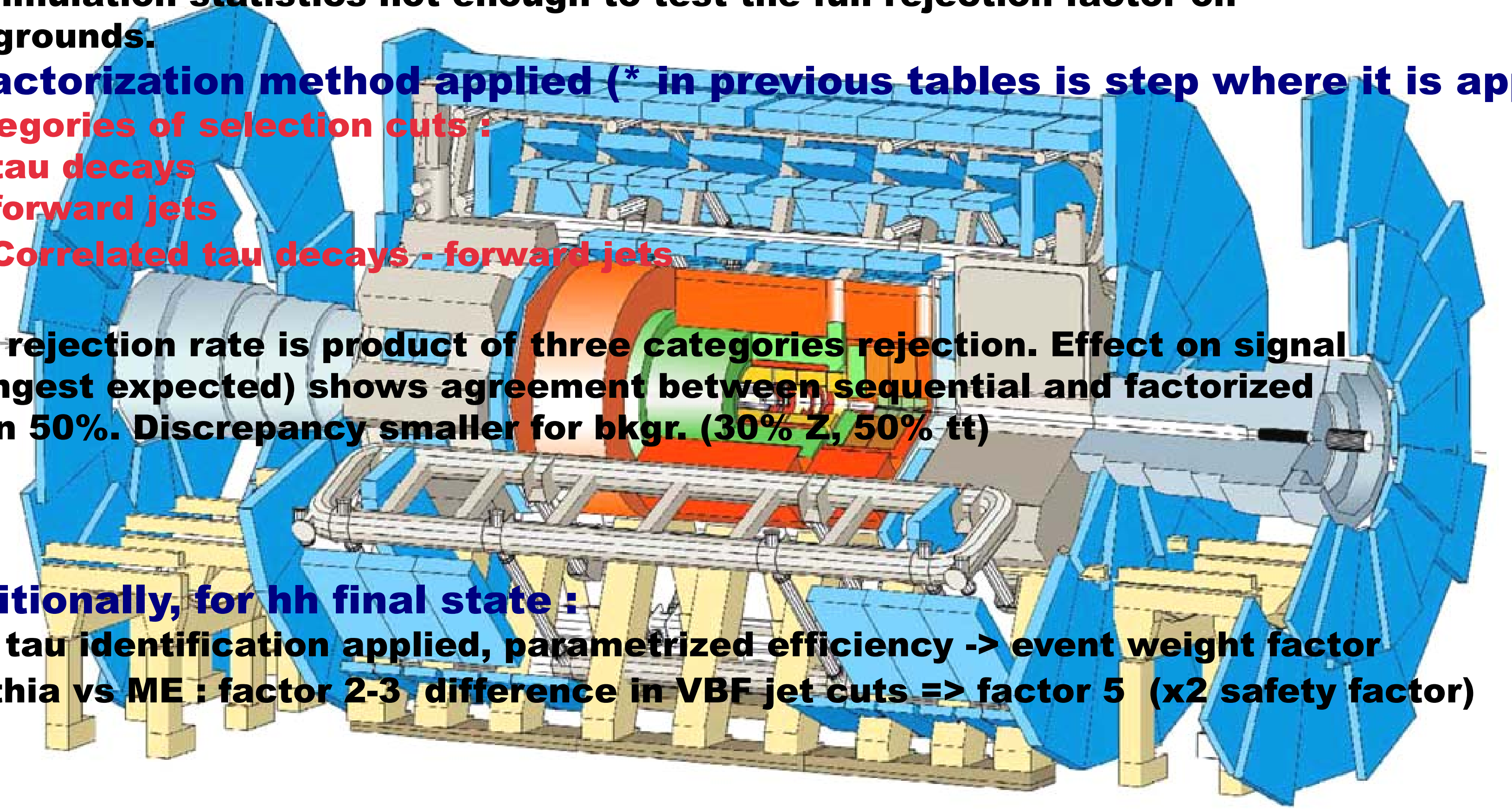


To be assessed with data

hh ~ 1.2

ith ATLAS

Details of background estimation on simulation



Full simulation statistics not enough to test the full rejection factor on backgrounds.

→ factorization method applied (* in previous tables is step where it is applied)

3 categories of selection cuts :

1. **tau decays**
2. **forward jets**
3. **Correlated tau decays - forward jets**

Total rejection rate is product of three categories rejection. Effect on signal (strongest expected) shows agreement between sequential and factorized within 50%. Discrepancy smaller for bkgr. (30% Z, 50% tt)

Additionally, for hh final state :

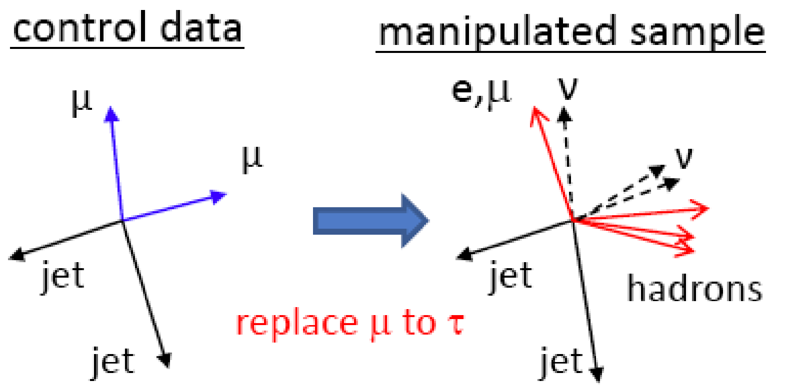
- **No tau identification applied, parametrized efficiency -> event weight factor**
- **Pythia vs ME : factor 2-3 difference in VBF jet cuts => factor 5 (x2 safety factor)**

Uncertainty on this affects only current estimates of significance, real measurement will not be affected by lack of background sample statistics

Details of background estimation on data

Example : Z→ττ + jets

Assume tau decay is well modelled by MC



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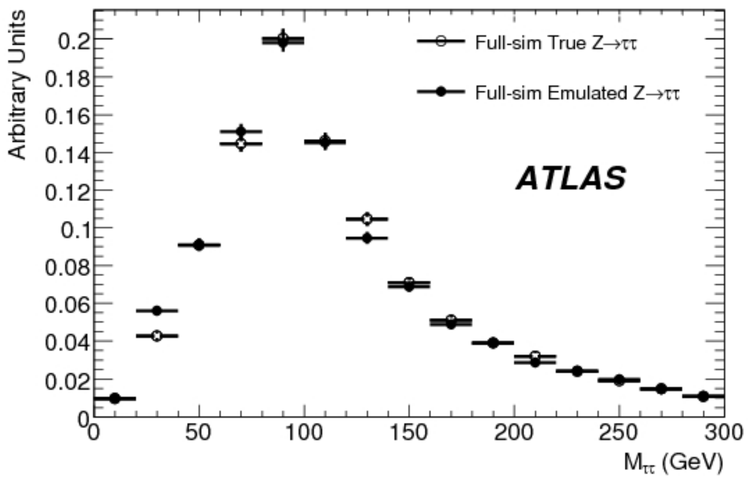
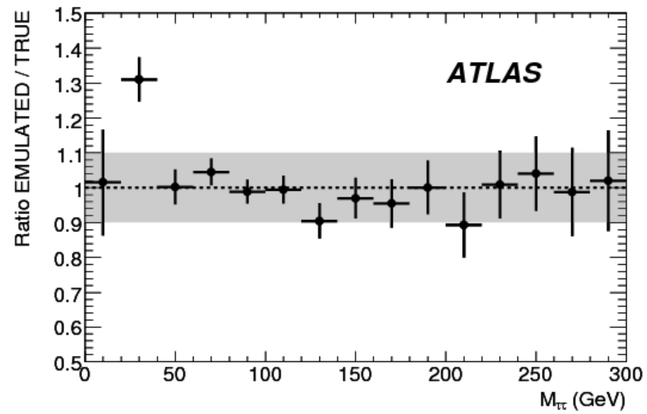


- Replace muon with tau
- Rerun Tauola
- Resimulate again

PRELIMINARY

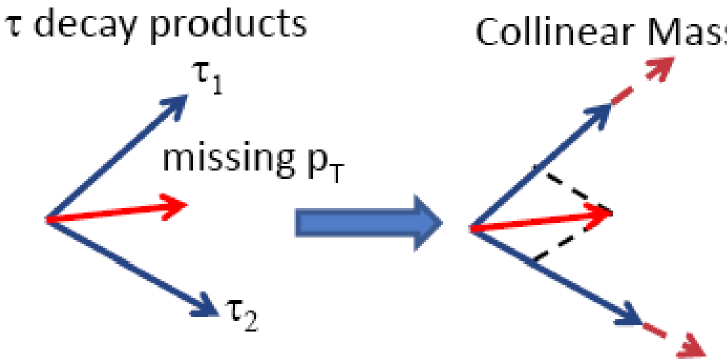


Missing E_T modelled by data
-> tails well described

QCD: OS = SS

this can have large difference and systematic (eg Tevatron, W+jets, 40%)

Mass reconstruction & collinear approximation



$$M_{\tau\tau} = \sqrt{2(E_h + E_{\nu h})(E_l + E_{\nu l})(1 - \cos\theta_{\tau\tau})}.$$

$$\Rightarrow \quad M_{\tau\tau} = \frac{M_{lh}}{\sqrt{x_{\tau l} x_{\tau h}}} \qquad \text{for } x_\tau > 0$$

where,

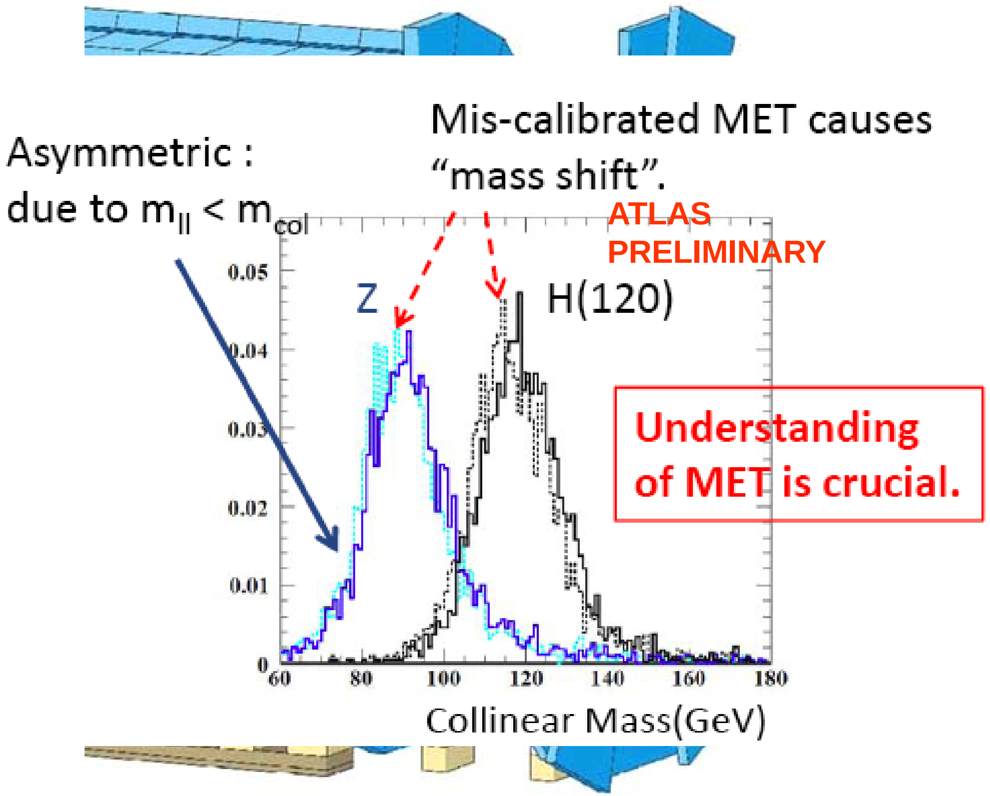
$$x_{\tau h} = \frac{E_h}{E_h + E_{\nu h}} = \frac{h_x l_y - h_y l_x}{h_x l_y + \not{E}_x l_y - h_y l_x - \not{E}_y l_x} = \frac{N}{D_l}$$

$$x_{\tau l} = \frac{E_l}{E_l + E_{\nu l}} = \frac{h_x l_y - h_y l_x}{h_x l_y - \not{E}_x h_y - h_y l_x + \not{E}_y h_x} = \frac{N}{D}$$

Jacobian

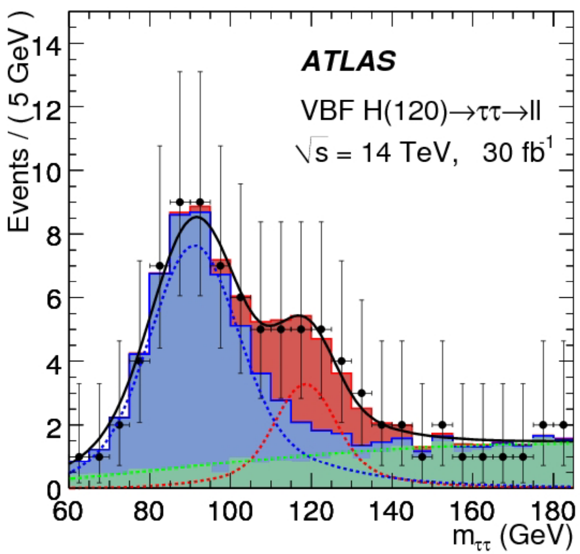
$$J = \frac{\Delta M_{\tau\tau}}{\Delta \not{E}_{x/y}} = \sqrt{\left(\frac{\partial M_{\tau\tau}}{\partial \not{E}_x}\right)^2 + \left(\frac{\partial M_{\tau\tau}}{\partial \not{E}_y}\right)^2}.$$

$$J = \frac{M_{lh}}{2} \frac{\sqrt{x_{\tau l} x_{\tau h}}}{|N|^3} \sqrt{\left(x_{\tau l} h_y D_h^2 - x_{\tau h} l_y D_l^2\right)^2 + \left(x_{\tau h} l_x D_l^2 - x_{\tau l} h_x D_h^2\right)^2}.$$



Mass distribution after all cuts

PRELIMINARY



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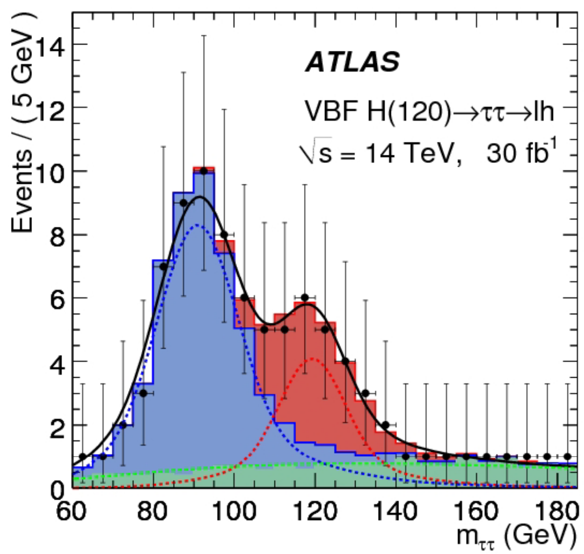

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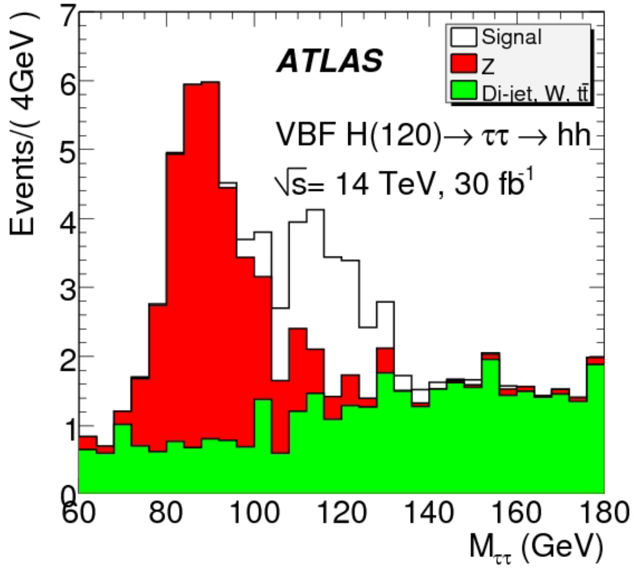
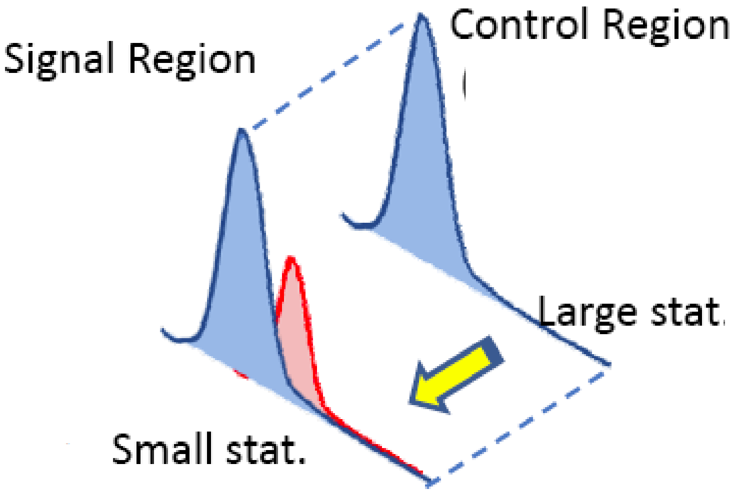
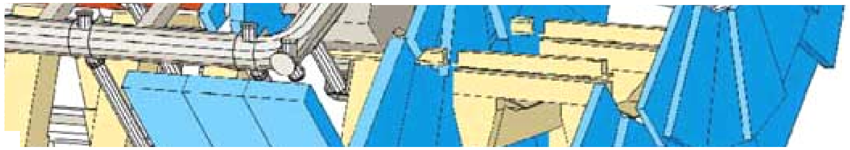


Simultaneous fit unbined

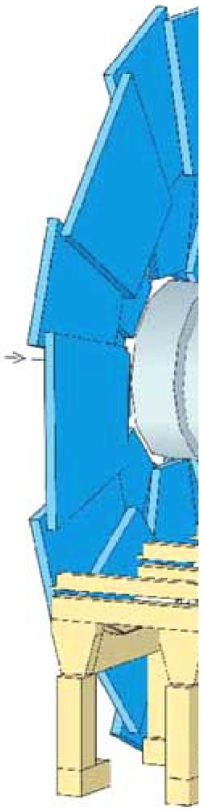




Likelihood function:

$$
\begin{aligned}
L(data|\mu, M_H, \nu) &= L_{track}(\text{track multiplicity}|r_{QCD}) \\
&\times\ L_Z(Z+\text{jets control}|\sigma_Z) \\
&\times\ L_{QCD}(\text{QCD control}|a_0, a_1, a_2, a_3) \\
&\times\ L_{s+b}(\text{signal candidates}|\mu, M_H, \sigma_H, \sigma_Z, r_{QCD}, a_0, a_1, a_2, a_3),
\end{aligned}
$$

Systematic effects on Higgs boson mass determination and on signal selection efficiency



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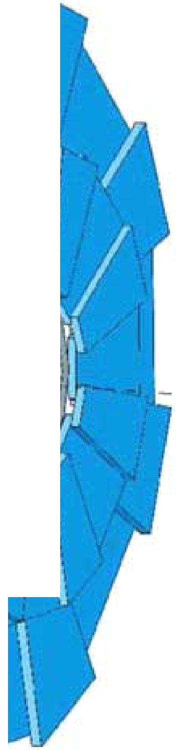

Significance using ll and lh final state

No pile-up

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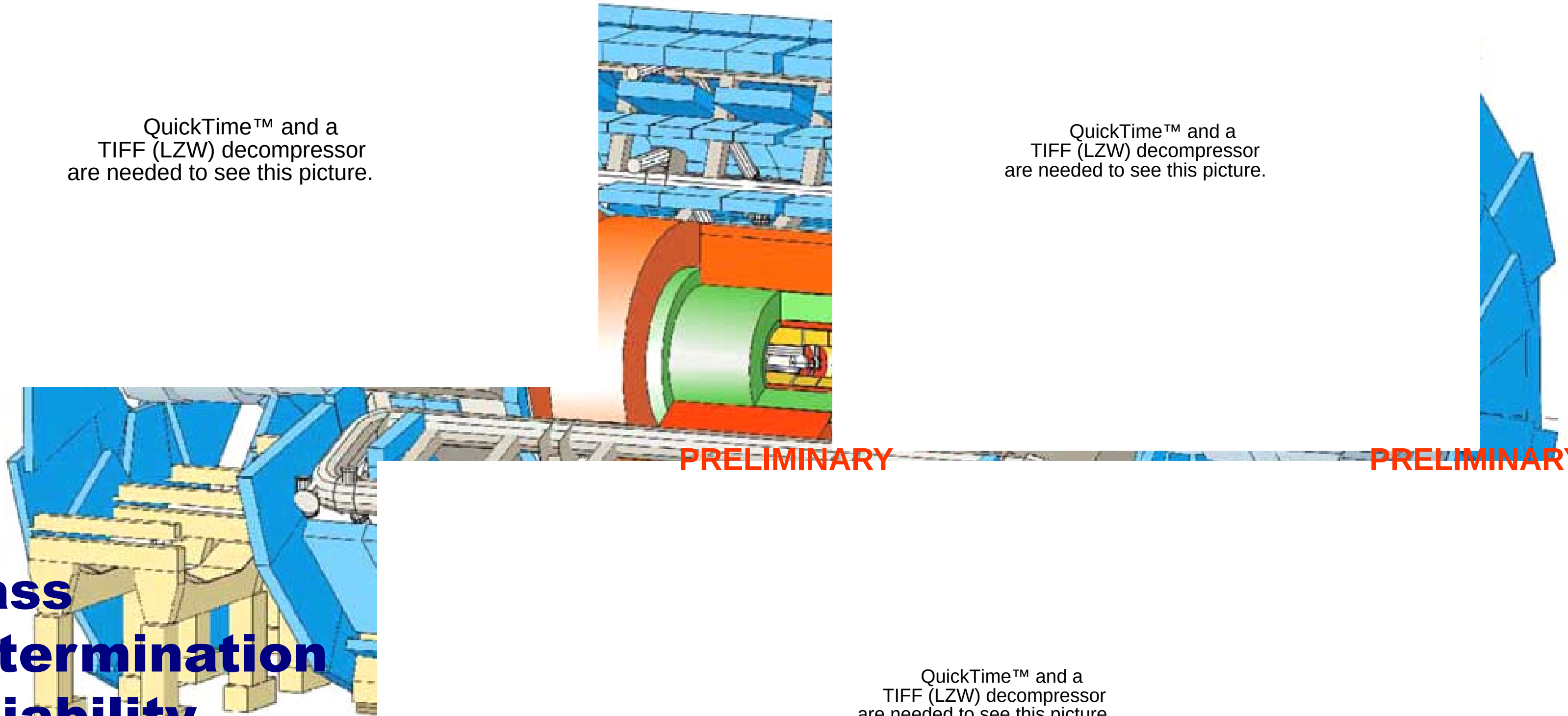

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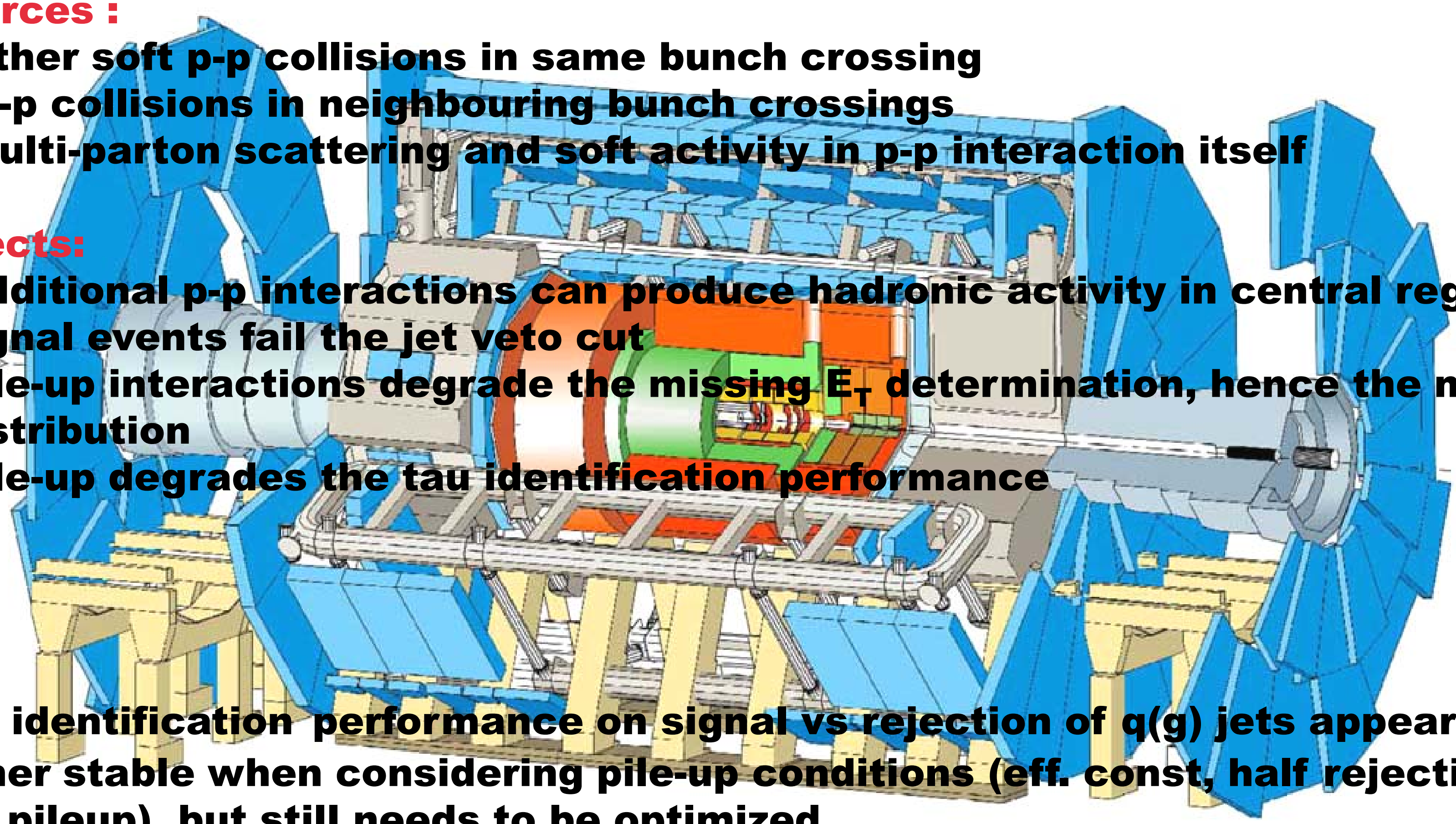
Mass determination reliability

Effect of pile-up



Sources :

- Other soft p-p collisions in same bunch crossing
- p-p collisions in neighbouring bunch crossings
- multi-parton scattering and soft activity in p-p interaction itself

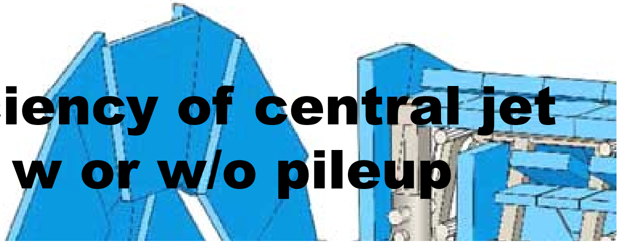
Effects:

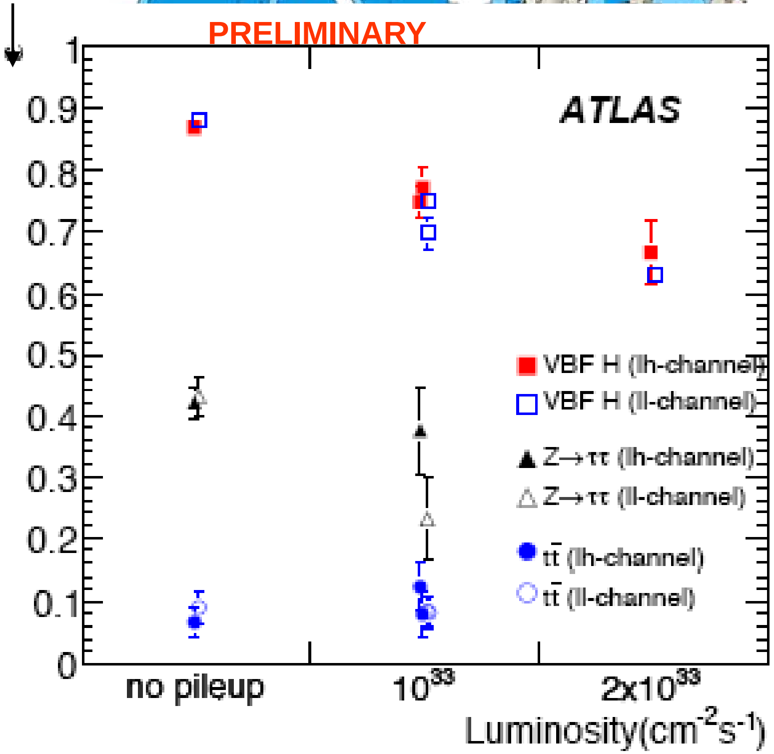
- Additional p-p interactions can produce hadronic activity in central region, signal events fail the jet veto cut
- pile-up interactions degrade the missing E_T determination, hence the mass distribution
- pile-up degrades the tau identification performance

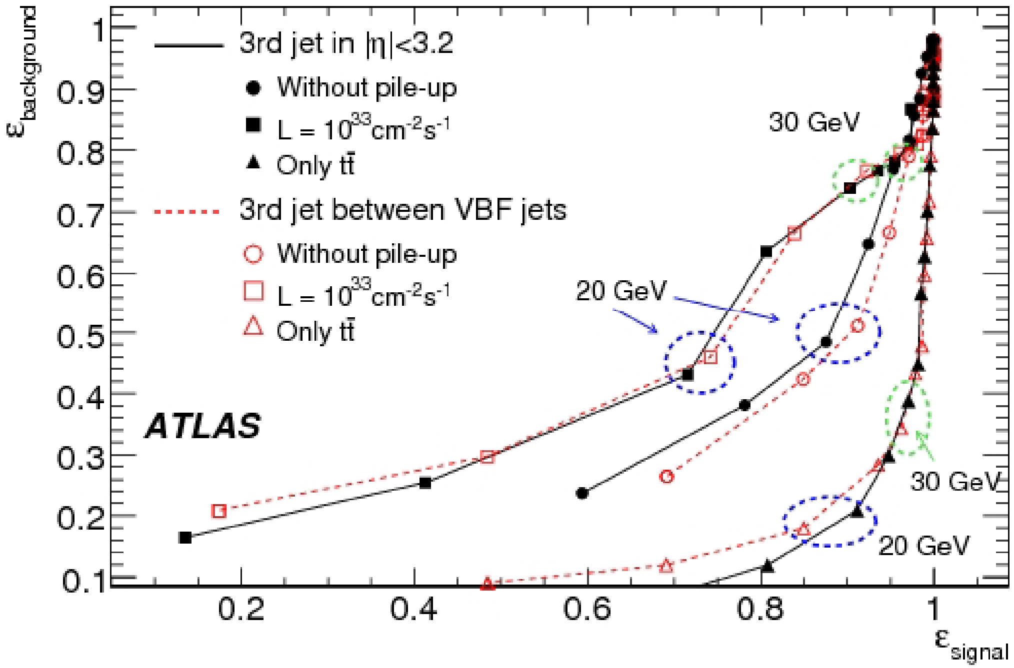
Tau identification performance on signal vs rejection of q(g) jets appears rather stable when considering pile-up conditions (eff. const, half rejection wrt w/o pileup), but still needs to be optimized

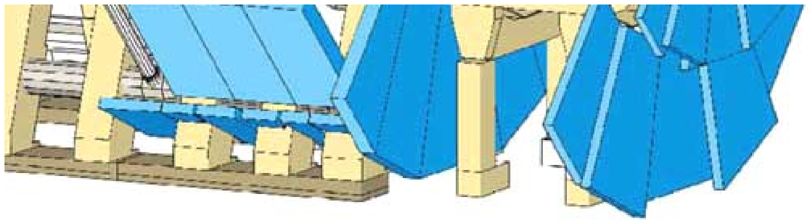
Effect of pile-up

Efficiency of central jet veto w or w/o pileup

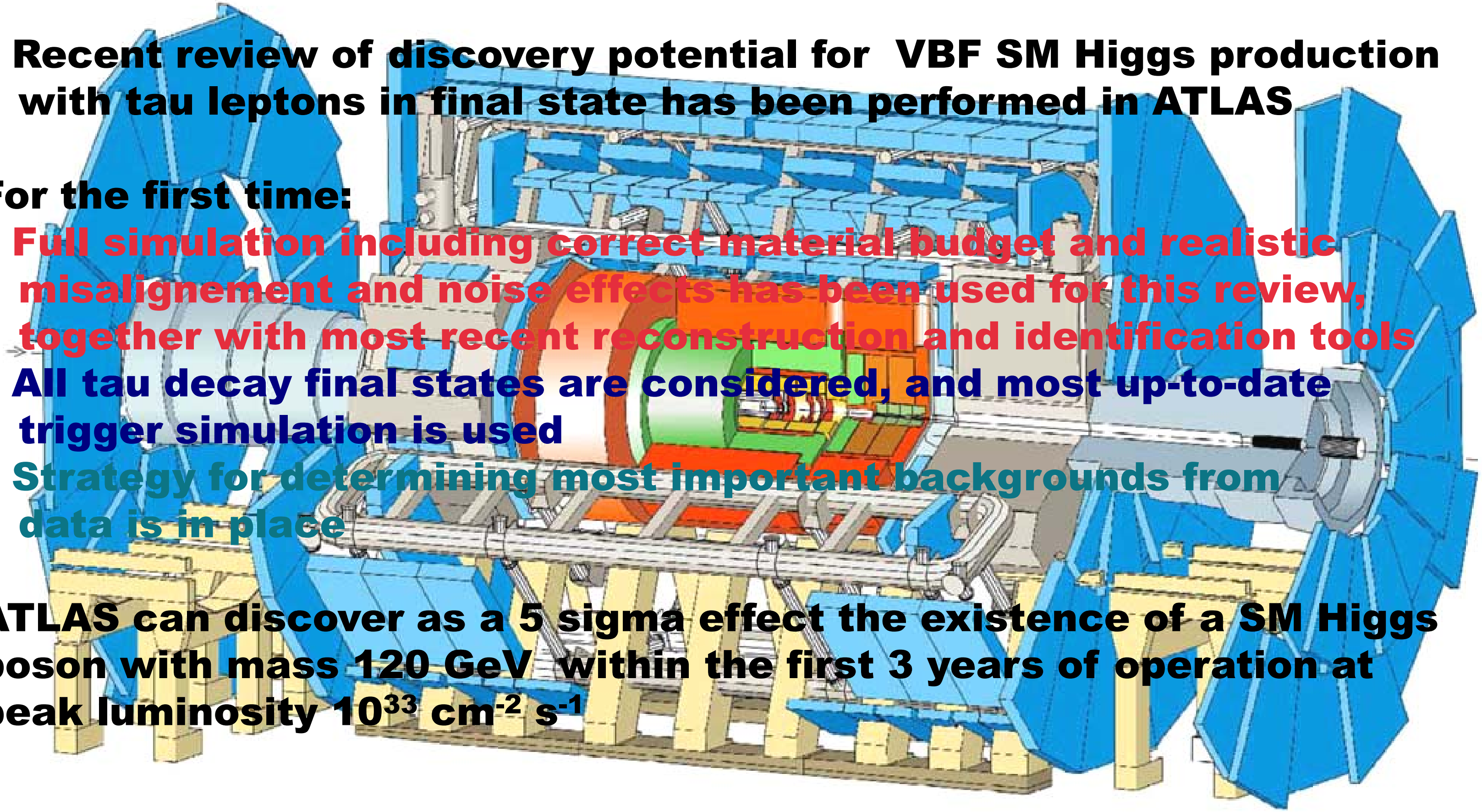








Outlook



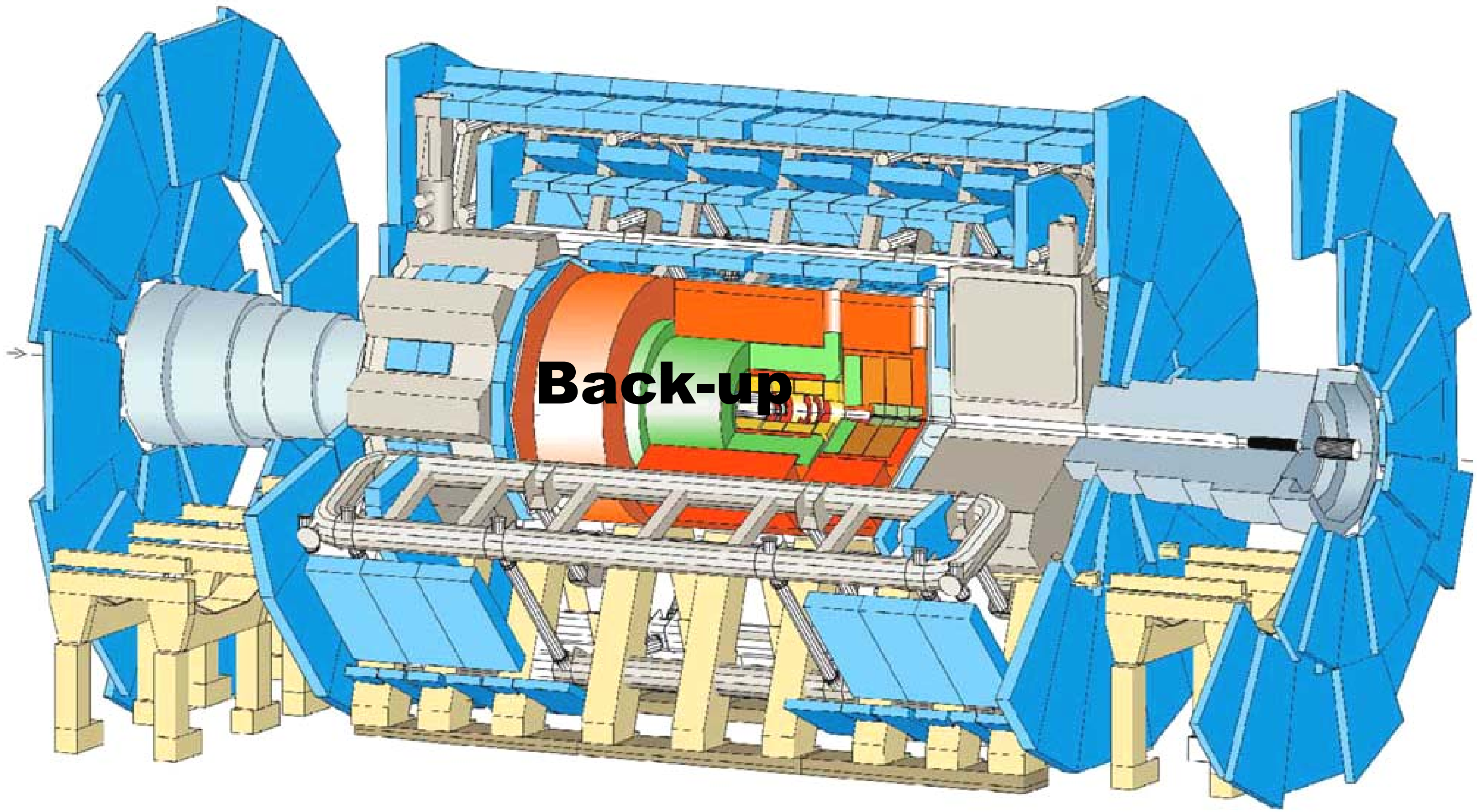
- Recent review of discovery potential for VBF SM Higgs production with tau leptons in final state has been performed in ATLAS

For the first time:

- Full simulation including correct material budget and realistic misalignement and noise effects has been used for this review, together with most recent reconstruction and identification tools
- All tau decay final states are considered, and most up-to-date trigger simulation is used
- Strategy for determining most important backgrounds from data is in place

ATLAS can discover as a 5 sigma effect the existence of a SM Higgs boson with mass 120 GeV within the first 3 years of operation at peak luminosity 10^{33} cm^{-2} s^{-1}

Back-up



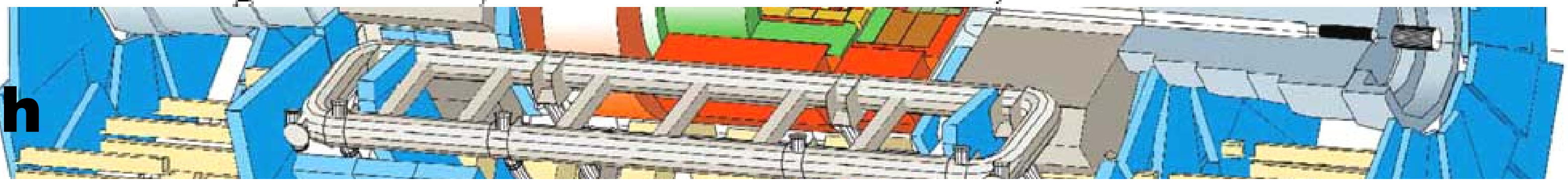
Event selection

lh

- Transverse mass: in order to further suppress the W + jets and $t\bar{t}$ backgrounds, a cut on the transverse mass of the lepton and $\not{E}_T$

$$m_T = \sqrt{2\, p_T^{lep}\, \not{E}_T \cdot (1 - \cos\Delta\phi)} \leq 30 \;\; \text{GeV} \tag{7}$$

is required, where p_T^{lep} is the transverse momentum of the lepton in the lh-channel and $\Delta\phi$ is the angle between that lepton and $\vec{\not{E}}_T$ in the transverse plane. The shape of the control samples used to estimate the signal sensitivity are obtained after these cuts; additional details of the data-driven



hh

- Di-tau transverse mass: in order to further suppress fake-τ candidates from W + jets and $t\bar{t}$ backgrounds, a cut on the di-tau transverse mass

$$m_T^{hh} = \sqrt{2\, p_T^{hh}\, \not{E}_T \cdot (1 - \cos\Delta\phi)} \leq 80 \;\; \text{GeV} \tag{8}$$

is required, where p_T^{hh} is the transverse momentum of the two hadronic tau system and $\Delta\phi$ represents the azimuthal angle between p_T^{hh} and $\vec{\not{E}}_T$. This variable has been identified as potentially useful for the analysis. The optimal value of this cut depends heavily on the relative amount of the W+jets, $t\bar{t}$ and QCD backgrounds, therefore, the requirement is kept fairly loose.

QCD fake rate from data

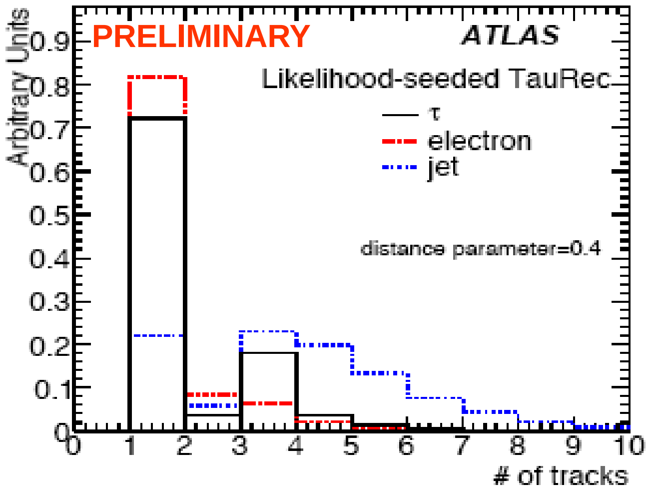


Figure 11: Track multiplicity distribution for QCD fake events and electron-fake events as well as the τ signal.

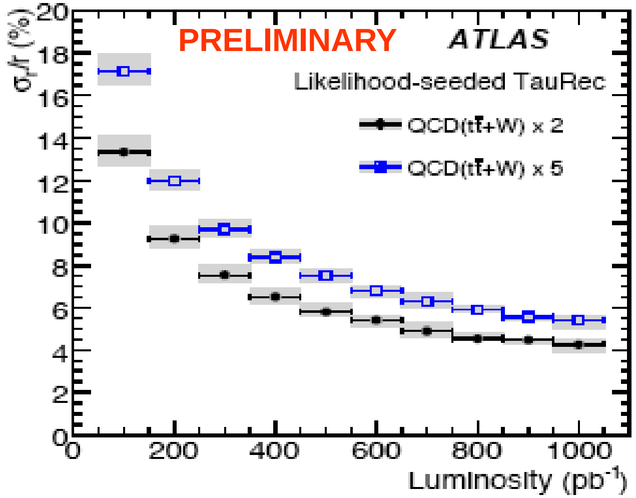


Figure 12: Expected errors of the fraction r_{tau} as a function of luminosity. The QCD events are scaled to $\times 2$ and $\times 5$.

Given a sample of tau candidates, the relative abundance of taus, electrons, and jets can be found by fitting the track multiplicity distribution with the extended likelihood function

$$\begin{aligned} L_{track}(r_{QCD}, r_{tau}) \; = \; & \prod_i^N Pois(n_{exp}^{tot} \times (r_{tau} f_{tau}^i + r_{QCD} f_{jet}^i + (1 - r_{tau} - r_{QCD}) f_{lep}^i) | N_{obs}^i) \\ & \times Gaus(N_{obs}^{tot} | n_{exp}^{tot}, \sqrt{n_{exp}^{tot}}) \qquad (10) \\ & \times Gaus(N_{lep}^{measured} | n_{exp}^{tot}(1 - r_{tau} - r_{QCD}), \Delta_{lep} n_{exp}^{tot}(1 - r_{tau} - r_{QCD})) \end{aligned}$$

where n_{exp}^{tot} is the total number of events estimated by the fit, r_{tau} (r_{QCD}) is the fraction of the tau (jet) contribution with respect to the estimated total number of events, $\Delta_{lep} = 10\%$ is the relative uncertainty on lepton measurement, and f^i is the normalized probability for the i^{th} bin of the track multiplicity distribution. The second term constrains the normalization, and the third term is an additional constraint term for the lepton contribution estimated by an independent analysis. The fit is performed to find the

tt and W+jets background shapes

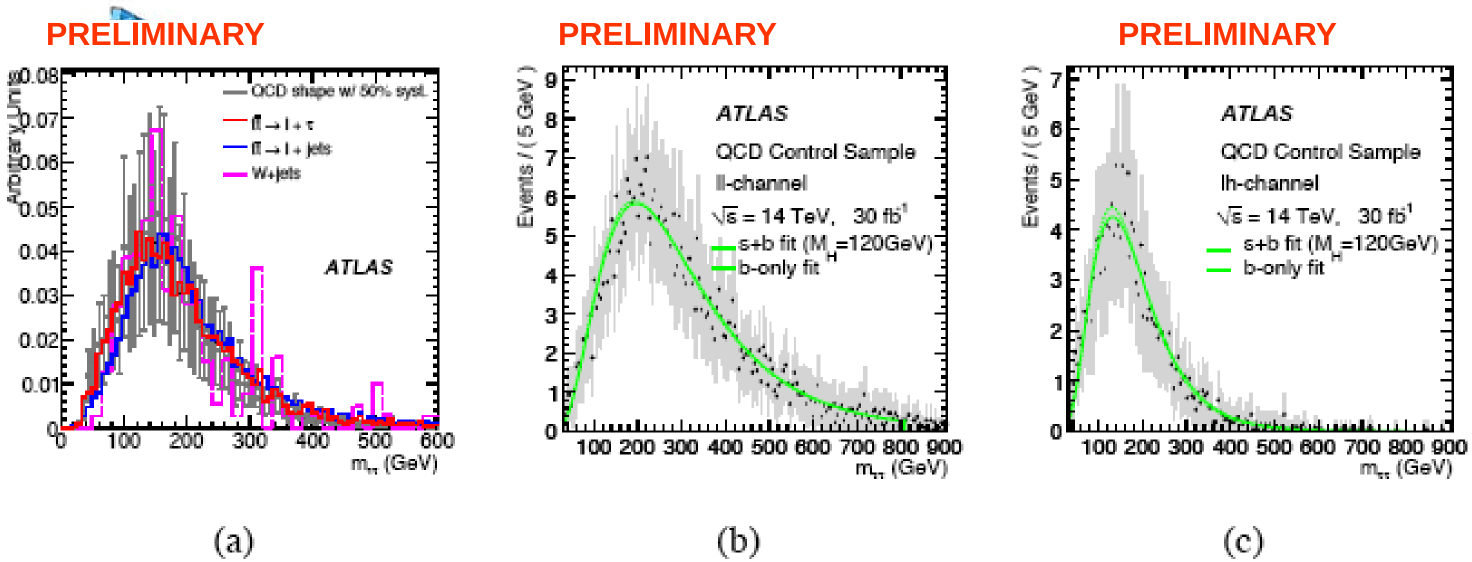
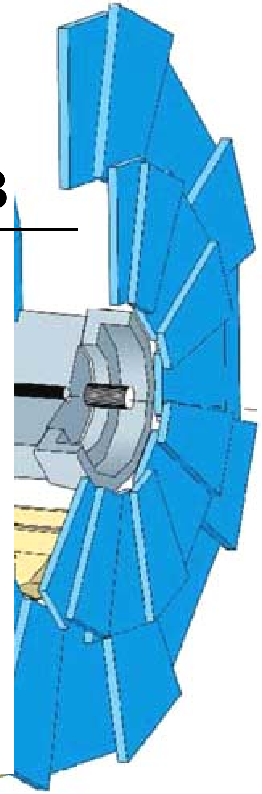


Figure 14: Figure (a) shows that the shapes are similar for these backgrounds and that the shape is stable in the final stages of the cut flow. The $m_{\tau\tau}$ spectrum for $t\bar{t}$ and W+jets backgrounds after all cuts for the ll-channel (b) and lh-channel (c) with a fit to the spectrum. The solid and dashed curves show the result of the simultaneous fit to the control sample and signal candidates with and without the signal contribution, respectively.

$$\frac{S+B}{B}$$

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Exclusion

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

No gg contribution included

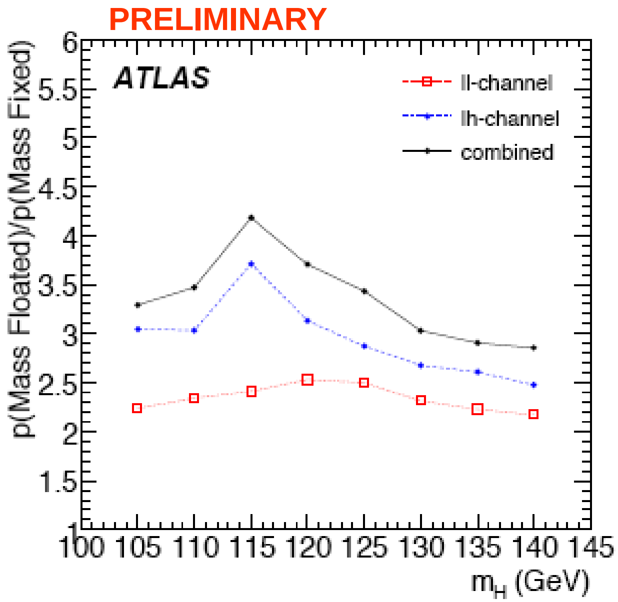


Figure 18: The ratio of expected p-values for the floating and fixed mass fits as a function of the Higgs boson mass. This plot summarizes the impact of the "look-elsewhere" effect in this analysis.

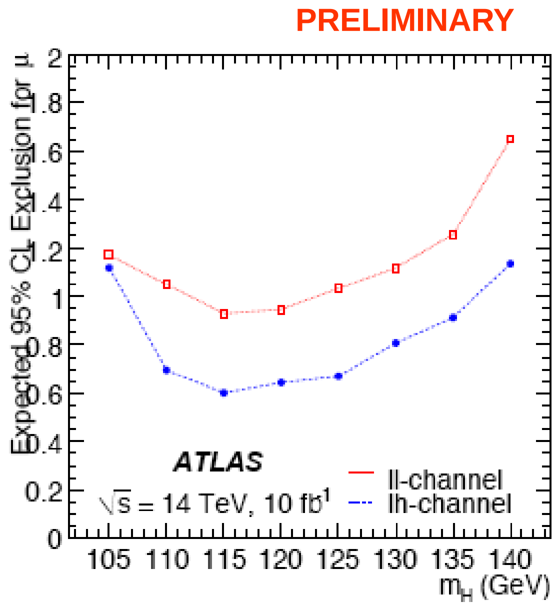


Figure 19: Expected 95% exclusion of the signal rate in units of the Standard Model expectation, μ, as a function of the Higgs boson mass for the ll and lh-channels with 10 fb^{-1} of data. The exclusion takes into account the uncertainty on the signal efficiency described in Section 5.