How to probe electroweak symmetry breaking mechanism through τ leptons ?

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Strasbourg seminar

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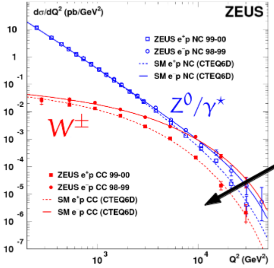
Overview

1. **Introduction and motivations**
2. **Analysis of $p\bar{p}$ collisions recorded by DØ**
   - Identification of τ lepton
   - Higgs boson search in $\mu + \tau_{\text{had}}$ - selected parts
3. **Analysis of pp collisions recorded by ATLAS**
   - On going work on τ lepton identification and modeling
   - Higgs boson search in the $\tau_\ell + \tau_{\text{had}}$ final state
4. **Summary and outlooks**



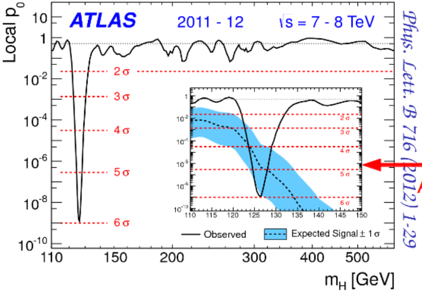
Unified theory of interactions

$$SU(2)_L \times U(1)_Y \times SU(3)_c$$
$+$ Higgs mechanism

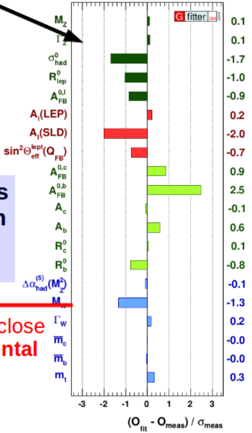
experimental trend for **unification** of EM and weak interaction for Q~100 GeV

Theoretical framework very predictive (and **experimentally validated**)

New particle ! compatible with the Higgs boson



Is the Higgs mechanism realized in Nature?

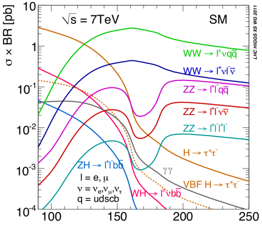


After 20 years : close to an **experimental answer !**

Physics probed by τ lepton, challenges

Understand electroweak symmetry breaking :

- Observation of $H \to \tau\tau$ process
- Unique test of $g_{Hf} \propto m_f$ in the fermionic sector
  (together with $H \to b\bar{b}$ measurement)
- sensitive probe of vector bosons fusion
- Possibility of polarization studies : access to $\mathcal{J}^{\mathrm{CP}}$



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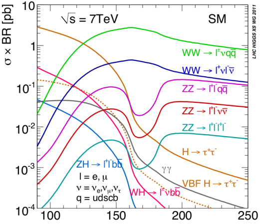

And go beyond : SUSY, Larger gauge group (doubly charged Higgs), new interaction (Z' search), lepton universality at the TeV scale, lepton flavor violation in Z (H ?) decay

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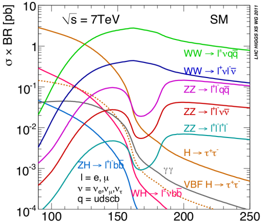

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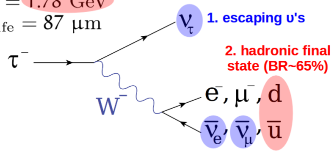
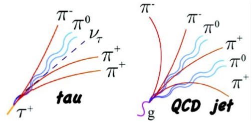
But experimentally challenging ! Jets contamination very frequent in hadrons collider !

$m_\tau = 1.78$ GeV
$c\tau_{life} = 87$ μm





$\tau_{had} \approx$ narrower jet with lower track multiplicities

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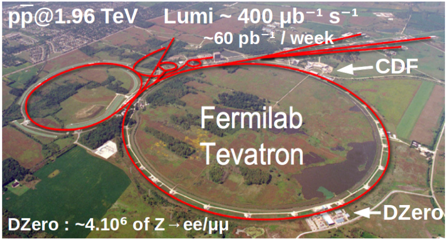
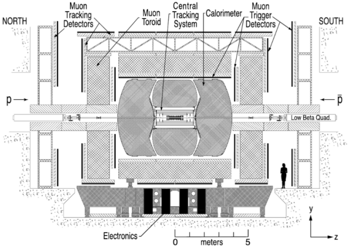
Tevatron and the DØ experiment





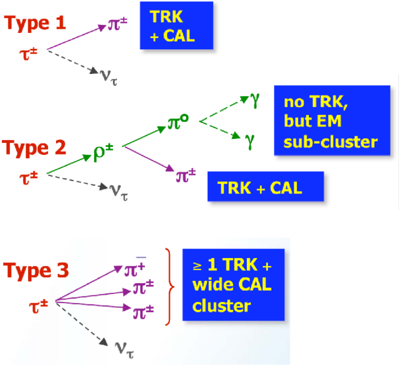
Comments :

- $qq \to VH$: second dominant Higgs production
- Worst σ_H/σ_Z than LHC ($q\bar{q}$ in initial state from $p\bar{p}$), $\langle\mu\rangle \sim 10$,
- $\Delta p_T/p_T$ at 50 GeV : $\sim 7\%$ (tracker) and $\sim 2.5\%$ (calo).
- Typical calorimeter segmentation : $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

Identification of τ lepton in DØ

Properties : $m_\tau = 1.78$ GeV, $c\tau_{\text{life}} = 87\ \mu$m, $\boxed{BR_{\tau\to\text{had}} \simeq 65\%}$

3 types of signature according to hadrons in the final state



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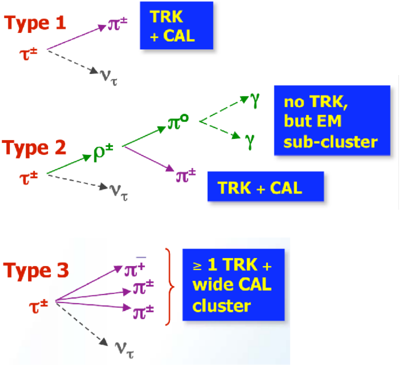
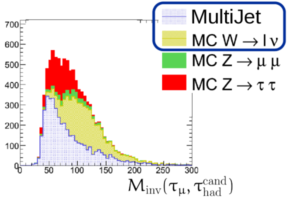


Important bkg "jet $\to\tau$"



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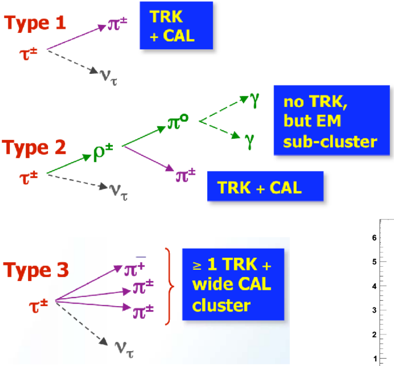

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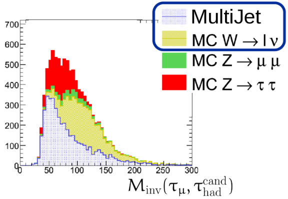
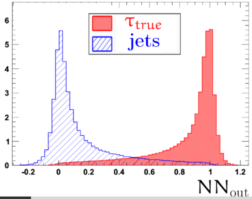


Discrimination of τ/jet



$\sim$ **10** **discriminating variables** combinned in a **neural network** **(NN)**

$\epsilon_{\text{sig}} \sim 67\%$

$\epsilon_{\text{bkg}} \sim 1\%$

Improvement of τ lepton identification

General point of view : Neural Network output $\eta^{\text{NN}}(\vec{X})$ **converges** to

$$\eta^{\text{true}}(\vec{X}) \equiv \frac{\mathcal{S}(\vec{X})}{\mathcal{S}(\vec{X}) + \mathcal{B}(\vec{X})}$$

best discriminating function, related to Prob$(S|X)$

where $\vec{X} \equiv (x_1, x_2, ..., x_n)$ describes the discriminating variables space.

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In the τ identification context :

A lot of ideas were tested to optimize the identification of τ leptons :

- Include preshower detector measurement ✗
- Exploit the long τ life time (like for b-jets) ✓

→ improve $\eta^{\mathrm{true}}(\vec{X})$

- Tune NN parameters (epoch, nodes, statistics) ✓
- Dedicated training for τ of high p_T ✓
- Dedicated training for high luminosity events ✗

→ minimize $|\eta^{\mathrm{NN}} - \eta^{\mathrm{true}}|$

✗ $\equiv$ no improvement ; ✓ $\equiv$ improvement

Final improvement on τ identification

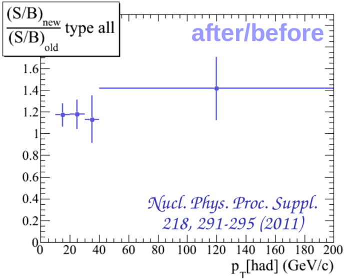
Final result :

comparaison of $S/B(p_T^{\tau_{\text{cand}}})$ before and after optimisations.

$\boxed{15 - 30\% \text{ improvement}}$

Tool used by the collaboration in τ related papers (arXiv :1211.6993, PRD)

Résultats présentés à TAU2010



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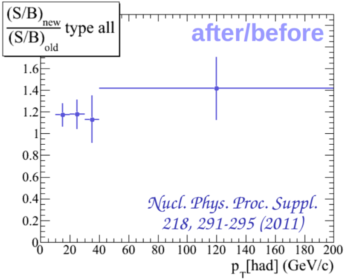

Experimental skills developped during this work on τ lepton identification

- Quite deep experience in multivariate classification,
- Reconstruction of EM energy deposit with scintillating strips detector, in an hadronic environnement (more in backup).
- Get familiar with couple of b-tagging algorithms.

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Analysis overview - flash

Motivations (out-of-date) **and strategy :**

- $H \to WW \to \tau\mu$ process allow to complete other $H \to WW$ channels
- Select events with one τ and one isolated μ (based on trigger mixture),
- Look for an excess of events at high $M(\mu, \tau_{\text{had}}, \not{E}_{\text{T}})$,
- Other variables are combined in a NN to exploit the full kinematic,
- Main background is due to fake τ : $W(\to \mu\nu)$+jets.

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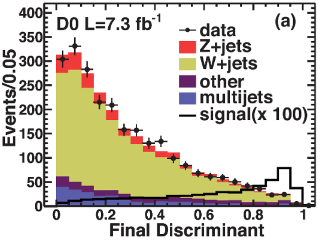
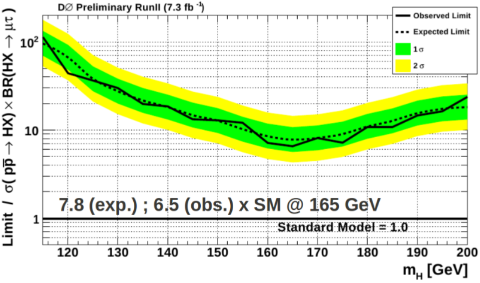
Phys. Lett. B 714, 237 (2012)





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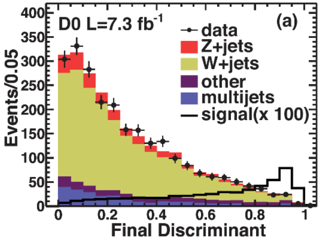
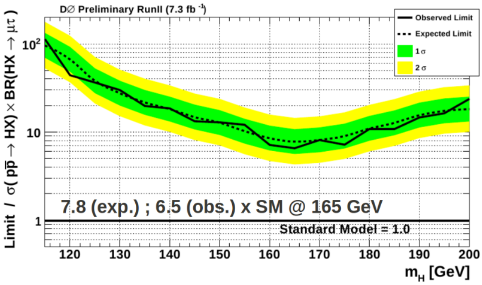
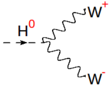
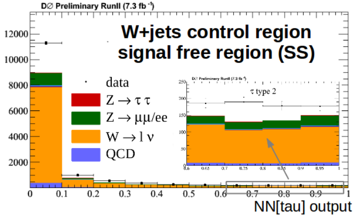




W+jets modelling (1/3)



signal
τ and μ of
opposite sign **OS**



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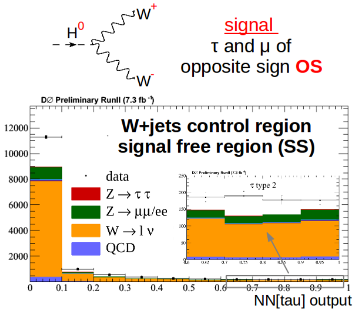
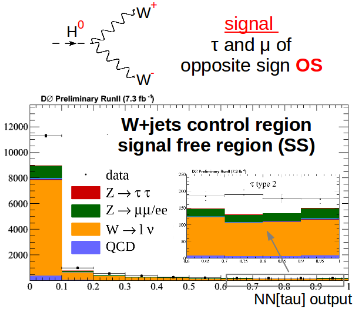


- scale W+jets in a control region (*ie.* signal free), selected in data (SS or OS low NN_τ)

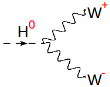
W+jets modelling (1/3)



- scale W+jets in a control region (*ie.* signal free), selected in data (SS or OS low NN_τ)
- **But** extrapolation in the signal region needs :

$$\left.\frac{\text{OS}}{\text{SS}}\right|_{\text{MC}} (\text{NN}_\tau) \;\rightarrow\; \text{well modeled ?}$$

W+jets modelling (1/3)



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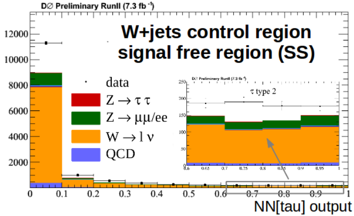

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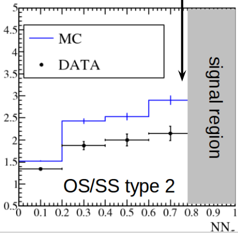
NO !

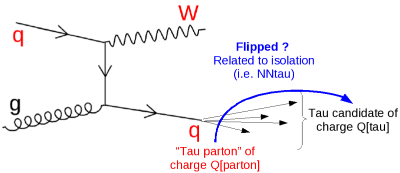


A new approach is needed :

1. understand the NN_τ variation of OS/SS,
2. build a model based on 3 parameters,
3. fit the model on data.

W+jets modelling (2/3)

Strategy : Understand the origin of the NN-dep. of OS/SS



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2. Charge correlation between the parton and the reconstructed τ depends on NN_τ

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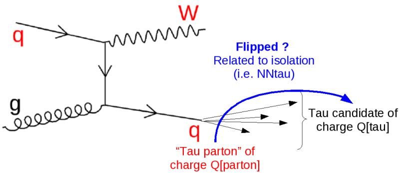

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Convolution of these two effects give specific OS/SS dependence with NN_τ :

3 possibilities at the generated level :

1. $Q_\mu \times Q_{\mathrm{parton}} < 0$ (gen OS)
2. $Q_{\mathrm{parton}} = 0$ (gluons)
3. $Q_\mu \times Q_{\mathrm{parton}} > 0$ (gen SS)

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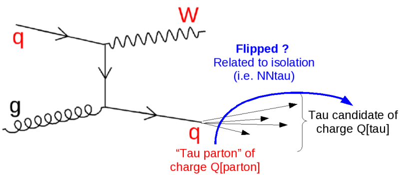

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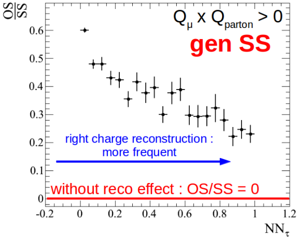
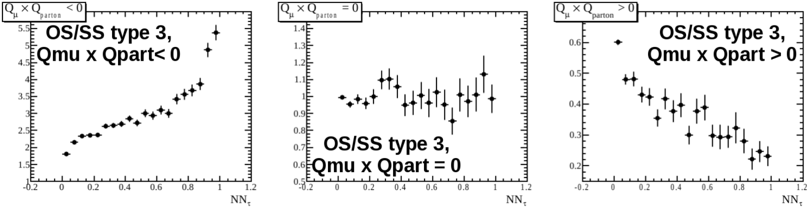
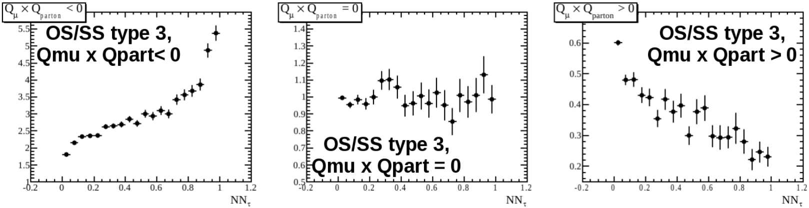


W+jets modelling (3/3)



Model : final prediction will be a "linear combination" of 3 above plots.
Roughly : fit the relative contributions - related to q/g fraction in W+jets.

W+jets modelling (3/3)



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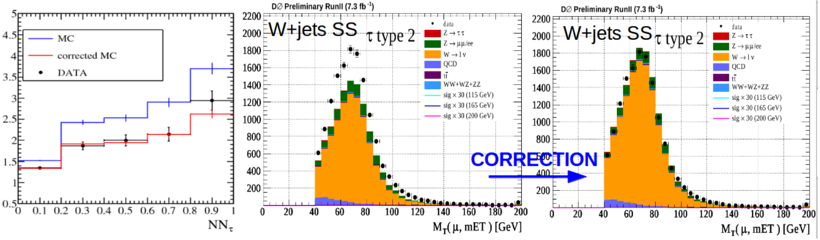

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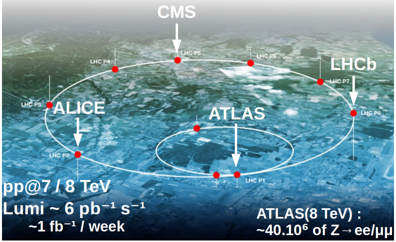
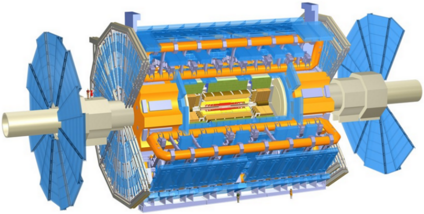
The LHC and ATLAS experiment

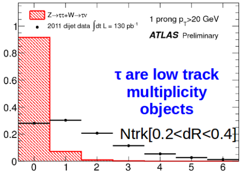


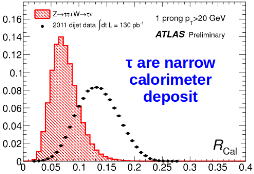


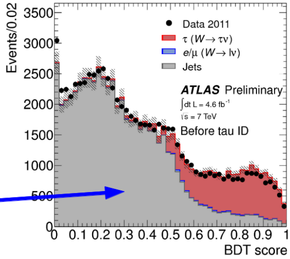
Comments :

- $qq' \to qq'H$: second dominant Higgs production (instead of VH for TeV)
- Better σ_H/σ_Z than TeV, "LHC$\approx$ gg collider", $\langle\mu\rangle \sim 20$,
- $\Delta p_T/p_T$ at 50 GeV : $\sim 2.7\%$ (tracker) and $\sim 2.0\%$ (calo).
- Typical calorimeter segmentation : $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$

Identification of τ lepton in ATLAS







+ 6 **others observables** combined in a Boosted Decision Tree (BDT)

$\varepsilon_{sig} \sim 65\%$ – $\varepsilon_{bkg} \sim 2\%$

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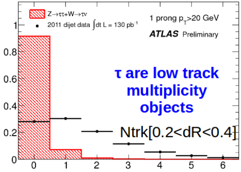
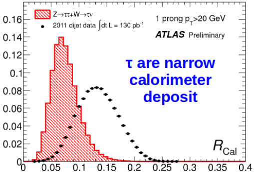
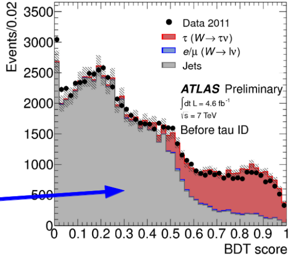


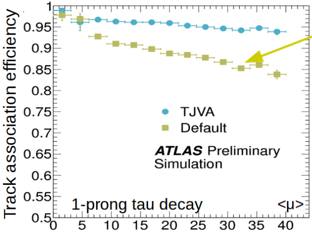




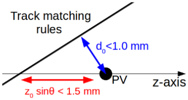
+ 6 **others observables** combined in a Boosted Decision Tree (BDT)

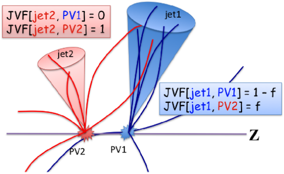
$\varepsilon_{sig} \sim 65\%$ – $\varepsilon_{bkg} \sim 2\%$

Pile-up robustness : Tau Jet Vertex Association (TJVA)



When **pile-up increases**, the PV might be wrongly selected : track-candidate matching will fail. Need to associate the right PV to the tau !





For each candidate : take the PV having the highest JVF

On going work : modeling of τ_{had}

Problem : τ_{had} ID relies on shower shape variable. If the simulation poorly models them, ϵ_{ID} from simulation might be wrong.

Solution : measure ϵ_{ID} in $Z \to \tau\tau$ events selected in data ("tag & probe").

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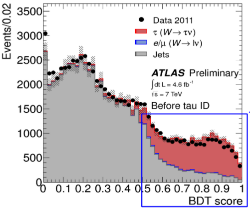
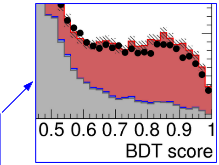
But how to go further ? undersdand the variable shape

- major impact on physics analysis via MVA signal extraction,
- undersdand correlations between input variables,
- look at different detector regions (fwd VS central).



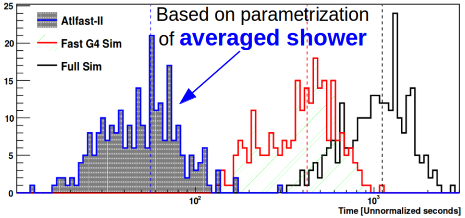


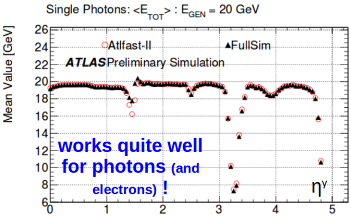
How the **shape** of the final discriminant is modeled ?

Cons : not clear if this will lead to a concluding result on the short term.
Pros : work at a deeper level for a better understanding of τ_{had}.

On going work : τ_{had} in fast simu (atlfast-II)

Goal and principle : the lack of MC is significant in some of the analysis





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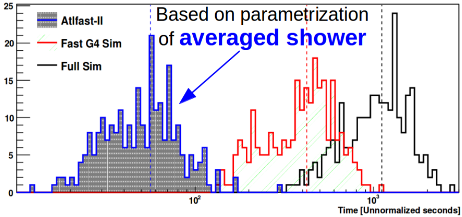

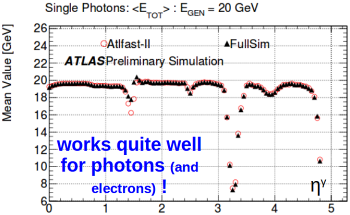

Connexion with τ leptons :

- hadrons : important shower fluctuations
- usually averaged in jets (high number of hadrons)
- $\tau_{\rm had}$: low multiplicity object $\rightarrow$ fluctuations become important

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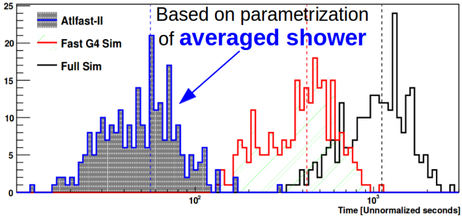

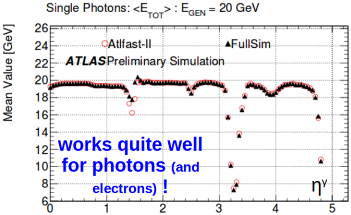

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On going work on this :

- particle gun experiment with π : shower at the cells and clusters level
- capure microscopic effects which lead to sizable effects at the reco level
- look at $Z \rightarrow \tau\tau$ events in the same perspective (calo noise, pile-up, ...)

Overview

$H \to \tau_\ell \tau_{\rm had}$ overview

Background estimation :

- MJ & W+jets[SS] : SS **data**
- W+jets add-on : (corrected) MC
- Z : either **data** or (corrected) MC

Categorization : 7 categories based on

- jet multiplicity and lepton flavor
- $p_T(\ell, \tau_{\rm had}, \not{E}_{\rm T})$ and VBF topology
- The **VBF** category is **the priority**

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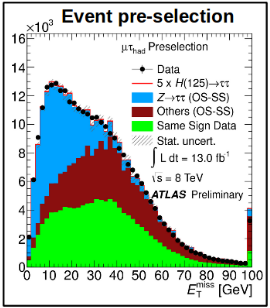
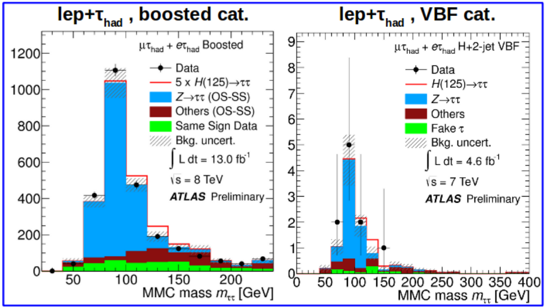




before signal extraction → Two most sensitive categories

- **mT<30 GeV** supress W+jets
- **mET>20 GeV** supress QCD
- more (complicated) cuts to reduce fake and top
- cut specific to each category

Contributions to the analysis

I was in charge to manage a group of 3 students who have important contributions in the listed items.

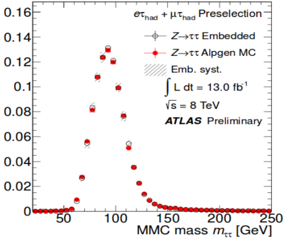
- 2011 analysis re-optimization (selections, fake rejection, boosted topology, ...)
- MVA signal extraction : input variables, systematics, limit extraction
- Exploit τ decay sub-structure to increase s/b - potential for spin/CP studies
- Signal modeling : impact of EW corrections on kinematic/acceptance
- Background modeling : τ_{had} modeling in Z CR - linked to τID work
- Background modeling : jets modeling in $Z \to \ell\ell$ CRs - crucial for VBF signal extraction
- Statistical treatement : sanity checks of profiling - designed a tool used in several analyses
- Orthogonal approach : unbinned fit to extract limit - under developpement

Chosen parts of the analysis to be described :

- $Z \to \tau\tau$ and W+jets bkg modeling
- EW corrections of $qq' \to qq'H$
- The boosted topolgy and result of all other optimizations
- Systematic uncertainties and result

Background modeling : $Z \to \tau\tau$ and W+jets

$Z \to \tau\tau$ modeling :



Data driven : τ "embedding" in $Z \to \mu\mu$ data events

- remove μ deposits and replace by a simulated τ.
- It's data (jets, pile-up, calo noise, soft radiations)
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- goal : more stat in VBF category,
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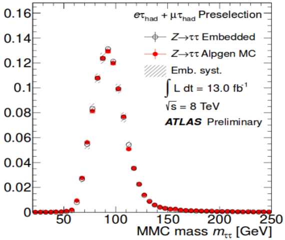

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- Norm corr factor (k_W) derived for $m_T > 70$ GeV
- Derived for OS and SS separatly : $k_W^{OS} \sim 0.6$ and $k_W^{SS} \sim 0.8$

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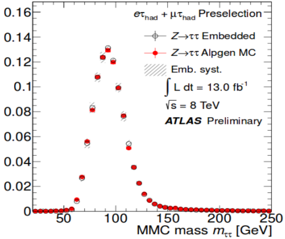
$Z \to \tau\tau$ modeling :



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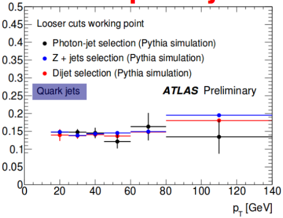
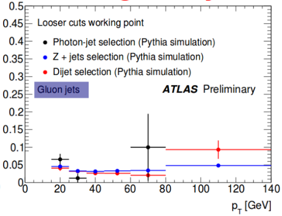
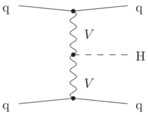
fake : quark jets



fake : gluon jets



Signal modeling : EW corrections of $qq' \to qq'H$



Motivations and goal :

- VBF@LO is EW : $\delta_{\mathrm{EW}} \sim \delta_{\mathrm{QCD}}$ (unlike $gg \to H$)
- σ_{tot} is already QCD+EW NLO : but shape effects of δ_{EW} ?

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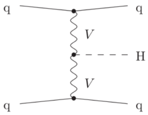

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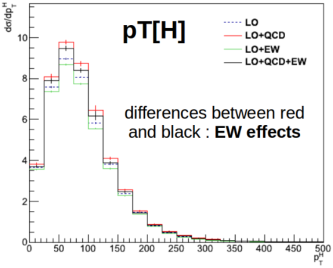
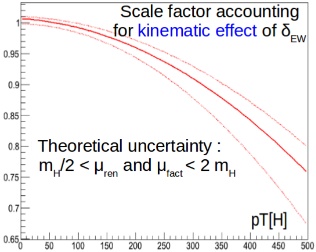
At generated level : most affected distribution is p_T^H - HAWK





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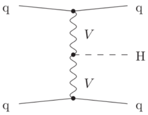

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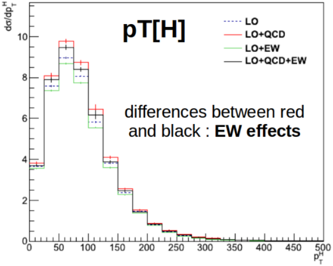
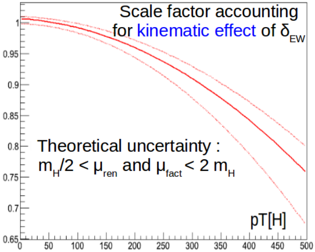


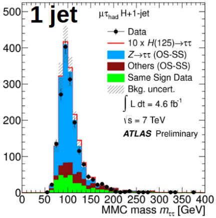


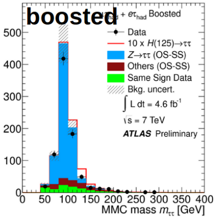
At reconstructed level :

- negligeable impact, wrt to other exisiting systematics,
- This spectrum distortions should be kept in mind for the future.

Re-optimization of 2011 analysis

The boosted topology : defined by $p_T^H \stackrel{\rm reco}{=} p_T(\ell, \tau_{\rm had}, \not{E}_T) > 100$ GeV





- better resolution on $m_{\tau\tau}$ for boosted system
- significantly reduce fake τs
- theo uncert. well under control for p_T^H, unlike $n_{\rm jets}$
- $\sim$ sensitive as VBF category

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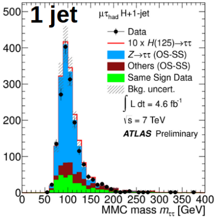

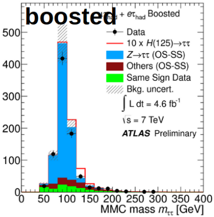

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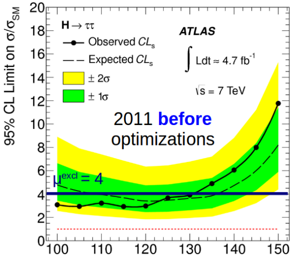

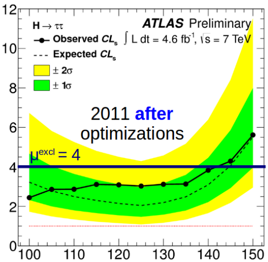

With other improvements :
expected sensitivity almost divided by 2 !

Uncertainty	$H \rightarrow \tau_{\text{lep}}\tau_{\text{lep}}$	$H \rightarrow \tau_{\text{lep}}\tau_{\text{had}}$	$H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$
		$Z \rightarrow \tau^+\tau^-$	
Embedding	1–4% (S)	2–4% (S)	1–4% (S)
Tau Energy Scale	–	4–15% (S)	3–8% (S)
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	5%	4% (non-VBF), 16% (VBF)	9–10%
		Signal	
Jet Energy Scale	1–5% (S)	3–9% (S)	2–4% (S)
Tau Energy Scale	–	2–9% (S)	4–6% (S)
Tau Identification	–	4–5%	10%
Theory	8–28%	18–23%	3–20%
Trigger Efficiency	small	small	5%

Most important systematic : **τ energy scale**

→ direct impact on final observable ($m_{\tau\tau}$)

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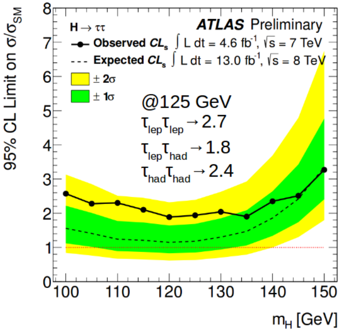

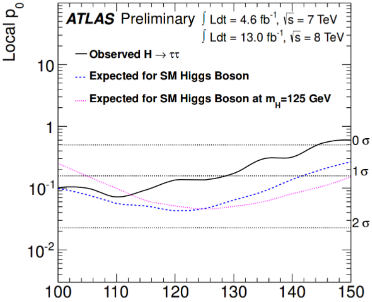

Overview

Summary and outlooks

The τ-lepton final states provide key informations to understand the EWSB mechanism at hadrons colliders

Researches on DØ :

- Improvement of the τ identification of 20%.
- Search for $H \to WW \to \tau\mu$, with a good background understanding.
- Deep understanding of jets faking τ-leptons in W+jets events.

On going researches on ATLAS :

- Understanding τ_{had} modeling in control region.
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What is the medium term future ?

Measuring $X(125)$ properties in the $\tau\tau$ final state (more in backup) !

Backup slides

Does the new resonance behave as the SM Higgs boson ?

- should be the quantum of scalar field - spin 0 particle.
- should be $\mathcal{J}^{\text{CP}} = 0^{++}$ (to avoid pseudo-mass for fermions).
- should have specific couplings $g_{HXX} \propto m_X$.

NO - the new boson doesn't behave like the SM Higgs boson

- What is its nature ? Does it come alone ?
- Which property is different from prediction ? all information will be valuable
- Search for new physics ! Supersymmetry, extra-dimension, ... ?

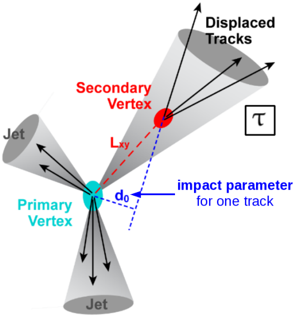
YES - the new boson does behave like the SM Higgs boson

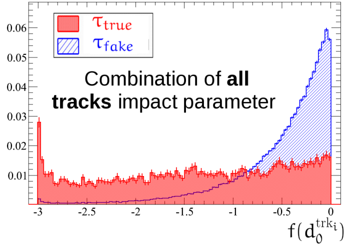
- Yes, but at which precision ? Mainly the scope of futur e^+e^- collider.
- Mass instability of elementary scalar field : is the new boson elementary ?
- **Many open questions** : dark matter, neutrinos masses, CP violation ...

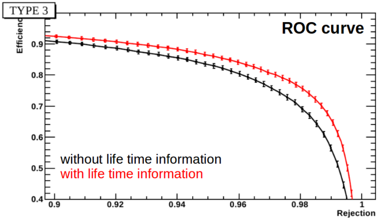
One needs new physics !

τ-lepton final states provide either an *exclusive way* or valuable *complementary information* to answer some of these questions.

τ is a long lived particle







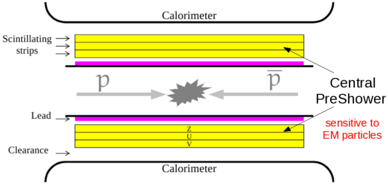
Use impact parameter to remove jets faking τ more efficiently.
(large $c\tau_{\text{life}} \Rightarrow$ large d_0)

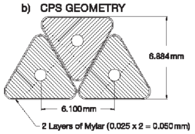
$\sim$ 10% more signal for the same bkg

Le détecteur de pieds de gerbe (CPS)

Idée physique : exploiter les résonances spécifiques de la désintégration des τ (type 2) : $\tau^{\pm} \to \rho^{\pm}\nu \to \pi^{\pm}\pi^{0}\nu$. Utiliser la segmentation de ce détecteur, plus fine que celle du calorimètre : $\Delta\phi_{\text{CPS}} \simeq 0.1 \times \Delta\phi_{\text{calo}}$

CPS sensible aux e, γ donc permet de reconstruire un dépôt dû au $\pi^0 \to \gamma\gamma$





3 bandes scintillantes

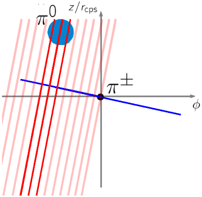
Radiateur (Pb) et 3 couches z, u, v d'environ 2600 bandes scintillantes chacunes :

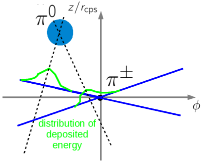
- couche z (ou axiale) : les bandes sont dirigées suivant l'axe du faisceau,
- couche u : les bandes font un angle de $+23^{\circ}$ avec la couche z,
- couche v : les bandes font un angle de -23° avec la couche z.

Reconstruction officielle de DØ : un dépôt CPS est reconstruit pour 85% des candidats τ et pas d'accès à l'extension transverse du dépôt. Développement d'une reconstruction dédiée à l'identification des τ.

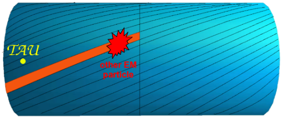
Détecteur de pieds de gerbe : reconstruction

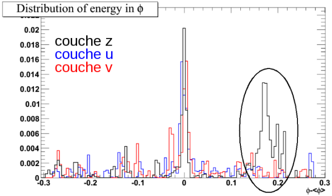
1. Pour chaque couche, on cherche un dépôt d'énergie au voisinage de la trace du candidat ($\approx \pi^{\pm}$).





2. Corrélations entre les couches : élimination des dépôts parasites

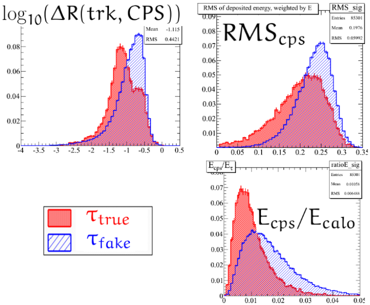




3. Les informations des 3 couches z, u, v sont combinées entre elles.

Résultat : un dépôt d'énergie $\equiv (\eta, \phi, E, \text{RMS})$ est reconstruit pour 95% des candidats

Détecteur de pieds de gerbe : résultats



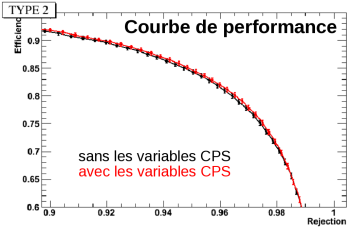
$$CPS_{\mathrm{cluster}} \approx \gamma\gamma\left[\pi^0\right], \mathrm{trk} \approx \pi^{\pm}$$

Observables :

- angle(dépôt CPS,trace)
- taille du dépôt CPS
- rapport de l'énergie calo et CPS

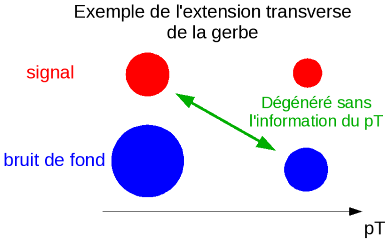
Après ajout de ces observables dans le NN, aucune amélioration significative n'a été observée.

Raison : ces informations sont fortement corrélées à celles du calorimètre.

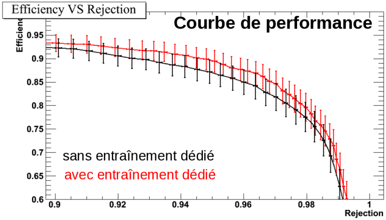


Prise en compte de la cinématique

Objectif : lever la dégénérescence entre des jets de haut p_T et des vrais τ de bas p_T



Méthode : Inclure l'information du p_T des candidats à travers un NN dédié à la région de haut p_T (45 GeV)



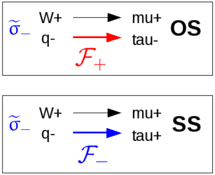
événements testés : $p_T(\tau) > 45$ GeV

W+jets modelling (2/3)

1. $W(\to \mu)$+jets$(\to \tau)$ composition assumed to have 3 componants :
   - $\widetilde{\sigma}_+$: μ and parton of same sign ;
   - $\widetilde{\sigma}_-$: μ and parton of op. sign ;
   - $\widetilde{\sigma}_0$: neutral parton (gluon).needs each

   where $\widetilde{\sigma} \equiv \epsilon_{\text{type}}\, \sigma\, \mathcal{L}$ (the τ reco. efficency ϵ can be type dependant)

2. The charge correlation have NN dependance (see previous plots). Lets consider 3 fake rates according to their charge correlation :
   - $\mathcal{F}_+(\text{NN})$: parton reconstructed as a same sign τ ;
   - $\mathcal{F}_-(\text{NN})$: parton reconstructed as an opposite sign τ ;
   - $\mathcal{F}_0(\text{NN})$: gluon reconstructed as a τ.



$$\text{N}_{\text{OS}} = \mathcal{F}_+\,\widetilde{\sigma}_- + \mathcal{F}_0\,\widetilde{\sigma}_0 + \mathcal{F}_-\,\widetilde{\sigma}_+$$
$$\text{N}_{\text{SS}} = \mathcal{F}_-\,\widetilde{\sigma}_- + \mathcal{F}_0\,\widetilde{\sigma}_0 + \mathcal{F}_+\,\widetilde{\sigma}_+$$

W+jets modelling (3/3)

Strategy : factorize the NN dependances of N_{OS} and N_{SS}. By rewritting previous equations, we have :

$$N_{\text{OS}} = F\ (\ 1\ +\ \rho_0\, R_0\ + \rho_-\, R_+\ ) \tag{1}$$

$$N_{\text{SS}} = F\ (\ \rho_-\ +\ \rho_0\, R_0\ +\ R_+\ ) \tag{2}$$

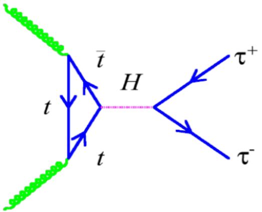
where

- $F = \mathcal{F}_+\, \tilde{\sigma}_-$ **fake(NN-dependant) + norm.** common for OS & SS ;
- $\rho_0 = \frac{\mathcal{F}_0}{\mathcal{F}_+}$, $\rho_- = \frac{\mathcal{F}_-}{\mathcal{F}_+}$ **explain the OS/SS(NN)** (NN-dependant) ;
- $R_+ = \frac{\tilde{\sigma}_+}{\tilde{\sigma}_-}$, $R_0 = \frac{\tilde{\sigma}_0}{\tilde{\sigma}_-}$ fixed by physics and reco. (not NN-dependant).

Method to measure W+jets in DATA

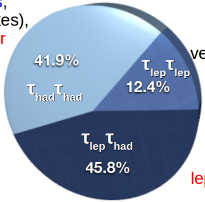
- assumtion : trust ρ_0(NN) and ρ_-(NN) in the MC (**ratio** of fake)
- find $(F_{\text{NN}}, R_0, R_+)_{\text{MC}}$ in MC by fitting distributions ;
- find $(F_{\text{NN}}, R_0, R_+)_{\text{DATA}}$ in DATA by fitting distributions ;
- **Correct the MC set of parameters by the data one**

Strategy and challenges



$\otimes$

high BR, 2 υ's,
high MJ bkg (fakes),
τ-based trigger



low BR, 4 υ's,
very clean signature,
lep-based trigger

high BR, 3 υ's,
~clean signature
(W+jets as bkg),
lep & τ-based trigger

- Each final state has specific backgrounds : dedicated analysis.
- Bump in $m_{\tau\tau}$ above the irreducible background $Z \to \tau\tau$.

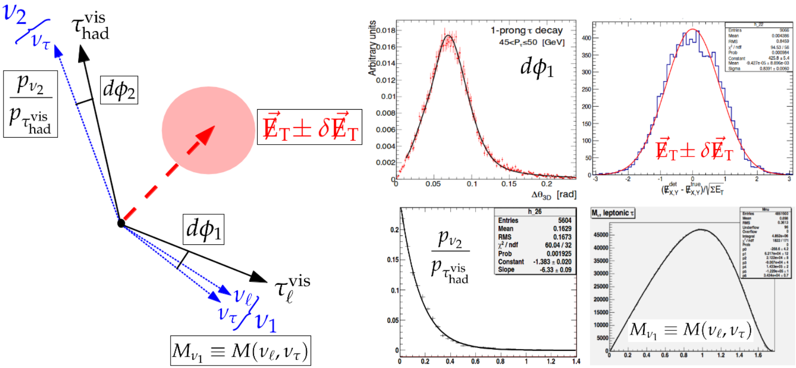
Main challenges of the $H \to \tau\tau$ search :

- Rejection (and modeling) of jet$\to$ τ_{had} backgrounds,
- $m_{\tau\tau}$ reconstruction with $\not{E}_T$ (because of escaping ν('s))
  1. $\not{E}_T \overset{\text{reco}}{=} \sum_\nu p_T^{\nu_i}$ but $\boldsymbol{m_{\tau\tau}}$ **needs each** $\boldsymbol{p_T^{\nu_i}}$: information lost (depends on $N_{\nu's}^{\text{final state}}$).
  2. $\not{E}_T$ is measured from the entire calorimeter : poor resolution.

I will mostly focus on $\tau_\ell\tau_{\text{had}}$ final state in the next slides.

7 TeV		8 TeV	
VBF Category	**Boosted Category**	**VBF Category**	**Boosted Category**
▹ $p_T^{\tau_{\text{had-vis}}}$ >30 GeV	–	▹ $p_T^{\tau_{\text{had-vis}}}$ >30 GeV	▹ $p_T^{\tau_{\text{had-vis}}}$ >30 GeV
▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV
▹ ≥ 2 jets	▹ $p_T^H > 100$ GeV	▹ ≥ 2 jets	▹ $p_T^H > 100$ GeV
▹ $p_T^{j1}, p_T^{j2} > 40$ GeV	▹ $0 < x_1 < 1$	▹ $p_T^{j1} > 40$, p_T^{j2} >30 GeV	▹ $0 < x_1 < 1$
▹ $\Delta\eta_{jj} > 3.0$	▹ $0.2 < x_2 < 1.2$	▹ $\Delta\eta_{jj} > 3.0$	▹ $0.2 < x_2 < 1.2$
▹ $m_{jj} > 500$ GeV	▹ Fails VBF	▹ $m_{jj} > 500$ GeV	▹ Fails VBF
▹ centrality req.	–	▹ centrality req.	–
▹ $\eta_{j1} \times \eta_{j2} < 0$	–	▹ $\eta_{j1} \times \eta_{j2} < 0$	–
▹ $p_T^{\text{Total}} < 40$ GeV	–	▹ $p_T^{\text{Total}} < 30$ GeV	–
–	–	▹ p_T^{ℓ} >26 GeV	–
• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV
• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 1.6$	• $\sum \Delta\phi < 2.8$	–
–	–	• b-tagged jet veto	• b-tagged jet veto
1 Jet Category	**0 Jet Category**	**1 Jet Category**	**0 Jet Category**
▹ ≥ 1 jet, p_T >25 GeV	▹ 0 jets p_T >25 GeV	▹ ≥ 1 jet, p_T >30 GeV	▹ 0 jets p_T >30 GeV
▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV
▹ Fails VBF, Boosted	▹ Fails Boosted	▹ Fails VBF, Boosted	▹ Fails Boosted
• m_T <50 GeV	• m_T <30 GeV	• m_T <50 GeV	• m_T <30 GeV
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_T^{\ell} - p_T^{\tau} < 0$	–	• $p_T^{\ell} - p_T^{\tau} < 0$

$m_{\tau\tau}$ reconstruction



= unknown value →

(1) **Perform a scan** over the unknowns, ie choose a config : q = ($d\Phi_1$, $d\Phi_2$, $M_{\upsilon 1}$, mET, p_υ/p_τ)

(2) For each configuration q_i : compute the **full invariant mass** m_i

(3) Fill an histogram of m_i **weighted by w_i=PDF(q_i)** , as a product each above PDF

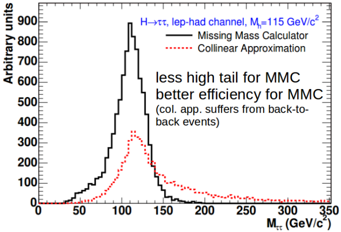
(4) Final reconstructed mass, **MMC**, is given by the **max of this histogram**

$m_{\tau\tau}$ reconstruction and boosted topology

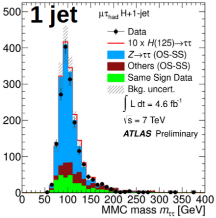
Missing Mass Calculator (MMC) :

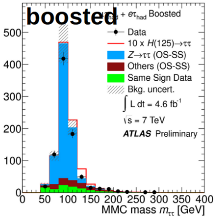
- single ν kinematic unknown
- scan the 4-vector of each ν
- scan $\vec{\not{E}}_{\mathrm{T}}$, given its resolution
- compute the most likely mass, according the τ decay ME

(more in backup ...)



The boosted topology : defined by $p_T^H \overset{\text{reco}}{=} p_T(\ell, \tau_{\text{had}}, \not{E}_{\mathrm{T}}) > 100$ GeV

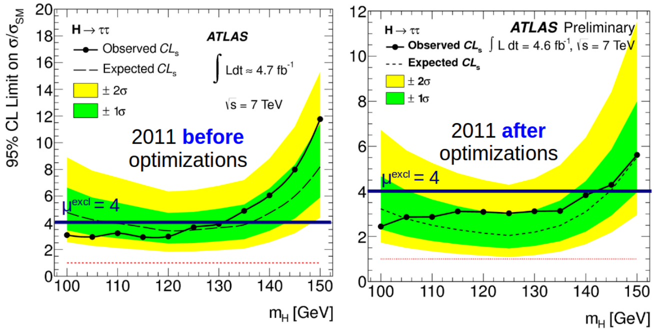




- better resolution on $m_{\tau\tau}$ for boosted system
- significantly reduce fake τs
- theo uncert. well under control for p_T^H, unlike n_{jets}
- $\sim$ sensitive as VBF category

Total improvement after all optimizations

Expected sensitivity almost divided by 2 for the same dataset !

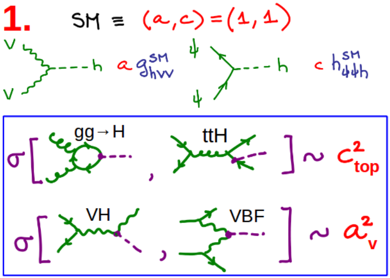


Main optimizations :

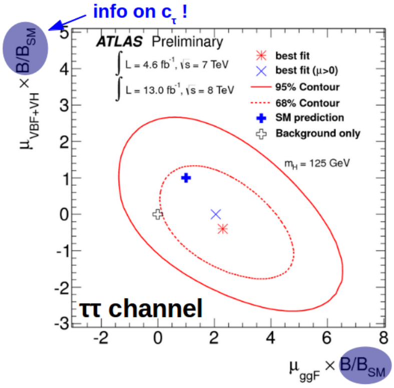
- Introduction of boosted category
- Optimize cuts of VBF category $(p_T^j, \Delta\eta_{jj}, m_{jj})$
- Improve the fake suppression (with $|d\phi(\ell, \not{E}_T)| + |d\phi(\tau_{had}, \not{E}_T)|, p_T^{\ell} - p_T^{\tau_{had}}, ...$)

3 type of property

1. other SM particles couplings constant : **observed event rate**
2. spin : **polarization, angular distributions**
3. CP : **angular correlation/distributions**

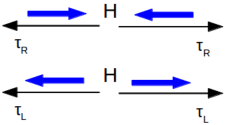


arXiv :1209.0040, ATLAS-CONF-2012-127



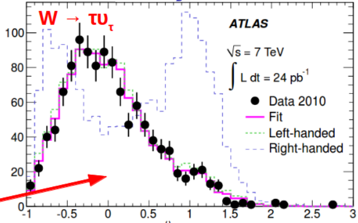
2.

Probe τ spin **correlations** :



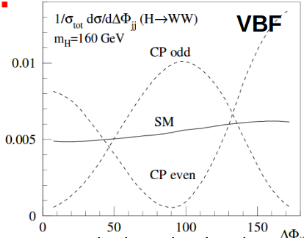
Be able to measure τ polarization ? **YES**

Eur.Phys.J. C72 (2012) 2062



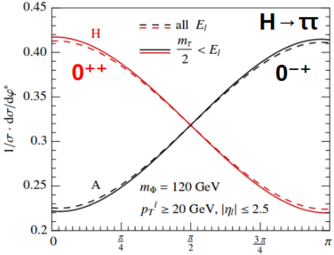
$$\frac{E_T^{\pi^-} - E_T^{\pi^0}}{p_T} \approx 2\frac{p_T^{\rm trk}}{p_T} - 1 = \Upsilon.$$

3. *Phys. Rev. Lett. 88 (2002) 051801*



tagging jets related angles

arXiv :1108.0670



φ^* (related τ angles)