ATLAS実験に於けるVBF Higgs粒子の探索

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ATLAS Collaboration

Physics strategy

シンポジウム講演参照。
(近藤氏、ZimmermannFrank**氏)**

最初の2，3年で、Higgs粒子、SUSY粒子発見。

2008(summer)/09: first 10/14 TeV physics run, initial L ~$10^{31}cm^{-2}s^{-1}$, L_{int} ~ $1fb^{-1}$
Detector commissioning : alignment, in-situ calibration / trigger menu
First SM measurements : W/Z/top & min.bias/jets & PDF ~$100pb^{-1}$

2009/10 : low luminosity run, instantaneous L ~$2x10^{33}cm^{-2}s^{-1}$, L_{int} ~ $10fb^{-1}$
First B rare decay searches,
First searches : high mass DY(Z'), ADD, BH, **SUSY** ~$1fb^{-1}$
First **Higgs** discovery : H→4leptons, WW, $\gamma\gamma$ & MSSM Higgs

2010/11 : low luminosity run, inst.L ~$2x10^{33}cm^{-2}s^{-1}$, L_{int} ~ $10fb^{-1}$/yr
Light Higgs searches, SUSY measurements (model specific), …

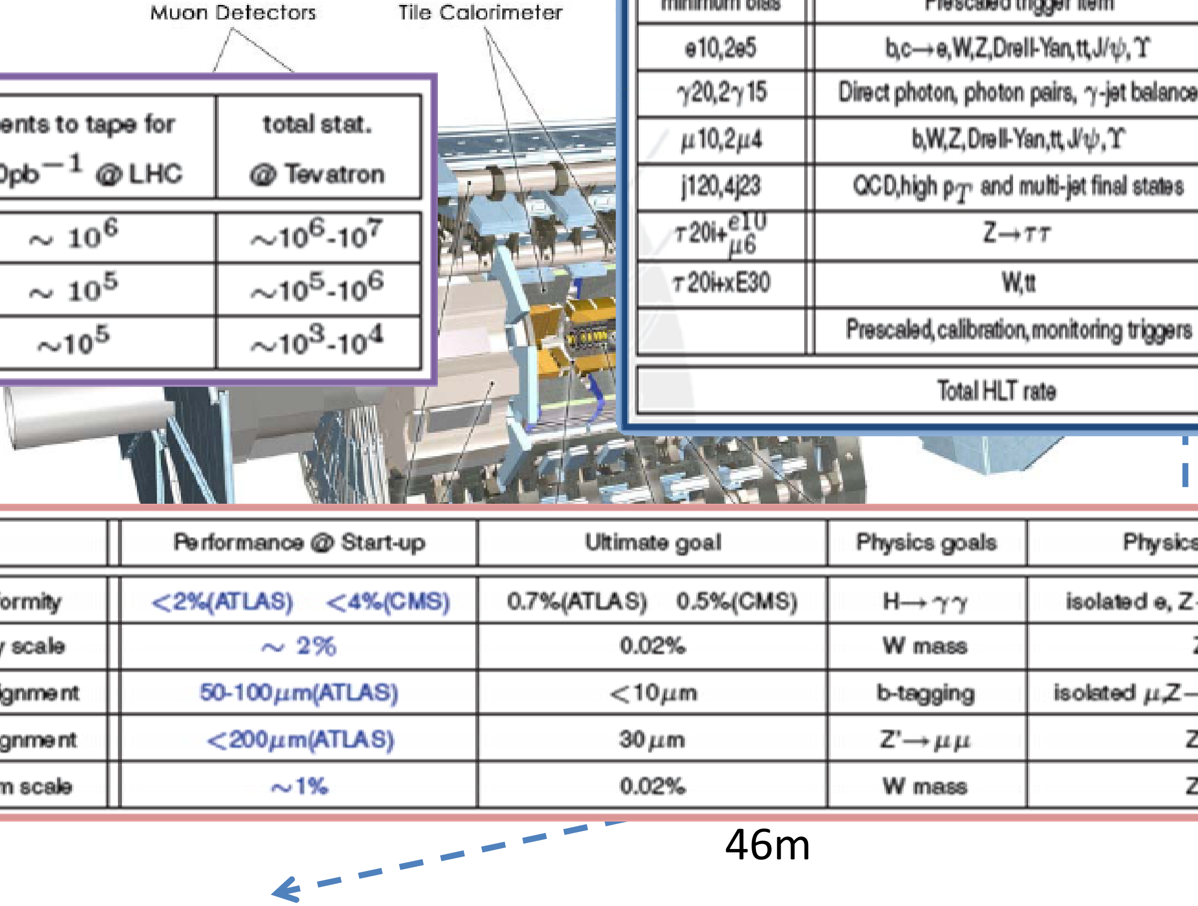
2012~ : high luminosity run, inst.L ~$2x10^{34}cm^{-2}s^{-1}$, L ~ $100fb^{-1}$/yr
many, many … toward SLHC…

ATLAS detector

シンポジウム講演参照。
(佐々木氏、海野氏、石野氏)

Tevatronにはない広い η の範囲をカバー。

- Muon standalone tracking
- Inner tracker coverage |η|~2.7
- Calorimeter coverage |η|~5.0



channels (examples)	events to tape for $100pb^{-1}$ @ LHC	total stat. @ Tevatron
$W \to \mu\nu$	$\sim 10^6$	$\sim 10^6$-10^7
$Z \to \mu\mu$	$\sim 10^5$	$\sim 10^5$-10^6
$t\bar{t} \to \mu\nu$+X	$\sim 10^5$	$\sim 10^3$-10^4

Illustrative trigger menu at $\mathcal{L} = 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (ATLAS):

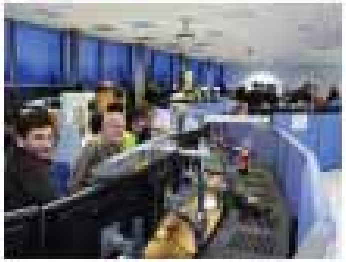
Signature	Examples of physics coverage		Rates(Hz)
minimum bias	Prescaled trigger item		10
e10,2e5	b,c→e,W,Z,Drell-Yan,tt,J/ψ,Υ	electrons	~27
γ20,2γ15	Direct photon, photon pairs, γ-jet balance	photons	~7
μ10,2μ4	b,W,Z,Drell-Yan,tt,J/ψ,Υ	muons	~22
j120,4j23	QCD,high p_T and multi-jet final states	jets	~13
τ20i+e10 μ6	$Z \to \tau\tau$	taus	4
τ20i+xE30	W,tt	tau+$\not{E}_T$	~10
	Prescaled, calibration, monitoring triggers		~17
Total HLT rate			~100

	Performance @ Start-up	Ultimate goal	Physics goals	Physics signals tools
EM energy uniformity	<2%(ATLAS) <4%(CMS)	0.7%(ATLAS) 0.5%(CMS)	$H \to \gamma\gamma$	isolated e, $Z \to ee$, ϕ-symmetry
Electron energy scale	~ 2%	0.02%	W mass	$Z \to ee$
Inner detector alignment	50-100μm(ATLAS)	<10μm	b-tagging	isolated μ,$Z \to \mu\mu$,generic tracks
Muon system alignment	<200μm(ATLAS)	30μm	$Z' \to \mu\mu$	$Z \to \mu\mu$
Muon momentum scale	~1%	0.02%	W mass	$Z \to \mu\mu$

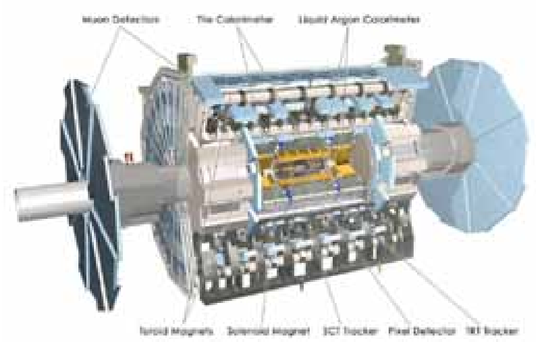
Analysis model

シンポジウム講演参照。
(上田氏)

Run operation



Control room



Full Dress Rehearsal
(FDR)

monitoring

Data quality

Trigger

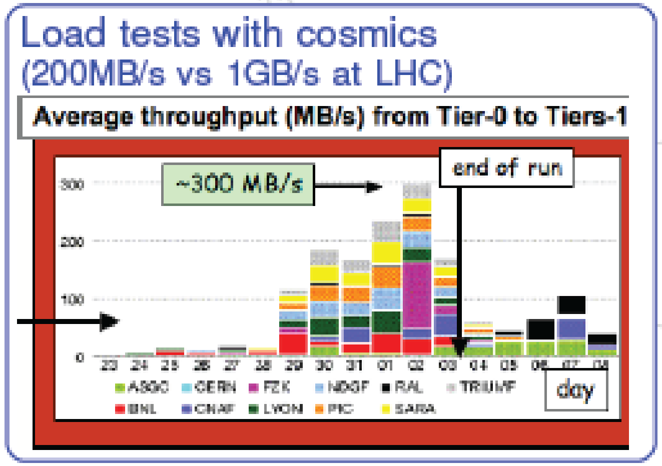
DATA

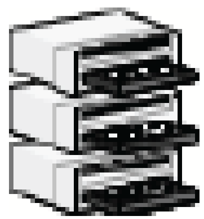
trigger

DAQ

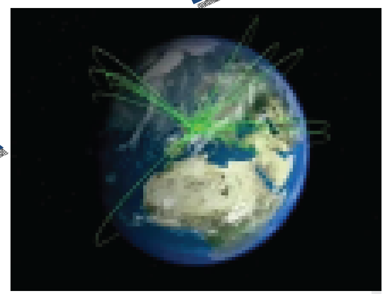
FDR

User
analysis





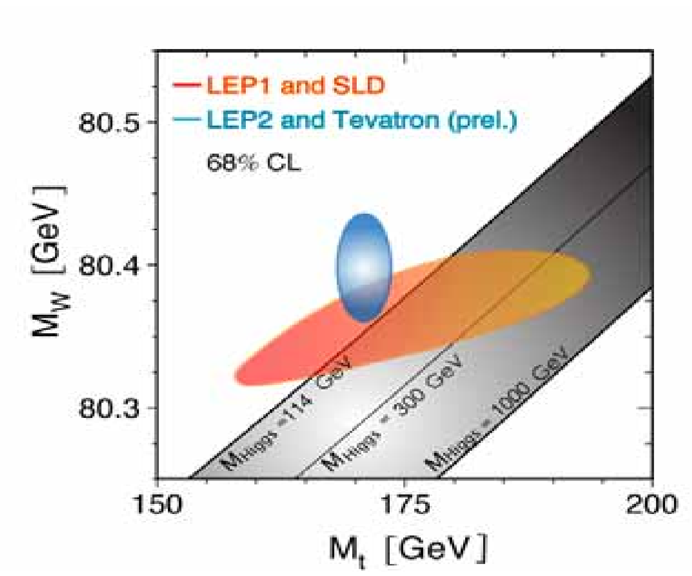
Tier-0 (CERN)



Grid throughout

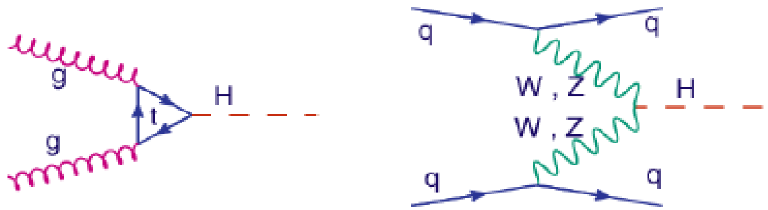
Higgs粒子探索

Tevatronから間接的にlow mass Higgsが好まれる。



LHCでのSM Higgs生成素過程は、

Gluon fusion **Vector Boson Fusion (VBF)**

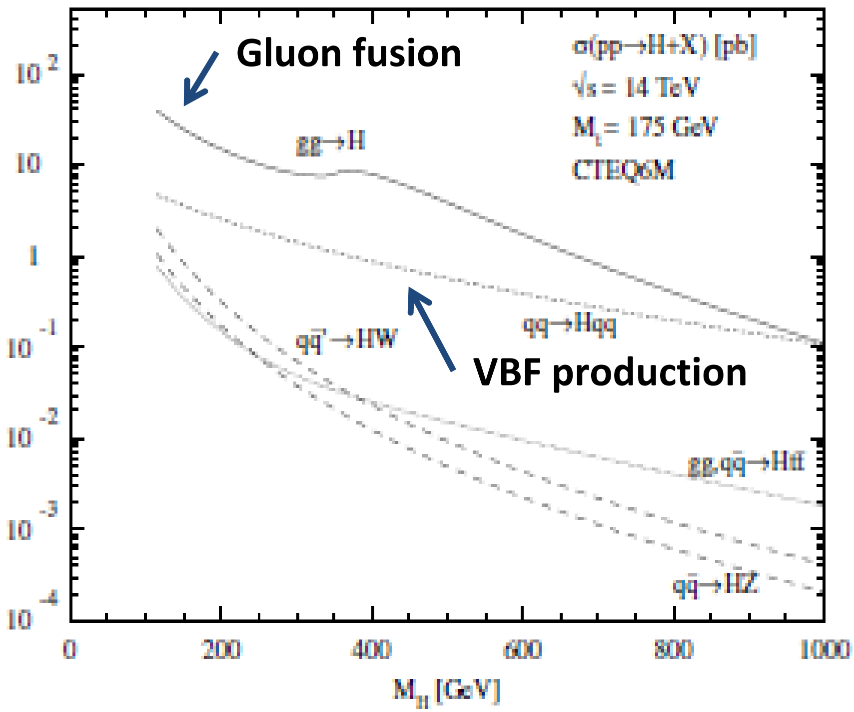


Gluon Fusion (GF) Vector Boson Fusion (VBF)

Gluon fusion ~ 10-50pb (~10,000 evts at $1fb^{-1}$)
VBF production ~ 2-8pb (~2000 evts at $1fb^{-1}$)

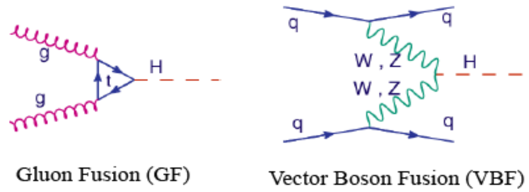
VBFは2番目に大きな断面積

VBF productionは、前後方にジェットを生み出すのが特徴。



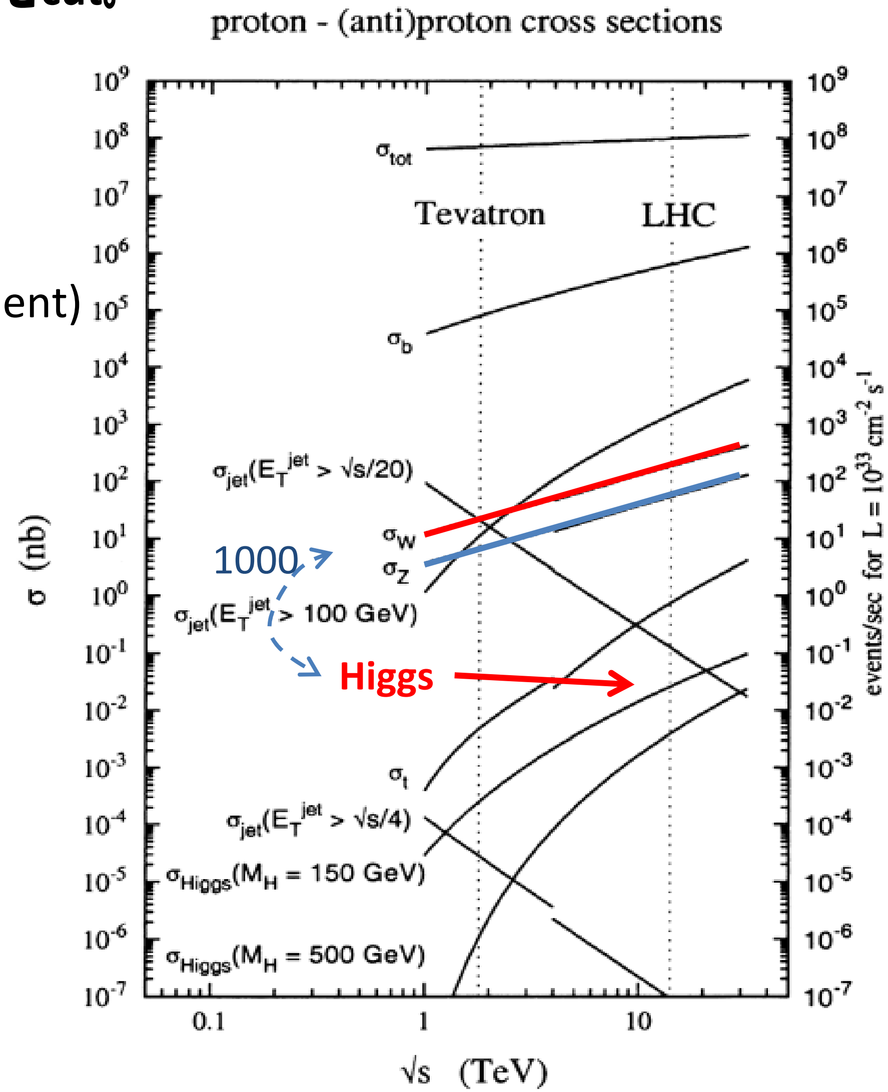
VBF Higgs粒子探索

event topologyを利用して、バックグランドをcut。



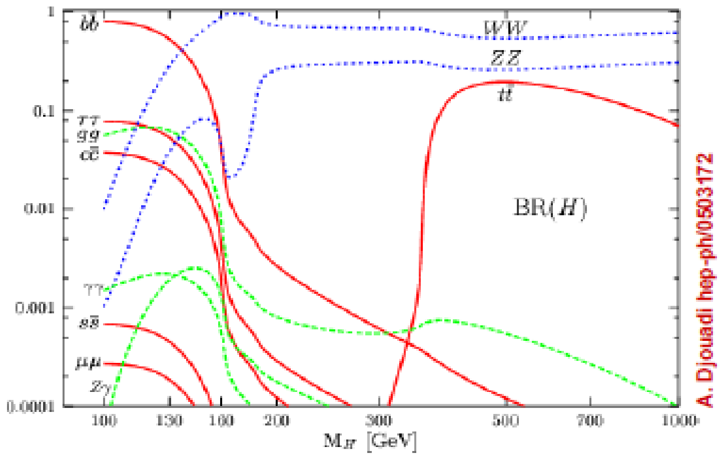
Gluon fusion v.s. VBF production
(High xsec) (High bkg. rejection)

Achieve factor 10^4 fake **+ 10^3 bkg.** rejection.
(by forward jet requirement)



LHCでの標準模型Higgs探索：

- H → γγ (σ_{MH}~1.7 GeV)
- H → WW (no mass reconstruction)
- H → ττ (σ_{MH}~9 GeV)



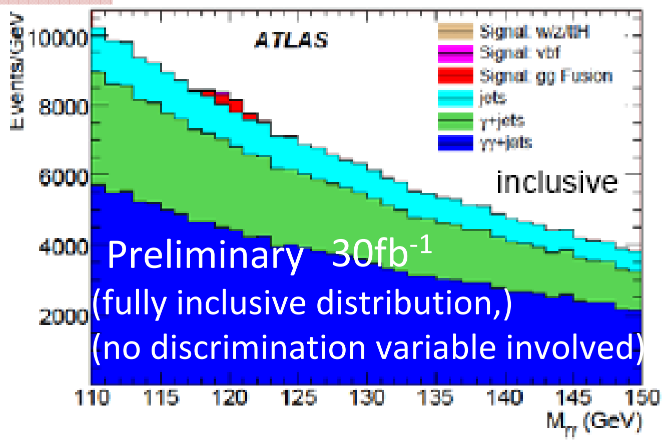
Computer System Commissioning (ATLAS CSC2008)

本実験と同じComputing Systemで解析。

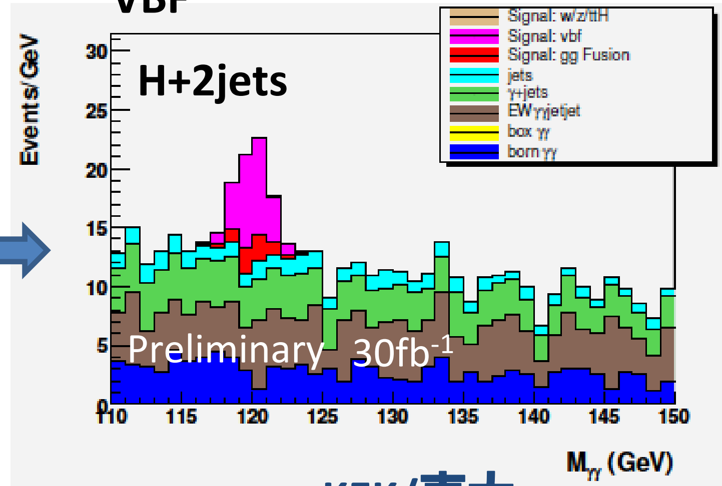
詳しくは、「LHCが切り開く物理」研究会で。

$H \rightarrow \gamma\gamma$

Inclusive

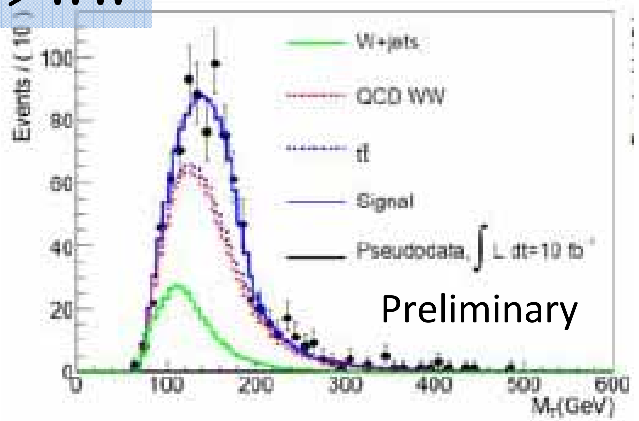


VBF **KEK/東大 group**

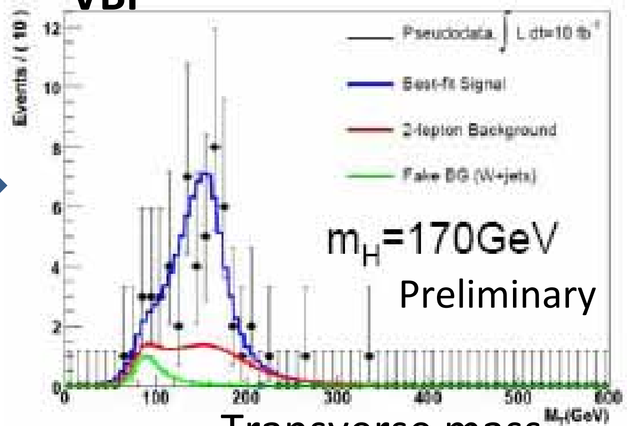


$H \rightarrow WW$

Inclusive



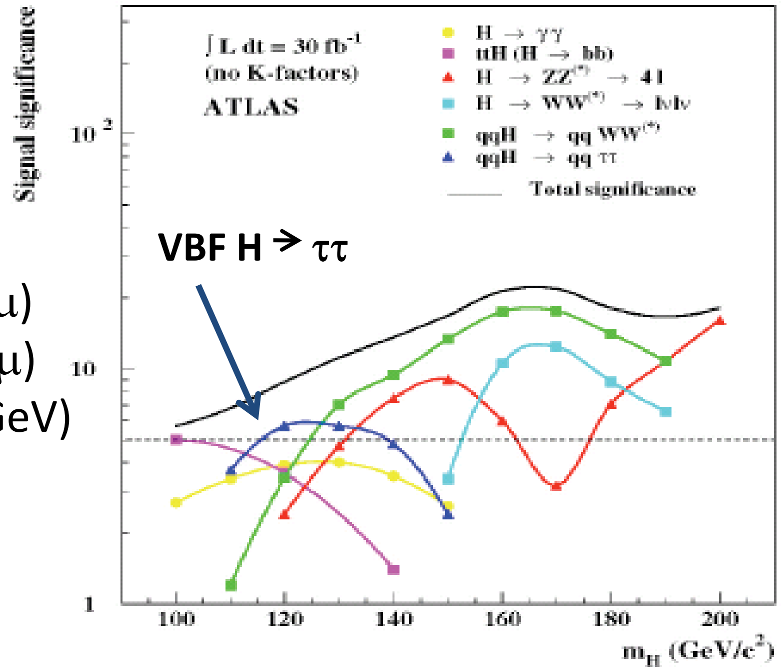
VBF **KEK/東大 group**



VBF H→ ττ

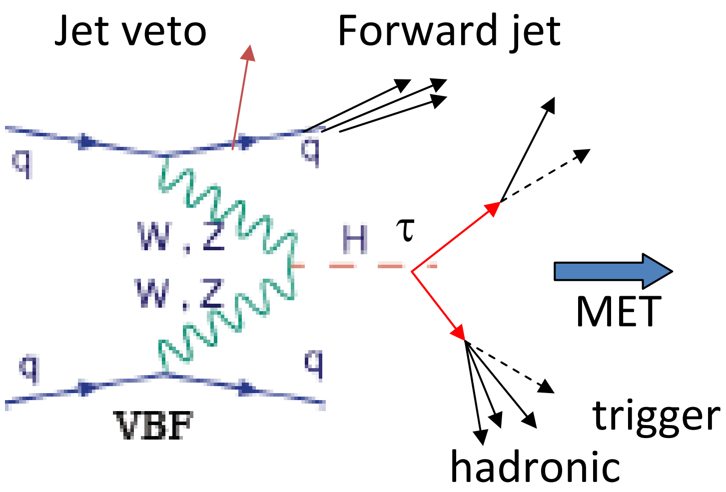
110GeV ~ 130GeVで最も感度が高い。

ATLAS 2003



解析モード：

ll-channel : Br.~12%, Trig.Acc~ 9.1%(e), 9.9%(μ)
lh-channel : Br.~46%, Trig.Acc~ 9.1%(e), 9.9%(μ)
(High p_T lepton, e p_T>25GeV, μ p_T>20GeV)
hh-channel : Br.~42%, Trig.Acc~3.7%
(Hadronic τ(p_T>35GeV, MET>40GeV)



解析に必要な事： **広範囲に渡って、日本groupがcontribute**

Tau ID : Likelihood, NN (KEK/**東大**)
Forward jet : Efficiency/Calibration (**東大**)
Missing Et : Resolution (**寺師氏**、next talk)
Trigger : Combined Trigger
Central Jet veto : **鈴木氏**、next talk
(b-jet veto) : **廣瀬氏**、next talk

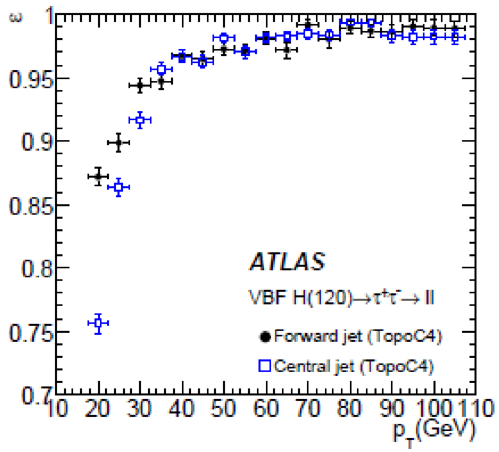
Forward Jet tagging

- Leading jet p_T>40GeV
- Jet p_T>20GeV, $|\eta|$<4.8

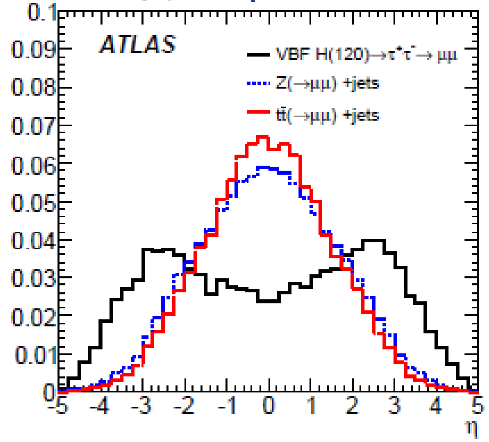
topology requirement

- Opposite hemisphere ($\eta_{j1} \times \eta_{j2}$<0)
- $\Delta\eta_{jj}$>4.4, m_{jj}>700GeV
- no 3rd jet

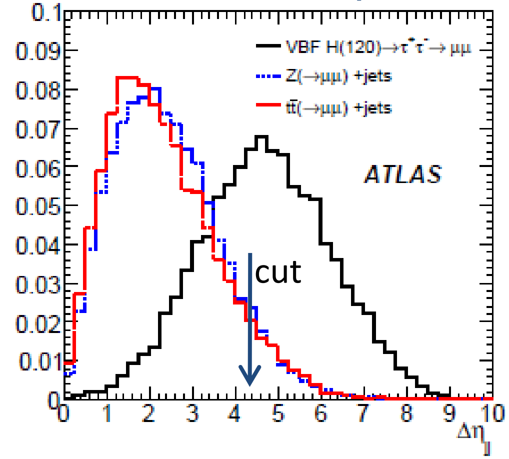
Forward jet reco. ε

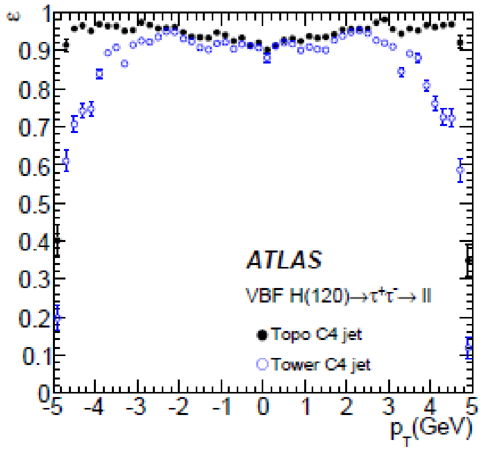


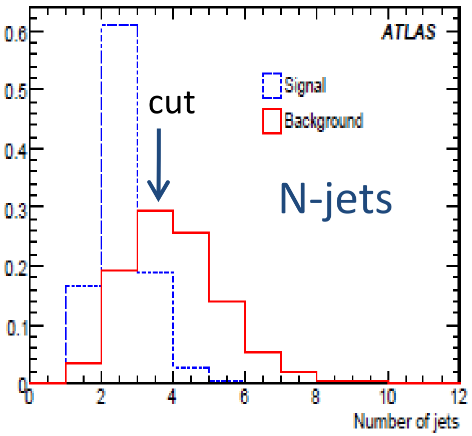
Leading jet η

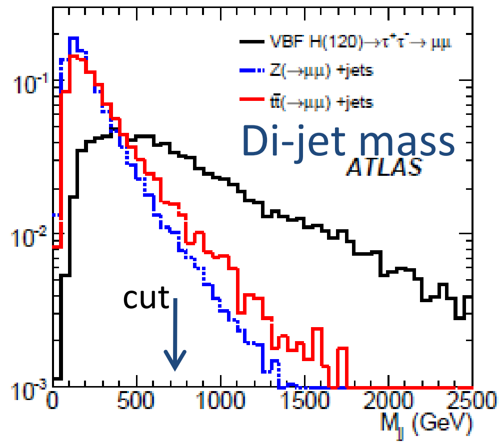


Di-jet separation η









Acceptance

Signal M_H=120GeV — Unit fb

Selection	Mass (GeV)	120	$Z \to \tau^+\tau^-$ +jets(≥ 1) QCD	ELWK	$t\bar{t}$ Full	$t\bar{t}$ Fast
	Cross section (fb)	309.1 (100%)	172.5×10^3	1693	833×10^3	
Detector oriented selection	Trigger	57.2(1) (18.5%)	$52.7(1)\times10^3$	230(1)	$209.8(2)\times10^3$	
	Trigger lepton	49.5(1) (86.5%)	$43.7(1)\times10^3$	190(1)	$179.1(2)\times10^3$	
	Di-lepton veto	43.4(1) (87.9%)	$39.3(1)\times10^3$	171(1)	$156.4(2)\times10^3$	
	Hadronic τ	8.02(7) (18.4%)	3137(43)	19.3(4)	5224(56)	
	Missing $E_T \geq 30$ GeV	4.96(5) (61.9%)	871(20)	12.1(3)	4251(50)	
	Collinear Approx.	3.34(5) (67.4%)	526(15)	7.8(2)	606(19)	
Kinematics oriented selection	Transverse mass	2.46(4) (73.6%)	425(14)	6.5(2)	176(10)	Atlfast
	N jets ≥ 2	2.02(4) (82.3%)	241(7)	6.0(2)	162(9)	166(1)
	Forward jet	1.52(3) (75.1%)	41(3)	2.3(1)	32(4)	25.7(4)
	Jet kinematics	0.82(2) (53.9%)	2.8(1)	0.72(6)	2.2(2)*	3.0(1)
	Central jet veto	0.72(2) (87.5%)	1.2(1)	0.49(5)	0.32(7)*	0.27(4)
	Mass window	0.61(2) (85.2%)	0.11(2)	0.04(1)	$\leq$0.04	0.03(1)

(Arrows from Transverse mass to Jet kinematics: 4 for signal, 400 for backgrounds.)

Remarks : Irreducible background : Zττ+jets

Reducible background : ttbar/W+jets etc. (ttbar is complicated object.)

(5% ll-mode, 45% real-tau mode, 50% l+jets mode)

Kinematics-oriented selection : factor ~4 for signal , ~**400** for backgrounds.

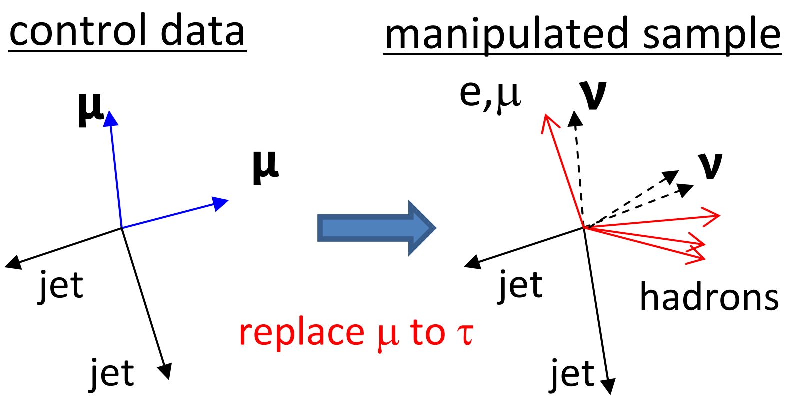
⇒ S/B ~ 100

Overall rejection ~$10^{7\text{-}8}$ rejection for reducible backgrounds.

Background estimation（Ⅰ）

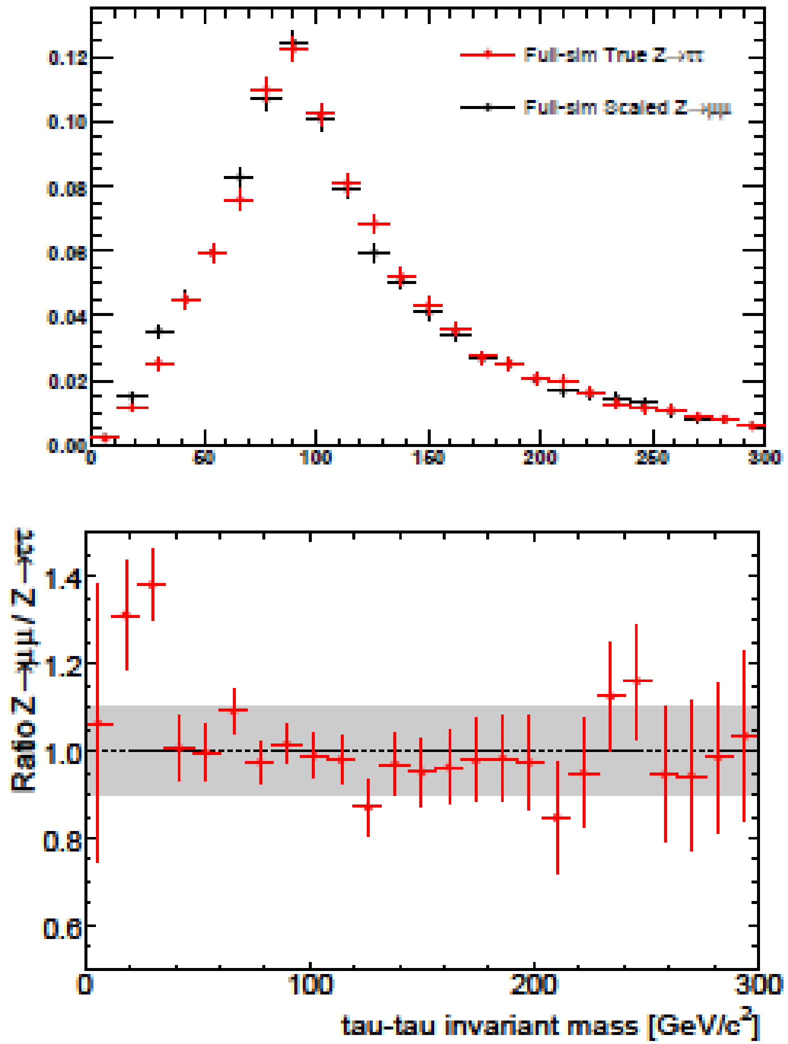
real dataを使って、バックグラウンドを評価。

Shape and acceptance estimation by DATA.



1) Replace muon to tau.
2) Re-run TAUOLA.
3) Re-simulation again.

- Missing Et is modeled by DATA.
  → Important for tail structure.
- Acceptance is also handled correctly.



Background estimation（II）

real dataを使って、バックグラウンドを評価。

Overall QCD fake estimation

Track multiplicity fit:

- count the track outside tau core region.
- fit the n-tracks by likelihood.

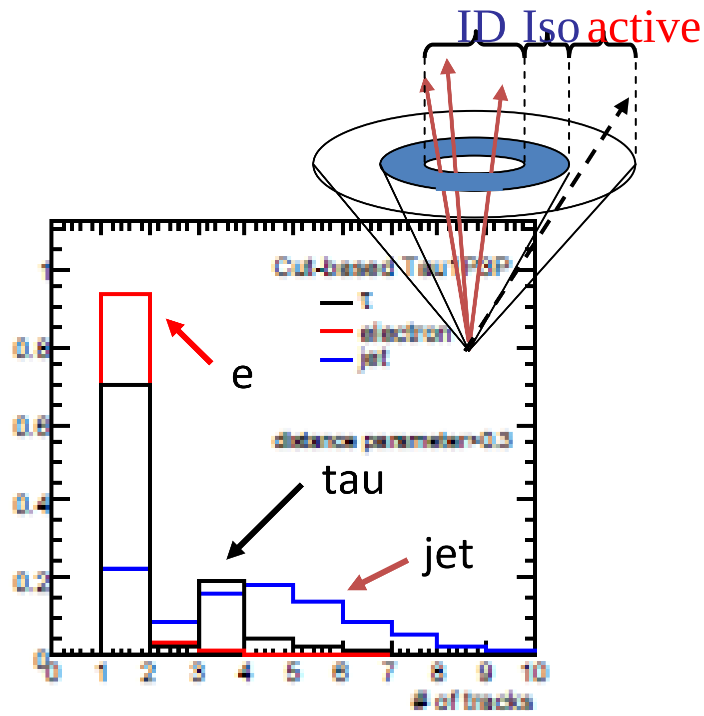
$$L = \prod_i^N Pois(n_{exp}^{tot} \times (r_{tau} f_{tau}^i + r_{lep} f_{lep}^i + (1 - r_{tau} - r_{lep}) f_{jet}^i), N_{obs}^i)$$

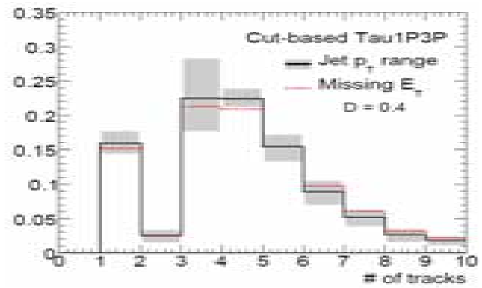
$$\times\, Gaus(n_{exp}^{tot}, N_{obs}^{tot})$$

$$\left(\times\, Gaus(n_{exp}^{tot} r_{lep}, N_{lep}^{measured}) \right)$$

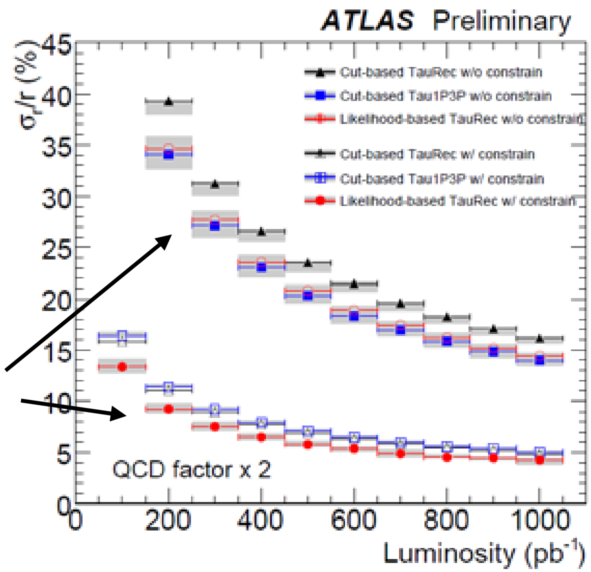
(fit the ratio)

- shape (pdf) are modeled by real-data.
  (ex. QCD jet shape by JET triggered data)





expected error of "ratio of tau" in the events



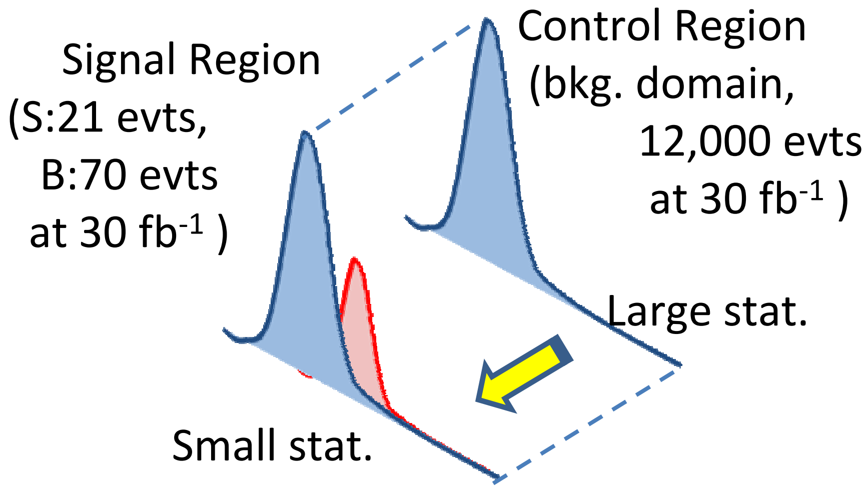
Signal sensitivity

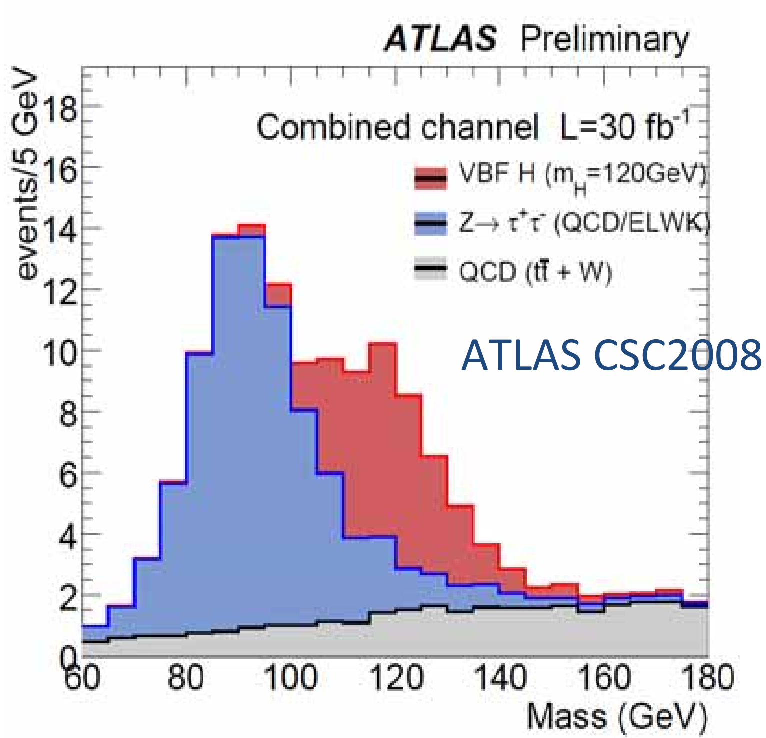
LLR(mass fit)によるsignificance。

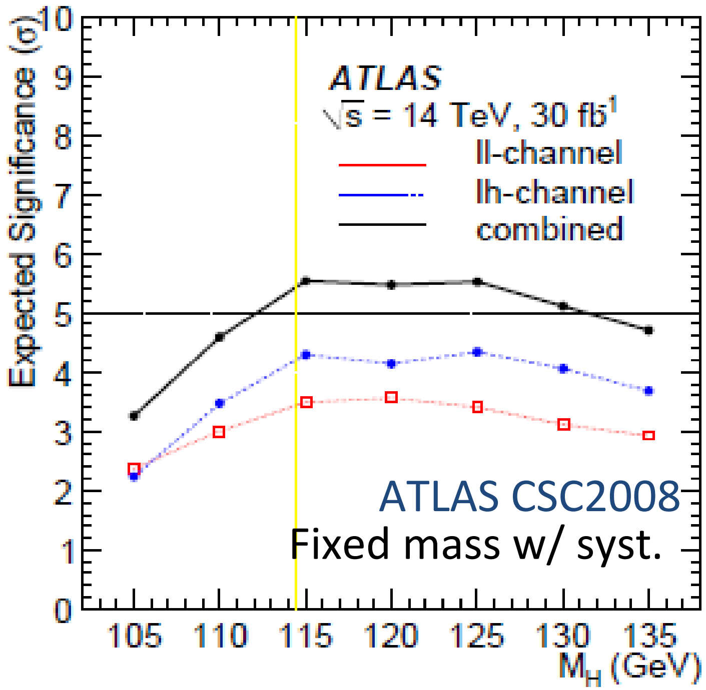
Background shape systematics :

- Z+jets : 10%
- QCD (ttbar/W+jets) : 50%

Simultaneous fit unbined





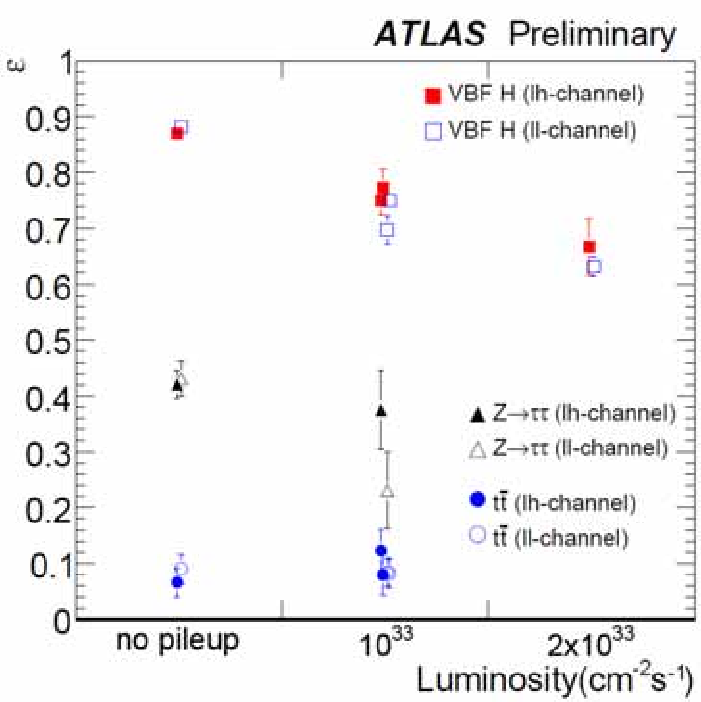


Systematic uncertainty

Dominant source of systematics:

- Jet Energy Scale (20%)
- Central Jet Veto (Theory) (30%)

Source	Relative uncertainty	Effect on signal efficiency
luminosity	$\pm 3\%$	$\pm$ 3%
muon energy scale	$\pm$ 1%	$\pm$ 1%
muon energy resolution	$\sigma(p_T) \oplus 0.011 p_T \oplus 1.7\ 10^{-4} p_T^2$	$\pm$ 0.5%
muon ID efficiency	$\pm$1 %	$\pm$ 2%
electron energy scale	$\pm$ 0.5%	$\pm$ 0.4 %
electron energy resolution	$\sigma(E_T) \oplus 7.3\ 10^{-3} E_T$	$\pm$ 0.3 %
electron ID efficiency	$\pm$ 0.2%	$\pm$ 0.4%
tau energy scale	$\pm$ 5%	$\pm$ %
tau energy resolution	$\sigma(E_T) \oplus 0.45\sqrt{E_T}$	$\pm$
tau ID efficiency	$\pm$ 5%	$\pm$ 5%
jet energy scale†	$\pm$ 7% ($\lvert\eta\rvert < 3.2$) $\pm$ 15% ($\lvert\eta\rvert < 3.2$) $\pm$ 5% (on $\not{E}_T$)	$^{+16\%}/_{-20\%}$
jet energy resolution	$\sigma(E_T) \oplus 0.45\sqrt{E_T}$ ($\lvert\eta\rvert < 3.2$) $\sigma(E_T) \oplus 0.67\sqrt{E_T}$ ($\lvert\eta\rvert > 3.2$)	$\pm$ 1%
b-tagging efficiency	$\pm$ 5%	$\pm$ 5%
forward tagging efficiency	$\pm$14 %	$\pm$ 2%
central jet veto efficiency	$\pm$11 %	$\pm$ 2%
total summed in quadrature		$\pm$18%



Source	Relative uncertainty	Effect on signal efficiency
PDF uncertanties	$\pm$3.5%	$\pm$3.5%
scale dependence on cross-section	$\pm$3%	$\pm$ 3%
scale dependence CJV efficiency	$\pm$ 1%	$\pm$ 1%
parton-shower and underlying event	$\pm <$10%	$\pm <$10%
total summed in quadrature		$\pm <$ 10%

Summary

新しい事:

- **発見のためのBaseline Analysis の確立。**

  -- **基本的にすべて**Full simulation
  -- Background estimation**は、**Data-driven analysis
  -- Mass Fitter **の開発。**
  -- **一つの解析チャンネルをグループとして解析。**
  (Author list 47**人、**12 **グループ**)

- **発見のためのロードマップの確立。**

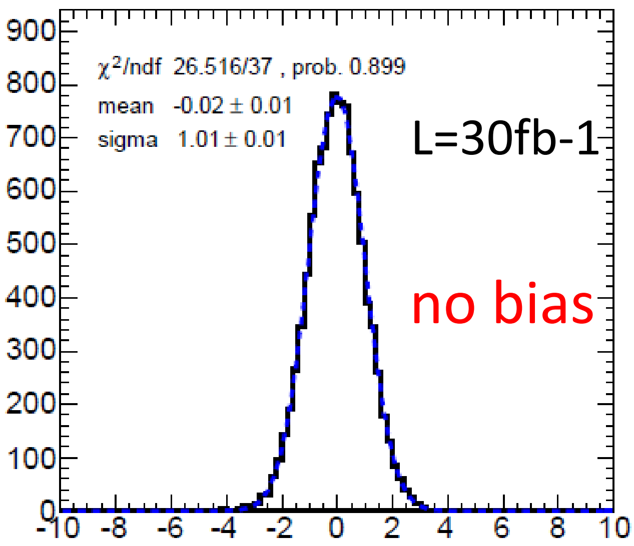
  -- **実験が始まるまでに必要な研究課題の把握。**
  -- **実験開始から発見までに必要な研究課題の把握。**

詳しくは、「LHCが切り開く物理」研究会で。

Consistency check

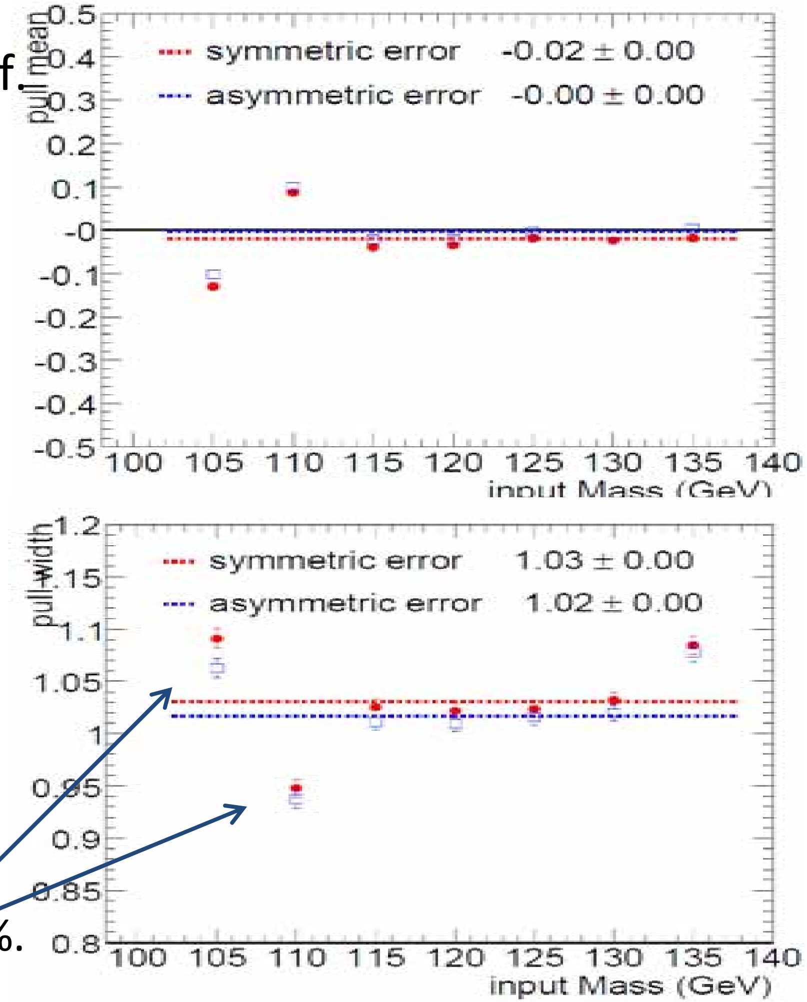
Only test the “lh-channel”.
Generate the “pseudo-DATA” by the p.d.f.

10000 pseudo-experiments at L=30fb-1 :



Fit Gaussian all range.

Pull distributions



Biased by 5%.

Basically, the (simplest) fitting seems to work.

Demonstration : simplest Likelihood function

Naïve construction :

$$L_{shape} = \frac{e^{-(n_s+n_{b1}+n_{b2}\cdots)}(n_s+n_{b1}+n_{b2}\cdots)^{N_{obs}}}{N_{obs}!}\prod_i^{N_{obs}}\frac{n_s f_s(m_H\,|\,\nu)+n_{b1}f_{b1}(m_H\,|\,\nu)+\cdots}{n_s+n_{b1}+n_{b2}+\cdots}$$

We would like to include "constraint term from the (independent) external measurements".
Following CDF top mass measurement,

$$L_{bkg} = Gauss(n_{b1}, N_{b1}^{\exp}, \sigma_{b1}^{\exp}) \times Gauss(n_{b2}, N_{b2}^{\exp}, \sigma_{b2}^{\exp})\cdots$$

The likelihood function is formed as

$$L = L_{shape} \times L_{bkg}$$

The combined likelihood function is formed as

$$L_{combined} = L_{lh-channel} \times L_{ll-channel} \times L_{hh-channel}$$

Significance and Mass Fit

The fitting procedure is not finalized yet.

Discussion items are :

Signal mass shape is not like Gaussian
as expected.

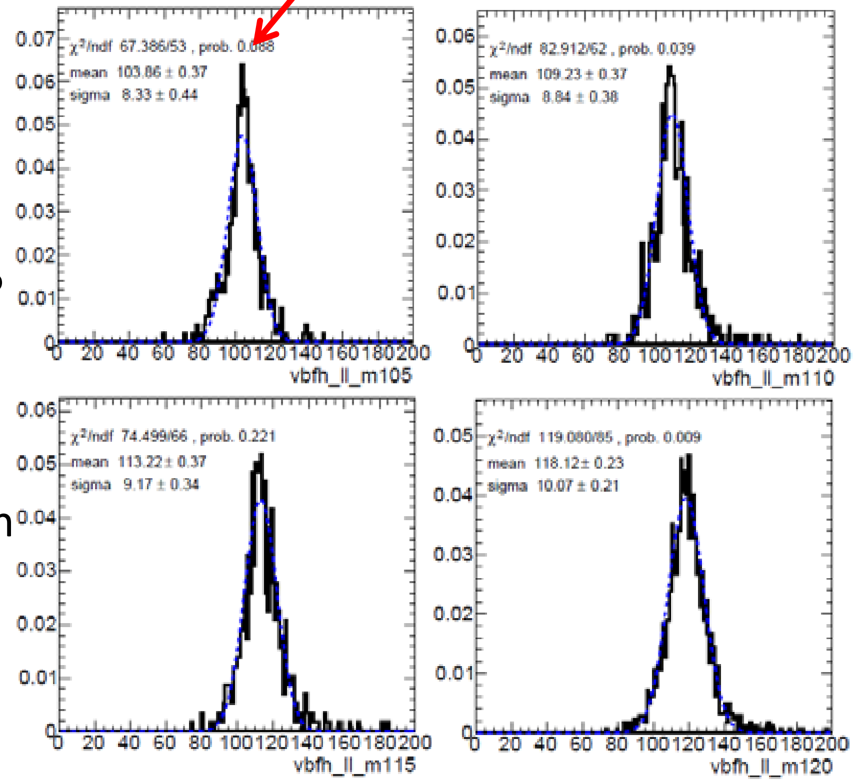
--- Parameterize “Multiple Asym.Gaussian”?
--- Binned fit (not unbinned) ?
--- Use Jacobian formalism ?

Note: whatever (moderated) parameterization is used, the result is not so sensitive for the modeling itself in the end.

How to include the normalization term.

--- Background normalization is constraint as the external term,
--- Or use the shape information from another measurement.

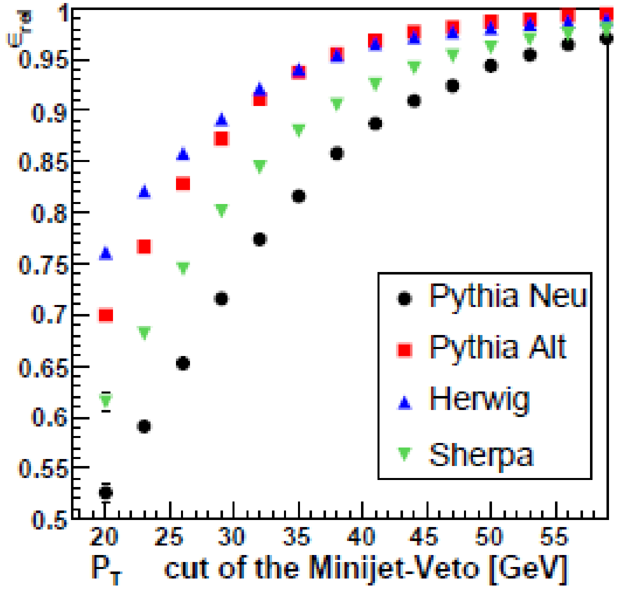
Very sharp peak



Almost triangle?

Impact on the generator difference

Matthias Roder, Nov.21.2007



CSC Full simulation

	VBF Higgs(120)	Pythia
Cross section (fb)	22.0 (100 %)	22.0 (100 %)
Trigger	13.04(3) (59.2(1)%)	13.12(5) (59.6(2)%)
Trigger lepton	11.63(3) (52.9(1)%)	11.66(5) (53.0(2)%)
Di-lepton	5.46(3) (24.8(1)%)	5.45(4) (24.7(2)%)
Missing p_T	3.16(2) (14.4(1)%)	3.30(3) (15.0(1)%)
Collinear Approx.	2.14(2) (9.7(1)%)	2.25(3) (10.2(1)%)
N jets $\geq$ 2	1.77(2) (8.05(9)%)	1.98(3) (9.0(1)%)
Forward jet	1.34(1) (6.09(8)%)	1.38(2) (6.2(1)%)
B-jet veto	1.15(1) (5.25(7)%)	1.16(2) (5.3(1)%)
Angular cut	0.92(1) (4.22(6)%)	0.93(2) (4.24(9)%)
Jet kinematics	0.51(1) (2.34(5)%)	0.48(1) (2.18(7)%)
Central jet veto	0.45(1) (2.06(4)%)	0.32(1) (1.46(5)%)
Mass window	0.37(1) (1.71(4)%)	0.26(1) (1.18(5)%)

Predicts 41% systematics as the maximum fluctuation.

While predicts 29% difference as the systematics.

Different event selection,
No collinear mass reconstruction,
Atlfast

← Those difference have to be investigated again.

Results from the fast simulation

Very preliminary

Sci. Note: PY62, fast simulation w/ event filter, mh=120GeV
hep-ph/0402254

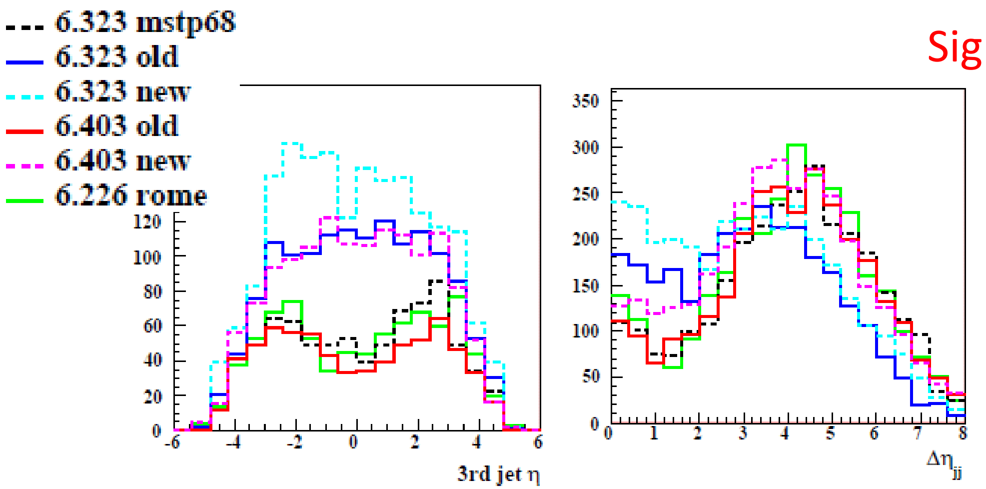
Rome : PY62, full simulation, w/ event filter, mh=115GeV

CSC Note : PY64, fast simulation w/o event filter,bmh=120GeV

Cut Name (fb)	Sci. Note	Rome	CSC PY64	CSC HW65
Trigger	13.7	12.0	73.5±0.2	72.3±0.9
Tight Tau	6.18	5.81	8.67±0.08	7.86±0.37
Forward tagging	1.97	2.33	2.41±0.04	2.46±0.20
Collinear Approx.	1.27	1.23	1.52±0.03	1.57±0.16
M_{τ}	1.02	1.0	1.21±0.03	1.20±0.14
Missing E_T	0.81	0.94	0.99±0.03	0.93±0.13
Di-jet Mass	0.71	0.89	0.87±0.02	0.77±0.11
Jet Veto	0.63	0.71	0.52±0.02	0.71±0.11
Mass Window	0.52	0.60	0.42±0.02	0.58±0.10

Table: lh-channel

Signal sensitivity is naively consistent.



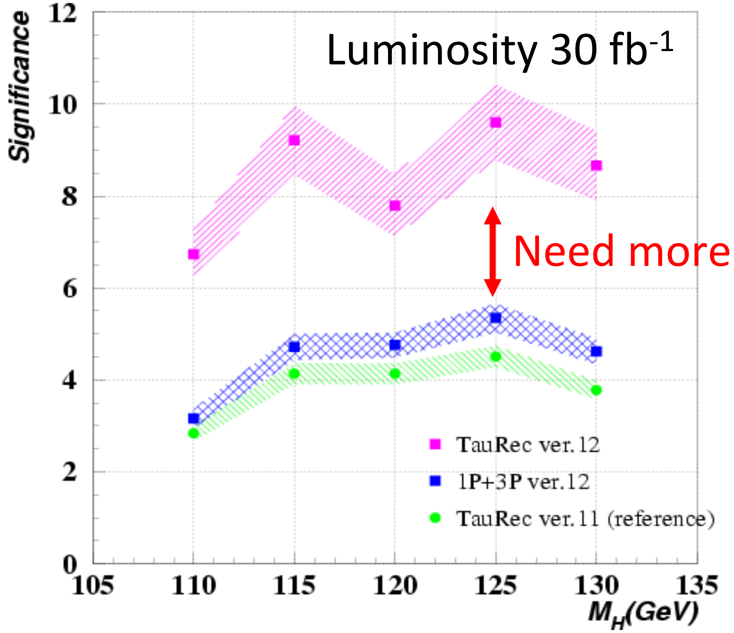
Known feature:
big difference in jet veto
between PY62,63,64.

Signal sensitivity

Soshi Tsuno(Tokyo) at Jan.17.2007

Very preliminary

Use the different parameterization from the different tau reconstruction algorithms.

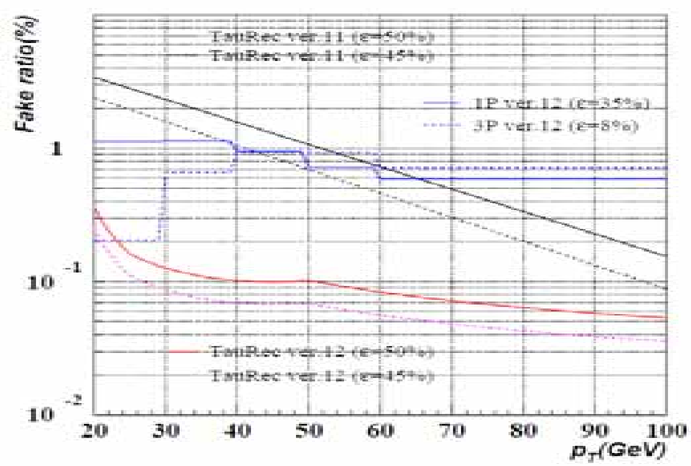


Default parameterization :

ε = 50% for TauRec,

ε = 45% for 1P3P

(38% for 1P, 8% for 3P)

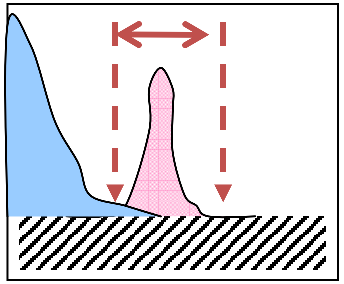


Many studies are necessary:

- Why parameterization is so different?
- How do we handle 1P3P parameterization?
- MC statistical treatment, etc…

Background Mass shape by Data (II)

Mass window

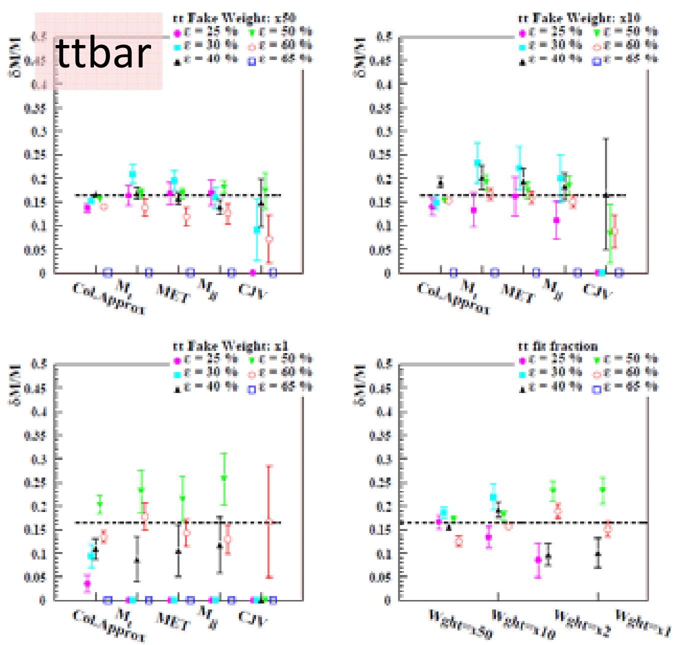


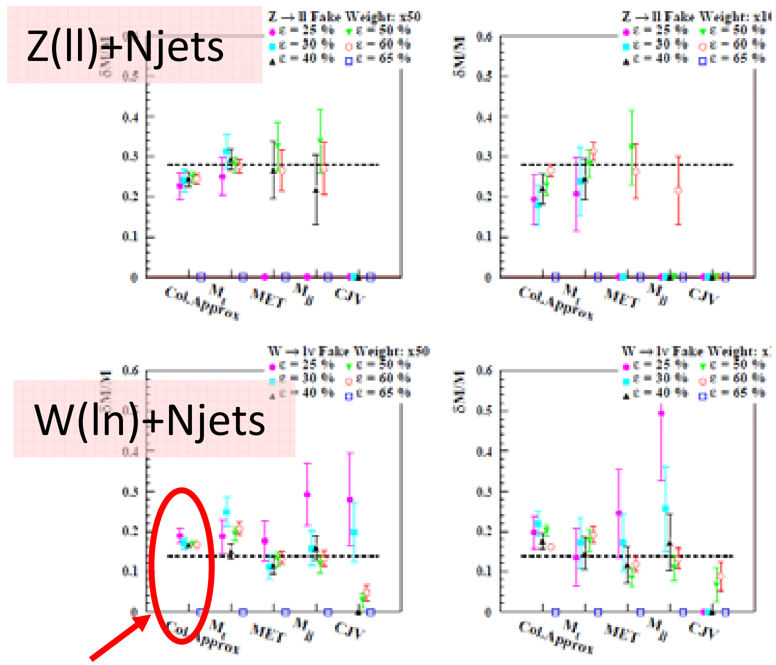
For the other background,

Define background mass shape on the midle of the cut flow.

Look at the event ratio in the mass window M_H ~ -10GeV +15GeV

Assume they are flat over cut flow.

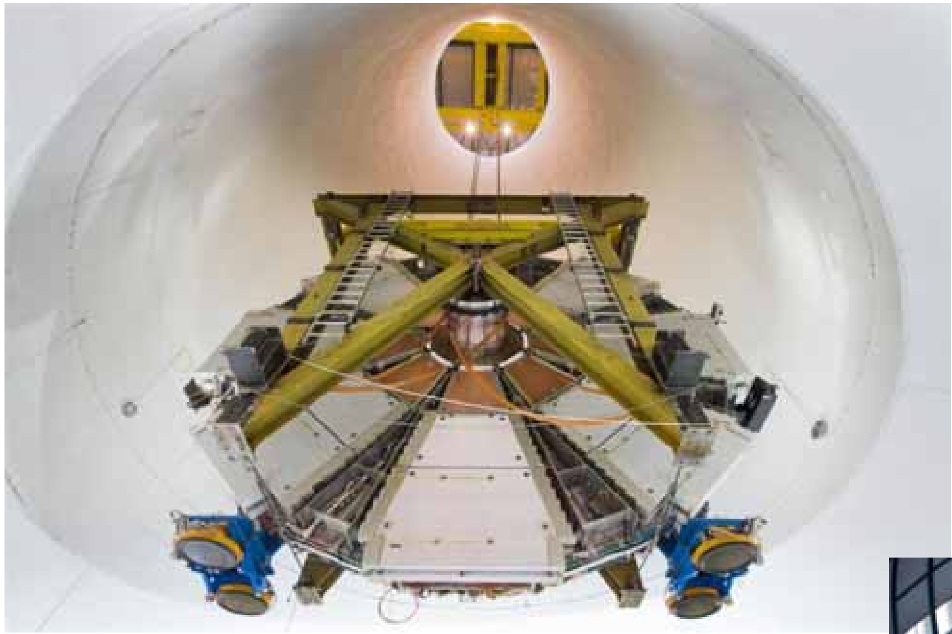




Soshi Tsuno(Tokyo) at Jan.17.2007

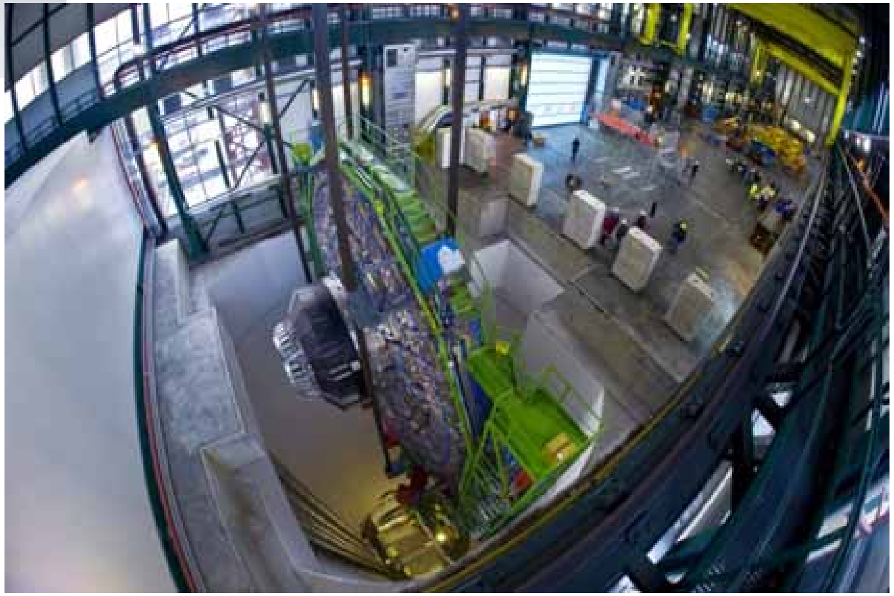
Using this events as the background mass shape, we obtain large statistics.

ATLAS / CMS Today



Feb.15.2008

ATLAS muon wheel goes in.
(second last piece)



Jan.2008

CMS final elements goes in.

SM Higgs discovery potential