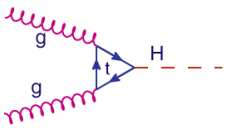
4　Higgs

1　Higgsの生成過程
2　崩壊過程
3A H → γ γ
3B H → ZZ* →4lepton
3C H → WW* →l ν l ν
3D H → τ τ
3E H → bb
4　Coupling, Spin, etc
5　MSSM Higgs

1. 生成過程

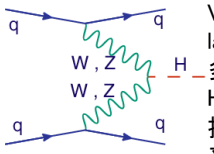
Gluon Fusion



gluonは、massless
higgsと直接接合しない。
top のloopで(Yt)
gluon多いのでσ大

γγ、ZZ,WW (lepton, photon
が出る奴)

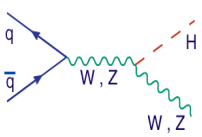
Vector Boson Fusion



Valenc quarkで
large Xのquarkが
多い
Higt Pt jetでBGを
押さえることが出
来る。

ττ

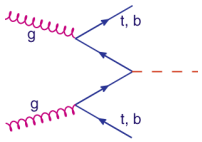
W・Zとの随伴生成



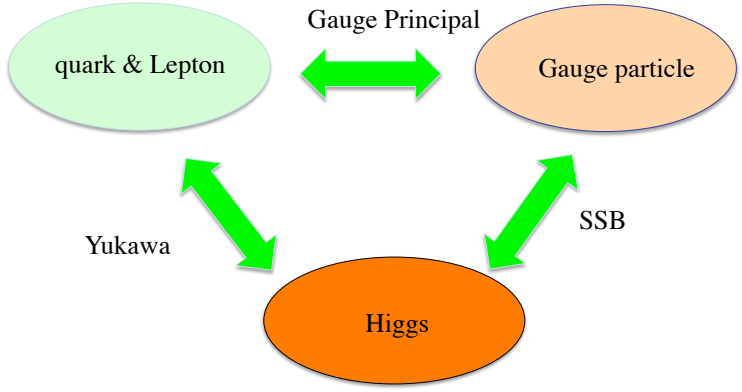
LEP,Tevatronの
主チャンネル。
W->lnuでtrigger
H->WWW

bb, ττ

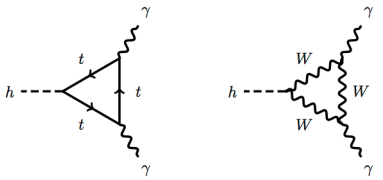
Top/bottomとの随伴生成



Topは特徴的なの
で発見しやすい。
Topの湯川結合測
定チャンネル
MSSM Higgsでは
$(\tan\beta)^2$ bbH/A

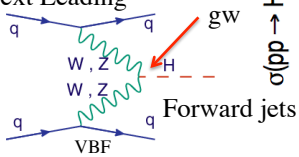


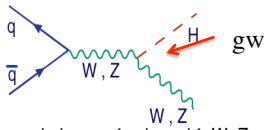
(1) Different mechanize works & Yukawa coupling is arbitrary
(2) Coupling for down type are suppressed in SUSY with large tanß
(3) various diagram contributes to H-> γγ
If new particle exists, also contribu



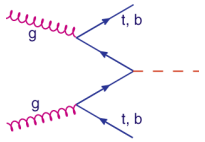
Leading

Next Leading



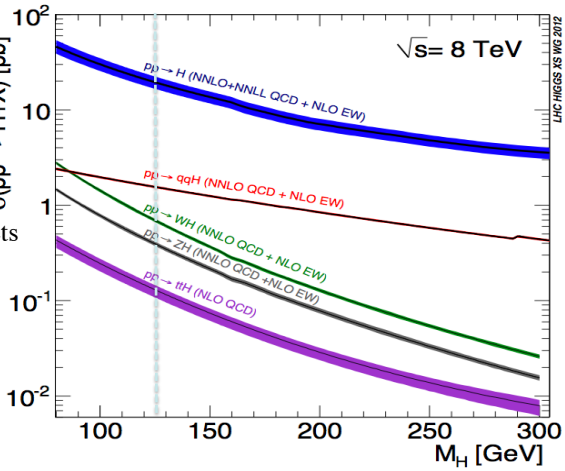


association production with W･Z



association production with top/b

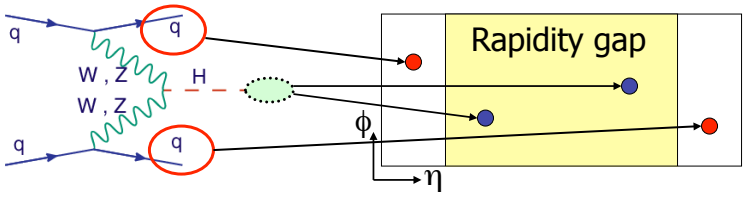
Cross-section @ 8TeV



cross-section (M～125 GeV)
GF σ～20 pb
VBF σ～2 pb
WH+ZH ~1pb

7,8TeVだとVBFが抑えられている

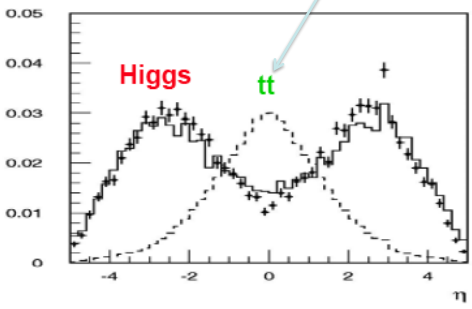
Vector Boson Fusion: Rapidity Gap



Heavy object is in central remember of rapidity

Forward High Pt Jet
No jet activity

Jet Pt ~ Mw
t-channel t~ Pt (small)
1/(t-Mw^2)



2 Higgsの崩壊モード

H → W+, Z, t, b, c, τ+,....., g, γ

H → W-, Z, t, b, c, τ− ,....., g, γ

$$WWH = \frac{e}{\sin\theta} m_W$$

$$ZZH = \frac{e}{\sin\theta\cos\vartheta} m_Z$$

$$f\bar{f}H = \frac{\sqrt{2}m_f}{v}$$

Massless -> No coupling
Loop

$$\int \frac{1}{2m_H} \sum_{spin,color} |M|^2 dLIPS$$

$$dLIPS = (2\pi)^4 \delta^4(q - p_1 - p_2) \frac{d^3p_1}{(2\pi)^3 2E_1} \frac{d^3p_2}{(2\pi)^3 2E_2}$$

2body phase space

$$\Gamma(H \to f\bar{f}) = N_f \frac{G_F m_H m_f^2}{4\sqrt{2}\pi} \left(1 - \frac{4m_f^2}{m_H^2}\right)^{\frac{3}{2}}$$

$$\Gamma(H \to WW) = \frac{G_F m^3{}_H}{8\sqrt{2}\pi} \left(1 - \frac{4m_W^2}{m_H^2}\right)^{\frac{3}{2}}$$

$$\Gamma(H \to ZZ) \approx \frac{1}{2}\Gamma(H \to WW)$$

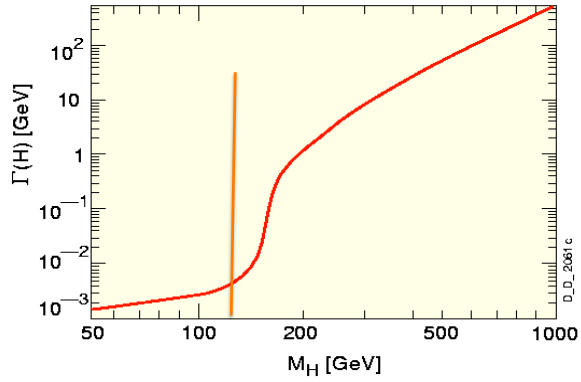
同種粒子の1/2

THS: β^3 スカラー 緩やかな立ち上がり

Bosonの3点結合 (mH^2/mw^2)

ー> mH^3

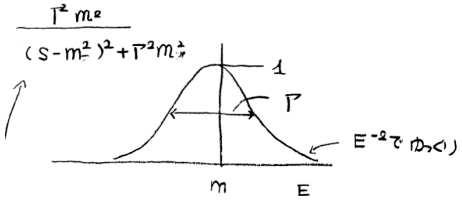
$$\sum_\lambda \varepsilon_\mu^{(\lambda)*} \varepsilon_\nu^{(\lambda)} = -g_{\mu\nu} + \frac{p_\mu p_\nu}{M^2}$$



傾きの違い
1乗 vs 3乗

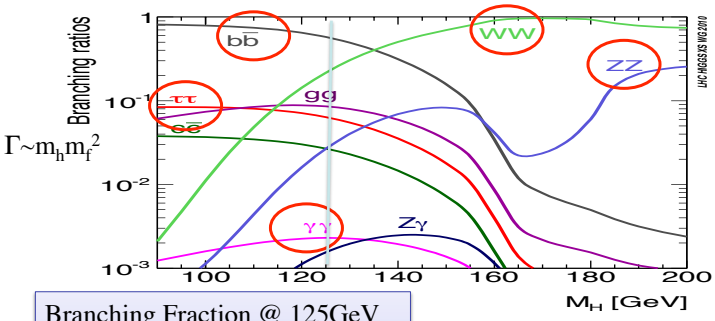
H->WWが開けると 3乗で大きくなる。
フェルミオンが主な時 Γ=O(1-10)MeV 細いBW共鳴
200GeV Γ=O(1GeV) 検出器の
分解程度になる。
直接幅を測定出来る。

125GeVだと数MeVの幅(細い)
直接幅を計ることはできない。



<120GeV
H→ bb, ττ
γγ

>140GeV H→ WW ZZ
WW,ZZ はM_h^3なので、非常に大きい
ttが開けても敵わない。
(Ytは生成でさぐるしかない)



decay width
$\Gamma \sim m_h^3$

$\Gamma \sim m_h m_f^2$

Branching Fraction @ 125GeV
bb ~ 60%
WW ~ 25% (leptonic ~ 1%)
tautau ~ 6% (HL,LL ~ 3%)
ZZ ~ 3% (4L ~ 0.02%)
γγ ~ 0.2%

自然は
本当に面白いところにあるな。。

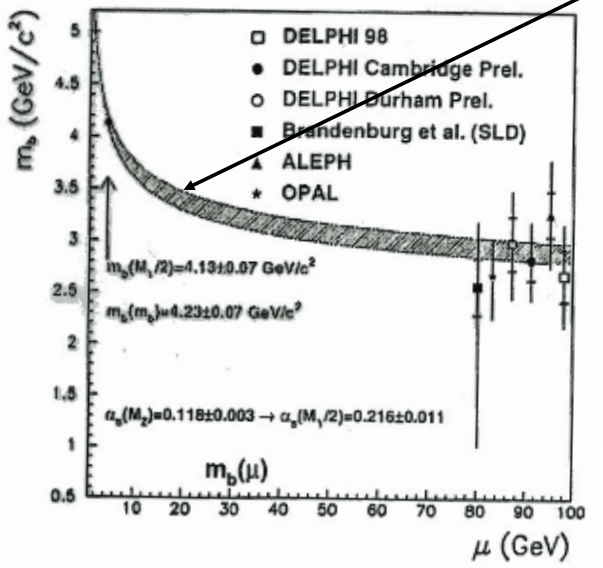
B,tauの崩壊分岐比の比較 約10倍違う理由 (5GeV vs 1.7GeV ?)

Massも走る。

Bottom massのうち、QCDの衣 1-2GeV
Mb=3GeV

yb=0.017

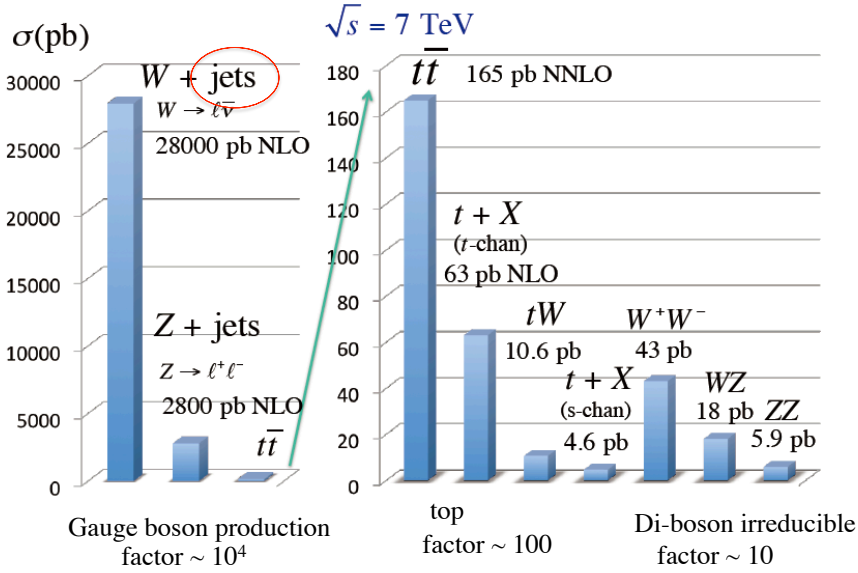
Ytau=0.01



Higgs起源のmass

QCD:
qq が真空期待値
Λ～ 200MeV
運度学的なmassをもつ

Production σ of the SM background processes



Gauge boson production
factor ~ 10^4

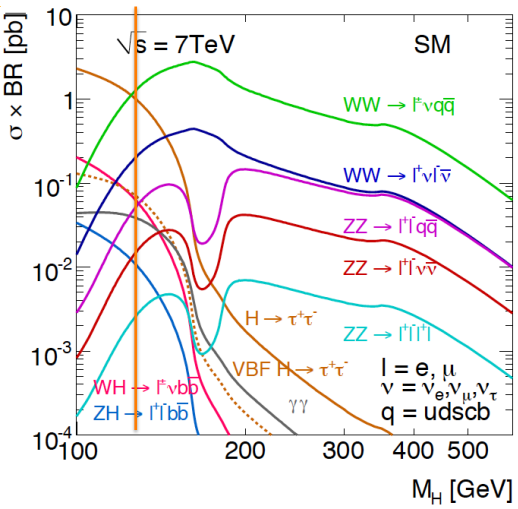
top
factor ~ 100

Di-boson irreducible
factor ~ 10

Fake lepton: Jet is misidentified as lepton (Prob. 10^{-4})

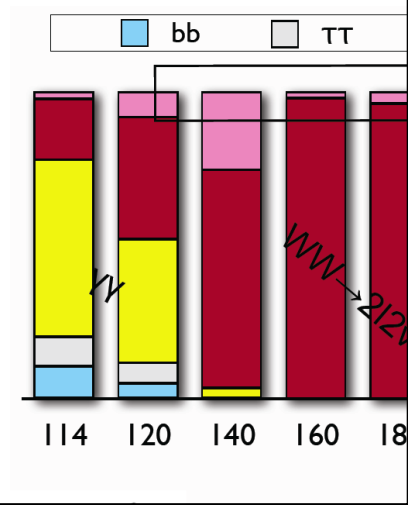
Sensitive channels

Resolutionが鍵



Sensitivity : BG is taken into account

γγ ~ ZZ(4l) ~ WW(lνlν) > tau > bb



Summary of measurement

SM Higgs boson (H~126GeV)

Decay modes

Production modes

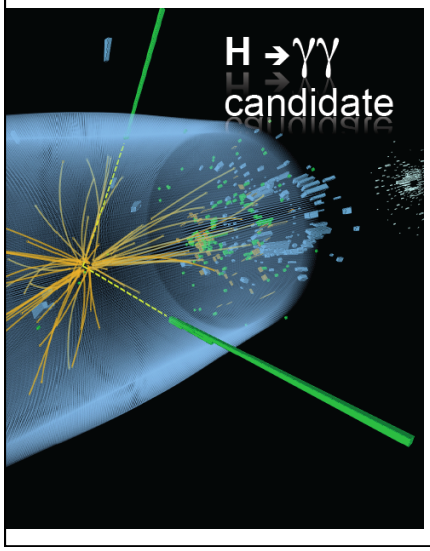
	bb	τ τ	γ γ	WW	ZZ
gg→H	×	×	Discovery Mass spin 0	Discovery Yt ? spin 0	Discovery Yt ? mass spin, P
VBF	×	Y_τ	Discovery	coupling spin0	mass
ttH	Y_t Y_b	×	Y_t high L	Y_t high L	------
WH	Y_b	×	------	------	------

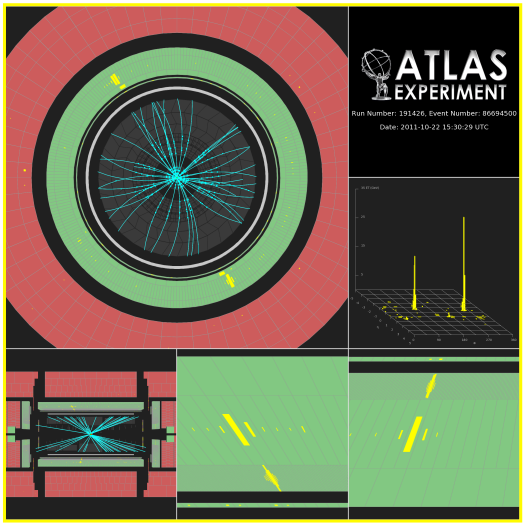
× : BG too high ------: σ ＊ Br too small

we can measure couplings and mass

[A] H→ γγ

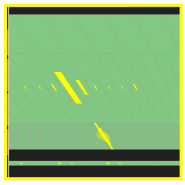
(1) 0.2% と Br が低い
(2) resolution 1.7GeVと細い
(3) BGも滑らか。



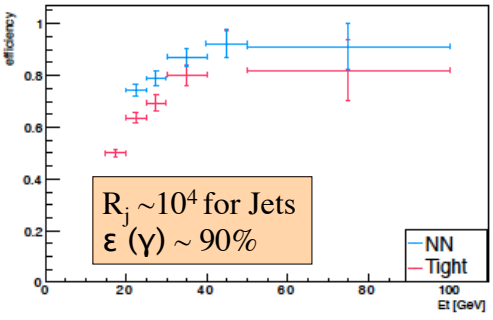


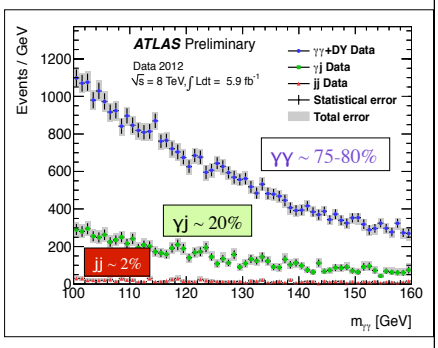
Photon ID using NN

EM 3層のシャワーの形（細さ:深さ)、
hadronへの漏れがない
Presamplerへのenergy deposit の仕方 (π0->2γ)
Isolation



実験データ

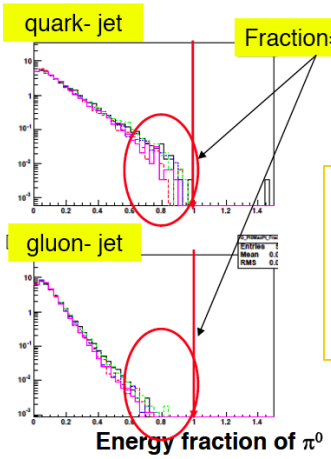


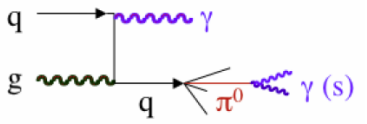


Fake Photonの寄与は小さい

Jetをphotonと間違える（フラグメンテーションのいたずら）

π^0 (10^{-16}秒程度で2γ　high PT one γに見える）
rejection factor 4　Isolationで除くしかない





-- π^0 in quark-jet carries more energy than in gluon-jet.

-- estimated "Fake Rate" on Full simulation

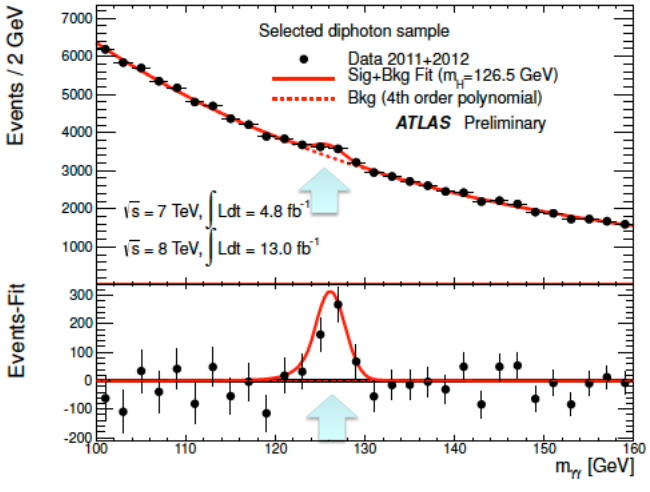
→ Fake Rate gluon jet : ~1/10000
quark jet: ~1/3000
} Factor 4

(HADRON化　gluonは2色もっている）

14

QCD jetの断面積は10^8くらいおおきいので、無視できないBG

Inclusive study



inclusive (σ=1.65GeV)

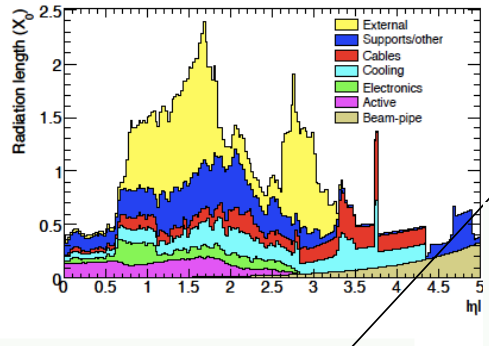
2 Photons with Pt > 40 GeV and 30 GeV are selected:
Also both photons are well isolated:
(Track isolation < 2.6 GeV in core R < 0.2
Calorimeter < 6 GeV in cone R<0.4)

Vertex is found with NN using ΣPt^2 of track

Then calculate an invariant mass inclusively

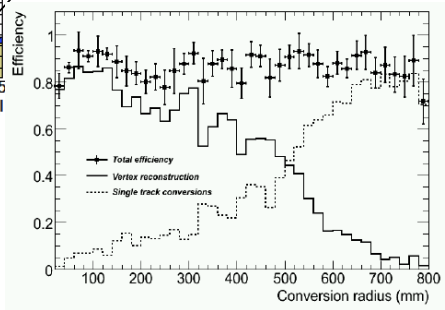
BG is estimated with data: fitted data with polynomial

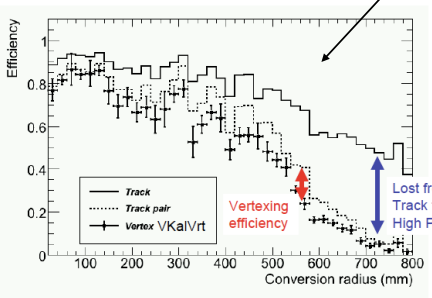
物質がけっこうある(γ conversion+energy補正)



γが無事、カロリメータに届く割合60%ほど。(検出器のところ思い出してください)
コンバージョンが結構多い。

2本みつけてvertex組める

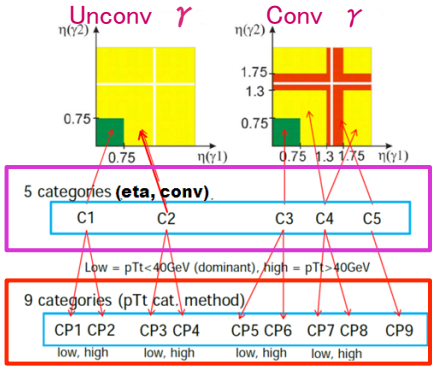




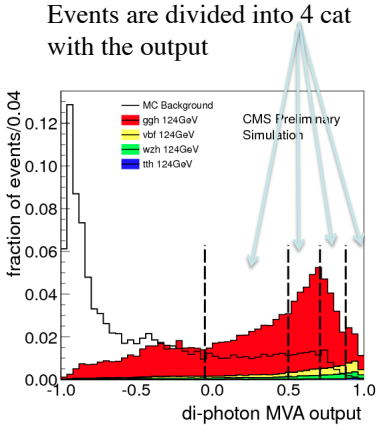
TRTだけやSCR+TRTのsingle trackでカバー
分解能もわるくなる

Selections are optimized for each category:

(1) Converted Photon or Uncoverted
(2) eta of Photons
-> These affect mass resolution



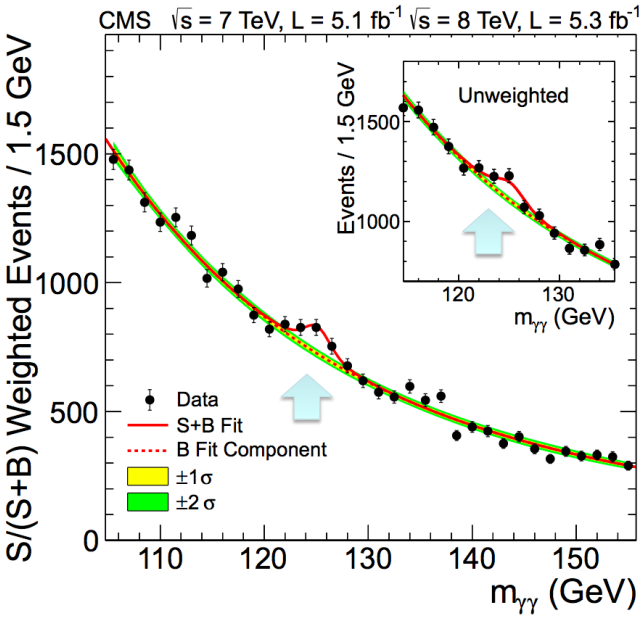
CMS: MVA technique is used (variables are similar to ATLAS)
Distribution of MVA output:
Events are divided into 4 cat with the output



(3) Kinematics
this affect background contributions

complicated!!!

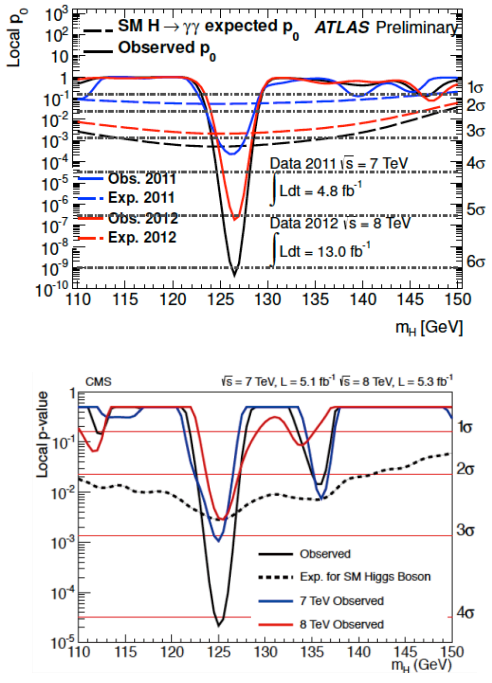
Background is estimated with read data, and significance is calculated in each category, and combined.



Similar Performance is obtained @ CMS; This is weighted results.
Event in Good category are weighted;

Mass resolution
σ=1.4GeV(2011)
σ=1.6GeV(2012)
vs σ=1.7GeV (ATLAS)

Since we have many pileup, we have to estimate pileup effect. PbWO4 granularity is not good,



ATLAS
126.6±0.3(stat) ±0.7(sys) GeV

energy scale uncertainties.
0.3% for electron calibration (Z->ee)
0.3% material in front of Cal.
0.6GeV in Total (calibration)

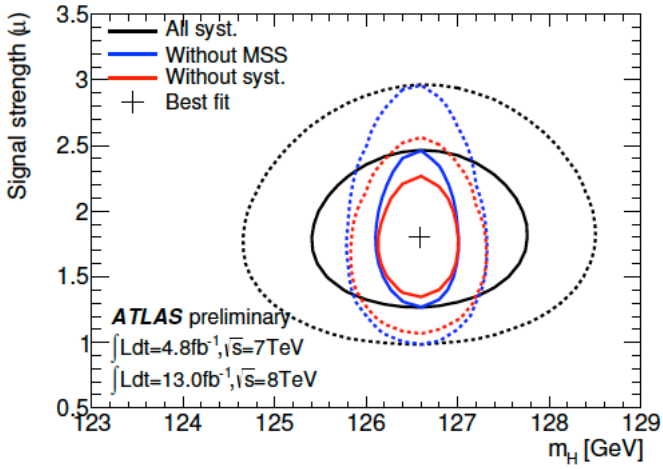
0.1% each maybe possible.
Furthermore precision is maybe difficult with my experience.

CMS
125.1±0.4(stat) ±0.6(sys) GeV

Why They did not update?
CMS: Only 5+5fb-1 data is used.

Rumor; They applied new calibration then center value change to 124GeV, $\mu < 1$ (now 1.6). So they are checking.

μ= observed yield / SM prediction = 1.8 + 0.42 – 0.36 Still high > 2σ (ATLAS)
Error is broken down to 0.3 (Stat) +0.21 -0.15 (sys.) +0.2 -0.14(theory)

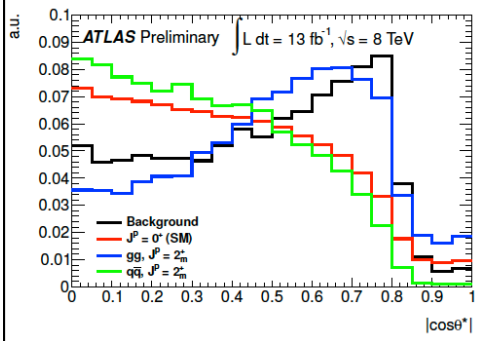


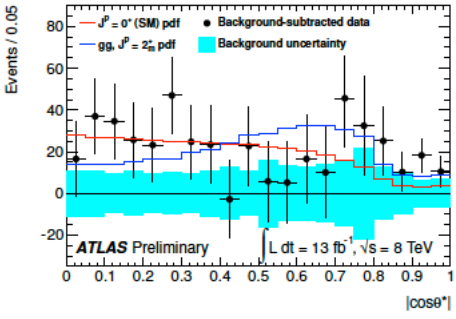
CMS μ=1.56 ± 0.43

2 σ level still statistical fluctuation…
If center value does not change,
3σ level…

2photon decay means Spin 0, 2

gluon gluon -> Spin2 state (Graviton) -> photon photon Photon emits in forward direction; on the other hand, scalar -> spherical

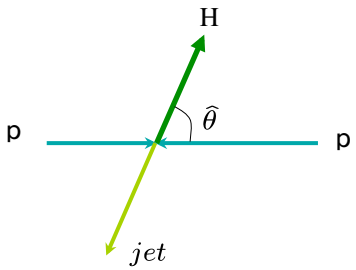




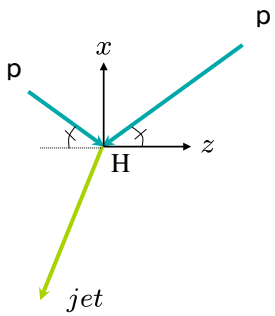
Frame work in Higgs system (Collins Soper coordination)

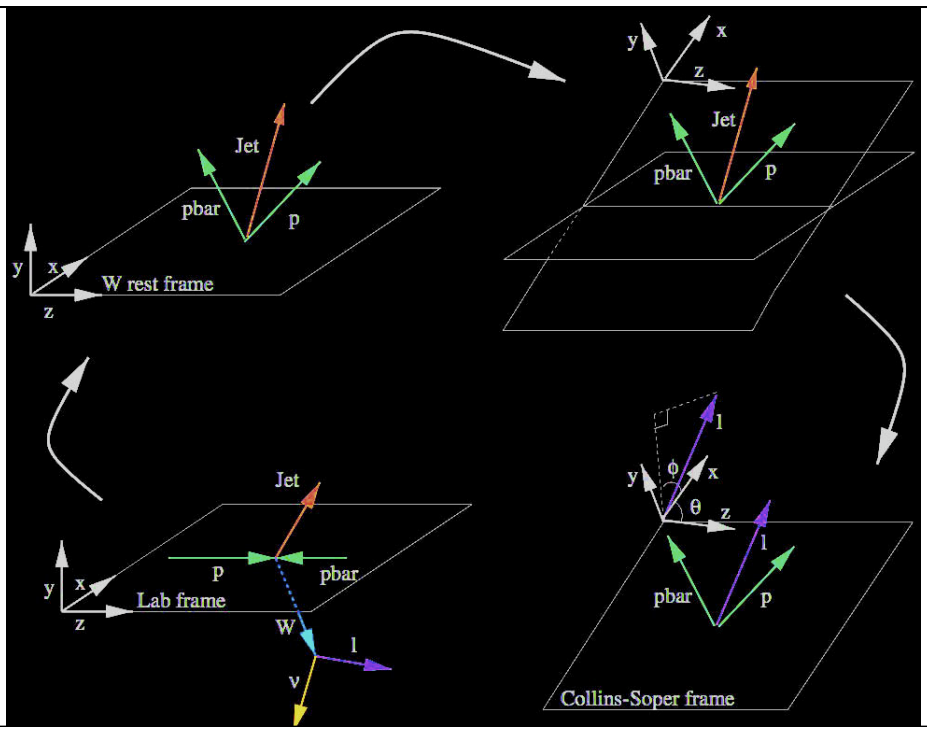
Data-BG distribution is consistent with spin 0, disfavor spin 2 distribution with 90%CL (Spin 2+ 8.9%(1.4σ)) Not yet excluded.
Furthermore distribution becomes similar when
qq_bar -> X(Spin2) -> photon photon: qq_bar will be checked eta

H-jet c.m. frame
(parton c.m. frame)



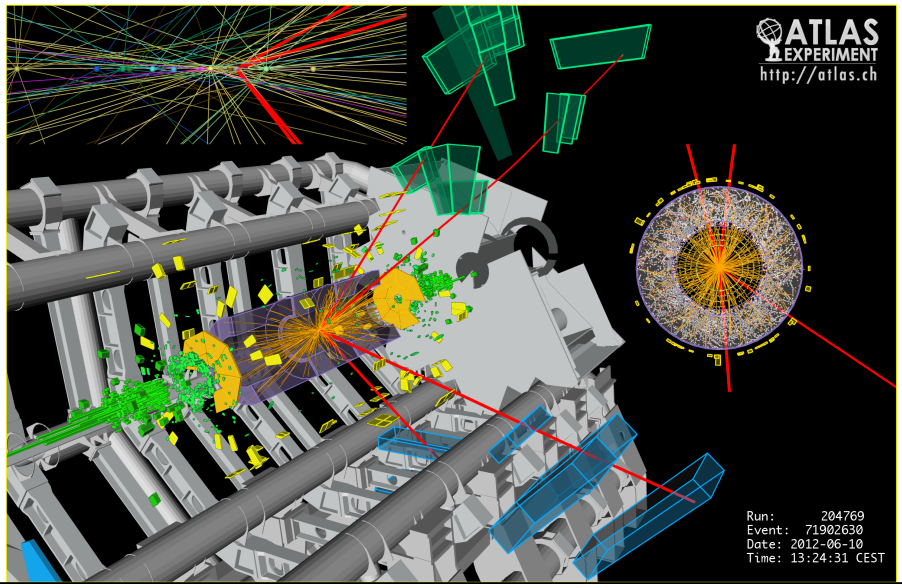
Collins-Soper frame
(H-rest frame)





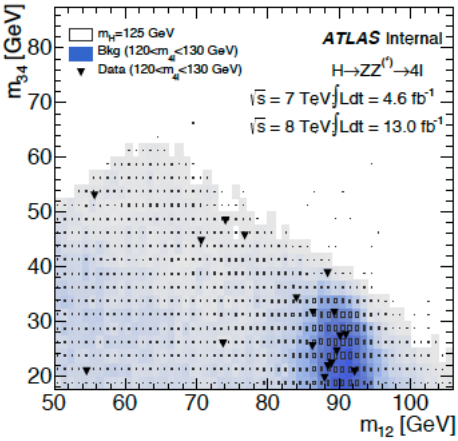
[B] H→ZZ→4lepton

4mu (mass=125GeV) PT=36.1, 47.5, 26.4, 71 .7GeV



H → On shell Z + off Shell Z* :

Breit- Wigner Resonance of Z



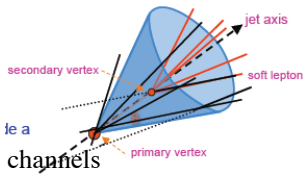
$$f(E) = \frac{k}{(E^2 - M^2)^2 + M^2\Gamma^2}.$$

decay width of Z Γ~ 2.5GeV

double suppression on Z*Z*

Higgs decays into one real Z
|M12-Mz| < 15 GeV

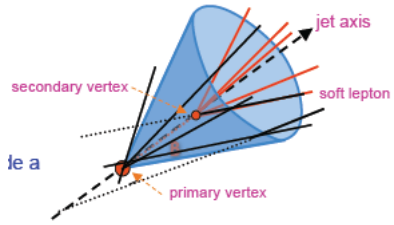
off Shell state mass M34 > 15GeV
to reduce gamma* -> ll

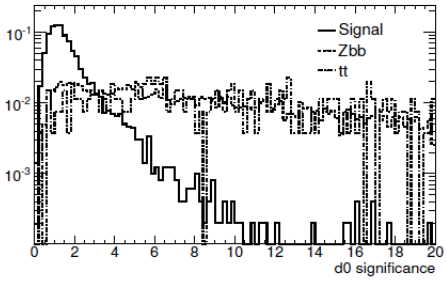


impact parameter of lepton is required to be small to reduce Zbb, tt -> bblnulnu BG

Detection efficiencies are 37/23/20% for 4mu 2mu2e, 4e channels

普通 bが崩壊すると、こんな風にみえる。

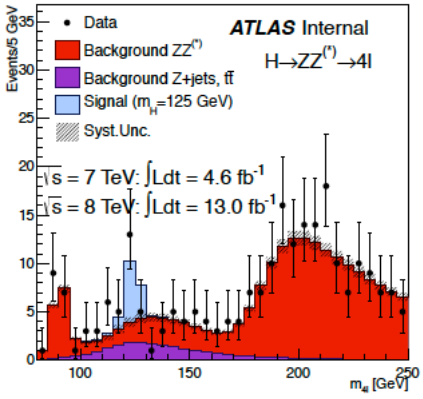


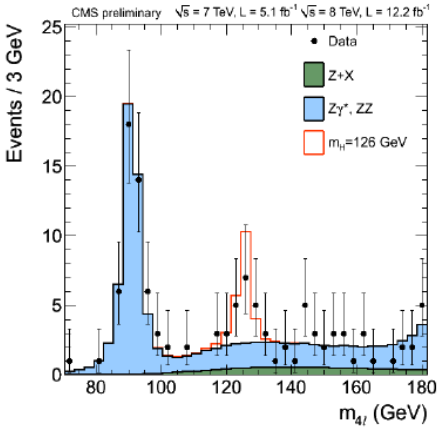


Lifetime の 物理　　b->c は KMでsuppressされるので、
Γ(b->X) << ΛQCD (bはmesonを作る　cτ300μ)
tは? cは?

これもfragmentの物理で jetがsoftになってしまうことがある(fake gammaと同じ)
leptonにみえてします。(leptonなんで)
これを抑えるために Isolationを厳しくとる。約1000のrejection
更に、impact parameterで落とす。
b,c起源のleptonはSUSYのSS dilepton のmain BG。(ここらへん実験的に大事)

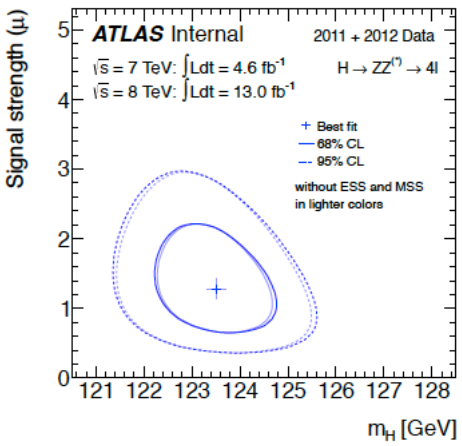
M_{4l} distributions

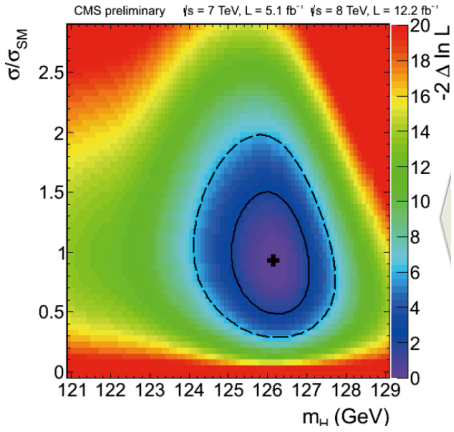




Statistic signal is small, but background contribution is also small; differ from γγ
Main BG is ZZ* -> continue spectrum
ATLASはLoose側に舵をきって fake lepton BGはふやして signal を確保
CMSは LH系の解析(あとで)

Mass and yield





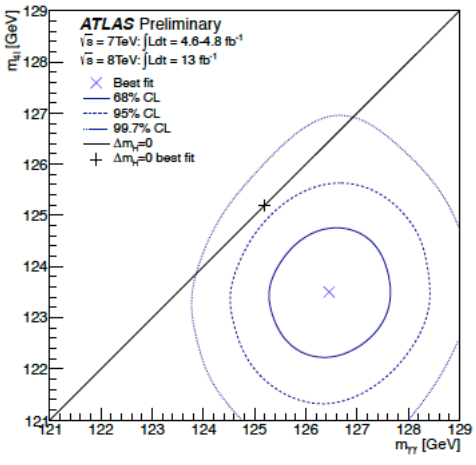
123.5±0.9(Stat.) +0.4-0.2(sys.) GeV
μ = 1.3 + 0.5 -0.4 Stll stat. dominant

126.2±0.6(Stat.) ±0.2(sys.) GeV
μ = 0.8 + 0.35 -0.28 Stll stat. dominant

Signal yield is consistent with SM Higgs
But mass observed at ATLAS is significantly light

ATLAS M(γγ) vs M(4L)

Δm=3.0 ± 0.8(stat.) +0.7-0.6(sys)

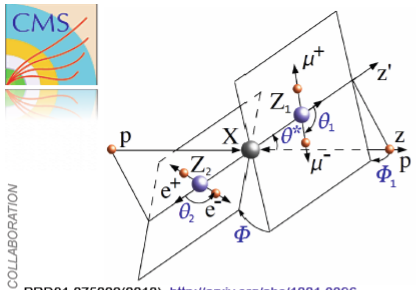


0.8%(2.8σ level)
discrepancy
We have checked
many things
but not found any problem.

So Just stat.?

Data will increase additional
8 fb-1,
Still checking dE/dx in material

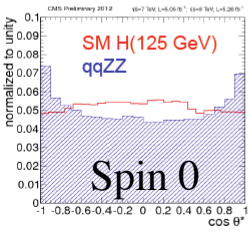
(1)可能性　統計
(2) Calibration Z->ee でする。-> Pt 依存
光と電子ではE-loss $1X_0$だけ違う

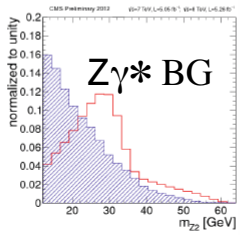


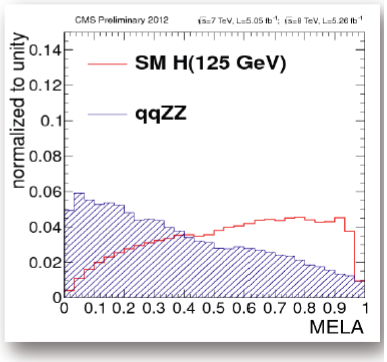
Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

PRD81,075022(2010) http://arxiv.org/abs/1001.3396
PRD82,013003(2010 http://arxiv.org/abs/1001.5300



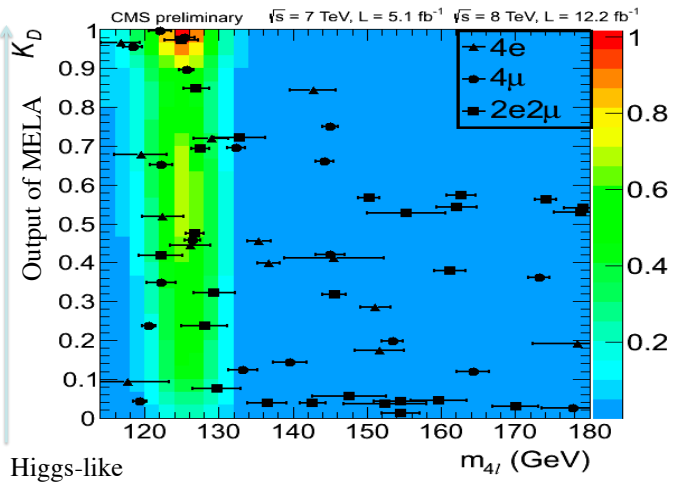




Discrimination with $m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1$

invariant masses of dilepton system, Larger is ~ Mz, softer has different distributio
Higgs is scalar, 2 Z distribution is spherical

July 9th 2012 ICHEP CMS Higgs J. Incandela for the CMS COLLABORATION



Higgs-like

Events @ 125GeV are enhanced:

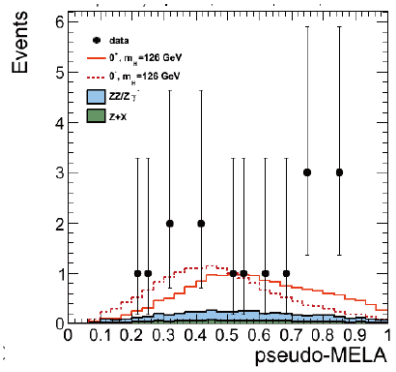
Lesson
Lepton can be assigned directly to hard process
We can use them safely:
Jets are different, since we can not say this jet comes from hard-processes or ISR/FSR

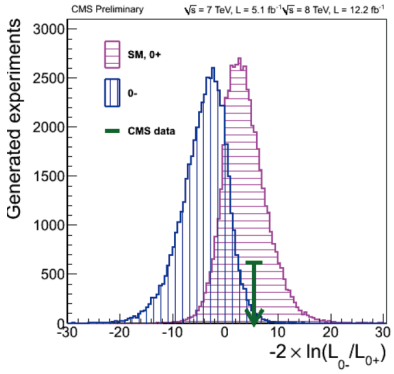
We can study the property of the new boson (J^P) using this channel / method.

Spin2?

$$A = v^{-1}\epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(a_1 g_{\mu\nu} m_H^2 + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\right) = A_1 + A_2 + A_3,$$

SM Higgs 0–



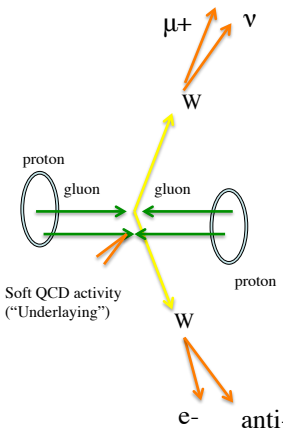


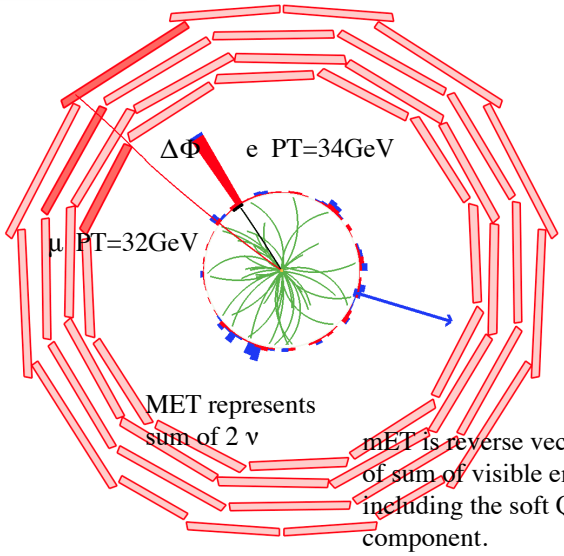
$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\rm SM}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

Pseudo-Experiments with different model and L is calculated with data

0- is disfavored by 2.4σ(2.4%)

[C] H→WW→lνlν





MET represents sum of 2 ν

mET is reverse vector of sum of visible energ including the soft QCD component.

2lepton + mET + (Jets) is basic topology
Events are categorized with number of the jets:
Different production process of H, different BG processes

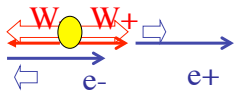
- 0 jet analysis (GF) dominate BG: WW
- 1jet(with b-jet veto) dominate BG: tt, WW (Next page)
- 2jet(VBF) dominant BG: tt

Then two important variables are calculated:

ΔΦ(ll) Azimuthal angle between dilepton

M_T(Transverse mass)

Higgs Spin0

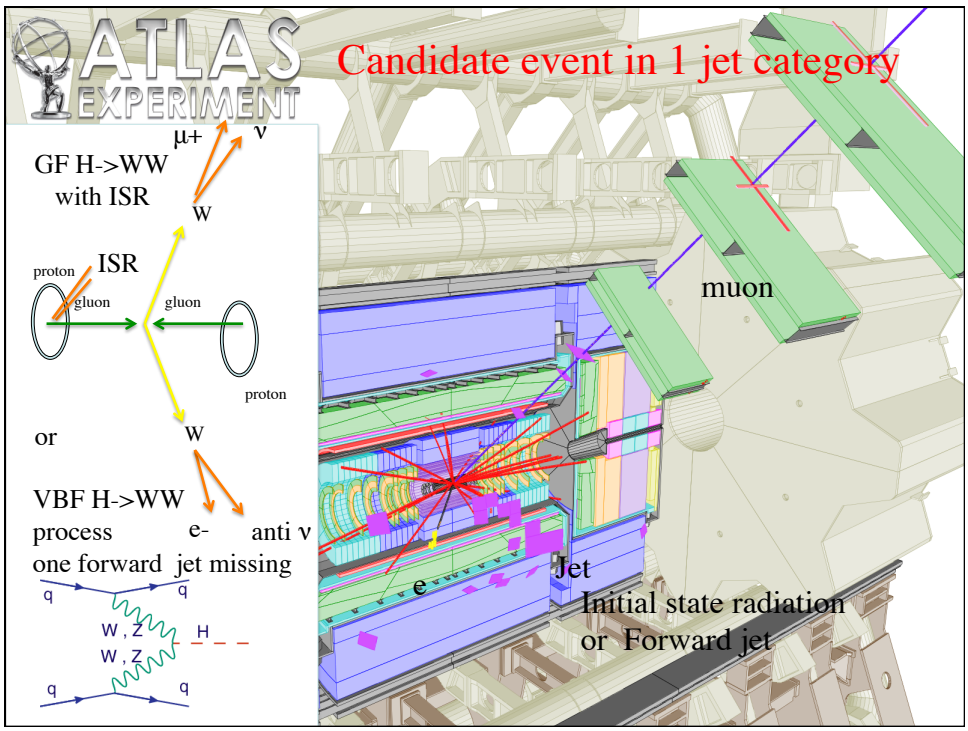


Higgs spin 0
Spin of W is opposite
Since Parity is 100% violated in leptonic decay of W, ΔΦ becomes smaller.

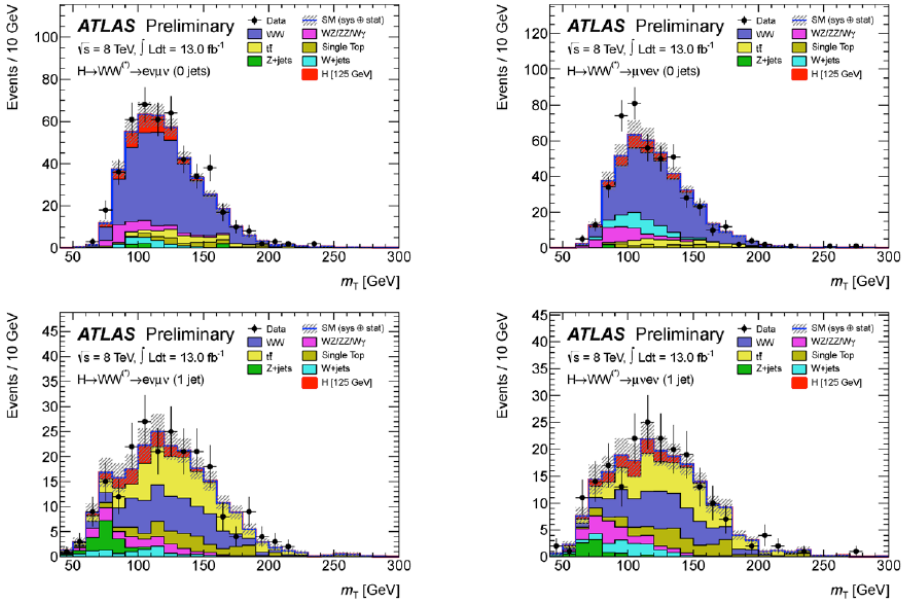
Since We do not have information of Pz of neutrinos, we can not calculate invariant mass:
Transverse mass is analogy of W(->l nu)

$$M_T^2 = (E_T^{ll} + E_T^{missing})^2 - (P_T^{ll} + P_T^{missing})^2$$

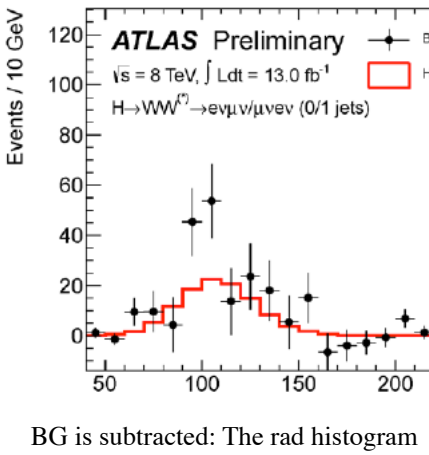
$M_T < M_{higgs}$ (MT=MH at Pz=0)



Transverse Mass distributions: 0/1 jets modes, 2 jet mode is still limited in stat.



Transverse Mass distributions: 0/1 jets modes, 2 jet mode is still limited in stat.

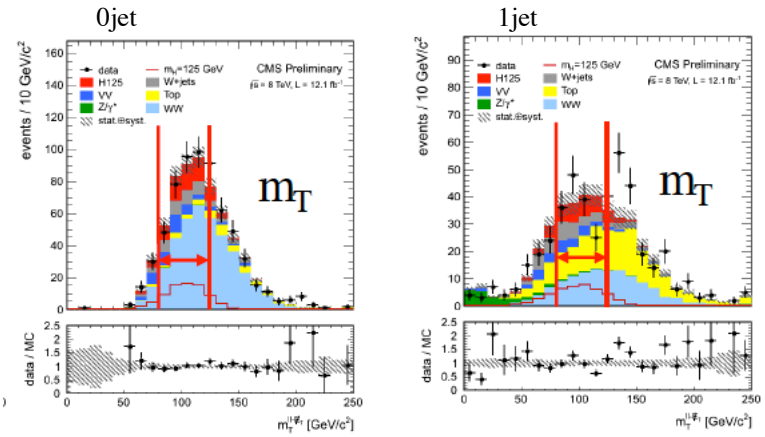


Main BG os WW and top: These are estimated with MC, but it is normalized with real data.
W+jet also contribute but small, (jet is mis-IDas lepton): This fake lepton BG is estimated with data

BG is subtracted: The rad histogram shows the expected signal:
2.6 σ excess is observed :Broad edge is related to Higgs mass.
Not good sensitive to Mh

Signal yield is consistent with SM Higgs

$$\mu = 1.48^{+0.35}_{-0.33}\,(\text{stat})^{+0.41}_{-0.36}\,(\text{syst theor})\,^{+0.28}_{-0.27}\,(\text{syst exp}) \pm 0.05\,(\text{lumi})$$

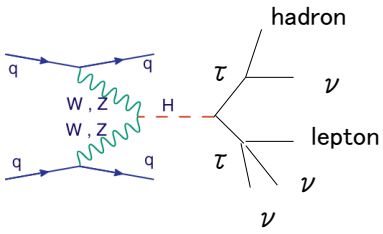


Excess 3.1 σ (2011+2012) WW channel is also in "evidence" level

Sensitivity @ LHC $\gamma\gamma > ZZ > WW > \tau\,\tau > bb$

Coupling to Gauge Boson looks Higgs boson !
Next target is " Yukawa coupling"

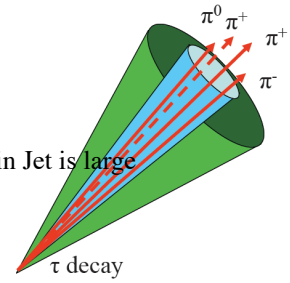
[D] H→ ττ

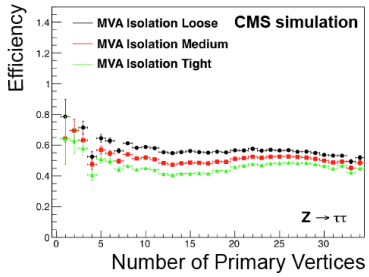


tau 34% leptonic decay

one tau decays hadronic decay HL mode
both leptonic LL mode
both Hadronic HH mode

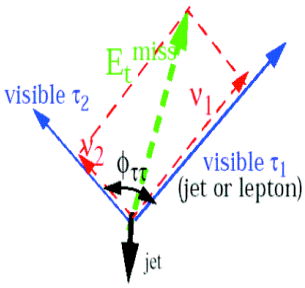
tau-jet
1,3 prong
narrow jet
EM component in Jet is large
since π0→γγ



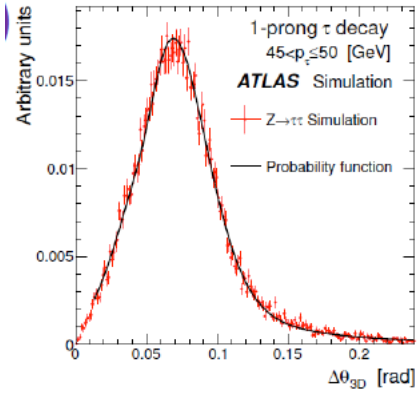


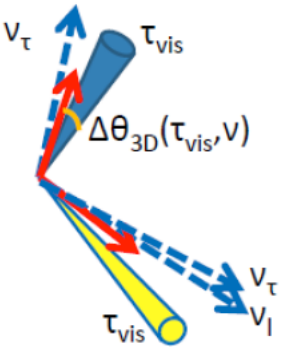
Efficiency ~ 50%
(Fake rejection 1/100)
Against pileup

Directions of ν is the same (close to) visible objects,
We can estimate ν momentum with mET -> Higgs mass can be reconstructed



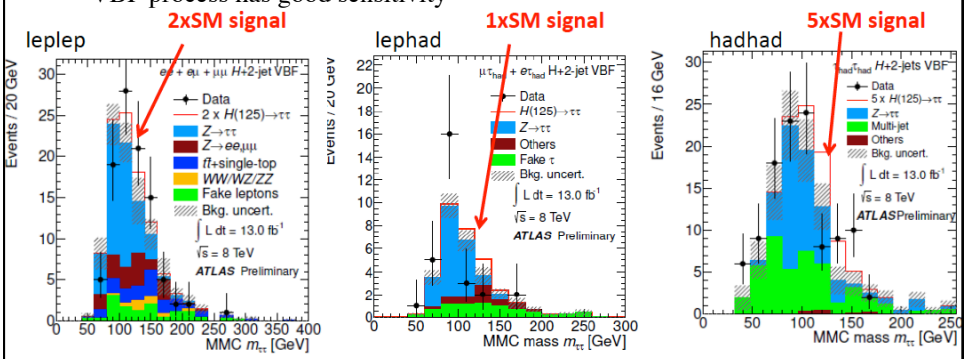
Now We use MC information to reconstruct mass
-> PDF is used for reconstruction





You can see direction tau is slightly differ from colinear

Sensitivity of GF process is not so high, since mET can not be solved.
DY Z->tautau BG is serious.
VBF process has good sensitivity



Excess is still small 1σ level
Yield μ= 0.7 ± 0.7
CMS is also similar excess (1σ level) μ= 0.7 +- -.5

Stat. is limited
But need to estimate BG

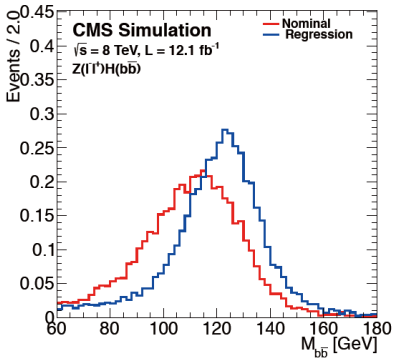
BG: tautau <- embedding by mumu (stat. is limited)
Z->ee,mumu top MC
Fake is estimate with Same Sign signal

Signal is enhanced @ 14TeV

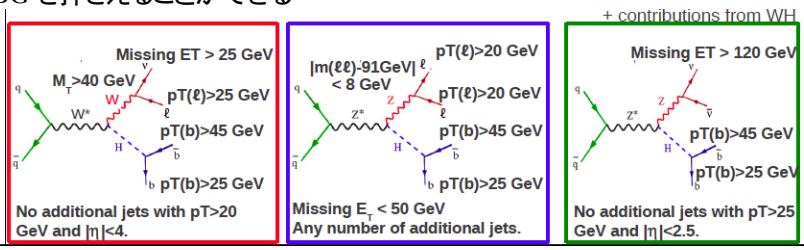
[E] H→bb

Analysis の鍵は3つ

(1) Mass resolution is key for this channel.
Kinematics、Soft lepton information
を使って Mbbの精度あげる。
（Tevatronではやっている 20%）

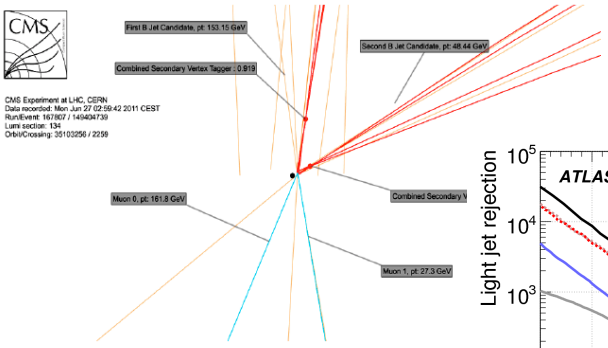


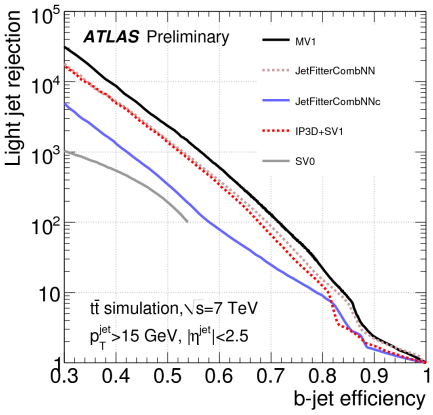
(2) Boosted PT(V)> 100(Z->ll)
> 170(W,Z->nunu) GeV
BG を押さえることができる



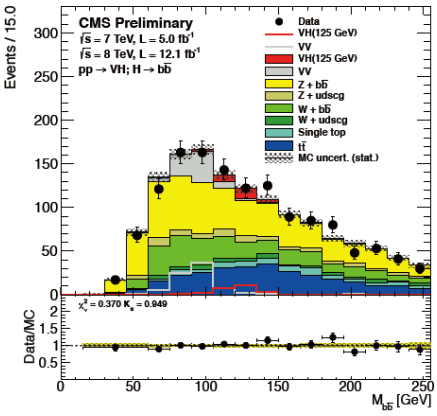
(3) b-tagging performance

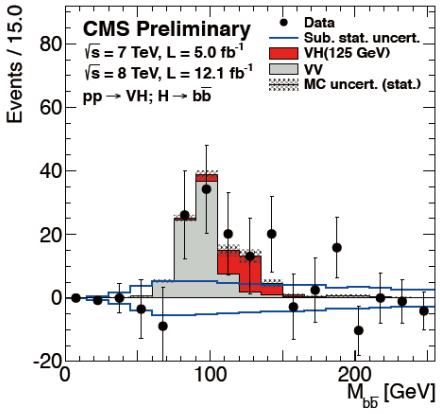
1) 2nd Vertex
2) Impact d0 track
3) Track mass





Rejection Power ～ 600 for udsg
Rejection Power ～ 10 for charm
efficiency = 60%

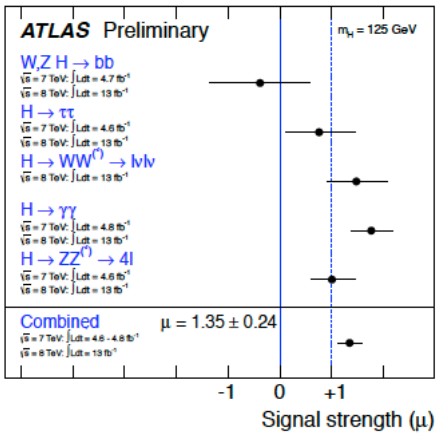


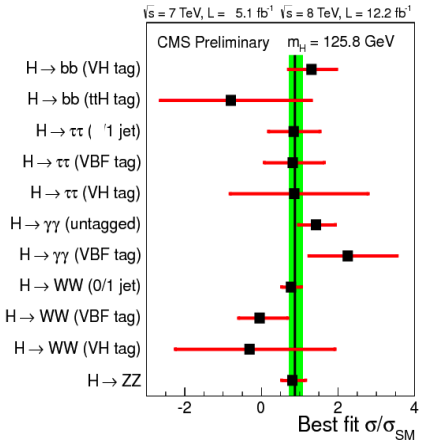


Z jj どこまで信用できるか?
MCを使って Normalizationを
どこか別のところで合わせている。

2σレベルの信号: μ = 1.3 +0.7 -0.6
ATLASは まだ見えてない。

4 Coupling H→γγ Still high ?

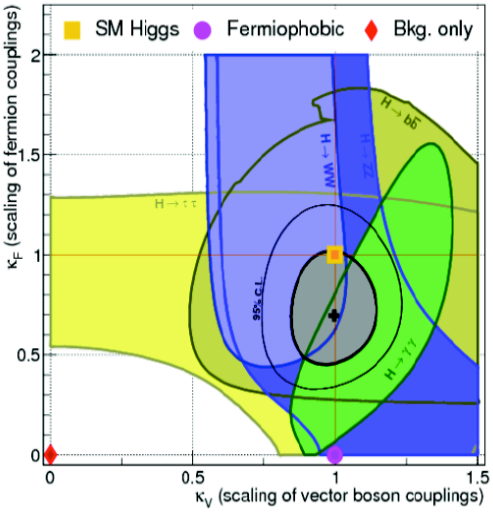




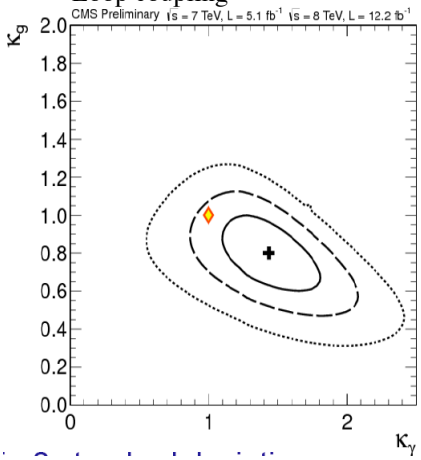
ATLAS μ=1.35 ± 0.24
CMS μ=0.88 ± 0.21 => Combined result is consistent with SM
H-> γγ still high, but consistent with SM within 2σ

Coupling

(1)Yukawa is Small? 1σ level



Loop coupling



Still 2 σ level
consistent with SM Higgs

Need data for Yukawa

Spin & Parity

(1) Spin 2 is already disfavored by angular distributions in γγ、ZZ,WW

(2) Parity + : ZZ （If Spin2 is excluded, then 0^- is already excluded 95%CL.)

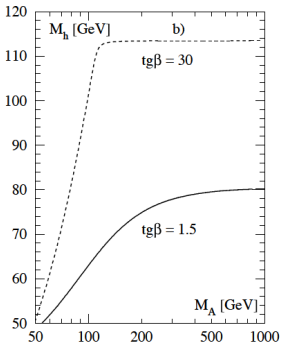
$J^P = 0^+$ is favored even with 5+12 fb^{-1} data
We will have more 10fb^{-1} data. -> We can conclude

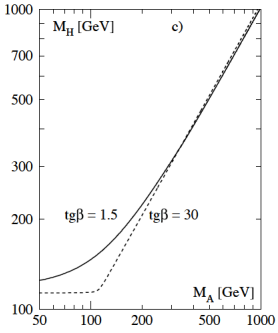
5 MSSM Higgs

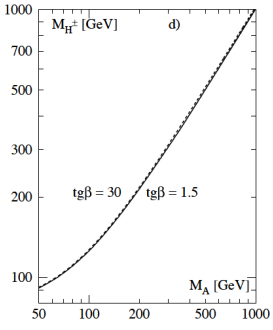
SM: 電荷共役でSU2の上下に質量与えて
いたがSUSYでは駄目：最低2個
SU2 doubletが必要 8 real scalar場

・h,H^0,A^0,H^{+-}の４種類
・Tree levelでtanβとM_Aの
2 parameterで記述

Mass: M_A が小さくない限り
SM-like h と 縮退した(H/A/H^{+-})



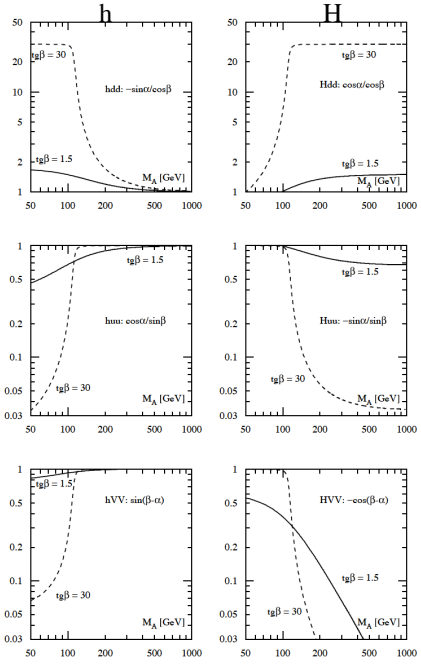




軽い、SMに似ている性質

H,Aは縮退

H^{+-}=SQRT(H^2+Mw^2)

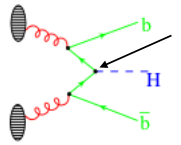


M_Aが大きい
hはSMと同じ

H:
tanβ>>1 down type
tanβ～1 SM
いずれにしても
Gauge bosonとは
decouple

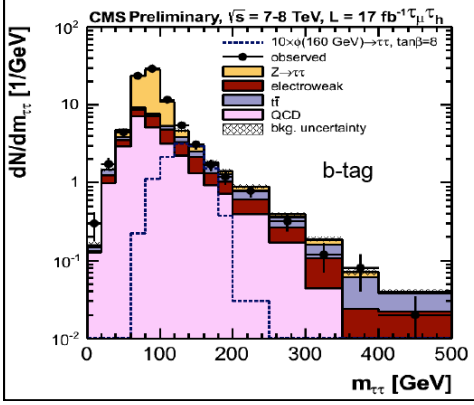
M_Aが小さい
いろいろまざる。
tanβ～1 SM

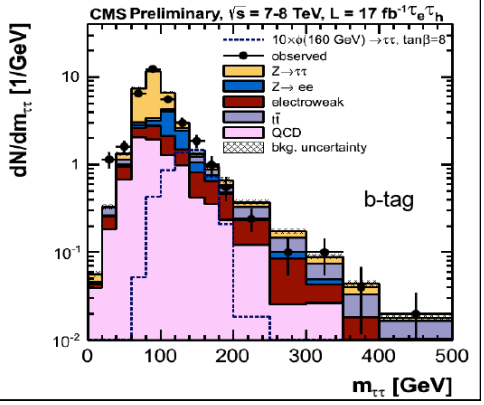
H/A → ττ

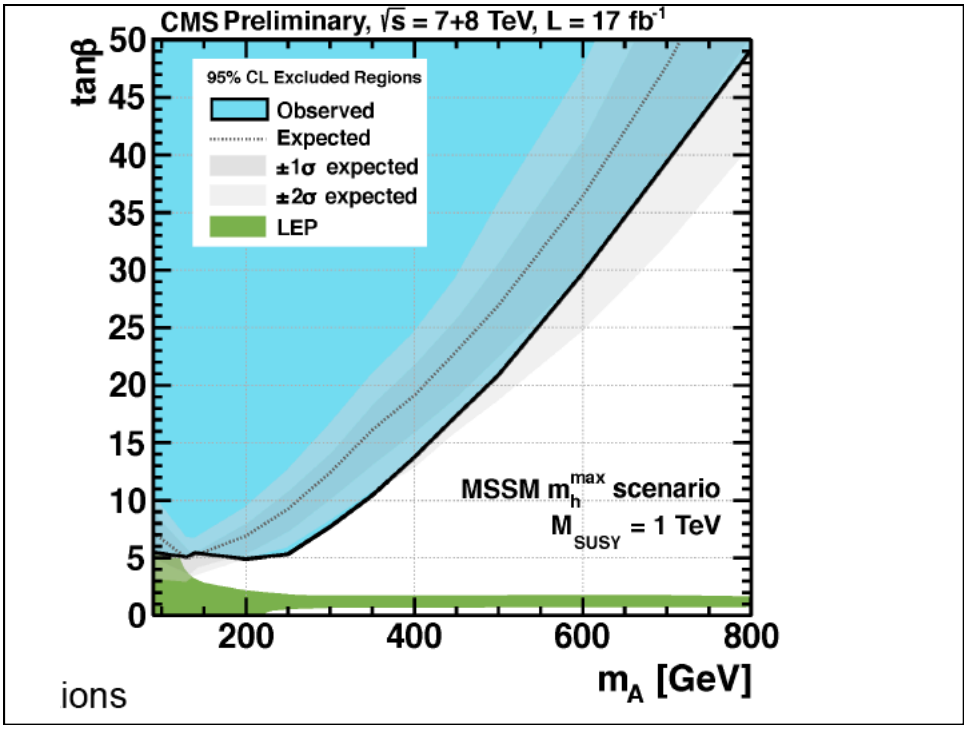


tanβ

H-> ττ 質量再構成は h->tautauと同じ
b-tag PT>20GeVを1つ要求







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