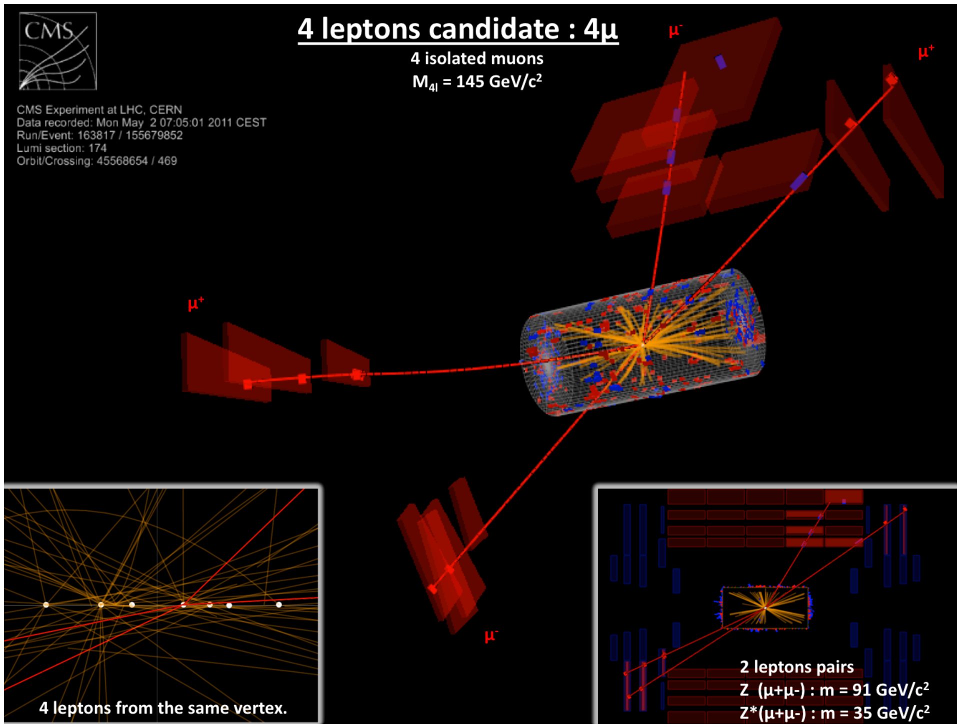
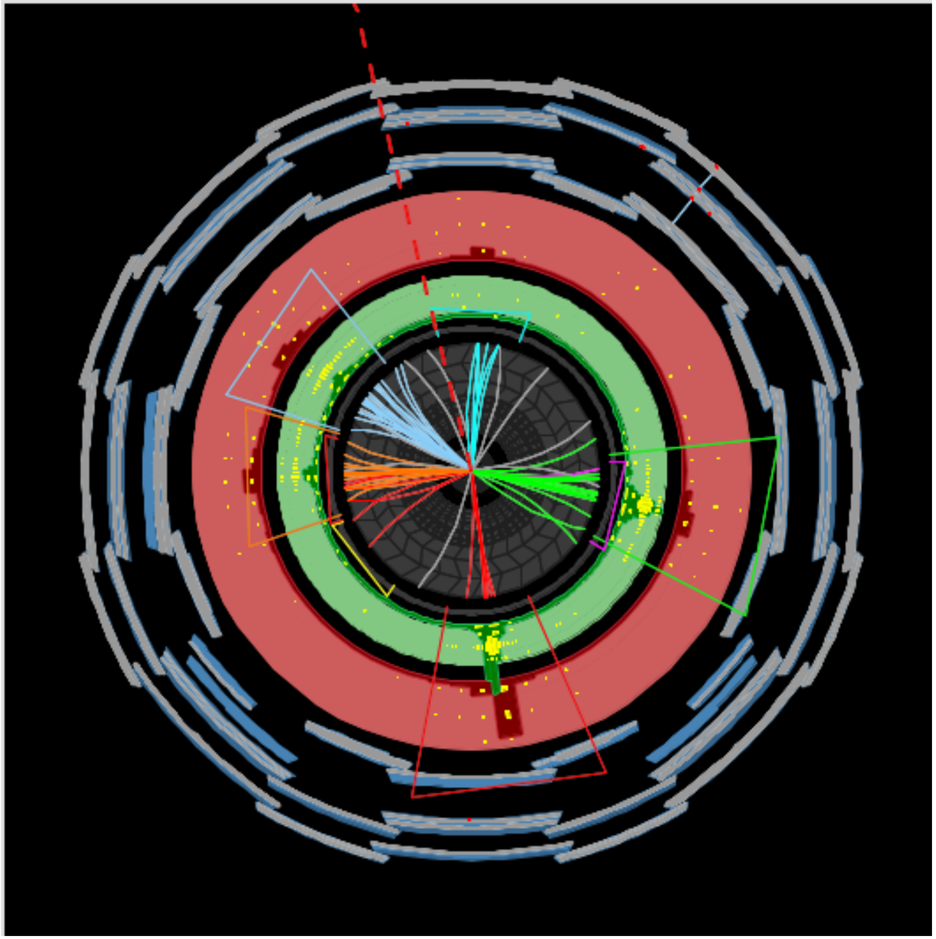
JGRG21

The Latest Results of LHC
Hint of Higgs and SUSY



Higgs candidate(CMS) H->ZZ*->4muon
M(H)=145GeV



SUSY Candidate (ATLAS)
high PT 4jets+mET(460GeV)

S.ASAI (U.Tokyo+ATLAS)

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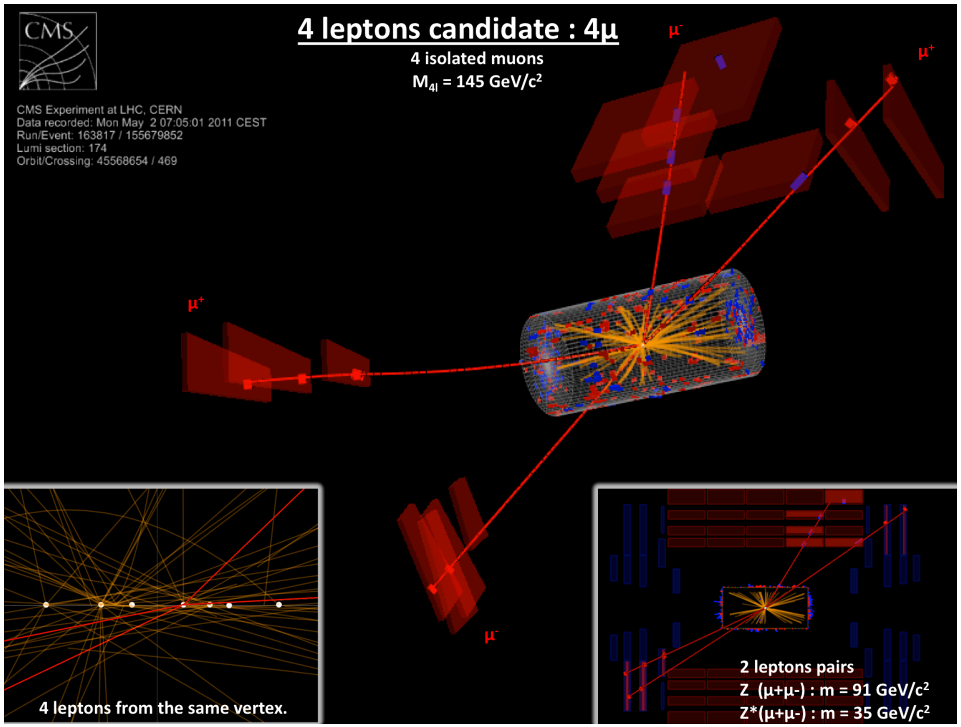
The Latest Results of LHC
Chaotic Hint of Higgs and SUSY



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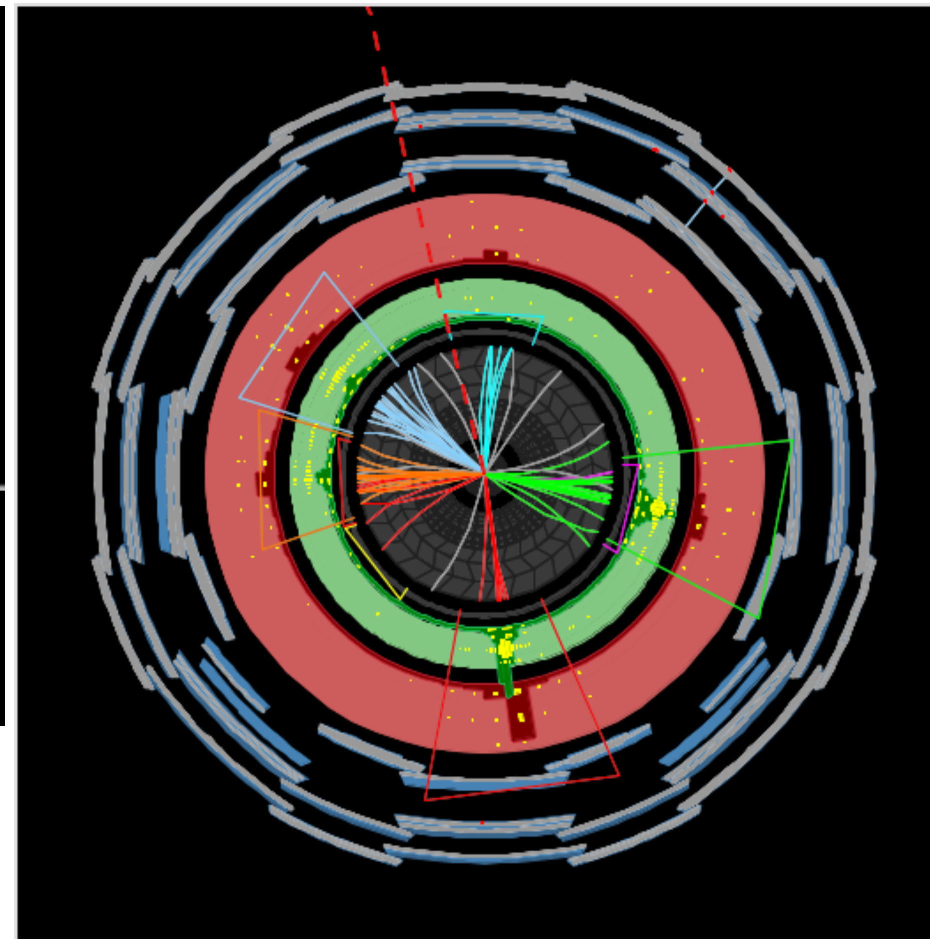

SUSY Candidate (ATLAS)
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S.ASAI (U.Tokyo+ATLAS)

Plan of my talk

1. LHC status and plan
2. Results of Higgs Hunting

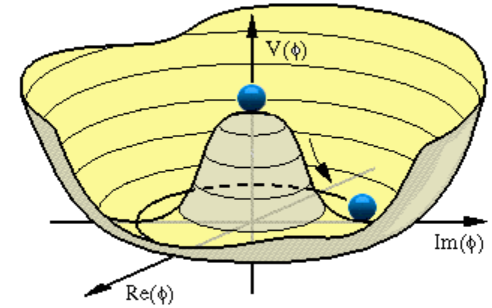
   proof of the phase transition of our vacuum,
   and origin of the symmetry breaking and mass.

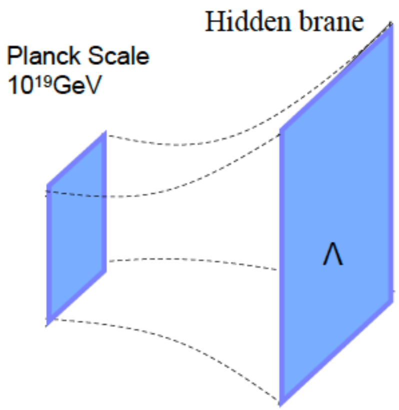
3. SUSY hunting related to Dark Matter

   SUSY is the most promising BSM
   LSP is the good DM candidate

4. Extra dimension (If I have time)

5. Summary and Perspective

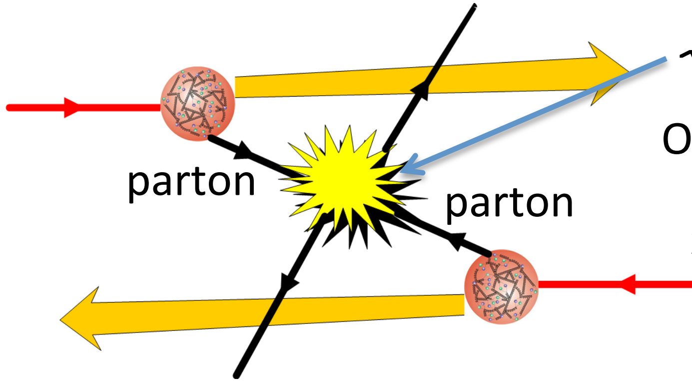




1. LHC Project

- Circumference 27km
  8.4T Superconductive magnet are installed.
- Proton-Proton colliders with ECM = 14TeV
  Now ECM= 7TeV (2010～2012)
- There are two general purpose detectors

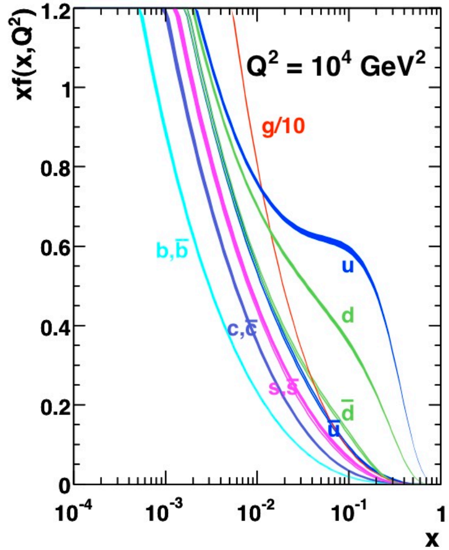
Luminosity is essential for Hadron collider



$$\sqrt{\hat{s}} = \sqrt{x_1 x_2}\sqrt{s_{pp}}$$

O(TeV) (7-- 14TeV)

x is ratio of P carried by the parton over Proton.



$$L = \frac{n_1 n_2}{4\pi\sigma_x\sigma_y} f$$

n: number of proton (1.4*10^{11}Proton)

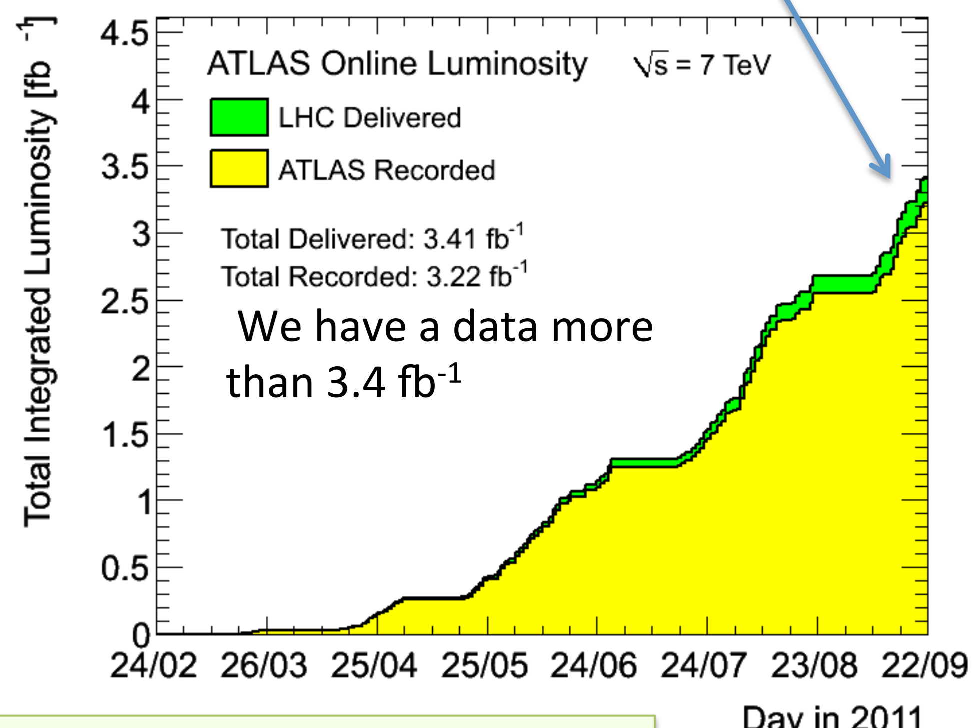
σ: beam size (23 μm)

f: frequency of collision (20MHz)

$L=3.3 * 10^{33} cm^{-s} s^{-1}$

Luminosity is above the first target (1* 10^{33} cm^{-s} s^{-1})

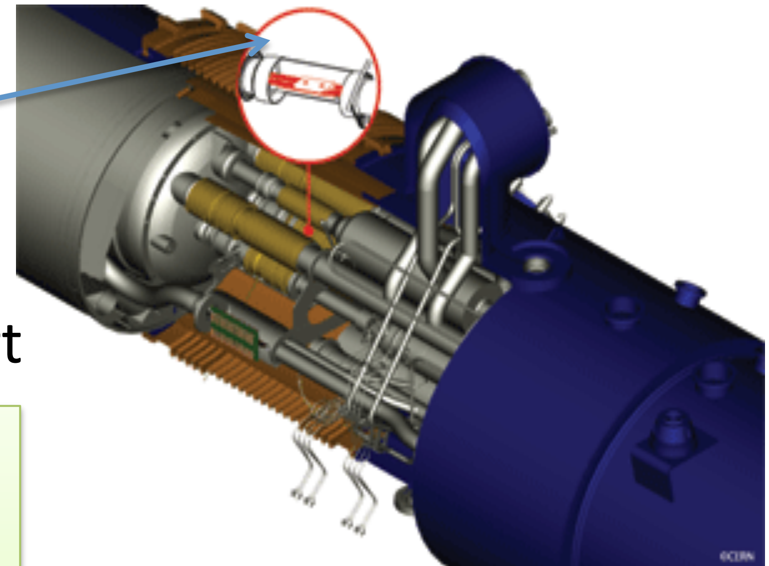
end of last week



Data more than 50 pb^{-1} / day are delivered now

LHC schedule

18 months to repair all bad connection of cupper bar between the SC magnets



2011 ECM=7TeV L~5fb^{-1}

2012 ECM=7 or 8 TeV L~20fb^{-1}

2013 Shut down

~

2014 Autumn ECM=13-14TeV restart

2015

~

2020

ECM=13-14TeV 10^{34}cm^{-s} s^{-1}
L > 300fb^{-1}
Targets are
Higgs coupling
SUSY upto 3TeV

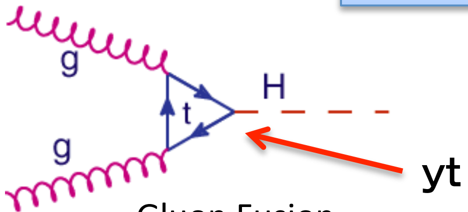
2018 Shutdown for High Luminosity
semi-conductor detectors
are replaced

2020- LH-LHC 10^{35} cm^{-s} s^{-1} L~ 1ab^{-1}/year Self coup. of H
2030- HE-LHC ECM ~40TeV depends on new physics

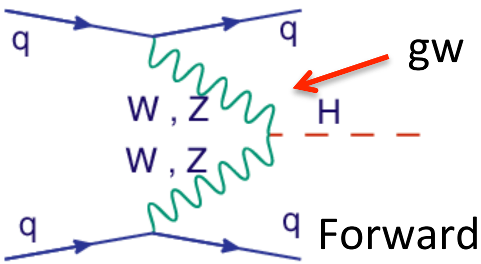
2. Results of Higgs Hunting

Leading

Production Process of Higgs @ LHC

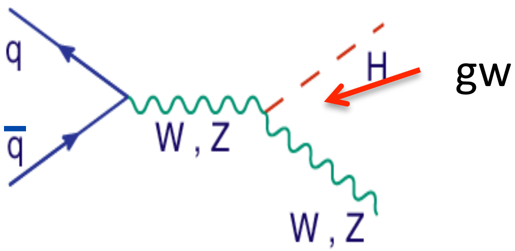


Gluon Fusion

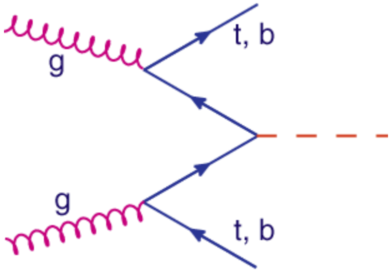


VBF

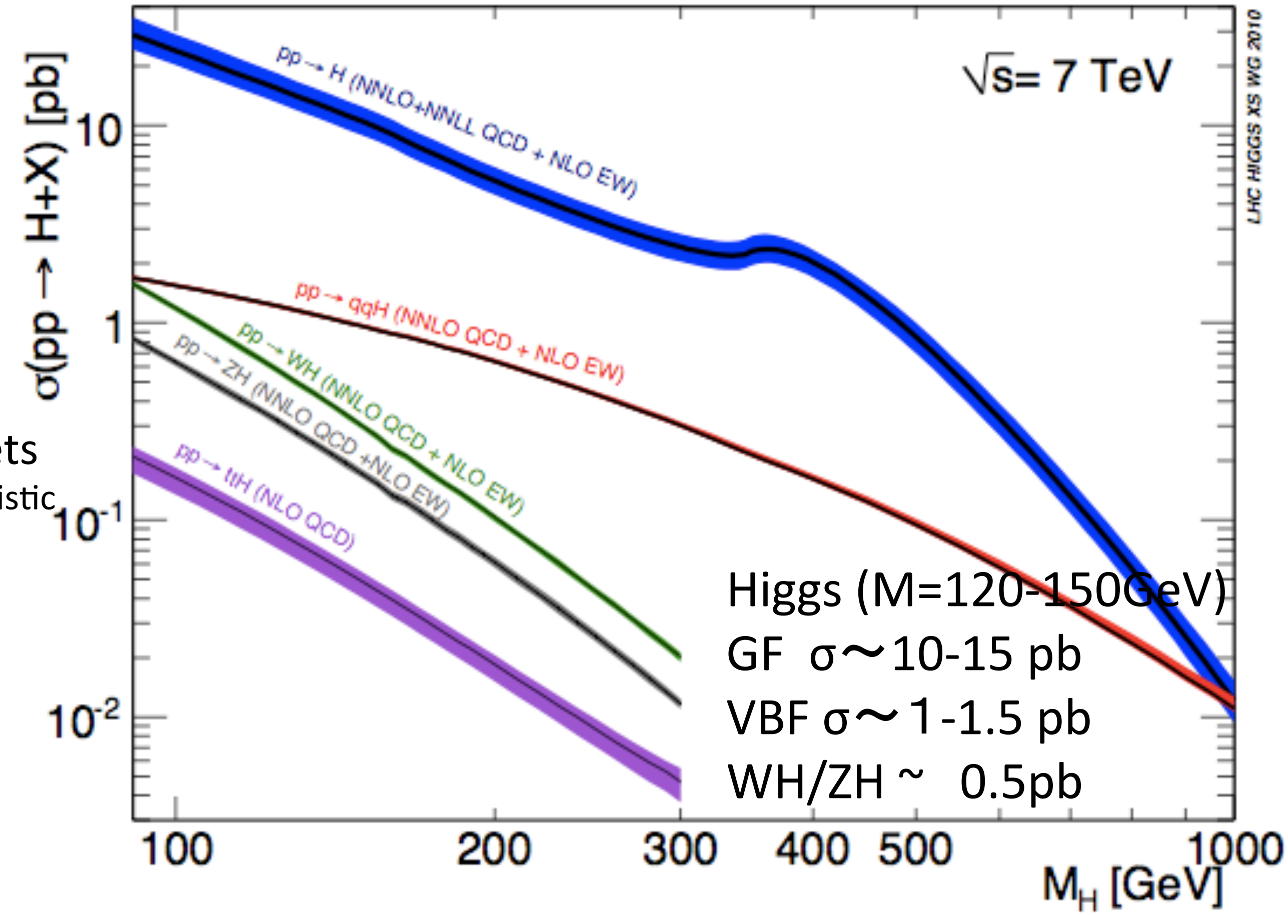
Forward jets
are characteristic



association production with W・Z



association production with top/b



Higgs (M=120-150GeV)
GF σ〜10-15 pb
VBF σ〜1-1.5 pb
WH/ZH ~ 0.5pb

Two different couplings can be examined in the early stage of LHC . Origin of fermion mass, “Yukawa coupling”, can be examined.

In SM Yukawa is not inevitably, just given by hand

Decay Branching Fraction

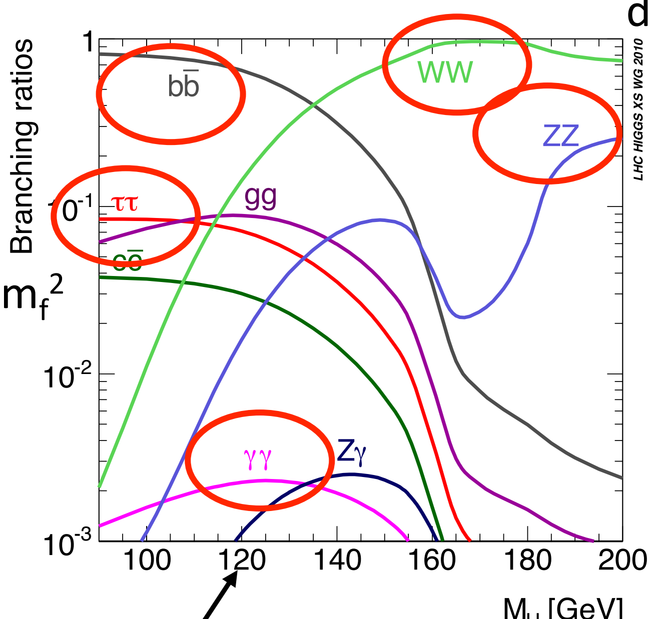
Higgs decays into heavy particles:

5 important decay channels:

decay width

$\Gamma \sim m_h^3$

$\Gamma \sim m_h m_f^2$

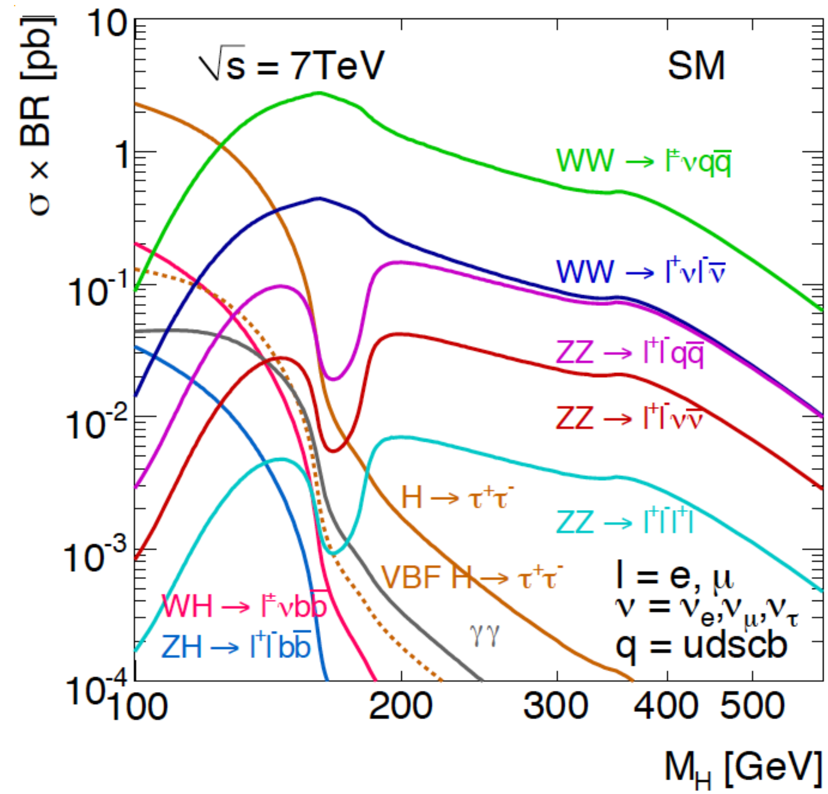


Br = $2*10^{-3}$ small but clean

bb, ττ, γγ mh < 135 GeV

WW , ZZ mh > 125 GeV

σ ∗ Br for analysis channel



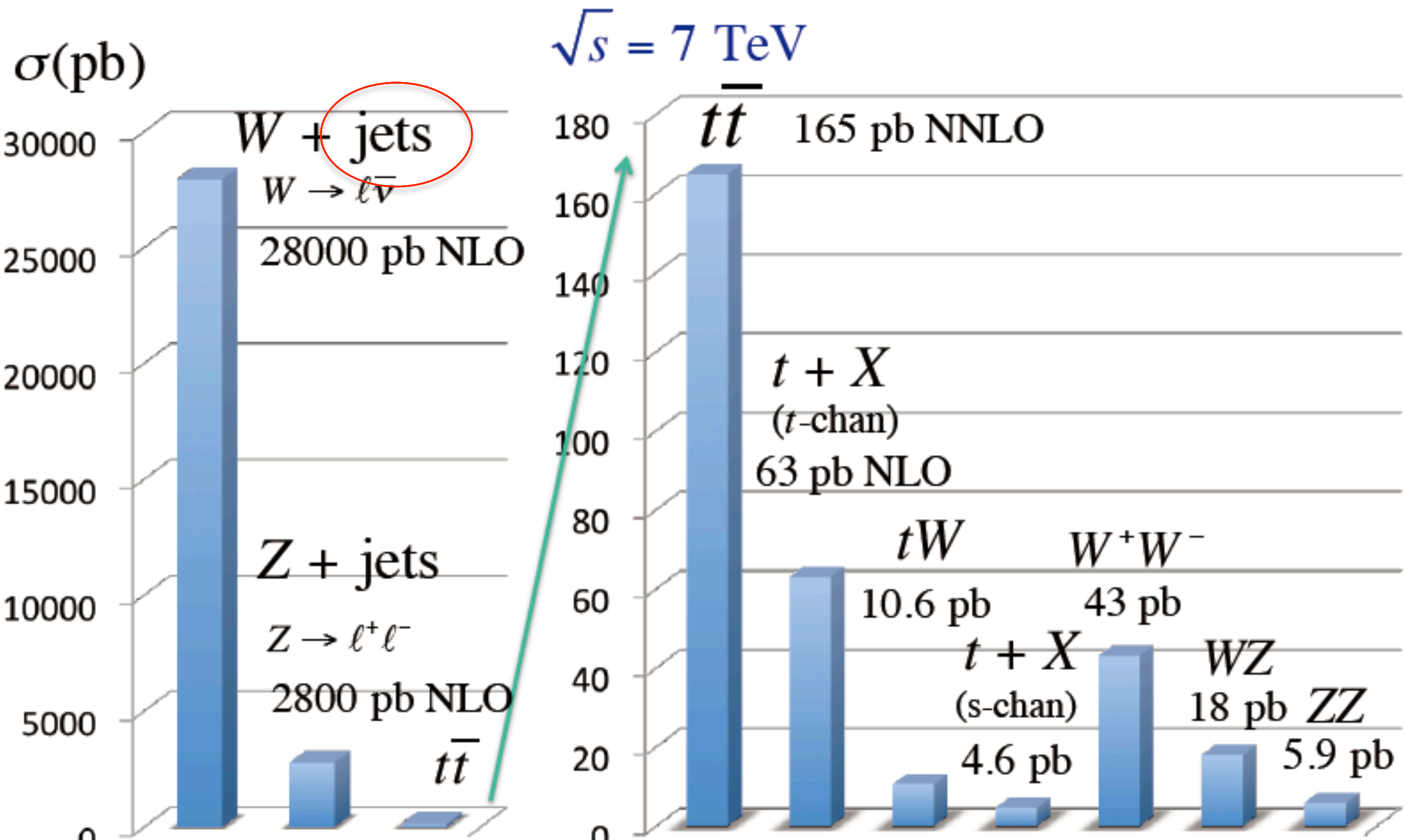
key channels are

GF(H-> γγ, WW(lvlv), VBF(tautau), WH(bb)
(M(H)∼120 GeV)

GF (H→ WW(lvlv), WW(lvqq),ZZ(4l), ZZ(llqq))
(M(H)>130GeV)

σ ∗ Br ~ 0.01-1 pb

Production σ of the SM background processes



Gauge boson (Fake lepton)
factor ~ 10^4

top
factor ~ 100

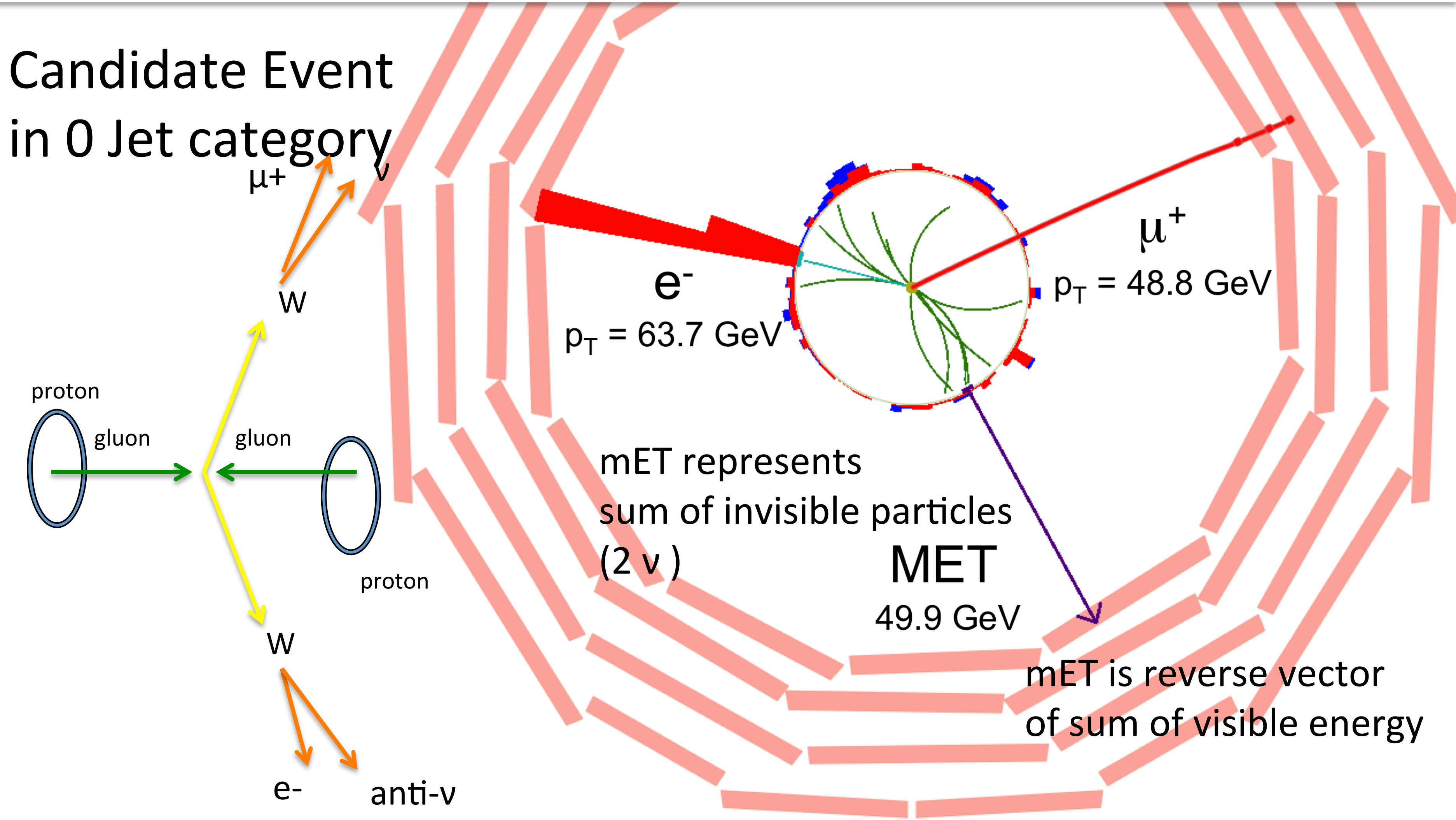
Di-boson irreducible
factor ~ 10

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

Not Easy work & Study BG

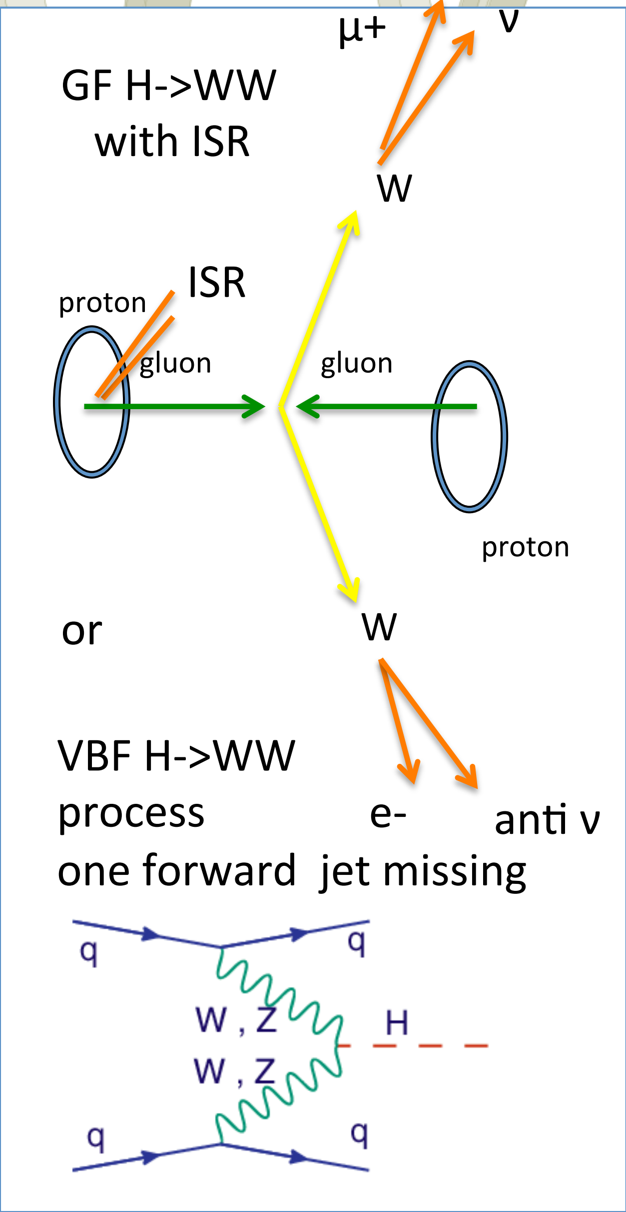
[1] H→WW→lνlν

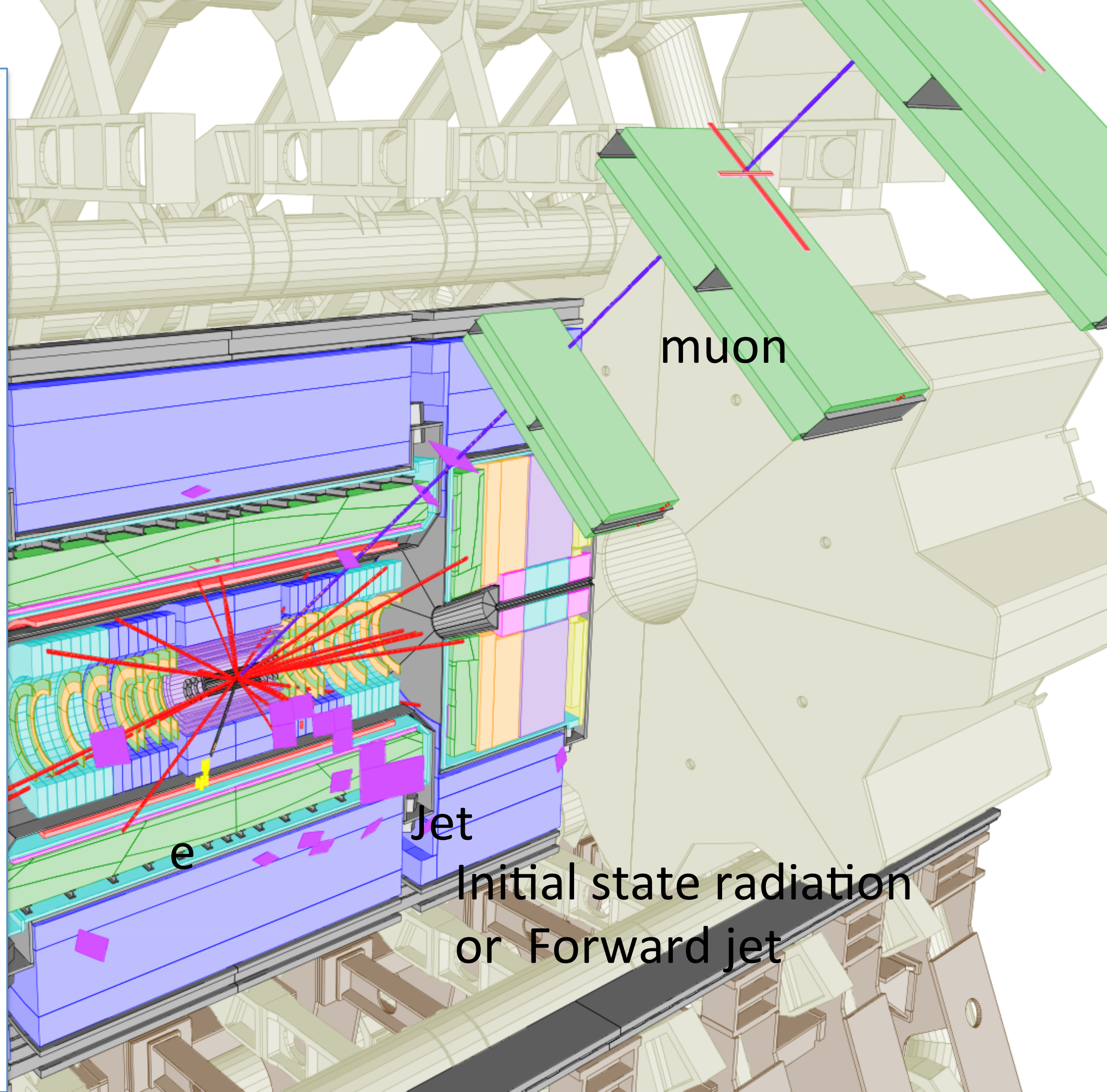
Opposite charge 2 leptons (ee,μμ or eμ) and mE_T(missing E_T) are required:
Then the events are categorized into with 0 jet, 1 jet and 2 jets:



ATLAS EXPERIMENT

Candidate event in 1 jet category

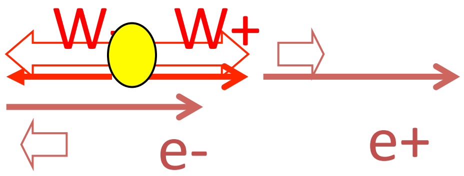




After these selections and categorization; check 2 crucial variables

ΔΦ(ll) Azimuthal angle of dilepton

Higgs Spin0



Higgs is scalar, so
spin combination of W pair
is always opposite.
Because of 100% parity violation
in the weak decay,
the lepton emits into
the similar direction.
so ΔΦ is expected smaller for Higgs signal.

M_T(Transverse mass)

two ν's emit in Higgs signal:
we can not reconstruct H mass.

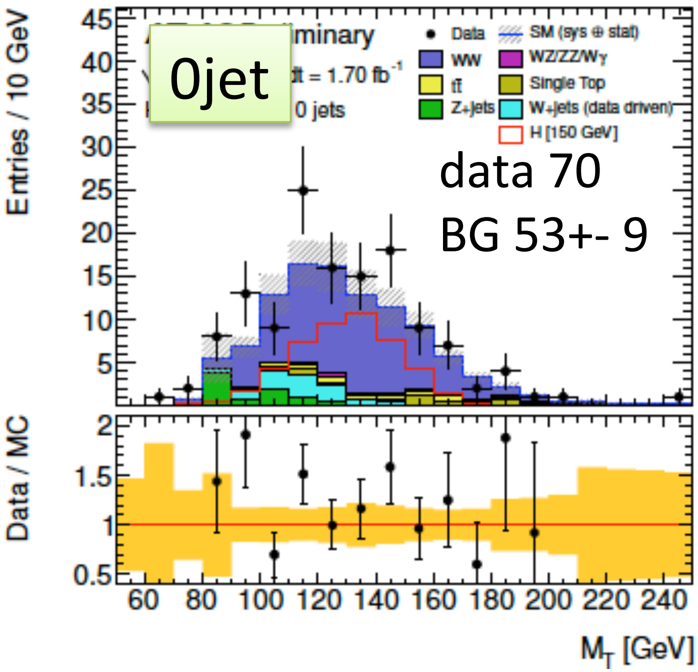
$$M_T^2 = (E_T^{ll} + E_T^{missing})^2 - (P_T^{ll} + P_T^{missing})^2$$

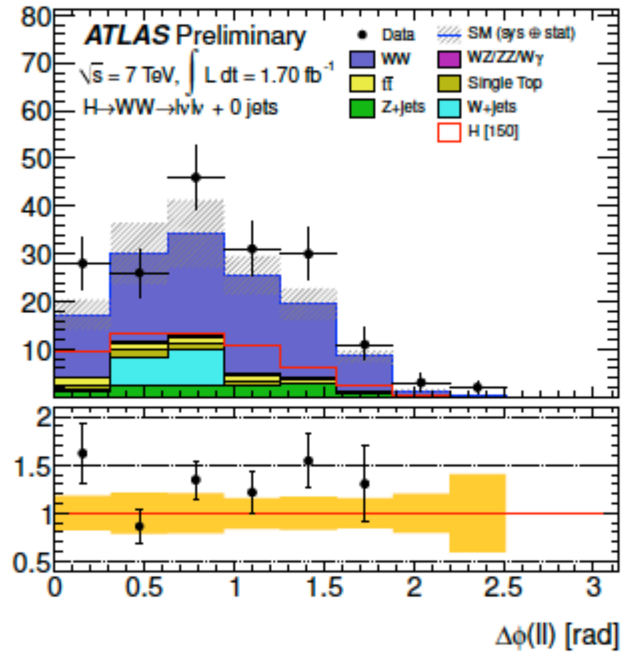
Signal $M_T < M_h$

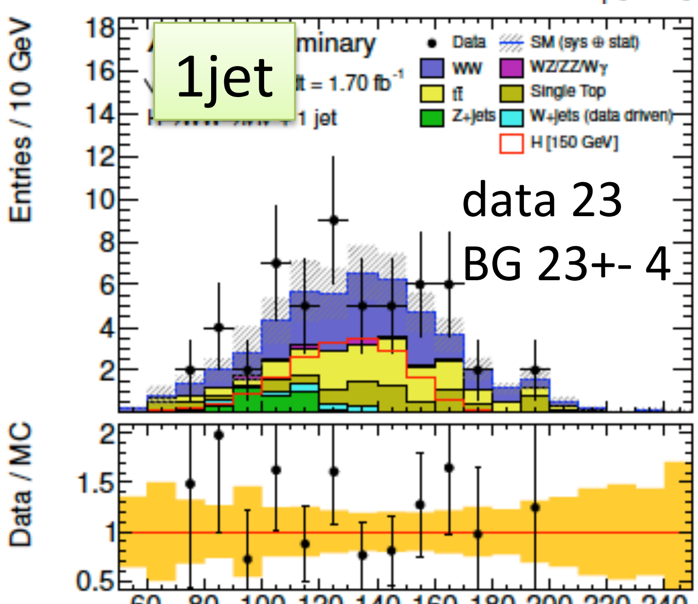
($M_T = M_h$ if P_z(Higgs)=0)

On the other hand
SM WW process have wide flat distribution
in the MT .

H→WW→lνlν @ ATLAS (L=1.7fb^{-1})







1. Small excess (2σ) is observed in 0 jet.
   Excess in M_T < 150GeV
   SM WW is main BG.
   Δϕ distribution looks reasonable as signal.

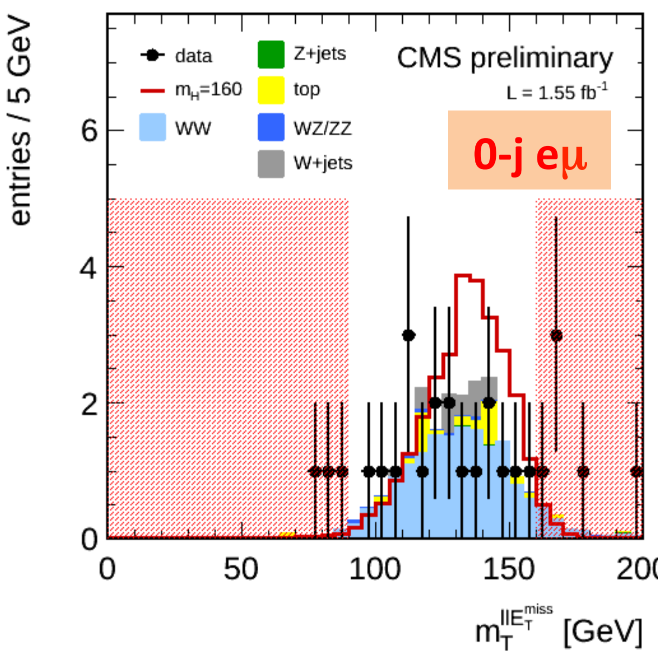
2. No excess was found in 1 jet category.

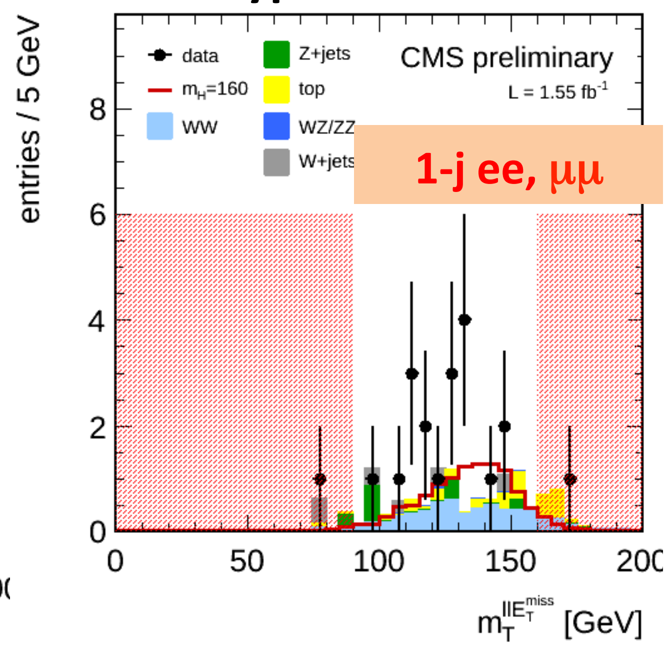
   SM WW and top pair production are main background processes

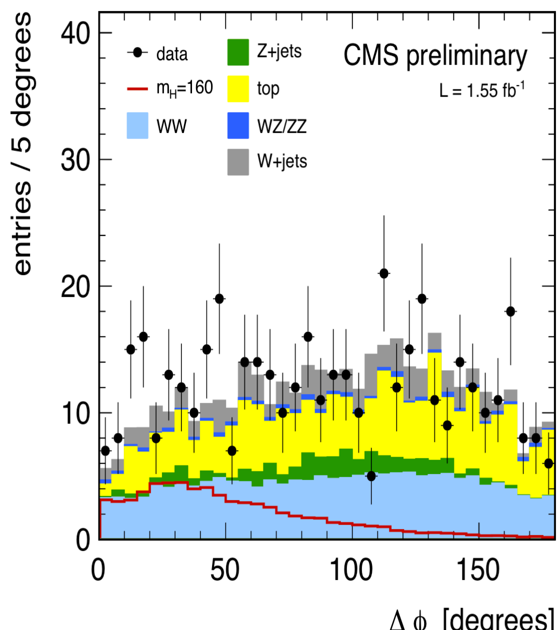
H→WW→lνlν @ CMS L=1.55fb^{-1}

	0-j ee, μμ	0-j eμ	1-j ee, μμ	1-j eμ	2-j
Background	44.0±6.2	40.6±7.0	12.6±3.7	17.8±3.5	5.3±1.7
Signal (m_h=140)	19.1±4.3	16.1±3.6	5.3±1.8	7.7±2.6	2.5±0.3
Data	46	41	23	23	7

Final M_T plots for M_H=160 GeV hypothesis



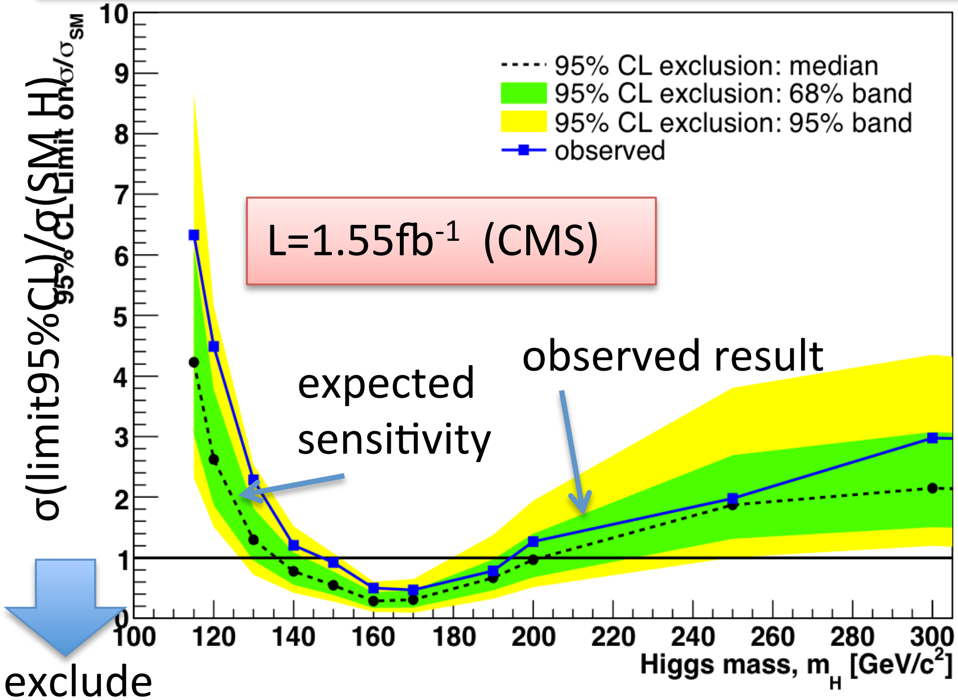


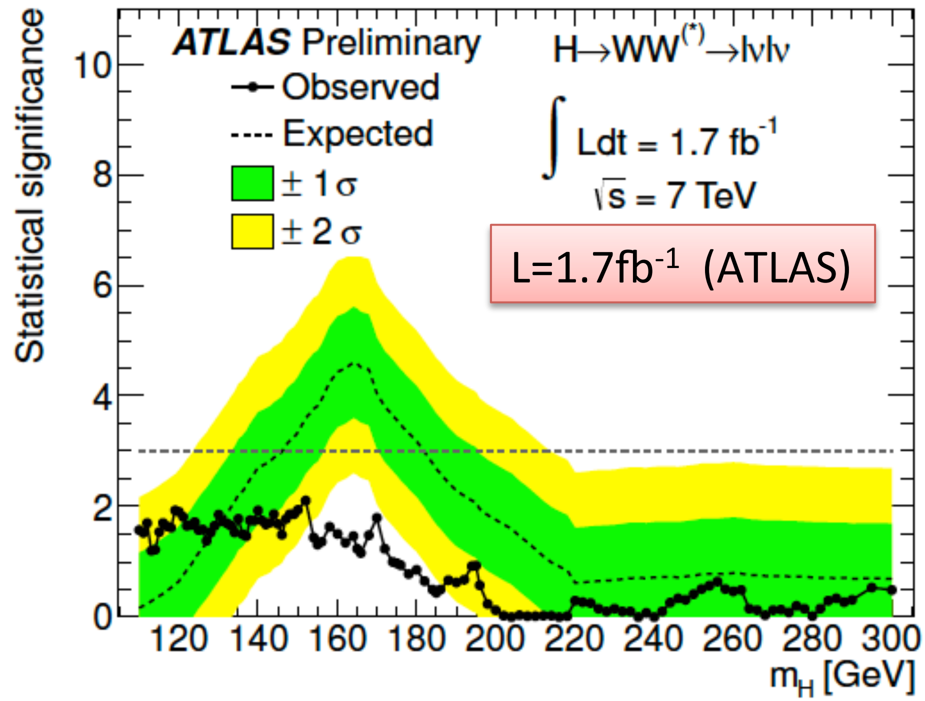


(not yet MT applied)

Excess is observed in 1 jet category $M_T < 140$GeV.
But No excess in 0 jet category.

Calculate 95% CL Limit on SM Higgs using WW channel





Higgs is excluded whose mass = 145-200 GeV

Signal significance considered as Higgs

(1) Observed results are worse than the expected sensitivity about 2σ.

(2) Both ATLAS and CMS have a small excess (about 2 σ) Mh < 150GeV

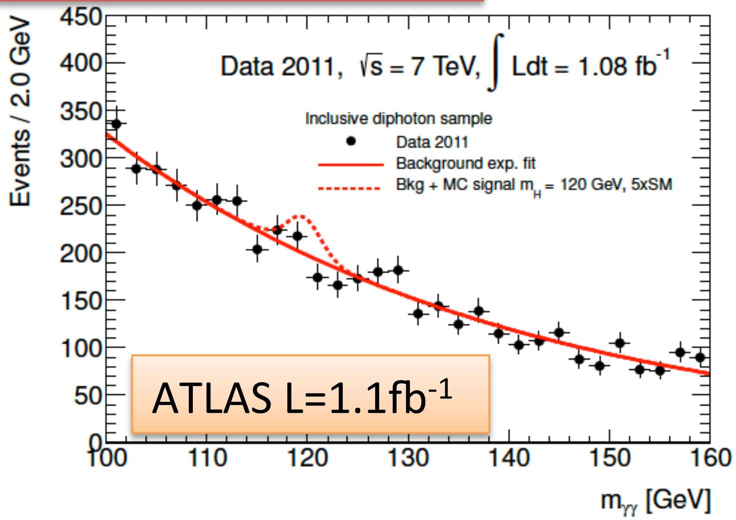
(3) Not independent for various mass points, they have correlation.

(4) Number of the observed excess is consistent with signal Mh=130GeV
But Not clear since wide distribution of M_T, ATLAS(0jet) CMS(1jet)

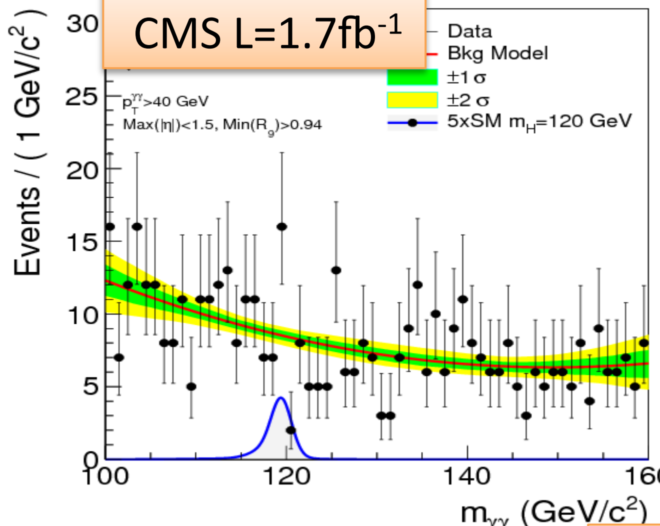
(5) Higgs > 135 GeV is disfavored, since more Higgs signal should be observed.

[2] H→ γγ

Branching fraction is small ($2*10^{-3}$), but good mass resolution and sharp peak is expected in γγ invariant mass distributions

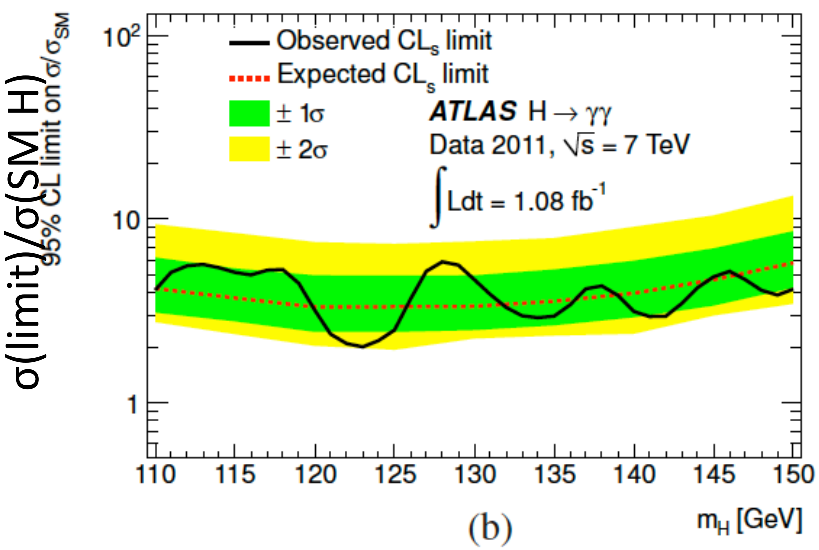


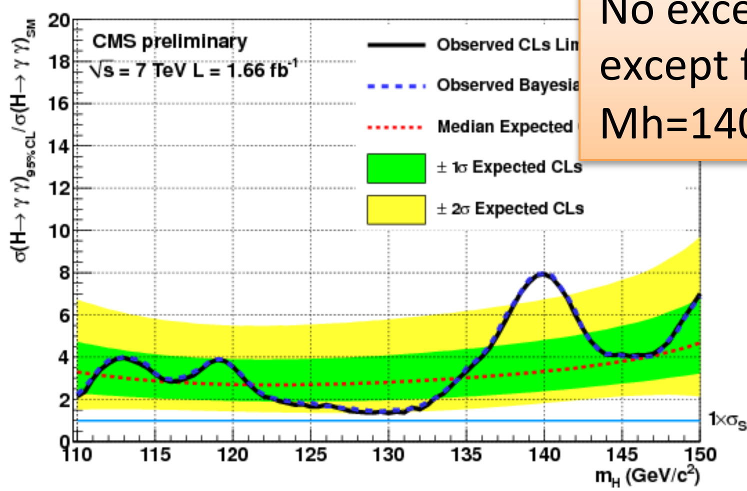
ATLAS L=1.1fb^{-1}



CMS L=1.7fb^{-1}

lines show fitted BG
Signal (120GeV) is also superimposed
(σ is enlarged by factor 5)



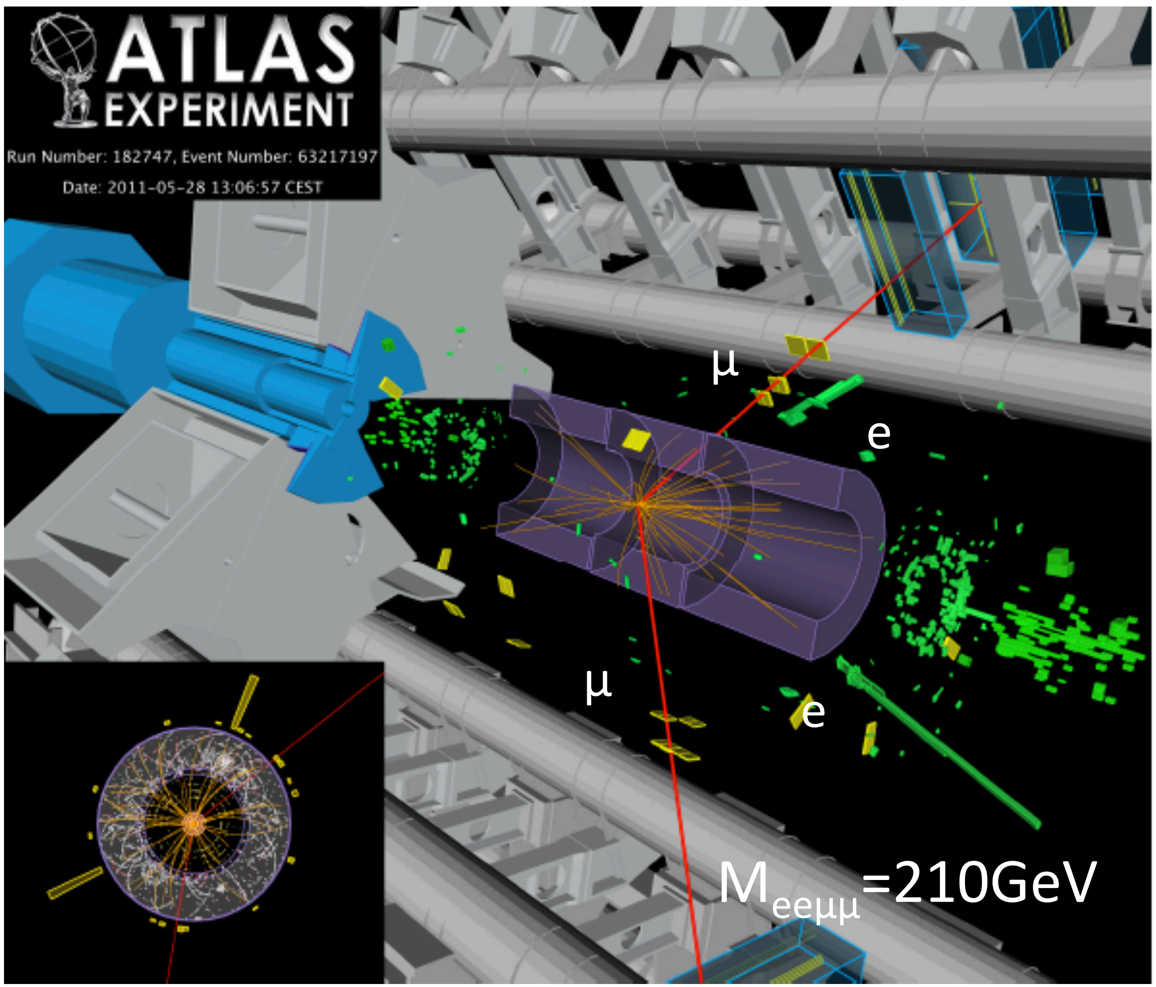


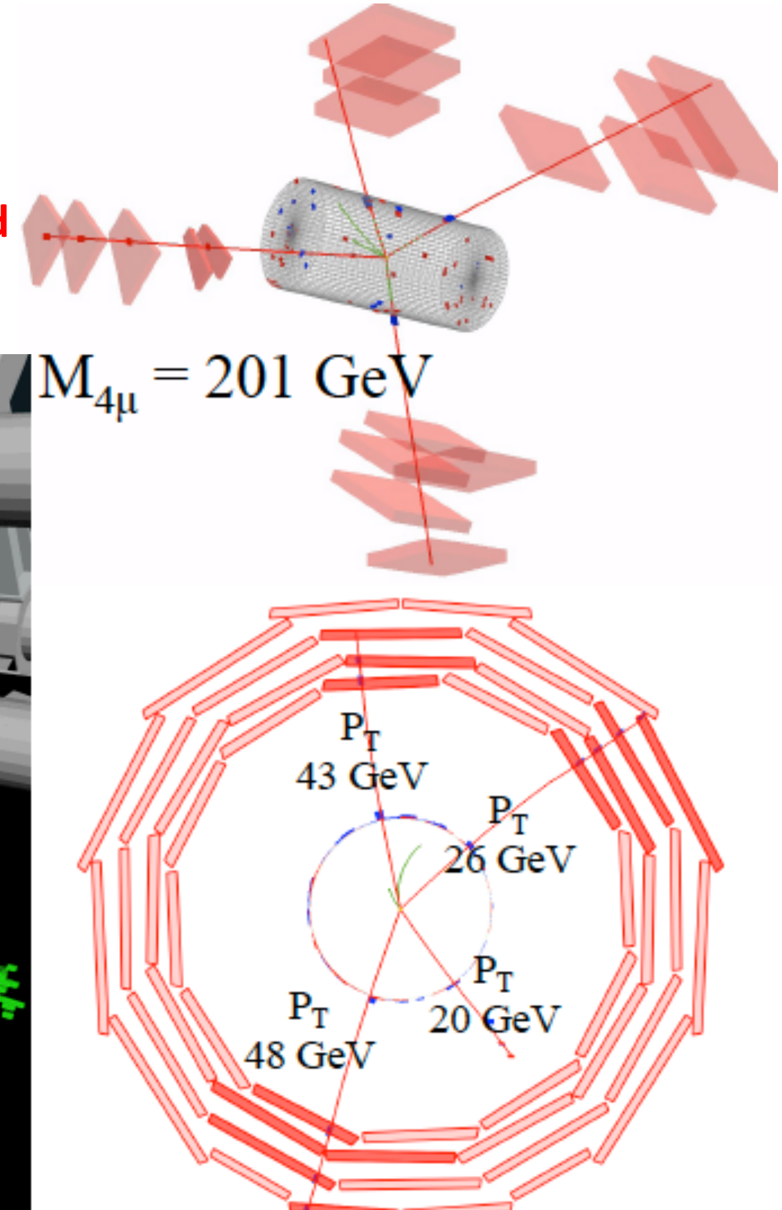
No excess is found except for Mh=140GeV @ CMS

σ(limit) ~ 3 × σ(SM) -> need more data by factor 10 (sensitivity ∼ √L , BG dominant)
Excess at 140GeV is 2.5σ level, But No excess in ATLAS(negative) , Signal yield = 5 * SM

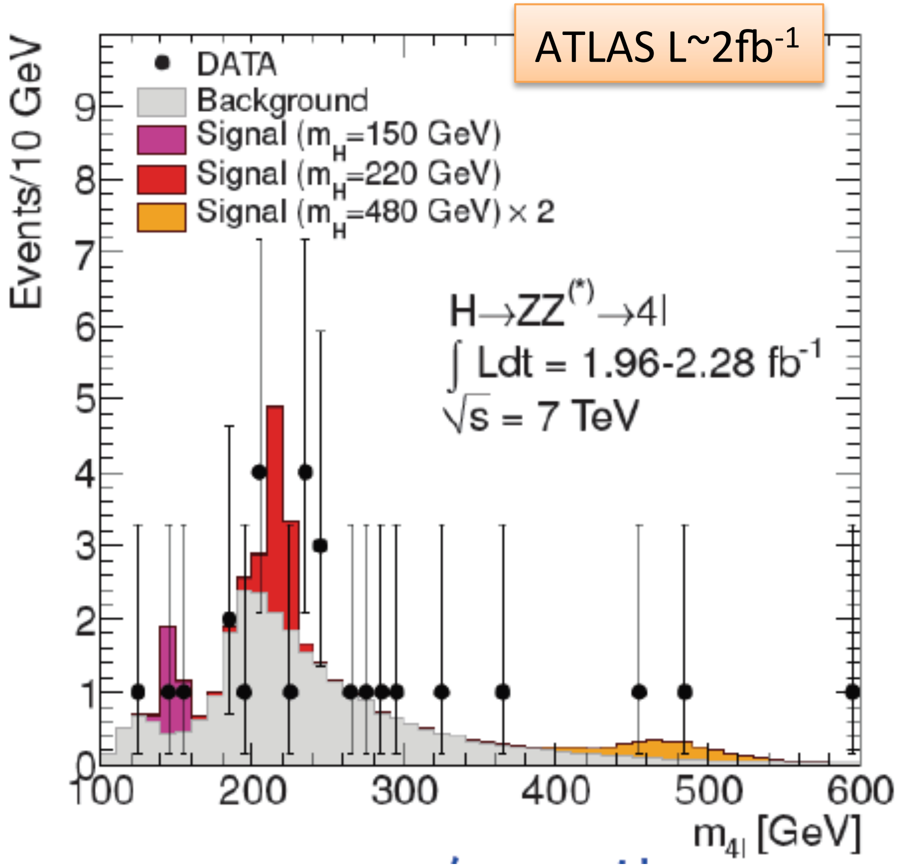
[3] ZZ→4lepton

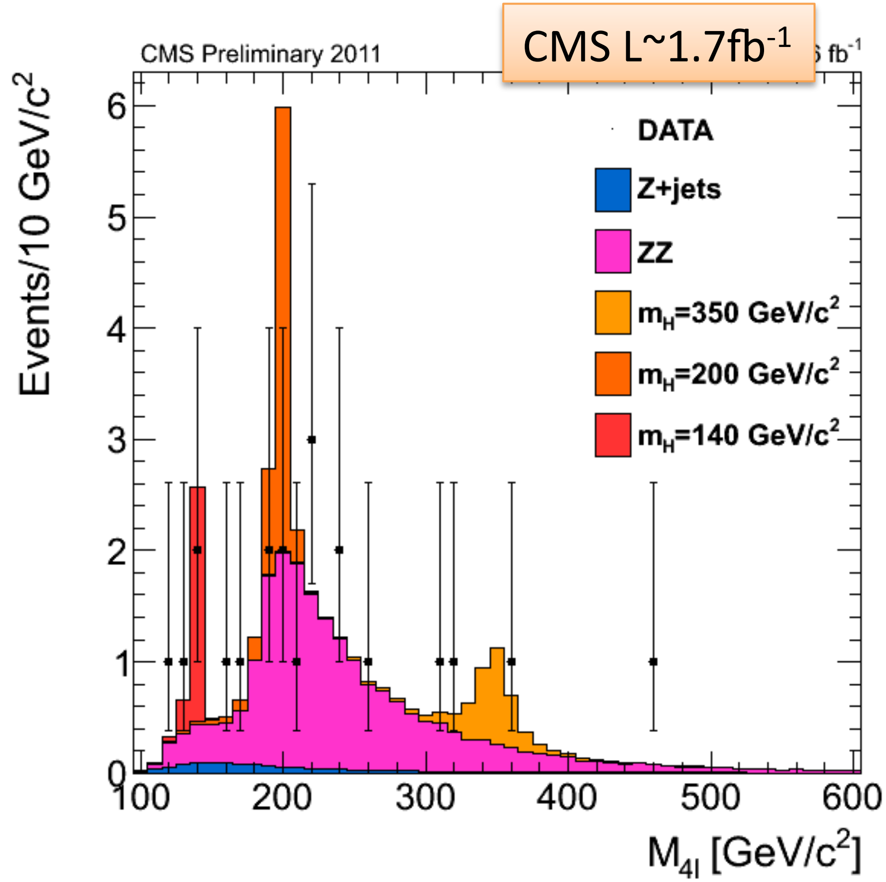
Good resolution of Lepton(e.mu) (ΔM_{4l}~ 2GeV)
Small BG (Almost BG free Mh<180GeV) **-> Gold-plated**
But Statistic is limited, since Br(Z->ee,mumu) is small





M_{4l} distributions





qq_bar->ZZ production is a dominant BG, threshold is 190GeV

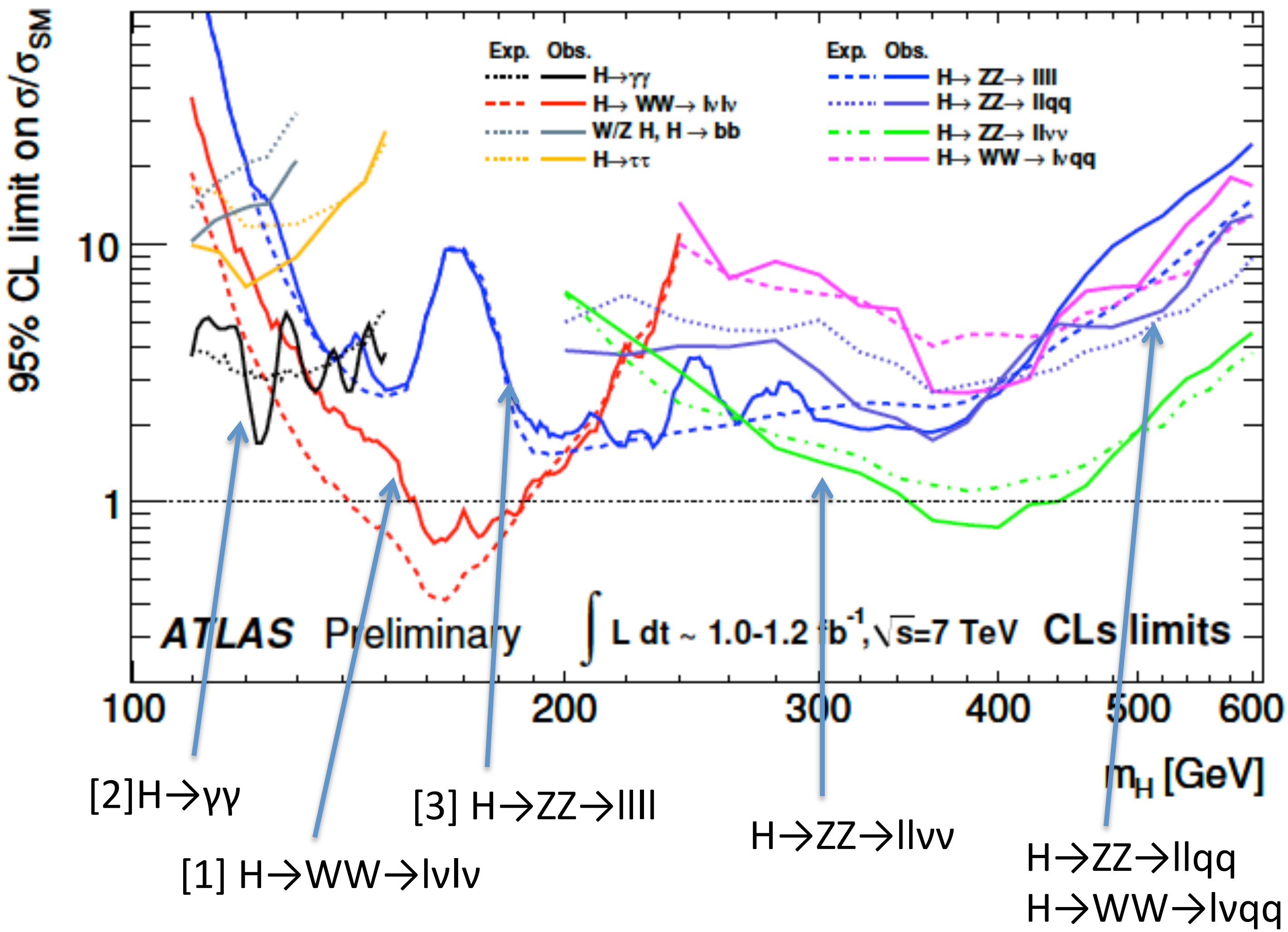
If Higgs > 200GeV, natural width ($\Gamma = M_h^3$) is larger than the detector resolution

No significant excess was found, (~2GeV)

But Mh<150GeV small excess 2σ level

[4] Combined Results

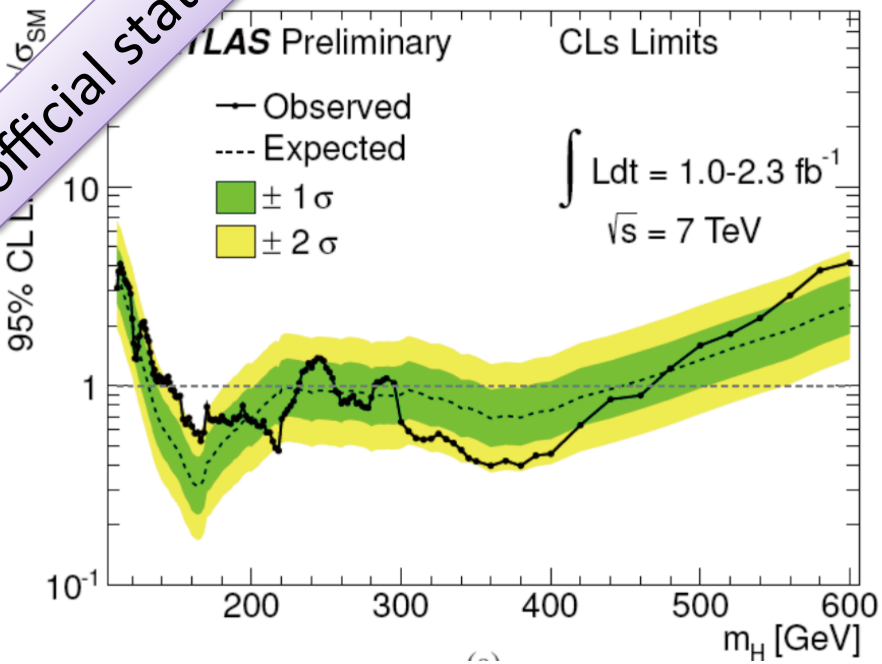
5 modes cover
the wide mass range

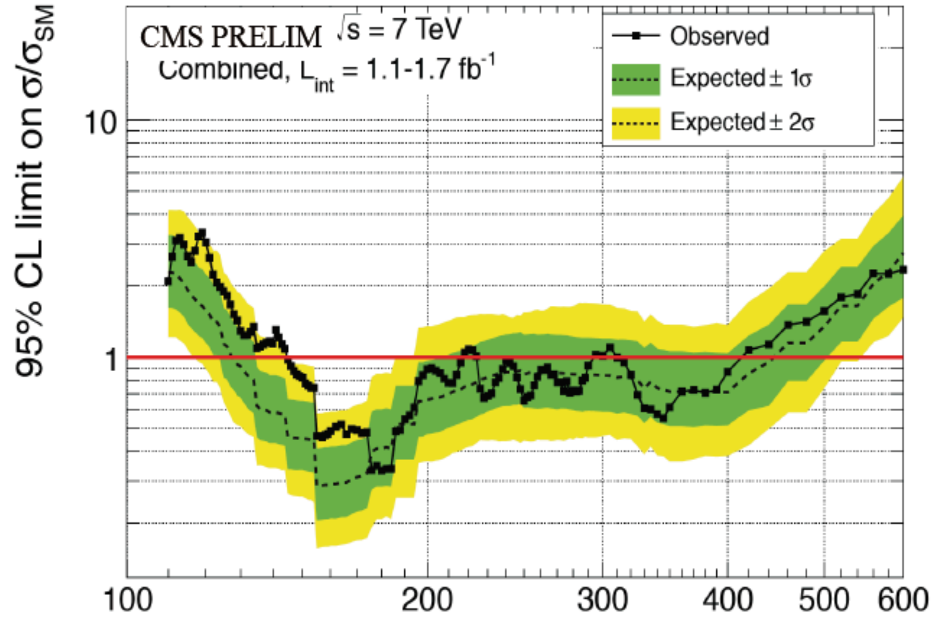


llll will gain approximately proportional to Luminosity for low mass region:
The other channels are proportional to √L, since already BG dominate.

95% CL Excluded mass region

official statement



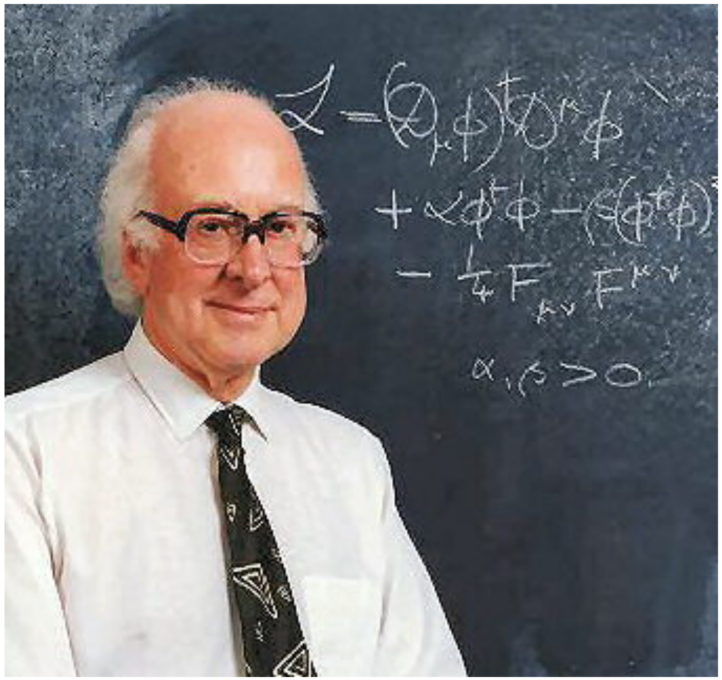


SM Higgs whose mass is 145-466 GeV excluded (95%CL)

Range of Higgs Boson mass is limited between 115 and 145GeV

Geneva, 22 August 2011. Results from the ATLAS and CMS collaborations, presented at the biannual Lepton-Photon conference in Mumbai, India today, show that the elusive Higgs particle, if it exists, is running out of places to hide. Proving or disproving the existence the Higgs boson, which was postulated in the 1960s as part of a mechanism that would confer mass on fundamental particles, is among the main goals of the LHC scientific programme. ATLAS and CMS have excluded the existence of a Higgs over most of the mass region 145 to 466 GeV with 95 percent certainty.

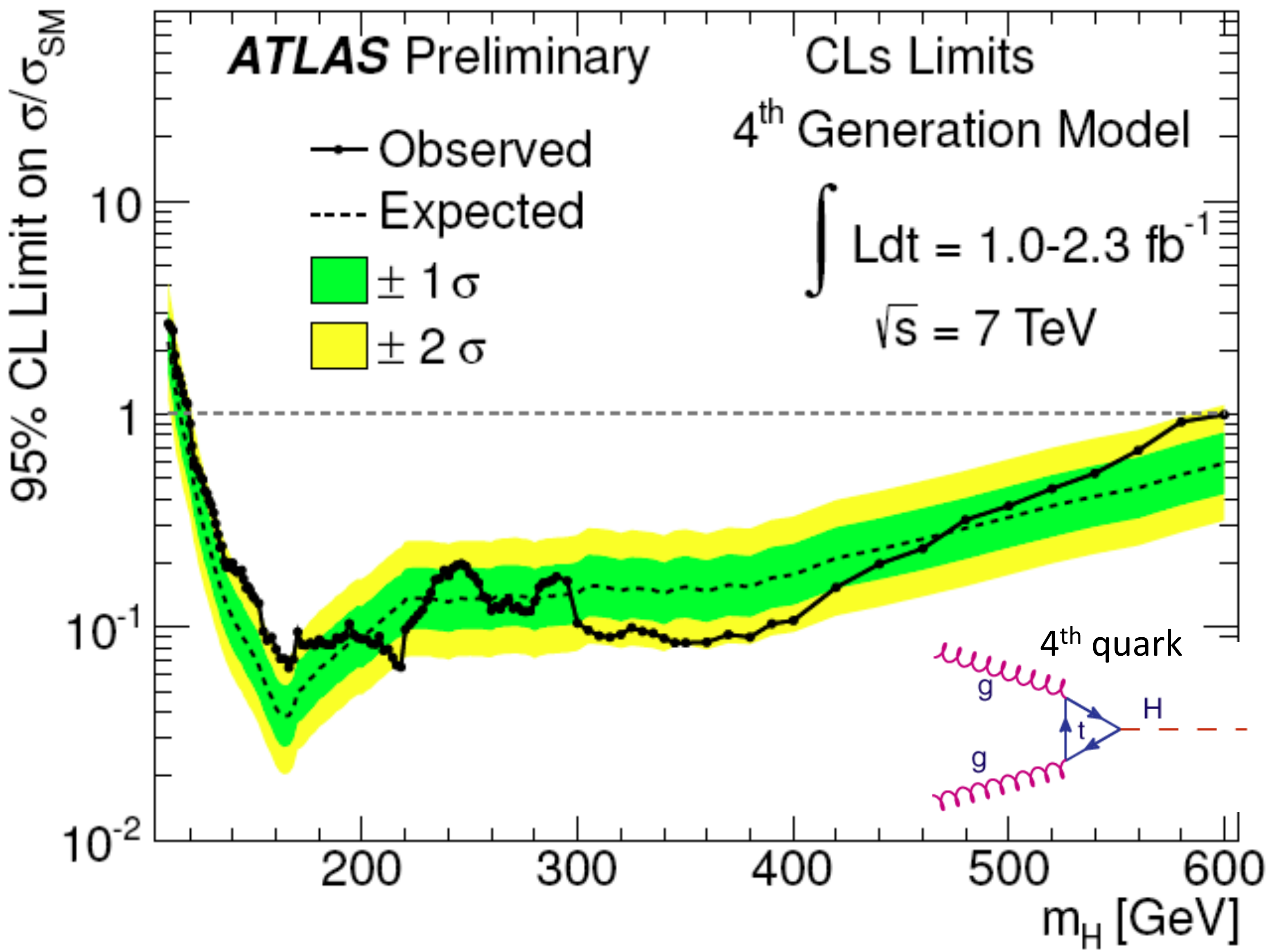
“These are exciting times for particle physics,” said CERN’s research director, Sergio Bertolucci. *“Discoveries are almost assured within the next twelve months. If the Higgs exists, the LHC experiments will soon find it. If it does not, its absence will point the way to new physics.”*



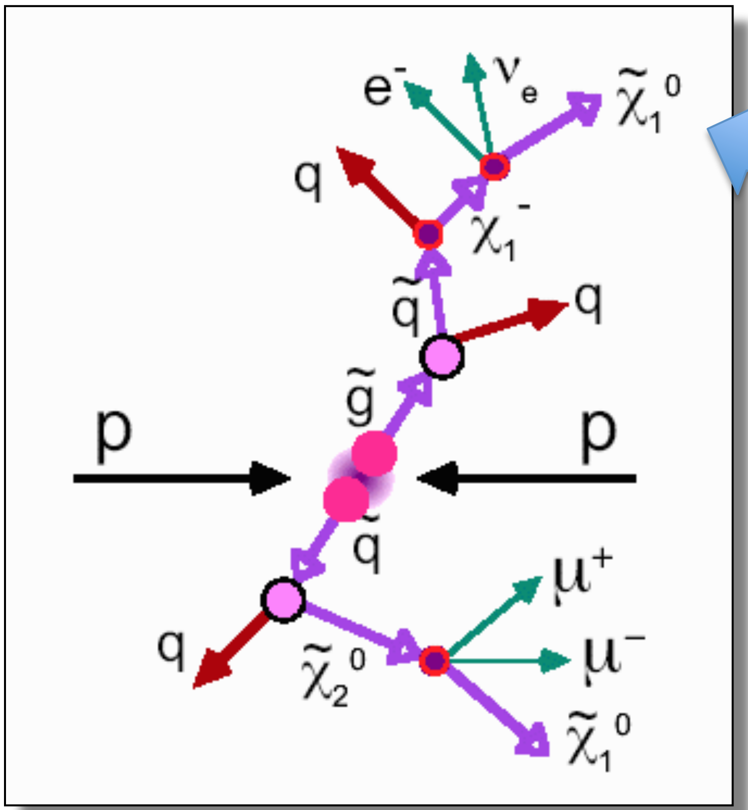
He looks shy.

Additional Result

4th Generation is disfavored



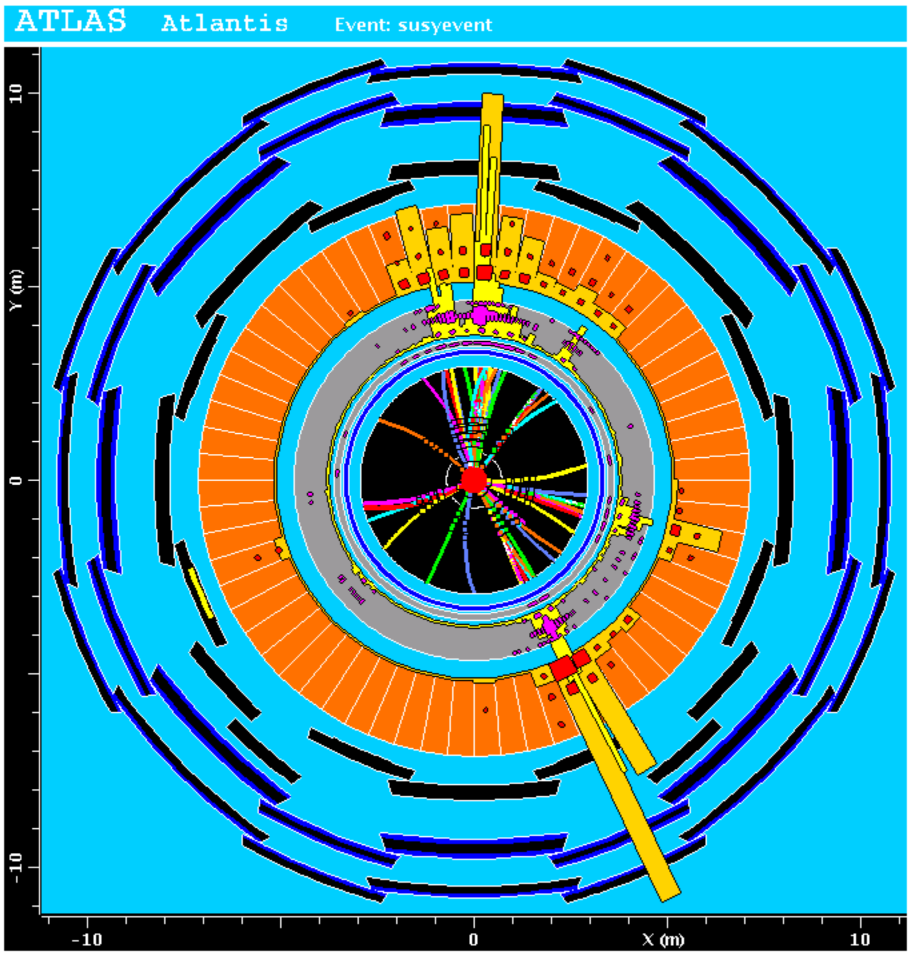
3. SUSY hunting and Dark matter



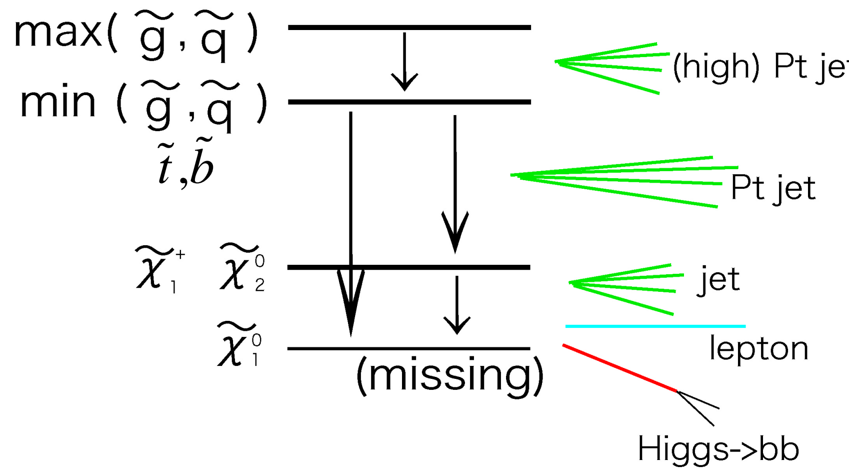
Event Topologies of SUSY Signal @ LHC

SUSY provides various interesting event topologies !!

"Typical" Events topology of SUSY signal is like this



Gluino/squark are produced first, then cascade decay is followed.



LHC is DM-factory

Event topologies of SUSY

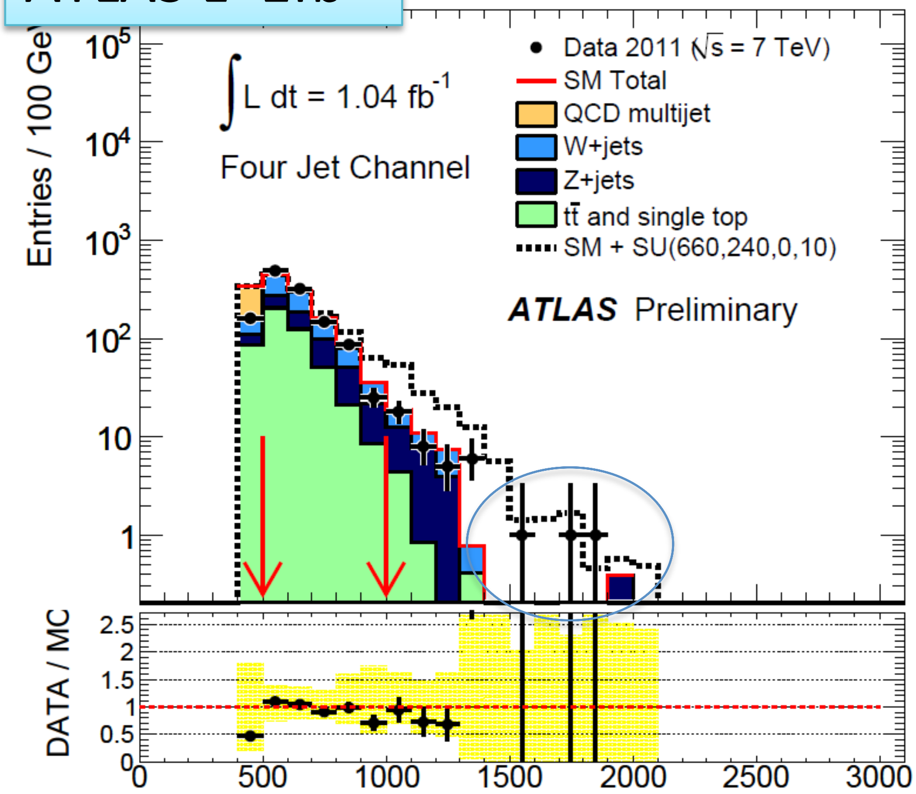
$$\not{E}_T + \text{High } P_T \text{ jets} + \begin{matrix}\text{multi leptons} \\ \text{b-jets} \\ \tau\text{-jets}\end{matrix}$$

No Lepton mode

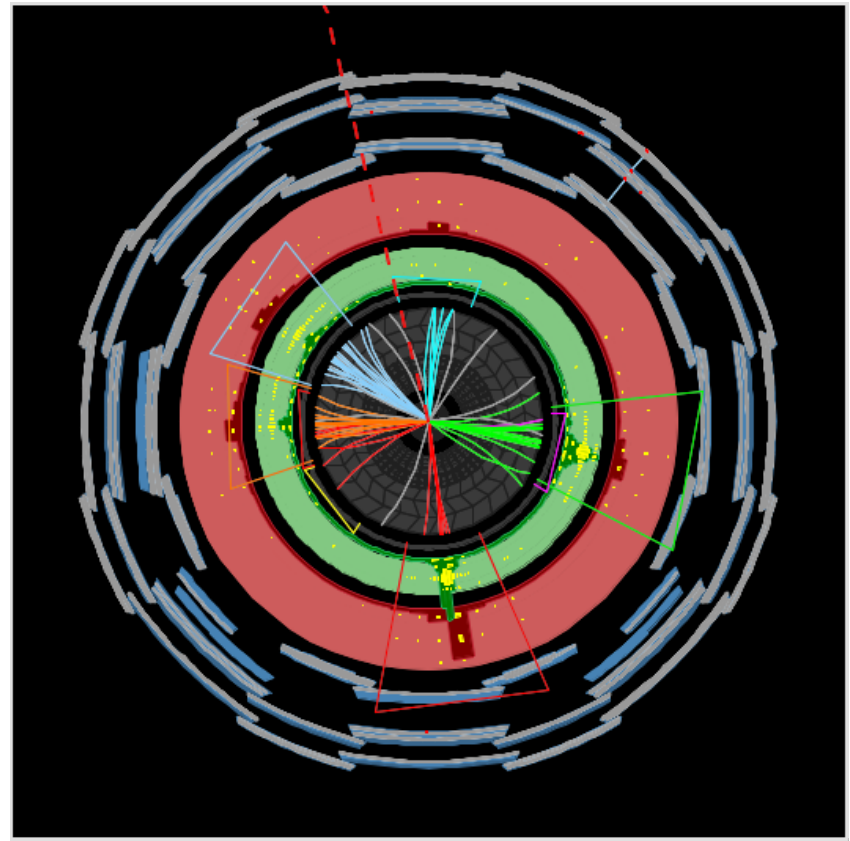
ATLAS L=1fb^{-1}

at least 4 (high PT) Jets & Large mET

This is candidate event(Highest)



Meff=mET+ΣPT (jet)



Meff >1000GeV (mET/Meff>0.25 mET>250GeV)

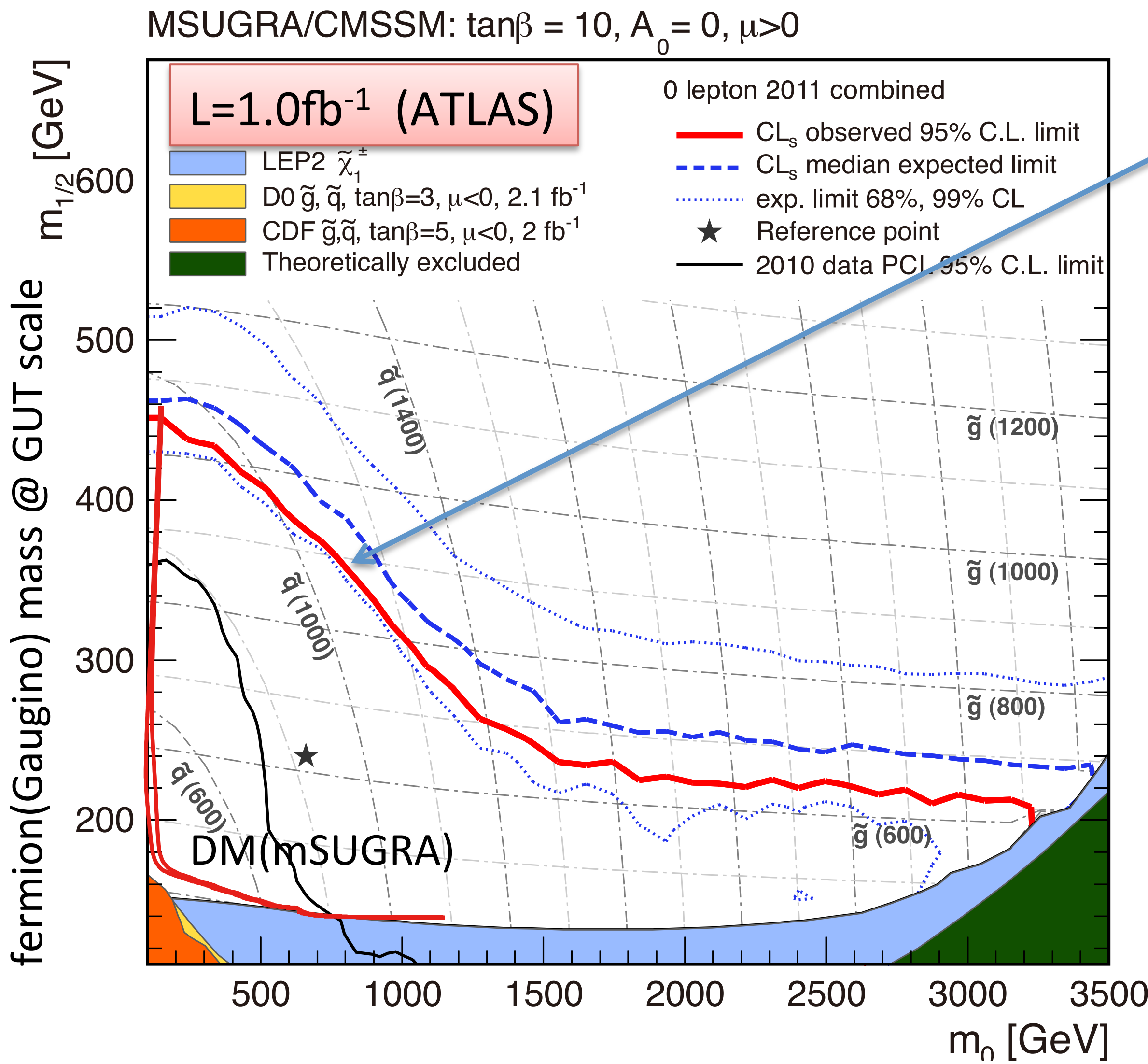
Data 40 events
BG 33.9+-2.9+-6.2 (Z 16 W 13 t 4)

3 candidates in high region

Meff = 1810 GeV
MET = 460GeV

If it is Sugra-like candidate
gluino,squark ~ 1.3-1.5TeV

Limit on CMSSM



scalar mass @ GUT scale

Exclude upto squark/gluino
1.1TeV for small m0
750GeV for heavy suark

Dark matter expected region

(1) Bulk region
(2) Focus Point (Large m0)
(3) small m0 coannihilation

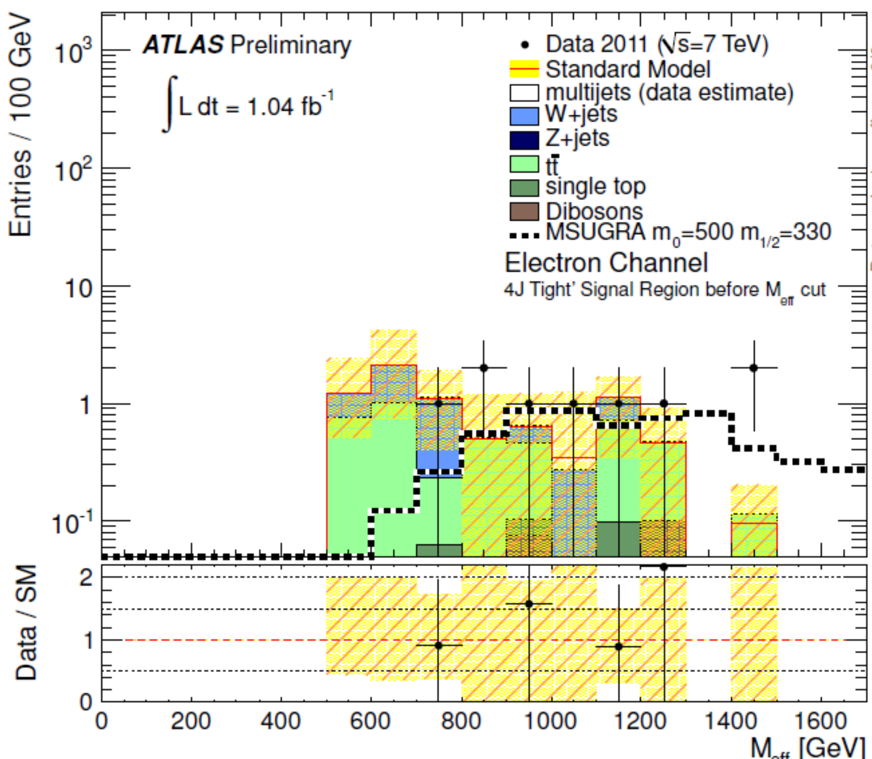
These are rejected.

gluino ~ 1.3-1.5TeV
where muon g-2 is predicted
are in reach now.

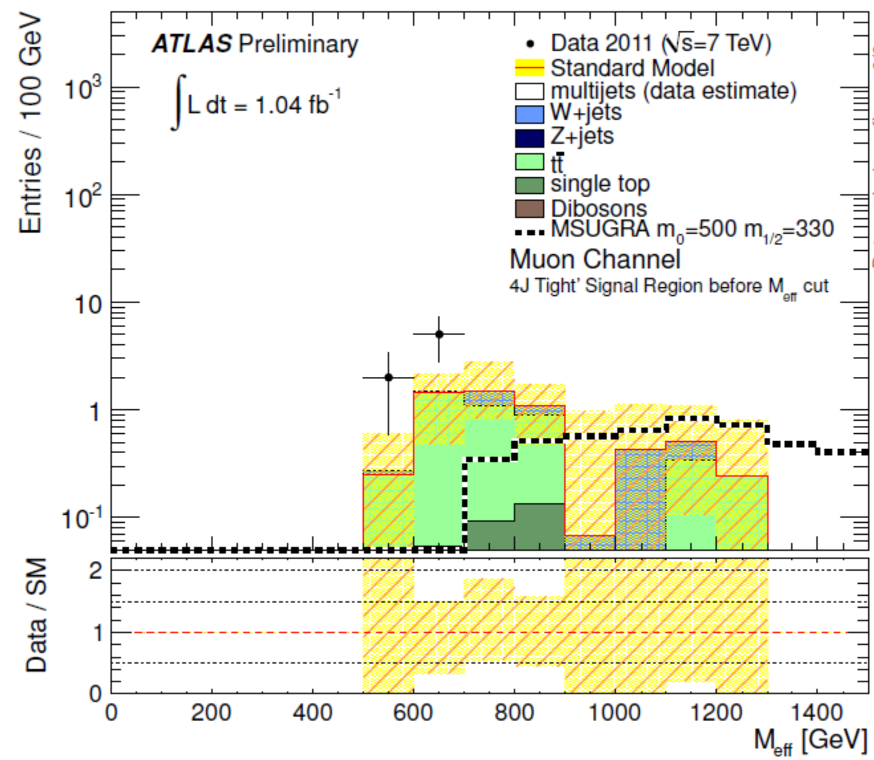
One lepton Mode

Electron (PT>25GeV) or muon (PT>20GeV) is required for trigger/ BG suppression
At least 4jets(PT>60,40,40,40 GeV) MET>200GeV MT>100GeV Meff>500GeV

electron



muon



Meff=mET+PT(lepton)+ΣPT (jet)

Data 9 events
BG 8 +-3.7 (W/Z 4 t 4)

Data 7 events
BG 6 +-3 (W/Z 2 t 5)

Consistent with BG
2 candidates are observed in electron channel Meff > 1400GeV

About Dark Matter

If naïve GUT relation is assumed, M1(Bino) : M2(Wino) : M3(Gluino) are predictable.
Limit on Bino mass is about 180GeV:
Universe is over-close such a heavy Bino-like DM

(1) Higgsino Dark matter case: In mSugra Higgsino mass (μ) is calculated &
$|\mu| \sim$ m1/2 except for Focus point. (it is over-constrained)
μ is smaller than 0.4*m1/2 -> Higgsino like LSP dark matter

LHC phenomenology (A) jets + mET + bjets (Higgsino coupling)
(B) Long cascade high jet multiplicity & less mET

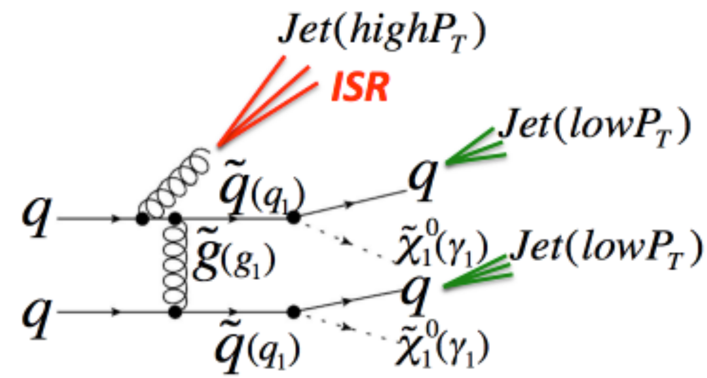
(2) Heavy Colored particle. @ GUT M3(gluino) > M2(Wino)=M1(Bino)
Colored particles are too heavy to be produced @ LHC , but Bino is about 100GeV

LHC phenomenology EW gaugino direct production

About Dark Matter II

(3) If all SUSY particles are degenerate as the same as UED:
jets emitted from the cascade becomes soft.

LHC phenomenology: ISR jet + soft object



(4) Non MSSM particle is DM (Gravitino / Axino/Axion)

LHC phenomenology:
GM SUSY: Gravitino GMSB
Gravitino is not so light (eV) if the DM is not hot.
NLSP is Long lived : Long-lived stau,
mET+jets (when NLSP is neutralino)
non pointing photon, kink in ID (when lifetime is middle)
tau+jets+mET or photon+jets+mET
on going No excess was found.

4. Extra-dimension searches based on Event-Topology

There are various models and predictions in ExtraDimension
We categorize the following event topologies.

(1) High mass lepton pair (ll) KK-graviton resonance (KK Graviton)

(2) Large mET +single jet (Monojet) Graviton emission (ADD Graviton)

(3) High Pt jet, High mass jets (KK Graviton, contact interaction)
-> both resonance or non-resonance

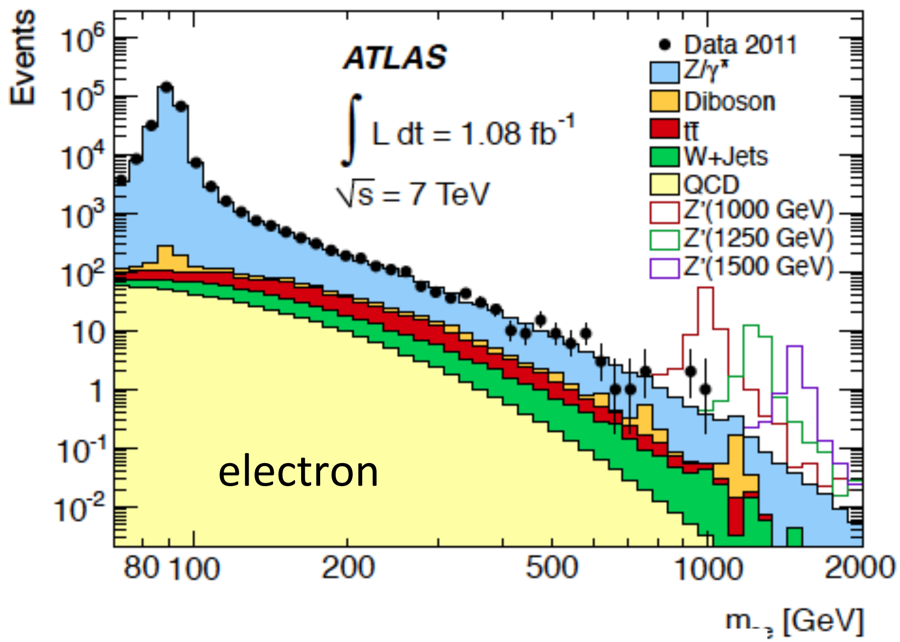
(4) small mET +jets (SUSY-like signal but small mET) (UED)

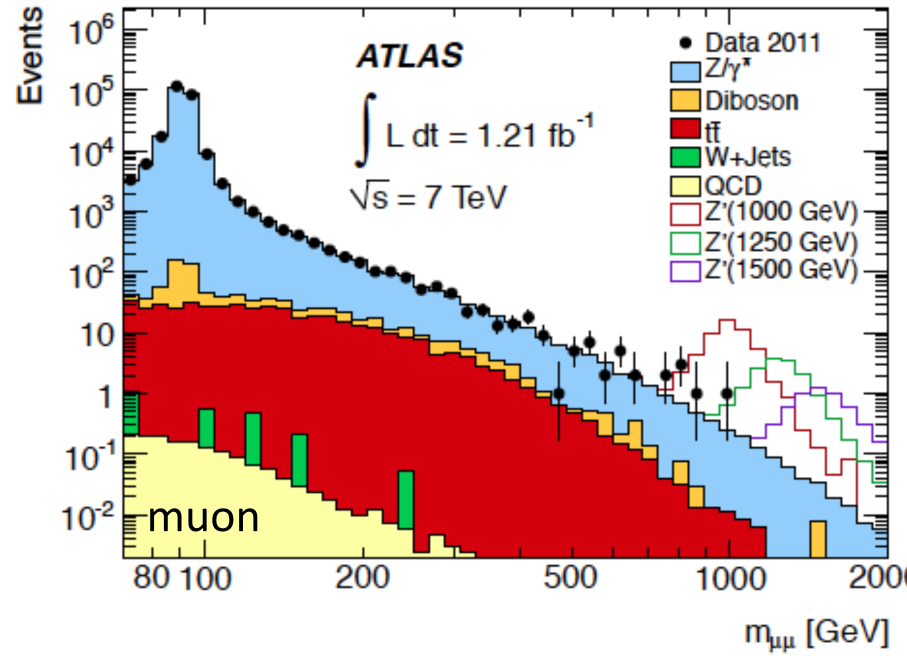
(5) High Pt, High mass diboson / high mass top pair
(KK Graviton and KK gluon)

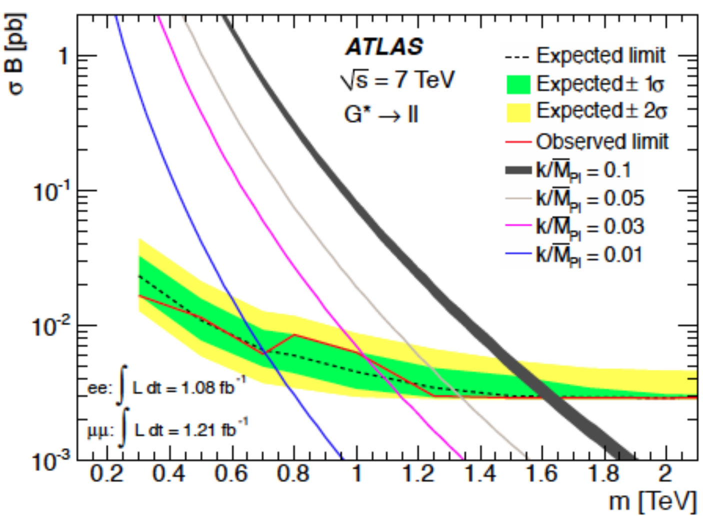
(6) High mass & High PT multi-object (mini-blackhole, String ball)

more complicated

DY Z(→l l) distributions and limits on RSKK Graviton







resolution is better for electron, number, Fake prob is better for muon

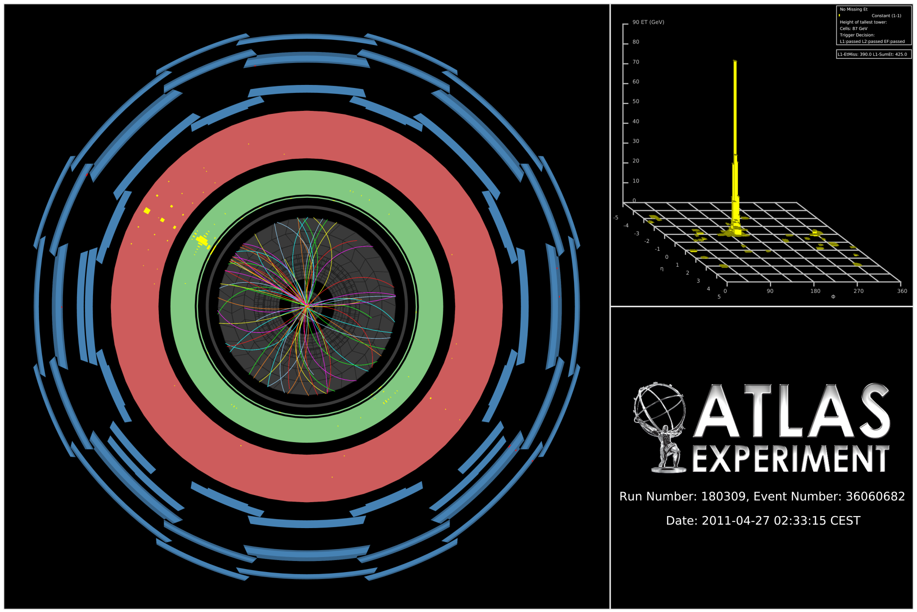
RS KK Graviton -> ll pair

mass(G)>**1.3-1.6 TeV**

k/Mpl =0.1-0.05

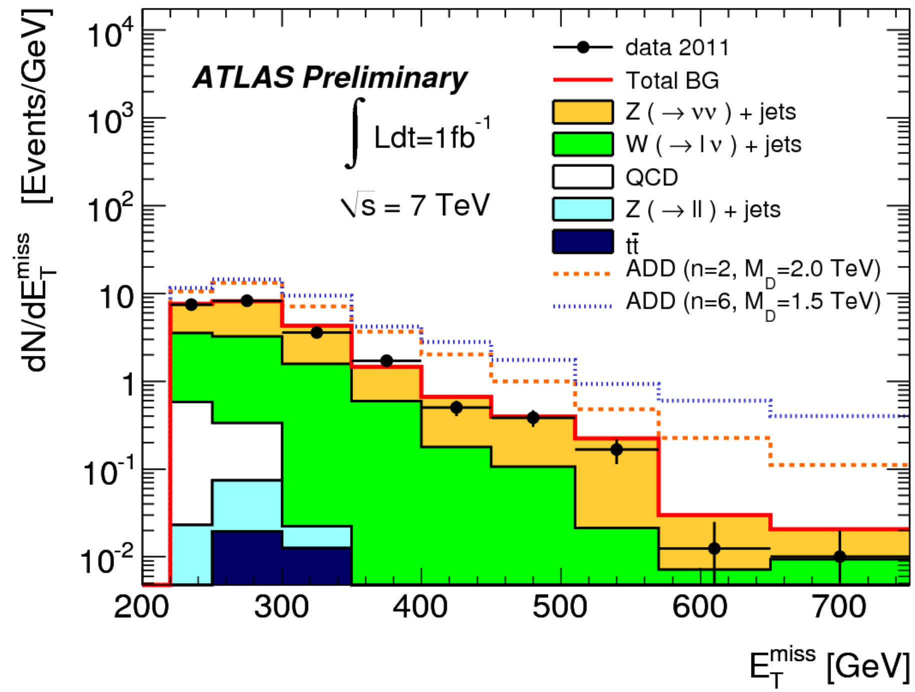
SM like Z' **1.8 TeV**

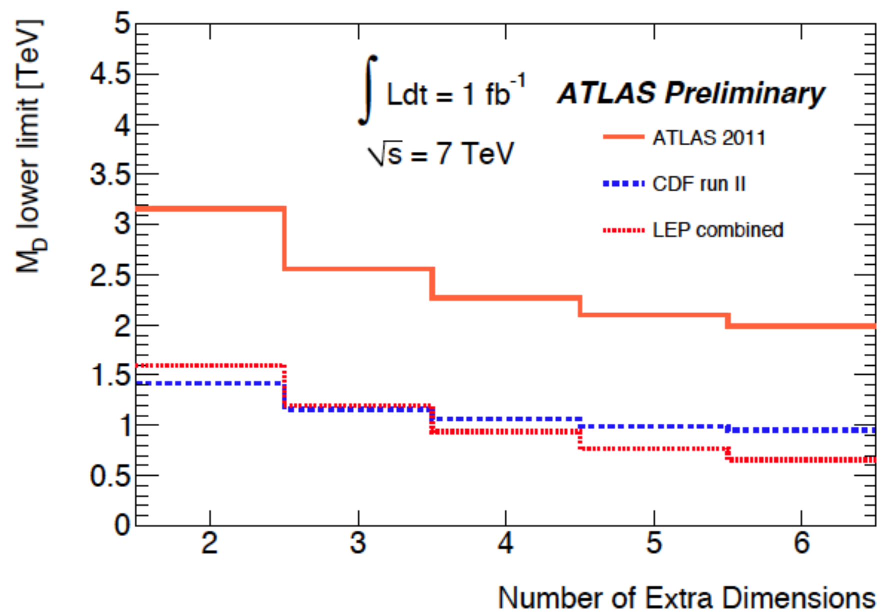
monojet



observed candidate event
PT=602GeV mET=523GeV

M_D(ADD) > 2-3 TeV (n=6-2)



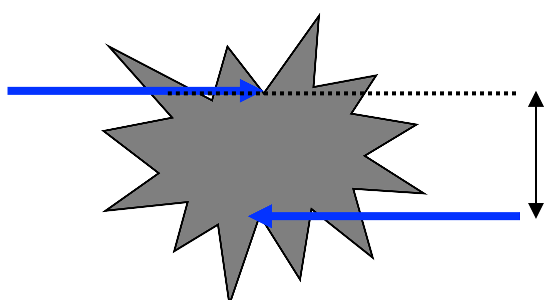


(1)生成過程

余剰次元nまで含めた重力定数 G_D
DLでの定義:
$M_P=1/G_D$ (Fundamental Planck scale ~ TeV)

このとき　シュバルツシルド半径

$$R_S = \frac{1}{\sqrt{\pi}M_P}\left[\frac{M_{BH}}{M_P}\left(\frac{8\Gamma(\frac{n+3}{2})}{n+2}\right)\right]^{\frac{1}{1+n}}$$



b < 2R$_s$

2Rsより小さい距離(インパクトパラメーターb)で2つのpartonが衝突するとミニブラックホールができる。

衝突するpatonの重心系
E/2のエネルギーのparton:
このpartonのドブロイ波長(2π/(E/2))
これが2Rsの半径の中にないと、
“点としてのparton”がぶつかると言う古典的な近似が駄目になる。

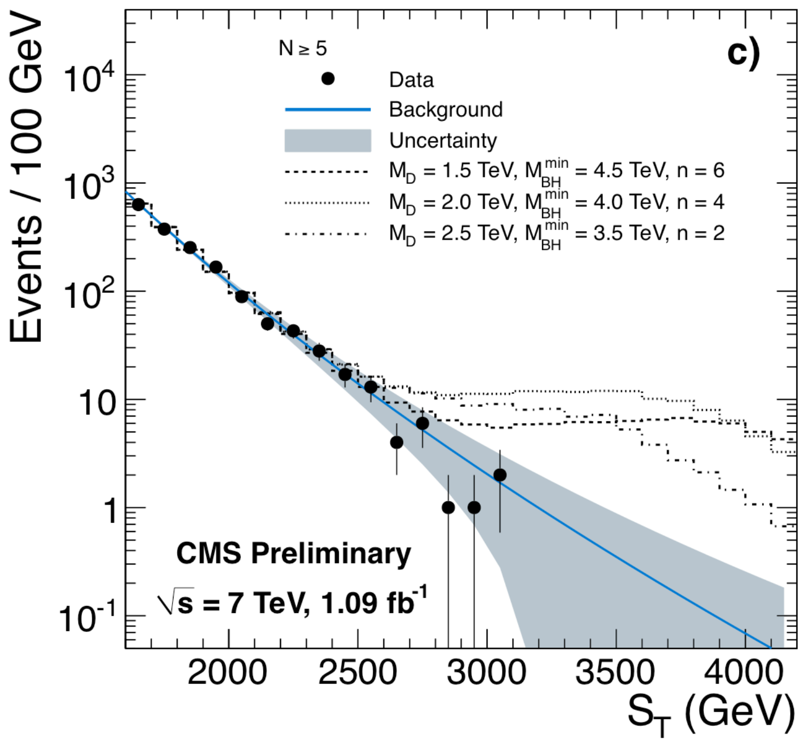
ブラックホールの質量 M_{BH} ～ E として、
（全部のenergyが中に入った）
$4\pi/M_{BH} < 2R_s$

$M_{BH} > (4\text{–}5.5)\ M_P$ （n=2–6）

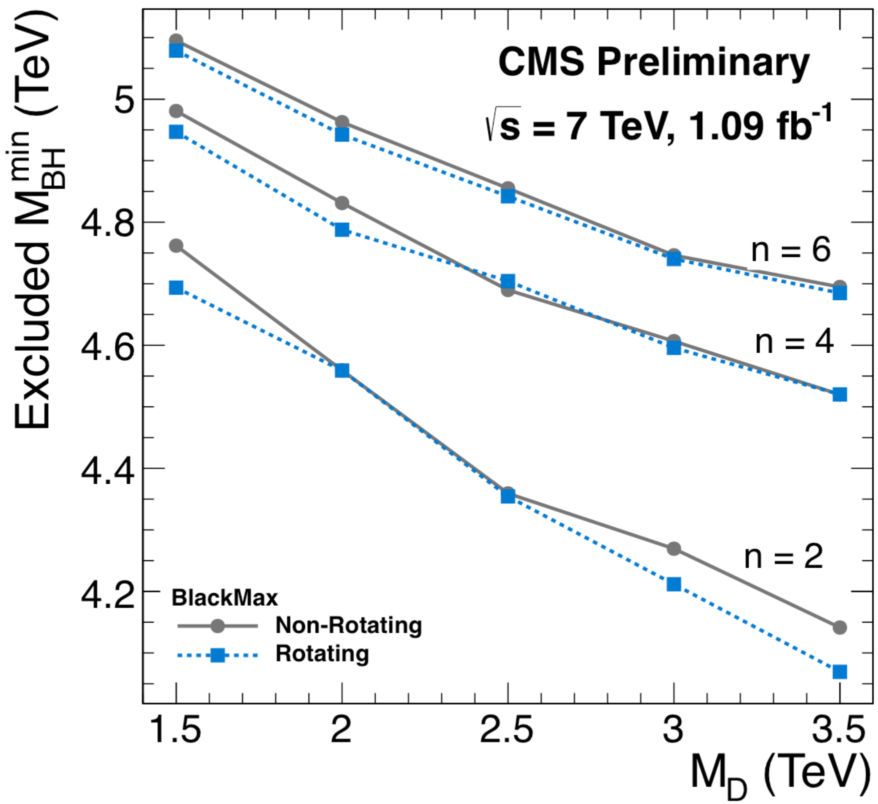
この最低値は、LHCではfix
不連続な閾値:
free parameterとして研究している。

古典的な近似:

$\sigma = \pi R_S^2 \sim M_P^{-2}\ (M_{BH}/M_P)^{2/(n+1)}$



N ≥ 5
Data
Background
Uncertainty
M_D = 1.5 TeV, M_{BH}^{min} = 4.5 TeV, n = 6
M_D = 2.0 TeV, M_{BH}^{min} = 4.0 TeV, n = 4
M_D = 2.5 TeV, M_{BH}^{min} = 3.5 TeV, n = 2
c)
CMS Preliminary
$\sqrt{s}$ = 7 TeV, 1.09 fb^{-1}
Events / 100 GeV
S_T (GeV)



CMS Preliminary
$\sqrt{s}$ = 7 TeV, 1.09 fb^{-1}
n = 6
n = 4
n = 2
BlackMax
Non-Rotating
Rotating
Excluded M_{BH}^{min} (TeV)
M_D (TeV)

Summary & Perspective

(1) LHC is good status.

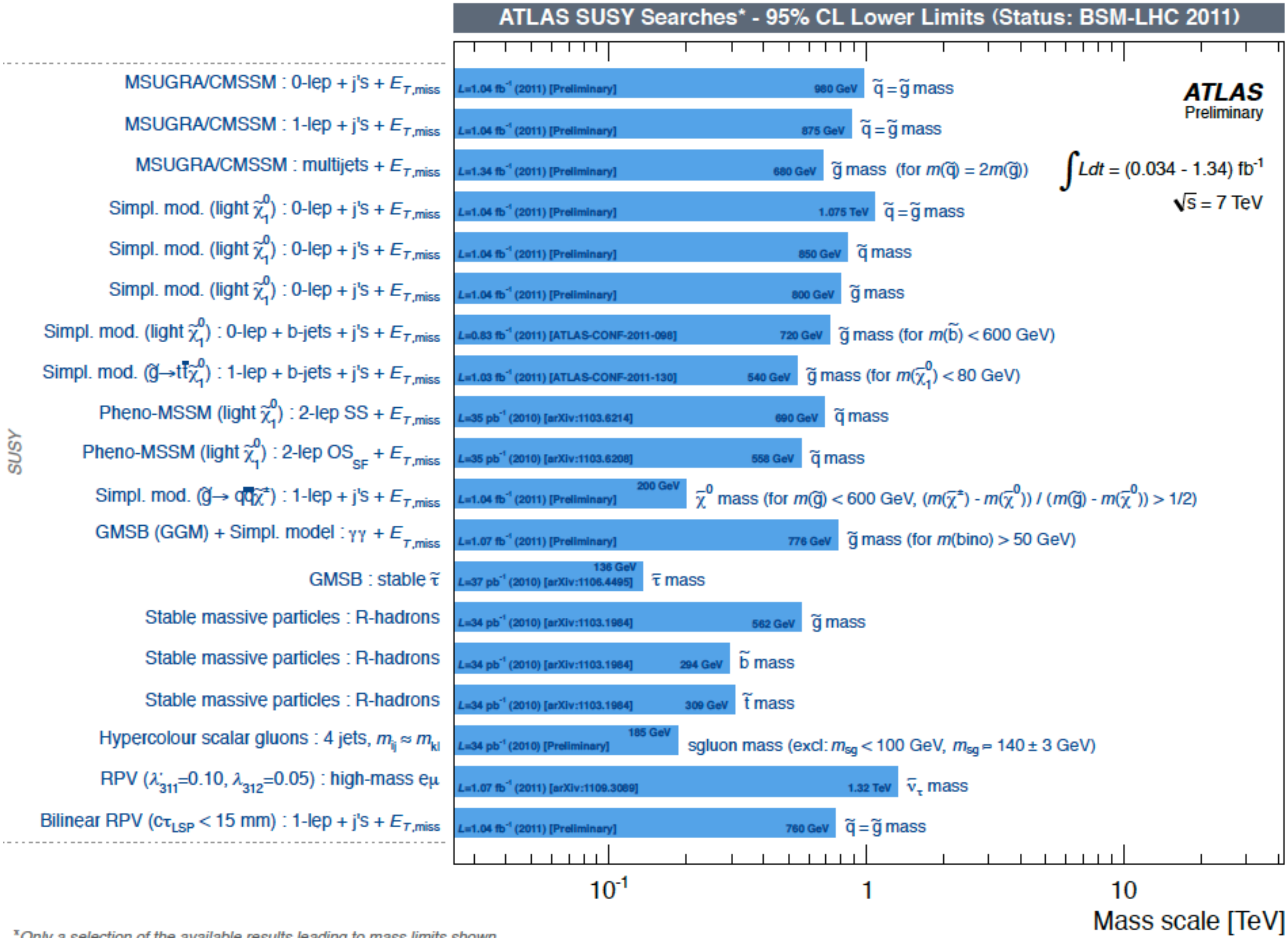
(2) Higgs is in 115-135GeV (145 officially)
It is good new for SUSY
130GeV this winter (5fb-1)
120GeV Next summer (10fb-1)

(3) SUSY Gluino/squark > 1.2TeV
DM of Naïve CMSSM is excluded.
(Higgsino, Degenerate model, hierarchy model, non MSSM becomes importanat)
We can check upto 1.5TeV in Next year, Finally upto 3 TeV with ECM=14TeV

(4) No excess is found in the various exotic searches
ED of ADD/RS are excluded upto a 2-3 /1.3-1.6 TeV, respectively.

(5) Data agree well with the SM predictions for the various topology. $< 2\sigma$

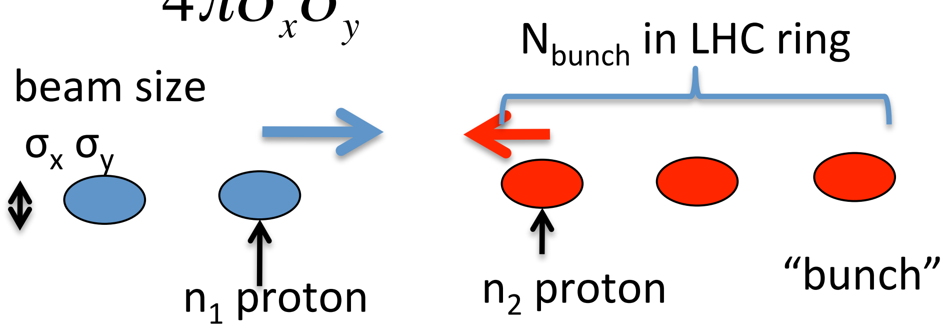
No excess (> 2σ) was found for all SUSY searches, strict limits are obtained.



おまけ

Bunch Structure of beam

$$L = \frac{n_1 n_2}{4\pi\sigma_x\sigma_y} f$$



Today

Nbunch 1380 (50nsec each 16m)
σ= 23 μm
n=1.4E11

$L=3.3 * 10^{33} cm^{-s} s^{-1}$

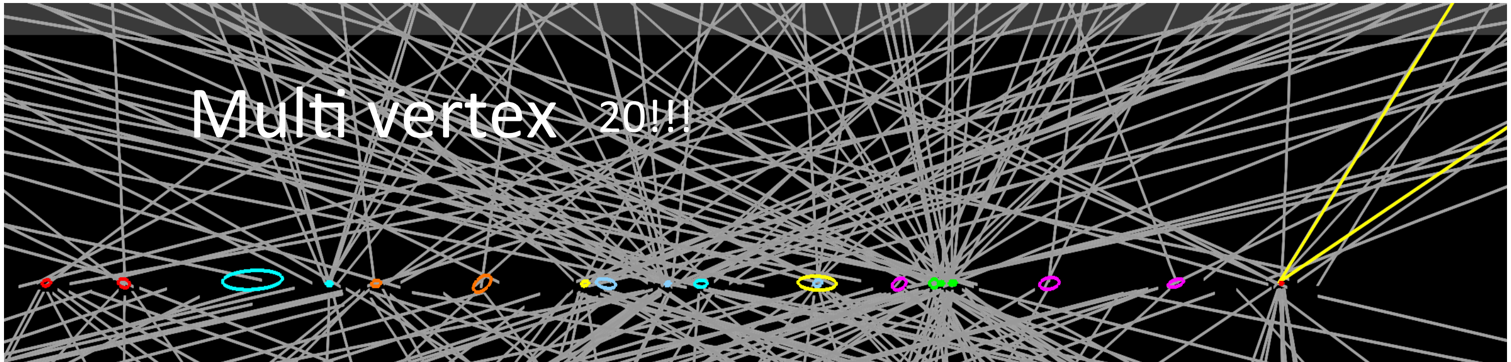
Design of LHC

Nbunch 2808 (25nsec each 8 m)
σ~17 μm
n=1.4E11

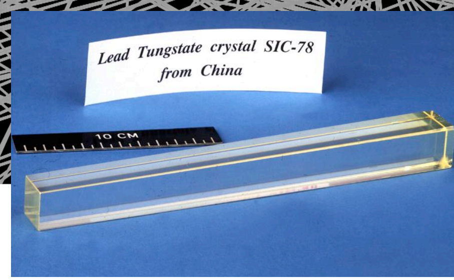
$L=1.2*10^{34} cm^{-s} s^{-1}$

The same as KEK B (not SUPER)
Integrated L = $100 fb^{-1}$ / year

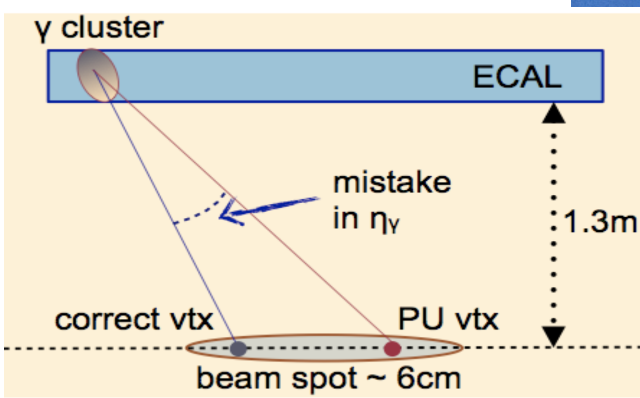
many proton crossing in one bunch crossing:
MB cross-section is as large as 70 mb, many hadronic collision are superimposed

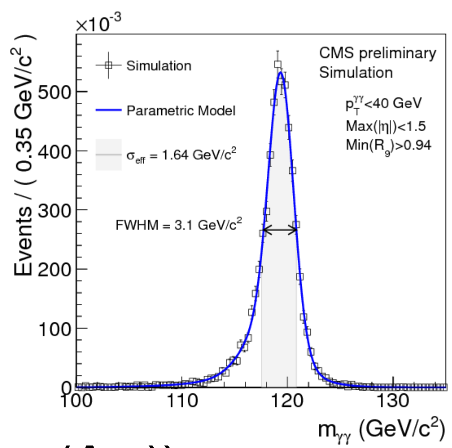


“pile-up”
mean
14

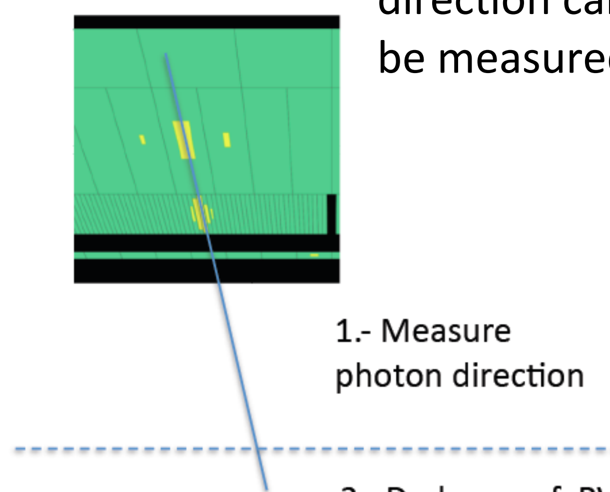


PbW04 Scintillator: Good energy resolution
But no layer -> no direct information.





ATLAS L.Ar 3 layer
direction can
be measured

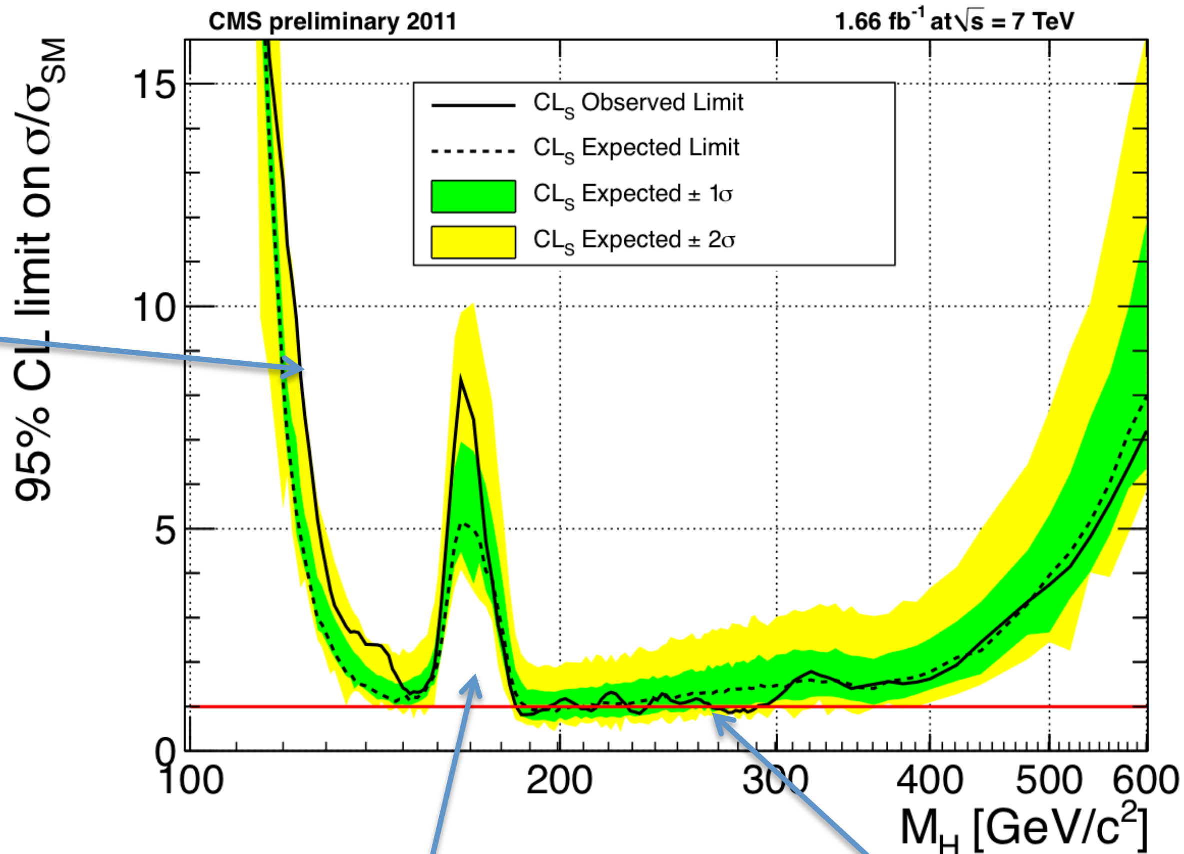


$\gamma\gamma$: $m^2 = 2E_{T1}E_{T2}(\cosh(\Delta\eta) - \cos(\Delta\varphi))$

error on $\Delta\eta$ is also propagated to mass resolution

Limit on the SM Higgs

2σ level excess
Mh<160GeV
Signal yield is
larger than SM
by factor 10
-> maybe Stat.



Mh=170GeV   H->WW dominant, No sensitivity on H->ZZ

almost exclude
Mh=180-300GeV

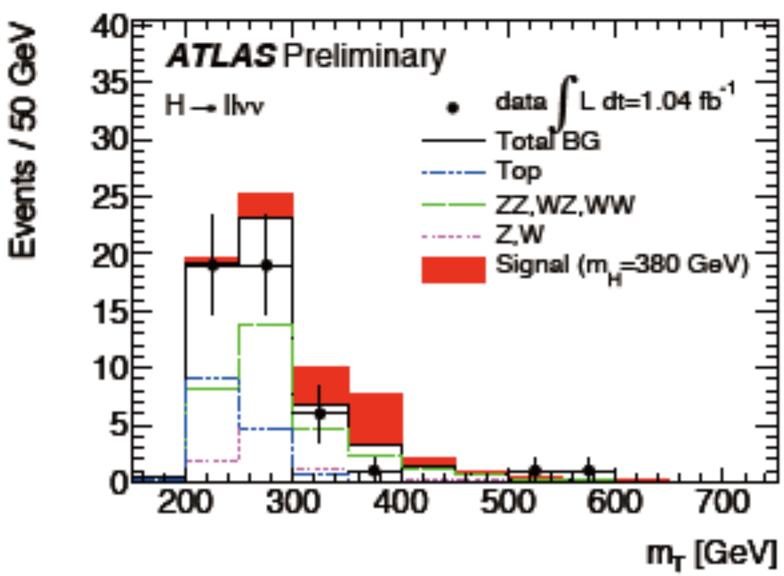
[4] Heavy Higgs (ZZ→llqq, llνν)

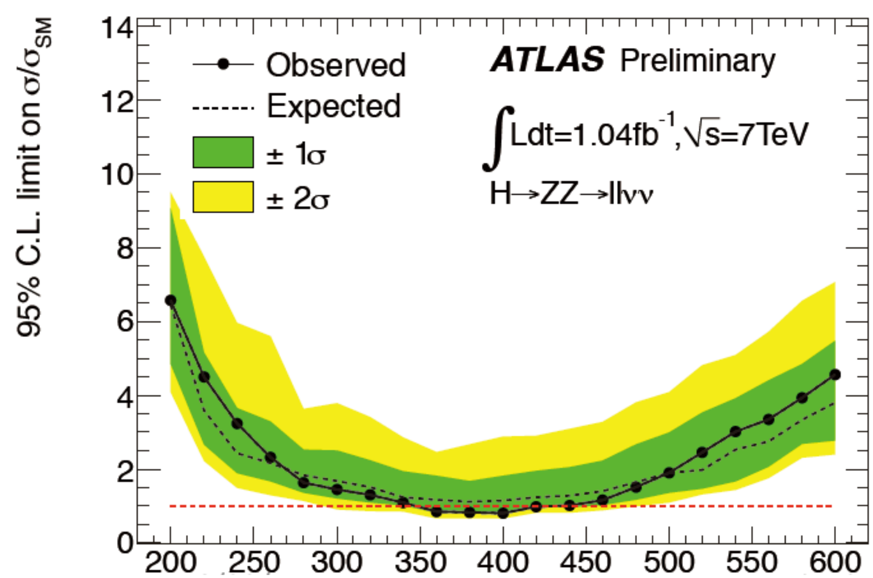
(1) $\Gamma \sim M_h^3$ becomes wide for heavy the higgs, the benefit using "lepton" becomes less.
(2) Br(Z->ee,mumu) is too small for heavy Higgs

H→ZZ→llνν and llqq help the sensitivity for the heavy Higgs.

H→ZZ→llνν : OS lepton pair whose invariant mass is Mz, and large mET
MT is calculated as follow, (MT < Mh, but there is Jacobian broad peak near Mh)

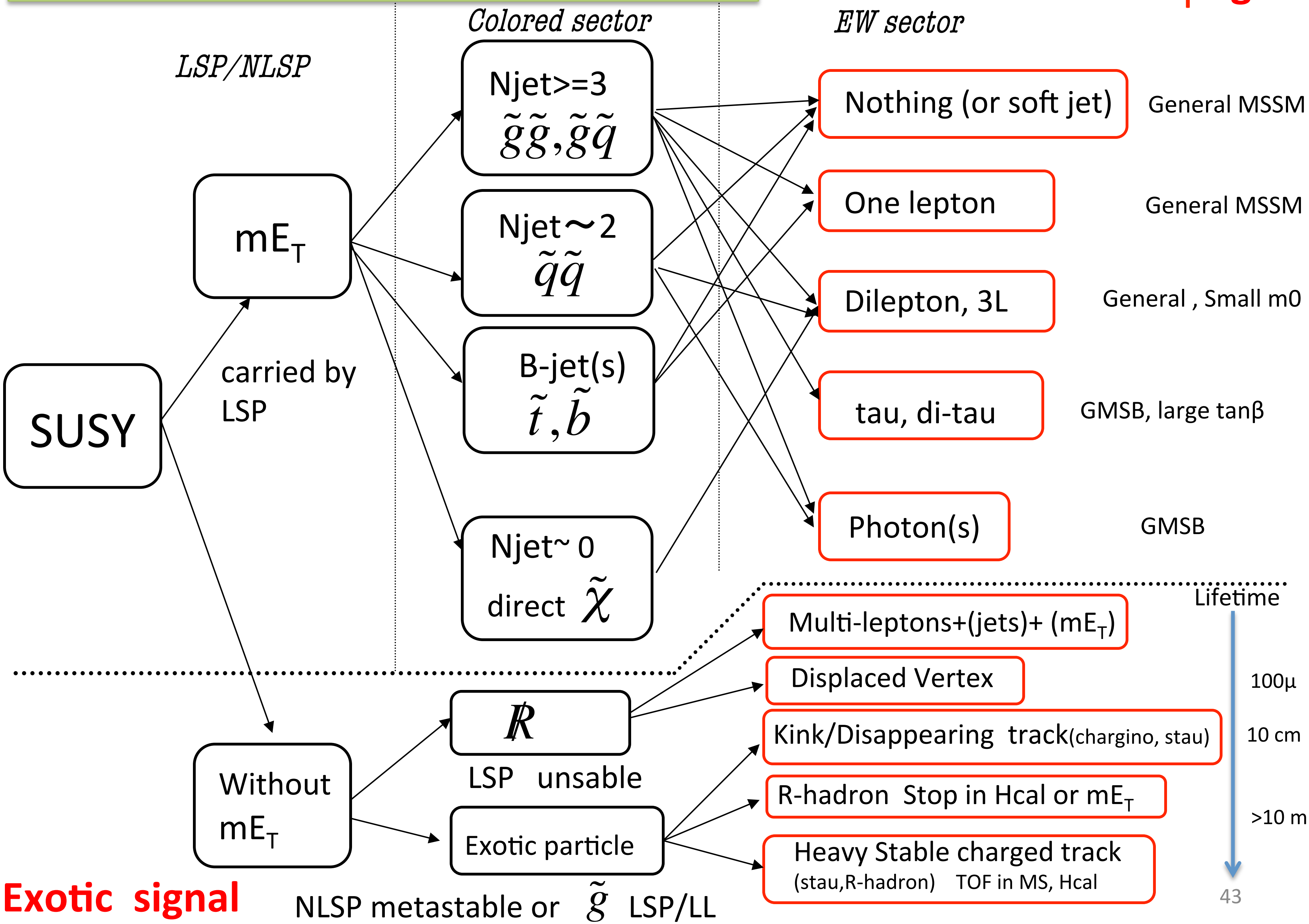
$$m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\mathrm{miss}}\right]^2$$



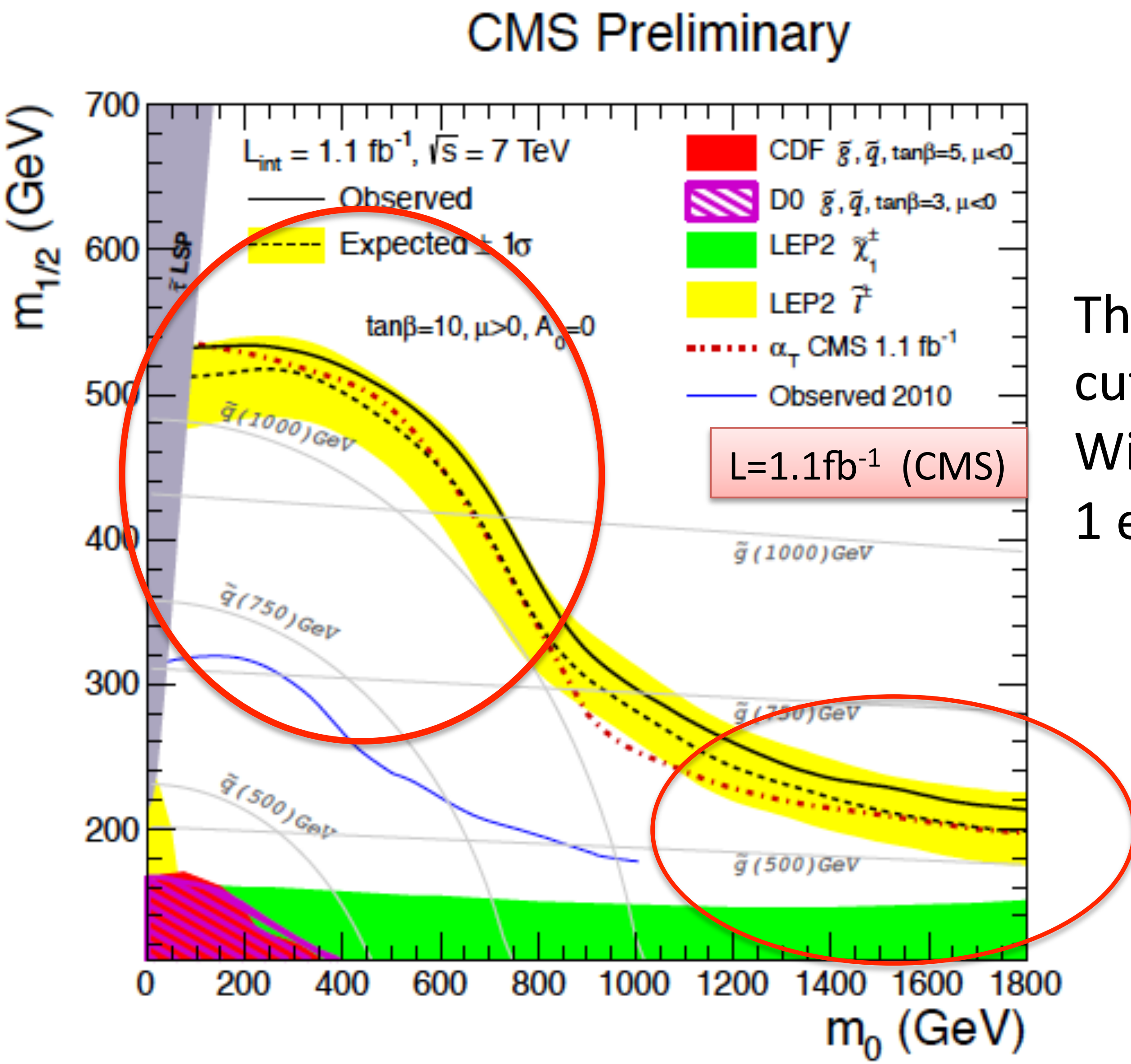


more detail classification are summarized in this figure:

Standard mE_T signal



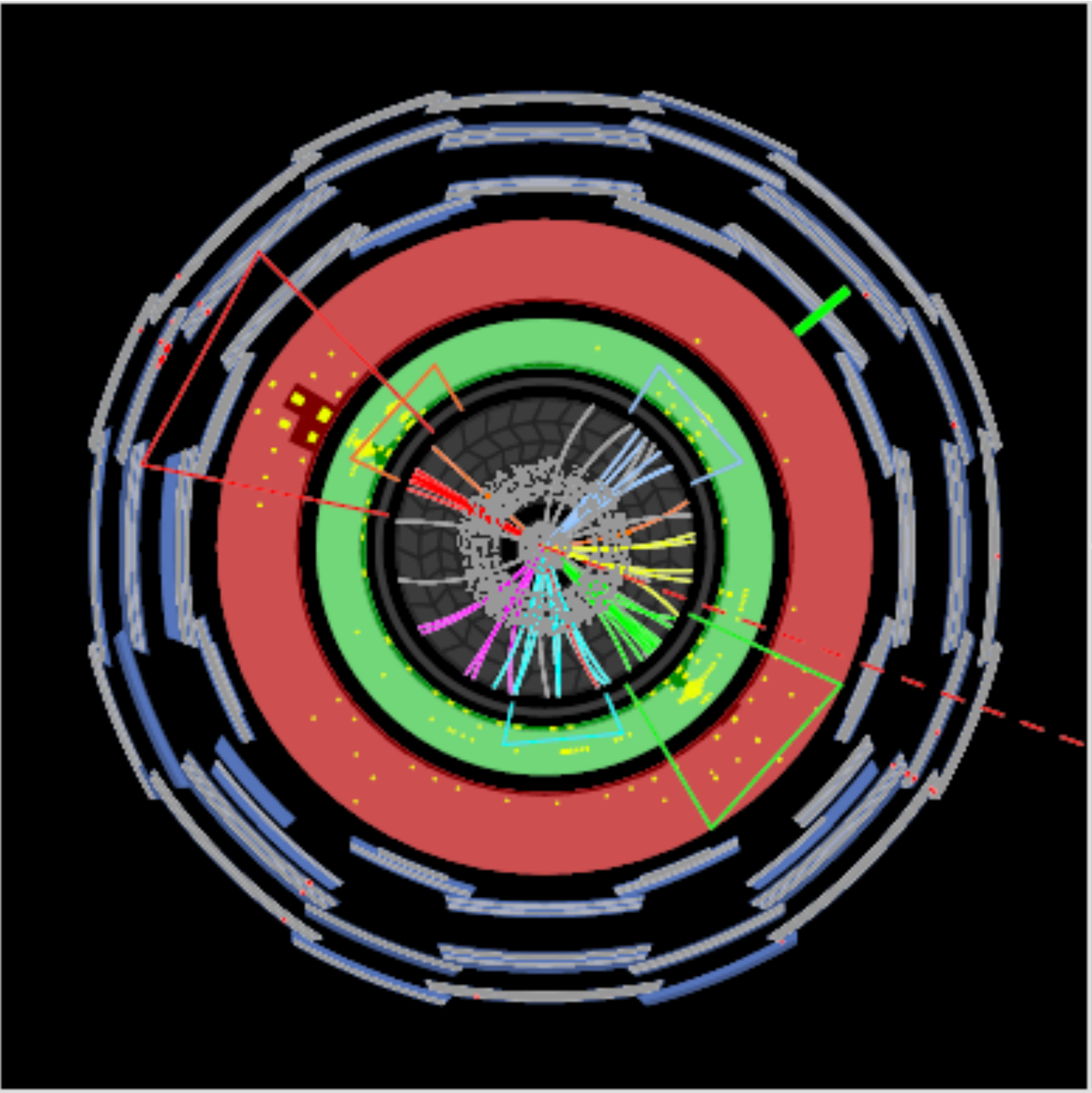
CMS has obtained the similar results. No excess was found and gluino ∼ 1.2 TeV, squark ∼ 1.1 TeV are obtained.



They applied tight cut (Best limit is obtained With tight selection. 1 event obs. 1.5 expect.)

At Large m0
gluino ~ 600GeV
gluino only
3body decay
high Jet multiplicity
s mall mET

Candidate events



Run=183391 #61816156

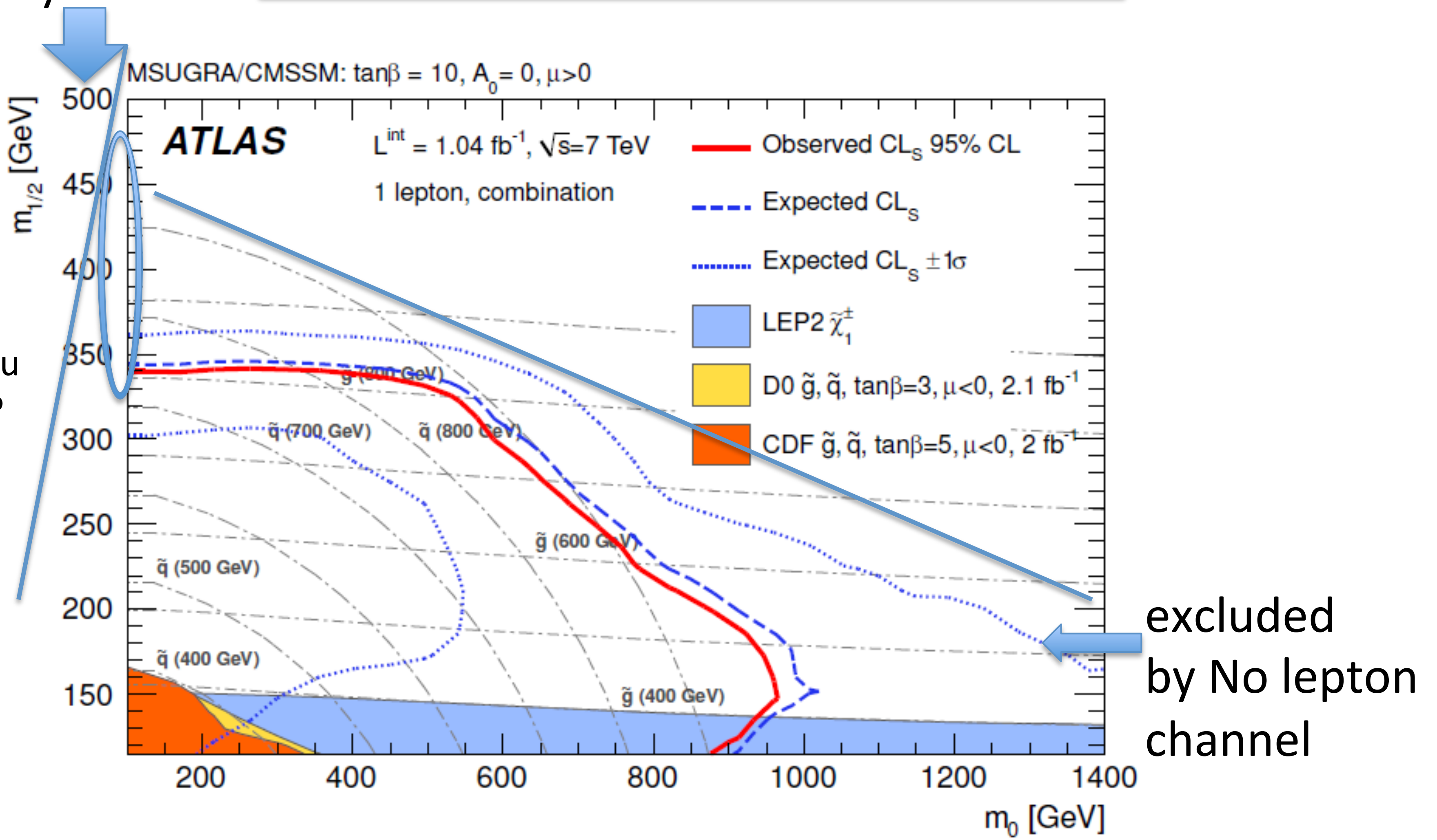
Meff(4j) = 1453 GeV
MET = 317 GeV phi=-0.34
Jets
pT=654 GeV eta=-0.07 phi=2.64
pT=305 GeV eta=-0.24 phi=-0.74
pT=70 GeV eta=-0.10 phi=0.71
pT=64 GeV eta=-1.44 phi=2.41
pT=51 GeV eta=-1.18 phi=-1.48

Electron
pT=42.8GeV eta=-1.4 phi=2.4

Nvtx = 4 with 103,19,10,4 tracks

constrained on CMSSM

Dilepton analysis



Squark, gluino ~ 800GeV

SUSY with B jet (stop search)

Stop is crucial for naturalness

(A) No Lepton + multijets(>=3) + mET + b-jet (at least 1 or 2)
gluino pair production
and gluino -> top stop
(gluino → b sbottom also contributes this stopology)

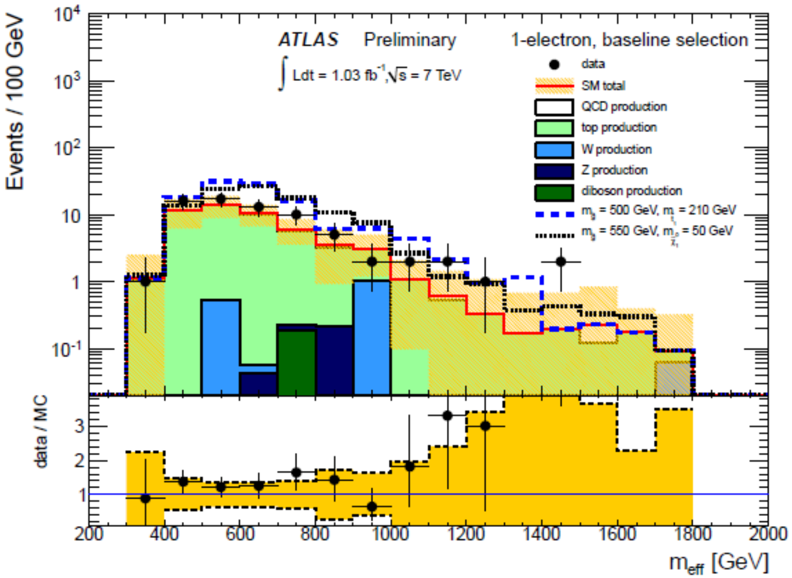
（B）One Lepton + multijets(>=3)+mET+bjet(at least 1)
gluino pair production
gluino -> btop stop & lepton is emitted from top decay or chargino

(C) No lepton + 2 b jets + mET (stop pair sbottom pair)
direct productio of stop/sbotom
stop/sbotom -> b + chargino/neutralino (chargino -> LSP+soft)

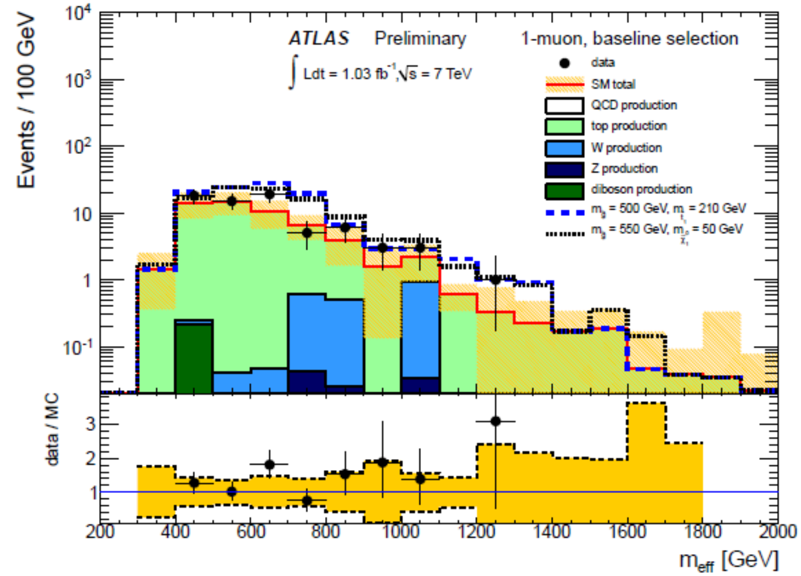
Results of Topology B

Exactly One lepton PT>25GeV (electron) PT>20GeV(muon)
At least 4jets(PT>50) MET>180GeV MT>100GeV Meff>600GeV
At least 1 b jet

Electron



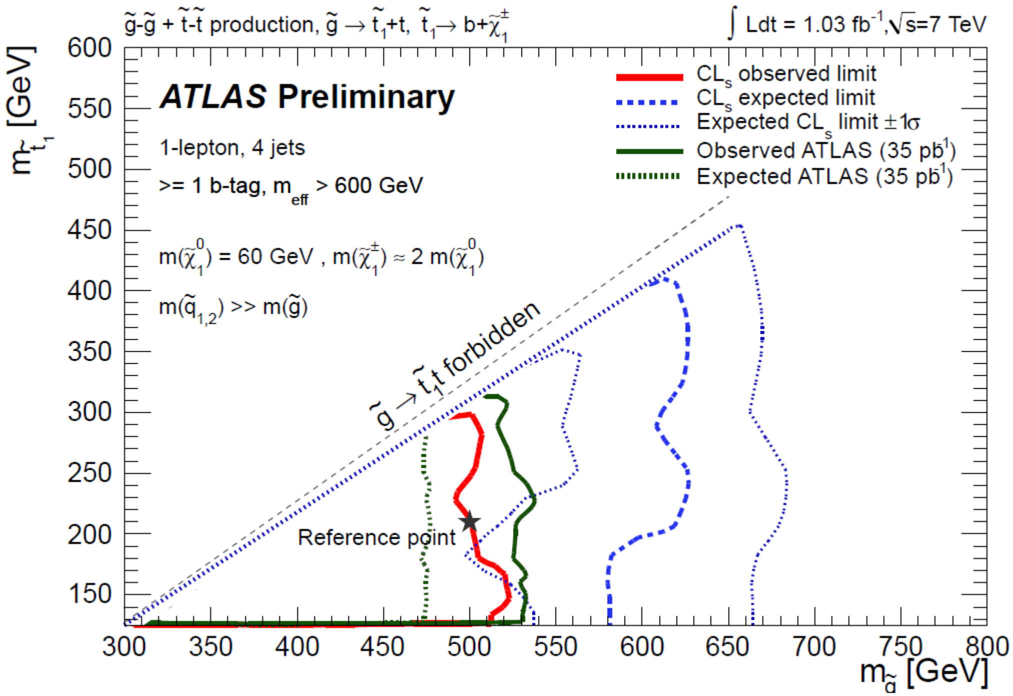
Muon

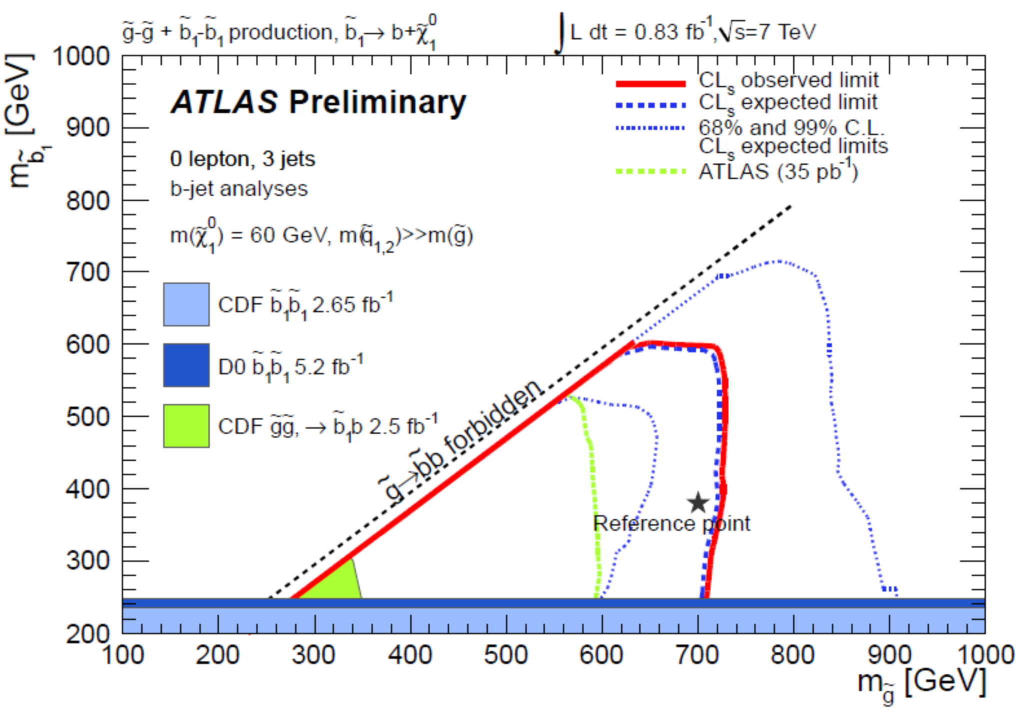


Data37 events
BG 28 +- 8 (t 23 W/Z 1 QCD 1)

Data37 events
BG 27 +- 5 (t 24 W/Z 2)

small excess (< 2σ) was found : tt+Njets


g̃-g̃ + t̃-t̃ production, g̃ → t̃₁+t, t̃₁→ b+χ̃₁±
∫ Ldt = 1.03 fb⁻¹, √s=7 TeV
ATLAS Preliminary
1-lepton, 4 jets
>= 1 b-tag, m_eff > 600 GeV
m(χ̃₁⁰) = 60 GeV , m(χ̃₁±) ≈ 2 m(χ̃₁⁰)
m(q̃₁,₂) >> m(g̃)
CLs observed limit
CLs expected limit
Expected CLs limit ±1σ
Observed ATLAS (35 pb⁻¹)
Expected ATLAS (35 pb⁻¹)
g̃ → t̃₁t forbidden
Reference point
m_t̃₁ [GeV]
m_g̃ [GeV]


g̃-g̃ + b̃₁-b̃₁ production, b̃₁→ b+χ̃₁⁰
∫L dt = 0.83 fb⁻¹, √s=7 TeV
ATLAS Preliminary
0 lepton, 3 jets
b-jet analyses
m(χ̃₁⁰) = 60 GeV, m(q̃₁,₂)>>m(g̃)
CLs observed limit
CLs expected limit
68% and 99% C.L.
CLs expected limits
ATLAS (35 pb⁻¹)
CDF b̃₁b̃₁ 2.65 fb⁻¹
D0 b̃₁b̃₁ 5.2 fb⁻¹
CDF g̃g̃, → b̃₁b 2.5 fb⁻¹
g̃→b̃b forbidden
Reference point
m_b̃₁ [GeV]
m_g̃ [GeV]