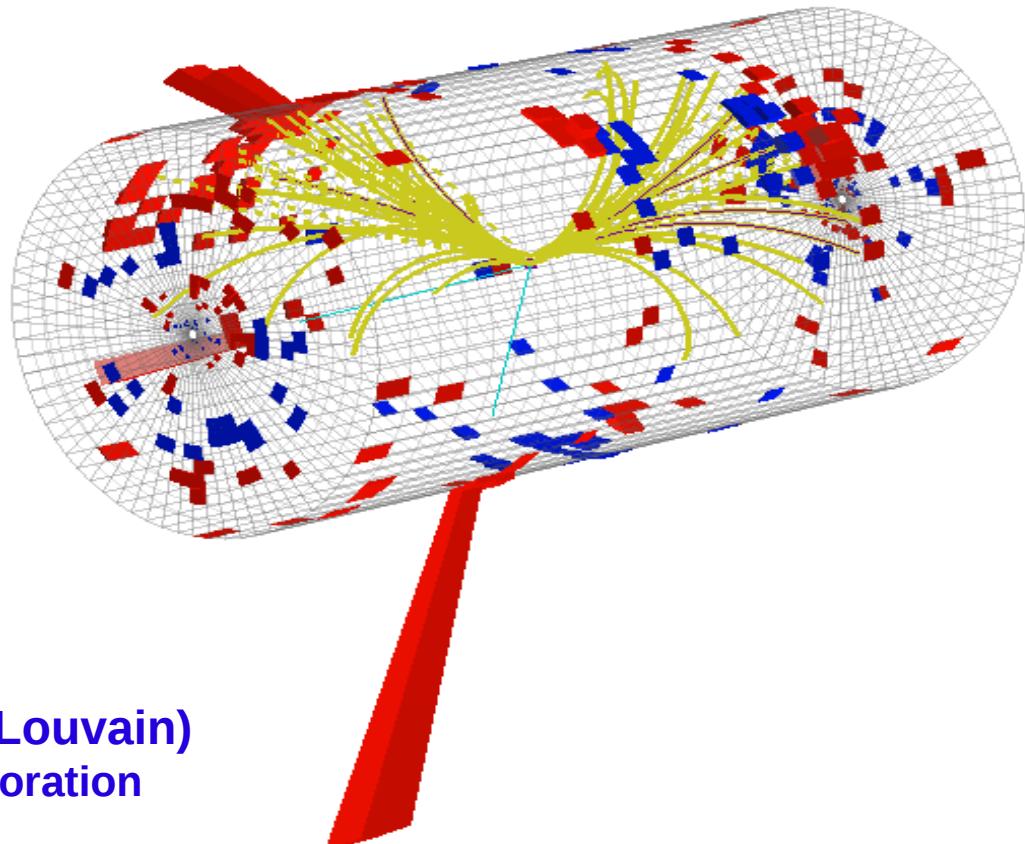


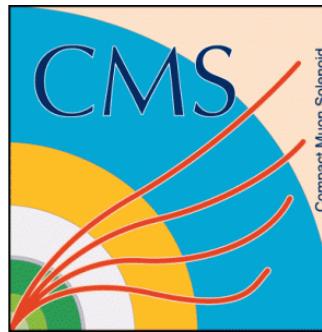
Measurement of the production cross sections of Z bosons in association with b jets in pp collisions at $\sqrt{s} = 7$ TeV



Fundamental



Ludivine Ceard (CP3, UCLouvain)
On behalf of the CMS Collaboration
8th of March 2013
Rencontres de Moriond 2013



- $Z+b$ -jets is background for many searches for undiscovered processes:

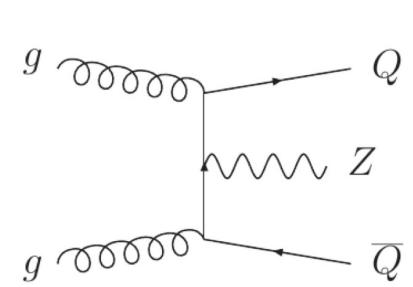
* SM Scalar:	$Z(\text{II}) H(\text{bb})$ $H \rightarrow Z(\text{II}) Z(\text{bb})$
* BSM Scalar:	$H \rightarrow Z(\text{II}) A(\text{bb})$ 2HDM/Susy-like

- Understand $Z+b$ -jets process
Study kinematics
- Test of perturbative QCD

4 flavor scheme

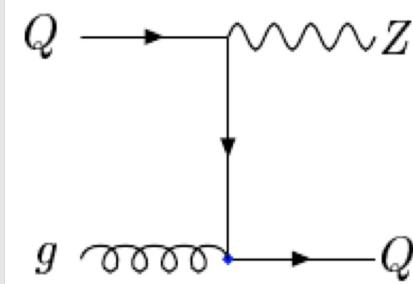
Massive b

Full event description
MadGraph+aMC@NLO



5 flavor scheme

Splitting inside PDF
Massless b
MadGraph



- Study $Z+bb$ production as function of bjet multiplicity

Signal:

$Z + 1 \text{ b} = \text{one } Z + \text{exactly 1 b-jet}$ (exclusive)
 $Z + 2 \text{ b} = \text{one } Z + \text{at least 2 b-jets}$ (inclusive)

Luminosity : 2.1 fb^{-1} at 7 TeV

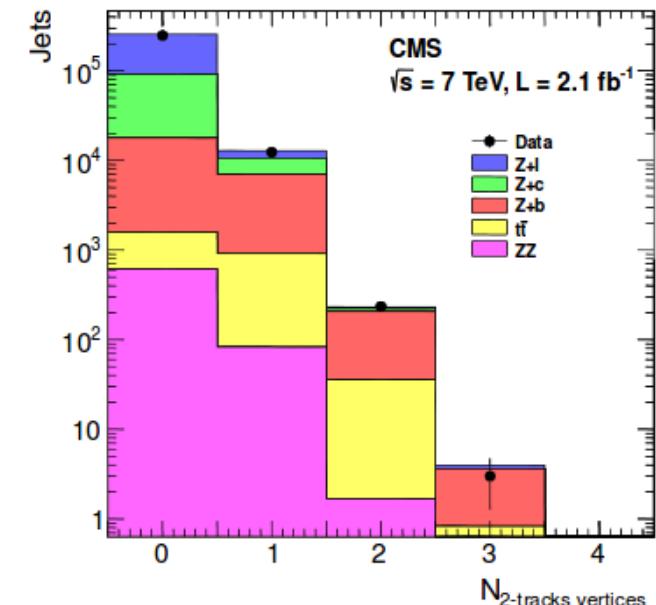
Phase space:

$$Z \rightarrow l^+l^-$$

- $l = \mu/e$, isolated
- $p_T > 20/25 \text{ GeV}$
- $| \eta | < 2.1/2.4$

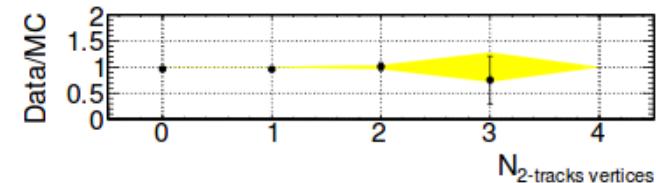
b-tagged jets

- anti k_T , $\Delta R = 0.5$
- $p_T > 25 \text{ GeV}$
- $| \eta | < 2.1$

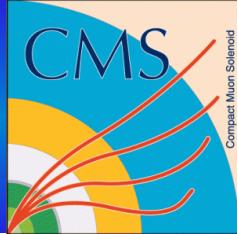


3 Backgrounds:

- $Z+c$ and $Z+l$ from Drell Yan
- $t\bar{t}$ bar
- ZZ : normalized to cross section from CMS measurement *

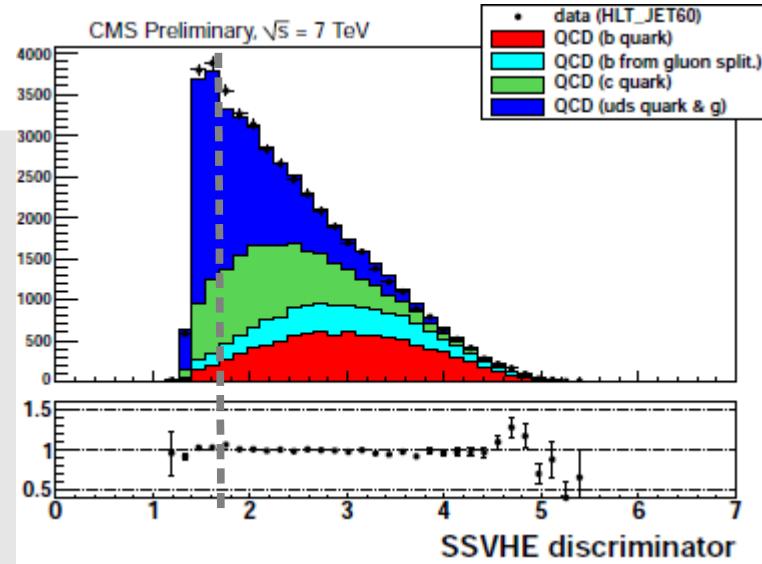


Background: Z + light jets

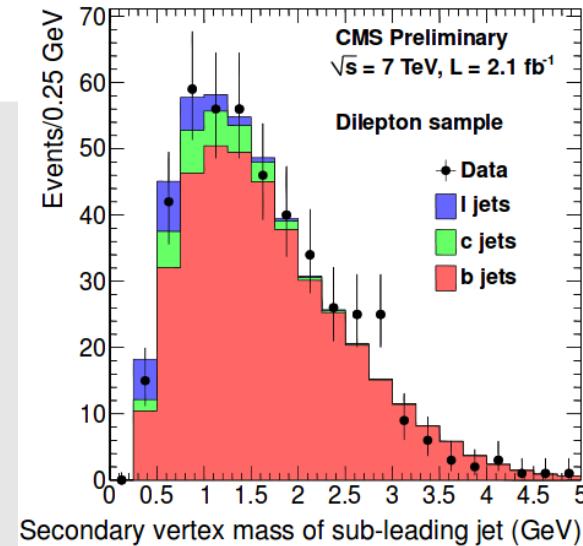


Z+c, Z+udsg

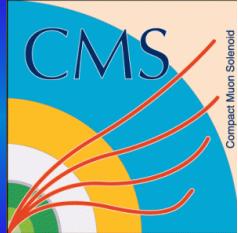
- **b-tagging: background reduction**
 - Detached secondary vertex
 - High efficiency selection: 55 %
 - 1% mistag



- **background estimate**
 - Template fit to the Secondary Vertices Mass
→ b purity



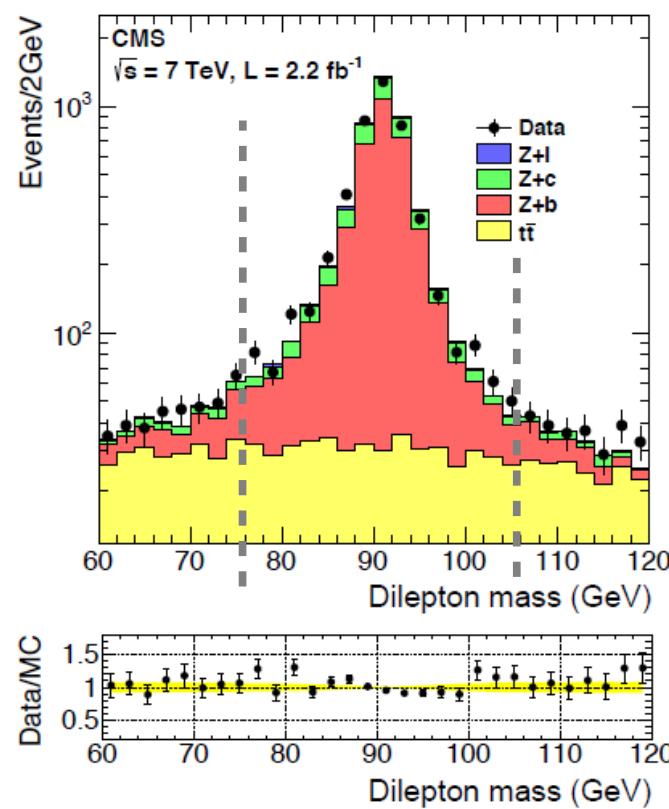
Background: ttbar



- ttbar reduction:

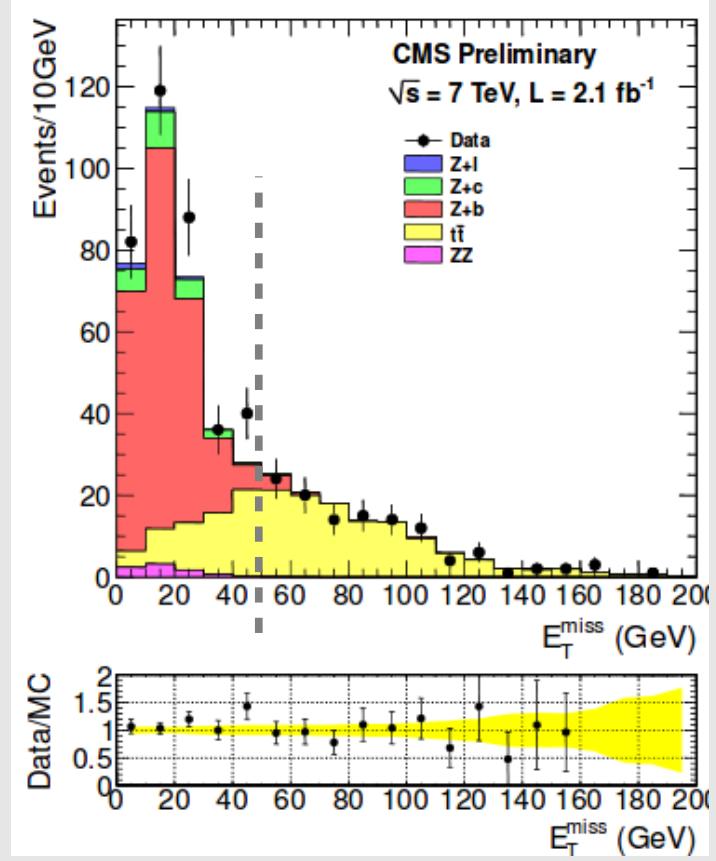
Z mass window

- $76 < m_{\parallel} < 106$ (GeV)



MET criterium

- MET < 50 GeV



- ttbar estimate: fit to m_{\parallel} from templates

Unfolding:

→ # reconstructed b-jets → # hadron-level b-jets

$$\begin{pmatrix} \sigma(Z+1b) \\ \sigma(Z+2b) \end{pmatrix} = \frac{1}{\mathcal{L}} \times A^{-1} \times E_r^{-1} \times E_l^{-1} \times E_b^{-1} \times \begin{pmatrix} N_{sig}^{Z+1b} \\ N_{sig}^{Z+2b} \end{pmatrix}$$

Corrections for all efficiencies and acceptance

Cross sections:

- Results for ee and $\mu\mu$ channels compatible and combined in a single measurement

Cross sections at the particle level	
Multiplicity bin	Combination
$\sigma_{hadron}(Z+1b, Z \rightarrow ll)(pb)$	$3.41 \pm 0.05 \pm 0.27 \pm 0.09$
$\sigma_{hadron}(Z+2b, Z \rightarrow ll)(pb)$	$0.37 \pm 0.02 \pm 0.07 \pm 0.02$
$\sigma_{hadron}(Z+b, Z \rightarrow ll)(pb)$	$3.78 \pm 0.05 \pm 0.31 \pm 0.11$

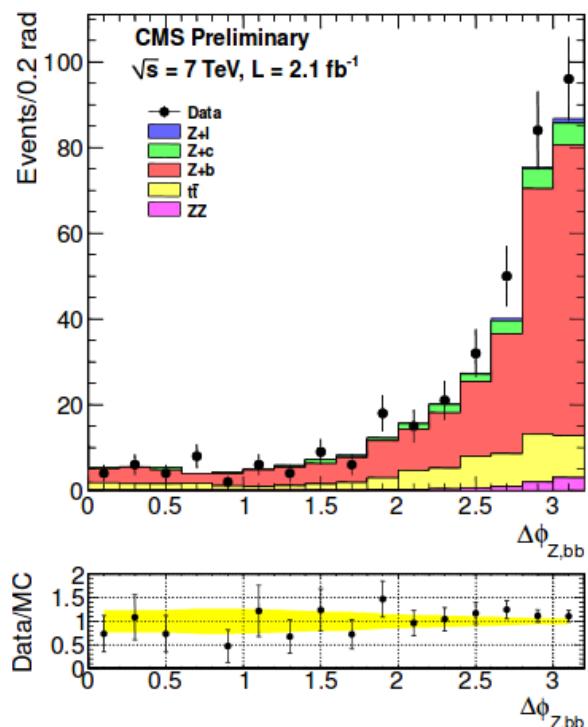
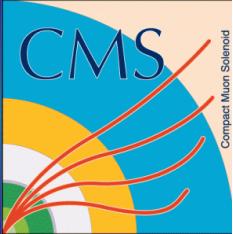
- Systematics dominated by b-tagging & ttbar background

Measurement: $\sigma(Z(ll)+2b) = 0.37 \pm 0.02 \text{ (stat.)} \pm 0.07 \text{ (syst.)} \pm 0.02 \text{ (theory)} \text{ pb}$

MadGraph expectation: $\sigma(Z(ll)+2b) = 0.33 \pm 0.01 \text{ (stat)} \text{ pb}$

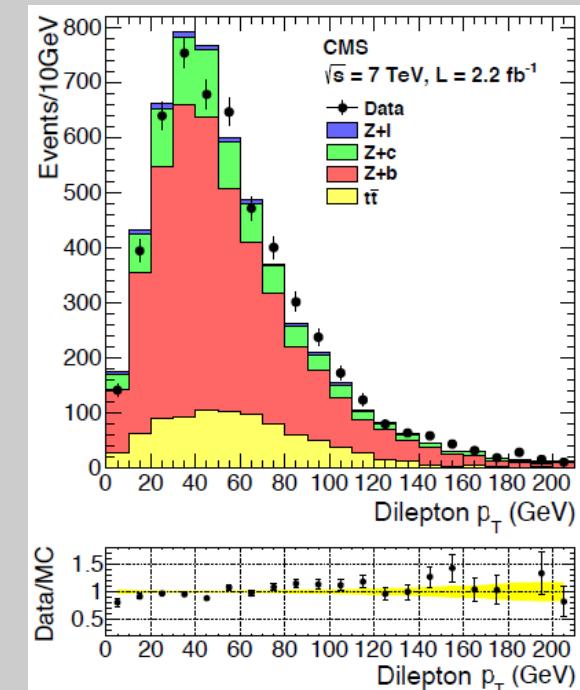
- Compatible with expectations from MadGraph 5 flavor corrected to NNLO

Prospects : kinematics



Angular distributions :

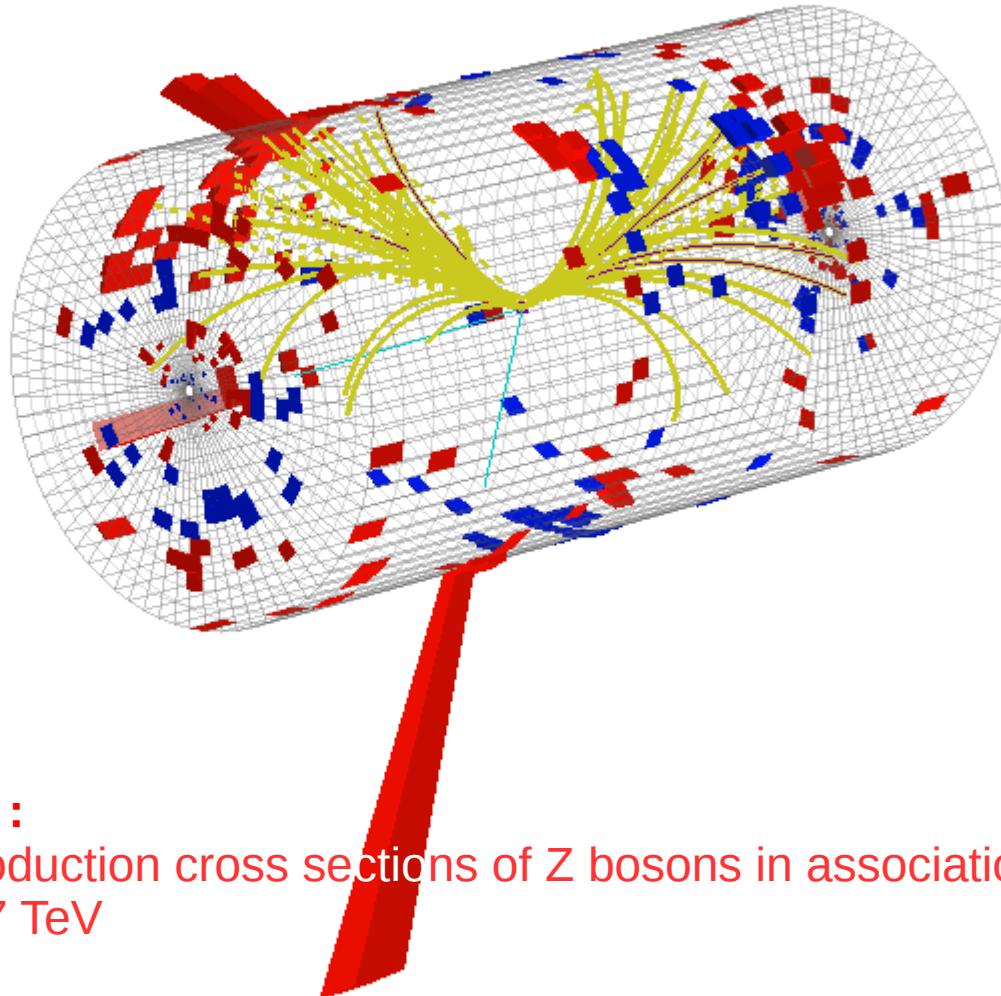
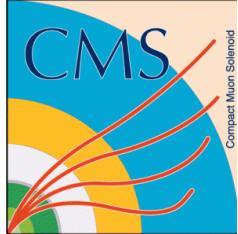
- General reasonable agreement data/MC (MadGraph)
- MPI contribution reasonably modeled from low values of $\Delta\phi_{Z,bb}$



Momentum distributions :

- Slightly harder spectrum for data than MC at LO
 \rightarrow NLO to be considered

Thanks for your attention. Any questions ?

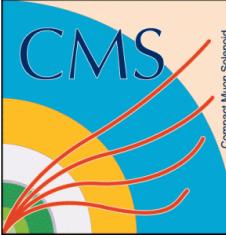


CMS PAS SMP-12-003 :

Measurement of the production cross sections of Z bosons in association with b jets
in pp collisions at $\sqrt{s} = 7 \text{ TeV}$

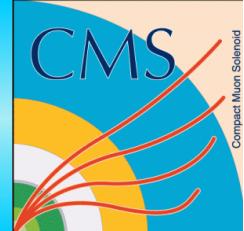
JHEP 1206 (2012) 126

Measurement of the Z/gamma*+b-jet cross section in pp collisions at 7 TeV



Back-up

Higgs Search

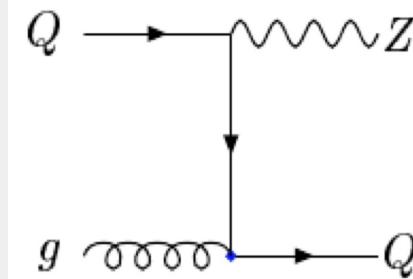
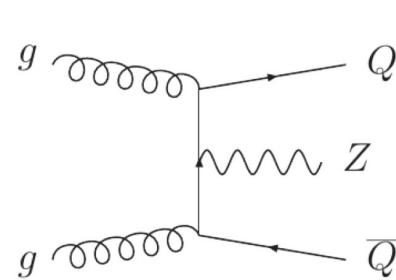


- Test of perturbative QCD

4 flavor scheme

Massive b

Full event description
MadGraph+aMC@NLO

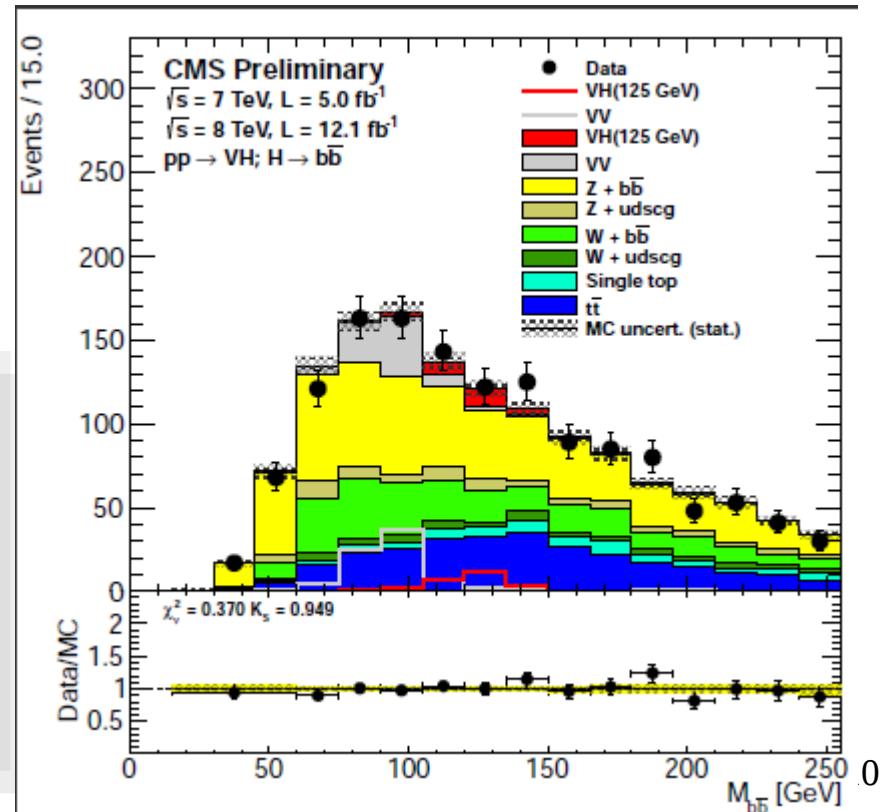


5 flavor scheme

Splitting inside PDF
Massless b
MadGraph

- Background for many searches for undiscovered processes:

- * **SM Higgs:** $Z(l\bar{l}) + H(b\bar{b})$
 $H \rightarrow Z(l\bar{l}) + Z(b\bar{b})$
- * **BSM Higgs:** $H \rightarrow Z(l\bar{l}) + A(b\bar{b})$
2HDM/Susy-like



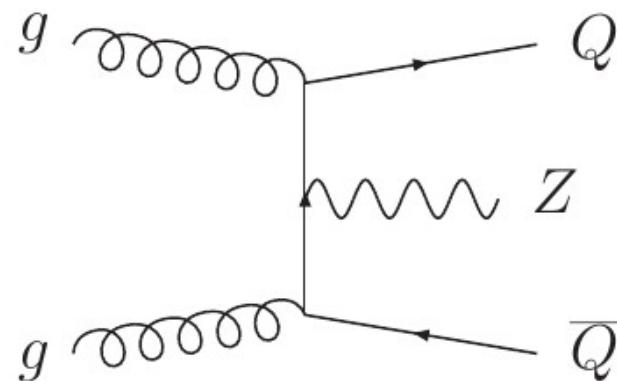
Calculations currently derived in 2 ways:

4-flavour scheme

Dittmaier, Kramer, Spira, Dawson,
Jackson, Reina, Wackerlo

Explicit gluon splitting \rightarrow divergences
if massless b.

massive b, $g \rightarrow bb$, 1 or 2 b observed

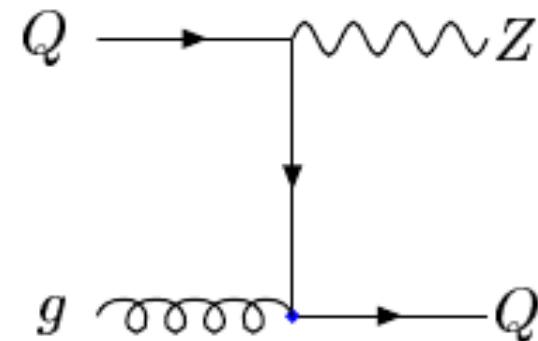


5-flavour scheme

Campbell, Ellis, Maltoni, Willenbrock

$g \rightarrow bb$ inside b-PDF \rightarrow all orders =
no divergences.

in calculations, b is massless.
second b added during parton shower
and hadronisation by Pythia



Should agree at NLO

4 and 5 flavors diagrams

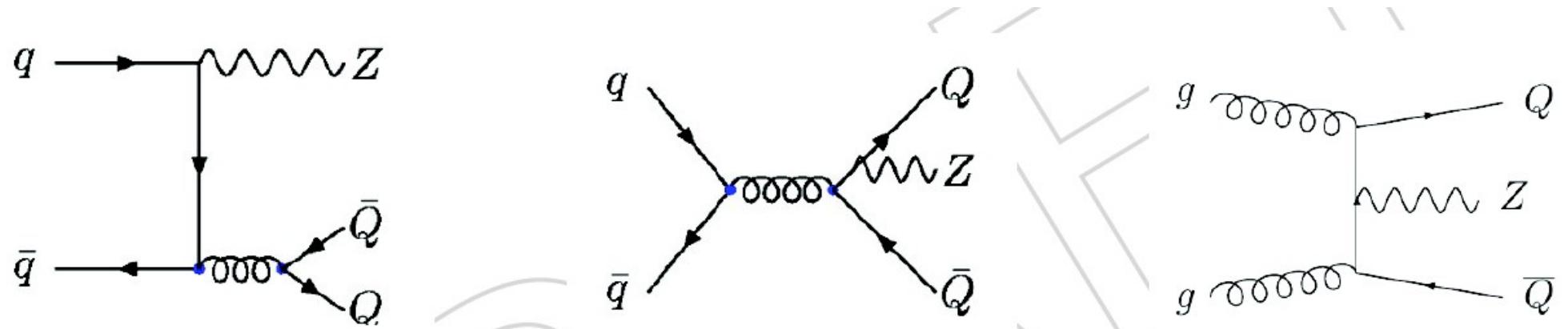
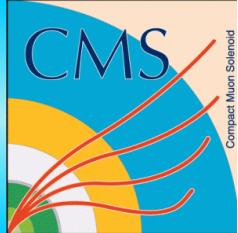


Figure 1: $q\bar{q}, gg \rightarrow Z + Q + \bar{Q}$, with $q = u, d, s, c$ and $Q = b, c$.

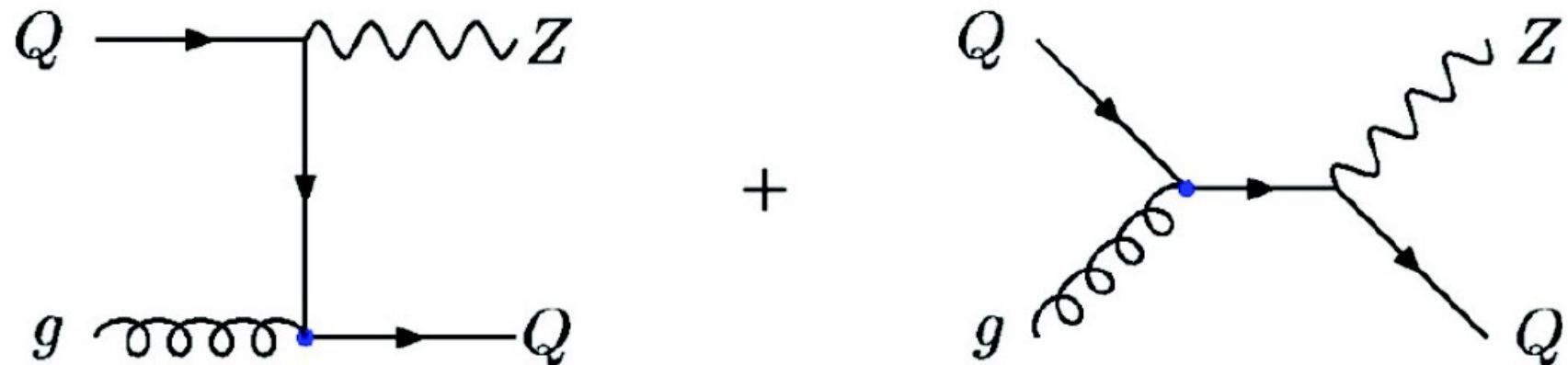
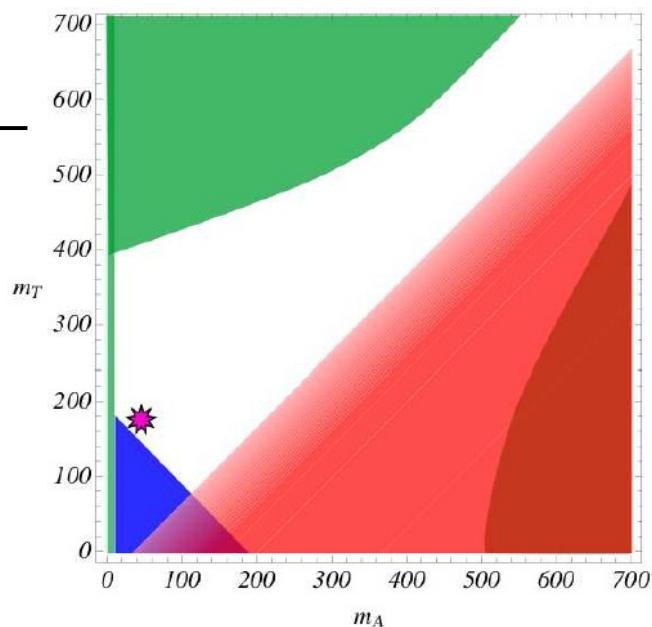


Figure 2: $gq \rightarrow Z + Q$ process, with $Q = b, c$.

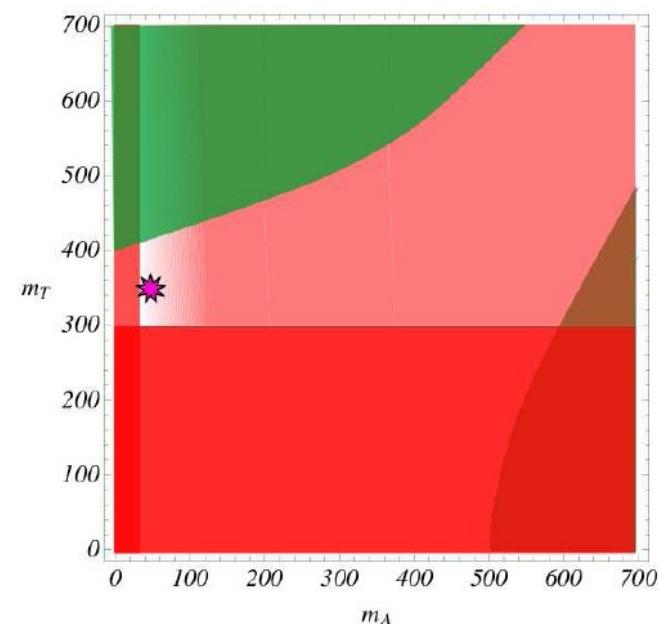
Type	Constraint	Origin
I & II	$m_h < 500 \text{ GeV}/c^2$	Unitarity
	$\sqrt{m_T^2 - m_A^2} < 400 \text{ GeV}/c^2$	Perturbativity
	$m_{H^0} \sim m_{H^\pm}$	ΔT if m_h is large
	$m_A << m_T$ $m_h > 114 \text{ GeV}/c^2$	ΔS if m_h is large LEP direct constraint
I	$m_T + m_A > 200 \text{ GeV}/c^2$ $\tan \beta < 0.5$	LEP $Z bbbb$ B -physics
II	$m_T > 300 \text{ GeV}$	$b \rightarrow s\gamma$
	$m_A > 30 \text{ GeV}/c^2$	R_b at $\tan \beta \sim 30$
	$m_A < 100 \text{ GeV}/c^2$	a_μ
	$m_A < 70 \text{ GeV}/c^2$ if $\tan \beta > 35$	Tevatron bbA
	$\tan \beta > 2$ $\tan \beta < 40$	$B_0 - \bar{B}_0$ mixing $B \rightarrow \tau\nu$

$A \rightarrow bb$
 $Z \rightarrow ll$

A low mass A and high mass H to escapes the indirect constraints

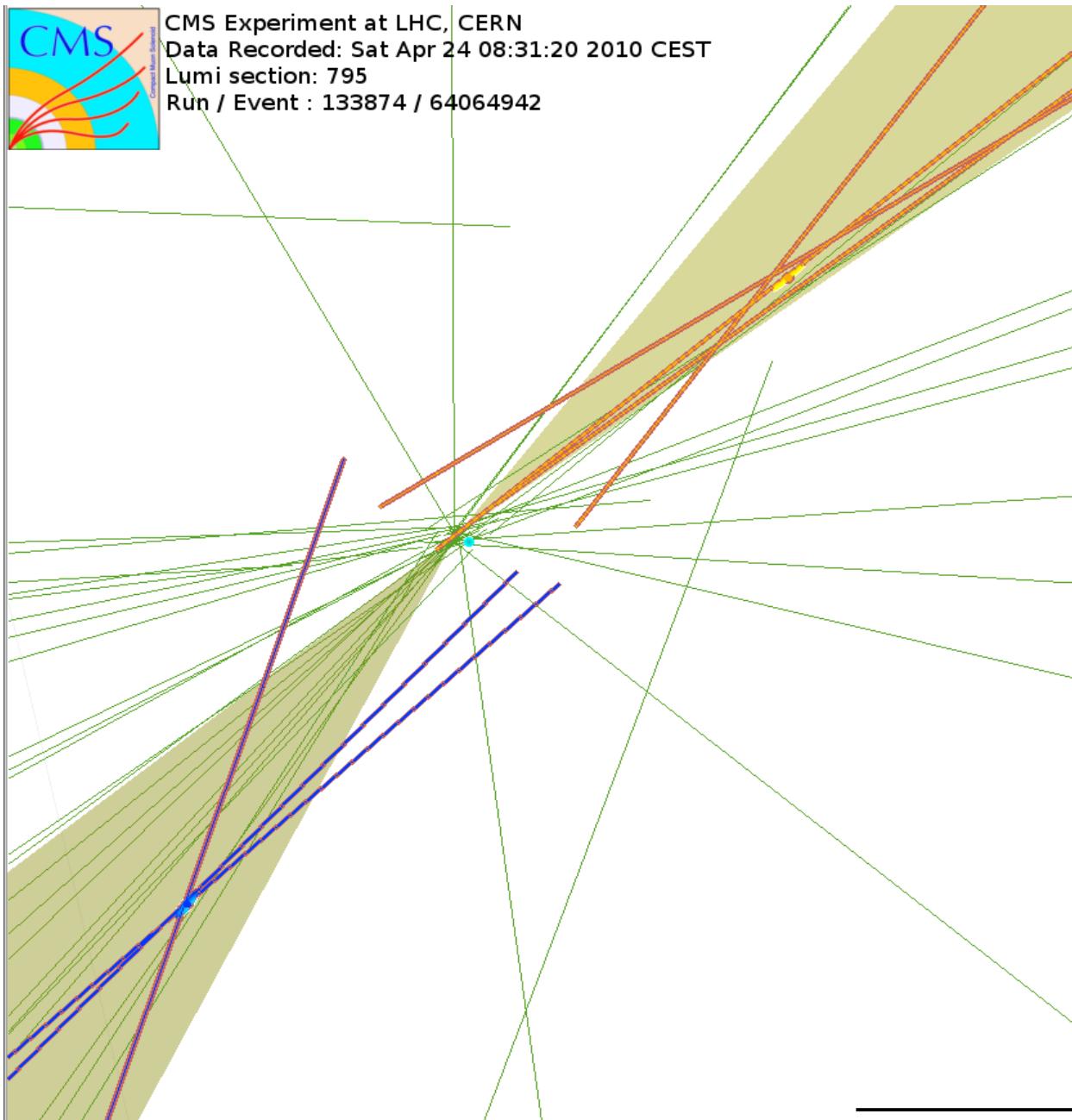


(a) Type I



(b) Type II

b-tagging

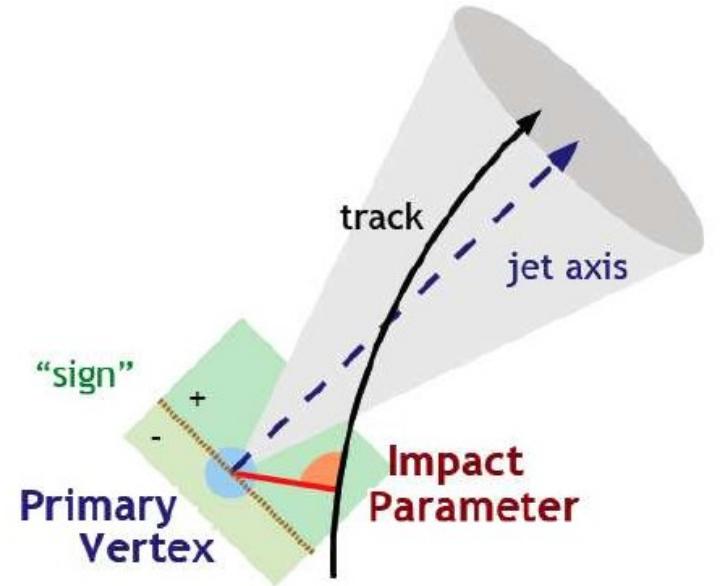


Bbbar event

- B hadron longer time of flight
- Reconstruction of a second vertex with dedicated algorithm
 - > Distance from primary vertex = d_0
 - > Mass
- Displaced tracks

b-tagging

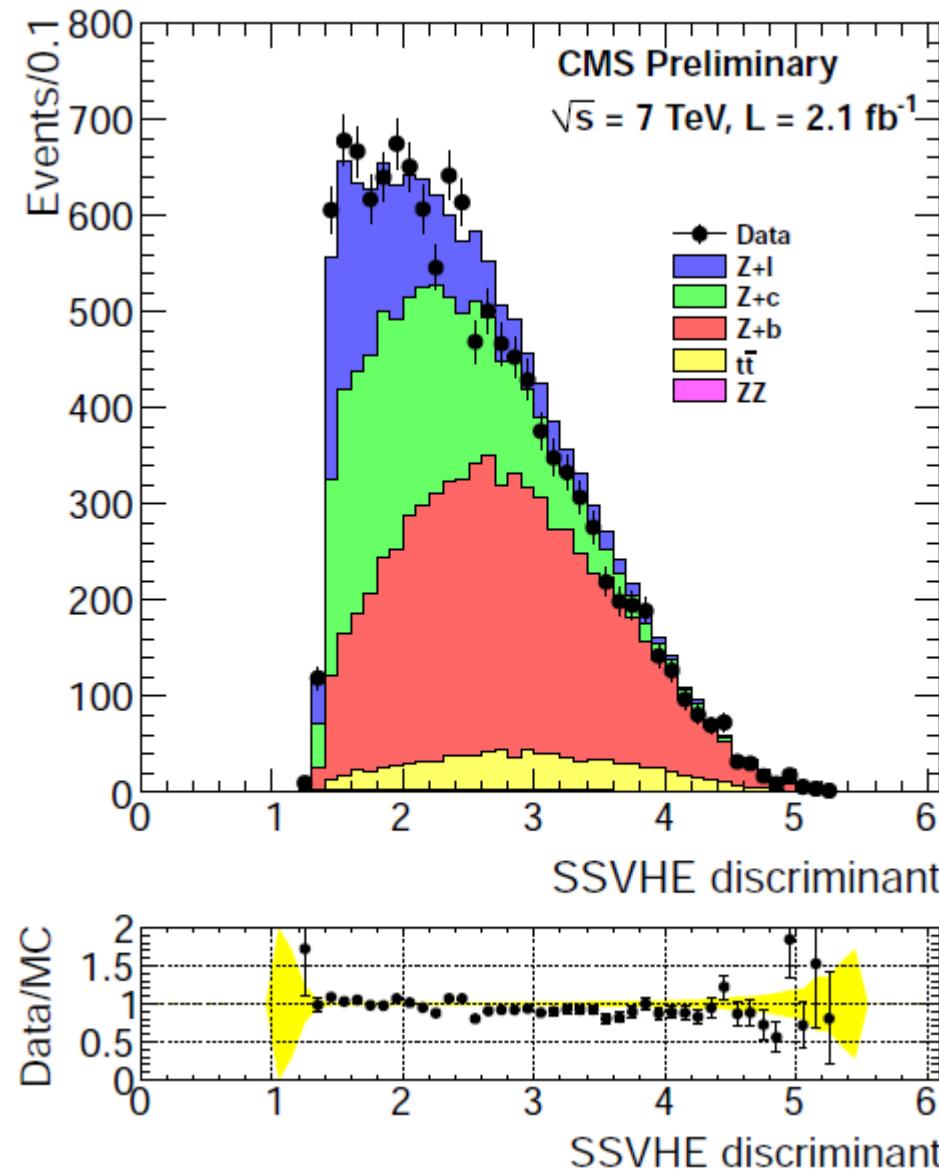
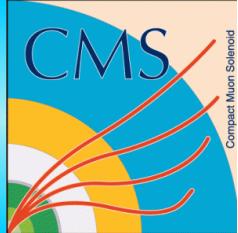
- **Track-counting (TC)**: tracks ordered by IP
 High-Eff (HE) = 2nd track,
 High-Pur (HP) = 3rd track.
- **Simple Secondary Vertex (SSV)**: at least
 2 (High-Eff) or
 3 (High-Pur) tracks in vertex fit.



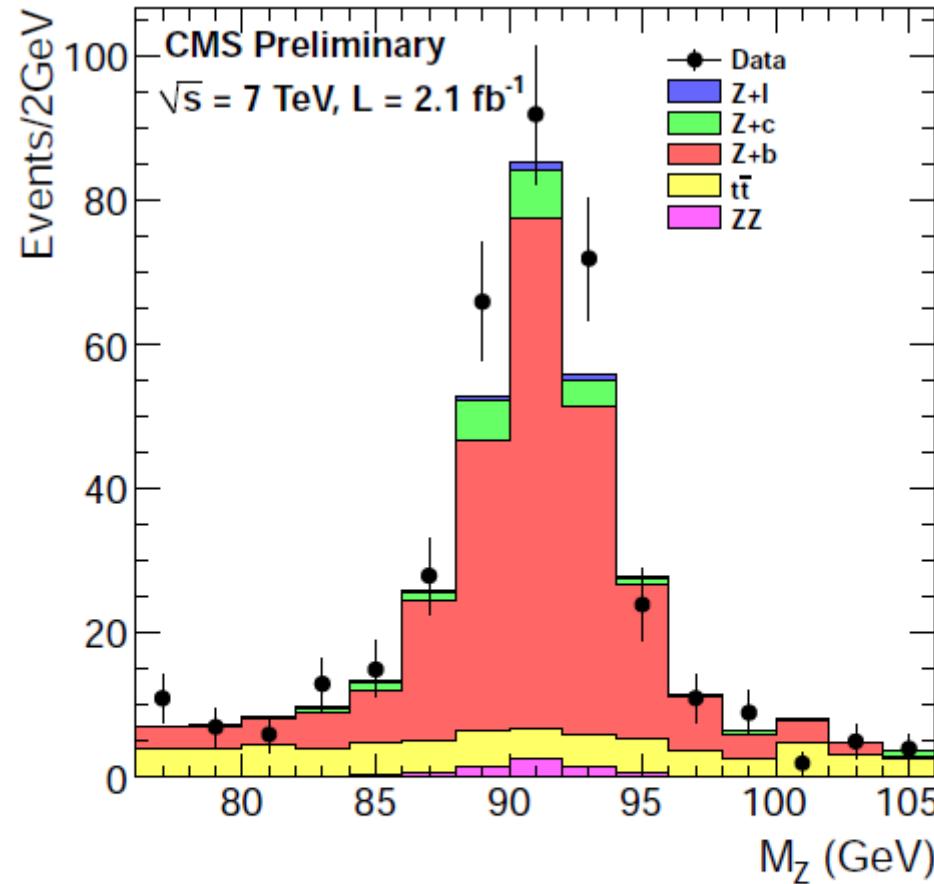
Working point	Requirement	Discriminant	Cut
SSVHEM	One secondary vertex with ≥ 2 tracks	$\text{Log}(1 + \frac{d_0}{\sigma_0})$	1.74
SSVHPT	One secondary vertex with ≥ 3 tracks		2.0

d_0/σ_0 = flight distance significance

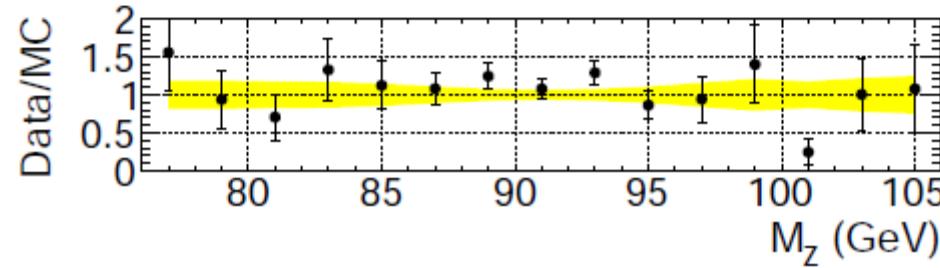
b-tagging



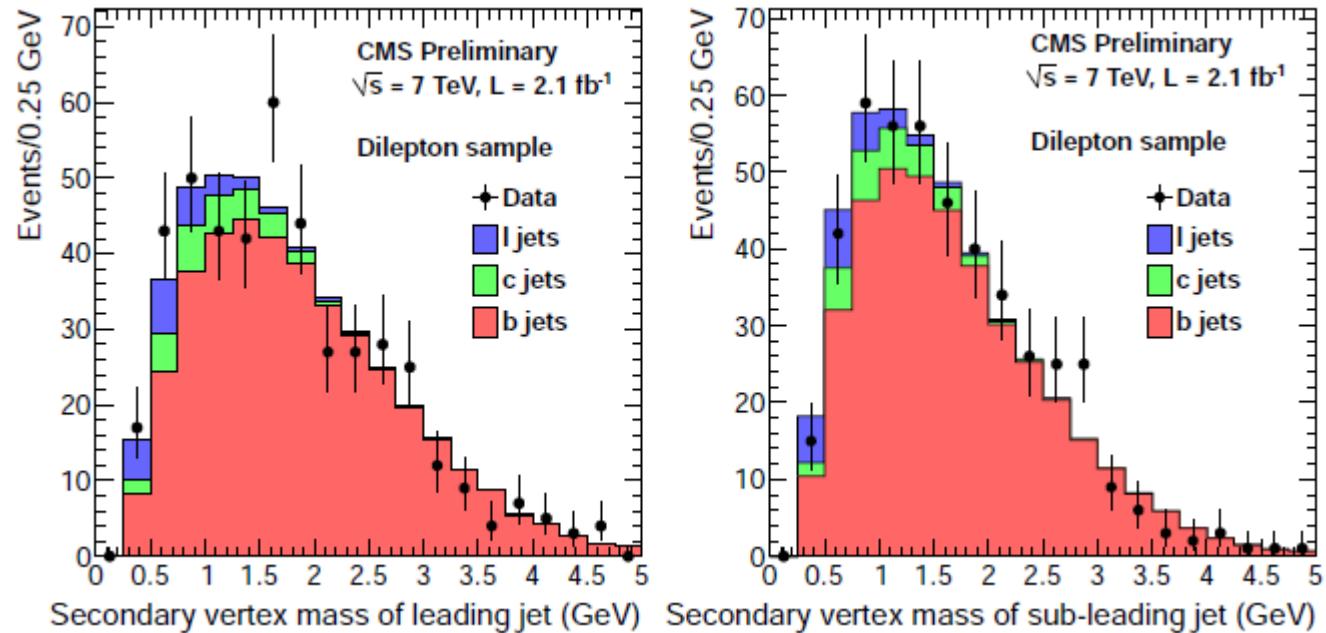
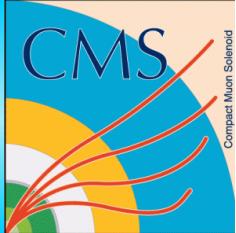
After Z + HE selection



Narrow Mass window



Secondary Vertices Mass fit

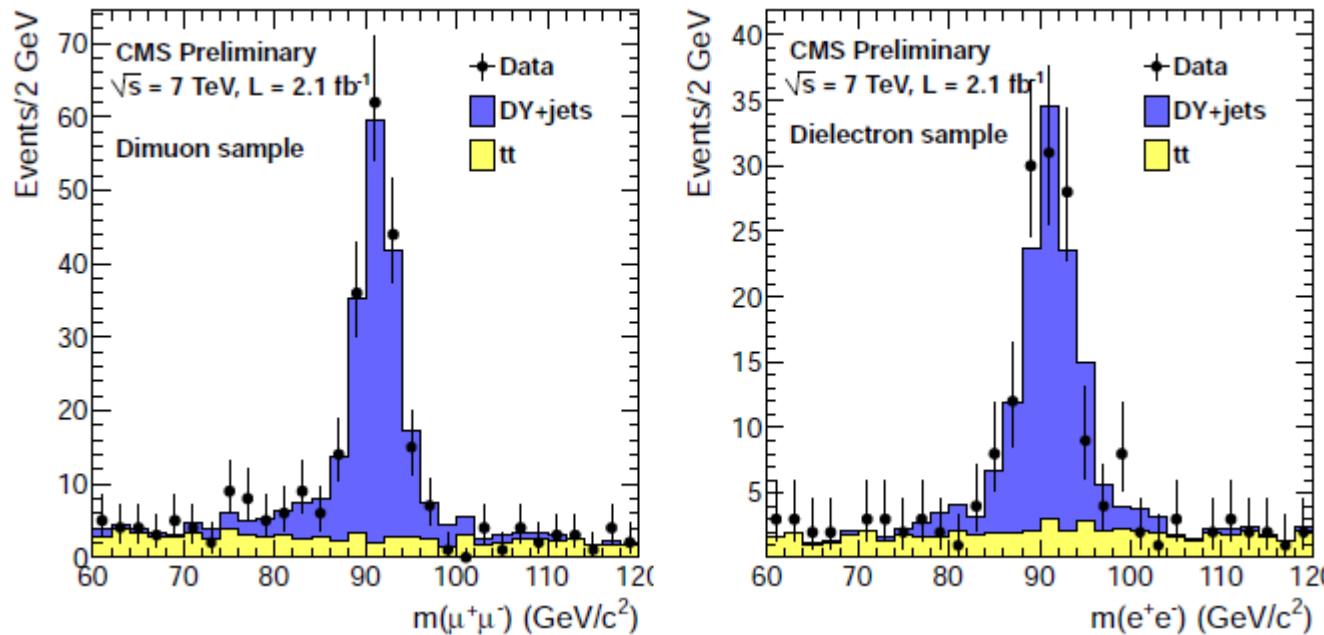
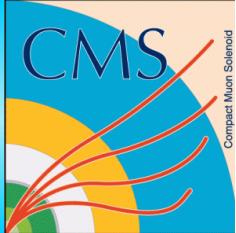


2*1D simultaneous fits

Purity :

$$f_{bb} = 1 - f_{cc} - f_{bl} - f_{lb} = (83.0 \pm 4.5) \%$$

Dilepton Mass fit Z+bb



Parameterizing the MC as binned pdf

Alternative = Z/g^* peak parameterize using a smooth key pdf
 + background as exponential curve with floating slope of pdf

$$f_{t\bar{t}}(\mu\mu) = (19 \pm 6)\% \text{ and } f_{t\bar{t}}(ee) = (17 \pm 7)\%,$$

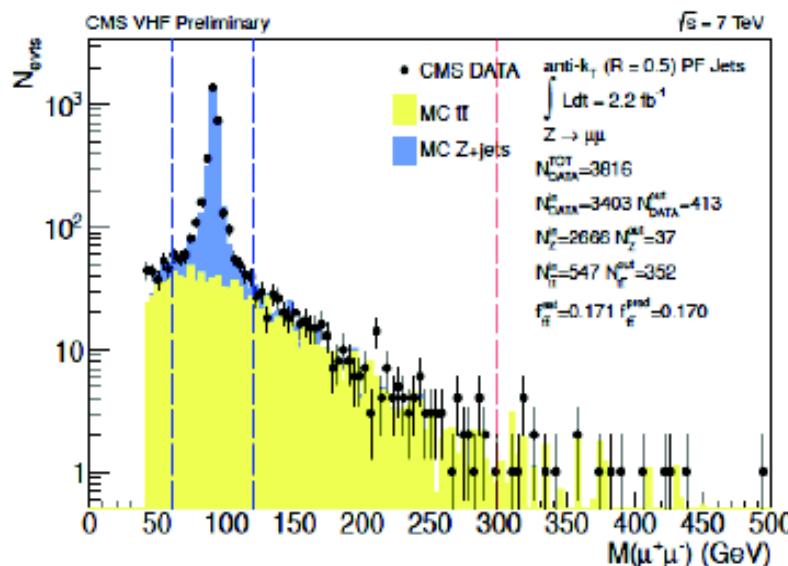
ttbar background estimation

- Method: discrimination variable fit
- ttbar background is extracted by extrapolation of the M(II) upper band under the signal region

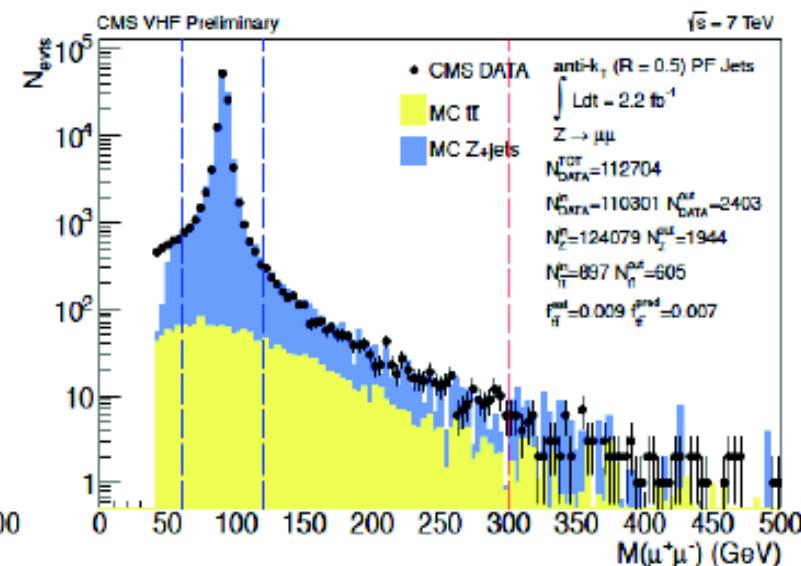
	$f_{t\bar{t}} \text{ (%)}$
ee+b	18.67 ± 2.16
$\mu\mu+b$	18.40 ± 2.27

$$N_{t\bar{t}}^{\text{est}}(\text{in}) = \left(\frac{\mathcal{R}_{t\bar{t}}^{\text{MC}}}{\mathcal{R}_Z^{\text{MC}} - \mathcal{R}_{t\bar{t}}^{\text{MC}}} \right) \times (\mathcal{R}_Z^{\text{MC}} \times N_{\text{obs}}(\text{out}) - N_{\text{obs}}(\text{in}))$$

$$\mathcal{R}_{t\bar{t}}^{\text{MC}} = N_{t\bar{t}}^{\text{MC}}(\text{in}) / N_{t\bar{t}}^{\text{MC}}(\text{out}) \quad \mathcal{R}_Z^{\text{MC}} = N_Z^{\text{MC}}(\text{in}) / N_Z^{\text{MC}}(\text{out})$$

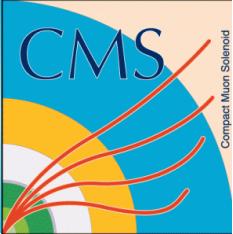


After Z+b



After Z+j

ZZ + Final Yields



- ZZ yields after selection and renormalization:

$$N_{\text{ZZ}}^{\mu\mu+\text{bb}} = 5.2 \pm 0.10 \text{ (stat.)} \pm 0.18 \text{ (syst.)}; N_{\text{ZZ}}^{ee+\text{bb}} = 3.0 \pm 0.10 \text{ (stat.)} \pm 0.14 \text{ (syst.)}$$

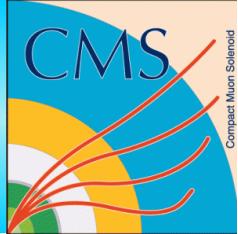
- Final yields :

$$N_{Z(\text{ll})+\text{bb}}^{\text{sig}} = N_{Z(\text{ll})+\text{bb}} \times (f_{\text{bb}} - f_{\bar{t}\bar{t}}) - N_{\text{ZZ}}.$$

Variable	Parameter	$\mu\mu + \text{bb}$	$ee + \text{bb}$
Z+bb yield	$N_{Z(\text{ll})+\text{bb}}$	219	148
bb-purity	f_{bb}	$(83 \pm 6)\%$	$(83 \pm 6)\%$
$t\bar{t}$ fraction	$f_{\bar{t}\bar{t}}$	$(20 \pm 5)\%$	$(17 \pm 5)\%$
Diboson yield	$N_{Z(\text{ll})Z(\text{bb})}$	5.2 ± 0.2	3.0 ± 0.2

	data	ZZ	$t\bar{t}$	Z+b	Z+c	Z+l	Total MC	Ratio	Deviation	S/B	S/sqrt(S+B)
Z+bb [HE*HE]	484 ± 22.0	8.3 ± 0.2	175.4 ± 4.0	240.7 ± 6.6	21.9 ± 2.0	3.0 ± 0.7	449.3 ± 8.0	1.08	1.48	1.2	11.4
Z+bb [HE*HE]+ E_T^{miss}	365 ± 19.1	8.2 ± 0.2	60.3 ± 2.3	235.8 ± 6.5	21.6 ± 2.0	3.0 ± 0.7	328.9 ± 7.2	1.11	1.77	2.5	13.0
Z+bb [HP*HP]	204 ± 14.3	3.6 ± 0.1	87.3 ± 2.8	105.5 ± 4.3	1.7 ± 0.6	0.0 ± 0.0	198.1 ± 5.2	1.03	0.39	1.1	7.5
Z+bb [HP*HP]+ E_T^{miss}	142 ± 11.9	3.5 ± 0.1	28.7 ± 1.6	103.7 ± 4.3	1.7 ± 0.6	0.0 ± 0.0	137.6 ± 4.6	1.03	0.34	3.1	8.8

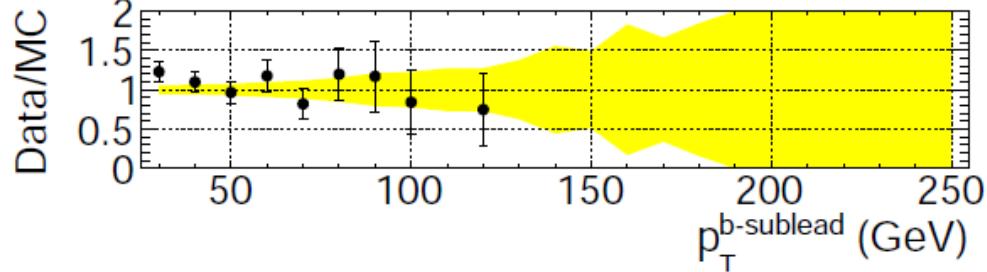
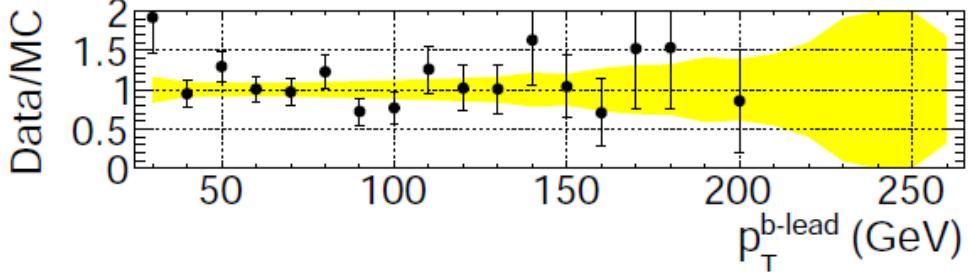
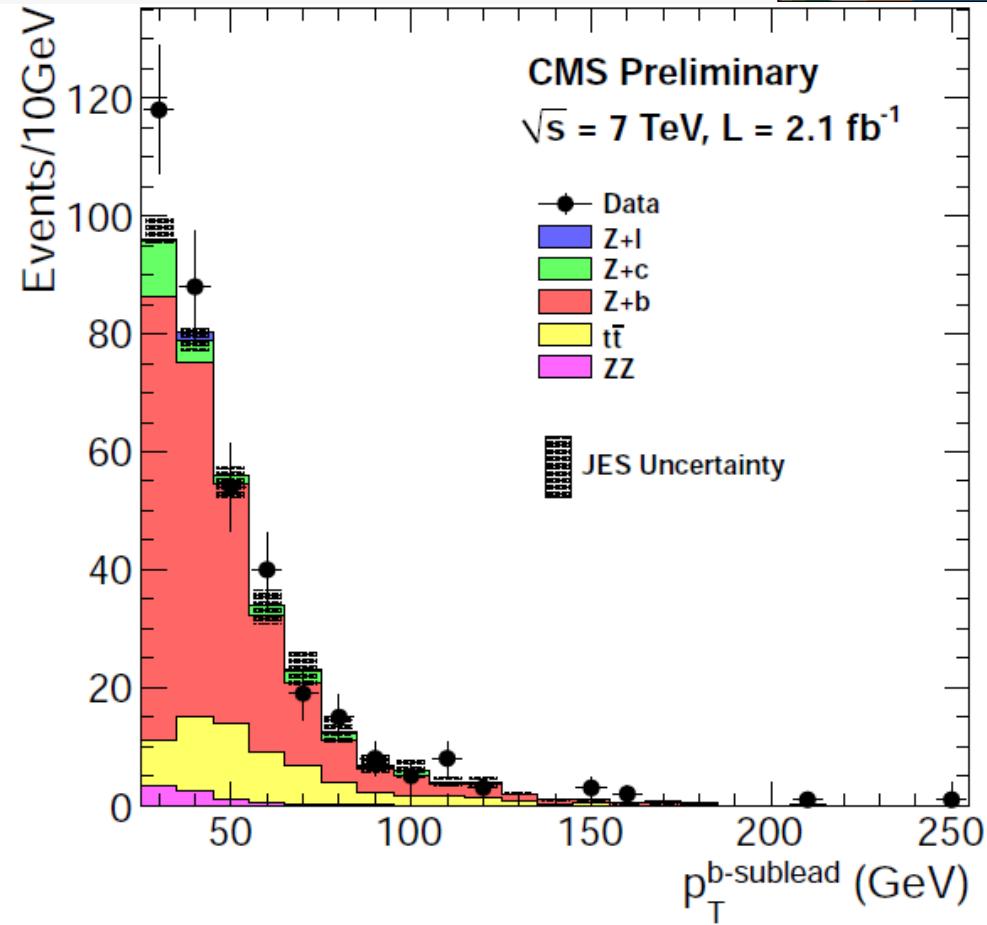
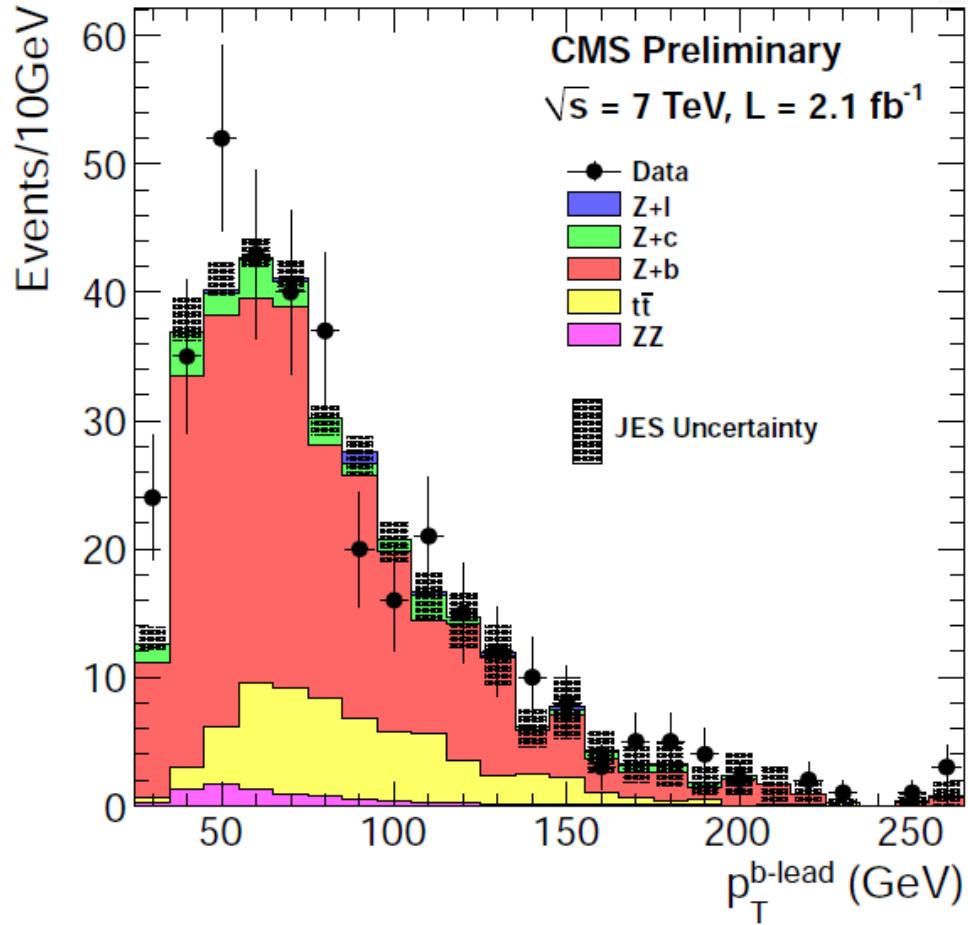
Systematics table



	ee(%)		$\mu\mu$ (%)	
Correlated sources	Z+1b	Z+2b	Z+1b	Z+2b
b-jet purity	3.5	10.3	2.5	11.0
t <bar>t</bar>				
b-tagging efficiency	4.0	7.4	3.9	7.5
Jet energy scale	3.9	6.9	3.8	6.4
Luminosity	4.5	4.5	4.5	4.5
E_T^{miss} selection	0.3	2.4	0.3	2.4
Pileup	1.7	1.8	0.3	0.3
ZZ contribution	0.1	0.5	0.1	0.7
Jet energy resolution	0.1	0.2	0.1	0.1
Mistagging rate	0.02	0.08	0.02	0.07
Theory (via \mathcal{A}_l)	1.8	5.9	3.0	6.4
Uncorrelated sources	Z+1b	Z+2b	Z+1b	Z+2b
MC sample stat.	1.2	5.1	0.9	4.2
Dilepton selection	4.0	4.0	1.9	1.9
Statistical	2.4	10.0	1.8	8.2
Experimental systematic	9.1	18.9	7.7	18.8
Theoretical systematic	1.8	5.9	3.0	6.4

Kinematics

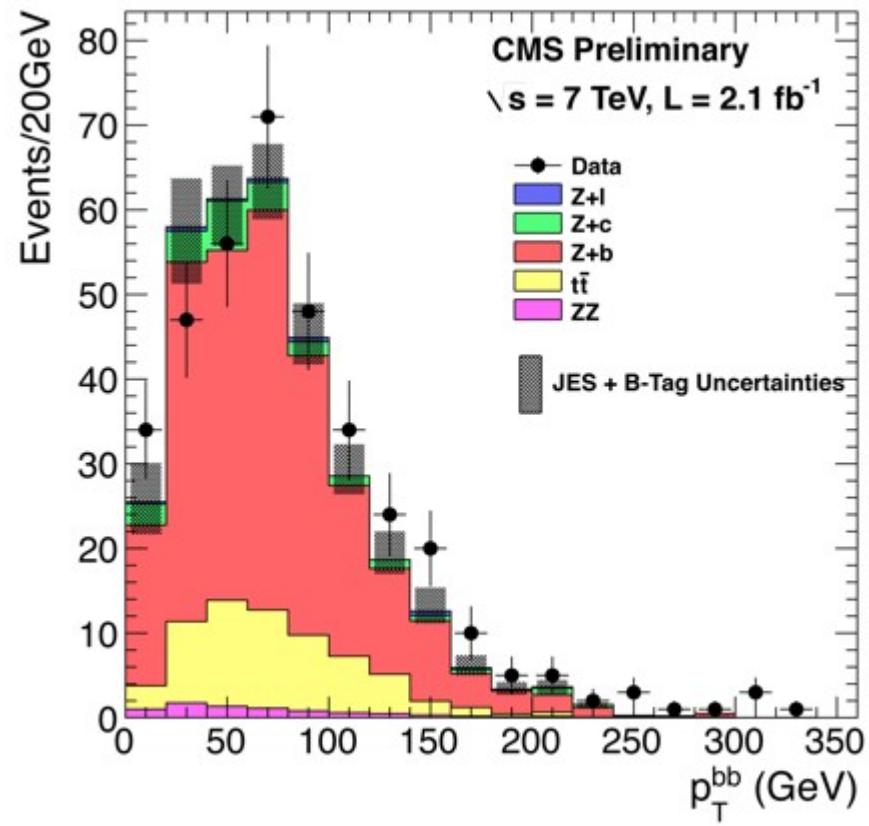
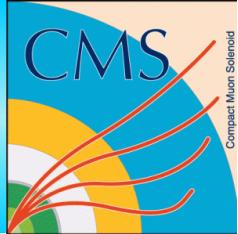
Z + 2b[HE] + MET



Additional jet VETO does not remove the overall excess of data

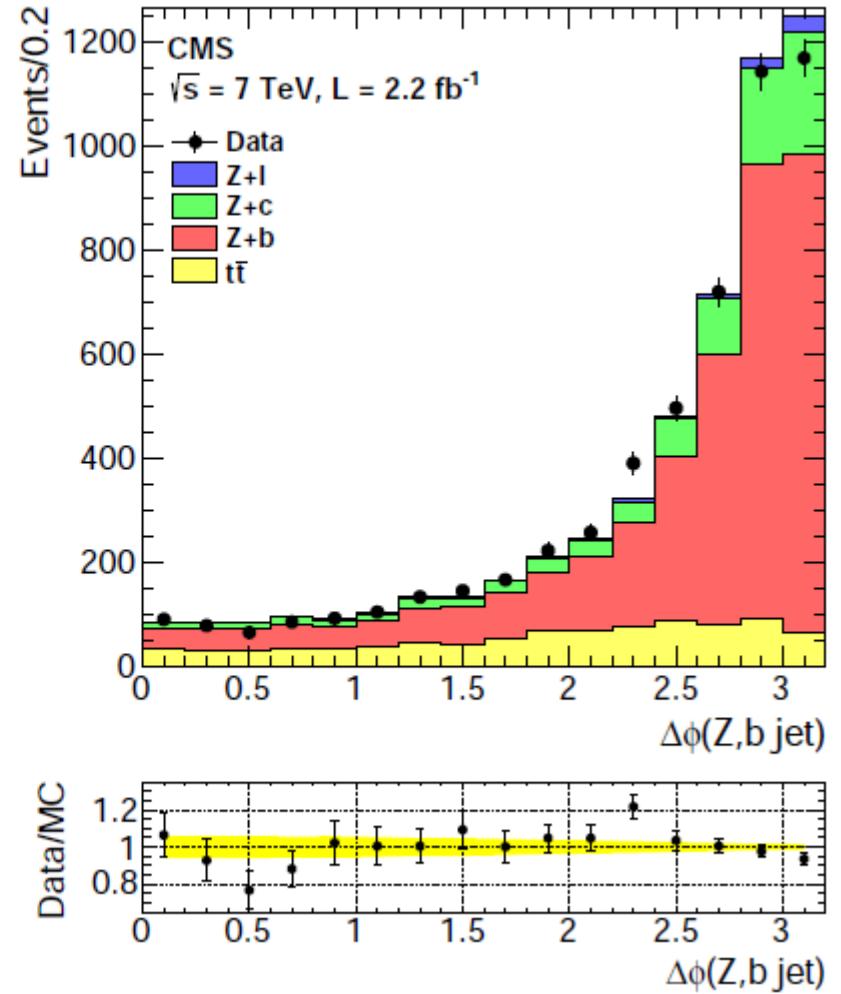
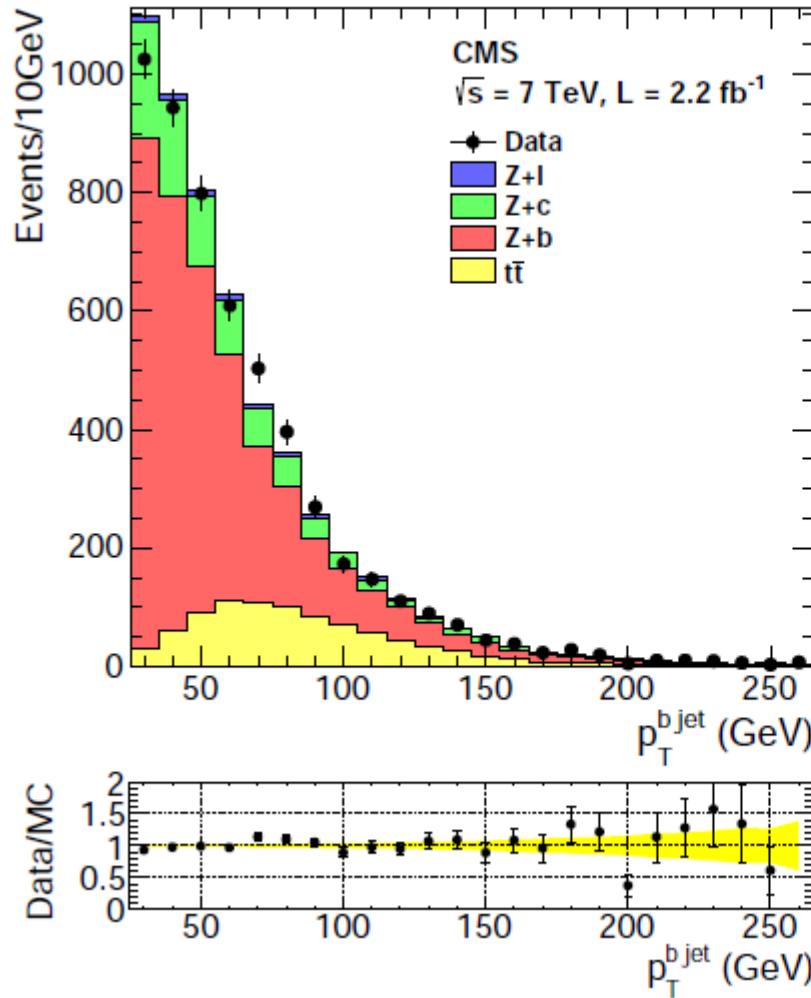
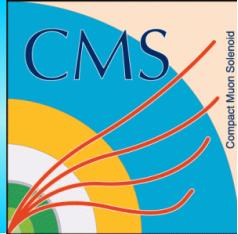
Kinematics

Z + 2b[HE] + MET

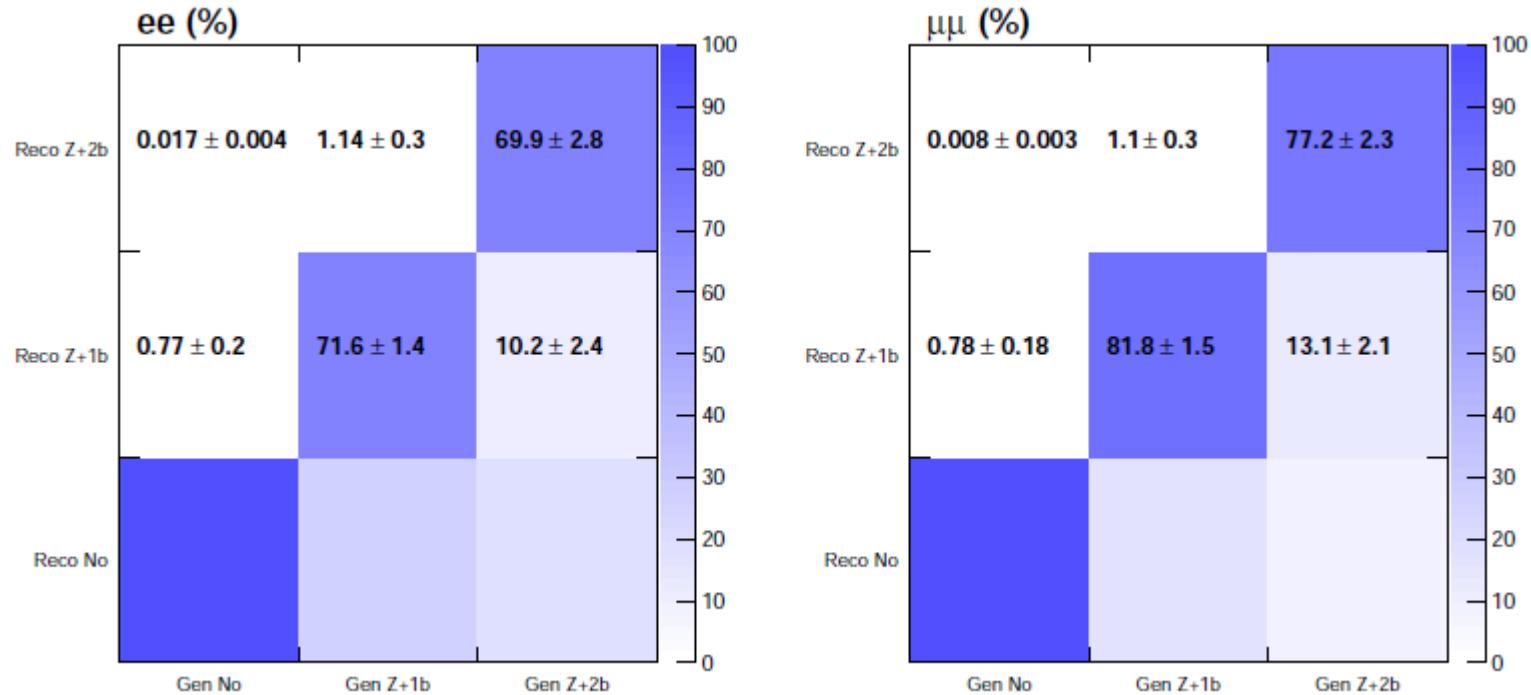
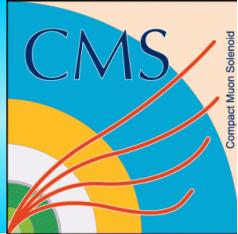


Kinematics

$Z + 1b$



Migration Matrices





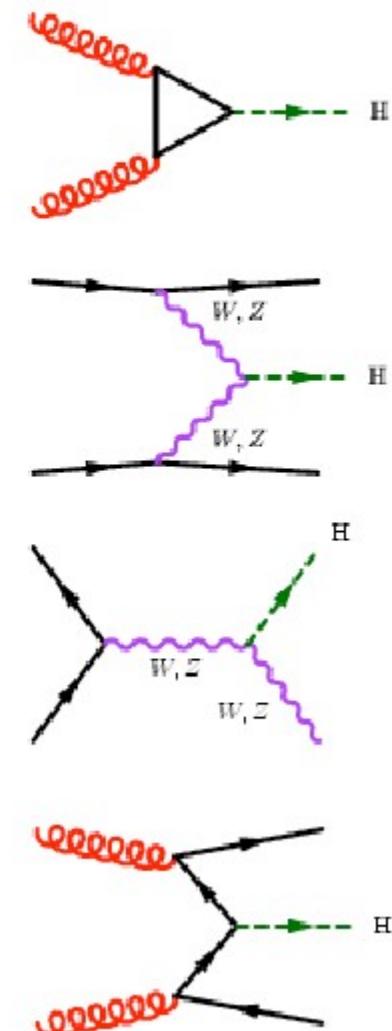
Cross Sections



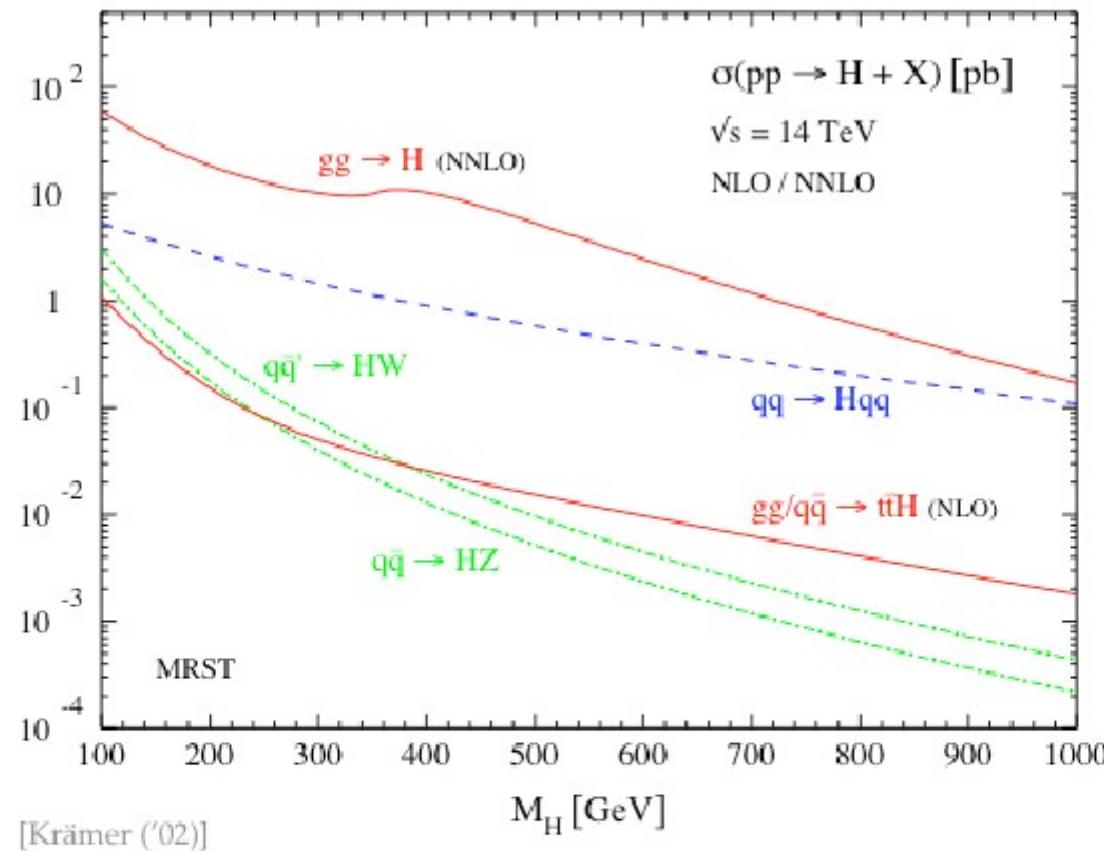
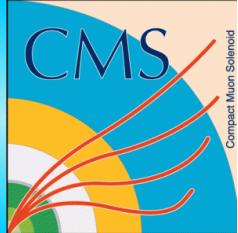
Multiplicity bin	ee	$\mu\mu$
$\sigma_{hadron}(Z+1b, Z \rightarrow \ell\ell)(pb)$	$3.25 \pm 0.08 \pm 0.29 \pm 0.06$	$3.47 \pm 0.06 \pm 0.27 \pm 0.11$
$\sigma_{hadron}(Z+2b, Z \rightarrow \ell\ell)(pb)$	$0.39 \pm 0.04 \pm 0.07 \pm 0.02$	$0.36 \pm 0.03 \pm 0.07 \pm 0.03$
$\sigma_{hadron}(Z+b, Z \rightarrow \ell\ell)(pb)$	$3.64 \pm 0.09 \pm 0.35 \pm 0.08$	$3.83 \pm 0.07 \pm 0.31 \pm 0.14$

In proton collisions at 14 TeV, and for $M_H > 100$ GeV the Higgs is produced mostly via

- gluon fusion $gg \rightarrow H$
 - largest rate for all M_H
 - proportional to the top Yukawa coupling y_t
- weak-boson fusion (WBF) $qq \rightarrow qqH$
 - second largest rate (mostly $u d$ initial state)
 - proportional to the WWH coupling
- Higgs-strahlung $q\bar{q} \rightarrow W(Z)H$
 - third largest rate
 - same coupling as in WBF
- $t\bar{t}(b\bar{b})H$ associated production
 - same initial state as in gluon fusion, but higher x range
 - proportional to the heavy-quark Yukawa coupling y_Q



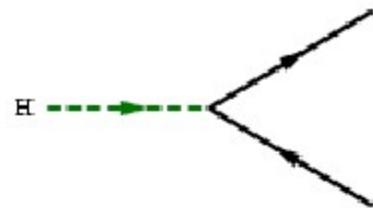
SM Higgs production at LHC



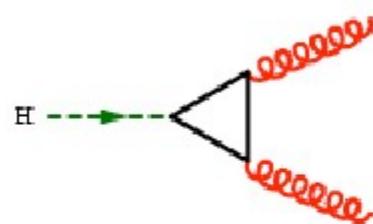
in the intermediate Higgs mass range $M_H \sim 100 - 200$ GeV

- gluon fusion cross section is $\sim 20 - 60$ pb
- WBF cross section is $\sim 3 - 5$ pb
- $WH, ZH, t\bar{t}H$ yield cross sections of $\sim 0.2 - 3$ pb

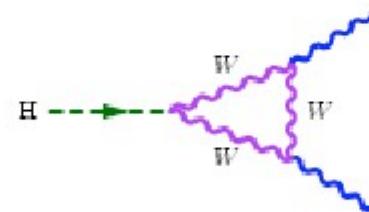
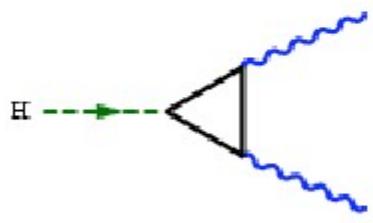
SM Higgs Decay



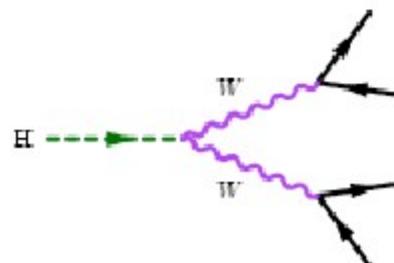
proportional to the Yukawa coupling squared,
and thus to m_f^2



proportional to m_f^4/m_H^4
but dominated by top quark Yukawa coupling

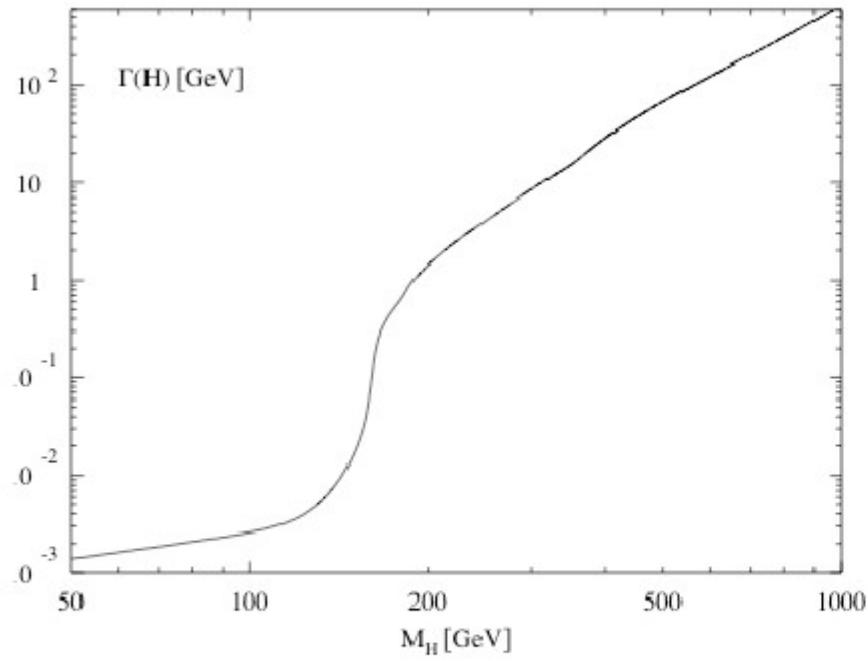
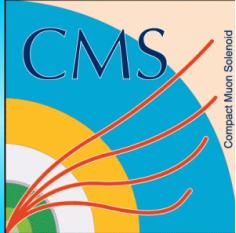


dominated by EW coupling

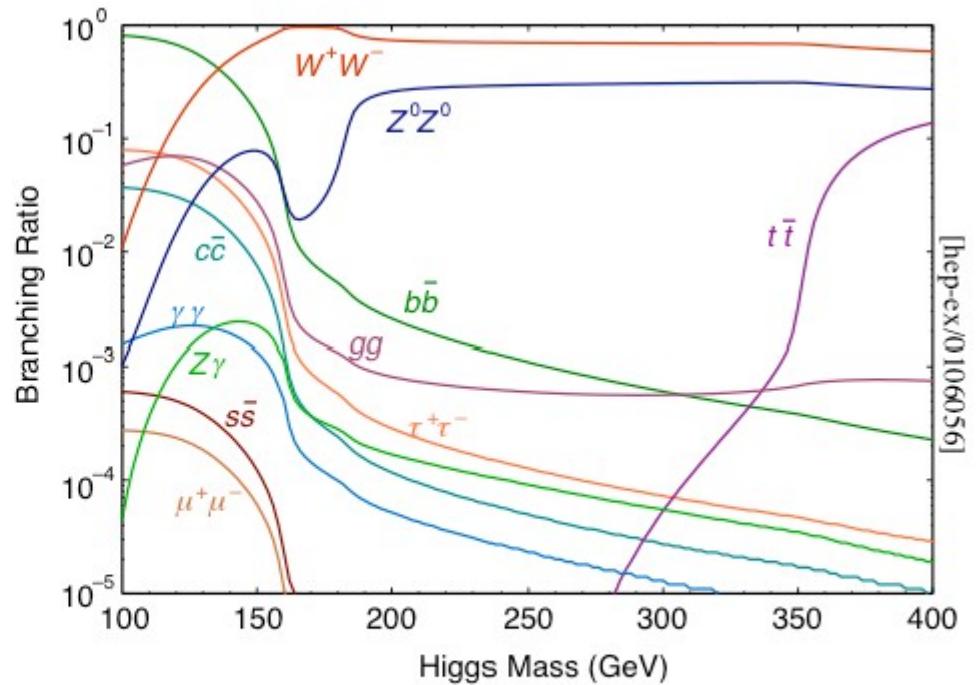


proportional to α_W
Decay width into W^*W^* plays a significant role

SM Higgs Decay



total width



branching fractions