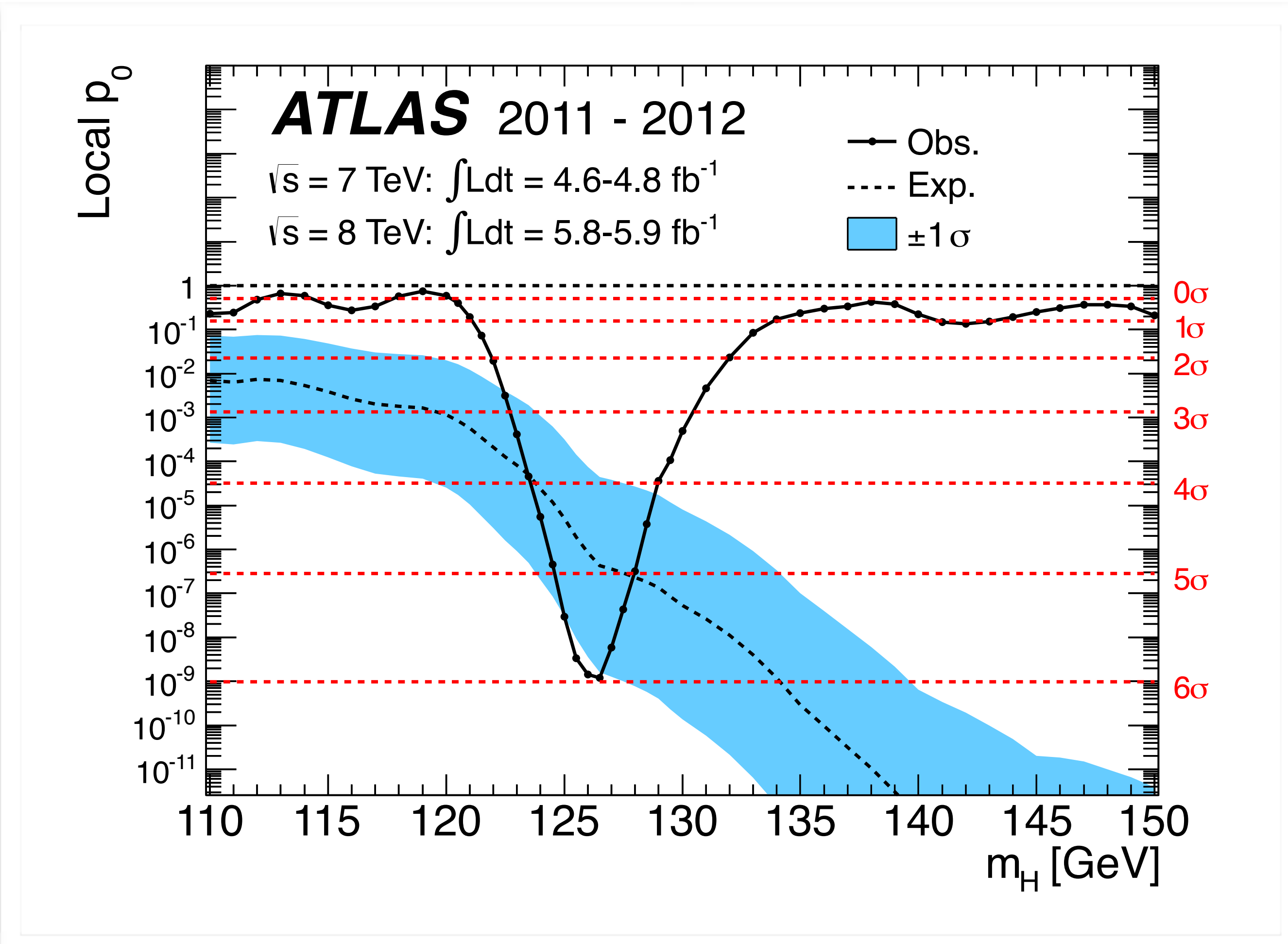
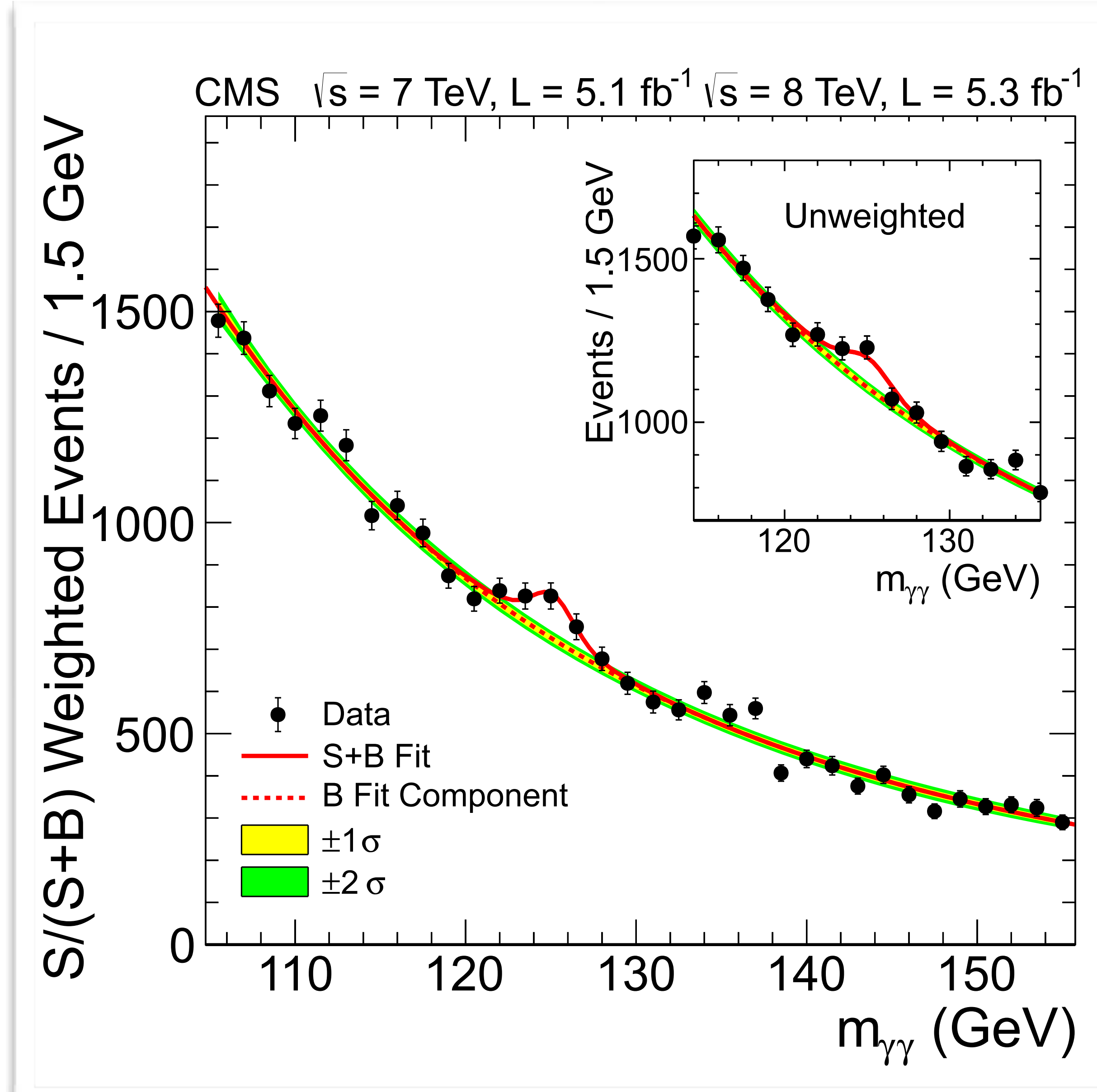
How to find a Higgs boson

Heather M. Gray, CERN
(へざあ)

higgs discovery (発見)





Seminar on 4 July 2012 by the ATLAS and CMS collaborations

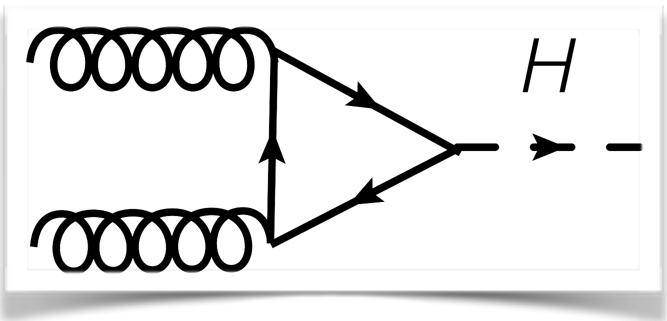
this talk (この話)

- NOT about the Higgs discovery
- NOT to discuss the latest Higgs results
  - There are many and they are interesting
  - Ask me about them later if you like
- But rather, to try to explain how we go about doing a Higgs analysis using a specific example
- Example: http://link.springer.com/article/10.1007/JHEP01(2015)069

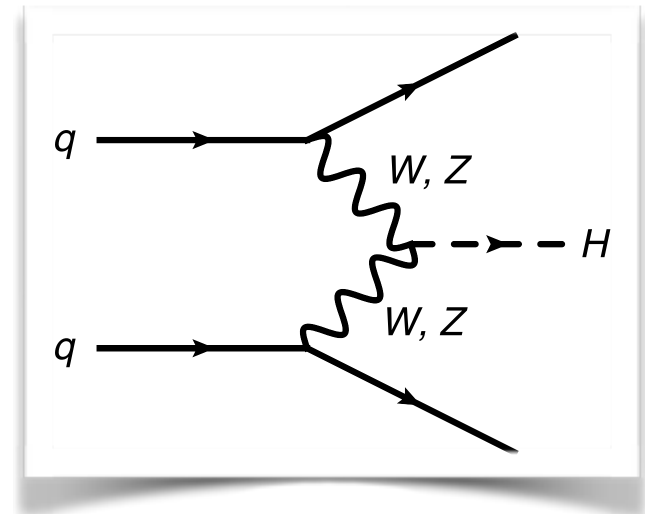
choose your channel I

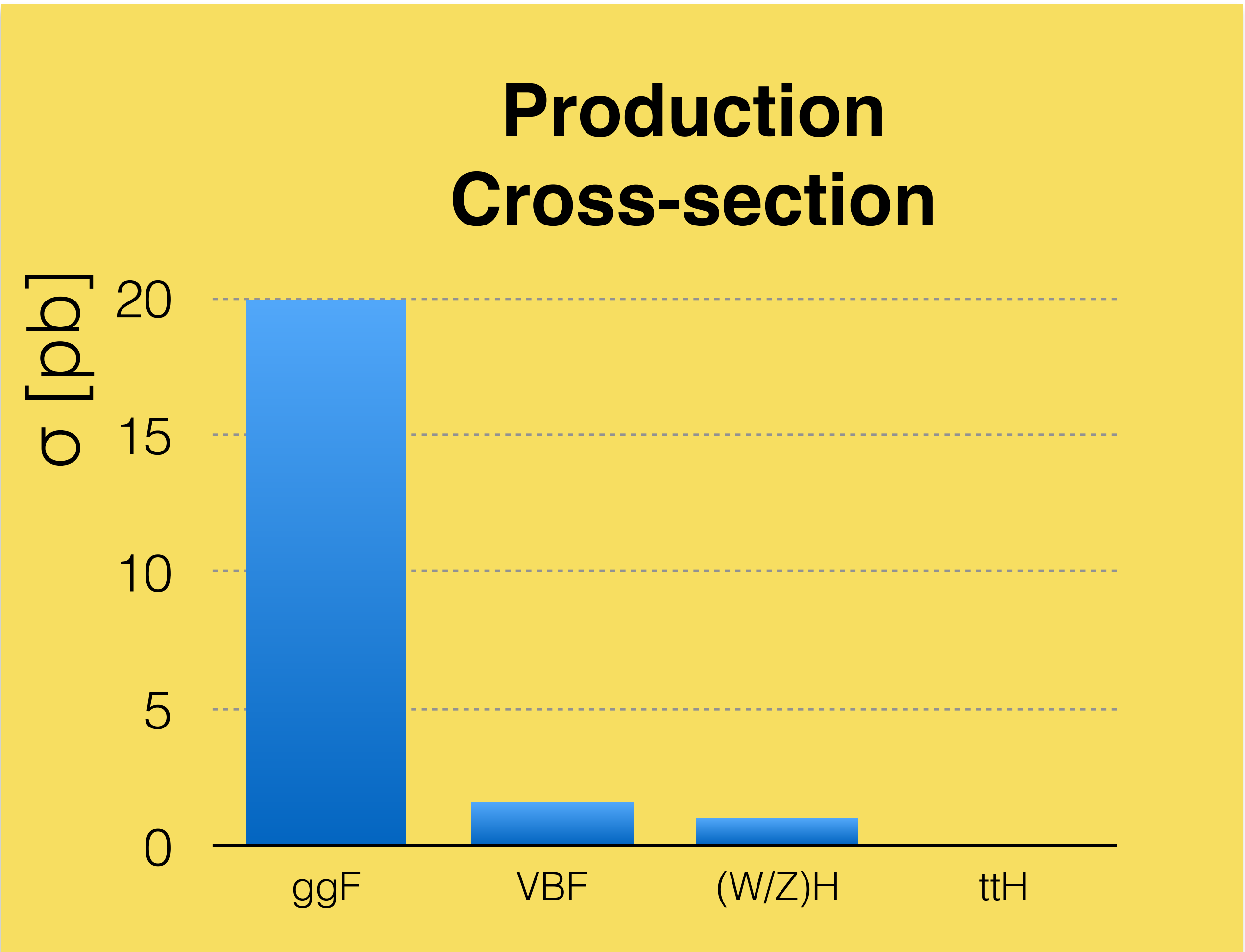
(あなたのチャンネルを選択)

Gluon fusion

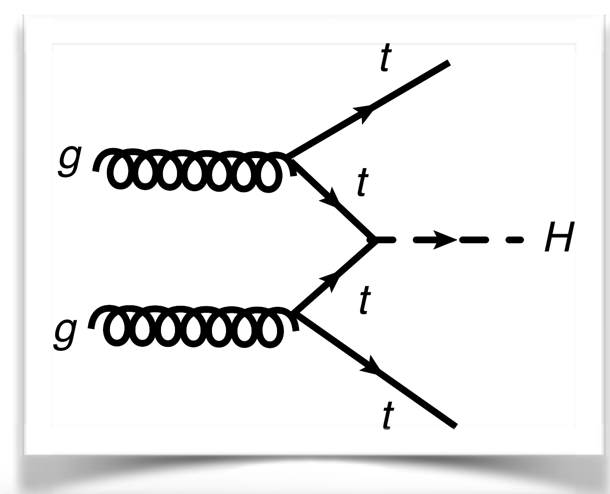


Vector Boson Fusion (VBF)

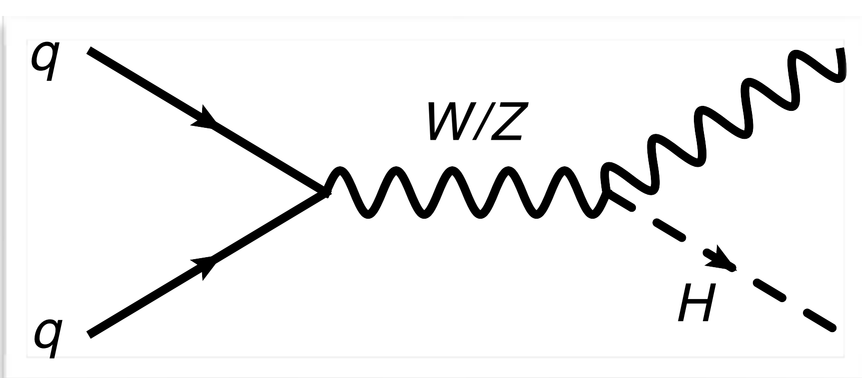




ttH Production

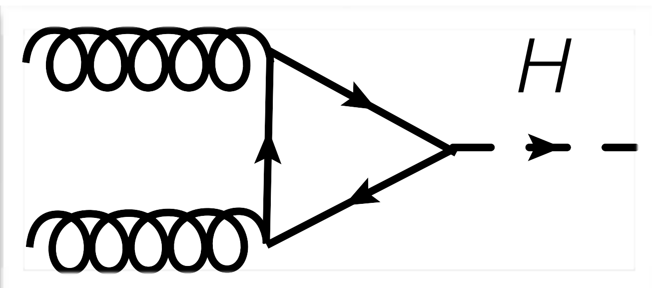


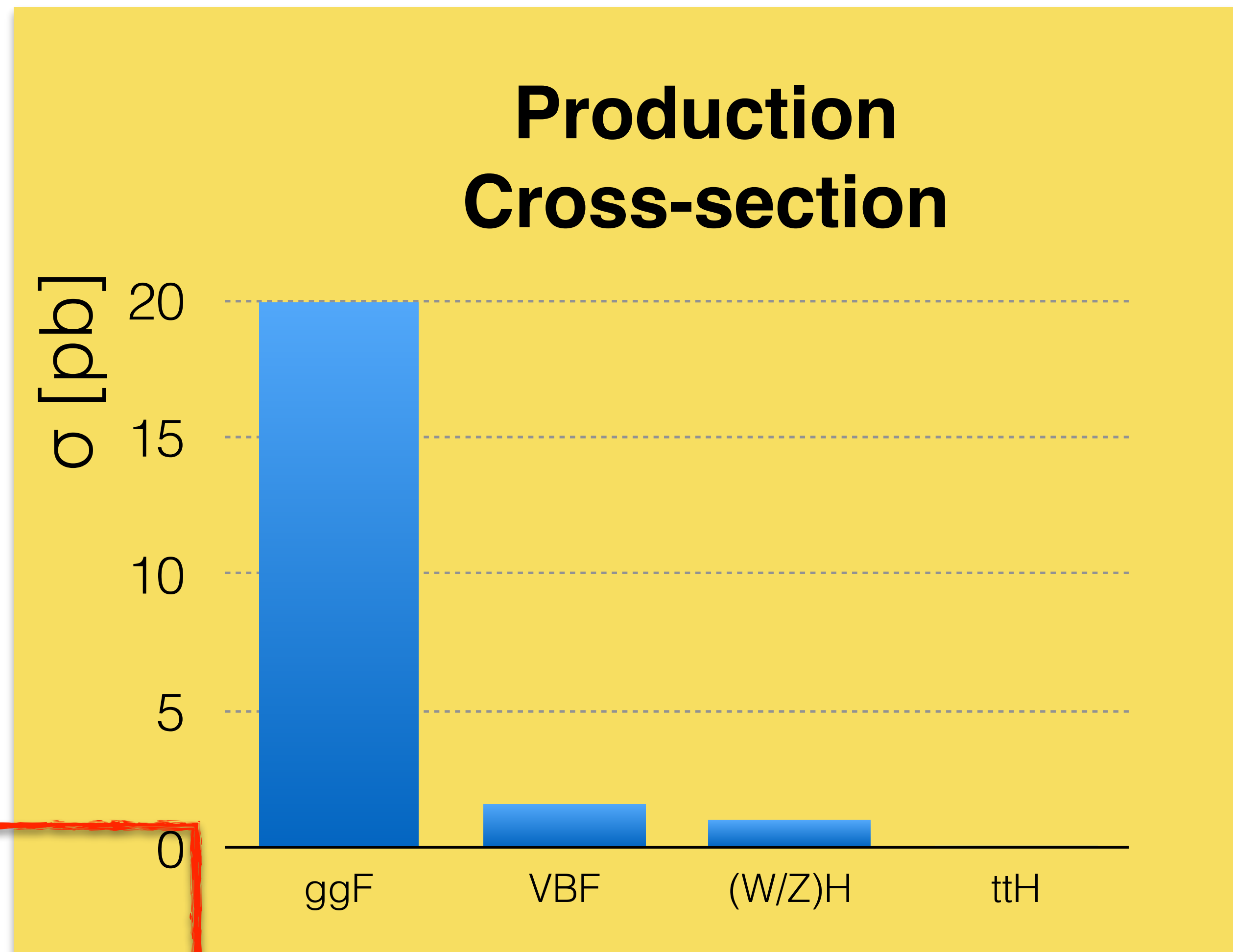
(W/Z)
Production



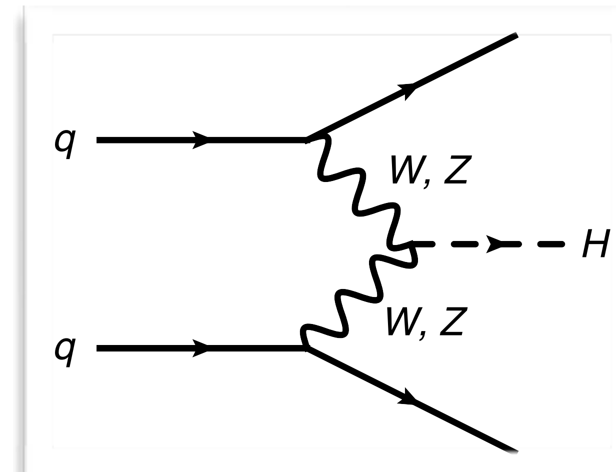
choose your channel I
(あなたのチャンネルを選択)

Gluon fusion

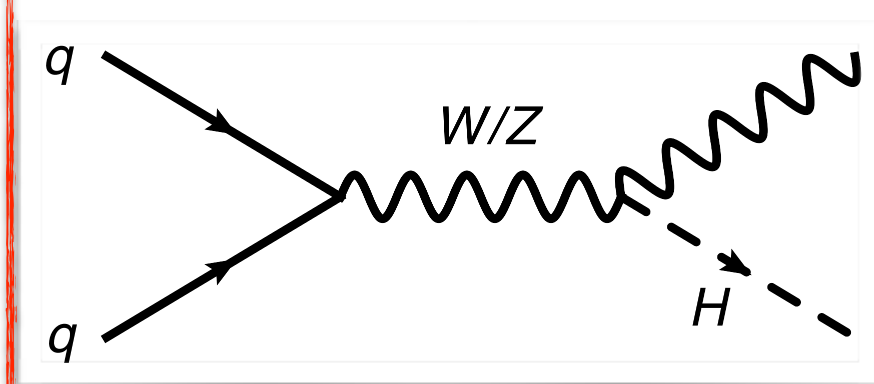




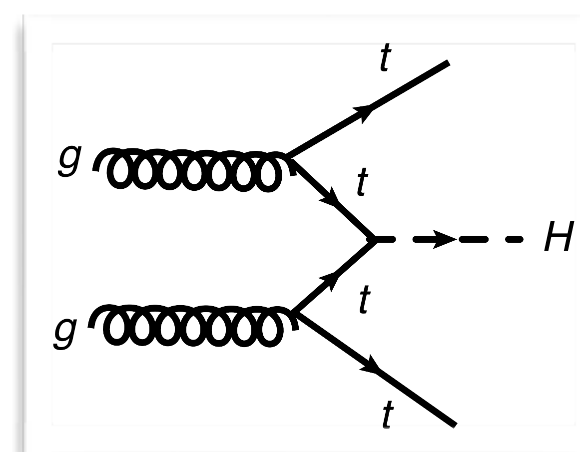
Vector Boson Fusion (VBF)



(W/Z) Production

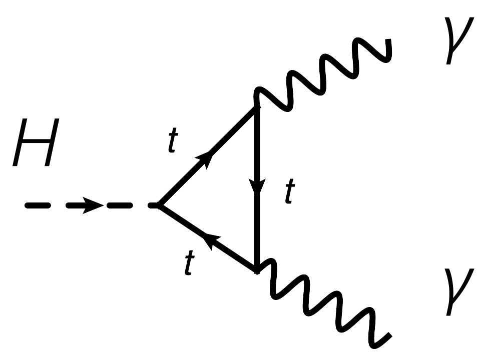


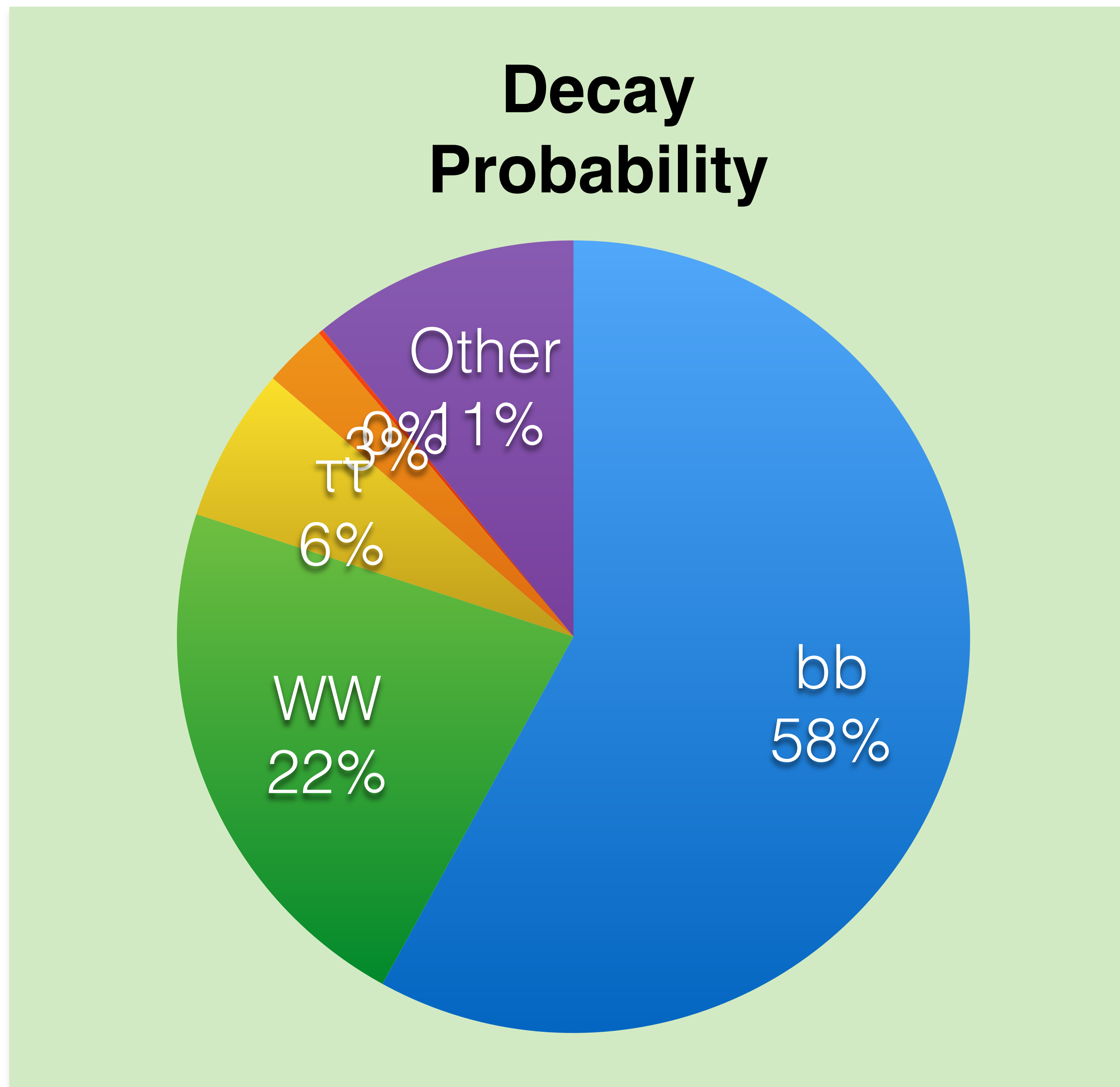
ttH Production

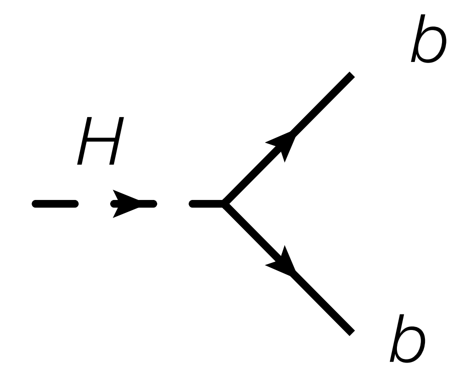


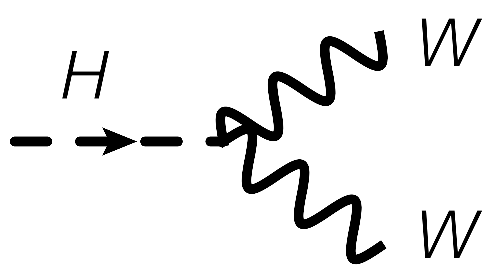
choose your channel II

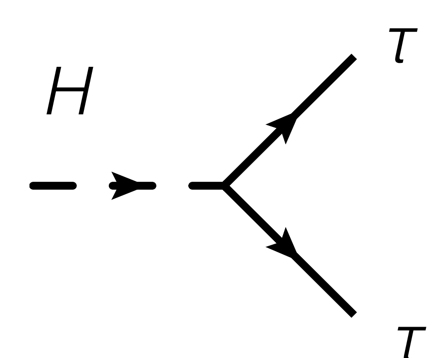
(あなたのチャンネルを選択)

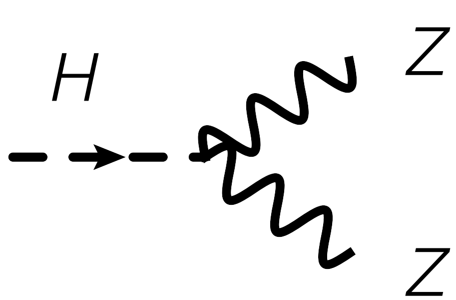






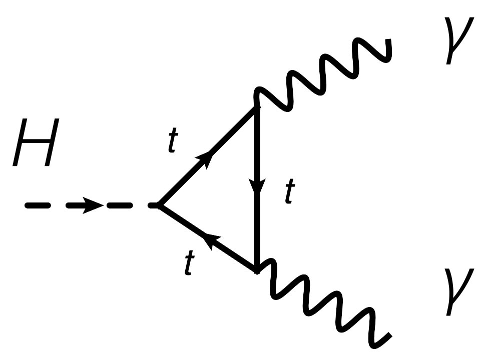


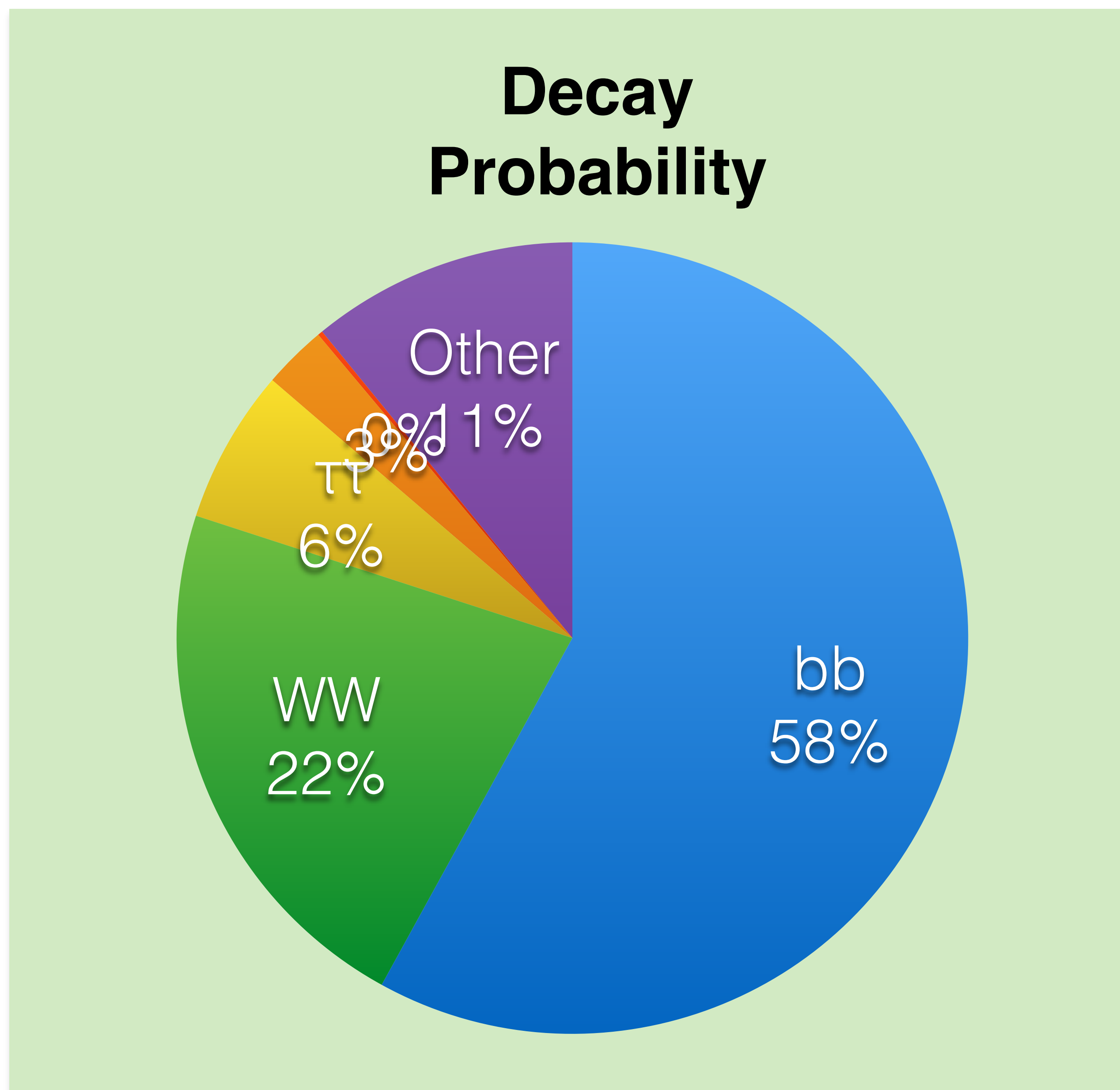


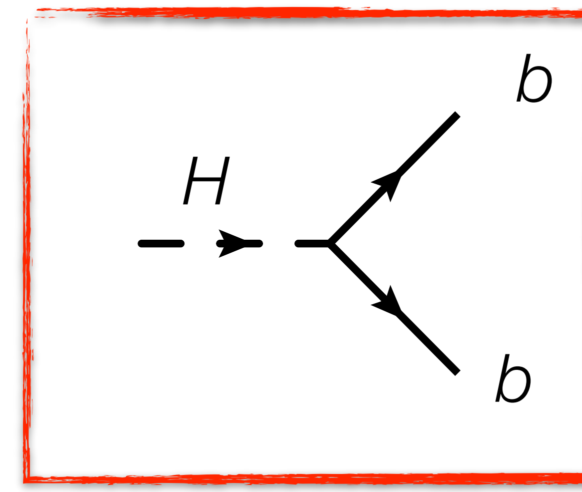


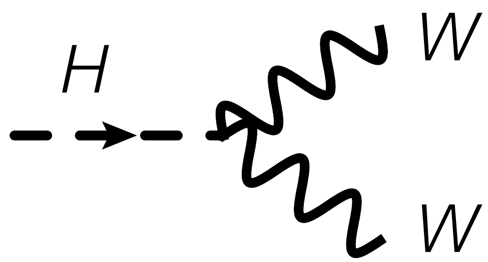
choose your channel II

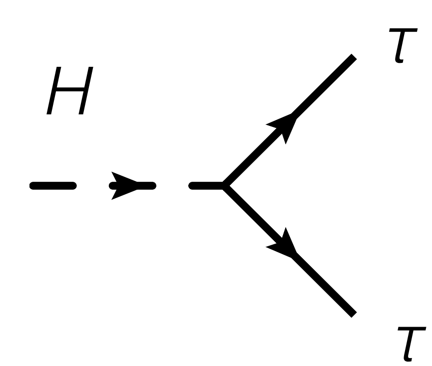
(あなたのチャンネルを選択)

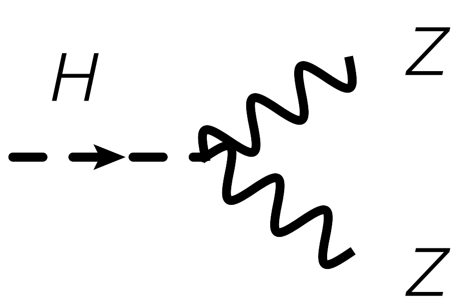






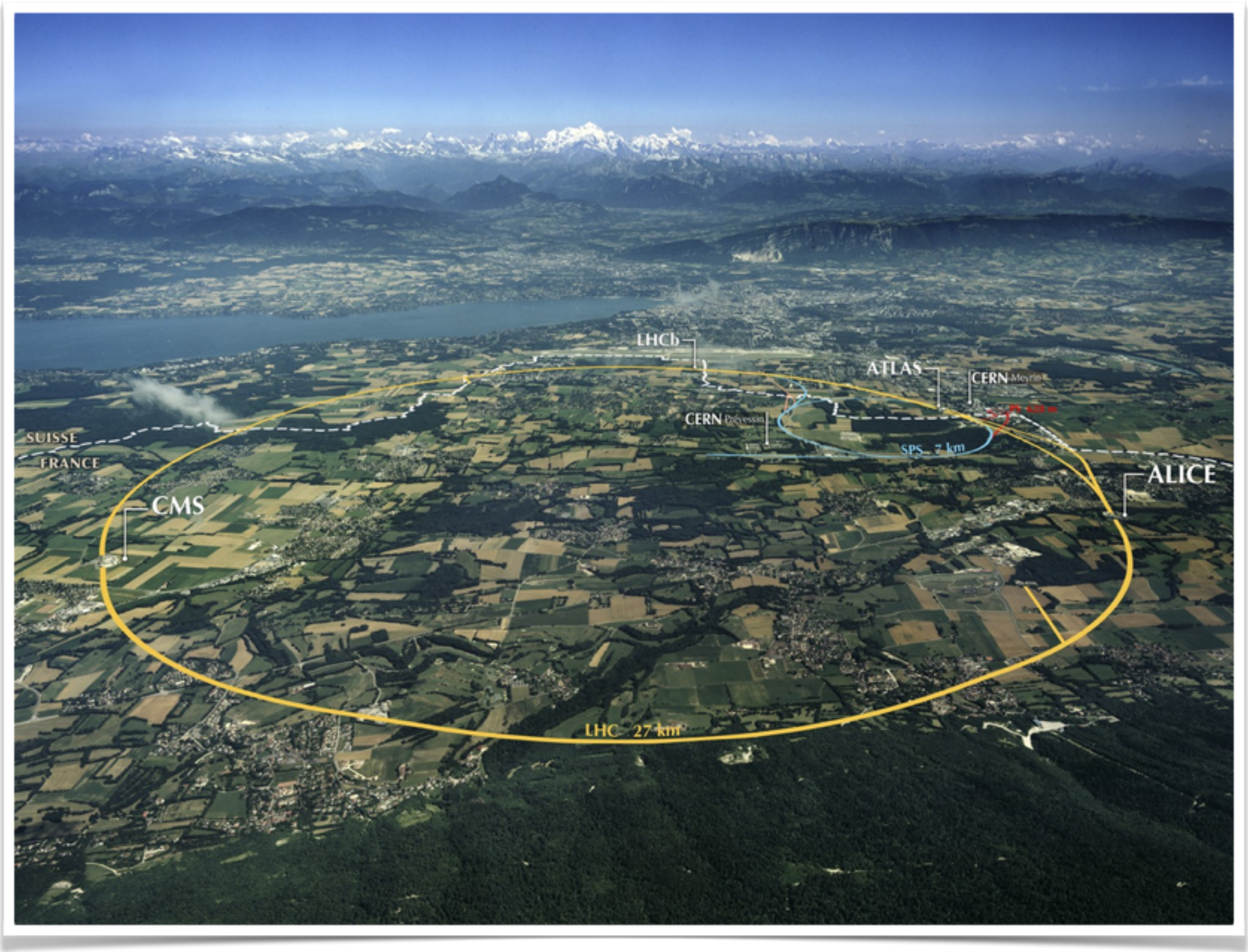






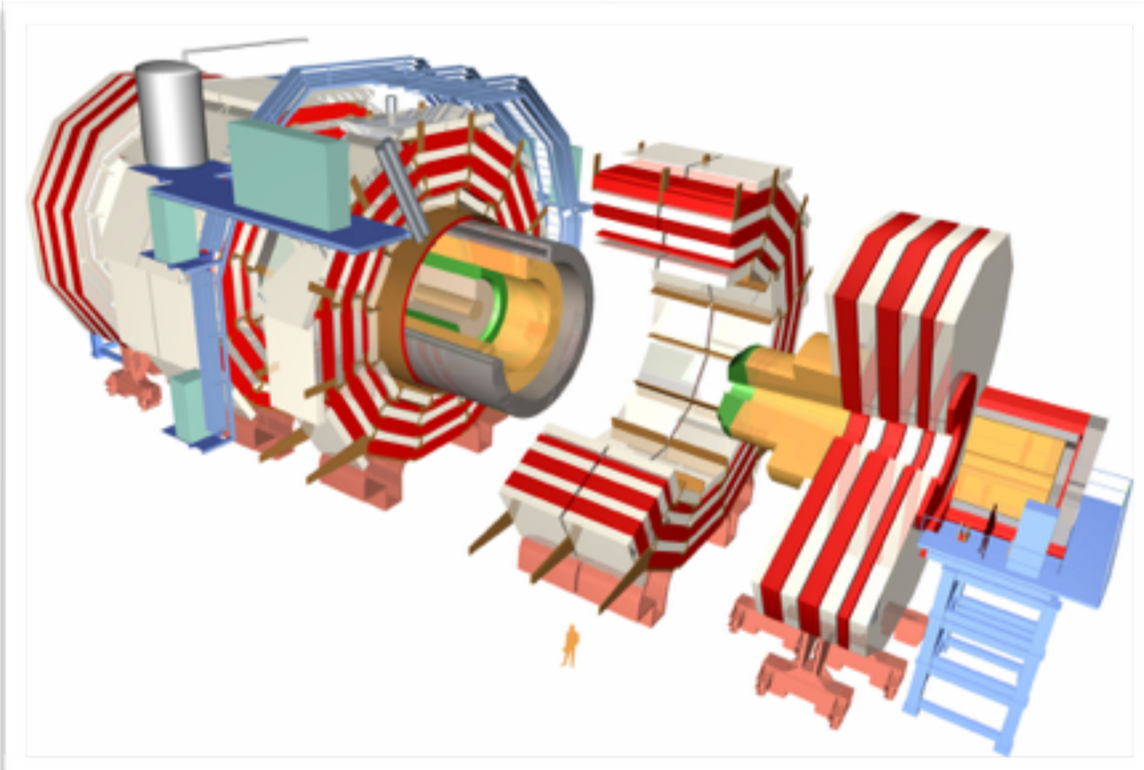
build a billion dollar collider

(十億ドルの加速器の建設)



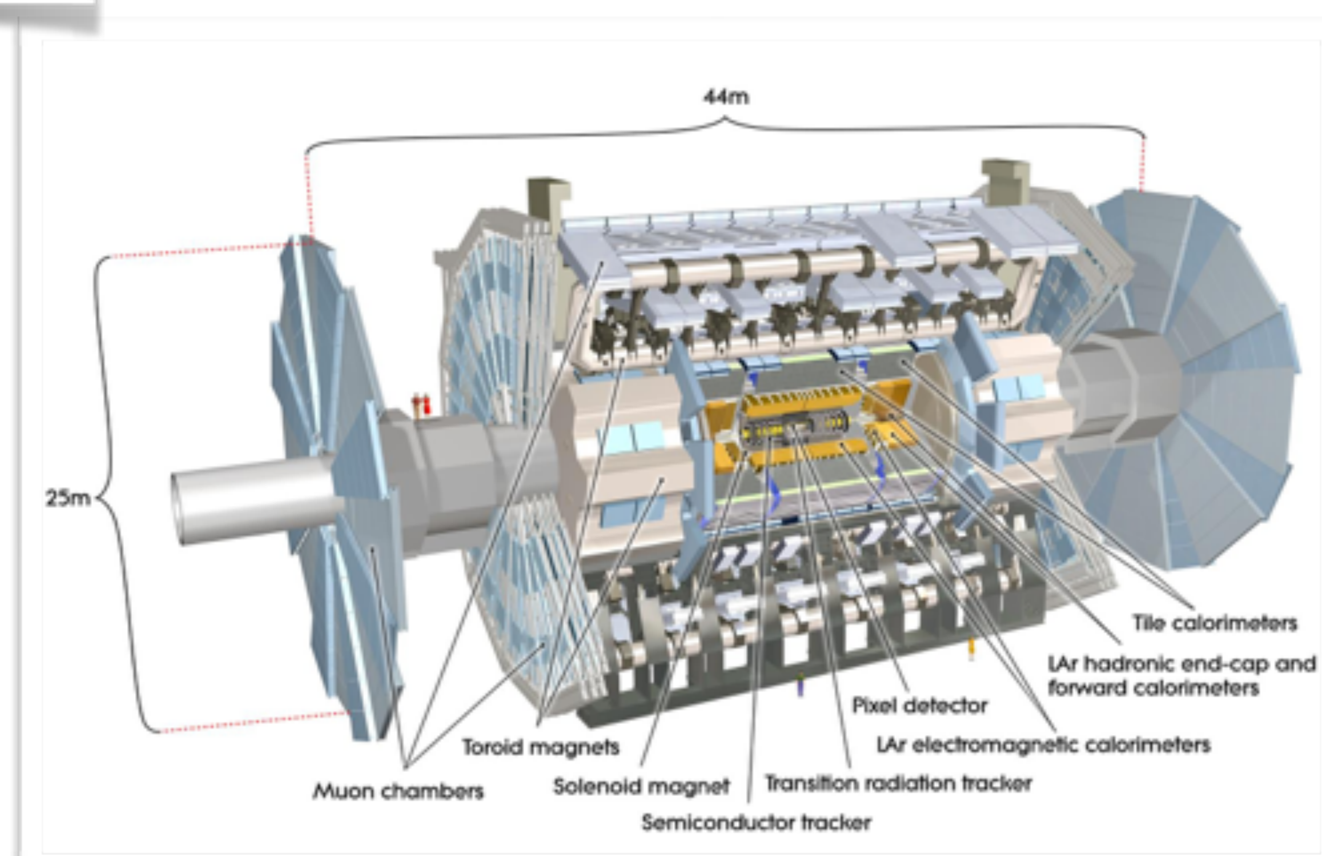
and a couple million dollar detectors

(そして数百万ドルの検出器)

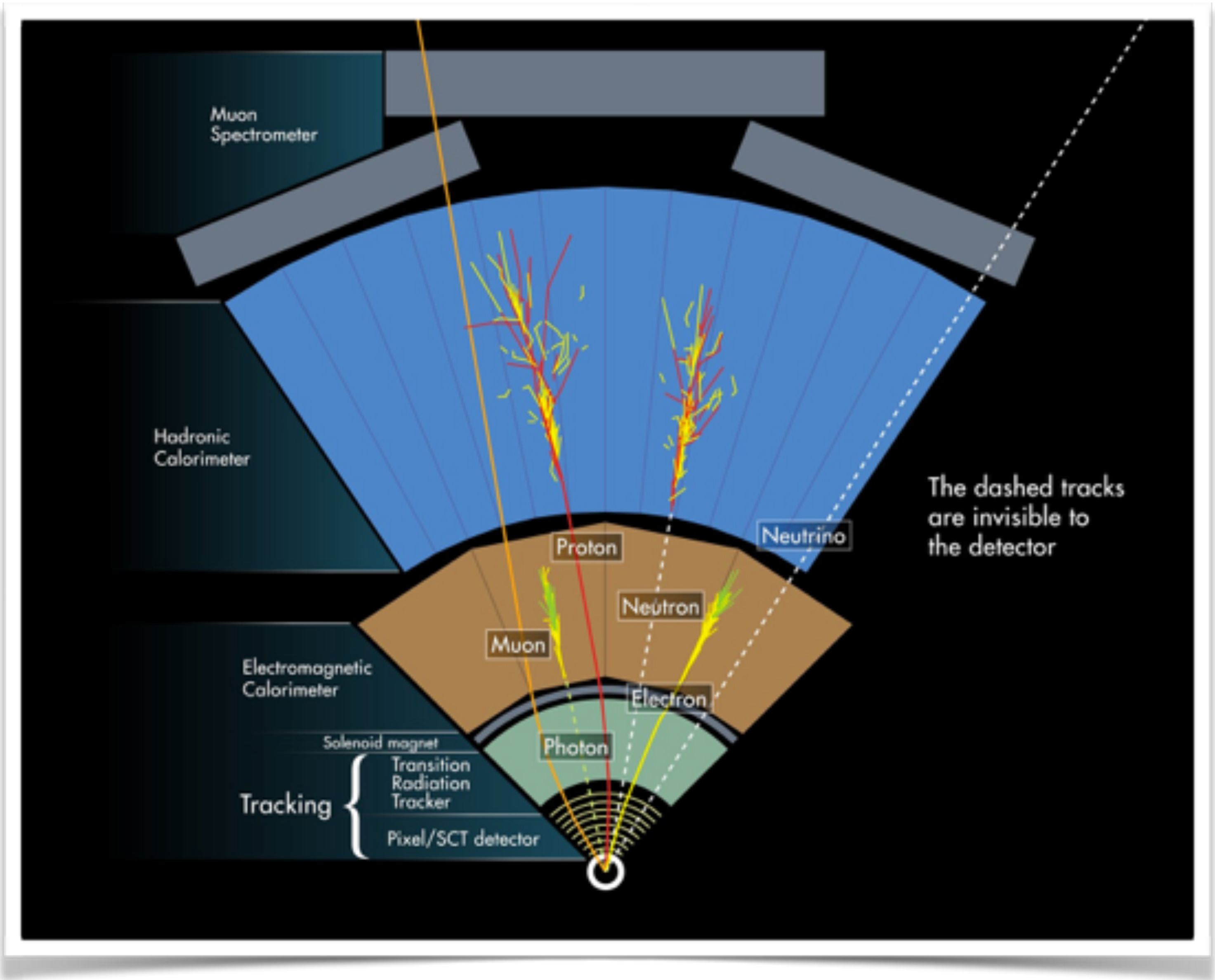


CMS
(Compact Muon Solenoid)

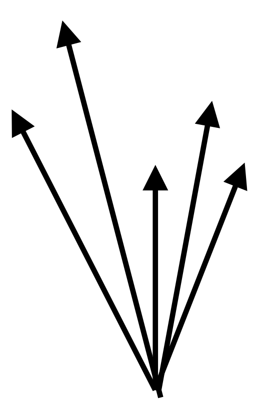
ATLAS
(A Toroidal ApparatuS)



reconstruction (再構築)

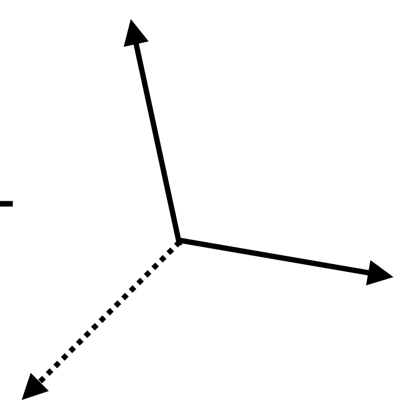


- Reconstruct electrons, muons, photons from energy deposits
- Reconstruct jets and tag b-jets with sophisticated algorithms
- Use conversation of (transverse) energy to calculate the missing energy (MET)



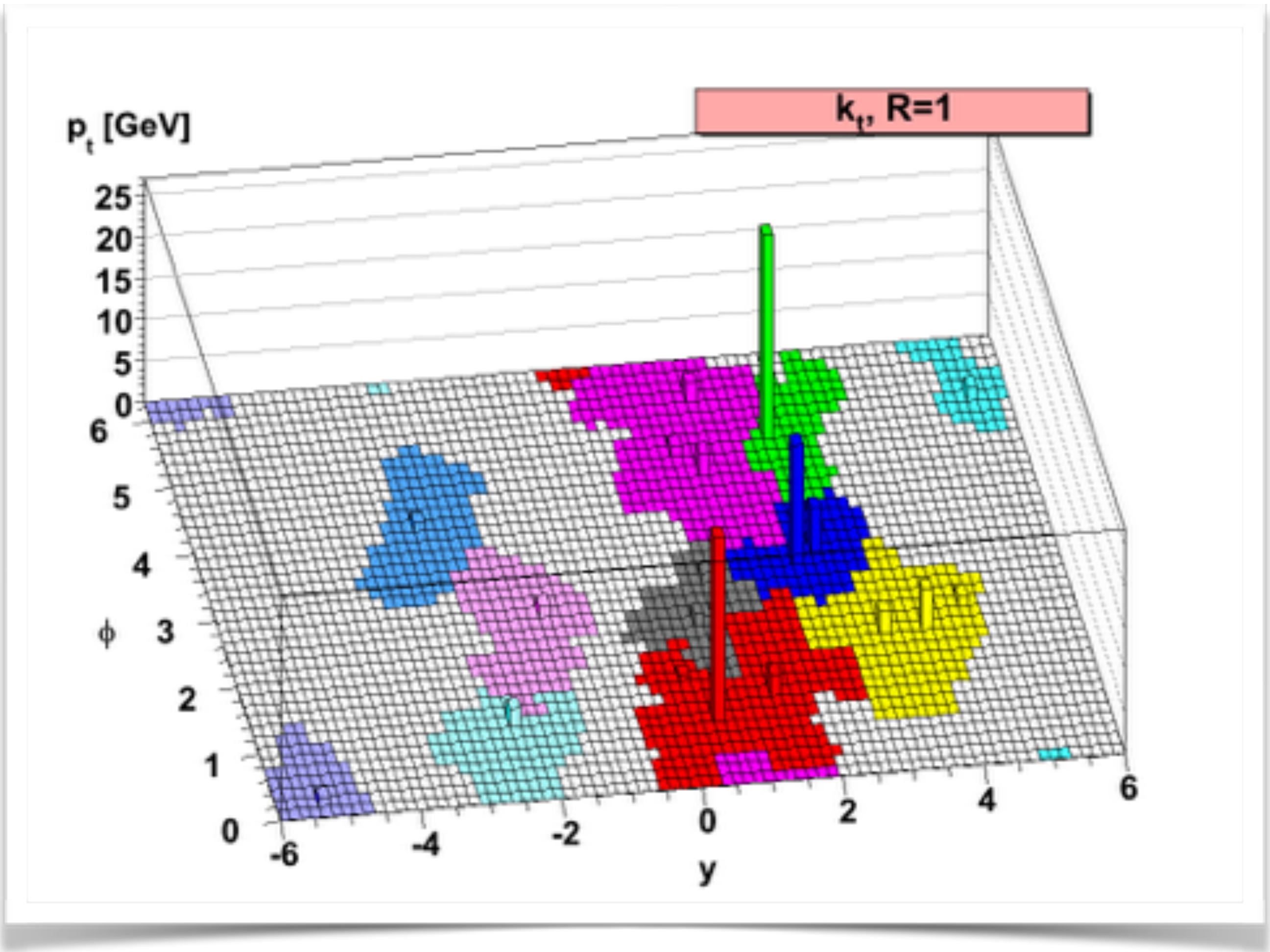
jet

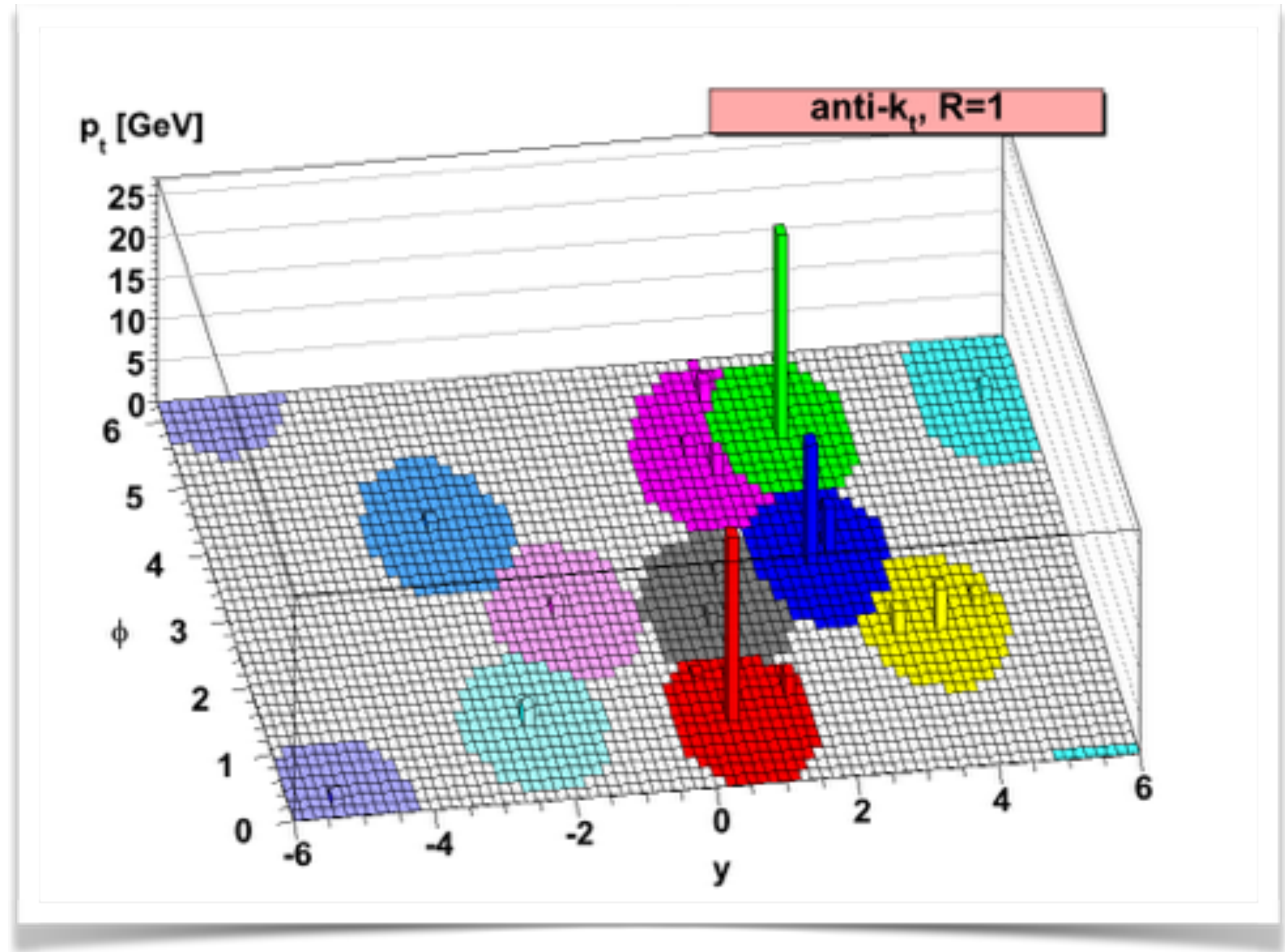
MET



jet reconstruction

(ジェット再構築)

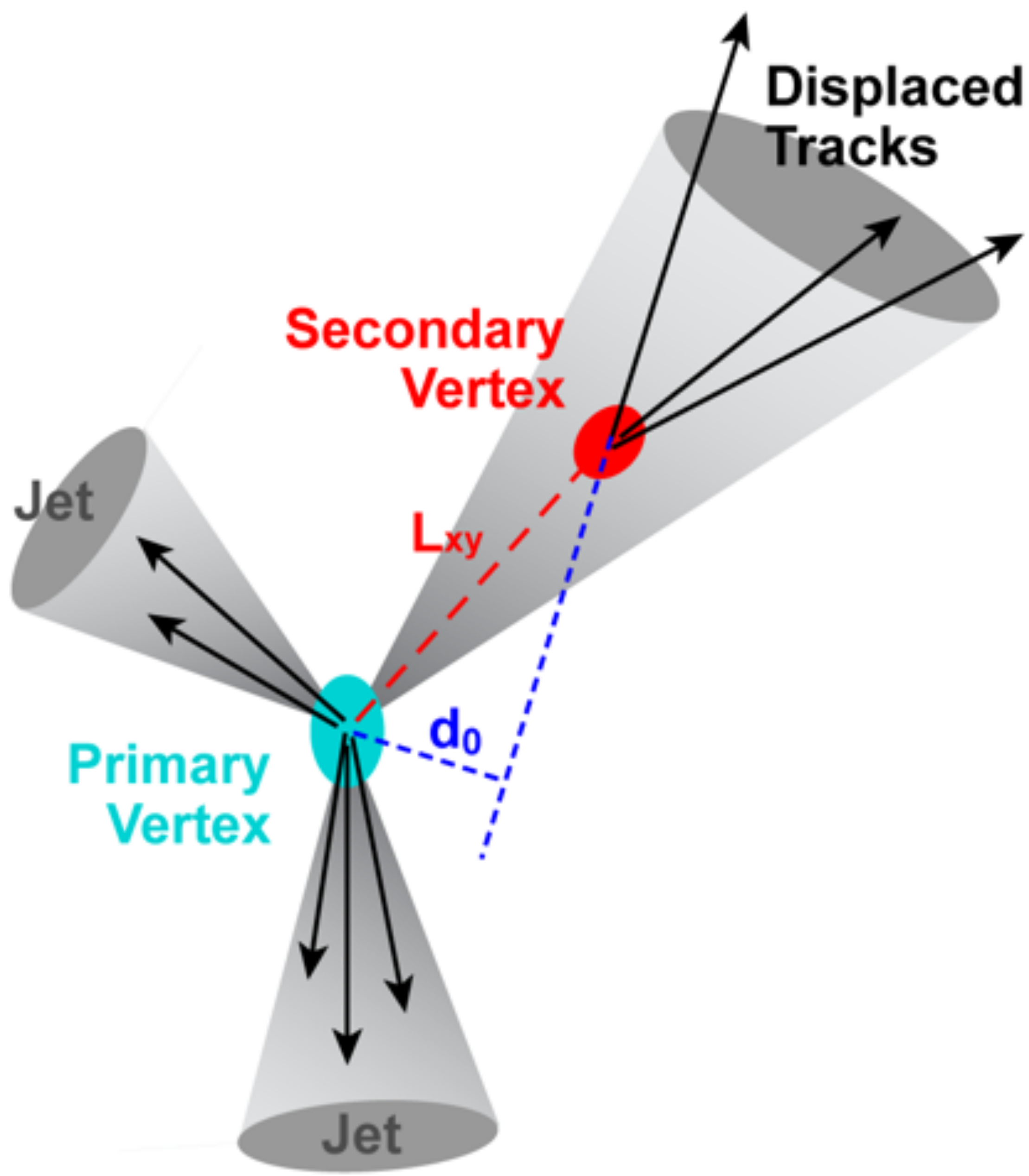




jet reconstruction algorithms group energy deposits together in different ways to form jets

b-jet reconstruction

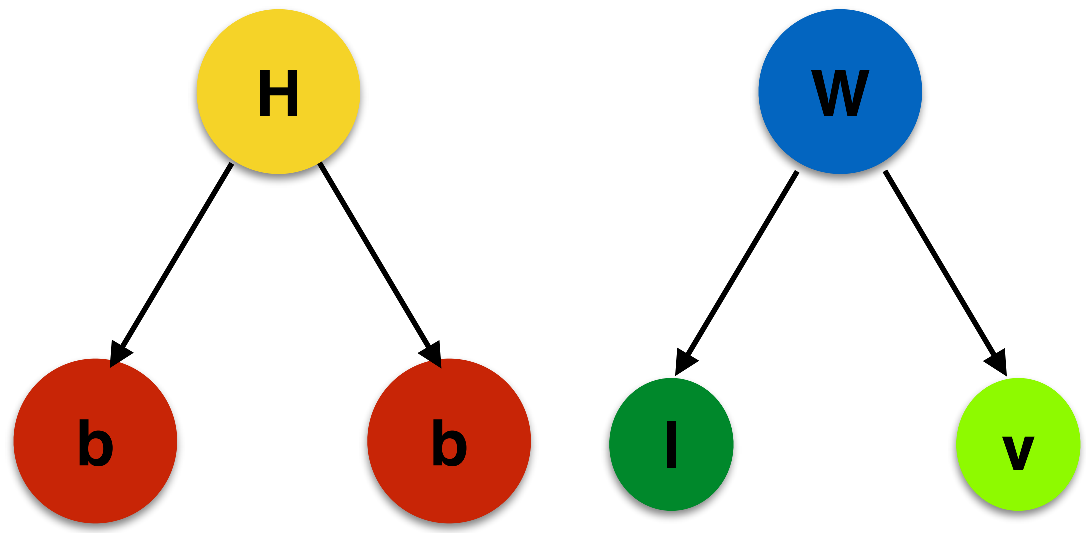
(ビージェット識別)



b-quarks have a longer lifetime than other elementary particles

identify b-jets by reconstructing displaced vertices from tracks

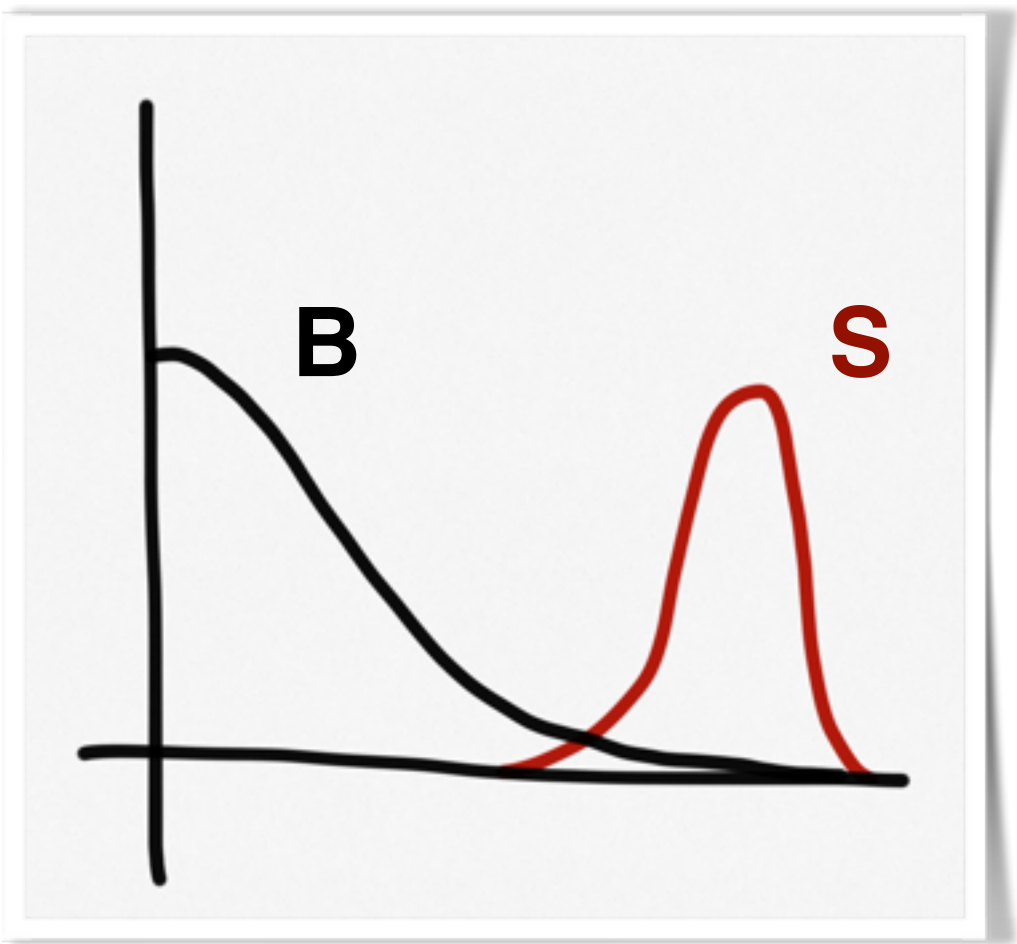
choose your cuts



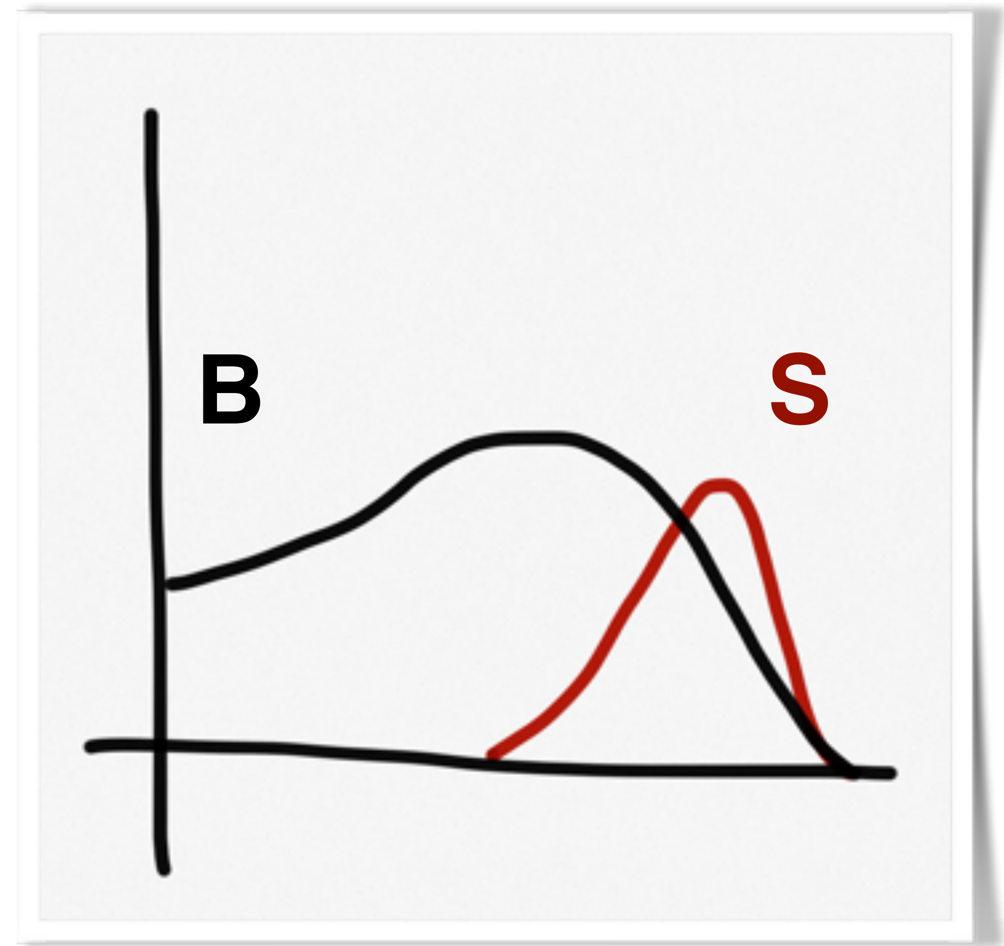
- Need events containing two b-jets, 1 lepton and MET
- $j_1 p_T$ > 45 GeV; $j_2 p_T$ > 20 GeV, MV1c > 80%
- l p_T > 20 GeV; isolated, MET > 20 GeV

choose discriminating variable

good discrimination



poor discrimination

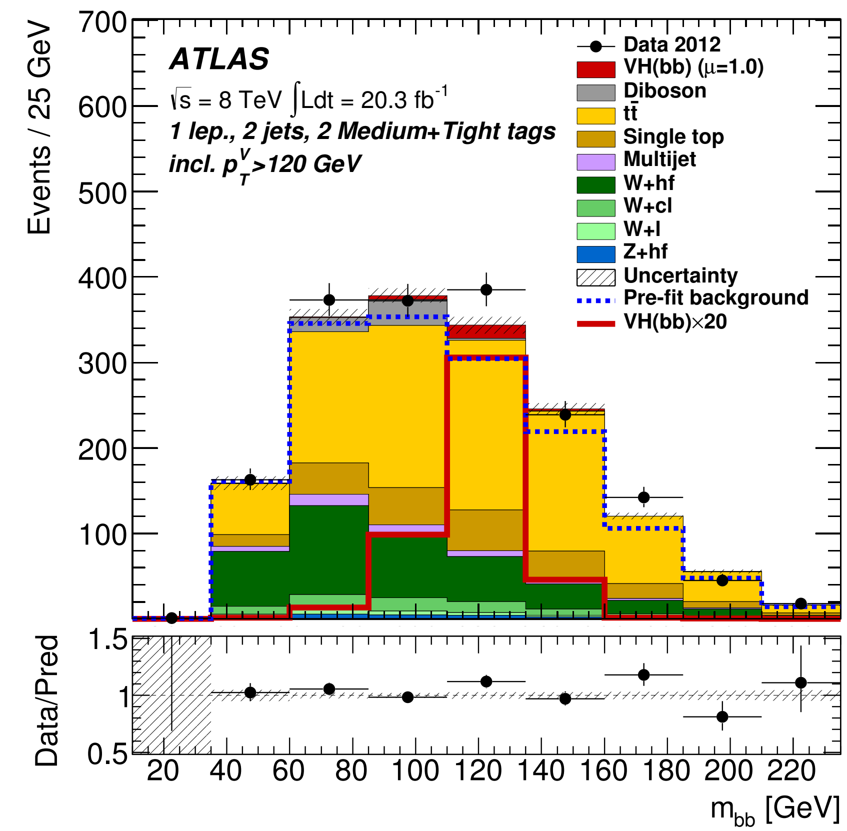


The better the discriminating variable, the larger the separation between signal and background

For the Higgs, a good variable is the **mass**

background (背景)

- Background events are other events that look just like signal
- Two types of background
  - Reducible
    - Experimental: better isolation cut, improved b-tagging algorithm
    - Physics: different final state, e.g. additional lepton, jets
  - Irreducible = same final state as signal
    - Often different kinematics or need to apply kinematic cuts



top

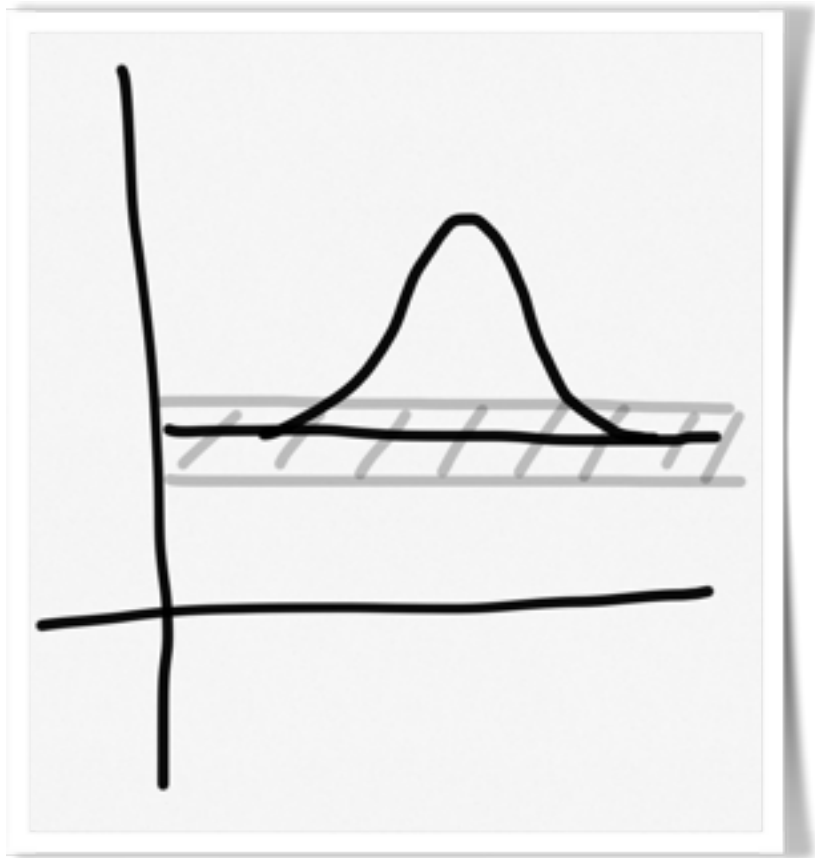
W+cl

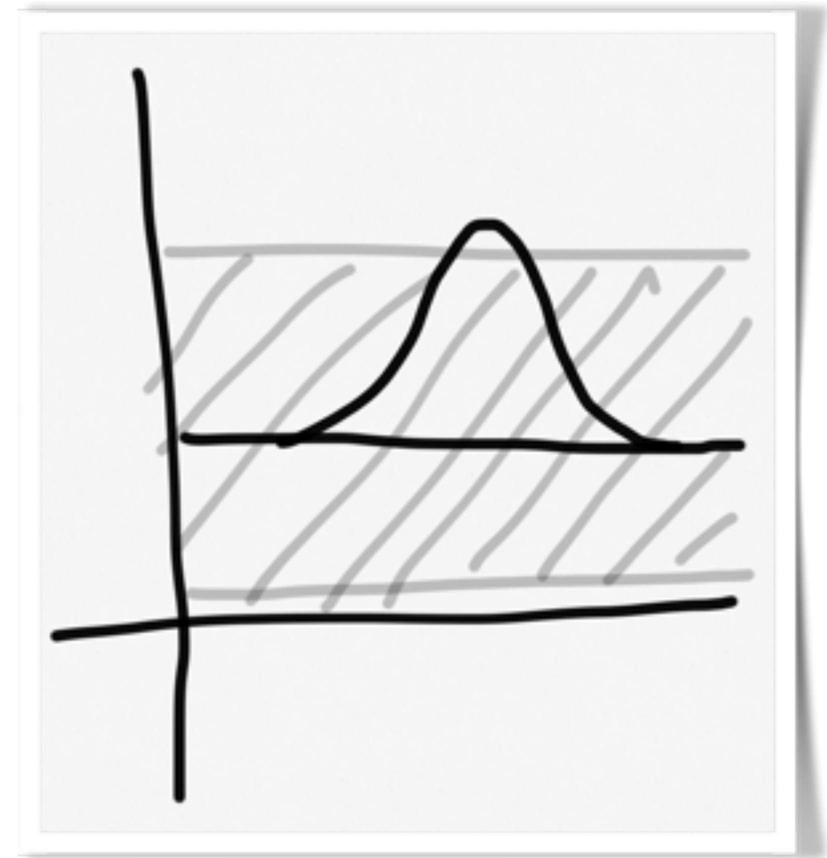
W+bb

WZ

background uncertainty

(背景の不確実性)





- Large uncertainties -> more difficult to extract the signal
- Uncertainties can be both statistical and systematic
- Decrease impact by either reducing background or reducing uncertainty: e.g. estimate in a control region

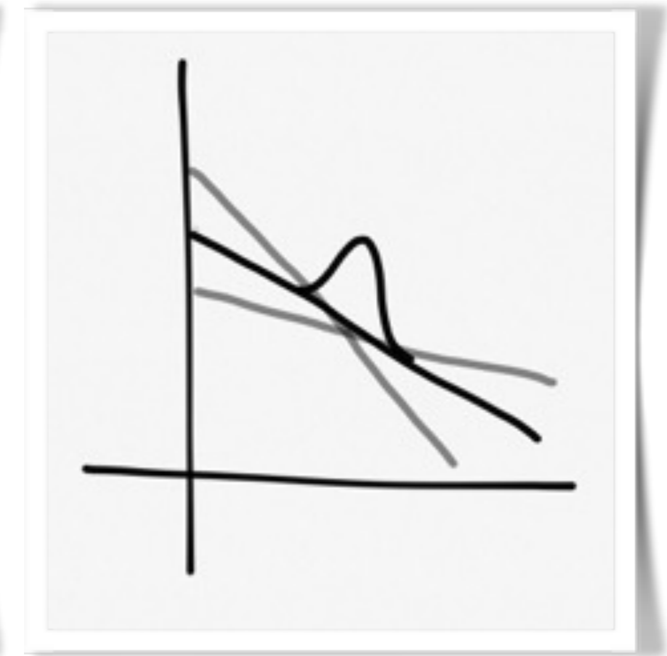
systematic uncertainties

(系統誤差)

Z+jets	
Zl normalisation, 3/2-jet ratio	5%
Zcl 3/2-jet ratio	26%
Z+hf 3/2-jet ratio	20%
Z+hf/Zbb ratio	12%
$\Delta\phi(\text{jet}_1, \text{jet}_2)$, p_{T}^{V}, m_{bb}	S
W+jets	
Wl normalisation, 3/2-jet ratio	10%
Wcl, W+hf 3/2-jet ratio	10%
Wbl/Wbb ratio	35%
Wbc/Wbb, Wcc/Wbb ratio	12%
$\Delta\phi(\text{jet}_1, \text{jet}_2)$, p_{T}^{V}, m_{bb}	S
$t\bar{t}$	
3/2-jet ratio	20%
High/low-p_{T}^{V} ratio	7.5%
Top-quark p_{T}, m_{bb}, $E_{\mathrm{T}}^{\mathrm{miss}}$	S
Single top	
Cross section	4% (s-,t-channel), 7% (Wt)
Acceptance (generator)	3%–52%
m_{bb}, $p_{\mathrm{T}}^{b_1}$	S
Diboson	
Cross section and acceptance (scale)	3%–29%
Cross section and acceptance (PDF)	2%–4%
m_{bb}	S
Multijet	
0-, 2-lepton channels normalisation	100%
1-lepton channel normalisation	2%–60%
Template variations, reweighting	S

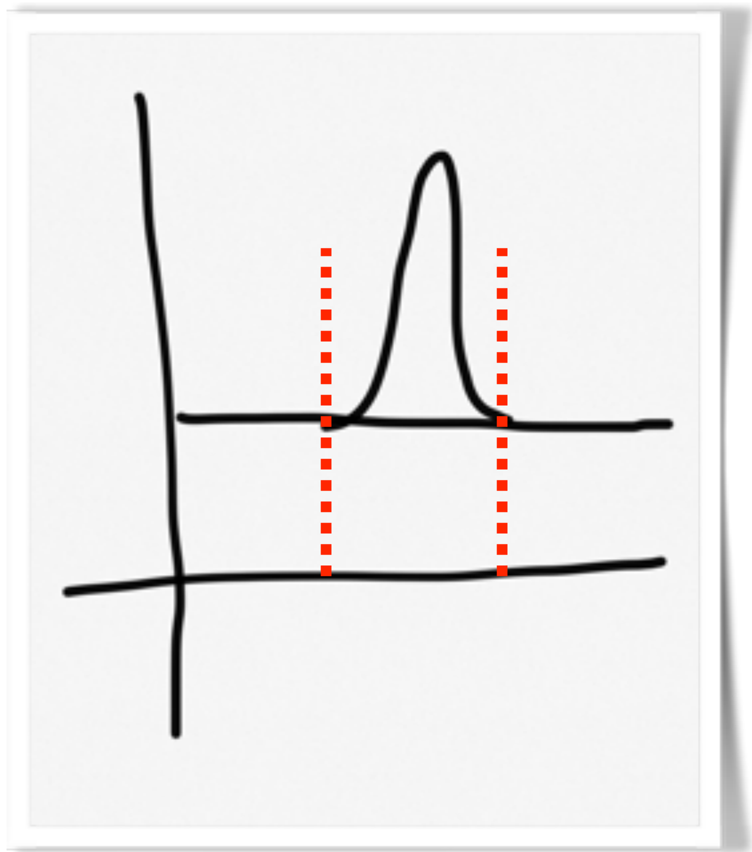
background normalisation

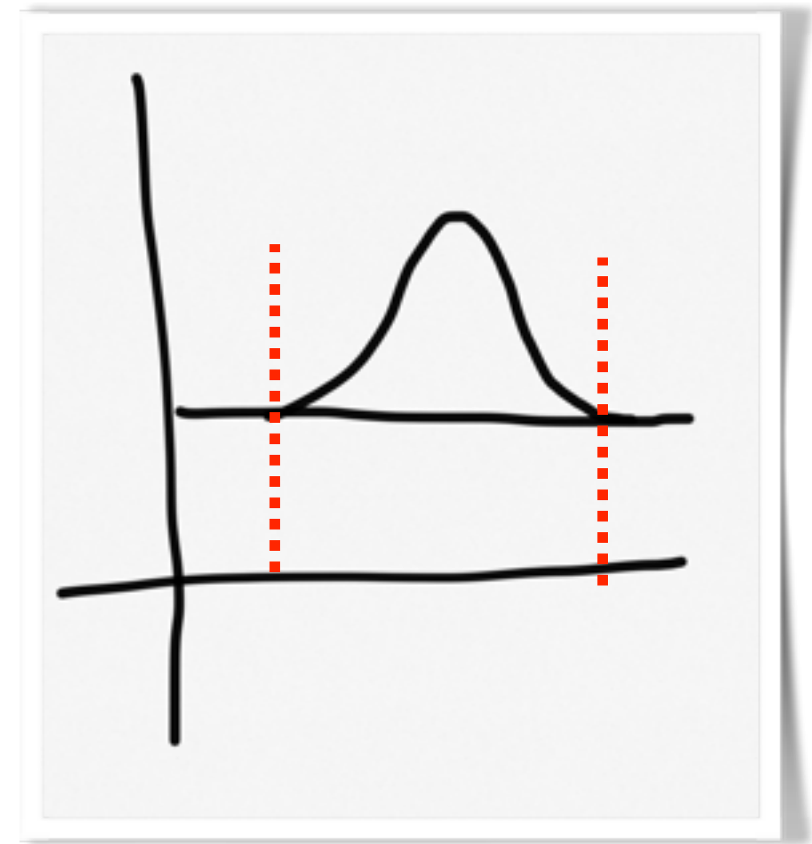
background shape



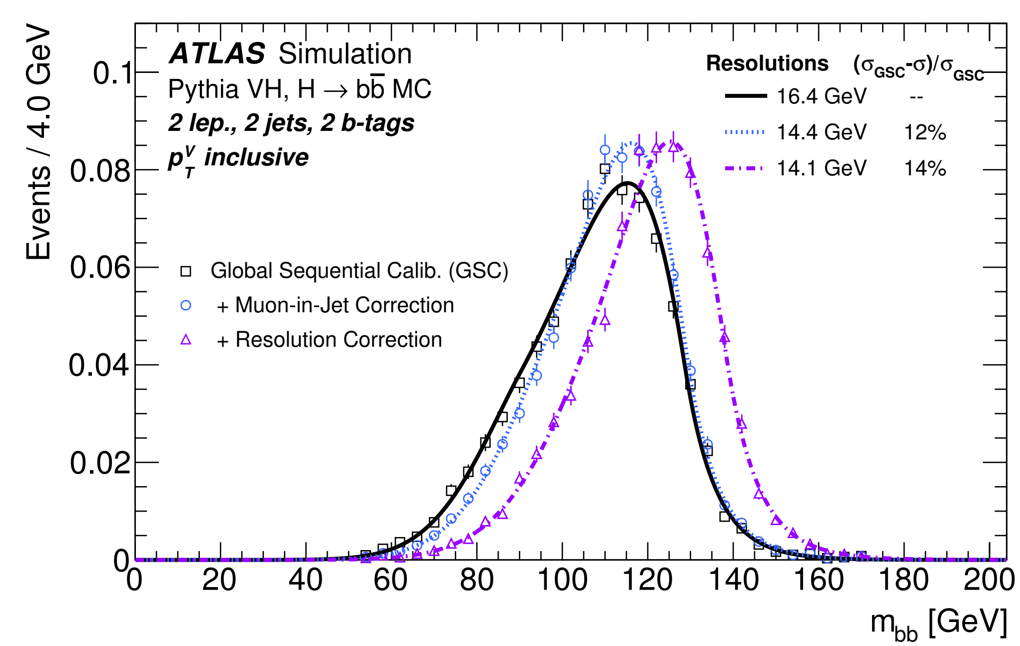
signal scale

improving sensitivity: mass resolution (質量分解能)

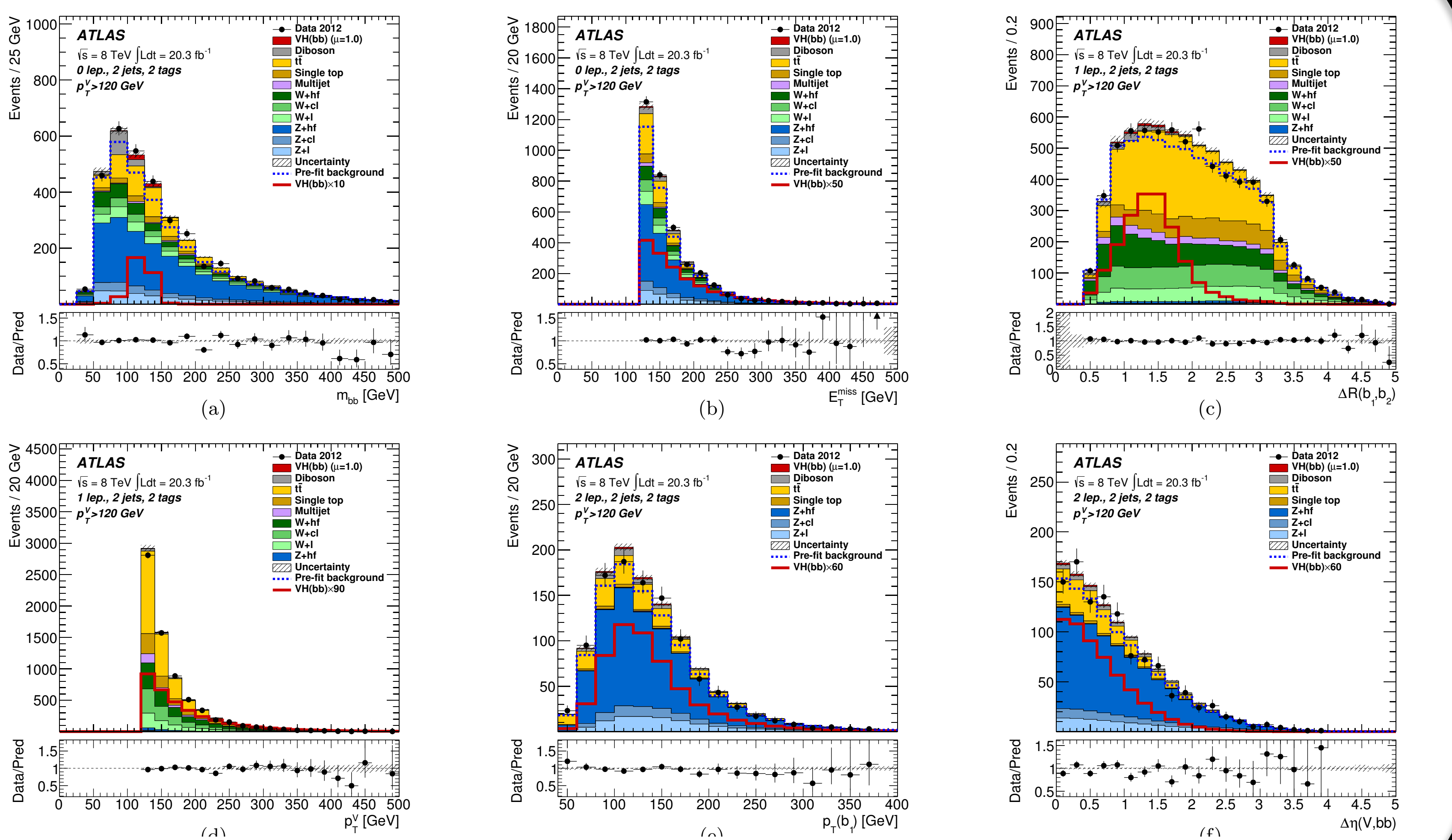


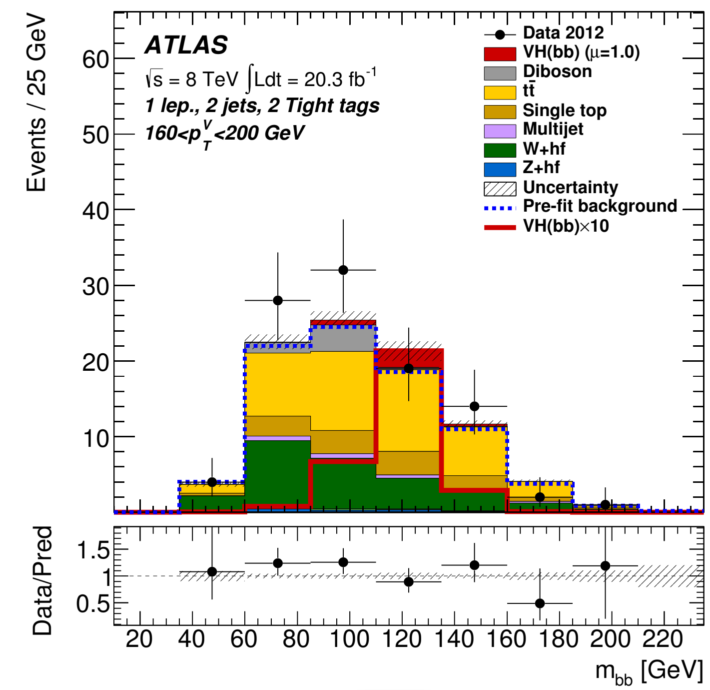


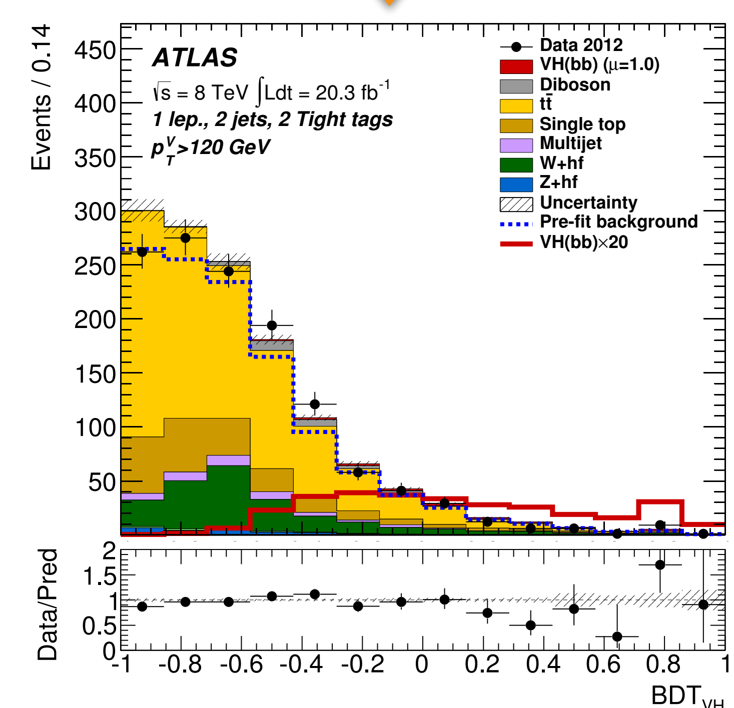
- The better the mass resolution, the smaller the amount of background that needs to be considered
- 14% improvement in resolution



improving sensitivity: MVA
(多变量解析)





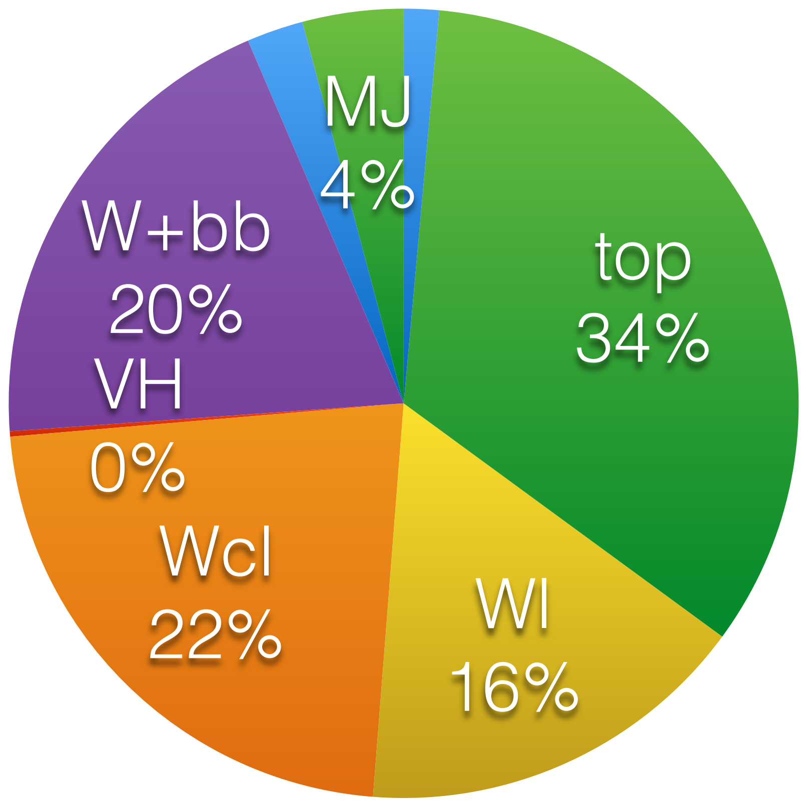


Multivariate techniques combine information from kinematic distributions into a single discriminating variable

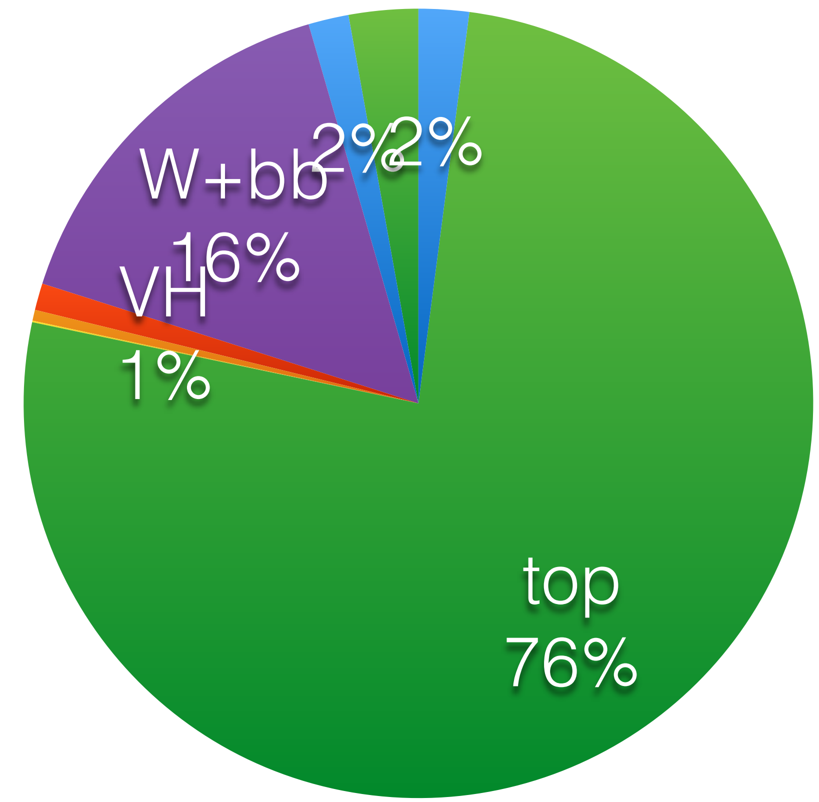
improving sensitivity: categories

(カテゴリ)

loose b-tag



tight b-tag

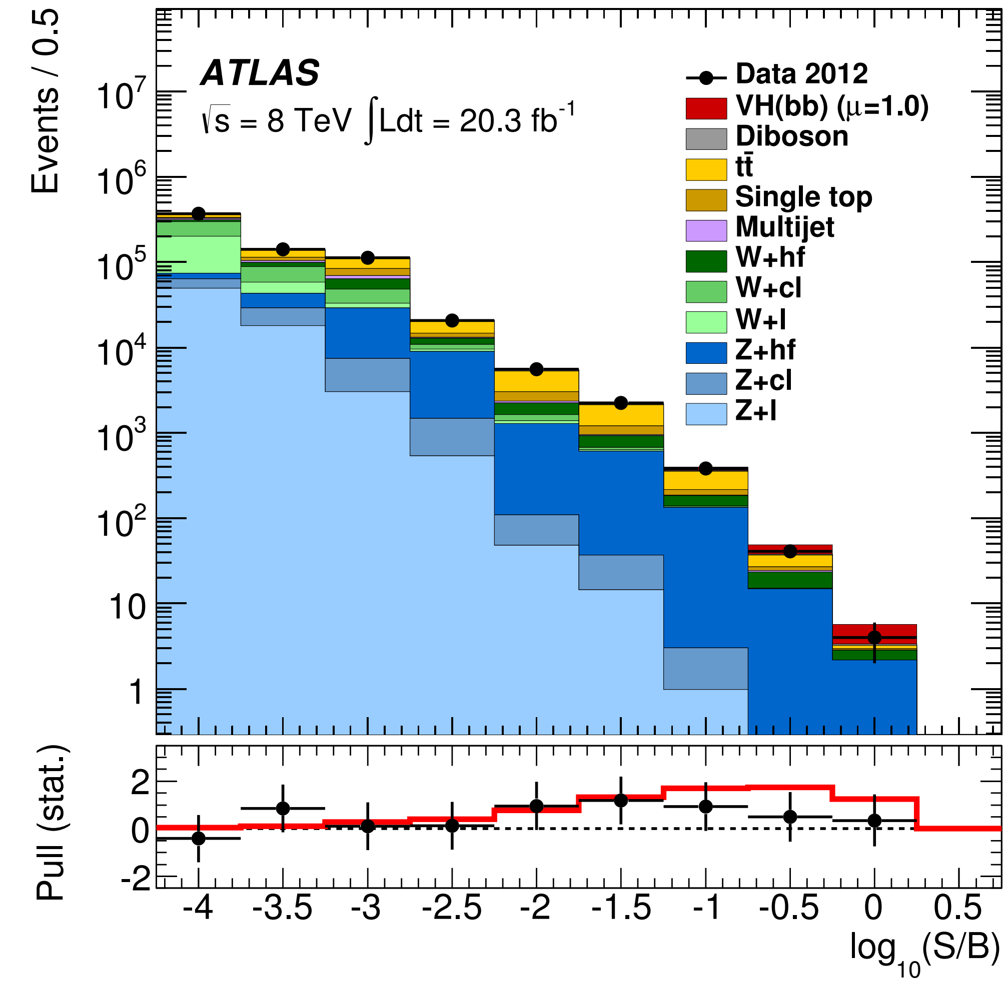


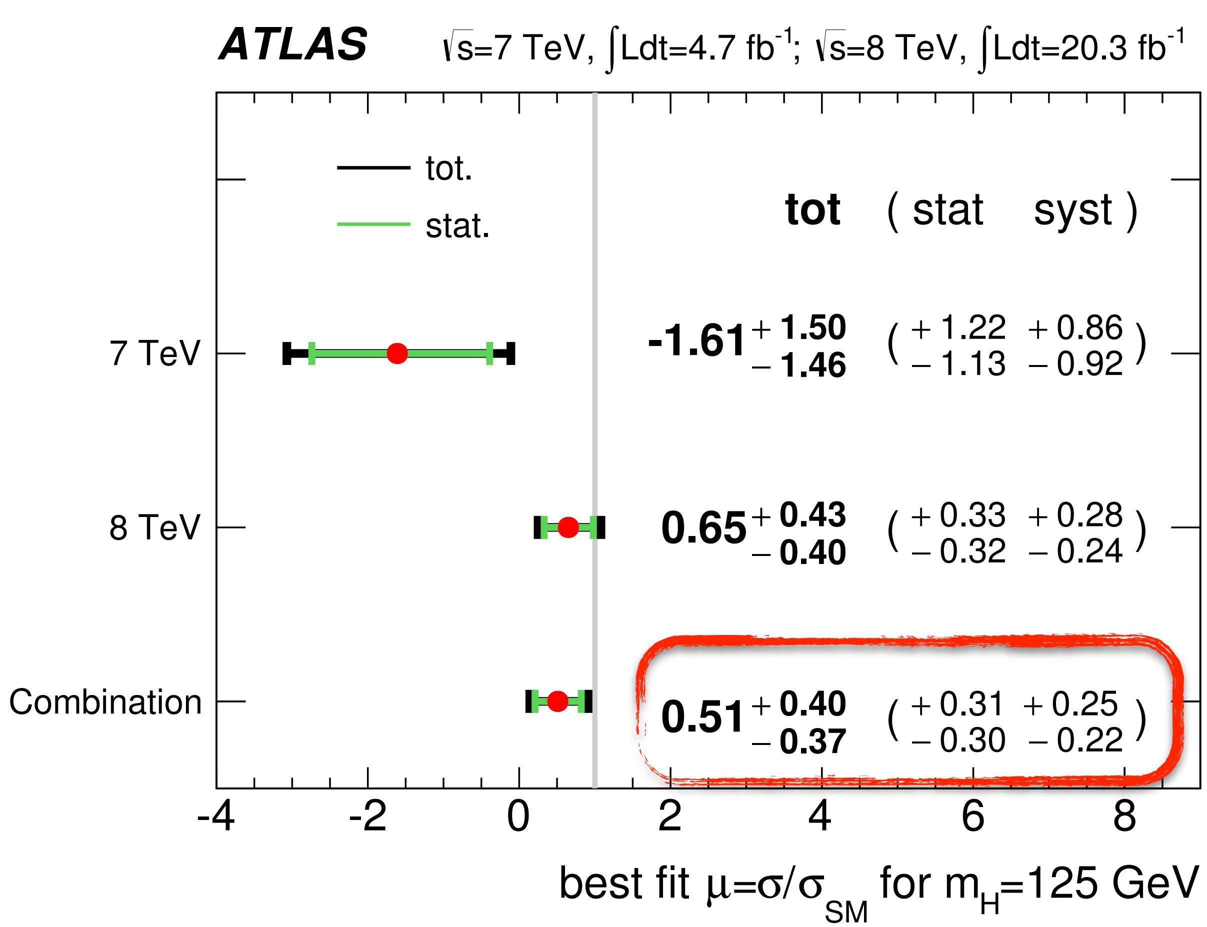
- Simple idea: add cuts to divide events into categories
  - Don't throw away any events
  - Separate out high S/B regions
  - Information to constrain backgrounds
- For VH(bb) we categorise depending on the number of jets x Higgs p_T x b-tagging quality
  - Huge improvement to sensitivity; largely from background constraint

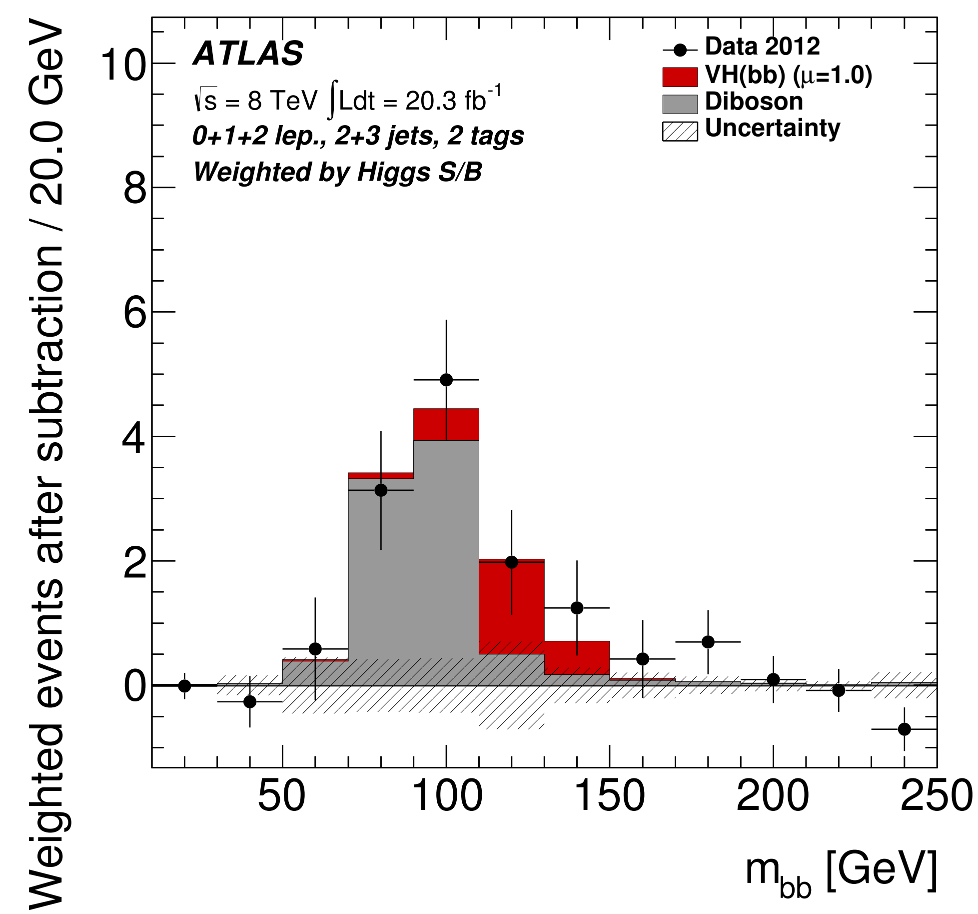
Process	Scale factor
$t\bar{t}$ 0-lepton	1.36 ± 0.14
$t\bar{t}$ 1-lepton	1.12 ± 0.09
$t\bar{t}$ 2-lepton	0.99 ± 0.04
Wbb	0.83 ± 0.15
Wcl	1.14 ± 0.10
Zbb	1.09 ± 0.05
Zcl	0.88 ± 0.12

result

- Look for an excess over background prediction
- Fit rate with respect to the Standard Model prediction
    - $\mu = \sigma/\sigma_{SM}$
- Small excess, but a little smaller than the SM prediction
    - More data needed !







conclusion (結論)

- A lightening tour of the >20 years of work it took to probe the **Higgs** coupling to b-quarks
- Discussed some key aspects of analysis design
  - Discriminating variable selection
  - Mass resolution
  - Background estimate
  - Systematic Uncertainties

- For bb, we're not quite there yet, but getting very close
  - Perhaps one of you, will be the one to observe it ?