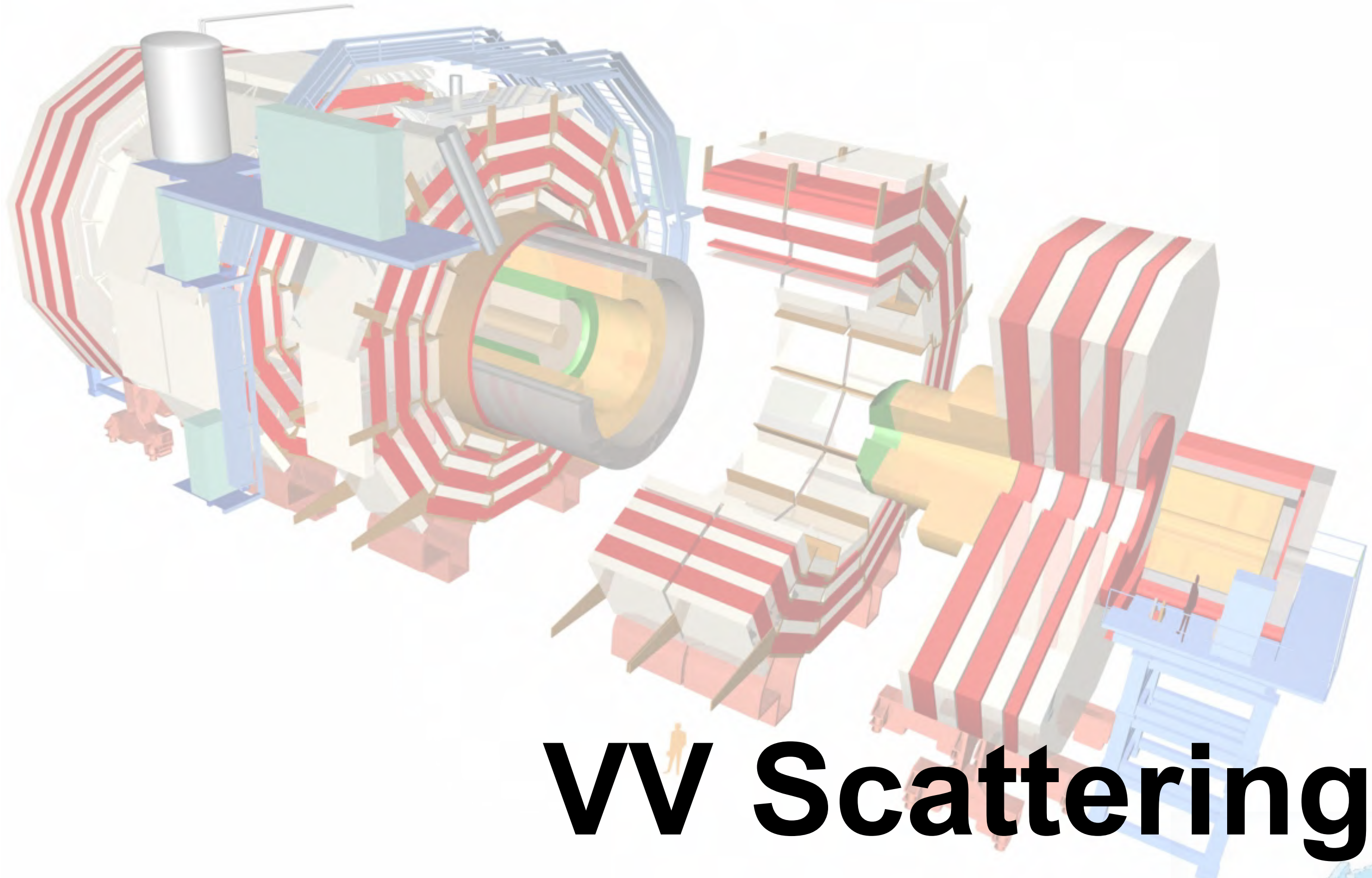
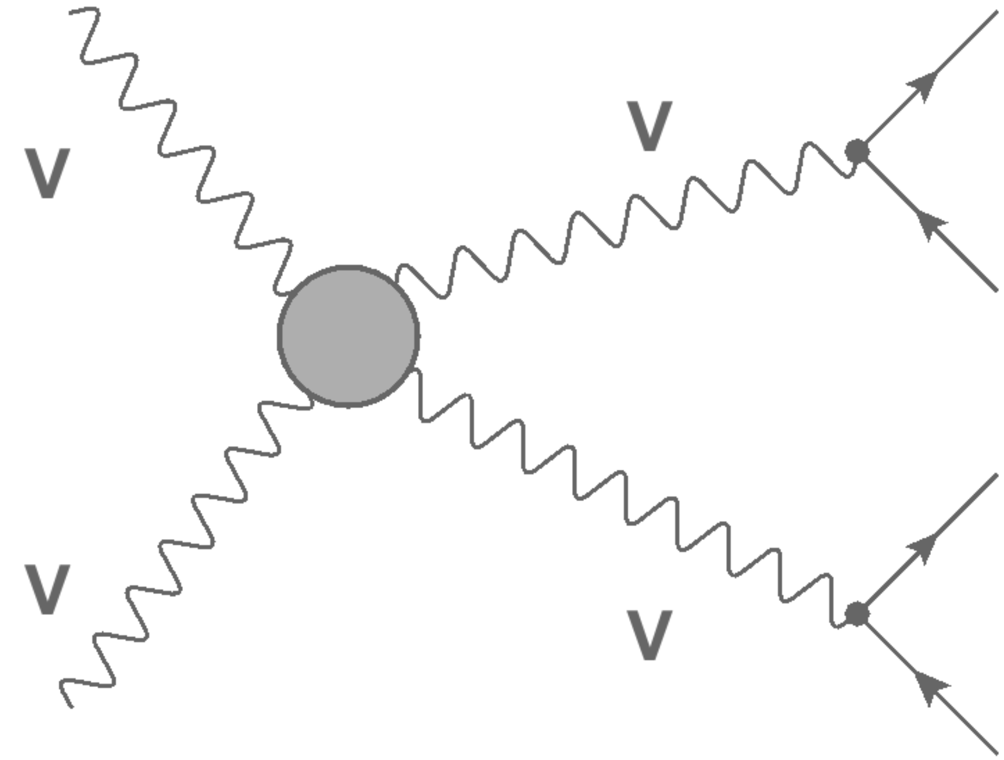
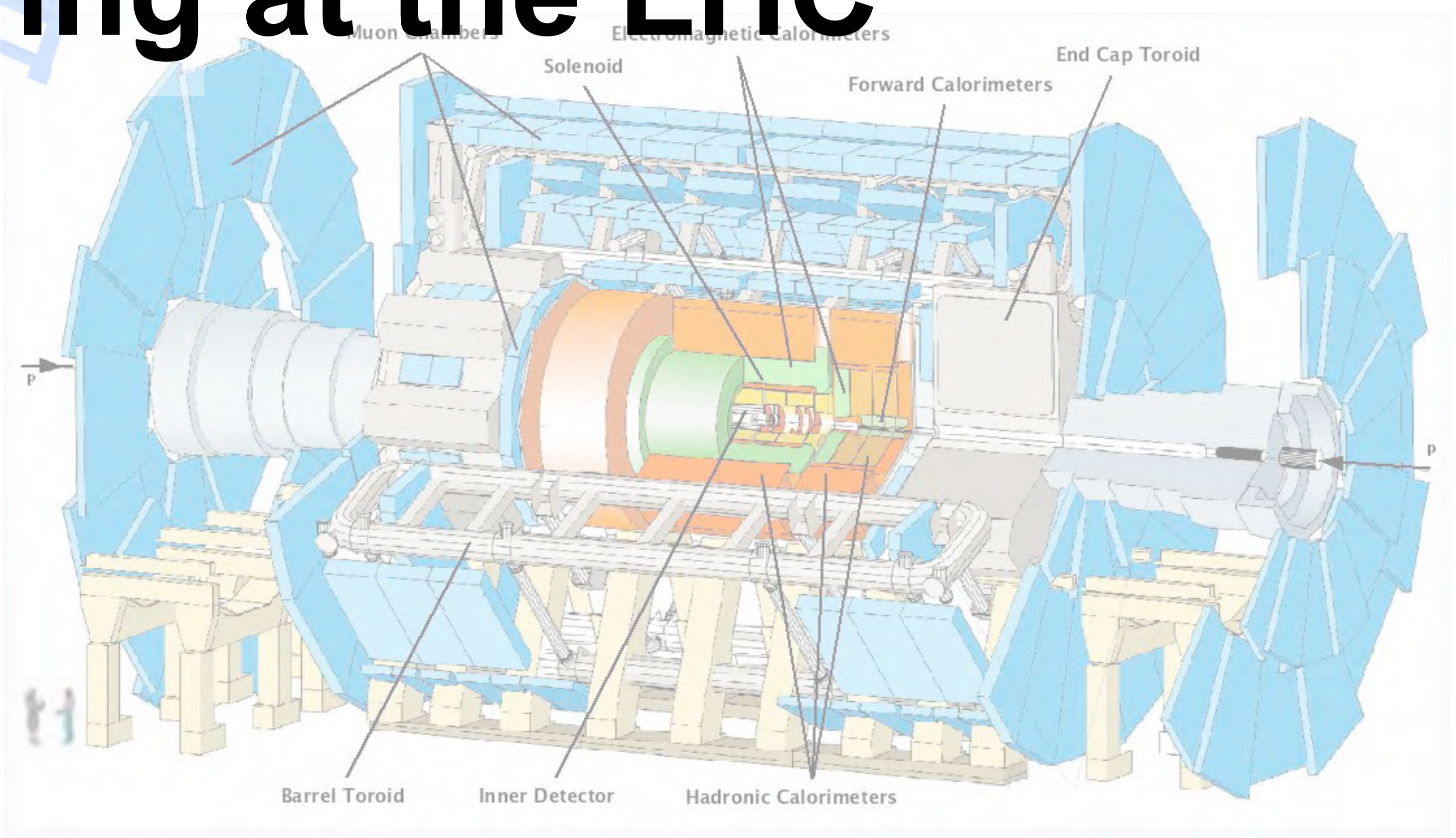




VV Scattering at the LHC



Paolo Giacomelli (INFN Bologna)
Higgs Quo Vadis
Sunday, March 10th, 2013

Special thanks to S. Bolognesi and P. Govoni

Outline

- Theoretical introduction
- 6-fermion final states
- VBF experimental signatures
- Prospects
- Summary

Why is the Higgs needed

The Higgs mechanism is a cornerstone of the SM and provides:

1) an explanation of the W, Z masses (EWSB)

2) a description of the fermion masses

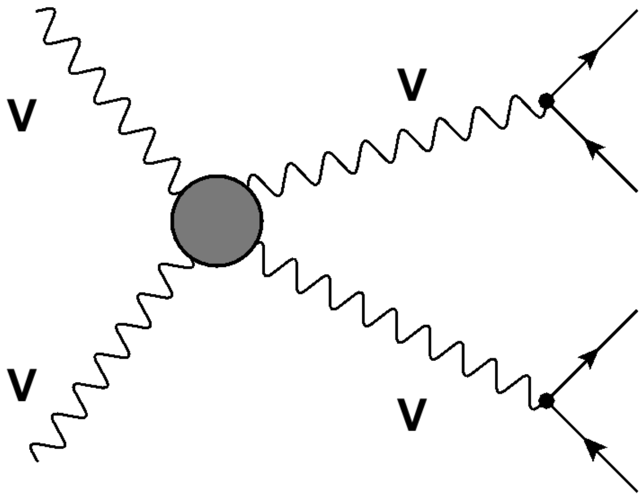
1) is the most fundamental argument that makes the SM "work"

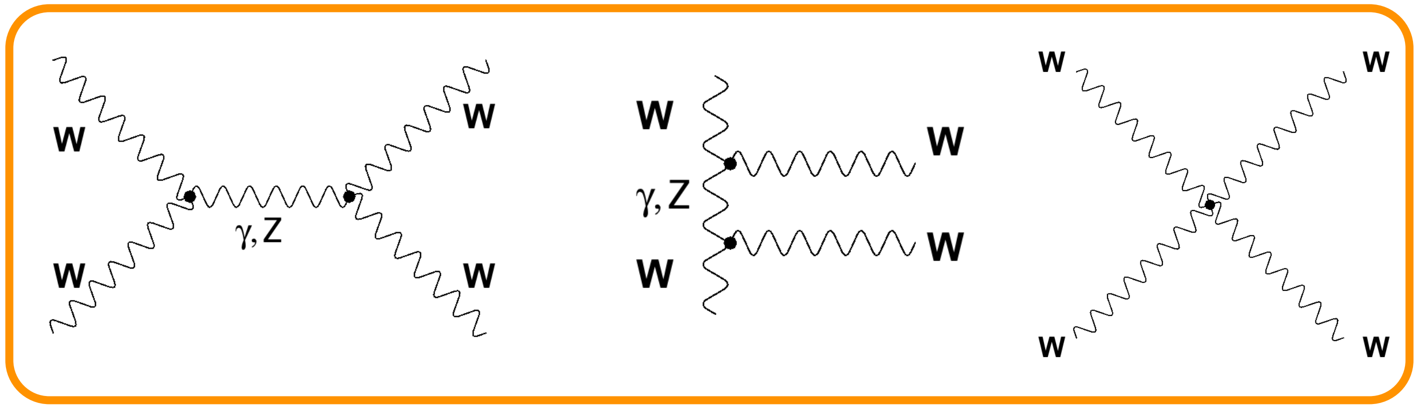
2) is another way of formulating the same question:
why do fermions have those specific masses?
why do fermions have those specific Higgs couplings?

(SM could work well also without 2)

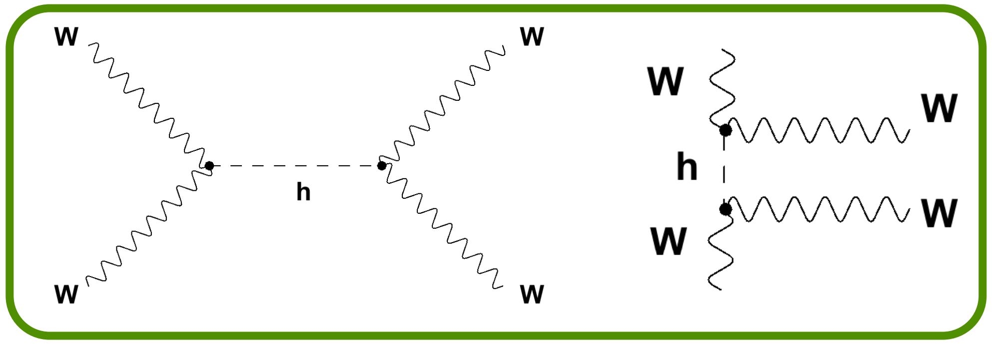
VV scattering: unitarity violation

VV→VV





S channel **T channel** **QGC**



Without the Higgs, $W^+_L W^-_L \rightarrow W^+_L W^-_L$ violates unitarity at $\sqrt{s} \geq 1.2$ TeV

W, Z masses (→ longitudinal degrees of freedom) arise from the Higgs mechanism:

$$A\left(W_L^+ W_L^- \rightarrow W_L^+ W_L^-\right) \approx \frac{1}{v^2}\left(\boxed{-s-t} + \boxed{\frac{s^2}{s-m_H^2} + \frac{t^2}{t-m_H^2}}\right)$$

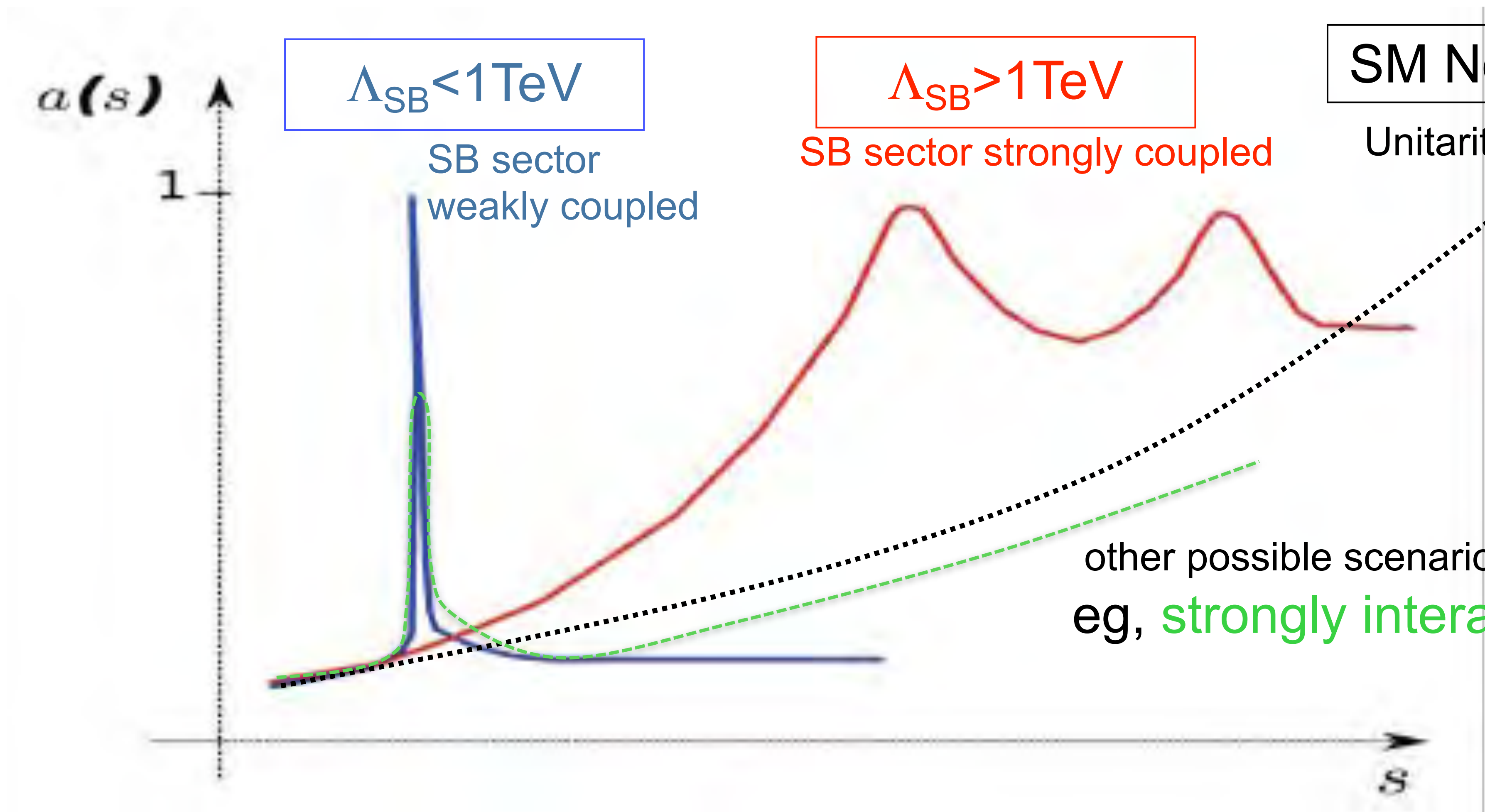
VV scattering is the smoking gun for EWSB!

Taken from **"Prospects for VV scattering: latest news"** by S. Bolognesi (JHU) talk at Implications of LHC results for TeV-Scale physics (March 2012)

VV scattering as a probe for EWSB

VV Scattering spectrum, σ(VV→VV) vs M(VV)

is the fundamental probe to test the nature of the Higgs boson or to find an alternative EWSB mechanism

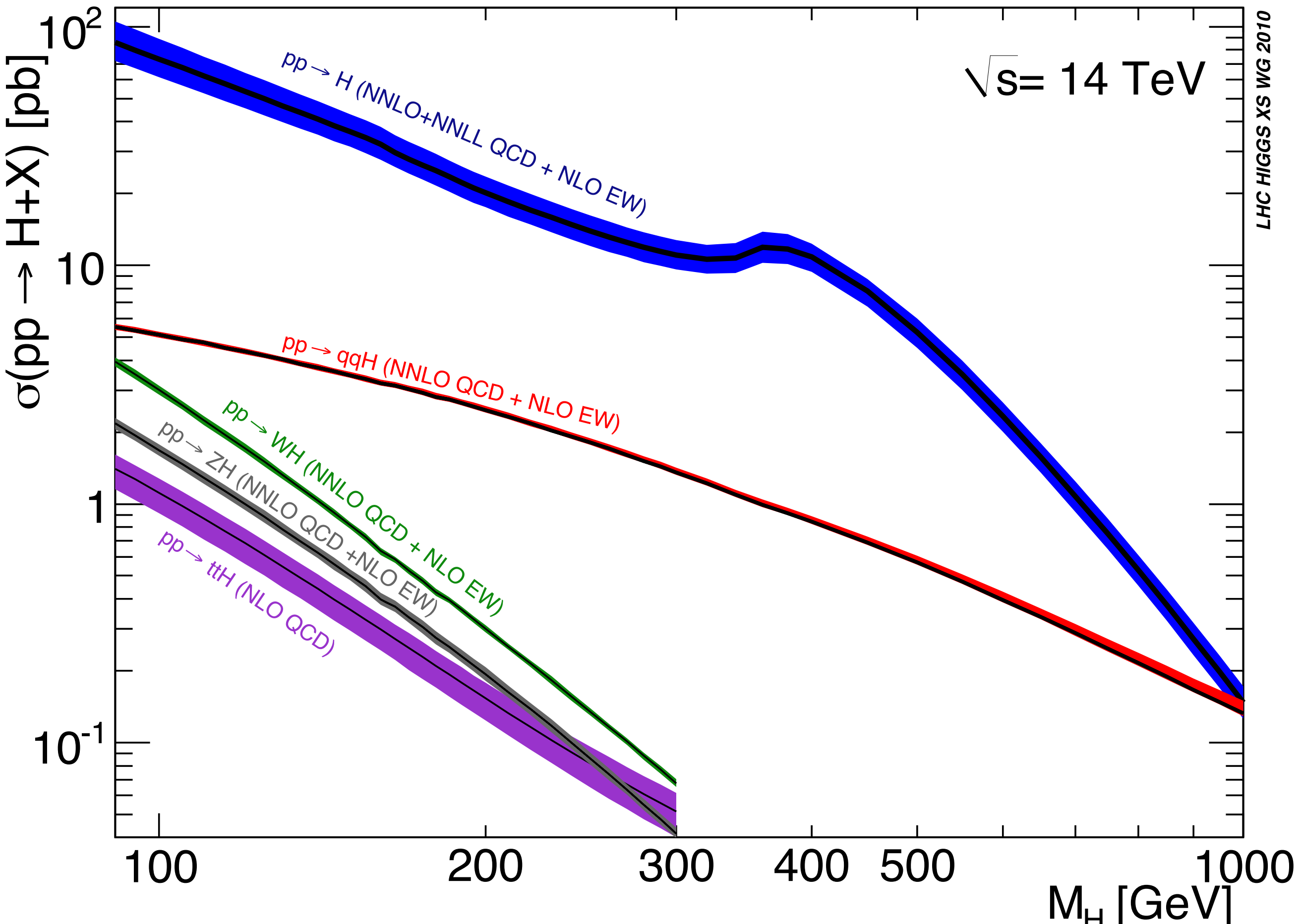


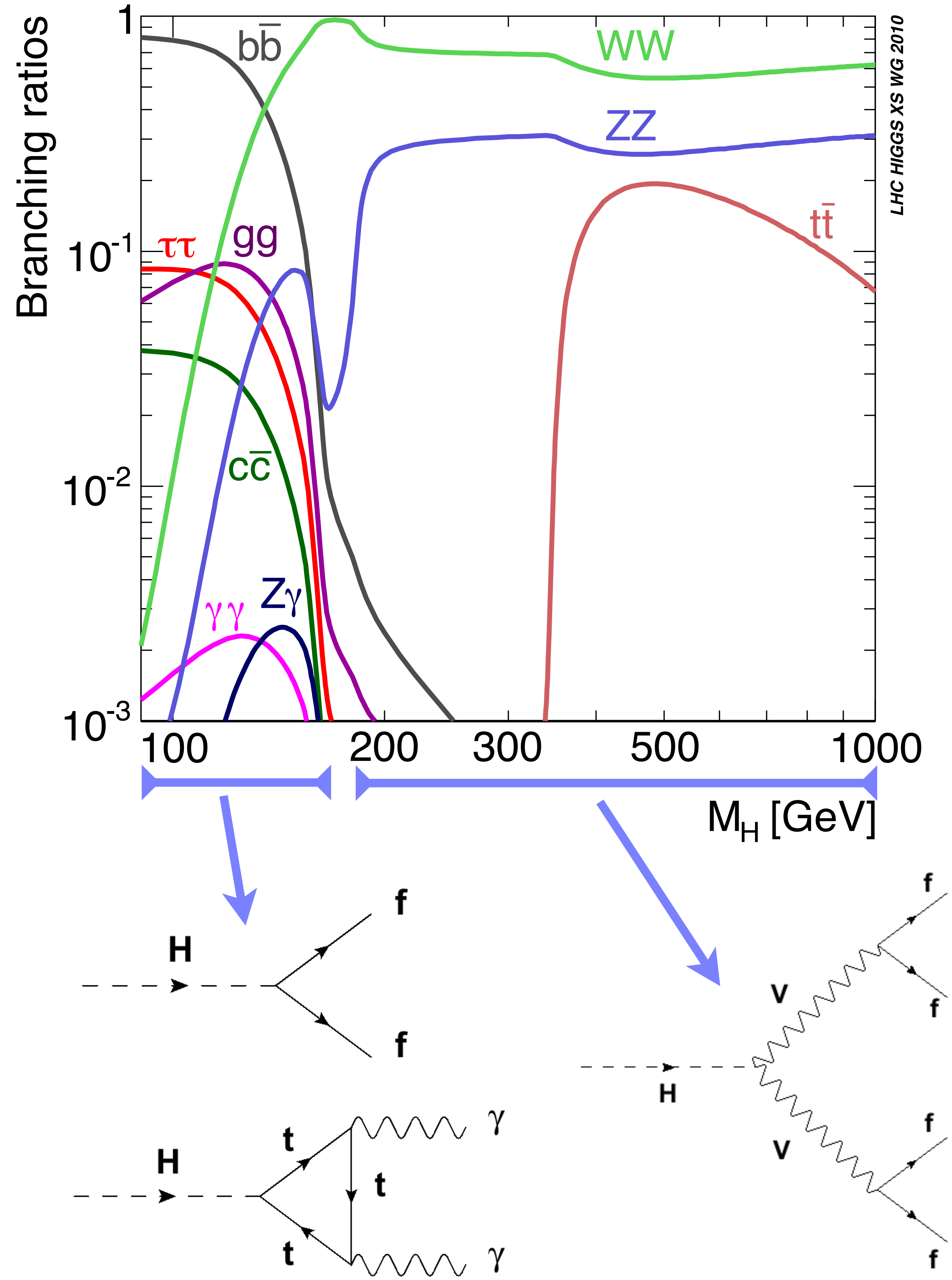
BSM models predict TeV-scale resonances "paired" with a light scalar particle

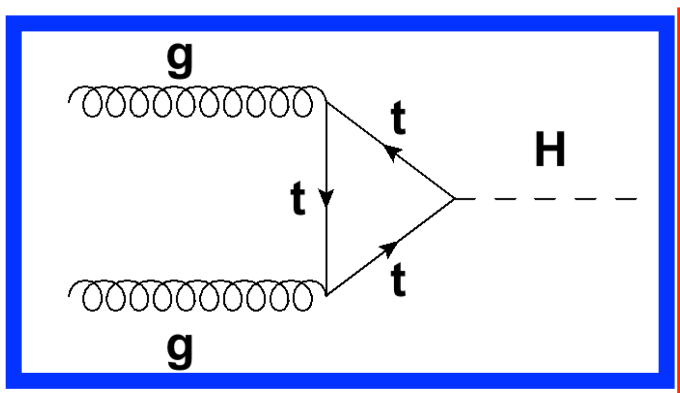
Search for possible resonances in VBF spectrum

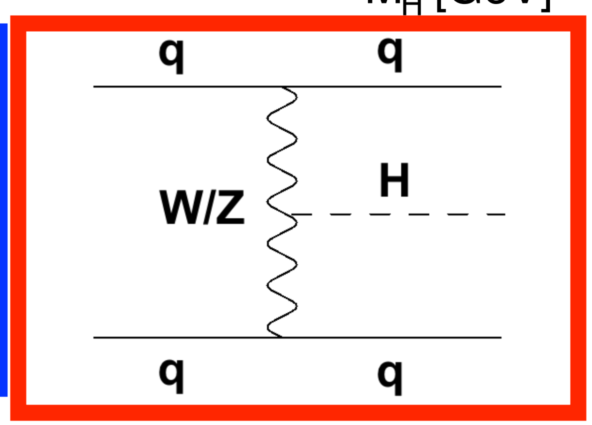
Adaptation from **"Boson Boson scattering analysis"** by A.Ballestrero (INFN Torino) talk at First LHC to Terascale Workshop (Sept 2011):

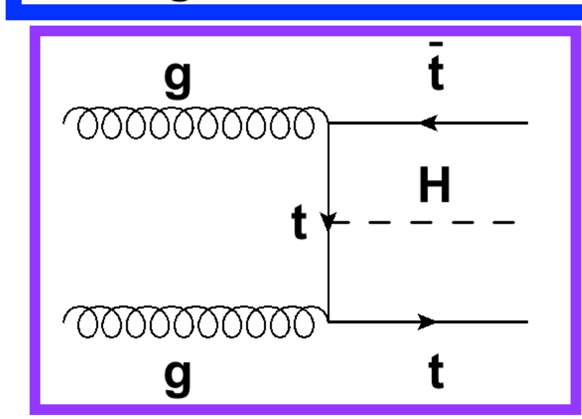
Higgs production and decay

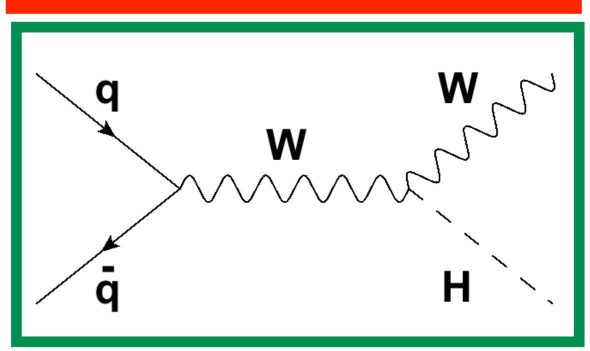






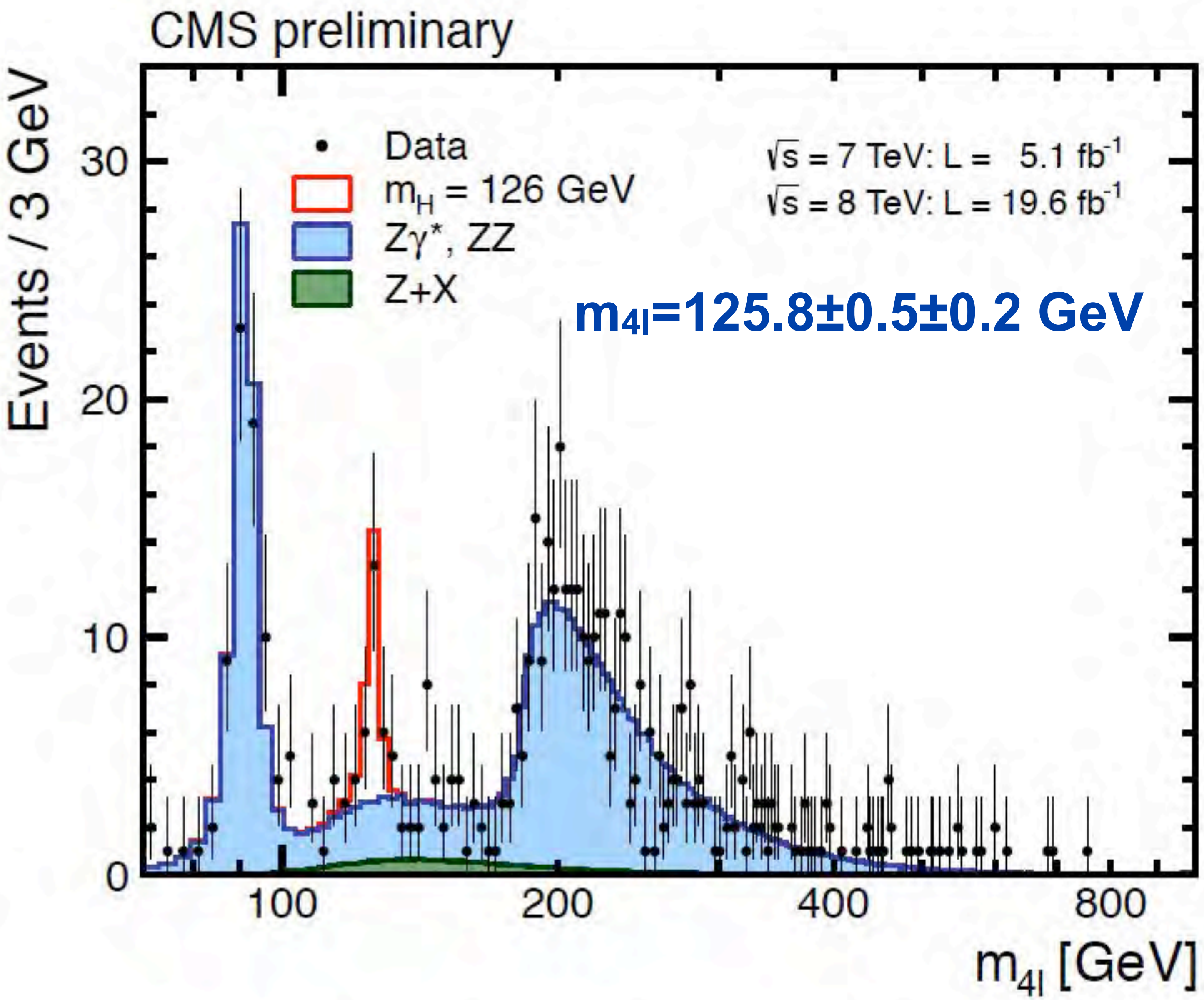


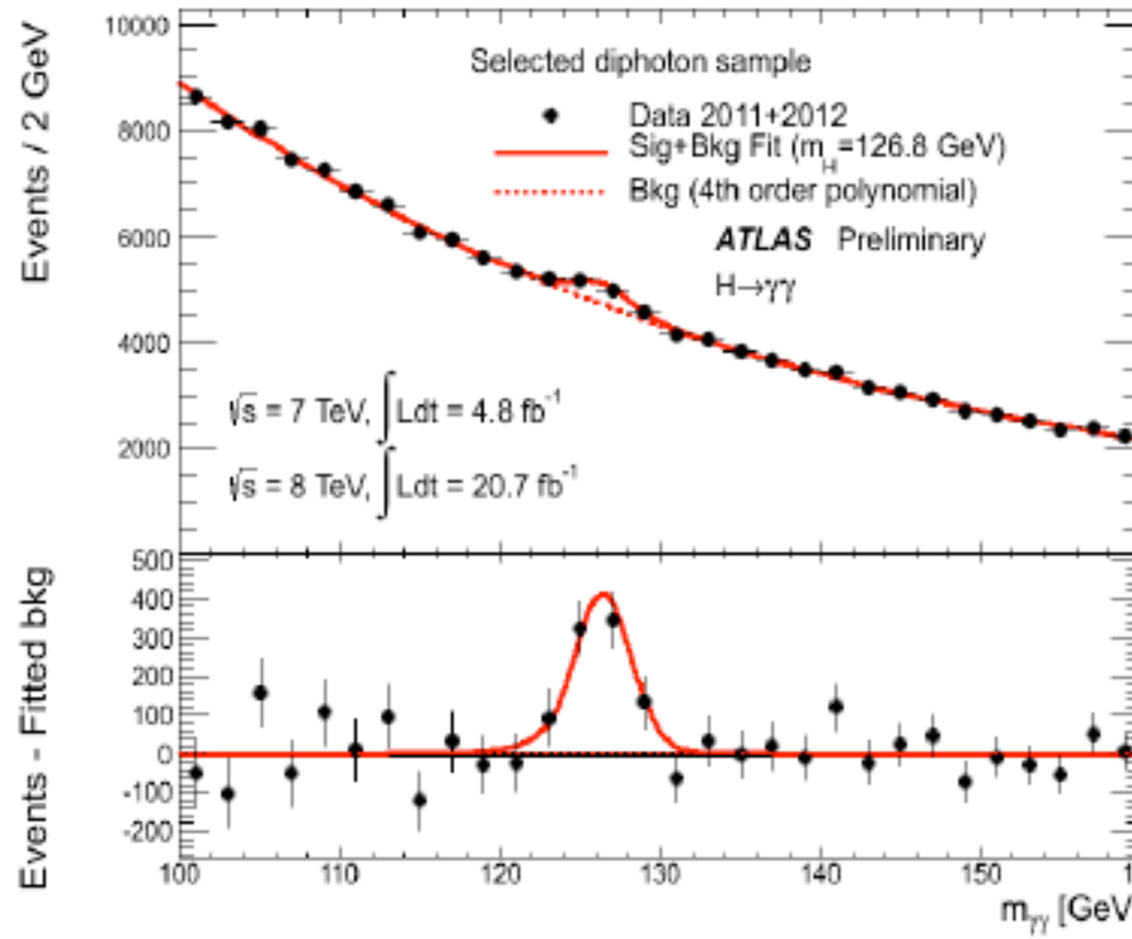




Higgs-like boson at ~125 GeV

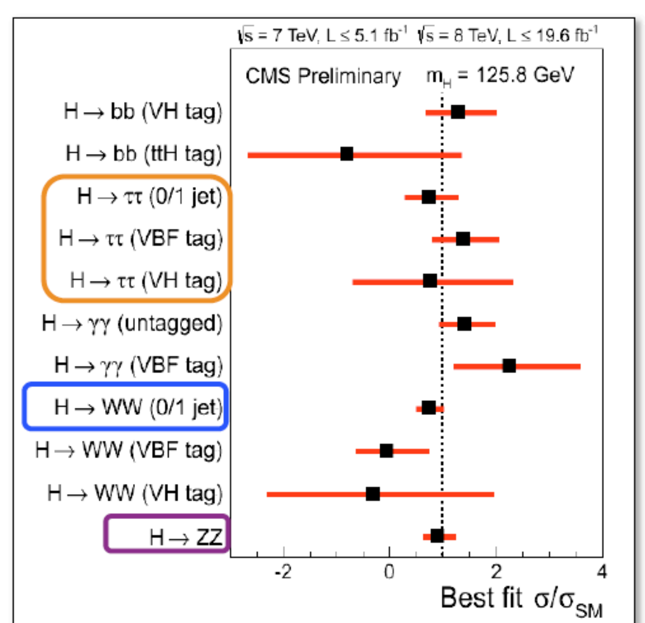
- We have discovered a Higgs-like boson with a mass of ~125 GeV.
- J^{PC}, consistent with SM Higgs boson, couplings will need more data.





The new boson is consistent with being the SM Higgs boson

σ/σ_{SM} = $0.84^{+0.32}_{-0.26}$

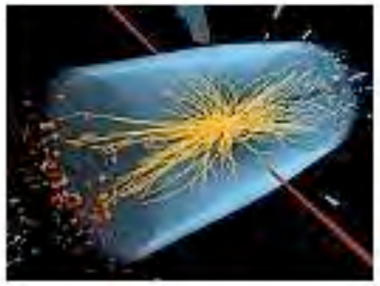


In case of doubts...ask the italian press

Corriere della Sera (6/3/13)

Cern, la conferma è arrivata quella particella è il bosone di Higgs

Video Le lacrime dello scienzato il giorno dell'annuncio

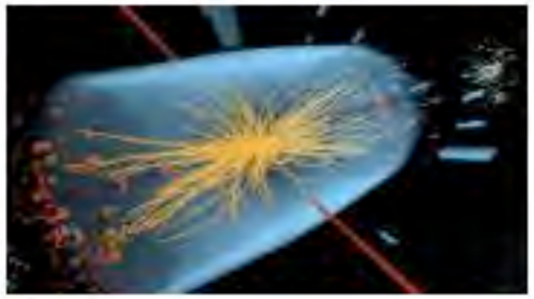


Il responso dal primo identikit presentato oggi dai fisici del Cern a La Thuile: quella scoperta nel 2012 è effettivamente la stessa prevista nel 1964 dal fisico inglese. Adesso c'è la certezza *di ELENA DUSI*

SPECIALE VIDEO

CONDIVIDI

Repubblica (6/3/13)



La conferma del Cern: "La particella scoperta è il bosone di Higgs"

La notizia arriva da La Thuile, in Valle d'Aosta

Il bosone di Higgs spiegato ai profani: "Come un fiocco di neve"

La particella individuata lo scorso luglio dagli scienziati del Cern di Ginevra è effettivamente il mitico 'bosone di Higgs', l'inafferrabile 'particella di Dio'. L'identikit completo sarà presentato a luglio

From italian newspaper language to “scientific” language:

At 100% CL CERN has found the SM Higgs boson...

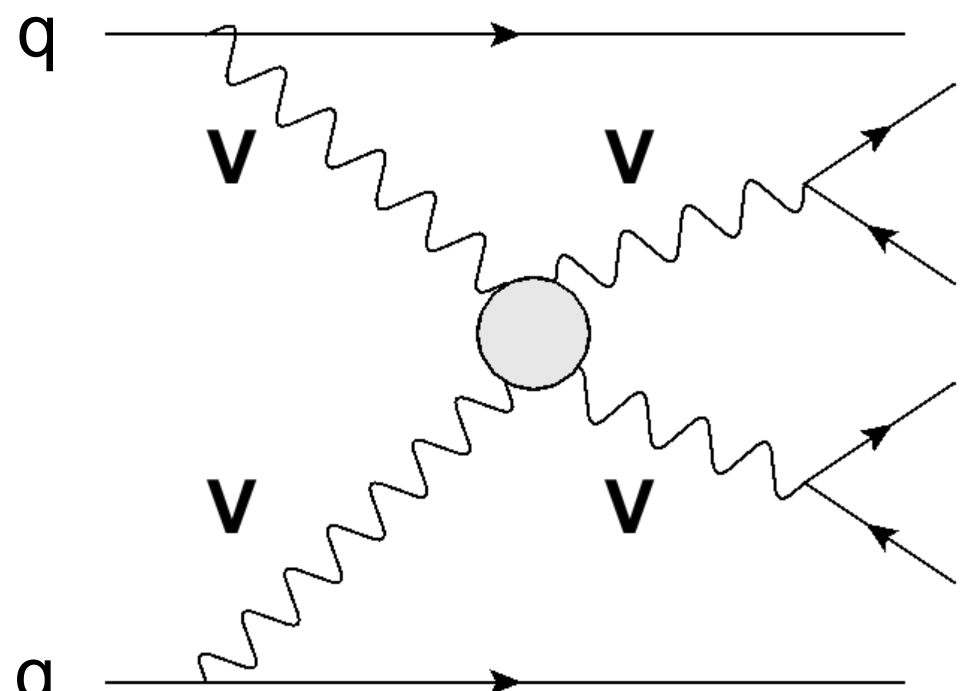
(I don’t think CERN ever stated this...)

so, for the italian press we can safely remove “like” from Higgs-like...

(this is for Eilam)

Vector Boson Fusion (VBF)

Generic diagram for vector boson fusion (VBF) process



Signature: forward-backward "spectator" jets with very high energy

- Once the vector bosons decay, we have a six-fermion final state
- The full set of qq→6 fermions diagrams has to be considered
- In order to investigate EWSB, one has to isolate VV processes from all other six-fermion final states

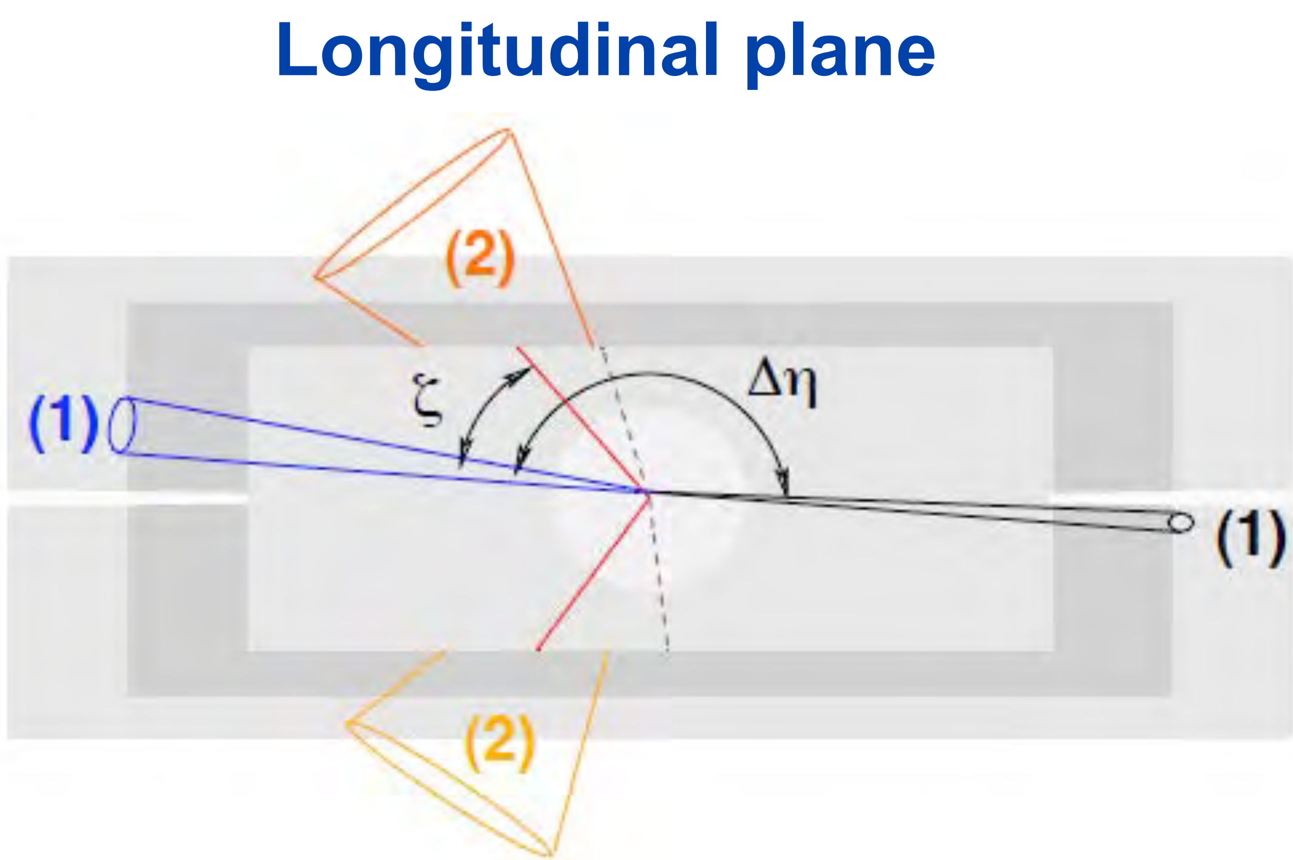
➡ Apply tight kinematic cuts

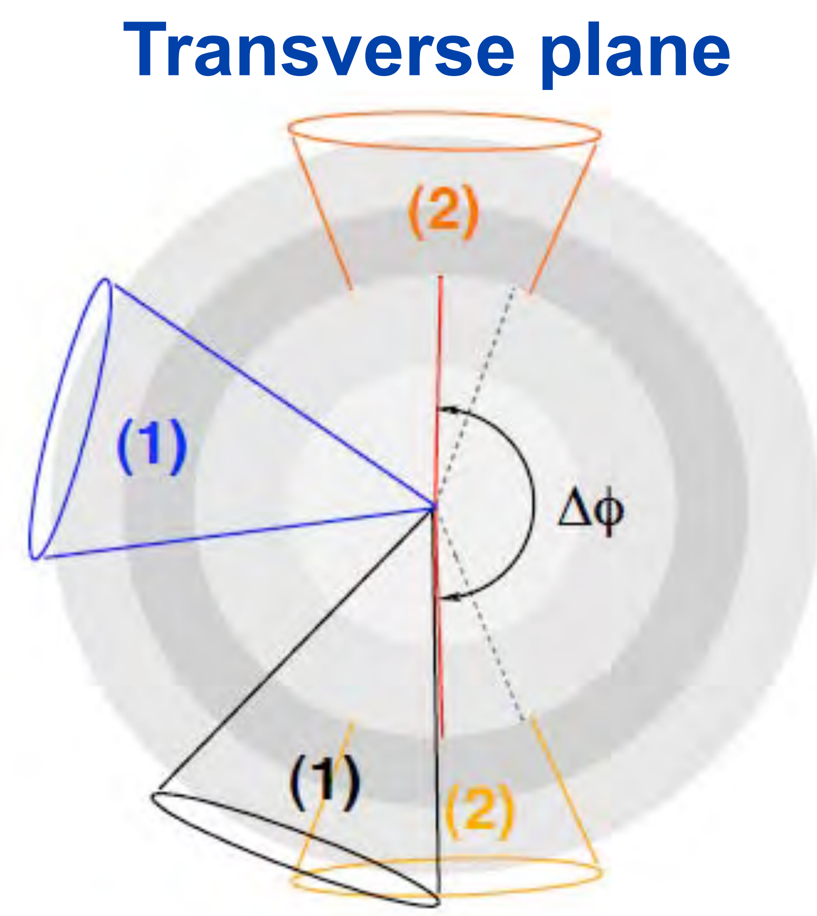
Typical kin. cuts

$p_{T,j} > 20$ GeV $|\eta_j|<5$ $p_T^{tag} > 30$ GeV **$|\eta_{j1}-\eta_{j2}|>4.0$**

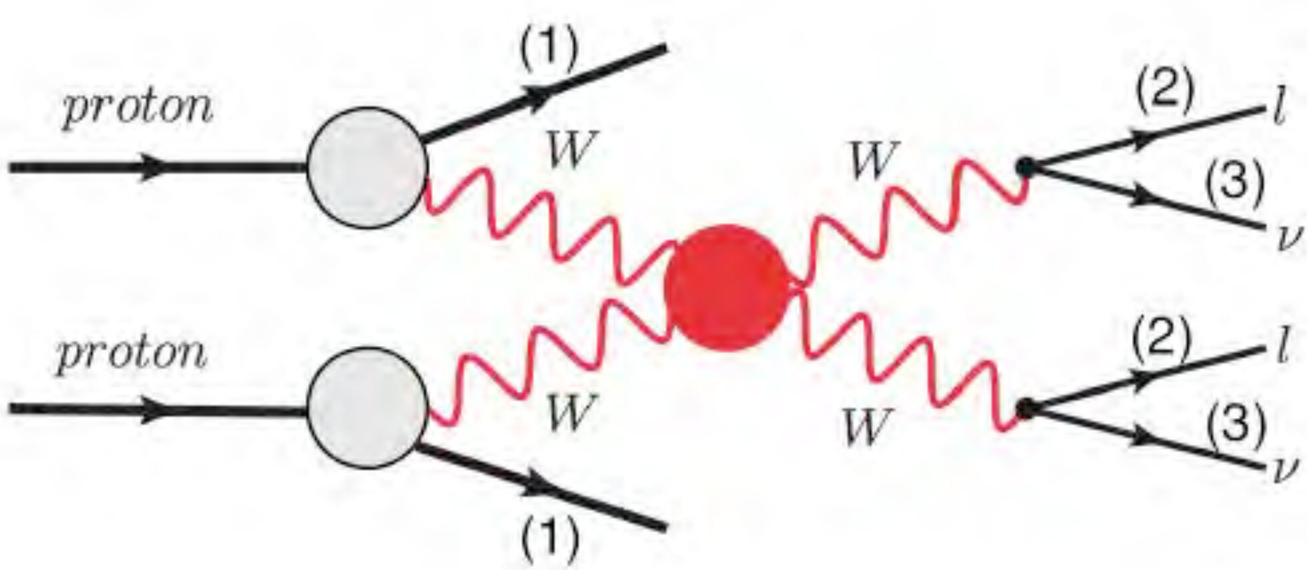
$\eta_{j1}\cdot\eta_{j2} < 0$ $m_{jj} > 600$ GeV

VBF experimental signature





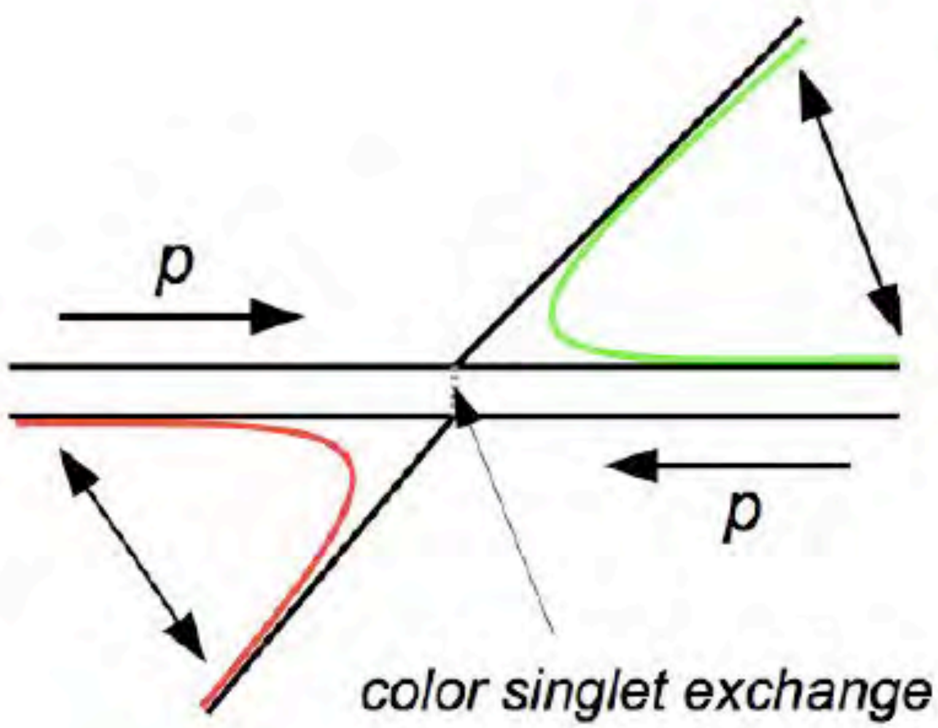
- *tagging jets* (1): large p_{T}, large $\Delta\eta$
- few jets between tagging jets
- final state $\ell\nu\ell\nu$:
  - *leptons* (2) between tagging jets
  - missing E_{T}(3)



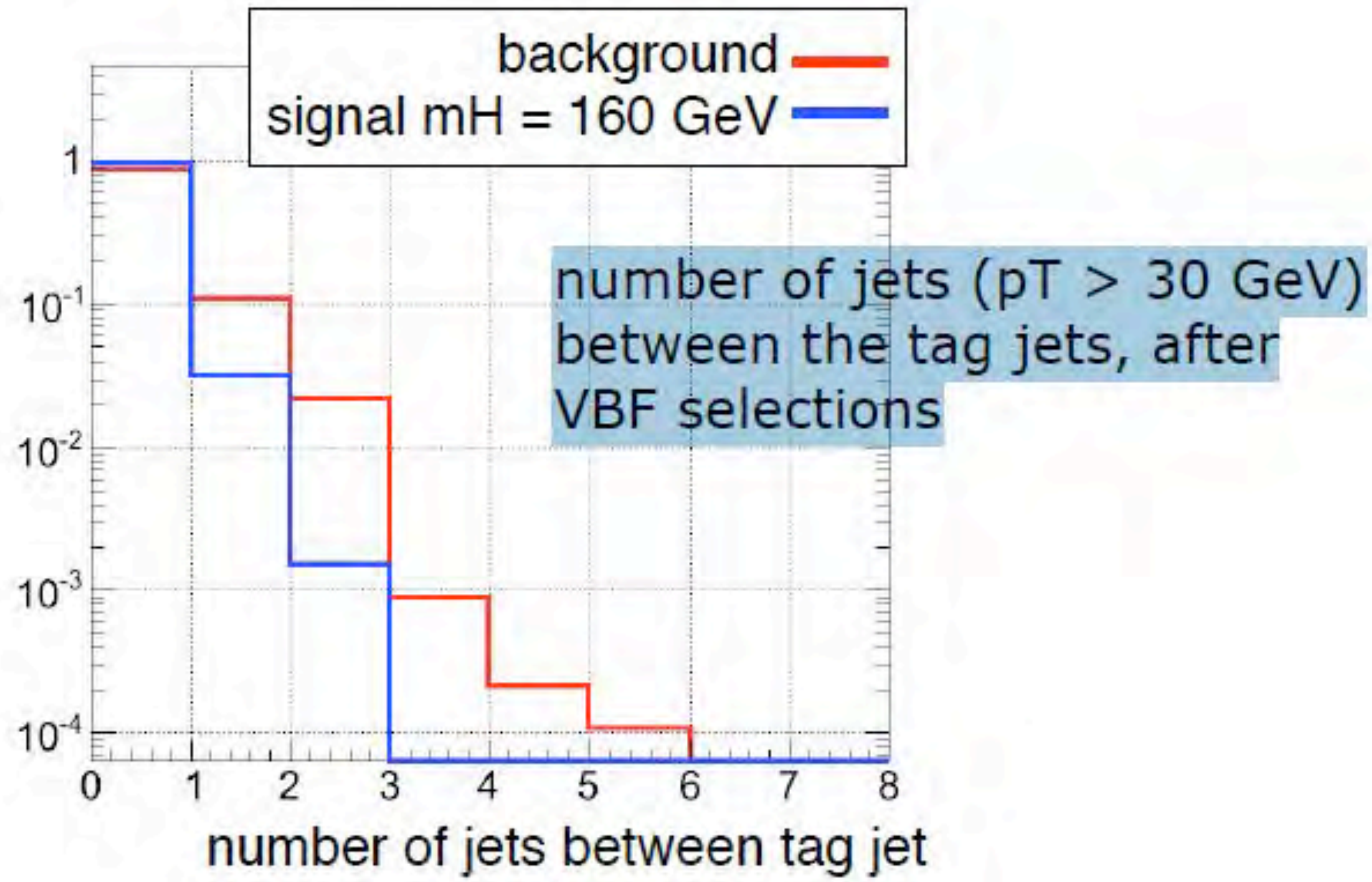
From **"Study of Vector Boson Scattering including Pile-up with the ATLAS Detector"** by P. Anger (TU Dresden), DPG Frühjahrstagung Karlsruhe 2011

Central rapidity gap

- **Central rapidity gap**: no hadronic activity between the two tag jets is expected, because of the EWK nature of the VBF



The two tag jets naturally define the region where no activity is expected

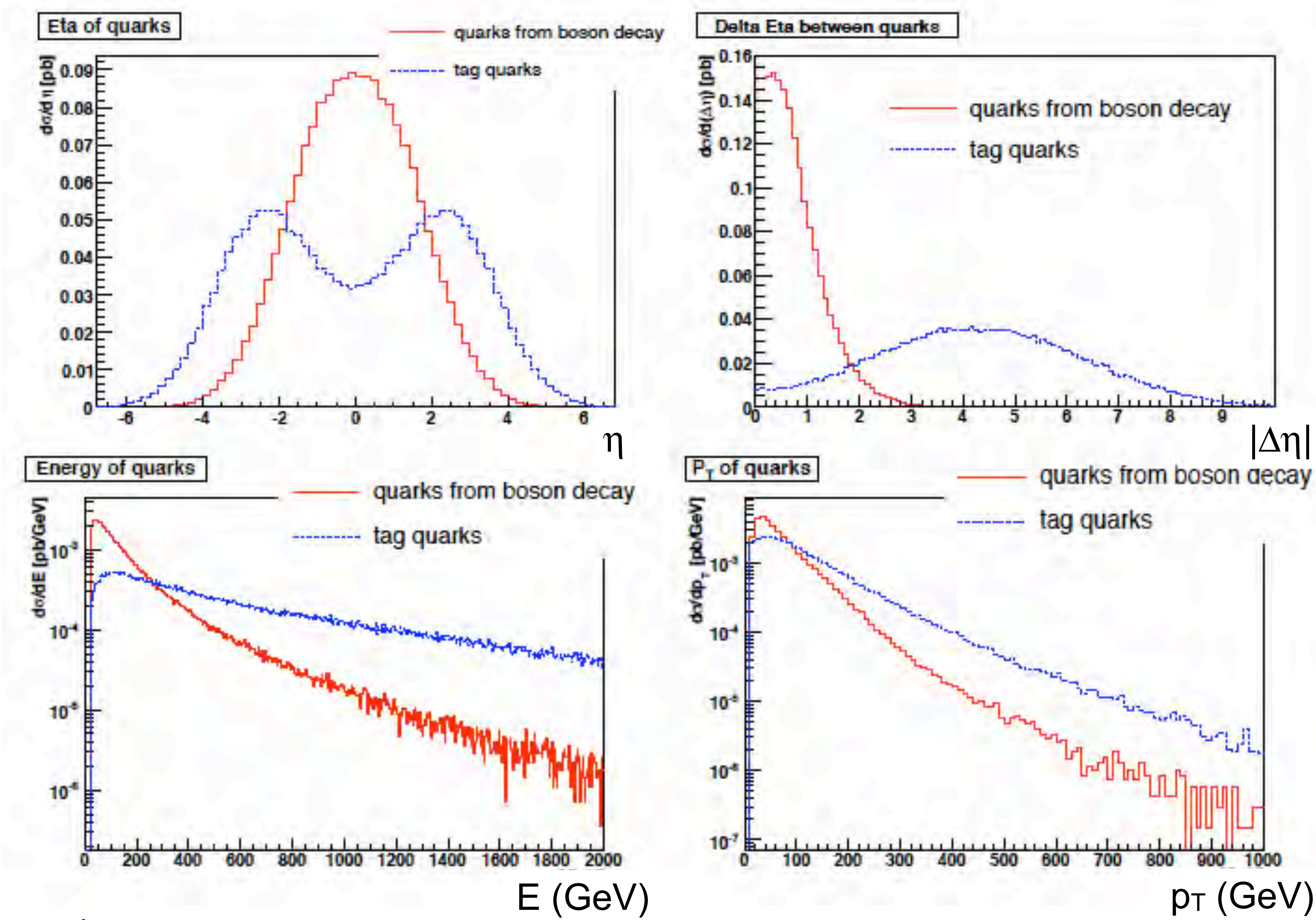


$$z_i^* = \frac{z_i}{\Delta\eta} = \frac{\eta_i - \langle\eta\rangle}{\Delta\eta}$$

The Zeppenfeld variable: a translation and scaling of the (pseudo)rapidity to the reference given by the tag jets

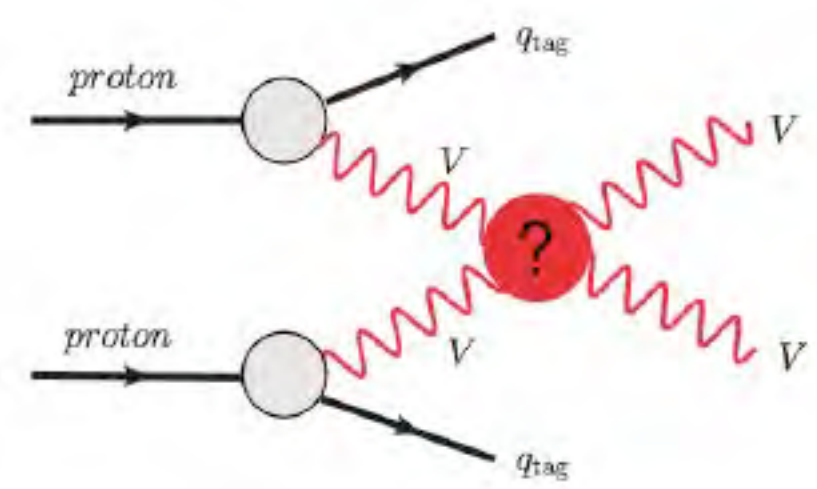
Taken from **"CMS-ATLAS VV scattering: any hope soon or reappraisal?"** by P. Govoni (CERN) at LHC results for TeV-scale physics, CERN,(August 2011):

VBF signature

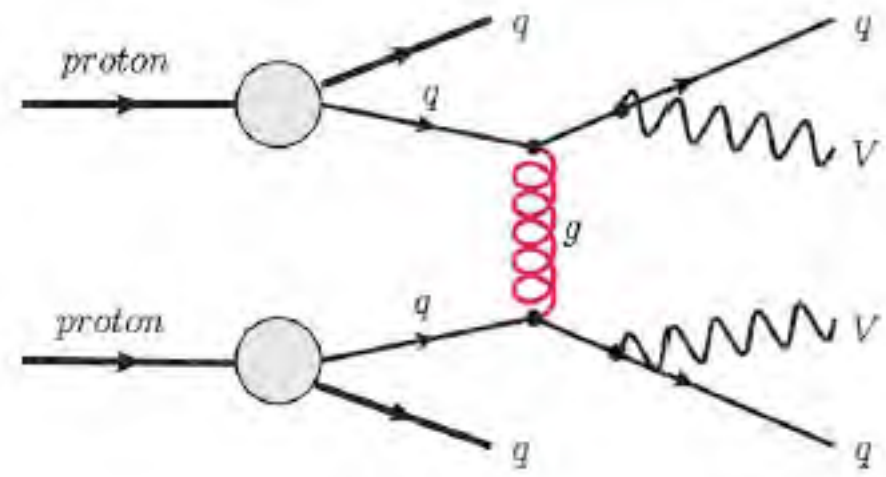


From **arXiV:hep-ph/0512219v2**

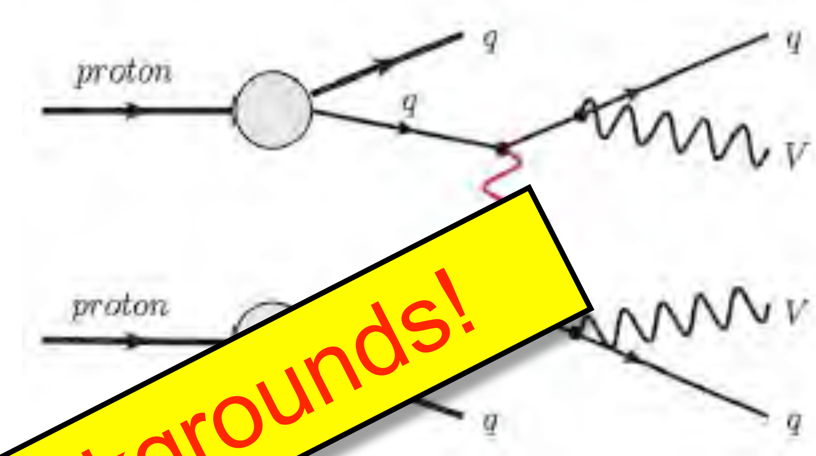
Signal and background processes



Signal: resonance



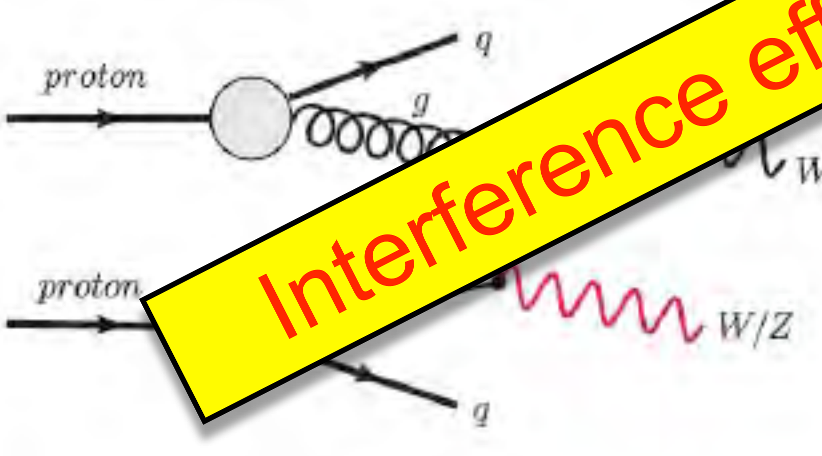
Irreducible BG: QC



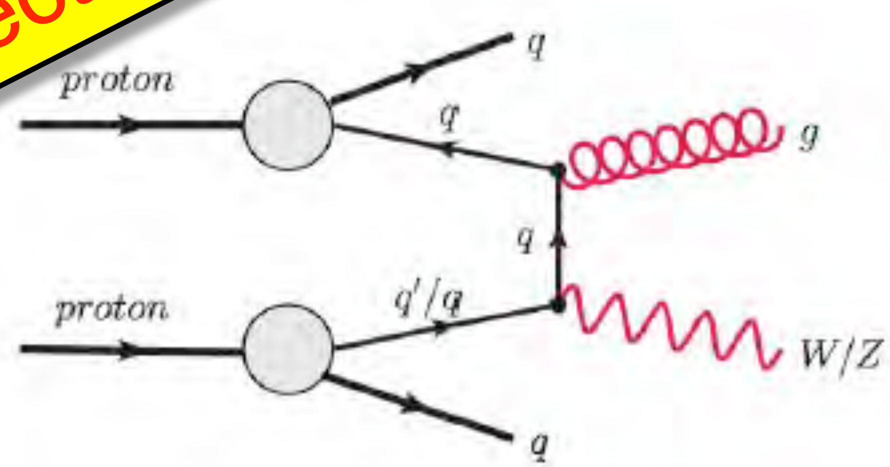
ducible BG: EWK

Also all SM triple and quartic boson (except Higgs) included

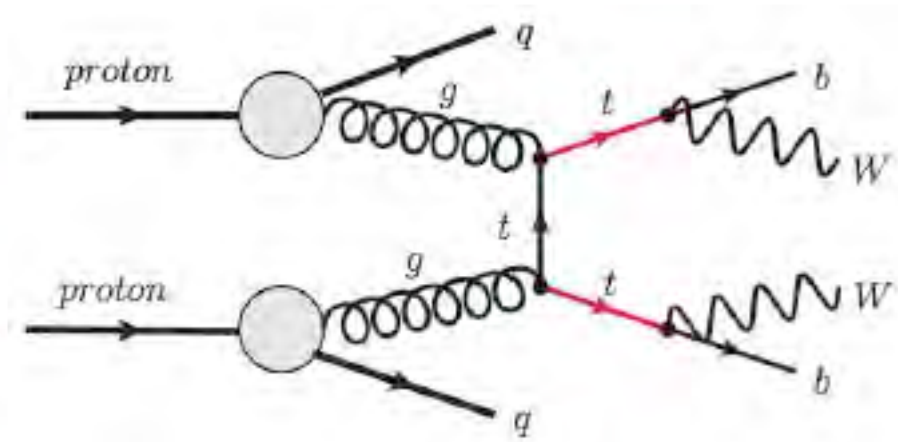
Interference effects between signal and backgrounds!



Single top (Wt)



W/Z + jets



Top pairs (tt)

VBF theoretical tools

- **VV2H** [M. Spira]: only t-channel, NLO QCD http://people.web.psi.ch/spira/vv2h/
- **VBFNLO** [D. Zeppenfeld et al.]: only t-channel, NLO QCD + NLO EW arXiv:1107.4038
- **MCFM** [J. M. Campbell, R. K. Ellis, C. Williams]: only t-channel, NLO QCD hep-ph/0403194
- **HAWK** [M. Ciccolini, A. Denner, A. Dittmaier, A. Mück]: NLO QCD and NLO EW, s- and t-channel (s-channel can be switched off), CPS reweighting arXiv:0707.0381
- **VBF@NNLO** [P. Bolzoni, F. Maltoni, S.-O. Moch, M. Zaro] only t-channel, CPS reweighting arXiv:1003.4451
- **POWHEG** [C. Oleari, P. Nason]: only t-channel, NLO QCD + PS, CPS reweighting arXiv:0911.5299
- **aMC@NLO** [S. Frixione et al.] t-channel only, s-channel can be included *paper to appear*
- **Sherpa**: [F. Krauss et al.] automatically includes s-channel https://sherpa.hepforge.org/trac/wiki
- **PHANTOM**: [A. Ballestrero, E. Maina et al.] full calculation @ LO for six fermions final state arXiv:0801.3359
- **Pythia/Fortran-Herwig**: only t-channel

Taken from "LHC Higgs Cross Section WG: VBF Status Report" by P. Govoni (CERN) at the 7th meeting of the LHC cross-section WG (December 2012):

VBF final states

- According to the vector bosons' decays we have a multitude of possible final states. We can group them in

  - Fully leptonic
    - pp→qq ℓℓℓℓ (ℓ=μ,e)
    - pp→qq ℓℓℓν
    - pp→qq ℓℓνν

Clean

Can reconstruct m_{VV} (not with 2ν)

Very low yields..

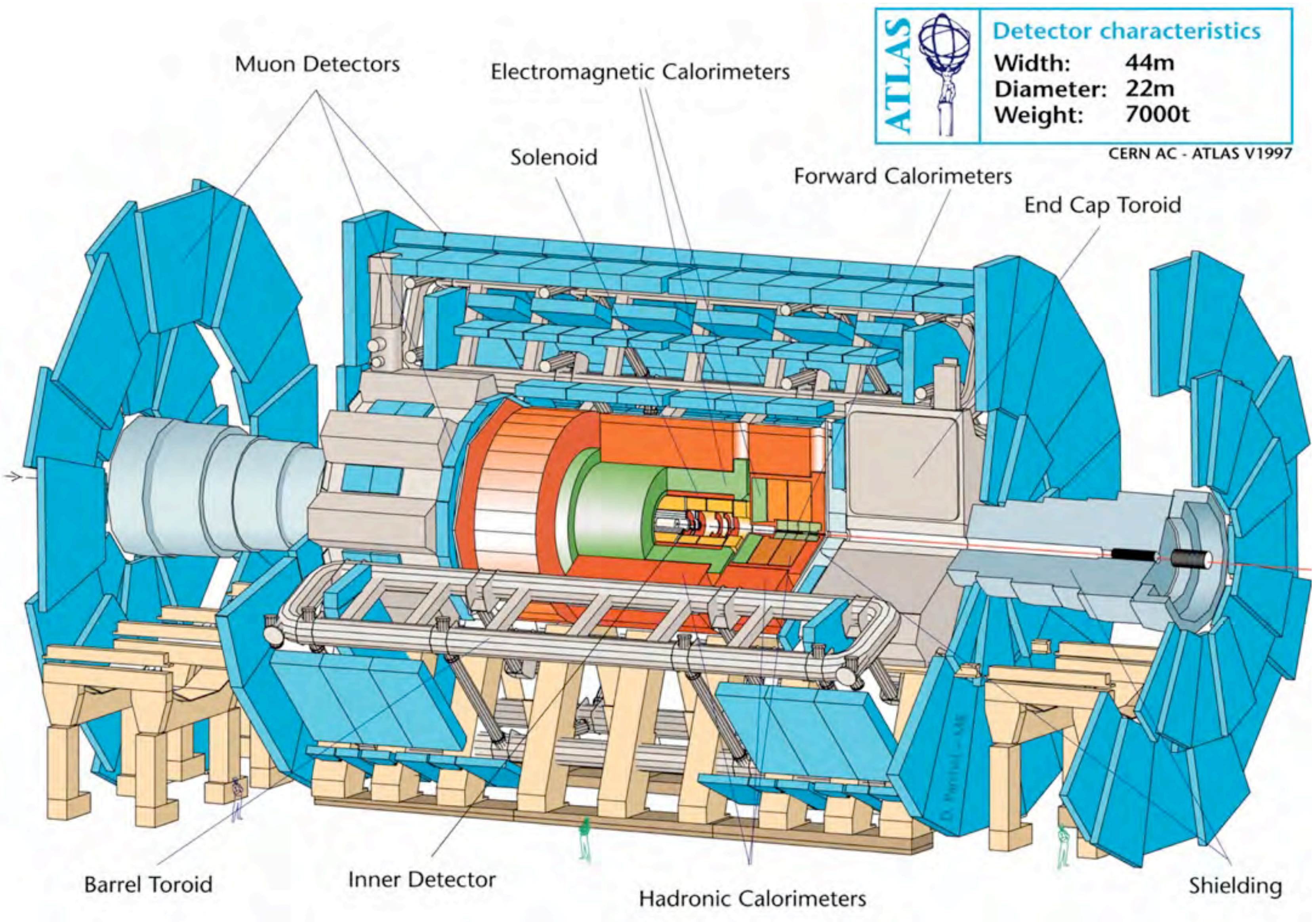
  - Semi-leptonic
    - pp→qq jetjet ℓℓ
    - pp→qq jetjet ℓν

Better yields..

Detector needs

Excellent lepton ID, energy resolution, hermeticity, jet tagging at high η

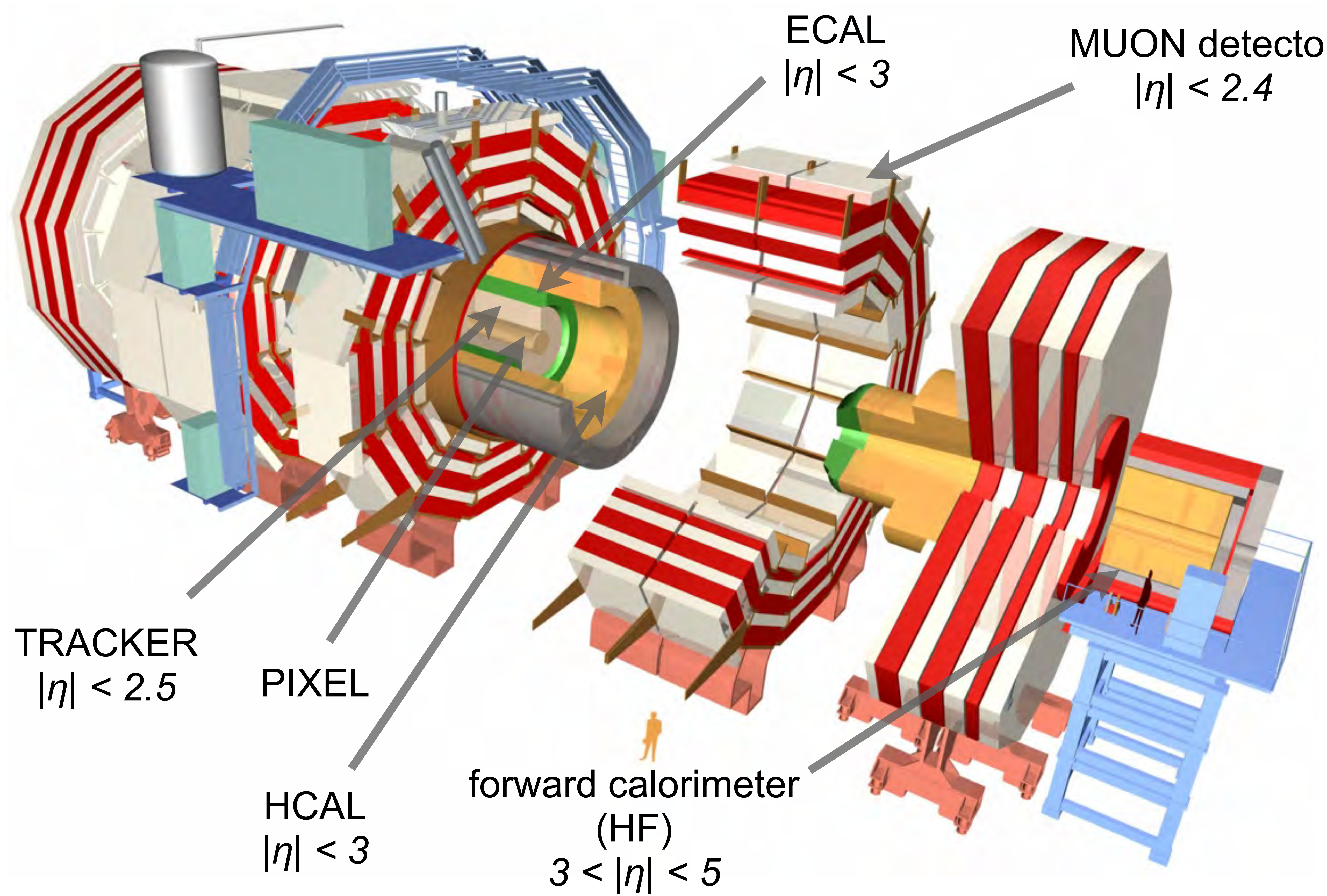
The ATLAS detector



- *e/γ energy resolution:*
  $\sigma/E \approx 10\text{-}15/\sqrt{E} \oplus \sim 1\%$
- *Central jet energy resolution*
  $\sigma/E \approx 60/\sqrt{E} \oplus 3\%$
- *Missing $E_{x,y}$ resolution*
  $\sigma \approx 0.55$ GeV x $\sqrt{(\sum E_T)}$
- *Track inverse-p_T resolution*
  $\sigma_{\{1/pT\}} \approx 35$ TeV^{-1} x $(1 \oplus 50/p_T)$
- Muon system standalone p_T resolution
  σ/p_T < 10% up to 1 TeV

- *Tracking and muon coverage: |η|<2.5*
- *Calorimeter with presamplers: |η|<1.8*
- *Forward calorimeters: 3.2<|η|<5.9*

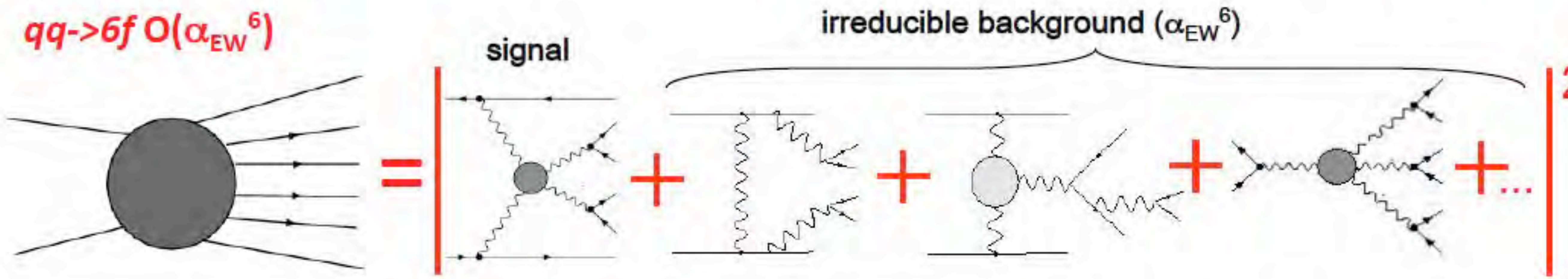
The CMS detector

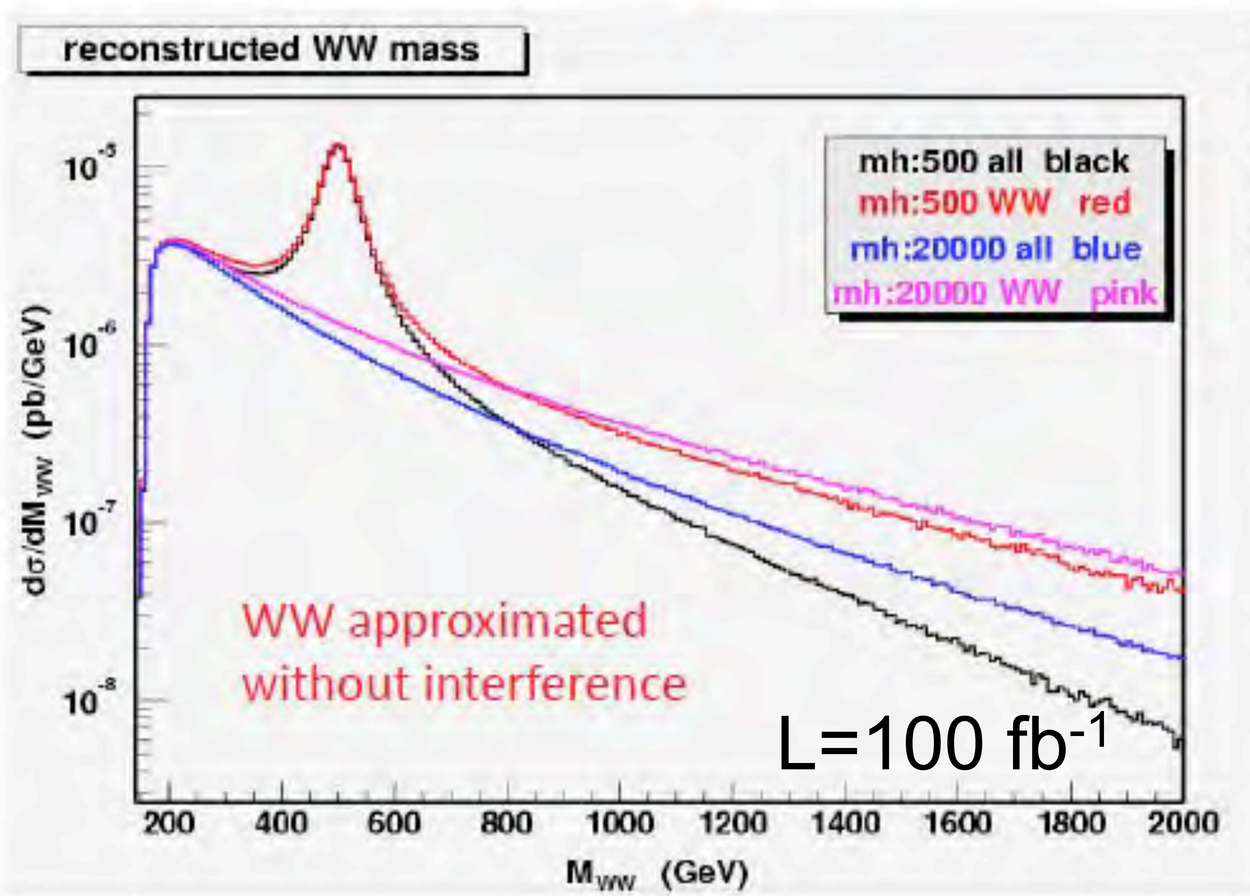


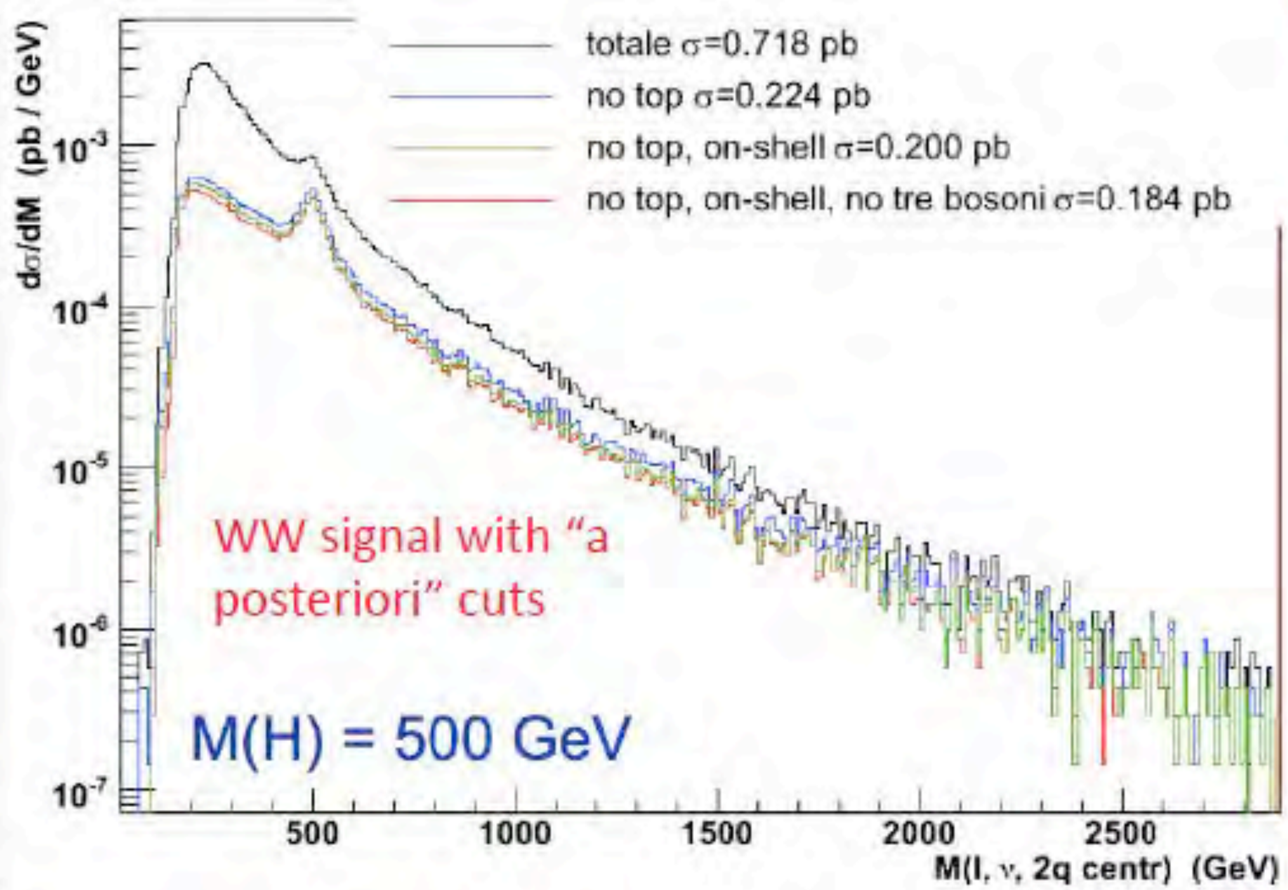
VV scattering: interference effects

JHEP 0603 (2006) 093
Accomando, Ballestrero, Bolognesi, Maina, Mariotti

- Big interference effects considered only in **Phantom**

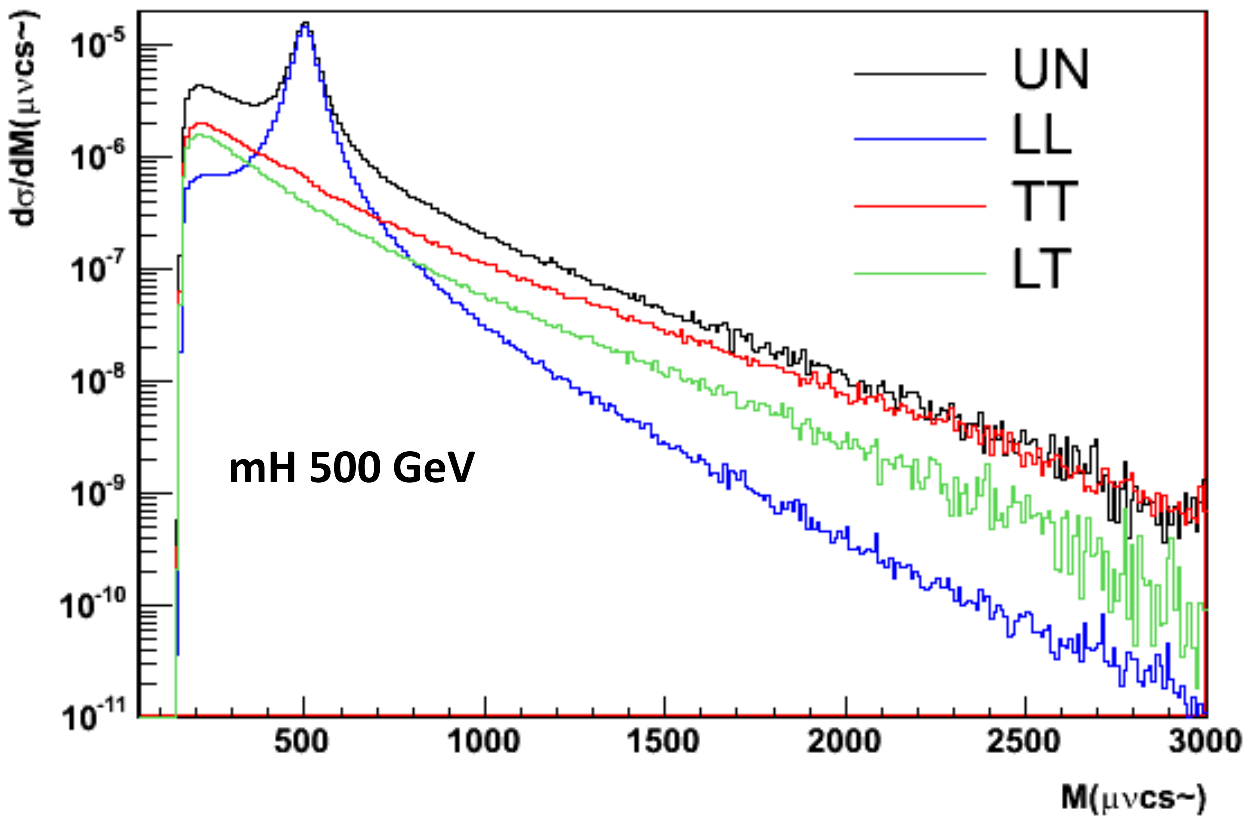


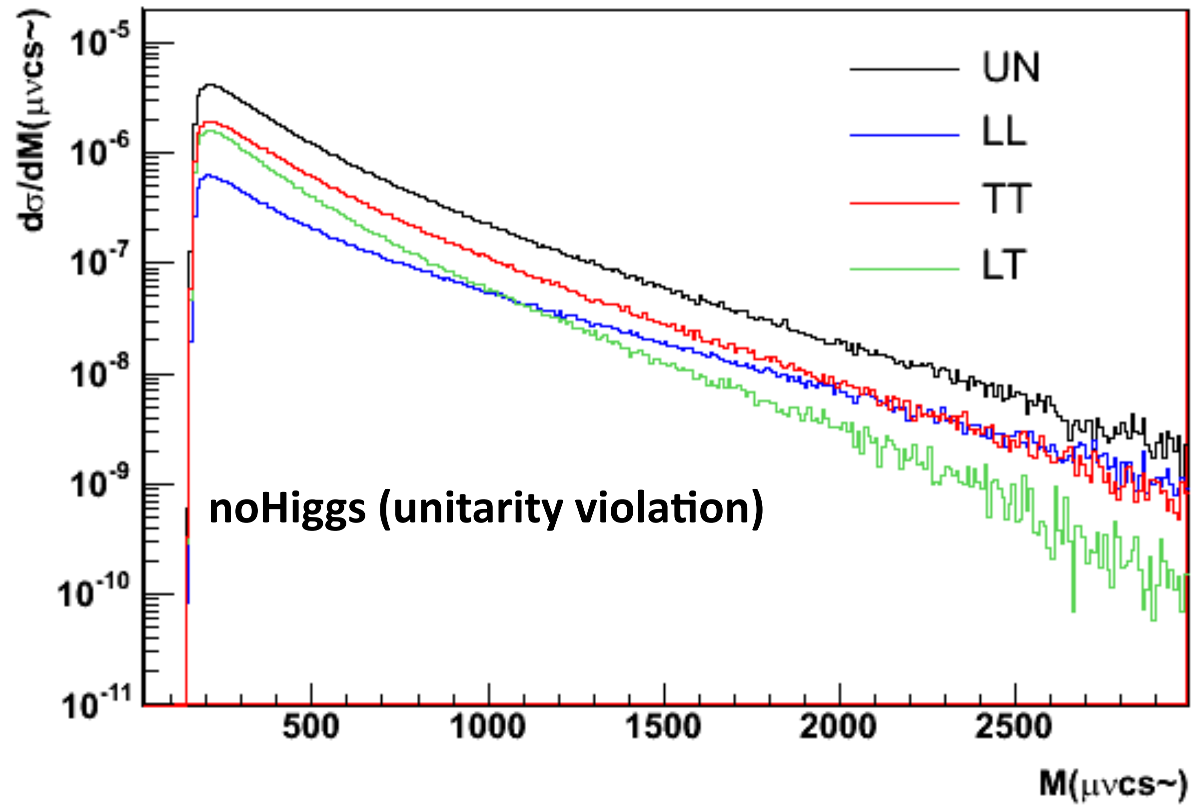




Longitudinal vs Transversal

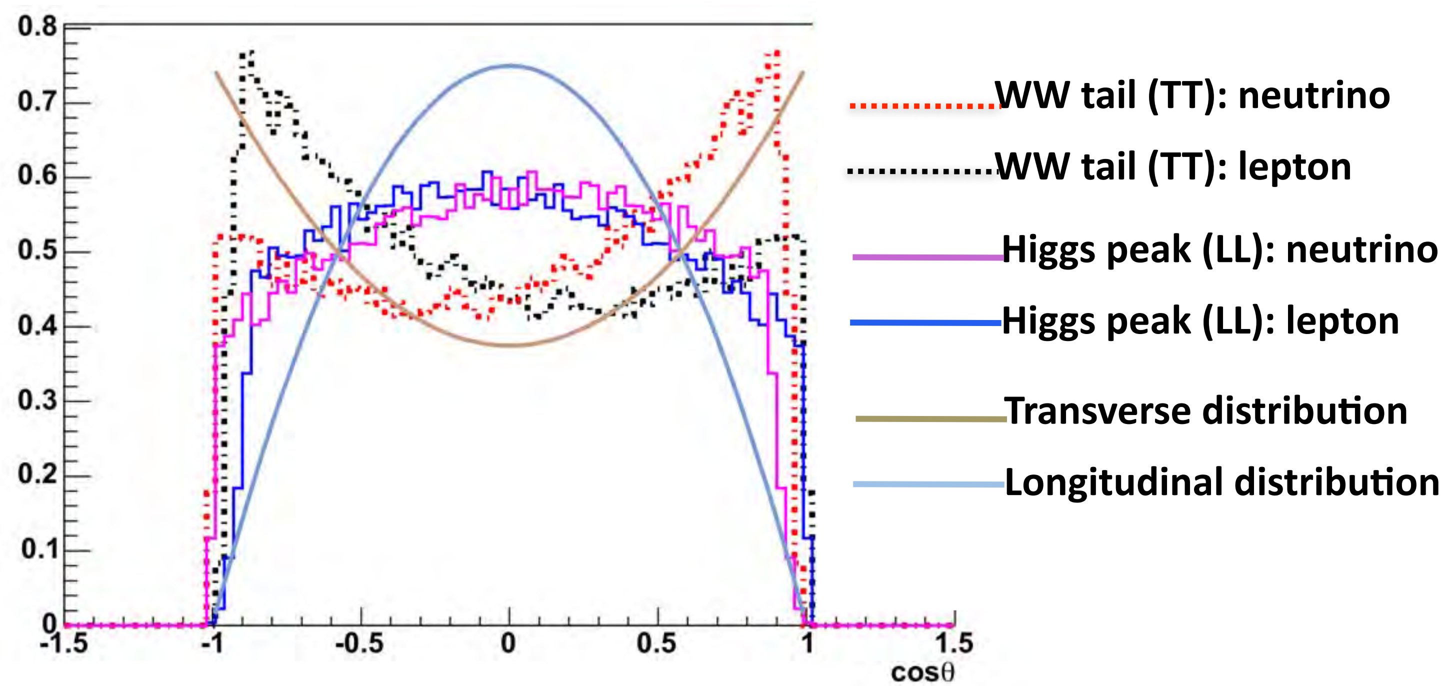
Contrary to what one expects LL does not dominate at high m_{VV}





Angular analysis can boost LL-TT separation (new!)

partonic study in the center of mass of W



VV scattering

Same issues (as Higgs search and) as expected in VV scattering search

- **fully leptonic:** much lower stat, much cleaner

  uncertainty on VV+2j production

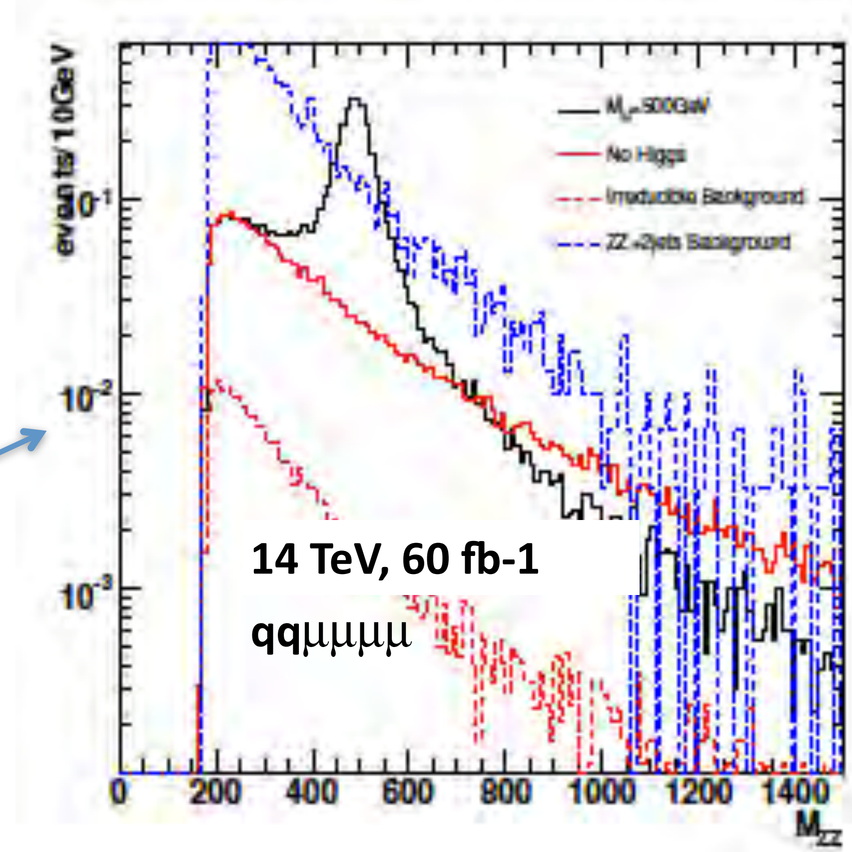
- **semileptonic:** larger yields, huge background

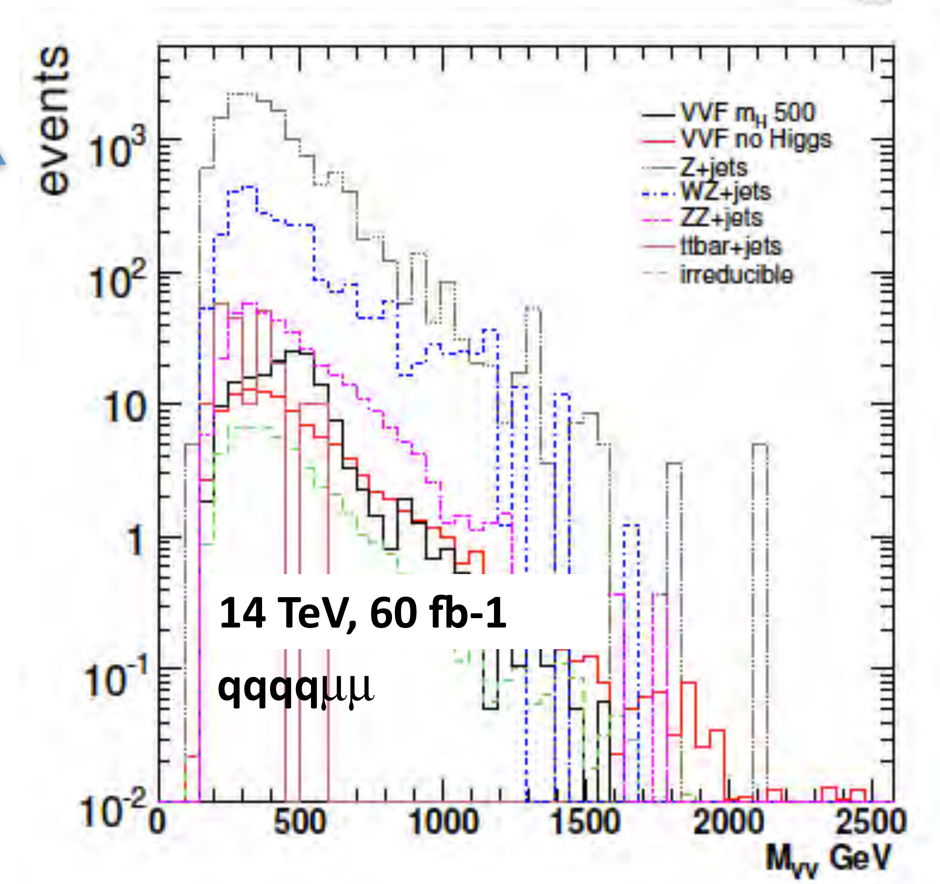
  V+jets control

  high VV mass → boosted V → jet merging

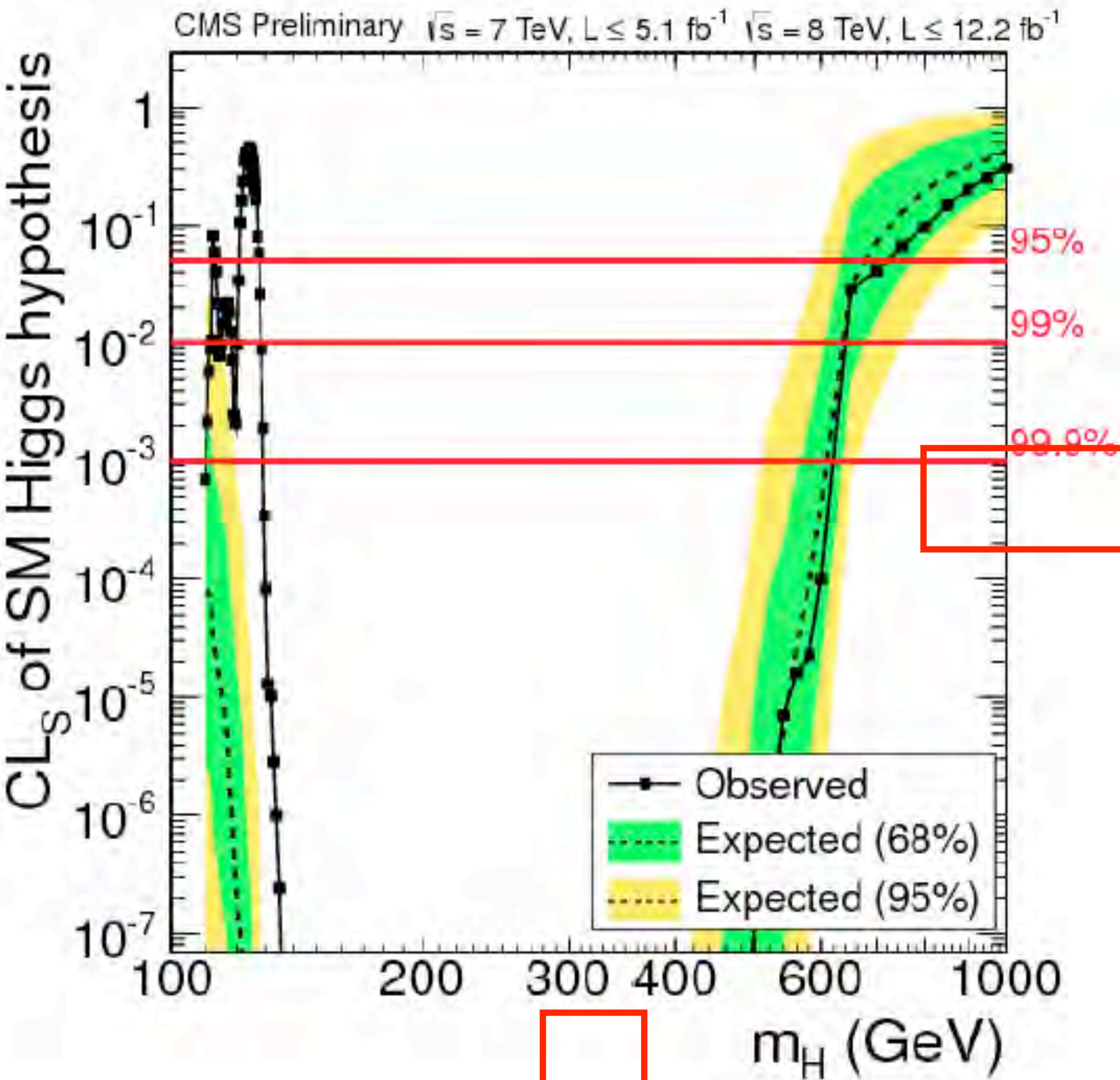
- first look at **fully hadronic** final state ongoing

  SUSY-like discriminators (eg, Razor)





News from experiments?



Some dedicated VBF analyses (H→ZZ→4l, H→WW→lνqq,2l2ν) already started

higher mass

BSM search for **VV resonance @ 1 TeV** (DY production)

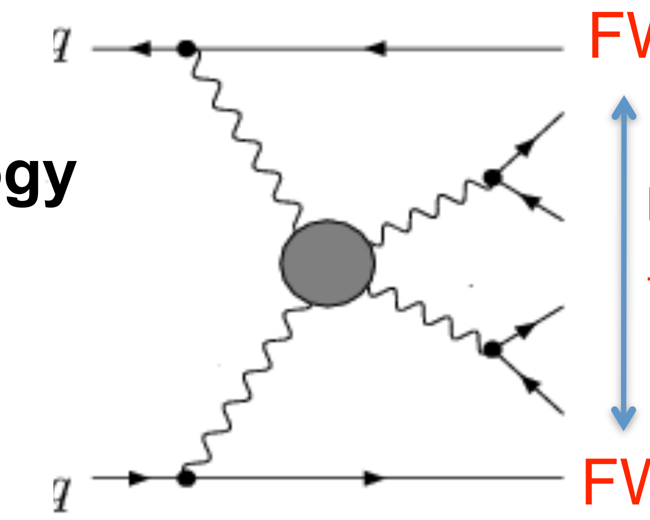
→ studying same final states as VV scattering

higher sensitivity

VBF dedicated search

→ characterization of tag jets signature

First look at tag jets



Starting to face issues related with tag jets topology and jet vetoing → very relevant for VV scattering:

- control of VV background in jet-multiplicity bins

  → **theoretical systematics (no control regions for ZZ, WW at high mass)**

- Z prodution in VBF: a candle for jet tagging and jet veto efficiency?

  → (after feasibility) real data analysis ongoing

- MC tools to describe FWD jets and gap events → related with description of UE, MPI and QCD at wide angle

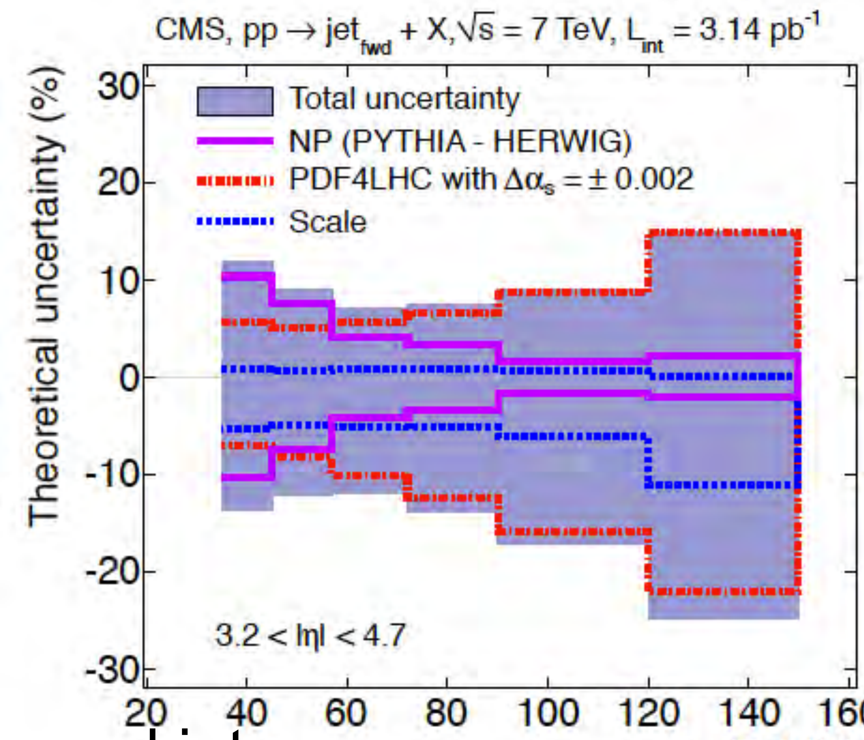
  → **many useful measurements can be done NOW to constrain FWD jets modeling**

  → TO BE REVIEWED WITH HIGHER PU

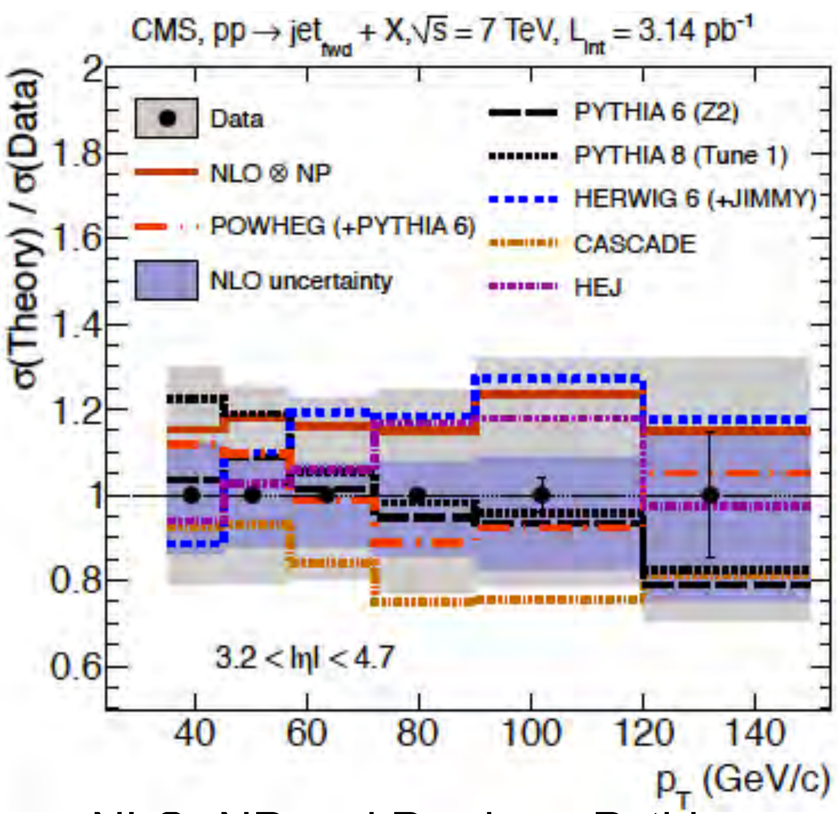
Fwd jets modelling

★ Non-perturbative effects:

- energy lost from jets due to hadronisation
- energy added to jets from UE



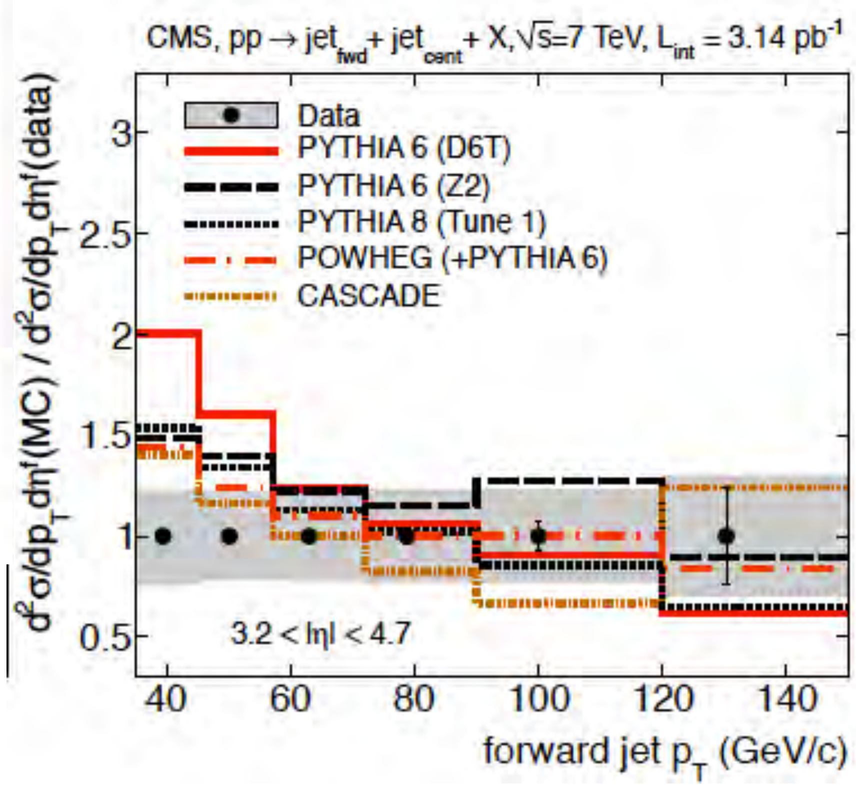
★ FWD jet spectrum (|η|3.2-4.7) with low PU events

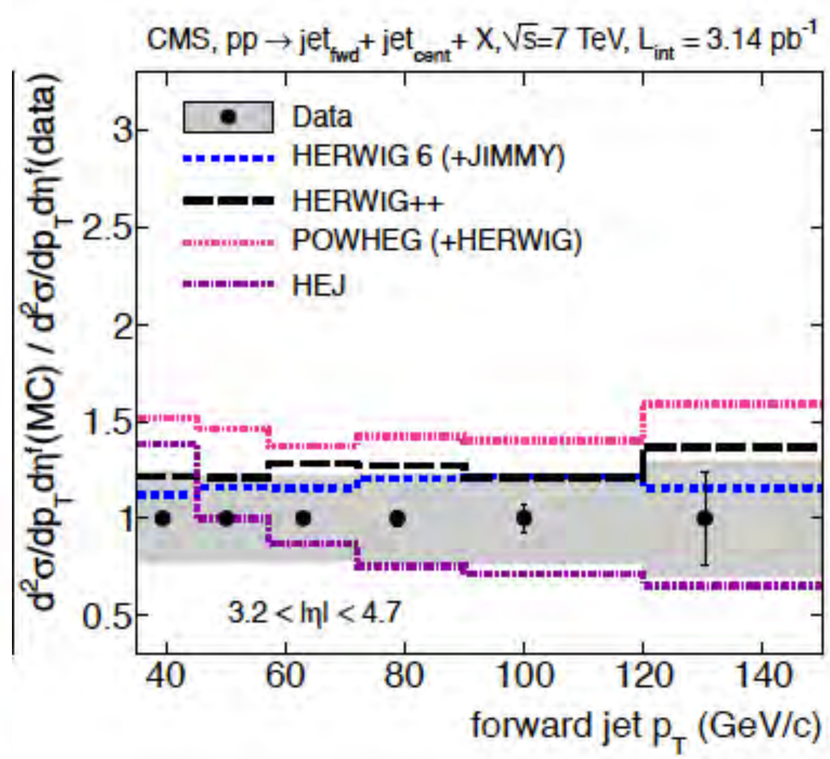


NLO+NP and Powheg+Pythia catch the dependence, not the xsec

Pythia Z2 tuned to LHC UE

central + forward jet



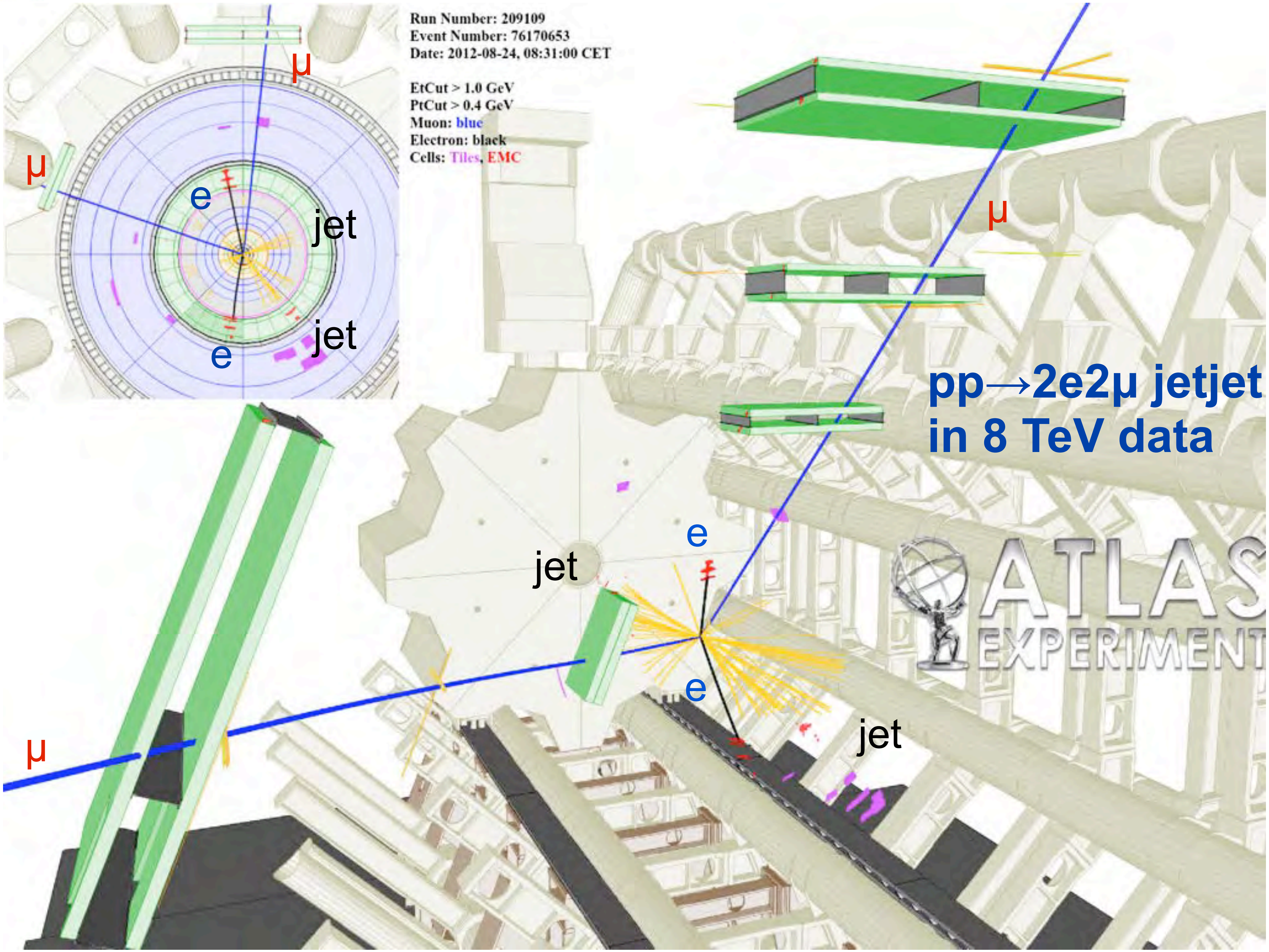


hep-ex arXiv:1202.0704

Herwig does a better job than pythia

★ useful also to commission detectors -> especially in view of pileup

VBF 2e2μ candidate event



pp→2e2μ jetjet in 8 TeV data

VV scattering: fully leptonic

CMS AN 2007-005

CERN-OPEN-2008-020

Only background VV+jets, very low xsec

Number of events for 20 fb^{-1} (fully MC based, no systematics, 14 TeV)

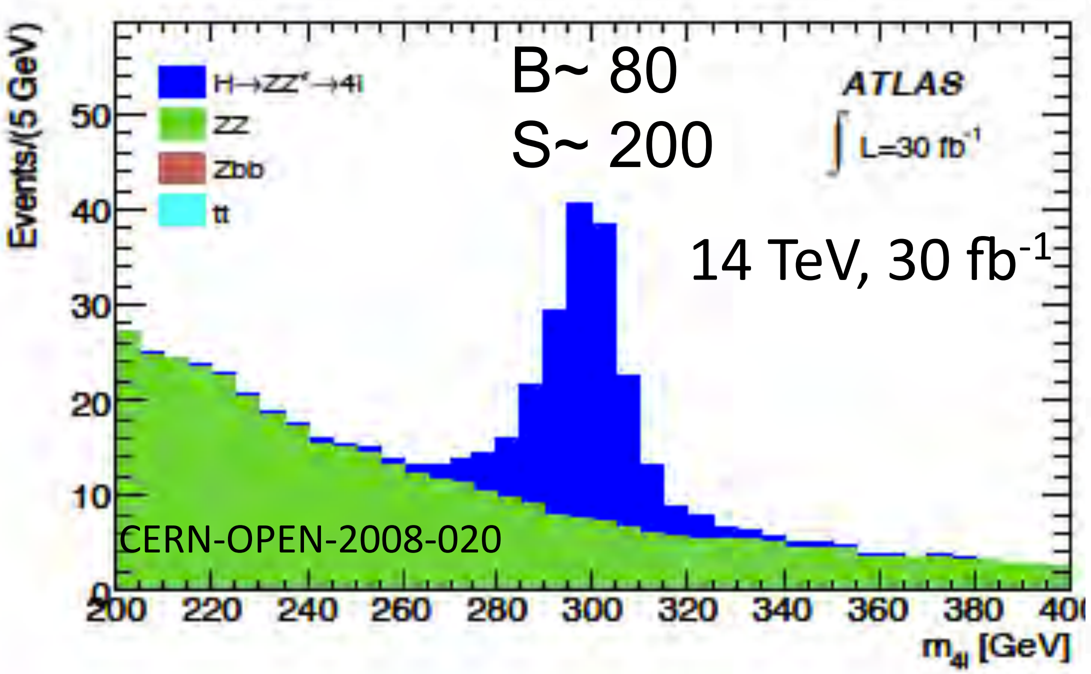
CMS ZZ->4e, 4μ	N signal	N back.
500 GeV	2.2	1.9
>1 TeV	0.1	0.2

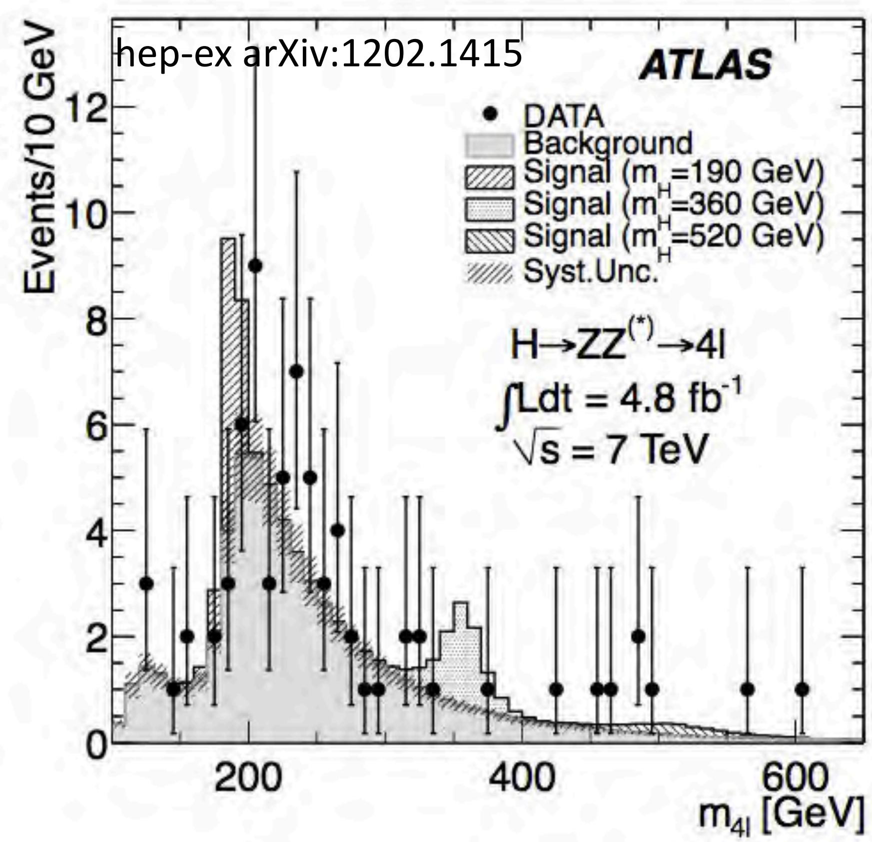
CMS ZW->μμμν	N signal	N back.
>1 TeV	0.9	0.8

ATLAS ZZ->2l2ν	N signal	N back.
500 GeV	6.4	3.0

ATLAS ZW->lllν	N signal	N back.
500 GeV	8	5
1.1 TeV	1.4	0.4

Example: ggF Higgs 300 GeV





Latest results:

B~ 6

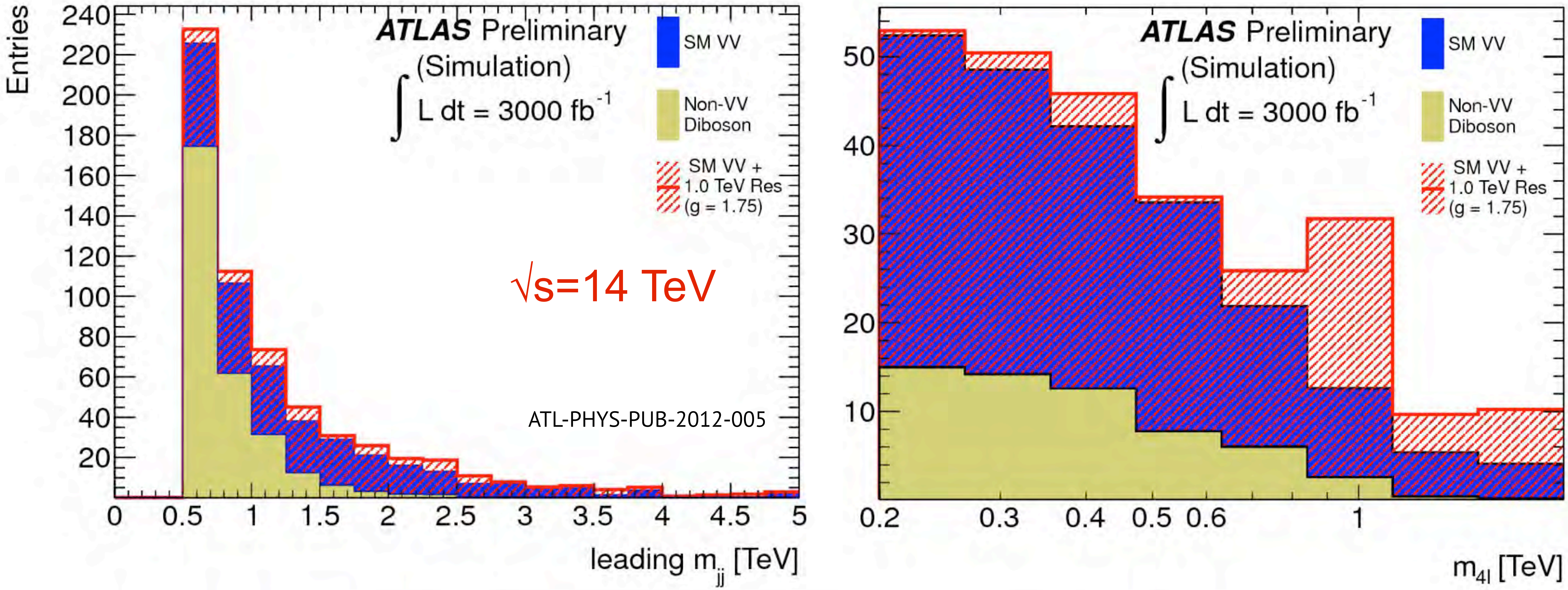
S~ 10

- reso m_{4l} as expected
- improved reco-id efficiencies

(eg ele ID: TDR time 85-90% -> today 95%)

ZZ resonance

pp→ZZ+2j→4ℓ+2j channel



model	300 fb^{-1}	3000 fb^{-1}
$m_{resonance}$ = 500 GeV, g = 1.0	2.4σ	7.5σ
$m_{resonance}$ = 1 TeV, g = 1.75	1.7σ	5.5σ
$m_{resonance}$ = 1 TeV, g = 2.5	3.0σ	9.4σ

Sensitivity to anomalous ZZ resonances in Vector boson scattering

VV scattering: semileptonic

Semileptonic is most promising: reasonable signal yield

Number of events for 20 fb^{-1} (fully MC based, no systematics, 14 TeV)

WV -> lnjj

ATLAS	N sign.	N back.
500 GeV	6.2	16
800 GeV	13	17
1.1 TeV	4.8	9.2

CMS	N sign.	N back.
500 GeV	337	20759
>1 TeV	45	3281

ZV -> lljj

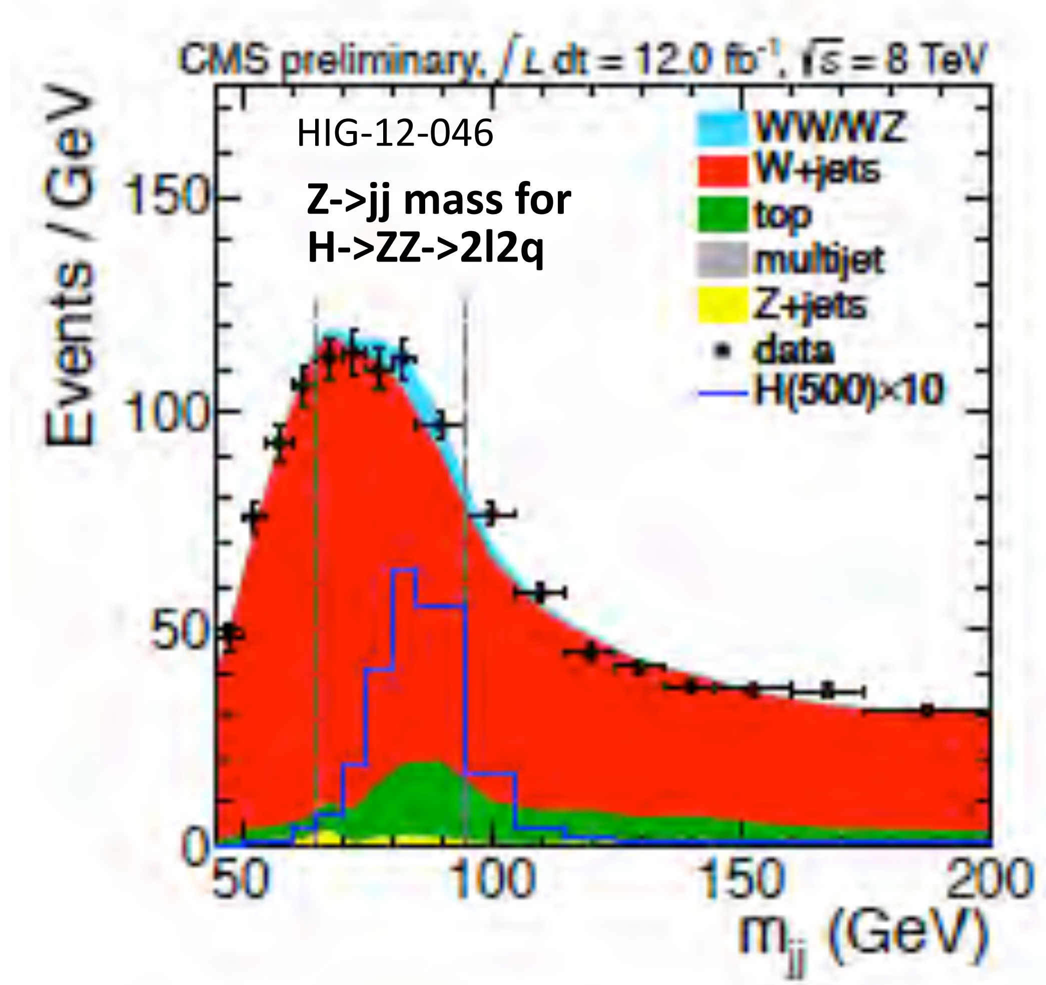
CMS	N sign.	N back.
500 GeV	62	3415
>1 TeV	5	348

For recent inclusive Higgs search:

- more sophisticated analysis developed (btag categories, angular analyses, $m_{jj} = m_Z$ kinematic fit)

- data driven background

Improved JES: m_{jj} reso from 20-25% to 10-15% !



CERN-OPEN-2008-020

Summary

- VV scattering is an essential process to verify EWSB
- It can shed light on the structure of the Higgs boson
- Challenging both theoretically (interference effects) and experimentally (small yields, wide pseudorapidity coverage, many channels)
- Both ATLAS and CMS have performed studies, but these will need to be re-visited and improved
- Some scenarios can be investigated with $L \geq 100\ fb^{-1}$ of data at $\sqrt{s}$=13-14 TeV. Other scenarios (like SILH) will require even more luminosity.
- HL-LHC should be able to provide answers to most benchmark cases.

Backup

EWSB and the W, Z masses

$$L_{gauge} = -\frac{1}{4}W^i_{\mu\nu}W^{\mu\nu i} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2 W^i_{\mu\nu}W^{\mu\nu i} + \frac{1}{2}m^2 B_{\mu\nu}B^{\mu\nu}$$

$$W^i_{\mu\nu} = \partial_\nu W^i_\mu - \partial_\mu W^i_\nu + g\varepsilon^{ijk}W^j_\mu W^k_\nu \quad \text{SU(2)} \times$$

$$B_{\mu\nu} = \partial_\nu B_\mu - \partial_\mu B_\nu \quad \text{U(1)}$$

Gauge invariance

complex scalar doublet of SU(2) $\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$

scalar potential (λ>0, μ<0) $V(\Phi) = \mu^2|\Phi^+\Phi| + \lambda(|\Phi^+\Phi|)^2$

with minimum **(= empty state)** at $\langle\Phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$ or $\langle\Phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} v \\ 0 \end{pmatrix}$ → ~~SU(2)~~

*(**v** = empty expectation value)*

generic Gauge

$$\Phi = \frac{1}{\sqrt{2}}e^{i\frac{\omega^i\tau^i}{2v}}\begin{pmatrix} 0 \\ v+h \end{pmatrix}$$

1 physical scalar field $\langle h \rangle = 0$

3 Goldstone bosons ω_i

4 Gauge fields $W^i_{\mu\nu}, B_\mu$

Gauge unitario

$$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+h \end{pmatrix}$$

1 physical scalar field -> Higgs

4 Gauge fields combined into known vector bosons: W,Z with mass, photon massless

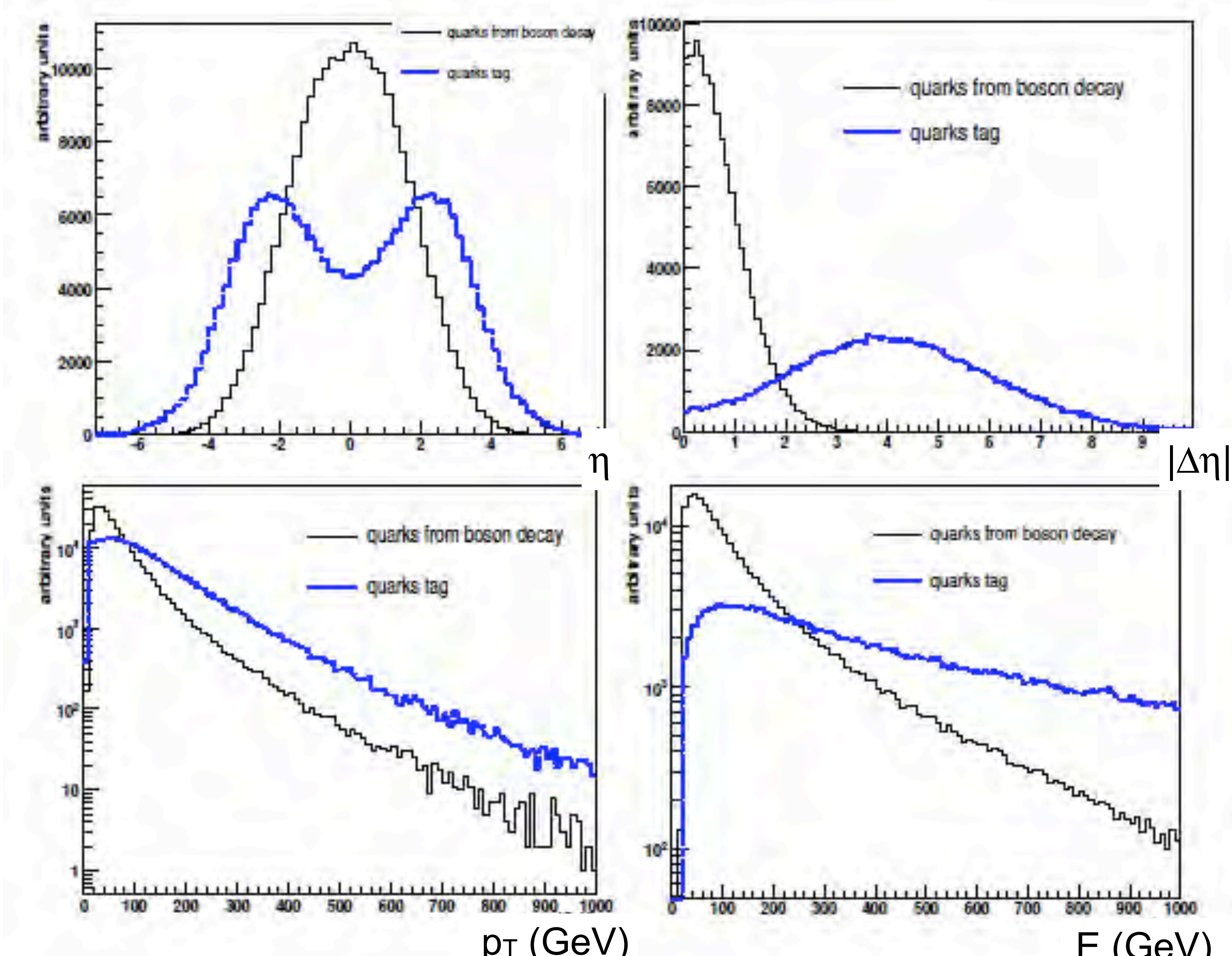
$$W^\pm_\mu = \frac{1}{\sqrt{2}}\left(W^1_\mu \mp iW^2_\mu\right) \quad M^2_W = \frac{1}{4}g^2v^2$$

$$Z^\mu = \frac{-g'B_\mu + gW^3_\mu}{\sqrt{g^2+g'^2}} \quad M^2_Z = \frac{1}{4}\left(g^2+g'^2\right)^2$$

$$A^\mu = \frac{-gB_\mu + g'W^3_\mu}{\sqrt{g^2+g'^2}} \quad M^2_A = 0 \quad \text{U(1)}_{EM}$$

01/18/2012 seminar 4

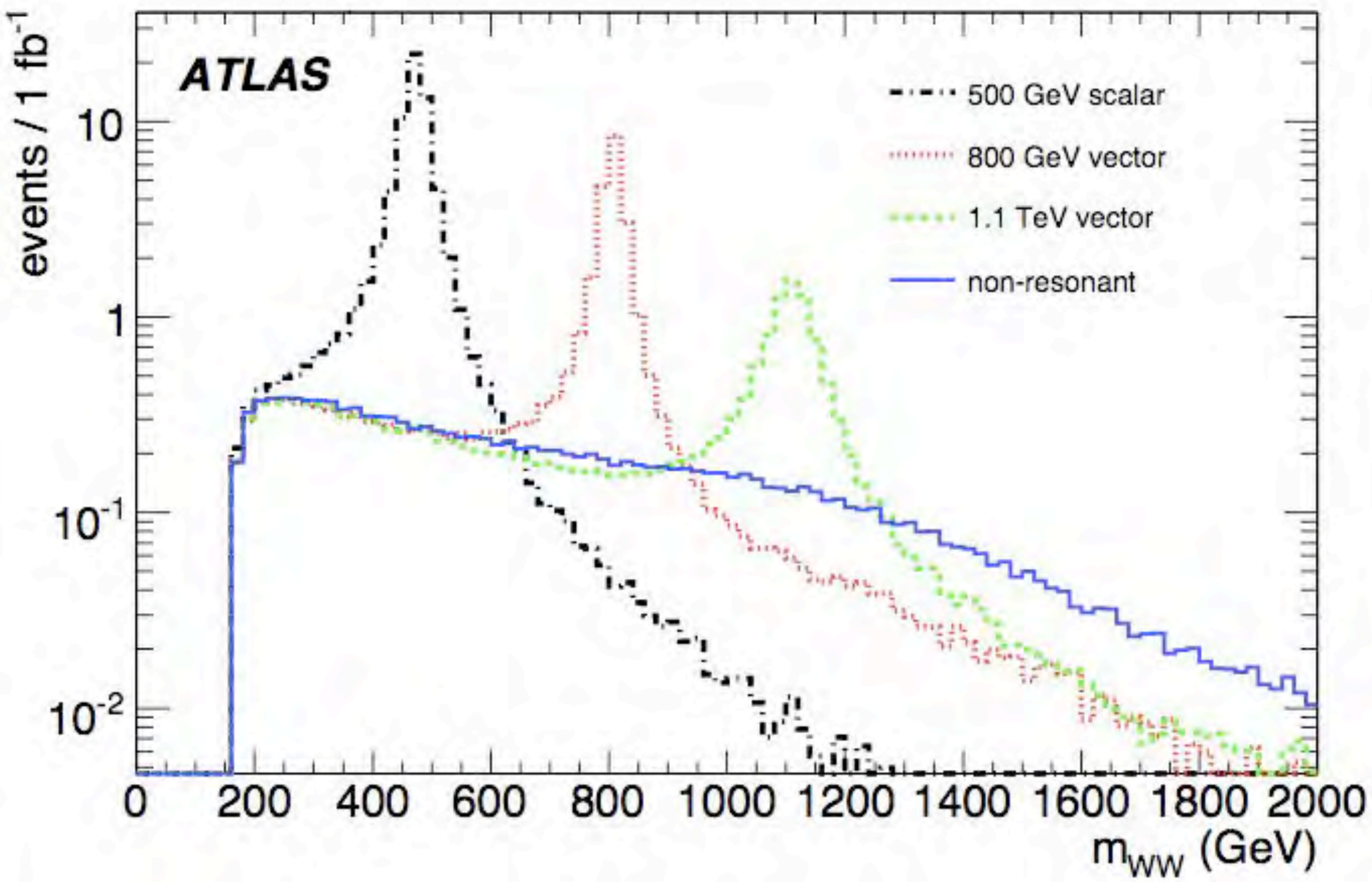
VBF signature

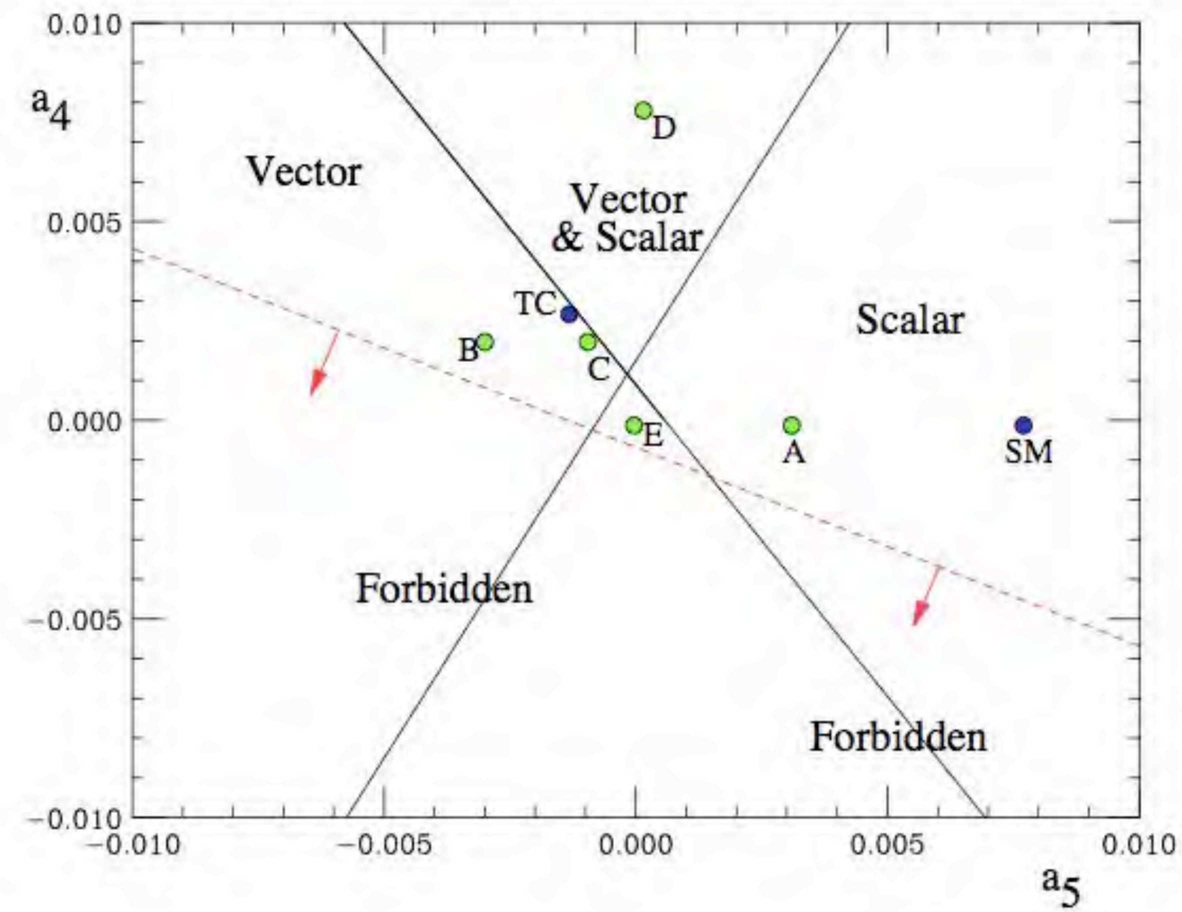


From **CMS AN-2007/05, arXiV:0812.2564**

VV resonances (EVBA studies)

- **Model-independent** treatment of physics below some scale Λ: electroweak chiral Lagrangian with Padé unitarization
- Tested different possibilities
- Special attention to **semi-leptonic processes: qqH → VV → jjX**





J.M. Butterworth et al., "**WW scattering at LHC**", arXiv:hep-ph/0201098v1

The ATLAS Collaboration et al., "**Expected Performance of the ATLAS Experiment Detector, Trigger and Physics**", CERN-OPEN-2008-02

Channel considered

Sample name	Generator	$\sigma \times Br$, fb
$qqWZ \to qqjj\ell\ell$, $m = 500$ GeV	PYTHIA-73	25.2
$qqWZ \to qq\ell\nu jj$, $m = 500$ GeV	PYTHIA-73	83.9
$qqWZ \to qq\ell\nu\ell\ell$, $m = 500$ GeV	PYTHIA-73	8.0
$qqWZ \to qqjj\ell\ell$, $m = 800$ GeV	PYTHIA-ChL	10.5
$qqWZ \to qq\ell\nu jj$, $m = 800$ GeV	PYTHIA-ChL	35.2
$qqWZ \to qq\ell\nu\ell\ell$, $m = 800$ GeV	PYTHIA-ChL	3.4
$qqWZ \to qqjj\ell\ell$, $m = 1.1$ TeV	PYTHIA-ChL	3.7
$qqWZ \to qq\ell\nu jj$, $m = 1.1$ TeV	PYTHIA-ChL	12.3
$qqWZ \to qq\ell\nu\ell\ell$, $m = 1.1$ TeV	PYTHIA-ChL	1.18
$qqWW \to qq\ell\nu jj$, $m = 499$ GeV (s)	PYTHIA-ChL	66.5
$qqWW \to qq\ell\nu jj$, $m = 821$ GeV (s)	PYTHIA-ChL	27.5
$qqWW \to qq\ell\nu jj$, $m = 1134$ GeV (s)	PYTHIA-ChL	17.0
$qqWW \to qq\ell\nu jj$, $m = 808$ GeV (v)	PYTHIA-ChL	29.8
$qqWW \to qq\ell\nu jj$, $m = 1115$ GeV (v)	PYTHIA-ChL	17.9
$qqWW \to qq\ell\nu jj$, non-resonant	PYTHIA-ChL	10.0
$qqZZ \to qq\nu\nu\ell\ell$, $m = 500$ GeV	PYTHIA-ChL	4.0
$jjWZ \to jj\ell\nu\ell\ell$, background	MADGRAPH	96
$jjZZ \to jj\nu\nu\ell\ell$, background	MADGRAPH	45.5
		σ (no Br), pb
$W^+ + 4$ jets	MADGRAPH	165 ± 0.1
$Z + 4$ jets	MADGRAPH	87 ± 0.7
$W^+ + 3$ jets	MADGRAPH	6.2 ± 0.02
$Z + 3$ jets	MADGRAPH	3.8 ± 0.02
$t\bar{t}$	MC@NLO	833 ± 100

$$\sqrt{s} = 14\ TeV$$

signals: rows from $qqWZ \to qqjj\ell\ell$, $m = 500$ GeV to $qqZZ \to qq\nu\nu\ell\ell$, $m = 500$ GeV

backgrounds: rows from $jjWZ \to jj\ell\nu\ell\ell$ to $t\bar{t}$

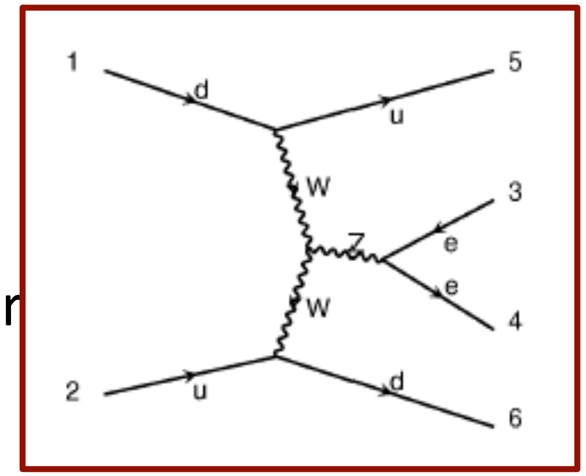
Z in VBF as standard candle?

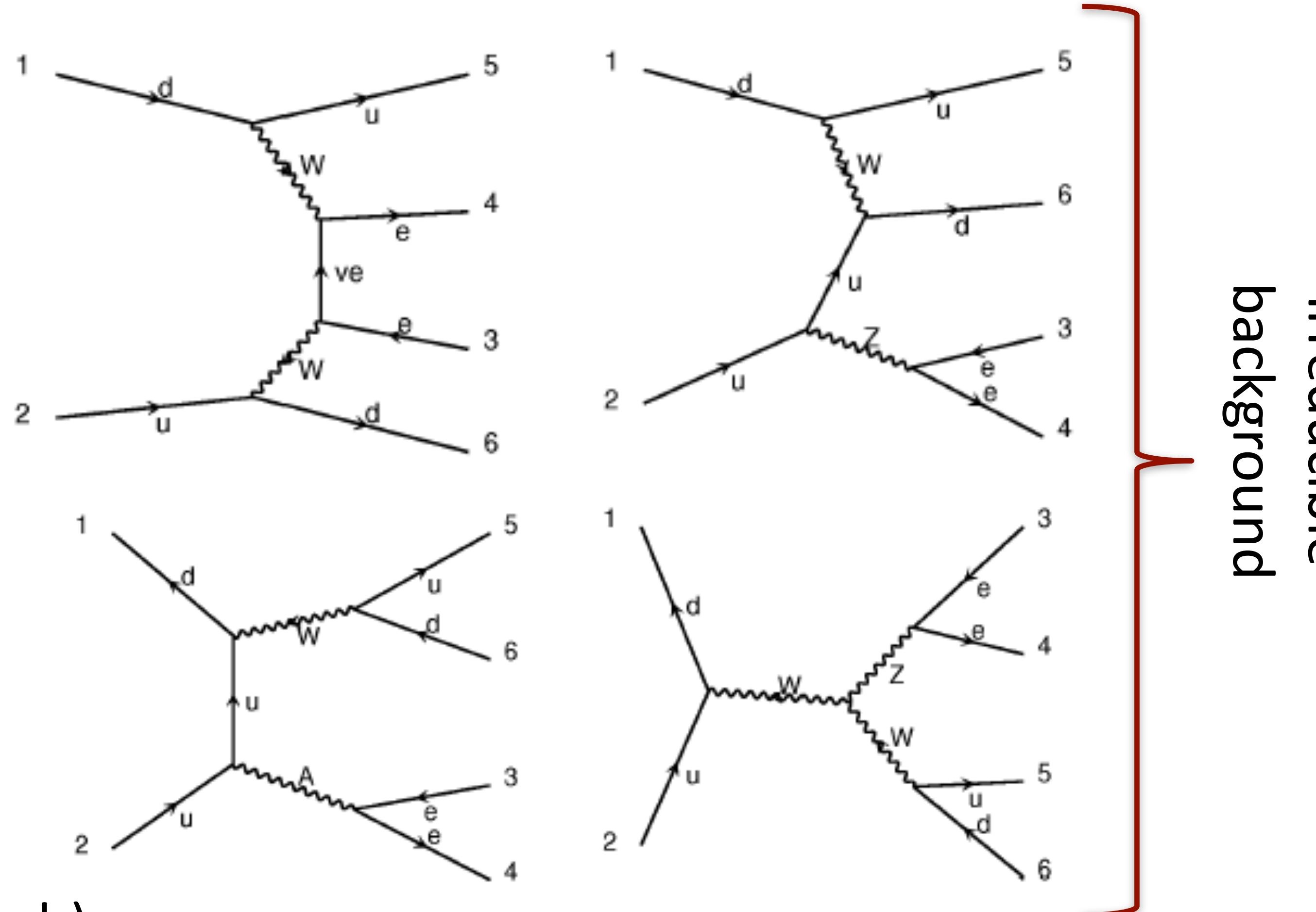
hep-ex arXiv:1001.4357

❑ VBF Z production as reference: feasibility study **at parton-level @ 10 TeV**

Z+qq (4 pb) :

signal (~5%)
isolated
“a posteriori” with par
cuts





-> 2700 events @ 15 fb-1

-> 45% eff for VBF-specific cuts

-> 23% tighter cuts against Z+jets QCD (2700 pb)

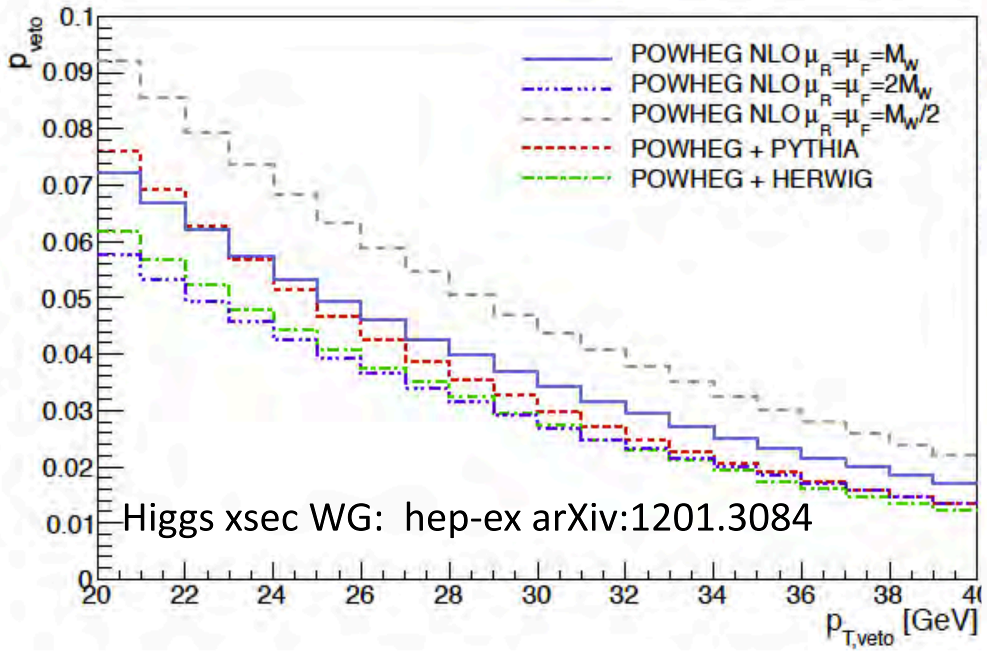
S/B improved of a factor 100: **600/78k events @ 15 fb-1** (S/sqrt(B)~ 2)

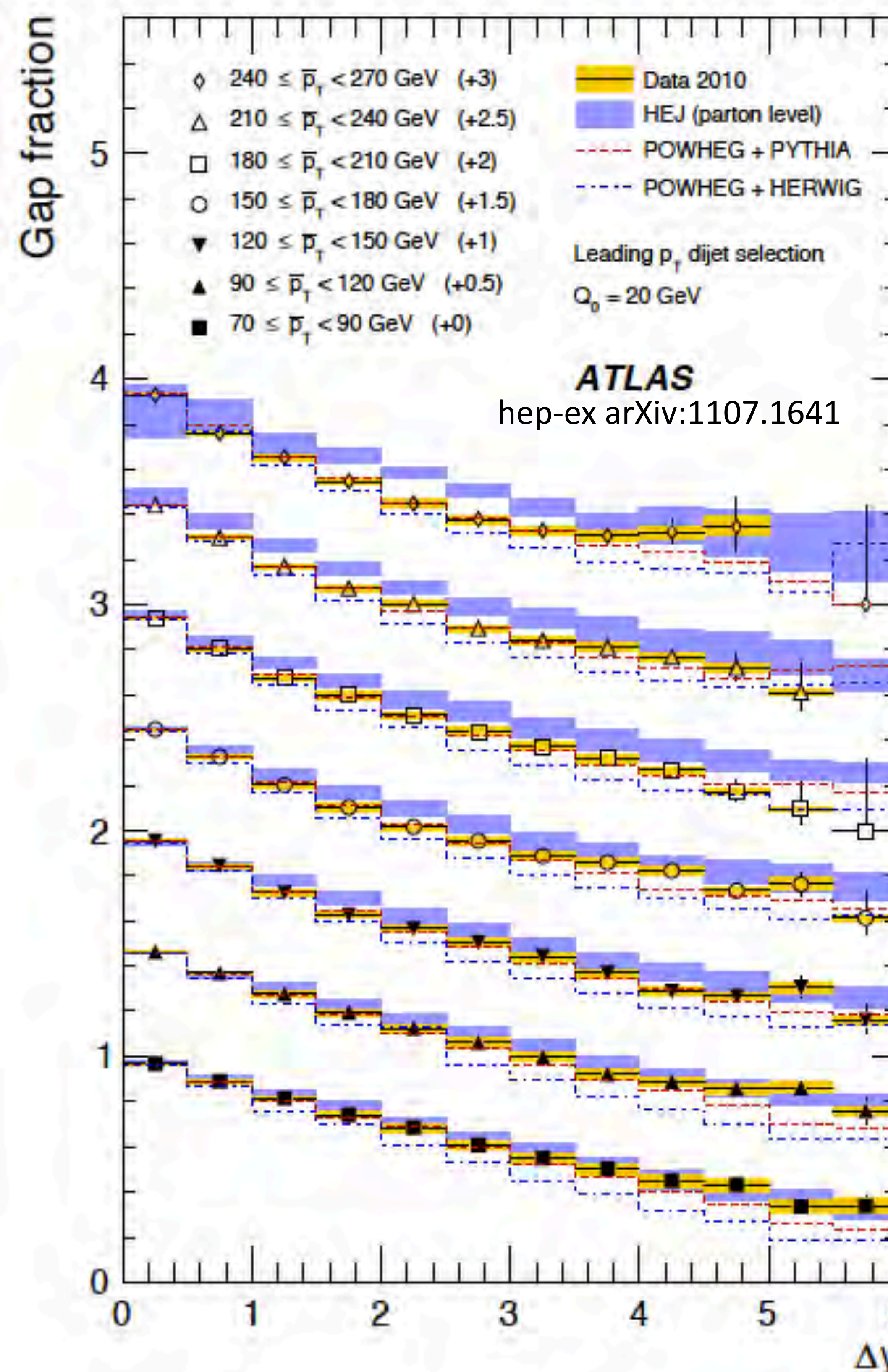
- Observation feasible but to use as reference **need high lumi and to know Z+jets with high precision**
- **Central jet veto suppress only 10% of Z+jets** (~useless!)

Jet veto

- ❑ 3rd jet not well modeled by PS,
  central veto Δε btw Pythia and Herwig ~ 40%

  -> POWHEG NLO: remaining uncertainty ~%





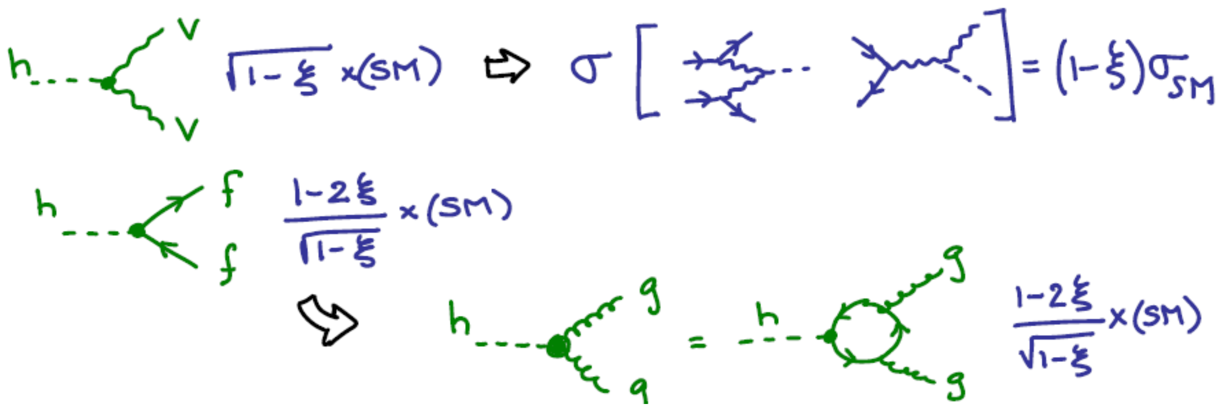
- ❑ Check with dijet events + rapidity gap (in low PU)
  (at large pTjet/pTveto or Δy -> fixed order fails)
  - NP effects<2% (pTveto > Λ_{QCD})
  - HEJ all-order resummation for wide-angle emissions of similar pT
    -> fails for pT jet>>pTveto
  - POWHEG+Pythia good agreement with data
    -> differences btw Herwig and Pythia
- ❑ Similar study in ttbar events ! hep-ex arXiv:1203.5015

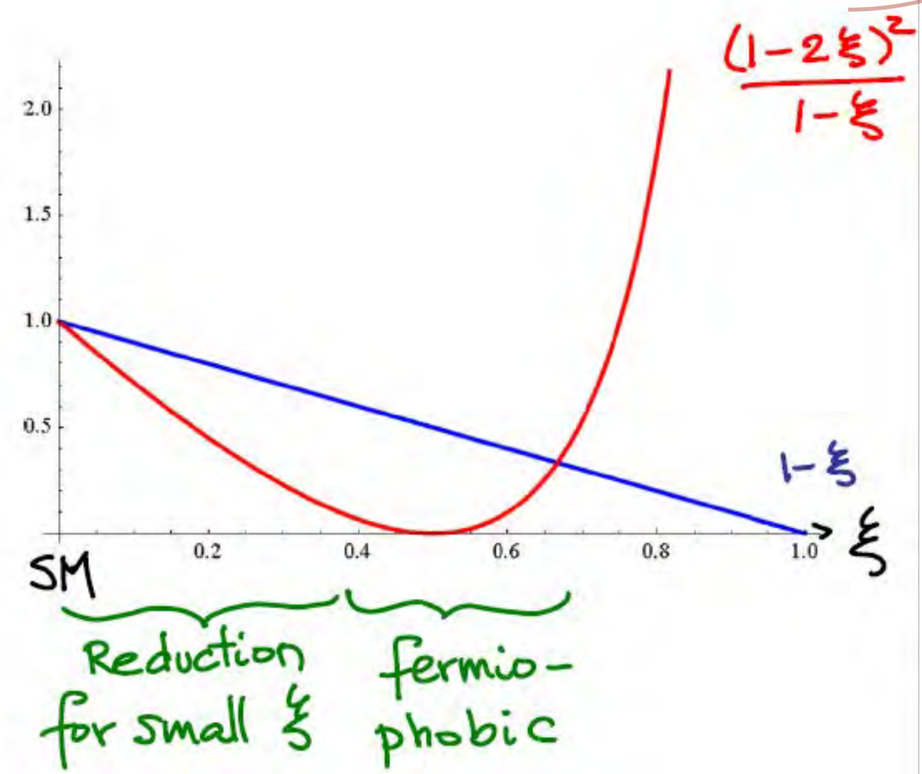
Fermiophobic like

- **WHY?**

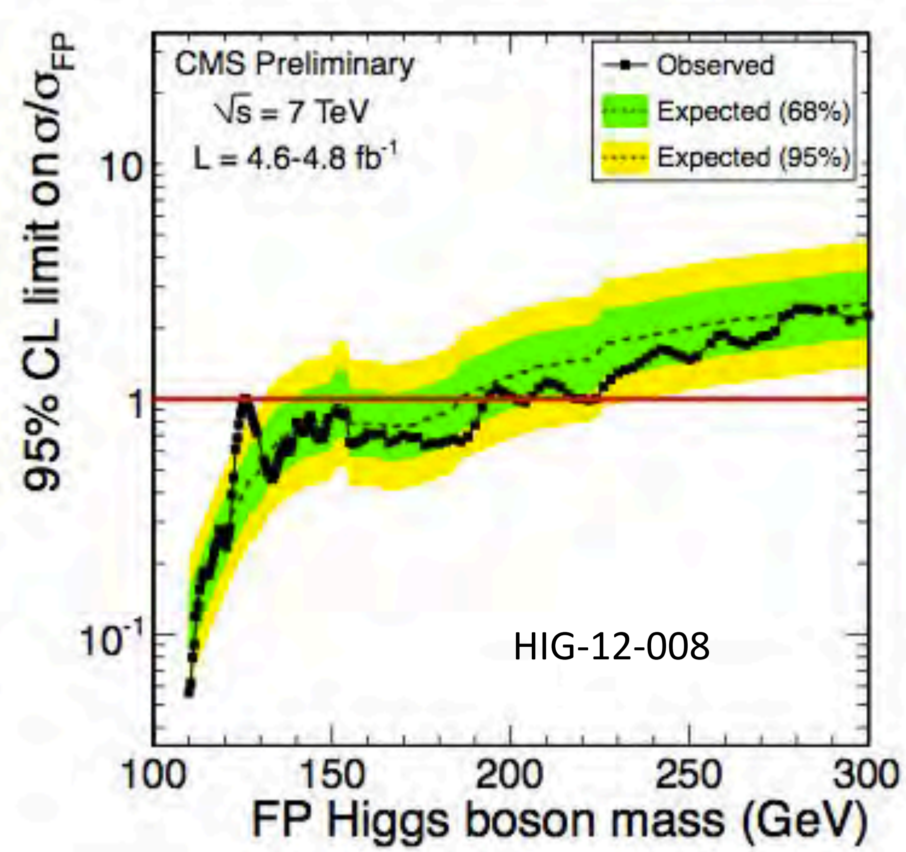
  Ex of (light) composite higgs:

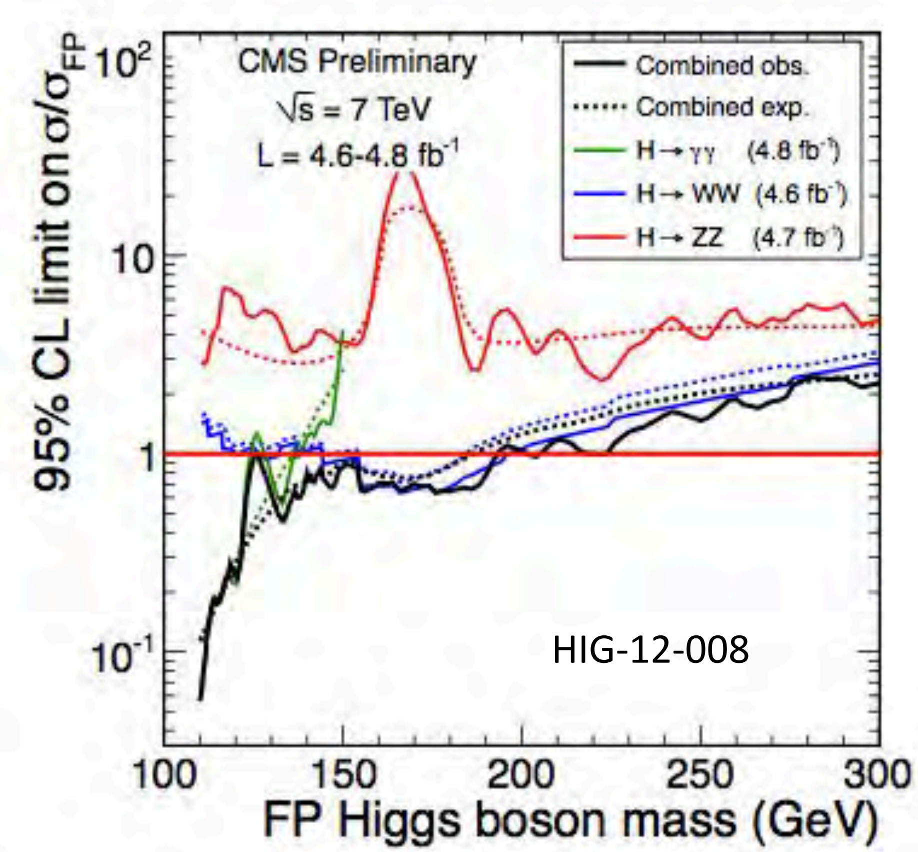
$$\frac{1}{p^2-m_H^2} \longrightarrow \frac{1}{1+\xi c_H}\,\frac{1}{p^2-m_H^2}$$





- **"State of the art"**
  - γγ at low mass, WW at high mass
  - NO dedicated VBF analysis yet for ZZ !!



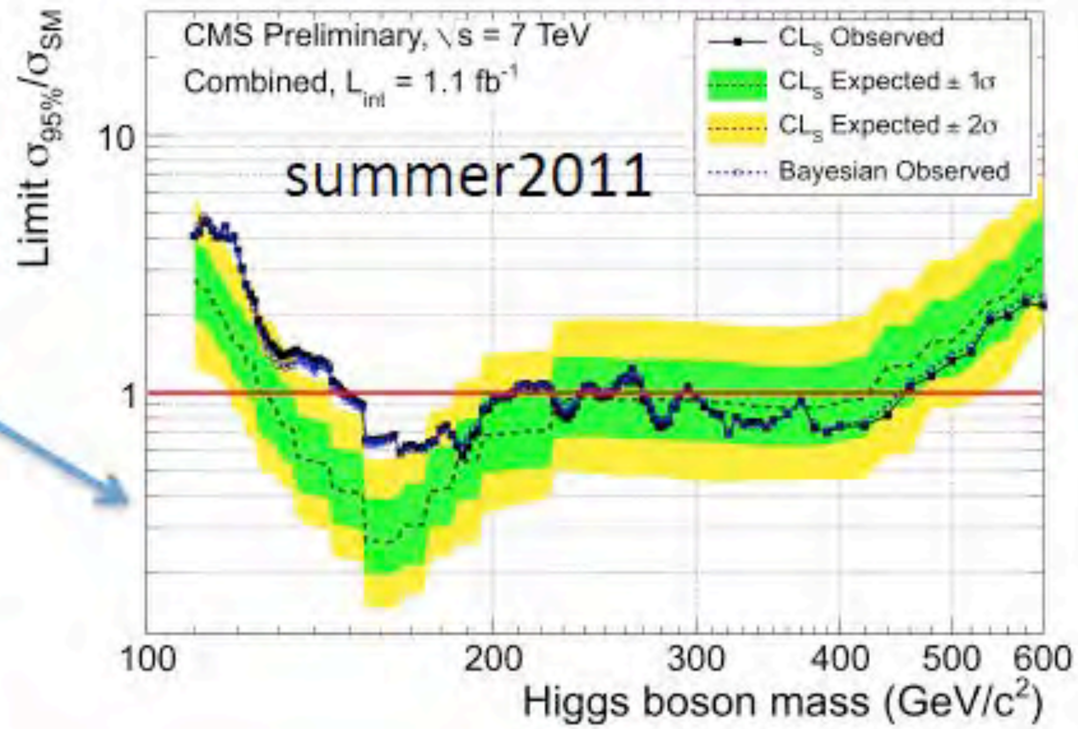


LCH at LHC by J.R. Espinoza
First LHC to Terascale Workshop (Sept 2011)

Higgs-like resonance in VBF

- **RE-DO all the analyses in VBF mode (eg, fermiophobic)**
- Today only WW→lnln. **Expectations for next year**:
  - lumi > 10 fb-1
  - σ(vbf) ~ 0.1×σ(gg)
  - 0.5 effic. VBF cuts

  } VBF yields in 2012 ~ 0.5 gg yields of 2011 summer results,



with much less background:

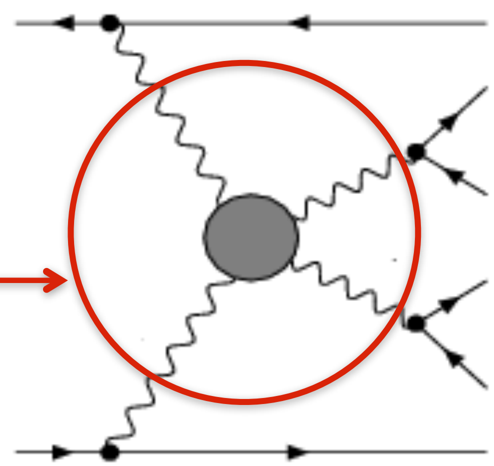
- ZZ→4l will be still limited by statistics
- WW→lnln will improve S/B (signal/10, WW*α_s^2)
- semileptonic final states will have **reasonable signal yields + much lower background** than inclusive analysis

eg, ZZ→lljj :
- signal yields for m_H 300-500 ~ 15 – 5 events
- V+(N+1)jets/V+N jets ~ 0.15 → asking 2 jets reduces background to 2%!
- S/B may increase of a factor 2 (eff 0.5 × σ 0.1 / 0.02)

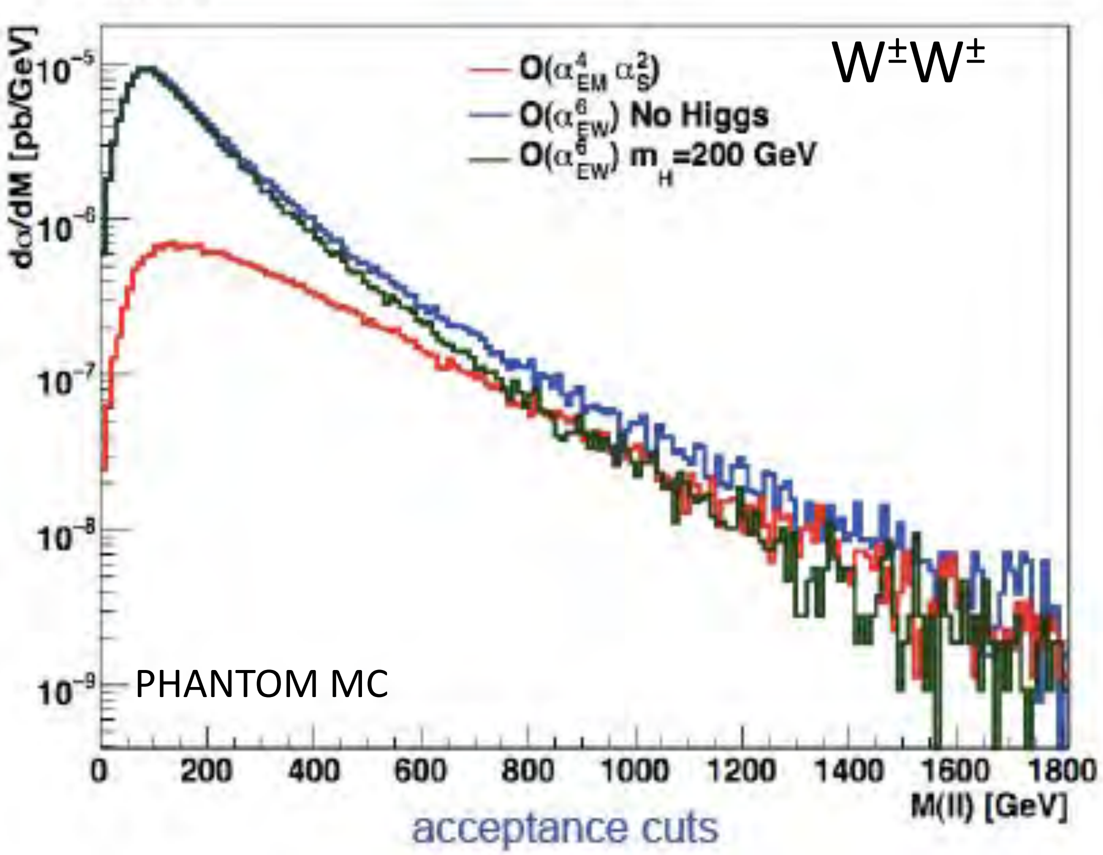
VV scattering spectrum

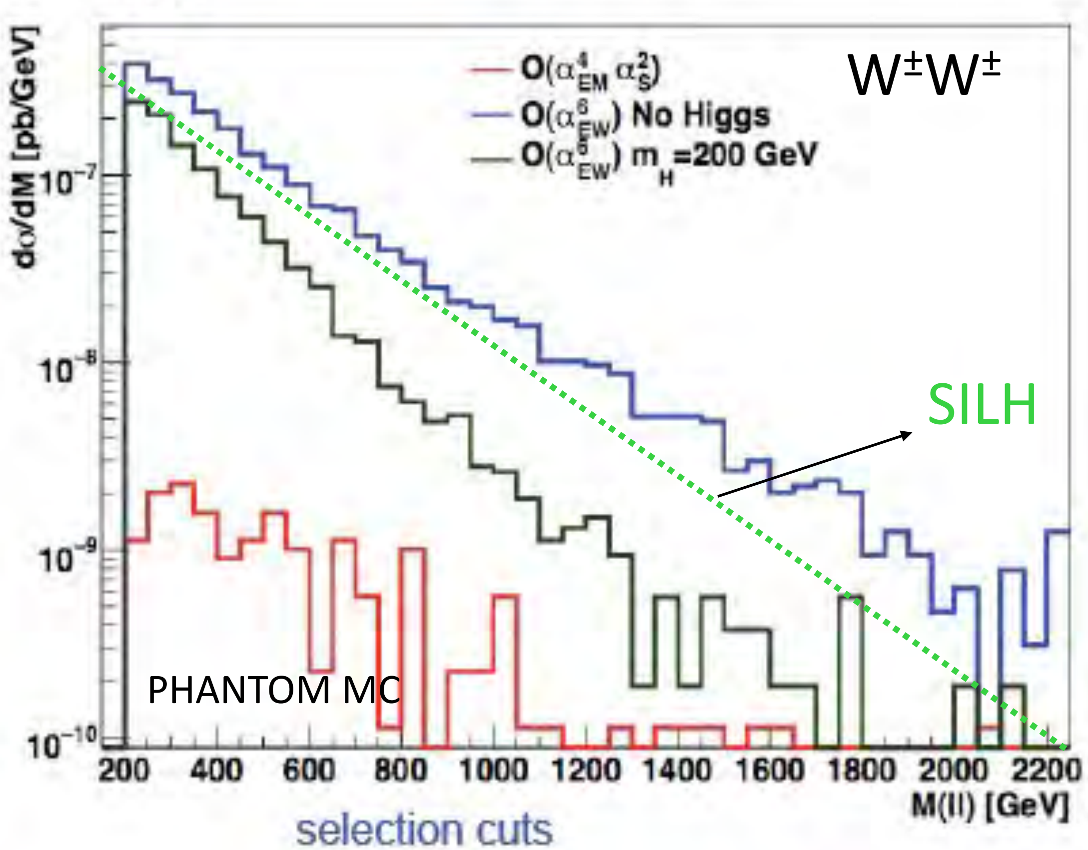
❑ In no Higgs case: increasing of xsec at high VV is suppressed by

- PDF
- offshell bosons
- unpolarized bosons



→ small difference between SM and violation of unitarity (no Higgs)





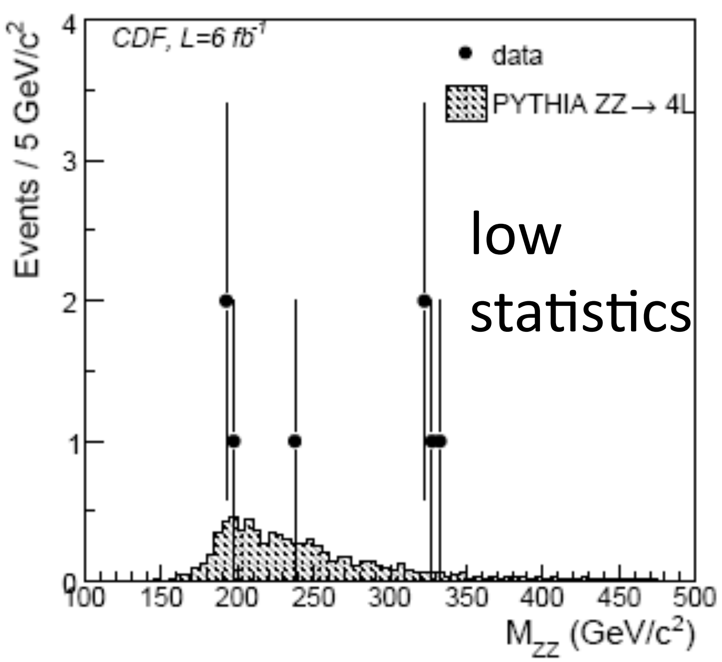
→ with proper cut (eg Δη jets) can be enhanced -> selection of the longitudinal W

Graviton → ZZ search

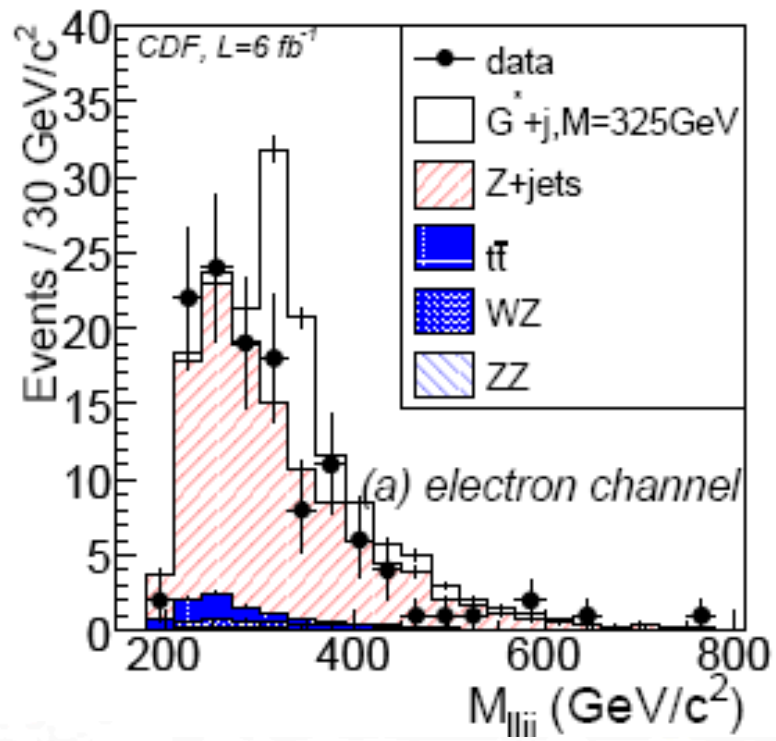
- **Search for G→ZZ**: same features discussed for high mass Higgs

Phys. Rev. D83, 112008 (2011)

ZZ→4l

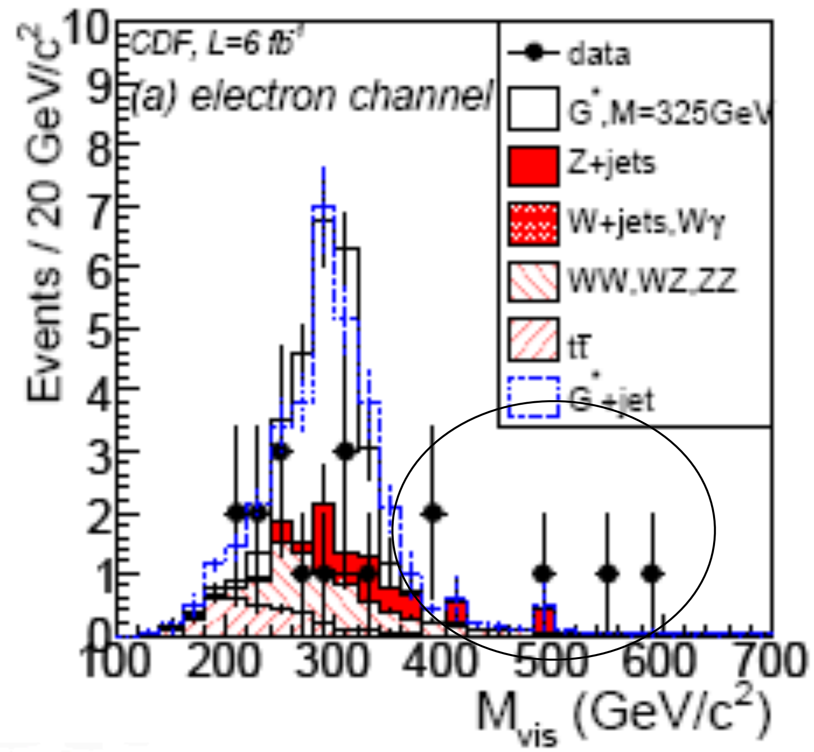


ZZ→lljj: large V+jets

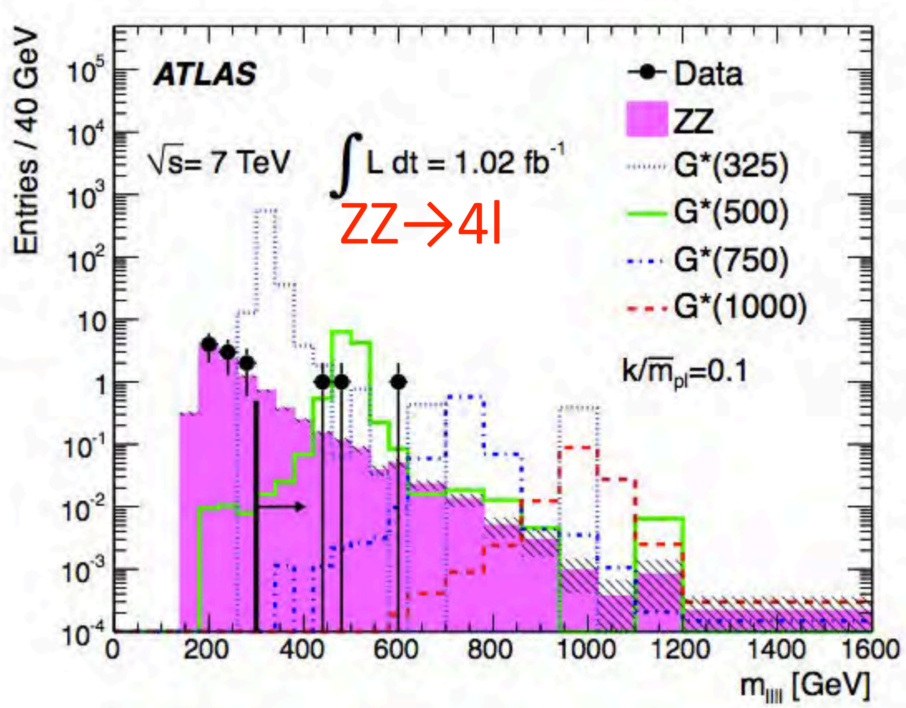


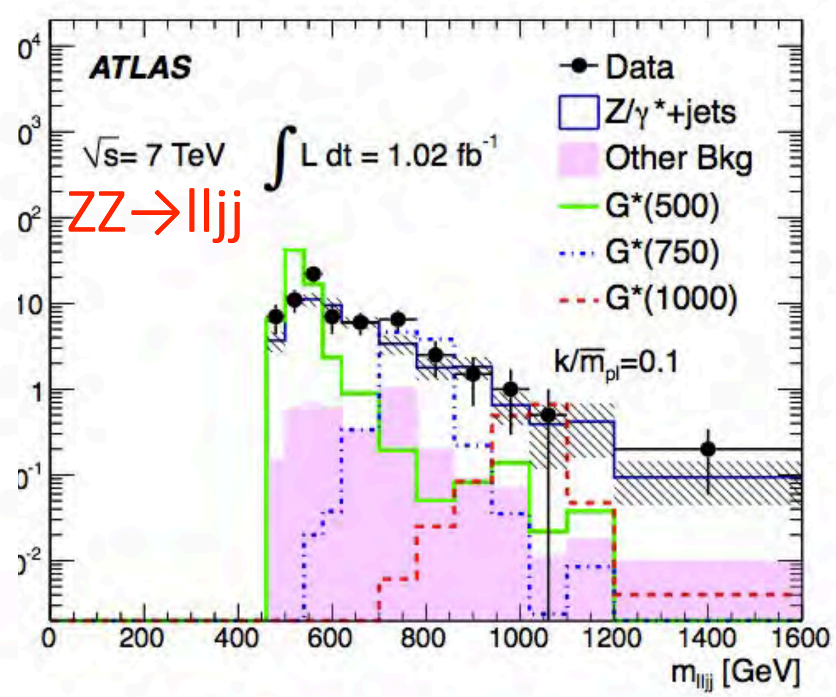
ZZ→llnn

MET control V+jets



hep-ex arXiv:1203.0718





CMS is working on

ZZ->2l2j (angular analysis)

ZZ->2l 1j (jet merging)