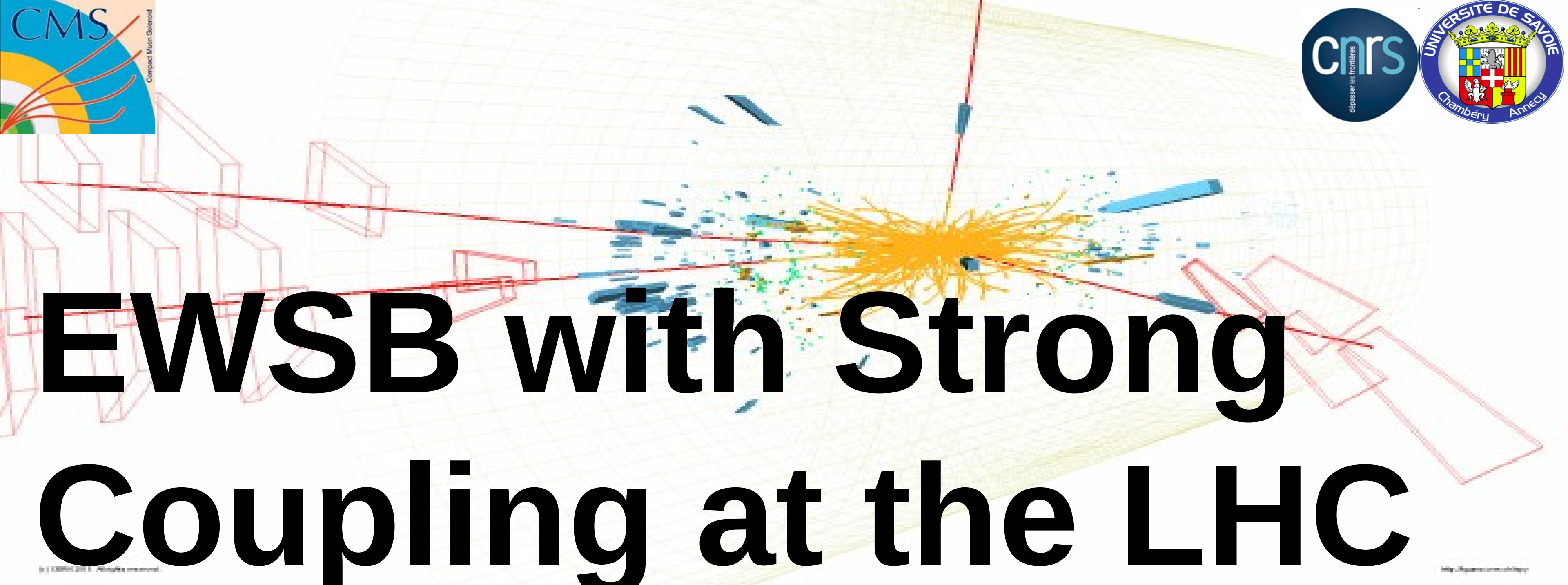
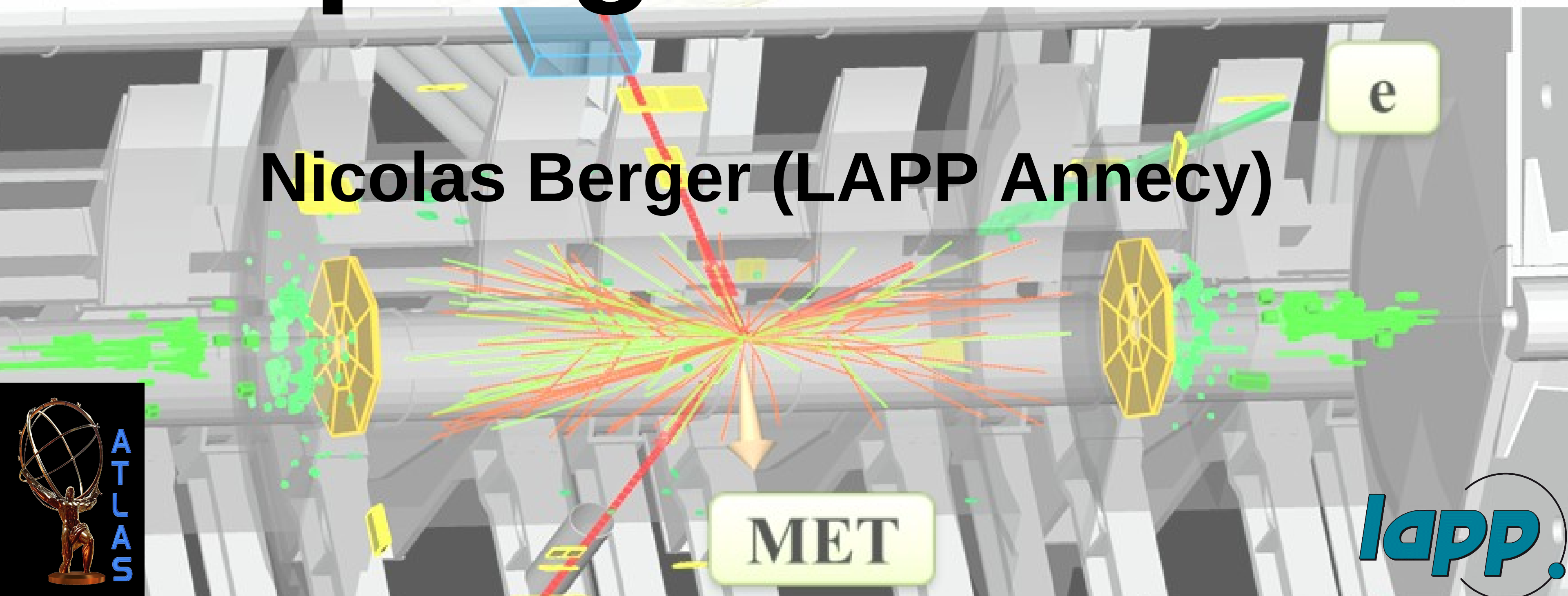
EWSB with Strong Coupling at the LHC



Nicolas Berger (LAPP Annecy)

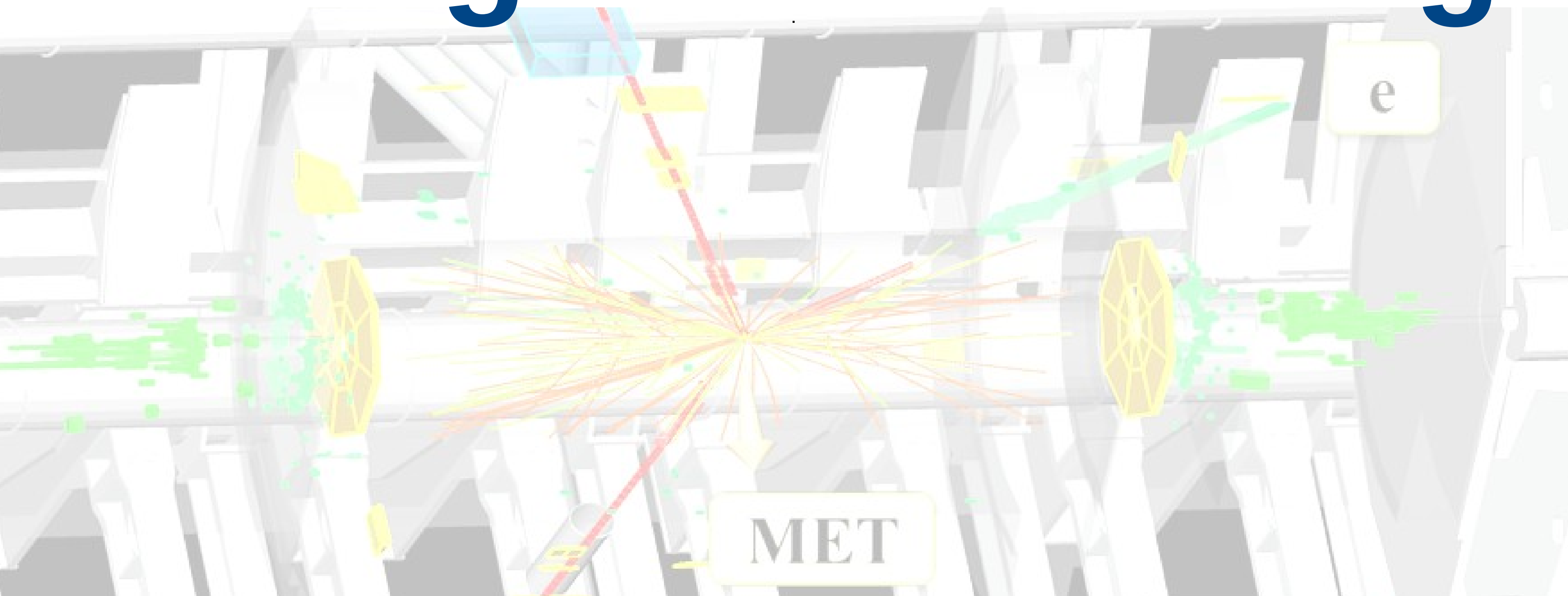


Contents

→ **Strong Vector boson scattering at LHC**
- **Motivation**
- **Signatures**
- **ATLAS & CMS analyses**

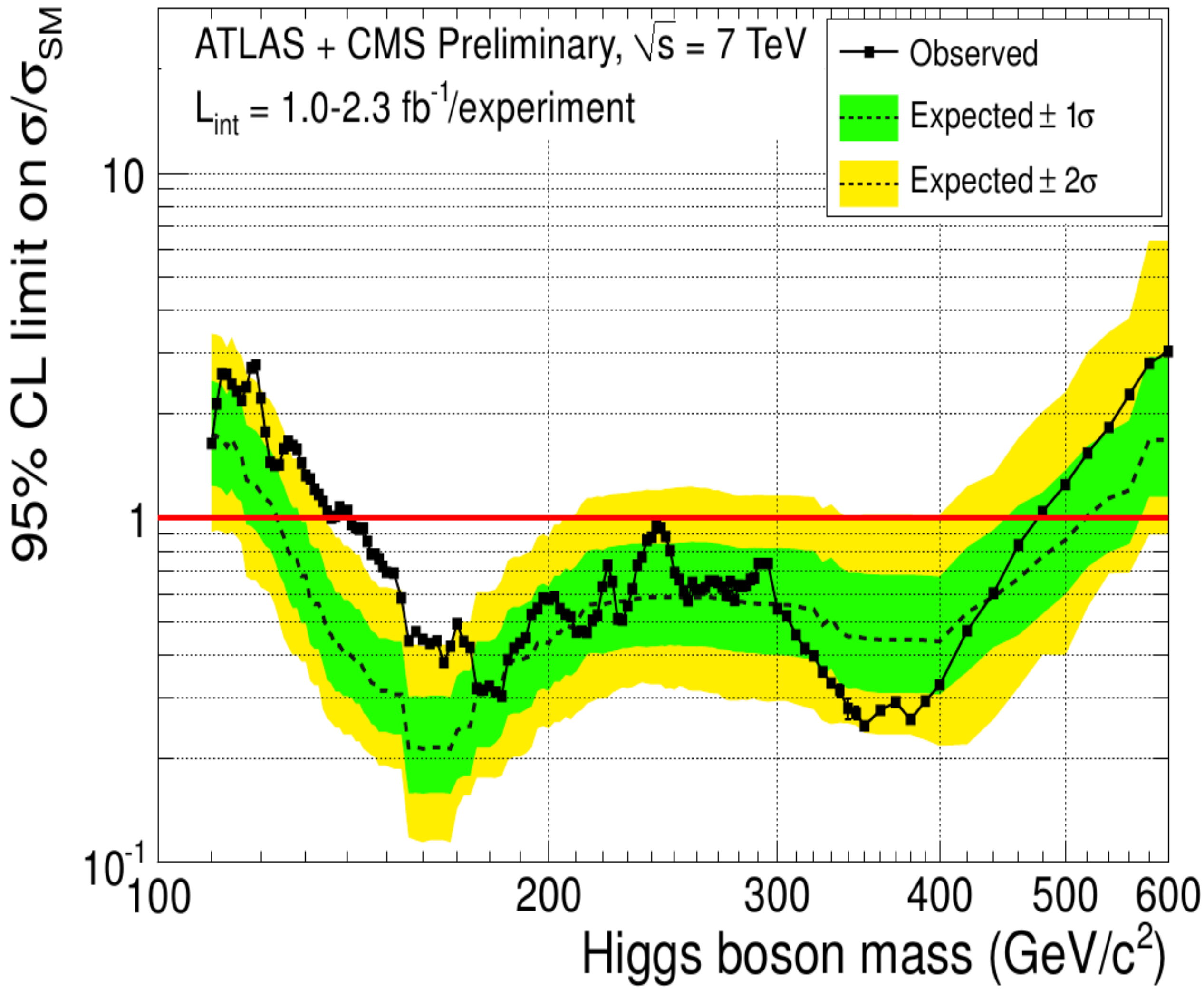
→ **Searches for technicolor signals at LHC**
- **Model overview**
- **ATLAS search in l^+l^- channel**
- **CMS search in WZ channel**

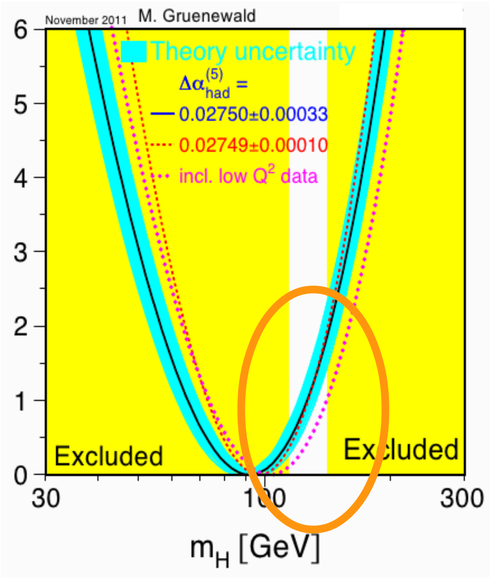
Strong VV Scattering



EWSB at the LHC

Higgs boson is severely constrained by recent LHC data





Could have a 95% exclusion over entire mass range at winter conferences

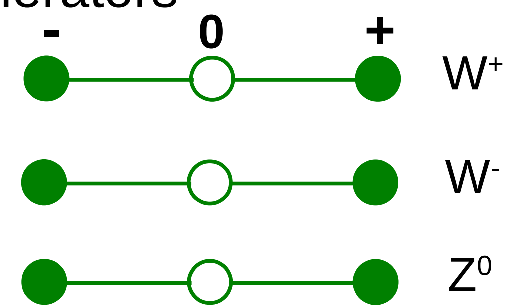
What if there is no Higgs ?

EWSB and VV Scattering

The good news: we already know 3 components of the EWSB sector:
$W^{\pm}_L$, Z_L , Goldstone bosons of broken SU(2)xU(1) generators

$\rightarrow$ In Higgs mechanism, part of the Higgs sector:

$$\phi \sim \begin{pmatrix} \phi^{+} + \phi^{-*} \\ \phi^{0} + \phi'^{0} \end{pmatrix}$$



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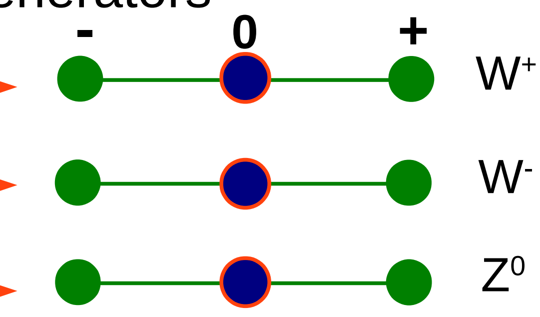

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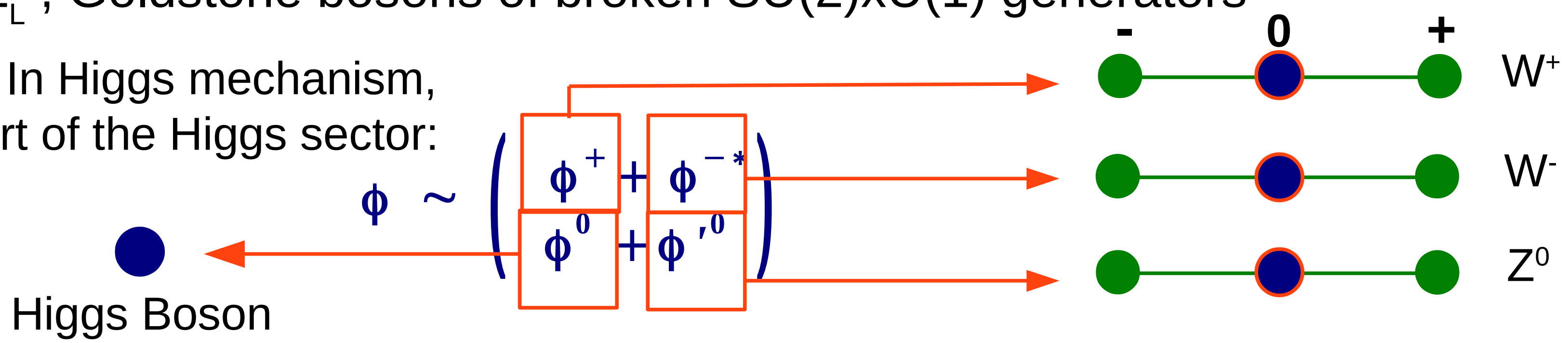

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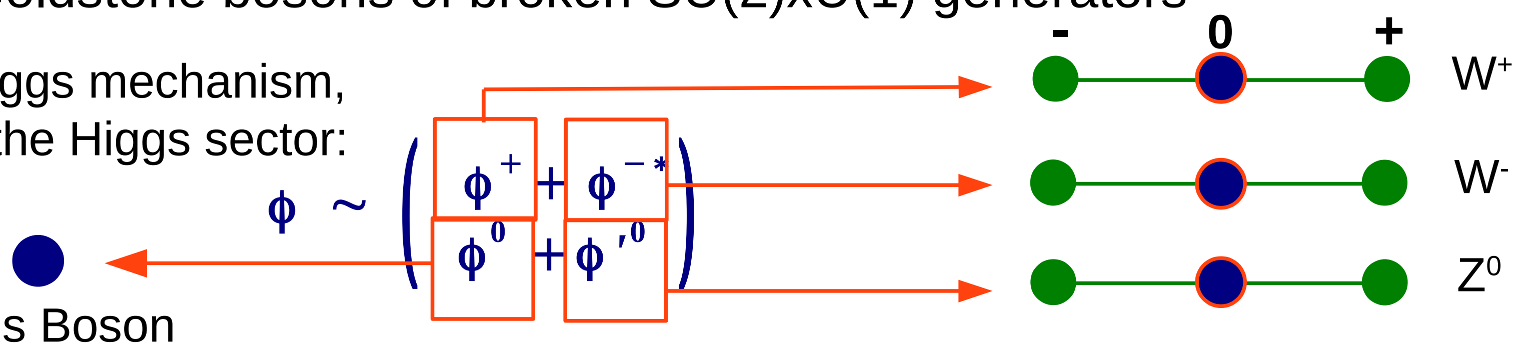

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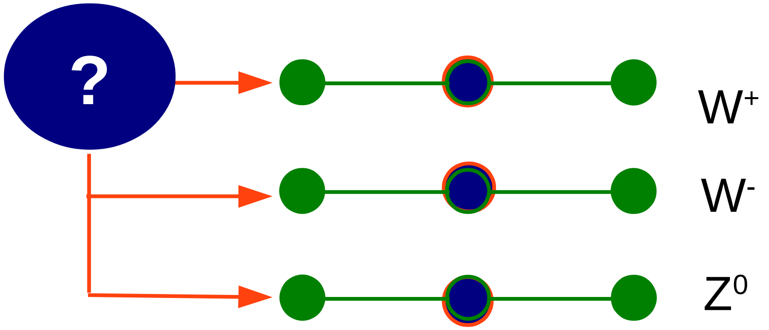
→ Even if no Higgs, EWSB sector should still provide those:



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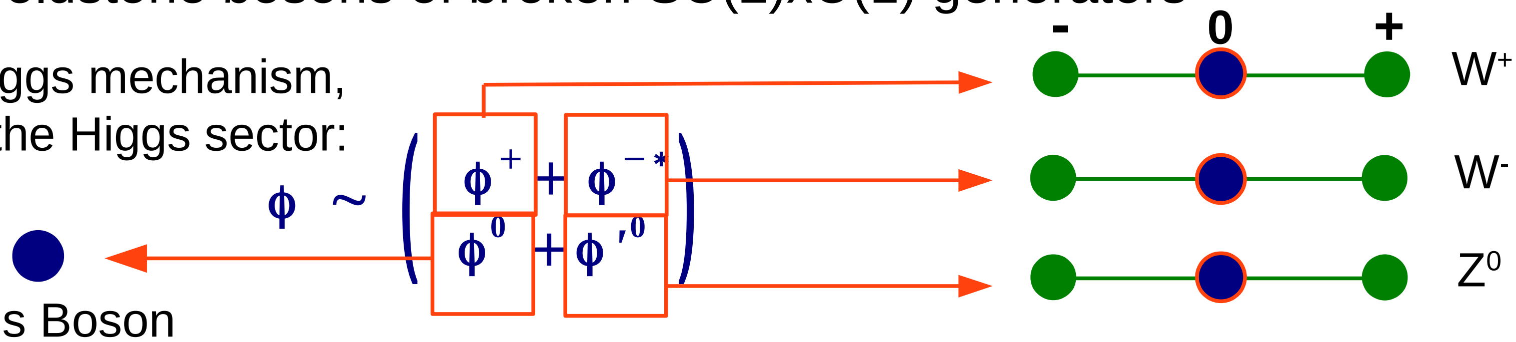

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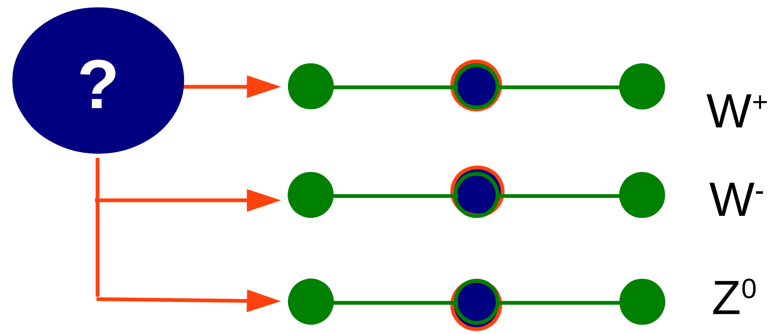
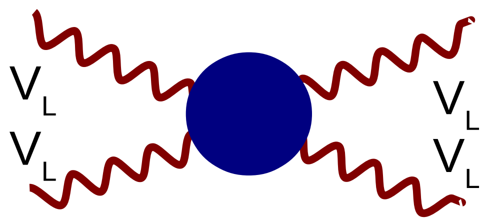


Consider $V_L V_L \to V_L V_L$:



→ involves only the GBs, so important whatever the actual EWSB mechanism

→ can compute low-energy behavior in model-independent way:

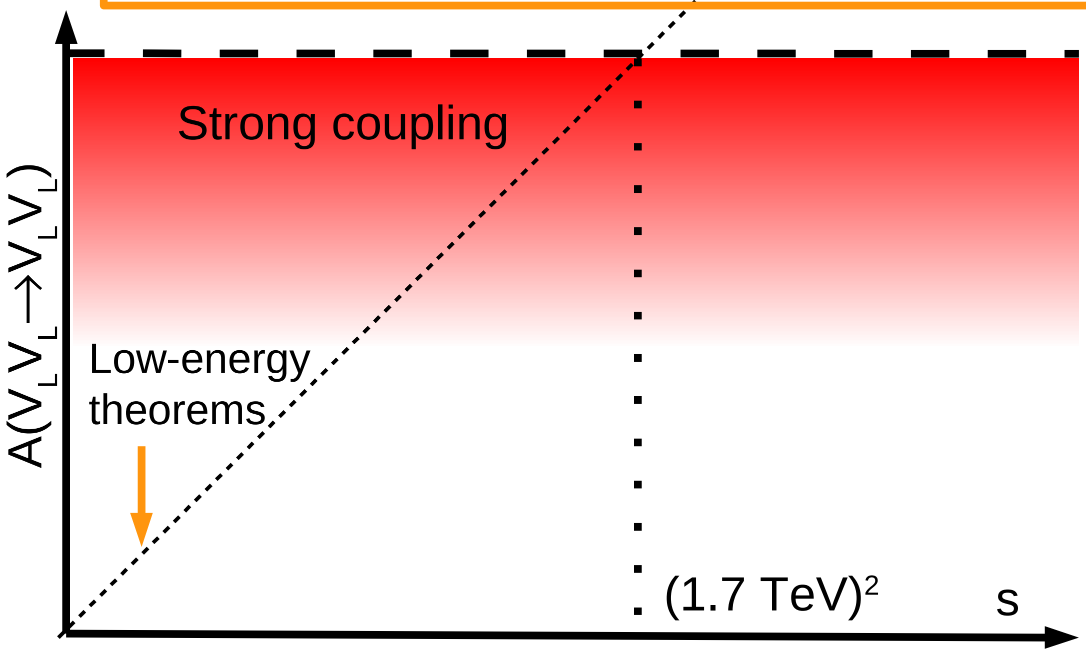
$$V_L V_L \to V_L V_L \sim \Pi\Pi \to \Pi\Pi \sim \frac{s}{v^2}$$

Equivalence theorem ($s \gg M_W^2$) Low-energy theorems ($s \ll M_{SB}^2$)

Violates unitary for large s ?

Large s behavior

As is, violation of perturbative unitarity for $\Lambda \sim 4\sqrt{\pi}v \sim 1.7$ TeV.



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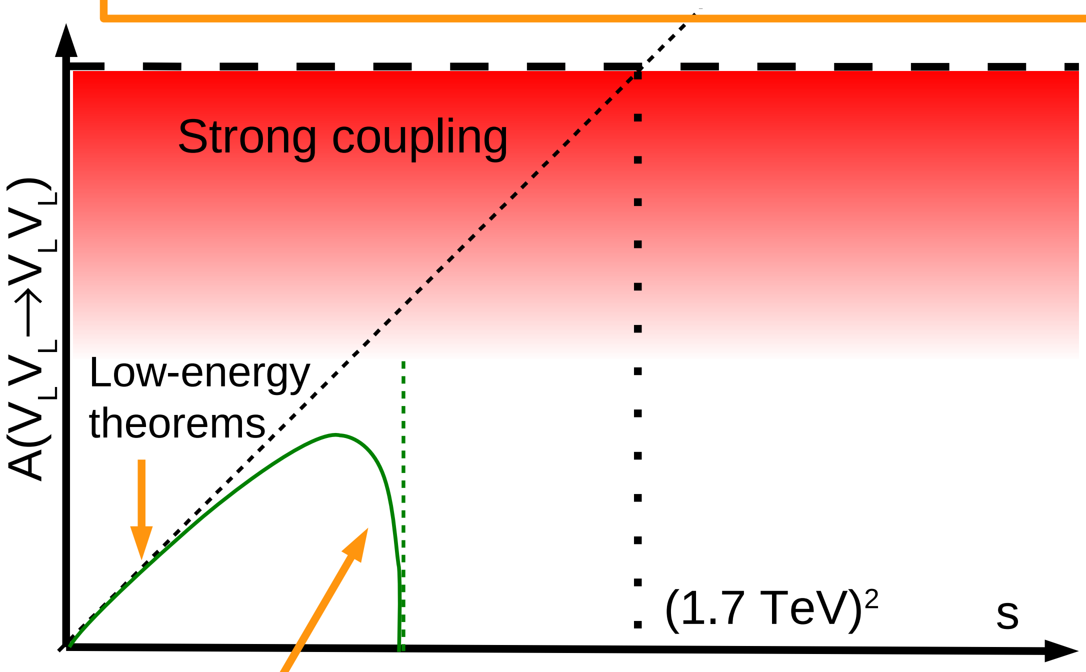

Higgs boson or other << 1 TeV resonance

→ cuts off the divergence << 1 TeV

→ $V_L V_L \to V_L V_L$ always perturbative

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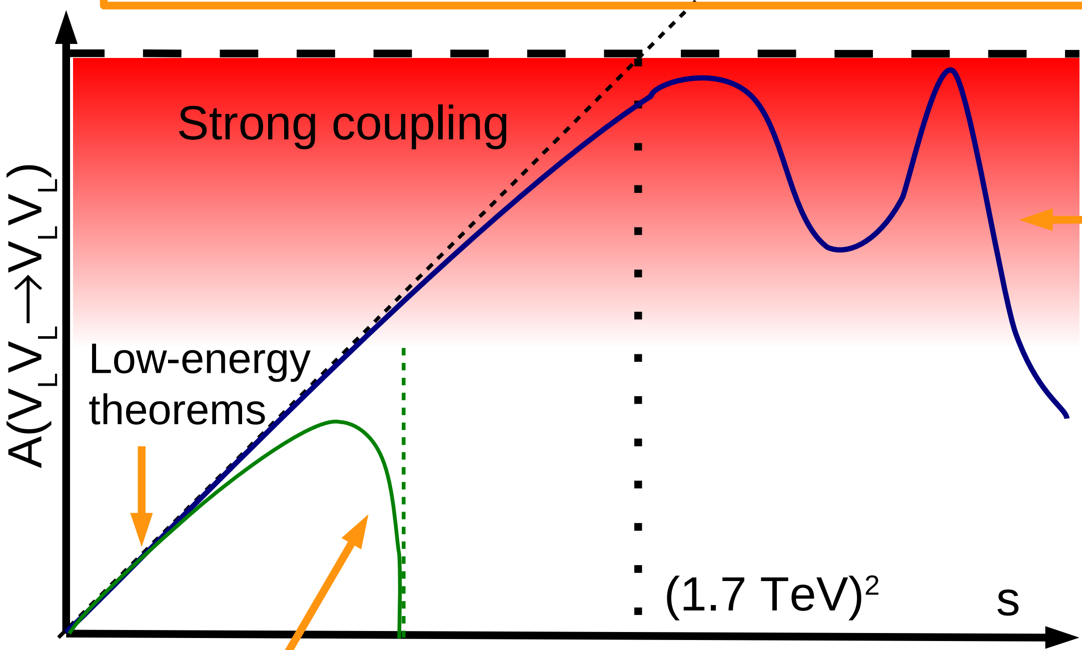
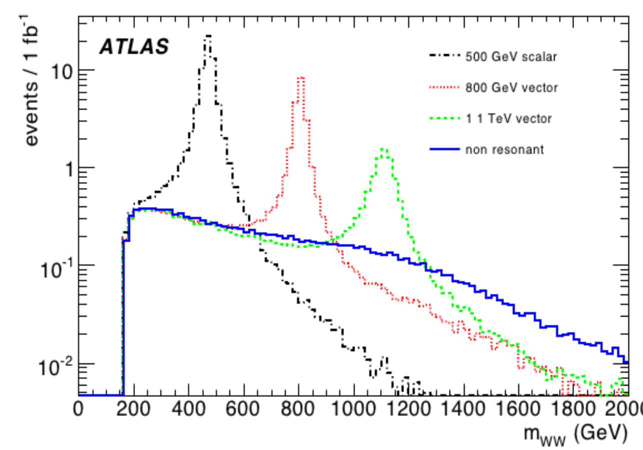


Higgs boson or other << 1 TeV resonance
→ cuts off the divergence << 1 TeV
→ $V_LV_L \to V_LV_L$ always perturbative

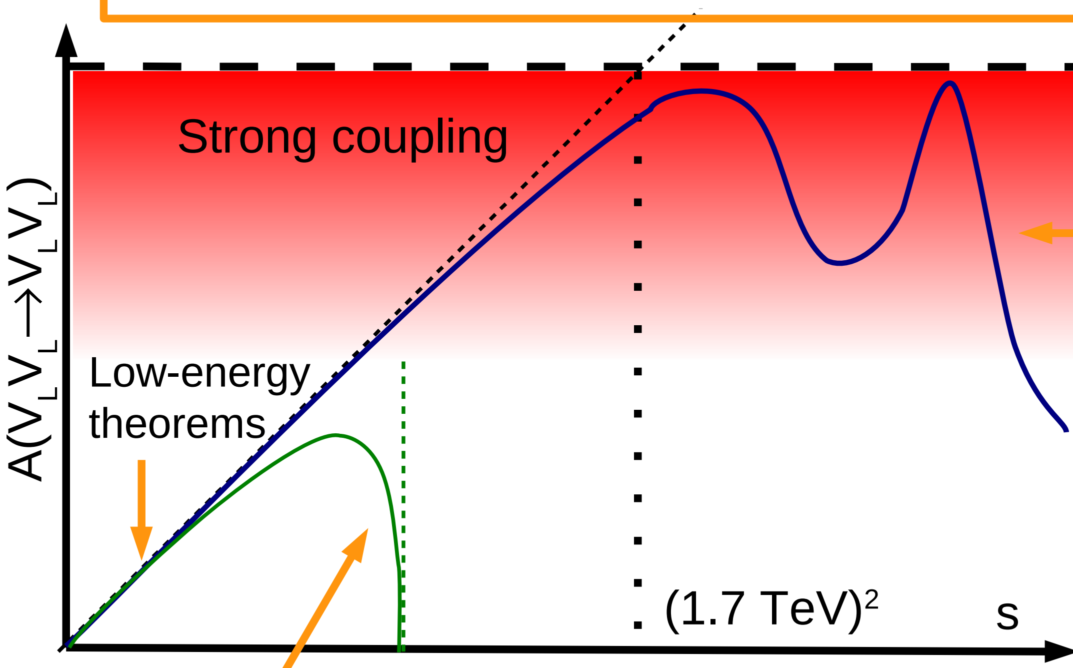
If no new physics << 1 TeV, unitarization by strong dynamics
→ Can be with resonances or without, depending on Chiral dynamics and unitarization scheme



Disfavored by EW fits : like ~1-2 TeV Higgs
⇒ Need other new physics

Large s behavior

As is, violation of perturbative unitarity for $\Lambda \sim 4\sqrt{\pi}v \sim 1.7$ TeV.



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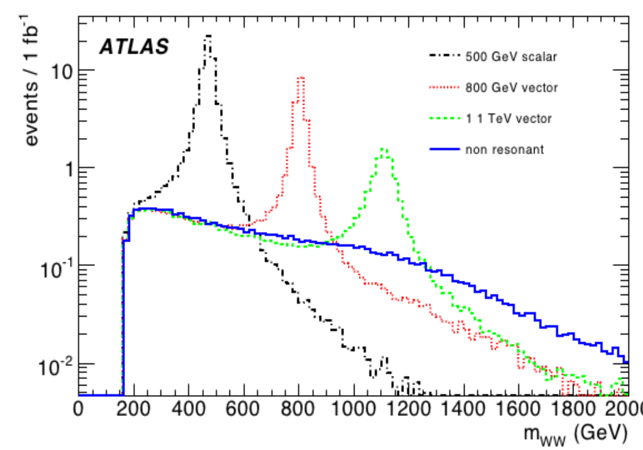

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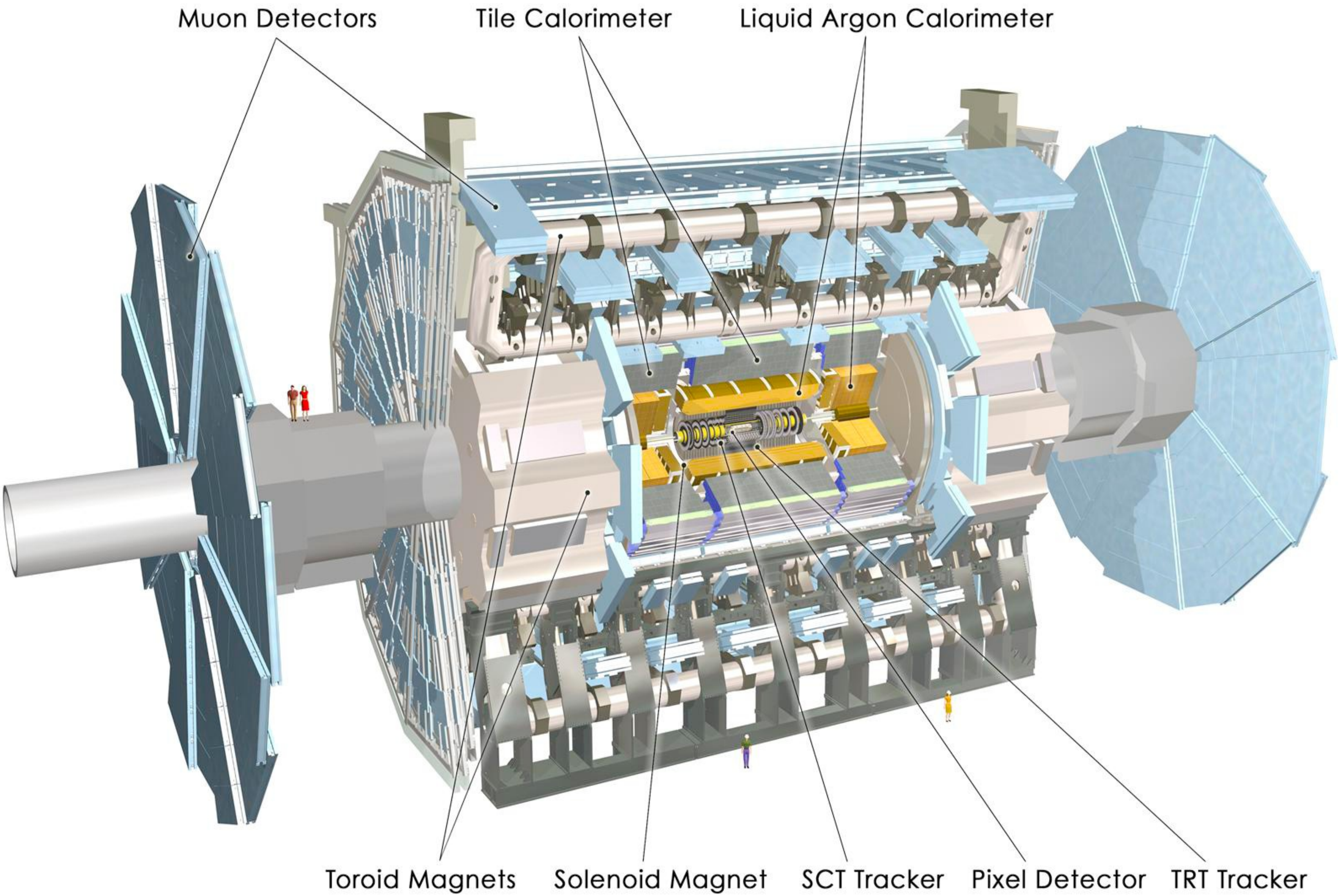
⇒ Need other new physics

Higgs boson or other << 1 TeV resonance
→ cuts off the divergence << 1 TeV
→ $V_L V_L \to V_L V_L$ always perturbative

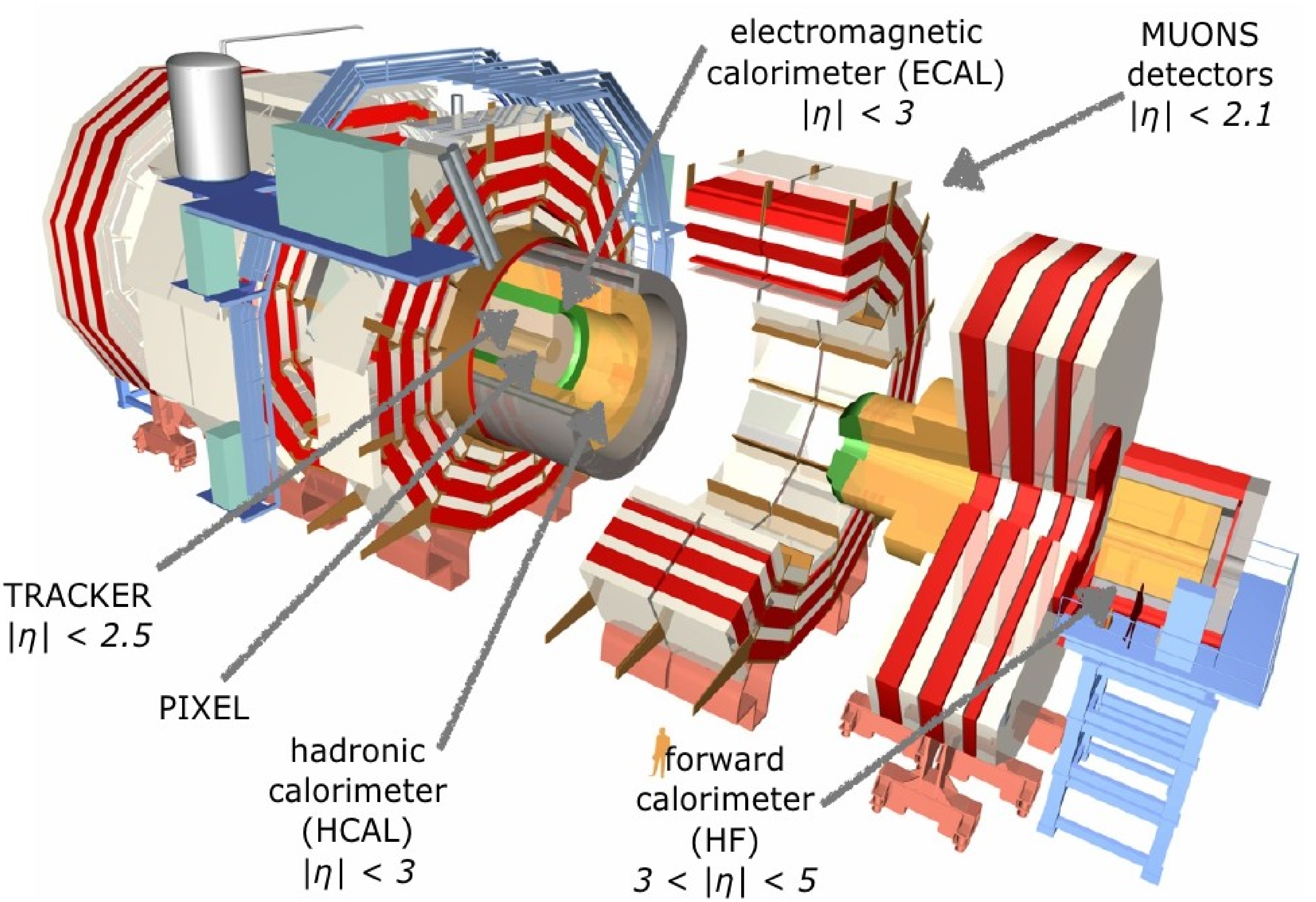
"No-lose" principle: one should either have
→ new states below 1 TeV, or
→ Strong WW scattering around 2 TeV

Usually true, but not guaranteed...

The ATLAS Detector



The CMS Detector

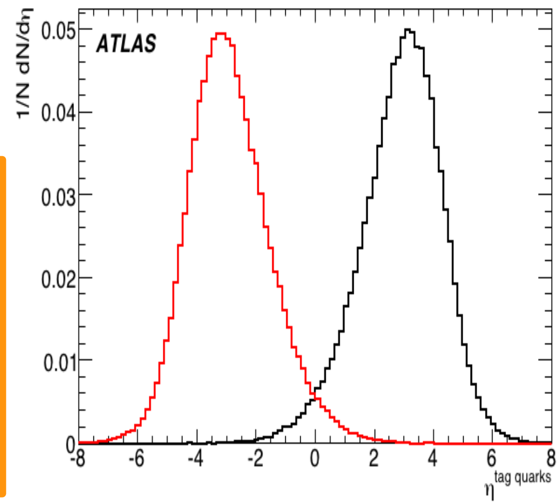


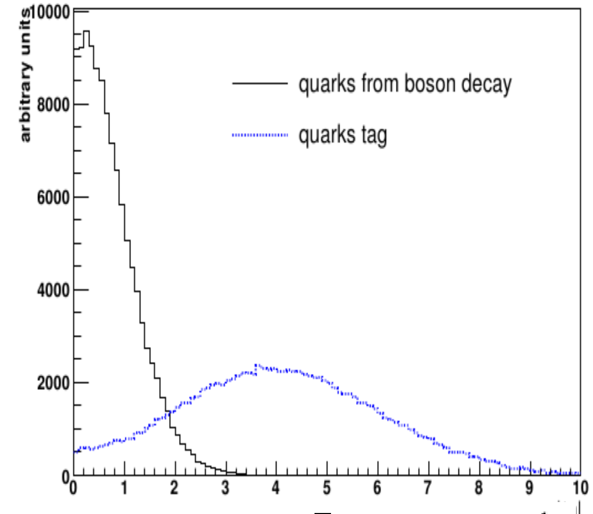
Signature

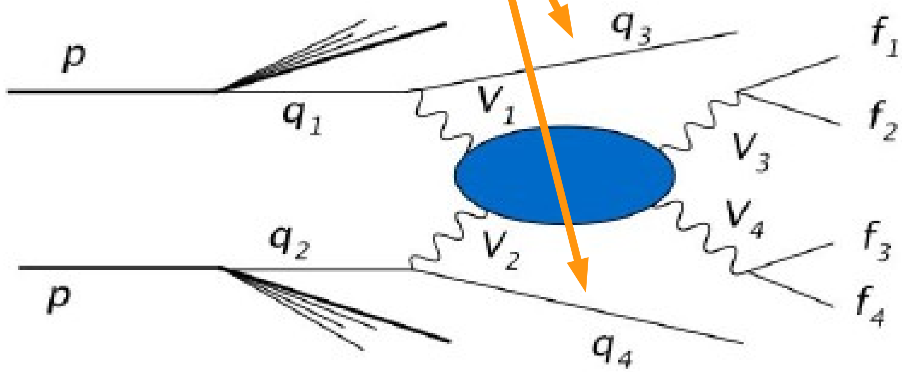
Tagging jets from quarks emitting the Ws

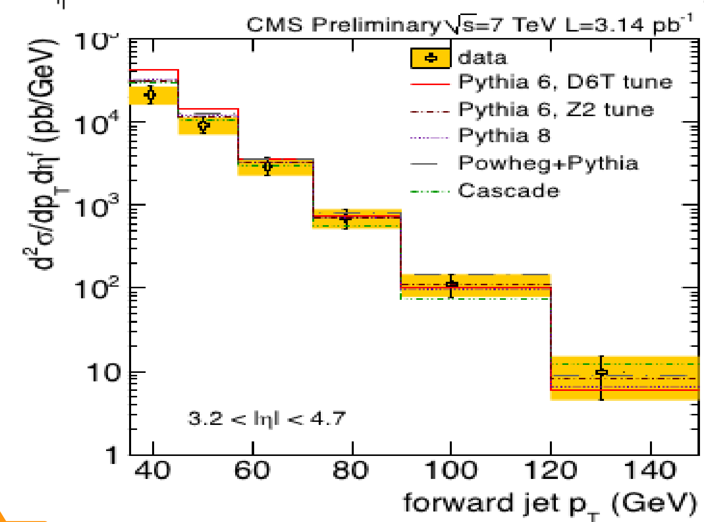
→ Typically at large η in each hemisphere

→ Large Δη between the 2 jets









Central Jet Suppression

→ No color flow between tagging jets

⇒ Hadronic activity in central region is suppressed

→ Useful to reject top background

→ Need to account for pileup

Same signature as VBF Higgs production

⇒ Extensive studies underway

ATLAS VV Searches

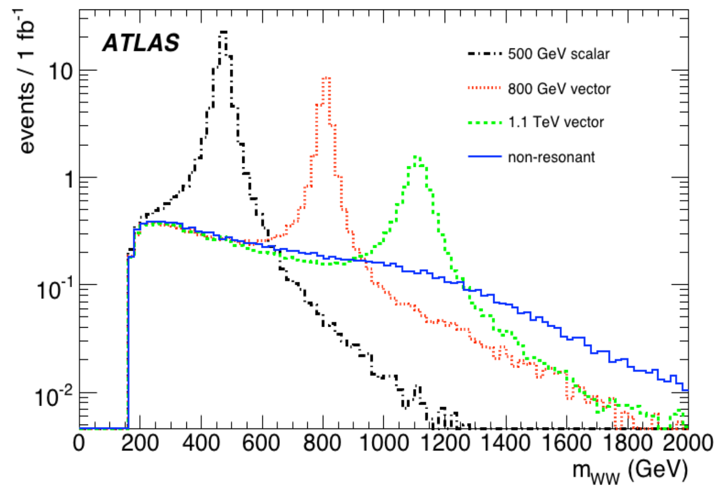
Search for resonances at 500, 800 GeV, 1.1 TeV, and a non-resonant scenario.
Need at least 1 lepton to reduce hadronic bkg.

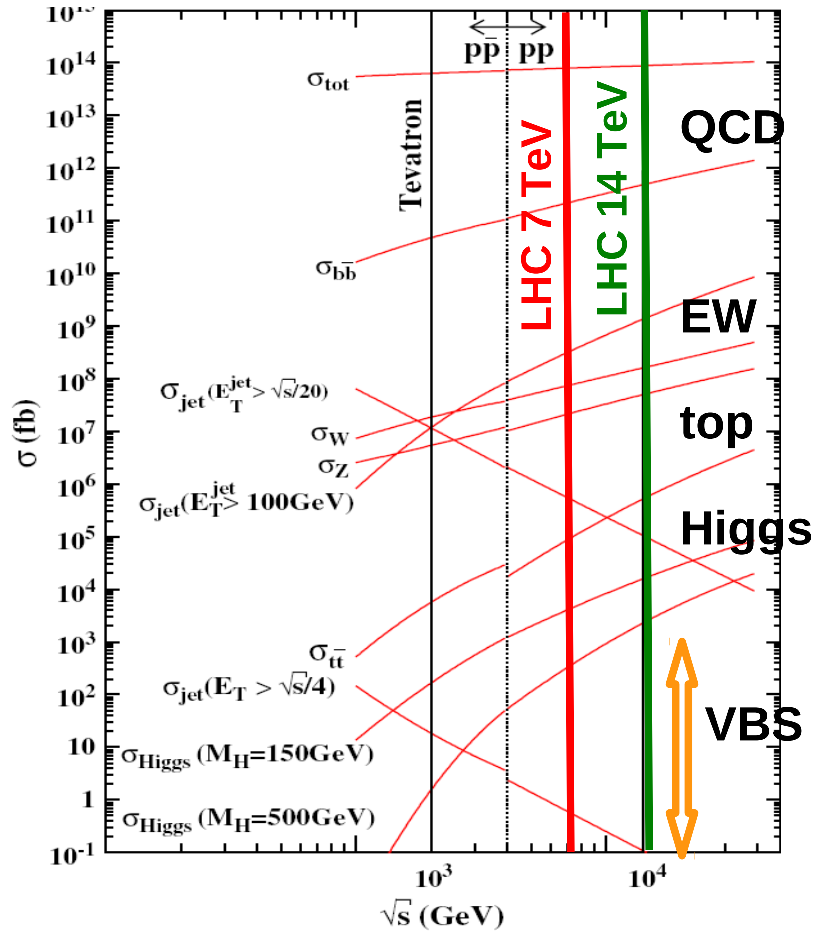
WW → lν qq — **~ 17 fb @ 1.1 TeV**, **~ 10 fb non-resonant**
→ Largest σ·BR
→ Large backgrounds: top and W+jets

WZ → lν qq — **~ 12 fb @ 1.1 TeV**
→ Same as above, considered together

WZ→ qq l^+l^- — **~ 4 fb @ 1.1TeV**
→ Z→ll reduces bkg levels. WZ+jets
→ Low σ·BR

WZ→ lν l^+l^- — **~ 1 fb @ 1.1TeV**
→ Fully leptonic, low bkgs (VV+jets)
→ Very small σ·BR

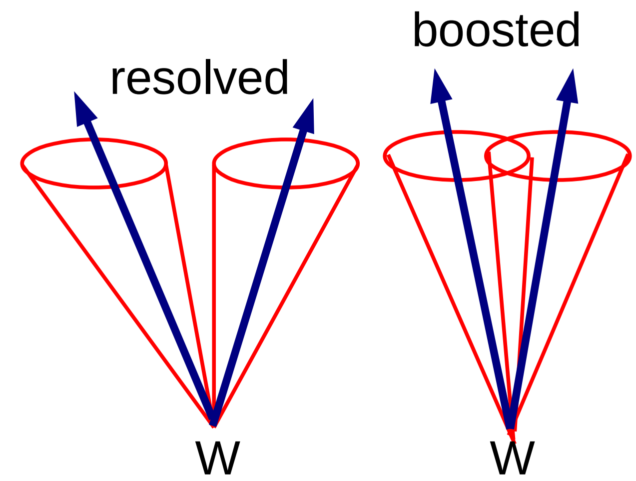


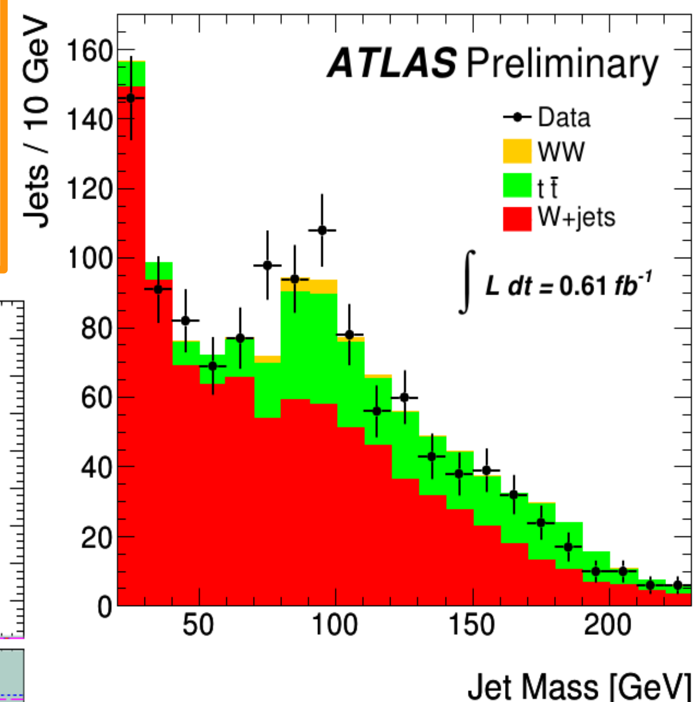


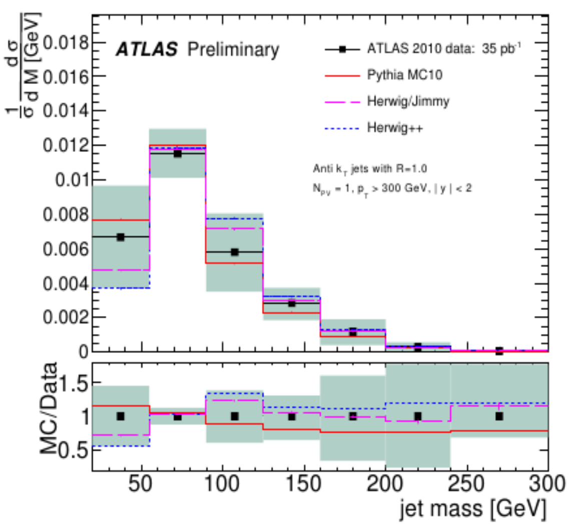
Results from CERN-OPEN-2008-020), at 14 TeV
Signals generated with pythia

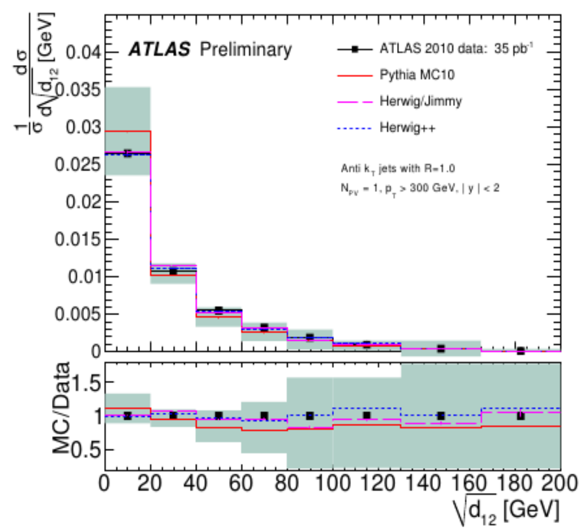
Boosted hadronic W's

- $W \rightarrow qq$ signature changes with resonance mass:
  - → **500 GeV**: 2 final state jets : "**resolved**" regime
  - → **1.1 TeV**: merged jets, "**boosted**" regime.
- General topic of interest for exotic physics (top resonances, high-p_T Higgs searches)
- Look at jet substructure:
  - → Jet mass
  - → For k_T jets, scale of last merging : $\sqrt{d_{12}}$
- Well described by MC in recent data
- Boosted analysis already does better at 800 GeV.









ATLAS-CONF-2011-103
in context of $pp \rightarrow WH$

ATLAS-CONF-2011-073

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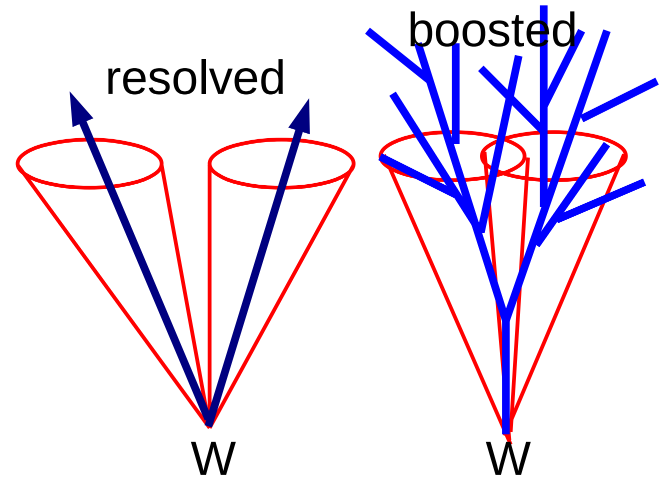

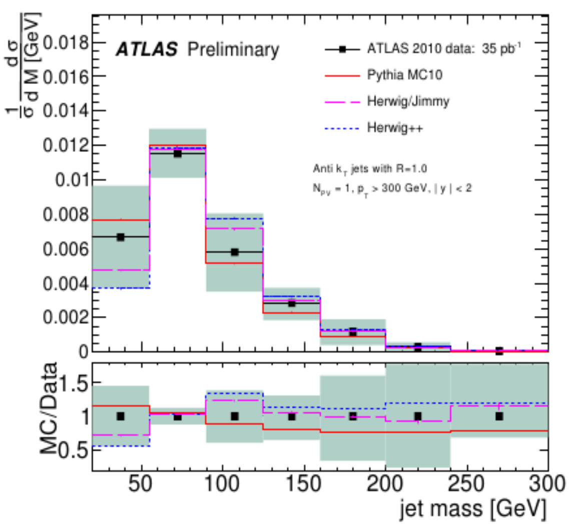

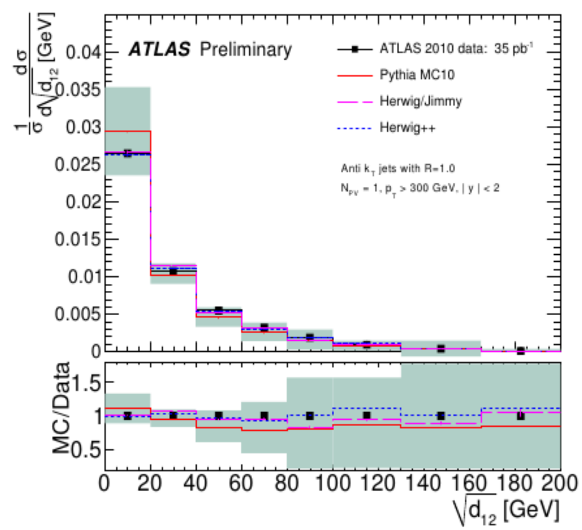

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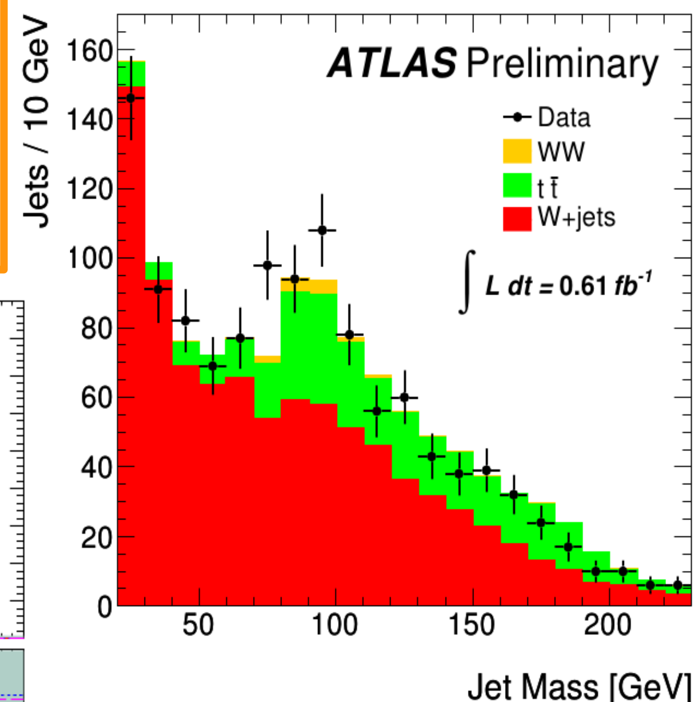

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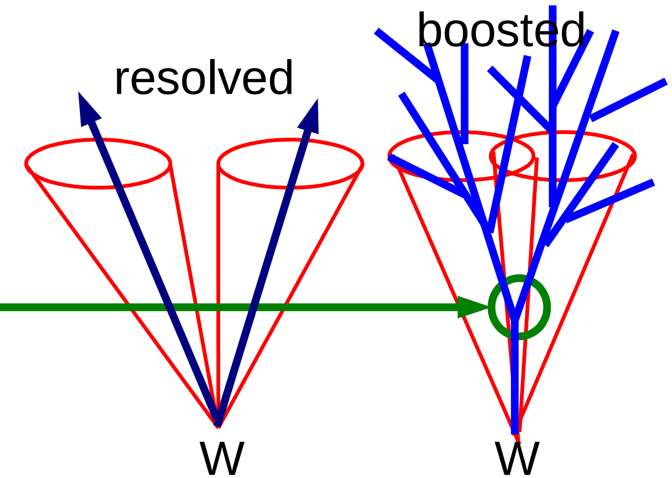
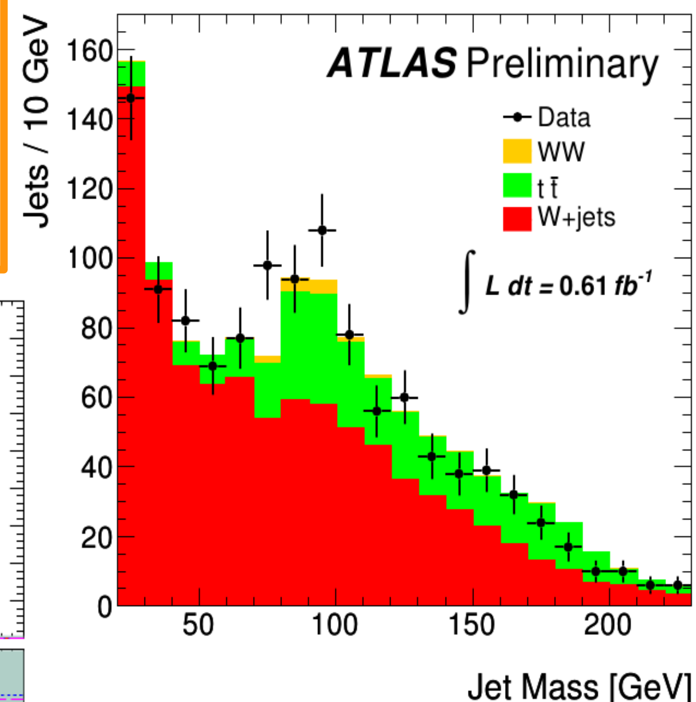
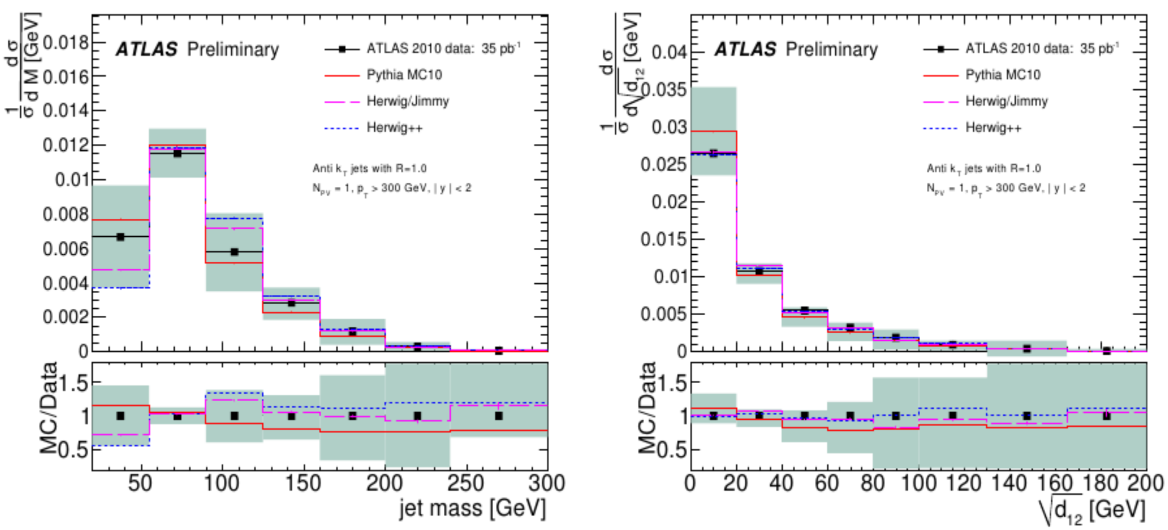




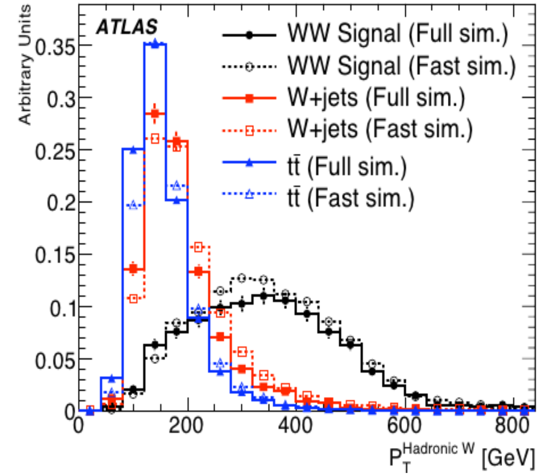
ATLAS-CONF-2011-103
in context of pp⟶WH

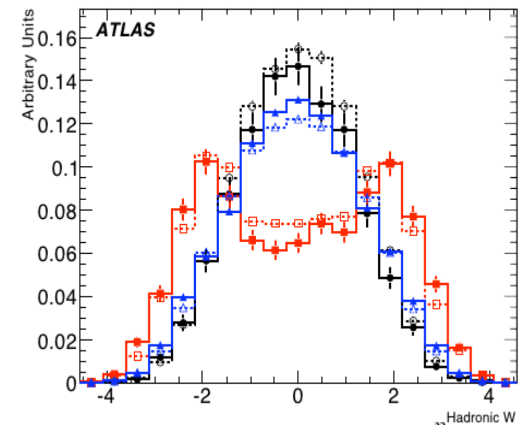


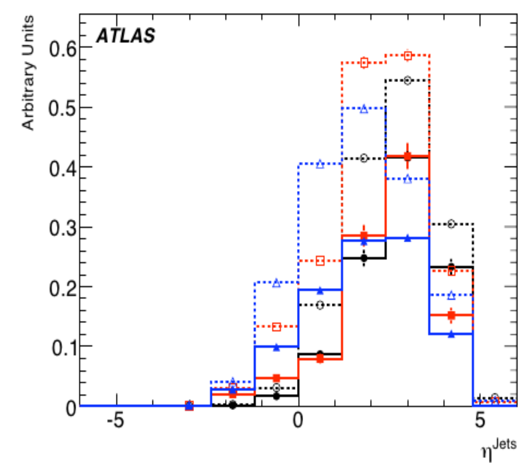
ATLAS-CONF-2011-073

$WW \rightarrow l\nu qq$ Selection

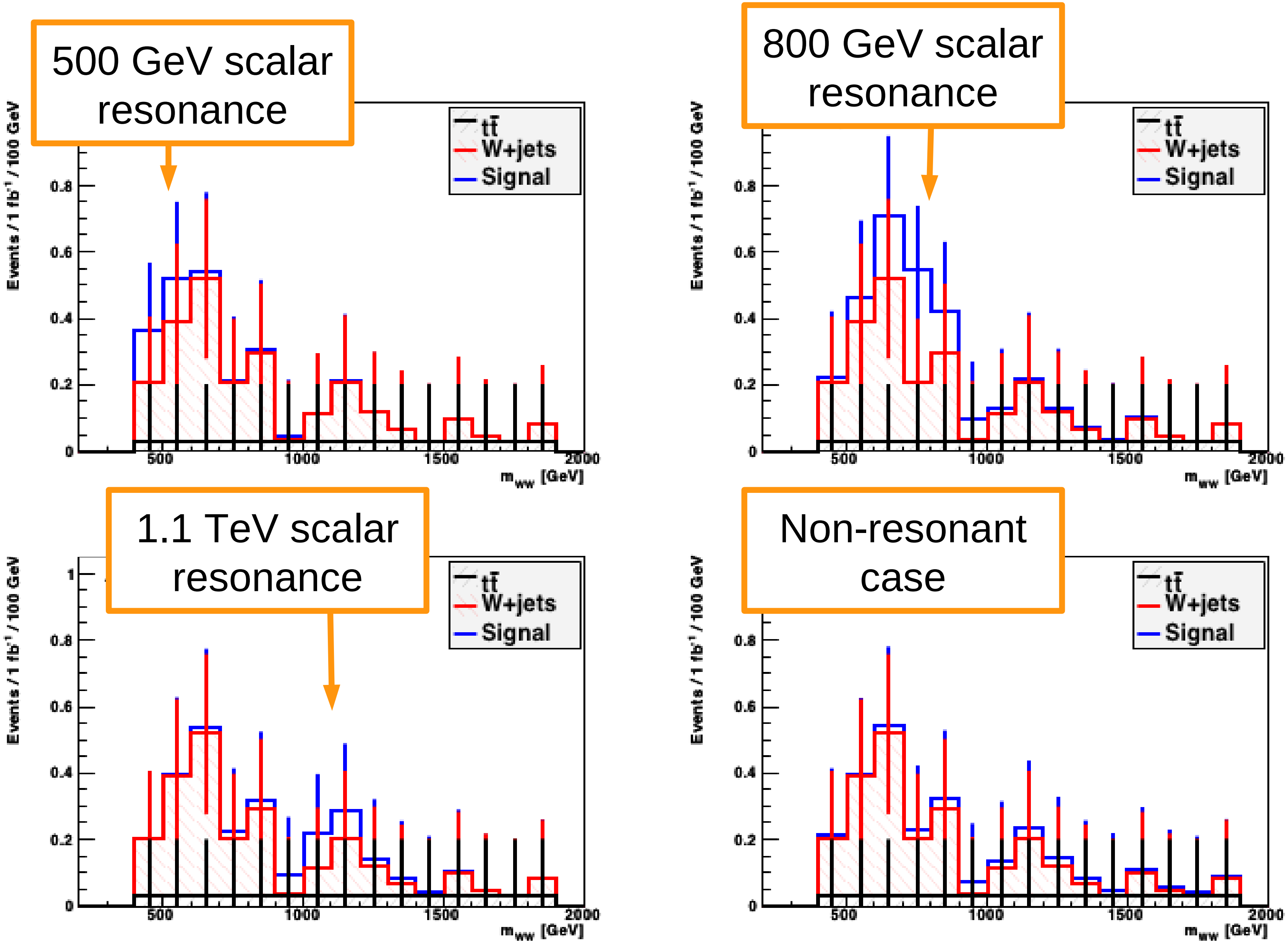
- **Hadronic W candidate** — ε ~40 %
  - Single jet with mass 68<m<97 GeV, 30 GeV/E_T<$\sqrt{d_{12}}$ <100 GeV/E_T -or-
  - Pair of jets with 67<m<106 GeV, 0.1<$\sqrt{d}$<0.45
  - p_T^W > 200 GeV, $|\eta^W|$<2
- **Leptonic W** — ε ~50 %
  - Use mass constraint to reconstruct p_z^ν
  - p_T^W > 200 GeV
- **Tagging jets** — ε ~40 %
  - 2 jets with p_T > 10GeV E > 300 GeV, $|\Delta\eta|$>5
- **Central jet veto** — ε ~90 %
  - No jet with p_T>30 GeV between tagging jets
- **Top veto** — ε ~ 50 %
  - Veto events with 130 < Wj mass < 240 GeV







WW→lνqq Mass Spectra



Results

All numbers for 14 TeV

Mass	Channel	Signal evts in 100 fb^{-1}	Bkg evts in 100 fb^{-1}	Significance for 100 fb^{-1}	Lumi for 3σ	Lumi for 5σ
500 GeV	**WZ→jj ll**	28	20	5.3σ	30 fb^{-1}	90 fb^{-1}
	WZ→lν ll	40	25	6.6σ	**20 fb^{-1}**	55 fb^{-1}
800 GeV	**WW/WZ→lν qq**	65	87	6.3σ	**20 fb^{-1}**	60 fb^{-1}
	WZ→jj ll (resolved)	24	30	3.9σ	60 fb^{-1}	160 fb^{-1}
	WZ→j ll (boosted)	27	23	4.9σ	38 fb^{-1}	105 fb^{-1}
1.1 TeV	**WW/WZ→lν qq**	24	46	3.3σ	85 fb^{-1}	230 fb^{-1}
	WZ→j ll (boosted)	19	22	3.6σ	68 fb^{-1}	**190 fb^{-1}**
	WZ→lν ll	7	2	3.6σ	70 fb^{-1}	**200 fb^{-1}**

Could start testing low-mass regions with **~20 fb^{-1} at 14 TeV**

⇒ ~40-50 fb^{-1} at 7 TeV ? ⇒ by 2015

Reaching 1 TeV and beyond will require **full LHC lumi + HL-LHC (>2018)**

→ Non-resonant scenarios are even less favorable...

→ Similar reach with high signal/high bkg and low signal/low bkg

CMS VV Searches

Scenarii considered:

→ M_H=500 GeV

→ "no Higgs"

Similar to ATLAS 500 GeV and non-resonant cases

Modes studied:

WW → lν qq, WW → lν qq

WZ → qq ll, ZZ → qq ll

WZ → μν μμ

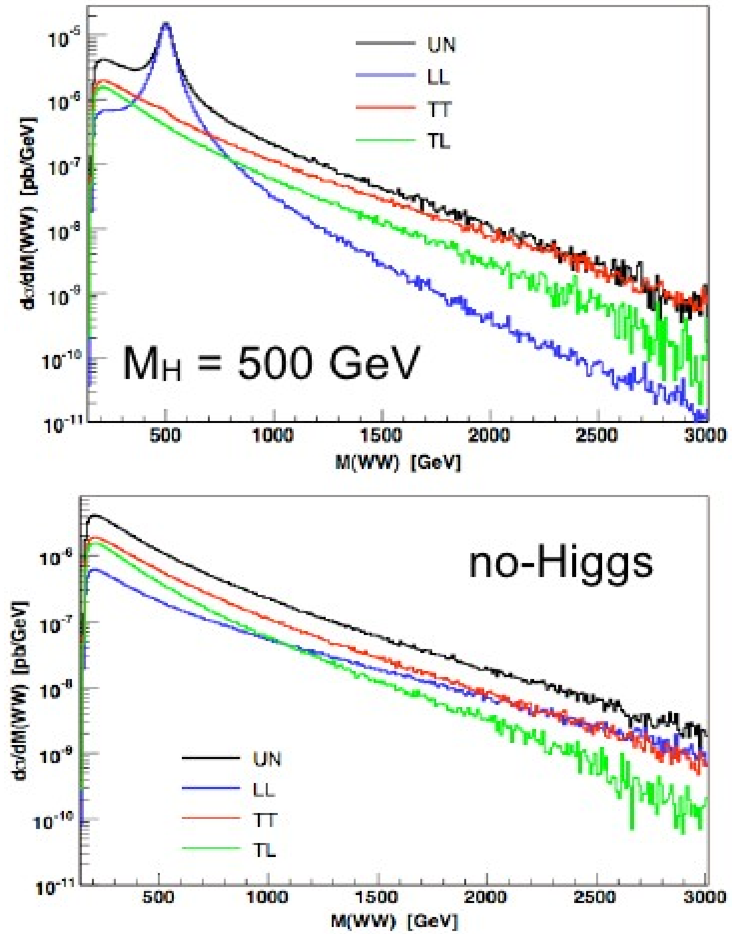
$W^\pm W^\pm$ → $l^\pm\nu$ $l^\pm\nu$

→2 neutrinos

⇒ Cannot reconstruct WW mass

→Feasible in same-sign signature

⇒ low background levels



E. Accomando *et al.* arXiv:hep-ph/0512219v2

N. Amapane et al. Study of VV-scattering processes as a probe of electroweak symmetry breaking, CMS AN-2007/005

Bo Zhu et al, "Same sign WW scattering Process as a probe of Higgs Boson in pp Collision at Sqrt(s) = 10 TeV", Eur. Phys. J. C71: 1514, 2011

Use the PHANTOM 2->6 fermion generator

CMS Analysis selections

μ: p_T > 20 GeV

e: E/p>0.8 , |1/E-1/p|<0.01 , H/E <0.02, Track Iso

jet: p_T > 30 GeV

Z→μμ,ee

- $p^+_z{}^*p^-_z > -2000\ GeV^2$
- choose pair with largest p_T
- $81 < M_Z < 101$ GeV
- $p_T^Z > 100$ GeV

W→μν,eν

- Fix p_z with $(p_\mu+p_\nu)^2 = M_W^2$
- MET > 30 GeV;
- MET/HT > 0.07

V→jj

- Couple of jets with minimum Δη

Tag jets:

- p_T>30 GeV, E_j > 100 GeV
- |η| >1 for at least one jet
- Pair with largest M_{jj}
- close jets merged
- |Δη| > 1.5
- M_{jj} > 500 GeV

Final cuts:

- M_{VWjj} > 1000 GeV
- anti b-tagging

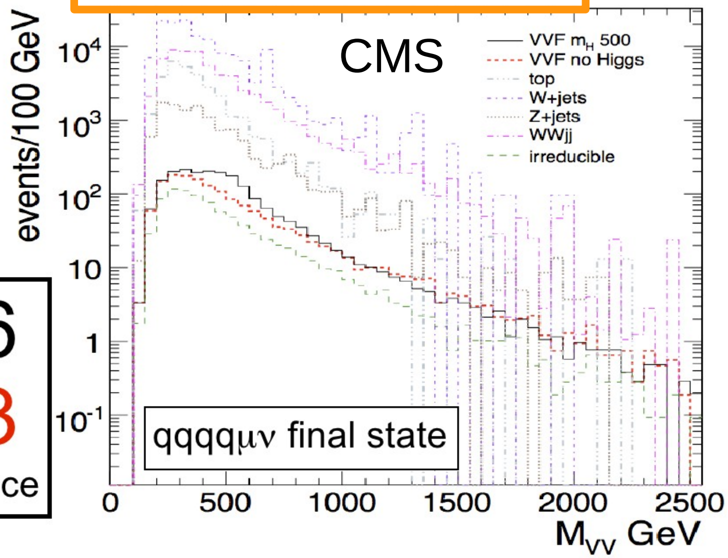
some additional selections among subchannels are different

P. Govoni - the CMS potential in the area of WW scattering 10 From the LHC to a Future Collider 2009

Slide from P. Govoni

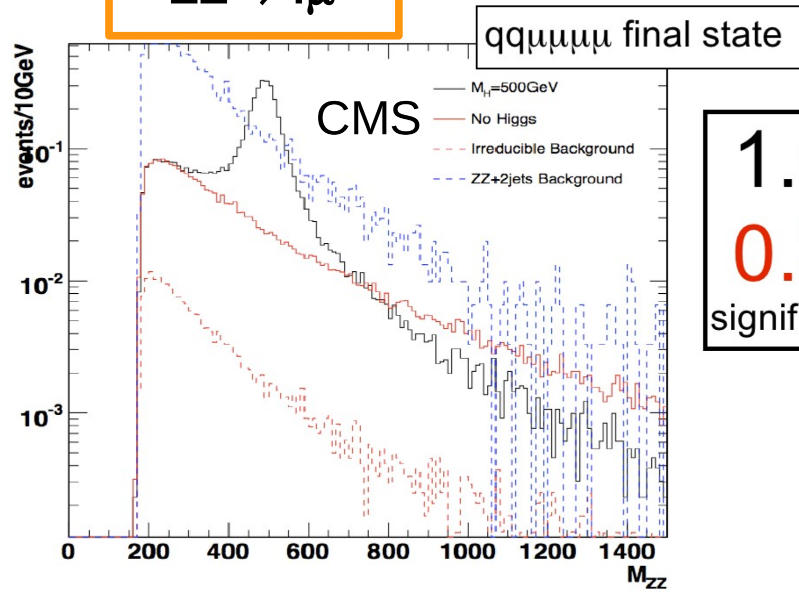
CMS Mass spectra (60 fb^{-1})

WW/WZ→μν qq



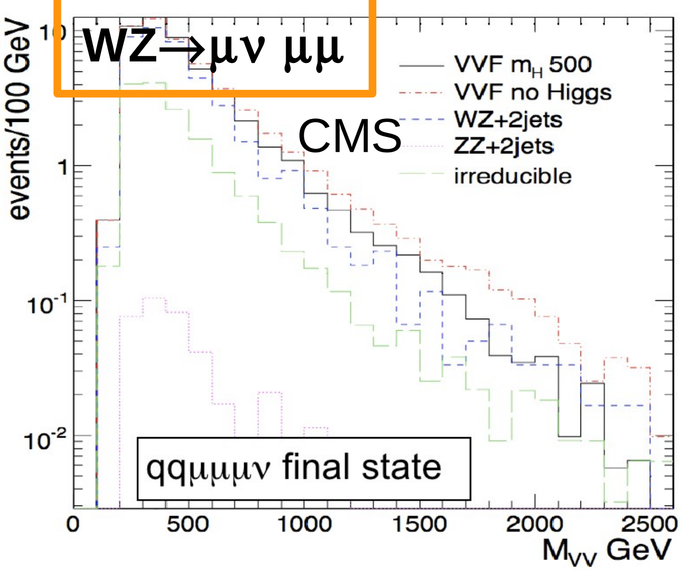
2.86
1.13
significance

ZZ→4μ



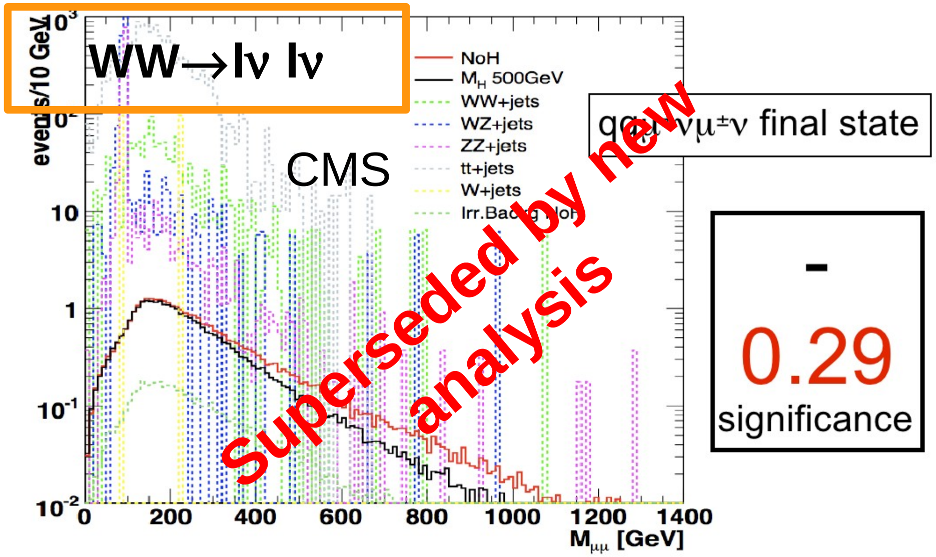
1.66
0.27
significance

WZ→μν μμ



-
1.51
significance

WW→lν lν



-
0.29
significance

Results

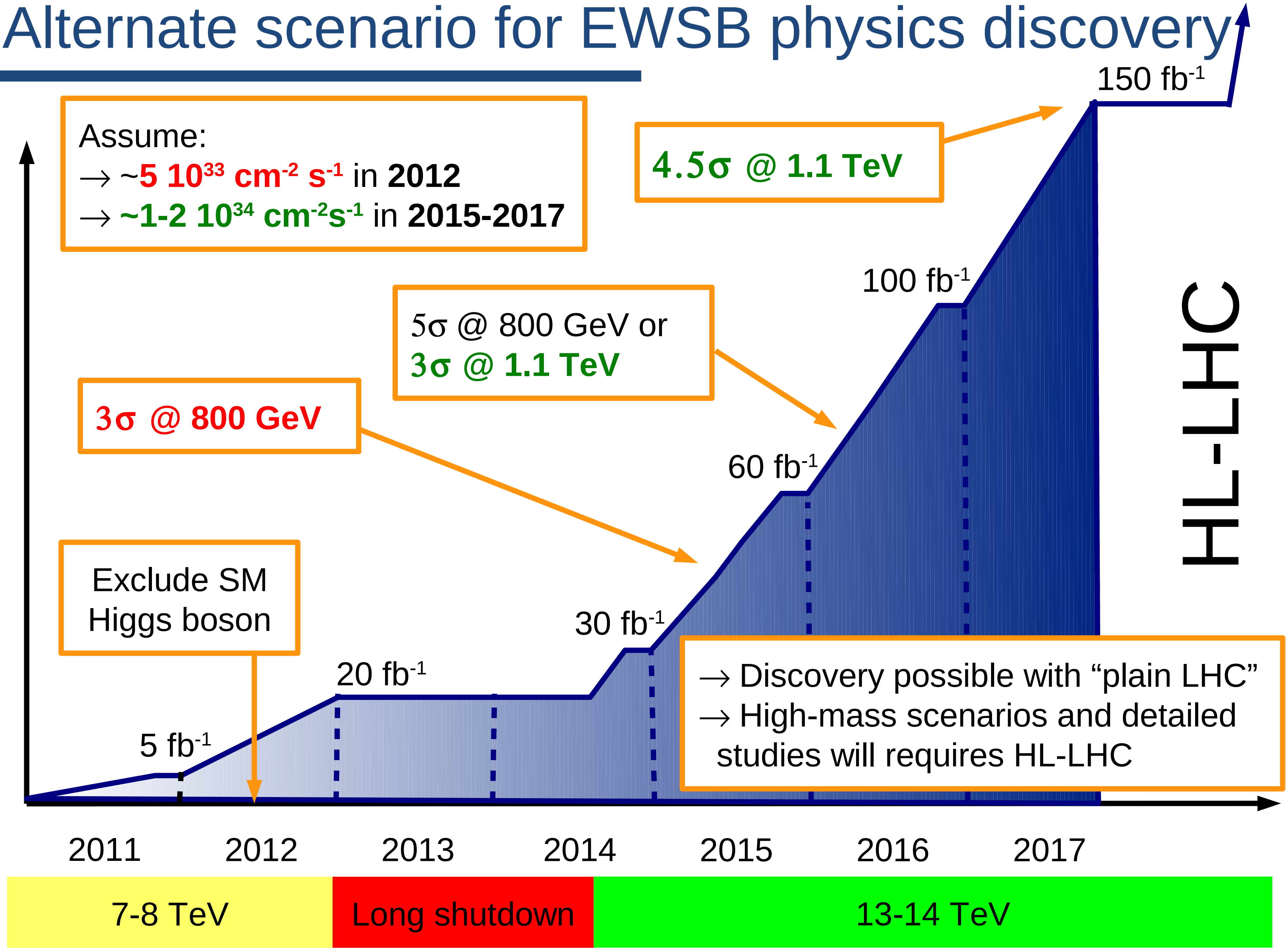
Significant improvement since these results (Particle Flow) ⇒ now better in hadronic modes

Mass	Channel	Signal evts in 60 fb^{-1}	Bkg evts in 60 fb^{-1}	Significance for 60 fb^{-1}
500 GeV	**WW,WZ→eν qq**	309	~2000	**6.7σ**
	WZ,ZZ→qq ll	186	~10^4	~1.8σ
	ZZ→ll ll	6.6	5.5	~2.4σ
no-Higgs	**WW/WZ→eν qq**	26	187	**1.9σ**
	WW/WZ→μν qq	111	~10^4	1.1σ
	WZ,ZZ→qq ll	15	~1000	~1.9σ
	ZZ→ll ll	0.36	0.50	0.5σ
	WZ→μν μμ	2.7	2.3	1.5σ
200 GeV	**$W^{\pm}W^{\pm}\to l^{\pm}\nu\ l^{\pm}\nu$**	6.5	3.5	2.4σ
no-Higgs	**$W^{\pm}W^{\pm}\to l^{\pm}\nu\ l^{\pm}\nu$**	5.4		2.8σ

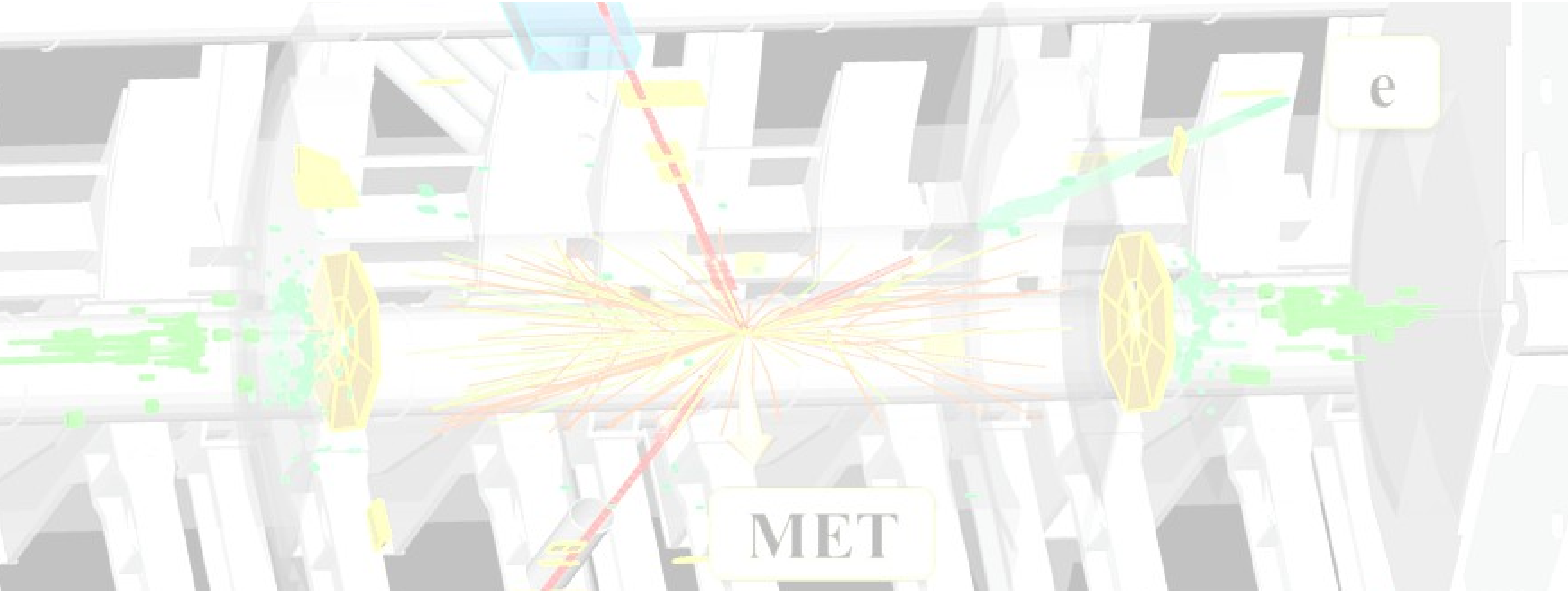
Results for 14 TeV

Results at **10 TeV**
Can also separate the m_H=200 GeV and no-Higgs scenarii at **4σ** with **6 ab^{-1}**

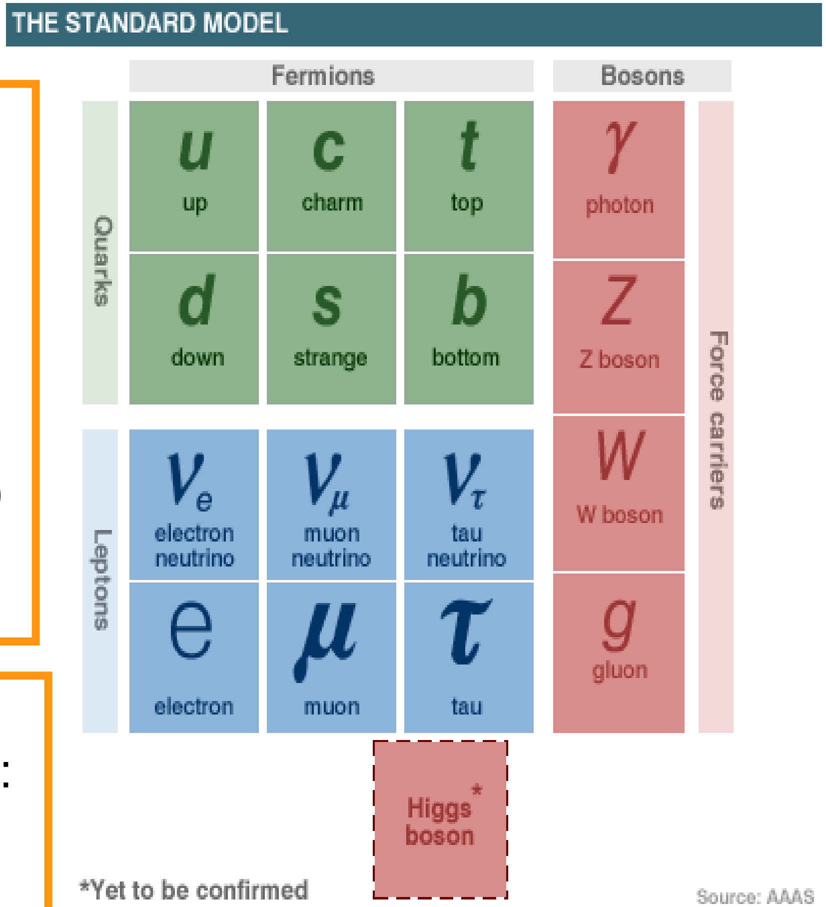
Alternate scenario for EWSB physics discovery



Technicolor



Technicolor



Technicolor:
No Higgs boson

Introduce:
A **new strong gauge interaction**
→ typically some $SU(N_{TC})$
New fermions sensitive to TC ("**techniquarks**")
→ typically N isospin doublets

EWSB:
TC coupling becomes large for Λ_{TC} ~ O(100 GeV):
⇒ **chiral symmetry breaking** : $\langle Q_L Q_R \rangle \neq 0$, ~ Λ_{TC}.

$\langle Q_L Q_R \rangle$ not invariant under $SU(2)\otimes U(1)$ ⇒ **EWSB**

EW precision constraints, FCNC:
→ "scaled-up QCD" models are excluded, but TC with a "**walking**" coupling is OK.

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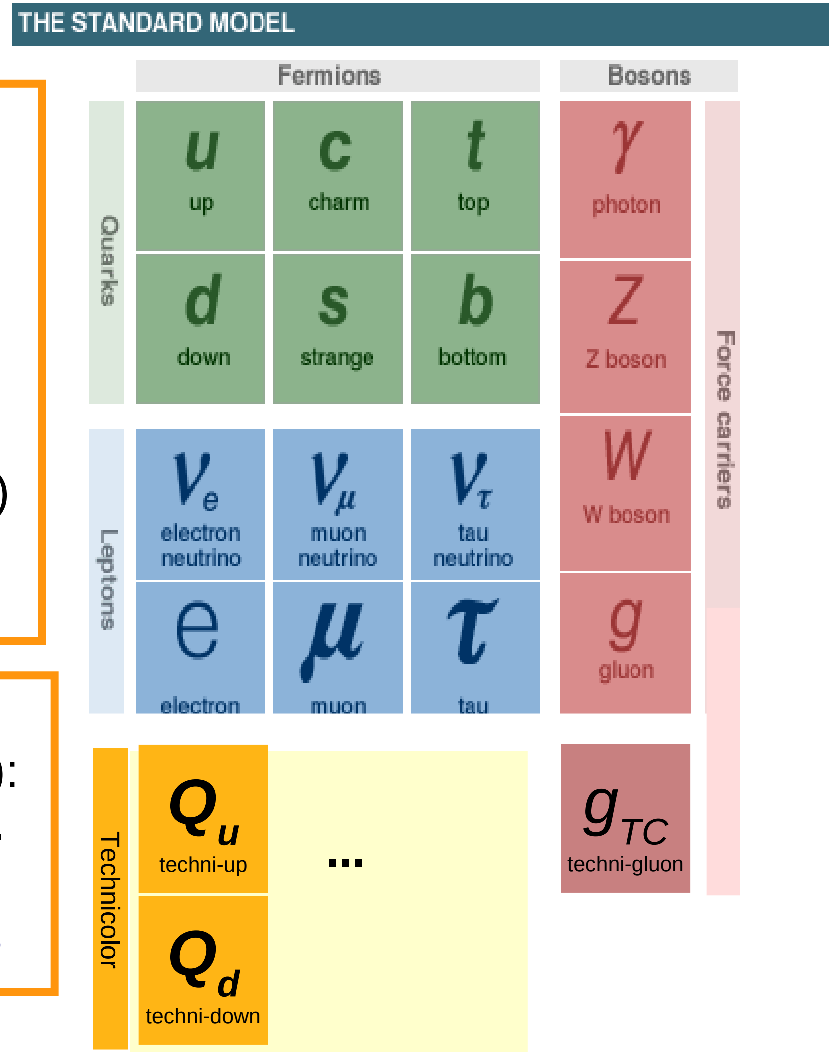

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Low-scale Technicolor

Lane and Eichten, Phys. Lett. **B222,** 274)

Low-scale Technicolor

$\rightarrow$ SU(**N_{TC}=4**)

$\rightarrow$ **N_D=9** isospin doublets of techniquarks

$\rightarrow$ Λ_{TC} ~ 246GeV/$\sqrt{N_D}$ ~ **100 GeV**

Chosen N_{TC}, N_D $\Rightarrow$ walking coupling

Particle spectrum

$\rightarrow$ **technipions** π_T (except 3 that give mass to W,Z)

$\rightarrow$ **technimesons** : near-degenerate ρ_T, ω_T, a_T, …

Walking decreases $M(\rho_T)/M(\pi_T)$

$\Rightarrow$ $V \rightarrow n\pi_T$ decays are typically forbidden

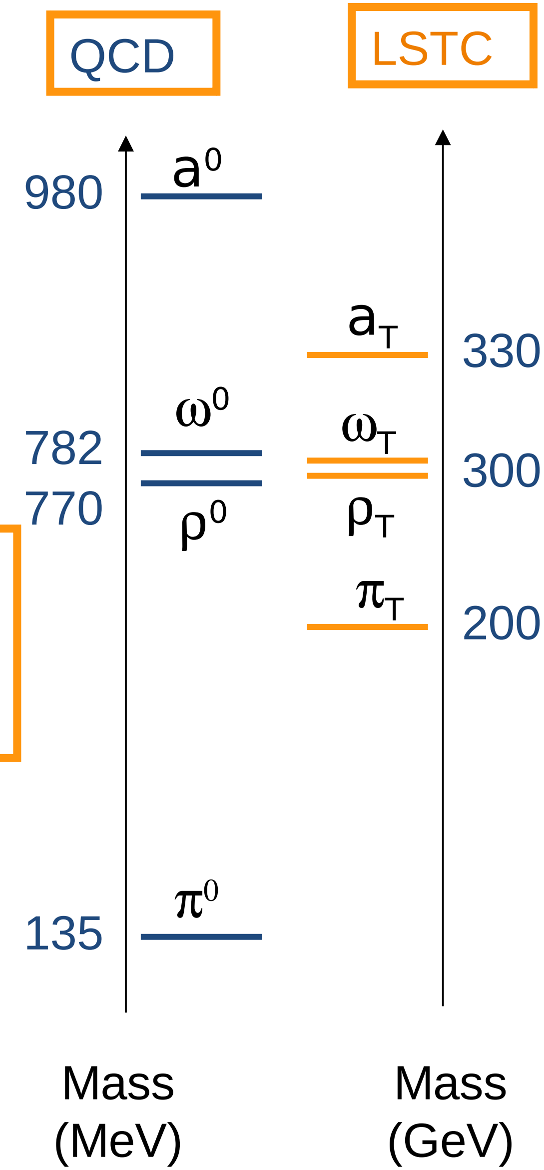
$\Rightarrow$ **Narrow resonances**

Main decay modes :

$\rightarrow$ $\pi_T \rightarrow jj$

$\rightarrow$ ρ_T^0, ω_T^0, a_T^0 $\rightarrow$ **l^+l^-**, $Z\gamma$

$\rightarrow$ $\rho_T^\pm$, $\omega_T^\pm$, $a_T^\pm$ $\rightarrow$ **$W^\pm Z$**, $W^\pm\gamma$

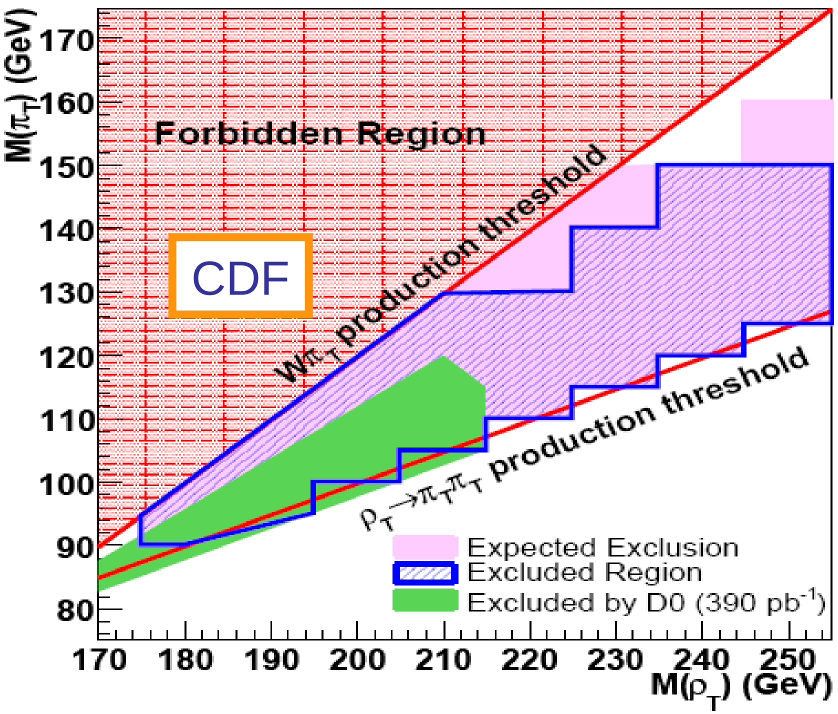


LSTC limits from Tevatron

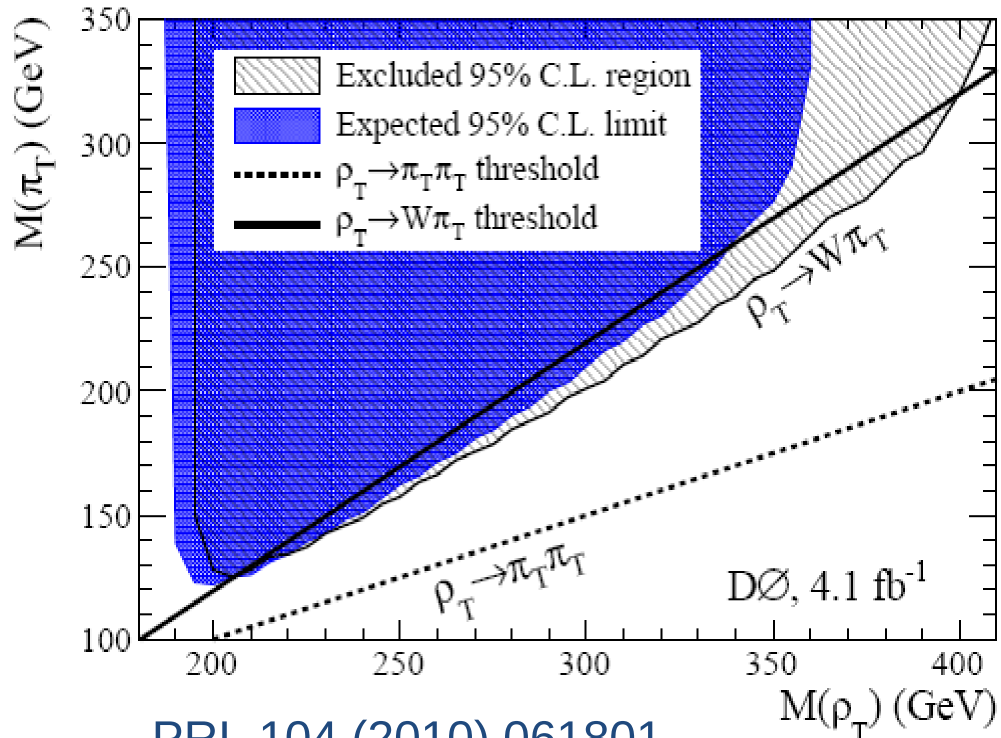
→ ρ_T, ω_T technimesons are easiest target

→ Limits usually presented in **($M(\rho_T)$, $M(\pi_T)$)** plane

π_T mass affects allowed decay channels, BFs.



PRL 104 (2010) 111802



PRL 104 (2010) 061801,

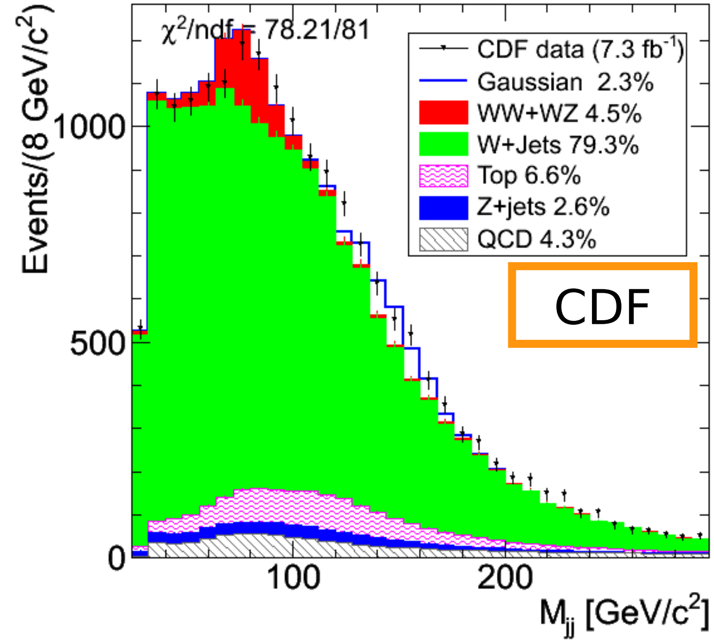
→ For lower $M(\pi_T)$, look for $\rho_T \to W\pi_T$. Best limit from CDF : $M(\rho_T) <$ **250 GeV**

→ For higher $M(\pi_T)$, use $\rho_T \to$ **WZ**. Best limit from DØ : $M(\rho_T) <$ **400 GeV.**

Technicolor at Tevatron ?

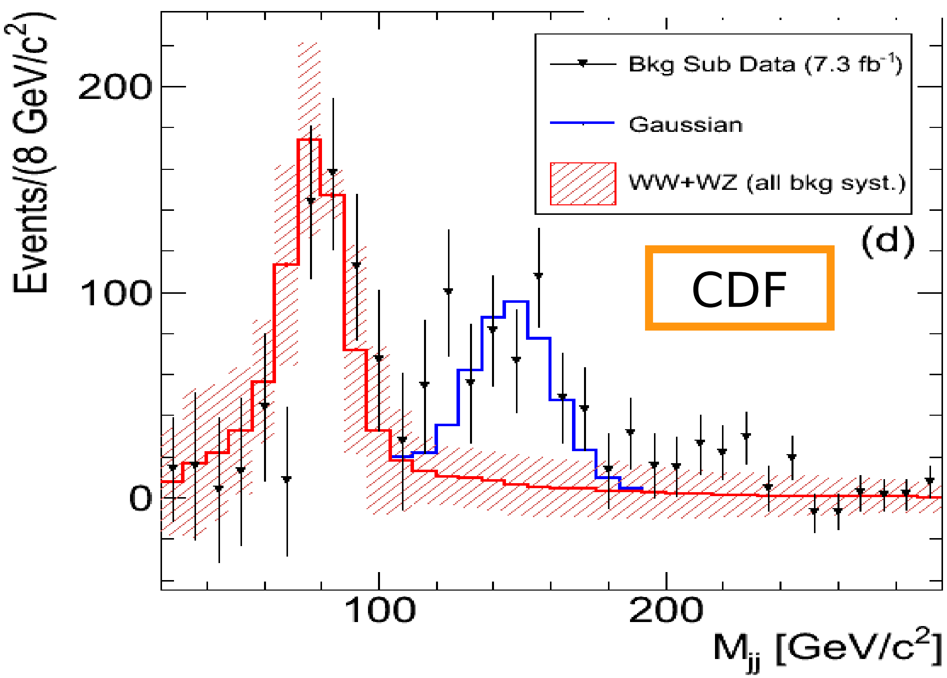
Excess in Wjj production seen by CDF for
m_{jj} = 144±5 GeV
→ **4.8σ** deviation with 7.3 fb^{-1}
→ width ~ detector resolution

PRL 106 (2011), 171801

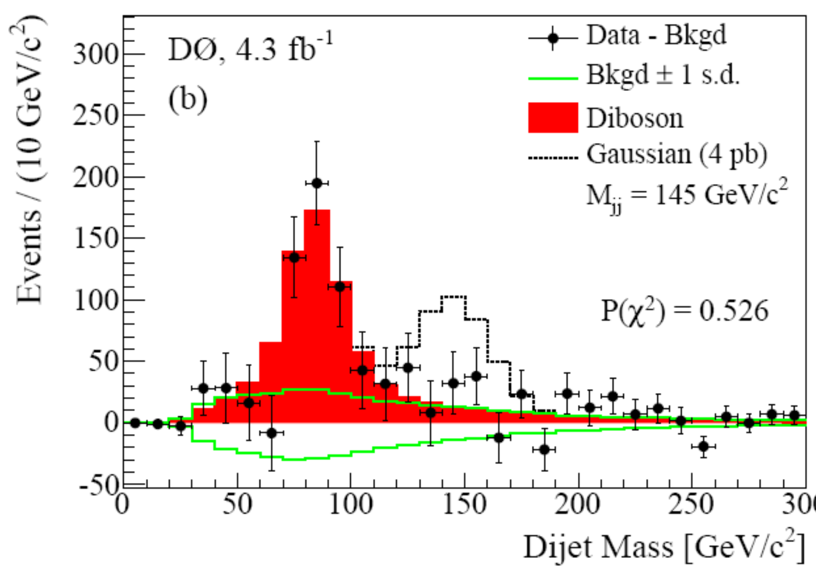


Can be interpreted as $\rho_T \to W + (\pi_T \to jj)$
→ **$M(\rho_T)$ ~ 290 GeV, $M(\pi_T)$ ~160 GeV**

PRL 106 (2011), 251803



Not seen by DØ (p-value = **0.53**)



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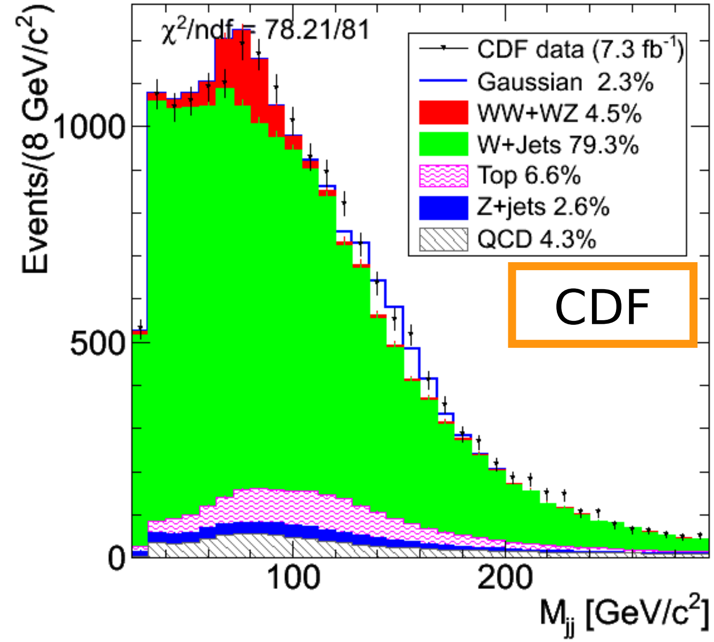

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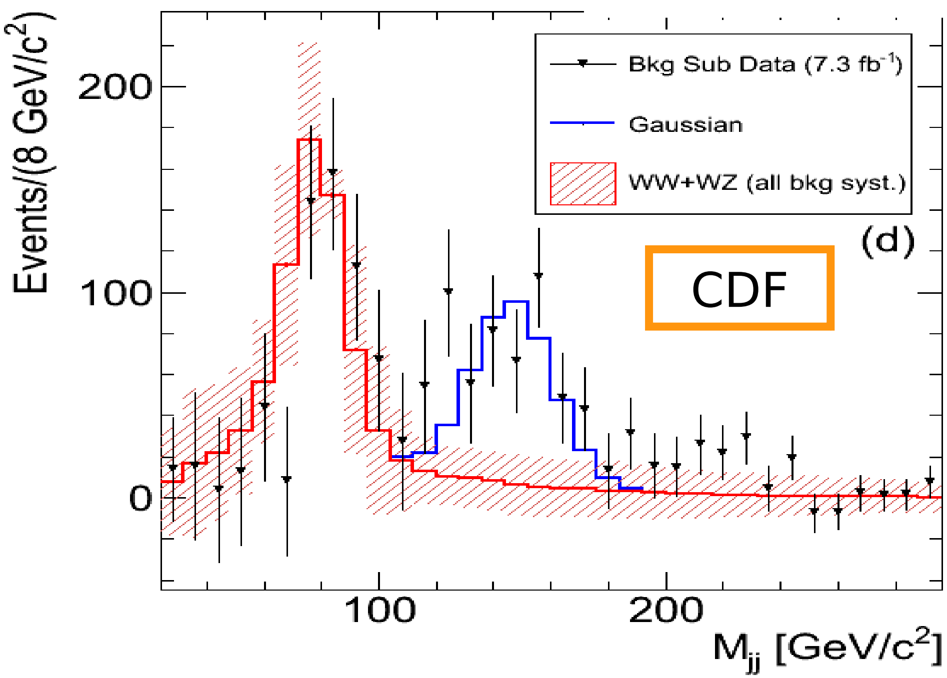
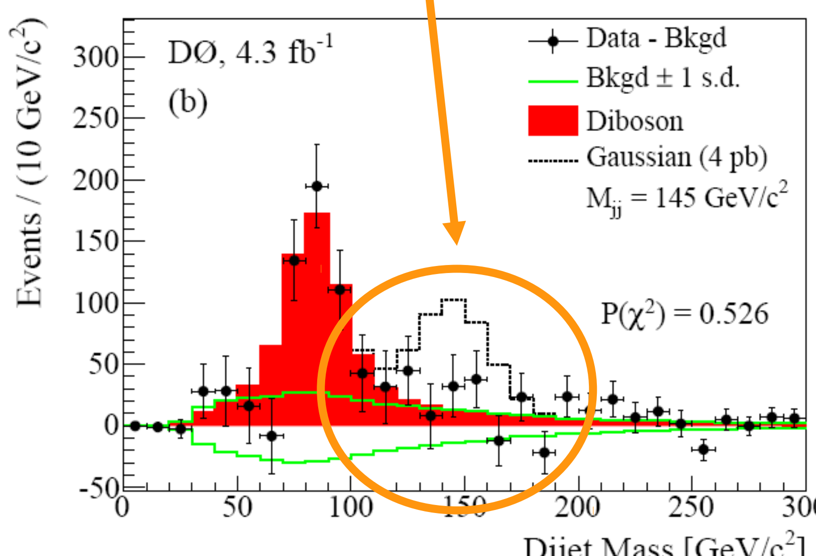
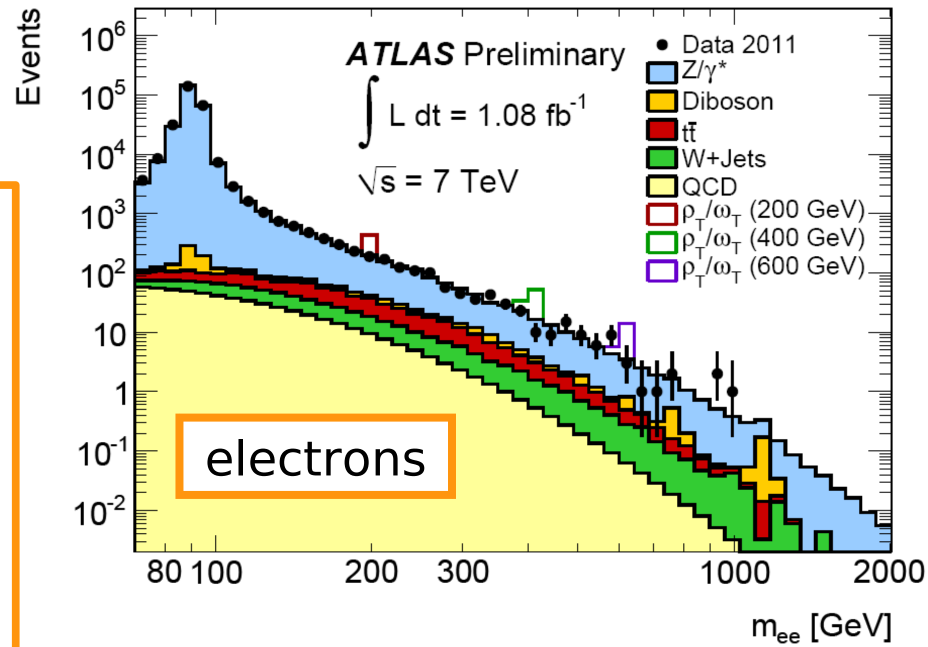


Not seen by D∅ (p-value = **0.53**)



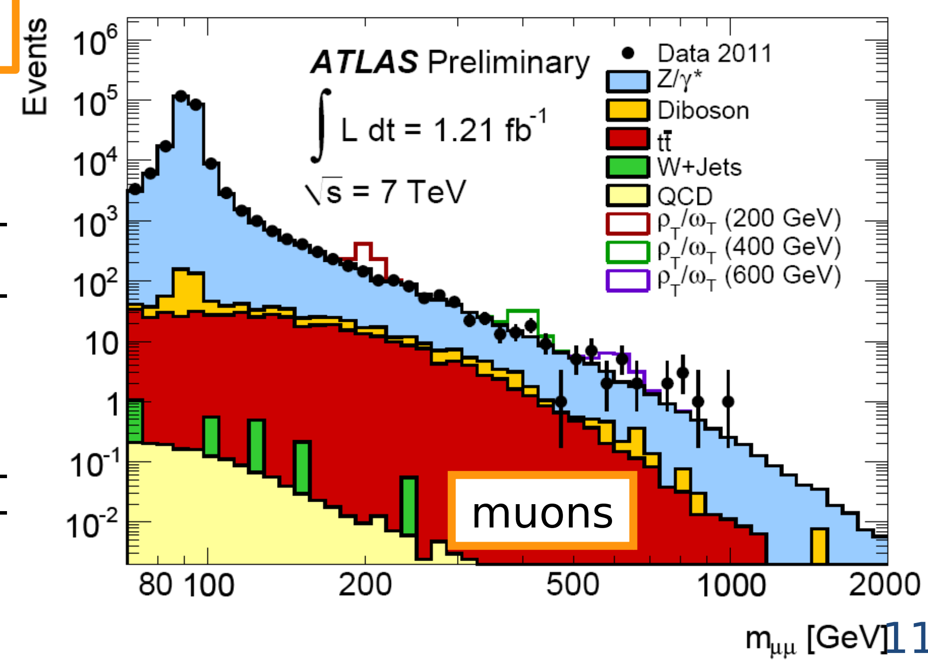
ATLAS l^+l^- search

→ Require 2 leptons with p_T>25 GeV
→ Main background: Drell-Yan
→ Excellent agreement between MC and the data in "LSTC region" (m_{ll} ~ **200-600 GeV**)
→ Quantify in terms of LSTC models with various $M(\rho_T)$, $M(\pi_T)$ values
→ assume **$M(\omega_T) = M(\rho_T)$, ignore a_T**
→ Since no excess observed, set limits



ATLAS-CONF-2011-125

Source	dielectrons		dimuons	
	signal	background	signal	background
Normalization	5%	NA	5%	NA
PDFs/α_S	NA	10%	NA	10%
QCD K-factor	NA	3%	NA	3%
Weak K-factor	NA	4.5%	NA	4.5%
Trigger/Reconstruction	negligible	negligible	4.5%	4.5%
Total	5%	11%	7%	12%



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ATLAS-CONF-2011-125

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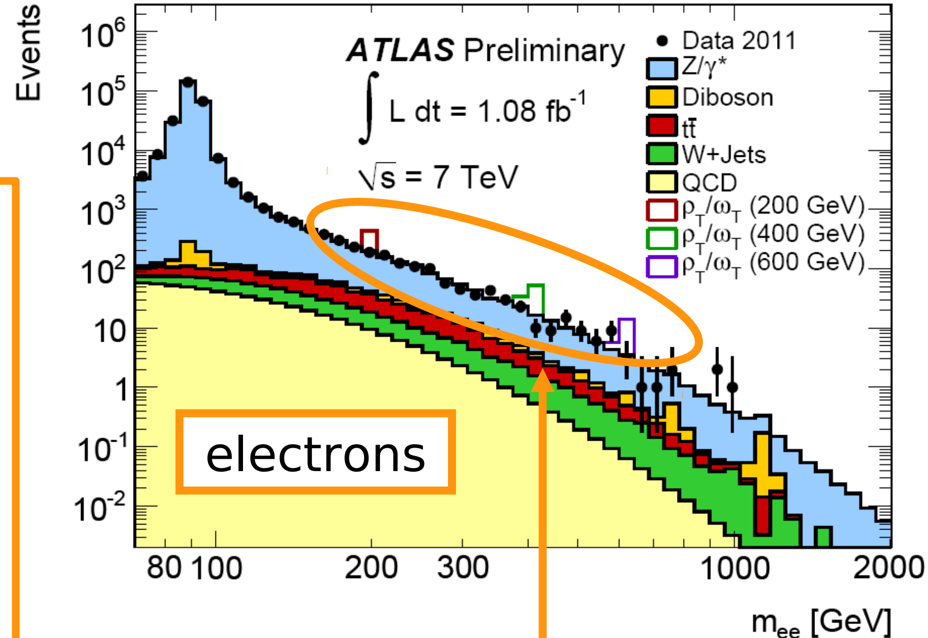
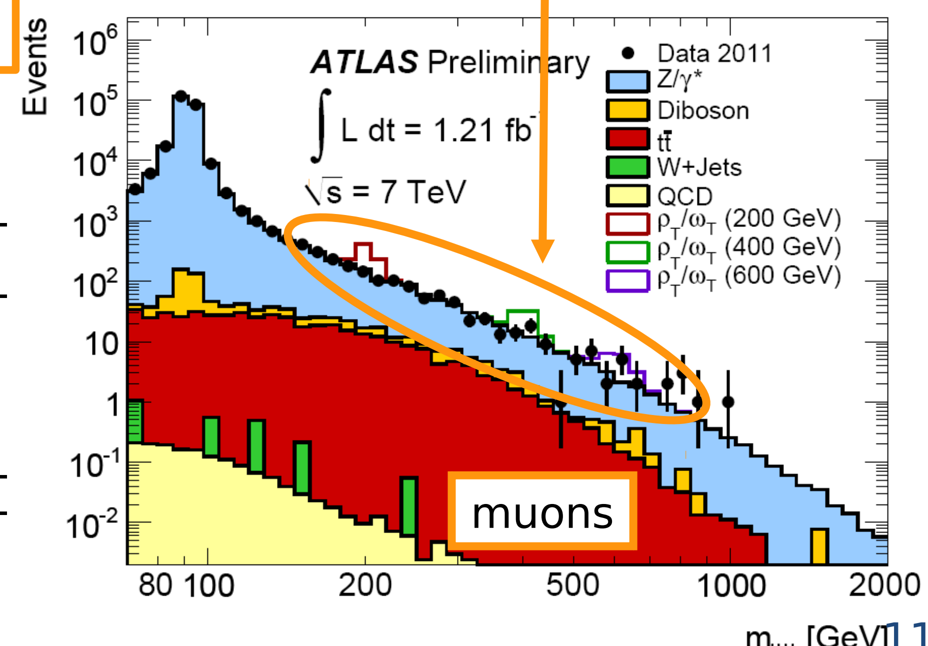


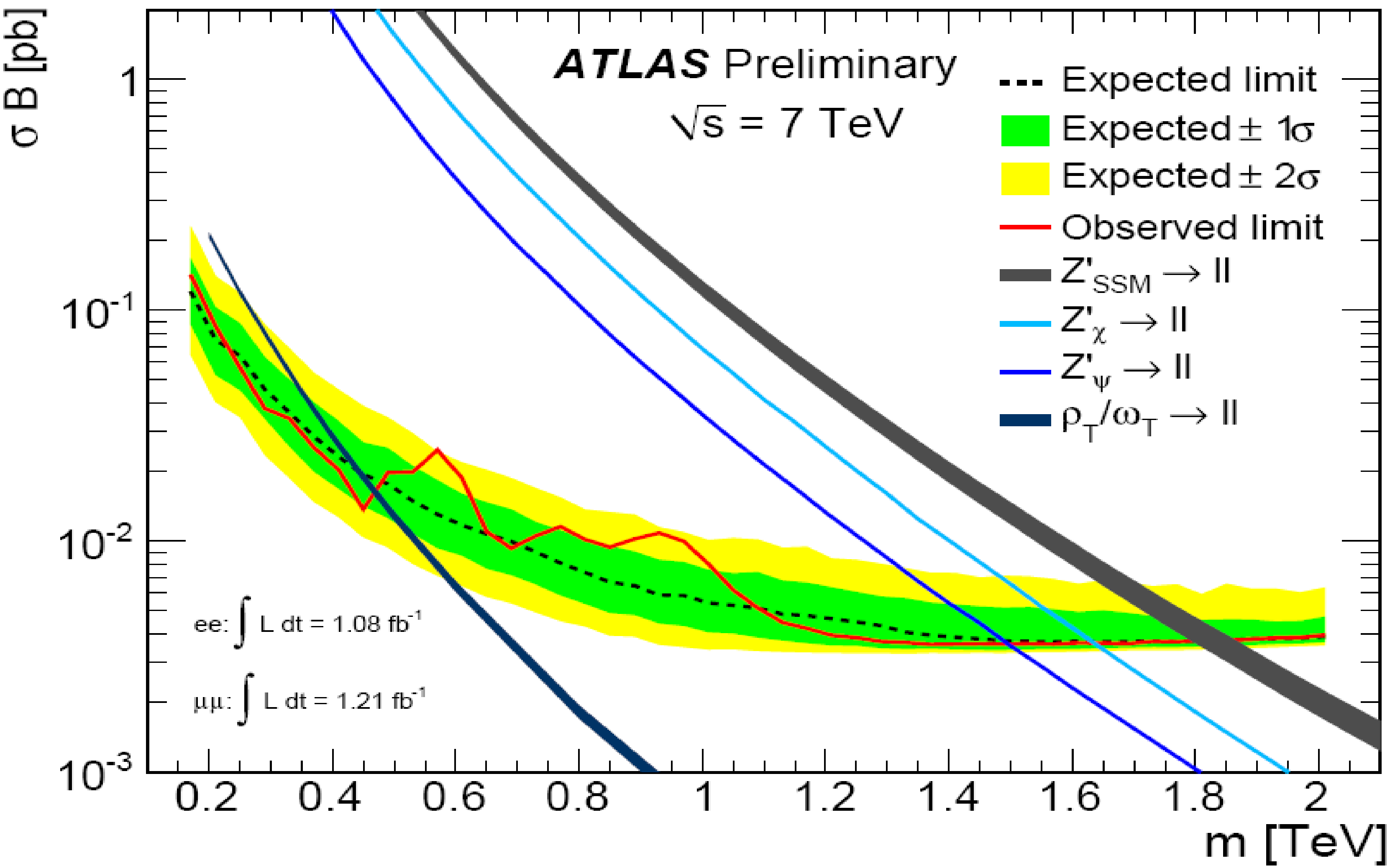
Examples of expected signal peaks



Limit on $M(\rho_T)$

→ Assume **$M(\pi_T) = M(\rho_T) - 100$ GeV** scan $M(\rho_T)$ values

→ Set 95% UL on $M(\rho_T)$ using the limit on production $\sigma.BR(l^+l^-)$



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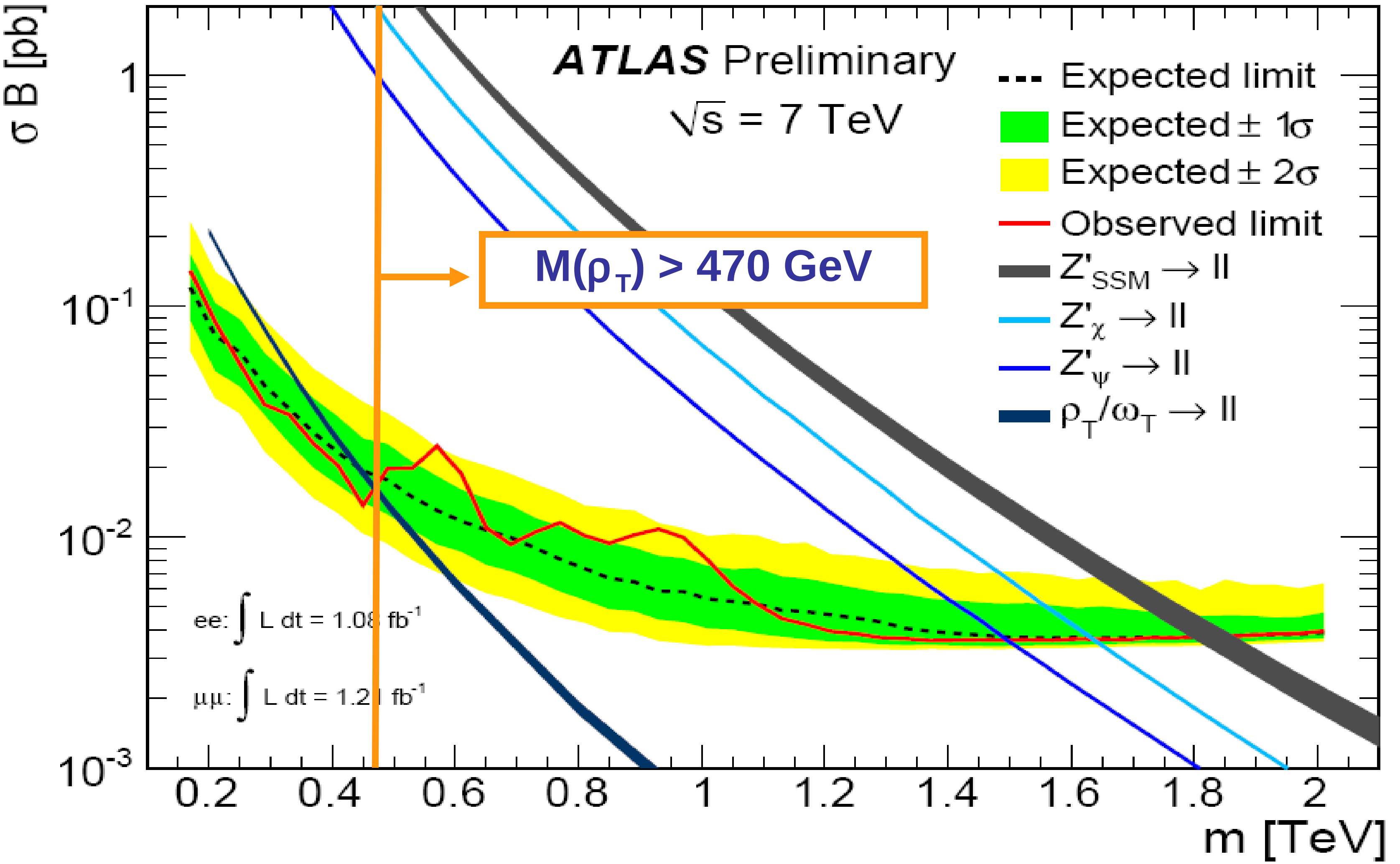
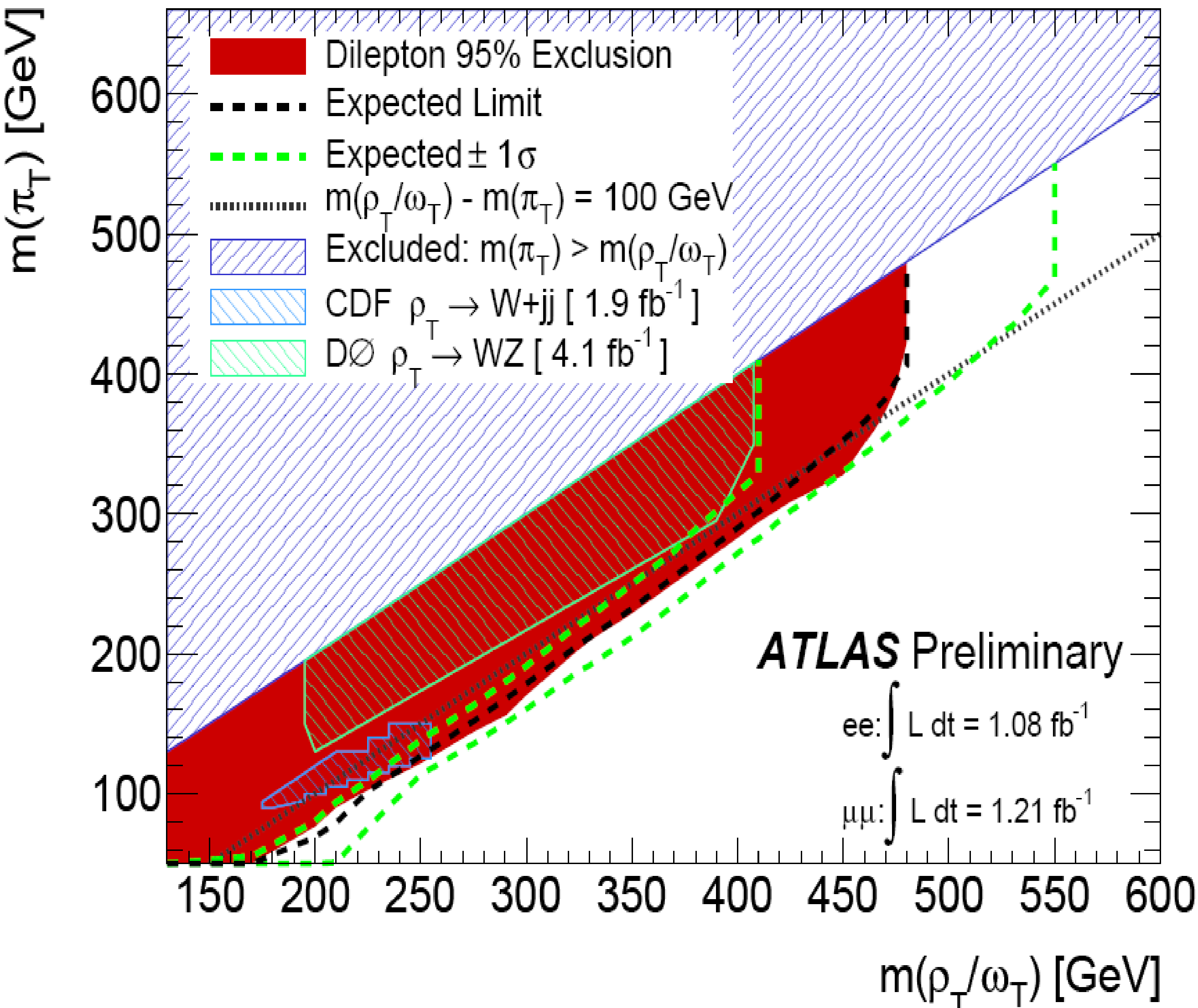


Limit in $M(\rho_T)$, $M(\pi_T)$ plane

→ Same with scan on both $M(\rho_T)$ and $M(\pi_T)$, limit in $(M(\rho_T), M(\pi_T))$ plane



Significant improvement over Tevatron results

Limit in $M(\rho_T)$, $M(\pi_T)$ plane

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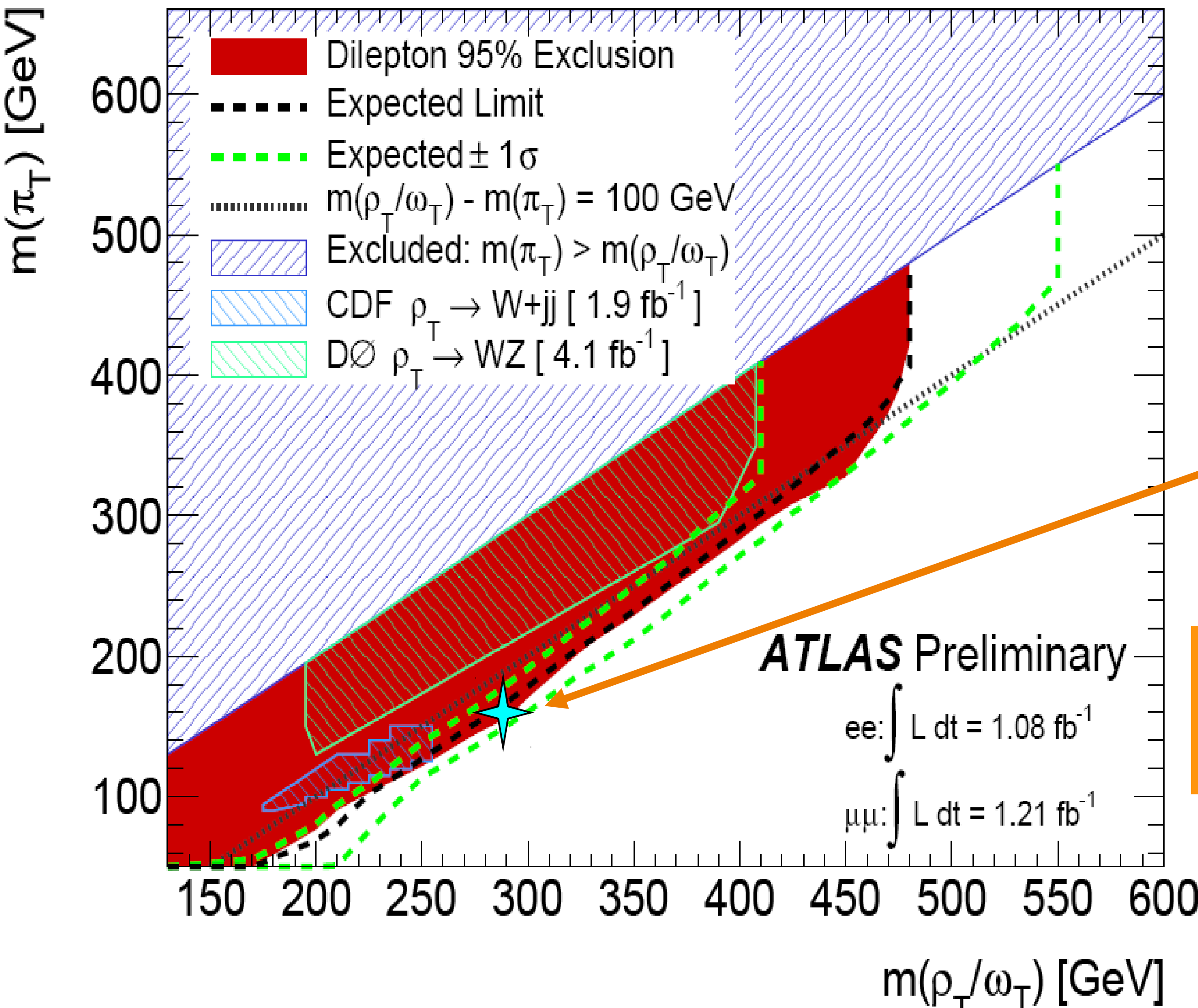


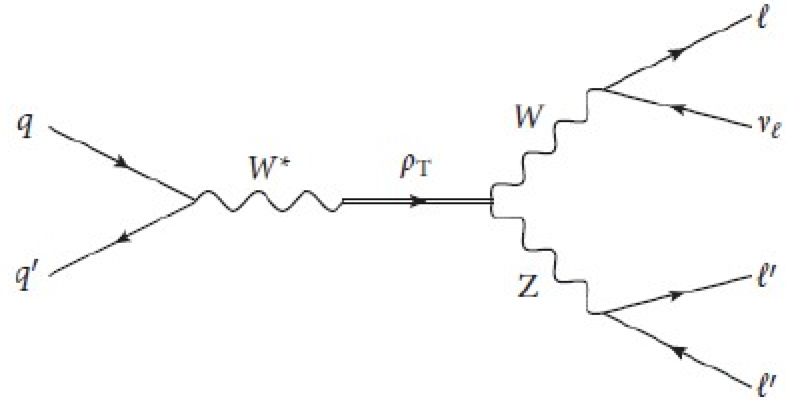
Significant improvement over Tevatron results

LSTC interpretation of CDF Wjj excess

Values for Wjj excess just inside excluded region

CMS $\rho_T \to WZ$ Search

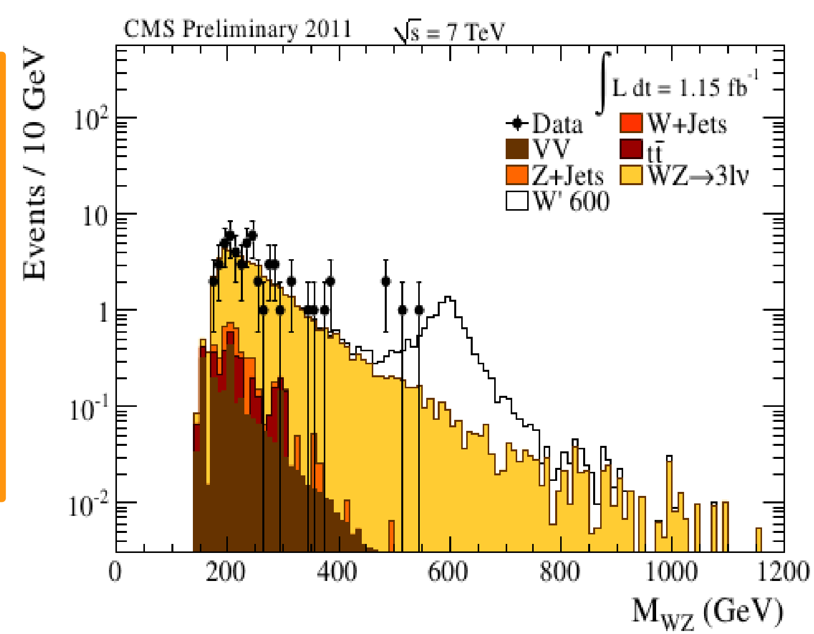
Search in $\rho_T \to$ **WZ** mode, dominant for heavy ρ_T ($m_{\rho T} < m_{\pi T} + m_W$)
Use **WZ→lν ll** decay mode. Main background: SM WZ→lνll



Parameter Set	$M(\rho_{TC}) = M(\omega_{TC})$	$M(a_{TC})$	$M(\pi_{TC})$	$M_V = M_A$	$\sigma \times BR$(fb) (WZ)
A	300	330	200	300	42.9
B	400	440	275	400	12.9
C	500	550	350	500	5.2

Selection:
→ Z: 2 leptons with 60 < m < 120 GeV
→ W:1 lepton with p_T>20 GeV, E_T>30 GeV

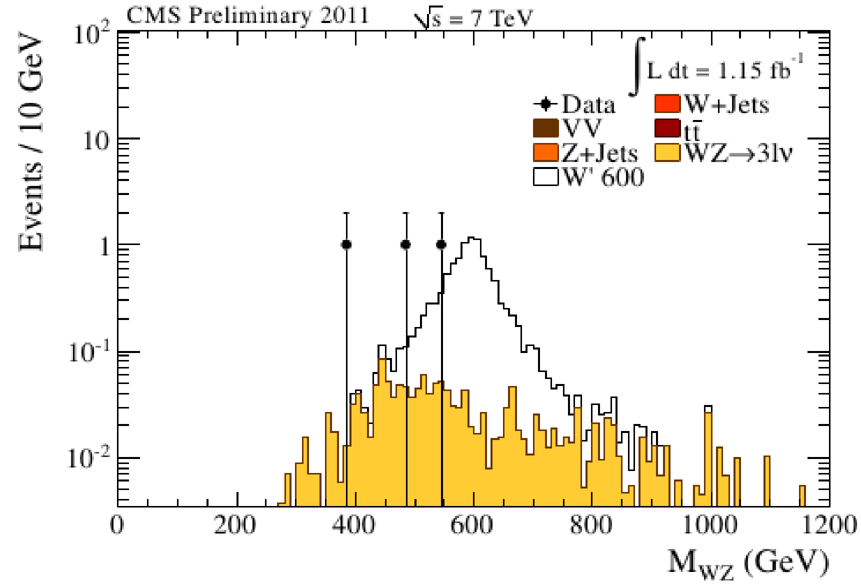
Reconstruct WZ mass using W mass constraint.

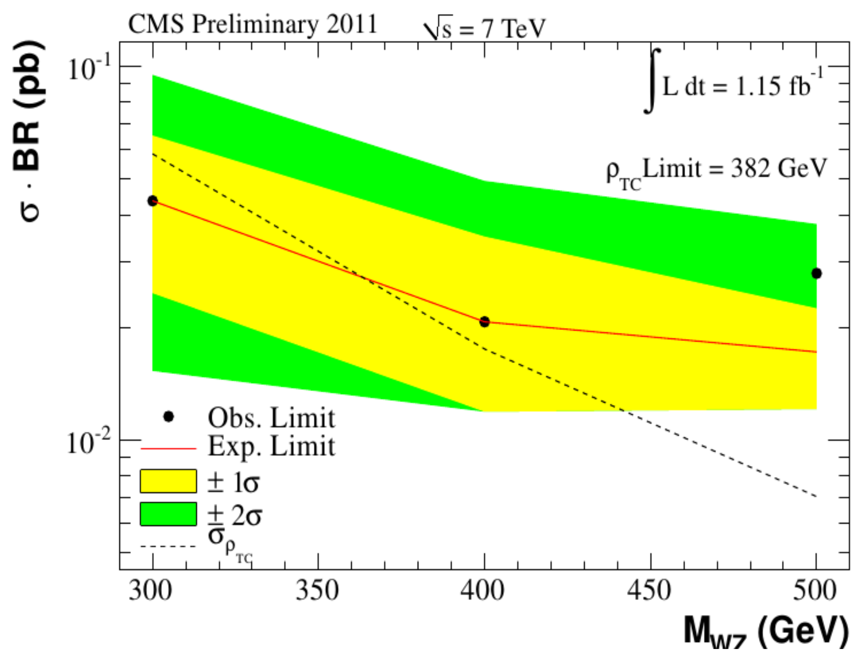


CMS PAS EXO-11-041

CMS $\rho_T \rightarrow WZ$ Results

For final result also require
$H_T = \Sigma\, p_T^{leptons}$ > 160-280 GeV,
with cut optimized for each point





Observed limit at $m_{\rho T}$ > 382 GeV

Reach should improve with statistics (already ~5x more available)

Mass point	Window (GeV)	N_{BkgMC}	ϵ_{Sig} (%)	N_{Sig}	Data	Exp. Limit (pb)	Obs. Limit (pb)
ρ_{TC} 300	253-352	5.7	17.3 ± 0.9	11	6	0.0436	0.0436
ρ_{TC} 400	347-455	2.0	22 ± 1	4	2	0.0207	0.0207
ρ_{TC} 500	430-555	0.7	22 ± 1	1	3	0.0172	0.0279

Conclusion

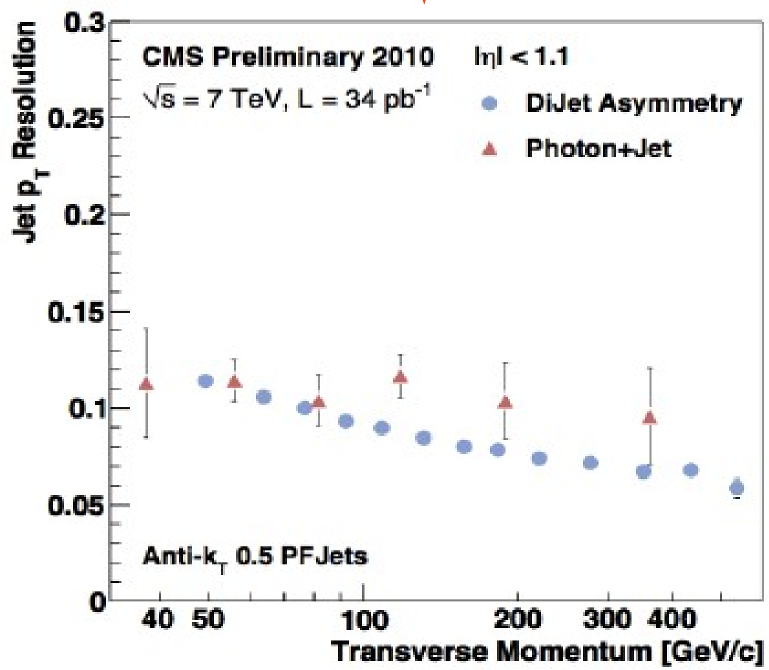
- Vector boson scattering is a powerful probe of EWSB whatever the underlying mechanism.
- Many experimental challenges, but already being adressed for other analyses.
- Small production cross-sections $\Rightarrow$ will need high luminosities to reach interesting mass ranges
- If strong dynamics leads to narrow sub-TeV resonances, could be observed earlier. Technicolor models provide good benchmarks for these scenarii.
- Everything depends on the results of Higgs search results in 2012... Exciting times ahead!

Backups

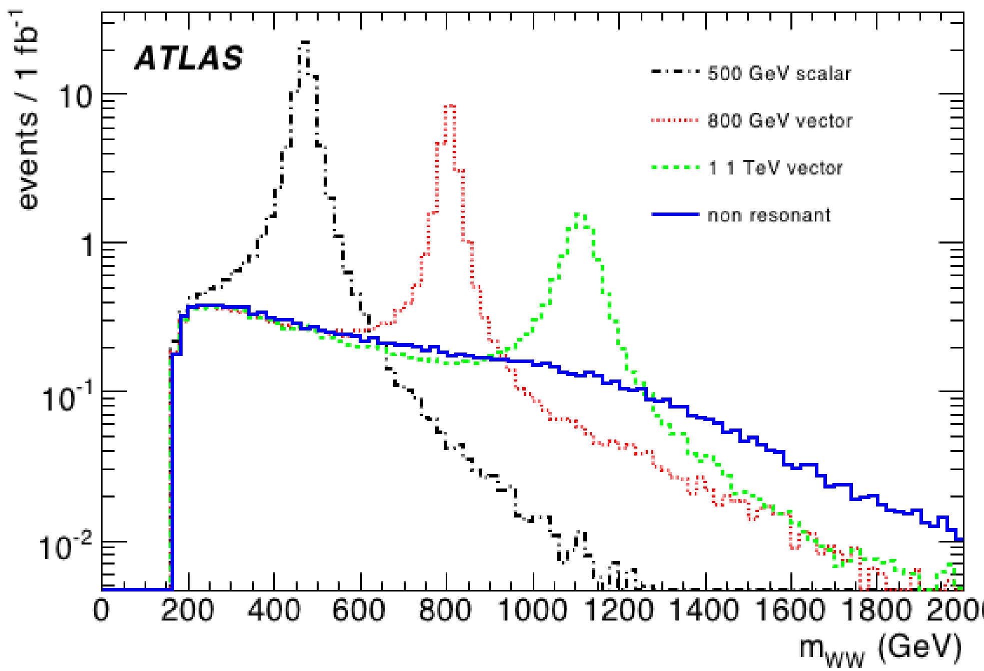
CMS mass resolutions

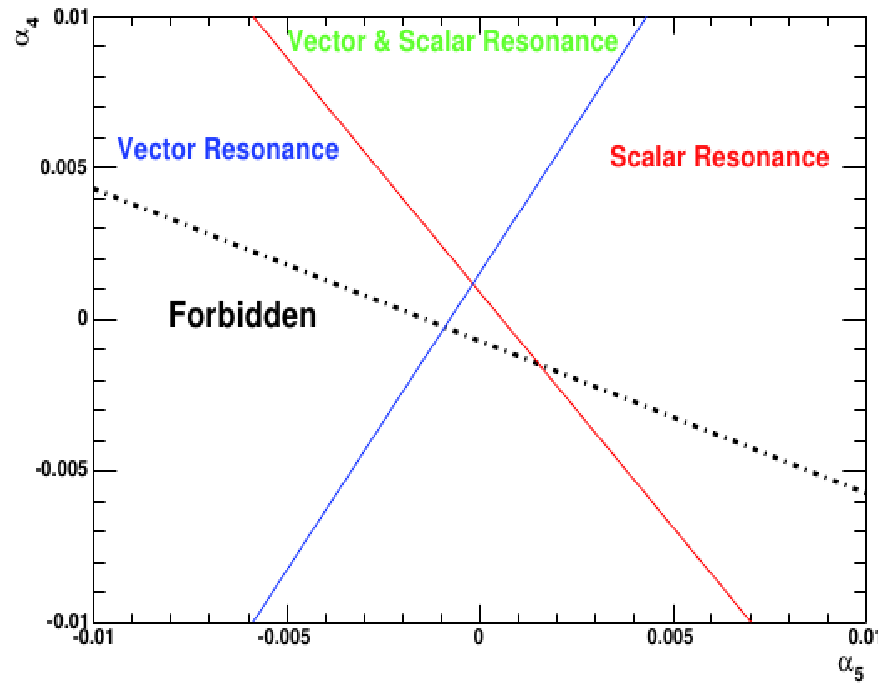
Mass resolutions

	$qqqq\mu\nu$	$qqqqe\nu$	$qqqq\mu\mu$	$qqqqee$	$qq\mu\mu\mu\mu$	$qqeeee$	$qq\mu\mu\mu\nu$
$Z \to ll$	—	—	1.5%	1.5%	1.5%	2.0%	2.1%
$W/Z \to jj$	27%	20.5%	20%	25%	—	—	—
$VV \to 4f$	22%	19.0%	9.5%	9.5%	1.1%	1.5%	9.4%



Chiral Lagrangian



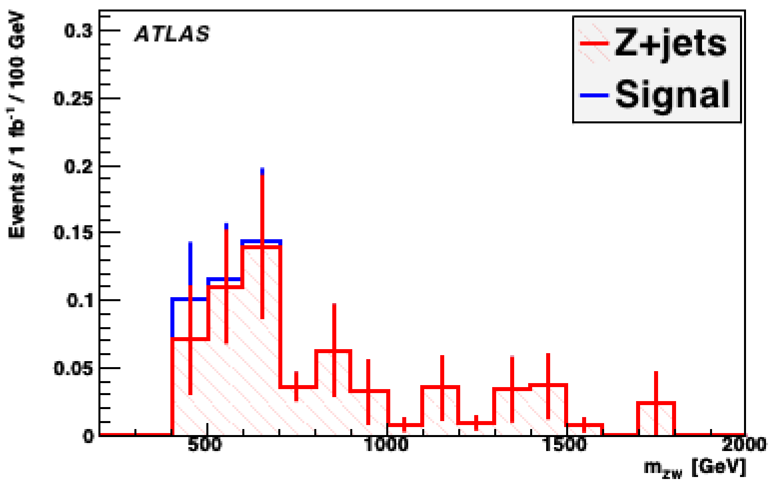


Full ATLAS Results

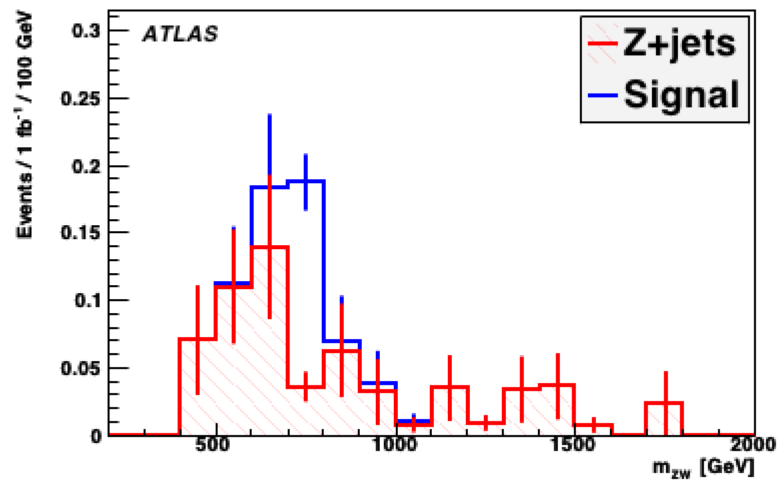
Process	Cross section (fb)		Luminosity (fb^{-1})		Significance
	signal	background	for 3σ	for 5σ	for 100 fb^{-1}
$WW/WZ \to \ell\nu\, jj$, $m = 500$ GeV	0.31 ± 0.05	0.79 ± 0.26	85	235	3.3 ± 0.7
$WW/WZ \to \ell\nu\, jj$, $m = 800$ GeV	0.65 ± 0.04	0.87 ± 0.28	20	60	6.3 ± 0.9
$WW/WZ \to \ell\nu\, jj$, $m = 1.1$ TeV	0.24 ± 0.03	0.46 ± 0.25	85	230	3.3 ± 0.8
$W_{jj}Z_{\ell\ell}$, $m = 500$ GeV	0.28 ± 0.04	0.20 ± 0.18	30	90	5.3 ± 1.9
$W_{\ell\nu}Z_{\ell\ell}$, $m = 500$ GeV	0.40 ± 0.03	0.25 ± 0.03	20	55	6.6 ± 0.5
$W_{jj}Z_{\ell\ell}$, $m = 800$ GeV	0.24 ± 0.02	0.30 ± 0.22	60	160	3.9 ± 1.2
$W_{j}Z_{\ell\ell}$, $m = 800$ GeV	$0.27 \pm 0.02 \pm 0.05$	$0.23 \pm 0.07 \pm 0.05$	38	105	4.9 ± 1.1
$W_{j}Z_{\ell\ell}$, $m = 1.1$ TeV	$0.19 \pm 0.01 \pm 0.04$	$0.22 \pm 0.07 \pm 0.05$	68	191	3.6 ± 1.0
$W_{\ell\nu}Z_{\ell\ell}$, $m = 1.1$ TeV	0.070 ± 0.004	0.020 ± 0.009	70	200	3.6 ± 0.5
$Z_{\nu\nu}Z_{\ell\ell}$, $m = 500$ GeV	0.32 ± 0.02	0.15 ± 0.03	20	60	6.6 ± 0.6

W(qq)Z(ll)

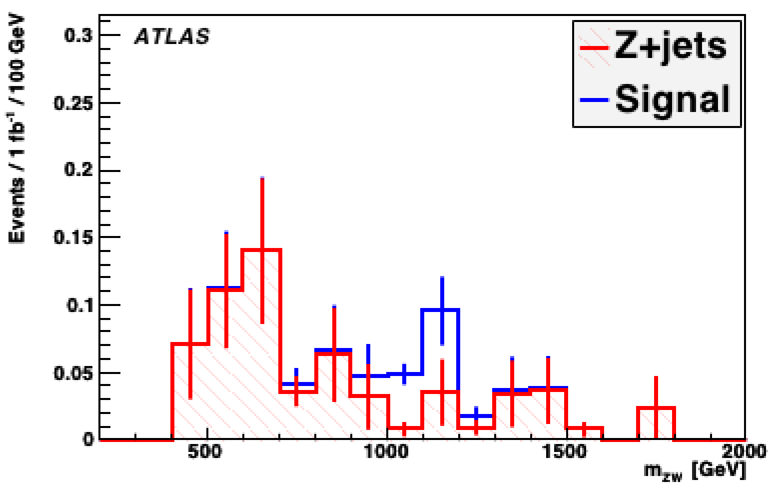
QCD-like 500 GeV



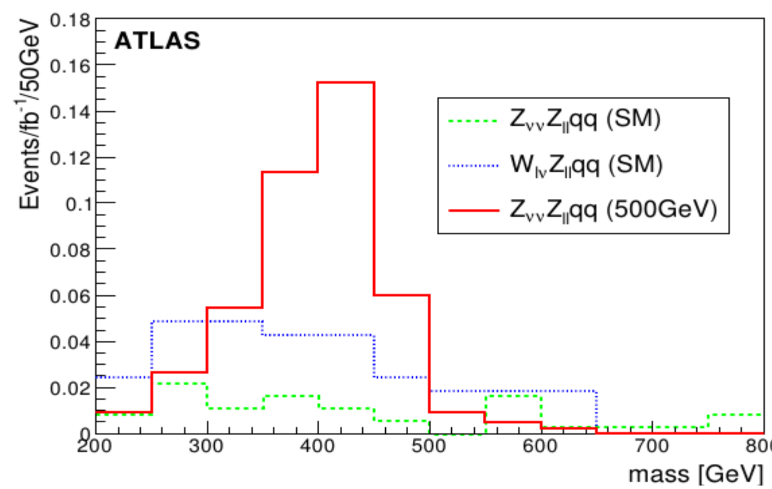
EWChL 800 GeV



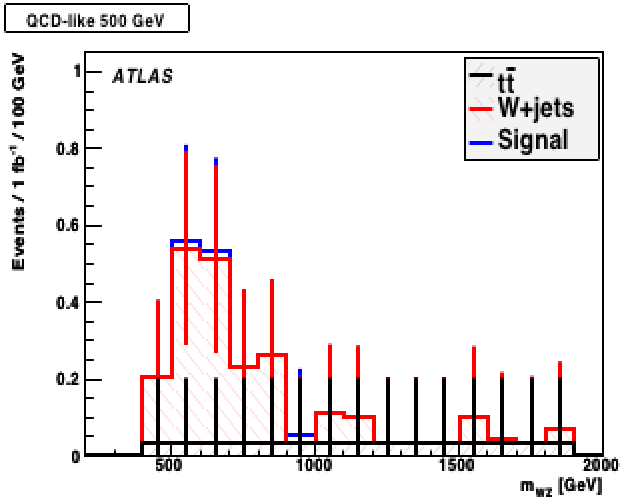
EWChL 1.1 TeV

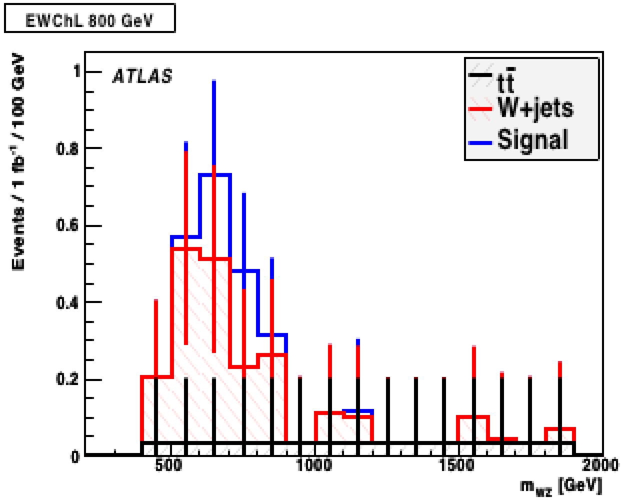


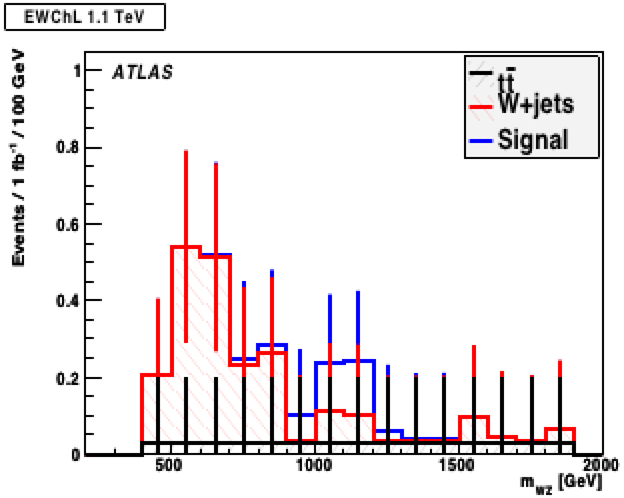
Resonance transverse mass



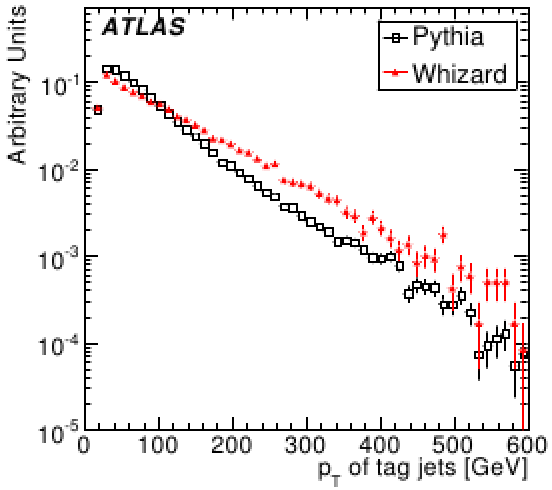
W(lν)Z(qq)


QCD-like 500 GeV
ATLAS
tt̄
W+jets
Signal
Events / 1 fb⁻¹ / 100 GeV
0
0.2
0.4
0.6
0.8
1
500
1000
1500
2000
m_WZ [GeV]

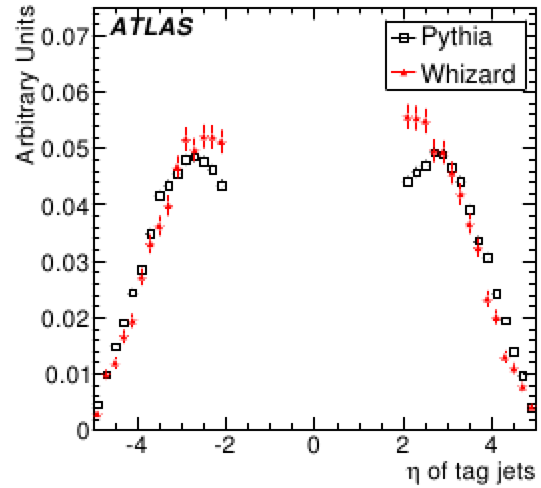

EWChL 800 GeV
ATLAS
tt̄
W+jets
Signal
Events / 1 fb⁻¹ / 100 GeV
0
0.2
0.4
0.6
0.8
1
500
1000
1500
2000
m_WZ [GeV]


EWChL 1.1 TeV
ATLAS
tt̄
W+jets
Signal
Events / 1 fb⁻¹ / 100 GeV
0
0.2
0.4
0.6
0.8
1
500
1000
1500
2000
m_WZ [GeV]

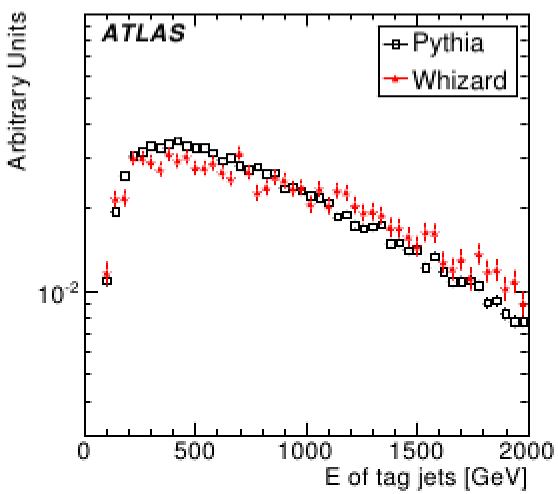
Pythia/Whizard comparison



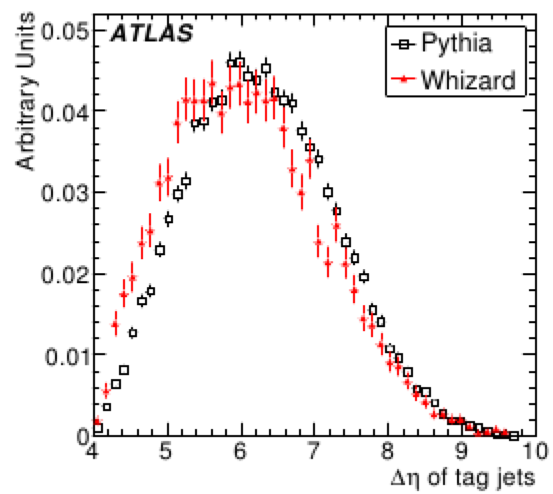
(a)



(b)



(c)



(d)

PHANTOM cross-sections (α_{EW}^6)

- **Two scenarios** have been compared
  - M_H = 500 GeV
  - no-Higgs ($M_H = \infty$)
- **after the signal definition**, the obtained cross sections are:

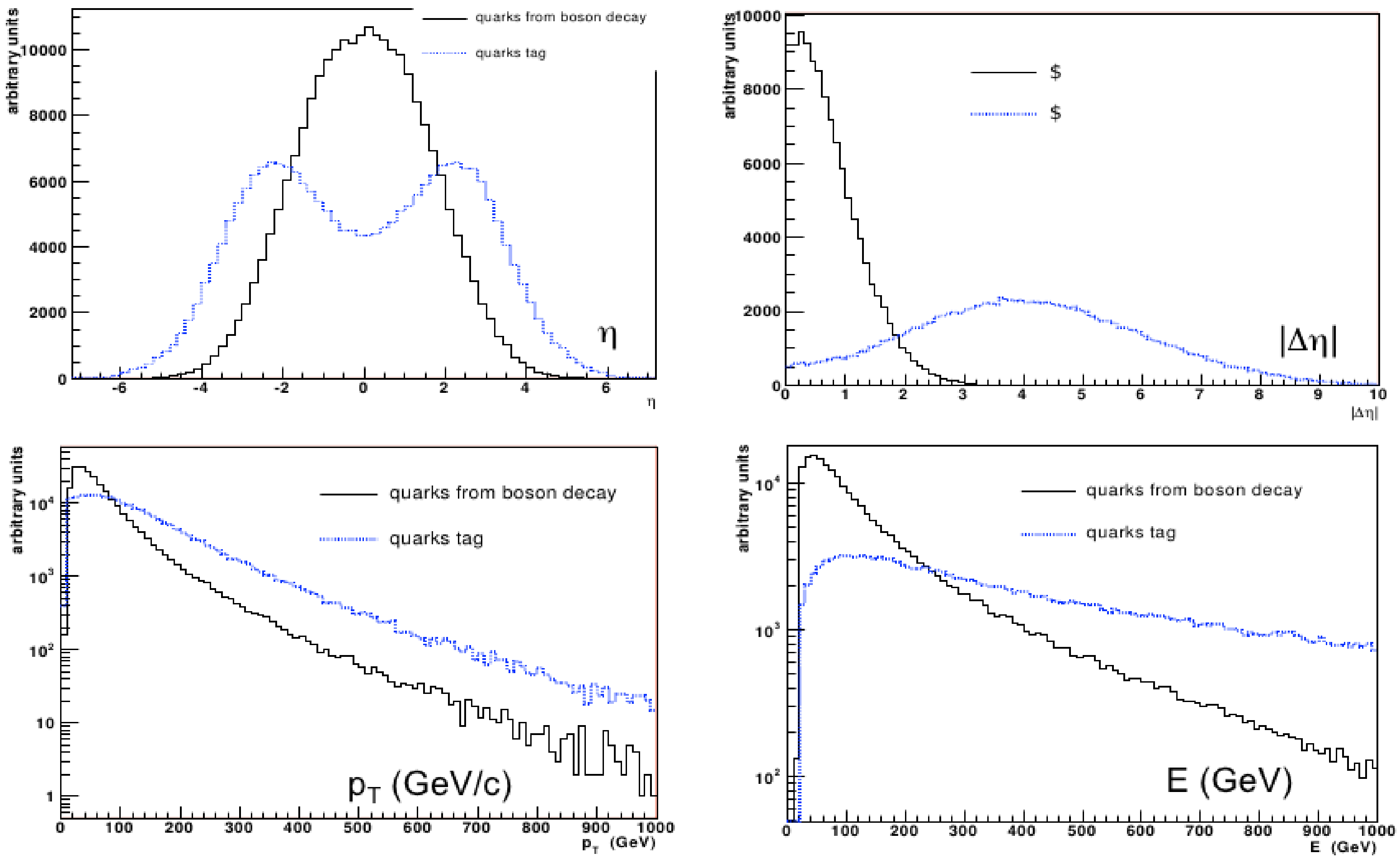
	$qqq\mu\nu/e\nu$				$qqq\mu\mu/ee$			
	no-Higgs		500 GeV		no-Higgs		500 GeV	
	σ (pb)	perc.	σ (pb)	perc.	σ (pb)	perc.	σ (pb)	perc.
total	0.689	100%	0.718	100%	0.0305	100%	0.0350	100%
signal	0.158	23%	0.184	26%	0.0125	41%	0.0165	47%
top	0.495	72%	0.494	69%	0.0137	45%	0.0137	39%
non resonant	0.020	3%	0.023	3%	0.0030	10%	0.0035	10%
three bosons	0.016	2%	0.017	2%	0.0012	4%	0.0014	4%

	$qq\mu\mu\mu\mu/eeee$				$qq\mu\mu\mu\nu$				$qq\mu^{\pm}\nu\mu^{\pm}\nu$			
	no-Higgs		500 GeV		no-Higgs		500 GeV		no-Higgs		500 GeV	
	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.
total	0.180	100%	0.310	100%	4.182	100%	4.152	100%	4.29	100%	4.16	100%
signal	0.120	66.4%	0.229	74.1%	1.317	31.5%	1.281	30.8%	3.26	76%	3.11	75%
top	0	0%	0	0%	1.817	43.5%	1.828	44.01%	0	0%	0	0%
non resonant	0.0364	20.2%	0.0533	17.2%	0.673	16.1%	0.651	15.7%	0.47	11%	0.46	11%
three bosons	0.0241	13.4%	0.0268	8.66%	0.375	8.9%	0.392	9.5%	0.56	13%	0.58	14%

- Cross sections for the analyzed final states vary of three orders of magnitude (0.1 → 100 fb)

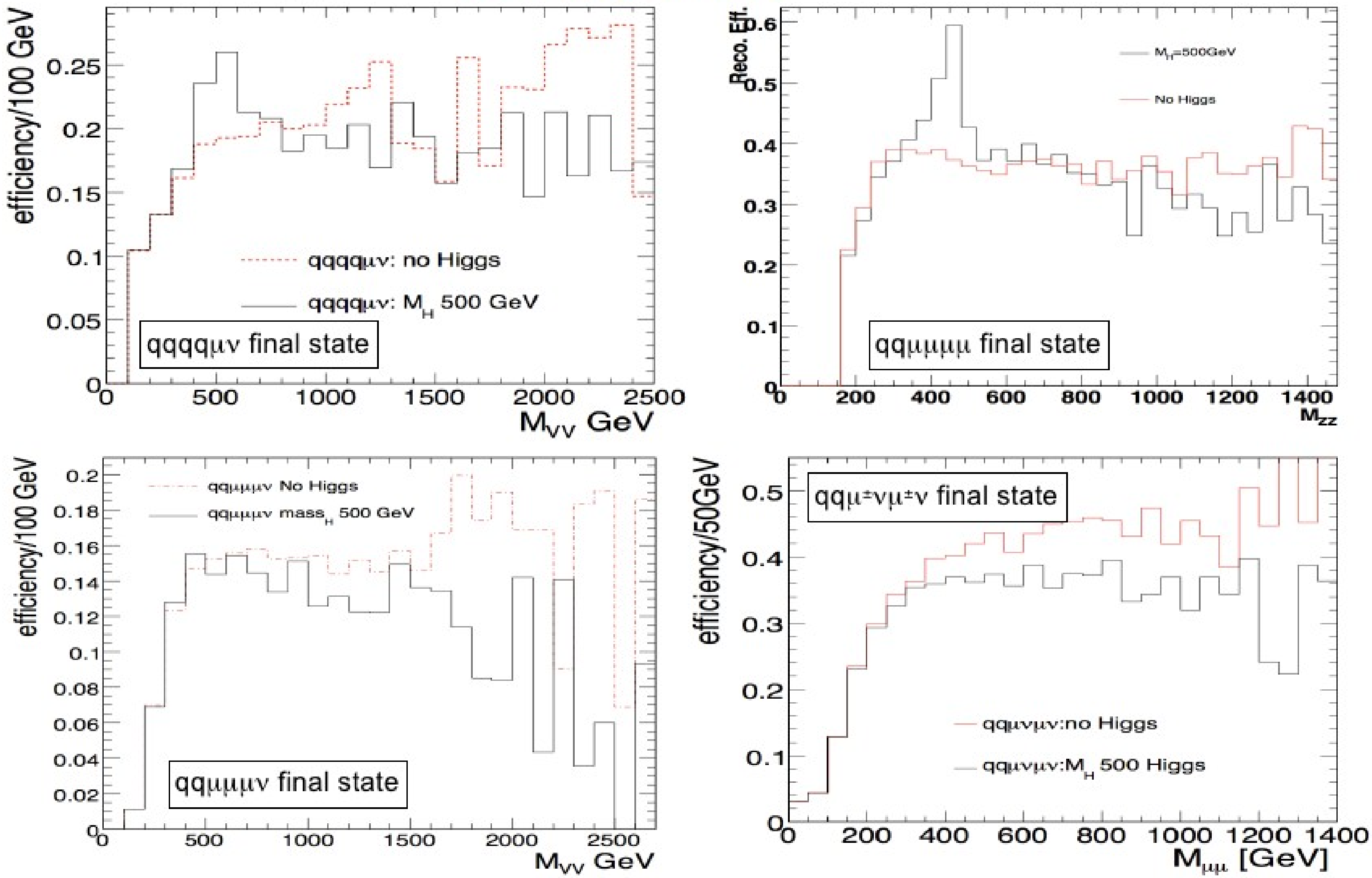
jets topology

- jets from the qqVZ (qqqqμμ) channel: **tag jets** and **V decay products**



selection efficiencies

- **selection efficiency** as a function of M_{VV}, for different channels
- **500 GeV Higgs** and **no Higgs cases**



Full CMS results (60 fb^{-1})

	$qqqq\mu\nu$	$qqqqe\nu$	$qqqq\mu\mu$	$qqqqee$	$qq\mu\mu\mu\mu$	$qqeeee$	$qq\mu\mu\mu\nu$	$qq\mu^{\pm}\nu\mu^{\pm}\nu$
signal	**111**	26	5	10	0.16	0.2	2.7	8.3
W + n jets	5570	166	-	-	-	-	-	0
Z + n jets	499	-	205	580	-	-	0	-
$t\bar{t}$	446	19	0	0	-	-	0	664
ZZ + n jets	-	-	10	17	0.3	0.2	0.02	110
ZW + n jets	-	-	139	93	-	-	2.21	20
WW + n jets	3094	-	-	-	-	-	-	37
irreducible backgrounds	47	3	1	1	0.009	0.001	0.09	1.3
backgrounds	9656	187	355	691	0.31	0.201	2.3	832
significance	1.13	1.87	0.28	0.38	0.27	0.39	1.51	0.29

no Higgs case

	$qqqq\mu\nu$	$qqqqe\nu$	$qqqq\mu\mu$	$qqqqee$	$qq\mu\mu\mu\mu$	$qqeeee$
signal	703	309	86	100	3.1	3.5
W + n jets	34840	1383	-	-	-	-
Z + n jets	3094	-	3798	4660	-	-
$t\bar{t}$	5976	609	30	14	0	-
ZZ + n jets	-	-	125	184	2.6	2.9
ZW + n jets	-	-	781	615	0	-
WW + n jets	16133	-	-	-	0	-
irreducible backgrounds	220	23	20	20	0.036	0.04
backgrounds	60263	2015	4754	5493	2.6	2.94
significance	2.86	6.72	1.24	1.34	1.66	1.76

Two different approaches for 4q$\mu\nu$ and 4qeν:
-high efficiency to study the high M_{VV} region
-high significance for a discovery

Higgs with m_H=500 GeV