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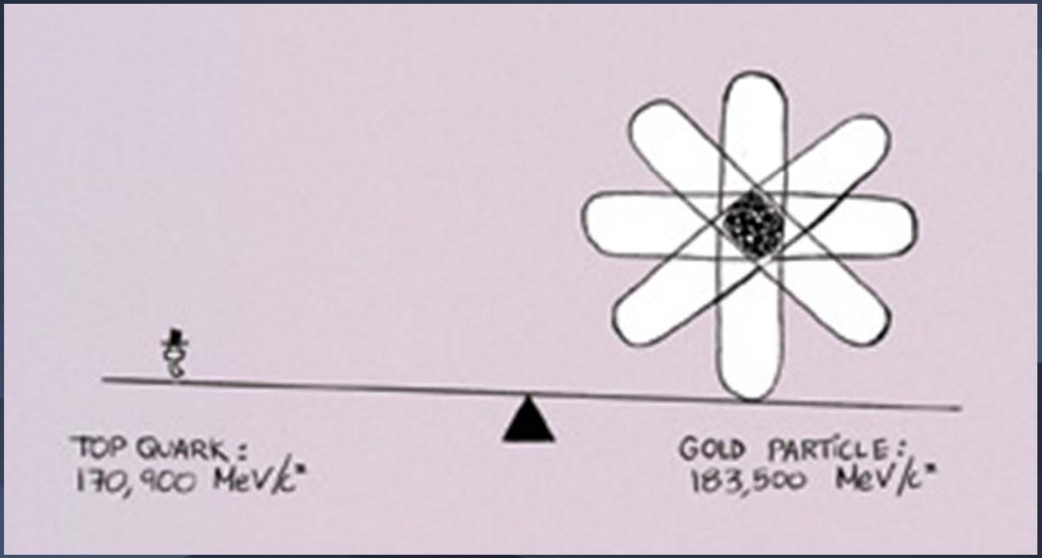
LCWS 2012 Summary: Higgs and top quark

IX Jornadas de Futuros Colisionadores
December 18-19, 2012

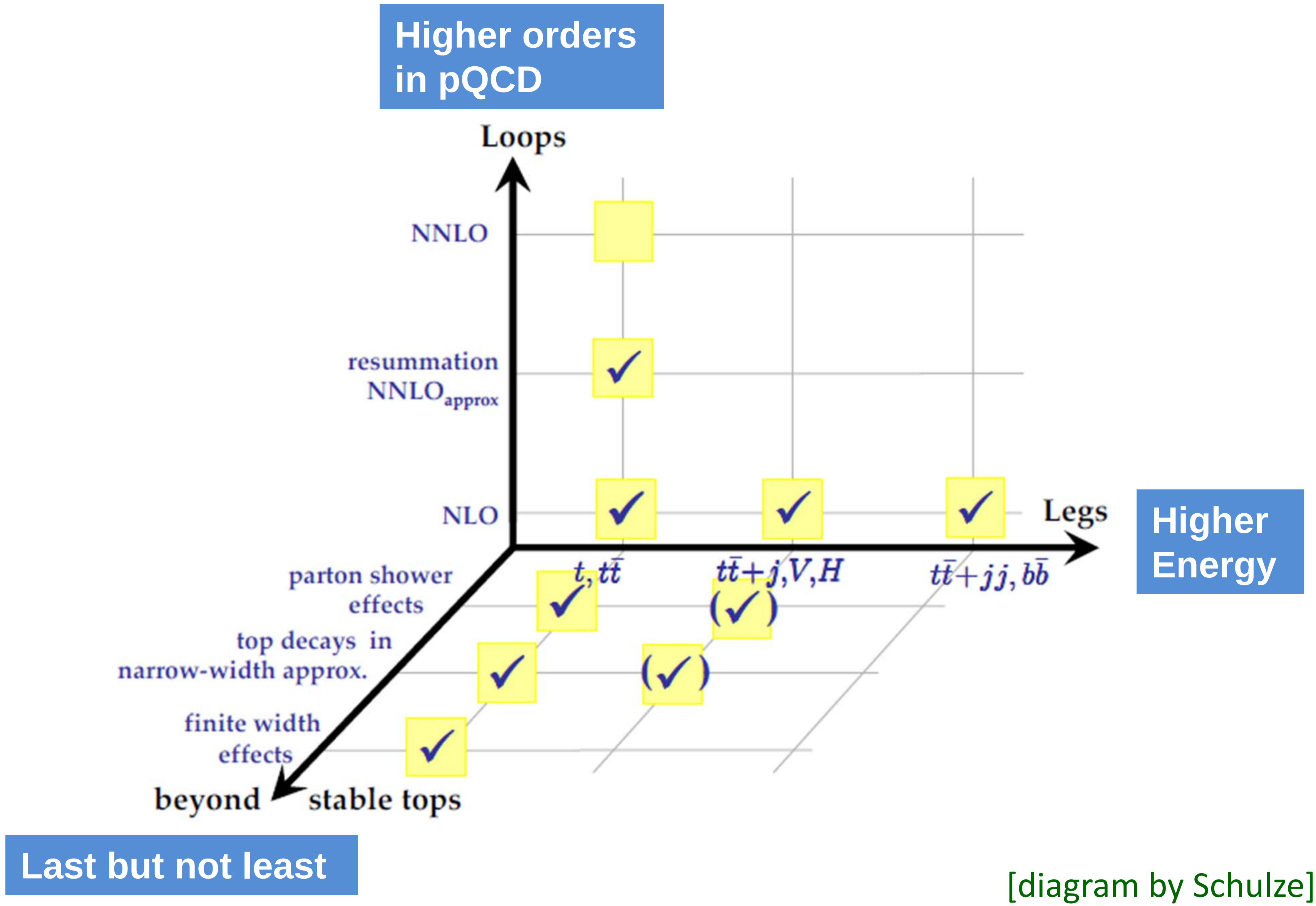
Seventh Framework Programme
Marie Curie Actions
LHCphenOnet

the god(damn) particle vs the gold(en) particle



- The heaviest known elementary particle
- Yukawa coupling to Higgs boson $y_t = \mathcal{O}(1)$: bridge to EWSB: Higgs and top strongly linked
- Special role in many BSM: a window to new physics that couples preferentially to top quarks

driving directions to precision in theory



[diagram by Schulze]

the NLO revolution

- 10 years ago 2→3 processes were at the border line
- With the development of **on-shell methods** based on analyticity/unitarity, which are a much more efficient than Feynman diagrams, today 2→4 (and even 2→5) have become state-of-the art
- Many contributors, and many new results ready for LHC phenomenology
- **Automated theoretical tools** @ NLO: BlackHat+Sherpa, aMC@NLO (CutTools, MadLoop, HELAC-NLO), Rocket, SAMURAI, NGluon
- Give also new insight into **structure and properties** of scattering amplitudes, not only in QCD

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- **NLO revolution driven by LHC:** higher order corrections in QCD at hadron colliders is not only a question of improving systematically the precision of theoretical predictions, but

NLO is the first reliable estimate of **central value**

the upcoming NNLO revolution

- **NNLO** at hadron colliders **(+ EW** corrections at NLO) is the first serious estimate of the theoretical error
- A very few NNLO results: e.g. e^+e^- →3jets (determination of α_S), $pp \to \gamma\gamma$ (main background to Higgs [Catani et al.]), $q\bar{q} \to t\bar{t}$ [Baernreuther, Czazon, Mitov]
- On-shell methods at two-loops and beyond [Catani et al., Mastrolia, Ossola, Kosower, Gluza, …] still at infancy phase

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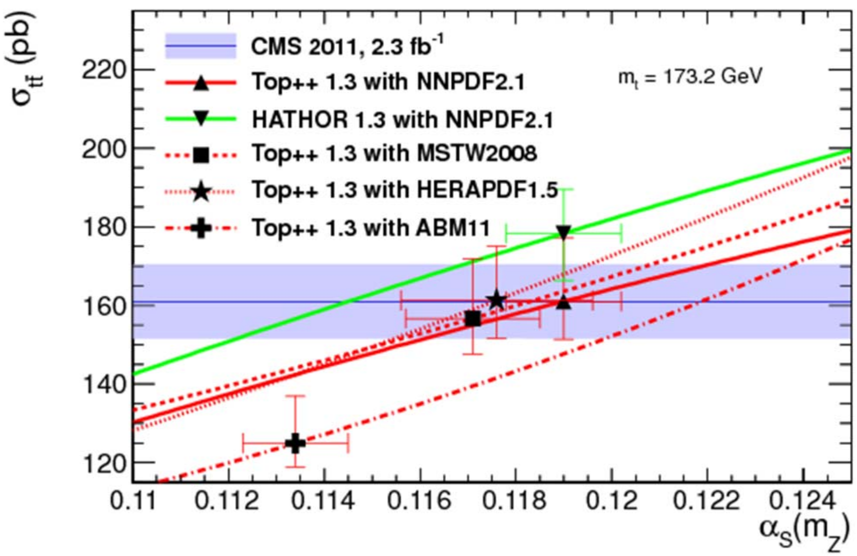
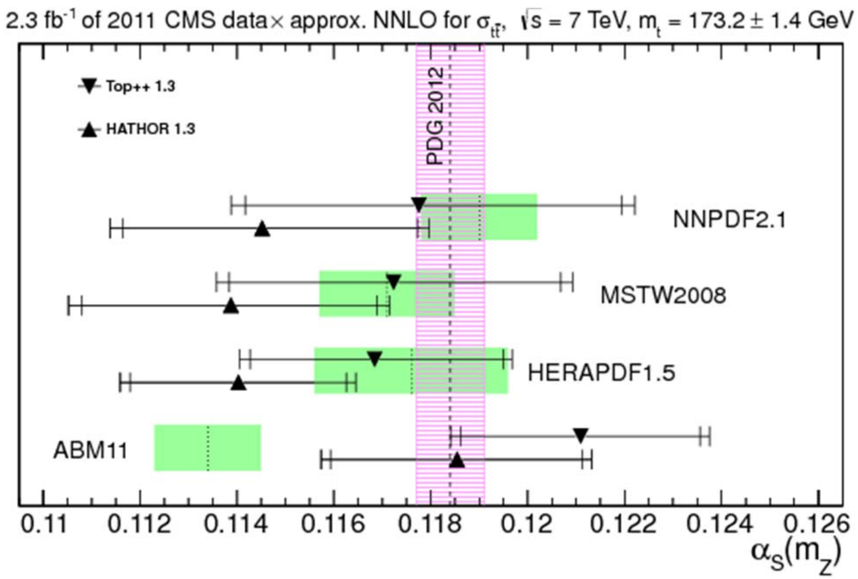
Teenager when

LC will be running

the top quark entering the precision era

- Close to use cross-section for determination of PDFs and/or αs [Huston]





CMS PAS TOP-12-022

$\alpha_S(m_Z) = 0.1178 \pm 0.0046 \pm 0.0040$ consistent with world average, although not competitive yet as a measurement

boosted tops / boosted W/Z/H

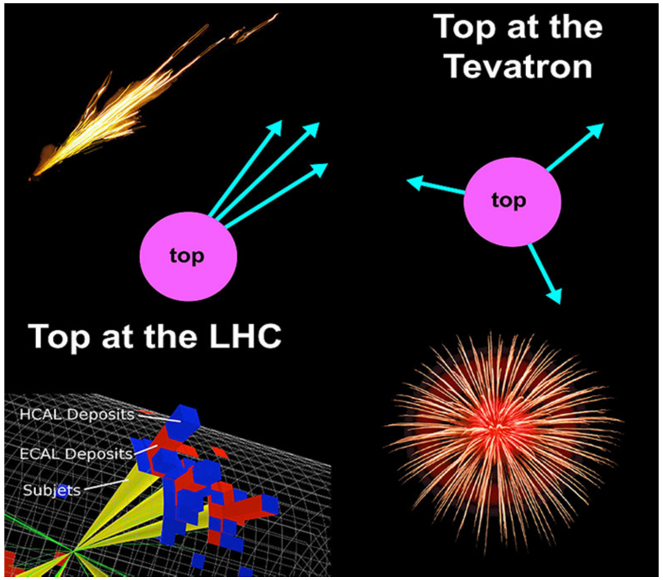
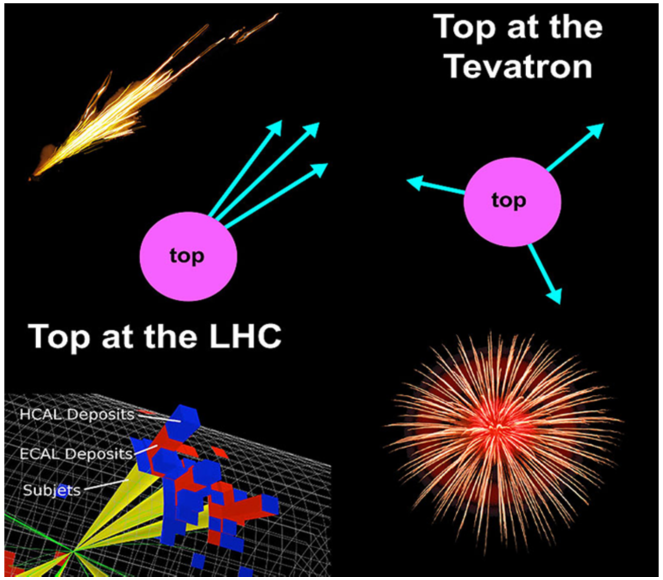


Image from Fermilab Today

- Boosted tops / objects fake QCD jets
- Look into substructure of fat jets
- Boosted Higgs to kill background in $b\bar{b}$ decay channel [Butterworth et al. 2008]
- Several boost taggers focus on $p_T > 500$ GeV, but moderately boosted tops $p_T > 200$ GeV also interesting [Takeuchi]

boosted tops / boosted W/Z/H



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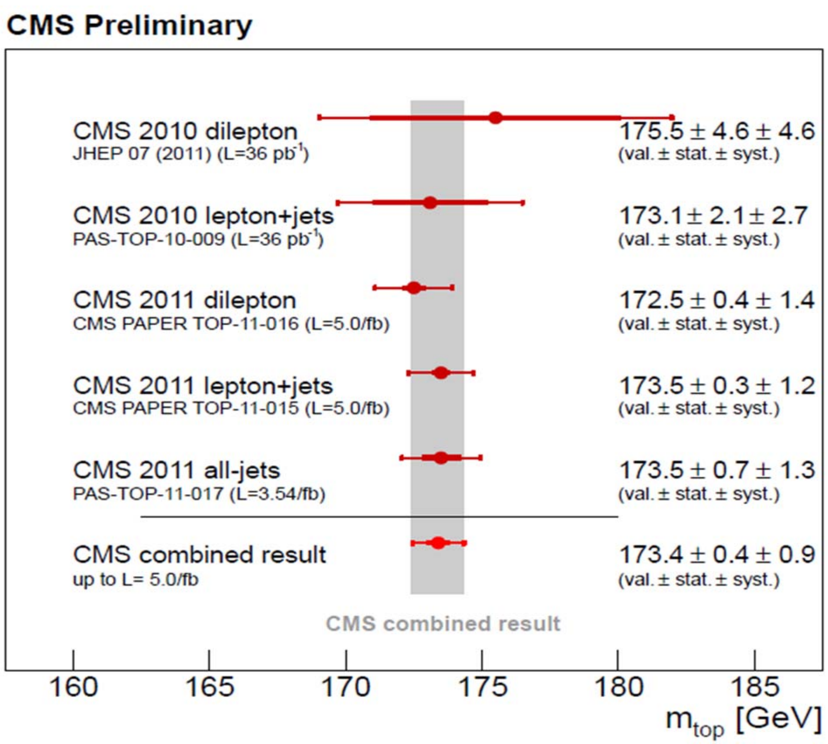
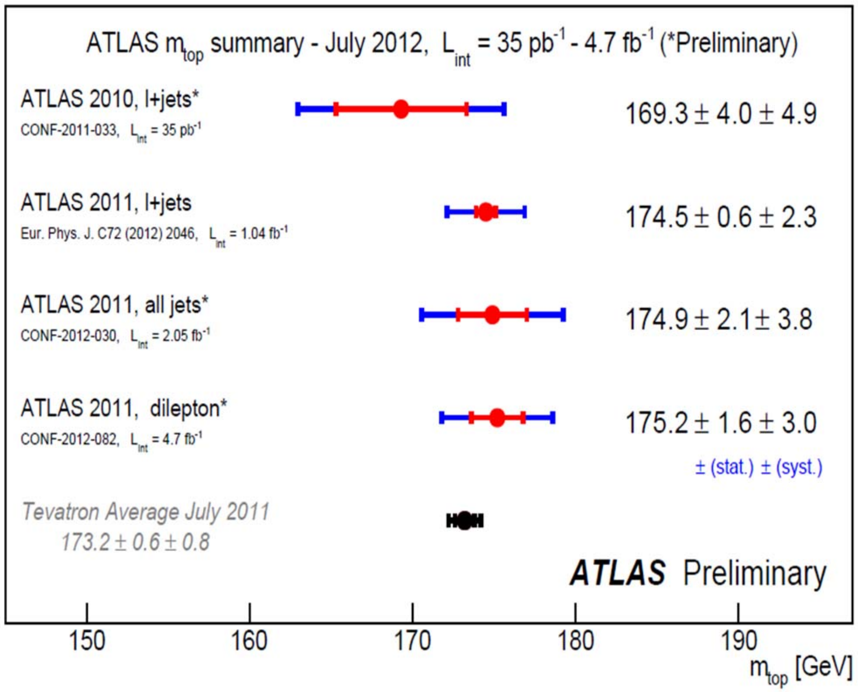
- Not enough boosted tops ($p_T > 150$ GeV) at a low energy LC
- But substructure methods for W/Z/H would be still possible [Takeuchi]

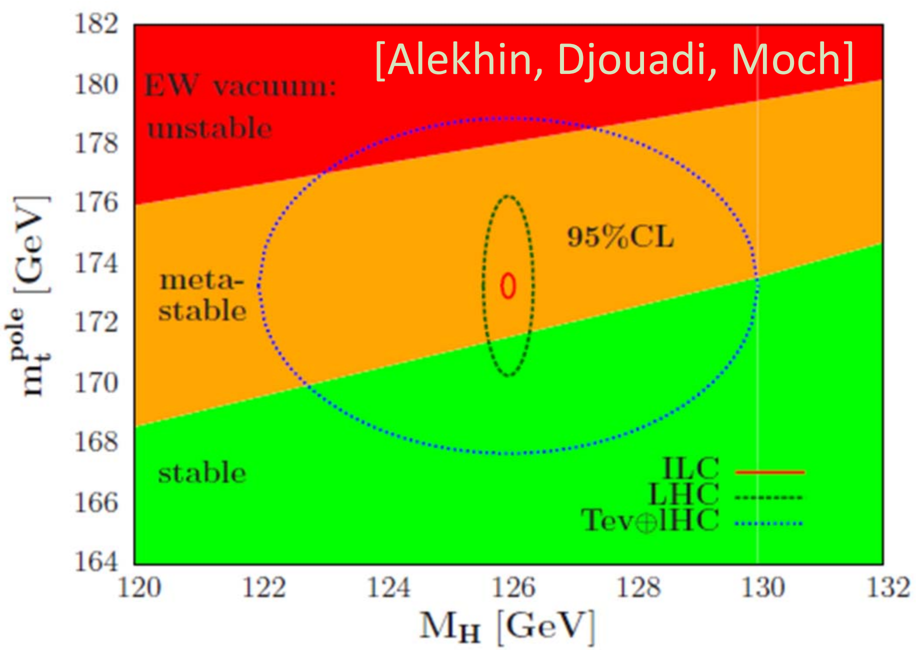
Top quark mass





stability of the EW vacuum

- Could one extrapolate the SM to higher scales while keeping the minimum of the scalar potential ? quartic Higgs coupling $\lambda_H(M_P) \geq 0$



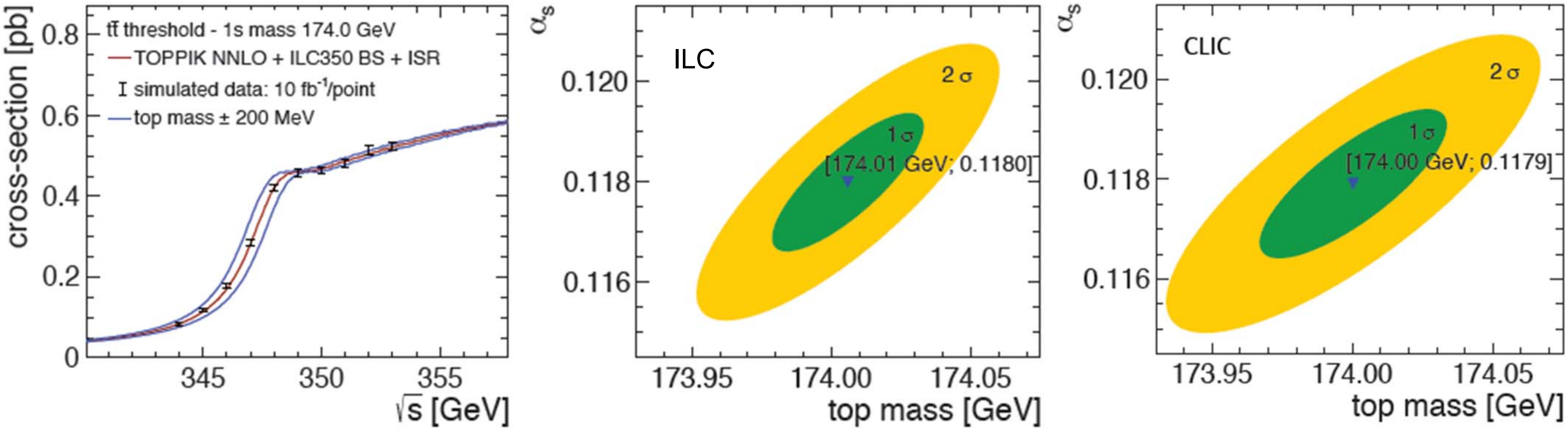
Critically depends on:

- The **Higgs boson mass**
- The **strong coupling**
- The **mass of the top quark**: value, MonteCarlo/pole/running mass, higher order QCD corrections

- Current values cover all possibilities within 2σ
- A precise assessment can only be made at the LC if $\Delta m_t{}^{pole} \approx 200\text{MeV}$ (by threshold scan), and order of magnitude better than LHC - Tevatron

top quark mass and α_S from energy scan and invariant mass

[Simon]



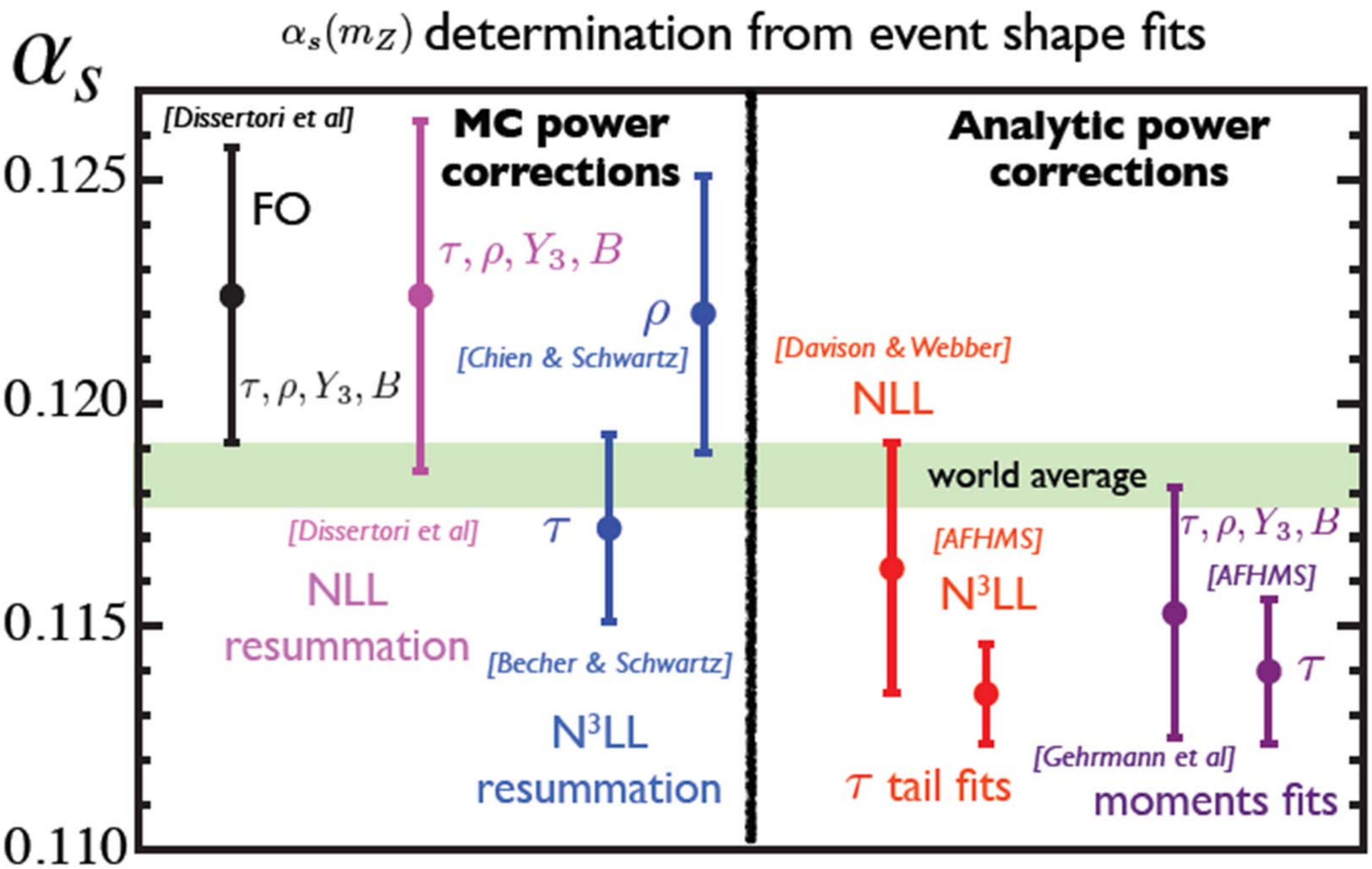
- CLIC above threshold (500 GeV) by reconstructing the **invariant mass**: **80 MeV** statistical precision with 100 fb^{-1}
- **Threshold scan** around 350 GeV at CLIC by fitting the 1S mass and αs: **34 MeV** statistical precision of the mass, **0.0009** statistical precision of αs with 100 fb^{-1} split across 10 equally spaced scan points
- 15% better at ILC due to different luminosity spectrum (threshold scan, invariant mass) and higher background (invariant mass)

[see Ruiz-Femenia´s talk]

[Mateu]

α_s determination: compendium

Only consider analysis with 3-loop input

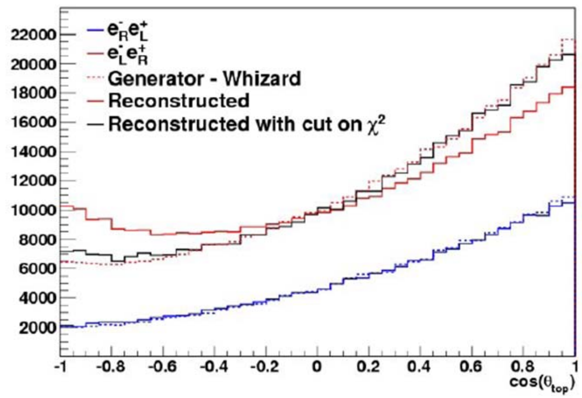


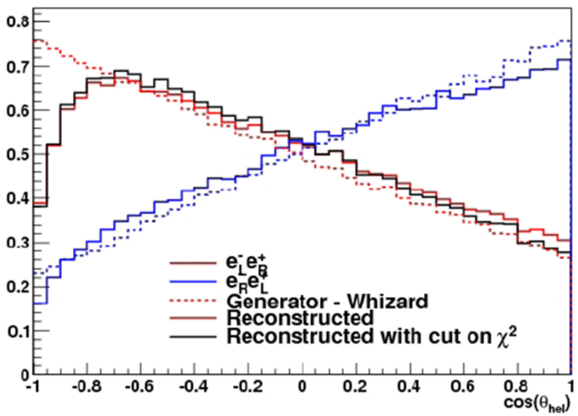
Negligible power corrections at ILC-CLIC energies

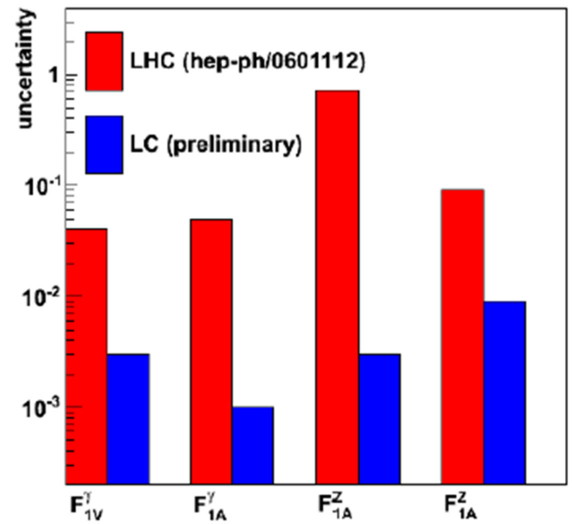
Top quark Couplings

$t\bar{t}Z$ and $t\bar{t}\gamma$ anomalous couplings

[Vos, Rouëné, see N. García´s talk]



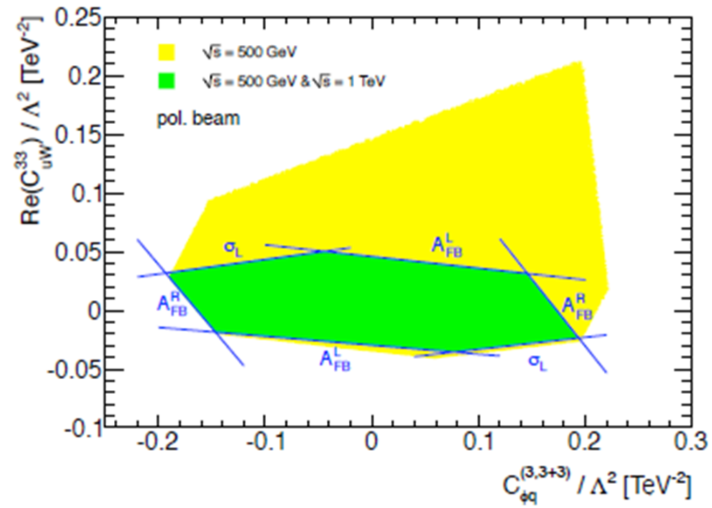




- Three observables (x 2 polarizations) to disentangle $t\bar{t}Z$ from $t\bar{t}\gamma$ couplings: cross-section, A_{FB} and helicity angle

- Effective operator framework allows to relate anomalous couplings in charge currents at LHC with $t\bar{t}Z$ and $t\bar{t}\gamma$ couplings at LC: from polazired observables

[Fiolhais]



Higgs Couplings

- Coupling with weak bosons: HZZ, HWW

consistency of EWSB

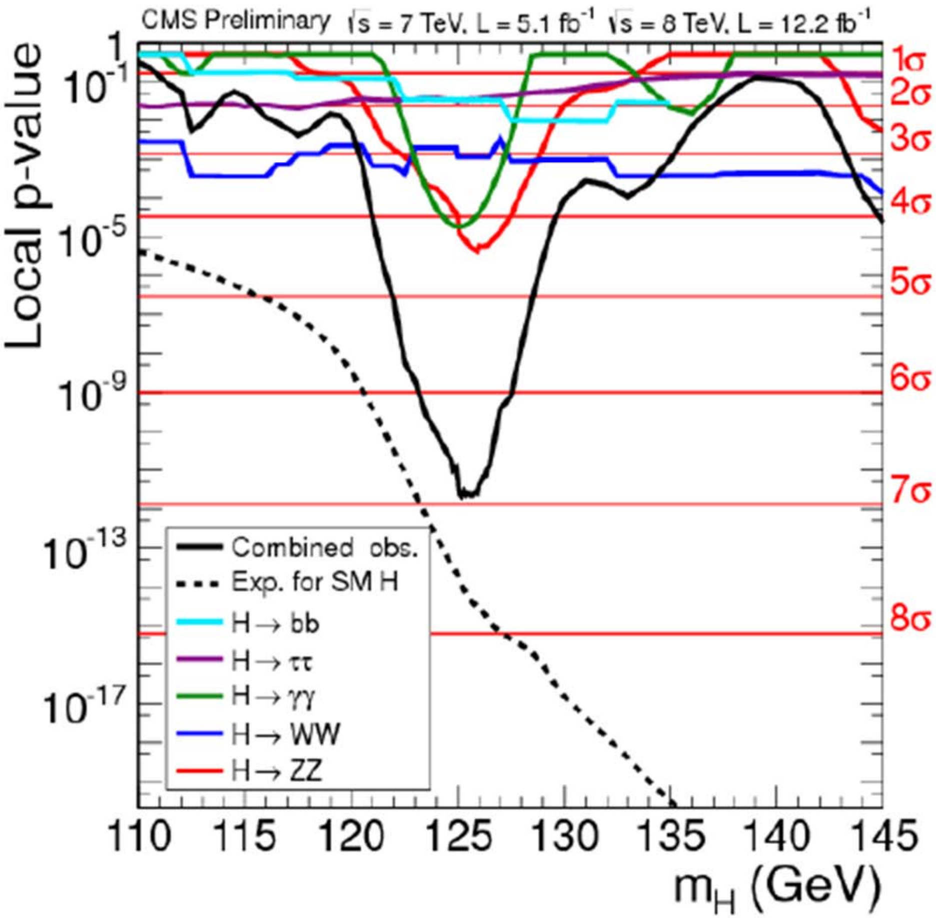
- Yukawa couplings: $Ht\bar{t}, Hb\bar{b}, H\tau\bar{\tau}, Hc\bar{c}, H\mu\bar{\mu}$

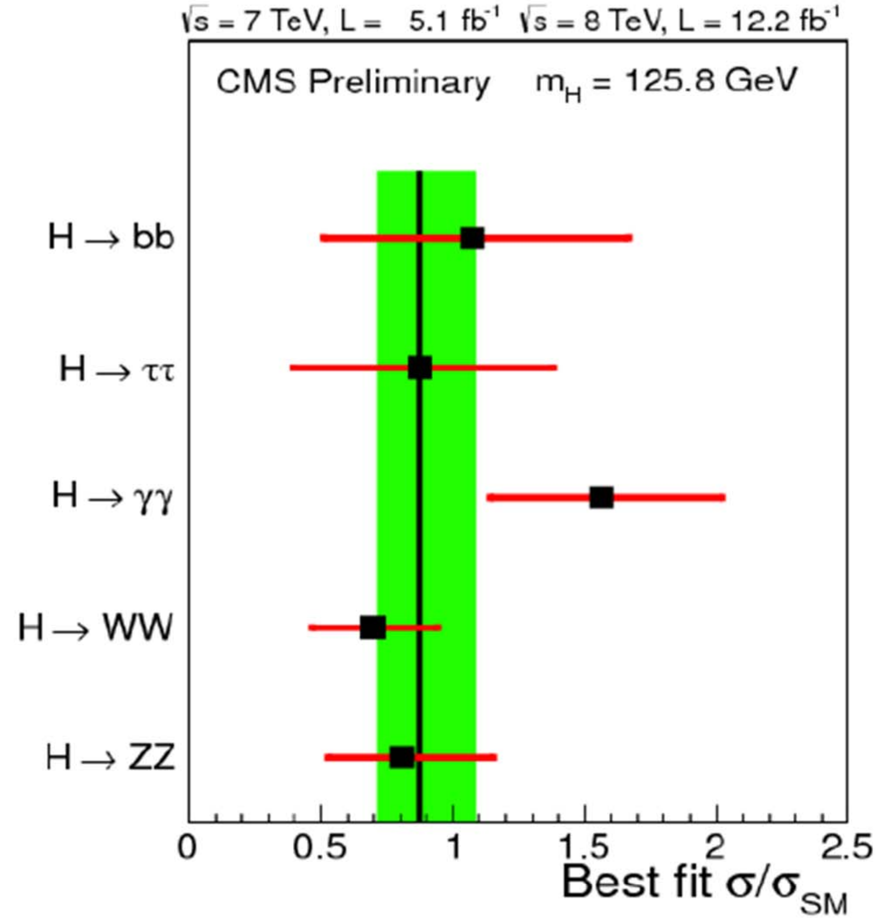
sensitive to mixing with extra Higgses

- Loop induced couplings: $H\gamma\gamma, Hgg, (HHH)$

sensitive to loop effects of top quark and new particles

Combination of Higgs Results



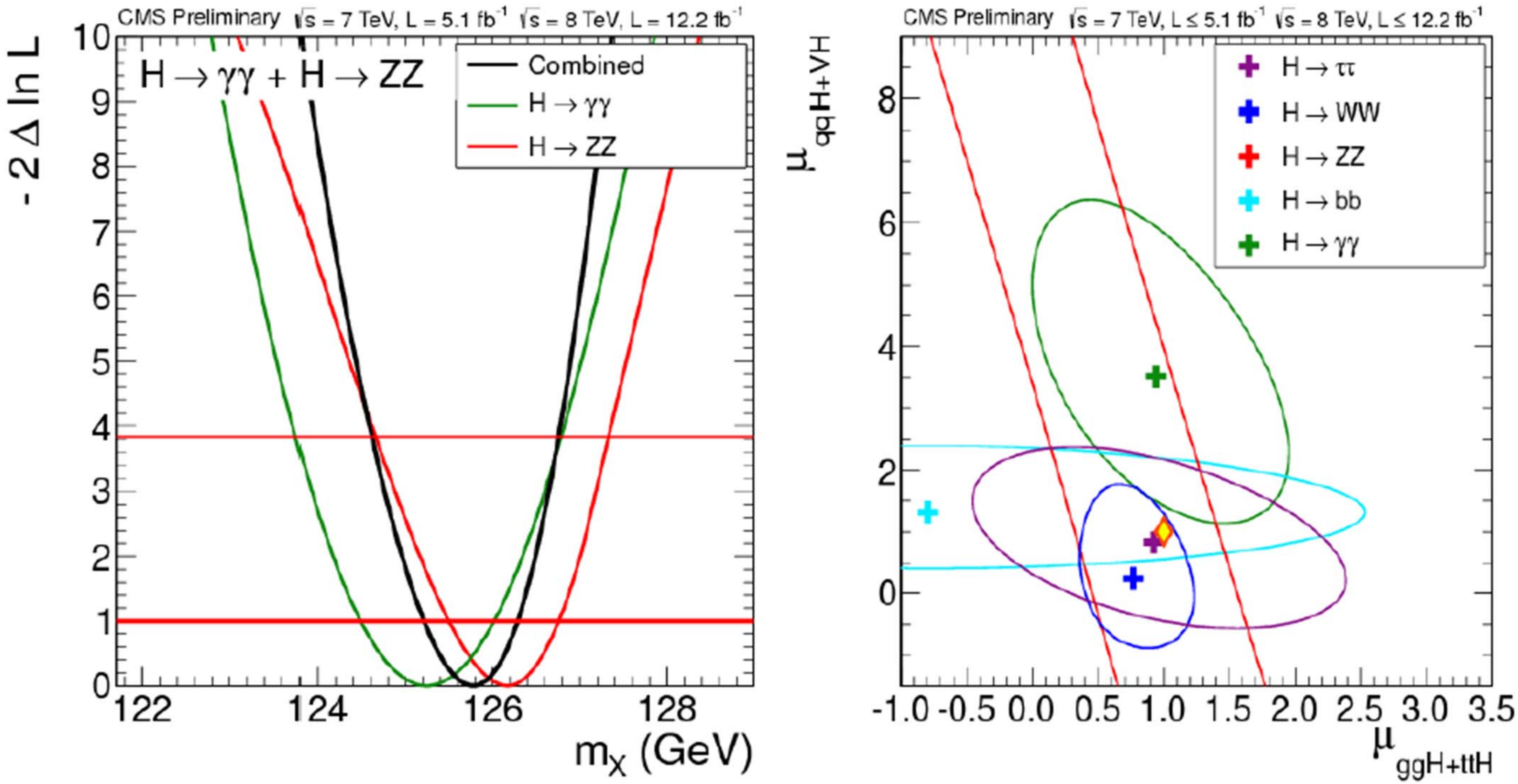


Overall significance and signal strength

– observed: 6.9; expected: 7.8 [signal strength: 0.88 ± 0.21]

[Paus @ HCP12 Kyoto]

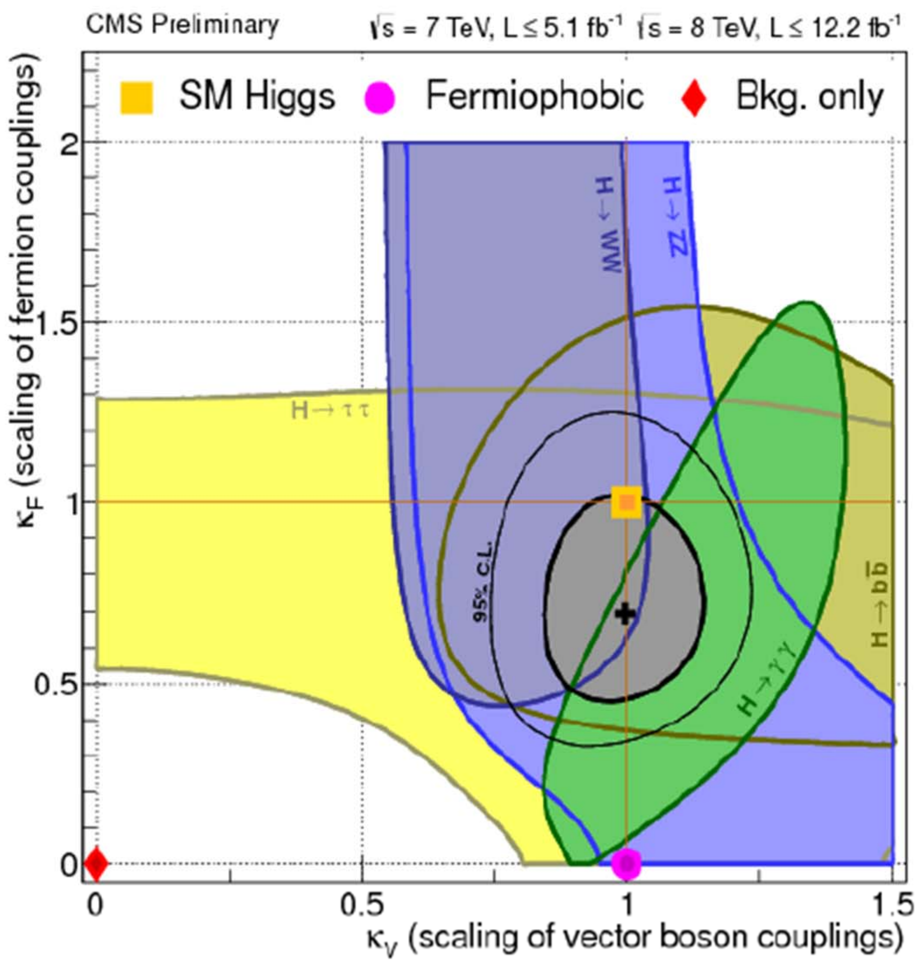
Combination of Higgs Results

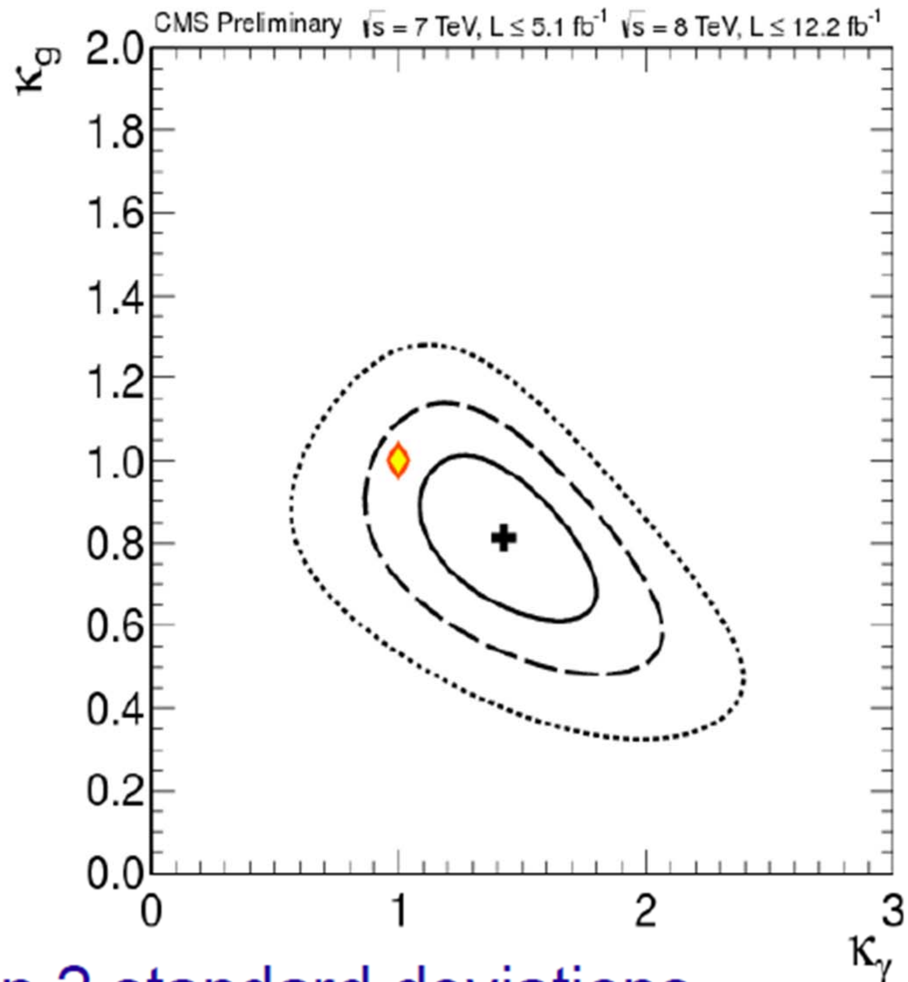


Mass measurement and production strength

- m_X = 125.8 ± 0.4(stat) ± 0.4 (syst) GeV
- Signal strengths consistent with each other and with SM

Combination of Higgs Results



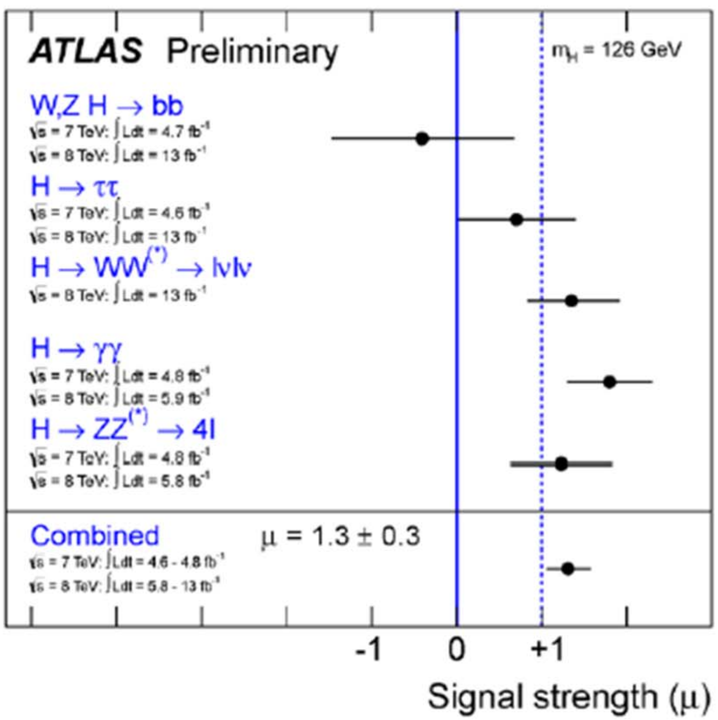


Couplings look consistent within 2 standard deviations

- Fermions versus vector bosons
- effective gluon versus photon couplings (loops)

SM Higgs Couplings

- Simplest analysis is to compute the combined signal strength μ, based on all available inputs.
- ATLAS has updated this combination using the three new results shown in this talk:



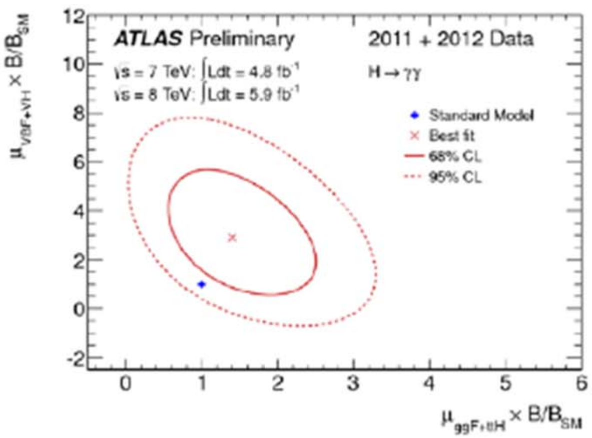
- Previous result in July paper, using 2011 analyses of ττ and bb, July analyses for γγ, 4-lepton, and WW, gave μ = 1.4 ± 0.3
- New result is μ = 1.3 ± 0.3
- Assuming a common μ for all measurements, compatibility is 36%.
- Compatibility with SM μ=1 with observed measurement is 23%.

ATLAS-CONF-2012-162

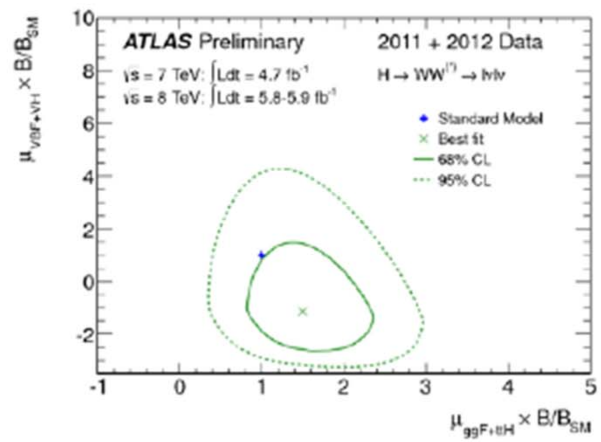
[Einsweitler @ HCP12 Kyoto]

SM Higgs Couplings

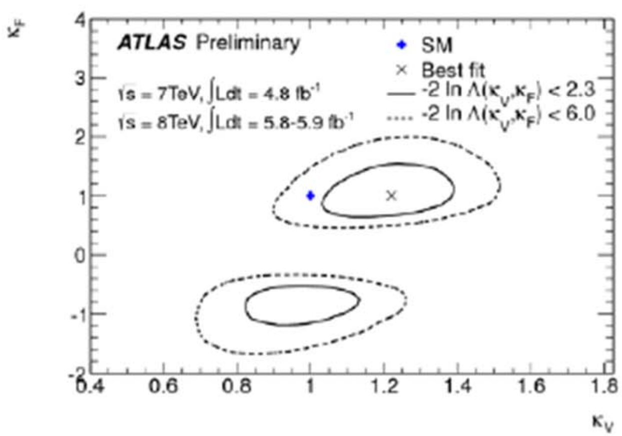
- ATLAS has performed a coupling analysis, using the recommended framework from the Higgs XSWG, based on effective field theory approach. arXiv 1209.0040
- This analysis was based on the data in the "Higgs Observation" paper, and has not yet been updated for HCP (only the signal strength plot was updated).



Signal strength fits for the $\gamma\gamma$ final state (left) and the WW final state (right).



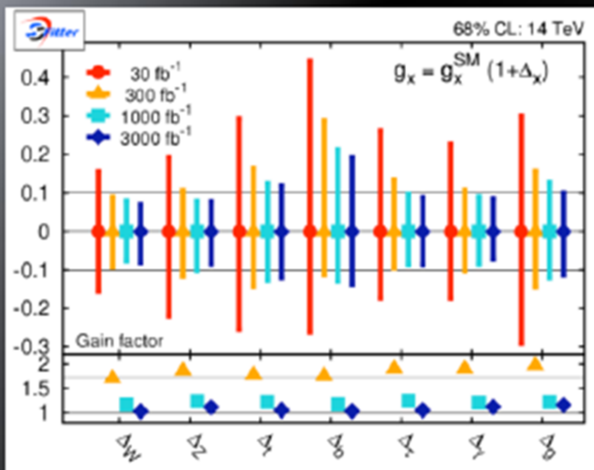
ATLAS-CONF-2012-127



- Fit for κ_V versus κ_F, assuming there is a single coupling for all fermions t, b, τ (κ_F) and a single coupling for vector bosons (κ_V).
- Sign comes from interference between t and W loops in $\gamma\gamma$ process.

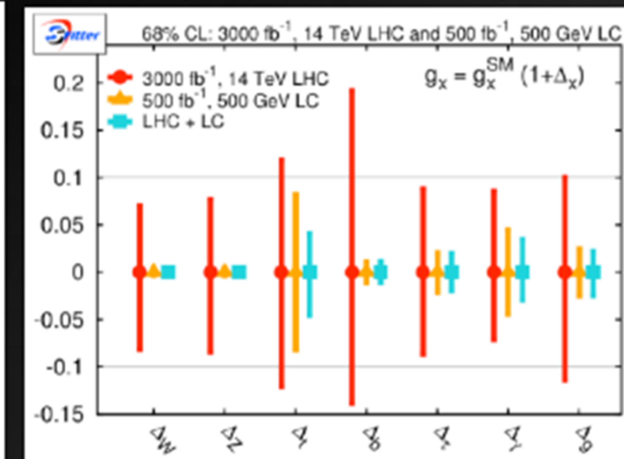
visualize the improvement of ILC over LHC

LHC (30/300/1000/3000 fb^{-1})



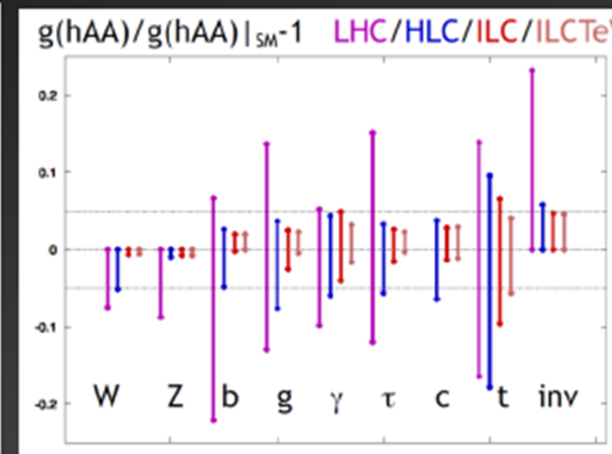
[D. Zerwas]

LHC (3000 fb^{-1}) and LC(500GeV/500fb^{-1})



[D. Zerwas]

LHC (3000 fb^{-1}) and LC(HLC/ILC/ILCTeV)



[M. Peskin]

At LHC, coupling determination starts limited by systematics for 300 fb^{-1}
⇒
No drastic improvement at 3000fb^{-1} ?

LC can measure independently
X-sections $\sigma(e^+e^- \to Zh)$ (250GeV)
$\sigma(e^+e^- \to \nu\nu h)$ (350-500GeV)
$\sigma(e^+e^- \to \nu\nu h)$ (700GeV-TeV)
Branching ratios
Invisible and unexpected *h* decays
hcc, hττ, hhh, htt, hγγ

ILC can measure the Higgs couplings acculately! ⇒ Use to test new physics

Summary

- The **Tevatron**, where the top quark was discovered, provided many precision measurements of the top quark (some anomalies persist, FB/charge asymmetries, single top)
- The **LHC** where the Higgs-like boson was discovered, brings top quark physics to a new level of precision, rapidly improving many Tevatron results, and can measure Higgs couplings to O(10-20%)
- Higher precision on the strong coupling, cross-sections, top quark mass and width (<100MeV / 30MeV), Higgs mass and width (<50MeV / 4%), anomalous top-gauge boson couplings (<1%) and top Yukawa coupling (~5%) other (~1%) reachable at a future **Linear Collider**

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- **Is that enough for new discoveries ?**

Few percent Needed

- Decoupling limit - deviations from SM could be quite small - Haber arxiv:9501320

- SUSY

$$g(\tau)/SM = 1 + 10\% \left(\frac{400\ \text{GeV}}{m_A}\right)^2$$

$$g(b)/SM = g(\tau)/SM + (1-3)\%$$

- Little Higgs

$$g(g)/SM = 1 + (5-9)\%$$

$$g(\gamma)/SM = 1 + (5-6)\%$$

- Composite Higgs

$$g(f)/SM = 1 + (3-9)\% \cdot \left(\frac{1\ \text{TeV}}{f}\right)^2$$

Peskin arxiv:1208.5152