What Next: Standard Model Group

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Disclaimer:

- This is not a review talk
- This is not a politically correct talk

What is SM Physics

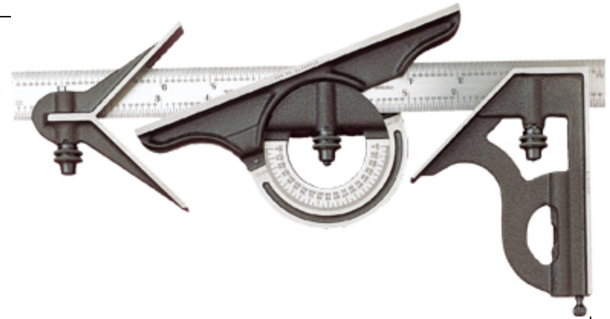
- SM is not theorem proving software or prediction of astronomical positions by classical Ptolemaic epicycles.
- **The SM is our current theory of fundamental interactions.**
  - It is a renormalizable theory so in principle it can be true at all scales.
- However
  - **Exp** It does not explain everything, e.g. Dark Matter
  - **Theo** at sufficiently high energy one hits Landau poles (coupling's divergence)
  - **Exp/Theo** at the Planck scale something must happen in order to accommodate gravity
- These are not necessarily all problems, and not all serious: e.g. gravity may come in before one hits the Landau pole. <u>But</u>

<u>something must happen Beyond the SM !</u>

WG SM

What are SM Physicists up to

- SM physics is the **study** of the theory of **fundamental interactions starting from its known end**: known particles, their interactions and their possible interplay with what we don't know yet.
- SM is the triumph of thinking simple but to love SM is to not always agree with SM: it is usually right, but not always right
  - The aim of SM physicists is not to stare at beautiful data/MC agreement, but to find a robust indication of discrepancy in a coherent picture !
- **exploration of the TeV scale is still in a preliminary stage and one should diversify strategies and motivations for the future**



What is Precision

No precision for precision's sake! It has to be precision for a discovery search

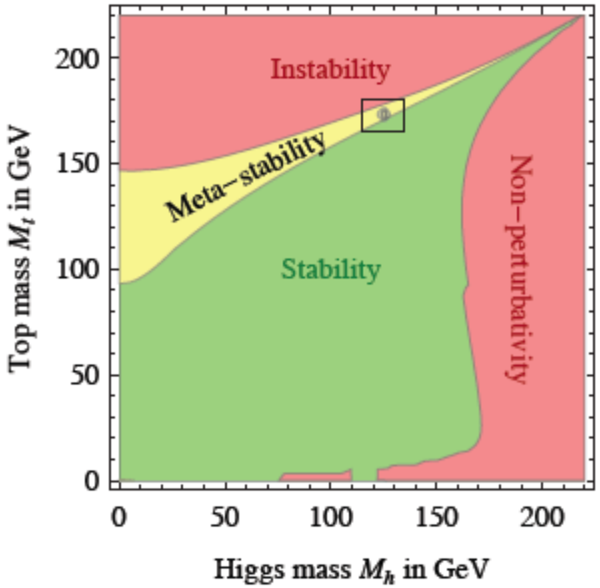
- **Discovery** no luck till now, but still plausible that new physics wait for us just beyond the TeV scale (**if we just miss it at LHC, which measurements are useful to better determine the scale ?**)
- **Discovery/Precision** the exploration of the Higgs sector of the theory has just started, very basic properties are unknown or poorly known (width, couplings to 2nd generation, coupling to top)
- **Precision** Some sectors of the theory are fairly known, **determine where more accurate knowledge is needed in order to confront with experiment**

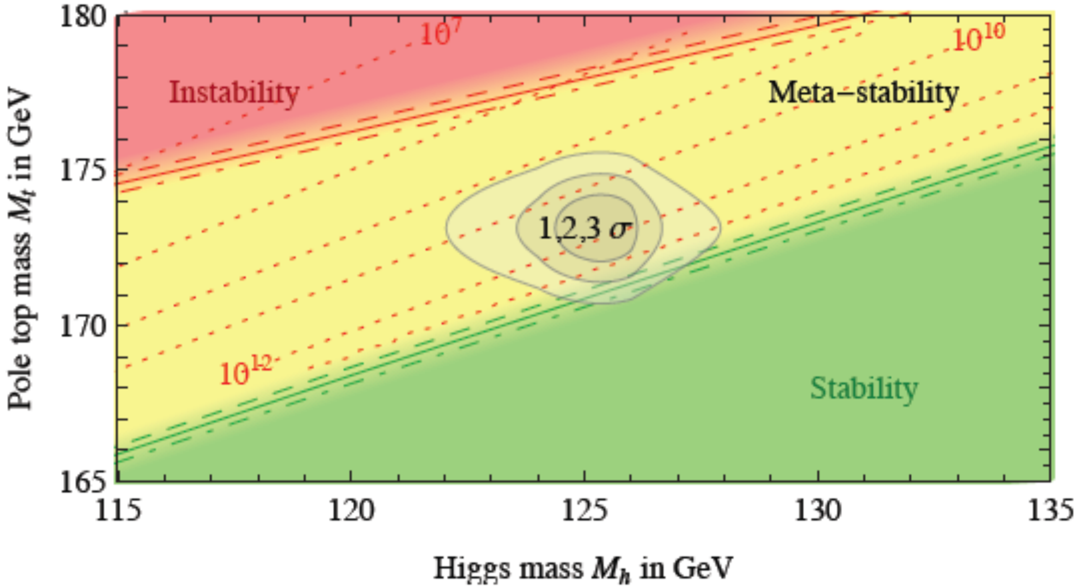
Precision: an example

- In the absence of New Physics the LHC-boson makes the universe metastable at a scale of $\approx 10^{10\text{-}12}$ GeV
- Quintessential Precision: we find ourselves in a just-so situation, the vacuum is at the verge or being stable or metastable.
  - **A sub-percent change of $\approx$ 1 GeV in either top or higgs mass is all it takes to tip the scales.**
- Ingredients of Precision discussion:
  1. **Precise calculations (2-loop/3-loop NNLO in this example)**
  2. **Precise measurements (top and Higgs mass at subpercent)**
  3. **Accurate interpretation of the measurements**

Relation between top and Higgs masses and stability of the vacuum in our universe

Electroweak Vacuum $\Rightarrow$ $V = \frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\Lambda(scale)\Phi^4$

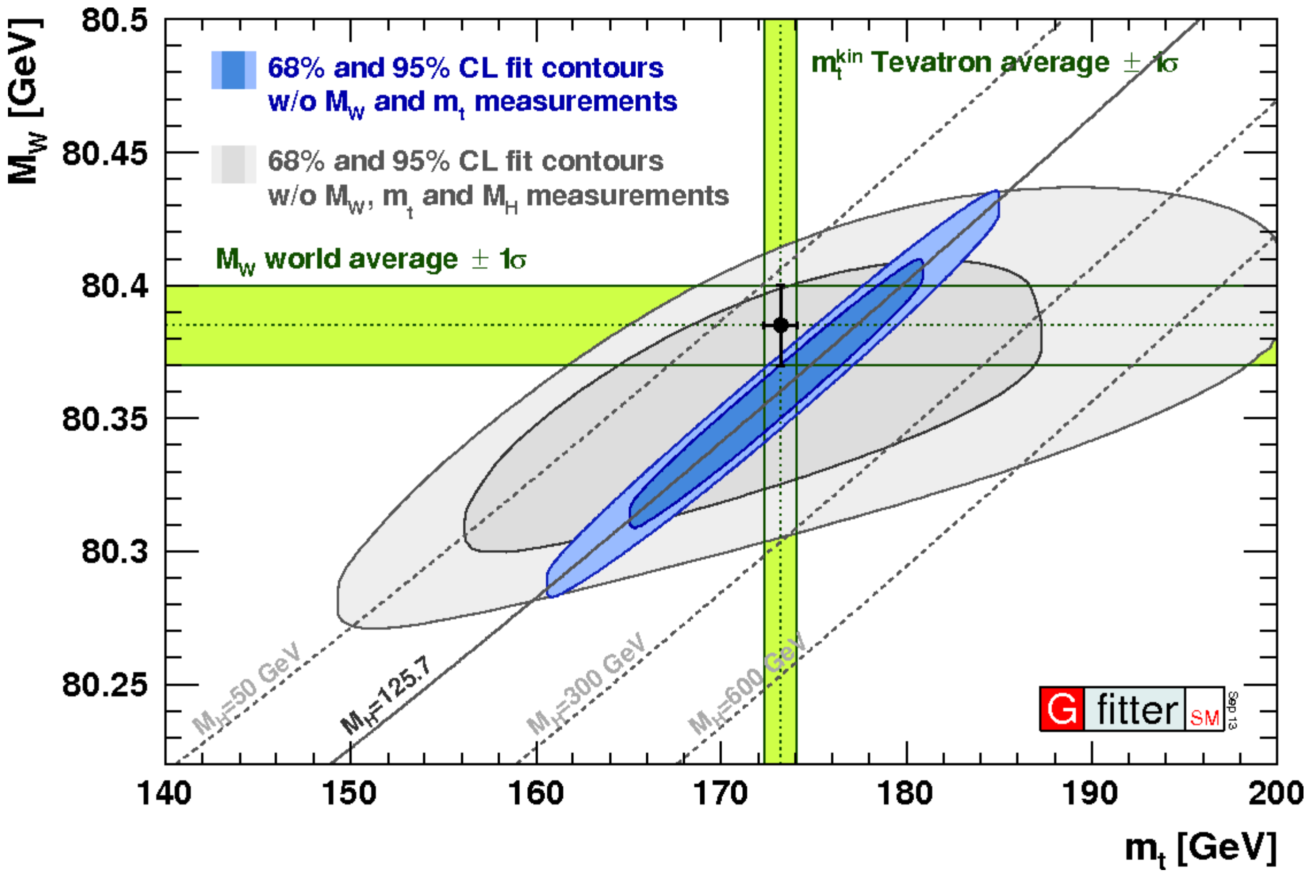




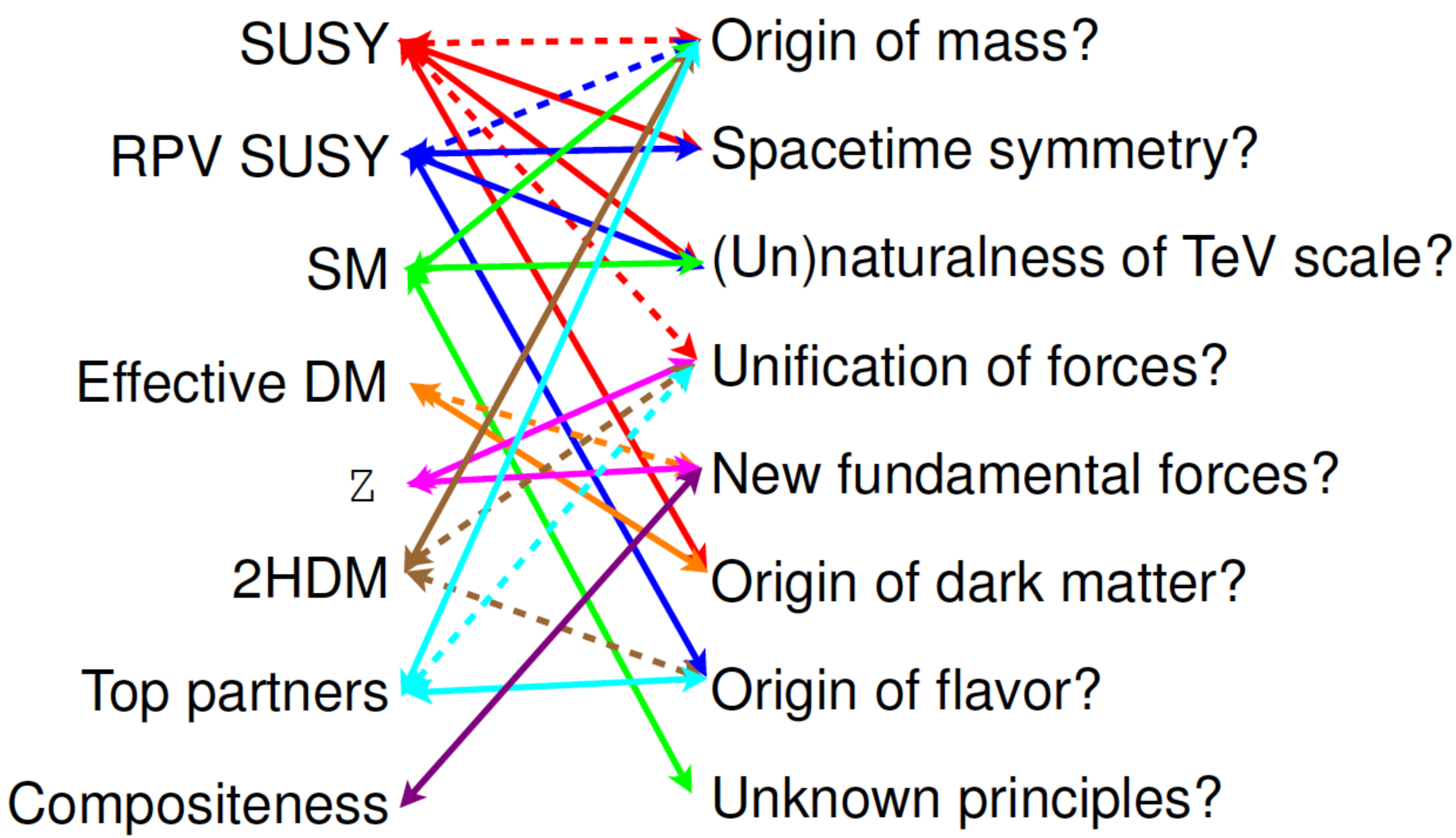
Degrassi et al. ArXiv:1205.6497, arXiv:1307.3536

back to Precision discussion

How this celebrated plot will evolve with precision and what will we learn ?



How will precision help with the BIG QUESTIONS ?



Timescale: present and future colliders

It is useful to discuss scenarios at different timescales:

- **The LHC era**, including the High Luminosity extension (HL-LHC), as suggested by the ECFA
  - We should consider also the physics potential of an energy upgrade of LHC (HE-LHC)
- **Future colliders**
  - A linear e^+e^- collider at centre-of-mass energy up to 500 GeV (ILC)
    - The physics potential of an increase to 1 TeV (ILC) and 3 TeV (CLIC) should also be considered
  - A circular e^+e^- collider at centre-of-mass energy up to 350 GeV (FCC-ee)
  - A circular pp collider at centre-of-mass energy of 100 TeV (FCC-pp)

A Few Typical Topics for the WG

… taking as driving choice the Higgs Boson and EWSB

Higgs properties and EWSB

- There are significant conceptual differences between ElectroWeak Symmetry Breaking and the Higgs-particle.
- If BR(H→X) differs from the SM value, we have two options open for investigation:
  - H is not the SM Higgs
  - there are BSM states contributing to the decay
- In both cases the experimental result is not telling us that EWSB-mechanism is different from what expected within the SM. We want to understand EWSB **and** use the Higgs as a probe to New Physics.
- **We explore for the first time the EW theory above the breaking scale !**

A roadmap for Higgs boson territory

- An overall roadmap to Higgs properties measurements has emerged (LPCC Higgs Working Group), need to further assess priorities and required precision.
- The crucial measurements appear to be:
  - mass and natural width
  - Spin and CP composition
  - Higgs couplings and rare decays
  - Higgs self-coupling
  - VV scattering (V=W or Z)
  - Measurements of top quark properties (very high Yukawa coupling)
  - Improve measurements for global EWK fits
- These measurements are the central point of the physics programme of LHC upgrades and future colliders

Higgs properties and precision

- The idea that electroweak symmetry is broken by **a single complex doublet of scalar fields has no compelling foundation**. At present the properties of the resonance agree with those of the SM Higgs boson to about **30%** of accuracy. This does not yet test the hypothesis of a single Higgs doublet.
- To discover a new structure in the Higgs sector we need to look for effects at ~ **5%** level or better.

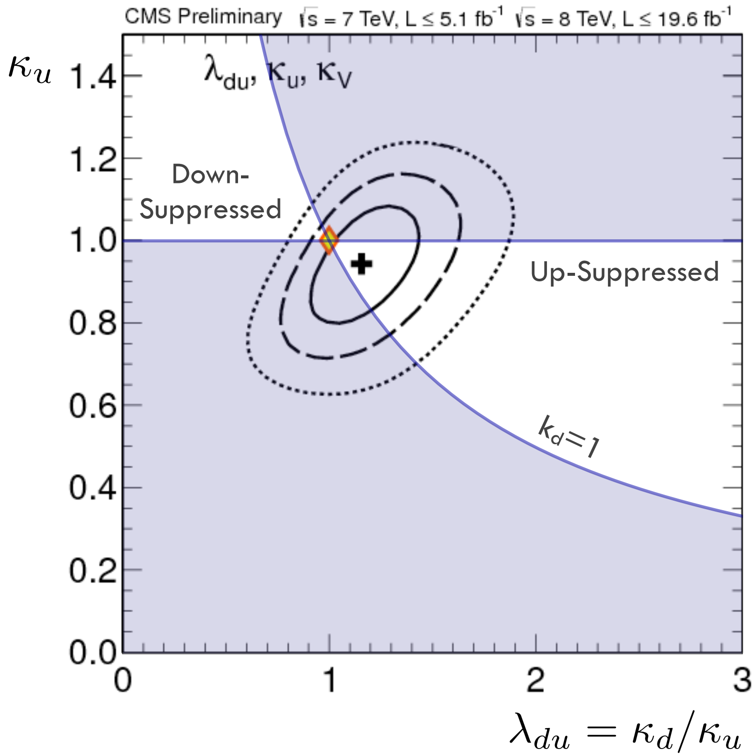
Higgs: why precision is required

- Take the 2HDM as an example

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \mathrm{Re}\, H_u^0 \\ \mathrm{Re}\, H_d^0 \end{pmatrix}$$

$$\tan\beta = \frac{v_u}{v_d}$$

- If one takes CMS data it is clear that precision needs to be considerably improved to claim inconsistency with a single doublet



Courtesy of R. Contino

Higgs: why precision is required

- Deviation from SM couplings as expected in a few benchmark models→

- Composite Higgs $\frac{\Delta g_H}{g_H} \cong 6\% \left(\frac{1\ \text{TeV}}{f}\right)^2$

$f \approx$ 246 GeV [vev, "natural value"]

$f \approx$ O(1 TeV) [LEP bounds, assuming no new physics in loops]

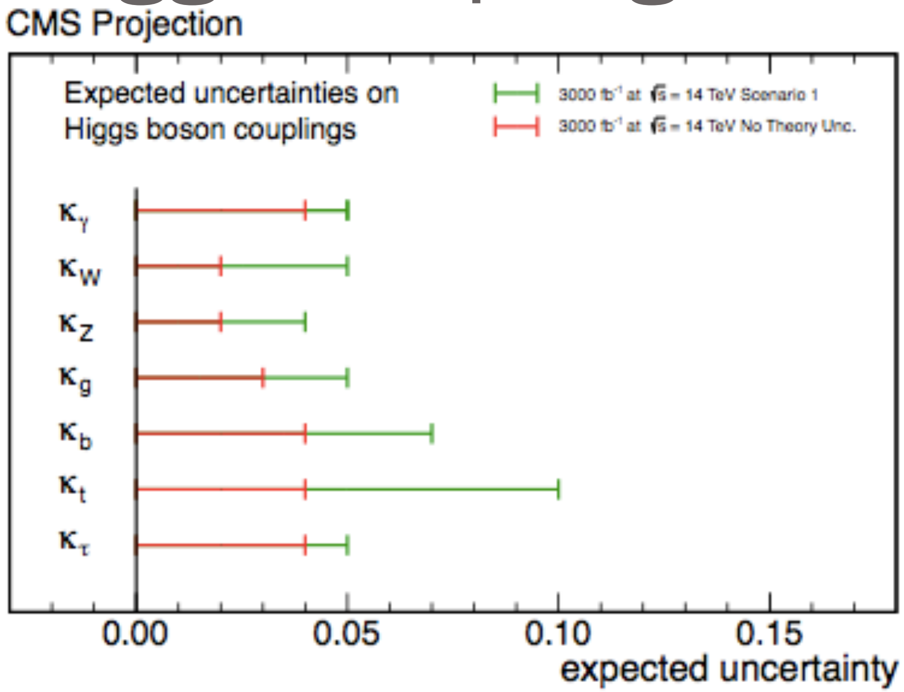
- Top partner $\frac{\Delta g_{h\_gg}}{g_{h\_gg}} \cong 3\% \left(\frac{1\ \text{TeV}}{M}\right)^2$

$M \geq 0.7$ TeV

- SUSY ($\tan\beta \geq 5$) $\frac{\Delta g_{h\_bb}}{g_{h\_bb}} \cong 1.6\% \left(\frac{1\ \text{TeV}}{m_A}\right)^2$

m_A lower bounds depend strongly on $\tan\beta$

Higgs Couplings and Properties: HL-LHC



Estimated precision on coupling modifiers. Projections assume 3000 fb^{-1} @ $\sqrt{s}$ = 14 TeV with (Scenario 1) or without theoretical uncertainties.

Model assumptions made: no Higgs boson decay in addition to those expected in SM, and no particles other than SM ones are present in the *gg*→H and H→γγ loops.

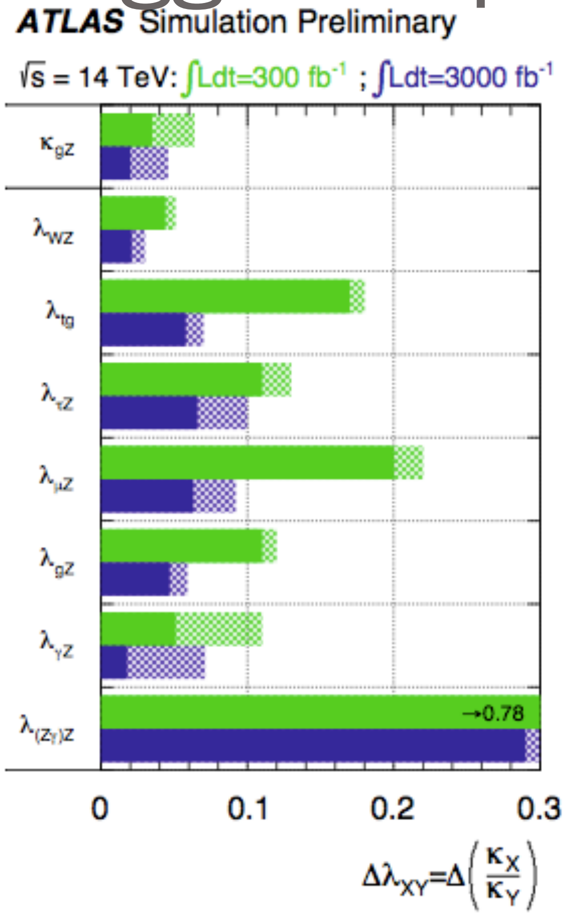
Projections at $\sqrt{s}$= 14 TeV with 300 fb^{-1} (LHC) and 3000 fb^{-1} (HL- LHC).

Numbers in brackets are % uncertainties on couplings.

L(fb^{-1})	Exp.	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$
300	ATLAS	[8,13]	[6, 8]	[7, 8]	[8, 11]	N/a	[20, 22]	[13, 18]	[78, 79]	[21, 23]
	CMS	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]
3000	ATLAS	[5, 9]	[4, 6]	[4, 6]	[5, 7]	N/a	[8, 10]	[10, 15]	[29, 30]	[8, 11]
	CMS	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]

[no theory uncertainty, current theory uncertainty] for ATLAS and [Scenario2, Scenario1] for CMS.

Higgs Couplings and Properties: HL-LHC



Relative uncertainty on the expected precision for the determination of coupling scale factor ratios λ_{XY} in a generic fit without assumptions, assuming a SM Higgs Boson with a mass of 125 GeV and LHC at 14 TeV, 3000 fb^{-1}. The hashed areas indicate the increase of the estimated error due to current theory systematics uncertainties.

Estimated precision on the measurements of ratios of Higgs boson couplings, at $\sqrt{s}$ = 14 TeV with 300 fb^{-1} (LHC) and 3000 fb^{-1} (HL-LHC). Numbers in brackets are % uncertainties on couplings for [no theory uncertainty, current uncertainty] for ATLAS and [Scenario2, Scenario1] for CMS

L(fb^{-1})	Exp.	$\kappa_g \cdot \kappa_Z / \kappa_H$	κ_γ/κ_Z	κ_W/κ_Z	κ_b/κ_Z	κ_τ/κ_Z	κ_Z/κ_g	κ_t/κ_g	κ_μ/κ_Z	$\kappa_{Z\gamma}/\kappa_Z$
300	ATLAS	[3,6]	[5,11]	[4,5]	N/a	[11,13]	[11,12]	[17,18]	[20,22]	[78,78]
	CMS	[4,6]	[5,8]	[4,7]	[8,11]	[6,9]	[6,9]	[13,14]	[22,23]	[40,42]
3000	ATLAS	[2,5]	[2,7]	[2,3]	N/a	[7,10]	[5,6]	[6,7]	[6,9]	[29,30]
	CMS	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]

Higgs Couplings and Properties: ILC

Canonical ILC program

250 GeV: 250 fb^{-1}
500 GeV: 500 fb^{-1}
1 TeV: 1000 fb^{-1}

($M_H = 125$ GeV)

P(e-,e+)=(-0.8,+0.3) @ 250, 500 GeV   P(e-,e+)=(-0.8,+0.2) @ 1 TeV

coupling	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
HZZ	1.3%	1.3%	1.3%
HWW	4.8%	1.4%	1.4%
Hbb	5.3%	1.8%	1.5%
Hcc	6.5%	2.9%	2.0%
Hgg	7.0%	2.5%	1.8%
$H\tau\tau$	5.7%	2.5%	2.0%
$H\gamma\gamma$	25%	12%	5.2%
$H\mu\mu$	-	-	16%
Γ_0	11%	5.9%	5.6%
Htt	-	16%	3.8%

Expected Higgs boson coupling accuracies at the ILC assuming different centre-of-mass energies and different integrated luminosities

Higgs Couplings and Properties: TLEP (FCC-ee)

Coupling	TLEP	
g_{HZZ}	**0.15%**	(0.18%)
g_{HWW}	**0.19%**	(0.23%)
$g_{Hb\bar{b}}$	**0.42%**	(0.52%)
$g_{Hc\bar{c}}$	**0.71%**	(0.87%)
g_{Hgg}	**0.80%**	(0.98%)
$g_{H\tau\tau}$	**0.54%**	(0.66%)
$g_{H\mu\mu}$	**6.2%**	(7.6%)
$g_{H\gamma\gamma}$	**1.5%**	(1.8%)
BR_{exo}	**0.45%**	(0.55%)

Relative statistical uncertainty on the Higgs boson couplings for TLEP at centre-of-mass 350 GeV.

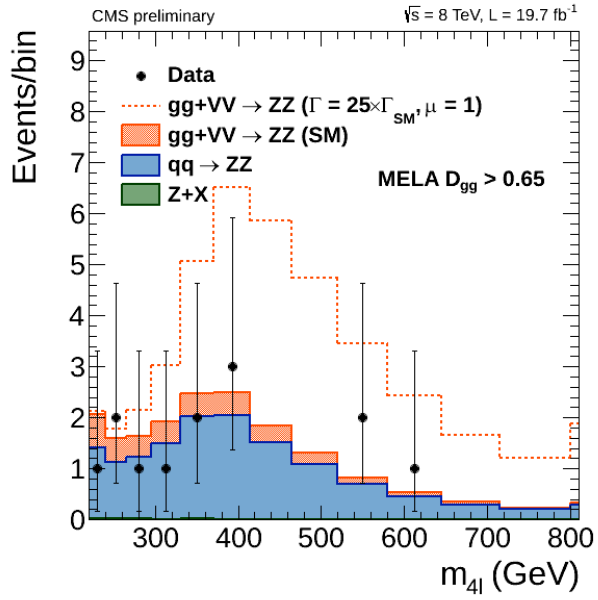
- The numbers between brackets indicates the uncertainties expected with two detectors instead of four.
- The last line gives the absolute uncertainty on the Higgs boson branching fraction to exotic particles (invisible or not).

Next Step for Higgs properties studies: EFT

- Instead of an experimentally-driven basis of parameters use a basis of QFT operators more aligned with BSM theory (SM with embedding)
- EFT allows accurate calculations to be performed
  - NLO effects, etc.
  - More sensitive interpretations
- Multiple sectors affected
  - EWK precision data
  - Triple Gauge Couplings
  - Higgs sector
- These are promising developments for interpretations !

Higgs boson natural width

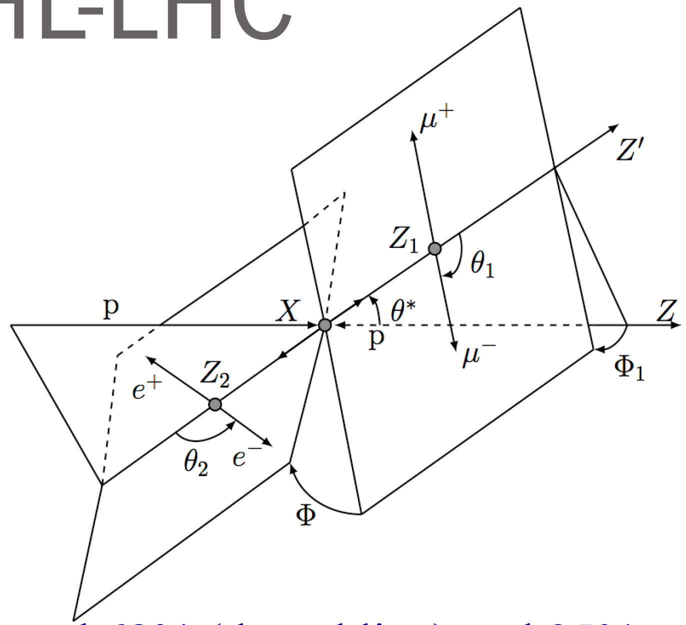
- At (HL-)LHC, an indirect determinations of the Higgs width can be obtained by using the interference of the Higgs boson signal H → $\gamma\gamma$/ZZ/WW with the $\gamma\gamma$/ZZ/WW continuum (Dixon, Martin, Kauer and Passarino). Preliminary studies with CMS @ 8 TeV and 20 fb-1 are very promising.
- At e+e- colliders, an indirect measurement is possible combining the measurements of the Higgs boson production from "Higgsstrahlung" and Vector Boson Fusion processes. It is expected that an accuracy of a few % is possible at ILC and TLEP.

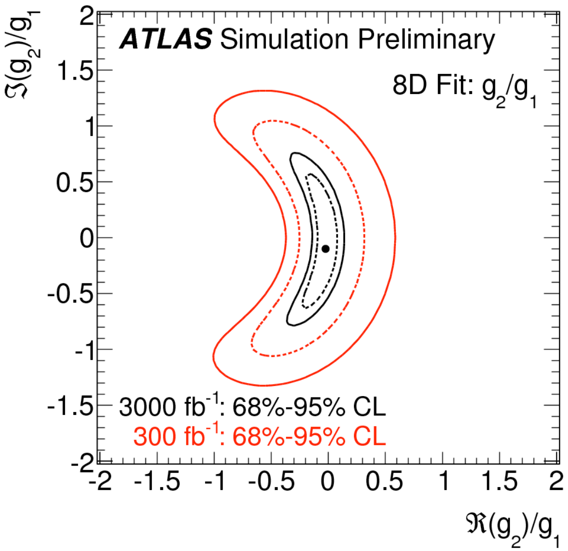


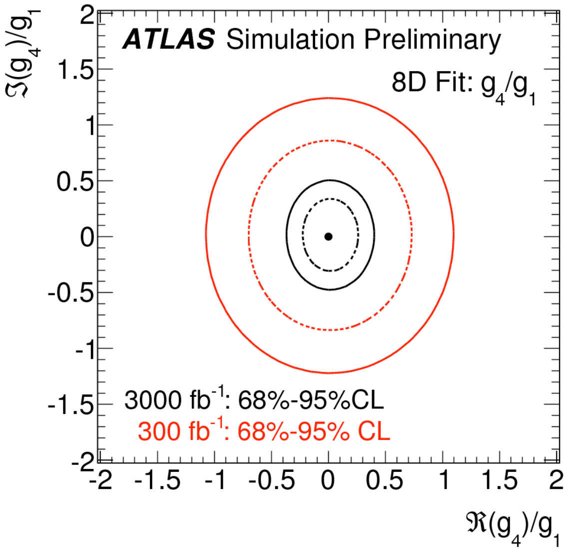
- Combined observed (expected) values
  - $r = \Gamma/\Gamma_{SM} < 4.2$ (8.5) @ 95% CL (p-value = 0.02)
  - $r = \Gamma/\Gamma_{SM} = 0.3^{+1.5}_{-0.3}$
- equivalent to:
  - $\Gamma < 17.4$ (35.3) MeV @ 95% CL
  - $\Gamma = (1.4^{+6.1}_{-1.4})$ MeV

Higgs boson spin/CP: HL-LHC

- Analyze decay angles of ZZ system
- Express CP-odd(CP-even) structure as g4(g2)
- Big sensitivity gains from HL-LHC





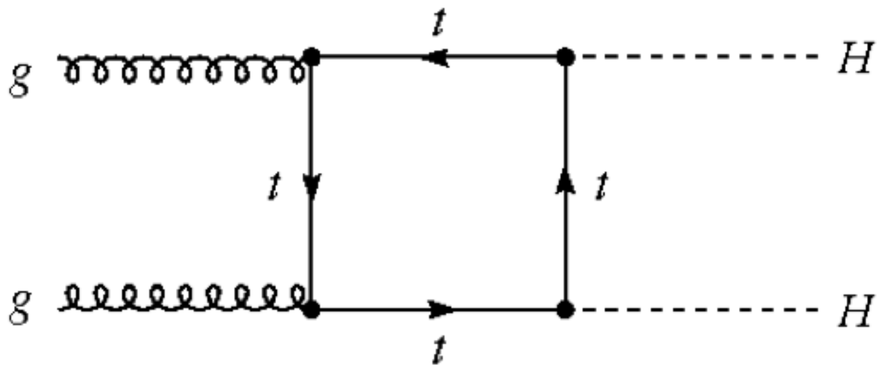


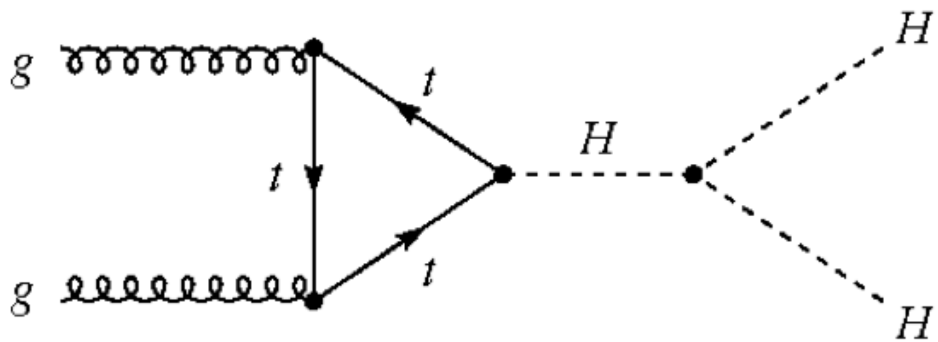
Expected 68% (dotted line) and 95% (full line) CL exclusion contours in the in the (Re(g2)/g1,Im(g2)/g1) [left] and (Re(g4)/g1,Im(g4)/g1) [right] plane for a Standard Model signal, estimated with the 8D likelihood fit method.

$\Re(g_4)/g_1$		$\Im(g_4)/g_1$		$\Re(g_2)/g_1$		$\Im(g_2)/g_1$	
<-0.34	>0.26	<-0.34	>0.48	<-0.30	>0.11	<-0.71	>0.68

Expected values excluded at 95% CL for the real and imaginary part of g4/g1 and g2/g1 couplings, assuming the Standard Model. These values are obtained at $\sqrt{s}$ = 14 TeV using an integrated dataset of 3000 fb^{-1} at HL-LHC.

Higgs boson pair production: HL-LHC





- Needs observation of Higgs pairs
  - Expected SM σ_{HH}=40±3fb → 120K events
  - Finding one was tough with ~500K events
- Both the above diagrams (and more) contribute: negative interference
- Ongoing ATLAS and CMS studies suggest some sensitivity
- Low rate makes high demands on trigger, detectors, lumi and analysis techniques
- Several theoretical studies suggest possible: as an example, see: arXiV: 1309.6318

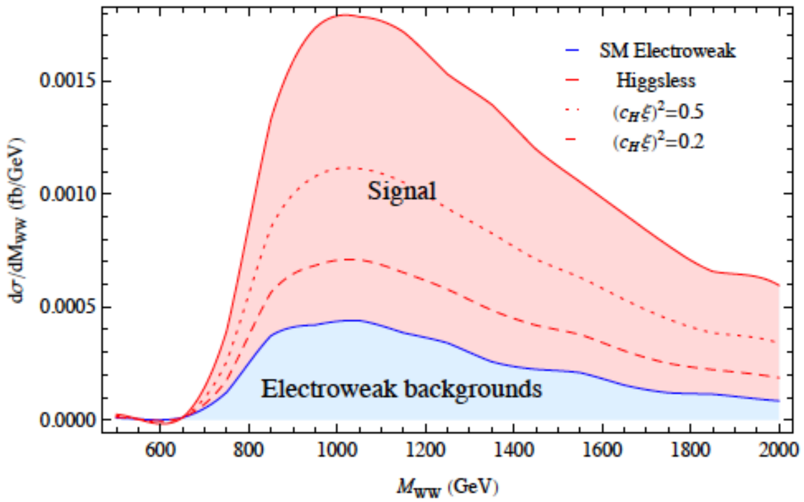
Expected HH events at L=3000 fb^{-1}

bbWW	30000
bbττ	9000
WWWW	6000
γγbb	320
γγγγ	1

Vector Boson Scattering

- If the LHC boson alone contributes to EWSB $V_L V_L$ scattering does not grow at high energies
- New Physics means the LHC boson is not alone but NP non-observed at 1 TeV tells us that the rest is heavy
  - the scattering could get strong for a range of energies, until the high-energy UV physics starts unitarizing.
- many channels and considerable luminosity is required

arXiv:1304.4599

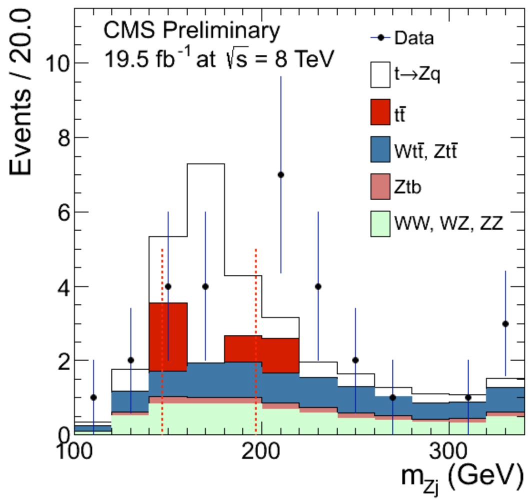


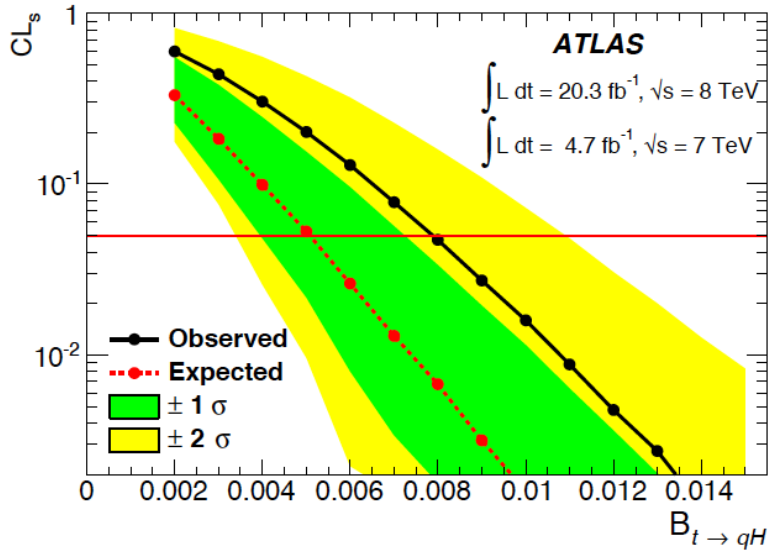
Invariant mass of the WW system in production with forward jets and $p_t^W > 350$ GeV.
- Blue is WWjj cross section with SM and Higgs 125 GeV
- Red are various NP scenari

The fermion with highest Yukawa coupling

- The **top quark is a gift**, which we must fully exploit. Its large Higgs-Yukawa couplings should tell us something about EWSB
- There is also a lucky hierarchy of CKM elements: in the SM the top quark decays essentially 100% to bW
  - → detection of other top decays is an unambiguous sign of New Physics
  - Examples: FCNC top decays (t→Zq), top decays to Higgs (t→cH), in both cases large statistics is required

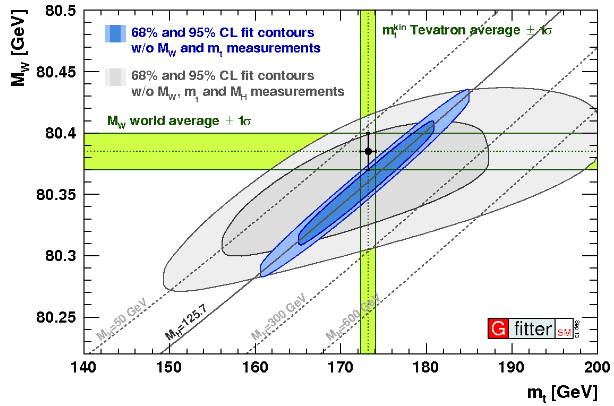
t → Zq < 0.07 % at the 95 % CL

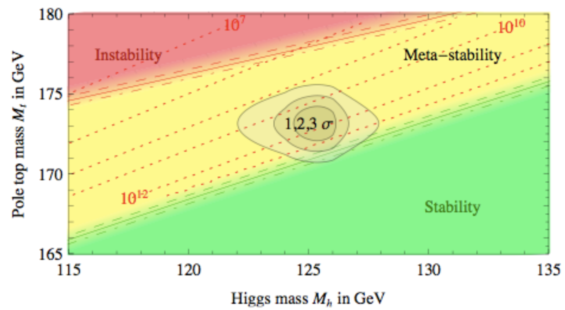


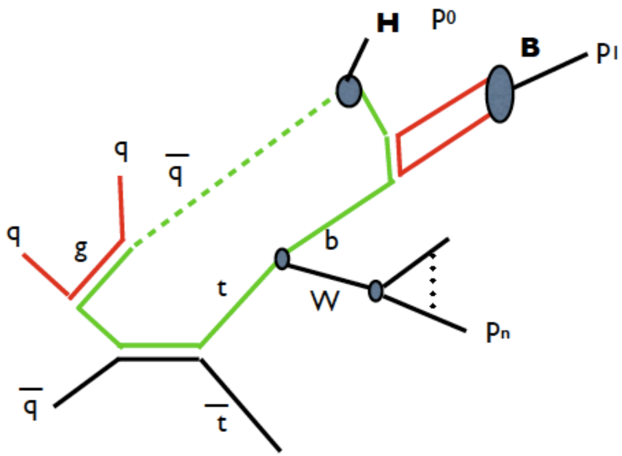


the top mass

- Current experimental measurements are used as "pole mass" in fits and calculations. This interpretation has difficulties related to the fact top is a coloured object, cannot be unambiguously linked to final particles.
- However there are is an emerging picture that the interpretation is reasonable at the level of ≈ 1 GeV
  - Hadron machines: more data is required to strengthen the picture
  - Lepton machine: will not be affected by the issue → threshold scan

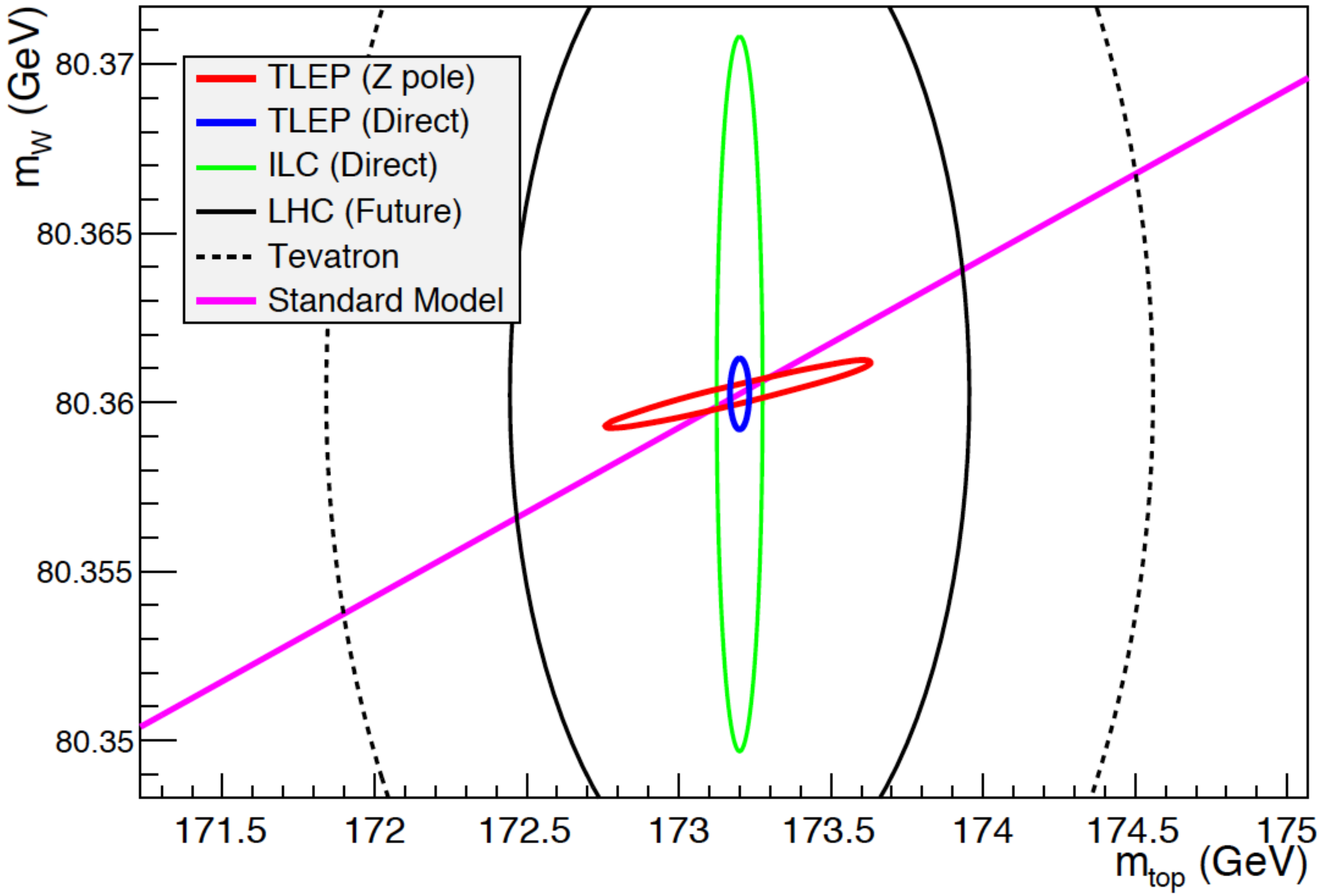




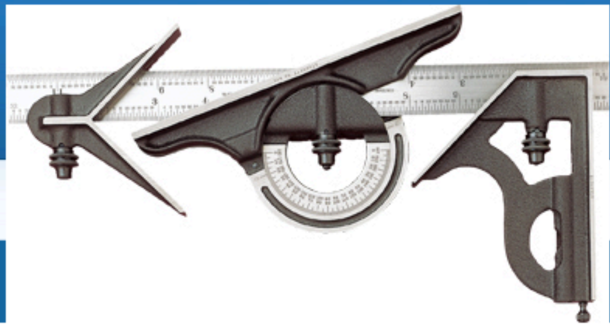


Possible evolution of EWK data

… it does not need to be centered to the SM, after predicting top and Higgs mass will we have predicting power for NP ?



Join the SM WG !



What Next: pagina del gruppo di lavoro "Standard Model"

7-8 April 2014
Europe/Rome timezone

- **Overview**
- Programma di lavoro
- Registration
  - Registration Form
- Call for Abstracts
  - View my abstracts
  - Submit a new abstract
- Contribution List
- My conference

Questa pagina rappresenta uno strumento di lavoro per il GdL Standard Model. Chi e' interessato a partecipare e contribuire e' invitato ad iscriversi, ed eventualmente inviare materiale inserendo un abstract a cui si puo' allegare una nota o un articolo ("Submit a new abstract" nel menu a sinistra).

Dates:	from 07 April 2014 08:00 to 08 April 2014 18:00
Timezone:	Europe/Rome
Location:	
Chairs:	Dainese, Andrea Forte, Stefano Nisati, Aleandro Passarino, Giampiero Tenchini, Roberto

List of current contributions to the SM GdL (more details on the web site)

- **Testing special relativity through decay of high energy particle** (P. Cattaneo)
- **Precise measurement of hadronic cross section at low energy for $\alpha_{em}(M_Z)$ and $(g\text{-}2)_\mu$** (G. Venanzoni)
- **New Physics signals from measurable polarization asymmetries at LHC** (G. Panizzo)
- **Thoughts about HE-LHC** (G. Chiarelli)
- **Prospects for measurements of the HZZ vertex tensor structure in $H \rightarrow ZZ^* \rightarrow 4l$ decay channel** (ATLAS Collaboration)
- **Projections for Top FCNC Searches in 3000 fb−1 at the LHC** (CMS Collaboration)

List of current contributions to the SM GdL (more details on the web site)

- **Projections for measurements of Higgs boson cross sections, branching ratios and coupling parameters with the ATLAS detector at a HL-LHC** (ATLAS Collaboration)
- **Projected Performance of an Upgraded CMS Detector at the LHC and HL-LHC: Contribution to the Snowmass Process** (CMS Collaboration)
- **Vector Boson Scattering and Quartic Gauge Coupling Studies in WZ Production at 14 TeV** (CMS Collaboration)
- **Projected improvement of the accuracy of top-quark mass measurements at the upgraded LHC** (CMS Collaboration)

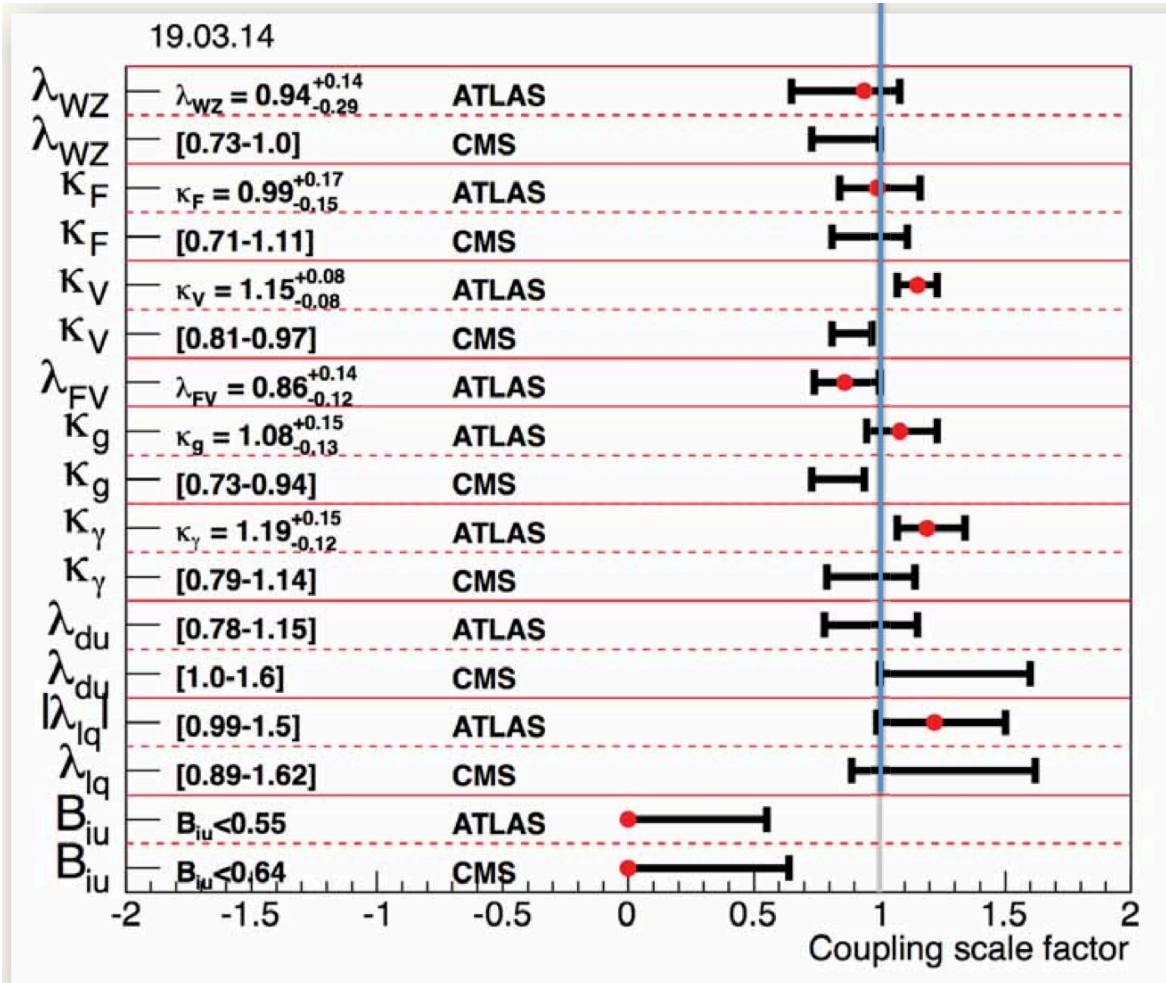
Possible topics for discussion (previously mentioned or not)

For discussion today and in the future in the GdL .

- QCD, including improved pdf
- W and Z physics
- Forward physics
- more on top physics
- precision needs for Higgs measurements
- an effective Lagrangian (EFT) to describe the Higgs and BSM
- $V_L V_L$ scattering
- Going higher in energy (e.g. LHC_HE, FCC-pp)
- The role of e+e- colliders
- improving EW precision measurements (theory and exp)
- How precision is going to help with the key questions ?
- Unconventional ideas ?

Backup

Status of Higgs Couplings measurements (Moriond EW 2014)



Higgs Couplings measurements as summarized in arXiv:1403.7191

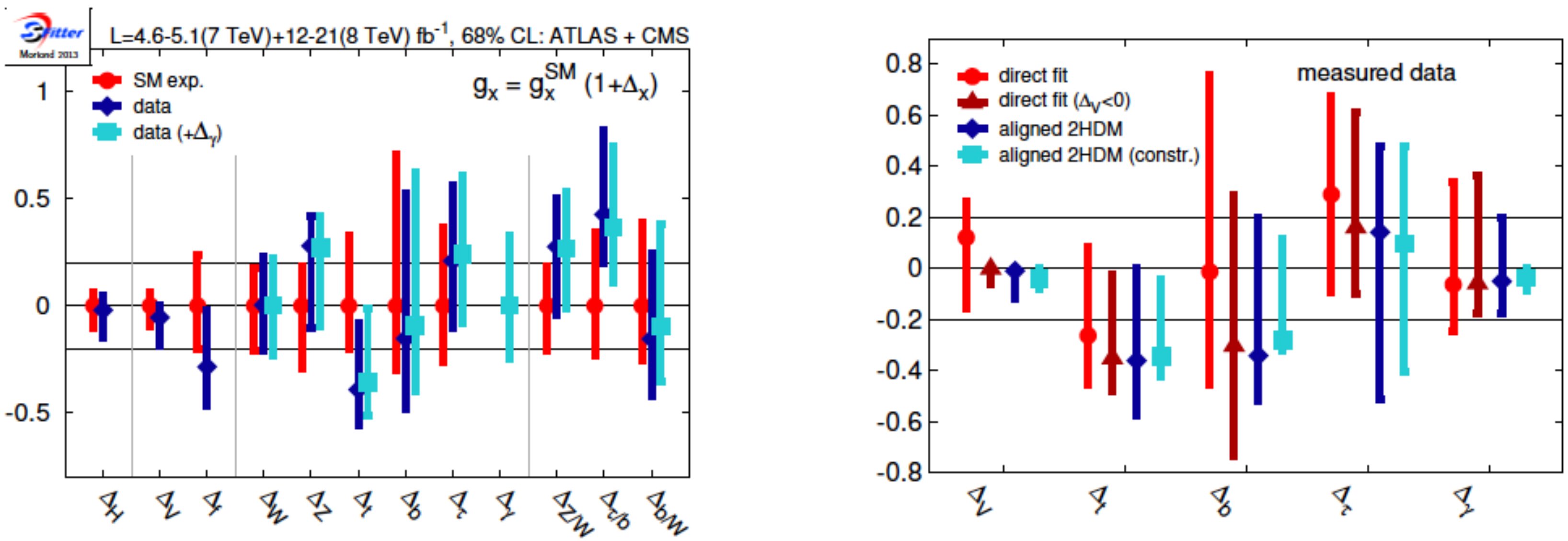


FIG. 1: Higgs coupling measurement based on all currently available ATLAS and CMS data. In the left panel we compare the SM expectation with a fit to the weak-scale Higgs Lagrangian with free couplings to the data, and either including a Higgs-photon coupling or not. In the last three columns we show errors on ratios of couplings, where, analogous to Eq.(2.1), Δ parametrizes the deviation from the corresponding SM ratio. In the right panel we compare the fits to the weak-scale couplings with a fit to the aligned 2HDM in terms of the light Higgs couplings. Figures from Ref. [19]. The only difference between the cyan results in the left panel and the lighter red ones in the right panel is that for the latter we set $\Delta_W = \Delta_Z \equiv \Delta_V$.

Effective New Physics scales (Λ*) [from arXiv:1403.7191]

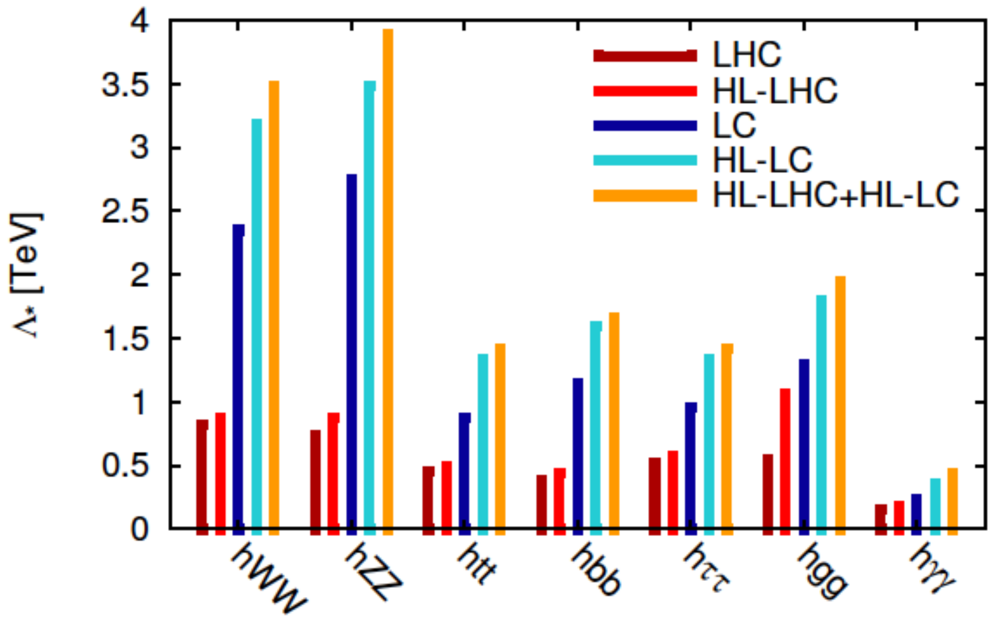
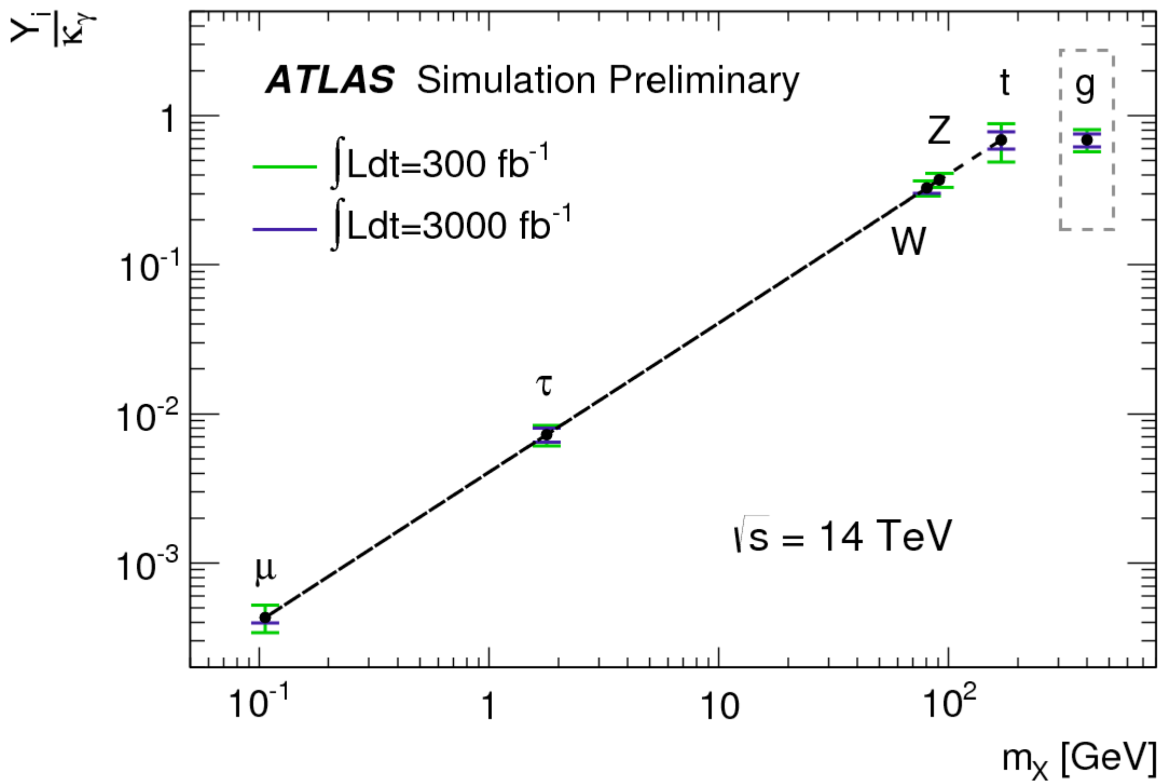


FIG. 2: Effective new physics scales Λ_* extracted from the Higgs coupling measurements collected in Table I. The values for the loop-induced couplings to gluons and photons contain only the contribution of the contact terms, as the effects of the loop terms are already disentangled at the level of the input values Δ. (The ordering of the columns from left to right corresponds to the legend from up to down.)

Higgs Couplings and Properties: HL-LHC

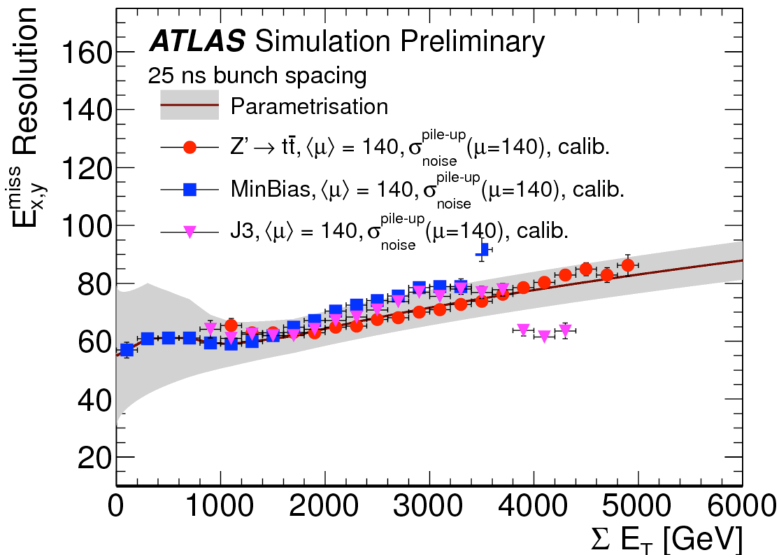


Fit results for mass-scaled coupling ratios $Y_f/\kappa_\gamma = \kappa_f/\kappa_\gamma (m_f/v)$ for fermions and $Y_V/\kappa_\gamma = \kappa_V/\kappa_\gamma (m_V/v)$ for weak bosons as a function of the particle mass, assuming 300 fb^{-1} and 3000 fb^{-1} at 14 TeV and a SM Higgs Boson with a mass of 125 GeV. For completeness, the uncertainty on the gluon-coupling ratio measurement κ_g/κ_γ, which can be used as an indirect measurement of the top-coupling through the gg to H process, is also shown next to the expected measurement for Y_t/κ_γ which uses the direct ttH process. The uncertainty on the coupling ratio $\kappa_{(Z\gamma)}/\kappa_\gamma$ is not shown.

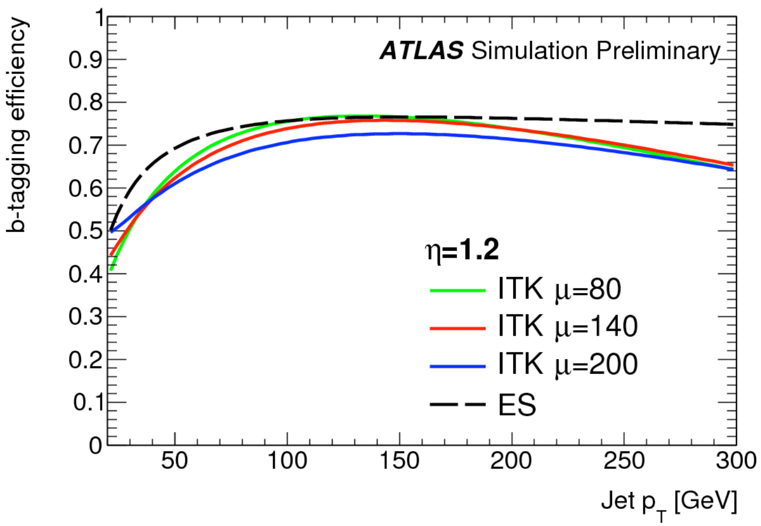
Physics simulation for HL-LHC

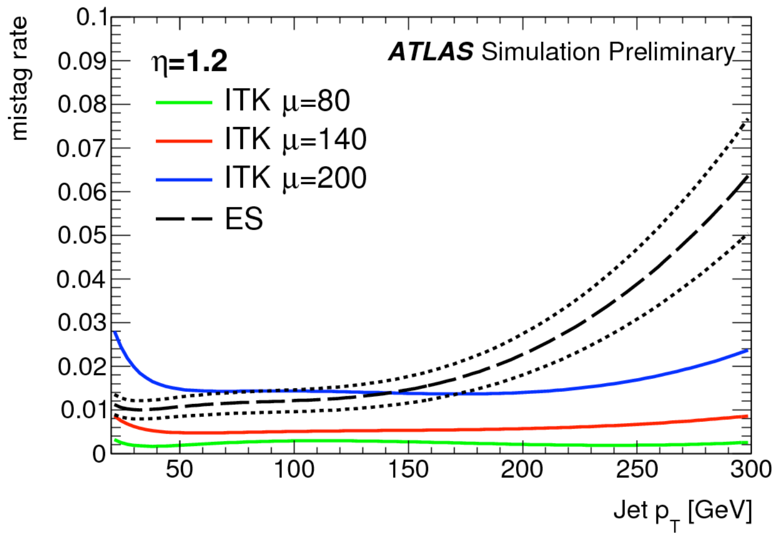
- Example from ATLAS
- establish "smearing" functions using a **full detector simulation, including the effects of event pile-up**, from which corresponding resolutions, detection and reconstruction efficiencies, and the rejection of fakes are extracted. This is done assuming a center-of-mass energy of $\sqrt{s} = 14$ TeV, a sustained instantaneous luminosity of $L = 5 \times 10^{34}$ $cm^{-2}s^{-1}$ and 25 ns bunch spacing. Documented inATL-PHYS-PUB-2013-009
  - **Physics objetcs studied in full simulation: jets, missing transverse energy, tagging efficiencies of b-jets, c-jets and light quarks, photons.**

ATL-PHYS-PUB-2013-009



The E_T^{miss} resolution as a function of $\sum E_T$ obtained from different physics samples, and compared with the parametrisation. They are all consistent with the nominal value obtained from the parametrisation within the systematic uncertainties





The parametrisations of b-jet (left) and light jet (right) tagging efficiencies, as function of p_T for fixed values of $|\eta|$. The new parametrisations with the Phase-II tracker, ITK, are shown with μ= 80, 140 and 200.

TLEP (FCC-ee) main parameters

Table 1: Preliminary values of the luminosity for TLEP in each of the four planned configurations [8]. Other parameters relevant for the physics potential of TLEP (beam size, RF cavity gradient, number of bunches, total power consumption and integrated luminosity per year at each IP) are also listed.

	TLEP-Z	TLEP-W	TLEP-H	TLEP-t
$\sqrt{s}$ (GeV)	90	160	240	350
L (10^{34} cm^{-2}s^{-1}/IP)	56	16	5	1.3
# bunches	4400	600	80	12
RF Gradient (MV/m)	3	3	10	20
Vertical beam size (nm)	270	140	140	100
Total AC Power (MW)	250	250	260	284
L_{int} (ab^{-1}/year/IP)	5.6	1.6	0.5	0.13

ILC main parameters

Table 3.1. Summary table of the 250–500 GeV baseline and luminosity and energy upgrade parameters. Also included is a possible 1st stage 250 GeV parameter set (half the original main linac length)

			Baseline 500 GeV Machine			1st Stage	L Upgrade	E_{CM} Upgrade	
								A	B
Centre-of-mass energy	E_{CM}	GeV	250	350	500	250	500	1000	1000
Collision rate	f_{rep}	Hz	5	5	5	5	5	4	4
Electron linac rate	f_{linac}	Hz	10	5	5	10	5	4	4
Number of bunches	n_b		1312	1312	1312	1312	2625	2450	2450
Bunch population	N	$\times 10^{10}$	2.0	2.0	2.0	2.0	2.0	1.74	1.74
Bunch separation	Δt_b	ns	554	554	554	554	366	366	366
Pulse current	I_{beam}	mA	5.8	5.8	5.8	5.8	8.8	7.6	7.6
Main linac average gradient	G_a	MV m^{-1}	14.7	21.4	31.5	31.5	31.5	38.2	39.2
Average total beam power	P_{beam}	MW	5.9	7.3	10.5	5.9	21.0	27.2	27.2
Estimated AC power	P_{AC}	MW	122	121	163	129	204	300	300
RMS bunch length	σ_z	mm	0.3	0.3	0.3	0.3	0.3	0.250	0.225
Electron RMS energy spread	$\Delta p/p$	%	0.190	0.158	0.124	0.190	0.124	0.083	0.085
Positron RMS energy spread	$\Delta p/p$	%	0.152	0.100	0.070	0.152	0.070	0.043	0.047
Electron polarisation	P_-	%	80	80	80	80	80	80	80
Positron polarisation	P_+	%	30	30	30	30	30	20	20
Horizontal emittance	$\gamma\epsilon_x$	μm	10	10	10	10	10	10	10
Vertical emittance	$\gamma\epsilon_y$	nm	35	35	35	35	35	30	30
IP horizontal beta function	β_x^*	mm	13.0	16.0	11.0	13.0	11.0	22.6	11.0
IP vertical beta function	β_y^*	mm	0.41	0.34	0.48	0.41	0.48	0.25	0.23
IP RMS horizontal beam size	σ_x^*	nm	729.0	683.5	474	729	474	481	335
IP RMS veritcal beam size	σ_y^*	nm	7.7	5.9	5.9	7.7	5.9	2.8	2.7
Luminosity	L	$\times 10^{34}$ $cm^{-2}s^{-1}$	0.75	1.0	1.8	0.75	3.6	3.6	4.9
Fraction of luminosity in top 1%	$L_{0.01}/L$		87.1%	77.4%	58.3%	87.1%	58.3%	59.2%	44.5%
Average energy loss	δ_{BS}		0.97%	1.9%	4.5%	0.97%	4.5%	5.6%	10.5%
Number of pairs per bunch crossing	N_{pairs}	$\times 10^3$	62.4	93.6	139.0	62.4	139.0	200.5	382.6
Total pair energy per bunch crossing	E_{pairs}	TeV	46.5	115.0	344.1	46.5	344.1	1338.0	3441.0

LHC main parameters

	2010	2011	2012	Nominal
Energy [TeV]	3.5	3.5	4	7
Bunch spacing [ns]	150	50	50	25
No. of bunches	368	1380	1380	2808
beta* [m] ATLAS and CMS	3.5	1.0	0.6	0.55
Max **bunch intensity** [protons/bunch]	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}	1.15×10^{11}
Normalized **emittance** [mm.mrad]	~2.0	~2.4	~2.5	3.75
Peak luminosity [$cm^{-2}s^{-1}$]	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}	1.0×10^{34}

LHC-HL main parameters

Baseline parameters of HL for reaching 250 -300 fb^{-1} / year

25 ns is the option

However:

50 ns should be kept as alive and possible because we DO NOT have enough experience on the actual limit ***(e-clouds, I_{beam})***

From Frederick Bordry talk at Aix-Les-Bains 1st October 2013

	25 ns	50 ns
# Bunches	2808	1404
p/bunch [10^{11}]	**2.0 (1.01 A)**	**3.3 (0.83 A)**
ε_L [eV.s]	2.5	2.5
σ_z [cm]	7.5	7.5
$\sigma_{\delta p/p}$ [10^{-3}]	0.1	0.1
$\gamma\varepsilon_{x,y}$ [μm]	**2.5**	**3.0**
β* [cm] (baseline)	15	15
X-angle [μrad]	**590 (12.5 σ)**	**590 (11.4 σ)**
Loss factor	0.30	0.33
Peak lumi [10^{34}]	6.0	7.4
Virtual lumi [10^{34}]	20.0	22.7
$T_{leveling}$ [h] @ 5E34	**7.8**	**6.8**
#Pile up @5E34	123	247

LHC-HE main parameters

Table 1: LHC main parameters compared with the HE-LHC with round beams (right column) and flat beam (middle column)

	nominal LHC	HE-LHC	
beam energy [TeV]	7	16.5	
dipole field [T]	8.33	20	
dipole coil aperture [mm]	56	40	
beam half aperture [cm]	2.2 (x), 1.8 (y)	1.3	
injection energy [TeV]	0.45	>1.0	
#bunches	2808	1404	
bunch population [10^{11}]	1.15	1.29	1.30
initial transverse normalized emittance [μm]	3.75	3.75 (x), 1.84 (y)	2.59 (x & y)
initial longitudinal emittance [eVs]	2.5	4.0	

Higgs rates at high energy

	σ(14 TeV)	R(33)	R(40)	R(60)	R(80)	R(100)
ggH	50.4 pb	3.5	4.6	7.8	11.2	14.7
VBF	4.40 pb	3.8	5.2	9.3	13.6	18.6
WH	1.63 pb	2.9	3.6	5.7	7.7	9.7
ZH	0.90 pb	3.3	4.2	6.8	9.6	12.5
ttH	0.62 pb	7.3	11	24	41	61
HH	33.8 fb	6.1	8.8	18	29	42

$R(E) = \sigma(E\,\text{TeV})/\sigma(14\,\text{TeV})$

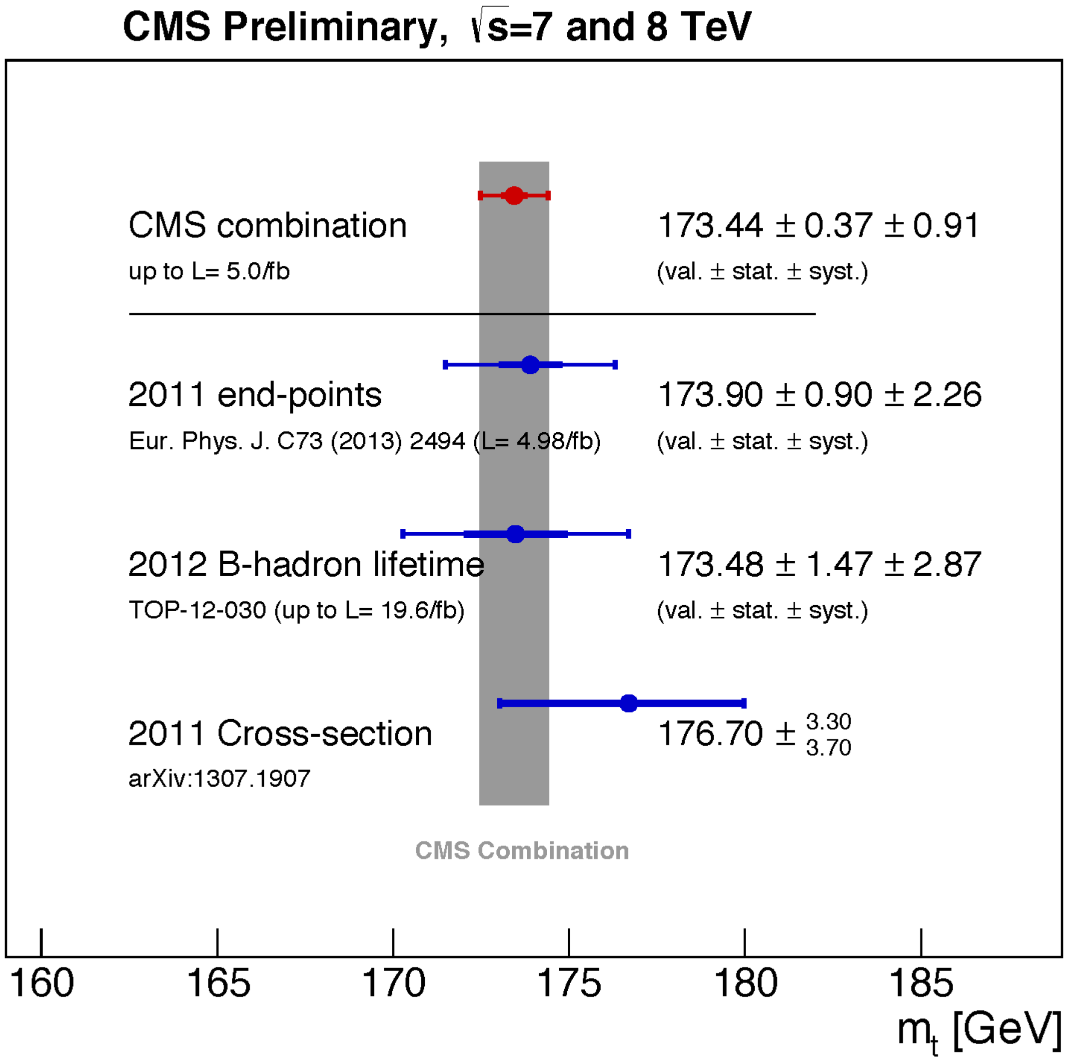
No study is available of the concrete performance in the measurement of Higgs couplings, self-couplings and other properties, by possible LHC detectors at these energies

From M. Michelangelo talk at "Frontier capabilities for hadron colliders 2013"

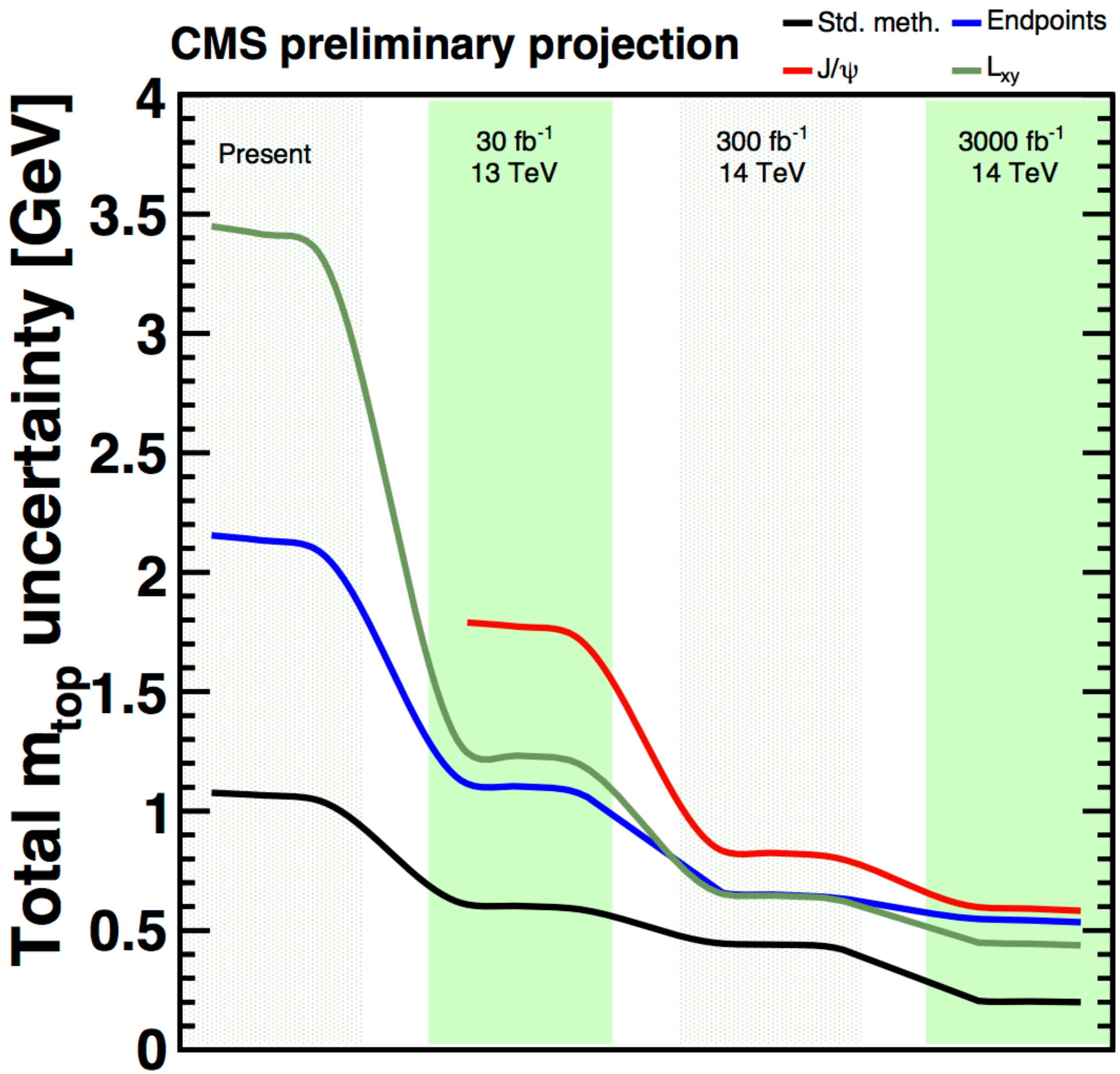
TOP mass from alternative techniques

- **Standard methods**: based on the invariant mass of decay products associated to the reconstructed top in a given channel (lepton+jets, dilepton, fully hadronic channels).
- Given the issues related to the top mass interpretation, important to explore **alternative techniques**, e.g.
  - Measure the **decay length** (the boost) of B hadrons produced in top decays, the boost is related to the original top mass
  - Measure the **endpoint** of the lepton **spectrum** or other quantities in top decays
  - Select **specific channels**, for example top with $W \rightarrow l\,\nu$ and $B \rightarrow J/\psi + X$ decays and measure the three-lepton invariant mass
- Alternative methods have typically larger statistical uncertainties, however at LHC we have large ttbar samples.
  - Systematic uncertainties can be controlled with data, again large samples help.

Standard vs alternative methods

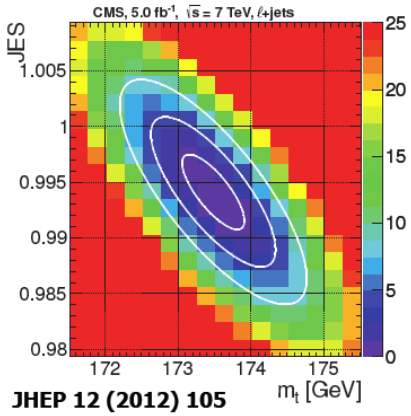


Prospects for top mass at the LHC

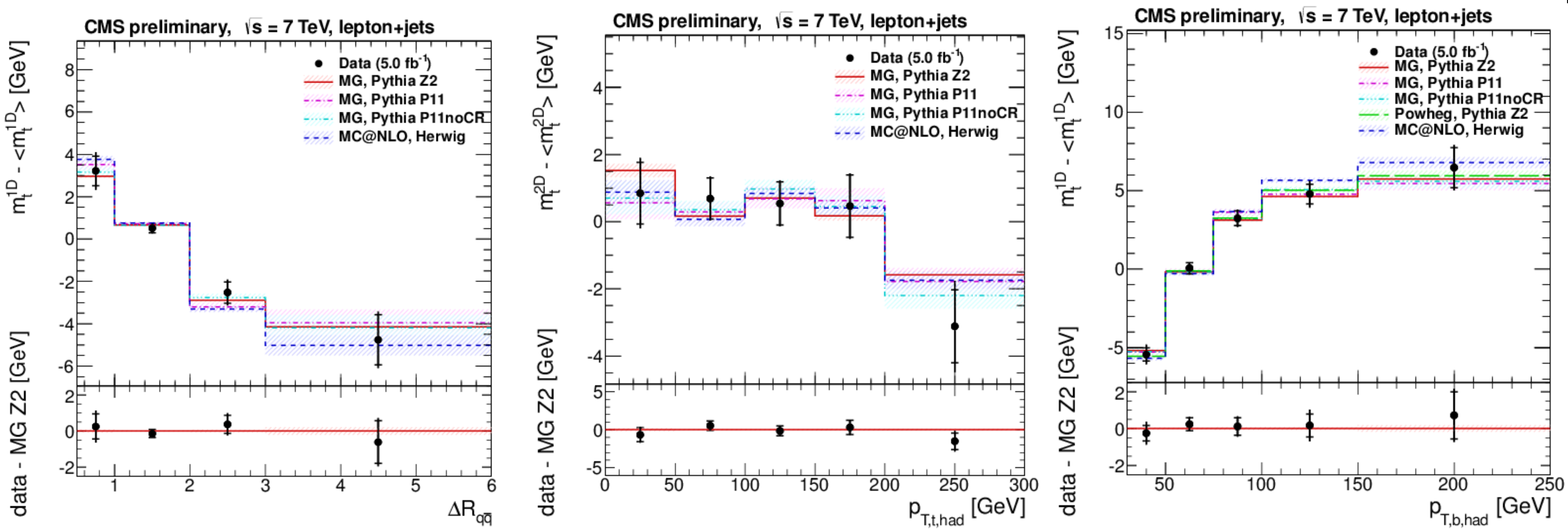


Dependence of Top Mass observable on event kinematics

- How does the measured m_t relate to the fundamental m_t parameter in the SM?
  - The relation contains (non)perturbative QCD corrections, expected to depend on event kinematics
  - Is this kinematic dependence properly modeled by MC? → 12 kinematic variables checked
  - Good data/MC agreement rules out dramatic effects



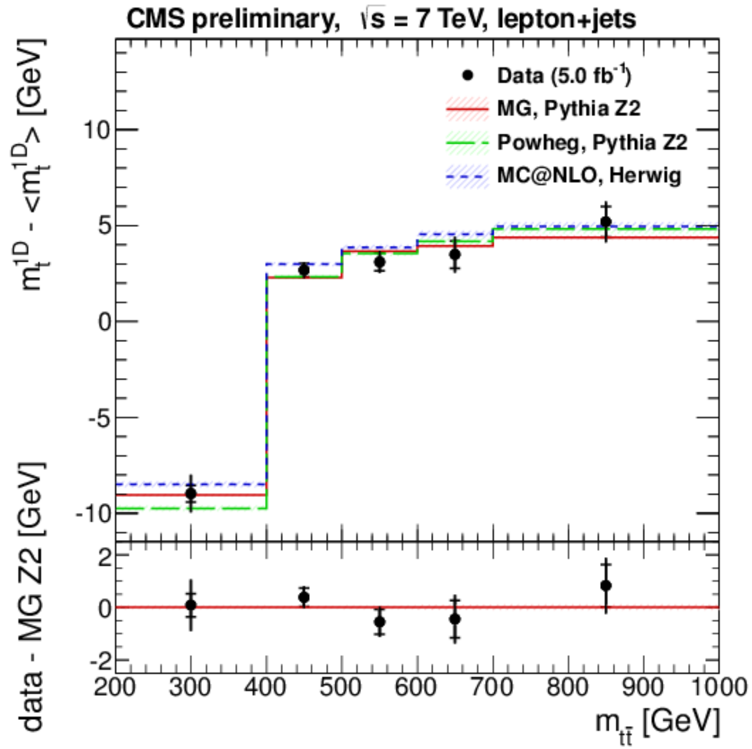
JHEP 12 (2012) 105



Dependence of Top Mass on Event Kinematics

CMS-PAS-TOP-12-029

	Fig.	Observable
color recon.	1	$\Delta R_{q\bar{q}}$
	2	$\Delta\phi_{q\bar{q}}$
	3	$p_{T,t,had}$
	4	$\lvert\eta_{t,had}\rvert$
ISR/FSR	5	H_T
	6	$m_{t\bar{t}}$
	7	$p_{T,t\bar{t}}$
	8	Jet multiplicity
b-quark kin.	9	$p_{T,b,had}$
	10	$\lvert\eta_{b,had}\rvert$
	11	$\Delta R_{b\bar{b}}$
	12	$\Delta\phi_{b\bar{b}}$



With the current precision, no mis-modelling found as function of variables related to color reconnection, ISR/FSR, b-quark kinematics.

The Electromagnetic Coupling $\alpha_{em}(M_Z)$ (and $(g-2)_\mu$)

- Precision Physics (EW fit) at ILC or TLEP needs precise knowledge of $\alpha_{em}(M_Z)$

$$\alpha(M_Z) = \frac{\alpha(0)}{1-\Delta\alpha(M_Z)} \qquad \Delta\alpha = \Delta\alpha_l + \Delta\alpha^{(5)}_{had} + \Delta\alpha_{top}$$

- Its uncertainty affects the prediction for M_W and $\sin^2\theta^l_{eff}$ [GFITTER, LEP Reports]
- It is dominated by non perturbative hadronic effects ($\Delta\alpha^{(5)}_{had}$) which can be related to measured hadr. cross sections (R(s)) at low energy (below 10 GeV)

$$\Delta\alpha^{(5)}_{had}(M_Z^2) = -\frac{\alpha M_Z^2}{3\pi}\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s-M_Z^2-i\varepsilon)}$$

$$\Delta\alpha^{(5)}_{had}(M_Z^2) = 0.027627 \pm 0.000138$$

$$\alpha^{-1}(M_Z^2) = 128.944 \pm 0.019$$

[HLMNT J. Phys. G 38 (2011) 085003]

- $\delta\alpha(M_Z)/\alpha(M_Z) \sim 1.5\times10^{-4} \rightarrow 5\times10^{-5}$ needed to match ILC/TLEP precision (a **x3** improvement) [FJ, TESLA,ILC, TLEP Reports]

- **Necessity** of an experimental program of precise measurement of R(s) at low energies. With a dedicated approach based on Adler function the dominant region is the one below 2.5 GeV.

[F.Jegerlehner, NPPS. 181-182 (2008) 135-140; NPPS 162 (2006) 22-32]

- Similar analysis for the hadronic contribution to the muon g-2 (a_μ^{had}). Very important the region below 2.5 GeV! [T. Blum et al, arXiv:1311]

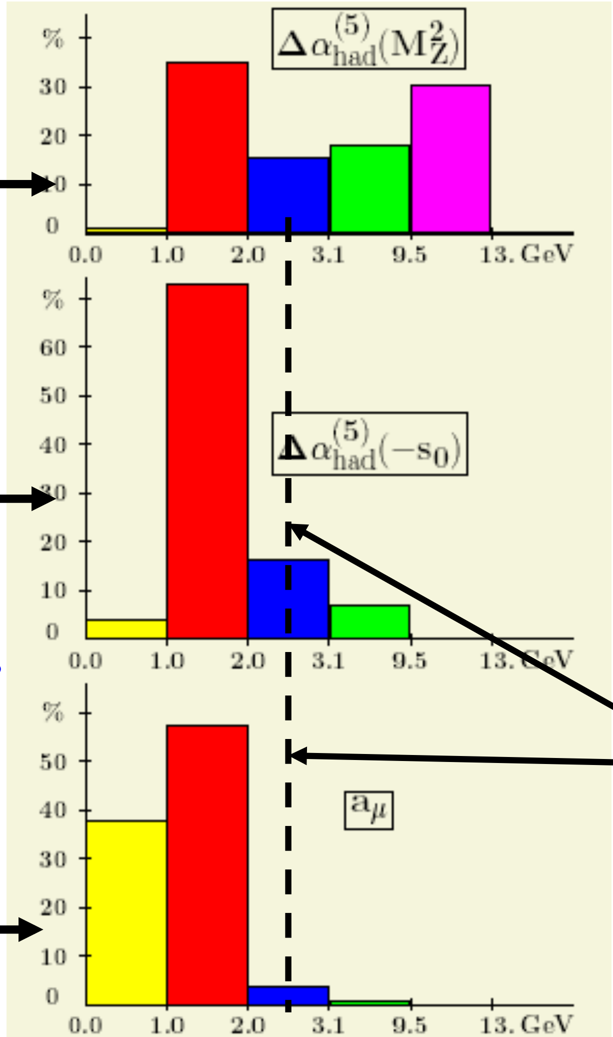
Error profiles for $\Delta\alpha^{(5)}_{had}(M_Z)$ and a_μ^{had}

Direct integration of energy points for $\Delta\alpha^{(5)}_{had}(M_Z)$

Use of Adler function for $\Delta\alpha^{(5)}_{had}(-s_0)$

[F.Jegerlehner, NPPS. 181-182 (2008) 135-140; NPPS 162 (2006) 22-32]

Direct integration of energy points for a_μ^{had}



δR at 1% in $\sqrt{s}$ < 10 GeV $\Rightarrow$ improvement of ~3 in $\delta\alpha(M_Z)$

δR at 1% in the region $1<\sqrt{s}<$ 2.5 GeV (which is known with 6% accuracy) $\Rightarrow$ similar improvement on $\delta\alpha(M_Z)$

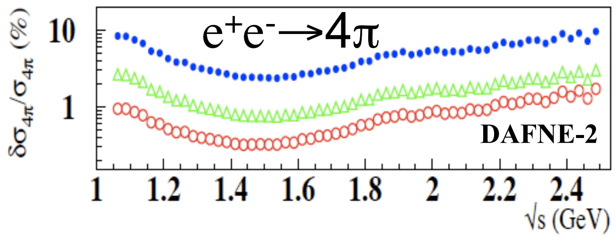
Region below 2.5 GeV
Extremely important!!!

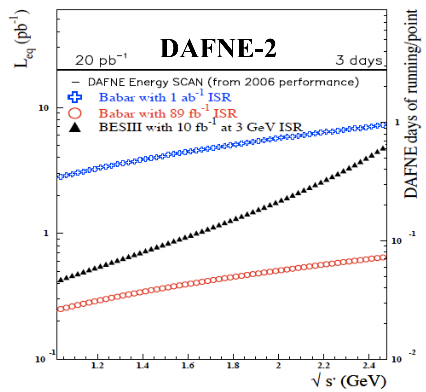
-**80%** of the total error on $\Delta\alpha^{(5)}_{had}$ (using Adler function)

- **95%** of the tot error on a_μ^{had}

Needs a dedicated experimental effort!

D. Babusci, et al **"Proposal for taking data with the KLOE-2 detector at the DAΦΦNE collider upgraded in energy"** **arXiv:1007.5219**

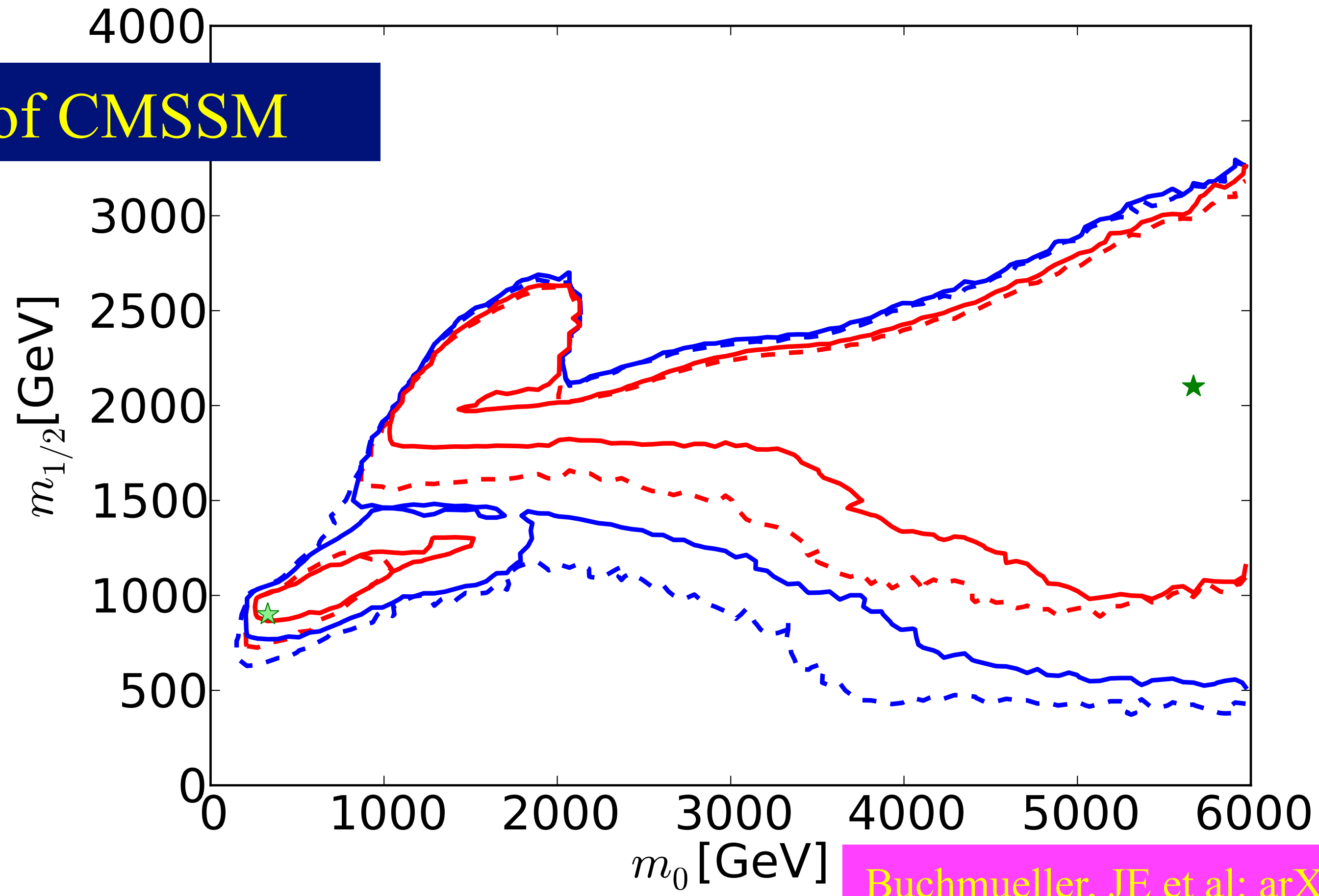




Post-LHC, Post-XENON100

2012 ATLAS + CMS with 20/fb of LHC Data

Scan of CMSSM

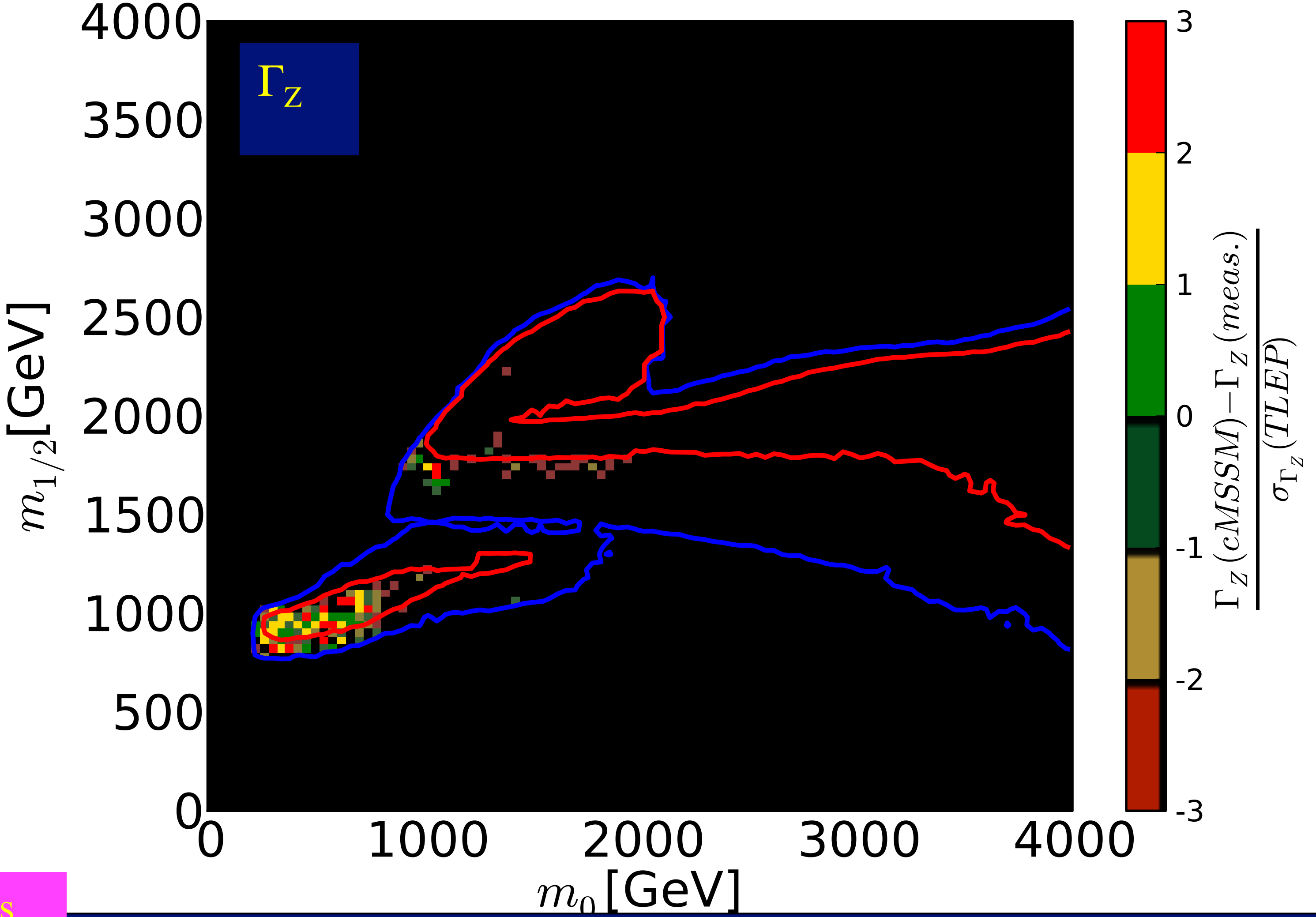


Buchmueller, JE et al: arXiv:1312.5250

Red and blue curves represent $\Delta\chi^2$ from global minimum, located at ☆

p-value of simple models ~ 5% (also SM)

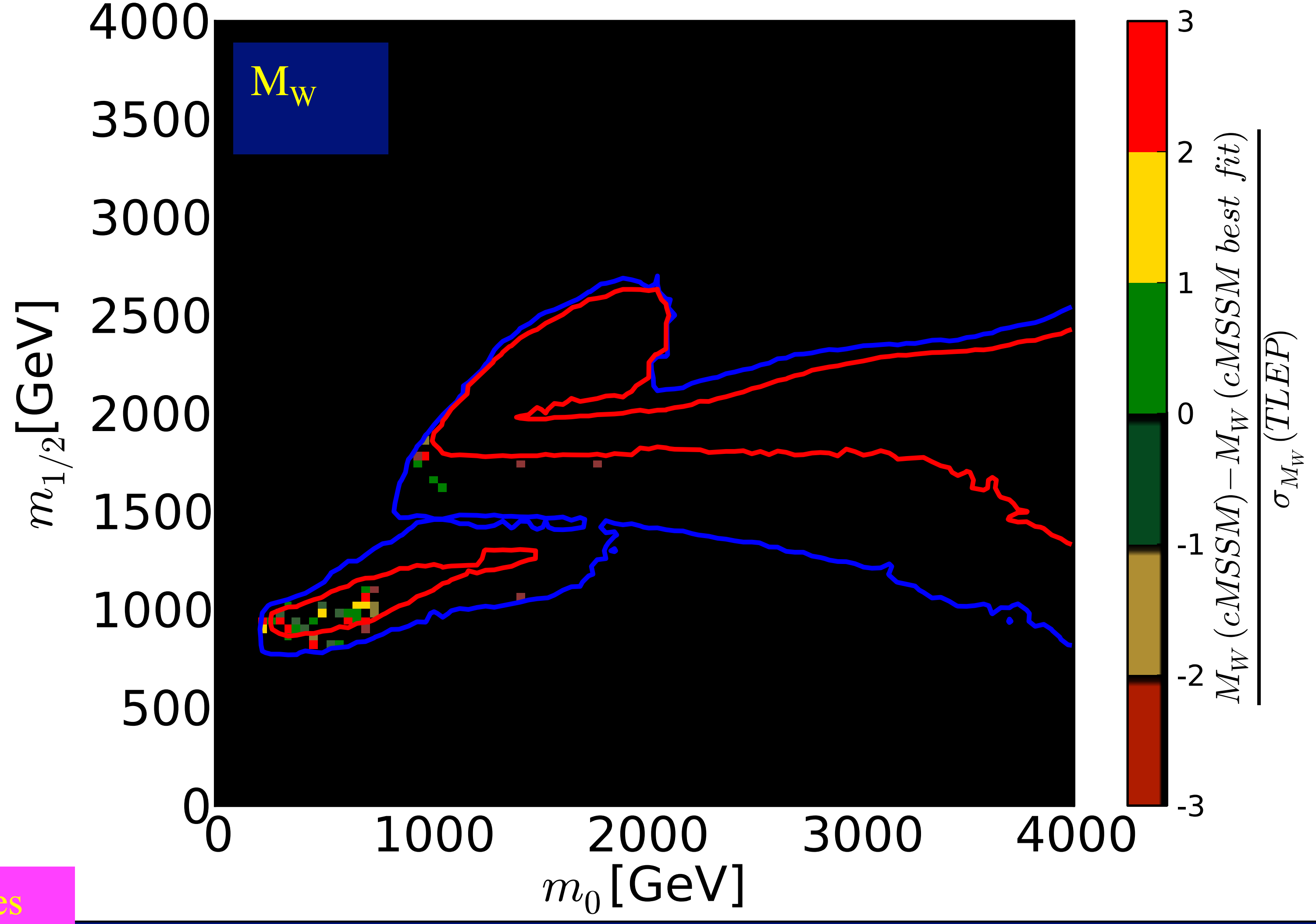
Impact of **FCC-ee** Precision on Susy



K. De Vries (MasterCode)

Γ_Z constraint on (m_0, $m_{1/2}$) plane in CMSSM:
Points within one, two, three TLEP σ of **low-mass best-fit** value

Impact of **FCC-ee** Precision on Susy



K. De Vries (MasterCode)

M_W constraint on (m_0, $m_{1/2}$) plane in CMSSM:

All points within one current σ of **low-mass best-fit** value

Workshop on the:
Long Term Strategy of INFN-CSN1
LTS1 2014 21-24 Maggio 2014 - Isola d'Elba

https://agenda.infn.it/conferenceDisplay.py?confId=7567

Gruppo di lavoro su QCD soffice e non-perturbativa

(coordinatori: Mauro Anselmino, Marta Ruspa, Luca Trentadue)

Eventi Diffrattivi a LHC, sezioni d'urto totali, elastiche,
Struttura del nucleone, TMDs, GPDs, fracture functions
DIS, SIDIS, Drell-Yan, esperimenti presenti e futuri
Quark-gluon plasma e nuovi stati della materia
Confinamento dei quark, stato e prospettive
QCD e reticolo, sviluppi recenti
Teorie Chirali e modelli,
Modelli di adronizzazione e di struttura degli adroni, ...

ad esempio il caso della :

Struttura 3-dimensionale del nucleone

nello spazio degli impulsi e delle coordinate

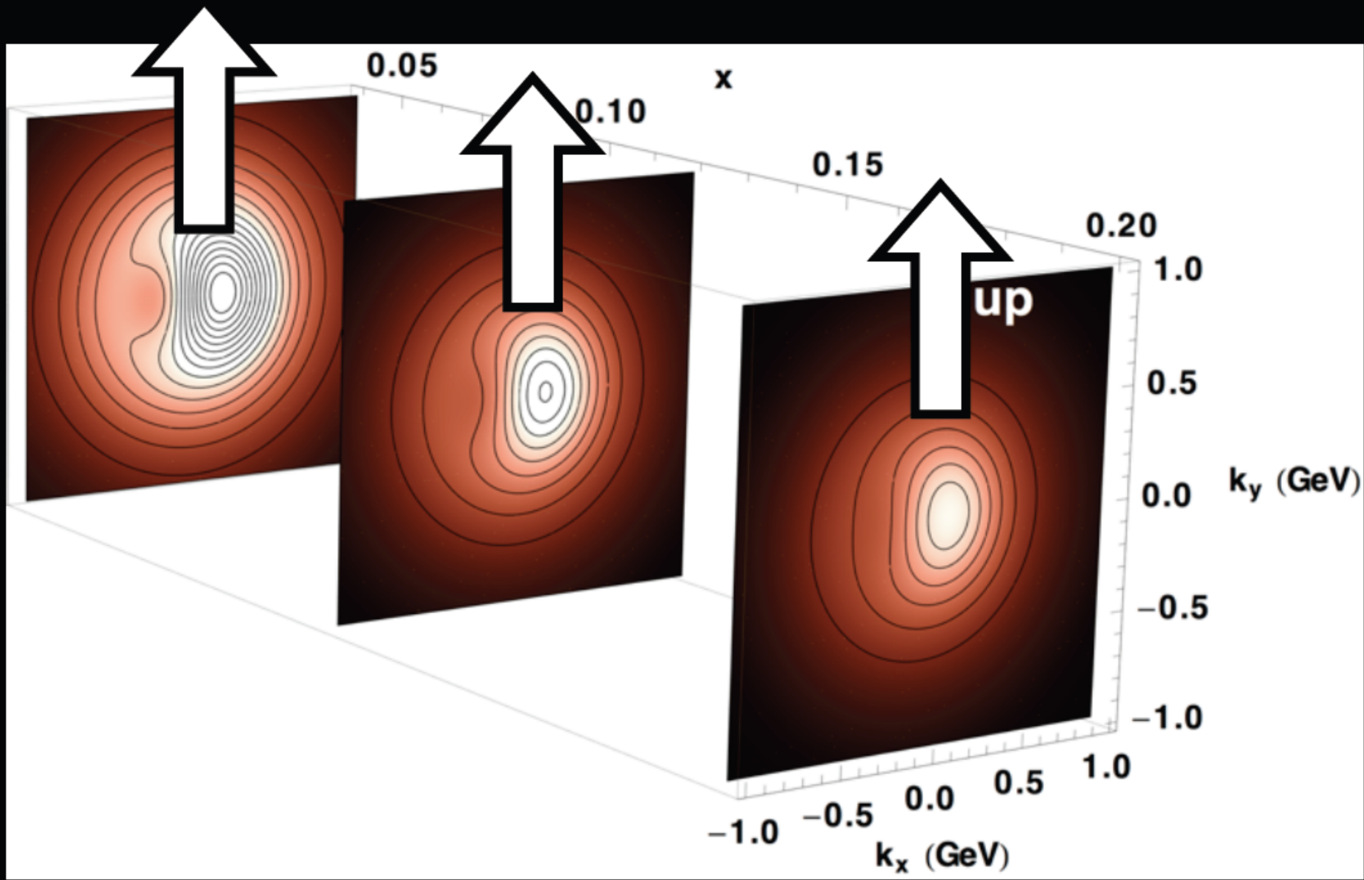
esperimenti dedicati: CERN-COMPASS, JLab, BNL-RHIC, KEK-Belle, EIC, ...
SIDIS, e+e-, Drell-Yan, pp → π X, ...

Spazio degli impulsi: Transverse Momentum Dependent parton distribution and fragmentation functions (TMDs); fracture functions

Spazio delle coordinate: Generalized Partonic Distributions (GPDs), collegate alla distribuzione spaziale dei partoni

Dati sperimentali;
informazioni sulle TMD e GPD;
modelli della struttura 3-dimensionale del nucleone, momento angolare orbitale dei partoni, effetti di spin, ...

esempio : il protone in moto lungo l'asse z, polarizzato lungo y; risulta una distorsione nella distribuzione in k_x dei quark *



* da parte di Alessandro Bacchetta

From the recommendations of the "European Strategy for particle physics"

The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the Field; the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.
A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.

From the recommendations of the "European Strategy for particle physics"

European theoretical physics has played a crucial role in shaping and consolidating the **Standard Model** and in **formulating possible scenarios for future discoveries**. **Strong theoretical research and close collaboration with experimentalists are essential to the advancement of particle physics and to take full advantage of experimental progress**; the forthcoming LHC results will open new opportunities for theoretical developments, and create new needs for theoretical calculations, which should be widely supported

From the Snowmass 2013 summary

The past successes of particle physics and its current central questions then call for a three-pronged program of research in collider experiments:

1. **We must study the Higgs boson itself in as much detail as possible, searching for signs of a larger Higgs sector and the effects of new heavy particles**.
2. **We must search for the imprint of the Higgs boson and its possible partners on the couplings of the W and Z bosons and the top quark.**
3. We must search directly for new particles with TeV masses that can address important problems in fundamental physics.