Assessment of the Higgs boson candidate: status and prospects

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Outline

- Summary of the Higgs searches status
- Higgs properties determination
- Projections for Higgs physics at the (HL-)LHC
- LHC issues for high precision Higgs measurements
- Higgs Factories

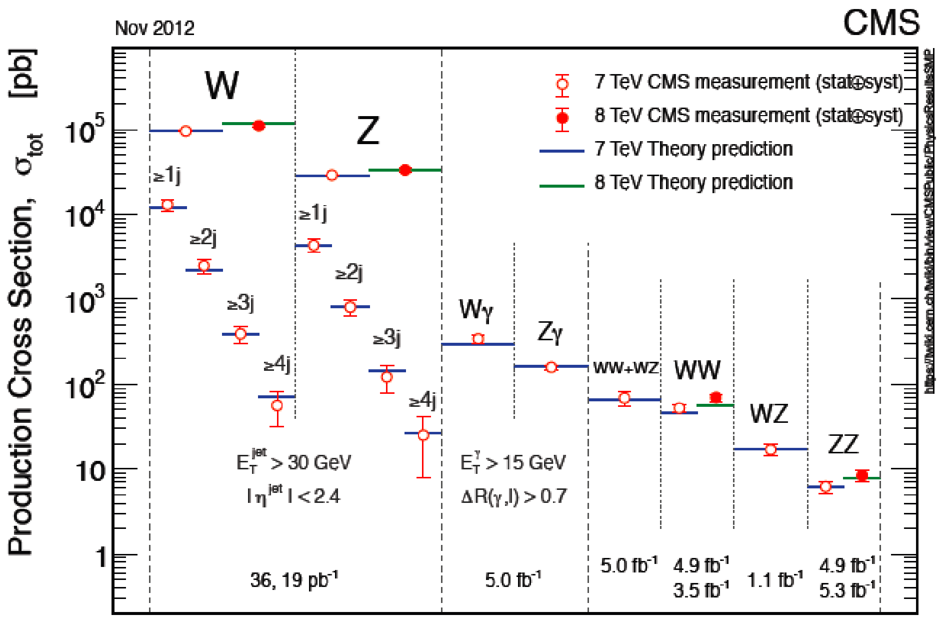
Disclaimer:

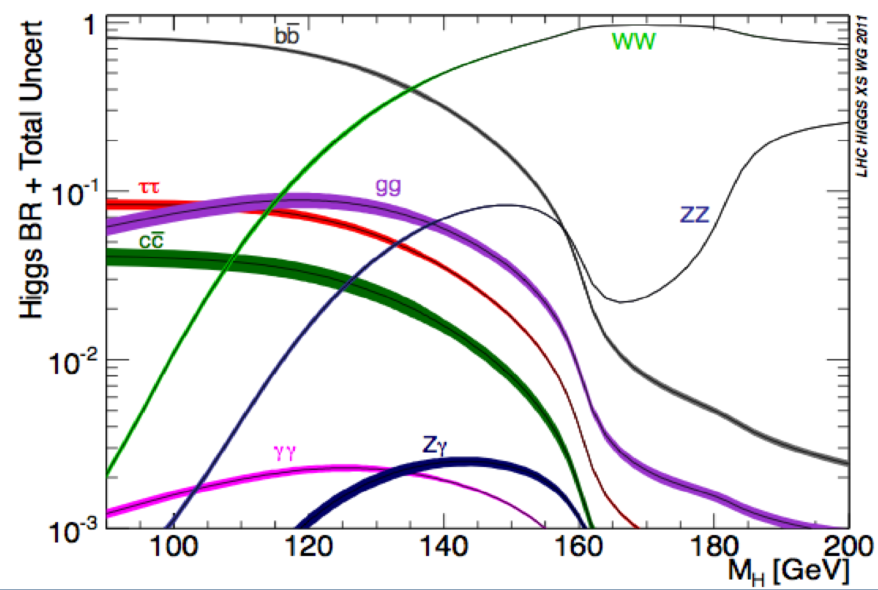
- I'm trying to follow a logical path, but I'll mention mainly things I worked on sometime zigzagging to expose them to your attention
- References in the backup, markers along the presentations

Higgs searches at LHC

Higgs at LHC

- LHC is a real Higgs factory:
  - σ(pp->H+X, √s=8TeV) = 20pb -> 0.2Hz at L=1e34 $cm^{-2}Hz$
  - σ(pp->H+X, √s=14TeV) = 50pb -> 1Hz at L=2e34 $cm^{-2}Hz$
- But background (both QCD and EWK) is many orders of magnitude larger
- Lucky to be around 125 GeV, most of the decay modes accessible both trigger and analysis wise

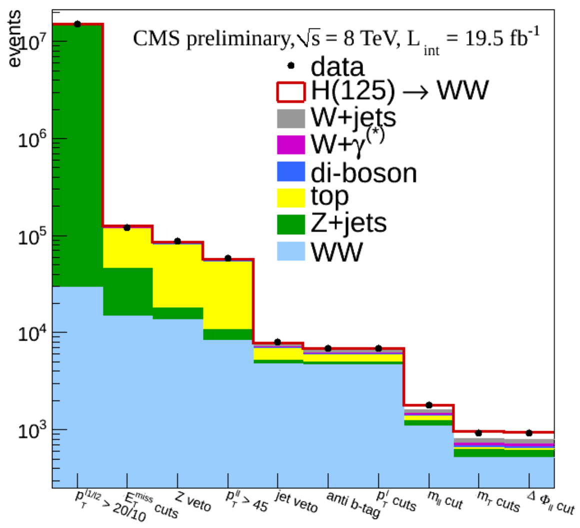




Higgs signal extraction

- We know exactly what to search for:
  - No undefined parameters other than the Mass
  - Signal model only affected by the precision of theoretical calculations
    - Production: ~15% for QCD processes (gluon fusion), ~4% for EWK (VH and VBF)
    - Decay: ~5%
- Define phase space region where signal is enhanced
- “Easy” and intuitive when invariant mass of well measured objects can be used:
  - H->ZZ:
    - Low event rate (signal and background), high S/B
    - Background shape from MC (ZZ continuum) and from data (fakes)
  - H->$\gamma\gamma$:
    - Low S/B but background entirely determined from sidebands
  - Mismodelling of efficiencies and resolutions leads to bias on signal strength
    - Watch out for other statistical subtleties like Bill Murrey’s effect
- Tough in all the other cases, some reliance on MC can’t be avoided

H->WW->2l2ν 1.a



- No sharp peak in any phase space corner
  - Enhancement for small opening angles between leptons (spin-correlation)
- Several competing backgrounds, the contribution of each of those have to be evaluated
  - WW, top, W+jets, dibosons (WZ,ZZ, Wγ*), DY
- Analysis strategy:
  - Per final state (number of jets, leptons flavor) identify phase space region with decent S/B
  - Define procedures for background normalization from data
  - When possible rely on background shape in the fit procedure, otherwise cut&count

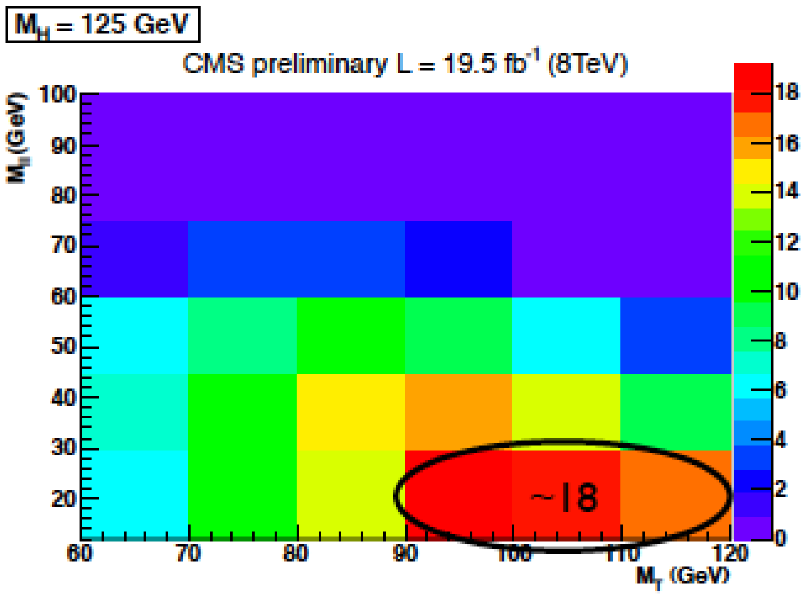
Background from the fit

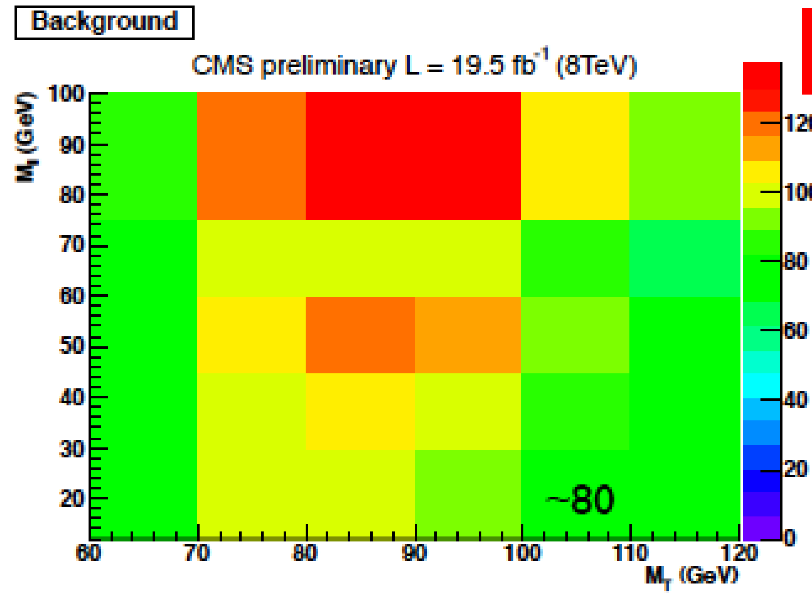
1.a

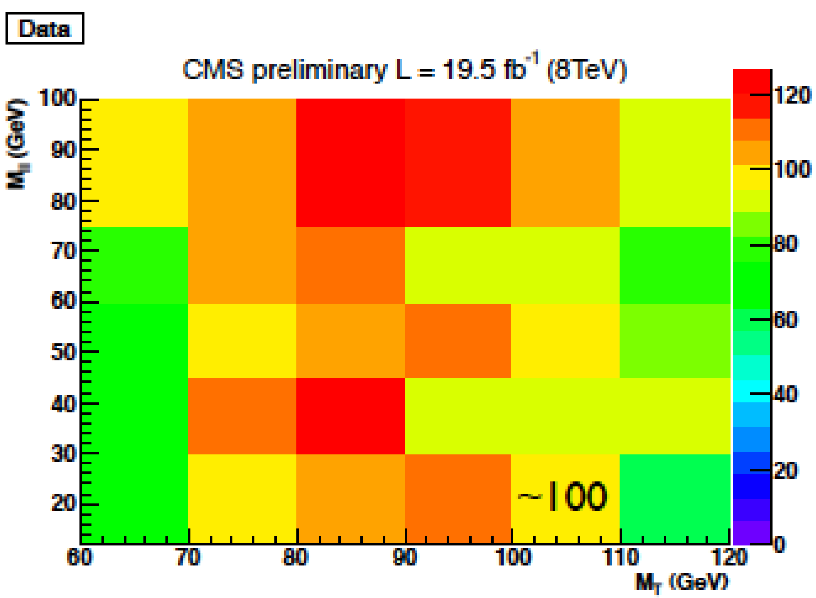
- Idea (imitating channels with peaks):
  - do not squeeze too much signal region
  - allow the fit constraining the background normalization from sidebands
  - Rely on MC for the background shape
- Multivariate analysis (BDT) typically provides best signal-bkgd discrimination, but shape is completely unpredictable and boundary conditions dependent
- Use 2D shapes instead with physically meaningful variables
  - m_{ll} and m_T for H->WW
- Background shape uncertainties:
  - Compare different MC programs (relying on different approaches) and vary scale parameters
  - Check dependency from nuisance PDF
- Cross check with cut-based analysis when possible

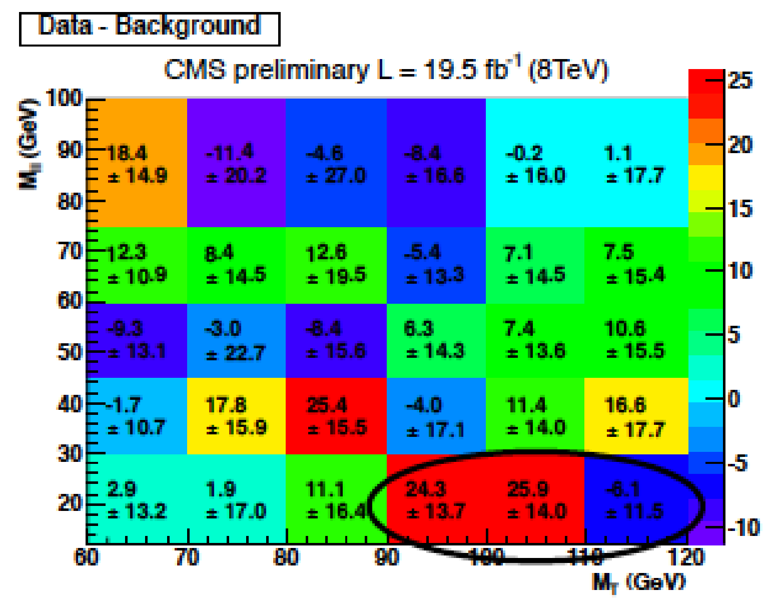
H->WW 2D fit

PAS

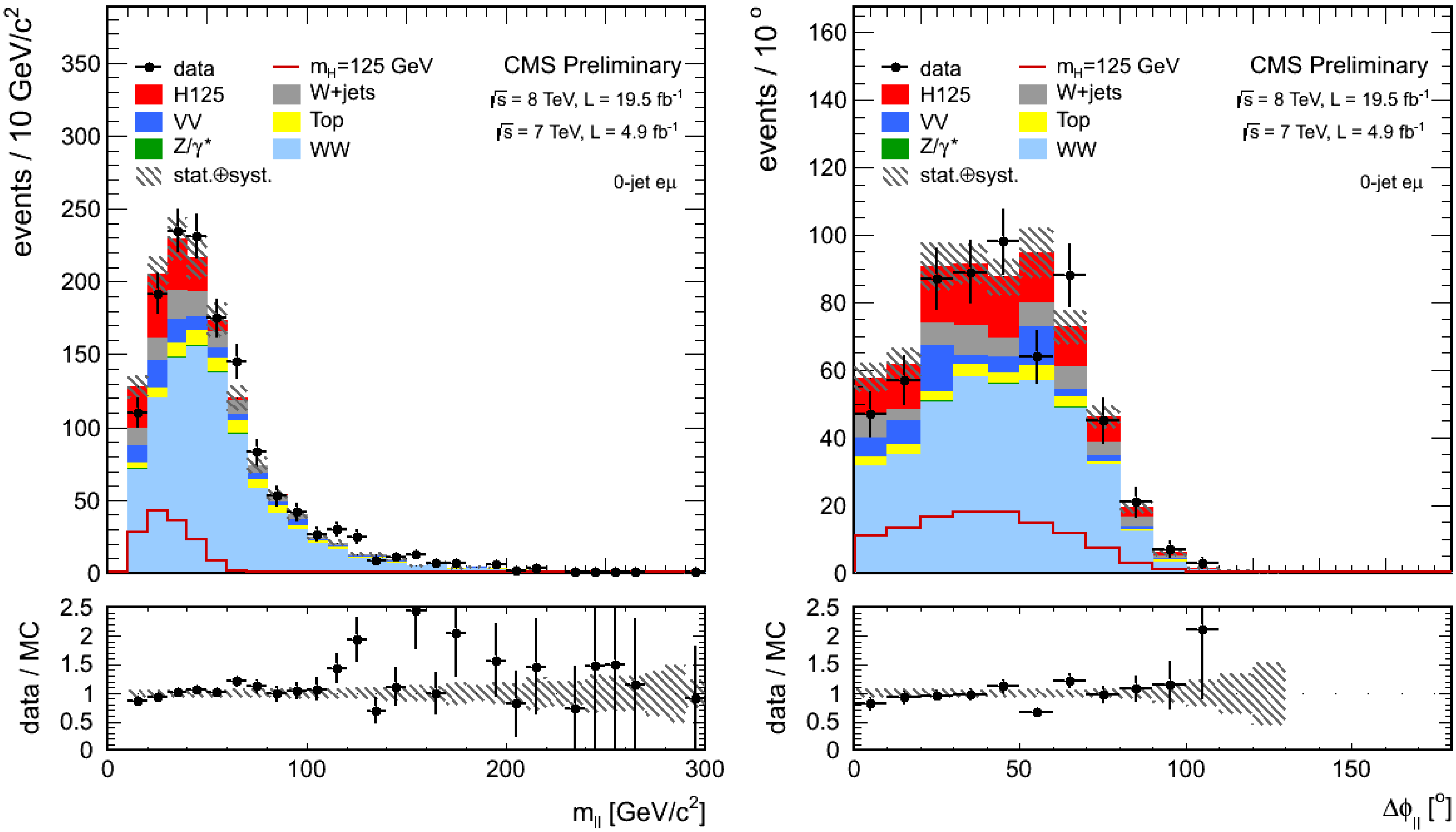








H->WW cut&count check

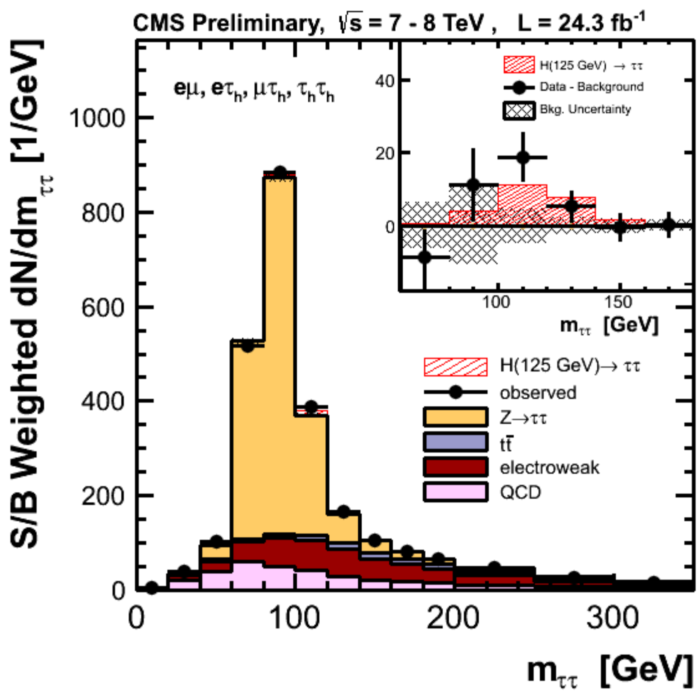


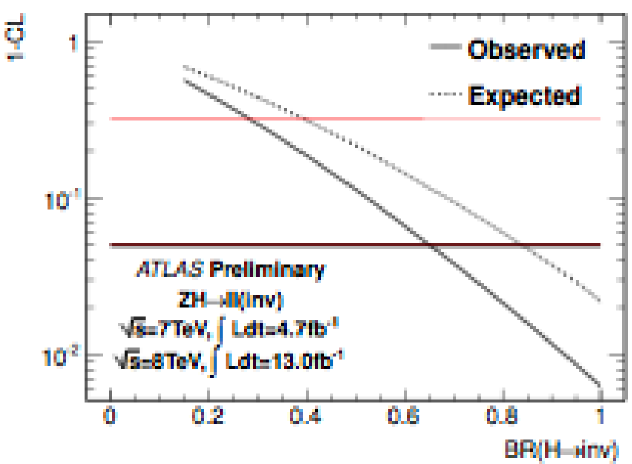
Results from Moriond

- H->WW:
  - ATLAS: expected=4.4σ, observed=6.1σ, μ=1.0$\pm$0.3 @124.3 GeV
  - CMS: expected=5.1σ, observed=4.0σ, μ=0.76$\pm$0.21 @125 GeV
- H->ZZ:
  - ATLAS: expected=4.4σ, observed=6.1σ, μ=1.7$\pm$0.4 @124.3 GeV
  - CMS: expected=7.2σ, observed=6.7σ, μ=0.9$\pm$0.25 @125.8 GeV
- H->$\gamma\gamma$:
  - ATLAS: expected=4.1σ, observed=7.4σ, μ=1.65$\pm$0.35 @126.5 GeV
  - CMS:
    - MVA: expected=4.2σ, observed=3.2σ, μ=0.8$\pm$0.27 @125 GeV
    - CiC: expected=3.5σ, observed=3.9σ, μ=1.1$\pm$0.32 @124.5 GeV
- H->$\tau\tau$:
  - ATLAS: still quoting limits, no significant excess observed
  - CMS: expected=2.62σ, observed=2.85σ, μ=1.1$\pm$0.4
- H->bb
  - ATLAS: still not sensitive (1.9xσ_{SM}), no deviation from bkgr only hypothesis
  - CMS: (no update), expected=2.0σ, observed=2.2σ, μ=1.3$\pm$0.6
- Others:
  - H->Invisible (ATLAS):BR<0.65 at 95% CL

Status after Moriond

- Signal well established, overall consistency with SM.
  - JCP results led to the "We have A Higgs Boson" press release
- Couplings to leptons also at ~3σ level
- A few 2σ effects here and there
  - e.g. ATLAS masses
- CMS results systematically better than ATLAS' in terms of expected sensitivity
  - This depends on how much reliance is put on the shapes
    - E.g. WW background for H->WW, kinematical discriminants for H->ZZ
  - CMS too aggressive or ATLAS too conservative?





Higgs couplings determination

Physics framework

2.a

- Goal: assess the compatibility of data with SM Higgs hypothesis
  - No specific assumptions on new physics
- Rely on the interim recommendations issued by the LHC Higgs XS working group:
  - **LHC HXSWG interim recommendations to explore the coupling structure of a Higgs-like particle,** *A. David, M. Zanetti et al.*, arXiv:1209.0040
- Assumptions:
  - Just one single narrow resonance
  - Higgs Width Γ_H is negligible, zero-width approximation is used:

$$\sigma \cdot BR(ii \rightarrow H \rightarrow ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_H}$$

- (For the moment) Only modifications of the coupling strengths are allowed, the SM tensor structure is assumed
  - The signal is a CP even scalar
- Personal remark: Current approach to Higgs spin analysis not so appealing..

Coupling scale factors

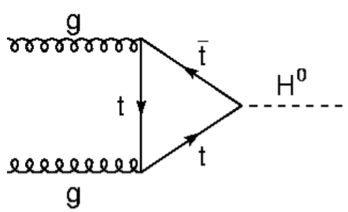
- A set of κ to scale the SM production cross sections and decay widths
  - SM predictions as from the LHC XS Yellow Reports (arxiv:1101.0593)

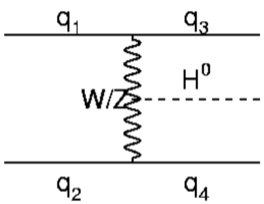
$$\sigma \cdot BR(ii \to H \to ff) = \sigma_{SM} \cdot BR_{SM} \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}$$

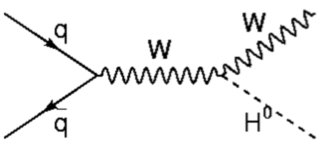
- Partial widths not detectable at LHC via proxies to detectable ones
- Scaling for couplings through loops defined either
  - As function of scale factors for the fields in the loop
  - As additional free parameter
- Total width can be either take as the sum of the partial widths or as additional degree of freedom
  - In the latter make other assumptions, i.e. κ_V<=1

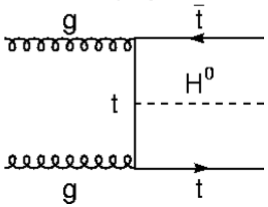
Analyses to Couplings

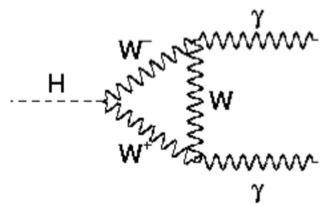
- Map exclusive production-decay chains to scale factors
  - Contamination across modes estimate from MC
- Group κ factors together to reduce the degrees of freedom in the fit

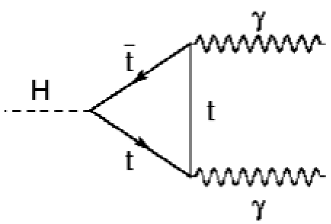






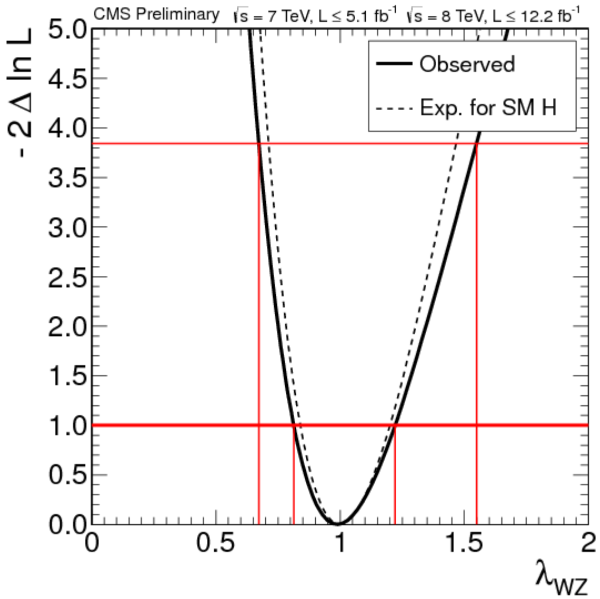


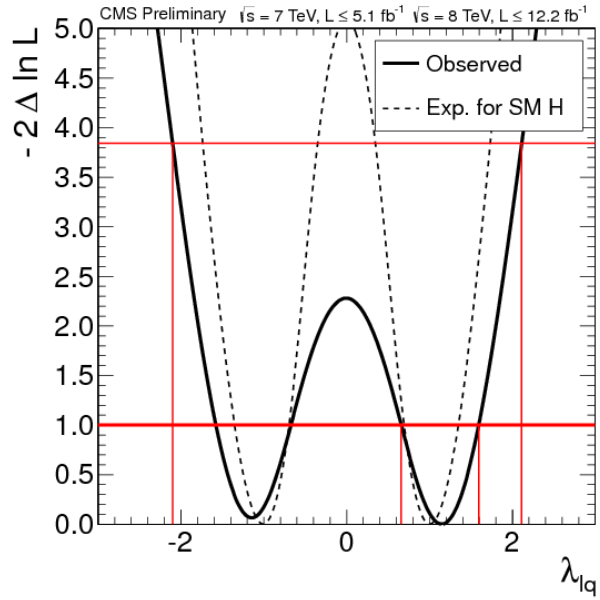


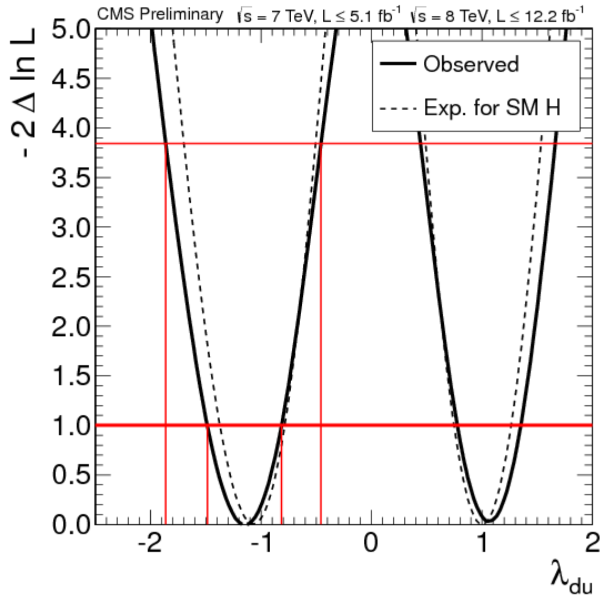


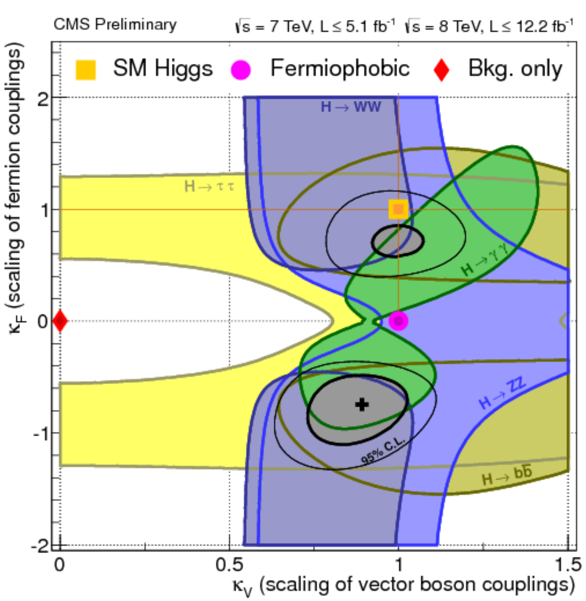
	Untagged	VBF-tag	VH-tag	ttH-tag
H→γγ	✔	✔		
H→bb			✔	✔
H→ττ	✔	✔	✔	
H→WW	✔	✔	✔	
H→ZZ	✔			

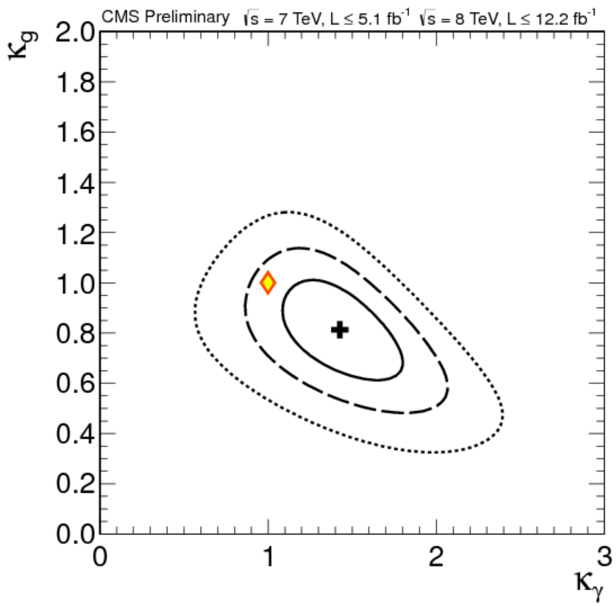
Coupling fit results





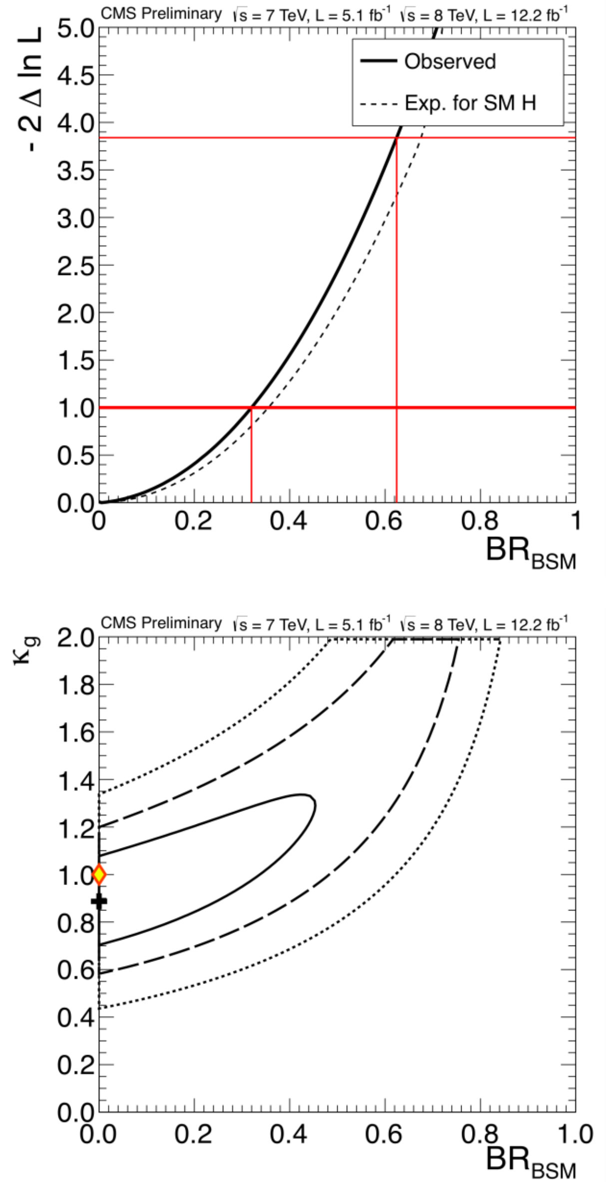






Total width

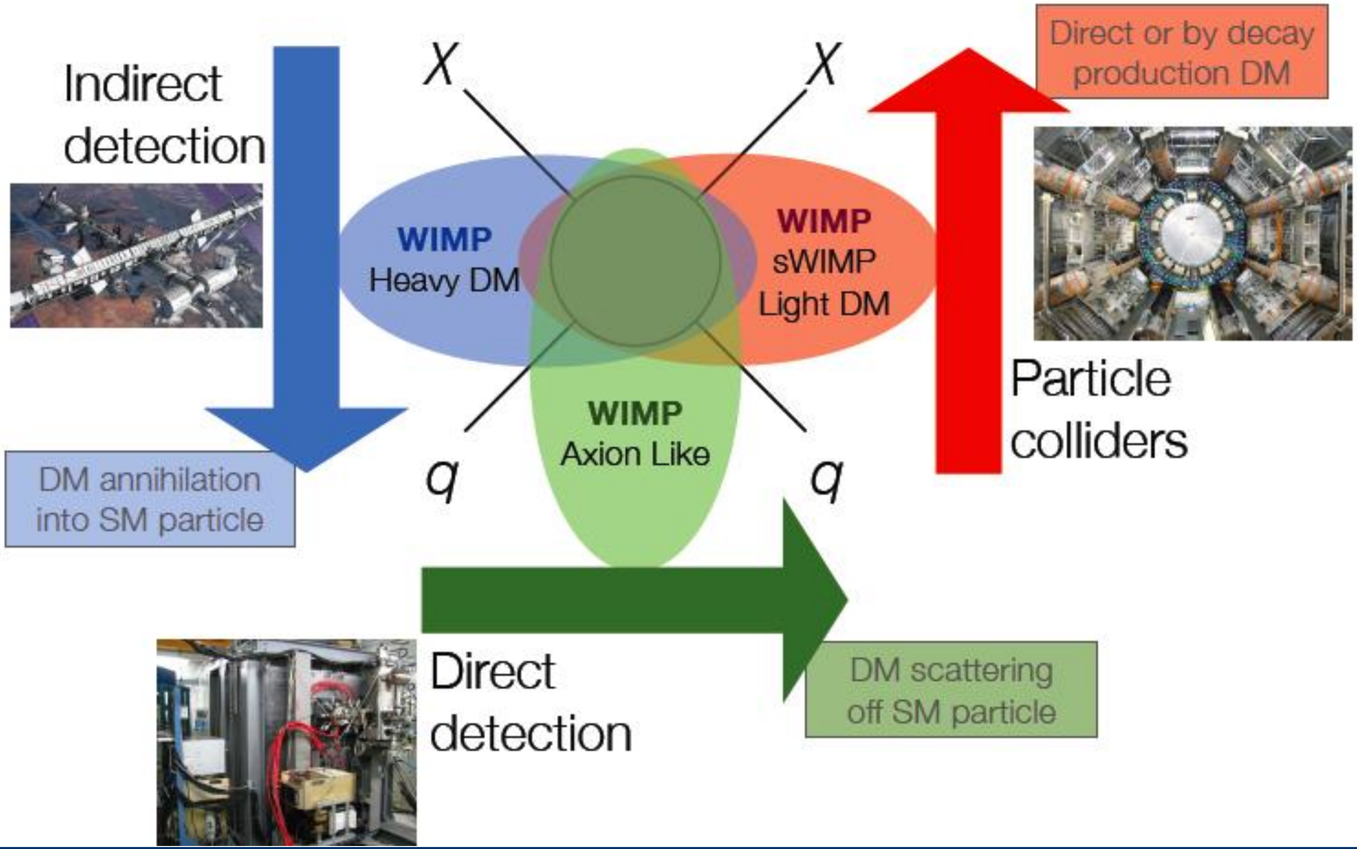
- Cannot be measured at the LHC without assumptions (convince yourself)
- So far assumed to correspond to the sum of the measured/inferred partial widths
  - Rely on SM for channels out of reach (e.g. charm):
    - Take direct SM prediction
    - Tie the given coupling to others of the same kind (e.g. charm->top)
  - No BSM decay allowed
- In the current measurement the latter hypothesis is relaxed and Γ_{inv} is fit together with k_γ and k_{glu}



Higgs and Dark Matter

Digression

- Higgs could mediate interaction between DM and SM fields
- Many options for DM (WIMP):
  - Spin0 -> Inert Doublet, Spin ½ -> Susy inspired, Spin 1 ->KK photon



Invisible Width

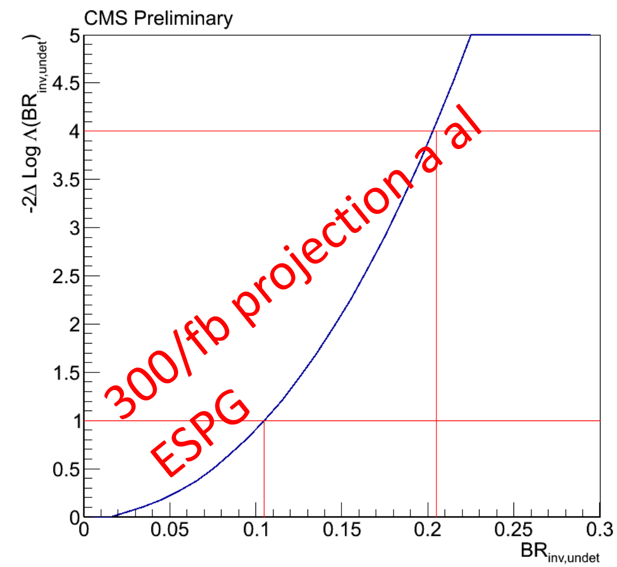
- Alternative hypothesis can be taken, e.g. k_V<~1 (quadratic scaling of the bound)
  - Very well justified in most of the BSM models, e.g. extra Higgs multiplets tighten the constrain
- Considering e.g. WH->WW:

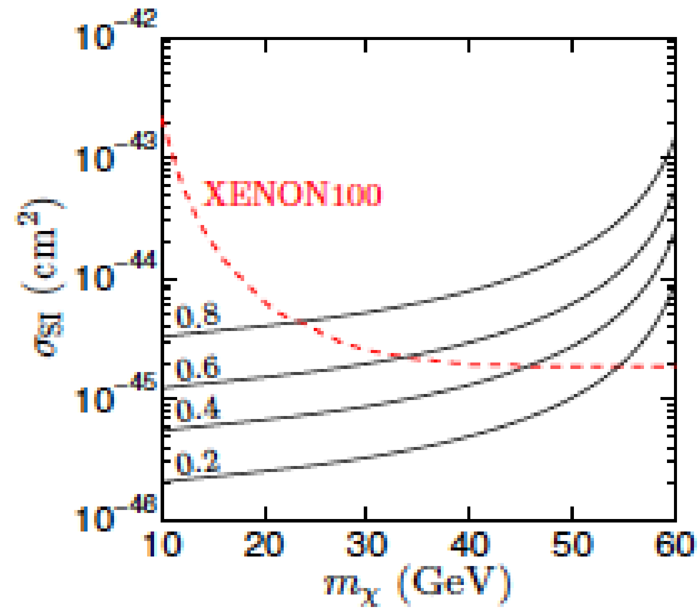
$$\frac{\kappa_W^4}{\kappa_T^2} = r \Rightarrow \kappa_T < \frac{1}{\sqrt{r}}$$

- Allows fitting for the total width:

$$\kappa_T = \kappa_{Inv} + \sum_{i \in SM} \kappa_i$$

- This in combination with direct H->Inv searches competes with direct DM searches

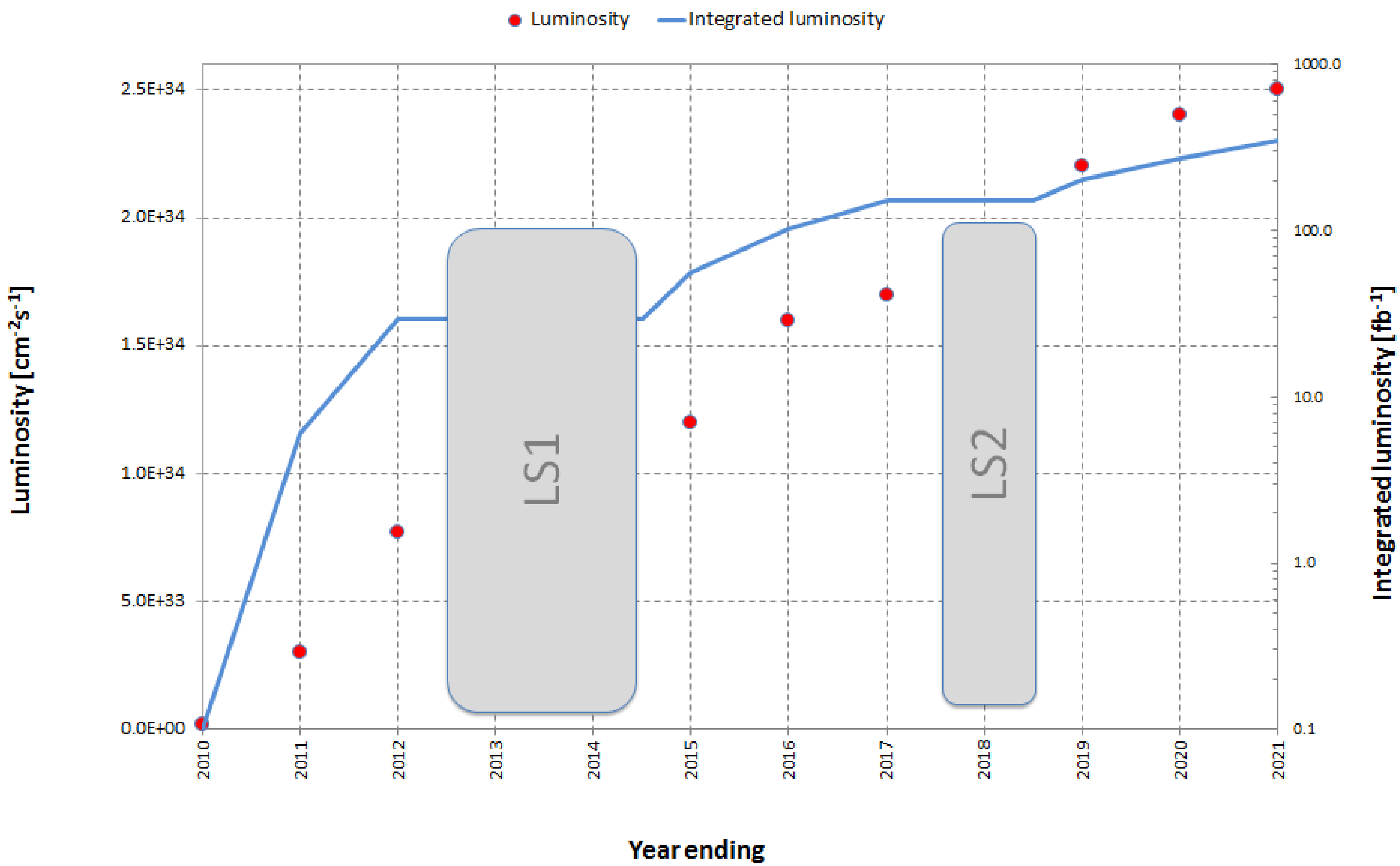




Projections

(HL-)LHC schedule

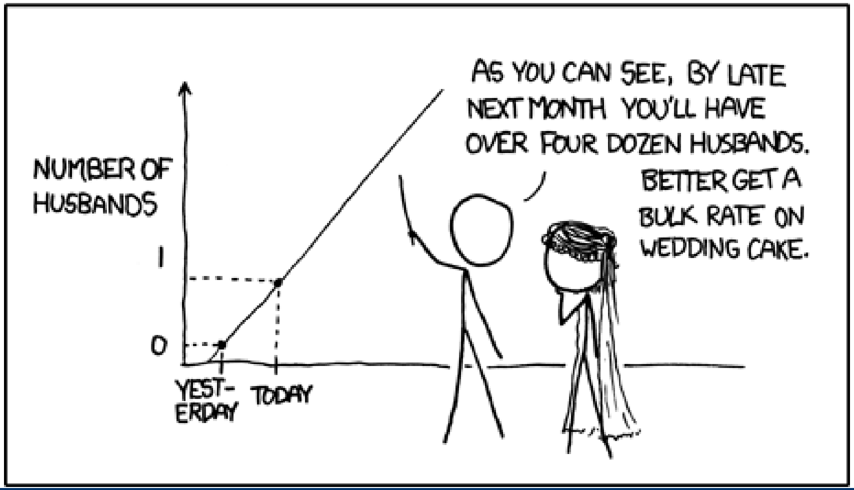
- ~300/fb assumed by the end of the LHC run
- HL-LHC should take over from then on, till up to 3/ab
  - Supported by Strategy group, but not yet endorsed



Projections

- In the context of the CMS Higgs study for European Strategy group (October 2012)
- Benchmarks: L=300/fb and L=3000/fb at √s=14 TeV
- Base assumption is that the tougher environmental conditions (luminosity, in and out of time pileup) will be balanced by the upgraded detector
- Three scenarios for systematic uncertainties:
  1. Identical as for L=10/fb
  2. Theoretical syst. halved, experimental syst. Scaled as 1/√L
  3. Theoretical syst set to 0
- Very little level arm: extrapolation from results based on L=10/fb

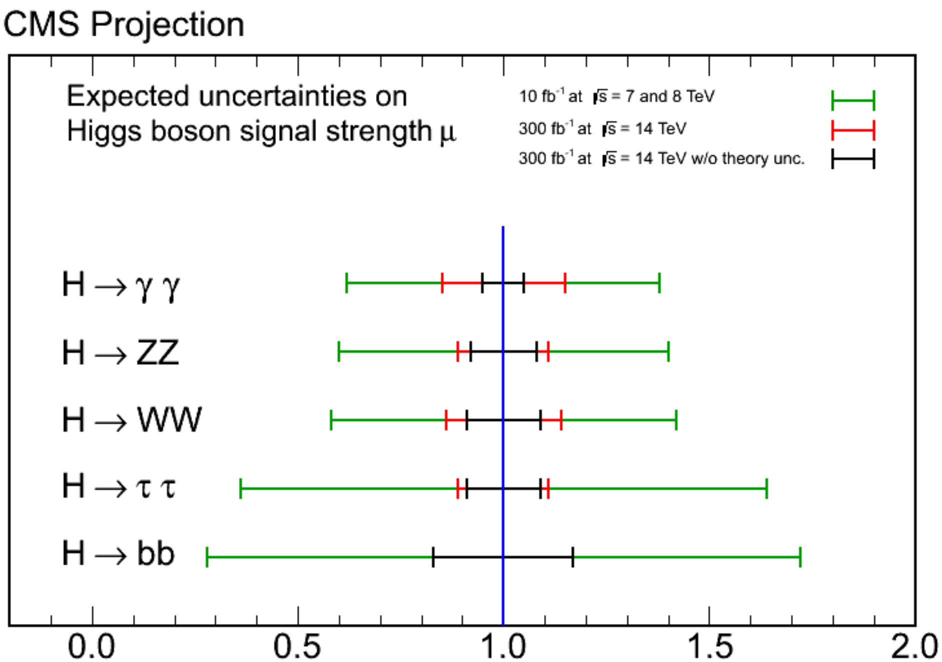
MY HOBBY: EXTRAPOLATING



CMS results

3.a

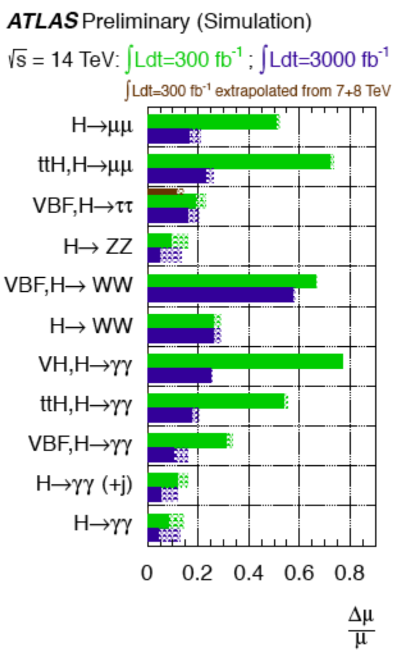
- Report results for each (accessible) coupling scale factor and for the uncertainty on the signal strength for the main modes
- 5-15% uncertainty on the couplings

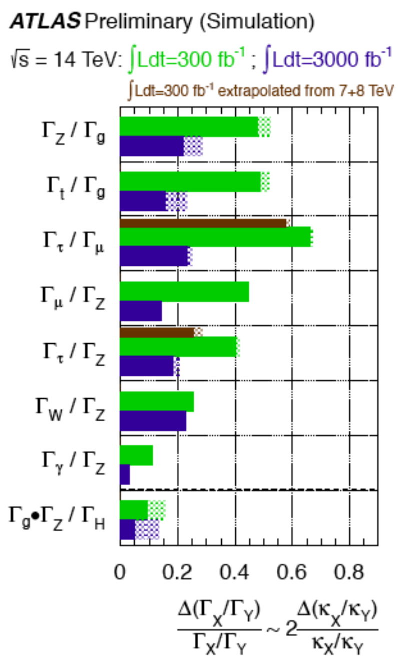


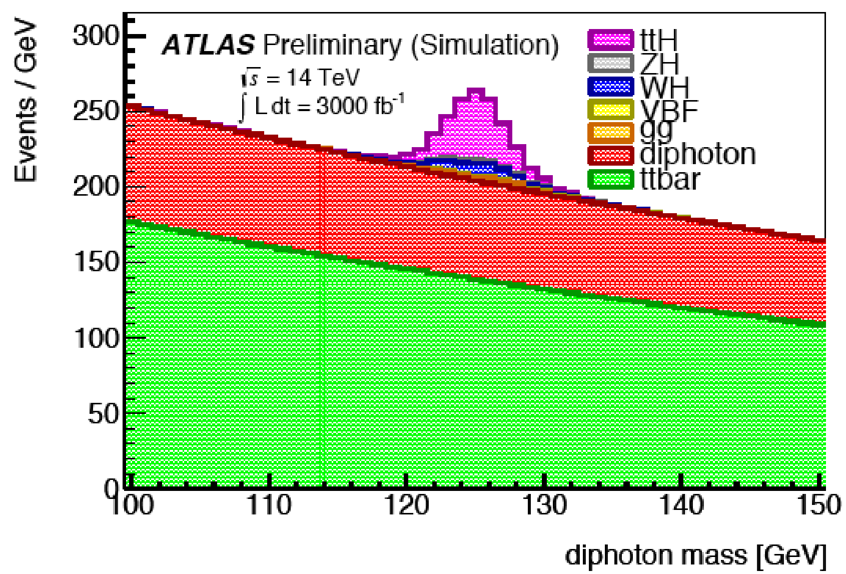
Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

Caveats

- We had not yet idea how the analyses will look like by then
  - ATLAS WW doesn’t scale already now, this cannot be..
  - But in several cases sensitivity saturation could occur before 300/fb
- Several exclusive channels not fully included yet, but will play an important role in coupling determination
  - Main example is Higgs self coupling
- Fundamental difference in couplings determination w.r.t e+e-







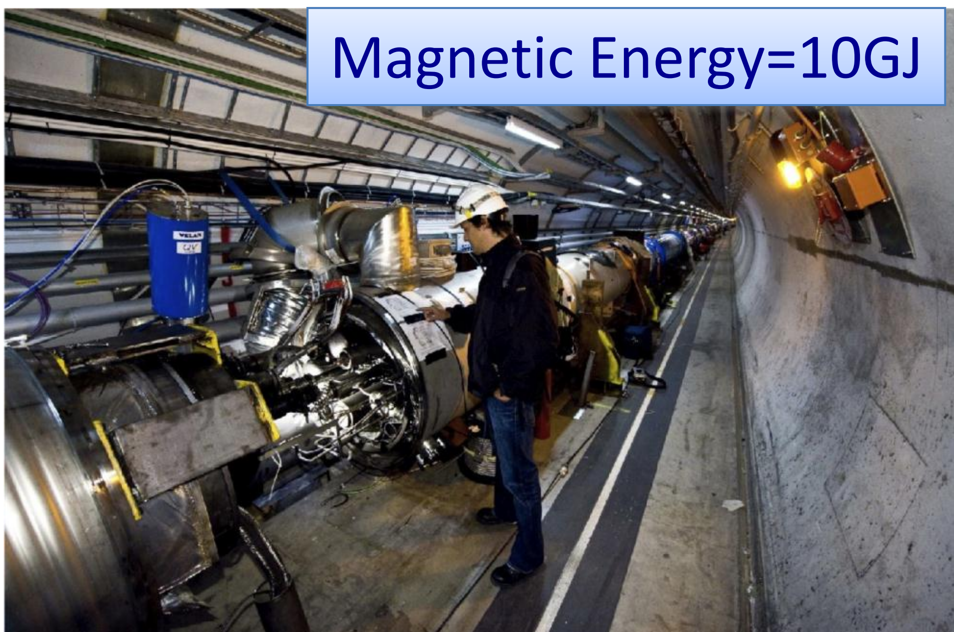
LHC challenges for Higgs precision physics

Do not forget Sep 19th 2008

- During the last step of the of the tests on the last superconducting circuit
  - Bad superconducting joint surrounded by a bad copper stabilizer
  - Ohmic resistance developed, producing electrical arc, releasing violently tons of liquid He
- >1km of the machine severely damaged (54 magnets substituted)

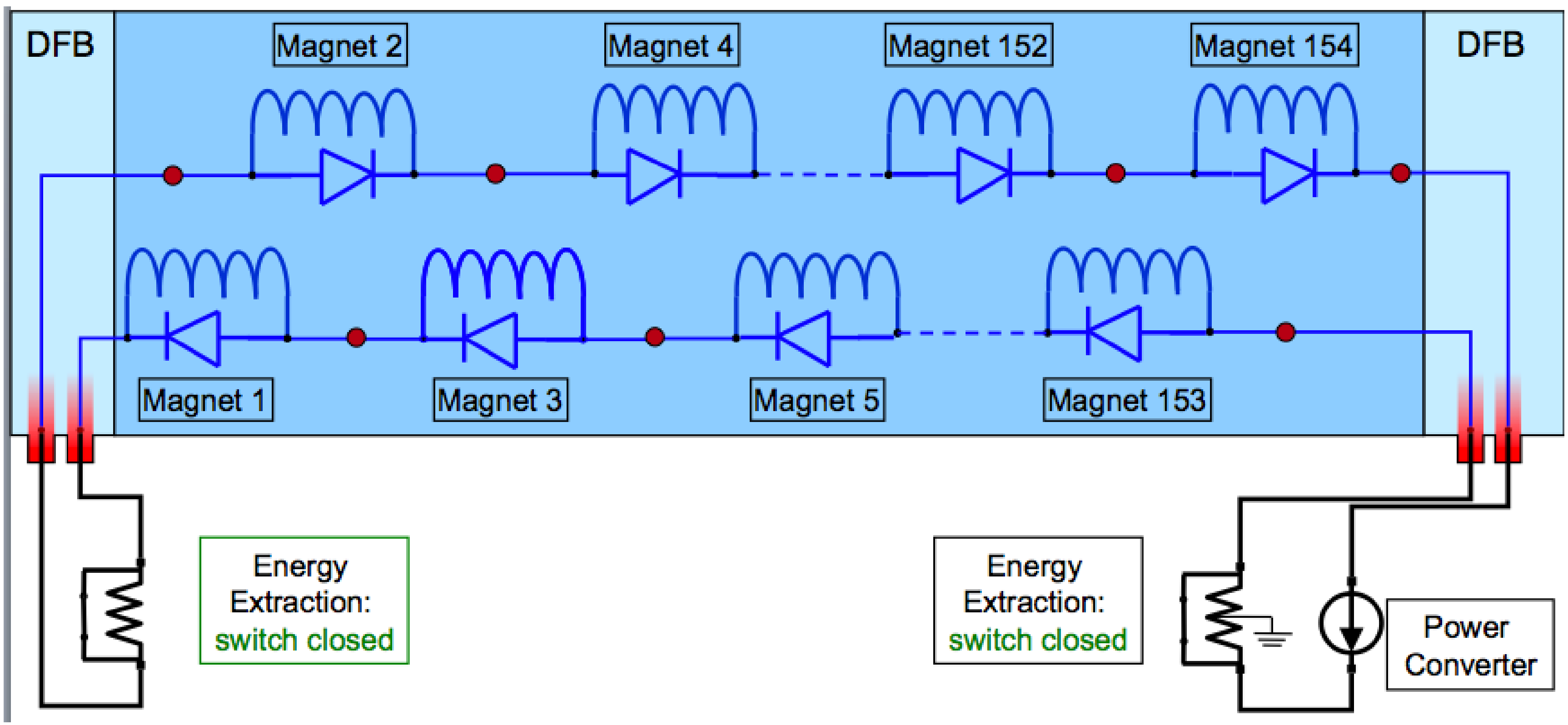
Magnetic Energy=10GJ

Beam Energy=300MJ



Quench in the LHC

Digression



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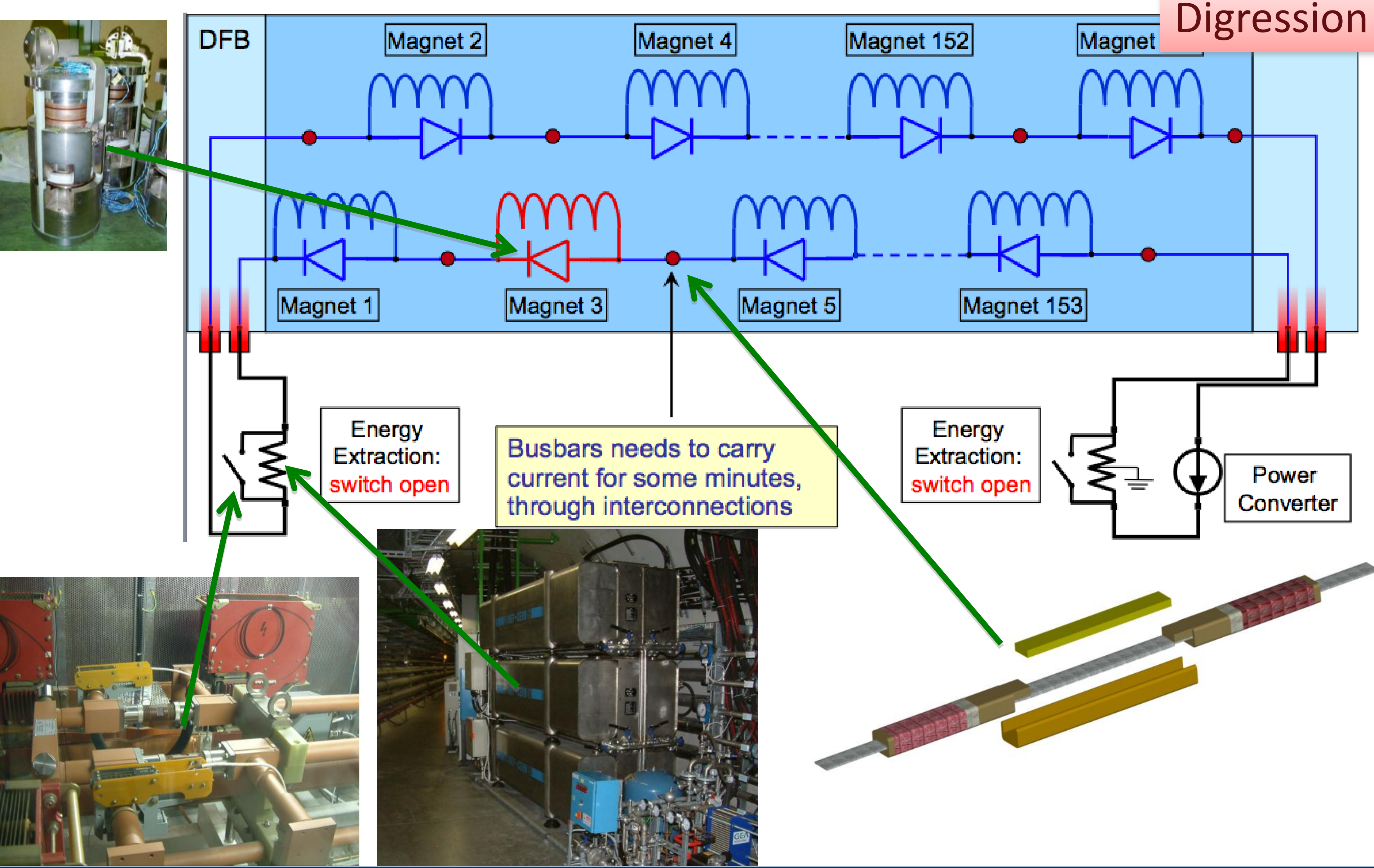


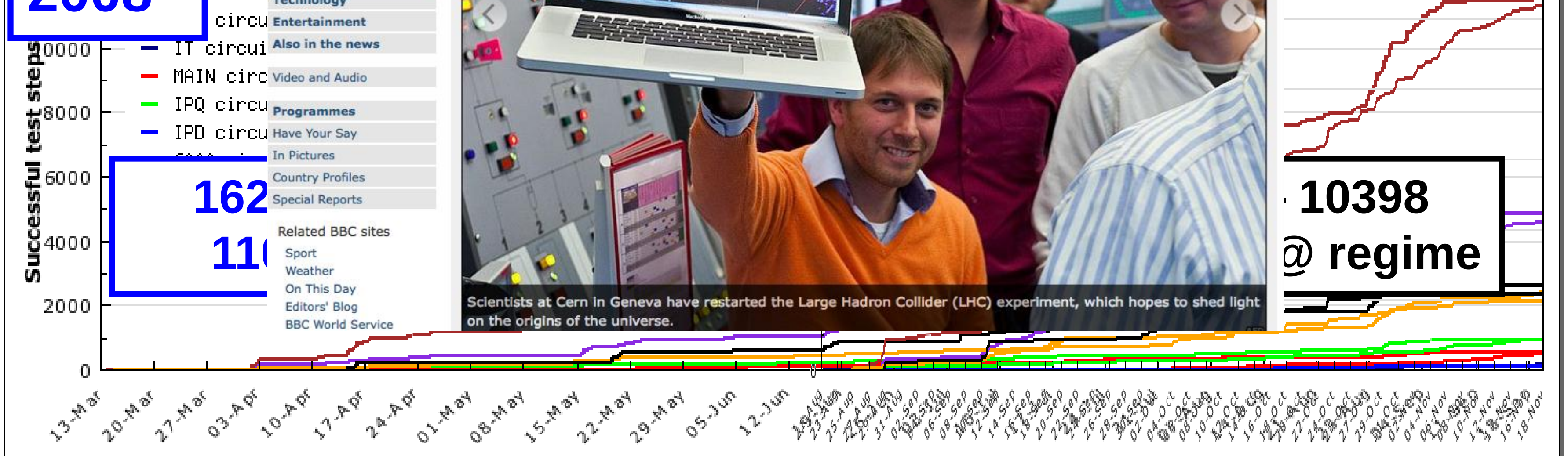
What has been done

4.a

Digression

- Forget nominal energy:
  - Cannot assess max excessive resistance at cold
  - Extrapolated value (~20k splices, only ~100 measured) did not allow excee
- Installati ore suited Quench
- Measure
- Electrica
- Powerin ated at 4 TeV

4.b



Consolidation during LS1

Getting back to 14 TeV?

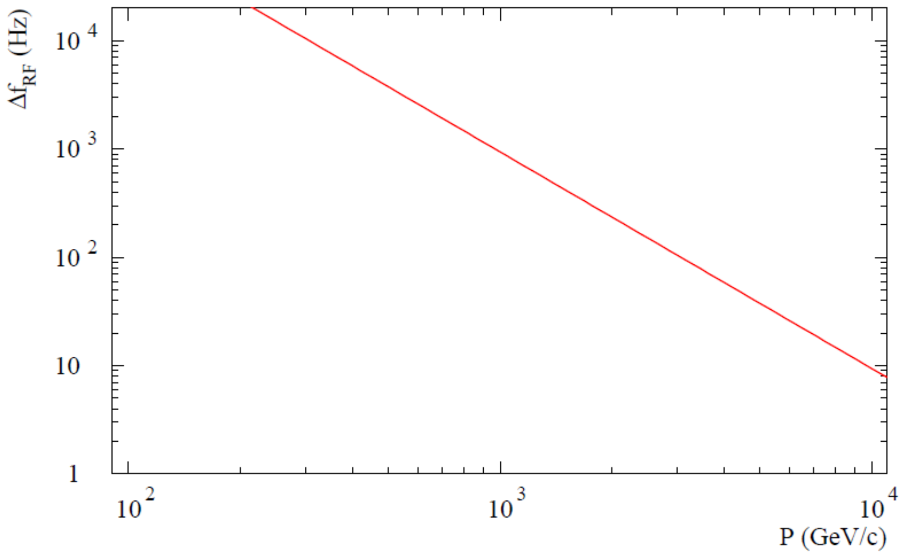
- Magnets coming from the damaged sector do not show degradation in performance
- Best estimates to train the LHC (with large errors)
  - ~30 quenches to reach 6.25 TeV
  - ~100 quenches to reach 6.5 TeV
- Bear in mind that each quench is a turbulent event..
- The plan
  - Try to reach 6.5 TeV in four sectors in March 2014
  - Based on that experience, we decide if to go at 6.5 TeV or step back to 6.25 TeV in March 2014
- During operations Machine Protection needs to be re-qualified
  - Other effects (radiation to electronics, UFO, etc) can harm perfomances

Beam Energy Calibration

- The beam energy is calibrated using p-Pb and Pb-p runs
- The momentum of the protons is estimated by comparing the difference in the RF frequencies for the two species
  - In practice one measure the difference in the orbit once the same RF frequency is set for the two

$$P \cong m_p c \sqrt{\frac{f_{RF}^p}{2\Delta f}(\mu^2 - 1)}$$

- Precision scale as 1/p (null in the relativistic limit)
- Currently the uncertainty is quoted to be 2.5%
  - Aiming at ~1% after full processing of p-Pb run data
- $\delta E/E=2.5\%$ => $\delta\sigma/\sigma>10\%$ for the Higgs at 13 TeV!!

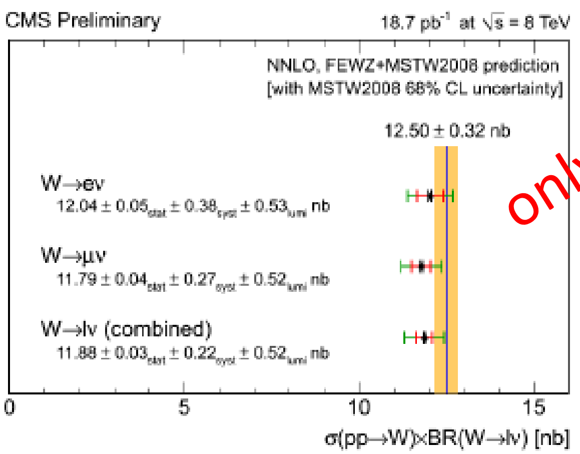


W and Z cross section @ 8TeV

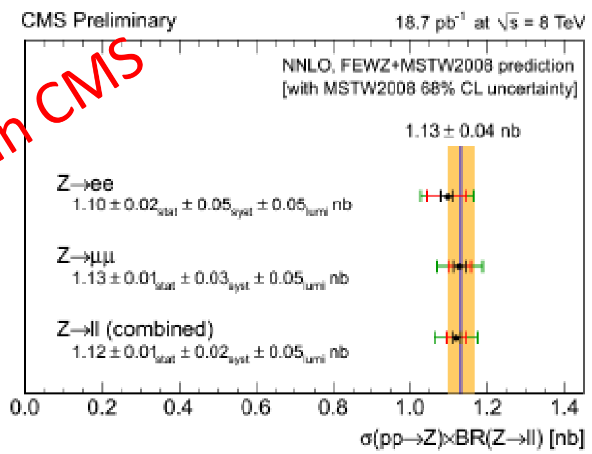
Digression

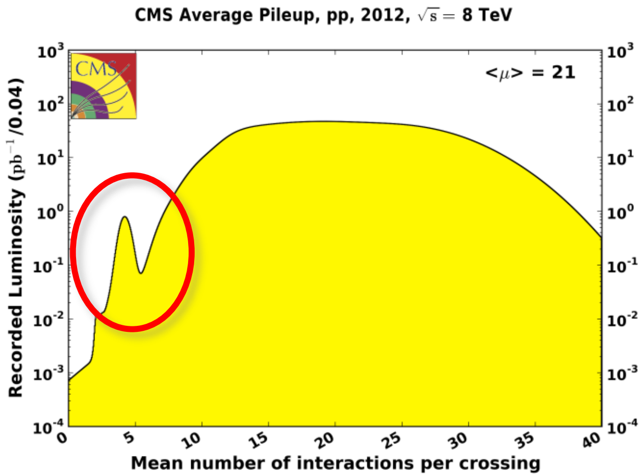
7.a

- Luminosity in 2012 makes the measurement unfeasible:
  - High PU => large uncertainty on MET modeling
  - High lumi => L1 trigger threshold too tight
- Idea:
  - Separate the beams at IP5 and level lumi at μ=5
  - Dedicate trigger menu to allocate high rate to single leptons
  - Profit from LHC beam current increase not too loose too luminosity
  - 2kHz on disk, same statistics (~25/pb) as measurement at 7 TeV
- Beam energy uncertainty matters:
  - Difference in acceptance~0.5%
  - Difference in absolute xsec~2.5%



only in CMS

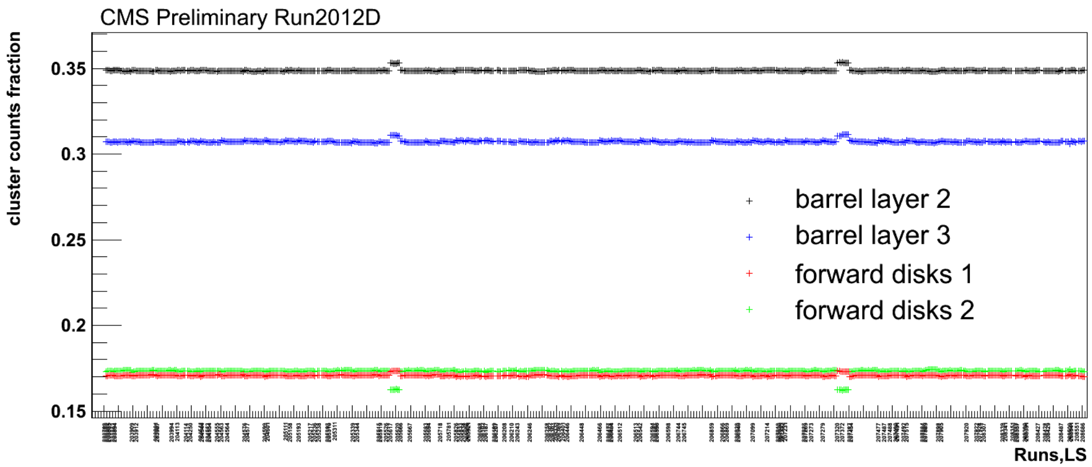


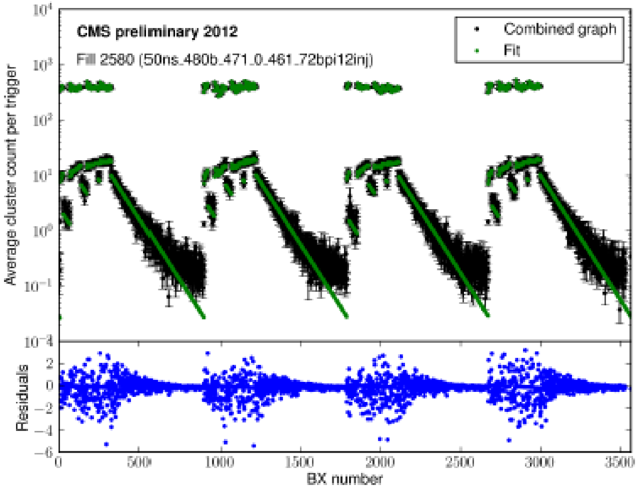


Luminosity

5.a

- Forward Hadron calorimeter is the CMS online luminometer
- Affected by harsh environmental conditions:
  - Response drifts with integrated lumi (radiation)
  - Needs to be re-calibrated with respect to a reference
- Pixel detector clusters counting used as offline luminometer and as reference (since 2011, not originally designed for)
  - Dedicated pixel data stream read out at high rate
  - Impressive stability over time and conditions
- After glow correction currently ~2%
  - 25ns spacing and high pileup might have a severe impact on performaces



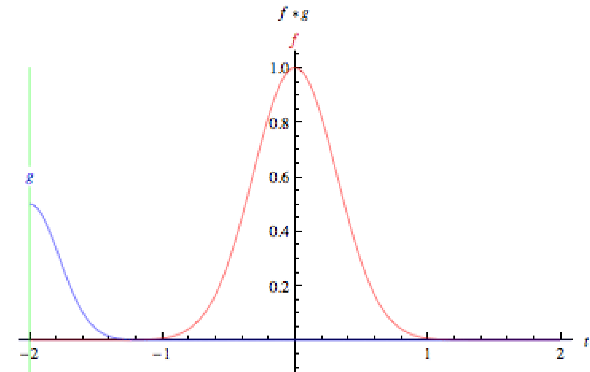


Absolute Lumi Calibration 5.a

Digression

- Van der Meer procedure: scan the beams to estimate the beam overlap region from the distribution of the rate as a function of separation

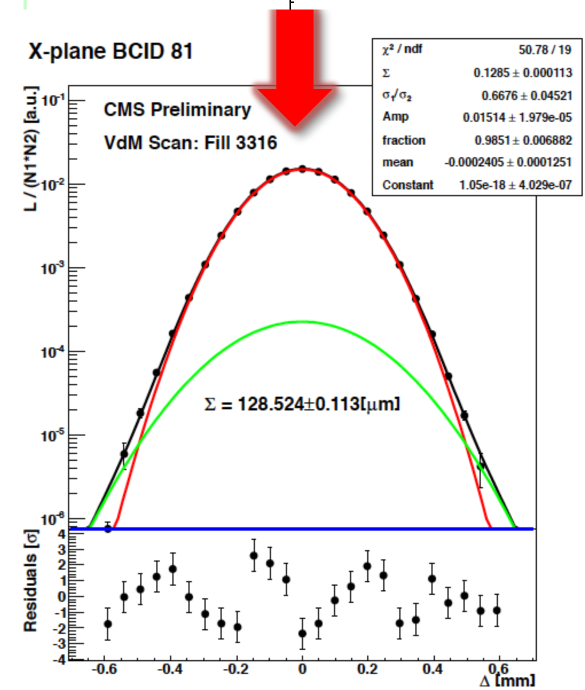
$$R(\Delta) = \sigma_{vis} \frac{fN_1N_2}{4\pi\sigma_x\sigma_y} \exp\left(-\frac{\Delta_x^{\ 2}}{\sigma_x^2}\right) \qquad R(\Delta) \propto \int \rho_1(x)\rho_2(\Delta - x)dx$$



- Length scale derived from magnetic field model, needs to be calibrated:
  - Use the movement of the luminous region centroid as measured by silicon detectors
- Alternatively exploit "beam imaging":

$$R(x) = \int R(x,\Delta)d\Delta = k\rho_1(x)\int \rho_2(\Delta - x)d\Delta = k'\rho_1(x)$$

- No need of scale calibration
- Get the profile of each beam, independently of beam shape

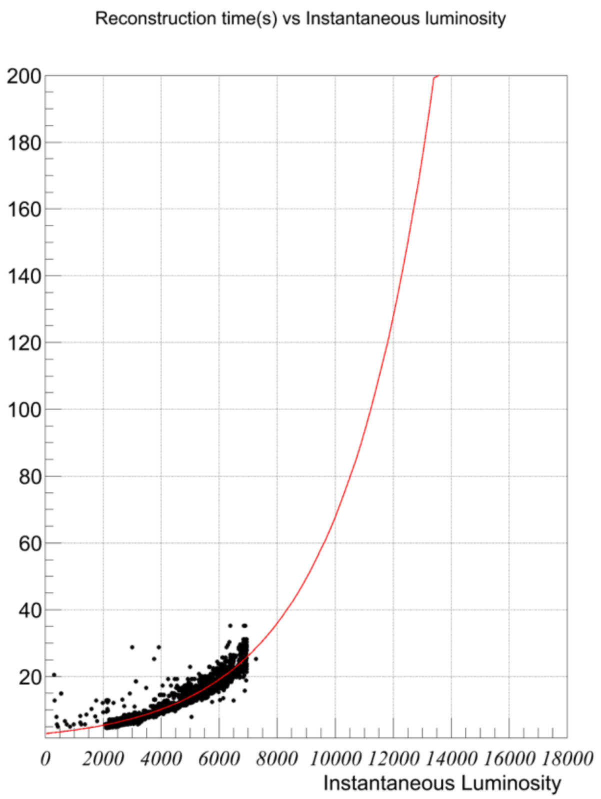


Pileup

- Directly or indirectly pileup is affecting everything
- Event processing time proven to scale exponentially with pileup
  - To cope with that tracking has to speed-up, increase minimum transverse momentum thresholds for tracks
  - Affects both online (HLT) and offline reconstruction (computing) 7.d 7.c
- Jets and Missing Energy resolution degrades
  - Corrections needs to be applied for in-time pu
  - Out-of-time pu cannot be estimated
  - Analysis with medium MET endangered (H->WW SF final state, H->Invisible, etc) 1.b

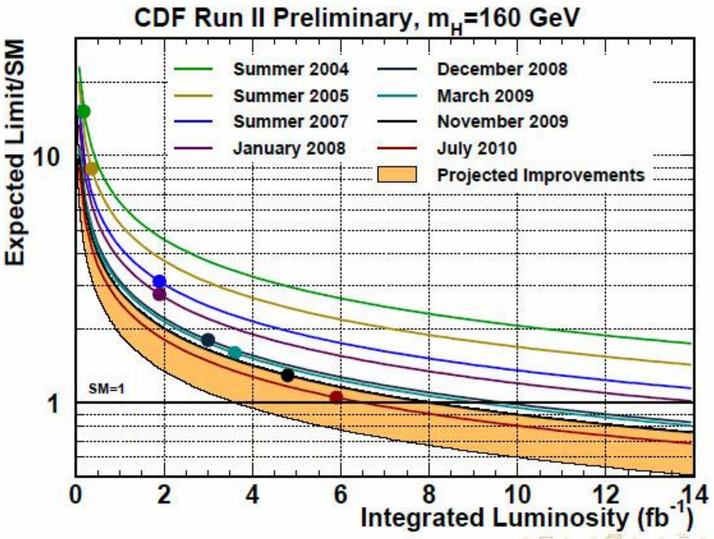
$$\mu(L) = \mu_{2012}\frac{L}{2L_{2012}}$$

$$\mu_{2012} \sim 35 \quad L_{2012} = 7e33cm^{-2}Hz$$



LHC Challenges

- No showstoppers, but several points to address carefully:
  - Getting to designed top energy not a piece of cake
  - Uncertainty on √s might not be negligible at high energy, affects directly comparison with theory cross sections
  - Luminosity determination much tougher at high pileup and small bunch separation
  - Pileup complicates reconstruction and triggering
- Projections looks good and past experience gives confidence



Ultimate Precision

- The banker question: how well do we need to measure the Higgs couplings to spot out New Physics effects?
  - Assuming pessimistically that nothing else is discovered at the LHC

arXiv:1206.3560 (R. Gupta, H. Rzehak, J. Wells):

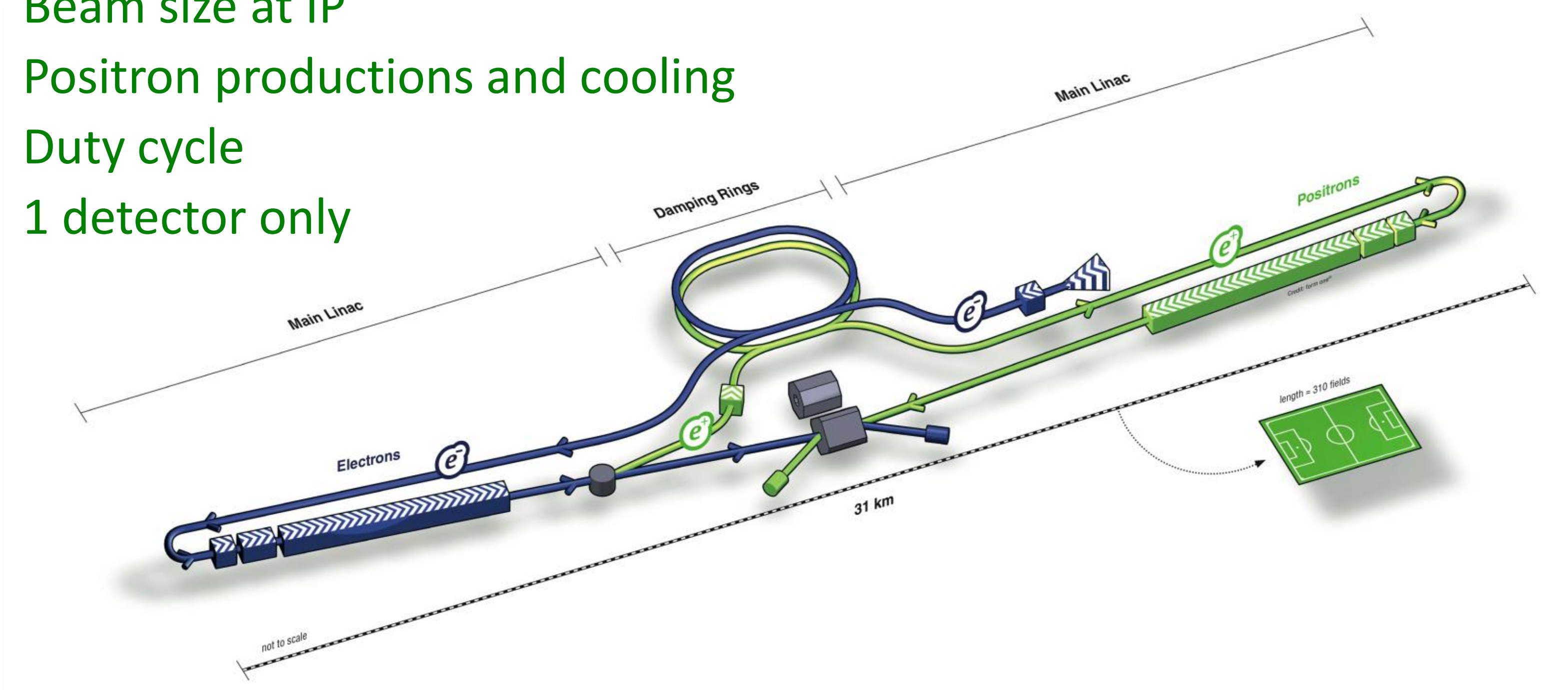
	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	$< 1\%$	3%	$10\%^a$, $100\%^b$

- Percent precision is required, likely not at reach for LHC
- Bear in mind that not all the Higgs properties accessible directly w/o assumptions
- A (few) dedicated Higgs factory is instrumental to fulfill completely the Higgs Physics program

Higgs Factories

International Linear Collider

- Long lasting R&D effort now becoming concrete on the basis of the Japanese proposal
- Staged approach, starting at the Higgs production threshold (250 GeV) to reach eventually ~1TeV
- A few non trivial issues:
  - Cost (O(10B$)) and timescale (2030)
  - Beam size at IP
  - Positron productions and cooling
  - Duty cycle
  - 1 detector only

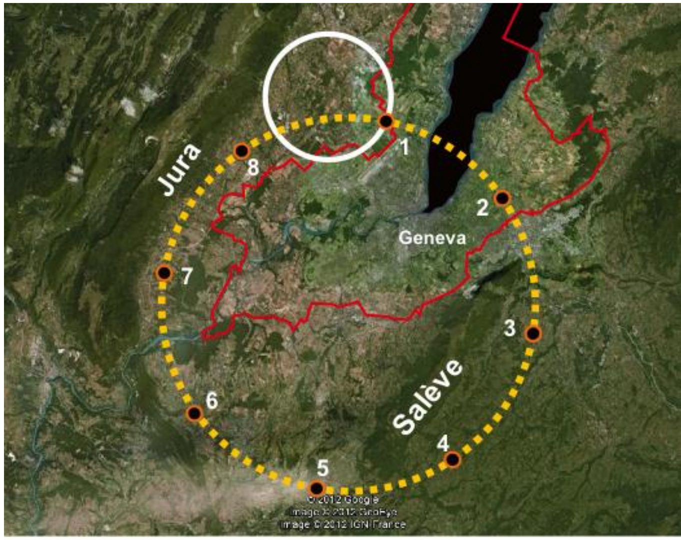


Circular e+e- (TLEP) 6.a

- After LEP2, banned due to limited energy reach, but what about a ~100 TeV pp machine as energy upgrade?!
- A 80 km tunnel in the CERN area would be affordable (3.2B$)
- As for LEP-LHC, idea is to have TLEP+XLHC
- TLEP would operate from Z pole to √s=350 GeV (top threshold)
- Keeping in mind:

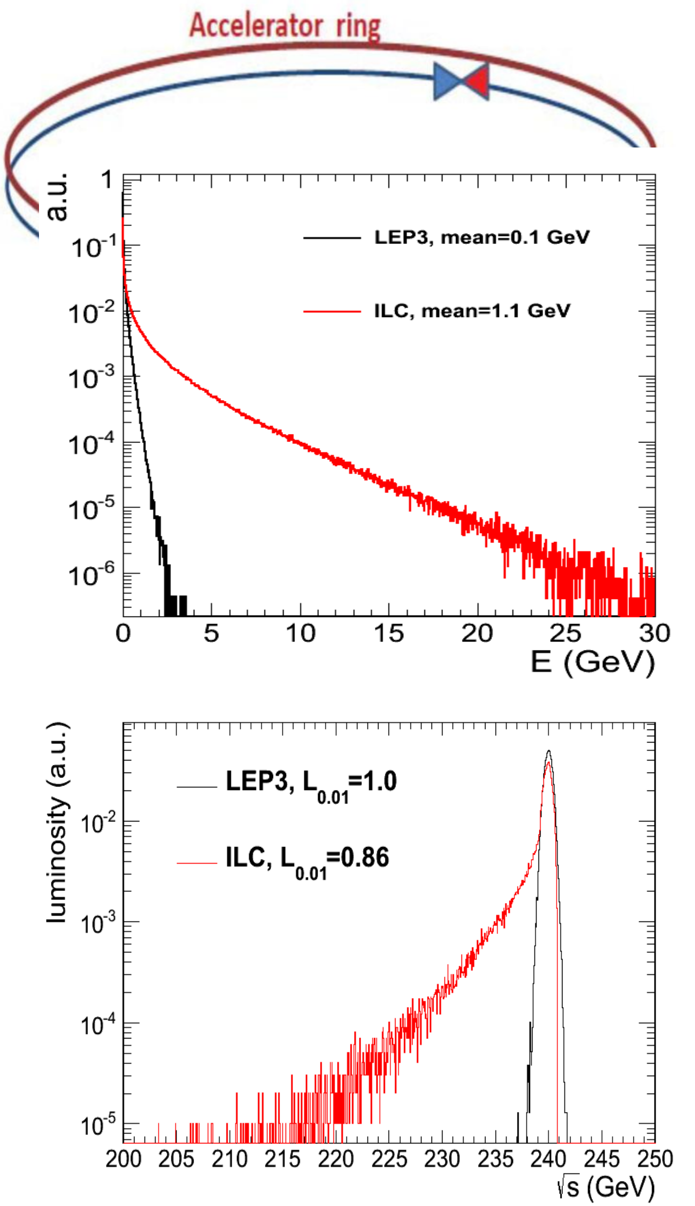
$$E^4[100GeV]N_e[10^{12}] \propto P[70MW]\rho^2[km]$$

  and assuming max 200 MW:
  - L=0.7e34 $cm^{-2}Hz$ @ √s=350 GeV
  - L=5e34 $cm^{-2}Hz$ @ √s=250 GeV
  - L=1e35 $cm^{-2}Hz$ @ √s=160 GeV
  - L=1e36 $cm^{-2}Hz$ @ √s=90 GeV
- Other ILC issues are also addressed



TLEP features

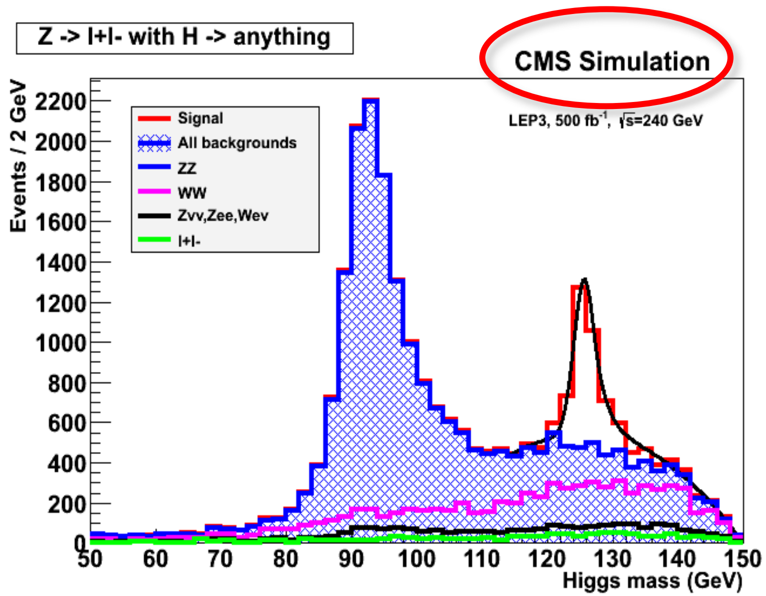
- Burn-off lifetime:
  - Bhabha x-sec so high that continuous refilling is required: top-up
  - Well established, would guarantee >70% duty cycle
- Beamstrahlung lifetime:
  - High lumi => squeezed beams at IP => beamstrahlung => high momentum acceptance
  - Moderate beamstrahlung =>
    - negligible beam background
    - Monochromatic luminosity profile
- Issues to be studied:
  - Absorption of high energy SR photons
  - High momentum acceptance
  - Integration with experiments

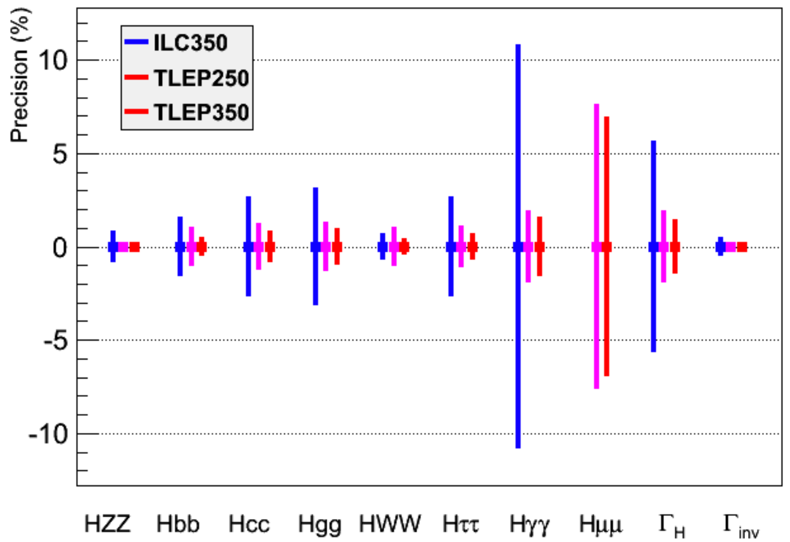


Physics at e+e-

6.b

- At e+e- Higgs physics can be fully addressed
  - E.g. total width measurement and Higgs to invisible
  - Self coupling not accessible
- Tera-Z and Giga-W modes will close the loop on EW precision tests
  - Beam polarization at the Z pole
  - Possibility of measuring beam energy ultra precisely continuously
- Precision scales with ~1/√L:
  - high inst lumi, 4 detectors, high duty cycle

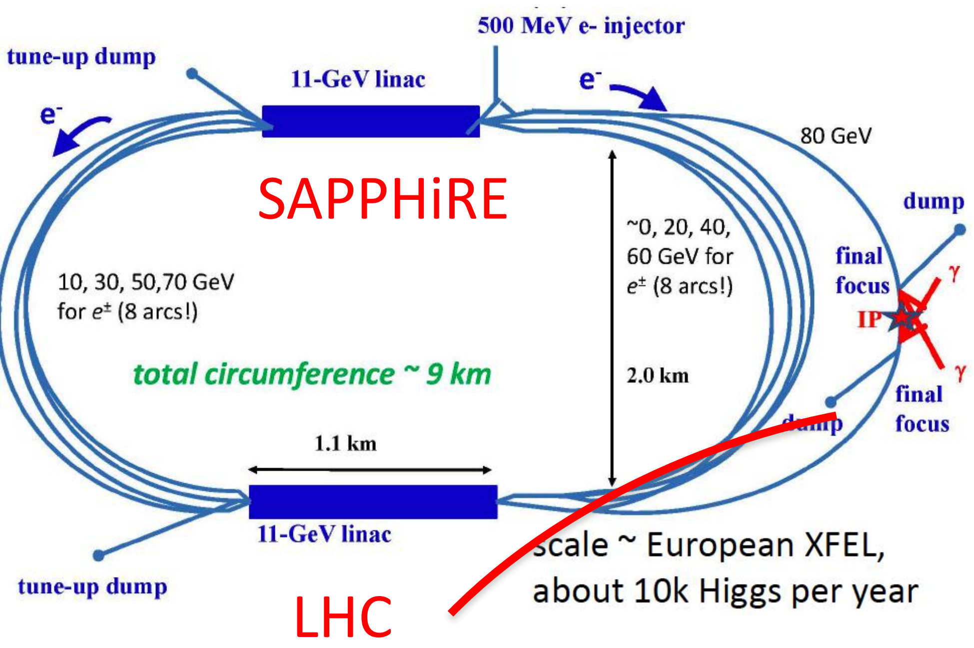


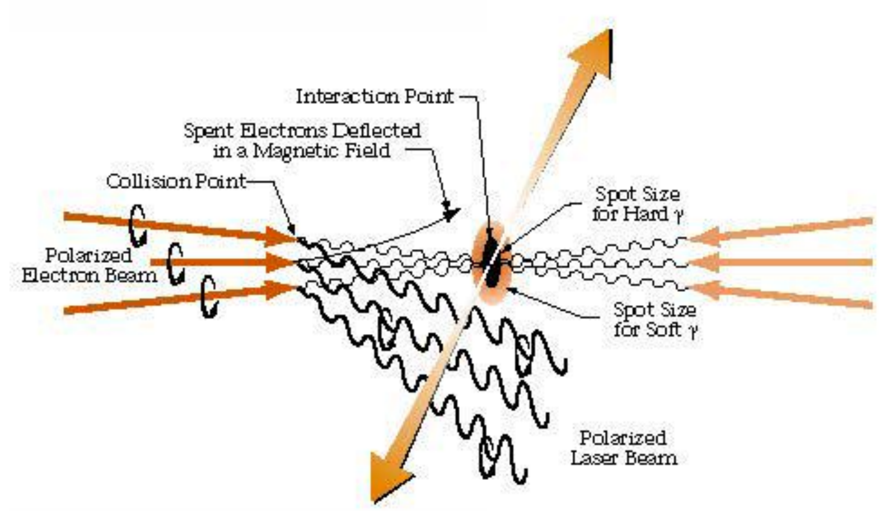


Photon Collider

6.c

- What about Higgs production in the s-channel with photons?

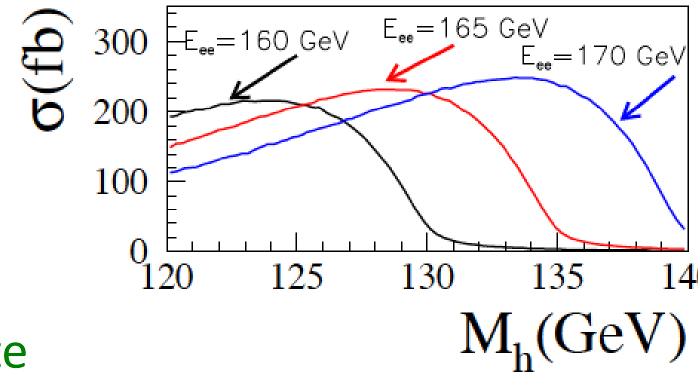




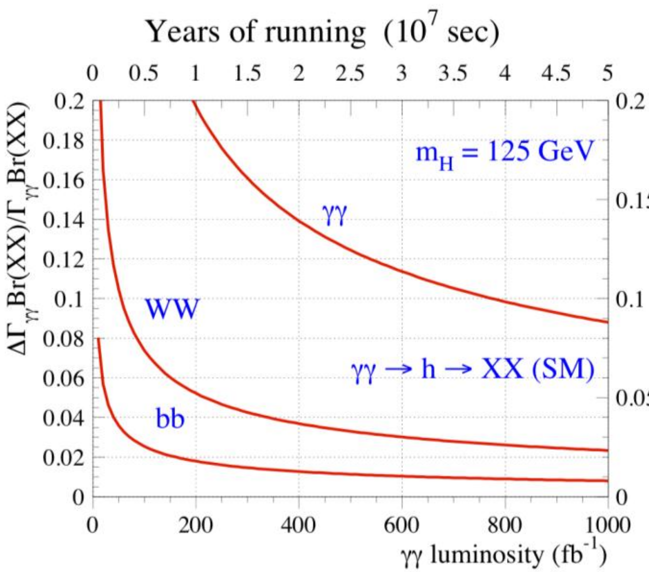
- e^-e^- colliders equipped with high power laser beams
- Compton backscattering of the laser photon off the electron beam
- Energy-angle correlation of the scatter photons => collimated $\gamma\gamma$ collisions at $\sim 0.8\sqrt{s_{ee}}$

Features

- Higgs Physics
  - High signal production cross section, small background
    - Similar number of Higgs events per year as ILC
  - Hγγ vertex interesting probe for new physics
  - Polarized collisions => control of the initial state CP => probe for BSM
  - Precise mass measurement

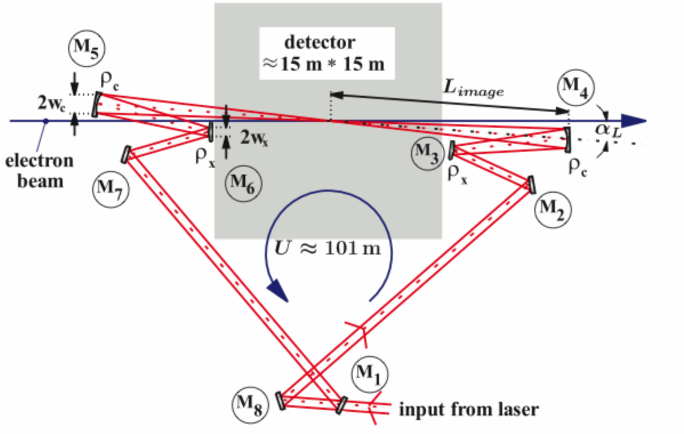


- Technical advantages
  - No need to mass produce positrons
  - s-channel production of the Higgs, smaller √s
  - Compact design, small budget
  - Interplay with other machines (LHeC)



Technological challenges

- Laser system
  - Pulse energy of a few J, 5 ps long pulse, 1MW average power
  - Stacked passive optical Fabry Perot cavity pumped by a laser via a semi-transparent mirror (F. Zomer et al)
- Accelerator:
  - Flat polarized e- guns
  - Emittance growth
- Integration with experiment
  - Spent beams



- Possibility of interplay with many other physics fields
  - Bright source (directional, ultra-fast), monochromatic scattered light (after collimation), tunable wavelength, less expensive than XFEL, broad energy reach (keV, MeV, GeV TeV), polarization
  - INFN IRIDE project and ELI-NP

Conclusions

- The discovery of “a Higgs Boson”™ is a tremendous achievement of the LHC and its experiments
- Coupling structure started to be explored, precision still limited by statistics
- Up to a factor 100 more statistics in the future of LHC, carrying though very though challenges requiring significant detector upgrades
- Ultimate Higgs precision might not be reached, the case for dedicated Higgs factories
- ILC not optimal as Higgs factories. Other options exists:
  - Circular e+e- in a large tunnel: high lumi, upgradable to O(100) TeV pp machine
  - Photon collider: complementary to e+e-, interplay with other projects in HEP and other sciences

Backup

Personal contributions

1. H->WW analysis:
   a) Analysis strategy, PhD thesis
      - Search for the standard model Higgs boson decaying to a W pair in the fully leptonic final state in pp collisions at sqrt(s) = 7 TeV, CMS Collaboration, Phys.Lett. B710 (2012) 91-113,
      - CMS Physics Technical Design Report, Volume II: Physics Performance, CMS Collaboration, J. Phys. G: Nucl. Part. Phys. 34 995
   b) Objects definition, pileup mitigation
   c) Top, WW, DY, Wγ* backgrounds normalization
      - Top background to SM Higgs searches in the W+W-→l+νl-ν decay mode at CMS, Davatz G., Giolo Nicollerat A., Zanetti M., PoS TOP2006:027, 2006, hep-ex/0604041
      - Les Houches workshop on Physics at TeV colliders 2005, standard model and Higgs working group: Summary report, Buttar, C. et al., hep-ph/0604120 (5 contributions)
2. Higgs properties
   a) Definition of the physics models
      - LHC HXSWG interim recommendations to explore the coupling structure of a Higgs-like particle, David A. et al, hep-ph/1209.0040
   b) CMS combination
      - Combination of standard model Higgs boson searches and measurements of the properties of the new boson with a mass near 125 GeV, CMS Collaboration, CMS-PAS-HIG-12-045

Personal contributions

3. LHC Projections:
   a) ESPG Higgs studies
      - CMS at the High-Energy Frontier. Contribution to the Update of the European Strategy for Particle Physics, CMS Collaboration, CERN-CMS-NOTE-2012-006
4. LHC Hardware Commissioning:
   a) Commissioning of superconducting circuits
      - Commissioning of the LHC Magnet Powering System in 2009. Solfaroli Camillocci, M. et IPAC-2010-MOPEB045, May 2010. In the Proceedings of 1st International Particle Accelerator Conference: IPAC'10, Kyoto, Japan, 23-28 May 2010
   b) Chair of Beam energy session in Chamonix 2011 LHC workshop
      - Consequences of LHC operations with beam energy at 3.5 TeV and beyond. Siemko, A. and Zanetti M., In the Proceedings of 2011 Chamonix LHC workshop, Chamonix, 24-28 January 2011
5. Luminosity:
   a) VdM analysis beam imagining:
      - Beams scan based Absolute Normalization of the CMS Luminosity Measurement. Zanetti M., In the Proceedings of LHC Luminosity Workshop, CERN, 13-14 January 2011, CERN-Proceedings-2011-001
      - Inclusive W/Z cross section at 8 TeV, CMS Collaboration, CMS-PAS-12-011 (appearing in PRL)

Personal contributions

6. Higgs Factories:
   a) TLEP machine
      - CLEP3: A High Luminosity e+e− Collider to study the Higgs Boson, Blondel A. et al., arXiv:1208.0504

   b) TLEP physics
      - Prospective Studies for LEP3 with the CMS Detector, Azzi P. et al., arXiv:1208.1662

   c) SAPPHiRE
      - SAPPHiRE: a Small Gamma-Gamma Higgs Factory, Bogacz S.A. et al., arXiv:1208.2827

7. Miscellanea:
   a) W/Z cross section analysis
      - Inclusive W/Z cross section at 8 TeV, CMS Collaboration, CMS-PAS-12-011 (appearing in PRL)

   b) CMS Muon Drift Tubes Chambers (PhD thesis)
      - The CMS muon barrel drift tubes system commissioning, Abbiendi, G. et al., Nucl.Instrum.Meth. A598: 192-195,2009
      - Precise Mapping of the Magnetic Field in the CMS Barrel Yoke using Cosmic Rays. CMS Collaboration, Oct 2009. arXiv:0910.5530

   c) Coordinator of CMS Tier0 computing center
   d) High Level Trigger
      - Commissioning of the CMS High Level Trigger, Zanetti M. et al. (corresponding author), arXiv:0908.1065, JINST 4 (2009) P10005
      - CMS Data Processing Workflows during an Extended Cosmic Ray Run, CMS Collaboration, arXiv:0911.4842, JINST 5 (2010) T03006

Coupling scale factors

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma_{\mathrm{ggH}}^{\mathrm{SM}}} = \begin{cases} \kappa_{\mathrm{g}}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, m_{\mathrm{H}}) \\ \kappa_{\mathrm{g}}^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma_{\mathrm{VBF}}^{\mathrm{SM}}} = \kappa_{\mathrm{VBF}}^2(\kappa_{\mathrm{W}}, \kappa_{\mathrm{Z}}, m_{\mathrm{H}})$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma_{\mathrm{WH}}^{\mathrm{SM}}} = \kappa_{\mathrm{W}}^2$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma_{\mathrm{ZH}}^{\mathrm{SM}}} = \kappa_{\mathrm{Z}}^2$$

$$\frac{\sigma_{\mathrm{t\bar{t}H}}}{\sigma_{\mathrm{t\bar{t}H}}^{\mathrm{SM}}} = \kappa_{\mathrm{t}}^2$$

Detectable decay modes

$$\frac{\Gamma_{\mathrm{WW}^{(*)}}}{\Gamma_{\mathrm{WW}^{(*)}}^{\mathrm{SM}}} = \kappa_{\mathrm{W}}^2$$

$$\frac{\Gamma_{\mathrm{ZZ}^{(*)}}}{\Gamma_{\mathrm{ZZ}^{(*)}}^{\mathrm{SM}}} = \kappa_{\mathrm{Z}}^2$$

$$\frac{\Gamma_{\mathrm{b\bar{b}}}}{\Gamma_{\mathrm{b\bar{b}}}^{\mathrm{SM}}} = \kappa_{\mathrm{b}}^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{\mathrm{SM}}} = \kappa_{\tau}^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{\mathrm{SM}}} = \begin{cases} \kappa_{\gamma}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa_{\gamma}^2 \end{cases}$$

$$\frac{\Gamma_{\mathrm{Z}\gamma}}{\Gamma_{\mathrm{Z}\gamma}^{\mathrm{SM}}} = \begin{cases} \kappa_{(\mathrm{Z}\gamma)}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa_{(\mathrm{Z}\gamma)}^2 \end{cases}$$

Undetectable decay modes

$$\frac{\Gamma_{\mathrm{t\bar{t}}}}{\Gamma_{\mathrm{t\bar{t}}}^{\mathrm{SM}}} = \kappa_{\mathrm{t}}^2$$

$$\frac{\Gamma_{\mathrm{gg}}}{\Gamma_{\mathrm{gg}}^{\mathrm{SM}}} : \text{see Section 3.1.2}$$

$$\frac{\Gamma_{\mathrm{c\bar{c}}}}{\Gamma_{\mathrm{c\bar{c}}}^{\mathrm{SM}}} = \kappa_{\mathrm{t}}^2$$

$$\frac{\Gamma_{\mathrm{s\bar{s}}}}{\Gamma_{\mathrm{s\bar{s}}}^{\mathrm{SM}}} = \kappa_{\mathrm{b}}^2$$

$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma_{\mu^-\mu^+}^{\mathrm{SM}}} = \kappa_{\tau}^2$$

scale factors for loops

- In the case of coupling via loops scale factors are functions of the other scale factors
- Example: the gluon fusion cross section scaling:

$$\kappa_g^2(\kappa_t,\kappa_b,M_H)=\frac{\kappa_t^2\cdot\sigma_{ggH}^{tt}+\kappa_b^2\cdot\sigma_{ggH}^{bb}+\kappa_t\kappa_b\cdot\sigma_{ggH}^{tb}}{\sigma_{ggH}^{tt}+\sigma_{ggH}^{bb}+\sigma_{ggH}^{tb}}$$

- Where $\sigma_{ggH}^{tt,bb}$ is the square of the top and bottom contributions and σ_{ggH}^{tb} is the square of the interference terms
  - Interference term is negative for M_H<200 GeV
- Similar expressions implemented for other loops ($\gamma\gamma$, $Z\gamma$)
  - VBF is also expressed as combination of κ_W and κ_Z
- Alternatively the dependency on other scale factors can be discarded and treat the loop scale factor as additional free parameter

Further assumptions

- NB: the document addresses the integrated luminosity envisaged for 2012 run => estimations are statistically limited
- Theoretical uncertainty:
  - Th. Uncertainties will directly affect the scale factors determination
- Zero width approximation
  - 1% effect in the low mass range
- Signal interference effects
  - H->ZZ->4f analyses correctly rely on BR(H->4f), at 125 GeV 10% effect w.r.t BR(H->ZZ)xBR(Z->2f)
  - H->ZZ and H->WW data are however scaled with κ_Z and κ_W
- Treatment of light fermions
  - Γ for electrons, up and down quarks are neglected
  - Proxies used for the undetectable ones
  - Light flavors also neglected in the loops

Parameters

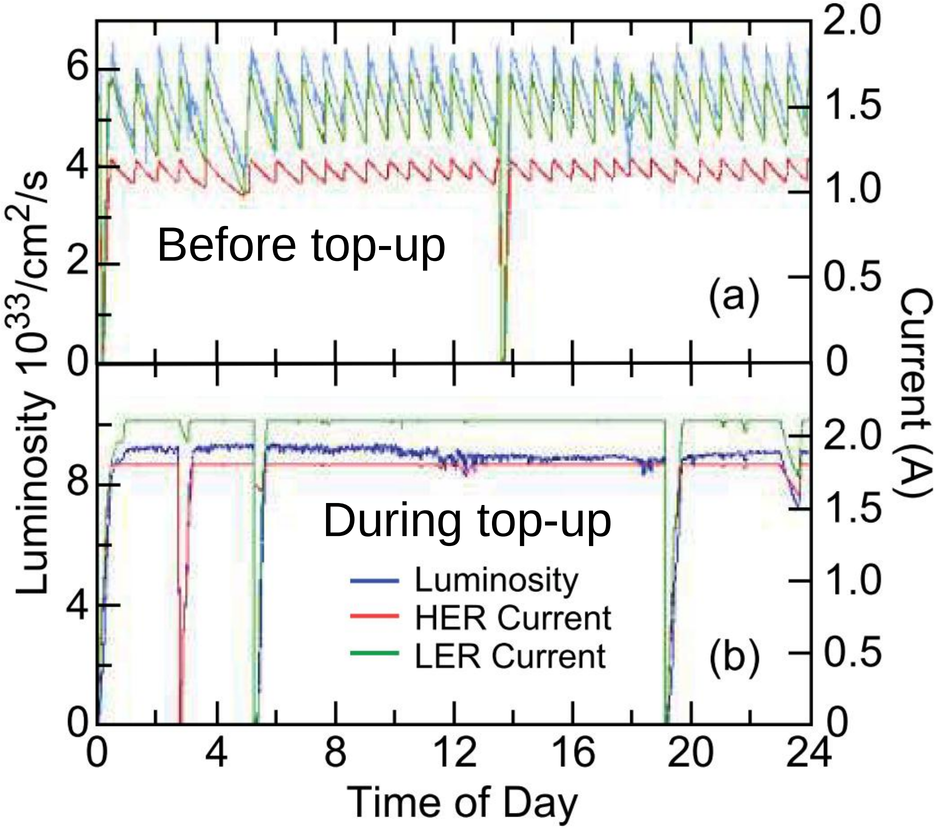
	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e-/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [µm]	270	30	71	78	43	63
σ^*_y [µm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.67	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

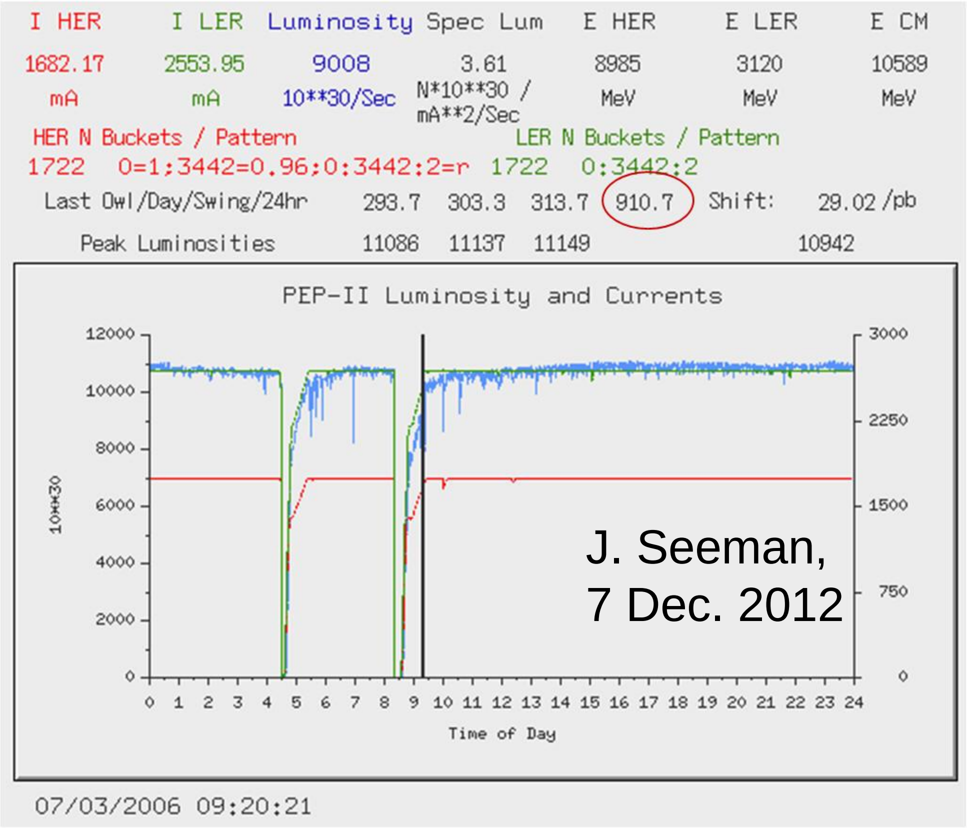
Parameters

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
$V_{RF,tot}$ [GV]	3.64	0.5	12.0	2.0	6.0	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	4.2	4.0	9.4	4.9
ξ_x/IP	0.025	N/A	0.09	0.12	0.10	0.05
ξ_y/IP	0.065	N/A	0.08	0.12	0.10	0.05
f_s [kHz]	1.6	0.65	3.91	1.29	0.44	0.43
E_{acc} [MV/m]	7.5	11.9	20	20	20	20
eff. RF length [m]	485	42	600	100	300	600
f_{RF} [MHz]	352	721	1300	700	700	700
$\delta^{SR}{}_{rms}$ [%]	0.22	0.12	0.23	0.06	0.15	0.22
$\sigma^{SR}{}_{z,rms}$ [cm]	1.61	0.69	0.23	0.19	0.17	0.25
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	N/A	107	10335	490	65
number of IPs	4	1	2	2	2	2
Rad.Bhabha b.lifetime [min]	360	N/A	16	74	32	54
Υ_{BS} [10^{-4}]	0.2	0.05	10	4	15	15
n_γ/collision	0.08	0.16	0.60	0.41	0.50	0.51
$\Delta\delta^{BS}$/collision [MeV]	0.1	0.02	33	3.6	42	61
$\Delta\delta^{BS}{}_{rms}$/collision [MeV]	0.3	0.07	48	6.2	65	95

Top-up performances

- Super efficient duty cycle achieved at PEPII
- H factor not far from 1:
  - July 3, 2006: *H*≈0.95
  - August 2007): H≈0.63





Synchrotron radiation

- 2x100 MW supplied to the beams need to be cooled away, heat load non negligible
- Previous machines (e.g. PEP-II and SPEAR) coped with much higher heat load per meter
- Need to manage higher max photon energy though

	PEPII	SPEAR3	LEP3	TLEP-Z	TLEP-H	TLEP-t
E (GeV)	9	3	120	45.5	120	175
I (A)	3	0.5	0.0072	1.18	0.0243	0.0054
rho (m)	165	7.86	2625	9000	9000	9000
Linear Power (W/cm)	101.8	92.3	30.5	8.8	8.8	8.8

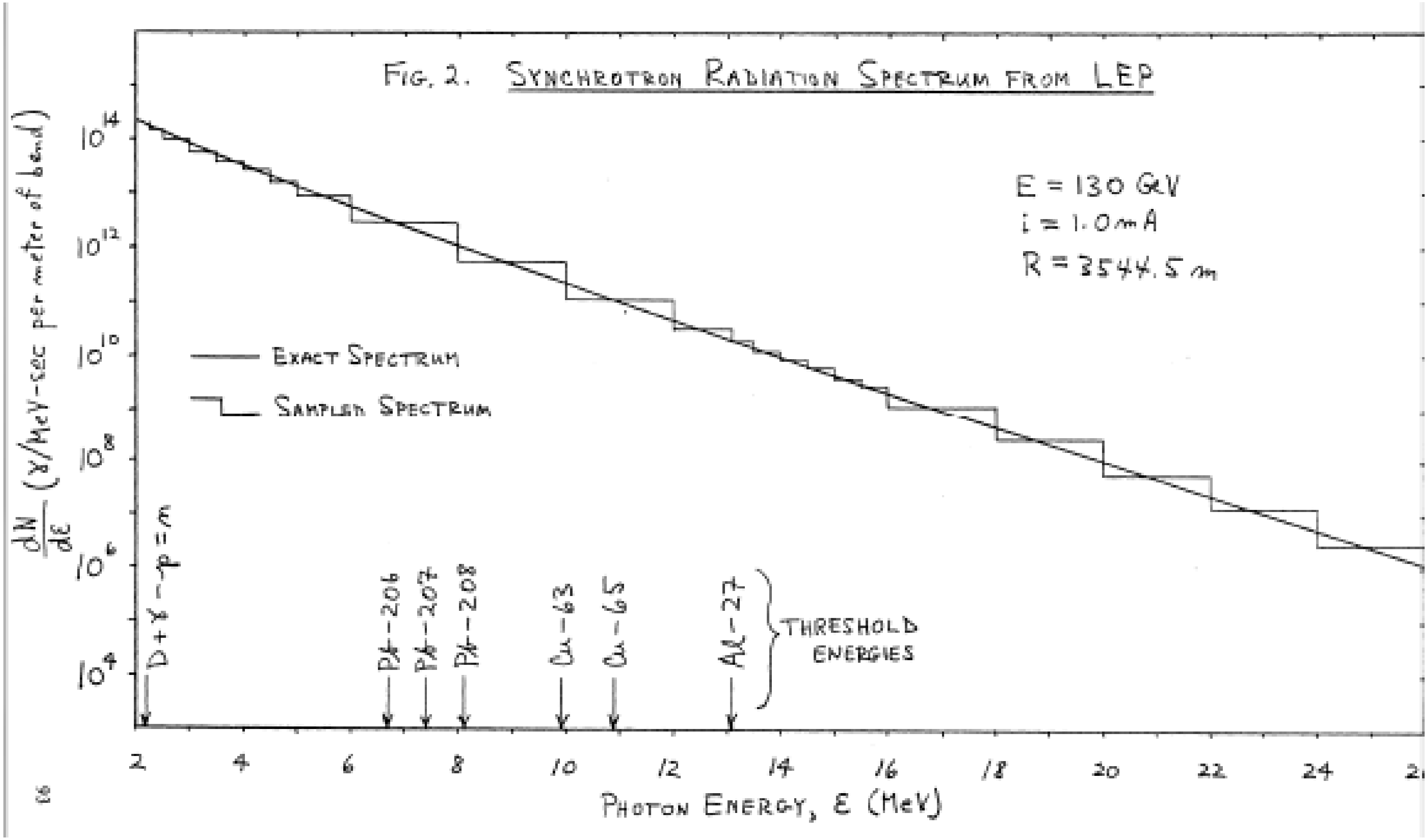
N. Kurita, U. Wienands, SLAC

Synchrotron radiation

NEUTRON PRODUCTION BY LEP SYNCHROTRON RADIATION USING EGS

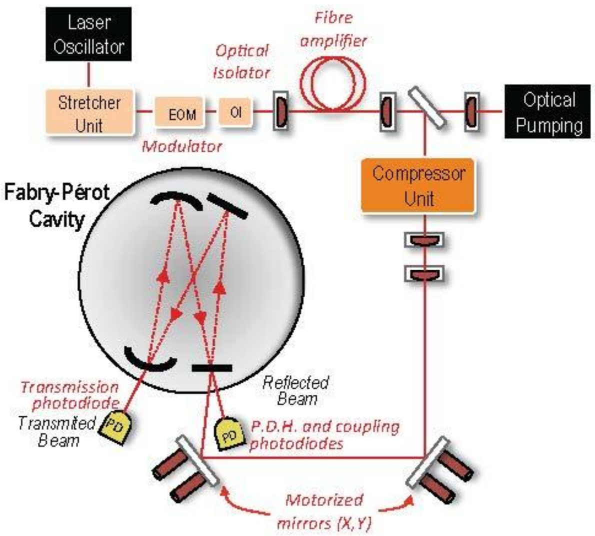
W.R.Nelson and J.W.N.Tuyn

A. Fasso
3rd TLEP3 Day



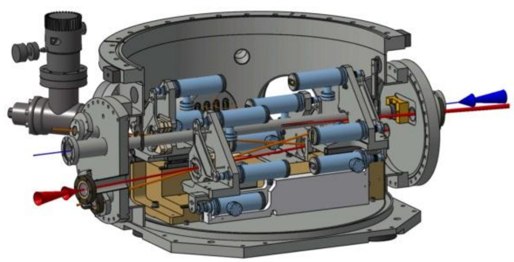
MightyLaser experiment at KEK-ATF

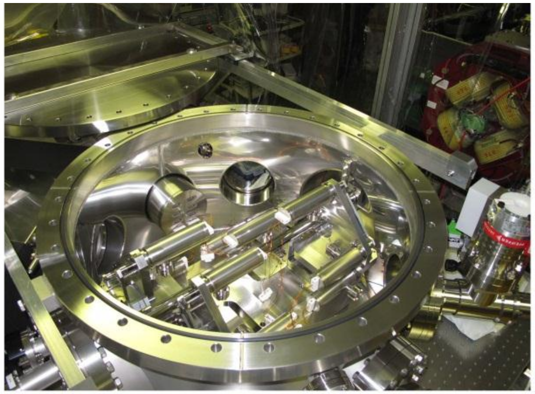
non-planar high finesse four mirror Fabry-Perot cavity;
first Compton collisions observed in October 2010



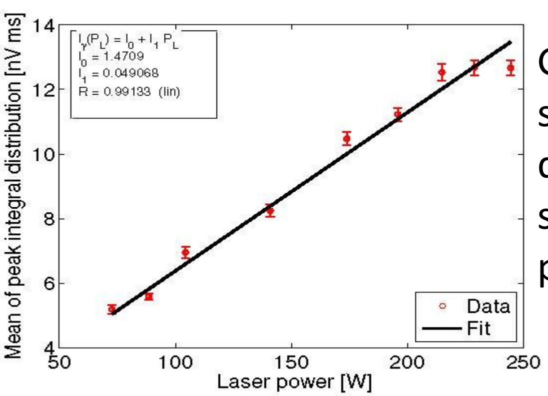
Optical system used for laser power amplification and to inject laser into FPC

I. Chaikovska, N. Delerue, A. Variola, F. Zomer et al

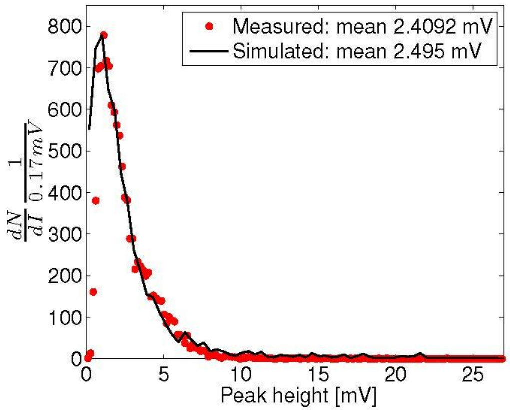




Vacuum vessel for Fabry-Perot cavity installed at ATF



Gamma ray spectrum for different FPC stored laser power

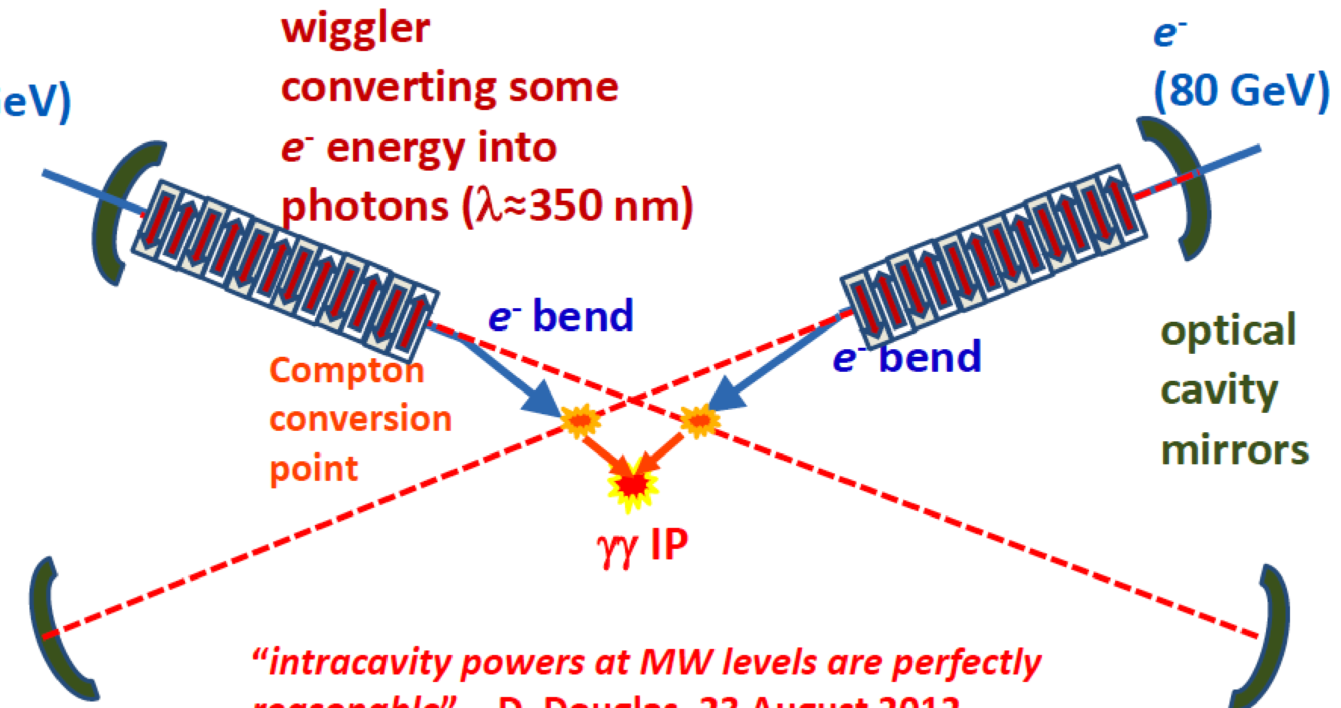


Comparison of measured and simulated gamma-ray energy spectra from Compton scattering

Plan: improve laser and FPC mirrors & gain several orders

Alternative approach (FEL)

- Possibility of coupling the setup to a free-electron laser is very interesting
- Get synchronization for free
- Reduction in cost and complexity



"intracavity powers at MW levels are perfectly reasonable" – D. Douglas, 23 August 2012