HEPAP Facilities Subpanel: Report on Energy Frontier Facilities

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General Approach

- Consider science questions
  - What are the important science questions the facility will address?
  - How well can the facility address the science questions?
  - Is the facility unique?
- Readiness of facility for construction by ***2024***
- No rank ordering of facilities

Discoveries at the LHC

- These discoveries inform future plans
- The Higgs!
- No beyond the Standard Model physics (yet)
  - Significant, fundamental scientific questions remain to be explored
  - The questions of naturalness that motivated exploration of the TeV scale are still unanswered

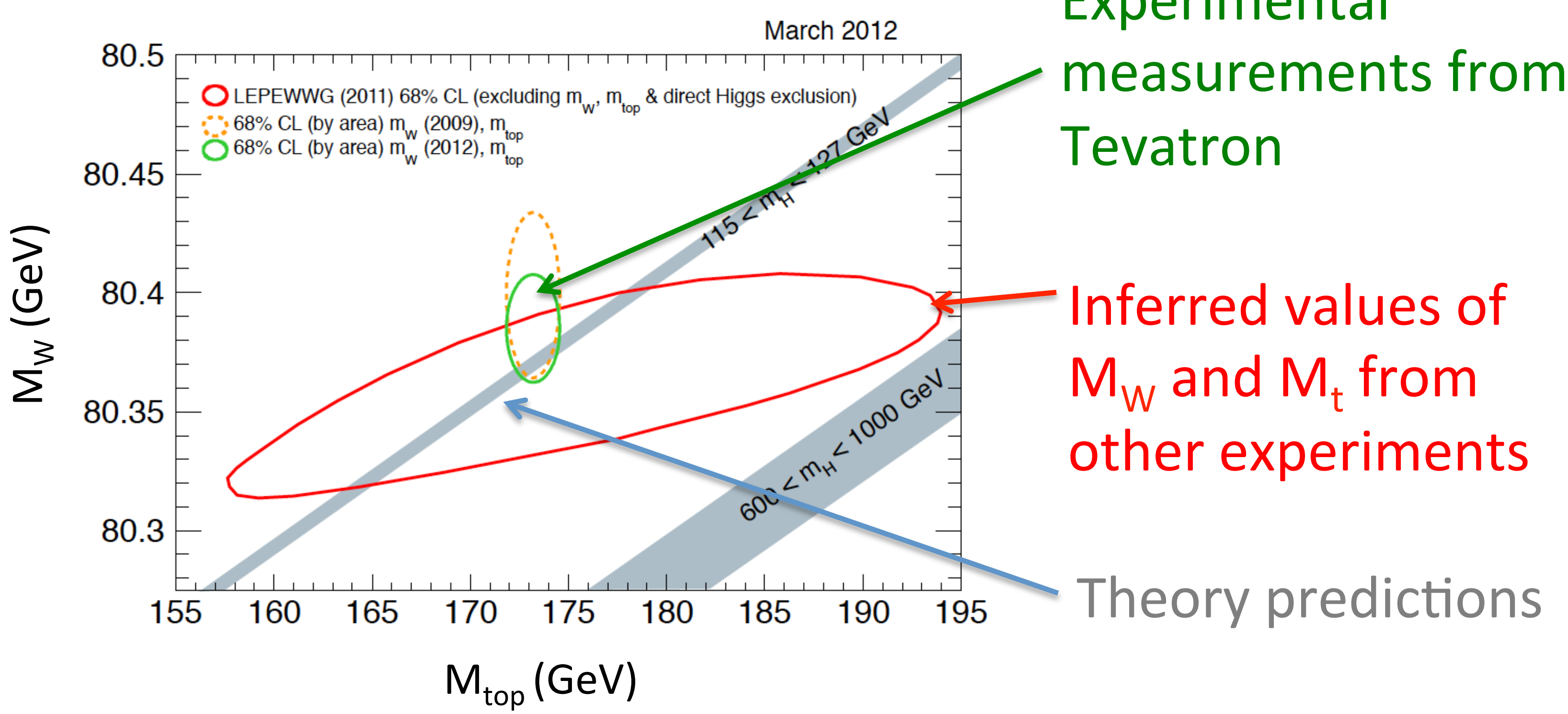
Science Questions

- Now that we've found the Higgs we need to:
  - Measure properties of the Higgs with increasing precision to test SM hypothesis
  - Observe rare decays and rare production modes
    - $H \to \mu^+\mu^-$, $H \to cc$
    - $H \to Z\gamma$
    - ttH production
  - Measure Higgs self-couplings
  - Measure Higgs total width and invisible width
  - Measure Higgs spin/parity

Science Questions: Is there physics Beyond the SM?

- TeV scale physics motivated by naturalness questions: Why is $M_W << M_{pl}$?
- Is there high scale SUSY?
  - Compressed spectra (small mass splittings)
  - Complicated cascade decays
  - Stealth or RPV scenarios without missing E_T
  - Long-lived sparticles
- Many possibilities for new physics
  - New resonances: techniparticles, Z', tt resonance

M_W, M_t limits from the Tevatron



Motivates precision top and precision electroweak studies

High Energy Hadron Colliders

- LHC upgrades
  - Luminosity upgrades: HL-LHC
  - Energy upgrades (not in the 2024 time frame)
- Very high energy pp?
  - No possibility of machine to be in construction by 2024
  - No clear energy scale to aim for
  - LHC results could provide science basis for such a machine eventually

LHC luminosity and detector upgrades on facilities list

High Luminosity at the LHC

- LHC has rapidly achieved high luminosity
  - 7.7 x 10^{33}/cm^2/sec at $\sqrt{s}$=8 TeV
  - By 2022:
    - Peak luminosity will exceed 2 x 10^{34}/cm^2/sec with 300 fb^{-1} recorded
  - Goals of HL-LHC (after 2022)
    - Maximum of 140 interactions/crossing
    - L=5 x 10^{34}/cm^2/sec
    - 250 fb^{-1}/year, 3000 fb^{-1} total

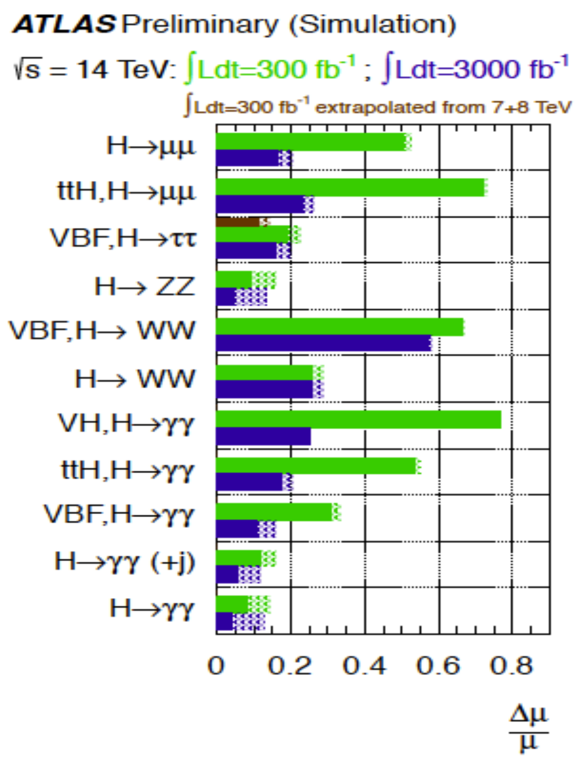
LHC Schedule & Plans

- LHC evolution to the High Luminosity LHC
- Accelerator/ATLAS/CMS upgrades considered together

Period	Activity	Label	Peak $\mathscr{L}$	Int $\mathscr{L}$ (fb^{-1})	$\sqrt{s}$ (TeV)	Bunch (ns)
2013-2014	Install Phase 0	LS1				
2015-2017	Running		10^{34}	~100	~14	25
2018	Install Phase I	LS2				
2019-2021	Running		$\sim 2 \times 10^{34}$	~300	~14	25
2022-2023	Install Phase II	LS3				
2024-2036	Running		$\sim 5 \times 10^{34}$	~3000	~14	25

Physics Goals for HL-LHC

- 300 - 3000 fb^{-1} at √s=14 TeV LHC explores Higgs properties with increasing precision to test SM



CMS

Coupling	inty (%)	
	3000 fb^{-1}	
	Scenario 1	Scenario 2
κ_γ	5.4	1.5
κ_V	4.5	1.0
κ_g	7.5	2.7
κ_b	11	2.7
κ_t	8.0	3.9
κ_τ	5.4	2.0

*Scenario 2 assumes systematic error scales as 1/√L and theory error halved

Physics Goals for HL-LHC

- LHC already tells us that the Higgs is a scalar
  - It could have small admixture of non-SM object
- HL-LHC will measure Higgs self-coupling to 15-20%, $H\mu\mu$ coupling to ~10%
- Physics opportunities greatly enhanced at HL-LHC
  - ***Study anything that is found in 14 TeV running***
  - Explore processes with smaller production cross sections
  - Use more complicated search strategies as the "easier" Beyond the SM scenarios are ruled out
  - Probe higher mass scales for SUSY and new resonances

LHC Upgrade

- High Luminosity accelerator upgrade
  - Nb_3Sn superconducting quadrupoles, crab cavities (Core US competencies)
  - Will require significant R&D and engineering
- High luminosity poses detector challenges
  - Maintaining high performance vertex/track reconstruction, lepton ID, and heavy flavor tagging
  - High data rate/high pile-up

ATLAS Phase II Upgrades

- All-silicon inner tracker replacement
  - Modern sensors and radiation tolerant ASICs
  - Improved geometrical acceptance and reduced upstream material
- Upgraded Trigger & Data Acquisition system for increased rates
  - Maintain low trigger thresholds and bandwidth
- New electronics for calorimeter, tracker and muon detector
  - Radiation hard
  - Handle large data rates/provide higher precision information to trigger

R&D ongoing to resolve significant scientific/engineering challenges before initiating construction

CMS Phase II Upgrade

- Goal: Keep detector as efficient for physics as it is now
- High pileup: Need to preserve resolution and calibration and efficiently tag e, μ, γ
- Radiation damage to detectors: Pixel detector/silicon strip tracker/forward calorimetry
- Upgrades:
  - Tracking (Increase coverage to |n|~ 4)
  - Forward calorimetry (important for VBF physics)
  - Trigger and data acquisition

R&D ongoing to resolve significant scientific/engineering challenges before initiating construction

LHC Upgrades

- Science questions drive the need to upgrade luminosity and detectors at the LHC
  - Accelerator and upgrades of both detectors are absolutely central to world-wide goals of particle physics
    - Proposed US roles in accelerator and detector upgrades are compatible with US leadership areas, although actual roles have yet to be determined
    - Contributions to both ATLAS and CMS upgrades are essential to maintain ongoing US participation

High Energy Lepton Colliders

- Many possibilities
  - e^+e^- ILC at √s=500 GeV in Japan with upgrade to 1 TeV
  - Circular e^+e^- machine at √s=250-400 GeV
  - TeV scale e+e- collider (CLIC)
  - $\mu^+\mu^-$ collider
- e^+e^- collider at √s=500 GeV in Japan is only lepton collider ready for construction in next decade
  - Upgrade from 500 GeV to 1 TeV possibility necessary to achieve science goals
- Japanese desire to host makes this a unique opportunity

500 GeV ILC in Japan on facilities list

ILC Physics Goals

- Initial phase: $\sqrt{s}$=250 GeV
  - 250 fb^{-1} yields 80,000 Higgs bosons
  - Higgs branching ratios to 1-5%
  - Higgs invisible decays at 1%
- Design phase: $\sqrt{s}$=500 GeV
  - 500 fb^{-1}
    - Observe $e^+e^- \rightarrow \upsilon\overline{\nu}H$
    - Total Higgs width gives absolute coupling normalizations
  - 1 ab^{-1}
    - Observe $e^+e^- \rightarrow t\bar{t}H$
    - Begin studies of Higgs self-coupling through $e^+e^- \rightarrow ZHH$

ILC Physics Goals

- Search for new physics
  - Color neutral states (dark matter candidates)
  - Precision SM measurements sensitive to high scale physics (beam polarization important): $e^+e^- \rightarrow f\overline{f}; e^+e^- \rightarrow W^+W^-$
- Top quark physics
  - Precision measurement of top mass and width
  - Scan at √s=350 GeV could get top mass to 100 MeV, top width to 30 MeV

ILC Detectors

- Intense global R&D for detectors with unprecedented precision
- Technology advances by ILC community:
  - Calorimetry/tracking/vertex detector/forward detectors
- ILD & SiD
  - 4π detectors with complementary designs
  - SiD: silicon tracking, gaseous digital hadron calorimeter, fast tracking and calorimeter
  - ILD: TPC tracking, scintillator steel hadron calorimeter

R&D ongoing to resolve significant scientific/engineering challenges before initiating construction

Global Plan for ILC Gradient R&D

Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in v. test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)				
System Test with beam acceleration			FLASH (DESY) , NML (FNAL) STF2 (KEK, test start in 2013)			
Preparation for Industrialization				Production Technology R&D		

Achieved!!

New baseline gradient:

Vertical acceptance: 35 MV/m average, allowing ±20% spread (28-42 MV/m)

Operational: 31.5 MV/m average, allowing ±20% spread (25-38 MV/m)

500 GeV ILC

- Technical design completed/reviewed, TDR complete
  - Successful multi-year world wide R&D on SRF Linac technology, high gradient SCRF cavities
  - Intense R&D on detector concepts
  - Detailed baseline designs for detectors
  - Global collaborations (GDE/detector concepts/physics)
- 9 years from ground breaking to start of beam commissioning
  - Technically ready to initiate construction

US Participation in Japanese Hosted ILC

- Science drives the need for e^+e^- collider
  - ILC addresses absolutely central physics questions and is complementary to the LHC
  - Japanese hosted ILC could be under construction before 2024
- Parameters of a potential US contribution are not known and depend on international agreements
  - The US has made substantial contributions to detector and accelerator development through the global effort
  - Should an agreement be reached, the US particle physics community would be eager to participate in both the accelerator and detector construction

Previous Reports

- P5 (2008):
  - "Significant US participation in the full exploitation of the LHC has the highest priority in the US high energy physics program. The panel recommends support for the US LHC program, including US involvement in the planned detector and accelerator upgrades."
  - "The international particle physics community has reached consensus that a full understanding of the physics of the Terascale will require a lepton collider as well as the LHC. The panel reiterates the importance of such a collider".

Conclusions

- Measuring Higgs properties and searching for Beyond the Standard Model effects are of primary scientific significance
- The LHC accelerator and detector upgrades and the 500 GeV ILC in Japan can address these questions in complementary fashions and are absolutely central to progress in high energy physics
  - The LHC accelerator and detector upgrades build on major US contributions to design, construction, operation, and physics at the LHC
  - The Japanese particle physics community desire to host a 500 GeV ILC offers a unique opportunity