Where we stand

After LHC Run 1:

- We have consolidated the Standard Model (a wealth of measurements at 7-8 TeV, including the rare, and very sensitive to New Physics, $B_s \rightarrow \mu\mu$ decay)

- We have completed the Standard Model: discovery of the messenger of the BEH-field, the Higgs boson discovery

- We found interesting properties of the hot dense matter

- We have NO evidence of New Physics
Higgs@LHC

No significant deviation from SM so far

<table>
<thead>
<tr>
<th>ATLAS Preliminary</th>
<th>Total uncertainty</th>
<th>± 1σ on μ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>m_H = 125.36 GeV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>H → γγ</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>μ</em> = 1.17±0.28</td>
<td>σ(stat.)</td>
<td>± 0.26</td>
</tr>
<tr>
<td><em>σ(sys inc.)</em></td>
<td>+0.03</td>
<td></td>
</tr>
<tr>
<td><em>σ(theory)</em></td>
<td>-0.18</td>
<td></td>
</tr>
<tr>
<td><strong>H → ZZ^</strong>*</td>
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<tr>
<td><em>μ</em> = 1.46±0.40</td>
<td>σ(stat.)</td>
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<tr>
<td><em>σ(sys inc.)</em></td>
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<td></td>
</tr>
<tr>
<td><em>σ(theory)</em></td>
<td>-0.11</td>
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</tr>
<tr>
<td><strong>H → WW^</strong>*</td>
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<tr>
<td><em>μ</em> = 1.18±0.24</td>
<td>σ(stat.)</td>
<td>± 0.34</td>
</tr>
<tr>
<td><em>σ(sys inc.)</em></td>
<td>+0.18</td>
<td></td>
</tr>
<tr>
<td><em>σ(theory)</em></td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td><strong>H → b̄b</strong></td>
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<td></td>
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<tr>
<td><em>μ</em> = 0.63±0.39</td>
<td>σ(stat.)</td>
<td>± 0.37</td>
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<tr>
<td><em>σ(sys inc.)</em></td>
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<tr>
<td><em>σ(theory)</em></td>
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<tr>
<td><strong>H → ττ</strong></td>
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<td></td>
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<td><em>μ</em> = 1.44±0.42</td>
<td>σ(stat.)</td>
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<tr>
<td><em>σ(sys inc.)</em></td>
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<td></td>
</tr>
<tr>
<td><em>σ(theory)</em></td>
<td>-0.28</td>
<td></td>
</tr>
</tbody>
</table>

CMS

19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)

(M, ε) fit

- 68% CL
- 95% CL

--- SM Higgs

Particle mass (GeV)
ATLAS+CMS Higgs mass combination

... and the ATLAS+CMS combined Higgs boson mass is:

\[ m_H = 125.09 \pm 0.24 \text{ GeV} \quad (0.19\% \text{ precision!}) \]

\[ = 125.09 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.}) \text{ GeV} \]
CMS and LHCb $B_{s,d}^0 \to \mu \mu$ combination

Fit to full run I data sets of both experiments, sharing parameters

Result demonstrates power of combining data from >1 experiment (an LHC first!)
It was presented at CKM conference in Vienna, & will be submitted to Nature

$$\mathcal{B}(B_{s}^0 \to \mu^+ \mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$$

6.2 $\sigma$ for the $B_{s}^0 \to \mu^+ \mu^-$

(Expected SM 7.6 $\sigma$)

* First observation

projection of invariant mass in most sensitive bins
Where we stand

- We have exhausted the number of “known unknowns” within the current paradigm.

- Although the SM enjoys an enviable state of health, we know it is incomplete, because it cannot explain several outstanding questions, supported in many cases by experimental observations.
Main outstanding questions in today's particle physics

Higgs boson and EWSB
- $m_H$ natural or fine-tuned?
  - if natural: what new physics/symmetry?
- does it regularize the divergent $V_L V_L$ cross-section at high $M(V_L V_L)$? Or is there a new dynamics?
- elementary or composite Higgs?
- is it alone or are there other Higgs bosons?
- origin of couplings to fermions
- coupling to dark matter?
- does it violate CP?
- cosmological EW phase transition (is it responsible for baryogenesis?)

Neutrinos:
- $\nu$ masses and and their origin
- what is the role of $H(125)$?
- Majorana or Dirac?
- CP violation
- additional species $\rightarrow$ sterile $\nu$?

Dark matter:
- composition: WIMP, sterile neutrinos, axions, other hidden sector particles, ..
- one type or more?
- only gravitational or other interactions?

The two epochs of Universe’s accelerated expansion:
- primordial: is inflation correct?
  - which (scalar) fields? role of quantum gravity?
- today: dark energy (why is $\Lambda$ so small?) or gravity modification?

Quarks and leptons:
- why 3 families?
- masses and mixing
- CP violation in the lepton sector
- matter and antimatter asymmetry
- baryon and charged lepton number violation

At what E scale(s) are the answers?
Looking for “unknown unknowns”

Needs a synergic use of:

- High-Energy colliders
- Neutrino experiments (solar, short/long baseline, reactors, $0\nu\beta\beta$ decays),
- Cosmic surveys (CMB, Supernovae, BAO, Dark E)
- Dark matter direct and indirect detection
- Precision measurements of rare decays and phenomena
- Dedicated searches (WIMPS, axions, dark-sector particles)
- …..
The success of the LHC is proof of the effectiveness of the European organizational model for particle physics, founded on the sustained long-term commitment of the CERN Member States and of the national institutes, laboratories and universities closely collaborating with CERN.

**Europe should preserve this model in order to keep its leading role**, sustaining the success of particle physics and the benefits it brings to the wider society.

The scale of the facilities required by particle physics is resulting in the globalization of the field. The European Strategy takes into account the worldwide particle physics landscape and developments in related fields and should continue to do so.
Particle physics is global. The United States and major players in other regions can together address the full breadth of the field’s most urgent scientific questions if each hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere. Strong foundations of international cooperation exist, with the Large Hadron Collider (LHC) at CERN serving as an example of a successful large international science project.

Reliable partnerships are essential for the success of international projects. Building further international cooperation is an important theme of this report, and this perspective is finding worldwide resonance in an intensely competitive field.
The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an $e^+e^-$ linear collider. In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.

Should the neutrino mixing angle $\theta_{13}$ be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations. This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

The discovery of the Higgs boson is the start of a major programme of work to measure this particle’s properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.

*Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*
<table>
<thead>
<tr>
<th>Project/Activity</th>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
<th>Science Drivers</th>
<th>Technique (Frontier)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large Projects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muon program: Mu2e, Muon g-2</td>
<td>Y, Mu2e small repopulation needed</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HL-LHC</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LBNF + PIP-II</td>
<td>Y, LBNF components delayed relative to Scenario I</td>
<td>Y</td>
<td></td>
<td>Y, enhanced</td>
<td></td>
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<tr>
<td>ILC</td>
<td>R&amp;D only</td>
<td>R&amp;D, possibly small hardware contributions. See text</td>
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<td>NuSTORM</td>
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<td>RADAR</td>
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<td><strong>Medium Projects</strong></td>
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<tr>
<td>LSST</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>DM G2</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>Small Projects Portfolio</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>Accelerator R&amp;D and Test Facilities</td>
<td>Y, reduced</td>
<td>Y, reduced with redirection to ILC-II development</td>
<td>Y, enhanced</td>
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<td>CMB-S4</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>DM G3</td>
<td>Y, reduced</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>PINGU</td>
<td>Further development of concept encouraged</td>
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<tr>
<td>ORKA</td>
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<td>N</td>
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<td>MAP</td>
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<td>LArI</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
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</tr>
<tr>
<td><strong>Additional Small Projects (beyond the Small Projects Portfolio above)</strong></td>
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<td></td>
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<tr>
<td>DESI</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short Baseline Neutrino Portfolio</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Summary of Scenarios A, B, and C. Each major project considered by PS is shown, grouped by project size and listed in time order based on year of peak construction. Project sizes are: Large (>$200M), Medium ($50M-$200M), and Small (<$50M). The science Drivers primarily addressed by each project are also indicated, along with the Frontier technique area (E-Energy, I-Intensity, C-Cosmic) defined in the 2008 PS report.
Where is New Physics?

The question

- Is the mass scale beyond the LHC reach?
- Is the mass scale within LHC's reach, but final states are elusive?

We should be prepared to exploit both scenarios, through:

- Precision
- Sensitivity (to elusive signatures)
- Extended energy/mass reach
The LHC timeline

New LHC / HL-LHC Plan

- **L~7x10^{33}**
  - Pile-up~20-35

- **L=1.6x10^{34}**
  - Pile-up~30-45

- **L=2-3x10^{34}**
  - Pile-up~50-80

- **L=5x10^{34}**
  - Pile-up~130-200

---

CERN

L.Rossi
Extending the reach…

- Weak boson scattering
- Higgs properties
- Supersymmetry searches and measurements
- Exotics
- t properties
- Rare decays
- CPV
- ..etc
14 TeV vs 8 TeV – Gain Factors

Use parton luminosities to illustrate the gain of 14 vs 8 TeV

**Higgs:**
pp → H, H→WW, ZZ and γγ
mainly gg: Factor ∼2

**SUSY – 3\textsuperscript{rd} Generation:**
Mass scale ∼ 500 GeV
qq and gg: Factor ∼ 8

**SUSY – Squarks/Gluino:**
Mass scale ∼ 2.0 TeV
qq,gg,qq: Factor ∼300

**Z’:**
Mass scale ∼ 5 TeV
qq: Factor ∼1000

For the searches increase in energy will help a lot!
Training quenches

All sectors fully qualified at 6.5 TeV
Easter 2015: beams are back!
...and at 6.5 TeV
Decision to run at a **maximum** energy of 6.5 TeV per beam during the powering tests and during 2015. (10 to 15 training quenches per sector are expected to be needed to reach that energy).

**NO change of beam energy in 2015.**

A decision regarding the possibility of increasing the energy will be taken later in 2015, based on the experience gained in all eight sectors at 6.5 TeV per beam during powering tests and operation with beams.
LHC goal for 2015 and for Run 2 and 3

Priorities for the 2015 run:
- Establish proton-proton collision at 13 TeV with 25ns and low $\beta^*$ to prepare production run in 2016.
  Optimisation of physics-to-physics duration
- Later in 2015: decision on special runs “when and duration” (90m optics): not in the 1st part of the year. Waiting LHCC recommendation
- Pb-Pb run: one month at the end of 2015

The goal for Run 2 luminosity is $1.3 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ and operation with 25 ns bunch spacing (2800 bunches), giving an estimated pile-up of 40 events per bunch crossing.

“A maximum pileup of ~50 is considered to be acceptable for ATLAS and CMS”
LHC goal for 2015 and for Run 2 and 3

Integrated luminosity goal:
2015 : 10 fb$^{-1}$
Run2: $\sim$100-120 fb$^{-1}$
(better estimation by end of 2015)
300 fb$^{-1}$ before LS3
The HL-LHC Project

- New IR-quads Nb$_3$Sn (inner triplets)
- New 11 T Nb$_3$Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- ...

Major intervention on more than 1.2 km of the LHC
Project leadership: L. Rossi and O. Brüning
Higgs couplings fit at HL-LHC

<table>
<thead>
<tr>
<th>Coupling</th>
<th>Uncertainty (%)</th>
<th>300 fb⁻¹</th>
<th>3000 fb⁻¹</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1</td>
<td>Scenario 2</td>
<td>Scenario 1</td>
</tr>
<tr>
<td>k_γ</td>
<td>6.5</td>
<td>5.1</td>
<td>5.4</td>
</tr>
<tr>
<td>k_V</td>
<td>5.7</td>
<td>2.7</td>
<td>4.5</td>
</tr>
<tr>
<td>k_g</td>
<td>11</td>
<td>5.7</td>
<td>7.5</td>
</tr>
<tr>
<td>k_b</td>
<td>15</td>
<td>6.9</td>
<td>11</td>
</tr>
<tr>
<td>k_t</td>
<td>14</td>
<td>8.7</td>
<td>8.0</td>
</tr>
<tr>
<td>k_τ</td>
<td>8.5</td>
<td>5.1</td>
<td>5.4</td>
</tr>
</tbody>
</table>

**CMS Projection**

**Assumption** NO invisible/undetectable contribution to \( \Gamma_H \):
- Scenario 1: system./Theory err. unchanged w.r.t. current analysis
- Scenario 2: systematics scaled by \( 1/\sqrt{L} \), theory errors scaled by \( \frac{1}{2} \)
  - \( \gamma\gamma \) loop at 2-5% level
  - down-type fermion couplings at 2-10% level
  - direct top coupling at 4-8% level
  - gg loop at 3-8% level
Fit to coupling ratios:
- No assumption BSM contributions to $\Gamma_H$
- Some theory systematics cancels in the ratios

Loop-induced Couplings $\gamma\gamma$ and $gg$
- treated as independent parameter
- $\kappa_\gamma / \kappa_Z$ tested at 2%
- gg loop (BSM) $\kappa_t / \kappa_g$ at 7-12%
- 2nd generation ferm. $\kappa_\mu / \kappa_Z$ at 8%

$\sqrt{s} = 14$ TeV: $L_{\text{int}} = 300$ fb$^{-1}$; $L_{\text{int}} = 3000$ fb$^{-1}$

$\Delta \Gamma / \Gamma = 2 \Delta \kappa / \kappa$
**Direct squark**

\[ m_{SUSY} = m_{\tilde{t}} \]

\[ \tilde{t} \rightarrow t\chi_1^0 \text{ATLAS-CONF-2013-037} \]

**Direct slepton**

\[ \tilde{\ell}_R \rightarrow \ell^\pm \chi_1^0 \text{ATLAS-CONF-2013-049} \]

**Direct** \[ \chi_1^\pm / \chi_2^0 \]

\[ \chi_1^\pm \chi_2^0 \text{(heavy \tilde{t})} \]

CMS-PAS-SUS-13-006

\[ m_{SUSY} = m_{\chi_1^\pm} = m_{\chi_2^0} \]

---

**LHC: 8 TeV 20 fb^{-1}**

Example of "difficult" SUSY channels!

Assume ATLAS and CMS detector performance remains the same

BR=100%

all limits are observed nominal 95% CLs limits RP conserved
**Direct squark**

$m_{SUSY} = m_{\tilde{q}}$

$\tilde{t} \rightarrow t\chi_1^0$ ATLAS-CONF-2013-037

---

**Direct slepton**

$\tilde{l}_R \rightarrow l^\pm \chi_1^0$ ATLAS-CONF-2013-049

**Direct** $\chi_1^\pm / \chi_2^0$

- $\chi_1^\pm \chi_2^0$ (heavy $\tilde{t}$)
- CMS-PAS-SUS-13-006
- $m_{SUSY} = m_{\chi_1^\pm} = m_{\chi_2^0}$

---

BR=100%

All limits are observed nominal 95% CLs limits RP conserved

---

- LHC: 8 TeV 20 fb$^{-1}$
- LHC: 14 TeV 300 fb$^{-1}$
**Direct squark**
\[ m_{SUSY} = m_{\tilde{q}} \]
\[ \tilde{t} \rightarrow t\chi_1^0 \text{ ATLAS-CONF-2013-037} \]

**Direct slepton**
\[ \tilde{\ell}_R \rightarrow \ell^{\pm}\chi_1^0 \text{ ATLAS-CONF-2013-049} \]

**Direct** \[ \chi_1^{\pm} / \chi_2^0 \]
- \[ \chi_1^{\pm}\chi_2^0 (\text{heavy } \tilde{t}) \]
- CMS-PAS-SUS-13-006

\[ m_{SUSY} = m_{\chi_1^{\pm}} = m_{\chi_2^0} \]

---

**LHC:**
- *8 TeV  20 fb\(^{-1}\)
- *14 TeV  300 fb\(^{-1}\)

**HL-LHC:**
- *14 TeV  3000 fb\(^{-1}\)

---

BR=100%
all limits are observed nominal 95\% CLs limits RP conserved
Luminosity Levelling, a key to success

- High peak luminosity
- Minimize pile-up in experiments and provide “constant” luminosity

- Obtain about 3 - 4 fb\(^{-1}\)/day (40% stable beams)
- About 250 to 300 fb\(^{-1}\)/year
### Baseline parameters of HL for reaching 250 - 300 fb⁻¹/year

<table>
<thead>
<tr>
<th>Parameter</th>
<th>25 ns</th>
<th>50 ns</th>
</tr>
</thead>
<tbody>
<tr>
<td># Bunches</td>
<td>2808</td>
<td>1404</td>
</tr>
<tr>
<td>p/bunch [10¹¹]</td>
<td>2.0 (1.01 A)</td>
<td>3.3 (0.83 A)</td>
</tr>
<tr>
<td>εₗ [eV.s]</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>σₗ [cm]</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>σₗδₚ/ₚ [10⁻³]</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>γεₓ,ᵧ [μm]</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>β* [cm] (baseline)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>X-angle [μrad]</td>
<td>590 (12.5 σ)</td>
<td>590 (11.4 σ)</td>
</tr>
<tr>
<td>Loss factor</td>
<td>0.30</td>
<td>0.33</td>
</tr>
<tr>
<td>Peak lumi [10³⁴]</td>
<td>6.0</td>
<td>7.4</td>
</tr>
<tr>
<td>Virtual lumi [10³⁴]</td>
<td>20.0</td>
<td>22.7</td>
</tr>
<tr>
<td>T_{leveling} [h] @ 5E34</td>
<td>7.8</td>
<td>6.8</td>
</tr>
<tr>
<td>#Pile up @5E34</td>
<td>123</td>
<td>247</td>
</tr>
</tbody>
</table>

**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, l_{beam})

Continuous global optimisation with LIU
7 – 11 orders of magnitude between inelastic and “interesting” - “discovery” physics event rate
The detectors challenge

In order to exploit the LHC potential, experiments have to maintain full sensitivity for discovery, while keeping their capabilities to perform precision measurements at low $p_T$, in the presence of:

- **Pileup**
  - $<\text{PU}> \approx 50$ events per crossing by LS2
  - $<\text{PU}> \approx 60$ events per crossing by LS3
  - $<\text{PU}> \approx 140$ events per crossing by HL-LHC

- **Radiation damage**
  - Requires work to maintain calibration
  - Limits performance-lifetime of the detectors
    - Light loss (calorimeters)
    - Increased leakage current (silicon detectors)
Try to visualize x5!
ATLAS Upgrade Roadmap

LHC
splice consolidation

LS1
~30 fb⁻¹
2013
13-14 TeV
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2035

LS2
~100 fb⁻¹
14 TeV

HL-LHC
installations
~300 fb⁻¹
~3000 fb⁻¹
until 2035

ATLAS Phase-0
New inner pixel layer
Detector consolidation
2015: FTK deployment

ATLAS Phase-1
Improve L1 Trigger, NSW
and LAr electronics to
cope with higher rates

ATLAS Phase-2
Prepare for 140-200 pile-up events
Replace Inner Tracker
New L0/L1 trigger scheme
Upgrade muon/calorimeter
electronics
Upgrade of DAQ detector readout

A long and exciting road ahead!
CMS Phase II Upgrade

New Tracker
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to $\eta \sim 4$

Muons
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to $\eta \sim 3$

Barrel ECAL
- Replace FE electronics
- Cool detector/APDs

Trigger/DAQ
- L1 (hardware) with tracks and rate up $\sim 750$ kHz
- L1 Latency 12.5 $\mu$s
- HLT output rate 7.5 kHz

New Endcap Calorimeters
- Radiation tolerant
- High granularity

Other R&D
- Fast-timing for in-time pileup suppression
- Pixel trigger
LHCb Upgrade

- RICH 1 redesigned; new photodetectors for RICH 1 and RICH 2
- Replacement of full tracking system
- All subdetectors are read out at 40 MHz

Calorimetry and muons:
- Redundant components of system removed; new electronics added; more shielding included
ALICE Upgrade

New Inner Tracking System (ITS)
- improved pointing precision
- less material -> thinnest tracker at the LHC

Time Projection Chamber (TPC)
- New Micropattern gas detector technology
- continuous readout

New Central Trigger Processor (CTP)

Data Acquisition (DAQ)/High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate

Muon Forward Tracker (MFT)
- new Si tracker
- Improved MUON pointing precision

MUON ARM
- continuous readout electronics

TOF, TRD
- Faster readout

New Trigger Detectors (FIT)
The data challenge
Data Management
Where is LHC in Big Data Terms?

Business emails sent 3000PB/year ( Doesn’t count; not managed as a coherent data set)

~14x growth expected 2012-2020

In 2012: 2800 exabytes created or replicated
1 Exabyte = 1000 PB

Google search 100PB

Facebook uploads 180PB/year

LHC data 15PB/yr

US Census

Wired 4/2013

http://www.wired.com/magazine/2013/04/bigdata/
Software

- Moore’s law only helps us if we can make use of the new multi-core CPUs with specialised accelerators etc. (Vectorisation, GPUs, …)
  - No longer benefit from simple increases in clock speed
- Ultimately this requires HEP software to be re-engineered to make use of parallelism at all levels
  - Vectors, instruction pipelining, instruction level pipelining, hardware threading, multi-core, multi-socket.
- Need to focus on commonalities:
  - GEANT, ROOT, build up common libraries
- This requires significant effort and investment in the HEP community
  - Concurrency forum already initiated
  - Ideas to strengthen this as a collaboration to provide roadmap and incorporate & credit additional effort
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. **CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.**
80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements with possibility of e+-e- (TLEP) and p-e (VLHeC)

Conceptual Design Report and cost review for the next ESU (≥2018)

FCC Design Study
Kick-off Meeting: 12-14. February 2014 in Geneva
Establishing international collaborations
• Set-up study groups and committees
Future high-energy circular colliders

**CERN FCC**: international design study for Future Circular Colliders in 80-100 km ring:
- 100 TeV pp: ultimate goal (FCC-hh)
- 90-350 GeV e^+e^-: possible intermediate step (FCC-ee)
- √s = 3.5-6 TeV ep: option (FCC-eh)

Goal of the study: CDR in ~2018.

**China**: 50-70 km e^+e^- √s=240 GeV (CepC) followed by 50-90 TeV pp collider (SppC) in same tunnel
- 50 km e^+e^- machine + 2 experiments:
  - pre-CDR: end 2014
  - construction: 2021-2027
  - data-taking: 2028-2035
  - cost (material): ~3 B$

Possible site: Qinghunghdao

Parameters are indicative and fast evolving, as no CDR yet

Best beach & cleanest air
Summer capital of China

Schematic of an 80 - 100 km long tunnel

Beijing
Qinhuangdao
Beidaihe
Cross sections vs $\sqrt{s}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma$ (100 TeV)/$\sigma$ (14 TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pp</td>
<td>1.25</td>
</tr>
<tr>
<td>W</td>
<td>$\sim 7$</td>
</tr>
<tr>
<td>Z</td>
<td>$\sim 7$</td>
</tr>
<tr>
<td>WW</td>
<td>$\sim 10$</td>
</tr>
<tr>
<td>ZZ</td>
<td>$\sim 10$</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$\sim 30$</td>
</tr>
<tr>
<td>$H$</td>
<td>$\sim 15$ (ttH $\sim 60$)</td>
</tr>
<tr>
<td>HH</td>
<td>$\sim 40$</td>
</tr>
<tr>
<td>stop (m=1 TeV)</td>
<td>$\sim 10^3$</td>
</tr>
</tbody>
</table>

→ With 10000/fb at $\sqrt{s}=100$ TeV expect: $10^{12}$ top, $10^{10}$ Higgs bosons, $10^8$ m=1 TeV stop pairs, ...
No time to idle (exp and theory)

Detectors R&D:

- Ultra-light, ultra-fast, ultra-granular, rad-hard, low-power Si trackers
- $10^8$ channel imaging calorimeters (power consumption and cooling at high-rate machines,..)
- Big-volume 5-6 T magnets ($\sim 2 \times$ magnetic length and bore of ATLAS and CMS, $\sim 50$ GJ stored energy) to reach momentum resolutions of $\sim 10\%$ for p$\sim 20$ TeV muons

Theory:

- Improved theoretical calculations (higher-order EW and QCD corrections) needed to match present and future experimental precision on EW observables, Higgs mass and branching ratios.
- Work together with experiments on model-independent analyses in the framework of Effective Field Theory.
In summary

An exciting period in front of us:

- We have finished the inventory of the “known unknown”…
- …but we have a vast space to explore, and tools to do it exhaustively.
- We have a solid physics program for the next 15 – 20 years
- In this time period we have to prepare for the next steps, setting directions, technologies and political frames.
In summary

**Experimental results** will be dictating the agenda of the field.

We will need:

- Flexibility
- Preparedness
- Visionary global policies
...and a bit of luck!

Thank you!