Report from the “Higgs as a Tool For Discovery” Group:

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Brief Introduction

- In the Standard Model the Higgs boson is the particle generating the masses for the other fundamental particles
- The recently discovered boson is consistent with being the SM Higgs boson but many questions remain open
  - What principles determine the values of its couplings to quarks and leptons?
  - How is it related to neutrino masses?
  - Does it couple to dark matter?
  - Is there one Higgs particle or many?
  - Is the Higgs boson really fundamental or is it composed of other constituent particles?
  - …

Structure of the Parallel Session

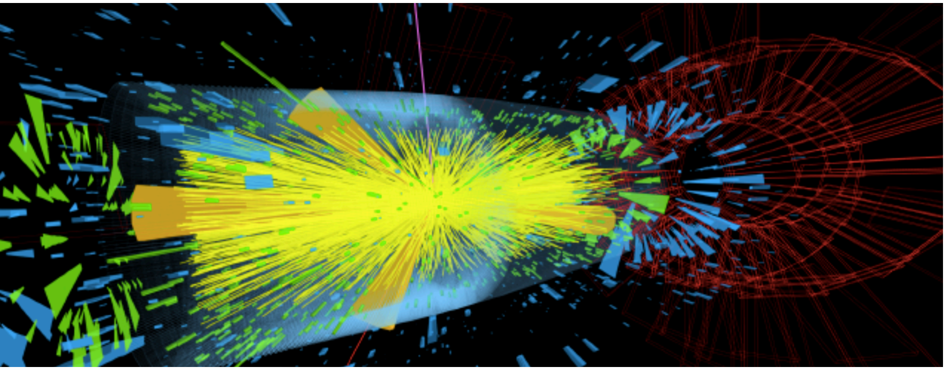
- Review of Higgs Physics
  - "Higgs physics at future machines: precision and discovery program", **Zhen Liu**
  - "Golden Probe of the Electroweak symmetry Breaking", **Joe Lykken**
- The LHC and the HL-LHC as the first laboratory to use the Higgs boson as a tool for discovery
  - "The Technological challenges for Higgs Physics"
    - ATLAS, **Stephane Willocq**
    - CMS, **Vivian O'Dell**
- The precision and discovery programs at future colliders
  - "The Technological challenges for Higgs Physics"
    - ILC, **Jim Brau**
    - Future Circular Colliders, **Ashutosh Kotwal**

Higgs Precision and Discovery Program: Findings (I)

- Higgs boson discovery substantiates (more) many big questions in nature and all connections can be revealed in measurements of vector boson scattering and of the Higgs boson interactions
  - With SM particles including neutrinos, with itself, with new particles
- The determination of these properties is one of the top priorities in the physics program of high-energy colliders.
- **The complementary aspects of hadron and electron-positron colliders is essential to carry out this program to its fullest extent**
  - *e.g*. pp colliders can explore the potential via HH production, while ee colliders probe loop-corrections in ZH production
  - pp and ee machines are sensitive to different exotics decays of the Higgs
  - Polarization at ee linear collider improves sensitivity to higher dimensional operators

Higgs Precision and Discovery Program: Findings (II)

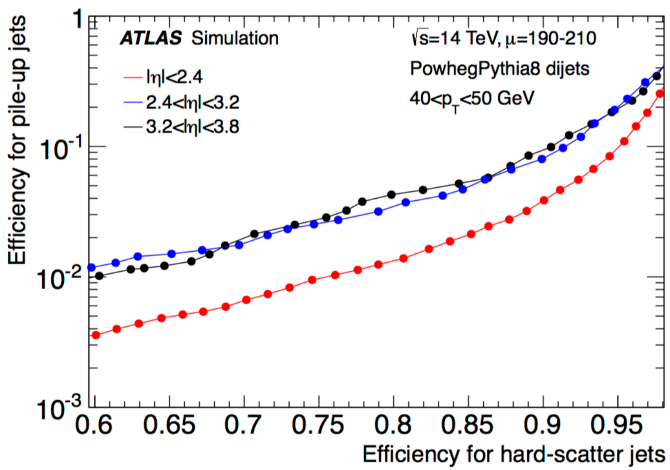
- **Both the precision and discovery programs require % level precision measurements of the Higgs properties**
- These translate into the following **science requirements**:
  - For all machines:
    - Excellent track momentum resolution and track-track separation
    - Highly efficient and pure b-tagging and c-tagging
    - Excellent jet energy resolution (➔ Etmiss resolution)
  - Additionally, for to pp machines:
    - Efficient and pure vertexing (primary and secondary)
    - Maintain low trigger thresholds for leptons, jets, photons

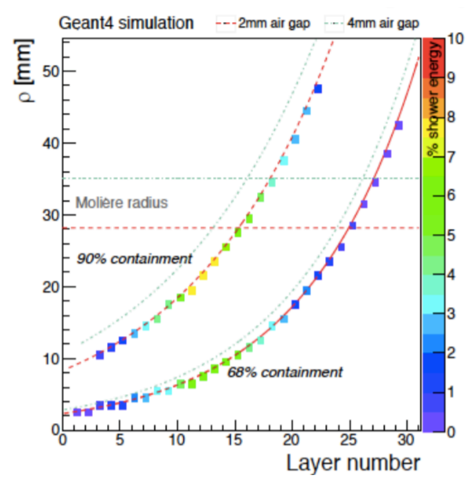


Pile Up suppression is the key at pp machines!

ATLAS and CMS at HL-LHC: Findings (I)

- Newly proposed TDAQs allow for low trigger thresholds and thus preserve large acceptance to EWK scale processes
  - Larger bandwidth and longer L1 latency
  - Tracking information early in the trigger chain (in LOIs with the L1TrackTrigger for ATLAS; global with TrackTrigger in CMS)
- Technical requirements of the new trackers (and calorimeters) are derived from the relevant science requirements
  - low material budget, high granularity, rad-hard sensors and electronics, high eta coverage





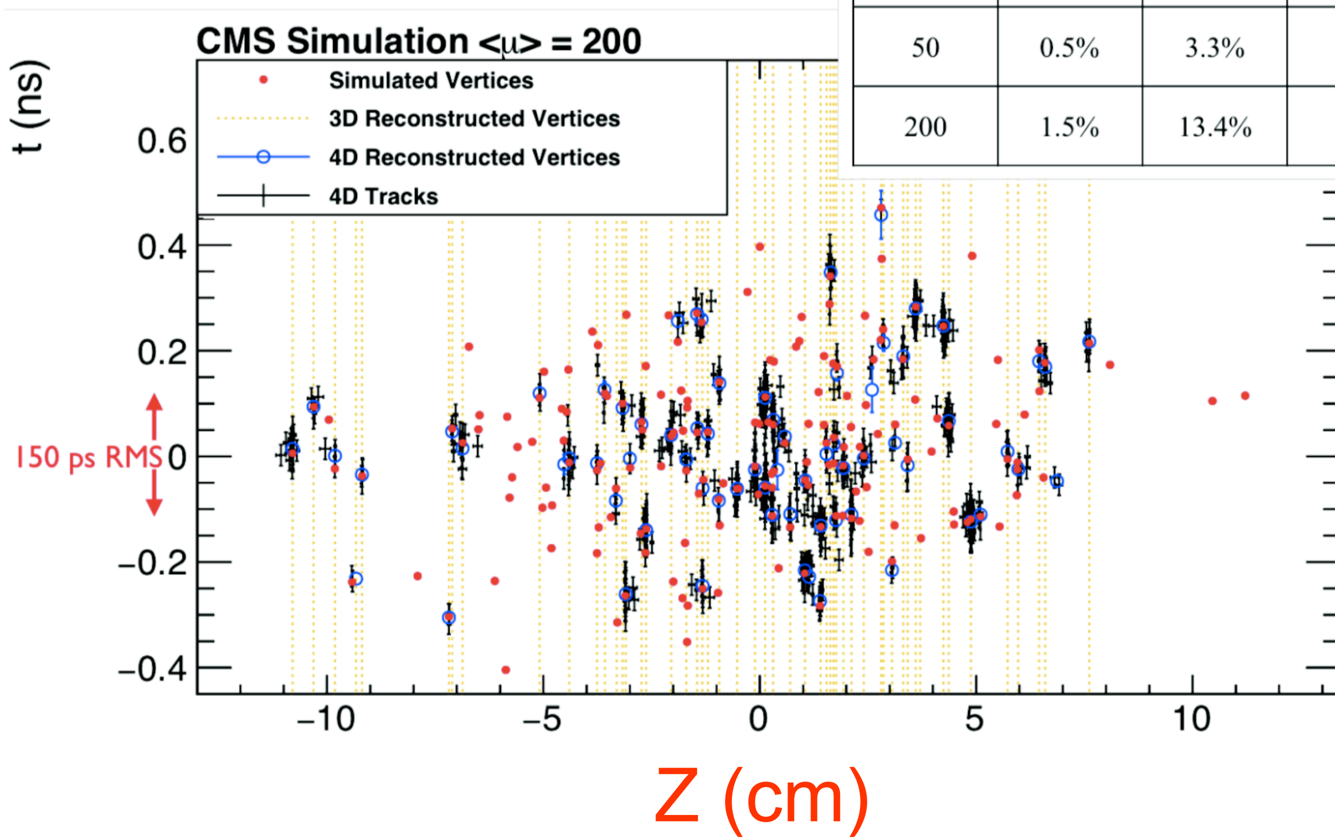
- High granularity, rad-hard sensors and electronics also improve PU suppression in CMS HGCAL

ATLAS and CMS at HL-LHC: Findings (II)

- Timing information has the potential to further enhance the capability to suppress pile-up

CMS Simulation

<μ>	4D Merged Vertex Fraction	3D Merged Vertex Fraction	Ratio of 3D/4D
50	0.5%	3.3%	6.6
200	1.5%	13.4%	8.9



ILC: Findings (I)

- The ee linear collider is the ultimate precision machine
- Precision achieved thanks to
  - **Simple initial and final states**
  - Limited radiation damage, trigger-less operations, pulse powering
  - And polarizable beam, tunable center-mass-energy
- **Tight detector requirements to exploit machine capabilities and clean environment**

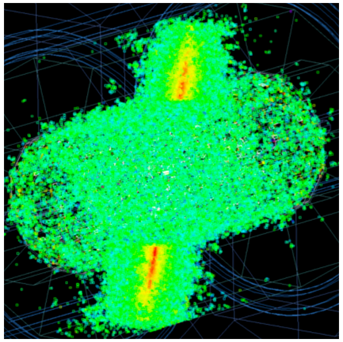
Critical Detector Characteristic	Required Performance
Impact parameter ⇒ Flavor tag	$\delta_b \sim 5\mu m \oplus 10\mu m/(p\sin^{3/2}\theta)$
Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ ⇒ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV^{-1}$
Jet Energy Resolution, σ_E/E ⇒ Di-jet Mass Res.	~3% for $E_{jet} > 100$ GeV $30\%/\sqrt{E_{jet}}$ for $E_{jet} < 100$ GeV
Momentum resolution, Hermiticity ⇒ Event Reconstruction	Maximal solid angle coverage

ILC: Findings (II)

Detector Design	Detector Comparison
Calorimeter granularity	~200 finer than LHC
Pixel size	~20 smaller than LHC
Material budget, central	~10 less than LHC
Material budget, forward	$\gtrsim$100 less than LHC

- Readout ~50 times per bunch train (or time stamp) to reduce occupancy in vertex detector
- Calorimeters suitable to particle flow and with large acceptance
- Two tracker detector designs considered:
  - SiD (silicon tracking with pixel tracking also considered)
  - ILD (TPC and Si)
- Various technologies explored for the calorimeters (scintillators, glass RPC, GEM, MM, Si or GaAs)

Future Circular pp Colliders: Findings



- The ultimate technological challenge
  - Un-precedent pile-up (up to 1000)
  - Both low momentum and highly boosted objects
- **Science requirements**
  - Excellent track momentum resolution → To maintain/improve *b*-tagging at high jet pT and high track density
  - Excellent vertexing → to suppress PU
  - Excellent jet energy resolution (requires confinement of jets)
  - Improve hadronic τ-lepton identification efficiency (requires high-granularity EMCAL)
  - Boosted H/W/Z/top substructure (requires high-granularity HCAL)
  - High acceptance to vector boson scattering, to rejecting top quark background and forward pileup jets (requires forward coverage to rapidity ~ 6)

Opportunities & Recommendations

- **Science Opportunities**
  - Improved b- and c-tagging capabilities (offline and trigger)
  - (Further) extension of eta coverage
  - Enhanced usage of timing (offline and trigger)
  - Improved energy resolution
- **Recommendation 1:** R&D in:
  - Rad-hard sensors and electronics
  - Wireless communication
  - Low power ASICs
  - New low mass material for structures
- **Recommendation 2: assessment whether the upgraded CMS and ATLAS remain optimal for (a potential) High-Energy HLC (28-33TeV)?**