Requirements to Event Generators

from experimentalists at LHC/ATLAS,

not from an NLO-WG member

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LHC

Large Hadron Collider

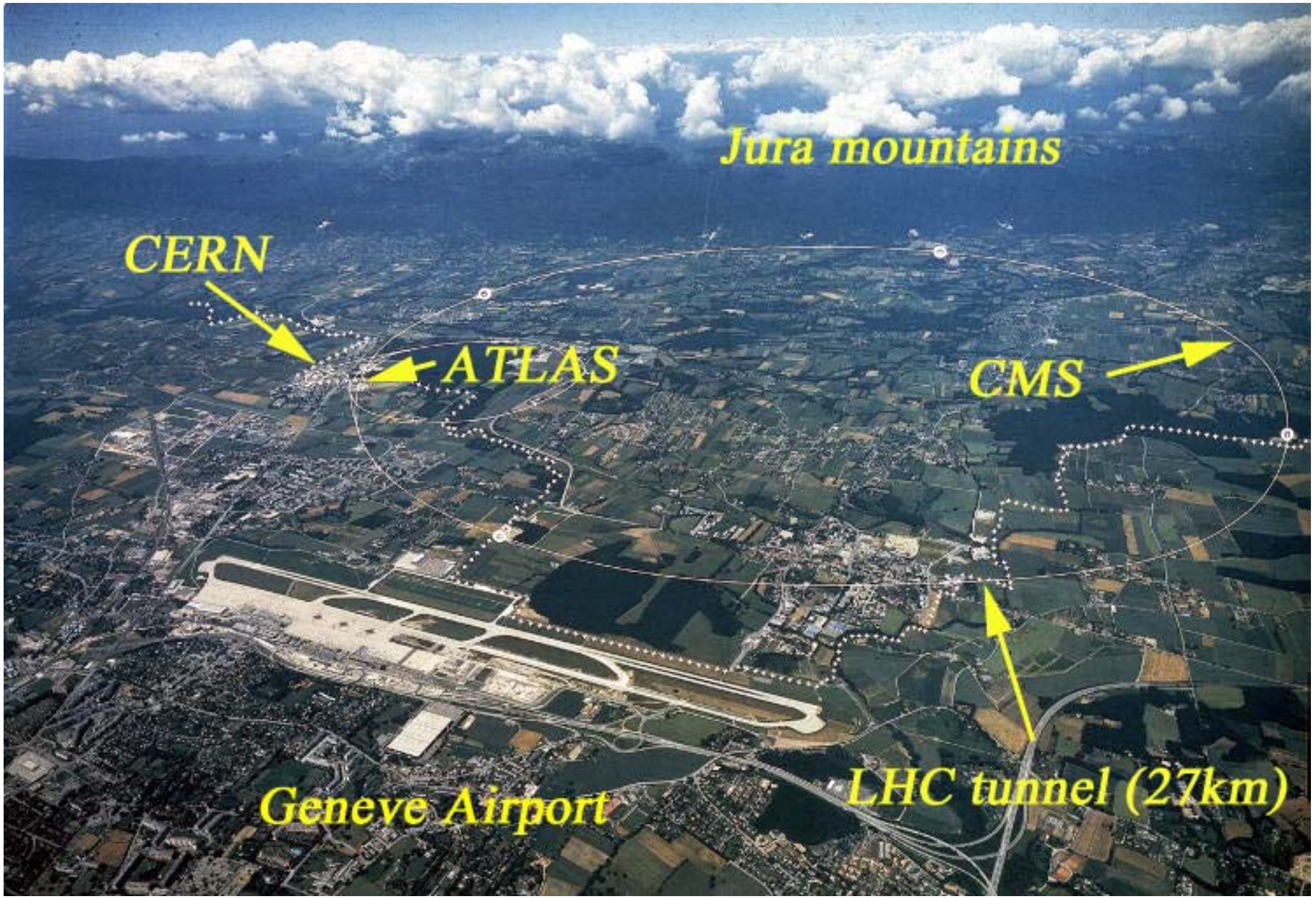
- 14 TeV (= 7 TeV + 7 TeV) proton-proton collider in the LEP tunnel
- Schedule:
  - End 2006: completion of the accelerator
  - Spring 2007: first beam circulation
  - Mid 2007: first collision
  - Aug. - Oct. 2007: first physics run
- Physics runs
  - 2007 - 2008: low luminosity (~ 10^{33} cm^{-2} / s)
    → ~20 fb^{-1}
  - 2009 (?) - : high luminosity (~ 10^{34} cm^{-2} / s)
    → ~100 fb^{-1}/year

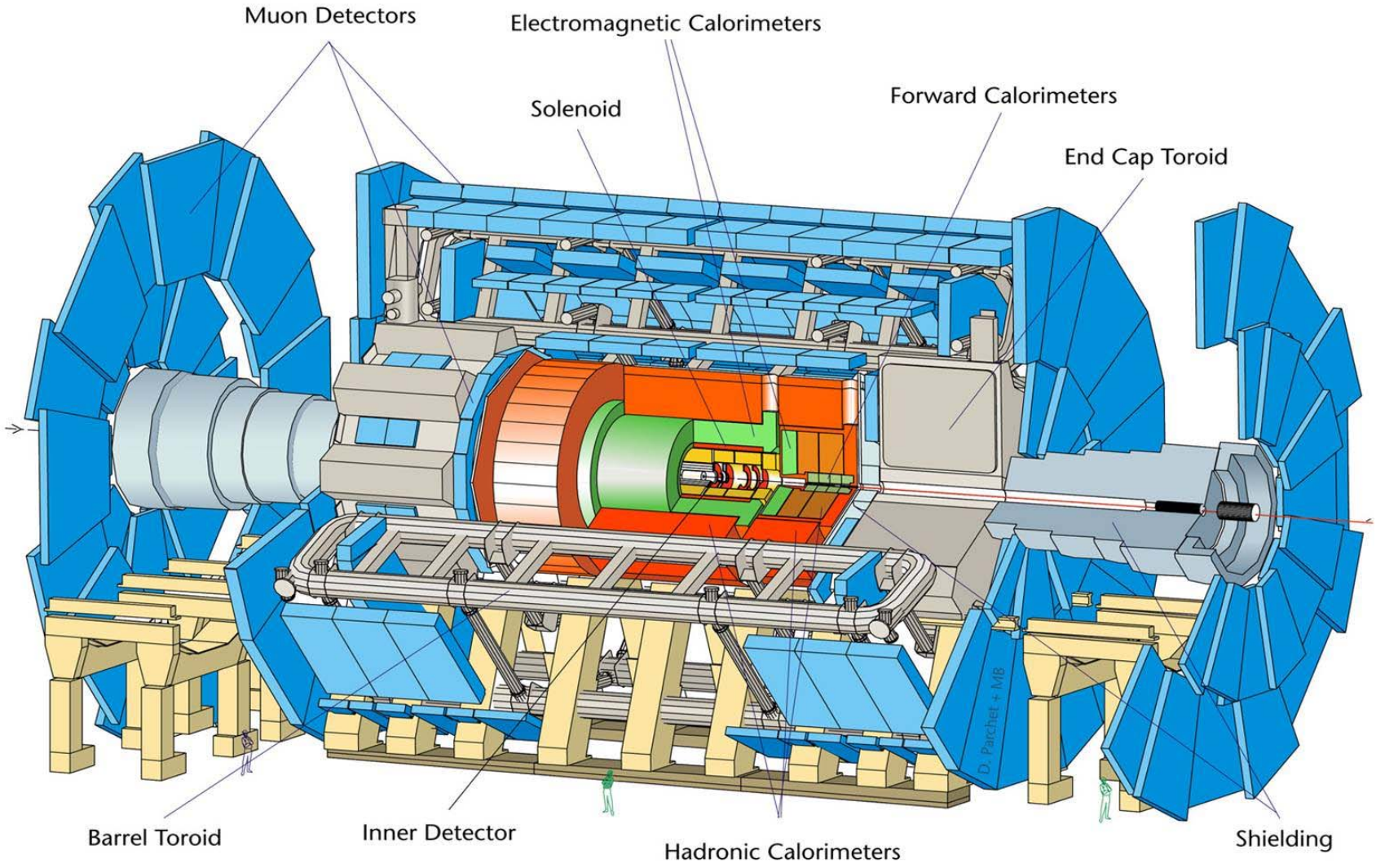
ATLAS

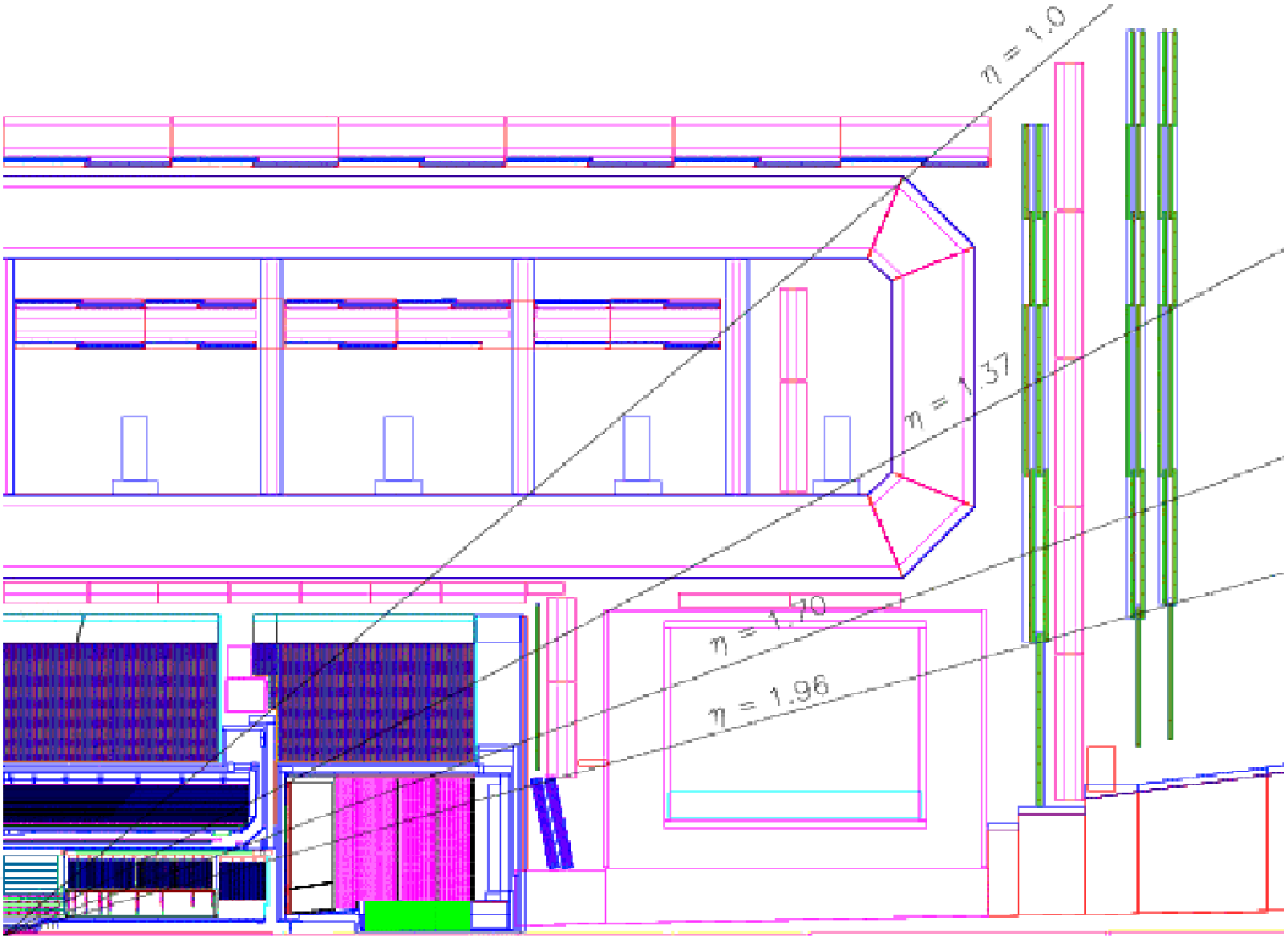
A Toroidal Lhc ApparatuS

- Good track/momentum measurement using superconducting air-core magnets
  - 2 T-solenoid for inner tracking and 4 T-toroids for outer muon-tracking
  - Inner tracking volume = 2.3 m^{ϕ} × 7 m

    Si-pixel, Si-strip and TRT (Transition-Radiation Tracker)
  - Precision drift-tubes (MDT) for muon tracking with RPC and TGC for trigger
  - Tracking/particle-ID (e, μ, τ, γ) up to $|\eta| = 2.5$
- Hermetic calorimetry up to $|\eta| = 4.9$
  - Accordion-Pb/LA for inner berrel/endcap (EM)
  - Fe/tile-scintillator for outer barrel (HAD)
  - Cu-plate/LA for outer endcap (HAD)
  - Rods-in-Cu/LA (EM) and rods-in-W/LA (HAD) in the forward region


Jura mountains
CERN
ATLAS
CMS
Geneve Airport
LHC tunnel (27km)


D712/mb-26/06/97
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding
D. Parchet + MB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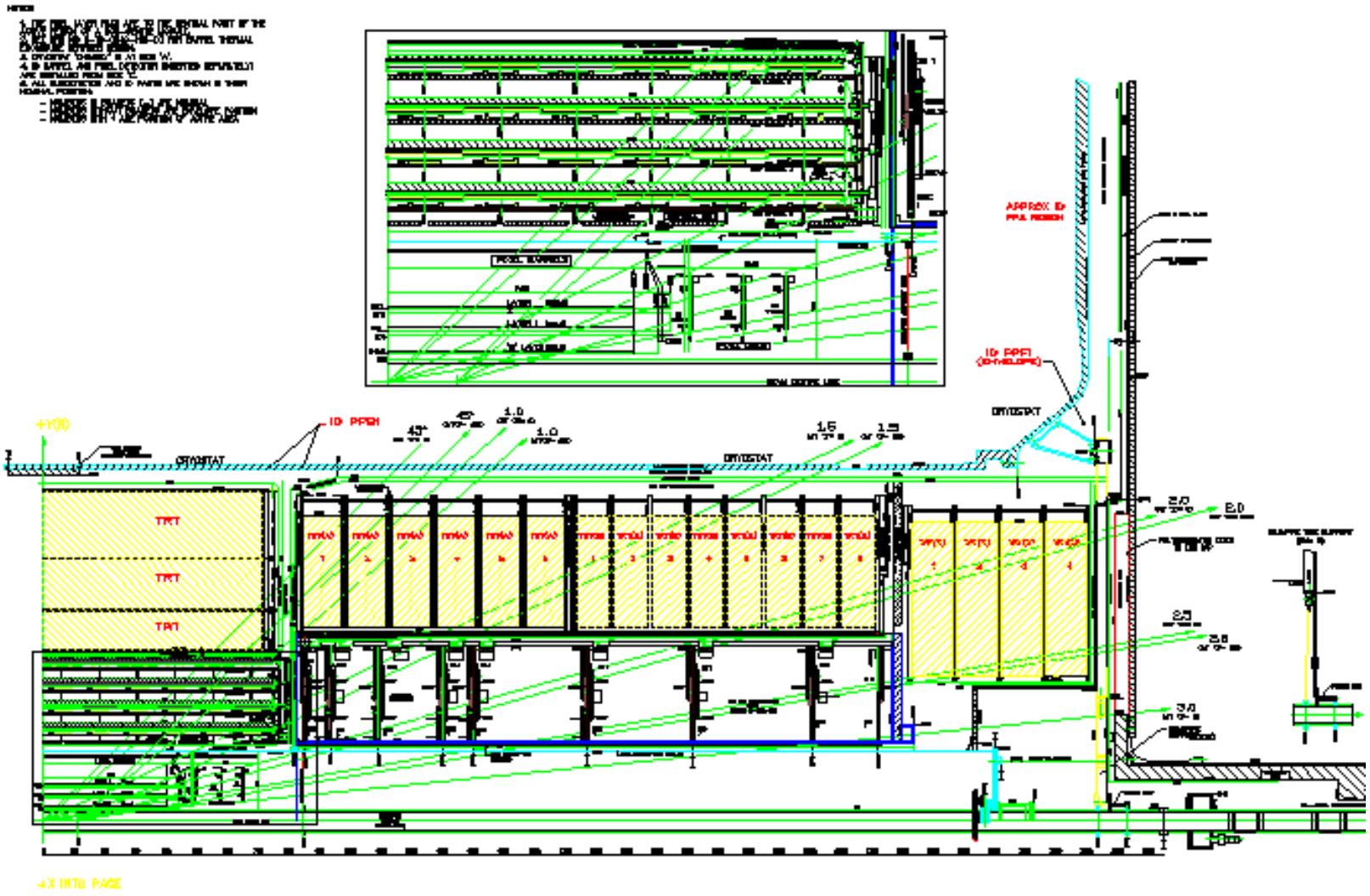
η = 1.37
η = 1.70
η = 1.96


ID PIPE
CRYOSTAT
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+Y(R)
+X INTO PAGE

Physics Subjects

- Measurement of unknown parameters within the SM
  - Discovery of the (SM) Higgs boson; i.e., determination of the Higgs-boson mass, the only missing parameter within the minimal SM
- Search/discovery of Physics beyond the SM
  - Search/discovery of new particles/new phenomena
    - Multiple Higgs bosons
    - SUSY particles
    - Other new particles (*W'/Z'*, new heavy quarks, heavy gravitons, …)
  - Validation of the Standard Model
    - Anomalous property of discovered "Higgs" boson(s)
      - Spin-parity, coupling to bosons and fermions
    - Anomalous cross section of known phenomena
      - Large-E_T jets, *W/Z* productions, heavy-quark productions, …

Event generators in physics analyses

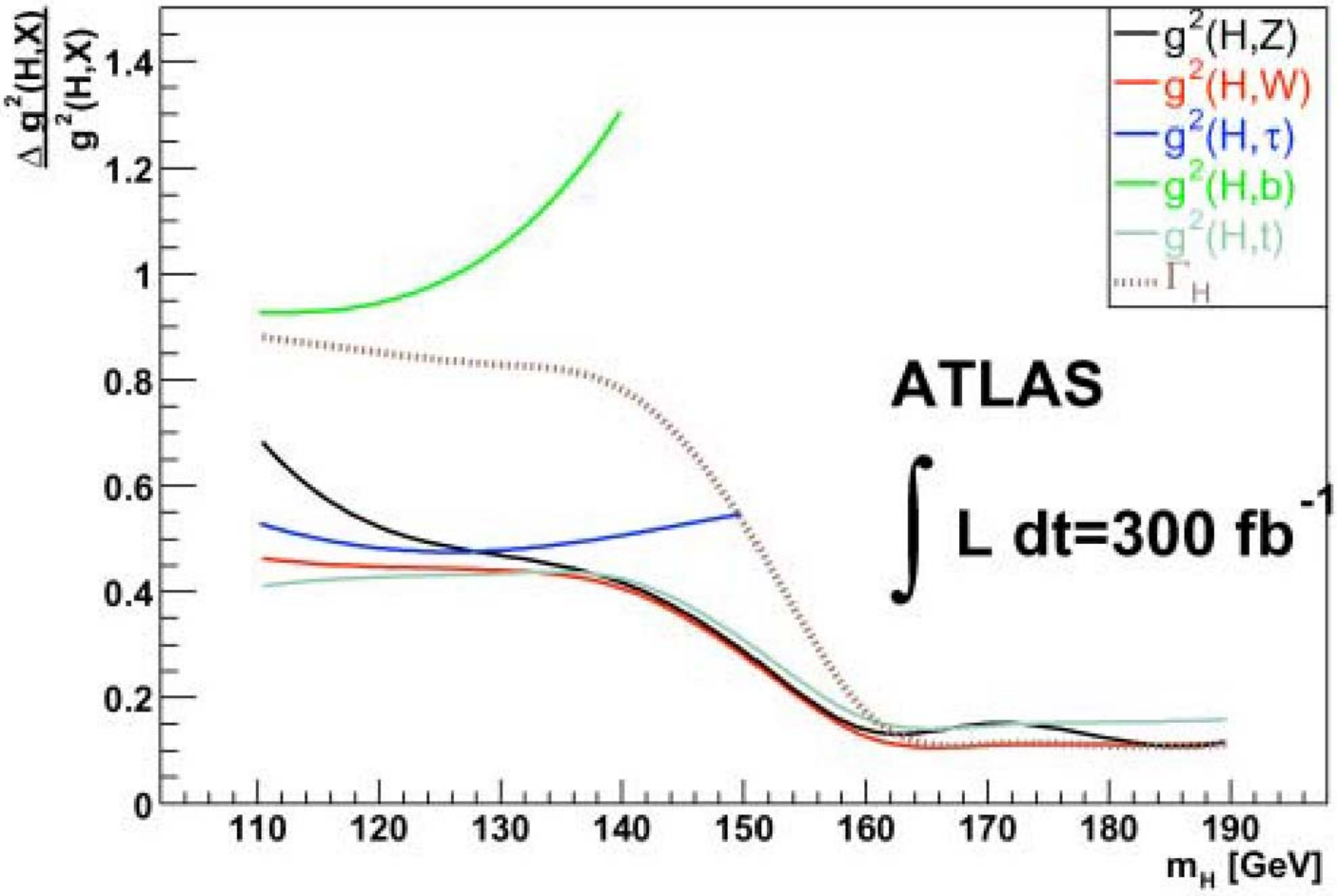
- Almost no need in the “discovery” of sharp peaks
  - But we never stop at the “discovery”; “measurement” follows.
- Important in discovery/confirmation of wide resonances and those with missing energies (e.g., top, SUSY, etc.)
- Necessary in cross-section measurements
  - Signal simulation
    - Event-topology simulation to evaluate the experimental acceptance
    - Comparison in the absolute value for searching anomalies
  - Background simulation
    - Accuracy can be worse if background is small, but large QCD background in many cases in hadron collisions.
- Various roles; required precision depends on the role.

Measurement precision

Stereotype summary

	e^+e^- collider	Hadron collider	Astronomy
Observation	Factor of two	Order of magnitude	Seen
Rough measurement	10%	Factor of two	Order of magnitude
Precise measurement	1%	**10%**	Factor of two

From a talk by S. Asai at the JPS meeting, Miyazaki, Sep. 2003



How to achieve a 10% theoretical accuracy

not easy in hadron collisions

- NLO corrections amount to 20% to 100% ⇒ necessary to include higher orders
- But how?
  - LO generator + analytical corrections (e.g., K factor)
  - NLO generator
  - NLO generator + analytical higher-orders (NNLO, …)
- The main role of event generators is to give us an estimation of experimental acceptance.
  - The accuracy in the event topology is most important.
  - Does NLO significantly change the event topology, or not? Maybe, process-dependent.

Background simulation

not always a small perturbation

- Event signature we can use for discriminating signal events
  - Inclusion of high-p_T EW particle(s): leptons, γ
  - Existence of large missing-E_T
- Thus, gauge-boson ($W/Z/\gamma$) productions (associated with jets) are dominant sources of background in many cases.
  - A good precision comparable to, or sometimes better than, the signal is required.
- Of course, many other processes would have to be evaluated.
  - LO simulations would be sufficient.
  - But need to cover a wide variety of processes.

But the future may be different.

- There may be no Higgs.
  - LO generators would be enough for SUSY searches.
- However, once SUSY particles found, we will want to have NLO-SUSY generators.
- There may be no SUSY particle, as well, in our reach.
  - If so, precise measurements of known processes would become important. People may want NLO and NNLO generators.
- We may find new unexpected particles.
- …
- I'm not sure what will be most spotlighted 5 years later.
- It would be most important to have established frameworks for constructing reliable tools.

Summary of the requirements

- Theoretical accuracy at a level of 10% for important processes: e.g., Higgs-boson production processes.
  - I'm not sure if this is a requirement to event generators.
- A similar level of accuracy for $W/Z/\gamma$ + jets.
  - This is desired to be achieved by event generators.
- LO event generators covering a wide variety of processes, including SUSY.
  - Fully automatic event-generator generation system, like CompHEP and MadEvent, is desirable for this purpose.
  - We frequently want to add certain anomalous interactions. A "model"-level flexibility is also desirable.

We don't require a single system should satisfy all these requirements.

We want to have as many tools as possible; not only MC event generators, but also analytical evaluations.

NLO WG

NLO Working Group

- Started in January 2000.
- Collaboration of people from the Minami-Tateya group and the ATLAS-Japan group
- Goal: to develop an NLO automatic event-generator generation system (including NLL-PS) for hadron interactions, based on the GRACE system.
- Present status:
  - The GR@PPA framework, an extension of the GRACE system to hadron collisions, has been established.
  - The first implementation for “four bottom-quark” production processes at LO (GR@PPA_4b) was published in CPC in Apr. 2003.
  - We are going to release a new package (GR@PPA_All) including other processes at LO: *W/Z* + jets, full 6-body top-pair, Di-boson.
  - The 1st NLO event generator (QED Drell-Yan) was composed early in this year to test new ideas: LL-subtraction from ME, *x*-deterministic forward PS evolution, ...
  - An NLO *W*-production generator is going to be completed.
- See http://atlas.kek.jp/physics/nlo-wg/ for more info.

Appendix

There is still something missing in understanding hadron collisions.

PDF/PS - ME mismatch

in jet-associated processes;
e.g., W + jets

- Traditional way to evaluate "W + jets" production:
  - p_T cut to the jets ≅ experimental E_T cut; *e.g.*, = 20 GeV
  - renormalization/factorization scale = $\langle m_T^2 \rangle = m_W^2/2 + \langle p_T^2 \rangle$
- If simply connect "W + jet" ME to a PDF/PS in this way, the cross section depends on the p_T cut even at large $p_T(W)$ regions.
- It may happen that p_T(jet in PS) > p_T(jet in ME).
- A certain phase space of the jet is counted both in PDF/PS and ME; *i.e.*, double-count.

PDF/PS - ME matching

- Roots of this problem
  - Two energy scales in ME: W-mass and p_T cut.
  - The traditional definition of the energy scale violates the virtuality ordering in the QCD evolution.
- **This is a common problem in all jet-associated processes.**
- Many people are trying to find a solution.
  - ME correction in PYTHIA and HERWIG at LO
  - LL subtraction of Kurihara in NLO generators; perhaps a similar way in MC@NLO (Frixione and Webber)
  - Now, the CKKW (Catani-Krauss-Kuhn-Webber) method is attracting much interests.
- These methods are not (very) easy to apply.
  - We need ME infos in the first two methods.
  - CKKW is process-independent, while needs to have "W + many jets" generators.
- *There must be a simple and ME-independent way; to be continued …*

Summary

- ATLAS will start experiment in Summer 2007.
- Experimental precision at a level of 10% will be achievable in important processes; e.g., Higgs-boson productions.
- Theoretical precision is desired to be better than that.
- We will need to have many tools in order to realize it; MC and analytical tools at NLO and hopefully NNLO, and flexible LO event generators with many-body final states.
- A similar accuracy is desired to $W/Z/\gamma$ (+ jets) generators.
- There still be a missing link between the theoretical and experimental worlds: PDF/PS - ME mismatch.
- There may be more lack-of-understandings or misunderstandings.