Introduction Talk, 06.06.01. D. Denisov

Snowmass 2001 Working Group E4: Hadron-Hadron and Lepton-Hadron Colliders

Hadron Detectors Subgroup (Subgroup C)

Working Group E4 group Conveners:
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Mike Albrow
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Charge

- From the interaction region environments and bunch structure configurations advertized by Working Group M4 and the instananeous luminosities determined by benchmarks Working Group E4B, investigate potential detector configurations which would be required for various CM energies, including the highest VLHC energy options.
- Consider the R&D requirements in order to successfully mount such experiments.
- Incorporate possible B physics detection needs as suggested by the physics discussion in both final and staged configurations.
- Include detectors upgrade consideration of staging scenarious for the accelerator complex.
- Consider the effects of an upgraded LHC on the VLHC experiments.

Activities/Schedules

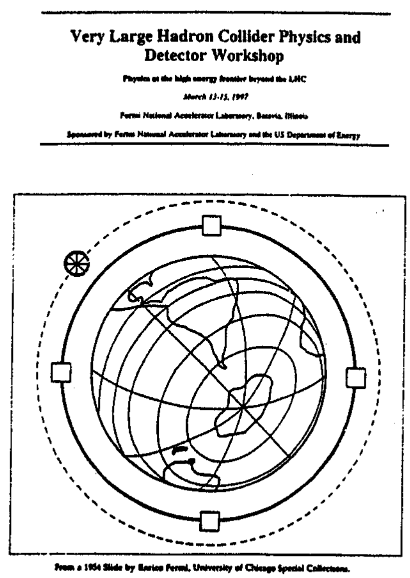
- July 3 (Tuesday): E4 plenary
- July 4 (Wednesday): E4 plenary
- → July 6 (Friday): Introductory Group C meeting
  - Review of previous VLHC detectors efforts and VLHC parameters tables- D. Denisov
  - Calorimetry for VLHC - M. Albrow
  - CMS calorimetry - A. Skuja
  - Optimization of calorimeter response - O. Lobban
  - Group goals and meetings schedule discussion

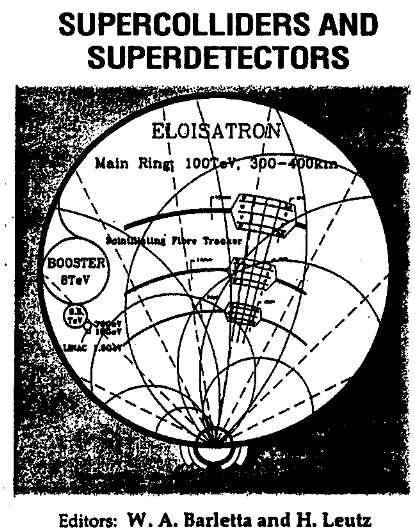
2001 VLHC Design Study Parameters

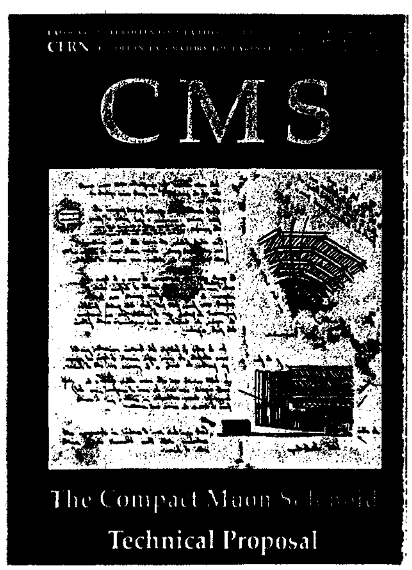
Table 1.1. The high-level parameters of both stages of the VLHC.

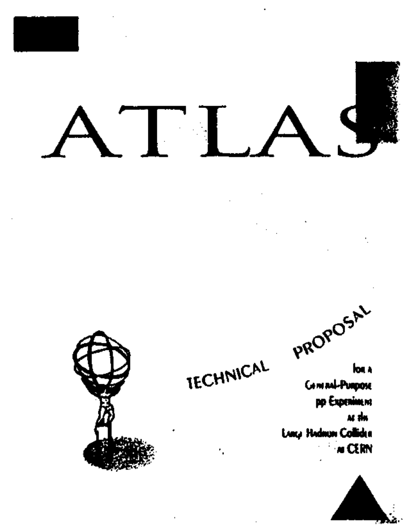
	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	175
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Luminosity lifetime (hrs)	24	8
Injection energy (TeV)	0.9	10.0
Dipole field at collision energy (T)	2	9.8
Average arc bend radius (km)	35.0	35.0
Initial number of protons per bunch	2.6×10^{10}	7.5×10^{9}
Bunch spacing (ns)	18.8	18.8
β^* at collision (m)	0.3	0.71
Free space in the interaction region (m)	± 20	± 30
Inelastic cross section (mb)	100	130
Interactions per bunch crossing at L_{peak}	21	54
Synchrotron radiation power per meter (W/m/beam)	0.03	4.7
Average power use (MW) for collider ring	25	100
Total installed power (MW) for collider ring	35	250

Most of results presented in this talk are compiled from Eloisatron studies, Snowmass '96 , '97 Physics Detectors Workshop and collider detectors proposals:









VLHC 2001 Design Study Report

What we would like to measure?

- Because there is no specific physics process to be studied, general purpose detector(s) is a must for an energy frontier machine

- In order to set benchmarks different process are used: top studies, Higgs/SUSY discovery, etc. Let's consider "recent" top quark discovery

- In order to discover top quark both CDF and D0 had to detect: leptons (e/μ), jets, tag b-quarks (leptons or displaced vertex), and neutrinos (missing E_t):

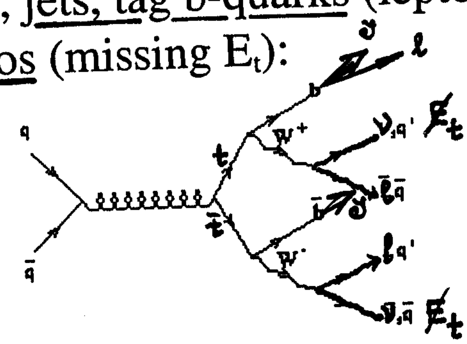


Figure 1: Tree level top quark production by $q\bar{q}$ annihilation followed by the Standard Model top quark decay chain.

Decay mode	Branching ratio
$t\bar{t} \longrightarrow (q\bar{q}'b)(q\bar{q}'\bar{b})$	36/81
$t\bar{t} \longrightarrow (q\bar{q}'b)(e\nu\bar{b})$	12/81
$t\bar{t} \longrightarrow (q\bar{q}'b)(\mu\nu\bar{b})$	12/81
$t\bar{t} \longrightarrow (q\bar{q}'b)(\tau\nu\bar{b})$	12/81
$t\bar{t} \longrightarrow (e\nu b)(\mu\nu\bar{b})$	2/81
$t\bar{t} \longrightarrow (e\nu b)(\tau\nu\bar{b})$	2/81
$t\bar{t} \longrightarrow (\mu\nu b)(\tau\nu\bar{b})$	2/81
$t\bar{t} \longrightarrow (e\nu b)(e\nu\bar{b})$	1/81
$t\bar{t} \longrightarrow (\mu\nu b)(\mu\nu\bar{b})$	1/81
$t\bar{t} \longrightarrow (\tau\nu b)(\tau\nu\bar{b})$	1/81

So, we needed tracker (e/μ, vertex), calorimeter (jets, electrons), and muon system

What we would like to measure (continue)

- LHC detectors are optimized for Higgs search as well as broad class of Standard Model and new physics. For ATLAS detector the goals set for detector elements are:

Detector component	Minimally required resolution, characteristics	η coverage Measurement	Trigger
e.m. calorimetry	$10\%/\sqrt{E} \oplus 0.7\%$	±3	±2.5
Preshower detection	Enhanced γ–π^0 and γ–jet separation, direction measurements, and b-tagging with electrons	±2.4	
Jet and missing E_T Calorimetry			
barrel and end-cap	$50\%/\sqrt{E} \oplus 3\%$	±3	±3
forward	$100\%/\sqrt{E} \oplus 10\%$	$3 < \lvert\eta\rvert < 5$	$3 < \lvert\eta\rvert < 5$
Inner detector	30% at $p_T = 500$ GeV	±2.5	
	Enhanced electron identification	±2.5	
	τ- and b-tagging	±2.5	
	Secondary vertex detection at initial luminosities	±2.5	
Muon detection	10% at $p_T = 1$ TeV in stand-alone mode at highest luminosity	±3	±2.2

For heavy objects $\varepsilon \sim$ solid angle
$|\eta| \lesssim 3 \rightsquigarrow 90\%$

- The major difference for VLHC detectors will be considerable (~7) 3÷12 increase in maximum energy of objects to be measured: jets, electrons, and muons.

Summary of existing collider detectors

- Similar overall design: central solenoid field, precision tracker, high resolution calorimetry and sophisticated muon system

- CDF/D0 vs ATLAS/CMS (factor of 7 in energy and 50 in luminosity)

- Calorimeter sizes are about the same: showers are ~ln(E)

- Considerably more sophisticated detectors:
  - Keep high momentum resolution: $\sigma_p/p \sim p \cdot \frac{\sigma_{det}}{B \cdot L^2}$
  - Keep occupancies low: larger number of channels
  - Cope with factor of 5 faster beam crossings
  - Use radiation hard detectors

- We will compare detector operating conditions at LHC and VLHC in order to understand problematic areas

Events pile-up

- Events overlapp creates serious problems for track reconstruction and vertex finding

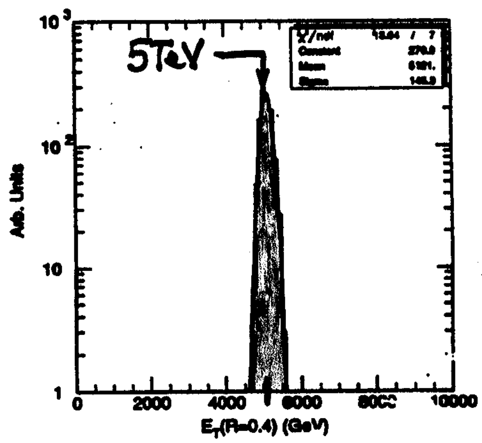
- Create "pedestal" background (with fluctuations) in calorimeter

↳ event
\# of events: statistics
Luminosity + bunch to bunch...

↱ $5 \cdot 10^{35}$

Combining 1000 events gives Gaussian distribution.

For $\sqrt{s} = 100\,\text{TeV}$, $R = 0.4$:



CALORIMETER E_T IN CONE $R = 0.4 = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

Fluctuations from pileup events large $\pm 145\,\text{GeV}$.

Comparable to jet pileup limit. • $10^{34} \rightarrow 100\,\text{GeV}$ •
$\pm$ a few GeV

- Luminosity above 10^{34} creates very high radiation doses and seriously deteriorate detector performance

Central tracker design

Radiation doses, occupancies, timing characteristics could be similar to LHC detectors:

- N_{vertex} ~20 (per event)
- N_{tracks} ~ $3 \cdot 10^3$ (per event)
- Doses ~50Mrad (~10cm from beam pipe)
  ↳ ~ 10 years
- Si-pixels: ~100μ pixels, radiation hardness ~30Mrad, good progress over last years
- Si-strips: ~100μ strips a few cm long, radiation hardness a few Mrad
  ↳ Micro Strip Gas Chambers
- MSGC: combination of semiconductor and gas chambers technology, ~200μ strips, Coulombs of charge per cm of wire
- "Straw" tubes: well known drift tubes technology with a few mm diameter tubes, accuracy ~50μ
- Total number of channels:

$$\underbrace{3 \cdot 10^3}_{\text{Tracks}} \times \underbrace{10}_{\text{Layers}} \times \underbrace{100}_{\text{1\% occupancy}} \Rightarrow 3 \cdot 10^6 \text{ ch}$$

Calorimetry

- Shower depth ~lnE, minor increase in comparison with LHC

- Energy resolution:

  - Electro-magnetic: ~20%/$\sqrt{E}$, 0.5% at 1TeV

  - Hadron : ~50%/$\sqrt{E}$, 2% at 1TeV

- Calorimetry gets very precise at high energy!

- Problem: events pile up: ~100GeV/jet cone (luminosity dependent + fluctuates)

- Main specifications:

  - Radiation hard: ~5Mrad in central region
    ~ 1Grad in forward region

  - Small constant term, stable, easy to calibrate

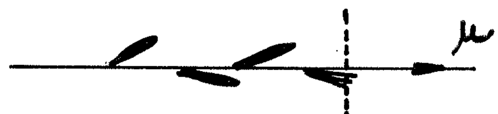
  - Thick ~ $\not{E}_t$, resolution

  - Fast ~ signal collection time less then bunch spacing

Detection of Muons

- High energy muons are important for search of heavy objects and low energy muons for t, b quarks tagging

- Radiation damage is less of a problem for muon detectors, but doses (especially from accelerator and neutrons) have to be carefully estimated



- High energy muons start to irradiate γ (showers) and loose more energy due to radiation losses at a few hundred GeV, then due to ionization. That effect creates backgrounds and requires corrections for momentum measurements

- Momentum resolution is limited by factors similar to central tracker: dp/p ~ $p \cdot \frac{\sigma_{det}}{B \cdot L^2} \oplus$ m.s.

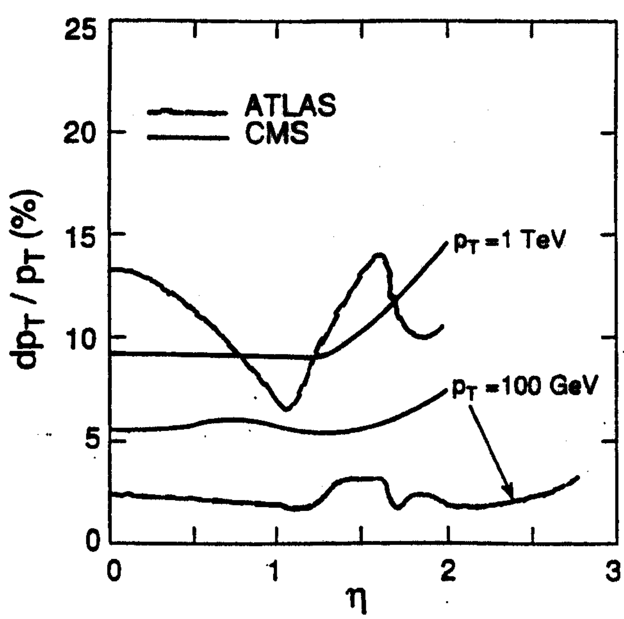


Figure 9 Transverse momentum resolution of ATLAS and CMS detectors for stand-alone muon measurement as a function of pseudorapidity, for two values of the transverse momentum p_T.

Stand alone muon system resolution ~10% @ p_t ~ 1 TeV

Summary

- Considerable amount of work has been done on detectors for high energy pp colliders which could be directly or after minor modifications used for VLHC: in terms of energy Stage 1 is equal to SSC and in terms of luminosity to LHC.

- While in central region radiation doses look "reasonable", forward detectors will have very high radiation fluxes (Monday, July 9 meeting). Going to 10^{35} is difficult: Jorgen Hansen on SLHC.

- Pileup of events is creating serious problems for detection: bunch crossing below 20ns?

- Cost of detectors and construction time reduction is very important.

- What R&D is needed to improve detectors performance and reduce cost?

- Stage 1 VLHC detectors (40TeV @ 10^{34}) are "doable" based on SSC/LHC experience. What is most natural upgrade path from Stage 1 to Stage 2 (175TeV @2. 10^{34})?