LHC Experiments: CMS & ATLAS

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Large Hadron Collider

- LHC will provide us with a 14 TeV center of mass energy in order to test many theoretical aspects of current models (e.g. existence of the Higgs particle, supersymmetry, etc.)
- Major experiments at LHC:
  - ATLAS (A ToroidaL ApparatuS)
  - CMS (Compact Muon solenoid)
- Other experiments running at LHC are ALICE and LHCb

LHC Status

- LHC will start running in April 2008, and the detectors are expected to start working in summer 2008

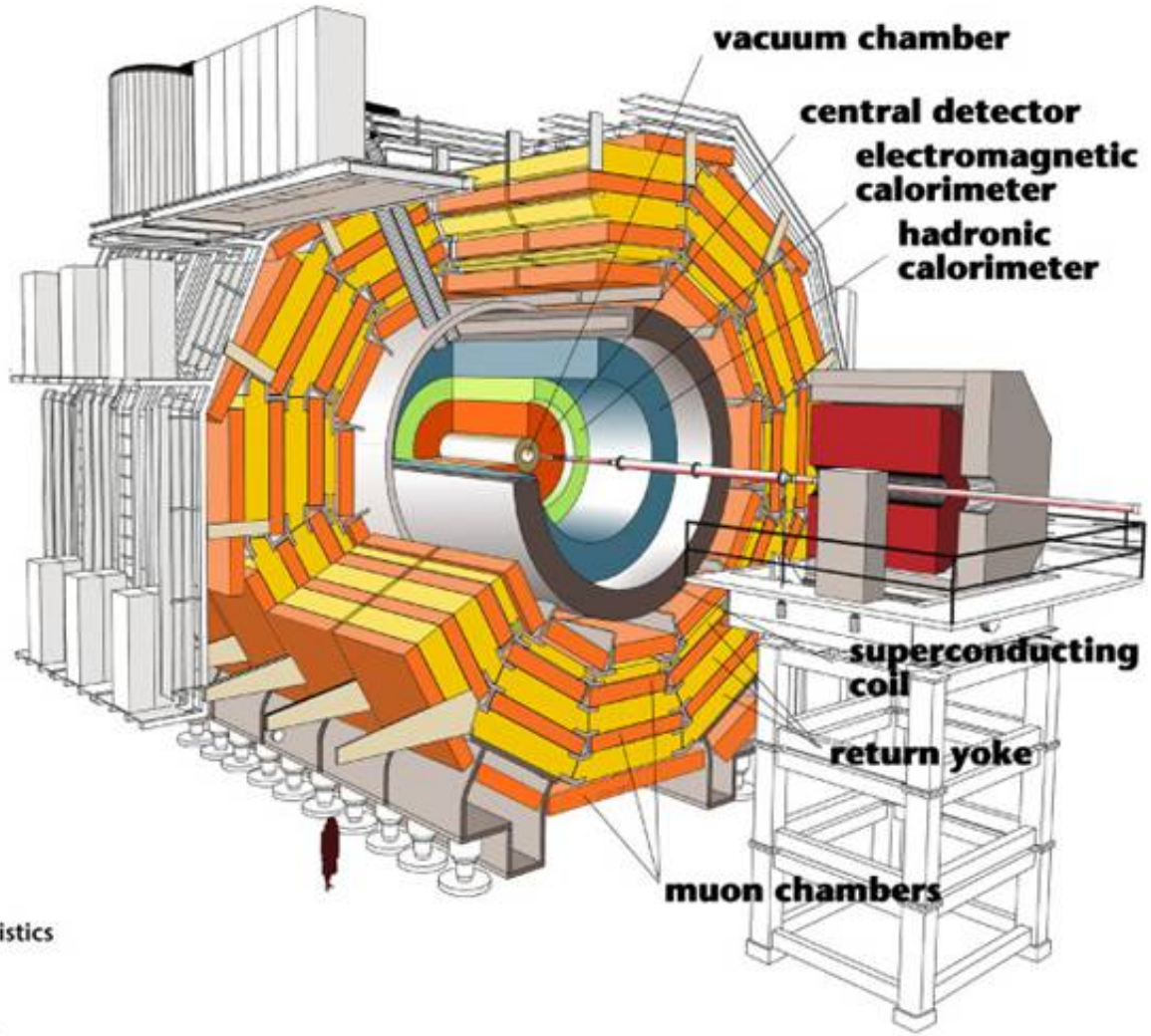
Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	6×10^{30}-10^{32}	10^{32}-10^{33}	$(1-2)\times10^{33}$	10^{34}

J. Wenninger

Main Differences to be Discussed

- Dimensions
- B field strength and orientation:
  - CMS uses only a solenoid (4T)
  - ATLAS uses three toroidal magnets in addition to a central solenoid (2T)
- Mun system:
  - Different layout due to different in magnetic field
  - Different track of muons
- Trigger strategy
  - CMS uses a 2-level trigger while ATLAS uses a 3-level strategy

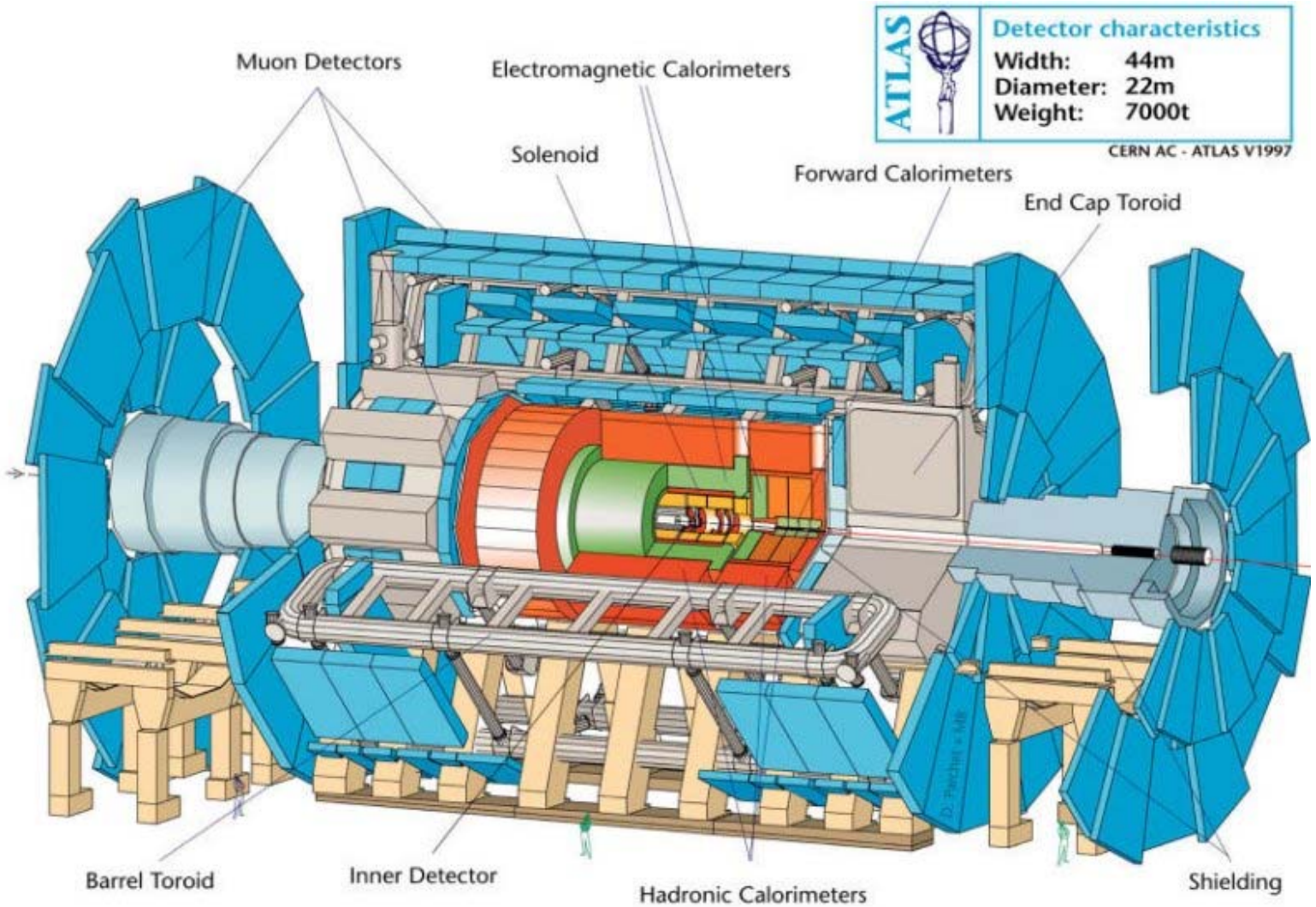
CMS: Dimensions



Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

ATLAS: Dimensions

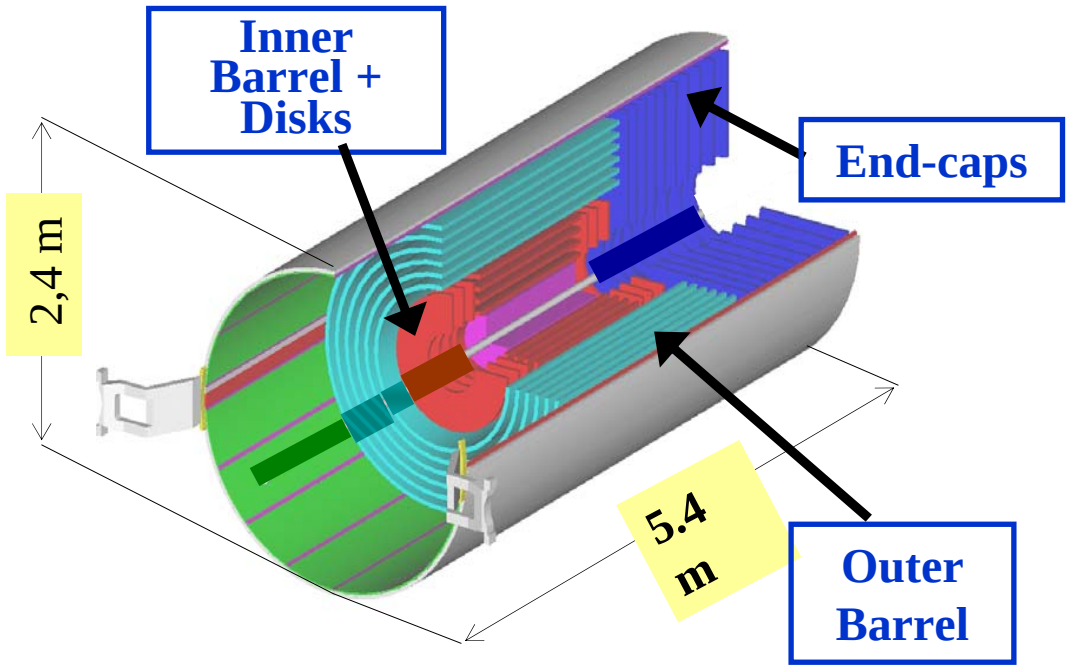


Order of Detectors

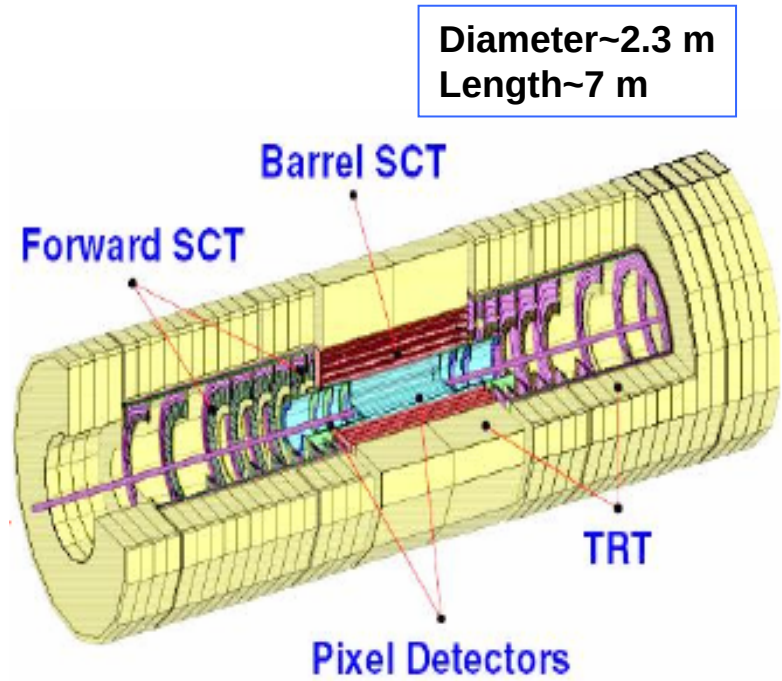
- **CMS:**
  - Inner Tracker
  - ECAL
  - HCAL
  - Magnetic Solenoid
  - Muon System
- **ATLAS:**
  - Inner Detector
  - Magnetic Solenoid
  - Calorimeters
  - Magnetic Toroids
  - Muon System

Inner Tracker Layouts

- Main Goal: to reconstruct isolated high Pt



CMS



ATLAS

Inner Tracker

CMS

- Based on the charged particle flux at various radii at high luminosity we have:
  - Pixel detector
  - Microstrip detectors
  - Larger-pitch silicon microstrips

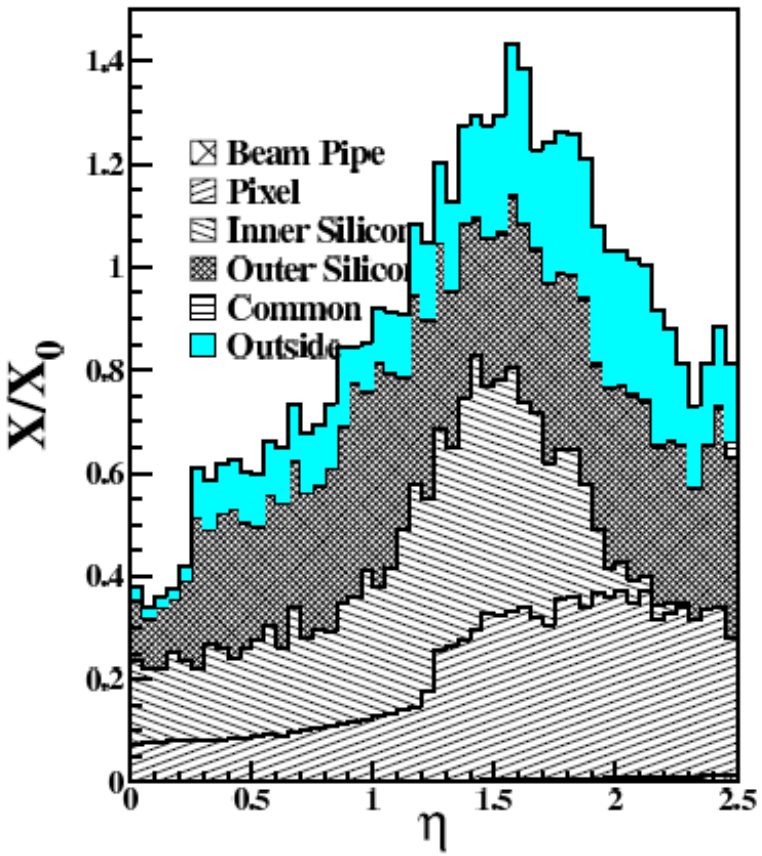
ATLAS

- Three main parts:
  - Pixel detector
  - Semiconductor detector
  - Transition radiation tracker (TRT)

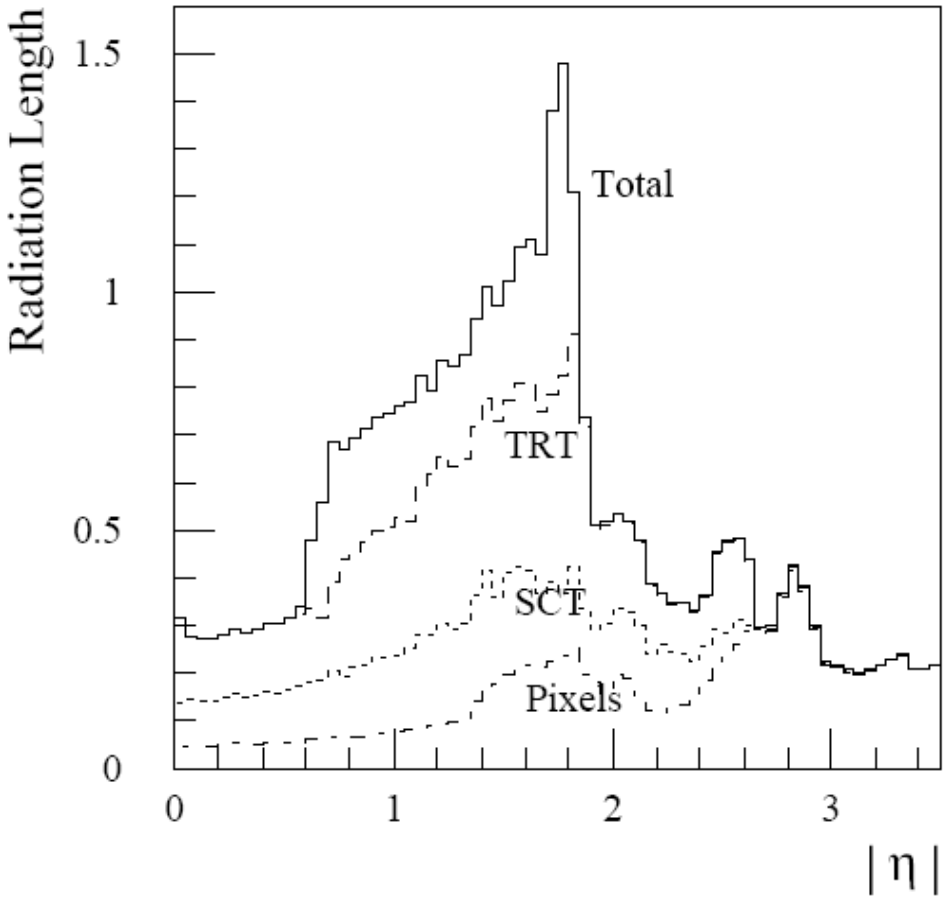
ATLAS: Transition Radiation Tracker

- large area coverage and low cost
- Outermost layer of inner detector
- Design goals:
  - Provide continuous tracking at larger radius and enhance momentum resolution
  - Particle identification capabilities
  - Fast level-2 trigger information
- Requirements for the detector:
  - Radiation hardness
  - Relatively low cost (silicon too expensive at volume)
- Combines traditional charged-particle track reconstruction with transition radiation information

Material Distribution of Tracker

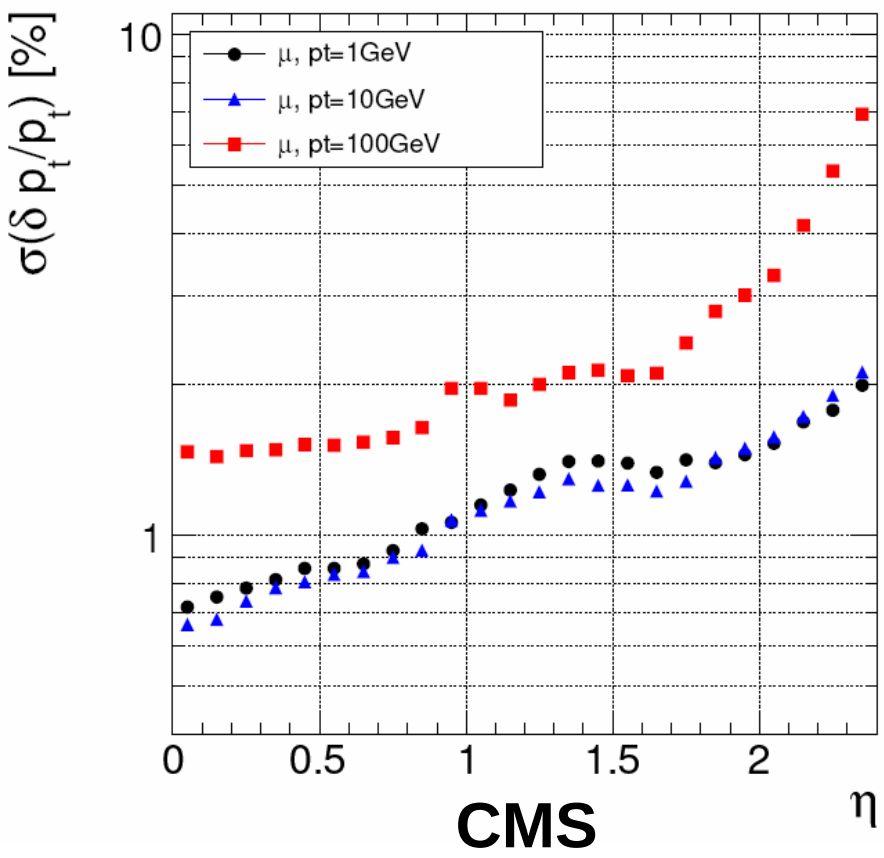


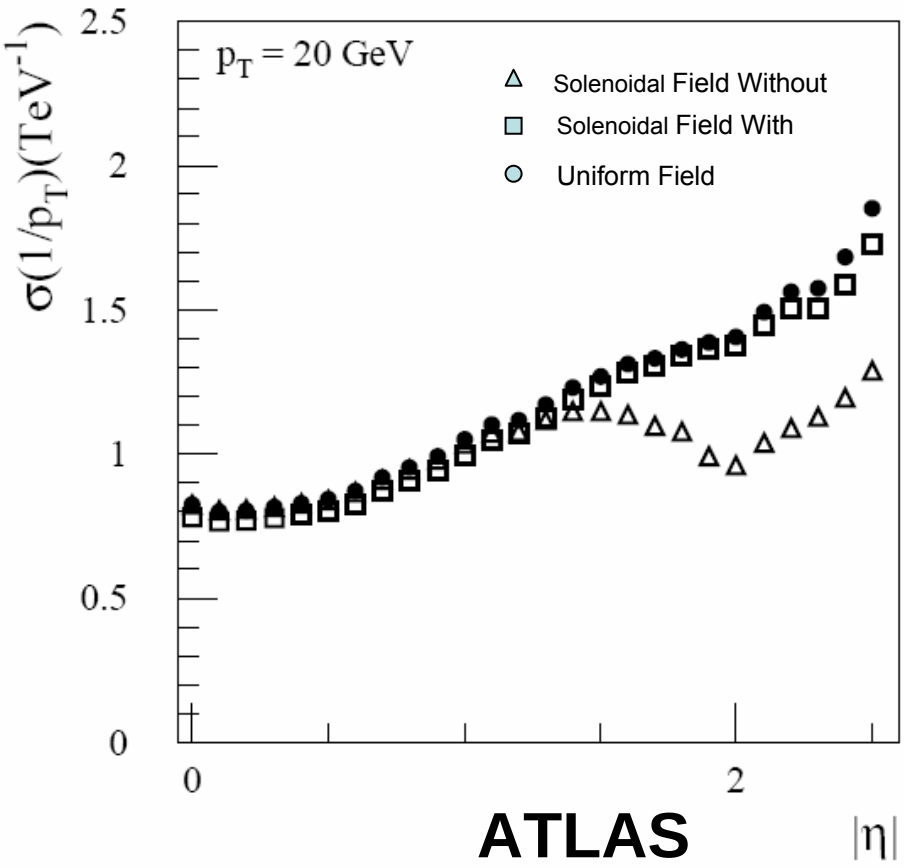
CMS



ATLAS

Pt Resolution for Muons





- Muon momentum follows the same pattern for both detectors
- Slightly better resolution for CMS

Calorimeters

- CMS:
  - Calorimeters surrounds the inner tracker
  - ECAL uses lead tungstate
  - HCAL uses plastic scintillating tiles
- ATLAS:
  - Calorimeters surrounds the magnetic solenoid
  - ECAL uses lead/liquid argon
  - HCAL uses plastic scintillating tiles
  - At large pseudorapidities lead/liquid argon is used for both calorimeters
- More will be discussed in more details by Mauricio Romo

CMS: Magnetic System

- Large Super Conducting solenoid that provides the magnetic field for the inner tracker and the muon system
- The magnetic field inside the solenoid and outside of it have different direction and strength (parallel to the beam direction)

Field	4 T
Inner Bore	5.9 m
Length	12.9 m
Number of Turns	2168
Current	19.5 kA
Stored energy	2.7 GJ
Hoop stress	64 atm

ATLAS: Magnetic System

- Composed of:
  - a central solenoid (2T) surrounded by a system of three large air-core toroids
  - Three toroids: two end-cap toroids (3.9T) and one barrel toroid (4T)

Property	Unit	Barrel Toroid	End-Cap Toroid (one)	Central Solenoid
Inner diameter	m	9.4	1.65	2.44
Outer diameter	m	20.1	10.7	2.63
Axial length	m	25.3	5	5.3
Number of coils	-	8	8	1

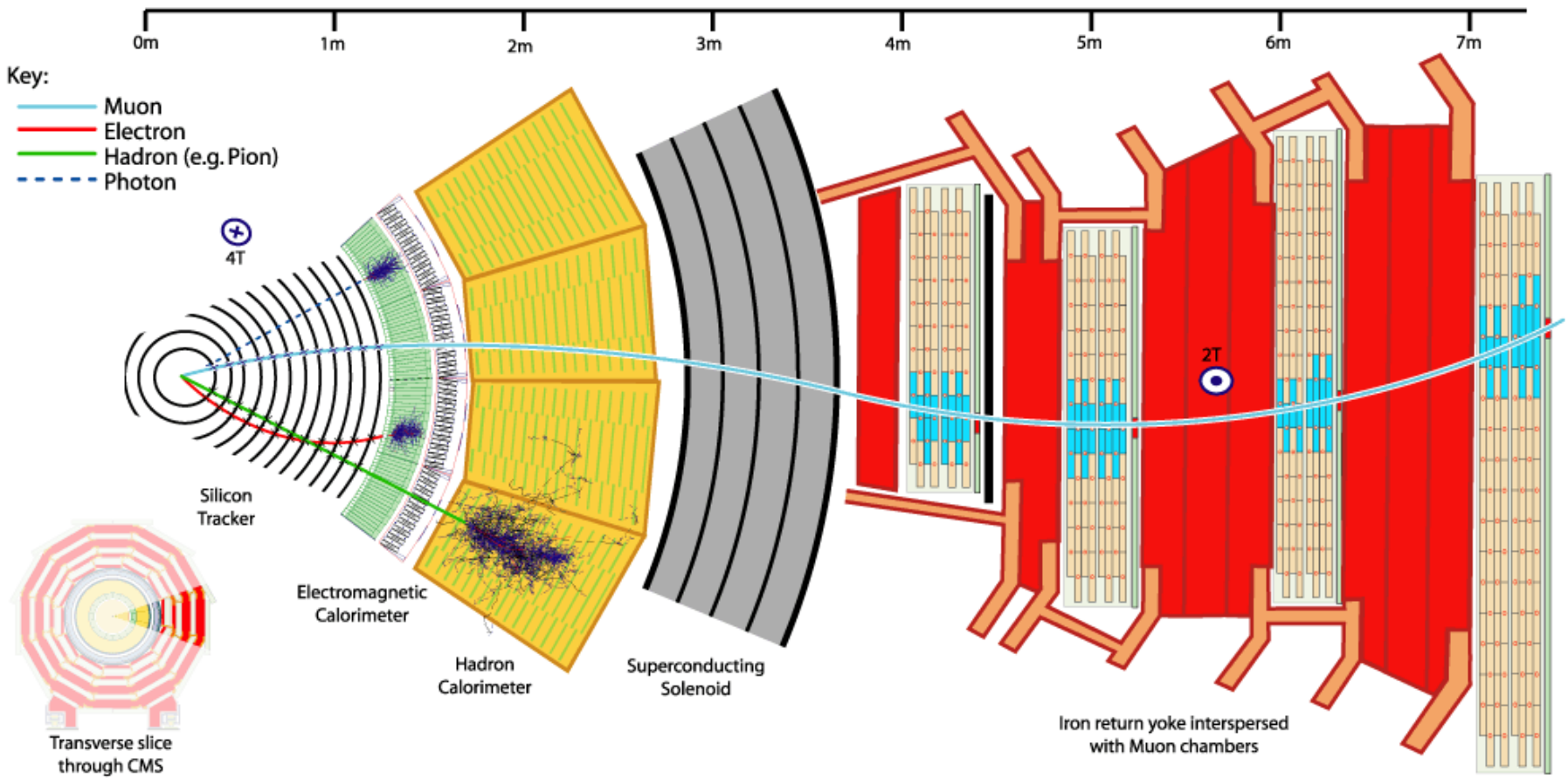
CMS: Muon System

- Muons are measured 3 times: inner tracker, after the coil, and in the return flux
- Momentum measured using only the muon bending angle inside a 4T magnetic field
- 3 types of gaseous detectors:
  - For low neutron background and low muon rate muon drift tubes are used
  - For high neutron background and muon rate cathode strip chambers are used
  - To ensure good operation at high rates resistive plate chambers are used both in the barrel and the endcap

ATLAS: Muon System

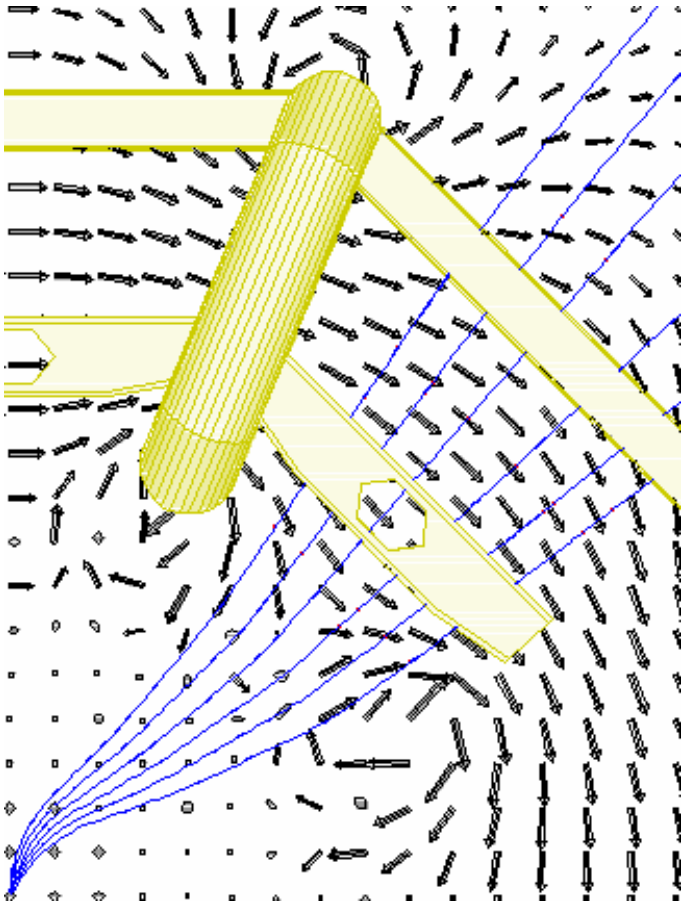
- ATLAS uses the same three types of muon chambers for momentum measurement
- Layout is quite different than CMS due to complicated magnetic field
- For different ranges of η the muon's track is bent by different toroids' magnetic field
- The magnetic field outside of the solenoid arrangement is in r-φ plane; thus, bending happens in a different direction as that of CMS

CMS: Muon System

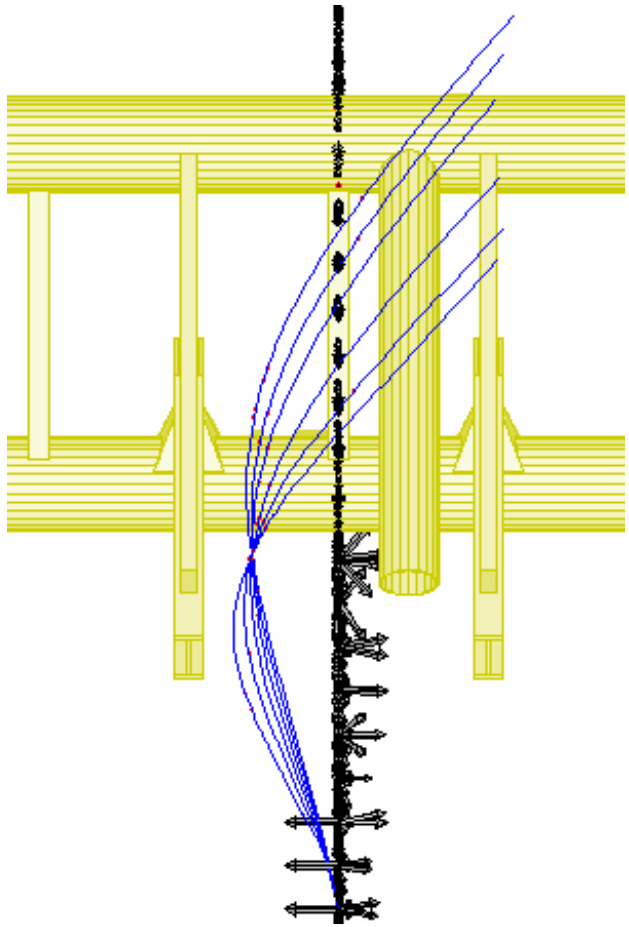


r-φ plane

ATLAS: Muon System

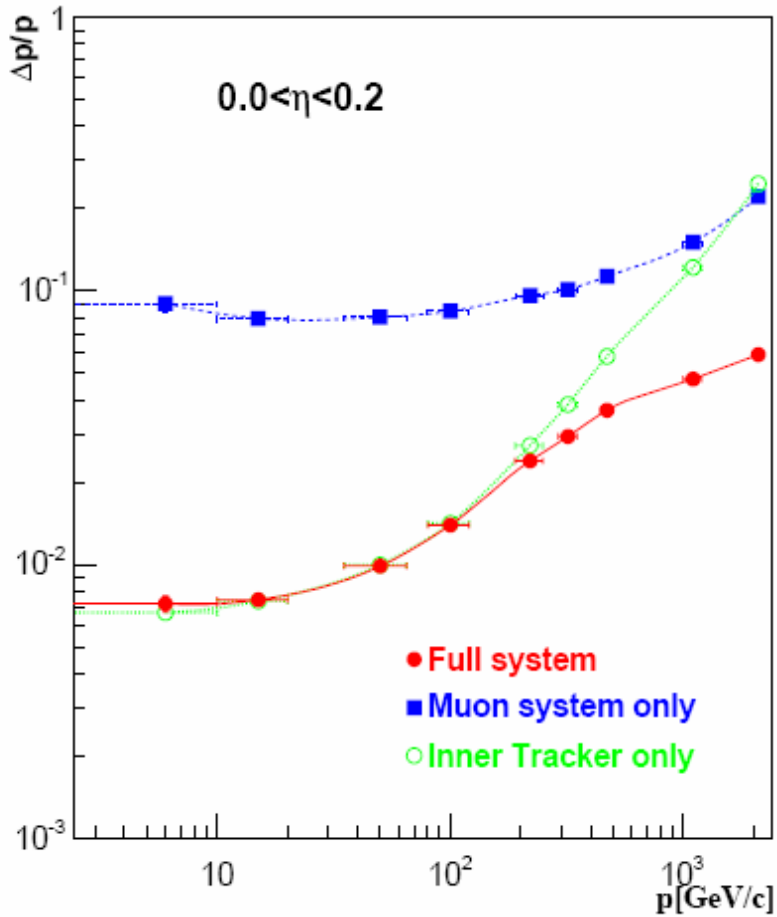


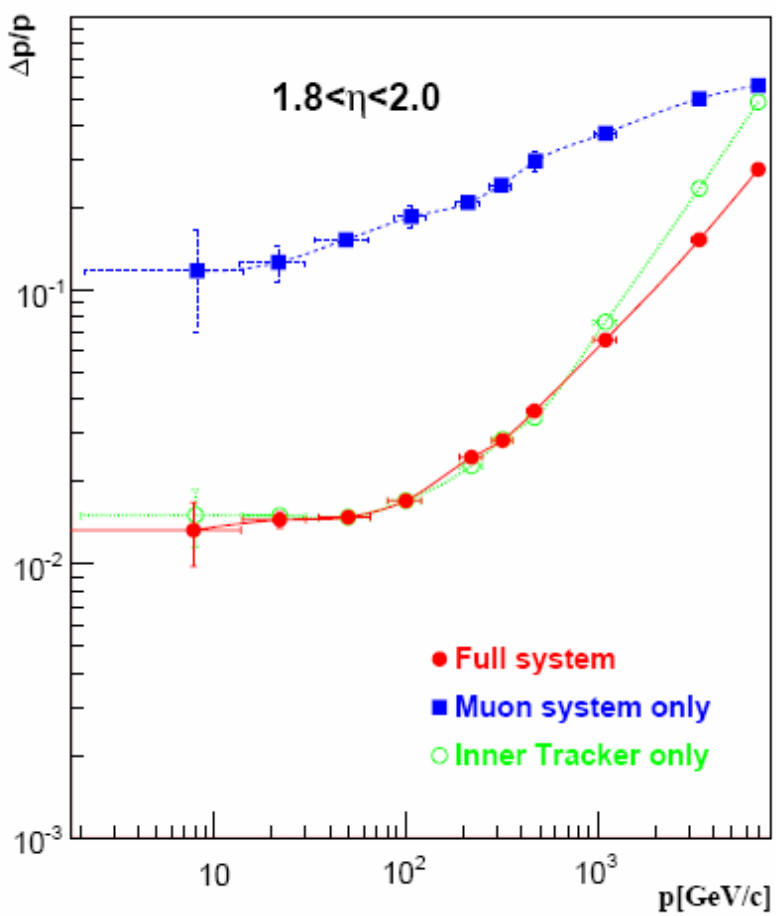
r-φ plane



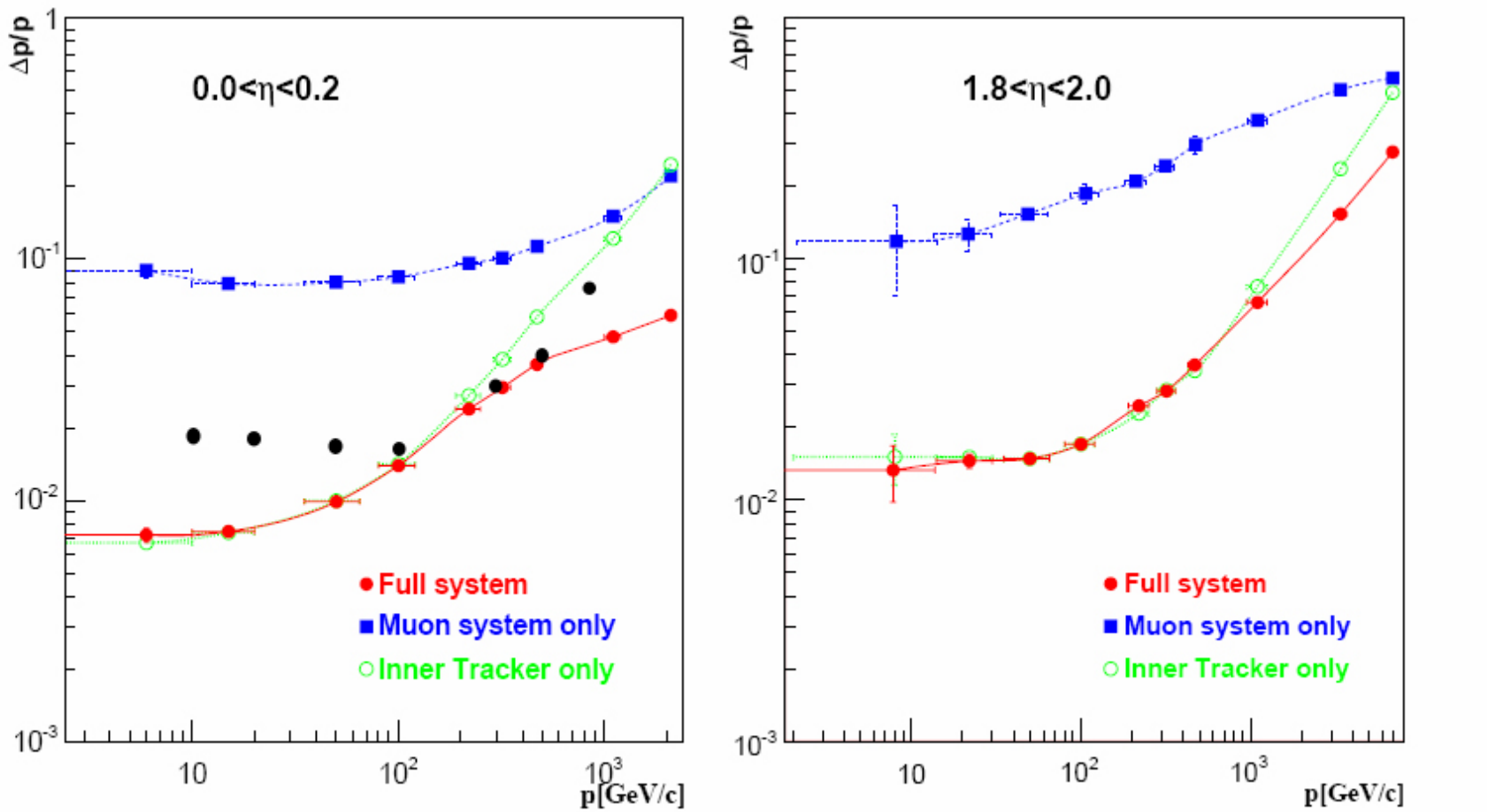
r-z plane

CMS: Muon System's Momentum Resolution





ATLAS: Muon System's Momentum Resolution



Black dots (right) are muon momentum resolution for ATLAS for $|\eta|<1.5$.

CMS: Trigger

- Level-1 trigger:
  - 40 MHz event input
  - Uses information from the calorimeters and muon systems and some correlation between the two
  - Startup rate of 50 kHz
  - Maximum design rate of 100kHz
- High-level trigger:
  - Reduces 100kHz rate to 300Hz
  - Event building happens here before further analysis
  - Effective mass cut and event topology

ATLAS: Trigger

- Level-1 trigger:
  - 40 MHz event input
  - Uses information from the calorimeters and muon systems
  - Maximum design rate of 75 kHz (upgradable to100kHz)
- Level-2 trigger:
  - Reduces the 75kHz rate to 1kHz
  - Uses full-granularity calorimeter information and high-Pt charged track of the inner detector
  - Event building happens here
- Event Filter:
  - Reduces the 1kHz input to 300 Hz
  - Uses offline algorithms and methods (calibration, alignment,etc.)

Summary

- Dimension
  - ATLAS is larger than CMS in size
- Tracker
  - ATLAS has the additional Transition Radiation Tracker
  - Slightly better momentum resolution for CMS
- Calorimeters
  - Different layout and material used
- Magnetic field
  - CMS: Solenoidal field of 4T
  - ATLAS: Solenoidal and Toroidal field of 2T
- Muon System
  - Different layout of chambers
  - CMS has a better muon momentum resolution
- Trigger
  - CMS: 2-level trigger system
  - ATLAS: 3-level trigger system

Questions

Sources:

1. **CMS Physics Technical Design Report Volume I: Detector Performance and Software**
2. ATLAS DETECTOR AND PHYSICS PERFORMANCE Technical Design Report Volume I