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LHC + Detectors

Fabian Schnell

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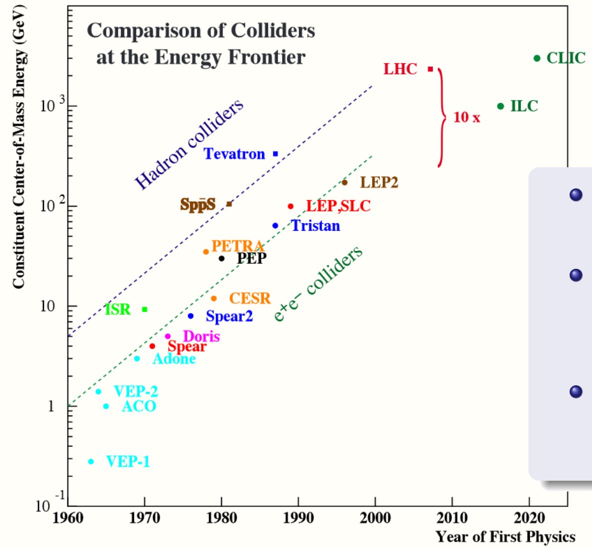
Table of Contents

Large Hardron Collider

- the LHC is a two-ring-superconducting-hadron accelerator and collider
- built in the former 26.7km long LEP tunnel, located near Geneva between 45m and 170m below the surface
- superconducting magnets deliver dipole field with 8.33T
- able to collide protons and Pb-ions
- reaches $E_{cms} = 14\text{TeV}$ and $L = 10^{34}\text{cm}^{-2}\text{s}^{-1}$ for protons and $E_{cms} = 2.8\text{TeV}$ and $L = 10^{27}\text{cm}^{-2}\text{s}^{-1}$ for Pb-ions

Figure: The Cern area with the LHC storage ring

LHC and Tevatron



- exponential growth of E_{cms} with time
- LHC biggest hadron collider followed by Tevatron
- new energy frontier $\Rightarrow$ great potential for discoveries

LHC and Tevatron

	LHC	LEP2	Tevatron
colliding beams of	p, p	e^+, e^-	$p, \bar{p}$
Momentum at collisions, TeV/c	7	0.1	0.98
Peak luminosity, $cm^{-1}s^{-2}$	10^{34} (design)	10^{32}	4.3×10^{32}
Dipole field at top energy, Tesla	8.33	0.11	4.4
Number of bunches, each beam	2808	4	36
Total beam current / beam, A	0.58	0.003	0.08
Particles / bunch, 10^{11}	1.15	4.2	2.9, 0.8
Typical beam size in the ring, μm	200 – 300	1800/140 (H/V)	500
Beam size at IP, μm	16	200 / 3 (H/V)	24
Fraction of energy lost in synchr.rad. per turn	10^{-9}	3%	10^{-11}
Total power radiated in synchr.rad., MW	0.0078	18	10^{-6}
Total energy stored in each beam, Megajoule	362	0.03	0.9
Total energy stored in the magnet system, Gigajoule	10	0.016	0.74

Event rate: $\frac{dN}{dt} = L\sigma$

- High energies are needed to produce new particles
- expected cross section for higgs $\sigma \sim 10 - 10^4$ fb ($1\text{fb}=10^{-39}\text{cm}^2$)
  $\Rightarrow$ high luminosity needed to see new particles
  easier to accomplish with *pp* colliders

Detector requirements

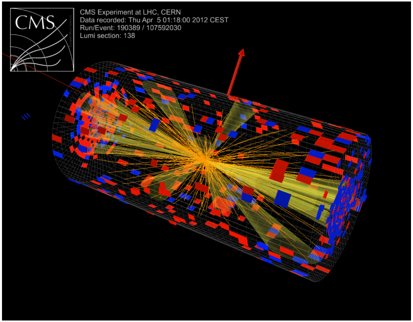


Figure: First pp collisions at 8 TeV observed in CMS

- strong interaction
- complex final states
- very high backround
- high collision rate (bunches cross every 25ns)
- high radiation can cause damages

Detectors need to measure particles as efficient and as precise as possible

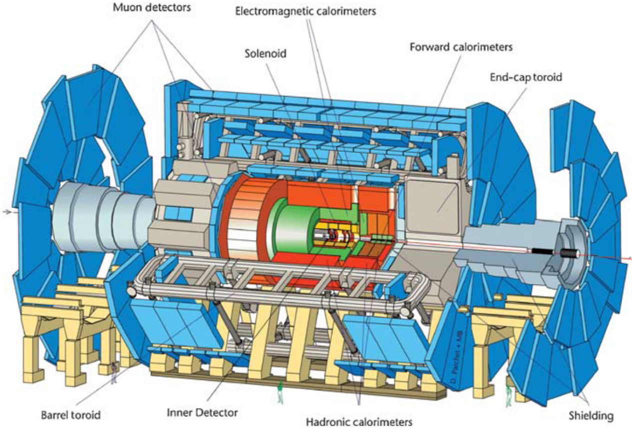
Harsh radiation conditions near the interaction point forces the collaborations to use radiation-hard materials.

Detector structure

Both ATLAS and CMS have similar structures to fullfill the requirements. They can be described as cylindrical detectors with different layers:

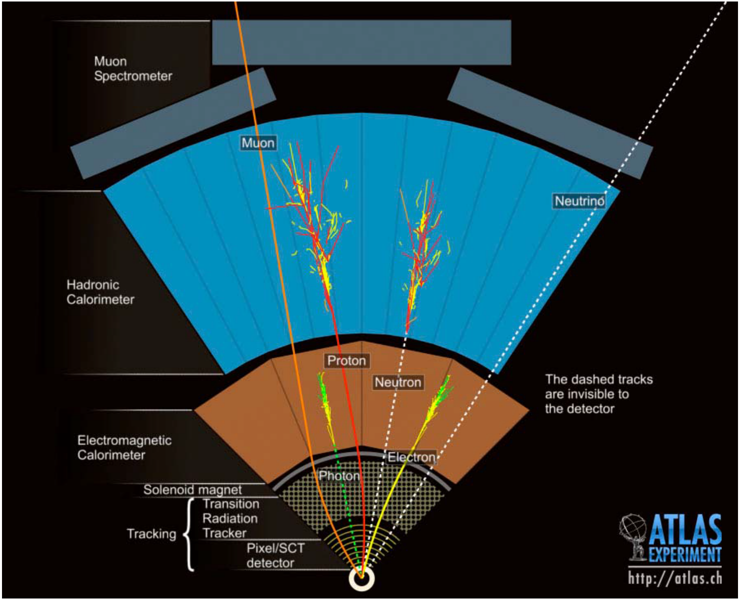
- an innermost layer sourrounded by a solenoidal magnetic field. It measures the direction and momenta of all charged particles (tracker)
- a intermediate layer absorbs and measures the energy of electrons, photons and hadrons. (calorimeter system)
- an outer layer to measure the momenta and direction of high-energy muons.(muon spectrometer)

A Toroidal Large ApperatuS



- Total weigth: 7000 t
- Diameter: 22m
- Length: 46m

A Toroidal Large ApperatuS



ATLAS - magnet system

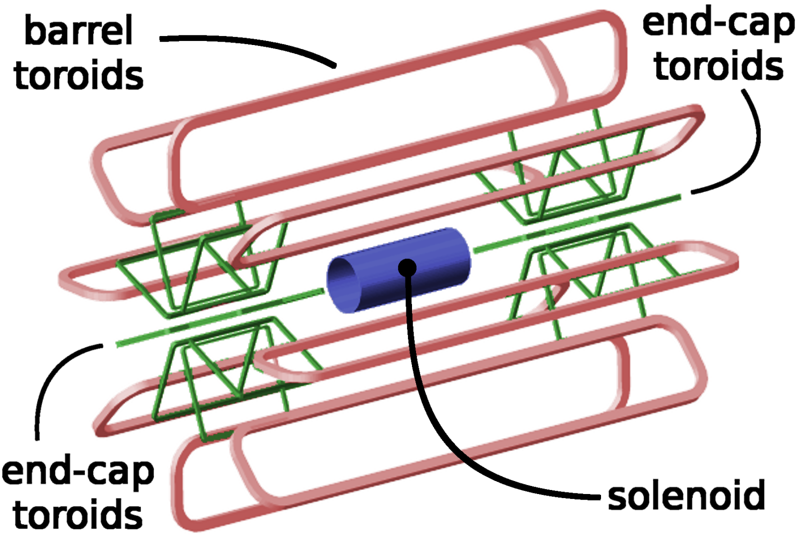
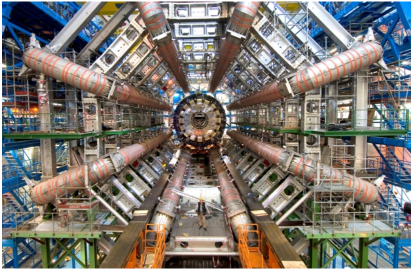


Figure: Overall layout of the ATLAS detector

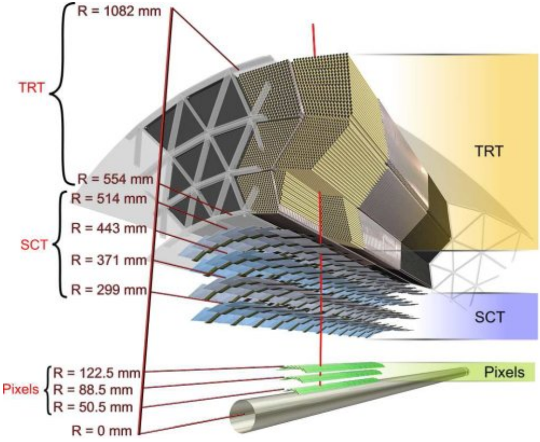
ATLAS - magnet system

Parameter	ATLAS Solenoid	Barrel toroid	End-cap toroids
Inner diameter	2.4 m	9.4 m	1.7 m
Outer diameter	2.6 m	20.1 m	10.7 m
Axial length	5.3 m	25.3 m	5.0 m
Number of coils	1	8	8
Number of turns per coil	1173	120	116
Conductor size (mm^2)	30×4.25	57×12	41×12
Bending power	$2\ T \cdot m$	$3\ T \cdot m$	$6\ T \cdot m$
Current	7.7 kA	20.5 kA	20.0 kA
Stored energy	38 MJ	1080 MJ	206 MJ

ATLAS - magnet system

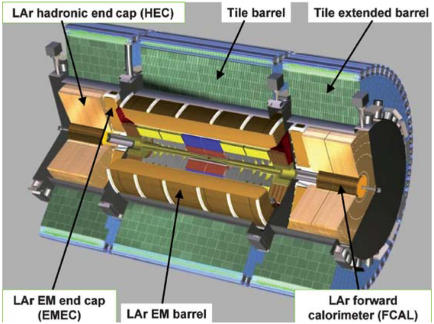


ATLAS - tracker



- designed to measure p_T above $\approx$1GeV
- covers $|\eta| < 2.5$
- silicon detetors operate at -7°C to reduce radiation damage
- TRT straw-tube detectors operate at 20°C with a Xe-CO_2-O_2 (70/27/3%) gas mixture
  -limited to $|\eta| < 2$

ATLAS - calorimeter systems



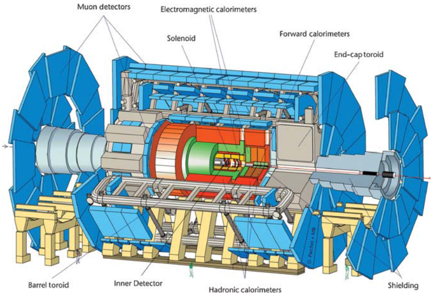
EM calorimeter

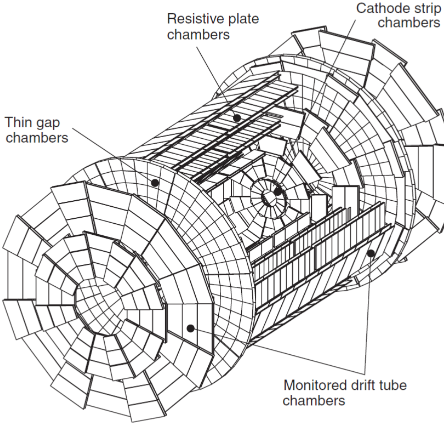
- liquid argon + Pb absorber
- barrel: $|\eta| < 1.5$
- end cap. $1.4 < |\eta| < 3.2$
- provides excellent lateral and longitudinal granularity
- energy loss through material in front of the calorimeter

Hadronic-calorimeter

- barrel: Fe + scintillator
- end caps: Cu + LAr
- forward: Cu(front)/W(back) + LAr

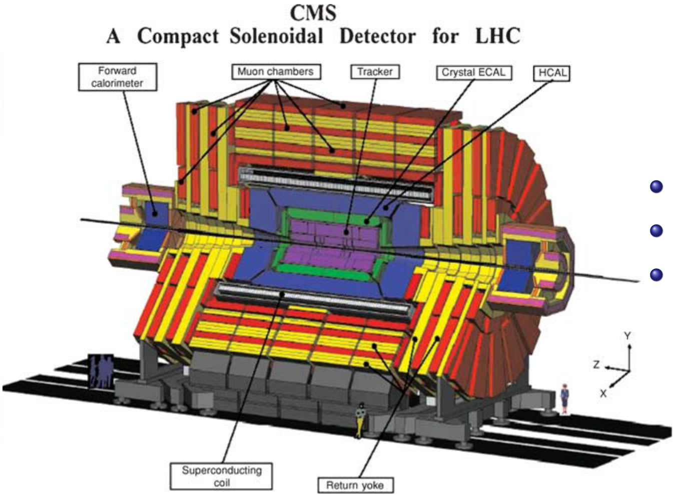
ATLAS - muon spectrometer system





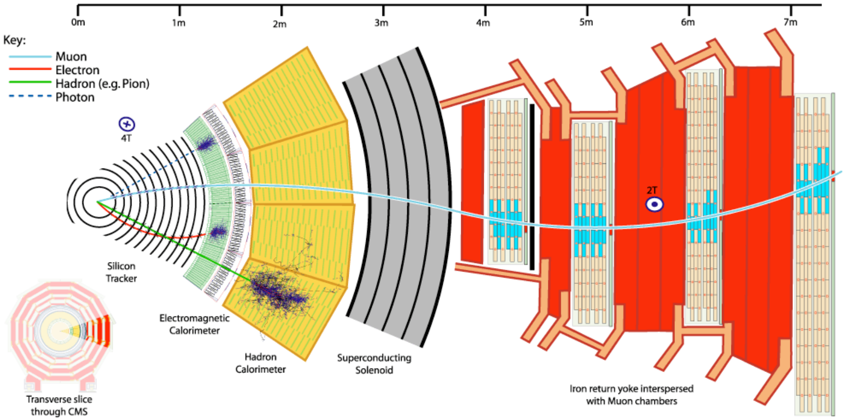
- MDTs: covers most the pseudorapidity region; $|\eta| < 2$
- CSCs: harsh backround/large muon rate; $2 < |\eta| < 2.7$
- RPCs: good time but coarser position resolution; $|\eta| < 1.05$
- TGCs: end cap region; $1.05 < |\eta| < 2$
- stand-alone measurement of muons

Compact Muon Solenoid

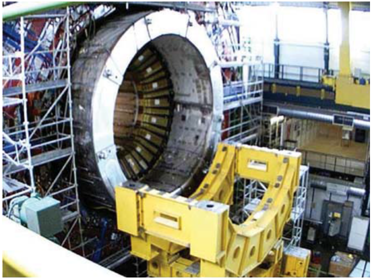


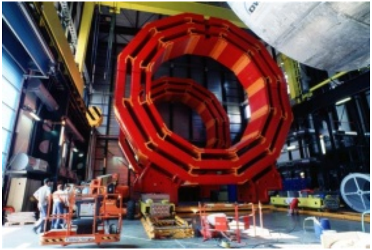
- weight: 12500t
- diameter: 15m
- length: 20m

Compact Muon Solenoid



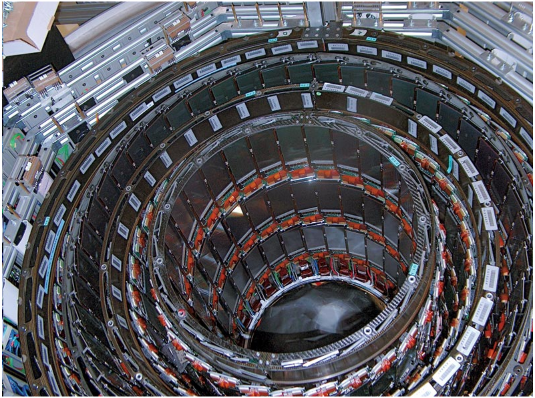
CMS - magnet system





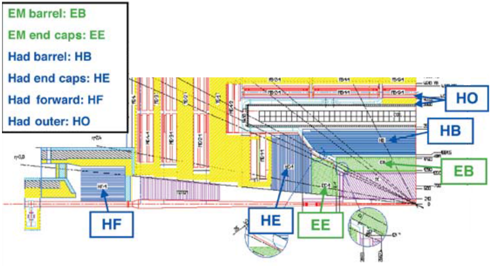
	CMS
Parameter	**Solenoid**
Inner diameter	5.9 m
Outer diameter	6.5 m
Axial length	12.9 m
Number of coils	1
Number of turns per coil	2168
Conductor size (mm^2)	64×22
Bending power	$4\ T \cdot m$
Current	19.5 kA
Stored energy	2700 MJ

CMS - tracker



- inner layer of silicon-pixel detectors near interaction point (r $>$ 4cm)
- outer layers of silicon-strip detectors (r $>$ 20cm)
- sensors operate with -10°C
- covers $|\eta| < 2.5$

CMS - calorimeter system



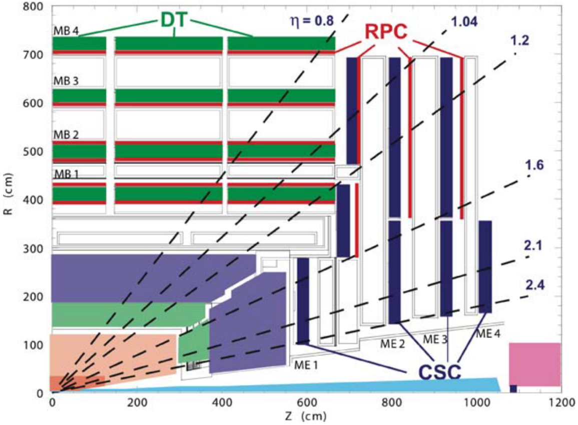
EM calorimeter

- tungsten scintillating crystals ($PbWO_4$)
  $\Rightarrow$ high intrinsic resolution
- barrel: $|\eta| < 1.5$
- end cap: $1.4 < |\eta| < 3.0$
- good lateral granularity

Hadronic-calorimeter

- barrel: brass + scintillator
- end caps: brass+scintillator
- forward: Steel + quartz
- insufficient absorption
  $\Rightarrow$ worse resolution

CMS - muon spectrometer system



- Drift Tubes: $|\eta| < 1.2$
- Resistive Plate Chambers: used in barrel and end-cap regions $1 < |\eta| < 2.1$
- Cathode Strip Chamber for big pseudorapidities; $1.2 < |\eta| < 2.4$

Differences ATLAS - CMS

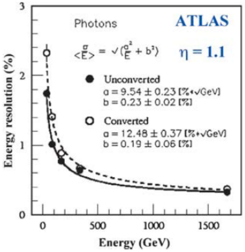
	ATLAS	CMS
Magnet system	2T solenoid, barrel and end-cap	4T Solenoid and return yokes
Tracker	Silicon pixel, silicon strip and transition radiation tracker	Silicon pixel and silicon strip
EM calorimeter	Liquid argon and Pb absorber outside of solenoid	$PbWO_4$ crystals inside solenoid better intrinsic resolution
Hadronic calorimeter	Fe/Cu/W+scintillator/LAr outside solenoid	BrassI+scintillator steel+quartz inside solenoid insufficient absorption causes lower resolution
Muon system	barrel and end cap magnets provide field bigger pseudorapidity	return yokes with solenoid provide field

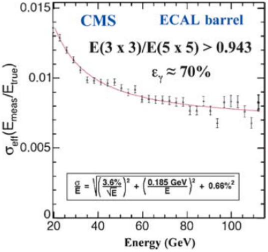
Performance - Tracker

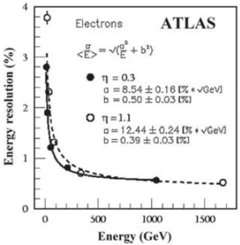
TABLE 7 Main performance characteristics of the ATLAS and CMS trackers

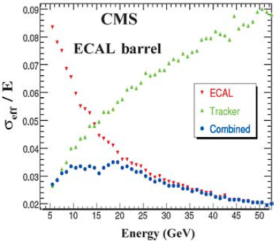
	ATLAS	CMS
Reconstruction efficiency for muons with $p_T = 1$ GeV	96.8%	97.0%
Reconstruction efficiency for pions with $p_T = 1$ GeV	84.0%	80.0%
Reconstruction efficiency for electrons with $p_T = 5$ GeV	90.0%	85.0%
Momentum resolution at $p_T = 1$ GeV and $\eta \approx 0$	1.3%	0.7%
Momentum resolution at $p_T = 1$ GeV and $\eta \approx 2.5$	2.0%	2.0%
Momentum resolution at $p_T = 100$ GeV and $\eta \approx 0$	3.8%	1.5%
Momentum resolution at $p_T = 100$ GeV and $\eta \approx 2.5$	11%	7%
Transverse i.p. resolution at $p_T = 1$ GeV and $\eta \approx 0$ (μm)	75	90
Transverse i.p. resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ (μm)	200	220
Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$ (μm)	11	9
Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$ (μm)	11	11
Longitudinal i.p. resolution at $p_T = 1$ GeV and $\eta \approx 0$ (μm)	150	125
Longitudinal i.p. resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ (μm)	900	1060
Longitudinal i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$ (μm)	90	22–42
Longitudinal i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$ (μm)	190	70

Performance - EM calorimeter









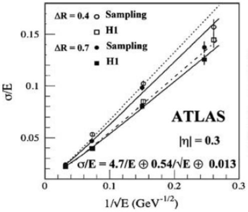
Photon with 100 GeV

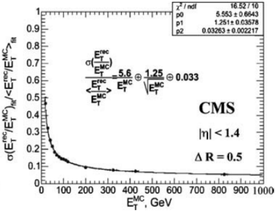
- ATLAS: 1-1.5% energy resolution
- CMS: 0.8% energy resolution

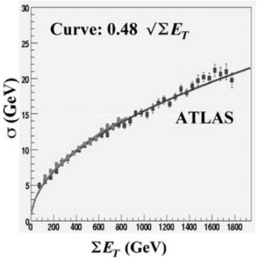
Electron with 20 GeV

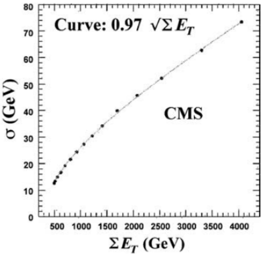
- ATLAS: 1.5-2.5% energy resolution
- CMS: 3.5% energy resolution

Performance - Hardron calorimeter









Jet with 600 GeV

- ATLAS: $\sim$2.5% energy resolution
- CMS: $\sim$5% energy resolution

$\Sigma E_{T,miss}$=1500Gev

- ATLAS: $\sigma \sim$ 19GeV
- CMS: $\sigma \sim$ 35GeV

Performance - Muon spectrometer

Parameter	ATLAS	CMS
Pseudorapidity coverage		
-Muon measurement	$\|\eta\| < 2.7$	$\|\eta\| < 2.4$
-Triggering	$\|\eta\| < 2.4$	$\|\eta\| < 2.1$
Dimensions (m)		
-Innermost (outermost) radius	5.0 (10.0)	3.9 (7.0)
-Innermost (outermost) disk (z-point)	7.0 (21–23)	6.0–7.0 (9–10)
Segments/superpoints per track for barrel (end caps)	3 (4)	4 (3–4)
Magnetic field B (T)	0.5	2
-Bending power (BL, in T· m) at $\|\eta\| \approx 0$	3	16
-Bending power (BL, in T· m) at $\|\eta\| \approx 2.5$	8	6
Combined (stand-alone) momentum resolution at		
-p = 10 GeV and $\eta \approx 0$	1.4% (3.9%)	0.8% (8%)
-p = 10 GeV and $\eta \approx 2$	2.4% (6.4%)	2.0% (11%)
-p = 100 GeV and $\eta \approx 0$	2.6% (3.1%)	1.2% (9%)
-p = 100 GeV and $\eta \approx 2$	2.1% (3.1%)	1.7% (18%)
-p = 1000 GeV and $\eta \approx 0$	10.4% (10.5%)	4.5% (13%)
-p = 1000 GeV and $\eta \approx 2$	4.4% (4.6%)	7.0% (35%)