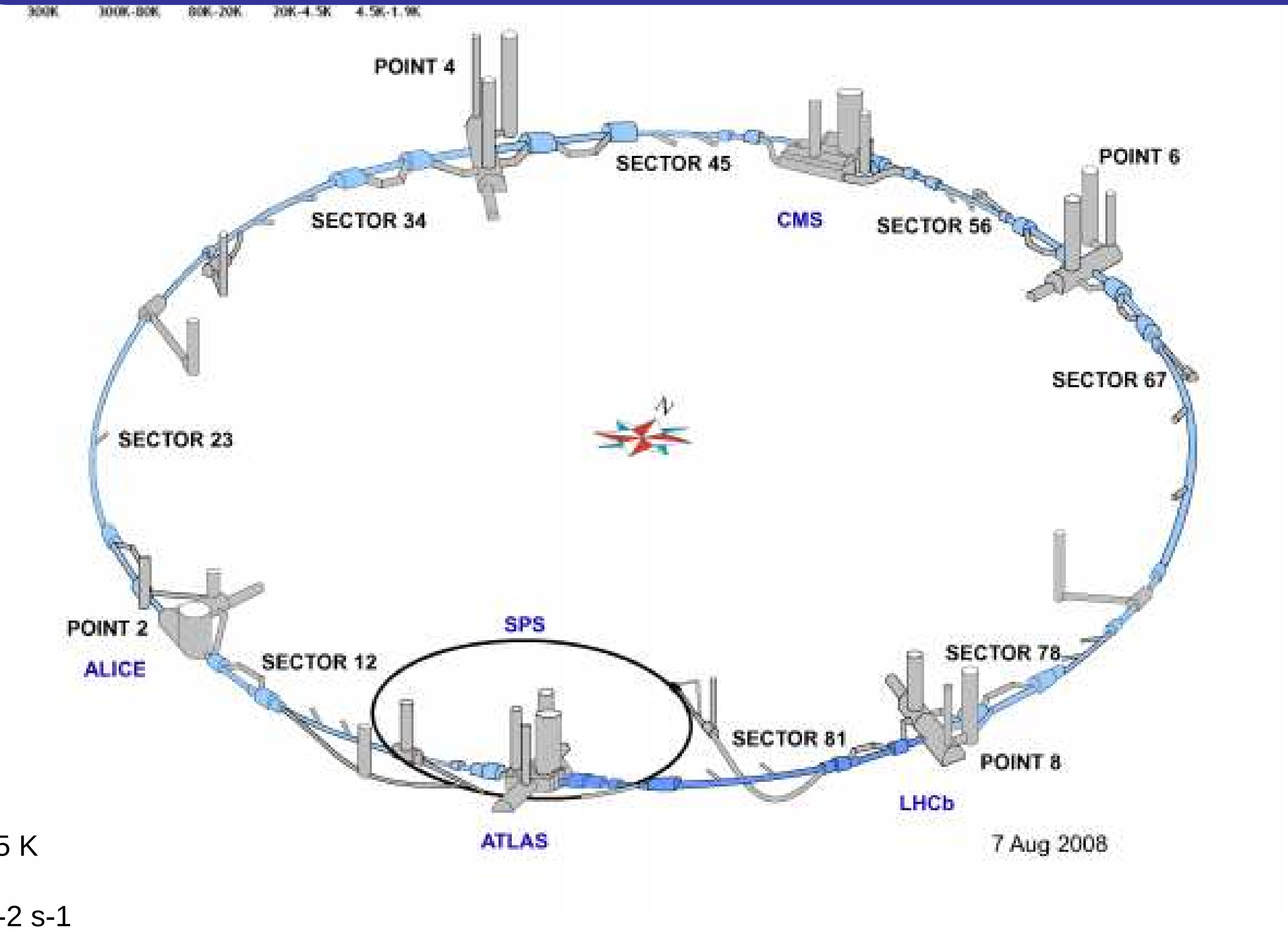
Detektoren am LHC

- LHC und die Experimente
- ATLAS
- CMS
- Physik

Johannes Hattendorff, August 2008, Neubeuern

Der Large Hadron Collider (LHC) – die Entdecker-Maschine

p-p-Collider
(Pb-Pb)



Umfang: 27 km
Temperatur: 1.9 – 4.5 K
Magnetfeld: 8.3 T
Luminosität: 10^{34} cm-2 s-1
Schwerpunktsenergie: 14 TeV
Crossingrate: 40 MHz
Proton-Kollision: $10^7 – 10^9$ HZ
Interessante Ereignise: ca. 10^{-5} Hz

Experimente am LHC

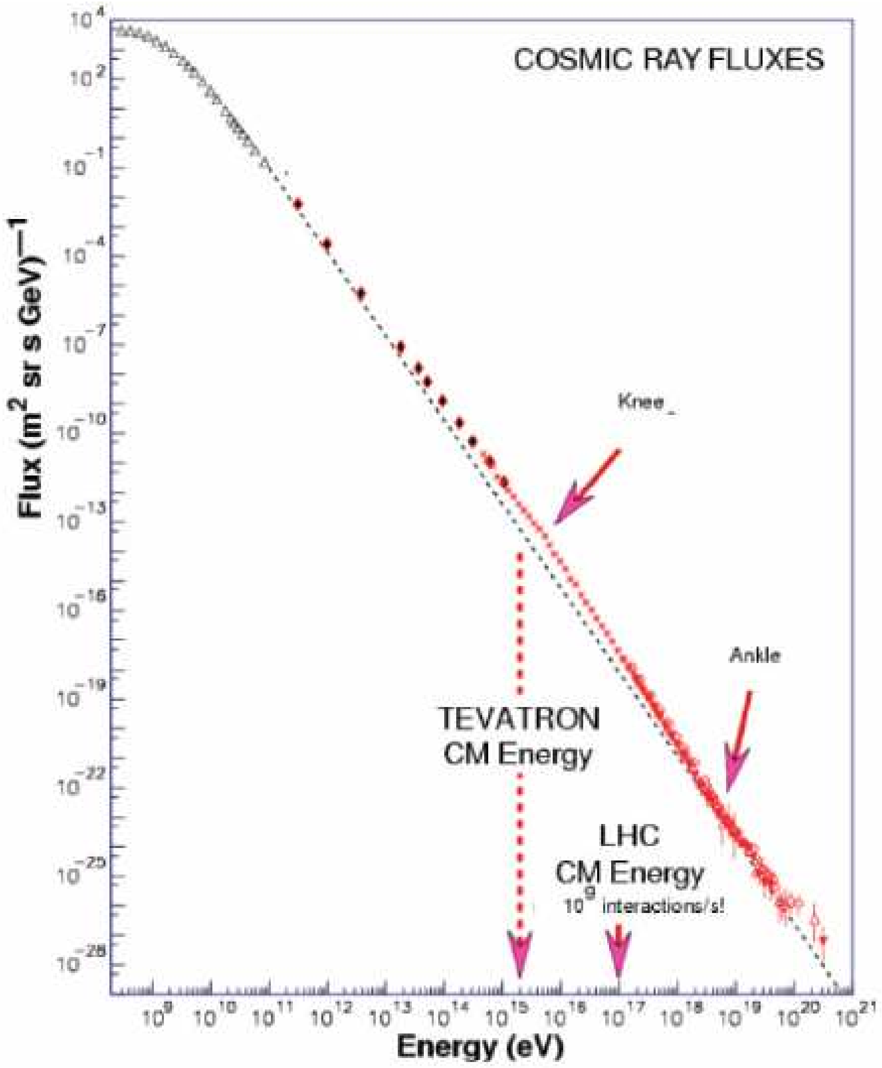
Wozu dient der LHC bzw. die Experimente?

•Higgs-Boson

•SUSY

•CP-Verletzung

•Genauere Messung von top-quark, W/Z-Bosonen

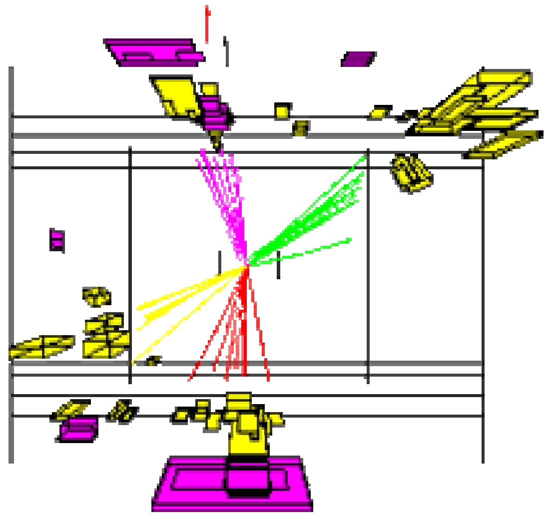


“There are many theories as to what will result from these collisions, but what's for sure is that a brave new world of physics will emerge from the new accelerator, as knowledge in particle physics goes on to describe the workings of the Universe.”

Überblick - Detektoren

Was wir messen wollen:

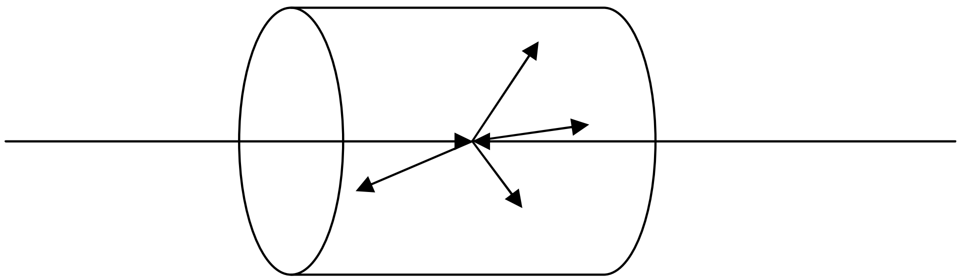
- Teilchenspur
- Zuordnung zum Ereignis (Zeit)
- Identität
- dE/dx
- Impuls
- Energie
- Missing parts



Überblick - Detektoren

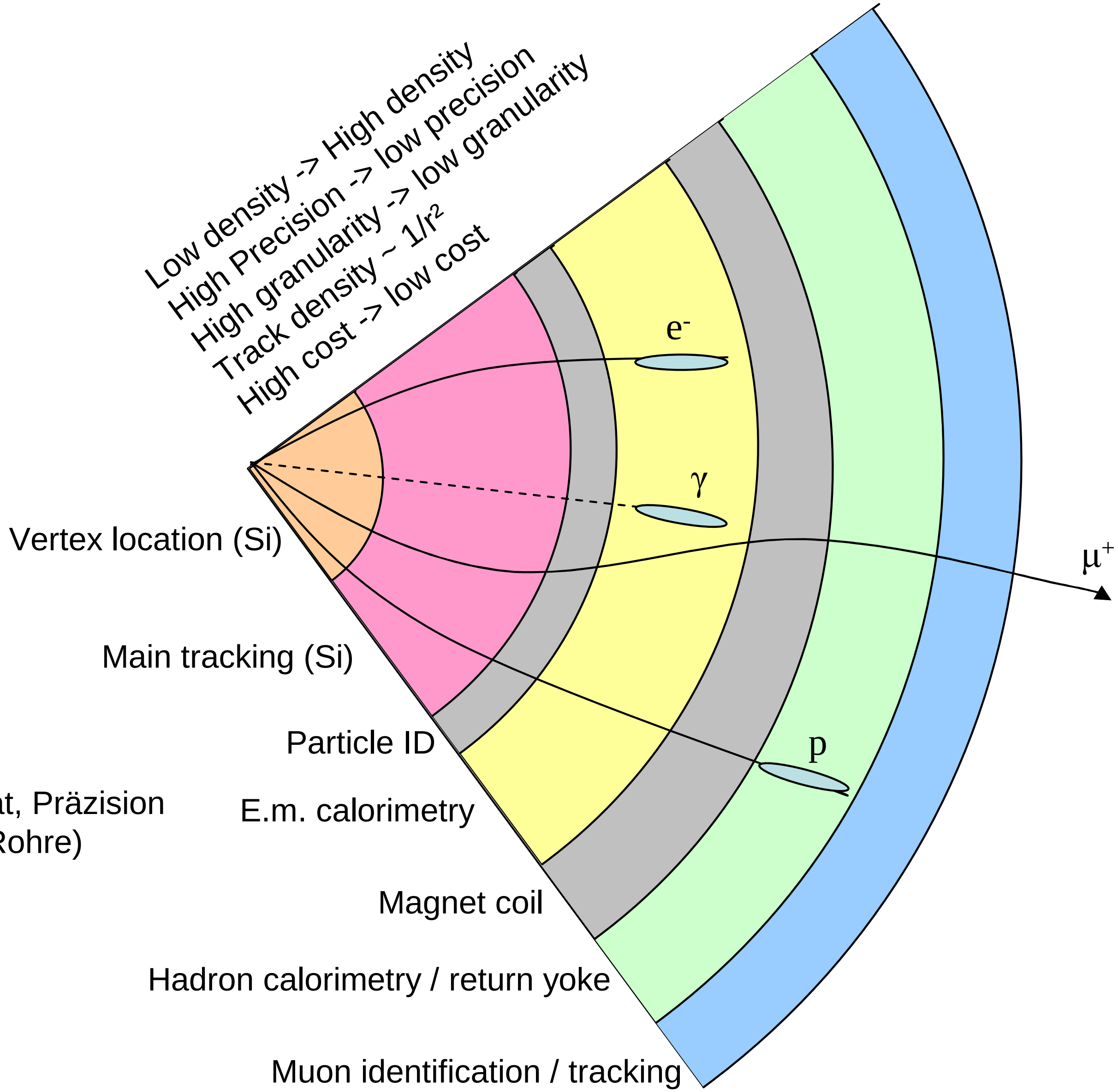
Collider-Anordnung

- 4π-Raumwinkel
- Schwieriger Zugang
- Technische Herausforderung



Hermetizität und Granularität

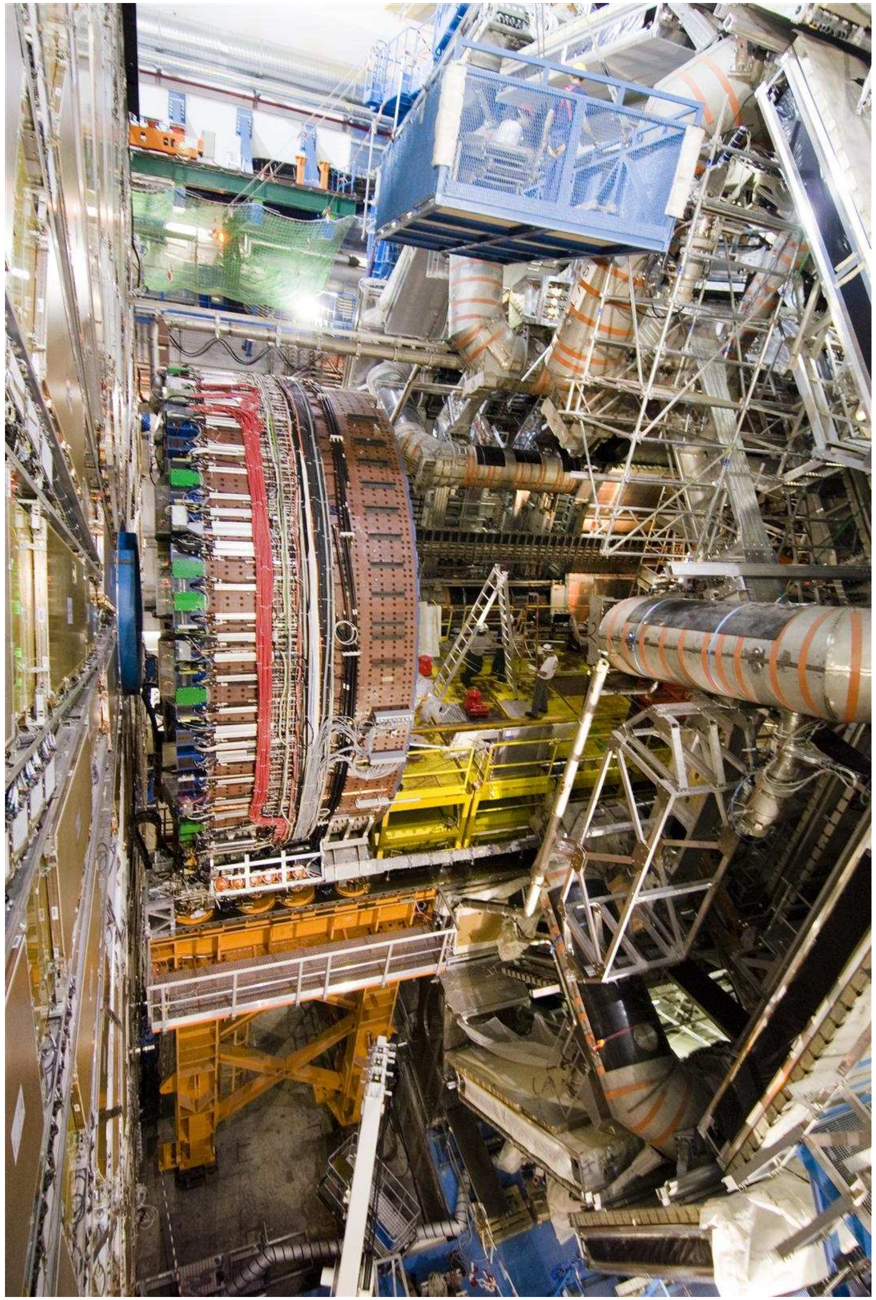
Überblick - Detektoren



Man bedenke:
- Mechanische Stabilität, Präzision
- Infrastruktur (Kabel, Rohre)
- Thermische Stabilität
- Zugang, Wartung
- Radiation-Hardness

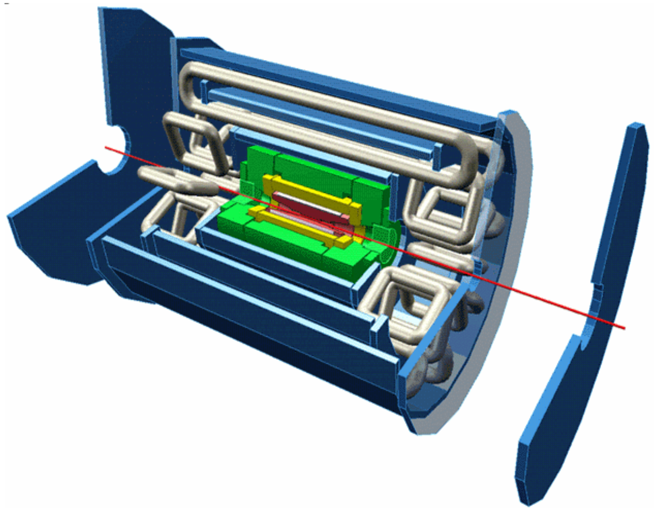
Überblick - Detektoren

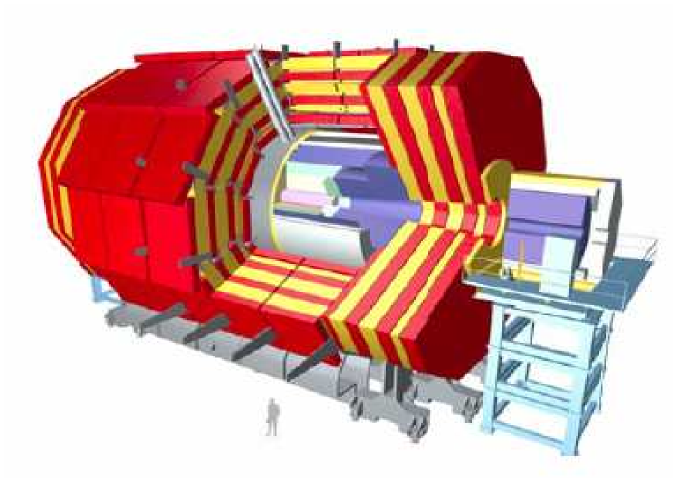
Wo ist mein Akkuschrauber?

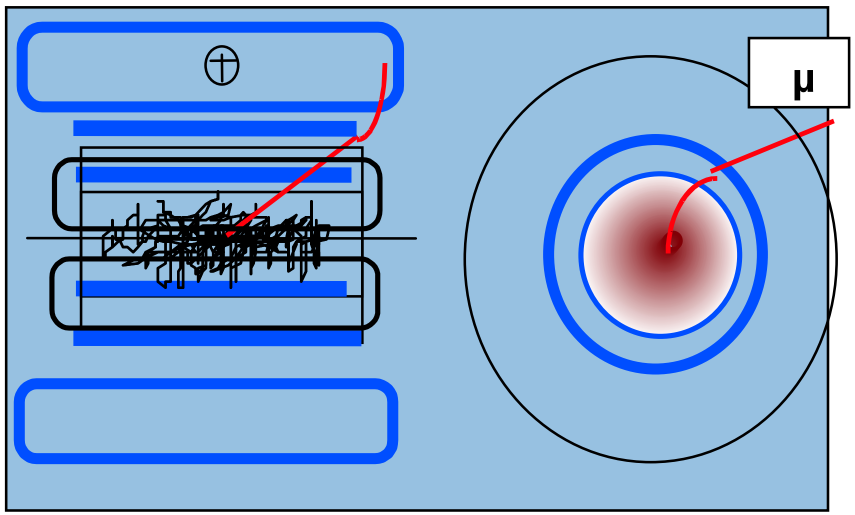


ATLAS und CMS

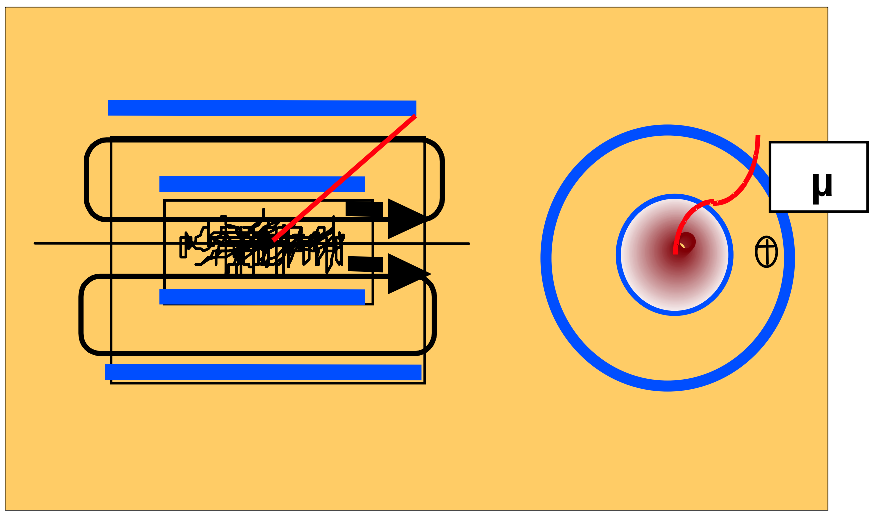
ATLAS **CMS**



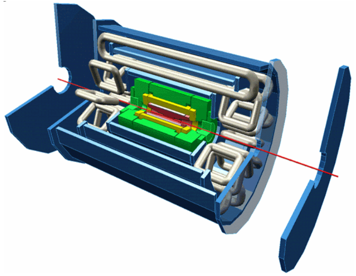




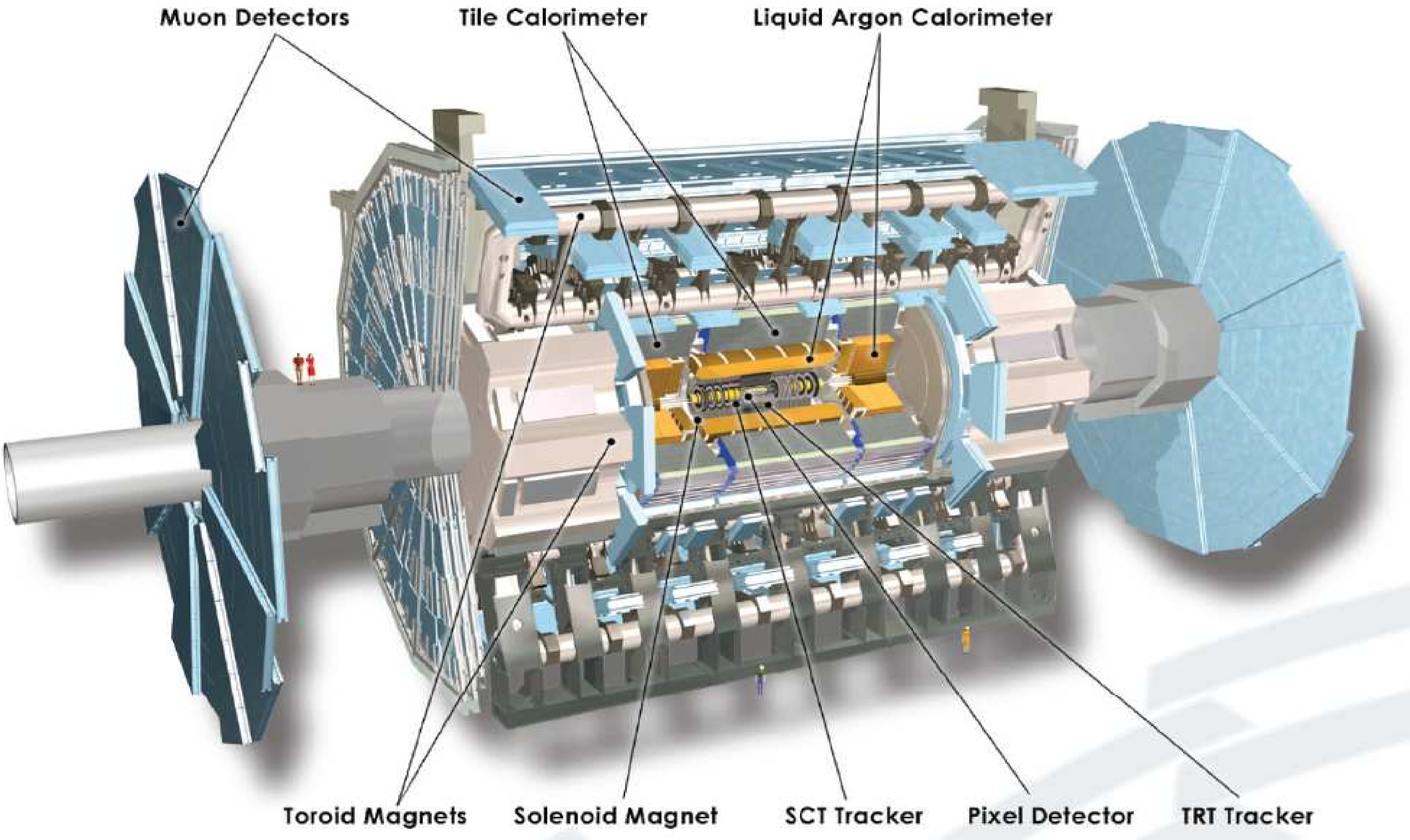
A Toroidal LHC ApparatuS

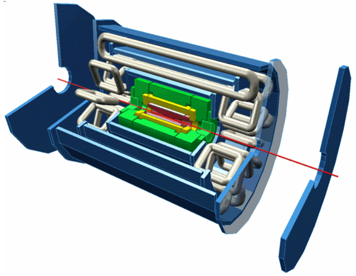


Compac Muon Solenoid



ATLAS


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker



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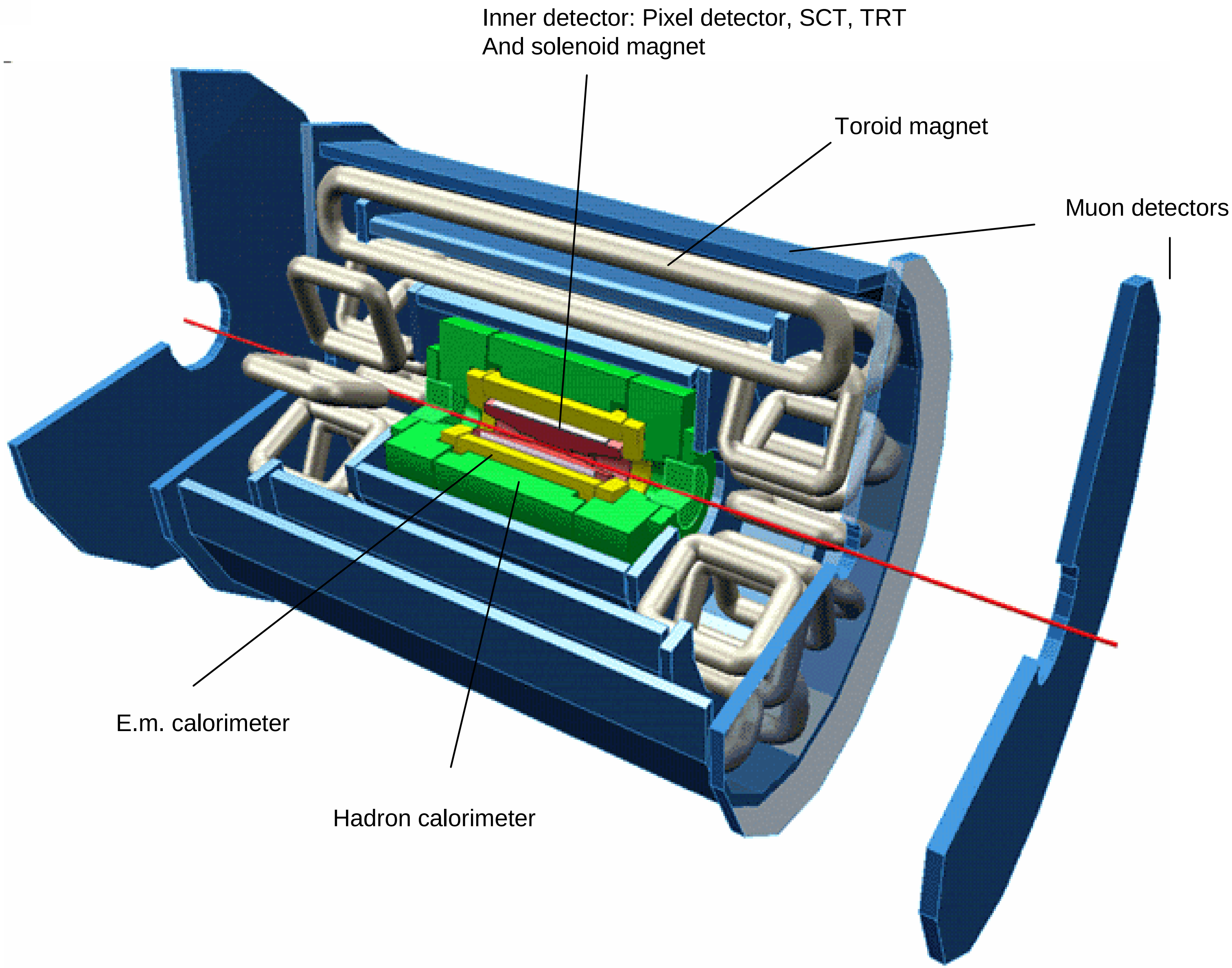
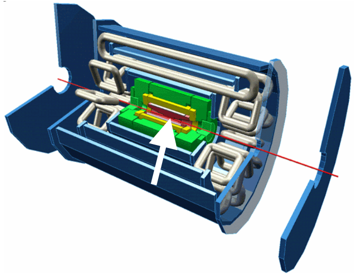
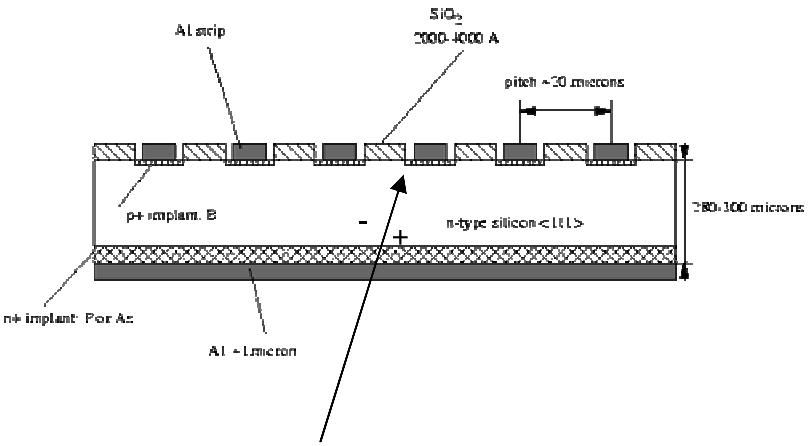


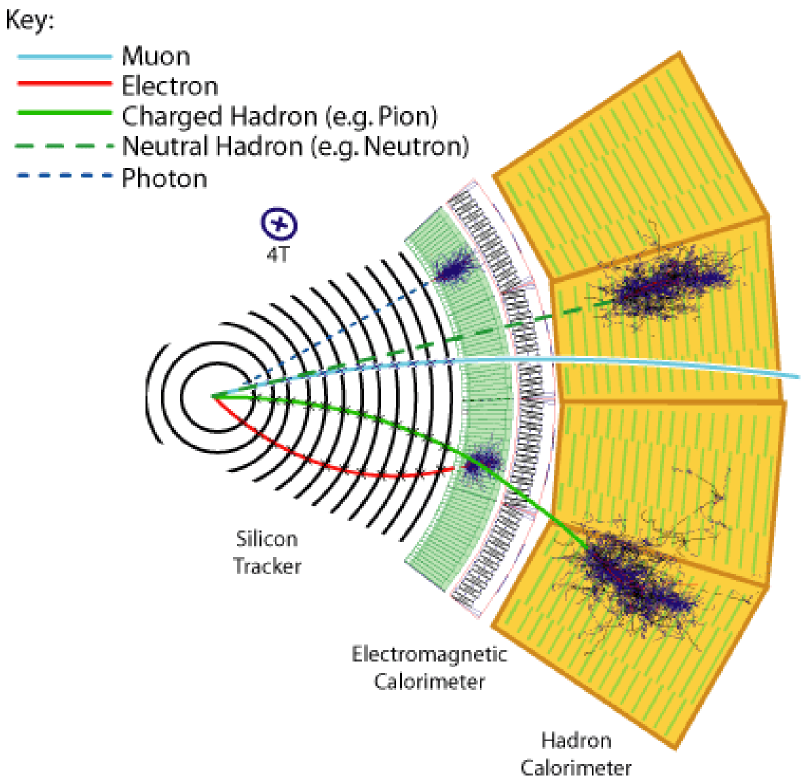
Definition der Winkel!

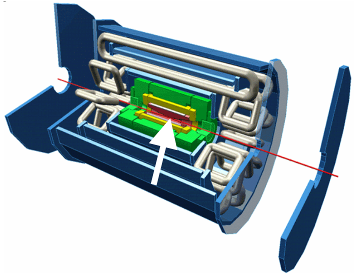


ATLAS – Innerer Detektor

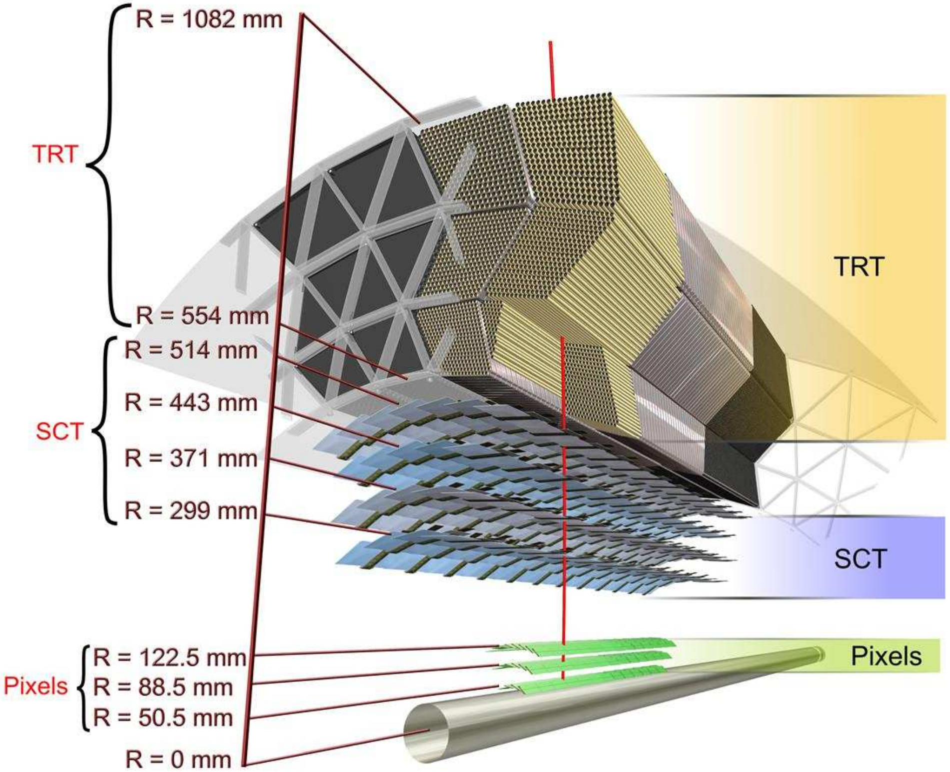
- Spur der geladenen Teilchen
- Identität und Impuls (Spurlänge, gekrümmte Bahnen im Magnetfeld)
- Startpunkt der Teilchen zur Identifikation von Zerfällen von Sekundärteilchen

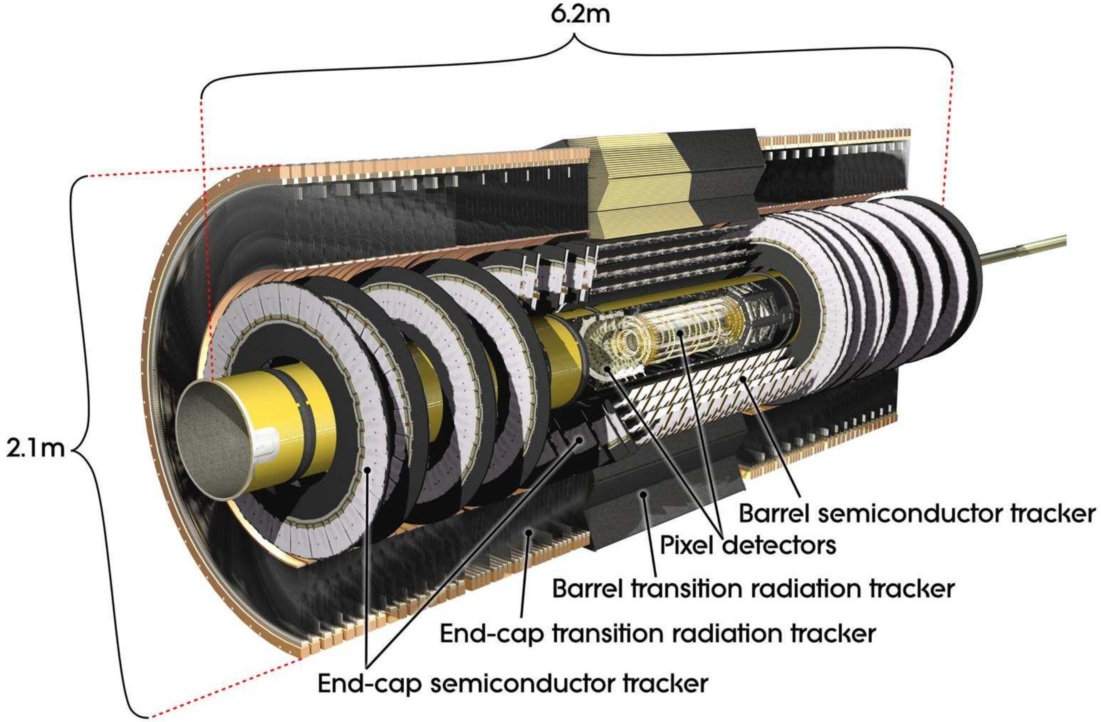


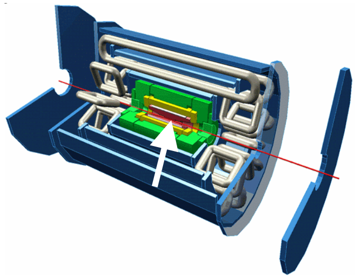




ATLAS – Innerer Detektor







ATLAS – Innerer Detektor

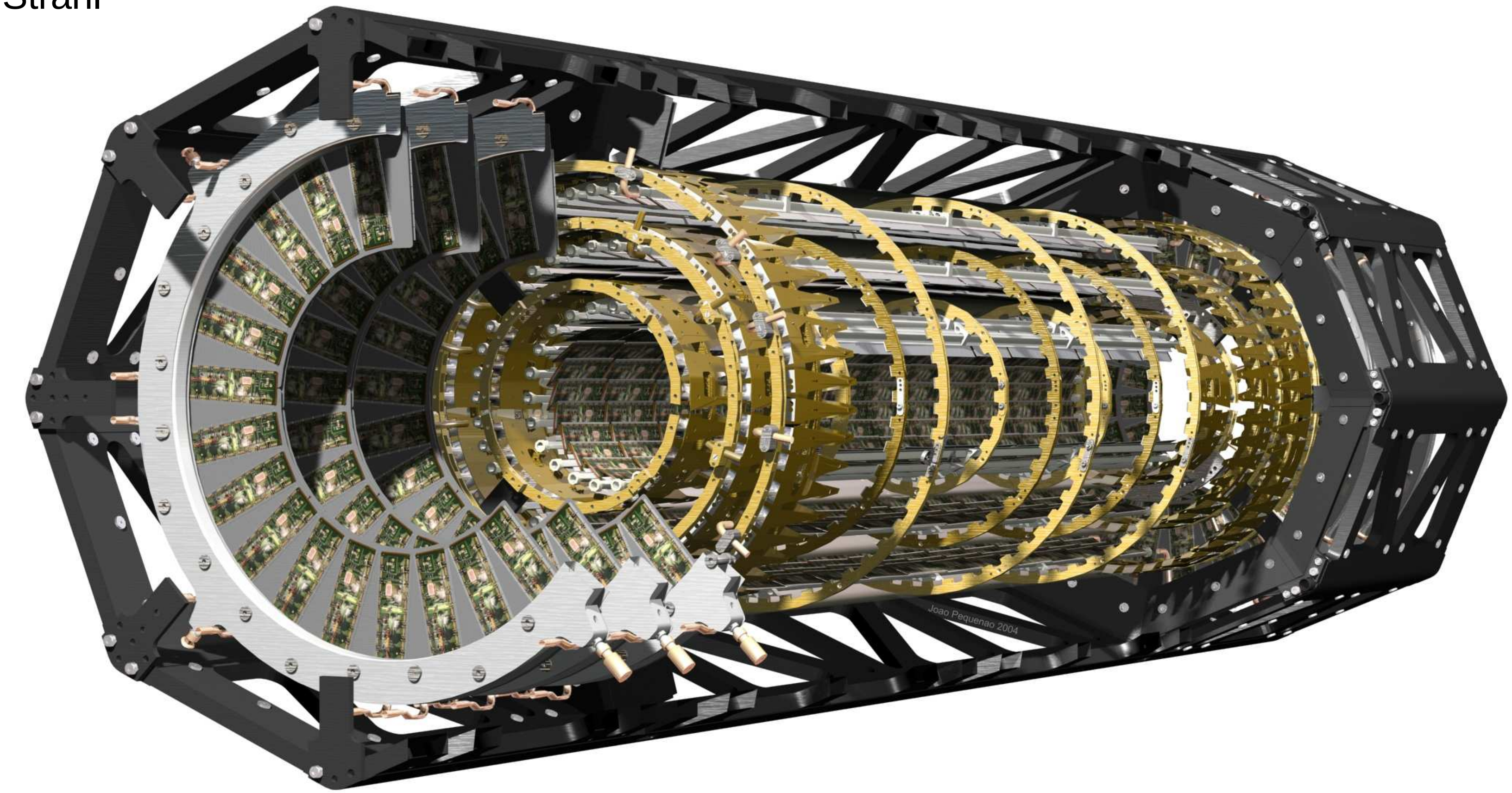
Pixel Detector ~8x10^7channels

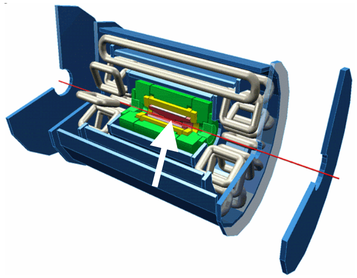
•Maßgeblich für den Inneren Detektor für B-Hadronen und t-Leptonen

•Bestehend aus drei Lagen: 2200 Module (2 mal 6 cm) mit 60000 Silizium Pixeln mit 50 mal 300 µm

•300 kGy und 5´1014 Neutronen pro cm² in zehn Jahren Betrieb

•4 cm vom Strahl

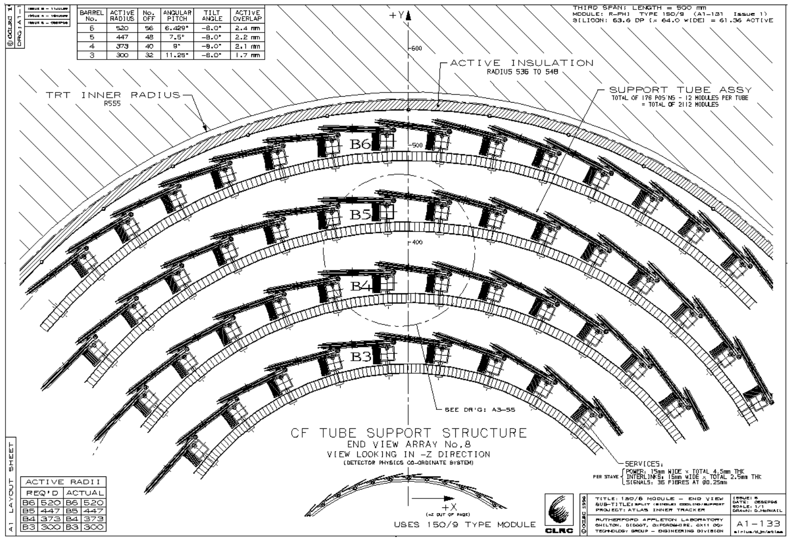


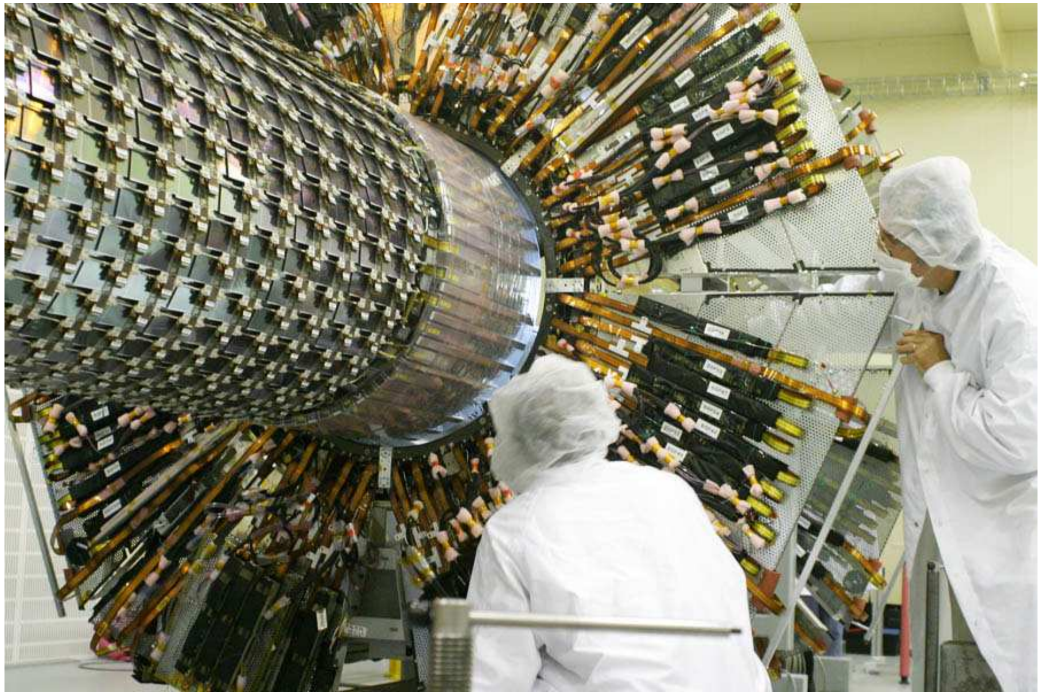


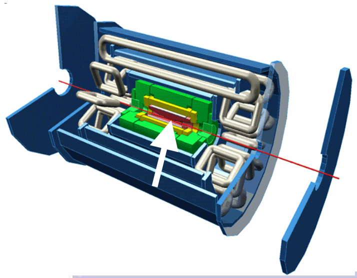
ATLAS – Innerer Detektor

Semi-Conductor Tracker (**SCT**) ~6x10^{6}channels
•Lange Silizium-Streifen (80 µm mal 12.6 cm)
•4 Space-points up to pseudo-rapidity of 2.5 (9°).
•**Small angle stereo** in order to avoid ambiguities.
•Each detector at least 97% efficiency.

„SCT designed to provide eight precision measurements per track in the intermediate radial range, contributing to the measurement of momentum, impact parameter and vertex position, as well as providing good pattern recognition by the use of high granularity.“







ATLAS – Innerer Detektor

Barrel

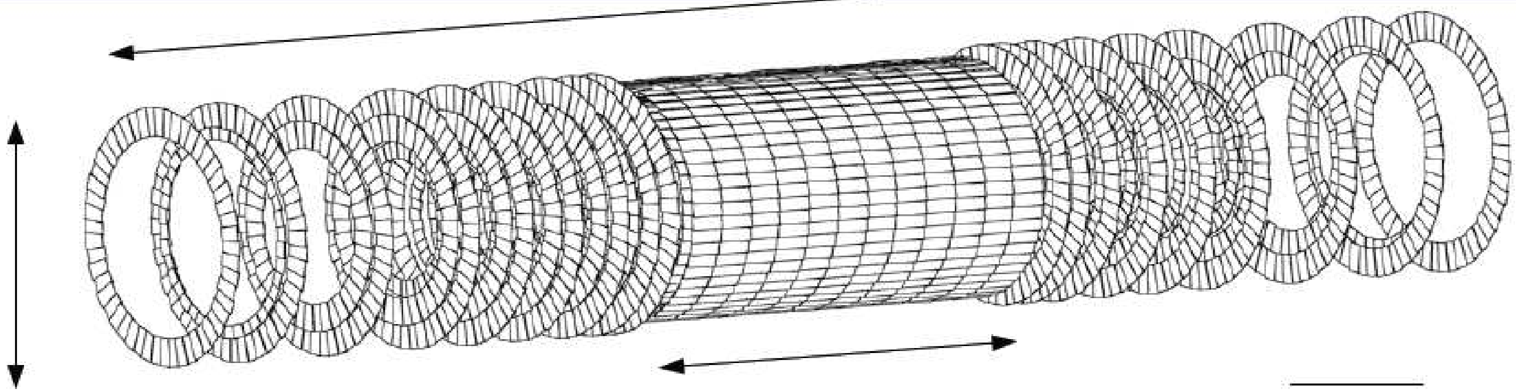
- 34.4 m^2 of silicon
- ~3.2 x 10^6 channels
- 2112 barrel modules (1 type)
- Space point resolution:
  - $r\varphi \sim 16$ mm
  - Z ~580 mm

  µm!
- Coverage: $|\eta| < 1.1$ to 1.4
- 4 Cylinders

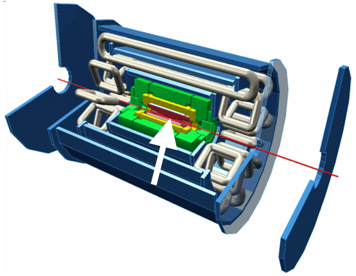
Forward

- ~26.7 m^2 of silicon
- ~3.0 x 10^6 channels
- 1976 modules (4 types)
- Space point resolution:
  - $r\varphi \sim 16$mm
  - R ~580 mm

  µm!
- Coverage: 1.1 to 1.4 $<|\eta| < 2.5$
- 9 disks



Spuren mit Abstand > 200 µm können unterschieden werden



ATLAS – Innerer Detektor

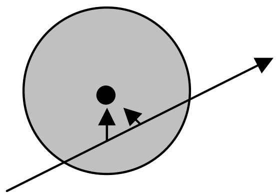
Transition Radiation Tracker (**TRT**) ~4x10^{5}channels

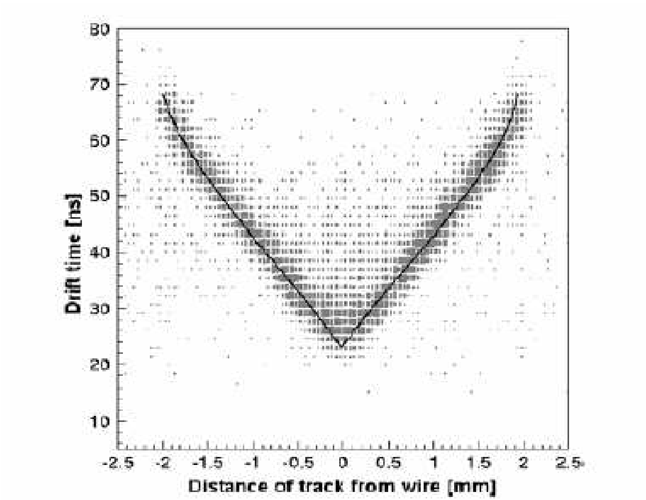
•Small diameter straw detectors operating at high rates

•Better identification of highly relativistc electrons which create transition-radiation photons in a radiator (polyethylen foam) between the straws, detection in xenon gas

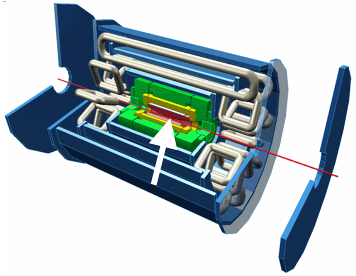
•Up to 36 measurements/path.

•Combined measurement accuracy of better than 50 µm at the LHC design luminosity, averaged over all straws and including a systematic error of ~30 µm from alignment.

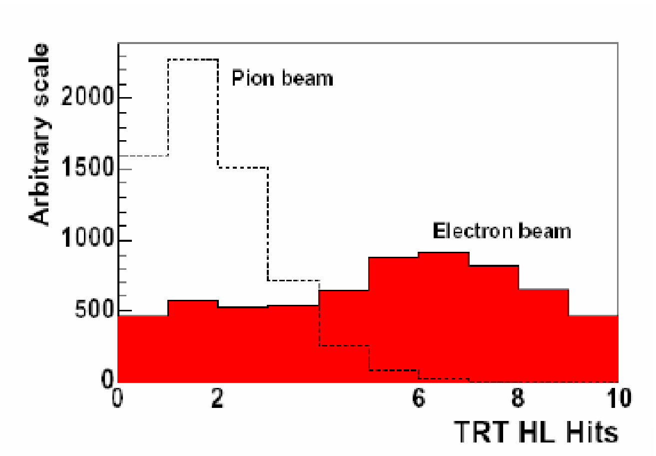


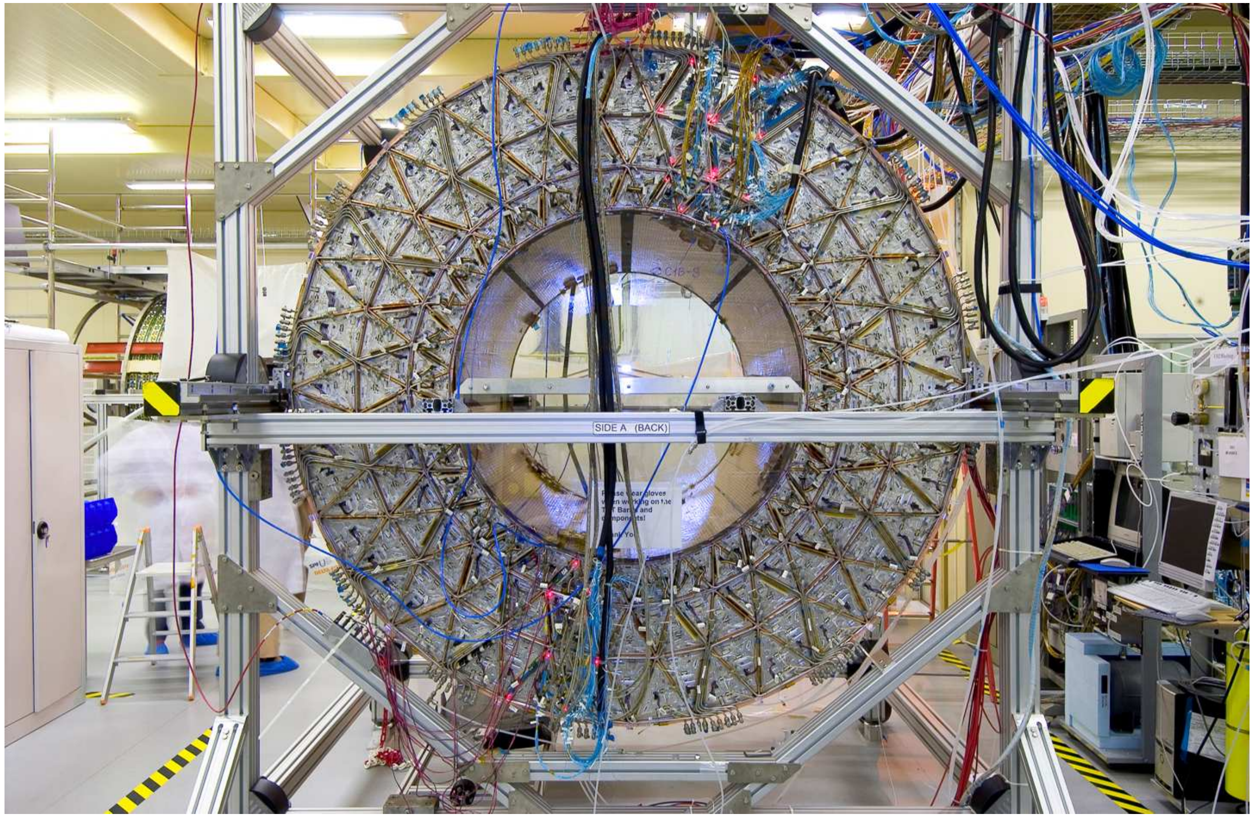


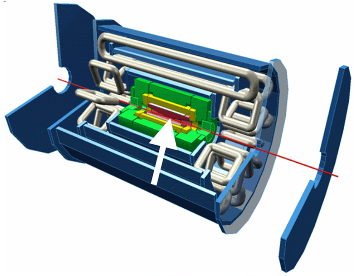
For a single straw, radius v. time measurements



ATLAS – Innerer Detektor





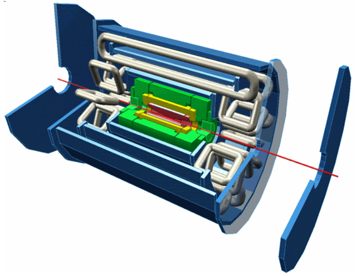


ATLAS – Innerer Detektor

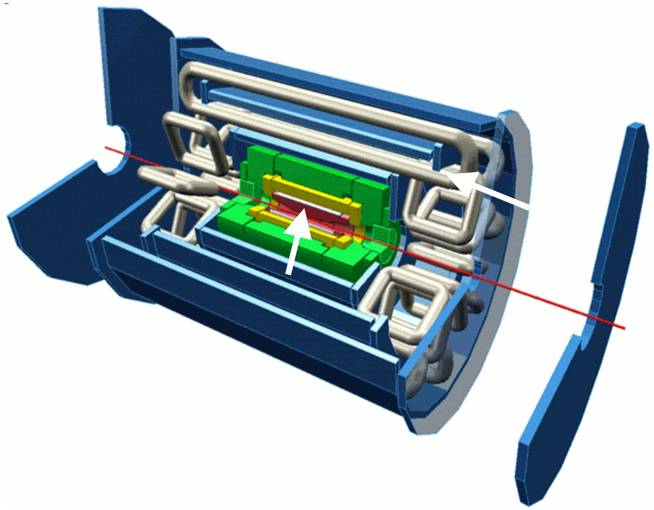
Table 1-2 Parameters of the Inner Detector. The resolutions quoted are typical values (the actual resolution in each detector depends on the impact angle).

System	Position	Area (m^2)	Resolution σ (μm)	Channels (10^6)	η coverage
Pixels	1 removable barrel layer (B-layer)	0.2	$R\phi = 12$, $z = 66$	16	± 2.5
	2 barrel layers	1.4	$R\phi = 12$, $z = 66$	81	± 1.7
	5 end-cap disks on each side	0.7	$R\phi = 12$, $R = 77$	43	1.7-2.5
Silicon strips	4 barrel layers	34.4	$R\phi = 16$, $z = 580$	3.2	± 1.4
	9 end-cap wheels on each side	26.7	$R\phi = 16$, $R = 580$	3.0	1.4–2.5
TRT	Axial barrel straws		170 (per straw)	0.1	± 0.7
	Radial end-cap straws		170 (per straw)	0.32	0.7–2.5
	36 straws per track				

Impact paramter resolution for high p_T
Transverse: 10-15 μm
Longitudinal: 100-150 μm



ATLAS – Magnet

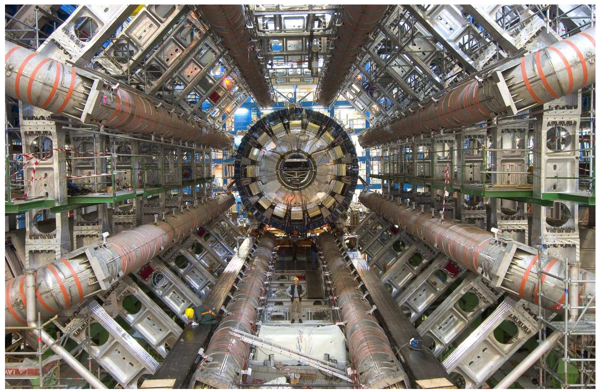


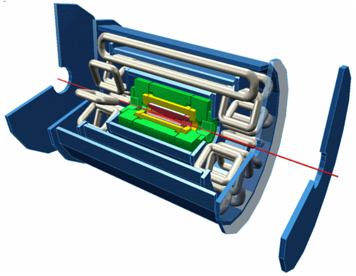
Supraleitender **Solenoid**-Magnet innerhalb der Kalorimeter

NbTi bei 4.5 K
2 – 2.6 T

Supraleitender **Toroid**-Magnet außerhalb der Kalorimeter für die Myonen

1300t Gewicht insgesamt
NbTi bei 4.5 K
4 T





ATLAS – Magnet

Auflösung für Impuls

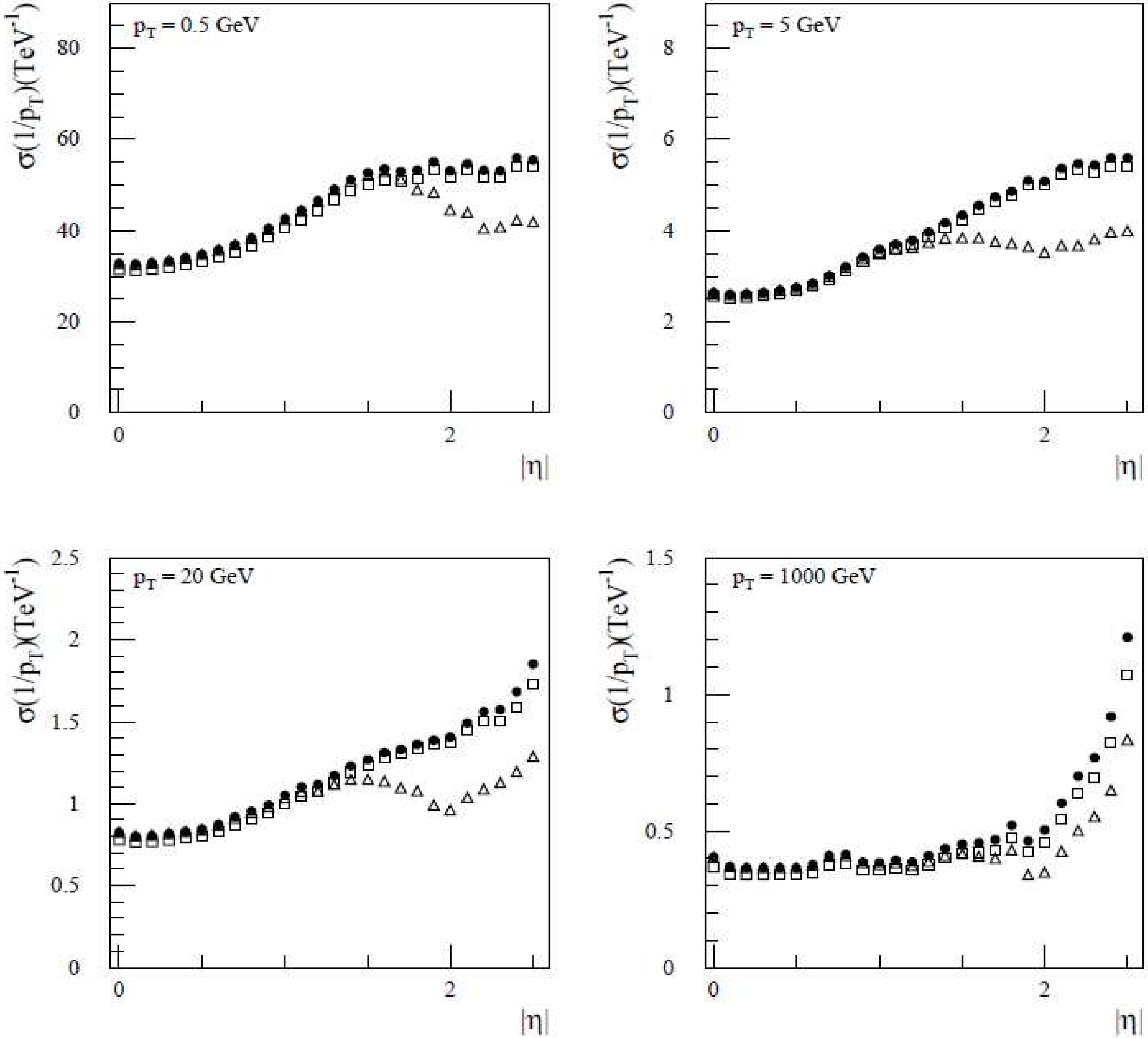
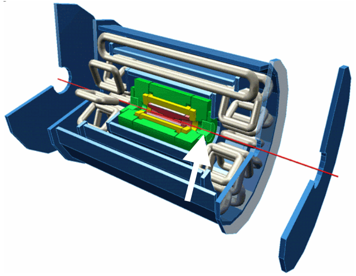


Figure 3-8 p_T resolution as a function of $|\eta|$ for muons of various momenta. Results are shown for a solenoidal field without (circles) and with (squares) a beam constraint, and for a uniform field without a beam constraint (triangles).

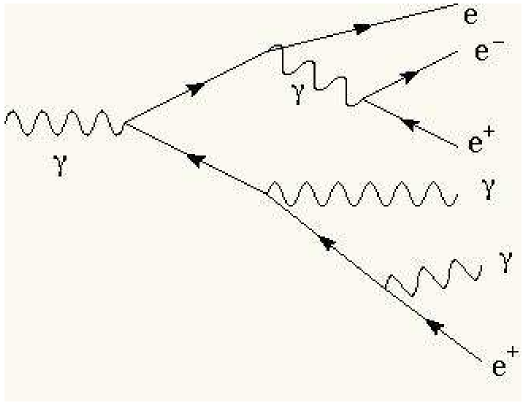
ATLAS TDR



ATLAS – Kalorimeter

Kalorimeter
Messung der Energie durch Absorption in Materialien mit hoher Dichte (für hohe Auflösung) und Nachweis der resultierenden Teilchen-Schauer

- Bremsstrahlung und Paar-Erzeugung
- Maximale Schauerausbreitung (E)
- Laterale Aufweitung durch Coulomb-Streuung



$$E_{tot} = w_{glob}(w_{ps}E_{ps} + E_{str} + E_{mid} + E_{back})$$

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2$$

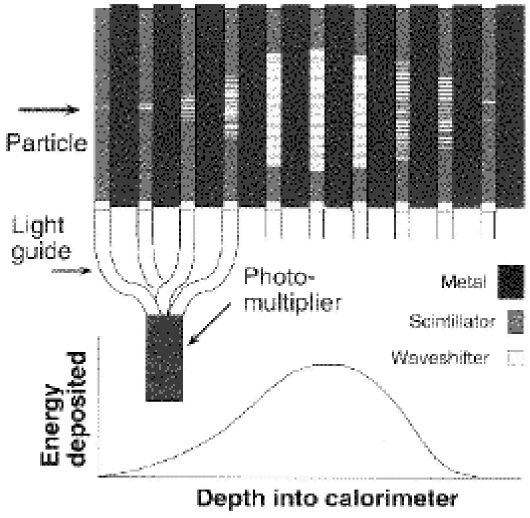
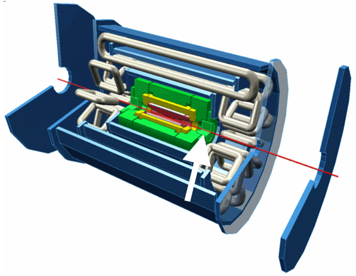
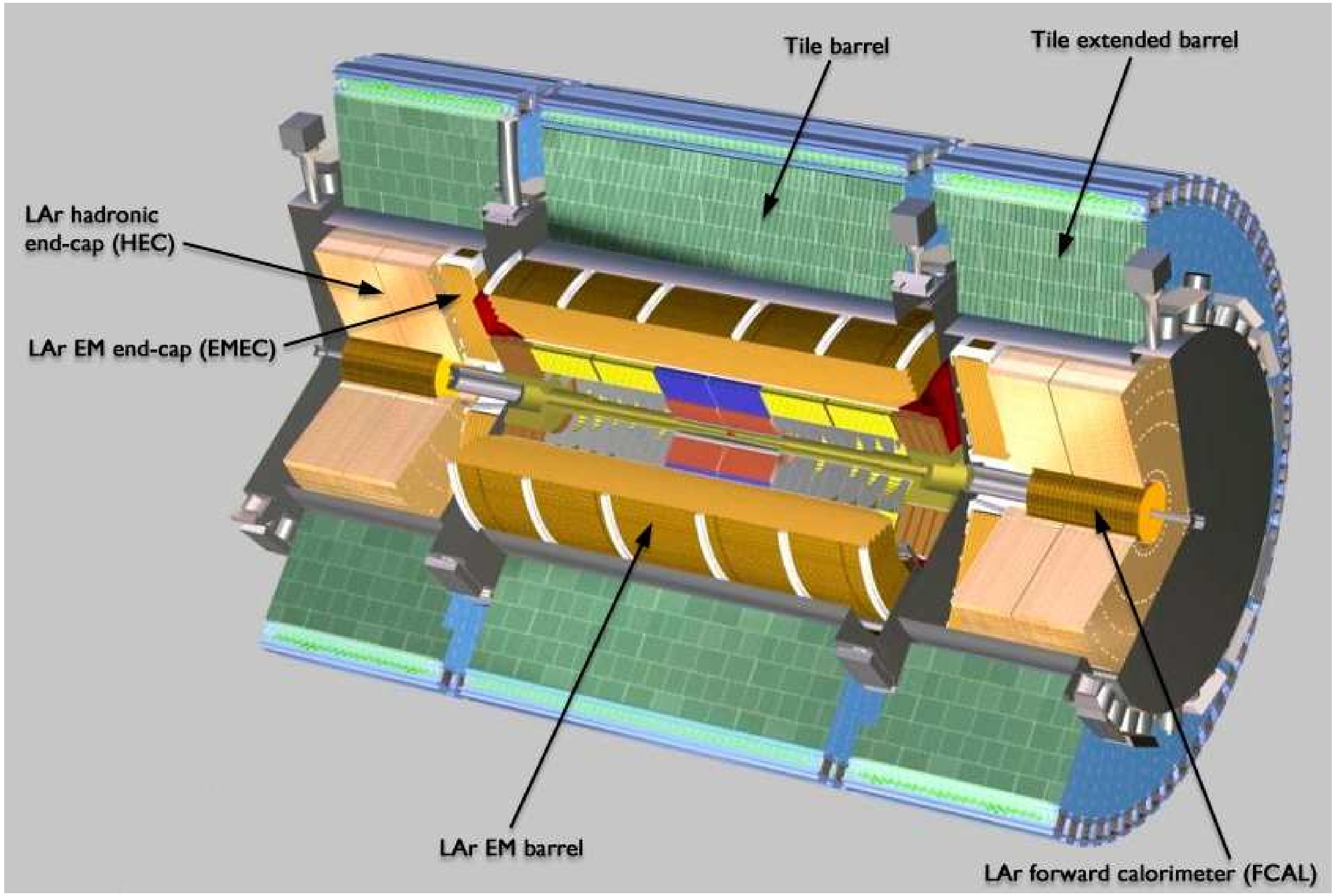
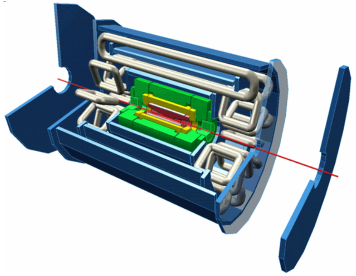


Figure 6.



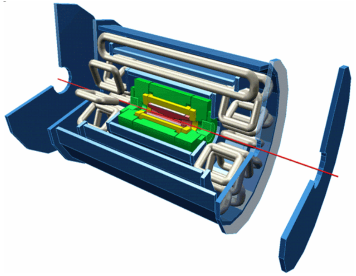
ATLAS - Kalorimeter





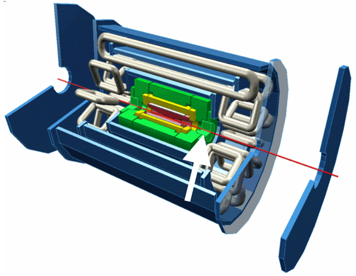
ATLAS - Kalorimeter

EM calorimeter:
•Lead/liquid-argon (LAr) detector
•Lead absorber and Argon ionization chamber
•Accordion geometry
•Total thickness of the EM calorimeter is
> 24-26 radiation lengths
•Cooling!



ATLAS - Kalorimeter

Hadronic tile calorimeter:
•Must contain hadronic showers (Missing Energy important for e.g. SUSY)
•Steel tiles with plastic scintillators
•Two sides of the scintillating tiles are read out by wavelength shifting (WLS) fibres into two separate photomultipliers (PMTs).



ATLAS – Kalorimeter

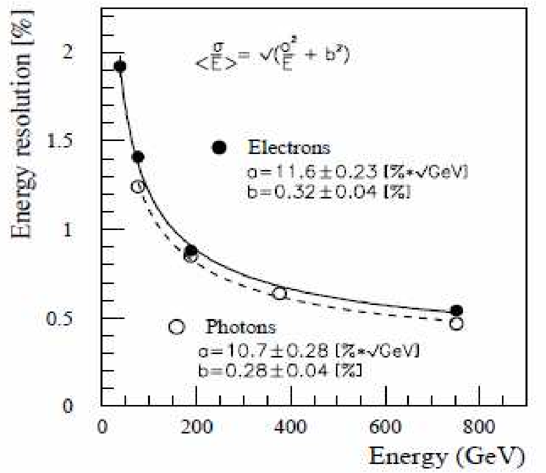


Figure 4-19 Energy resolution for electrons and photons at η = 2.0, as a function of the incident energy.

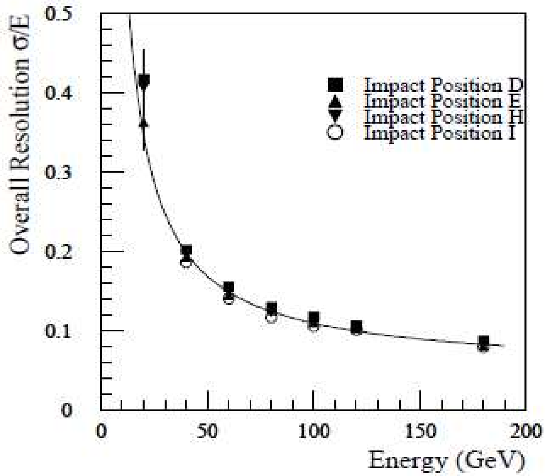
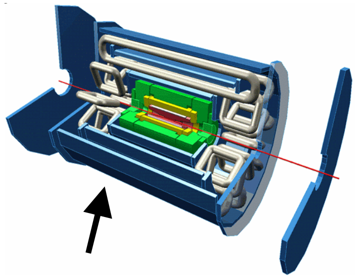


Figure 5-11 Energy dependence of the energy resolution for pions at four different impact points. These

Table 1-3 Pseudorapidity coverage, granularity and longitudinal segmentation of the ATLAS calorimete

EM CALORIMETER	**Barrel**	**End-cap**	
Coverage	$|\eta| < 1.475$	$1.375 < |\eta| < 3.2$	
Longitudinal segmentation	3 samplings	3 samplings	$1.5 < |\eta| < 2.5$
		2 samplings	$1.375 < |\eta| < 1.5$
			$2.5 < |\eta| < 3.2$
Granularity ($\Delta\eta\times\Delta\phi$)			
Sampling 1	0.003×0.1	0.025×0.1	$1.375 < |\eta| < 1.5$
		0.003×0.1	$1.5 < |\eta| < 1.8$
		0.004×0.1	$1.8 < |\eta| < 2.0$
		0.006×0.1	$2.0 < |\eta| < 2.5$
		0.1×0.1	$2.5 < |\eta| < 3.2$
Sampling 2	0.025×0.025	0.025×0.025	$1.375 < |\eta| < 2.5$
		0.1×0.1	$2.5 < |\eta| < 3.2$
Sampling 3	0.05×0.025	0.05×0.025	$1.5 < |\eta| < 2.5$
PRESAMPLER	**Barrel**	**End-cap**	
Coverage	$|\eta| < 1.52$	$1.5 < |\eta| < 1.8$	
Longitudinal segmentation	1 sampling	1 sampling	
Granularity ($\Delta\eta\times\Delta\phi$)	0.025×0.1	0.025×0.1	
HADRONIC TILE	**Barrel**	**Extended barrel**	
Coverage	$|\eta| < 1.0$	$0.8 < |\eta| < 1.7$	
Longitudinal segmentation	3 samplings	3 samplings	
Granularity ($\Delta\eta\times\Delta\phi$)			
Samplings 1 and 2	0.1×0.1	0.1×0.1	
Sampling 3	0.2×0.1	0.2×0.1	
HADRONIC LAr		**End-cap**	
Coverage		$1.5 < |\eta| < 3.2$	
Longitudinal segmentation		4 samplings	
Granularity ($\Delta\eta\times\Delta\phi$)		0.1×0.1	$1.5 < |\eta| < 2.5$
		0.2×0.2	$2.5 < |\eta| < 3.2$
FORWARD CALORIMETER		**Forward**	
Coverage		$3.1 < |\eta| < 4.9$	
Longitudinal segmentation		3 samplings	
Granularity ($\Delta\eta\times\Delta\phi$)		$\sim 0.2 \times 0.2$	



ATLAS – Myon-Spektrometer

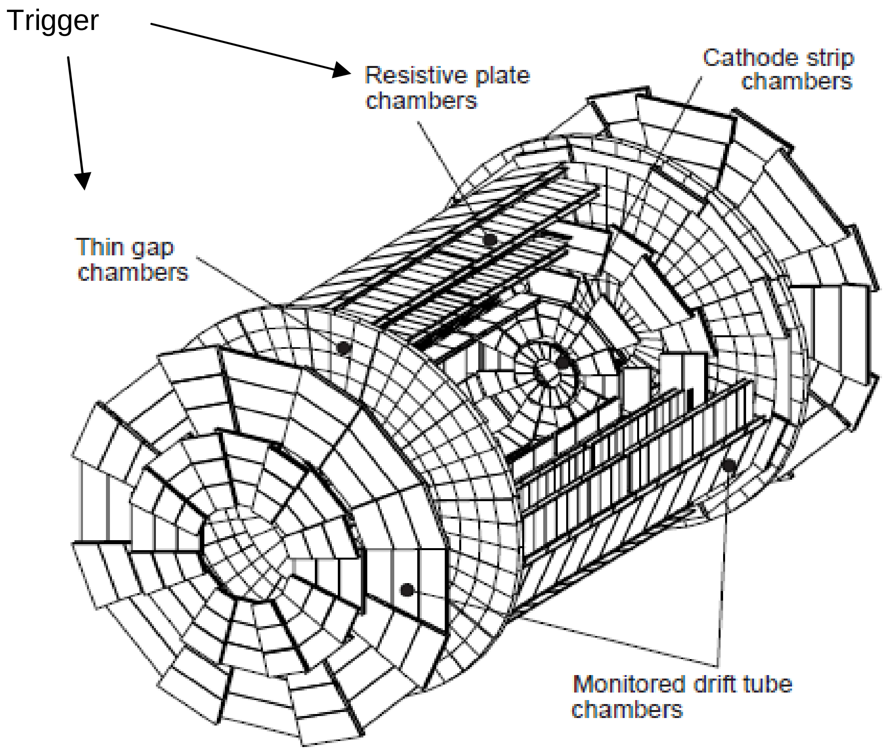
p_T range from 5 to about 1000 GeV/c

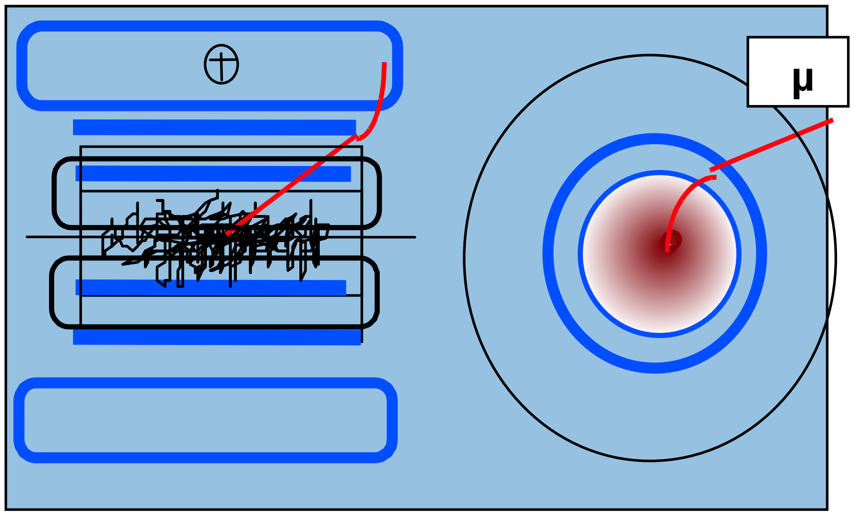
Magnetic deflection of muon tracks in the large superconducting air-core toroid magnets

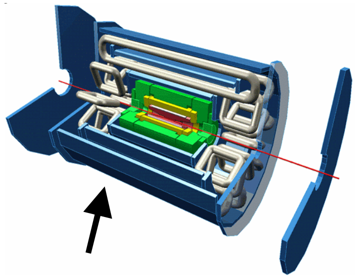
Seperate **trigger (bg!)** and high-precision tracking chambers

Different types of detectors according to their purpose and position

Precision measurement in R-z-projection parallel to B



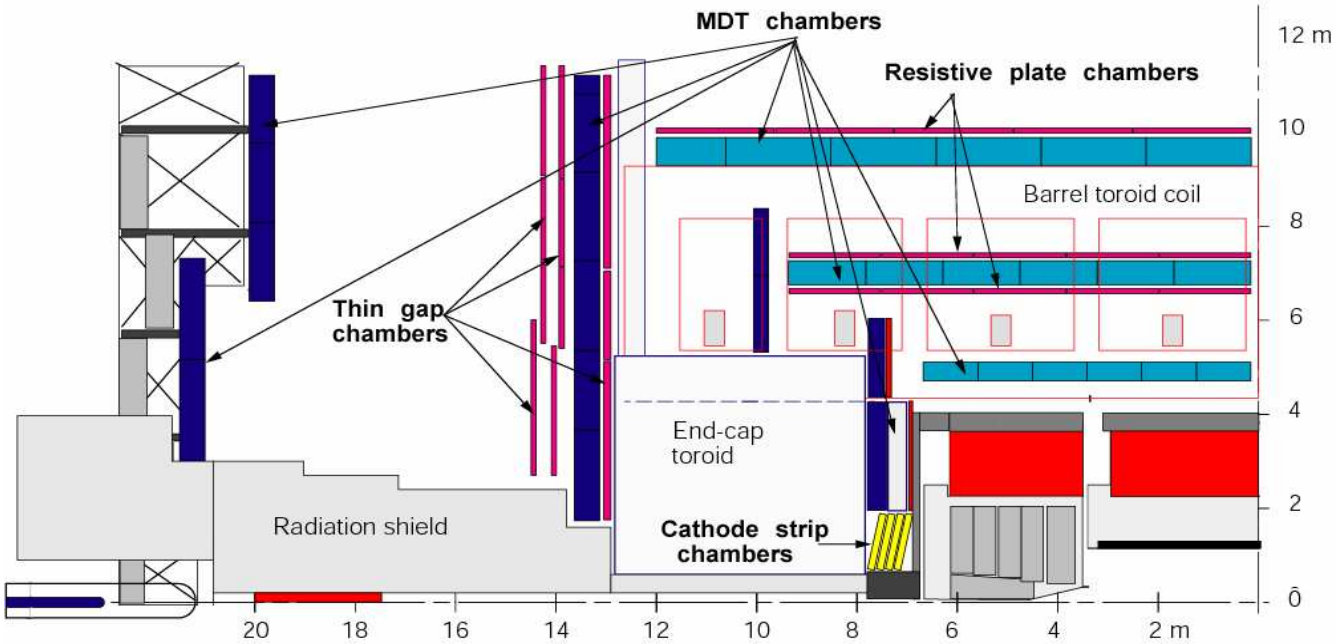


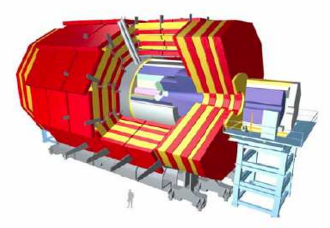


ATLAS – Myon-Spektrometer

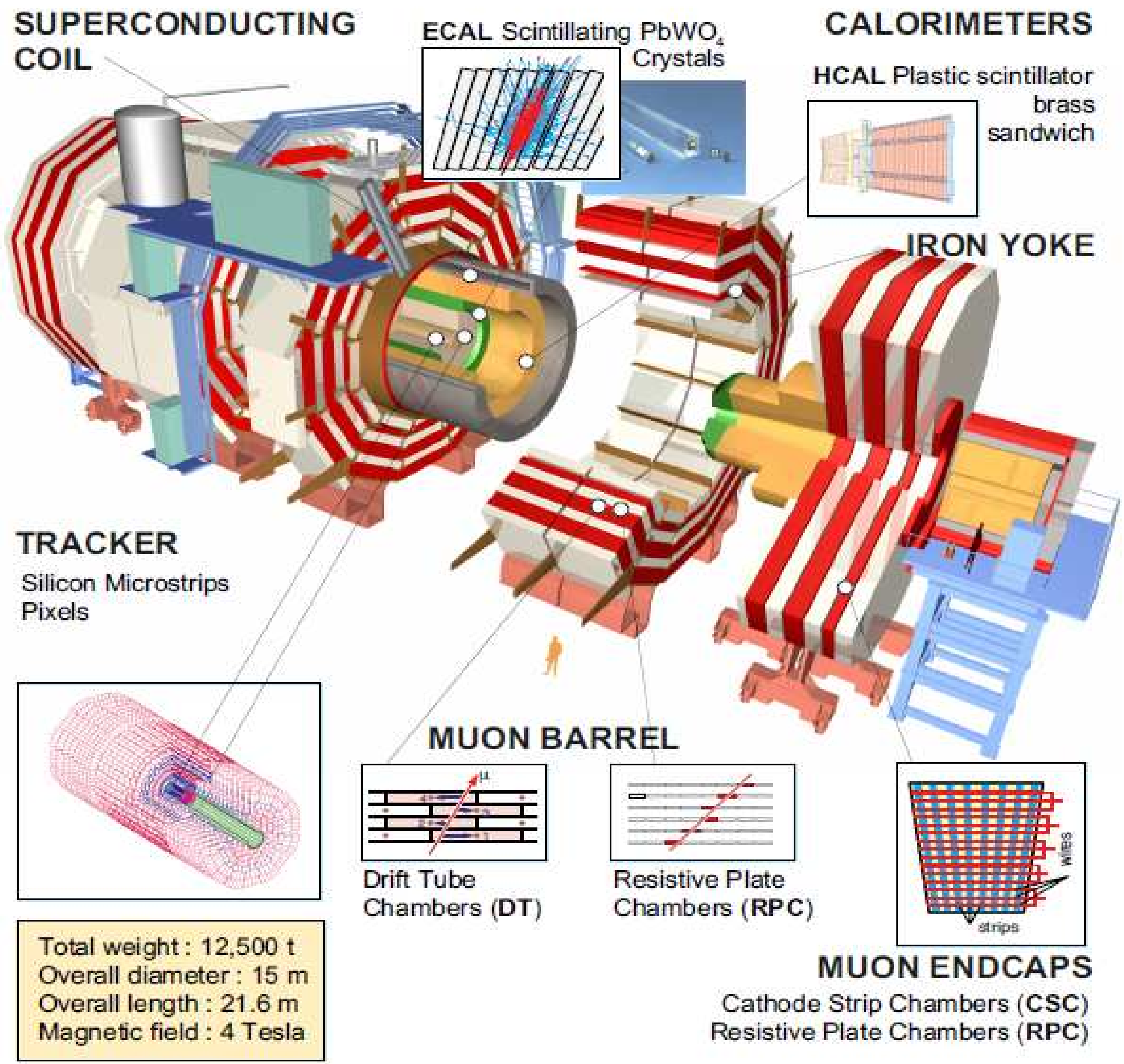
Trigger purposes:
• bunch crossing identification (time coordinate), requiring a time resolution better than the LHC bunch spacing of 25 ns;
• a trigger with well-defined p_T cut-offs in moderate magnetic fields, requiring a granularity of the order of 1 cm;
• measurement of the second coordinate in a direction orthogonal to that measured by the precision chambers, with a typical resolution of 5–10 mm.

Alignment mechanisms

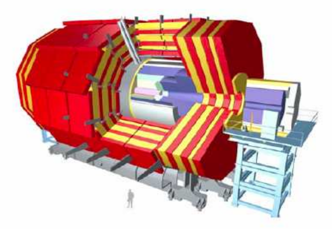




CMS



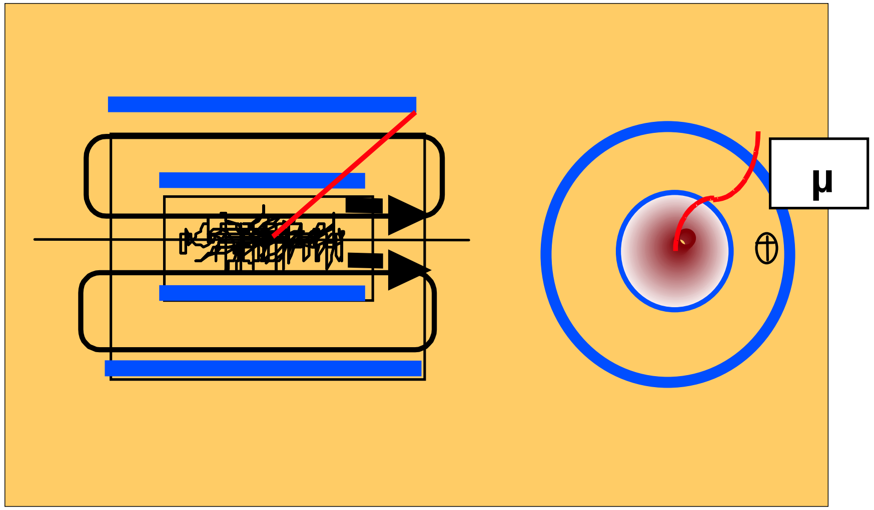
CMS Brochure



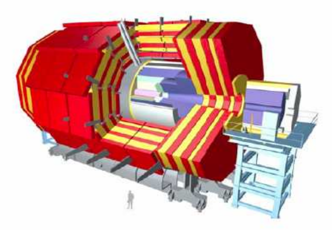
CMS - Magnet

Required performance of the muon system (bending power) defined by the narrow states decaying into muons and by the unambiguous determination of the sign for muons with a momentum of ca. 1 TeV/c.

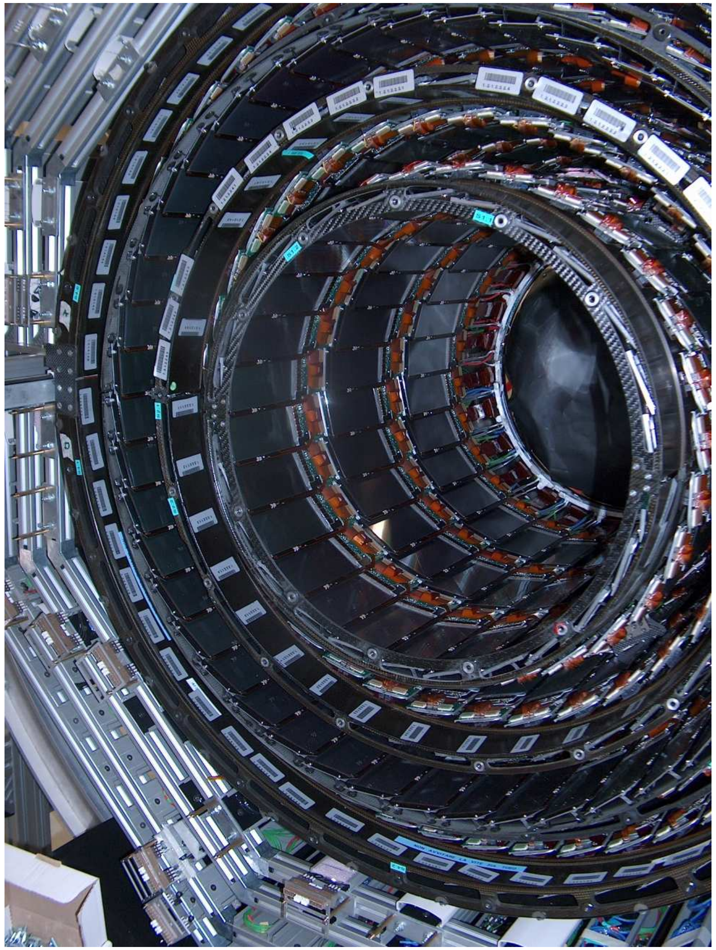
Requires a momentum resolution of dp/p = 10% at p = 1 TeV/c.



Solenoid magnet contains calorimeters: 4 T



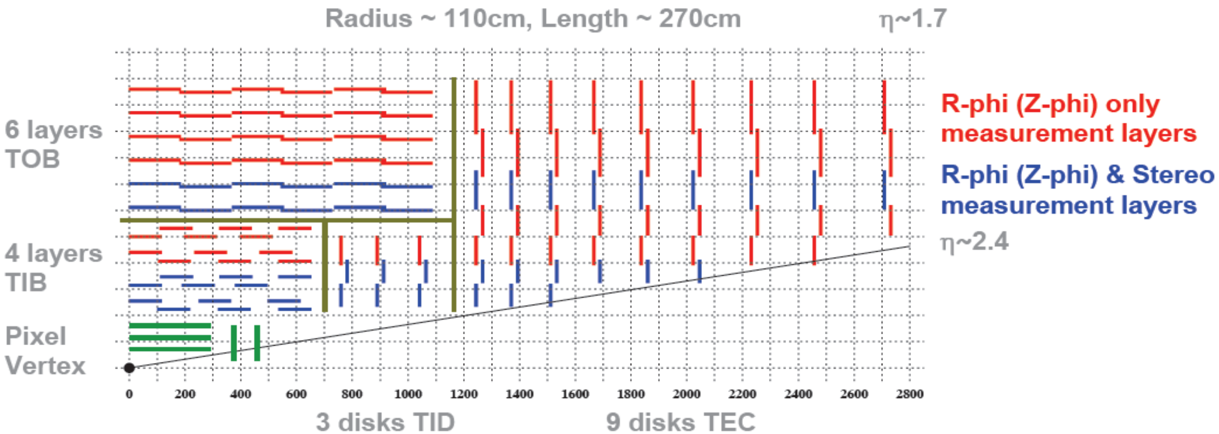
CMS – Innerer Detektor

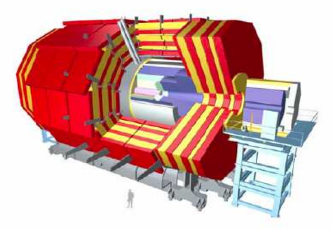


- Silicon Pixel Detector
rφ: ~23-24µm
rZ : ~23µm

- Silicon Microstrip (125x64 mm²,pitch: 50µm)

Impact paramter resolution for high pT (>100 GeV)
Transverse: 10-11 µm
Longitudinal: 20-100 µm



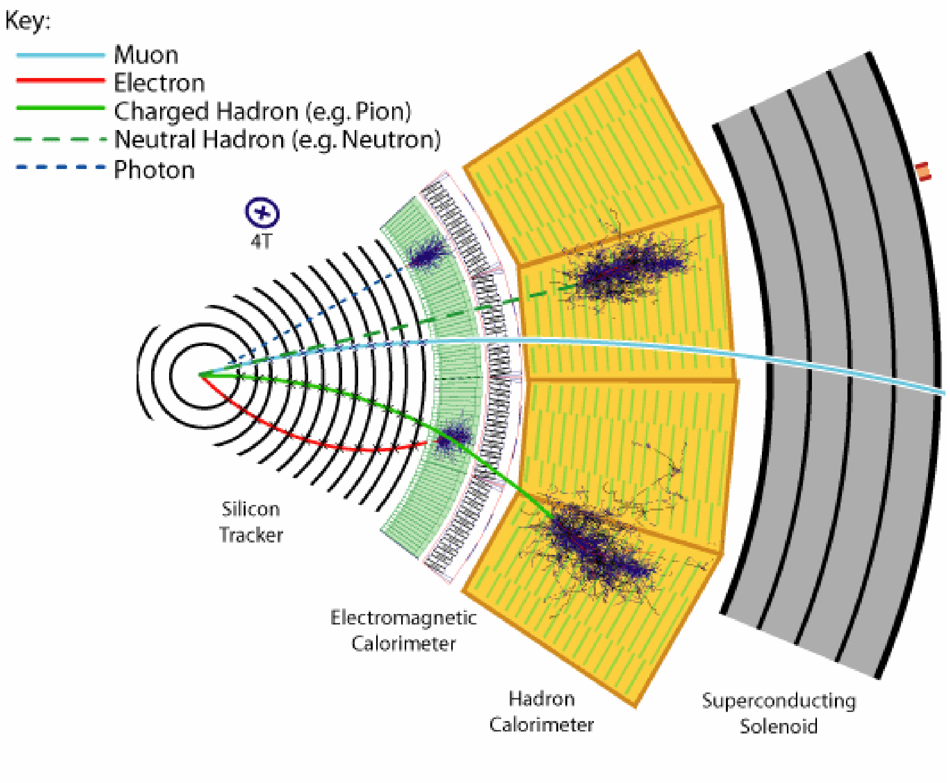


CMS - Kalorimeter

The EM calorimeter (**ECAL**) uses lead tungstate ($PbWO_4$) scintillators (75000 in total!) with coverage in pseudorapidity up to $|\eta| < 3.0$.

Preshower-Detectors (π_0 underground)

High resolution for high energy photons (Higgs result)



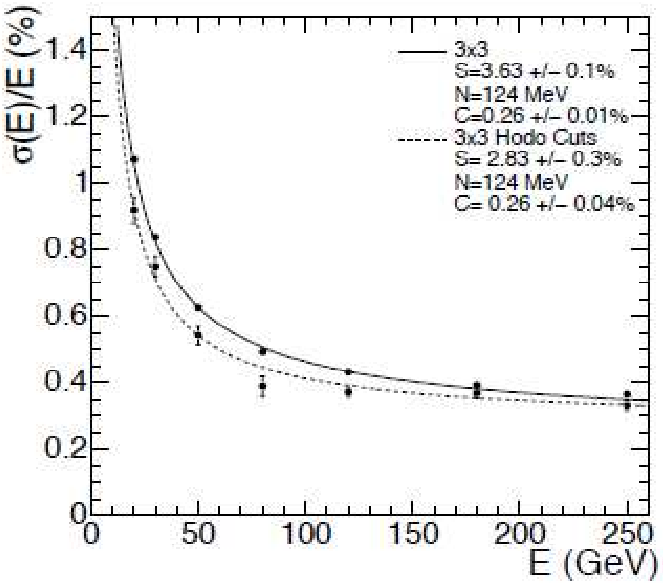
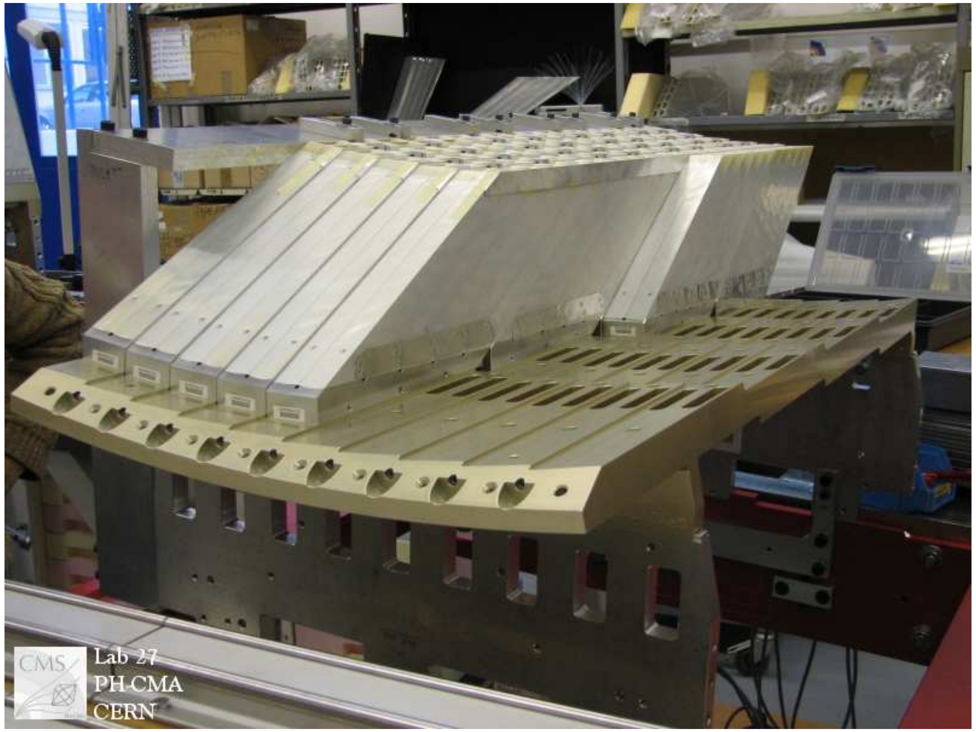
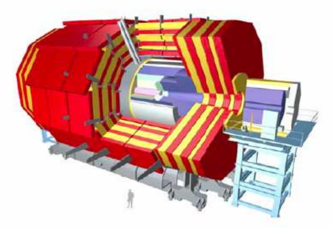


Figure 1.7: ECAL supermodule energy resolution, σ_E/E, as a function of electron energy as measured from a beam test. The upper series of points correspond to events taken with a 20×20 mm^2 trigger and reconstructed using a containment correction described in Section 4.3.2.2. The lower series of points correspond to events selected to fall within a 4×4 mm^2 region. The energy was measured in an array of 3×3 crystals with electrons impacting the central crystal.

CMS Technical Design Report

CMS - Kalorimeter





CMS - Kalorimeter

Brass/scintillator sampling hadron calorimeter (**HCAL**) with coverage up to |n| < 3.0
Most of HCAL packed inside magnet, HO outside for better measure of missing energy

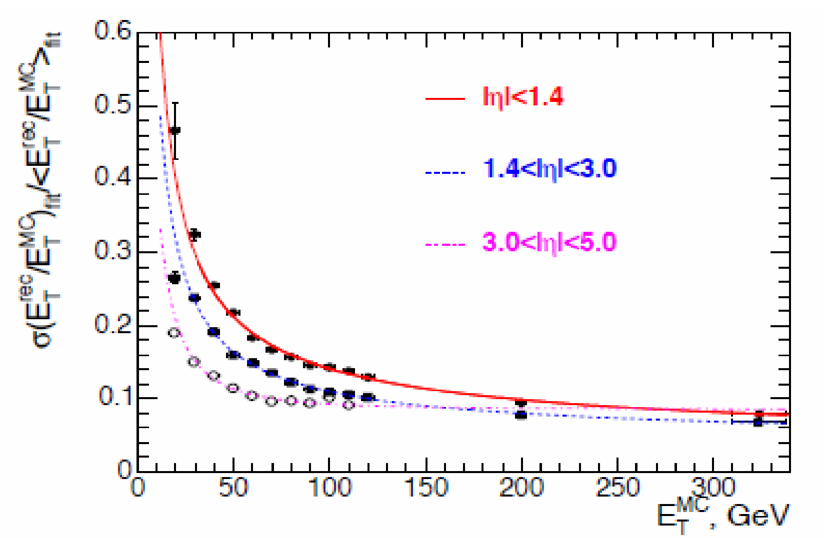
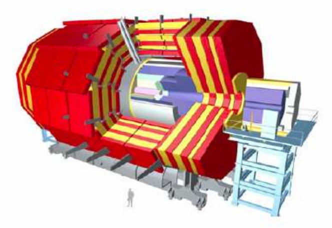


Figure 1.8: The jet transverse energy resolution as a function of the simulated jet transverse energy for barrel jets ($|\eta|$ <1.4), endcap jets (1.4< $|\eta|$ <3.0) and very forward jets (3.0< $|\eta|$ <5.0). The jets are reconstructed with the interative cone $R = 0.5$ algorithm. See Section 11.4 for further details.

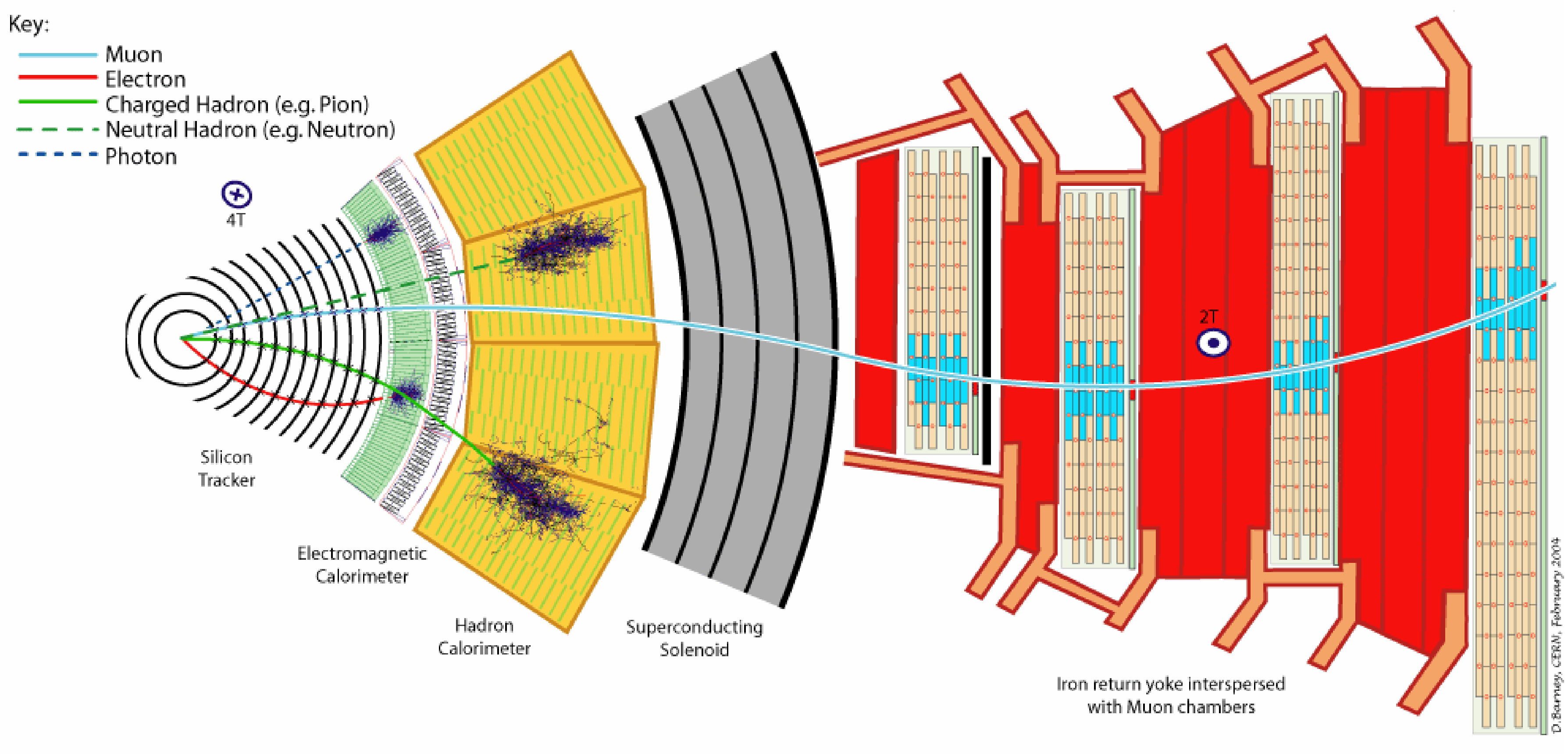


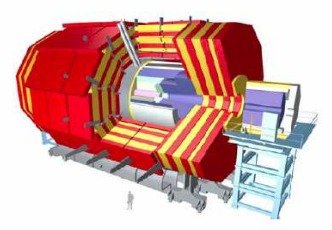
CMS – Myon-System

Detektiert Spur und Impuls der Myonen (besonders der hochenergetischen)

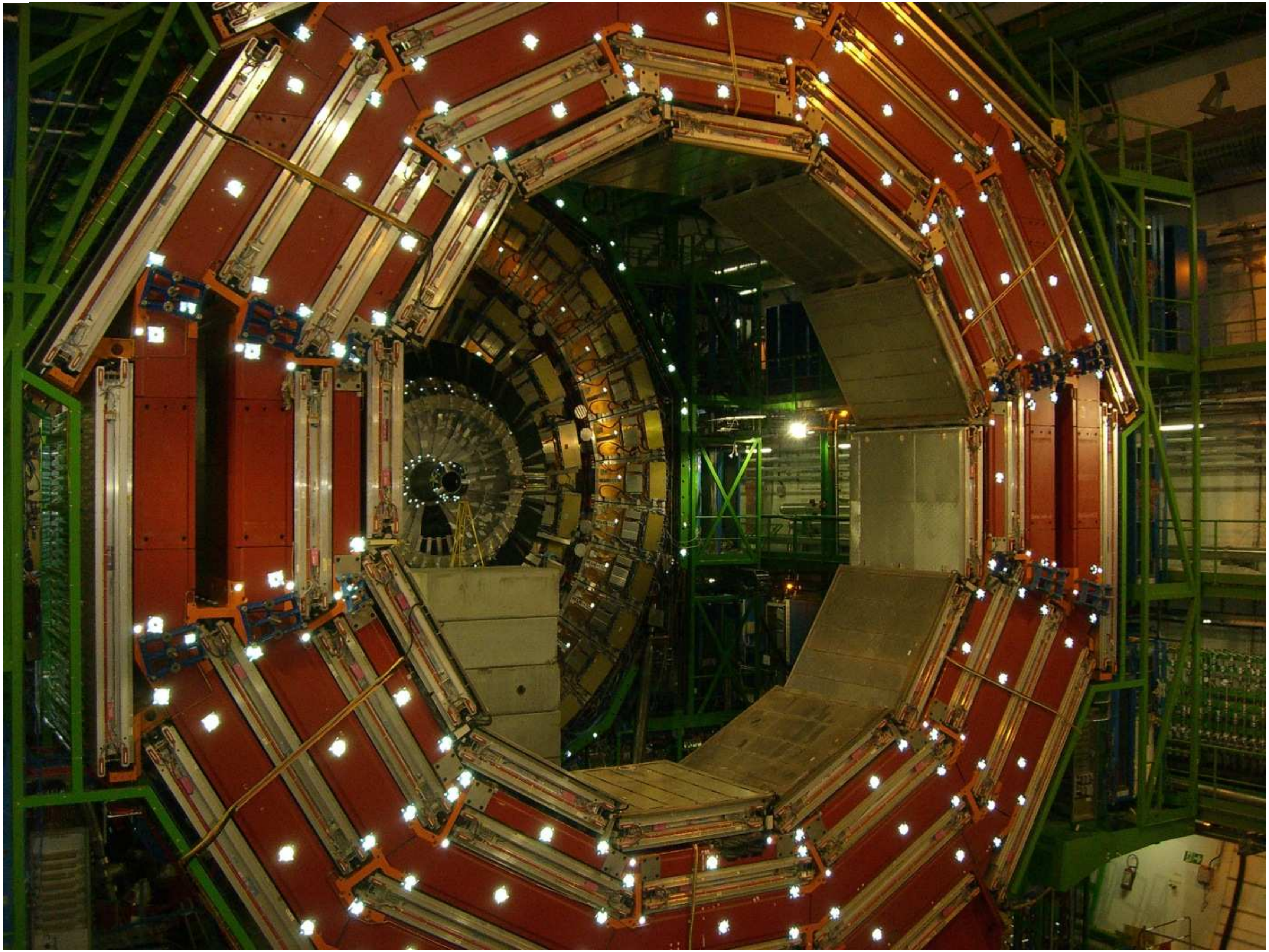
3 Arten von Ionisationskammern werden verwendet:

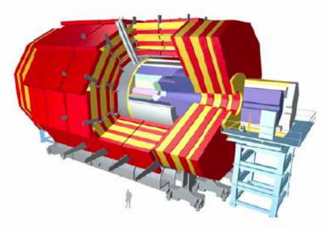
Drift Tubes
Cathode Strip Chamber
Resistive Plate Chamber





CMS – Myon-System

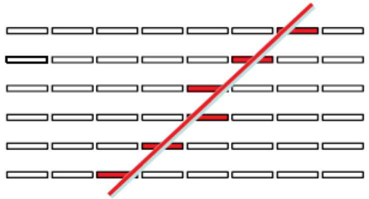




CMS – Myon-System

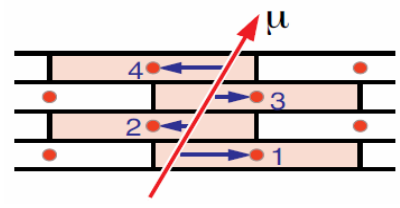
RPC

Time

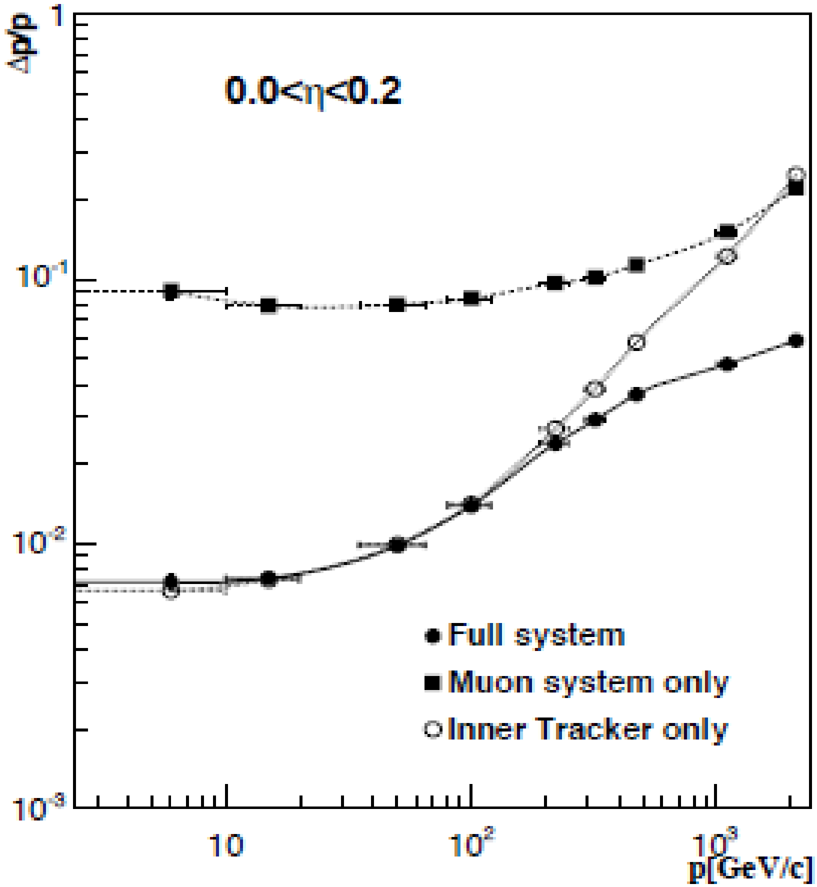


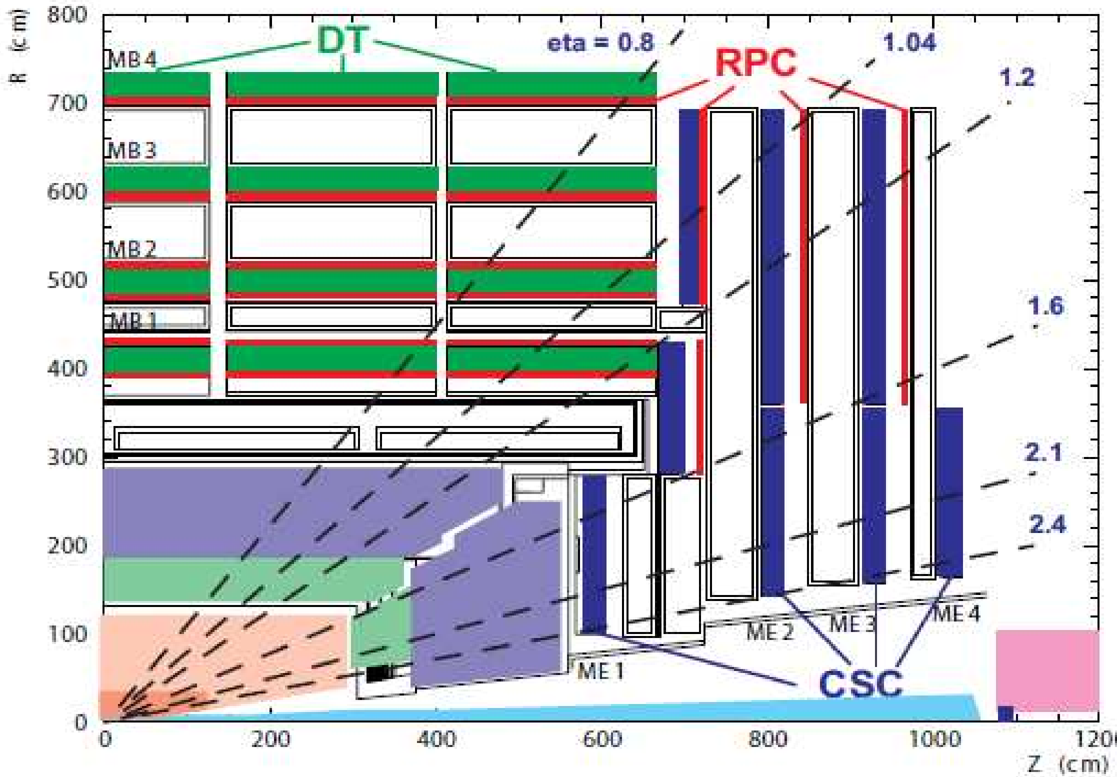
DT

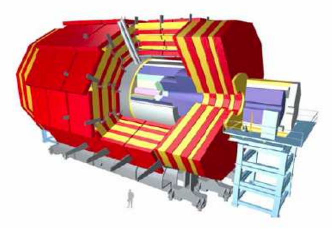
Position



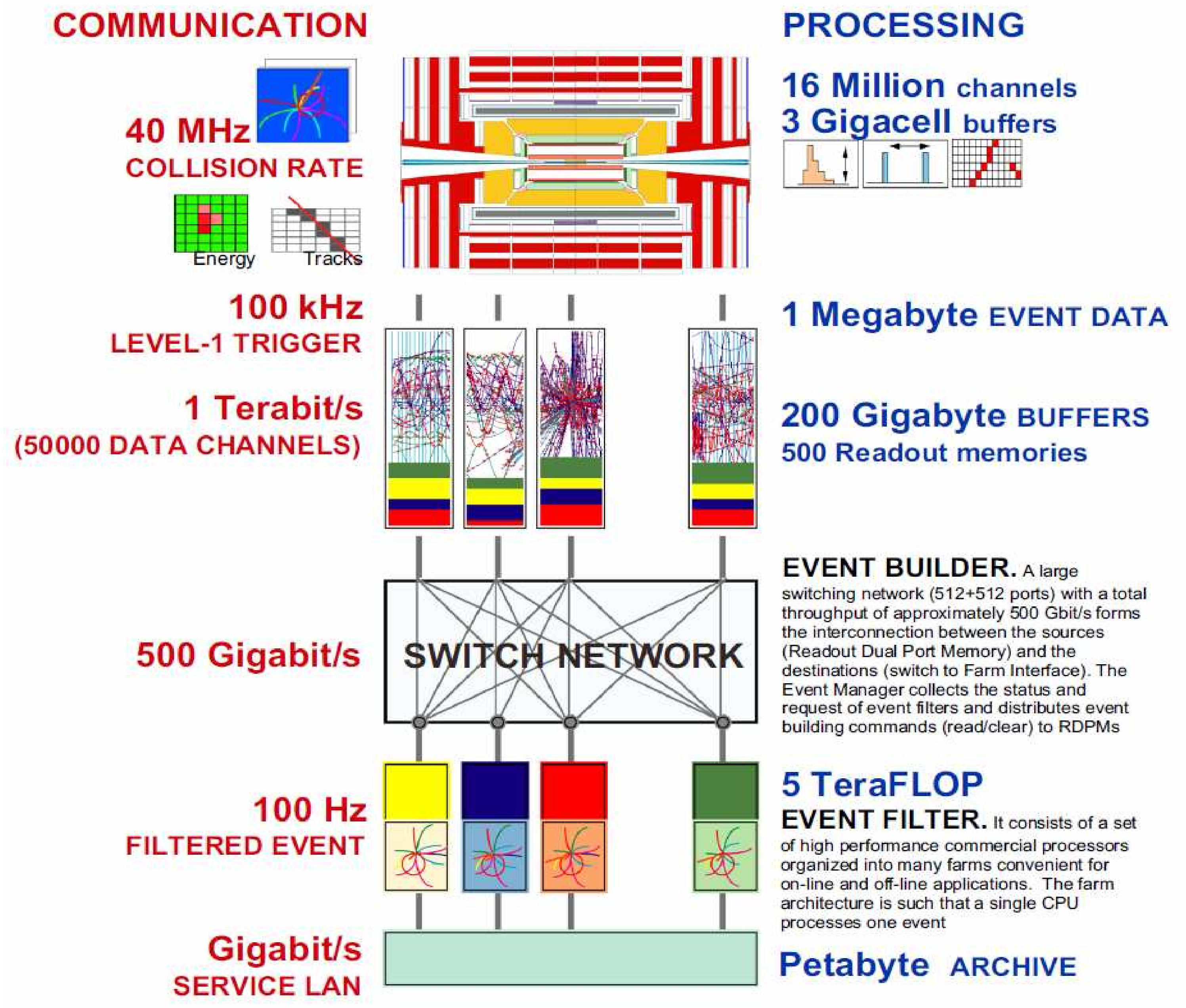
Impuls-Auflösung als Funktion des Impulses und gemessen an verschiedenen Stellen:



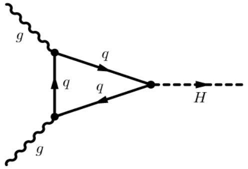




CMS – Data Aquisition



CMS Brochure



Physik - Higgs

Produktion:

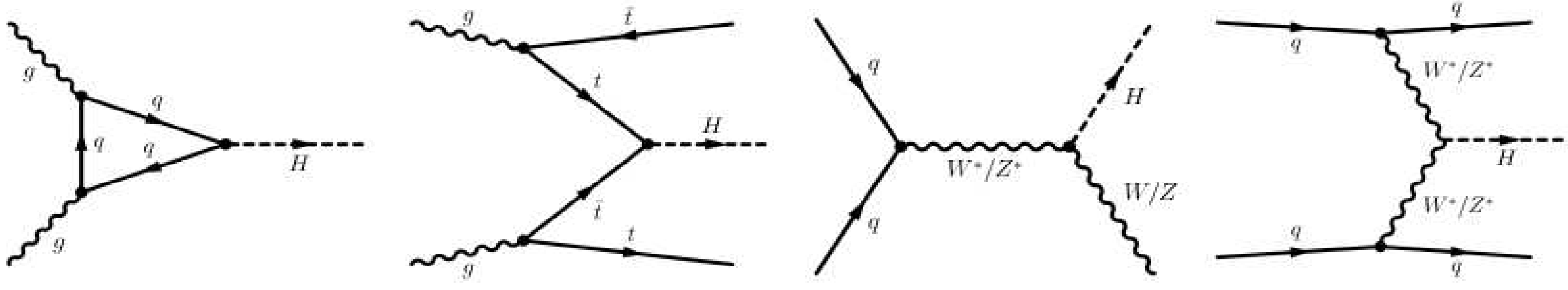
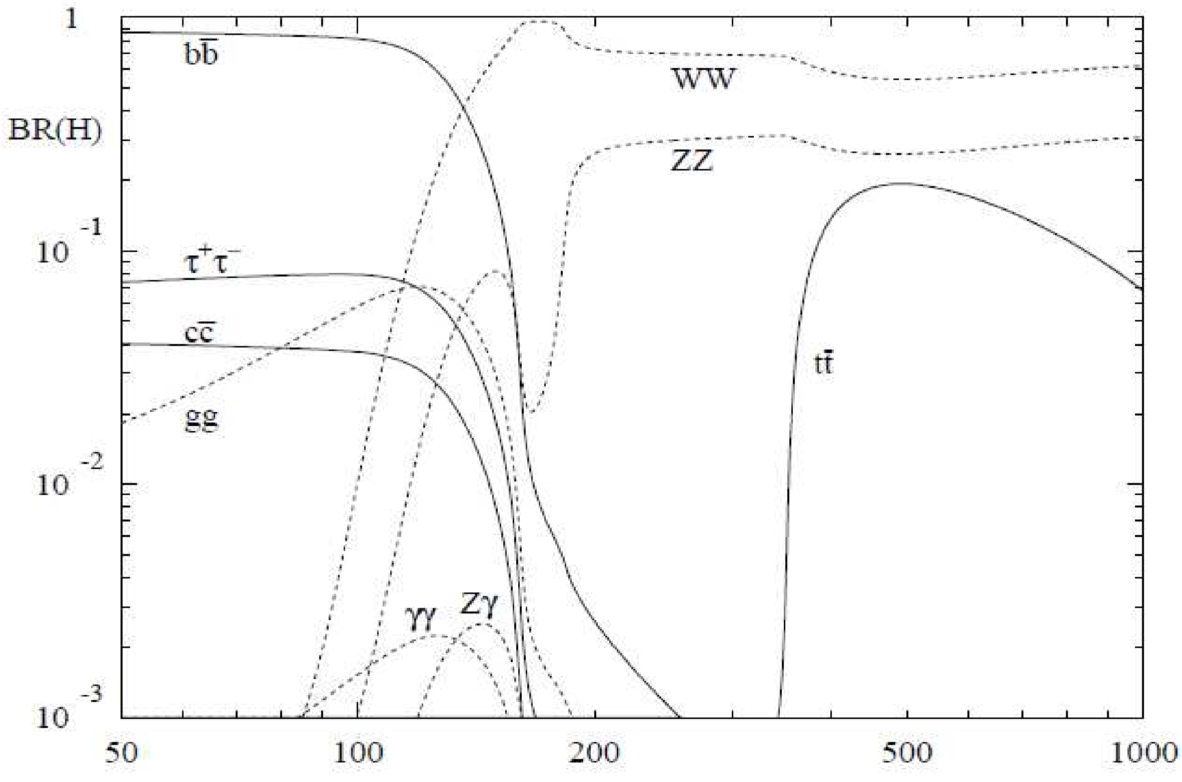
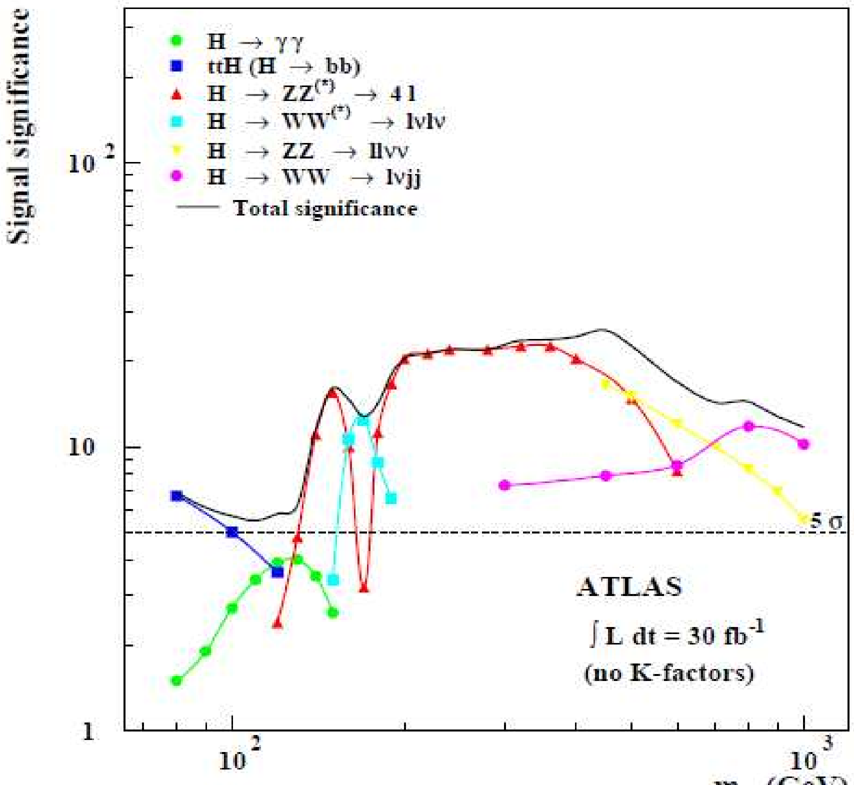
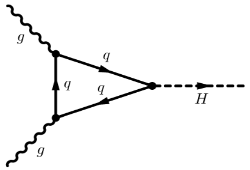


Abb. 1.6: Higgsproduktion durch a) Gluonfusion, b) Fusion aus $t\bar{t}$, c) Bremsstrahlung des W oder Z, d) WW bzw. ZZ-Fusion.

Zerfallskanäle:

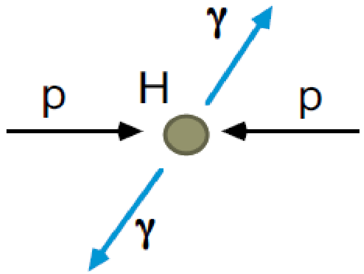


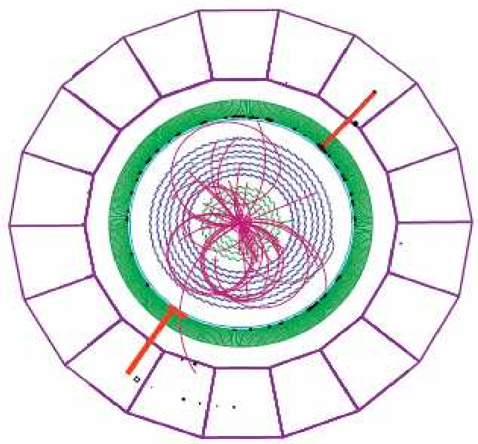




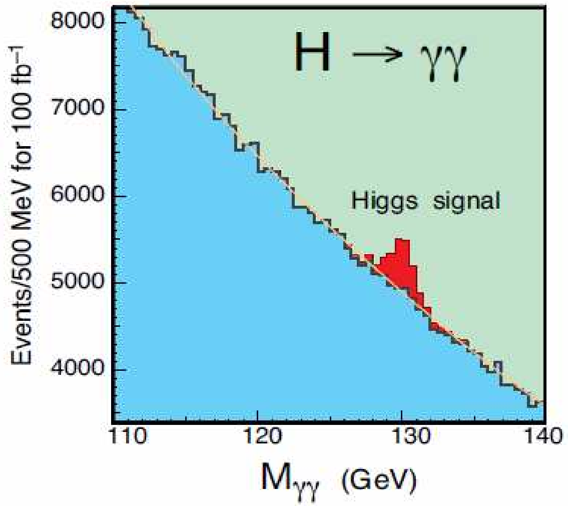
Physik - Higgs

Higgs to 2 photons (MH < 140 GeV)
CMS ECAL optimized

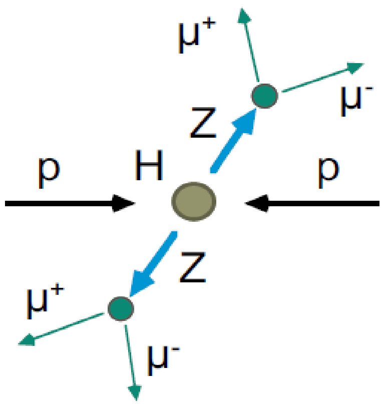


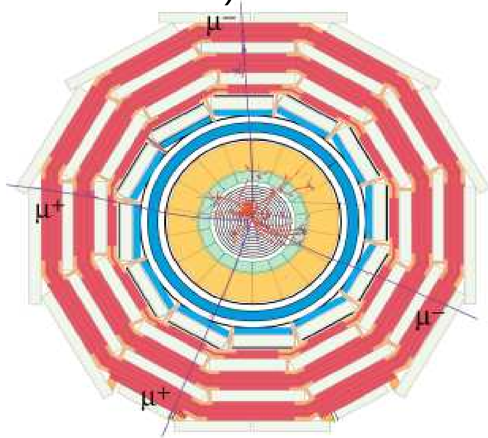


M_{Higgs} = 100 GeV

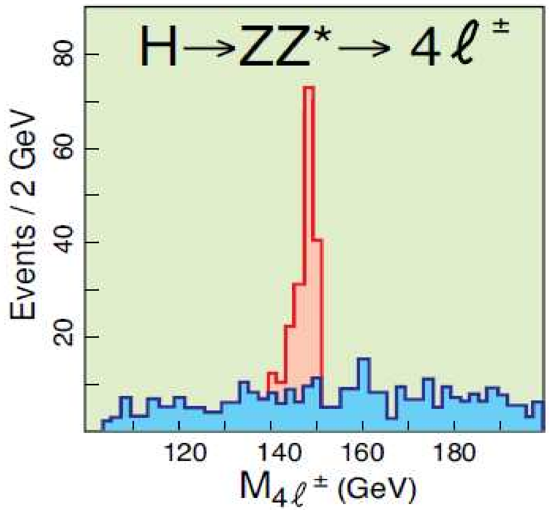


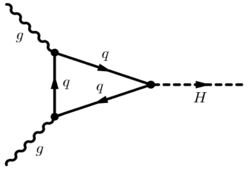
Higgs to 4 leptons (140 < MH< 700 GeV)
Myon spectrometer yields mass res. of ca. 1 GeV
(below 180 GeV decay into ZZ* -> l ν l ν oder selten 4 l)





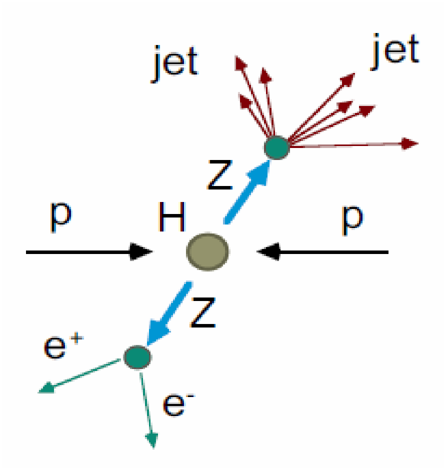
M_{Higgs} = 150 GeV



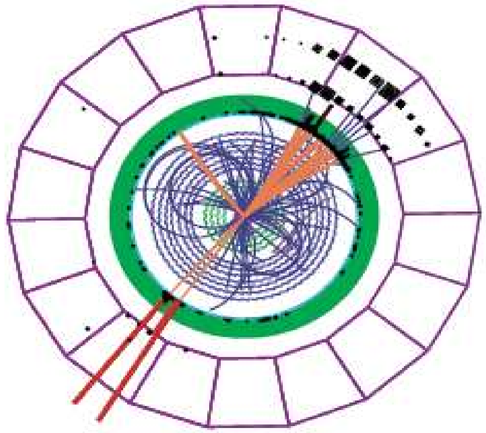


Physik - Higgs

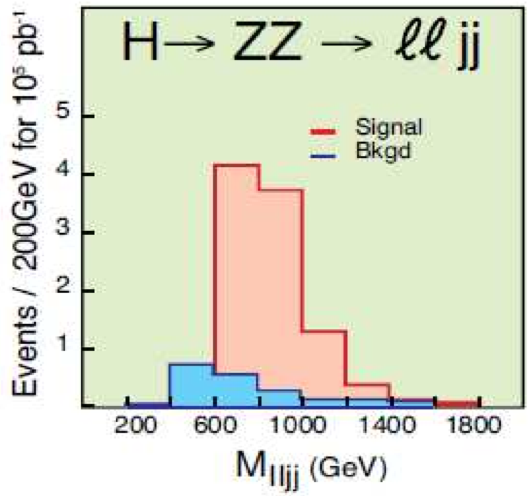
Higgs to 2 leptons+2 jets (MH > 500 GeV up to 1 TeV)!



$H^0 \to ZZ \to ,^+,^- \nu\nu,$
$H^0 \to ZZ \to ,^+,^-$ jj and
$H^0 \to W^+W^- \to ,^\pm \nu$ jj .



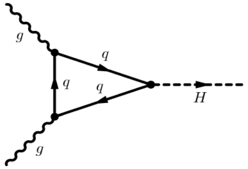
M_{Higgs} = 800 GeV



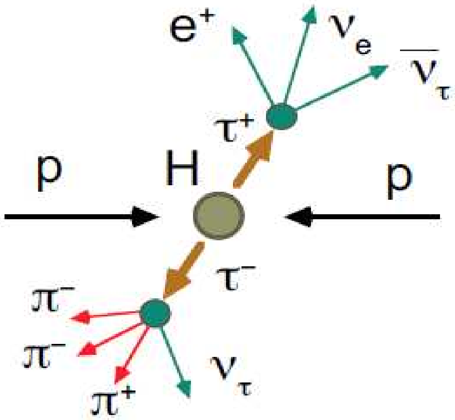
$800\ GeV < M_H < 1\ TeV:$	$H \to Z\ Z$ $H \to W^+W^-$	$l^\pm\ \nu\ 2\ j$ $2\ l^\pm\ 2\ j$ $2\ l^\pm\ 2\ \nu$ $4\ l^\pm$

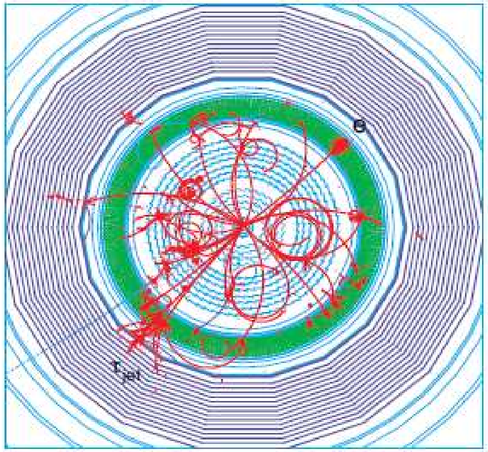
Bis jetzt Schranken: 114 Gev < MH < 1000 (160) Gev
Bereich wird bei ATLAS/CMS abgedeckt, Higgs muss gefunden werden

CMS Brochure

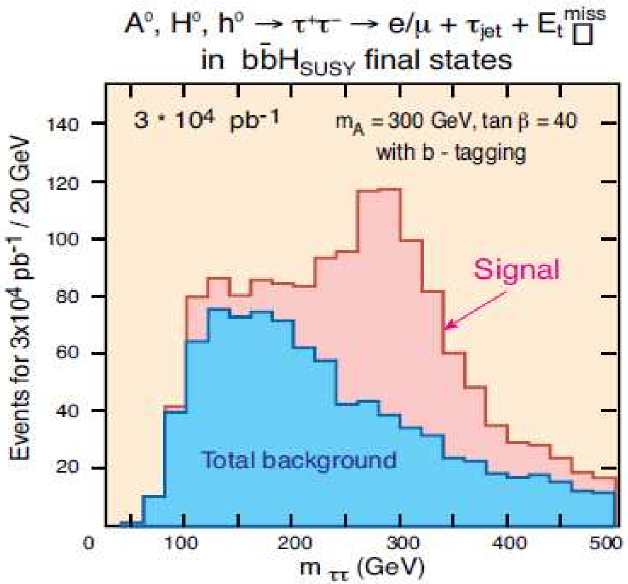


MSSM – SUSY Higgs Bosons





$H \rightarrow \tau\tau \rightarrow e + \tau_{jet}$("3-prong")



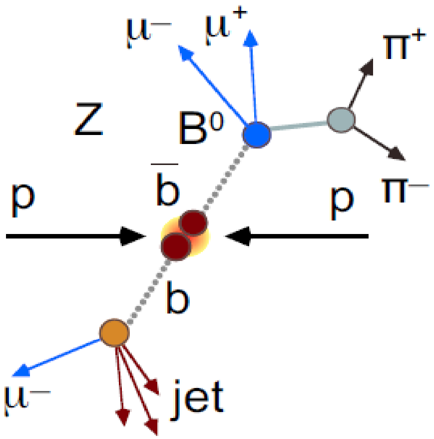
In the MSSM there are 5 Higgs bosons: h^0, H^0, A^0 and $H^{\pm}$ decaying through a variety of decay modes to γ, $e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$ and jets in final states. Below left: an example of a SUSY Higgs decay to $\tau\,\tau$ in CMS. On the right is the reconstructed $\tau\tau$ mass spectrum

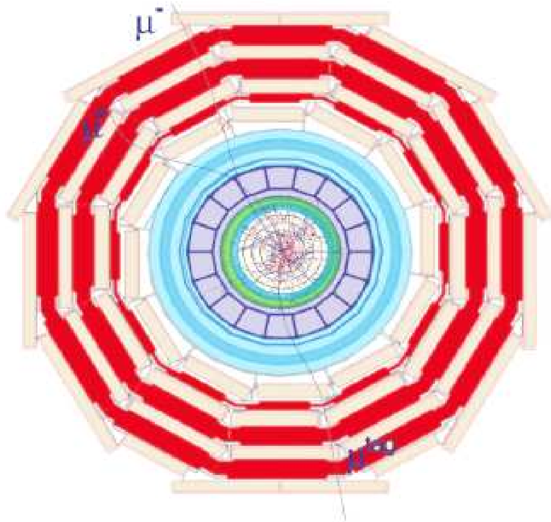
And more Sparticles…

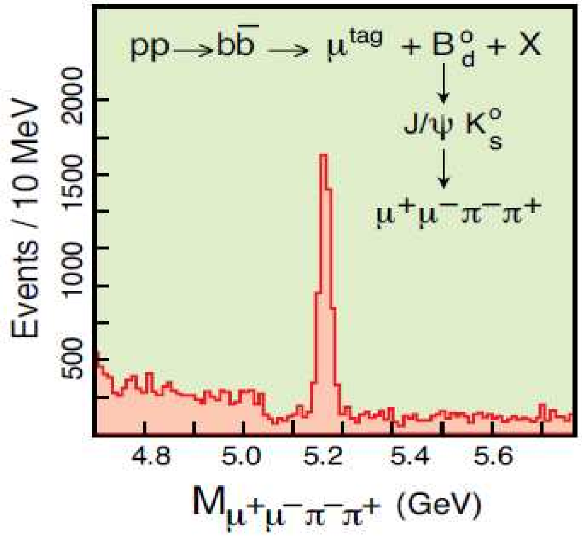
Wenn SUSY auf TeV-Skala müssten schwere supersymmetrische Teilchen gefunden werden

Physik – CP Violation

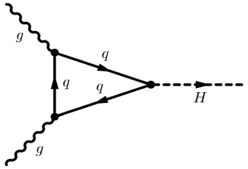
B-physics







CP-Verlestzung nachweisbar durch Asymmetrie zwischen B0 und B̄0-Zerfall
Unabhängig vom K0-Zerfallskanal



Physik - Sonstige

Genauere Messungen zum Standard Modell:

•Eigenschaften schwerer Teilchen wie der W-Bosonen und Top-Quarks

Schwarze Löcher, magnetische Monopole und das Ende der Welt

Higgs - schon gefunden? (April 2008)

Sonstige Bilder: ATLAS und CMS collaboration