The ATLAS TRT

Two in One: Transition Radiation and Tracking

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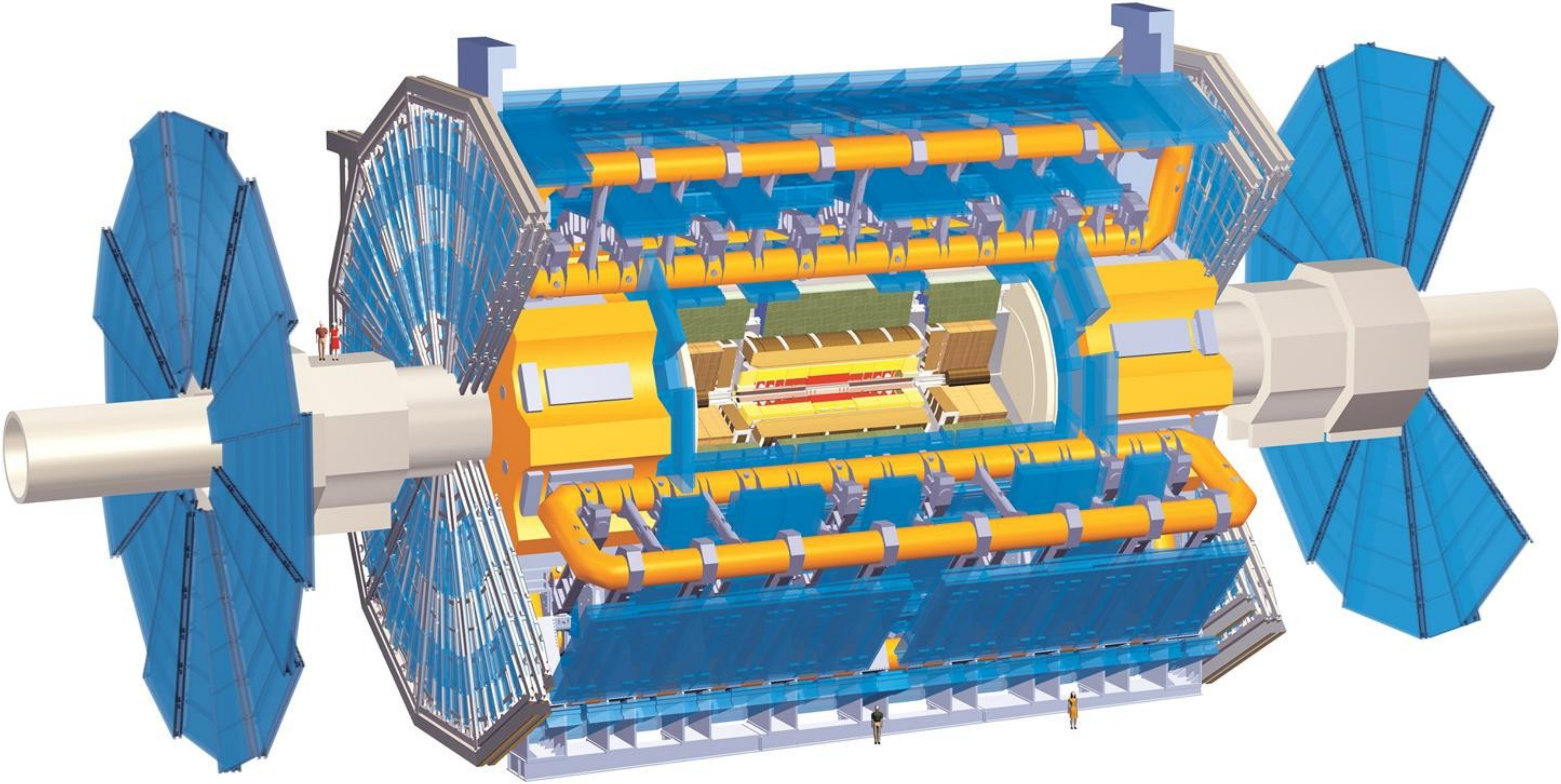
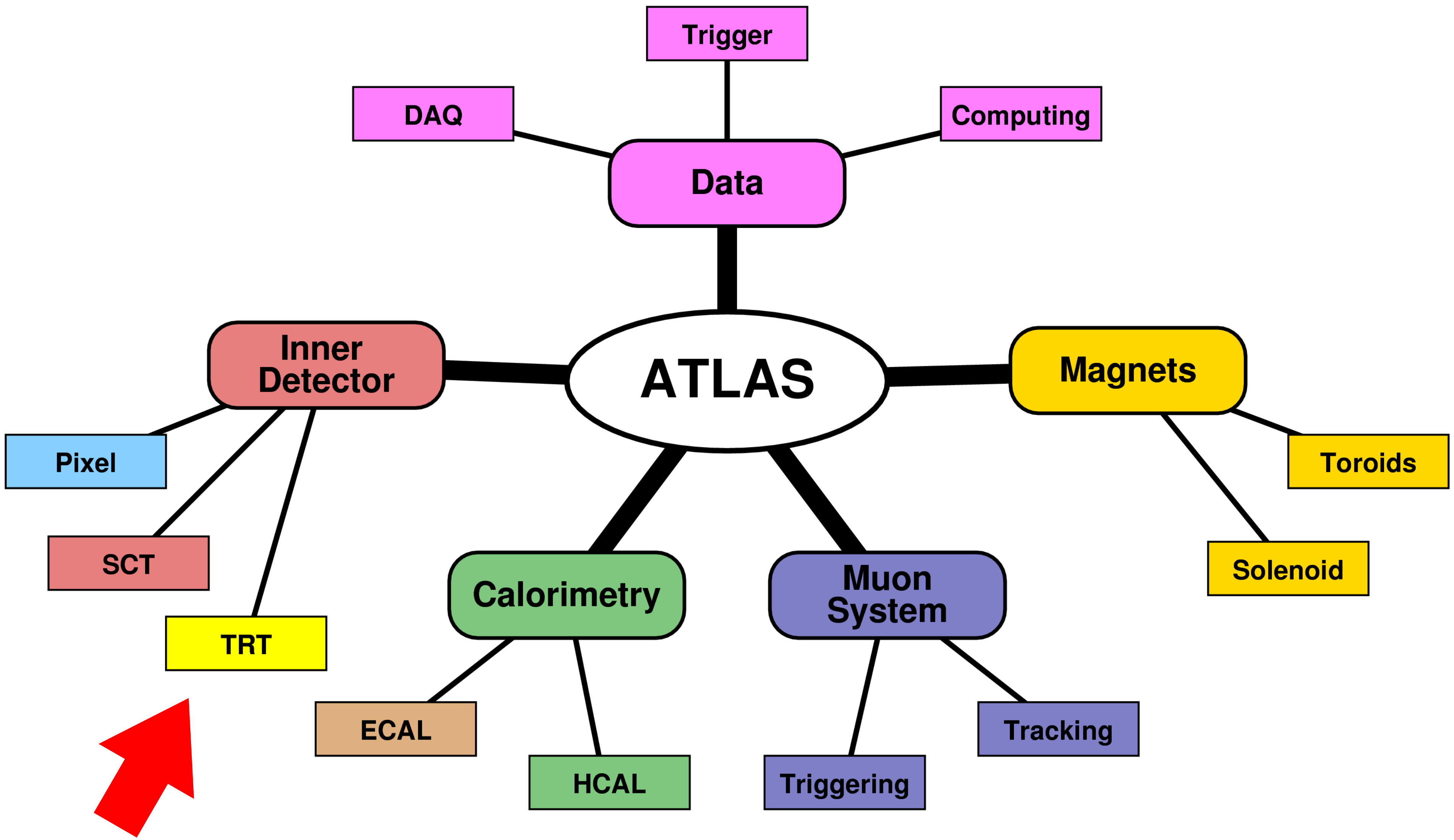
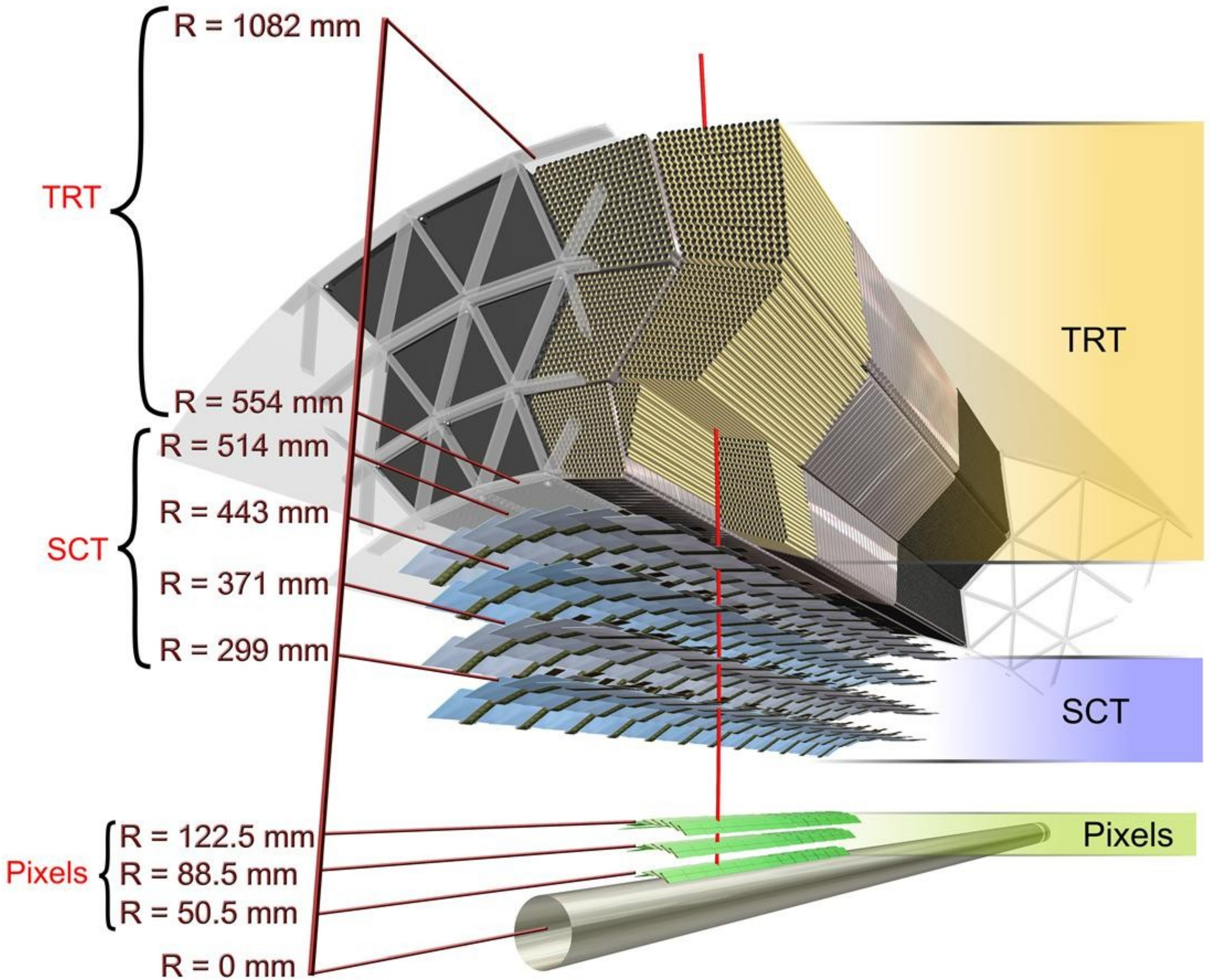
A Toroidal LHC Apparatus



ATLAS Components



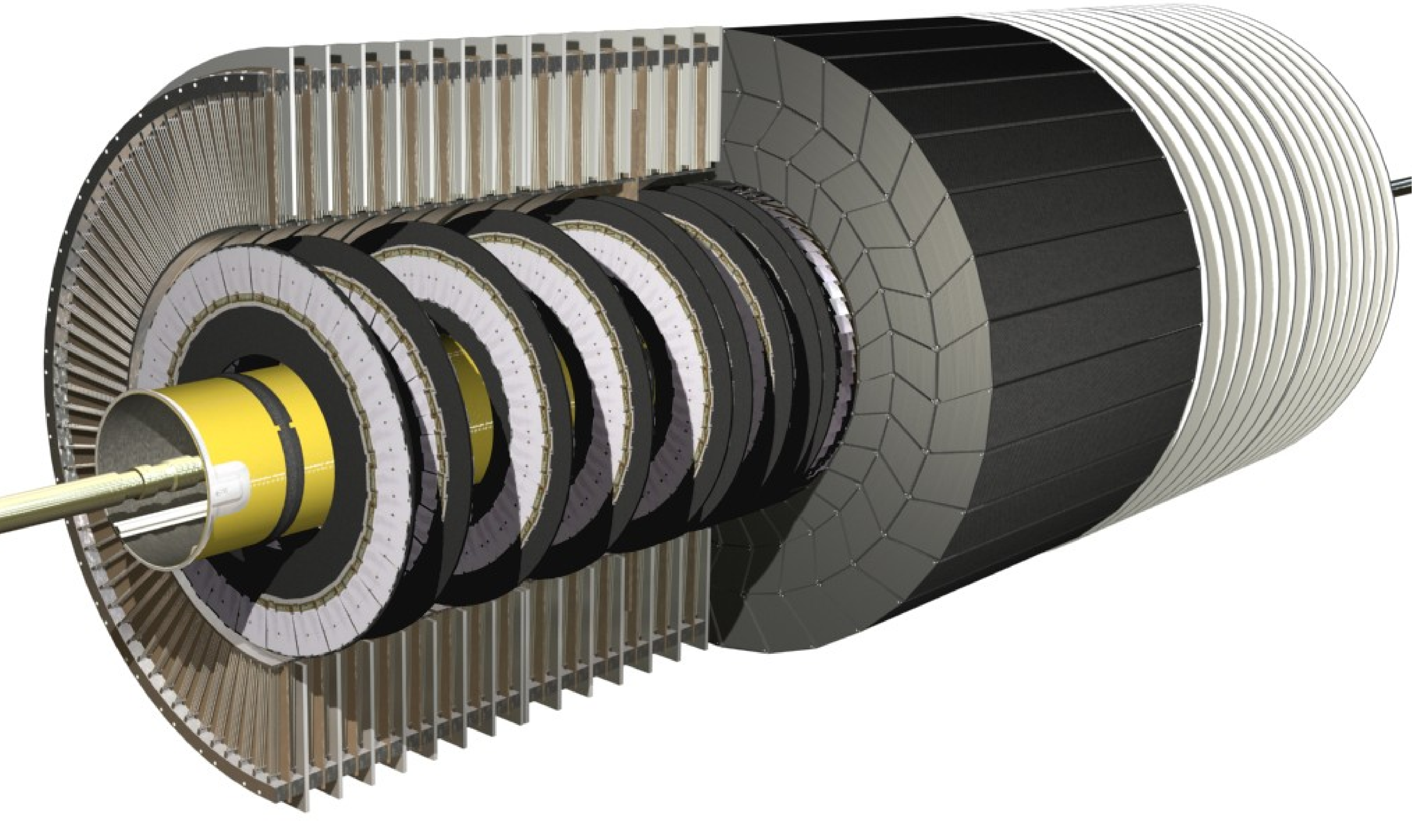
Inner Detector – Layers



Inner Detector – Numbers

Pixel	**SCT**	**TRT**
Si pixels	Si stereo strips	straw tubes
50 μm × 500 μm	80 μm × O(5 cm)	4 mm ∅ × O(1 m)
3 barrel layers	4 barrel layers	3 barrel layers
3 endcap discs	9 endcap discs	20 endcap discs
3 points per track	4 points per track	35 points per track
$8 \cdot 10^7$ pixels	4000 modules	300 000 straws
1.7 m^2 area	61 m^2 area	15 m^3 volume

Inner Detector – Total



Transition Radiation Tracker

Tasks of the Inner Detector

- measure paths (and momenta) of charged particles
- contribute to particle identification

The TRT is a dual-purpose detector

- quasi-continuous tracking with straw tubes
- particle ID with the help of transition radiation

Outermost part of the Inner Detector

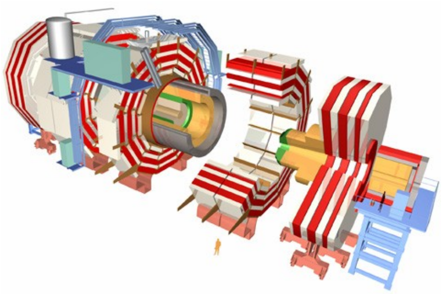
- located between Si strip detector and ECAL
- rather large: 0.7 m $< r <$ 1.1 m, $|z| <$ 3.4 m, $m \approx$ 1.5 tons

The TRT can be used as an L1 trigger (for cosmics)

Other LHC Detectors

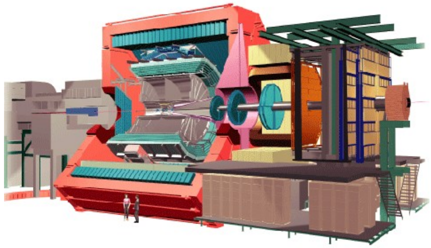
CMS

- has no counterpart to the TRT
- Si pixels → Si strips → ECAL → HCAL → muons



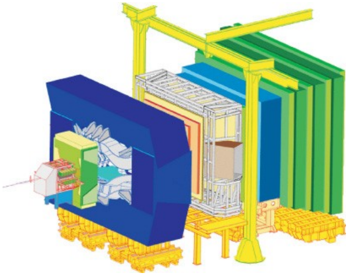
ALICE

- TRT for pion rejection and fast triggering
- Si → TPC → TRT → ToF → MRPCs → ECAL → muons



LHCb

- straw tube device as Outer Tracker
- Si strips → RICH → trackers → calo → muons



TRT Straws

Composite material tube

- carbon, polyimide, aluminium, polyurethane
- 60 μm thin wall, reinforced by 4 carbon fibre sticks
- on negative high voltage of approx. 1400 V

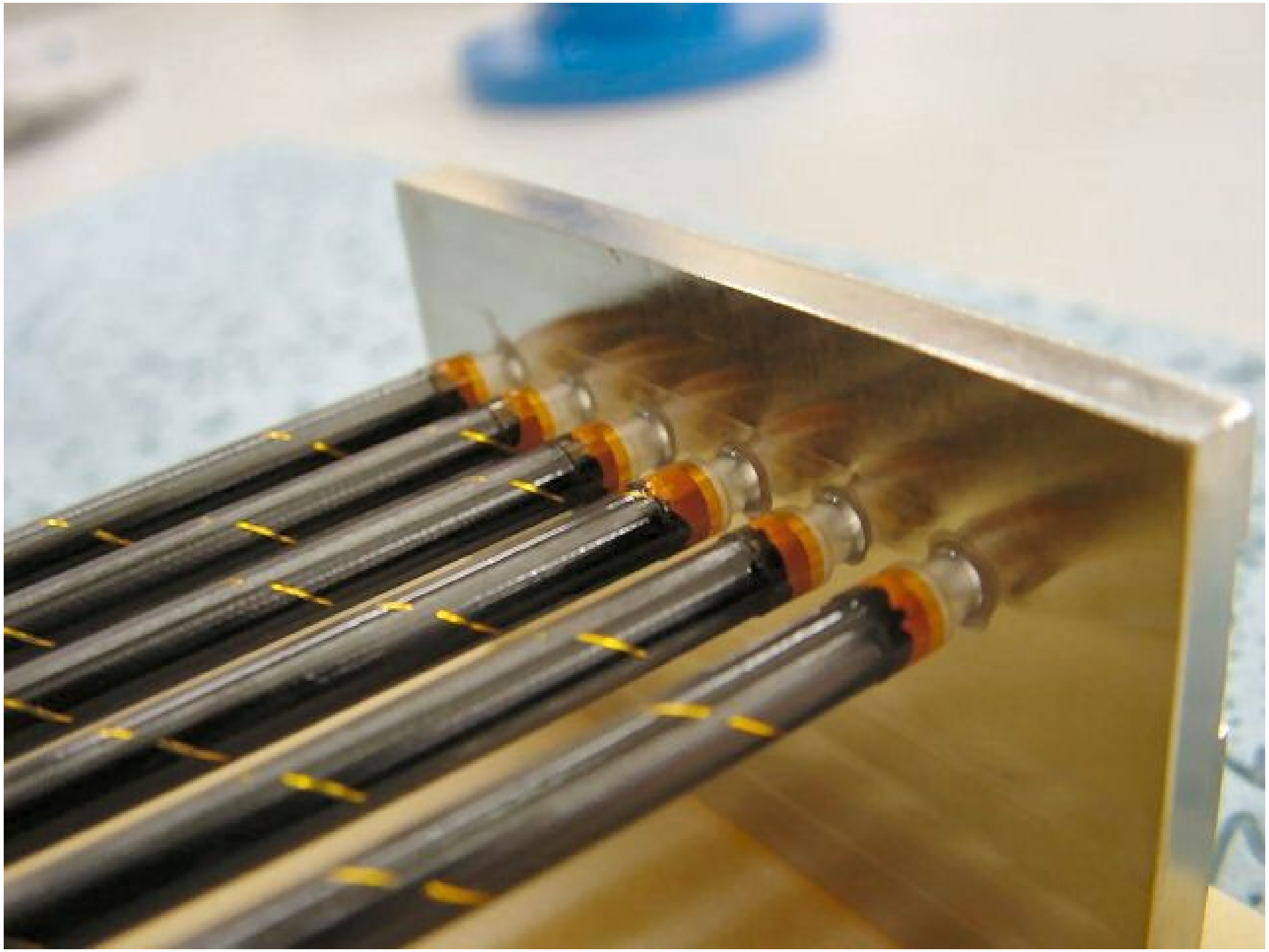
Amplification wire inside the tube

- 30 μm ∅ W, 0.5 μm Au coating, glass joints in the middle
- must be circular, placed centrally
- on ground, connected to electronics

Basically a thin, long proportional counter

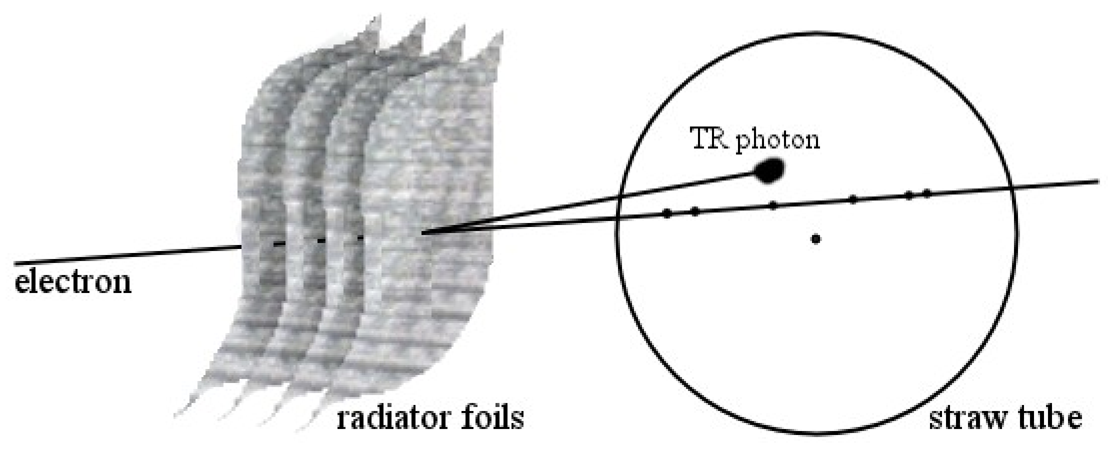
- gas gain around 30 000, continuously monitored

TRT Straws – Test Setup



Transition Radiation

- **Relativistic** particle travels across **material boundaries**
- **Photons** are radiated, strongly **peaked forward** (along track)
- Probability depends on $m \cdot \gamma$, highest for **electrons**
- Energy depends on difference of plasma frequencies, typically around **10 … 30 keV** (soft X-rays)
- Predicted by Ginsburg and Frank in 1945
- Experimental proof of principle in the 1970s
- Nowadays used in several particle physics detectors: **ZEUS**, **ATLAS**, ALICE, PHENIX, AMS, …



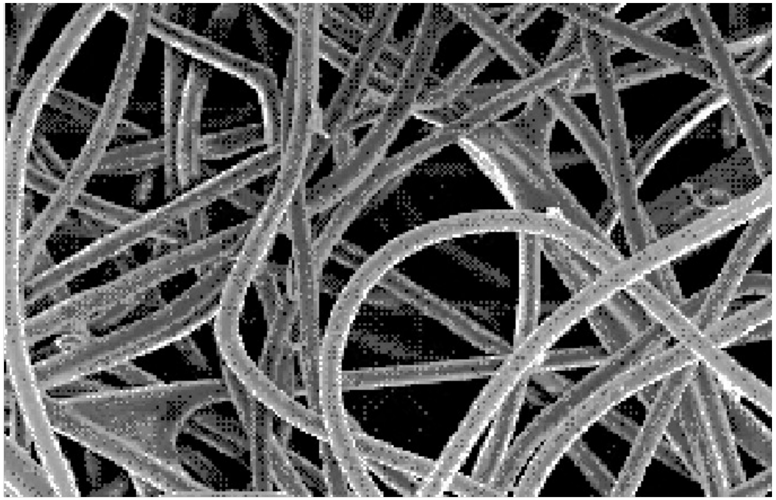
TRT Radiators

Charged particles must traverse (many) boundaries

- surrounding gas: CO_2
- radiators: polypropene, polyethene

Barrel region:

- irregularly distributed PP/PE fibres



Endcaps:

- a dozen PP foils of 15 µm
  in front of each straw layer
- separated by PP spacer mesh
  of 200 µm thickness

Straw Tube Gas – Good

Xe (70%)

- transition radiation X-ray absorption (high *Z*)

CO_2 (27%)

- good drift properties, low longitudinal diffusion
- UV absorption, “Self-Quenched Streamer” mode

O_2 (3%)

- stabilises operation above 2% (O_3 captures UV)
- does not affect performance below 3.5 … 4%
- signal strength degrades only by O(10%)
- remember: drift distance is less than 2 mm

Straw Tube Gas – Bad

No hydrocarbons

- ageing effects in high-radiation environment
- polymer deposits on the amplification wires

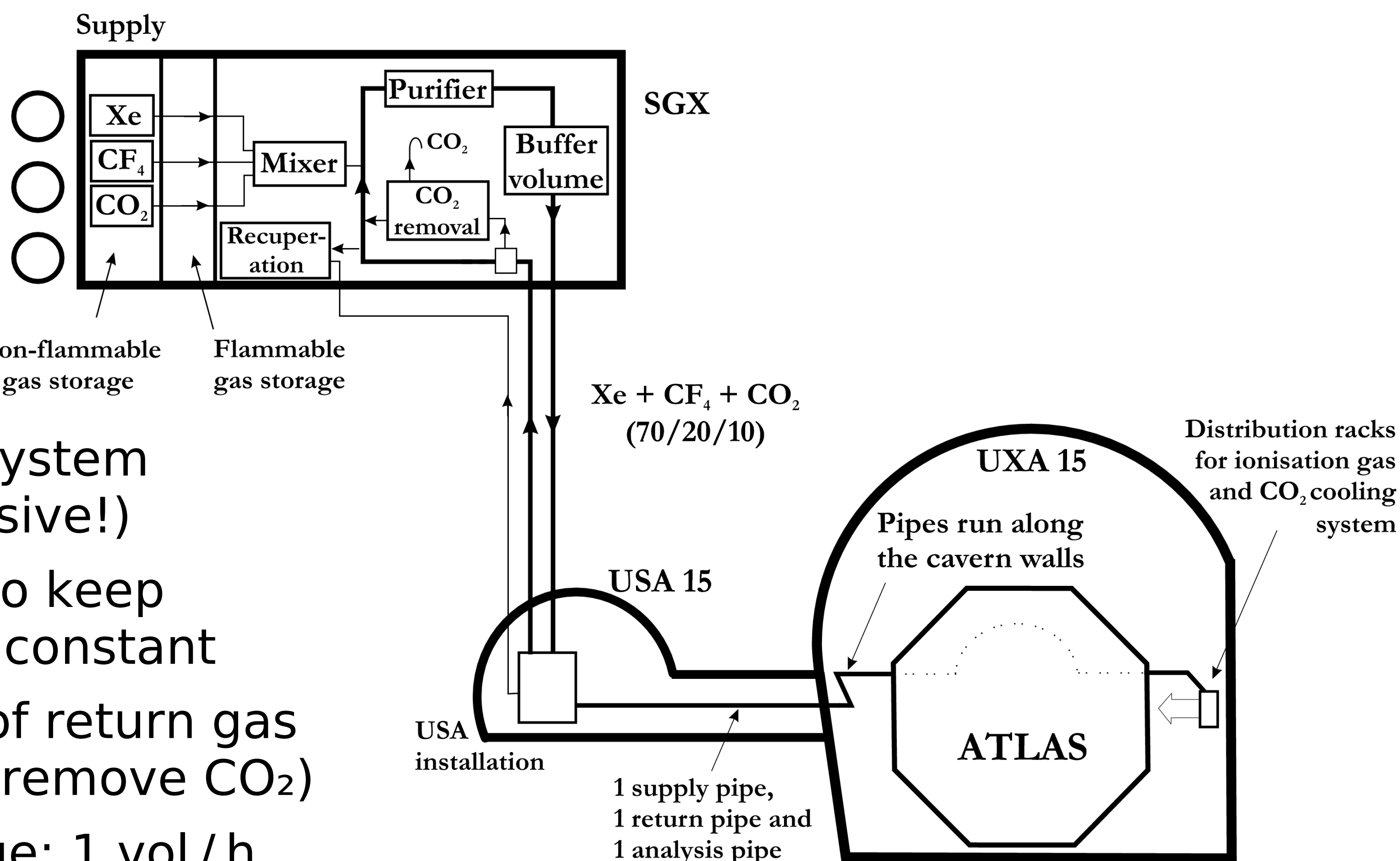
No flammable gases

- safety concerns, especially in underground areas
- strict regulations for all large experiments

No CF_4

- initially the preferred admixture for Xe / CO_2, but:
- F radicals and HF attack glass joints and Au coating
- use it for occasional “cleaning runs” against deposits?

Gas System



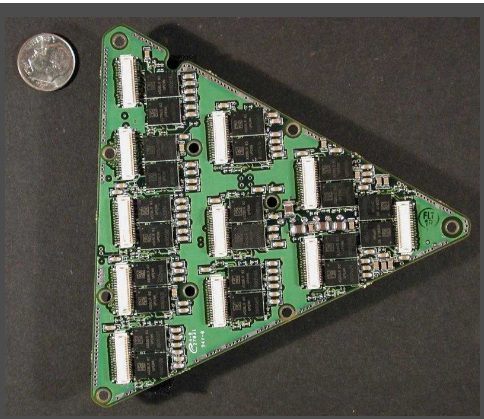
- Closed gas system (Xe is expensive!)
- Gas mixing to keep abundances constant
- Purification of return gas (convert O_3, remove CO_2)
- Gas exchange: 1 vol / h
- 2.5 m³ of circulating gas
- Losses of only 0.15 ℓ / h

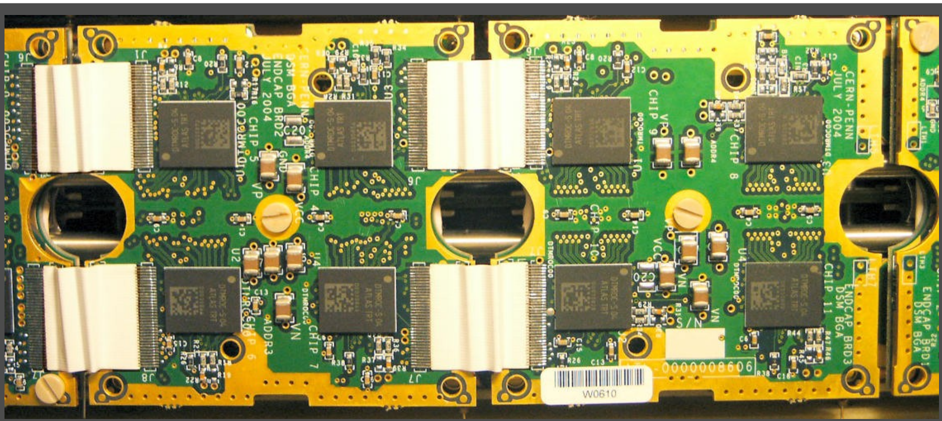
TRT Electronics

Custom-made electronics: ASDBLR + DTMROC

- amplification, shaping
- low threshold + high threshold
- time binning (3.125 ns sampling)
- pipelining, readout

Ternary output: nothing – low – high

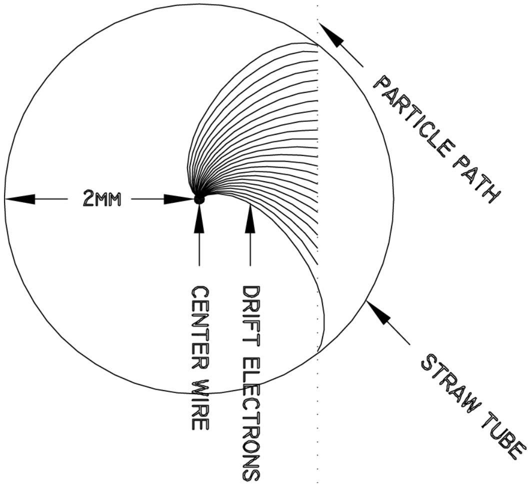


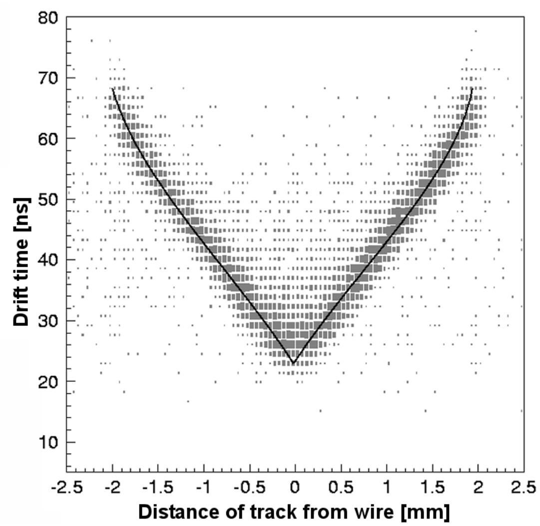


Tracking with the TRT

Drift time measurement

- reconstruct “drift circles”, i. e. shortest distance from track to wire
- provides better spatial resolution than just the straw position
- $R(t)$ relation initially determined from test beam measurements
- regularly adjusted with calibration analyses using known tracks





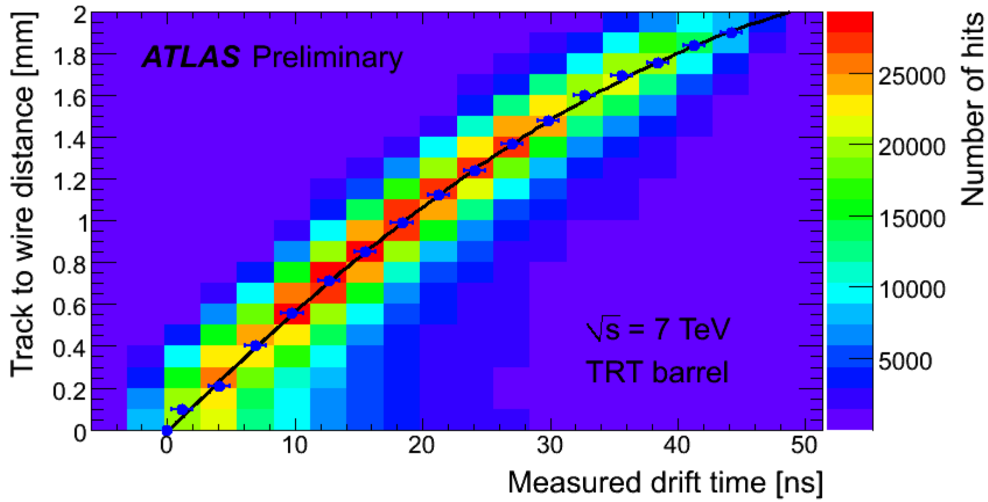
Continuous tracking

- average of 35 points in $r\varphi$-plane for $|\eta| < 2$ and $p_T > 0.5$ GeV

Tracking – Recent Results

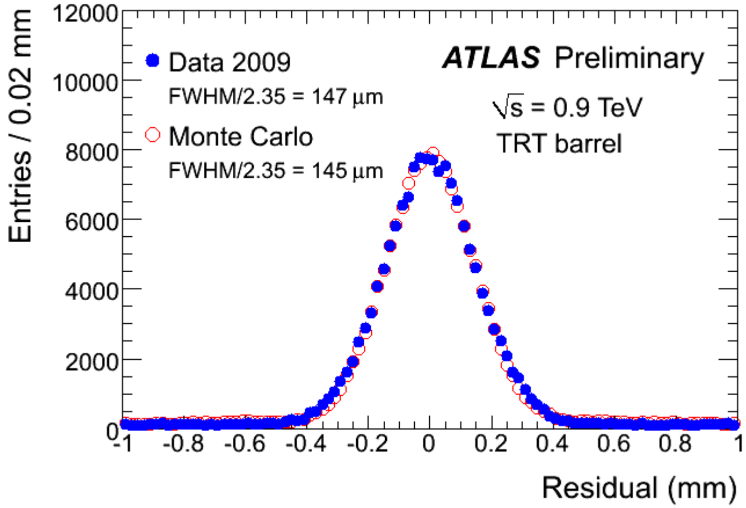
R(*t*) relation

- raw drift time corrected for signal delays
- distribution fitted with third-order polynomial
- slightly different for endcaps due to *B* field orientation



Spatial residual

- here: 900 GeV, p_T > 1 GeV
- has become even better in the meantime (mostly due to improved alignment)



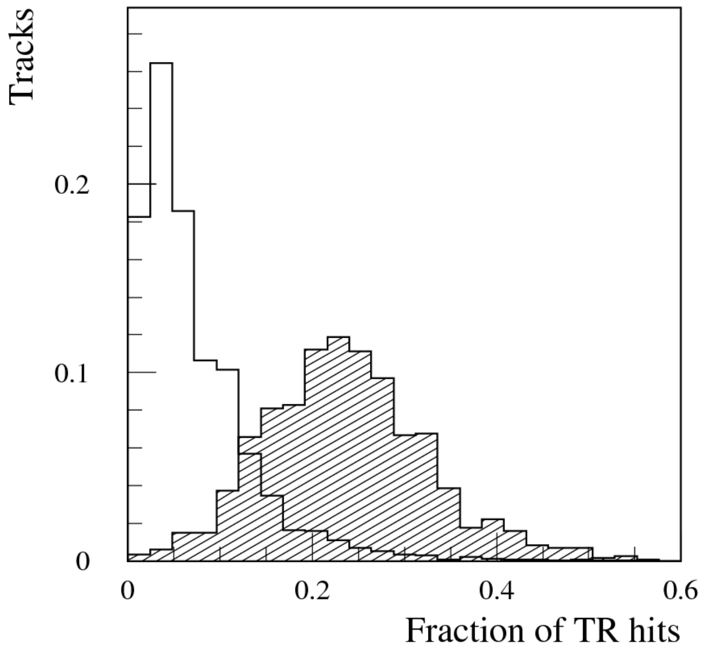
Particle ID with the TRT

Electron/hadron discrimination for $p = 1 \ldots 100$ GeV

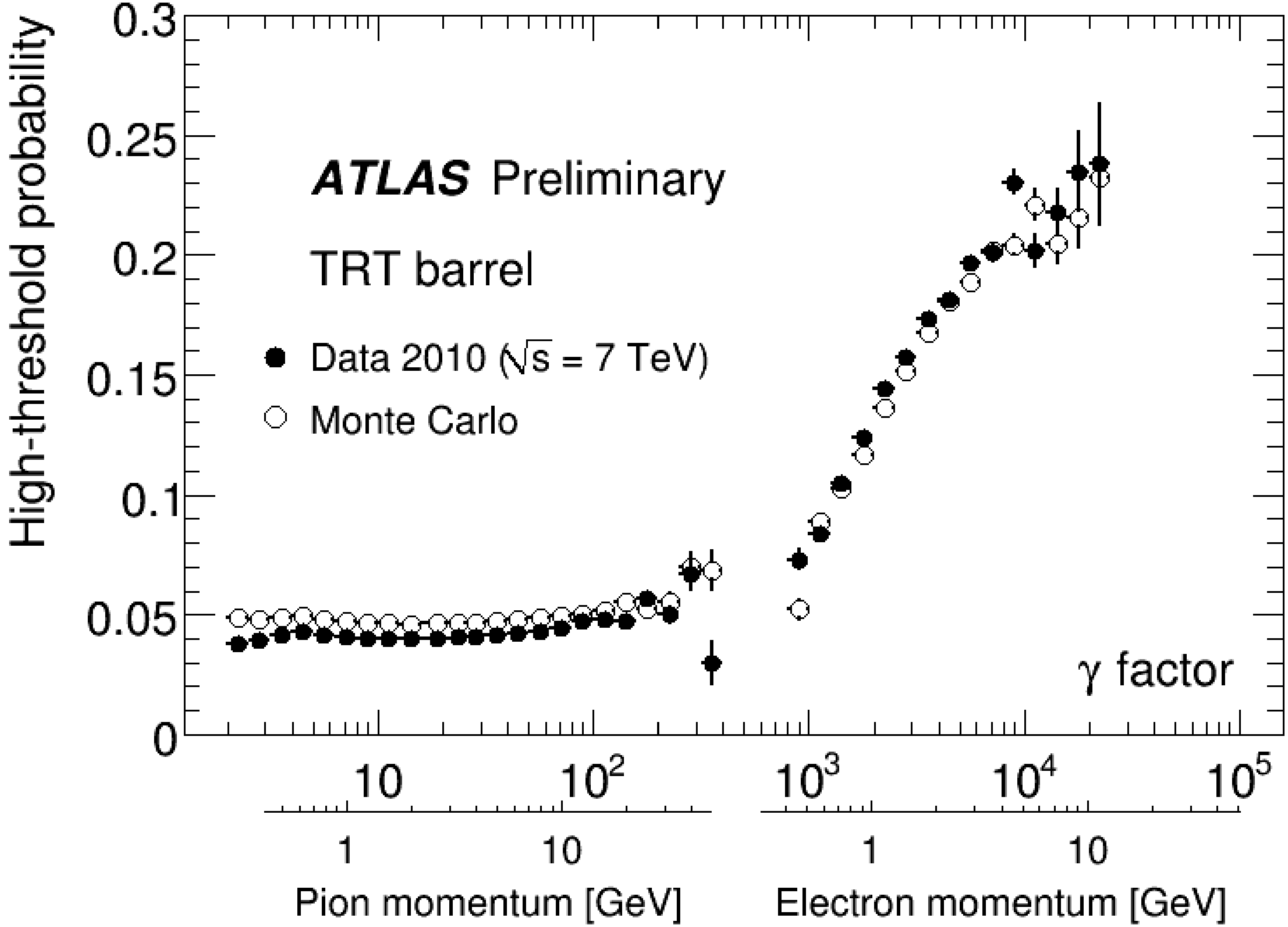
- electrons create transition radiation, other particles don't
- pion rejection of 100 for electron efficiency of 90%
- Čerenkov radiation or dE / dx wouldn't work so well here!

Photons are detected

- Xe works as X-ray absorber
- electrons give significantly more "high-energy" hits (dE / dx plus photon energy)
- but: Landau tail of dE / dx distribution smears things out → no perfect separation



Particle ID – Recent Results



Strengths and Weaknesses

Pros:

- large tracking device
- continuous tracking
- particle ID capabilities
- radiation hardness
- relatively low cost

Actually quite similar to a TPC!

Cons:

- occupancy can become a problem at high luminosities
- limited spatial resolution in the $r\varphi$ plane
- almost no spatial information along z axis

Remember: the TRT is only one piece of a larger system

Physics Examples

Find high-p_T electrons (e / jet ≈ 10^{-5})

- with E/p calculation: S / B ≈ 0.3
- using transition radiation: S / B ≈ 6

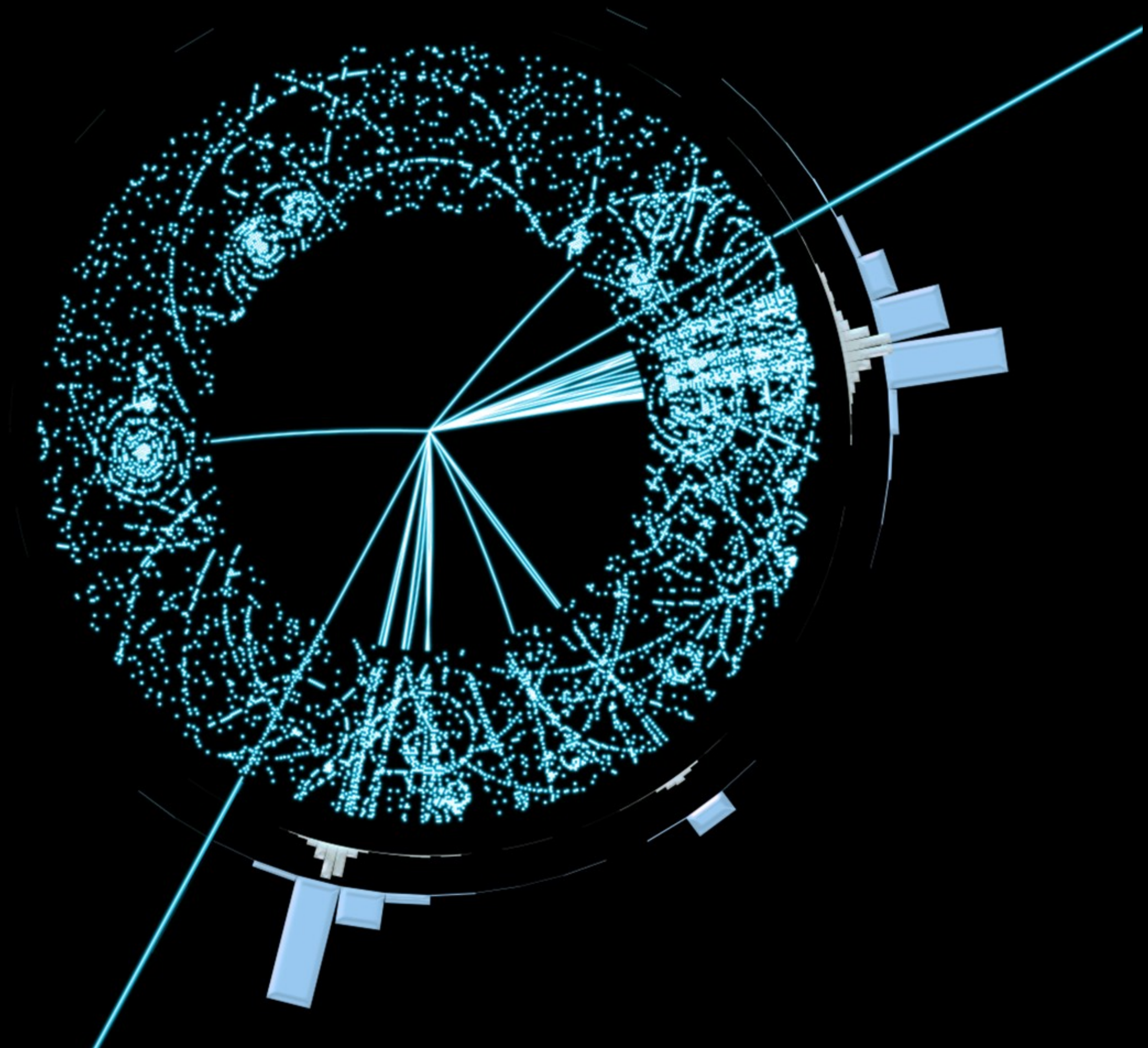
Remove high-p_T electrons as background

- $Z \to e^+e^-$ + bremsstrahlung is background for $H \to \gamma\gamma$
- using transition radiation: S / B ≈ 10

Robust tracking and pattern recognition

- precise (Pixel, SCT) plus continuous (TRT) tracking: good!
- TRT improves p_T resolution by a factor of 2 (formally)

Simulated SUSY Event



Summary

The TRT is a part of the ATLAS detector

- outermost piece of the Inner Detector
- straw-tube tracker, 2 m diameter, 6.5 m long

The TRT can achieve two goals at once

- tracking with O(35) points and O(150 μm) resolution
- particle ID, particularly electron / hadron discrimination

The TRT has fulfilled all expectations so far

- good performance with cosmics, protons and heavy ions
- smooth operation despite the complex technical details

The TRT is ready for the 2011 data taking – now!

References

Pictures taken from:

- `atlas.ch` (slides 2, 4, 6, 12, 24)
- ATLAS Public Results (slides 19, 21)
- ATLAS Technical Design Report (slide 20)
- CERN-THESIS-2006-025 (slides 9, 11, 17, 18)