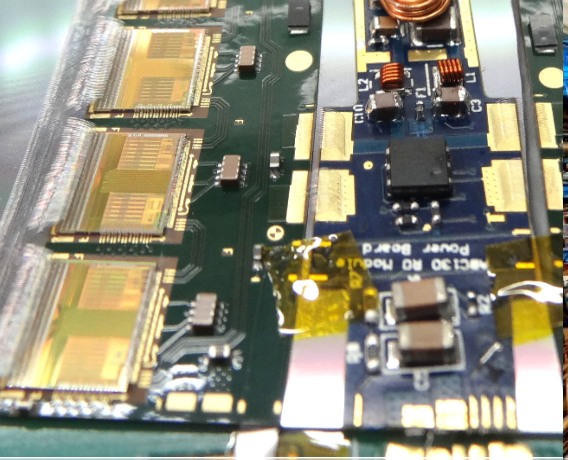
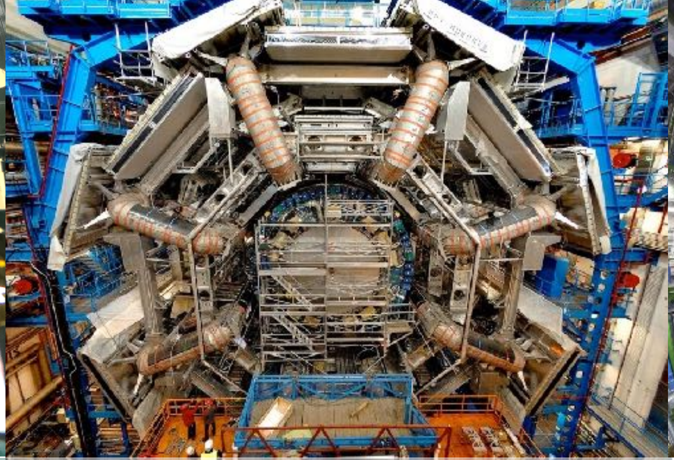
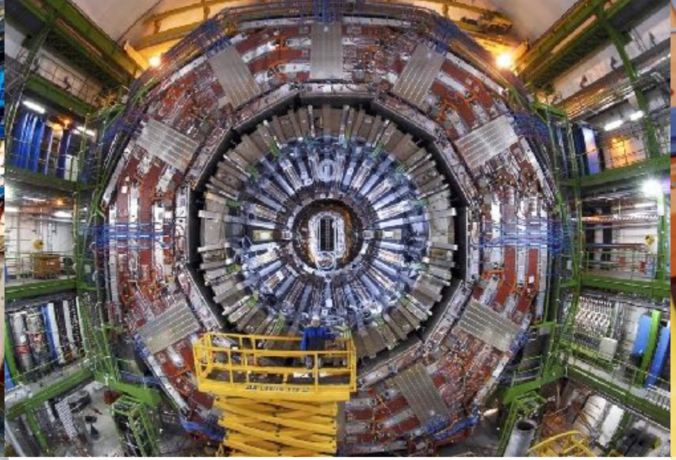





Detectors: Great Concepts and Glorious Failures

Or: Lessons learned

Ingrid-Maria Gregor
DESY/Universität Bonn

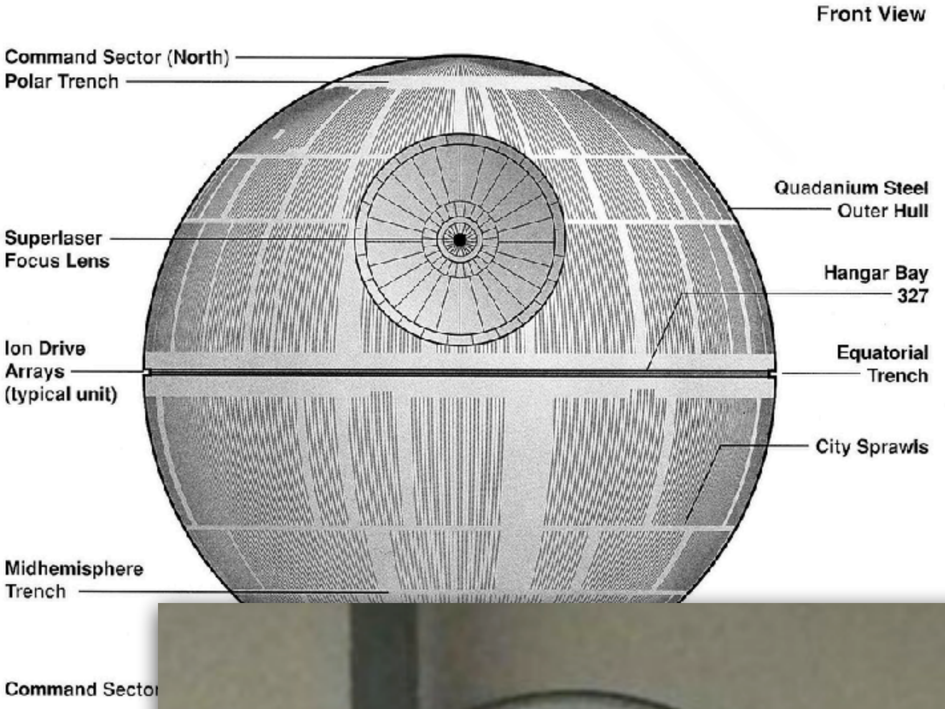
EDIT School 2020

Disclaimer

- Designing a particle physics detector is a very complex business
- Many very nice examples exist
- Also some examples of failures

- Idea of this talk: some stuff you don't find in textbooks
- Collection of failures might give the impression of overall incompetence
  - Overwhelming majority of detectors run like a chime
  - Unbelievable effort to get large accelerators and experiments in a global effort to run so nicely
  - Even sociologists are interested in how we do this …

Some bias in the selection of detectors and examples based on my experience, my friends and other factors …



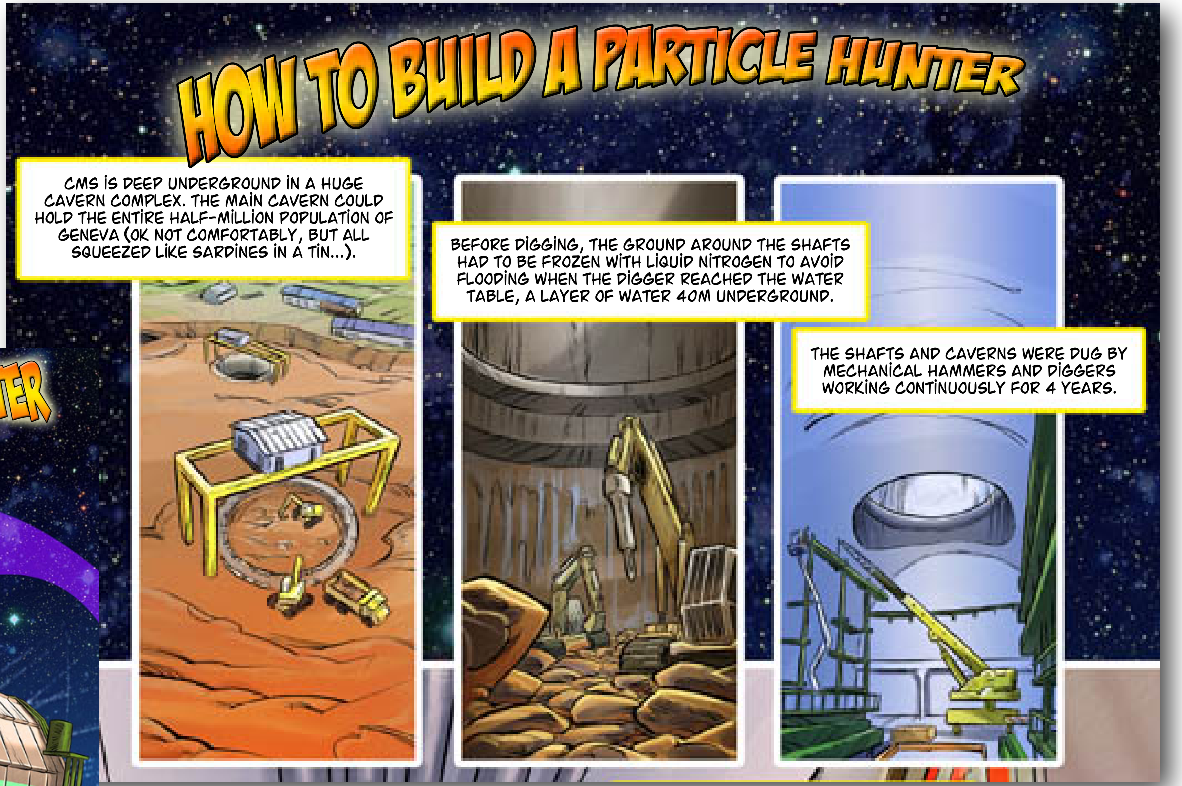
Great Concepts ....

Some examples

Current HEP Detector R&D

- Detector development is always an important topic in high energy physics
- Technical demands are constantly increasing due to new challenges in particle physics
  - higher occupancy, smaller feature size, larger trigger rates, radiation level, …..

- New HEP detector projects are planned for
  - Detector upgrades during different LHC phases up to HL-LHC (ATLAS, CMS, ALICE, LHCb)
  - Detector R&D for a future linear collider (ILC and CLIC)
  - Belle II (construction phase ongoing)
  - PANDA and CBM @Fair
  - …..



source: “CMS Particle Hunter”

How to do a particle Physics Experiment ?

- Ingredients needed:
  - particle source
  - accelerator and aiming device
  - detector
  - trigger
  - recording devices
- Recipe:
  - get particles (e.g. protons, antiprotons, electrons, …)
  - accelerate them
  - collide them
  - observe and record the events
  - analyse and interpret the data

typical HERA collaboration: ~400 people
LHC collaborations: >2000 people

Pic: DESY

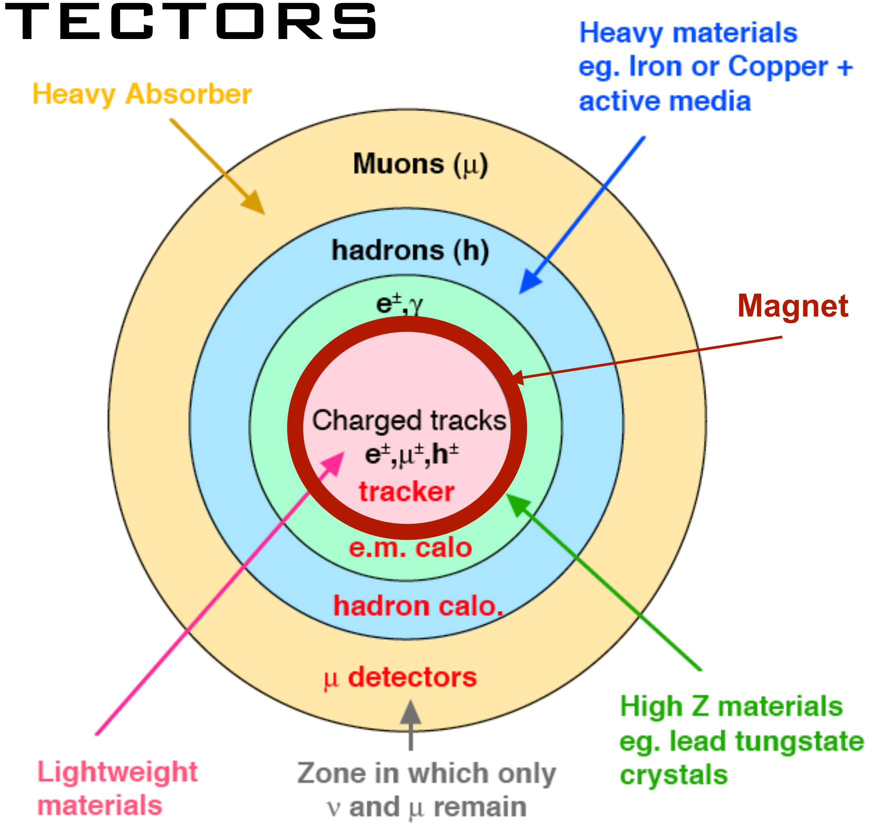
  - many people to:
    - design, build, test, operate accelerate
    - design, build, test, calibrate, operate, understand the detector
    - analyse data
- lots of money to pay all this ….

Conceptual Design of HEP Detectors

- Need detailed understanding of
  - processes you want to measure ("physics case")
  - signatures, particle energies and rates to be expected
  - background conditions

- Decide on magnetic field
  - only around tracker?
  - extending further ?

- Calorimeter choice
  - define geometry (nuclear reaction length, X0)
  - type of calorimeter (can be mixed)
  - choice of material and granularity depends also on funds



at a collider experiment

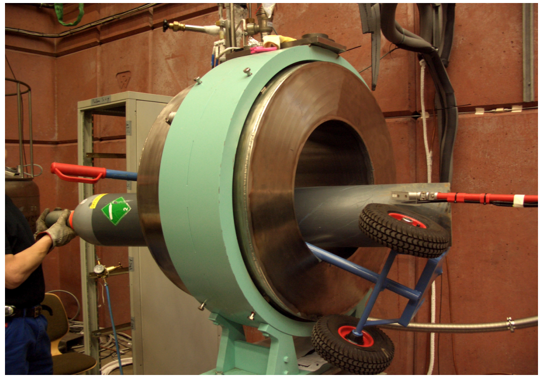
- Tracker
  - technology choice (gas and/or Si?)
  - number of layers, coverage, …
  - pitch, thickness, ….
  - also here money plays a huge role

Detailed Monte Carlo Simulations need to guide the design process all the time !!

A magnet for a LHC experiment

- **Wish list**
  - big: long lever arm for tracking
  - high magnetic field
  - low material budget or outside detector (radiation length, absorption)
  - serve as mechanical support
  - reliable operation
  - cheap
  - ….

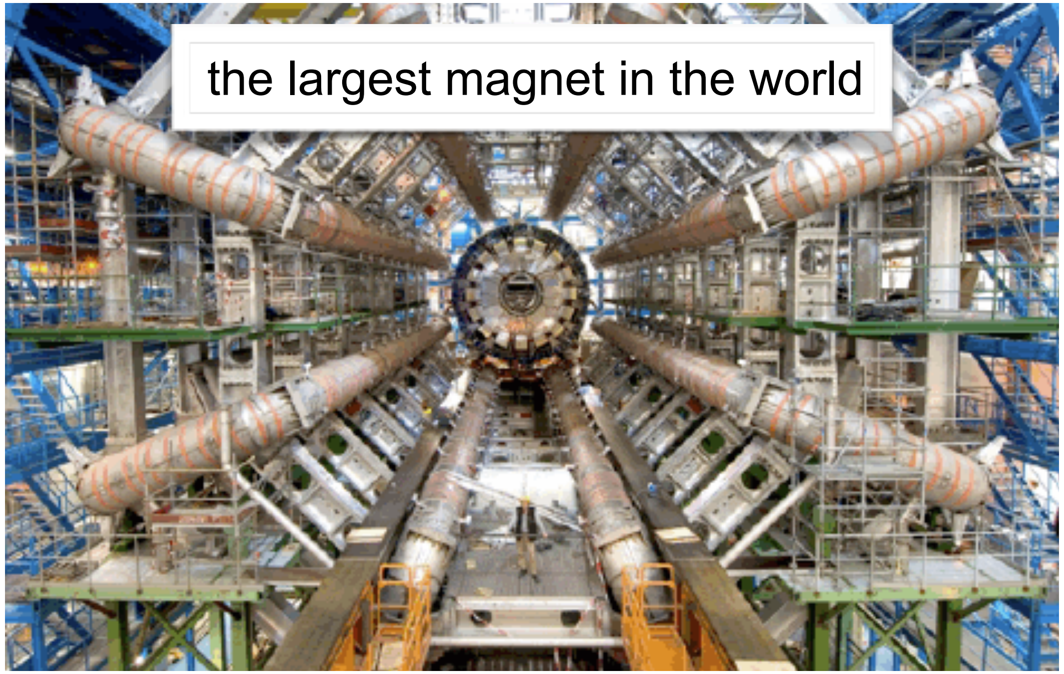
$\Delta p_T/p_T \approx 1/BL^2$

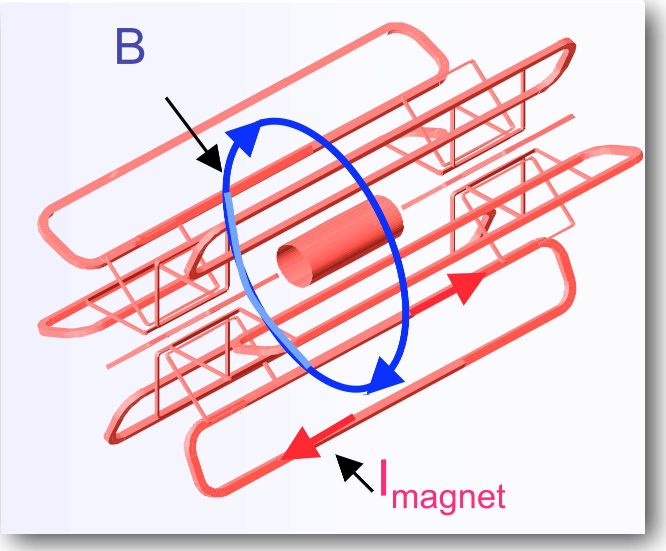


- **ATLAS decision**
  - achieve a high-precision stand-alone momentum measurement of muons
  - need magnetic field in muon region -> large radius magnet

- **CMS decision**
  - single magnet with the highest possible field in inner tracker (momentum resolution)
  - muon detector outside of magnet

Magnet-Concepts: ATLAS -> Toroid

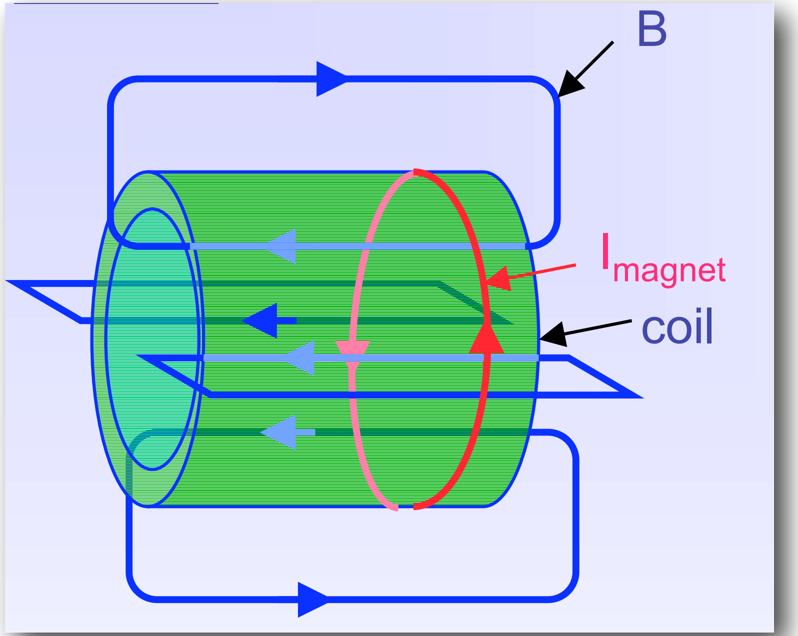




- Central toroid field outside the calorimeter within muon-system: <4 T
  - Closed field, no yoke
  - Complex field
- Thin-walled 2 T Solenoid-field for trackers integrated into the cryostat of the ECAL barrel

+ field always perpendicular to $\vec{p}$
+ relative large field over large volume
- non uniform field
- complex structure -> limited accessibility

Magnet-Concepts: CMS -> Solenoid



- Super-conducting, 3.8 T field inside coil
- Weaker opposite field in return yoke (2T)
- Encloses trackers and calorimeter
- 13 m long, inner radius 5.9 m, I = 20 kA, weight of coil: 220 t

+ large homogeneous field inside coil
+ weak opposite field in return yoke
+ easier to access
- size limited (cost)
- relative high material budget

ATLAS@LHC

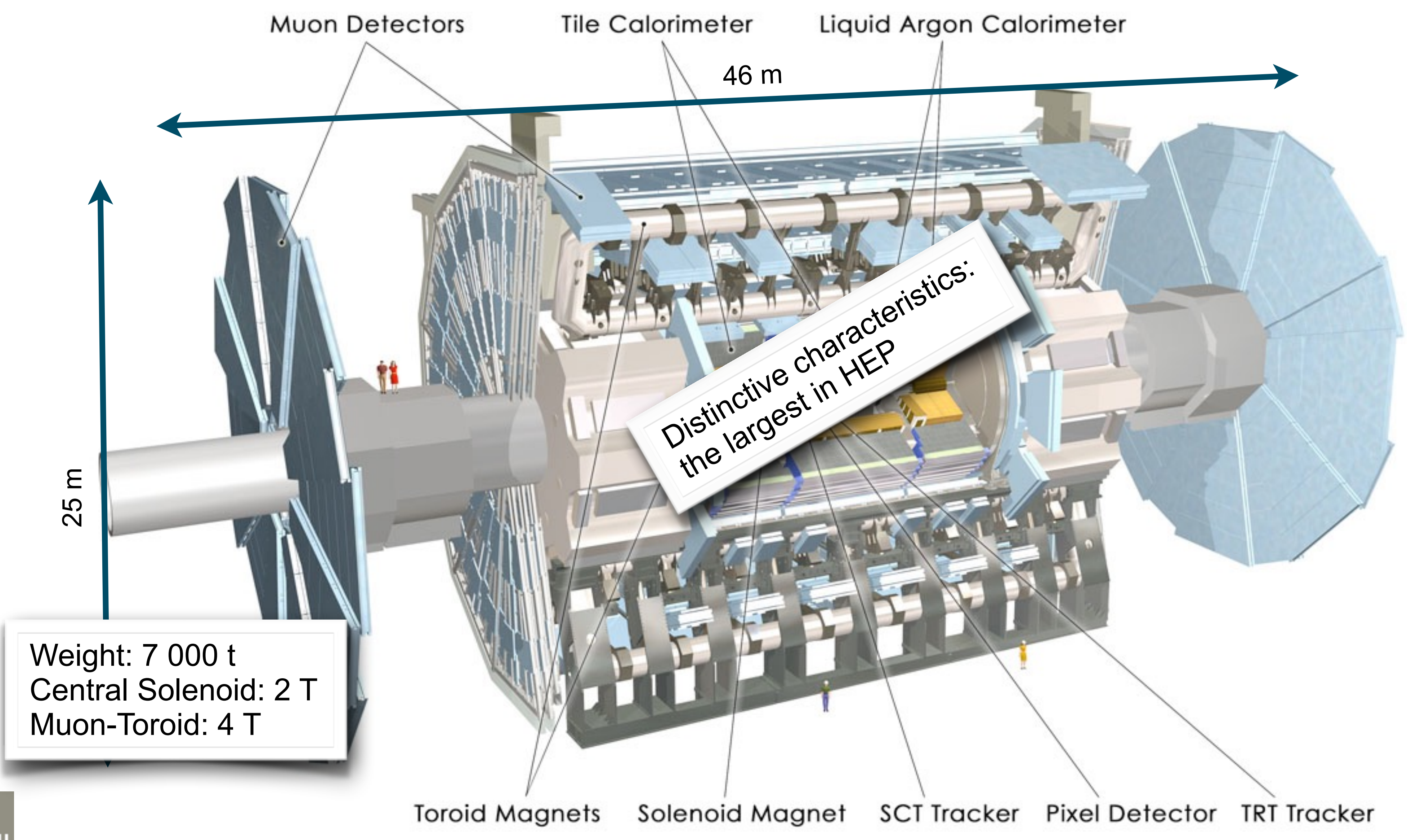


Illustration: CERN

ATLAS Cross Section

Example@LHC

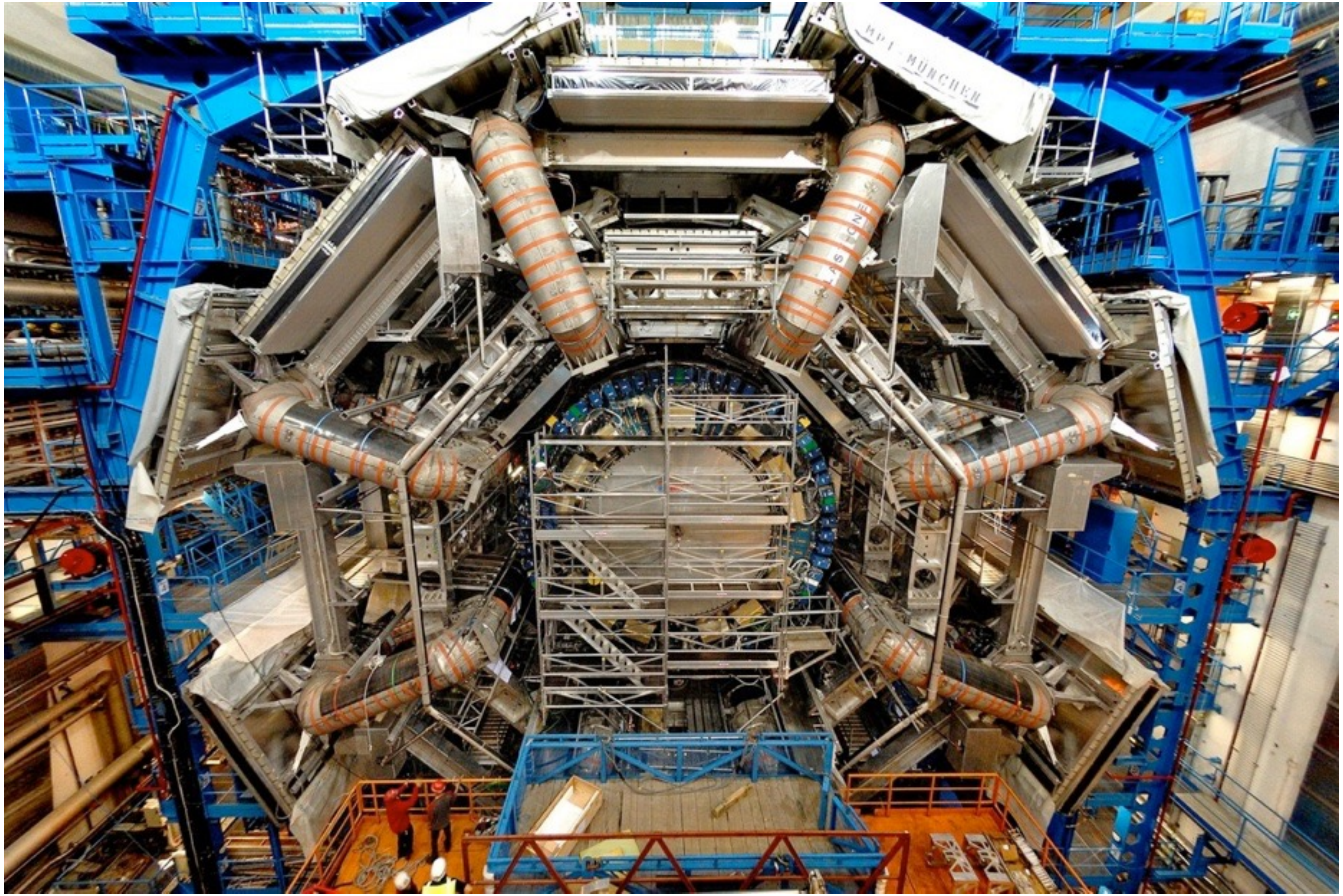
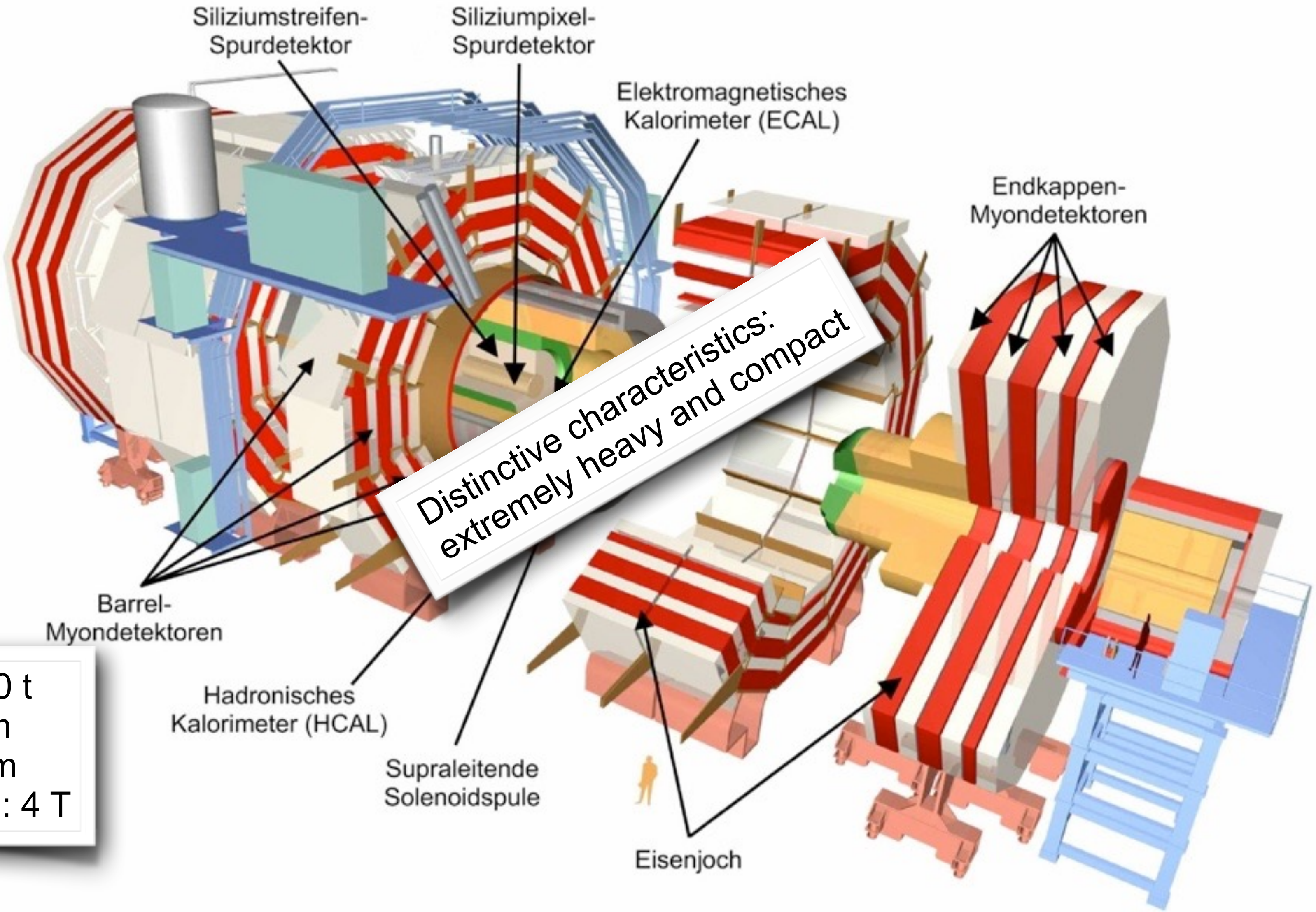


Foto: CERN

CMS@LHC



Distinctive characteristics:
extremely heavy and compact

Weight: 12 500 t
Length: 21.5 m
Diameter: 15 m
Solenoid-Field: 4 T

CMS Cross Section

Example@LHC

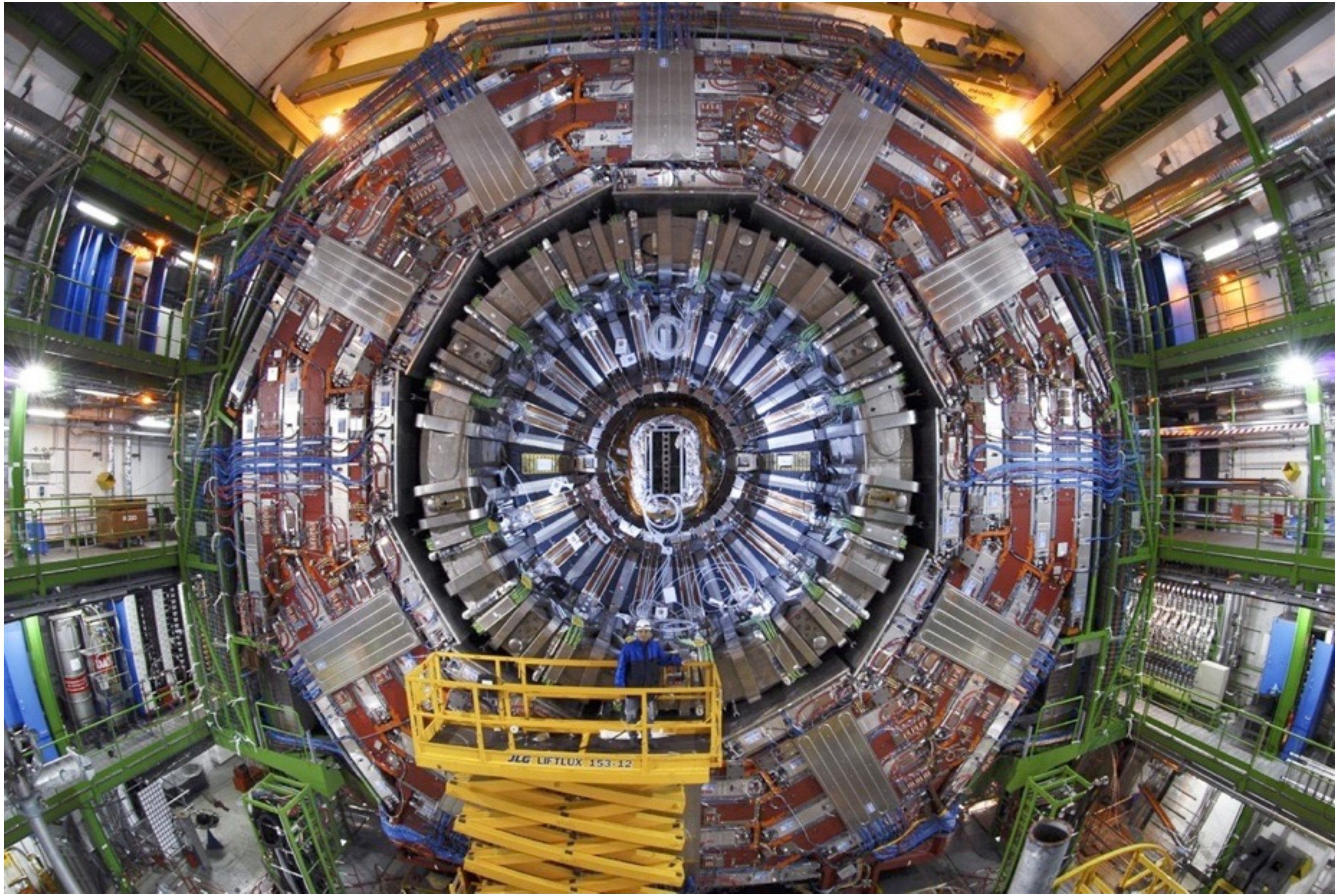
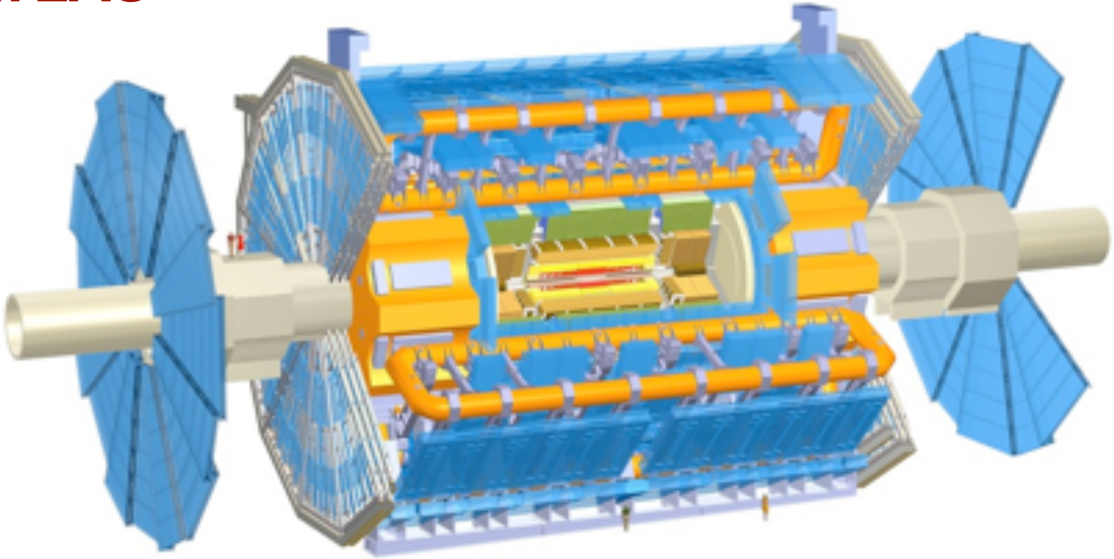


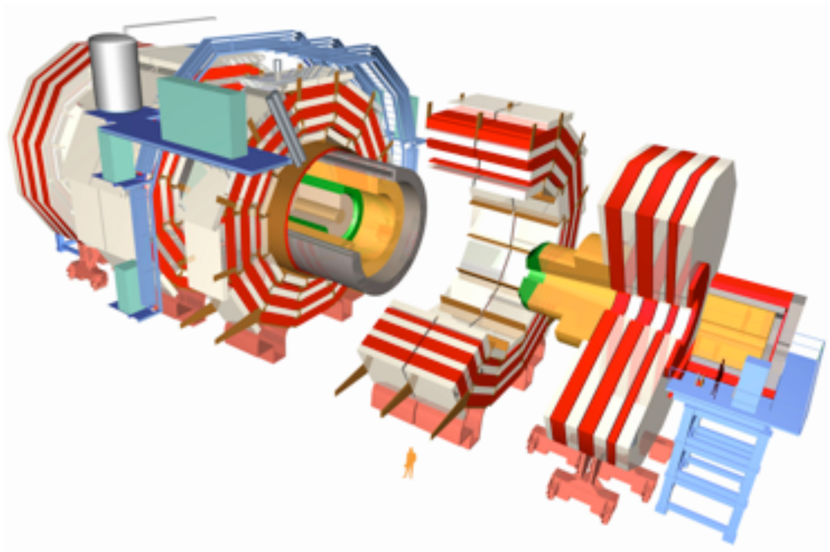
Foto: CERN

The Big Ones at LHC ....

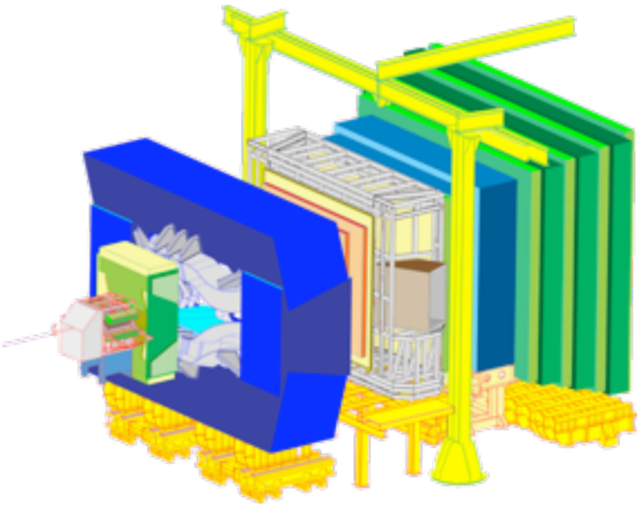
ATLAS



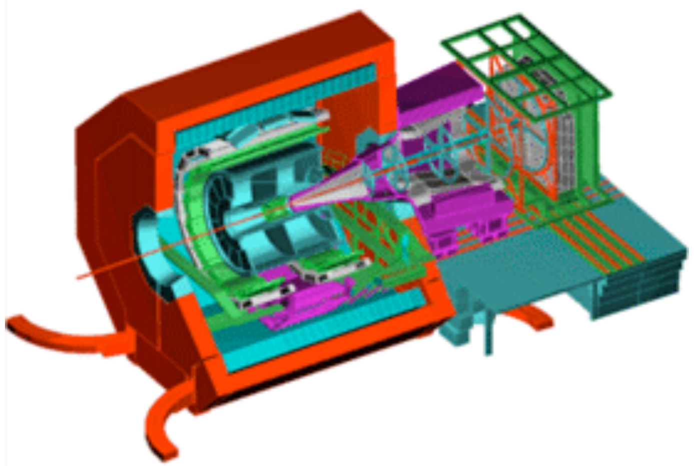
CMS



LHCb

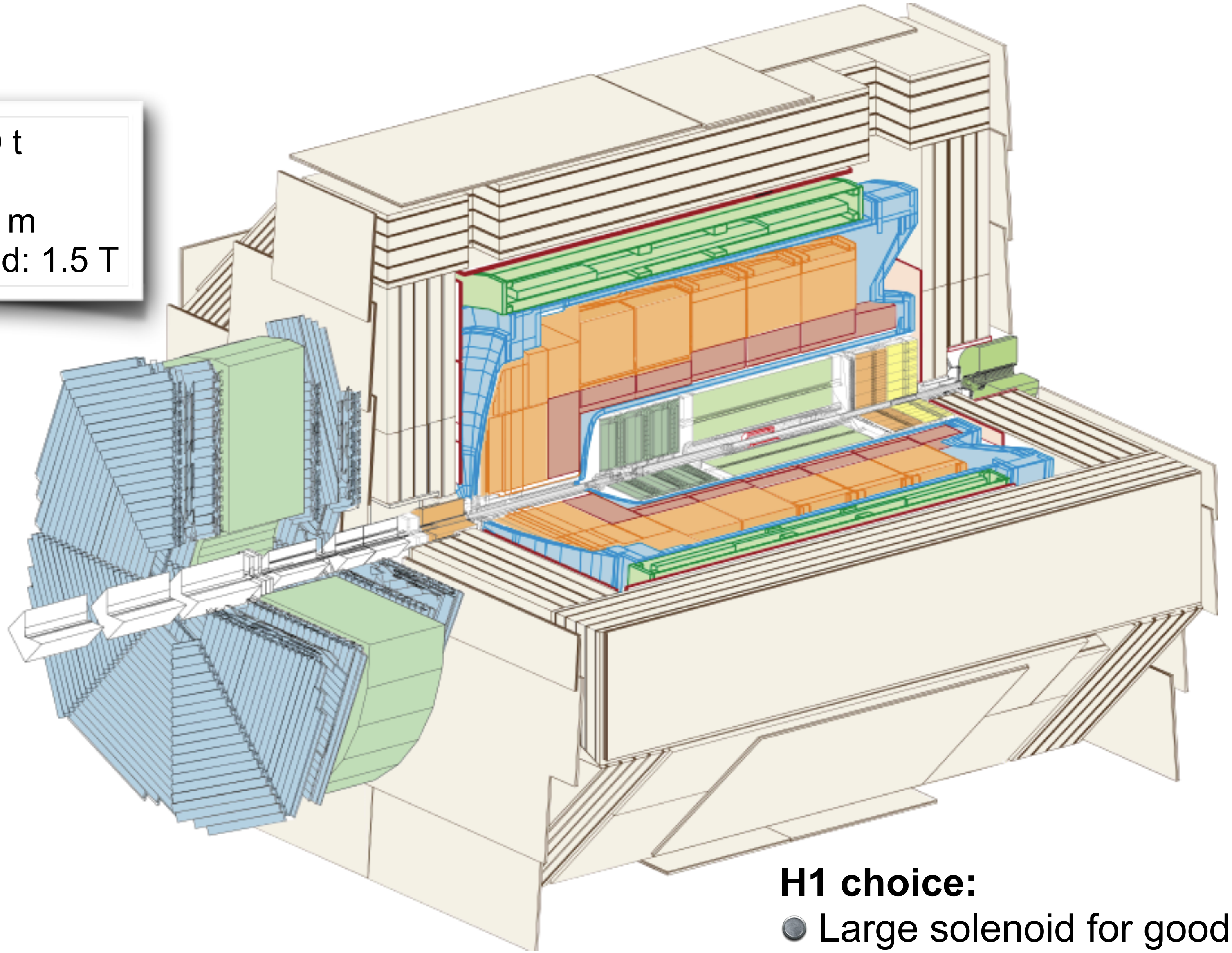


ALICE



The H1 Detector

Weight: 2800 t
Length: 12 m
Diameter: 15 m
Solenoid-Field: 1.5 T

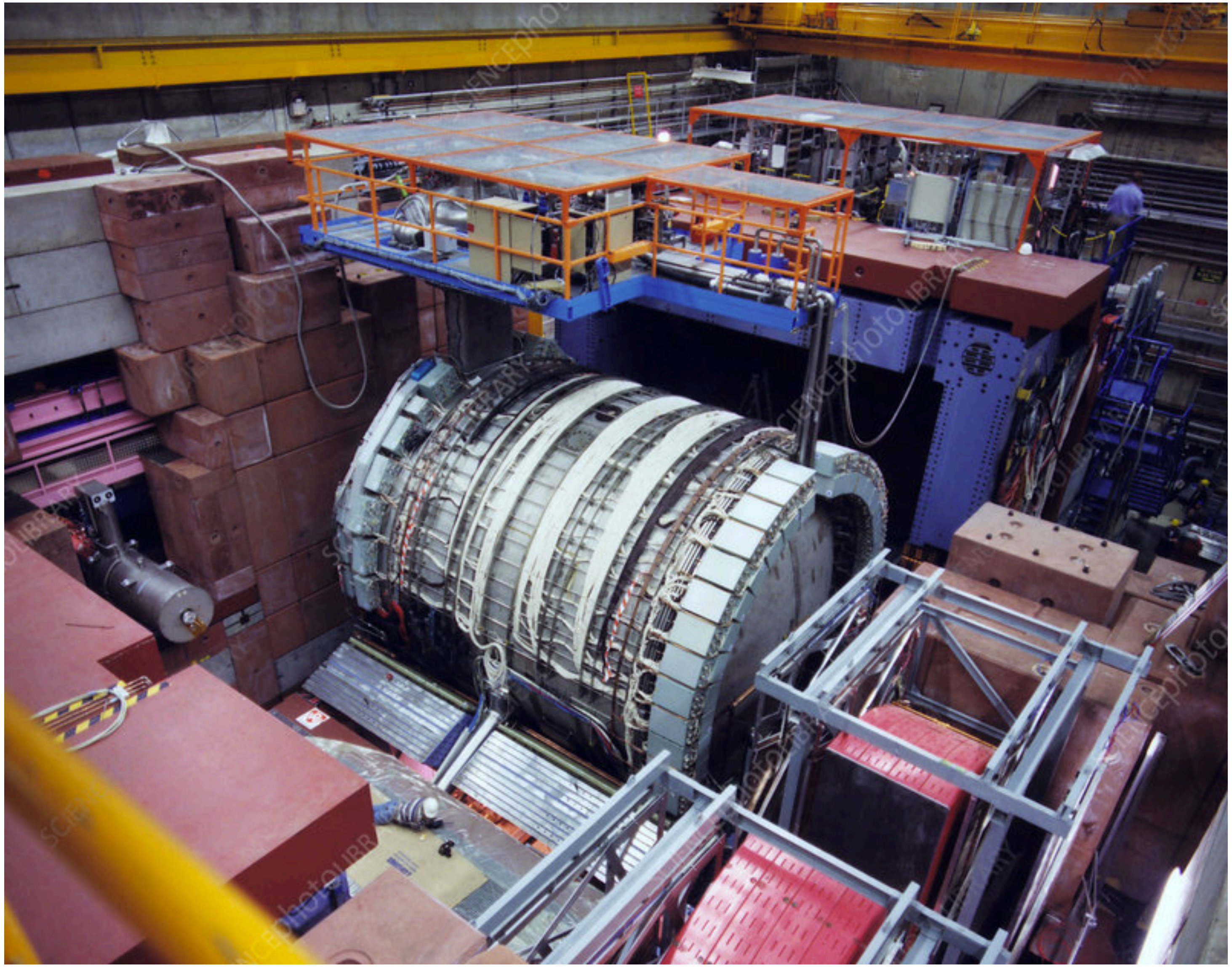


H1 choice:

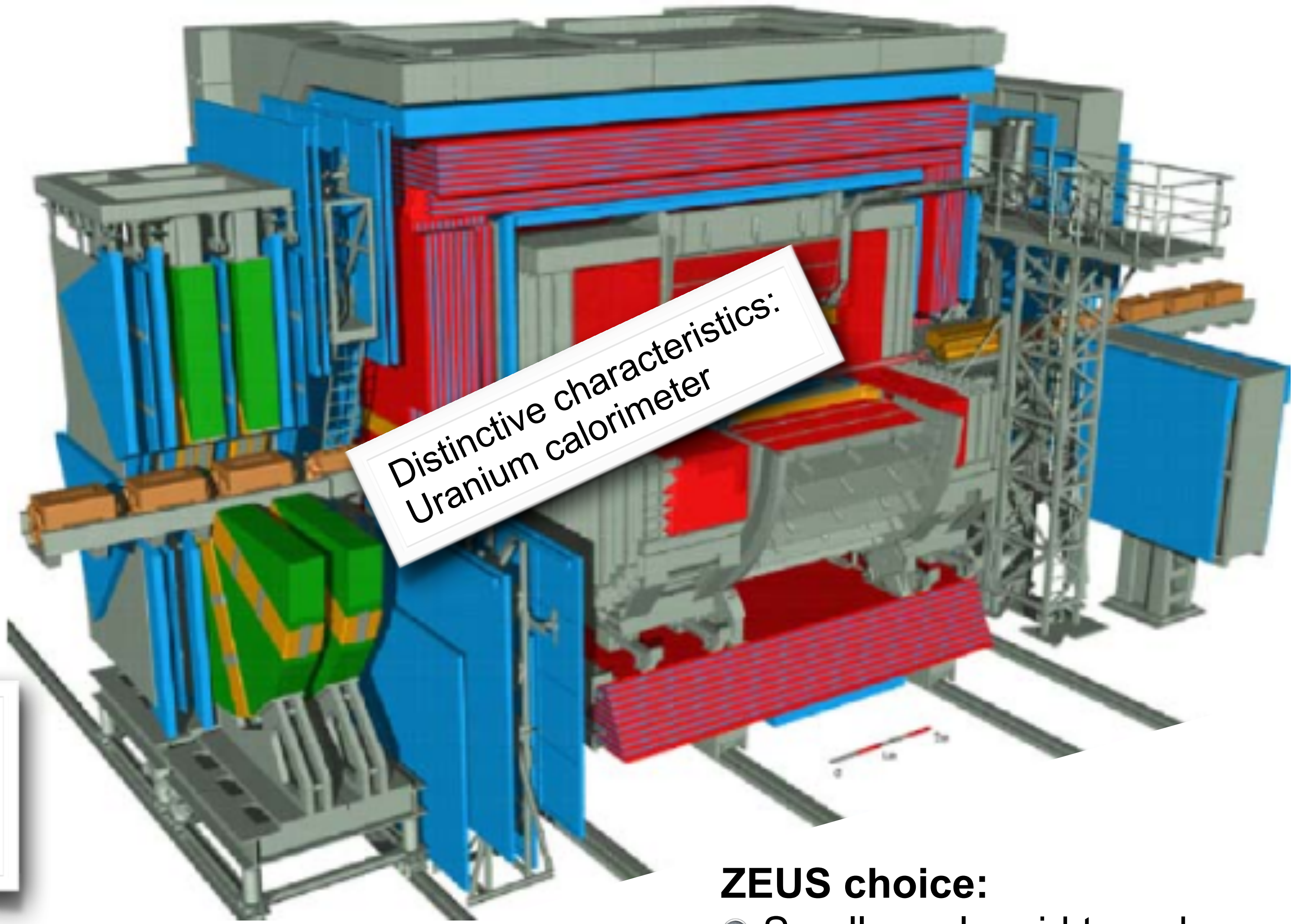
- Large solenoid for good momentum resolution with the tracking detector
- Cost efficient scintillator tungsten calorimeter

H1 Detector

Example@HERA



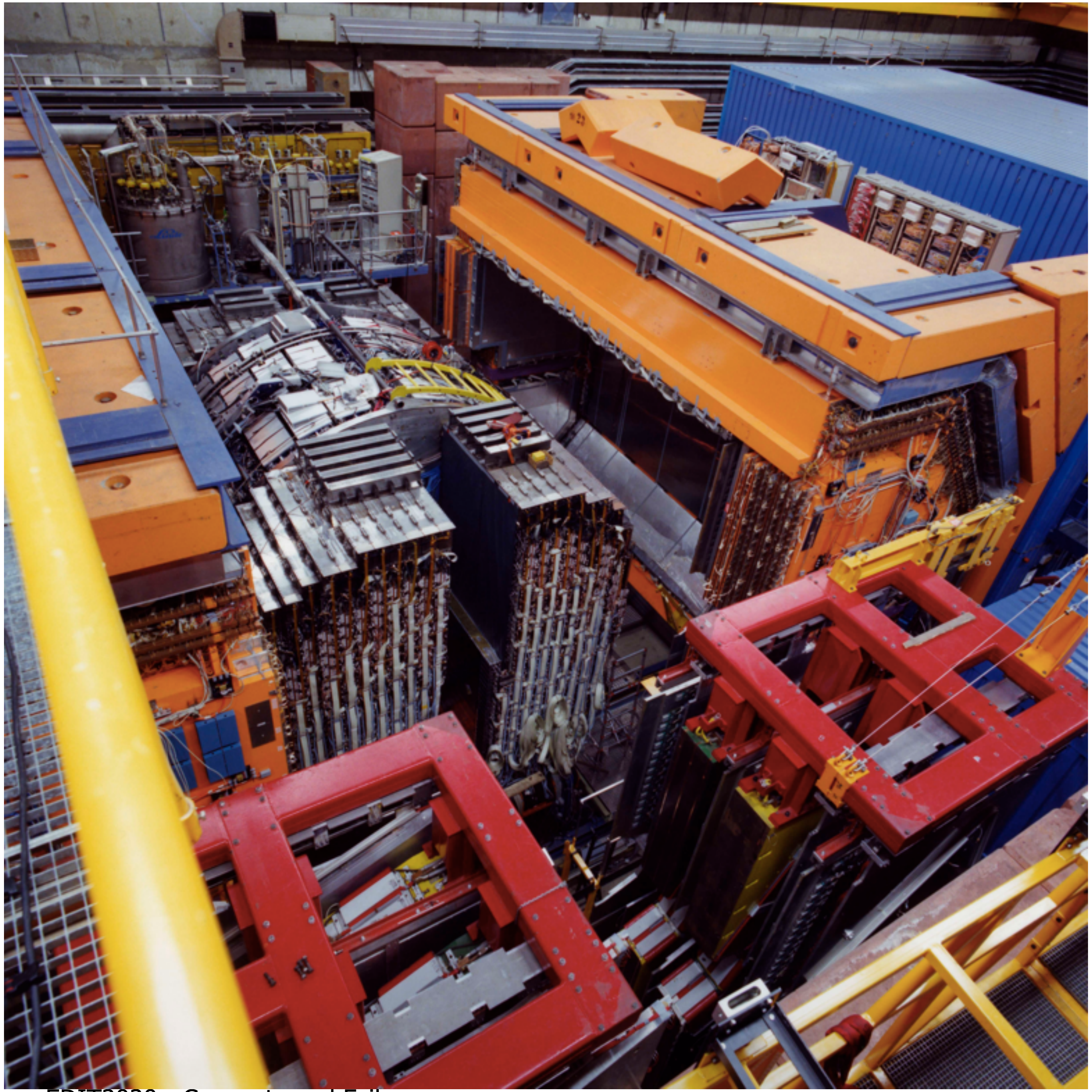
The ZEUS Detector



Weight: 3600 t
Length: 19 m
Diameter: 11 m
Solenoid-Field: 1.5 T

ZEUS choice:
- Smaller solenoid to reduce costs
- Expensive Uranium scintillator calorimeter

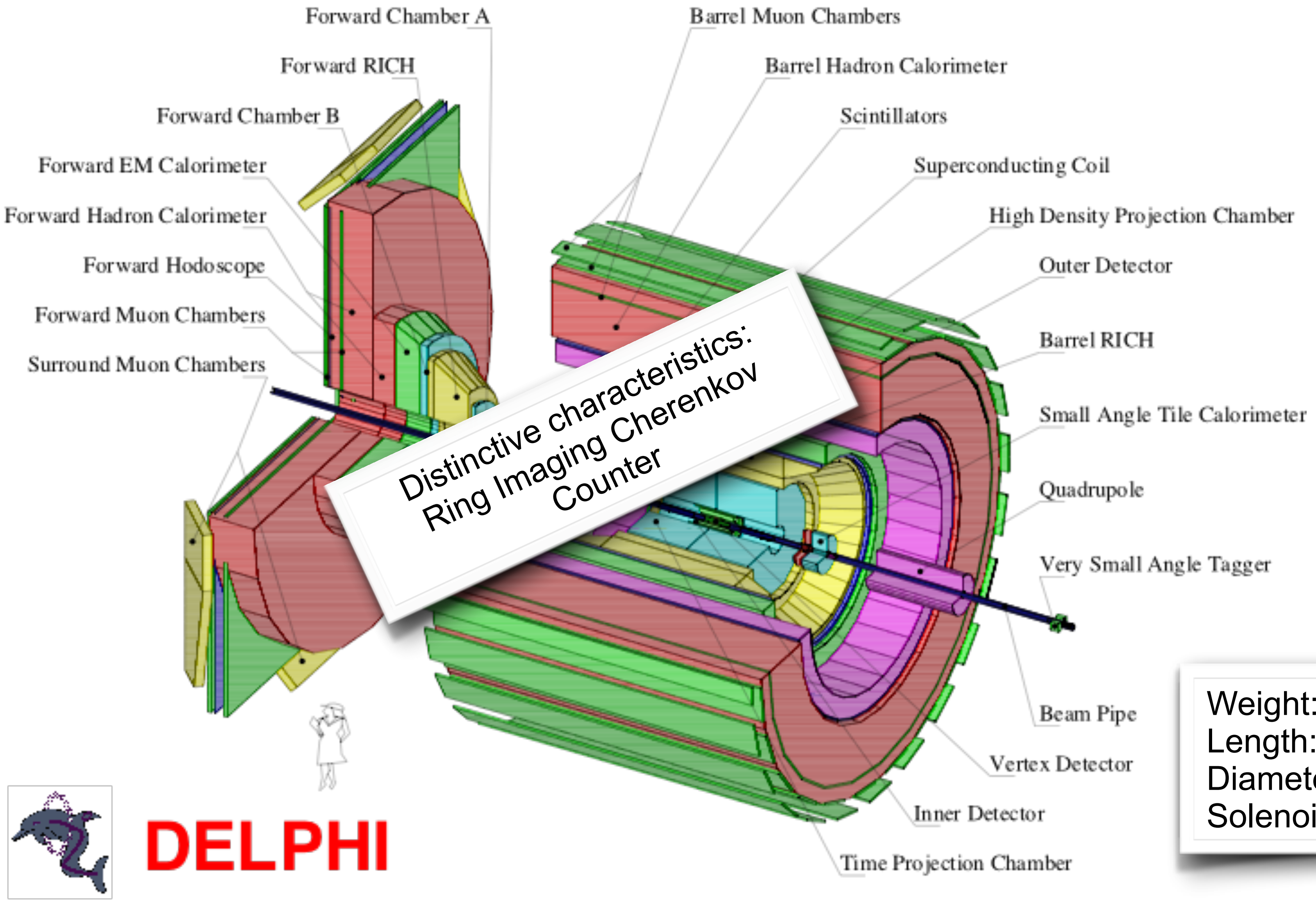
ZEUS



The DELPHI Detector

Example@LEP

Pic: DELPHI Collaboration

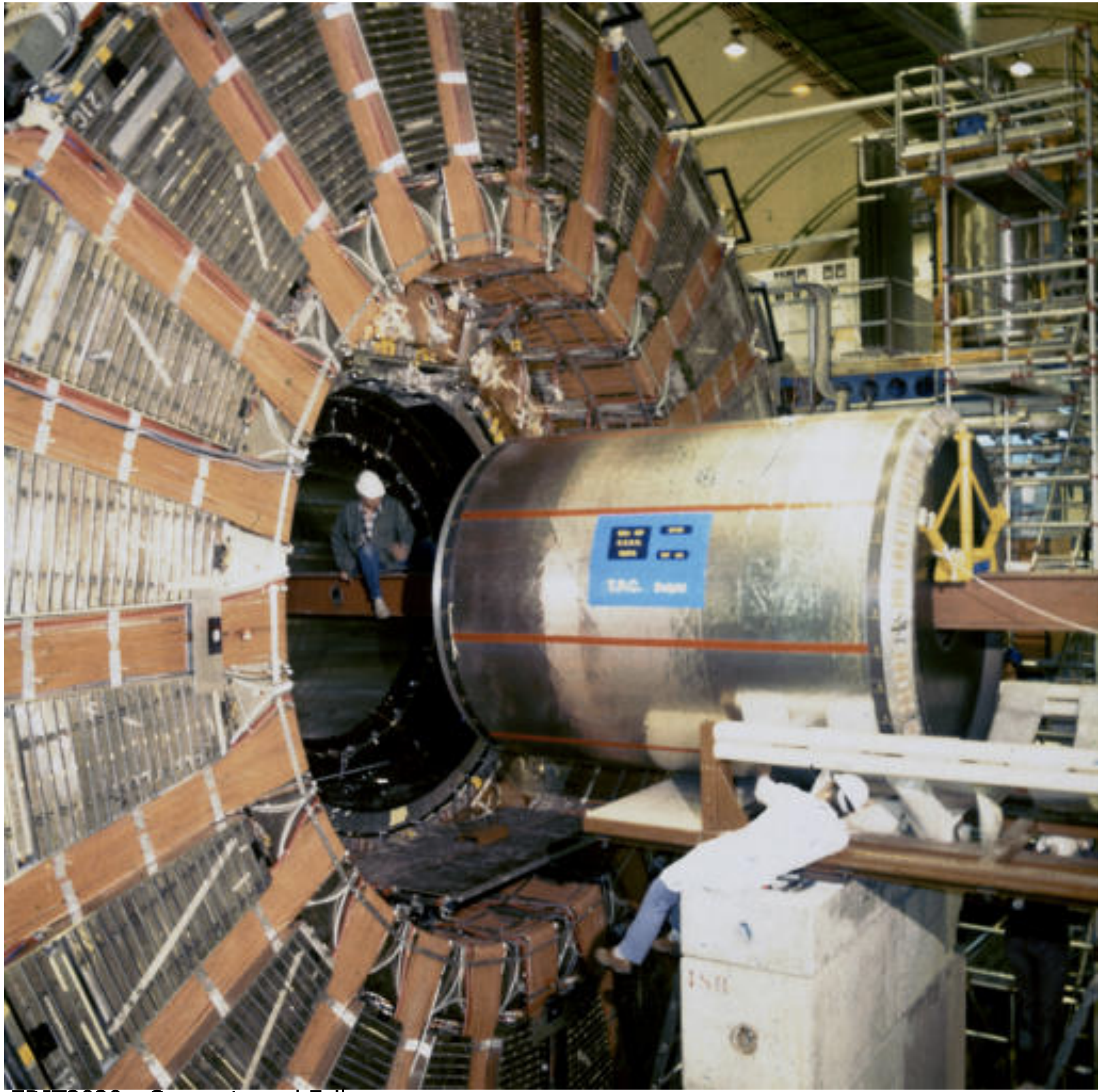


Distinctive characteristics: Ring Imaging Cherenkov Counter

Weight: 3500 t
Length: 10 m
Diameter: 10 m
Solenoid-Field: 1.2 T

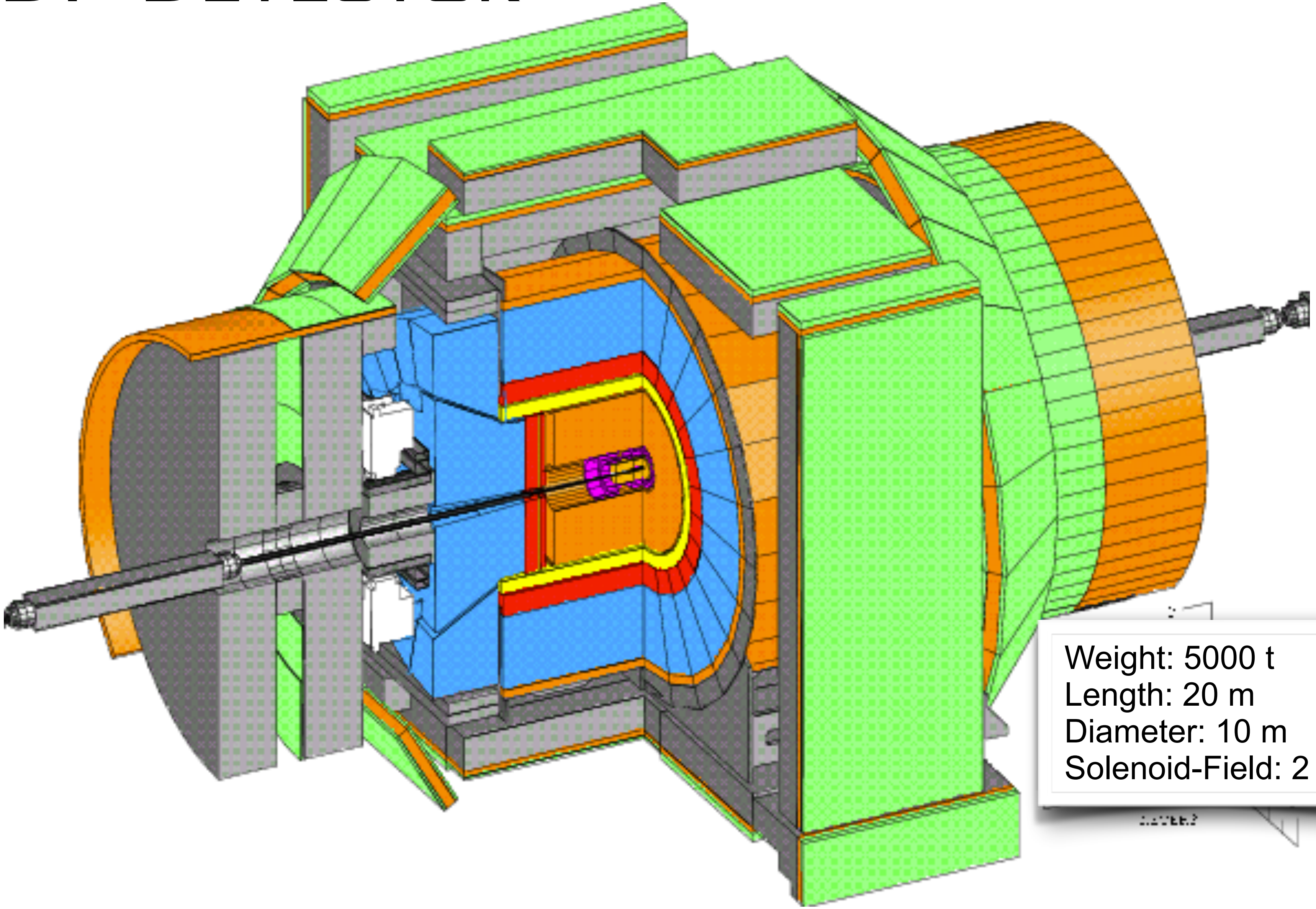
Delphi

Example@LEP



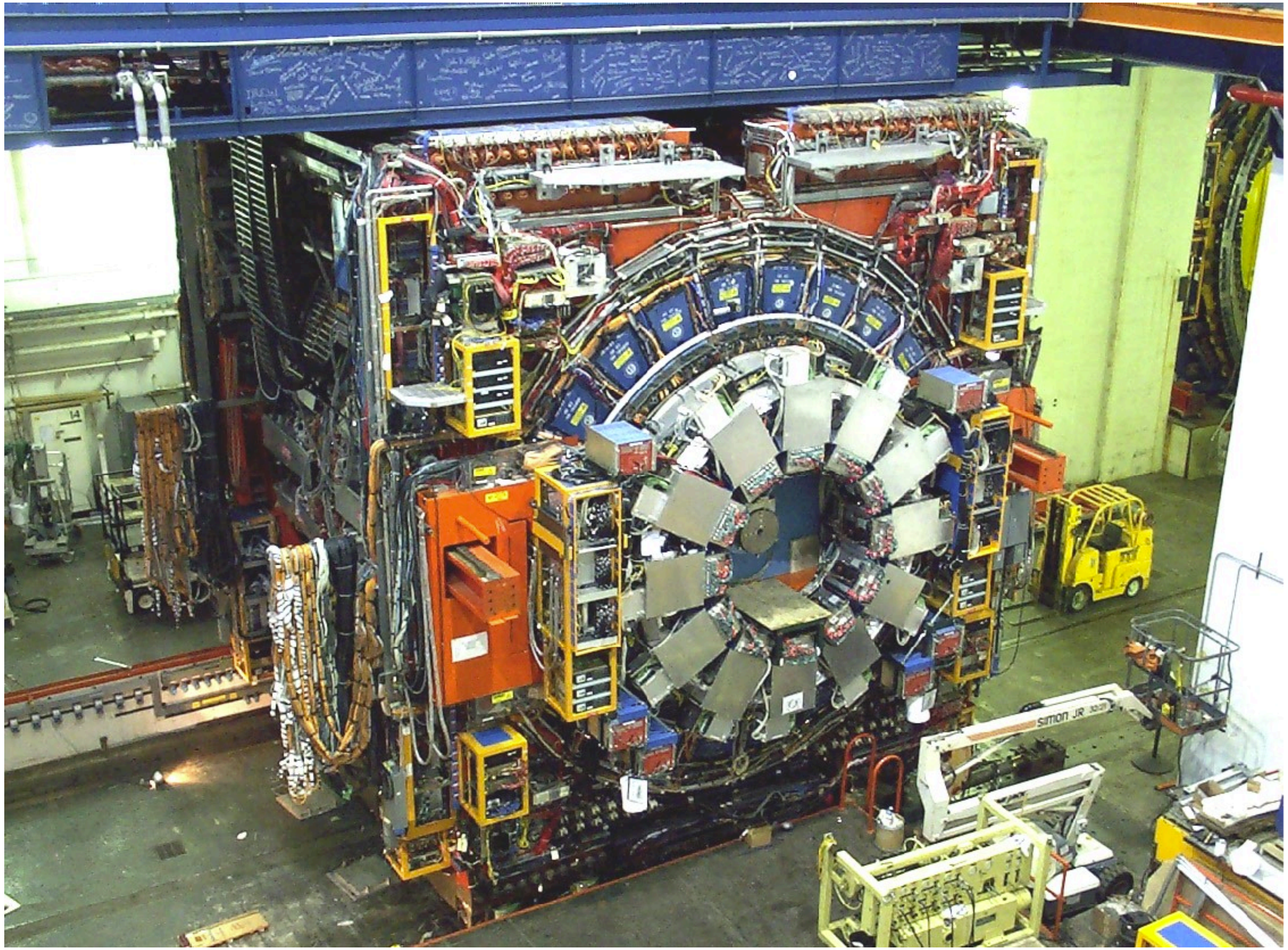
The CDF Detector

Example@Tevatron



Weight: 5000 t
Length: 20 m
Diameter: 10 m
Solenoid-Field: 2 T

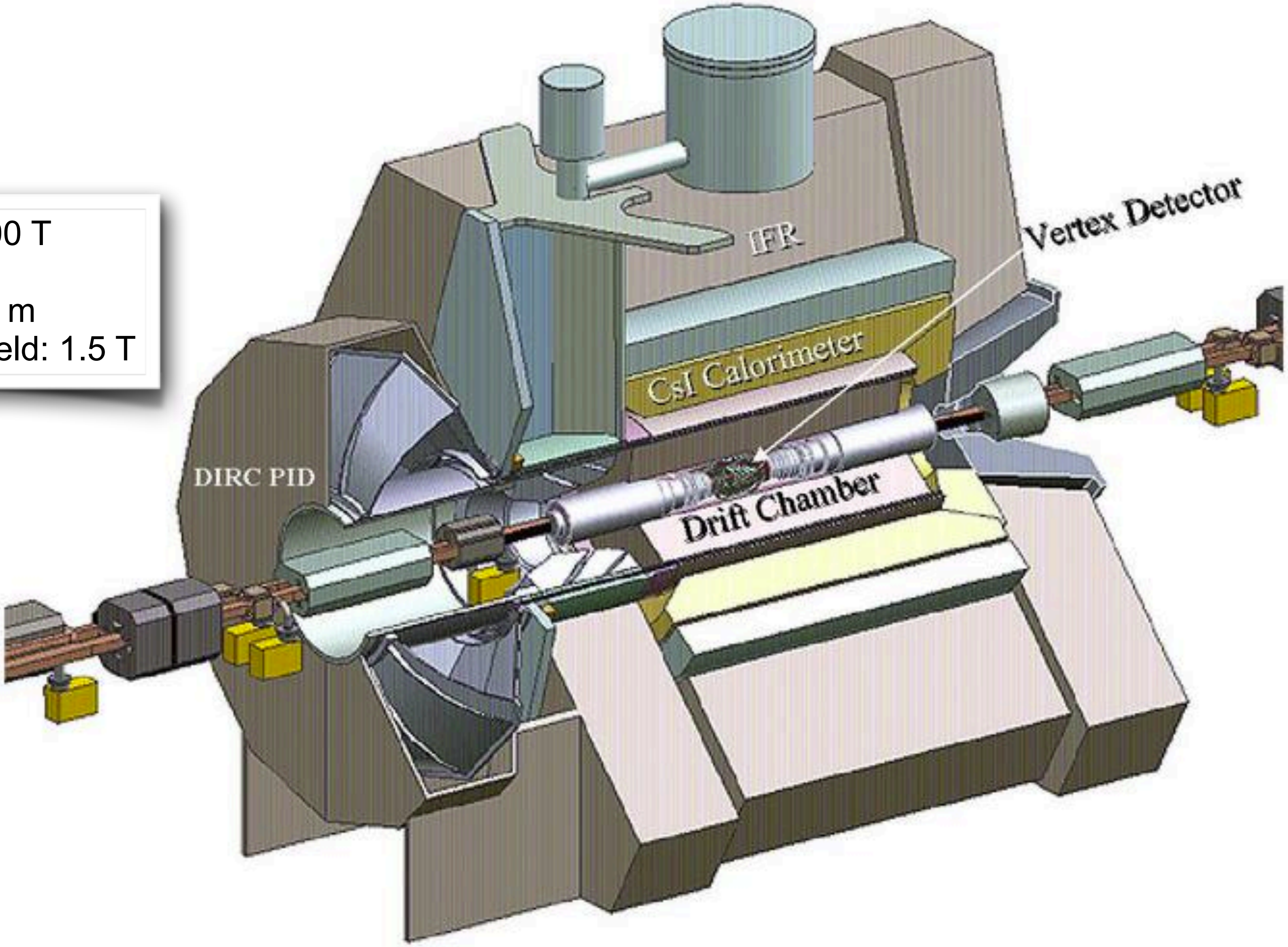
CDF



The BaBar Detector

Example@SLAC

Weight: 1200 T
Length: 6 m
Diameter: 6 m
Solenoid-Field: 1.5 T



Pic: BaBar Collaboration

BaBar

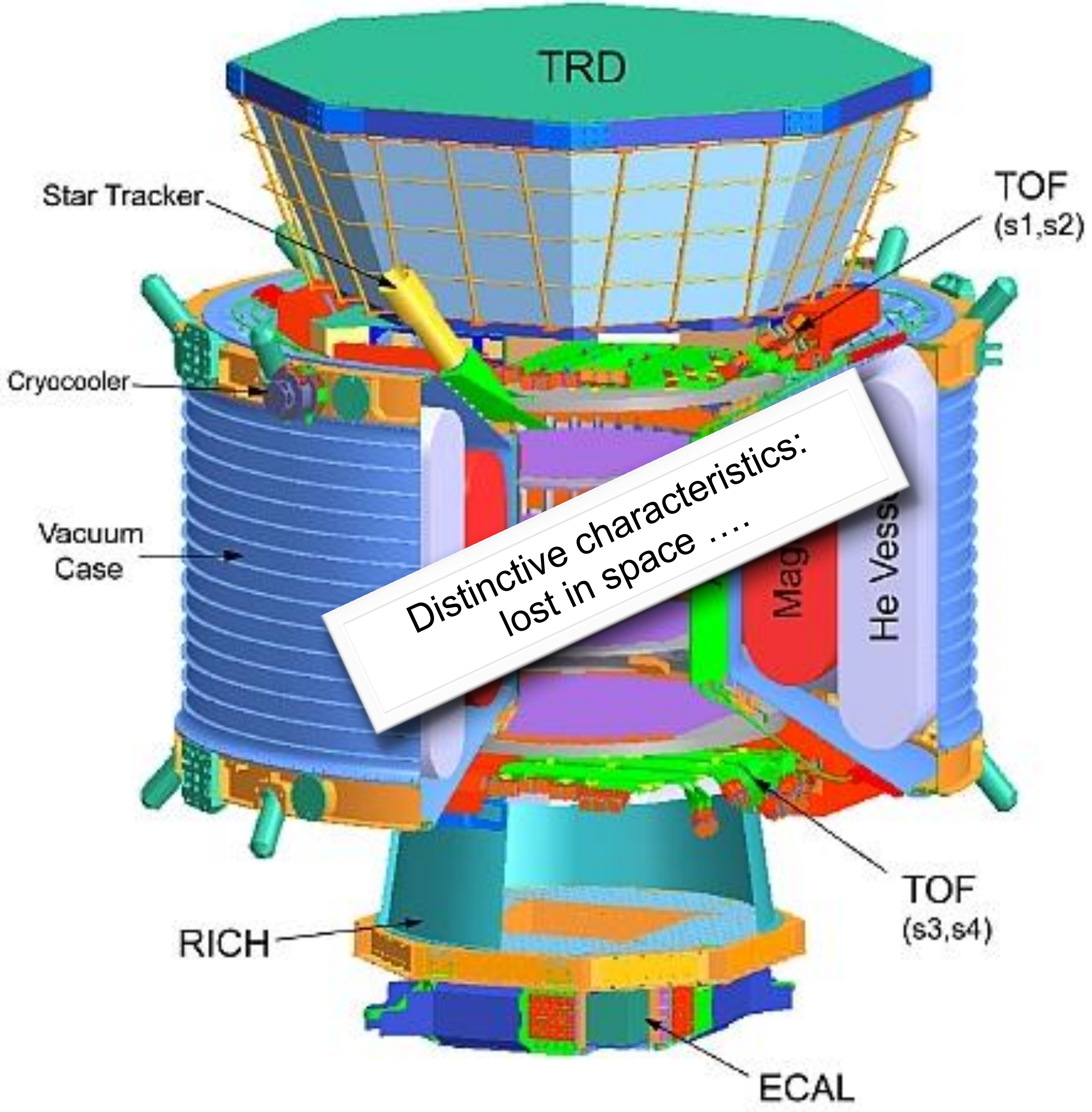
Example@SLAC

BaBar

Collaboration Home Page

AMS

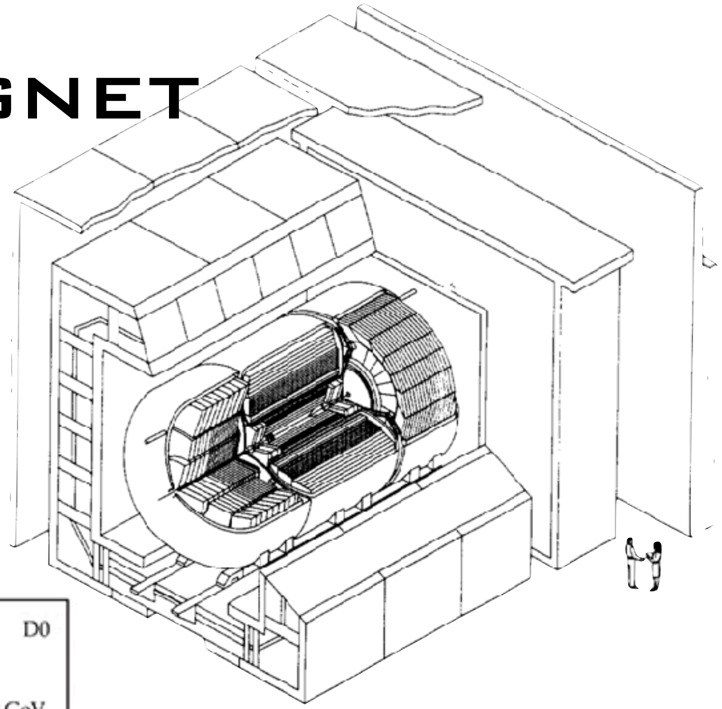
Weight: 8.5 t
Length: 6 m
Diameter: 6 m
Solenoid-Field: 1.5 T



picture: AMS collaboration

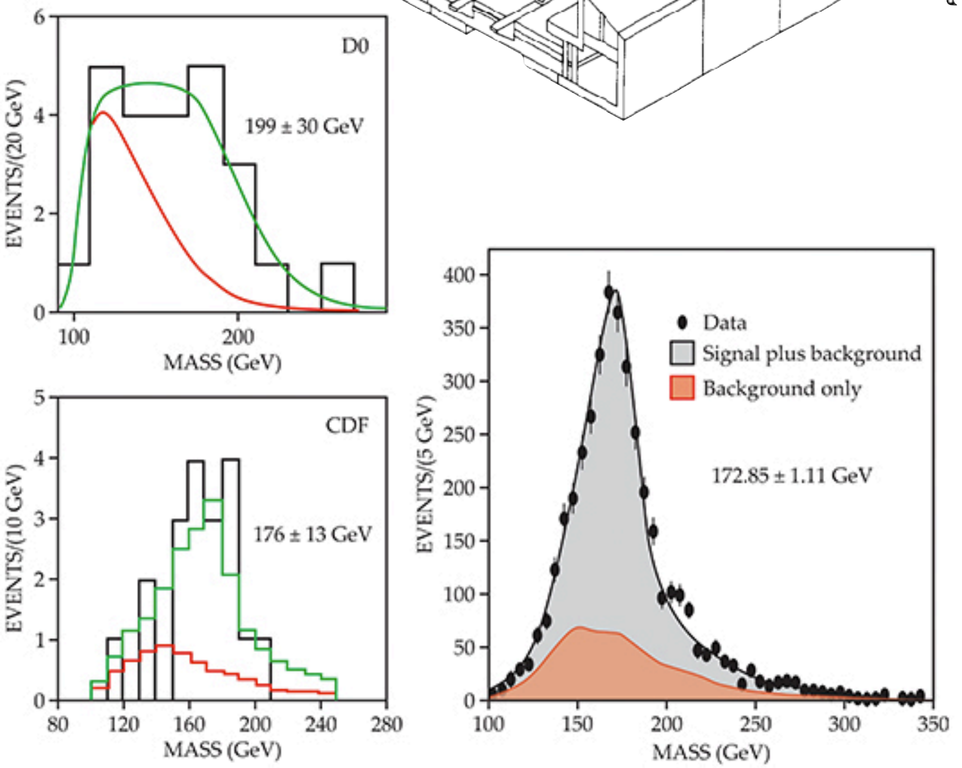
Problems in overall Concept

D0 without Inner Tracking Magnet



- D0 Experiment at Tevatron constructed to study proton-antiproton collisions
- **Top discovery** in 1995 together with CDF experiment
- Original design for Run I: no magnet for tracking
  - "Focussing on parton jets for deciphering the underlying physics than emphasis on individual final particle after hadronisation"
  - Very compact tracking system
  - Uranium-liquid argon calorimeter for identification of electrons, photons, jets and muons
- Effect of low momentum charged particles greatly underestimated resulting in analysis difficulties.

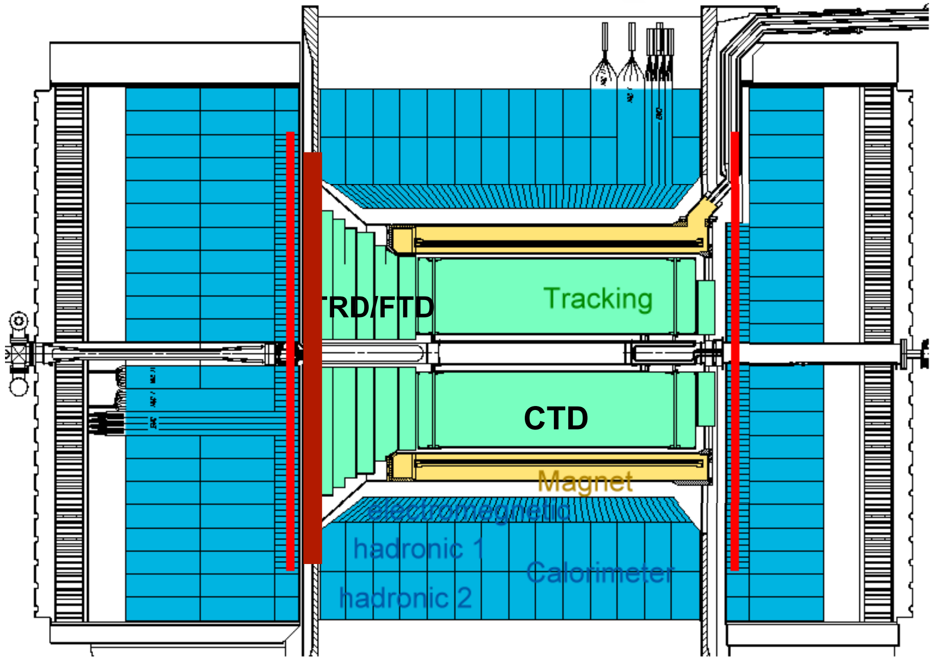
Run II system included a silicon microstrip tracker and a scintillating-fibre tracker located within a 2 T solenoidal magnet.



Top quark discovery

ZEUS TRD

TRD see Christoph on Feb 24

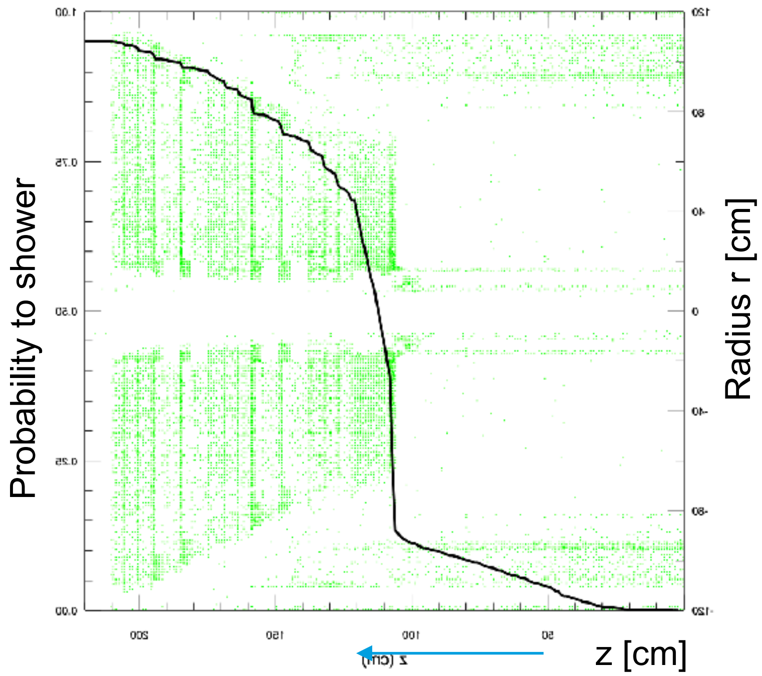


- Zeus Transition Radiation detector for electron identification.
- Aim: h/e rejection ratio of about 10^{-2} for electron tracks embedded in jets (1 - 30 GeV/c).

- However - central tracking detector (wire chamber) had 2cm end-plate for wire fixation
  - Electrons 100% probability to shower and thus were not present in showers anymore

- Reason for mishap: no proper Monte Carlo simulation tools available at time of detector design

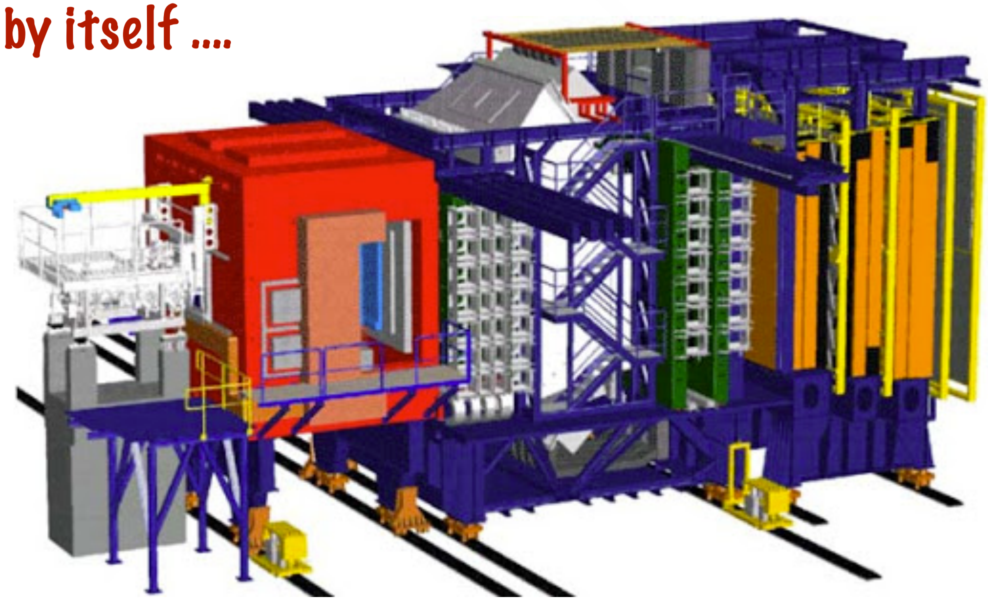
> Simulate everything incl. ALL cables and mechanics



- TRD used for Here Run I Replaced by Straw Tube Tracker for Run II

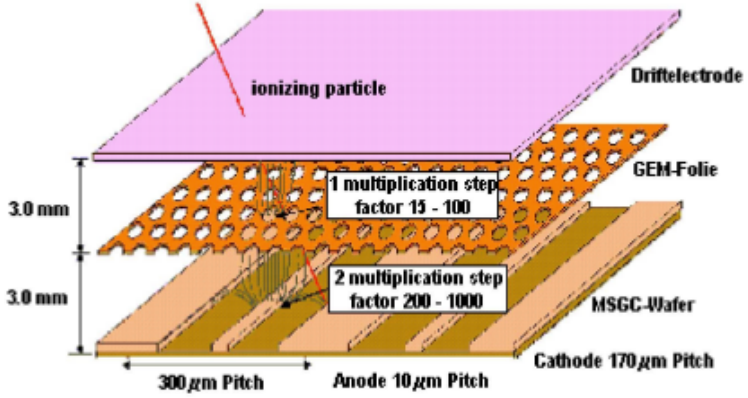
Hera-B

Would be a full lecture by itself ….

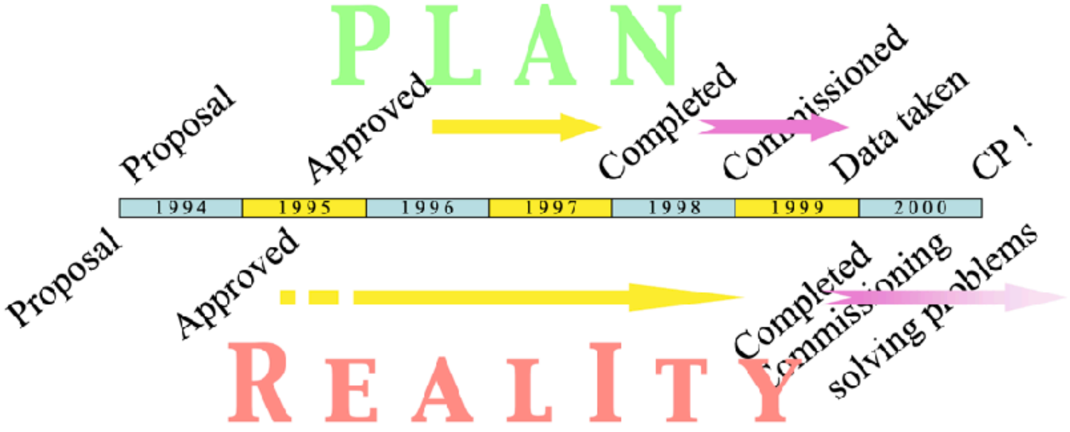


- HERA-B started as a search for CP violation in $B \rightarrow J/\psi K_s^0$.
  - Fixed target hadronic b-factory
- **Bad surprises:**
  - Inner tracker: Microstrip gas chamber breakdowns occurred at the intolerable high rate of a few sparks per hour
  - Outer tracker: rapid ageing of chambers due to radiation environment
  - Additional R&D required for the tracking system: two year delay.

- In the mean time Belle and BaBar measured CB violation in B meson decays (ICHEP 2000)
- Decided to ramp Hera-B slowly down …..



Frontier detector technology: microstrip gas chambers



http://www-hera-b.desy.de/general/info/CERN-Seminar.pdf

Reasons

- Very challenging particle physics experiment
  - Particle flux in detector
  - Radiation damage
  - Event rate
  - Data throughput

03/03/03 06:10
7
Comment from **SG, UH**
Arriving at Hall West at 6:00, we don't see anybody around. The control room is dark and locked, and the HERA display announces "SHUTDOWN" (sounds a bit like Genesis 1,1, but that was a beginning...)

03/03/03 07:16
8
Comment from **Bernhard Schmidt**
... in fact, at 6:45 the darkness was quite complete.
And nobody around to say goodbye...Sleep well, old lady ;-)

- Hera-B was a "flip/flop" experiment
  - Only one physics measurement:
    CP violation in B decays
  - No backup plan for reduced requirements

Not all bad ….

- More than 100 Phd theses
- Most technical challenges solved
- CMS changed tracking design

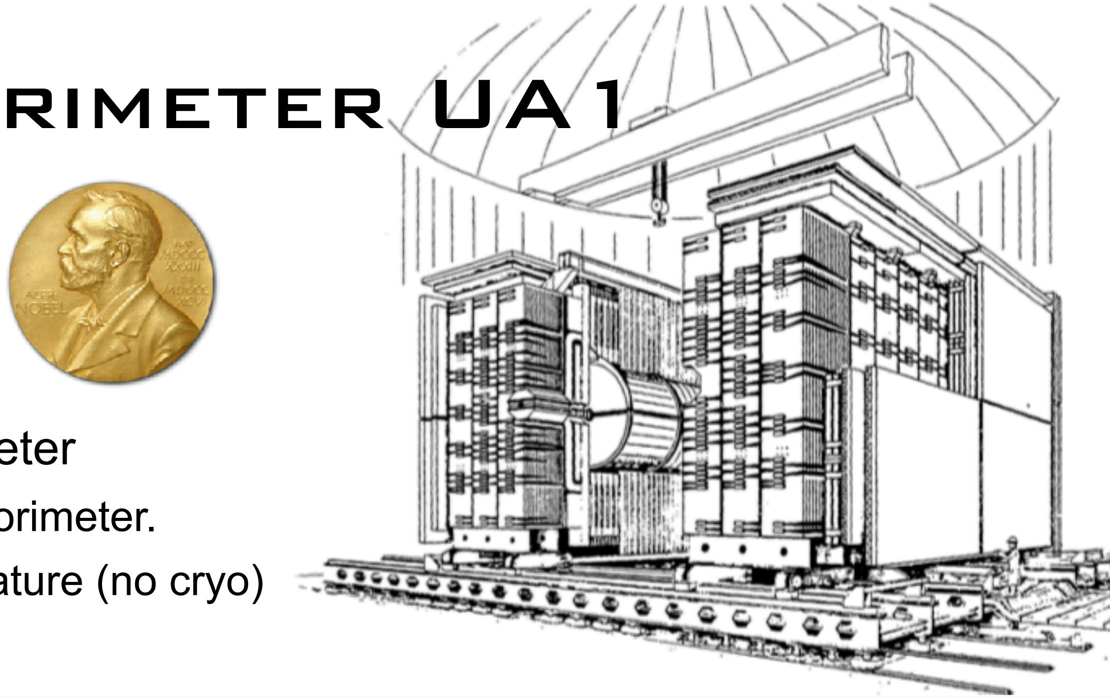
- Schedule from the start very tight in light of a challenging project
  - B-factories (e^+e^-) BarBar (SLAC) and BELLE (KEK) in construction
  - Competing with B-factories: HERA-B without a chance

  2002 : CP-Verletzung mit > 5σ gemessen

Hera-B: LHC detector prototype !

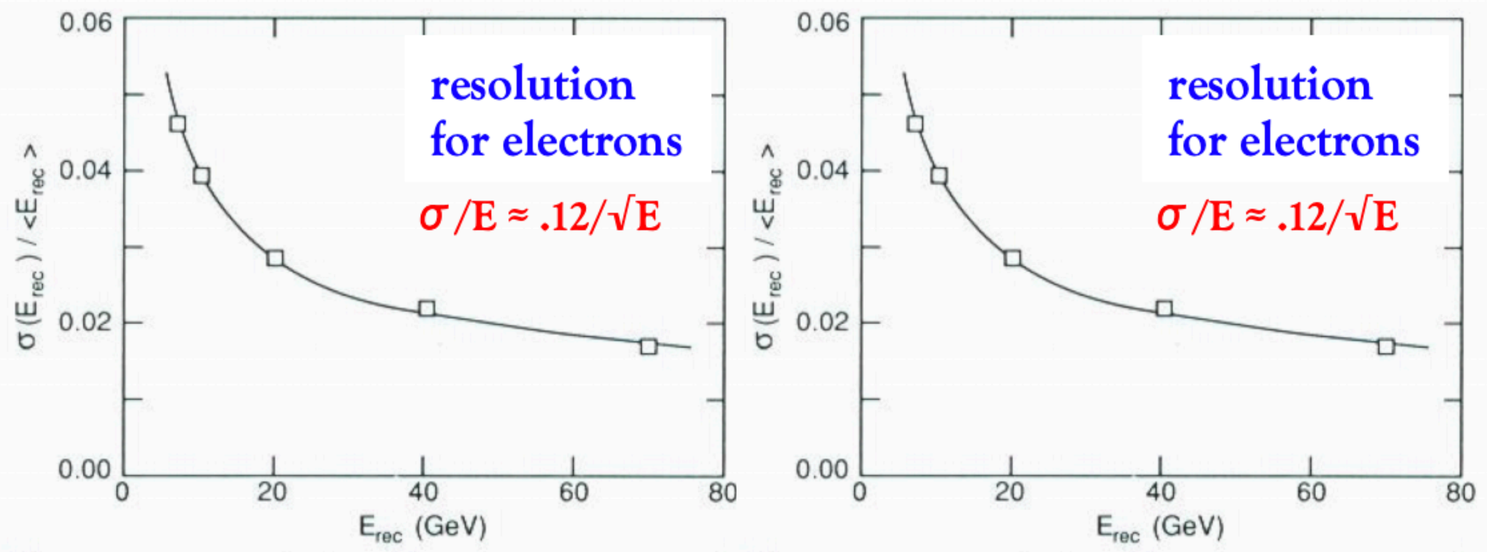
Liquid Scintillator Calorimeter UA1

- UA1 experiment at SPS to discover the W and Z boson
  - **Very successful experiment per say**



- UA1 decided to built a Uranium-Liquid scintillator calorimeter
  - Uranium: Compact enough to replace the lead-scintillator calorimeter.
  - Liquid-scintillator: tetramethylpentane (TMP) at room temperature (no cryo)
  - Challenging calorimeter concept - and cost intensive …

- Unfortunately severe difficulties were encountered in the production of clean and planar boxes filled with TMP and the project was cancelled.



see Stefan on Feb 28

http://www.roma1.infn.it/~lacava/UA1_Experiment.pdf

http://cdsweb.cern.ch/record/197057/files/198905600.pdf

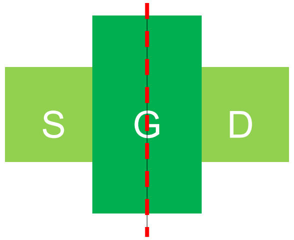
Unexpected Irradiation Failure

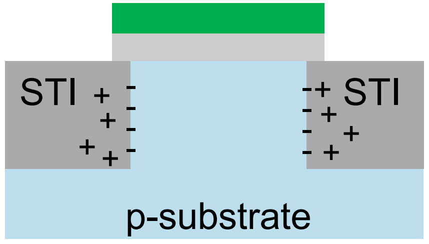
Problem: Radiation Damage

see Doris on Feb 17
and Norbert on Feb 19

- Radiation damages the silicon on atomic level significantly leading to macroscopic effects.

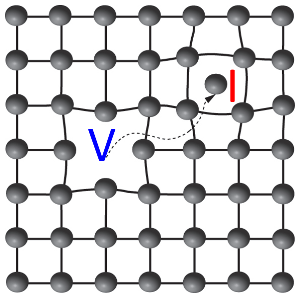
- **Surface effects:** Generation of charge traps due to ionising energy loss — Total ionising dose, TID **(problem for sensors and readout electronics).**
  - Cumulative long term trapping of positive charge
  - Increase of leakage current and oxide breakdown





STI = shallow trench interface

- **Bulk effects:** displacement damage and build up of crystal defects due to non ionising energy loss (NIEL) **(main problem for sensors).**
  - Unit: 1MeV equivalent n/cm^2



Defects composed of:
Vacancies and Interstitials

Compound defects with impuriti
possible!

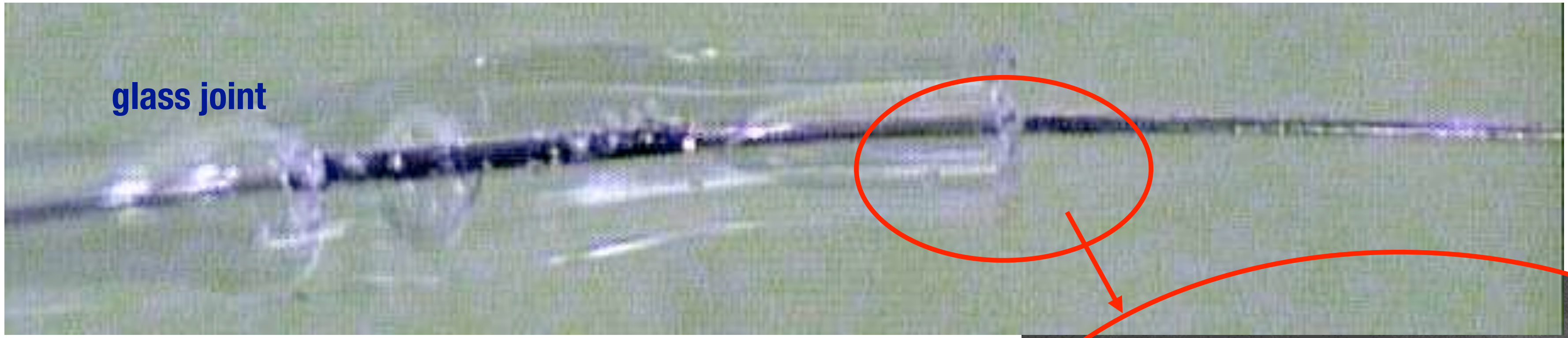
- **Transient effects:** Radiation induced **errors in microelectronic** circuits
  - caused by passing charged particles leaving behind a wake of electron-hole pairs
  - single event upsets, single event latch-ups, ….

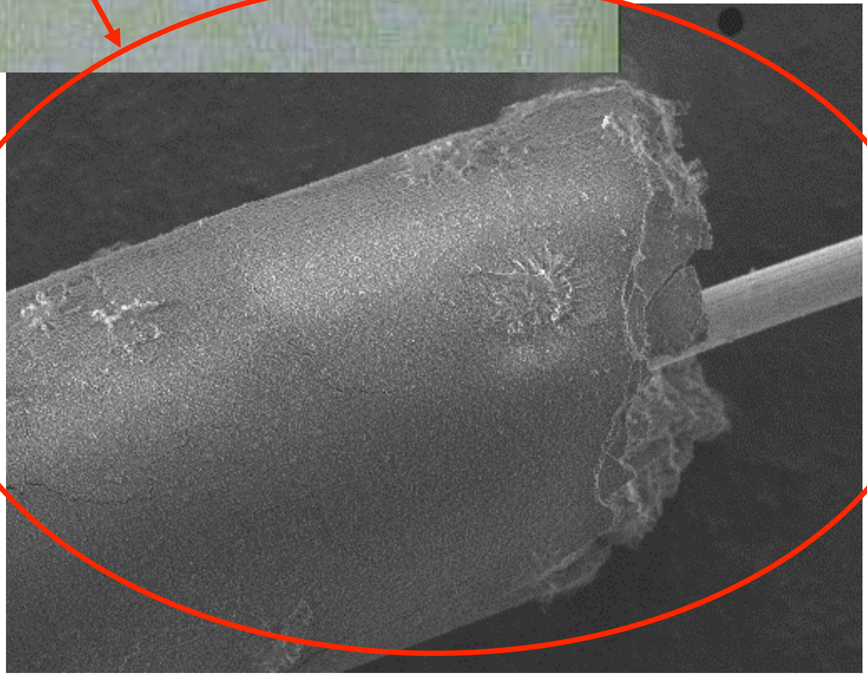
Generations of scientists worked on understanding failures connected to radiation damage and how to mitigated the effects - however …

ATLAS BARREL TRT

see Christoph R. on Feb 24

- Gas mixture: 70% Xe + 20 CF_4 + 10% CO_2
- Observed: destruction of glass joint between long wires after 0.3 - 0.4 integrated charge (very soon after start up)





At high irradiation C_4F turns partially into HF,F,F2 (hydrofluoric acid)
-> attaches Si-based materials in the detector

- Changed gas mixture, after ~10 years of R&D with old mixture

during production

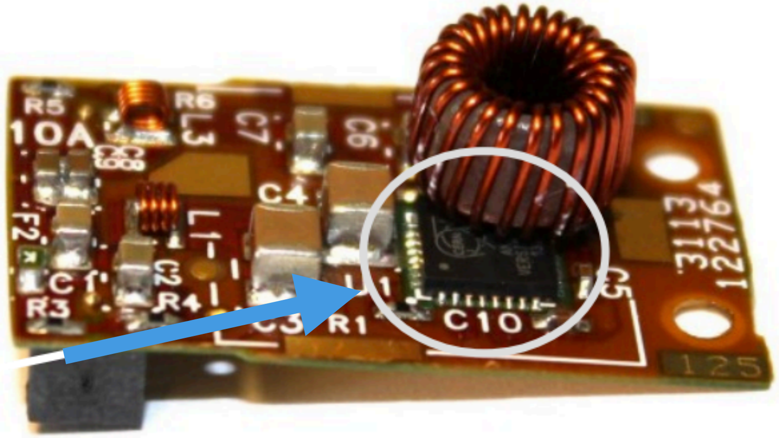
CMS DC-DC Converter

during running

- During 2017 new pixel detector installed in CMS with DC-DC converter for powering
  - After a few months, about 5% of the deployed converters failed.
  - During winter shutdown another about 35% of the converters were found affected by a damage mechanism.

DC-DC in a nutshell:
transfer energy into detector with higher voltage/lower current and transform just before the load to operation voltage

- Extremely difficult to identify problem - over months multiple tests conducted
- Found strong correlation between radiation background and failures, as well as the functional sequence necessary for the damage to happen.
  - Damage caused by TID radiation damage opening a source-drain leakage current in **one** transistor in Feast2.1 chip
  - High-voltage transistors can not be designed in an enclosed layout to prevent this problem



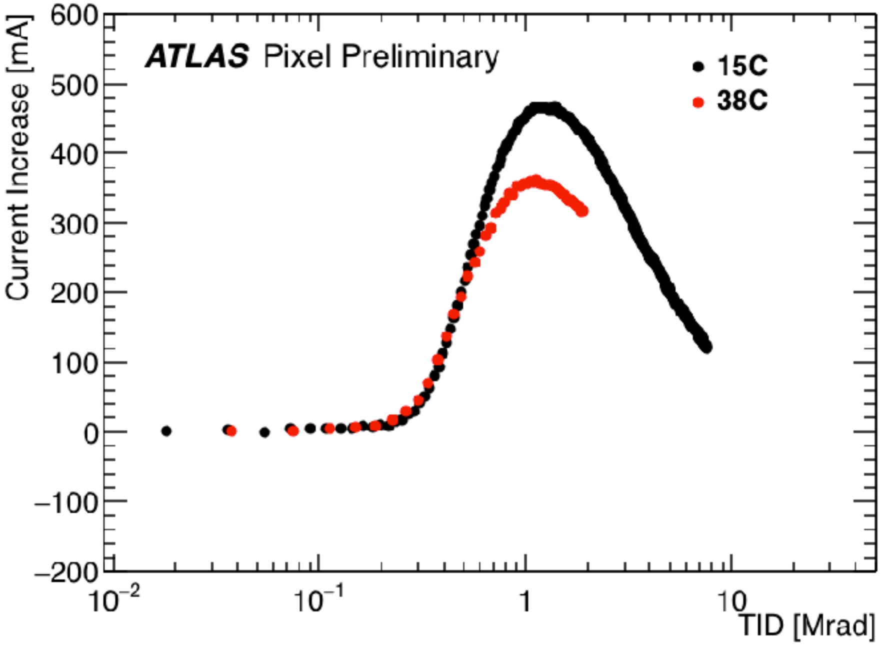
Feast2

Consequences for operation
- lower input voltage helps
- stop disabling the output

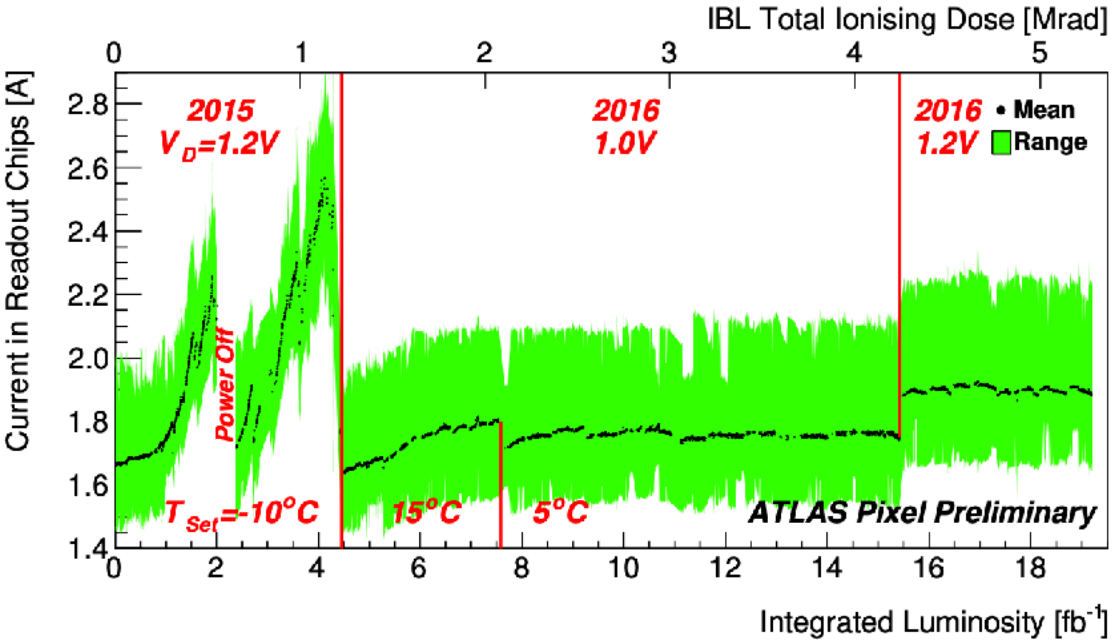
https://project-dcdc.web.cern.ch/project-dcdc/public/Documents/ExecutiveSummary2018.pdf
https://instrumentationseminar.desy.de/sites2009/site_instrumentationseminar/content/e70397/e282395/e287407/20190614_pixelphase1JIS.pdf

ATLAS IBL TID Bump

- Steep increase in power consumption of IBL during operation increasing the temperature
- Effect of total ionising dose on front-end chip FE-I4B
- Caused by the effect of TID on NMOS transistors:
  - Leakage current was induced by positive charge trapped
    in the bulk of the shallow trench isolation (STI)
  - Temperature and voltage depending



during running



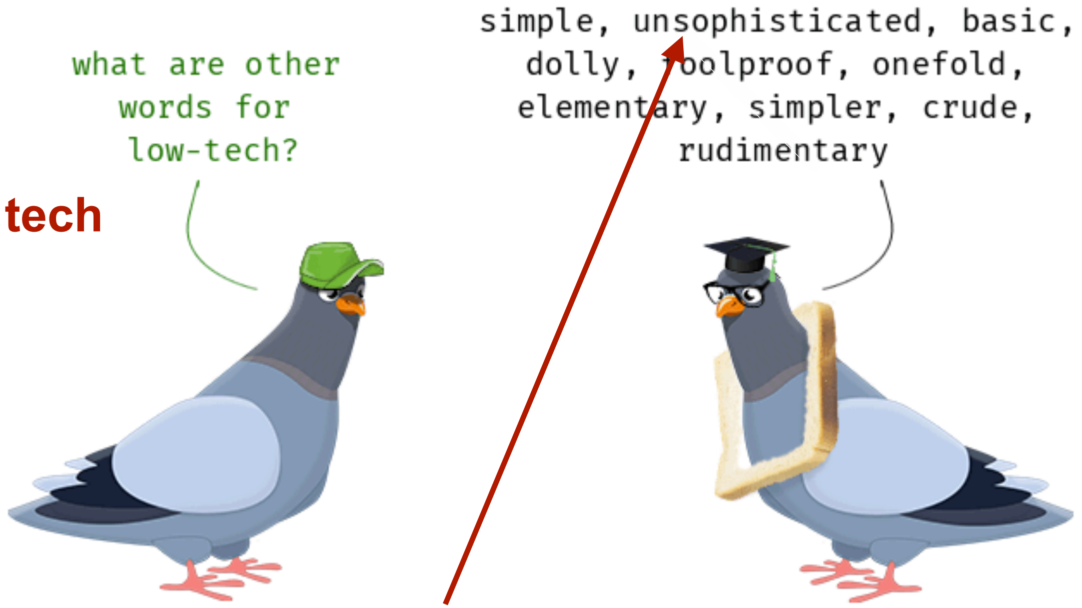
Mitigation plan:

- Operating temperature was increased from −10 ◦C to and 10 ◦C then decreased to 5 ◦C.
- Digital supply-voltage was decreased to from 1.2 V 1.0 V until TID approached more than 4 MRad.

"Low Tech" Failures

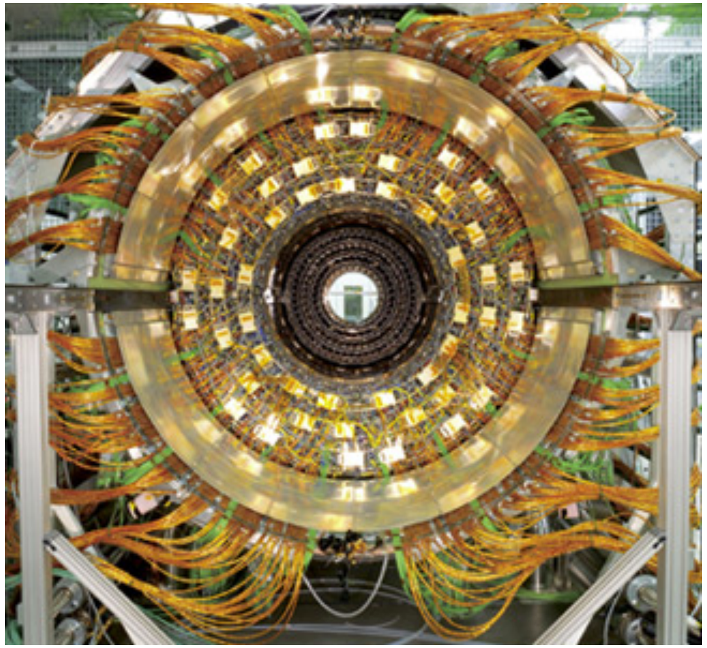
What is "Low" Tech ?

- In particle physics experiments almost everything is **high tech**
  - Need extreme reliability
  - Radiation tolerance
  - Precision
  - Mostly running longer than originally planned



For particle physics experiments this is not true !

- However - some areas considered as "low tech" and people (and funding agencies) don't like to invest research money into those areas
  - Cables for powering
  - Power plants
  - Cooling
  - Data transfer (optical and electrical)
  - Non sensitive materials (mechanics)
  - Glues
  - …..

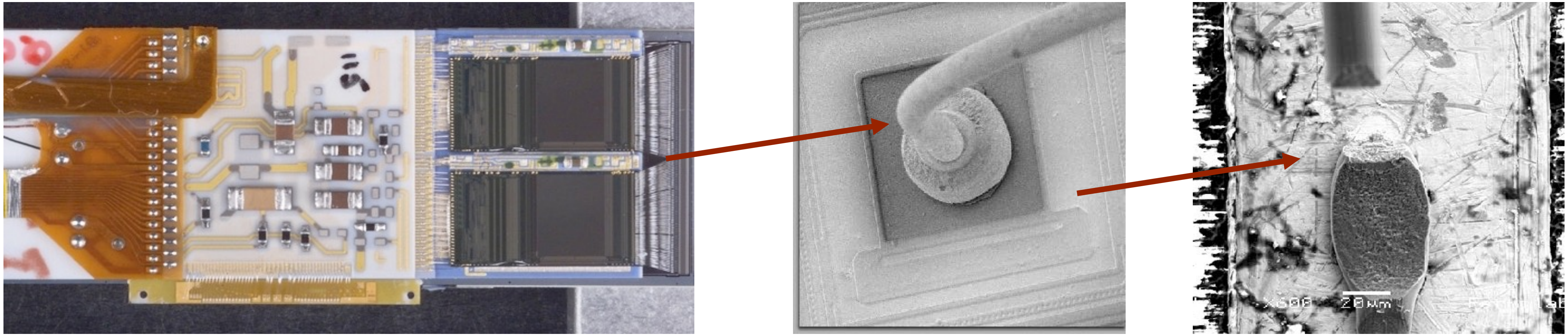


Wire-Bonds and Wire Breakage

Problems with Wire Bonds (CDF, D0)

during running

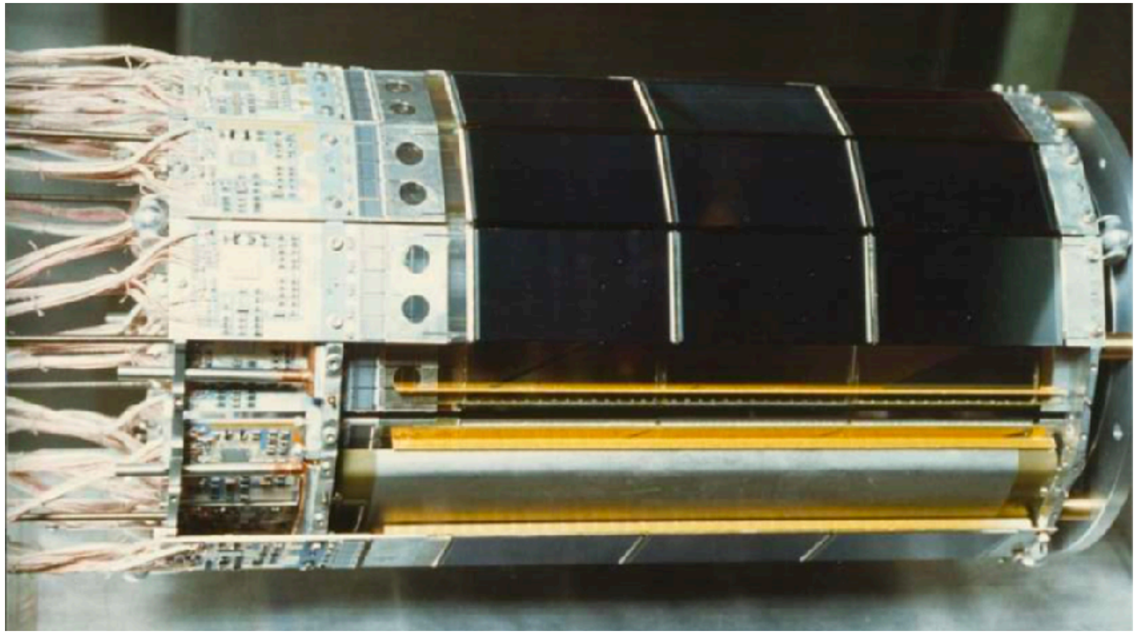
- Very important connection technology for tracking detectors: wire bonds:
  - 17-20 um small wire connection -> terrible sensitive ….
- Observation: During synchronous readout conditions, loss of modules (no data, Drop in current)



- Tests revealed:
  - Bonds start moving due to Lorentz Force in magnetic field
  - Wire resonance in the 20 kHz range
  - Current is highest during data readout
  - Already a few kicks are enough to get the bond excited

Implemented “Ghostbuster” system which avoids long phases with same readout frequency

OPAL MVD 1994



- OPAL MVD ran for a short while without cooling water flow.
- Temperature of the detector rose to **over 100°C.**
  - Most of the modules to fail or to be partially damaged.
- Chain of problem causing damage:
  - MVD expert modified the control/monitoring software between consecutive data taking runs.
  - Inserted bug which stopped software in a state with cooling water off but with the low voltage power on.
  - Stopped software also prevented the monitoring of the temperature from functioning
  - Should have been prevented by additional interlock but that was also disabled….

Lucky outcome:

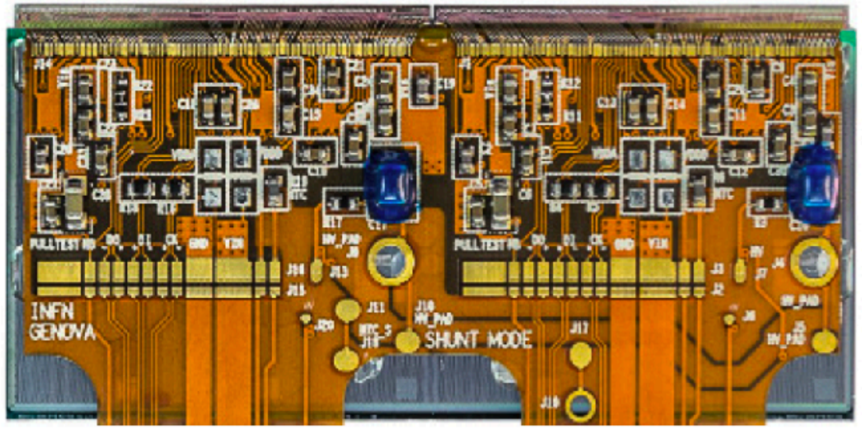
- Damage was mostly melted wire bonds
- Detector could be fixed in winter shutdown

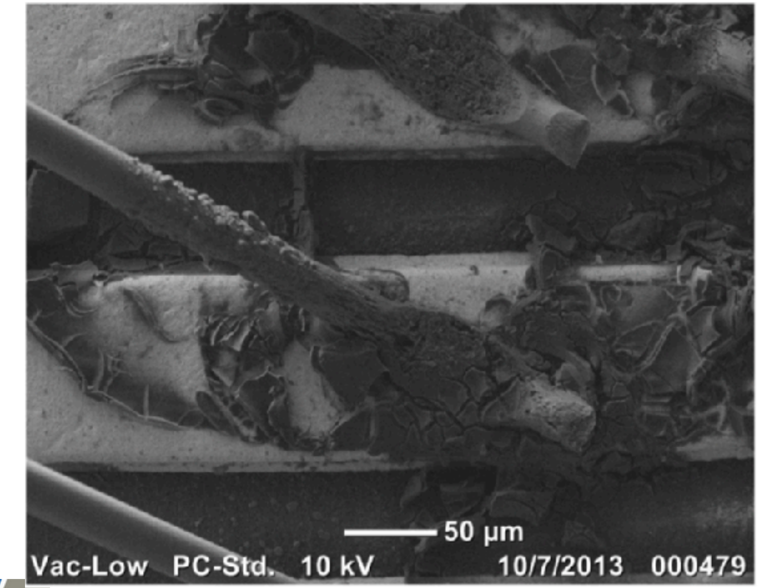
Mitigation plan:

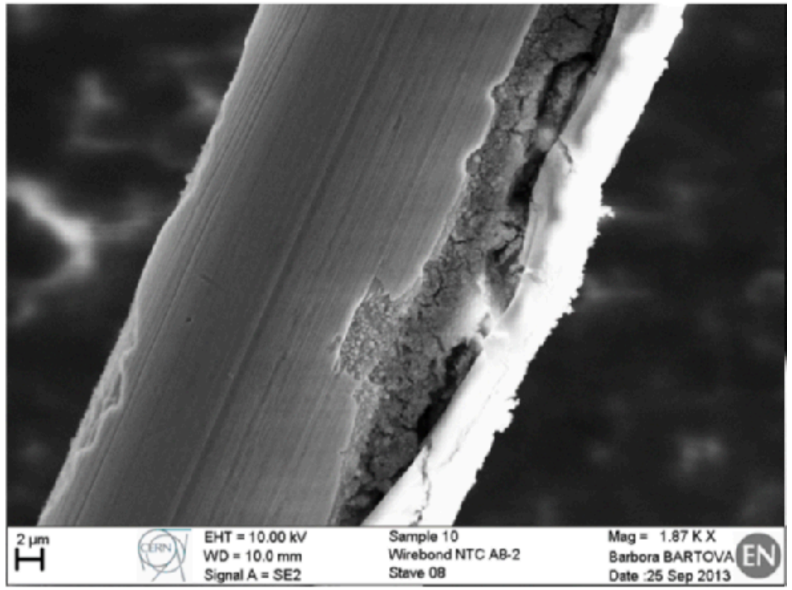
- new and more rigorous interlock system that could not be in a disabled state during data taking conditions.
- rule was implemented that prohibited software modifications between consecutive data taking runs.

ATLAS IBL - Wire Bond Corrosion

- Additional pixel layer for ATLAS installed in 2015
- Five months **before** installation: corrosion residues observed at wire-bonds after cold tests (-25 C)
  - Severe damage of many wire-bonds
- Residue showed traces of chlorine: catalyst of a reaction between Aluminium (wire-bonds) and H_2O (in air)
- Origin of chlorine in system never fully understood







- Emergency repair and additional staves from spare parts

during production

https://indico.cern.ch/event/435798/contributions/1074098/attachments/1134177/1622192/encapsulation_study_-_Oxford.pdf

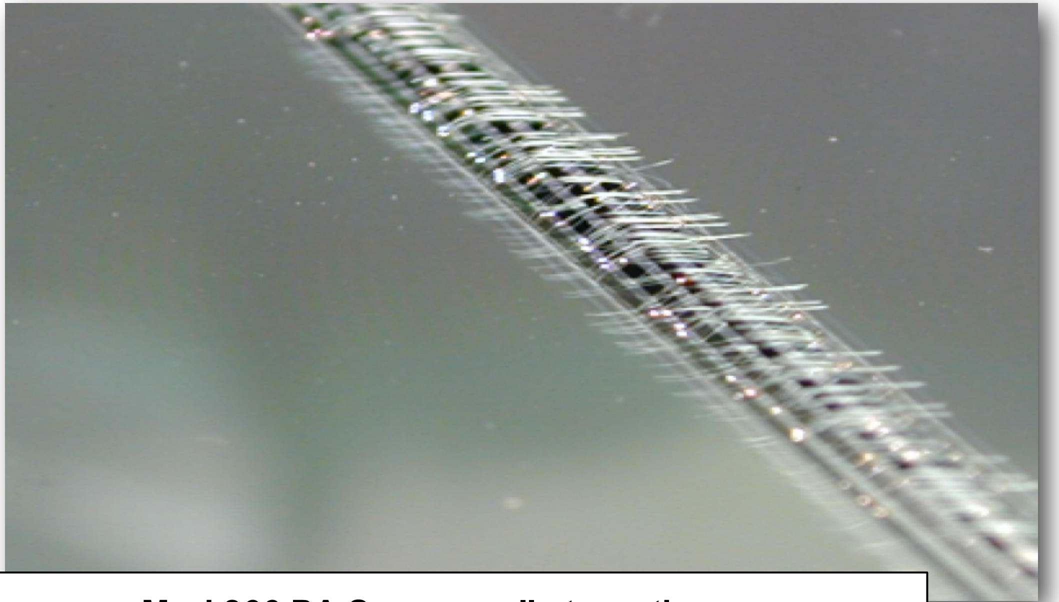
More Wire Bond Wreckage

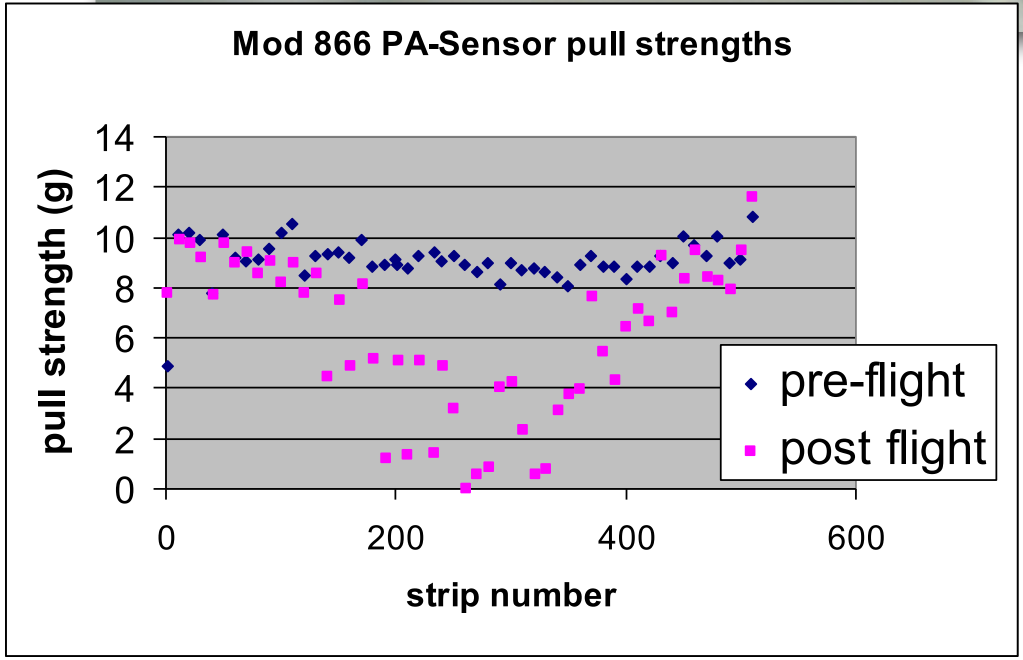
- During CMS strip tracker production quality assurance applied before and after transport
  - Quality of wires is tested by pull tests (measured in g)

- Wire bonds were weaker after transport with plane
- Random 3.4 g NASA vibration test could reproduce same problem

- Problem observed during production -> improved by adding a glue layer
- No further problems during production

during production

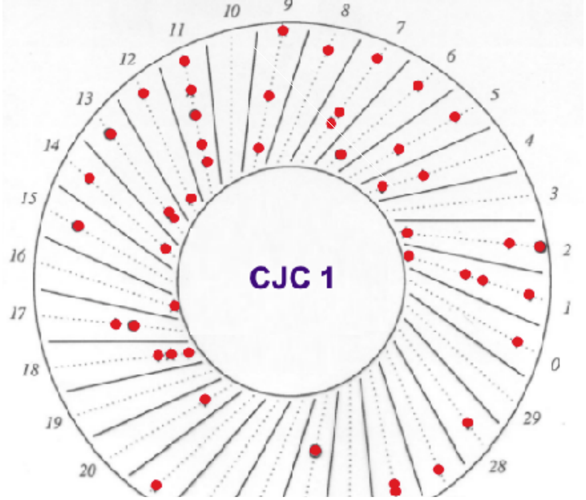




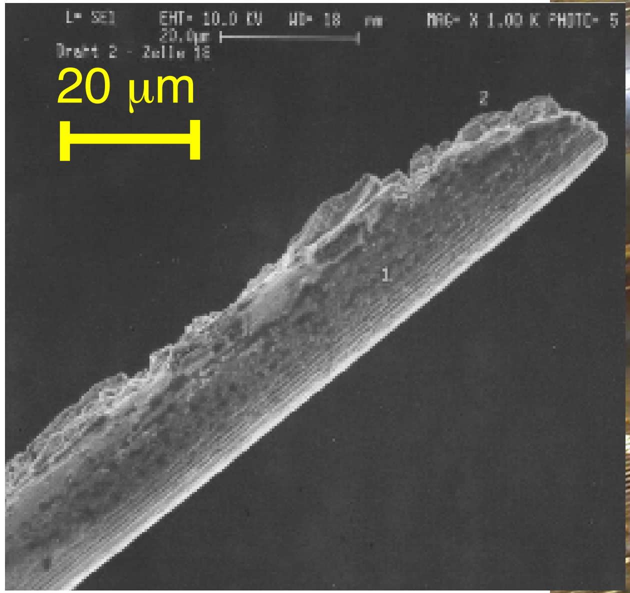
Wires H1 Central Jet Chamber

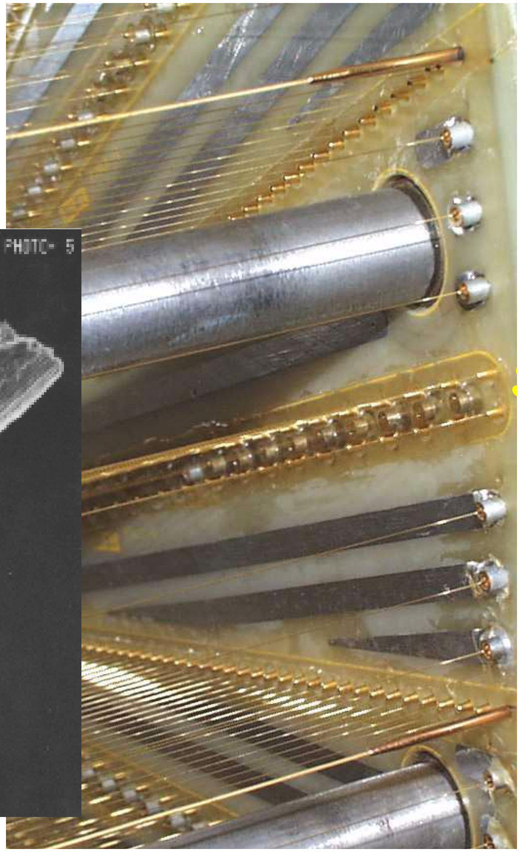
- Outer tracker of H1@HERA spontaneously broken wires in CJC1 observed during first shutdown (Dec 92)
- Observation / possible reason:
  - All wires broken close to wire ends
  - Remnants from gilding process of wire feed through
  - Sharp edges cause damage of gold layer on wires
  - Lead to complex chemical reactions
  - H induced brittle fracture

during running



- Replaced broken wires during next shutdown
- New design of crimp tube:
  - replace brass inserts in wire feed through by jewels
  - better quality control





Cathode

Sense/Pot

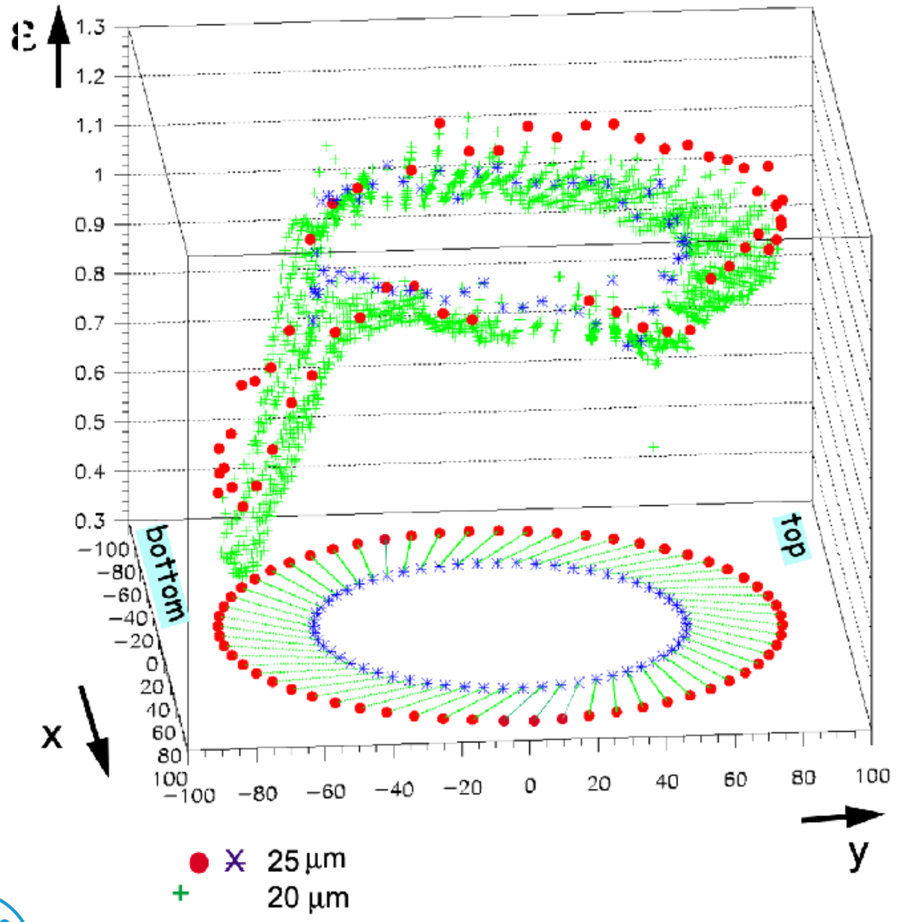
Cathode

http://www.desy.de/agingworkshop/trans/ps/niebuhr.pdf

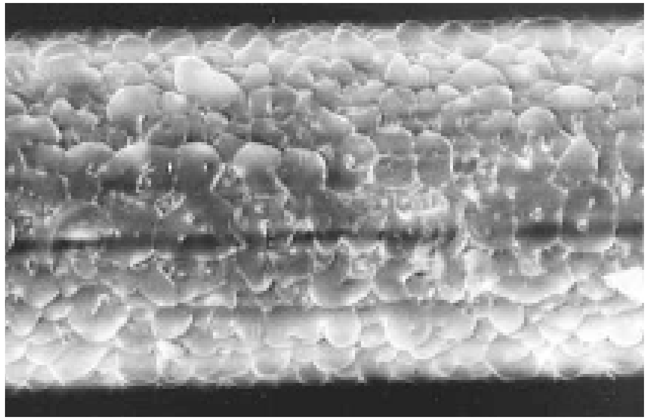
Wires H1 Central Jet Chamber

during running

Wire efficiency vs. position end of 1997



- Sense Wire Deposits in outer jet chamber CJC2
- Observation / possible reason:
  - y dependence implies most likely gas impurity
  - Source of contamination not clear
  - Problem was not observed in CJC1 which had the same gas system
  - Only difference: gas ring



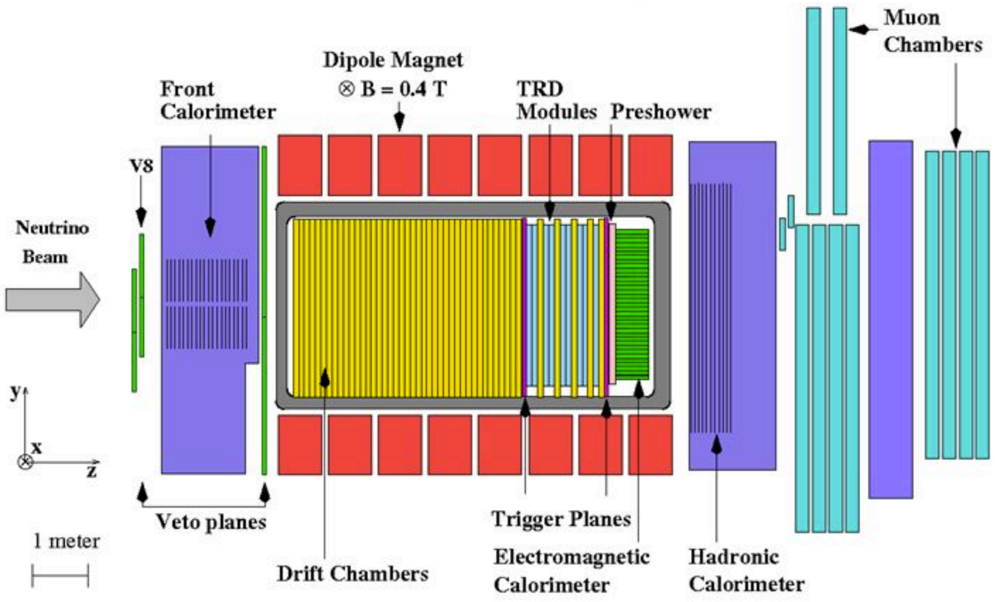
Sample wire with substantial deposit

Consequences:
- sense wires replaced
- changes in gas distribution
- increased gas flow

http://www.desy.de/agingworkshop/trans/ps/niebuhr.pdf

Nomad Detector

- NOMAD (neutrino oscillation magnetic detector) experiment which took data in the CERN wide-band neutrino beam from 1995 to 1998
- Drift-chambers: glued strip bands with adhesive technique and carefully tested this method
- After several weeks of operation suffered from short circuits in many chambers
  - Honeycomb material developed gas bubbles and came apart
  - Probably due to the moisture gradient between the outside of the chamber and the dry gas in the drift gap



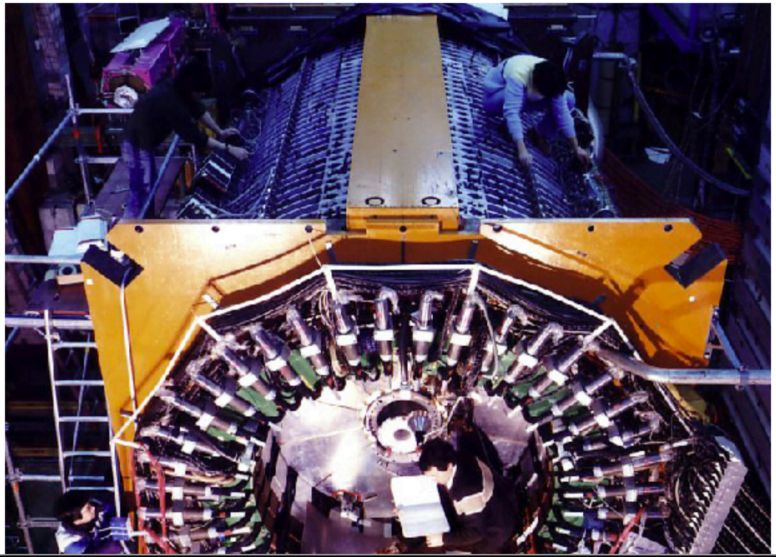
during commissioning

Repaired 25 chambers with different glue technique.

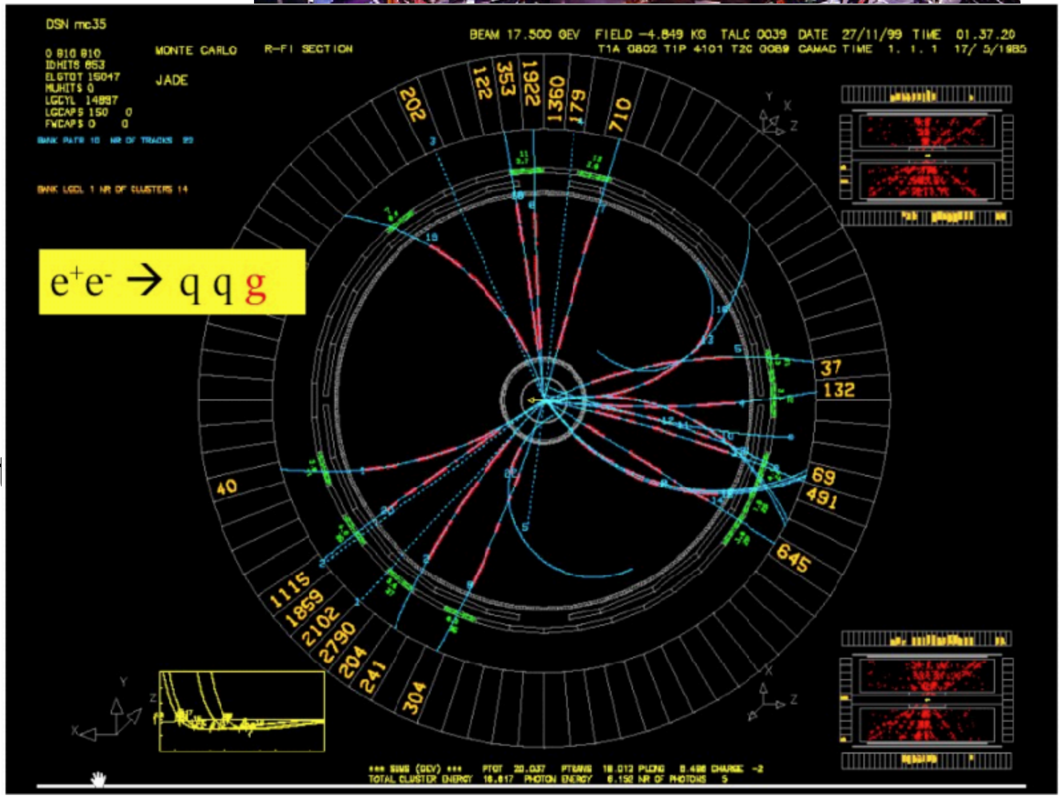
https://www.sciencedirect.com/science/article/pii/S0168900201013717

JADE@PETRA

during commissioning



- Going back to 1978 …
- One of the Petra experiments
  (besides MARK J, PLUTO, TASSO, CELLO)
- During beam commissioning the Petra beam was dumped directly into the central jet chamber
  - too high beam current
  - damaging a number of cells
- Chambers had to be taken out and repaired

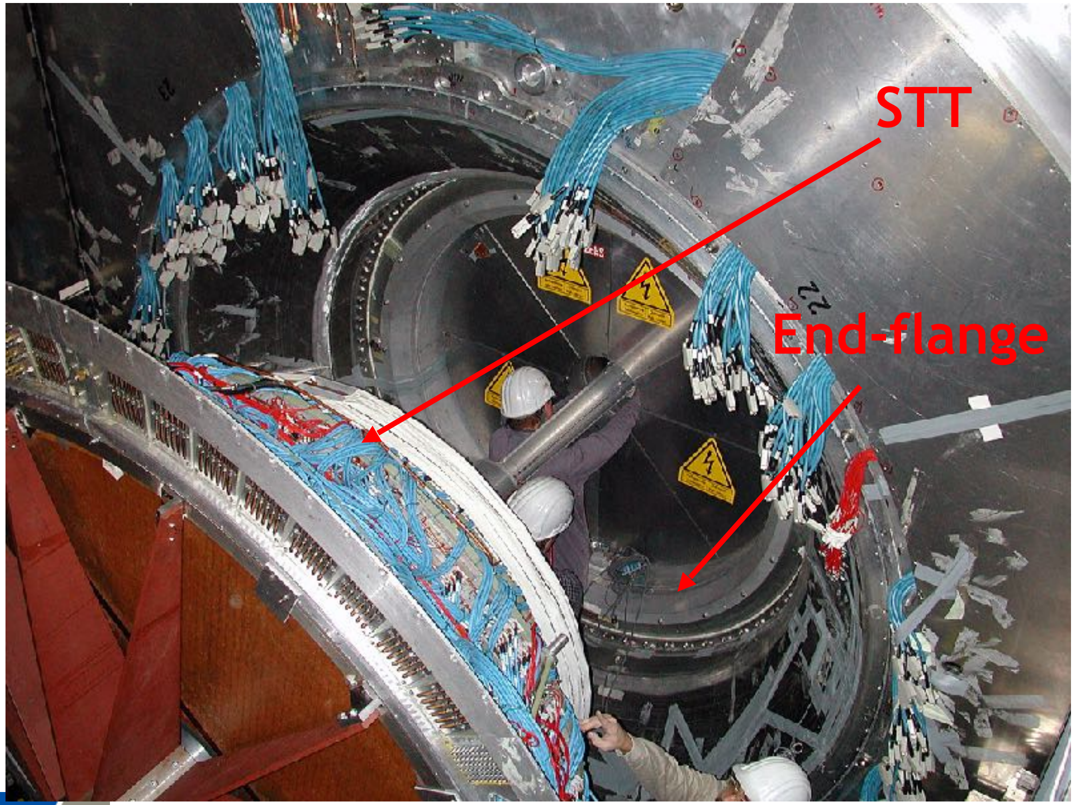


- Reinstallation and commissioning still in time to be part of t
  gluon discovery in 1979

Cooling Damages

Cooling of ZEUS Straw Tube Tracker (STT)

- After an upgrade of the on-board electronics, the STT caused instabilities of the insulation vacuum of the ZEUS Magnet
- FDET cooling is insufficient (thermal contact between electronics and cooling)
  - Heating of inner cylinder of solenoid (1 kW cooling power missing)

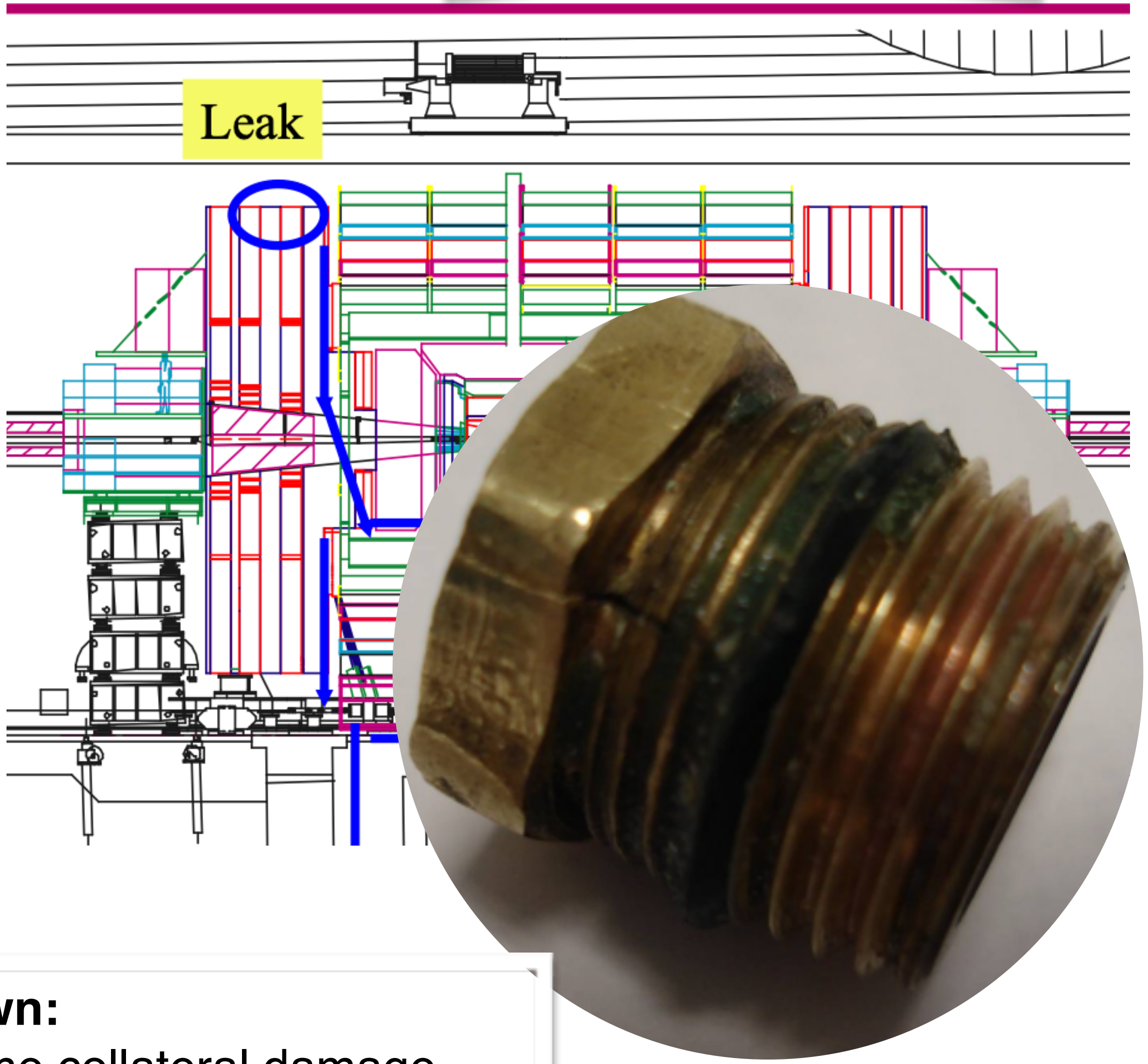


Solution
Winter Shutdown 2005/06: removal of STT with special Jig
- Add cooling on STT
- Exchange and re-tighten all screws of the end-flange of the ZEUS magnet

CMS Water Leak

during commissioning

- In October 2009 a sever water leak was observed in the CMS experiment
- An initially small leak dramatically worsened, about 100 litres of water were released affecting several subsystems.



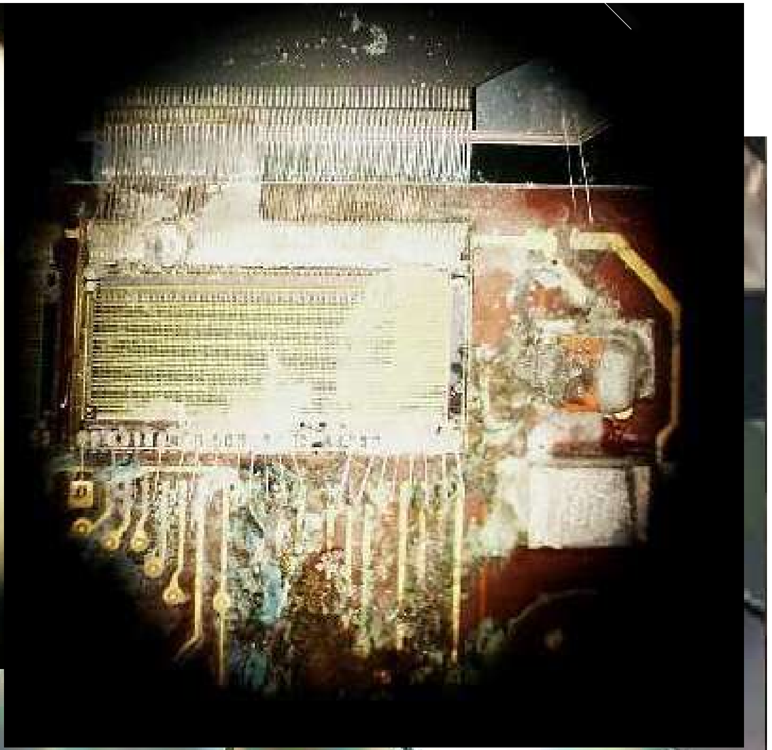
- Cause: Stress corrosion phenomenon due to
  - geometry of the bushing (very thin section)
  - probable over-tightening
  - type of alloy used, particularly susceptible to stress corrosion cracking

Repair during winter shutdown:
396 bushings changed and some collateral damage repaired

Water Damage in Tracker …

- H1@HERA FST in 2004
- Imperfect crimp + hardening of plastic (age, irradiation) => water leak
- Water condensation => damage
- Tracker segment had to be rebuilt

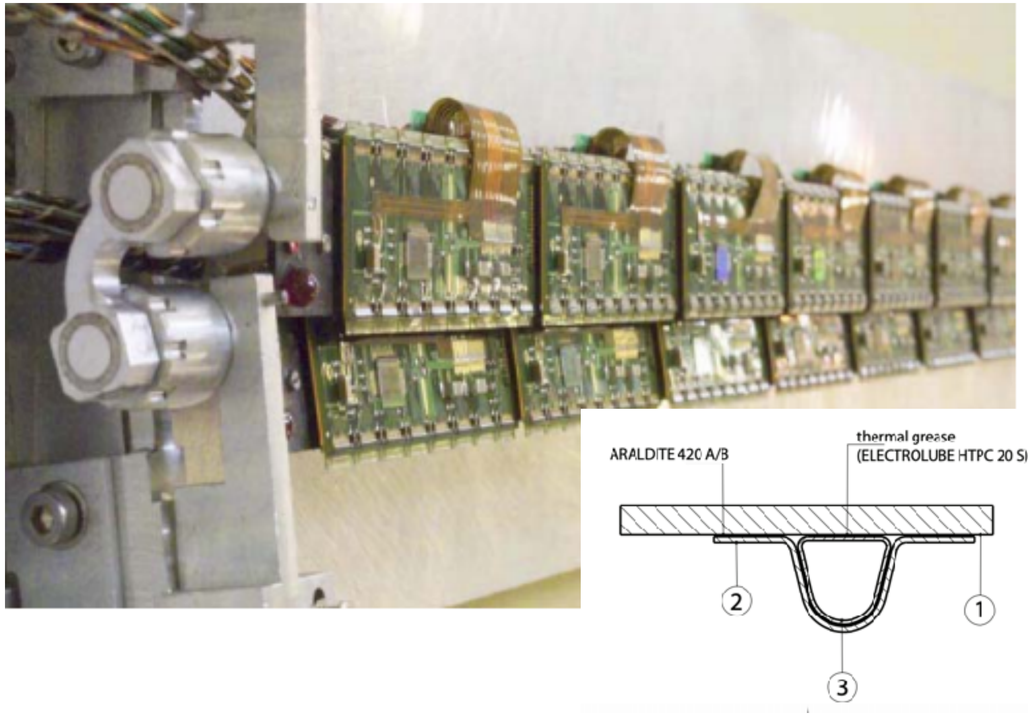
during running

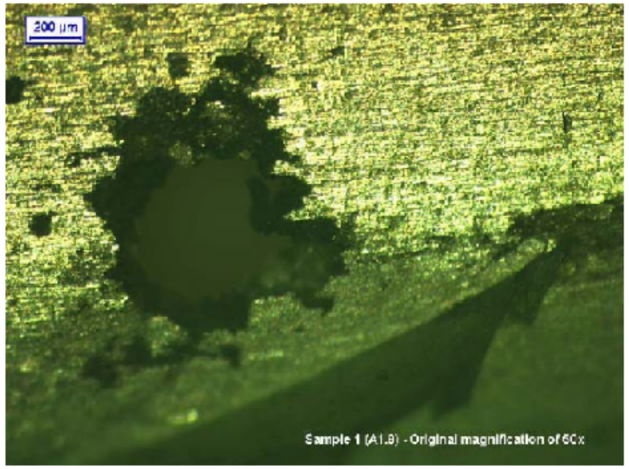


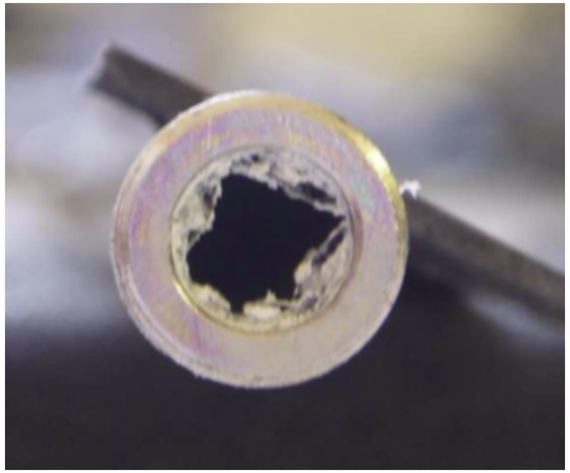
ATLAS Pixel Tube Corrosion

during production

- Cooling tube of current pixel layers were supposed to be very light in material
  - Bare pipe material (Al)
  - Ni plating used to allow for brazing of the pipe fittings
  - No proper drying procedure → water
- Water triggered corrosion process in the aluminium pipes.
  - Corrosion was due to galvanic process where water and traces of halogen (like Cl) acted as electrolyte.
  - Effect of the galvanic corrosion led in some cases to holes in the pipe.



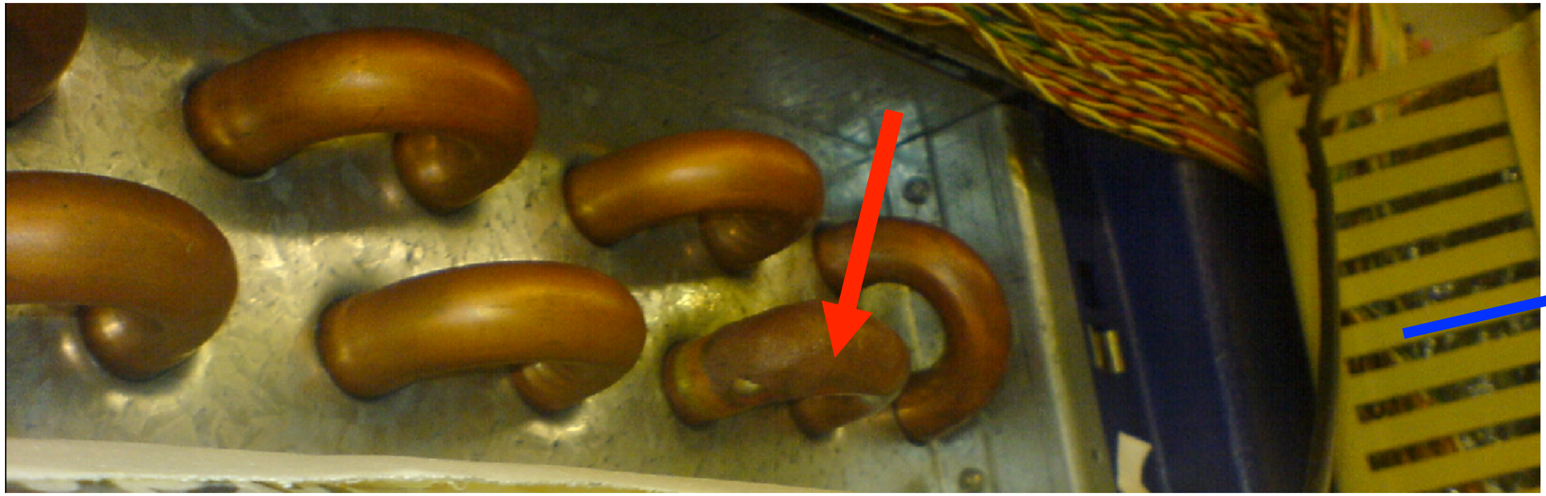


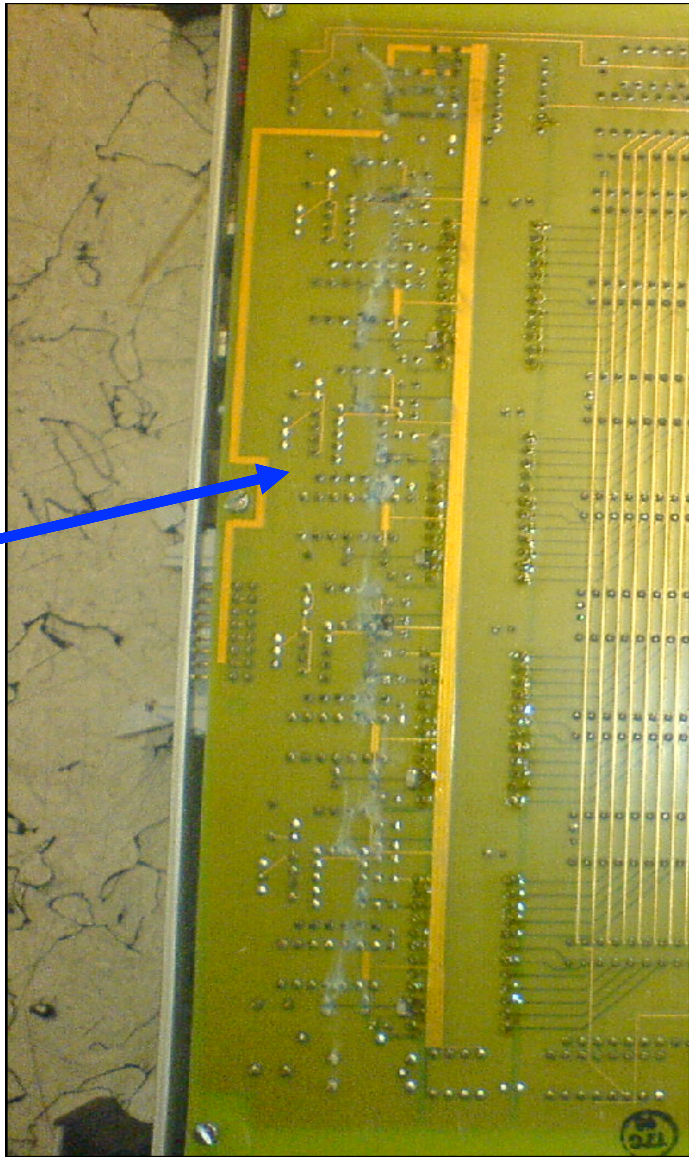


Six months delay in schedule
- Repair the 43 loaded staves with a pipe-inside-the-pipe
- Production of new staves with new Al compound and laser welding
- Repair of bare staves (~100)

ZEUS Calorimeter - One more Water Leak

- Micro hole in copper hose led to water in the digital card crates
- Four crates were affected, but only seven cards were really showing traces of water





- Where ever you chose to cool with a liquid - it will leak one day !

during running

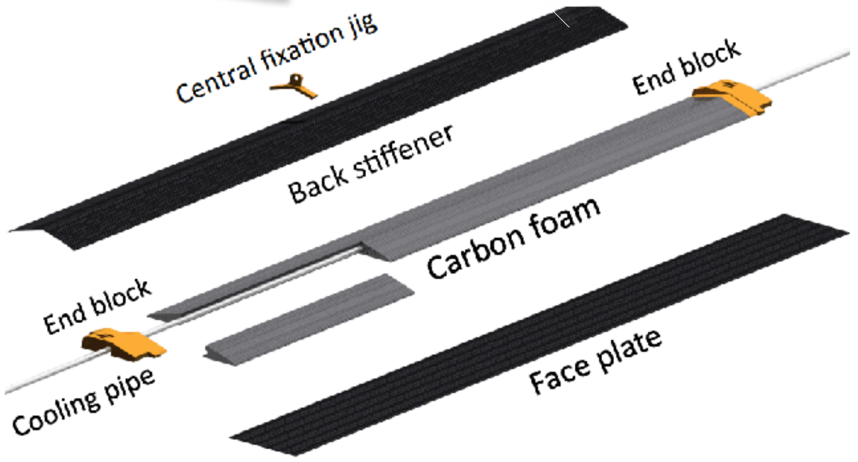
Of course this all happened on a Saturday morning at 5am ….

Other Problems and Famous Problems

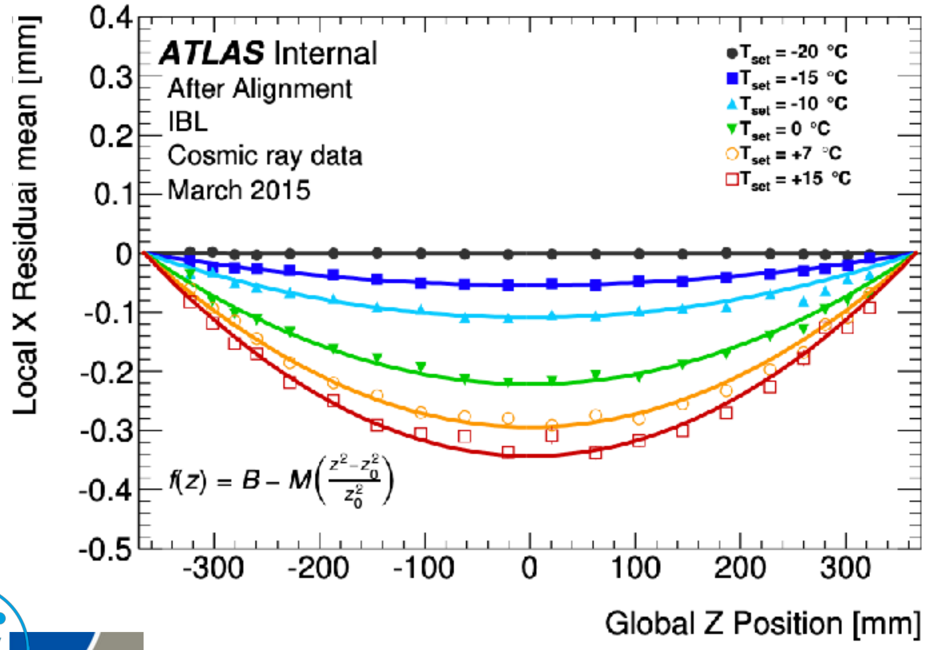
ATLAS IBL Stave Bow

during commissioning

see Petra on Feb 25

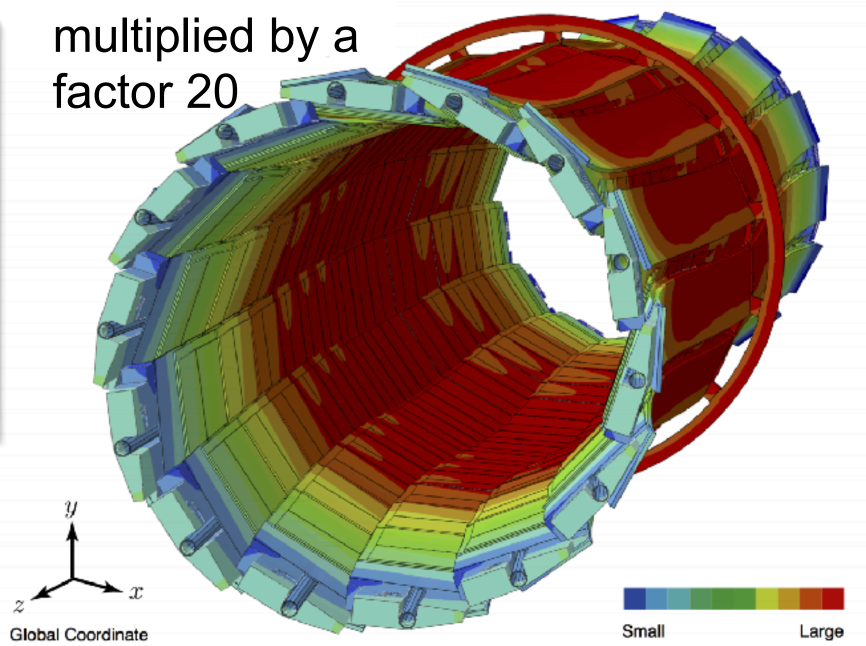


- Distortion depending on the operating temperature was observed.
- Caused by a mismatch between the coefficients of thermal expansion (CTE) of a bare stave made with the carbon foam and the flex attached on the bare stave.
- Maximum more than 300 μm at -20 ◦C with respect to the nominal position at the room temperature.



Mitigated by temperature control at the level of 0.2 K and the regular alignment correction in the offline reconstruction

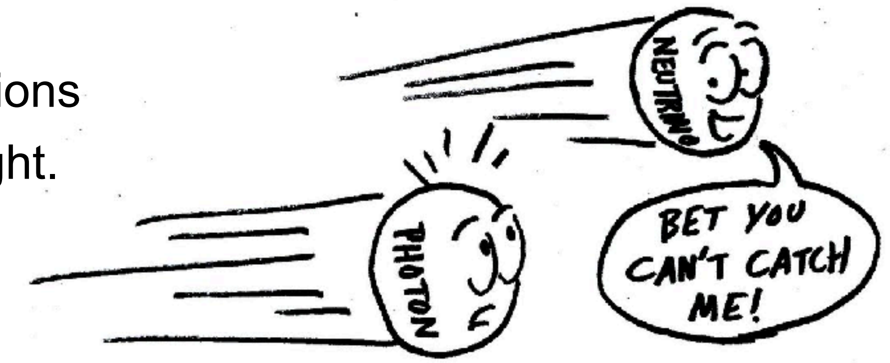
multiplied by a factor 20



http://cds.cern.ch/record/2022587/files/ATL-INDET-PUB-2015-001.pdf

Cable Problem with Press Coverage

- Oscillation Project with Emulsion-tRacking Apparatus — **OPERA:** instrument for detecting tau neutrinos from muon neutrino oscillations
- In 2011 they observed neutrinos appearing to travel faster than light.
  - Very controversial paper also within collaboration



The top 10 biggest science stories of the decade

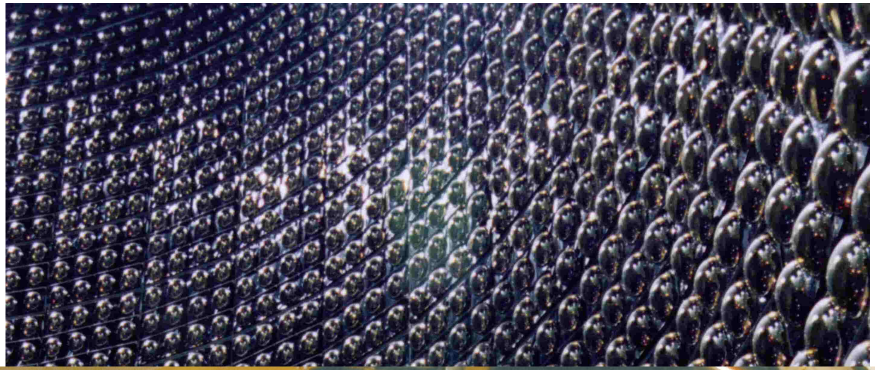
- Kink from a GPS receiver to OPERA master clock was loose
  - Increased the delay through the fibre resulting in decreasing the reported flight time of the neutrinos by 73 ns,
  - making them seem faster than light.

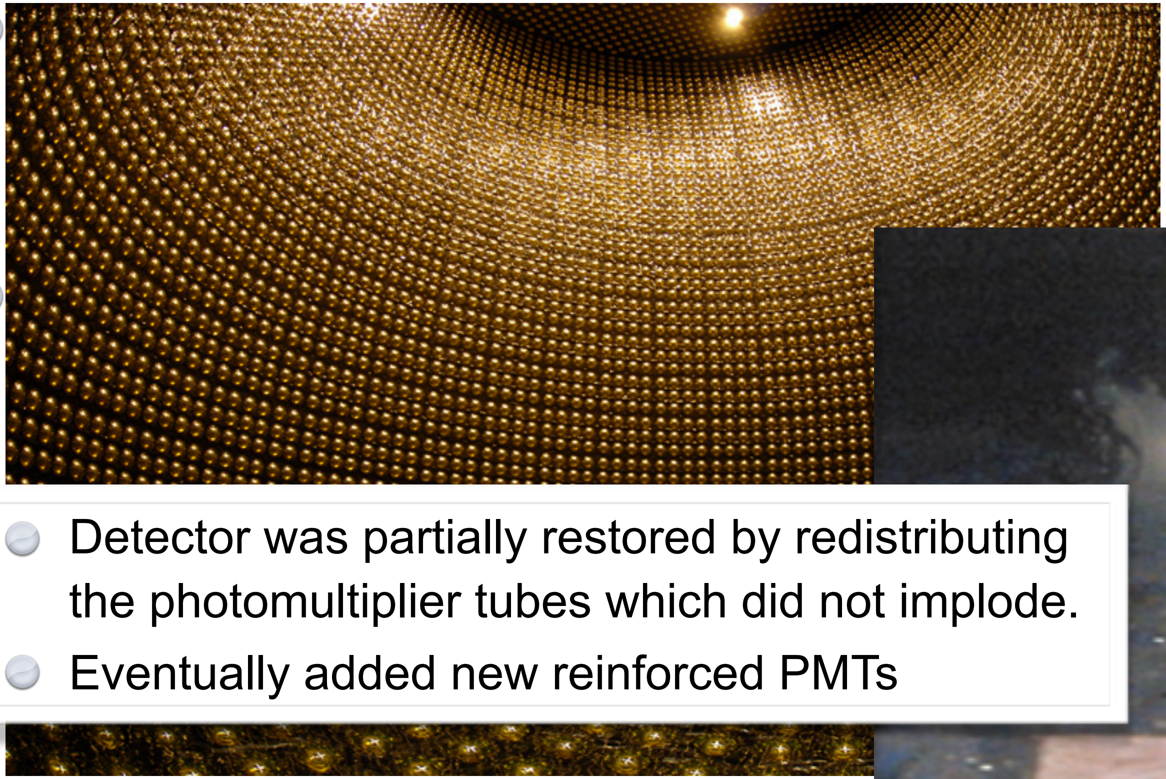
> After finding the problem, the difference between the measured and expected arrival time of neutrinos was approximately 6.5 ± 15 ns.

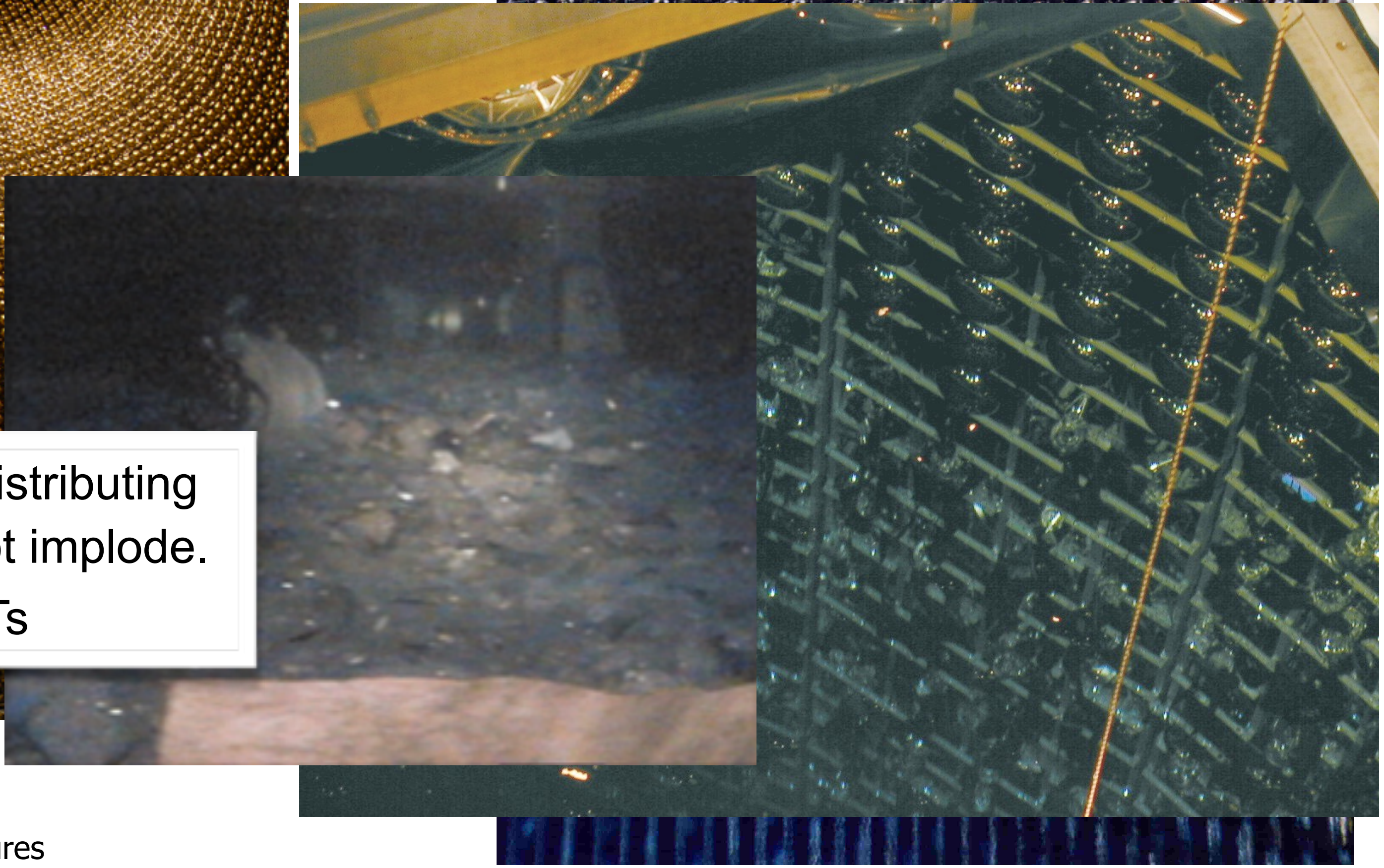
Maybe Most Famous Damage ....

during commissioning

- Underground water Cherenkov detector with 50,000 tons of ultrapure water as target material
- Nov 2001: One PMT imploded creating shock wave destroying about 7700 of PMTs







- Detector was partially restored by redistributing the photomultiplier tubes which did not implode.
- Eventually added new reinforced PMTs

Pic: unknown source....

Conclusions

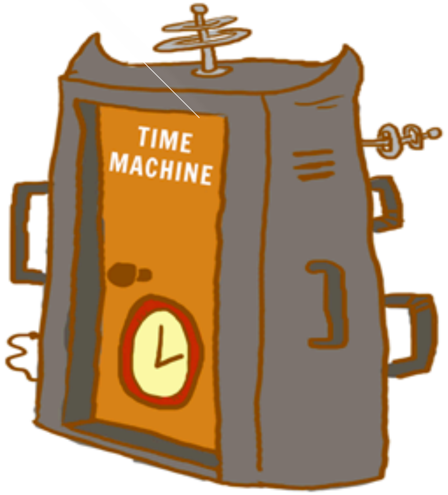
- Large detectors are typically build up in layers
  - Inner tracking: momentum measurement using a B-field
  - Outside calorimeter: energy measurement by total absorption
  - Many factors play a role in the overall concept
- Many different technologies:
  - Gas- and semiconductors (light material) for tracking
  - Sampling and Homogeneous calorimeters for energy measurement
- A lot of effort and good ideas are put into the main detecting technologies to develop cutting-edge detectors for the next generation particle physics experiments

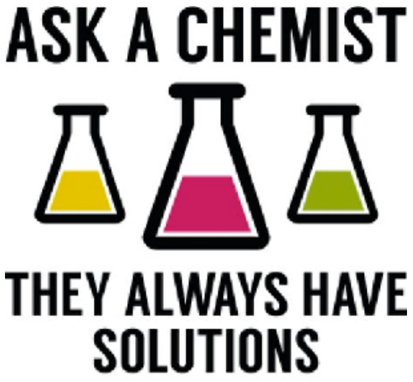
- **BUT: the devil sits in the details**

Lessons Learned ?

- Spend enough time on simulating all aspects of your detector with ALL materials implemented
- Don't underestimate the "low tech"
  - Cables
  - Cooling
  - Mechanics including FEA
  - Radiation damage of non-sensitive materials
  - …..
- Make sure the overall timeline is not completely crazy (tough job)
- When mixing materials — ask a chemist once in a while
- Better is the enemy of good enough (Marty Breidenbach)
- …..

Solving and preventing theses kind of problems is also part of the fascination of detector physics!!





"To succeed planning alone is insufficient. One must improvise as well."

Isaac Asimov

Important ....

Lots of input from

Alan Homna

Christoph Rembser

Daniel Pitzl

Doris Eckstein

Benno List

Achim Geiser

Didier Ferrer

Frank Hartmann

Carsten Niehbuhr

Marcel Stanitzki

Fabian Hügging

Ulrich Koetz

Wolfram Zeuner

Katja Klein

Jaehoon Yu

Google search ;-)

Bernhard Schmidt

Ties Behnke

.... and many more!

TID Bump

Surface effects: Generation of charge traps due to ionising energy loss (Total ionising dose, TID)
(main problem for electronics).

- The leakage current is the sum of different mechanisms involving:
  - the creation/trapping of charge (by radiation)
  - its passivation/de-trapping (by thermal excitation)
- These phenomena are dose rate and temperature dependent!

- Charge trapped in the STI oxide
  - +Q charge
  - Fast creation
  - Annealing already at T_{amb}
- Interface states at STI-Silicon interface
  - -Q for NMOS, +Q for PMOS
  - Slow creation
  - Annealing starts at 80-100C

STI = shallow trench interface