Particle showers

Lessons from high energy physics

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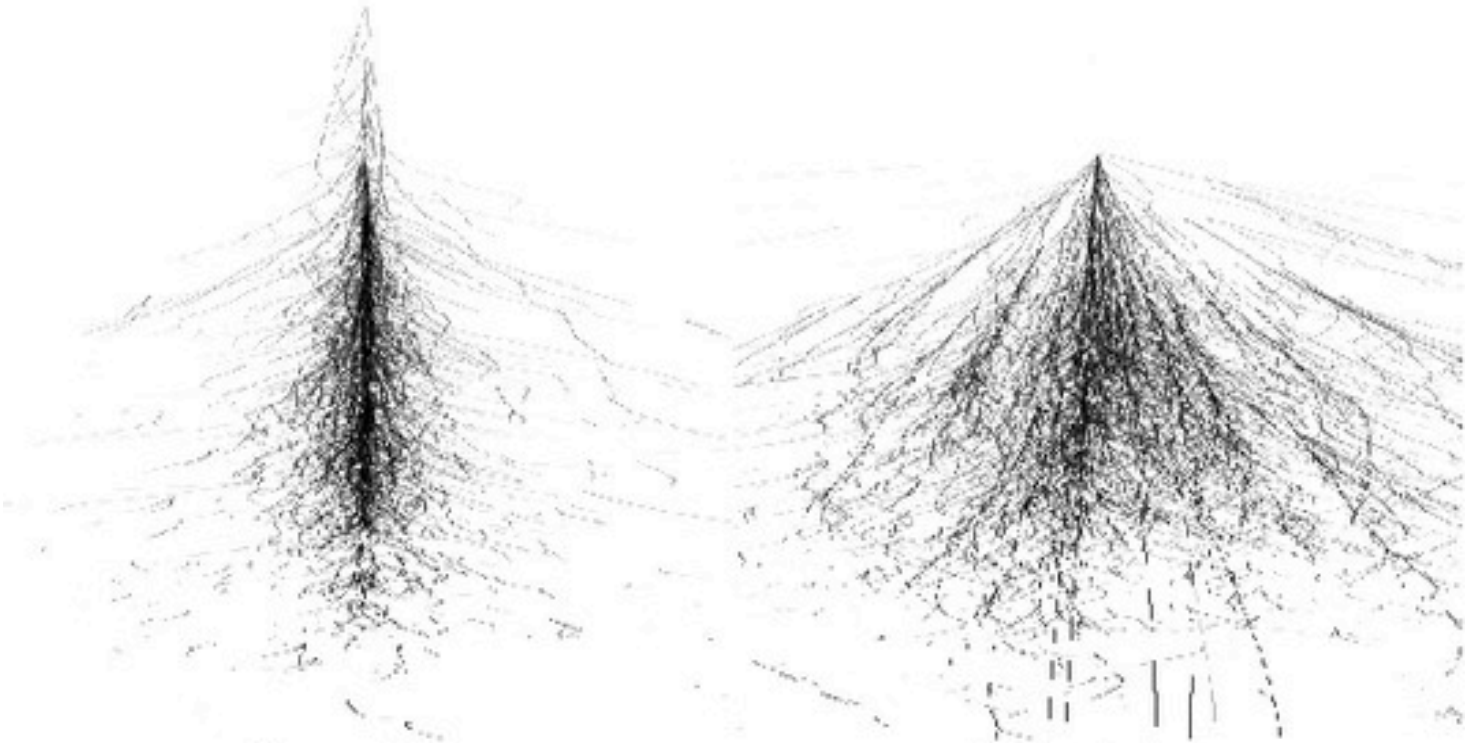
Topics addressed

- Electromagnetic & hadronic particle showers
- Useful quantities for their description
- Applications & experience from other fields
  - High Energy Physics (CMS, ZEUS, ALICE, HADES)
- Simulation tools (GEANT)

Electromagnetic vs. hadronic showers

- slender shape
- axially symmetric around the primary direction

- irregular shape due to large p_t particles
- contain EM showers



Gamma shower

Hadronic shower

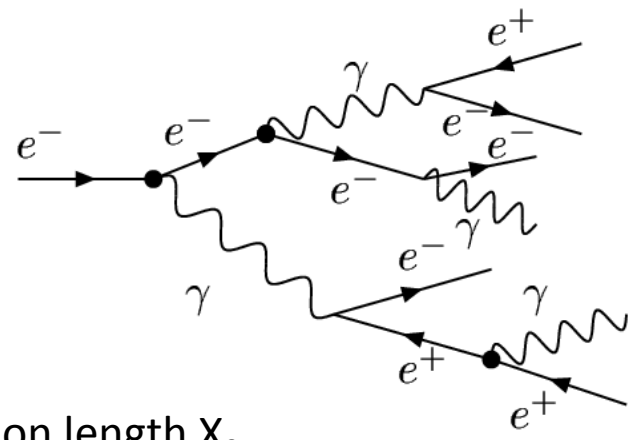
Physics processes within a shower

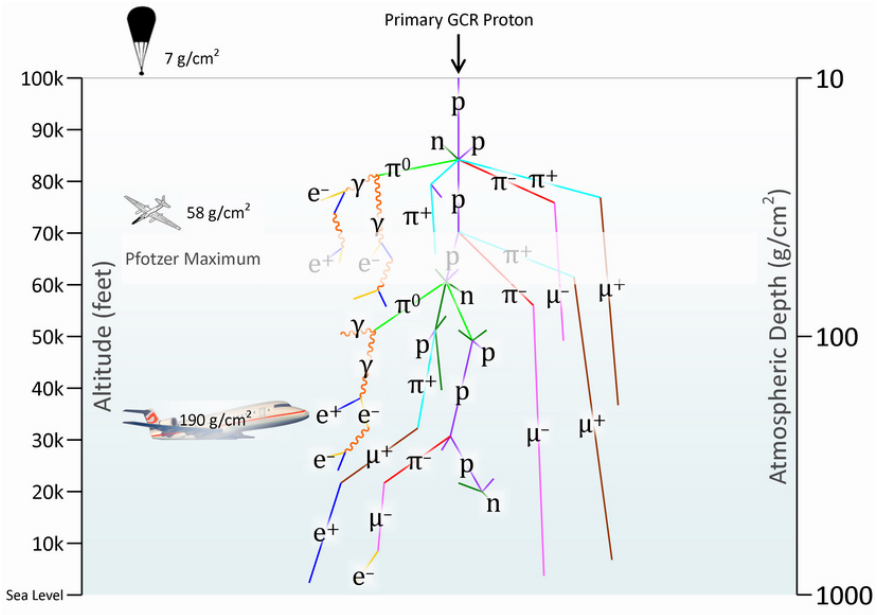
- bremsstrahlung
- photon conversion
- particle-antiparticle annihilation
- hadronic processes -> baryons + light mesons + leptons
- nuclear effects, e.g nucleon evaporation, spallation, excitation
- particle decays (2-body, Dalitz)
- photonuclear interactions, e.g. (γ,p), (γ,n), (γ,2p)
- production of heavier (strange) baryons

Need for

- a suitable validated simulation tool
- reliable measurements of energies and particle species

Useful quantities





radiation length X_0

- material dependent, f(A, Z)
- mean distance over which a high-energy electron loses all but 1/e of its energy via bremsstrahlung

or

- 7/9 of the mean free path for pair production

shower depth $X = X_0 \ln(E_0/E_c)/\ln 2$

- logarithmic increase with energy

Molière radius: transverse scale of the EM shower

- $f(X_0, Z)$

interaction length λ

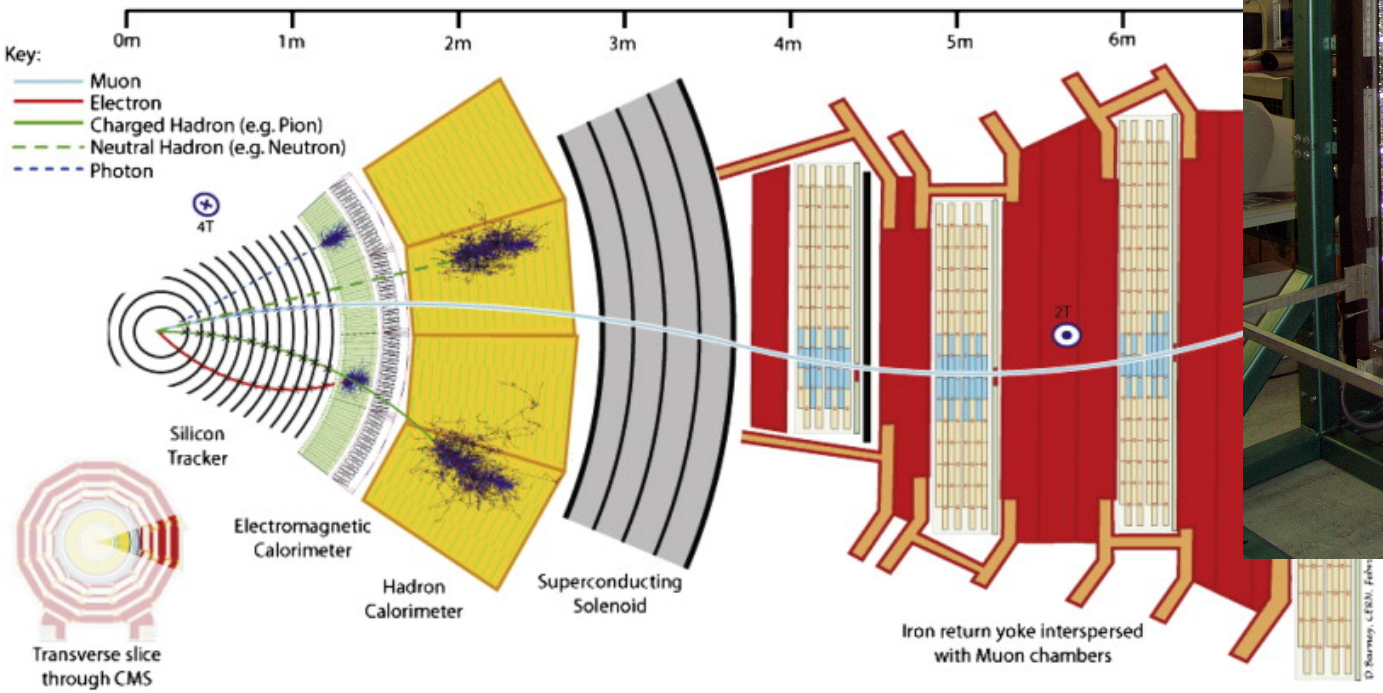
- material, particle and energy dependent
- mean distance travelled by a hadron before undergoing an inelastic nuclear interaction
- inverse of macroscopic cross section
- usually 5-10 > X_0 hence the large size and weight of hadronic calorimeters

Calorimetry Principles

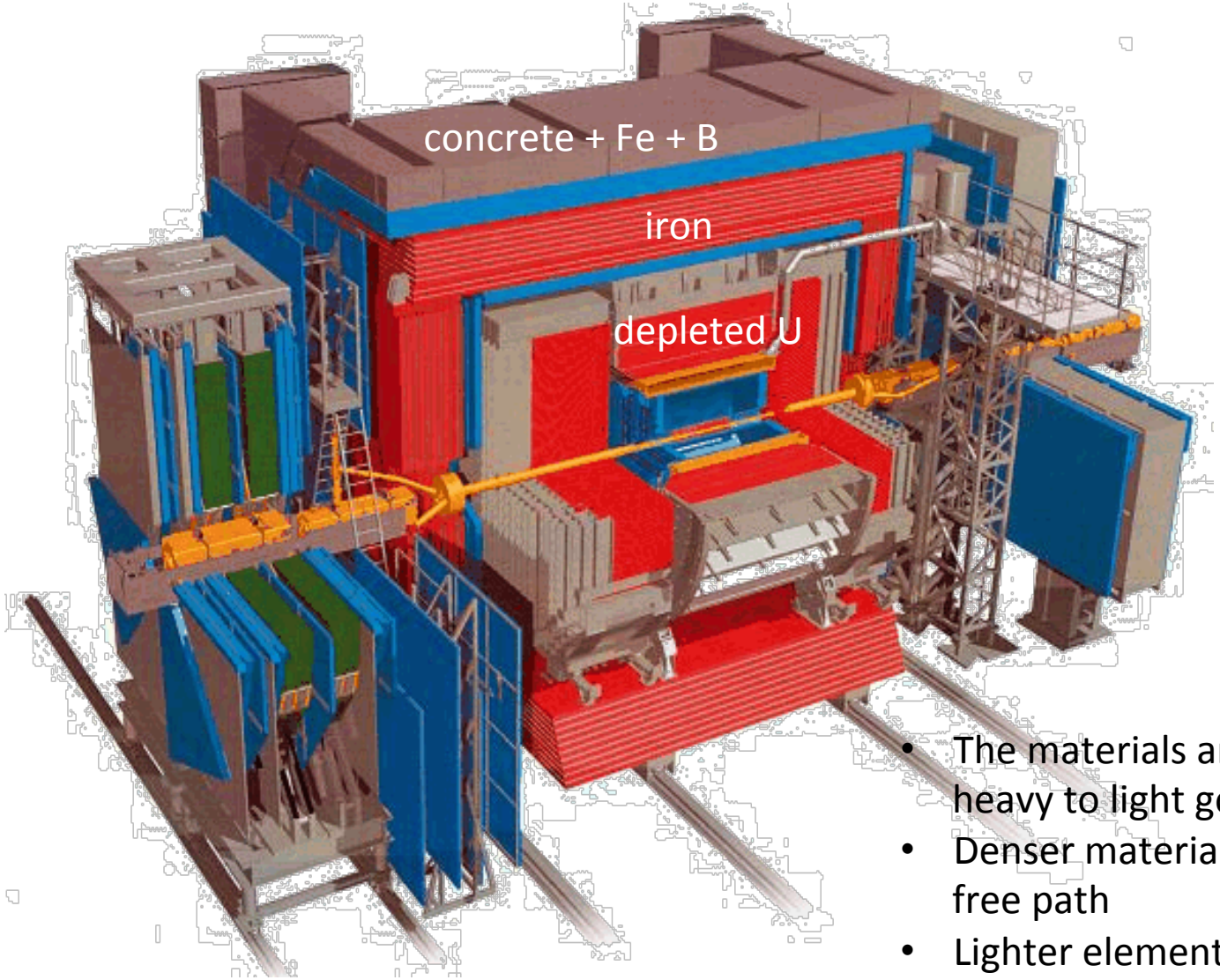
- Destructive detection technique
- Full dissipation of particle energy, particles are stopped
- Calorimeters are placed in the outer part of the detector
- Common materials used: PbWO4, U, Fe, brass, steel
- However there are additional requirements:
  - Energy resolution and particle identification

ALICE EM calorimeter

CMS EM and hadronic calorimeter



The ZEUS spectrometer



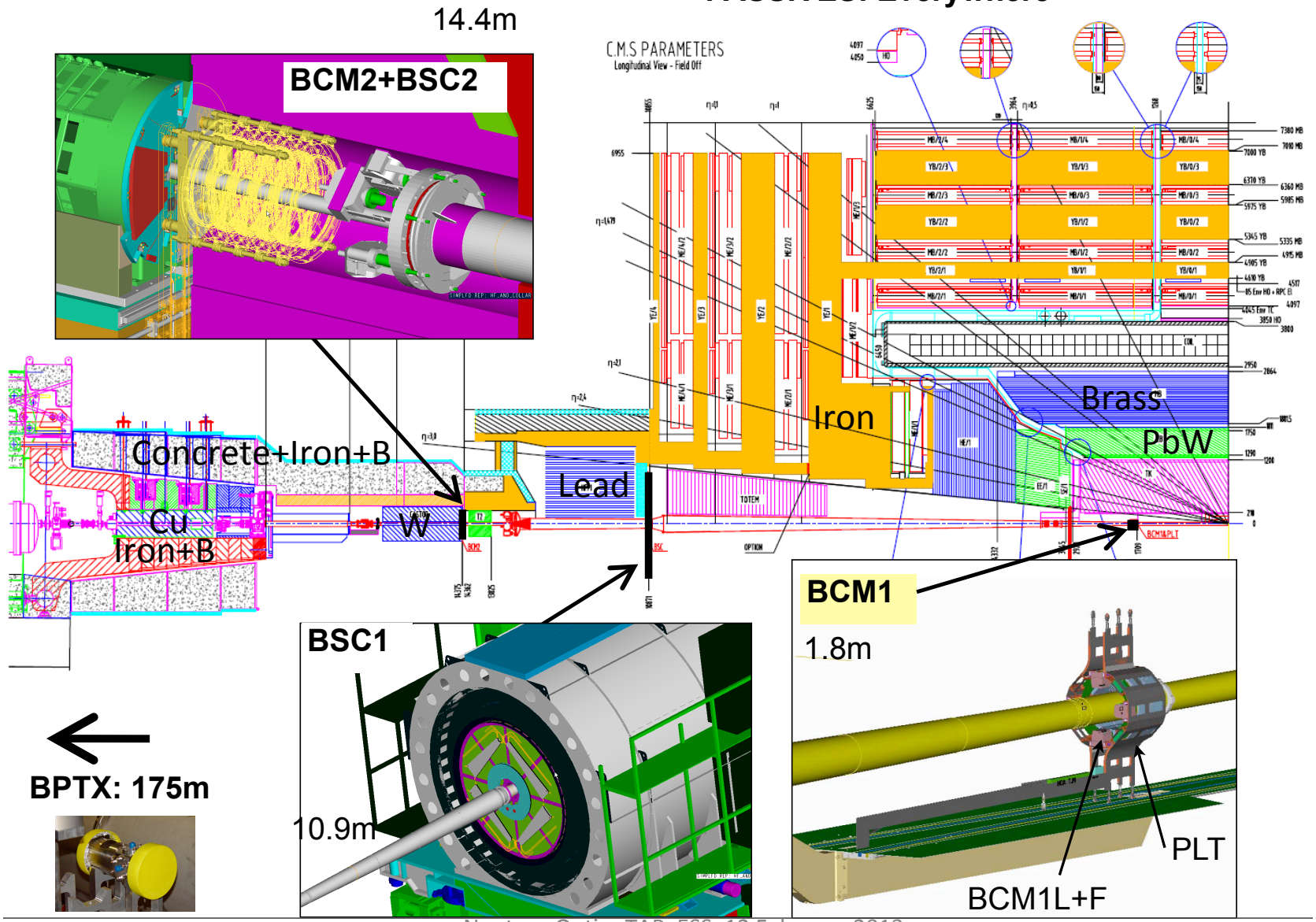
- The materials are ordered from heavy to light going outwards
- Denser materials reduce the mean free path
- Lighter elements at the end produce fewer photons

Overview of CMS beam and radiation monitoring

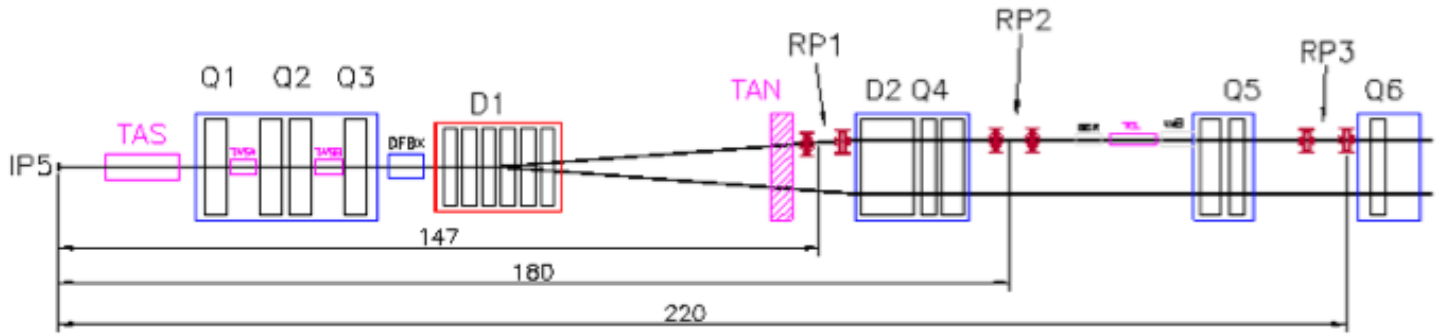
Diagram of Location of BRM+PLT Subsystems

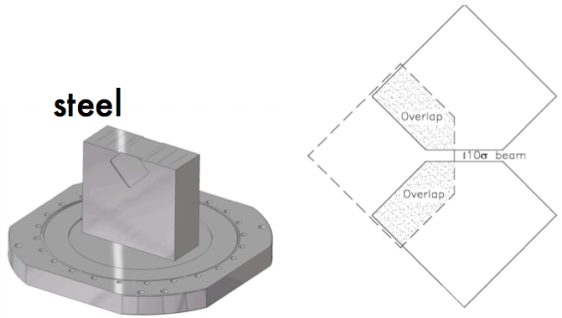
RADMON: 18 monitors around UXC

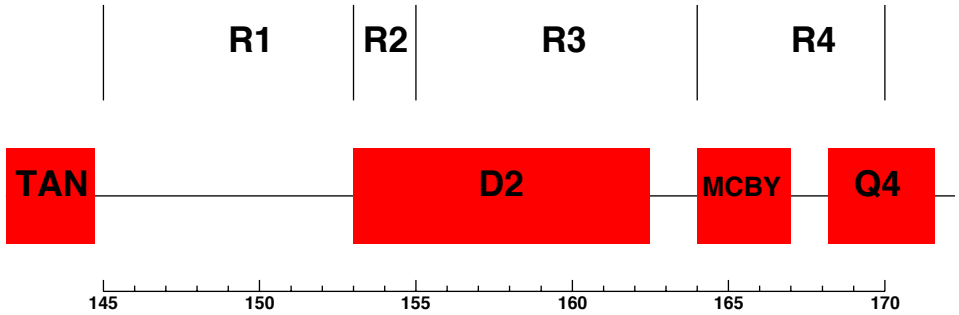
PASSIVES: Everywhere



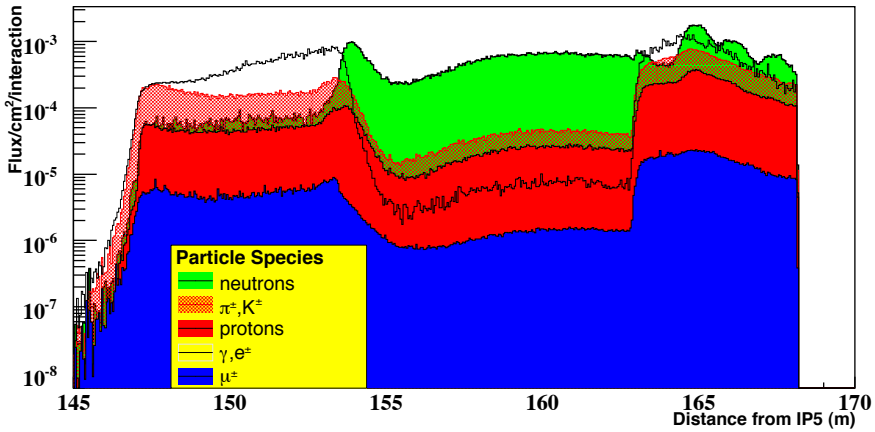
Large Hadron Collider: Detector in the Beam



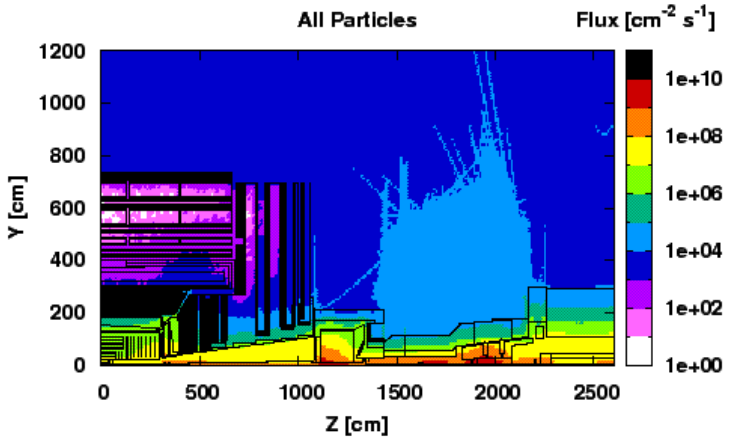




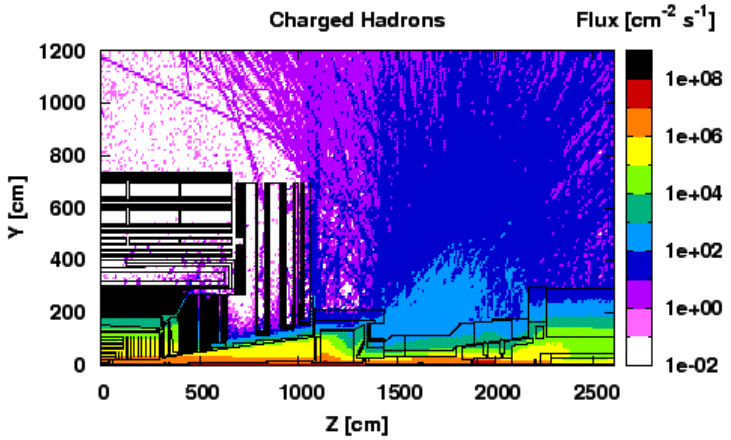
- "Shielding" may cause backgrounds to go up before going down
- Particle species mix will change also



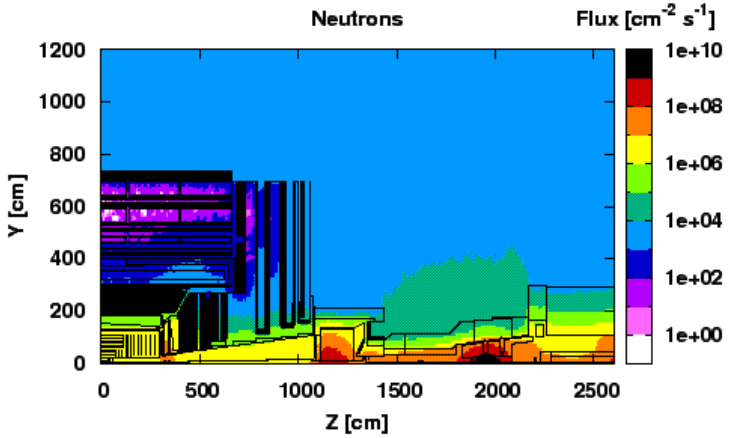
CMS background simulations (FLUKA)



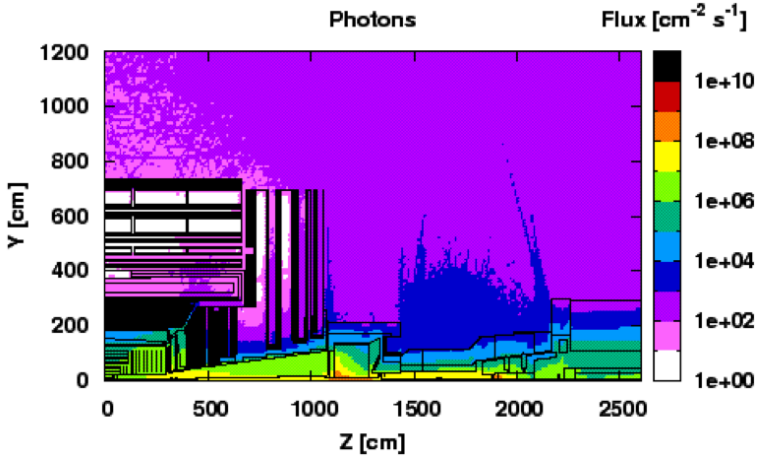
(a)



(b)



(c)



(d)

Figure 9.6: Fluxes for 7TeV collisions in the CMS cavern.

The triptych of success

- Detectors
  - Is the sensitivity of detectors to all relevant particle types and energies known and measured?
  - Differences between detector types and what you see is golden information
- Data:
  - Use all existing data you can get your hands on, flux maps, particle species, energy spectra
- Simulation:
  - Simulate instruments in detail
  - Preferably with competitive codes (e.g. GEANT/FLUKA/MCNP/MARS)

Remember there may be several sources of problems, not just one ...

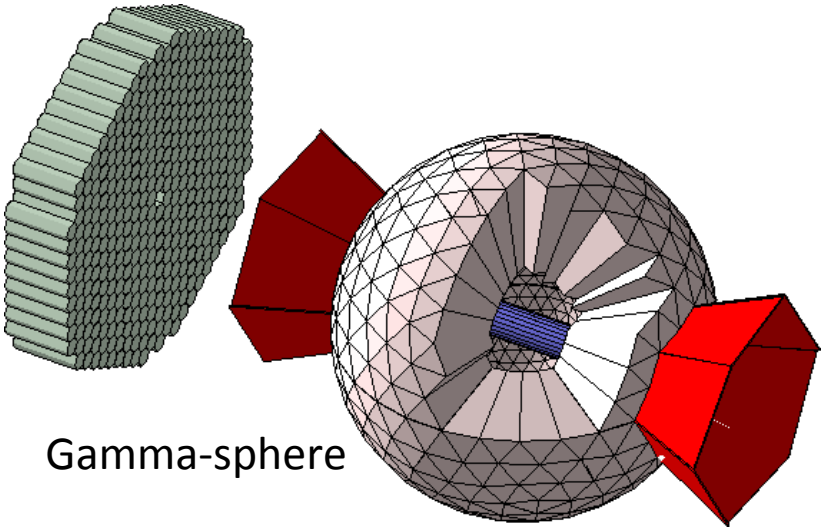
Diagnostic Data

- A list of detector information that may be useful to try ...
  - Flux map from simple handheld h10 electronic dosimeters
  - Flux map from simple electronic handheld neutron dosimeters
  - Hand-held gamma spectrometers - what gammas do you see? Where can they come from?
- Activation map of activated material along guideline - it tells you what material is being activated
- Flux map of fast neutrons (neutron camera, organic scintillator, diamond, He-4)
- SEU in RAM within instruments, and inside guide shielding? (neutrons >10-20 MeV)
- Determine particle species where possible (a la Neutron Camera, IAEP Prague, D. Pfeiffer et al., JINST 6 (2011) P08005)
- Map and directionality of muons - indicative of hadronic showers along the guides? Look for loss locations (2-3 layers plastic scintillator in coincidence, separated by lead)
- Charged particle concentrations - indicative of unshielded particle showers (2-3 layers plastic scintillator in coincidence)
- Try different detector technologies at the instrument locations - do features change?
- Timing features

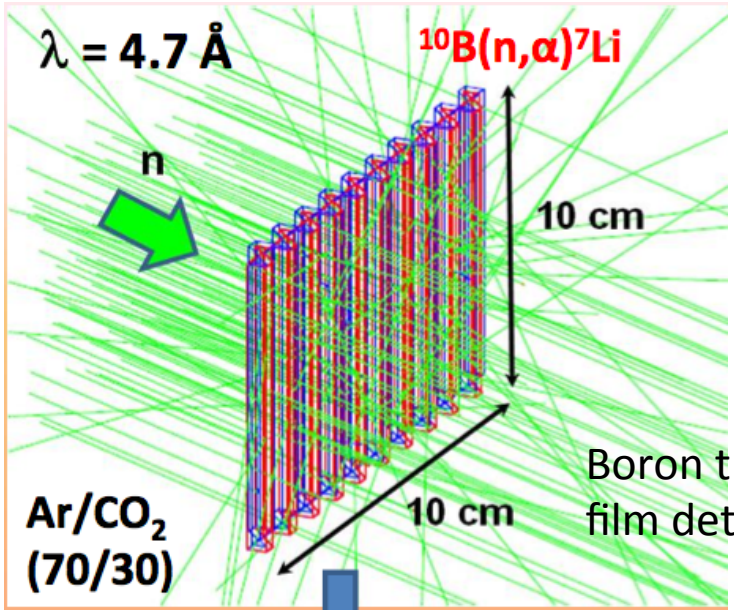
GEANT: A simulation tool for HEP

- toolkit for the simulation of the passage of particles through matter
- high energy physics, nuclear physics, accelerator physics, medical physics, space science, DNA response to radiation
- includes all relevant EM & hadronic interactions, particle decays and slow neutron related cross sections
- provides special physics lists for shielding applications
- open source
- huge community of users

GEANT application examples

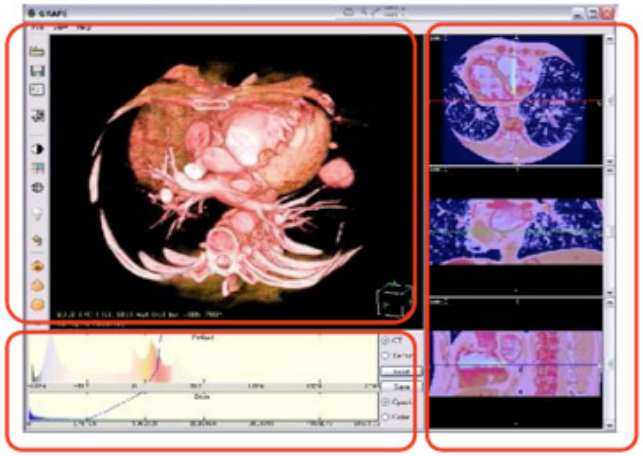


Gamma-sphere

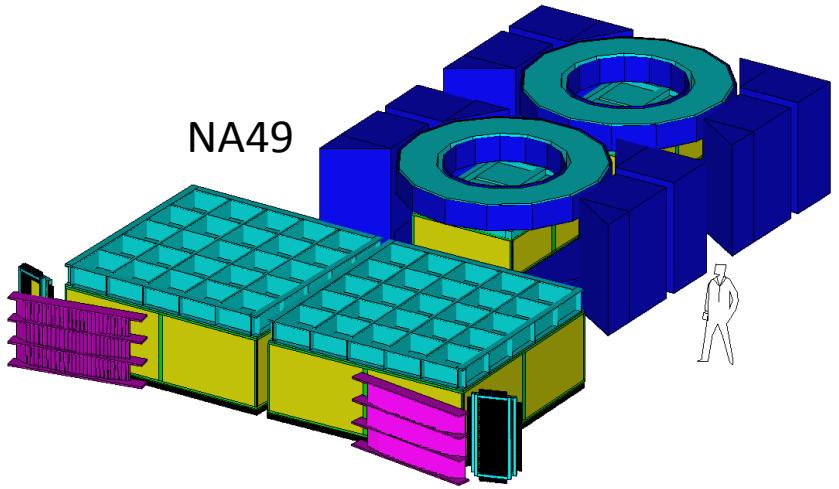


Boron thin film detectors

medical physics



Opacity curve and color map editor



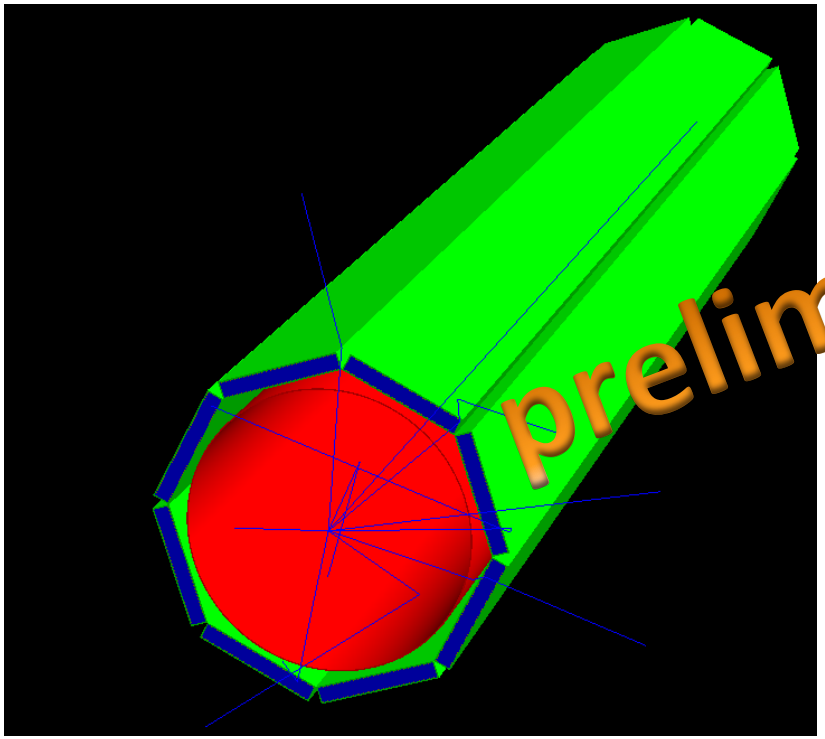
DGCODE simulation software framework

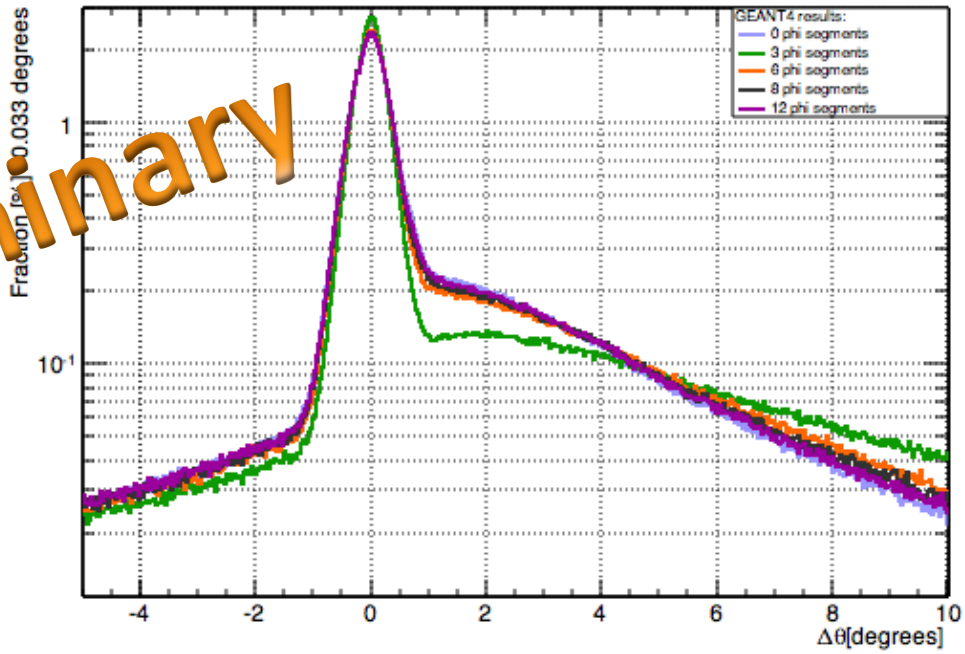
- effort initiated by FRM-II/ESS/ILL
- framework to share simulation code
- facilitate debugging
- better code maintenance
- modular development
- avoid duplication

Already in place and qualified!

To be announced this afternoon …

GEANT simulation of scattering effects





courtesy T. Kittelmann

Thank you for your attention!