Fluka 2006 calculations in CMS

Comparison with earlier results

Markus Brugger
Steffen Müller
Witold Pokorski
Riccardo Ranieri
Stefan Roesler
Rob Veenhof

Goals

- Perform, and provide the means to perform, activation calculations of the materials in the LHC experiments, and of CMS in particular, using Fluka 2006.

- Verify key elements of the CMS INB reports.

Outline

- Background
  - move to regular Fluka for INB reports,
  - concern about neutrons,
  - concern about isotopes.
- Strategy:
  - Use Geant 4 geometry or update existing Fluka 95 files,
  - comparison with published calculations & data,
  - geometric update.
- Geant 4 geometry
  - Flugg and Fluka can cope,
  - failure due to overlaps in Geant 4.
- Update existing files
  - new event generator,
  - symmetry,
  - magnetic field,
  - scoring / biasing.
- Verification
  - crystal to check decay chain
  - track length in air of neutrons, photons and charged hadrons to check generator and neutrons
  - activation of cavern air
- Applications
  - BCM
  - ECAL cooling water
- Description update
  - Si tracker

Strategy

- Two candidate starting points:
  - use the CMS Geant 4 geometry as basis and import it into Fluka 2006 using Flugg and GDML, or
  - adapt for use with Fluka 2006 the geometry description that has sofar been used by CMS.
- Compare Fluka 2006 values and those produced earlier; understand the differences, if any.
- Update the geometry to match the detector as-built.
- Apply for further calculations.

Approach using Geant 4 geometry

- Technique:
  - Make Fluka swallow all or part of the Geant 4 CMS geometry using GDML and Flugg.
  - Complement with absorbers outside the sensitive volume, absent in the Geant 4 model.

- Benefits and concerns:
  - Updates will be simpler when the setup changes.
  - The Geant 4 model focuses on tracking, not activation:
    - no attention to the precise chemical composition, nor on
    - components in the vicinity of the detector.
  - The size of the Geant 4 model is very large.

Geant 4 – steps taken and failure

- After increasing the limits on the number of volumes and materials in Fluka, Fluka was able to read the entire CMS description.
- The correctness of the model could be checked using non-interacting particles (“rays”).
- Minor problems of material descriptions were solved.

- But ... the Geant 4 CMS model has numerous, often minute, geometric overlaps while Fluka requires a strictly overlap-free geometry.

[Witold Pokorski]

Approach using Fluka directly

- Technique:
  - Use the existing model described in Fluka cards:.
- Benefits and concerns:
  - Direct comparisons with earlier calculations.
  - The existing model is specifically designed for radiation.
  - Converges fast: this is a 2-dimensional model.
  - The existing model is not up to date and any new model will require work to be kept up-to-date.

CMS model – history

- CMS radiation calculations so far were based on Fluka 95 and used a detector description written by Mika Huhtinen.
- The model describes the $z>0$ part and is ϕ-symmetric,
  - without read-out channel segmentation,
  - designed to study radiation damage to electronics and
  - trigger background from neutrons,
  - also suitable for the study of activation.
- The model needs updating in some areas:
  - amount of polyethylene;
  - Si-tracking (redone as a result of a misunderstanding);
  - beam pipe.

FLUKA History

The early days

The beginning:

1962: Johannes Ranft (Leipzig) and Hans Geibel (CERN): Monte Carlo for high-energy proton beams

The name:

1970: study of event-by-event fluctuations in a NaI calorimeter (FLUktuierende KAskade)

Early 70's to ≈1987: J. Ranft and coworkers (Leipzig University) with contributions from Helsinki University of Technology (J. Routti, P. Aarnio) and CERN (G.R. Stevenson, A. Fassò)

Link with EGS4 in 1986, later abandoned

The modern code: some dates

Since 1989: mostly INFN Milan (A. Ferrari, P.R. Sala): little or no remnants of older versions. Link with the past: J. Ranft and A. Fassò

1990: LAHET / MCNPX: high-energy hadronic FLUKA generator *No further update*

1993: G-FLUKA (the FLUKA hadronic package in GEANT3). *No further update*

1998: FLUGG, interface to GEANT4 geometry

2000: grant from NASA to develop heavy ion interactions and transport

2001: the INFN FLUKA Project

2003: official CERN-INFN collaboration to develop, maintain and distribute FLUKA

FLUKA versions

A multipurpose Interaction and Transport MC code

- FLUKA 95 (never released, obsolete)
  - **Authors:**
    - **A. Fassò, A. Ferrari, J. Ranft, P.R. Sala**
  - **References**
    - ``**FLUKA: present status and future developments",** A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala, Proceedings of the IV International Conference on Calorimetry in High Energy Physics, La Biodola (Elba), September 19-25 1993, A.Menzione and A.Scribano eds., World Scientific, p.493-502 (1994)
    - **"An update about FLUKA",** A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala, SARE-2, CERN Geneva, October 9-11 1995, CERN/TIS-RP/97-05, p.80-98 (1997)
- FLUKA 96 – FLUKA 2005 **(same authors)**
- FLUKA 2006
  - Developed and maintained under a CERN-INFN agreement
  - **Main authors:**
    - **A. Fassò, A. Ferrari, J. Ranft, P.R. Sala**
  - **Contributing authors:**
    - **G.Battistoni, F.Cerutti, T.Empl, V.Patera, S.Roesler, V.Vlachoudis**
  - **References**
    - **"FLUKA: a multi-particle transport code",**
      A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala,
      CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
    - **"The physics models of FLUKA: status and recent developments",**
      A. Fasso`, A. Ferrari, S. Roesler, P.R. Sala, G. Battistoni, F. Cerutti, E. Gadioli, M.V. Garzelli, F. Ballarini, A. Ottolenghi, A. Empl and J. Ranft,
      Computing in High Energy and Nuclear Physics 2003 Conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003, (paper MOMT005), eConf C0303241 (2003), arXiv:hep-ph/0306267
  - http://www.fluka.org

CMS model – model updates

- The following updates to the model have been applied:
  - replaced the track collection (DPMJET II + Pythia $b\bar{b}$) by the DPMJET III generator (PHOJET, based on the DPM);
  - z=0 mirror symmetry replaced by a "lattice";
  - existing magnetic field map, mirror symmetry added;
  - adjusted step sizes, biasing, energy cut-offs;
  - standard Fluka scoring throughout;
  - volumes given names rather than numbers.

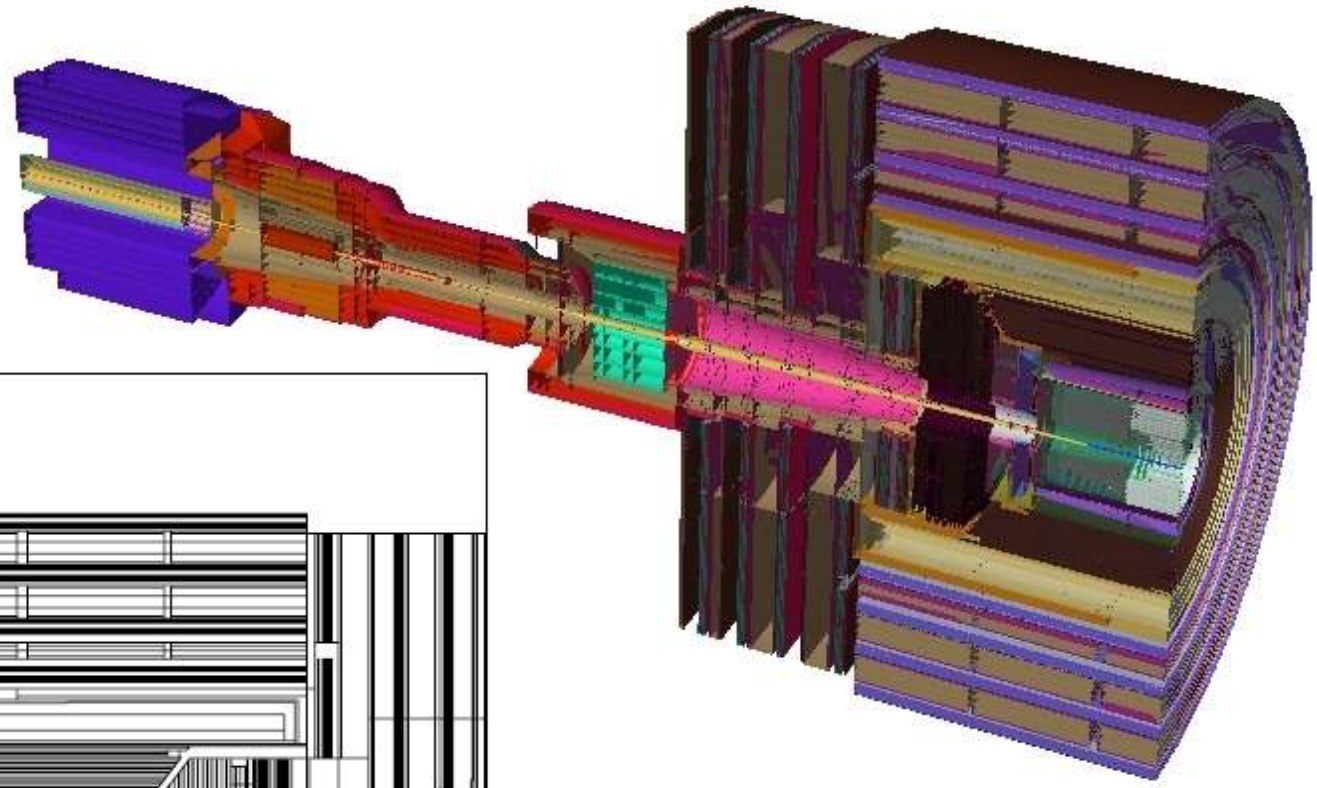
- As-built geometric descriptions for the Si-tracking system have been written, but are not used during the tests which are described here.

[Markus Brugger]

Fluka developments

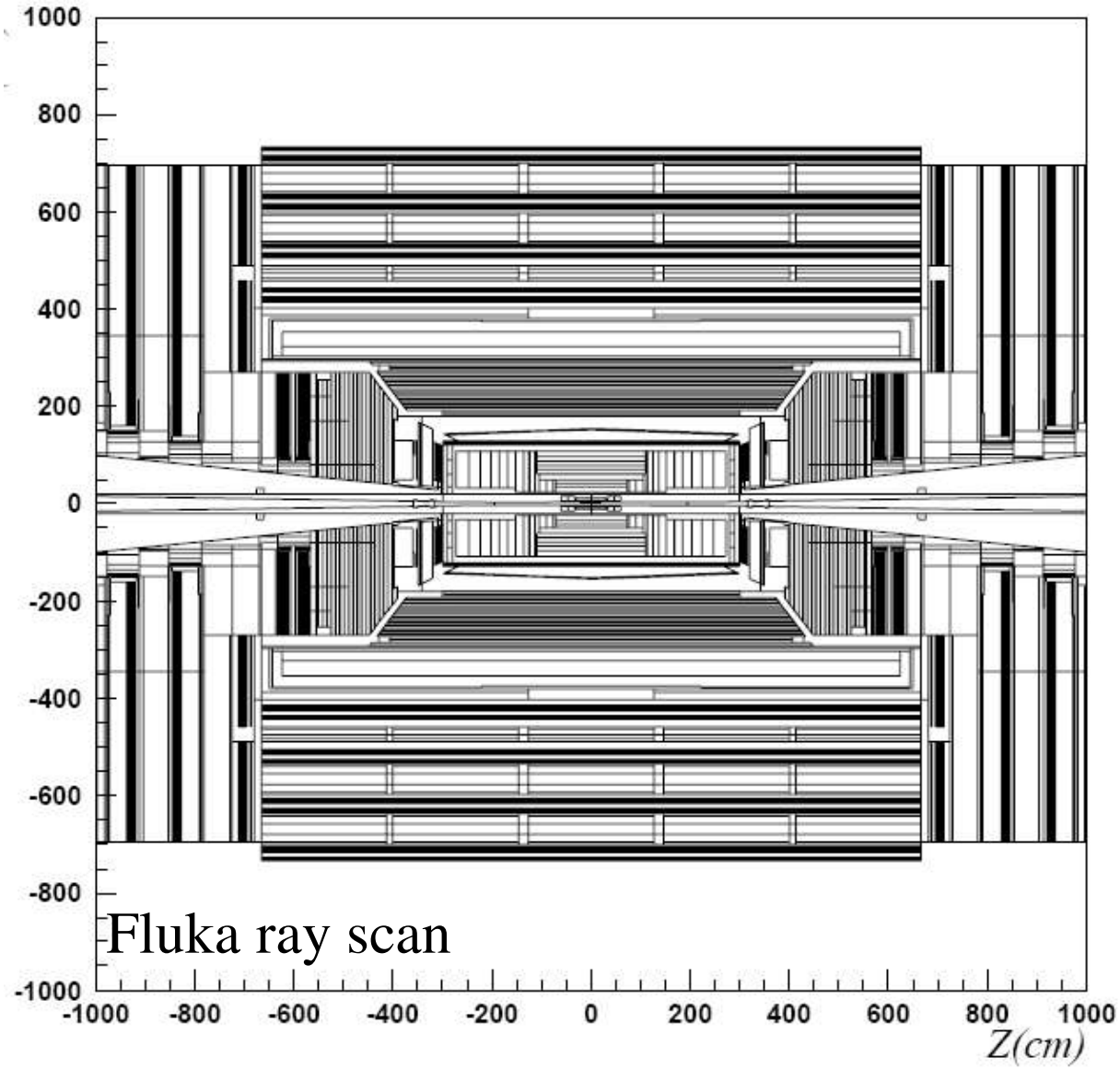
- Obsolete version used in the past by CMS: FLUKA 95 (~140 klines)
- Current release: FLUKA 2006.3b (~480 klines) which benefits from numerous developments and continues to be improved. E.g.:
  - Vastly improved high-energy model [NIM A 449 (2000) 609-623]
  - New evaporation-fragmentation model, including fragments up to mass 25
  - New, vastly improved, fission model
  - Extension of PEANUT (the intermediate energy hadronic model of Fluka) to $K^-, \bar{K}^0, \bar{p}, \bar{n}, \mu^-$ capture, and to several GeV (elimination of the obsolete NUCRIN model)
  - Coalescence throughout the PEANUT reaction chain
  - Updated and extended low-energy neutron library (*esp.*, activation)
  - Heavy ion transport and interactions
  - Online evolution of radioactive products and associated residual dose rates (extensive benchmarking of isotope production and residual dose rate estimation)
  - New electron and photon cross sections based on recent evaluations
  - Extension of the geometry package (names, parentheses, voxels, FLUGG...)

CMS layout



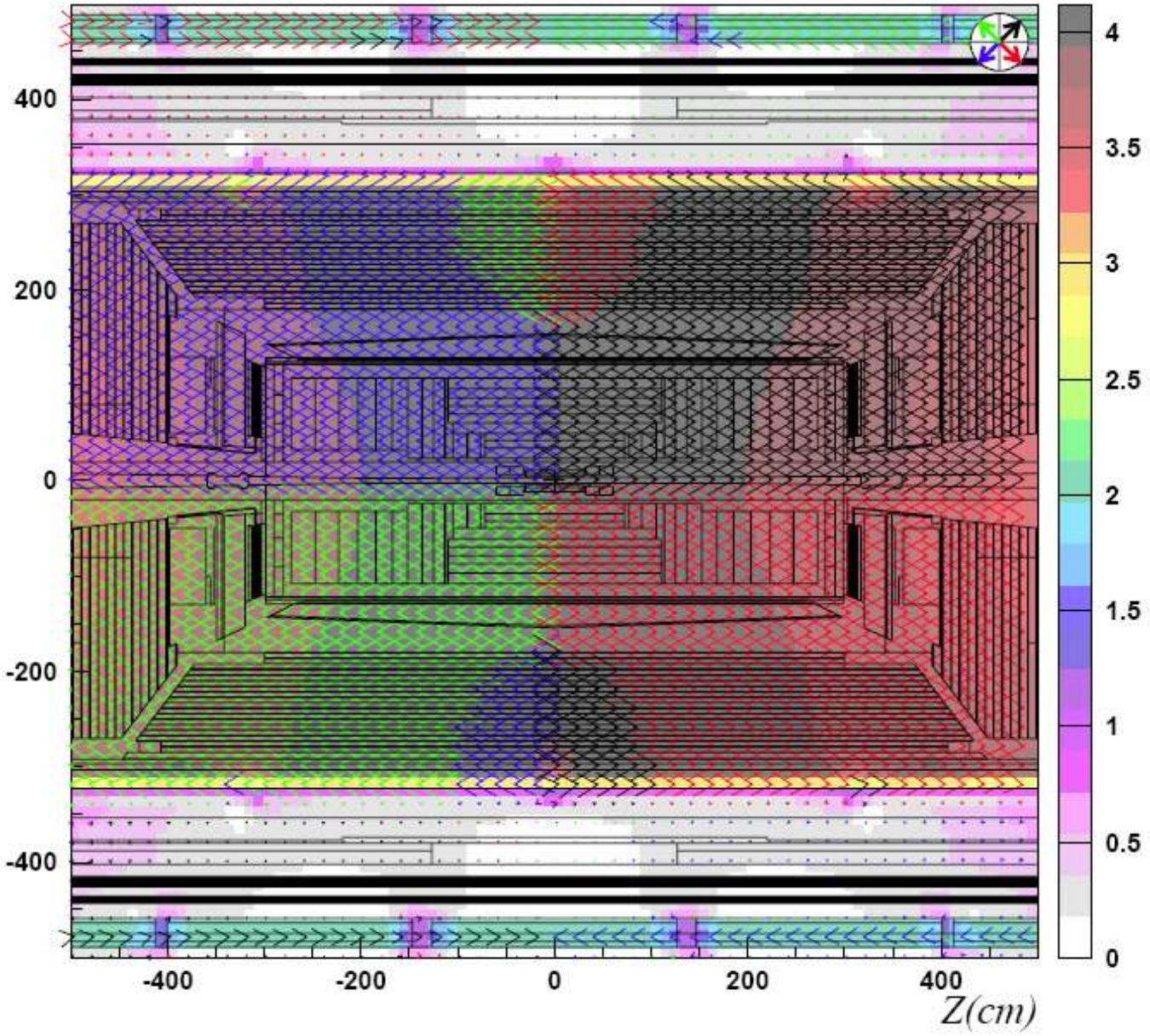
SimpleGeo

[C. Theis *et al.*, NIM A 562 (2006) 827-829]



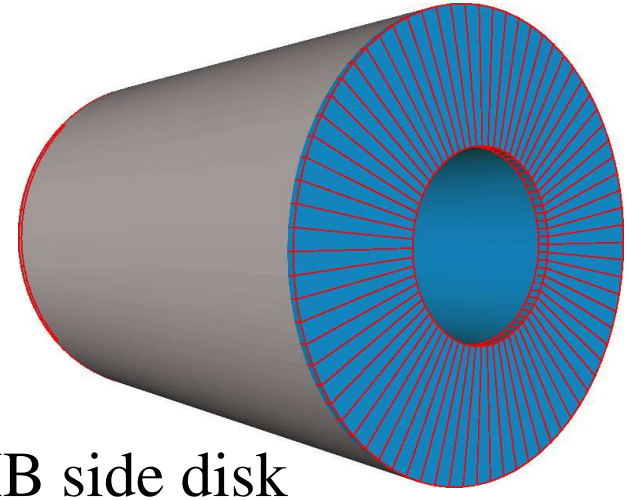
Fluka ray scan

CMS magnetic field

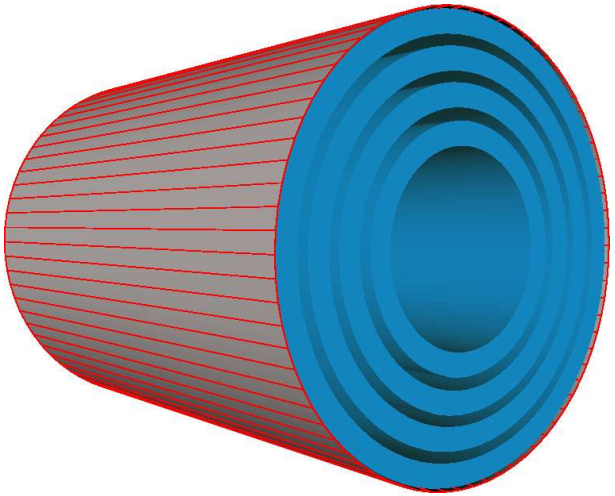


Si tracking detectors

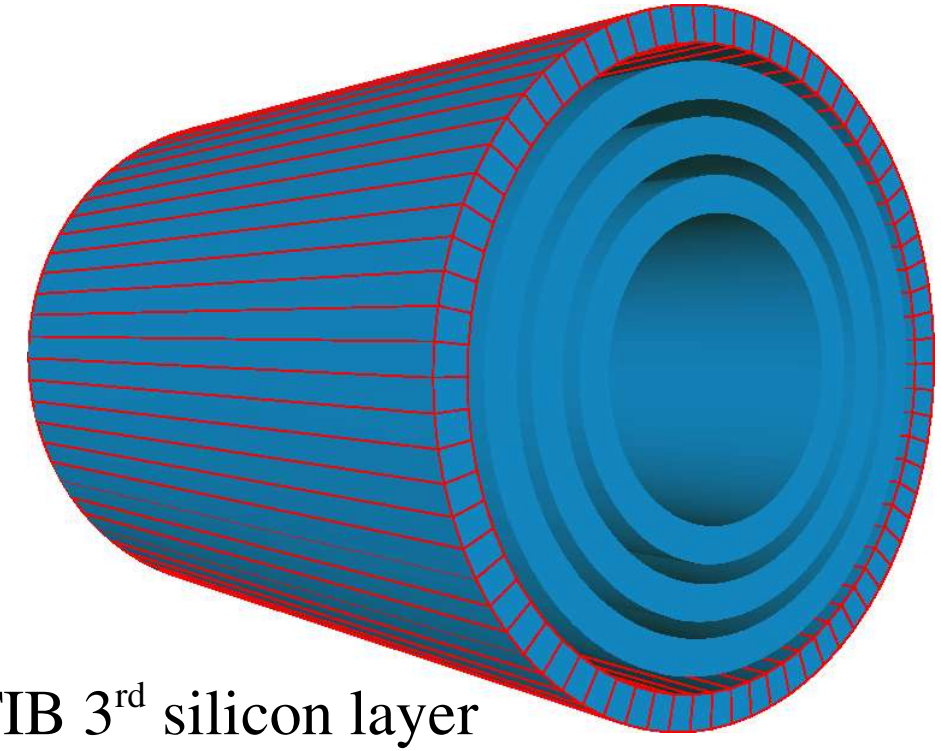
- Axial average of detectors, support structures and cabling.



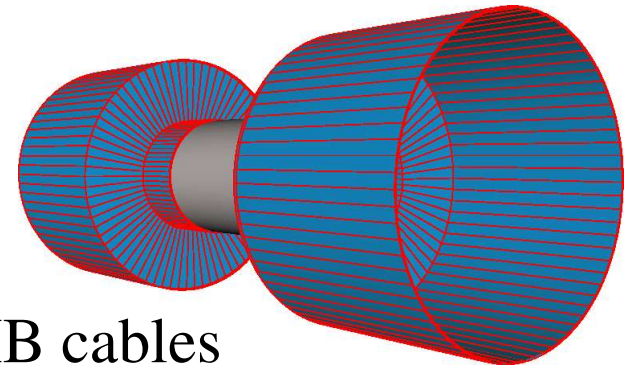
TIB side disk



TIB outer support



TIB 3rd silicon layer



TIB cables

Si tracking detectors - composition

- As an example, the as-built composition of the 3rd tracking layer of the TIB:

Element	Mass [kg]	Mass Fraction
Oxygen	8.370	0.1543
Hydrogen	1.857	0.0342
Carbon	16.136	0.2975
Nickel	0.016	0.0003
Copper	8.246	0.1520
Aluminium	10.106	0.1863
Silver	0.277	0.0051
Silicon	5.927	0.1093
Fluorine	2.448	0.0451
Tin	0.148	0.0027
Bromine	0.713	0.0131
Total	**54.243**	**1.0000**

[Riccardo Ranieri]

Verifications

- Three verifications have so far been carried out:
  - Long-term residual radioactivity of ECAL crystals;
  - Flux of neutrons, charged hadrons and photons;
  - Activation of the air in the cavern.

Fluence, flux, track-length ...

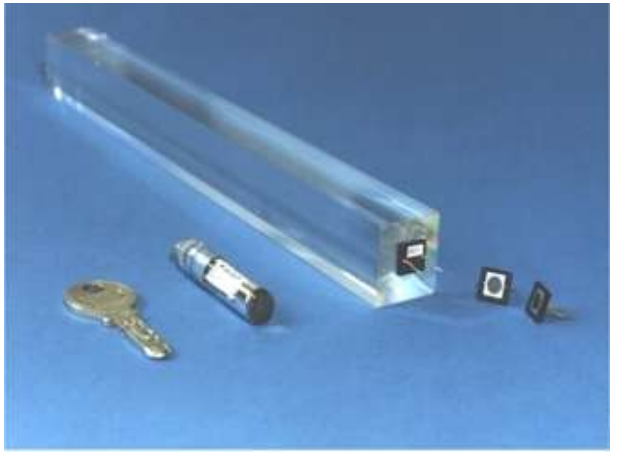
- Fluence:
  - particles incident on a sphere with unit cross section,
  - also, total track-length in a unit volume,
  - quoted in $1/cm^2$, or in $1/cm^2$ per p-p interaction,
  - sometimes (not here) weighed by energy, effect ...

- Flux:
  - particles crossing a unit area per unit time.
  - Note: this quantity would more correctly be called "fluence-rate".

Verification of isotope production & decay

- Using CMS electromagnetic calorimeter crystals:
  - $PbWO_4$ crystals have been irradiated at the CERN PS with 20 GeV protons, total fluence up to 5 10^{13} /cm^2, flux of 10^{12}-10^{13} p/cm^2h.
  - The actual fluence was calculated from the ^{22}Na presence in Al foils placed near the crystals.
  - The residual dose-rate was regularly measured with an Automess 6150AD6 over a period of a year.
  - Some 1800 isotopes are formed during the irradiation – the measurement is sensitive to the production of isotopes and their decay chains.
  - Data and curves: private communication Mika Huhtinen.

Original calculation



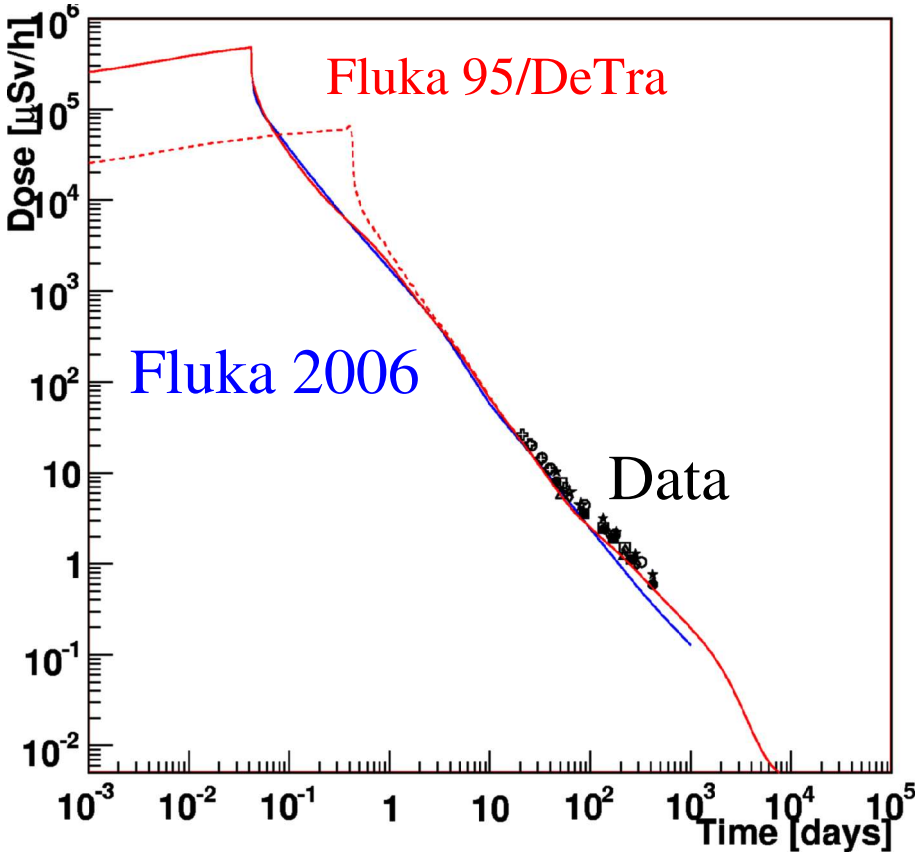
- Activation calculations by relying on particle flux and measured activation cross sections are possible only for a few cases (Al and Fe, and even these only partly).
- The ^{22}Na normalisation is taken from such tabulated cross sections, but the isotope production in the crystal, in Fluka 95, is entirely by the nuclear models.
- The decay chains of the nuclides was calculated outside Fluka 95 with the DeTra program.

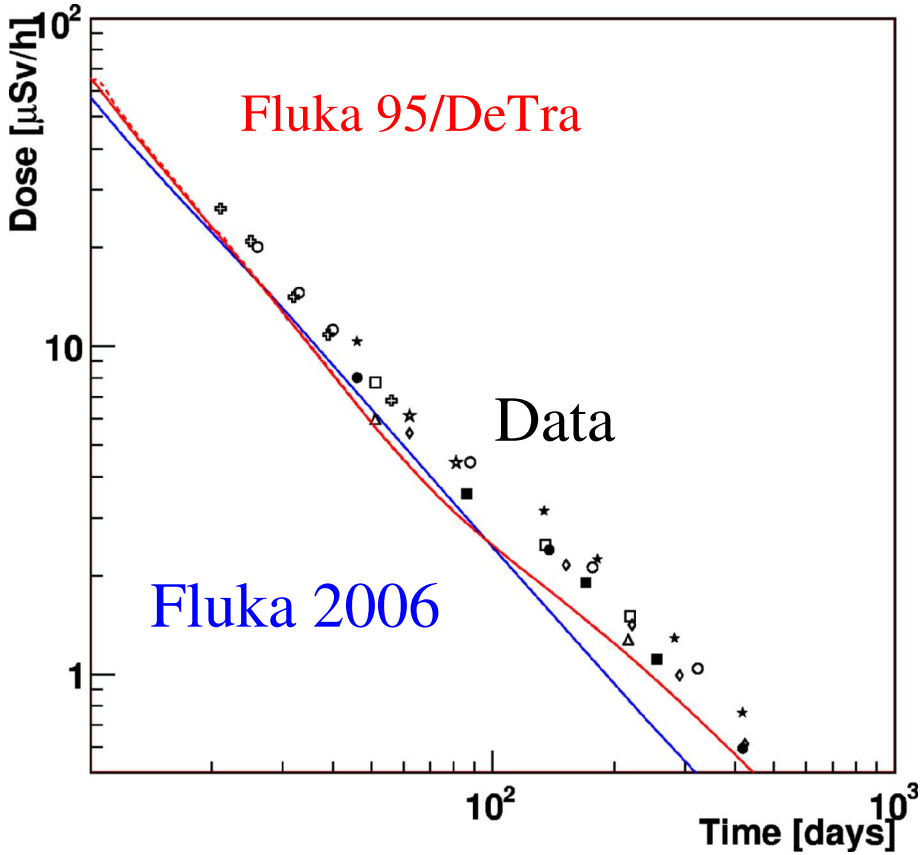
Fluka 2006 calculation

- The Fluka 2006 calculation made two simplications:
  - the crystal was not taken out of the irradiation setup while it was left to cool,
  - 2-dimensional *r*-*z* scoring.

Crystal – comparison

- Fluka 2006 and Fluka 95/DeTra values agree.





Verification of the flux

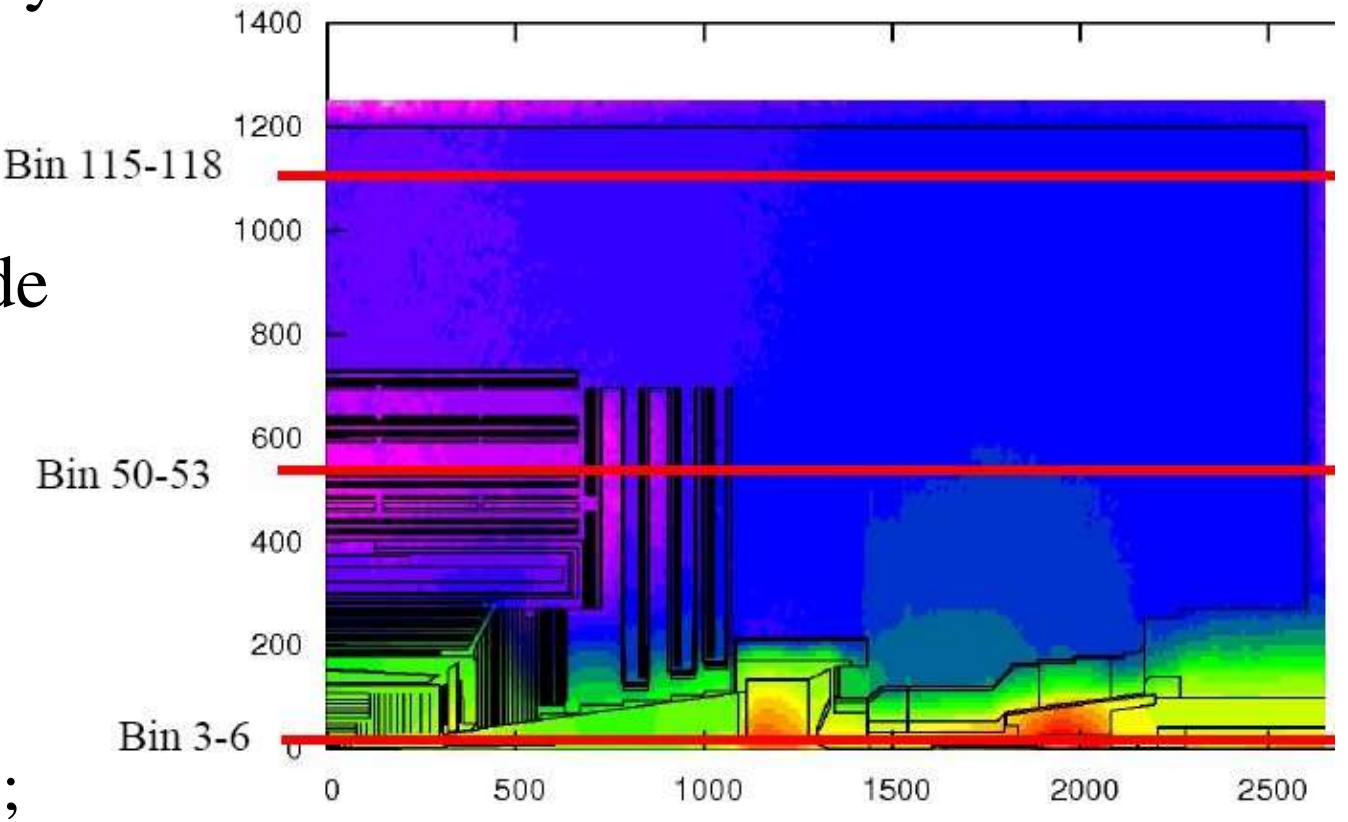
- The particle flux as calculated using Fluka 95 for the INB report (Feb 2006) has been compared with those computed using Fluka 2006.

- Basically everywhere, good agreement has been found.

[Steffen Müller]

Particle flux

- Fluka computes the track-length density over an (r,z) grid.
- Normalised outside Fluka to a flux.
- Collected for:
  - neutrons;
  - charged hadrons;
  - photons.



[Track-length density of neutral particles, before normalisation.]

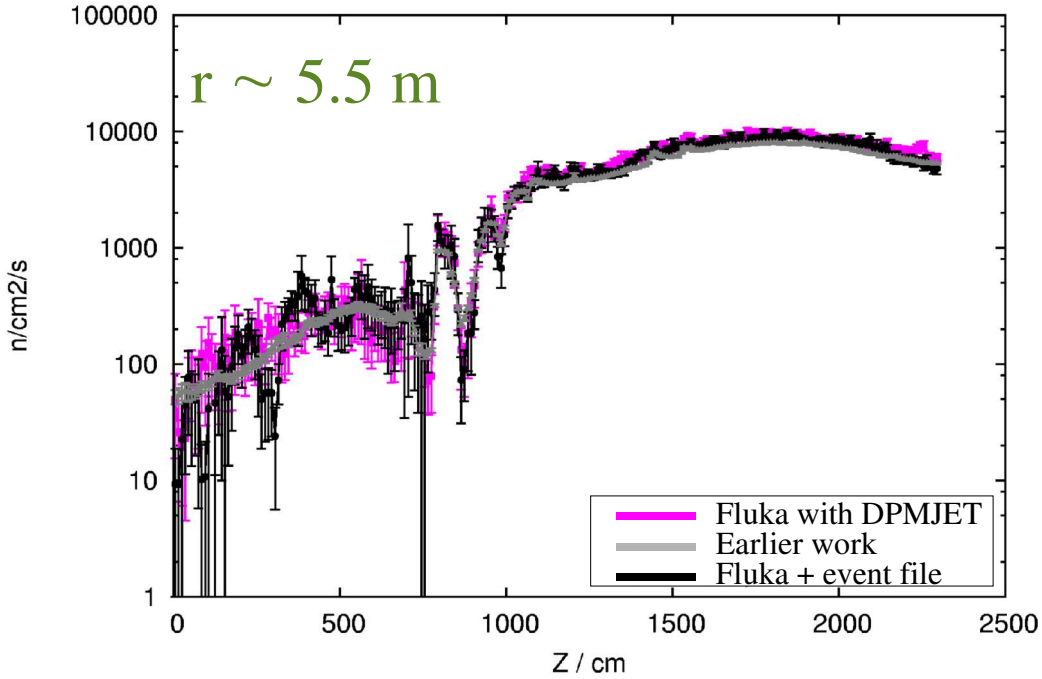
Particle flux: normalisation

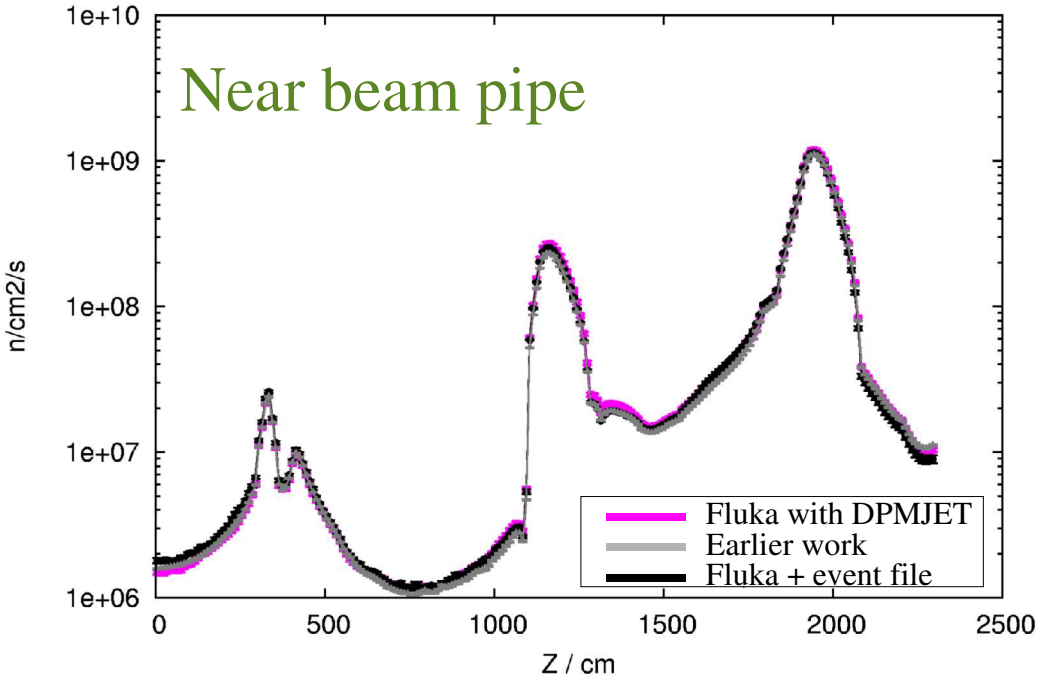
- The plots show the particle flux in 1/cm^2.sec
  - particle fluence (particles/cm^2, via USRBIN),
  - $\times$ 40 MHz bunch-crossing,
  - $\times$ 20 p-p interactions per bunch-crossing,
  - $\times$ 125 secondaries per p-p interactions (at 7+7 TeV).

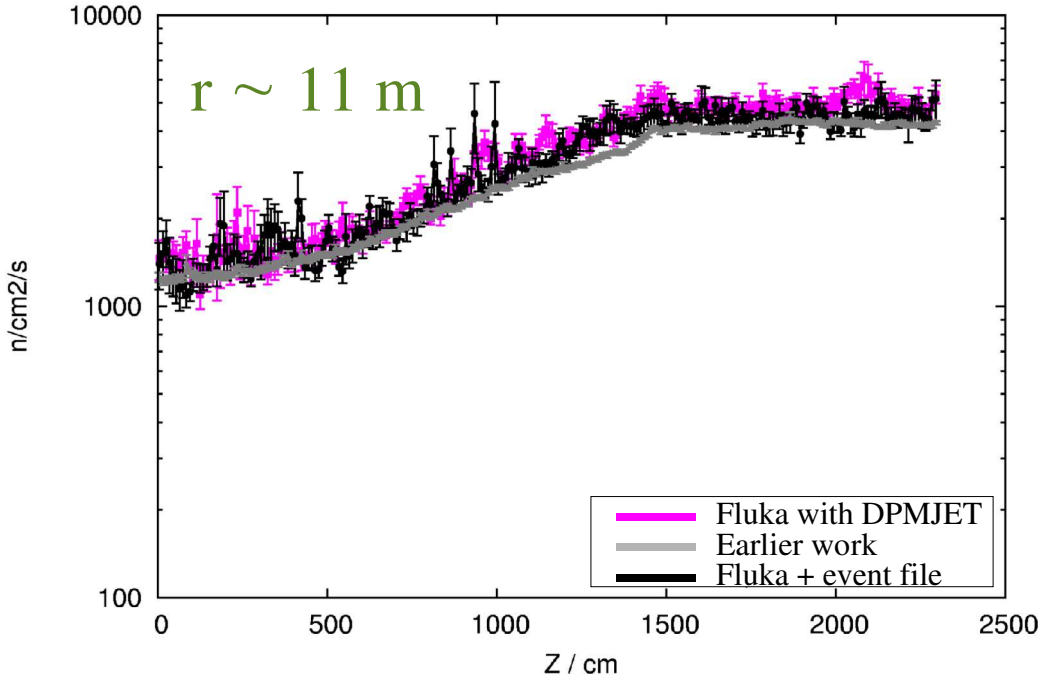
- Compared are:
  - Mika Huhtinen's original fluxes,
  - Fluka2006 with Mika's secondary particle file,
  - Fluka2006 using DMPJET III to generate the events.

Neutrons

- Good agreement.

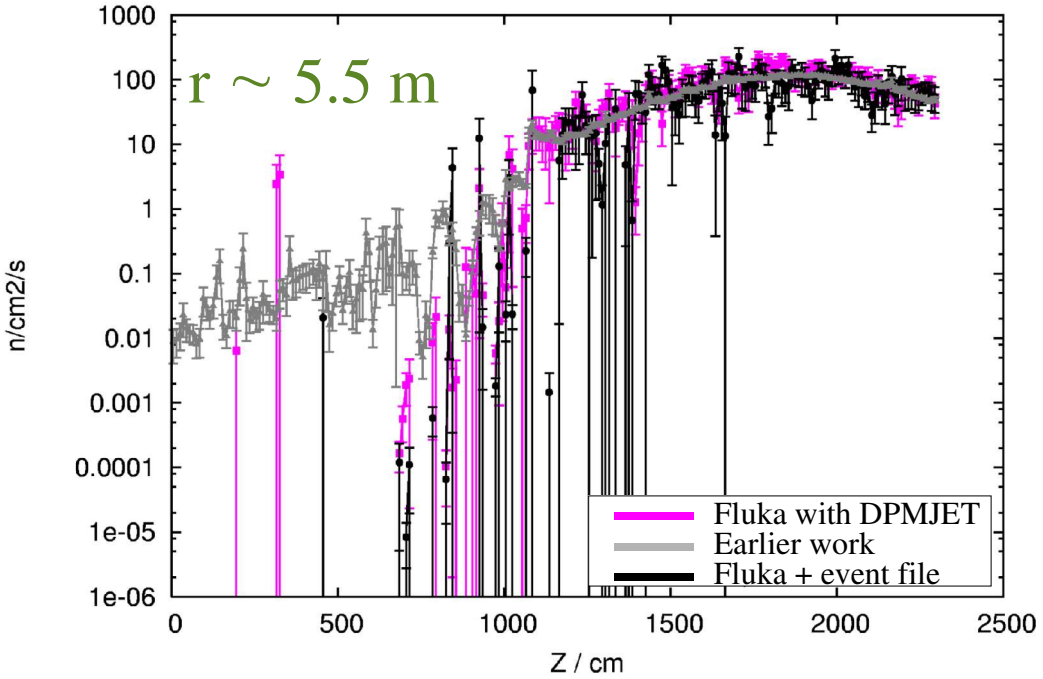


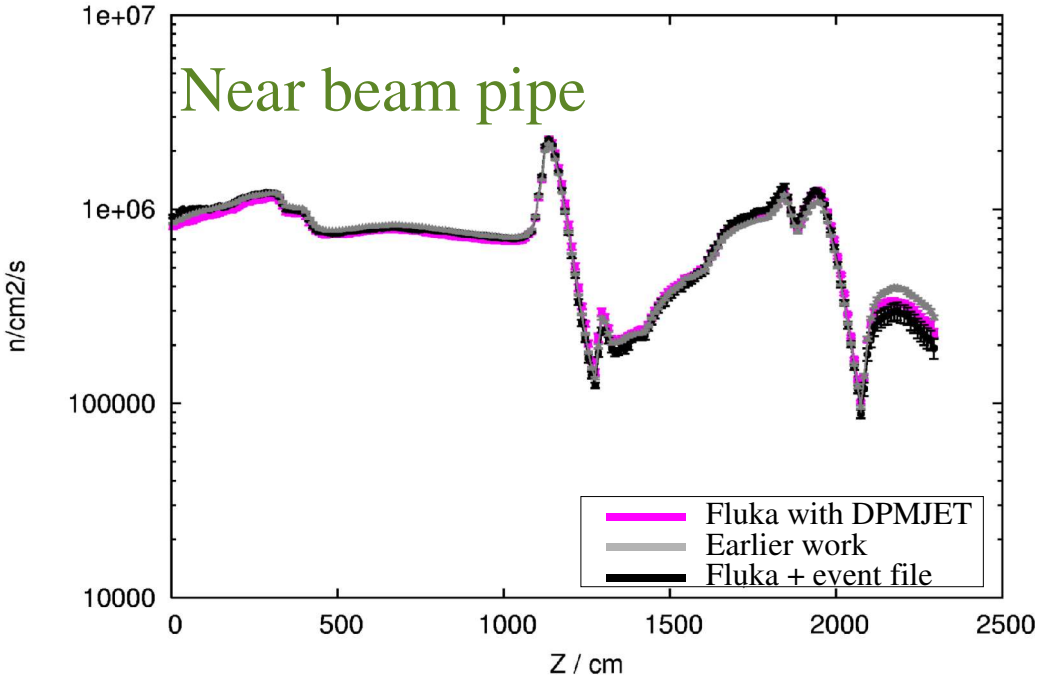


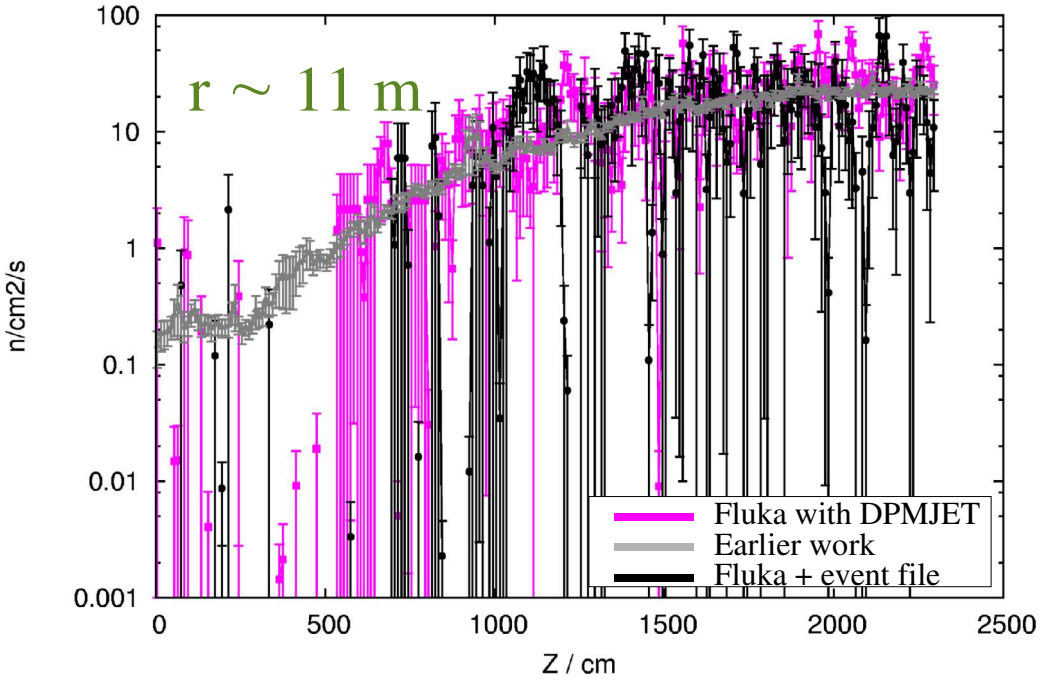


Charged hadrons

- Good agreement.

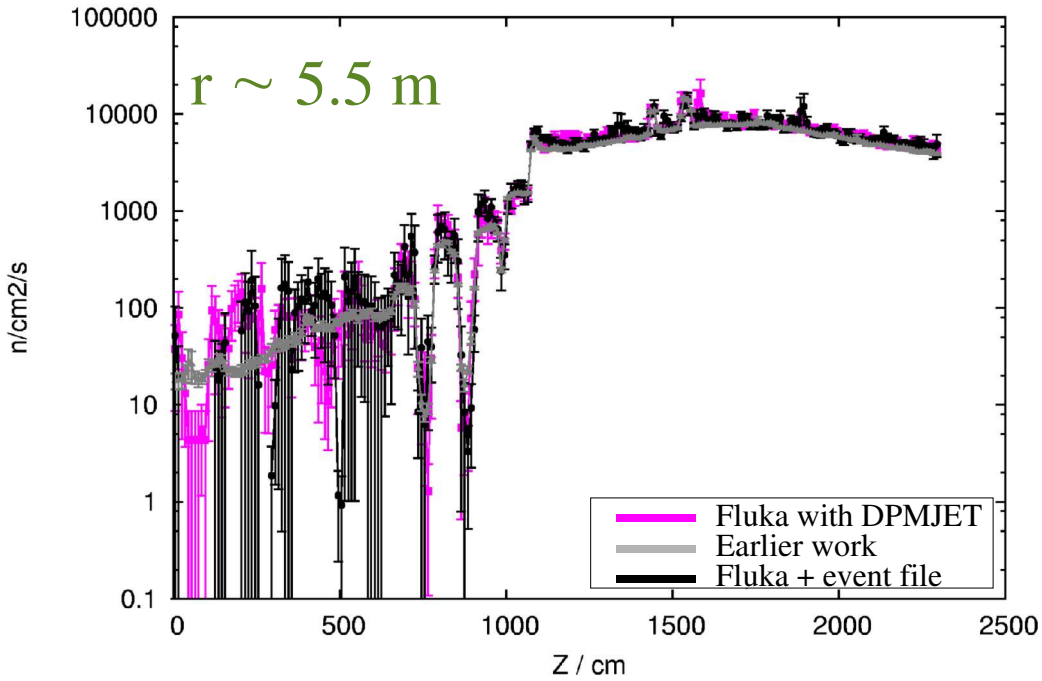


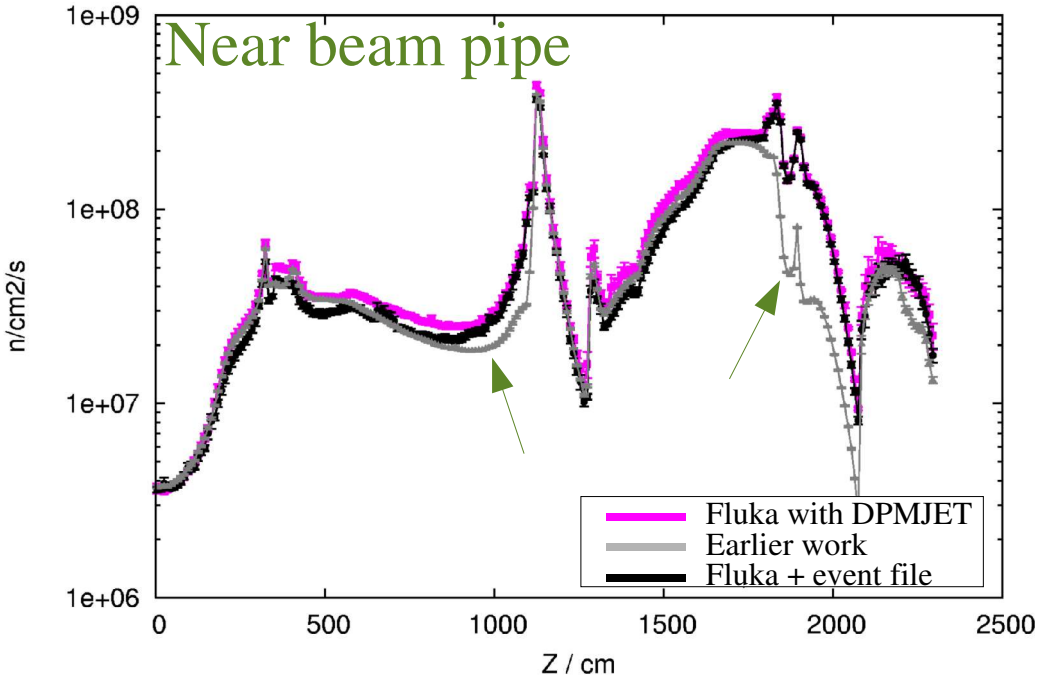


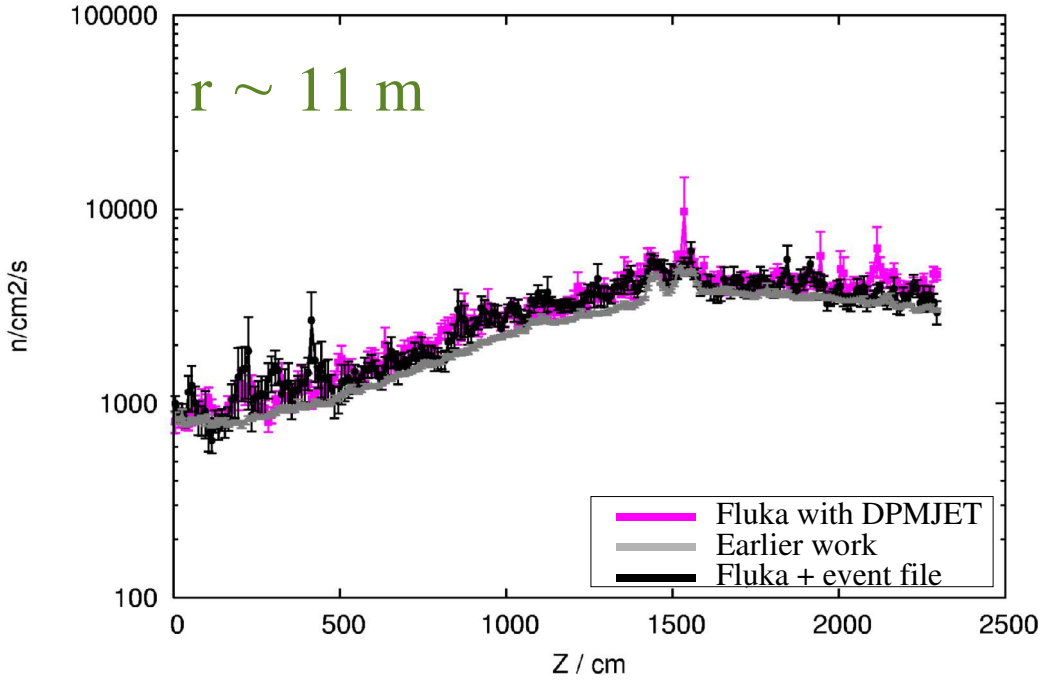


Photons

- Disagreement near the beam pipe, as a result of a different γ momentum cut-off (3 MeV → 3 keV).







Particle flux: what we learned

- The agreement near the target is evidence that the DPMJET III generator produces events which are similar to those used in the earlier studies.
- The agreement further away shows that transport of charged particles, neutrons and photons agrees.
- The disagreement in the photon spectra near the beam pipe is believed to be related to the energy cut-offs.

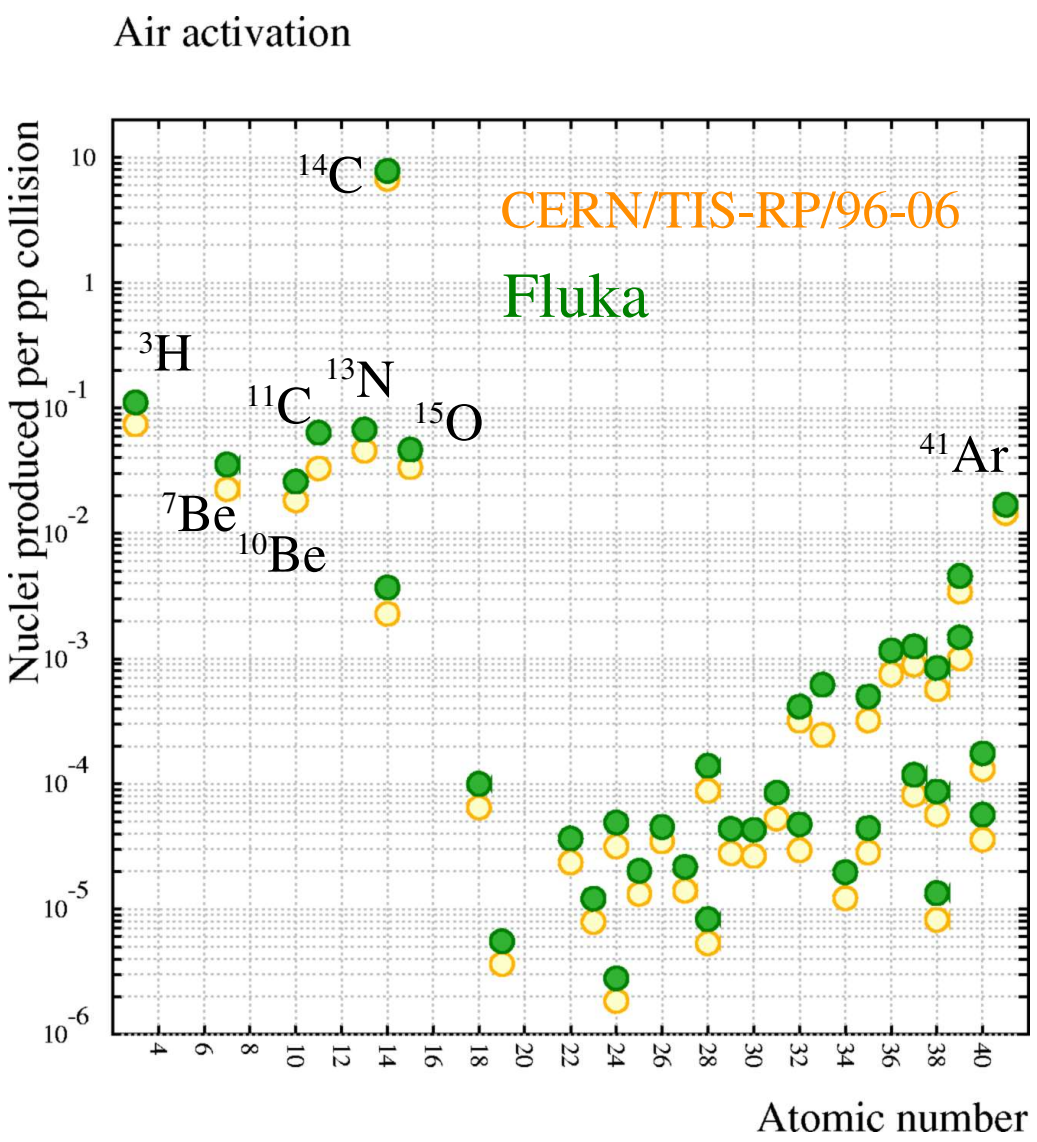
Verification of the air activation

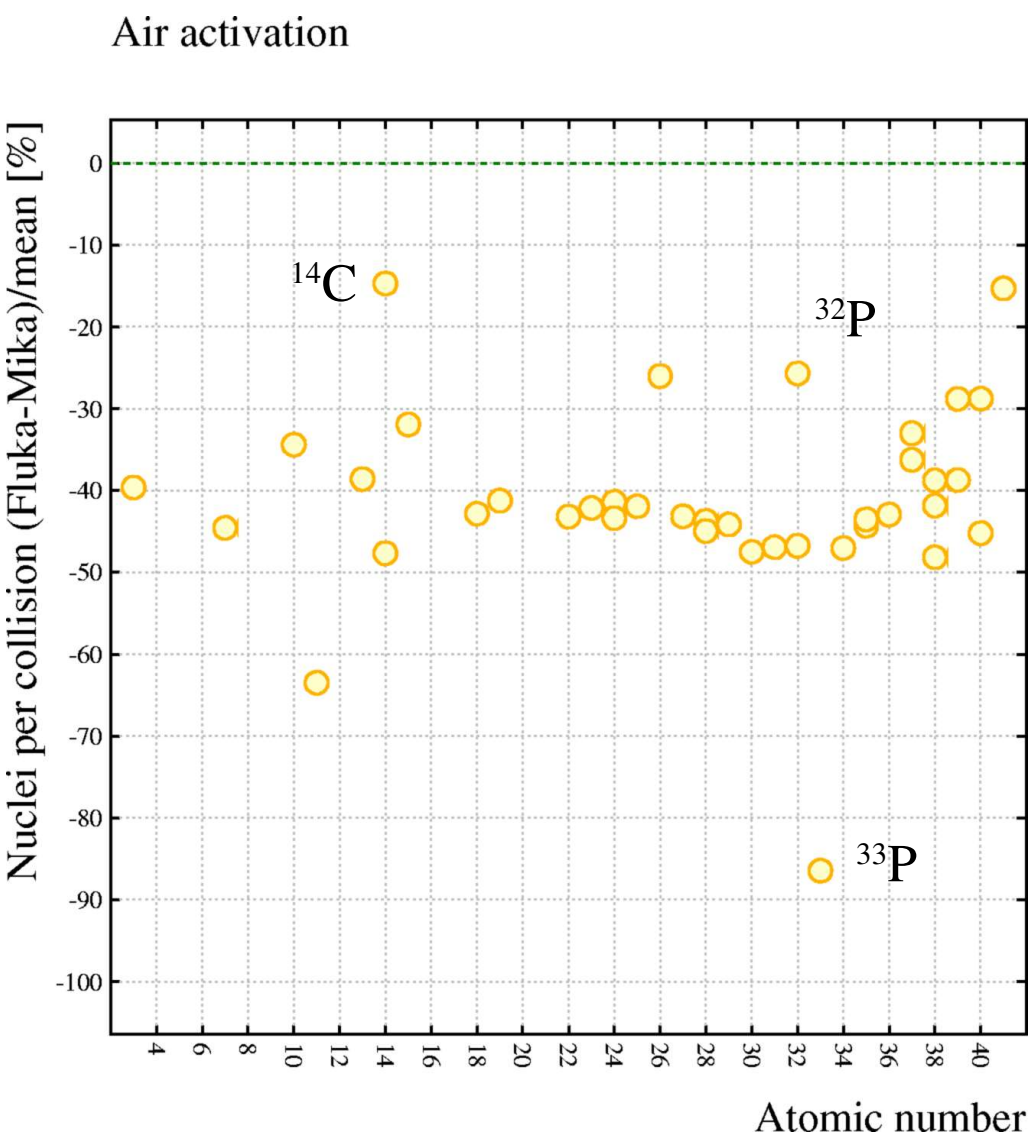
- Activation of the air in the cavern has been reported in CERN/TIS-RP/96-06. These calculations used a simplified geometric model of CMS.

- The isotope production has been recomputed using Fluka 2006 and has been found to agree: Fluka 2006 predicts 40% less activation than the report (which is conservative in its estimates).

[Stefan Roesler]

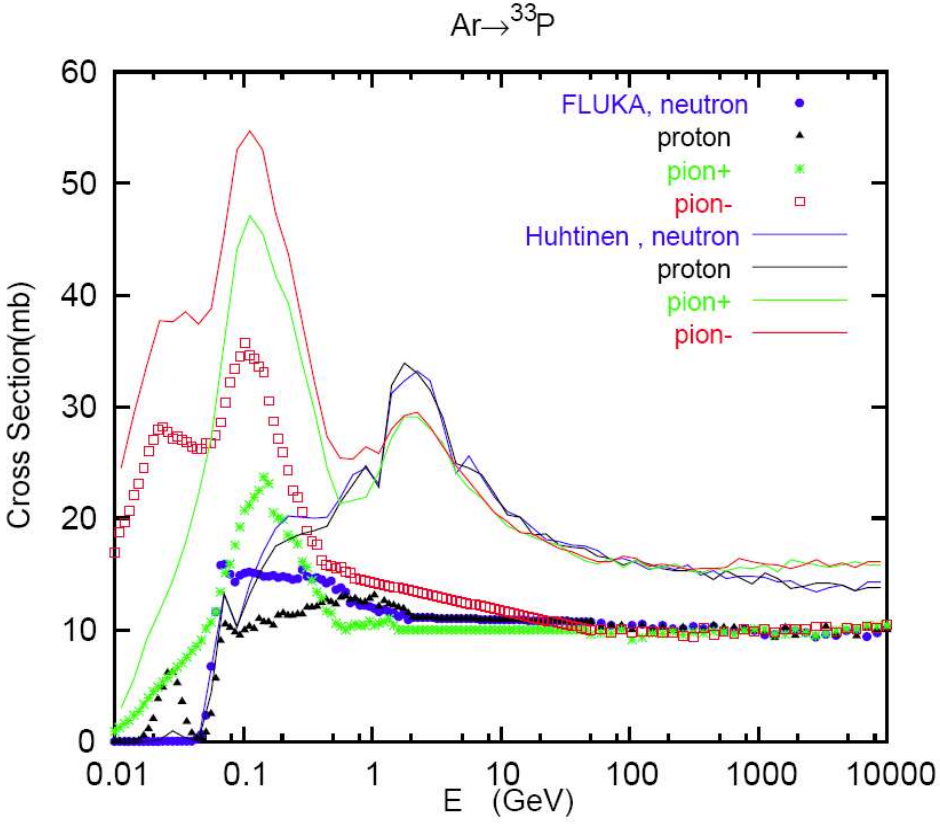
Activation cavern air: comparison





Air activation – approach with Fluka

- Monte-Carlo simulation to calculate hadron fluences in the air volumes.
- Determination of isotope production by folding fluences with an evaluated set of cross-sections.
- Refinements envisaged: flow, geometry update, environmental simulation.



[M. Brugger *et al.*, CERN-SC-2004-064-RP-TN.]

Future

- Activation of air and water, in progress.
- Diamond beam conditions monitor (BCM), starting.
- Shielding around the beam pipe in the event of an upgrade, planned.
- ...

Conclusion

- Fluka 2006 confirms earlier calculations.
- Fluence, dose and activation calculations can be performed entirely within the Fluka 2006 framework.

The FLUKA international Collaboration

- **INFN & Univ. Milano**
  - **G. Battistoni, F. Broggi, M. Campanella, E. Gadioli, M.V. Garzelli, M. Lantz, A. Mairani, S. Muraro, P.R. Sala**
- **INFN Frascati**
  - **M. Carboni, C. D'Ambrosio, A. Ferrari, A. Mostacci, V. Patera, M. Pelliccioni, R. Villari**
- **Univ. Rome**
  - **C.Morone**
- **INFN & Univ. Bologna**
  - **M. Sioli**
- **CERN**
  - **M. Brugger, F. Cerutti, A. Ferrari, S. Roesler, G. Smirnov, F. Sommerer C.Theis, S. Trovati, H.Vincke, V. Vlachoudis**
- **SLAC**
  - **A. Fassò**
- **Univ. of Siegen**
  - **J. Ranft**
- **Univ. of Houston**
  - **T. Empl, L. Pinsky**
- **NASA-Houston**
  - **K. Lee, T. Wilson, N. Zapp**

CERN/INFN Agreement

A CERN/INFN agreement signed in 2003 established the framework for the development and use of FLUKA worldwide

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  - Mike Doser CERN/PH
  - Johannes Ranft Siegen Un.
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  - Federico Carminati CERN/PH
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  - Alberto Fasso` SLAC
  - Alfredo Ferrari CERN/AB (coordinator)
  - Maurizio Pelliccioni INFN/LNF
  - Larry Pinsky UH
  - Johannes Ranft Siegen Un.
  - Stefan Roesler CERN/RP
  - Paola R. Sala INFN/Milan
  - Vasilis Vlachoudis CERN/AB