Short history of fluka

P.Sala

Short history

- Born for SPS construction, as a code mainly for shielding.
- Overhauled (..like WA104?) starting 1989
- Now a complete package for full simulations, still evolving
- In the next slides, a few steps in this evolution, with examples of comparisons with exp. data
- For more: www.fluka.org
- For fun: www.youtube.com/user/Flair4Fluka

Atlas: backgrounds and testbeams(1989- 1998)

- Work on low energy neutrons, low energy hadrons, muons, multiple scattering…

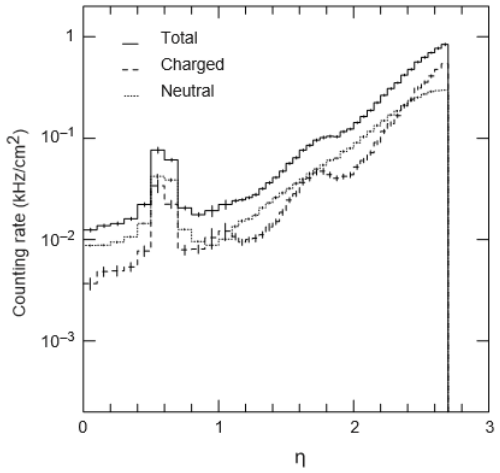


Figure 2-4 Pseudorapidity dependence of the counting rate in the innermost MDT station at nominal luminosity

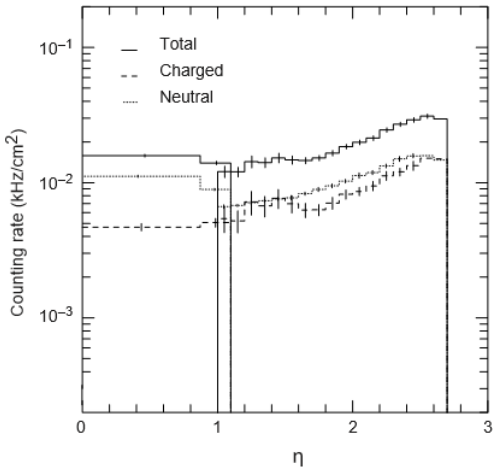


Figure 2-5 As Figure 2-4, for the middle MDT station

In particular: development of the PEANUT package for interactions in nuclei

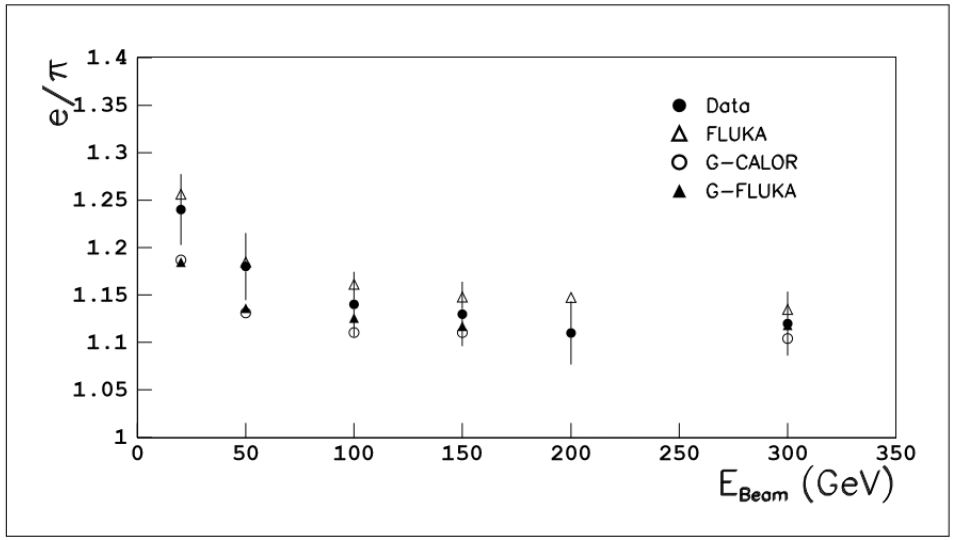
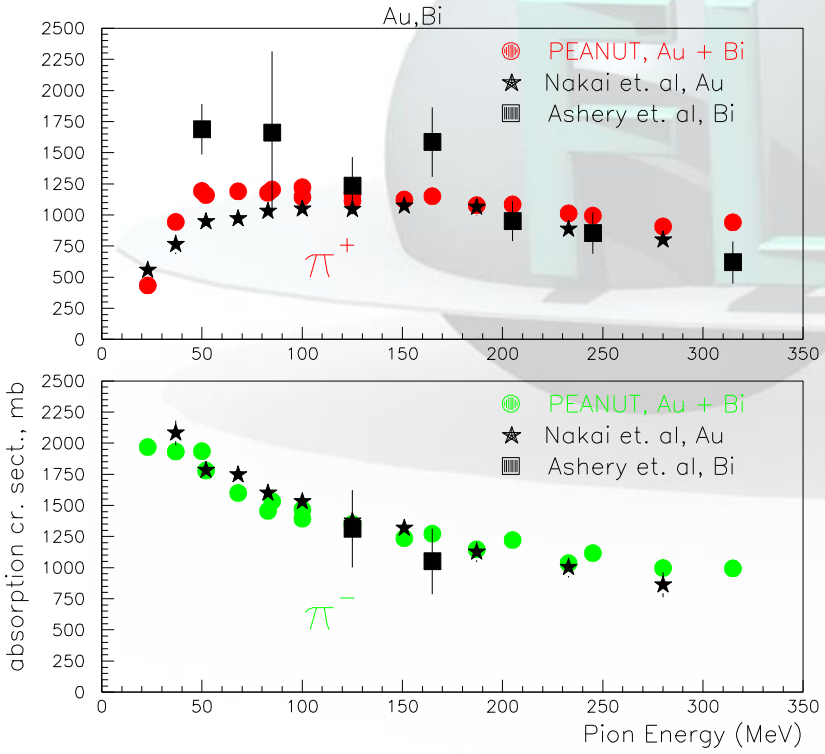


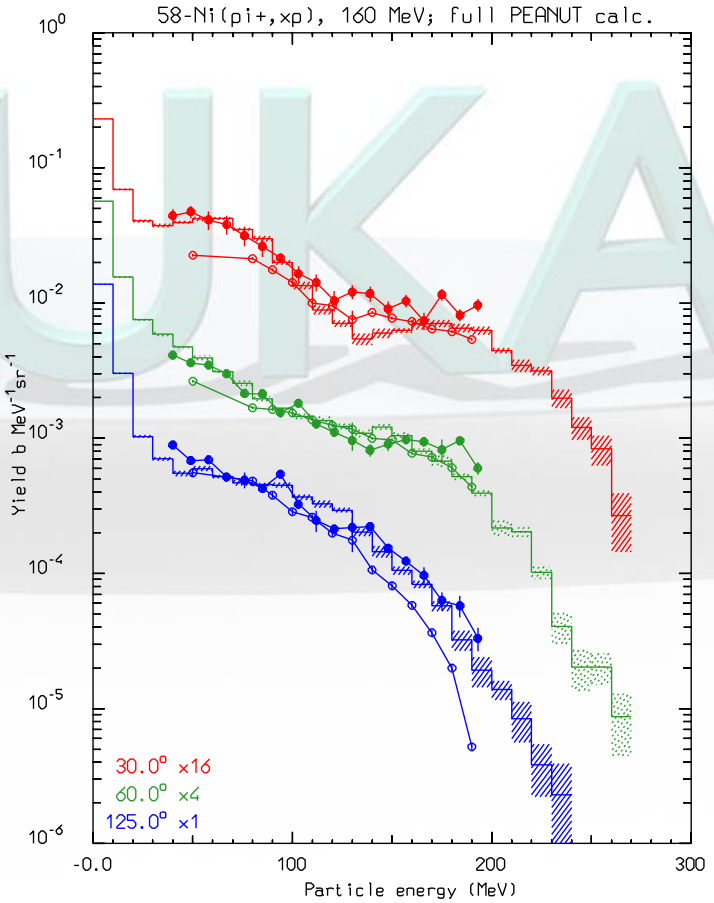
Figure 3-4 e/π for combined Tile and LAr test data compared to G–FLUKA, G–CALOR and stand-alone FLUKA.

Pion absorption examples

Pion absorption cross section on Gold and Bismuth in the Δ resonance region (multibody absorption in PEANUT)

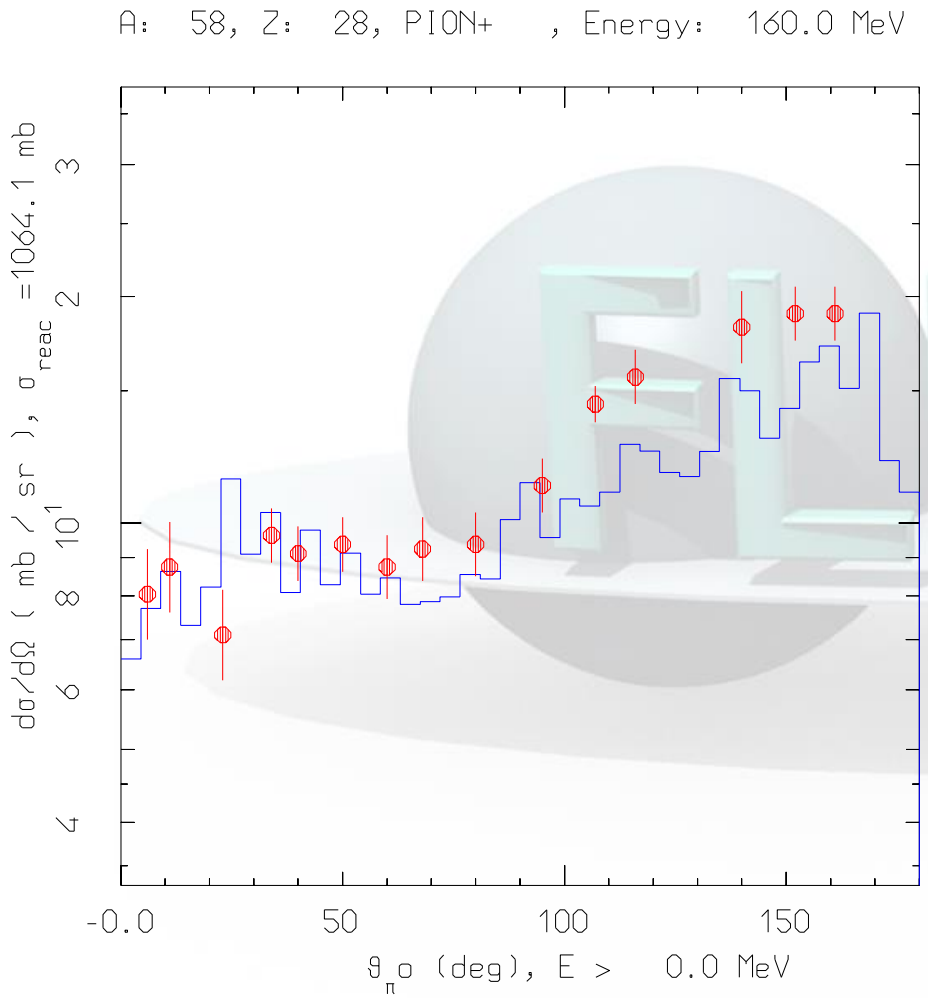


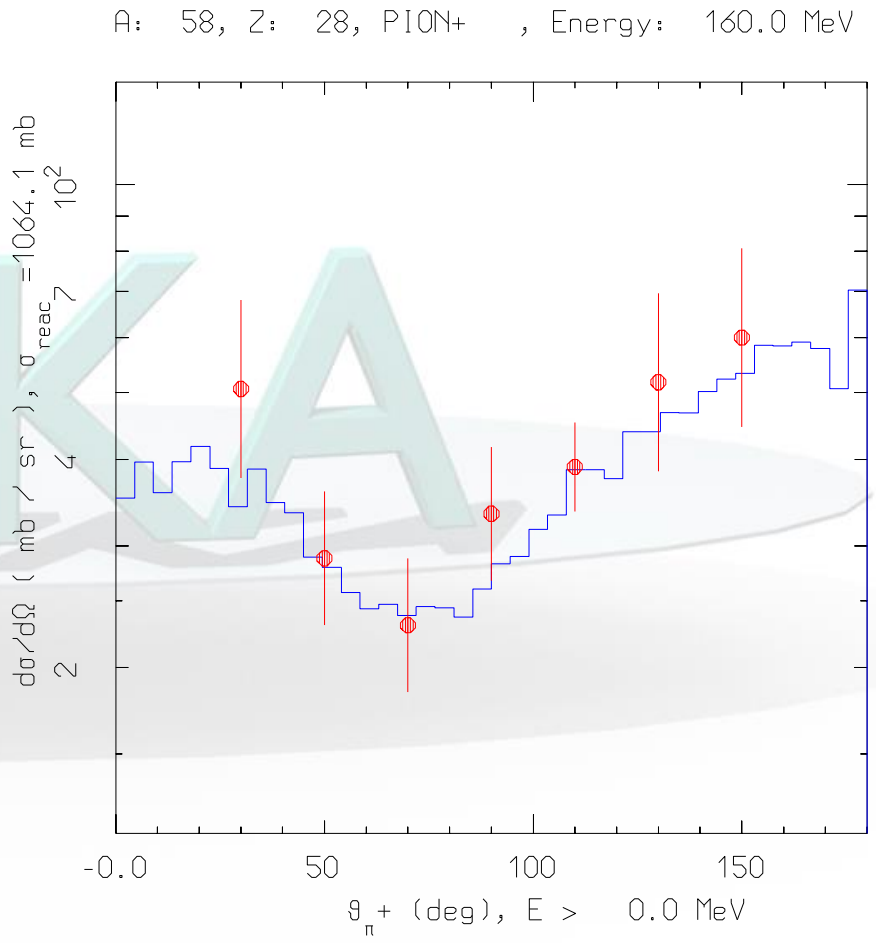
Emitted proton spectra at different angles , 160 MeV π^+ on ^{58}Ni
Phys. Rev. C41,2215 (1990)
Phys. Rev. C24,211 (1981)
Proton spectra extend up to 300 MeV



Around 1993:
The low energy hadronic interaction part part goes in GEANT3, (those old enough will remember geant-fluka, also GCALOR used it)

More low energy pions

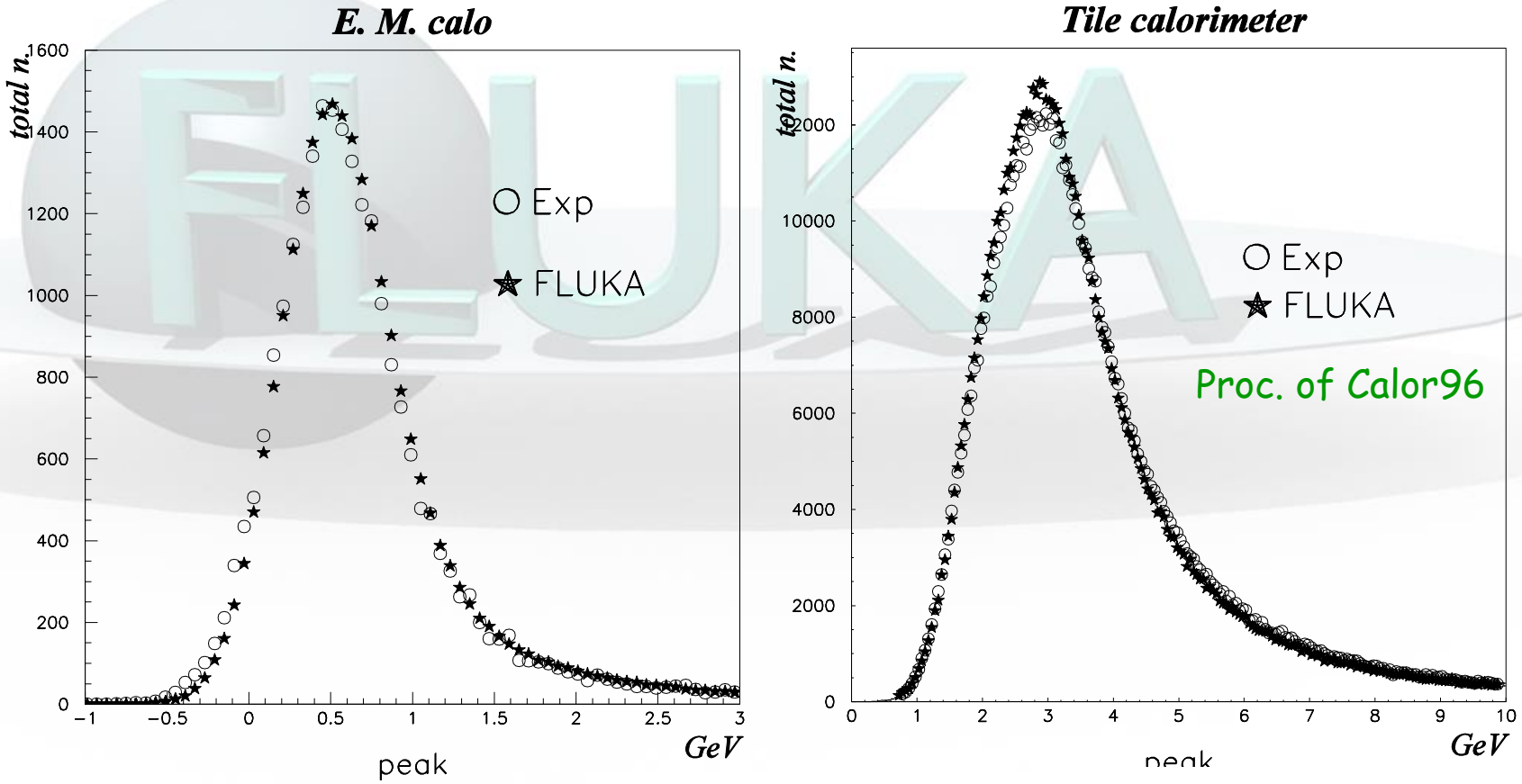




300 GeV μ in the ATLAS comb. calo test beam

- Study of muon dE/dx and muon bremsstrahlung in the ATLAS Accordeon + TILE prototypes

Same algorithm for all charged particles and all energies



Calibration in electron scale (e/μ correct), electronic noise added

End of 90^{ties}: cosmic rays and neutrinos

User-ready module with primary spectra, geomagnetic field, atmosphere layers
Start the work on ion-ion interactions

Around 2003: interface in CORSIKA for E<50 GeV

ELSEVIER

Astroparticle Physics 12 (2000) 315–333

Astroparticle Physics

www.elsevier.nl/locate/astropart

A 3-dimensional calculation of the atmospheric neutrino fluxes

G. Battistoni [a,*], A. Ferrari [a,1], P. Lipari [b], T. Montaruli [c], P.R. Sala [a,1], T. Rancati [a]

[a] INFN and Dipartimento di Fisica dell' Università, 20133 Milano, Italy
[b] INFN and Dipartimento di Fisica dell' Università "La Sapienza", 00196 Roma, Italy
[c] INFN and Dipartimento di Fisica dell' Università, 70126 Bari, Italy

Received 26 July 1999; received in revised form 24 August 1999; accepted 24 August 1999

ELSEVIER

Astroparticle Physics

Volume 19, Issue 2, May 2003, Pages 269–290

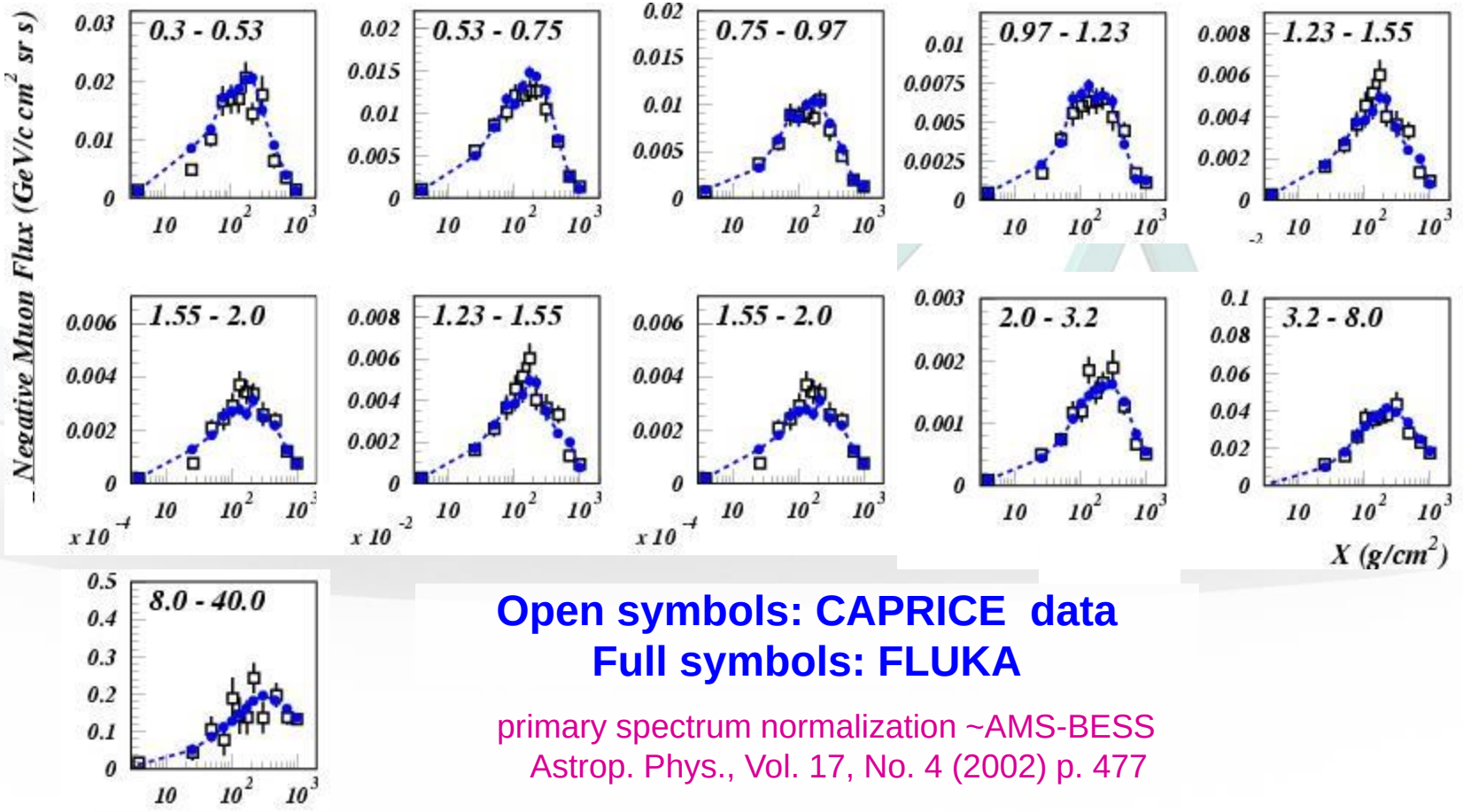
The FLUKA atmospheric neutrino flux calculation

G. Battistoni[a], A. Ferrari[b, 1], T. Montaruli[c], P.R. Sala[d, 1]

Show more

doi:10.1016/S0927-6505(02)00246-3

Negative muons at floating altitudes: CAPRICE94



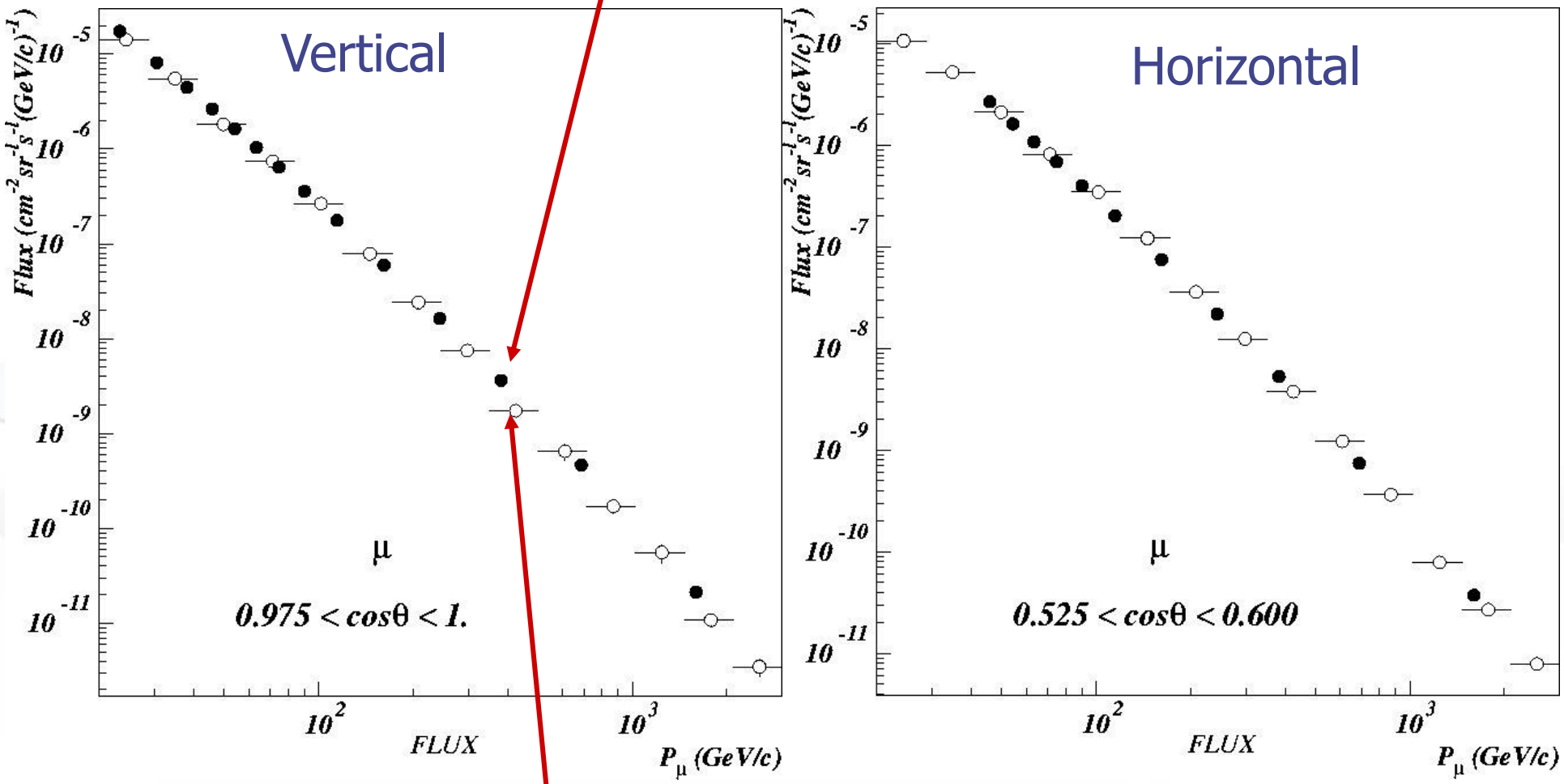
Open symbols: CAPRICE data
Full symbols: FLUKA

primary spectrum normalization ~AMS-BESS
Astrop. Phys., Vol. 17, No. 4 (2002) p. 477

(S.Muraro, PhD thesis Milano)

L3 Muons

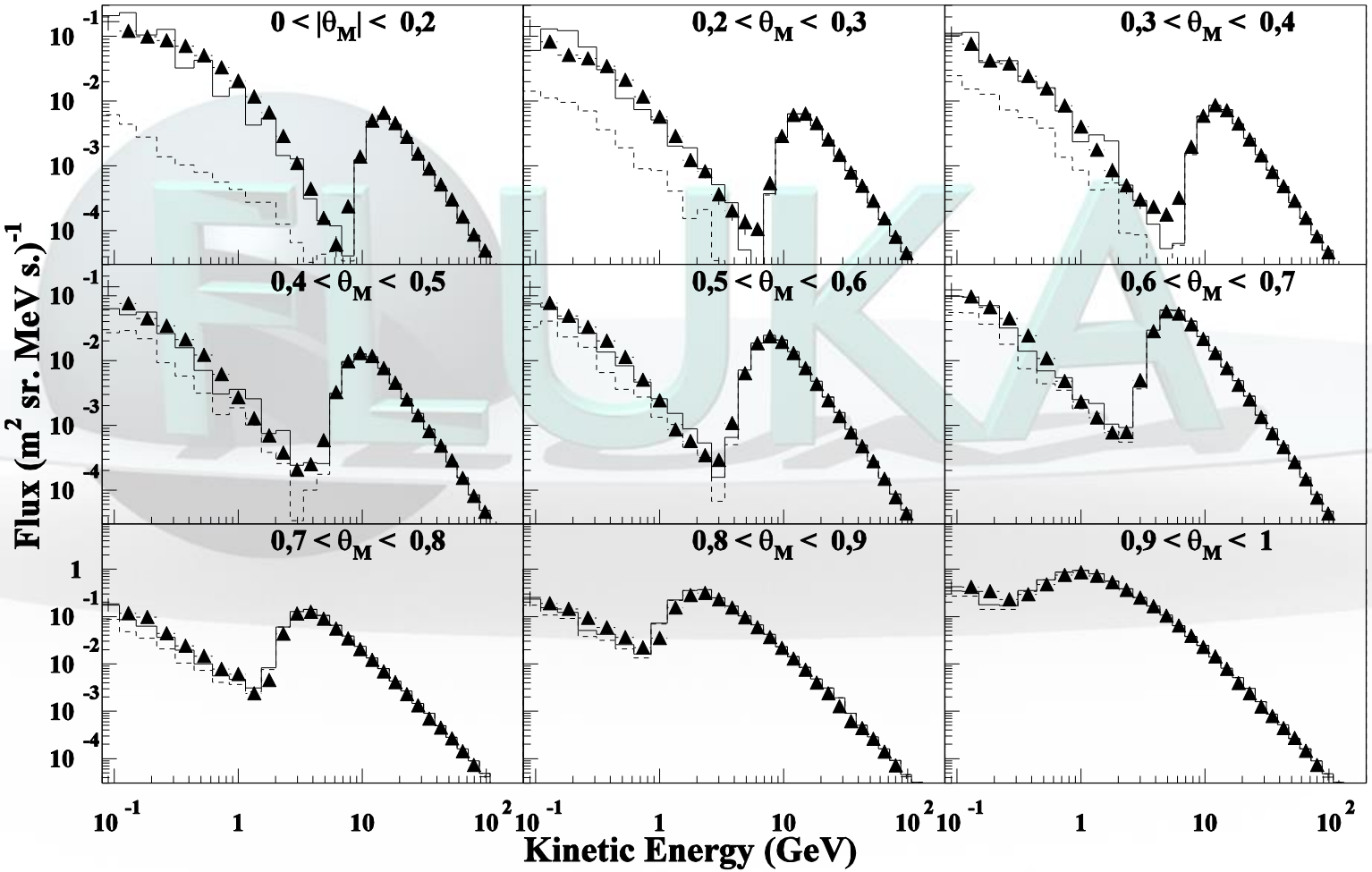
exp. data



FLUKA simulation

Comparison with AMS data

Protons and leptons below the geomagnetic cutoff have been measured by the AMS experiment at altitudes 370-390 Km, latitude ±51.7^0 Astrop. Phys. 20,221 (2003)



Downgoing proton flux, simulation(solid line) AMS data(triangles). θ_M is the geomagnetic latitude in radians

Up to now..

Astroparticle Physics 81 (2016) 21–38

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

Production of secondary particles and nuclei in cosmic rays collisions with the interstellar gas using the FLUKA code

M.N. Mazziotta[a,*], F. Cerutti[b], A. Ferrari[b], D. Gaggero[c,d,1], F. Loparco[a,e], P.R. Sala[f]

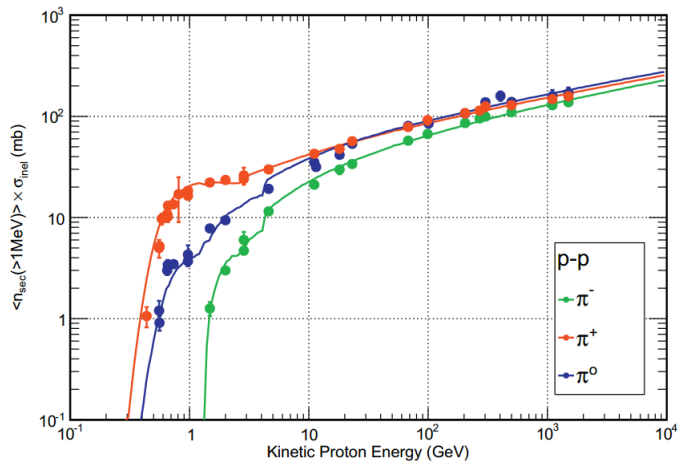


Fig. 2. Inclusive cross sections for the production of π^0 (blue), π^+ (red) and π^- (green) in p–p collision as function of the incoming proton kinetic energy. Lines: FLUKA simulation; points: data from Ref. [28]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

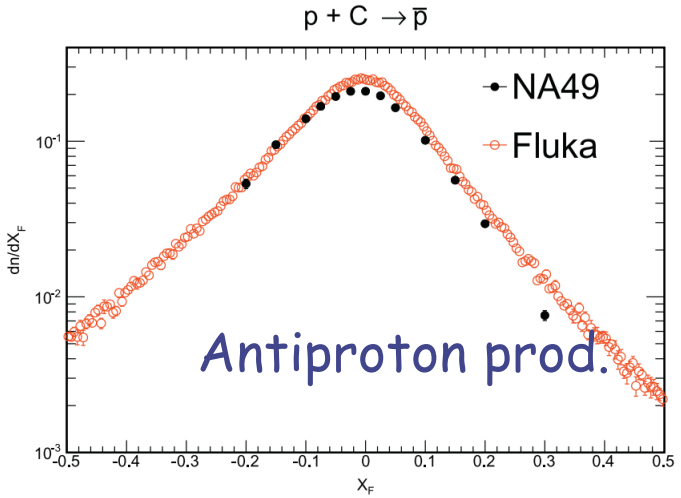
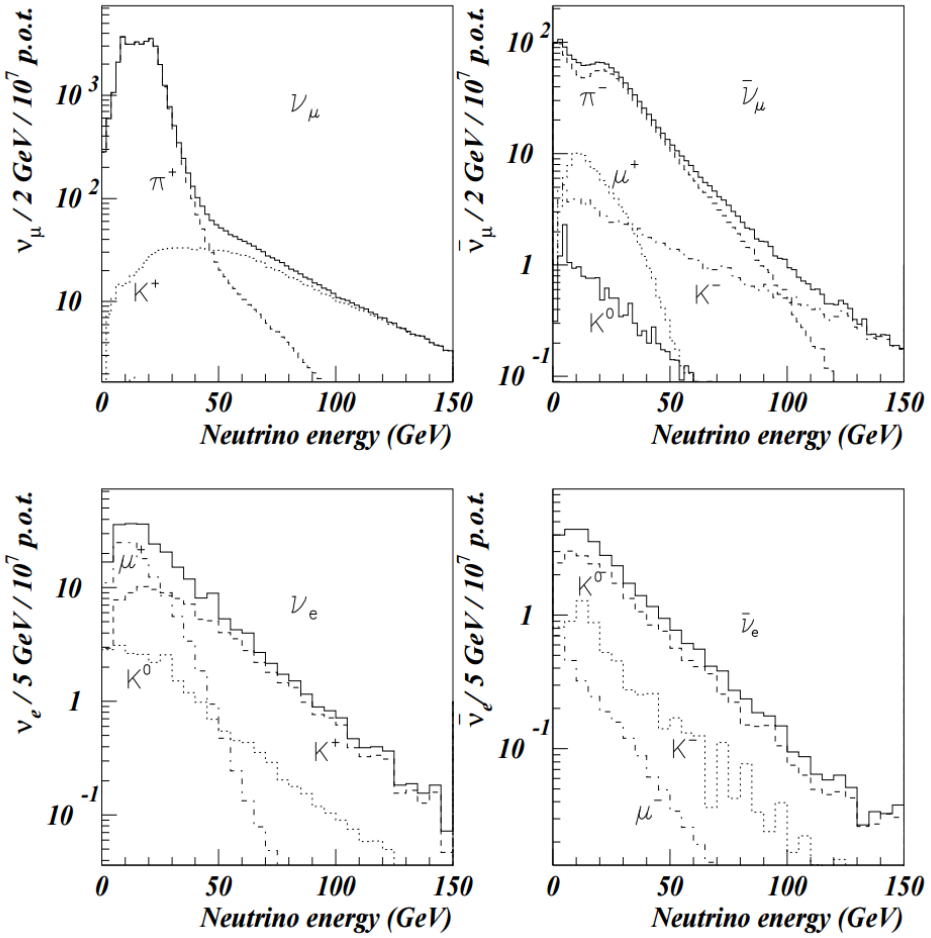
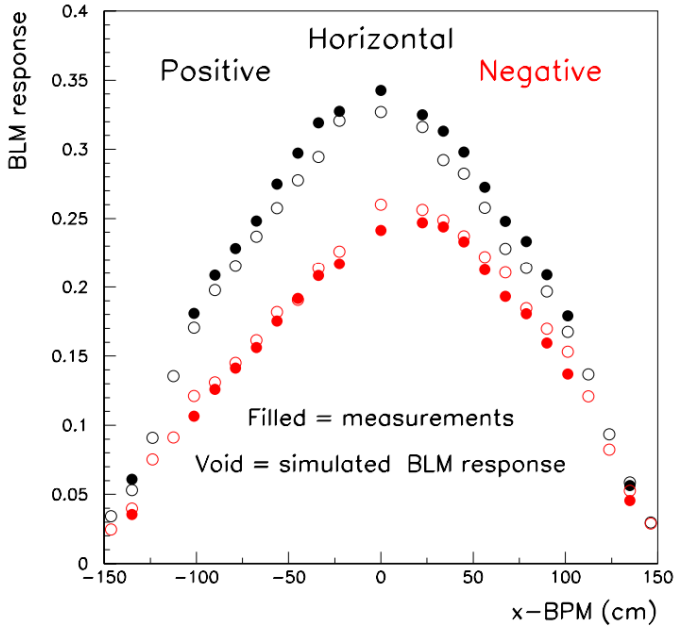


Fig. 3. Feynman X (X_F) distribution for $\bar{p}$ production in proton interactions on carbon at 158 GeV/c beam momentum. The NA49 data [64] (black points) are compared with the predictions by FLUKA (red points). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Neutrino beam(s)

- CNGS: design of the beam line, engeneering, radiation protection, neutrino fluxes
- CERN-AB-Note-2006-038 , EDMS No. 745389
- Fluxes available at http://www.mi.infn.it/~psala/Icarus/cngs.html



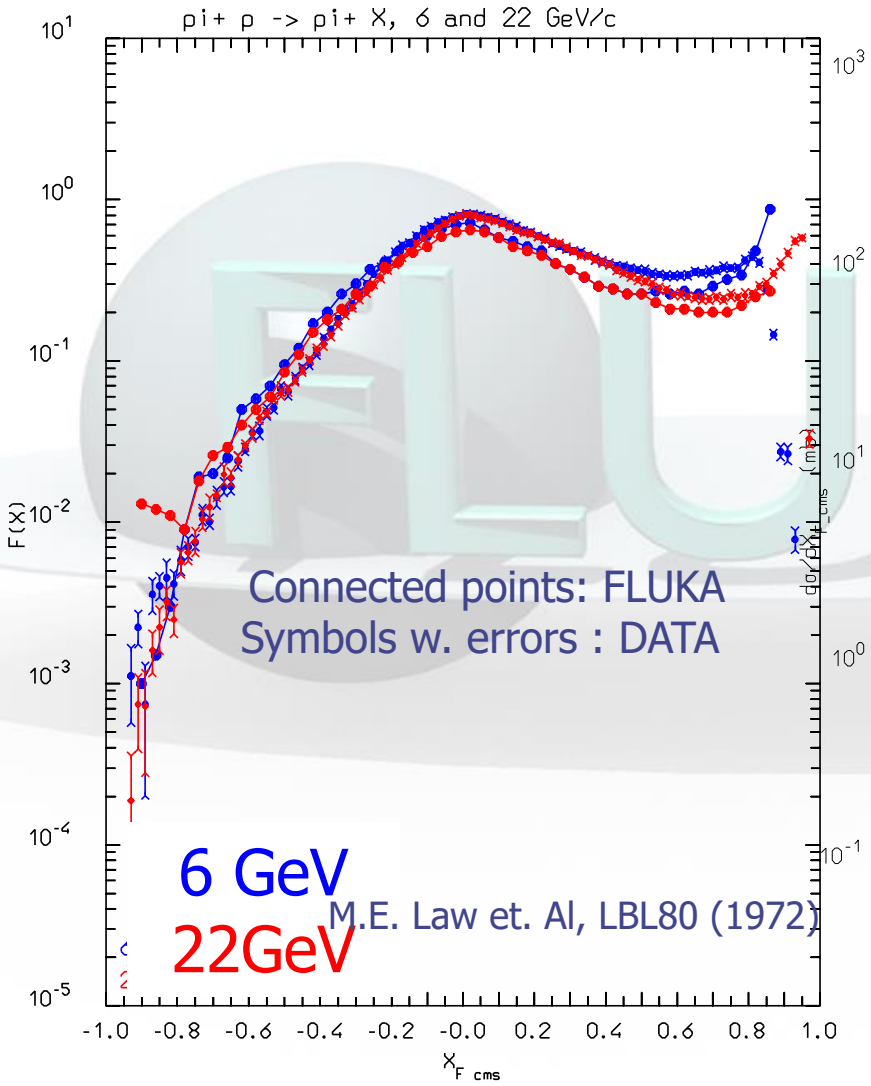


Muon pits

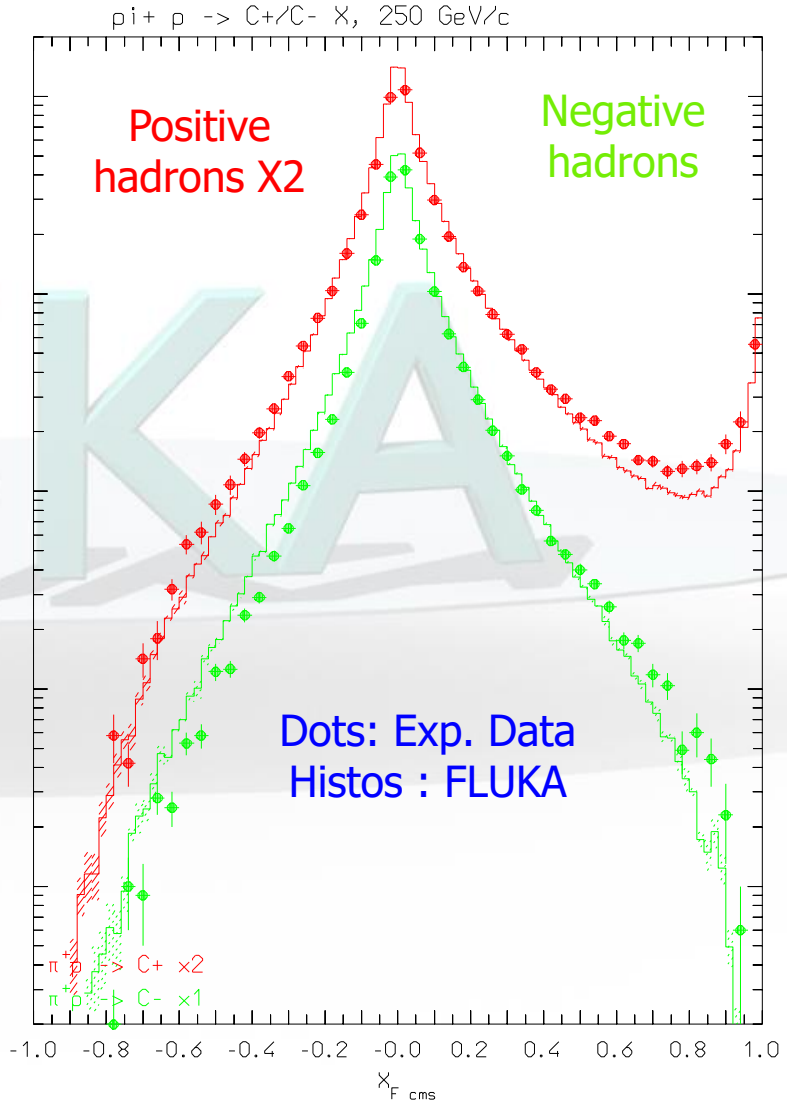
D. Autiero et al. / Nuclear Physics B (Proc. Suppl.) 188 (2009) 188–190

Inelastic hN interactions: examples

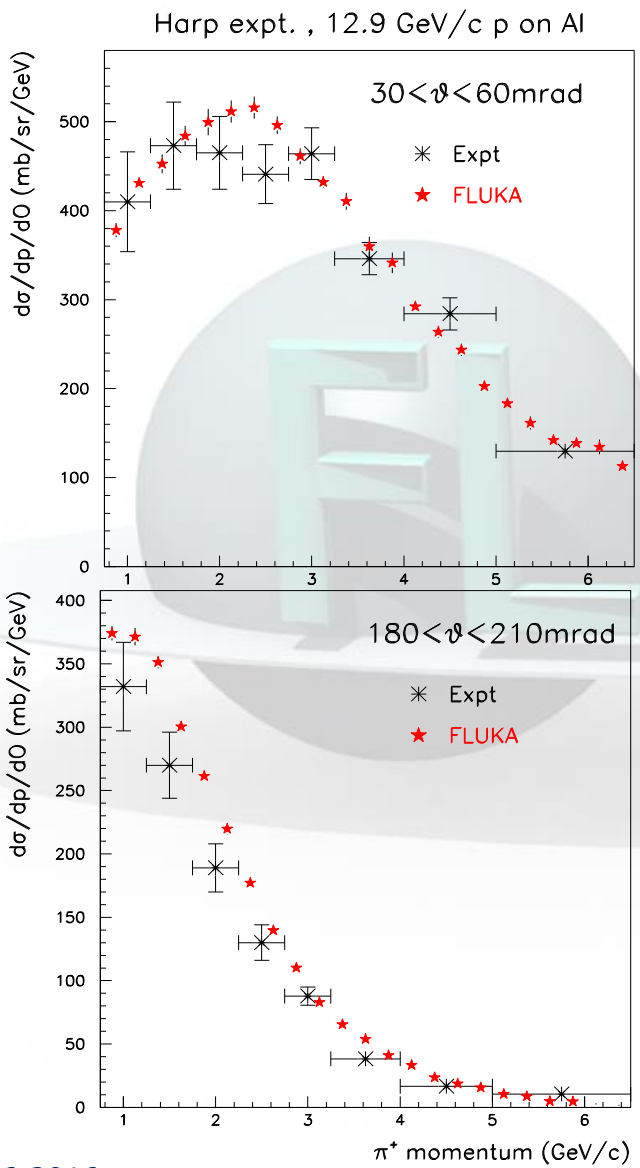
$\pi^+ + p \rightarrow \pi^+ + X$ (6 & 22 GeV/c)



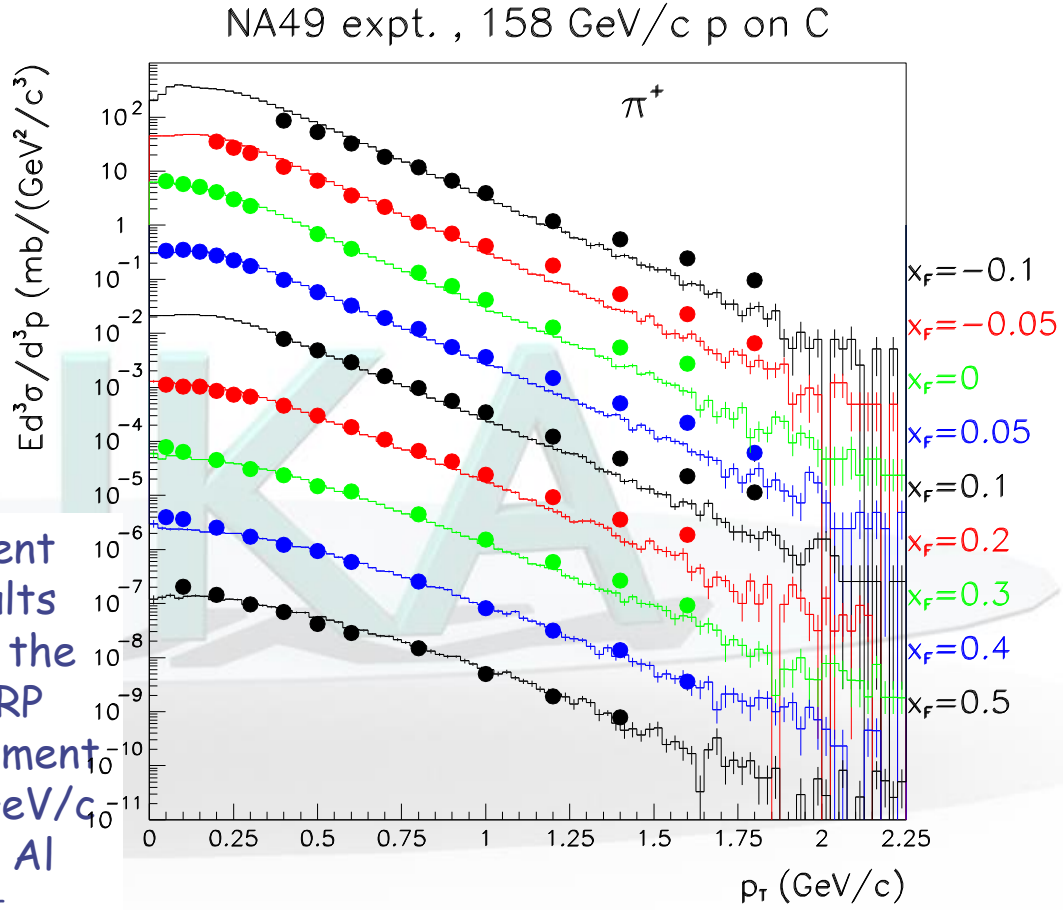
$\pi^+ + p \rightarrow Ch^+/Ch^- + X$ (250 GeV/c)



Nonelastic hA interactions at high energies: examples



Recent results from the HARP experiment 12.9 GeV/c p on Al π^+ production at different angles



Double differential π+ production for p C interactions at 158 GeV/c, as measured by NA49 (symbols) and predicted by FLUKA (histograms)

Other neutrino beams

- MINOS: "The simulation of neutrino production and detection is accomplished with a model of hadron production in the target using FLUKA [15] and a GEANT3 [16] simulation of the beam line and detector" PRL 101, 131802 (2008)
- T2K "We use the FLUKA 2008 package [12,13] to model the interactions of the primary beam protons and the subsequently produced pions and kaons in the graphite target." PHYSICAL REVIEW D 91, 072010 (2015)

Nucleon Decay

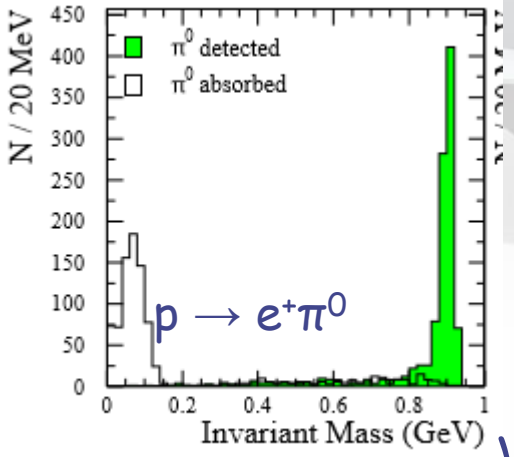
- Proton decay generator implemented for the ICARUS T1800 proposal (spsc-p-323)
- Uses all the details of the nuclear models in FLUKA

Nucleon decay searches with large liquid Argon TPC detectors at shallow depths: atmospheric neutrinos and cosmogenic backgrounds

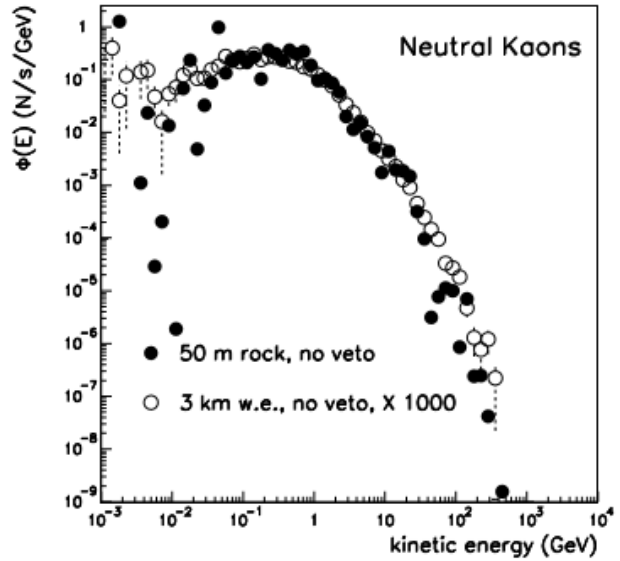
JHEP 04 (2007) 041

Antonio Bueno,[a] Antonio J. Melgarejo,[a] Sergio Navas,[a] Zuxiang Dai,[b] Yuanyuan Ge,[b] Marco Laffranchi,[b] Anselmo Meregaglia[b] and André Rubbia[b]

"The atmospheric neutrino flux has been computed by several groups. We take results from the FLUKA group [78] "



"The nuclear effects, the distortions of the energy and momentum distributions due to Fermi motion (since the recoil nucleus is not measured), and the reinteraction of decay particles with the nucleus have been treated with the FLUKA package".



We thank P. Sala for help with FLUKA while she was an ETH employee.

"we will use the yields from FLUKA to estimate (cosmog.) backgrounds. "

User interface

- Input parameters and geometry given with datacards
- Broad set of built-in estimators allow to get results without coding (energy depositions on mesh, energy/angle fluxes and many more
- Templates for user routines provided for specific needs, from source to biasing to scoring (yes, they are in fortran, but nobody prevents to plug in C or C++ code.
- NO physics lists. Only one model for each process/energy range.
- =➔ very easy-to-use for "basic" users
- =→ very flexible for advanced users
- => reproducible results

- Since 2005: distributed on web-site, discussion mailing list, user courses
- www.fluka.org

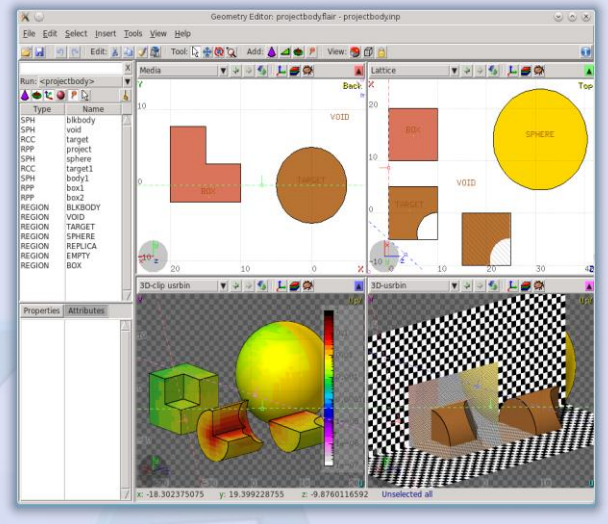
Flair: user Interface

…

- Everything can be managed with a few clicks from Flair, powerful graphical interface!
  - Geometry input, debugging, visualization (2D/3D)
  - Material, physics, scoring input
  - Run submission and management
  - Analysis and plots of the results
  - Patient CT scan import

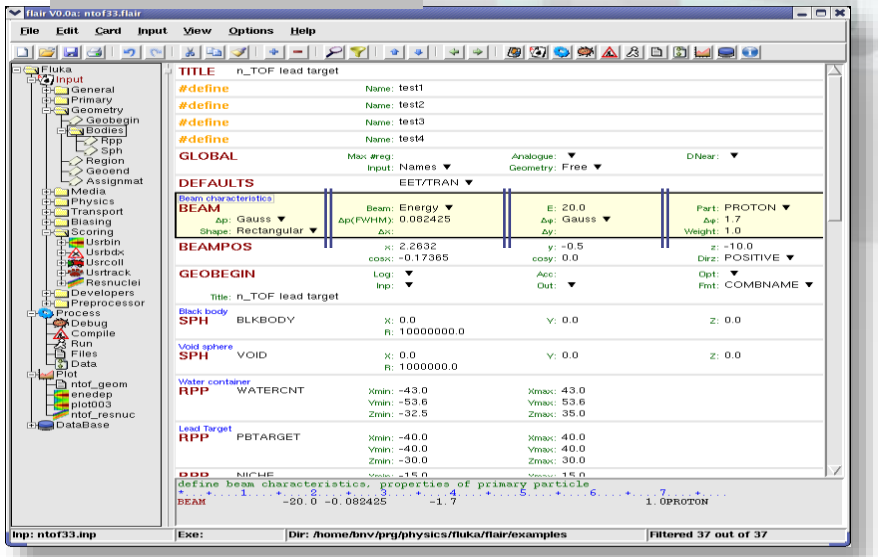
… with no programming skill or file editing requirement!

Graphical Geometry Editor/Debugger



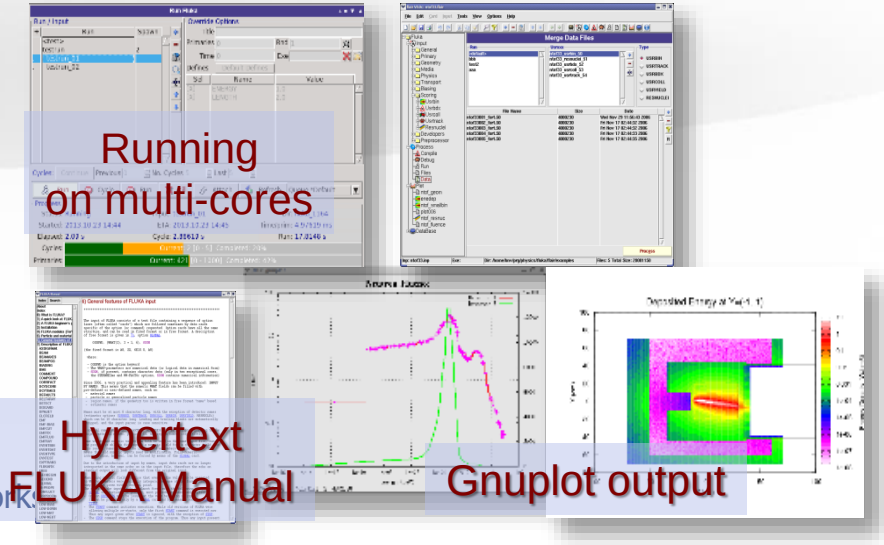
Videos available: www.youtube.com/user/Flair4Fluka

Input creation

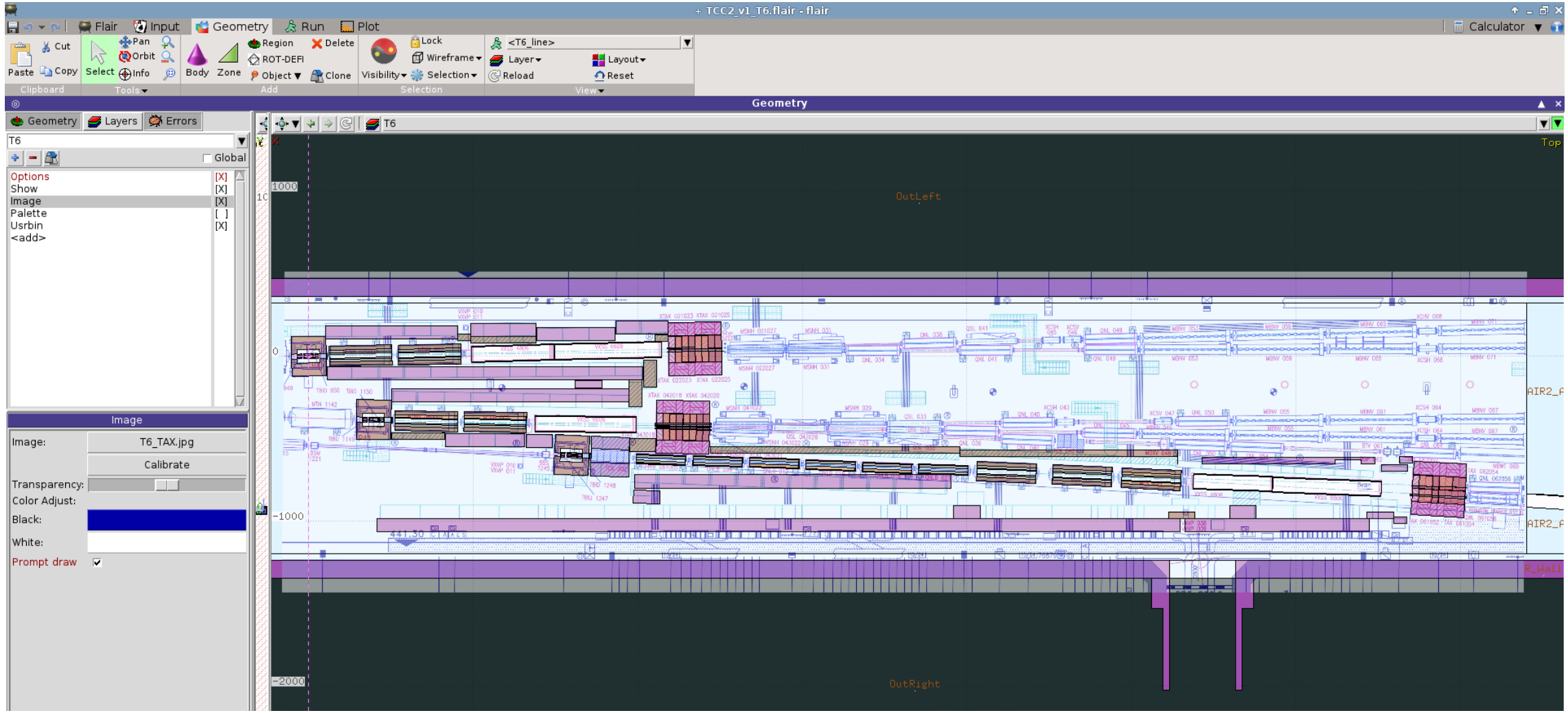


FLAIR main application window

Running / Processing / Analyzing



Overlay of geometry and drawings



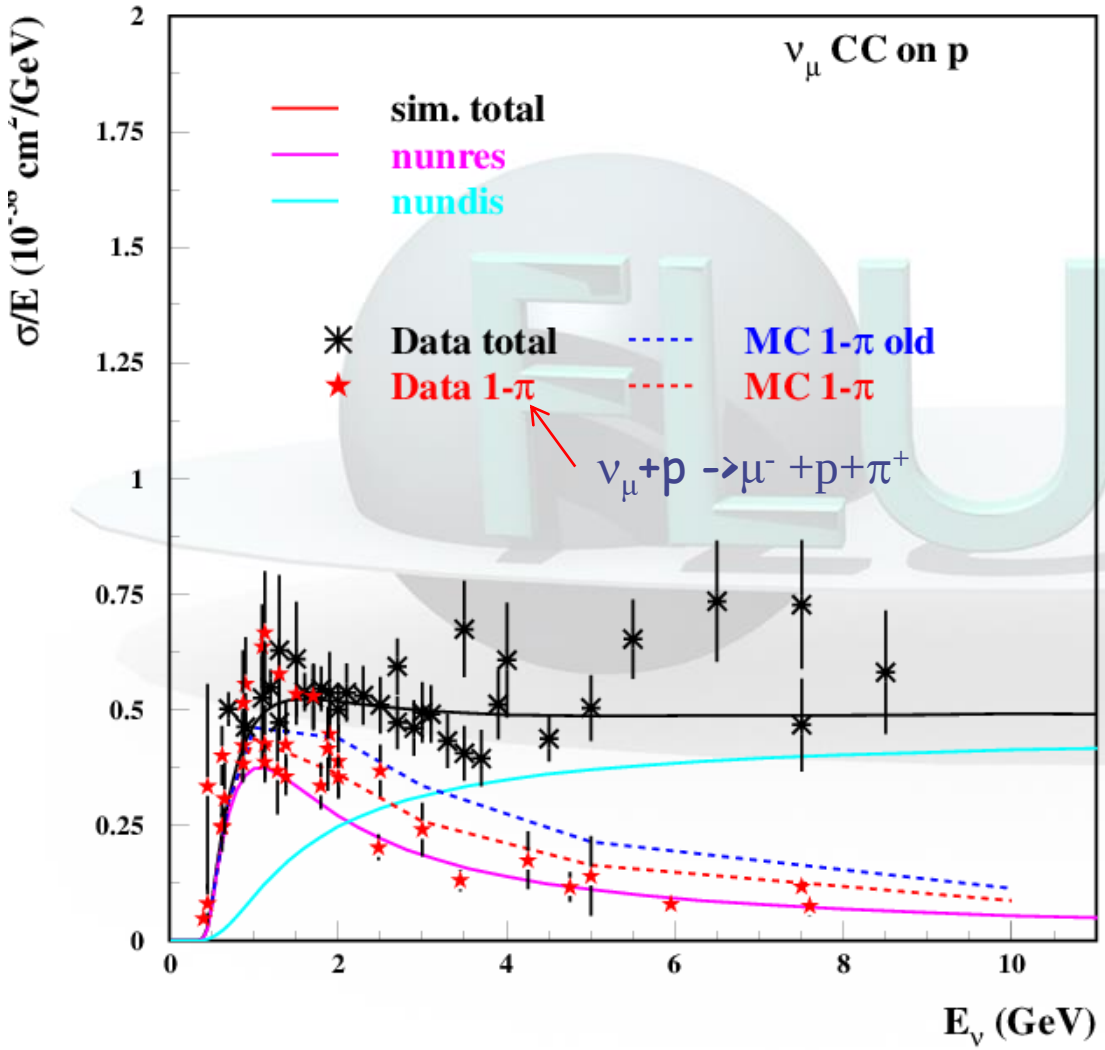
Neutrino interactions in FLUKA: NUNDIS

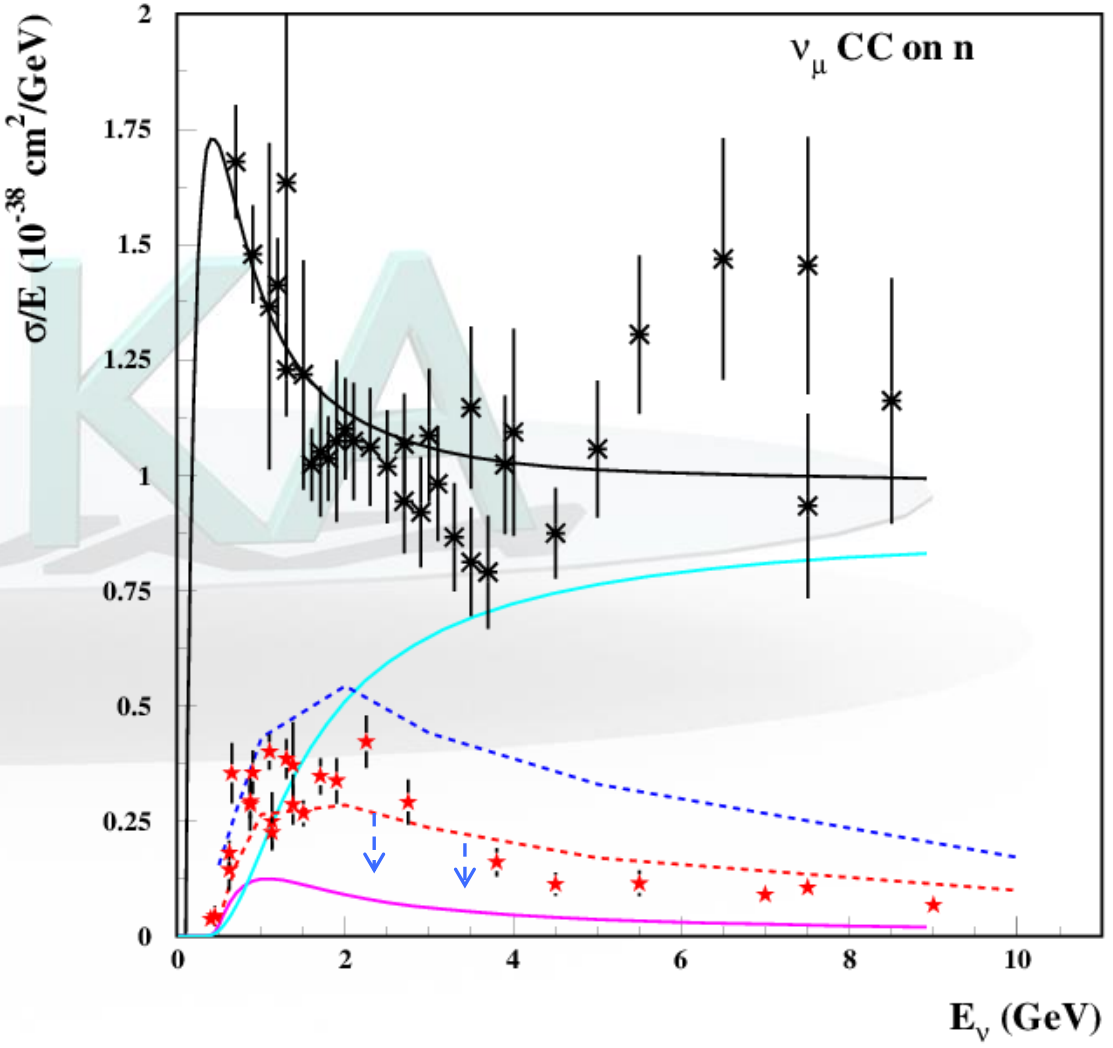
M. Antonello, G. Battistoni, A. Ferrari, M. Lantz, P. Sala, G. Smirnov

1997: QE in the fLUKA nuclear environment
≈2000 NUX-FLUKA (no longer active)
2008: NUNDIS: DIS + Resonances

Low energy and single pion

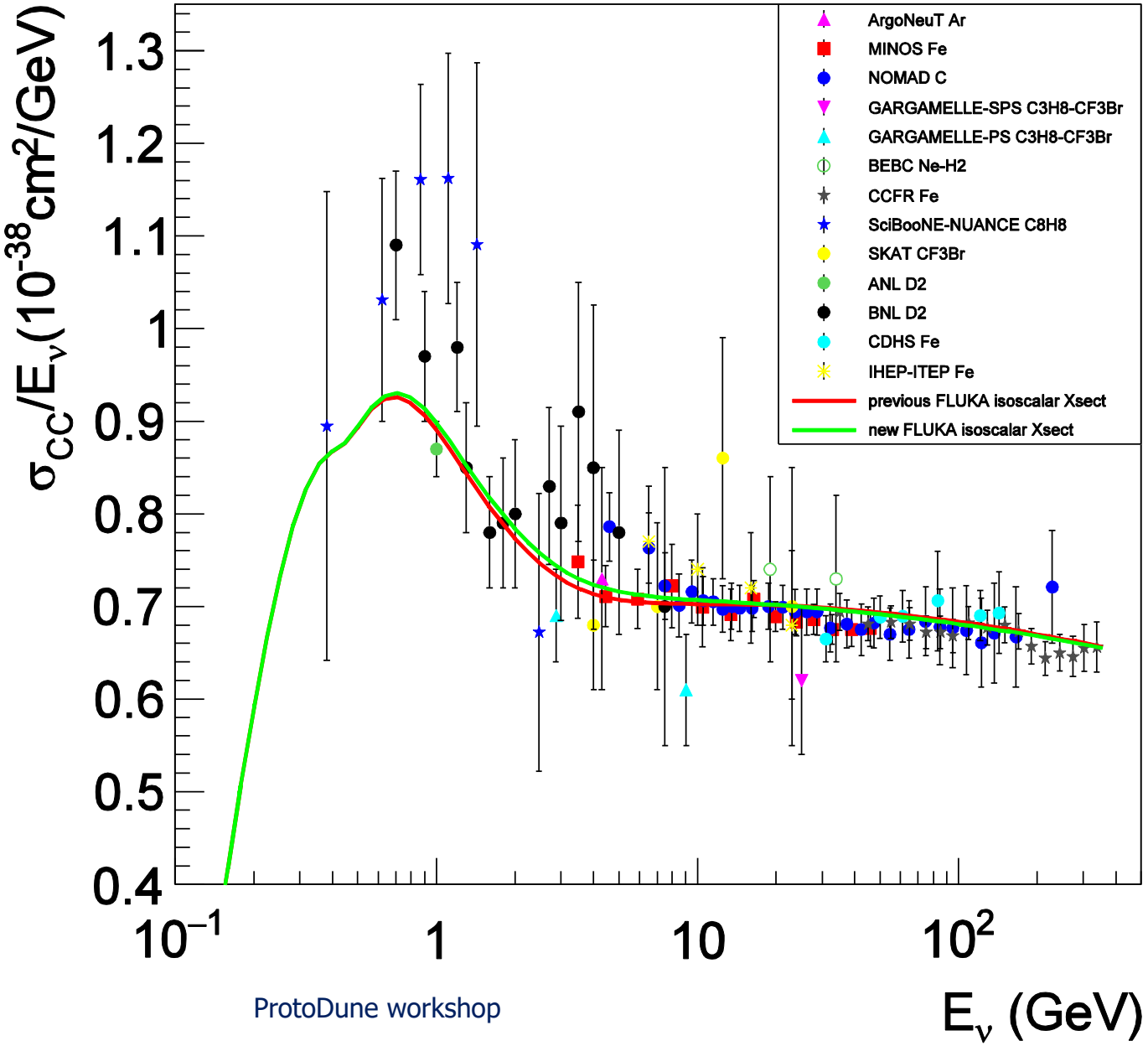
New ***low-mass chain treatment***-> improvements in the **RES-DIS** transition





Comparison with data on total cross section

Isoscalar
ν_μ - Nucleon total CC cross section
Fluka (lines) with two pdf options
Vs
Experimental data



Nuclear effects in Minerva

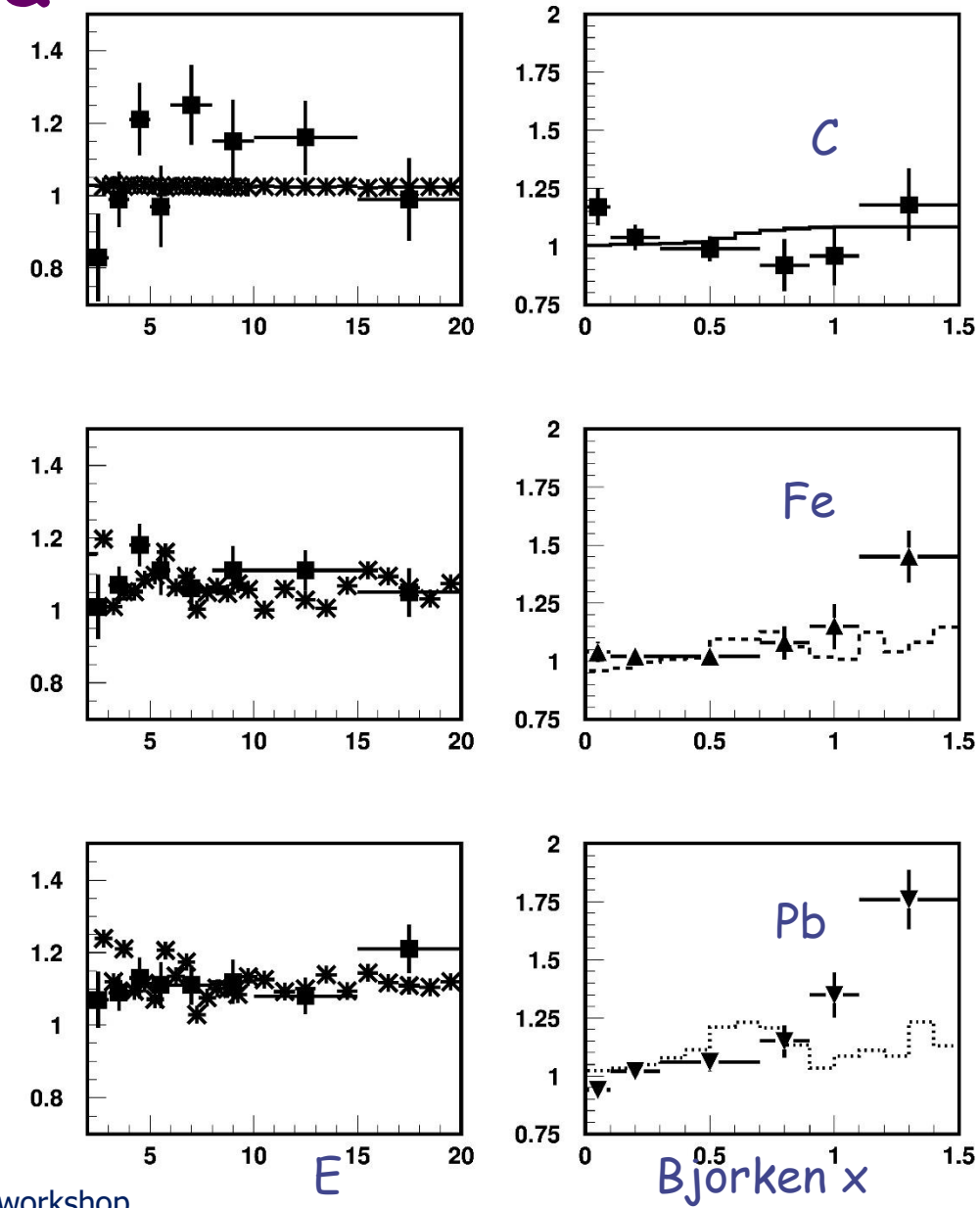
Beam: $\nu\mu$ NuMi Low Energy (average 4 GeV)
Main Target : CH

Measured also with C, Fe, Pb targets
PRL 112, 231801 (2014)

Here: ratio of cross sections / the one in CH

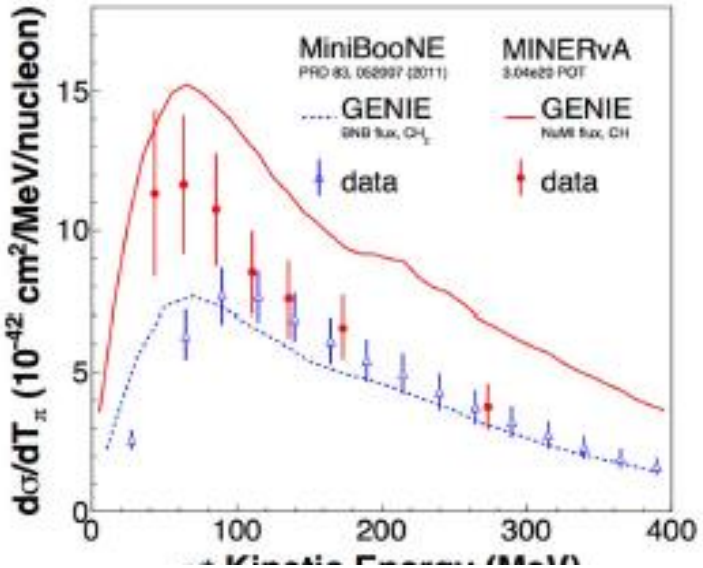
Left: total CC vs neutrino Energy :
squares: data
crosses: FLUKA

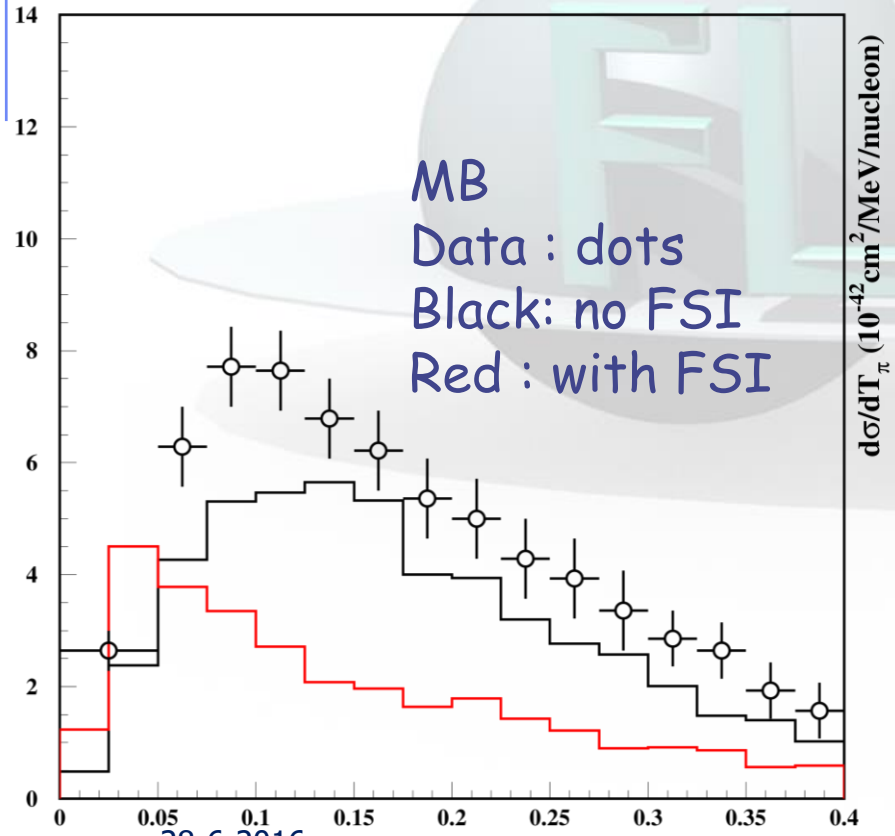
Right: $d\sigma/dx$
symbols: data histos: Fluka
expt: reduction at low x and
enhancement at high x with incr. A
Fluka: fails the highest x (same for Genie)

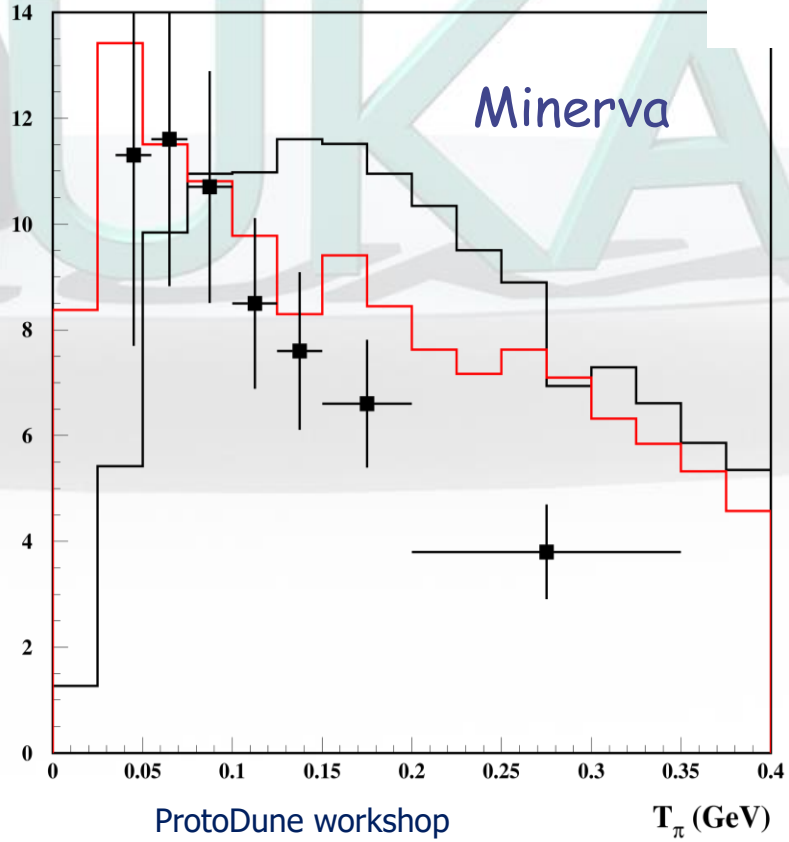


MB and Minerva

Dytman





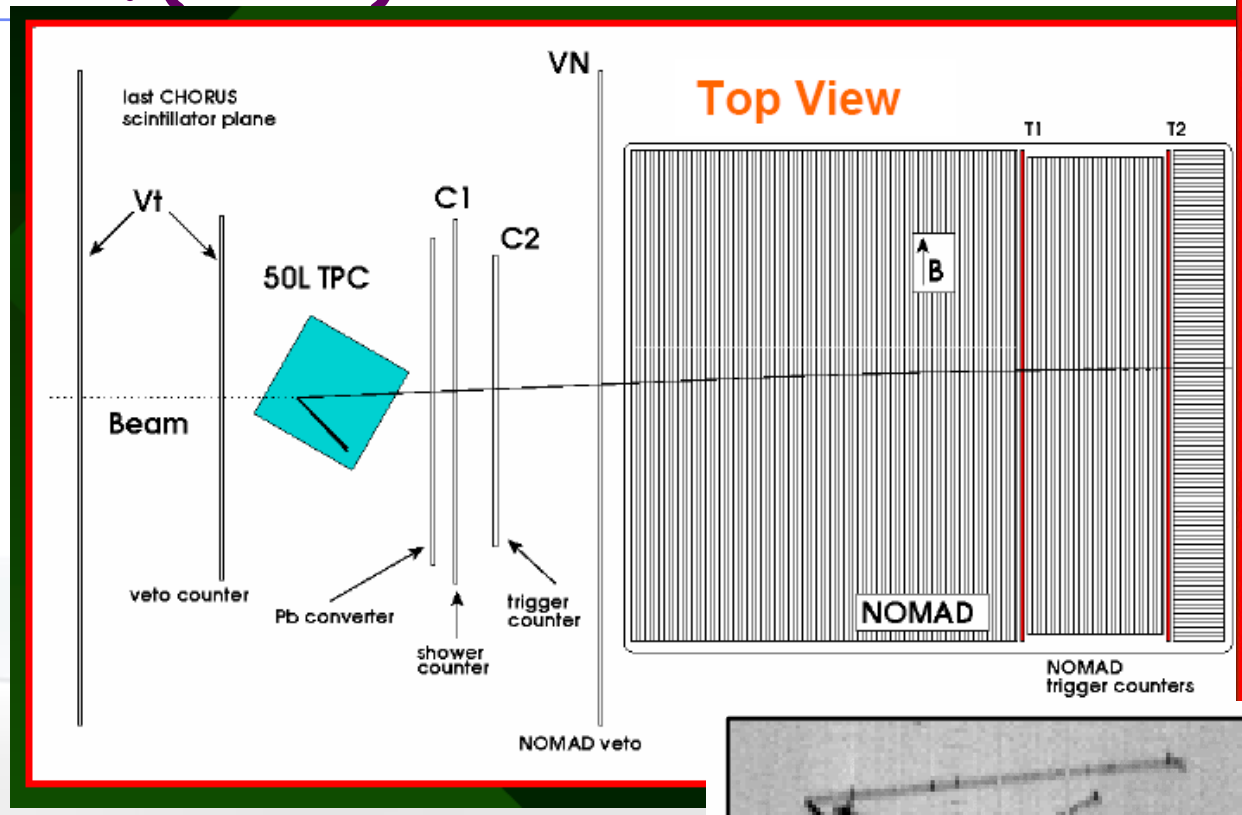


MiniBoone : CH_2, Eν ≈0.8 GeV, cut on single pion, PHYS. REV.D 83, 052007 (2011)

Minerva : CH, Eν ≈4 GeV, cut on W<1.4 arXiv:1406.6415v3 (2015)

Tension betw the two data sets vs models/ extent of FSI

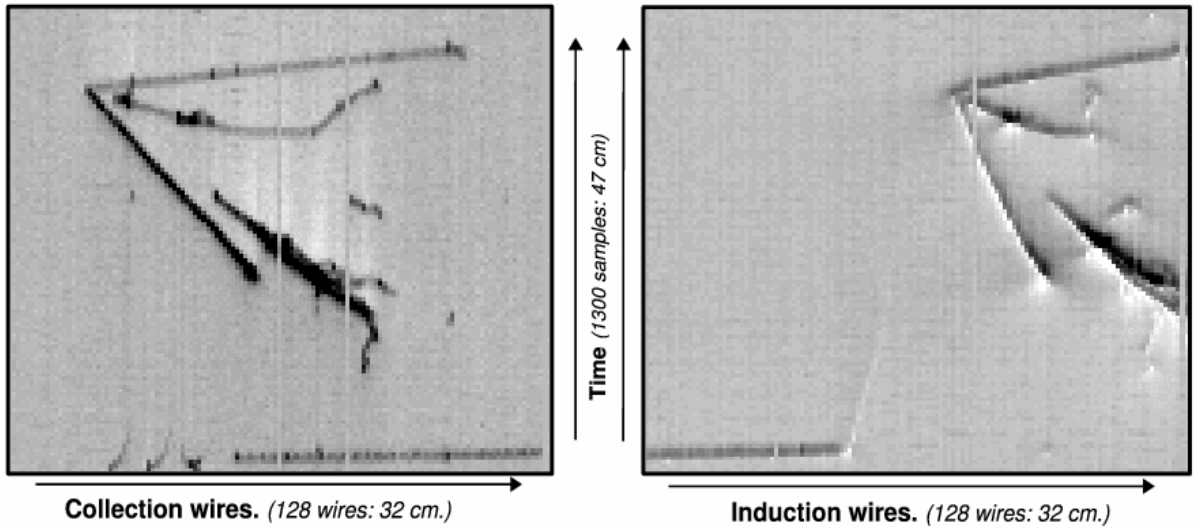
The 50l LAr TPC in the WANF neutrino beam(1997)

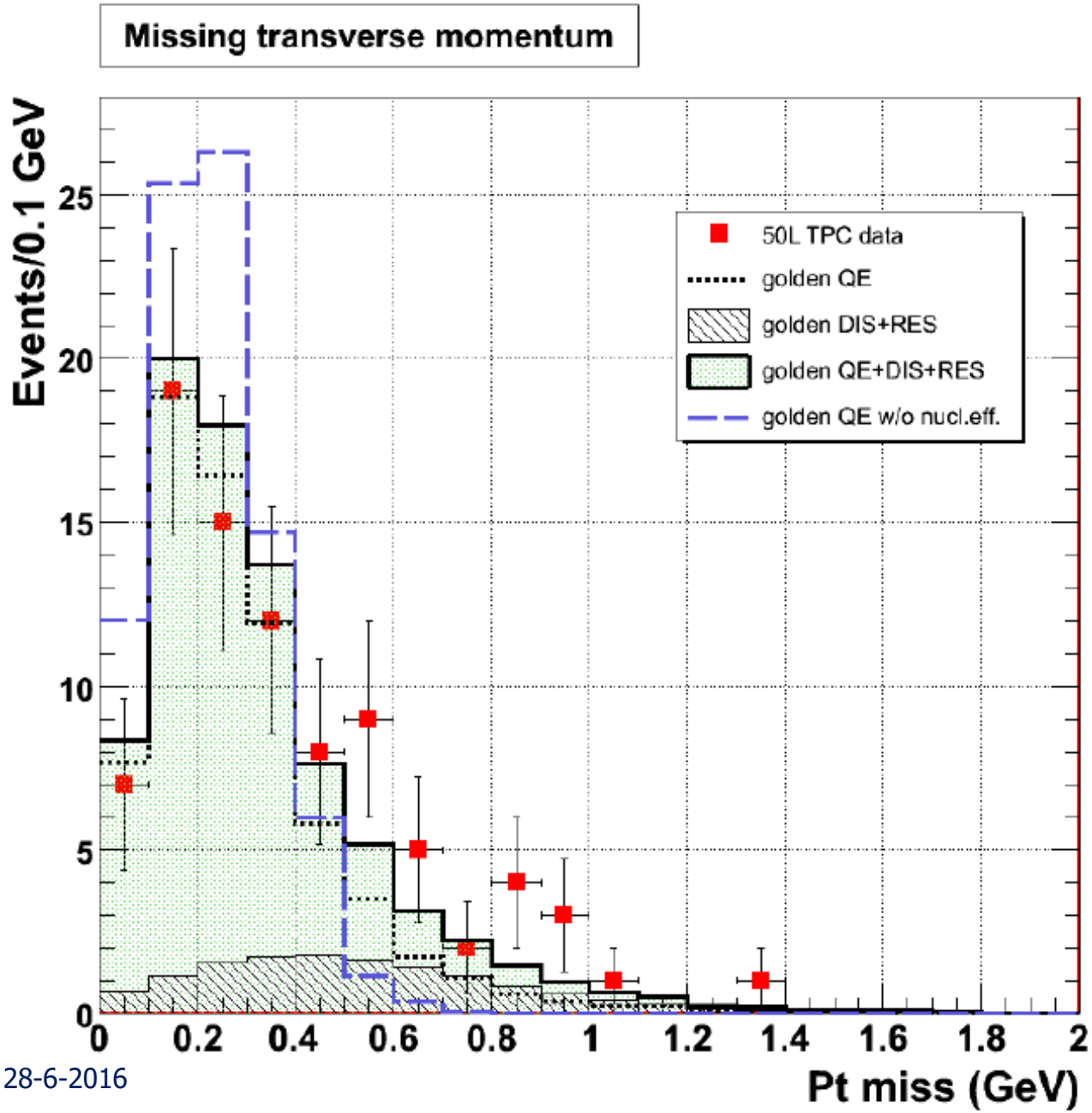


Trigger and μ reconstruction: NOMAD

Event selection: "GOLDEN sample"
= 1 μ and 1 proton >40MeV fully contained

Phys.Rev. D74 (2006) 112001





- from 400 QE – golden fraction 16%
- background – additional 20%

finally expected

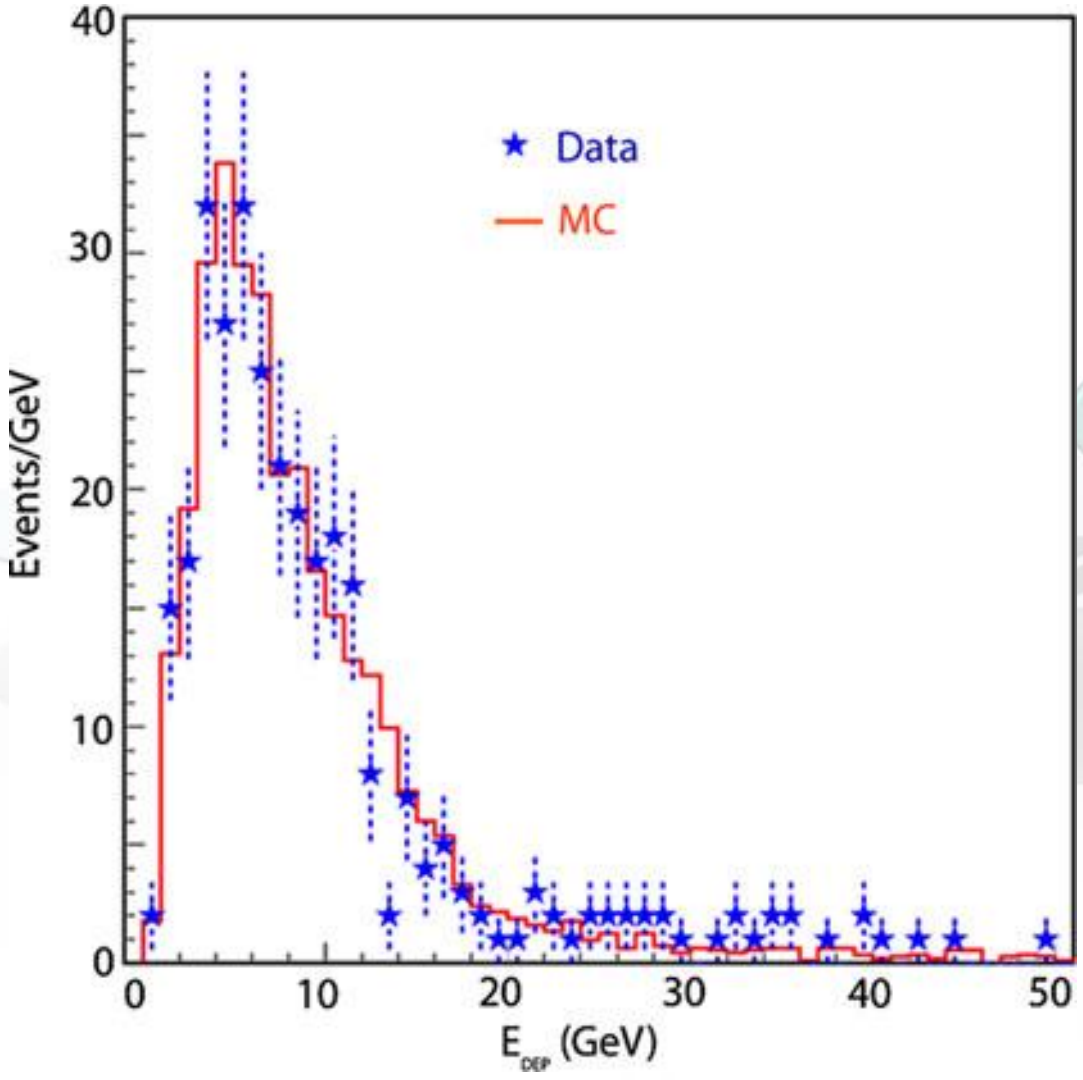
80±9(stat.)±13(syst.→ mainly QE fraction and beam simul)

to be compared with **86** events observed

Very good consistency with expectations

Note: here DIS and RES from old coupling with the NUX code (A. Rubbia)

CNGS data



Distribution of total deposited energy in the T600 detector
CNGS numuCC events
Same reconstruction in MC and Data
Neutrino fluxes from FLUKA cngs simulations

Absolute agreement on neutrino rate within 6%

Nundis: Conclusions and perspectives

- A neutrino event generator (NUNDIS) is implemented in FLUKA
- QE, RES, DIS interactions
- Hadronization as for hadronic interactions in FLUKA
- Nuclear effects from the FLUKA nuclear models
- Encouraging comparisons with expt data

- More has to be done:
  - Coherent pion production
  - Coherent effects (see high x in Minerva and proton pairs in Argoneut)
  - More coherent / nuclear structure effects for low energy QE
  - Meson exchange in QE (high x in Minerva)
  - Radiative corrections in DIS (ongoing)
  - ..nobody likes Rein-Sehgal..
  - Comparisons against data
- !

Medical applications: the growing application

- Hadrontherapy and conventional therapy
- Automatic imptort of CT scans, Region of interest, TPS
- Major Treatment Planning System vendors have bought FLUKA licenses
- Further work on dE/dx
- Further work on low energy ion-ion generator
- Prompt gamma production for imaging

frontiers in Oncology

ORIGINAL RESEARCH
published: 11 May 2016
doi: 10.3389/fonc.2016.00116

The FLUKA Code: An Accurate Simulation Tool for Particle Therapy

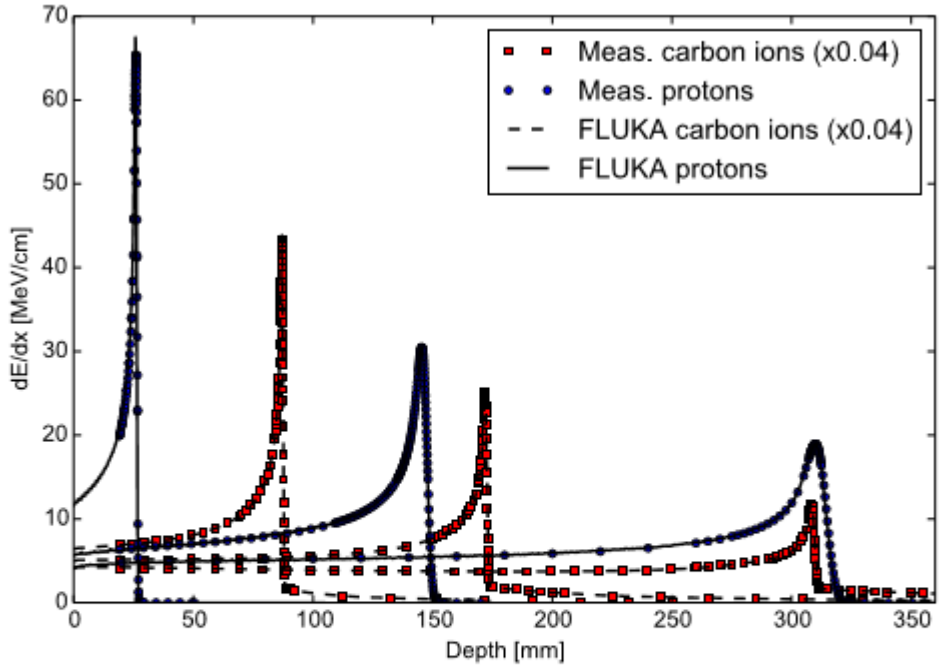
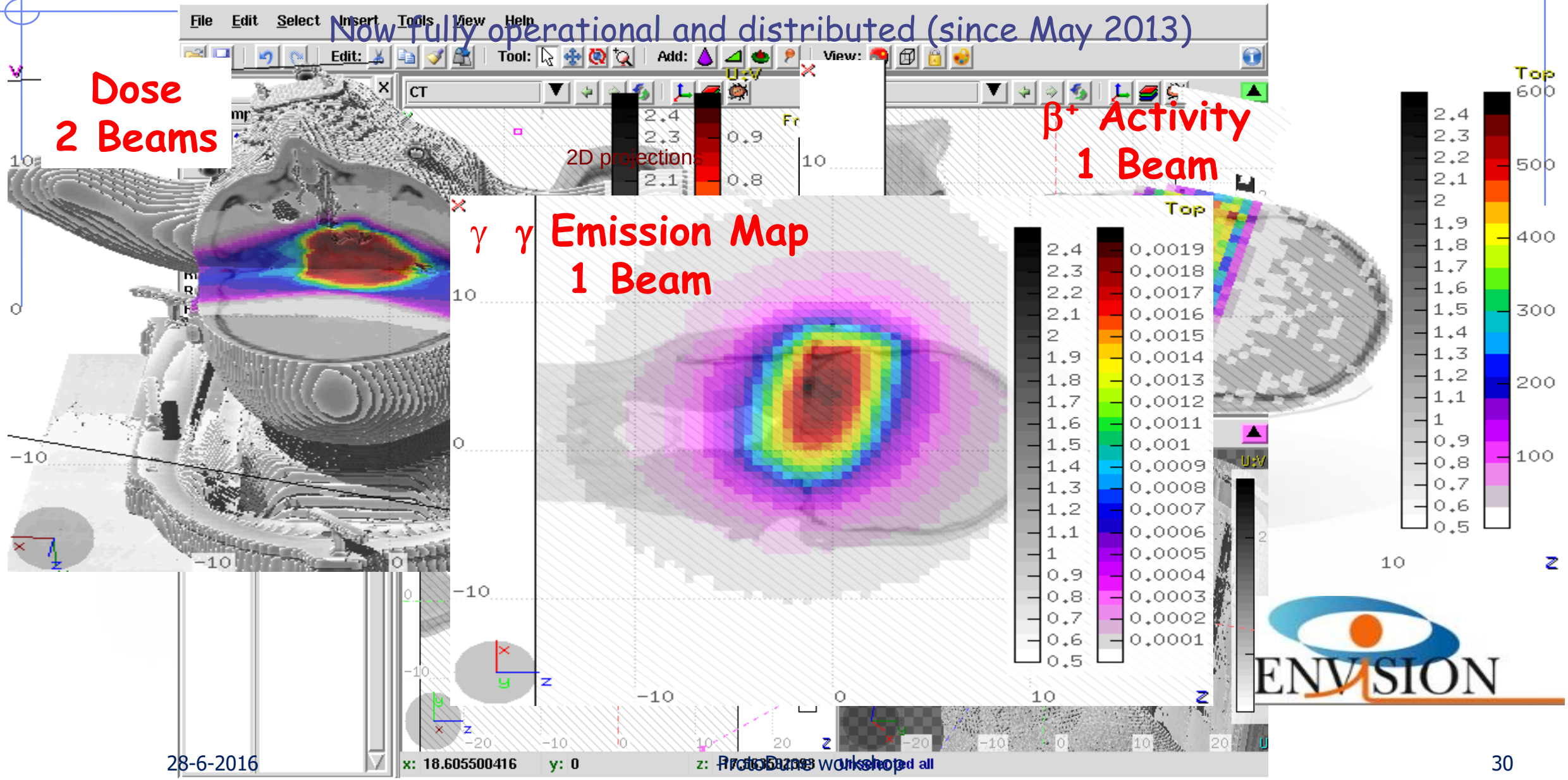


FIGURE 3 | FLUKA simulations of depth–dose profiles of protons and carbon ions with therapeutic ranges in comparison with measured data at HIT (61). The nominal energies before the beamline are 54.19, 142.66, and 221.05 MeV/u forprotons, and 200.28, 299.94, and 430.10 MeV/u for carbon ions.

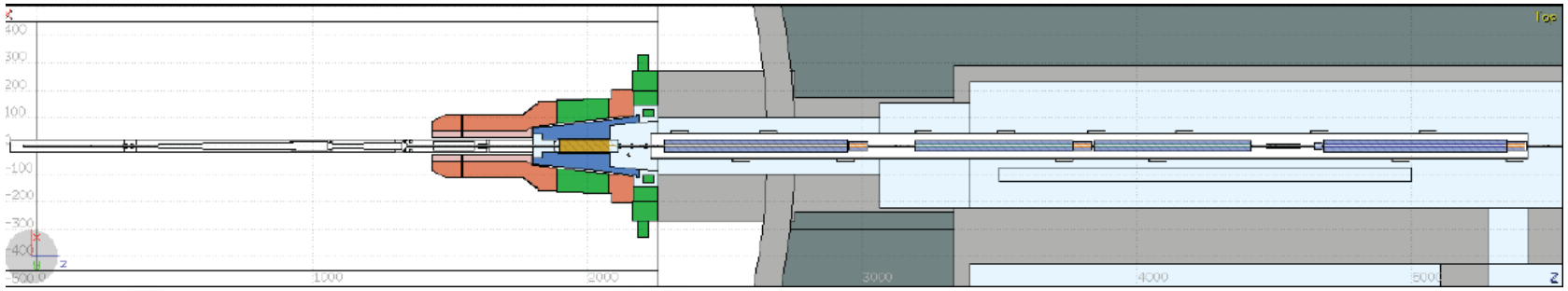
Flair/FLUKA interface: superimposing results to CT images

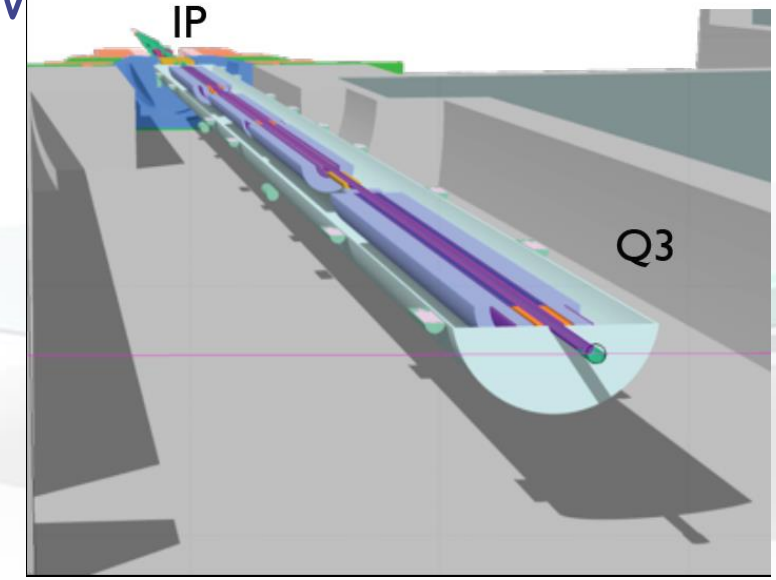
Now fully operational and distributed (since May 2013)

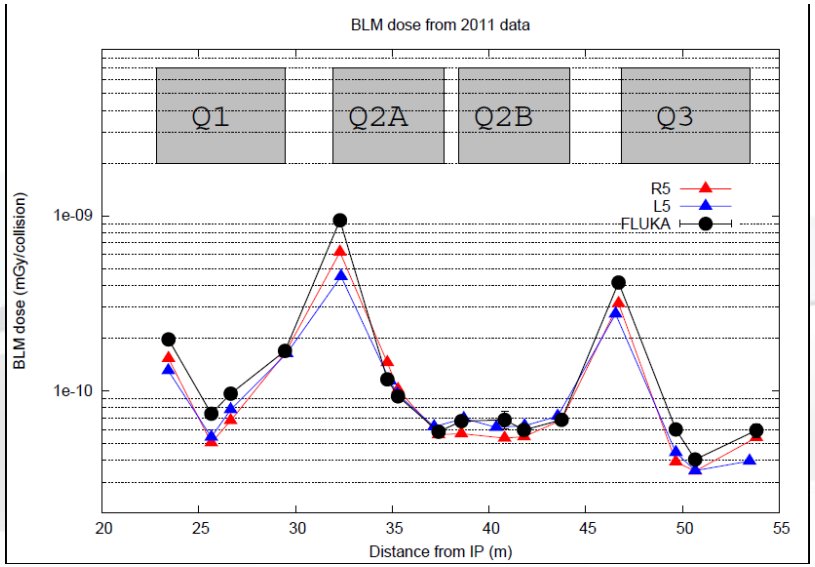


LHC and other accelerators

3.5+3.5 TeV







BLM response along triplet right of IR5

- BLM dose per collision assuming CMS luminosity measurement and 73.5 mb proton-proton cross-section (from TOTEM)
- Discrepancy possibly due to geometry model (e.g. interconnections are not modeled in detail)

Radiation protection

This chapter summarizes the legal Radiation Protection (RP) framework to be considered in the design of HiLumi LHC.

Prompt and delayed dose calculated online
Prediction of residual (radioactive) nuclei: nuclear models again

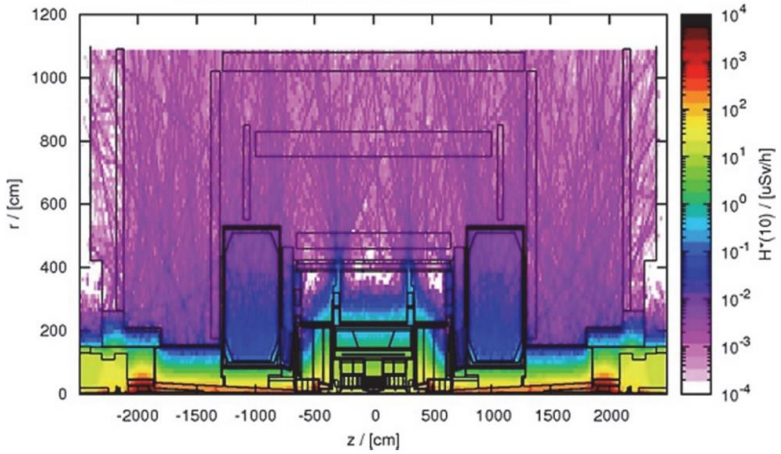


Fig. 3. Ambient dose equivalent rates (H*(10)) in μSv/h around the ATLAS detector one week after completion of the proton physics run in 2012.

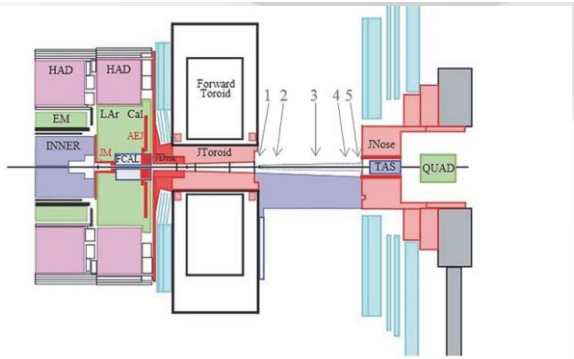


Fig. 4. Schematic representation of the ATLAS detector. Measurement locations are labelled by "1–5" (see also Table 1).

: http://dx.doi.org/10.1142/9789814675475_0011

alent rates along the ATLAS beam pipe at the locations as indicated in Fig. 4. The uncertainties indicated for the FLUKA results include statistical errors only.

Location	Measurement [μSv/h]	FLUKA [μSv/h]
1	19	13 (±0.3)
2	10	13 (±0.3)
3	7.2	10 (±0.2)
4	47	46 (± 0.5)
5	42	72 (± 0.5)

Radiation damage to electronics and materials

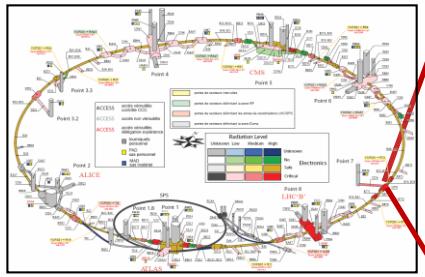
FLUKA Calculations & R2E

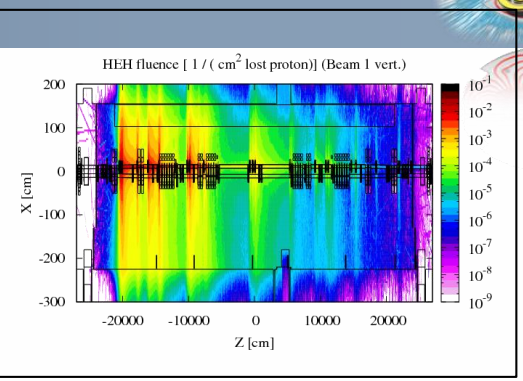
Radiation damage to electronics and materials,
Online estimators

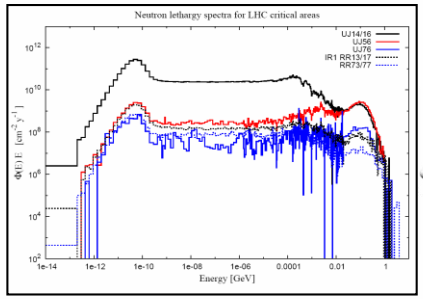
R2E==
Radiation
To
Electronics
At
CERN

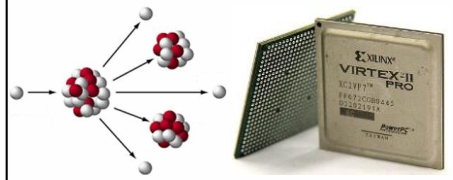
The project aimed at making LHC operations robust wrt radiation effects on electronics (a few tens of MCHF)

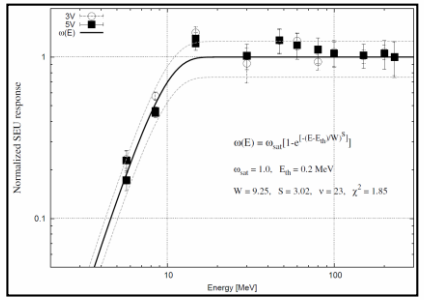
- **Critical areas in the accelerator**
  - Study of mitigation options (shielding, relocation)
- **Radiation field studies**
  - Characteristic spectra
  - Monitoring and calibration
- **Benchmarking**
  - Cross check calculations (often within 20% accuracy!)
  - Determine safety margins
- **Test facility design**
  - Starting from the first idea
  - Implementation studies
  - Constraints (radiation protection, shielding,
- **Modelling of Radiation Effects**
  - Device/Technology studies



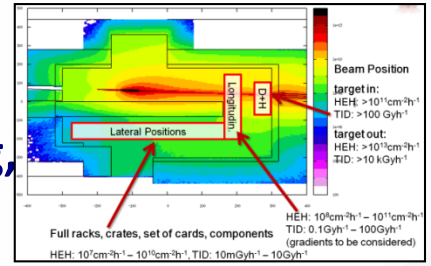


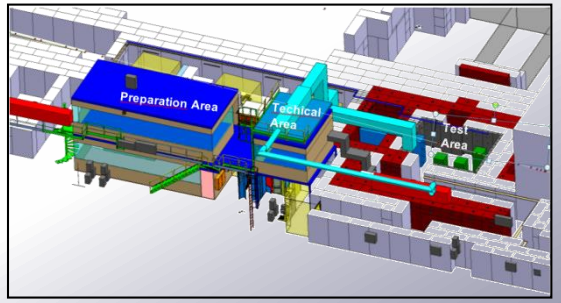






Location	RadMon [Error]	FLUKA [Error]	Ratio (R/F)
TSG45	1.9 x 10^{-7} [20.0%]	2.1 x 10^{-7} [5.7%]	0.9
TSG46	2.0 x 10^{-8} [20.0%]	1.9 x 10^{-8} [6.8%]	1.05





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