Atmospheric Cascades with FLUKA

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- Generalities about FLUKA
- The hadronic sector of FLUKA
- FLUKA and QCD
- Applications in C.R. Physics
- Future developments

FLUKA: generalities

Complete Monte Carlo code (stand-alone) for transport and interaction of particles and nuclei (~350000 lines of code)

Authors: A. Ferrari, A. Fassò, J. Ranft, P.R. Sala

- h-h and h-A Interactions 0-10000 TeV
- A-A Interactions up to 0-10000 TeV/A
- e.m. and muon interactions 0-10000 TeV
- Photo-nuclear interactions
- Neutron interaction and transport down to thermal energies (multi-group for E< 20 MeV)
- Residual nuclei calculations
- Neutrino interactions (using a special driver)
- Optical photon generation and transport

- Combinatorial geometry
- Interface to GEANT4 geometry
- Voxel (3D pixel) geometry
- Analog and biased (Variance reduction) calculations

Now developed, distributed (http://www.fluka.org) and maintained according to a specific INFN-CERN agreement (Dec. 2003)

The FLUKA Collaboration (INFN+others)

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J. Ranft	*Siegen Univ., Germany*
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A. Fassò	*SLAC, USA*
T.N. Wilson, N. Zapp	*NASA/JSC, USA*

HE Physics, CR, Neutrinos, Accelerator Physics

General Model building

(Low energy) Nuclear Physics

Radiobiology, Hadrotherapy

CR Dosimetry

CR, radiation physics in space

Software technology

Applications

High Energy Physics (exp. + engineering)

(examples: ATLAS, ALICE, LHC machine, CNGS beam)

Cosmic Rays, Aircraft and Space applications

Radiation protection and Shielding

Dosimetry

Medical Physics

Radiation Inventory and Nuclear waste transmutation

Why FLUKA is appreciated

Very high Accuracy level

Successful benchmark to a wide set of experimental data

Energy/mom. conserved up to machine accuracy

The hadronic sector of FLUKA (1)

hadron-hadron collisions

Elastic, Charge exchage	P< 3-5 GeV/c	High Energy
Isospin, data, phase shifts	Resonace production and decay	Dual Parton Model Hadronization

hadron-Nucleus collisions

P< 4-5 GeV/c	High Energy
PEANUT: a sophisticated Generalized INC, Preequilibrium model	Glauber-Gribov multiple interaction Coarse G-INC

"Microscopic" approach

Details of the hadronic sector of FLUKA can be found in:

FLUKA: Status and Prospective for Hadronic Applications

A. Fassò, A. Ferrari, P.R. Sala,

invited talk in the Proceedings of the MonteCarlo 2000 Conference, Lisbon, October 23--26 2000, A. Kling, F. Barao, M. Nakagawa, L. Tavora, P. Vaz eds., Springer-Verlag Berlin, p. 955-960 (2001).,

The hadronic sector of FLUKA (2)

Nucleus-Nucleus Collision	
E< 5 GeV/nucleon	**E> 5 GeV/nucleon**
"Quantum Mechanical Dynamics" **(QMD)** **approach** ***(adapted from a Sorge et al. model)*** **A relativistic (RQMD) version is in preparation**	**Interface to DPMJET-II.5 (J.Ranft)** **2-component (hard+soft) DPM, minijets, Glauber-Gribov multiple interactions, etc.** *Now also interface to* ***DPMJET-III*** *(Engel, Ranft, Roesler)*

Allows FLUKA to extend its capabilities to the EHE sector

Some general features deriving from this kind of DPM modelling relevant for C.R.s

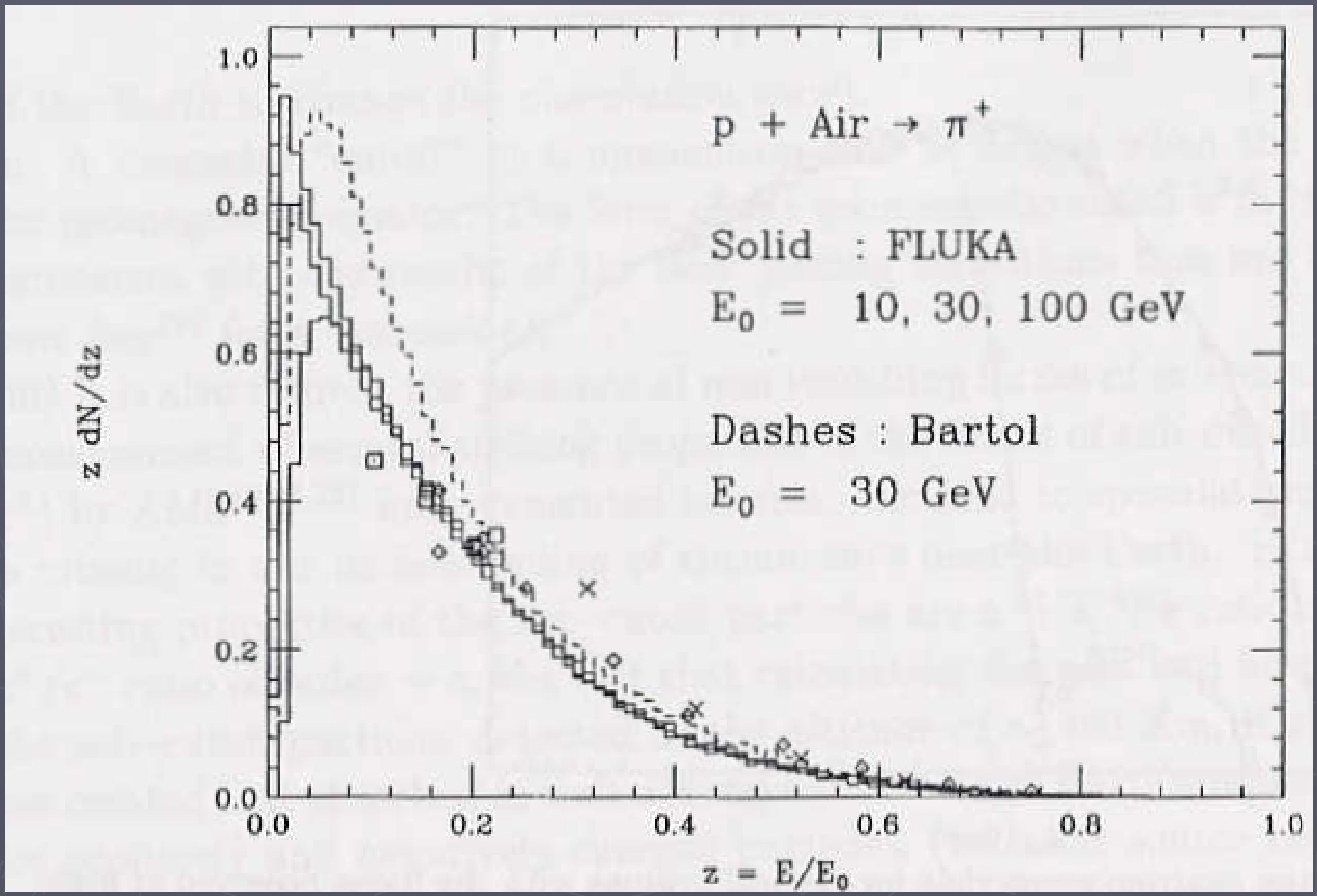
Rather good scaling in high X_f region (however broken by diffraction)

Rather good reproduction of leading particle properties

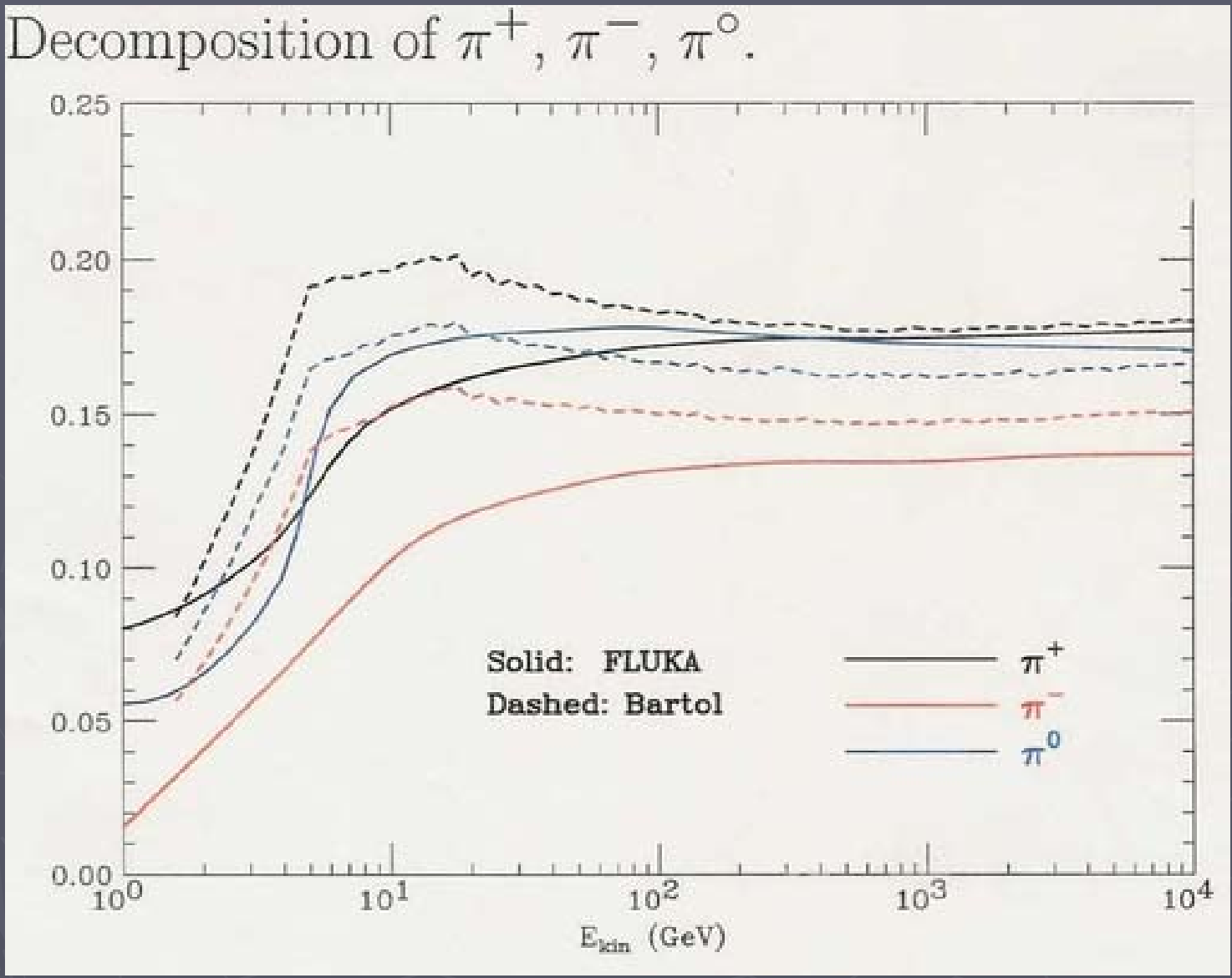
Quantum numbers are conserved

Nuclear target effects are taken into account

There may be problems at the low limit in energy, expecially in hadronization sector.


p + Air → π+
Solid : FLUKA
E0 = 10, 30, 100 GeV
Dashes : Bartol
E0 = 30 GeV
z dN/dz
z = E/E0
0.0
0.2
0.4
0.6
0.8
1.0

Decomposition of π^+, π^-, π°.



FLUKA and QCD (the high energy part)

Key role is played by what we are not able to calculate:

non-perturbative QCD

DPM algorithm (Pomeron exchange and color string production)

hadronization of color strings

these two aspects are factorized:
a common ansatz to many MC model
of this kind!

But remember that this is not exact theory!

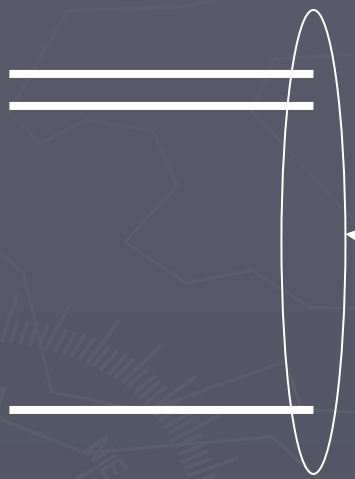
perturbative QCD

through DPMJET: the tree level graphs are included as part of the model
(the “hard” sector)

An example: the p p $\rightarrow \Lambda$ K + X production

This channel is relevant for HE atmospheric neutrinos

from DPM:



diquark from projectile
(carries the largest fraction of momentum)

color string to be hadronized

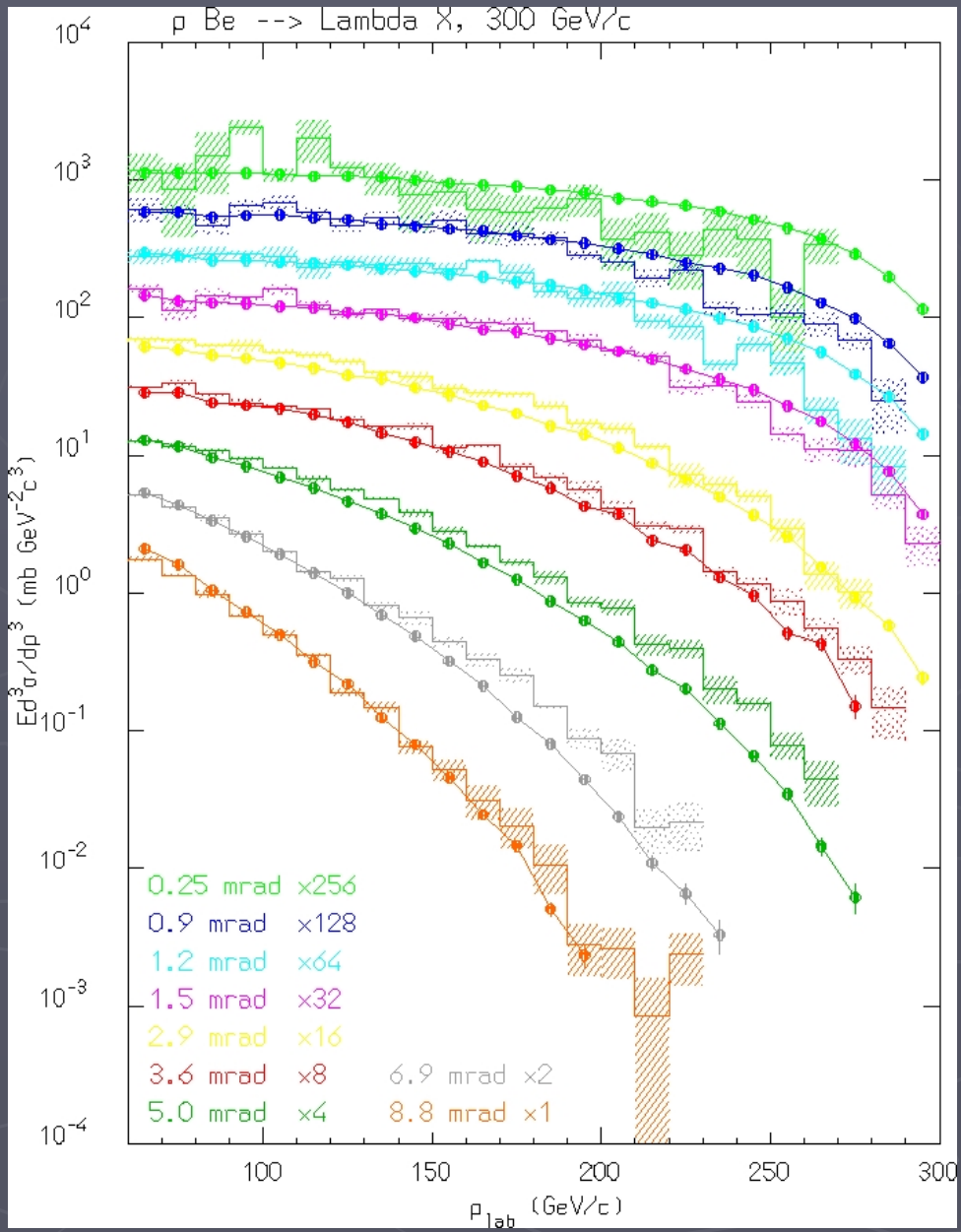
quark from target

If...


u
d
s
Λ
Highest rapidity product
s̄
associated meson with s̄ (K+)
(the closest product in rapidity)

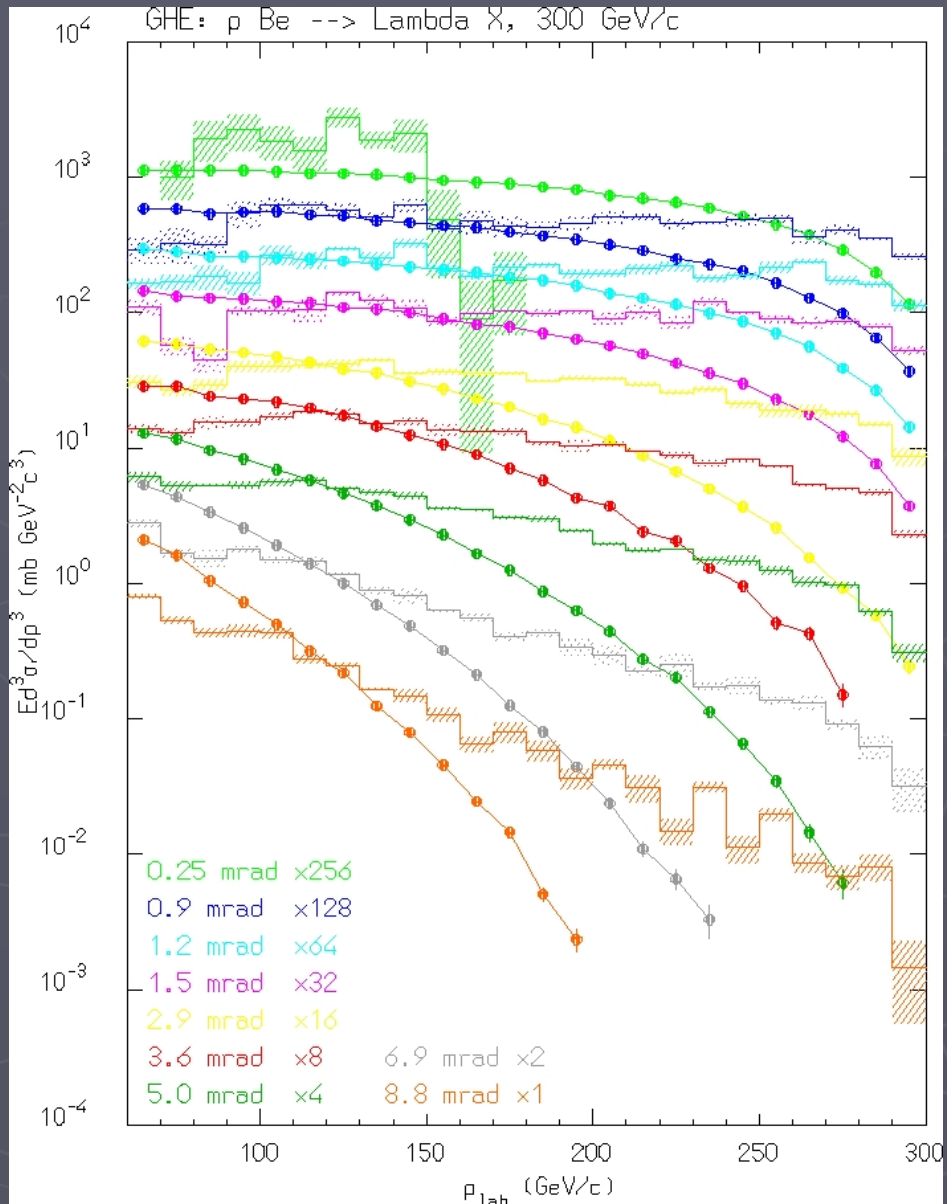
A comparison with experimental data: the Λ case

pBe collisions
@300 GeV



MC is histogram

comparison of an unsatisfactory (parametrized) model



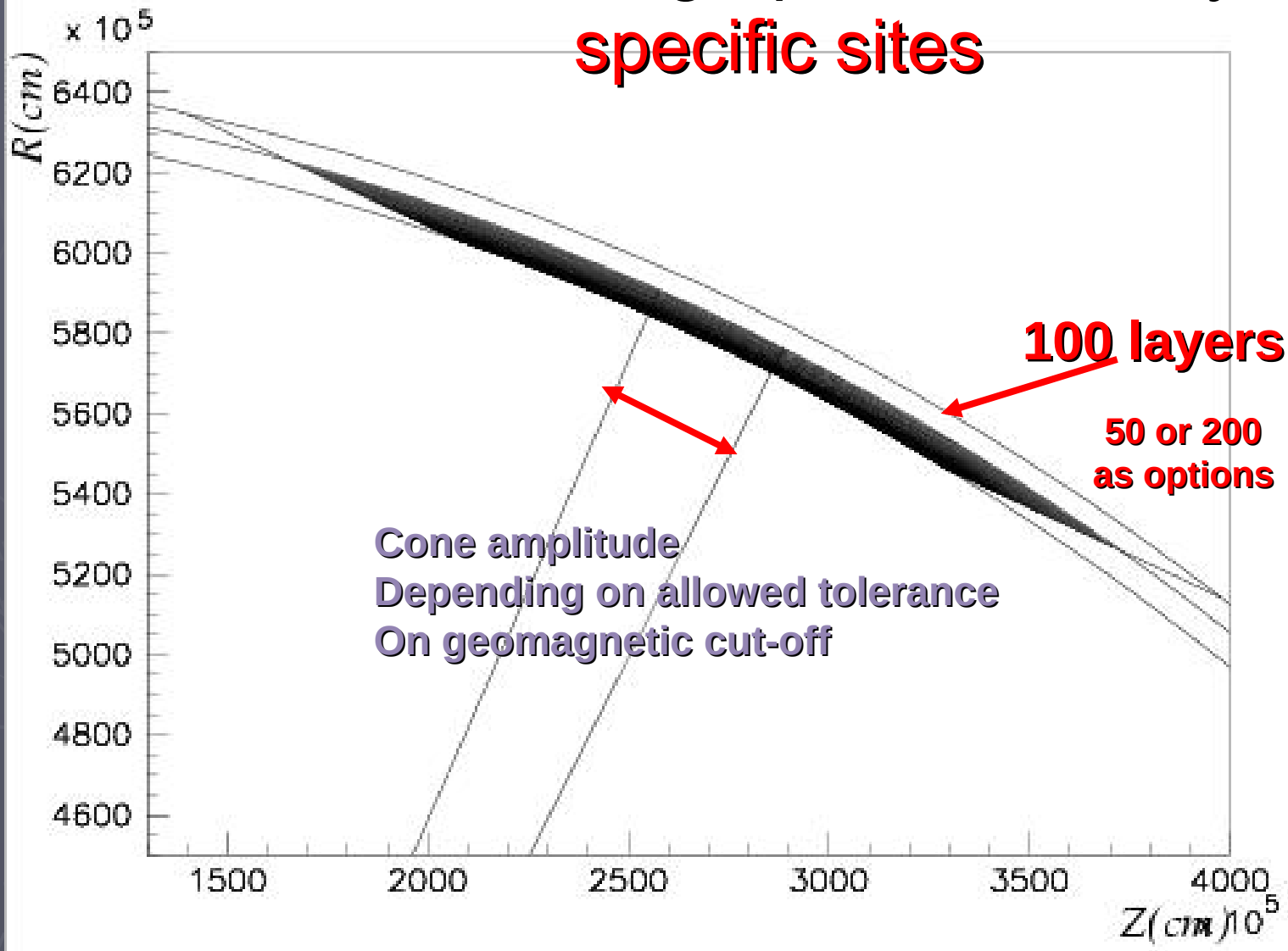
Application of FLUKA to atmospheric showers

2 different streams:
- basic research exp. activities on c.r. physics (muons, neutrinos, EAS, underground physics,...)
- application to dosimetry in civil aviation (DOSMAX)

Available dedicated FLUKA library + additional packages including:

- Primary spectra from Z=1 to Z=28 (derived from NASA and updated to most recent measurements.)
- Solar Modulation model (correlated to neutron monitors)
- Atmospheric model (now MSIS)
- 3D geometry of earth+atmosphere
- Geomagnetic model

The local Geographic Geometry for specific sites



Output:

Charged/neutral particles in atmosphere at different altitudes

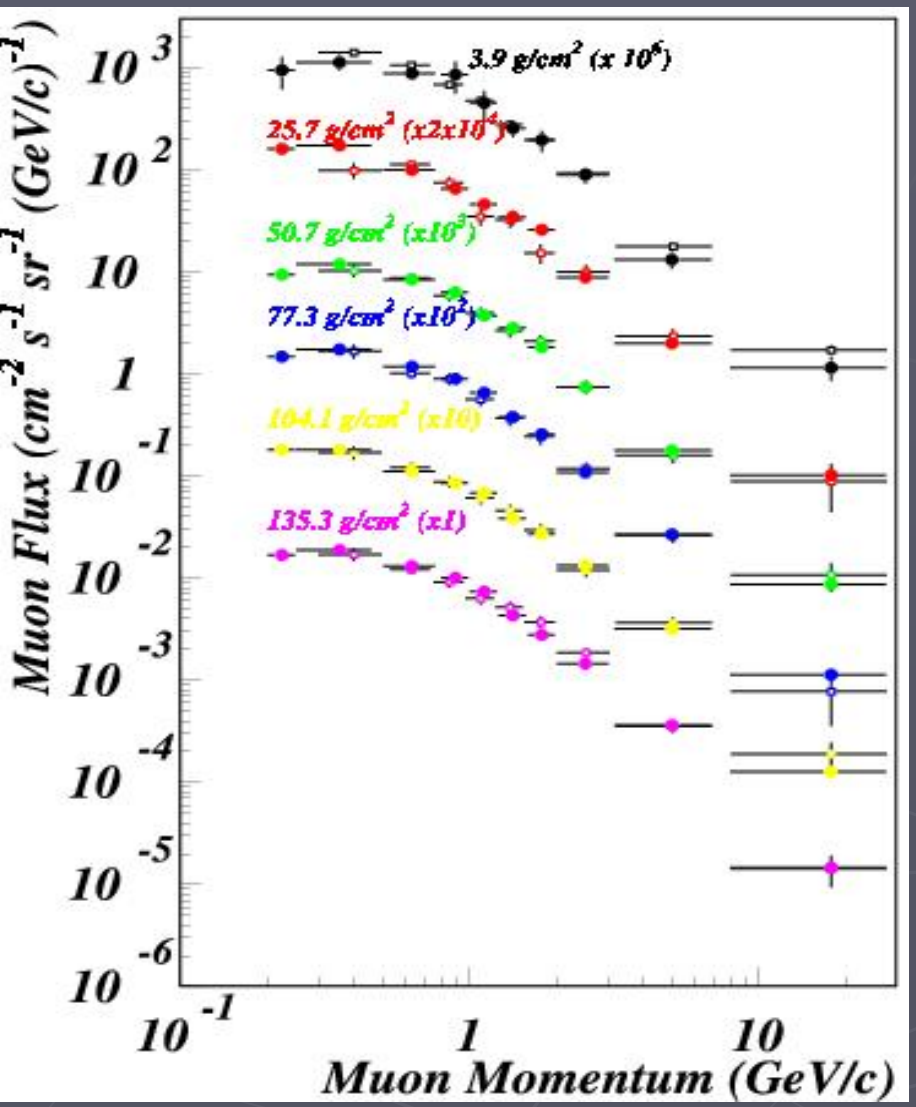
Benchmarks(*): muon fluxes (ground level and altitude)
hadron fluxes (ground level)

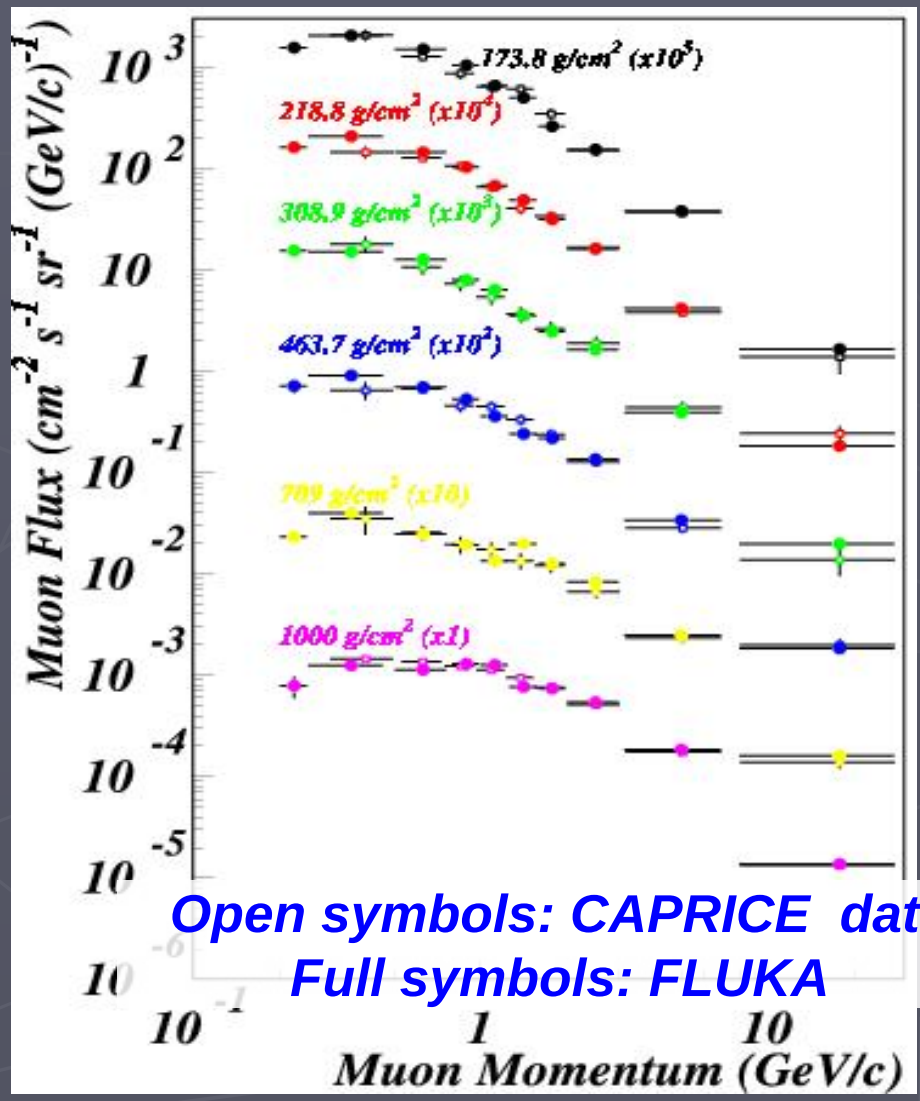
Still in progress with new set of data:
- lepton spectra
- secondary gamma spectra

Research projects: atmospheric neutrinos (*)

(*) G.Battistoni et al, Astropart.Phys. 19 (2003) 269-290, Erratum-ibid.19:291-294 e-Print Archive: hep-ph/0207035s.

Negative muons @ floating altitudes: CAPRICE94

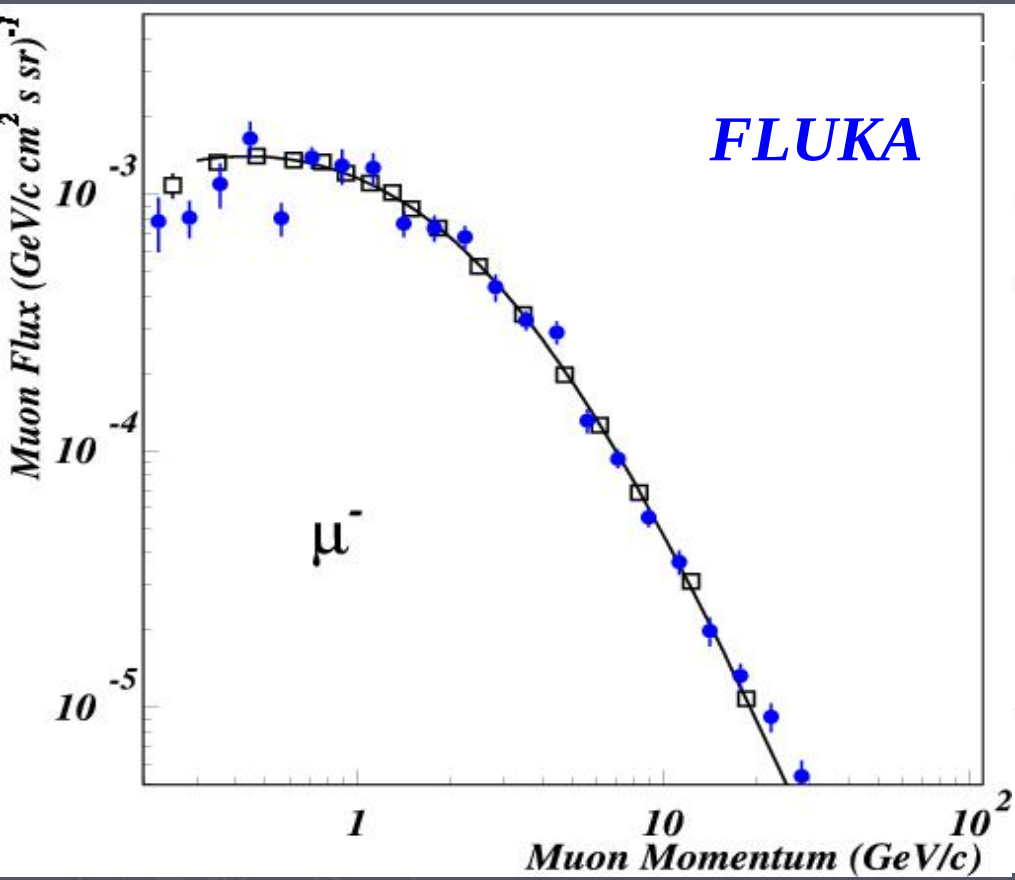


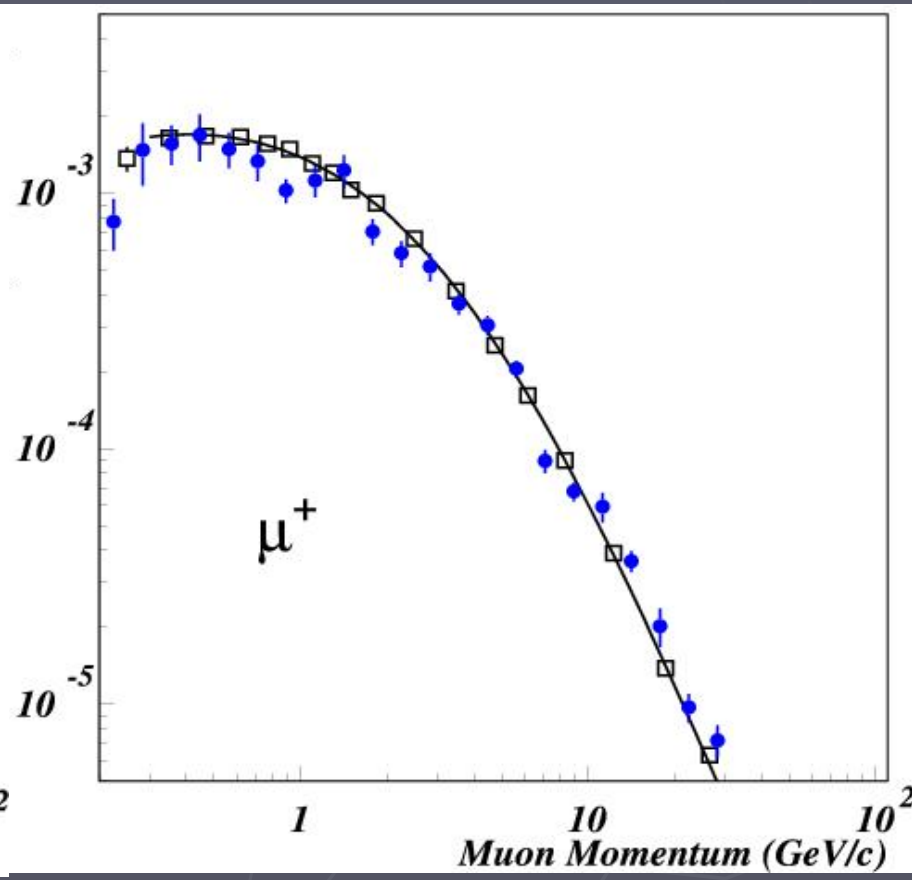


Open symbols: CAPRICE data
Full symbols: FLUKA

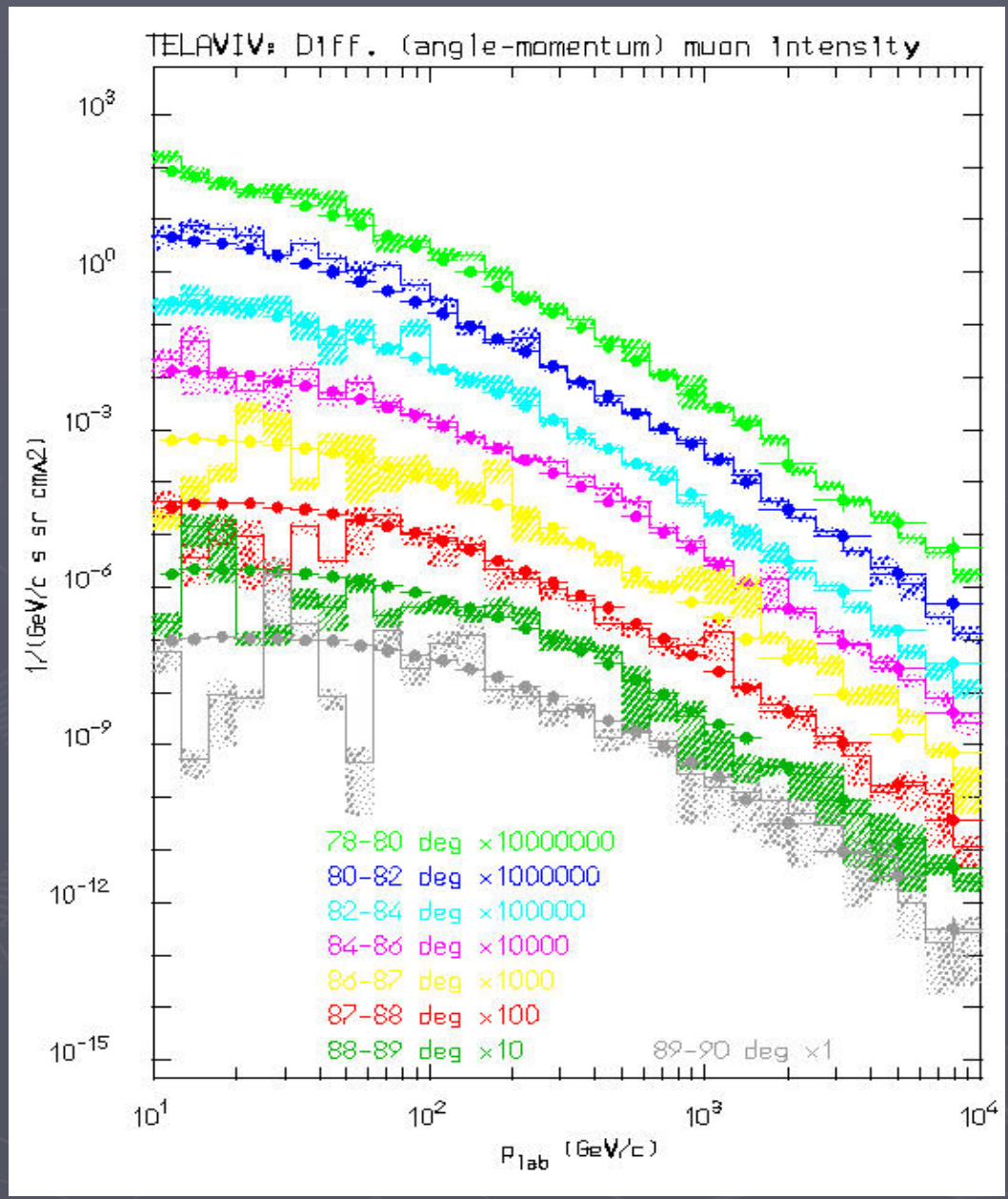
primary spectrum normalization ~AMS-BESS
(Astroparticle Physics, Vol. 17, No. 4 (2002) p. 477)

Muons @ ground level

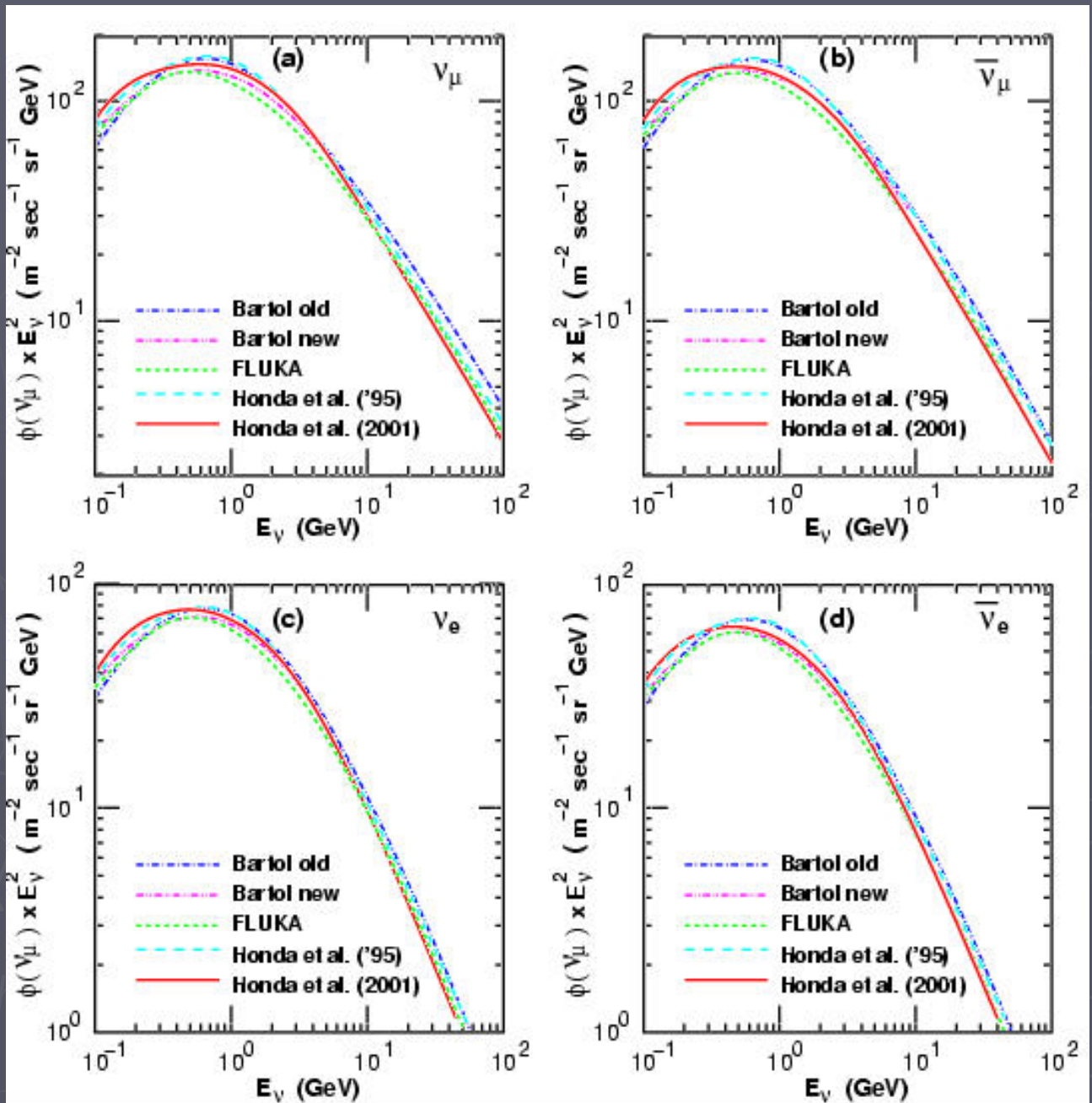




Horiz. Atmospheric Muons (DEIS: Allkofer et al.)

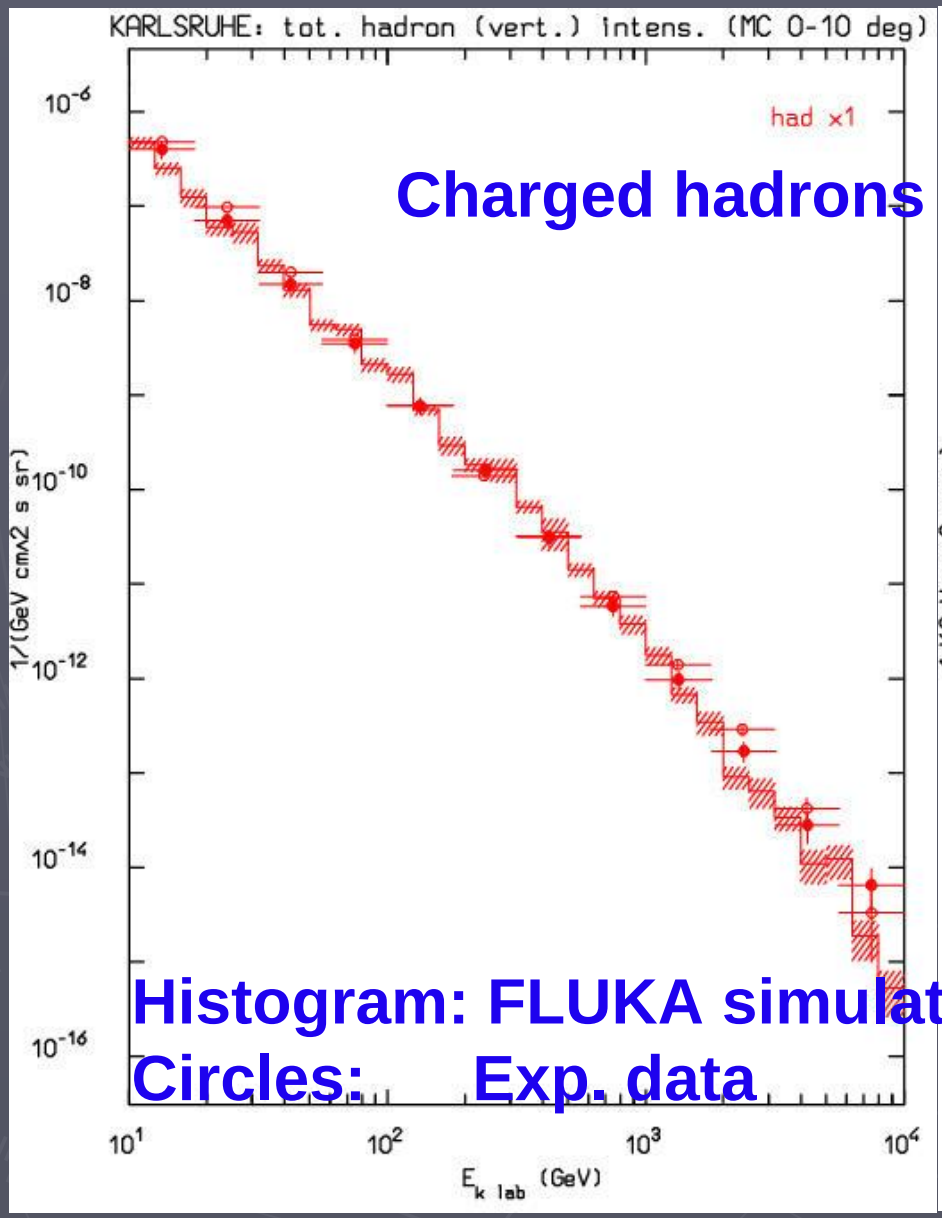


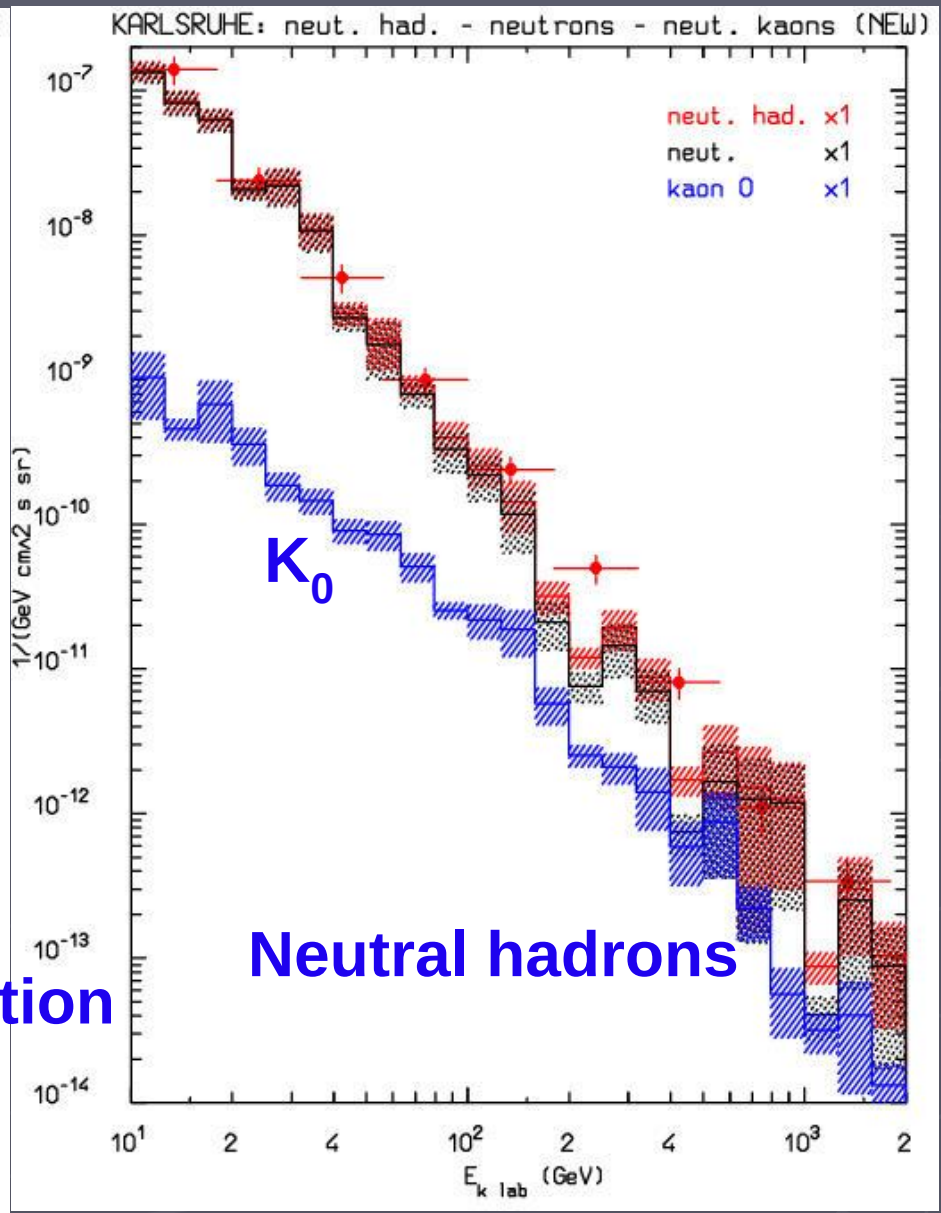
(3D) Calculation of Atmospheric Neutrino Flux



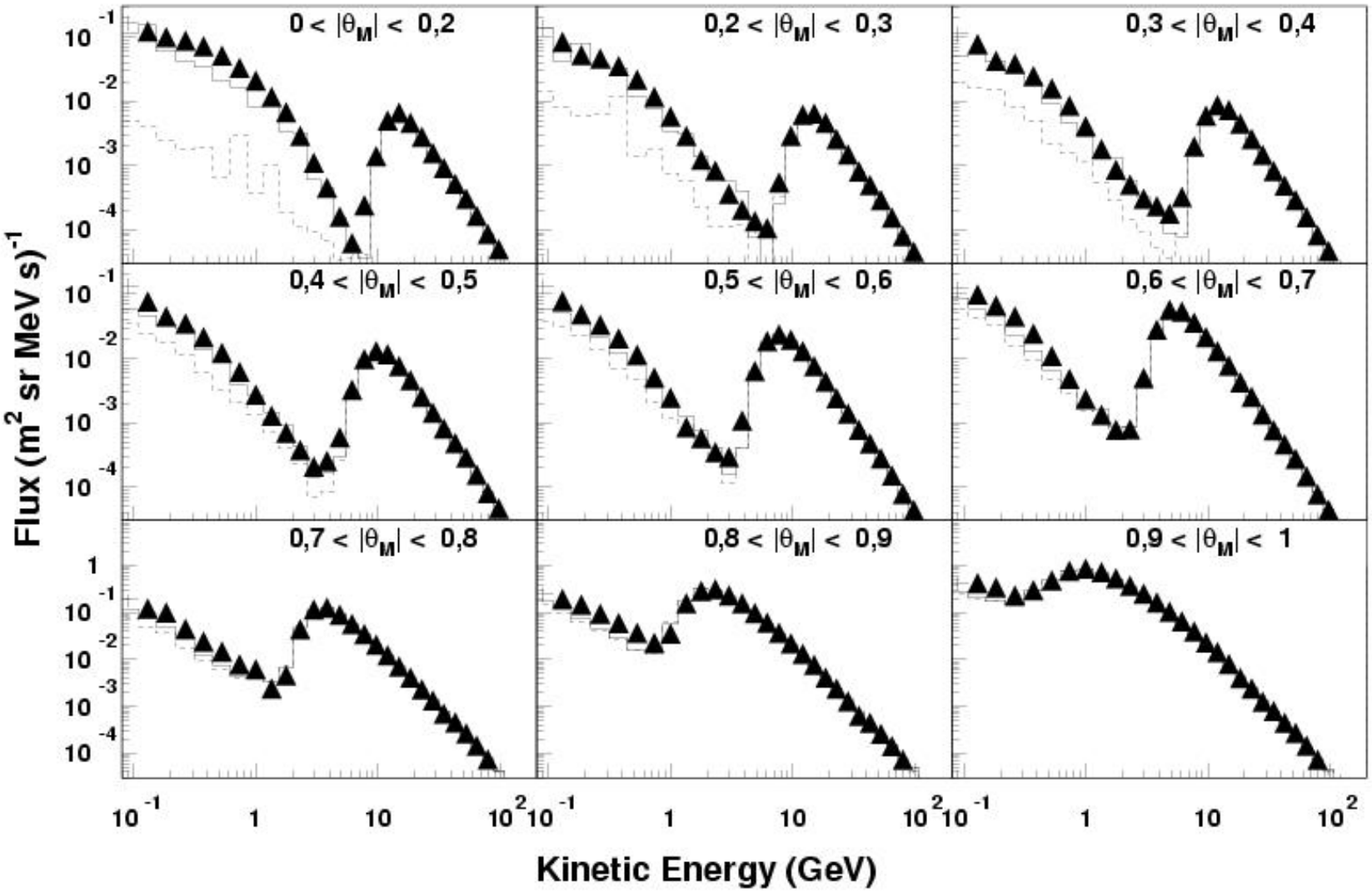
From a review by
T.K.Gaisser
& M.Honda

Hadrons in KASKADE calorimeter

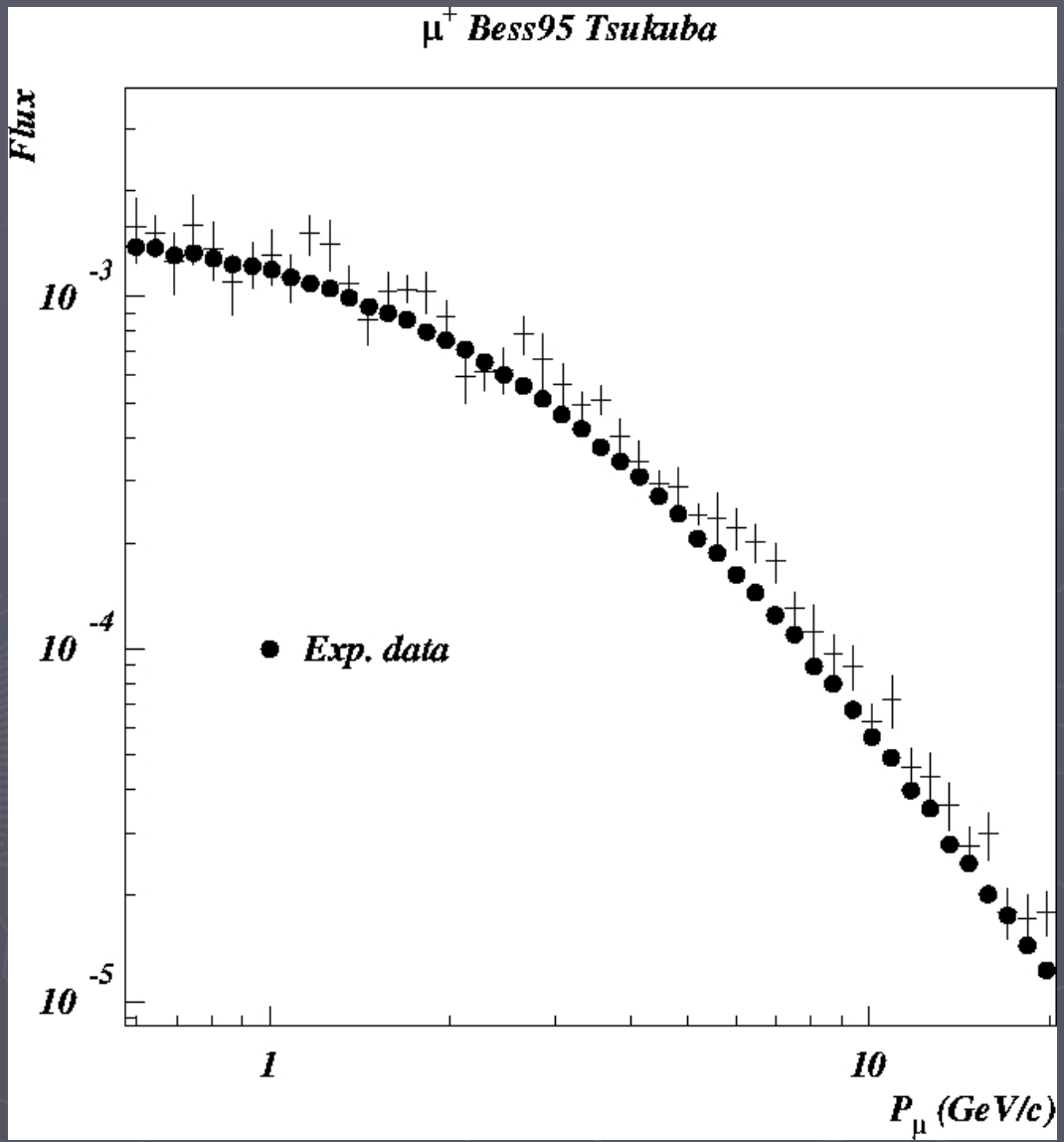




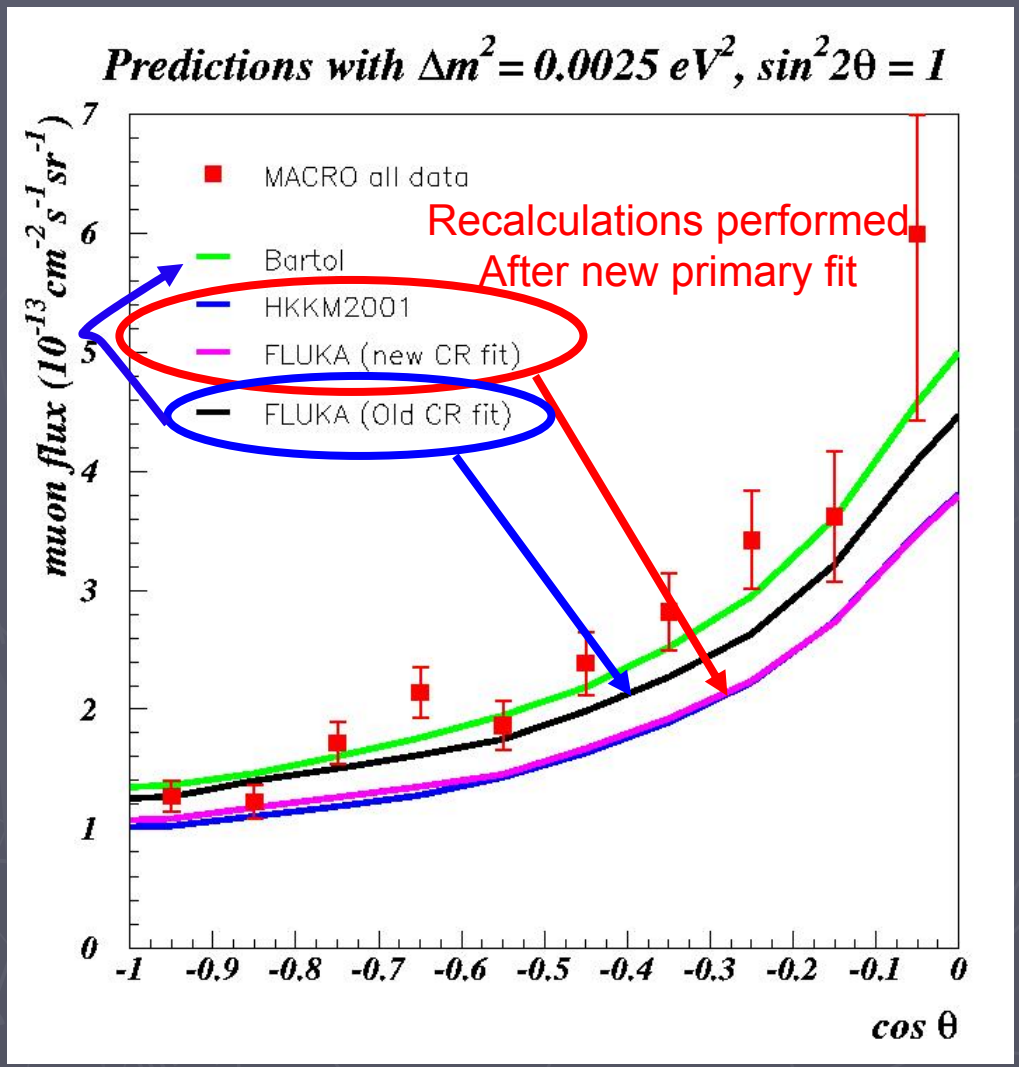
Reproduction of subcutoff structure in primary protons detected by AMS



New investigations (preliminary)



Atmopsheric ν's (E>100 GeV)



MACRO exp. @LNGS

Major issue seems to be the input model for primary spectrum beyond hadronic physics…

G.Battistoni et al., HIGH-ENERGY EXTENSION OF THE FLUKA ATMOSPHERIC NEUTRINO FLUX., Proc. 28th ICRC, Tsukuba, Japan, 31 Jul - 7 Aug 2003.; e-Print Archive: hep-ph/0305208

A very recent addition to FLUKA: e.m. dissociation of nuclei

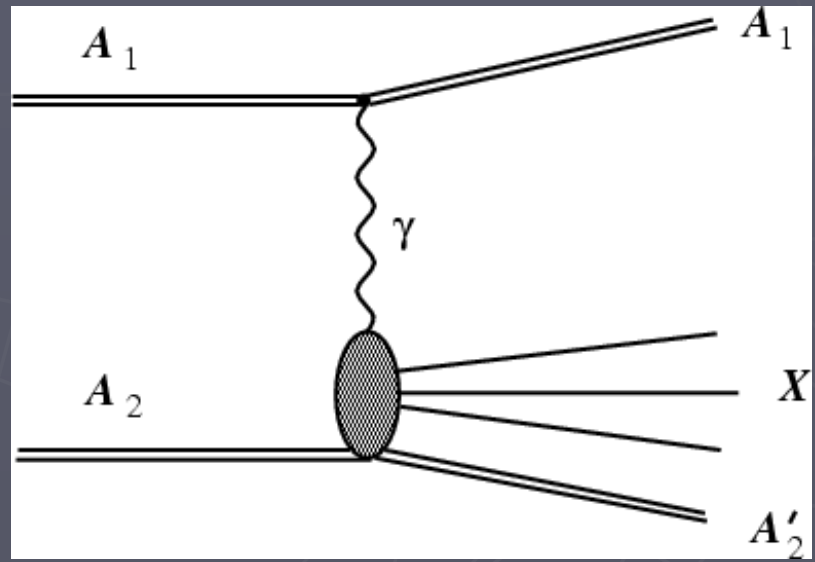
- **One-photon process** ⇨

Ultrarelativistic ions:

RHIC: $\gamma \approx 100$

LHC: $\gamma \approx 3000$

- **Equivalent photon number (photon spectrum)** ⇩



(Leading logarithmic approximation)

Database containing 500 (γ,1n) and (γ,2n) cross sections Total and 1nX, 2nX

electromagnetic dissociation cross sections for Pb-A relativistic collisions are simulated

Results of simulution are verified by comparing with cross sections 1nX and 2nX measured in reactions of 30 A GeV Pb ions incident on Al, Cu, Sn and Pb targets

Other features useful for atmospheric cascades (not yet really exploited)

Optical photon (Light+UV) generation

Processes:
scintillation/Cherenkov/Transition Radiation

Transport: reflection/refraction/absorption/Rayleigh scattering

Simulation Benchmarked with light detected in coincidence with long muon tracks in Liq. Argon (ICARUS)

FLUKA and atmospheric cascades: possible future developments

Extensive comparison with some experimental data sets using different conditions for primary spectrum, atmosphere, solar modulation etc.

CR Physics at the knee

Investigation of TeV Muon production for undeground physics

Charm (prompt muon) production

Introduction of Mie scattering for optical photons
A CPU affordable way for the e.m. component of cascades (not a priority)