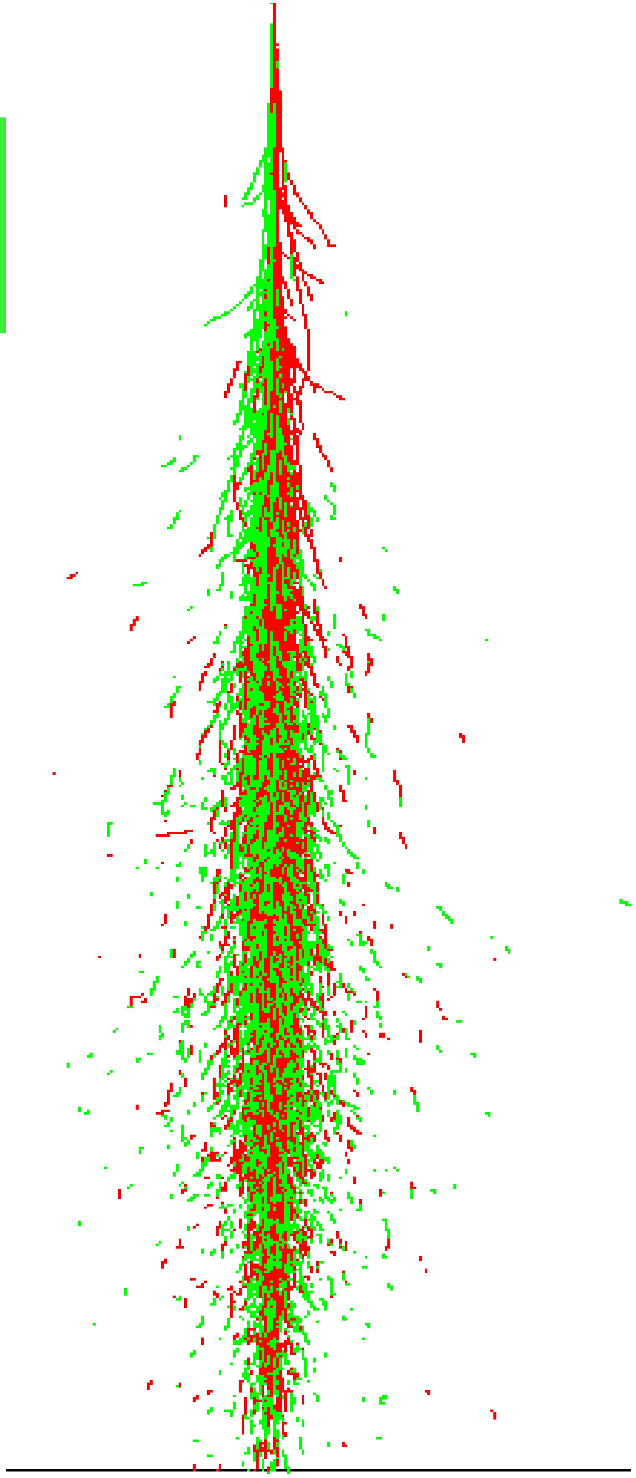
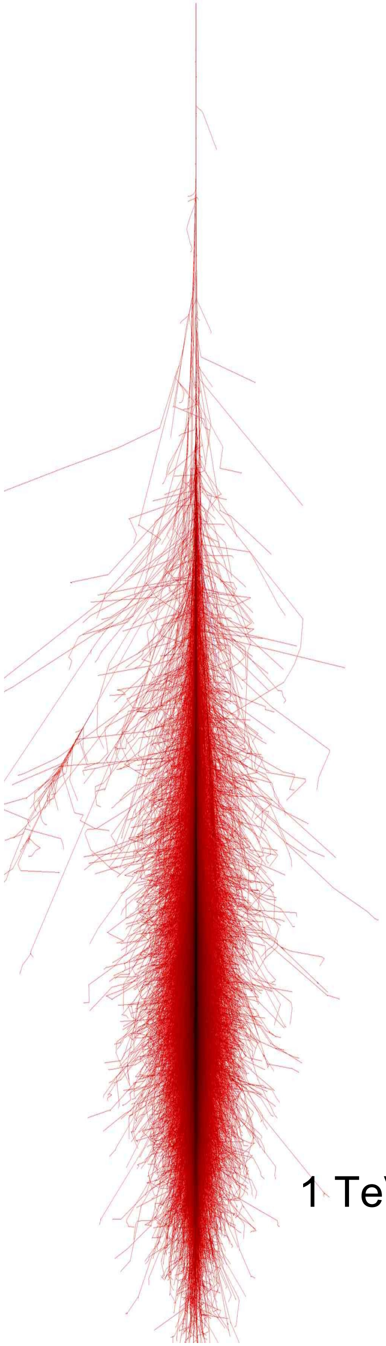
Simulations for HESS-2:
Part 1. Air Shower Simulations

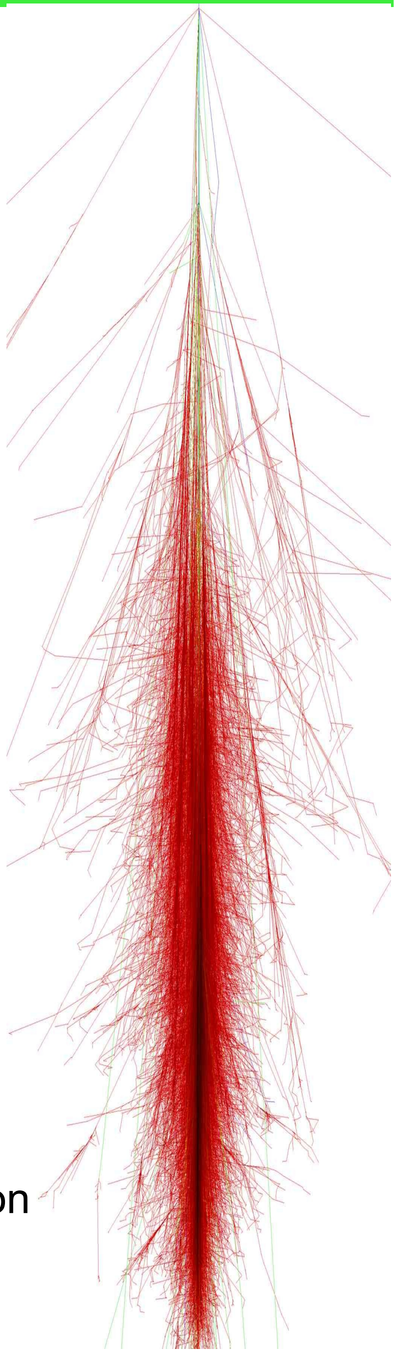
A. Zech
HESS workshop
11/2007 in Warsaw



Outline



- Overview of MC Simulations in HESS
- KASKADE
- CORSIKA
- Verification of MC programs
- Air showers at Lyon & Outlook



1 TeV gamma

1 TeV proton

F. Schmidt, "CORSIKA Shower Images", http://www.ast.leeds.ac.uk/~fs/showerimages.html

Overview of MC Simulations in HESS

The purpose of simulations

- MC used in the event reconstruction:
  - rejection of background events: Scaled Cuts Tables (msw, msl, ...):
    C (image amplitude, impact parameter, zenith angle)
  - energy reconstruction: Energy Lookup Tables:
    E (image amplitude, impact distance, zenith angle)

- MC used in the calculation of the energy spectrum:

  expected number of gammas in a reconstructed energy bin E_i:

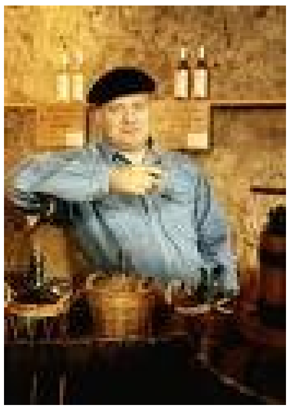
$$n_\gamma = \int_{E_i-\Delta E}^{E_i+\Delta E} \int_0^\infty \Phi(E) A(E,\theta,\delta) R(E,E',\theta,\delta) dE \; dE'$$

  - Effective Area (Acceptance) Tables: ***A (true E, zenith angle, offset, cuts)***
  - Energy Resolution Tables: ***R (true E, rec. E, zenith angle, offset, cuts)***

- Development of new detectors (HESS-2, CTA):
  - estimation of trigger rate, resolution, sensitivity for given layout
  - tests of event reconstruction algorithms

Event Simulation in France and Germany

Air Shower Simulation | Detector Simulation



Kaskade C++
Kaskade Fortran
Corsika
→ p.e. on the ground → output
→ Smash detector sim. at several opt. eff.
→ DST with raw data + MC inputs → output

Corsika
→ photons on the ground (files not kept)
→ sim_hessarray detector sim. at average opt. eff.
→ DST with raw data + MC inputs → output

KASKADE

KASKADE history and documentation

- KASCADE developed by Kertzman and Sembroski in 1989 (DePauw-Purdue University) for ACTs.
  (Nucl. I. & M. A 343 (1994) 629-643)
  (http://www.physics.purdue.edu/astro/KASCADE/kascade.html)

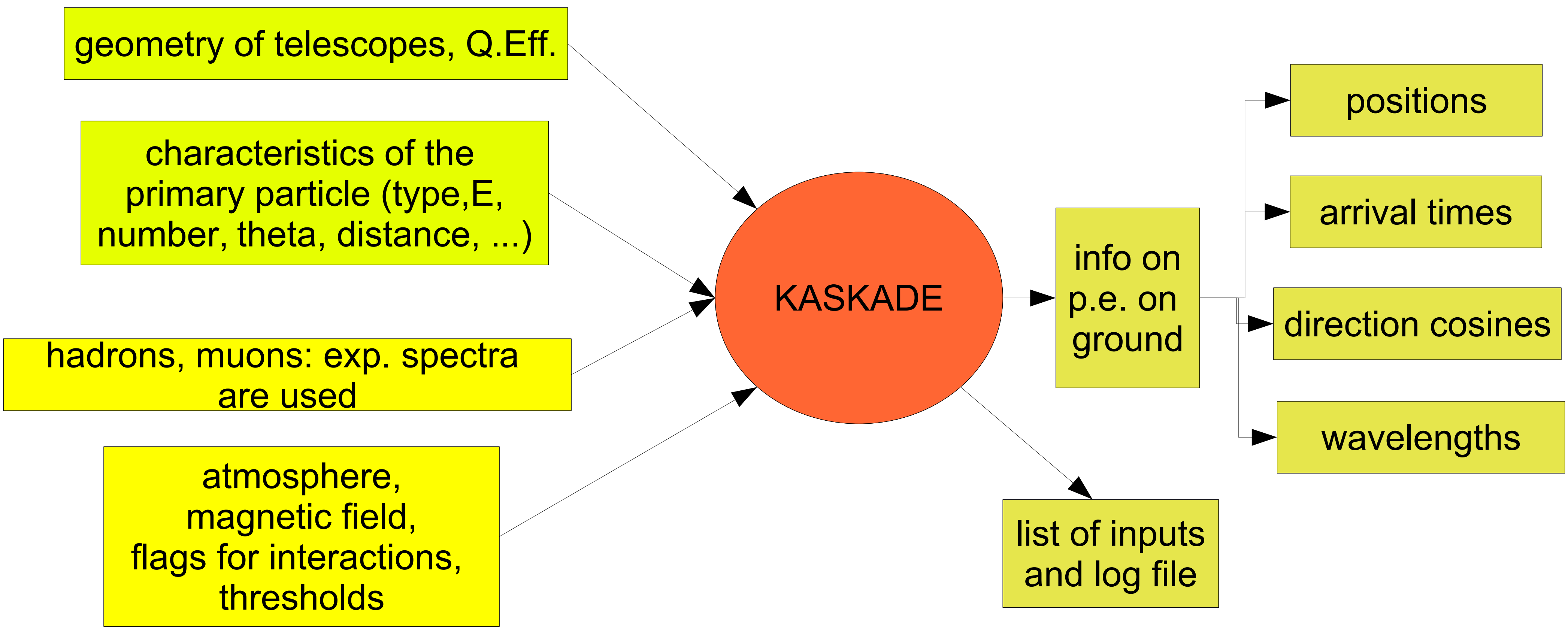
- used by Whipple and now by Veritas

- a version of the code (KAS**K**ADE) was used by CAT (ACT) and CELESTE (heliostats)

- KASKADE Fortran translated to KASKADE C++ by Mathieu, J.Guy...; this is the version used by French HESS groups
  (http://lpnp90.in2p3.fr/~denauroi/protected/Doc/)

KASKADE: inputs and outputs

3 D simulation of e.m. or hadronic air showers at GeV - TeV energies.
Full MC simulation follows each particle, which allows to preserve fluctuations between showers.



processes included in KASKADE

- **e.m., muons, pions ...**: bremsstrahlung, pair production/annihilation, multiple scattering, Compton scattering, ionization, delta rays, Bhabha and Møller scattering, decay
- **interactions of shower hadrons and mesons with air nucleus** based on a model by Gaisser and Stanev
- **Cherenkov light emission**: Cherenkov photon spectrum and emission angle calculated for all particle tracks as function of refractive index *n* (wavelength dependence of *n* is not taken into account)
- **magnetic field** bending included
- **atmospheric transmission** uses input from MODTRAN: Rayleigh, aerosol, Ozone
- **atmospheric density**: parametrization of balloon-sonde data from Windhoek; 4 layers with exponential development in each layer
- PMT **quantum efficiency** is applied in the shower simulation. Only p.e. that would hit the telescopes are saved.

CORSIKA

CORSIKA

- "COsmic Ray SImulation for KAscade"
  developed at the FZK Karlsruhe for the Kascade air shower array
  http://www-ik.fzk.de/corsika/
- 3D air shower simulation with detailed info on lateral particle/energy profiles at different observation levels, longitudinal profiles, etc...
- standard program for cosmic ray experiments up to highest energies (HiRes, Auger ...); Cherenkov option included for ground arrays (AIROBBIC)
- **e.m. simulation**: EGS4, developed at SLAC
- framework for comparison of different hadronic interaction models
- **hadronic simulations (low energies < ~80 GeV):**
  choice between: GHEISHA, FLUKA, UrQMD ;
- **hadronic simulations (high energies):**
  choice between: QGSJet, SIBYLL, Venus, DPMJet, HDPM, EPOS (neXus)

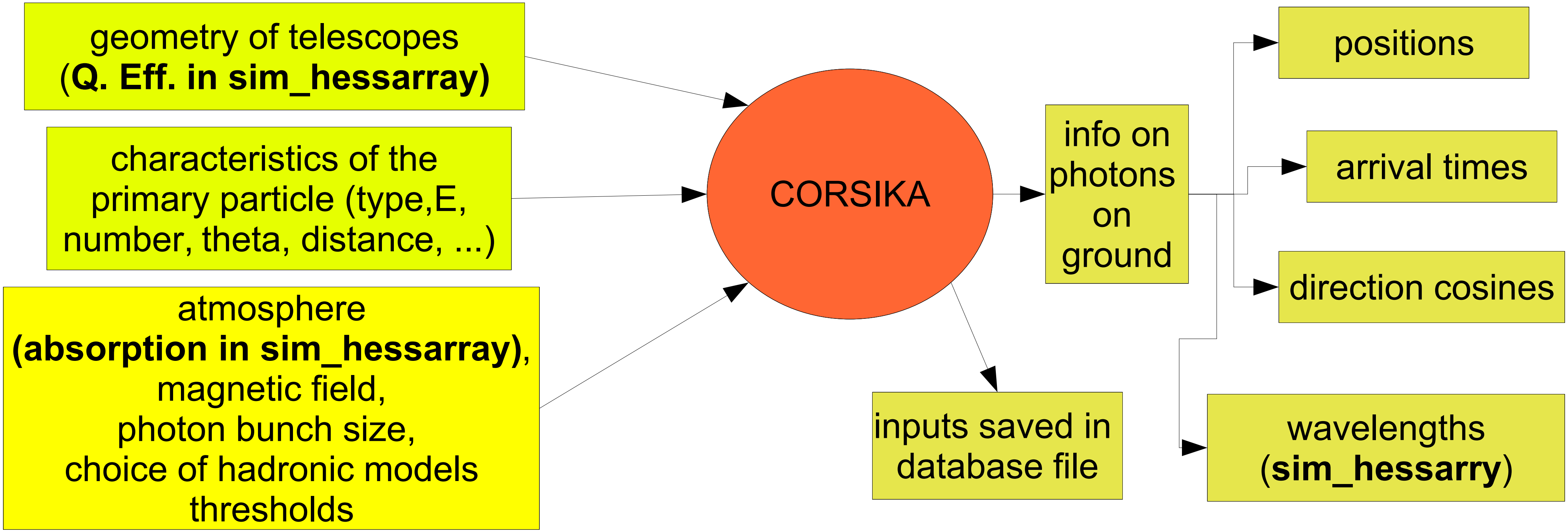
=> may be better suited for generation of hadronic background than KASKADE

=> a lot slower than KASKADE (at least in our current implementation)

CORSIKA & IACT/ATMO

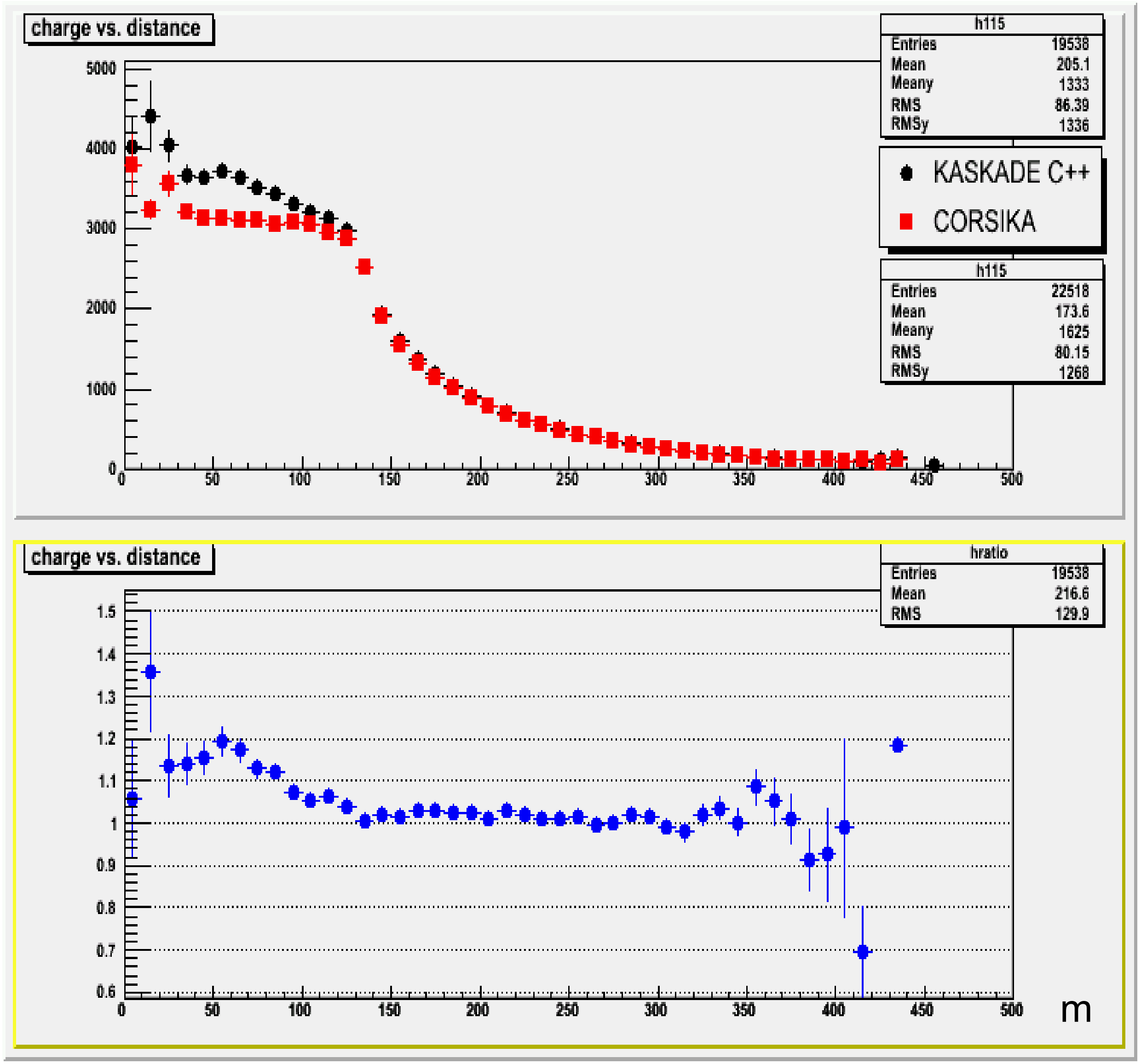
package IACT/ATMO (K. Bernlöhr)

- Windhoek atmosphere has been added to CORSIKA, interpolation between tabulated values
- definition of telescopes as spheres instead of rectangles on ground
- random translation of the telescope array for recycling of generated air showers



Verification of MC Programs

lateral p.e. distributions Corsika / Kaskade



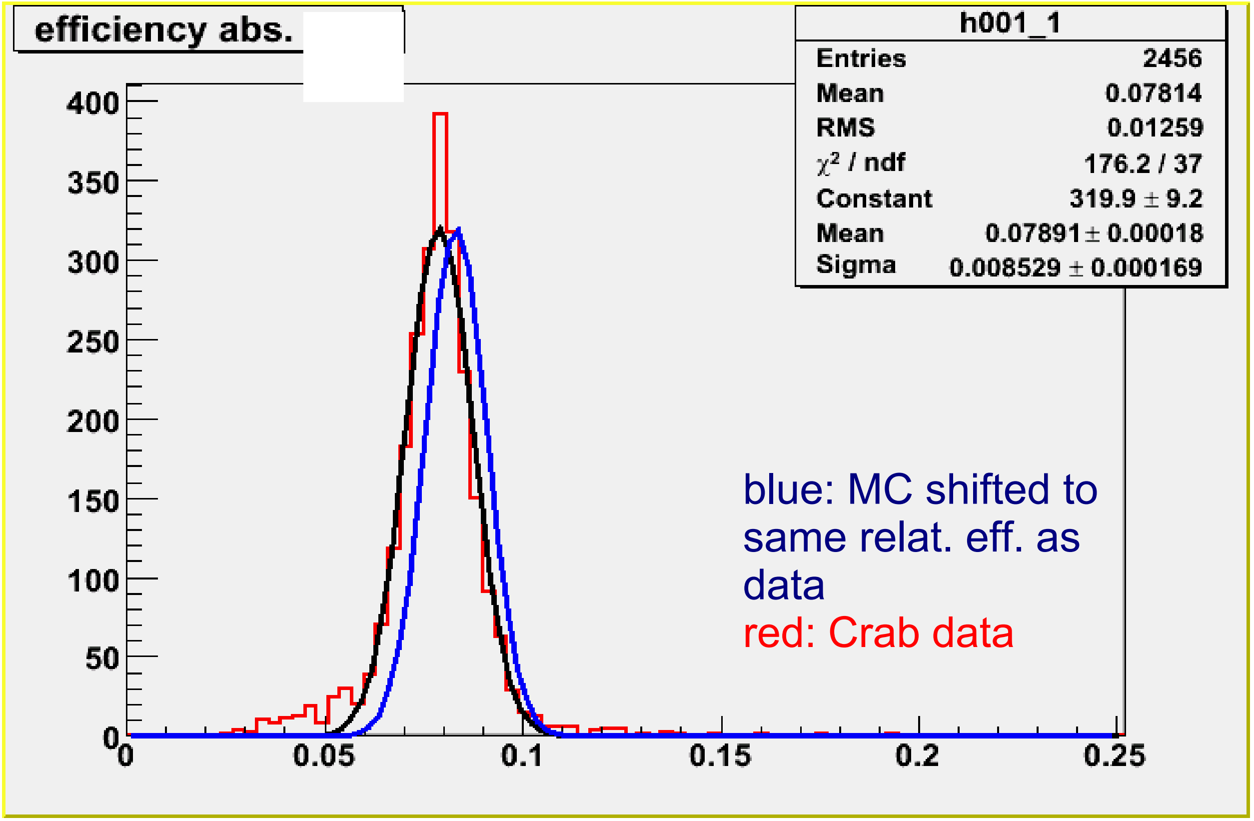
1 TeV gamma rays , 0 deg: charge vs. radius

-> Kaskade ~12-15% more p.e. at small radius

Verification against muons

reconstruction of muon rings from MC (Kaskade & Smash) and data (Crab data from 2005)

-> yields absolute efficiency



data:

absolute efficiency: **mean 0.079 , sigma 0.009** @ 71% relative efficiency

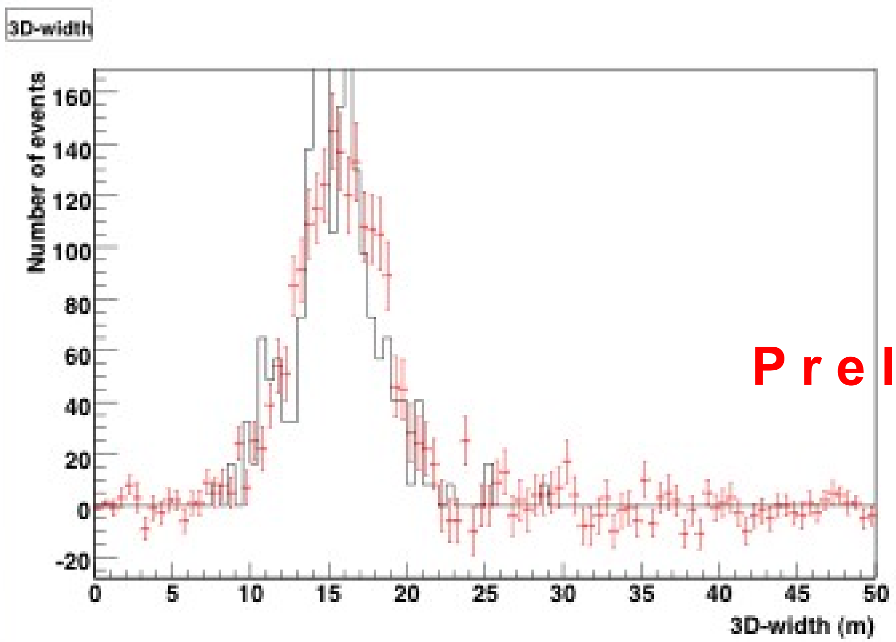
MC:

absolute efficiency: mean 0.117 , sigma 0.008 @ 100% relative efficiency

=> absolute efficiency: **mean 0.083, sigma 0.006** @ 71% relative efficiency

Comparison of Crab data to MC
(Model3D analysis, *thanks to Melitta Naumann-Godo*)

3D-WIDTH: σ_T

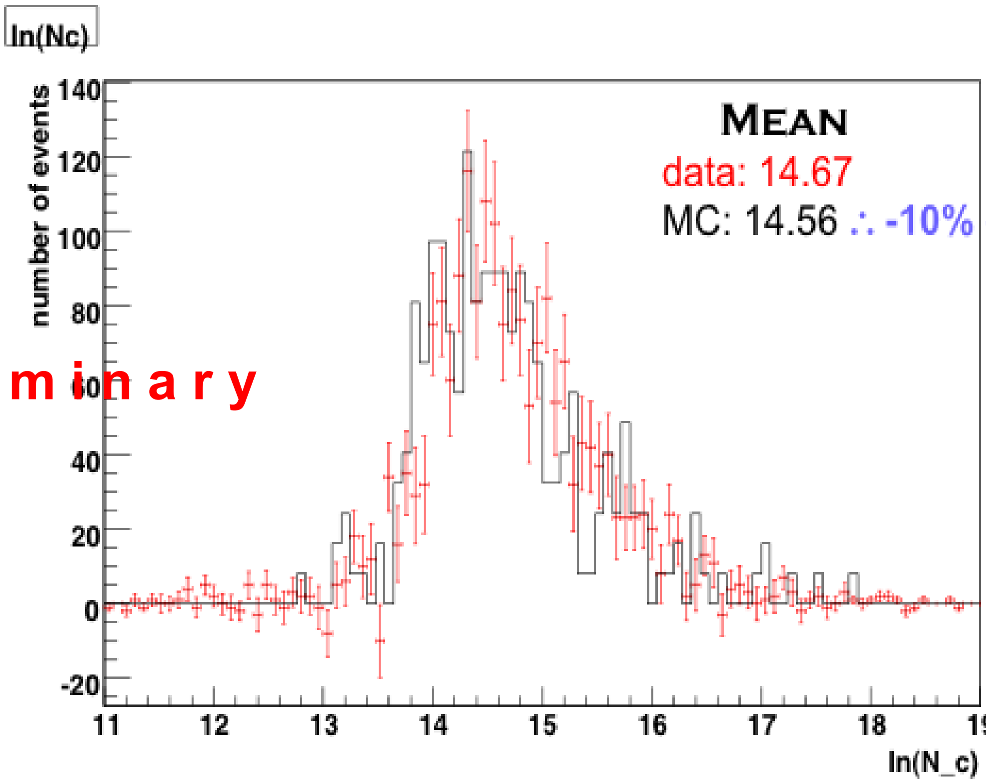


GAUSSIAN FIT

data mean: 15.67 m

MC_1 mean: 15.50 m ∴ 1%

LOGARITHM OF THE TOTAL NUMBER OF CHERENKOV PHOTONS: $\ln(N_C)$



P r e l i m i n a r y

Melitta Naumann-Godó

Air showers at Lyon & Outlook

Air shower generation with Kaskade C++

Nom	Type	Description	Total Size	Showers	Runs
gFixedEnergy_paris_0-8-8-8	PRODUCTION	Gammas, Energies fixes, HESS II	**10 TB**	**32 10^6**	**10946**
gSpectrum_paris_0-8-8-8	PRODUCTION	Spectres (Index -1.8 -> -3,4), HESS II	**3 TB**	**190 10^6**	**3723**
eSpectrum_paris_0-8-8-8	PRODUCTION	Spectres Electrons (Index -2.6, -3, -3.6), HESS II	**90 GB**	**7 10^6**	**90**
pSpectrum_paris_0-8-8-8	PRODUCTION	Spectres Protons 2.7, 0°, 26°, 46° HESS II	**220 GB**	**120 10^6**	**300**
gSpectrumFortran_paris_0-8-8-8	TEST	Spectres (Index -2) Simulation Fortran 0°=>70° HESS II	**58 GB**	**2.8 10^6**	**112**

taken from Mathieu's website:
http://lpnp90.in2p3.fr/~denauroi/protected/hessphp/showshowerprods.php

What lies ahead ?

- Comparison of the French and German simulation chains to resolve differences.

  More data-MC comparisons with the high statistics data from PKS2155.

- Development of a realistic HESS-II detector simulation (-> next talk)

- Massive Generation of HESS-II MC preferably in the first half of 2008 (while the Computer Center at Lyon is not yet busy searching for the Higgs in the LHC data)

- Completing the integration of CORSIKA into our simulation chain.

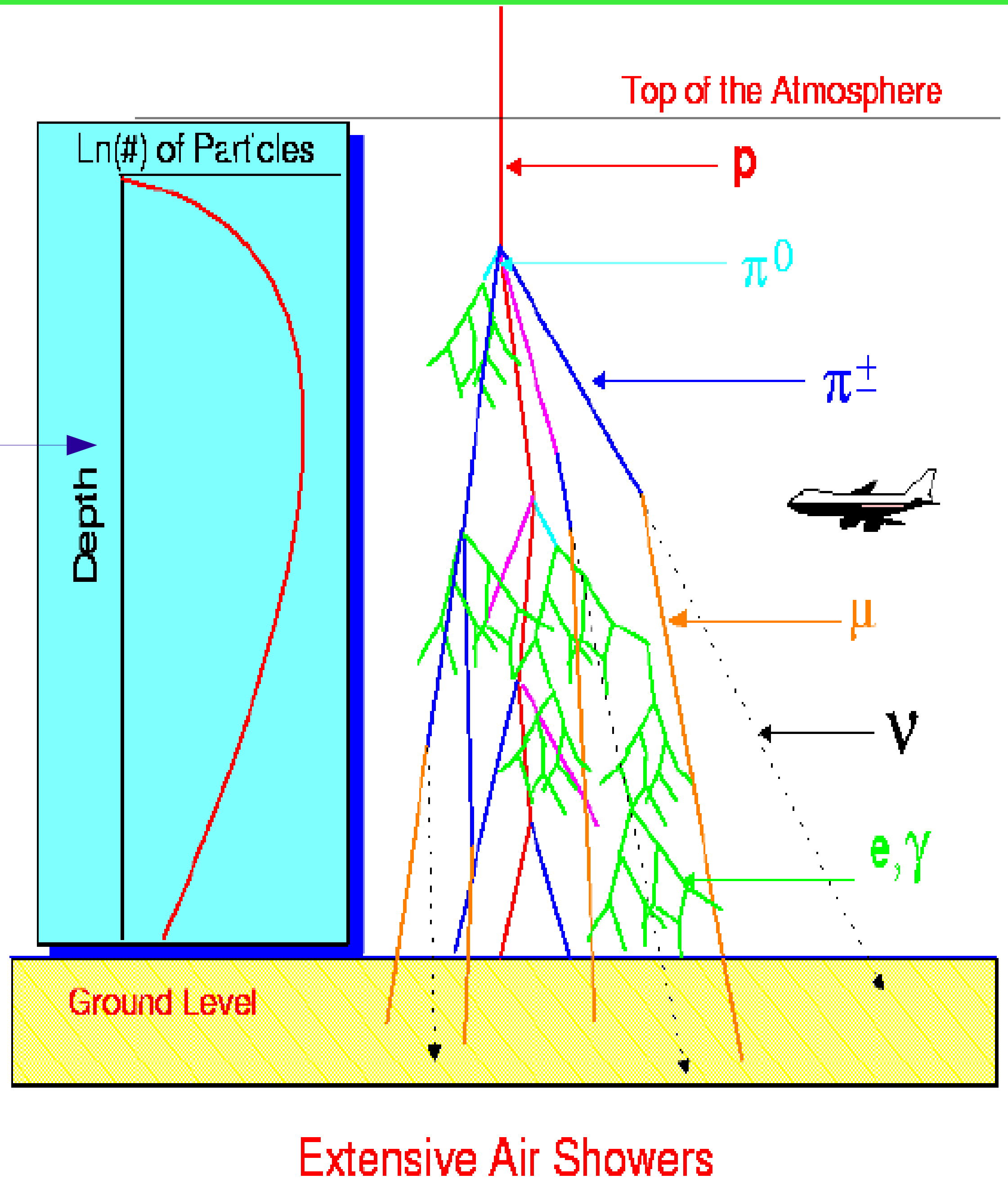
Simulations at Lyon

- simulation of air showers (KASKADE) and detector response (SMASH) via user interface for registered users (**production version** or **user version**).
  -> see Mathieu's website
  Production is connected to a database that saves info on generated events.
- alternative (for tests): local copy of KASKADE and SMASH, linked to SASH.
- CORSIKA + SMASH works currently only for vertical showers and outside of the user interface.

Air shower development

shower maximum

for vertical gamma-induced showers at ~TeV energies: ~ 10 km altitude



Air shower simulation at TeV energies

- gamma showers
  - mostly electromagnetic interactions (bremsstrahlung, pair production, ...)

    in air: $\sigma(\gamma \rightarrow \pi x) / \sigma(\gamma \rightarrow e^{+} e^{-}) \approx 4 x 10^{-3}$

- hadronic showers
  - hadronic interactions important, esp. hadron + air nucleus
  - simulation of cosmic ray background is very time-consuming due to large, isotropic flux

- geomagnetic field needs to be included

- atmosphere
  - important for shower development
  - light transmission: Rayleigh and Mie scattering
  - Cherenkov emission: refractive index is function of atmospheric density