CORSIKA Code

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Outline

- Introduction
  - Origin
  - Developments
  - Users
- Technicalities
- New development

Origin

Introductory talk given by J. Knapp

- Reminder :

COsmic Ray SImulations for KASCADE

- 1989 : original design optimized for vertical showers on a flat array detector using monte-carlo technique
- 1994< : extension to different type of experiments
  - Cherenkov, fluorescence light, inclined showers, ...
- 2010< : extension to new type of simulations
  - cascade equations, parallelization, different media ...

Wedding of the year 1994.

CORSIKA Development

- 1994 CORSIKA Vers. 4.06
  - GHEISHA (Fesefeldt, 1985):
    - low-energy hadronic interactions
  - VENUS (Werner, 1993):
    - high-energy hadronic interactions
  - CERENKOV (HEGRA Collaboration, 1993):
    - treatment of Cherenkov radiation

CORSIKA Development

- 1997 CORSIKA Vers. 5.20
  - SIBYLL (Fletcher, Gaisser et al., 1994):
    - high-energy hadronic interactions
  - QGSJET (Kalmykov et al., 1993):
    - high-energy hadronic interactions
  - DPMJET (Ranft, 1995):
    - high-energy hadronic interactions

CORSIKA Development

- 2000 CORSIKA Vers. 6.00
  - NEXUS 2 (Drescher et al., 2001):
    - high-energy hadronic interactions
  - CURVED (Schdöder, 2001):
    - option for very inclined showers
  - IACT (Bernlöhr, 2000):
    - Cherenkov routines incl. telescopes
  - URQMD (Bleicher et al., 1999):
    - low-energy hadronic interactions

CORSIKA Development

- 2004 CORSIKA Vers. 6.20
  - PRESHOWER (Homola et al., 2004):
    - UHE primary gammas
  - FLUKA (Fassò, Ferrari et al., 2001):
    - low-energy hadronic interactions
  - NUPRIM (Ambrosio, Pisanti et al., 2003):
    - primary neutrinos (HERWIG)
  - muons (Bottai & Perrone, 2001):
    - improved muon interactions
  - SLANT option (Heck):
    - slant depth (instead of vertical depth)

CORSIKA Development

- 2006 CORSIKA Vers. 6.500
  - QGSJETII-3 (Ostapchenko, 2006):
    - high-energy hadronic interactions
  - NEXUS 3.97 (Pierog et al., 2003):
  - UPWARD (for all particles)
    - upward going particles and showers
  - ./corsika-install (Pierog):
    - automated installation of CORSIKA

CORSIKA Development

- 2007 CORSIKA Vers. 6.600
  - EPOS 1.6 (Werner et al., 2006):
    - high-energy hadronic interactions
- 2008 CORSIKA Vers. 6.760
  - CHARM option (Heck):
    - treatment of charmed hadrons (PYTHIA)

CORSIKA Development

- 2009 CORSIKA Vers. 6.900
  - EPOS 1.99 (Pierog et al., 2009):
    - update of high-energy hadronic interactions
  - ./coconut (Ulrich):
    - installation of CORSIKA using GNU standard
- 2010 CORSIKA Vers. 6.970
  - EHISTORY option (Heck):
    - history of produced muons up to grand-mother
  - TAULEP option (Heck):
    - treatment of Tau lepton

Users

am	=	Armenia	fi	=	Finland	pe	=	Peru
ar	=	Argentina	fr	=	France	pl	=	Poland
at	=	Austria	ge	=	Georgia	pt	=	Portugal
au	=	Australia	gr	=	Greece	ro	=	Rumania
be	=	Belgium	hk	=	Hong Kong	ru	=	Russia
bg	=	Bulgaria	hr	=	Croatia	se	=	Sweden
bo	=	Bolivia	ie	=	Ireland	si	=	Slovenia
br	=	Brazil	il	=	Israel	tw	=	Taiwan
ca	=	Canada	in	=	India	ua	=	Ukraine
ch	=	Switzerland	ir	=	Iran	uk	=	United Kingdom
cn	=	China	it	=	Italy	edu/org	=	USA
cz	=	Czech Republic	jp	=	Japan	ve	=	Venezuela
de	=	Germany	kr	=	Korea	vn	=	Vietnam
dk	=	Denmark	kz	=	Kazakstan	yu	=	Serbia
dz	=	Algeria	mx	=	Mexico	za	=	Republic South Africa
es	=	Spain	nl	=	Netherlands	nl	=	Netherlands

In 47 countries ~ 750 registered CORSIKA users (outside FZKA).

Experiments

AGASA	Japan
ALEPH	Switzerland
ALICE	Switzerland
AMANDA	Antarctica
ANTARES	France
ARGO-YBJ	China (Tibet)
Auger (PAO)	Argentina
Baikal	Russia
CACTUS	USA
CAKE	USA
CANGOROO	Australia
CASA-BLANCA	USA
CASA-MIA	USA
CAT	France
CELESTE	France
Chacaltaya	Bolivia
CMS	Switzerland
CORAL	Switzerland
DECOR	Russia
DICE	USA
EAS-TOP	Italy
EAS-1000	Russia
Fly’s Eye	USA
Frejus	France
GRAAL	Spain
GRAPES	India
Guwahati	India
Havera Park	UK
HEGRA-AIROBICC	Spain
HEGRA-CT	Spain
HESS	Namibia
HiRes	USA
IceCube	Antarctica
JEM-EUSO	space
KASCADE-Grande	Germany
LOFAR	Netherland
LOPES	Germany
L3-cosmic	Switzerland
MACRO	Italy
MAGIC	Spain
MAKET-ANI	Armenia
MILAGRO	USA
NEMO	France
NESTOR	Greece
NuTel	USA (Hawaii)
PAMIR	Tajikistan
Sky-View	Germany (NRW)
STACEE	USA
TACTIC	India
Telescope Array	USA
THEMISTOCLE	France
TIBET	China (Tibet)
TUNKA	Russia
VERITAS	USA
WACT	USA
WILLI	Rumania
WHIPPLE	USA

CORSIKA is used for ~ 57 cosmic ray experiments.

Technicalities

- source code :
  - ~ 69 500 lines (without external programs) ~ 290 routines
  - optional code
    - ~ 50 preprocessor options selectable during installation with ./coconut
  - program language (portability)
    - Fortran 77 / 90 + some few C-routines
- steering input :
  - free format with key words + parameters
    - ~ 90 key words
- documentation:
  - physics: FZKA 6019 (1998)
  - User's Guide: http://www-ik.fzk.de/corsika/
  - variables used in COMMONS
    - list in corsika.h
- availability:
  - download from anonymous ftp

Monte Carlo Simulations of EAS

- Random Numbers
- Environment:
  - atmosphere (composition, density $\propto e^{-h/c}$)
  - Earth magnetic field (strength, orientation)
- Particles:
  - type, energy, position, direction, time
- Range estimation:
  - cross section σ
  - life time τ
- Particle transport:
  - ionization energy loss dE/dx
  - multiple scattering (for leptons)
  - deflection in Earth magnetic field
  - particle reaches detector or cut
- Interaction / decay with production of secondaries:
  - high-energy hadronic interaction model
  - low-energy hadronic interaction model
  - particle decay (branching ratio > 1 %)
  - electromagnetic interaction (EGS4)
- Secondary particles:
  - store particles on stack

Random Number Generator

Key point of any monte carlo :

- CORSIKA uses the random number generator RMMARD
  - modification of CERN random generator RM48 with extension to 5 independent sequences
- Range: $0 < RNDM < 1$
- Precision: 48 significant bits ~ 4.10^{-15}
- Sequence length: 2^{144} ($\sim 10^{43}$) random numbers
- Seed: every integer number I with $1 \leq I \leq 900\,000\,000$ starts an independent random number sequence
  - different seed = different shower

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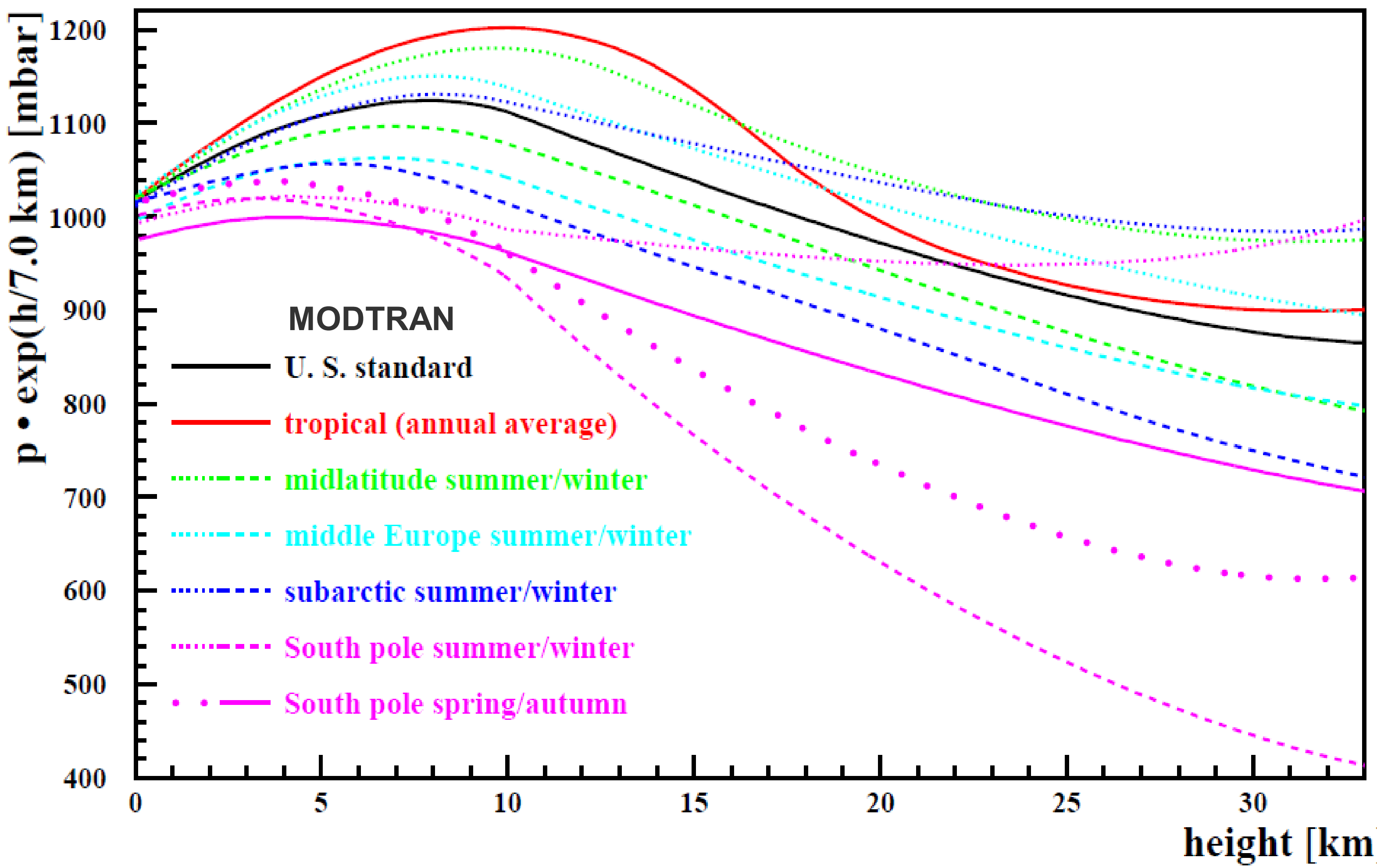
Atmosphere

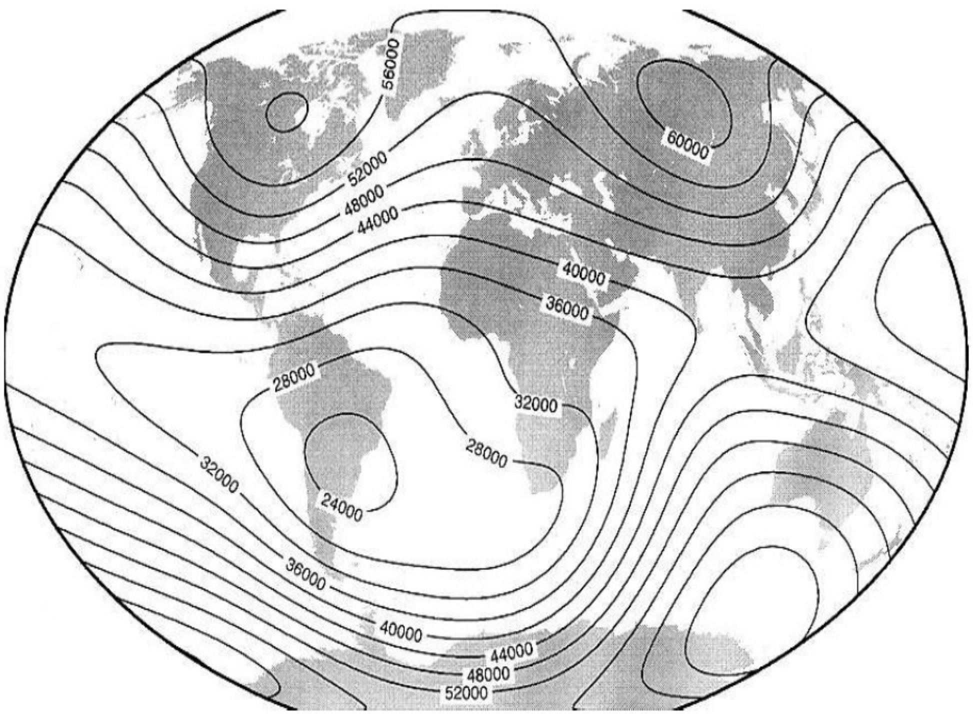
Different atmospheres available

- default : US standard

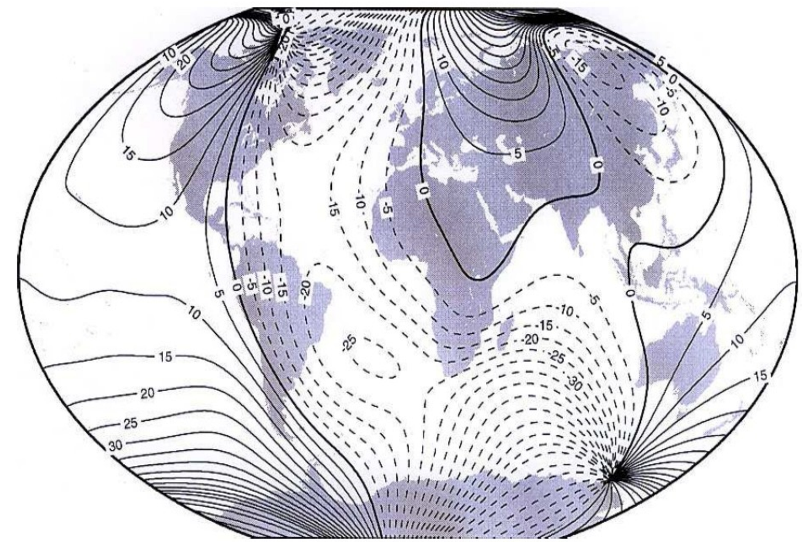


Earth Magnetic Field

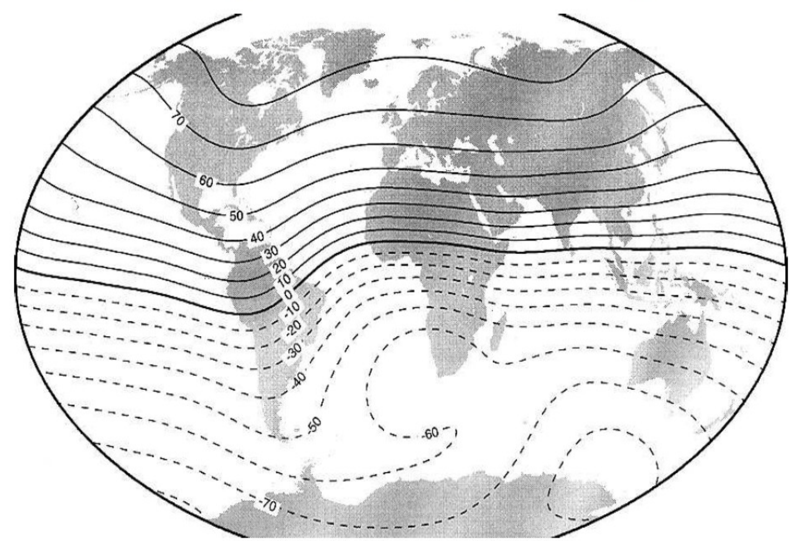
- Earth Magnetic Field has to be defined according to experiment position on Earth



Total strength (nT) of Earth magnetic field for year 2000.



Declination (degrees) of Earth magnetic field for year 2000.



Inclination (degrees) of Earth magnetic field for year 2000.

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Particles

Identification	Particle	Identification	Particle	Identification	Particle	Identification	Particle
1	γ	17	η	50	ω	66	ν_e
2	e^+	18	Λ	51	ρ°	67	$\overline{\nu}_e$
3	e^-	19	Σ^+	52	ρ^+	68	ν_μ
		20	Σ°	53	ρ^-	69	$\overline{\nu}_\mu$
5	μ^+	21	Σ^-	54	Δ^{++}		
6	μ^-	22	Ξ°	55	Δ^+	71	$\eta \rightarrow \gamma\gamma$
7	π°	23	Ξ^-	56	Δ°	72	$\eta \rightarrow 3\pi^\circ$
8	π^+	24	Ω^-	57	Δ^-	73	$\eta \rightarrow \pi^+\pi^-\pi^\circ$
9	π^-	25	$\overline{n}$	58	$\overline{\Delta}^{--}$	74	$\eta \rightarrow \pi^+\pi^-\gamma$
10	K°_L	26	$\overline{\Lambda}$	59	$\overline{\Delta}^-$	75	μ^+ add. info.
11	K^+	27	$\overline{\Sigma}^-$	60	$\overline{\Delta}^\circ$	76	μ^- add. info.
12	K^-	28	$\overline{\Sigma}^\circ$	61	$\overline{\Delta}^+$		
13	n	29	$\overline{\Sigma}^+$	62	$K^{*\circ}$		
14	p	30	$\overline{\Xi}^\circ$	63	K^{*+}		
15	$\overline{p}$	31	$\overline{\Xi}^+$	64	K^{*-}		
16	K°_S	32	$\overline{\Omega}^+$	65	$\overline{K^*}^\circ$		

Charmed Particles

Identification	Particle	Identification	Particle	Identification	Particle
116	D°	133	ν_τ	153	$\overline{\Sigma_c}^{-}$
117	D^{+}	134	$\overline{\nu}_\tau$	154	$\overline{\Sigma_c}^{\circ}$
118	$\overline{D}^{-}$			155	$\overline{\Xi_c'}^{-}$
119	$\overline{D}^{\circ}$	137	Λ_c^{+}	156	$\overline{\Xi_c'}^{\circ}$
120	D_s^{+}	138	Ξ_c^{+}	157	$\overline{\Omega_c}^{\circ}$
121	$\overline{D_s}^{-}$	139	Ξ_c°		
122	η_c	140	Σ_c^{++}	161	Σ_c^{*++}
123	$D^{*\circ}$	141	Σ_c^{+}	162	Σ_c^{*+}
124	D^{*+}	142	Σ_c°	163	$\Sigma_c^{*\circ}$
125	$\overline{D^{*}}^{-}$	143	$\Xi_c'^{+}$		
126	$\overline{D^{*}}^{\circ}$	144	$\Xi_c'^{\circ}$	171	$\overline{\Sigma_c^{*}}^{--}$
127	D_s^{*+}			172	$\overline{\Sigma_c^{*}}^{-}$
128	$\overline{D_s^{*}}^{-}$	149	$\overline{\Lambda_c}^{-}$	173	$\overline{\Sigma_c^{*}}^{\circ}$
130	J/ψ	150	$\overline{\Xi_c}^{-}$		
131	τ^{+}	151	$\overline{\Xi_c}^{\circ}$		
132	τ^{-}	152	$\overline{\Sigma_c}^{--}$		

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Range of Particle for Interaction

- The probability P_{int} to traverse a layer with thickness χ without interaction is :
  - $$\mathbf{P_{int}}(\chi) = \frac{\mathbf{1}}{\lambda_{\mathbf{int}}}\mathbf{e}^{-\chi/\lambda_{\mathbf{int}}}$$
- The individually traversed matter thickness χ is :
  - $$\chi = -\mathbf{ln}(\mathbf{RNDM}) \cdot \lambda_{\mathbf{int}}$$
  - with random number 0 < RNDM < 1
- The mean free path λ_{int} is given by $\lambda_{\mathbf{int}} = \frac{\sum_{\mathbf{i=1}}^{\mathbf{3}} \mathbf{n_i A_i}}{\sum_{\mathbf{i=1}}^{\mathbf{3}} \mathbf{n_i}\sigma_{\mathbf{i_{int}}}} \frac{1}{N}$
  - with A_i = atomic weight of component I and N is the avogadro number
  - $\sigma_{i_{int}}$ = (energy dependent) cross-section of component i
- The atomic fractions n_i (volume) of air are adopted to
  - N_2 0.7848 (78.084%)
  - O_2 0.2105 (20.948%)
  - Ar 0.0047 (0.934%)

Range of Particle for Decay

- The probability P_D to traverse a path ℓ=-l without decay is
  - $$\mathbf{P_D}(\ell) = \frac{\mathbf{1}}{\ell_\mathbf{D}} \mathbf{e}^{-\ell/\ell_\mathbf{D}}$$
- The individually traversed path length ℓ=-l is
  - $$\ell = -\,\mathbf{ln}(\mathbf{RNDM}) \cdot \ell_\mathbf{D}$$
  - with random number $0 < \text{RNDM} < 1$
- The mean free path ℓ_D=(is given by $\ell_\mathbf{D} = \mathbf{c} \cdot \tau \cdot \gamma \cdot \beta$
  - c = vacuum speed of light,
  - τ = particle life time at rest,
  - γ = particle Lorentz factor and
  - β = particle velocity in units of c

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Hadronic Interaction Models

- Why so many hadronic interaction models ?
  - Different interaction models produce different mean values.
    - Scattering of mean values gives estimation on systematic uncertainty introduced by different extrapolations of accelerator data to high energy and forward direction.
  - High energy model
    - main development (Xmax, muons)
  - Low energy model
    - particles far from the core (e/m and muons)
- See various lectures during school for details

Particle Stacks

register / stack name	number of particles	content	comment
PRMPAR	1	primary particle	common PARPAR
CURPAR	1	current particle	common PARPAR
PROPAR	1	propagated particle	AAMAIN, BOX3, MUTRAC
OUTPAR	1	output / propagated particle	common PARPAR
AMUPAR	1	additional muon info	common MUPART
SECPAR	1	secondary particle	common PARPAR
STACKINT	200 000	intermediate stack for thinning	common STACKINT
STACKI	680 (624) (512)	intermediate stack for ext. file	common STACKF
(MEXST)	∞	particle stack	(scratch file)
DATAB	39	output buffer	common BUFFS
(STACKE)	60	em-particle stack	common STACKE

Particle Register

	stack position	equivalence	meaning
	CURPAR(0)	(ITYPE)	particle identifier
	CURPAR(1)	GAMMA	γ Lorentz factor
	CURPAR(2)	COSTHE	$\cos(\theta)$ vertical direction cosine [1]
	CURPAR(3)	PHIX	$\sin(\theta)\cdot\cos(\phi)$ horizontal direction cosine [1]
	CURPAR(4)	PHIY	$\sin(\theta)\cdot\sin(\phi)$ horizontal direction cosine [1]
	CURPAR(5)	H	height [cm]
	CURPAR(6)	T	time [sec] (since first interation)
	CURPAR(7)	X	horizontal position [cm]
	CURPAR(8)	Y	horizontal position [cm]
different definitions in SECPAR	CURPAR(9)	CHI	χ depth to next interaction [$g{\cdot}cm^{-2}$]
	CURPAR(10)	BETA	β =v/c fraction of speed of light
	CURPAR(11)	GCM	γ Lorentz factor in cms-system
	CURPAR(12)	ECM	energy in cms-system [GeV]
if THIN	CURPAR(13)	WEIGHT	weight for thinning (THIN option)
if CURVED	CURPAR(14)	HAPP	apparent height [cm] (CURVED option)
	CURPAR(15)	COSTAP	$\cos(\theta^*)$ apparent zenith angle cosine (CURVED option)
	CURPAR(16)	COSTEA	$\cos(\theta_E)$ angle at Earth center cosine (CURVED option)
if INTTEST	CURPAR(17)		transverse momentum [GeV/c] (INTTEST option)

[1] θ = zenith angle, ϕ = azimuth angle

New Developments

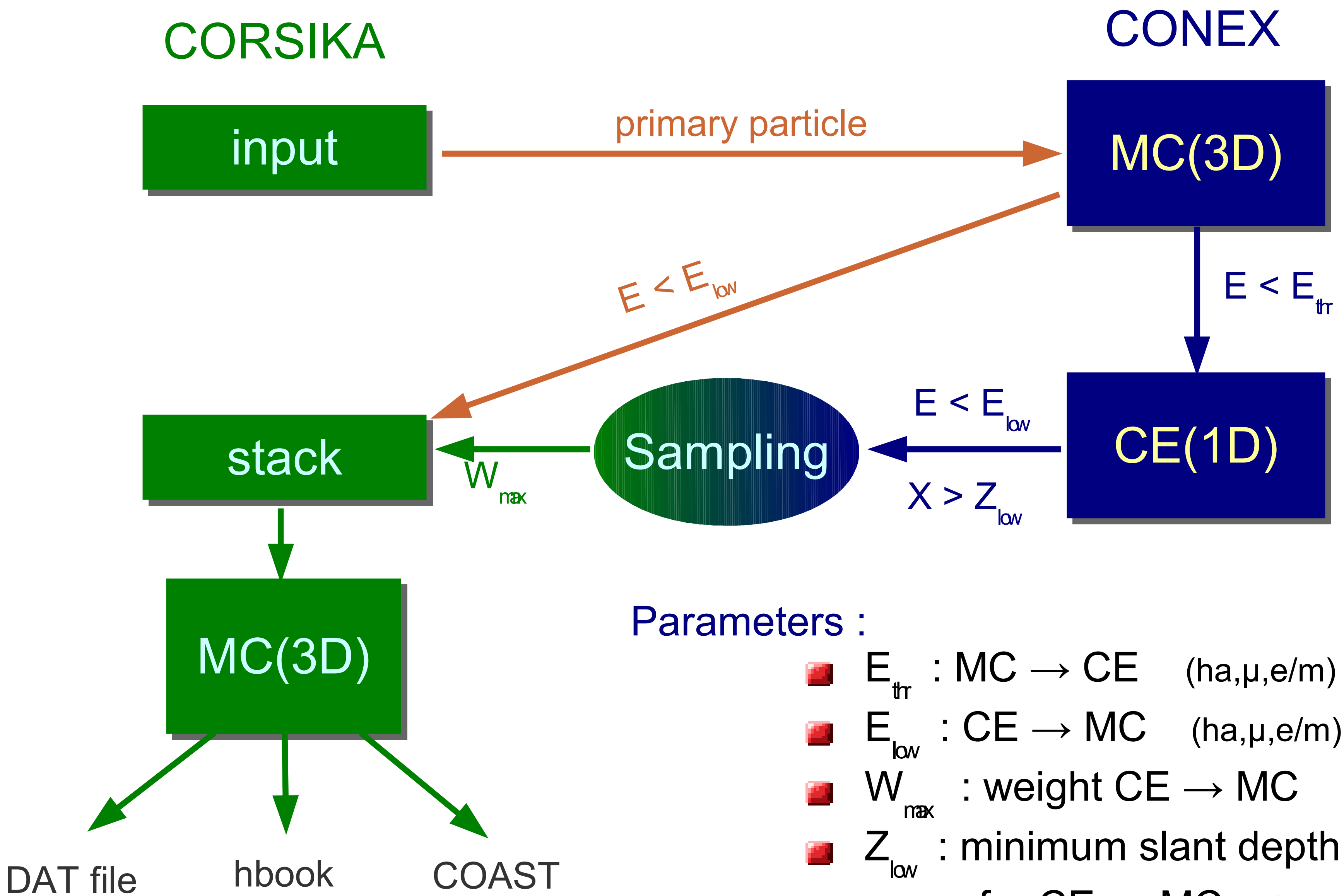
CONEX in CORSIKA

Idea : use CONEX as an option in CORSIKA

- CORSIKA running script and installation
- CORSIKA input
  - one more line in steering file for CONEX parameters
- CORSIKA output
  - no new interface
- CORSIKA low energy hadronic interactions models
  - while only GHEISHA in CONEX
- CONEX high energy hadronic interaction models
  - EPOS, QGSJET01, QGSJETII, SIBYLL 2.1, NEXUS 3.97

CONEX used as a new type of thinning in CORSIKA :
transparent for users !

CORSIKA with CONEX



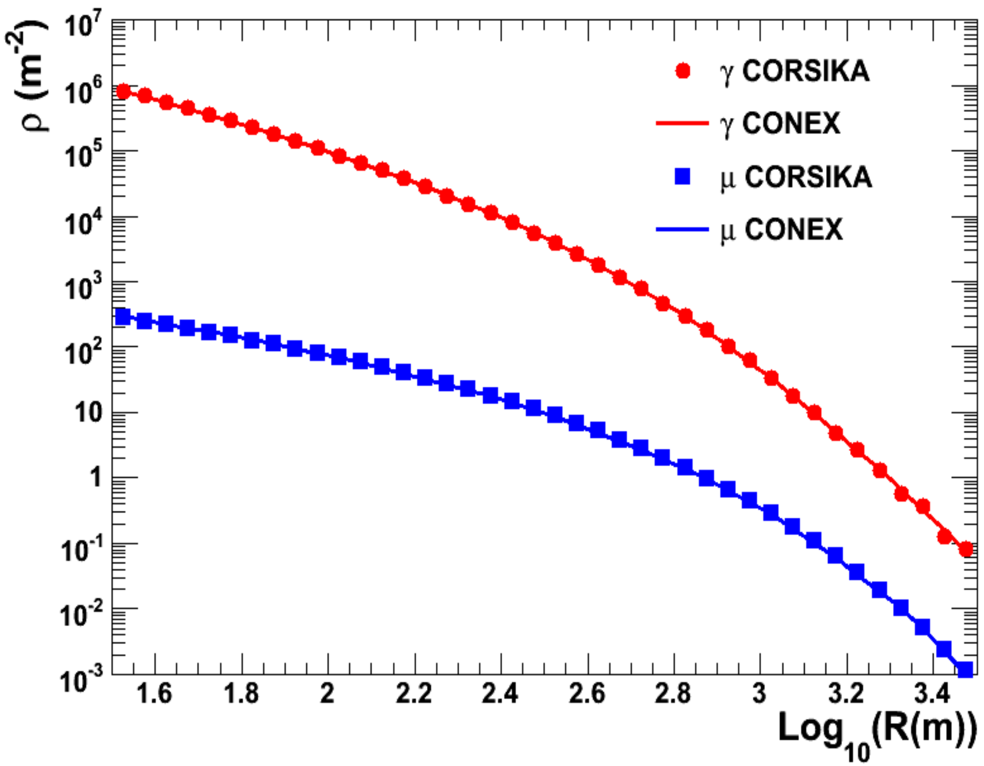
Parameters :

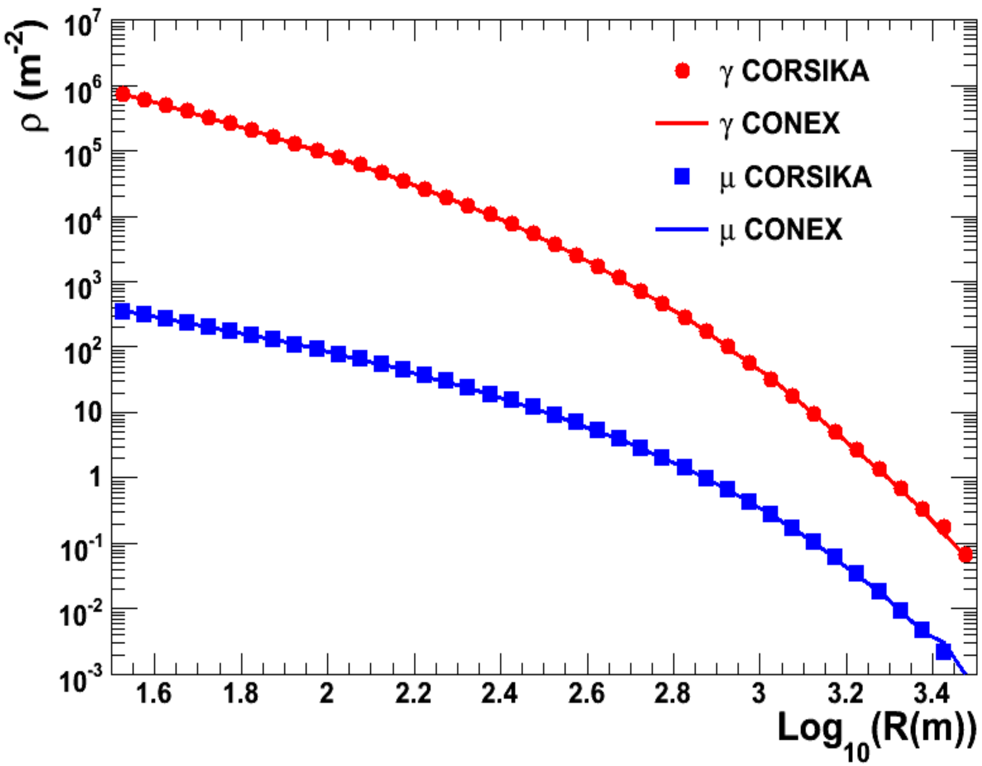
- E_{thr} : MC → CE (ha,μ,e/m)
- E_{low} : CE → MC (ha,μ,e/m)
- W_{max} : weight CE → MC (ha,μ,e/m)
- Z_{low} : minimum slant depth to ground for CE → MC (only e/m)

Test : lateral distribution functions

Simulations proton 10^{19} eV :

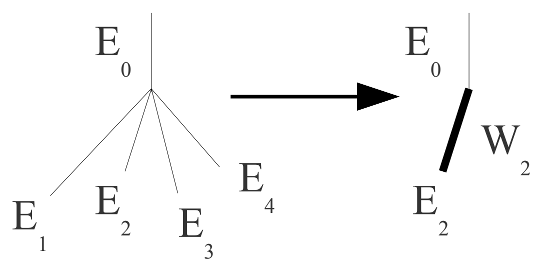
- EPOS 1.6 + FLUKA : fixed first interaction
- QGSJET01 + FLUKA : random first interaction





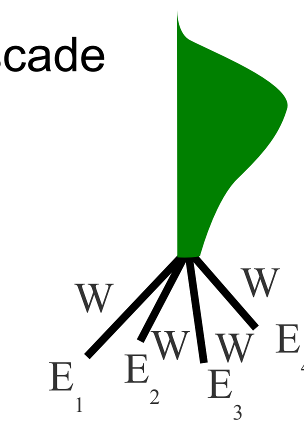
Cascade Equations vs Thinning

- Both save computation time by reducing the number of particles : a weight is introduced
  - thinning : randomly selected particle carry the weight of all particles produced at the same time to conserve energy
    - large spread of weight = large artificial fluctuations !



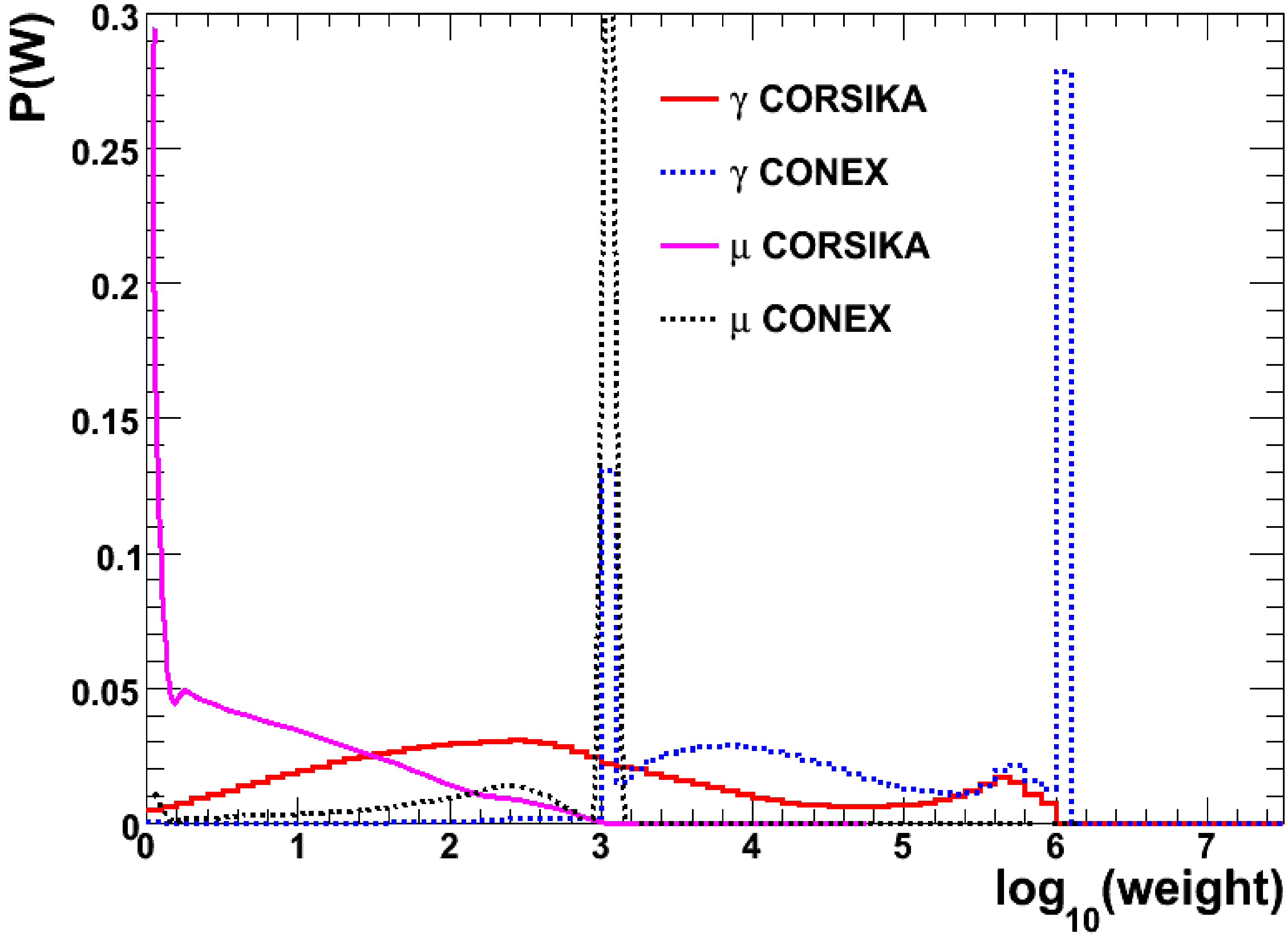
$$W_2 = \frac{E_0}{E_2}$$

  - cascade equations : same weight for all particles sampled from the cascade equations :
    - unique weight = no artificial fluctuations !
    - less fluctuations = larger weight can be used
    - larger weight = less particles
    - less particles = less time



- More time saved with cascade equations and less fluctuations

Weight Distributions



To come : CORSIKA 7.xxx (2011)

- CONEX as an option in CORSIKA
  - fast 1D simulations
  - faster 3D simulations
  - easy selection of shower for event-by-event analysis
  - …
- COAST distributed with CORSIKA
  - new extended ROOT output
  - inclined observation planes
  - user defined histogramming
  - ...
- PARALLEL option
  - easy management of sub-showers with proper random number seed

Thank you !