CORSIKA 8

Astroparticle cascade simulation framework

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for the Corsika 8 collaboration

CRIS-MAC
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CORSIKA

Cosmic Ray Simulation for KASCADE

KASCADE: an experiment to measure cosmic ray composition
in Karlsruhe (Germany)
first ideas: 1987, first data ~1997,
KASCADE-Grande ~2003
end data taking 2009

(J. Knapp "first 30 years of corsika", ISAPP school 2018)

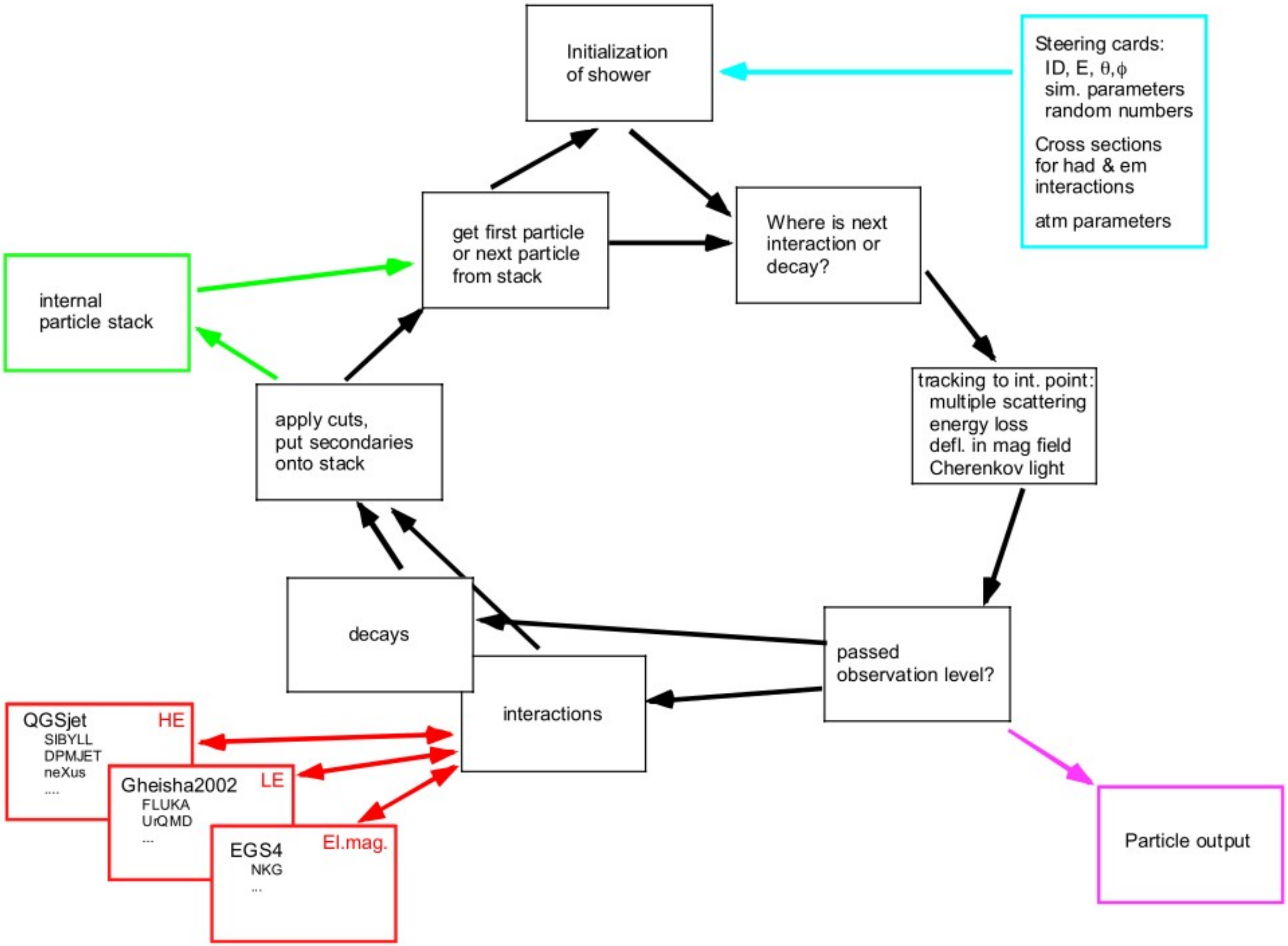
CORSIKA

Air shower simulation codes

Program	Reference	Method	Language	EM model	Hadronic model	
					Low E	High E
AIRES	Sciutto (1999)	MC	Fortran	custom+LPM	HS	S, Q, E
CONEX	Bergmann et al. (2007)	MC+CE	Fortran	EGS4+LPM	U	S, Q, E
COSMOS	Kasahara and Cohen (2007)	MC	Fortran	Tsai+LPM	J, JQ, B, D	S, Q, E, D
CORSIKA	Heck et al. (1998)	MC+CE	Fortran	EGS4+LPM	G, F, U	S, Q, E, D
CORSIKA 8	Engel et al. (2019)	MC+CE	C++	PROPOSAL	U	S, Q
MCEQ	Fedynitch et al. (2015)	CE	Python	EMCA (Tsai)	D	S, Q, E, D
MOCCA (⋆)	Hillas (1997)	MC	Pascal	custom	HS	HS
SENECA (⋆)	Drescher and Farrar (2003a)	MC+CE	Fortran	EGS4	G	Q

* first version 1989!
* 83 k lines of FORTRAN code!
* developed for vertical EAS of hadronic primaries
* extended over the years for generic air showers

CORSIKA flow diagram



(J. Knapp)

Main task of corsika:

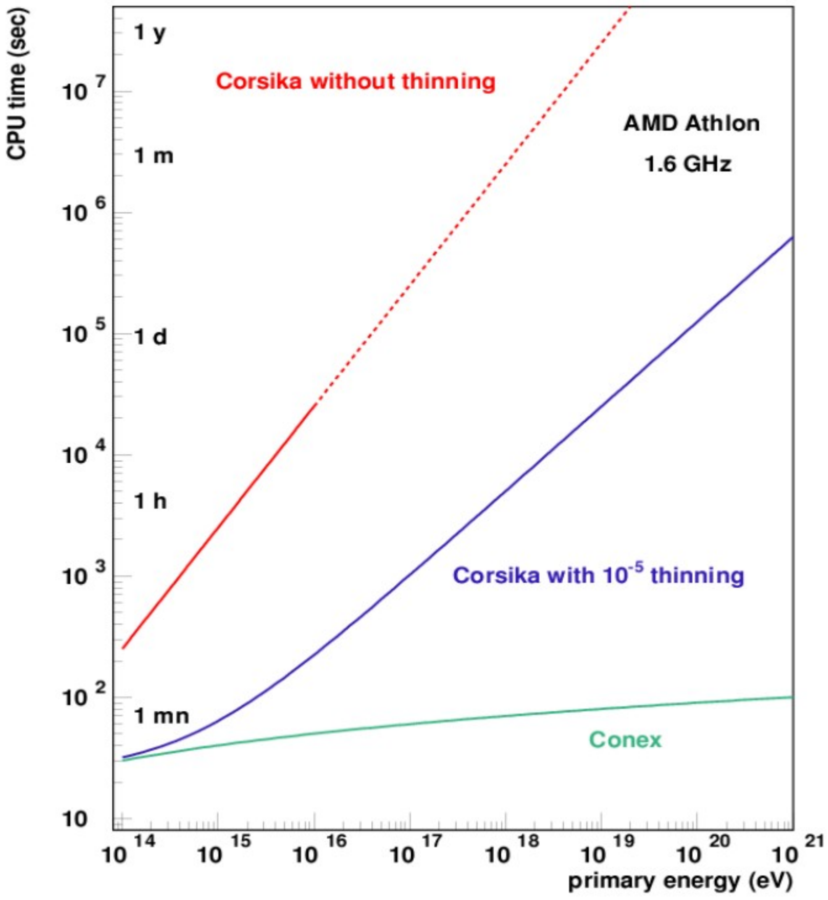
* tracking of particles through the atmosphere

* invoking the correct physics modules

~= HE version of GEANT, FLUKA ...

Why start over?

“standard air shower: vertical proton”



* computing infrastructure changed since 1990 (parallel computing, dedicated accelerators (GPUs,FPGAs,..))

Why start over?

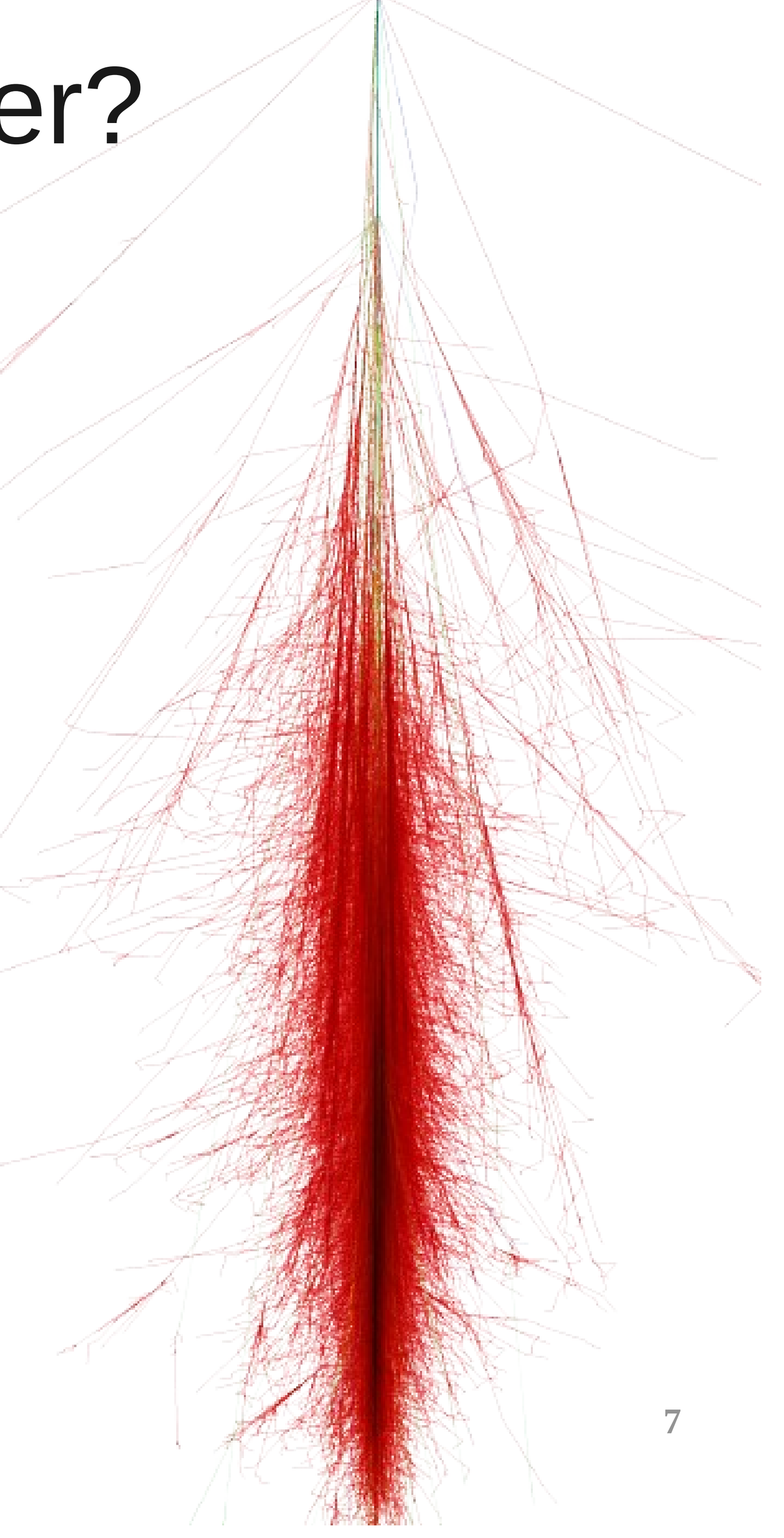
```
#else
            IF ( THETAP .GT. 70.D0*(PI/180.D0) ) GOTO 46
#endif
            IF ( XVC2 .NE. 0.D0  .OR.  YVC2 .NE. 0.D0 ) THEN
              PHIP = ATAN2(YVC2,XVC2) + PHIPR(1)
            ELSE
              PHIP = PHIPR(1)
            ENDIF
            IF ( PHIP .GT. PI2  ) PHIP = PHIP - PI2
            IF ( PHIP .LT. 0.D0 ) PHIP = PHIP + PI2
          ENDIF
#endif
#if __IACT__
          CALL EXTPRM(PRMPAR(0), PRMPAR(1), THETAP, PHIP)
          CTT = COS( THETAP )
#endif
#if __CURVED__
C  COSINE OF APPARENT ZENIT ANGLE IS PUT IN PRMPAR(15)
C  (COSINE OF LOCAL ZENIT ANGLE IS IN PRMPAR(2))
          PRMPAR(15) = COS( THETAP )
#else
          PRMPAR(2) = COS( THETAP )
#endif
        ELSE
#if __CURVED__ && __UPWARD__
          IF ( FIMPCT ) THEN
C  SKIMMING INCIDENCE, COSTAP AT DETECOR IS 0
            THETAP = 0.5D0 * PI
            CTT    = 0.D0
C  CHOOSE IMPACT PARAMETER AT RANDOM
            CALL RMMARD( RD,1,1 )
```

* FORTRAN
* multiple extensions over the years, patched on

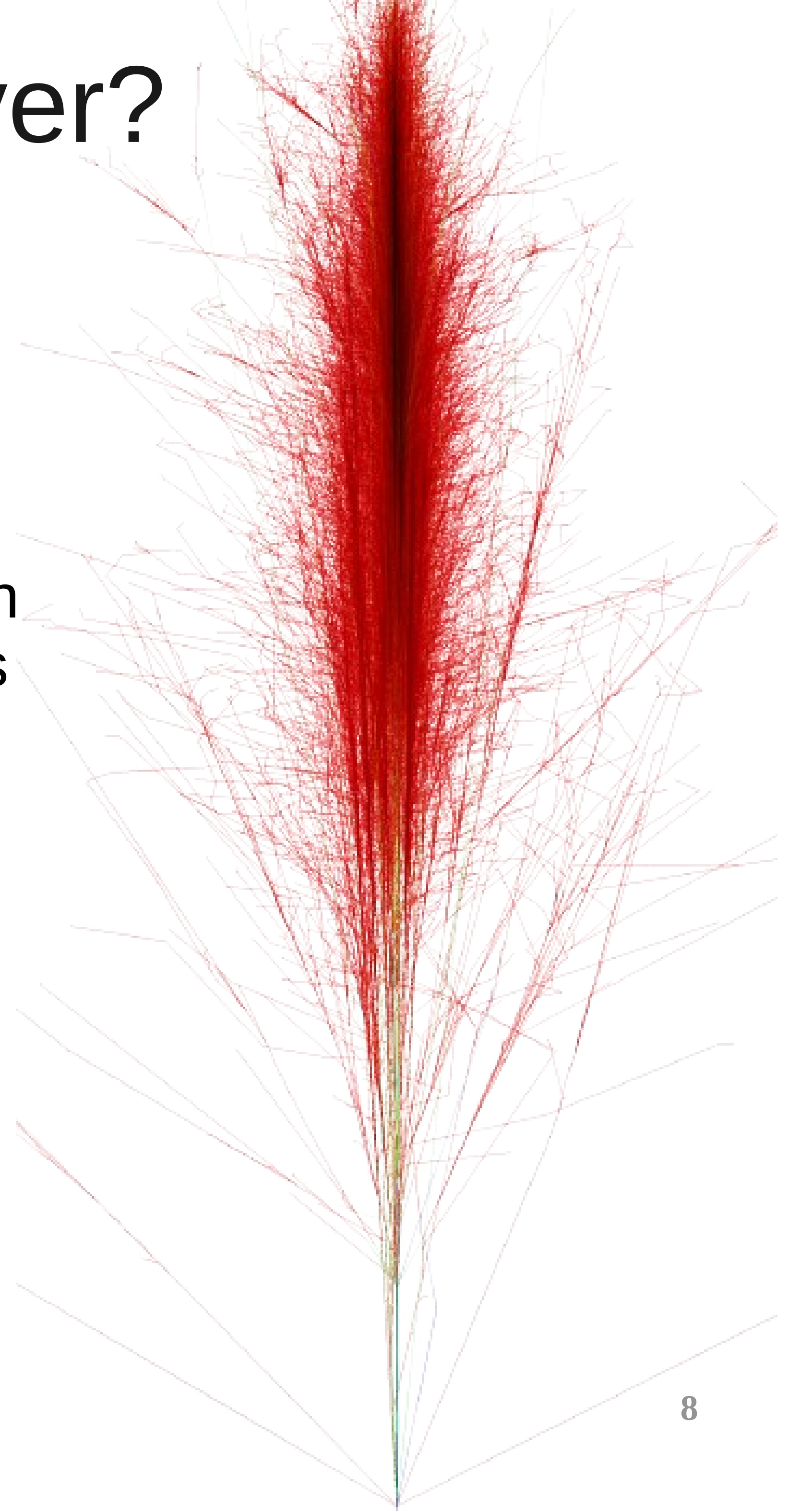
→ hard to maintain

Why start over?

Astroparticle physics is much more than hadron induced downgoing ***air*** showers



Why start over?



Astroparticle physics is much more than hadron induced downgoing ***air*** showers

Also need:
* arbitrary media
* arbitrary geometries
* arbitrary primary particles

==> be ready for anything

CORSIKA 8 project

* started in 2018
* open development on gitlab
* c++ (17)
* very modular design
* split code into framework and application

Aim for: “GEANT-4 for the outdoors”

CORSIKA 8 collaboration

CORSIKA 8 framework

* split air shower simulation code into separate pieces that work by themselves

Particle stacks

Geometry

Environment
material properties

Interaction (models)
- hadronic
- electromagnetic

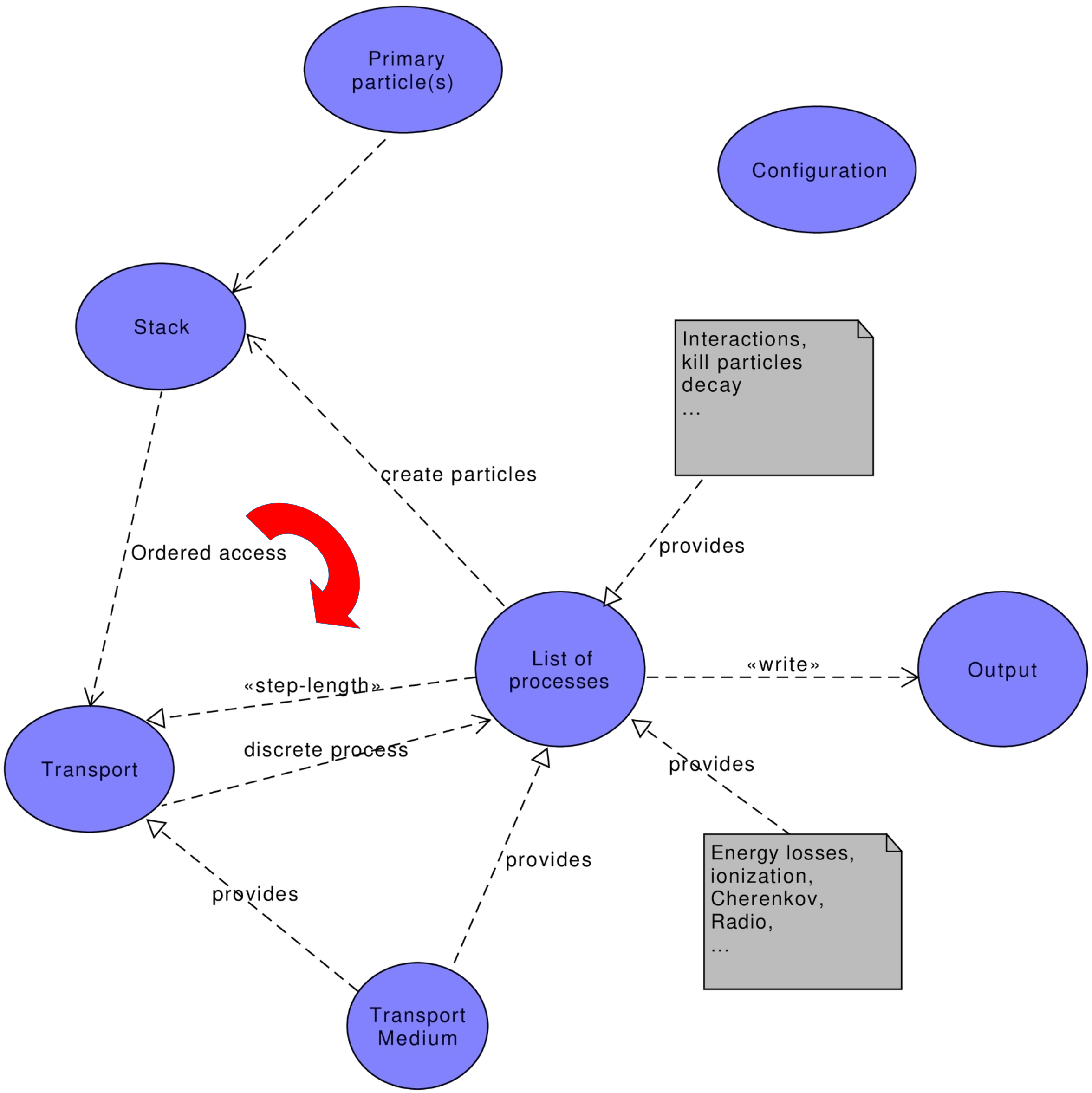
Emission
- Radio
- Cherenkov
- acoustic

Output

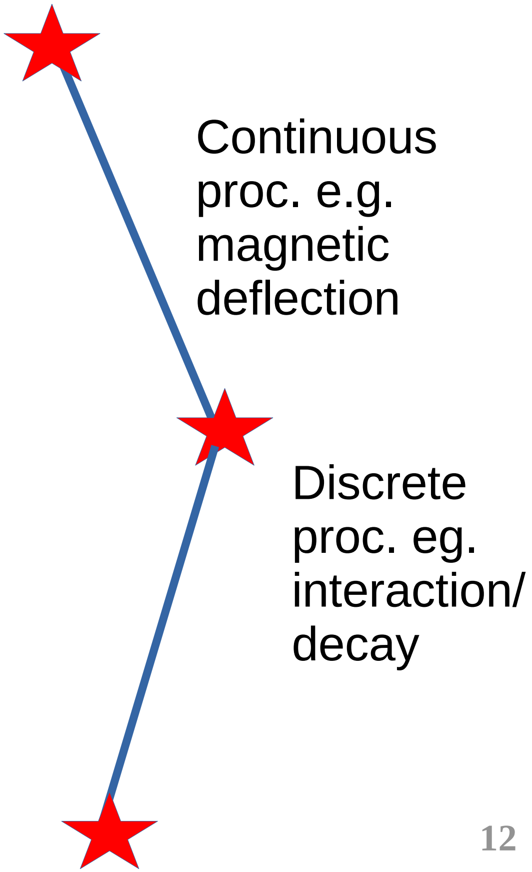
Hoping that the pieces can be put together to simulate any astroparticle application

Propagation
/ Tracking

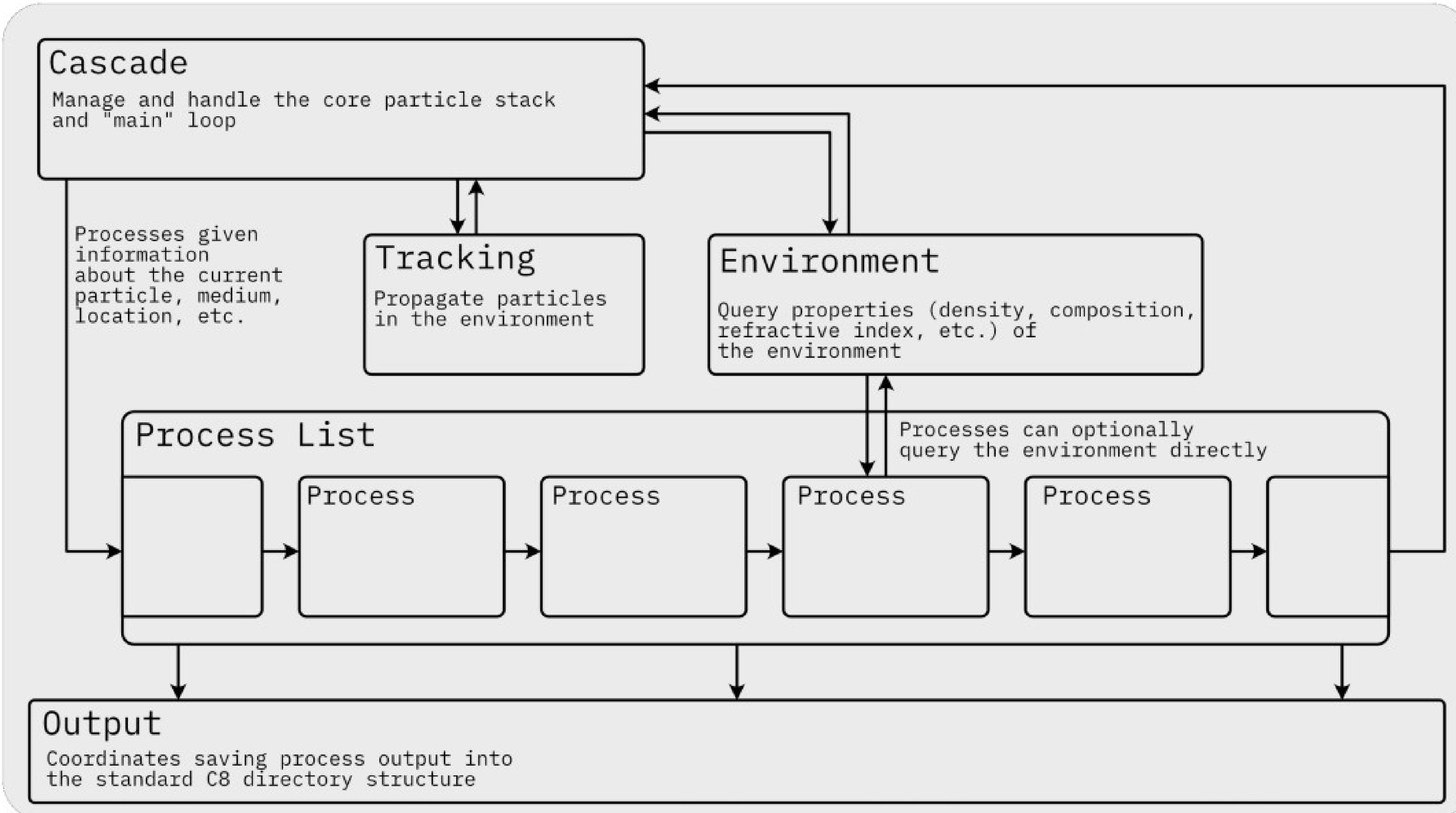
EAS/Cascade application

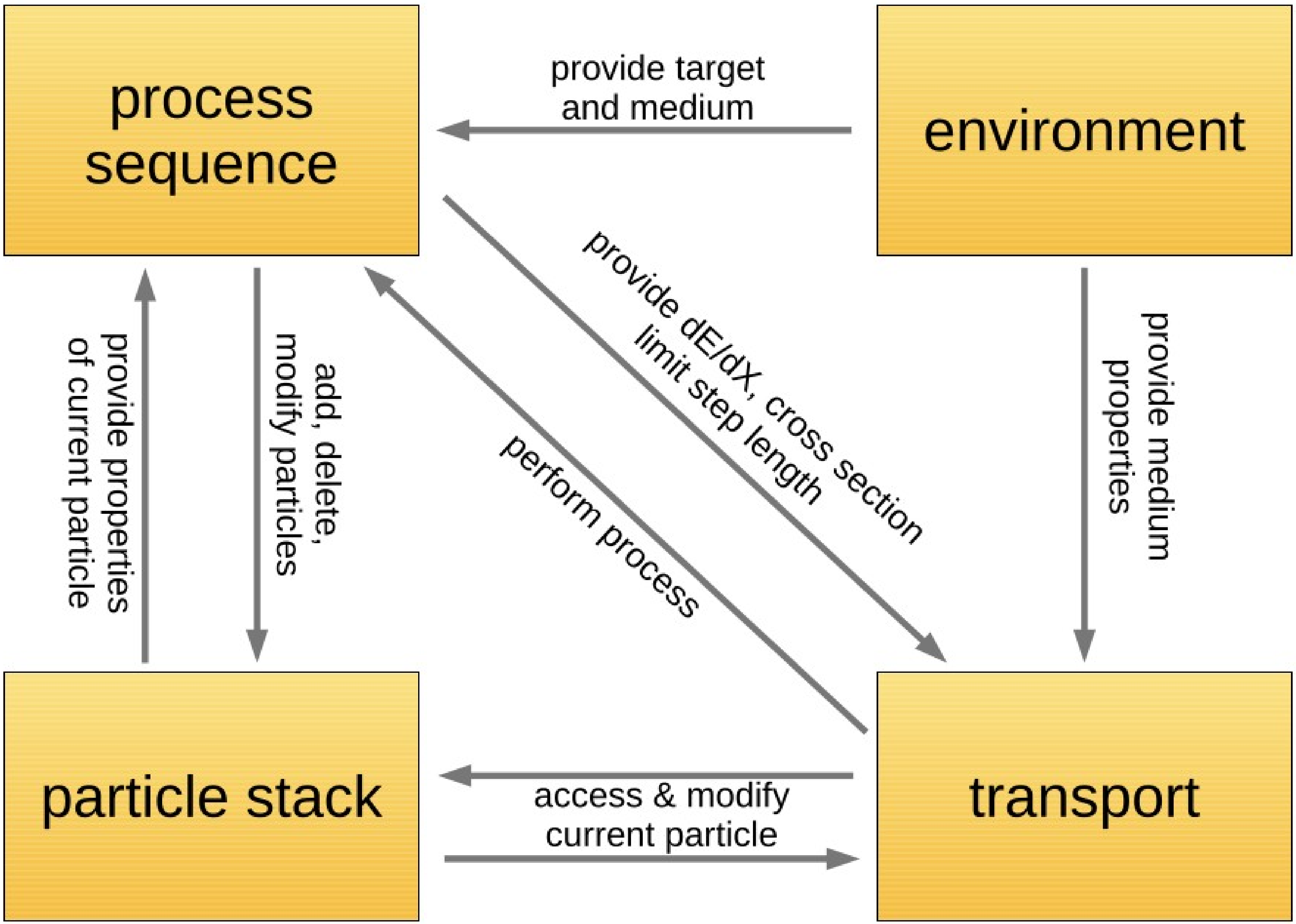


Iterate through "process list"
- step length determined by all processed
- continuous & discrete processes



CORSIKA 8 cascade application




process sequence
environment
particle stack
transport
provide target and medium
provide dE/dX, cross section
limit step length
perform process
provide properties of current particle
add, delete, modify particles
provide medium properties
access & modify current particle

Status of development

framework has sufficient functionality to simulate
downgoing hadronic air showers:

- hadronic interactions
  - High energy (Epos, Sibyll, QGSjetII-04)
    + Pythia 8 (ongoing)
  - Low energy (FLUKA, UrQMD)
- EM interactions (PROPOSAL + SOPHIA for photo-had)
- Radio emission (ZHS & CoREAS)
- Tracking/Propagation w magnetic fields
- Thinning algorithm
- 5 layer exponential atmosphere “a la corsika 7”

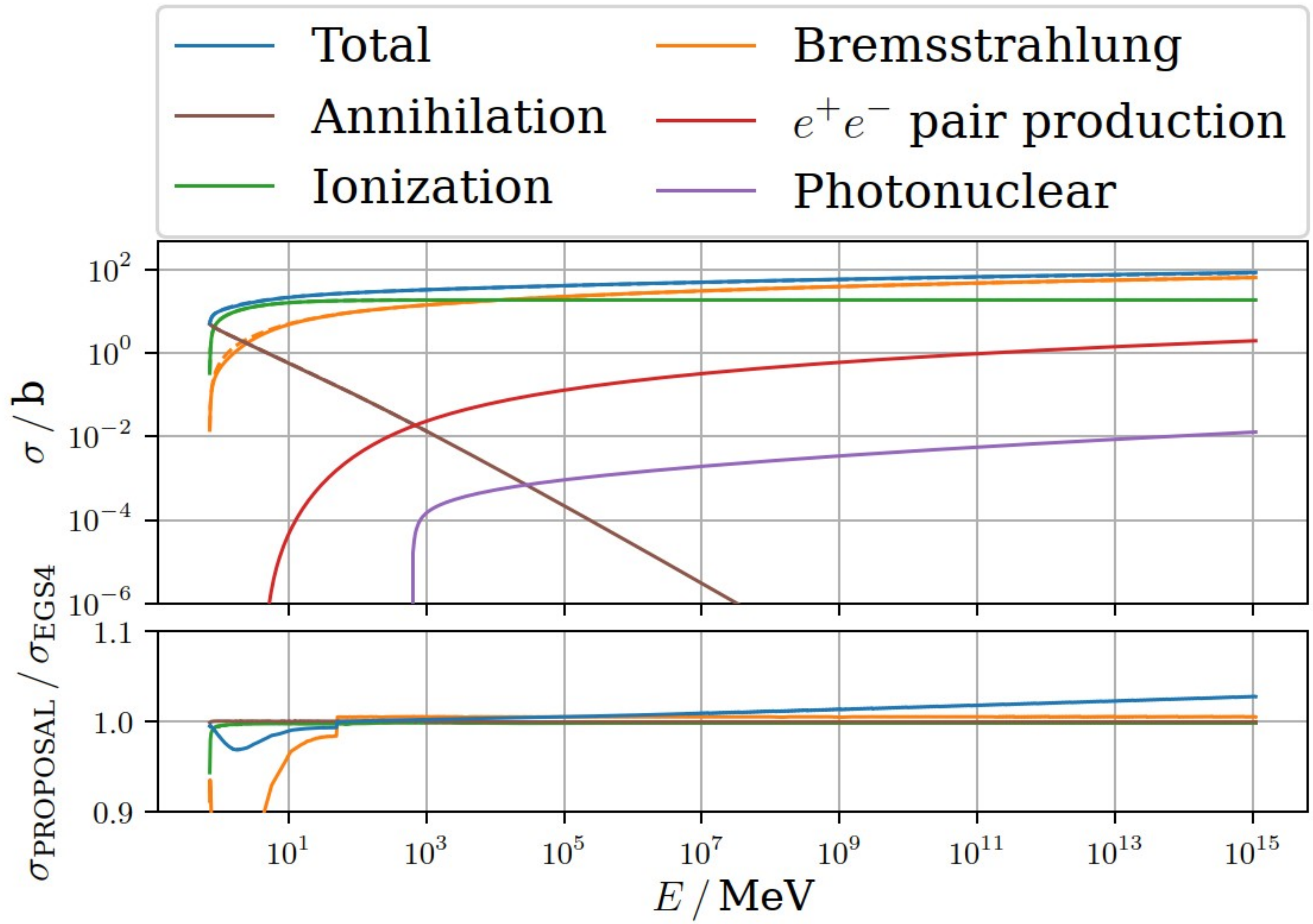
- neutrino interaction + tau decay
- Cherenkov emission via external code

same functionality (not necessarily the same algorithm)
as CORSIKA 7 ==> detailed comparison

EM showers

Same processes as CORSIKA 7 (EGS) but different implementation (PROPOSAL) and cross sections

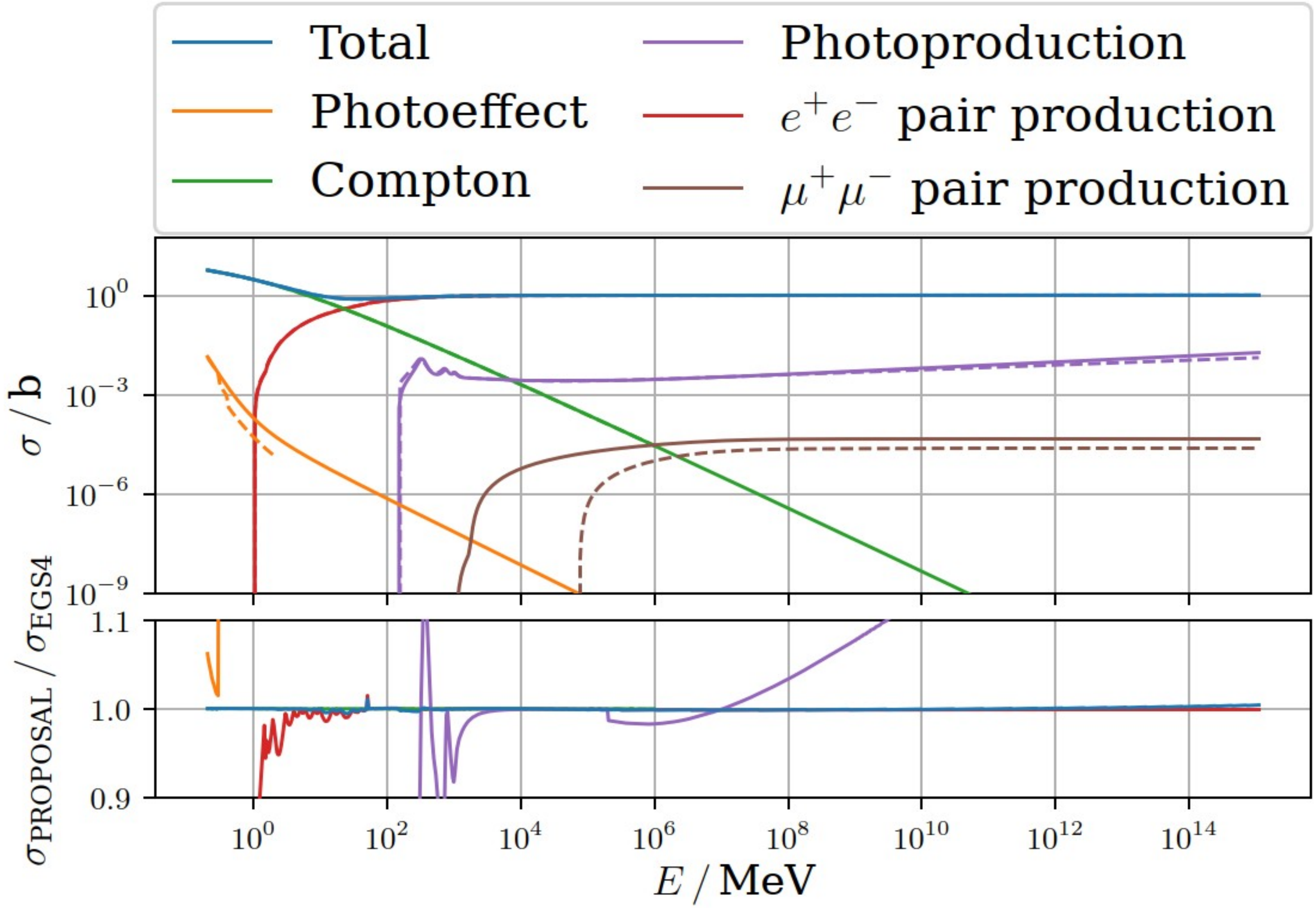
Electron/Positron cross sections



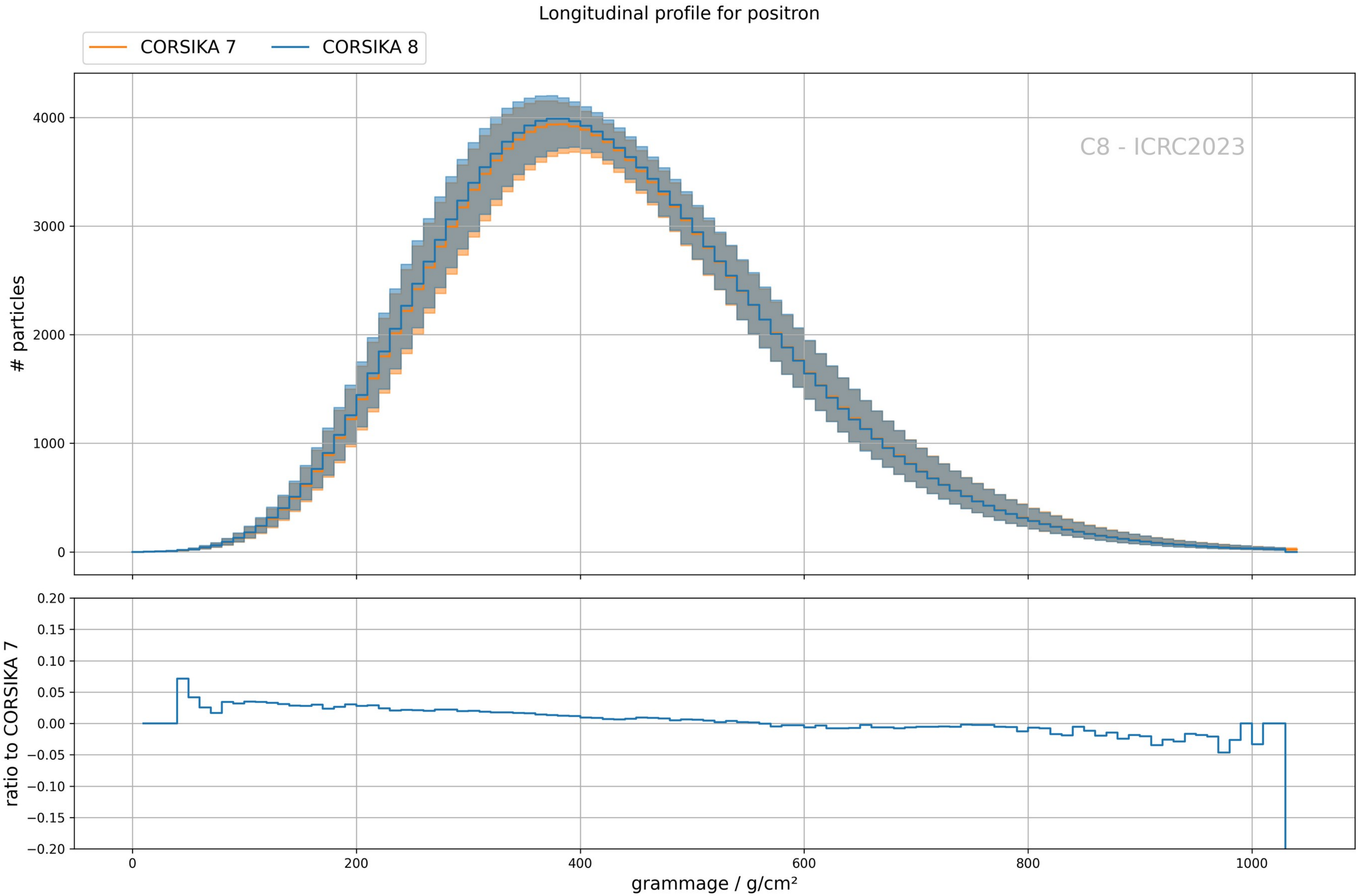
EM showers

Same processes as CORSIKA 7 (EGS) but different implementation (PROPOSAL) and cross sections

Photon cross sections

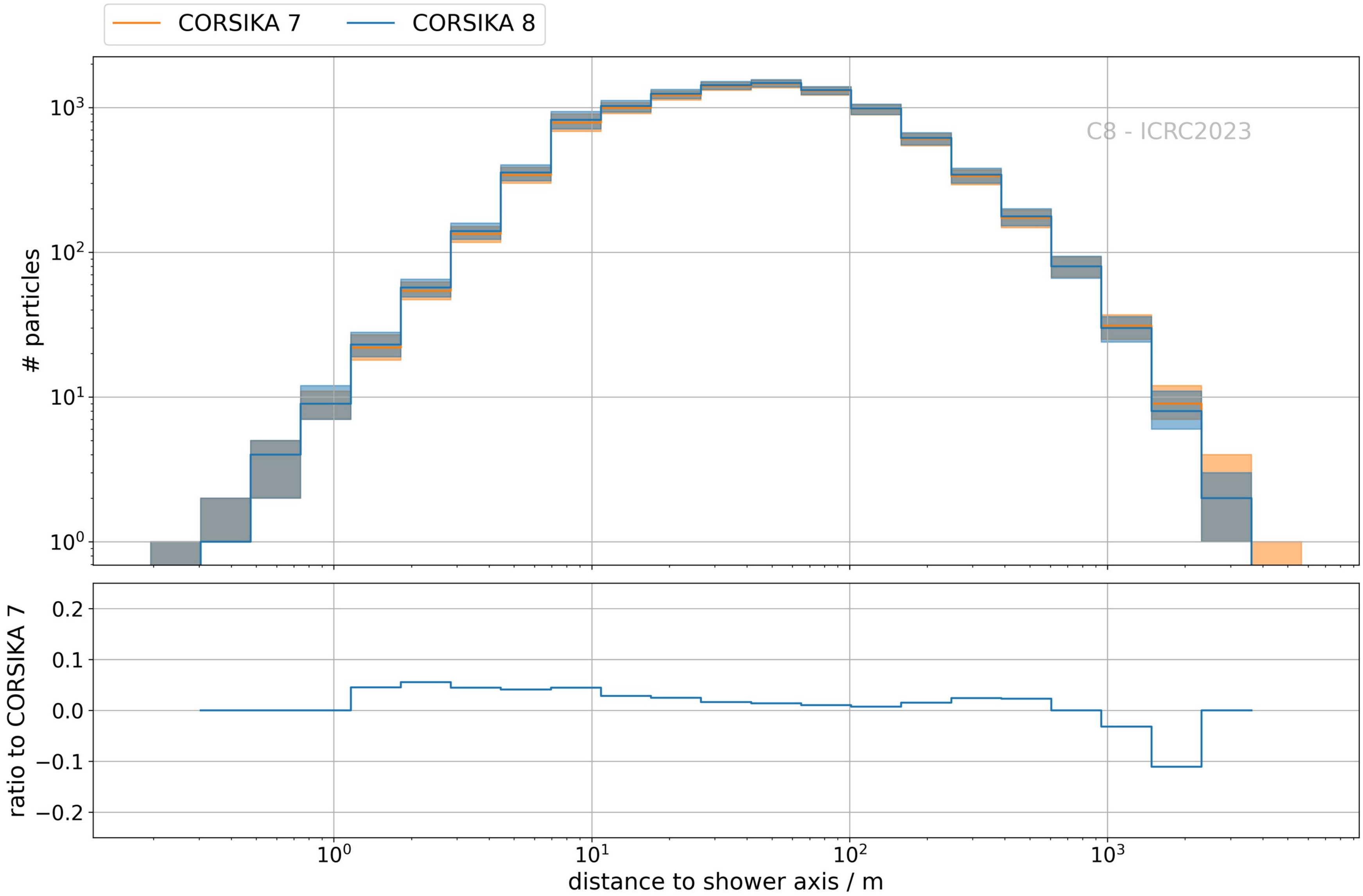


EM showers



Longitudinal profile of positrons with E>1MeV in a 10 TeV photon shower.
~%-level agreement

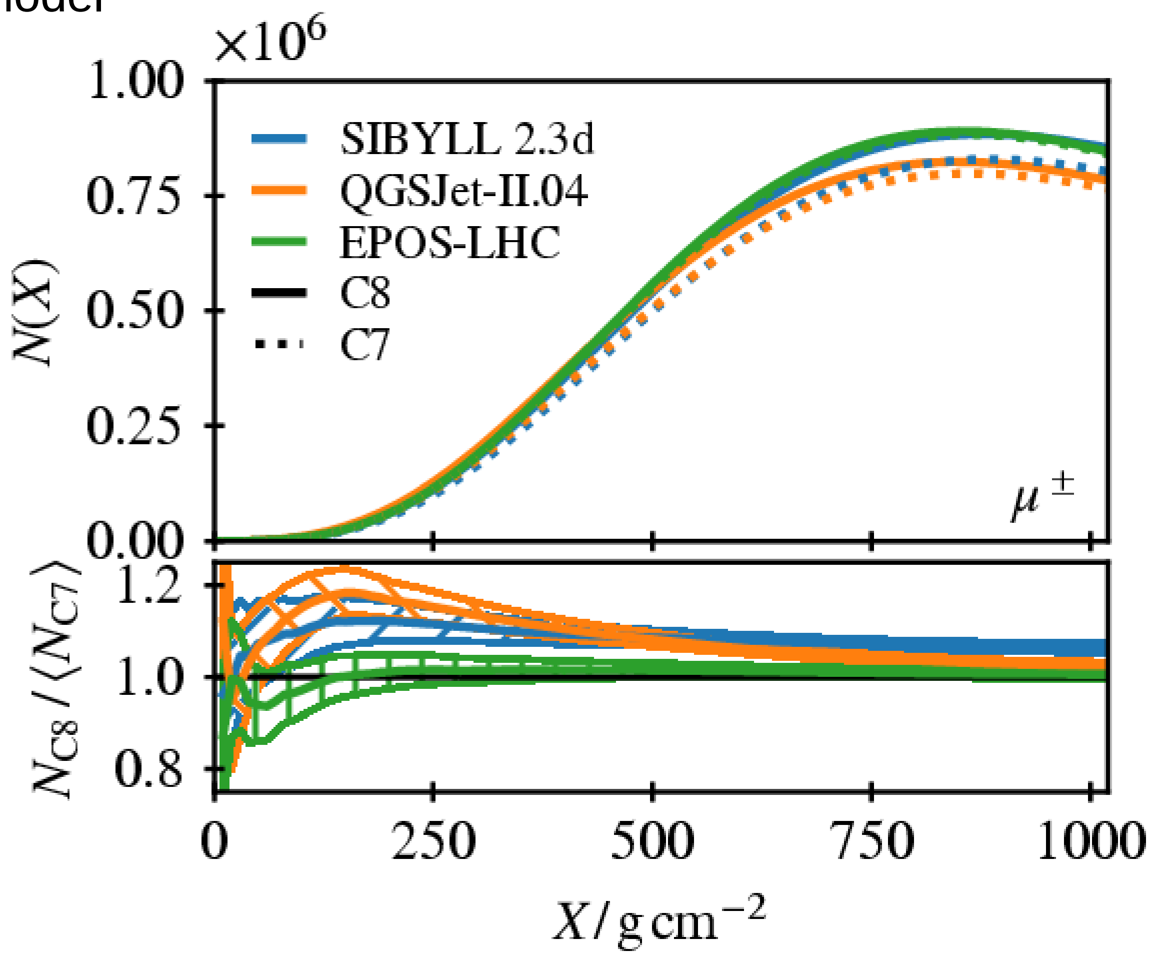
EM showers



Lateral profile of e+- with E>1MeV in a 10 TeV photon shower.
~%-level agreement

Hadron showers

100 PeV proton
EM > 10 MeV
Hadr./Muon> 300 MeV
FLUKA LE model



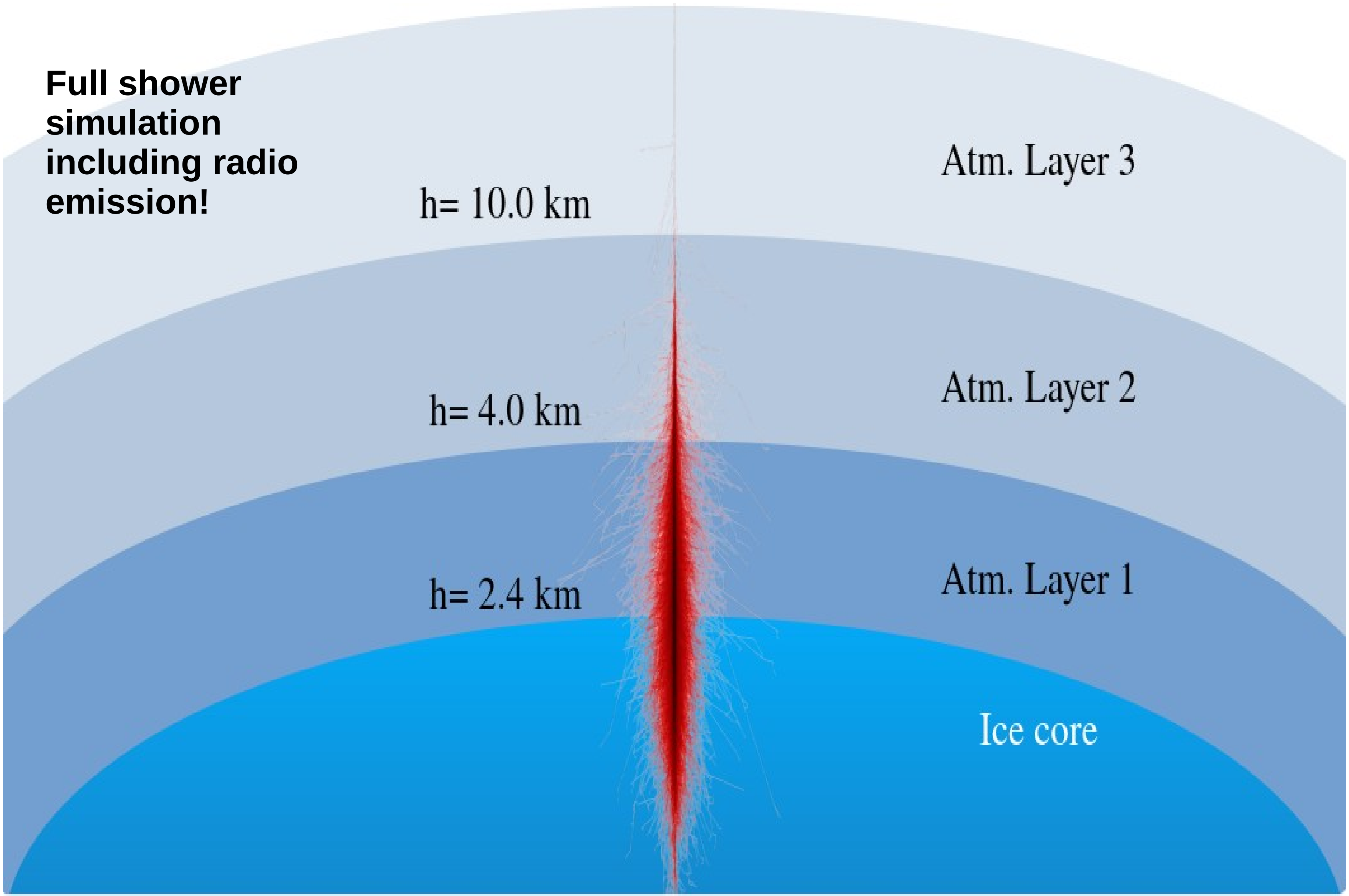
==> 10-20% difference! (or agreement as the optimist would say)
Under investigation..

CORSIKA 8 – unique features

Cross media showers

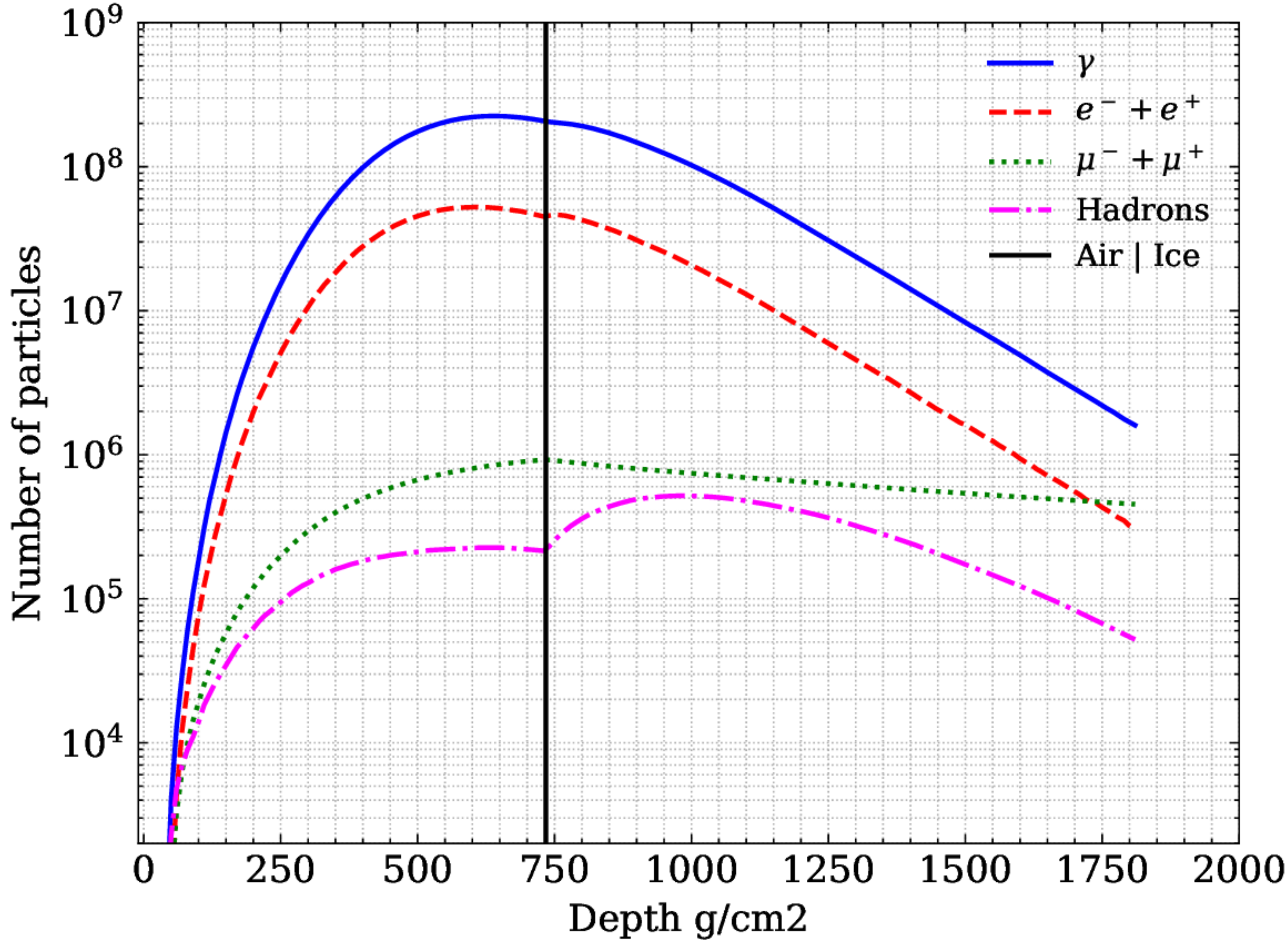
J. Ammerman-Yebra, ICRC 2023

Full shower simulation including radio emission!



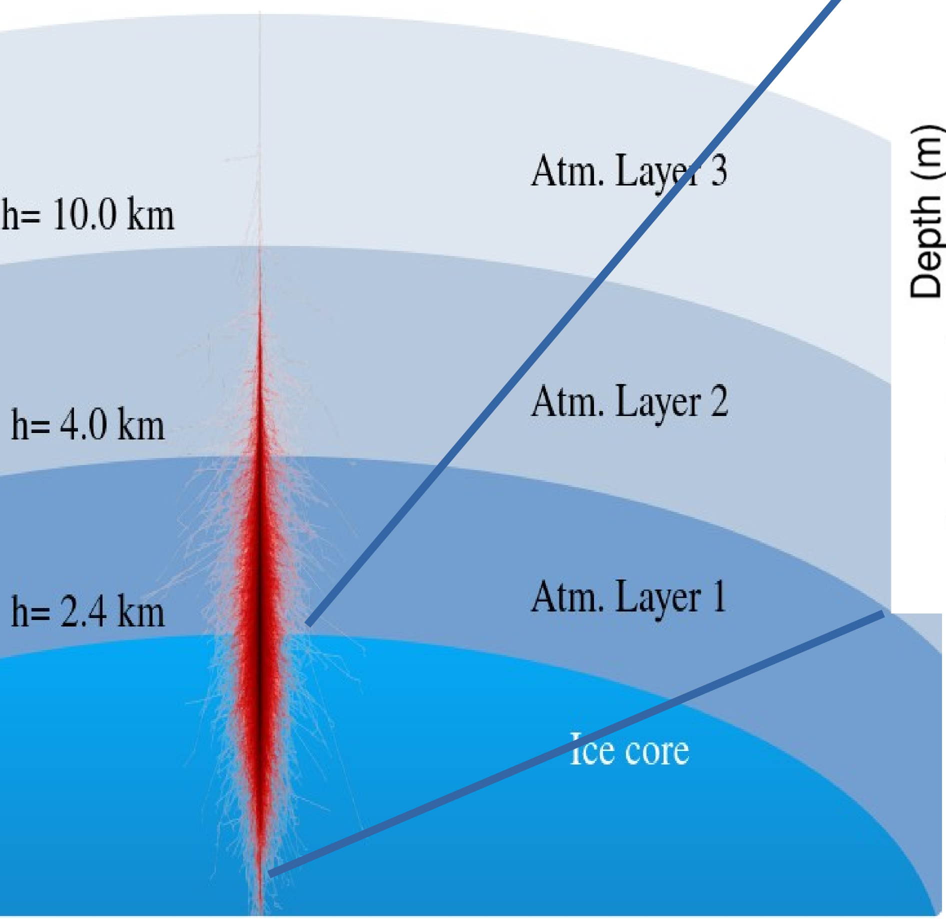
CORSIKA 8 – unique features

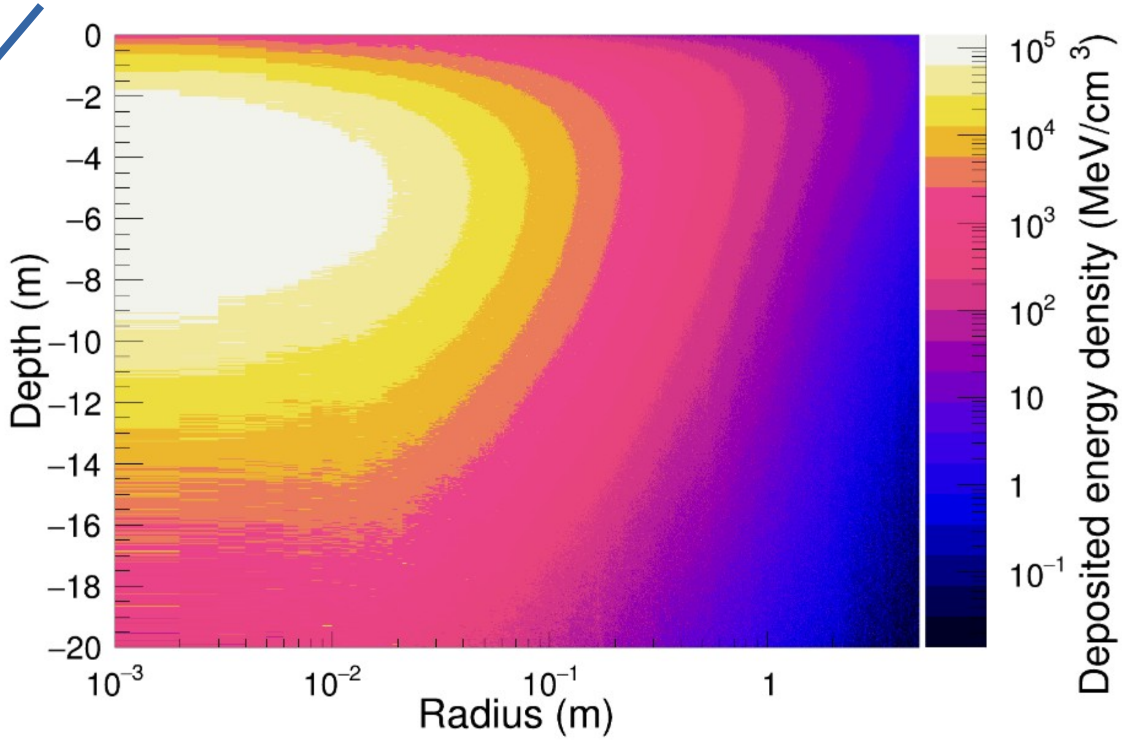
Cross media showers



CORSIKA 8 – unique features

Cross media showers



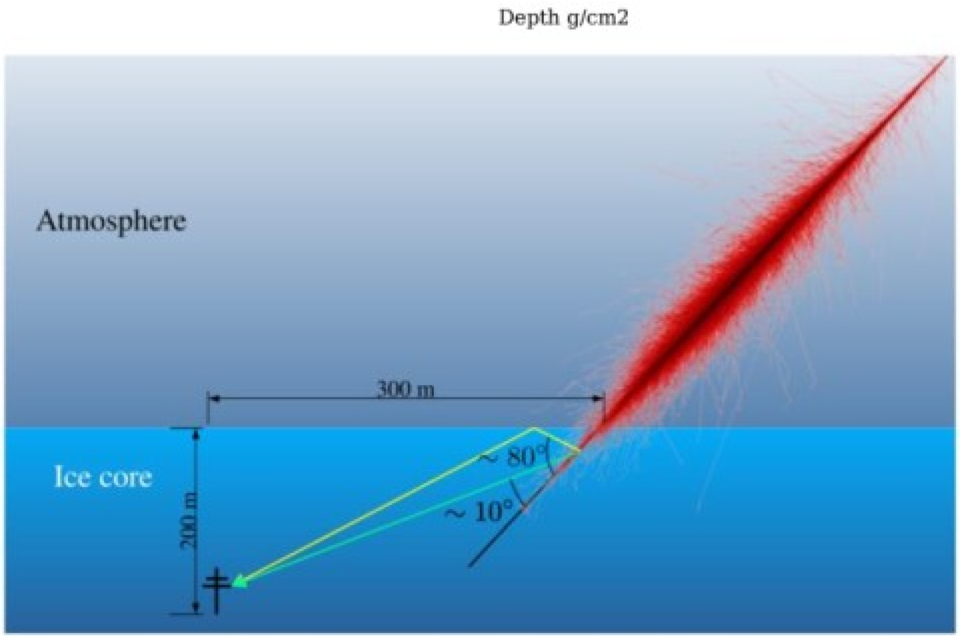


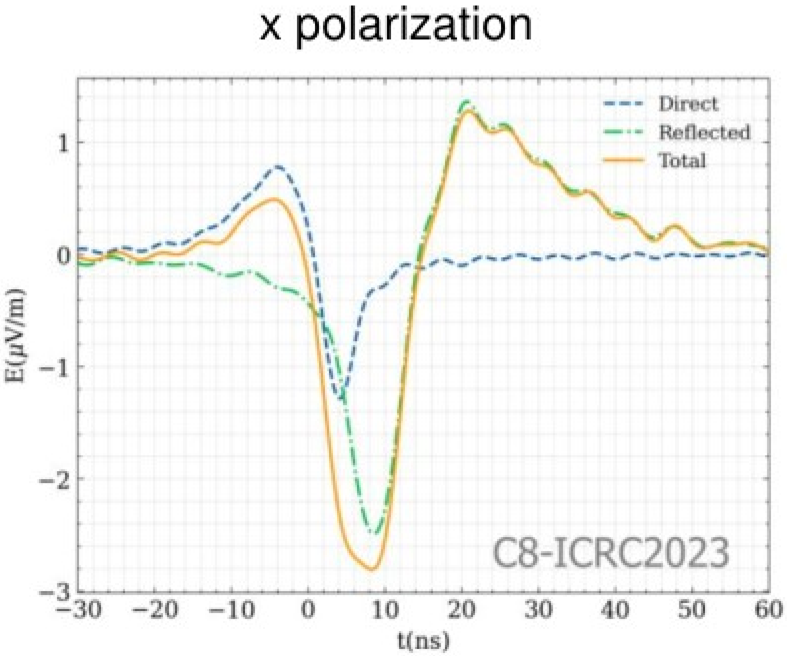
→ module for detailed tracking of energy deposit (2D,3D..)

CORSIKA 8 – unique features

Cross media showers

Radio emission in ice





CORSIKA 8 – beta release

* first release planned for September/October

* aim for beta-release:

  - get feedback on
    * user interface / steering
    * output format

  - new applications from community
    on going collab.:
    * TAMBO (mountain/valley showers)
    * TRIDENT (neutrino ind. showers in water)

  ==> find missing functionality

CORSIKA 8 – how to participate

Stay informed: **corsika-devel email list**
(https://www.lists.kit.edu/sympa/subscribe/corsika-devel)

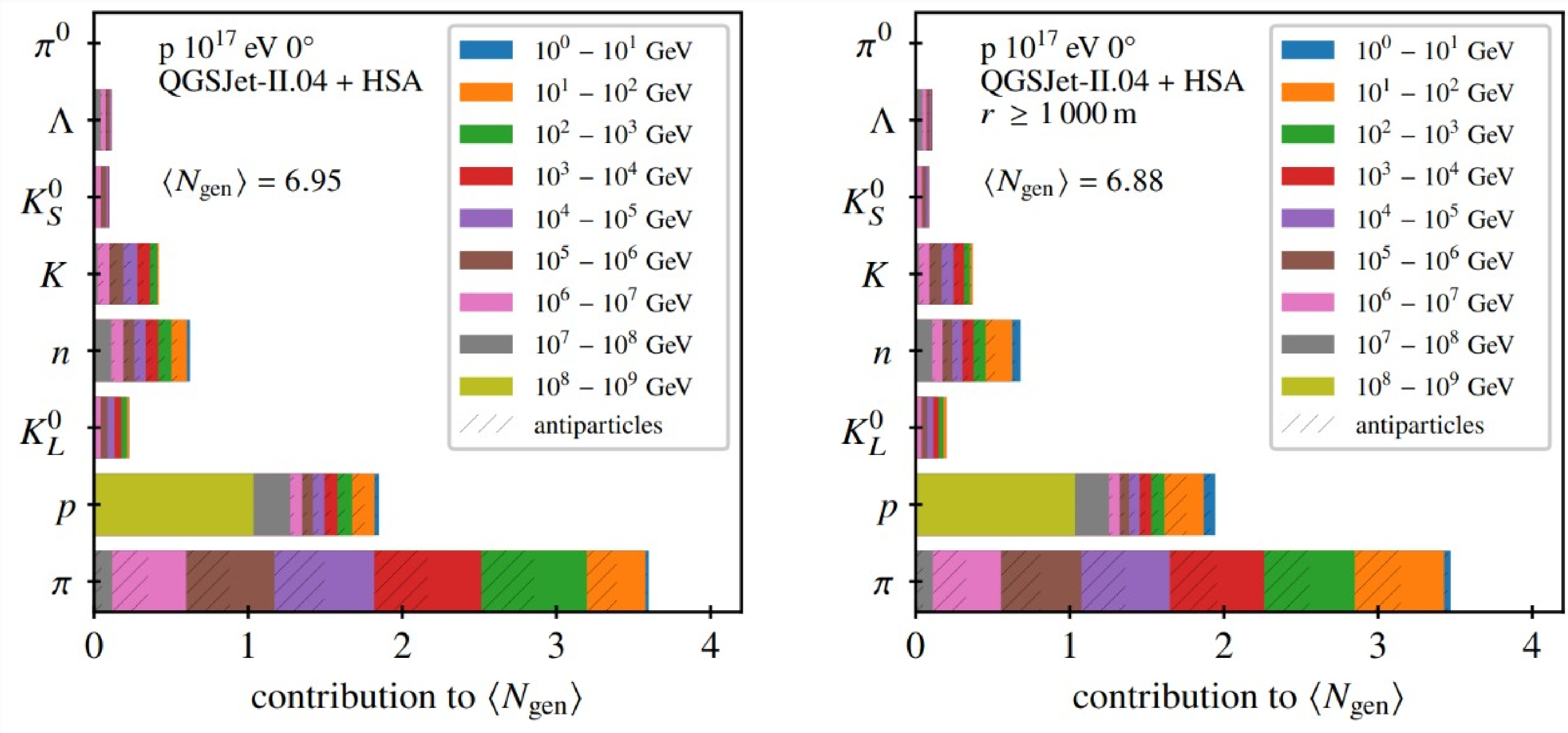
Contribute: **gitlab**
(https://gitlab.iap.kit.edu/AirShowerPhysics/corsika)

Ask questions: **Mattermost** (https://mattermost.hzdr.de/corsika8)

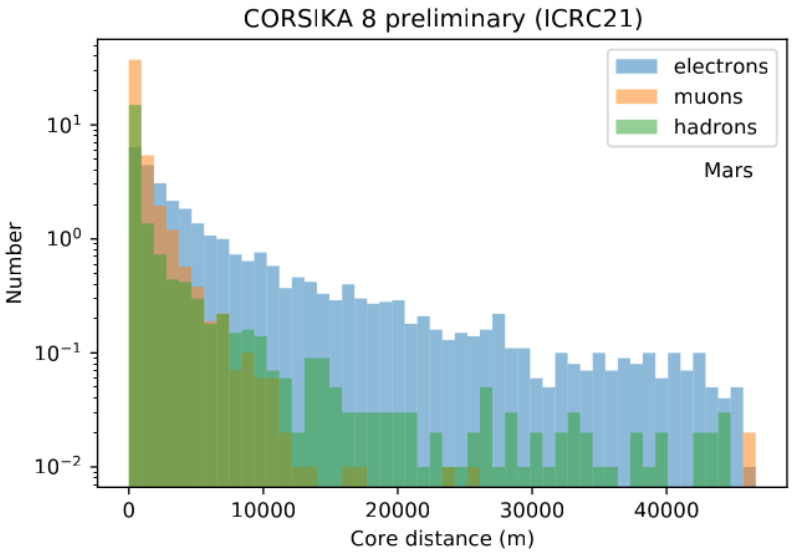
Register:
* workshop (end of September 2024)

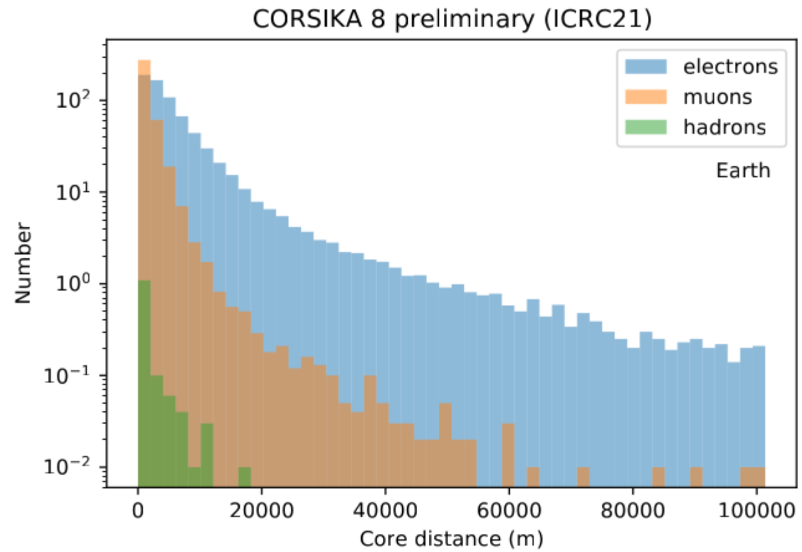
Genealogy

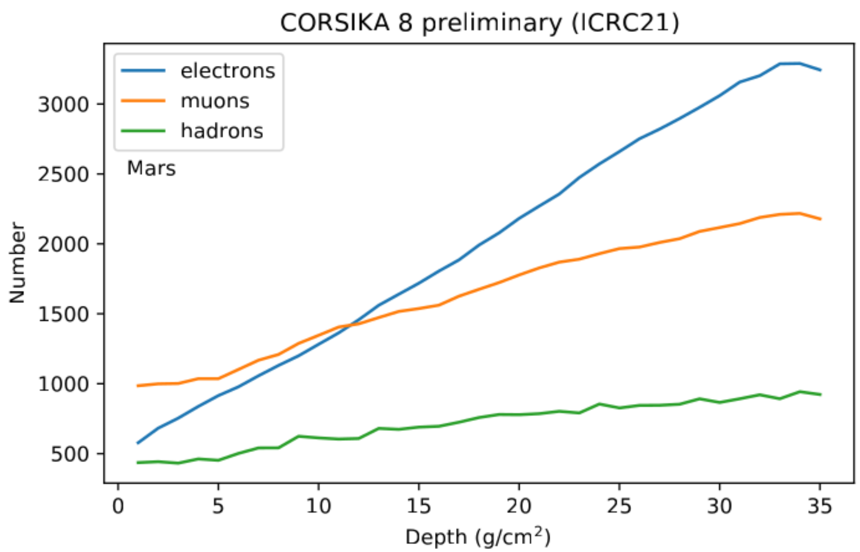
Extend stack with bookkeeping

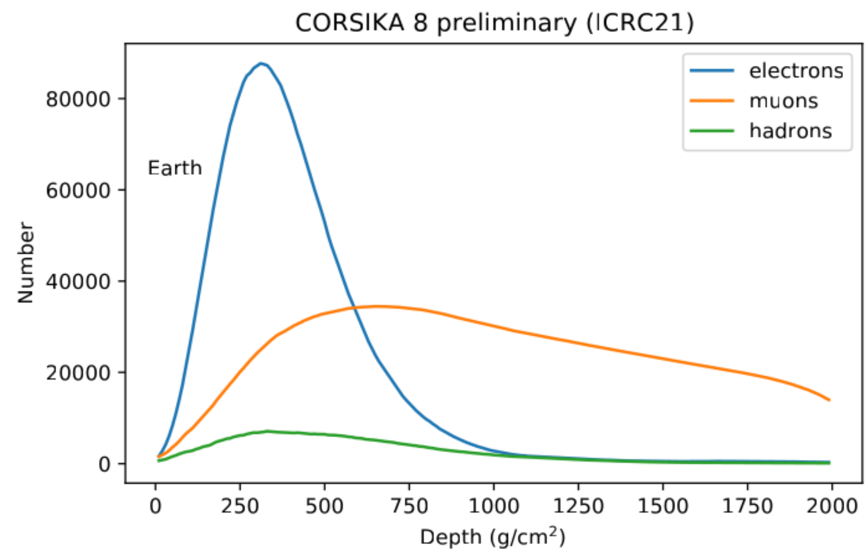


Different planets









CORSIKA 8 – unique features

Ice showers

In-ice Showers and Verification of NuRadioMC

work by Alan Coleman, Maria Duran, Christian Glaser (Uppsala University)

UPPSALA UNIVERSITET

CORSIKA 8 can be used in dense media (ice)
Here: homogeneous ice with n=1.78 with antennas 1km from interaction vertex

CORSIKA 8 prediction reproduces previous results (ARZ model parameterized from ZHAireS simulations)

Next step: Study effect of inhomogeneous media (now enabled by CORSIKA8)