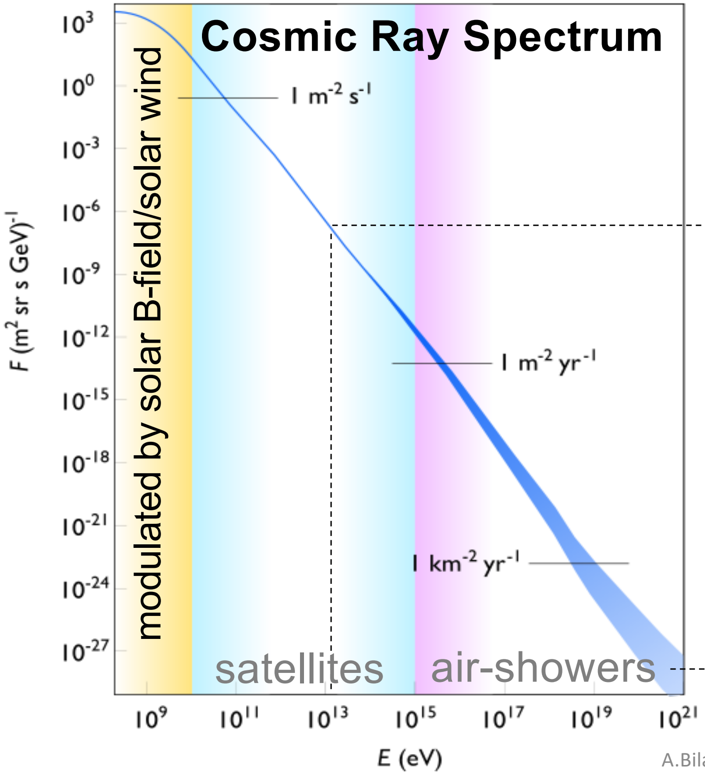
Background Rejection in Cherenkov Telescopes

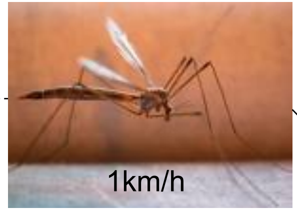
IPA ML Workshop

A.Biland, 21.3.2023

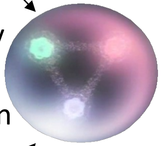
(Original) Task: Identify Cosmic Accelerators

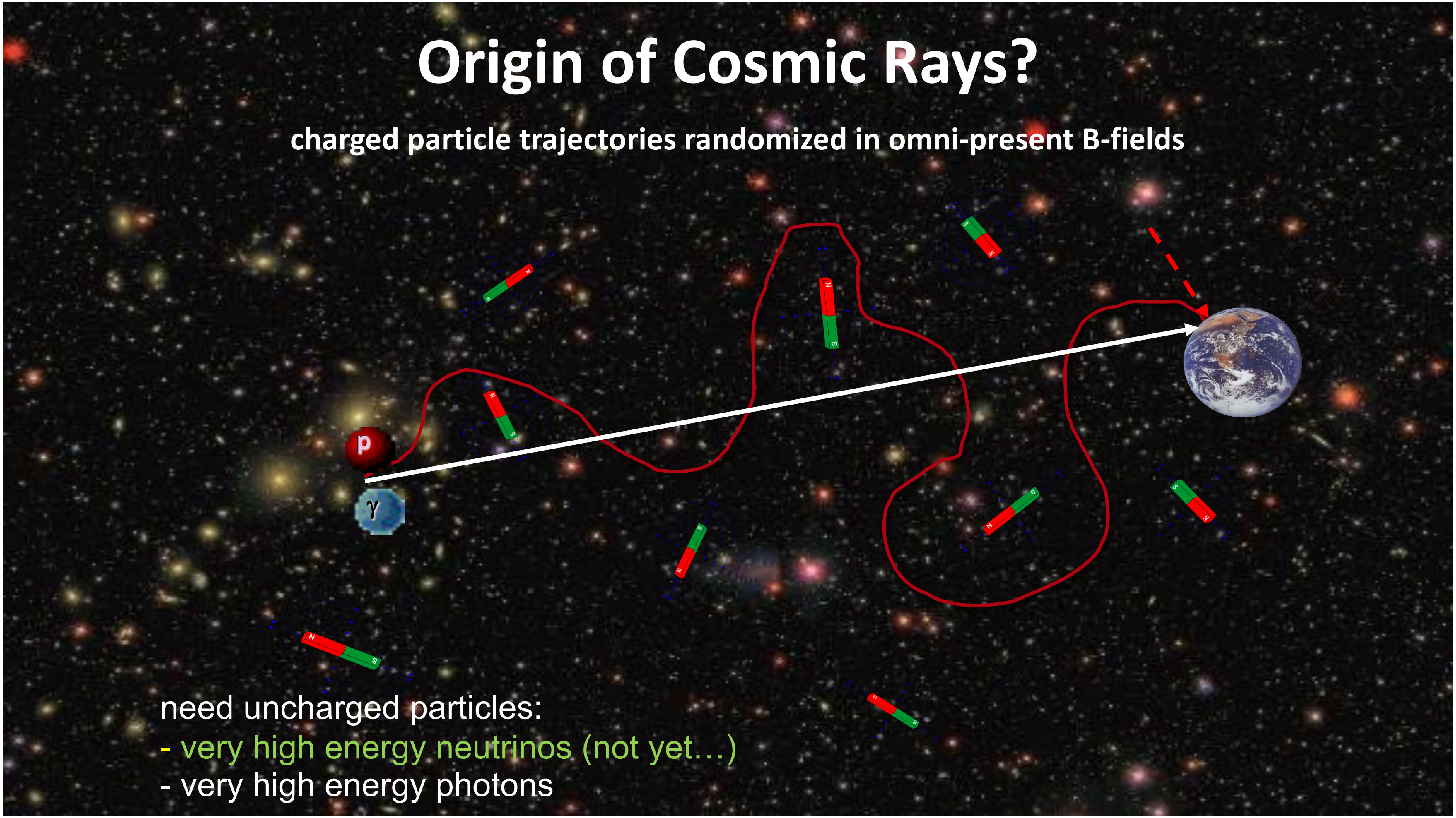


LHC beam

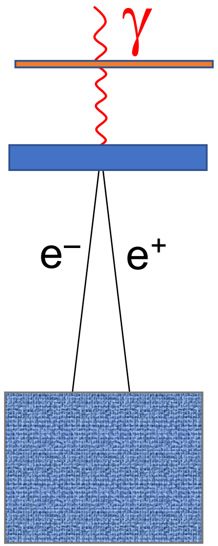


kinetic Energy concentrated in single proton




Origin of Cosmic Rays?
charged particle trajectories randomized in omni-present B-fields
p
γ
need uncharged particles:
- very high energy neutrinos (not yet…)
- very high energy photons

How to measure VHE photons?



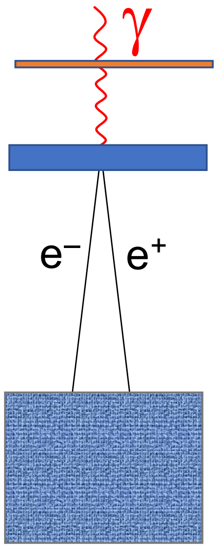
Anti-Coincidence
(filters out charged particles)

Converter foil
→ Pair Production

Tracker
(--> direction of γ)

Calorimeter
(--> energy of γ)

How to measure VHE photons?



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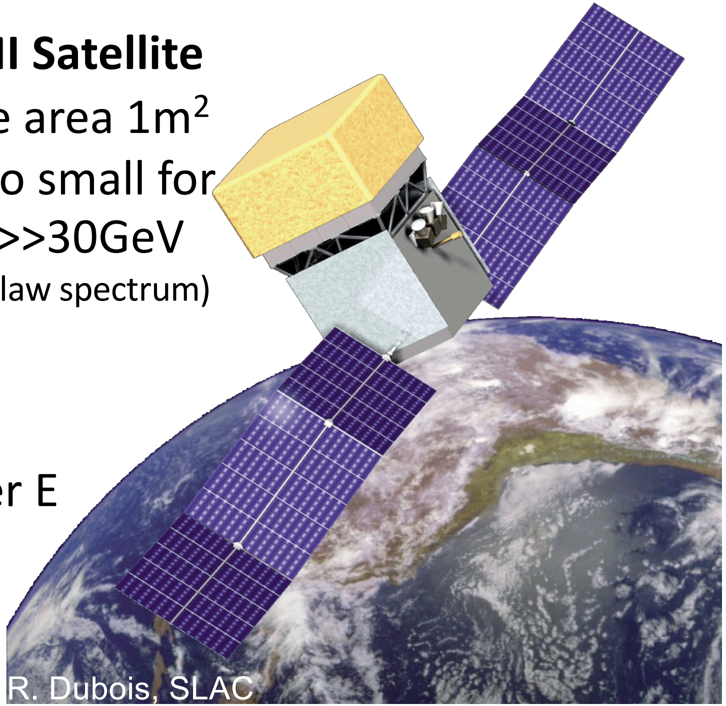
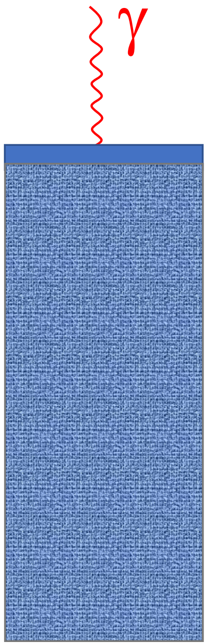
➔ **FERMI Satellite**
active area $1m^2$
➔ too small for
E >>30GeV
(power law spectrum)

➔
for higher E
must go
ground
based



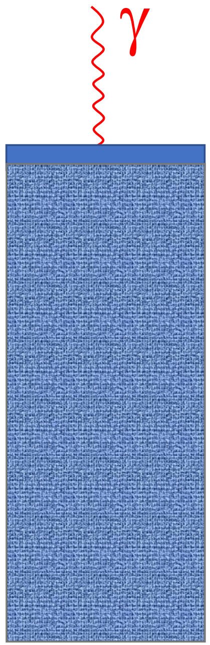
Ground Based VHE Measurement



Use Atmosphere
as Calorimeter

Ground Based VHE Measurement

electromagnetic shower: in average each rad.lenght R: pair-prod | Bremsstrahlung



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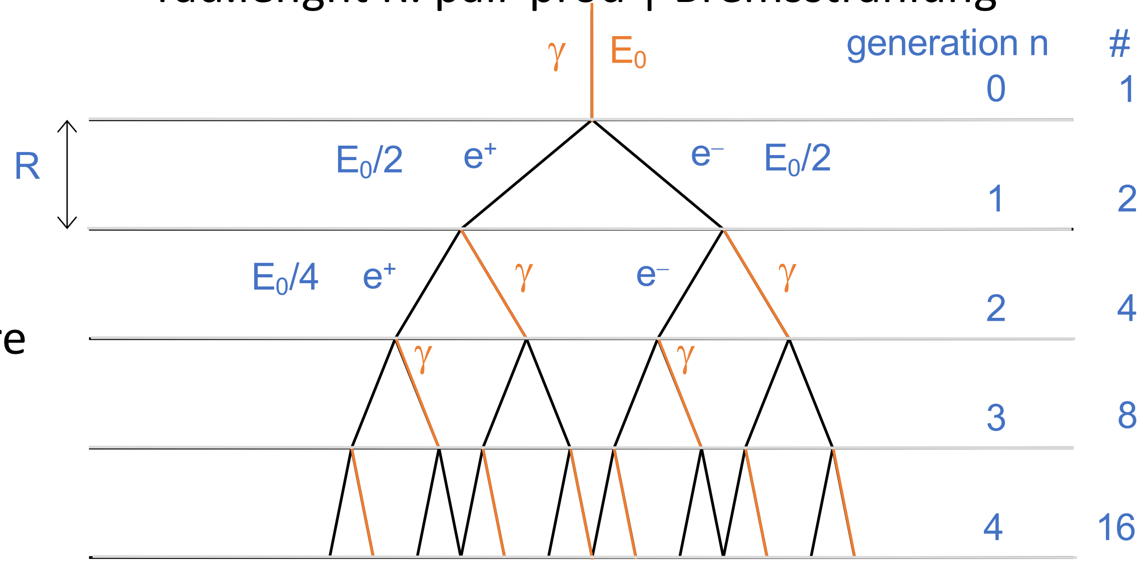


until E<80MeV (in atmosphere)

➔ E_0 < 1TeV: shower tail does not reach ground

Ground Based VHE Measurement

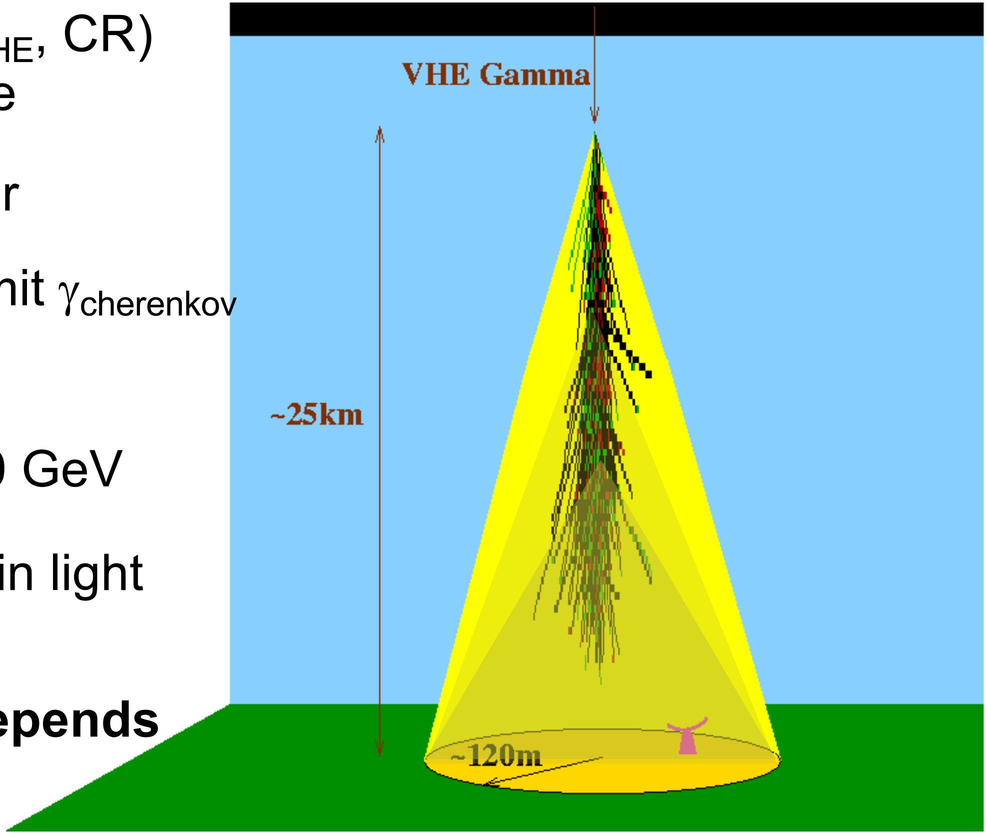
primary particle (γ_{VHE}, CR) enters atmosphere

produces air-shower

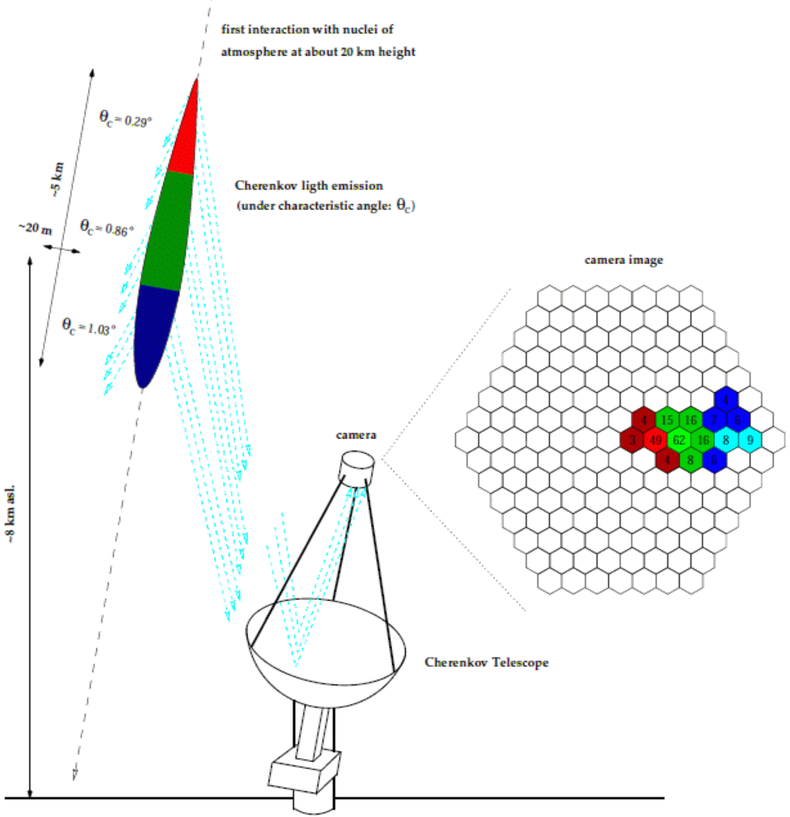
shower-particles emit $\gamma_{cherenkov}$
==> light pool:
Flash: ~1ns
~1γ_c/m^2 @100 GeV

detector anywhere in light pool sees shower

Emission angle depends on altitude



Cherenkov Telescope



Emission angle depends on altitude
➔ camera image represents
a sideway projection of
air shower

Several telescopes measure same shower ➔ better '3d reconstruction'

➔ direction (orientation of image) and energy (brightness of image) of primary VHE photon

Background I: identify air-shower images

each camera pixel:

~0.1deg field of view

➔ ~30MHz night-sky-background photons in dark night

(much more with bright star; >>20times more Fullmoon over horizon)

Cherenkov Flash:

~1 photon/m^2 per 100GeV ➔ need large mirror area

duration ~1ns ➔ need fast camera & single photon sensitivity

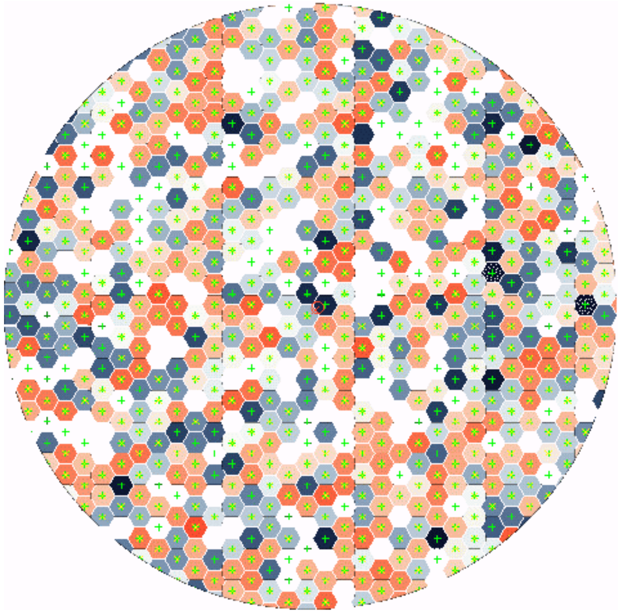
trigger on >30 clustered photons within few ns (30% photon sensitivity)

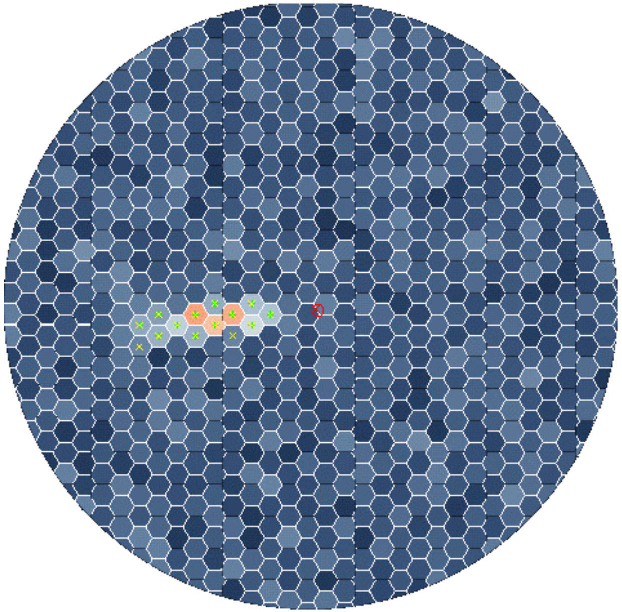
Background I: identify air-shower images

camera integration time:

10^{-6} seconds | 10^{-9} seconds

NSB Fluctuations





Cherenkov Flash

Background I: identify air-shower images

2GHz sampling:

2'000'000'000/s images taken

~2'000/s air shower candidates triggered ➔ event stored

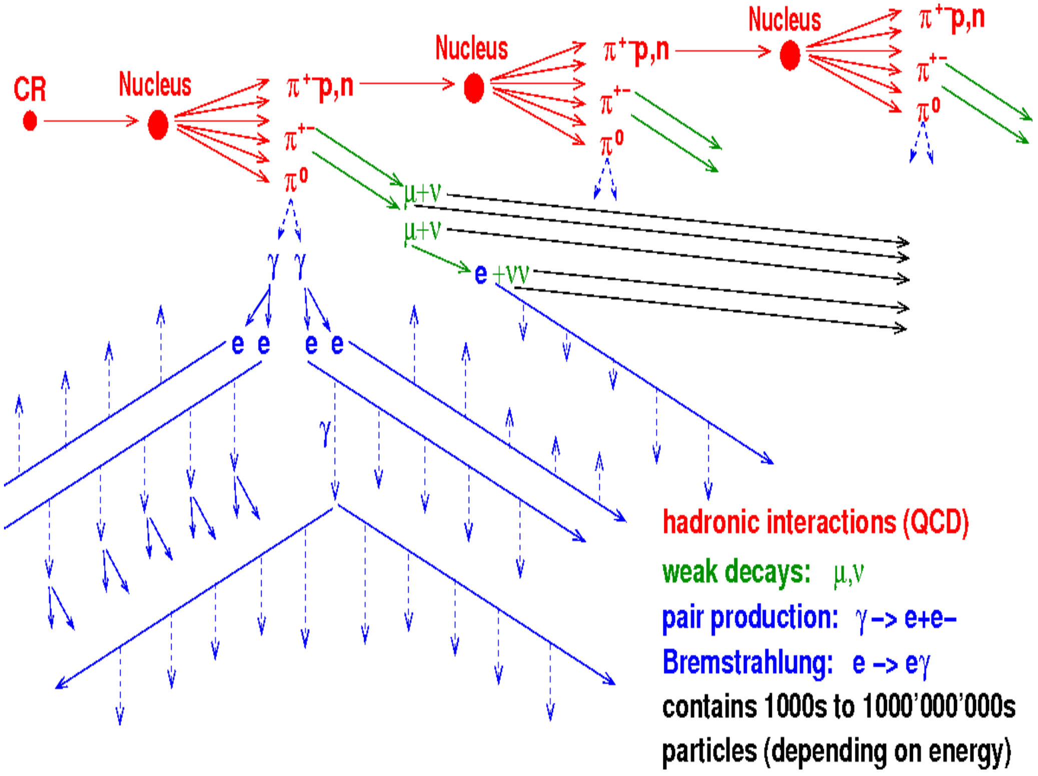
~1'000/s offline analysis confirms air shower

[rather simple, no ML necessary to deal with night-sky-background photons …]

~0.1/s VHE photon from brightest steady source?!?!

[vast majority of air showers due to charged Cosmic Ray particles ➔ use ML?]

air-shower induced by charged CR particle



far more complicated process than elm shower

(➔detection of e^+,μ^{+-},π^{0+-},K^+)

QCD processes cannot be calculated precisely

➔ air-shower images tend to look more fuzzy

➔ ideal for ML approach?

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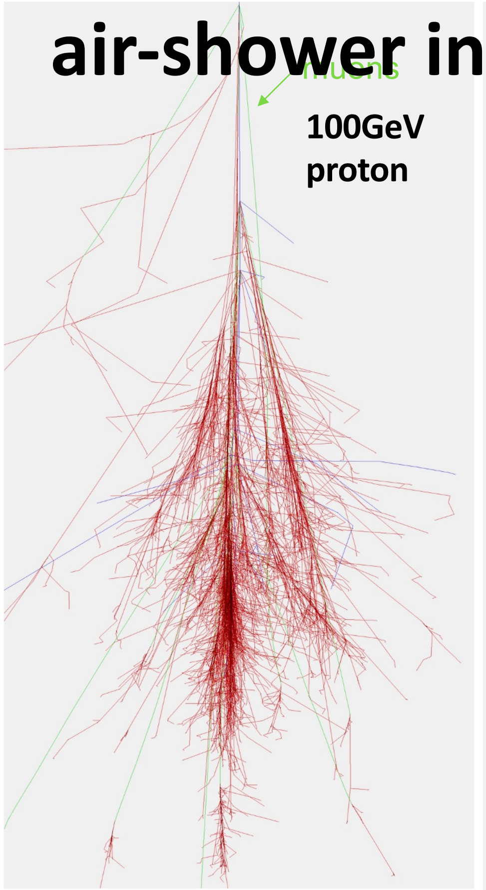

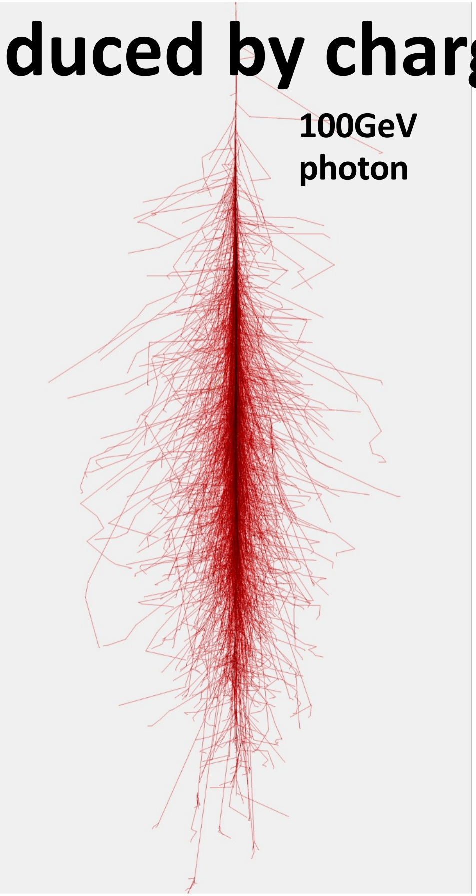

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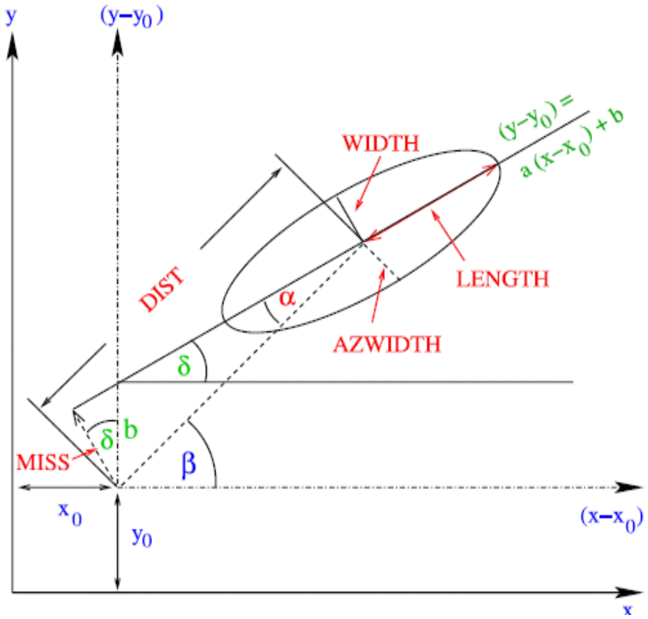
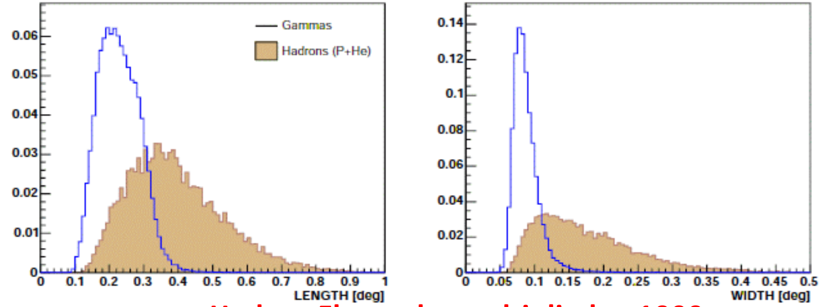
Background II: reject hadronic air-showers

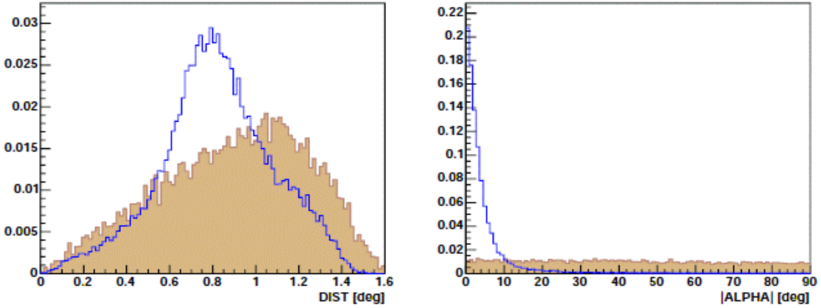
Hillas approach: parametrisation of shower image (ellipse)

cut to reject hadron events





Hadron Flux to be multiplied >>1000



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Today: ~20 parameters; multi-dimensional cuts
➔ 'random forrest' (boosted decision tree) for selection
[kind of tamed neuronal network]

Advantage: it works successfully since 20 years ☺
(opened a new field of Astronomy: far more galactic and extragalactic classes of objects than anybody dreamed of)

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Disadvantage: throw away huge amount of information in parametrisation

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'Detector systematics':

- zenith dependence (distance to shower and shower evolution)
- azimuth dependence (geomagnetic field affects shower evolution)
- source dependence (different starfield background)
- atmosphere dependence
    - temperature/density (affects shower evolution)
    - dust concentration (affects transmission of Cherenkov photons)
    - humidity/clouds (affects transmission of Cherenkov photons)
- telescope performance (dust on mirrors, ageing, …)

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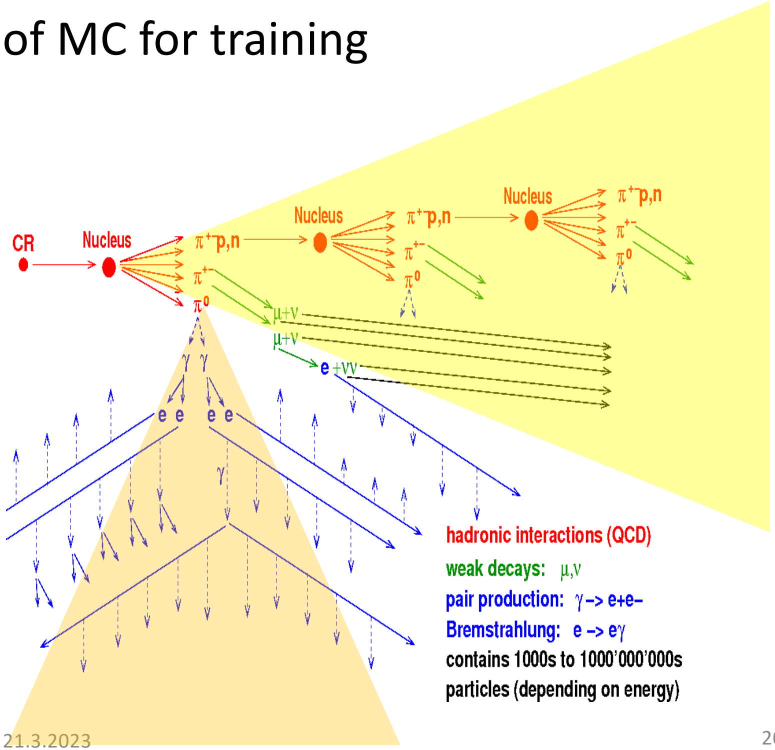
'rare background events':

- e.g. isolated pi0 producing
  isolated elm shower

➔ not enough computing power to produce sufficient (hadronic) MC events



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cunning idea: exists plenty of real hadronic data in archive
➔ use photon MC plus hadronic real data for training
(no clean sample of real photon signals exist)

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Experience: - many trials in the past 20 years;
- usually highly efficient on (MC) test-sample
- 'fail' on real data (i.e. worse than Hillas approach)
- but excellent in distinguishing MC vs. real data
  (➔ still some unknown parameters in MC …)

But we do not give up ☺ (yet)

General Personnel Remark

Key problem of (supervised) training:

we do not know on what (hidden) parameters the NN is basing its decision

➔ IMHO, many ML tasks will be highly successful (perfect training sample!)
If no perfect(!!!) training sample: approach bound to fail

Key problem: how to know if training sample is perfect ?

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My fear: due to many successful cases, people start to believe also the output in case the training sample is flawed …