Neutrino und Gammaastronomie Stichpunkte:

Abstract:

* Observe high energy cosmic rays (CR) through air showers in earth’s atmosphere
* Need: accurate air shower models -> challenge and test QCD models in extreme conditions
* Air showers: hadronic cascades (bild dazu) -> rise in muon component (final state)
* Muon number -> mass composition of cosmic ray
* Simulations show deficit versus measurements 🡪 that ist the muon puzzle!
* Model starts at TeV scale 🡪 am LHC beobachtbar
* Enhancement in strange hadron production observed in high density events -> maybe solution? -> more info needed from forward production processes and oxygen beam collisions

Introduction:

* Cosmic rays:

1. Fully ionised nuclei
2. Relativistic kinetic energies arriving at earth
3. Elements: protonen bis zu Eisen (vernachlaessigbarer anteil von schwererem zeugs)
4. Herkunft: unknown sources outside the solar system
5. 🡪 messengers oft he high energy universe

* Flux:
  + Total flux at the top oft he atmosphere dominated by protons (few GeV)
  + Differential flux J(E) is proportional to dN / DE is approx a power law (potenzfunktion) E^alpha (alpha = spektraler index)
  + Spektraler index von alpha=2.6 to compress large scales
  + Die energy range is huge (11 orders of magnitude in E, 30 orders in flux)
  + Covered by multiple experiments with differnent techniques
  + Isotropic -> charged and scattered through space by inhomogenous galactic and extra-galactic fields
  + Diffusive flow, random arrival directions
  + Angle of deflection decrease with more energy BUT, E > EeV: anisotropy
* Classification:
  + Highest E cosmic ray: 320 EeV = 3.2 x 10^11 GeV (1 EeV = 10^9 GeV)
  + Cosmic ray below 1 PeV = 10^6 GeV assumed to come from shock acceleration in super nova remnants (SNR)
  + Cosmic rays with higher than 1 PeV have unclear origins
  + “ higher than 1 EeV -> unknown extra-galactic origin
* Spectral flux bild mit heel und knee:
  + Steil abfallender flux mit E\_kin^2.6 scaliert
  + Offene symbole: air shower experimente messen „all particle cosmic ray flux“
  + Farbige symbole: flux of individual measurements from balloon and satelite gebundene experimente
  + Empirischer fit an die daten
  + Alles ueber 10^6 GeV („knee“) ist interessant -> elemental composition
  + Fig 2 left: ankle is shown and predictions of logarithmic masses fort hat range
  + 🡪 helps later to build detector fort he specific masses observed
  + 🡪 precise measurements can rule out many competing theories (whether CR at highest E are light or heavy is crucial)
  + Fig 2 right: 2 main features X\_max = depth of shower maximum, N\_mu = number of muons produced in the shower
  + X\_max = the number of secondary particles reaches a maximum at that height (between 2km and 7km altitude)
  + 🡪 good mass estimate since nearly all primariy particles have decayed to secondary particles which can be observed!
  + 🡪 large systematic uncertainties -> unsatisfying since N\_mu discriminates better than X\_max between light and heavy in EeV scale.
  + N\_mu theoretical uncertainty does not come from particle transport -> but from evolution of hadronic cascades that drives muon production
  + 🡪 cascade dominated by hadronic collisions with small momentum transfer 🡪 no good calculation with pertubative QCD 🡪 better generators in latest version
  + 🡪🡪 Result: generators predict lower muon number han observed!!
* Experiments to observe cosmic rays:
  + Bis 100 TeV: directly observed by space-based experiments
    - AMS-02
    - High-altitude balloons: CREAM
* Higher energies: no direct observation (flux too low)
* INSTEAD: ground based experiments with huge aperture (Pierre Auger Observatory and Telescope Array) used
* Observe CR indirect through air showers produced in atmosphere
* The muon discrepancy is called muon puzzle since authors were not able to resolve the discrepancy by parameter tuning.
* The required changes are not allowed from the existing data constraints therefore physical effect must be missing in the generators which acts on the soft hadronic interactions
* More puzzling: CR cms energy of first interaction with atmosphere is roughly 8 TeV.
  + Could be studied at LHC but was not observed yet! (more discrepancy into puzzle)
  + Answer: we have not looked at he right place
  + Solution: soft hadronic is at rapidty range of eta >= 2
  + 🡪 future: instrument LHCb to take a closer look because it is operated at: 2 < eta < 5
* N\_mu is very sensitive to energy fraction carried away by photons coming from pi^0 decays (explained in 2.2, 2.8)
* 🡪 ALICE experiment saw universal enhancement of strangeness production therefore less pions in mid-rapidity range
* Previously only in heavy ion collisions
* 🡪 this might be a hint to the puzzle
* Question: ist he universal enhancement of final state strangeness in the forward region as well? 🡪 yes, there is already data which can be studied
* Solving the muon puzzle could have huge impact on astroparticle physics.
* 🡪 reduce size of N\_mu bands by factor of 2.5 to 4 depending on energy (Fig2 right)
* 🡪 resolve ambiguity of cosmic ray mass composition at EeV level
* 🡪 improve the generators and increase accuracy of CR mass composition, as well as make lepton fluxes more precise which ist he main background for IceCube!
* Modern air shower detection:
  + Fully characterize by CR-mass A and energy E and arrival direction phi, theta
  + Energy = number of particles produced in atmosphere
  + Mass = longitudinal evolution oft he shower and number of MUONS!
  + Ground based telescopes duty cycle nearly 100%
  + Nearly no chance to miss also the muons produced
  + Muons with E = 10 to 100 GeV come from last stage of showers
* What do you need to measure the discrepancy?
  + Simultanous measurement of shower energy E and X\_max (must be observed independently)
  + With that measure:
    - CR mass
    - Lateral muon density at ground = rho\_mu(r)
    - 🡪 integrate to get N\_mu
    - Lateral density depends on
      * Energy E and mass M, zenith angle theta, and shower age (slant depth)
* Muon puzzle and connected challenges:
  + Many experiments utilized to increase experimental significance
    - Pierre Auger Experiment
    - IceCube Neutrino Observatory
    - Telescope Array
    - Akeno Giant Air Shower Array (AGASA)
    - Yakutsk Array
    - SUGAR Array
    - KASCADE-Grande experiment
    - NEVOD-DECOR experiment
* These form Working group of Hadronic Interactions and Shower Physics (WHISP)
* Observation of muon discrepancy:
  + Arbitrary z-scale: z = (ln<N\_mu> - ln<N\_mu>\_p) / (ln<N\_mu>\_Fe - ln<N\_mu>\_p)
    - <N\_mu> = muon number
    - <N\_mu>\_{p, Fe} = from simulated air showers undergone full detector simulation -> reduce biases
    - Z range is [0, 1]
* Results connected to puzzle:
  + Refers to deficit in GeV muons from end of cascades in simulation
  + Other discrepancies found:
    - Shower-to-shower fluctuations in N\_mu
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