Mass composition studies of cosmic rays with muons & experiences with the DDAp

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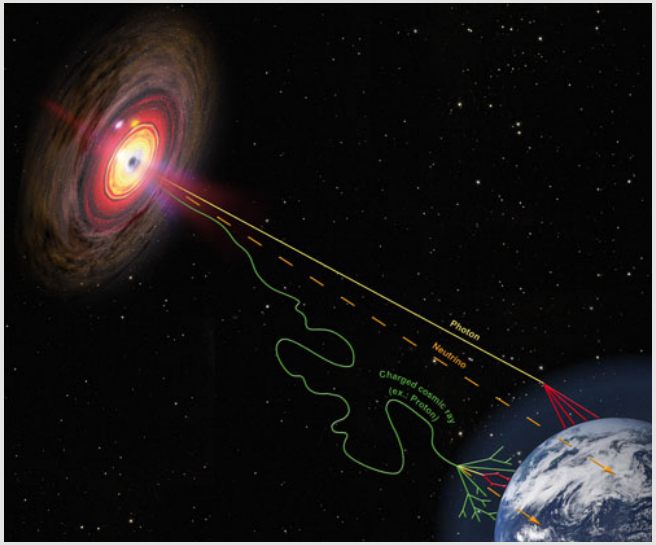
Origin of Cosmic Rays



- Particles accelerated at astrophysical sources
- Which sources?
- Transition from galactic to extra-galactic?
- Propagation effects?

How to find out experimentally

- Energy distribution of CRs
- Elemental composition
- Arrival directions

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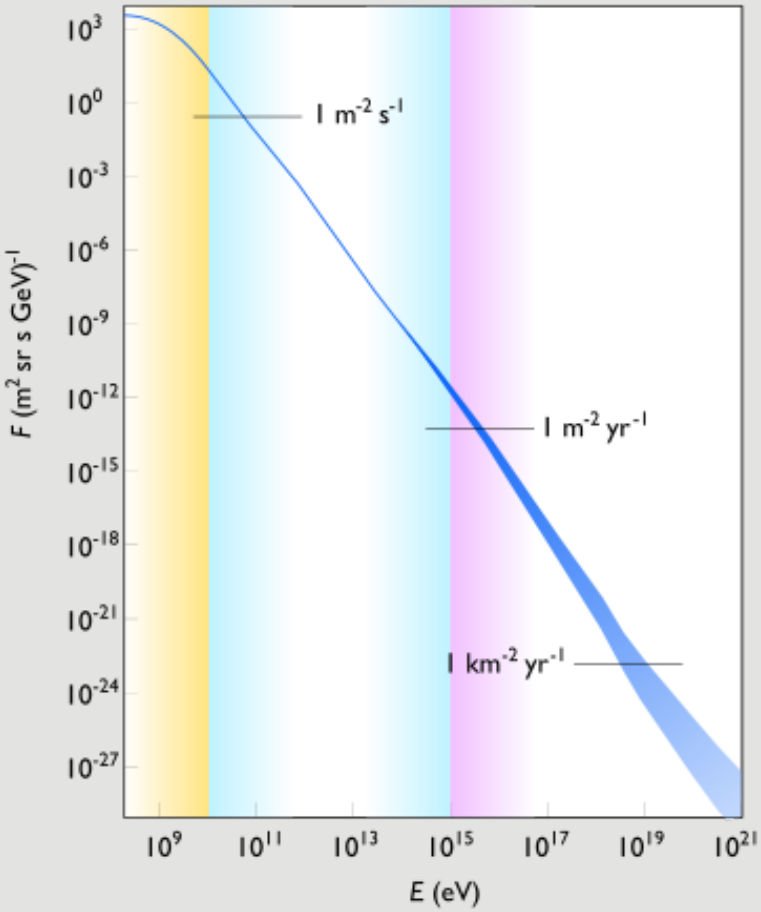
Detection of Cosmic Rays

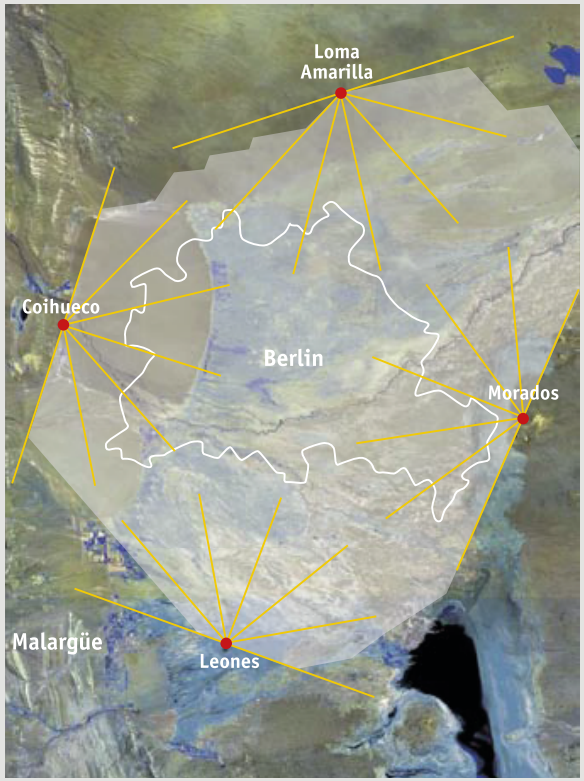
Low energies

- direct detection of cosmic rays



High energies

- measurement of air showers at earth



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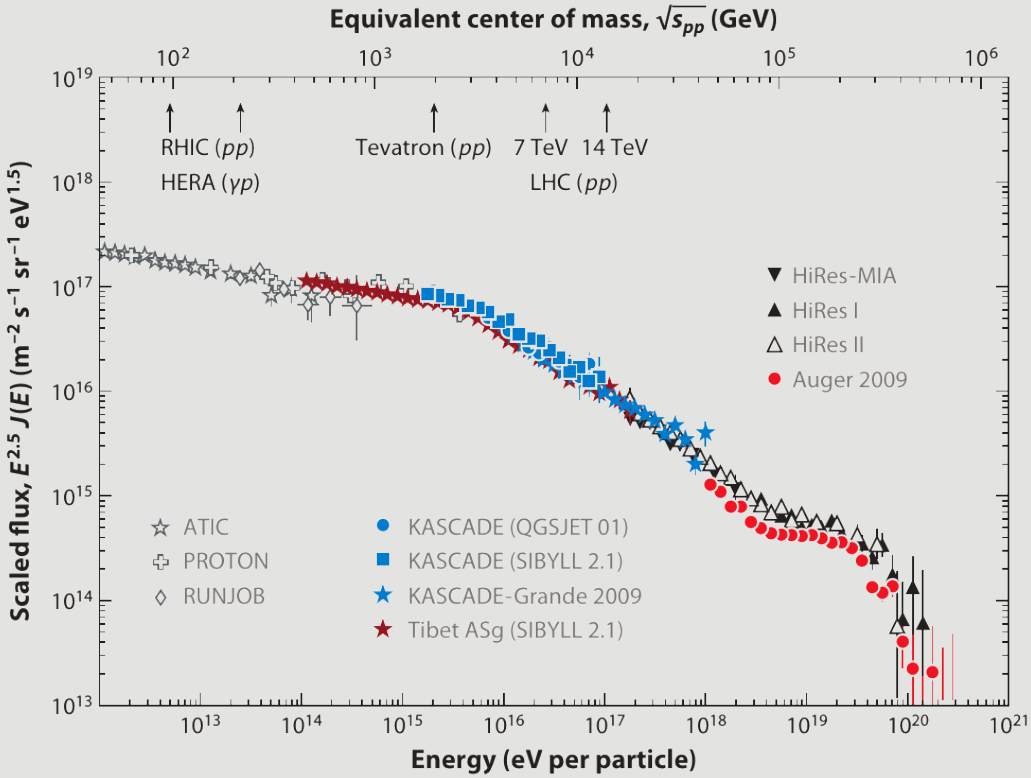
Energy Spectrum



- $E \leq 10^{14}\,\mathrm{eV}$: acceleration in galactic SNRs (favored interpretation)
- $10^{14}\,\mathrm{eV} < E \leq 10^{17}\,\mathrm{eV}$ ("knee"): acceleration limit of galactic SN?
- $E > 10^{17}\,\mathrm{eV}$ ("ankle"): transition to extra-galactic CRs?

$\Rightarrow$ Experimental check: Elemental composition of CRs

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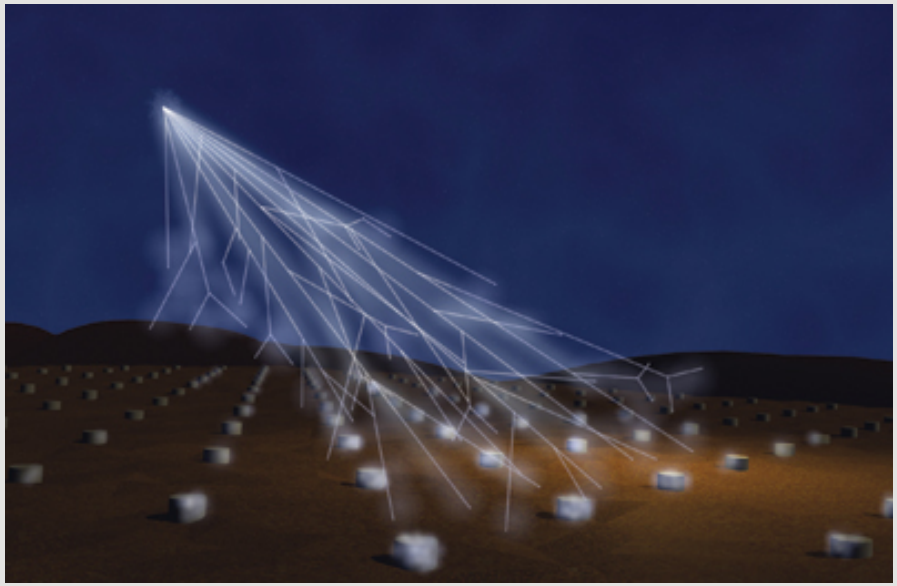
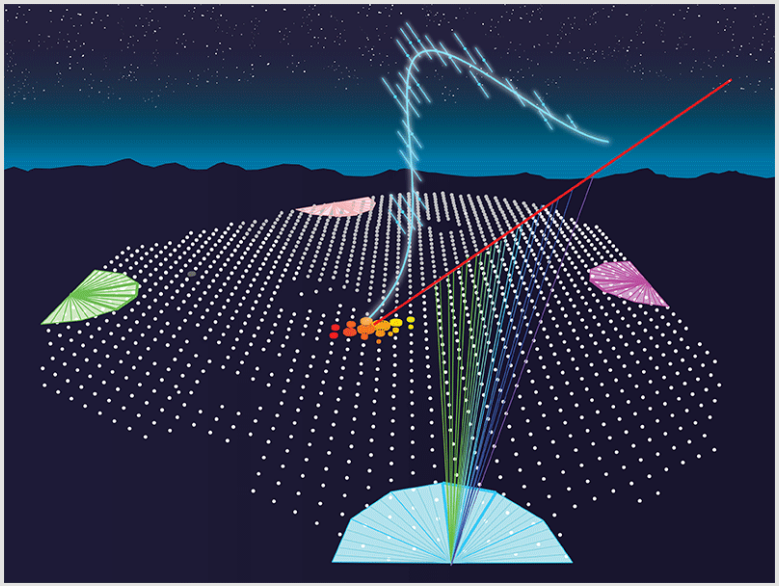
Measurement of High Energy CRs





- Primary CR produces particle cascade in atmosphere
- Signal: footprint on ground & development in atmosphere

Def.: Depth of Shower Maximum X_{max}

- X denotes atmospheric column density
- X_{max}: density where number of particles is maximal

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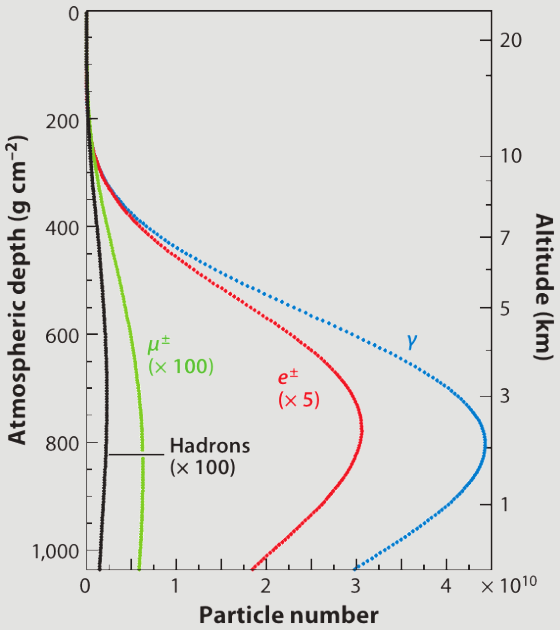
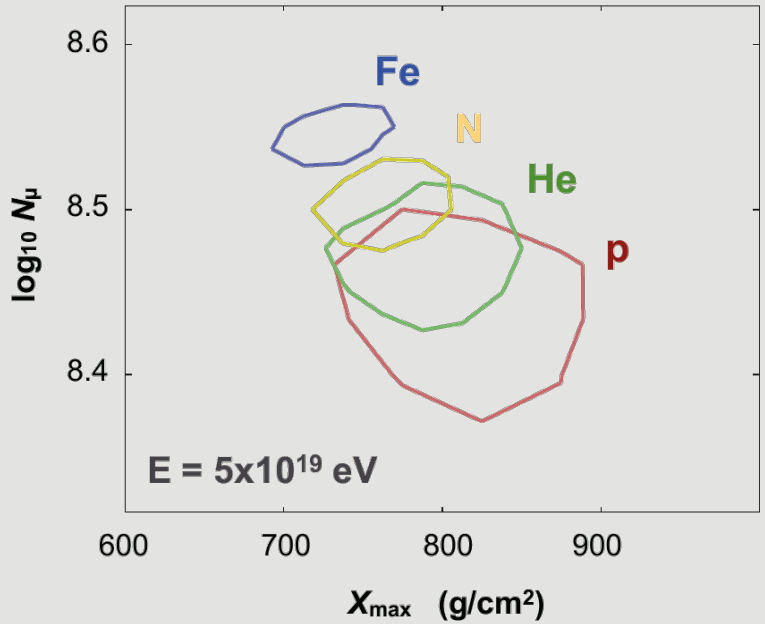
Separation of Light and Heavy Primaries





- Light CRs (p): Deep showers (large $X_{\max}$) with few muons
- Heavy CRs (Fe): High showers (small $X_{\max}$) with many muons

Superposition model

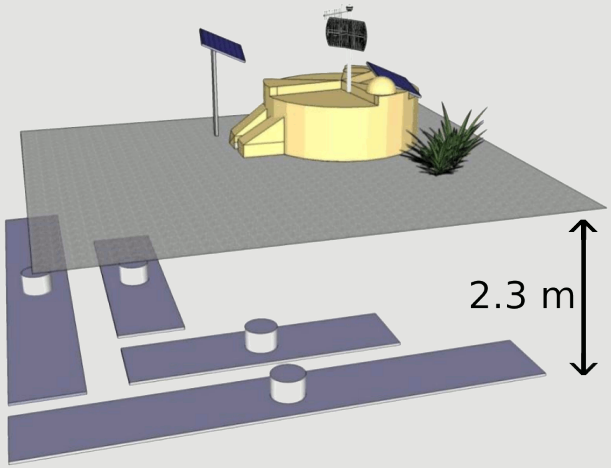
Nucleus of mass $A \approx A$ independent nucleons with $E_h = E_0/A$

Upgrade of Pierre Auger Observatory

Muon measurements with

- Scintillation detectors on top of each water-Cherenkov detector
- Buried scintillation detectors (AMIGA) as direct verification

⇒ Energy thresholds of few tens of Mev to 1 GeV



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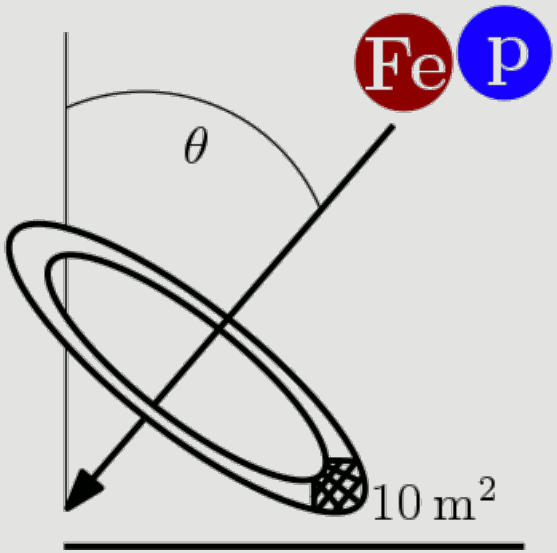
Simulation Study

How does the energy threshold of muon detectors influence the separability of primaries?



Shower library

- p & Fe primaries (115 unthinned showers each)
- $E = 3.16 \times 10^{18}\,\mathrm{eV}$
- $\theta = 38°$, ϕ random

- Ideal muon detectors in shower plane
- Account for detection fluctuations by resampling "true" N_μ:

$$P_\lambda(k) = \frac{\lambda^k}{k!} e^{-\lambda}, \quad \lambda = \rho_\mu A = N_\mu \qquad \text{(Poisson)}$$

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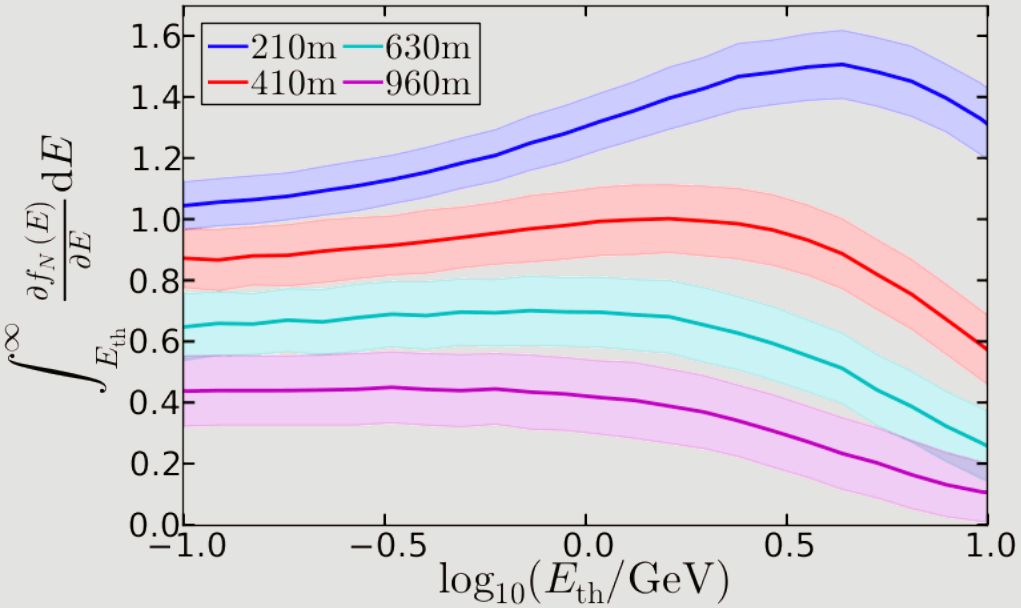
Threshold Dependence of Separability



$$f_N = \frac{\overline{N}_{\mathrm{Fe}} - \overline{N}_{\mathrm{p}}}{\sqrt{\sigma^2_{N,\mathrm{p}} + \sigma^2_{N,\mathrm{Fe}}}}$$

Best separability at small core distances for $E_{\mathrm{th}} \approx 4\,\mathrm{GeV}$?!

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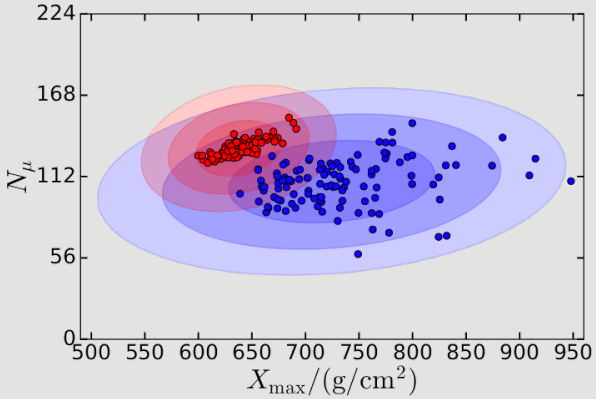
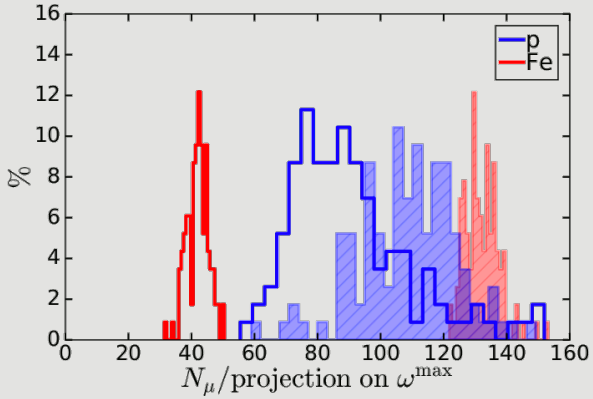
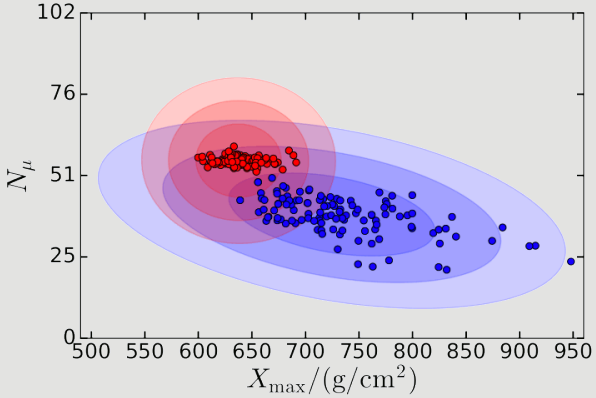
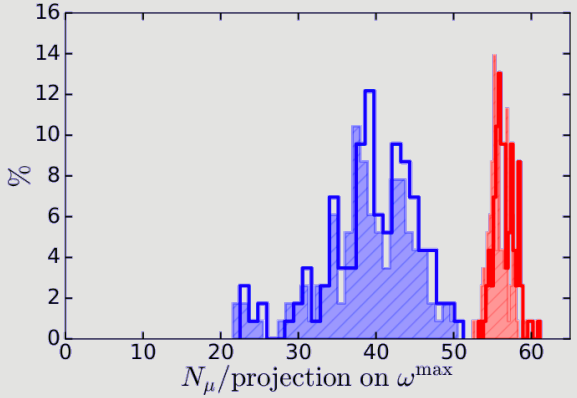
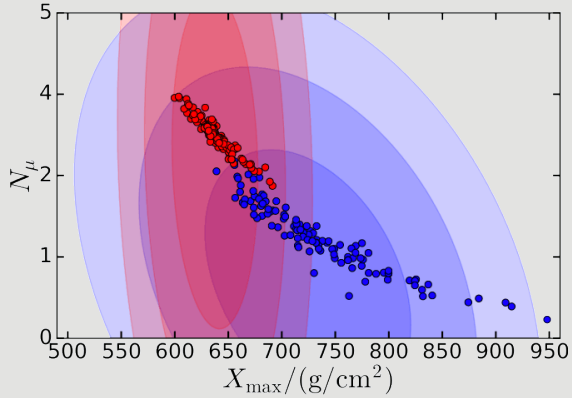
$N_\mu - X_{\max}$ ($r = 210\,\mathrm{m}$)

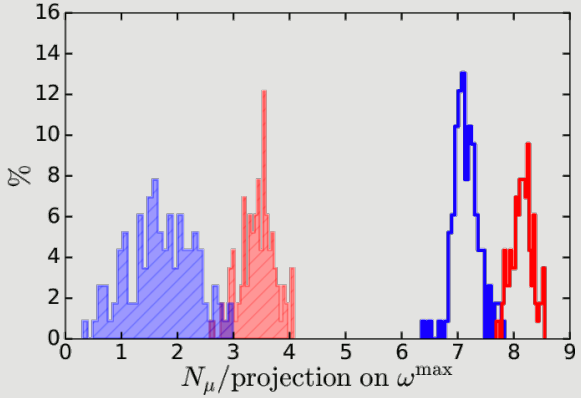












- $E_{\mathrm{th}} = 0.1\,\mathrm{GeV}$: overlapping muon number distributions
- $E_{\mathrm{th}} = 4\,\mathrm{GeV}$: clear separation
- $E_{\mathrm{th}} = 26\,\mathrm{GeV}$: small overlap, large fluctuations

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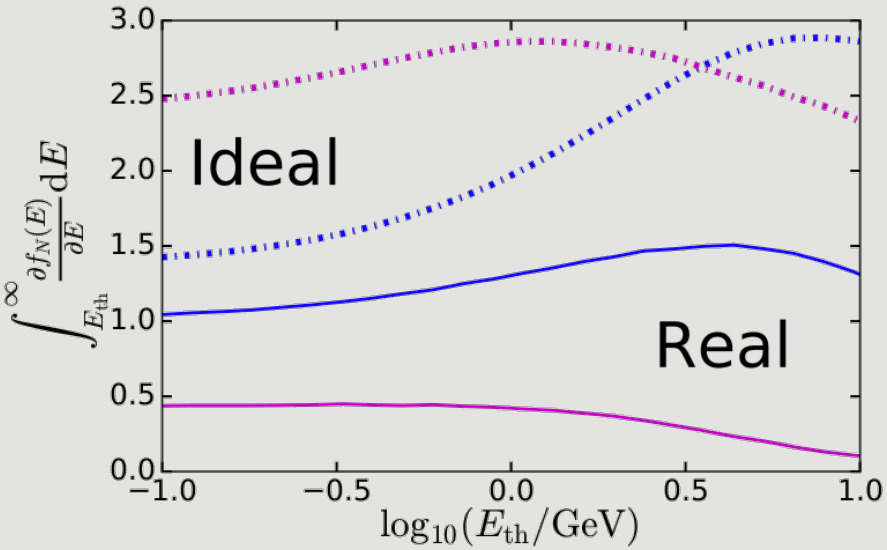
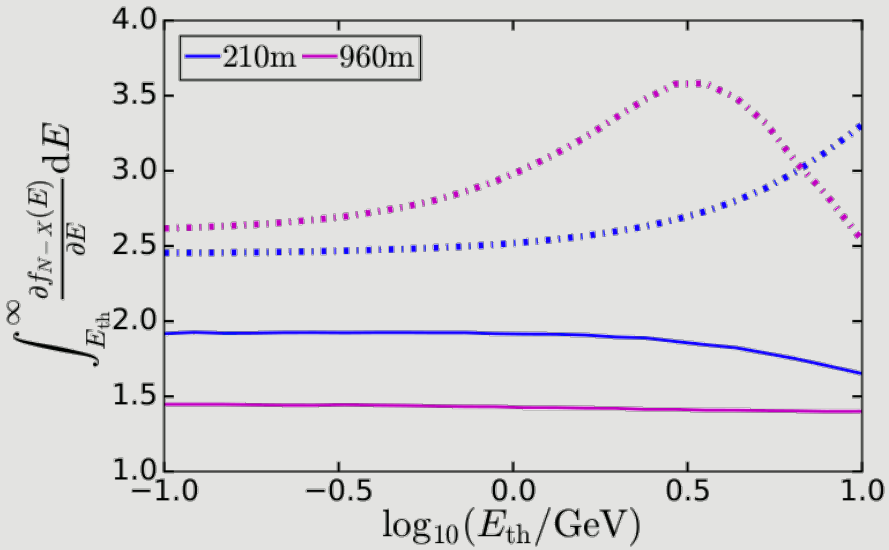
Effect of Detection Fluctuations



Separability based on N_μ



Separability based on $N_\mu - X_{\rm max}$

- Ideal: high thresholds and large core distances favored
- Real: detection fluctuations worsen separability for large r or $E_{\rm th}$
- Threshold dependence of separability still visible for small r

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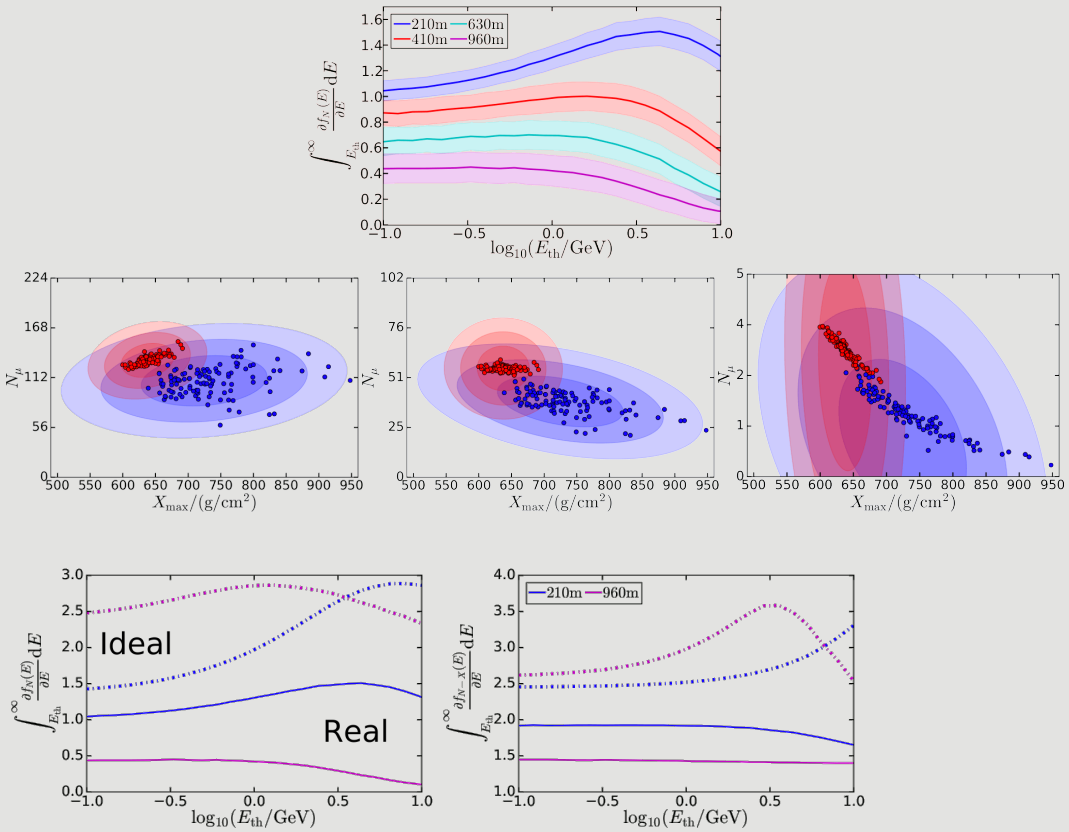
Questions?

- Best separability for threshold $E_{\mathrm{th}} \approx 4\,\mathrm{GeV}$?!
- Change of $N_\mu - X_{\mathrm{max}}$ correlation with E_{th}
- Fluctuations reduce effect, however still noticeable for small r



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2 Double Degree program in Astrophysics

Combine two doctoral programs

Doctorado en Astrofísica

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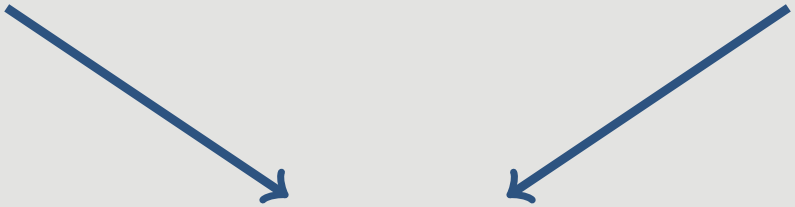
newly created for the DDAp,
directed together with KIT

Doktor in Physik

KIT
Karlsruhe Institute of Technology

already existent program,
integrated into KSETA



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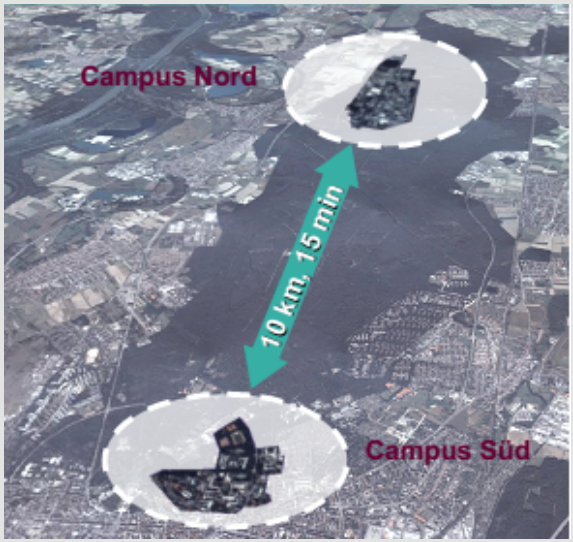
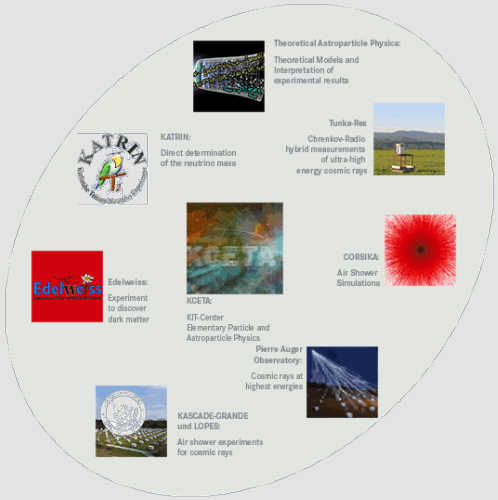
Karlsruhe Institute of Technology

- Merge of university & national large scale research center
- 25000 students, 6000 scientists
- Astroparticle research at the Institute for Nuclear Physics (IKP)





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Universidad Nacional de San Martín

- Public university
- Established 1992
- 22000 students

- Astroparticle research at

ITeDA Instituto de Tecnologías en Detección y Astropartículas

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Program Overview

- Co-supervised scientific research
- 2 stays of at least 12 months at other place
- Complementary lectures in physics & language courses

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Typical Plan of a PhD Student

Choose **joint scientific topic**

Exemplary schedule (for German participants)		
Orientation, start with scientific work	1/2 year at KIT	(Germany)
	1/2 year at UNSAM	(Argentina)
Scientific work on topic	1 year at KIT	(Germany)
	1/2 year at UNSAM	(Argentina)
Finish thesis	1/2 year at KIT	(Germany)

Lectures (20 credits)

↓

Defense with joint final examination

↓

Doctoral degree of both universities

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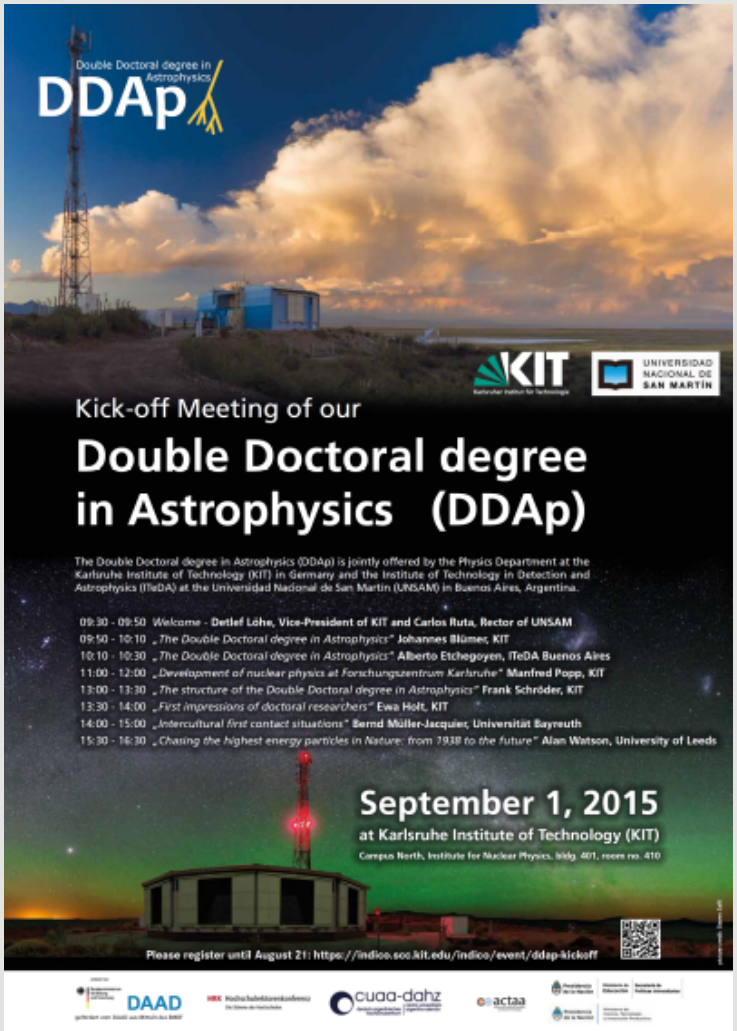
Inauguration of the Program



- 2012 first individual “cotutelle”
- 2014 first participants at KIT
- 2015 first participants at UNSAM
- May 2015 Kick-Off at UNSAM
- September 2015 Kick-Off at KIT

Supported by

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deutsch-argentinisches hochschulzentrum | centro universitario argentino-alemán

DAAD
Deutscher Akademischer Austausch Dienst
German Academic Exchange Service

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

HRK Hochschulrektorenkonferenz
Die Stimme der Hochschulen

actaa
Asociación Argentino-Alemana de Ciencia y Tecnología

Presidencia de la Nación | Ministerio de Ciencia, Tecnología e Innovación Productiva

Presidencia de la Nación | Ministerio de Educación | Secretaría de Políticas Universitarias

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DDAp Participants

Karlsruhe Institute of Technology

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Ewa H. Sarah M.
David S. Álvaro T.

Nico G. Ana B. Johan H.
Gaia S. Ana M. Matías P.

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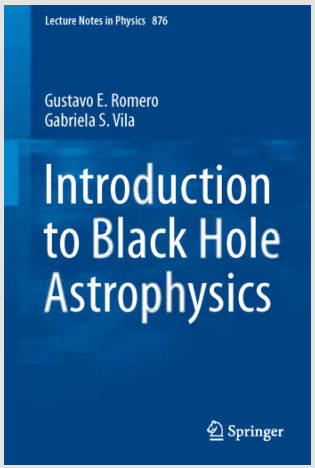
DDAp Lectures

Lecturers from UNSAM/KIT come for 1-2 weeks to KIT/UNSAM

- G. Romero: Introduction to Black-Hole Astrophysics (2015, KIT)
  Scientific Philosophy (2016, UNSAM)
- E. Roulet: Neutrino Astrophysics (2016, KIT)
- D. Zeppenfeld: Particle Physics at Colliders (2016, UNSAM)
- S. Mollerach: Cosmology and Statistical Methods (2016, KIT)



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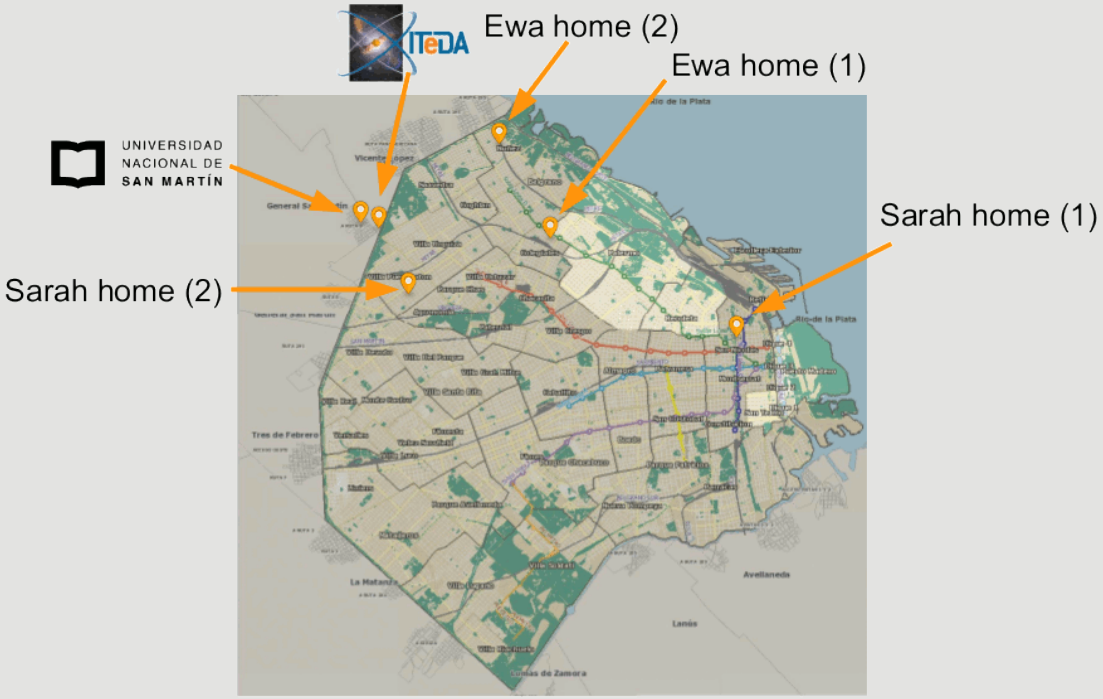
Buenos Aires - Home and Work



- Organizational and financial support with apartments (& everything else)
- 1st stay: 45 min/1.15 h to work
- 2nd stay: much nearer :)

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ITeDA Institute

$\sim$ 60 staff, technicians, doctoral researchers, students, ...

institutes leader
Alberto Etchegoyen

supervisor
Federico Sanchez

- Office with other doctoral researchers
- Group meeting every week
- Lunch together at cantine

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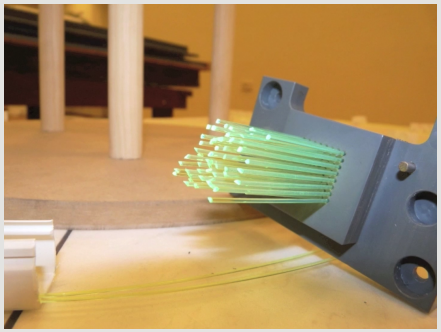
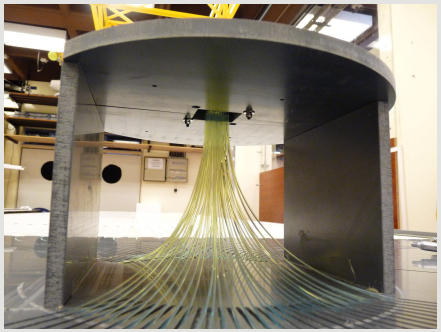
Muon Detectors @ ITeDA

- Development of AMIGA muon detectors
- Design of analysis software
- Data analysis





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Language & Culture

Thanks for your attention!

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