Tunka-Rex:
Radio Detection of Air Showers

Frank G. Schröder
for the Tunka-Rex Collaboration

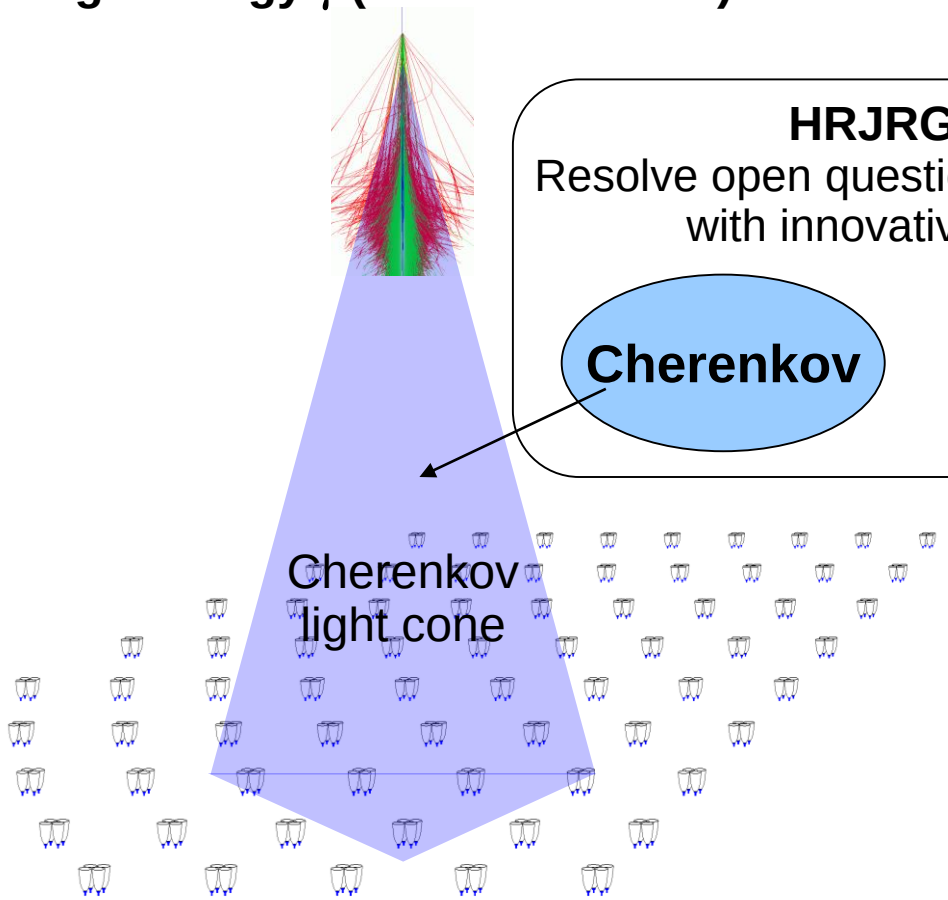
Karlsruhe Institute of Technology (KIT), Institut für Kernphysik, Karlsruhe, Germany

High energy γ (GeV / TeV / PeV):

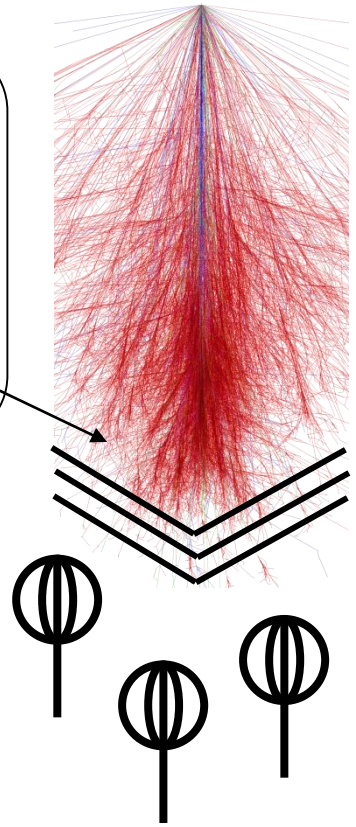
Ultra-high energy CR (PeV - EeV):

HRJRG-303:
Resolve open questions of cosmic rays with innovative methods

Cherenkov | **Radio**



HiSCORE



Tunka-Rex

Tunka-Rex

- Funding
  - 2012 –15: HRJRG
  - 2016 –17: DFG + Russia
  - HAP *iProgress*

Tunka-Rex Collaboration

P.A. Bezyazeekov[a], N.M. Budnev[a] , O. Fedorov[a], O.A. Gress[a], A. Haungs[b], R. Hiller[b], T. Huege[b], Y. Kazarina[a], M. Kleifges[c], E.E. Korosteleva[d], D. Kostunin[b], V. Kungel[b], O. Krömer[c], L.A. Kuzmichev[d], N. Lubsandorzhiev[d], R.R. Mirgazov[a], R. Monkhoev[a], E.A. Osipova[d], A. Pakhorukov[a], L. Pankov[a], V.V. Prosin[d], G.I. Rubtsov[e], F.G. Schröder[b], R. Wischnewski[f], A. Zagorodnikov[a] - Tunka-Rex Collaboration

[a] Institute of Applied Physics ISU, Irkutsk, Russia
[b] Institut für Kernphysik, Karlsruhe Institute of Technology (KIT), Germany
[c] Institut für Prozessdatenverarbeitung und Elektronik, KIT, Germany
[d] Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
[e] Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
[f] DESY, Zeuthen, Germany

Tunka-Rex Journal Papers

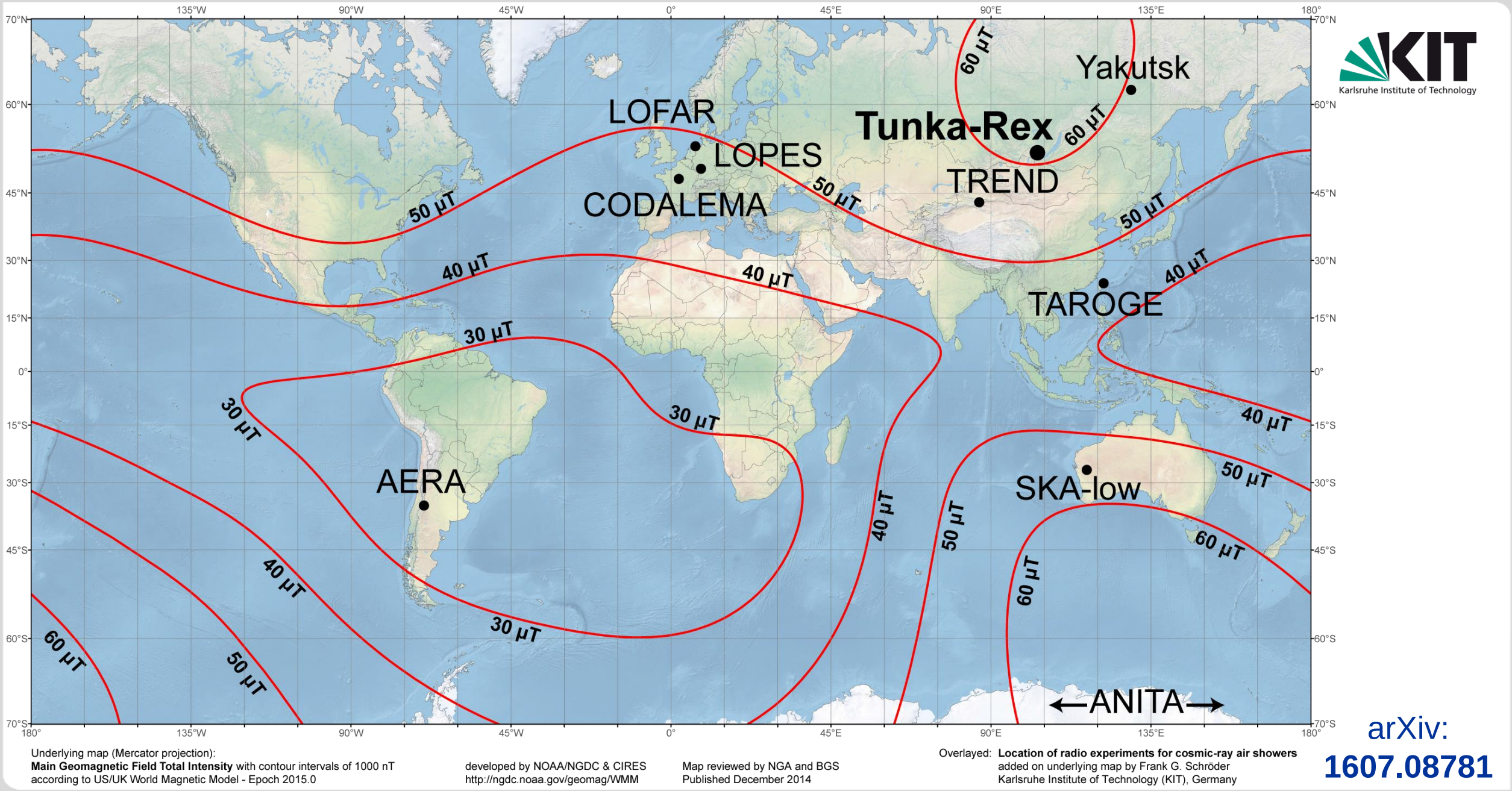
Measurement of cosmic-ray air showers with the Tunka Radio Extension (Tunka-Rex)
P.A. Bezyazeekov et al. - Tunka-Rex Collaboration,
Nucl. Instr. and Meth. A 802 (2015) 89-96

Reconstruction of air-shower parameters for large-scale radio detectors using the lateral distribution
D. Kostunin, et. al (short authorlist),
Astropart.Phys. 74 (2016) 79-86

Radio measurements of the energy and depth of maximum of cosmic-ray air showers by Tunka-Rex
P.A. Bezyazeekov et al. - Tunka-Rex Collaboration,
JCAP 01 (2016) 052 – *open access*

A comparison of the cosmic-ray energy scales of Tunka-133 and KASCADE-Grande via their radio extensions Tunka-Rex and LOPES
Tunka-Rex + LOPES Collaborations,
submitted to PLB

frank.schroeder@kit.edu
Institut für Kernphysik



Underlying map (Mercator projection):
Main Geomagnetic Field Total Intensity with contour intervals of 1000 nT
according to US/UK World Magnetic Model - Epoch 2015.0

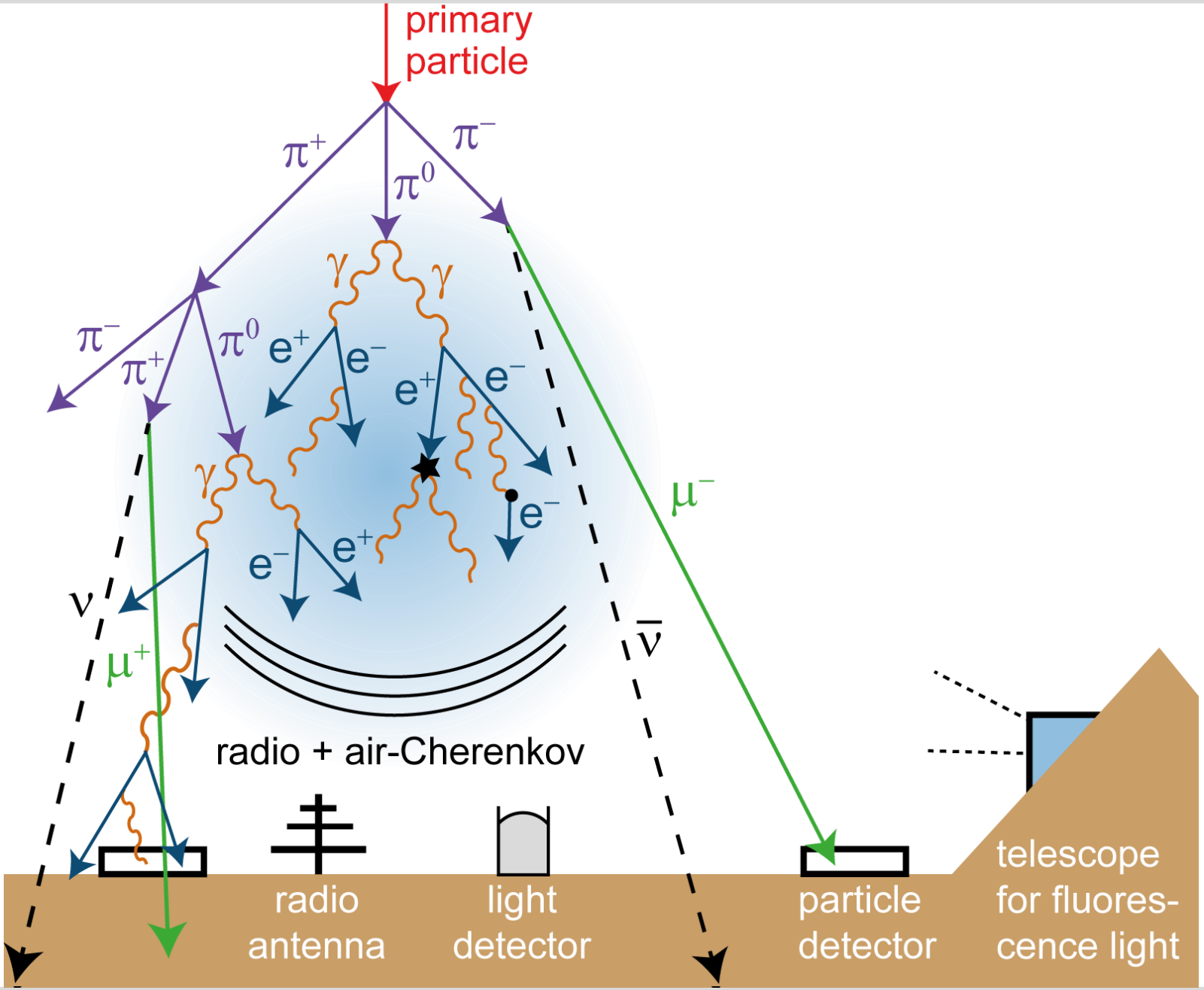
developed by NOAA/NGDC & CIRES
http://ngdc.noaa.gov/geomag/WMM

Map reviewed by NGA and BGS
Published December 2014

Overlayed: **Location of radio experiments for cosmic-ray air showers**
added on underlying map by Frank G. Schröder
Karlsruhe Institute of Technology (KIT), Germany

arXiv:
1607.08781

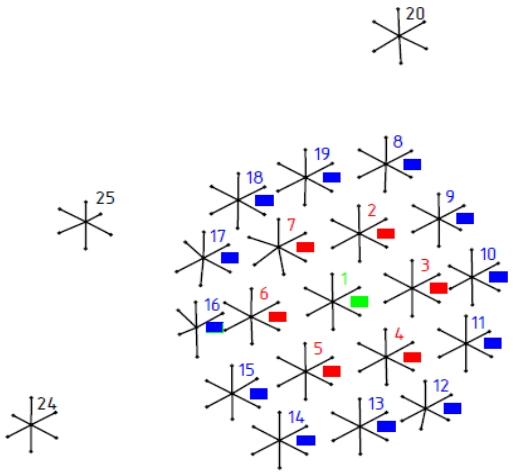
frank.schroeder@kit.edu
Institut für Kernphysik

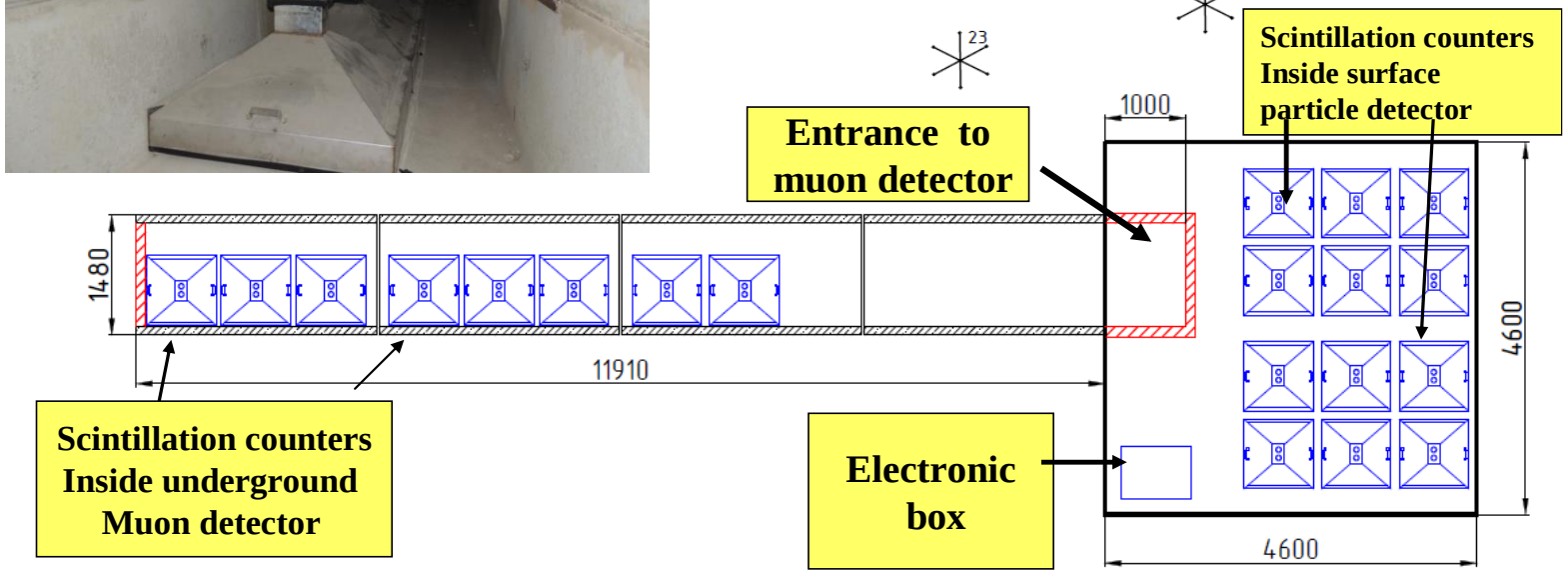


arXiv:
1607.08781

frank.schroeder@kit.edu
Institut für Kernphysik

Tunka-133 and Tunka-Grande at TAIGA



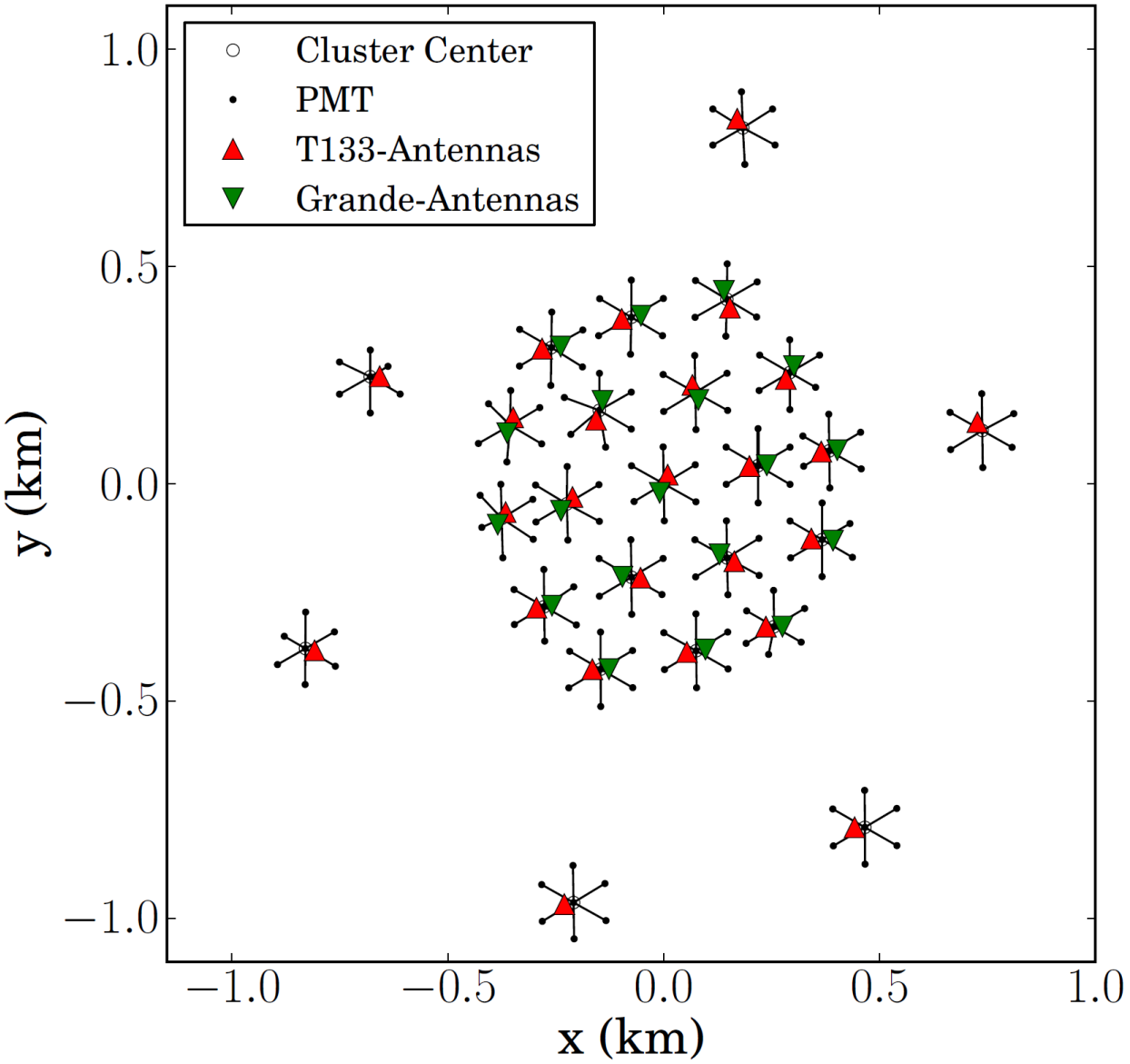


- Cosmic Rays
  - Tunka-133
  - Tunka-Grande
  - Tunka-Rex
- Gamma Rays
  - HiSCORE
  - IACT
  - Muon detectors as veto

ECRS 2014
Tunka Coll.

frank.schroeder@kit.edu
Institut für Kernphysik

Layout of Tunka-Rex

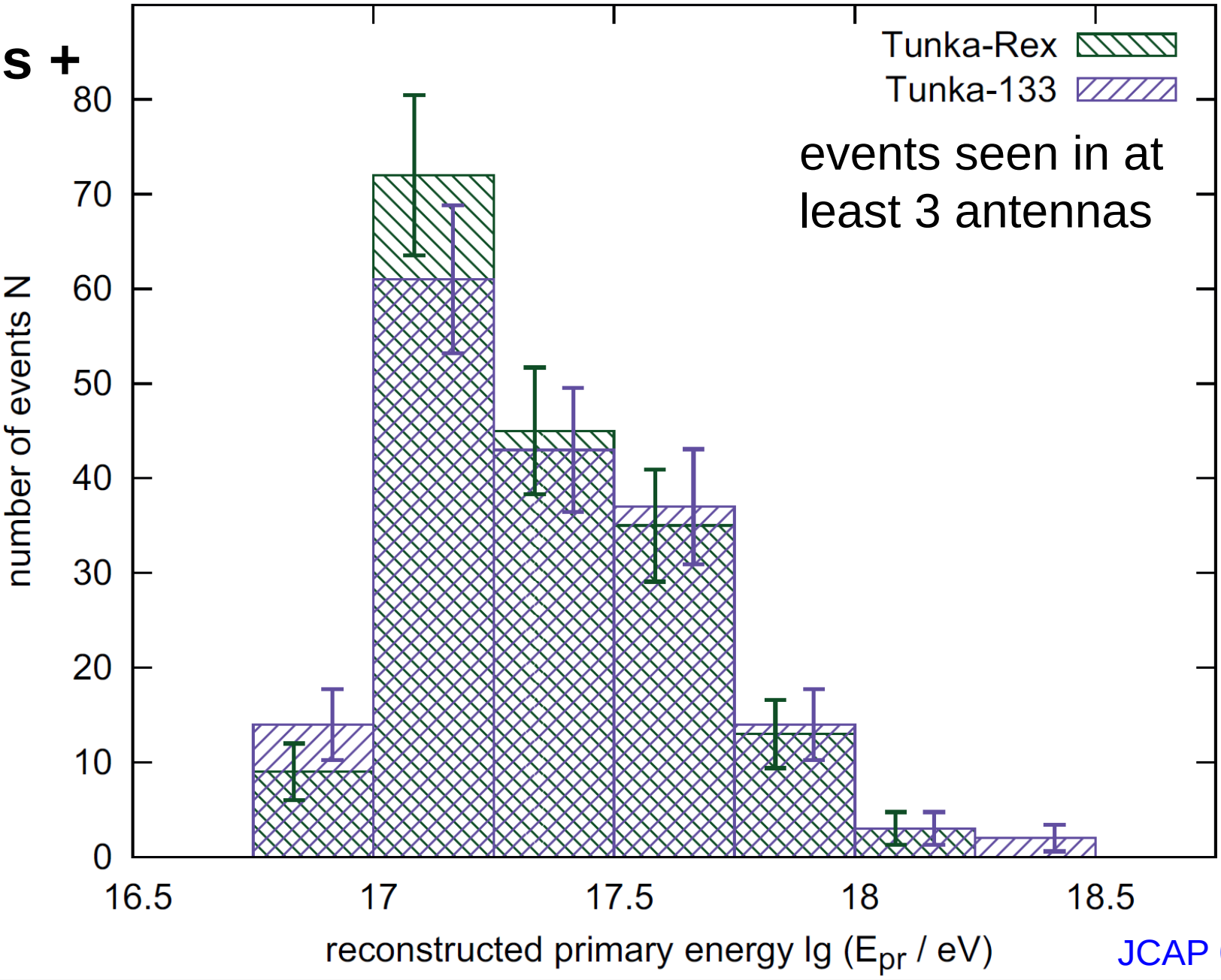


- Array layout
  - 200 m spacing in 1 km² inner area
- Fully analyzed: Oct 2012 – Apr 2014

Year	Stations	Trigger
2012	19	Tunka-133
2013	25	Tunka-133
2014	timing problem	
2015	44	Tunka-133 + Grande
2016	44 + 19 in autumn	Tunka-133 + Grande

frank.schroeder@kit.edu
Institut für Kernphysik

Event Statistics + Energy Range



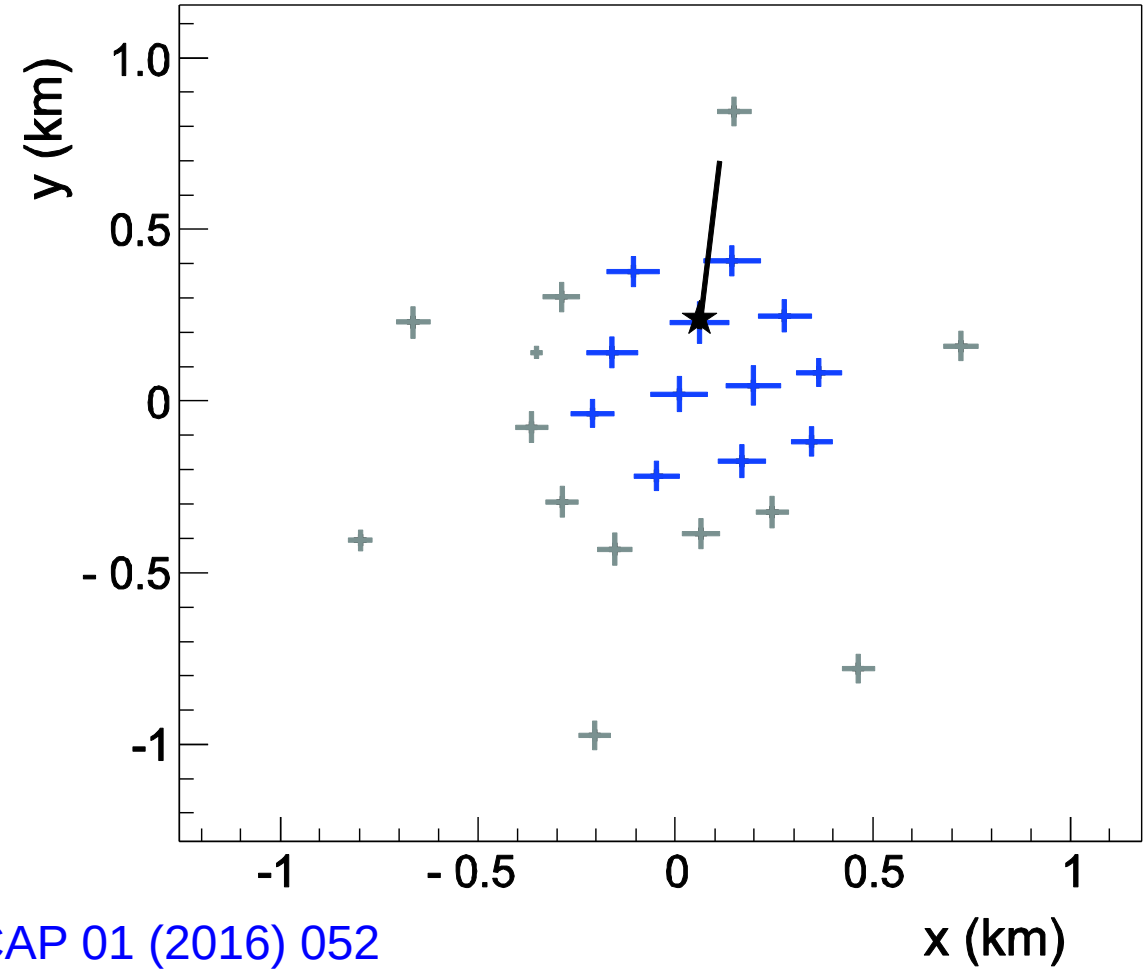
Data analysis with
Auger Offline
software framework.

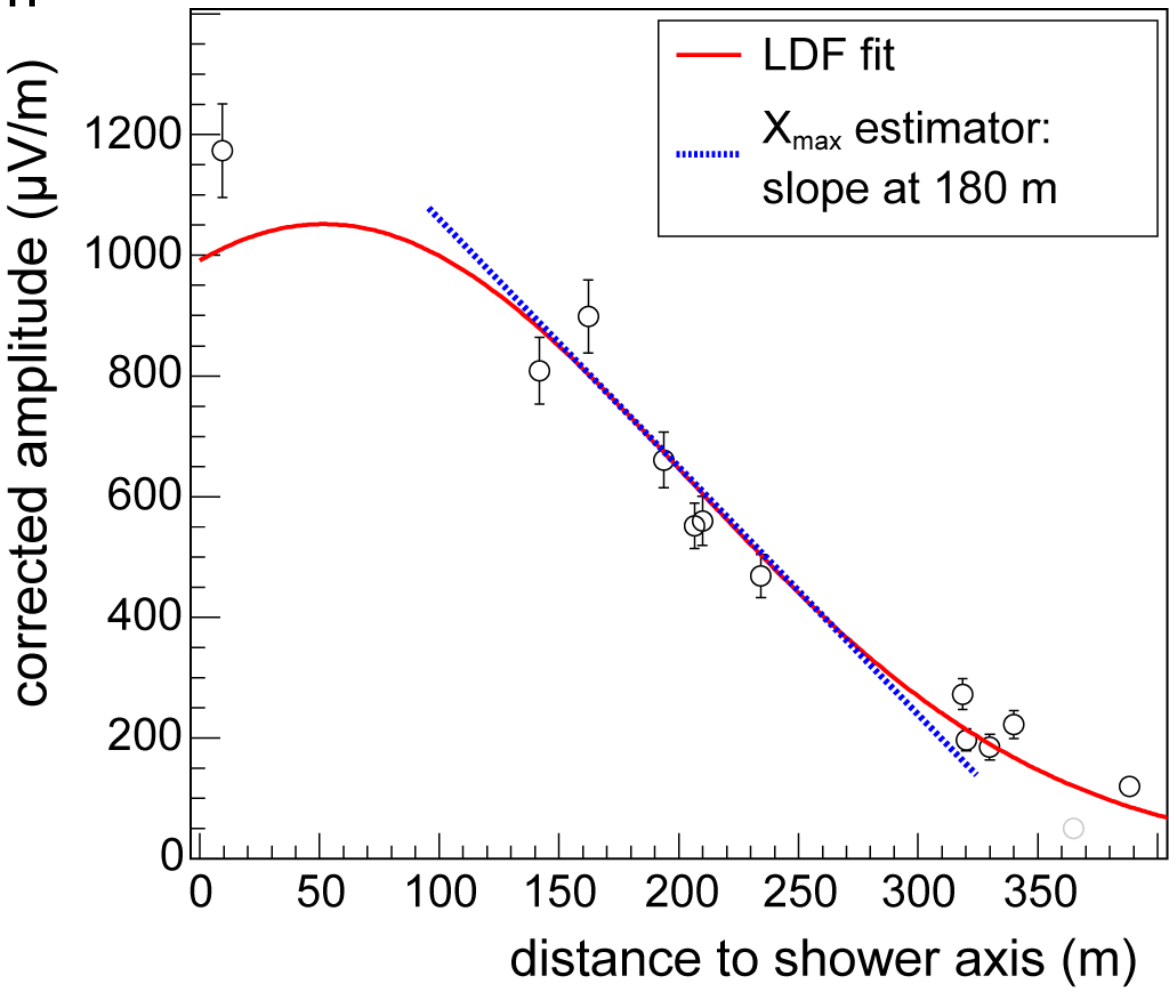
JCAP 01 (2016) 052

frank.schroeder@kit.edu
Institut für Kernphysik

Example Event: Footprint + Lateral Distribution

- Amplitude at 120 m used as energy estimator
- X_{max} by slope of lateral distribution at 180 m



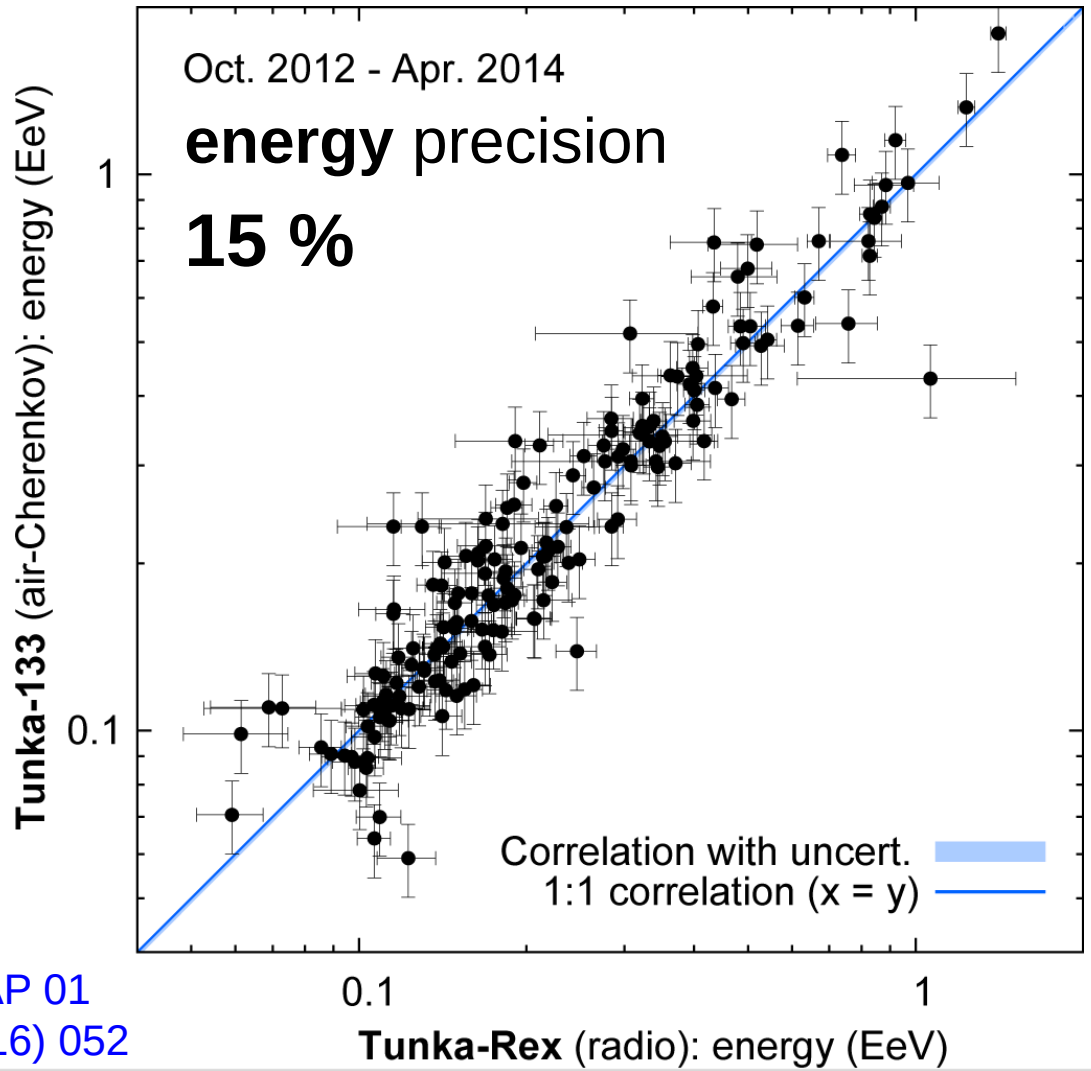


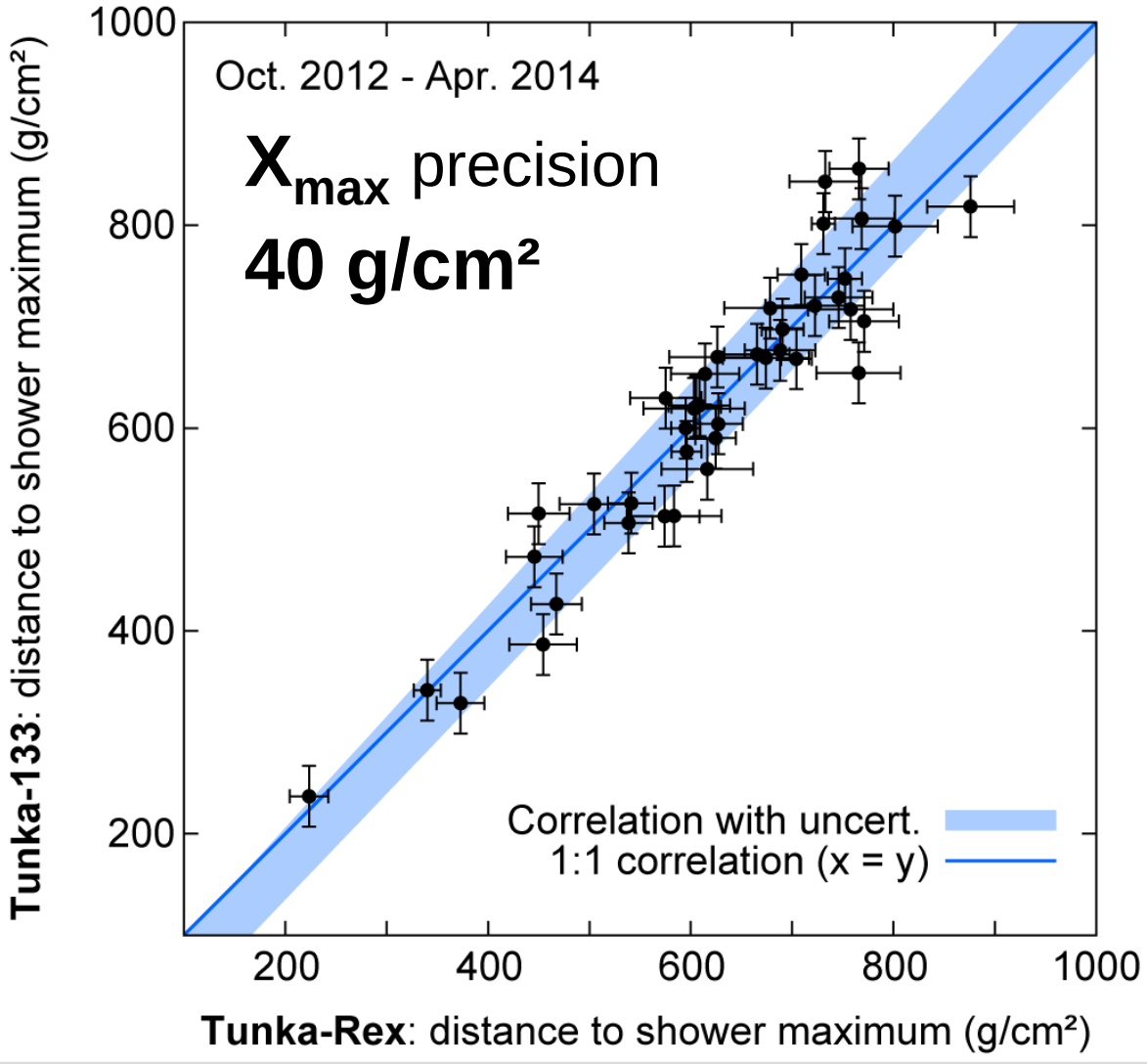
JCAP 01 (2016) 052

frank.schroeder@kit.edu
Institut für Kernphysik

Tunka-Rex vs. Tunka-133

- Radio calibrated on CoREAS simulations agrees with air-Cherenkov



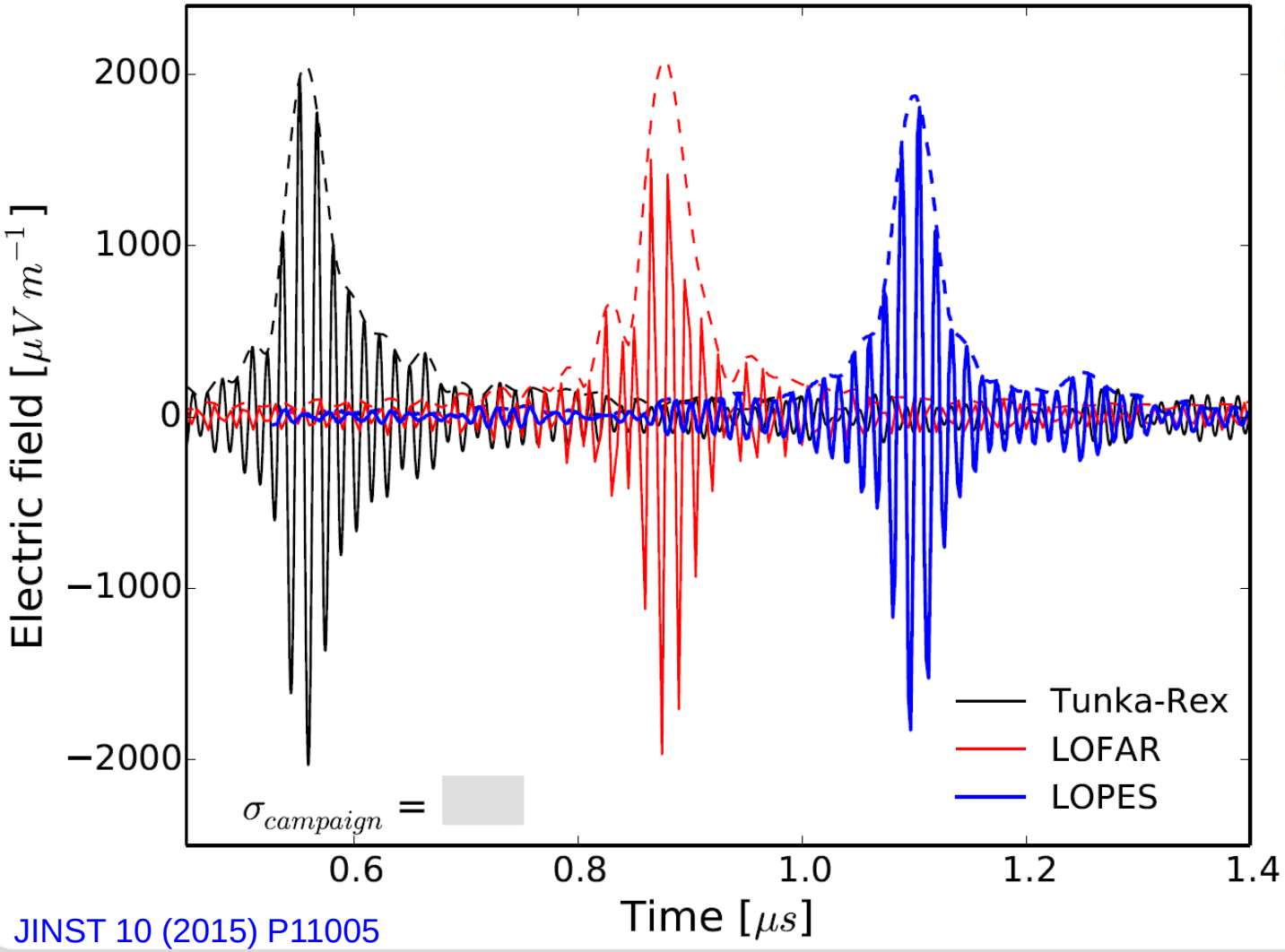


JCAP 01 (2016) 052

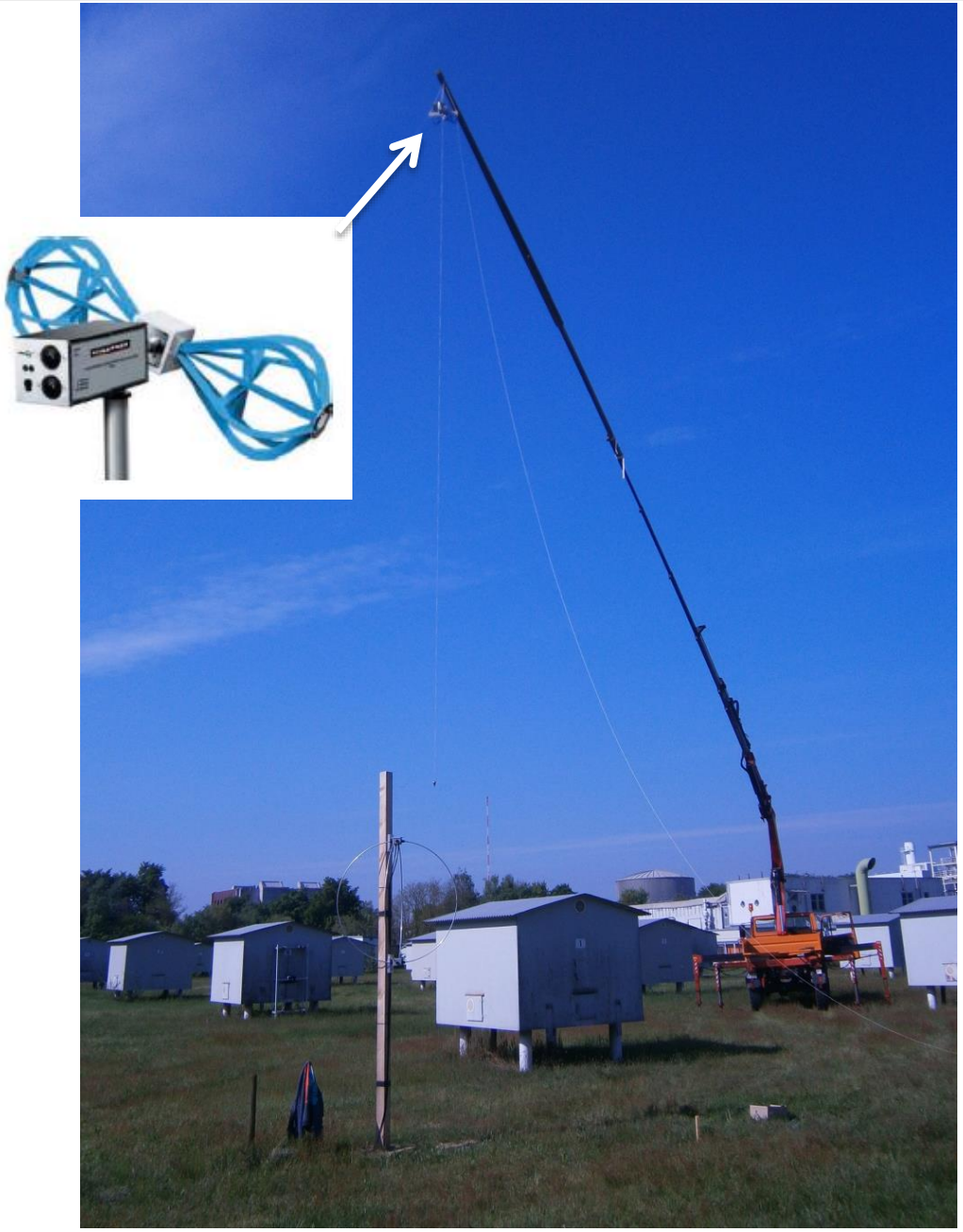
frank.schroeder@kit.edu Institut für Kernphysik

Amplitude Calibration

- Same reference as for LOPES and LOFAR

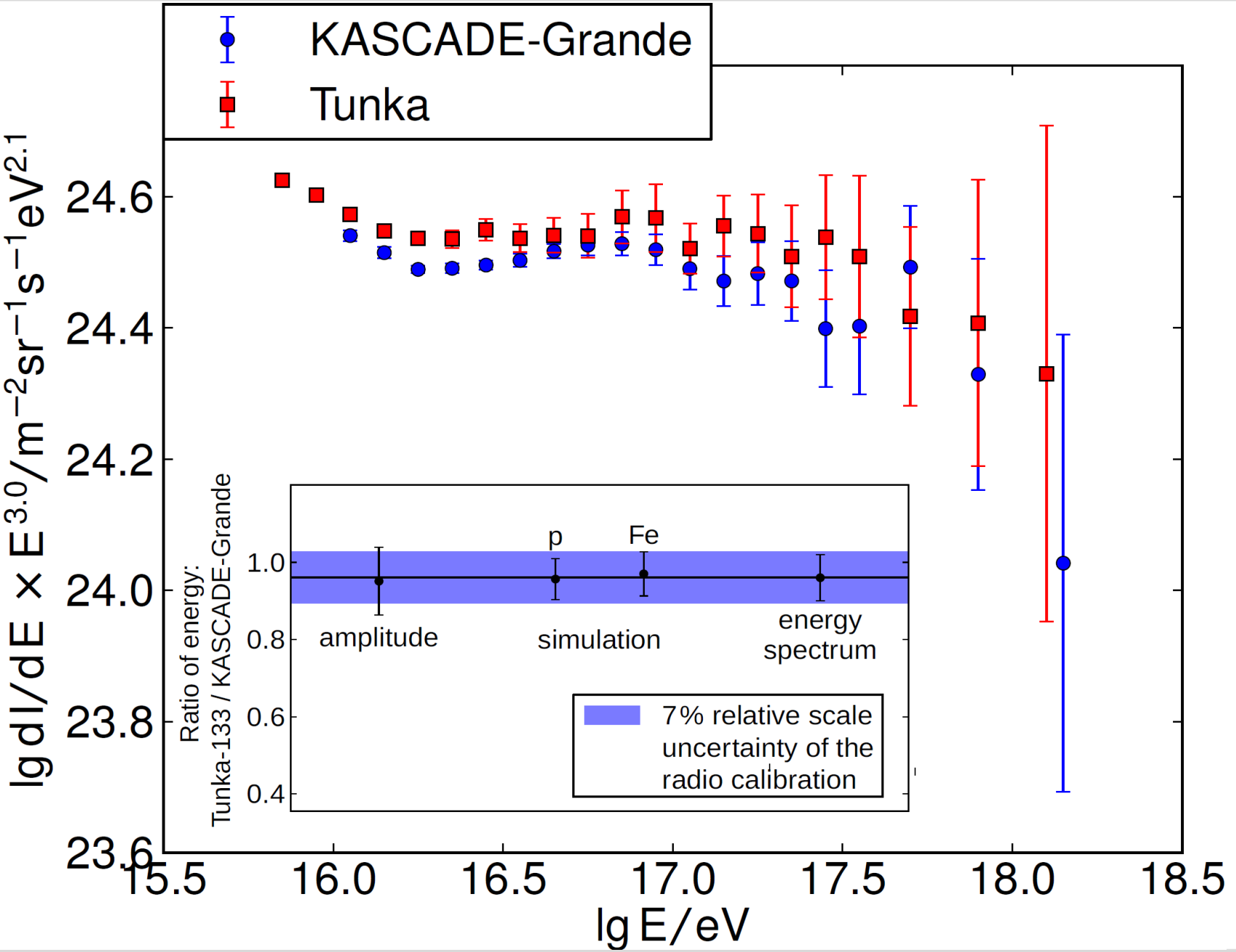


JINST 10 (2015) P11005



frank.schroeder@kit.edu
Institut für Kernphysik

Comparing energy scales via radio



Tunka-Rex + **LOPES** Colls., submitted to PLB

frank.schroeder@kit.edu Institut für Kernphysik

Conclusion

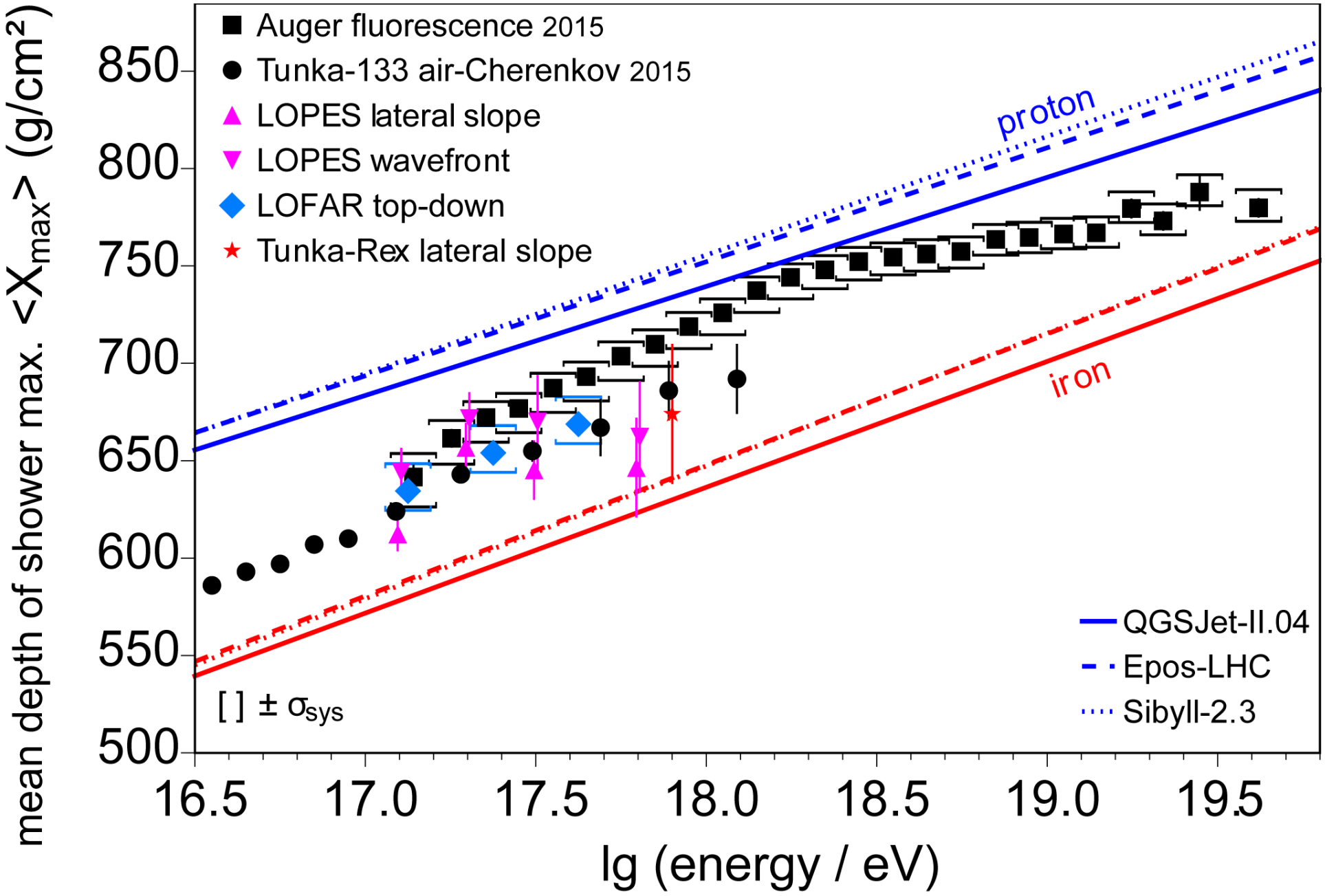
- Tunka-Rex successful and in time
  - Project, antenna deployment, and physics measurement all started in 2012
  - Main scientific goal X_{max} *cross-calibration* achieved in 2015 (as planned)
- Main results
  - Energy precision of 15 % with 20 % absolute scale accuracy
  - X_{max} precision of 40 g/cm² - improvements under study
- Outlook
  - Extension to 3 antennas per cluster will be finished next month
  - Trigger by Tunka-Grande scintillators boosts the event statistics

  → Mass composition between 10^{17} and 10^{18} eV

frank.schroeder@kit.edu
Institut für Kernphysik

Backup

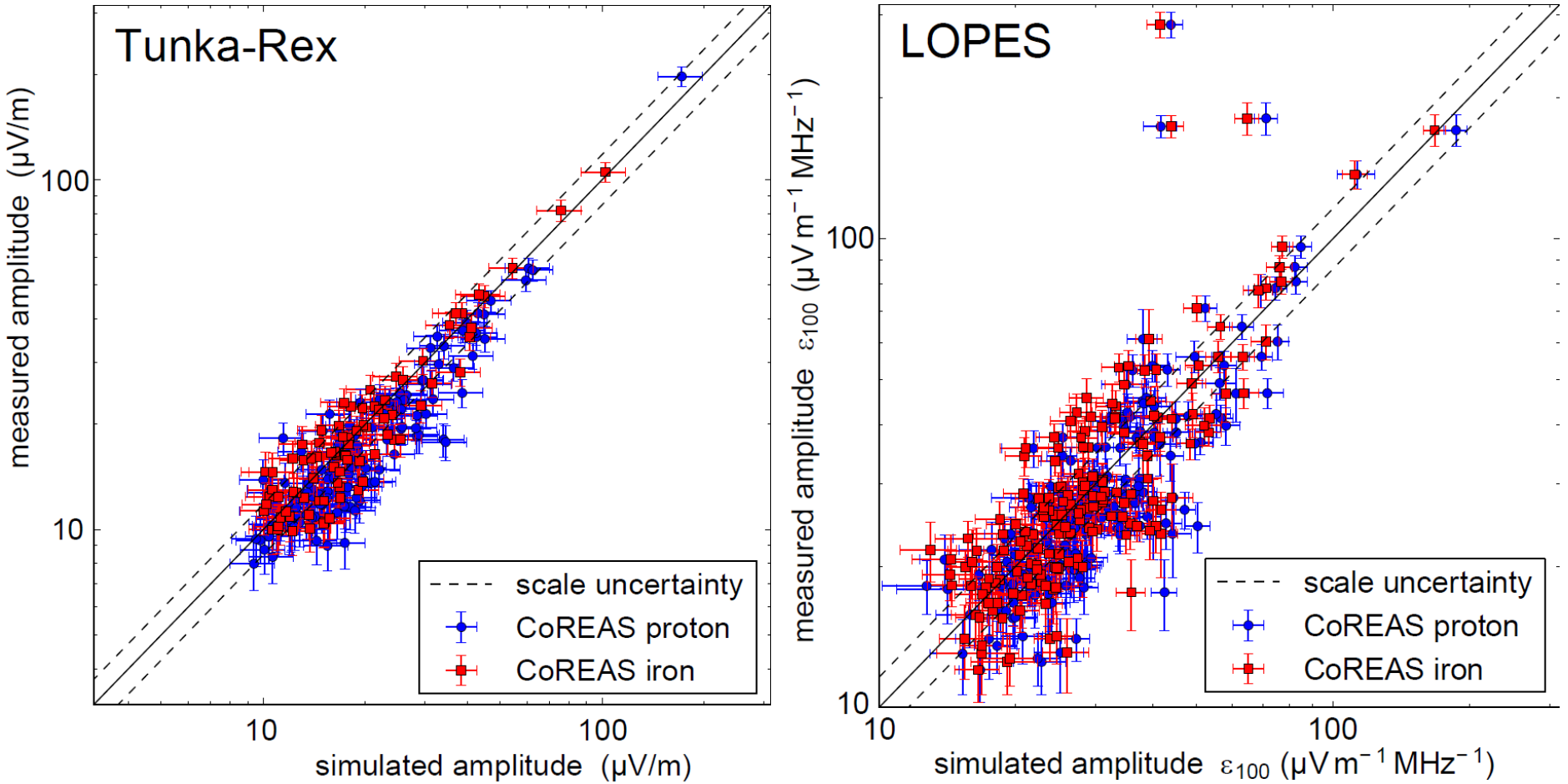
frank.schroeder@kit.edu
Institut für Kernphysik



frank.schroeder@kit.edu
Institut für Kernphysik

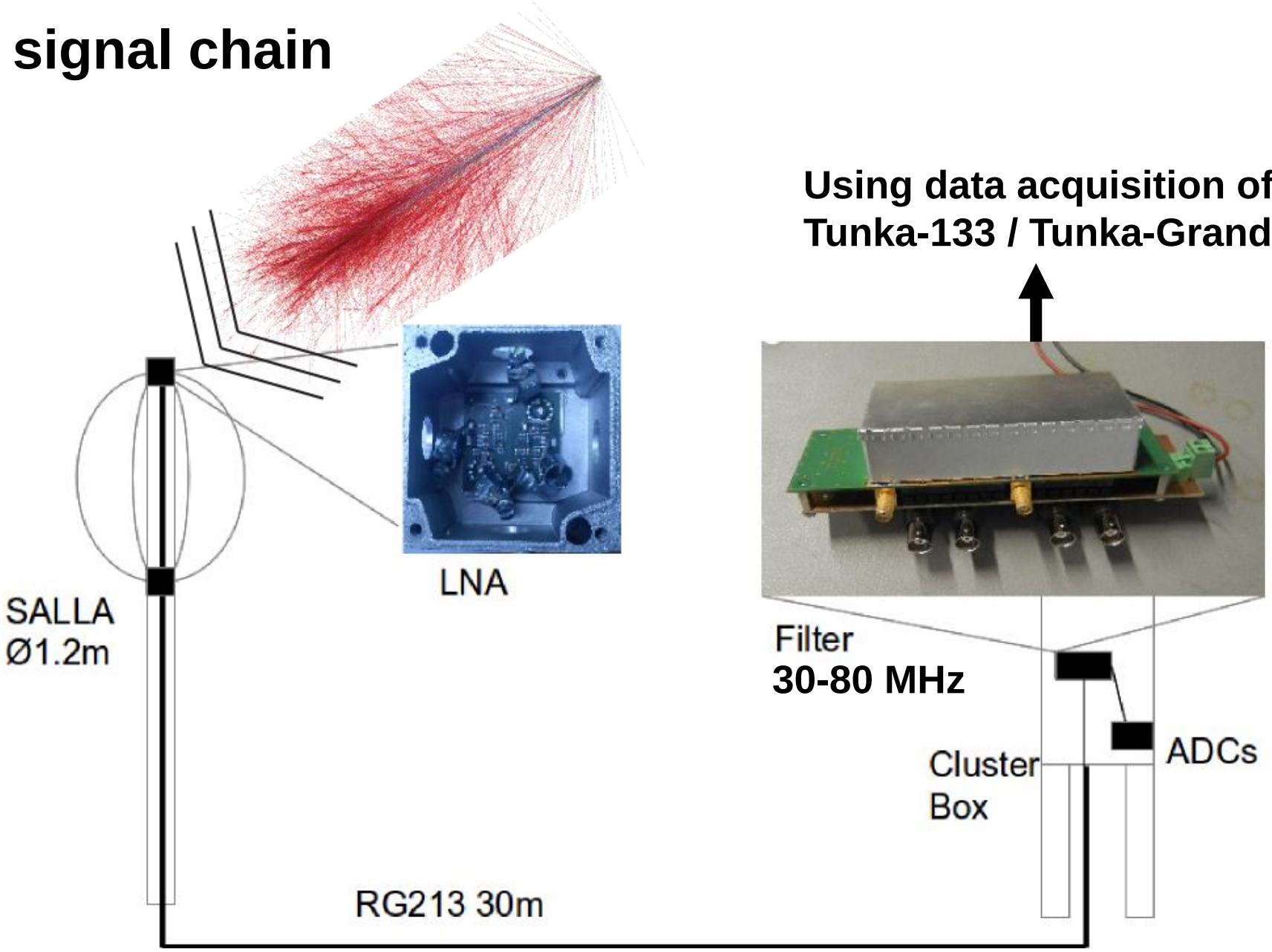
Comparison of energy scales

- Simulations with energy reconstructed by host experiments



frank.schroeder@kit.edu
Institut für Kernphysik

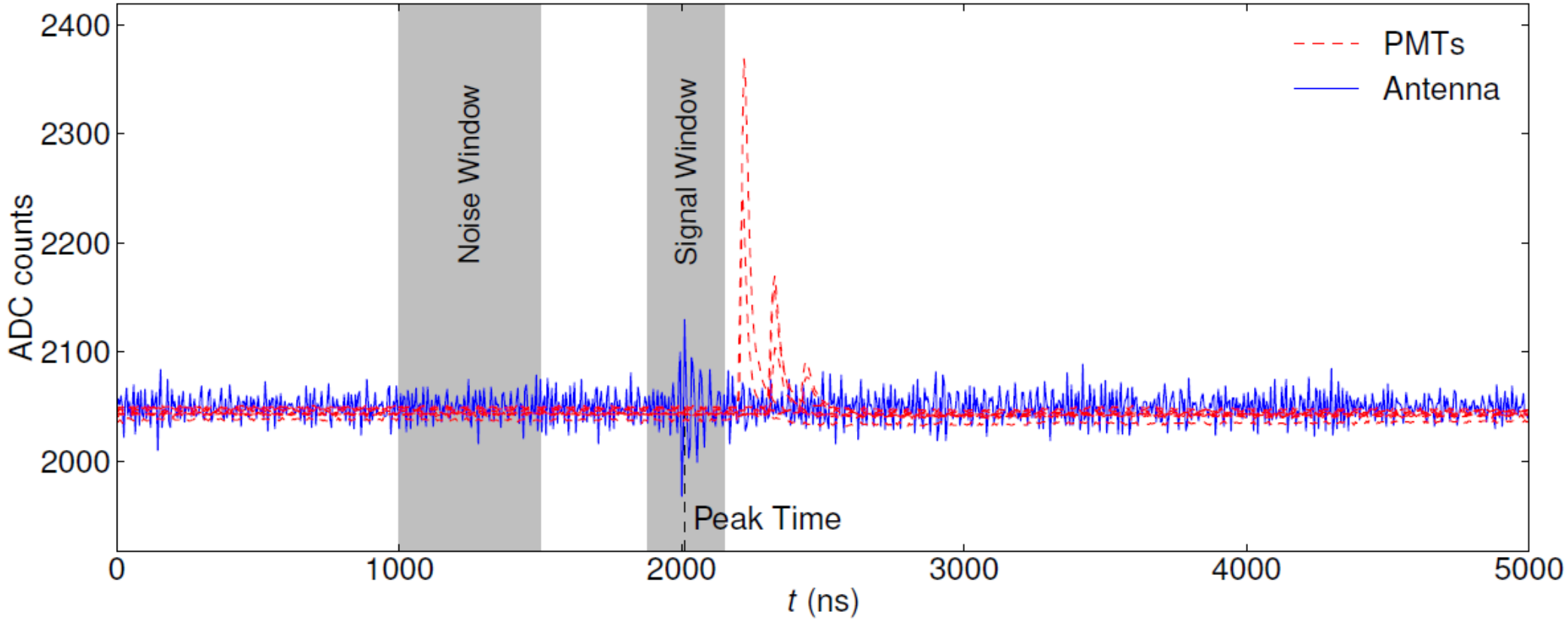
Tunka-Rex signal chain



frank.schroeder@kit.edu
Institut für Kernphysik

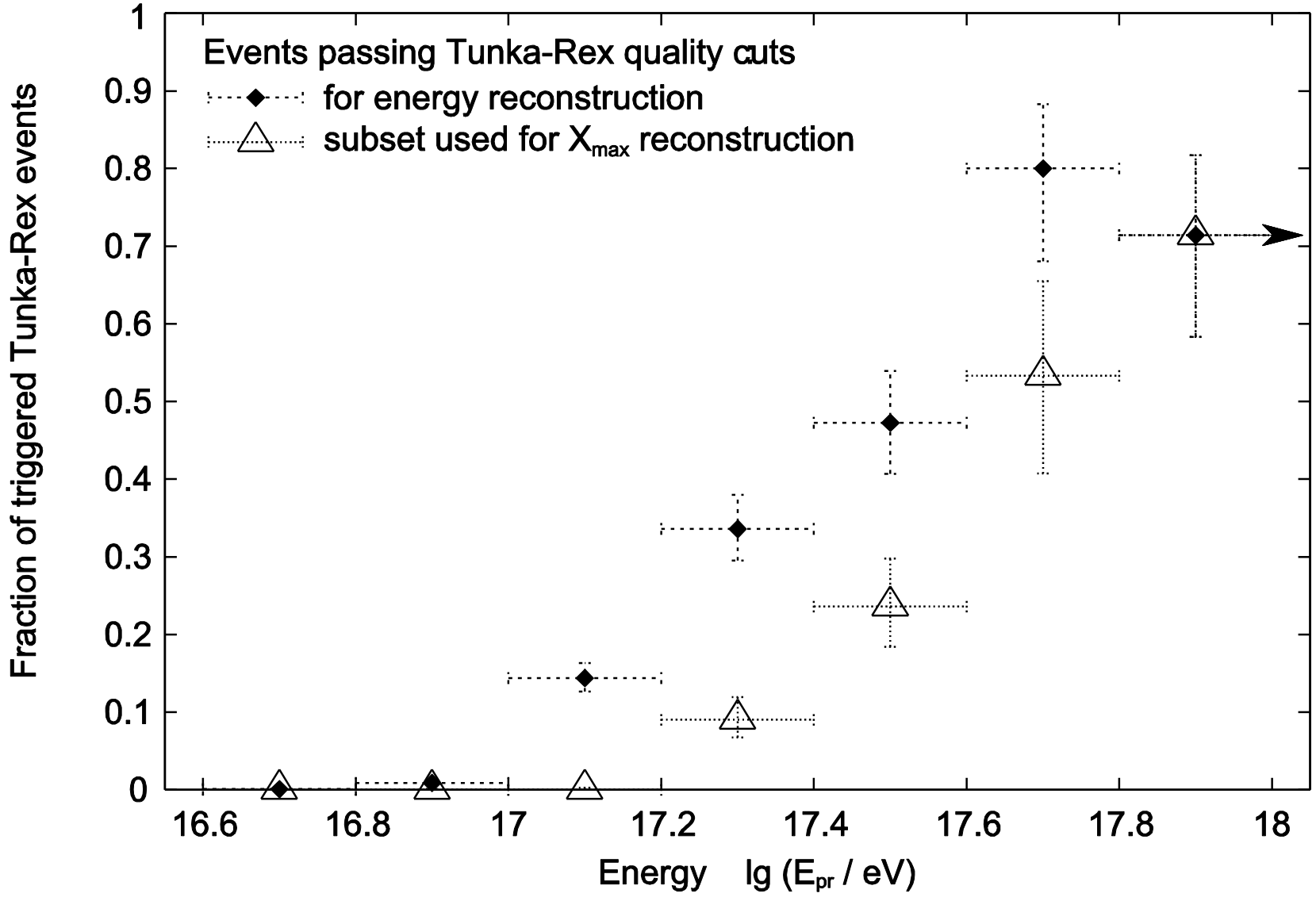
Reconstruction of Tunka-Rex event

- Signal-to-noise ratio (in power) > 10
  - 5% chance probability of false-positive detection in a single antenna
- 3 antennas + direction agreement with Tunka-133 required



frank.schroeder@kit.edu
Institut für Kernphysik

Efficiency of Tunka-Rex standard reconstruction



frank.schroeder@kit.edu
Institut für Kernphysik