

SCORE

Gamma-ray and Cosmic ray astrophysics from 10TeV to 1EeV



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- Aim of SCORE
- How SCORE ?
- What SCORE ?
- First simulation results

Astroparticle Physics in UHE regime

Gamma-ray Astronomy

- VHE spectra: where do they stop ?
- Origin of cosmic rays: pевatrons
- Absorption in IRF & CMB
- Diffuse emission:
 - Galactic plane
 - Local supercluster (Poster: T. Kneiske)

Charged cosmic ray physics

- Composition / anisotropies
- Sub-knee to pre-ankle

Particle physics beyond LHC scale

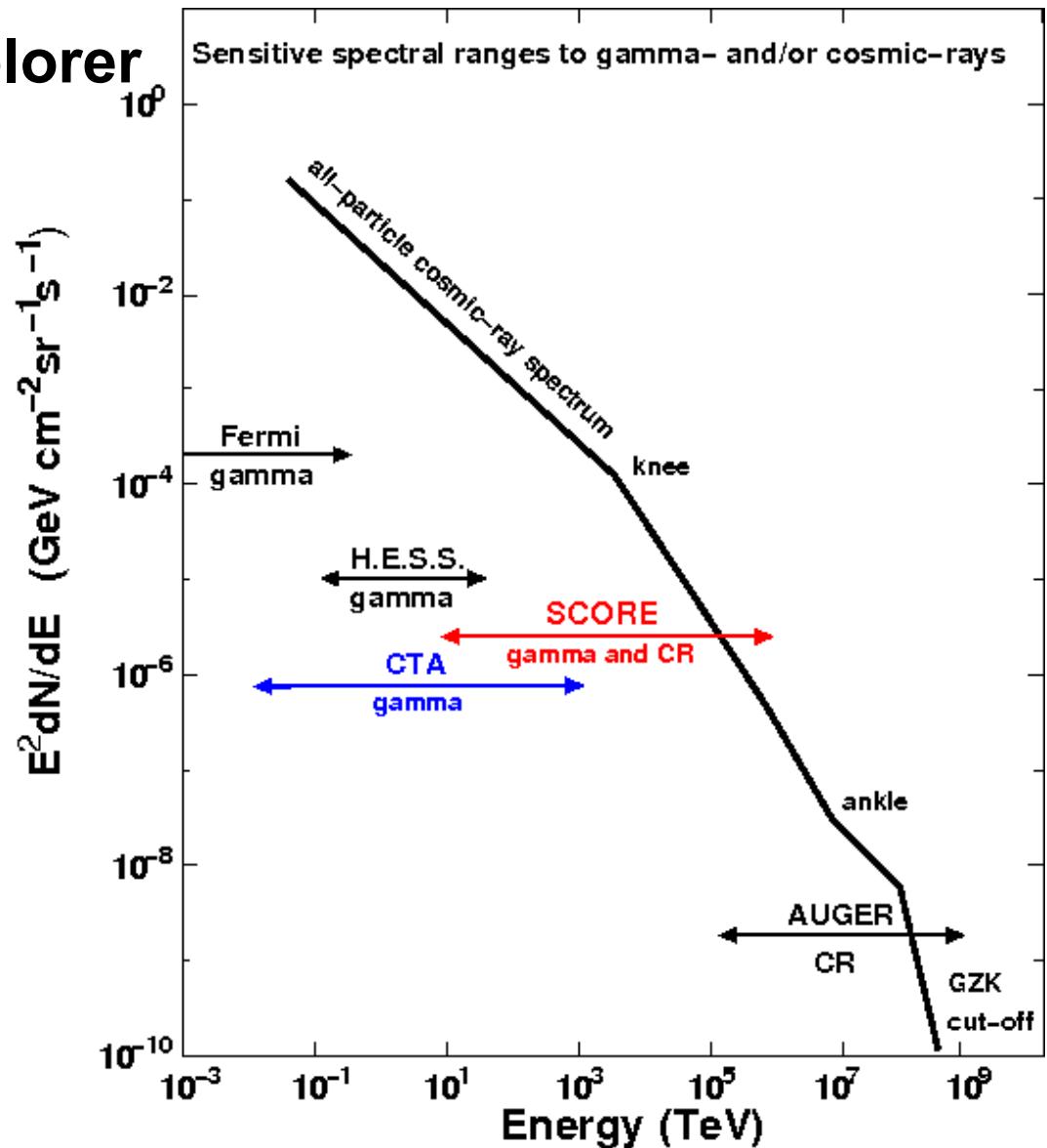
- Axion / photon conversion
- Hidden photon / photon oscillations
- Lorentz invariance violation
- pp cross-section measurements

The aim of SCORE

- **Study for a Cosmic ORigin Explorer**
- **Ultra High energies**
 - Gamma-rays: $E > 10 \text{ TeV}$
 - Cosmic-rays:
 $100 \text{ TeV} < E < 1 \text{ EeV}$
- **Large area:** 10 km^2
- **Large Field of view:** 1 sr



Roadmap phase I:
“recommendation for
development of ground-based
wide-angle gamma-ray
detectors”



The aim of SCORE

- Study for a Cosmic ORigin Explorer

- Ultra High energies

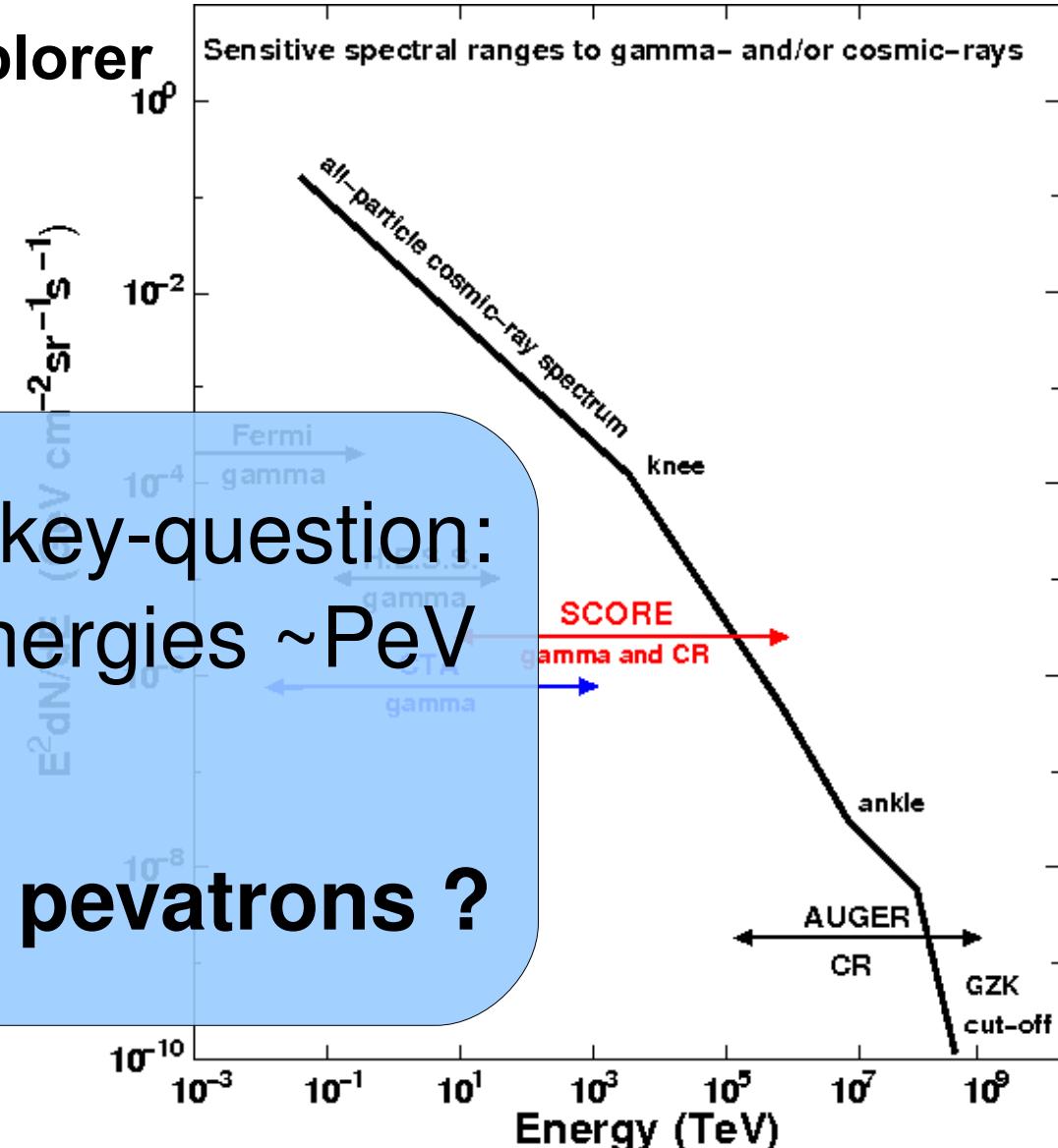
- Gamma-rays: $E > 10 \text{ TeV}$
- Cosmic-rays:

100 TeV $< E < 1 \text{ EeV}$

- Origin of cosmic rays – key-question:
- Acceleration to knee-energies $\sim \text{PeV}$

ASPERA

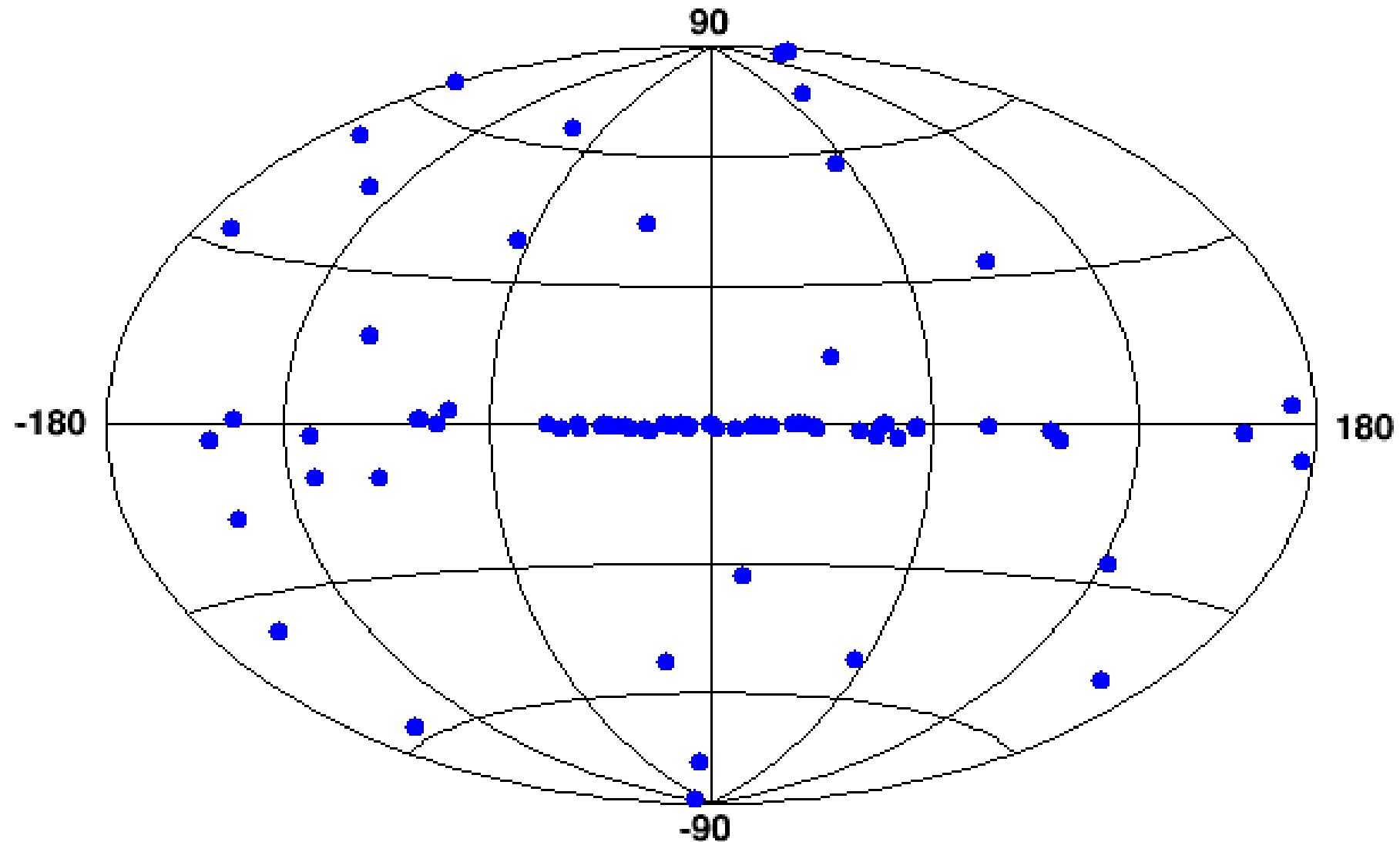
Roadmap "Recommendation for development of ground-based wide-angle gamma-ray detectors"



Where are the cosmic pevatrons ?

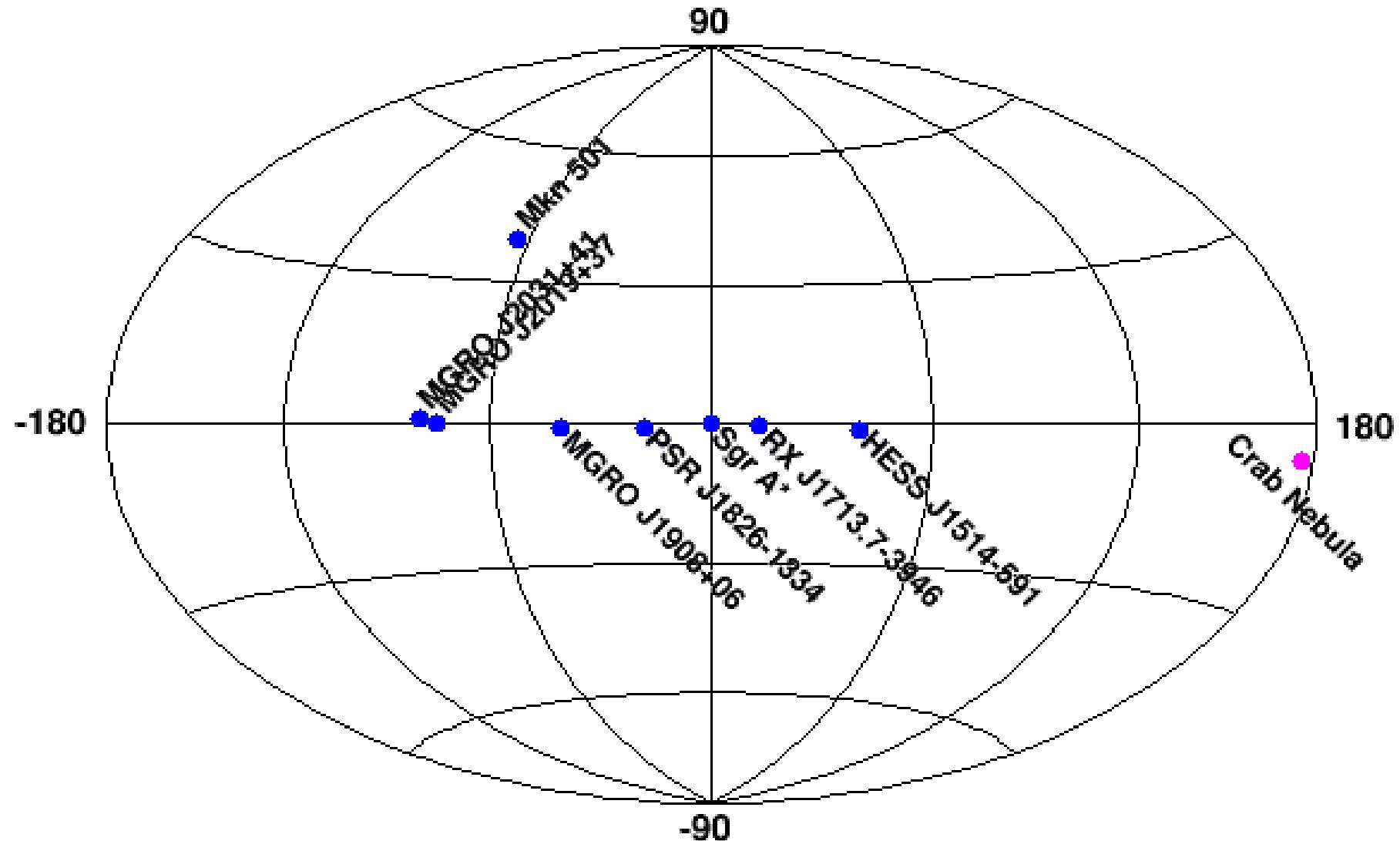
Gamma-Ray Sky

VHE gamma-ray sky 2009



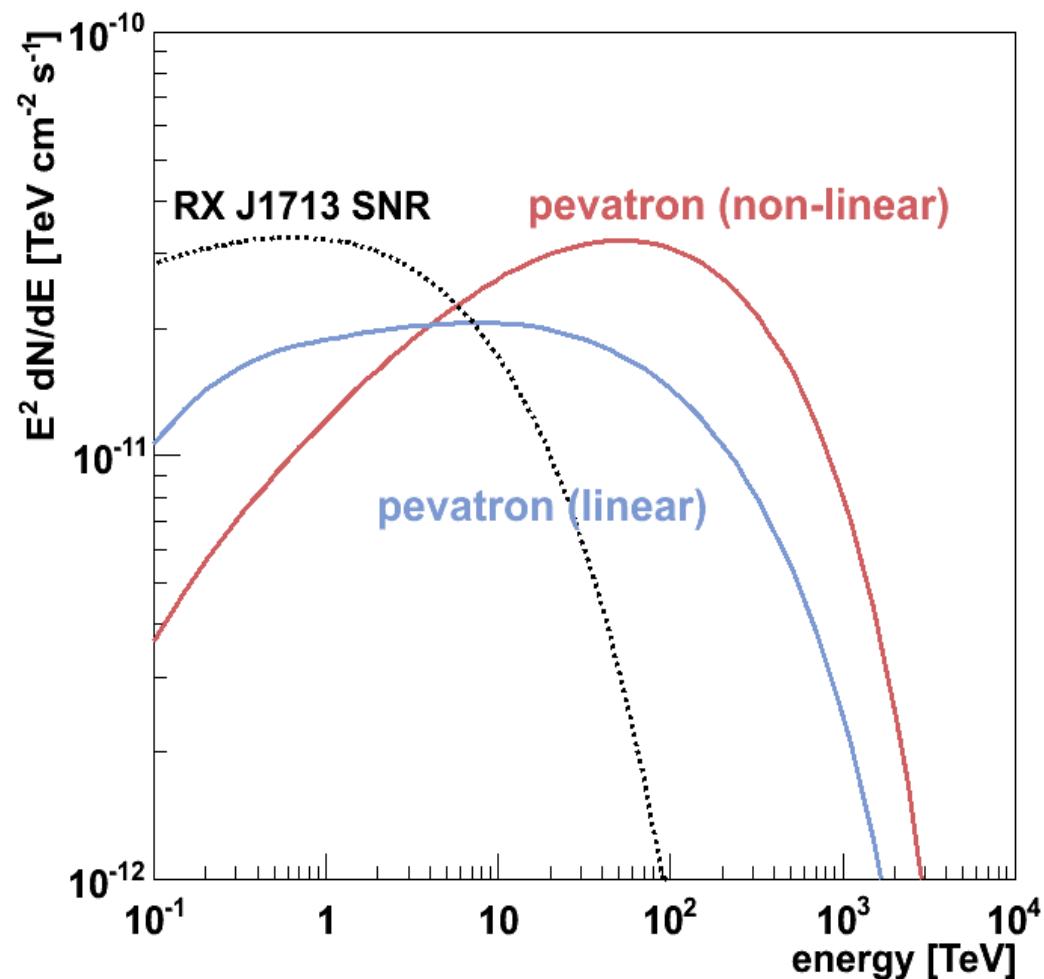
Gamma-Ray Sky

UHE Gamma-Ray Sky ($S > 5 \sigma$, $E > 10 \text{ TeV}$), May 2009



Where are the cosmic pevatrons ?

The main goal of SCORE

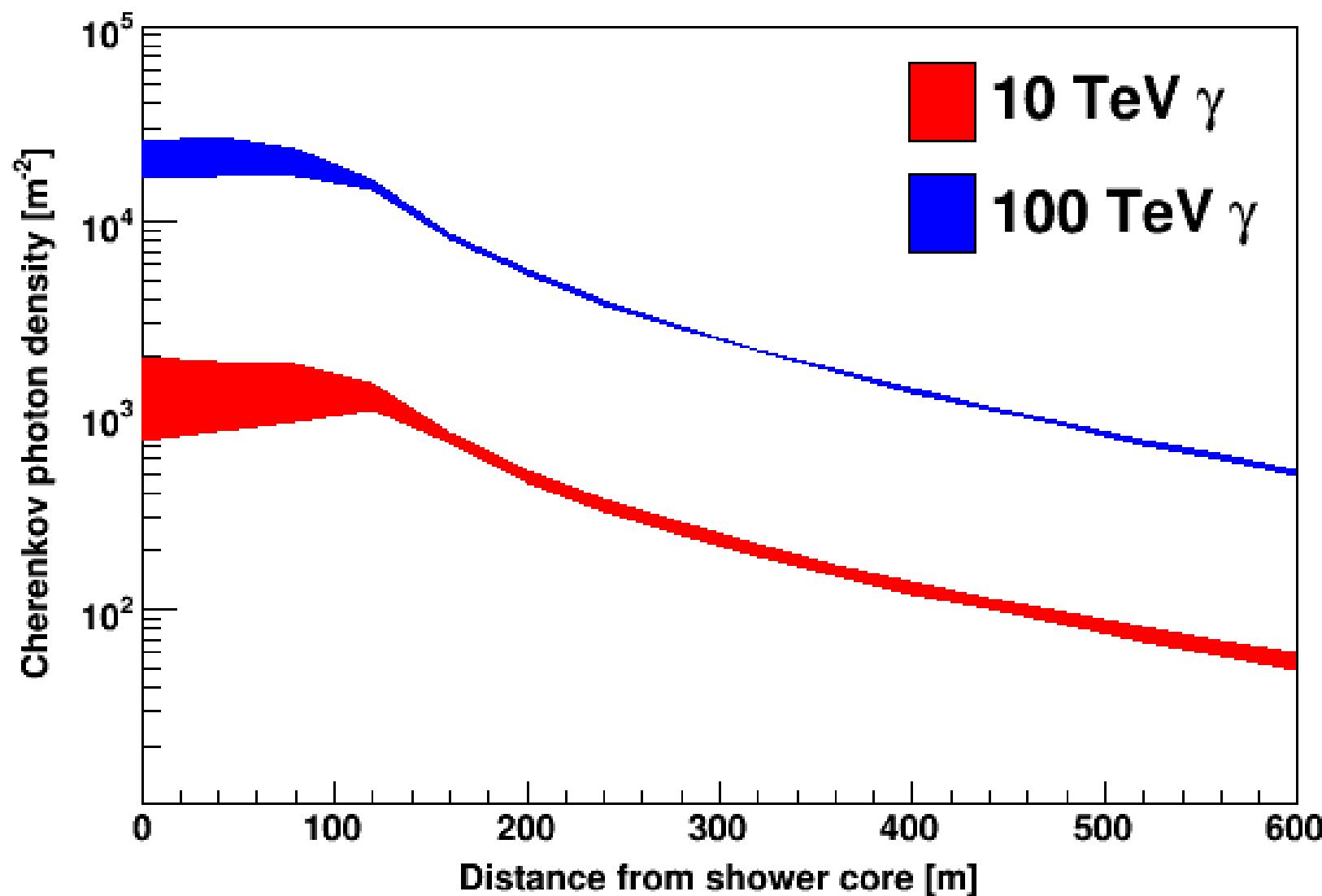


The SCORE principle

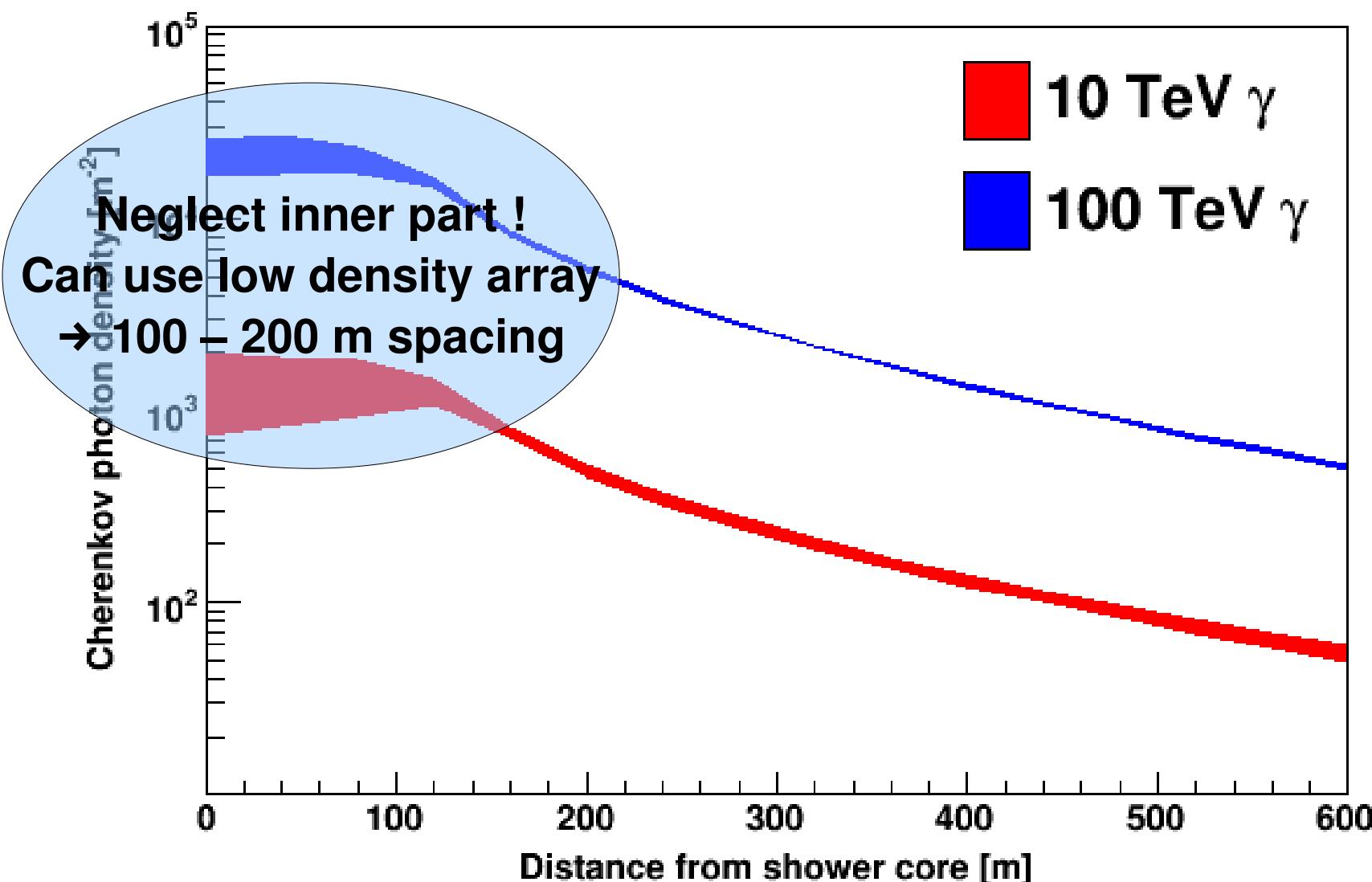
- Ultra-High energy regime: **large effective area !**
- Imaging ACTs: ~ 25000 channels / km^2
- **Use non-imaging Cherenkov technique**
 - SCORE: < 200 channels / km^2
 - Cherenkov light-front sampling
 - a) Light amplitude
 - b) Timing information

A look at the lateral photon distribution...

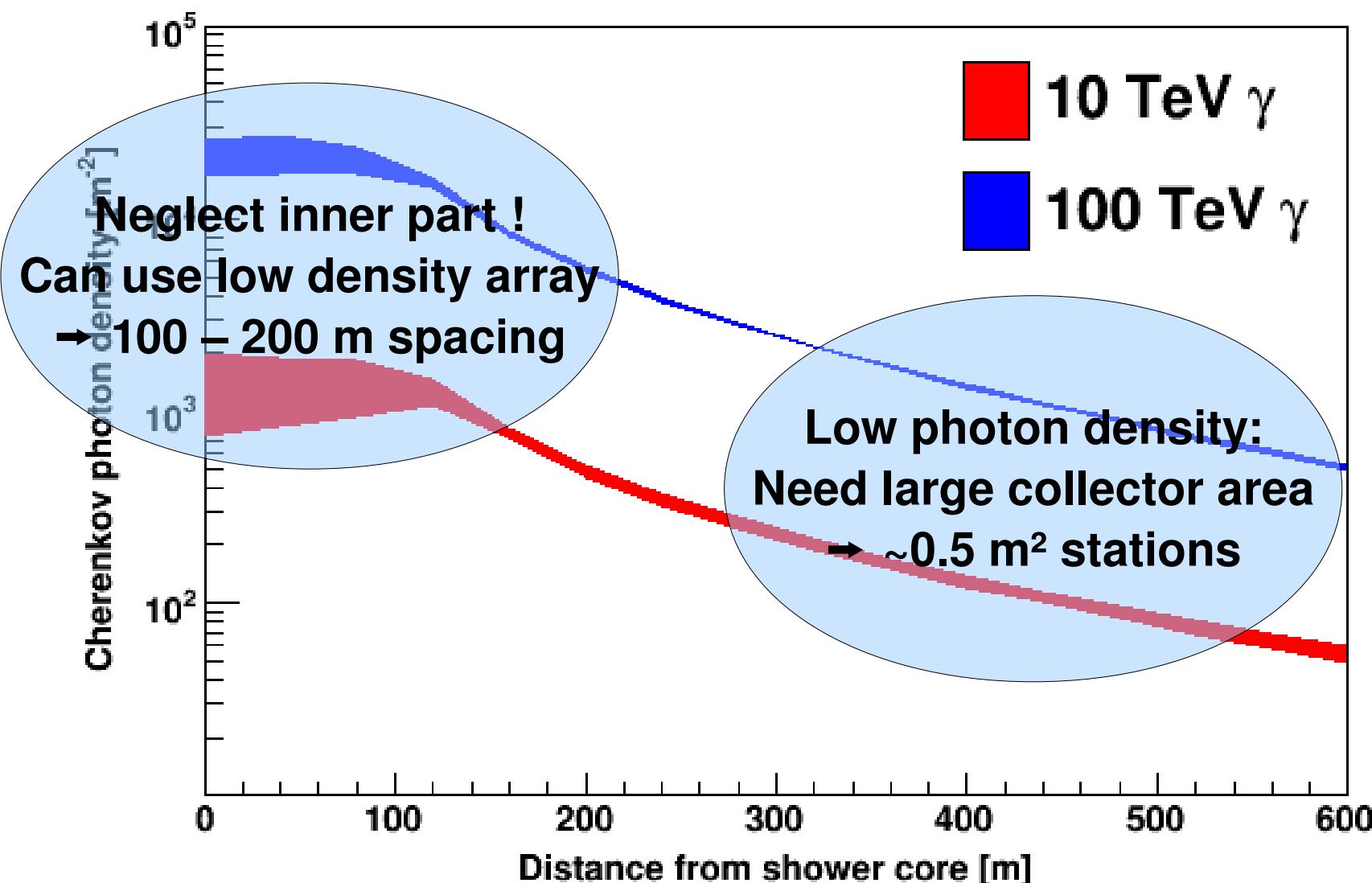
Lateral Cherenkov Photon Distribution



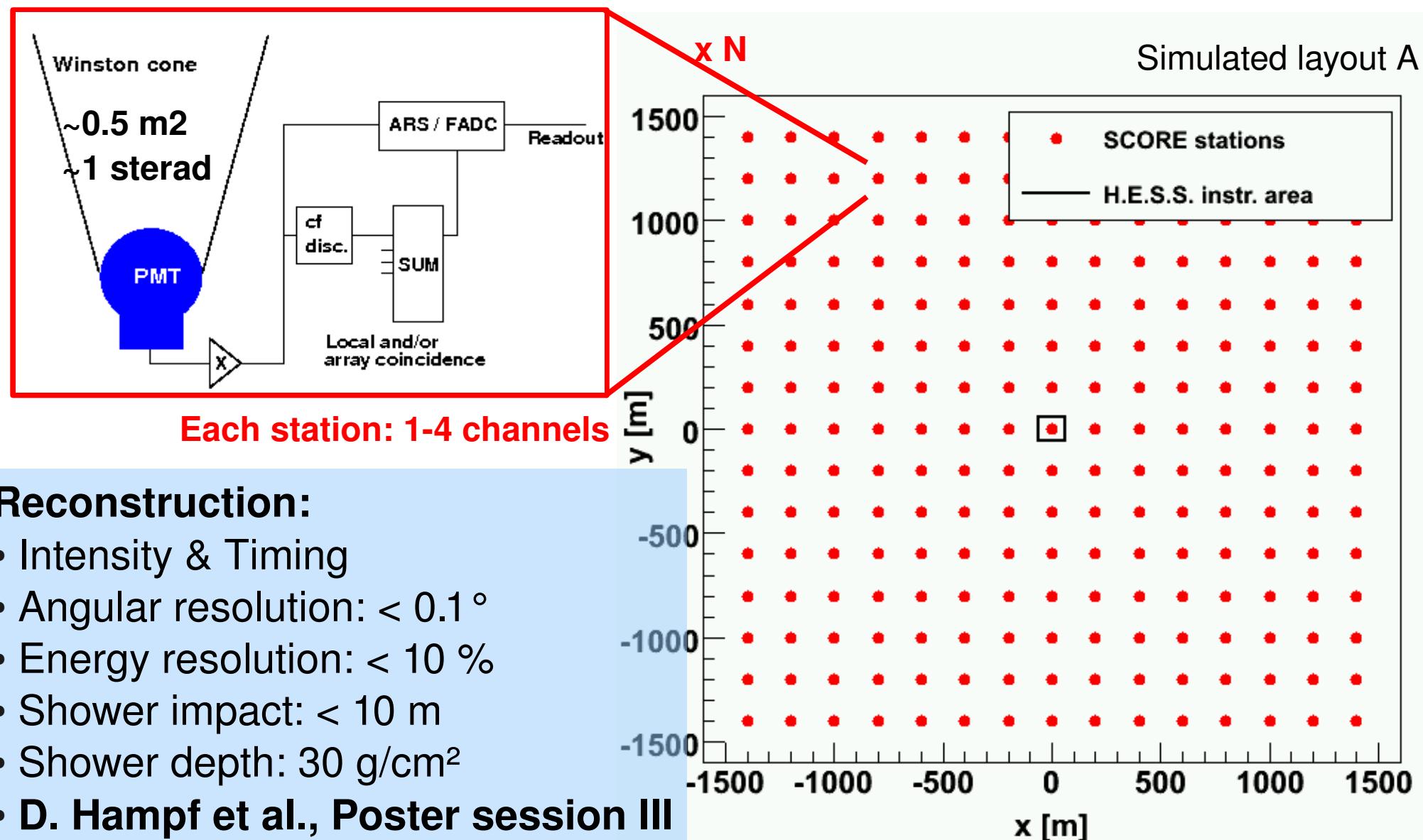
Lateral Cherenkov Photon Distribution



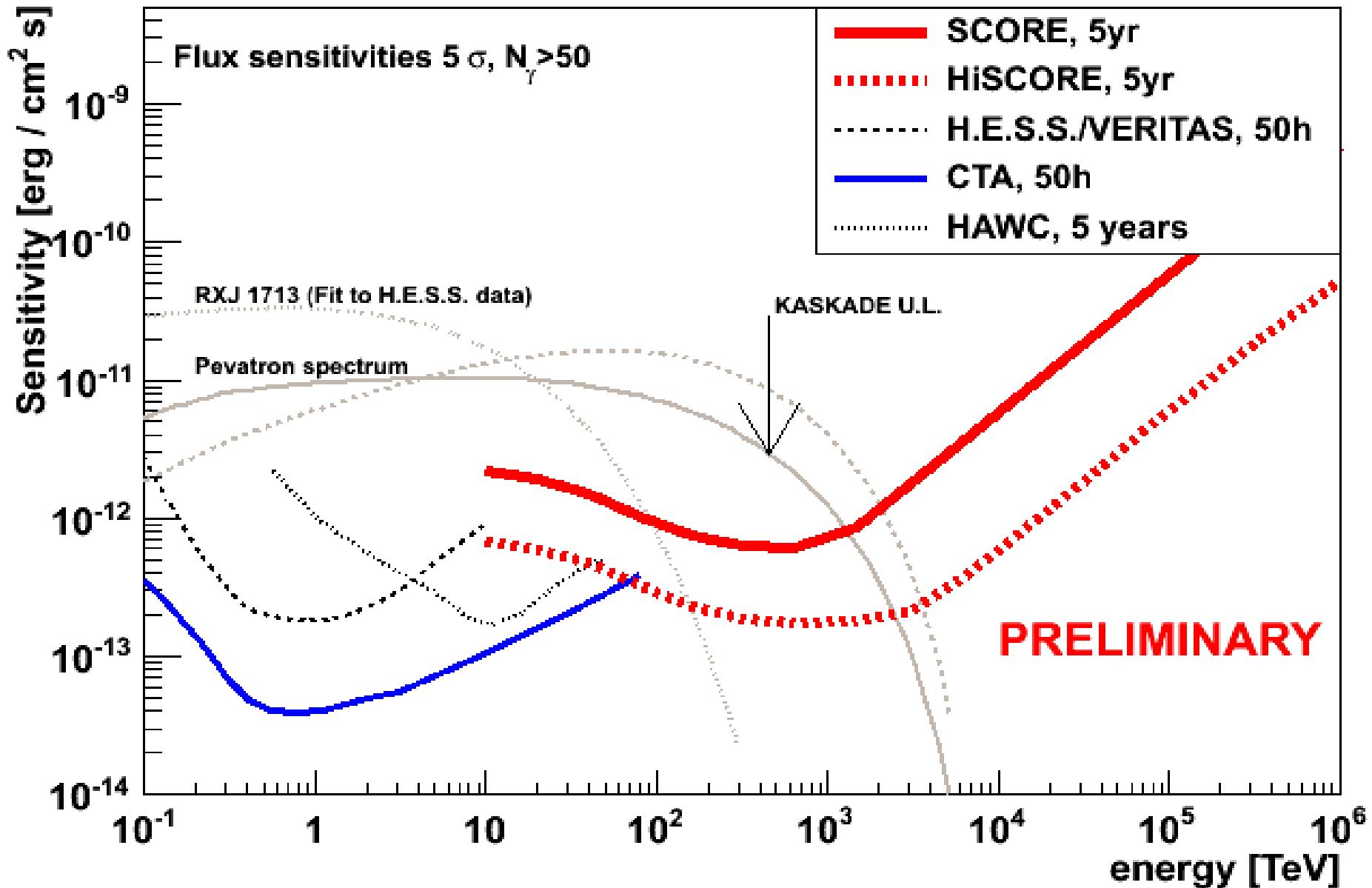
Lateral Cherenkov Photon Distribution



The SCORE Detector



SCORE First Simulation Results



Summary

- **Many physics cases beyond 10 TeV primary energy**
 - Gamma-ray astronomy (Origin of cosmic rays, ...)
 - Cosmic-ray physics
 - Particle physics
- **SCORE**
 - Opens the last remaining Gamma-ray observation window
 - Spans sub-knee to pre-ankle CR-energy range

Outlook

- We invite for collaboration !
- **H_iSCORE**
Hundred Square-km Cosmic ORigin Explorer
- Extension / Synergies with other techniques
 - Radio (LOFAR)
 - Szintillation counters (hybrid array)
 - Possible combination with imaging Cherenkov technique

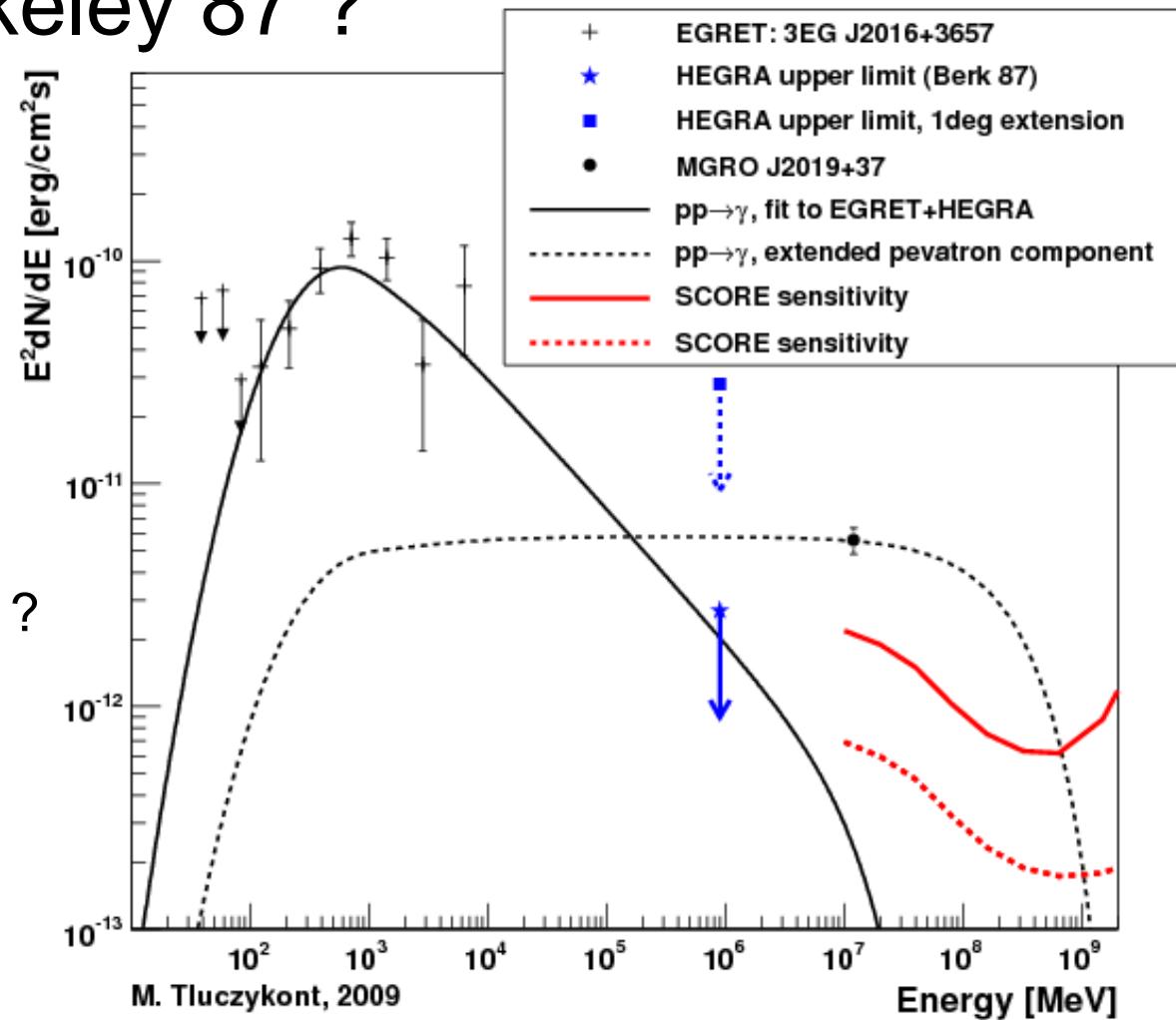
Status

- Full detector simulation complete
 - Testing different layouts
 - Optimizing reconstruction
 - Studying combination with IACTs
- Studies of first Hardware components in progress
- Construction of first prototype station in progress
- Funding for first SCORE stage pending
- Collaboration from other institutes is welcome !

Pevatron emission from Cygnus ?

MGROJ2019+37 & Berkeley 87 ?

- Composite Milagro signal
Diffuse + unresolved
- HEGRA upper limit
(converted for extension)
- HE signal associated to pulsar ?
Fermi: J2020.8+3649
EGRET: 3EG J2021+3716



- **Milagro signal might be dominated by extended pevatron emission !**
- **SCORE: resolve emission from 10 TeV – 1 PeV**

Local Supercluster and UHECRs

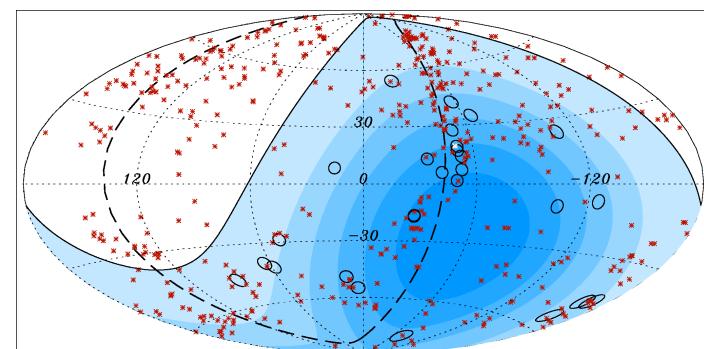
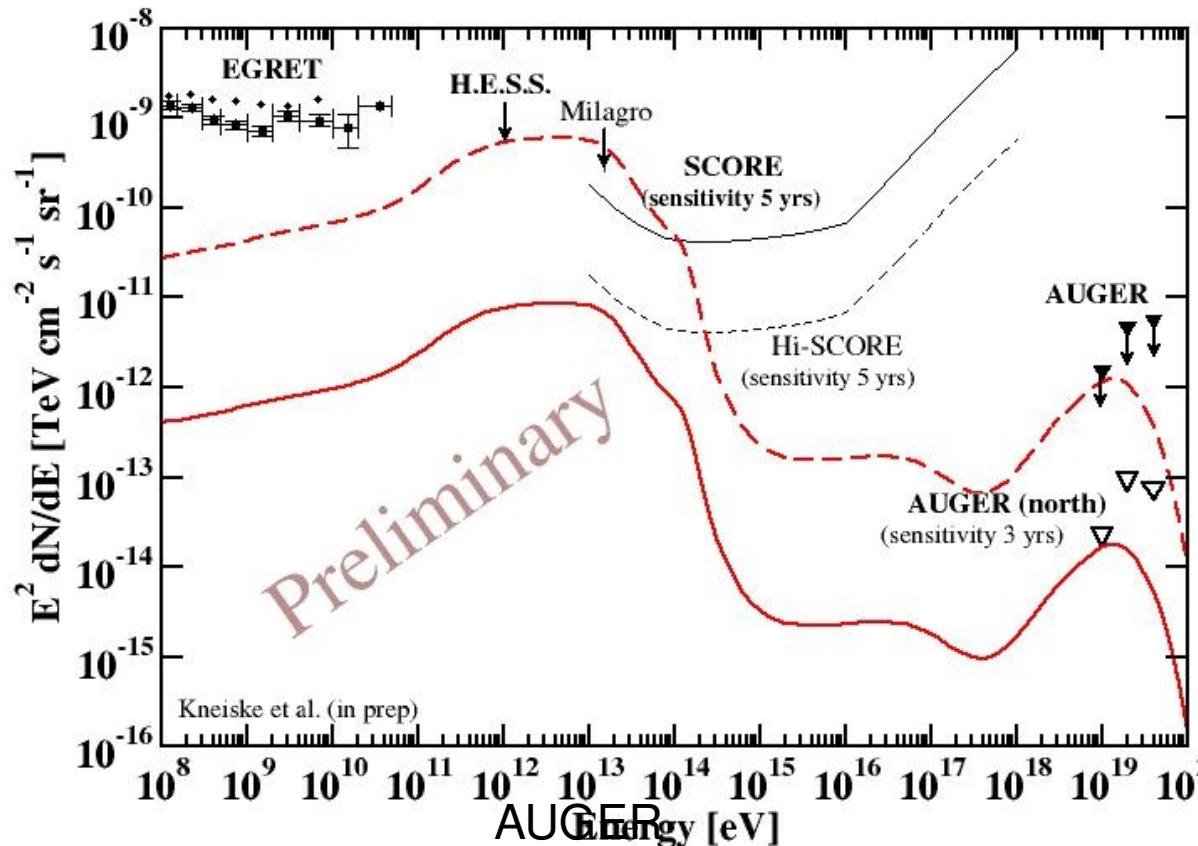
- UHECRs

confined in **local supercluster**

Expect diffuse emission

Poster: *T. Kneiske*

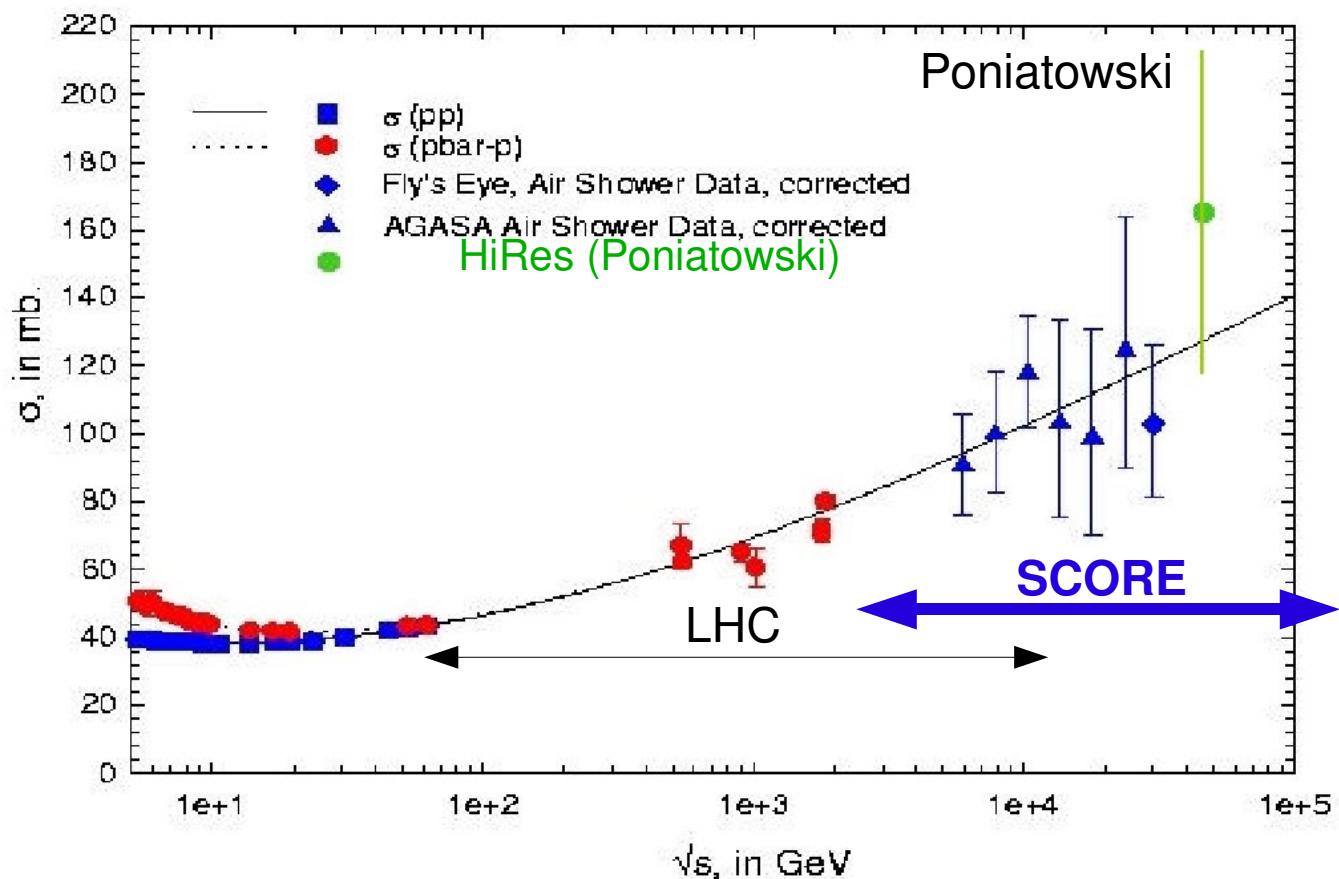
- Point-sources from AGN ?
 - IC Pair-cascading
 - Haloes ?



p-p cross-section

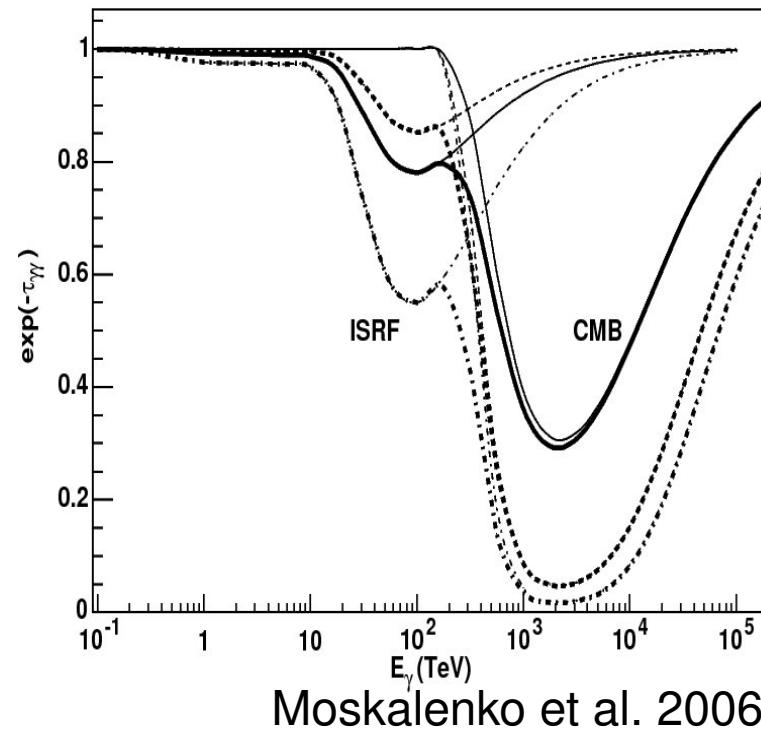
- Correlation shower depth / first interaction
→ measure interaction length in air $\sigma(p\text{-}p)$
- SCORE: $1 < E_{\text{CM}} < 150 \text{ TeV}$

- Overlap: LHC,
CR experiments



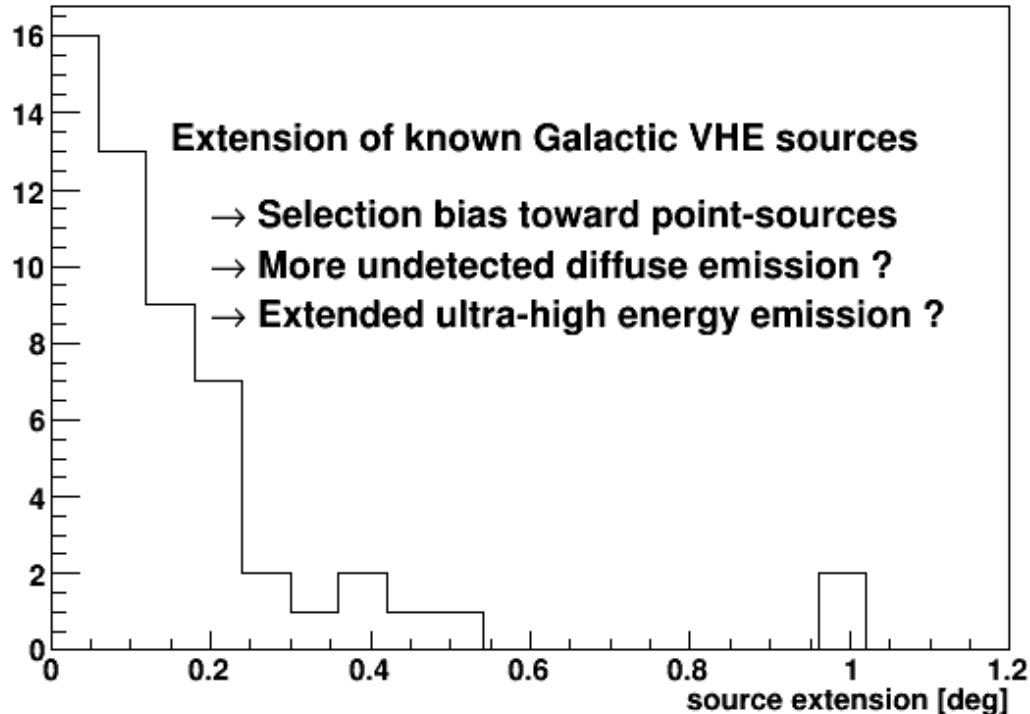
Propagation: Galactic Absorption & CMB

- e^+e^- pair production: Interstellar radiation field (ISRF) and CMB
- **estimate ISRF density**
- CMB well known: **distance estimate?**
- Weakening of absorption by:
 - **Photon / axion conversion** in Galactic Magnetic field
 - **Photon / hidden photon oscillation**
 - **Lorentz invariance violation** (modification of e^+e^- threshold)



Moskalenko et al. 2006

Source Extension



- Many Galactic objects are extended
- Extended emission: more background, less sensitivity
- Expect so far undetected extended sources !

The case of *pevatrons*

- Acceleration up / beyond knee = 3 PeV
- Need long acceleration time / large scales
- Extended pevatron emission ?

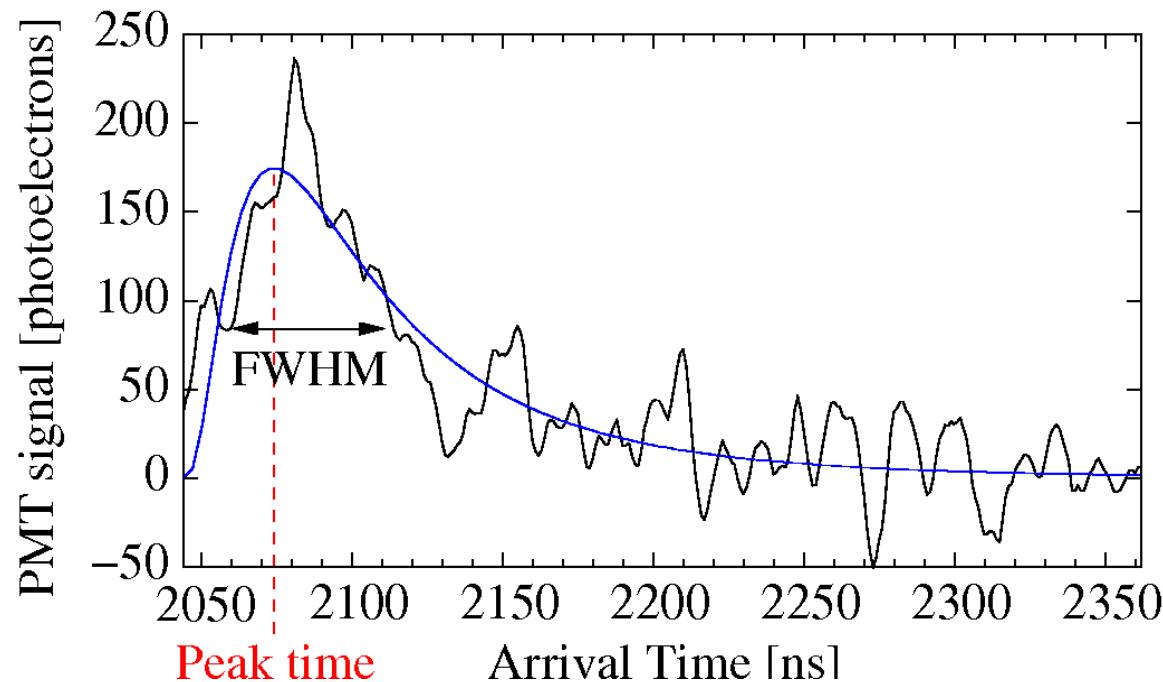
Alternatives / Extensions

- Daytime-measurements with scintillator material in lid: 100% duty cycle
- Combination with imaging technique:
 - provide core-reconstruction for low-density telescope grid (even monoscopic ?)
 - Instrumentation of larger area for highest energies
- Combination with radio detection technique ?
- ...

Reconstruction

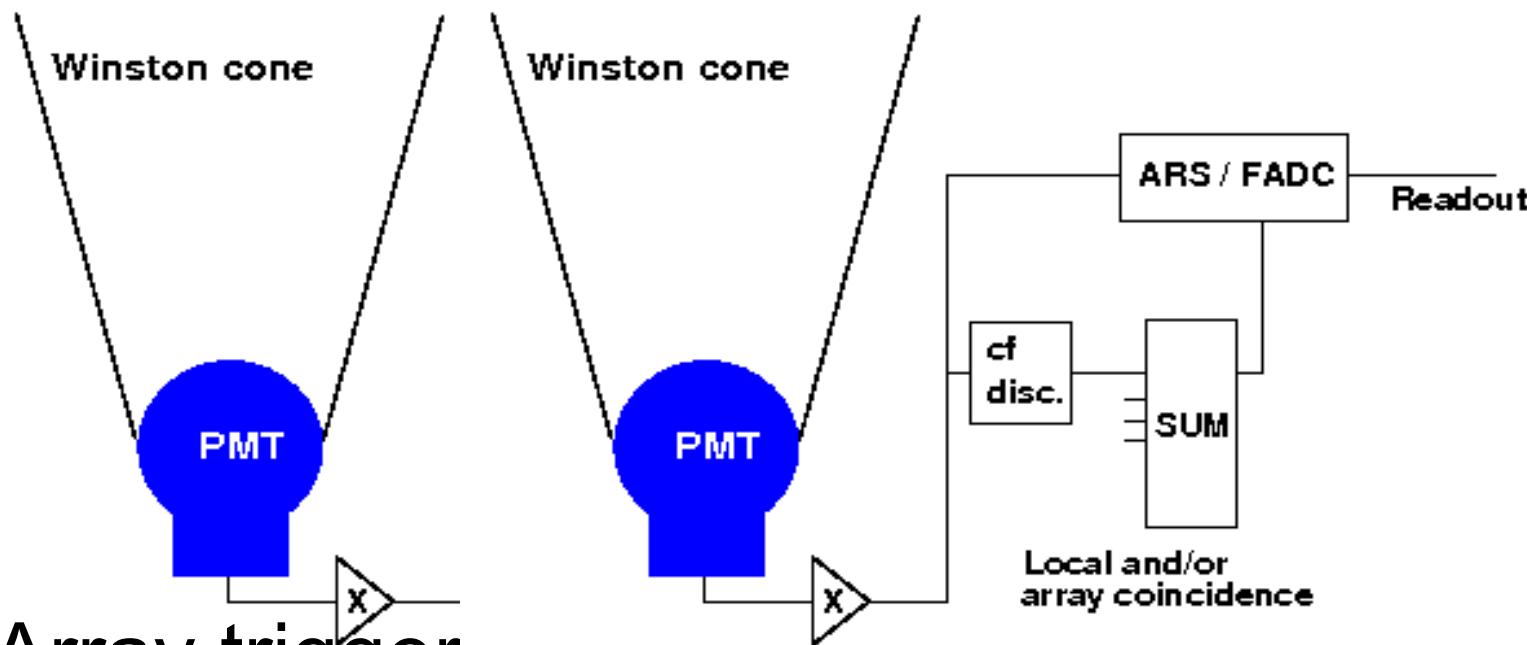
Poster by D. Hampf: Session III

- Using intensity and timing
 - Shower core impact position
 - Direction
 - Energy
 - Shower depth
 - γ /hadron separation
(depth / width)



Trigger levels

- Local station trigger:
 - multi-PMT station, e.g. 4 channels
 - 4-fold local coincidence ($\Delta t = 1\text{ns}$)

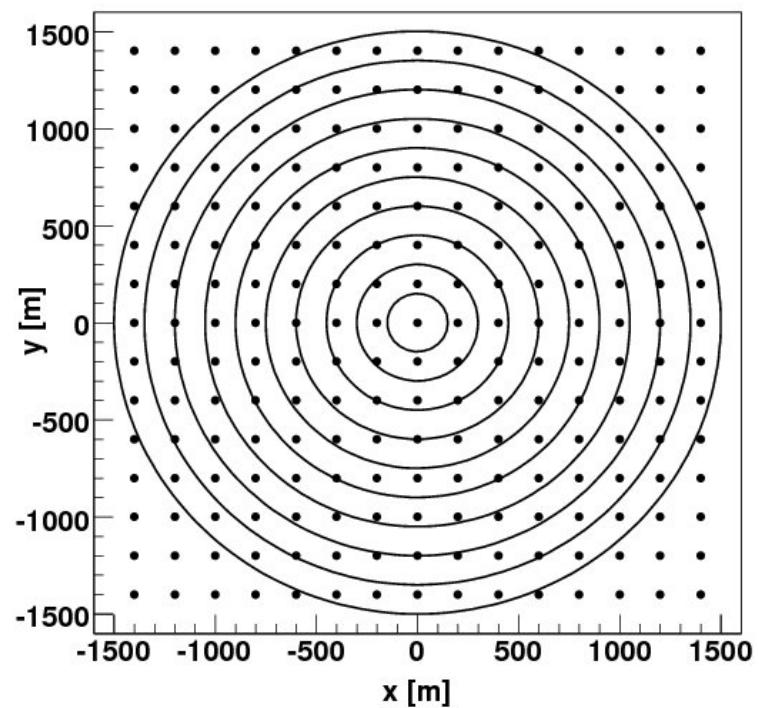
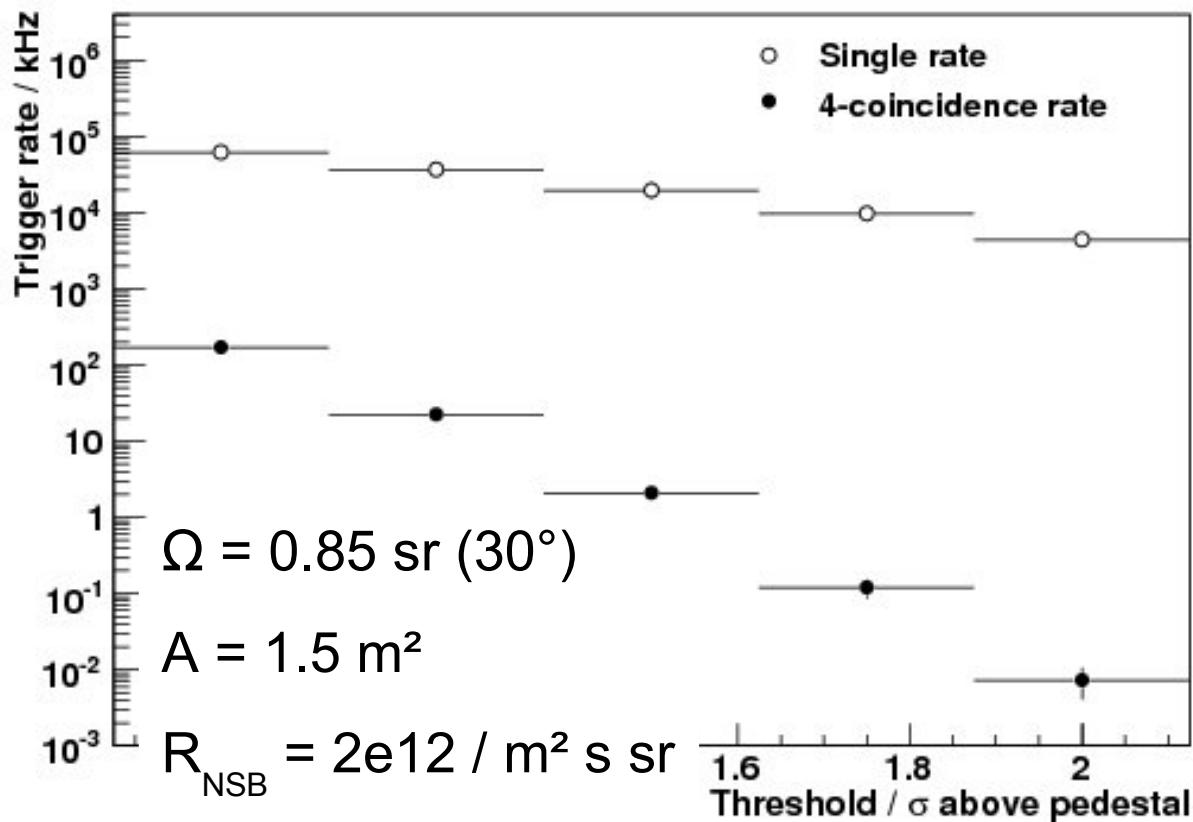


- Array trigger. Neighbouring station trigger ($\Delta t = 1\mu\text{s}$)

Coincidence: benefits

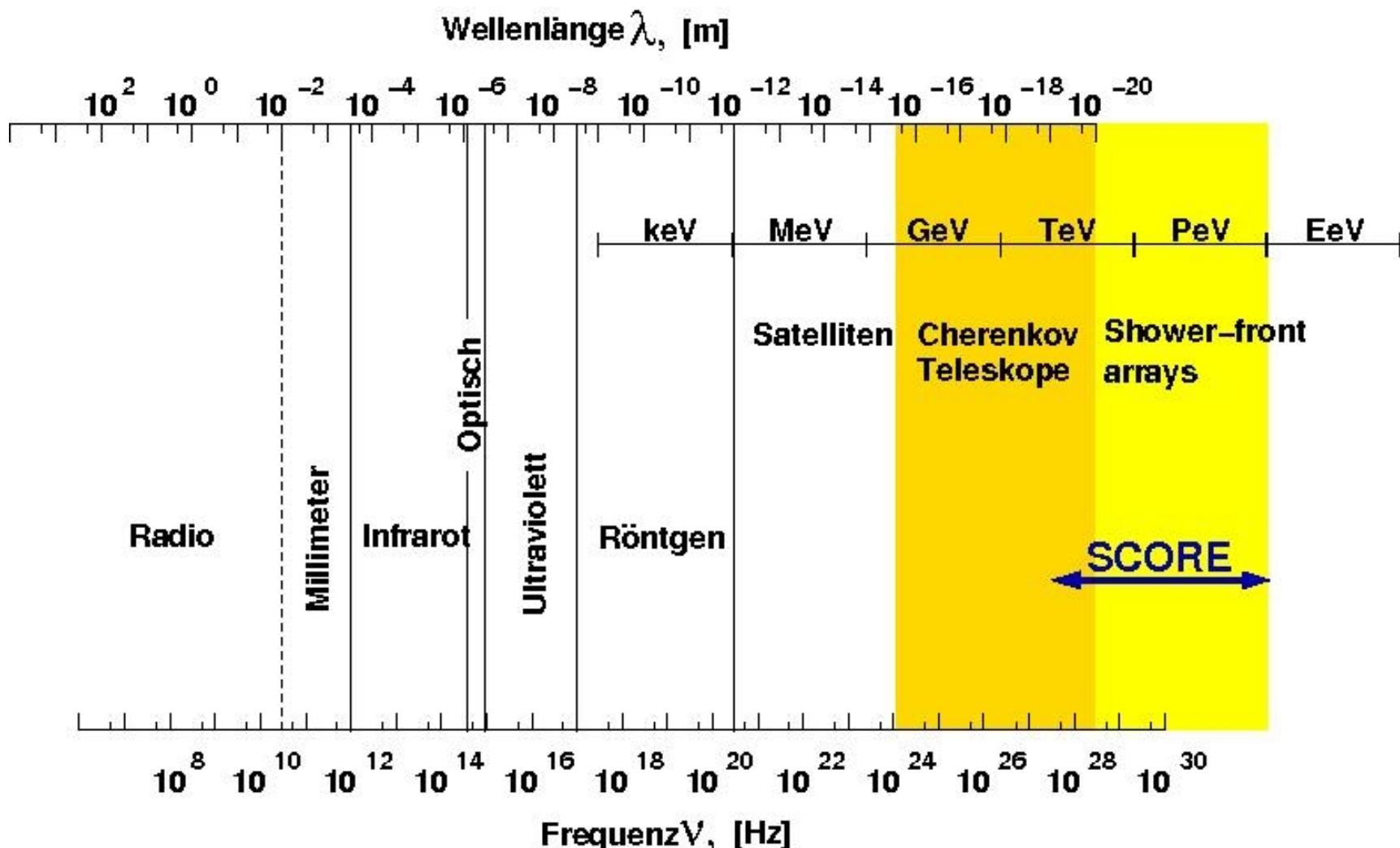
SUPPRESS NSB → Channel threshold as low as possible:

- Trigger threshold energy
- Station stacking: sum weak signals in concentric circles around core



→ Reconstruction: D. Hampf, this conf.

The last Observation Window



SCORE = Study for a Cosmic ORigin Explorer
Aim at: $10 \text{ TeV} < E < 1 \text{ EeV}$

(Some) Physics Cases for SCORE

Gamma-rays: $E > 10 \text{ TeV}$

Cosmic-Rays: $100 \text{ TeV} < E < 1 \text{ EeV}$

- **Astroparticle physics**
 - Origin of Cosmic-Rays
 - Unidentified sources: where do they stop?
 - Local Supercluster
 - Absorption in Galactic radiation fields and CMB
- **Particle physics**
 - Axion / hidden photon search (propagation)
 - Lorentz Invariance violation (propagation)
 - Measurement of p-p cross-section

Cherenkov Technique

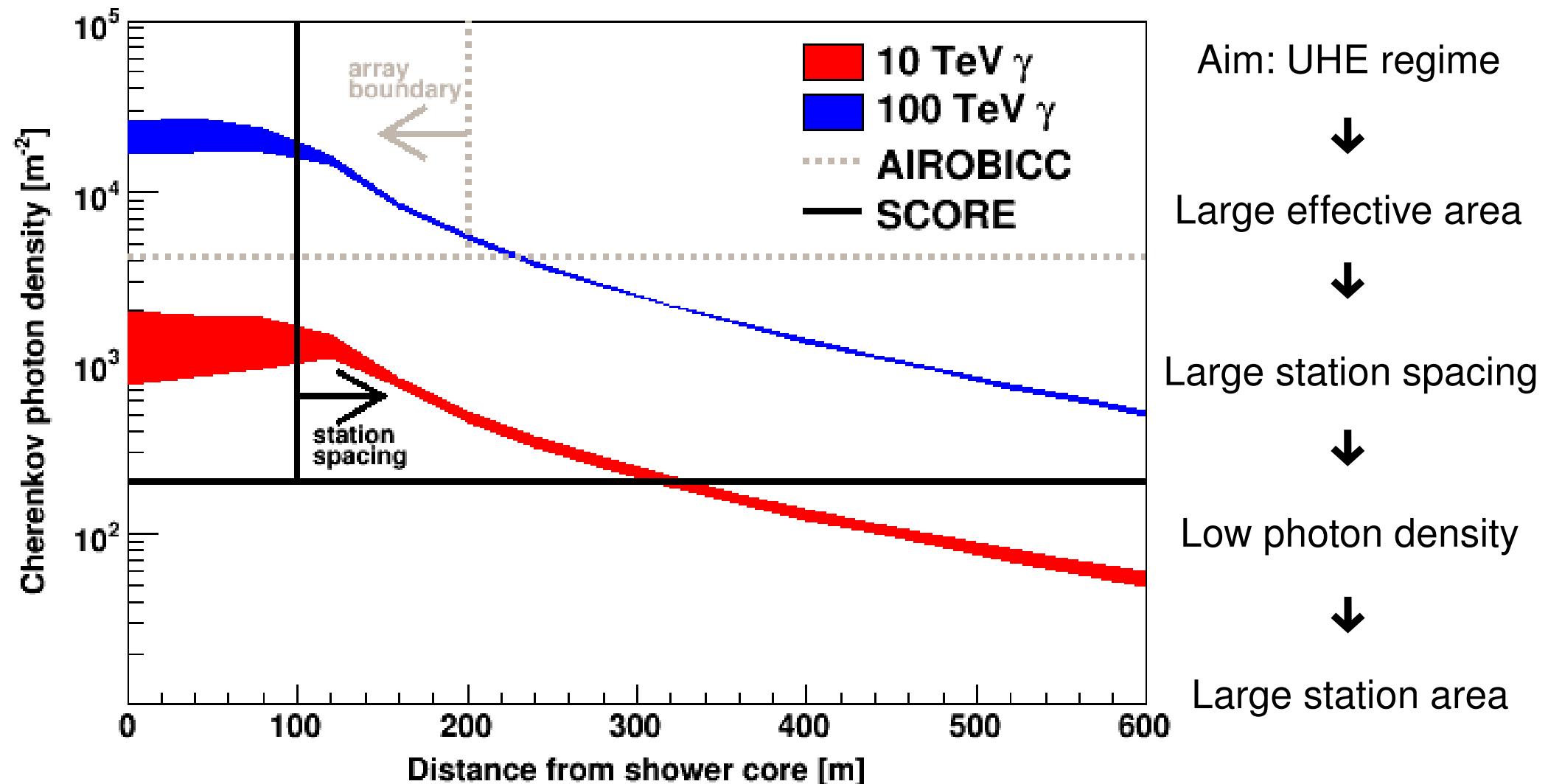
Challenges

- Gamma-hadron separation
- Night-Sky Background suppression

Benefits

- High photon-statistics per shower
- Channel-per-km² factor
 - IACTs: ~25000
 - SCORE: < 200
- **Lateral photon density distribution ...**

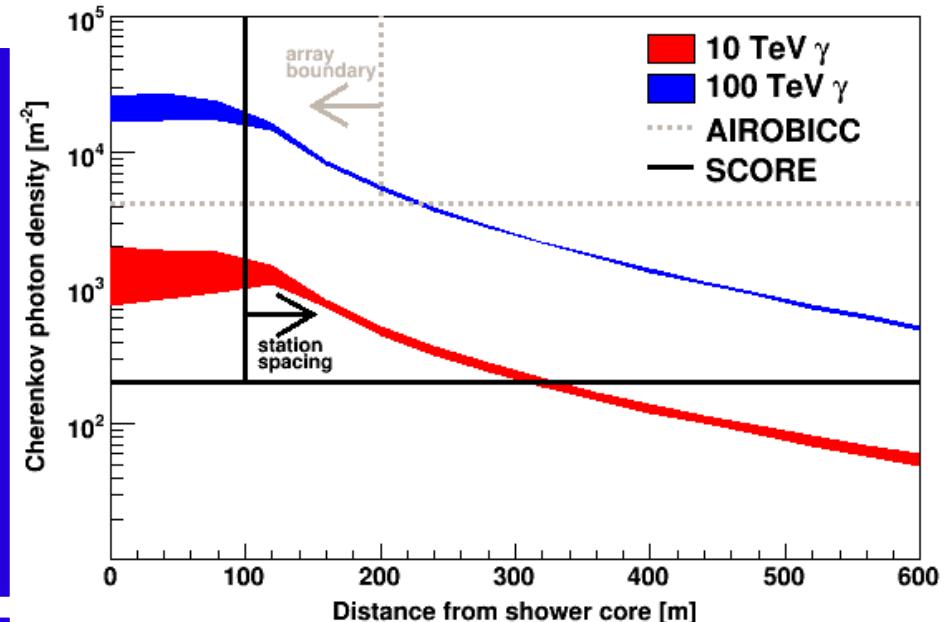
The SCORE Detector



Cherenkov Technique

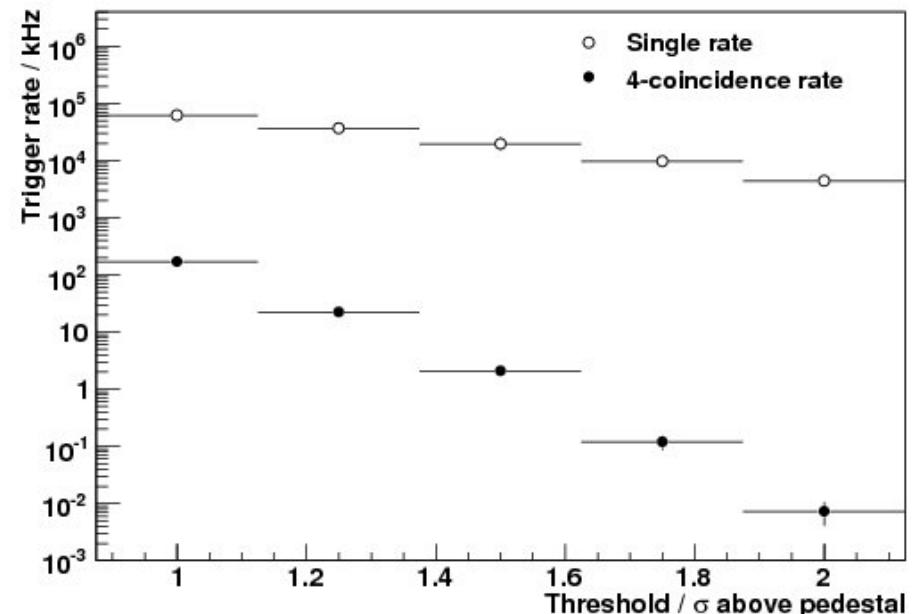
Benefits

- High photon statistics
- Lateral density falls off slowly
- >120m core: low fluctuations



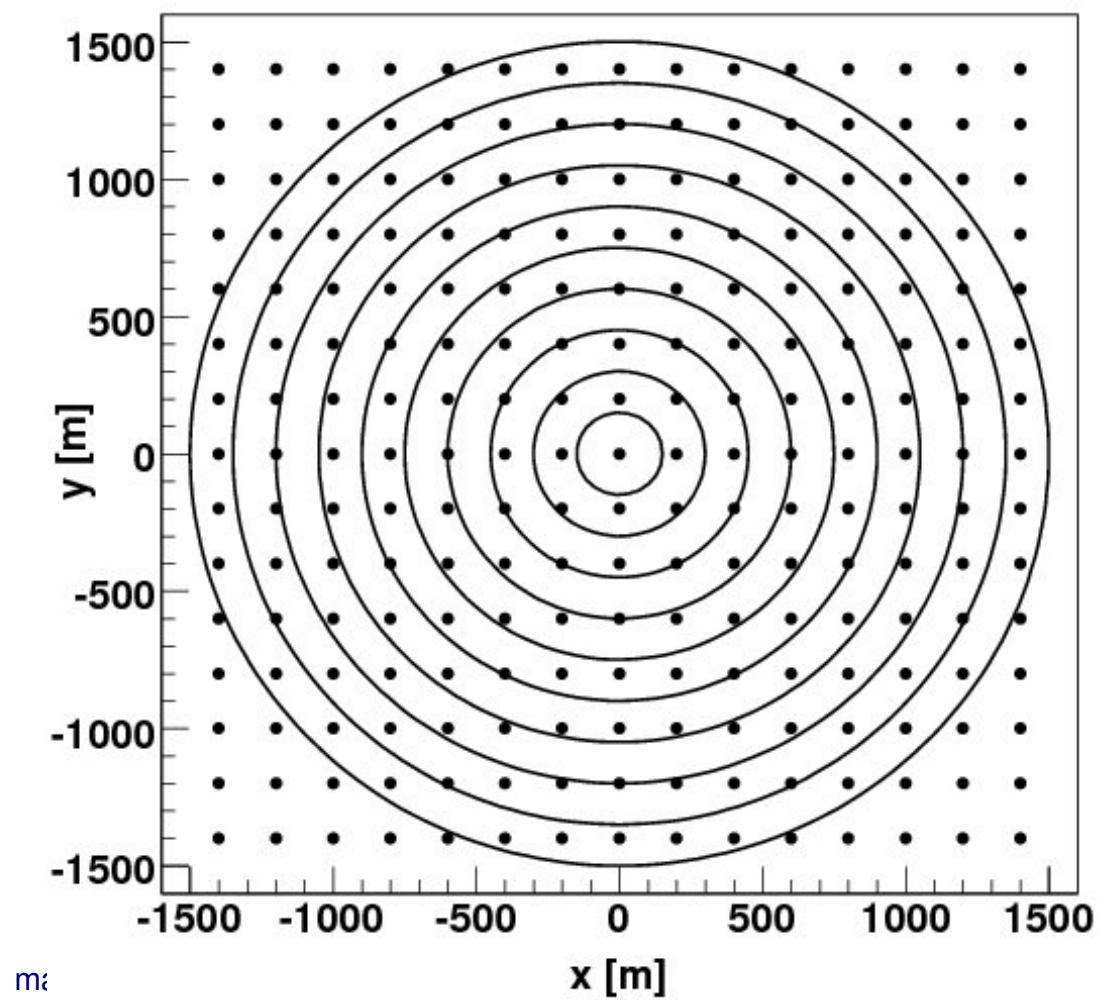
Limiting factors

- Channel-per-km²
 - IACTs: ~ 25000 (imaging)
 - SCORE: < 200 ! (non-imaging)
- Night-Sky-Background



Station Stacking

- Many stations with same core distance
- Stack stations
- Improves S/N



Shower-front sampling arrays

	SCORE	HiSCORE	TUNKA	BLANCA	AIROBICC
instrumented area [km ²]	10	100	1	0.2	0.04
detector station area [m ²]	~0.5	~0.5	0.2	0.1	0.13
field of view [sterad]	0.84	0.84	1.8	0.12	1
station spacing [m]	200	200	85	35	30
# of modules	256	2601	133	144	49