The HiSCORE Project

M. Tluczykont, D. Horns, D. Hampf, R. Nachtigall, U. Einhaus, M. Kunnas, M. Büker
University of Hamburg

G. P. Rowell
School of Chemistry and Physics, Adelaide

L. Kuzmichev, V. Prosin, L. Sveshnikova, E. Korosteleva

MSU

V. Zirakashvili, V. Ptuskin,

IZMIRAN

R. Wischnewski, C. Spiering

DESY

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DFG Deutsche Forschungsgemeinschaft

Outline

- **The HiSCORE detector**
- **Physics**
- **Hardware status**

HELMHOLTZ | GEMEINSCHAFT

HRJRG

HRJRG-303
Helmholtz Russia Joint Research Group

"Measurements of Gamma Rays and Charged Cosmic Rays in the Tunka-Valley in Siberia by Innovative New Technologies"

Starting 2012

G. Rubtsov, I. Tkatchev (*INR)*

A. Konstantinov, L. Kuzmichev (*MSU)*

R. Vasilyev, N. Budnev (*ISU)*

R. Wischnewski, C. Spiering (*DESY)*

F. Schröder, A. Haungs (*KIT)*

M. Tluczykont, D. Horns (*U. Hamburg)*

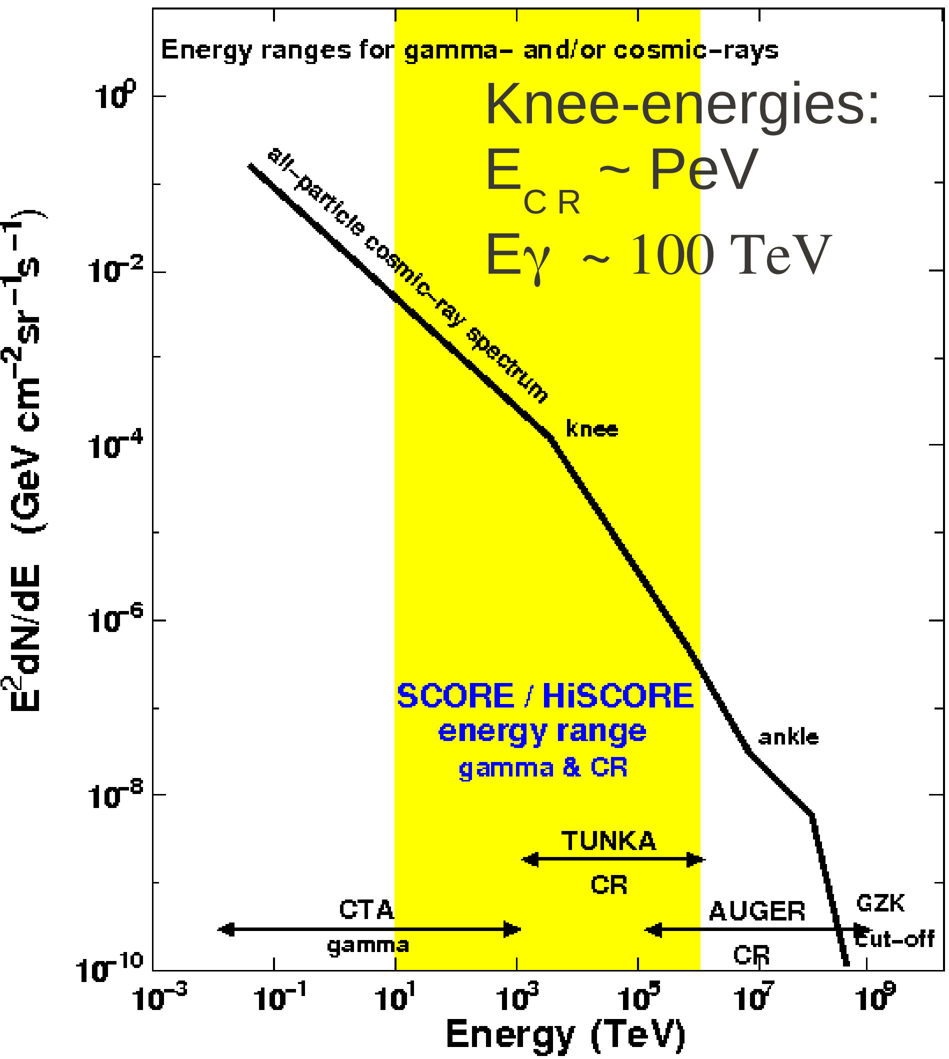
HiSCORE and Radio detectors @ Tunka

Innovation
Proof-of-principle
Synergies

THE HiSCORE DETECTOR

HiSCORE

- The **H**undred***i S**quare-km **C**osmic **OR**igin **E**xplorer



- **Cosmic-rays:**
  100 TeV < E_{CR} < 1 EeV
- **Gamma-rays:**
  $E\gamma$ > 10 TeV
- **Large area**: up to few 100 km²
- **Wide-angle**: ~ 0.6 sr
- **Concept:** non-imaging Cherenkov technique

"development of ground-based wide-angle gamma-ray Detectors"

ASPERA

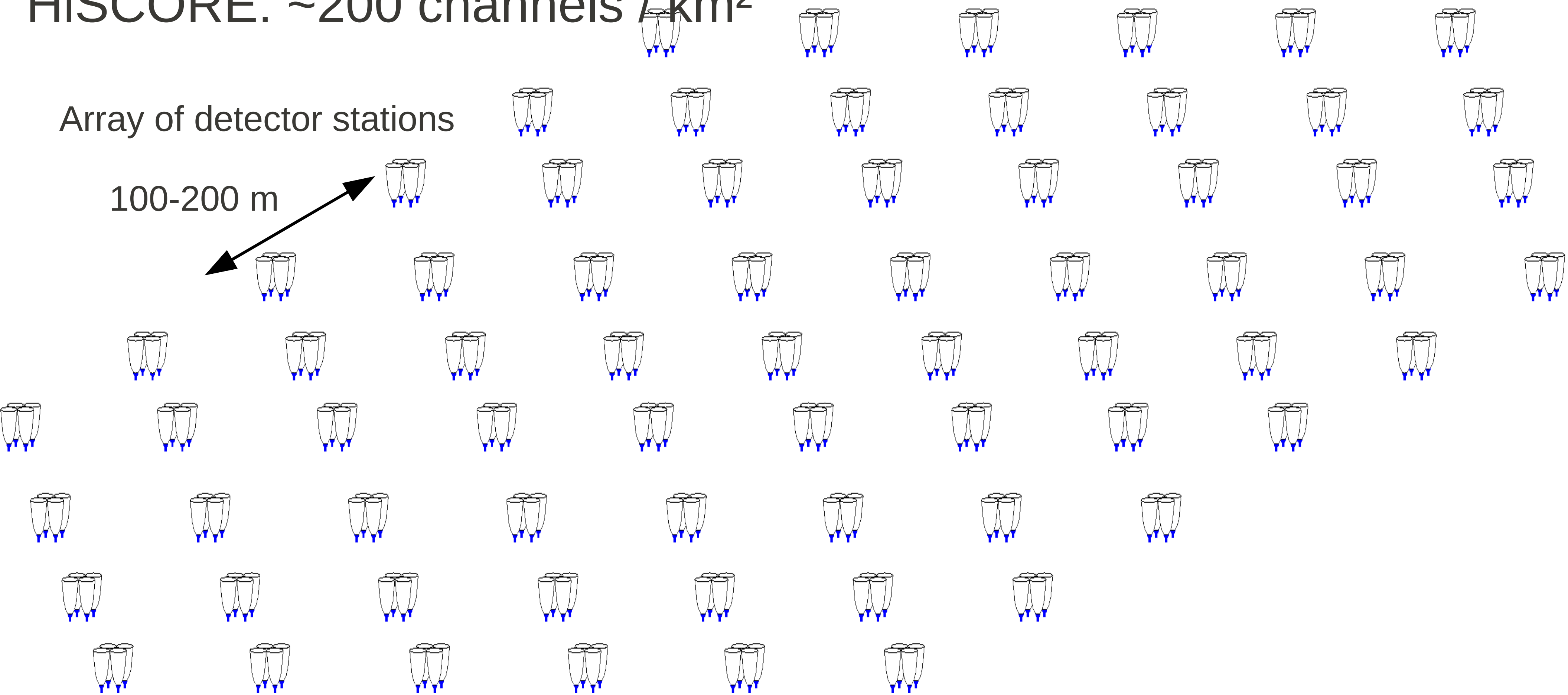
Latest version: ***SCORE*** *explicitly mentioned*

HiSCORE principles

Ultra-High energy regime: **need large effective area !**

Imaging ACTs: > 10000 channels / km²

Non-imaging Cherenkov light-front sampling
HiSCORE: ~200 channels / km²



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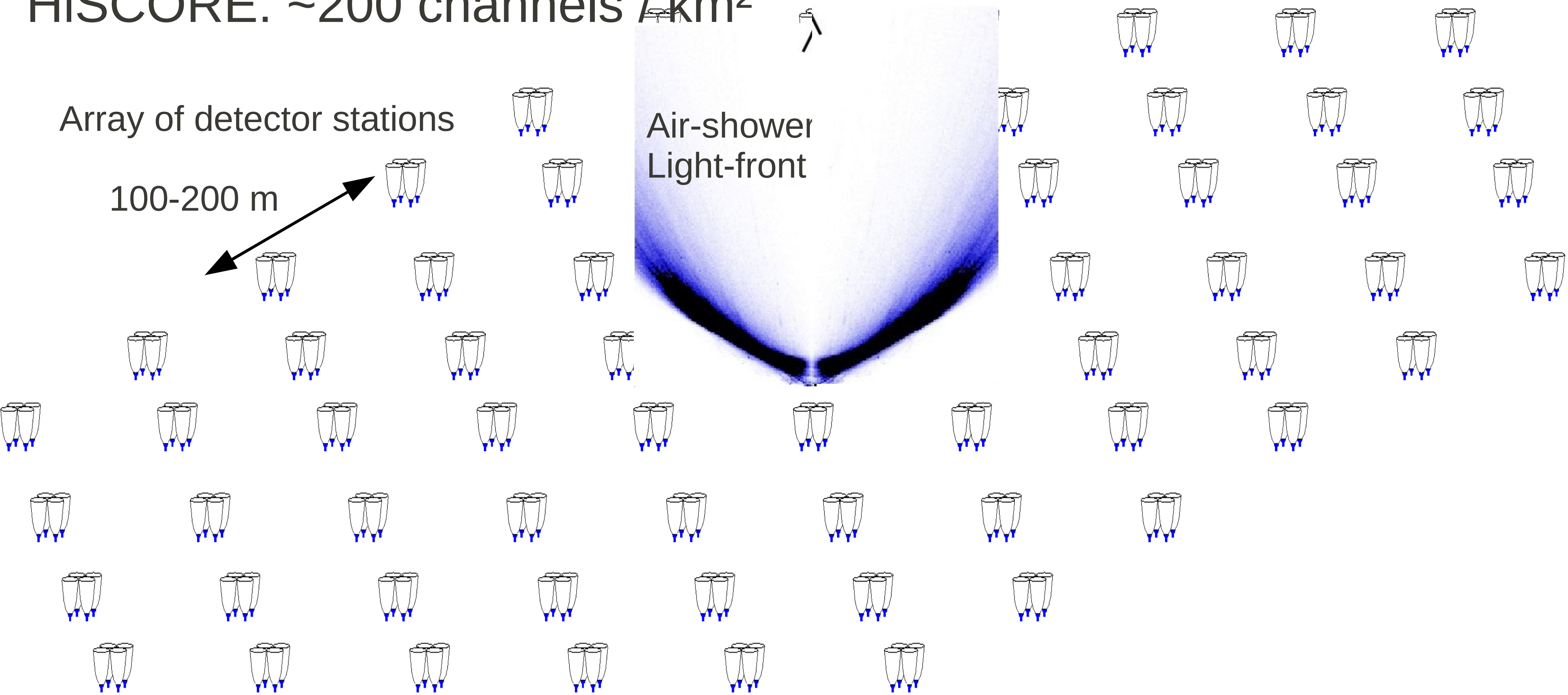
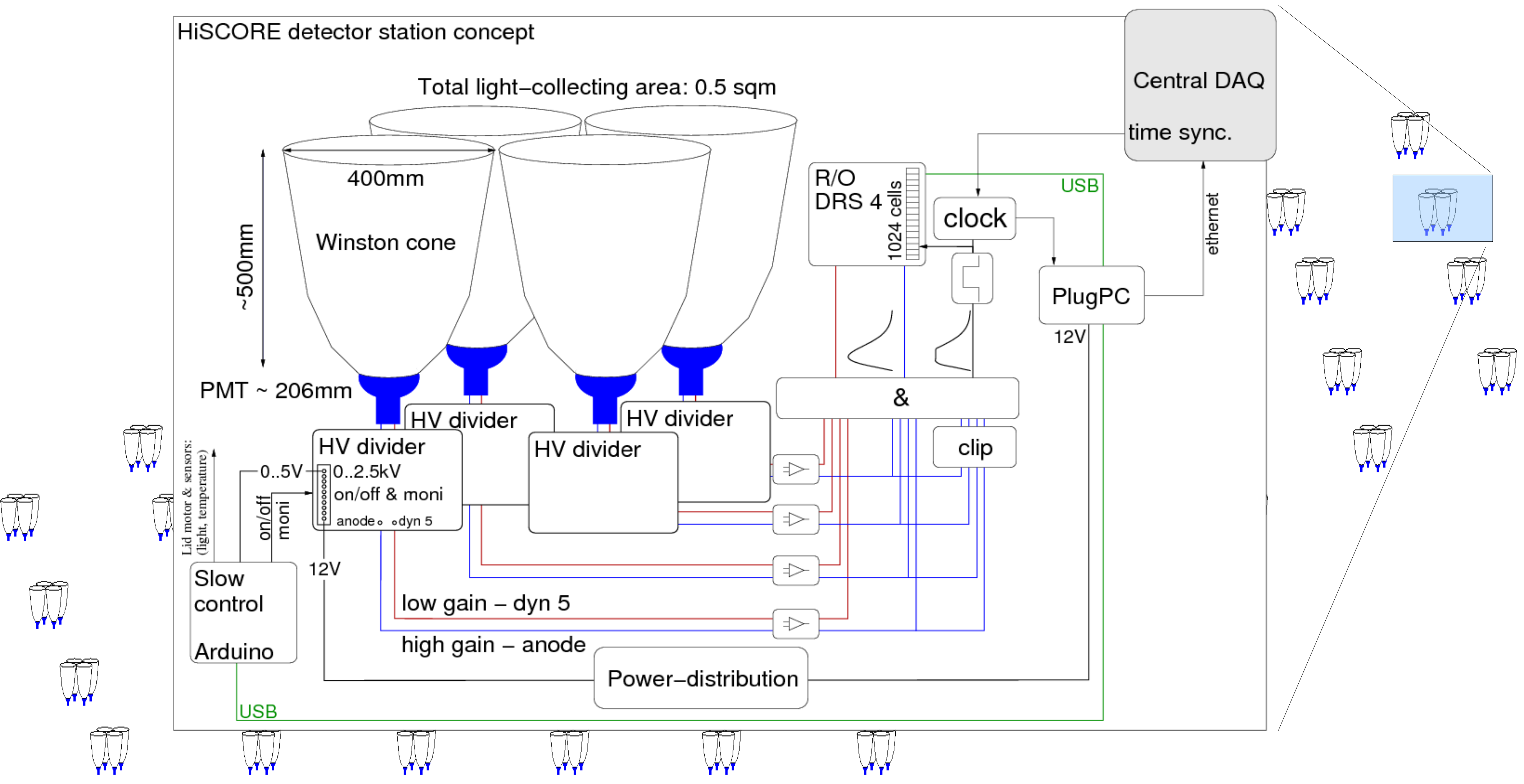


HiSCORE principles

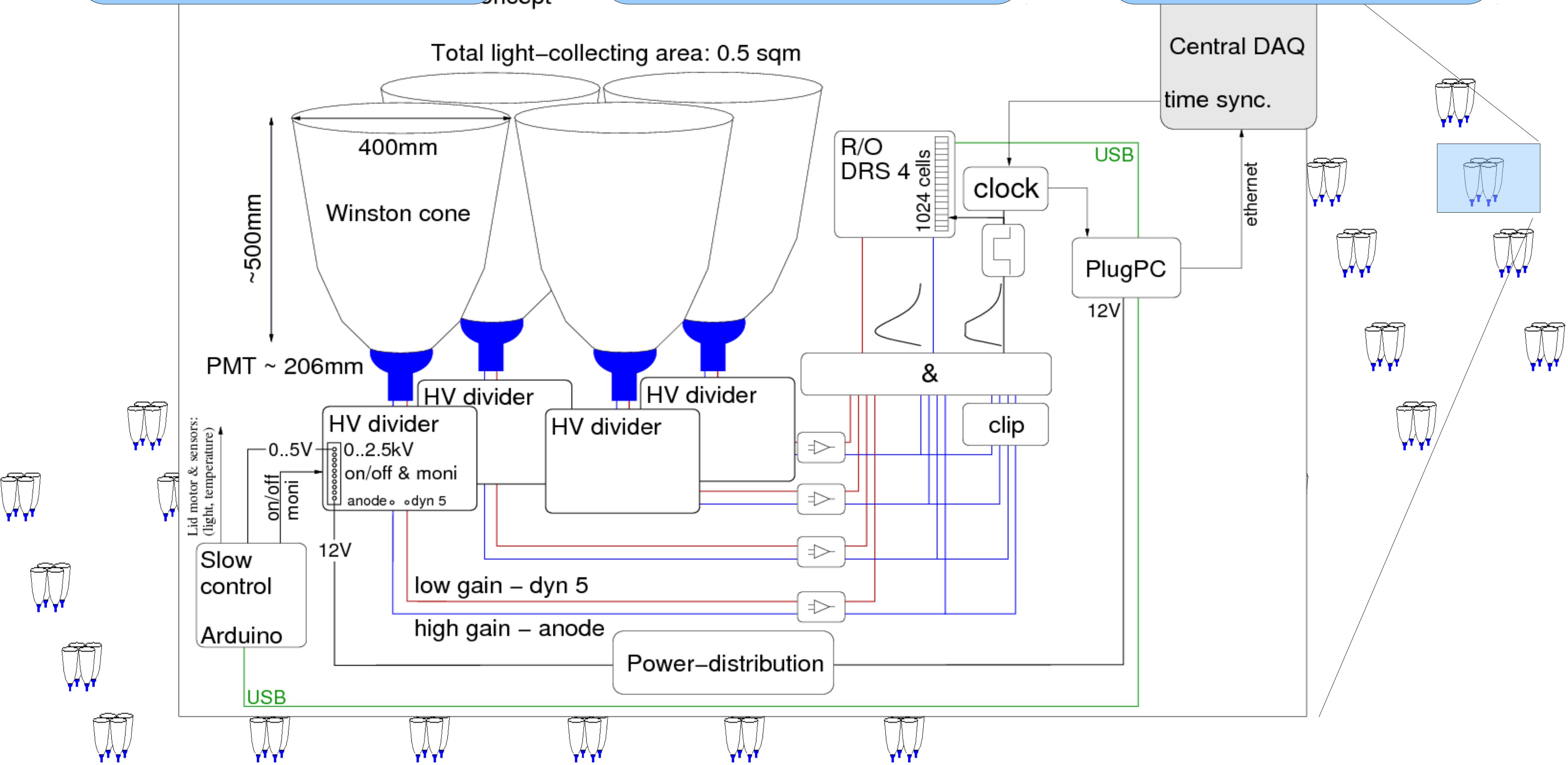


HiSCORE principles

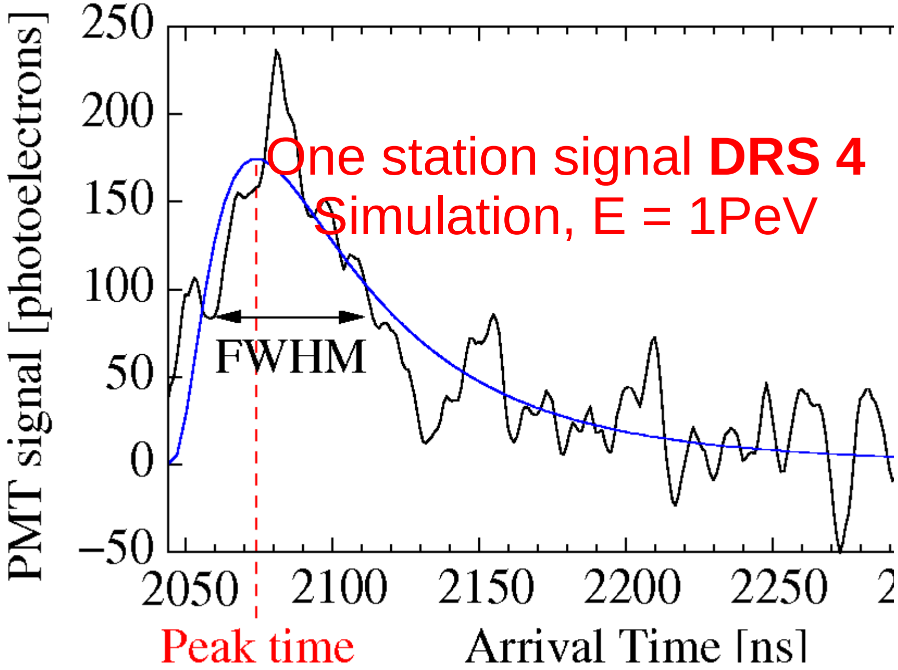
0.5 m² station area: E_{thr}

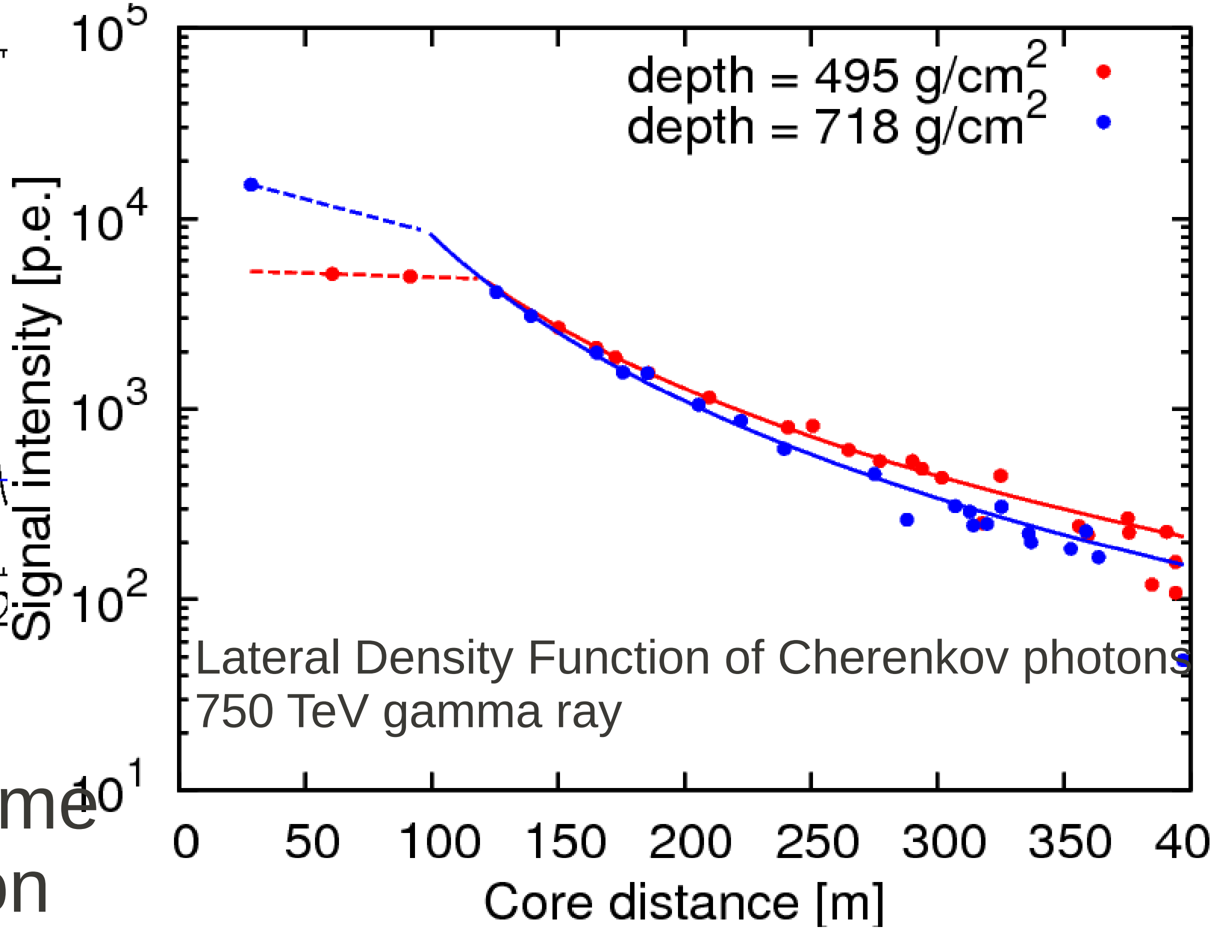
Readout: GHz sampling

1ns time synch.



HiSCORE principles





- **Reconstruction** using time and amplitude information
- **Gamma-hadron** separation:
  a) shower depth vs. energy
  b) signal rising edge

HiSCORE @ Tunka

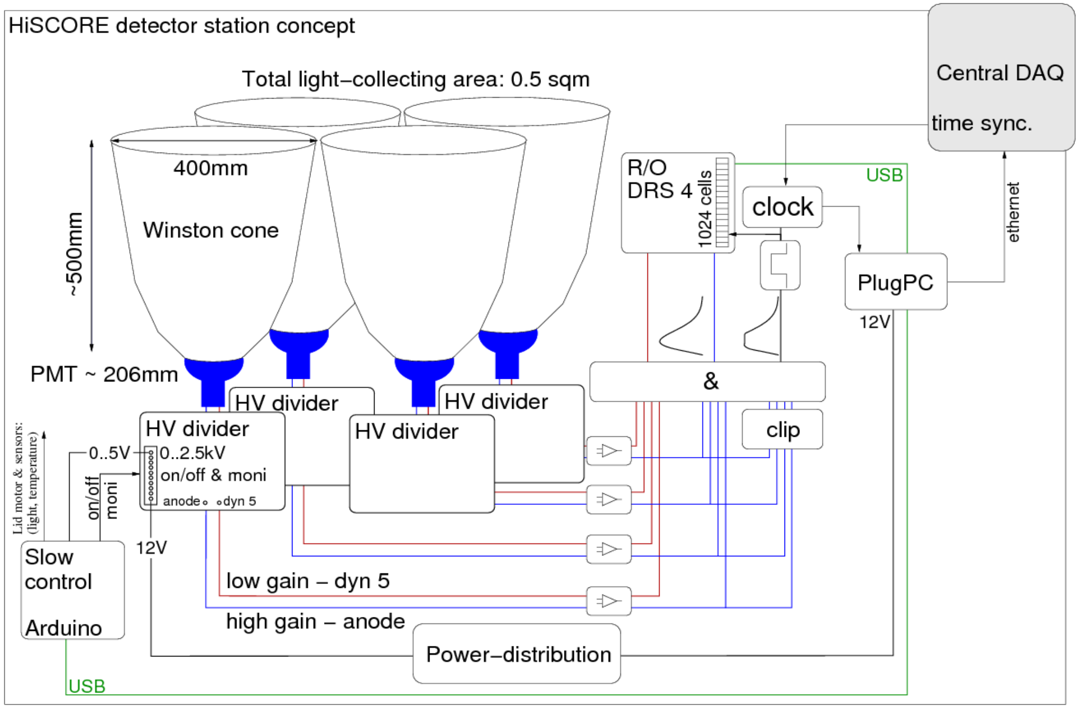
Within HRJRG:

- Build an engineering array at the Tunka site HiSCORE-EA → 1 km^2
- Proof-of-principle
- Synergies with Tunka & Radio detectors
- First physics

PHYSICS GOALS

Goals

Me: “Look that's what we want to build”
My wife: “Ah! It's a milking machine!”



Goals

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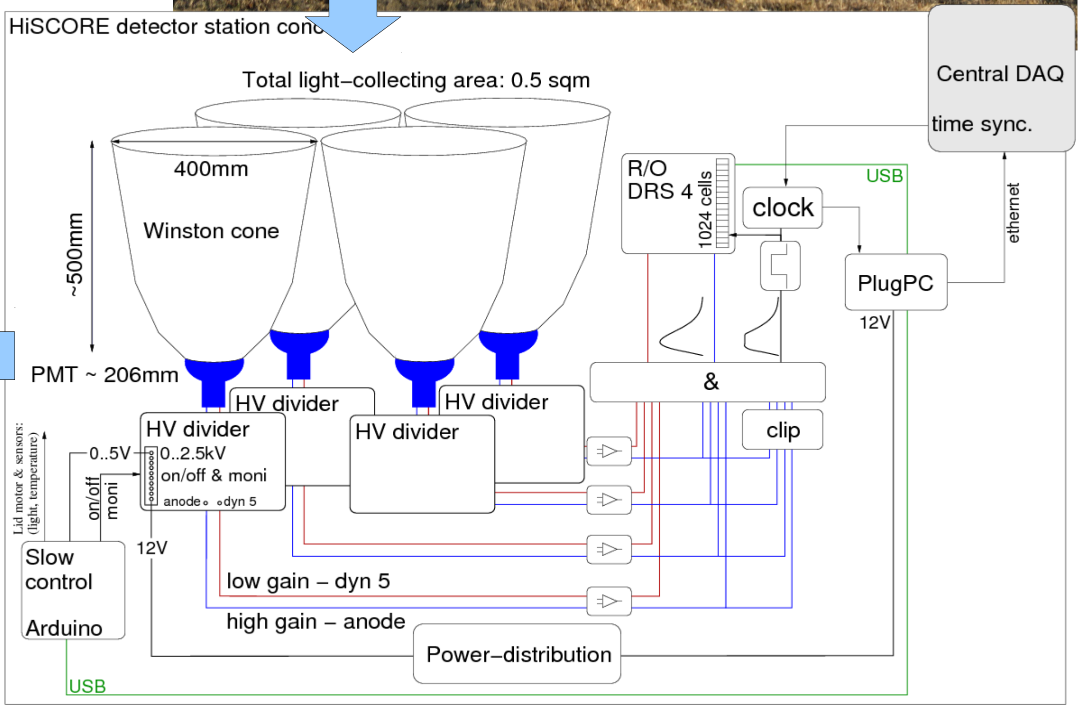


Smetana production ?

Goals

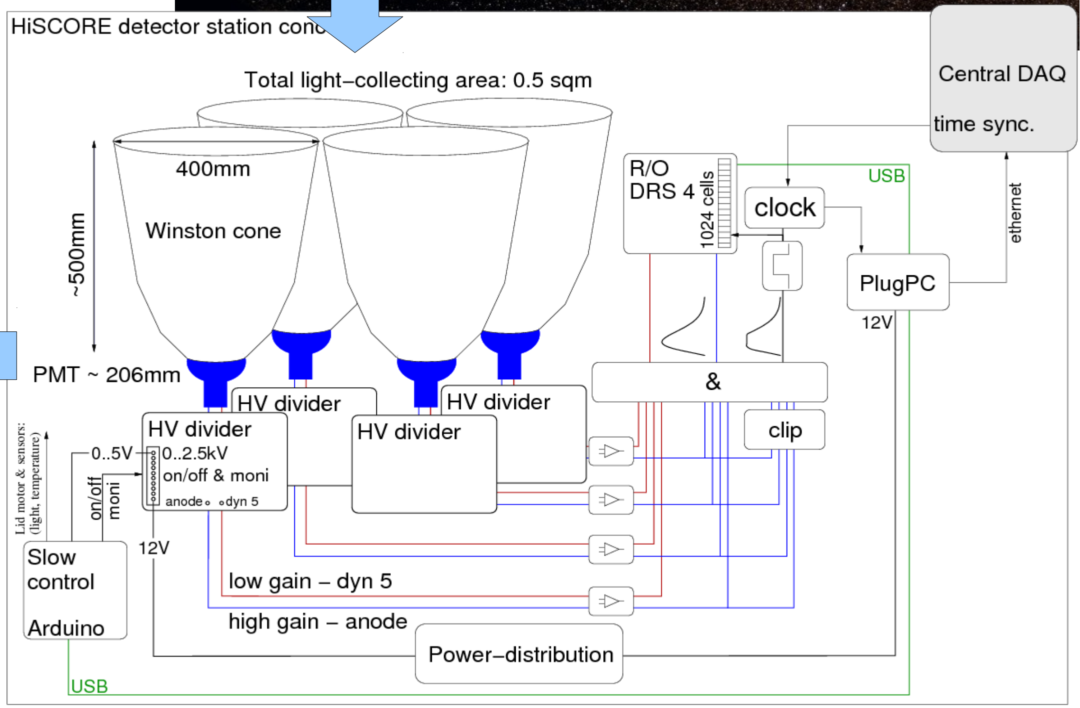
Me: “Look that's what we want to build”
My wife: “Ah! It's a milking machine!”

Important journal

Discovery of 1st pevatron

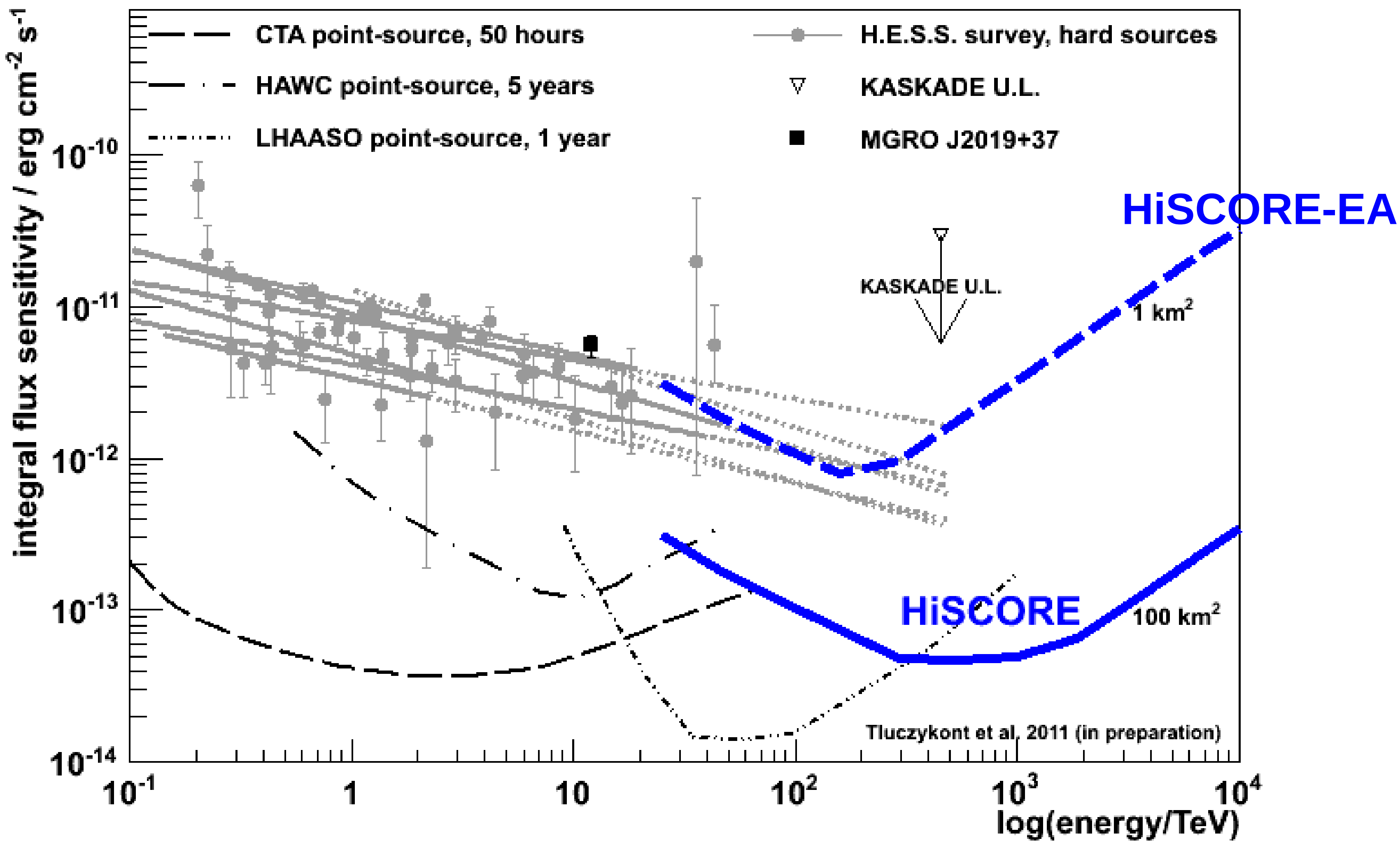
The HiSCORE-EA Cygnus region scan

100TeV photons from M87



Going beyond 10 TeV gamma-rays

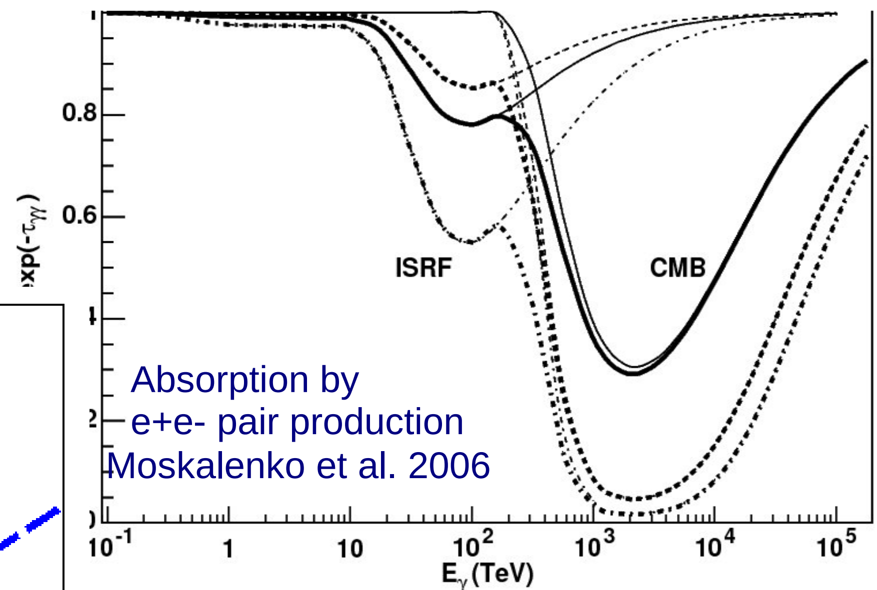
Ultra-High-Energy Gamma-ray observations window

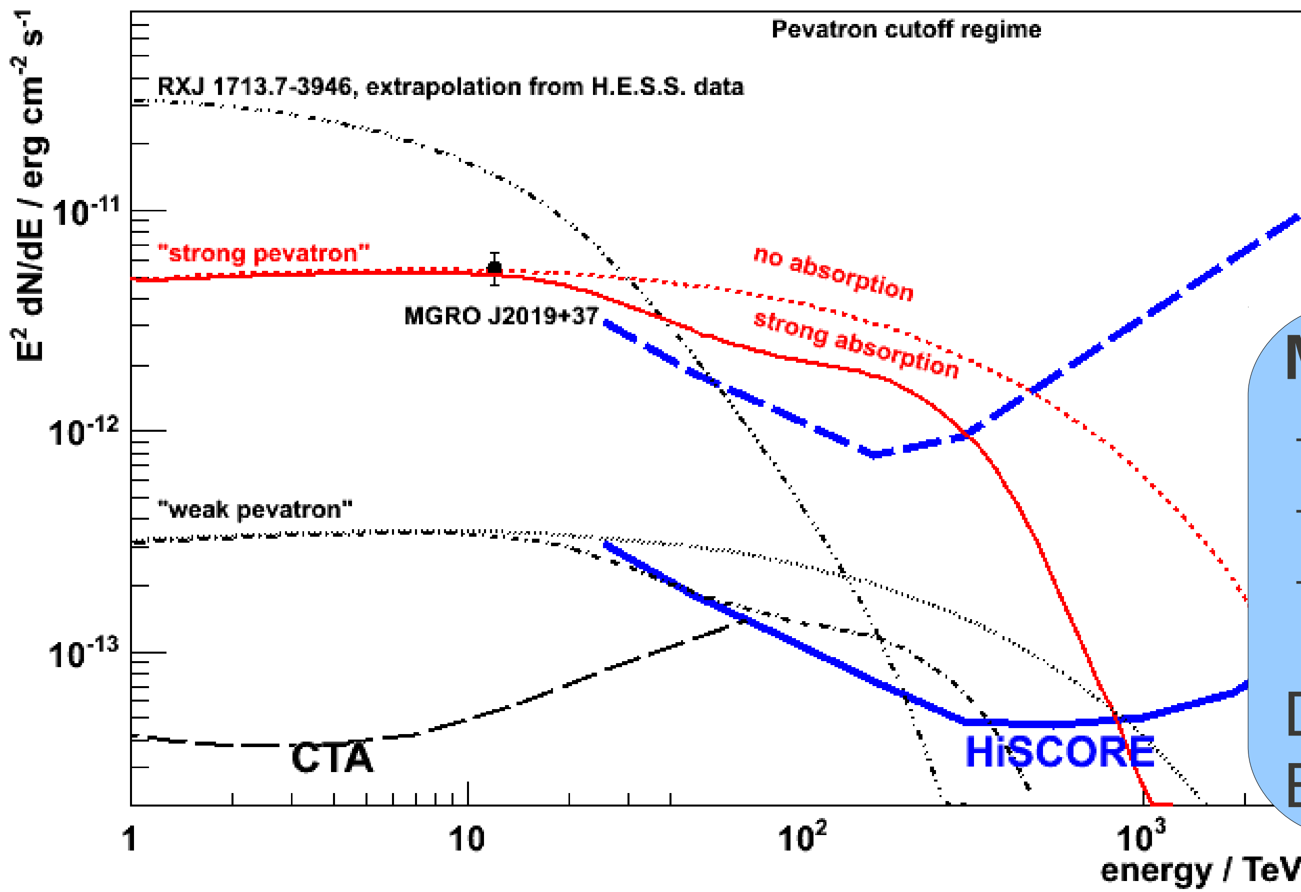


Galactic Pevatrons

- Galactic Absorption is relevant
  - ➔ ISRF @ 100 TeV
  - ➔ CMB @ 3 PeV

E~100TeV: absorption in ISRF relevant
E~1PeV: strong CMB absorption
→ use cutoff feature for distance measurement ?





Model:
→ pevatron model
→ MGRO J2019+37 scaling
→ include strong absorption

Detection possible with Engineering array !

Astroparticle Physics with HiSCORE

Charged cosmic ray physics

Composition
anisotropies
Sub-knee to pre-ankle

Gamma-ray Astronomy

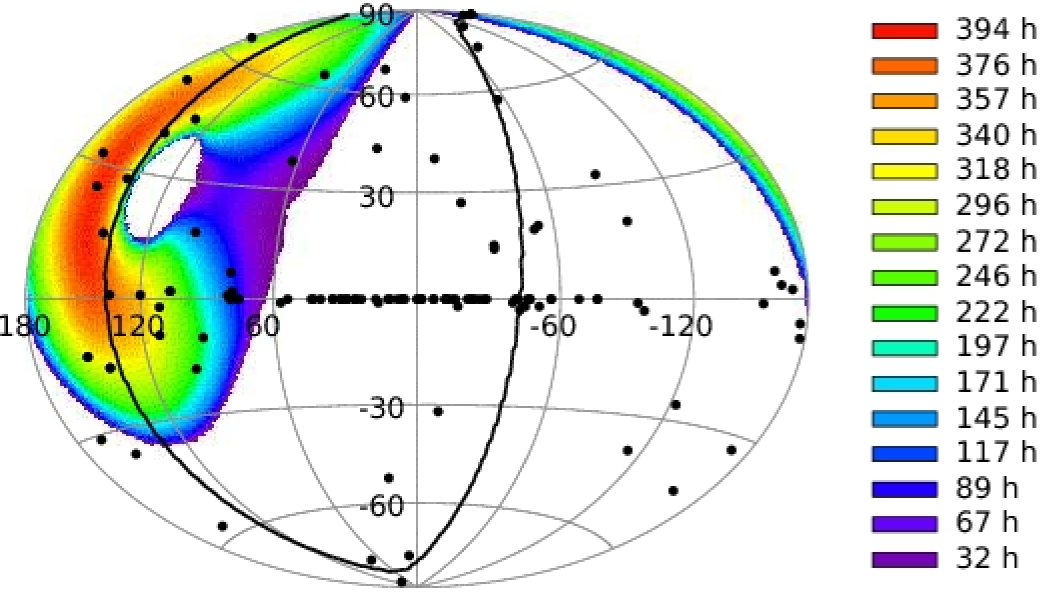
VHE spectra: where do they stop ?
Origin of cosmic rays: pevatrons
Absorption in IRF & CMB
Diffuse emission:

- Galactic plane
- Local supercluster

Particle physics beyond LHC

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

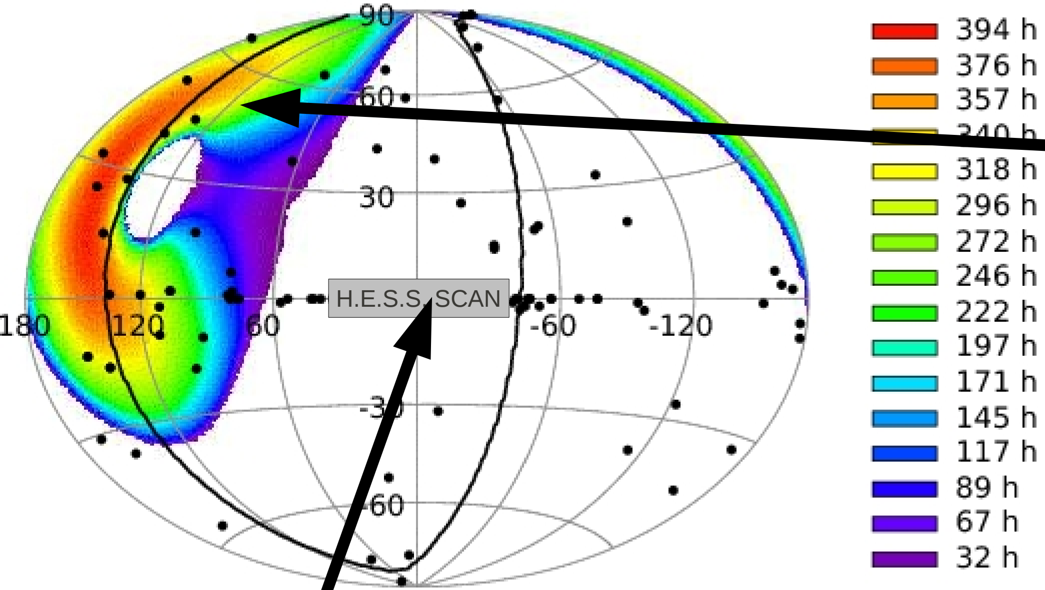
HiSCORE exposure



Tunka site exposure map

Field of view: π steradian

HiSCORE exposure



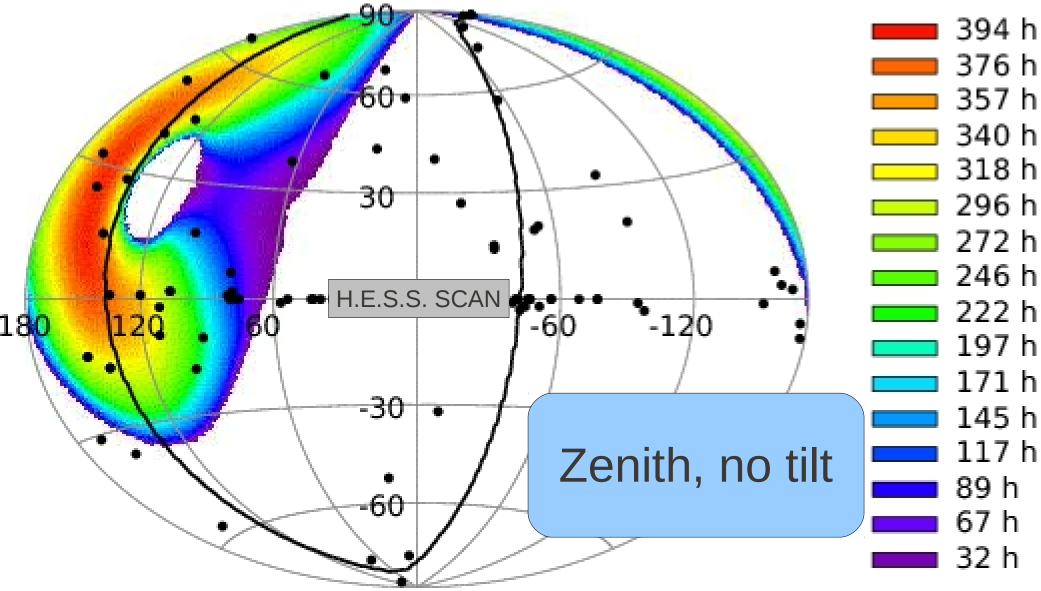
HiSCORE scan normal mode

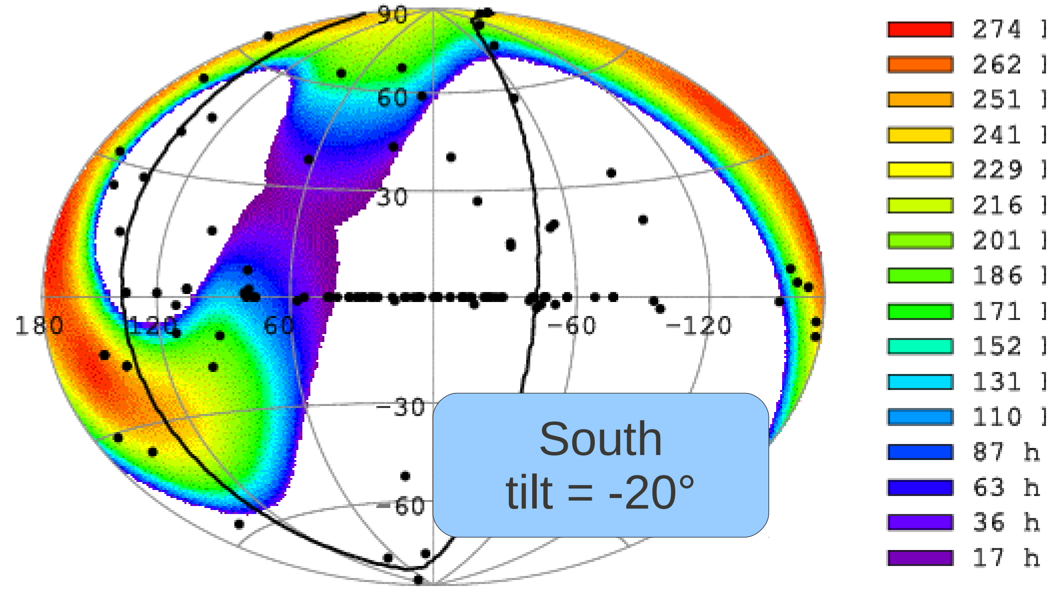
First H.E.S.S. Galactic plane scan

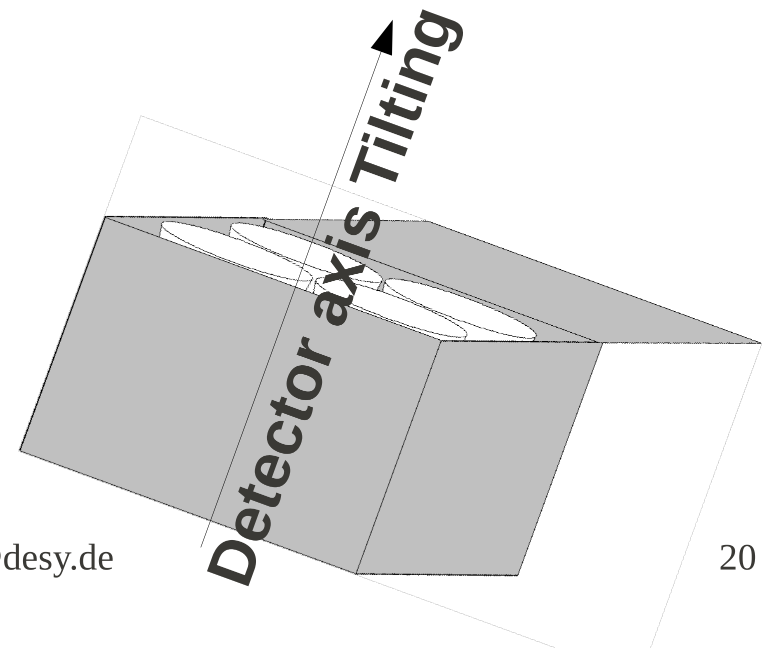
Tunka site exposure map

Field of view: π steradian

HiSCORE “pointing” = *tilting*







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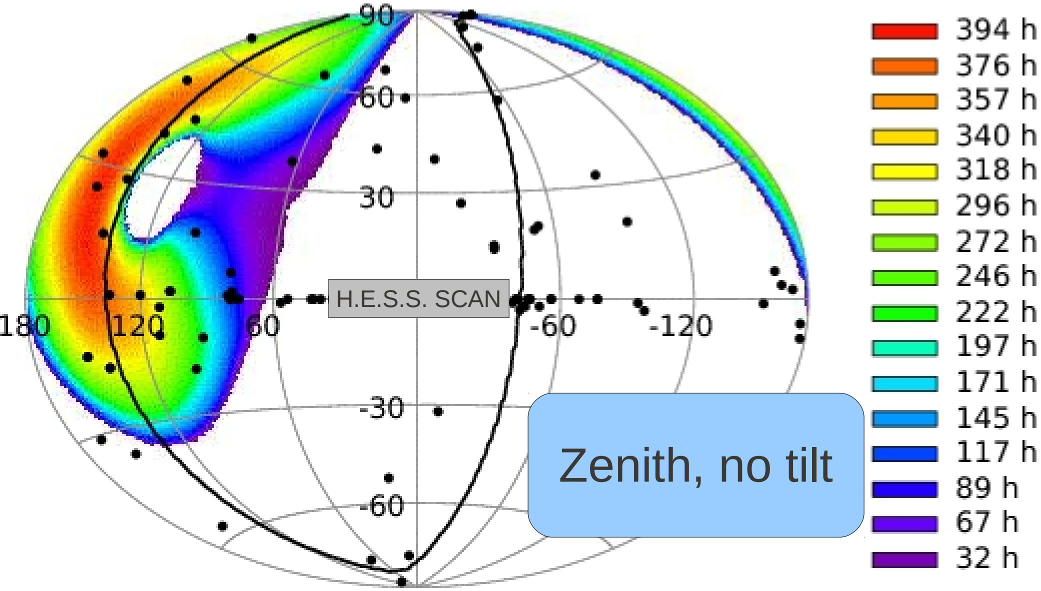
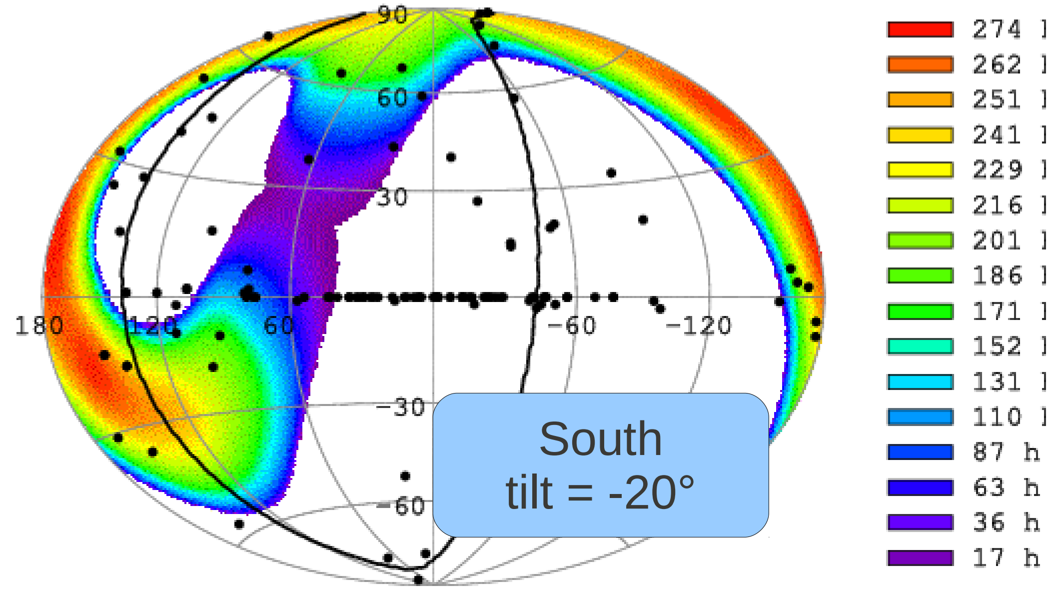
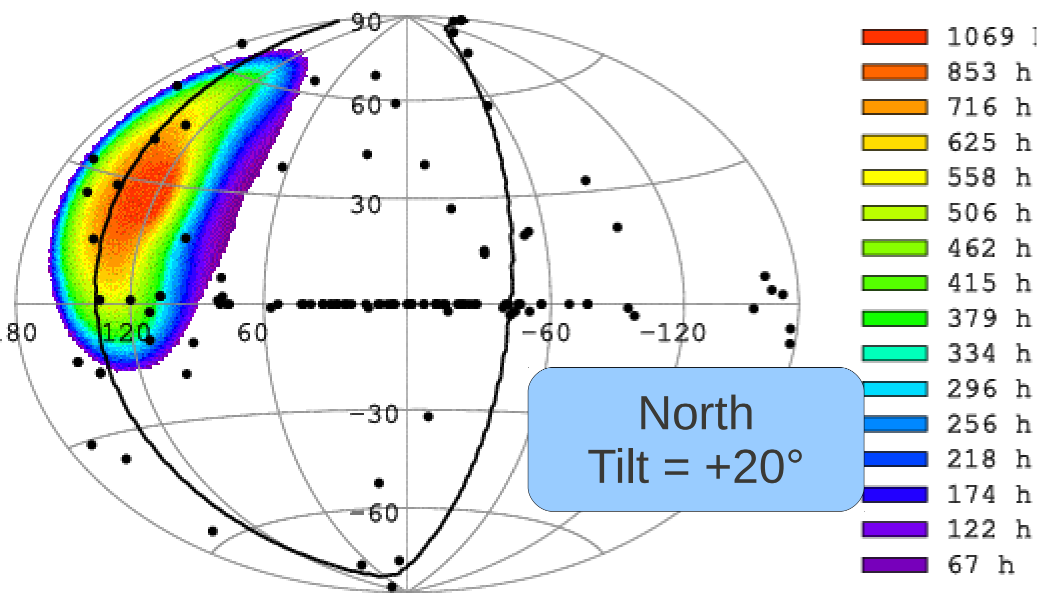
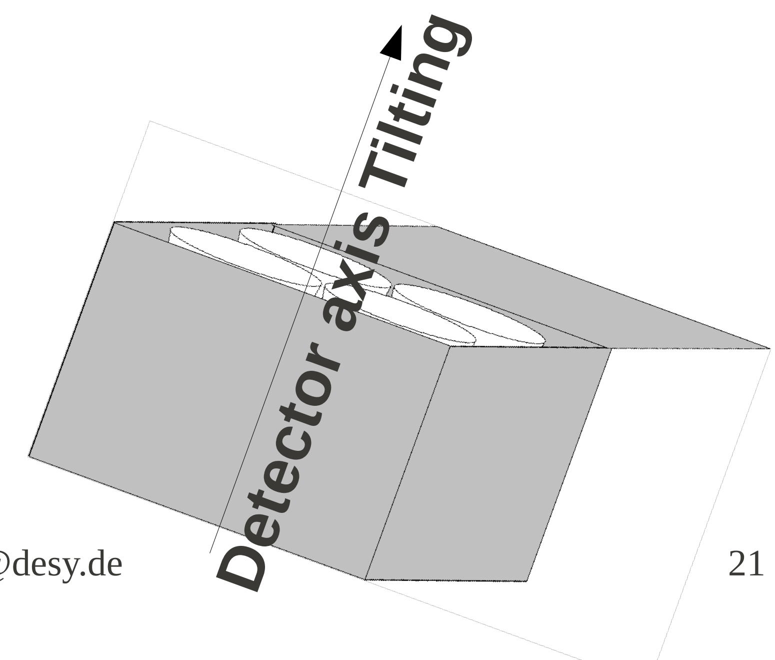








HiSCORE "pointing" = *tilting*

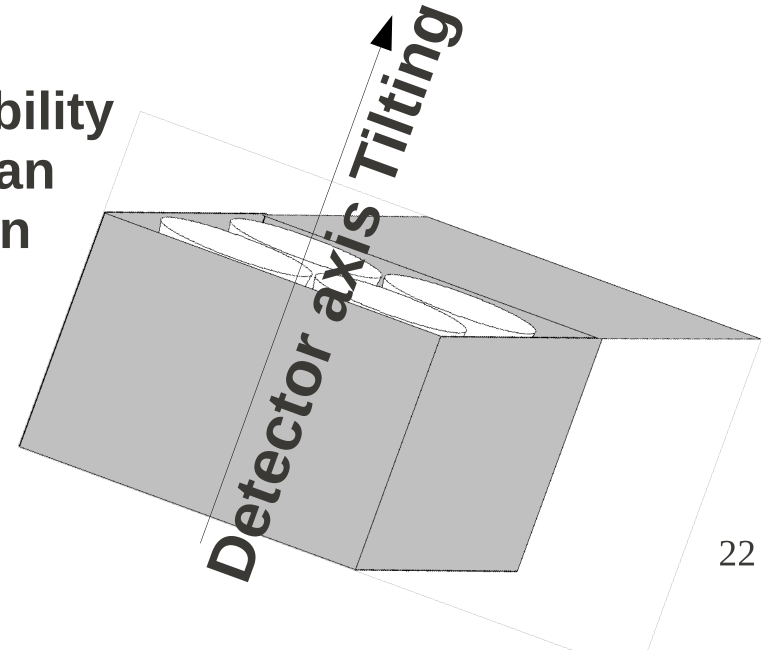
NORMAL | **SOUTH** | **NORTH**

Zenith			
Name	long.	lat.	Exp.
1ES 1218+304	-174°	82°	137 h
1ES 1215+303	-172°	82°	131 h
W Comae	-159°	83°	83 h
Markarian 501	63°	38°	57 h
MGRO J2019+37	75°	0°	97 h
MilagroDiffuse	76°	0°	103 h
H 1426+428	77°	64°	210 h
VER J2019+407	78°	2°	112 h
MGRO J2031+41	79°	0°	121 h
MAGIC J2001+435	79°	7°	107 h
TeV J2032+4130	80°	1°	126 h
BL Lacertae	92°	-10°	209 h
B3 2247+381	98°	-18°	213 h
1ES 1959+650	98°	17°	136 h
G106.3+2.7	106°	2°	275 h
Boomerang	106°	2°	275 h
Cassiopeia A	111°	-2°	312 h
1ES 2344+514	112°	-9°	312 h
Tycho	120°	1°	342 h
Markarian 180	131°	45°	305 h
LSI +61 303	135°	1°	377 h
3C66A	140°	-16°	307 h
MAGIC J0223+403	140°	-16°	307 h
M82	141°	40°	332 h
1ES 0502+675	143°	15°	367 h
S5 0716+714	143°	28°	307 h
IC 310	150°	-13°	308 h
NGC 1275	150°	-13°	308 h
RGB J0710+591	157°	25°	394 h
1ES 1011+496	165°	52°	348 h
1ES 0806+524	166°	32°	373 h
Markarian 421	179°	65°	255 h

Tilted SOUTH			
Name	long.	lat.	Exp.
3C66A	140°	-16°	244 h
MAGIC J0223+403	140°	-16°	244 h
1ES 0229+200	152°	-36°	221 h
IC 310	150°	-13°	261 h
NGC 1275	150°	-13°	261 h
RBS 0413	165°	-31°	218 h
VER J0521+211	-177°	-8°	234 h
Crab	-176°	-5°	239 h
IC443	-171°	2°	240 h
Geminga	-165°	3°	206 h
VER J0648+152	-162°	6°	194 h
1ES 0806+524	166°	32°	181 h
1ES 1011+496	165°	52°	205 h
Markarian 421	179°	65°	250 h
1ES 1215+303	-172°	82°	239 h
1ES 1218+304	-174°	82°	240 h
W Comae	-159°	83°	235 h
4C +21.35	-105°	81°	204 h
M87	-77°	74°	127 h
PKS 1424+240	29°	68°	179 h
H 1426+428	77°	64°	185 h
1ES 1440+122	8°	59°	101 h
PG 1553+113	21°	43°	47 h
Markarian 501	63°	38°	52 h
W49B	43°	0°	7 h
HESS J1912+101	44°	0°	11 h
G54.1+0.3	54°	0°	44 h
HESS J1943+213	57°	-1°	56 h
MAGIC J2001+435	79°	7°	82 h
MGRO J2019+37	75°	0°	103 h
VER J2019+407	78°	2°	102 h
MilagroDiffuse	76°	0°	106 h
MGRO J2031+41	79°	0°	112 h
TeV J2032+4130	80°	1°	110 h
BL Lacertae	92°	-10°	181 h
B3 2247+381	98°	-18°	206 h
1ES 2344+514	112°	-9°	151 h

Tilted NORTH			
Name	long.	lat.	Exp.
Local Supercluster		≈xx h	
Tycho	120°	1°	506 h
LSI +61 303	135°	1°	525 h
1ES 0502+675	143°	15°	680 h
RGB J0710+591	157°	25°	507 h
S5 0716+714	143°	28°	791 h
1ES 0806+524	166°	32°	322 h
M82	141°	40°	712 h
1ES 1011+496	165°	52°	228 h
Markarian 180	131°	45°	626 h
1ES 1959+650	98°	17°	272 h
G106.3+2.7	106°	2°	344 h
Boomerang	106°	2°	344 h
Cassiopeia A	111°	-2°	382 h
1ES 2344+514	112°	-9°	272 h

Flexibility of scan region



Event rate estimation

University of Hamburg:

- Spectrum → Generate random event list
- Fold with effective area, angular resolution energy response
- Estimate exposure time for individual sources

→ **Predicted reconstructed HiSCORE spectrum**

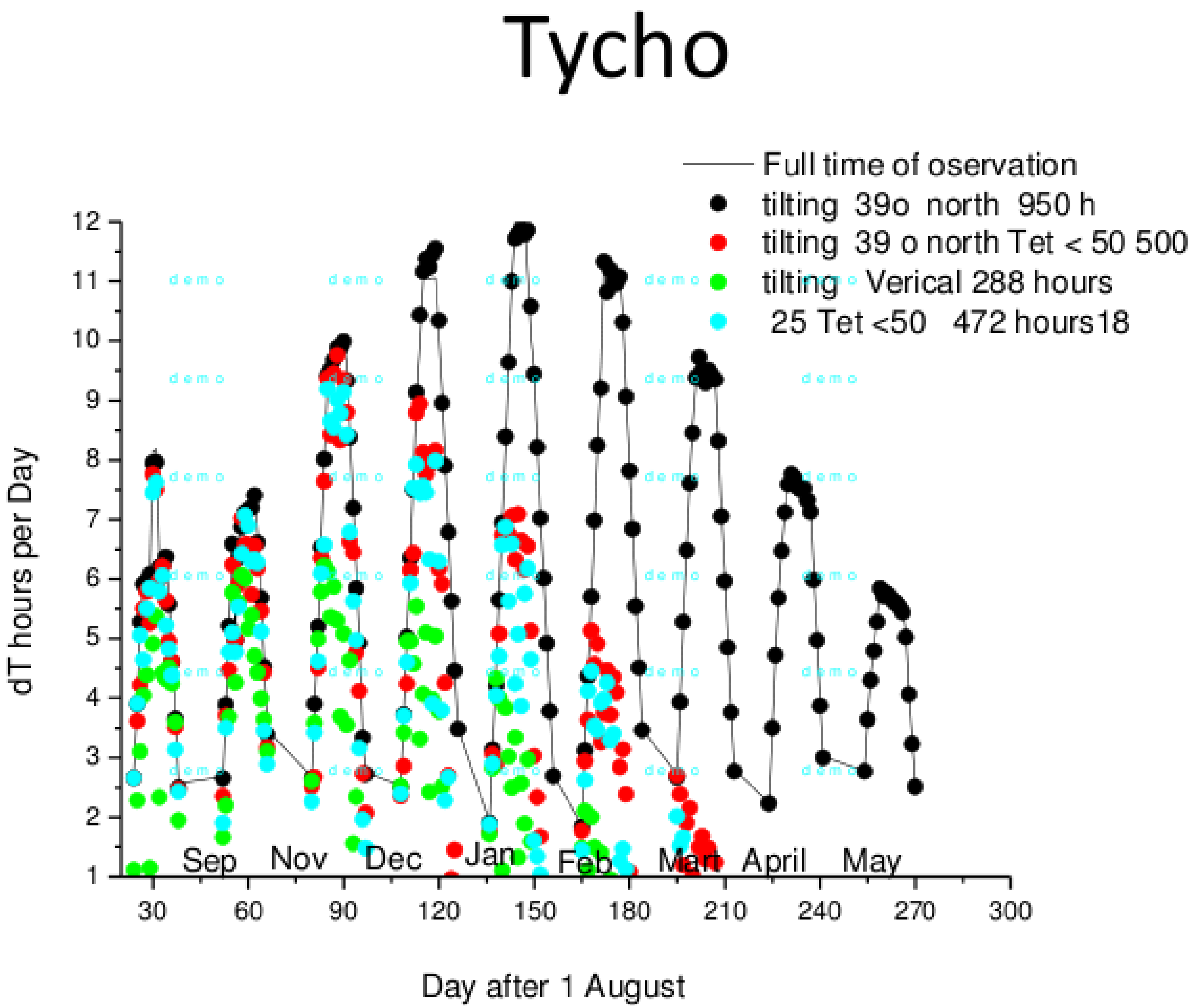
Moscow State University:

- Estimate exposure time for individual sources
- Extrapolate known sources spectra

→ **Estimated event rates**

Event rates

Preliminary



Event rates

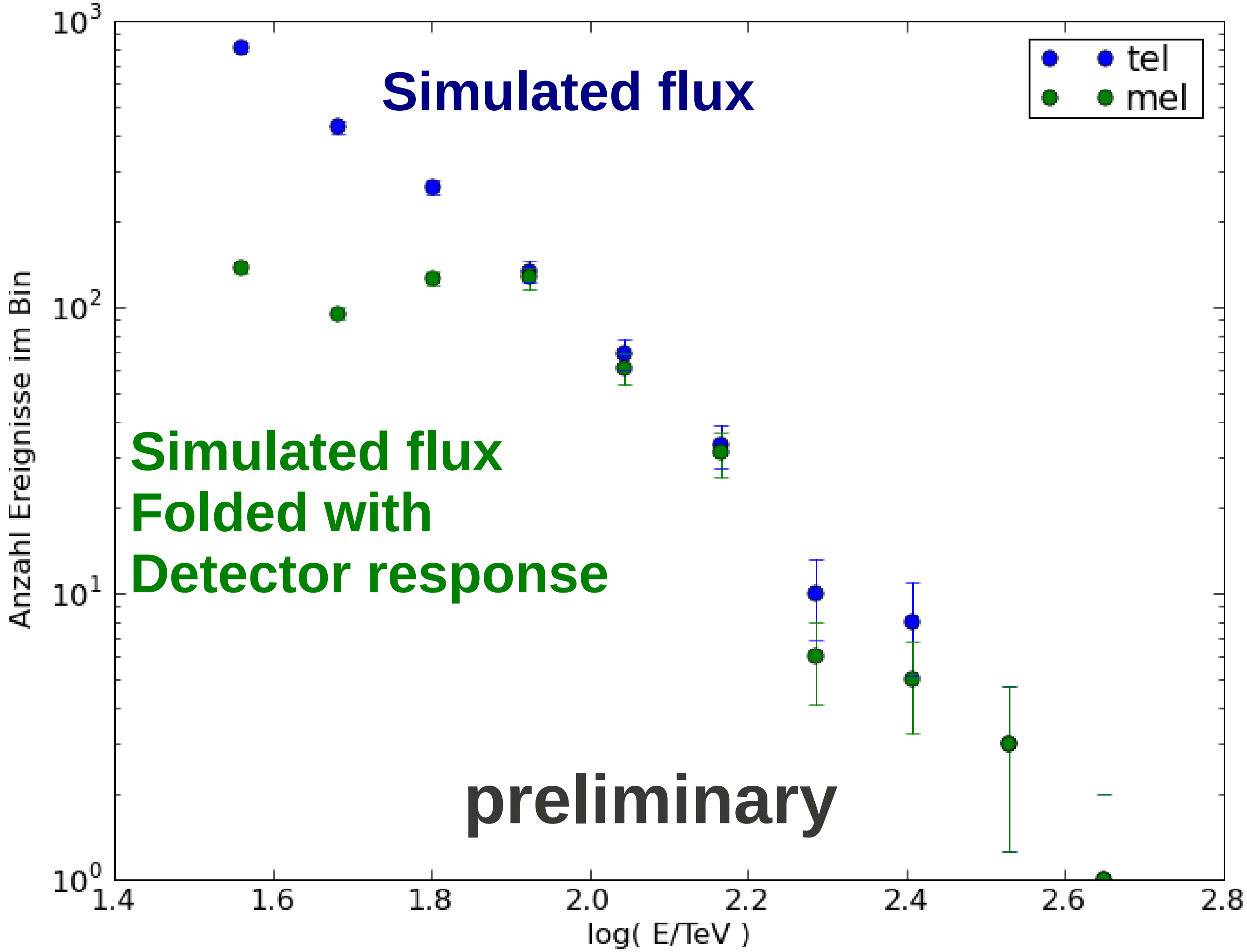
Efficient observation of large declinations

Preliminary

Name	RA degrees	Decl	GL	GB	Flux F at 1 TeV, $10^{-12}cm^{-2} s^{-1}TeV^{-1}$	Γ	Flux F at 35 TeV, $10^{-17}cm^{-2} s^{-1}TeV^{-1}$	Comment	Ref.	dT hour (dT/2)	N>20TeV* event/ year int-1TeV	N>20** TeV Event/ year	N>35*** TeV event/ year
MGRO J2019+37	305.024	36.7191	75.0	0.2			8.7 1.4	Extended: 1.1deg, PSR, flux at 20 Tev 10^{-15}	1	48		576	
J2021.5+4026	305.40	40.44	78.23	2.07			35.8 8.5	PSR PWN	2	54			46
MGRO C2	307.747	36.5184	76.1	-1.7			3.4 0.8	PWN Flux at 20 TeV 10^{-15}	1	52		245	
TeV J2032+4130	308.029	41.5083	80.254	1.074	0.45 0.03	2.0 0.3	63.3 8.3	UnID: Cyg OB2? / MGO J2031+41 PSR	2,15	60	130		90
MGRO J2031+41	308	41	80.3	1.1			9.8 2.9	Flux at 20 TeV 10^{-15}	1	40		200	
MGRO C1	310.976	36.3057	77.5	-3.9			3.1 0.6	PWN Flux at 20 TeV 10^{-15}	1	57		246	
SNR G106.6+2.9 J2229.0+6114	337.26	61.34	106.64	2.96	1.42 0.33 0.41	2.29 0.33 0.30	70.9 10.8	PSR MGRO C4 PWN Bumerang	2,5	140	290		240
Cas A	350.853	58.8154	111.736	-2.13	1.26 0.18	2.61 0.24 0.2		SNR, G111.7-2.1	6	162	92		

Event rate estimation

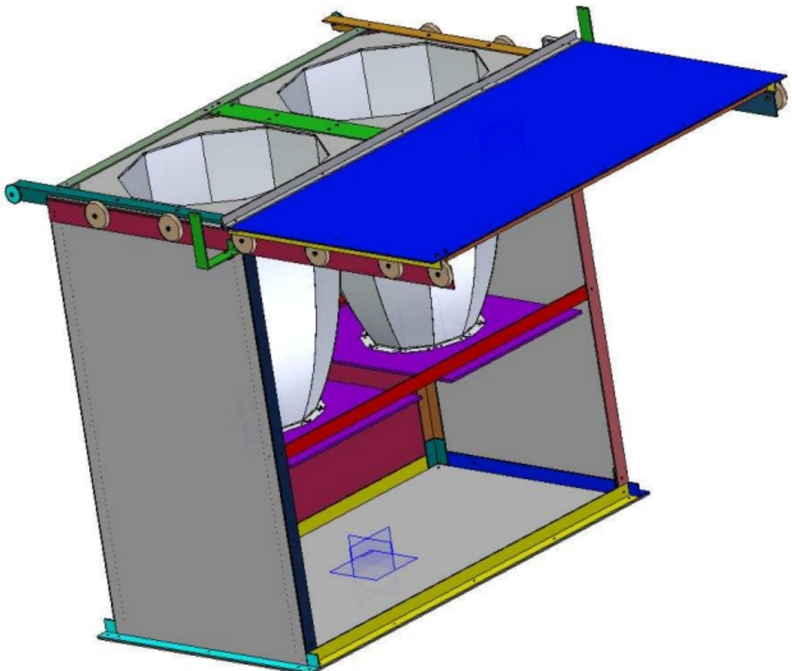
MGRO J2019+37



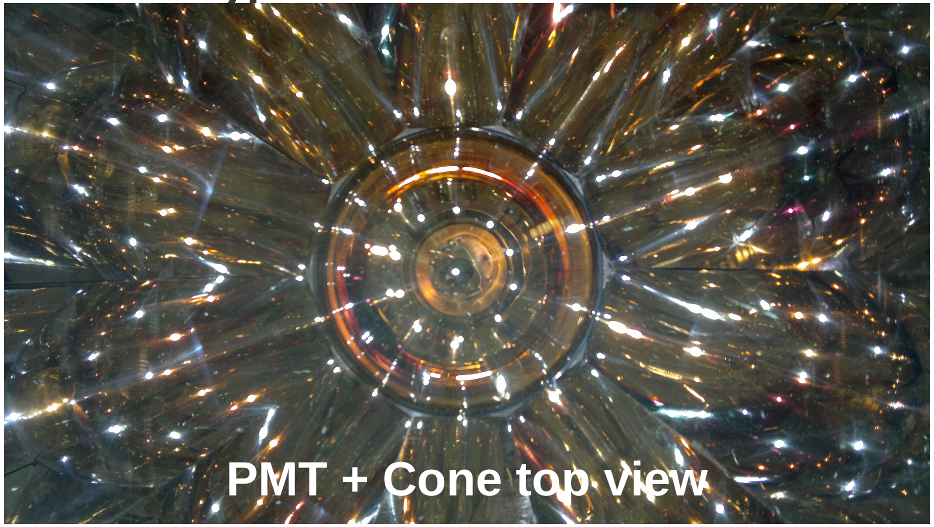
~500 events per year

HARDWARE STATUS

Station mechanics

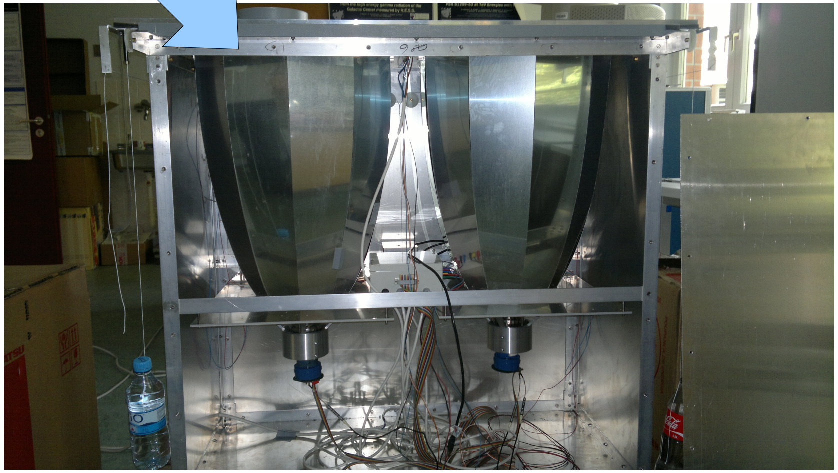


Prototype: 2-channel station

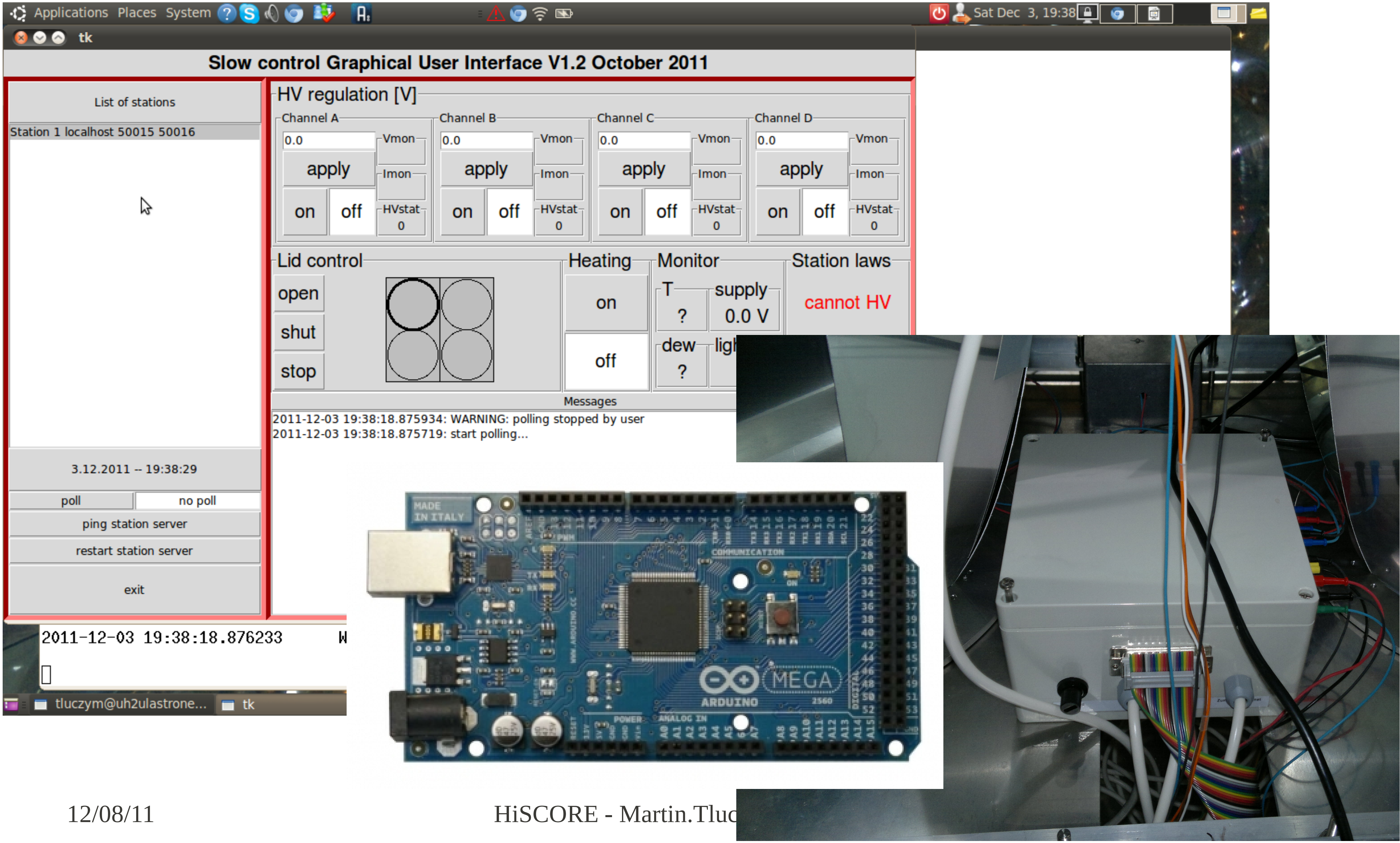


PMT + Cone top view

Cone segments

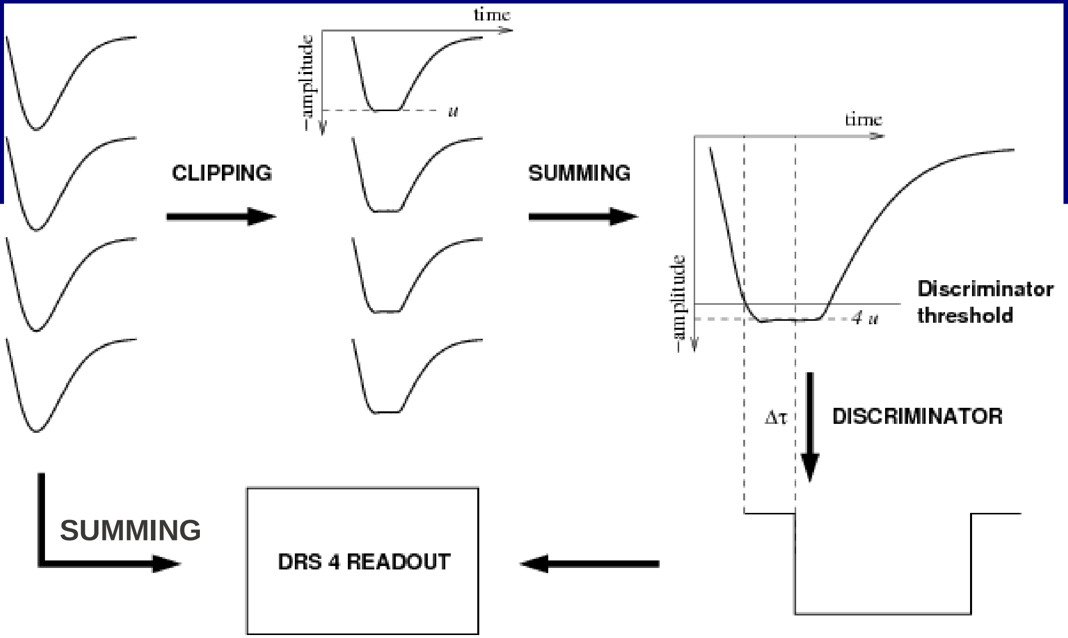


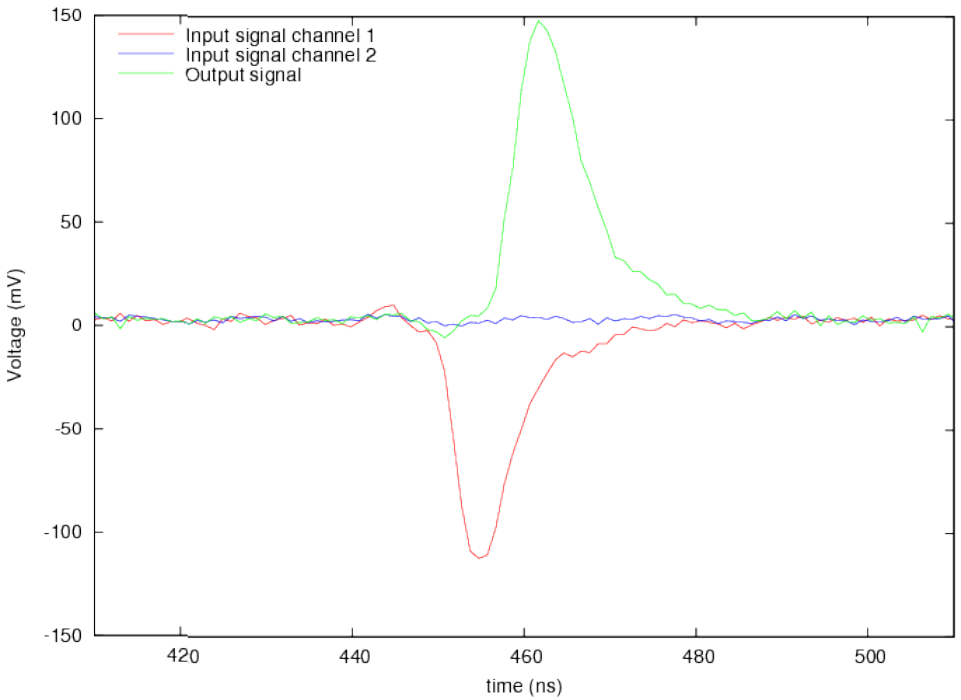
Slow control

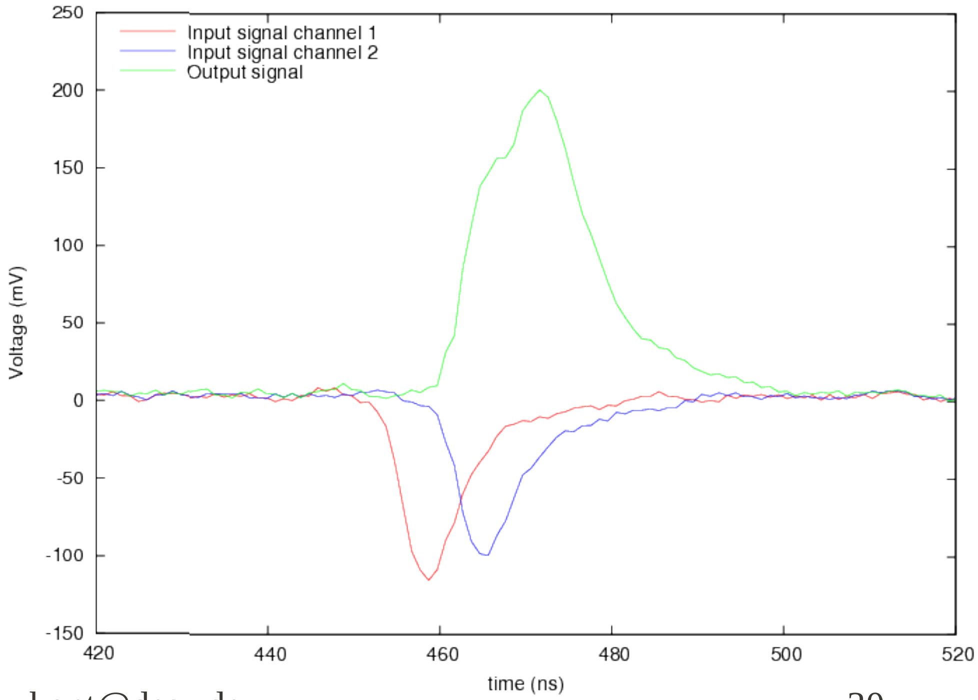


Trigger & R/O

- 1st component: summing module

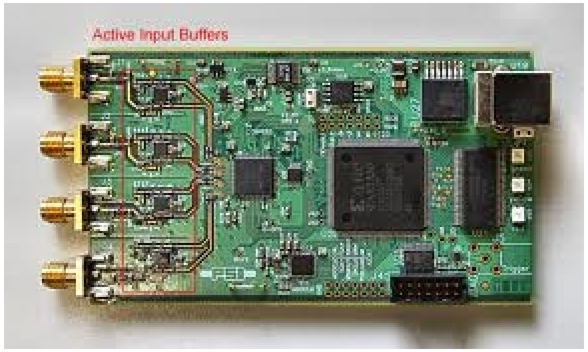






Trigger & R/O

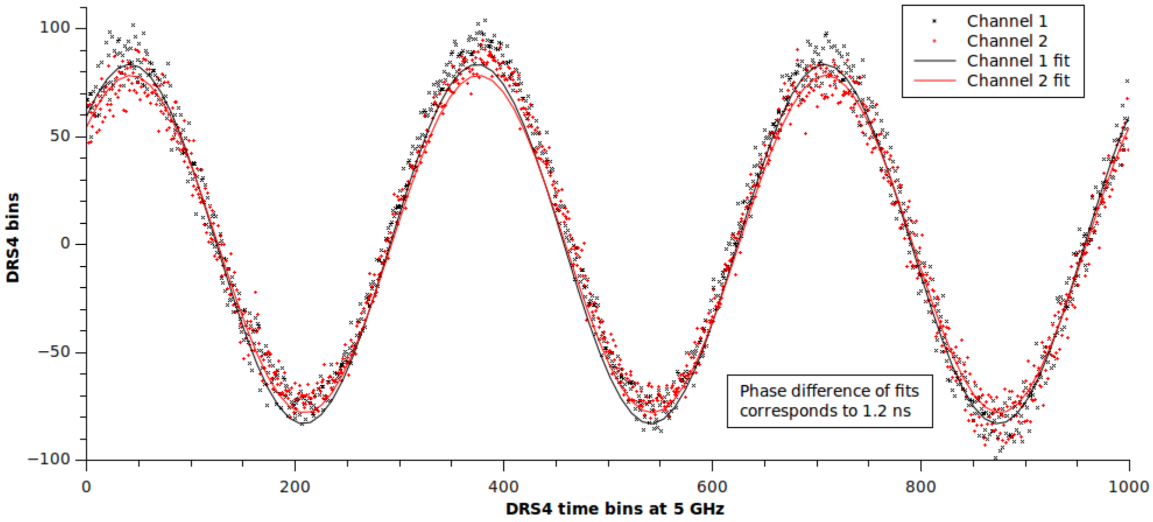
- DRS4 evaluation board



- 2 DRS4 chip channels summed (noise red.)

Investigating alternatives & own R/O board R&D

→ Synergies with CTA



- 4 channels with 1024 cells, up to 5 GHz sampling rate

Schedule

HiSCORE 1st prototype at TUNKA 2012
PhD positions from Helmholtz Russia Joint Research Group

HiSCORE prototype at AUGER ~2012
PhD position from Helmholtz alliance, HAP

Engineering array at TUNKA:
start deployment ~ end of 2012

HiSCORE: 10—100 km^2 in 2015 ?

Summary

- **Many physics cases beyond 10 TeV primary energy**
  The sensitivity goal is already **reached by 10km² stage**
- **Detector fully simulated**
- **R&D advanced**
  80% of components developed
- **Cooperation with TUNKA started**
  → Prototype deployment prepared
  → Engineering array ~2013
- **Synergy effects with CTA**
- **Further ideas:**
  Combination with radio / scintil. / imaging technique under stud

Backup slides

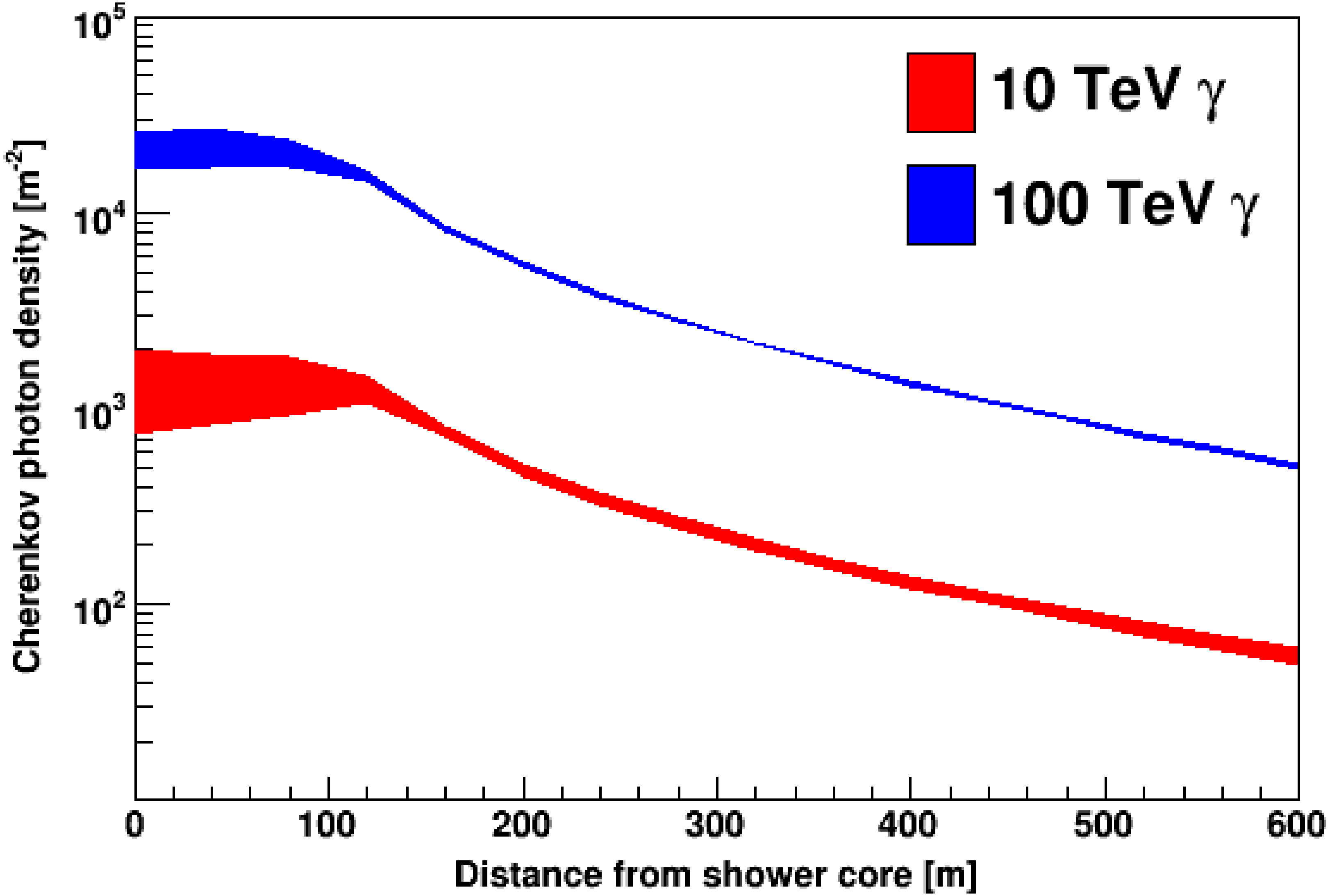
- Reconstruction
- More physics cases

RECONSTRUCTION

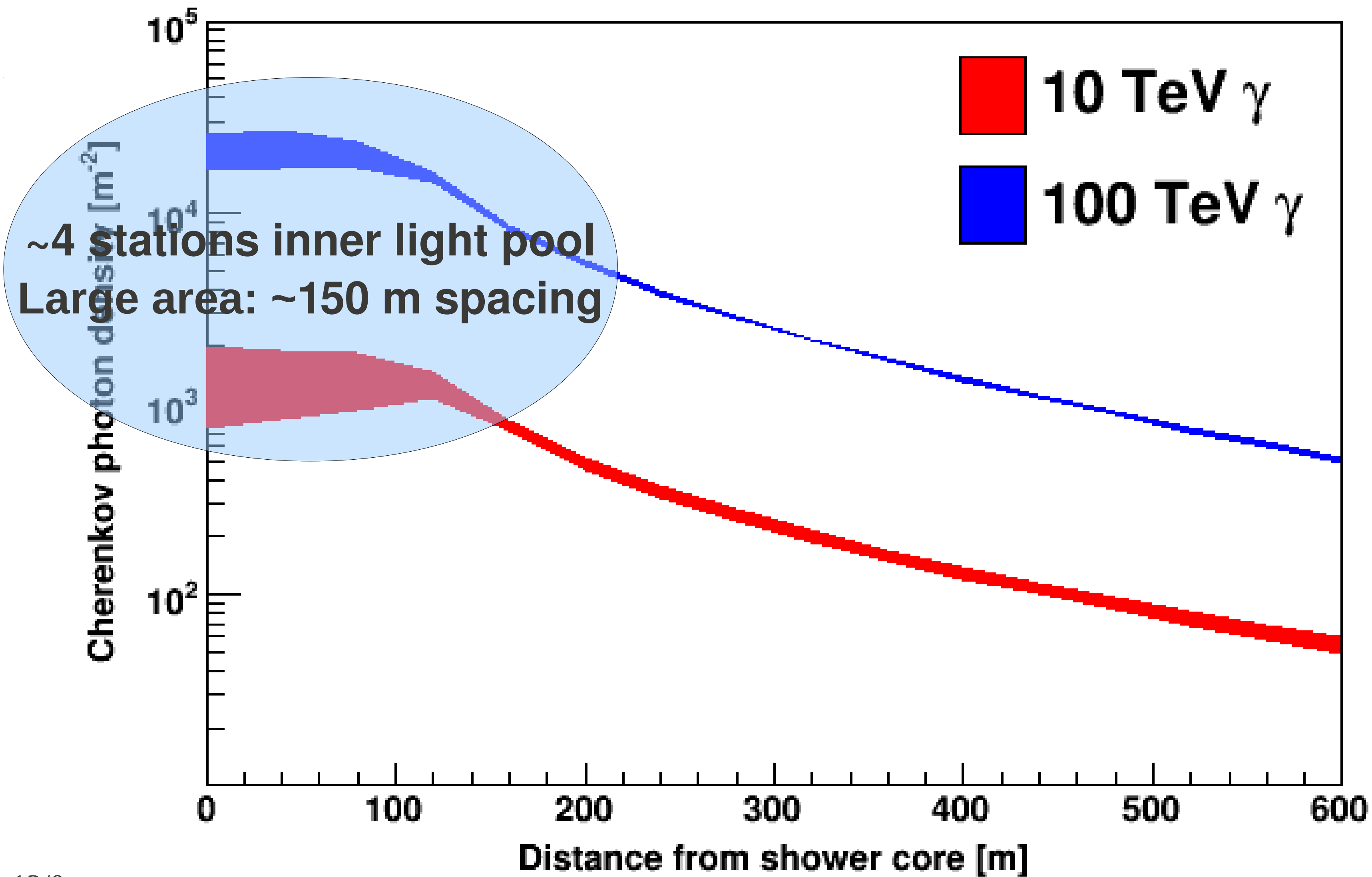
RECONSTRUCTION

GAMMA-HADRON SEPARATION

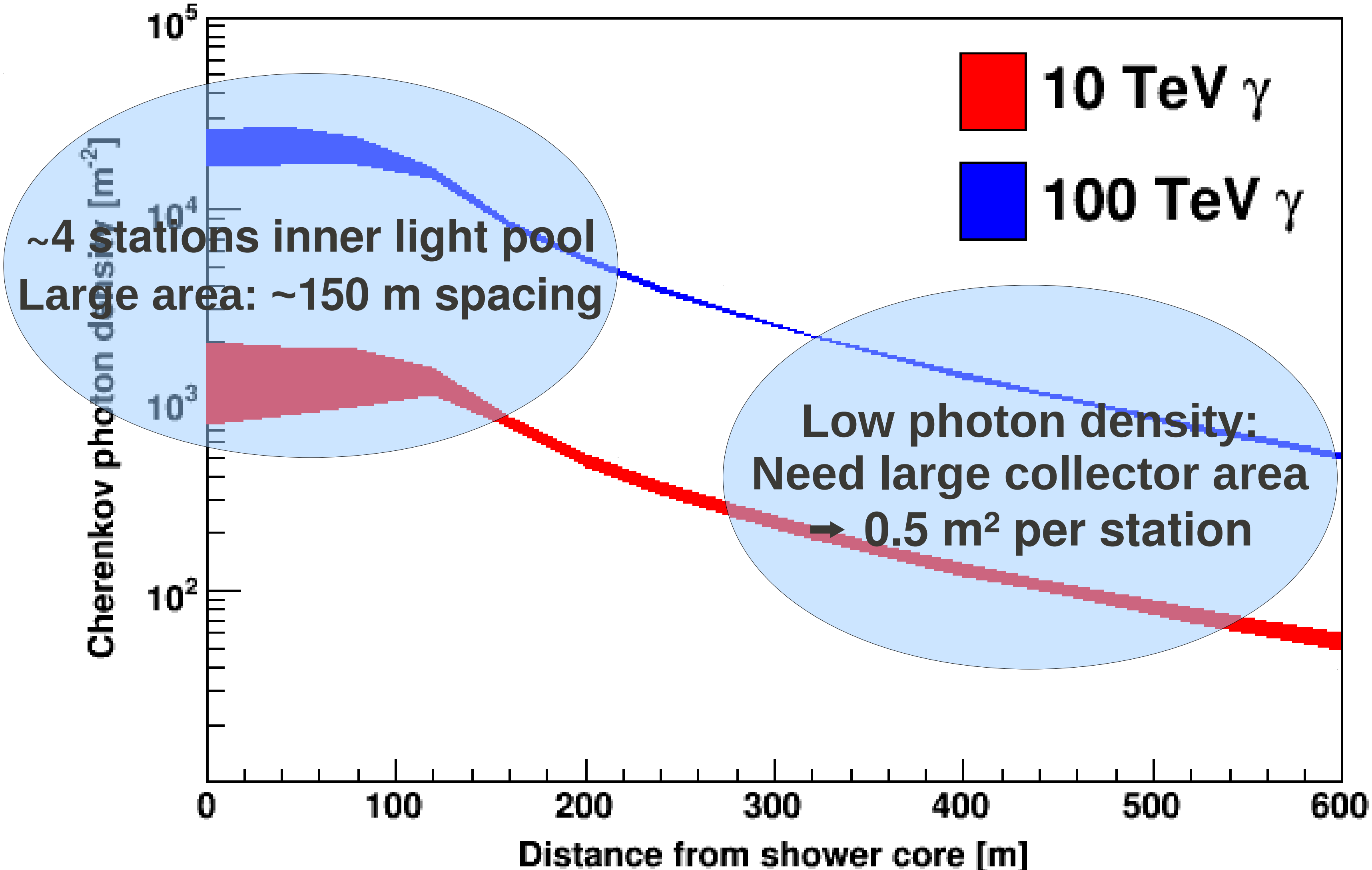
Lateral Cherenkov Photon Distribution



Lateral Cherenkov Photon Distribution



Lateral Cherenkov Photon Distribution



Shower core reconstruction

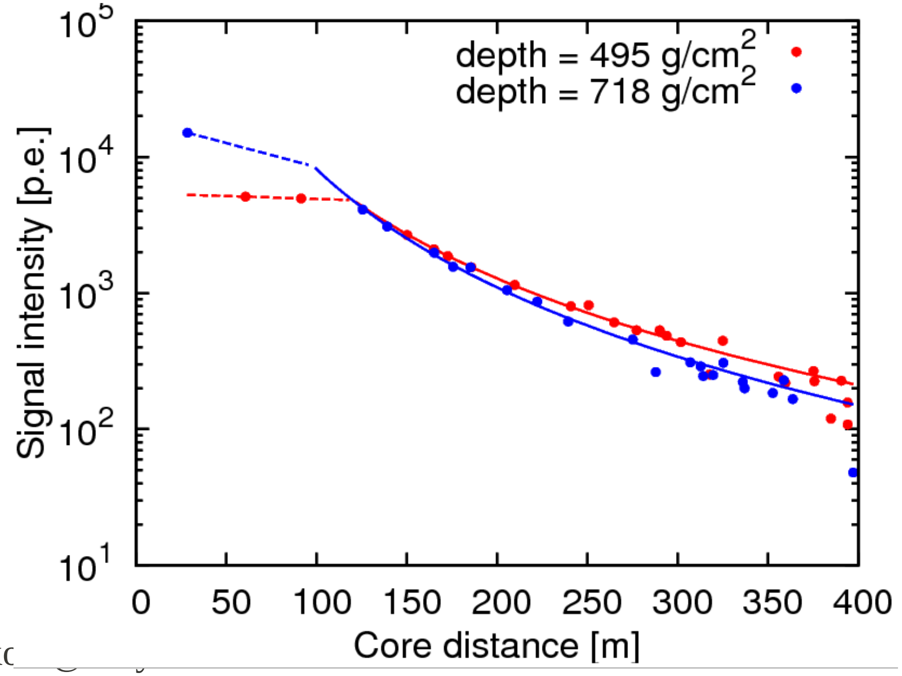
- Nstations < 5: weighted center of gravity
- Nstations >= 5 : Fit to LDF

$$\mathrm{LDF}(r) = \begin{cases} P\,\exp(d\,r) & \text{for } r < c_{LDF} \approx 120\,\mathrm{m} \\ Q\,r^k & \text{for } r > c_{LDF} \end{cases}$$

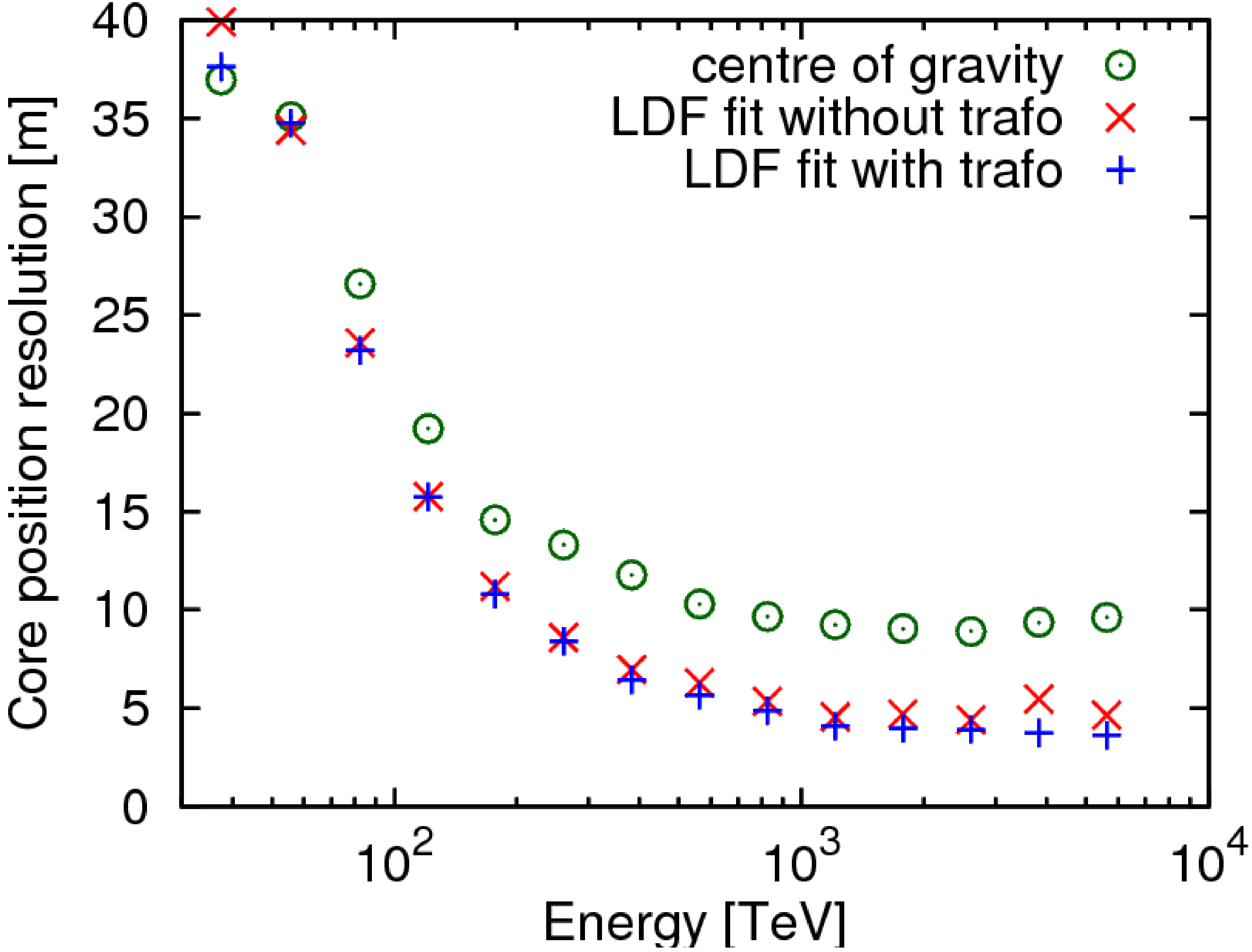
$$r = r(x,y) = \sqrt{x^2 + y^2}$$

$$Q = \frac{P\,\exp(d\,c_{LDF})}{(c_{LDF})^k}$$

- Free parameters P, d, k, (x,y). Nstations >= 6: c_{LDF} free parameter
- To come: use width for outside showers



Shower core resolution



Direction reconstruction

- >3 stations: model fit adapted from Stamatescu et al. 2008, Parametrization of time-delay *dt* at detector position

$$dt(k,z) = \frac{1}{c}\left(\sqrt{k} - \frac{z}{\cos(\theta)} + \frac{8.0}{z}\sqrt{k}\,\eta_0\left(1 - \exp\left(\frac{-z}{8.0}\right)\right)\right)$$

$$k(r,z) = r^2 + z^2\,\frac{1}{\cos(\theta)^2} + 2\,r\,z\,\tan(\theta)\,\cos(\delta)$$

$$\delta = \phi + \mathrm{atan2}\left((x_{Det} - x_{core}),(y_{Det} - y_{core})\right)$$

Direction reconstruction

- >3 stations: model fit adapted from Stamatescu et al. 2008, Parametrization of time-delay *dt* at detector position

Slope of atmospheric refractive index

r: Distance from shower core to detector

Shower height in km

$$dt(k,z) = \frac{1}{c}\left(\sqrt{k} - \frac{z}{\cos(\theta)} + \frac{8.0}{z}\sqrt{k}\,\eta_0\left(1 - \exp\left(\frac{-z}{8.0}\right)\right)\right)$$

$$k(r,z) = r^2 + z^2\,\frac{1}{\cos(\theta)^2} + 2\,r\,z\,\tan(\theta)\,\cos(\delta)$$

$$\delta = \phi + \mathrm{atan2}\left((x_{Det} - x_{core}),(y_{Det} - y_{core})\right)$$

Zenith angle

Direction reconstruction

- >3 stations: model fit adapted from Stamatescu et al. 2008, Parametrization of time-delay *dt* at detector position

Slope of atmospheric refractive index

r: Distance from shower core to detector

Shower height in km

$$dt(k,z) = \frac{1}{c}\left(\sqrt{k} - \frac{z}{\cos(\theta)} + \frac{8.0}{z}\sqrt{k}\,\eta_0\left(1 - \exp\left(\frac{-z}{8.0}\right)\right)\right)$$

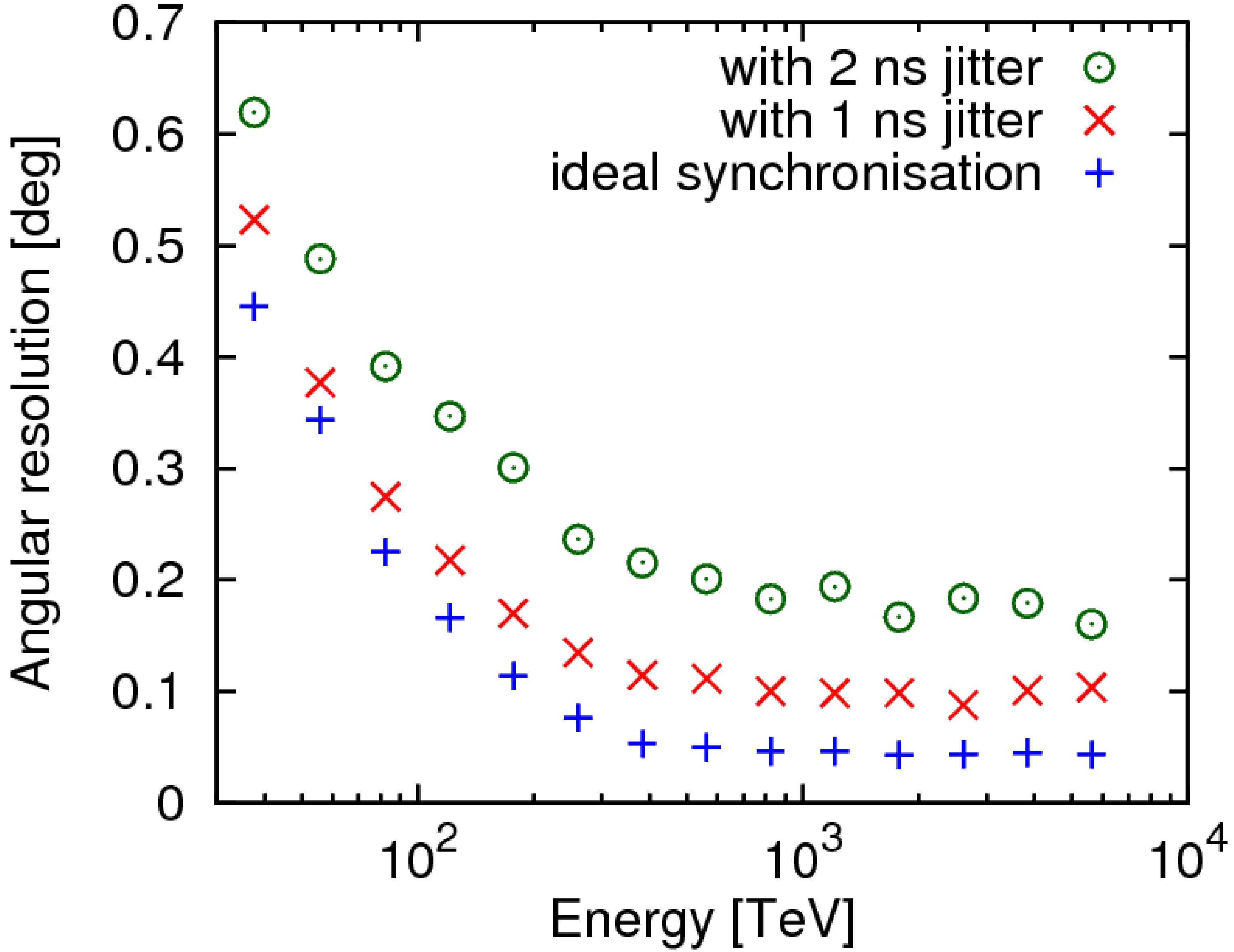
$$k(r,z) = r^2 + z^2\,\frac{1}{\cos(\theta)^2} + 2\,r\,z\,\tan(\theta)\,\cos(\delta)$$

Zenith angle

Free parameters: height & direction

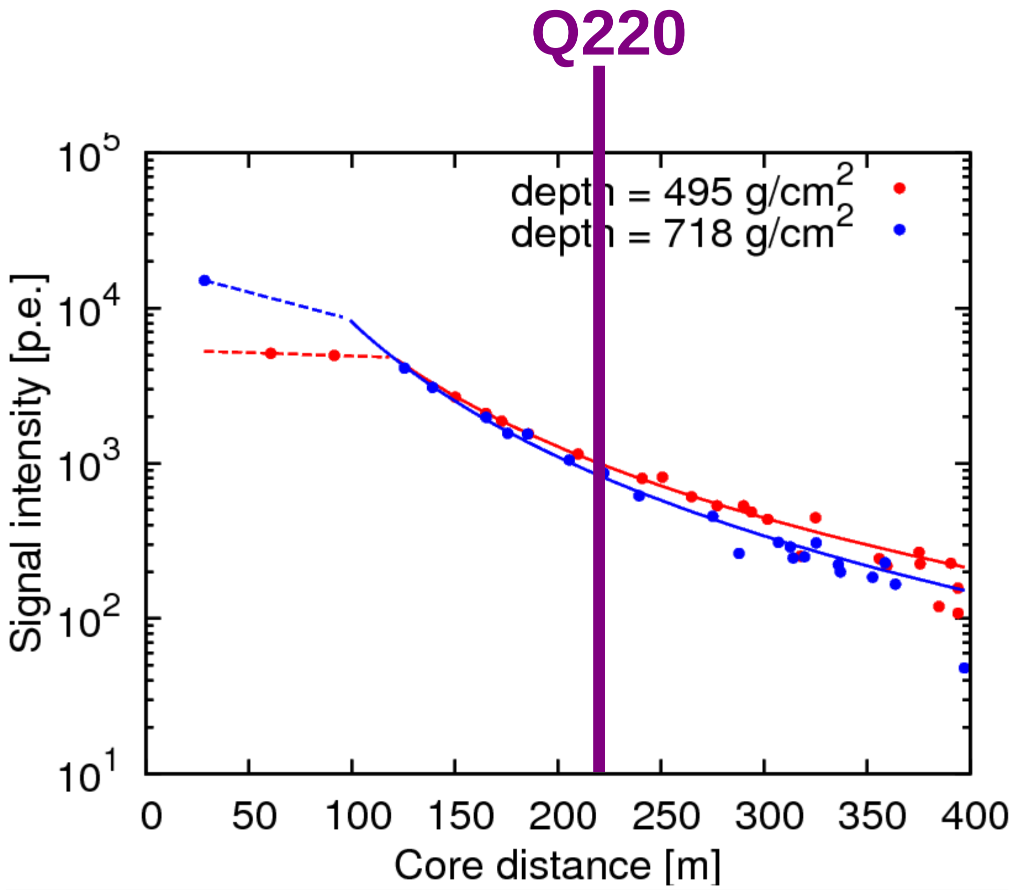
Results in good angular reconstruction
And rough 1st order shower max. estimation

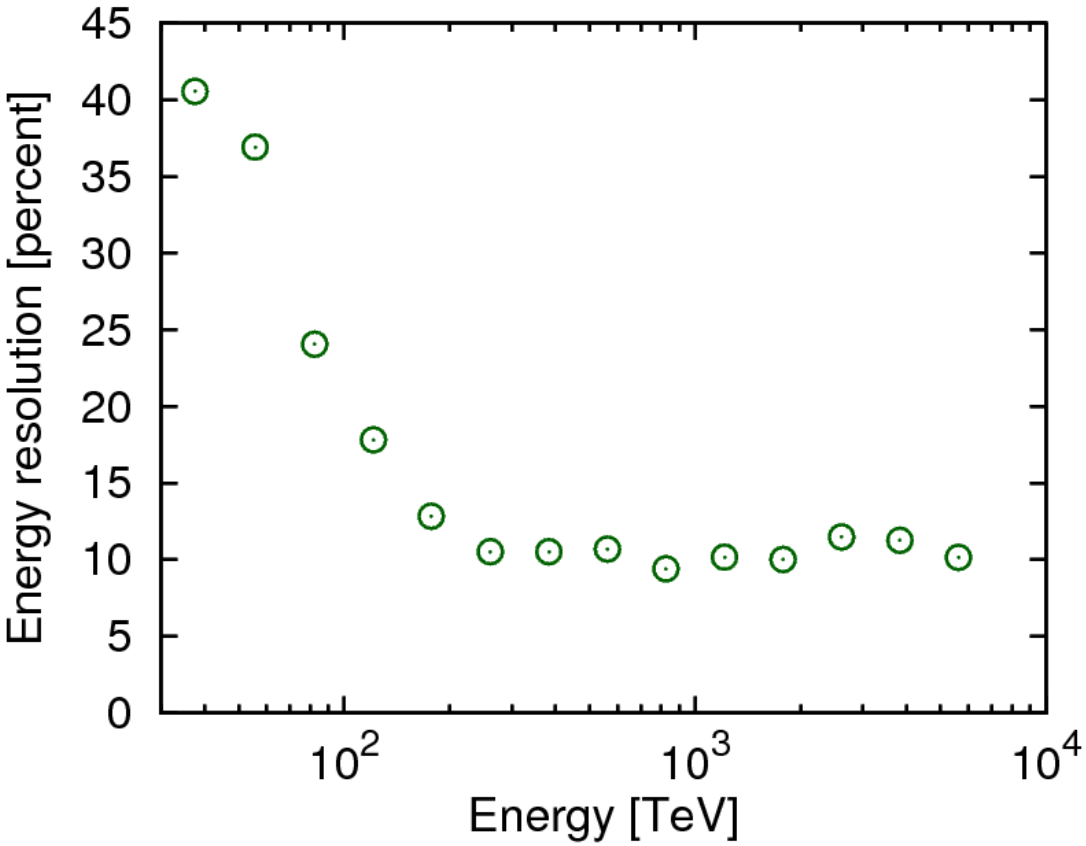
Angular resolution



Energy reconstruction

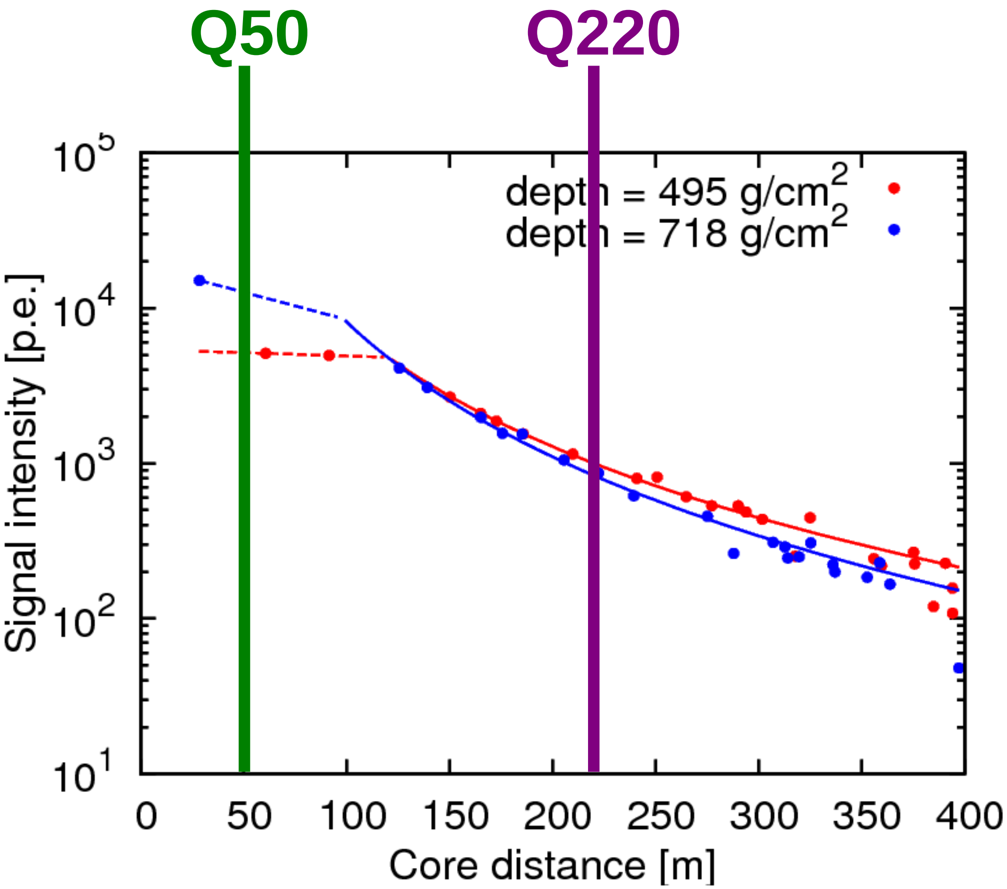
- Smallest impact of shower depth on photon density at 220m



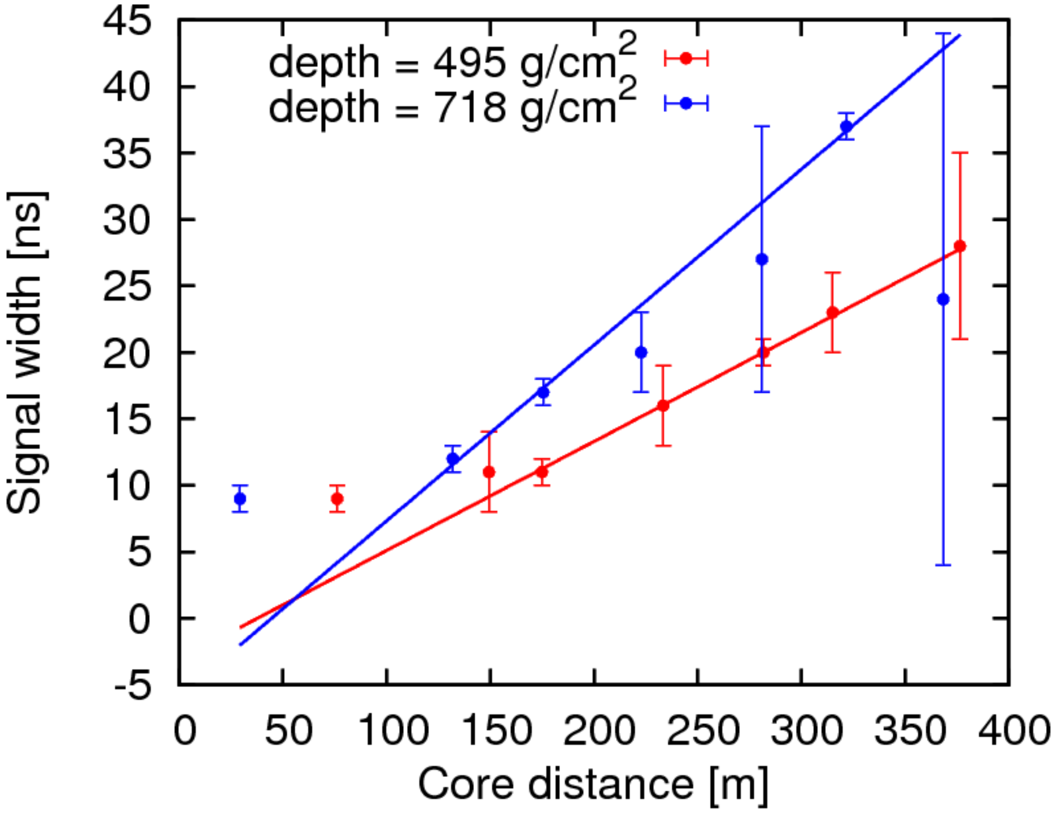


Shower depth reconstruction

- **Ds:**
  Depth from LDF slope, Q50/Q220

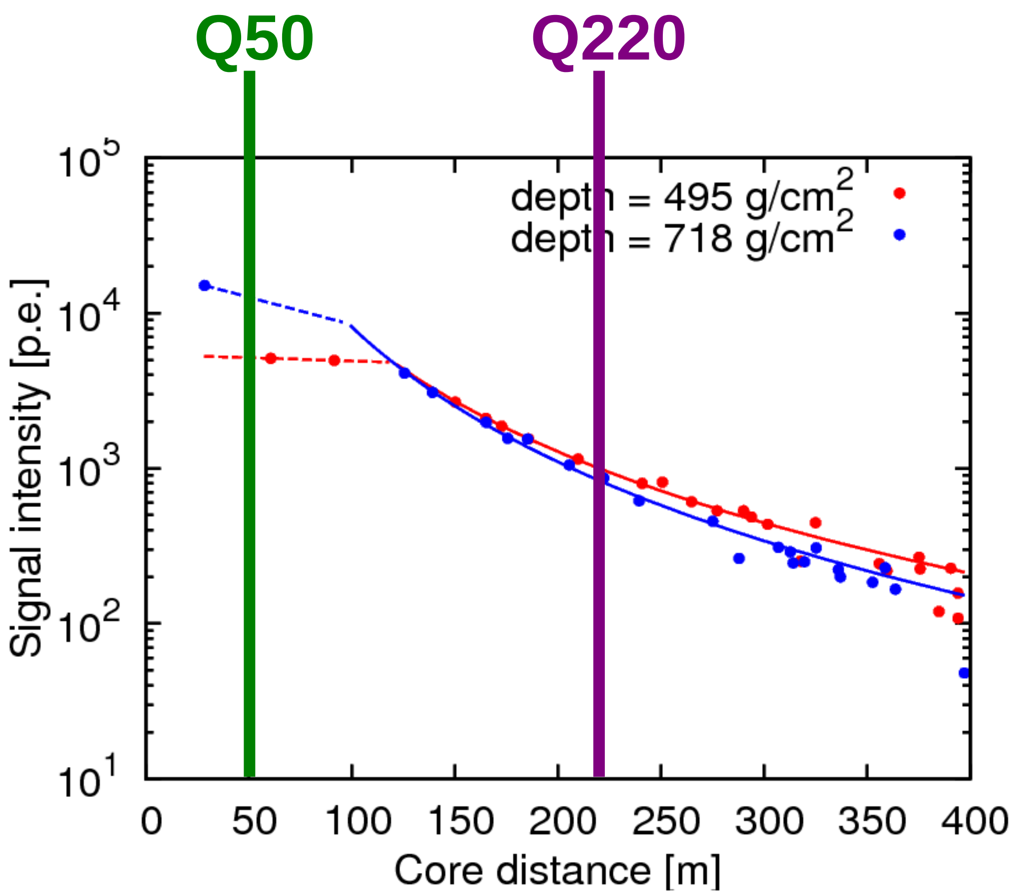


- **Dw:** Depth from signal width
- signal-stacking: add signals with same core-distance
- effective at core-distance > 150m

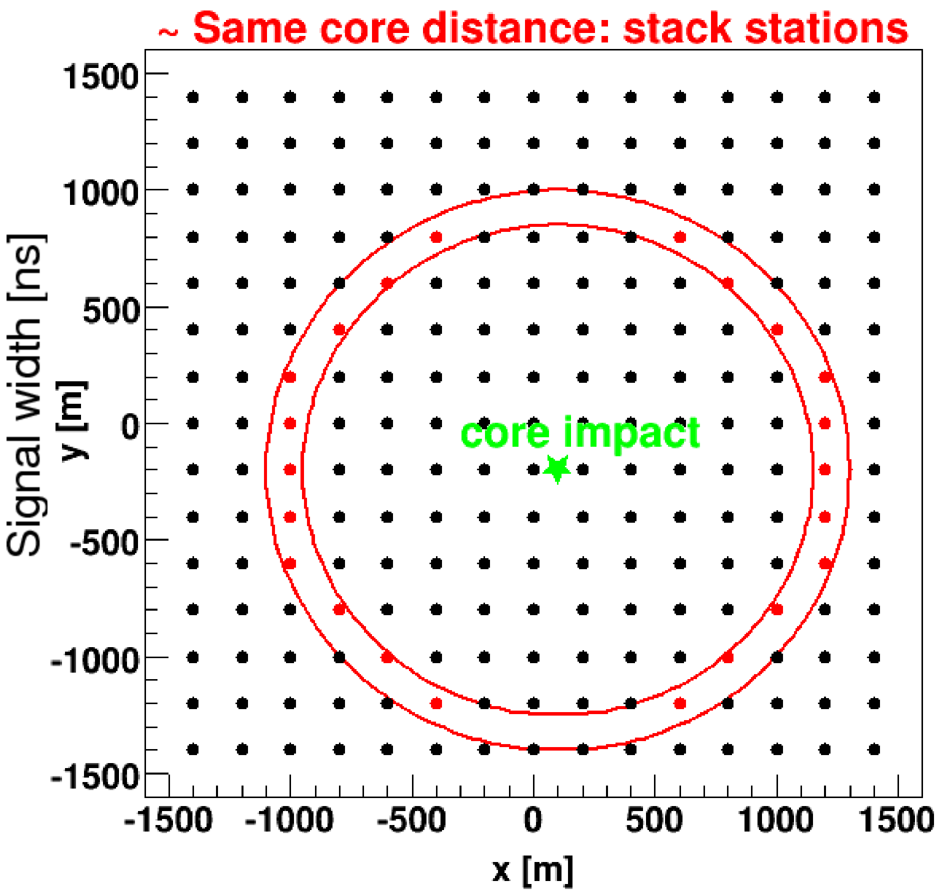


Shower depth reconstruction

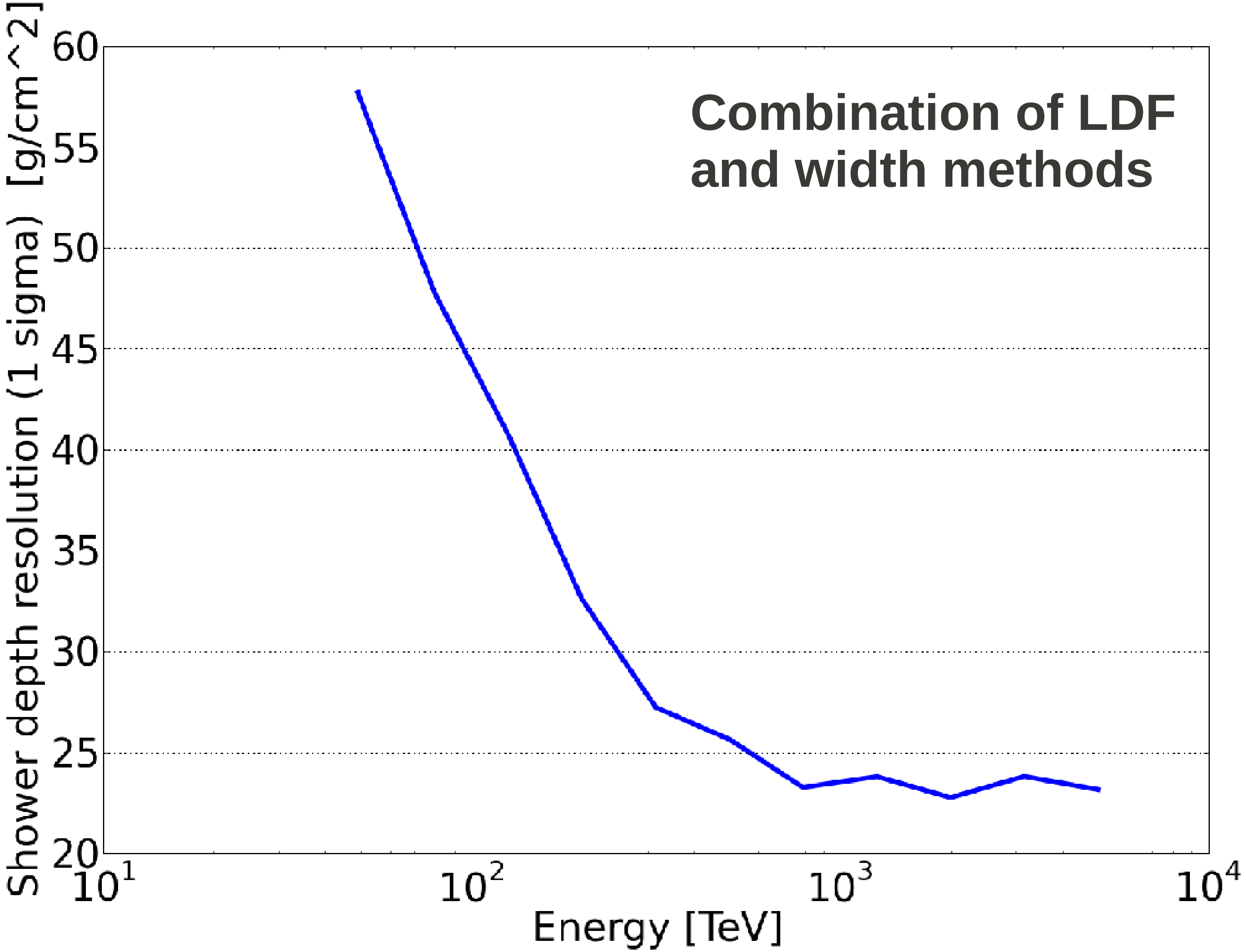
- **Ds:**
Depth from LDF slope: Q50/Q220



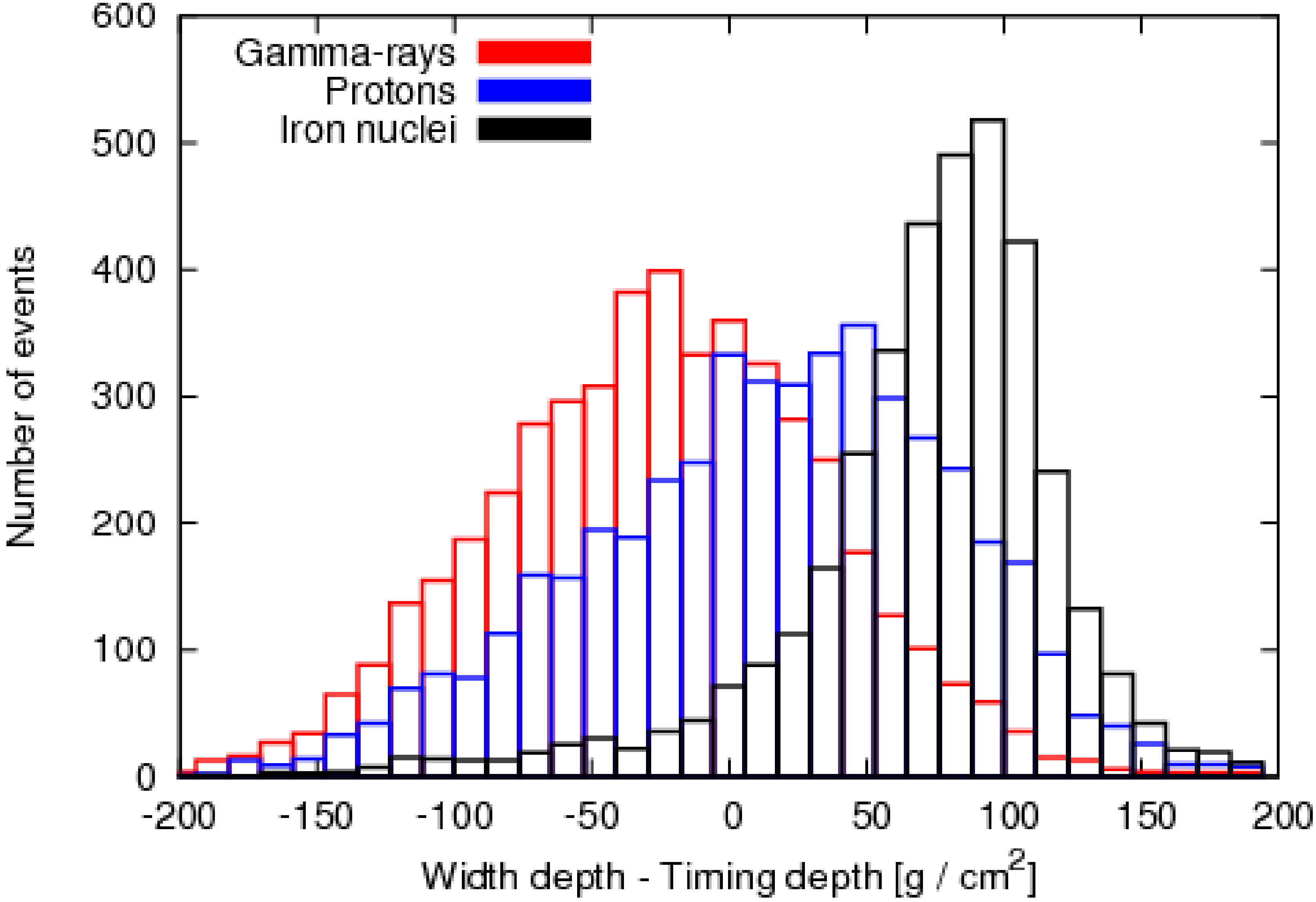
- **Dw:** Depth from signal width
- signal-stacking: add signals with same core-distance



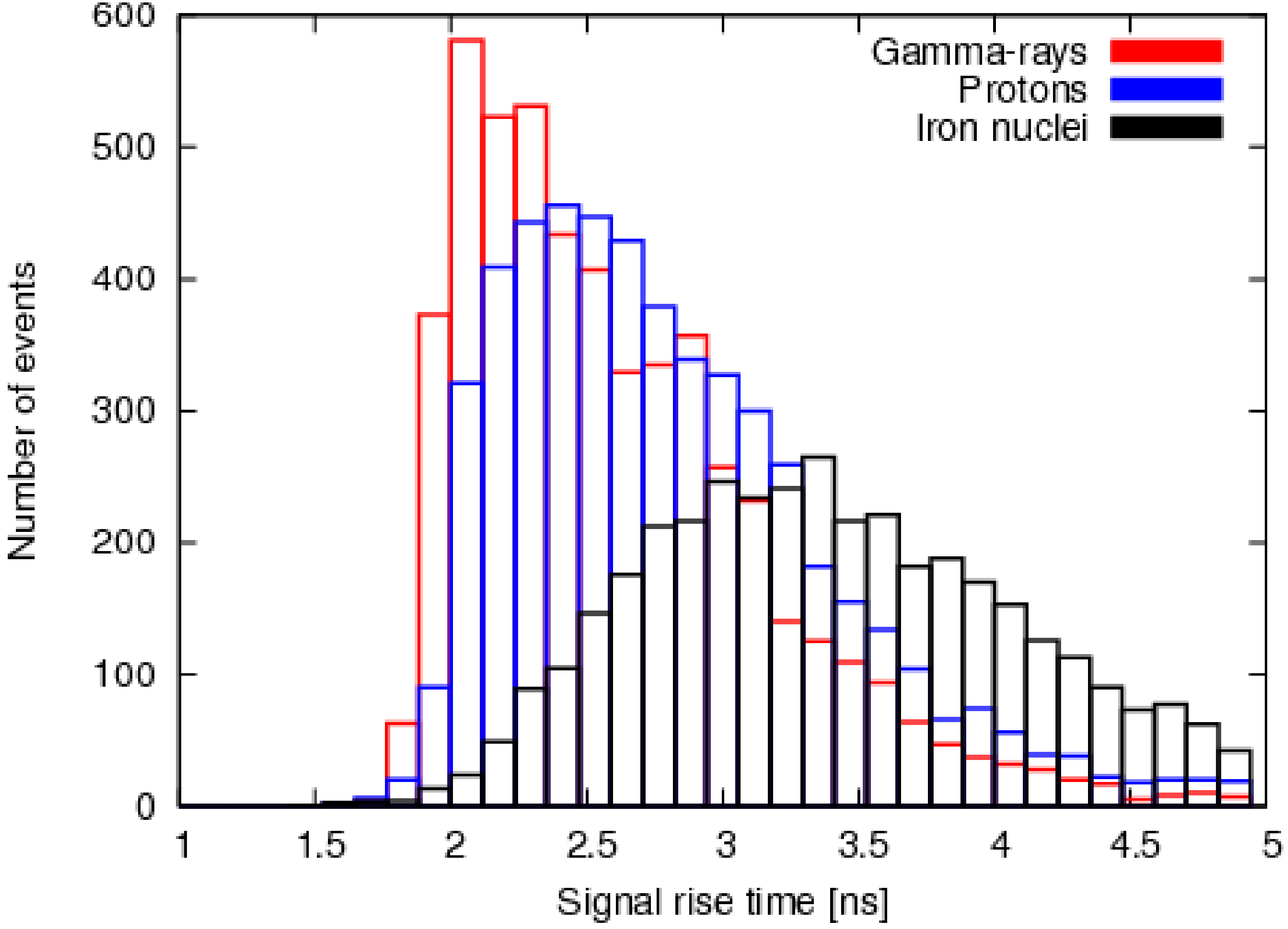
Shower depth resolution



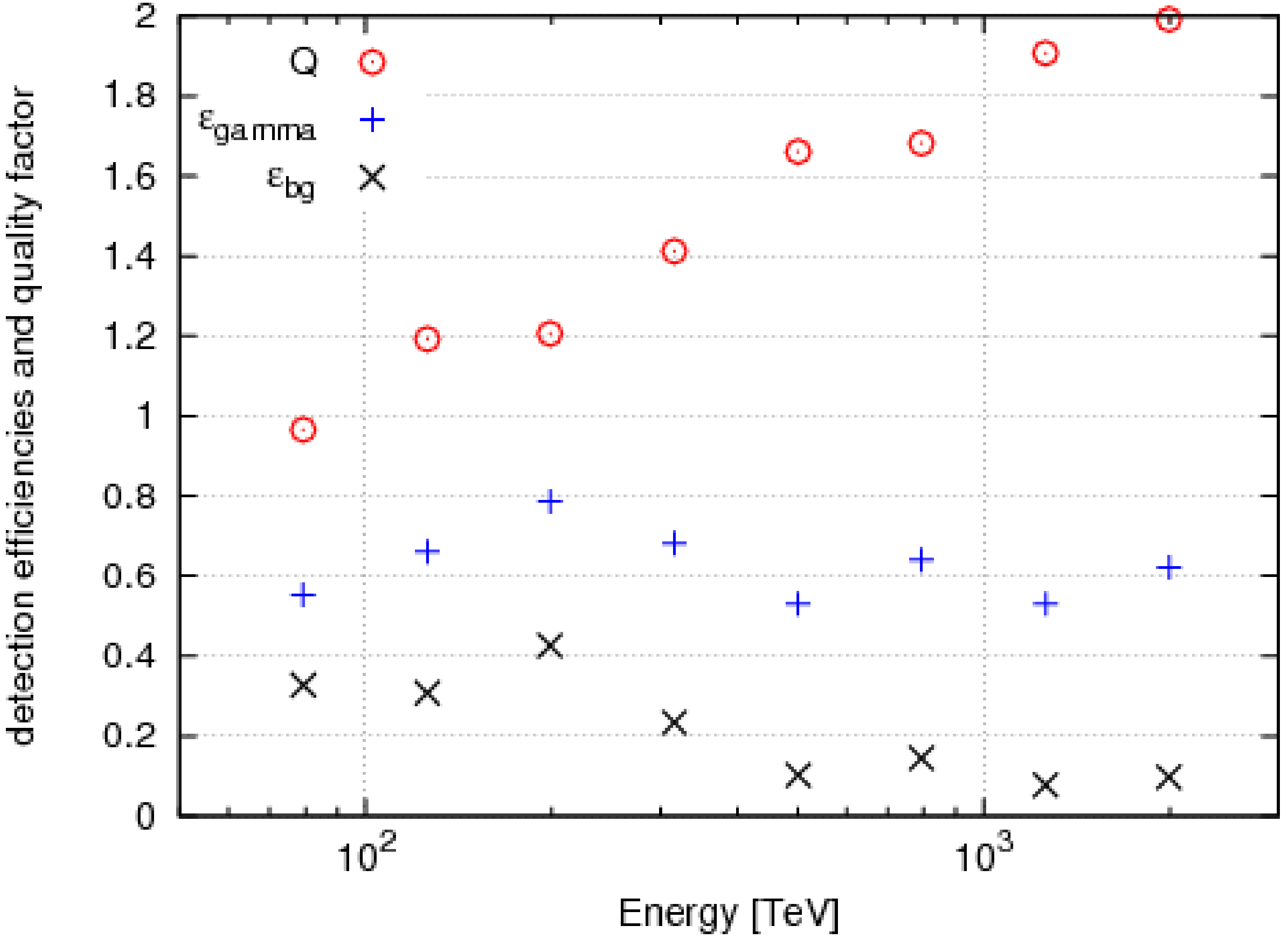
Gamma-hadron separation (1)



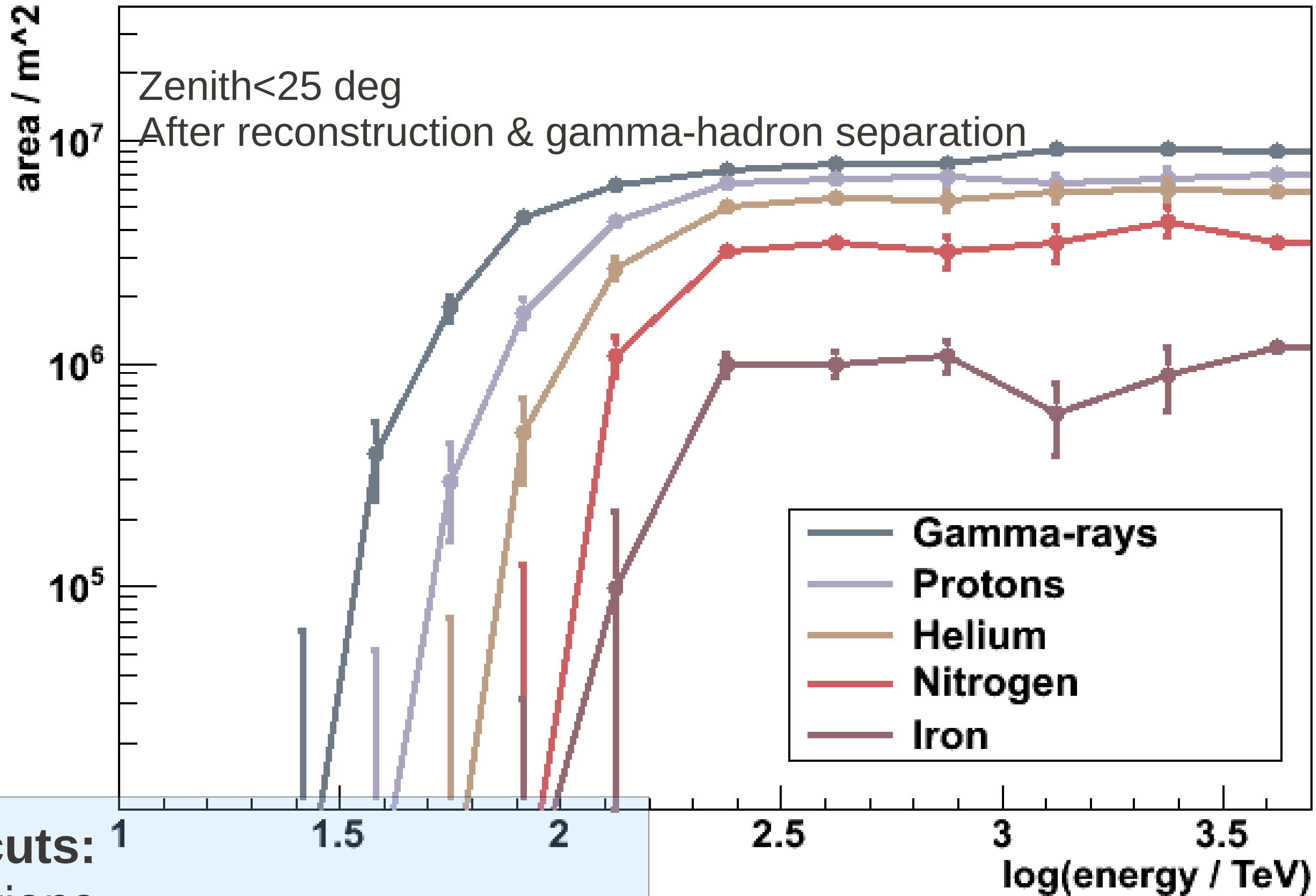
Gamma-hadron separation (2)



Gamma-hadron separation (combi)



Effective area @ reconstruction level

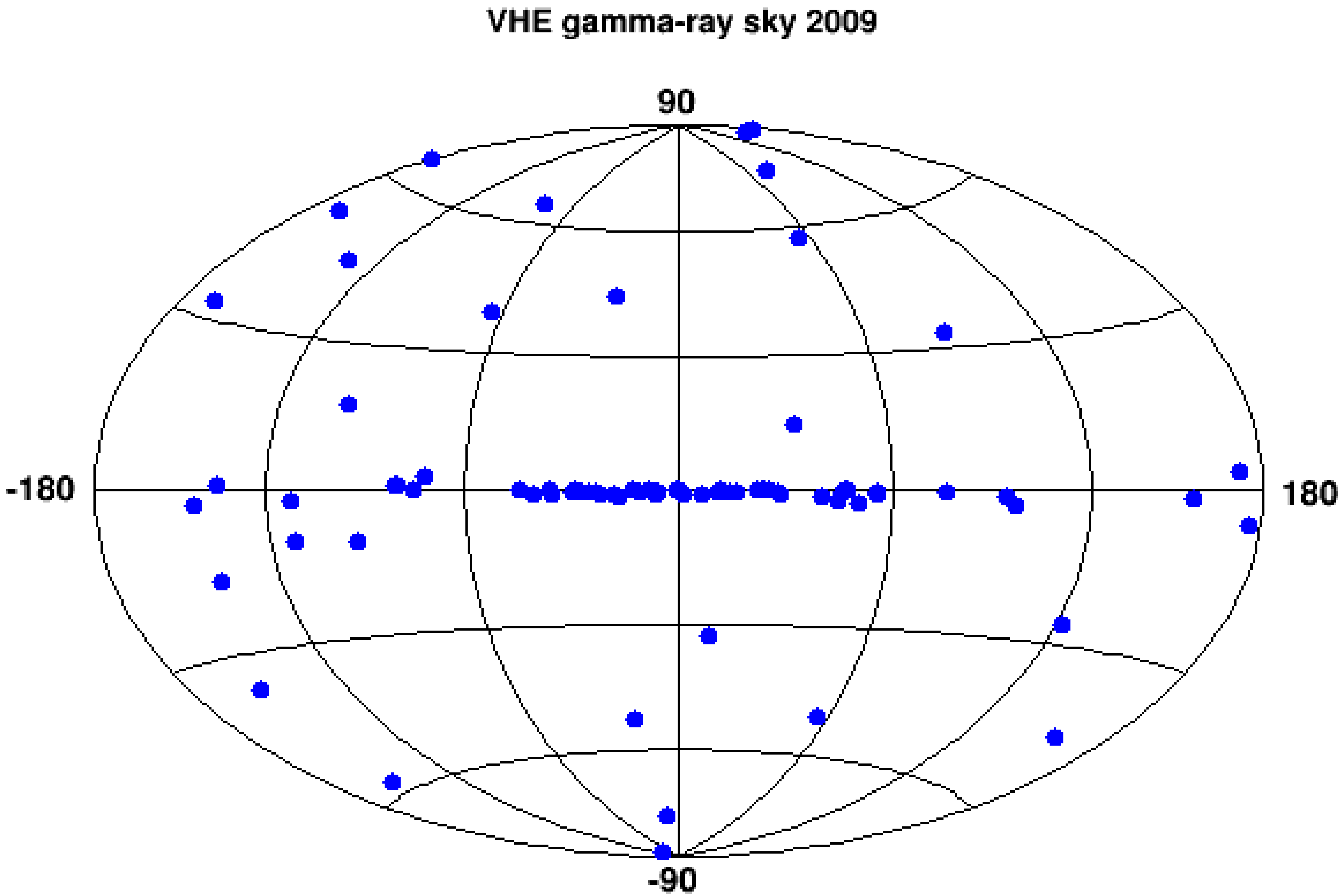


Reconstruction cuts:
- ≥ 3 triggered stations
- Contained reconstructed core impact position
- Separator ≥ 400

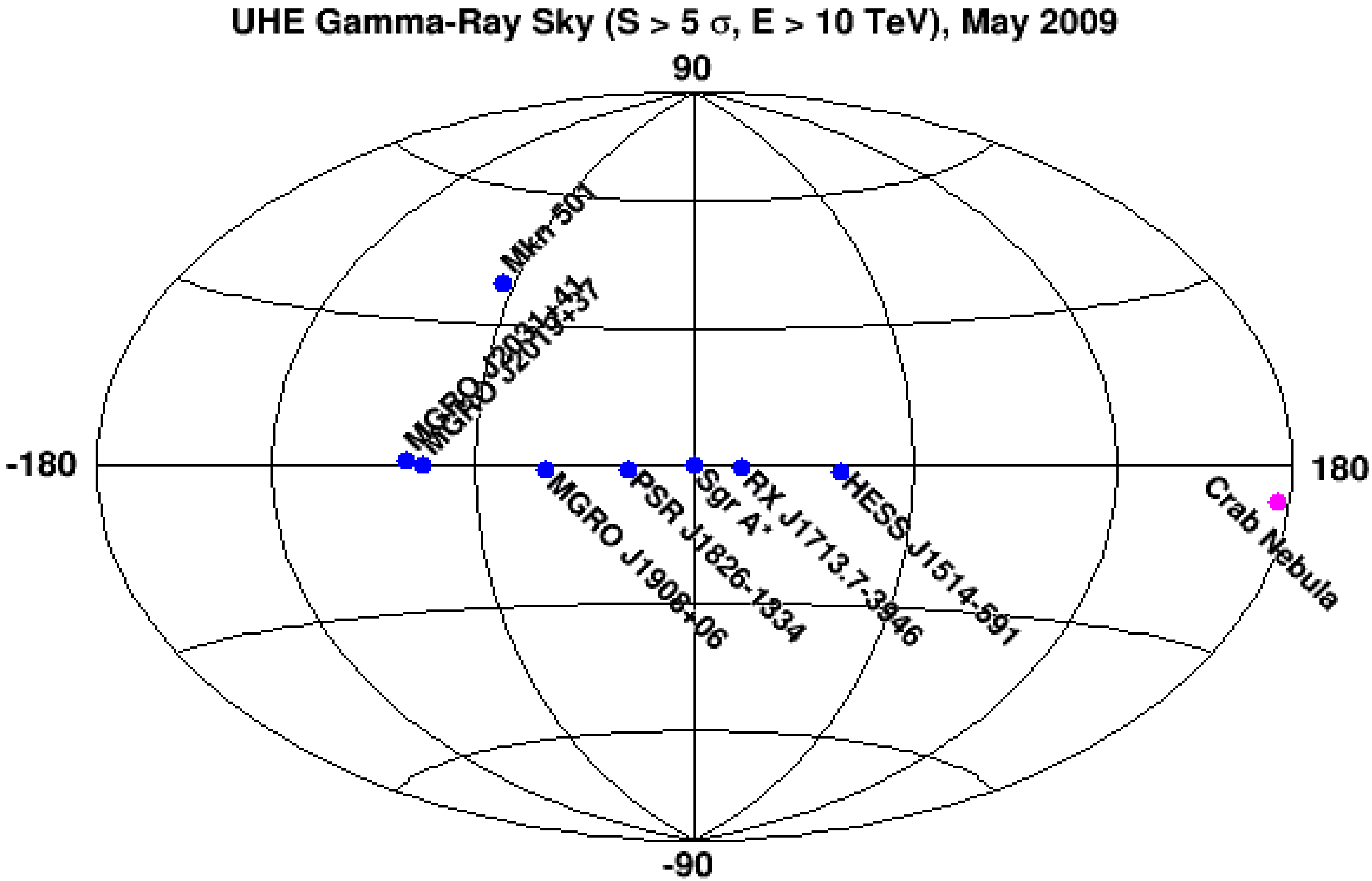
PHYSICS

PHYSICS CASES

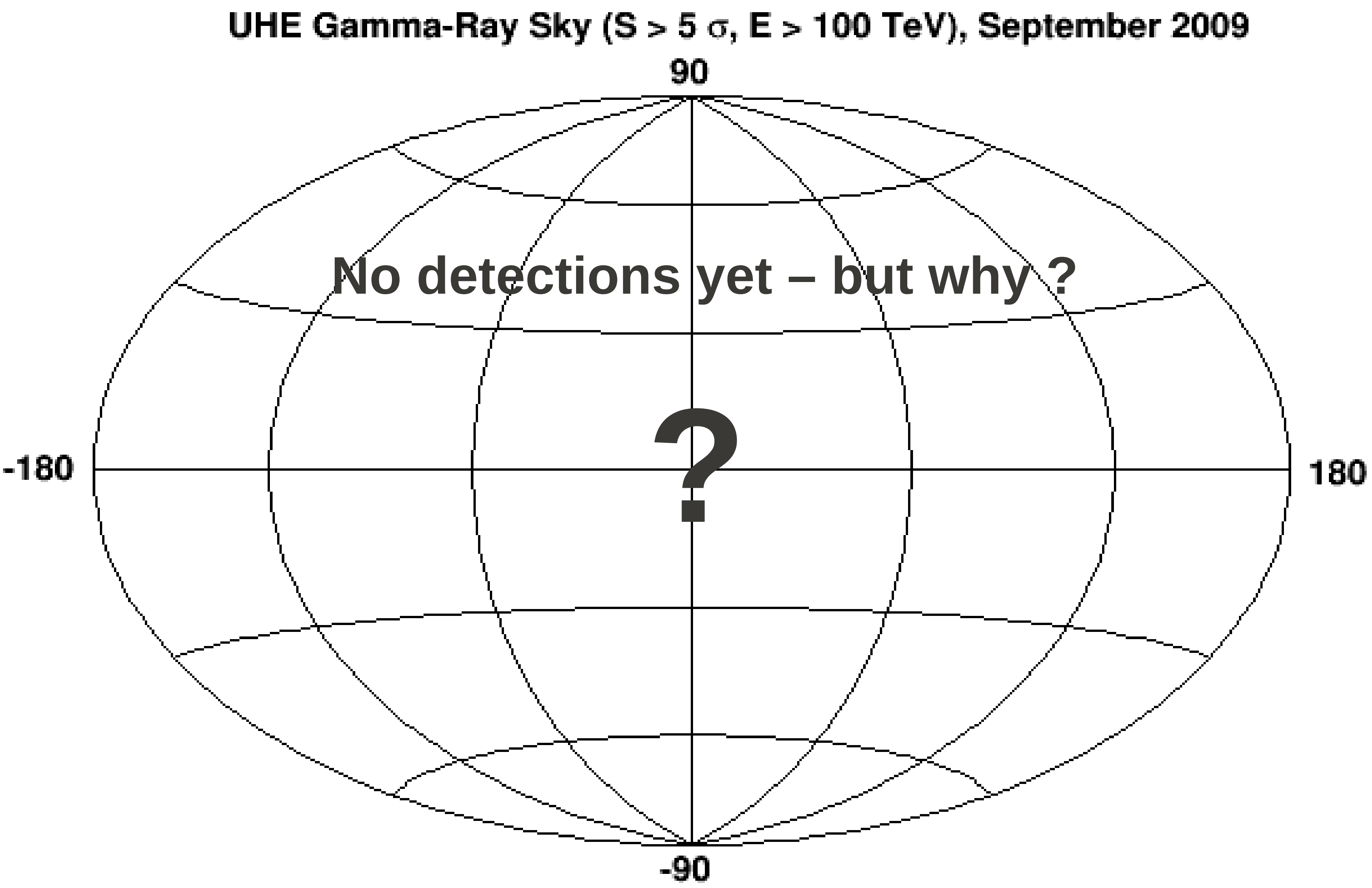
Gamma-Ray Sky, E>100GeV



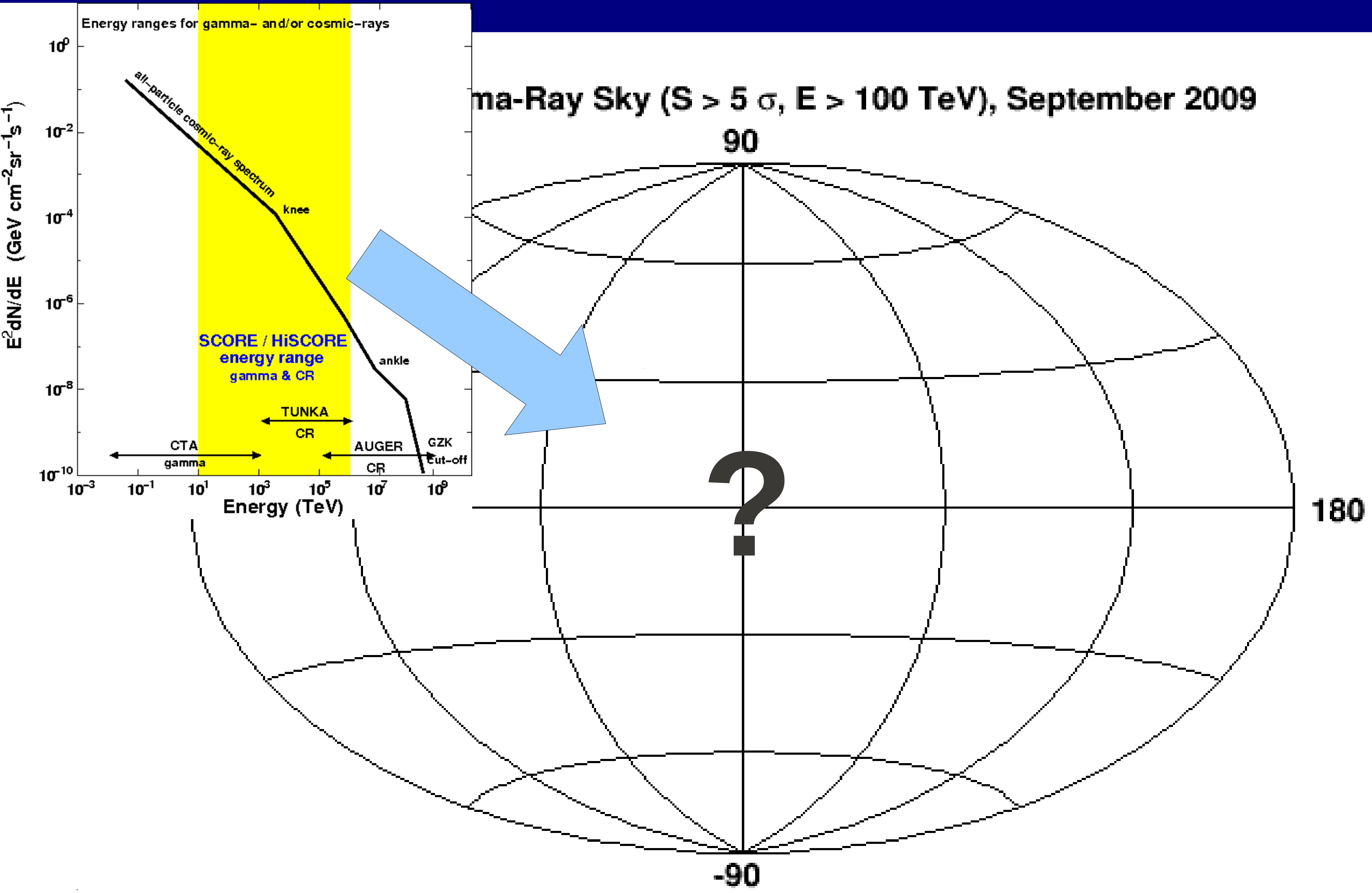
Gamma-Ray Sky, E > 10 TeV



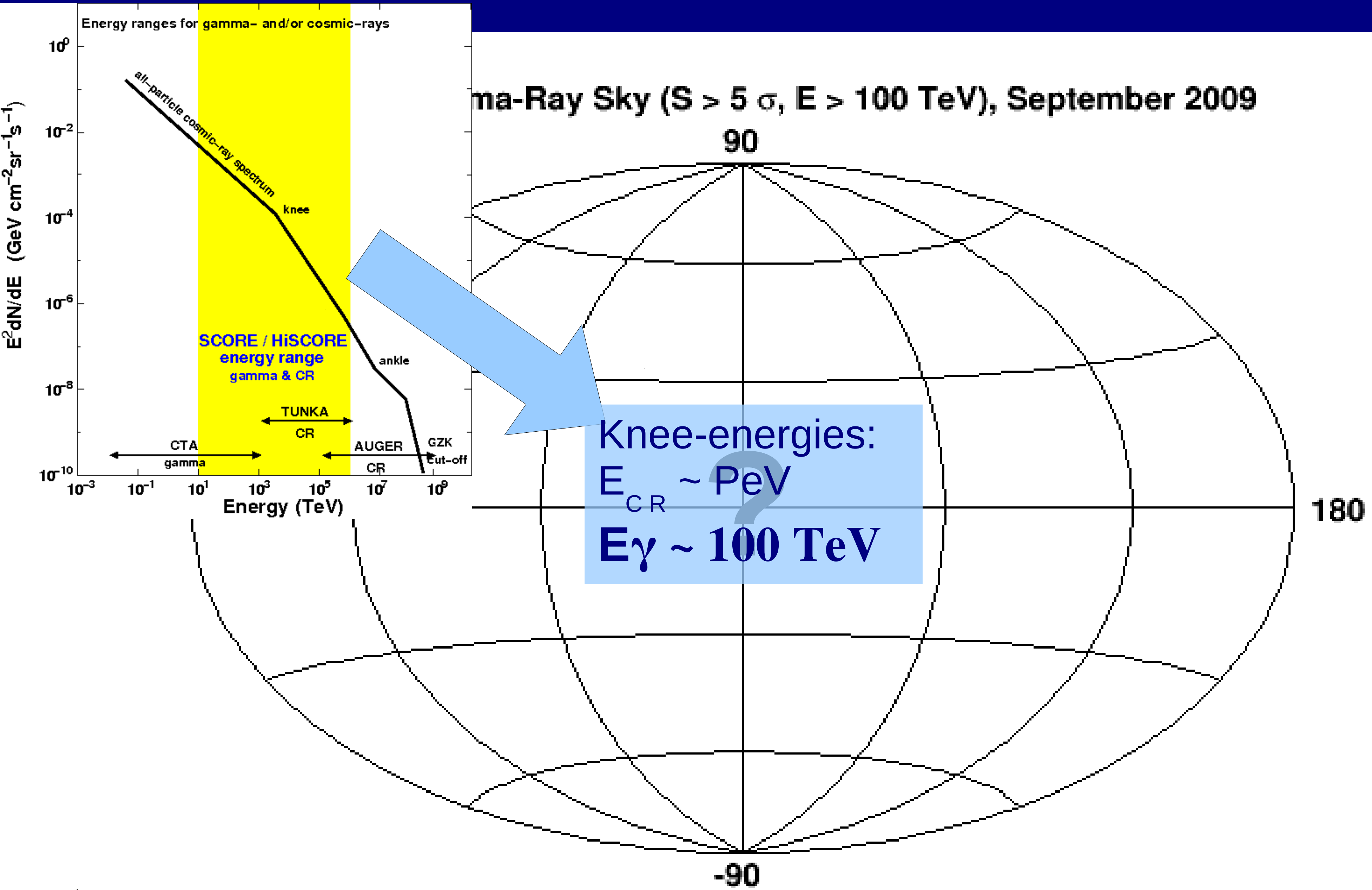
Gamma-Ray Sky, E > 100 TeV



Gamma-Ray Sky, E>100TeV



Gamma-Ray Sky, E>100TeV

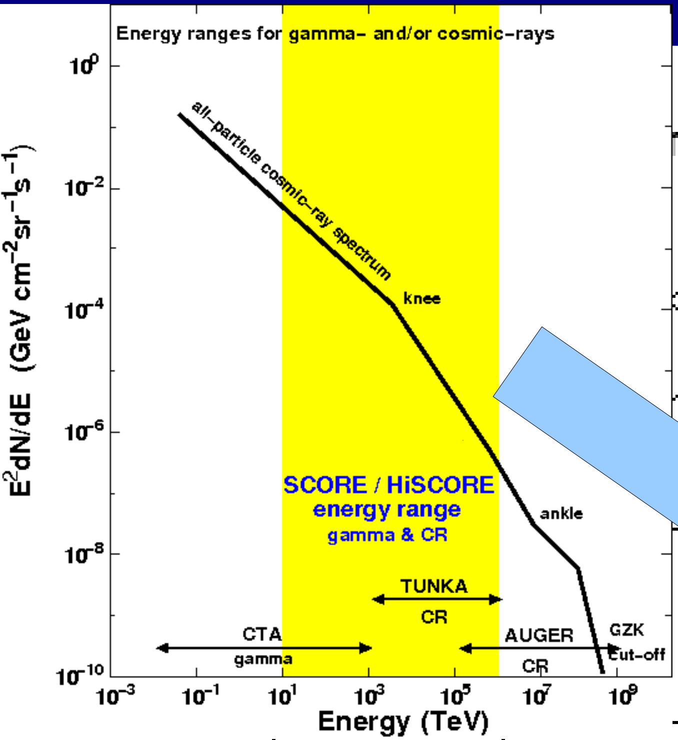


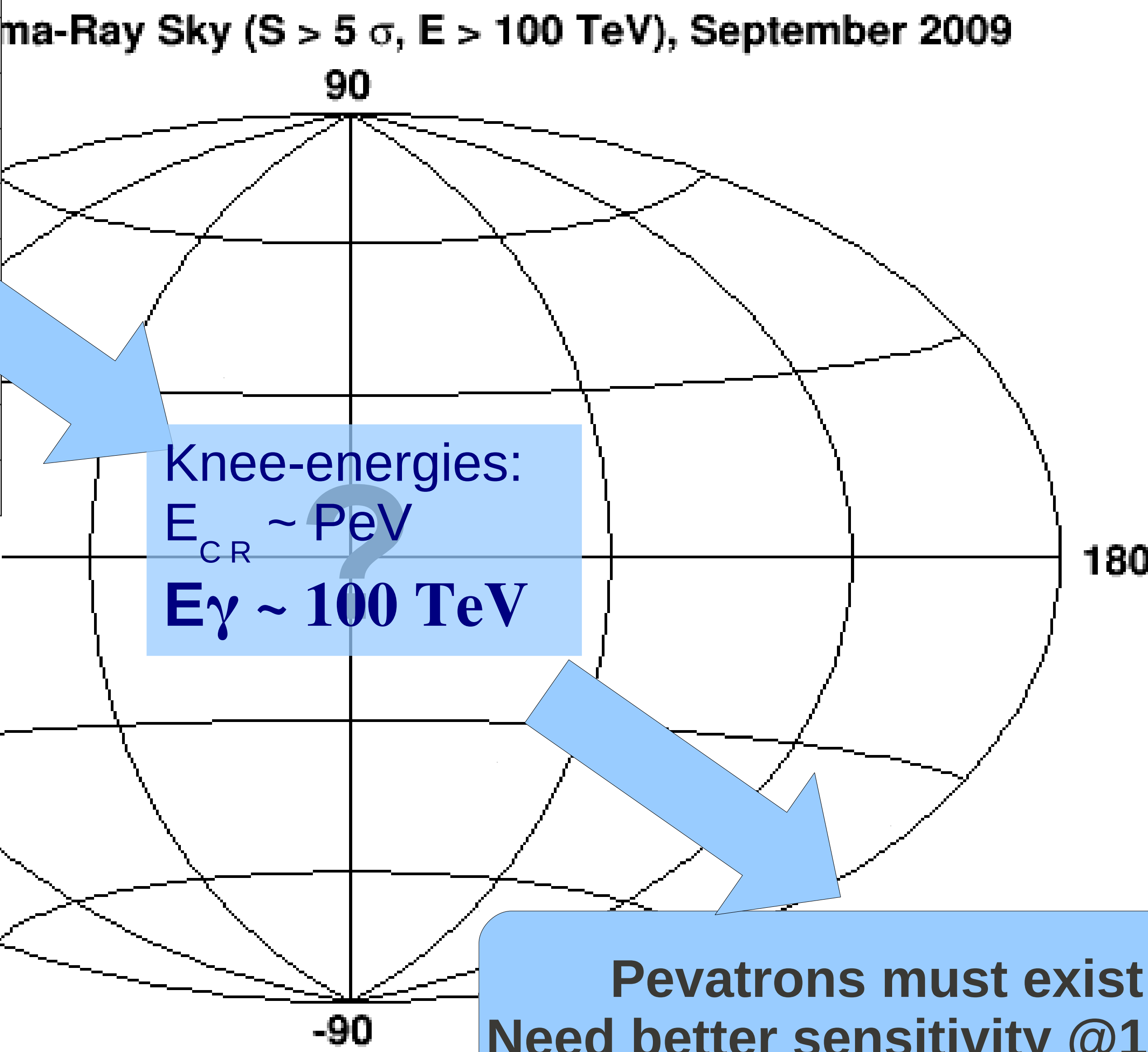
Knee-energies:

E_{CR} ~ PeV

Eγ ~ 100 TeV

Gamma-Ray Sky, E>100TeV





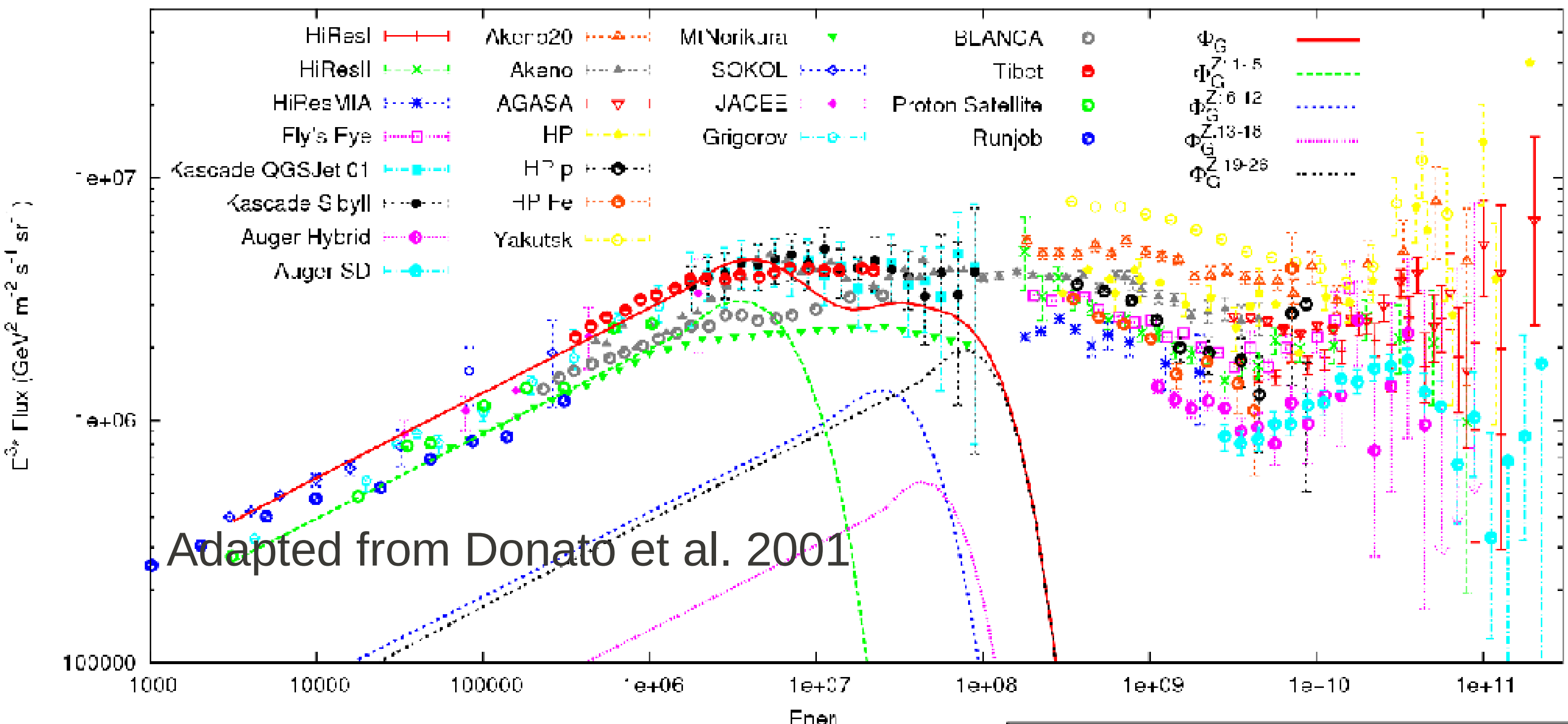
Knee-energies:

E_{CR} ~ PeV

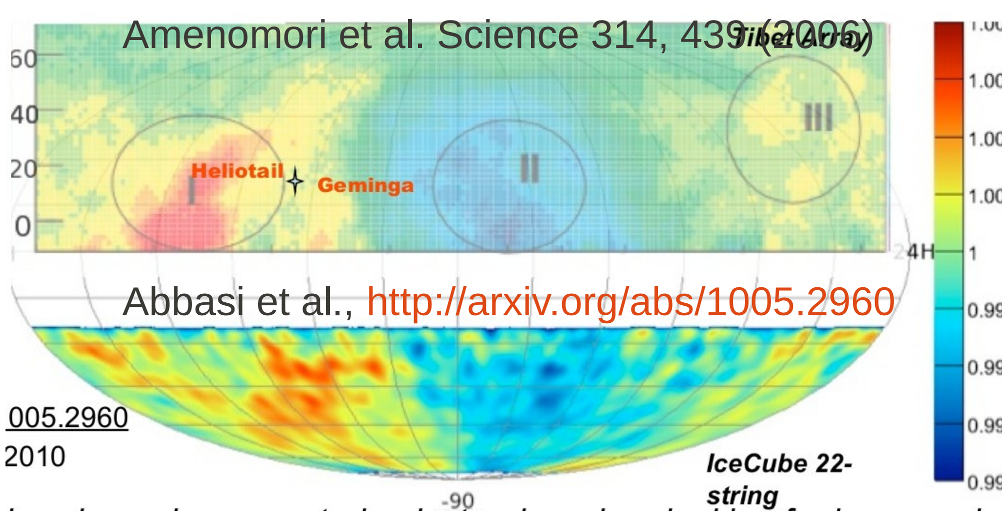
Eγ ~ 100 TeV

Pevatrons must exist !
Need better sensitivity @100TeV

Cosmic ray physics



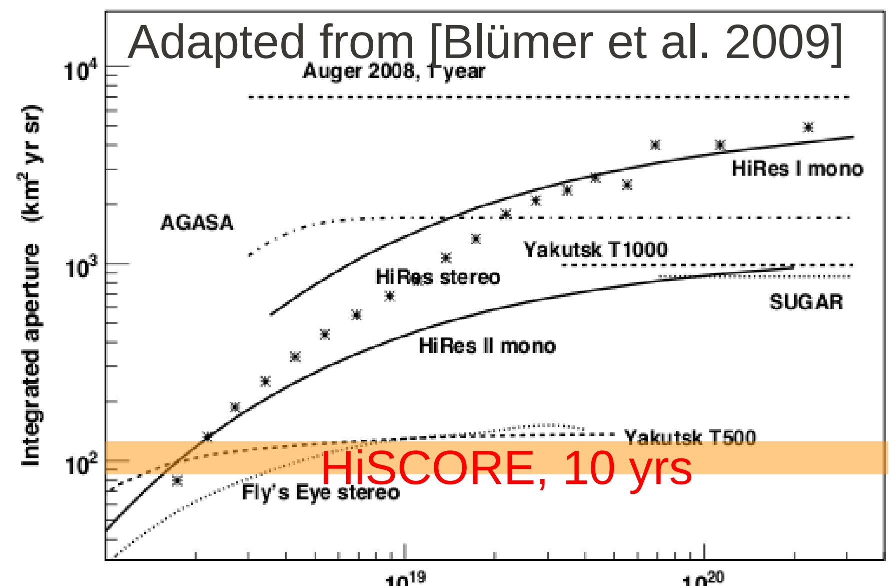
Adapted from Donato et al. 2001



Amenomori et al. Science 314, 439 (2006)

Abbasi et al., http://arxiv.org/abs/1005.2960

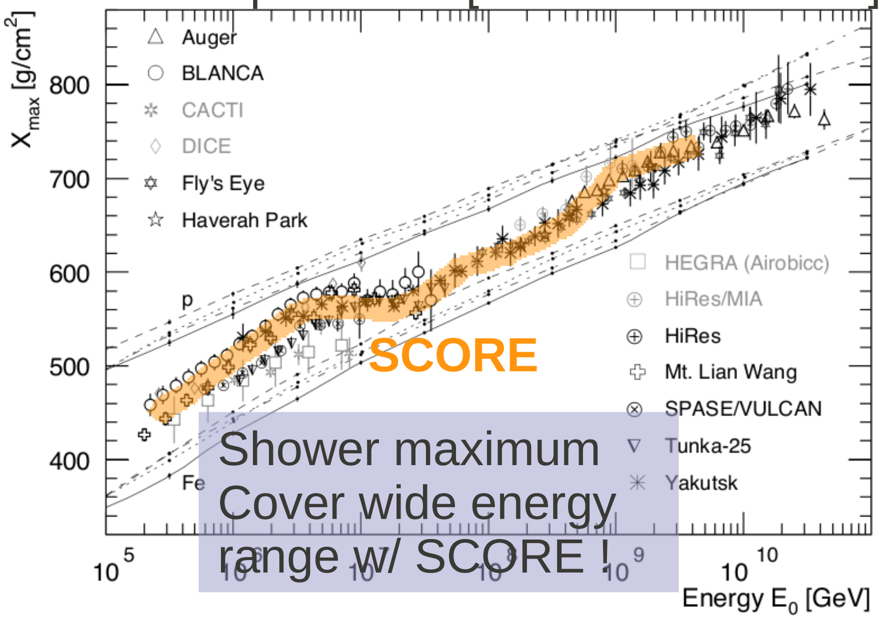
005.2960
2010



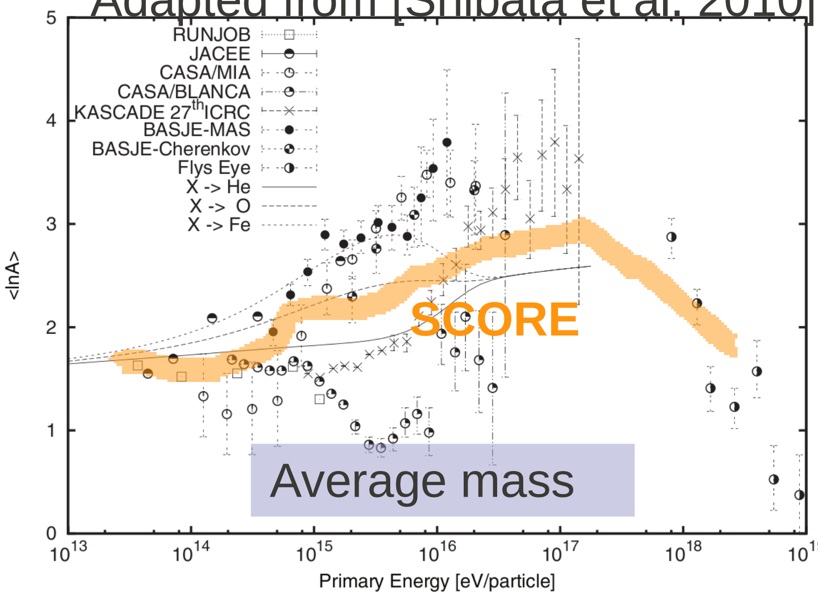
Adapted from [Blümer et al. 2009]

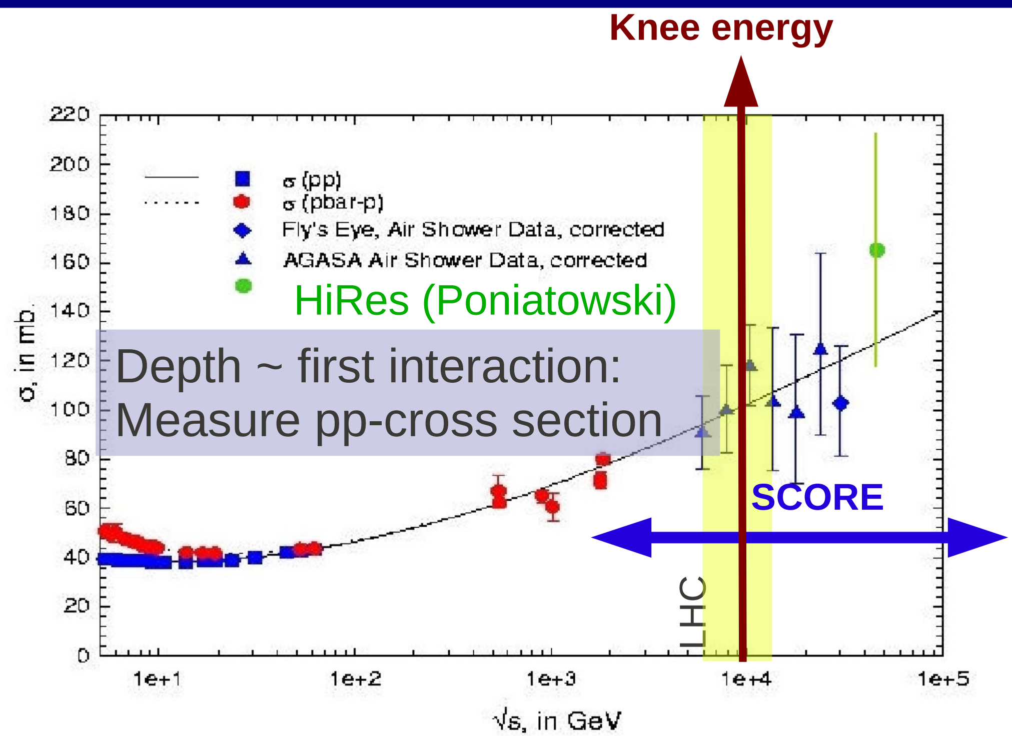
Cosmic rays Particle physics

Adapted from [Blümer et al. 2009]



Adapted from [Shibata et al. 2010]





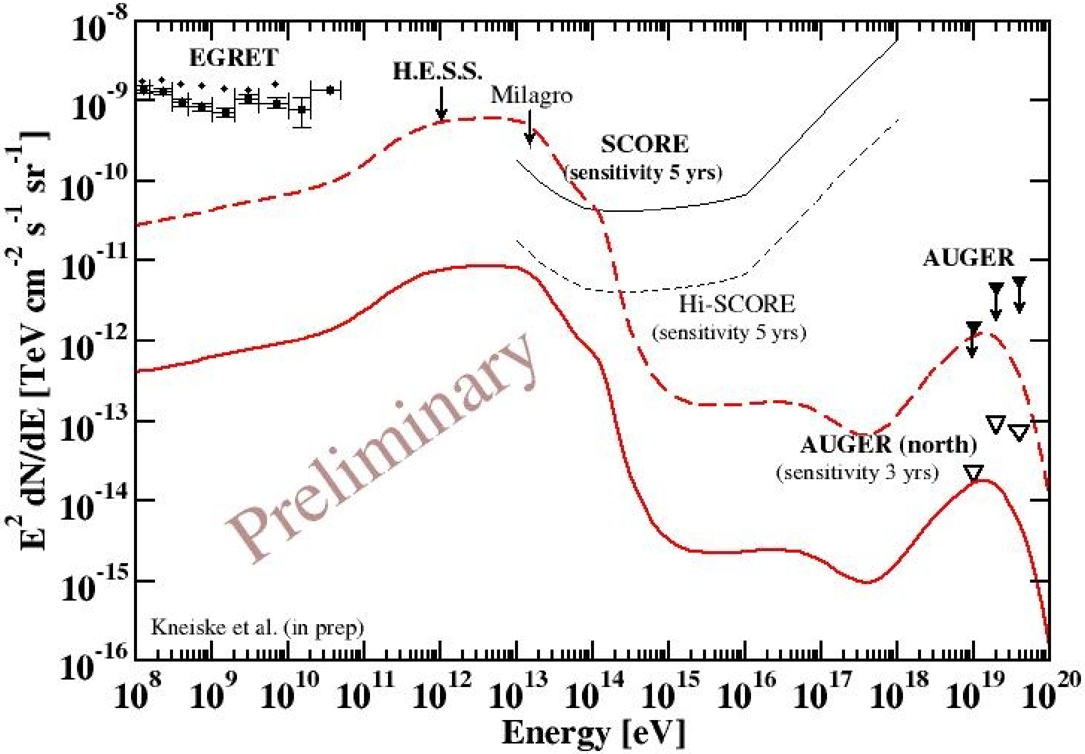
Further particle physics topics:

- Axion search: photon/axion conversion & reconversion → absorption-free propagation
- Hidden sector
- Heavy dark matter

Galactic supercluster

UHECRs

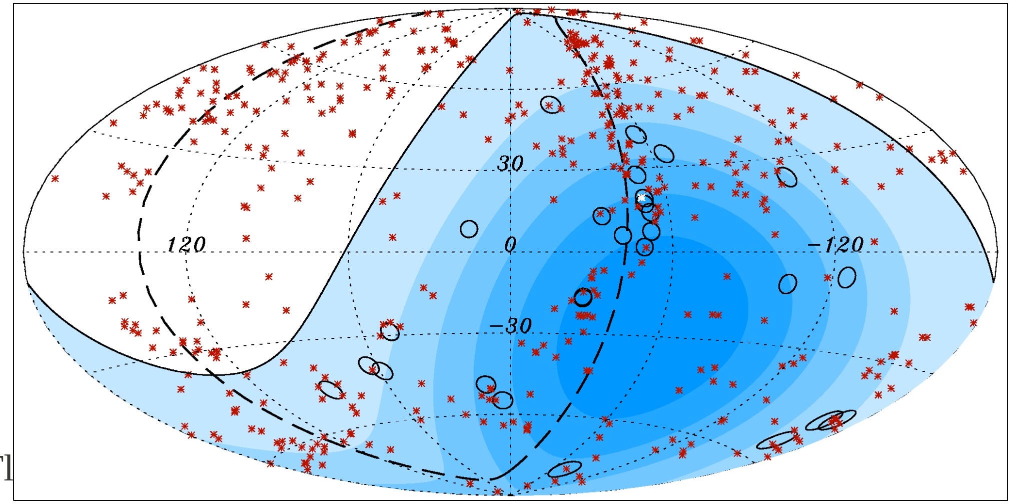
- confined in **local supercluster**
- **CR – CMB interaction** → intergalactic pair cascades
- **Expect diffuse gamma-ray emission**
- *Kneiske, Lodz 2009*



Point-sources from AGN ?

IC Pair-cascading

Haloes ?



AUGER

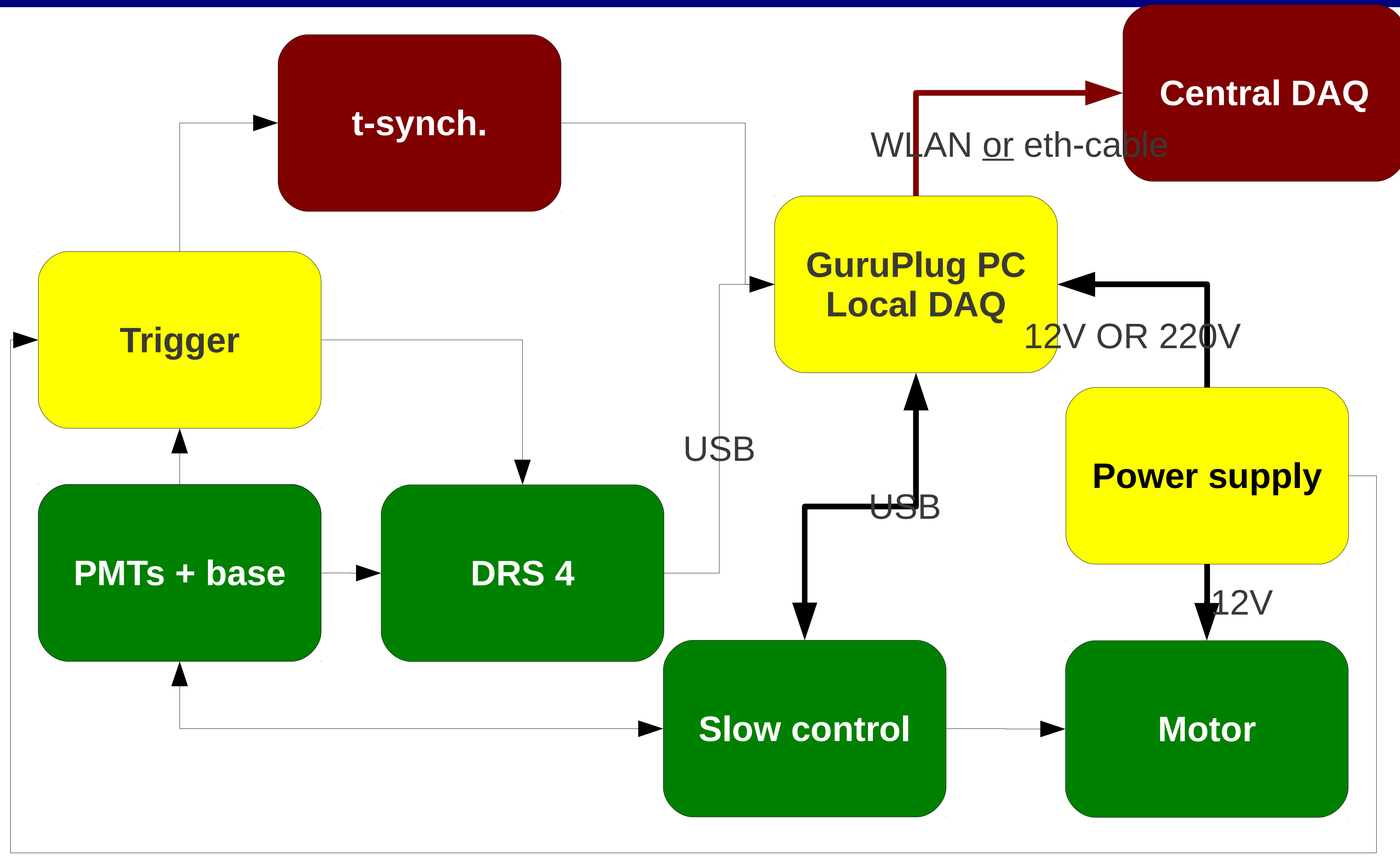
HARDWARE

HARDWARE STATUS

Hardware status

component	status	comment
PMTs	25 Available / tested	Await further delivery 75
DRS4 R/O	25 Available / tested	
HV sup/div	5 Available / tested	
PlugPC	25 Available / tested	
Microcontroller	25 Available / tested	
SlowCtrl board	Prototype available, tested	Developing final version
Sensors	Available / tested	
Trigger	Protype Summer Developing full board	Fall-back: internal DRS4 trigger
GUI-client / server connection	Available / partly tested	Further development Full test with all station components @ UHH

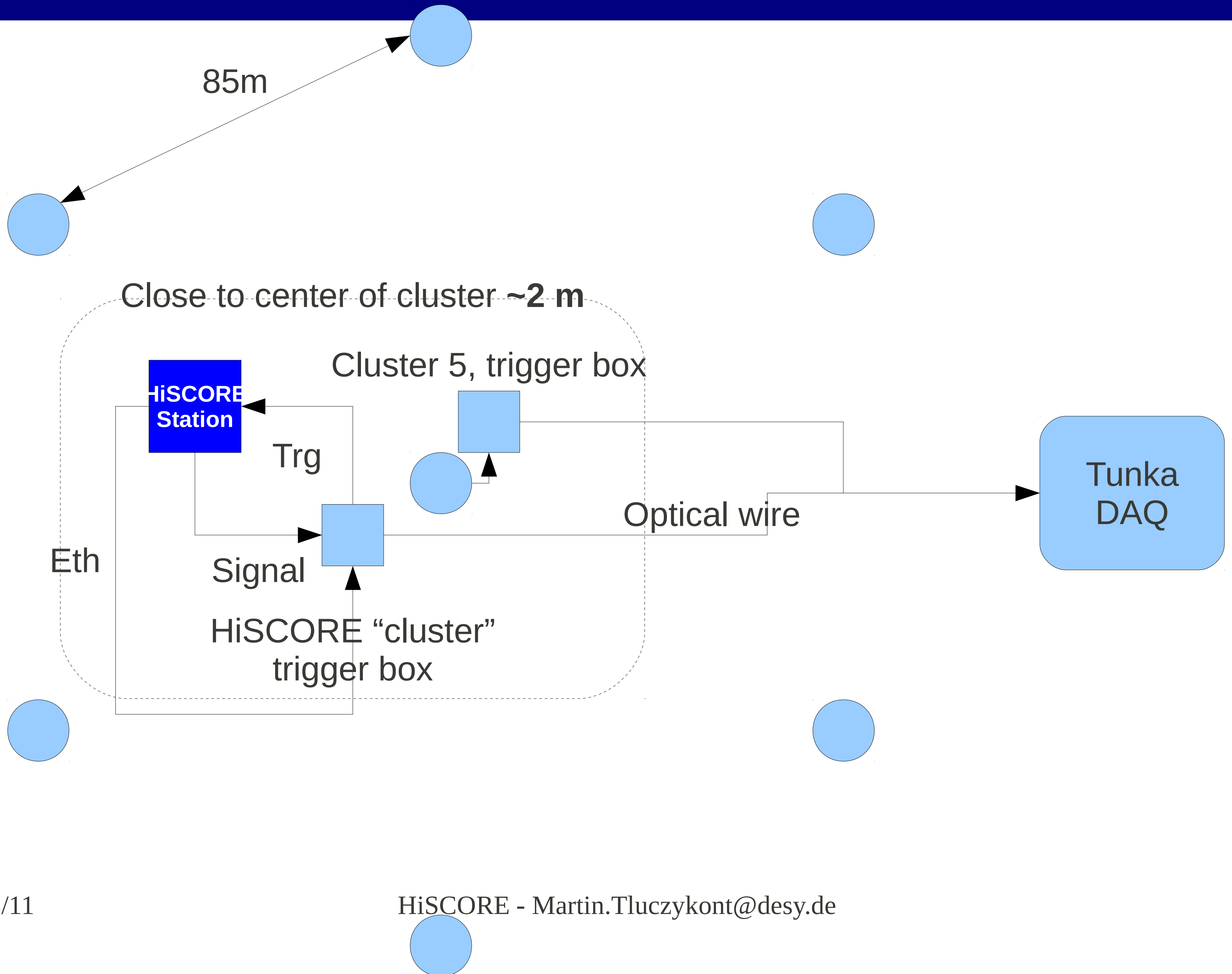
Hardware status



HiSCORE prototype @ Tunka

- 2 prototypes in 2012
- Cross-calibration with TUNKA Cherenkov
- Potential of joint operation with muon detectors
- Synergies with radio detectors
- First use TUNKA trigger / DAQ
- During 2012: develop HiSCORE local trigger
- 2012+: start deployment of engineering array for proof of principle and first physics

HiSCORE prototype @ Tunka



Current activities

- Local trigger development (UniHH)
- Improvement of Tunka time-synchronization (MSU)
- Alternative time-synchronization (UniHH, KIT)
- Finalizing slow control (UniHH)
- DAQ software (UniHH)
- Phenomenology (UniHH, MSU, Grisha?)
- Simulation & reconstruction software (UniHH)
- Prototype station tests (UniHH)
- Preparatory work for prototype deployment (MSU)

SIMULATION

SIMULATION

Shower simulation

Air-shower simulation CORSIKA 6735 [1]:

using the hadronic interaction model Gheisha [2]
including the iact Cherenkov photon package [3]

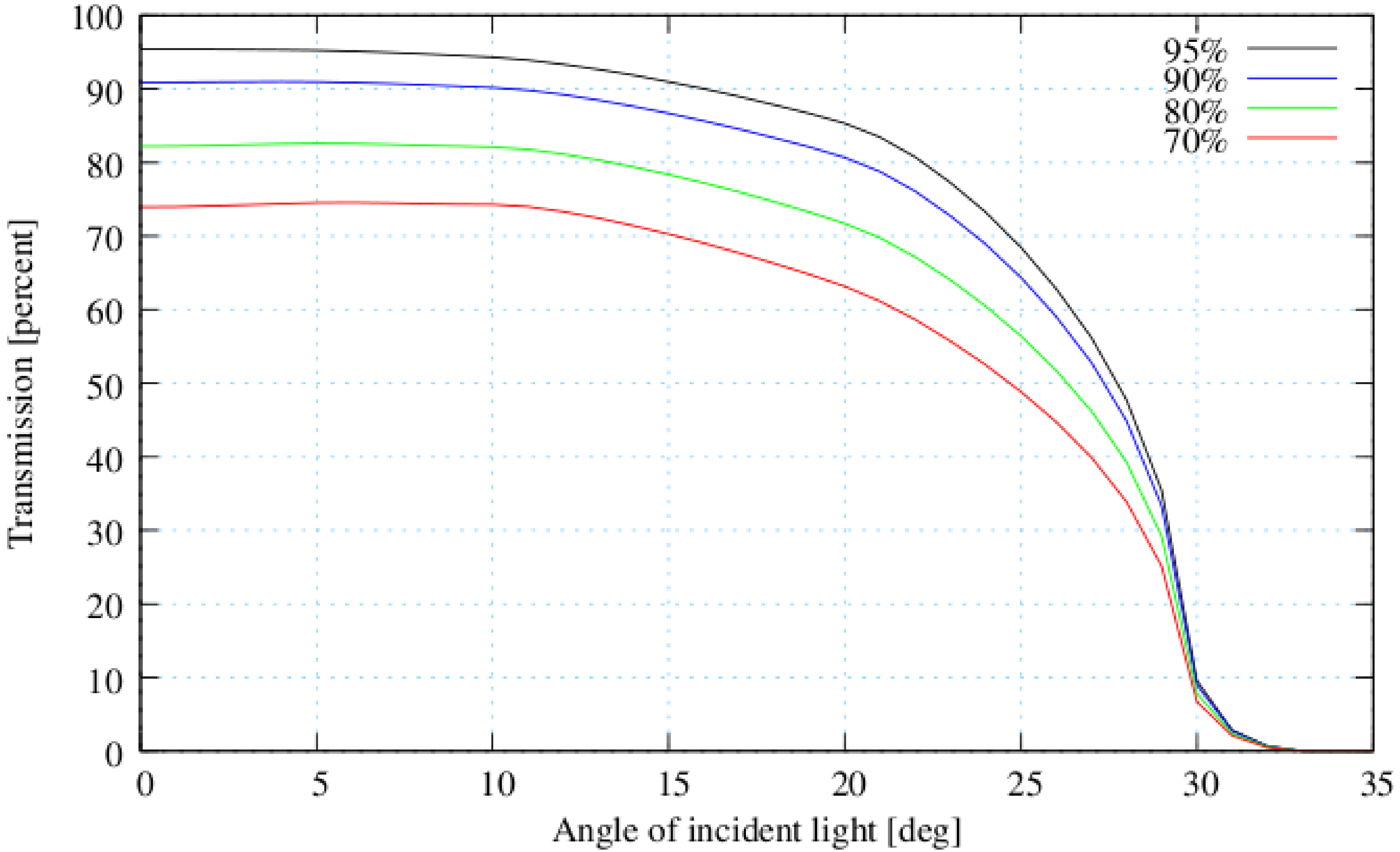
- Gamma, H, He, N, Fe
- 1/E powerlaw from 10 TeV (H: 5 TeV) to 5 PeV
- New production using Fluka planned

Detector simulation

Full detector simulation – sim_score [5]:

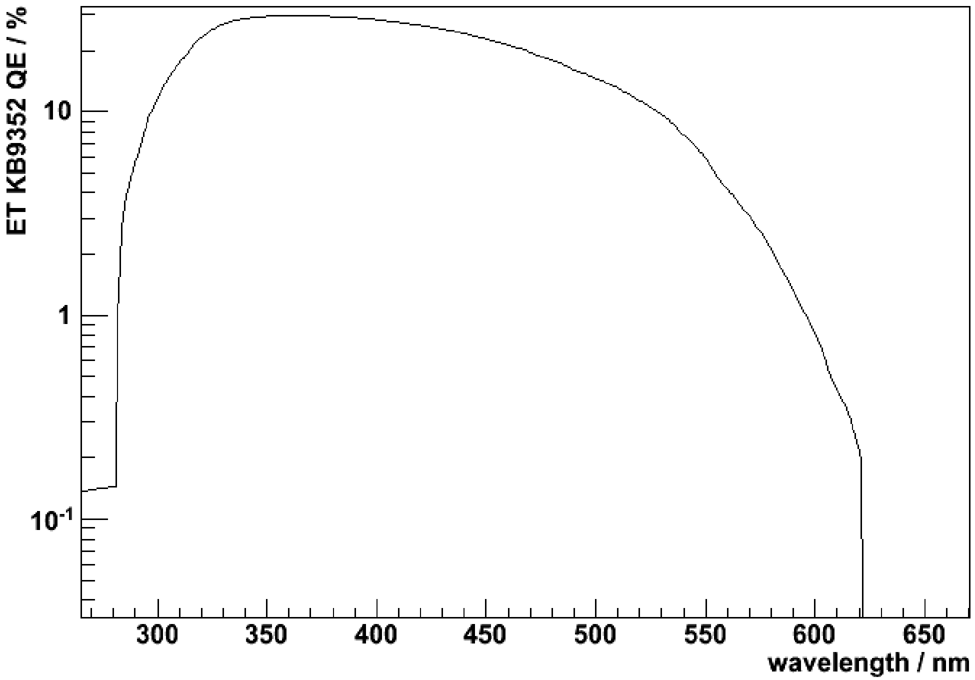
- Using iact package I/O routines, provided by [3]
- Winston cone acceptance included by ray-tracing simulation
- PMT quantum efficiency (Electron Tubes 8'' PMT, data sheet)
- Electron collection efficiency
- PMT signal pulse-shape parameterization [4]
- Afterpulsing simulated w/ $P = 10^{-4}$ at 4 p.e.
- Local trigger: sum of 4 clipped channels
- Night-sky background (including pulse shaping), added to signals
- Array trigger: 1-station or 2-station NN (1µs coincidence window)

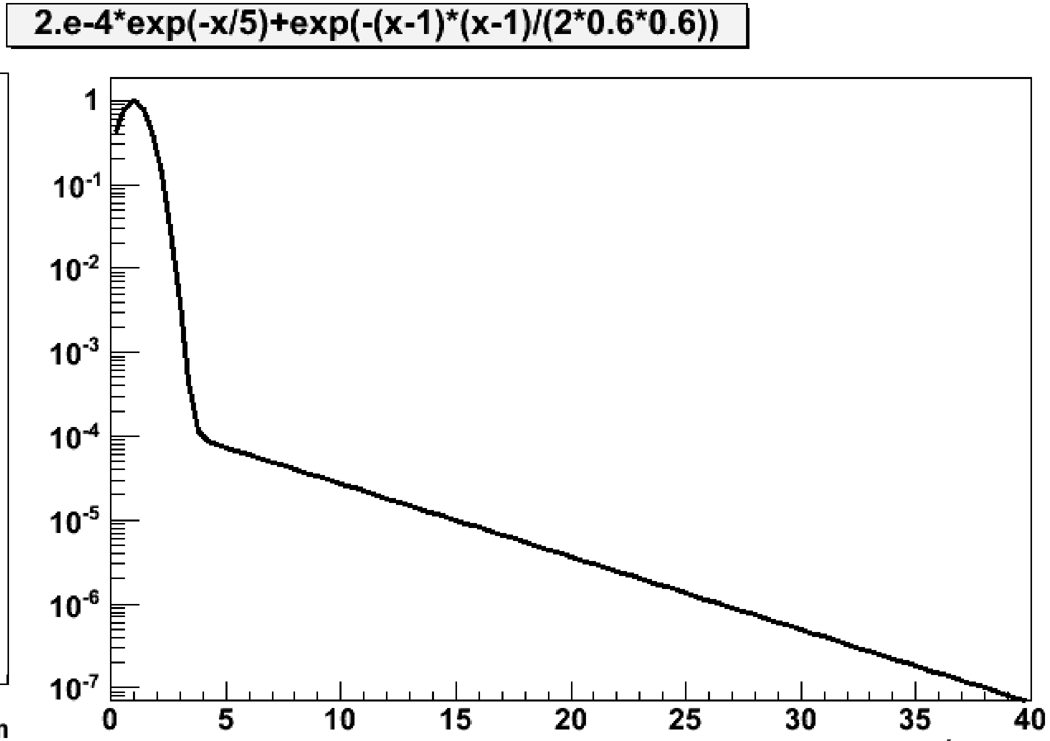
Winston cone acceptance



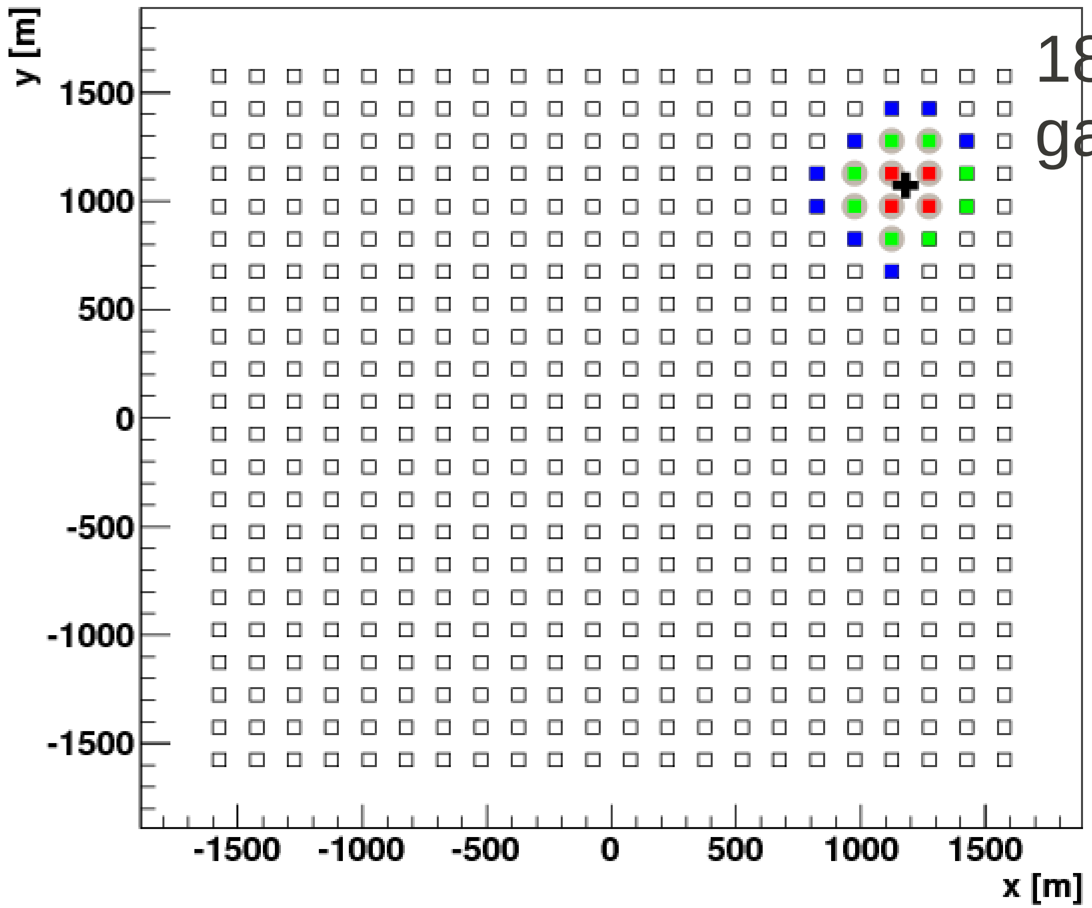
PMT simulation

- Wavelength-dependent QE simulated
- Photomultiplier response including afterpulses



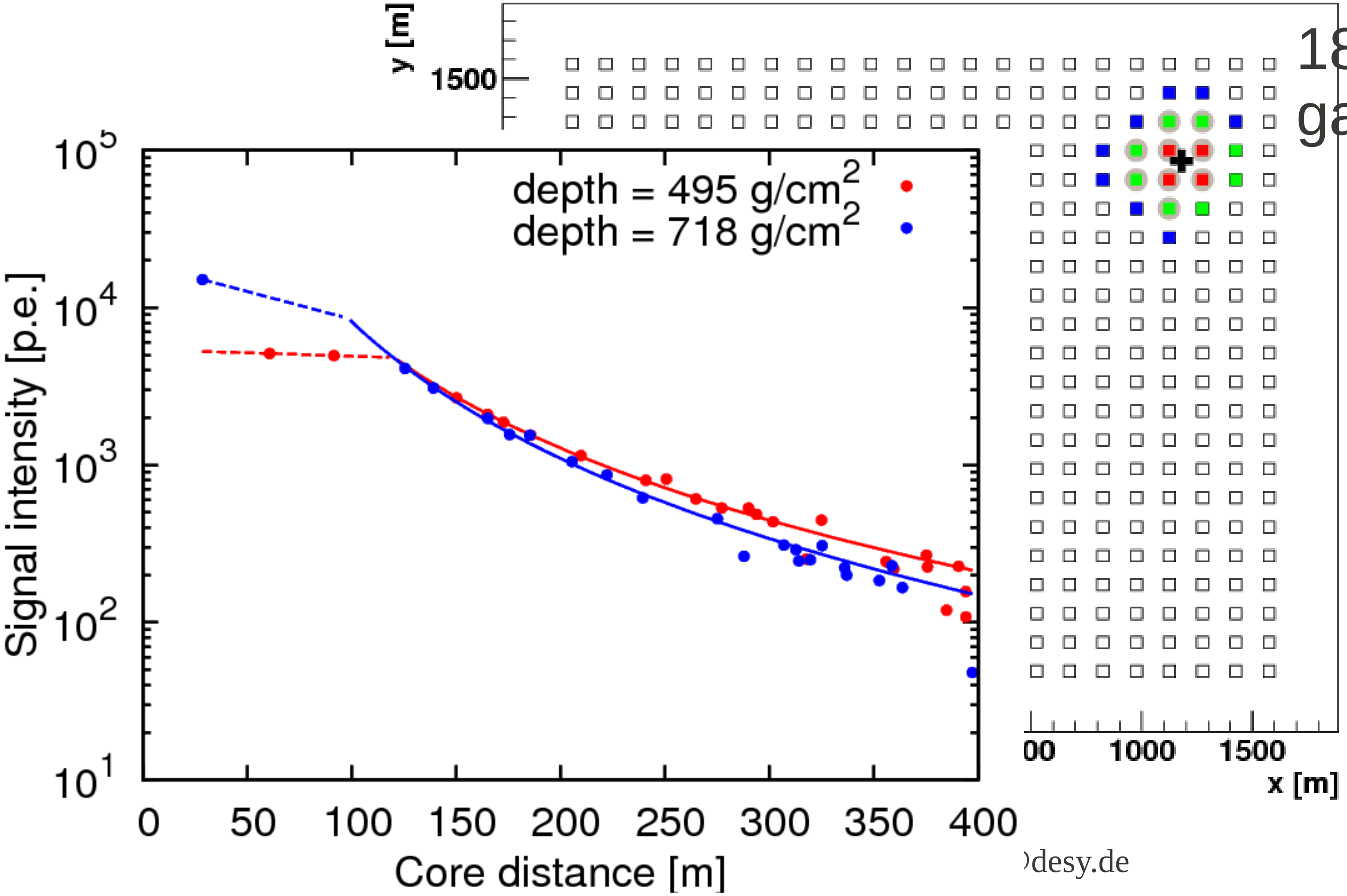


An event example



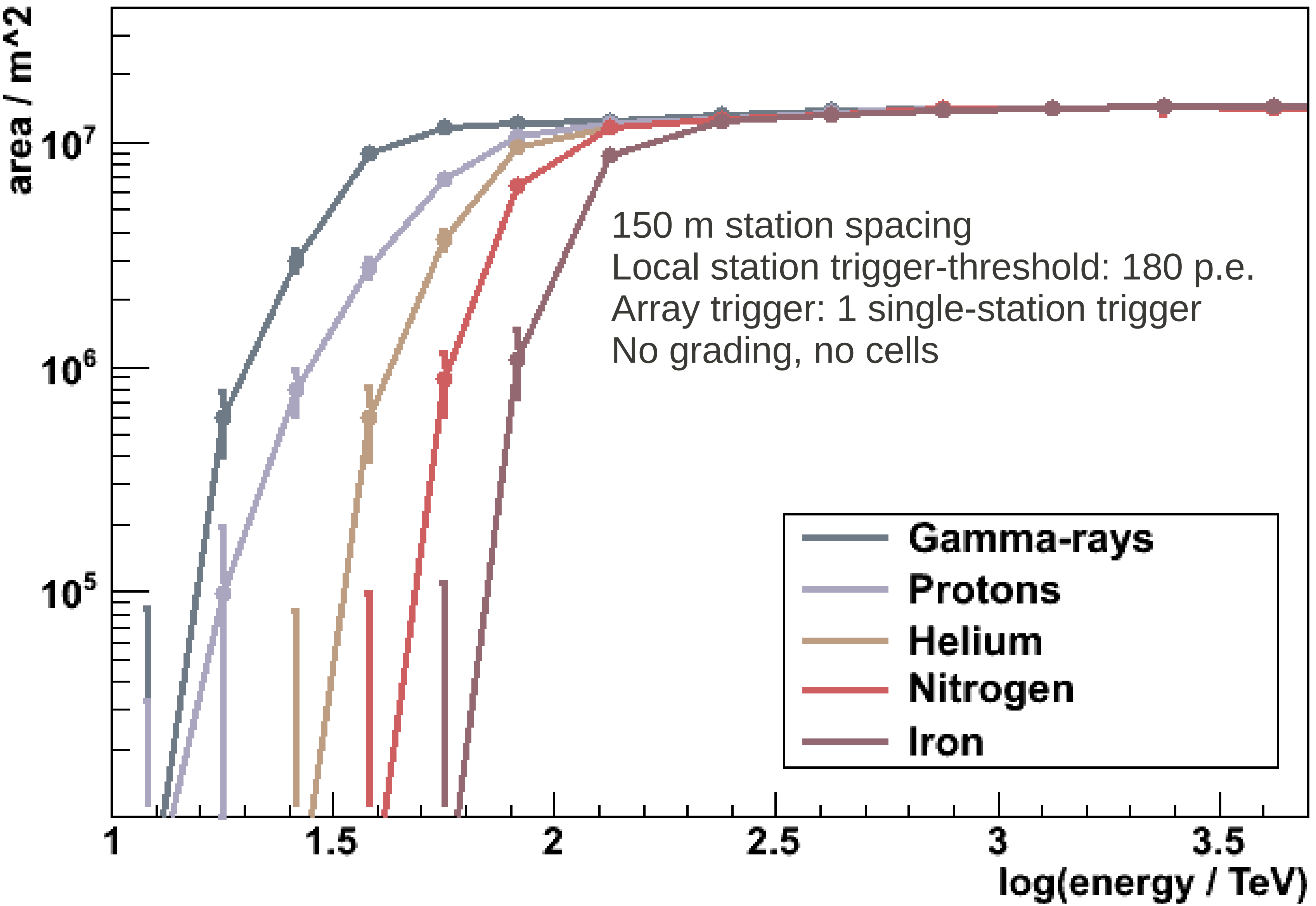
187 TeV
gamma-ray

An event example

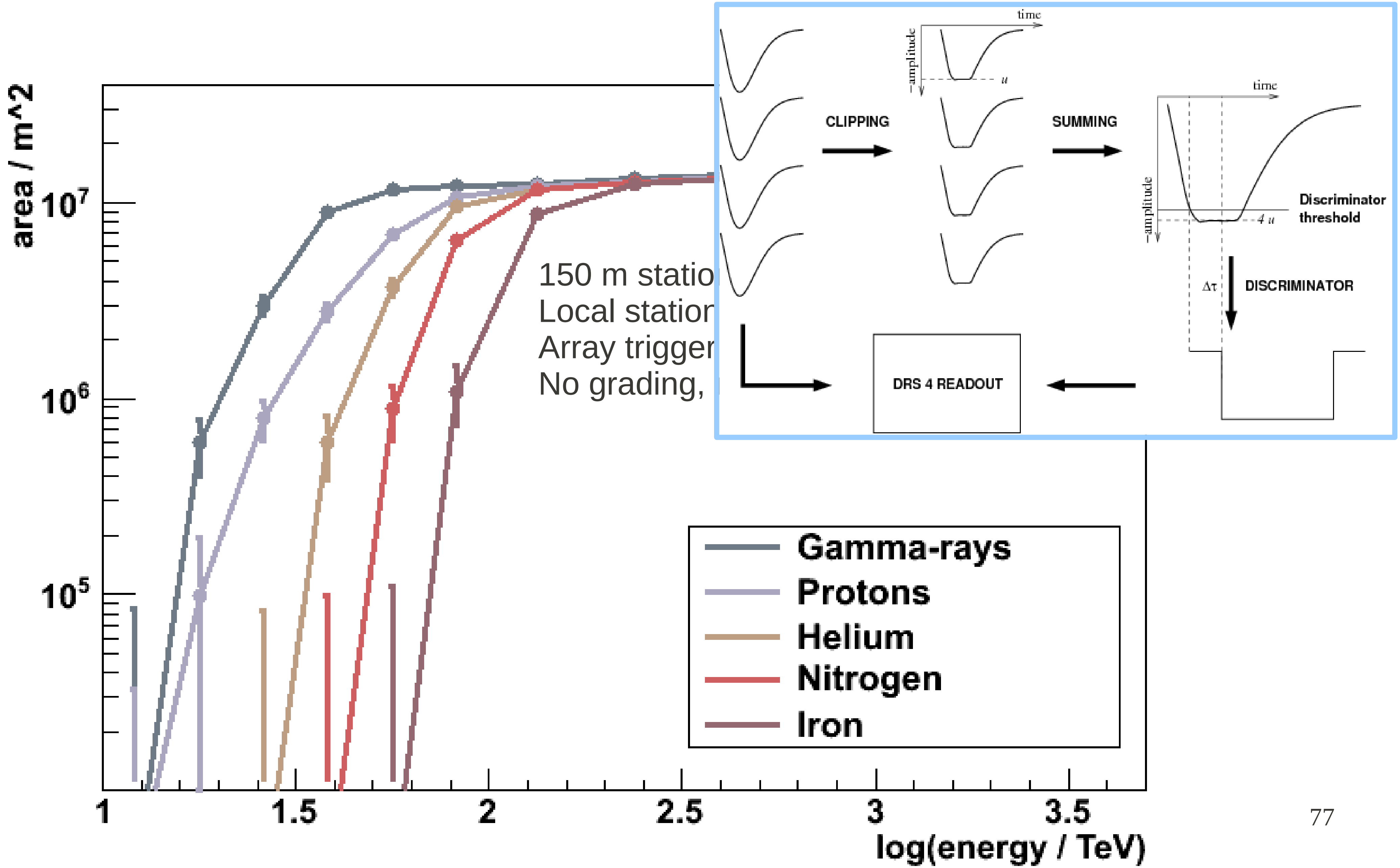


187 TeV
gamma-ray

Effective CR trigger area



Effective CR trigger area

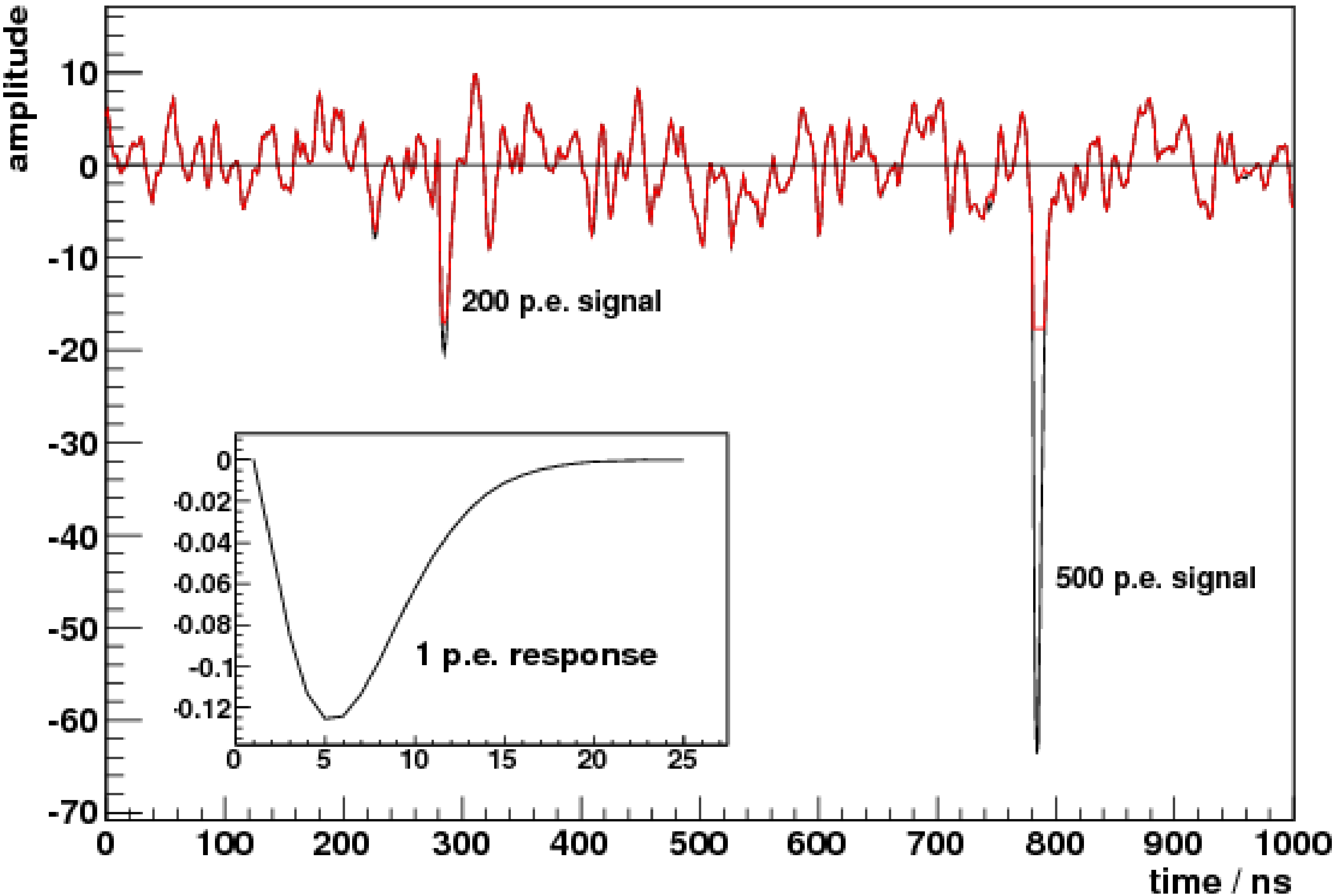


Expected night-sky background trigger rate

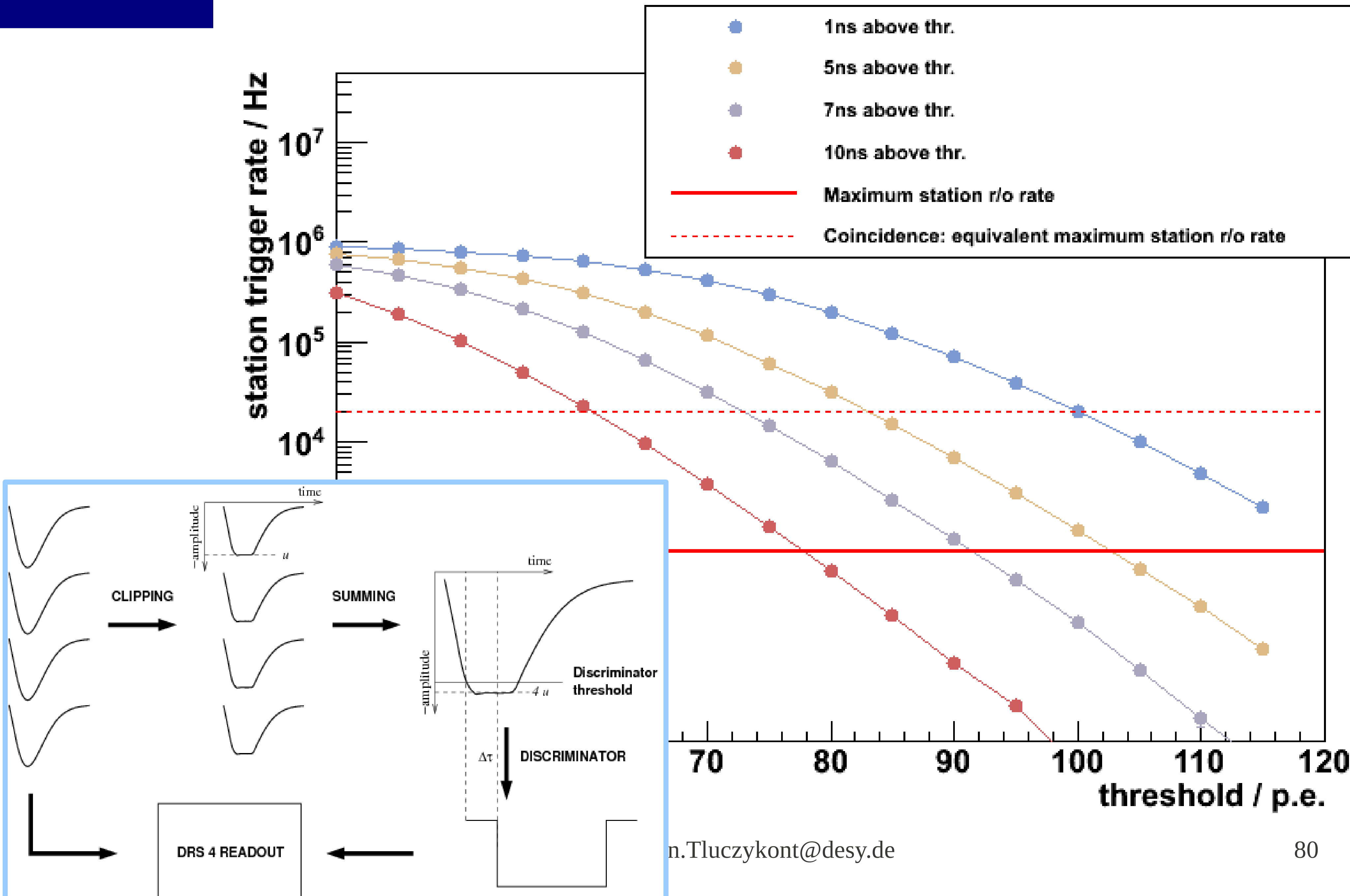
Separate NSB simulation, 4-channel station:

- NSB-rate from measurement in Australia [Hampf et al. 2010]
- Arrays of Photon times: equally distributed random numbers
- Pulse shaping + afterpulsing
- 4-channel coincidence trg:
  → channel-amplitude-clipping
  → analog sum of 4 clipped signals
  → discriminate sum
- Resulting **noise file:** 2s in 1ns bins
- Noise added segment-wise from file to simulated air-shower signal

Signal and noise

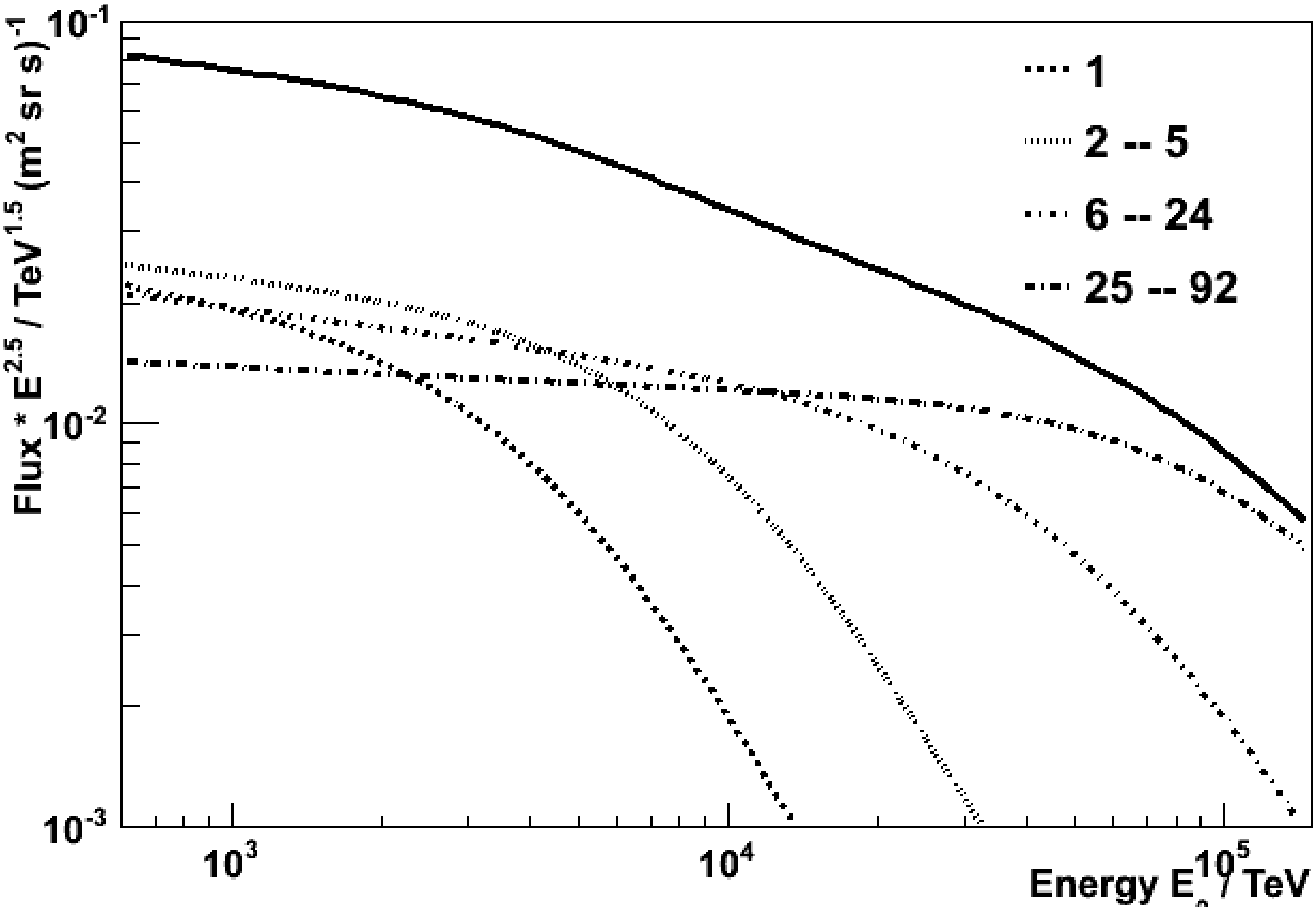


Expected night-sky background trigger rate



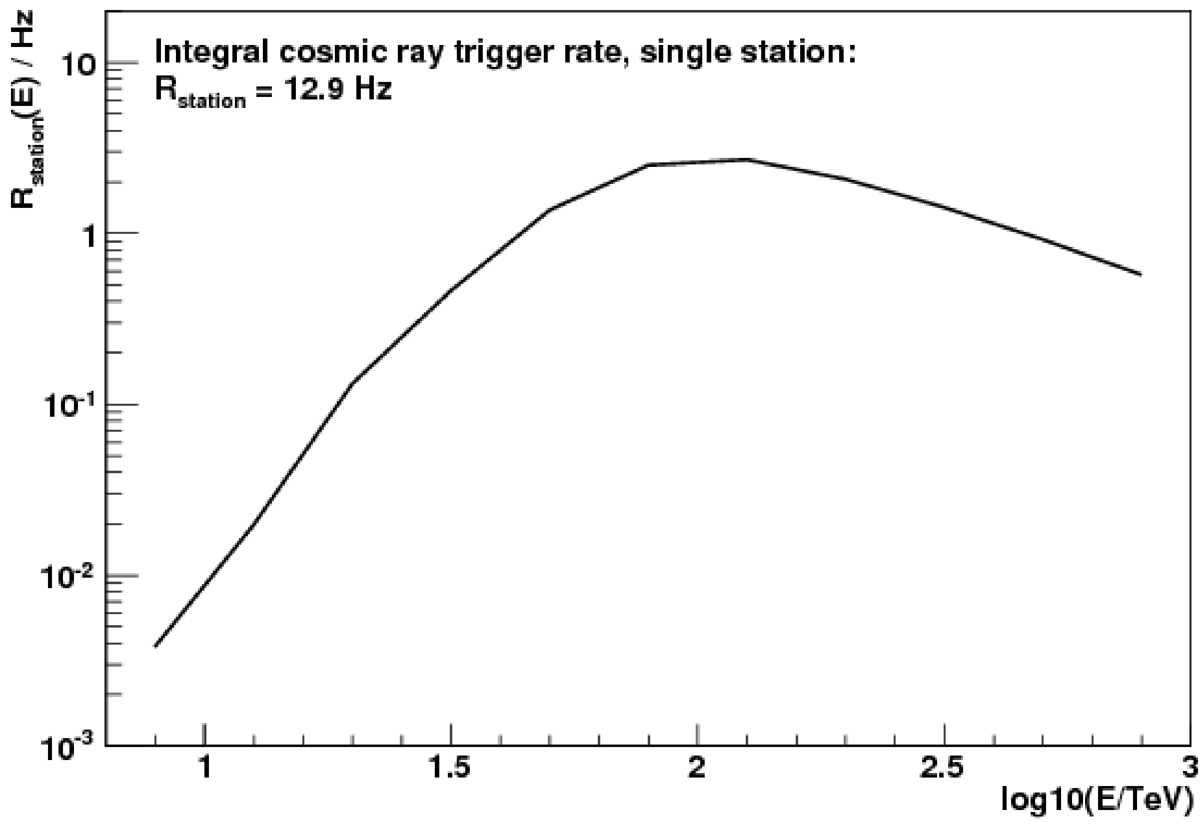
Hadron parametrization

Hoerandel 2003: polygonato model



Station hadron trigger rate

- Simulated average number of stations ber bin
- Folding with polygonato model
- ~13Hz single station hadron trigger rate

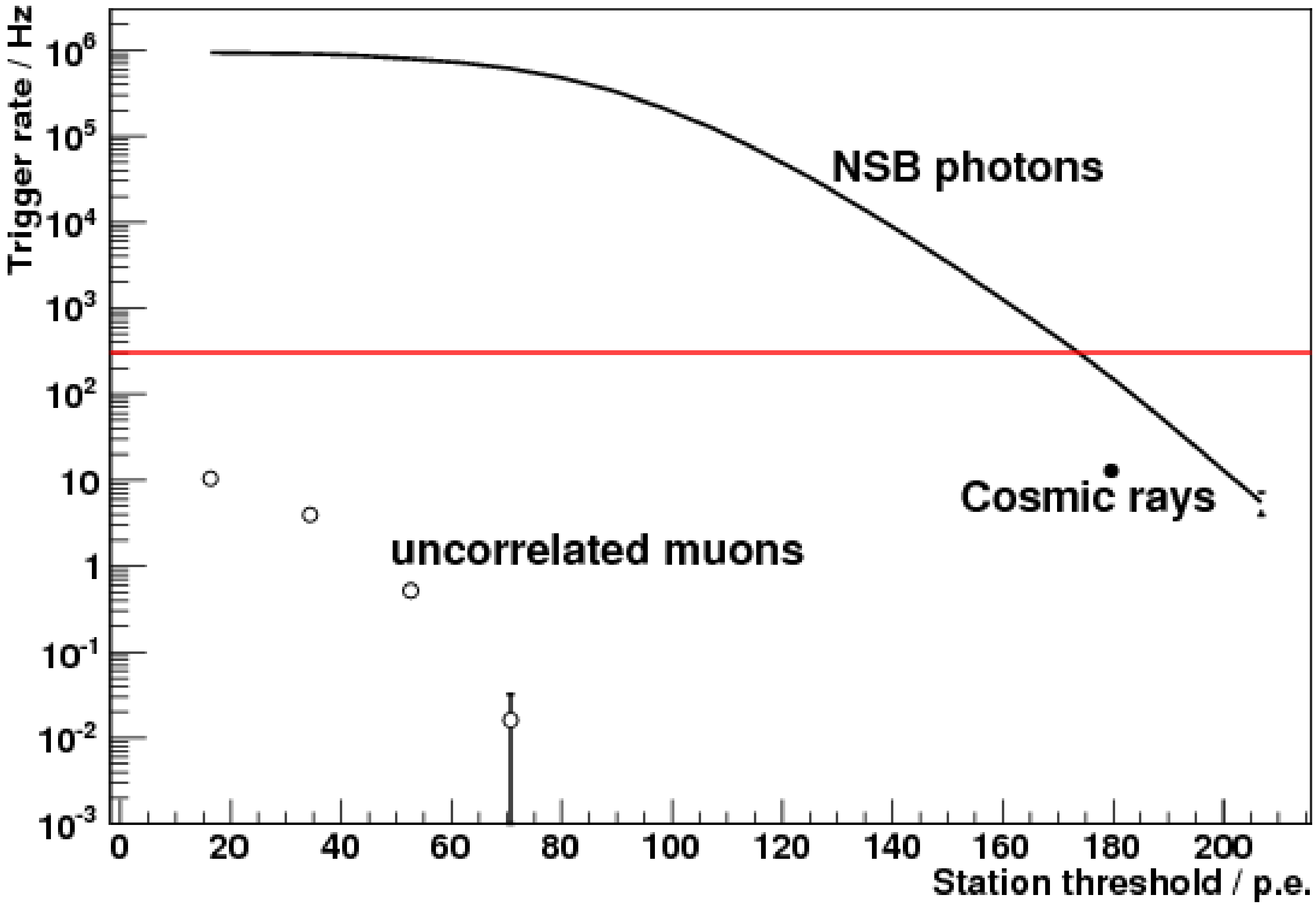


Array hadron trigger rates

Trigger rates for E > 10 TeV, before reconstruction cuts
Detector layout: simple grid, 10 km² (SCORE)
Trigger condition: single station trigger

Proton	774 Hz
He	436 Hz
N	257 Hz
Fe	90 Hz
Array rate, all particles	~ 2 kHz
Single station rate	~ 13 Hz
NSB per station	< 300 Hz

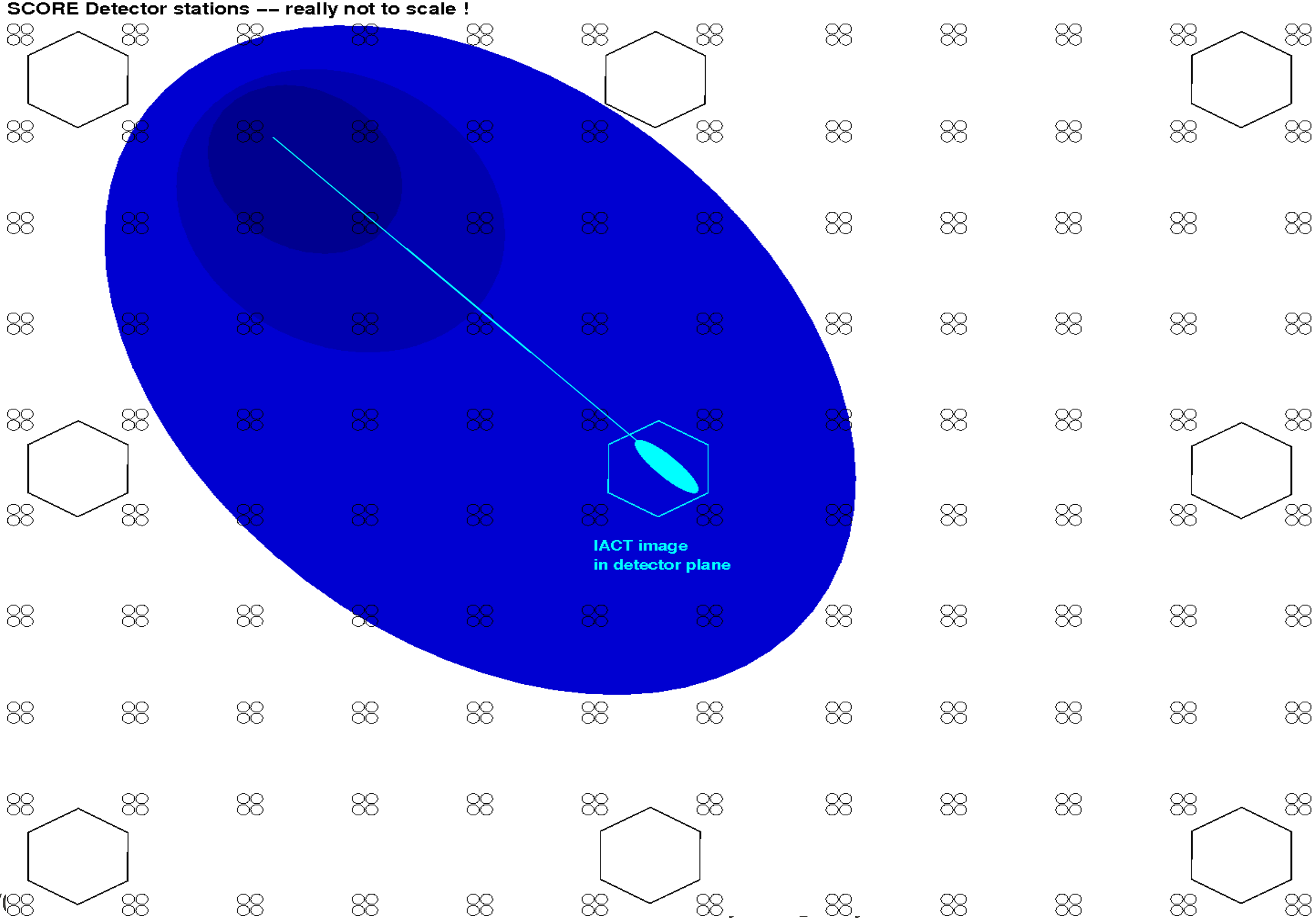
Trigger rates summary



Alternatives / Extensions

- Improvements of layout:
  - **4-channel-cells, 7m X 7m:** Operate each channel independently 2-by-2 sub-arrays for better low-energy reconstruction
  - **Graded array:** decreasing station density towards array edge maximizes area for large energies
  - **Daytime-measurements** with scintillator material in lid: 100% duty cycle
  - **Muon detector:** much better g/h separation
- Combination with imaging technique:
  - provide core-reconstruction for low-density telescope grid (even monoscopic ?)
  - Instrumentation of larger area for highest energies
- Combination / cross-calibration with radio detection technique ?

Combination with IACTs



Combination with IACTs

- Sharing site infrastructure
- Use SCORE stations for **shower impact reconstruction**
  - ➔ **improvement for large stereo angles**
  - ➔ **monoscopic telescopes** distributed on **larger area.**
    E.g. CTA: same number of small telescopes but larger distances giving **higher Aeff / channel ratio !**

- Caveat: observations constrained to station viewcone – might be overcome by using timing stereo at large zenith angles.
- Working on … testing this in simulation

References

[1] D. Heck, J. Knapp, J.N. Capdevielle, G. Schatz, and T. Thouw, Report **FZKA 6019** (1998), Forschungszentrum Karls\-ruhe; available from http://www-ik.fzk.de/~heck/publications

[2] H. Fesefeldt, Report **PITHA-85/02** (1985), RWTH Aachen

[3] K. Bernlöhr (2008), astrop-ph preprint, arXiv:0808.2253

[4] V. Henke (1994), Diploma thesis, University of Hamburg

[5] M. Tluczykont, T. Kneiske, D. Hampf & D. Horns (2009), Proc. of the ICRC 2009, arXiv e-print (arXiv:0909.0445v1)

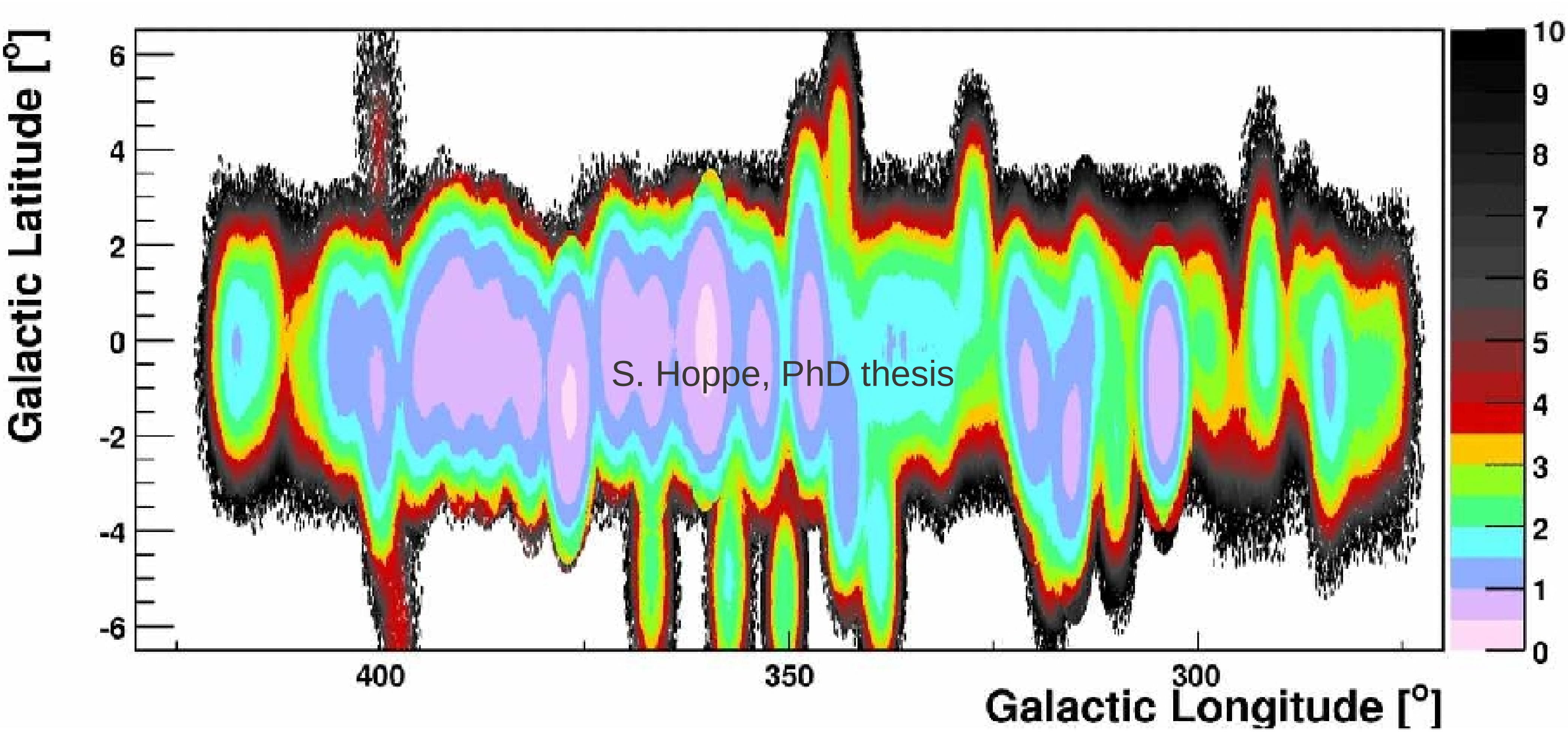
[6] D. Hampf, M. Tluczykont & D. Horns (2009), Proc. of the ICRC 2009, arXiv e-print (arXiv:0909.0663v1)

[7] J.R. Hörandel, Astropart. Phys., 19, 193 (2003)

[Shibata et al. 2010] M. Shibata, Y. Katayose, J. Huang and D. Chen, ApJ 716, 1076 (2010)

[Blümer et al. 2009] Blümer, Engel & Hörandel Progr. in Part. and Nucl. Phys., 63/2, p 293 2009

H.E.S.S. survey sensitivity



Expected pevatron signal

Assuming MGRO 2019+37 is a pevatron
(1deg extension, 3.49 10^{-12} TeV cm^{-2} s^{-1} @ 12 TeV)

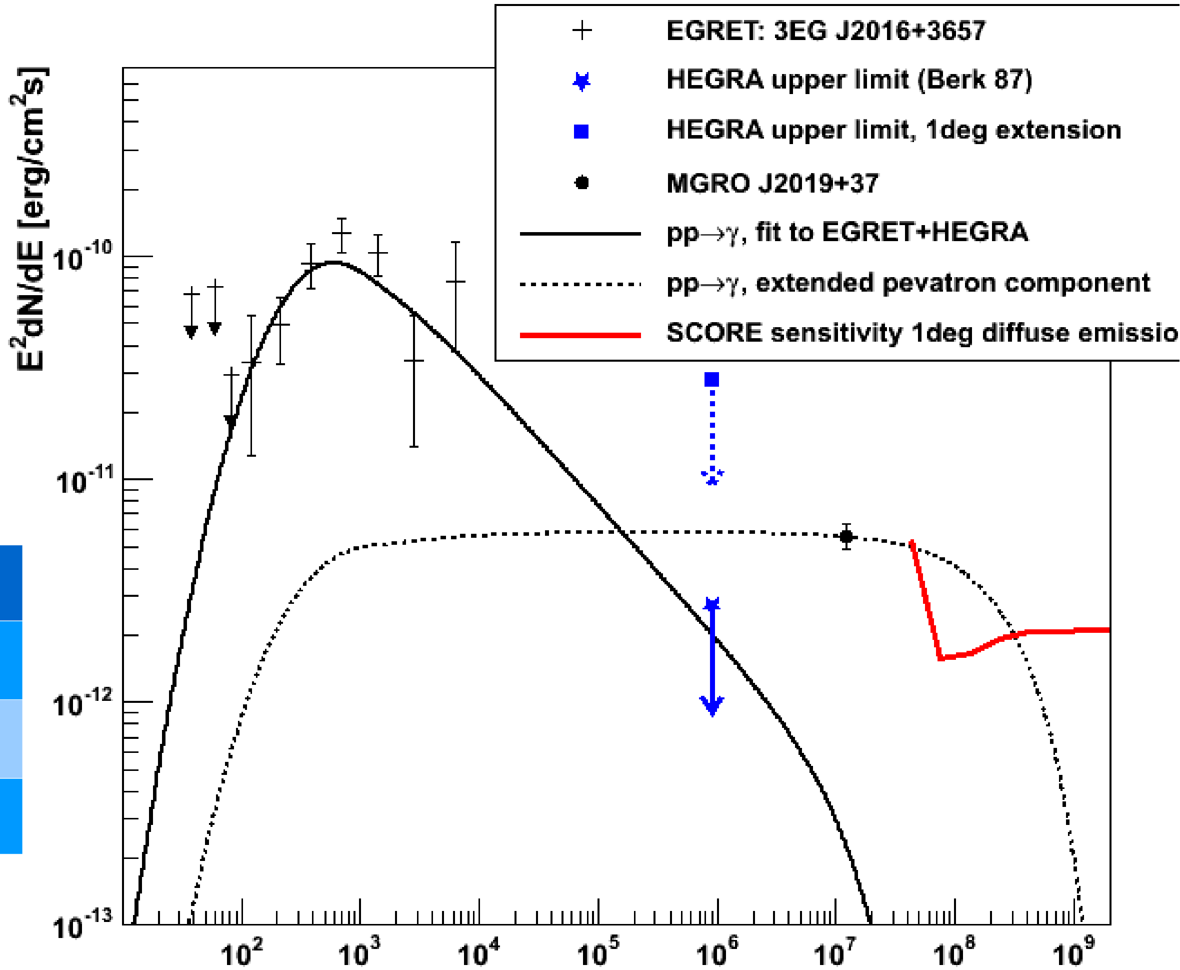
$dN/dE = 4.26\ 10^{-12} (E/TeV)^{-2}\ e^{-sqrt(x/300TeV)} [TeV^{-1} cm^{-2} s^{-1}]$

Fold dN/dE and Hörandel
w/ post-reconstruction area

Integral event numbers

- 2deg source region
- 5 years observation time

Energy	gammas	hadrons	Signific.
>50 TeV	7000	1050000	6.8
>100 TeV	4000	450000	5.9
>1PeV	100	20000	0.7



M. Tluczykont, 2009

p-p cross-section

Correlation shower depth / first interaction
→ measure interaction length in air **σ(p-p)**

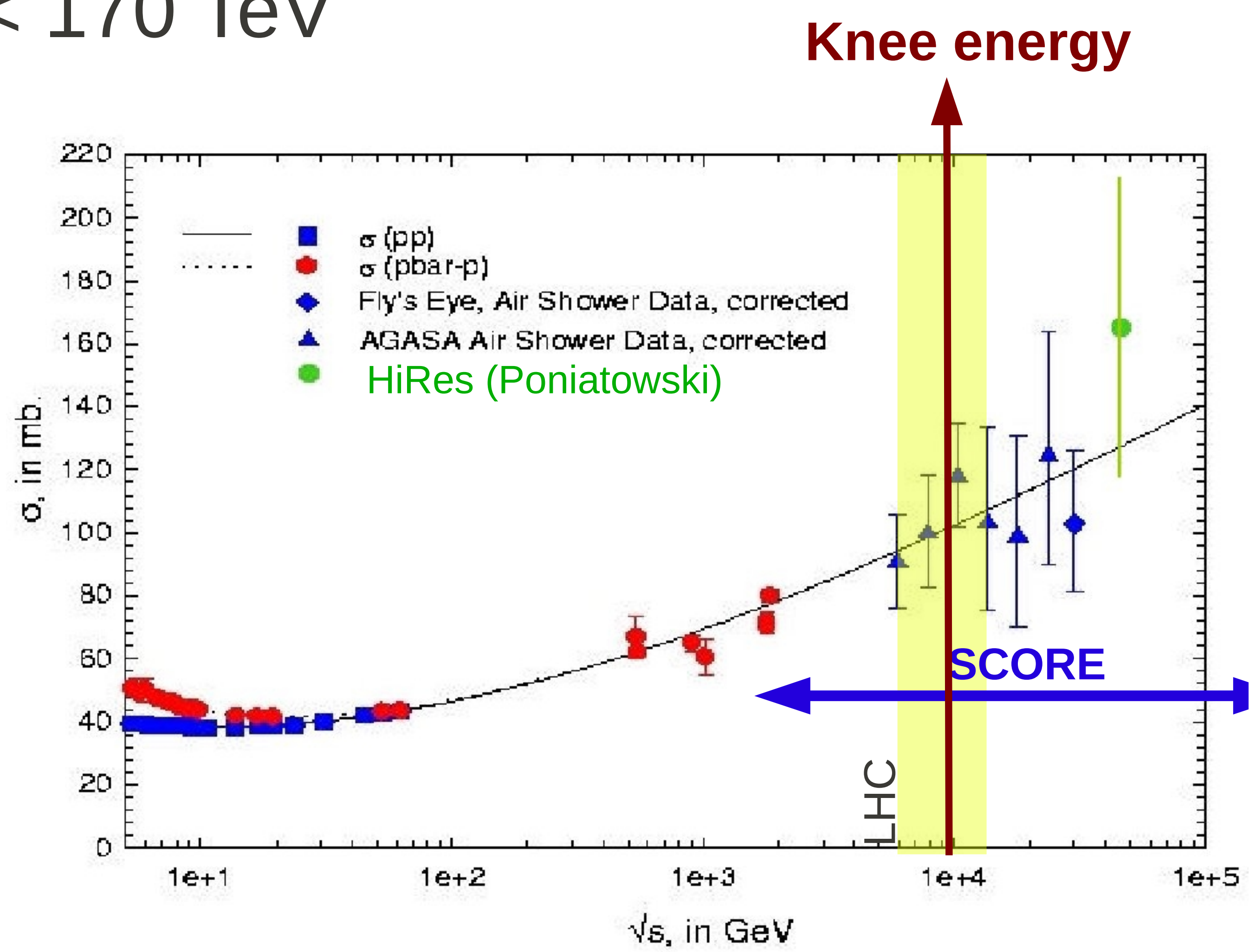
SCORE: 1.7 < E_{CM} < 170 TeV

Particle physics- origin of knee ?

Overlap:

LHC

CR experiments

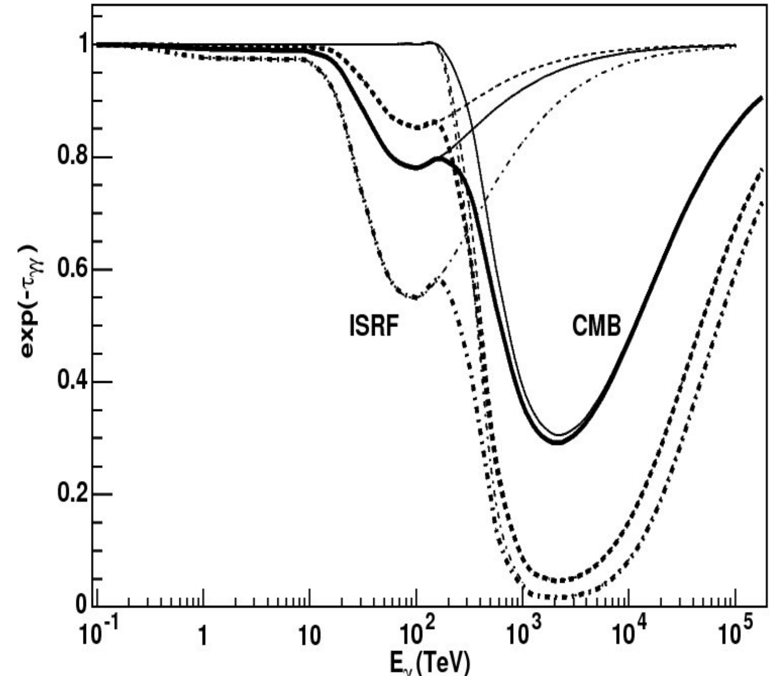


Propagation: Galactic Absorption & CMB

e^+e^- pair production: Interstellar radiation field (ISRF) and CMB

estimate ISRF density

CMB well known: **distance estimate?**



Moskalenko et al. 2006

Weakening of absorption by:

Photon / axion conversion in Galactic Magnetic field

Photon / hidden photon oscillation

Lorentz invariance violation (modification of e^+e^- threshold)