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# Kosmické záření (KZ)

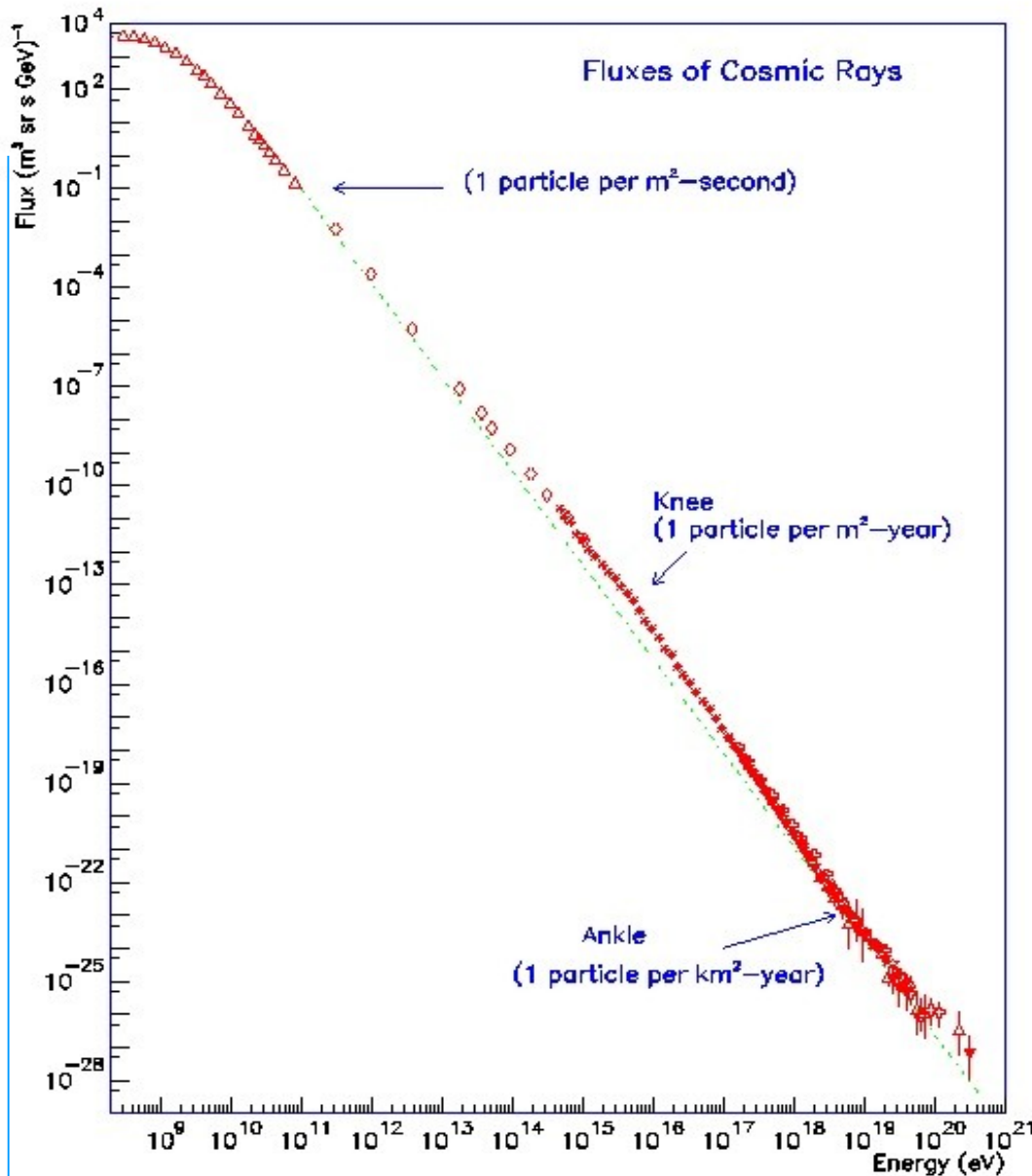
- Úvod
- Objev
- Měření a detektory
- Konec energetického spektra
- Observatoř Pierra Augera
- a něco chutného na závěr



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# Spektrum KZ

- Tok částic
- protony, atomová jádra, elektrony, pozitrony, fotony
- Slunce:  $E < 10 \text{ GeV}$
- Power-law  $E^{-\alpha}$

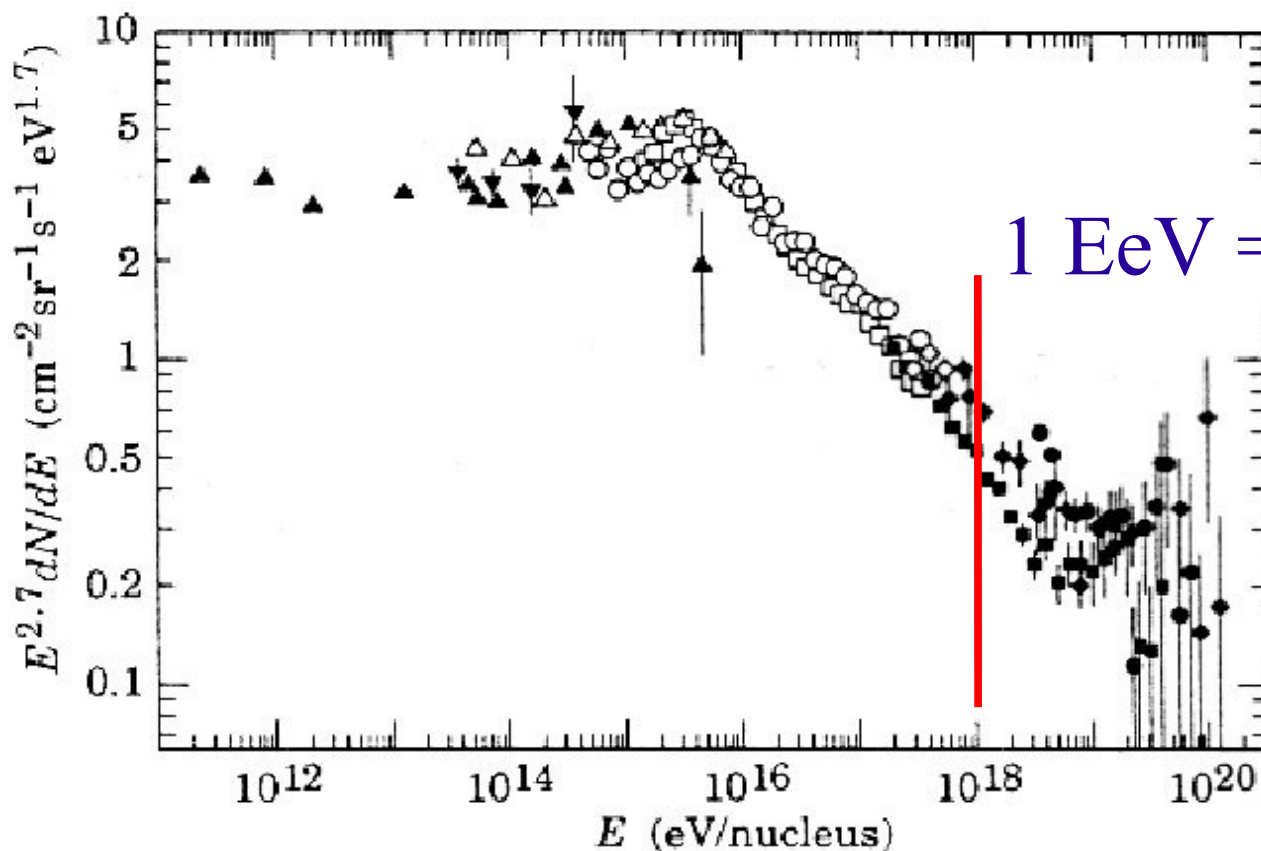


Fermiho urychlování?  
(mnohonásobný odraz  
nabité částice)



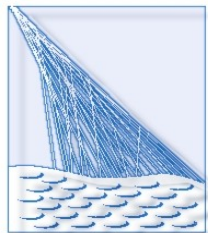
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# Spektrum KZ



- Koleno  $3 * 10^{15}$  eV
- Kotník  $4 * 10^{18}$  eV

Ultra High Energy  
Cosmic Rays

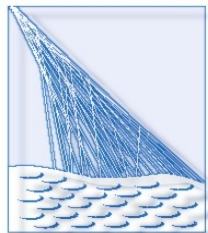


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# Objev

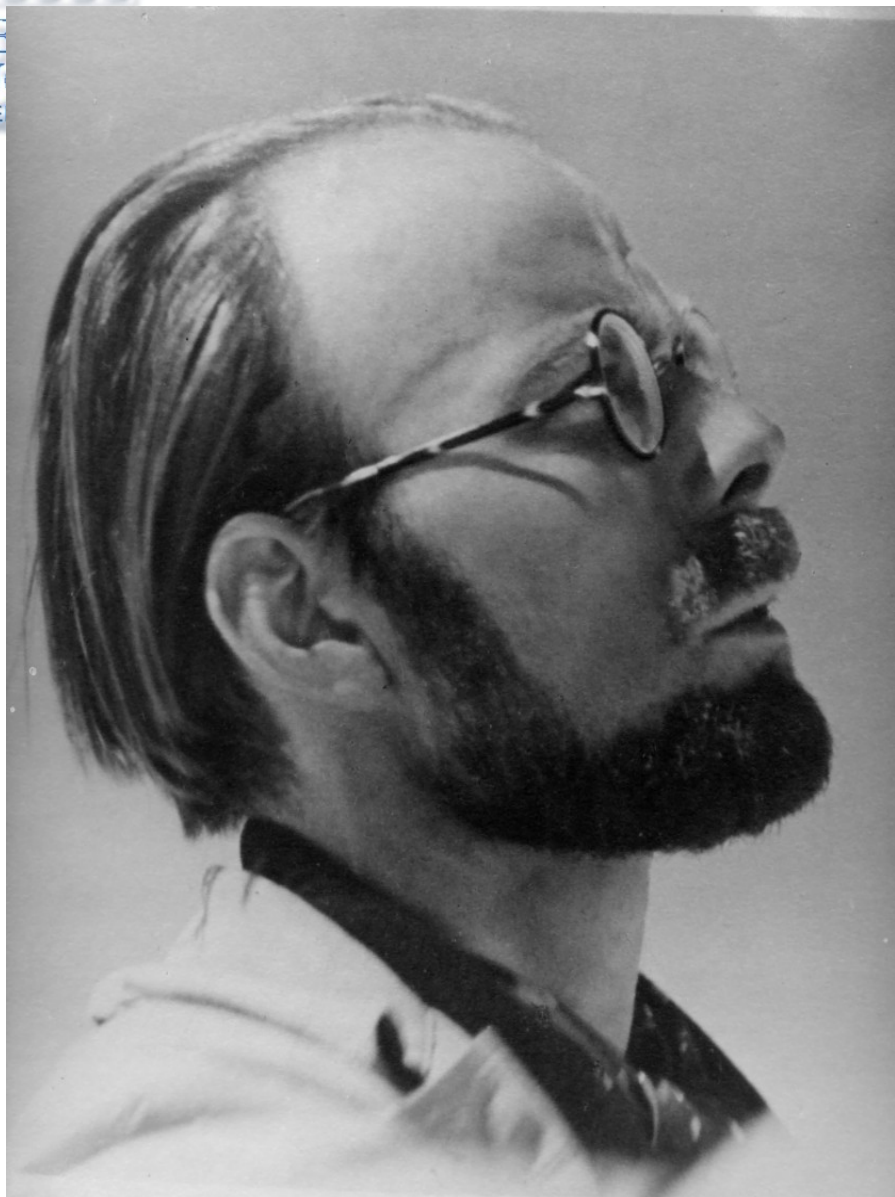


- 1912 Viktor Hess
- Lety balónem (5,5 km)
- Ionizace v atmosféře
- 1936 Nobelova cena
  
- 1925 R. Millikan  
("cosmic radiation")



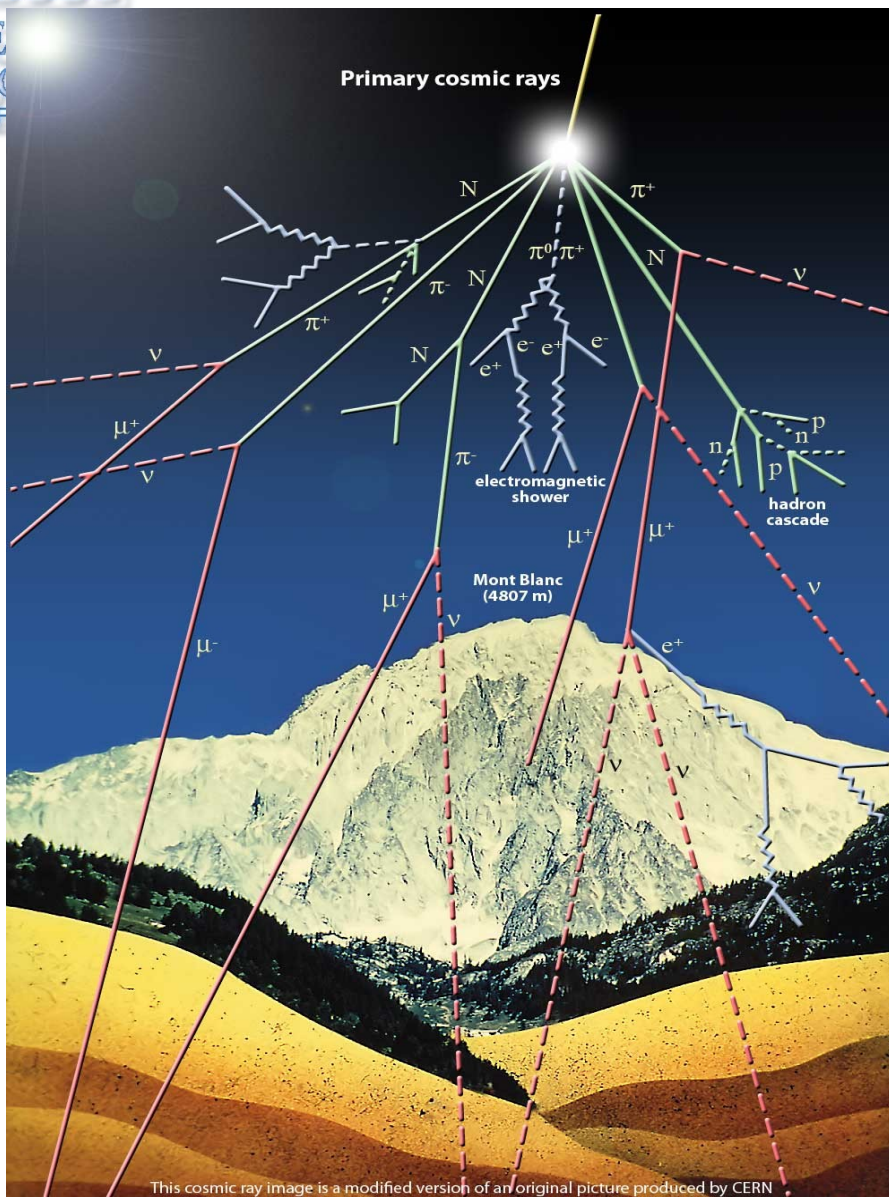
# Atmosférické spršky

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- 1938 Pierre Auger
- Koincidence signálu v detektorech
- Rozsáhlé spršky částic
- Sekundární částice
- Primární částice mají energii  $\sim 10^{15}$  eV

# Atmosférické spršky

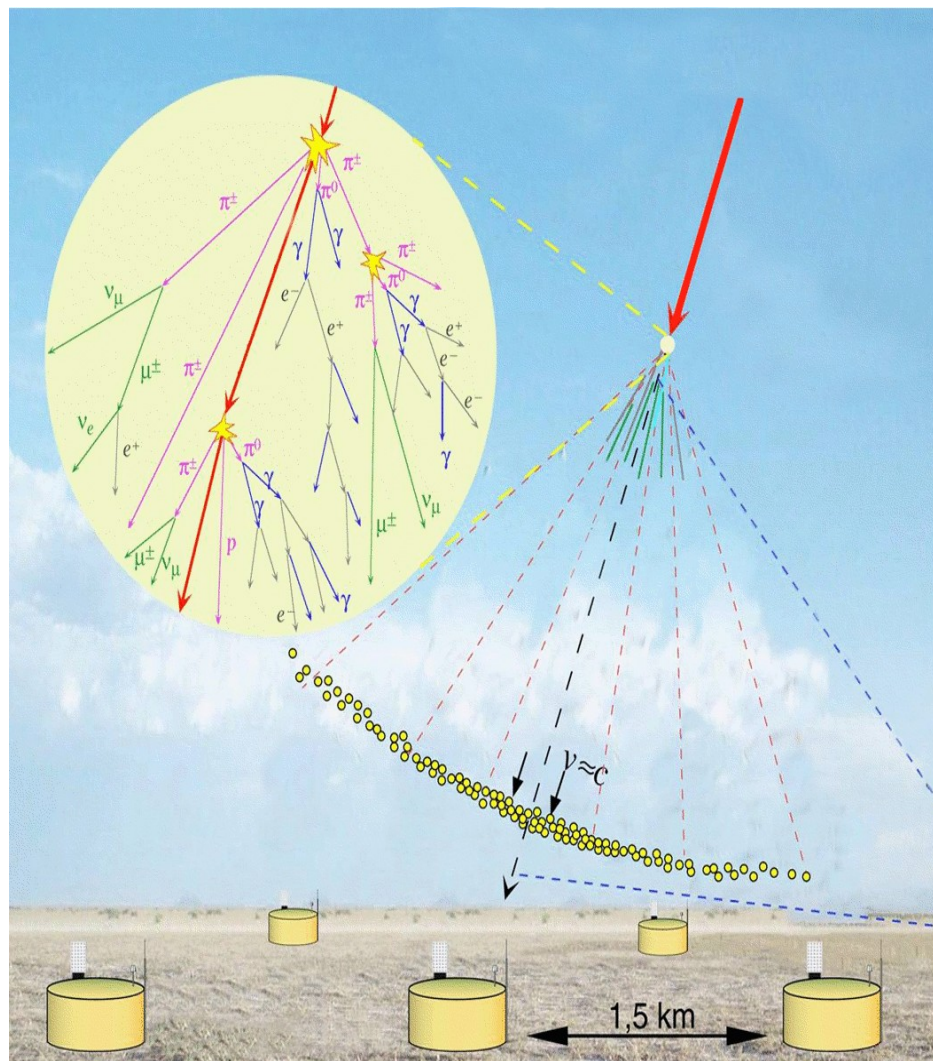


- První srážka 20 - 30 km
- Kaskády částic:
  - Electromagnetická
  - Hadronová
- Vznikají miliardy částic
- Na povrch dopadne jen malá část

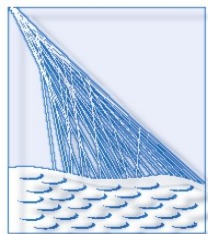


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# Pozemní detektor

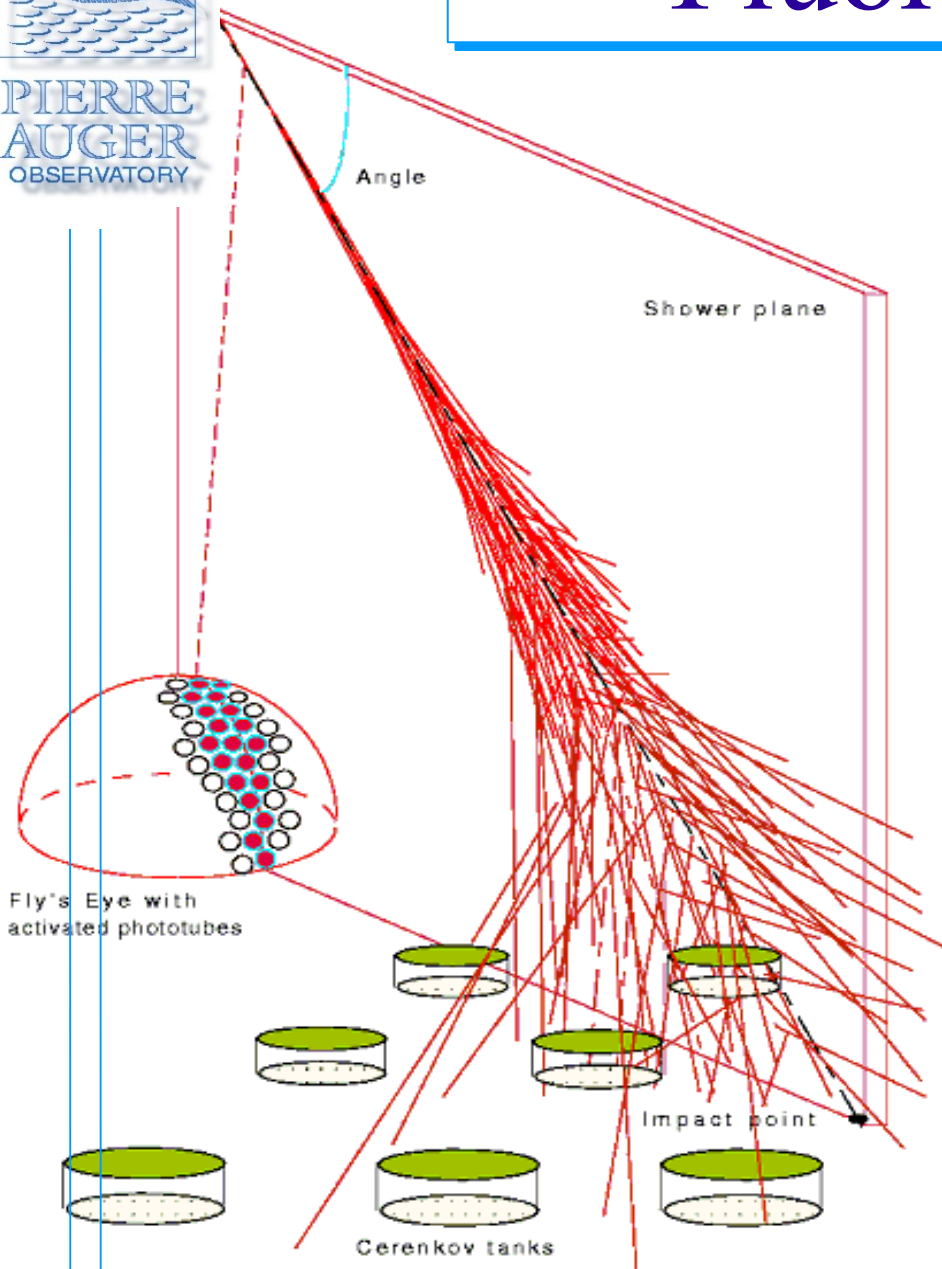


- Detekuje pouze čelo spršky
- Vodní Čerenkovské nebo scintilátory
- Časový sled signálu -> směr příletu
- Hustota částic -> energie primární částice
- Poměr  $e^\pm / \mu^\pm$  -> typ primární částice



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# Fluorescence



- Reionizace  $N_2$  podél podél dráhy spršky
- Vidí průběh spršky
- Časový struktura signálu -> směr příletu
- Intenzita a vzdálenost -> energie primární č.
- Profil spršky -> typ primární částice





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# Detektory KZ



**Volcano Ranch**  
(1959-1963), 19 SC (8  
km<sup>2</sup>)



J. Linsley (1963):  $E > 10^{20}$  eV



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# Detektory KZ

## Volcano Ranch

(1959-1963)  
SC (8 km<sup>2</sup>)

## Haverah Park

(1968-1987)  
WC (12 km<sup>2</sup>)

## Yakutsk

(1974 - ...)  
SC (18 km<sup>2</sup>)  
AC (10 km<sup>2</sup>)

## Fly's Eye

(1981-1993)  
FD

## HiRes

(1997-2006)  
FD

## AGASA

(1984-2004)  
SC (100 km<sup>2</sup>)



## Auger - south

(2004 - ...)  
hybrid (3000 km<sup>2</sup>)

## Sugar

(1968-1979)  
SC (60 km<sup>2</sup>)

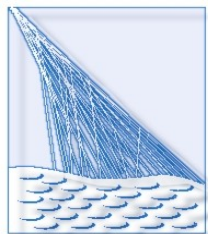


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# Fly's Eye & HiRes

- Fluorescenční detektor
- $E = 3.2 * 10^{20}$  eV (Listopad 1991)

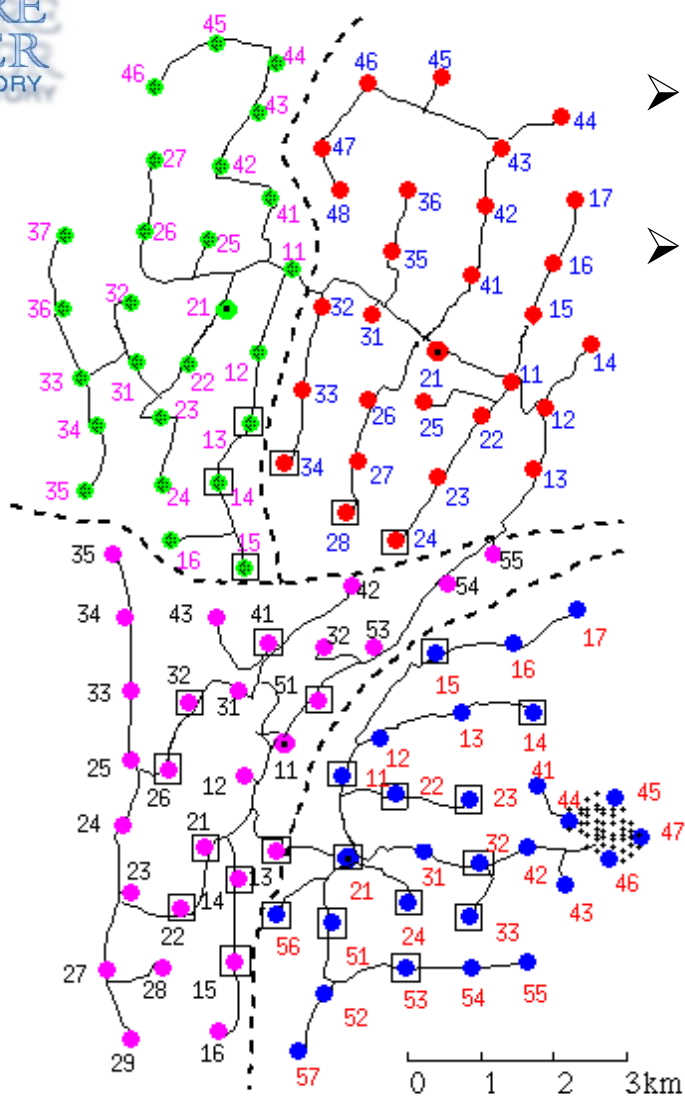


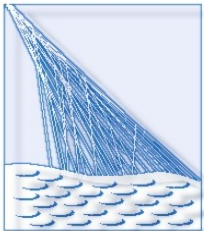


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# Agasa

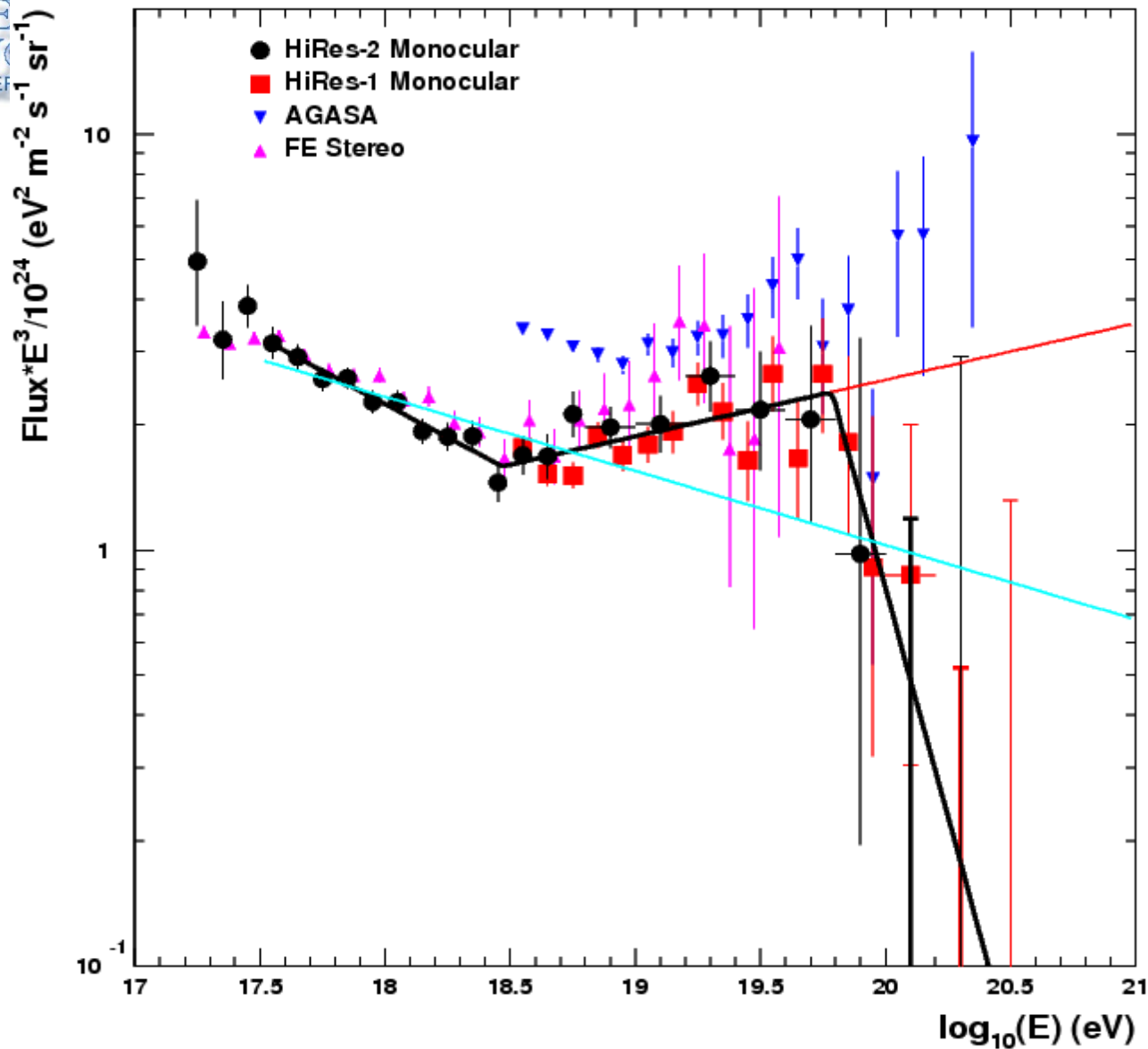
- Pole scintilátorů (100 km<sup>2</sup>)
- $E = 2.0 * 10^{20}$  eV (Prosinec 1993)





# Spektrum KZ

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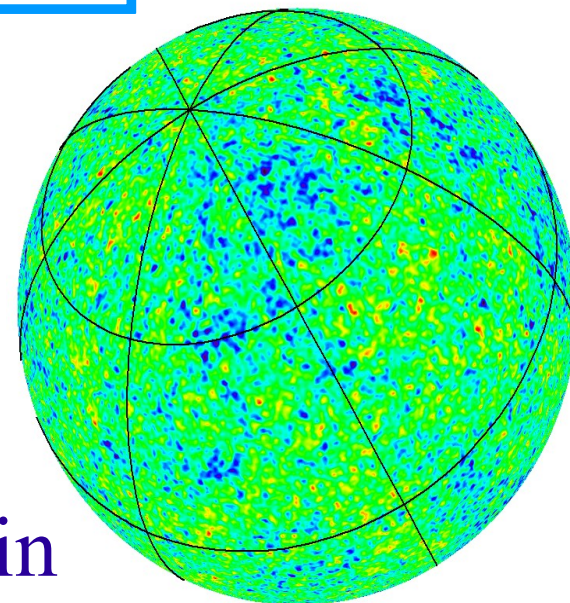


- Nesouhlas
- Agasa:  
nezačíná klesat
- HiRes:  
konec spektra

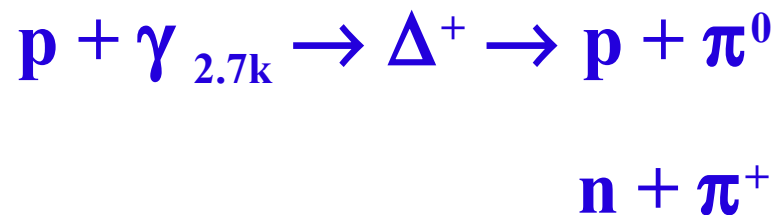


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# Reliktní záření



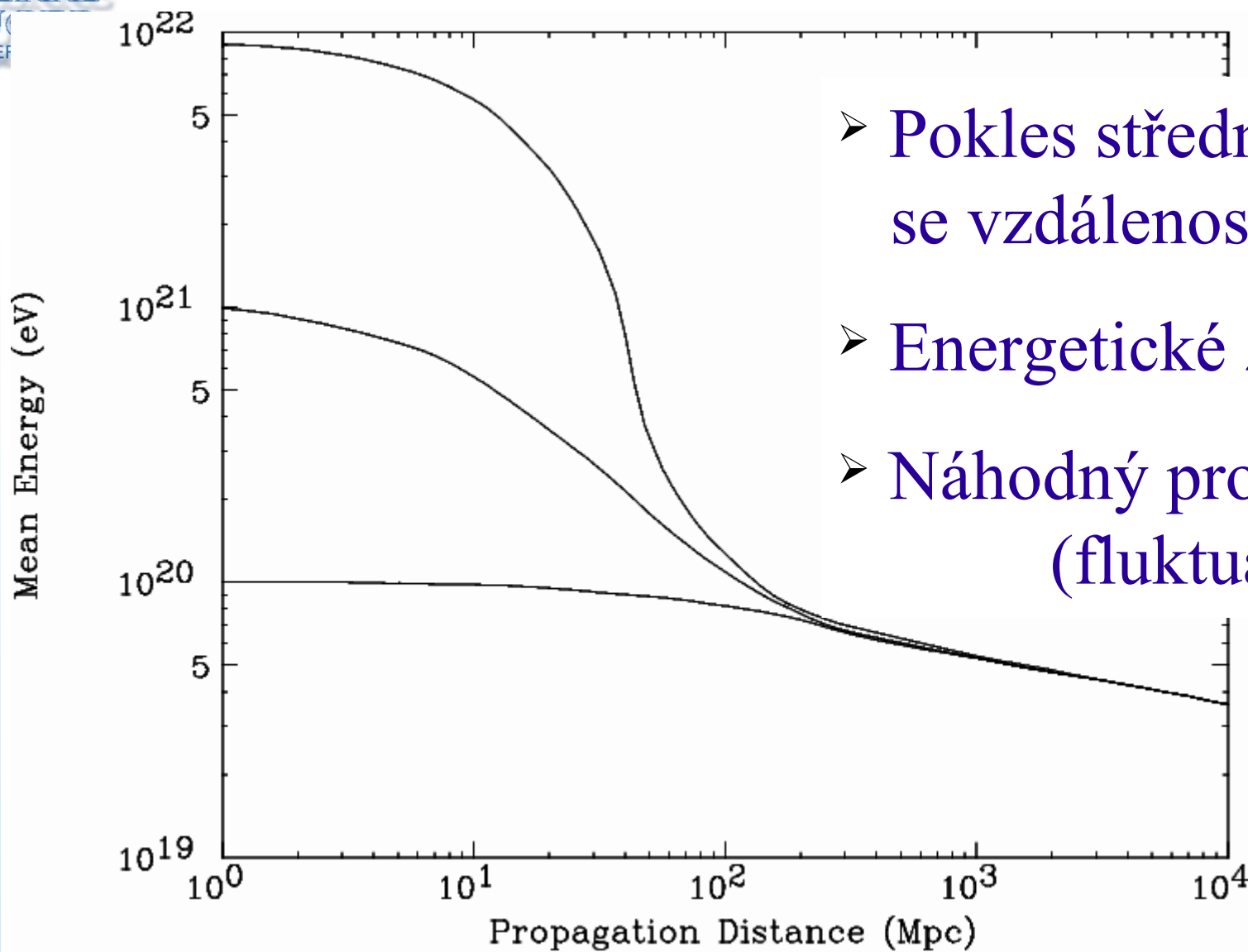
- 1964: reliktní záření (2.7 K)
- 1966: Greisen, Zatsepin & Kuzmin  
ztráta energie KZ díky interakci s reliktním  
zářením



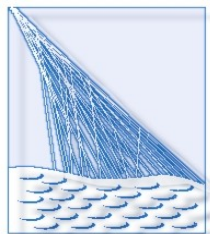


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# GZK mez

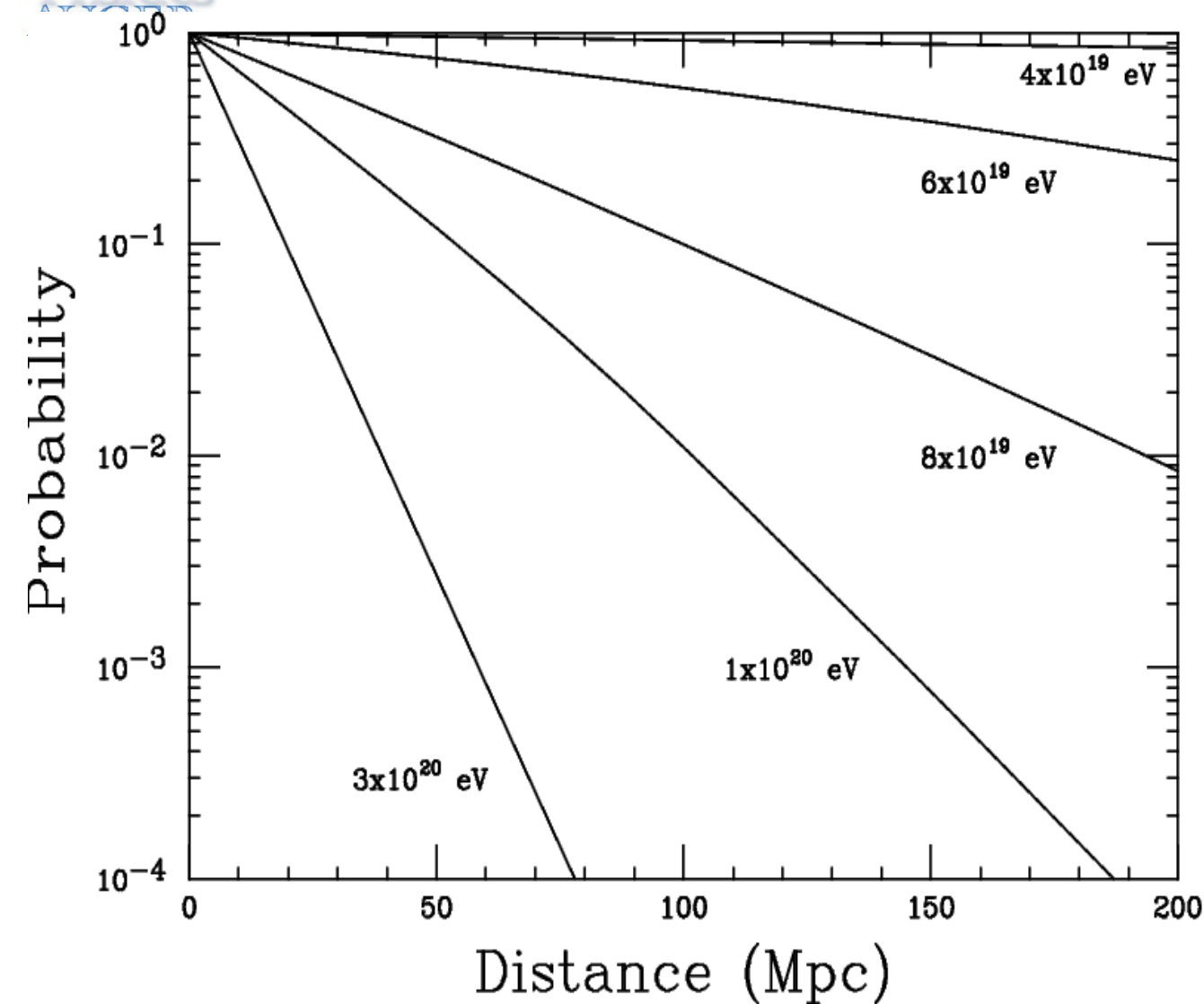


- Pokles střední energie se vzdáleností od zdroje
- Energetické ztráty
- Náhodný proces (fluktuace energie)



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# GZK mez



- Pravděpodobnost příletu částice ze vzdálenosti větší než na ose x
- Předpokládané spektrum zdroje  $E^{-2.5}$
- $P=10\%$  pro 80 EeV, 100 Mpc



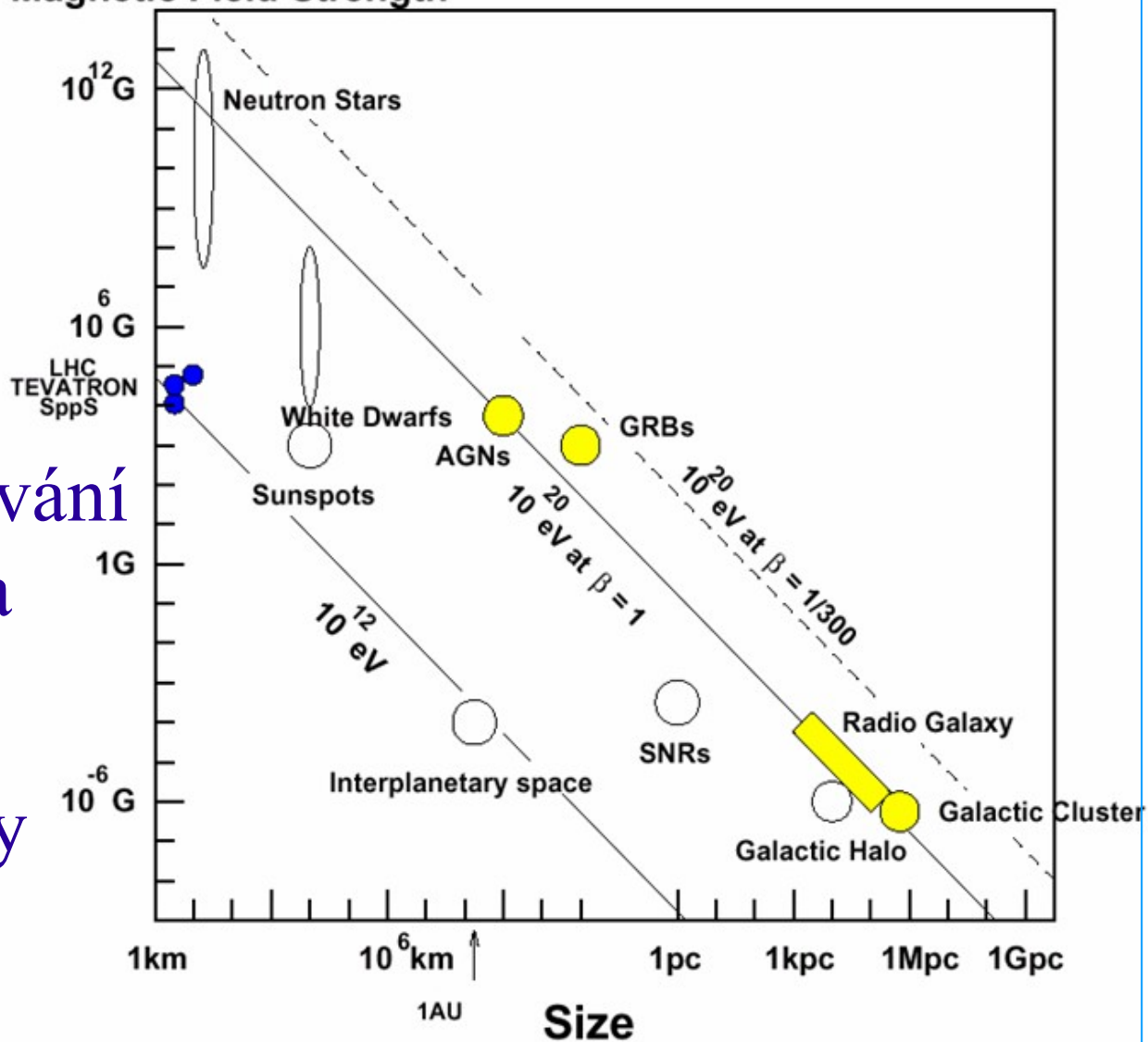


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# Hillasův graf

- Lokální zdroje
- Izotropně rozmístěné
- Postupné urychlování (velikost objektů a síla magnet. pole)
- Top-down modely (rozpady temné hmoty)

Magnetic Field Strength

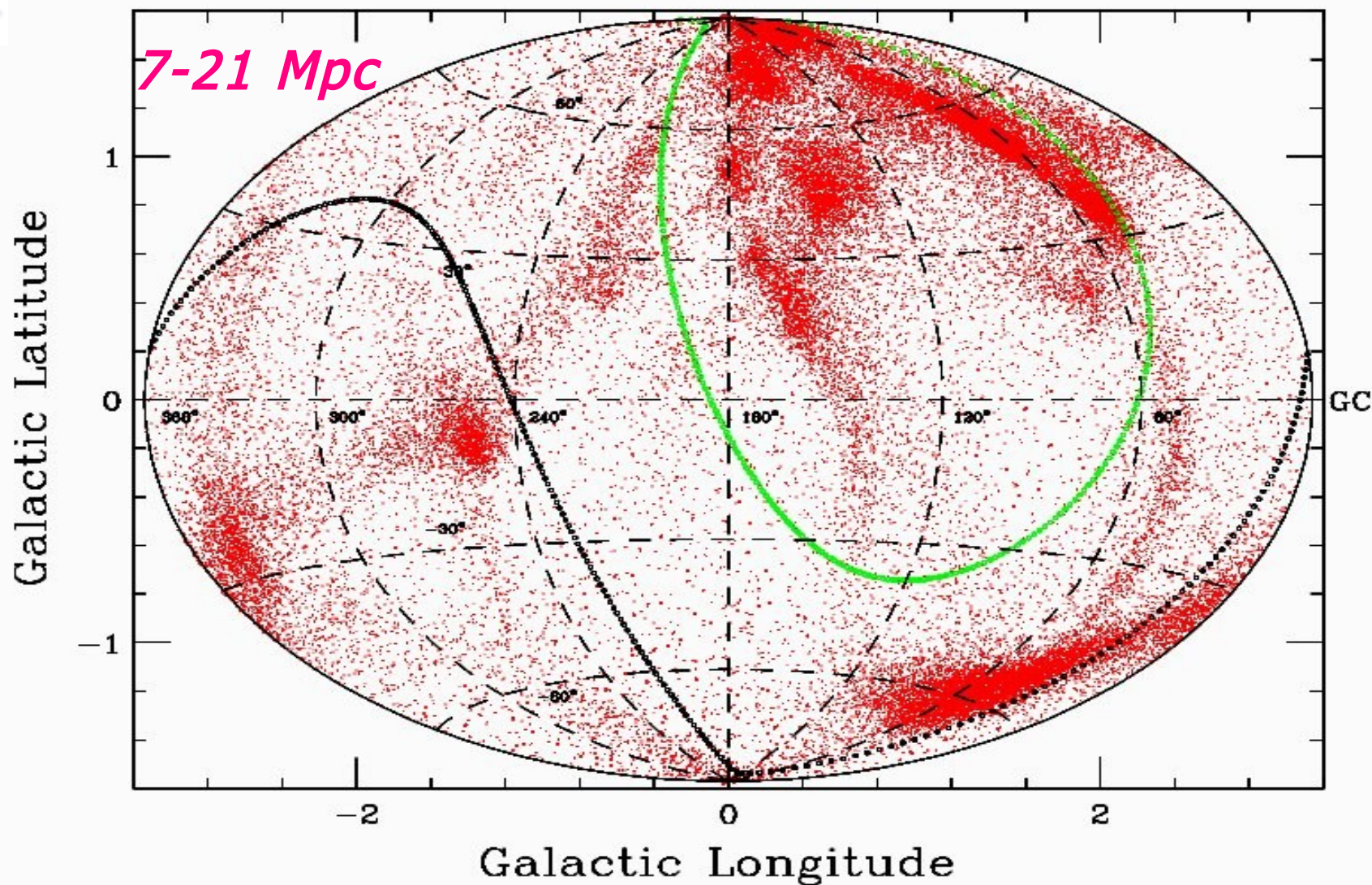


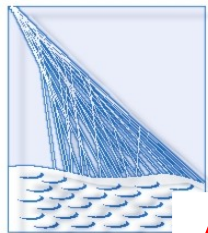


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# Rozmístění hmoty

Matter distribution 7–21 Mpc. Exclusion zones; north array (black), south array (green)

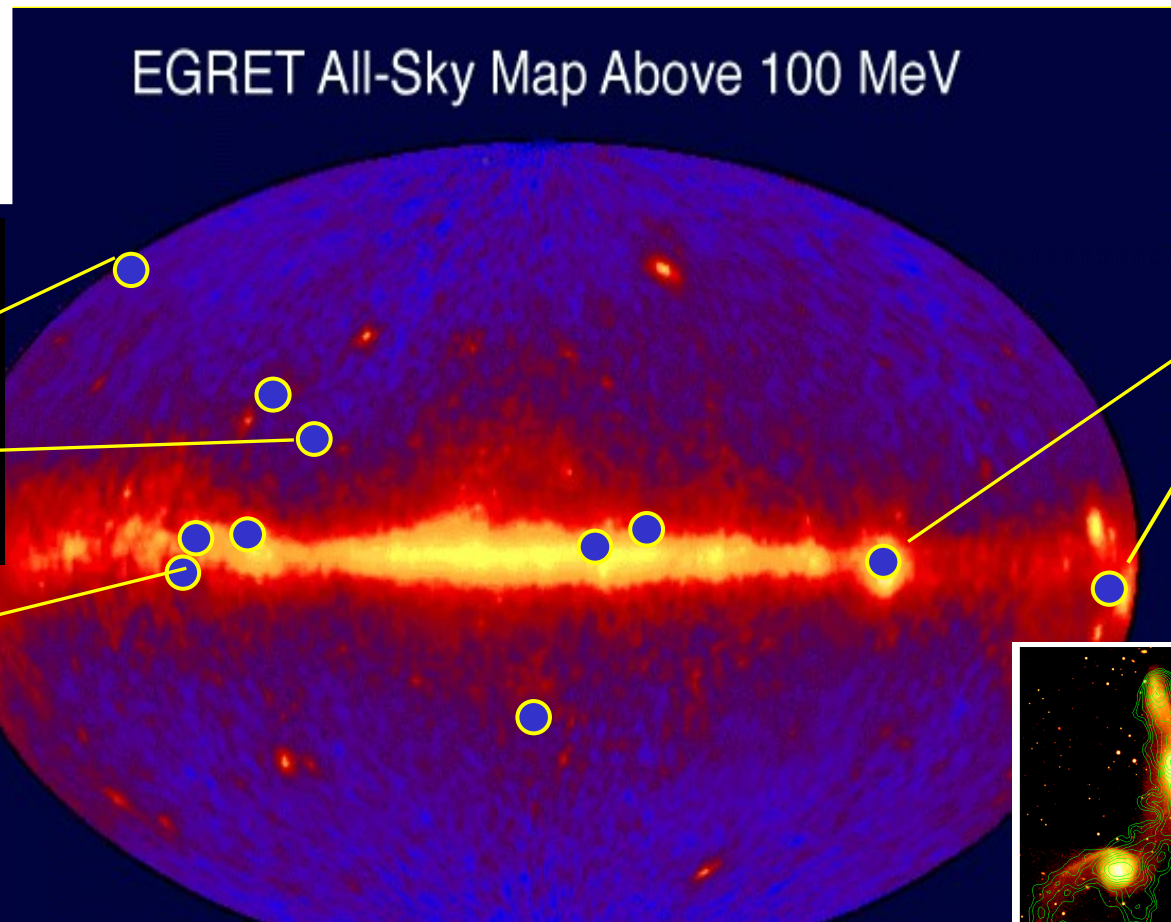
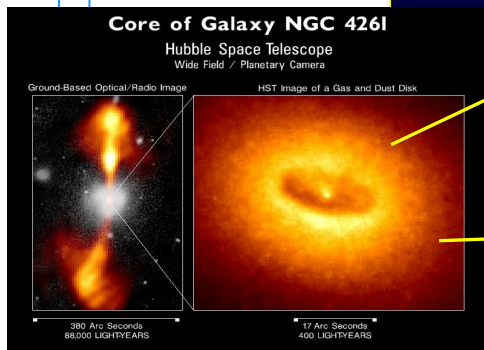




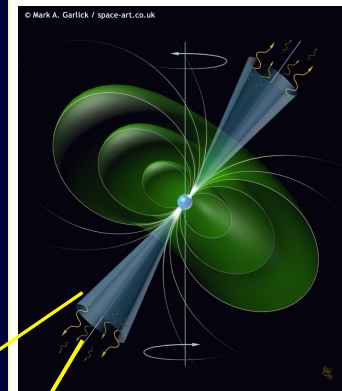
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# Obloha v $\gamma$

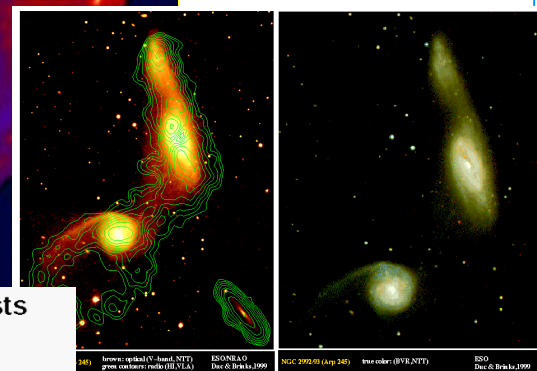
**Aktivní galaktická jádra**



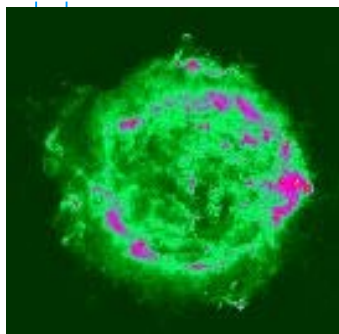
**Pulsary**



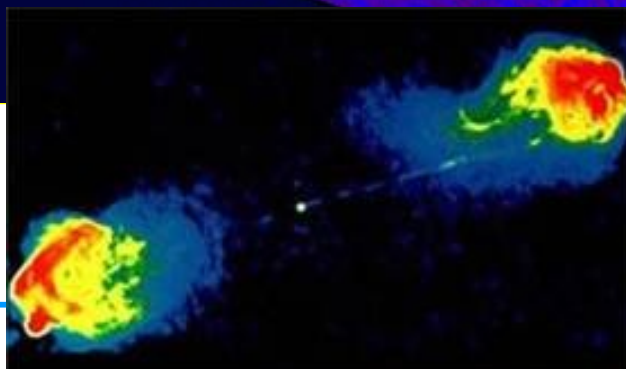
**Srážky galaxií**



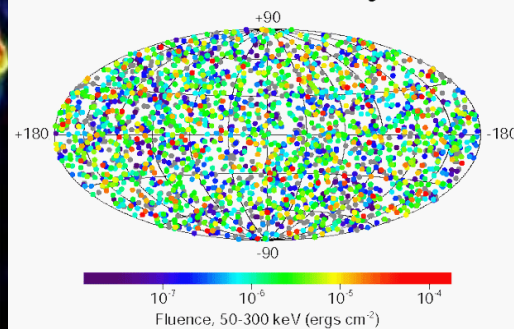
**Zbytky supernov**



**Rádio vé galaxií**

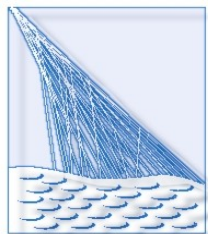


2704 BATSE Gamma-Ray Bursts



**Gamma záblesky**

Šmída, smida@fzu.cz



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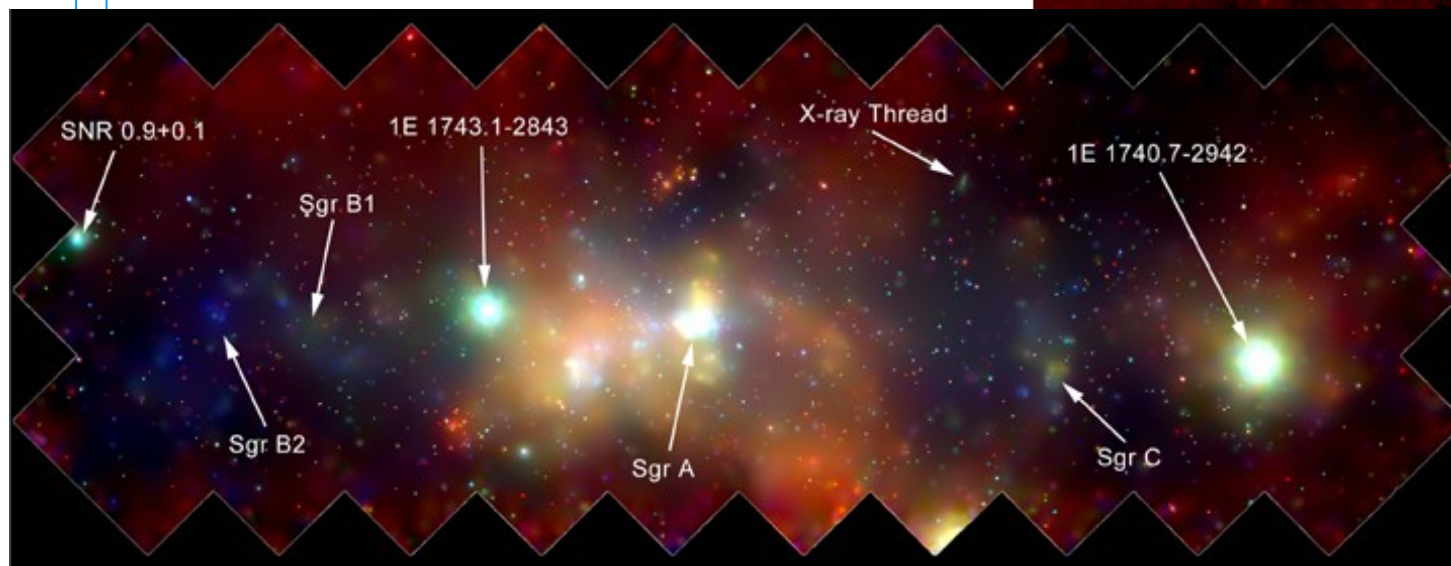
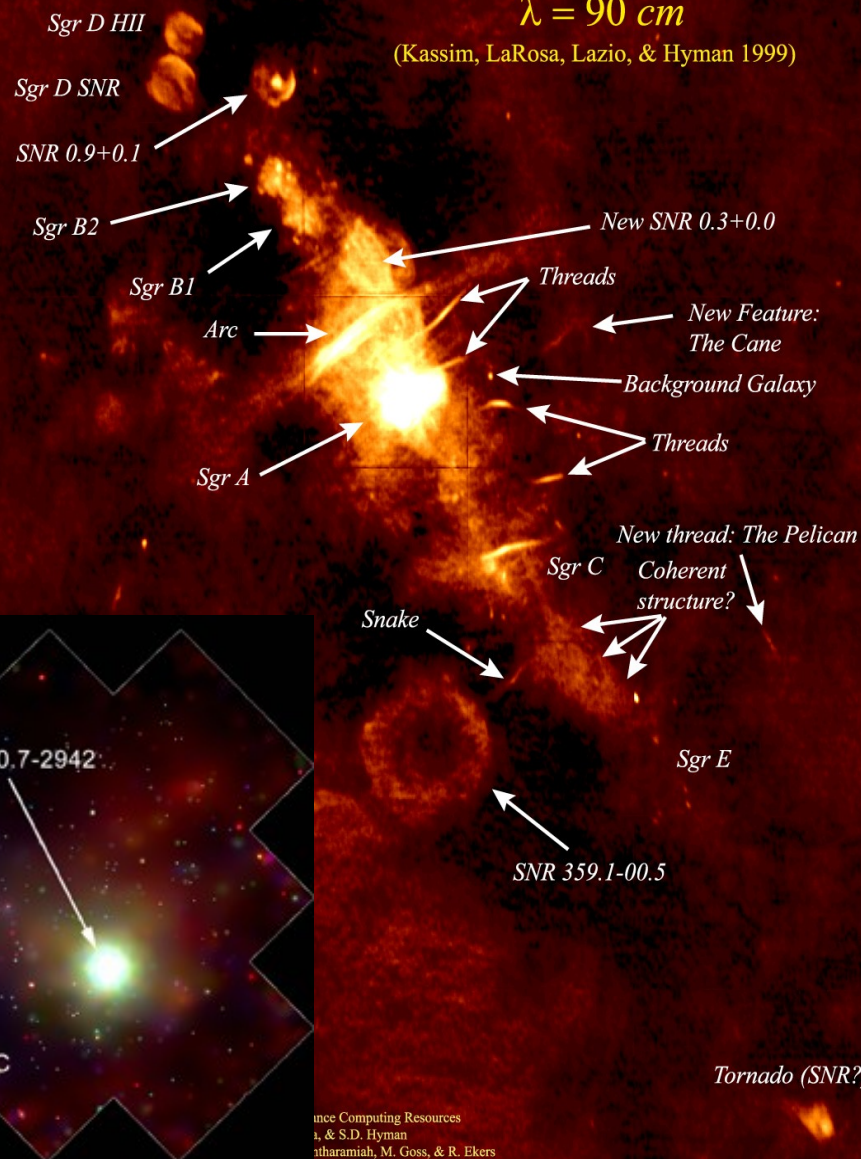
# Galaktické centrum

- Galaktické centrum
- Galaktická rovina
- Egret, Chandra, Integral, HESS, ....

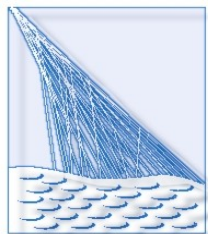
*Field Radio Image of the Galactic Center*

$\lambda = 90 \text{ cm}$

(Kassim, LaRosa, Lazio, & Hyman 1999)



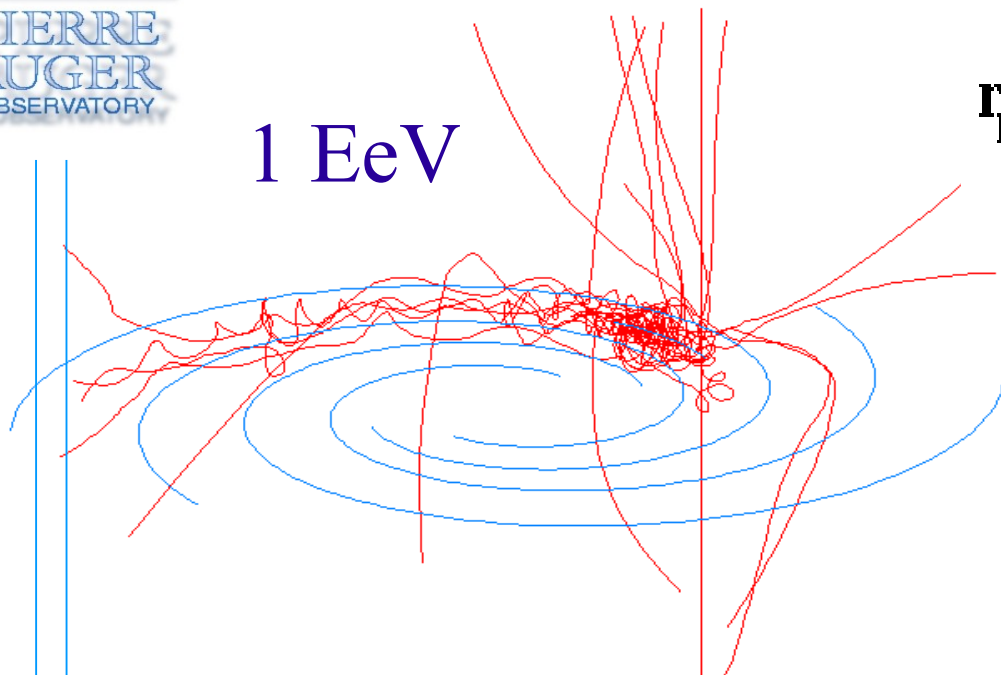
Advanced Computing Resources  
Kassim, S.D. Hyman  
Lazarian, M. Goss, & R. Ekers



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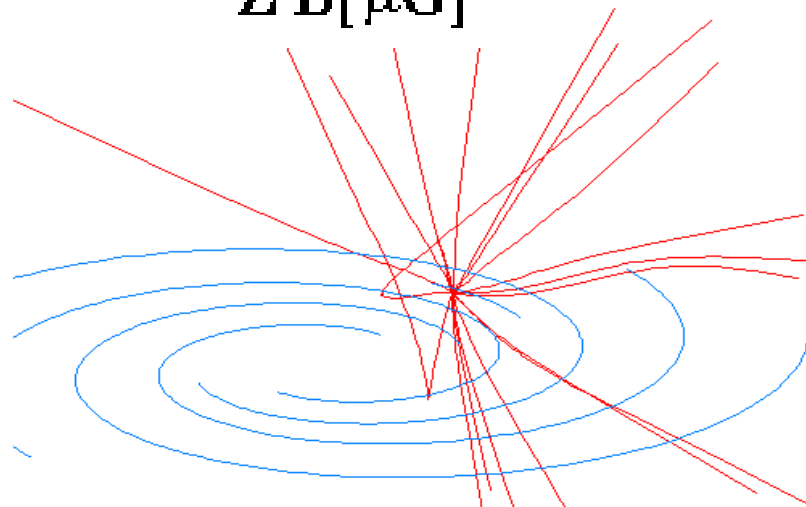
# Magnetické pole

1 EeV



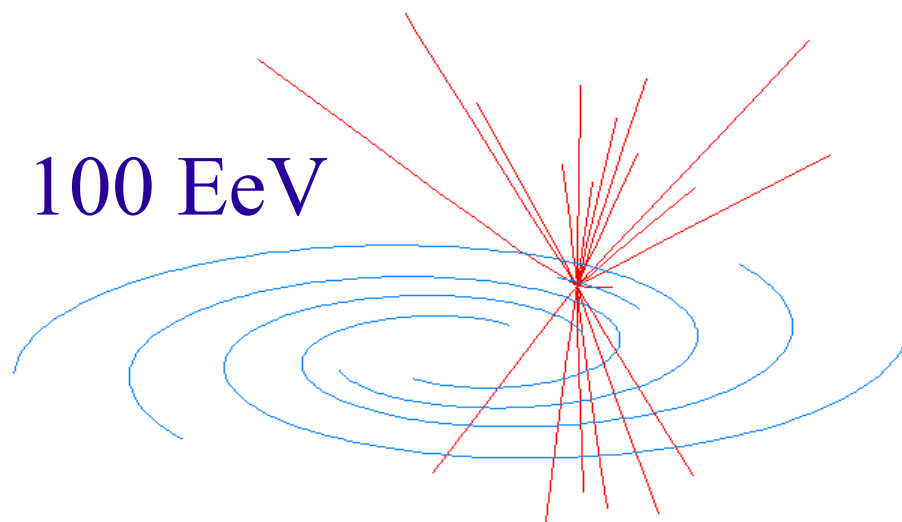
$$r_L [\text{kpc}] = \frac{E [\text{EeV}]}{Z B [\mu\text{G}]}$$

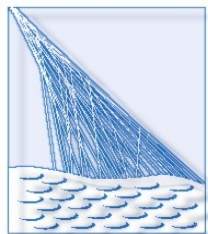
10 EeV



- Galaktické  $\sim \mu\text{G}$
- Extragalaktické  $\sim \text{nG}$
- Ohyb méně než  $3^\circ$   
pro 100 EeV proton

100 EeV





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# Před Augerem...

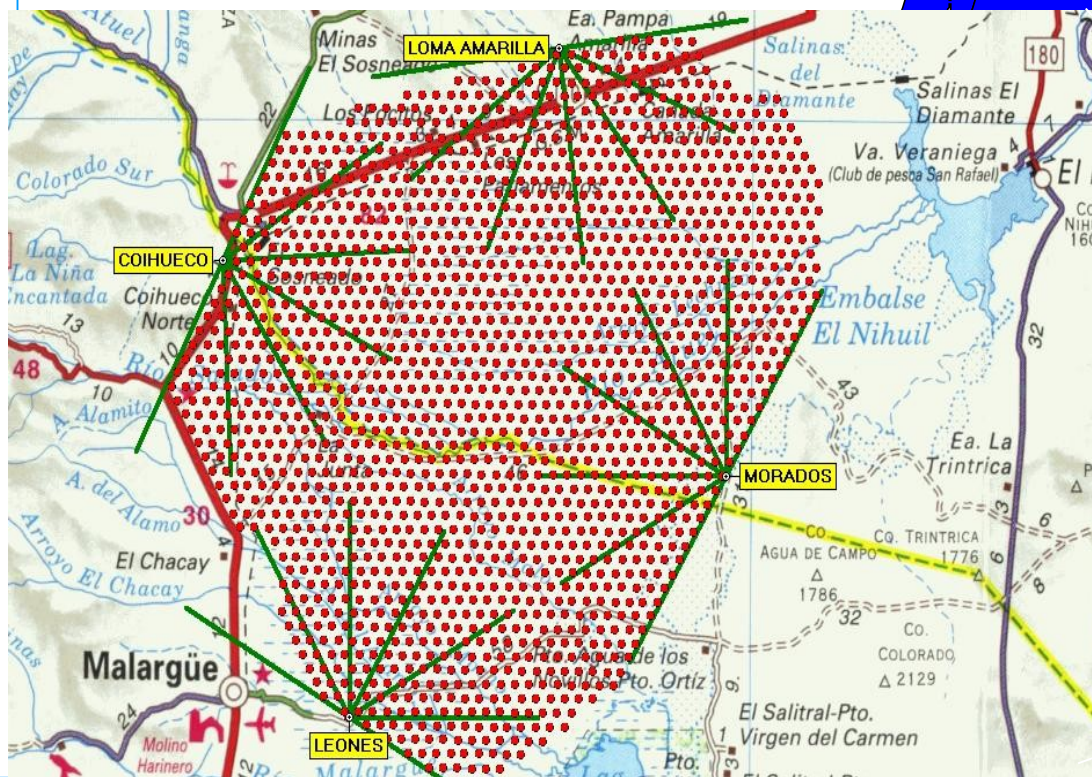
- Nesouhlas energetického spektra (FD a SD detektory)
- Absolutní kalibrace, výtěžnost fluorescence
- GZK mez?
- Velmi malý počet částic (pouze 11 eventů nad  $10^{20}$  eV)
- Anizotropie (Galaktické centrum, BL Lacs)
- Seskupování KZ

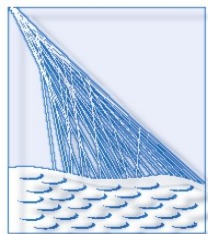


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# Auger

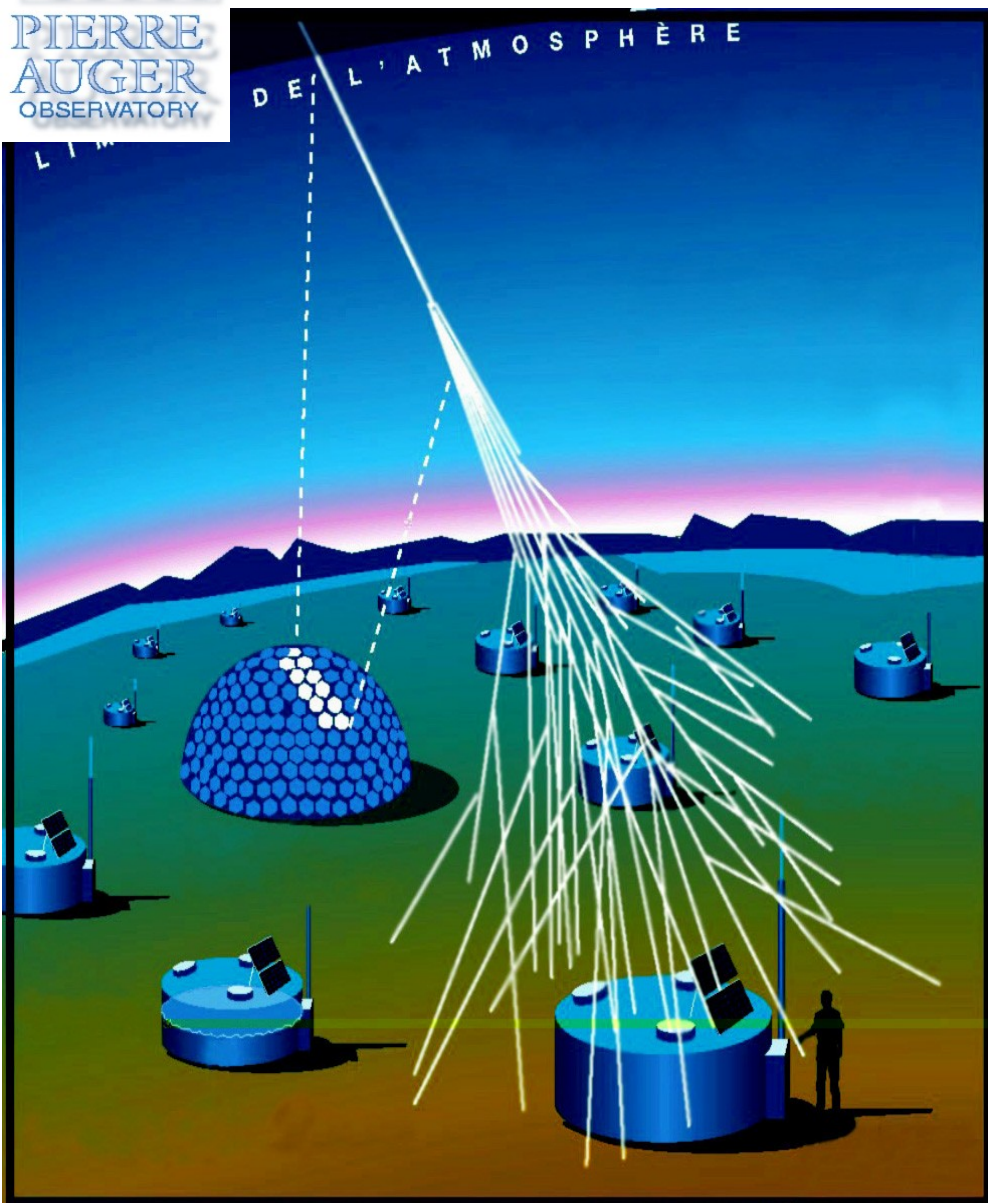
- Malargue, Argentina
- 3000 km<sup>2</sup>
- 4 FD, 1600 SD





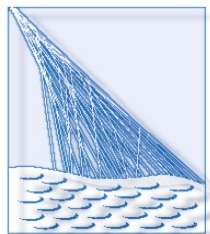
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# Hybridní detector



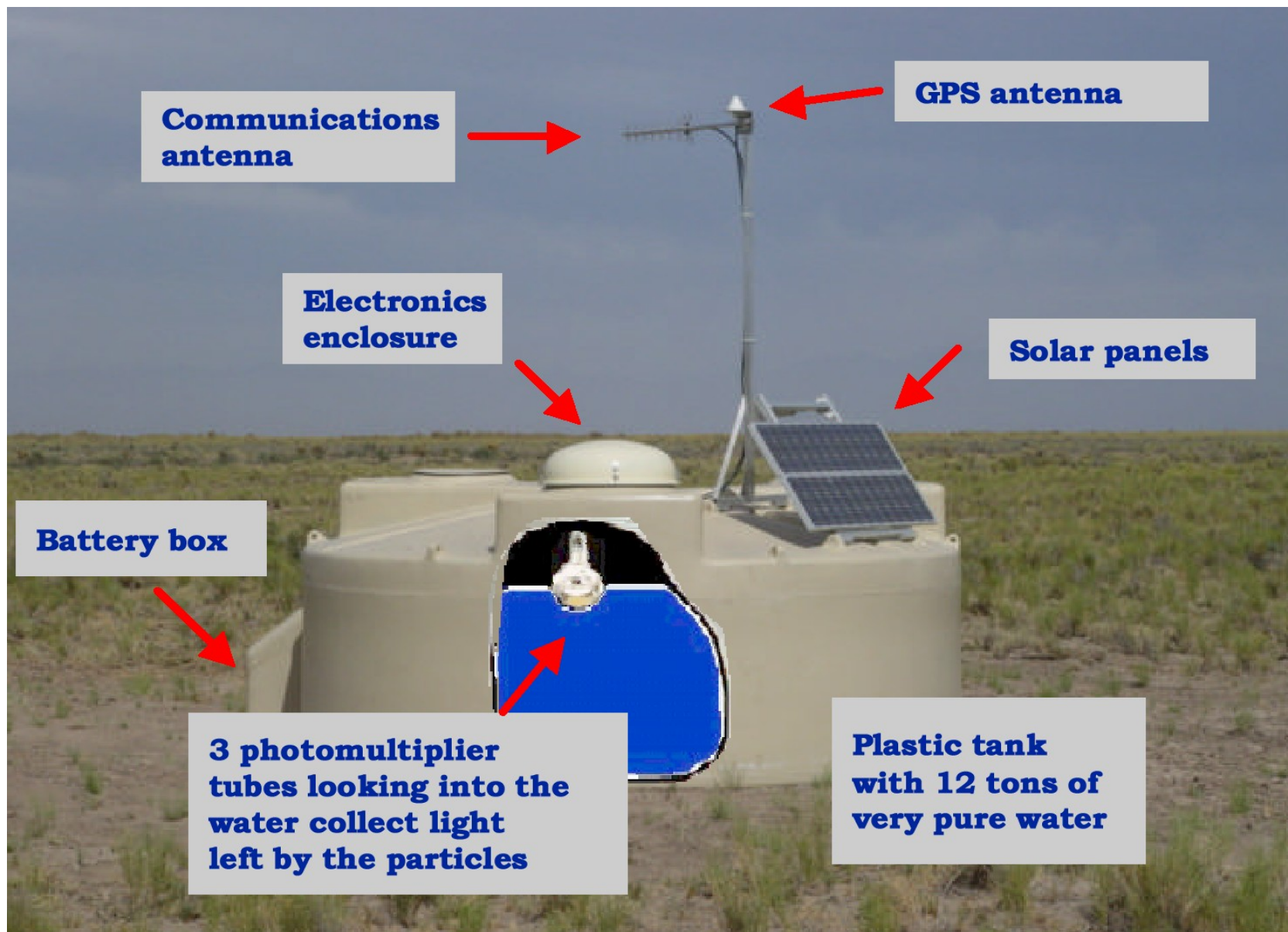
- Hybridní: FD + SD
- SD neomezený pozor. čas
- FD 10% času SD (pouze jasné a bezměsíčné noci)
- Geometrická rekonstrukce
- SD kalibrace

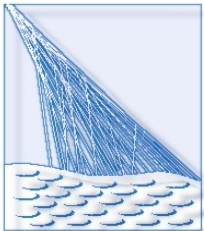




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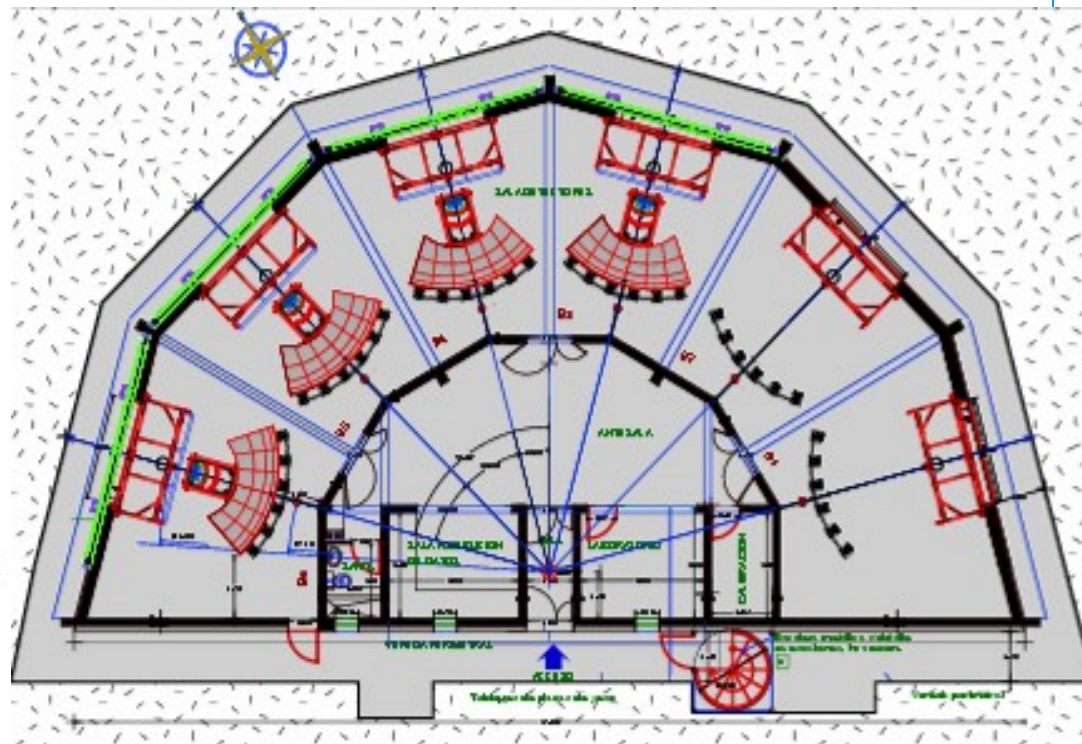
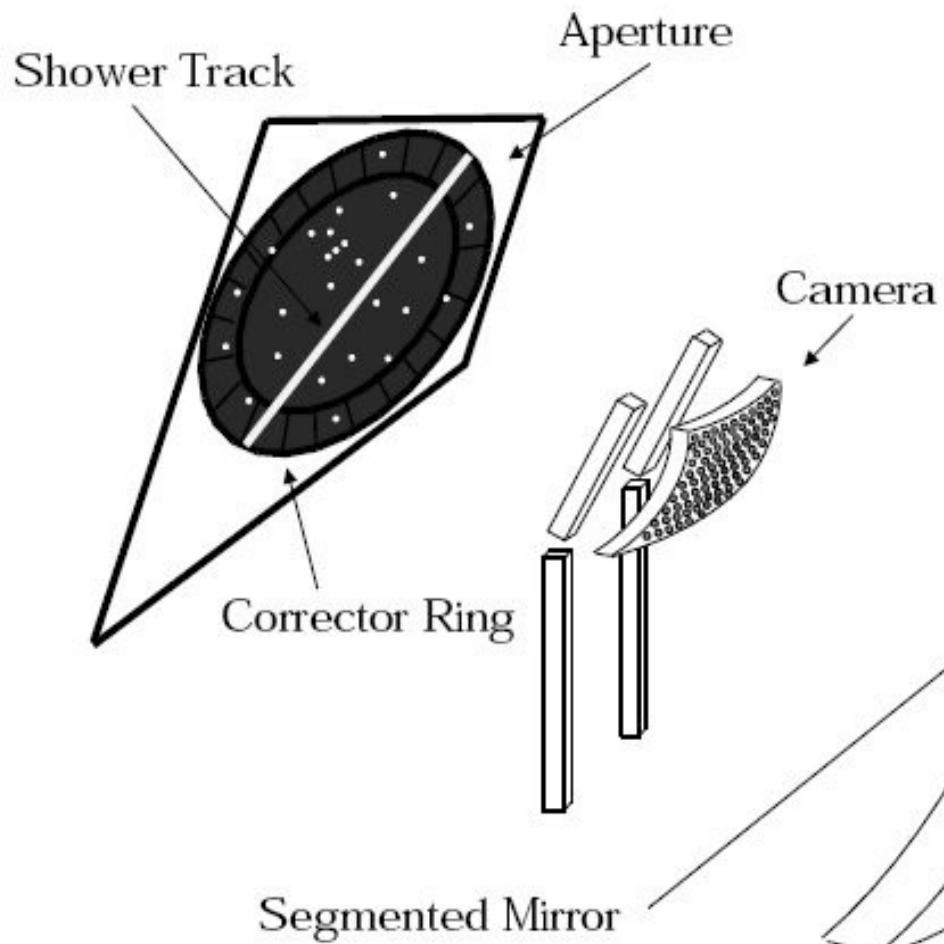
# SD





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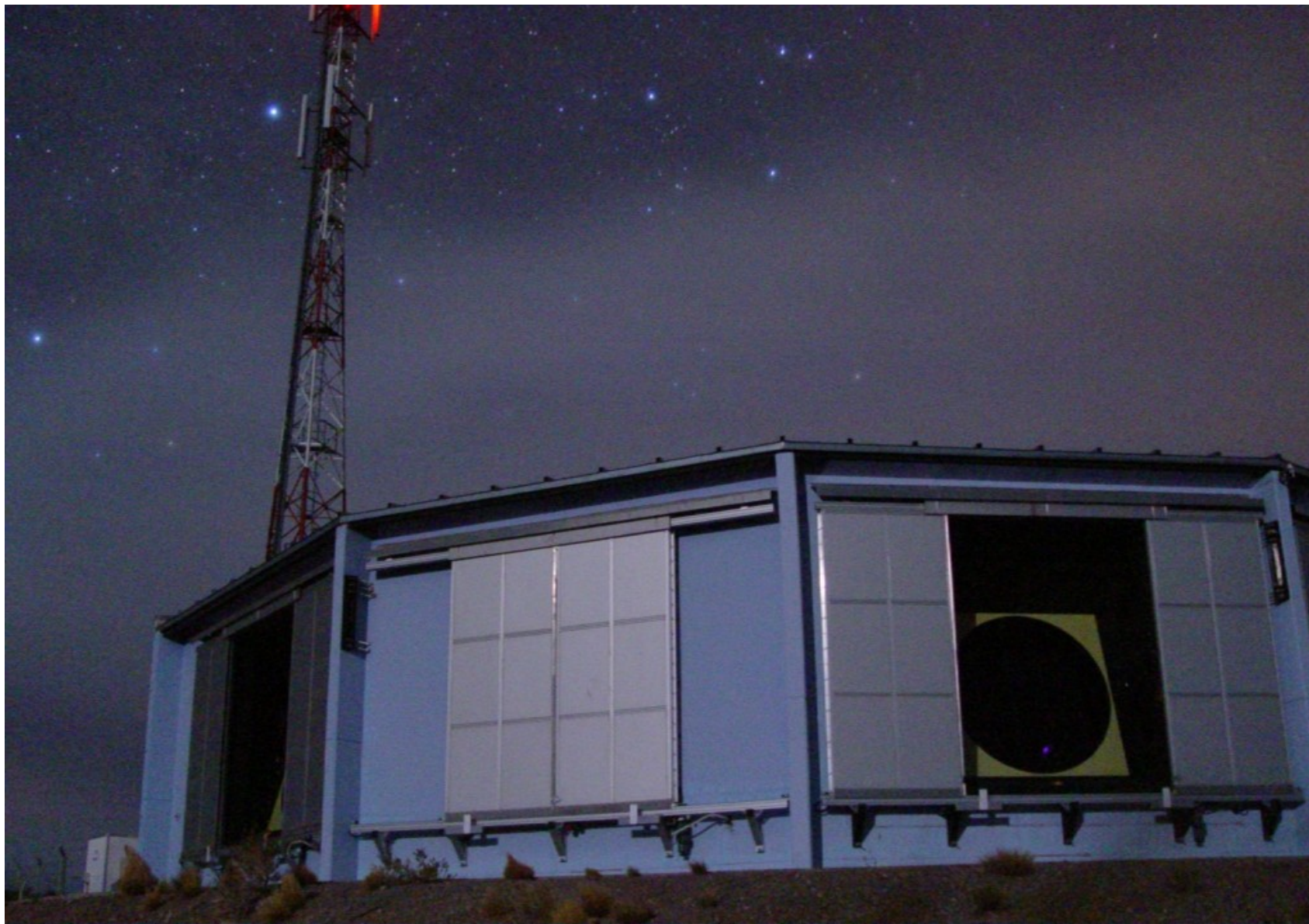
# Schéma FD

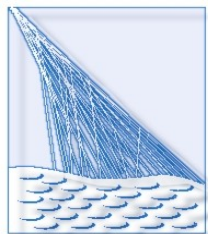




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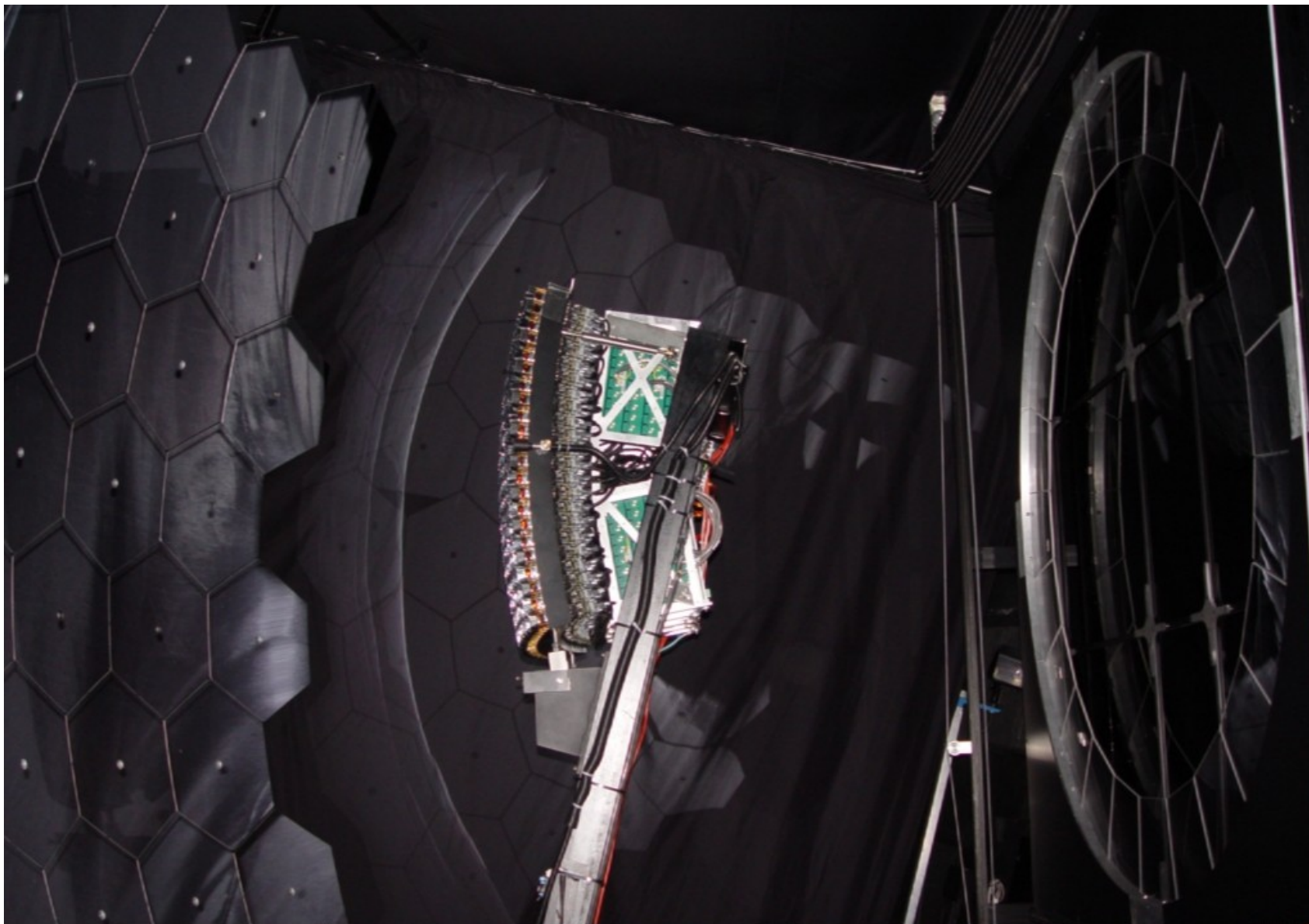
# FD

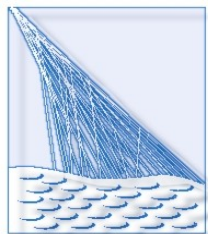




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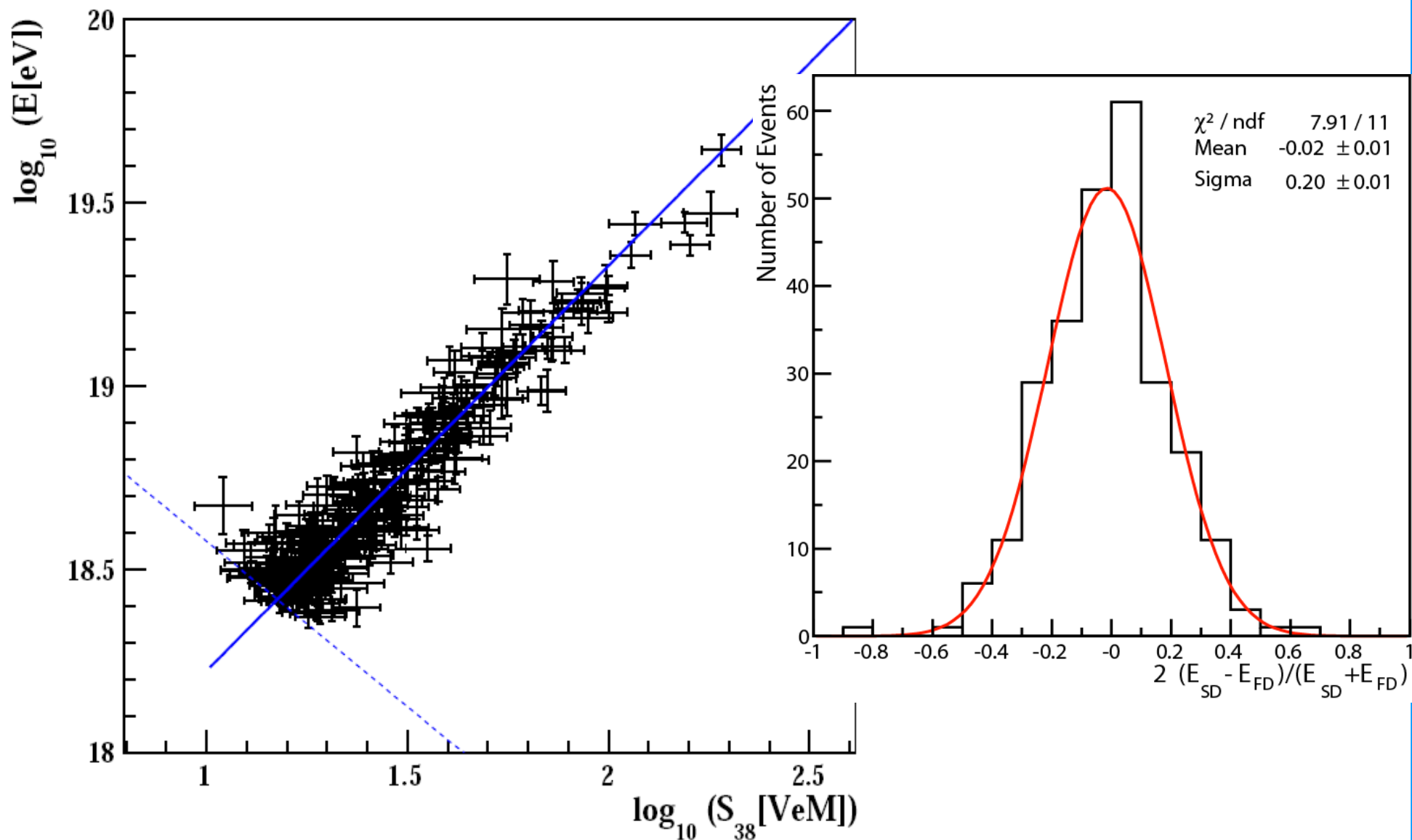
# FD komora

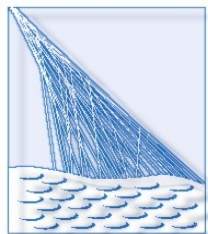




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# Kalibrace SD





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# Fluorescence

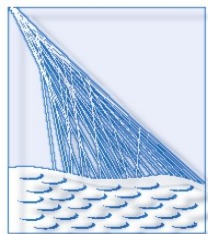
- Molekuly atmosférického dusíku
- 300 - 400 nm
- Experiment Airfly a jiné
- Absolutní výtěžnost
- Závislost na teplotě, tlaku, vlhkosti



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# Kalibrace FD

- Absolutní (minimálně dvakrát za rok)
- Relativní (během měření)
- Kontrola časové závislosti
- Citlivost fotonásobičů
- Odraznost zrcadel, ...



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# Atmosféra

- Sledování aktuálního stavu atmosféry
- Lokální model atmosféry
- Lasery (Lidars, Central Laser Facility)
- Nízké vrstvy atmosféry (HAM, APF)
- Cloud cameras, meteorological balloons
- FRAM
- Chyba v rekonstrukci energie ( $< 5 \%$ )





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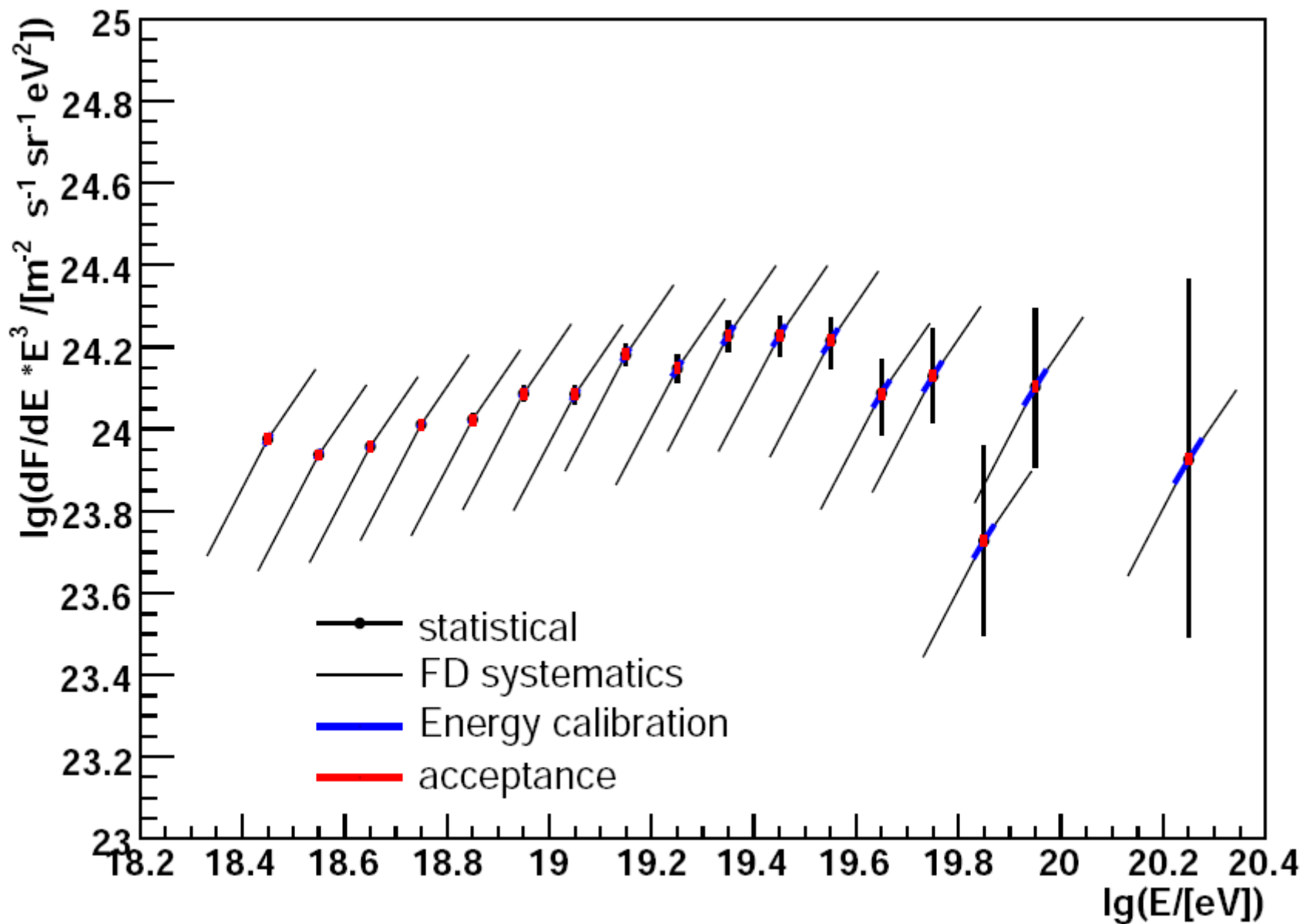
# Systematické chyby

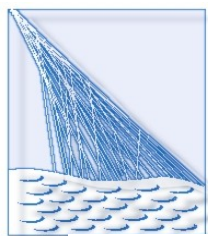
Source	$\Delta E_{SD}/E_{SD}(\%)$
Absolute Fluorescence Yield	14
Pressure dependence of Fluorescence Spectrum	1
Humidity dependence of Fluorescence Spectrum	5
Temperature dependence of Fluorescence Spectrum	5
FD absolute calibration	11
Time dependence of FD calibration	10
FD wavelength dependence response	3
Rayleigh atmosphere	1
Wavelength dependence of aerosol scattering	1
Aerosol phase function	1
FD reconstruction method	10
Invisible energy	4
<b>TOTAL SYST.</b>	<b>24</b>



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# Spektrum KZ

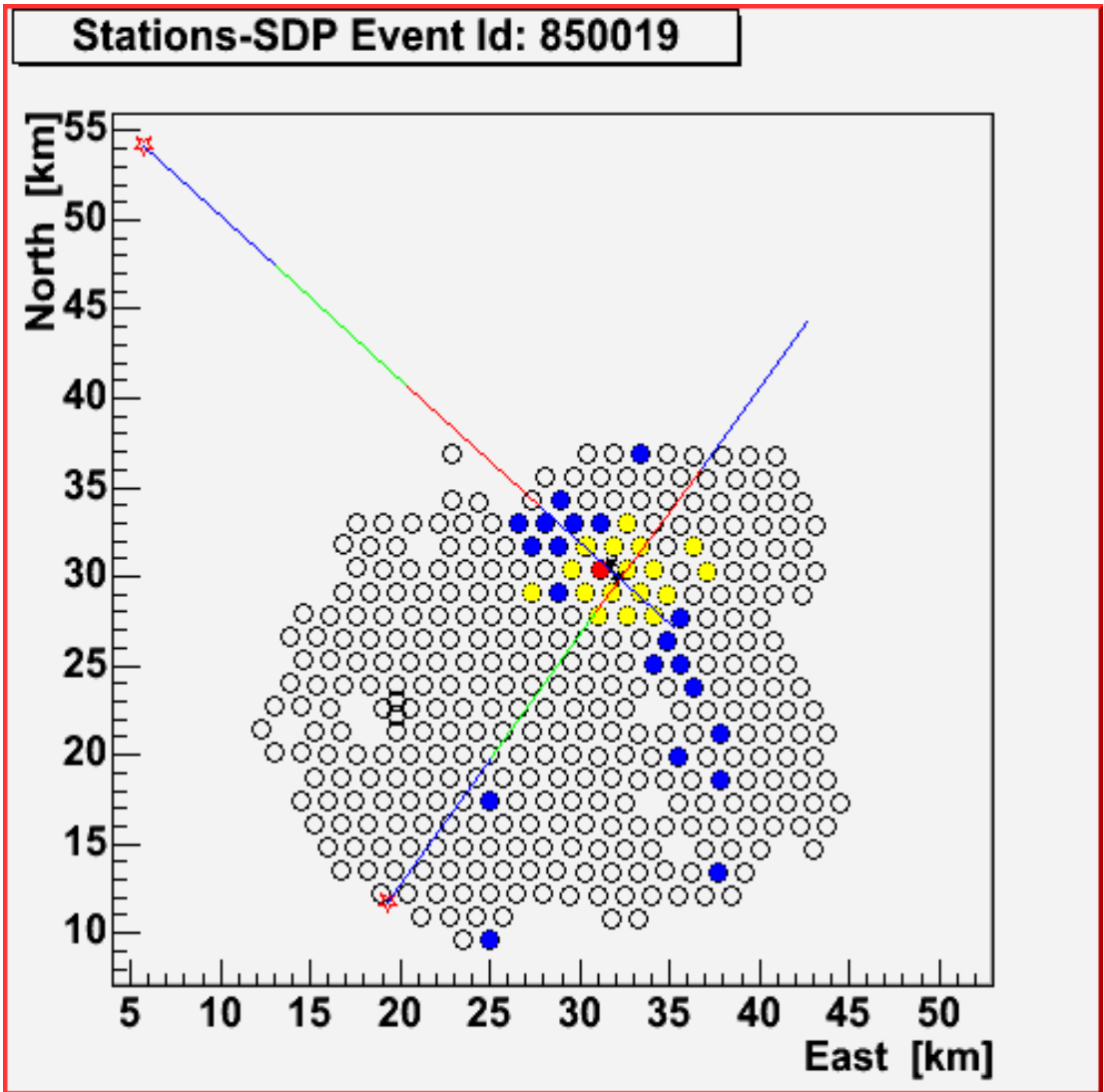
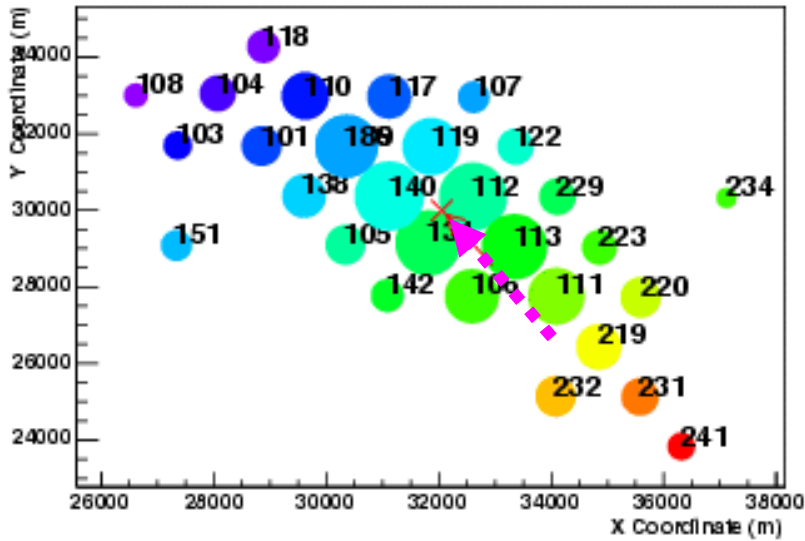




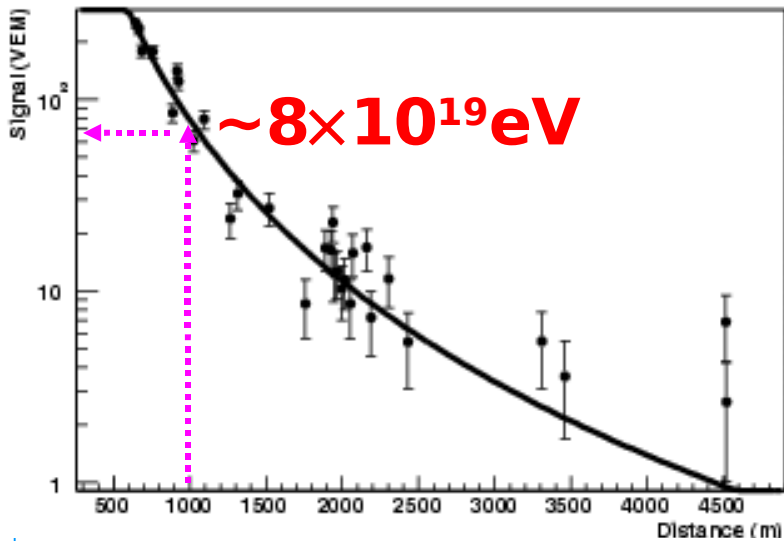
# Stereo hybrid

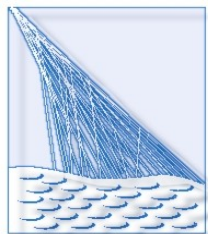
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Hit Locations (Red: First, Violet: Last)



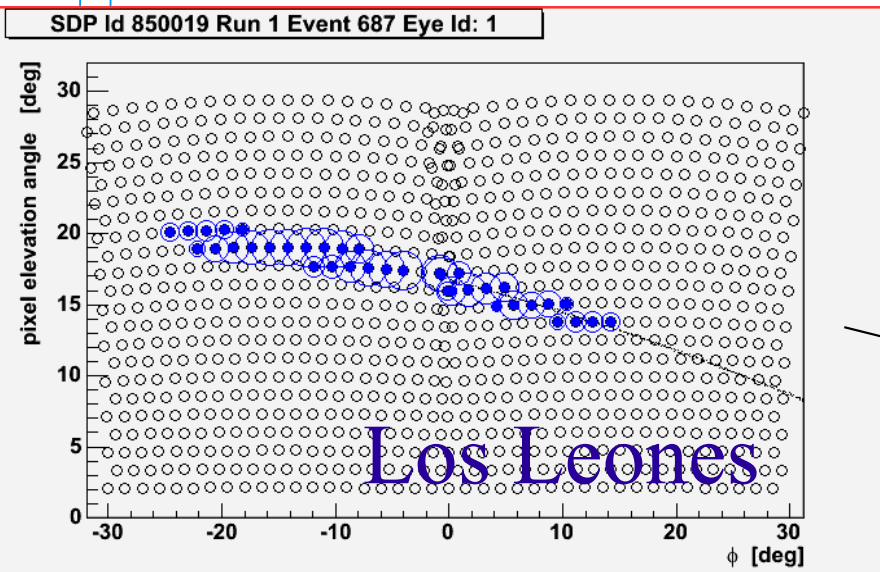
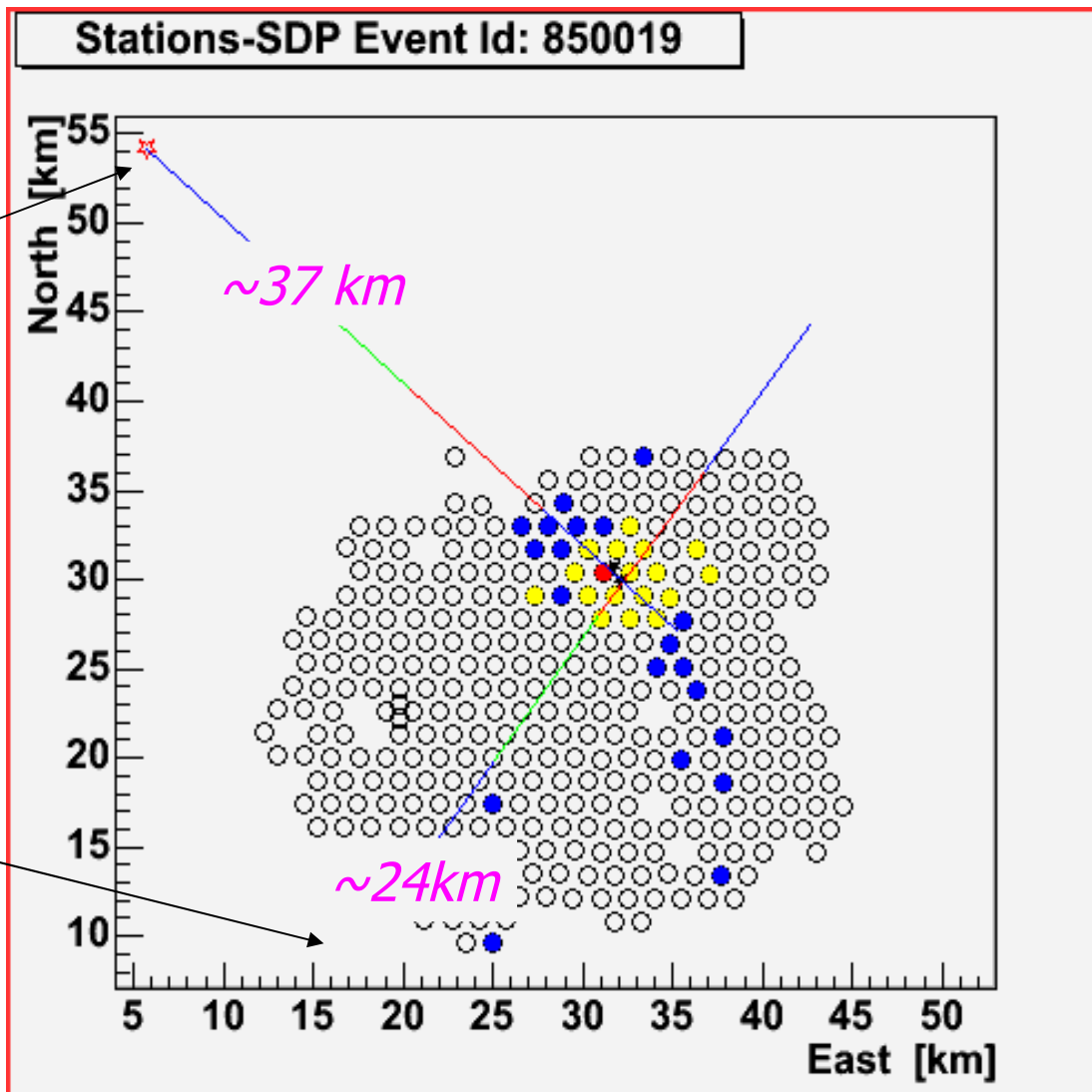
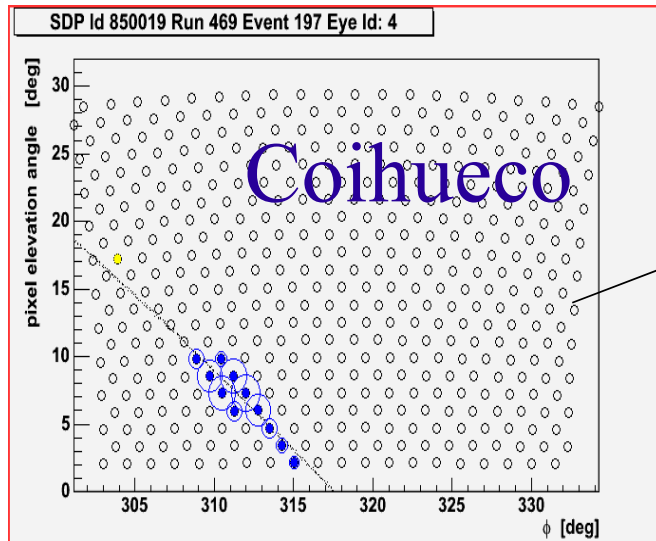
## Lateral Distribution Function

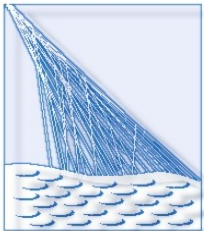




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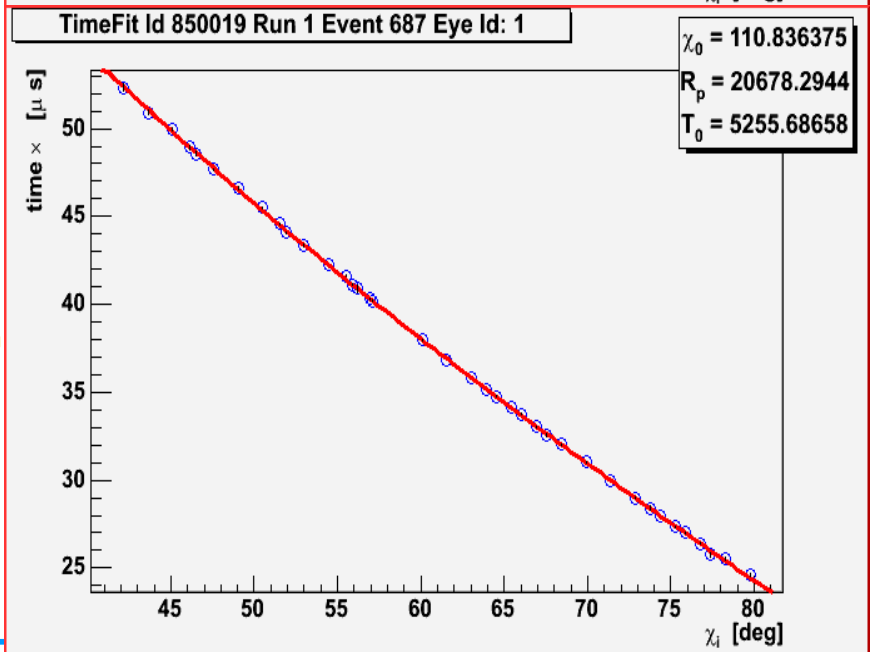
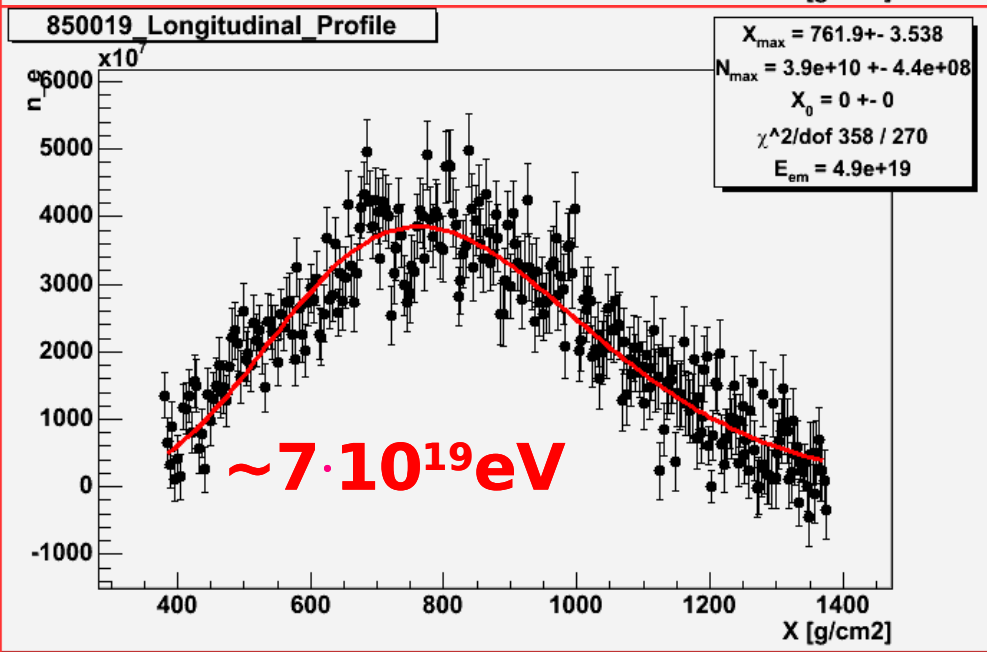
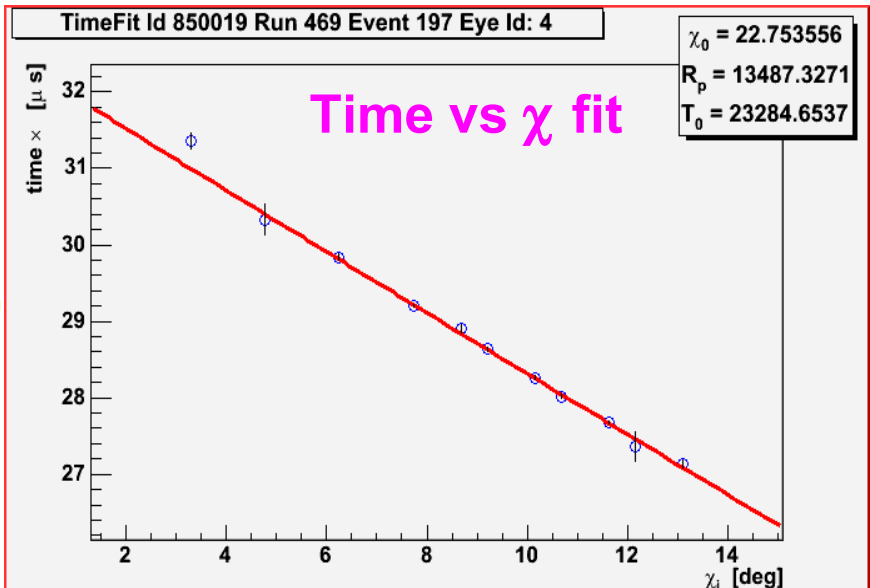
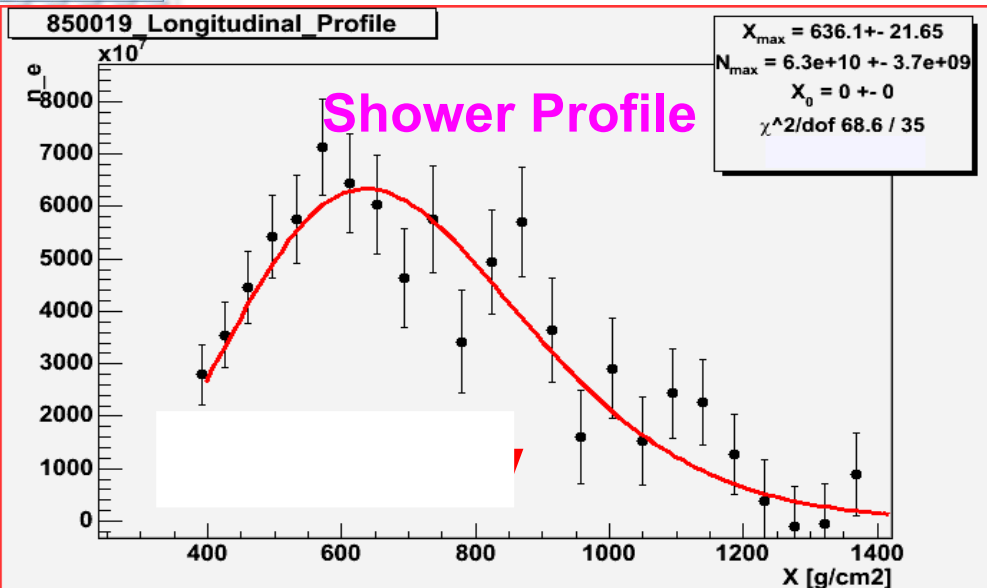
# Stereo hybrid

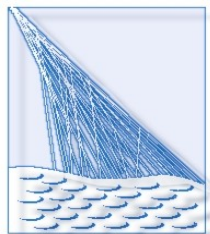




# Stereo hybrid

PAO





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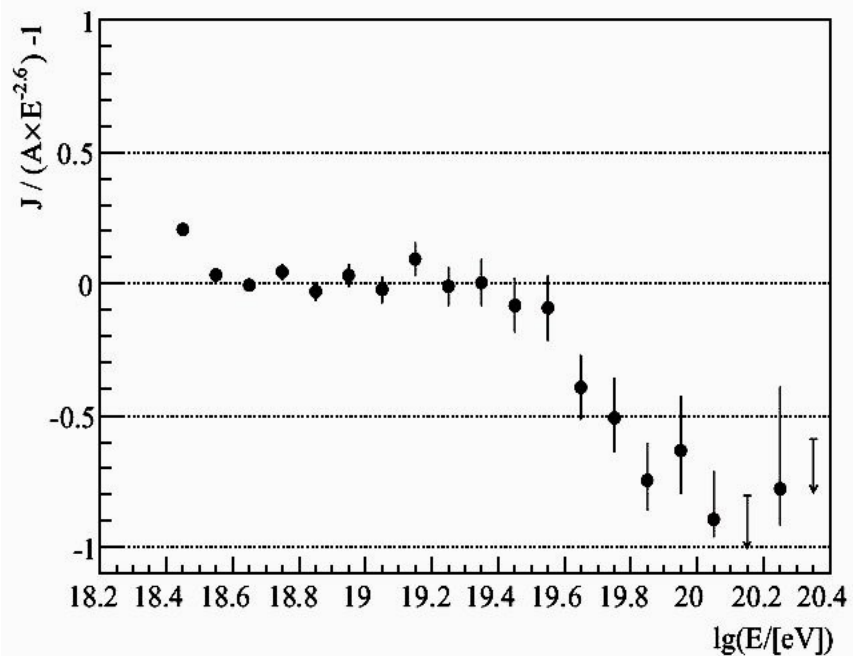
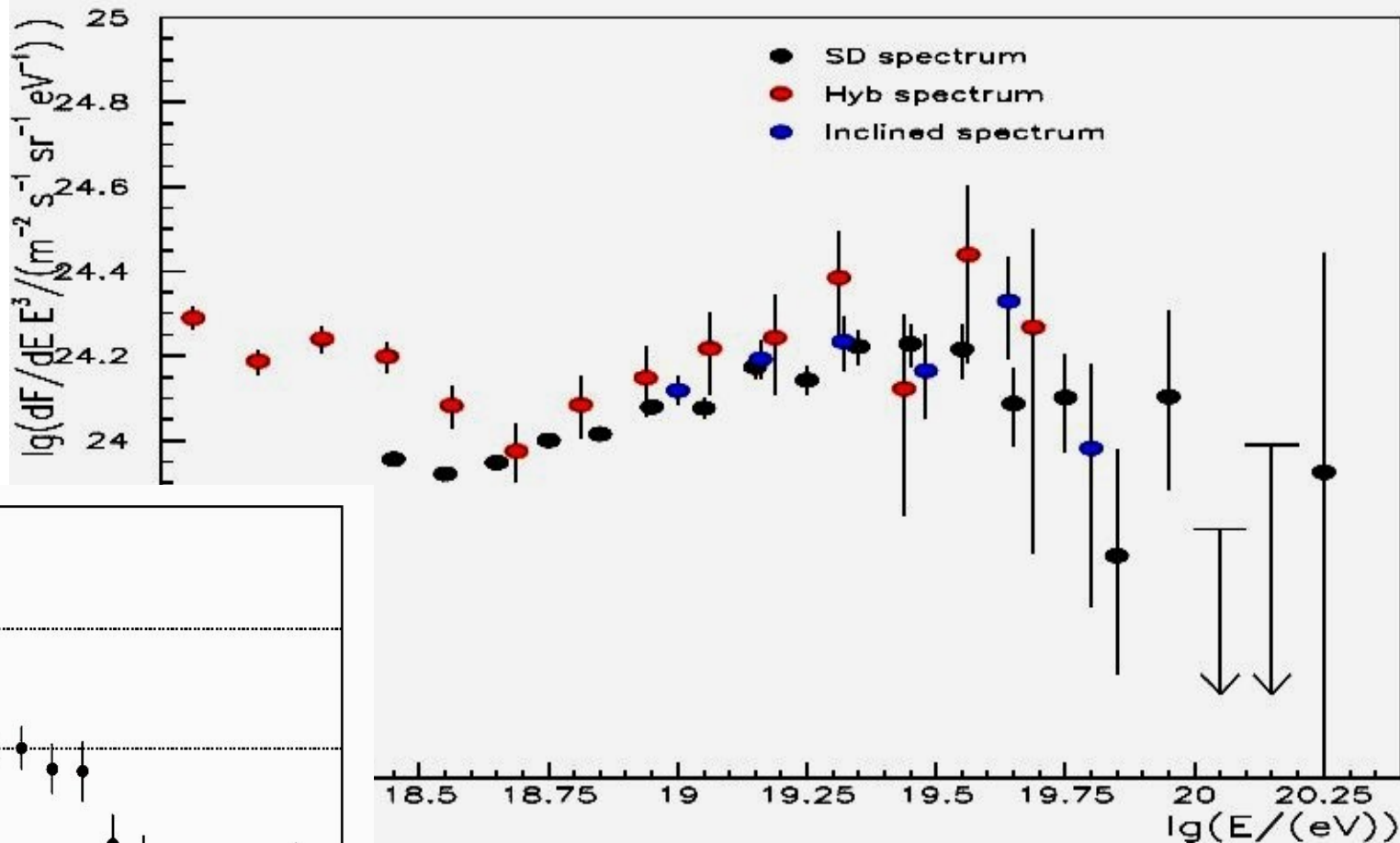
# Výsledky

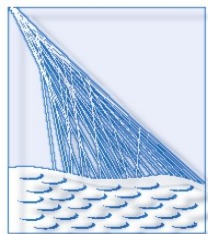
- Předběžné výsledky!
- International Cosmic Ray Conference,  
Mexico 2007



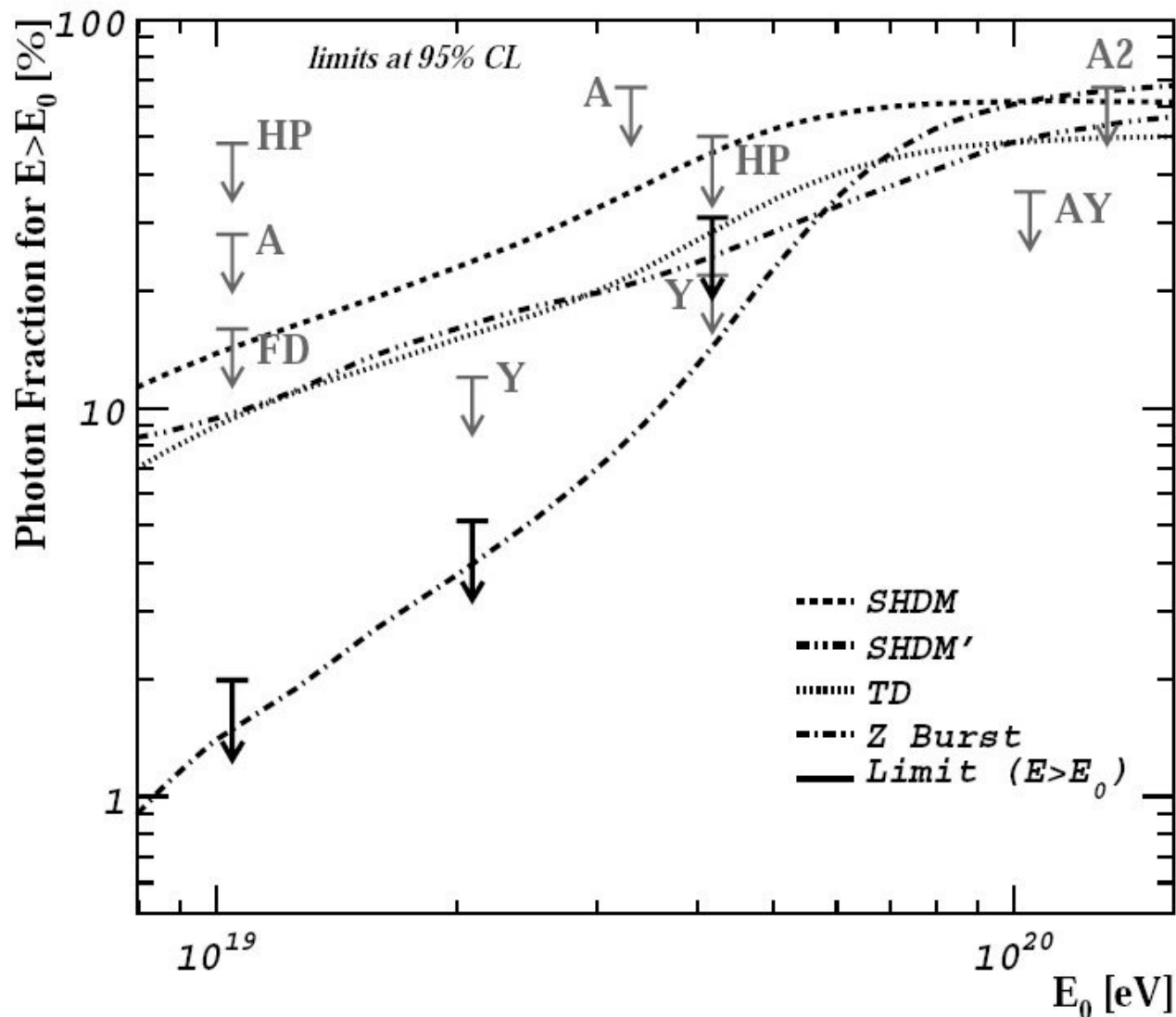
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# Spektrum KZ





# Fotonový limit







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# Anizotropie

- Velkoškálová anizotropie
- Seskupování eventů
- Spojitost s pozicemi pozorovaných  
astronomických objektů
- Žádný signál nebyl dosud pozorován
- Potřebujeme více naměřených dat



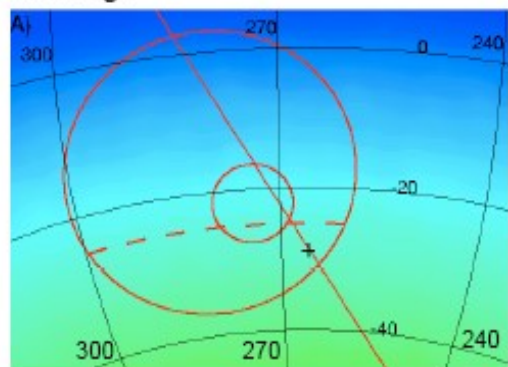
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# Galaktické centrum

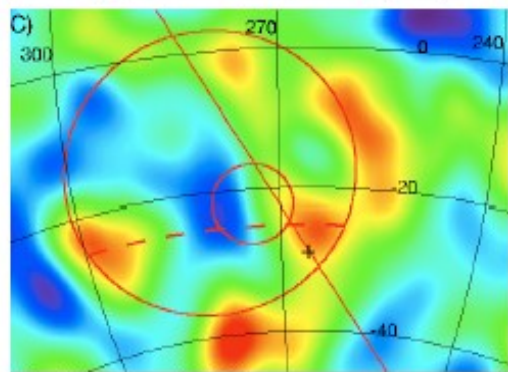
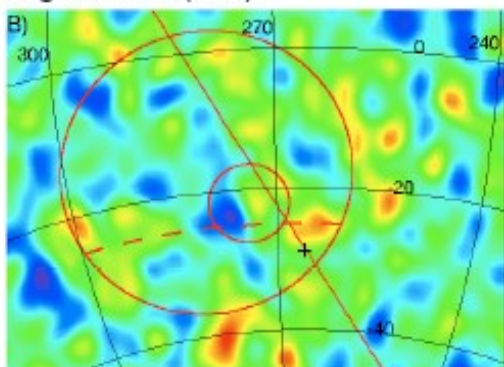
$1 < E < 10 \text{ EeV}$

search	window size	$n_{obs}/n_{exp}$
extended	$10^\circ$ (TH)	$1463/1365 = 1.07 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$
	$20^\circ$ (TH)	$5559/5407 = 1.03 \pm 0.02(\text{stat}) \pm 0.01(\text{syst})$
point-like	$0.8^\circ$ (G)	$16.9/17.0 = 0.95 \pm 0.17(\text{stat}) \pm 0.01(\text{syst})$

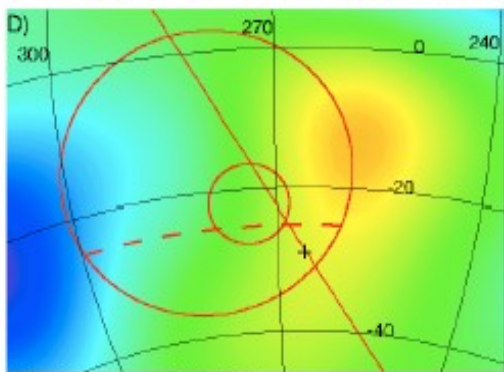
Coverage



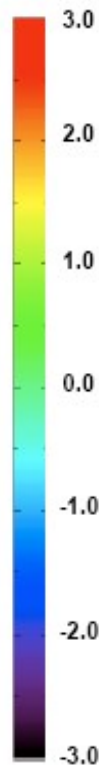
Significance ( $1.5^\circ$ )



Significance ( $3.7^\circ$ )



Significance ( $13.3^\circ$ )

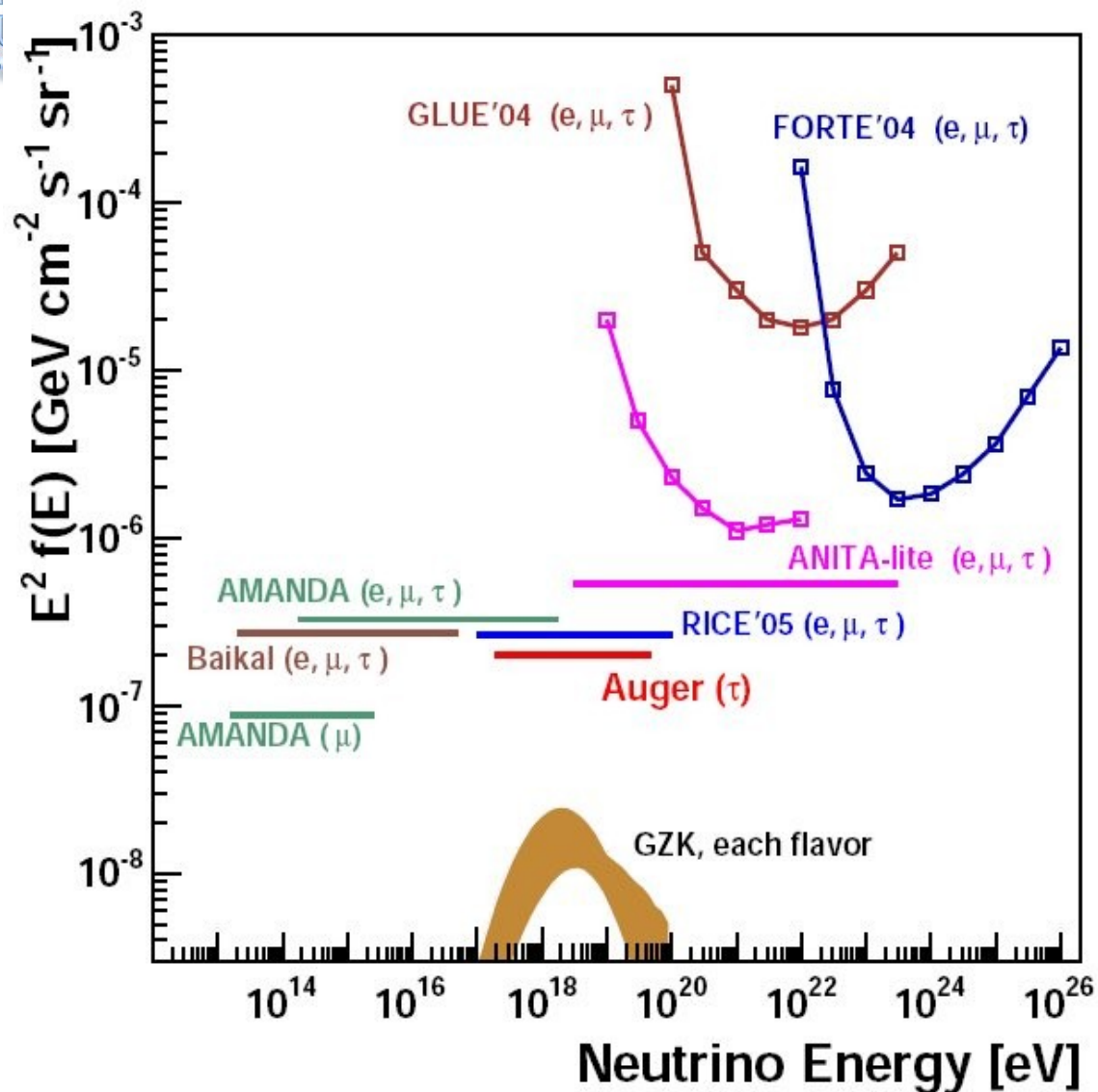


- 8.5 kpc
- GC pozorovatelné
- Žádný pozitivní signál (nepotvrzeny výsledky z experim. Agasa a Sugar)

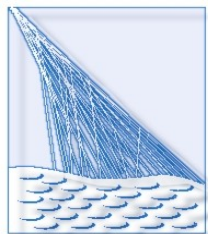


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# Tau neutrino

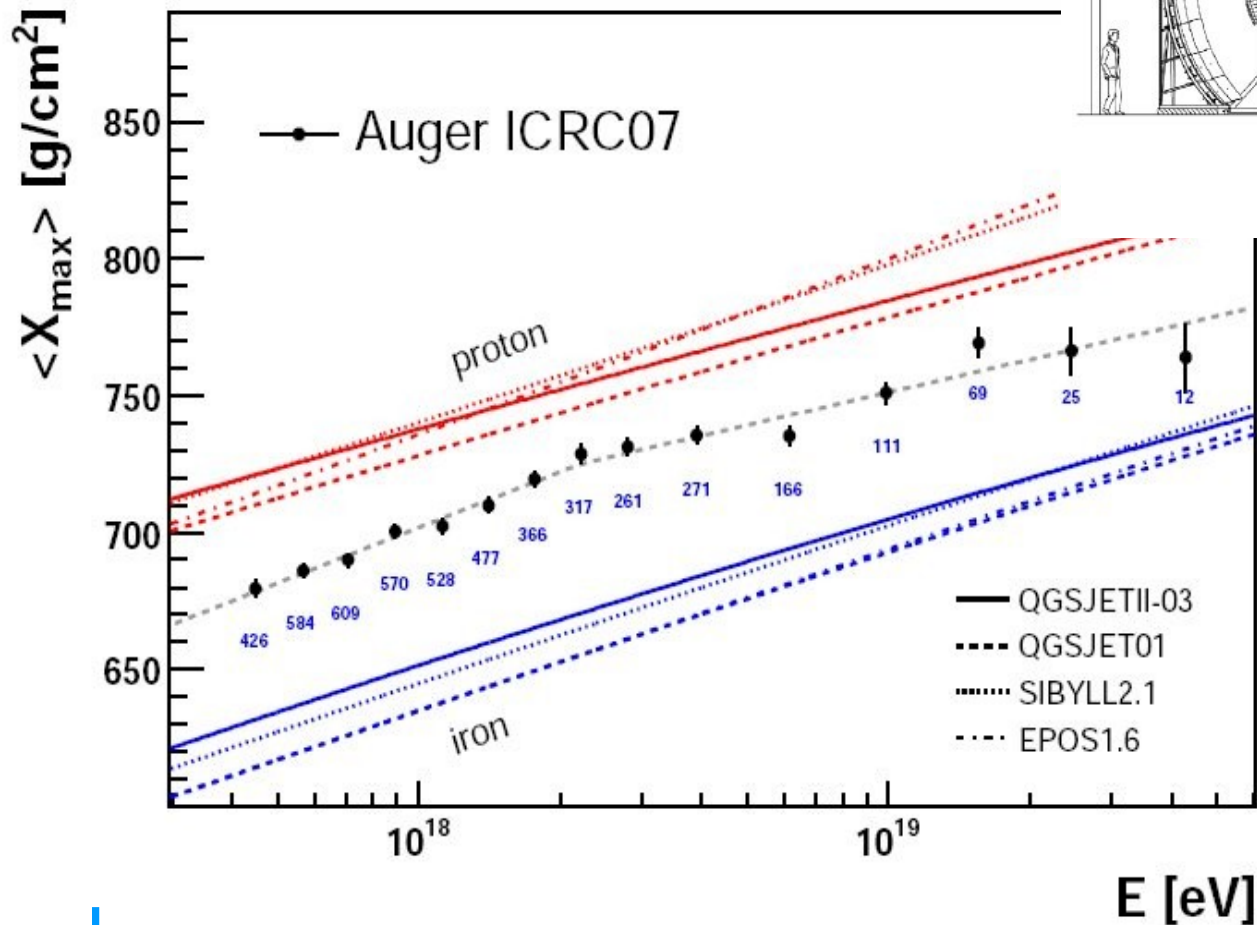
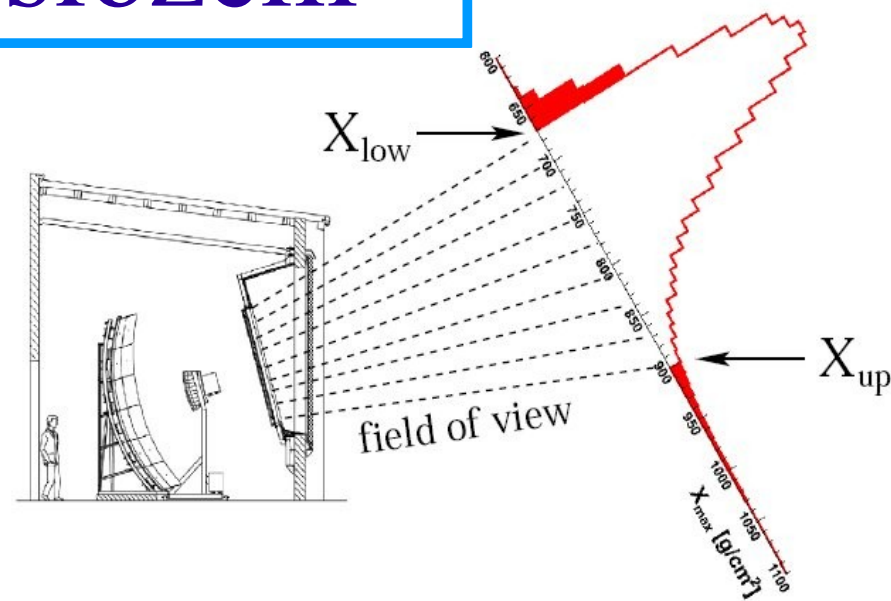


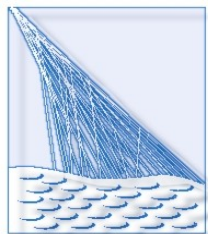
- Skloněné spršky
- $\theta < 60^\circ$
- Hluboko v atmosféře (až 36,000 g cm<sup>-2</sup>)
- Vzestupné spršky



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# Chemické složení

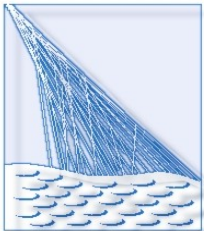




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# Shrnutí

- Úspěšný provoz od roku 2004
- Nyní: 4 FD, 1200 SD
- Projekty detektorů KZ nižších energií
- Severní část observatoře (?)



# Výstavba FD

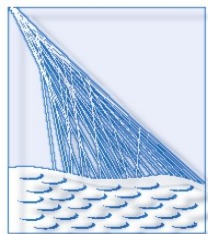




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# Výstavba FRAMu





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# Hanáci



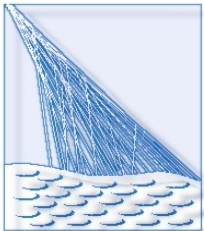




# Doprava

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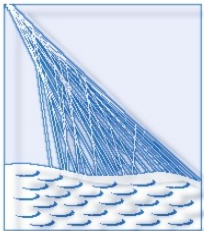




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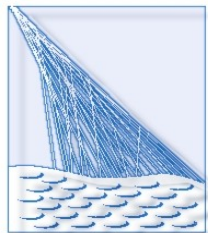
# Fauna - krásná





# Fauna - nebezpečná





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# Fauna - chutná

