Estimation of the spectrum of atmospheric neutrons at sea level in the energy range 0.05-1 GeV

Lukyashin A.V., Akimov D.Yu., Belov V.A., Bolozdynya A.I., Dedenko L.G., Etenko A.V., ...

National Research Nuclear University «Moscow Engeneering Physics Institute»

NRC «KI» - Institute for Theoretical and Experimental Physics

M.V. Lomonosov Moscow State University Faculty of Physics

Skobeltsyn Institute of Nuclear Physics

National Research Center «Kurchatov Institute»

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Content

Introduction and Motivation

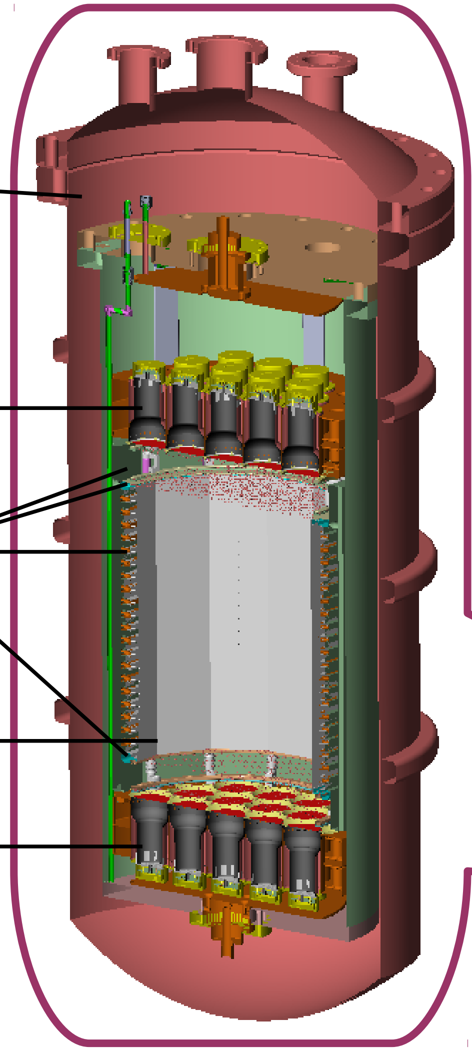
1) This work is associated with the calculation of the background (extraneous signal) to take into account in experiments rare event search.

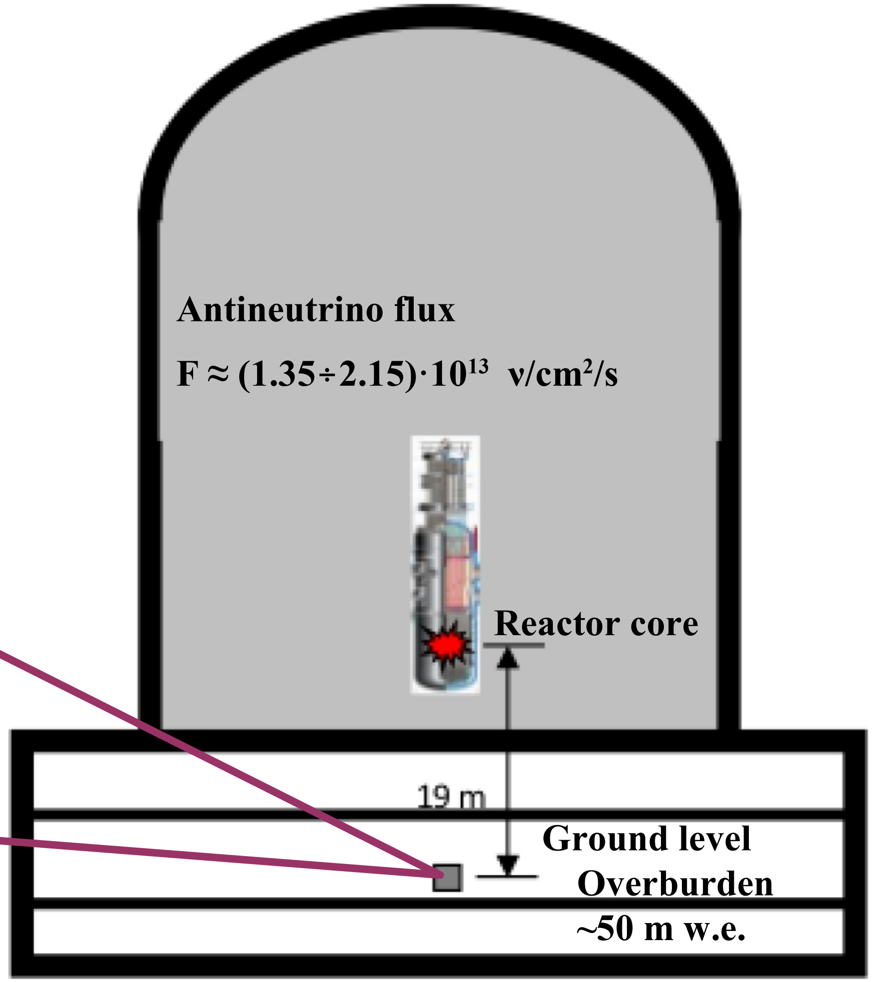
2) The RED-100 detector have a powerful sensitivity to single electron ionisation. More detail in report «Two-phase emission liquid xenon detector RED-100 for rare events search at ground level laboratory» by Alexander Khromov

3) The key strategy for neutrino detecting base on the CEνNS-effect. More detail in report «Experimental study of CEνNS process» by Dmitry Akimov (also "Observation of coherent elastic neutrino-nucleus scattering" Science: eaao0990 DOI: 10.1126/science.aao0990)

Introduction and Motivation

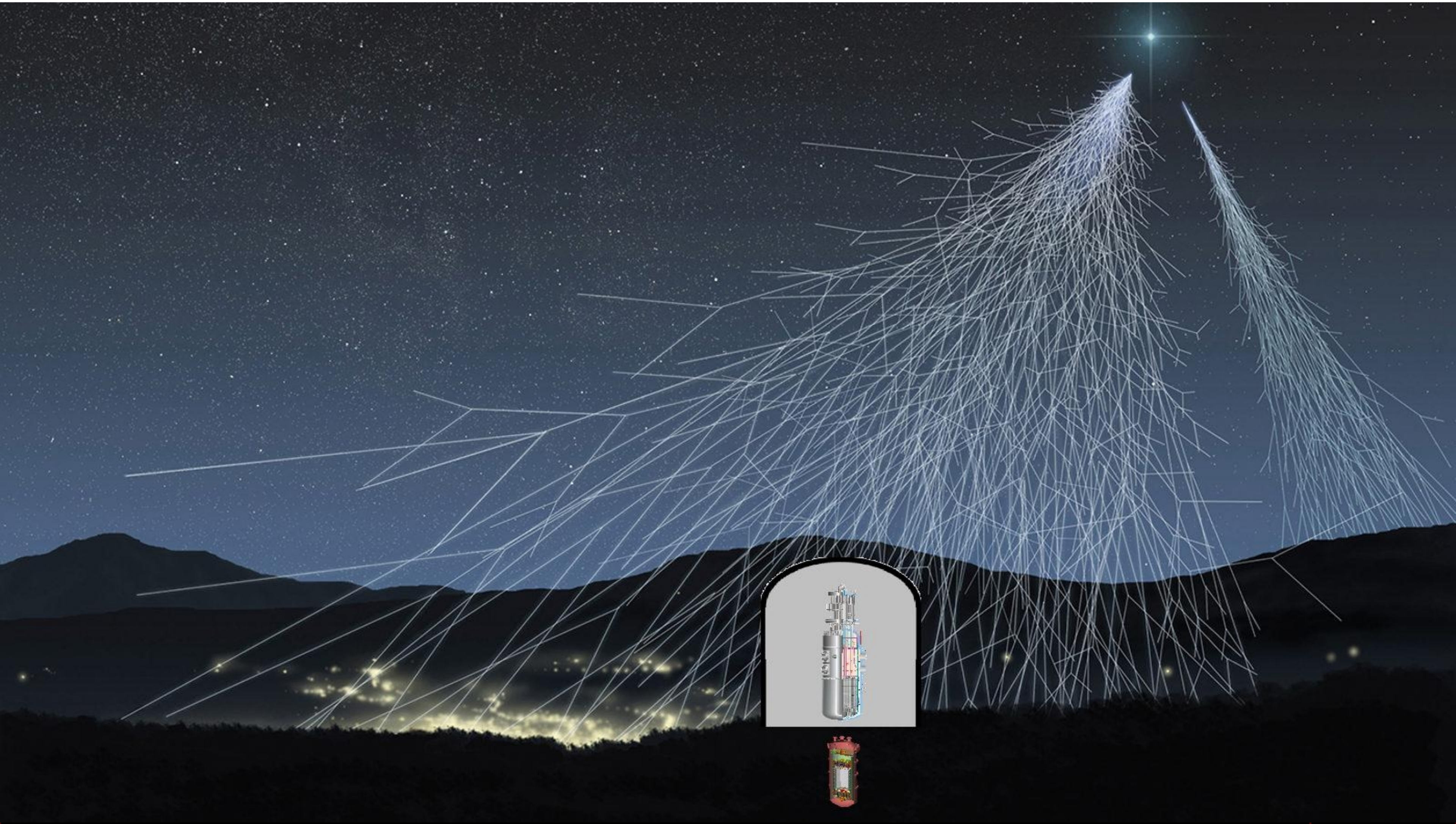
The one of the purpose of the RED-100 detector is to determine the flux of nuclear reactor antineutrino via CEνNS effect.





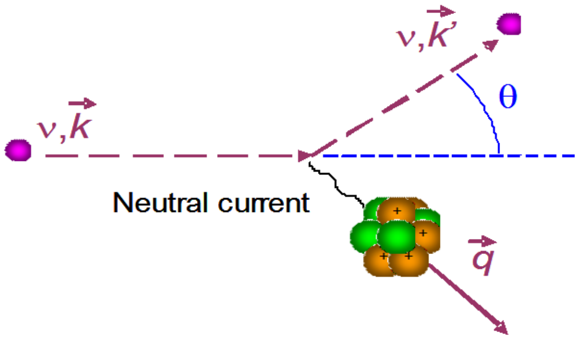
Introduction and Motivation

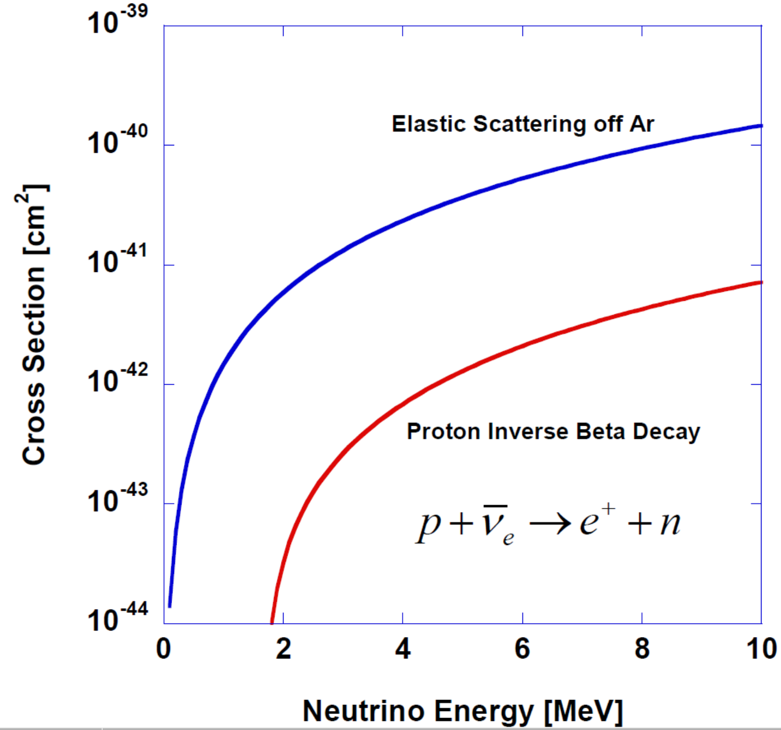
We have to estimate the background effects. The atmospheric neutrons with energies ~100-200 MeV produced in cosmic rays is very important.



Introduction and Motivation

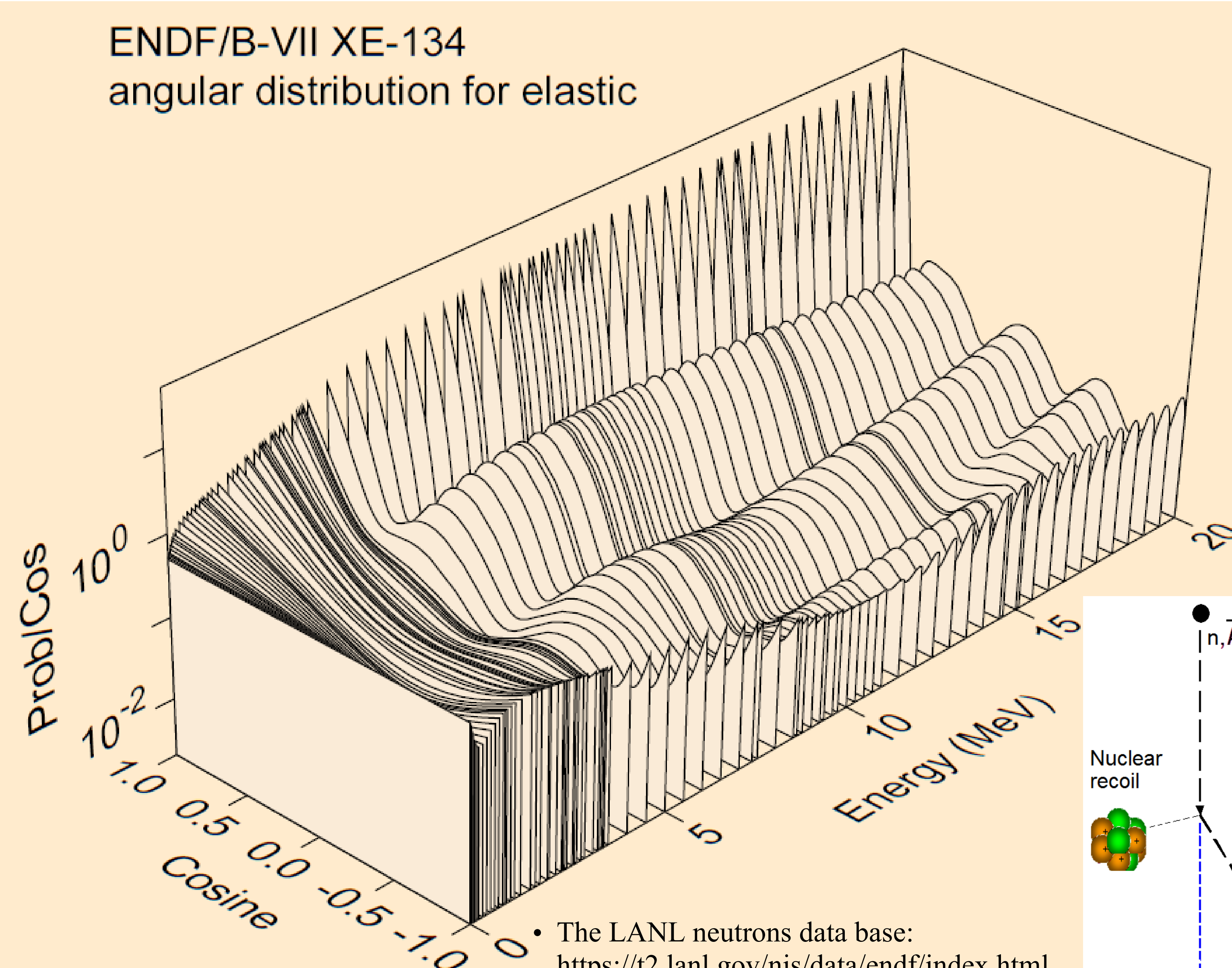
- CENNS process
- IBD process



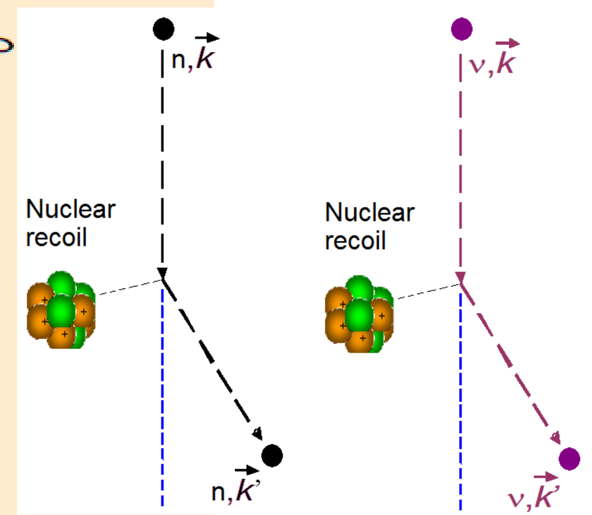


	CEνNS-effect	Inverse Beta Decay
Facility	RED-100	SAN Onofre, Rovno, DANSS..
Reaction for $\tilde{\nu}$ detection	Nuclear recoil (≤keV)	$\tilde{\nu}_e + p \rightarrow e^+ + n$
Average cross-section	~40 ab (E_ν≈5 MeV; model)	~1 ab (E_ν≈5 MeV; model)
Signature of event	Single EL-impuls	Multipulse signature
Influence of background	Atmospheric neutrons	
Average count rate	~$4 \cdot 10^4$ event/day (1T KNPP)	~$3 \cdot 10^3$ event/day (1T KNPP)

Introduction and Motivation



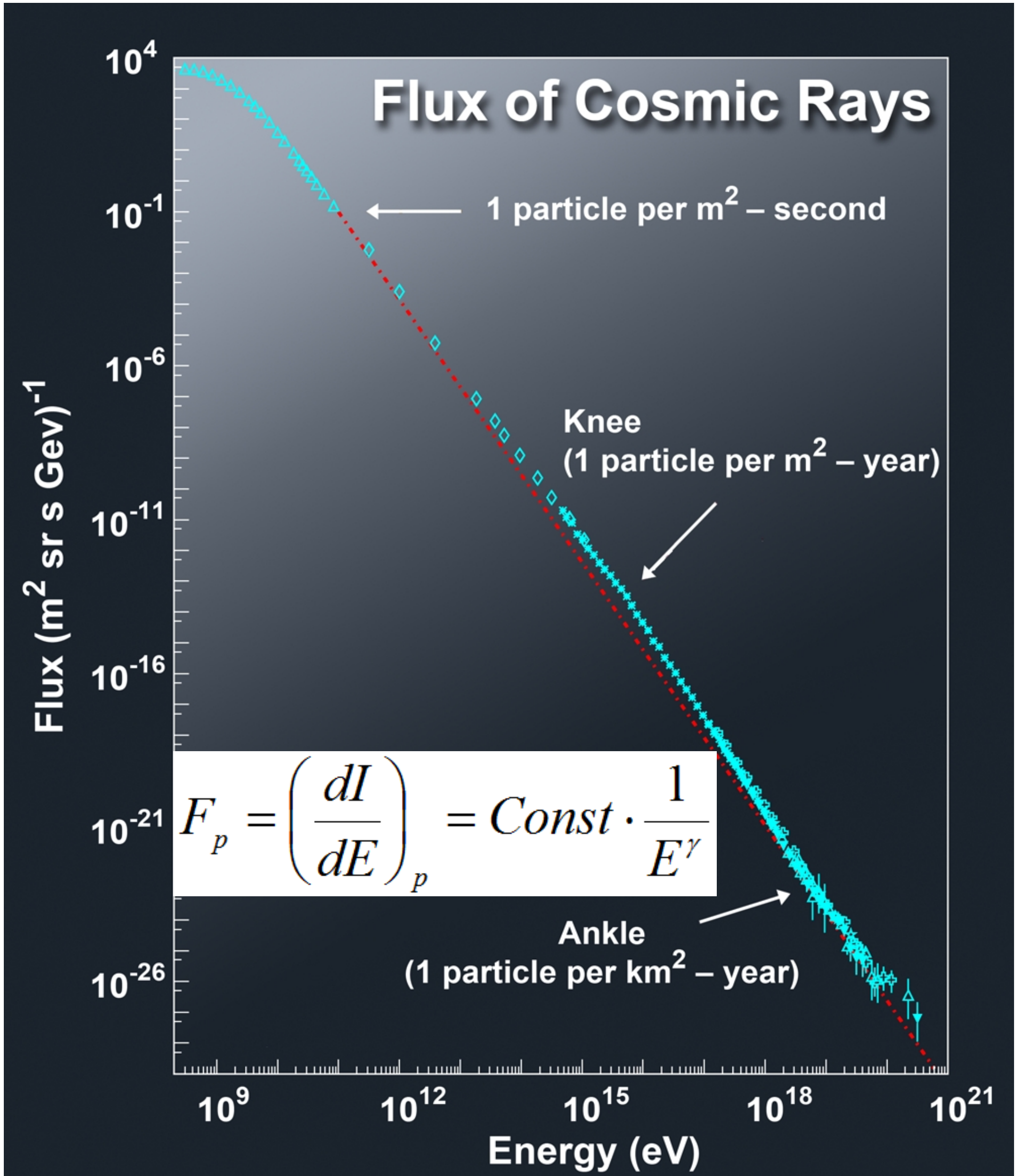
How to recognize the initial particle?



- The LANL neutrons data base: https://t2.lanl.gov/nis/data/endf/index.html

Feature of calculation and modeling

- Energy range: E∈10-10^6 GeV the slope of spectra γ=2.7
- Energy range: E<1GeV (rare <10 GeV) the itensity of spectra depends on Solar activity
- High energy hadronic interaction models: QGSJET, DPMJET, SIBYLL, EPOS, VENUS…
- Low energy hadronic interaction models: GHEISHA, FLUKA, UrQMD...



Method of estimaton

1) The estimation of the atmospheric neutron flux with high accuracy. (As a function of external source.)
2) We have to know the primary cosmic rays spectra.
3) We have to know the average production of neutrons induced by cosmic rays in the atmosphere. [Package for simulation: CORSIKA, FLUKA, GEANT4,...]
4) We have to compare result with neutron energy spectrum data. (Reliable data).

- CORSIKA+GHEISHA
- CORSIKA+UrQMD
- ….

Method of estimaton

- We have estimated differential energy spectra of atmospheric neutrons as integrals.

$$D(E_n) = \int_{E_{th}}^{E_{max}} \left(\frac{dI}{dE} \right)_p \cdot S_p(E_n, E) \cdot dE$$

$\left(\frac{dI}{dE} \right)_p$ — Intensity of primary protons

$S_p(E_n, E)$ — Partial energy spectrum of neutrons induced by protons at fixed energies

- $D(E_n)$ — differential energy spectrum of atmospheric neutrons [1/(GeV·m^2·s·sr)].

Cosmic Rays DataBase

Welcome | Experiments/Data | Data extraction | $\Phi^{NM}(t)$ and J^{TOA} | Links | New data

Database of Charged Cosmic Rays

D. Maurin (LPSC), F. Melot (LPSC), R. Taillet (LAPTh)

If you use this database, please cite Maurin, Melot, Taillet, A&A 569, A32 (2014) [arxiv.org/abs/1302.5525].

New release V3.1 - August 2016
[changelog]
Last code modification: 10/01/2017

Description

This database is a compilation of experimental cosmic-ray data. The database includes electrons, positrons, antiprotons, and nuclides up to Z=30 for energies below the knee. If you spot any errors or omissions, want to contribute, or simply comment on the content of the database, please contact us. We are eager to extend the database to Z>30 and to higher energy ground measurements and any help is welcome.

Warning: several sets of Solar modulation values are provided per sub-experiment. We refer the user to Sect.2.3 of Maurin et al. (2013) for a complete discussion, and only give below a brief description of the different sets of modulation parameters available in the CRDB: [read more]

Current version / Latest data added / Acknowledgements

Structure of the database

This is a mySQL database containing lists of experiments (name, dates of flight, experimental technique in brief, website), the corresponding publications (ref. and link to the ADS database), and all available data points (fluxes and ratios of leptons, nuclides, and anti-protons including their statistical and systematic error whenever available).

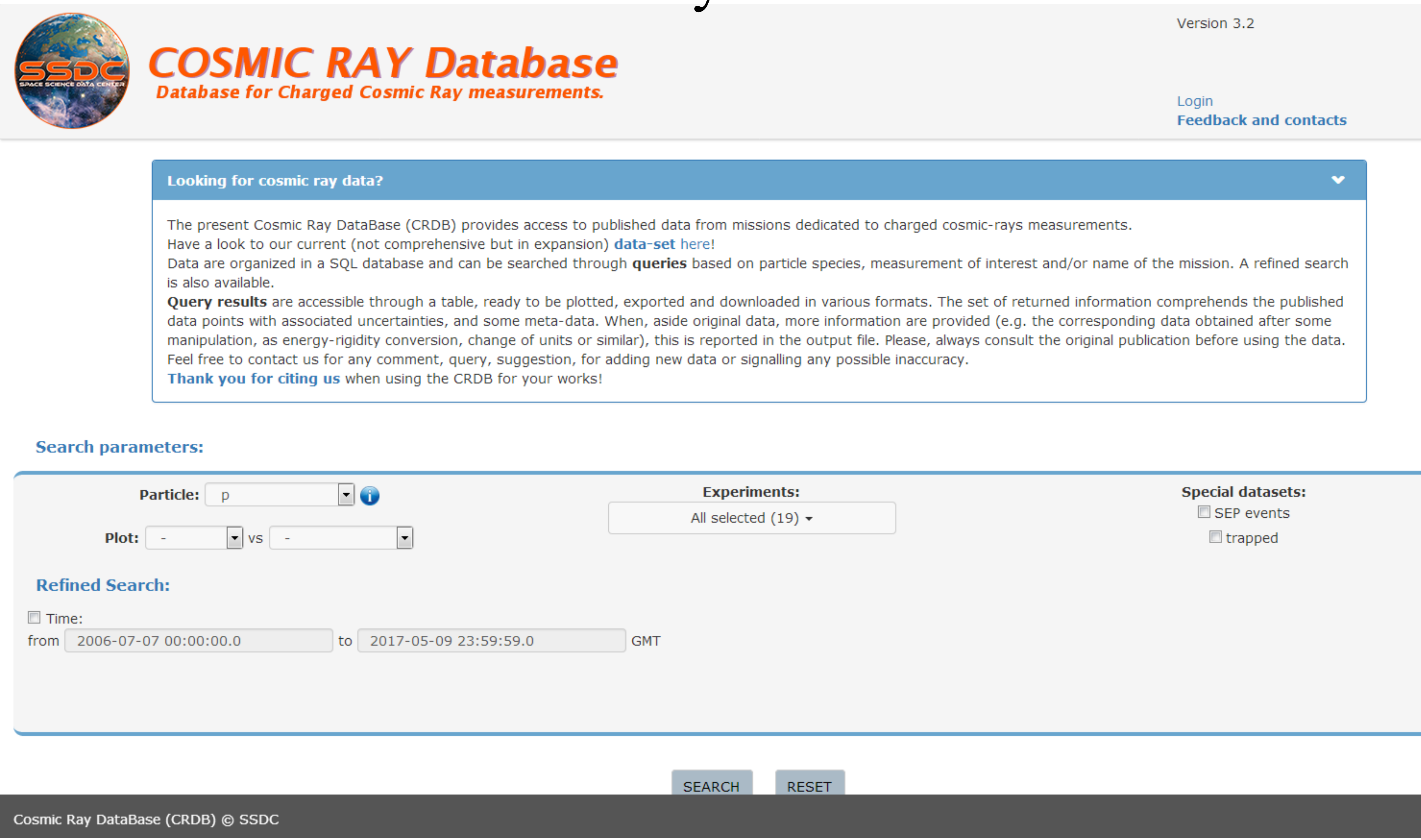
Accessing the database

- Experiments/Data: list of experiments, publications, data
- Data extraction: selection by flux/ratio/energy range... (on this web site or via a REST interface)
- Export database content in USINE or GALPROP compliant format (ASCII files)
- Get all bibtex entries and Latex cite (by sub-experiment)

Acknowledgements: this project has been financially supported by the PNHE

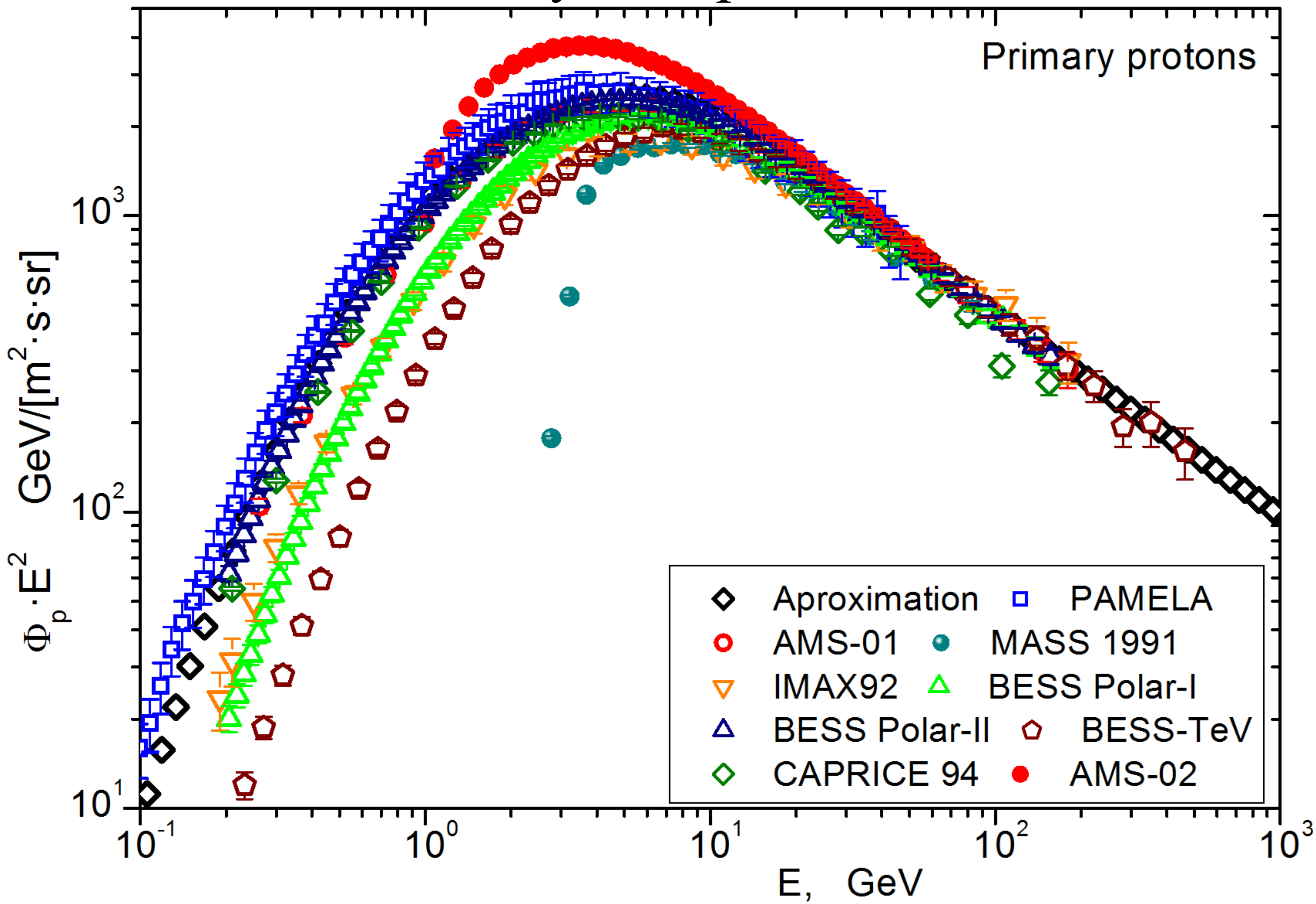
Maurin D., Melot F., Taillet R., Astronomy & Astrophysics, 569, A32 (2014). (http://lpsc.in2p3.fr/cosmic-rays-db/)

Cosmic Rays DataBase



Cecilia Pizzolotto, Valeria Di Felice, Domenico D'Urso, et al PoS(ICRC2017)227 (2017). (https://tools.ssdc.asi.it/CosmicRays/)

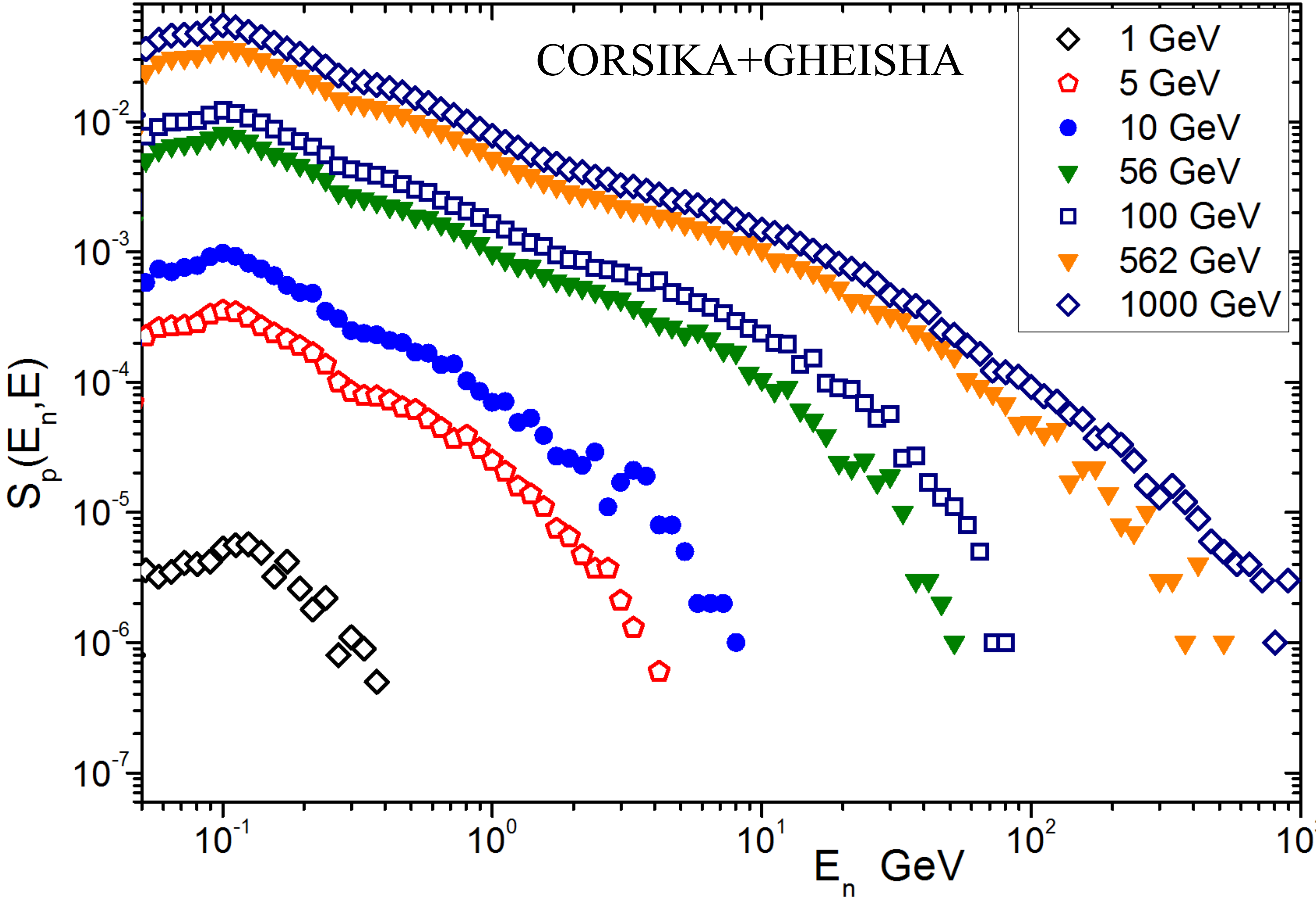
Primary CR spectrum



Primary cosmic rays data

1) AMS-01: Alcarez et al PLB, 490, 1-2, p. 27 (2000).
2) AMS-02: PRL 121, 051101 (2018)
3) IMAX92: Menn et al., ApJ 533, 281 (2000)
4) PAMELA: Adriani et al., ApJ 765, 91 (2013)
5) MASS 1991: Bellotti et al., PRD 60, 052002 (1999)
6) BESS PolarI: Abe et al., ApJ 822, 65, p16 (2016)
7) BESS PolarII: Abe et al., ApJ 822, 65, p16 (2016)
8) BESS-TeV: Shikaze et al., APh 28, 1, p154 (2007); Haino et al., PLB 594, 1-2, p35 (2004)
9) CAPRICE94: Boezio et al., ApJ 518, 1, p457 (1999)

Partial neutron energy spectra



Comparison

- Energy spectrum of neutrons

$x = Ln(E_n/[1 MeV])$

- Neutrons (E_n>10 MeV) =0.00555877 [$1/cm^2/s$]
- Neutrons (E_n>20 MeV) =0.0043992 [$1/cm^2/s$]
- Neutrons (E_n>50 MeV) =0.0029109 [$1/cm^2/s$]
- Neutrons (E_n>100 MeV) =0.00189186 [$1/cm^2/s$]
- Neutrons (E_n>1000 MeV) =0.0001592 [$1/cm^2/s$]

$$Flux = 1.5 \cdot Exp[A \cdot x^4 + B \cdot x^3 + C \cdot x^2 + D \cdot x + E]$$

A	B	C	D	E	Range [MeV]	Accuracy
0.003694	-0.08915	0.5985	-2.6043	-5.2752	$10\text{-}10^4$	~2%

This curve close to satisfactory fit of the neutron data

Threshold energy	10 MeV	20 MeV	50 MeV	100 MeV	1000 MeV
Rate [$1/m^2/day$]	$4.8\cdot10^6$	$3.8\cdot10^6$	$2.5\cdot10^6$	$1.6\cdot10^6$	$1.38\cdot10^5$

Data of the neutron spectra

1) W.N. Hess, et al Phys Rev 116, 445 (1959).

2) E. Heidbreder, et al J. Geophys. Rev. 76, 2905 (1971).

3) A.M. Preszler, et al J. Geophys. Rev. 79, 17 (1974).

4) G. Brooke, et al Proc. Phys. Soc. 83, 843 (1964).

5) J.M. Ryan, et al «Ground Level Neutron Measurements from 10 — 170 MeV» Proceedingd of the 1996 Topical Meeting, American Nuclear Society 219-226, (1996).

6) F. Ashton et al J. Phys. A: Gen. Phys. 4, 352 (1971).

Results and Conclusion

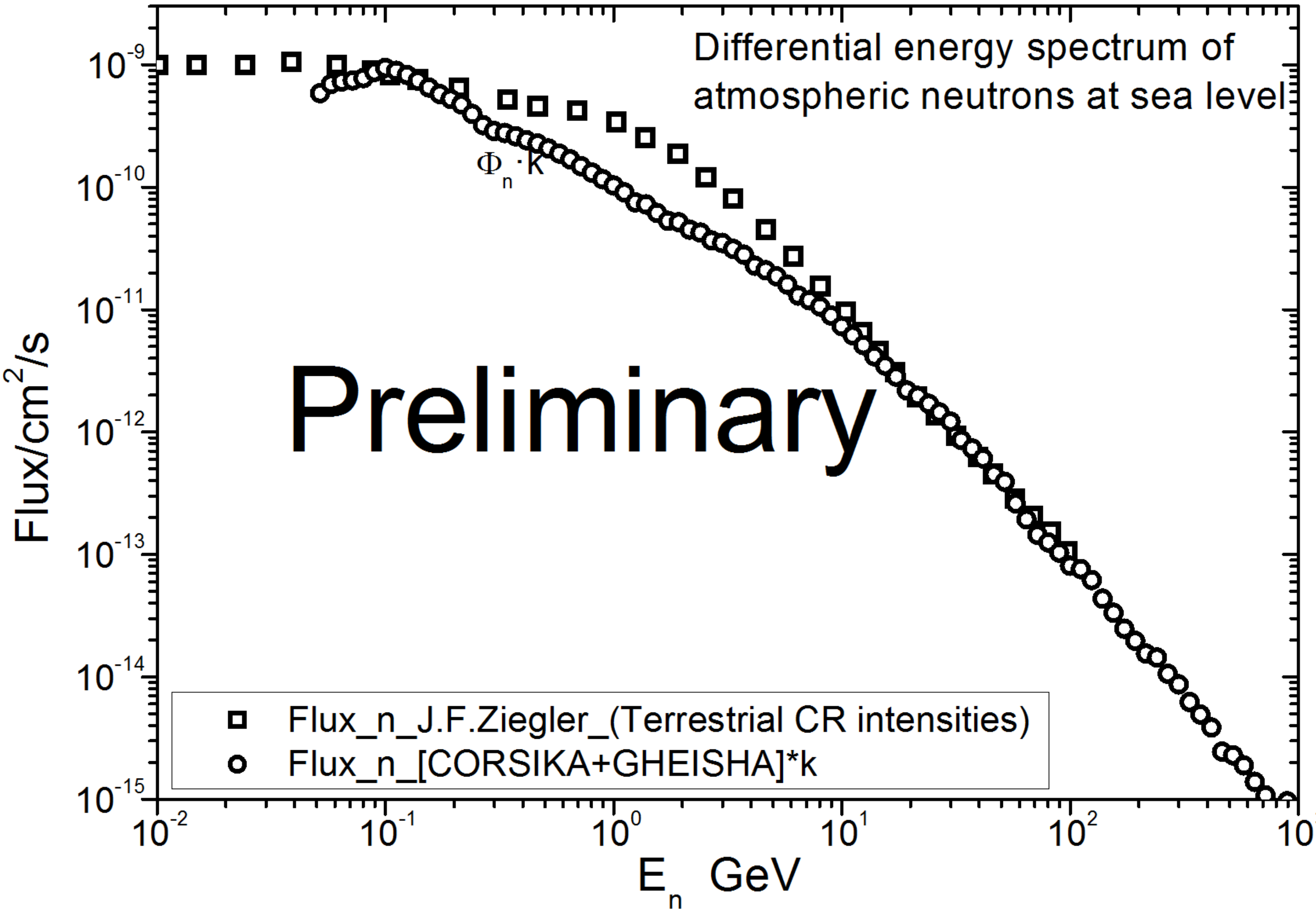
- Neutrons flux (50 MeV<E_n <1000 MeV) =0.00275169 [1/cm^2/s]; Rate = 2.37·10^6 counts/m^2/day
- Neutrons flux (E_n >1000 MeV) = 1.6·10^6 [1/m^2/day] ~0.3 [1/m^2/s/sr]
- Average fraction of neutron flux (E_n >10MeV @100%):
- (10 MeV<E_n <20 MeV) 20,8%
- (20 MeV<E_n <50 MeV) 26,8%
- (50 MeV<E_n <100 MeV) 18,3%
- (100 MeV<E_n <1000 MeV) 31,2%
- Primary estimates of counts rate (neutrino) for detector ~3.5·10^3 events/day
- Primary estimates of background rate for detector with coating *at situ* is at the same range [~15 cm of lead, ~20 cm of water]

- The authors are grateful for the financial support of the Russian Science Foundation (grant №18-12-00135, 12.04.2018, RFBR №17-02-01077) and the Competitiveness Program of NRNU MEPhI (contract № 02.a03.21.0005, 27.08.2013)

Thank you for attention!

Backup slides

Preliminary result



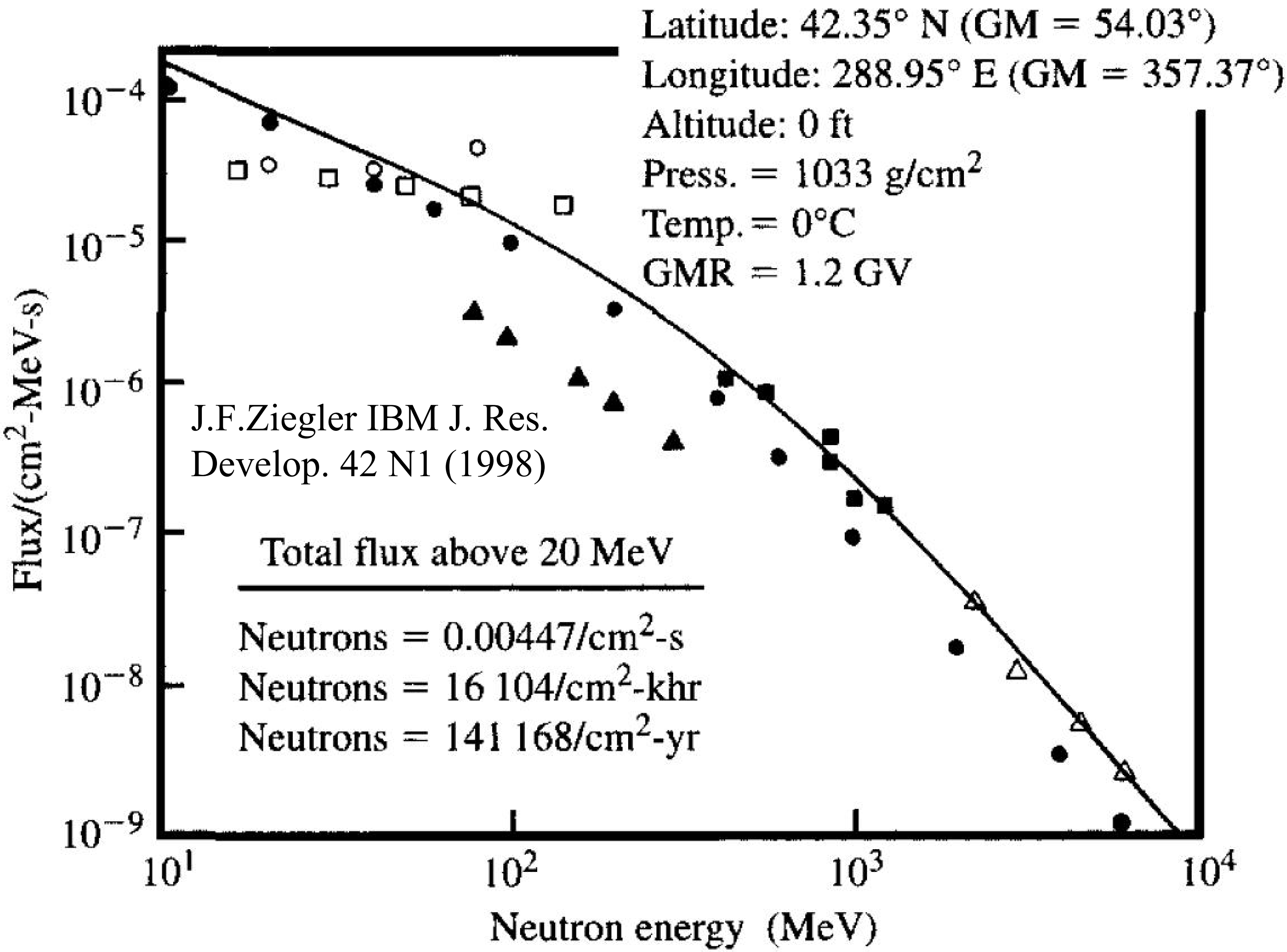
$$D_p(E_n) = \int_{E_{th}}^{E_{\max}} \left(\frac{dI}{dE}\right)_p \cdot S_p(E_n, E) \cdot dE$$

$$D_{He}(E_n) = \int_{E_{th}}^{E_{\max}} \left(\frac{dI}{dE}\right)_{He} \cdot S_{He}(E_n, E) \cdot dE$$

$$D(E_n) = D_p(E_n) + D_{He}(E_n)$$

$$D(E_n) = \int_{E_{th}}^{E_{\max}} \int_{\theta_0}^{\theta_{\max}} \left(\frac{dI}{dE}\right)_p \cdot S_p(E_n, E, \theta) \cdot Sin\theta \cdot d\theta \cdot dE$$

$$D(E_n) = \int_{E_{th}}^{E_{\max}} \int_{\theta_0}^{\theta_{\max}} \left(\frac{dI}{dE}\right)_p (E, \theta) \cdot S_p(E_n, E, \theta) \cdot Sin\theta \cdot d\theta \cdot dE$$



Latitude: 42.35° N (GM = 54.03°)
Longitude: 288.95° E (GM = 357.37°)
Altitude: 0 ft
Press. = 1033 g/cm2
Temp. = 0°C
GMR = 1.2 GV
J.F.Ziegler IBM J. Res. Develop. 42 N1 (1998)
Total flux above 20 MeV
Neutrons = 0.00447/cm2-s
Neutrons = 16 104/cm2-khr
Neutrons = 141 168/cm2-yr
Flux/(cm2-MeV-s)
Neutron energy (MeV)

References

● W.N. Hess et al Phys Rev 116, 445 (1959)

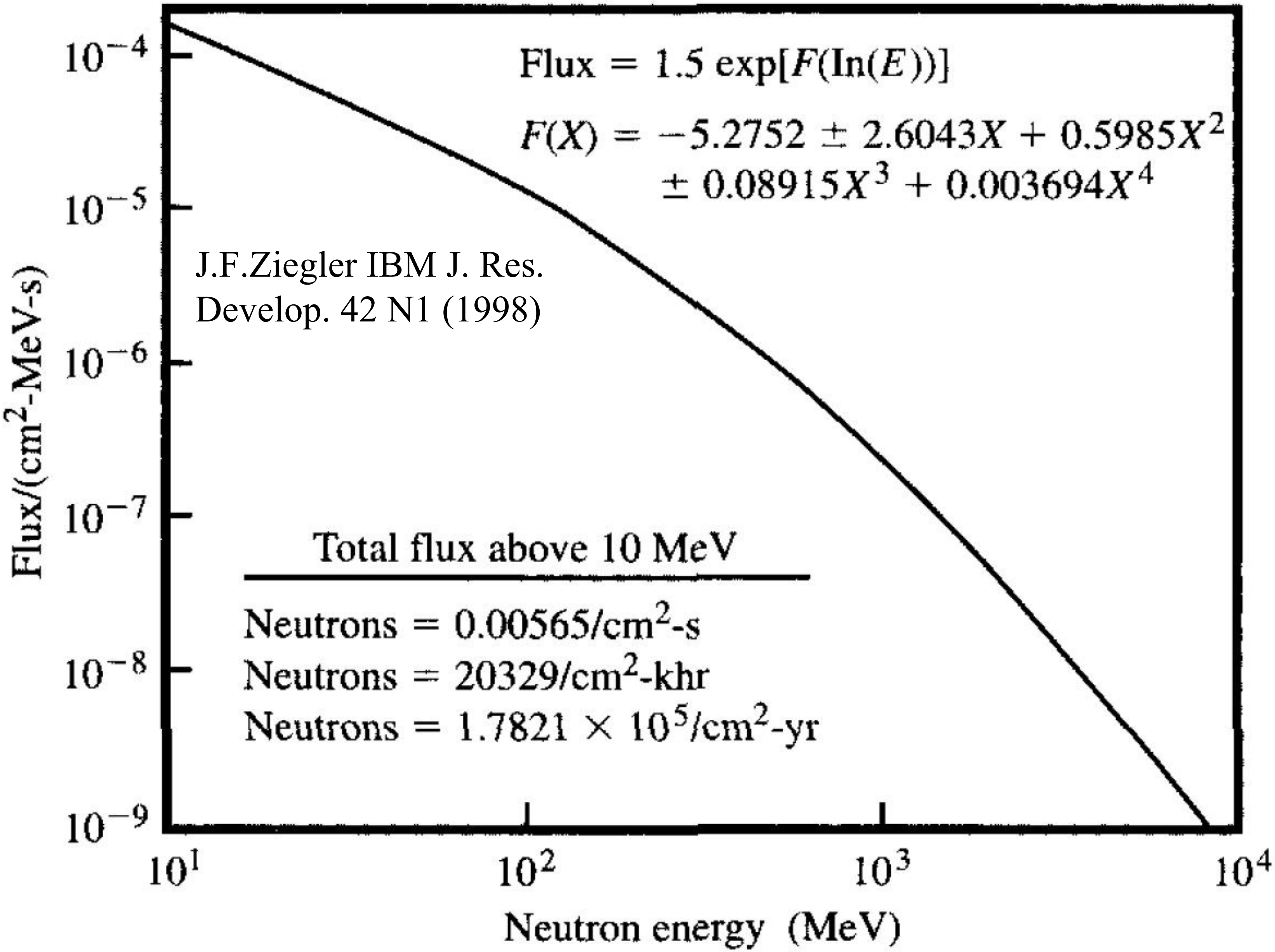
▲ E. Heidbreder et al J. Geophys. Rev. 76, 2905 (1971)

○ A.M. Preszler et al J. Geophys. Rev. 79, 17 (1974)

Δ G. Brooke et al Proc. Phys. Soc. 83, 843 (1964)

□ J.M. Ryan et al «Ground Level Neutron Measurements from 10 — 170 MeV» Proceedingd of the 1996 Topical Meeting, American Nuclear Society 219-226, (1996)

■ F. Ashton et al J. Phys. A: Gen. Phys. 4, 352 (1971)


Flux = 1.5 exp[F(In(E))]
F(X) = −5.2752 ± 2.6043X + 0.5985X²
± 0.08915X³ + 0.003694X⁴
J.F.Ziegler IBM J. Res.
Develop. 42 N1 (1998)
Total flux above 10 MeV
Neutrons = 0.00565/cm²-s
Neutrons = 20329/cm²-khr
Neutrons = 1.7821 × 10⁵/cm²-yr
Flux/(cm²-MeV-s)
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10¹
10²
10³
10⁴
Neutron energy (MeV)

Web-links

- Alexander Bolozdynya
- http://charm.lebedev.ru/wp-content/uploads/participants-database/bolozdynya__registration_of_weakly_ionizing_particles_with_emission_detectors_2016_11_11.pdf
- Dmitry Akimov
- https://indico.particle.mephi.ru/event/4/contributions/538/attachments/406/435/4._Akimov_RED-100.ppt
- Viacheslav Egorov
- http://nanpino2013.blogspot.com/p/scientific-program.html; https://docs.google.com/file/d/0Bz9CH4rPsAnTdUVlS3kxS09ERG8/edit
- https://indico.cern.ch/event/394248/contributions/1831691/attachments/789227/1081771/DANSS_Egorov.pdf

- Авторы выражают благодарность за финансовую поддержку Российскому научному фонду (грант №18-12-00135, 12.04.2018) и Программе повышения конкурентоспособности НИЯУ МИФИ (контракт № 02.a03.21.0005, 27.08.2013)

Thank you for attention!