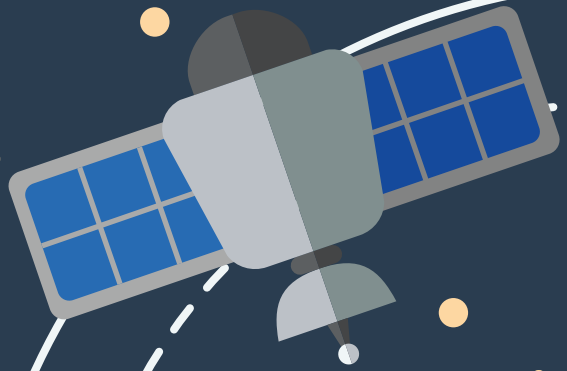
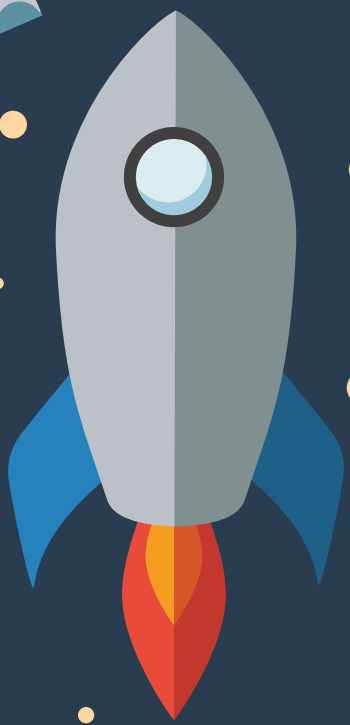


AMS-02 ACTIVITY

Search for Solar Energetic Particles with AMS-02 on the International Space Station

V. Bindi, C. Consolandi, C. Corti, K. Whitman



Check for some other awesome physics stuff on our website!
http://bit.ly/amshawaii-outreach

Search for Solar Energetic Particles with AMS-02

V. Bindi, C. Consolandi, C. Corti, K. Whitman

JD Armstrong, T. Chun, P. Grach, W. Huelsnitz, M. Kadoka, C. Kobashigawa, M. Nassir, D. Ong.

Goal of Activity

In this activity, you are challenged to identify particles accelerated by the Sun, called Solar Energetic Particles measured by Alpha Magnetic Spectrometer (AMS-02) a particle detector flying onboard the International Space Station (ISS).
Each team will be provided with a different time period during which SEPs occurred.
After you have found your SEP event, you will compare it with other teams' events to discover which SEP event is the most intense, which has the highest energy SEPs, and more.

Background Info: AMS-02

AMS-02 is a state-of-the art particle detector located in space which was installed onboard the International Space Station (ISS) on May 19th, 2011. It measures particles and photons with energies between 500 MeV ($5x10^8$ eV) to a few TeV ($1x10^{12}$ eV). AMS-02's primary mission is to search for Dark Matter, new types of matter that don't exist on Earth, antimatter, make precision measurements of galactic and extragalactic cosmic rays (GCR), and measure the highest energy solar energetic particles (SEPs) generated by the Sun. Because AMS-02 is in space, it makes direct measurements of the actual cosmic rays that arrive at Earth, which is an advantage over ground-based detectors that can only observe reactions caused by incoming particles when they slam into the atmosphere.

ISS
International Space Station

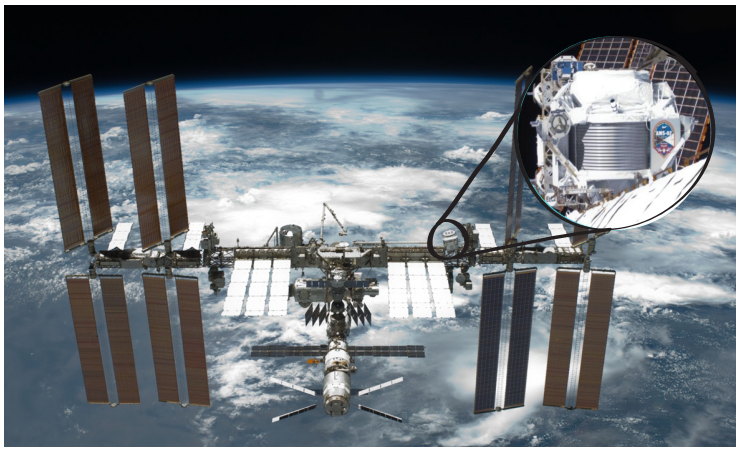
Year of launch: 1998

Speed:4.8 miles per second (7.66 km per sec)

Altitude: 259 miles (416 km)

Orbital period: 92.69 minutes

The Space Station is as big as a football field: 360 ft long (109 mt)



AMS
Alpha Magnetic Spectometer

Date of Launch:May 2011

Launch vehicle:
Space Shuttle Endeavour

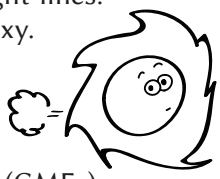
Mass: 14,809 lb (6,717 kg)

About 1,000 cosmic rays are recorded by the instrument per second, generating about one GB/sec of data

Check out the web site:
http://www.ams02.org/

Cosmic Rays

Cosmic rays are charged particles in space, like electrons, protons, and ions, that travel at very high speeds close to the speed of light. These particles lost their electrons and became charged when they were accelerated in extremely energetic environments like supernova explosions, active galactic nuclei (AGN), colliding galaxies, and black holes. Cosmic rays are generated inside of our Milky Way galaxy and in other galaxies, then travel long distances before they are observed by particle detectors at Earth. Because cosmic rays are charged particles, they do not travel in straight lines. Rather, they follow curving and looping paths through the magnetic fields within our galaxy.



Solar Energetic Particles

The Sun experiences many explosive events, such as flares and coronal mass ejections (CMEs), called solar activity. The largest and most energetic of these explosive events can accelerate charged particles up to energies measured by AMS.

Team Members

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

Team Name

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

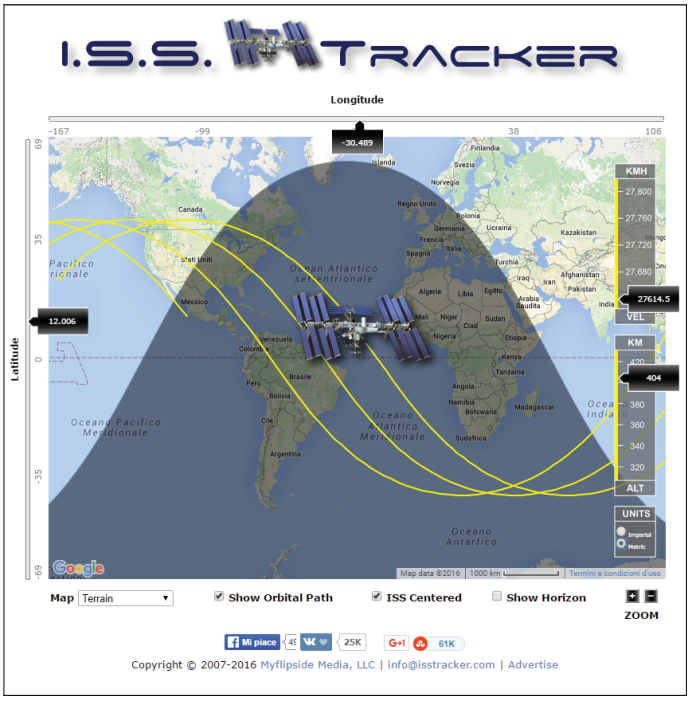
What does your team name mean?
Your team is named after an astrophysical object that accelerates cosmic rays.
Do a quick internet search and write down a short definition of your team's name :

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

Locate AMS-02 SECTION 1

1. Do you know where ISS and AMS are now? Go find out on the website and check its location with the rest of the class! http://www.isstracker.com/



Location:_ _ _____ _____ _____ _____ Latitude: _ _ _____ _____ _____ Longitude:_ _ _____ _____ _____

Date: _____ _____ _____ _____ _____ Time: _____ _____ _____ _____ _____

At home: check when the International Space Station in visible form your home town!
https://spotthestation.nasa.gov/sightings/

Access AMS-02 Measurements SECTION 2

(2) You will be given login information for the UH AMS-02 outreach gmail account.

(3) The files that you need are in Google Drive: AMS-02 For Teachers, for this account under the folder "Search for SEPs." Choose your team's spreadsheet. Each spreadsheet contains one week of data. The first column of the spreadsheet is Energy in GeV. The remaining seven columns are measurements of the AMS-02 daily proton rate (# of protons/second averaged over a 24 hour period) for an entire week.
Each column is labeled with the date of when the data is collected.

One or more of the days in your dataset contains a signal of solar energetic particles.
It is your mission to discover which one(s).

Energy - eV and GeV
An electron volt (eV) is the amount of kinetic energy an electron has after it has been accelerated by an electric potential of 1 volt. Because an electron is so small, an eV is a very small amount of energy that is equivalent to 1.6x10^(-19) joules. A giga electron volt (GeV) is 1 billion (10^9) eV. An electron with a kinetic energy of 1 GeV is traveling at 99% the speed of light.

Dates of Data Taking

fx | Energy

	A	B	C	D	E	F	G	H	I
1	Energy (GeV)		18-Jan-12	19-Jan-12	20-Jan-12	21-Jan-12	22-Jan-12	23-Jan-12	24-Jan-12
2	0.131441		462.834	459.8	464.593	478.075	439.989	855.261	438.643
3	0.145141		458.1	458.204	480.45	474.474	442.137	801.636	467.239
4	0.160173		463.018	462.821	473.695	477.638	439.88	742.307	437.036
5	0.176646		465.969	462.169	468.65	463.546	441.548	705.1	451.657
6	0.19468		463.383	476.072	470.878	468.466	440.769	641.515	440.644
7	0.214397		463.443	461.575	473.353	472.616	443.345	575.101	433.177
8	0.23593		466.842	475.61	468.156	482.944	446.669	535.45	421.493
9	0.259414		482.938	471.71	472.924	476.439	452.382	508.601	428.298
10	0.284995		464.768	469.723	482.047	479.046	446.978	485.426	424.965
11	0.31282		468.478	467.697	472.666	473.69	443.664	460.299	422.703
12	0.343046		470.587	469.821	474.572	474.269	446.129	441.301	428.493
13	0.375834		467.856	459.161	467.643	461.805	438.586	417.977	411.784
14	0.411352		449.181	453.771	459.53	452.09	429.689	403.315	406.069
15	0.449773		442.712	446.494	451.799	443.698	422.695	383.327	399.999
16	0.491277		428.51	430.474	444.239	429.711	407.699	367.428	386.494
17	0.536049		414.918	416.365	419.513	418.101	396.636	358.851	376.409
18	0.584279		403.358	400.374	405.401	407.812	382	342.208	363.323
19	0.636168		384.412	386.284	388.783	391.062	369.271	333.181	351.479
20	0.691918		372.537	371.528	369.33	373.221	352.364	315.574	338.138
21	0.751741		350.731	350.276	353.018	352.15	332.258	301.118	319.811
22	0.815859		328.918	330.618	331.235	332.658	318.573	283.421	302.694
23	0.884497		310.399	312.283	311.568	312.664	296.103	268.506	285.516
24	0.957892		291.078	290.788	292.215	292.088	278.464	252.444	270.038
25	1.03629		273.69	272.855	271.921	274.525	260.71	241.793	252.834
26	1.11995		250.23	251.54	252.881	250.376	241.405	223.261	232.782
27	1.20914		231.626	235.789	236.695	231.834	224.077	208.18	215.497
28	1.30414		214.195	215.729	216.445	215.068	205.394	192.955	200.513

Energy Bin
In nature cosmic rays are emitted in a continuum at all kinetic energies. Because of finite detector resolution we cannot distinguish between all the infinite values of kinetic energies but we can group them in discrete intervals called bins.

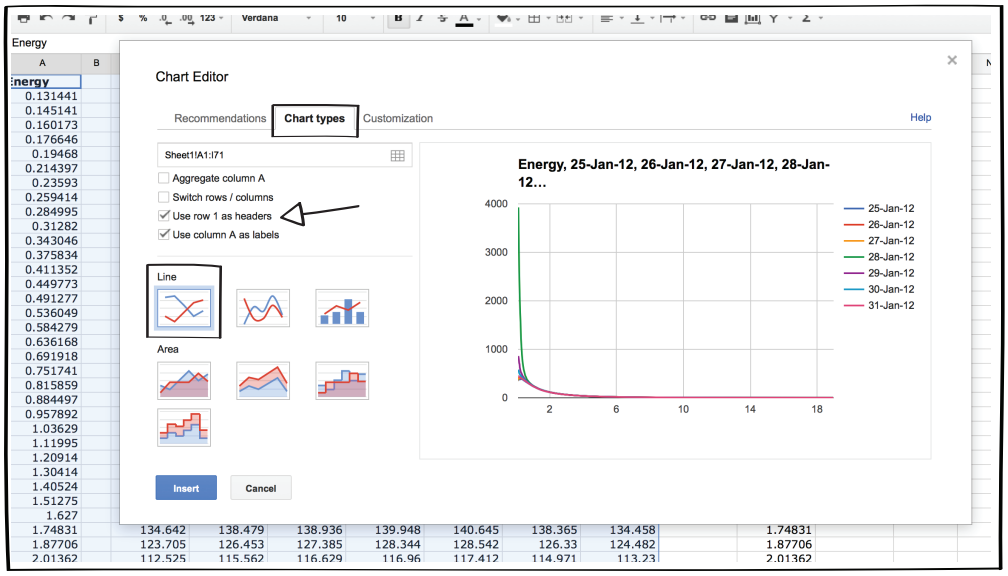
Proton Rate
The proton rate is obtained by counting the number of protons that pass through our detector for each second. The system of units is [particles/sec] or [Hz] the same as the frequency.

Plot the Data SECTION 3

④ Double click on your team's excel spreadsheet and click on Open at the top, to open it in Google Sheets. Highlight all of the Energy and Date columns all the way down to the very last numbers in the columns.
Do NOT include the rightmost 'Energy and SEPs' columns.

⑤ Click on Insert and choose Charts.

⑥ When the Chart Editor pops up with the Recommendations, use the default chart type (top left selection).

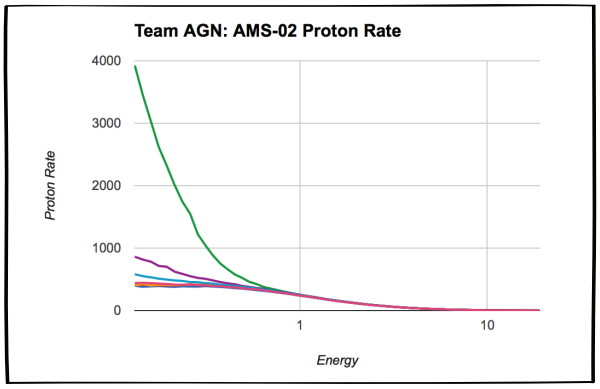


⑦ Click on the **Chart Types** tab and use the defaults: "Use row 1 as headers" and the top left line chart should already be selected. Also select "Use column A as labels".

⑧ Now edit the axes and titles. Select the Customization tab in the Chart Editor.
Change the Title to **Team AGN: AMS-02 Proton Rate** (of course, write your own team name).

⑨ Scroll down to the Axis box.
Set the X-axis (horizontal) title to **Energy (GeV)**, and the Y-axis (left vertical) title to **Proton Rate**.

⑩ Select the Horizontal axis again from the drop down menu. Scroll down and click on the box that says **Log Scale**.



⑪ Click on **Insert** to put the chart into your spreadsheet. It should look like the example above.
The dates in this example have been removed so that the date of the SEP event isn't given away!

Identify the Signal of SEPs SECTION 4

(12) Date Range Analyzed:___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

The rate for most of the days should overlap. Which date(s) shows an increase in proton rate due to a Solar Energetic Particle event?___ - ____ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ -

___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - -

Confirm that the Signal is Real SECTION 5

(13) Double check that this signal is real. If the signal is real, there should be X or M class flares and a fast coronal mass ejection in the 24 hours prior to the first day of the SEP event.

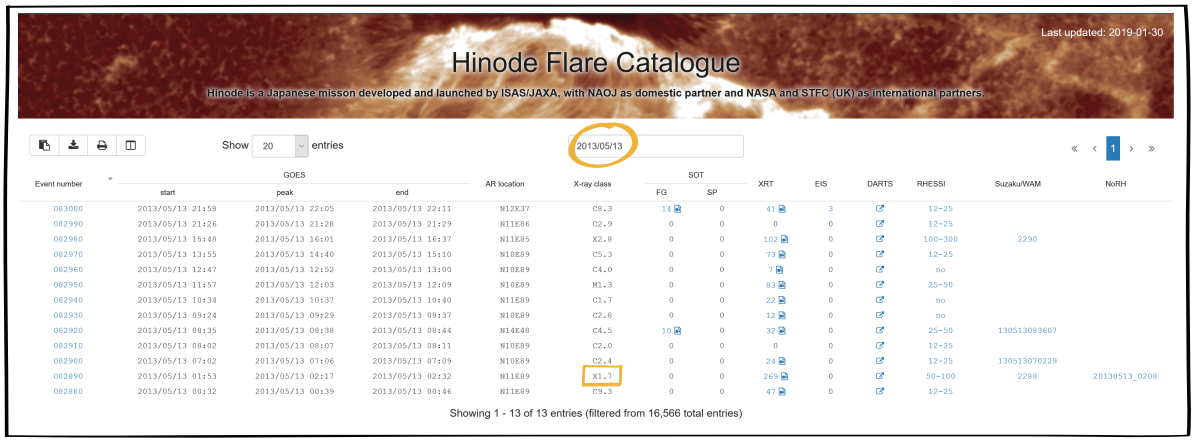
Flares

(14) Search the Hinode/EIS catalogue for strong flares on the day of or the day before your possible SEP event: **https://hinode.isee.nagoya-u.ac.jp/flare_catalogue/**

Insert the date in the search box in the following format: yyyy/mm/dd (2013/05/13).
Look for an M or X class flare in the table.

Solar Flare

A solar flare is a sudden flash of light observed near the Sun's surface. It involves a very broad spectrum of electromagnetic emissions. Flares are often, but not always, accompanied by a coronal mass ejection.



Event number	GOES start	GOES peak	GOES end	AR location	X-ray class	SOT FG	SOT SP	XRT	EIS	DARTS	RHESSI	Suzaku/WAM	NoRH
083000	2013/05/13 21:58	2013/05/13 22:05	2013/05/13 22:11	N12E37	C8.3	14	0	41	3		12-25		
082990	2013/05/13 21:26	2013/05/13 21:28	2013/05/13 21:29	N11E86	C2.9	0	0	0	0		12-25		
082980	2013/05/13 15:48	2013/05/13 16:01	2013/05/13 16:37	N11E85	X2.8	0	0	102	0		100-300	2290	
082970	2013/05/13 13:55	2013/05/13 14:40	2013/05/13 15:10	N10E89	C5.3	0	0	73	0		12-25		
082960	2013/05/13 12:47	2013/05/13 12:52	2013/05/13 13:00	N10E89	C4.0	0	0	7	0		no		
082950	2013/05/13 11:57	2013/05/13 12:03	2013/05/13 12:09	N10E89	M1.3	0	0	83	0		25-50		
082940	2013/05/13 10:34	2013/05/13 10:37	2013/05/13 10:40	N11E89	C1.7	0	0	22	0		no		
082930	2013/05/13 09:24	2013/05/13 09:29	2013/05/13 09:37	N10E89	C2.8	0	0	12	0		no		
082920	2013/05/13 08:35	2013/05/13 08:38	2013/05/13 08:44	N14E48	C4.5	10	0	32	0		25-50	130513083607	
082910	2013/05/13 08:02	2013/05/13 08:07	2013/05/13 08:11	N10E89	C2.0	0	0	0	0		12-25		
082900	2013/05/13 07:02	2013/05/13 07:06	2013/05/13 07:09	N10E89	C2.4	0	0	24	0		12-25	130513070229	
082890	2013/05/13 01:53	2013/05/13 02:17	2013/05/13 02:32	N11E89	X1.7	0	0	269	0		50-100	2288	20130513_0208
082880	2013/05/13 00:32	2013/05/13 00:39	2013/05/13 00:46	N11E89	C9.3	0	0	47	0		12-25		

Solar Flare Information

Date : ___ - ____ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ____

Start Time : ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - __

X-ray class : ___ - ____ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ____

AR Location (if available) : ___ - ___ - ___ - ___ - ___ - ___ - ___ - ___ - ___ - ___

Coronal Mass Ejections

A coronal mass ejection (CME) is the release of a huge amount of plasma and magnetic fields from the sun. CMEs often follow solar flares. This expanding ball of plasma can be observed by coronagraphs as it moves outwards into space and consists primarily of electrons, protons, and other ions. CMEs typically move at speeds between 400 - 3000 km/s. They move so fast compared to the material around them that they create shocks and it is believed that these shocks accelerate SEPs.
See what a CME looks like: **https://www.youtube.com/watch?v=uecMk8ZZ1uE**

⑮ Search the NASA CDAW CME Catalog to look for a very fast halo CME associated with the solar flare you identified above. **http://cdaw.gsfc.nasa.gov/CME_list/**

The First Appearance Time should be close to the flare time that you found in the flare catalogue, the Central PA should be HALO, and the Linear Speed should be greater than 800 km/s.
Feel free to click on the links to see videos and plots associated with the CMEs.

watch the movies!

First C2 Appearance Date	Time [UT]	Central PA [deg]	Angular Width [deg]	Linear Speed [km/s]	2nd-order Speed at final height [km/s]	2nd-order Speed at 20 Rs [km/s]	Accel [m/s^2]	Mass [gram]	Kinetic Energy [erg]	MPA [deg]	Movies, plots, & links	Remarks
2013/05/01	02:24:06	80	50	389	380	0	-6.9*1	2.4e+15*2	1.8e+30*2	92	C2 C3 195 PHTX DST Java Movie	Only C2
2013/05/01	03:12:08	Halo	360	762	572	626	-21.7	----	----	42	C2 C3 195 PHTX DST Java Movie	
2013/05/01	04:36:05	141	33	614	479	450	-14.5	5.2e+14	9.8e+29	149	C2 C3 195 PHTX DST Java Movie	
2013/05/01	07:00:05	220	59	379	419	673	13.9*1	1.6e+14	1.1e+29	224	C2 C3 195 PHTX DST Java Movie	Poor Event; Only C2

CME Information

Date : ___ - ____ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ____

Time : ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - -

Central PA : ___ - ____ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ --

Linear Speed : - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___

Are you convinced that your proton increase is associated with solar activity and is a real SEP event (motivate your answer)?

___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - .

___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ _

___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - - ___ - .

Plot the SEPs SECTION 6

On days without solar activity, the proton rate is due only to cosmic rays (CR) and can be written mathematically as: **Total Protons = CR**

For a day during an SEP event, the proton rate is due to both cosmic rays and SEPs and can be written mathematically as : **Total Protons = (CR + SEPs)**

Can you think of a way to get only the SEP signal?
Read ahead after you have thought about this for a moment.

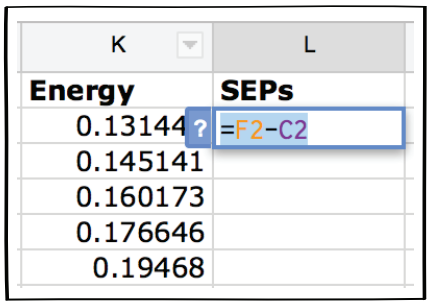
In order to get the SEP signal, we need to subtract the background cosmic ray protons:
(CR + SEPs) - CR = SEPs

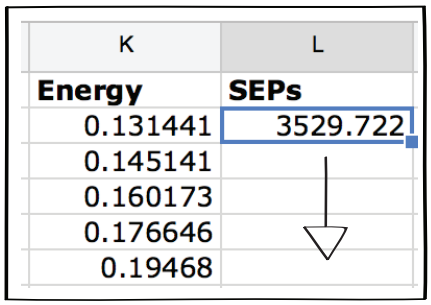
(Proton rate on day with SEPs) - (Proton rate on day before SEPs) = SEP proton rate

- Do you know how to do math with excel? -

(16) You will do this calculation in the rightmost Energy and SEPs columns of the excel sheet. Write the equation as shown below. In the example, column F is the day of an SEP event and column C is a day of only cosmic rays and no SEP signal.

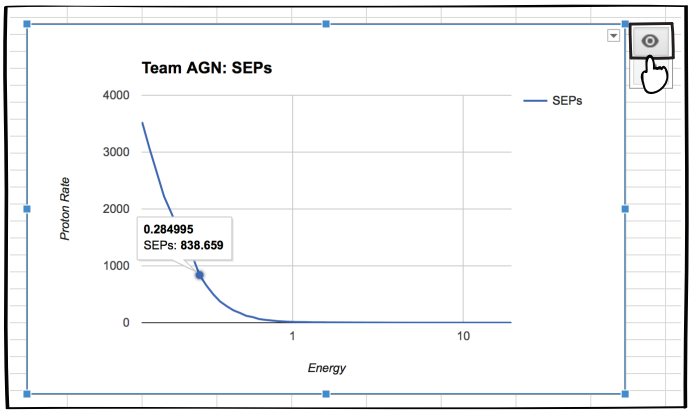
(17) After you hit enter, drag the little blue box in the corner of the cell down to the bottom of the column to fill in the SEPs values automatically.





(18) Now highlight the **red Energy and SEPs columns**, and insert a line char, setting up the formatting as before. This time, your title should read : **Team AGN: SEPs**.

(19) Your plot should look like this one. After you have inserted the graph into your spreadsheet, click on the **graph** and then click on the eye.
Put your cursor on the plot to see the values for each data point.



- Nice you did it! -

SEP Event Characteristics SECTION 7

By moving your cursor along the data points, find the last point were the SEP proton rate is greater than 10. The energy of that data point is the maximum SEP energy.
What is the maximum SEP energy that you measured?___ ___ ___ ___ ___ ___

What is the largest value of the SEP proton rate? This is the maximum SEP intensity.

Is there anything strange, unusual or confusing that you would like to note about your SEP proton rate?___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ __

You may compare with the other group's SEP plots to see if yours looks similar or different.

SEP Event Summary

Report the characteristic of your SEP event.

Date Observed by AMS-02	
Duration of SEP Event (# of Days)	
Date of Solar Flare Time of Solar Flare Solar Flare Class	
CME Linear Speed (km&s)	
SEP Maximum Energy (GeV) SEP Maximum Intensity (Proton Rate) Was there a Forbush Decrease?	

And Now Some Questions SECTION 8

Compare the event with the ones obtained by the other teams.

1. Which SEP event is associated with the strongest flare? Fastest CME?

2. Which SEP event is associated with the weakest flare? Slowest CME?

3. Which SEP event has SEPs with the highest maximum energy? Lows max energy?

4. Which SEP event is the most intense? Is the least intense?

5. Which SEP event was associated with a Forbush decrease?

6. Which SEP event lasted the longest number of days?

What did you learn after this activity?

Glossary Index in alphabetic order