Balloon Measurements of Cosmic Ray Muons in the Atmosphere

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Ballooning for muons

- The balloon approach
  - Advantages & Drawbacks
- The available measurements
  - Early (non-balloon) measurements
  - The WiZard Collaboration contribution
  - Other experiments
- Can we draw any conclusions from such data?
  - Maybe some implications, at least...
- What can a balloon do at its best??
  - Difficult to say, but we will try…

The WiZard contribution...

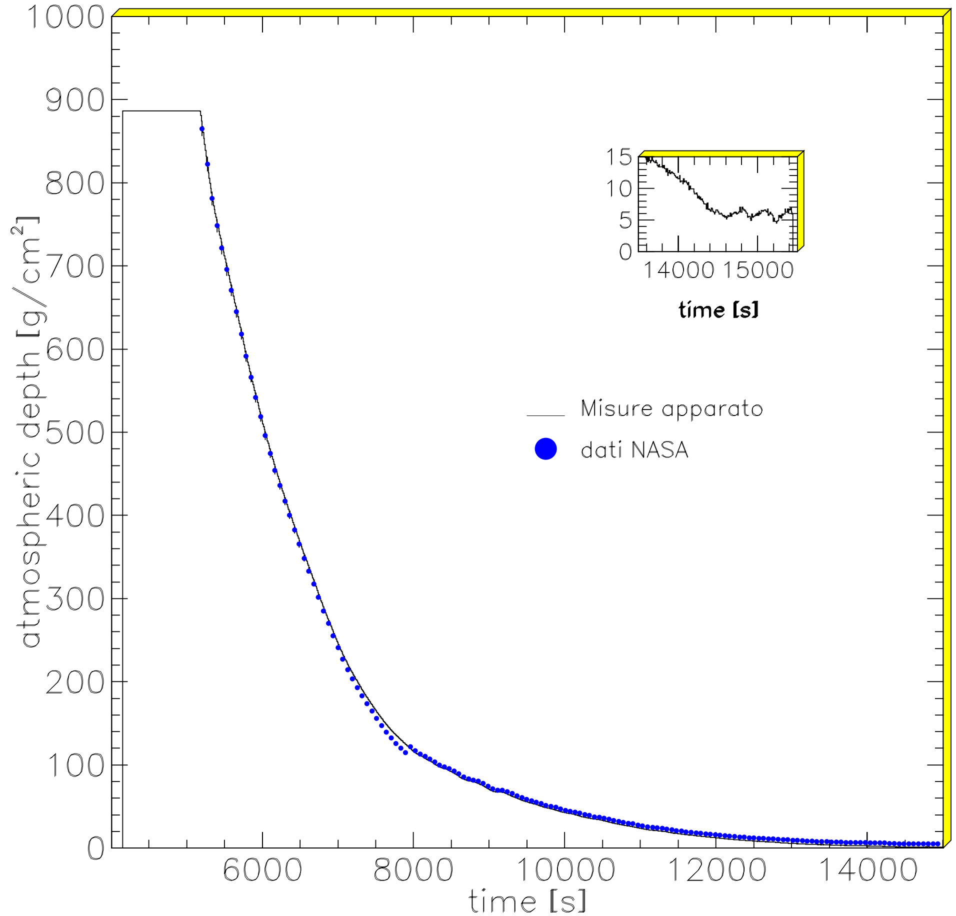
- The WiZard Collaboration has reported muon results from the balloon measurements of the Matter Antimatter Spectrometer System (MASS, 1989 and 1991) and of the Cosmic AntiParticle Ring Imaging Cherenkov Experiment (CAPRICE, 1994).
- These experiments were performed with similar (but not identical) detectors in different experimental conditions.
- Results from the latest CAPRICE flight (1998) are forthcoming.
- The first MASS results were reported at the Calgary ICRC, 1993.
- Non-WiZard balloon measurements are now available from the HEAT, IMAX and BESS experiments.

Low Cutoff		High Cutoff	
MASS	1989		
		MASS2	1991
IMAX	1992		
CAPRICE	1994		
		HEAT	1994
HEAT	1995		
		CAPRICE	1998

WiZard Exp.

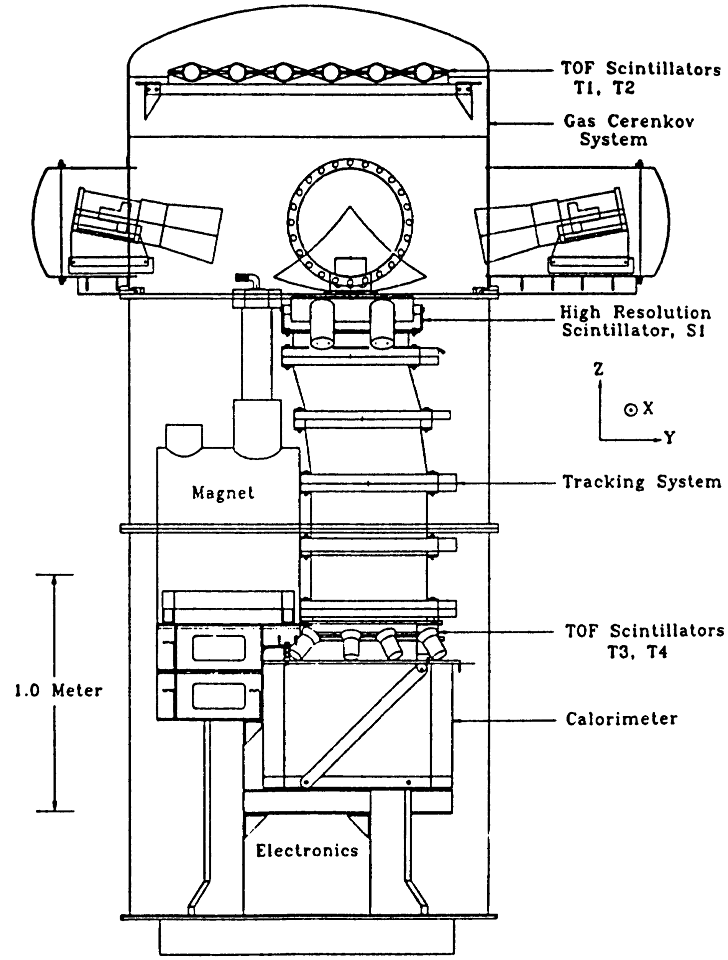
The Balloon approach

- Balloon detectors allow a large range of atmospheric depth (from ground level down to a few g/cm^2) to be explored.
- The ascent typically lasts for 2-3 hours, the payload altitude changing continuously with time.
- Main advantages: large depth and energy ranges can be explored in one experiment; muons can be measured with the same apparatus simultaneously to primaries.
- Main drawbacks: low exposure time and related difficulties (low statistics!), little or no control over the flight profile, difficulties in the interpretation of the results.



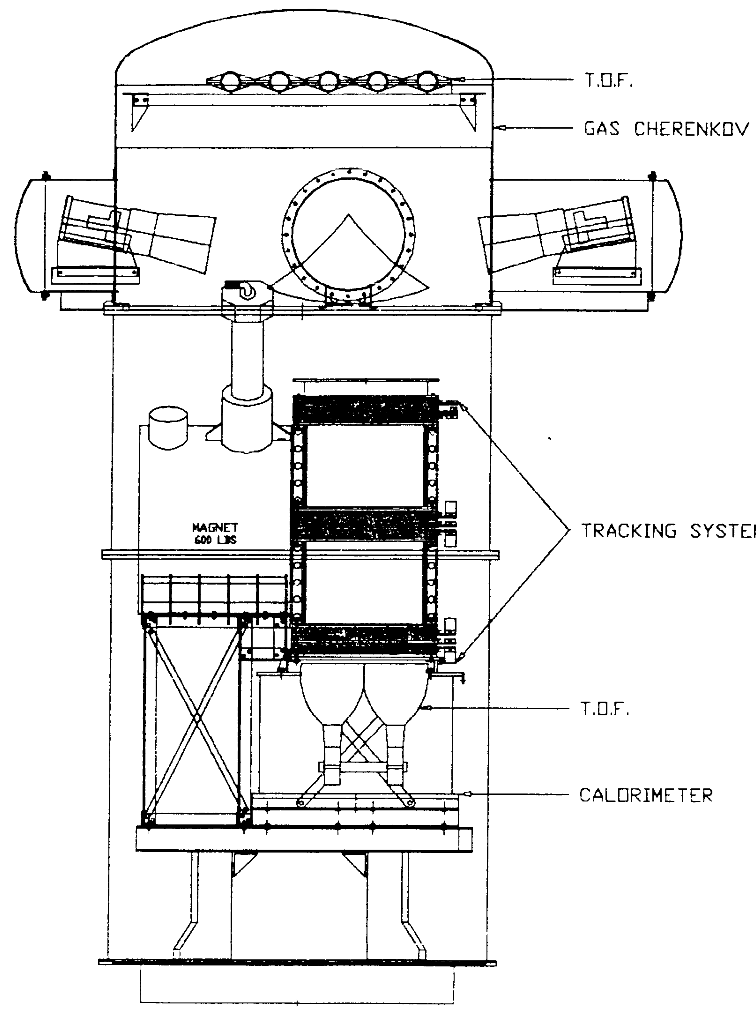
The Magnetic Spectrometer MASS

- It consisted of a superconducting magnet spectrometer with 8 MWPC's (σ_{MWPC} ~ 250 μm, 12 readouts, MDR ~ 120 GV), a time of flight scintillator device (σ ~ 300 ps), a threshold gas Cherenkov detector (γ_{th} ~ 23) and an imaging brass streamer tube calorimeter (30 sens. planes, 6.3 X_0, 0.75 λ).
- It was launched from Prince Albert, Saskatchewan (Canada) on Sept. 5, 1989 in conditions of (particularly) high solar modulation and low geomagnetic cutoff (R_c ~ 0.5 GV).
- It collected μ^- between 0.3-40 GeV/c in the depth range 5-960 g/cm^2.



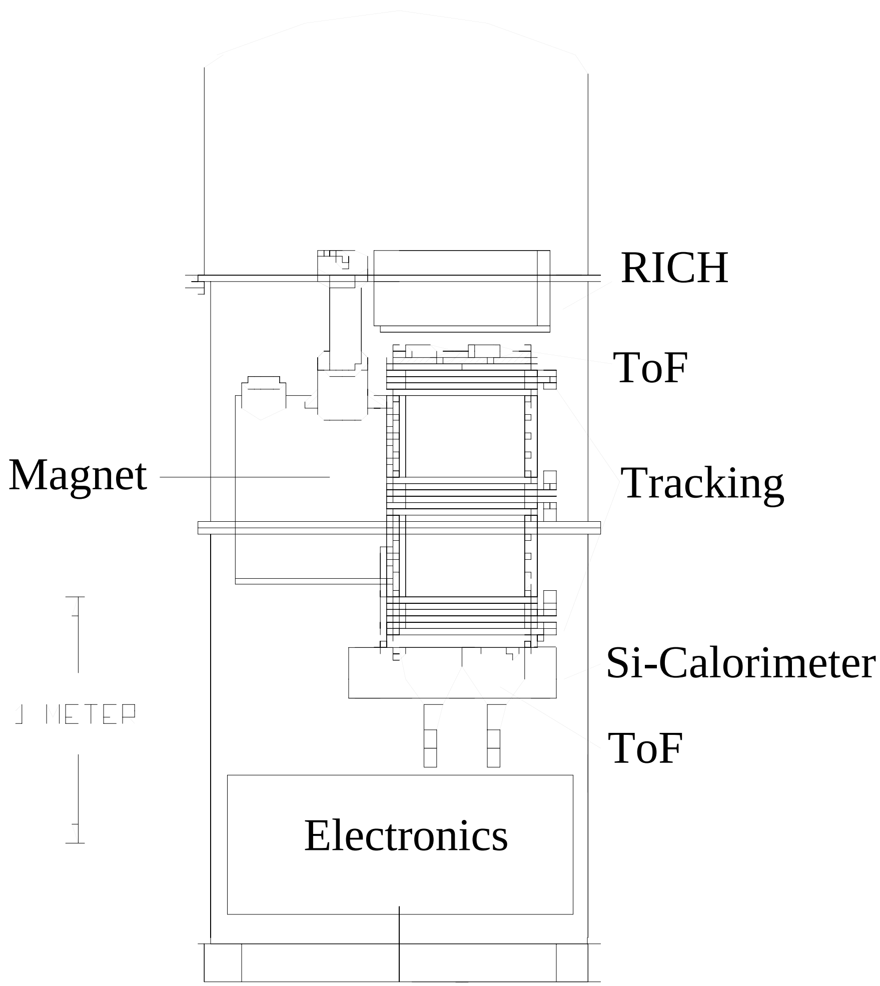
The Magnetic Spectrometer MASS2

- It consisted of a superconducting magnet spectrometer with 8 MWPC's and 2 drift chambers (σ_{MWPC} ~ 250 μm, σ_{DC} ~ 100 μm, 32 readouts, MDR ~ 210 GV), a time of flight scintillator device (σ ~ 300 ps), a threshold gas Cherenkov detector (γ_{th} ~ 25) and an imaging brass streamer tube calorimeter (7.3 X_0, 0.75 λ).
- It was launched from Ft. Sumner, NM on Sept. 23, 1991 in conditions of high solar modulation and high geomagnetic cutoff (R_c ~ 4.5 GV).
- It collected μ^- between 0.3-40 GeV/*c* and μ^+ between 0.3-1.5 GeV/*c* in the depth range 5-886 g/cm^2.



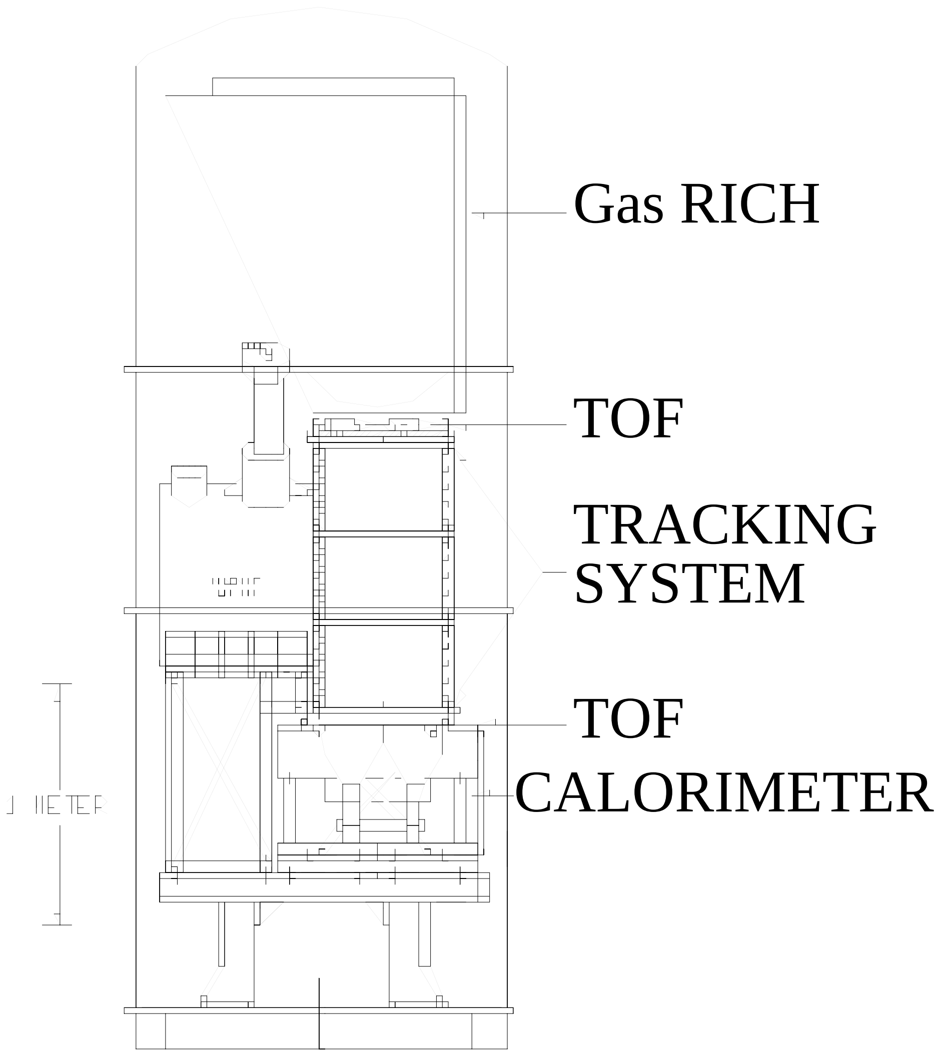
The Magnetic Spectrometer CAPRICE

- It consists of a superconducting magnet spectrometer with 8 MWPC's and 2 drift chambers (σ_{MWPC} ~ 250 μm, σ_{DC} ~ 100 μm, 32 readouts, MDR ~ 210 GV), a time of flight scintillator device (σ ~ 230 ps), a solid radiator RICH Cherenkov detector (γ_{th} ~ 1.5) and an imaging Si-W calorimeter (16 sens. planes, 7 X_0, 0.25 λ).
- It was launched from Lynn Lake, Manitoba (Canada) on August 8, 1994 in conditions of low solar modulation and low geomagnetic cutoff (R_c ~ 0.5 GV).
- It collected μ^- between 0.3-40 GeV/c and μ^+ between 0.3-2 GeV/c in the depth range 3.9-1000 g/cm^2.

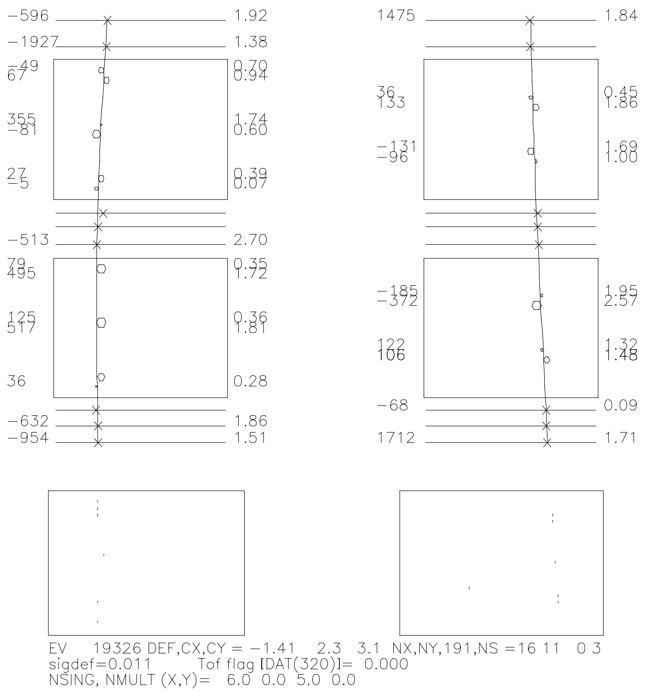


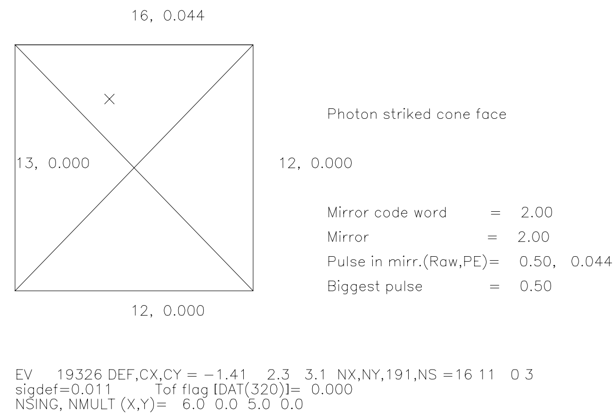
The Magnetic Spectrometer CAPRICE98

- It consists of a superconducting magnet spectrometer with 3 drift chambers (σ_{DC} ~ 100 μm, 30 readouts, MDR > 300 GV), a time of flight scintillator device (σ ~ 230 ps), a gas RICH Cherenkov detector (γ_{th} ~ 20) and an imaging Si-W calorimeter (16 sens. planes, 7 X_0, 0.25 λ).
- It was launched from Ft. Sumner, NM on May 28, 1998 in conditions of high solar modulation and high geomagnetic cutoff (R_c ~ 4.5 GV).
- It collected μ^- and μ^+ during the ascent in the depth range 5-886 g/cm^2.
- It can perform a p/μ^+ discrimination up to 20 GeV/c, and a pion rejection below 3 GeV/c.



Muon Selection in MASS2

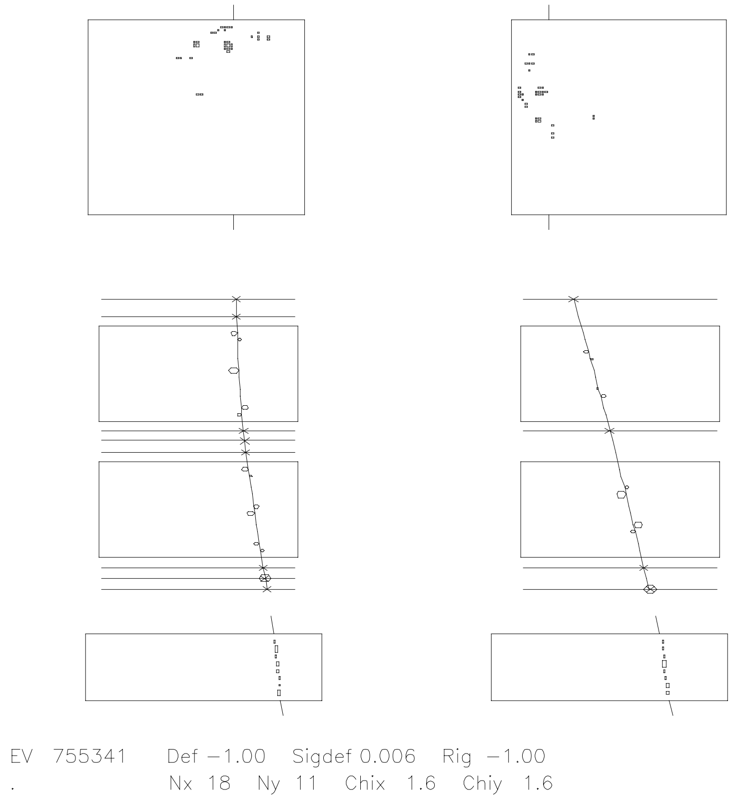




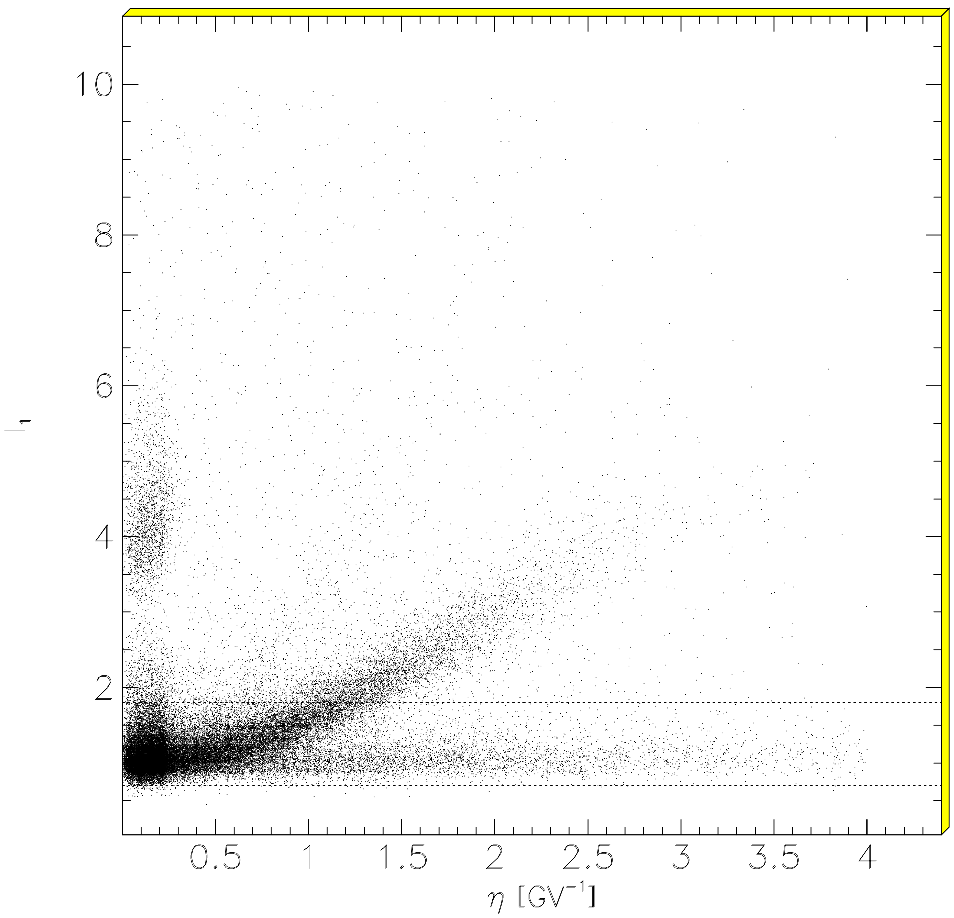
- Muons are selected by looking for single particles which do not interact in the calorimeter.
- The track reconstruction in the spectrometer allows the deflection, hence momentum and sign of charge of the particles, to be determined.
- The scintillators provide a measurement of the pulse height and time of flight.
- The Cherenkov detector allows contaminating low-energy electrons/positrons and high-energy protons to be removed.

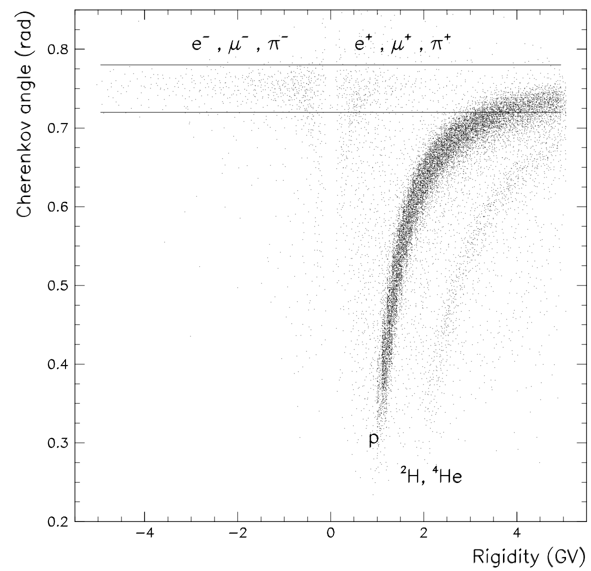
Muon Selection in CAPRICE

- Muons are selected by looking for single particles which do not interact in the calorimeter.
- The track reconstruction in the spectrometer allows the deflection, hence momentum and sign of charge, to be determined.
- The scintillators provide a measurement of the pulse height and time of flight.
- The RICH detector allows a clear muon-proton discrimination below 2 GeV/c.



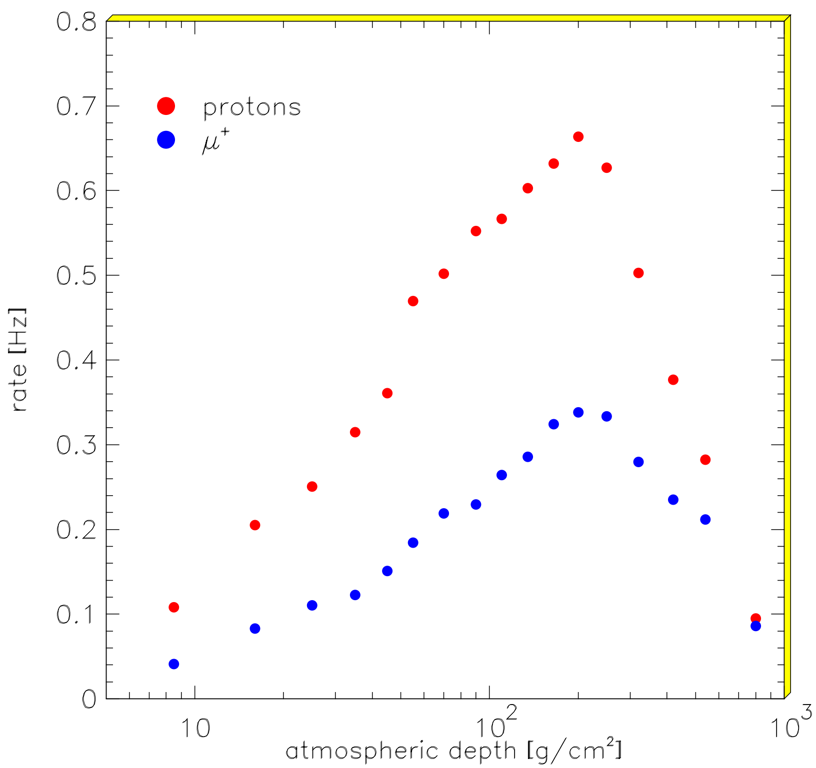
Geomagnetic Effects (& the difficult proton rejection…)

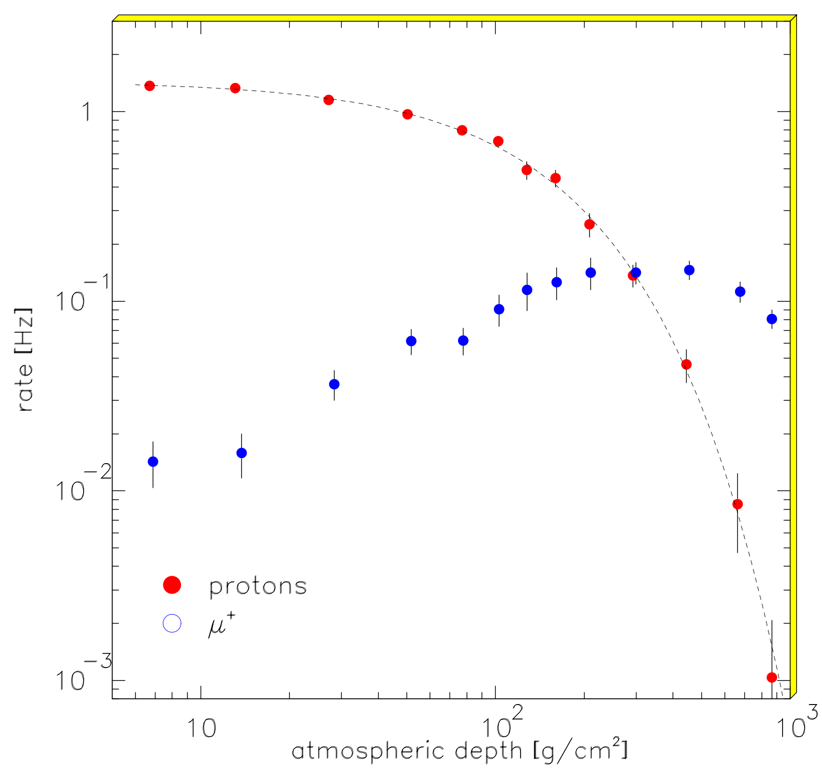




- Low-energy primaries are geomagnetically rejected during the experiment MASS2 (left).
- This allows positive muons to be selected below 1.5 GeV/*c*.
- The CAPRICE- RICH allows a good μ^+/p discrimination at low-energy despite the less favorable experimental conditions (above).

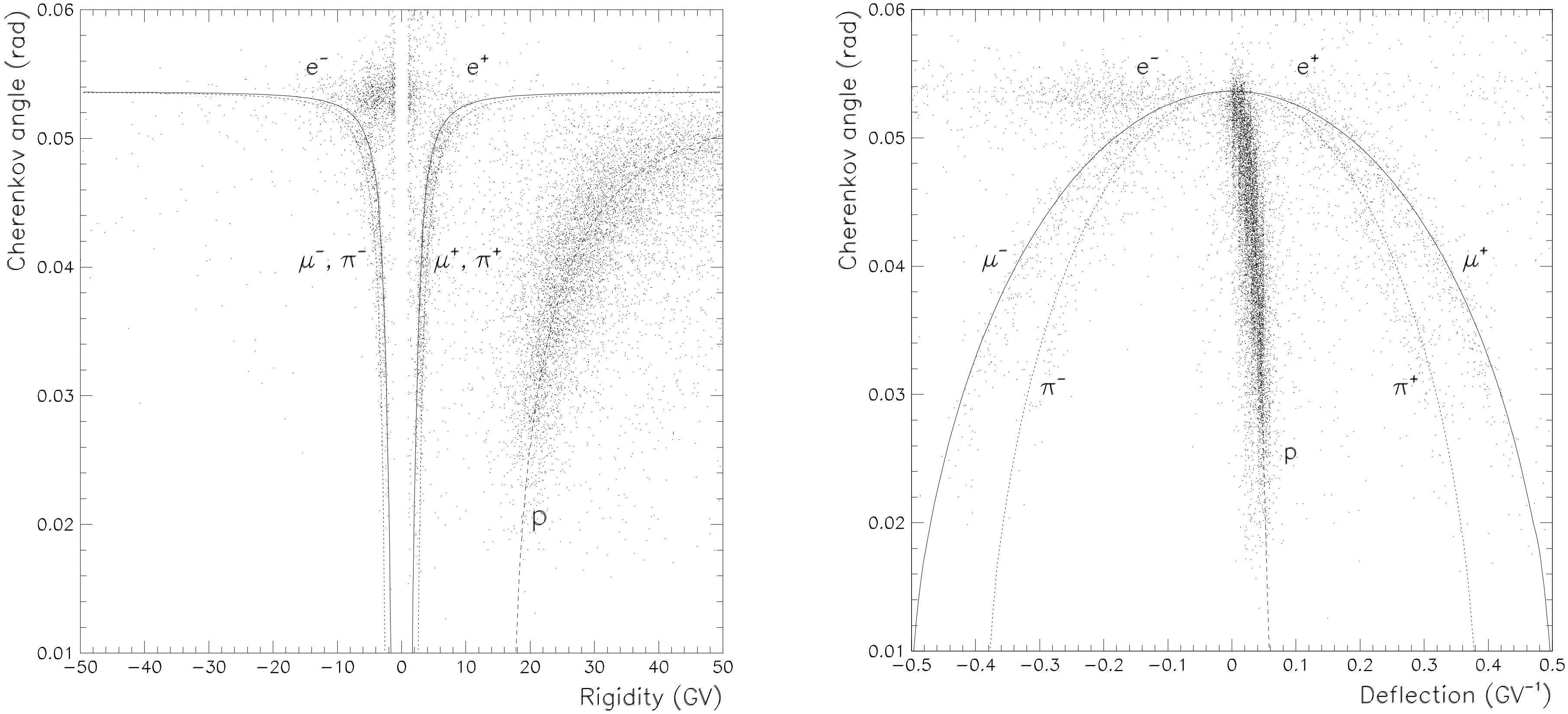
Proton Rejection in MASS2





- Protons are discriminated from positive muons by means of the time of flight measurement at low energy (0.3-1.5 GeV/*c*, left) and by a Cherenkov selection at higher energy (5-15 GeV/*c*, right).
- The dependence on atmospheric depth of low-energy protons is a clear signature of their secondary nature.

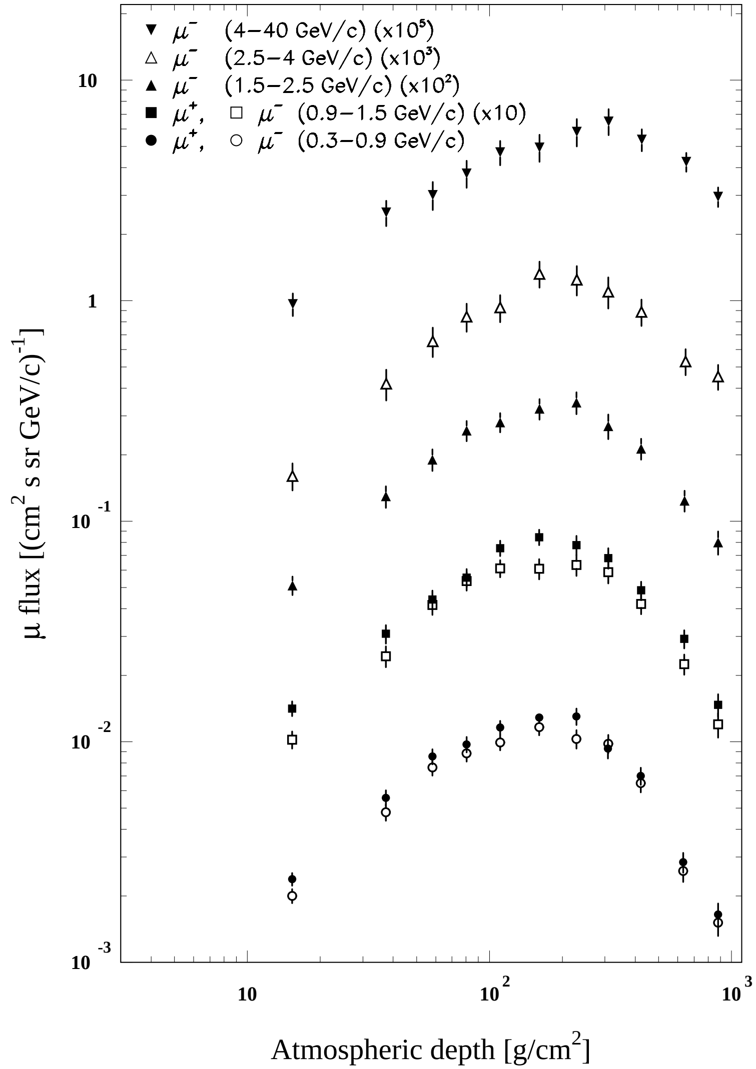
The Promises of CAPRICE98



The deployment of a gas RICH in CAPRICE98 allows both to discriminate protons from positive muons, in a large range of rigidity (left) and to reject pions from muon measurements at low energy (right).

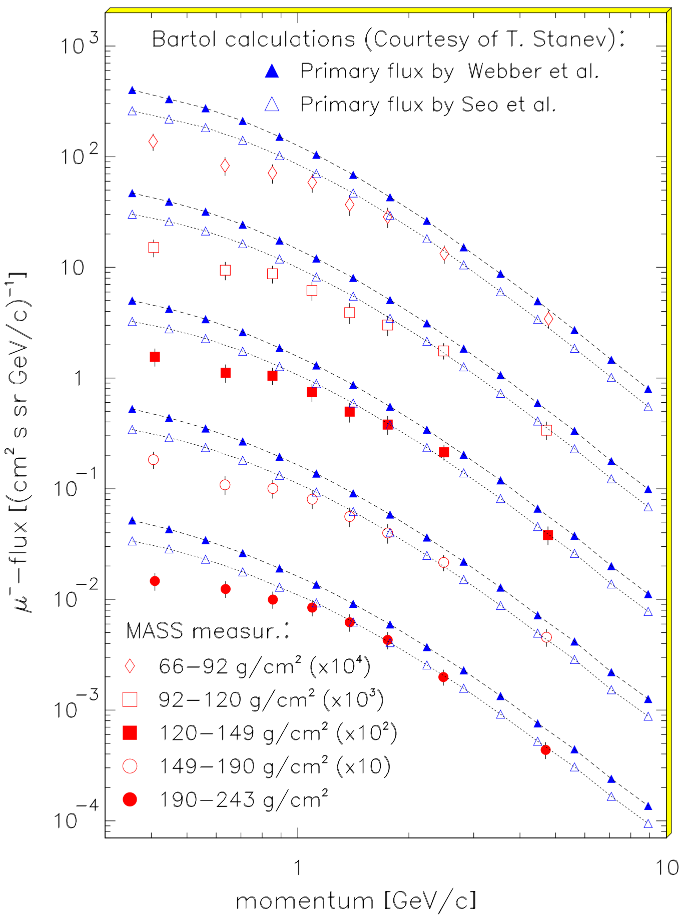
Balloon Measurements of Muons in the Atmosphere

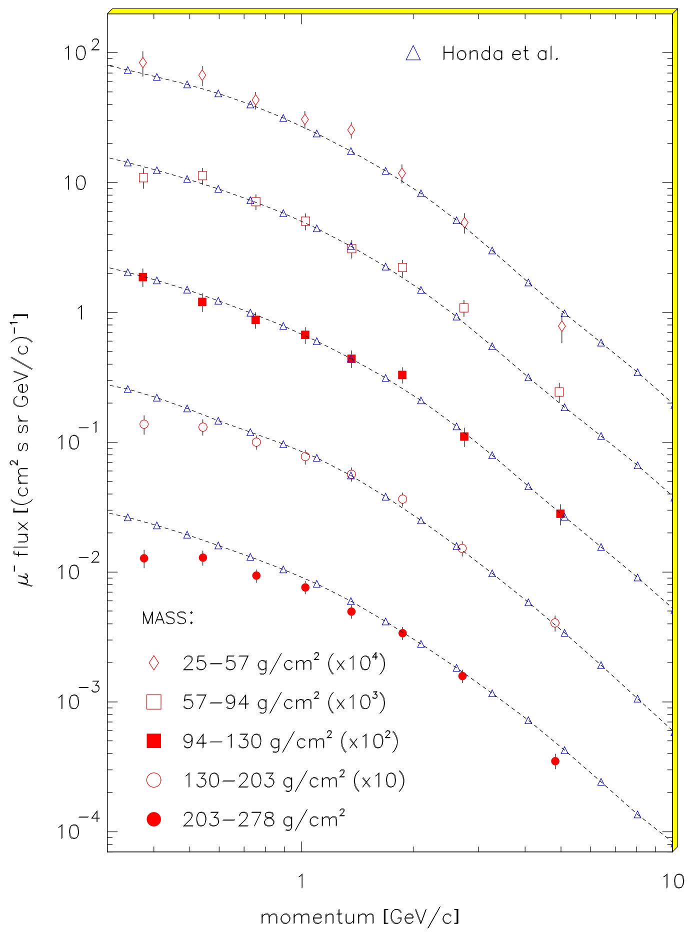
	μ^-	μ^+
MASS	2,893 (0.3-40 GeV/*c*)	
MASS2	4,471 (0.3-40 GeV/*c*)	2,856 (0.3-1.5 GeV/*c*)
CAPRICE	4,627 (0.3-40 GeV/*c*)	1,878 (0.3-2 GeV/*c*)
HEAT	10,665 (0.3-50 GeV/*c*)	4,762 (0.3-0.9 GeV/*c*)
IMAX	prel. (0.42-0.47 GeV/*c*)	prel. (0.42-0.47 GeV/*c*)



MASS2 results

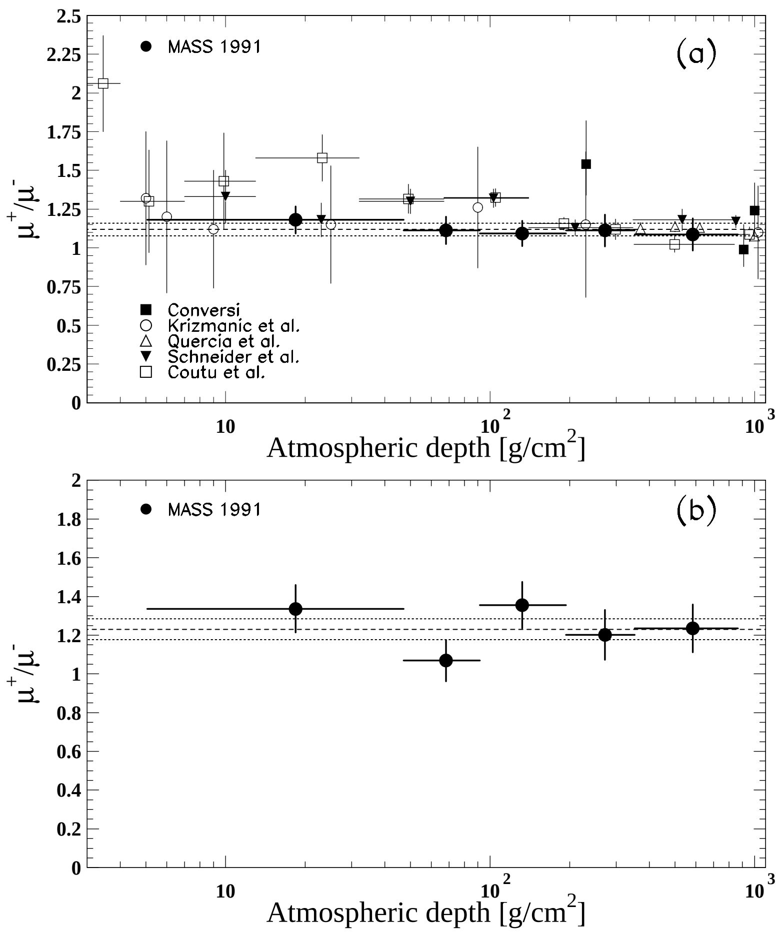
Results I: Muon Spectra in the Atmosphere

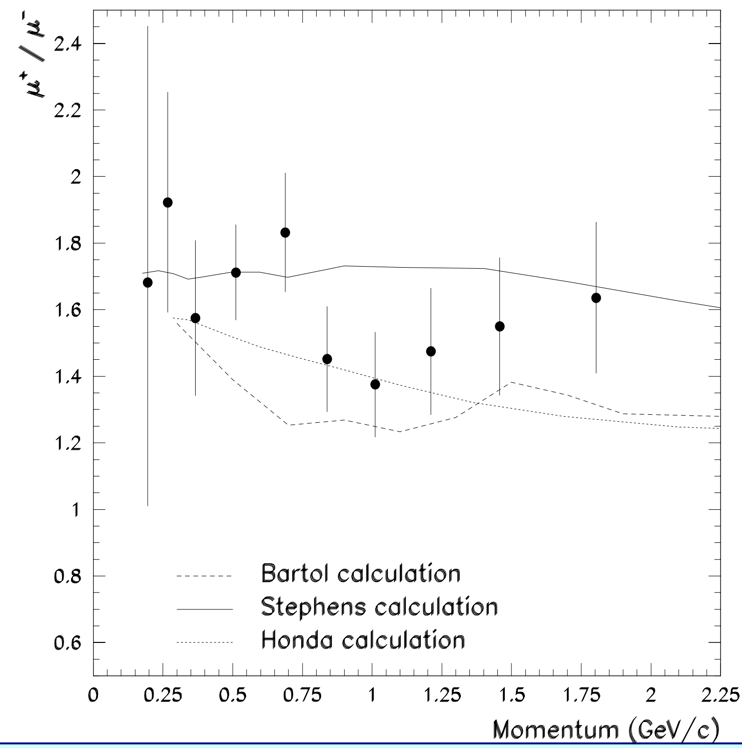




The comparison of measurements to calculations show depth- and energy-dependent discrepancies.
The reason for such discrepancies has yet to be fully understood.

Results II: Muon Charge Ratio



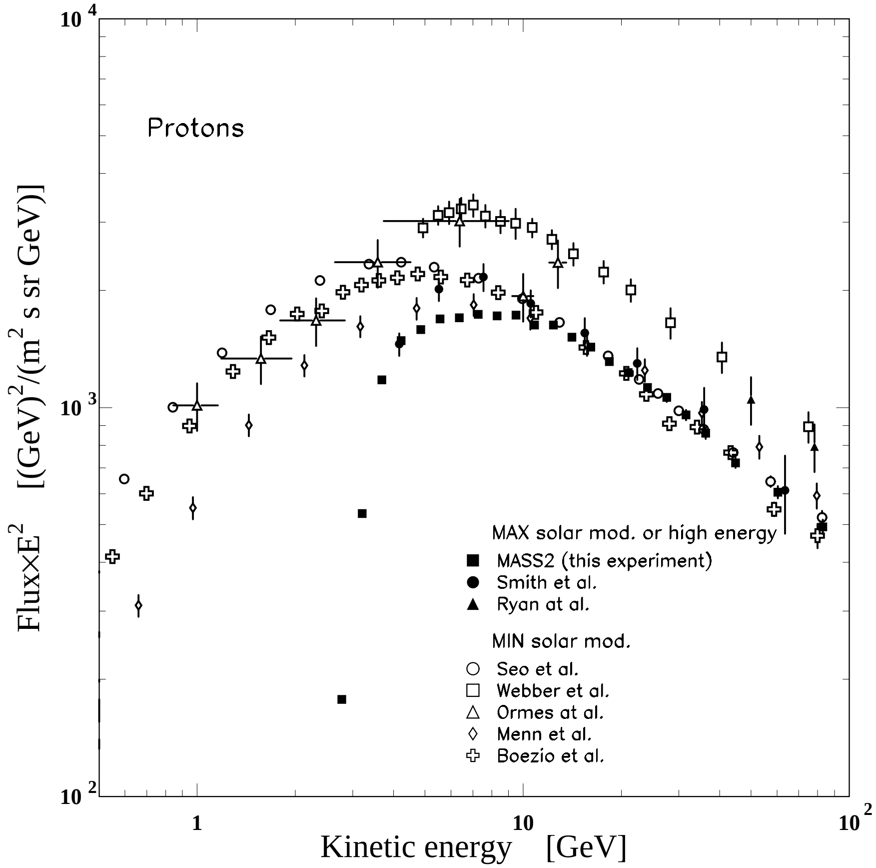


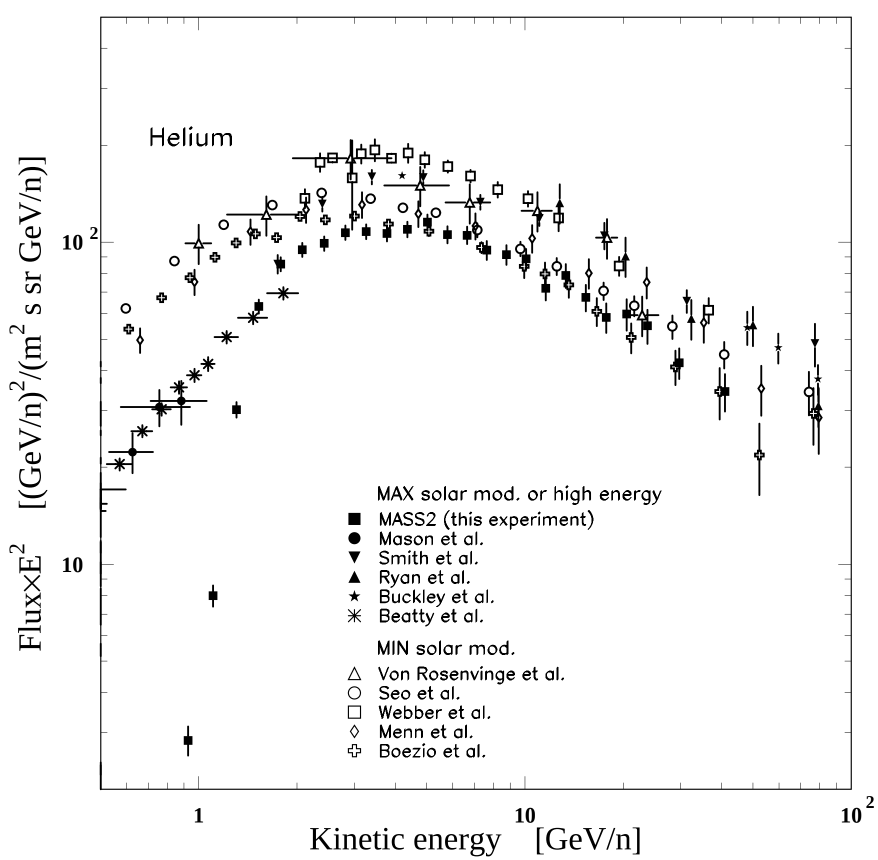
The comparison of measurements taken in different experimental conditions allows the effects due to the geomagnetic suppression to be observed.

Left: MASS2, (a) 0.3-0.9 GeV/*c*; (b) 0.9-1.5 GeV/*c*

Above: CAPRICE, 3.9 g/cm^2

Results III: primaries with MASS2 and CAPRICE

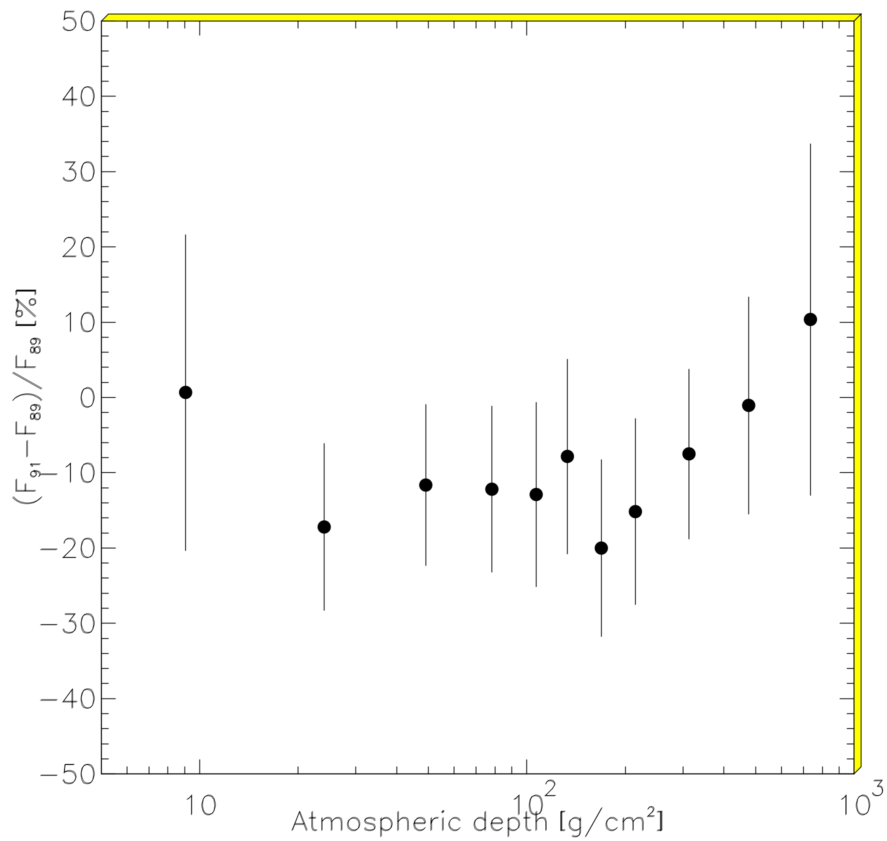




Simultaneous measurements of μ's and primaries can provide valuable constraints to the atmospheric shower calculations. The normalization of the primary flux is still among the main sources of uncertainty for such calculations.

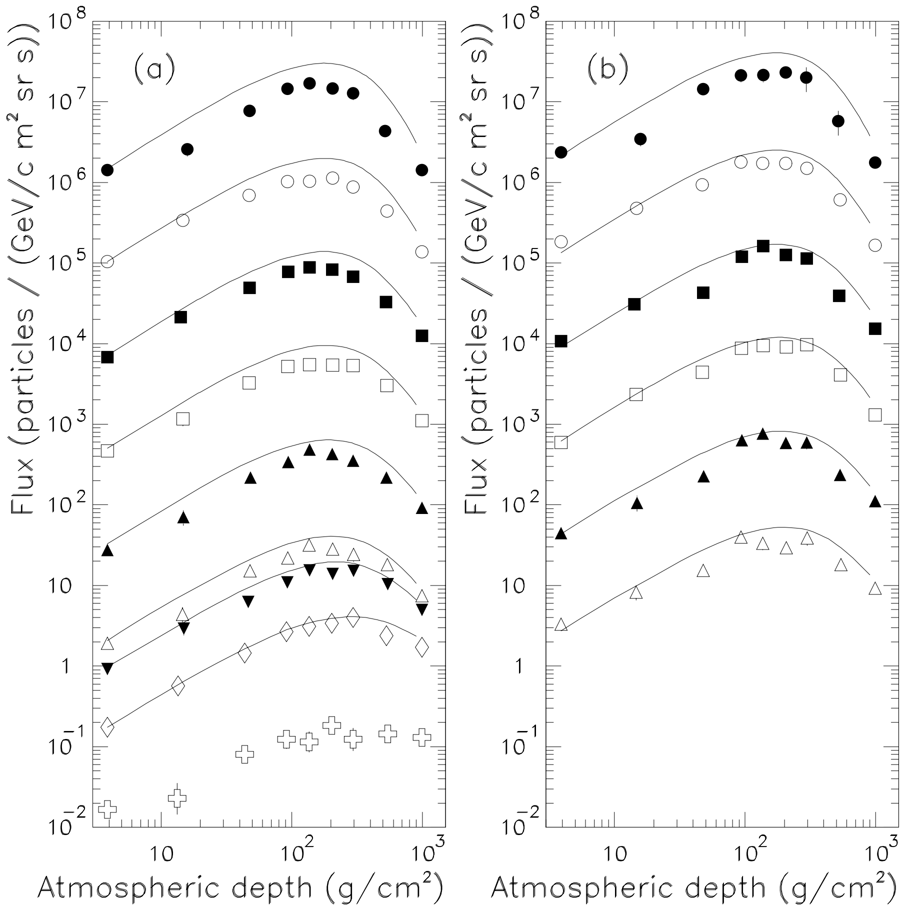
Geomagnetic effects on low-energy muons

- A comparison between the measurements of MASS e MASS2 allows to search for geomagnetic effects at low energy (below 1 GeV/*c*, right) and to check for the overall normalization accuracy of the two sets of results.
- Comparisons to the results from the other experiments is less straightforward due to the signicant differences in the experimental conditions.



Comparisons to Theory: Implications of CAPRICE

- CAPRICE has measured a significant deficit of muons with respect to calculations (solid lines, Bartol calculations).
- The discrepancies with theory are more apparent at low energy.
- More detailed comparisons need to be performed.

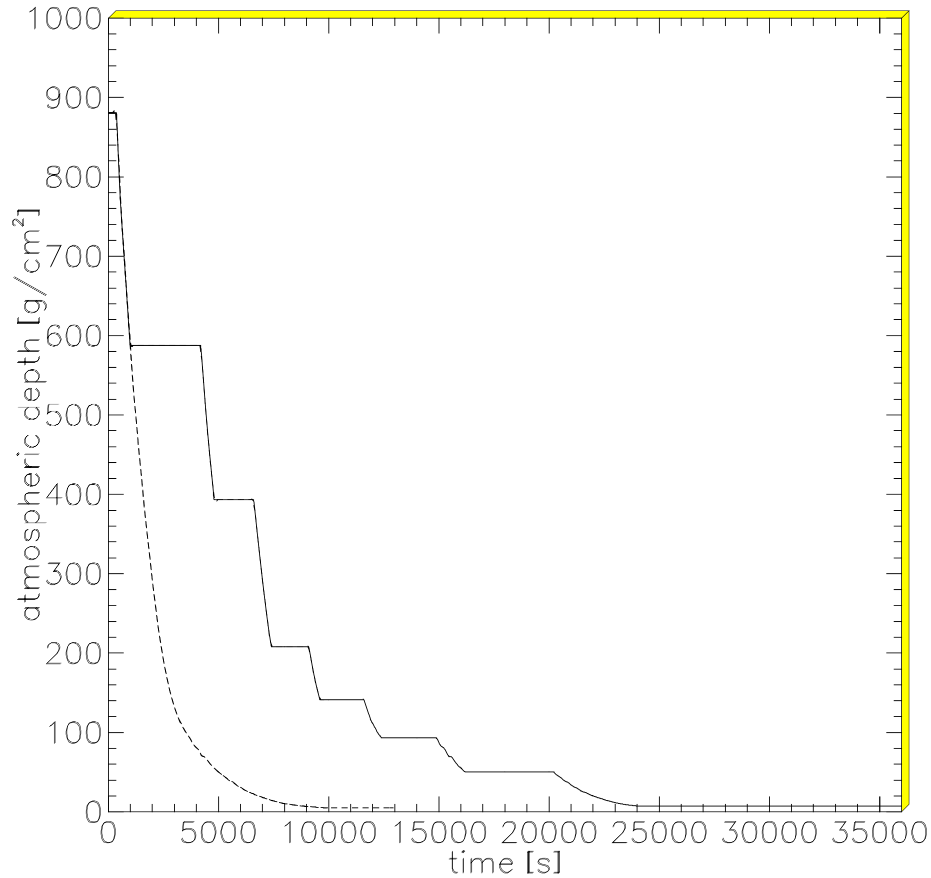


(a) μ^-
(b) μ^+

(some of the distributions have been scaled)

Yet to come...

- Measurements from several balloon experiments are now available.
- The CAPRICE98 measurements are forthcoming.
- The comparisons to theory have still to be investigated in details.
- A dedicated balloon flight (CAPRICE2000??) is possible.



Solid line, proposed profile.

Dashed line, current profile.