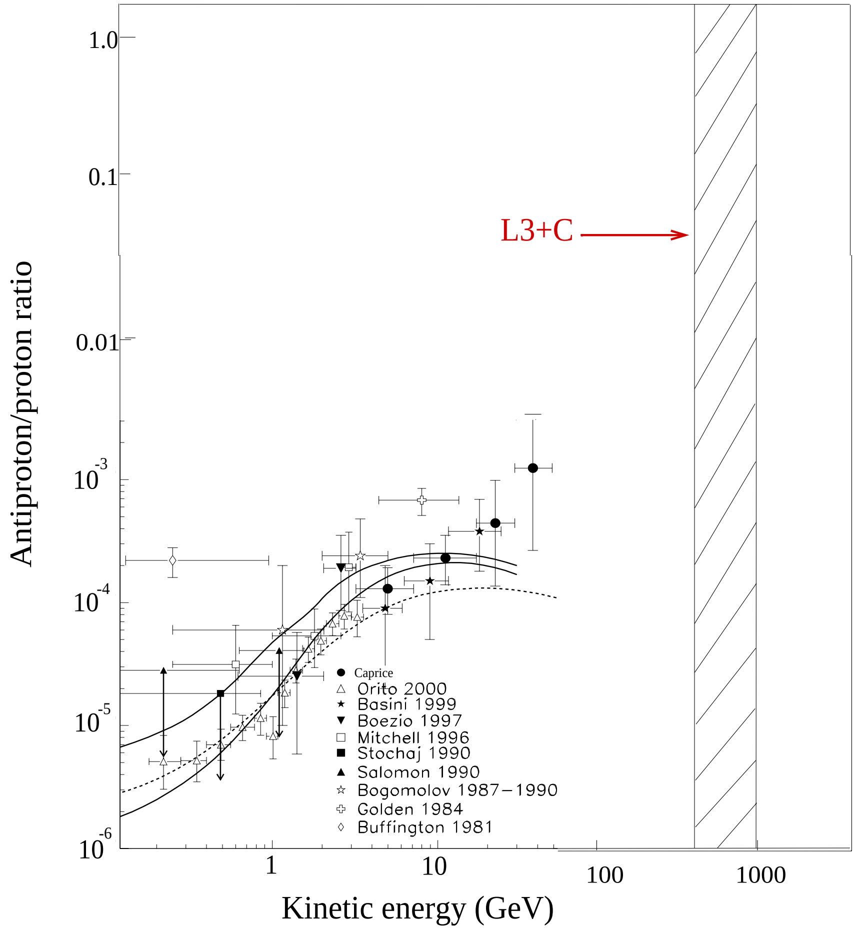
Measurement of the $\overline{p}/p$ ratio using the Moon shadow with the L3 detector

Jean-François PARRIAUD
on behalf of the L3 collaboration

- L3+Cosmics: experimental setup and topics
- Principle of the Moon shadow technique
- Observation of the Moon shadow in L3+Cosmics
- $\overline{p}/p$ ratio: measurement and limits

- Conclusion



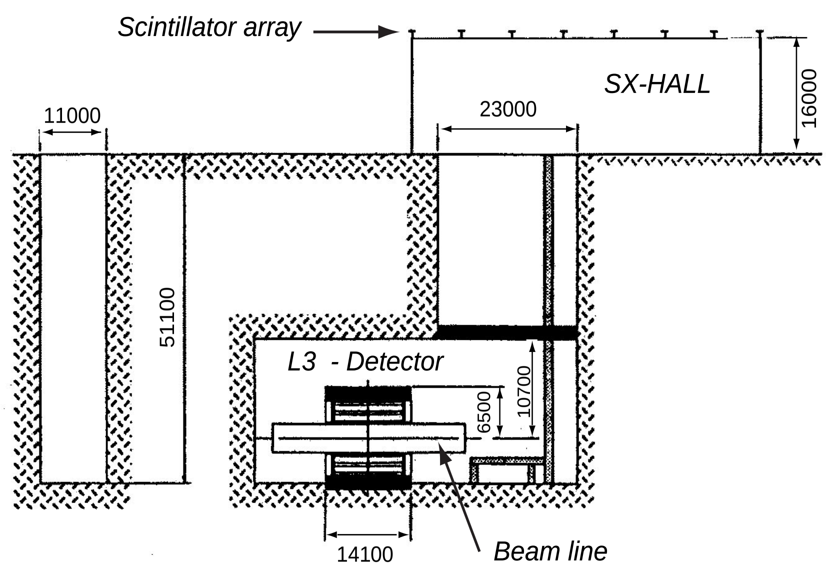
L3+Cosmics: experimental setup

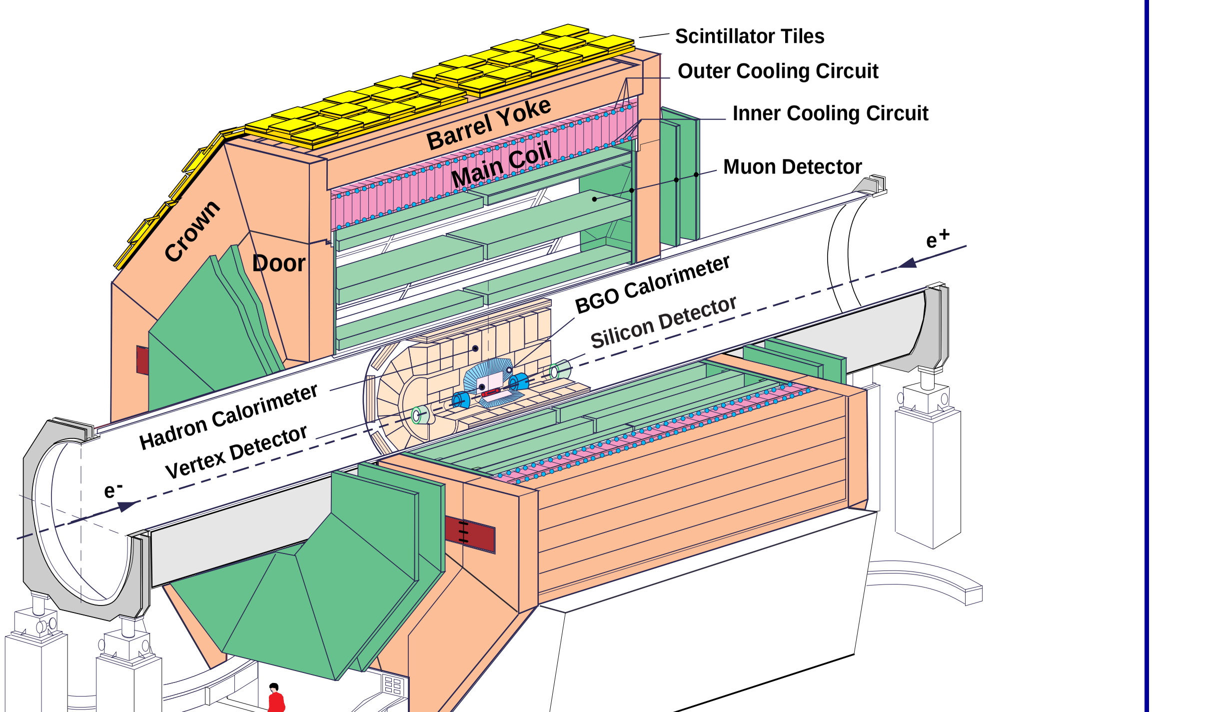
L3:
- ★ high precision muon chambers
- ★ solenoid 14x10x10 m^3: 0.5 T
- ★ 30 m of molasse $\rightarrow$ 15 GeV/c threshold

+Cosmics:
- ★ scintillators : 200m^2
- ★ independent DAQ
- ★ air shower array 30x54 m^2

$\Longrightarrow$ precise independent measurement at Z-peak:

- ✦ muon detection efficiency
- ✦ muon momentum: 4.6% at 45 GeV/c





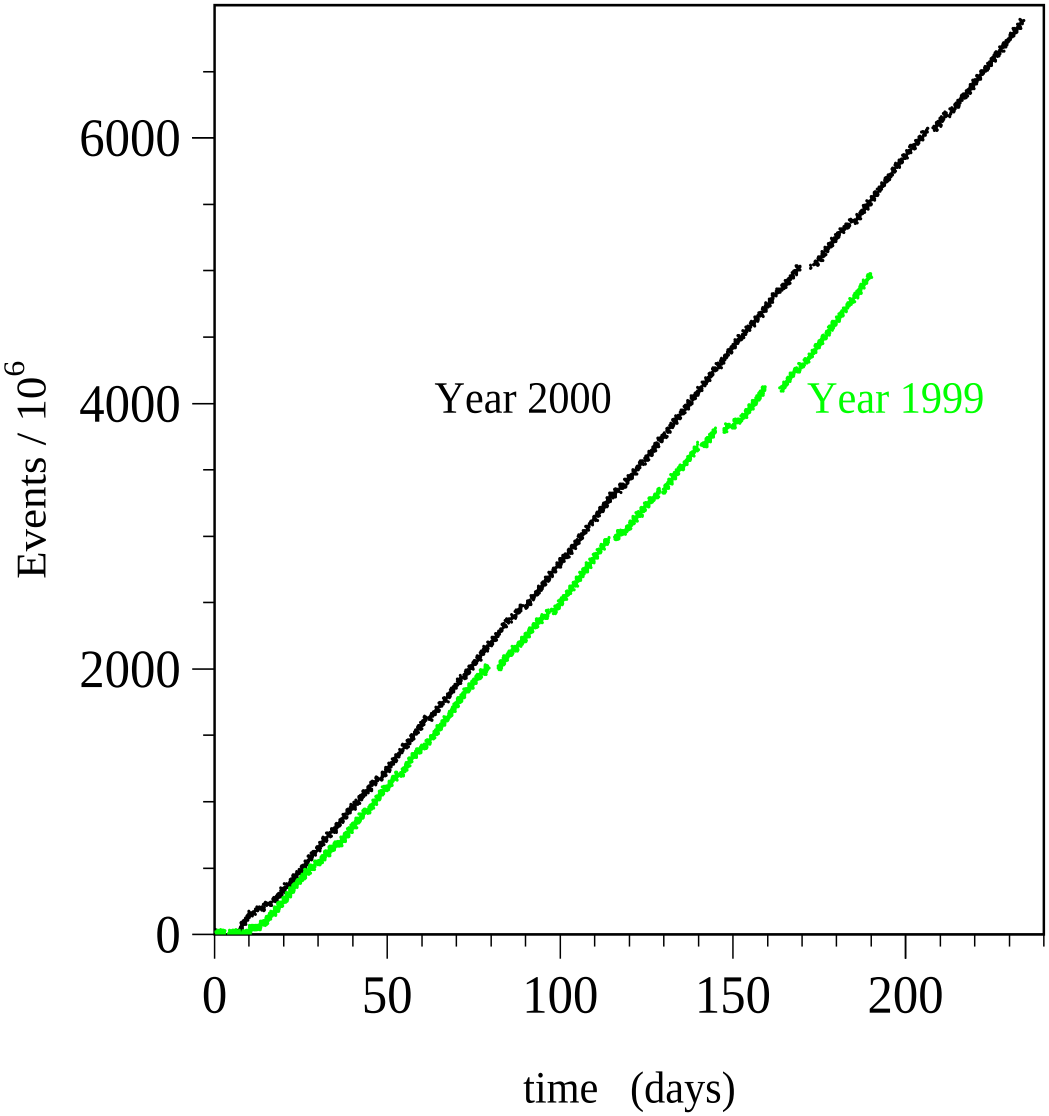
L3+Cosmics: topics

2 years running: 1999-2000

Statistics: $12 \text{x} 10^9$ muon events

Topics:

- ✦ Muon momentum spectrum in the 20-2000 GeV/c range at the % level
- ✦ Primary composition around the "knee"
- ✦ Gamma-Ray Bursts, point sources
- ✦ Moon shadow
- ✦ ...



Moon shadow

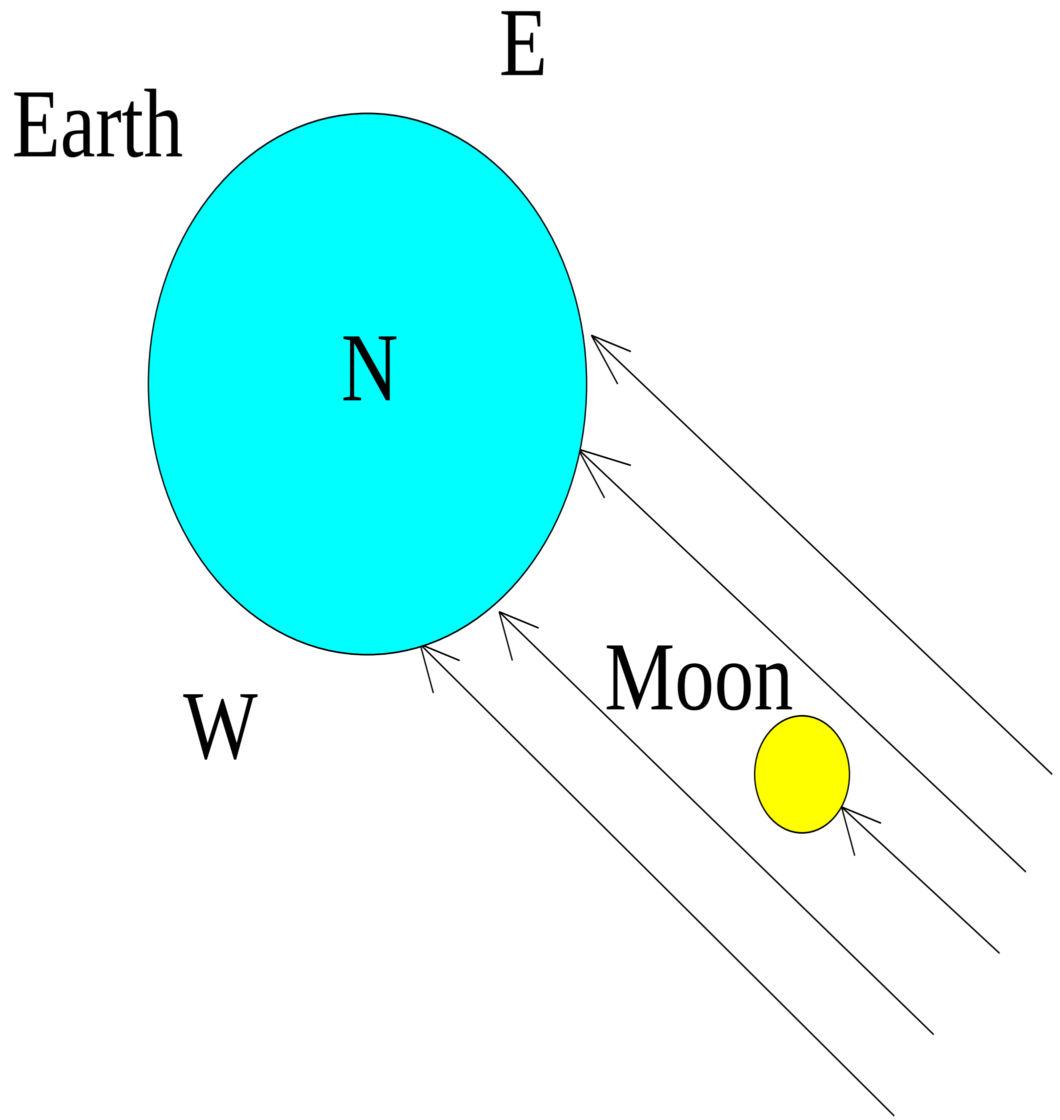
Cosmic rays are blocked by the Moon. (Clark 1957)

$\Longrightarrow$ Deficit of cosmic rays in the direction of the Moon.

☛ Size of the deficit → angular resolution of the experiment.

☛ Position of the deficit → pointing error.

Observed in the 90's (SOUDAN, MACRO, CASA . . .)



Moon shadow

Geomagnetic field: positively charged particles deflected to the East

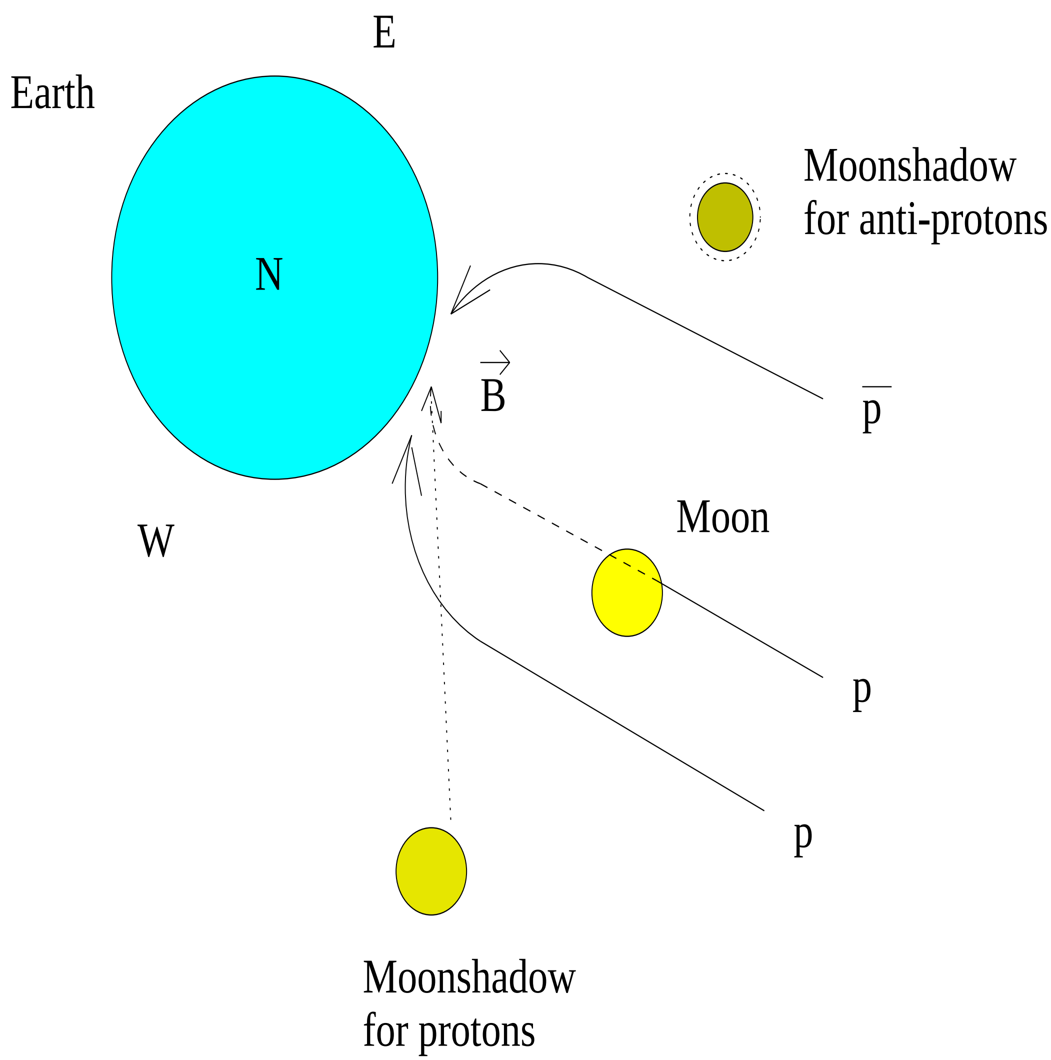
$\Longrightarrow$ Deficit appears shifted to the West.

$\Longrightarrow$ If present, antimatter in cosmic rays will induce a deficit on the opposite side.

☛ Earth-Moon = ion spectrometer (Urban et al., ARTEMIS experiment)

Deflection $\simeq \dfrac{1^\circ}{E(TeV/c)}$

GENEVA $(6.02^\circ N, 46.25^\circ E)$



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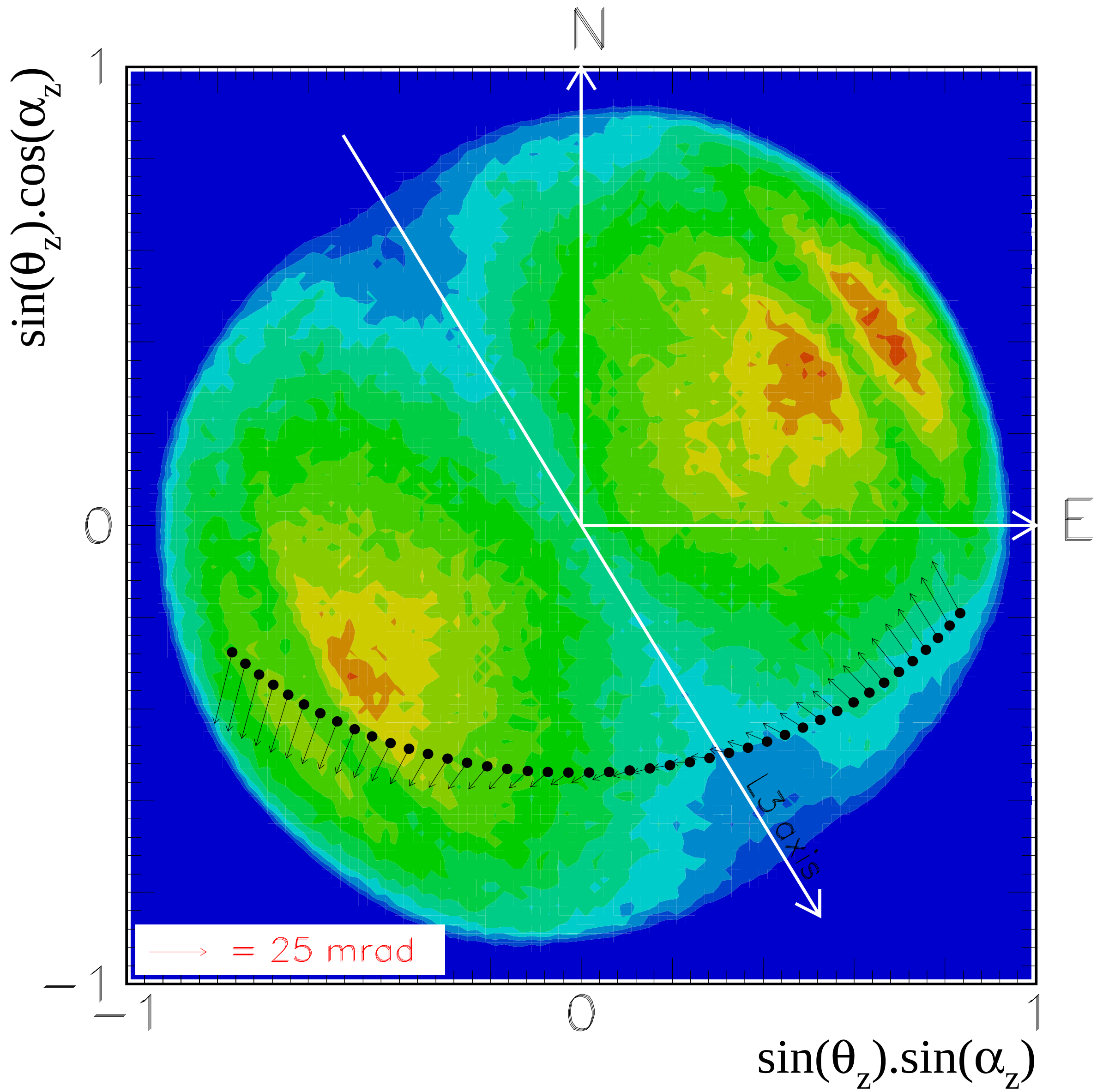
Moon shadow

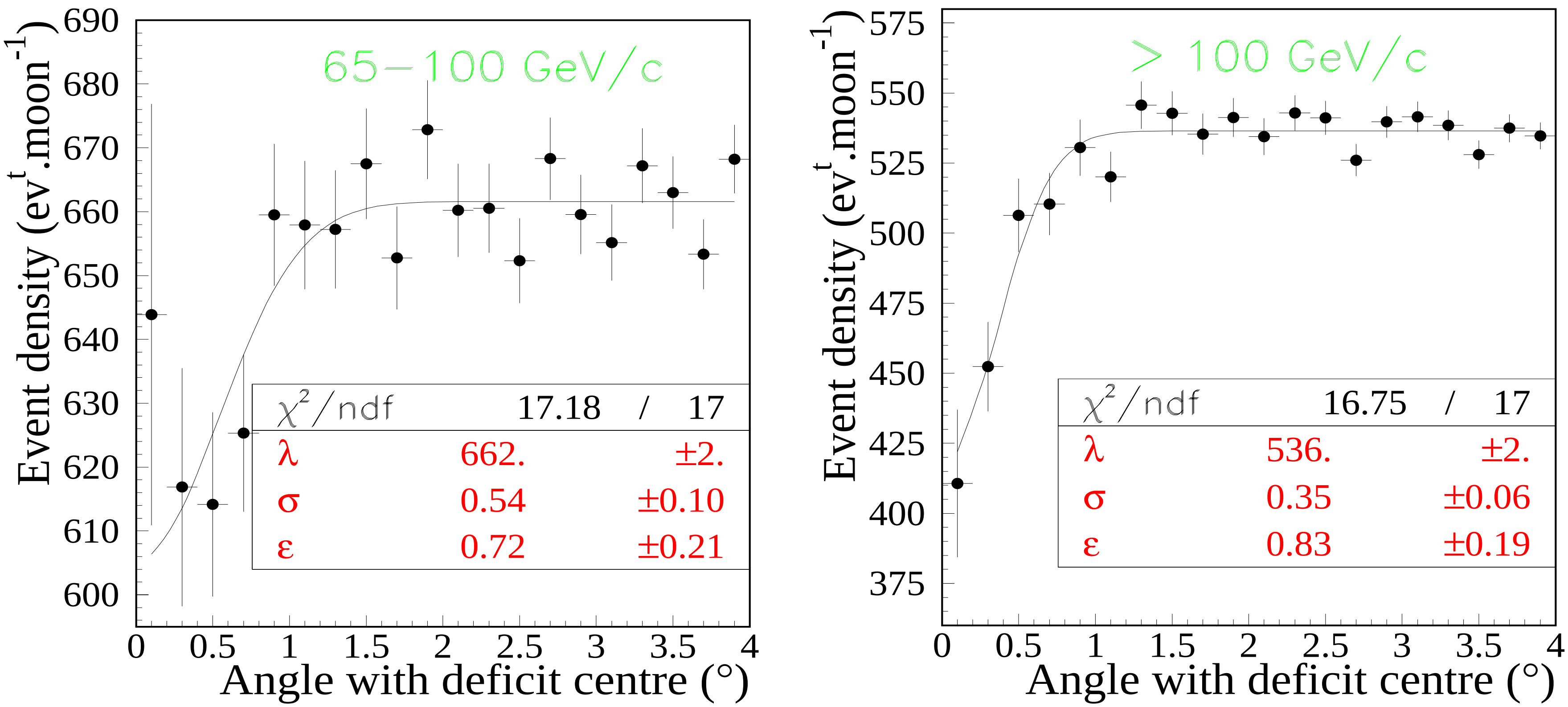
Sky seen by L3+C:
1 pixel = 1 direction

Moon trajectory:
Deflection = f(Moon location)



Observation of the Moon shadow in L3+Cosmics

$$f(\theta) = \lambda \cdot \left(1 - \epsilon \cdot \frac{R^2_{Moon}}{2\cdot\sigma^2} \cdot e^{-\frac{\theta^2}{2\cdot\sigma^2}}\right)$$



Experimental angular resolution:

- ✦ Angle between muon and primary particle
- ✦ Multiple scattering in molasse
- ✦ Detector angular resolution

\+ Moon shadow elongation by geomagnetic field

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Determination of the pointing error

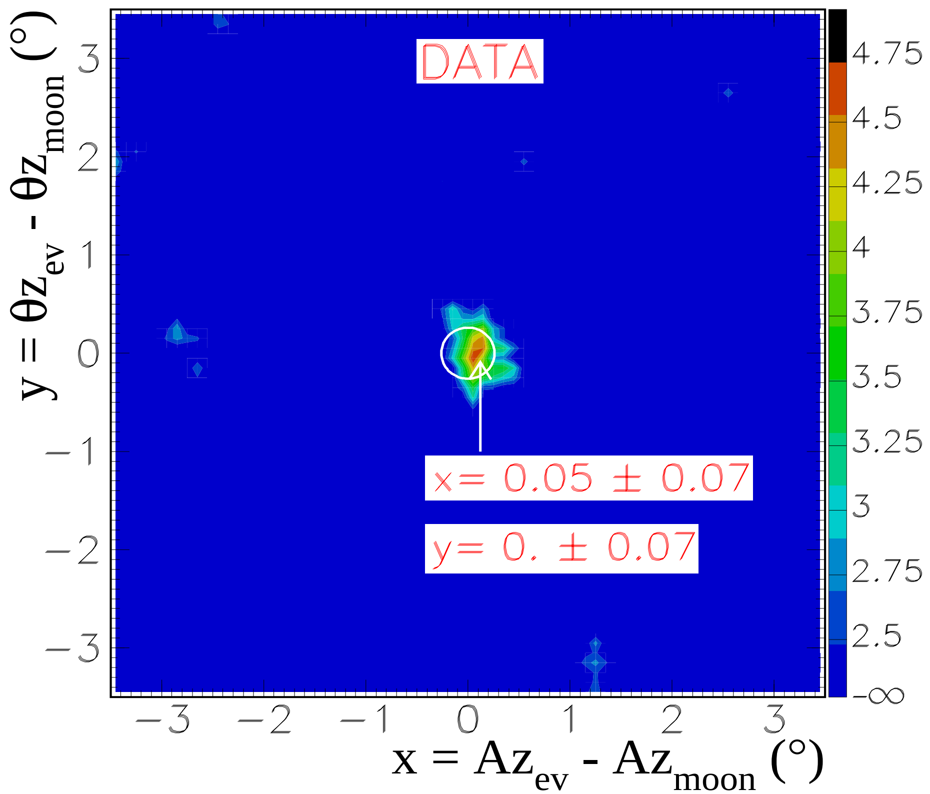
$|p_\mu| > 100$ GeV/c, use of the local coordinates system Zenith vs Azimuth

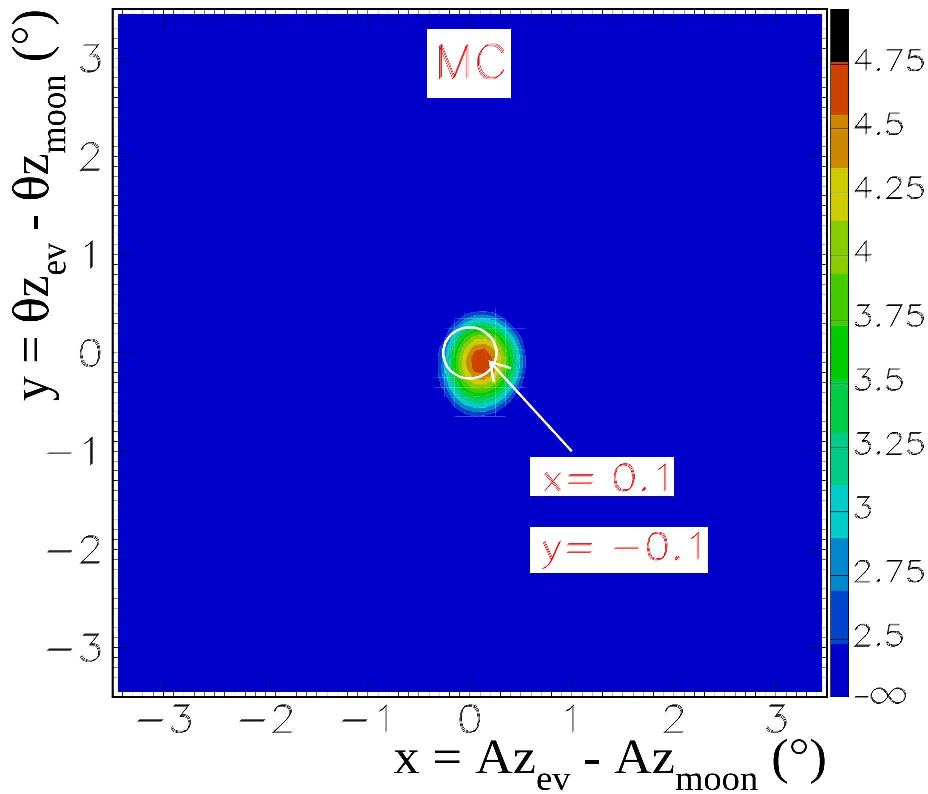
Background: Moon's path in the sky, delayed in time.

Substracted to source map $\rightarrow$ Moon effect.

Smoothing: uniform distribution.

Result in standard deviations from normal distribution.





Comparison Data-MC: pointing error $\simeq 0.1°$.

Observation of the geomagnetic field effect

Deflection $= \Delta\theta \cdot \overrightarrow{u_{defl}}$

$\Delta\theta = f(Az, \theta_z, p_{proton}(unknown))$

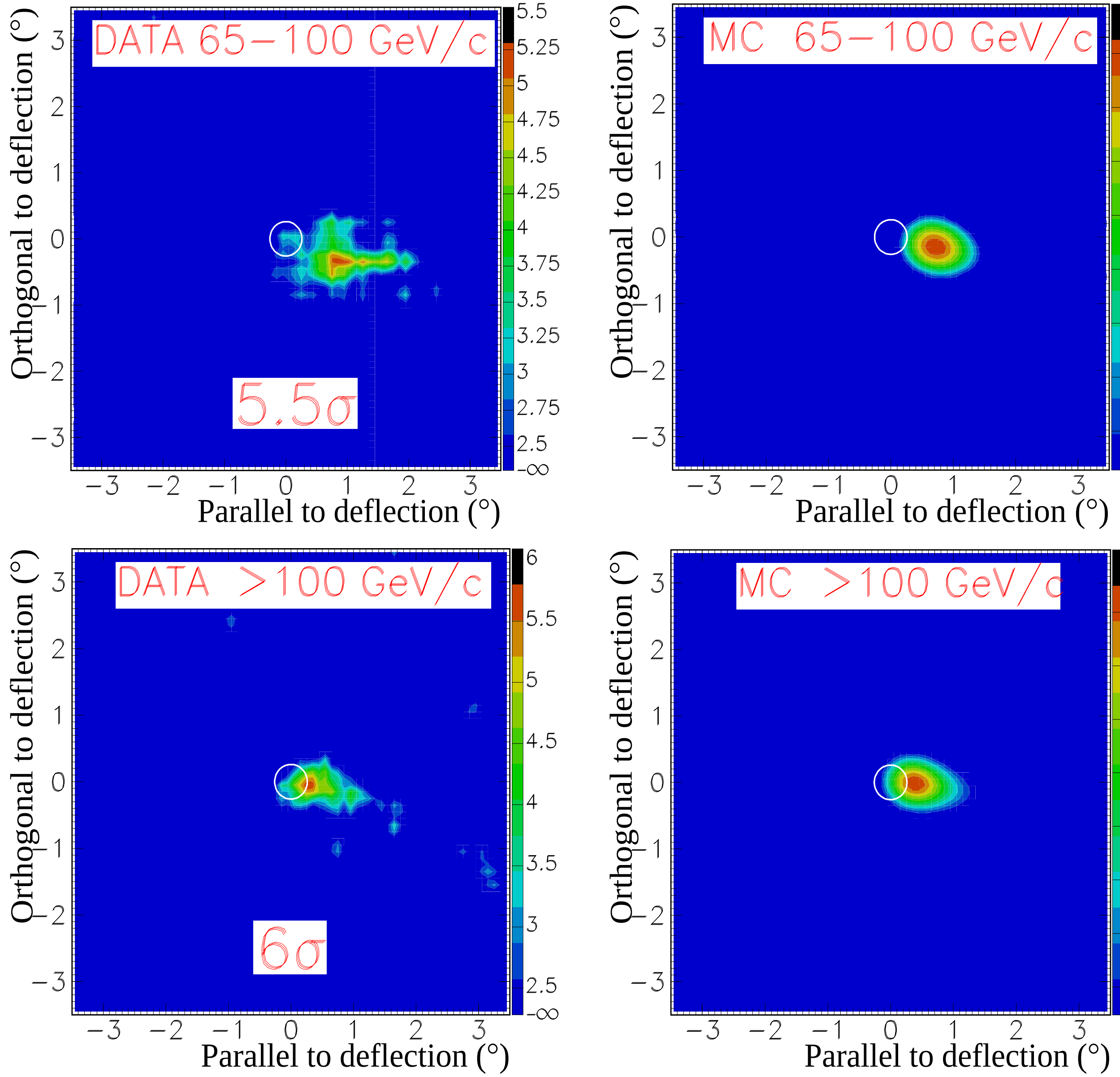
Simulation: $\overrightarrow{u_{defl}} = g(Az, \theta_z)$

Horizontal axis = - $\overrightarrow{u_{defl}}$

$\Longrightarrow$ Deficit along this axis.

$65 - 100$ GeV/c: Δx $= 0.8°$

> 100 GeV/c: Δx $= 0.25°$



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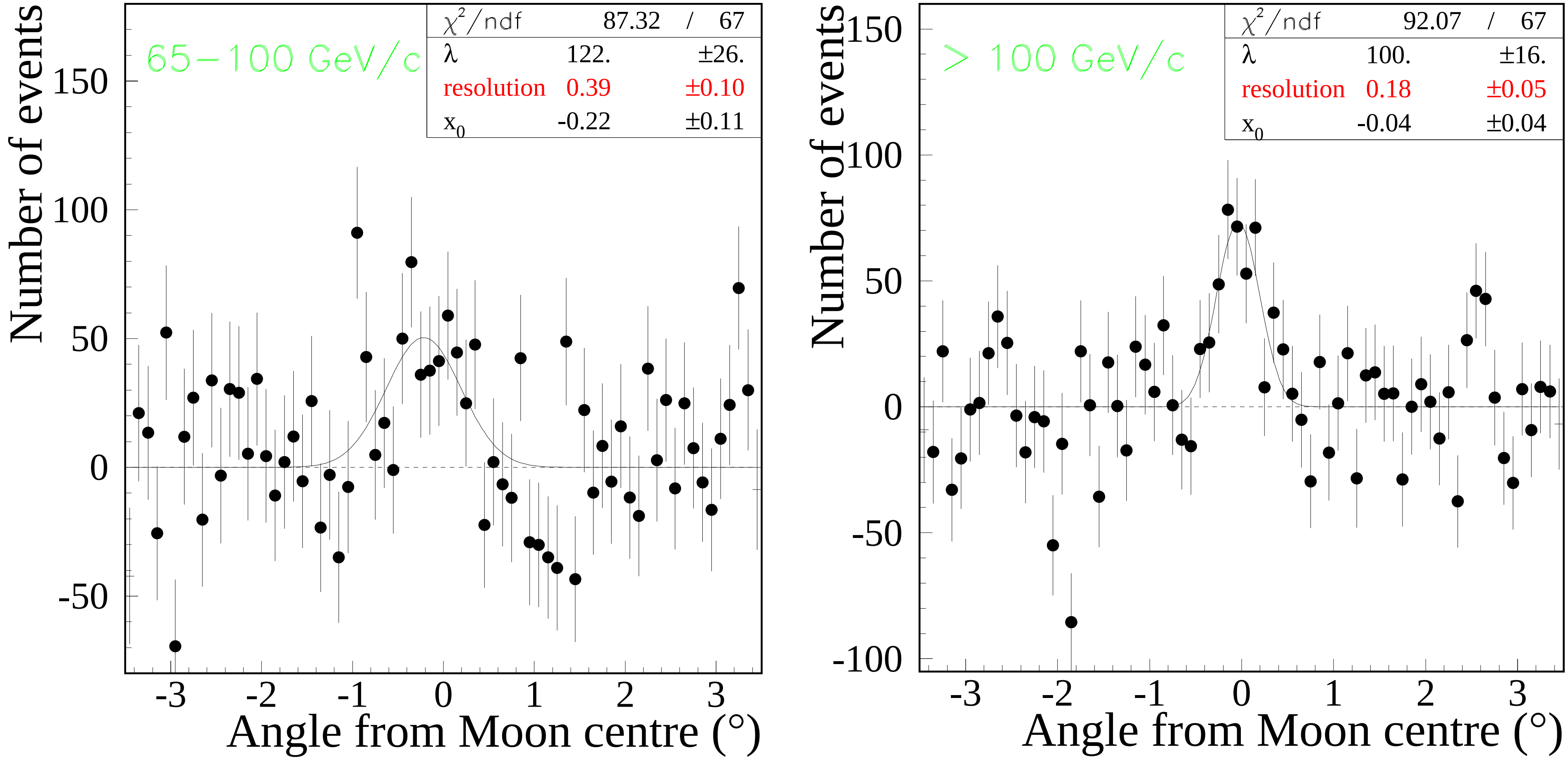
Determination of the angular resolution

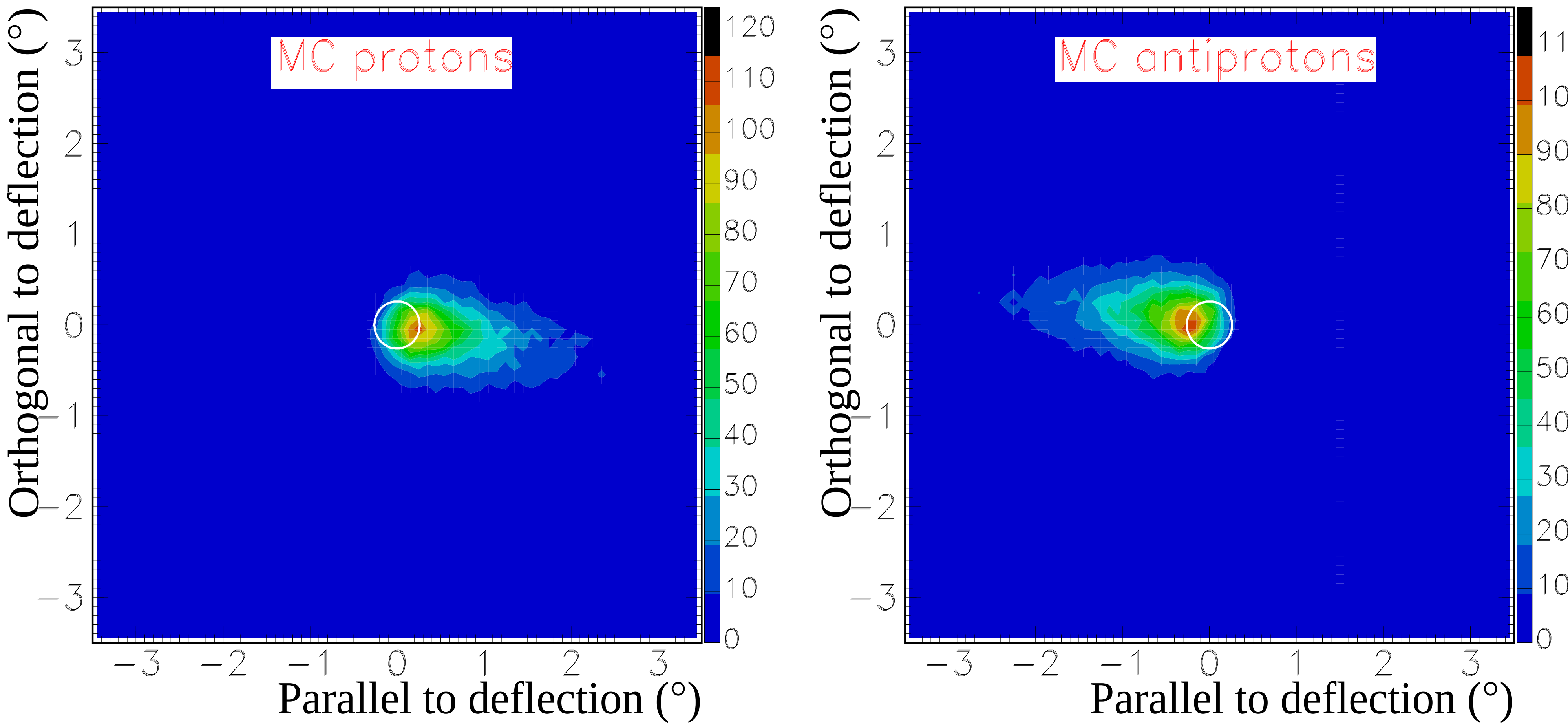
Geomagnetic field → horizontal axis.
⟹ Projection on vertical axis: angular resolution only.



Difference with previous estimates due to geomagnetic field.

Simulation: "anti-shadow" symmetric to Moon shadow.

$|p_\mu| > 100$ GeV/c.



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Measurement of the $\overline{\mathrm{p}}/\mathrm{p}$ ratio

$|p_\mu| > 65$ GeV/c, deflection coordinates system.

Hypothesis: $\overline{\mathrm{p}}, \mathrm{p}$ spectrums with same index.

Maximum likelihood fit:

$$f(x,y) = \underbrace{ax + by + c}_{plane} - N[\underbrace{G(x_0, y_0, \sigma)}_{\mathrm{p}\ deficit} + \underbrace{r}_{\overline{\mathrm{p}}/\mathrm{p}\ ratio} \underbrace{G(-x_0, -y_0, \sigma)}_{\overline{\mathrm{p}}\ deficit}]$$

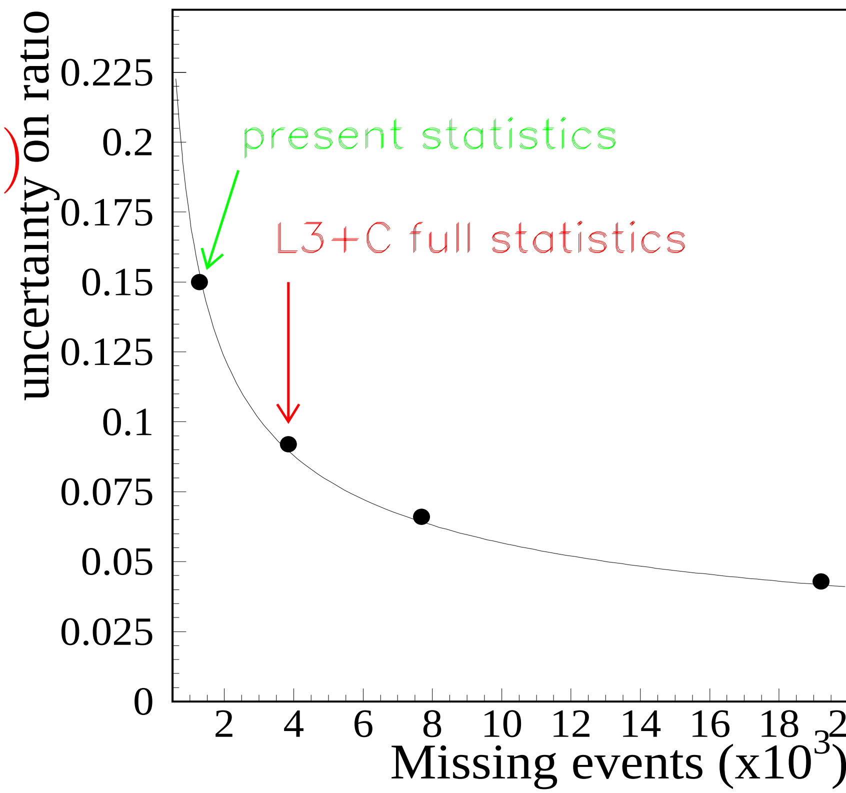
$\Longrightarrow$ Moon shadow observation with 8σ significance.

Simulation $\rightarrow$ uncertainty on the measured ratio.

Preliminary measurement:

$$r = -\,0.1 \pm 0.15 \rightarrow r < 0.25\,(90\%\,C.L.)$$

$\Delta ln\mathcal{L}$	31. 5
Missing events	944. $\pm$320.
x_0	0.41°$\pm$ 0.14
y_0	- 0.05°$\pm$ 0.05
r	- 0.1 $\pm$ 0.15



Conclusion

- The Moon shadow has been observed with 8σ significance.
- Preliminary measurement of $\overline{\mathrm{p}}/\mathrm{p}$ ratio is -0.1 ± 0.15 for a primary energy between .5 TeV and 1 Te
(from MC).
90% C.L. upper limit is 0.25
At the moment, 33% of events reconstructed.
With full statistics, uncertainty on the ratio could be reduced down to 0.09.

- HEP detectors can be used for muon astronomy with success.
implementation relatively unexpensive
continuously monitored
designed for 10 years of running

Generate protons around the Moon location
and remove protons hitting the Moon

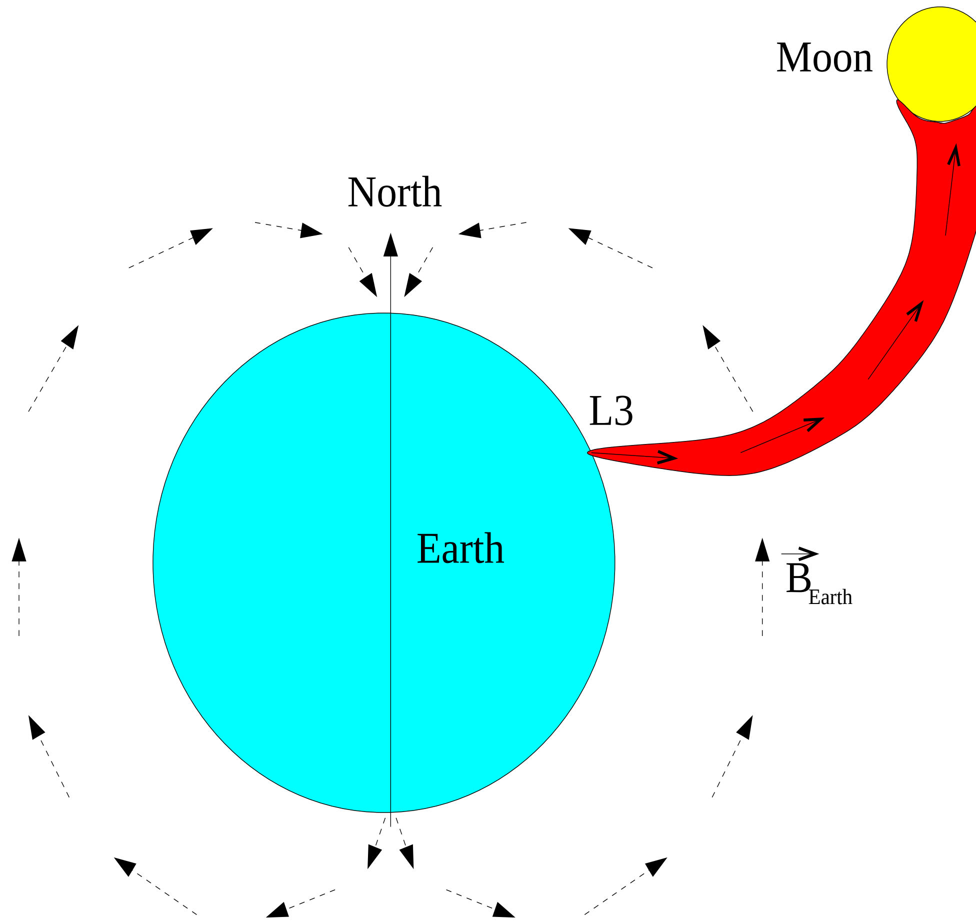
$\Updownarrow$

Generate protons at the Moon location

From the Moon to the Earth

$\Updownarrow$

From the Earth to the Moon



- p spectrum $\Longleftarrow$ data μ spectrum and MC
- p generated within $0.27°$ from $\theta_{Moon} - \Delta\theta_p \overrightarrow{u_{defl}}$
- p tracked through geomagnetic field (IGRF model) up to 5 Earth radii from the Earth
- p trajectory prolongated $\rightarrow$ Earth-Moon distance
- Check that p hits the Moon

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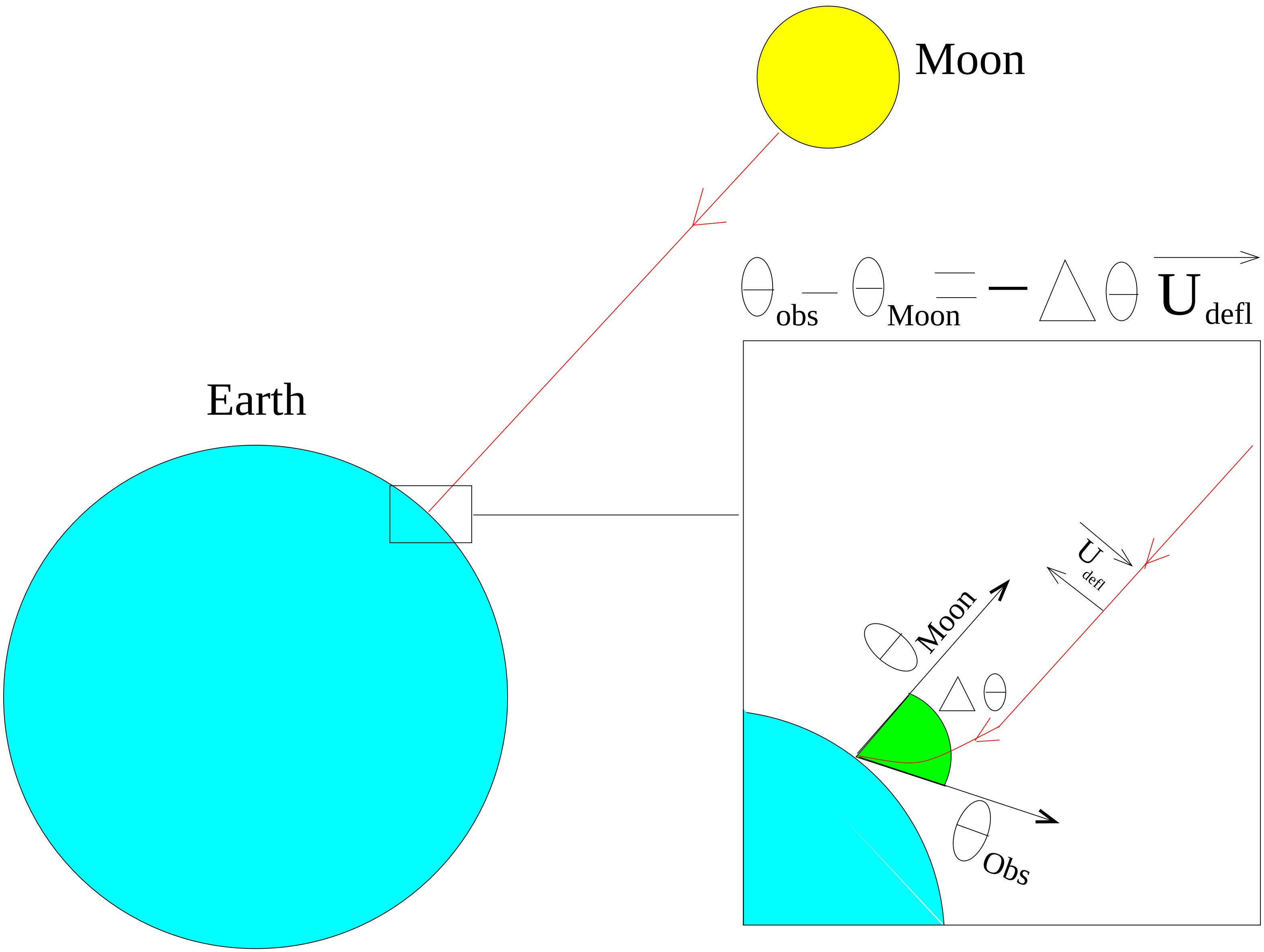
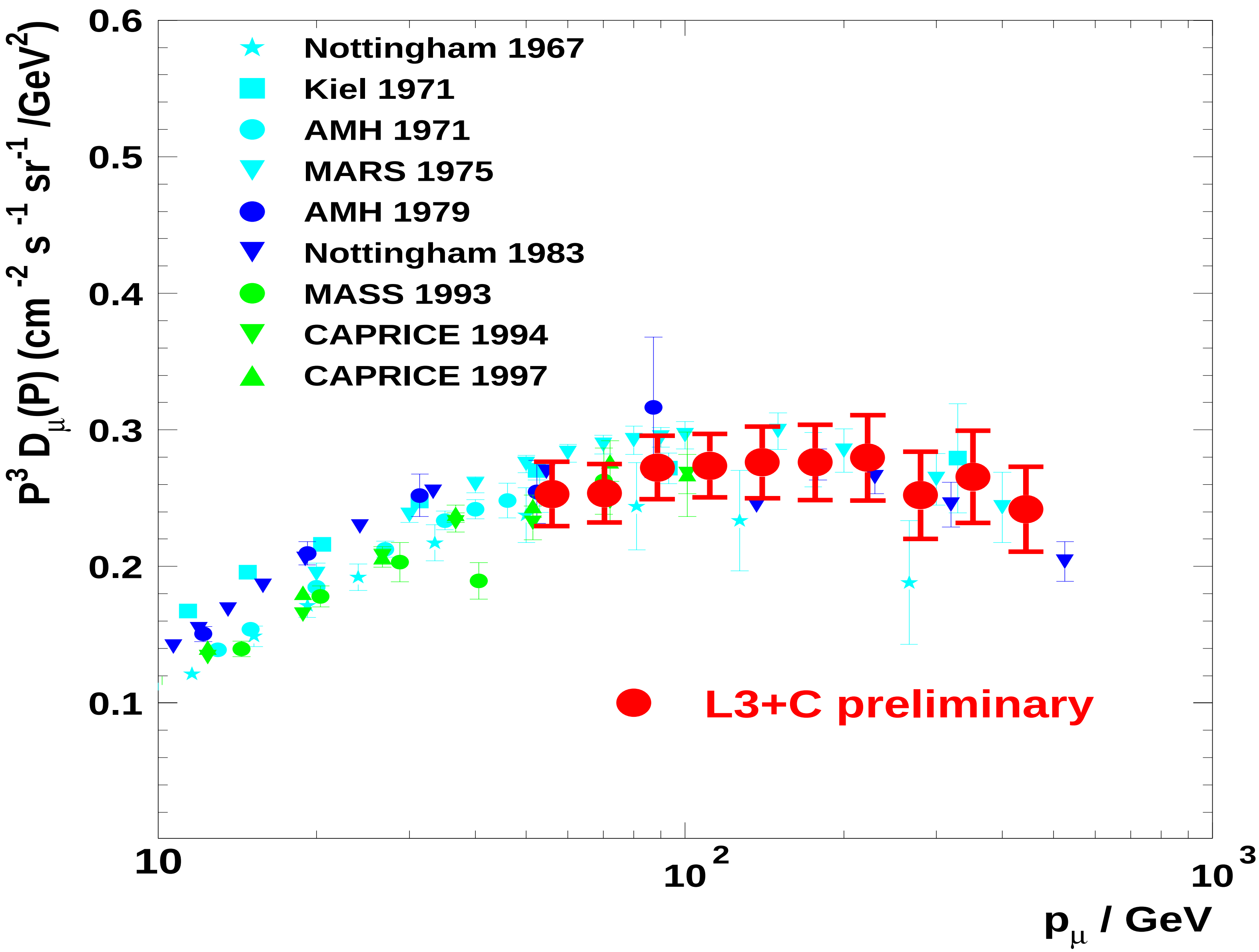
Deflection coordinates system



Muon momentum spectrum



Muon charge ratio