



# Cosmic Ray Shadows of the Moon and Sun

---

- Detector Angular Resolution
- Geomagnetic Field
- Cosmic Ray Shadow of the Moon
- Possible Magnetotail “Source”
- Solar/Interplanetary Magnetic Field
- Cosmic Ray Shadow of the Sun



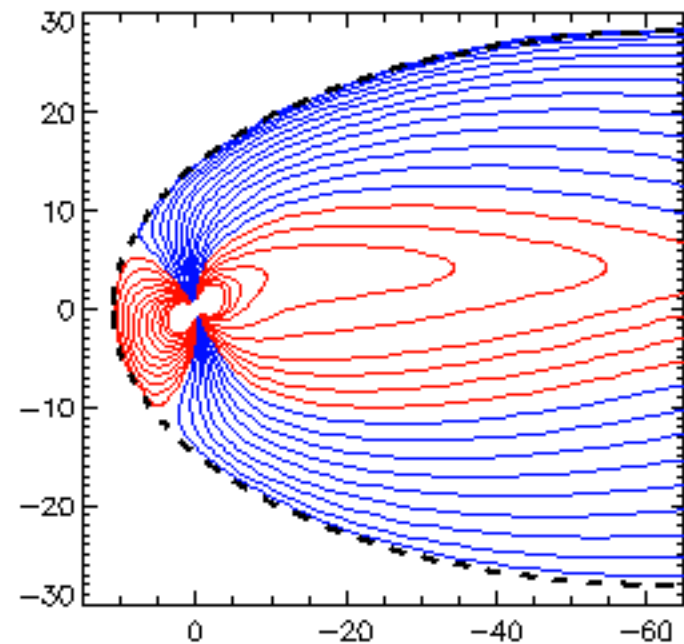
# Detector Angular Resolution

---

- Soudan 2: Spatial resolution: 1 cm; track length: 3 m; hits per track: 100 =  $\pm 0.3$  mr
- MINOS: Spatial resolution: 4 cm; track length: 6 m; hits per track: 50 =  $\pm 1$  mr
- Resolution for both detectors is  $< 0.1^\circ$ ; MINOS can use momentum measurement to eliminate some low energy tracks

# Geomagnetic Field

- Moon is 60 earth radii from earth. Dipole field is 50,000 nT at Earth's surface and decreases as  $1/r^3$ . Field integral due to dipole field is  $\leq 160$  T-m. Assume that magnetospheric field is uniform 50 nT. Field integral due to magnetospheric field is  $\leq 20$  nT.
- For a 20 Tev/c particle, the bend angle due to a field integral of 180 T-m is 2.7 mr.



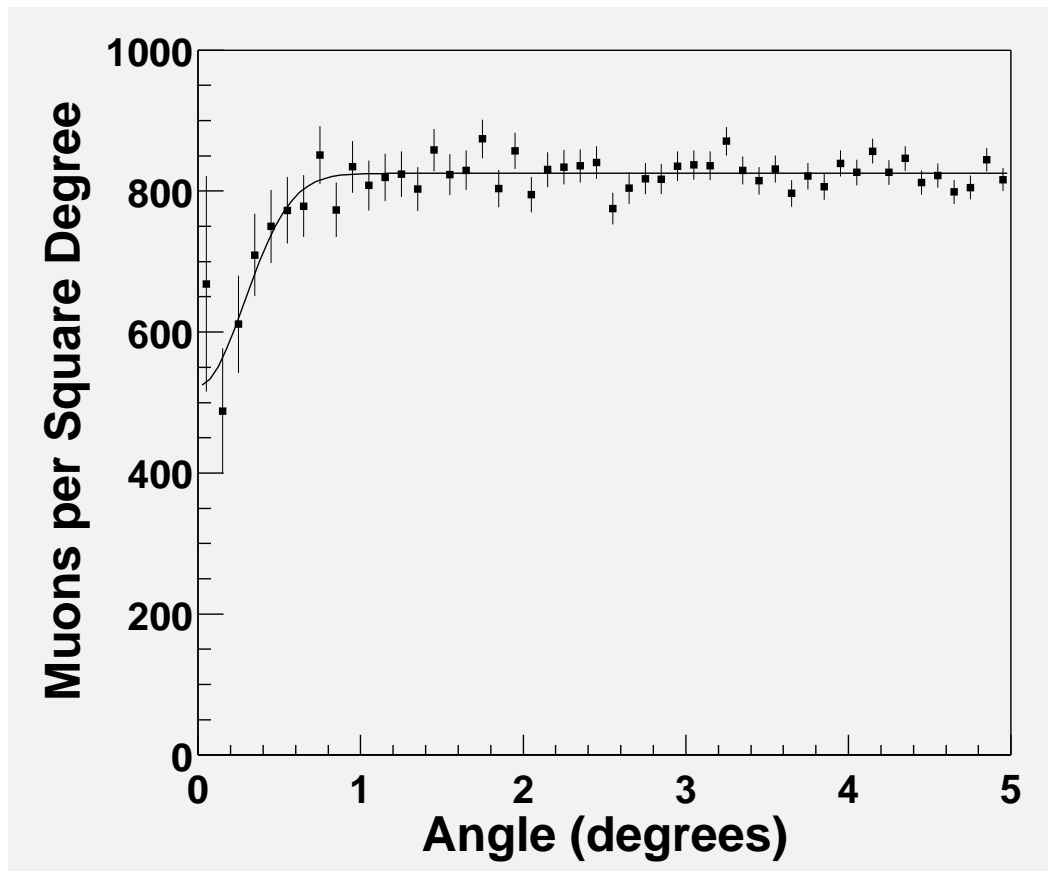


# Geomagnetic Field

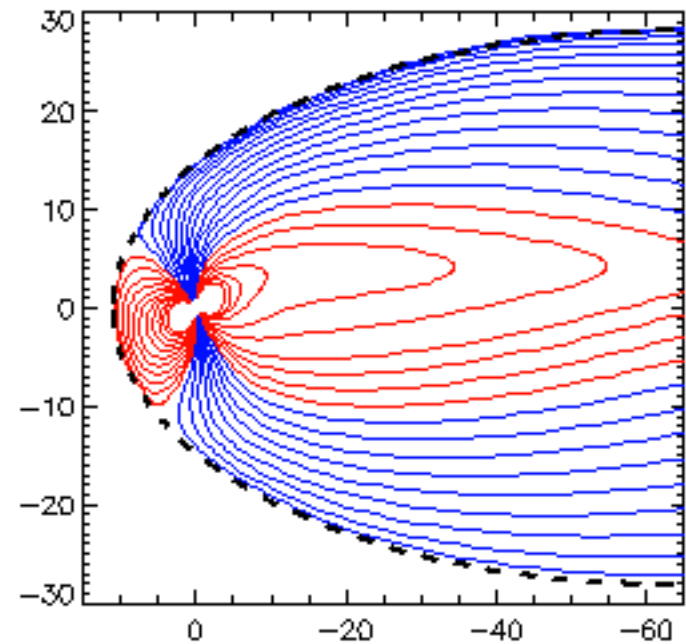
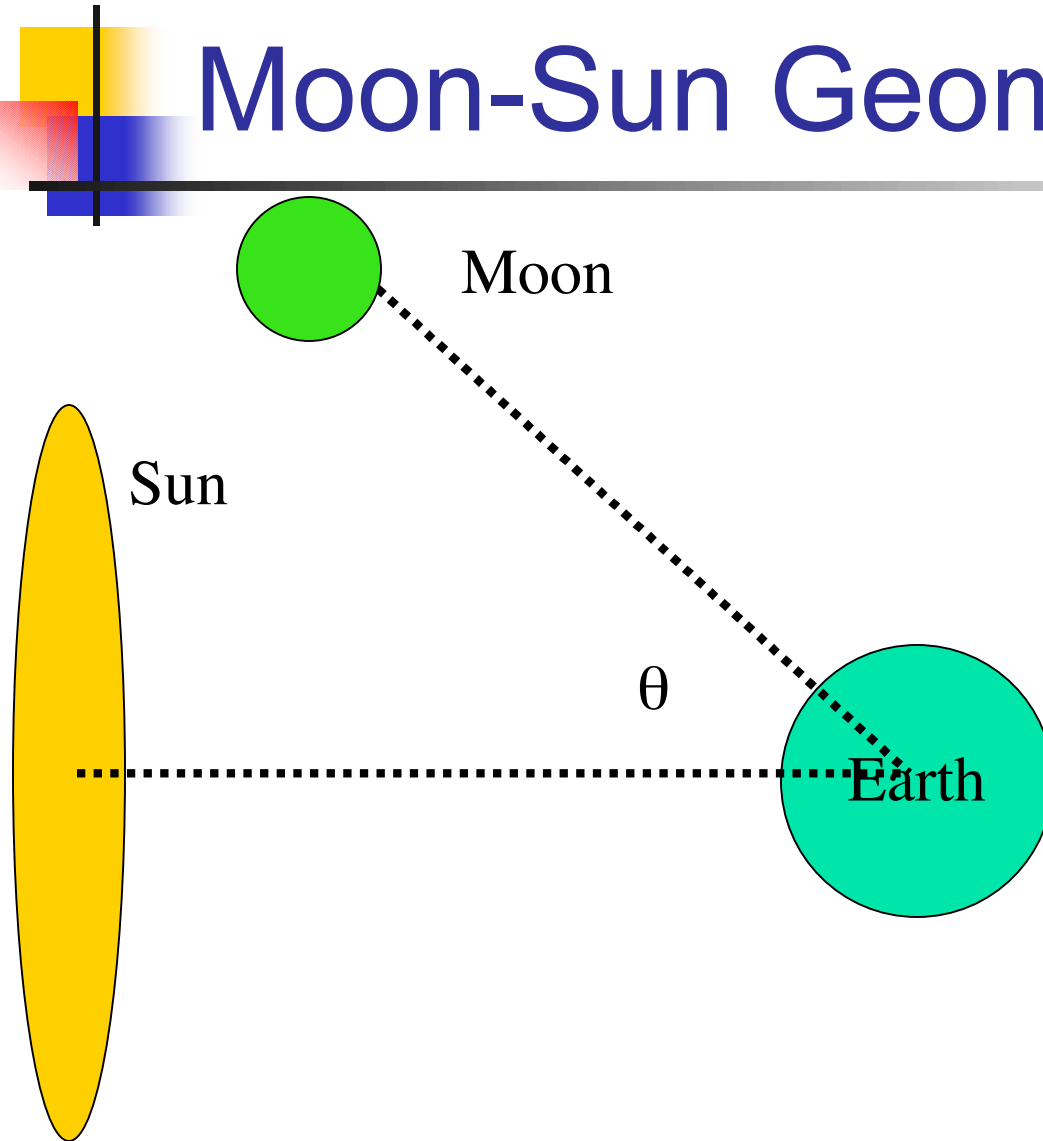
---

- Conclusions: moon shadow should be dominated by size of moon ( $0.25^\circ$ )
- Even if shadow is affected by the geomagnetic field, the shadow should be stable in time

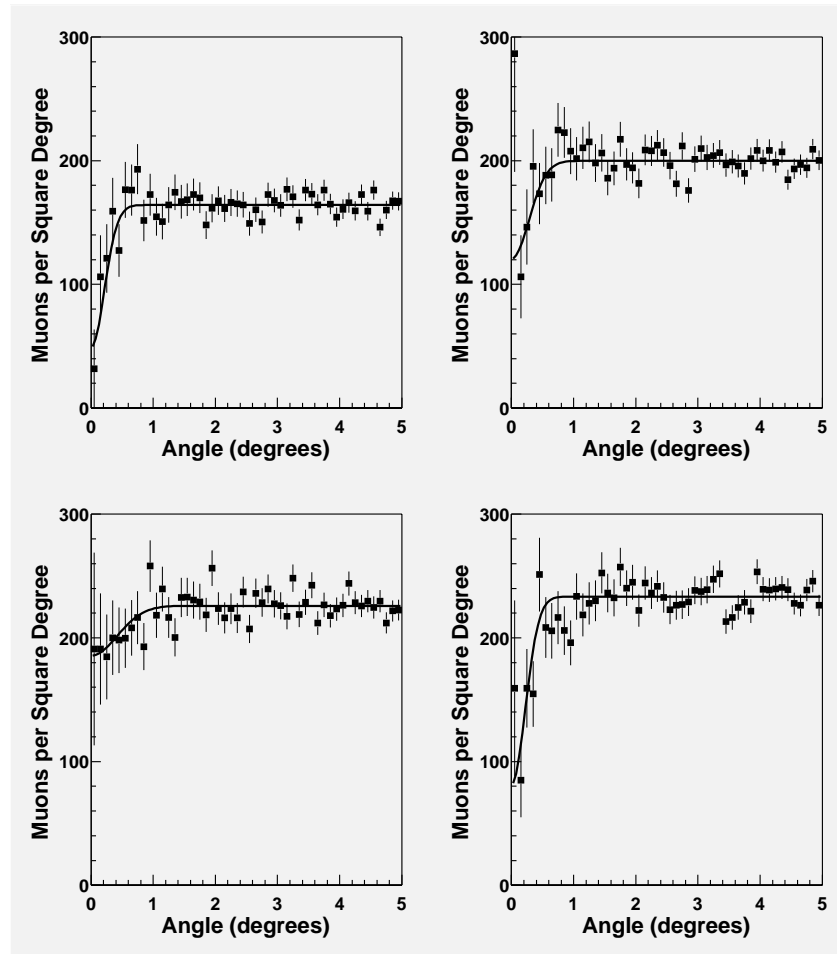
# Cosmic Ray Moon Shadow



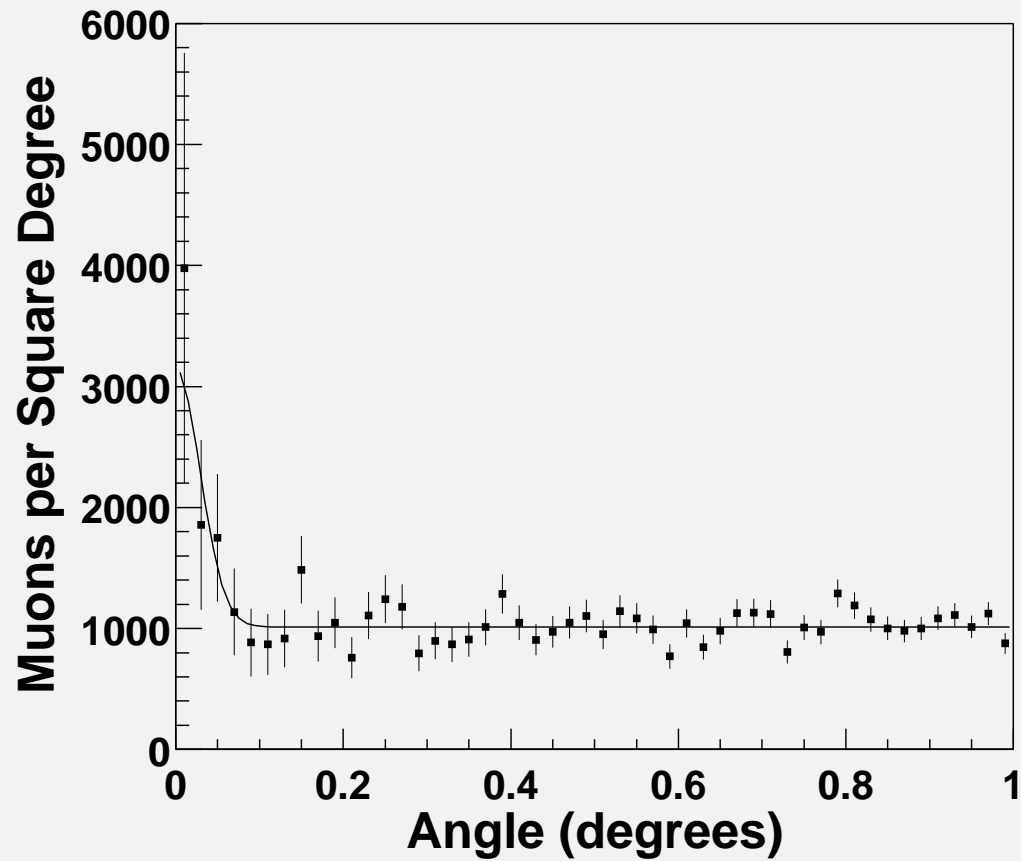
# Moon-Sun Geometry



# Moon Shadow



# Magnetotail





# Solar/Interplanetary Magnetic Field

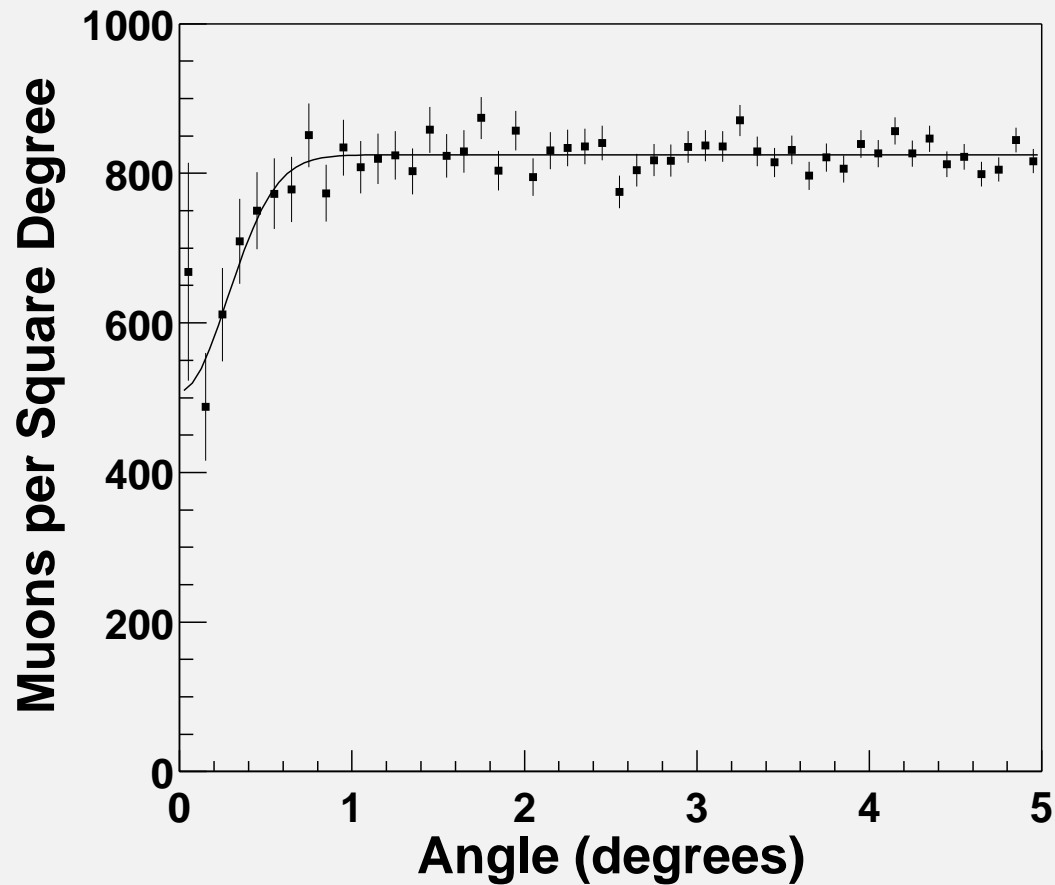
---

- Sun is  $2 \times 10^{11}$  m (287 solar radii) from Earth.  
Average transverse field at  $L_1$  point is 3 nT.
- Field is constant: field integral is 600 T-m, bend for 20 TeV particle is 9 mr
- Field goes as  $1/r$ : field integral is 3390 T-m, bend for 20 TeV particle is 51 mr
- Field goes as  $1/r^2$ : field integral is 171000 T-m, bend for 20 TeV particle is 2.57 radians

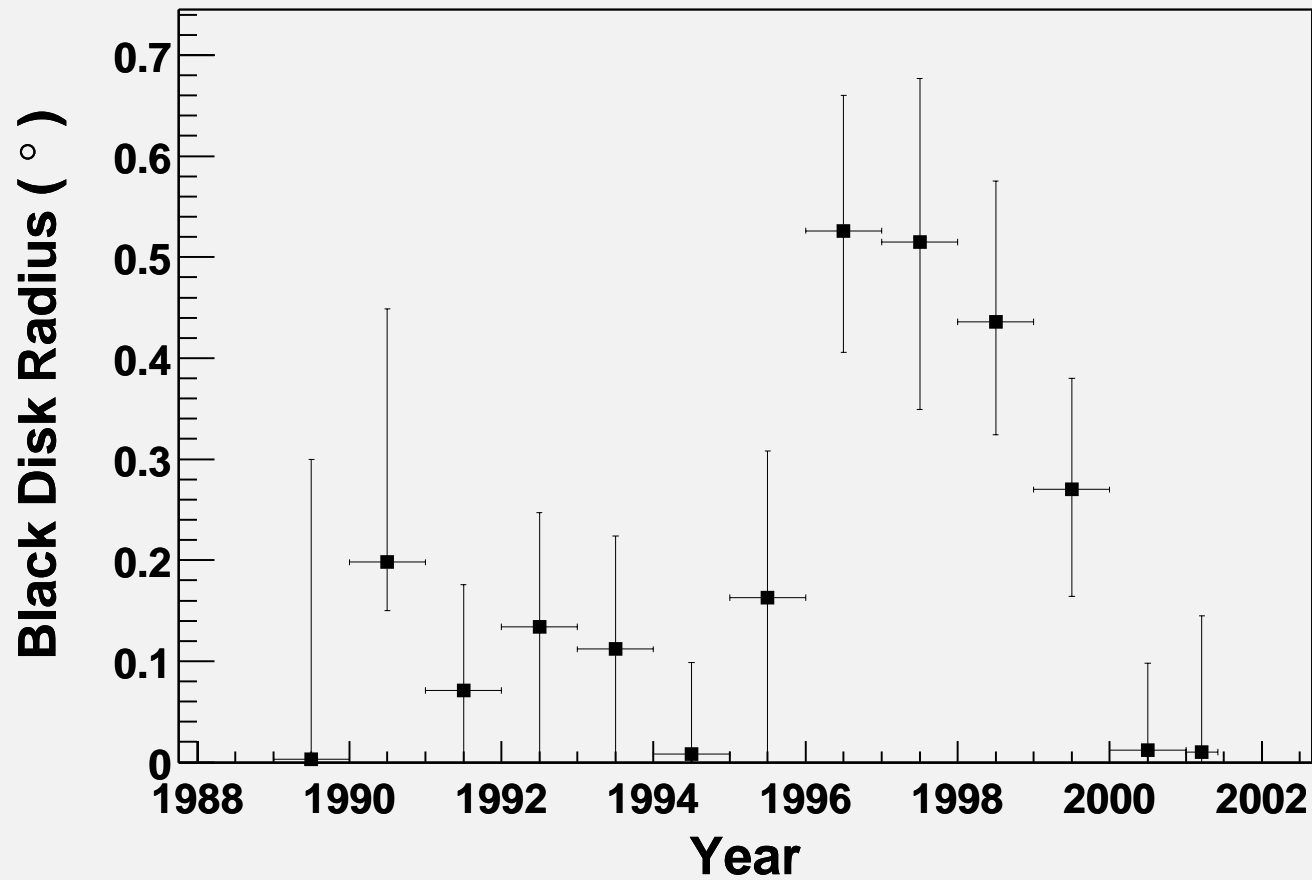
# Sun Shadow

$$\frac{dN}{d\Omega} = \lambda \left( 1 - \frac{r^2}{2\sigma^2} \right) e^{-\frac{\theta^2}{2\sigma^2}}$$

$$N = (2\pi \sin \theta d\theta) \lambda \left( 1 - \frac{r^2}{2\sigma^2} \right) e^{-\frac{\theta^2}{2\sigma^2}}$$



# Sun Shadow By Year





# Summary

---

- Soudan 2 data raises several interesting questions about moon and sun shadows that MINOS can investigate