Study on heavier nuclear CRs
- A challenge for the future -

XSCRC2017 at CERN
Tsuneyoshi (Tune) Kamae
Univ of Tokyo and SLAC/KIPAC

Introduction to myself and my involvement in the Fermi-LAT collaboration

1. Direct measurements (My contribution has been minimum.)
   a. CR electrons + positrons
   b. CR positron/electron
   c. More to come?

2. Indirect measurements of Gal CRs (I have worked on a few SNRs and mol clouds.)
   a. Nuclear CRs at SNRs: Evidence for HE nuclear and/or electron CRs at SNRs
   b. Electron spectra at PSRs and associated PWNe: Accel sites, spectral evolution
   c. Nuclear CRs at molecular clouds: Density of gas measured with nuclear CRs
   d. Use less-complicated region in the Galaxy and extract info on CRs

3. Reuse knowledge acquired with analyses on Fermi-LAT for other CR experiments
   a. Gammas from the Earth limb: cleaner place to extract nuclear CR spectra
   b. Can we extract heavy nuclei CR contribution from diffuse Galactic emission?

4. Generation of exclusive air-shower events up to 10^{15}eV
Let’s start from lower energies

In general:
• Higher fluxes of CRs
• More experimental data available
• Easier to simulate
SigInel(pp) below $E_{cm}<3-4$GeV
SigInel(np) below $E_{cm} < 3-4$GeV
"Discovery" of pp→direct pions near thres
"direct" pions in Gal CRs (PL=-2.75)
Nuclear enhancement factor: energy dependent

Ratio pp>pi0 Gam and p+He, He+p, Dir Pi0, Dir Gam

Red: \frac{\text{all}(pp+p Dir+p He+HeP)}{\pi0(pp)}

Blu: \frac{\pi0(pp+p Dir+p He+HeP)}{\pi0(pp)}

E_{\text{Gam}} [\text{GeV}] (binning 10/decade)
Then realized: Spallation gammas!
Spallation gammas are non-negligible

Calculated by Tatsuhiko OGAWA using Boudard et al. PR C 87, 014606 (2013)
But how am I going to test the results?
Attempt 1: Earth-limb gamma rays by Fermi LAT

Abdo et al. PR D 80, 122004 (2009)
“Fermi large area telescope observations of the cosmic-ray induced gamma-ray emission of the Earth's atmosphere”

Ackermann et al. PRL 112, 151103 (2014)
“Inferred Cosmic-Ray Spectrum from Fermi Large Area Telescope \( \gamma \)-Ray Observations of Earth’s Limb”
Earth-limb gamma rays

Atm density model: NRLMSISE2000

\[ R_0 = 6371 \text{ km} \]
\[ h_0 = 565 \text{ km} \]
\[ d = (R_0 + h_0) \cos(\theta) \]
\[ R = (R_0 + h_0) \sin(\theta) \]
\[ h = R - R_0 \]
Fermi Earth Limb

Slope = 1/75 per 0.5 deg

Integrated Column Density [g cm$^{-2}$] vs $\Theta_{Nadir}$ [Deg]

3 g/cm$^2$
Are we seeing spallation gammas?

Nuclear effect? (+psf)
Column density (+psf)
Nuclear effect? (+psf)
Column density (+psf)
Simulation: Earth limb location for protons

Col dens & Int of >30GeV gam VS thNadir, h0=534-558km, proton

Model of Earth atm NRLMSIS00
Dash: Column density
Sid: Gamma Flux >30GeV
NRL 2 Time-Lon-Lat comb
h0=534(blk), 538(blu), 542(grn), 546(red), 550(yel), 554(mag), 560(blk)
Simulation: Earth limb location for Fe

Col dens & Int of >30GeV gam VS thNadir, h0=534-558km, Fe

Model of Earth atm NRLMSIS0
Dash: Column density
Std: Gamma Flux >30GeV
NRL 2 Time-Lon-Lat comb
h0=534(blk), 538(blu), 542(grn)
546(red), 550(yel), 554(mag), 560(blk)
Earth limb location depends on Sig(inel)

\[ \text{Gam Int} > 30\text{GeV VS thNadir, } h_0 = 534.0\text{km for } p, \text{He, CNO, Mg, SiSAr, Fe} \]

**Impossible to see!**
But spallation gammas seem to be there

\[ \text{thNadirMax} = 68.0 - 0.02 \times (h0 - 542) \]

LAT data: red diamond
Fe on N: 1GeV/n (red), 10GeV/n (green)

Calculation by T. Ogawa (JAEA)
C on N: 1GeV/n (red), 10GeV/n (green)

Calculation by T. Ogawa (JAEA)

C: 10GeV/n => 1TeV/n

=> 30GeV
Fragmentation model for Hydrogen target of Webber (2003) - No.1-
CR composition meas. in air showers

Spallation at the top of atmosphere dictates the energy deposition pattern on the surface
Fragmentation model for Hydrogen target of Webber (2003) - No.2-
Very extensive experimental study
C. Villagrasa-Canton et al, PRC 75, 044603 (2007)

I could not find comparison with Webber et al (2003)
Very extensive experimental study

C. Villagrasa-Canton et al, PRC 75, 044603 (2007)

No comparison with Webber et al. (2003)
Very extensive experimental study
C. Villagrasa-Canton et al, PRC 75, 044603 (2007)

Questions to experts:
1) How do exps compare with Webber (2003)
2) New models?
Questions to experts:
1) INCL4-GEMINI is the best choice?
$p_T$ of fragments: any suggestions

$p_T$ distribution dictates the lateral development and fluctuation of air-shower development.

Can some exp in RHIC measure $p_T$ of fragments?
New simple exp to test fragmentation models?
- Tot Xsec by Cecchini et al (2008) -

\[ \sigma_{tot} = \pi r_0^2 \left( A_P^{1/3} + A_T^{1/3} - b_0 \right)^2 \]

Can they measure \( p_T \) of fragments?

\[ r_0 = 1.31 \text{ fm}, \ b_0 = 1.0, \ A_P \text{ and } A_T \text{ are the projectile and target mass numbers,} \]

Figure 3: Total fragmentation cross sections for (a) Fe ions of different energies in CH\(_2\) and Al targets and (b) for Si ions in CH\(_2\), CR39 and Al targets. For comparison the measured cross sections from refs. [6, 7, 8, 9] are also shown, together with the predictions from Eq. 2.
We need experiments on
Fe+N/O, C+N/O, O+N/O, Ne+N/O

I found a nice solid target with approx. right mix of N and O

$\text{N}_2\text{O}$: Nitrous oxide, known as laughing gas, is used as a dissociative anaesthetic.

A colorless, odorless non-flammable gas at room temperature.
Safety code: ICSC 0067 (Avoid direct contact, Skin:Frostbite, Eyes:Frostbite)
Melting point = $-102^\circ\text{C}$
Probably stay solid if put on a cold plate submerged in liq $\text{N}_2$
Density of solid $\text{N}_2\text{O}$ = about 1.0
Thank you for invitation to this Nice Conference and your attention