MC study of proton-Nitrogen collisions at RHIC for cosmic-ray physics

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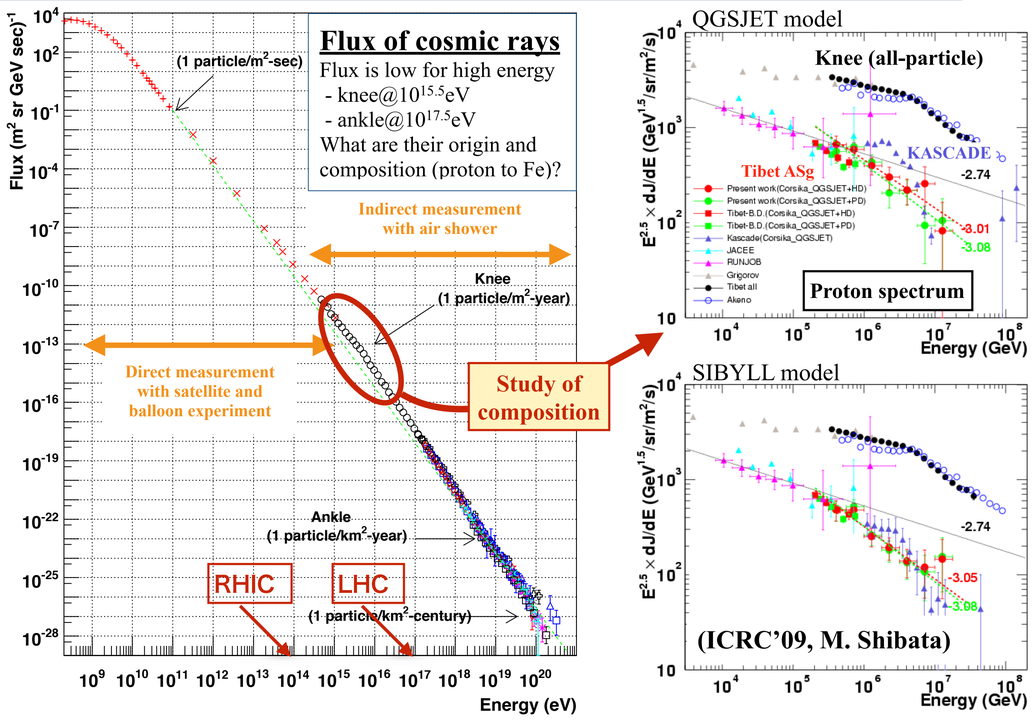
Abstract: To have a correct understanding of air shower development, accurate measurements of nuclear effect with accelerators are necessary. RHIC is a good candidate to provide the first light-ion collision. We propose a short period experiment measuring the nuclear effect incorporated in each interaction models in proton-nitrogen (p-N) collision at $\sqrt{s_{NN}}$=200 GeV.

Observation of Cosmic Rays: What Is The Composition?



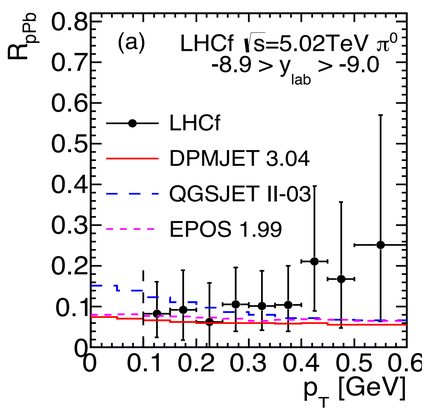
Knee is proton dominant? or heavy dominant?

Interpretation of the knee region differs from experiments. But their interpretation relies on the hadronic interaction model used. These are the main source of uncertainties.

Nuclear Effect And Impact On Air Shower

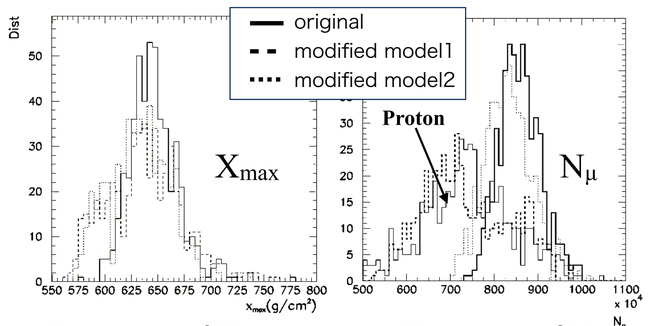
Nuclear modification factor from accelerator experiments: **(PRC89, 065209)**

$$R_{\mathrm{pPb}} \equiv \frac{\sigma_{\mathrm{inel}}^{\mathrm{pp}}}{\langle N_{\mathrm{coll}} \rangle \sigma_{\mathrm{inel}}^{\mathrm{pPb}}} \frac{Ed^3\sigma^{\mathrm{pPb}}/dp^3}{Ed^3\sigma^{\mathrm{pp}}/dp^3}$$



Strong suppression confirmed.

Simulation of air shower introducing a strong field that decelerate nucleons. **(Astro. Phys.23 435–443)**



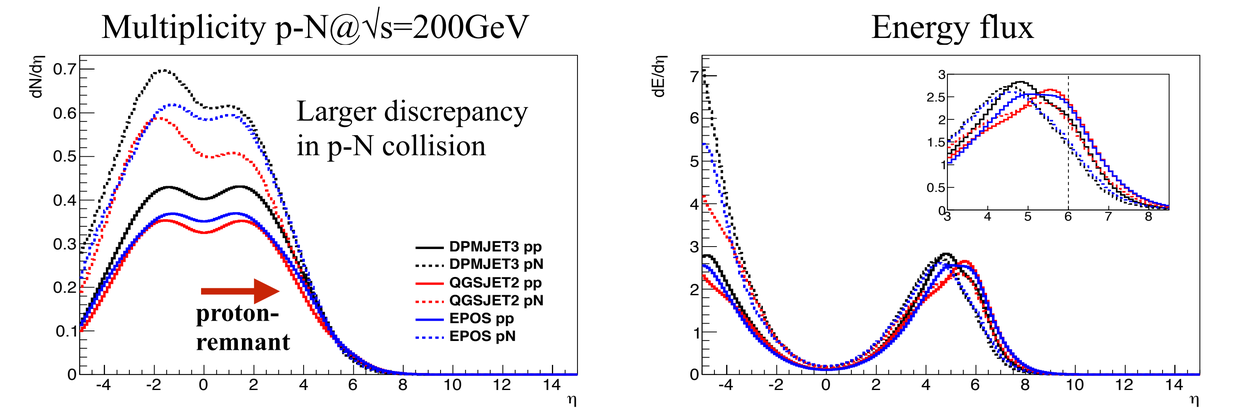
Decrease of X_{max} → Heavier primary

Decrease of N_μ → Lighter primary

Nuclear effect can have critical impact on the determination of composition.

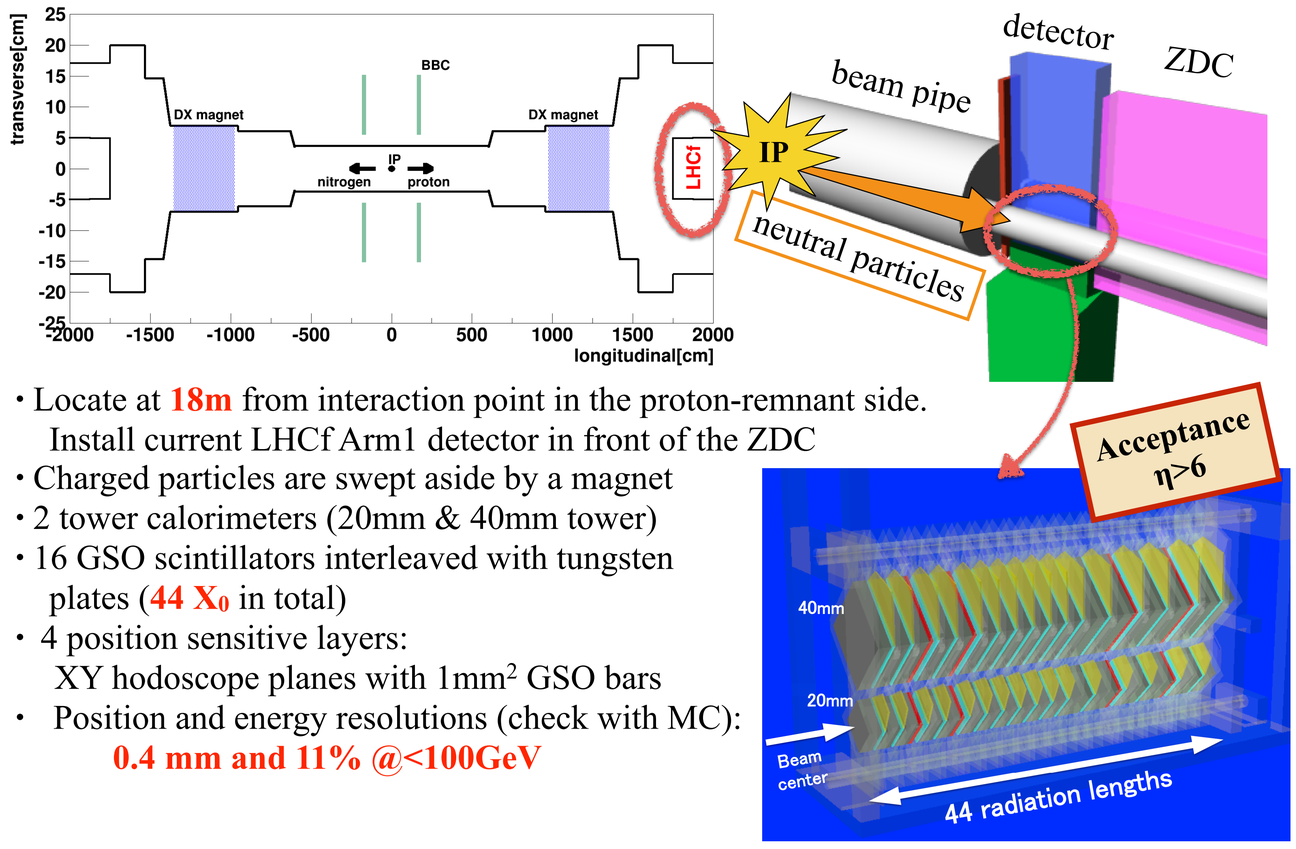
Many measurements with heavy ion collision were carried, but no measurement with **light-ion target** is available. RHIC and LHC are good candidates.

p-N Collision: Comparison With p-p Collision



The forward region is very effective on air shower development. This region has a small multiplicity, but carries most of the energy. Small instrument such as the LHCf detector is necessary to achieve accurate measurement in this region.

Experimental Setup With LHCf Detector



- Locate at **18m** from interaction point in the proton-remnant side. Install current LHCf Arm1 detector in front of the ZDC
- Charged particles are swept aside by a magnet
- 2 tower calorimeters (20mm & 40mm tower)
- 16 GSO scintillators interleaved with tungsten plates (**44 X_0** in total)
- 4 position sensitive layers: XY hodoscope planes with 1mm² GSO bars
- Position and energy resolutions (check with MC): **0.4 mm and 11% @<100GeV**

Analysis With MC

We simulate 10^8 inelastic collisions to determine the nuclear effect incorporated in each interaction model. We define the nuclear effect with the following formula:

$$R = \frac{(dN/dE)_{pN}}{(dN/dE)_{pp}}$$

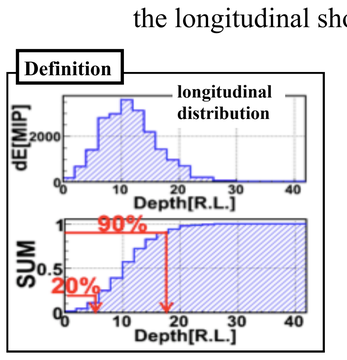
	p-p	p-N
σ_{ine}(mb)	40	330
L(10^{30}cm^{-2}s^{-1})	16.5	2.0
N_{coll}	1x10^8	1x10^8
time(min)	5	5

Expected Results: Photon Spectrum

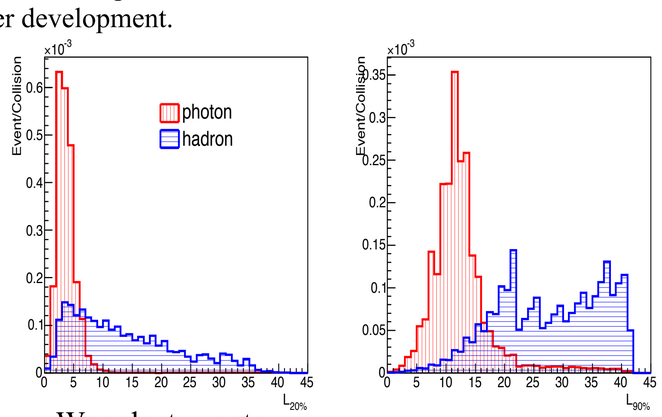
Selection of photon events:

1. 3 successive layers with an energy deposit larger than 10 MIPs (Trigger photons above 10 GeV)
2. Reconstructed position within 2mm from the edge
3. Photon identification cut:

   EM and hadronic showers are separated with a method based on a difference of the longitudinal shower development.



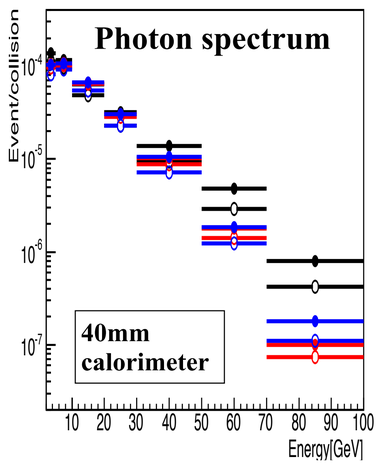
The thresholds are calculated with p-p collision in order to keep the detection efficiency to 90% independently.

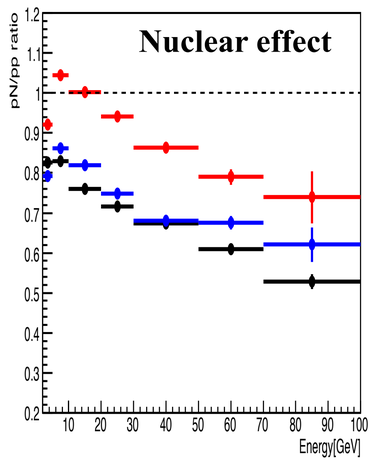


We select events:

<L20% threshold &&<L90% threshold

Applying 2 criteria gives a purity of 80% in all energy ranges.





The discrepancy between models can be evaluated with a simple χ^2 method.

$$\chi^2_{model} = \sum_i \frac{(R_{model_i} - R_{EPOS_i})^2}{\sigma^2_{model_i} + \sigma^2_{EPOS_i}},$$

χ^2 (Prob)	20mm		40mm	
DPMJET3	7.09	(0.21)	362	(10^{-20})
QGSJET2	102	(10^{-20})	1262	(10^{-20})

→ **Good rejection power**

Summary

We performed a MC simulation with the LHCf Arm1 detector installed in the proton-remnant side of p-N collision. Nuclear effect is evaluated from the ratio between the photon energy spectrum of p-N and p-p collisions. The detector has enough power to discriminate the nuclear effect incorporated in each model with a simple χ^2 method in a short time.