Anisotropy of cosmic rays

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LAPTH

December 5, 2011

Le problème des rayons cosmiques

Composition

- p,$e^{+,-}$, noyaux accélérés directement dans les sources: **primaires**
- p,$e^{+,-}$, noyaux produits par interactions nucléaires des primaires avec le milieu interstellaire **secondaires**

+ Propagation des cosmiques→Phénomènes astrophysiques de haute énergie
+ Propagation décrite par plusieurs paramètres :
  le coefficient de diffusion, la géométrie de la galaxie
+ **Objectif : trouver des observables capables de contraindre ces paramètres.**
  exemple: le rapport Secondaire/Primaire

⇒ ANISOTROPIE (signal quasi isotrope)

Introduction

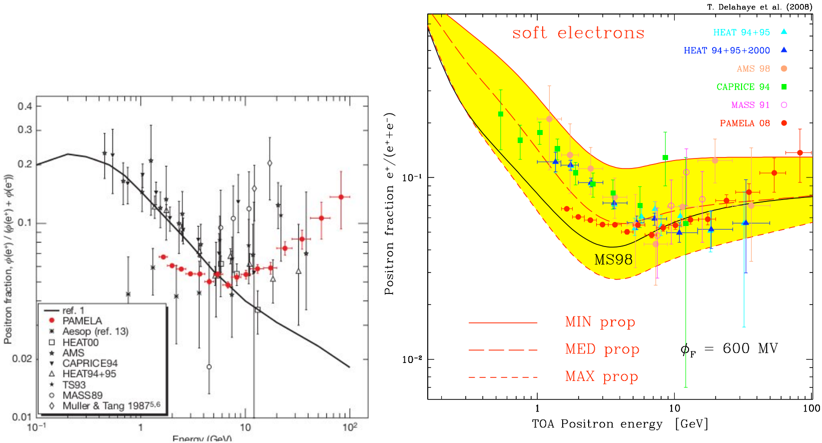


Figure: positronic fraction

Introduction

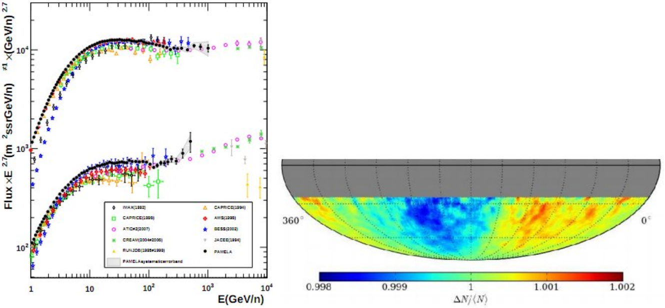


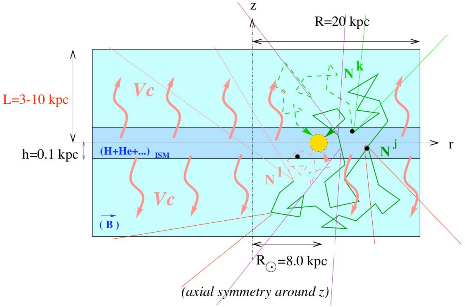
Figure: Proton Flux as observed by PAMELA Colaboration. Adriani et al arxiv:1103.4055,Cosmic rays anisotropy as observed by IceCube Toscano et al arxiv:1110.207

Outline

Outline

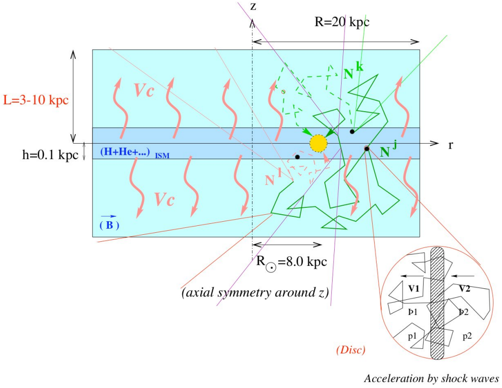
Galaxy model

Cylindrical symmetry



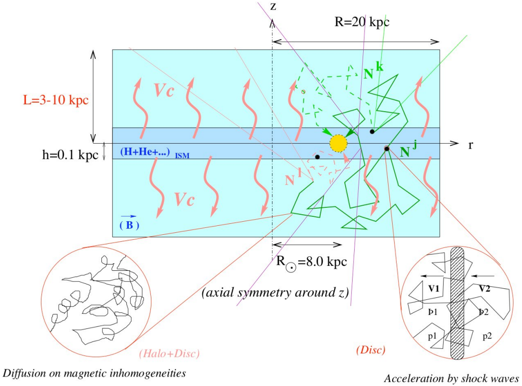
Galaxy model

Cylindrical symmetry



Galaxy model

Cylindrical symmetry



Galaxy model

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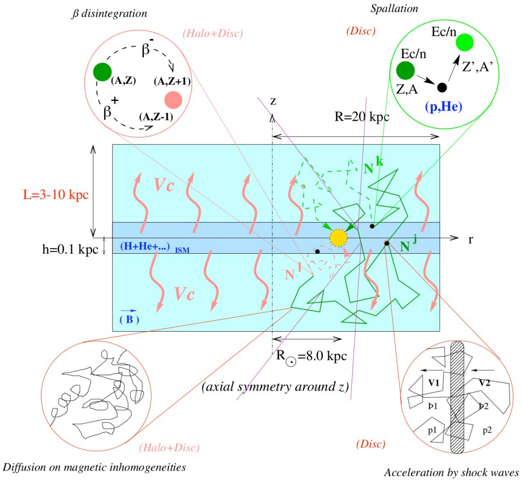

Galaxy model

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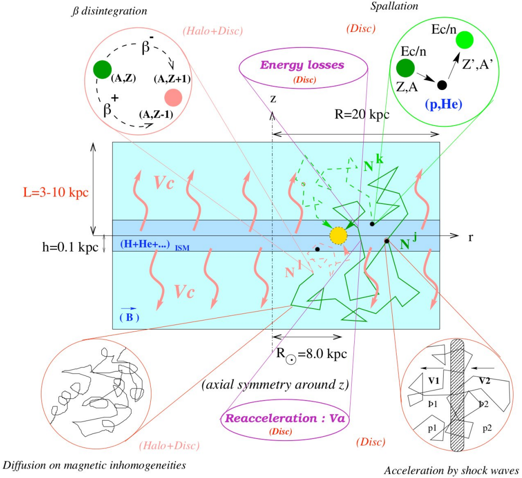

Diffusion Model

Magnetic Halo : It keeps charged particles inside the galaxy
2 components :

- Regular one (around 2μgauss)
- Turbulent component

→Decomposition of the turbulence in power spectra → **multi size turbulences**

Turbulence ∼ Larmor Radius

Slightly turbulent

On each little turbulence : the particle is slightly deflected in a random direction.

→ **Diffusion process**

Defined by a diffusion coefficient $K = K_0 \beta R^{\delta}$.

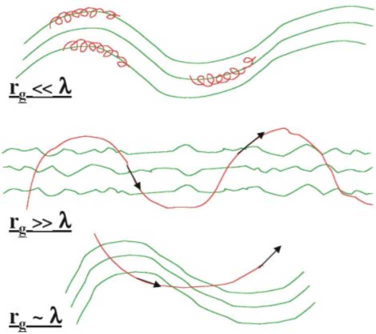

Figure: Illustration of the resonant interaction (ref : HDR Etienne Parizot)

The diffusion equation

Stationary diffusion equation :

$$\frac{\partial^2 N(r,z)}{\partial z^2} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right)N(r,z) - \frac{V_c}{K}\frac{\partial N(r,z)}{\partial z} = \left(-\frac{q_r(r)}{K} + \frac{h\Gamma}{K}N(r,z) + 2\frac{V_c}{K}N(r,z)\right)\delta(z) \quad (1)$$

The Sources

Outline

Anisotropy of cosmic rays

Origins of anisotropy

- Compton-getting effect : motion of the solar system into the galaxy $\rightarrow$ quite well defined
- Heliosphere effects
- Large scale anisotropy

Anisotropy

Previous works :
δ_{dip} dipole anisotropy
I flux of cosmic rays in a given direction on earth

Definitions of anisotropy in the literature

$$I = < I > (1 + \delta_{dip} \cos\theta) \quad \text{or} \quad \delta_{dip} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \quad \text{or} \quad \delta_{dip} = \frac{3K}{c} \frac{1}{N} \left| \vec{\nabla} N \right| \qquad (2)$$

Using the steady state model : $\delta_{dip}(E) \sim K$

The anisotropy holds 2 informations :

- The absolute value of δ_{dip} : constrain K0 and δ_s
- The direction of the maximum (the phase) : gives clues on the origin of anisotropy
- The dipole is not enough

Outline

Experiments

Principle of the experiments :

- Scanning each declination band in the sky
- Harmonic decomposition of each dec band signal
- Drawing a map of the sky

$\rightarrow$ One loses the correlation between each dec band.

Transformation : $f(\alpha, \delta) = \sum_j A_j cos\left[j(\alpha - \phi_j)\right] + B_j$

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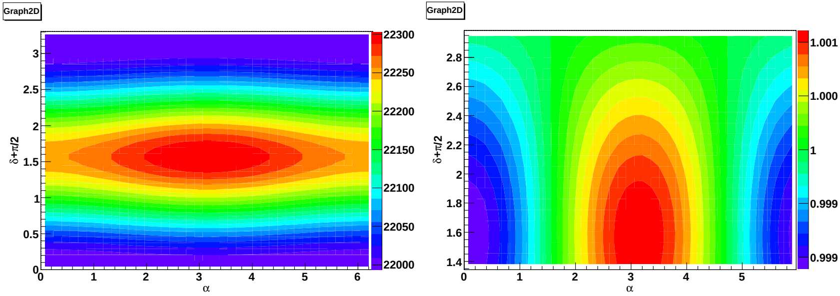


Figure: Signal in equatorial coordinates - Signal as viewed by experiments

experiments

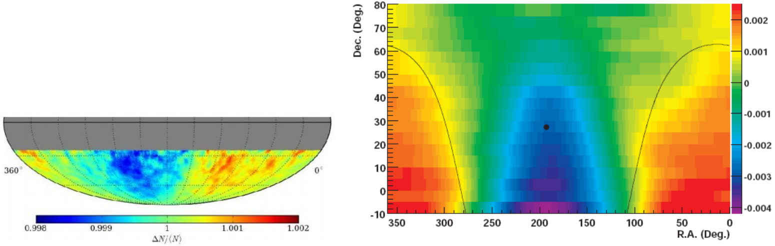


Figure: IceCube ~ 20 TeV - Milagro ~ 6 TeV

Energy dependance

Increasing with energy from few GeVs to ~ 1 TeV
Stays constant from ~ 1 TeV to ~ 100 TeV
Vanishes after few hendreds GeVs

different models of anisotropy

- Distribution of sources
- Local bubble (local diffusion coefficient)
- Pointlike sources

Outline

Large scale anisotropy

Thanks to the diffusion model we can build our own maps of anistropy
Anisotropy induced by source distribution in the galaxy

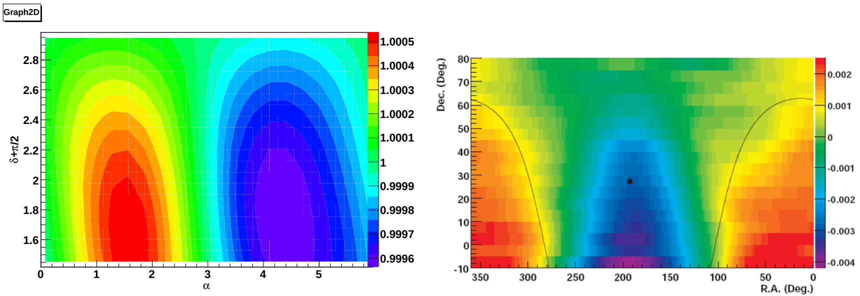


Figure: Signal using pulsar distribution $\delta \sim 5.10^{-3}$ - Signal detected by milagro $\delta \sim 2.5.10^{e-3}$

→ The positions of the maximum don't match !

constraining K0 and δ_s

Using the results of milagro ($\delta = 2.4910^{-3} \pm 0.09$) one can manage to constrain K0 and δ_s

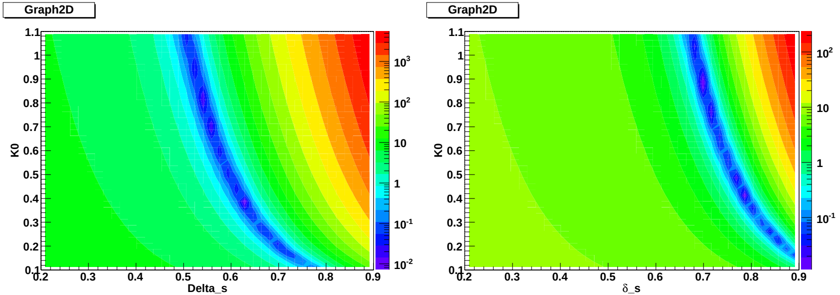


Figure: Chi2 test computed with milagro data and with a pulsar distribution - and a SNR distribution

→ very sensitive to the source distribution
→ cannot fit the energy dependance of anisotropy

Solar system is located in a low density zone → local bubble
Possibility of two different diffusion coefficients

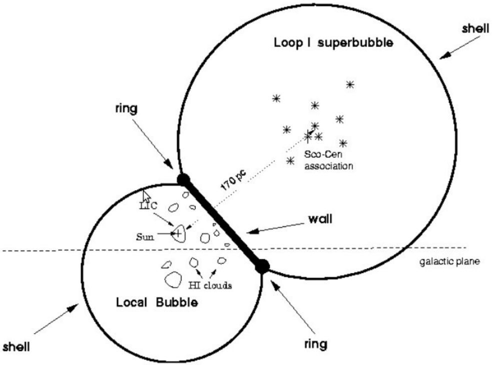


Figure: The local bubble

Local bubble

The possible anisotropy from the local bubble

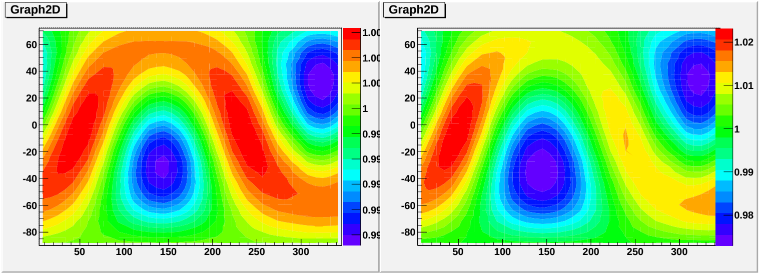


Figure: $K_{bubble} = K$, $K_{bubble} = 10 * K$. $\delta_1 = 210^{-3} \delta_2 = 10^{-2}$

$\rightarrow$ A local change in the diffusion coefficent can lead to an important anisotropy

Pointlike sources

Anisotropy is highly sensitive to local effects $\rightarrow$ We may be sensitive to time dependant effects.
We consider now time dependant solutions of diffusion equation. $\rightarrow$ Sources are now considered as beeing pointlike in space and time and distributed as **pulsars**.
Sources are choosen in a catalog of SNR and Pulsar for close ones (distance $<$ $2kpc$) and randomly for other ones

Pointlike sources

solution

$$N(r,z,t) = \sum_s \frac{1}{4.\pi K(t-t_s)} e^{-\frac{-r_s^2}{4.K(t-t_s)}} e^{\frac{V_c}{2K}(|z_s|-|z|)}$$
$$\times \sum_{n=1}^{\infty} [\frac{e^{-\alpha_n (t-ts)}}{C_n} \sin(k_n(L-|z_s|)). \sin(k_n(L-|z|))$$
$$+\frac{e^{-\alpha_{n'}(t-ts)}}{C_{n'}} \sin(k_{n'}(L-z)) \sin(k_{n'}(L-z_s))] \quad (3)$$

Pointlike sources

We choose sources from a Pulsar and a SNR catalog in a 2kpc radius

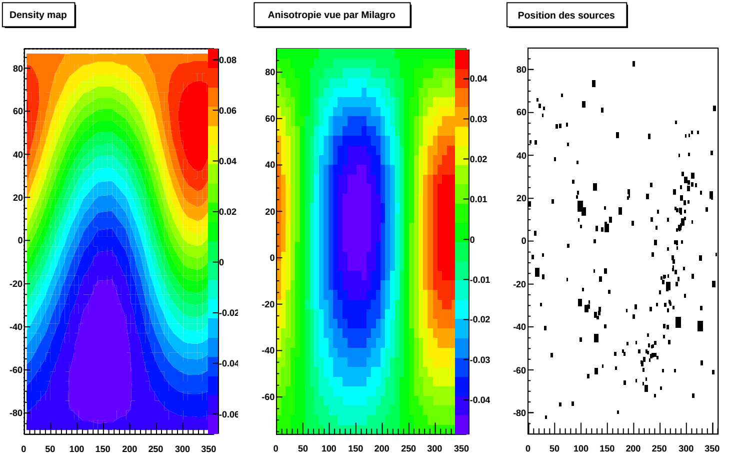


Figure: Anisotropie àt 6TeV

Pointlike sources

Comparison with milagro measurements

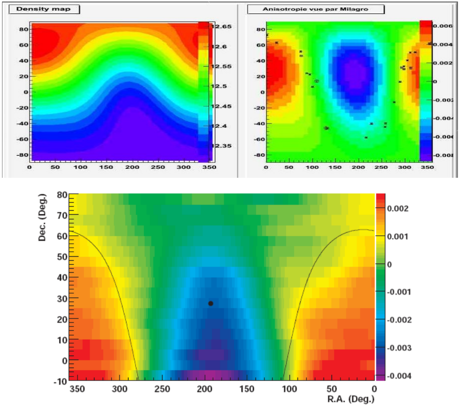


Figure: PRELIMINARY Results of the diffusion equation and Results from Milagro

→ The agreement is quite good

Pointlike sources

We compute the anisotropy for two different parameters set

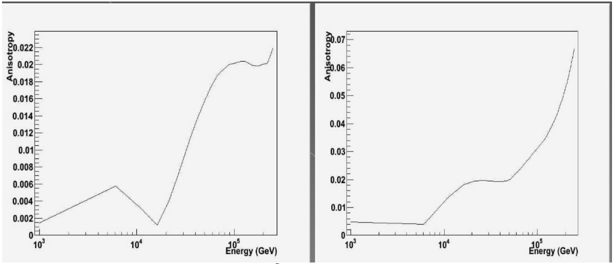
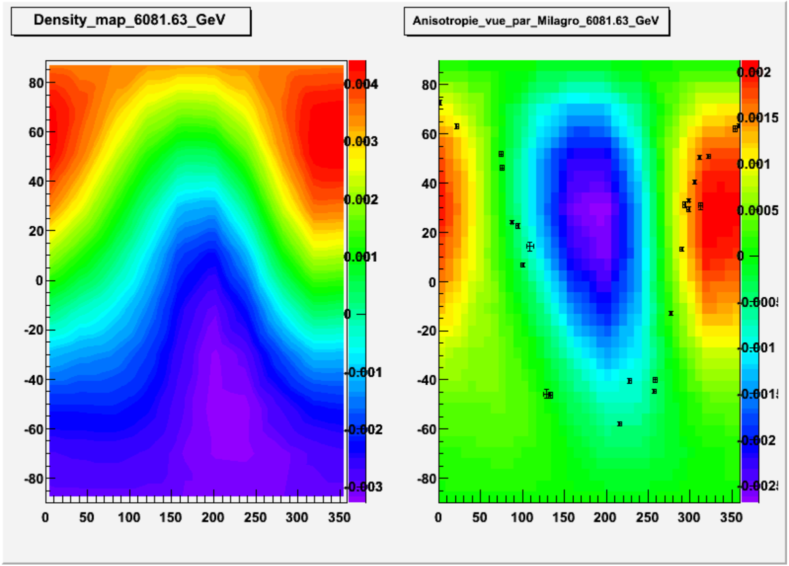


Figure: $K = K_0 \beta R_s^{\delta}$ with$\delta_s = 0.8$ and $\delta_s = 0.86$

$\rightarrow$ We can manage to have a good agreement with measurements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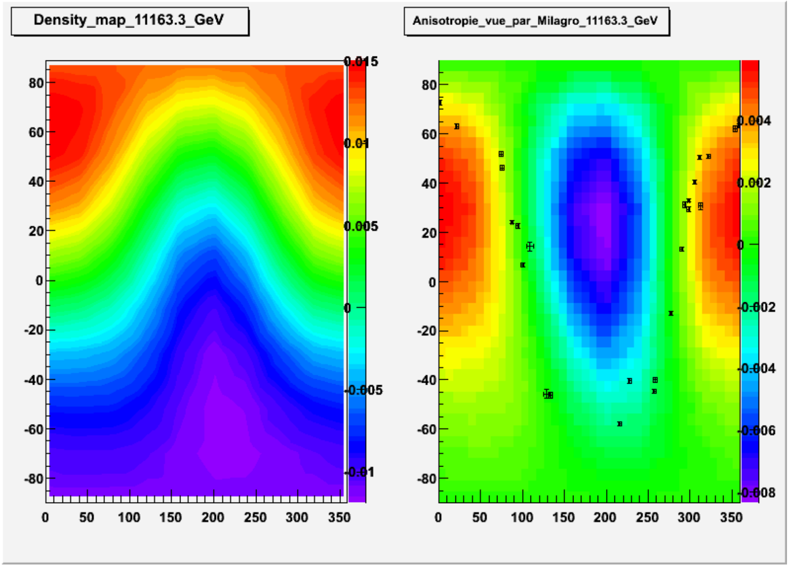
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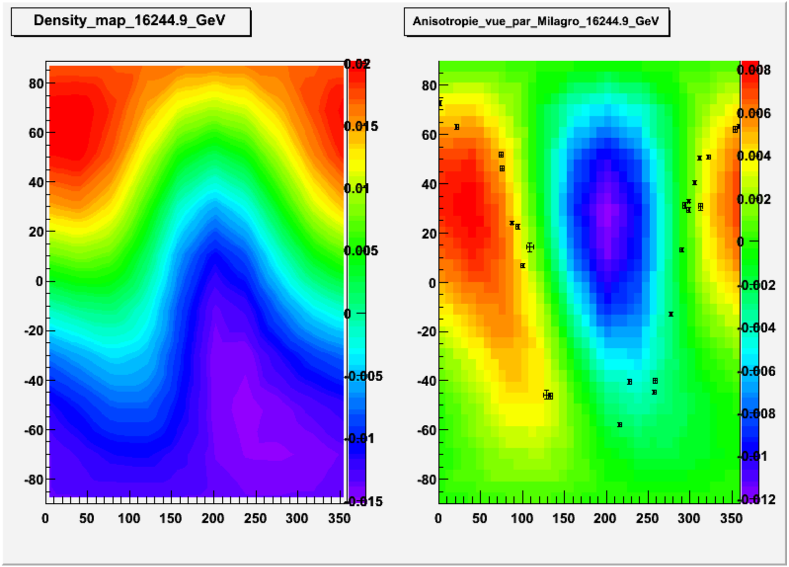
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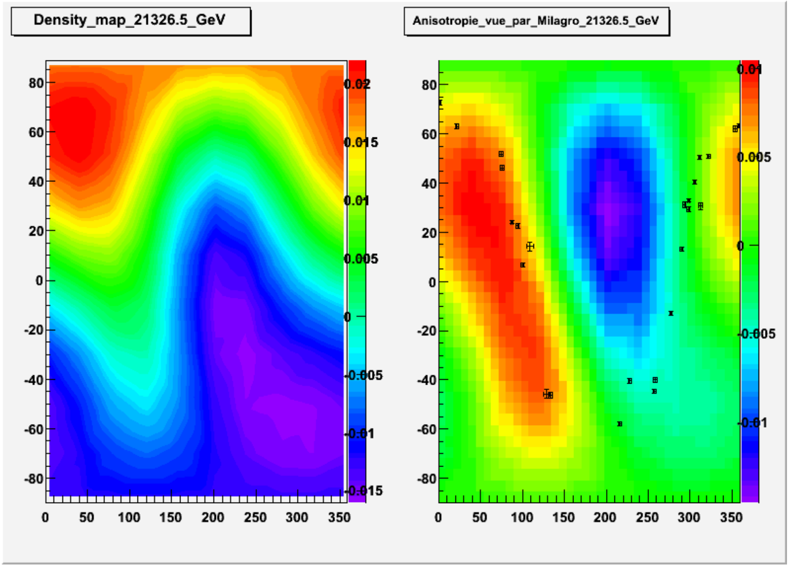
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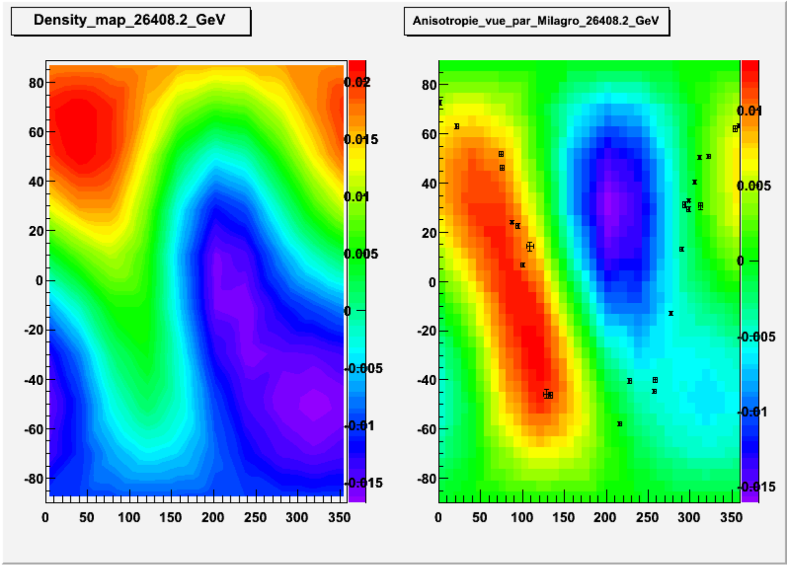
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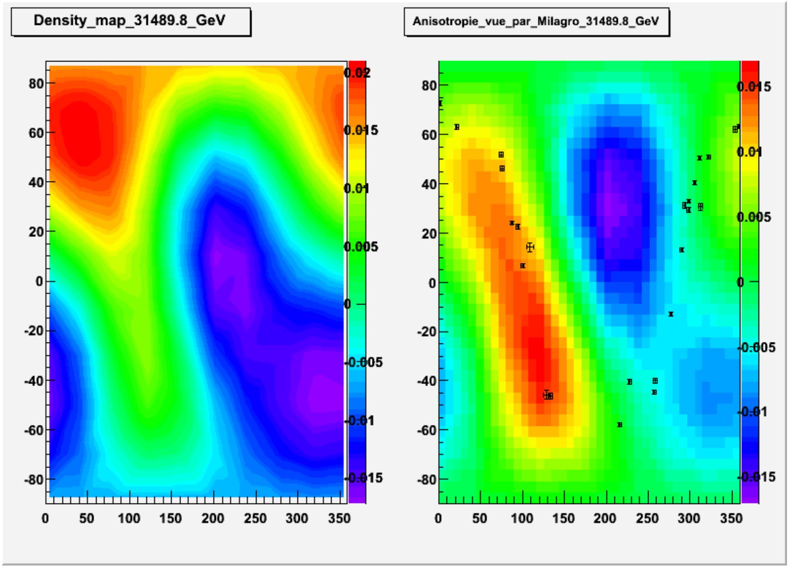
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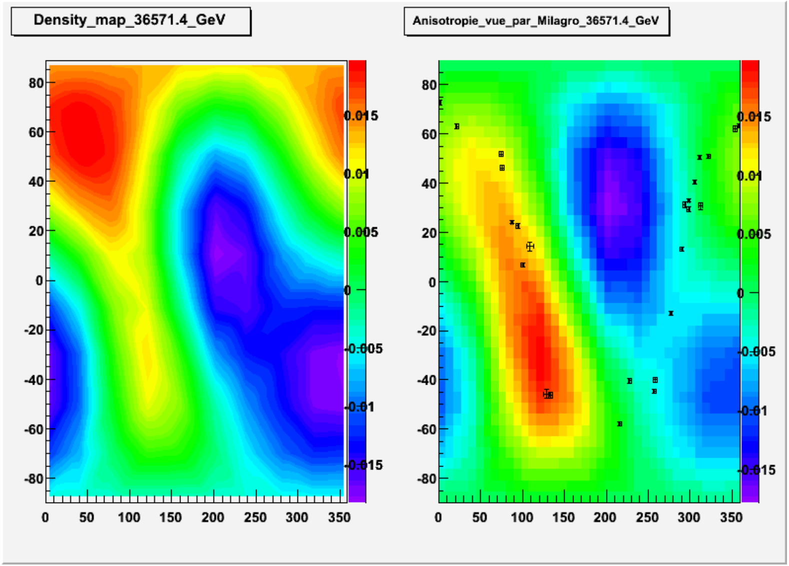
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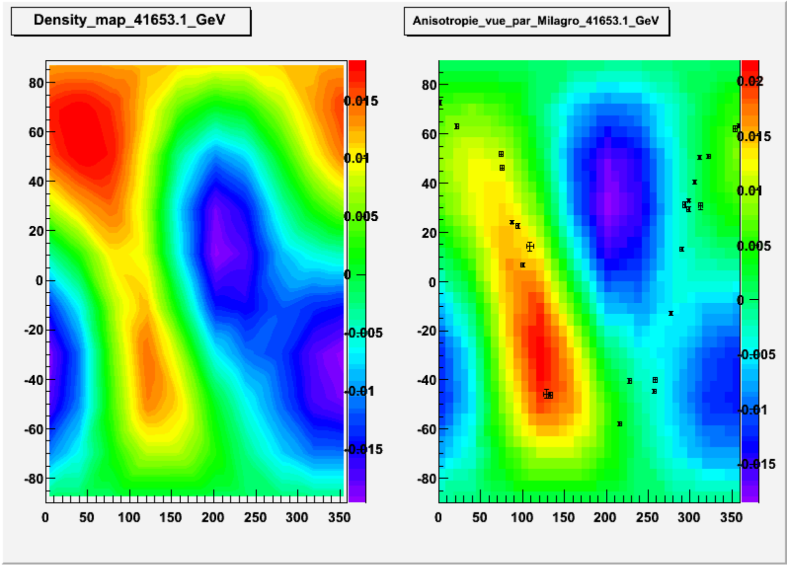
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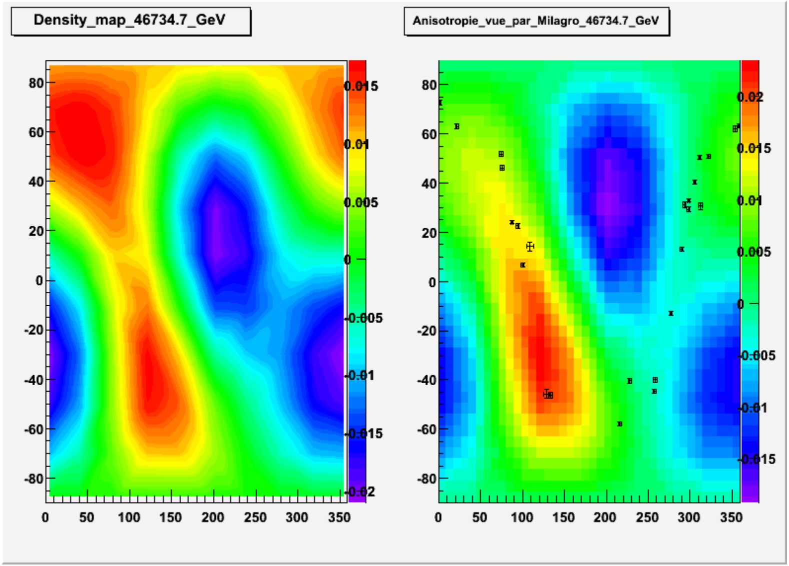
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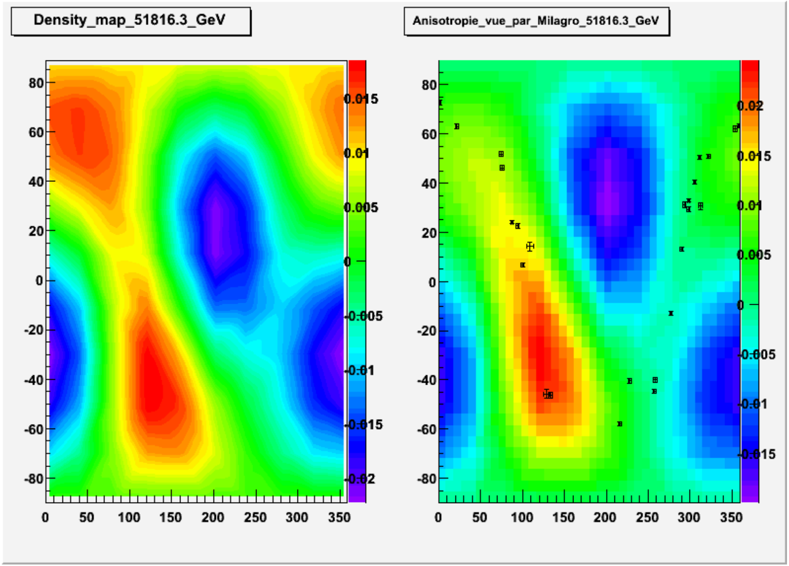
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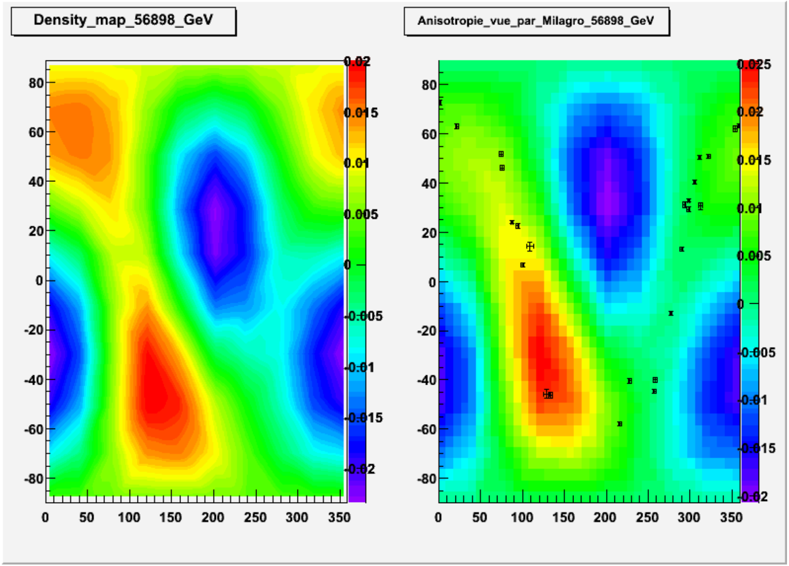
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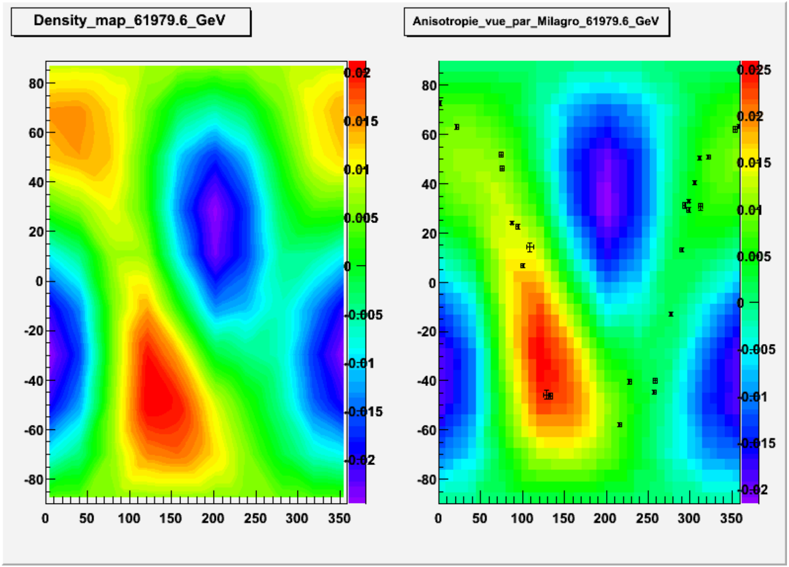
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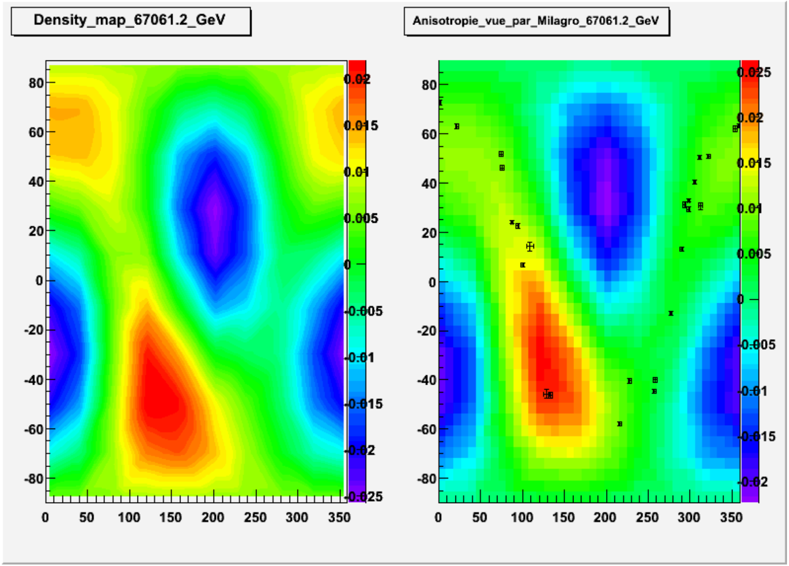
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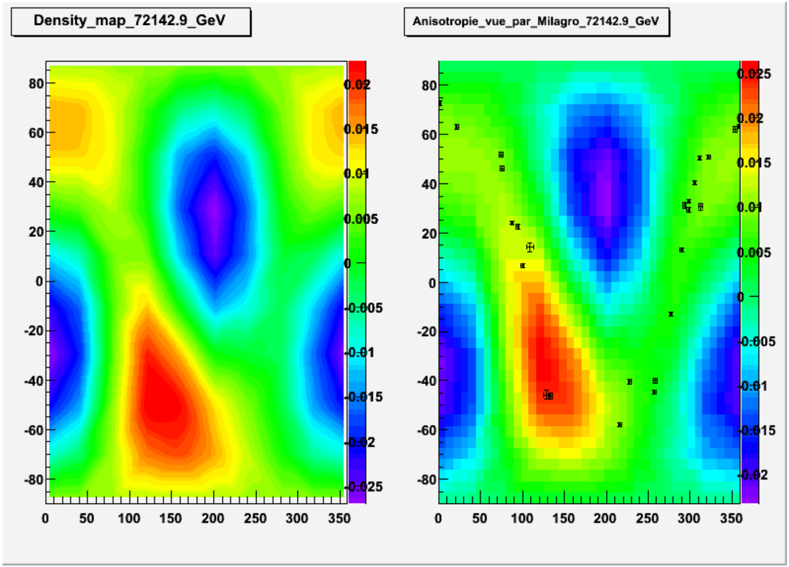
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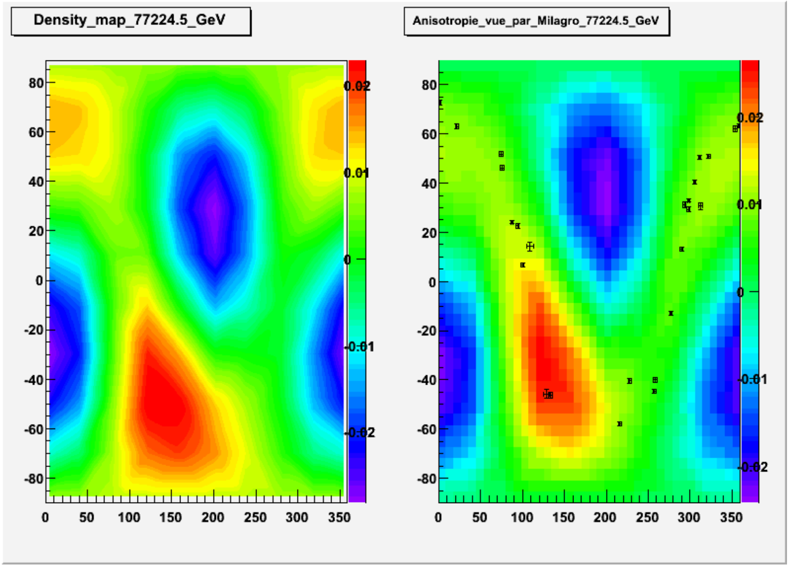
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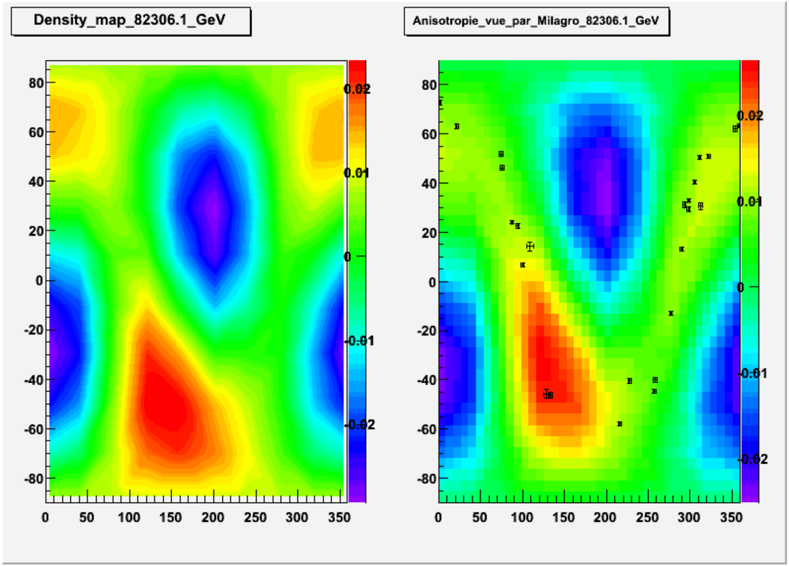
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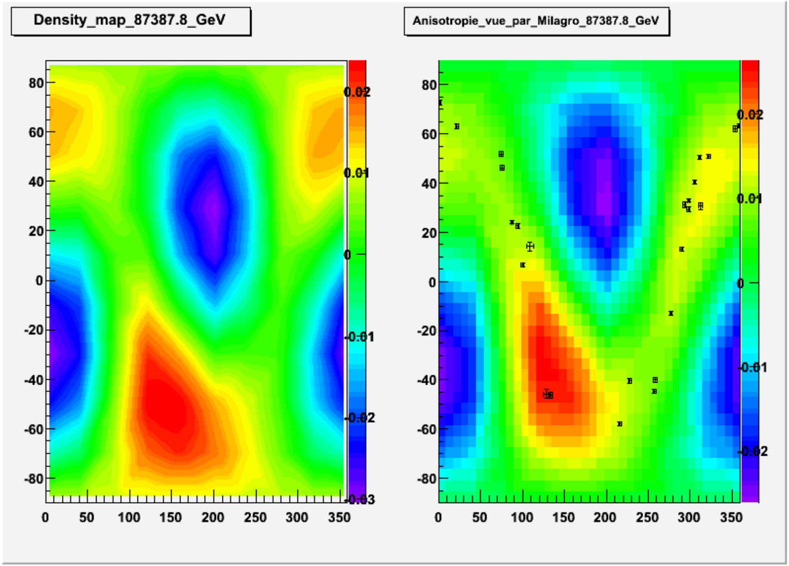
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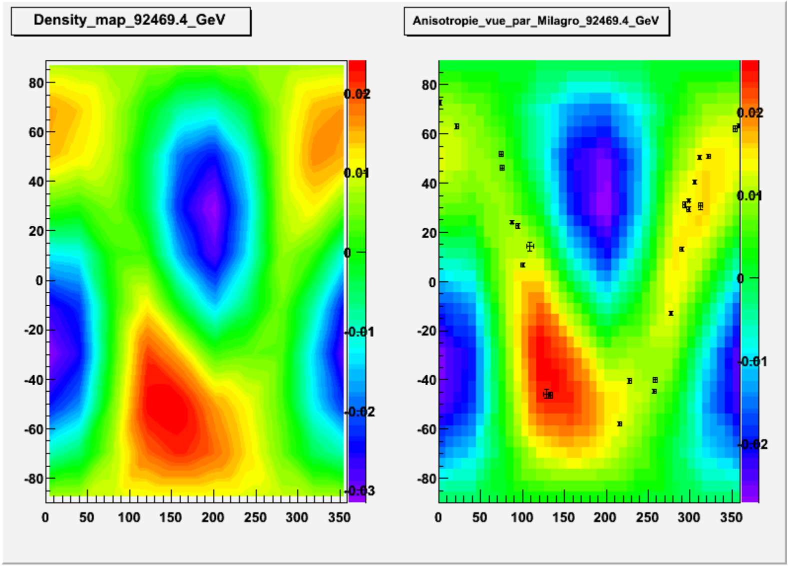
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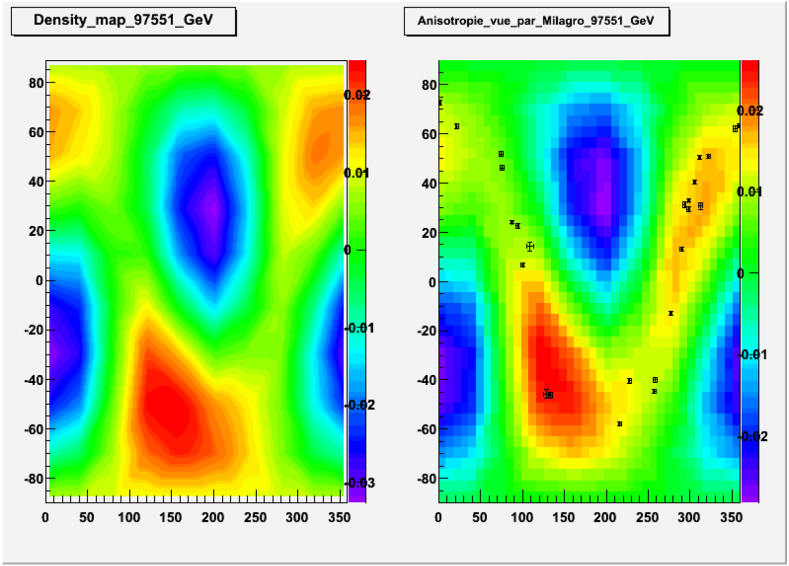
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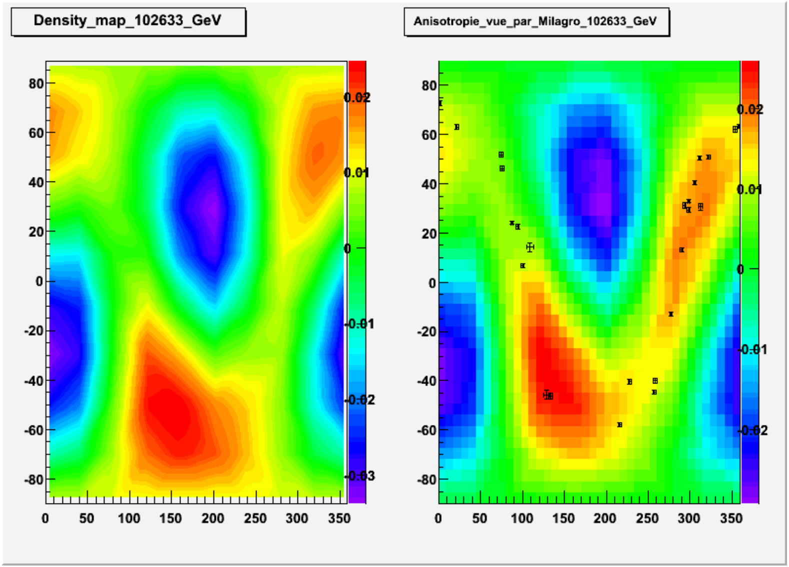
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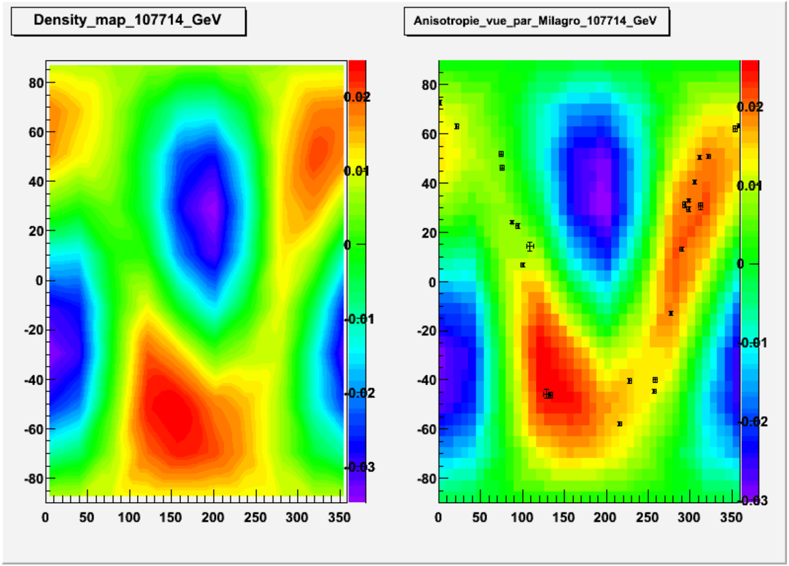
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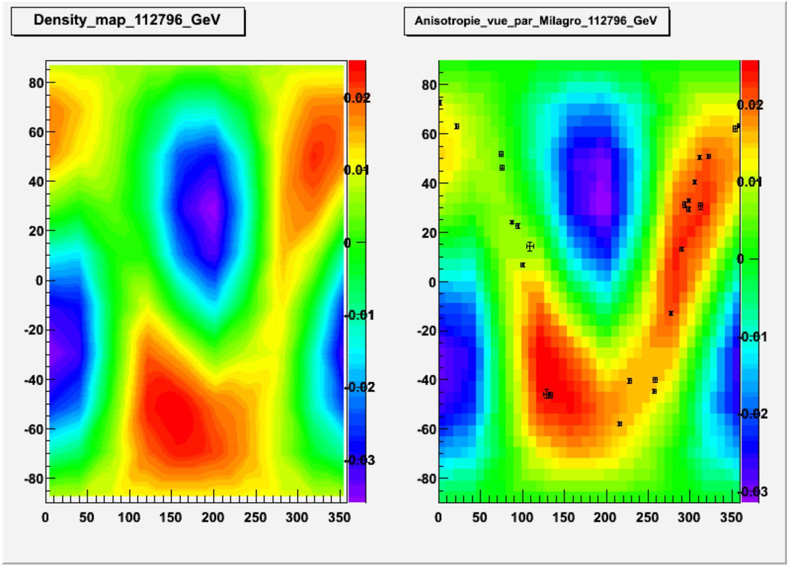
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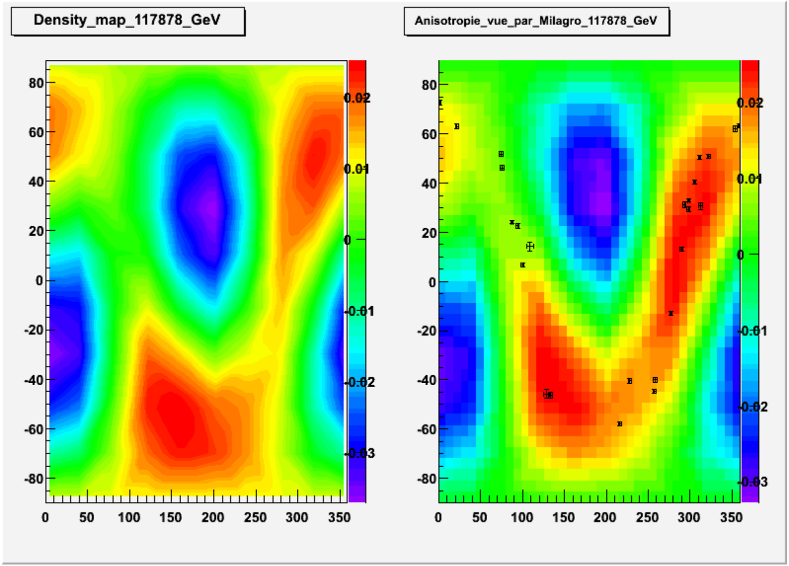
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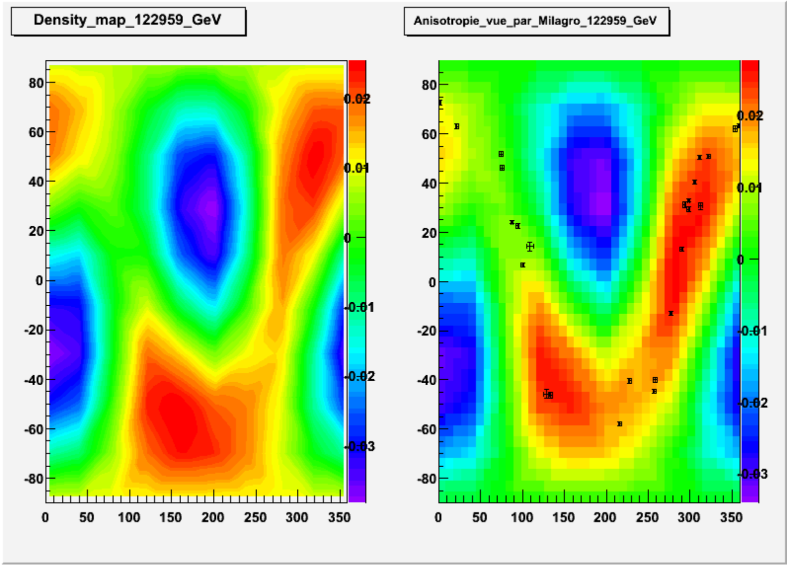
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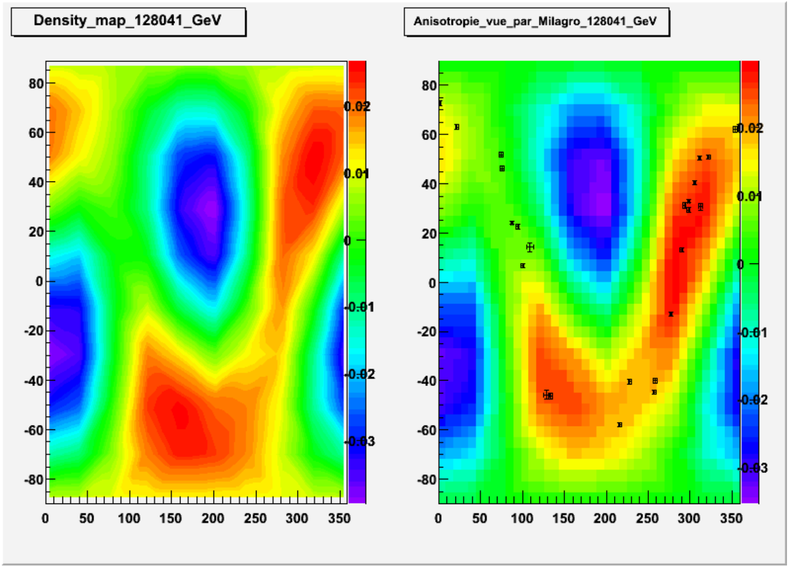
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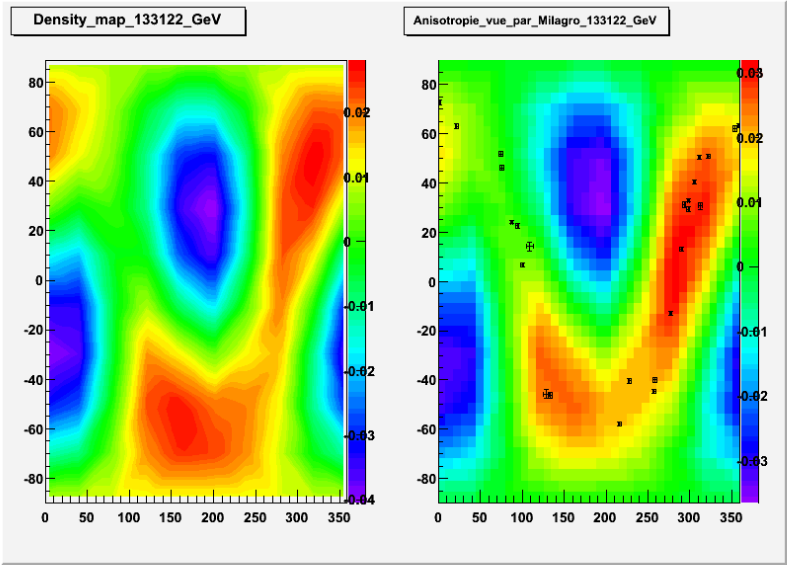
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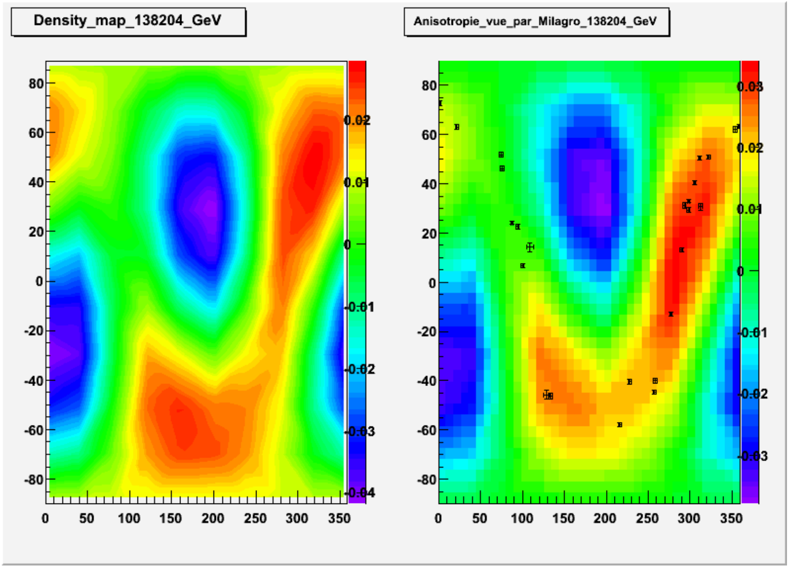
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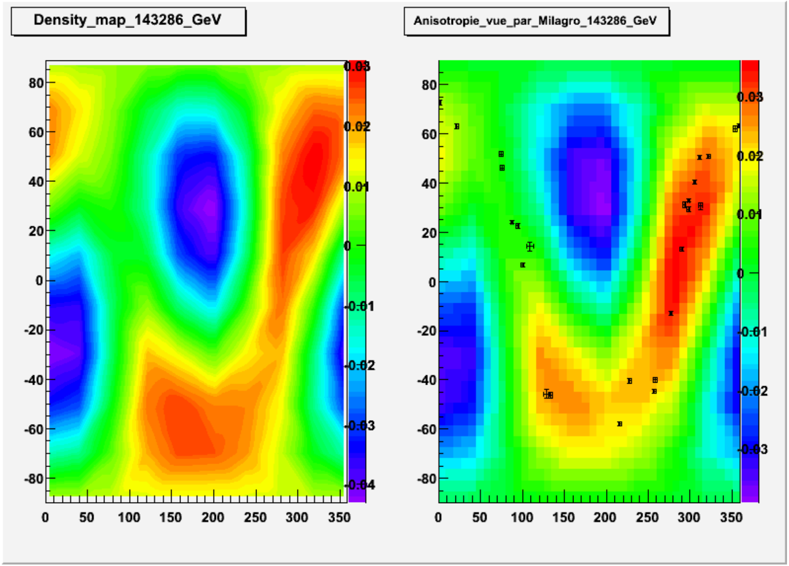
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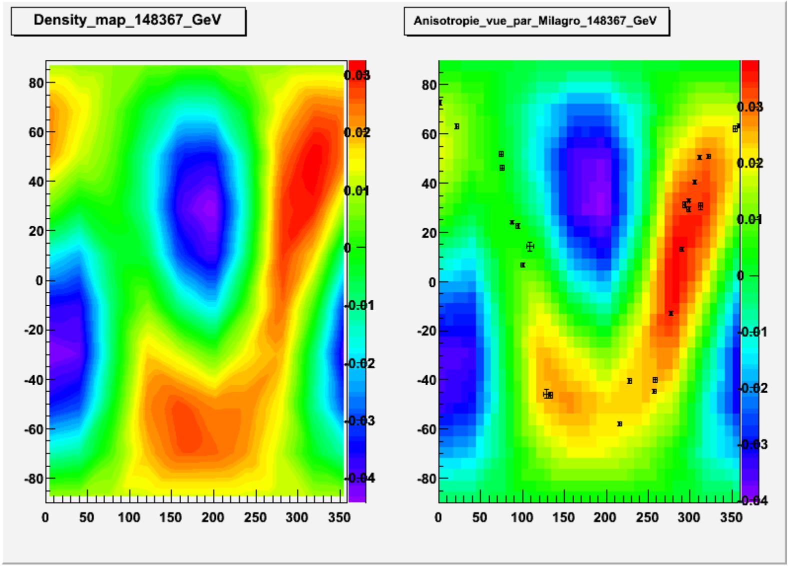
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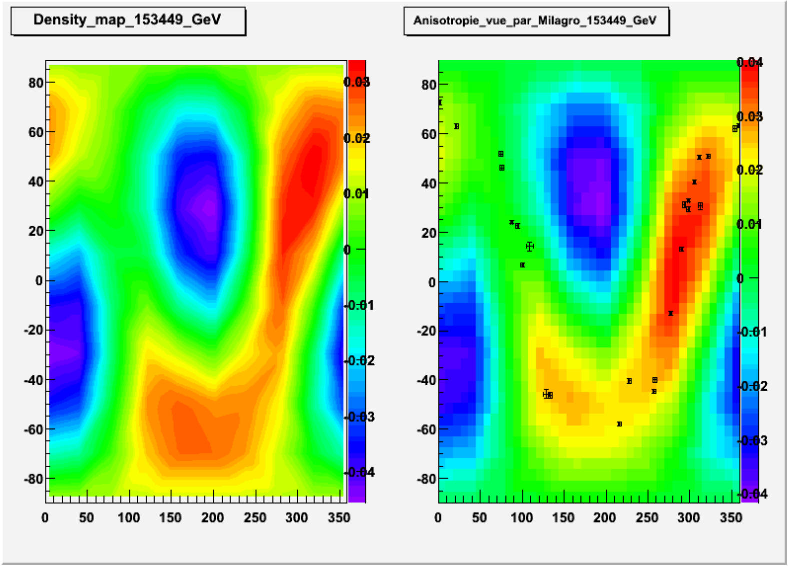
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Anisotropie_vue_par_Milagro_153449_GeV
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-0.04

Outline

Proton Flux

Aim : Try to explain the anomaly observed by PAMELA in the proton flux
Ideas : As we are choosing sources from a catalog and randomly, this should induce a variance in the flux, so that a slight change in the flux is not forbidden by the model

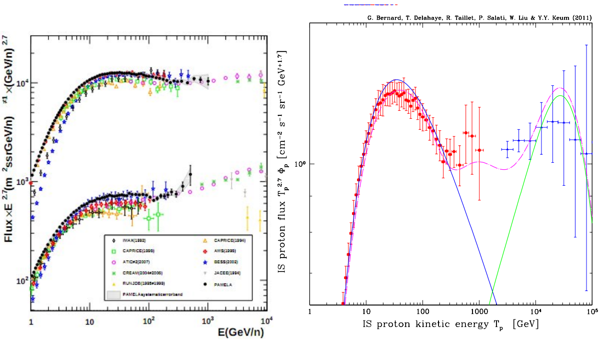

Figure: Proton Flux as observed by PAMELA Colaboration. arxiv:1103.4055, our calculations

Conclusion and prospects

- The model can constrain δ_s but still need to check the energy dependance
- We need to do the calculations with Heliums and electrons
- Influence of the local bubble and others local effects
- Influence of continuous injection of cosmic rays in the insterstellar medium
- Limit of the models (mean free path $>$ distance of the sources) ?
- Higher orders than dipole ?