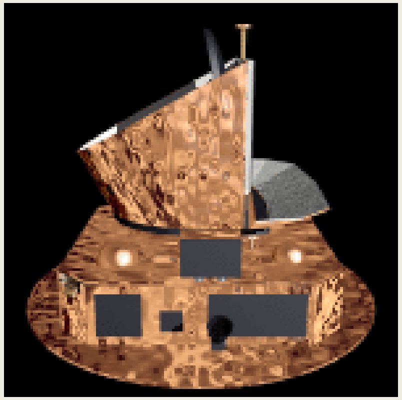
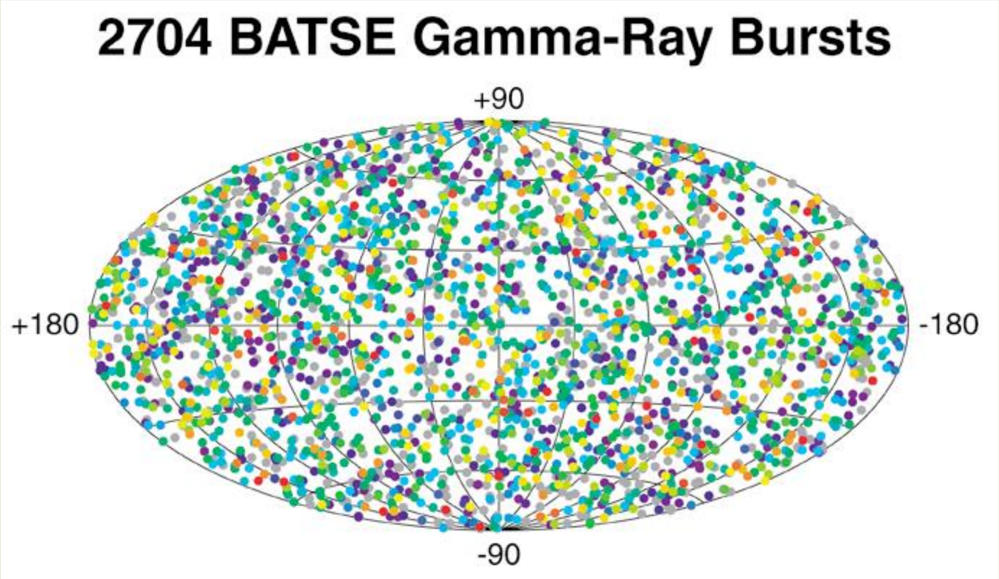
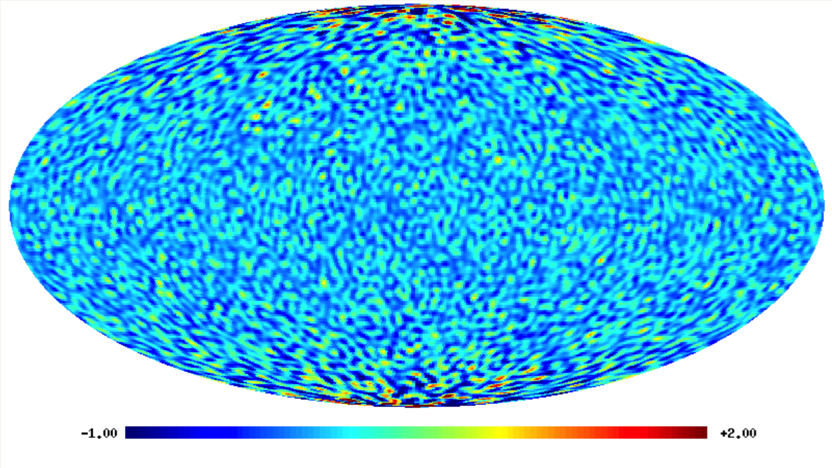
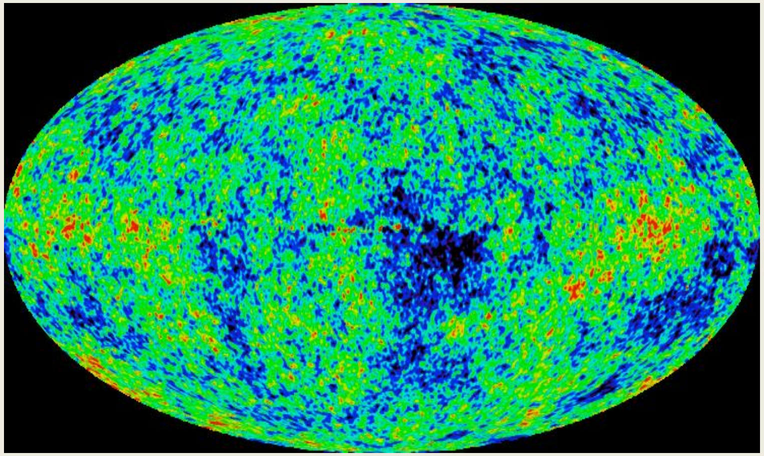
DISCOVERY ALICE-HEP-PLANCK TEAM







ALICE model



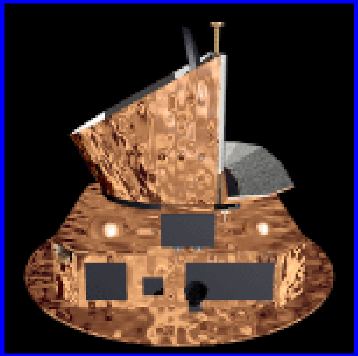
CMB

Morphology of HIC single event.

P. Naselsky &

PLANCK, NBI &DISCOVERY Center team

The DISCOVERY Team



- Per Rex Christensen
- Anne Mette Freisel
- Poul Henrik Damgaard
- Jens Jørgen Gaardhøje
- Pavel Naselsky
- Bastian Poulsen
- Oleg Verkhodanov
- Christian Holm Christensen
- Kris Gulbrandsen
- Martin Hansen


MMM...V_n ?
Only a few around here know how to read and write, Sir!
DON'T SHOOT THE PIANO MAN
search ID: dbnn161
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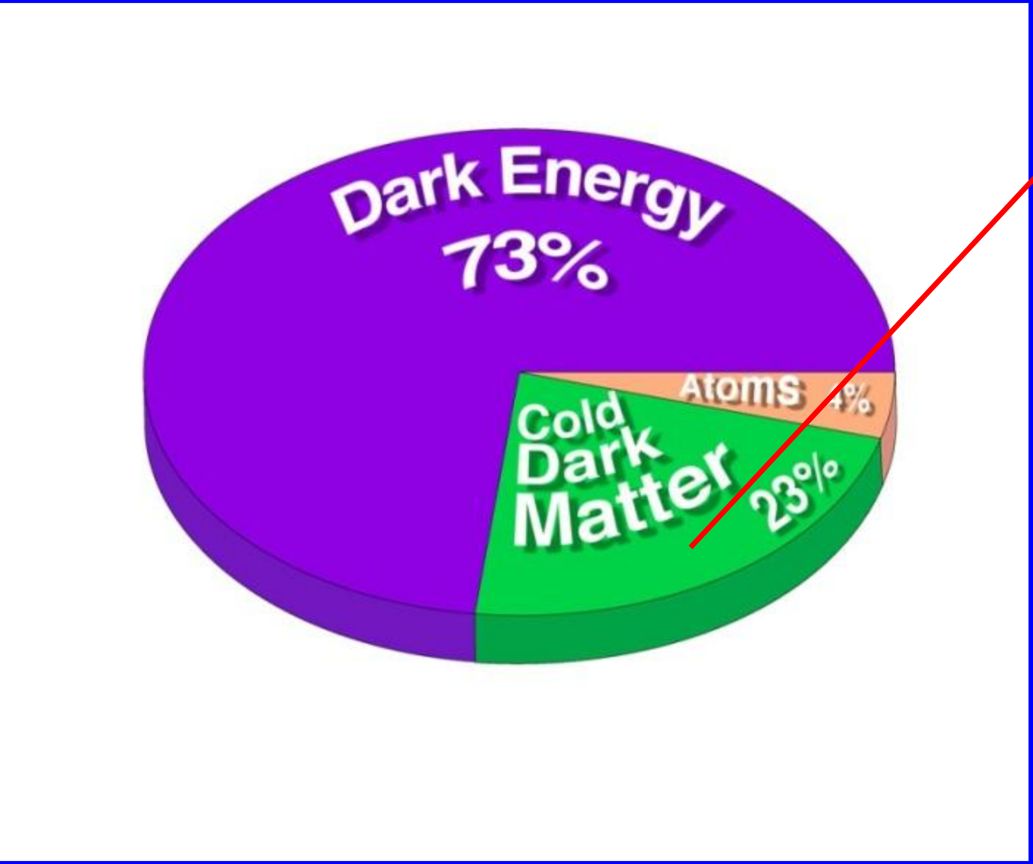
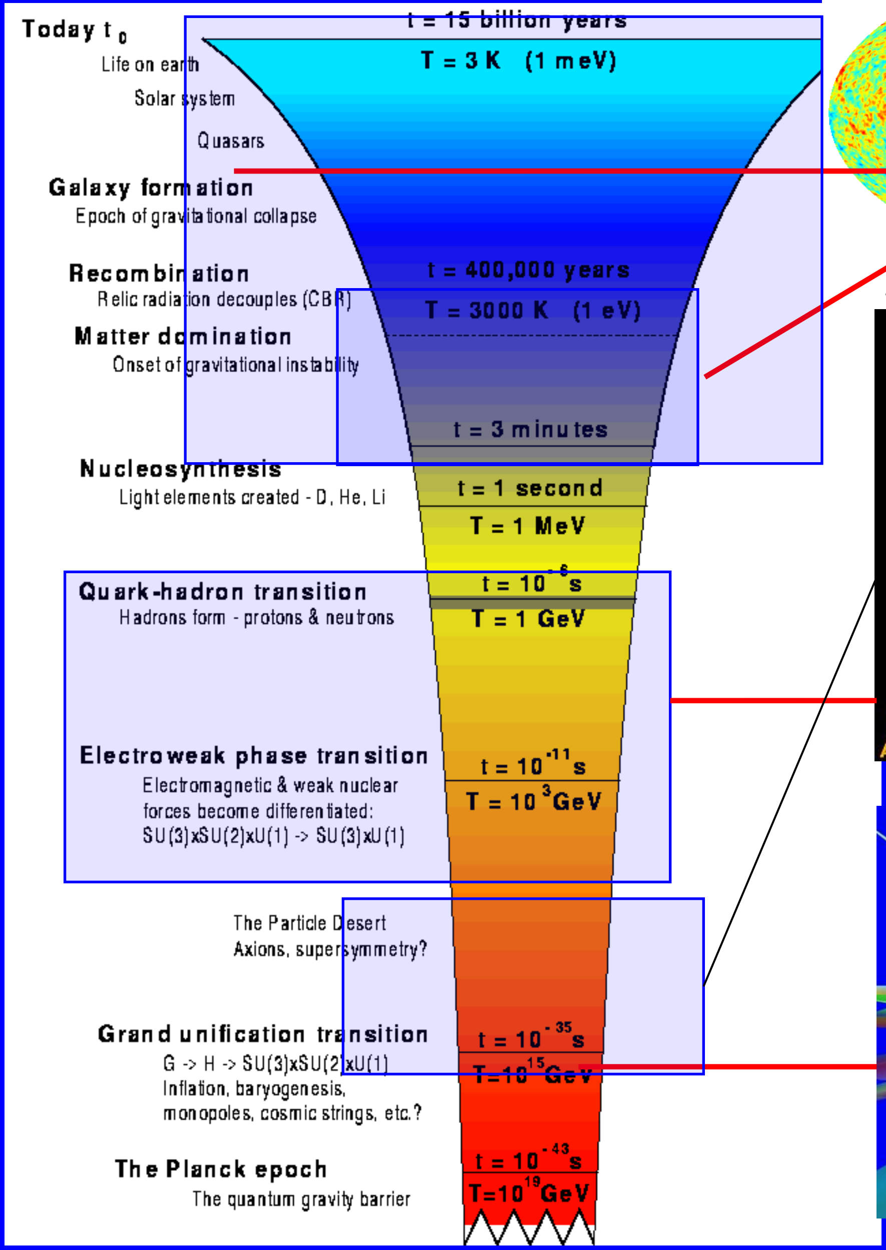
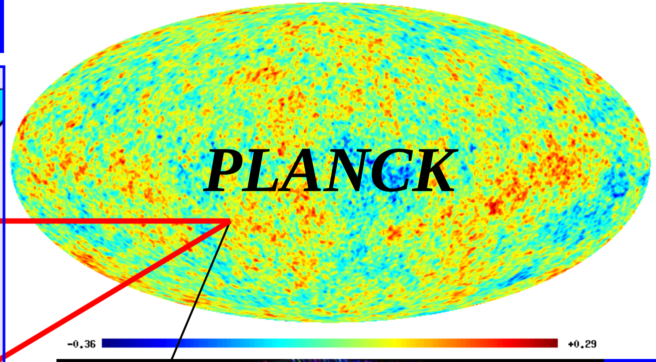
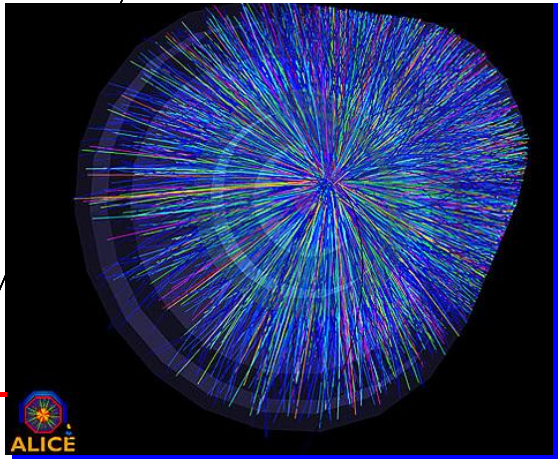
Why the Universe is DARK ?

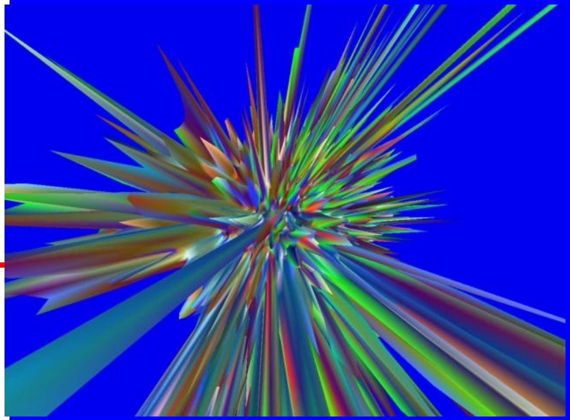


Isocurvature perturbations from the QCD phase

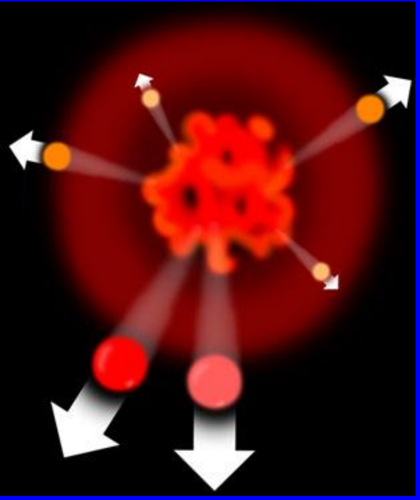




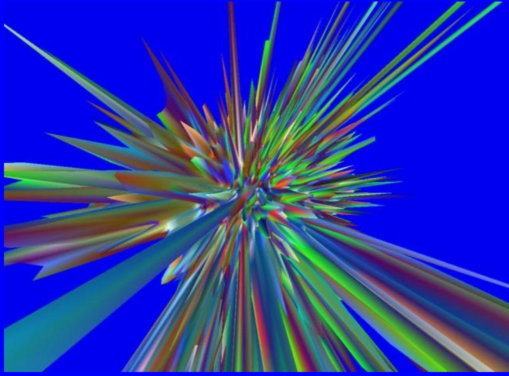


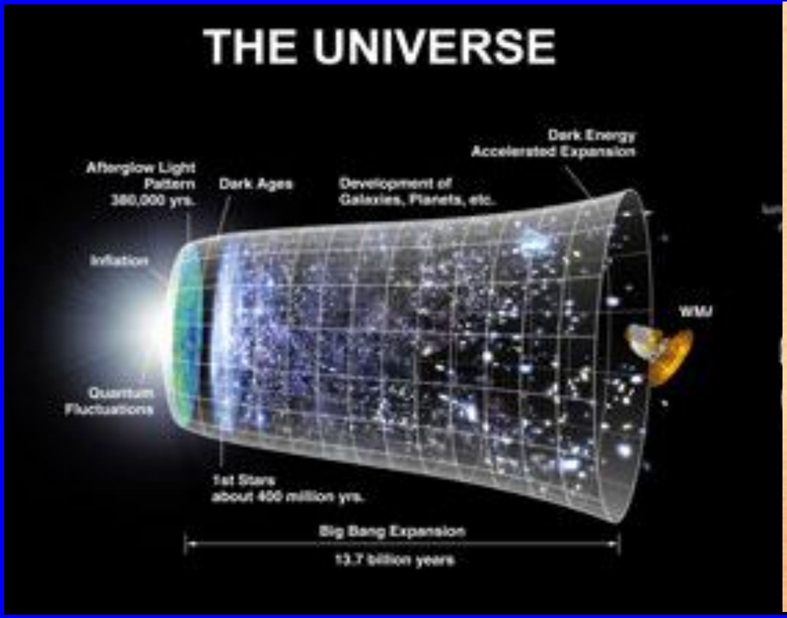


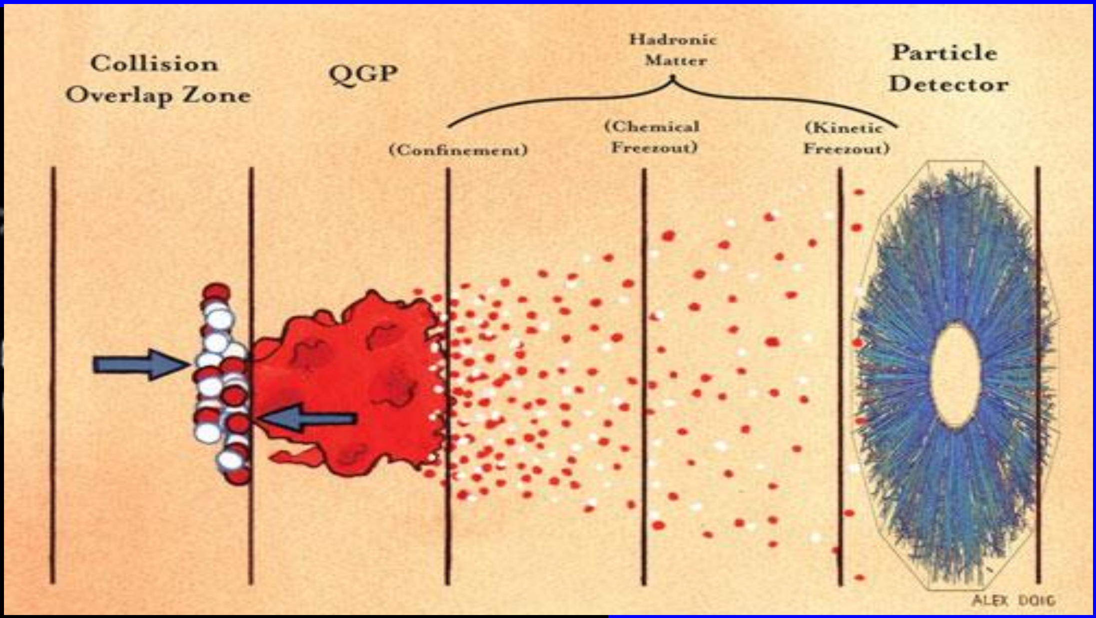
Theory of Inflation



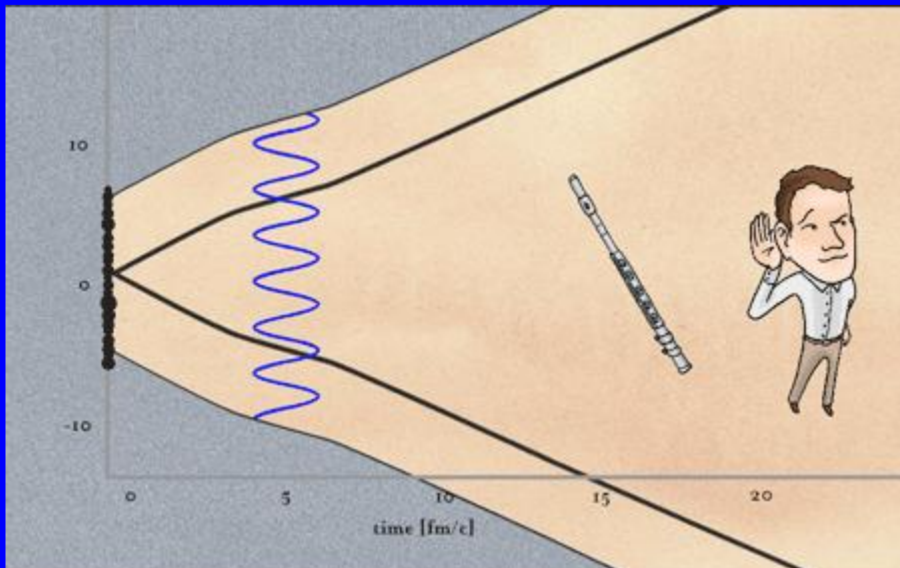
HIC-CMB similarity

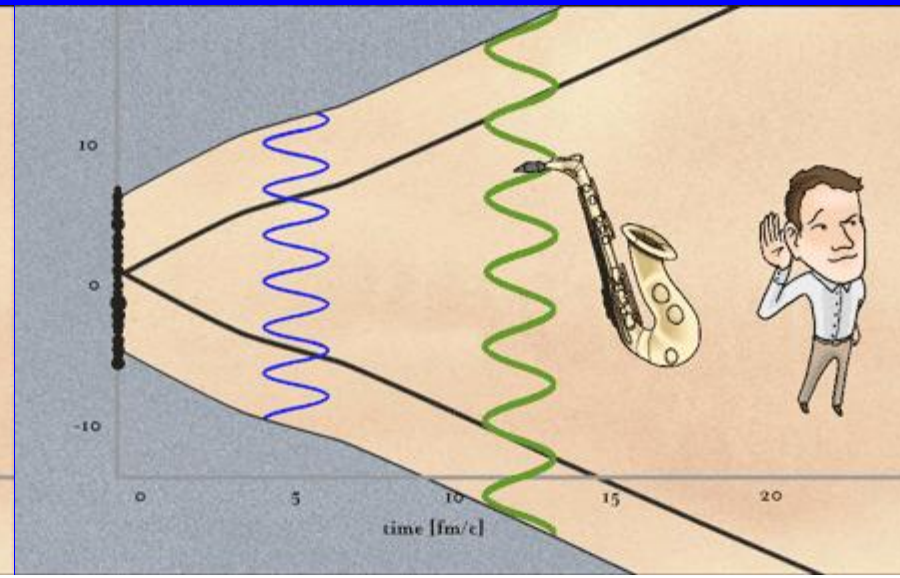


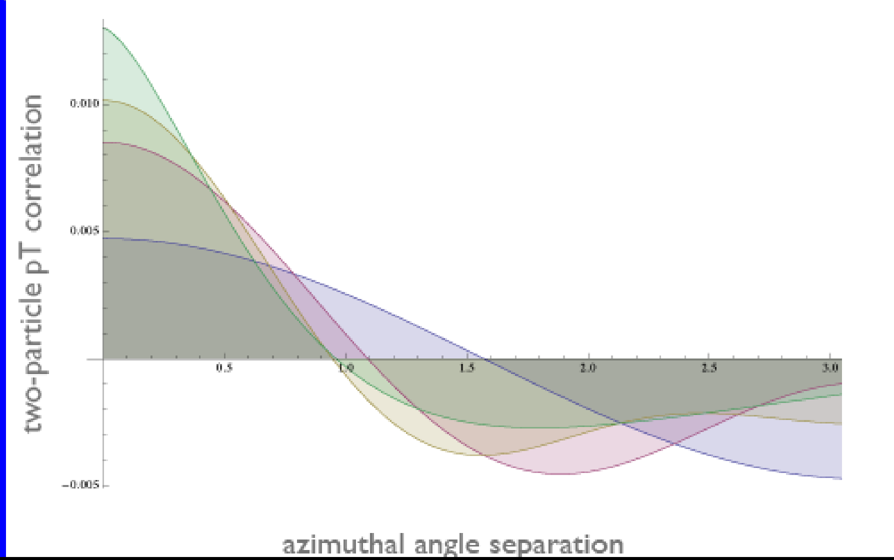


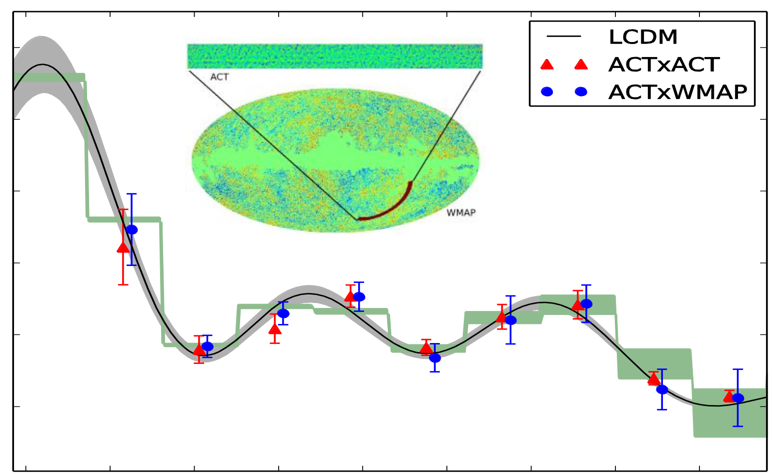


Hearing the sound









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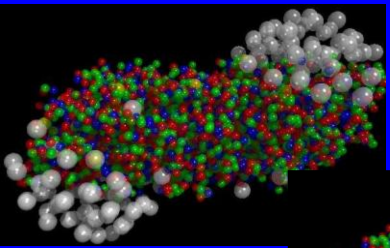
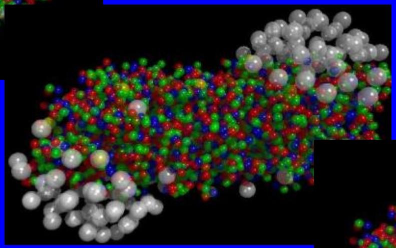
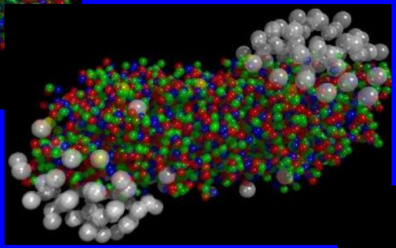
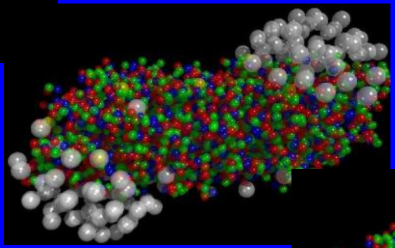
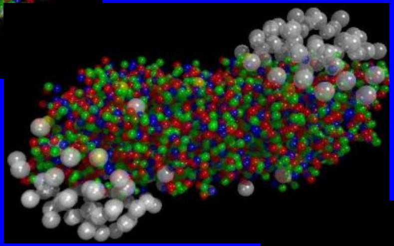


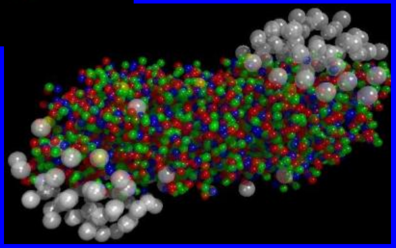


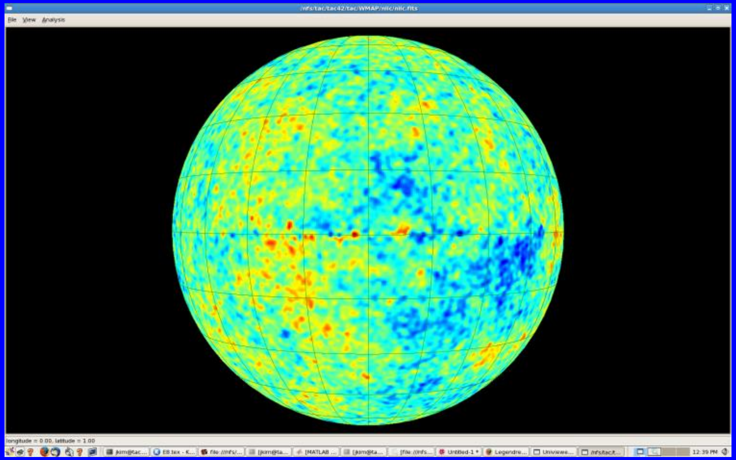
Statistical ensemble







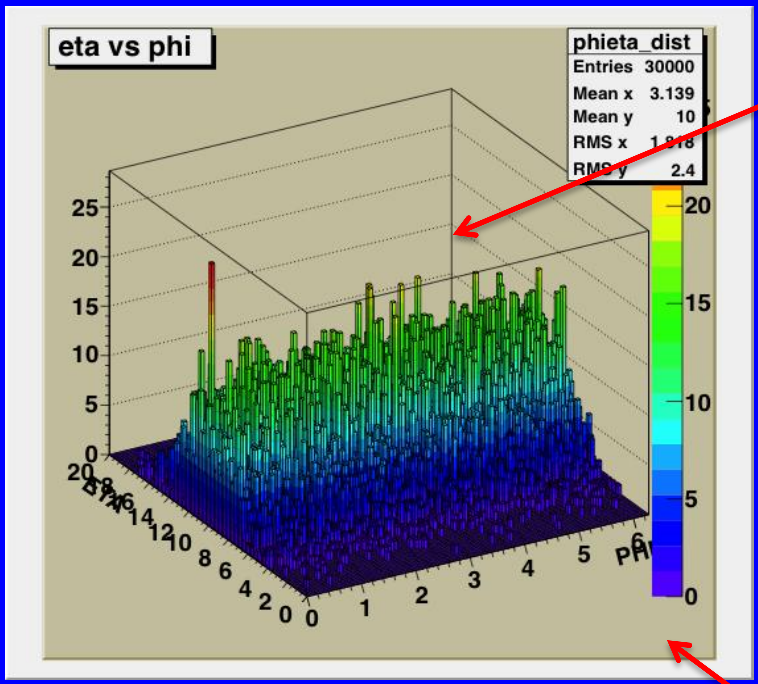


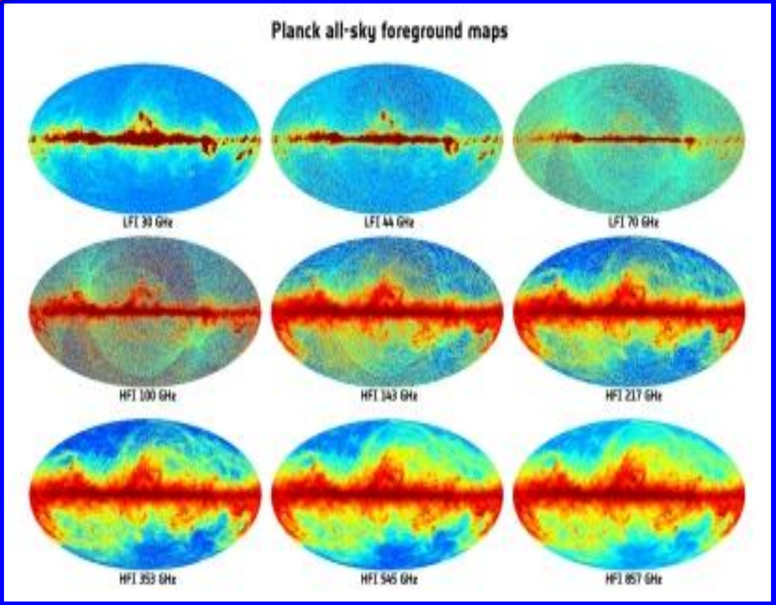


The only one realization of the CMB sky

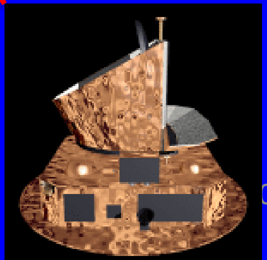
Pseudo-rapidity:
$\eta = -\ln(tg(\theta/2))$

Mapping the data

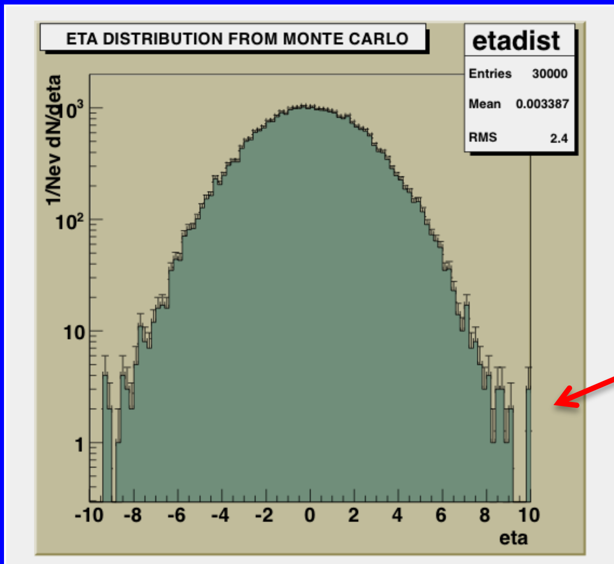




M(x,y,S)=0

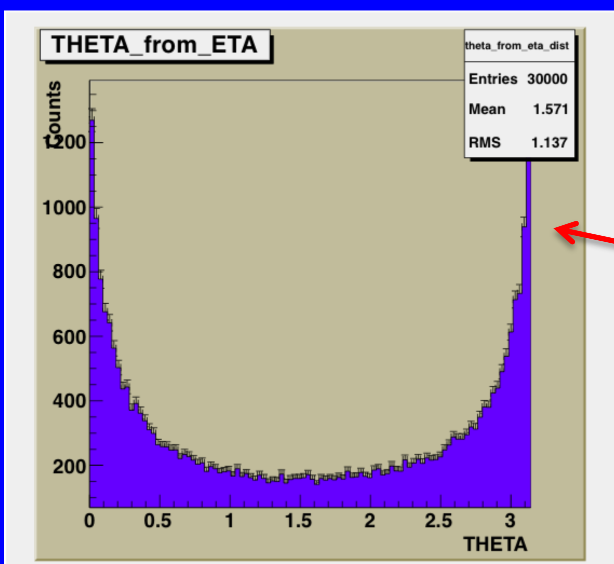


Simulating the number of produced particles in HI collisions

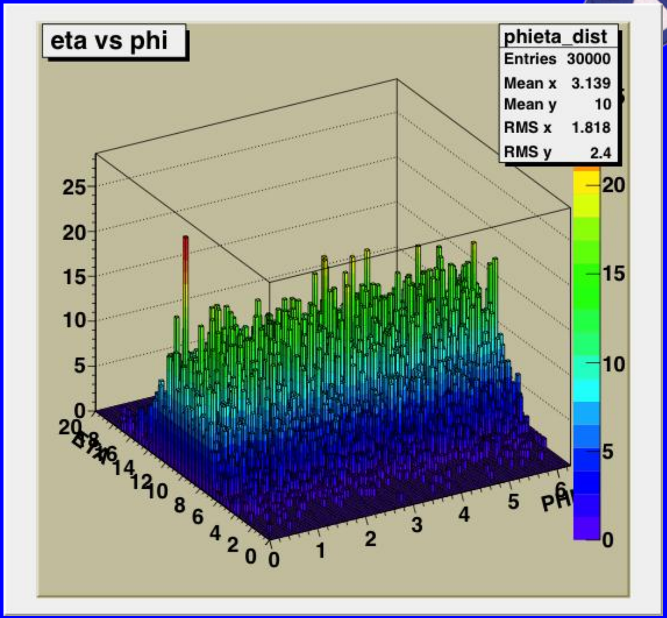


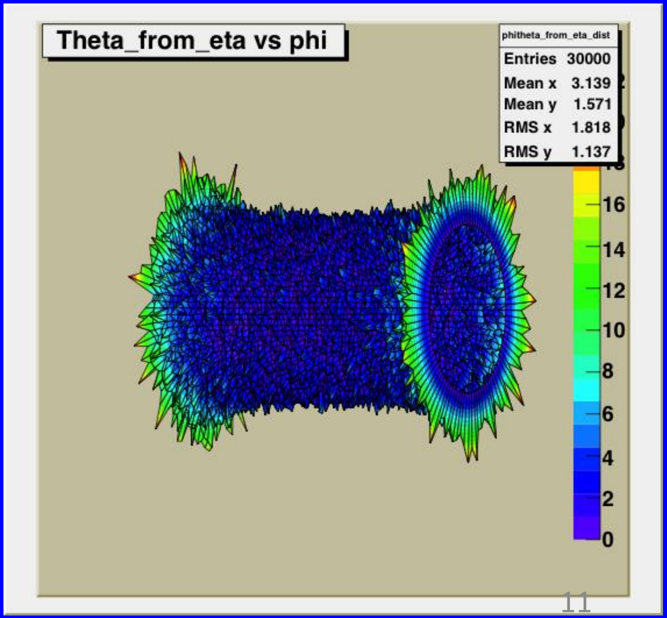
Pseudo-rapididity distribution: dN/dη

Pseudo-rapidity: η=-ln(tg(θ/2))



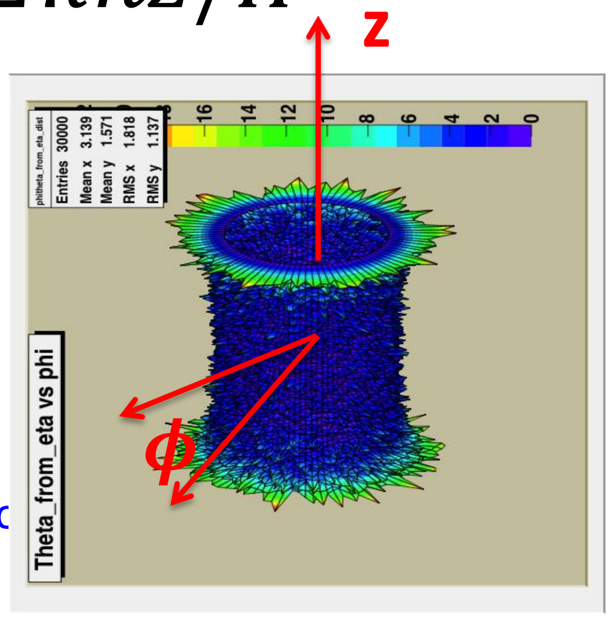
Polar angle distribution: dN/dθ





Morphological analysis in terms of eigenfunctions of cylinder

$$S(z,\phi)=\sum_{n,m}^{\infty} S_{n,m}\, e^{im\phi+i2\pi nz/H}$$



$$S(z=H/2,\phi)=S(z=-H/2,\phi)$$

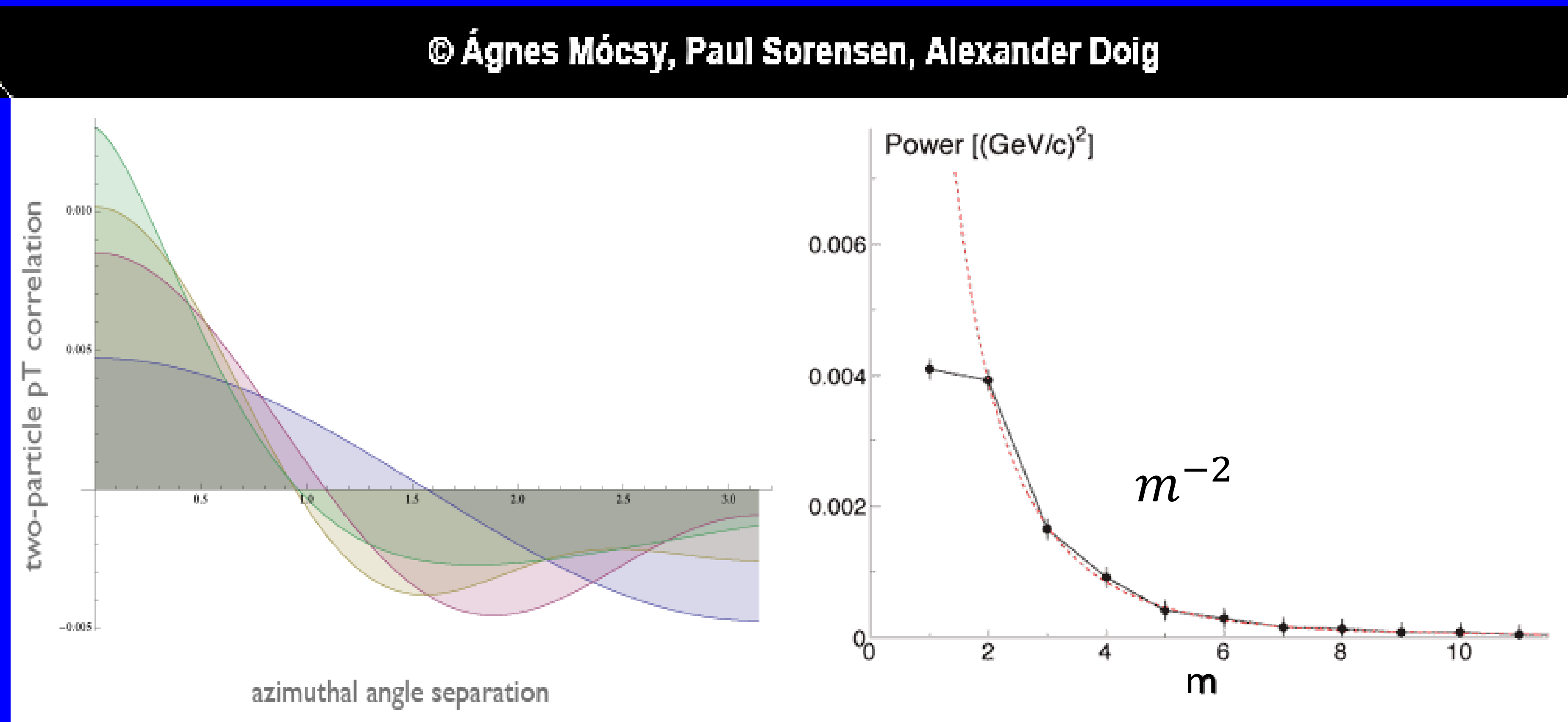
$$z=R\cot(\theta)=\frac{R}{2}\left(e^{\eta}\text{-}e^{-\eta}\right)$$

Power spectrum

$$P(\mathrm{n})=\frac{1}{2\pi}\sum_{m}^{\infty}\left|S_{n,m}\right|^{2}\ \underset{FFT}{\Longrightarrow}\ \mathbf{C(\Delta\eta)}$$

Power in φ-direction

$$P(\mathrm{m}) = \frac{1}{2\pi}\sum_{n}^{\infty}|S_{n,m}|^2$$



Transition from cylinder to sphere

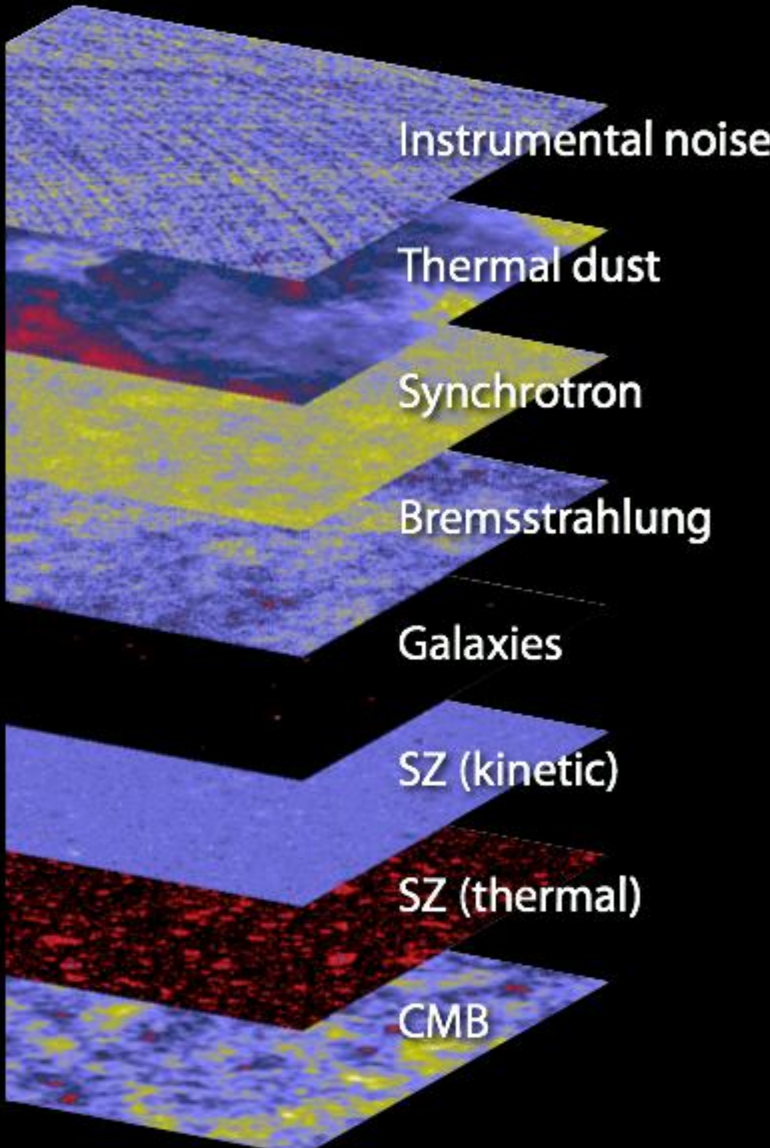
$$e^{i\vec{k}\vec{r}} = 4\pi \sum_{l,m} i^l j_l(|k||r|) Y_{lm}(\hat{k}) Y_{lm}(\hat{r})$$

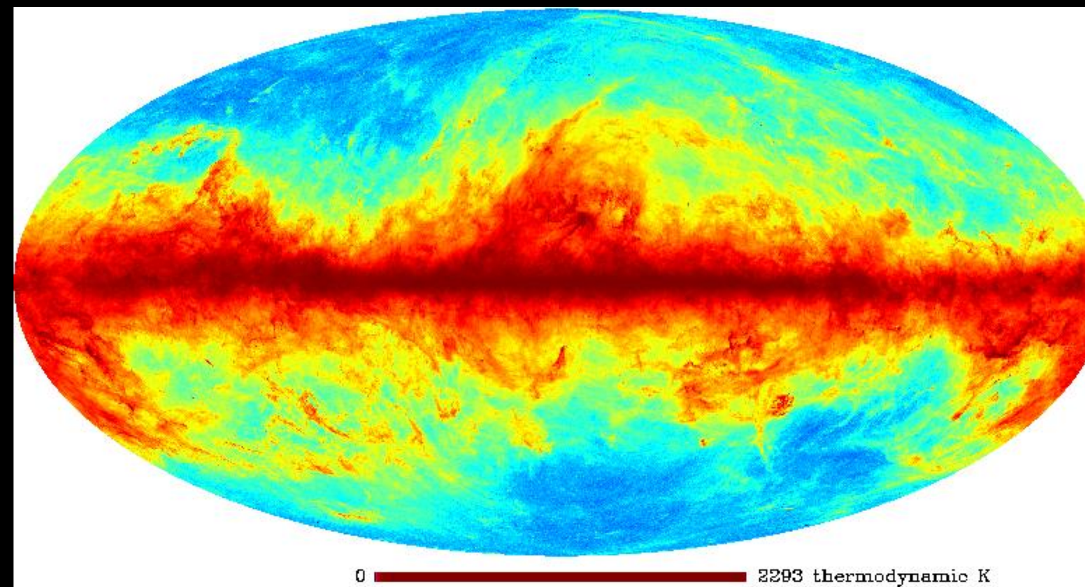
where $\hat{r} = (\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta)$

Re-mapping

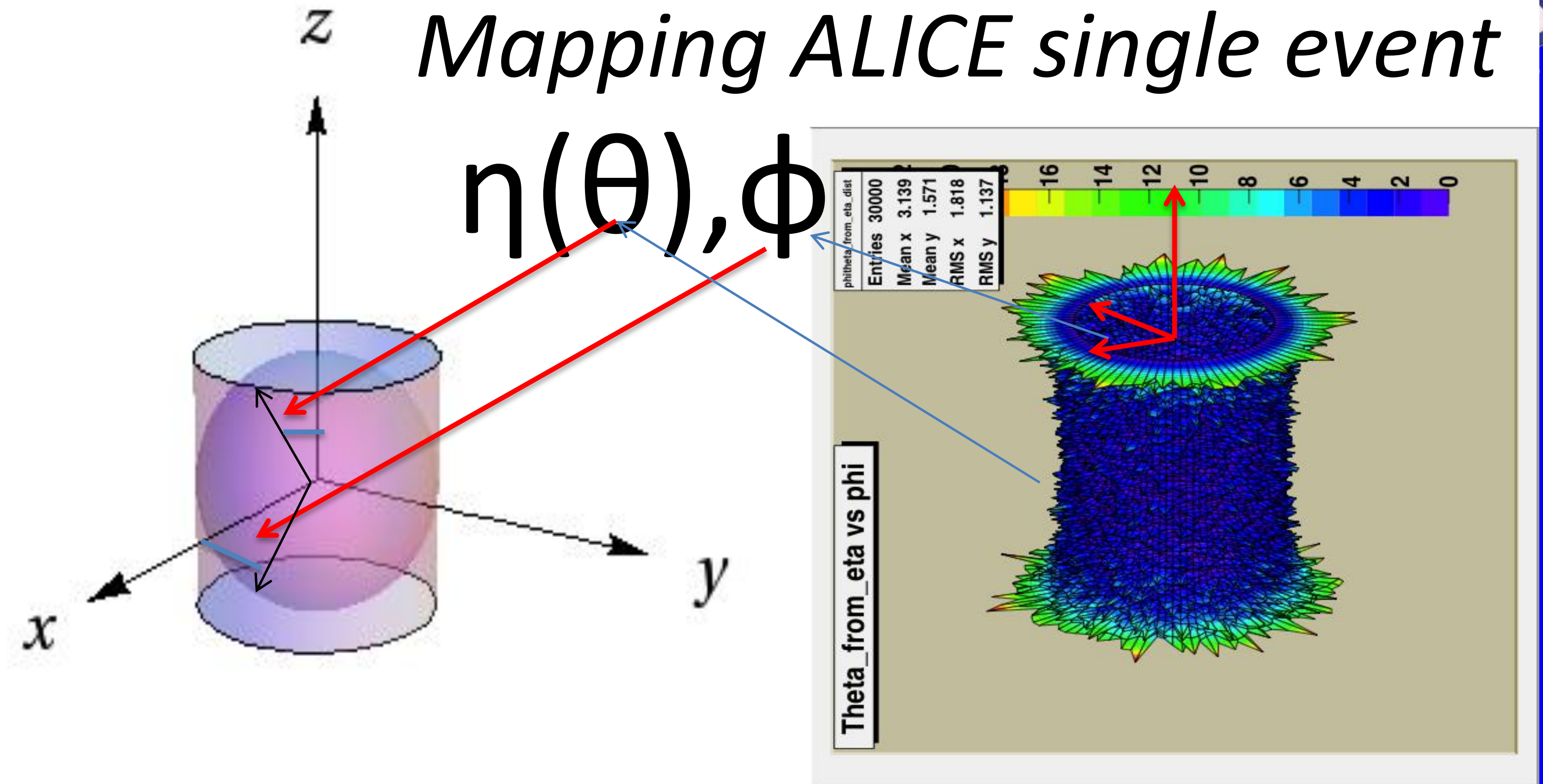
$\eta, \phi \Leftrightarrow \theta, \phi$

?


Instrumental noise
Thermal dust
Synchrotron
Bremsstrahlung
Galaxies
SZ (kinetic)
SZ (thermal)
CMB


0
2293 thermodynamic K

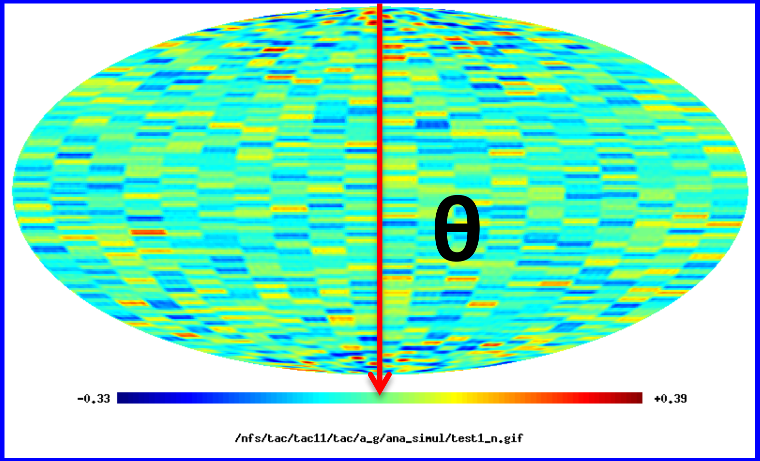
Mapping ALICE single event

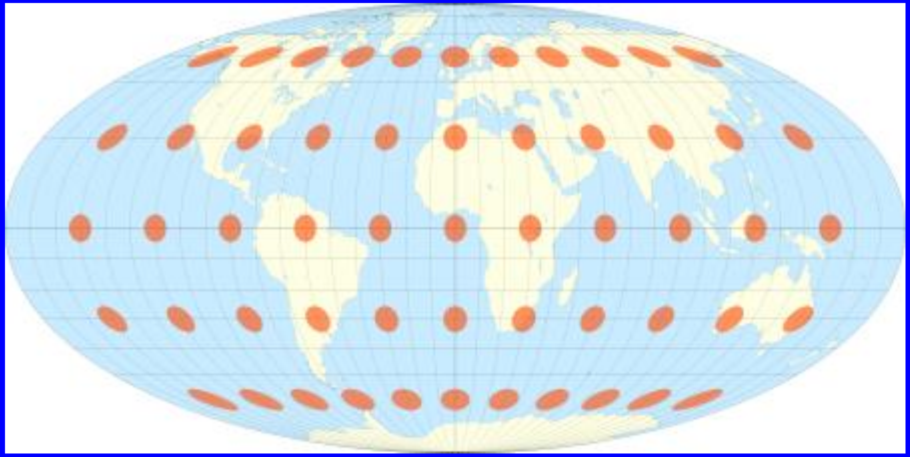


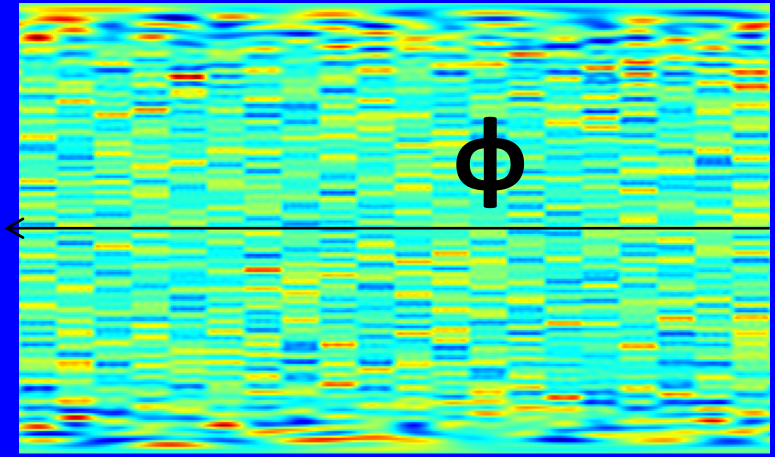
We look at the Universe from the inside of the celestial sphere: from the Earth.
We have but ONE Universe to look at.

We look at the HI mini-verses from the outside of a sphere : the ALICE detector.
We create a new mini-verse 1000 times/sec.

Molldweide projection versus rectangular one







Morphological analysis in terms of spherical harmonics

l= 2π / θ

$$\Delta T(\theta,\phi)=\sum_{l=2}^{\infty}\sum_{m=-l}^{m=l}a_{l,m}Y_{l,m}(\theta,\phi)$$

$$a_{l,m}=\int_{-1}^{1}dx\int_{0}^{2\pi}d\phi\Delta T(\theta,\phi)Y^{*}_{l,m}(x,\phi)$$

Power spectrum

$$C(l)=\frac{1}{2l+1}\left[|a_{\ell 0}|^2+2\sum_{m=1}^{l}|a_{l,m}|^2\right]$$

GLESP analysis package

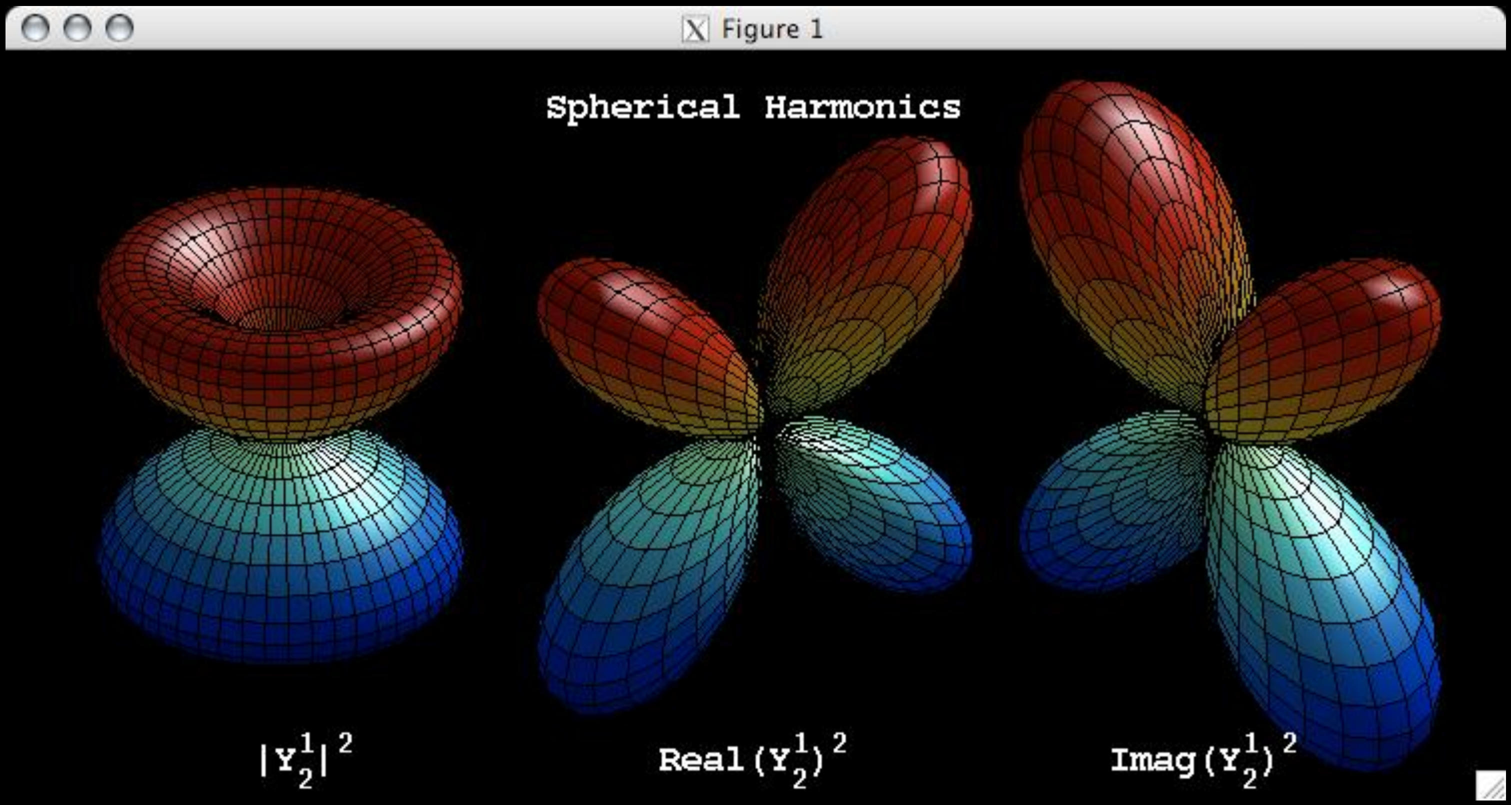
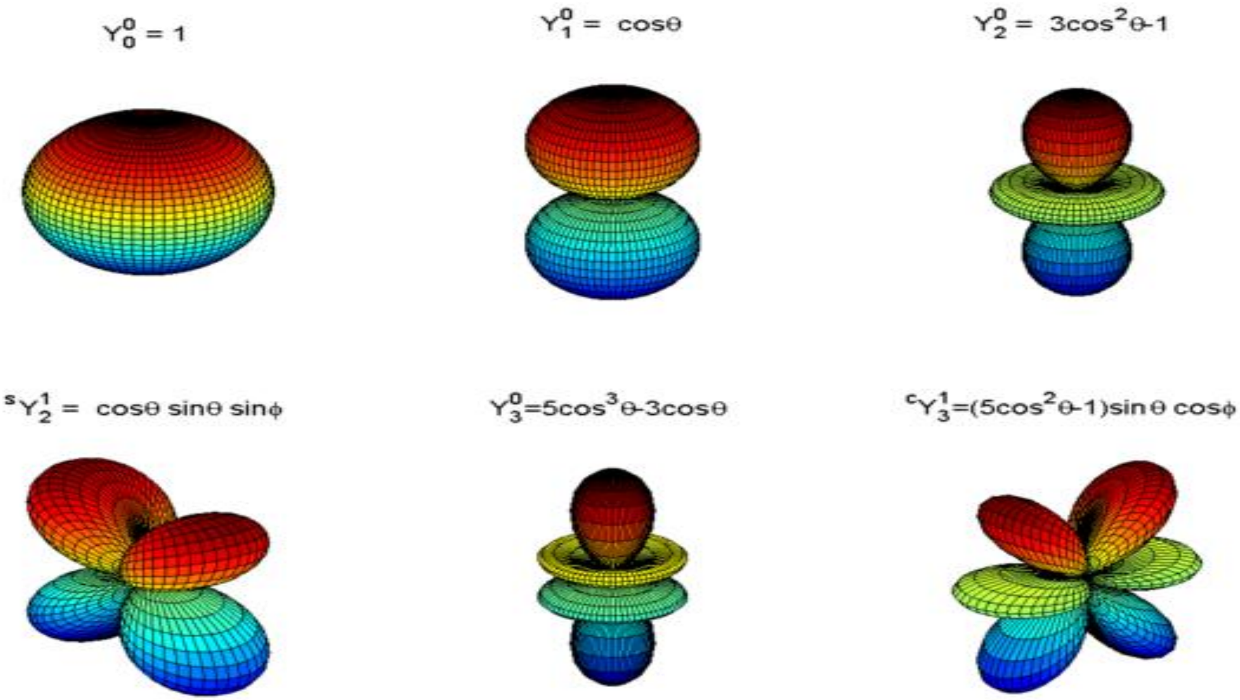
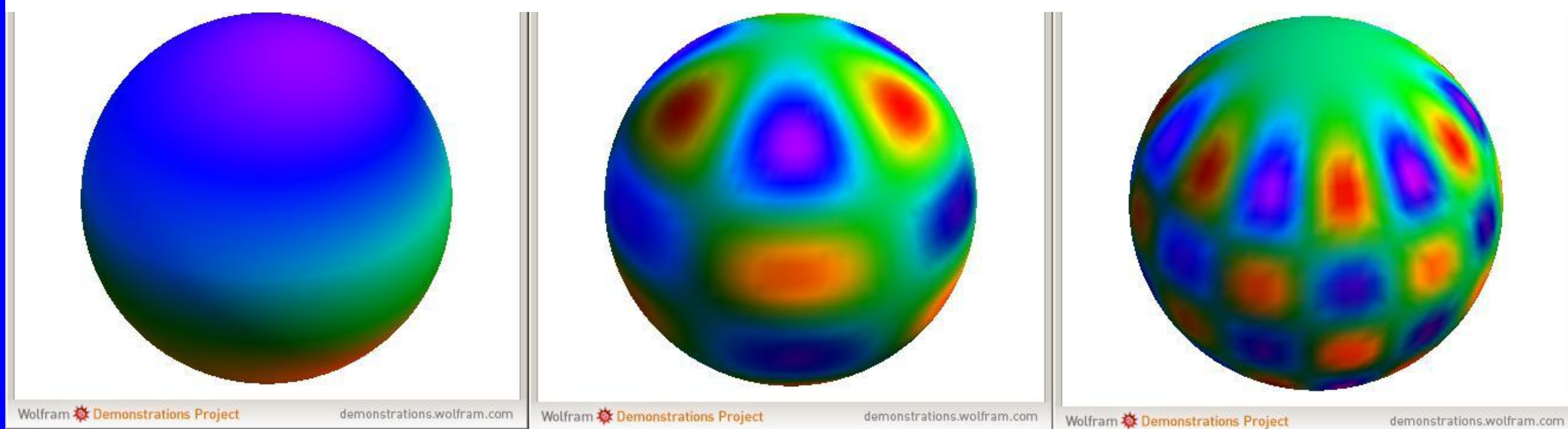
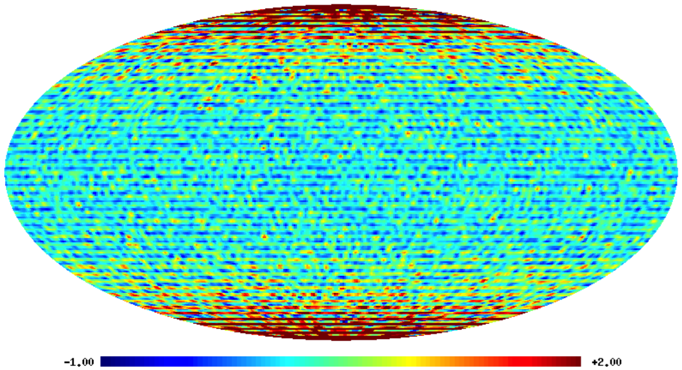


Figure 1
Spherical Harmonics
$|Y_2^1|^2$
$\mathrm{Real}(Y_2^1)^2$
$\mathrm{Imag}(Y_2^1)^2$

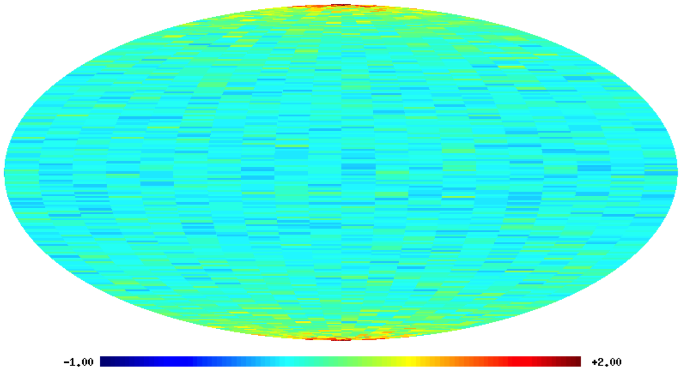

$Y_0^0 = 1$
$Y_1^0 = \cos\theta$
$Y_2^0 = 3\cos^2\theta - 1$
${}^sY_2^1 = \cos\theta \sin\theta \sin\phi$
$Y_3^0 = 5\cos^3\theta - 3\cos\theta$
${}^cY_3^1 = (5\cos^2\theta - 1)\sin\theta \cos\phi$


Wolfram Demonstrations Project
demonstrations.wolfram.com
Wolfram Demonstrations Project
demonstrations.wolfram.com
Wolfram Demonstrations Project
demonstrations.wolfram.com

Heavy Ion event as Mollweide map

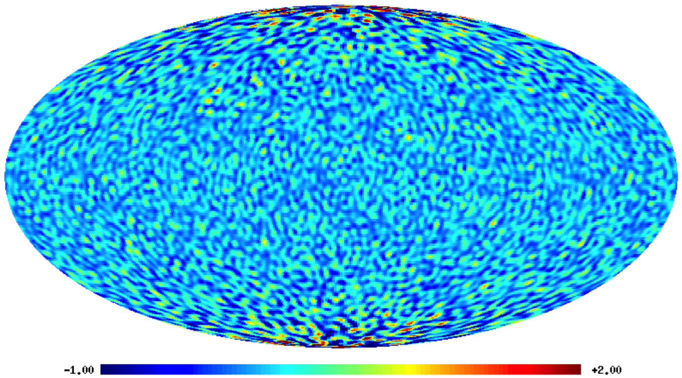


All m values

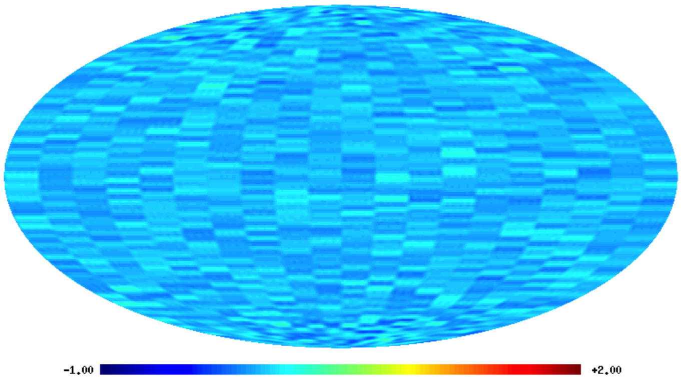


Infinite Resolution in θ and Φ

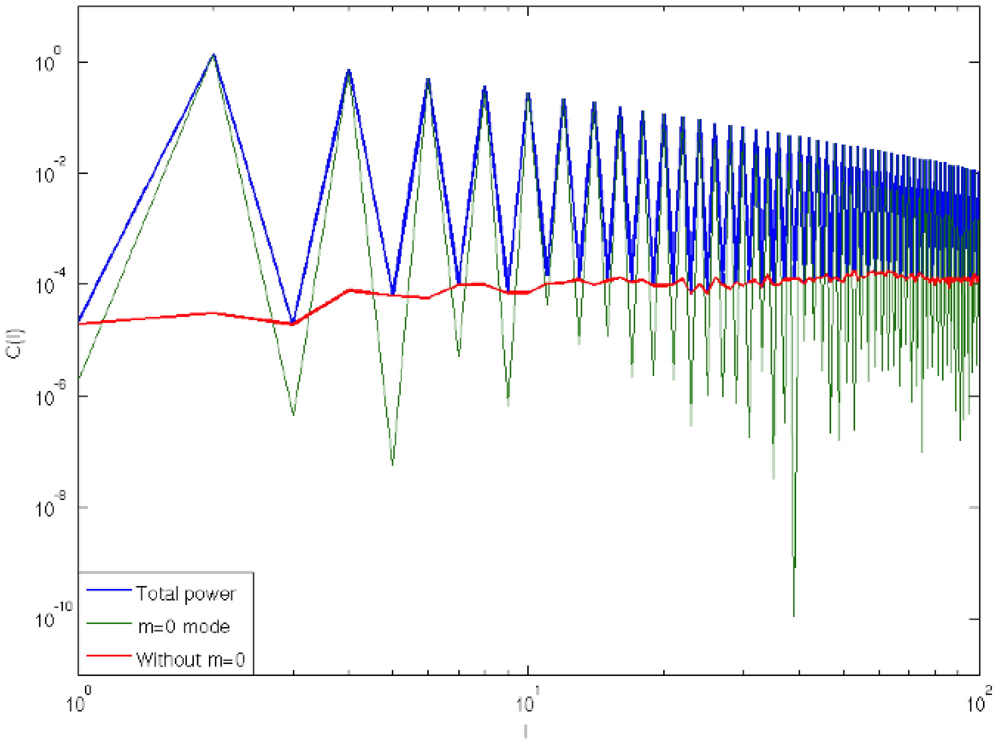
100 bins in θ and 20 bins in Φ

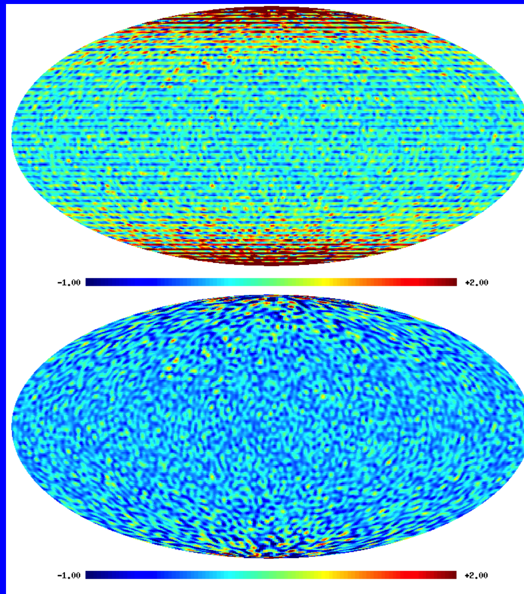


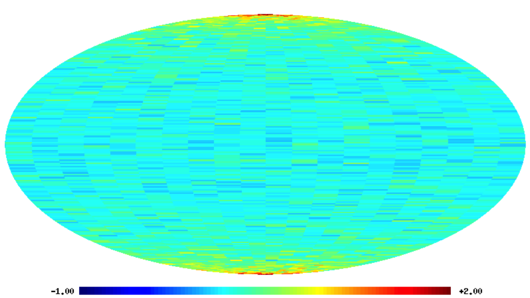
m=0
excluded

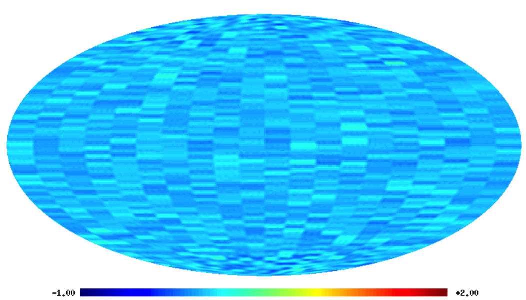


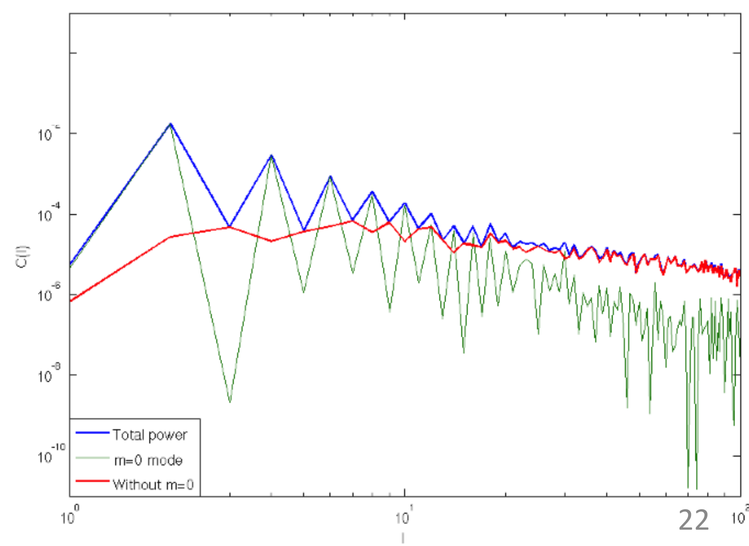
The Power spectrum.



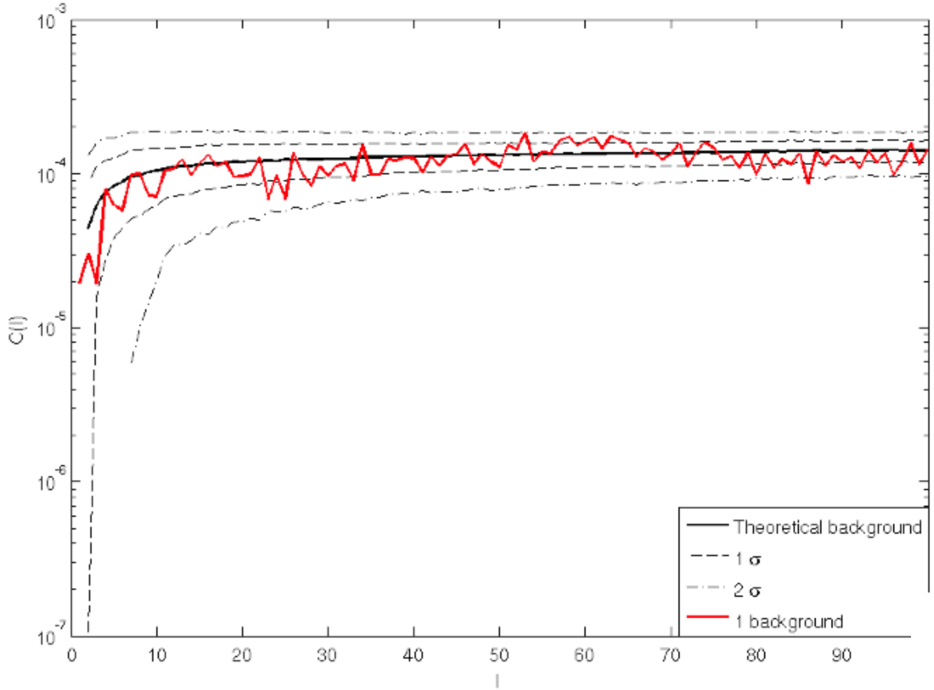






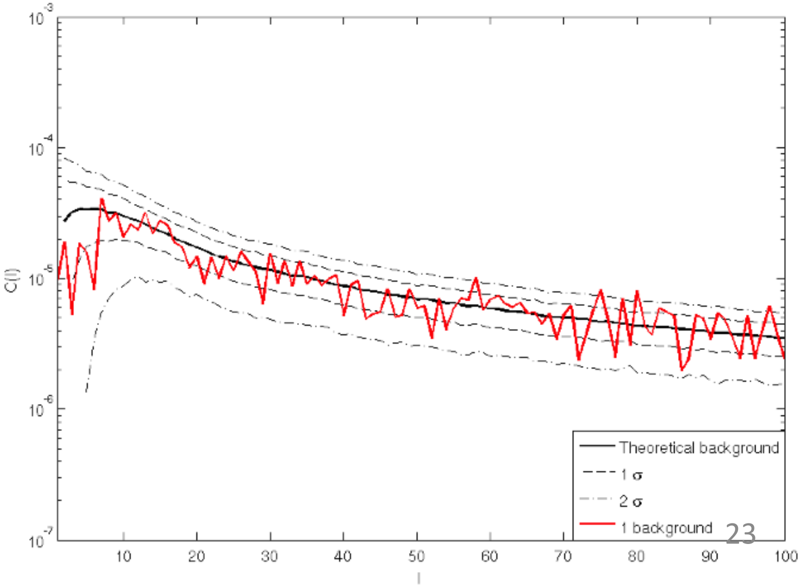


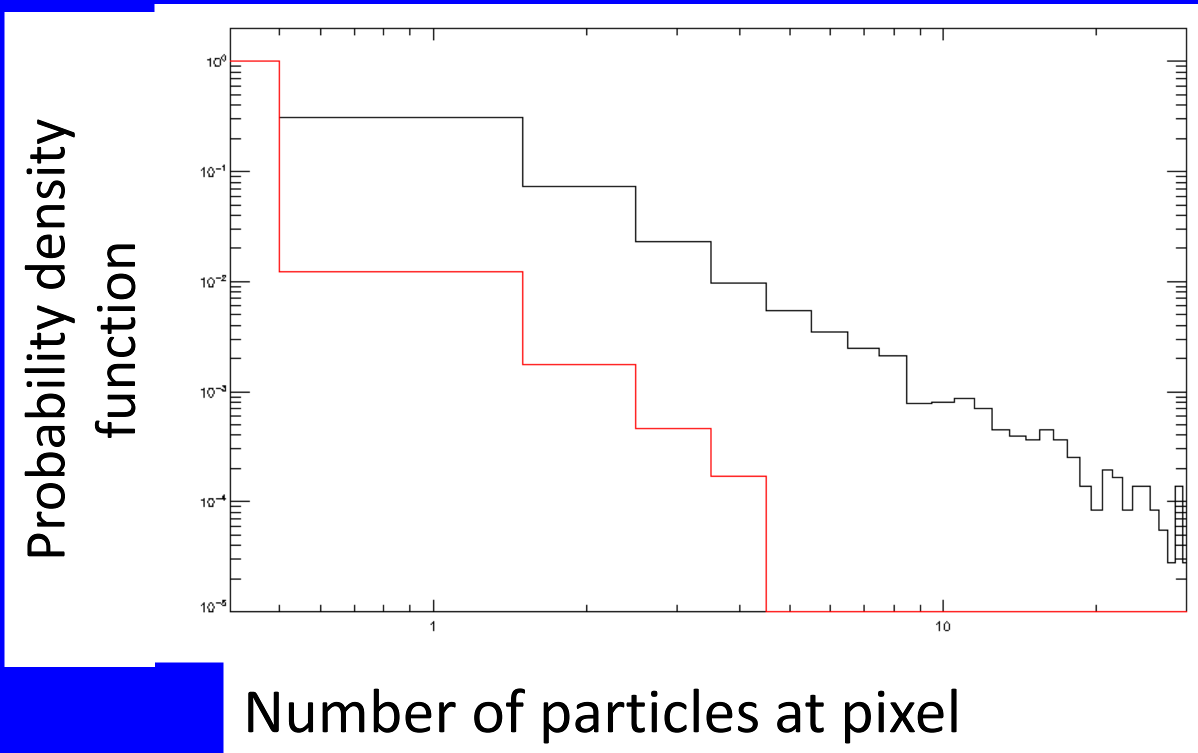
The ’trivial’ background: 1000 events

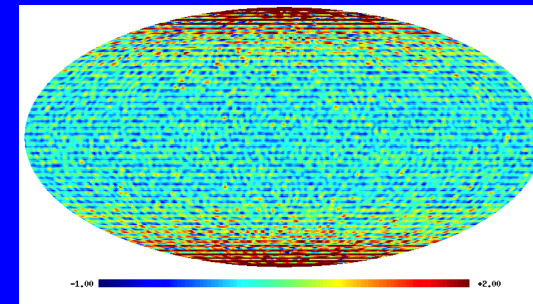


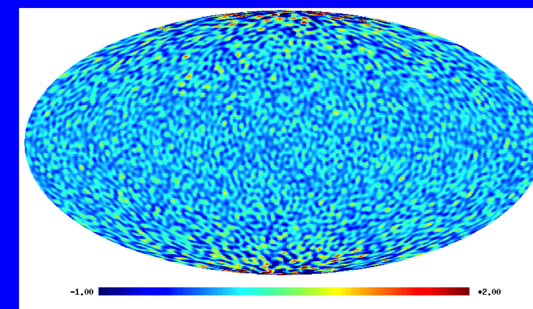
Infinite resolution

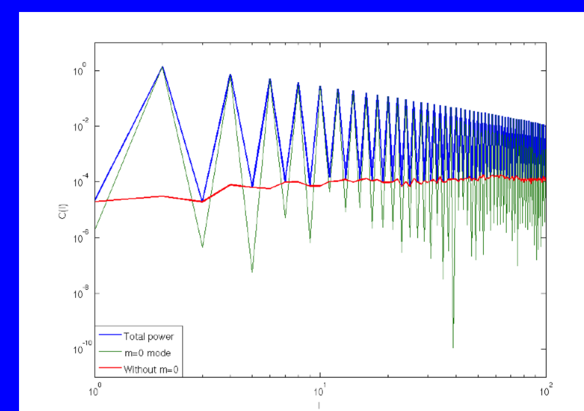
Finite resolution




Probability density function
Number of particles at pixel
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1
10

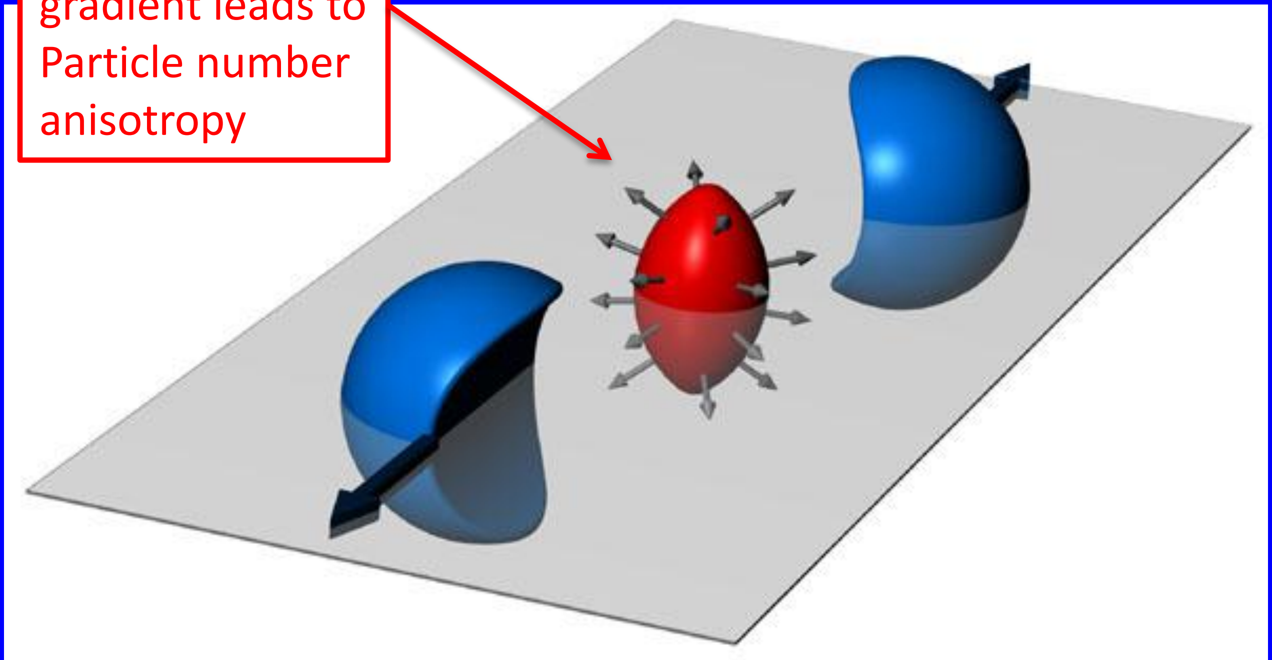

-1.00
+2.00


-1.00
+2.00

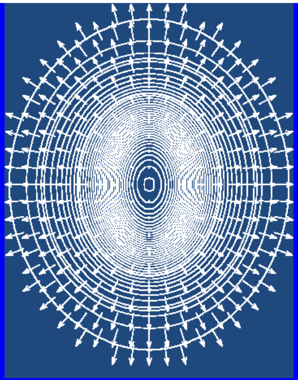

Total power
m=0 mode
Without m=0
C(l)
l

Elliptic flow

Anisotropic pressure gradient leads to Particle number anisotropy



Spatial anisotropy translates into momentum anisotropy due to bulk collective motion



$$\frac{Ed^3N}{dp^3} = \frac{d^3N}{p_T dp_T dy d\phi} = \frac{d^3N}{2\pi p_T dp_T dy}[1+2v_1\cos(\phi-\Phi_R)+2v_2\cos 2(\phi-\Phi_R)+\cdots]$$

Hydro models reproduce v_2. Require short interaction times and large cross sections => Liquid

Elliptic flow. Single realization

$$\frac{Ed^3N}{dp^3} = \frac{d^3N}{p_T dp_T dy d\phi} = \frac{d^3N}{2\pi p_T dp_T dy}[1+2v_1\cos(\phi-\Phi_R)+2v_2\cos 2(\phi-\Phi_R)+\cdots]$$

$$S(z,\phi)=R(z,\phi)\{1+\sum_{n\geq 1} V_n \cos[n(\phi-\Phi_R)]\}$$

↓ FFT

$$S(z)_m=R(z)_m+\frac{1}{2}\sum_{n\geq 1} V_n[e^{-i\Phi_R n}R(z)_{m+n}+e^{i\Phi_R n}R(z)_{m-n}]$$

$\boldsymbol{m \Leftrightarrow m+n}$ *Well known effect in CMB science*

Elliptic flow. Single realization

$$K(V_2)=\frac{<S(m)S^*(m+2)+S^*(m)S(m+2)>}{2\sqrt{<|S(m)|^2><S(m+2)|^2>}} = V_2\cos(2\Phi_R) + O(V_n \ll V_2)$$

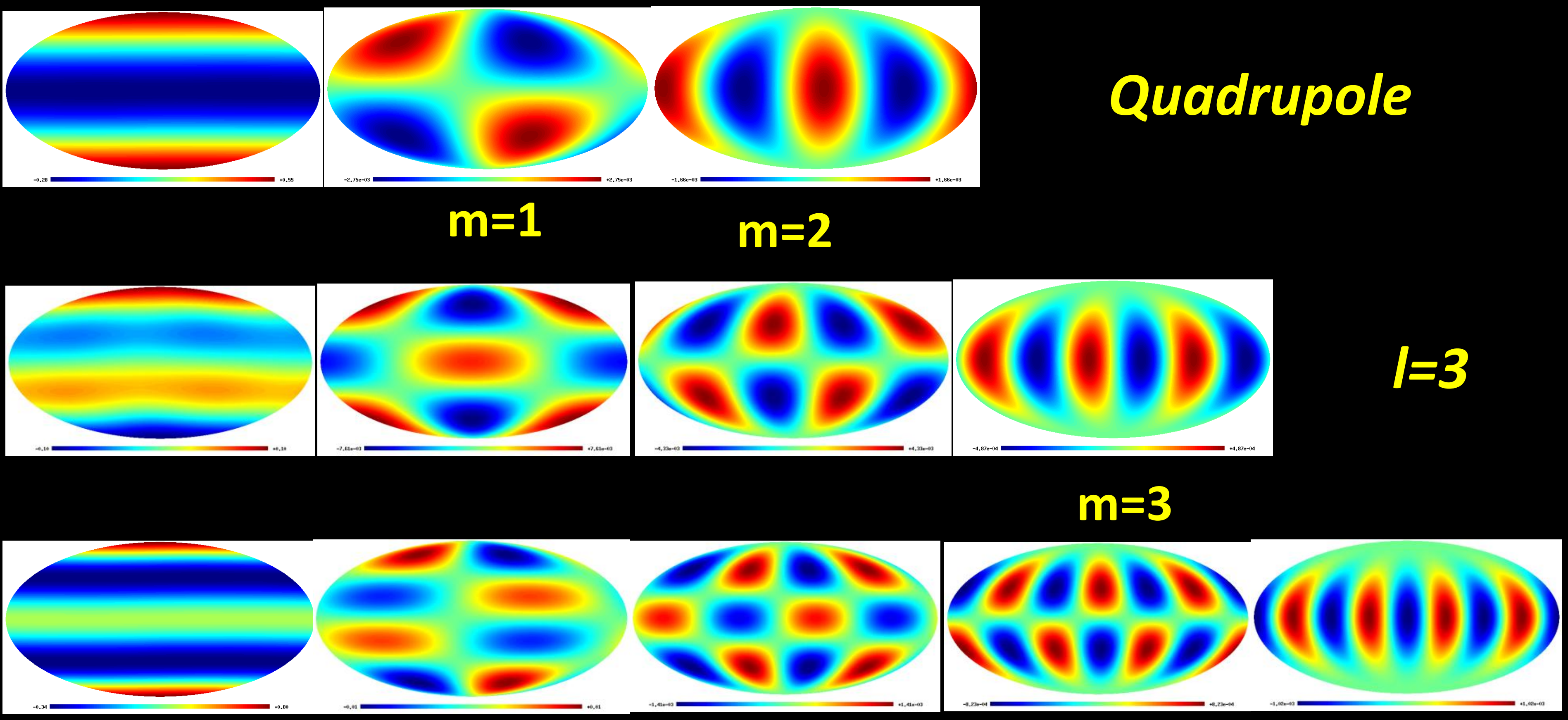
?

$$\chi(V_2)=\frac{<S(m+2)S^*(m)-S^*(m+2)S(m)>}{2i\sqrt{<|S(m)|^2><S(m+2)|^2>}} = V_2\sin(2\Phi_R) + O(V_n << V_2)$$

where $<...>=\sum_m \int_{-H/2}^{H/2} dz$

$$\tan(2\Phi_R) = \frac{\chi(V_2)}{K(V_2)};\; V_2 = \sqrt{\chi(V_2)^2 + K(V_2)^2}$$

Elliptic flow. Single realization. Spherical harmonics



Some of the components of a_{lm} could be in resonance with V_n

Elliptic flow. Single realization. $a_{l,m}$

$$S(z,\phi)=R(z,\phi)\{1+\sum_{n\geq 1} V_n \cos[n(\phi-\Phi_R)]\}$$

$$z = R\cot(\theta) = \frac{R}{2}(e^{\eta}\text{-}e^{-\eta}) \qquad \Rightarrow$$

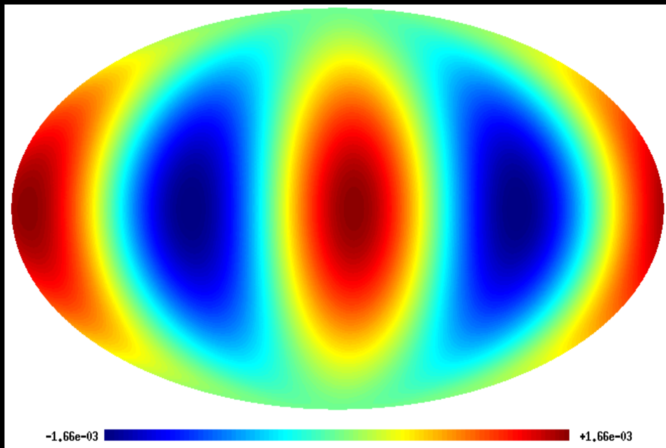
$$S(\boldsymbol{\theta},\phi)=R(\boldsymbol{\theta},\phi)\{1+\sum_{n\geq 1} V_n \cos[n(\phi-\Phi_R)]\}$$

$$\Downarrow$$

$$a_{l,m} = c_{l,m} + \frac{1}{2}\left[\sum_n V_n\left(c_{l,m+n}e^{-in\Phi_R} + c_{l,m-n}e^{in\Phi_R}\right)\right]$$

Elliptic flow. Single realization. l,m-domain

$$m \leftrightarrow m+n, m-n \text{ for the same } l$$



Quadrupole($l = 2, m \pm n \leq l$)

$$a_{2,2} \Leftarrow c_{2,2-2}$$

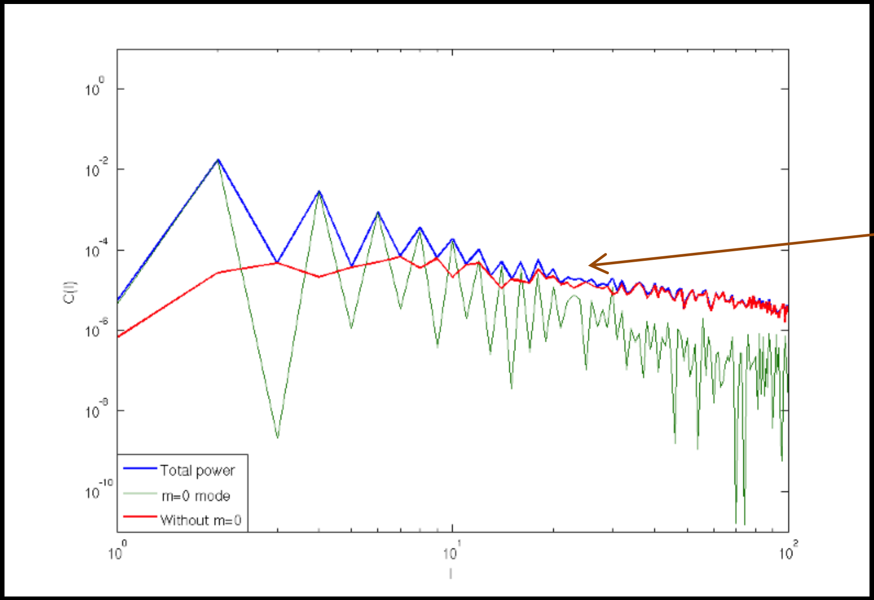
Only V_2 !!!

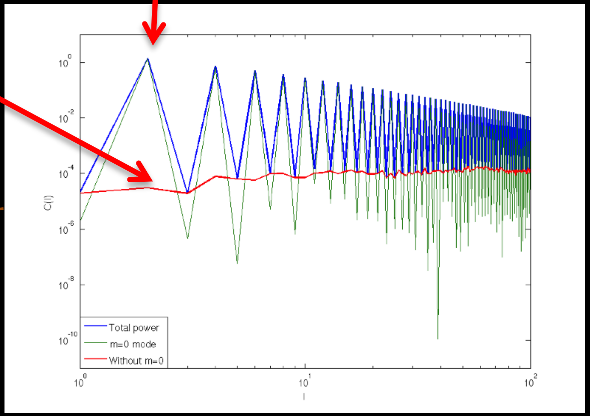
$$a_{2,2} \Leftarrow V_2(c_{2,2+2} + c_{2,2-2})$$

l=m=n-resonance

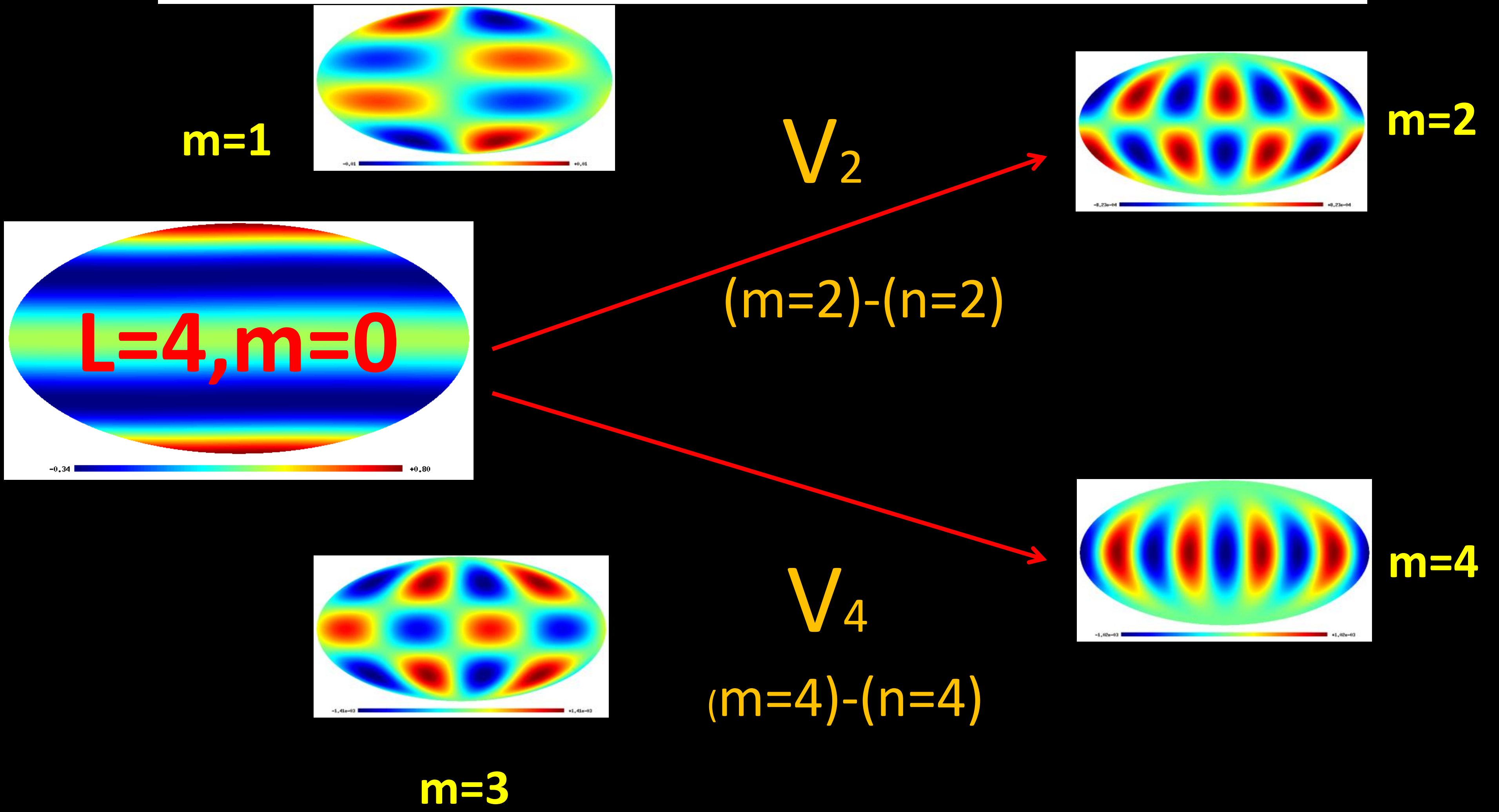
$$a_{n,n} \Leftarrow V_n(c_{n,0})$$

n=1,2,.....N

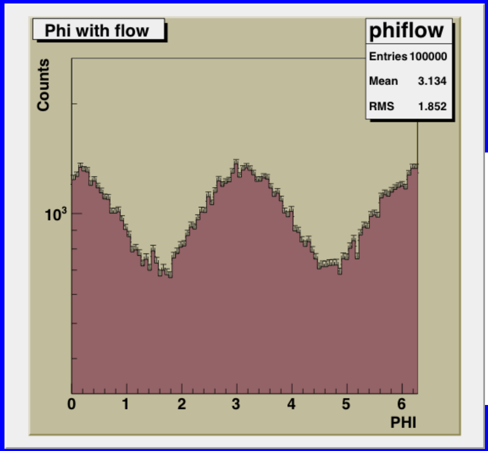




Spherical harmonics. Resonance to Vn



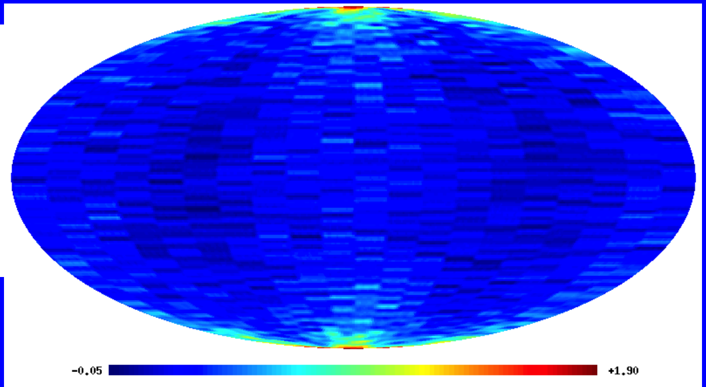
Elliptic flow . Simulations

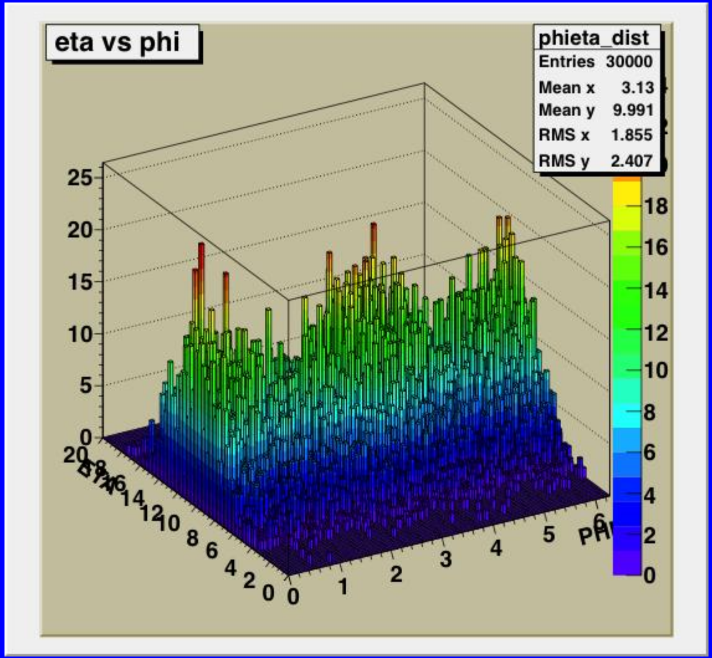


Input Phi modulation:

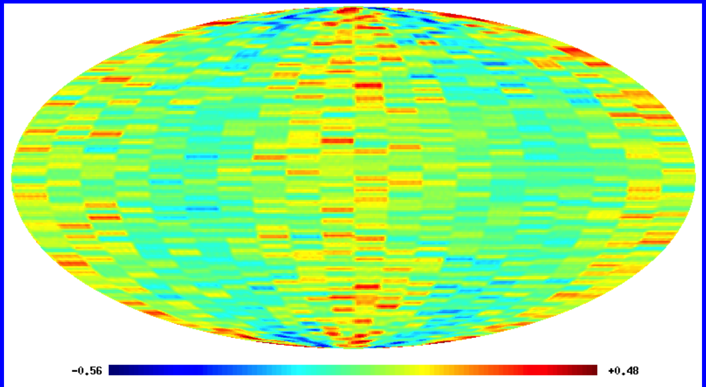
$$dN/d\Phi = N_0 (1+2v_2\cos(2\Phi))$$

All m values

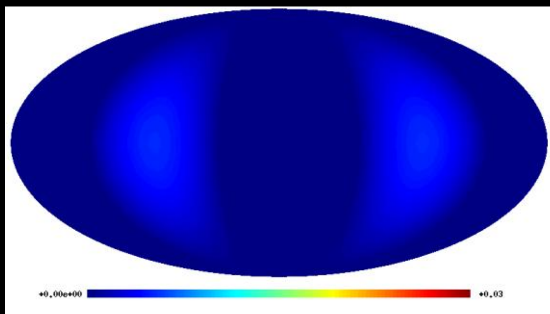




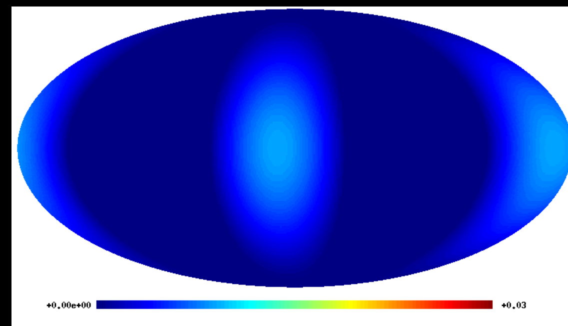
m=0 excluded



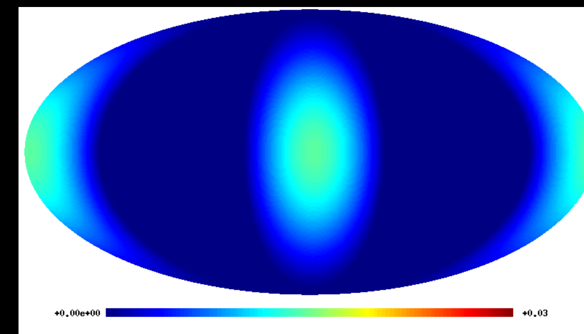
B_{22} versus V_2



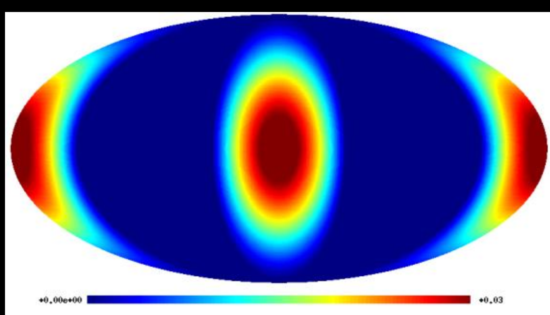
V2=0



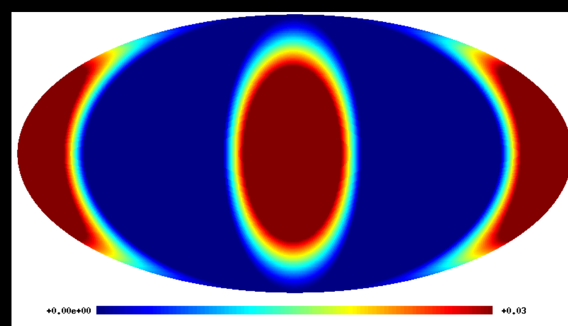
V2=0.01



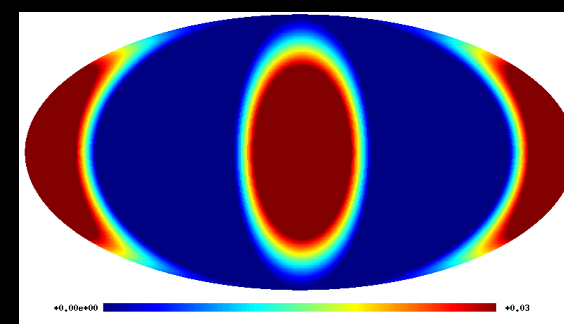
V2=0.05



V2=0.15



V2=0.25

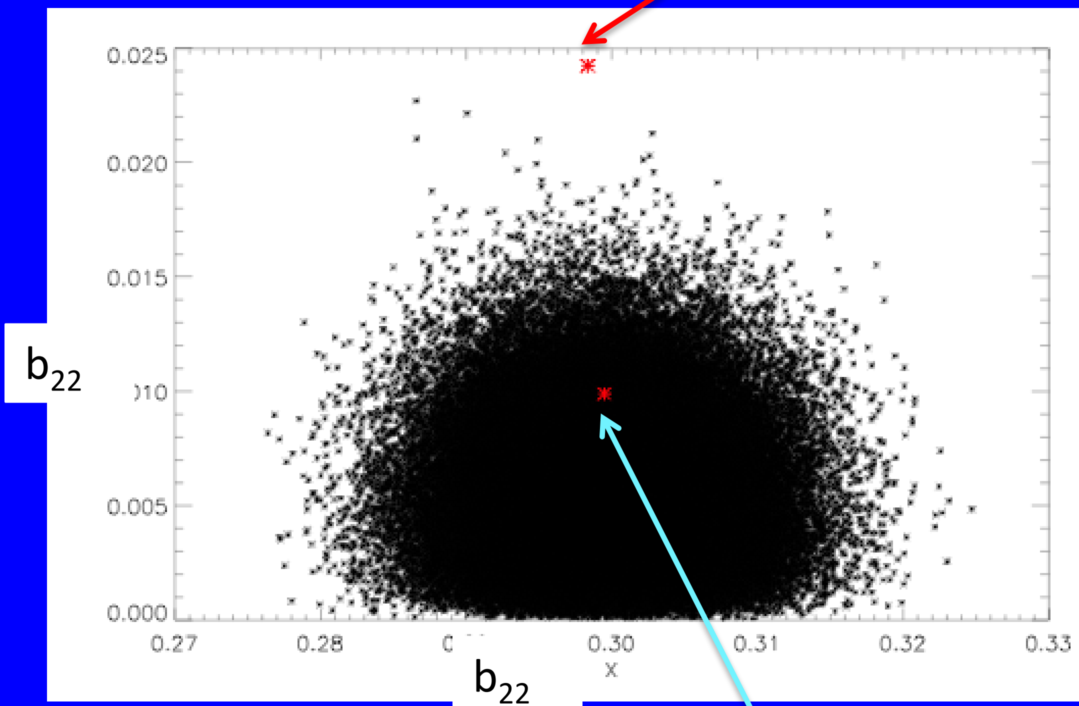


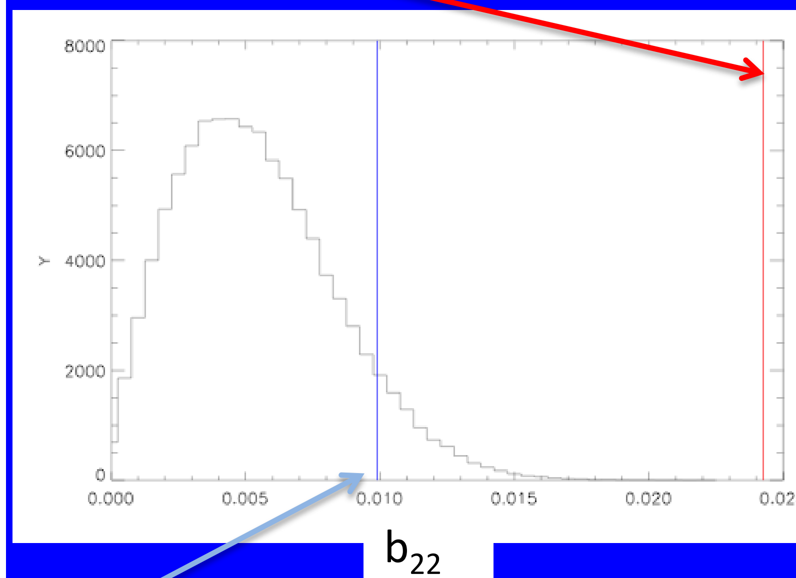
V2=0.30

Quadrupole amplitude is sensitive to V_2

V2=0.05

Detection prob. 99.999%



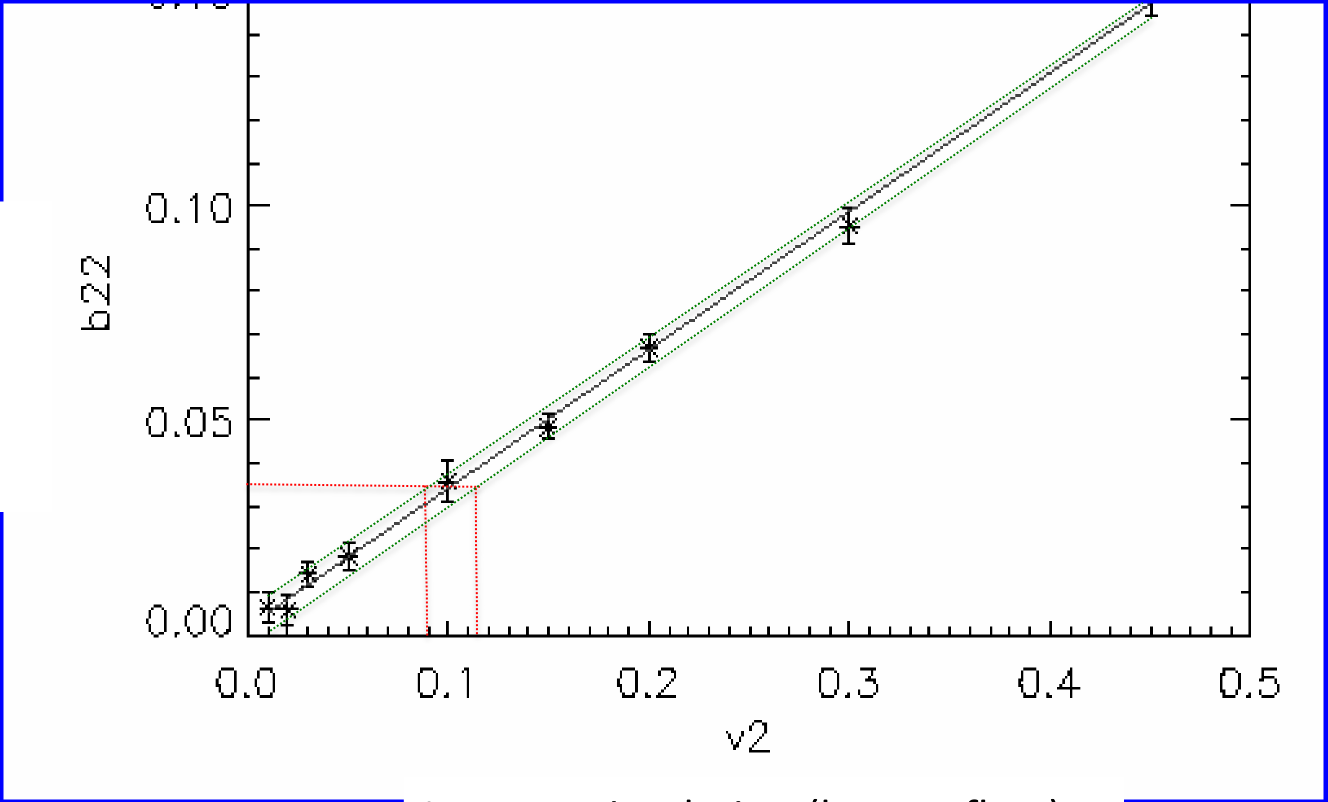


V2=0.01

Detection prob. 91%

Tight correlation between harmonic coefficients and elliptic flow

Analyzed simulated map with finite resolution



Input to simulation (known flow)

Ex: b_{22}=0.035=> V_2= 0.1±0.01

Summary

- A new method to analyse the event morphology in Heavy Ion and Particle physics has been proposed.
- Toy model analysis suggest good resolution for collective phenomena (elliptic flow) and point sources (jets)
- Next steps:
  - Full simulation with realistic event generator and detector transport code
  - Develop analysis for additional physics effects
  - Analyse ALICE events from LHC Pb+Pb (2.76 A.TeV)

Thanks !