TIFPA
Trento Institute for
Fundamental Physics
and Applications

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Napoli

Precision Measurement of Cosmic Deuterons with AMS-02

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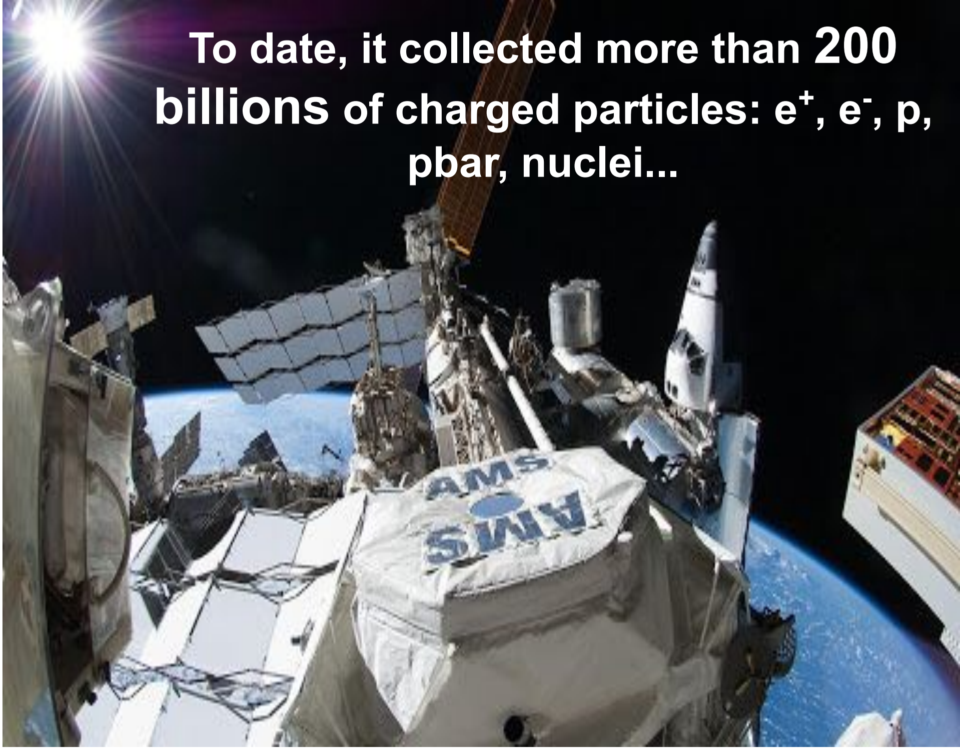
On behalf of the AMS-02 Collaboration

AMS - 02

AMS was
installed on ISS
in May 2011.

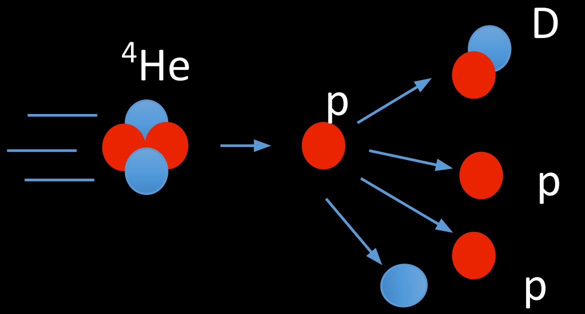
An unique TeV precision, accelerator-type spectrometer in space

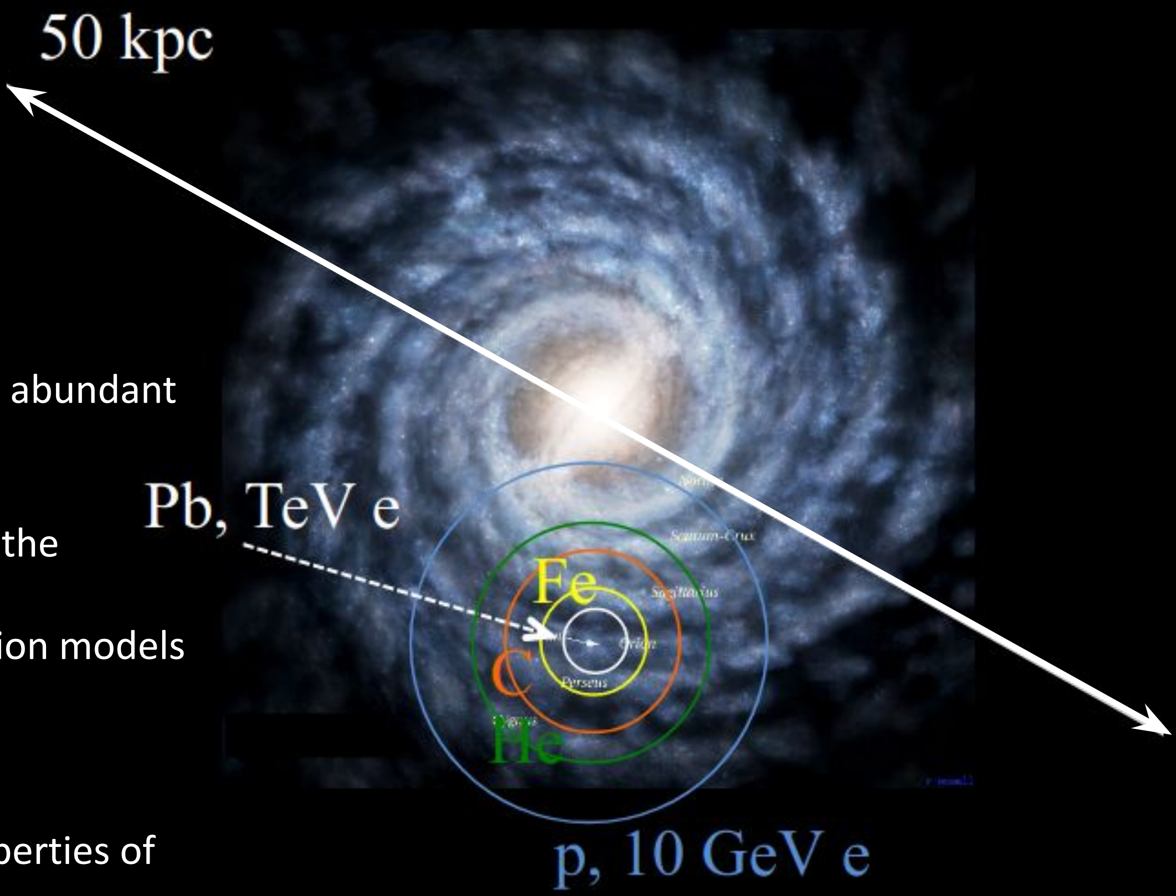


To date, it collected more than 200 billions of charged particles: e^+, e^-, p, pbar, nuclei...

Thanks to UTTPS, it will continue through the lifetime of ISS

Why Z=1&2 isotopes?





- Helium nuclei are the second most abundant nuclei in cosmic rays.

- D and ^{3}He are mostly produced by the fragmentation of ^{4}He:
simpler comparison with propagation models wrt heavy nuclei

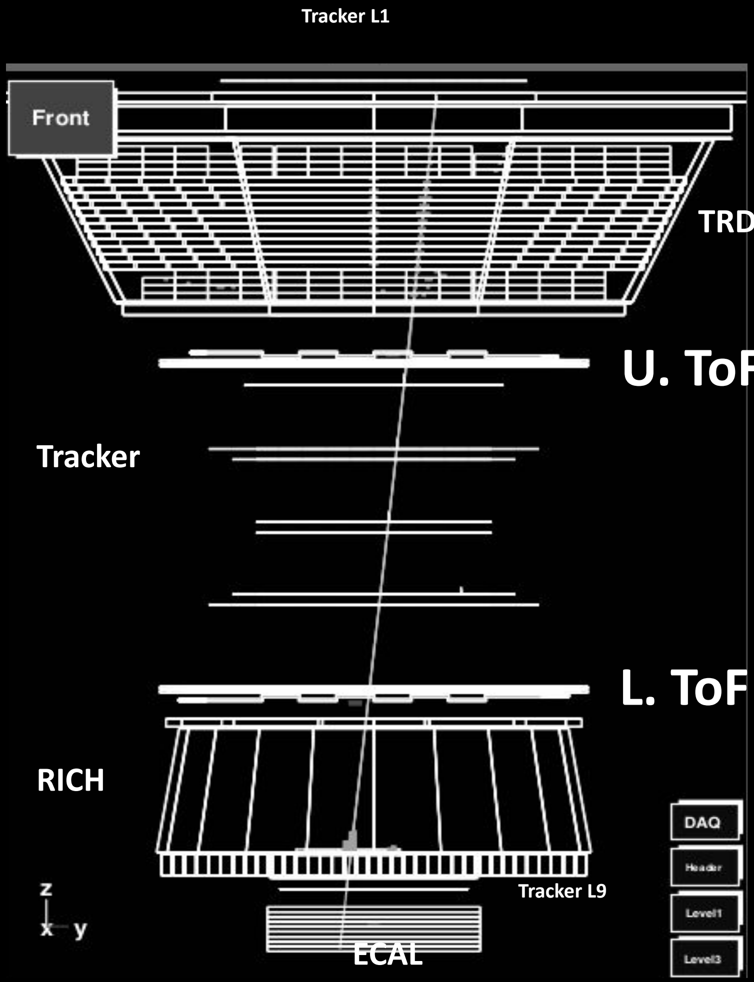
- Smaller cross section of He:
D/^{4}He and ^{3}He/^{4}He probe the properties of diffusion at larger distances

- Different A/Z ratios of D and ^{3}He allow to disentangle kinetic energy and rigidity dependence of propagation.

Light isotope measurements with AMS02

- AMS is composed by different sub-detectors for the redundant ID of the elements in CR
- The **Mass** is identified from the concurrent measurement of **Rigidity, Velocity** and **Charge**
- **Mass resolution** not good enough for event-by-event isotope ID -> Fit of distribution

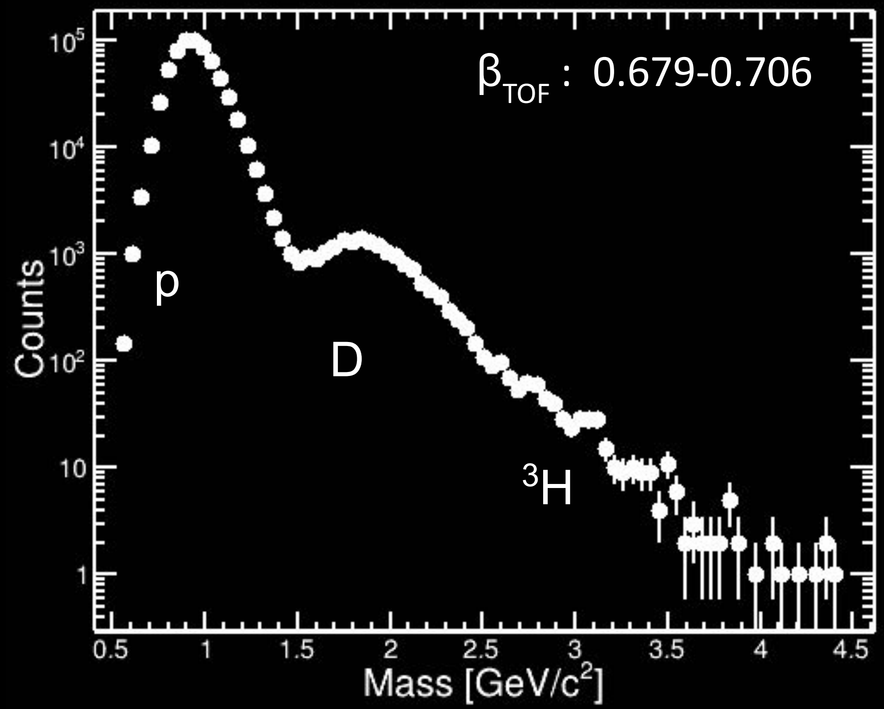
TOF	$\sigma_\beta/\beta \sim 3\%$	$0.2 < E_k < 1.1$ GeV/n
RICH NaF	$\sigma_\beta/\beta \sim 0.3\%$	$0.7 < E_k < 3.7$ GeV/n
RICH AgI	$\sigma_\beta/\beta \sim 0.1\%$	$2.6 < E_k < 8.9$ GeV/n



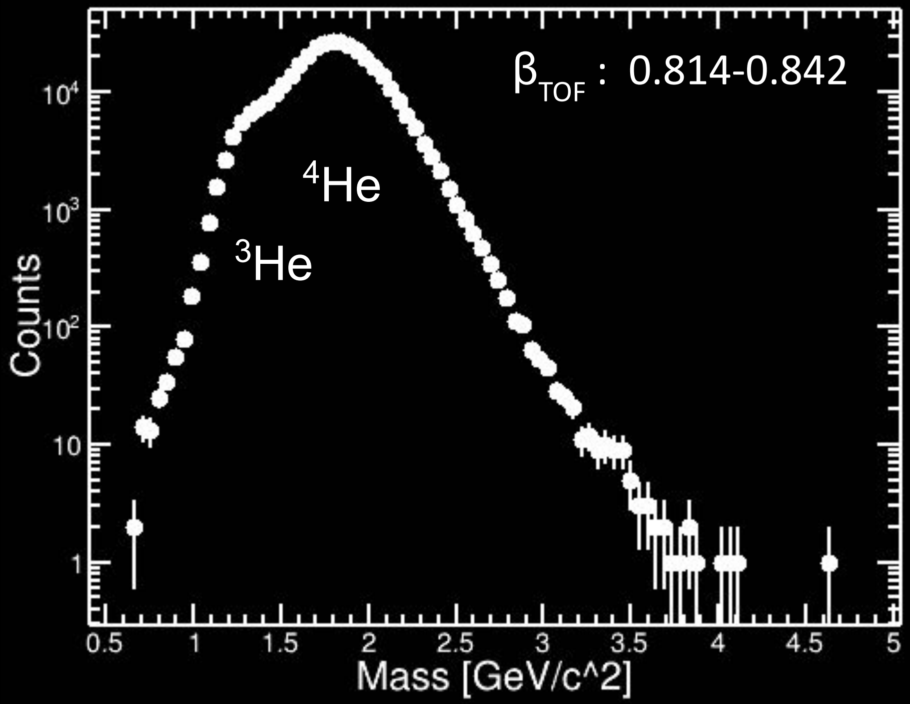
Isotope separation: $m = \frac{RZ}{\beta\gamma}$

The separation can be better achieved at constant velocity (not biased by geomag. cutoff)

Z=1



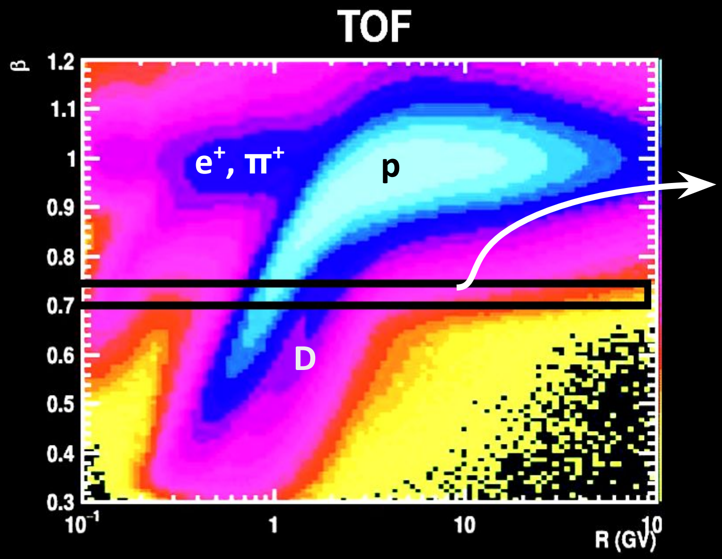
Z=2



The separation power depends on rigidity and velocity (β) resolutions

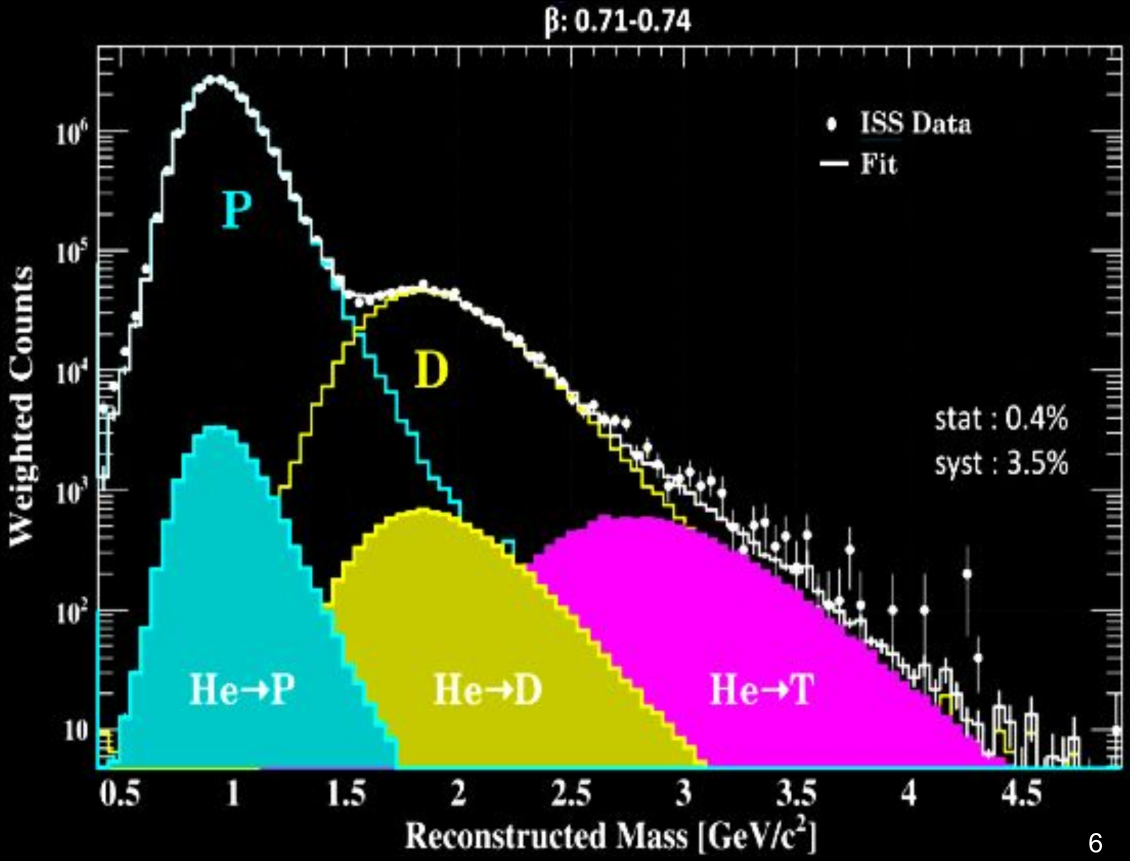
$$\left(\frac{\Delta m}{m}\right)^2 = \left(\frac{\Delta R}{R}\right)^2 + \gamma^4\left(\frac{\Delta\beta}{\beta}\right)^2$$

- **Low energies:** dominated by the ΔR/R term (~10% almost constant for R<20 GV)
- **Higher energies:** γ^4 factor makes β resolution dominant



Fit of the mass with templates from MC

- MC templates tuned using data
- data driven estim. fragmentation from Z>1
- D’Agostini iterative method for bin-to-bin migration

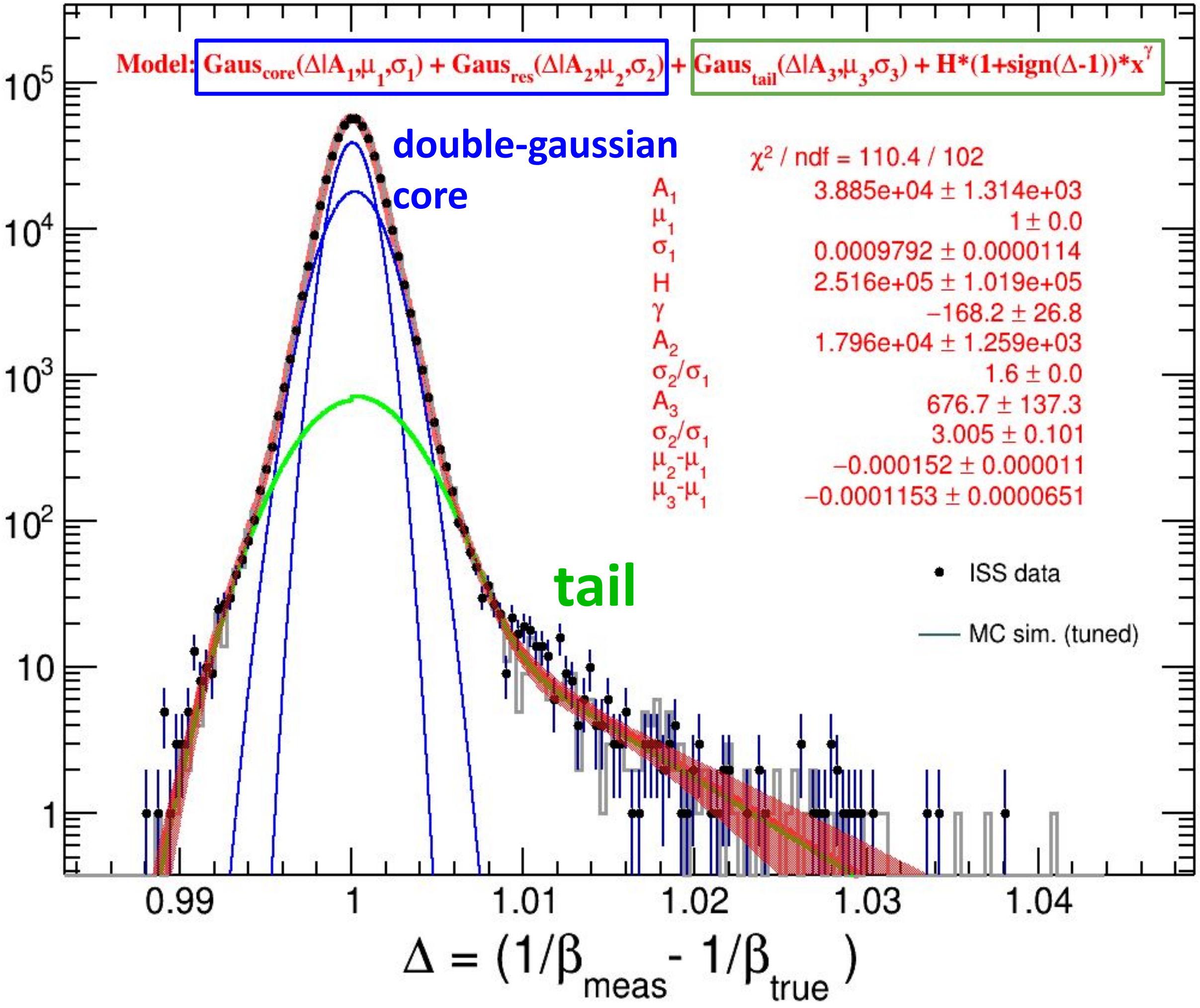


General Parametrization of the velocity resolution (Z=1 - AgI)

The velocity response was modeled from high energy flight data: **(R>50 GV)**

→ **β_{true}≈1:** distribution not influenced by isotopic composition

RICH (AgI):



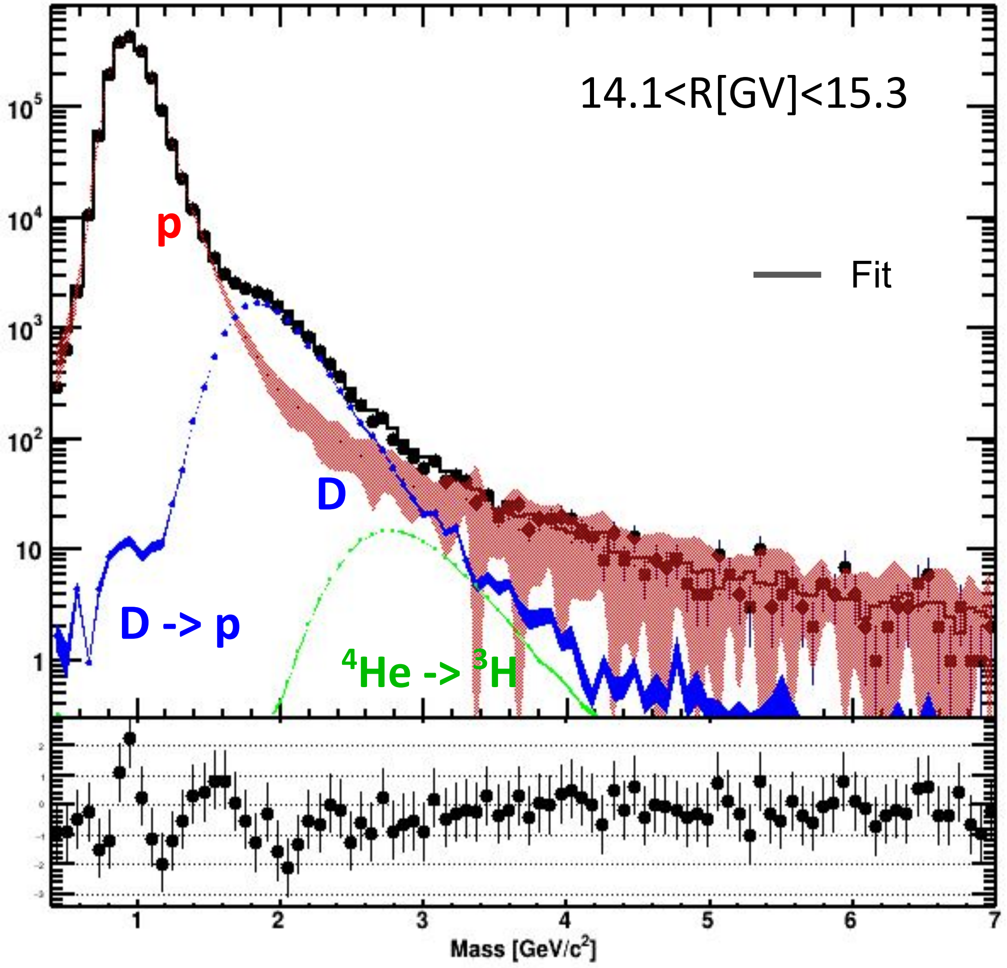
σ_1 and μ_1 are the only free parameter of the model

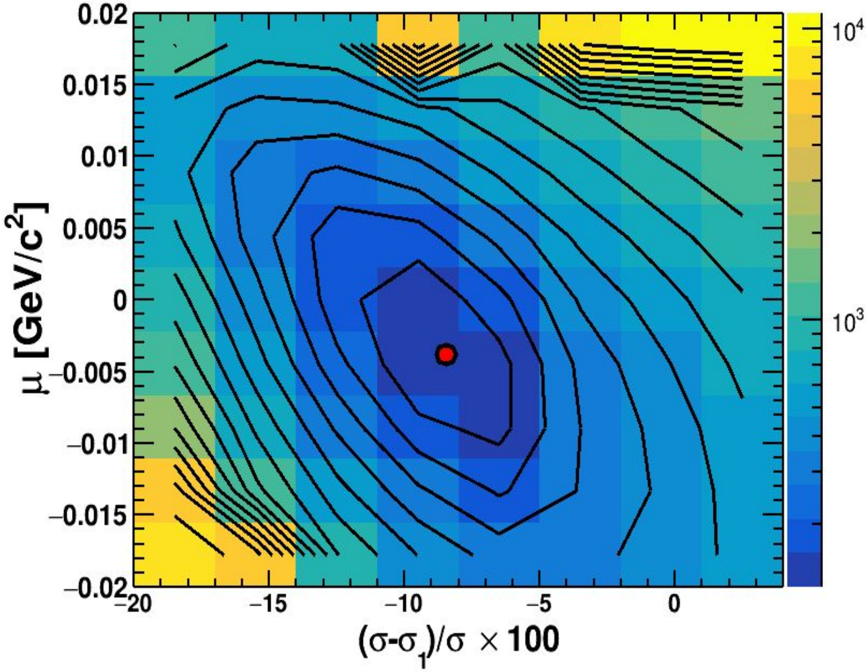
other parameters are kept rigidly related to them at all velocities

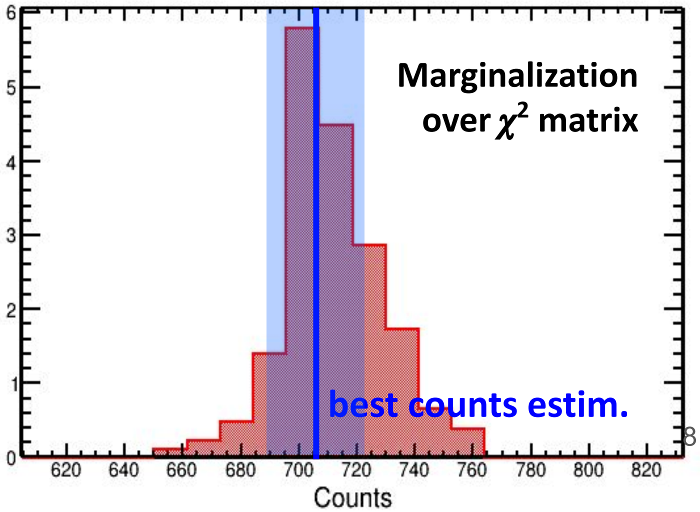
Fit to data (on Mass distributions)

- NxN mass templates obtained changing σ_1 and μ_1 in a ±20% range
- **Marginalization:** To every template fit a weight is assigned: **w = exp(- $\square^2$ / 2)**

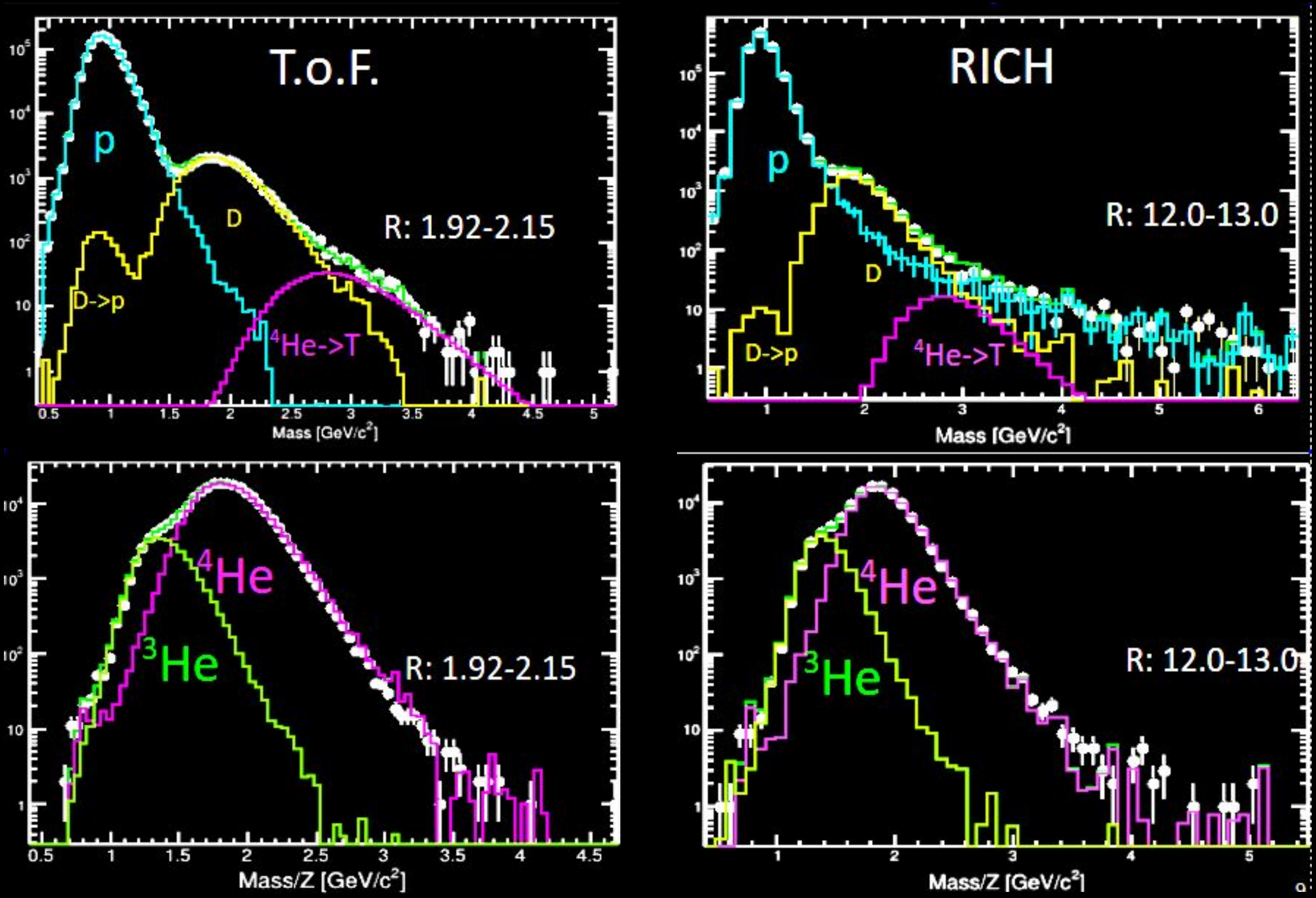
The two remaining free parameters (σ_1 and μ_1) are fixed bin-by-bin directly fitting the mass distributions







Z=1 and Z=2 Template fits

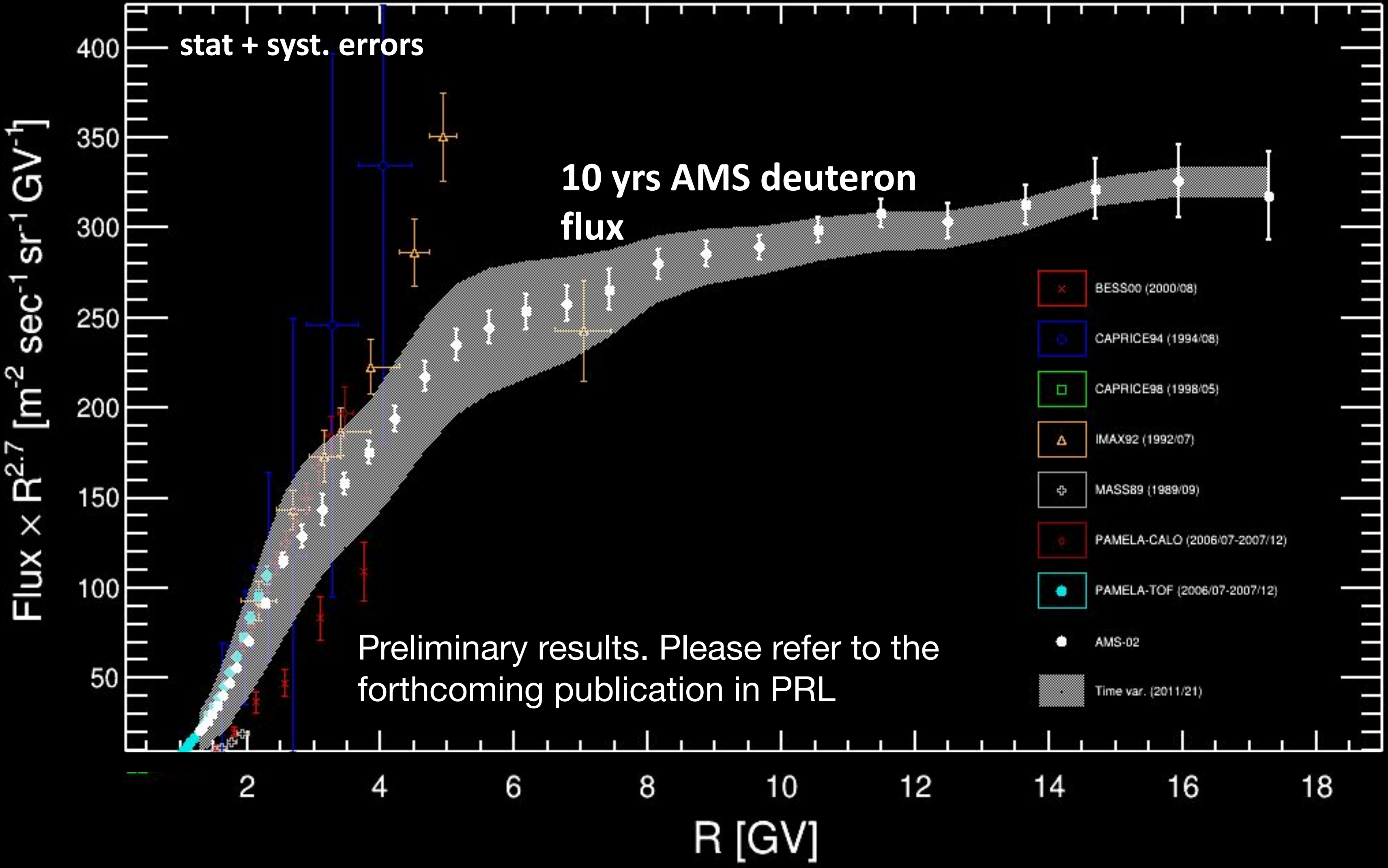


Isotope Fluxes

MC templates carry informations about:

- Detector Efficiency
- Bin-to-bin migration

It is possible to directly use them to calculate **Acceptance** and **Unfolding factor** to normalize the counts and obtain **fluxes**



stat + syst. errors

10 yrs AMS deuteron flux

Preliminary results. Please refer to the forthcoming publication in PRL

Isotope Fluxes

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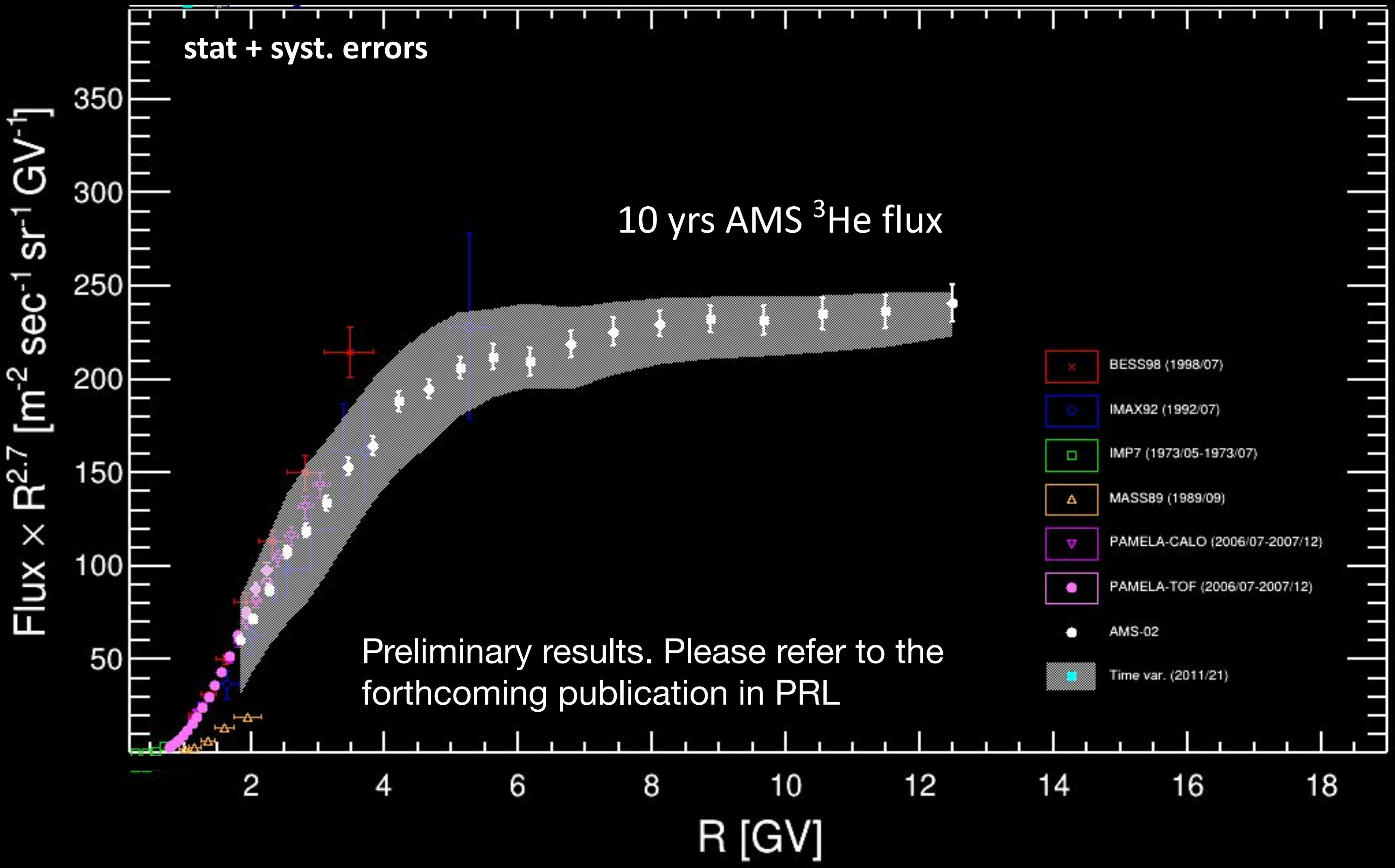

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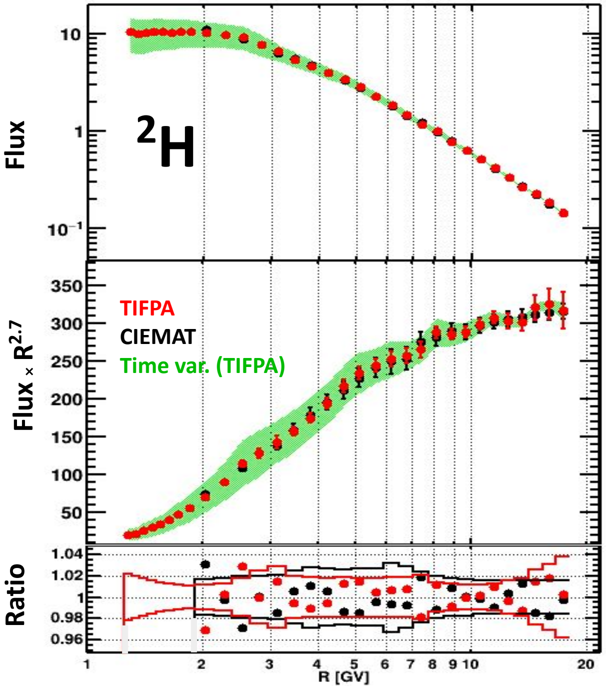
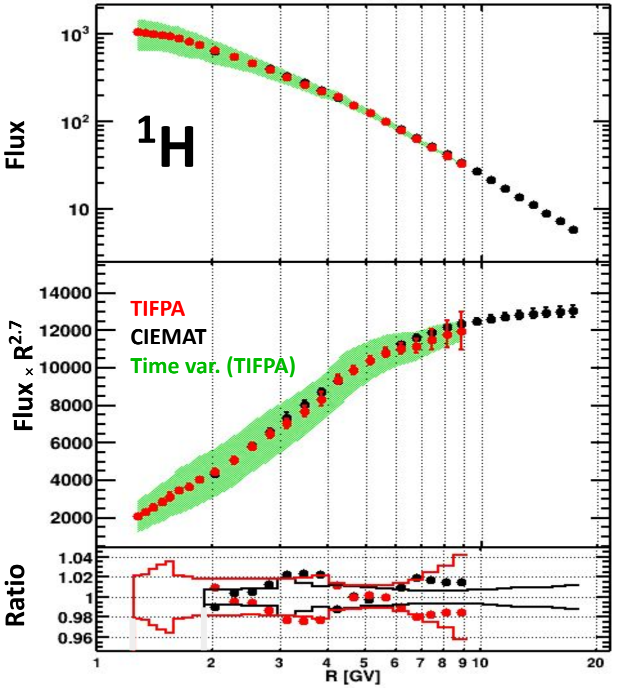
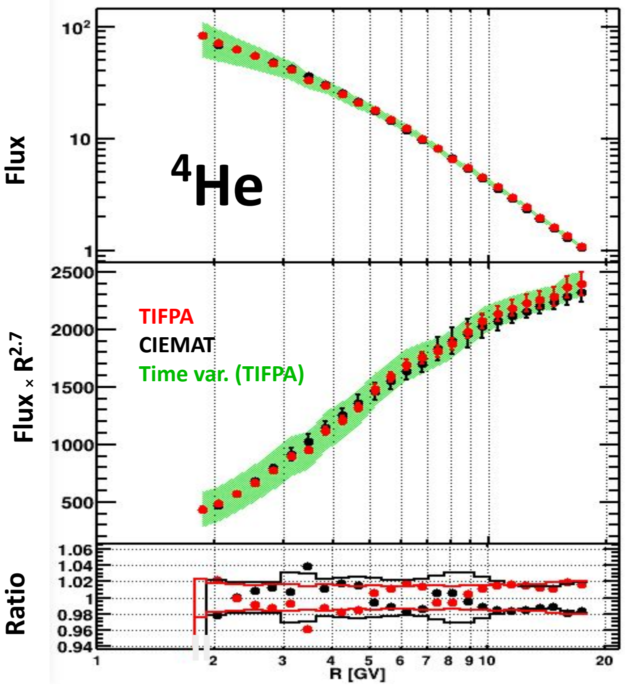
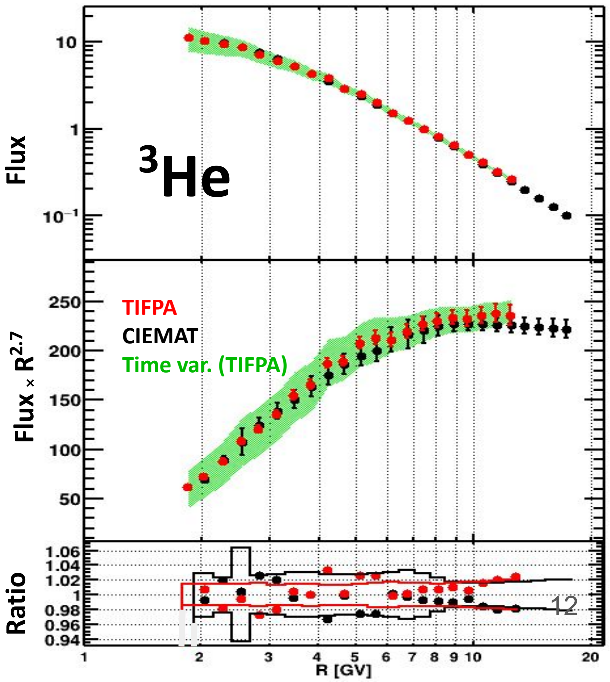
Comparison with Independent analysis (CIEMAT - Madrid)





- The results of the two groups are compatible within the respective error band estimations
- They are mostly within a ±2%
- The differences are dominated by systematics on the mass fit



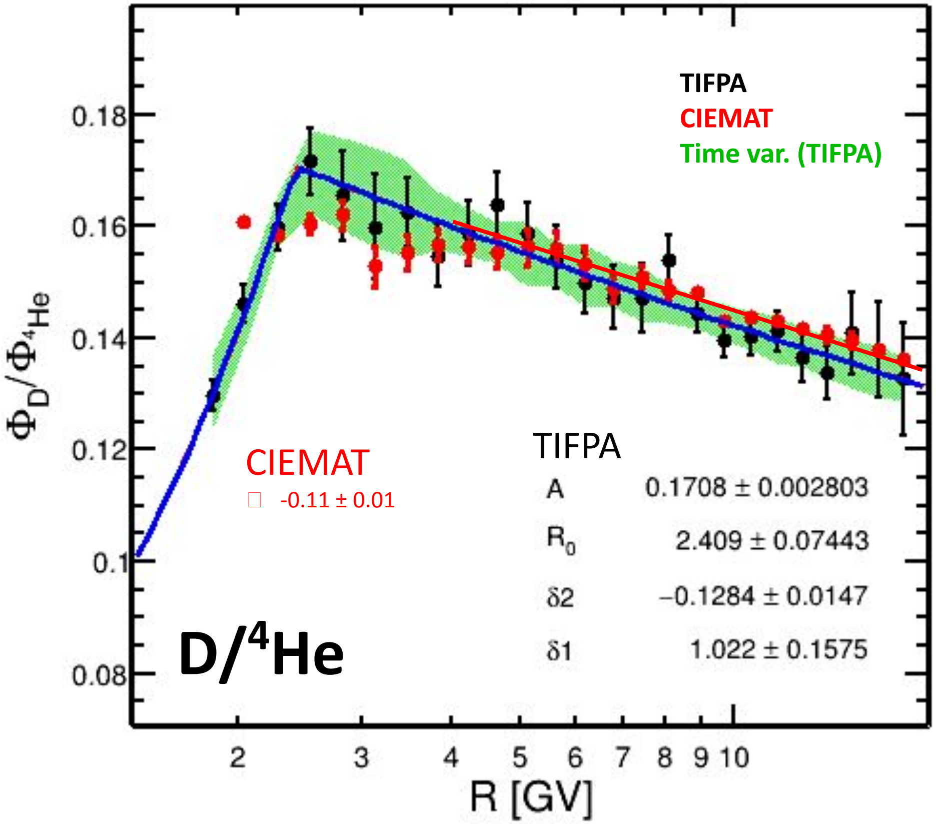


Average Deuteron Ratios Fit

Ratios against rigidity factor out the solar modulation -> ~ Time independent

TIFPA Fit: $A \cdot \begin{cases} R^{\square 1} & R<R_0 \\ R^{\square 2} & R>R_0 \end{cases}$

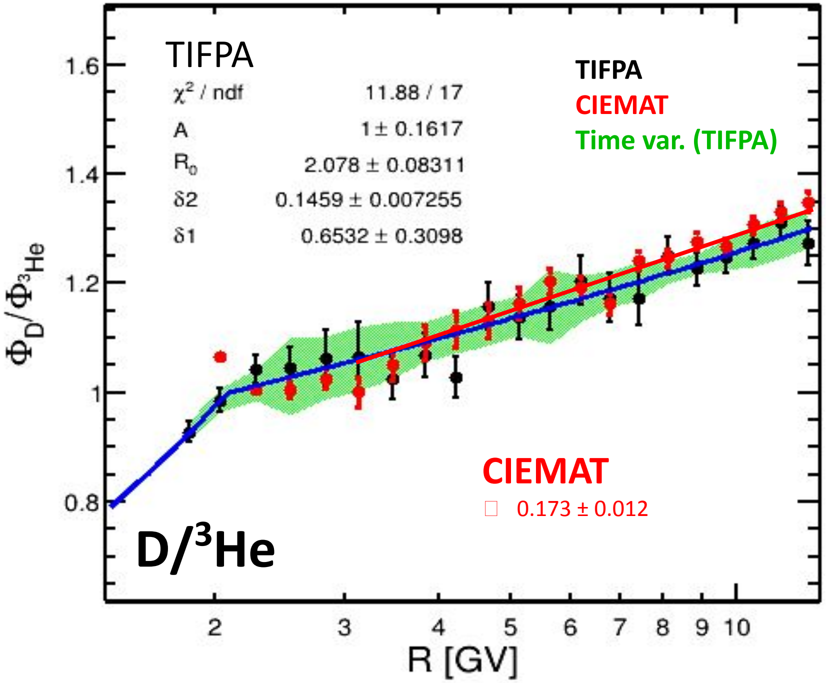
CIEMAT Fit: $A \cdot R^{\square}$



TIFPA
CIEMAT
Time var. (TIFPA)

CIEMAT
□ -0.11 ± 0.01

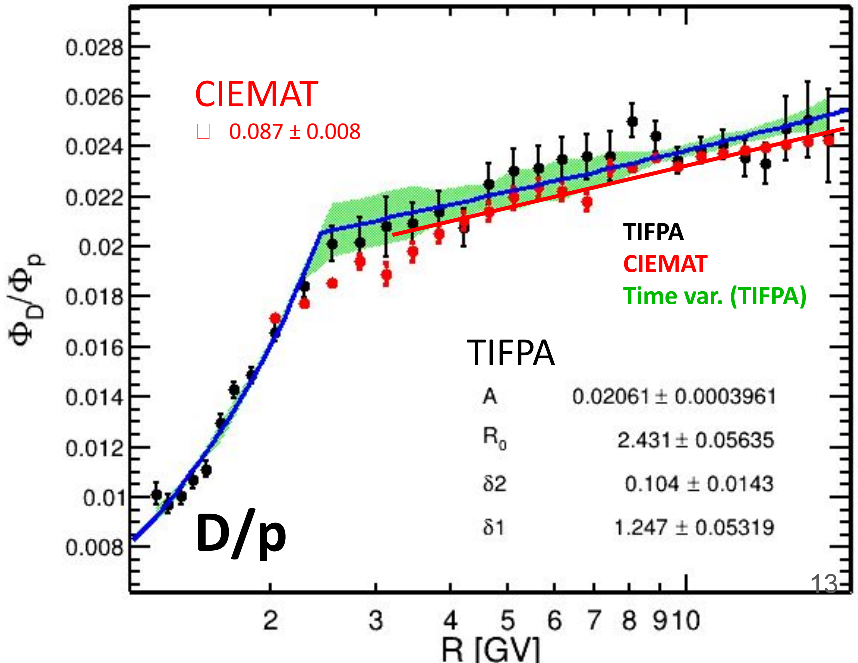
D/^{4}He



TIFPA
CIEMAT
Time var. (TIFPA)

CIEMAT
□ 0.173 ± 0.012

D/^{3}He

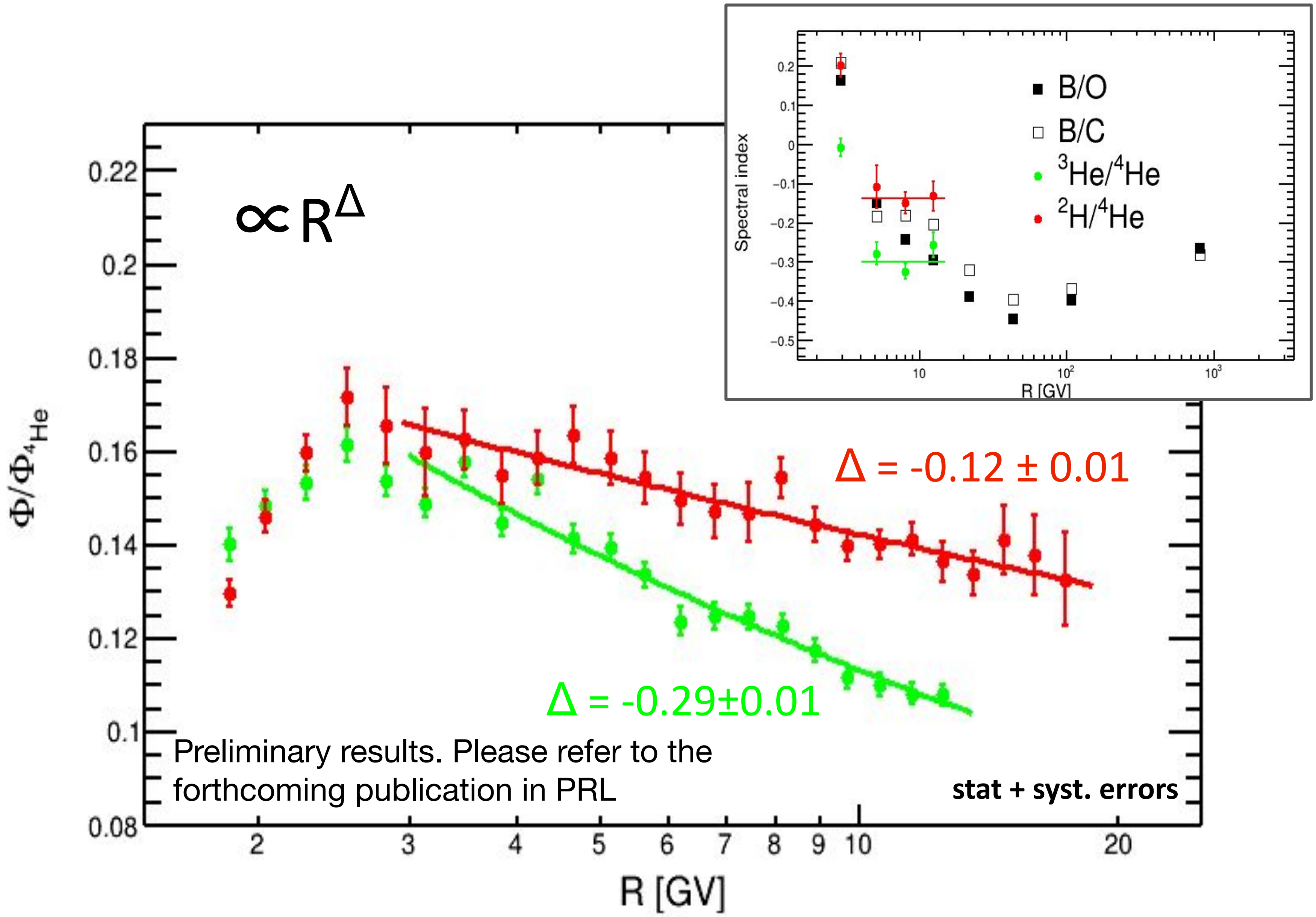


CIEMAT
□ 0.087 ± 0.008

TIFPA
CIEMAT
Time var. (TIFPA)

D/p

D/^{4}He vs ^{3}He/^{4}He Spectral index



$\propto R^{\Delta}$

$\Delta = -0.12 \pm 0.01$

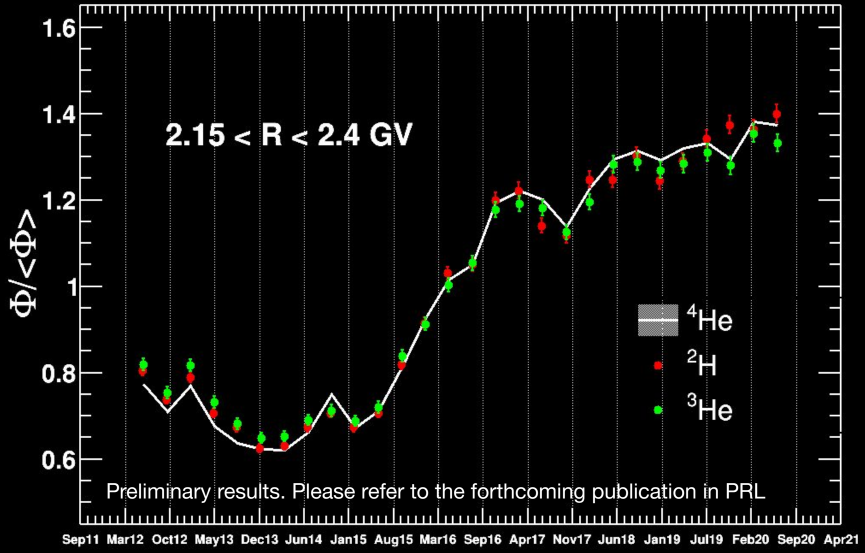
$\Delta = -0.29 \pm 0.01$

Preliminary results. Please refer to the forthcoming publication in PRL

stat + syst. errors

Fluxes time dependence

- Time variation are visible above systematics only below ~ 5 GV
- ^{2}H and ^{3}He qualitatively follow the same time evolution of ^{4}He
- More sophisticated analysis is needed



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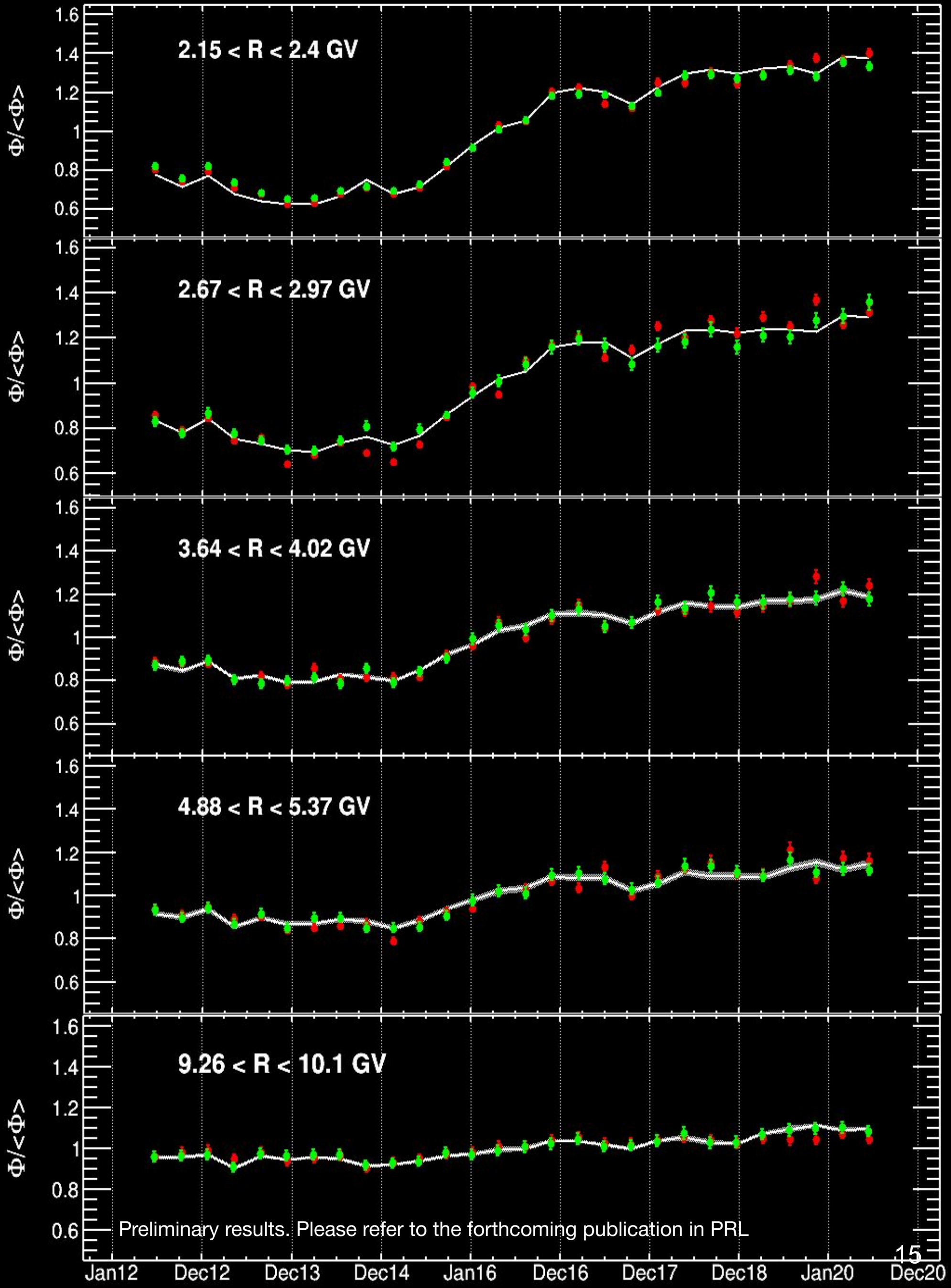

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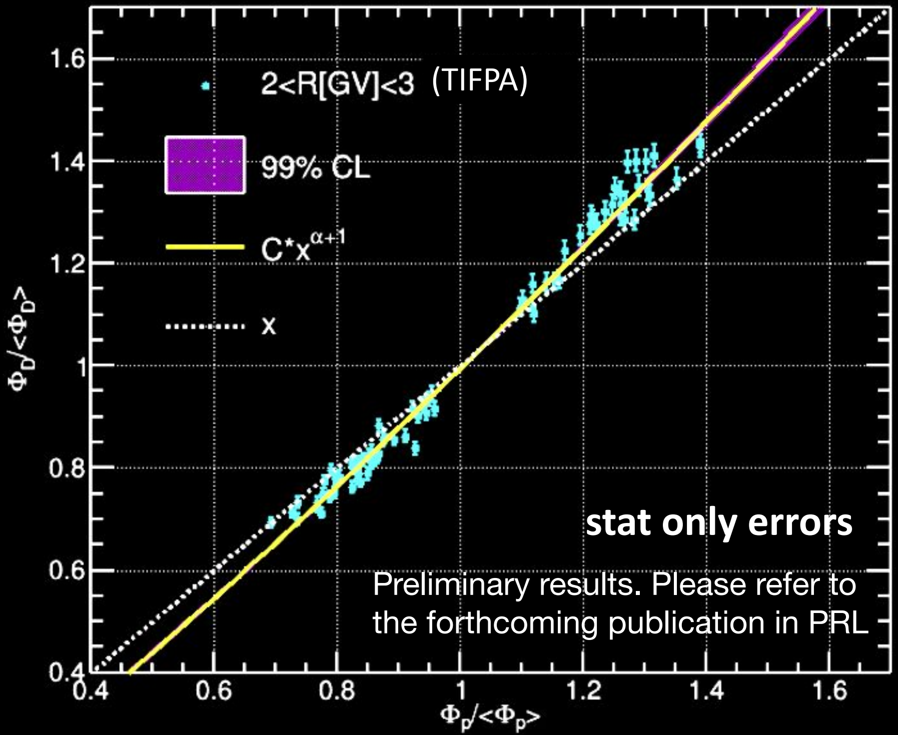
Time evolution of D vs ^{4}He



(TIFPA)

stat only errors

Preliminary results. Please refer to the forthcoming publication in PRL

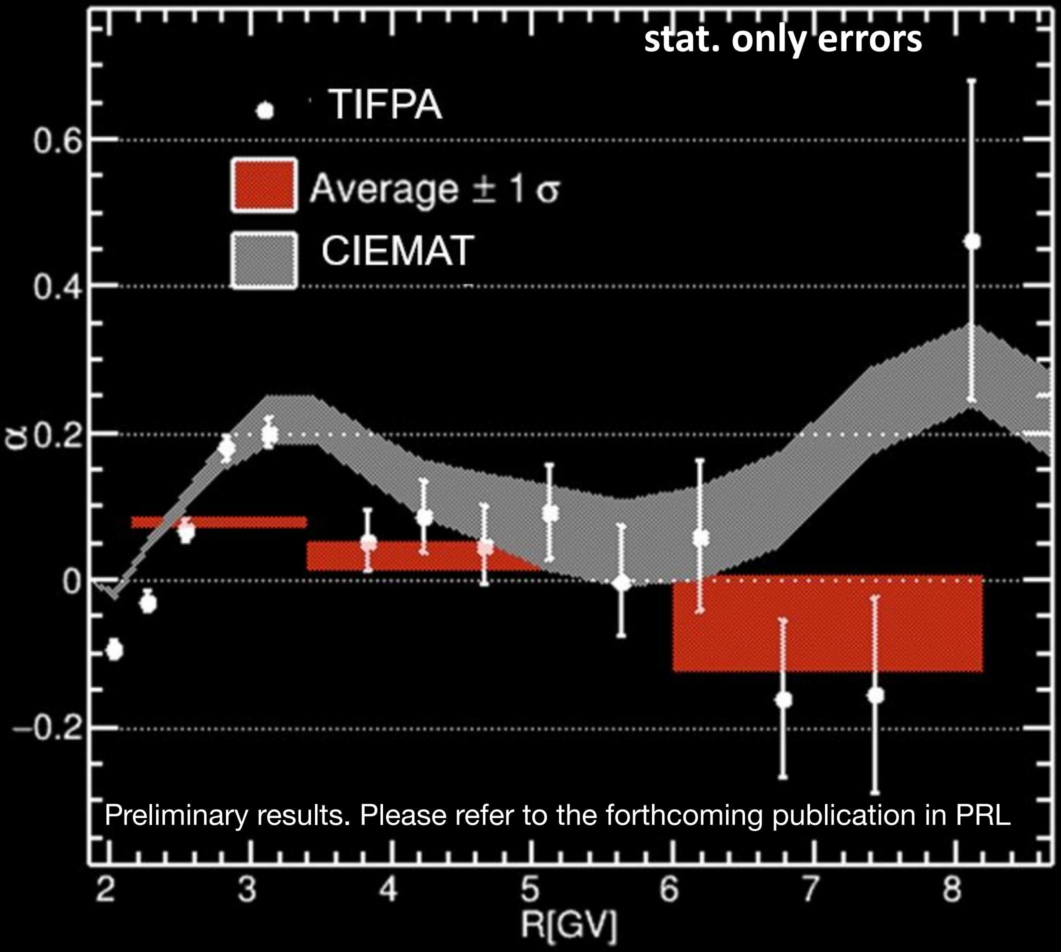
Comparison of the relative time evolution of the flux of ^{2}H and ^{4}He

For each R bin, fitted to

$$\frac{\Phi(^2H)}{\Phi(^4He)} \sim \frac{<\Phi(^2H)>}{<\Phi(^4He)>} \times \left(\frac{\Phi(^4He)}{<\Phi(^4He)>}\right)^{\alpha}$$

$\alpha = 0$ if the evolution of the two species is the same

Time evolution of D vs ^{4}He

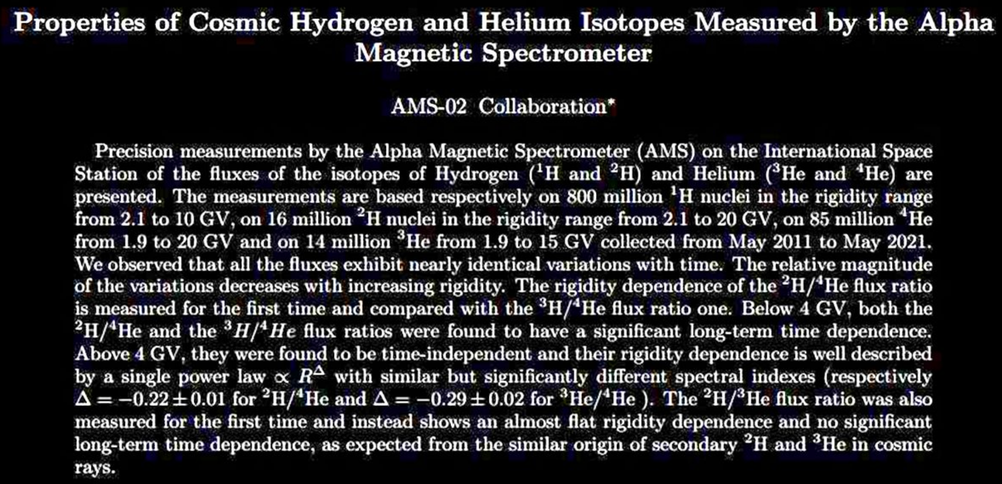


- Only fit statistical errors are shown
- For R<3.5 GV, both groups see hints of significative time dependence of the ratio
- For R>3.5 GV, the two species show evolution compatible within the errors

Summary

- **AMS-02 measured the ^{3}He and D fluxes using 10 years of data in the rigidity range from 2GV to 20 GV.**
- **Below ~4GV:** solar modulation induces a time evolution of the the measured fluxes larger than the systematics of the measurement.
- **Above ~4GV:** the ratio of ^{3}He and D to ^{4}He are compatible with a power law function. The spectral indexe seem to be different for the two species.
- The fluxes time evolution are qualitatively similar to those of ^{4}He. We observe hints of significantly different behaviour of the two species below ~3GV

… On track for drafting the paper



Properties of Cosmic Hydrogen and Helium Isotopes Measured by the Alpha Magnetic Spectrometer

AMS-02 Collaboration*

Precision measurements by the Alpha Magnetic Spectrometer (AMS) on the International Space Station of the fluxes of the isotopes of Hydrogen (^{1}H and ^{2}H) and Helium (^{3}He and ^{4}He) are presented. The measurements are based respectively on 800 million ^{1}H nuclei in the rigidity range from 2.1 to 10 GV, on 16 million ^{2}H nuclei in the rigidity range from 2.1 to 20 GV, on 85 million ^{4}He from 1.9 to 20 GV and on 14 million ^{3}He from 1.9 to 15 GV collected from May 2011 to May 2021. We observed that all the fluxes exhibit nearly identical variations with time. The relative magnitude of the variations decreases with increasing rigidity. The rigidity dependence of the ^{2}H/^{4}He flux ratio is measured for the first time and compared with the ^{3}H/^{4}He flux ratio one. Below 4 GV, both the ^{2}H/^{4}He and the $^{3}H/^{4}He$ flux ratios were found to have a significant long-term time dependence. Above 4 GV, they were found to be time-independent and their rigidity dependence is well described by a single power law $\propto R^{\Delta}$ with similar but significantly different spectral indexes (respectively $\Delta = -0.22 \pm 0.01$ for ^{2}H/^{4}He and $\Delta = -0.29 \pm 0.02$ for ^{3}He/^{4}He). The ^{2}H/^{3}He flux ratio was also measured for the first time and instead shows an almost flat rigidity dependence and no significant long-term time dependence, as expected from the similar origin of secondary ^{2}H and ^{3}He in cosmic rays.

Thanks for your attention

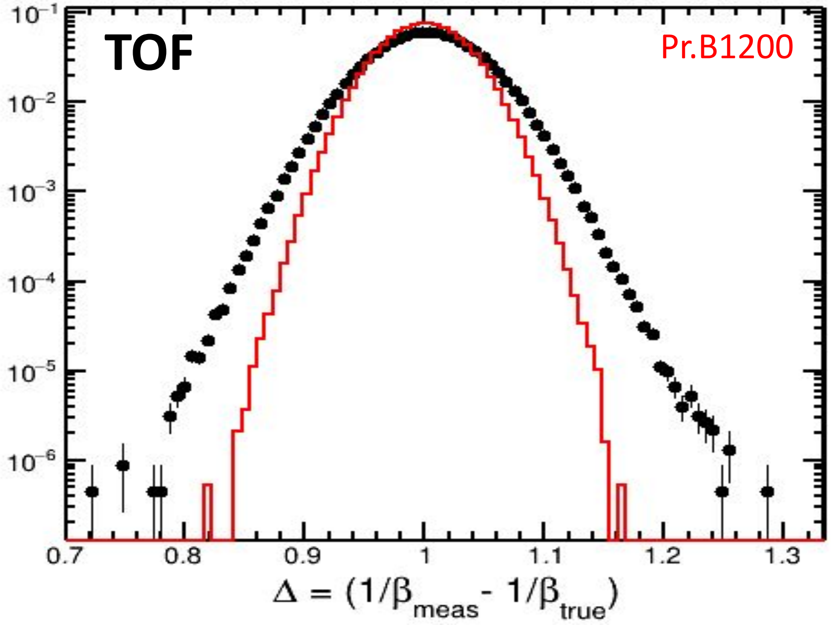
Disclaimer: numbers in the shown abstract are only tentative.

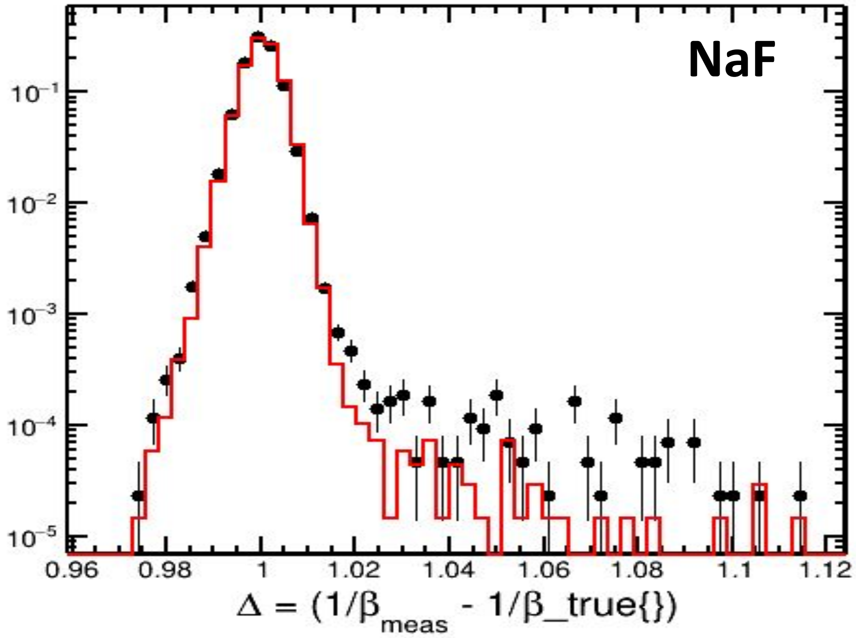
Backup

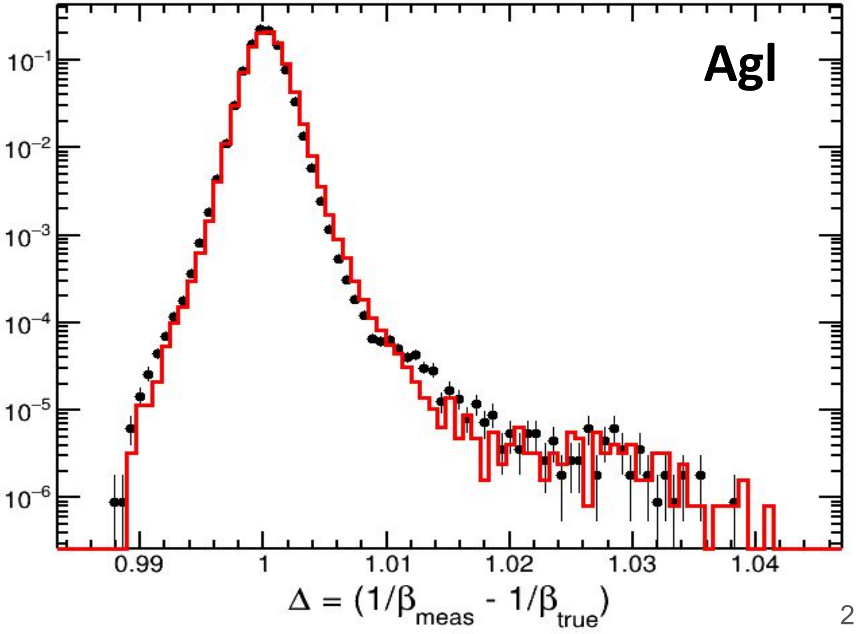
General Parametrization of the velocity resolution

Data/MC comparison at β=1

- **R > 50 GV**
- **TOF:** MC is completely off
- **NaF:** Data has tail of bad events
- **AgI:** MC is wider than data

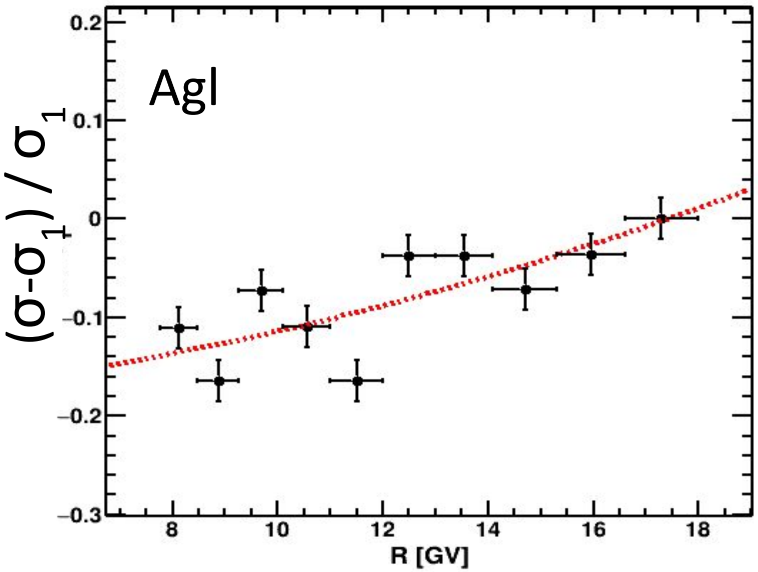




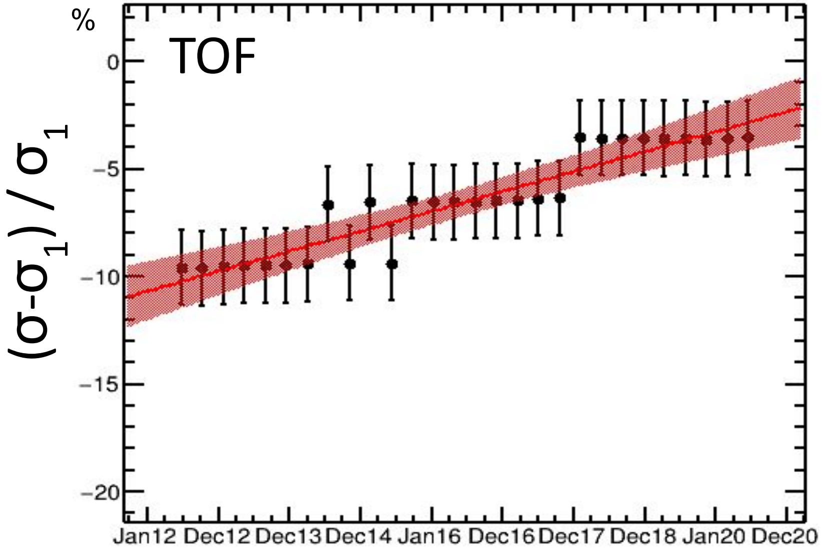


Trends for the free parameter were extracted as a function of:

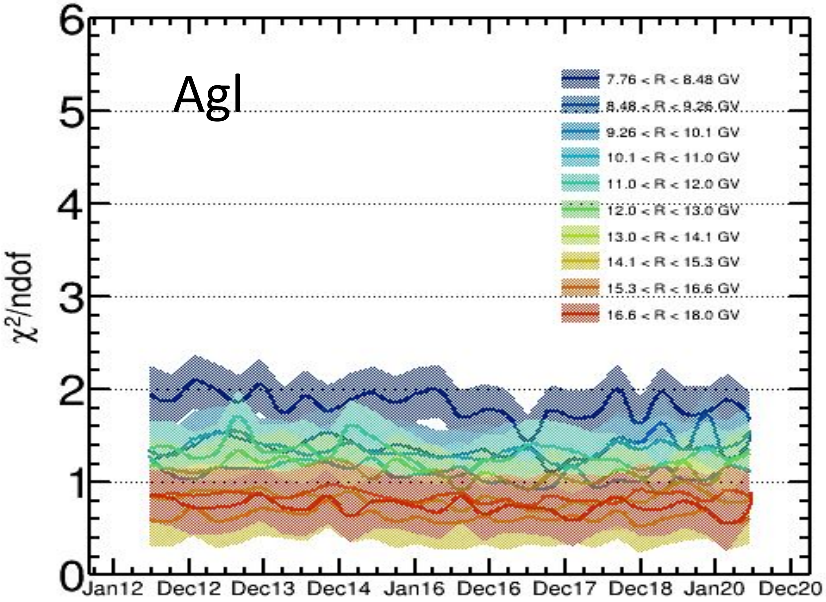
Energy



Time

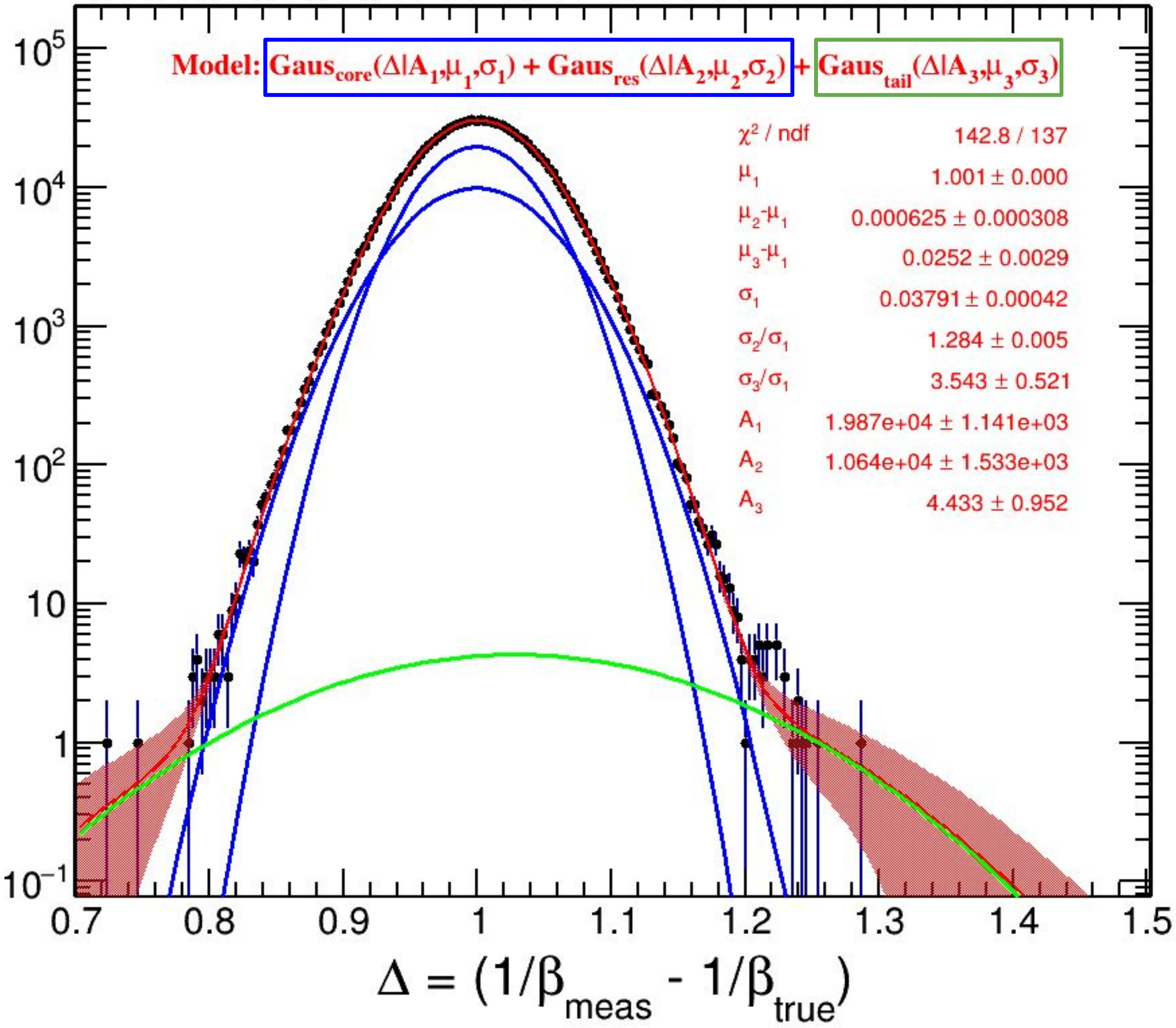


The stability of fit results were also checked to be stable against time



General Parametrization of the velocity resolution (Z=1 - TOF)

double gaussian core + tail of bad reconstructed events (not in MC)



σ_1 is the only free parameter of the model

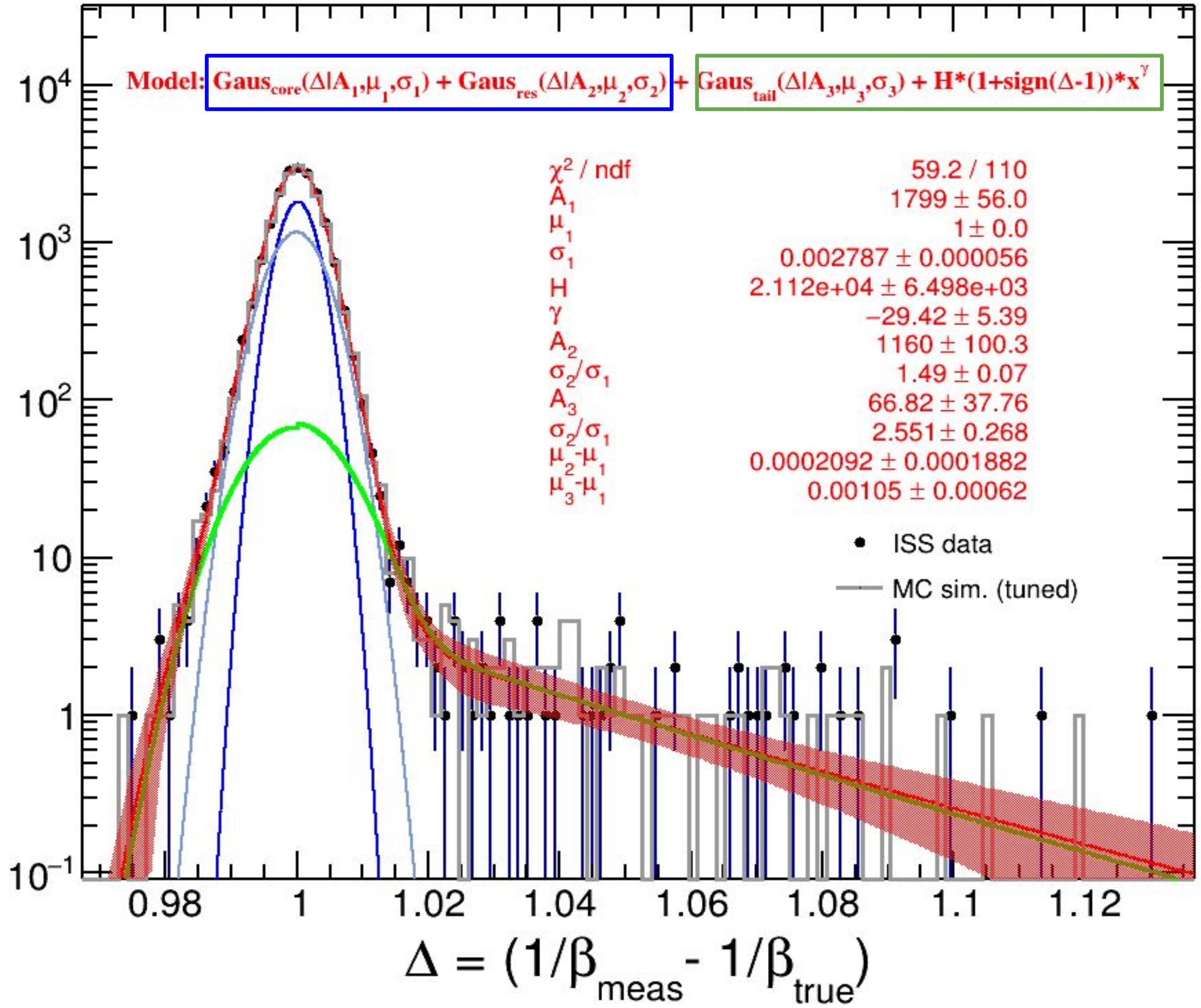
other parameters are fixed by the high velocity behaviour

TOF:

bad rec. events modeled as third gaussian

General Parametrization of the velocity resolution (Z=1 - NaF)

double gaussian core + tail of bad reconstructed events (not in MC)



σ_1 is the only free parameter of the model

other parameters are fixed by the high velocity behaviour

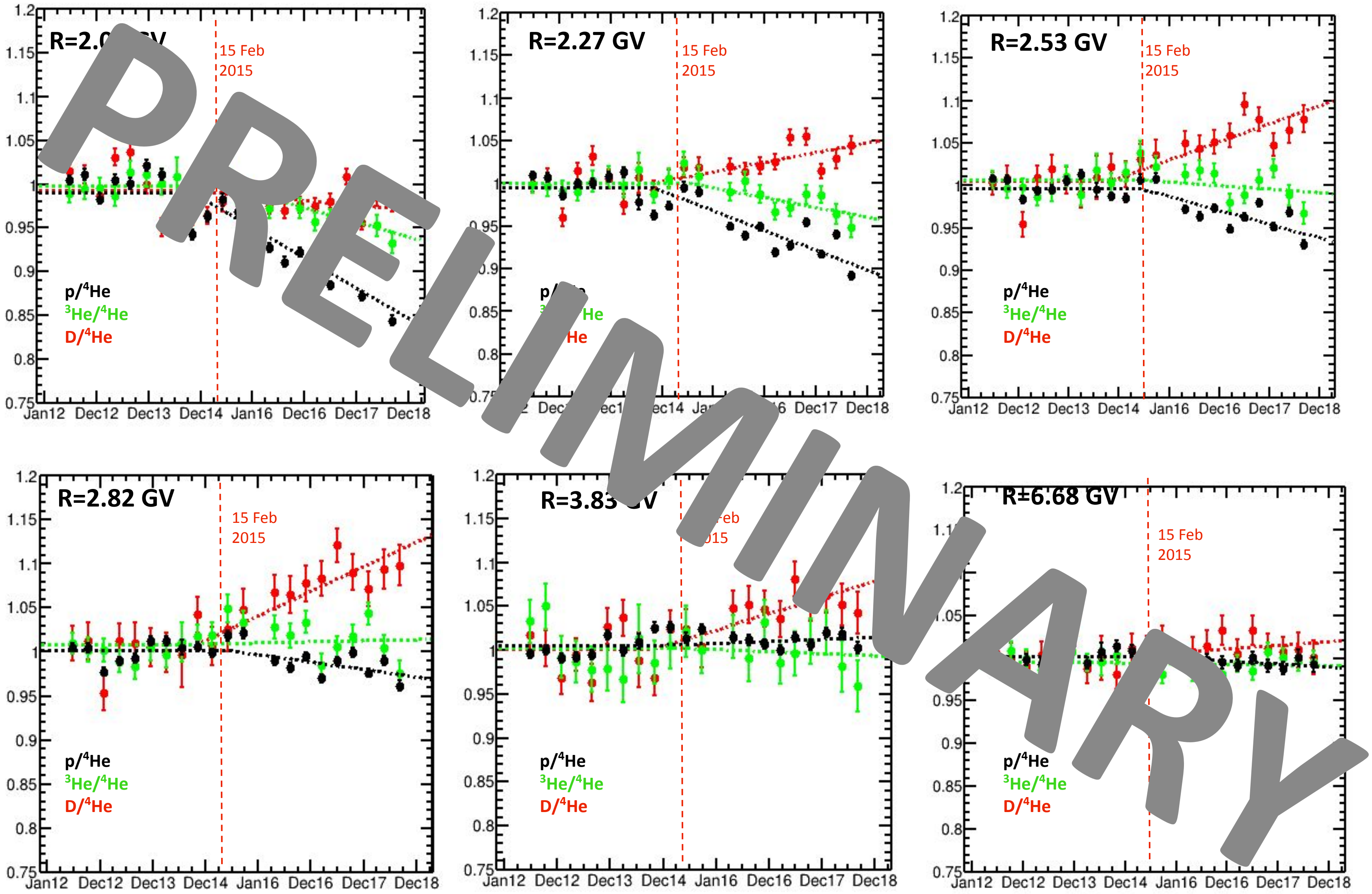
RICH (NaF):

bad rec. events modeled as gaussian + power law tail

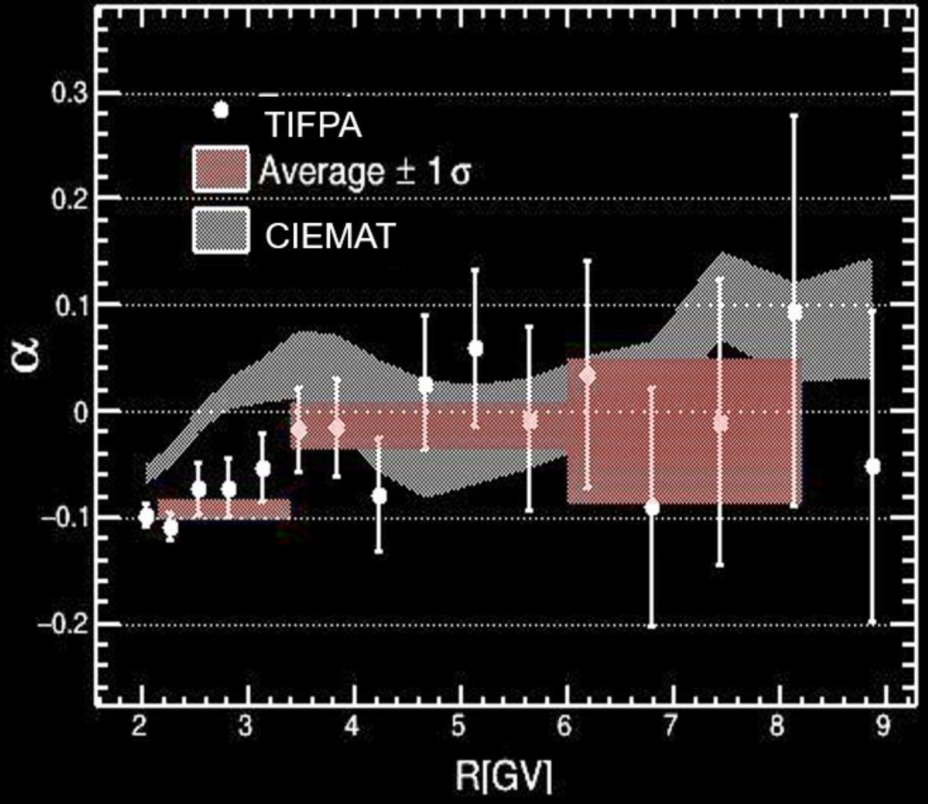
Time dep against ^{4}He summary

errors: stat (fit) + stat (eff. corr)

$$r_i(t) = \begin{cases} a_i & t < t_i \\ a_i + b_i(t - t_i) & t \geq t_i, \end{cases}$$



Time evolution of ^{3}He vs ^{4}He (work in progress)



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