A bayesian analysis of FAZIACOR (very preliminary results)

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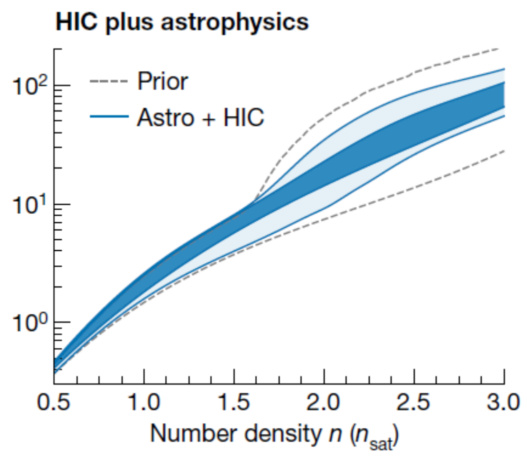
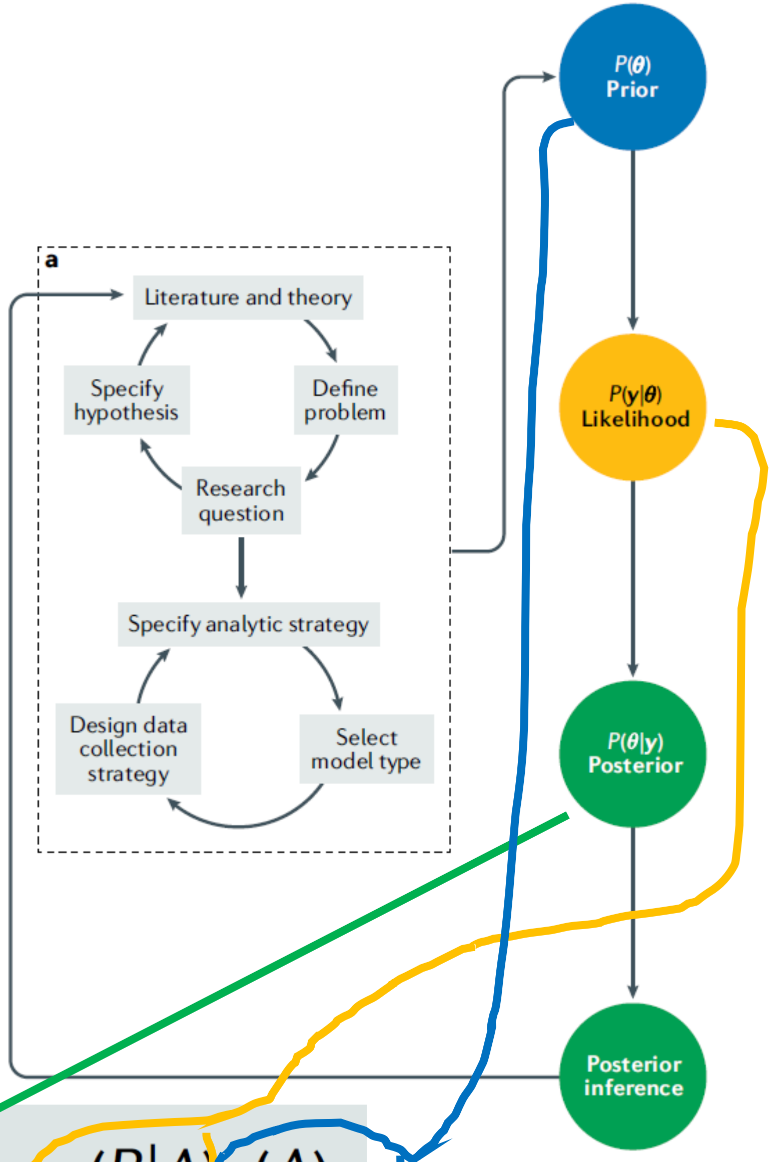
Bayesian analysis: motivations

- The Bayesian analysis is widely used to constrain parameters of theoretical models by means of experimental results coming from different experiment
- Recent examples can be found in the study of the symmetry energy and of the equation of states: e.g. Huth et al., Nature 606 (2022) 276
- In Huth et al., Nature 606 (2022) 276 results coming from HIC and astrophysics observations (GW from neutron star megers) are combined together to put constraints on the EOS predicted by the Chiral Effective Theory



The technique

- In the Bayesian analysis there is a theory able to predict an experimentally measured observable M. The predicted value depends on a (or more than one) parameter p of the model, which presents a statistical distribution.
- We assume a distribution for this parameter p (the prior distribution Prior), which can be also a flat one or which can come from previous studies
- If we have an experimental value for M, we can calculate the likelihood function L(M|p) which is the probability to obtain M for the theory for the value p of the parameter. We can calculate it for a distribution of values of the parameter p.
- The posterior distribution Post of the parameter p is given by Post=L(M|p)*Prior
- Therefore Post gives the distribution of p values with which we have the best reproduction –within the model – of the experimental value M
- If we have a new measurement of M, we can start from the Post distribution and use it as new Prior, in order to refine the p distribution to keep into account the new experimental value
- And so on for each new measurement
- Sometimes the posterior associated to different measurement do not converge => there is a tension in the data

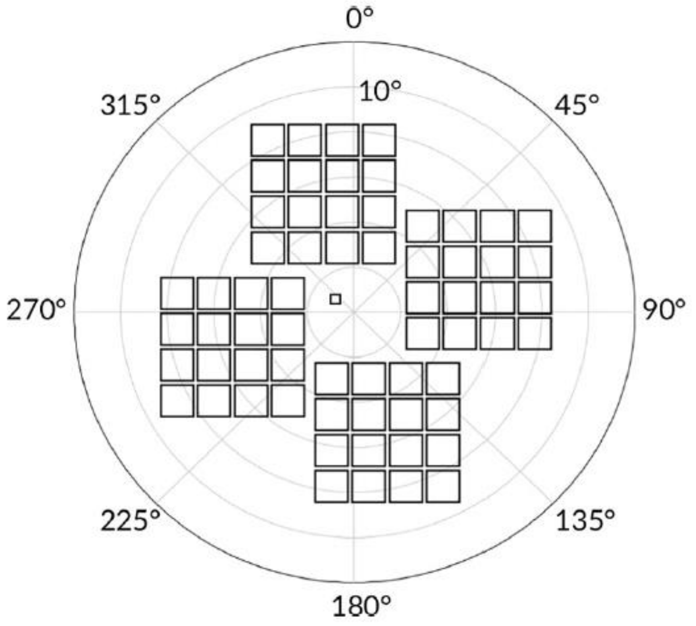


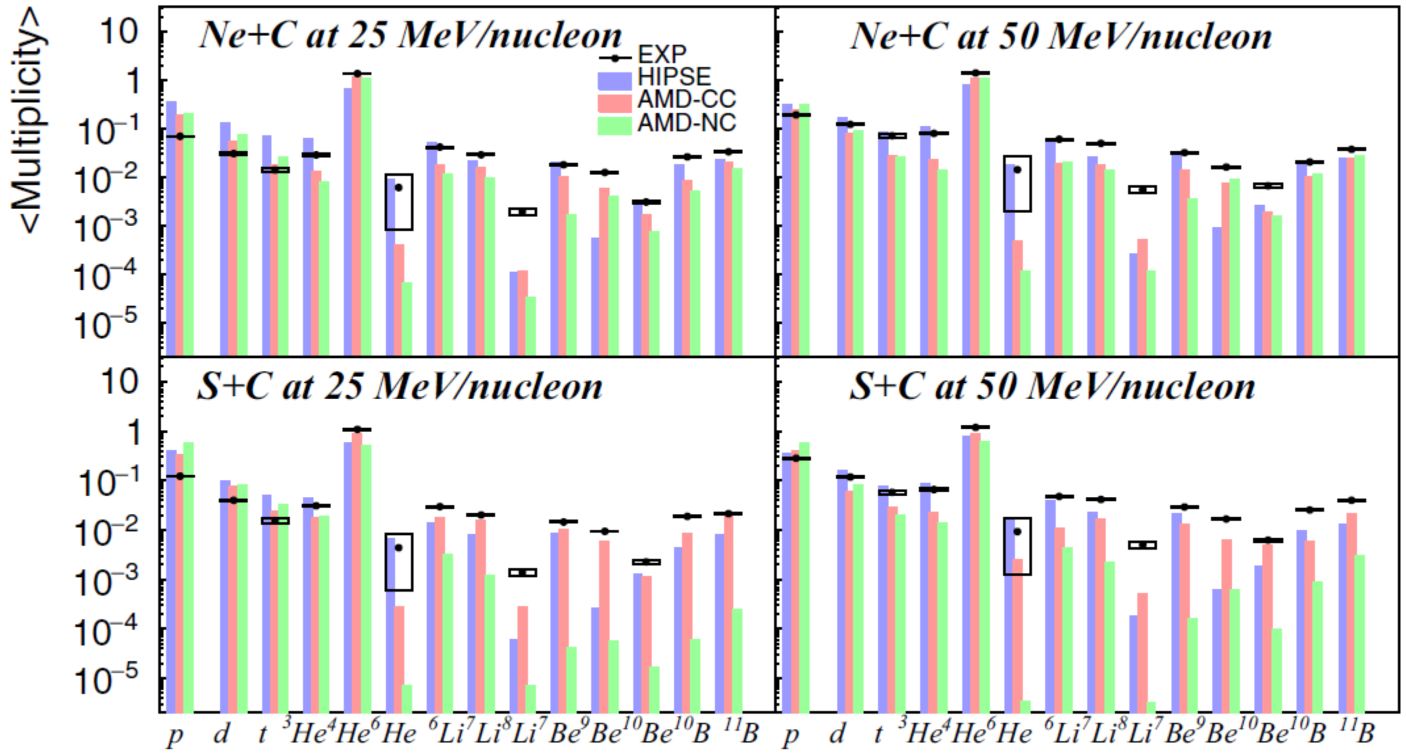
$$p(A|B) = \frac{p(B|A)p(A)}{p(B)}.$$

Bayes theorem

What we are doing on FAZIACOR data

- FAZIACOR: $^{20}Ne+^{12}C$@25,50AMeV and $^{32}S+^{12}C$@25,50AMeV
- Data collected at LNS@INFN in 2017 with 4 FAZIA blocks in wall configuration
- A paper was recently published C.Frosin et al., PRC 107 (2023) 04461, where particle multiplicities, energy and angular distributions are compared with the prediction of AMD+HFl with and without clustering





HFl is a statistical decay code based on the Hauser Feshbach formalism particularly adapted for light nuclei, where all known discrete levels are included G.Baiocco et al., PRC 87 (2013) 054614

Our goal: the investigation of the in-medium NN cross section and of the clustering parameter using the AMD model

- We focused on $^{20}Ne+^{12}C$@50AMeV (the smallest system => faster calculations; the highest energy => reaction more focused in the forward cone where we have a relatively good coverage; more sensitivity to NN cross section and to clustering)
- We are testing 2 parameters:
  - The y parameter of the in-medium NN cross section

$$\sigma = \sigma_0 \tanh(\sigma_{\text{free}}/\sigma_0) \qquad \sigma_0 = y\,\rho^{-2/3}$$

D. D. S. Coupland, W. G. Lynch, M. B. Tsang, P. Danielewicz, and Y. Zhang, Phys. Rev. C **84**, 054603 (2011).

  - The clustering parameter

$$v d\sigma = \frac{2\pi}{\hbar} P(C_1, C_2, p_{\text{rel}}, \Omega) \, |M(p_{\text{rel}}^{(0)}, p_{\text{rel}}, \Omega)|^2 \, \frac{p_{\text{rel}}^2 d\Omega}{\partial E/\partial p_{\text{rel}}},$$

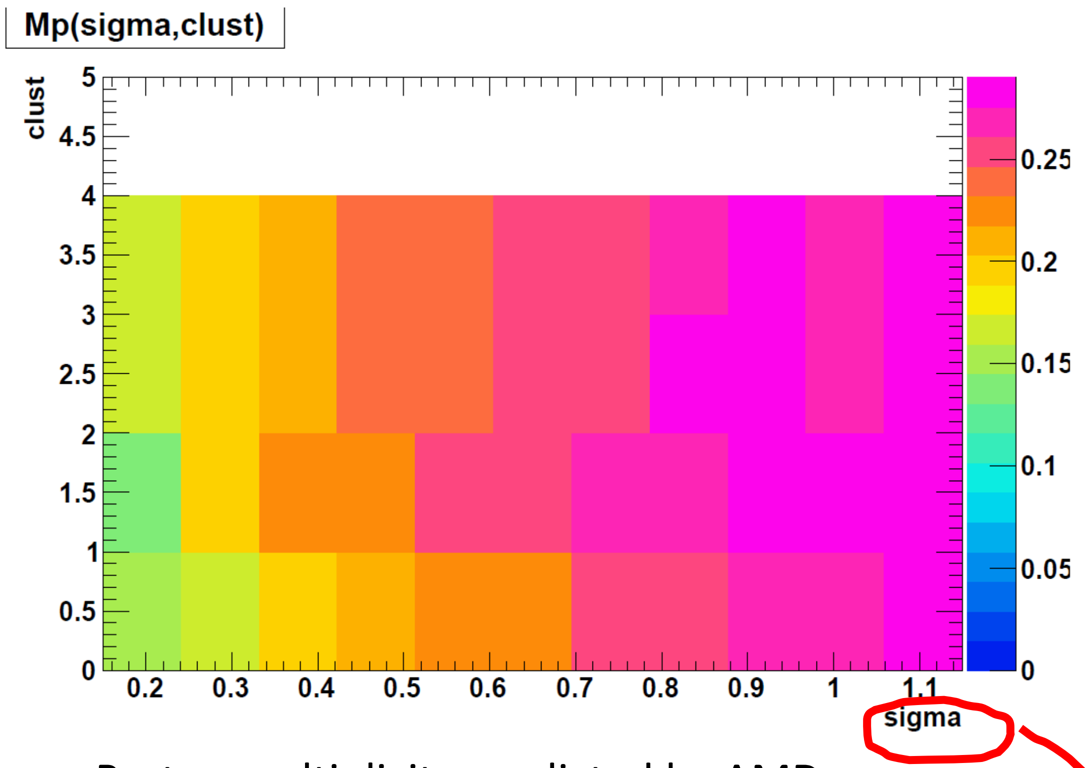
Collision probability for the formation of a specific cluster

The matrix element is directly related to the in-medium NN cross section

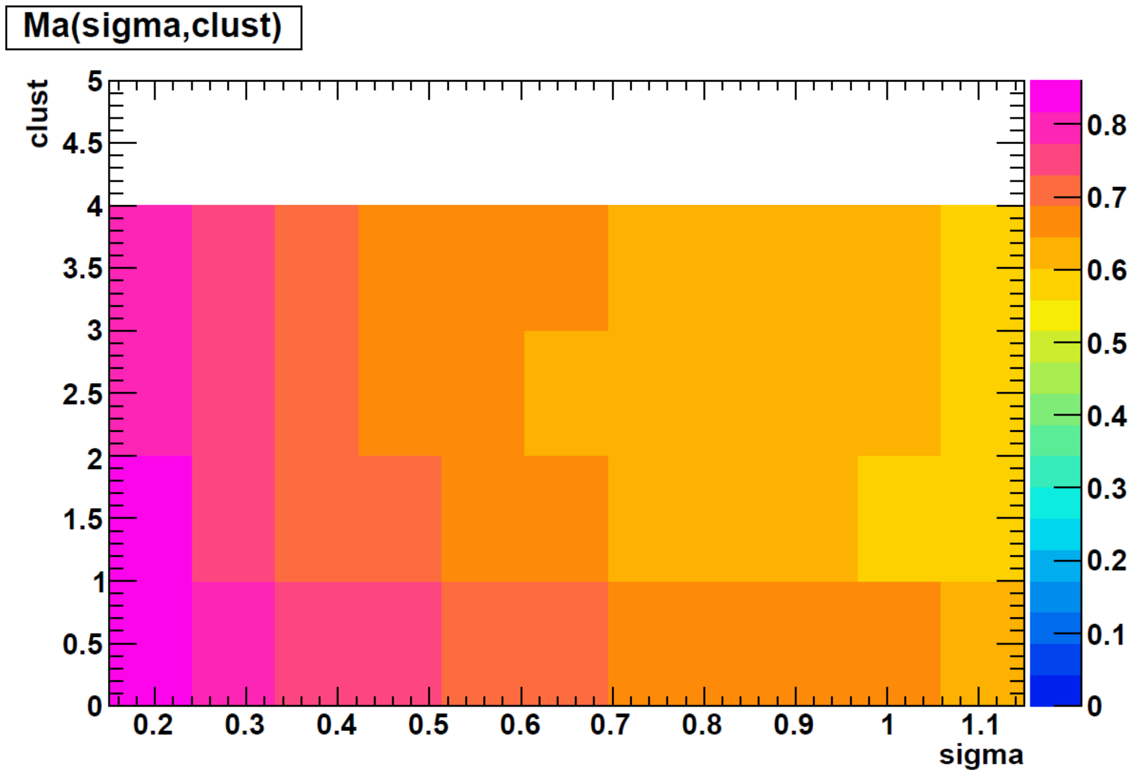
Operationally:

- We are running many AMD runs for the system 20Ne+12C@50AMeV (6000 events for each run) changing the in-medium cross section and the clustering parameter on a grid of values (121 cases)
- soft symmetry energy, with the ground state energy recalculated for each Z,A with the internal cooling procedure of AMD (instead of using Wapstra mass table) to calculate the E* for the afterburner. This method reduces the situations in which negative excitation energies for light fragments are obtained.
- We are applying GEMINI++ with a multiplication factor of 100 (100 secondary events for each primary event)
- We are applying the same analysis used in the paper by Catalin Frosin to the simulated data (including the filtering for the geometrical efficiency)
- We are going to apply the Bayesian technique on different observables, assuming as starting point a prior distribution reflecting the actual knowledge on NN cross section and clusterization in matter
- The work is in progress, primary data are still under production
- We did some preliminary tests on the whole machinery

We are using proton and α multiplicities as observables



Proton multiplicity predicted by AMD (+GEMINI++) as a function of the in medium NN cross section and of the clustering parameter

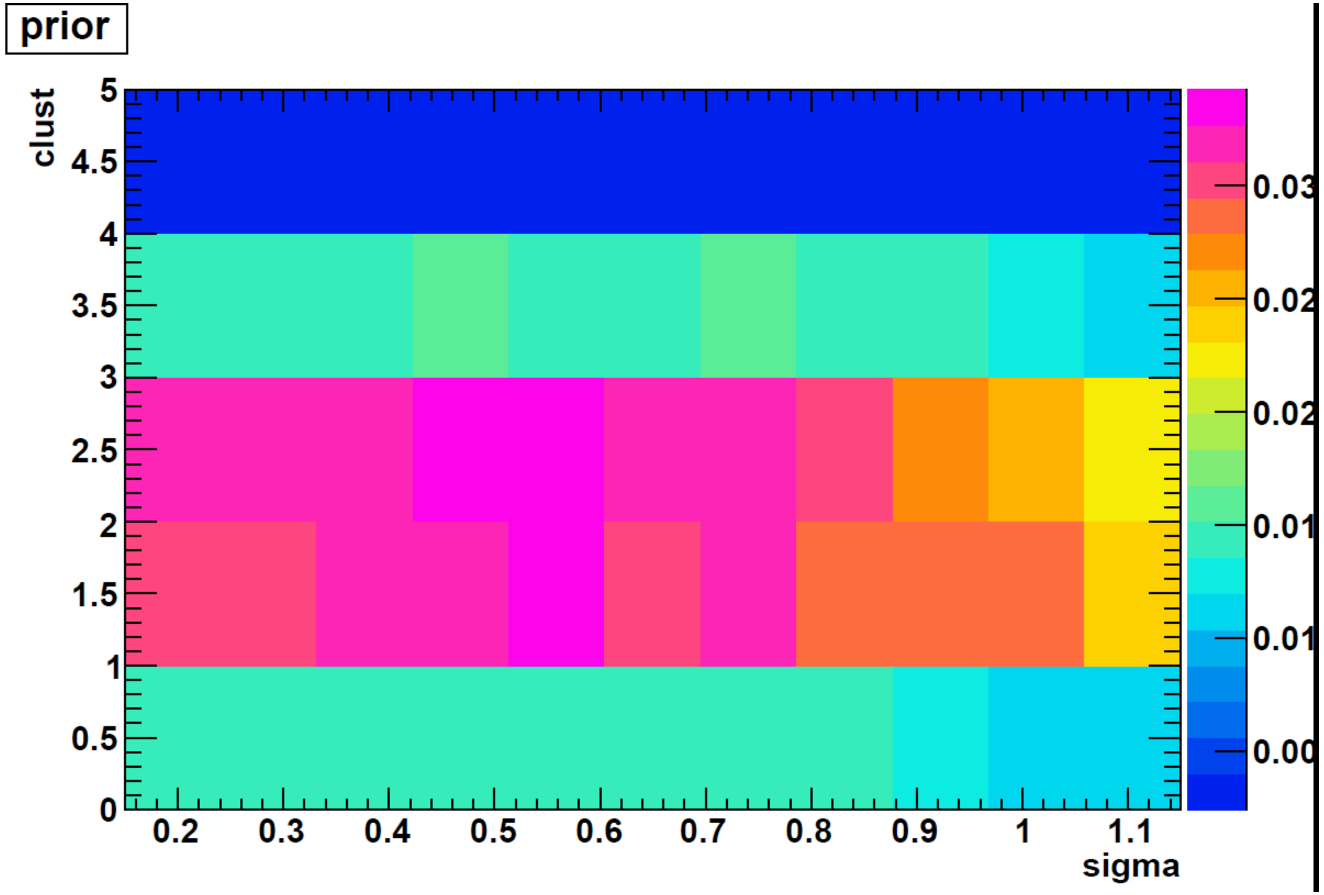


Alpha multiplicity predicted by AMD (+GEMINI++) as a function of the in medium NN cross section and of the clustering parameter

This means y

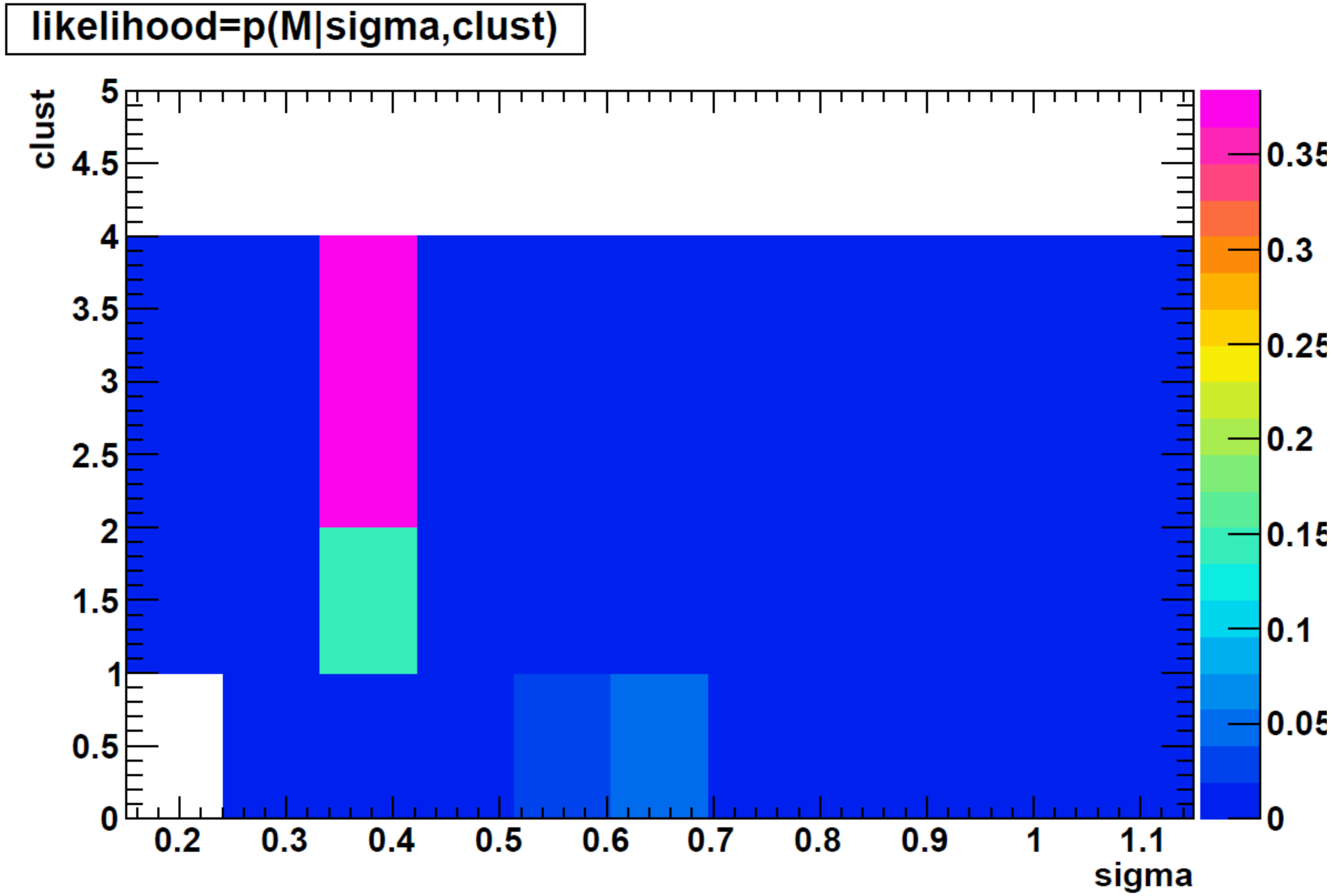
$$\sigma = \sigma_0 \tanh(\sigma_{\rm free}/\sigma_0) \qquad \sigma_0 = y\,\rho^{-2/3}$$

To test the machinery we used a not uniform prior distribution



DUMMY

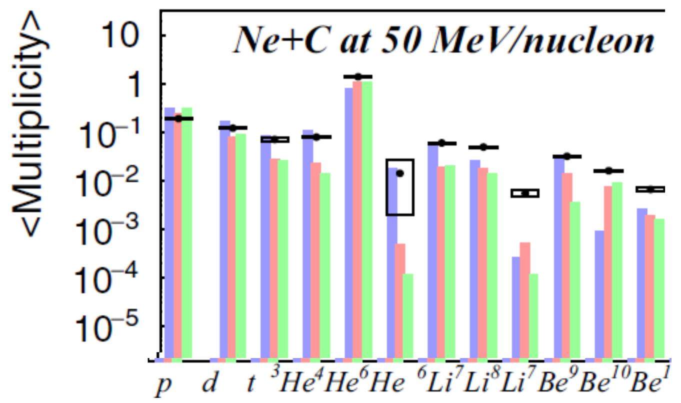
The likelihood for m_{pexp}=0.21 with σ_p=0.01 and $m_{\alpha exp}$=0.71 with σ_α=0.01:



$$\mathcal{L}(\sigma NN, clust) = \mathcal{L}_p(\sigma NN, clust)\mathcal{L}_\alpha(\sigma NN, clust)$$

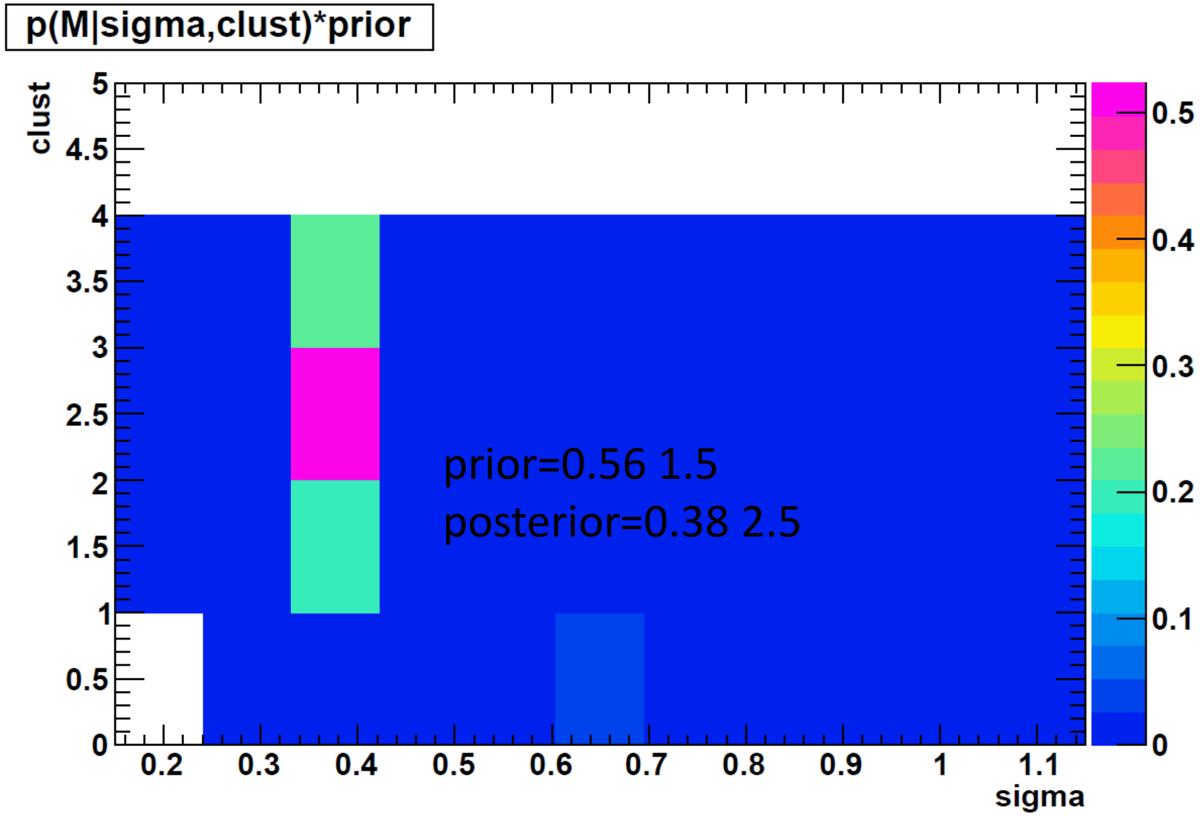
$$\mathcal{L}_i(\sigma NN, clust) = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(m_{iexp} - M_{iAMD}(\sigma NN, clust))^2}{2\sigma_i^2}}$$

NB These are not experimental values taken by the paper of FAZIACOR, because the experimental ones are not covered by the values predicted by AMD in the grid run up to now



The adopted values corresponds to sigmaNN=0.35 and clustering parameter 3

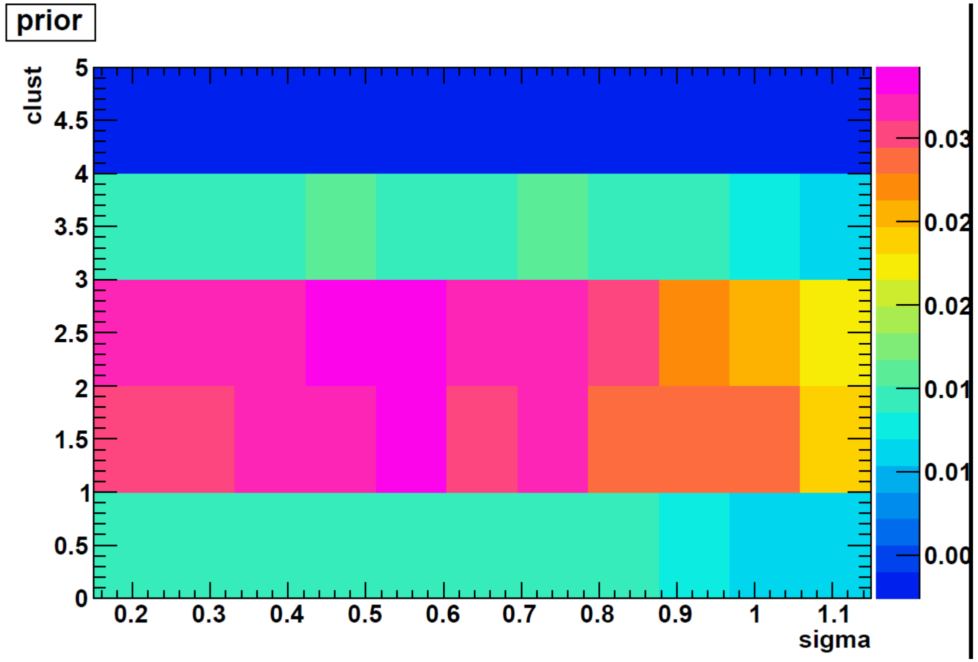
Therefore the posterior distribution is



The adopted values of «experimental» multiplicities corresponds to sigmaNN=0.35 and clustering parameter 3

The maximum of the posterior is for σ_{NN}=0.38 and clustering=2.5

We started with a prior having the maximum for σ_{NN}=0.56 and clustering=1.5



The procedure seems to work

Next steps:

- We will end the grid production (1 month total)
- We will try with experimental values of the observables, not only proton and α multiplicities, but also other available observables
- We will see what happens changing the afterburner to HFl
- We will extend the test to the other systems of FAZIACOR (maybe after trying a first paper on only one system)
- We can try to use also other experimental data available in the literature in an iterative procedure
- This work could be useful in order to present a (hopefully succesful) proposal for the PAC