Extraction of the properties of nucleon resonances by means of a Genetic Algorithm

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Our pion photoproduction model

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- Nucleons, pions, photons [Born terms]
- Vector mesons (ρ and ω)
- Nucleon resonances
  - Up to 1.8 GeV
  - Up to spin-3/2
  - Δ(1232), Δ(1620), and Δ(1700)
  - N(1440), N(1520), N(1535), N(1650), and N(1720)

Fernández-Ramírez, Moya de Guerra, Udías, AP(NY) 321 (2006) 1408

The underlying physics is embedded in the constants of the model $\rightarrow$ obtained fitting the data

Optimization

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- Gradient-based routines are the usual optimization tools (MINUIT, NAG)

  CERN, MINUIT 95.03, CERN Library D506 Edition, 1995
  Numerical Algorithms Group Ltd., http://www.nag.co.uk

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- In complex optimization problems these routines may get easily stuck in local minima
- Alternative: Stochastic optimization $\rightarrow$ Genetic algorithms
- Example: E04FCF from NAG by itself is useless for our problem: gradient based methods alone fail
- Hybrid optimization: combine GA with gradient based routine E04FCF from NAG libraries

$$\boxed{\text{GA}} + \boxed{\text{E04FCF}} \longrightarrow \boxed{\text{Parameters}}$$

- GA provides E04FCF the initial value

Evolution (optimization)

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- Evolution as an optimization scheme
- The different kinds of species evolve to the optimal adaptation to the surrounding environment. Thus, evolution is an 'algorithm' that searchs for the best solution creating a set of individuals (a generation), it decides which individuals are the best ones, and, by means of crossover, keeps the good genetic characteristics for the next generation – that will be closer to the optimal solution – and removes the individuals with worst genetic content

Biology $\leftrightarrow$ GA

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Environment	$\leftrightarrow$	Objective function (v.g. χ^2)
Individual	$\leftrightarrow$	Set of parameters
Generation (set of individuals)	$\leftrightarrow$	Set of possible solutions

How a GA works

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- We start with a first generation randomly generated (N individuals)
- Each individual encodes a complete set of parameters

G_E	G_M	M_Δ	$\cdots$

each parameter is a "gene"

- Scale population, v.g. using the χ^2, to assign a survival and mating probability to each individual
- Generate the offspring (fight, crossover, and mutation of individuals)
- Repeat process until a given number of generations is reached

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Simulate evolution in a computer!

- We perform several optimizations to obtain a set of minima

Particularities of GAs

- Whereas most methods employ a single solution which evolves to reach the local optimum, GAs work on a population of many possible solutions simultaneously
- GAs only need the objective function to determine how fit an individual is. Neither derivatives nor other auxiliary knowledge are required
- GAs use probabilistic rules to evolve (randomness does not mean directionless!)

Evolution of the optimization

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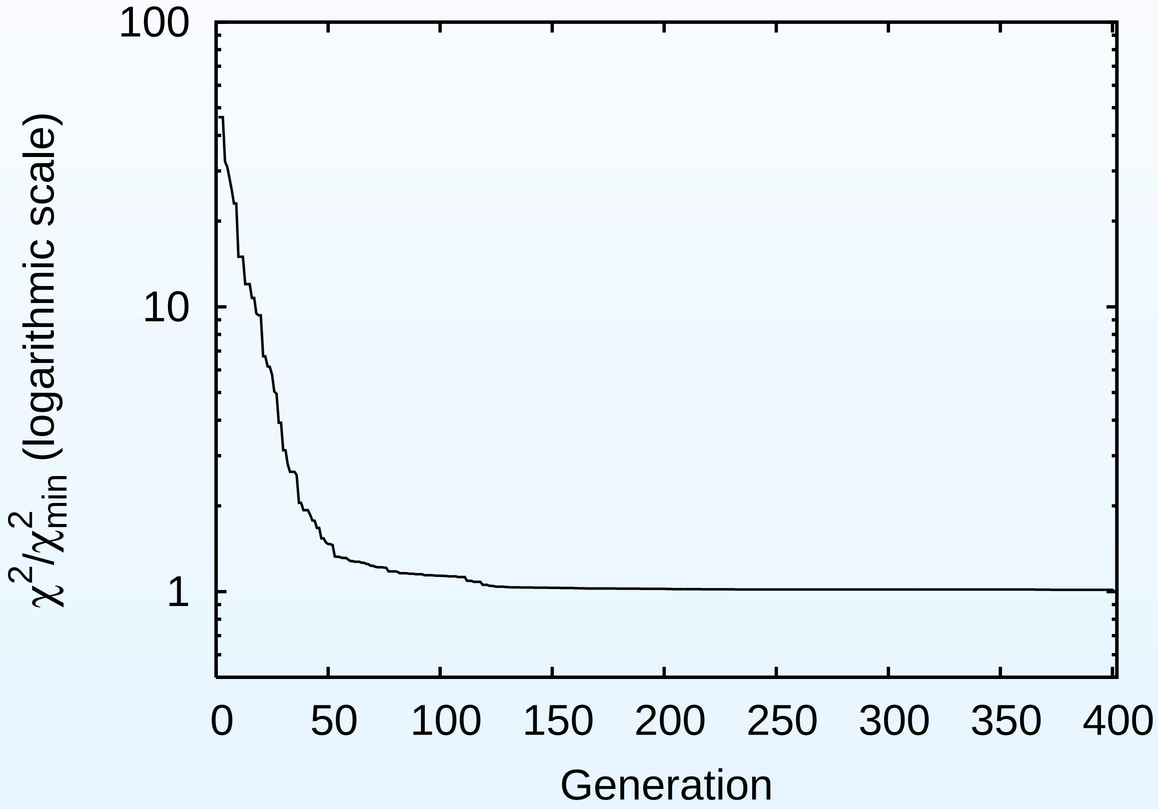

Evolution of the χ^2 normalized to the final χ^2

The best individual of each generation is plotted

Effect of the gradient-based routine

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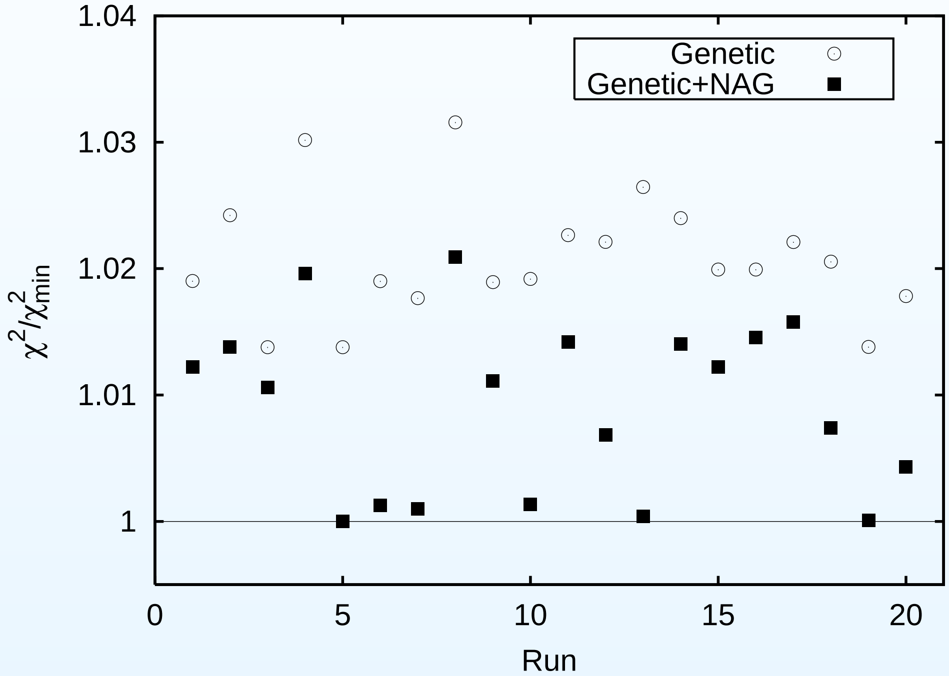

We have performed several optimizations (20), for each run (x-axis) we get a different minimum (y-axis). We normalize all of the minima to the best one and we plot the minima given by the GA alone and the improvement achieve by the NAG routine for each run

Δ(1232) parameters and E2/M1 ratio

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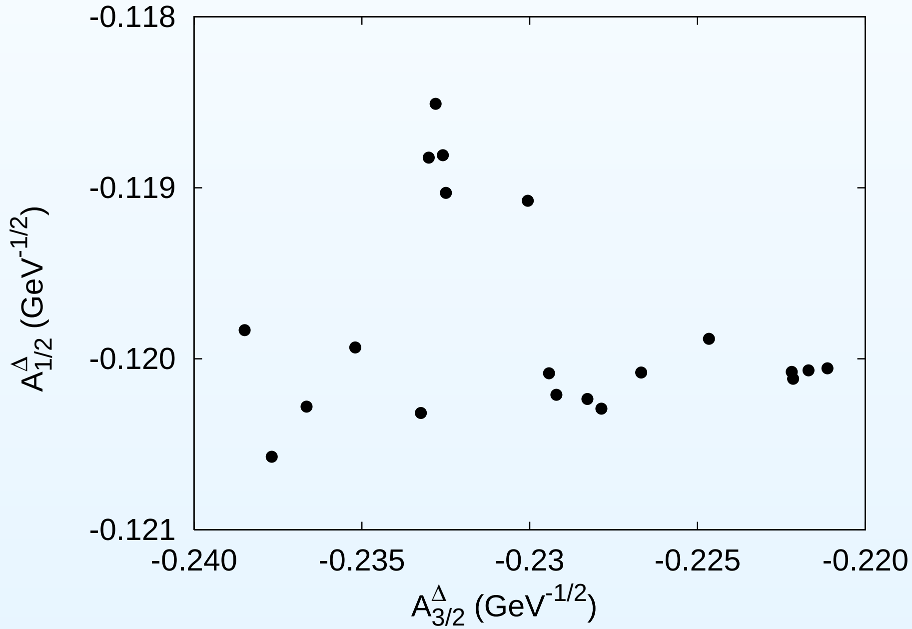
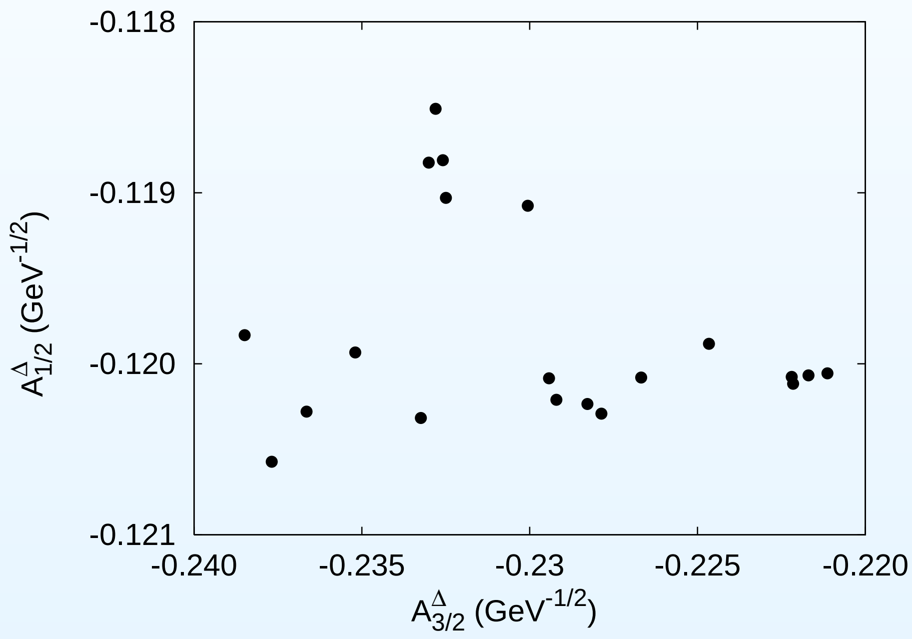
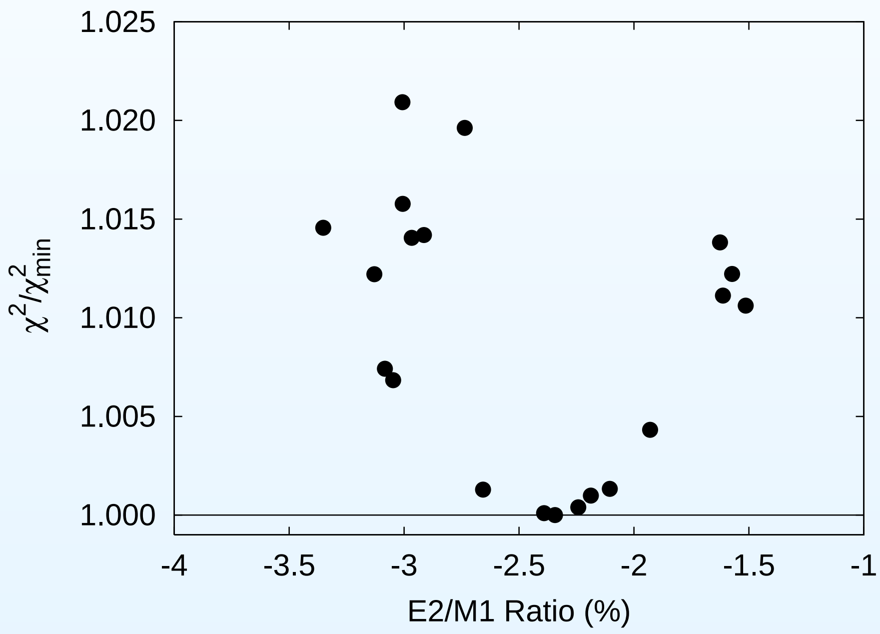


Δ(1232) parameters and E2/M1 ratio





Δ(1700) parameters and model and database effects

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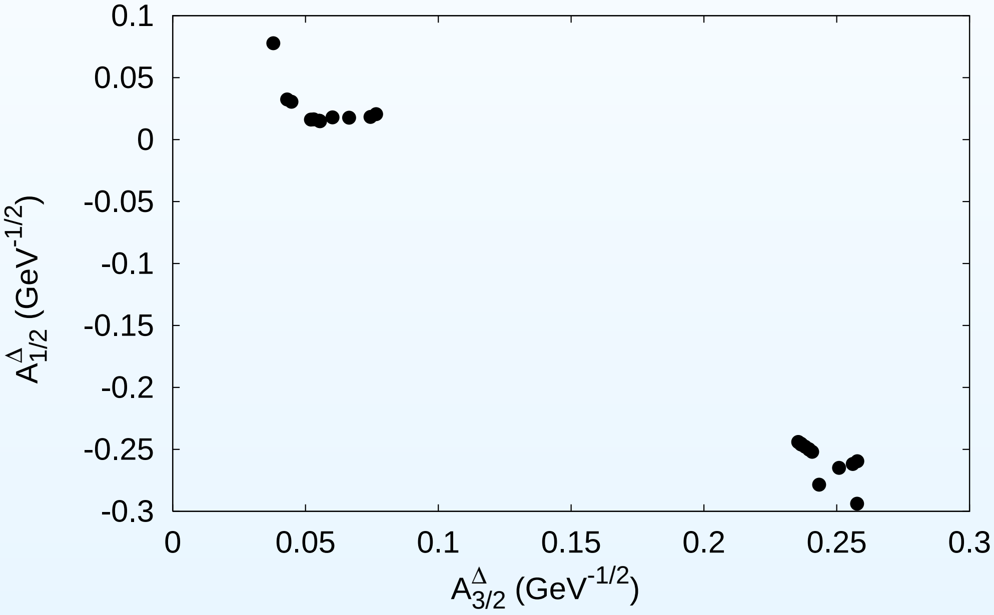

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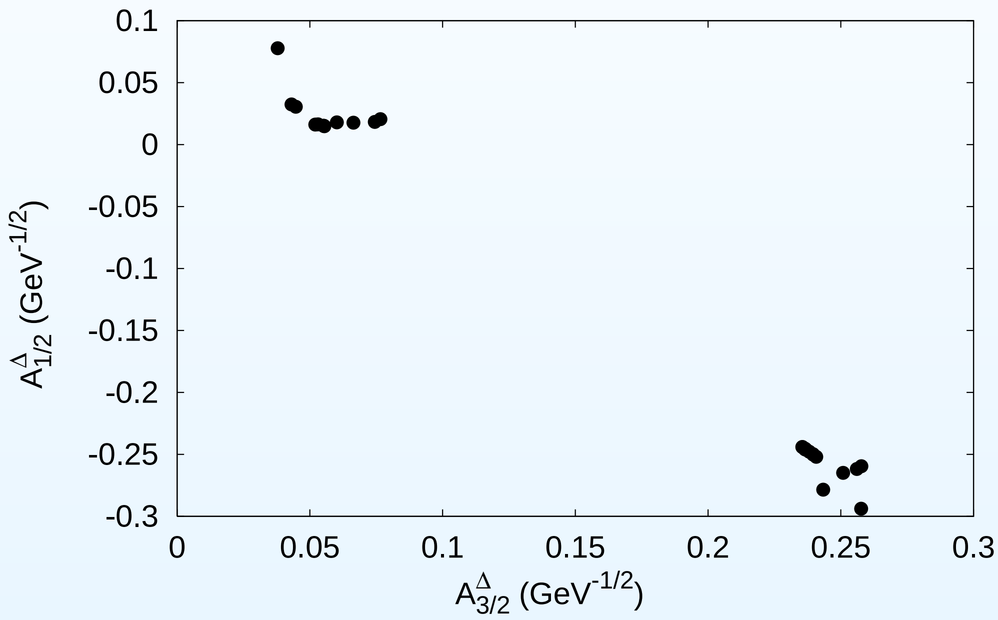

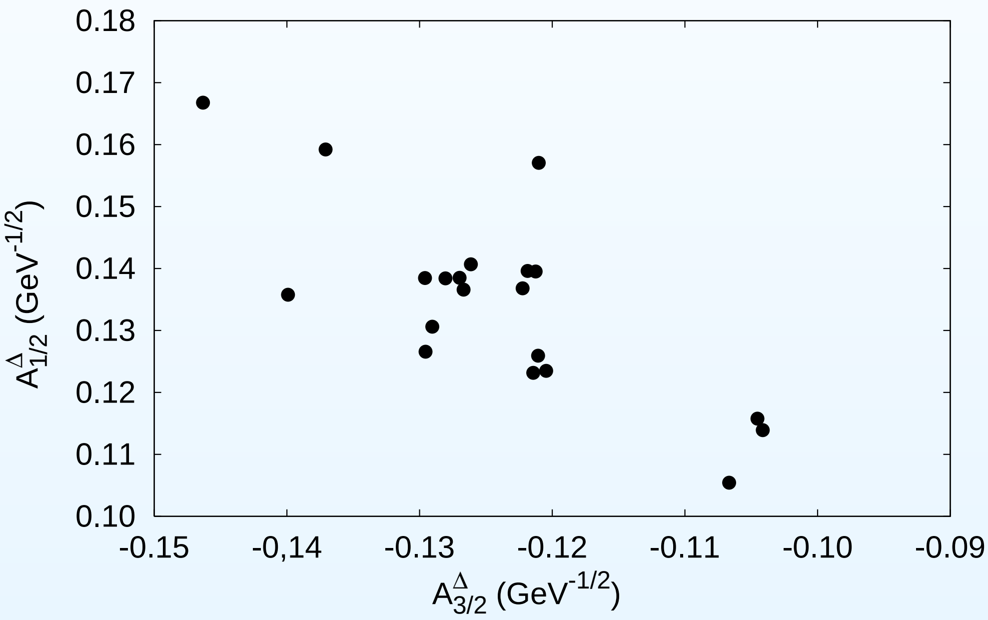

2005 SAID database

Model up to 1 GeV

2006 SAID database

Model up to 1.2 GeV

Δ(1700) tail fully covered

Fits to electromagnetics multipoles

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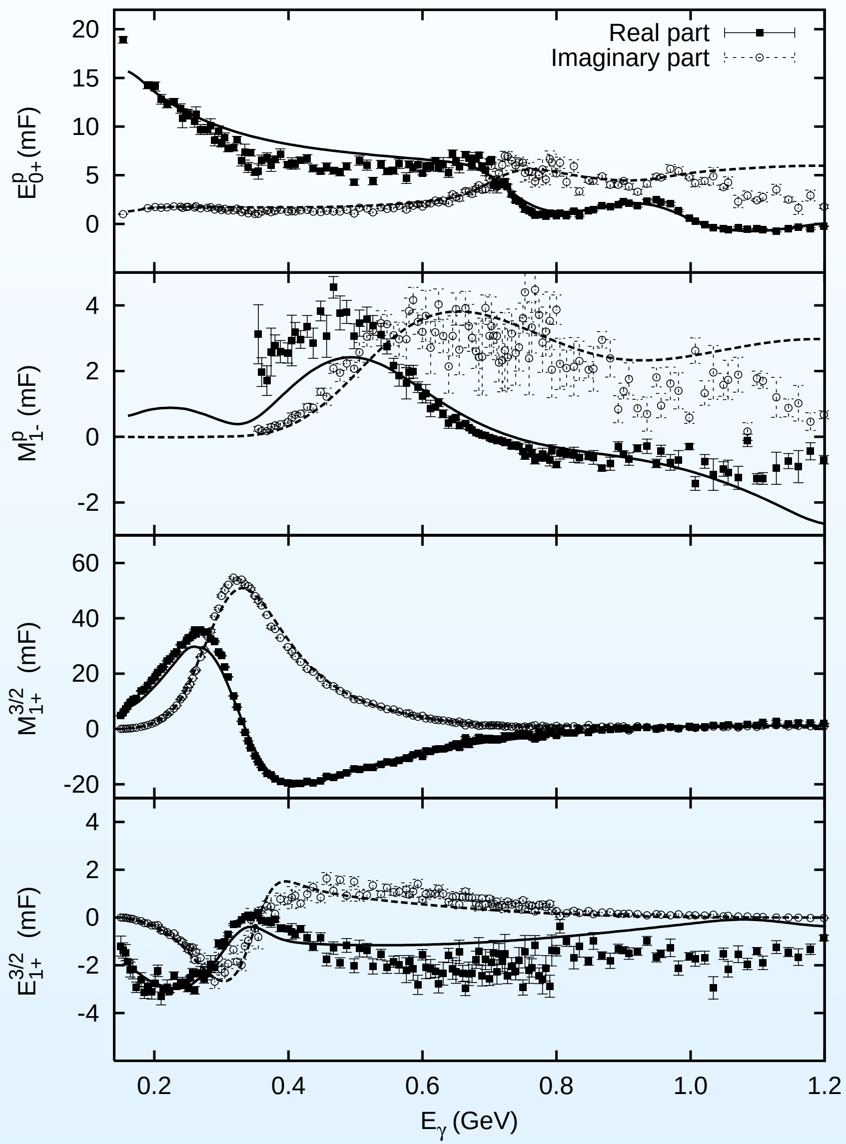

GAs in experimental nuclear physics at JLab

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- Hall A experiment E06-007: "Impulse approximation limitations to the $(e, e'p)$ on ^{208}Pb, identifying correlations and relativistic effects in the nuclear medium"
- Optics calibration using GAs
- Allows to get all the parameters of the optics database at the same time
- More efficient procedure (unattended optimization)

J.L. Herraiz, PhD Thesis (UCM, expected in 2009)

Conclusions (I)

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- Optimization is not a trivial problem
- Traditional optimization tools are often useless for this kind of multi-parameter optimizations when the parameter space is large and the function to fit presents many local minima
- If the parameters of a resonance want to be assessed its energy range has to be fully covered, tail included. If not, misleading results may be obtained

Conclusions (II)

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- The hybrid optimization procedure presented in this talk is a powerful and versatile optimization tool that can be applied to many problems in physics that involve the determination of a set of parameters from data
- It is a promising method for extracting both reliable physical parameters as well as their confidence intervals, probably more meaningful than the simple covariance matrices returned by gradient based optimization routines
- Not only the error bars have to be considered when quoting the uncertainty in the determination of a parameter, but also whether the minima are concentrated into one single region or split into several ones, and the possible physical implications of such situation

References

- **GAs:**

  Fernández-Ramírez, Moya de Guerra, Udías, Udías, PRC 77 (2008) 065212

- Pion photoproduction model:

  Fernández-Ramírez, Moya de Guerra, Udías, AP(NY) 321 (2006) 1408; PRC 73 (2006) 042201(R); EPJA 31 (2007) 572; PLB 660 (2008) 188

- Extension to nuclei:

  Fernández-Ramírez, Martínez, Vignote, Udías, PLB 664 (2008) 57

  RPWIA asymmetry prediction for ^{16}O($\vec{\gamma}$,$\pi^- p$) compares well to data from Hicks *et al.* PRC 61 (2000) 054609