Fitting and selecting scattering data

E. Ruiz Arriola

Universidad de Granada
Atomic, Molecular and Nuclear Physics Department

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Rodrigo Navarro Pérez (Athens, Ohio)
José Enrique Amaro Soriano (Granada),

The question

- We have N DATA with UNCERTAINTIES

$$O_1 \pm \Delta O_1 \quad \dots \quad O_N \pm \Delta O_N$$

- We have a theory depending on M-PARAMETERS

$$O_1(p_1, \dots, p_M) \quad \dots \quad O_N(p_1, \dots, p_M)$$

- Does theory EXPLAIN data ?
  YES (Validate) NO (Falsify)
- Statistical Answer:
  If uncertainties are a gaussian distribution

$$O_i^{\rm exp} = O_i^{\rm th} + \xi_i \Delta O_i$$

Define the LEAST SQUARES SUM

$$\chi^2_{\rm min} \equiv {\rm min}_{p_1, \dots p_M} \sum_{i=1}^N \left[\frac{O_i(p_1, \dots p_M) - O_i^{\rm exp}}{\Delta O_i} \right]^2$$

The probability p that the theory explains the DATA is $> 68\%$ if

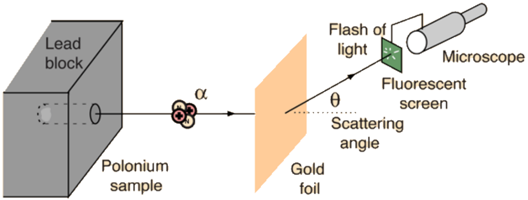
$$\frac{\chi^2_{\rm min}}{\nu} = 1 \pm \sqrt{\frac{2}{\nu}} \qquad \nu = N - M \quad {\rm d.o.f\ (degrees\ of\ freedom)}$$

Theory versus experiment

- A good theory can tell us what experiments are wrong
- A good experiment can tell us what theories are wrong
  1. Assume theory AND experiment to be correct
  2. If we find no contradiction we validate theory and experiment
  3. Experiment , finite number of data, finite precision
  4. Theory , approximations
- Important questions
  1. Does QCD describe hadronic interactions ?
  2. Does ChPT describe low energy hadronic interactions ?
- Confidence level (statistics)
  Example: **AB scattering is described by scheme S with 68 percent confidence**

SCATTERING

Scattering experiment



- Scattering experiments measure FORCES
- Counting rates

$$\frac{R^2 N_{\rm out}(\theta,\phi)}{N_{\rm in}} \to \sigma(\theta,E) \equiv \frac{d\sigma}{d\Omega} = |f(\theta,\phi)|^2$$

- Local Normalization

$$\sigma(\theta,E) \underbrace{\to}_{\theta\ll 1} \sigma_{\rm Ruth}(\theta,E)$$

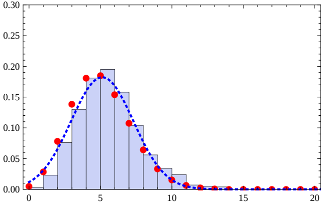
- Total Normalization (mean free path, no Coulomb)

$$l = \frac{1}{n\sigma_T} \quad , \quad \sigma_T = \int d\Omega \frac{d\sigma}{d\Omega}$$

Counting statistics

- Binomial distribution (p scattering probability)

$$P_{N,k} \quad = \quad p^k (1-p)^{N-k} \begin{pmatrix} N \\ k \end{pmatrix} \quad , \quad \langle k \rangle = Np \quad , \quad (\Delta k)^2 = \langle k^2 \rangle - \langle k \rangle^2 = Np(1-p)$$



- Binomial $\rightarrow$ Poisson $\rightarrow$ Gauss

$$P_{N,k} \underbrace{\rightarrow}_{p \ll 1} \frac{e^{-Np}(Np)^k}{k!}$$

$$\underbrace{\rightarrow}_{k \gg 1} \frac{e^{-(k-Np)^2/2}}{\sqrt{2\pi}\Delta k}$$

$$p = 0.1 \quad N = 50$$

- $$N_{\rm out} = \bar{N}_{\rm out} \pm \Delta N_{\rm out} \qquad , \qquad \Delta N_{\rm out} = \sqrt{\bar{N}_{\rm out}}$$

- $\sigma(\theta, E)$ is Gauss distributed

$$\sigma(\theta, E) = \bar{\sigma}(\theta, E) \pm \Delta(\theta, E)$$

Partial wave expansion (No spin)

- Scattering amplitude

$$f(\theta,\phi) = \sum_{l=0}^{\infty}(2l+1)\frac{e^{2i\delta_l}-1}{2ip}P_l(\cos\theta) \quad , \qquad E = \frac{p^2}{2\mu}$$

- Schrödinger Equation

$$\left[-\frac{\nabla^2}{2\mu} + V(\vec{x})\right]\Psi(\vec{x}) = E\Psi(\vec{x})$$

- Spherical symmetry $V(r)$

$$\Psi(\vec{x}) = \frac{u_l(r)}{r}Y_{lm}(\hat{x})$$

- Reduced radial equation

$$-u_l''(r) + \left[\frac{l(l+1)}{r^2} + 2\mu V(r)\right]u_l(r) = p^2 u_l(r)$$

- Asymptotic conditions

$$u_l(r) \underbrace{\rightarrow}_{r\rightarrow 0} r^{l+1} \quad , \qquad u_l(r) \underbrace{\rightarrow}_{r\rightarrow\infty} \sin\left(pr - \frac{l\pi}{2} + \delta_l\right)$$

- GOAL : Determine $V(r) \pm \Delta V(r)$

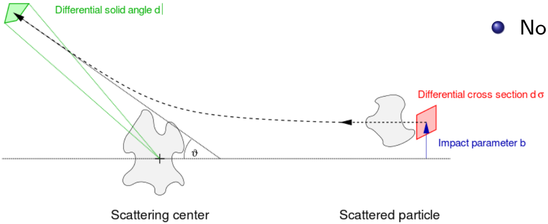
Finite range forces

- Meson exchange picture $\to$ Longest range $\equiv$ Lightest particle

$$r_c \sim \frac{\hbar}{m_\pi c} \sim 1.4\text{fm}$$

- Impact parameter

$$|\vec{L}| = |\vec{x} \wedge \vec{p}| \to bp \qquad L^2 = l(l+1)^2 \sim (l+1/2)^2 \to l + \frac{1}{2} = bp$$



- No scattering condition

$$\begin{array}{rcll} V(r) & \sim & 0 & r \gtrsim r_c \\ \delta_l(p) & \sim & 0 & b \gtrsim r_c \\ \to l_{\max} + \frac{1}{2} & \sim & pr_c \sim p/m_\pi & \end{array}$$

- Truncation in the partial wave expansion

$$f(\theta,\phi) = \sum_{l=0}^{l_{\max}} (2l+1) \frac{e^{2i\delta_l} - 1}{2ip} P_l(\cos\theta) = \frac{e^{2i\delta_0} - 1}{2ip} + 3 \frac{e^{2i\delta_1} - 1}{2ip} \cos\theta + \ldots$$

FITTING

Single energy fits

- Complete data in a GIVEN energy E

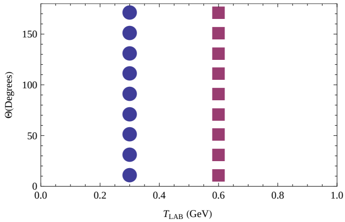
$$\sigma(\theta, E) \to \qquad \sigma(\theta_1, E), \dots, \sigma(\theta_N, E)$$

- Fitting function → Fitting parameters $\delta_1(E), \dots, \delta_l(E)$

$$\chi^2(\delta_1(E), \dots, \delta_l(E), \nu) = \sum_{i=1}^{N} \left[\frac{\sigma^{\mathrm{exp}}(\theta_i, E) - \nu \sigma^{\mathrm{th}}(\theta_i, \delta_1(E), \dots, \delta_l(E))}{\Delta\sigma(\theta_i, E)} \right]^2 + \left(\frac{1-\nu}{\Delta\nu} \right)^2$$

- Normalization is COMMON for ONE energy
- Phase-shifts are "experimental" and MODEL INDEPENDENT

$$\delta_l^{\mathrm{exp}}(E) \pm \Delta\delta_l^{\mathrm{exp}}(E) \quad , \qquad l = 0, \dots, l_{\mathrm{max}}$$



Multienergy analysis

- Incomplete Data in several energies and angles

$$\sigma(\theta, E) \to \qquad \sigma(\theta_1, E_1), \ldots, \sigma(\theta_N, E_N)$$

- The need for interpolation (Smoothness in (θ, E))
- Fitting function *to* Fitting MODEL DEPENDENT parameters $\mathbf{p} = (p_1, \ldots, p_M)$

$$\chi^2(\mathbf{p}, \nu) = \sum_{i=1}^{N} \left[\frac{\sigma(\theta_i, E_i)^{\rm exp} - \nu \sigma^{\rm th}(\theta_i, E_i, \mathbf{p})}{\Delta\sigma(\theta_i, E_i)} \right]^2 + \left(\frac{1-\nu}{\Delta\nu} \right)^2$$

- The statement

$$\sigma(\theta_i, E_i)^{\rm exp} = \nu_0 \sigma^{\rm th}(\theta_i, E_i, \mathbf{p}_0) \pm \Delta\sigma(\theta_i, E_i)$$

- Too large χ^2/ν
  - Bad model $\to$ SELECT MODEL
  - Bad data $\to$ SELECT DATA
  - Bad model and data

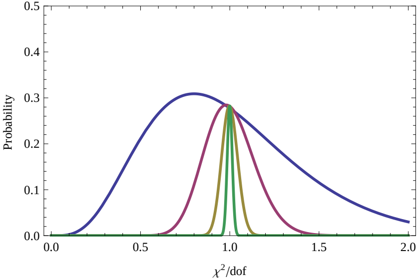
The χ^2-test

- If $\xi_n \in N(0,1)$

$$P_\nu(\chi^2) = \prod_{n=1}^{N} \left(\int_{-\infty}^{\infty} d\xi_i \frac{e^{-\xi_i^2/2}}{\sqrt{2\pi}} \right) \delta(\chi^2 - \sum_{n=1}^{N} \xi_n^2) = \frac{e^{-\chi^2} \chi^{\nu-2}}{2^{\nu/2} \Gamma\left(\frac{\nu}{2}\right)}$$

- Mean and Variance

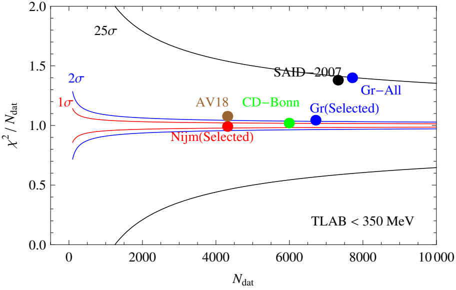
$$\langle \chi^2 \rangle = \nu \,, \qquad \langle (\chi^2 - \langle \chi^2 \rangle)^2 \rangle = 2\nu^2 \,, \qquad \to \chi^2 = \nu \pm \sqrt{2\nu}$$



ν	χ^2/ν (68%)
10	1 ± 0.447
100	1 ± 0.141
1000	1 ± 0.044
10000	$1 \pm 0.014.$

To believe or not to believe

$N_{\rm data}$	HJ62	Reid68	TRS75	Paris80	Urb81	Arg84	BonnR	Bonn89	Nijm93
1787	13.5	2.9	3.4	4.5	6.0	7615	1090	25.5	1.8

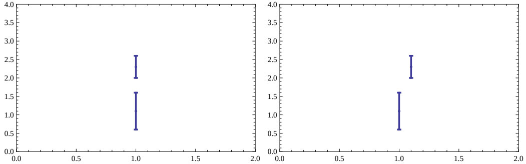


$$\chi^2_{\rm min}/\nu = 1 \pm \sqrt{2/\nu}$$

- Charge dependence in OPE
- Magnetic-Moments, Vacuum polarization, ...

The need for selection

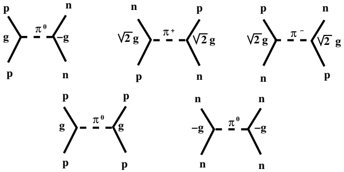
- Example: THE SAID DATABASE
  - PP Data No=25188 Chi2= 48225.043
  - NP Data No=12962 Chi2= 26079.973
  - πN 41926 Chi2= 166585.05
  - πN 2599 Chi2= 4586.26 (TLAB ¡ 300)
- Which experiments are INCOMPATIBLE ?



- Contribution the χ^2 will be large (discard BOTH ?)
- If errorbar includes BOTH no contribution to the χ^2
- Incompatibility is DESTRUCTIVE
- Real physical effect ?

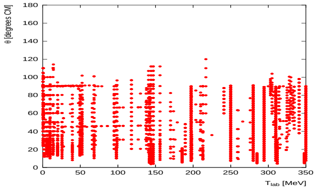
Long distances

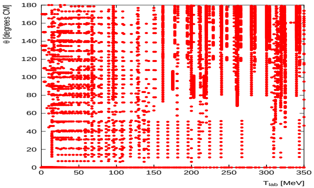
- Nucleons exchange JUST one pion



- Low energies (about pion production) 8000 pp + np scattering data (polarizations etc.)
- Granada coarse grained analysis (2016) (isospin breaking !!)

$$g_p^2/(4\pi) = 13.72(7) \neq g_n^2/(4\pi) = 14.91(39) \neq g_c^2/(4\pi) = 13.81(11) \qquad \chi^2/\nu = 1.02$$





COARSE GRAINING NN (LOW ENERGY)

Nucleon-Nucleon Scattering

- Scattering amplitude

$$
\begin{aligned}
M &= a + m(\sigma_1\cdot\mathbf{n})(\sigma_2\cdot\mathbf{n}) + (g-h)(\sigma_1\cdot\mathbf{m})(\sigma_2\cdot\mathbf{m}) \\
&+ (g+h)(\sigma_1\cdot\mathbf{l})(\sigma_2\cdot\mathbf{l}) + c(\sigma_1+\sigma_2)\cdot\mathbf{n} \\
\mathbf{l} &= \frac{\mathbf{k}_f+\mathbf{k}_i}{|\mathbf{k}_f+\mathbf{k}_i|} \qquad \mathbf{m} = \frac{\mathbf{k}_f-\mathbf{k}_i}{|\mathbf{k}_f-\mathbf{k}_i|} \qquad \mathbf{n} = \frac{\mathbf{k}_f\wedge\mathbf{k}_i}{|\mathbf{k}_f\wedge\mathbf{k}_i|}
\end{aligned}
$$

- 5 complex amplitudes $\to$ 24 measurable cross-sections and polarization asymmetries
- Partial Wave Expansion

$$
\begin{aligned}
M^s_{m_s',m_s}(\theta) &= \frac{1}{2ik}\sum_{J,l',l}\sqrt{4\pi(2l+1)}Y^{l'}_{m_s'-m_s}(\theta,0) \\
&\times \; C^{l',s,J}_{m_s-m_s',m_s',m_s}\, i^{l-l'}(S^{J,s}_{l,l'}-\delta_{l',l})C^{l,s,J}_{0,m_s,m_s}, \qquad (1)
\end{aligned}
$$

- S-matrix

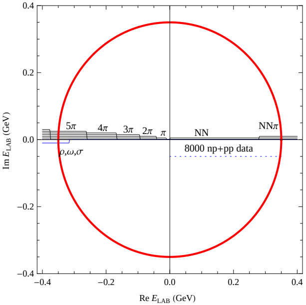
$$
S^J = \begin{pmatrix} e^{2i\delta^{J,1}_{J-1}}\cos 2\epsilon_J & ie^{i(\delta^{J,1}_{J-1}+\delta^{J,1}_{J+1})}\sin 2\epsilon_J \\ ie^{i(\delta^{J,1}_{J-1}+\delta^{J,1}_{J+1})}\sin 2\epsilon_J & e^{2i\delta^{J,1}_{J+1}}\cos 2\epsilon_J \end{pmatrix}, \qquad (2)
$$

Analytical Structure

- $s = 4(M_N^2 + p^2) \to E_{\rm LAB} = 2p^2/M_N$
- Partial Wave Scattering Amplitude analytical for $|p| \le m_\pi/2$

$$T^J_{ll'}(p) \equiv S^J_{ll'}(p) - \delta_{l,l'} = p^{l+l'} \sum_n C_{n,l,l'} p^{2n}$$

- Nucleons behave as elementary (AT WHAT SCALE ?)



- Nucleons are heavy → Local Potentials

$$V_{n\pi}(r) \sim \frac{g^{2n}}{r} e^{-n m_\pi r}$$

- Crucial long range electromagnetic effects are local

The number of parameters (for $E_{\mathrm{LAB}} \leq 350$ MeV)

- At what distance look nucleons point-like ?

$$r > 2\mathrm{fm}$$

- When is OPE the ONLY contribution ?

$$r_c > 3\mathrm{fm}$$

- What is the minimal resolution where interaction is elastic ?

$$p_{\max} \sim \sqrt{M_N m_\pi} \to \Delta r = 1/p_{\max} = 0.6\mathrm{fm}$$

- How many partial waves must be fitted ?

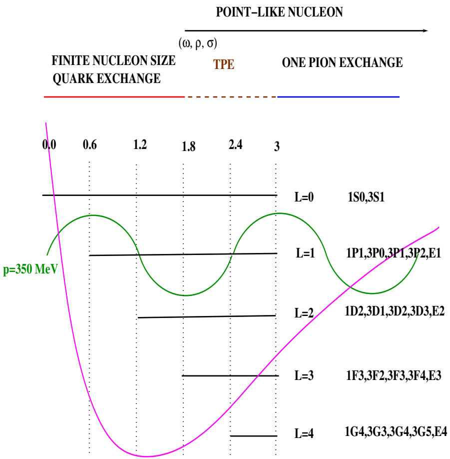
$$l_{\max} = p_{\max} r_c = r_c/\Delta r = 5$$

- Minimal distance where centrifugal barrier dominates

$$\frac{l(l+1)}{r_{\min}^2} \leq p^2$$

- How many parameters ?
  $({}^1S_0, {}^3S_1)$, $({}^1P_1, {}^3P_0, {}^3P_1, {}^3P_2)$, $({}^1D_2, {}^3D_1, {}^3D_2, {}^3D_3)$, $({}^1F_3, {}^3F_2, {}^3F_3, {}^3F_4)$

$$2 \times 5 + 4 \times 4 + 4 \times 3 + 4 \times 2 + 4 \times 1 = 50$$


POINT–LIKE NUCLEON
(ω, ρ, σ)
FINITE NUCLEON SIZE
QUARK EXCHANGE
TPE
ONE PION EXCHANGE
0.0
0.6
1.2
1.8
2.4
3
L=0
1S0,3S1
L=1
1P1,3P0,3P1,3P2,E1
p=350 MeV
L=2
1D2,3D1,3D2,3D3,E2
L=3
1F3,3F2,3F3,3F4,E3
L=4
1G4,3G3,3G4,3G5,E4

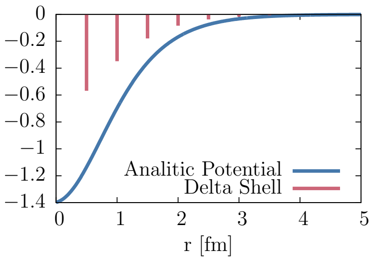
Delta Shell Potential

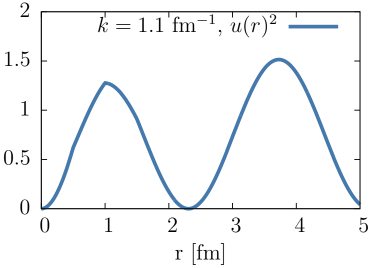
- A sum of delta functions

$$V(r) = \sum_i \frac{\lambda_i}{2\mu} \delta(r - r_i)$$

[Aviles, Phys.Rev. C6 (1972) 1467]

- Optimal and minimal sampling of the nuclear interaction
- Pion production threshold $\Delta k \sim 2$ fm^{-1}
- Optimal sampling, $\Delta r \sim 0.5$fm





Delta Shell Potential

- 3 well defined regions
- Innermost region $r \leq 0.5$ fm
  - Short range interaction
  - No delta shell (No repulsive core)
- Intermediate region $0.5 \leq r \leq 3.0$ fm
  - Unknown interaction
  - λ_i parameters fitted to scattering data
- Outermost region $r \geq 3.0$ fm
  - Long range interaction
  - Described by OPE and EM effects
    - Coulomb interaction V_{C1} and relativistic correction V_{C2} (pp)
    - Vacuum polarization V_{VP} (pp)
    - Magnetic moment V_{MM} (pp and np)

Fitting NN observables

- Delta shell potential in every partial wave

$$V_{l,l'}^{JS}(r) = \frac{1}{2\mu_{\alpha\beta}} \sum_{n=1}^{N} (\lambda_n)_{l,l'}^{JS} \delta(r - r_n) \qquad r \leq r_c = 3.0\text{fm}$$

- Strength coefficients λ_n as fit parameters
- Fixed and equidistant concentration radii $\Delta r = 0.6$ fm
- EM interaction is crucial for pp scattering amplitude

$$\begin{aligned}
V_{C1}(r) &= \frac{\alpha'}{r} \, , \\
V_{C2}(r) &\approx -\frac{\alpha\alpha'}{M_p r^2} \, , \\
V_{VP}(r) &= \frac{2\alpha\alpha'}{3\pi r} \int_1^\infty dx \, e^{-2m_e r x} \left[1 + \frac{1}{2x^2}\right] \frac{(x^2-1)^{1/2}}{x^2} \, , \\
V_{MM}(r) &= -\frac{\alpha}{4M_p^2 r^3} \left[\mu_p^2 S_{ij} + 2(4\mu_p - 1)\mathbf{L}\cdot\mathbf{S}\right]
\end{aligned}$$

STATISTICS

Self-consistent fits

- We test the assumption

$$O_i^{\mathrm{exp}} = O_i^{\mathrm{th}} + \xi_i \Delta O_i \qquad i = 1, \dots, N_{\mathrm{Data}} \qquad \xi_i \in N[0,1]$$

- Least squares minimization $\mathbf{p} = (p_1, \dots, p_M)$

$$\chi^2(\mathbf{p}) = \sum_{i=1}^{N} \left(\frac{O_i^{\mathrm{exp}} - F_i(\mathbf{p})}{\Delta O_i^{\mathrm{exp}}} \right)^2 \to \min_{\mathbf{p}} \chi^2(\mathbf{p}) \equiv \chi^2(\mathbf{p}_0) \tag{3}$$

- Are residuals Gaussian ?

$$R_i = \frac{O_i^{\mathrm{exp}} - O_i^{\mathrm{th}}}{\Delta O_i} \qquad O_i^{\mathrm{th}} = F_i(\mathbf{p}_0) \qquad i = 1, \dots, N \tag{4}$$

If $R_i \in N[0,1]$ self-consistent fit.

- Normality test for a finite sample with N elements $\to$ Probability (Confidence level) p-value

$$\chi^2_{\mathrm{min}} = 1 \pm \sigma \sqrt{\frac{2}{\nu}} \qquad \nu = N_{\mathrm{Dat}} - N_{\mathrm{Par}} \qquad p = 1 - \int_{\sigma}^{\sigma} dt \frac{e^{-t^2}}{\sqrt{2\pi}}$$

Histograms, Moments, Kolmogorov-Smirnov, **Tail Sentitive** QQ-plots

Normality tests

- Does the sequence

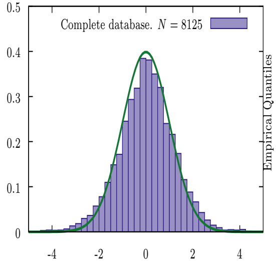
$$x_1^{\rm exp} \le x_2^{\rm exp} \le \cdots \le x_N^{\rm exp} \in N[0,1]$$

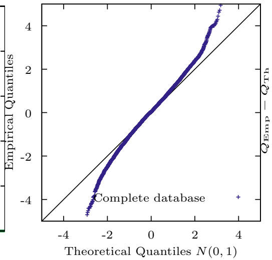
- We compute the theoretical points

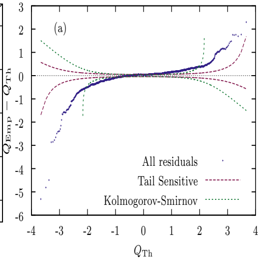
$$\frac{n}{N+1} = \int_{-\infty}^{x_n^{\rm th}} dt \frac{e^{-t^2/2}}{\sqrt{2\pi}}$$

- The Q-Q plot is $x_n^{\rm th}$ vs $x_n^{\rm exp}$
- For large N

$$x_n^{\rm th} - x_n^{\rm exp} = \mathcal{O}(1/\sqrt{N})$$



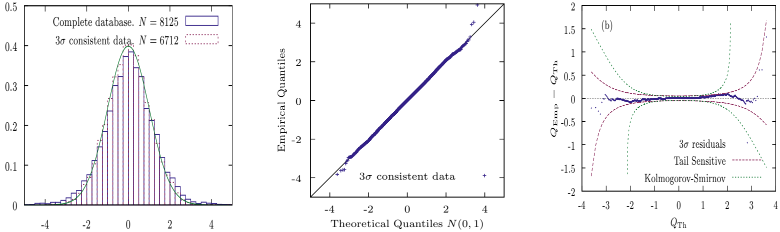




Granada-2013 np+pp database

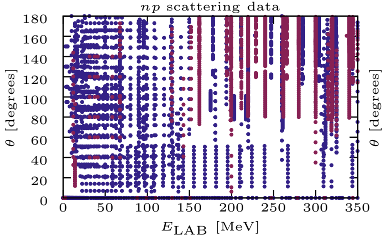
Selection criterium

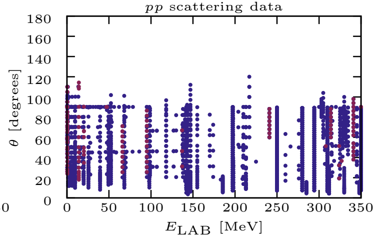
- Mutually incompatible data. Which experiment is correct? Is any of the two correct?
- Maximization of experimental consensus
- Exclude data sets inconsistent with the rest of the database
  1. Fit to all data $(\chi^2/\nu > 1)$
  2. Remove data sets with improbably high or low χ^2 (3σ criterion)
  3. Refit parameters
  4. Re-apply 3σ criterion to all data
  5. Repeat until no more data is excluded or recovered



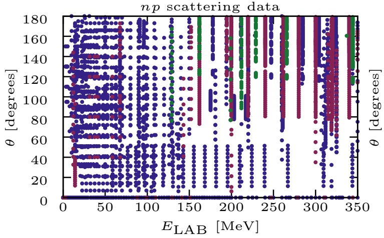
Selection of data

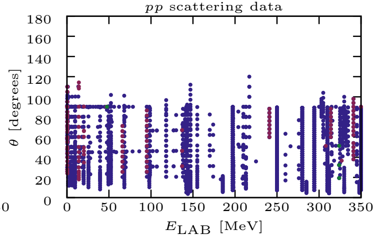
Usual Nijmegen 3σ criterion (1677 rejected data)





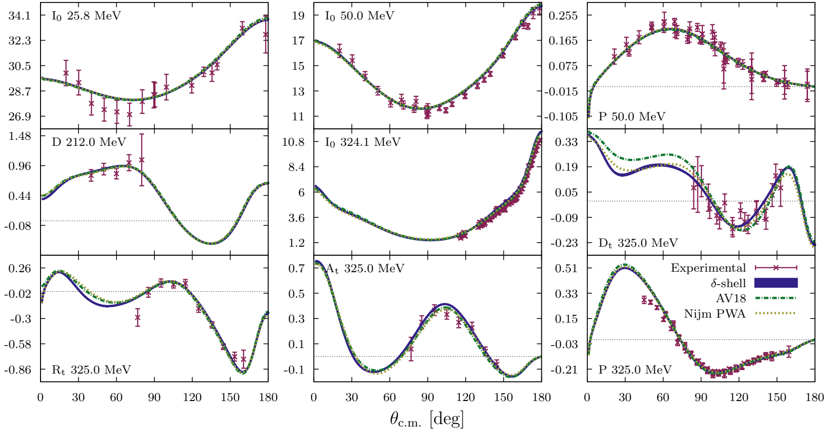
300 recovered data with Granada procedure (consistent database)





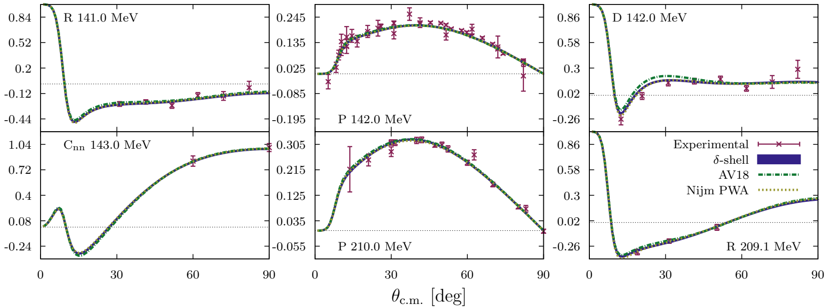
Scattering Observables

- Comparing with Potentials and Experimental data
- np data



Scattering Observables

- Comparing with Potentials and Experimental data
- pp data



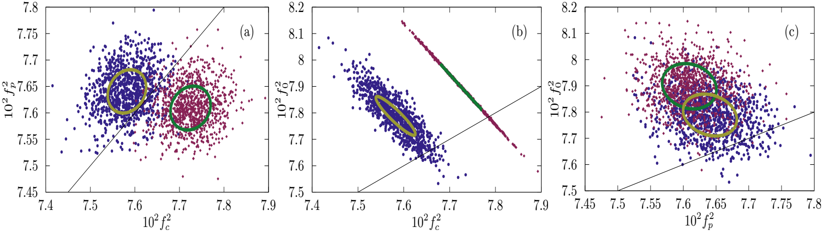
- $\chi^2/\text{d.o.f.} = 1.06$ with $N = 2747|_{\rm pp} + 3691|_{\rm np}$

[RNP, Amaro & Ruiz-Arriola. Phys.Rev.C88 (2013) 024002]

STATISTICAL CONSEQUENCES

Coupling constants

Bootstrapping 6713 np+pp data (benchmark $\sim 0.5\%$)

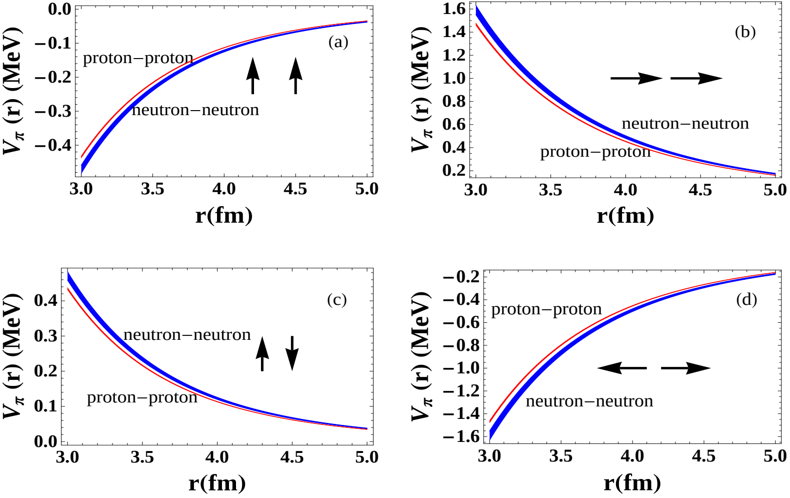


Fits to the Granada-2013 database.

f^2	f_0^2	f_c^2	CD-waves	χ^2_{pp}	χ^2_{np}	$N_{\rm Dat}$	$N_{\rm Par}$	χ^2/ν
0.075	idem	idem	$^1S_0$	3051	3951	6713	46	1.051
0.0761(3)	idem	idem	$^1S_0$	3051	3951	6713	46+1	1.051
-	-	-	$^1S_0, P$	2999	3951.40	6713	46+3	1.043
0.0759(4)	0.079(1)	0.0763(6)	$^1S_0, P$	3045	3870	6713	46+3+9	1.039

Neutron-Neutron vs Proton-Proton (Polarized)

nn interaction is more intense than pp interaction



Arqueological Flashback

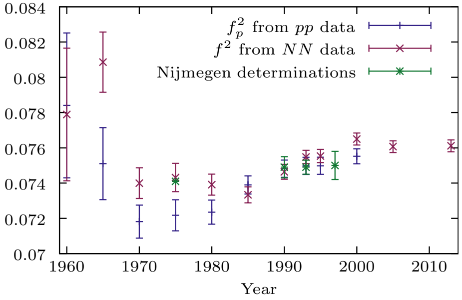
- Can we witness isospin breaking in the couplings ?

$$\frac{dg}{g}\Big|_{\rm QCD} = \mathcal{O}(\alpha, \frac{m_u - m_d}{\Lambda_{\rm QCD}}) = \mathcal{O}(\alpha, \frac{M_n - M_p}{\Lambda_{\rm QCD}}) \sim 0.01 - 0.02$$

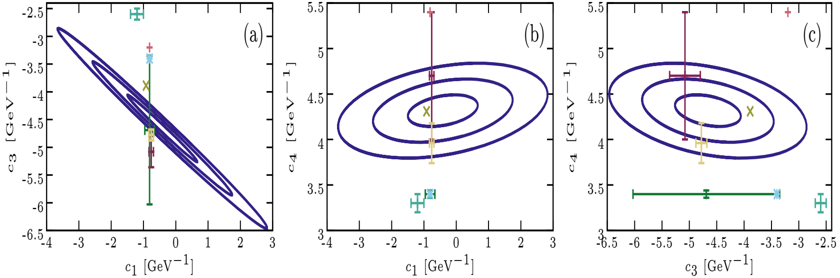
- Statistically yes ! Granada NN $N = 6713$

$$\frac{dg}{g}\Big|_{\rm stat} = \mathcal{O}(\frac{\Delta N_{\rm Dat}}{N_{\rm Dat}}) = \mathcal{O}(\frac{1}{\sqrt{N_{\rm Dat}}}) \to N \sim 7000 - 10000$$

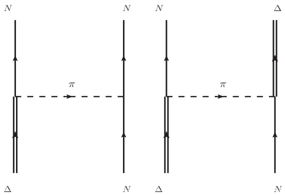
- Chronological recreation of pion-nucleon coupling constants



Chiral Two Pion Exchange from Granada-2013 np+pp database



$f_{\pi N\Delta}$ from Granada-2013 np+pp database



- NN potential in the Born-Oppenheimer approximation

$$\bar{V}^{1\pi+2\pi+\cdots}_{NN,NN}(\boldsymbol{r}) = V^{1\pi}_{NN,NN}(\boldsymbol{r}) + 2\,\frac{|V^{1\pi}_{NN,N\Delta}(\boldsymbol{r})|^2}{M_N - M_\Delta} + \frac{1}{2}\,\frac{|V^{1\pi}_{NN,\Delta\Delta}(\boldsymbol{r})|^2}{M_N - M_\Delta} + \mathcal{O}(V^3)\,,$$

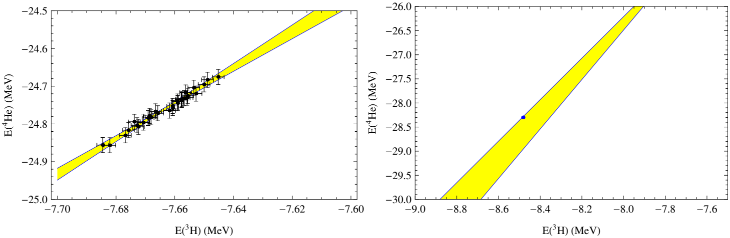
- Bulk of TWO-Pion Exchange Chiral forces reproduced
- Fit with $r_e = 1.8\text{fm}$ to $N = 6713 pp + np$ scattering data

$$f_{\pi N\Delta}/f_{\pi NN} = 2.178(14) \qquad \chi^2/\nu = 1.12 \rightarrow h_A = 1.397(9)$$

Tjon-Lines: numerical accuracy of $A = 2, 3, 4$ Nuclei

(with A. Nogga)

$$\Delta E^{\rm stat}_{\rm triton} = 15 {\rm KeV} \qquad \Delta E^{\rm stat}_{\alpha} = 50 {\rm KeV}$$



- 4-Body forces are masked by numerical noise in the 3 and 4 body calculation if

$$\Delta^{\rm num}_t > 1 {\rm KeV} \qquad \Delta^{\rm num}_t > 20 {\rm KeV}$$

To count or not to count: The Falsification of Chiral Forces

- We can fit CHIRAL forces to ANY energy and look if counterterms are compatible with zero within errors
- We find that if $E_{\rm LAB} \le 125 {\rm MeV}$ Weinberg counting is INCOMPATIBLE with data.
- You have to promote D-wave counterterms.
  N2LO-Chiral TPE + N3LO-Counterterms $\to$ Residuals are normal
  Piarulli,Girlanda,Schiavilla,Navarro Pérez,Amaro,RA, PRC
- We find that if $E_{\rm LAB} \le 40 {\rm MeV}$ TPE is INVISIBLE
- We find that peripheral waves predicted by 6th-order chiral perturbation theory ARE NOT consistent with data within uncertainties

$$|\delta^{\rm Ch,N5LO} - \delta^{\rm PWA}| > \Delta\delta^{\rm PWA,stat}$$

5 σ incompatible

CONCLUSIONS

Conclusions

- Fitting and selecting scattering databases allows to pose and ANSWER important questions
- Coarse graining is a simple method to analyze and select data using a statistical framework
- Self-consistent databases allow to determine coupling constants
- Validate power countings in NN (Weinberg is not)
- It could be a possible way to do Nuclear Physics AND Hadronic physics

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