Pole Extraction from a World Collection of PWA

M. Hadžimehmedović[1], H. Osmanović[1], J. Stahov[1]
S. Ceci[2], A. Švarc[2], B. Zauner[2]

[1]University of Tuzla
Faculty of Science
Bosnia and Herzegovina

[2]Rudjer Boskovic Institute
Zagreb, Croatia

The 5th International Pion-Nucleon PWA Workshop and
Interpretation of Baryon Resonances
Trento, Italy, 1st - 5th June 2009

Questions

- How many partial wave analyses do we have up to now, and how many we will have from now on?
- How many extraction methods for resonance parameters, poles … do we have up to now?
- What can we do with all of them?
- Can we compare them?

Let see what happens if we do so.

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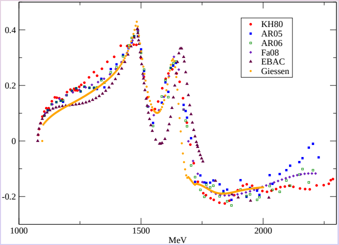
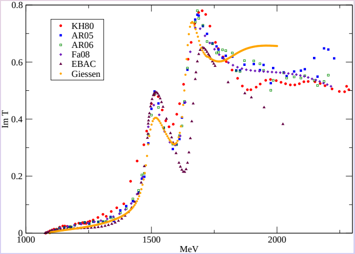
Comparation

... of apples and pears





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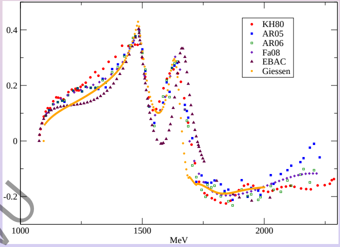

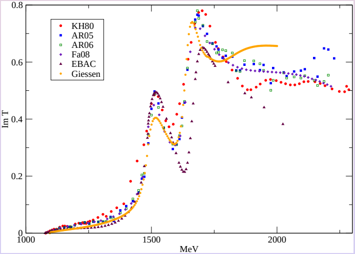

GWU

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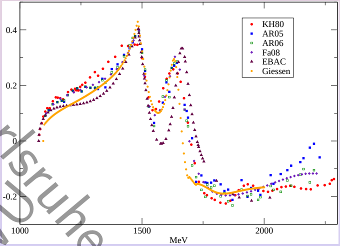

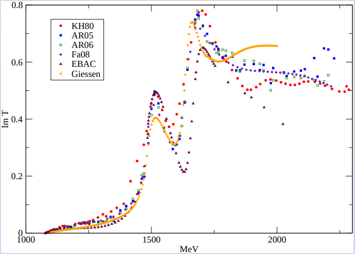

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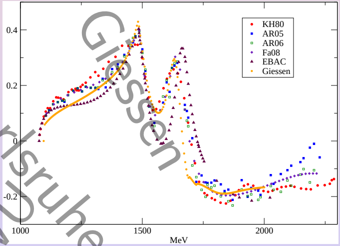

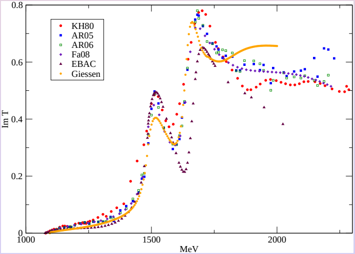

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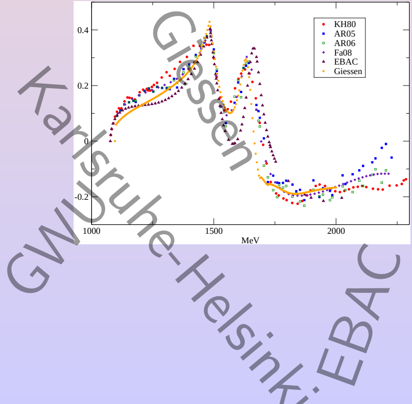

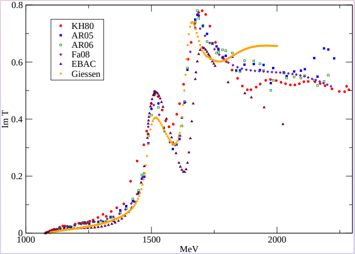

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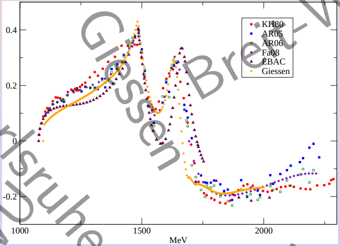

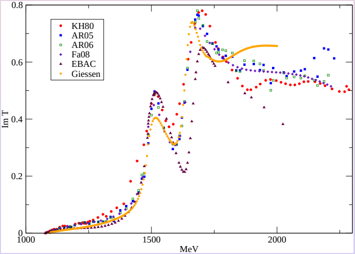

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Giessen

Breit-Wigner

EBAC

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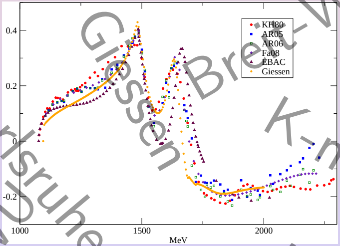

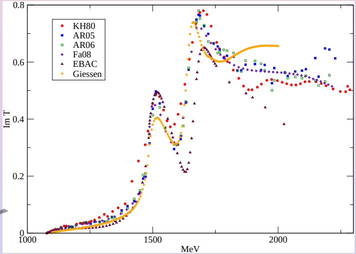

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K-matrix

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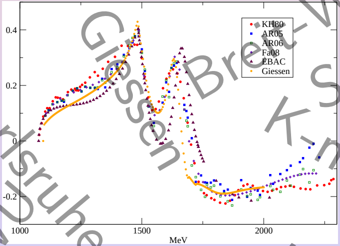

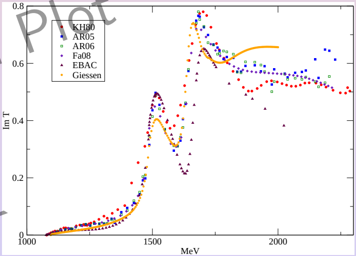

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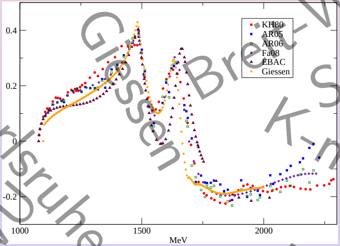

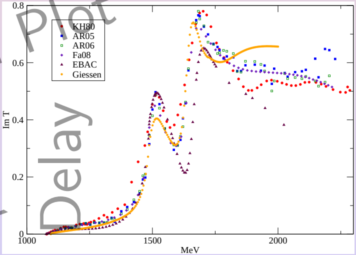

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K-matrix
Speed Plot
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Time Delay

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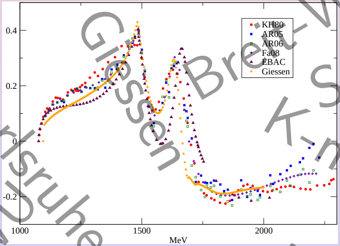

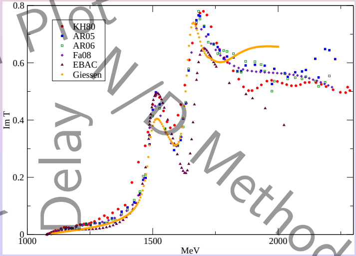

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N/D Method

Time Delay

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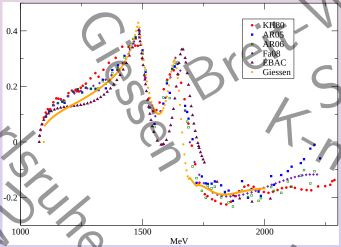

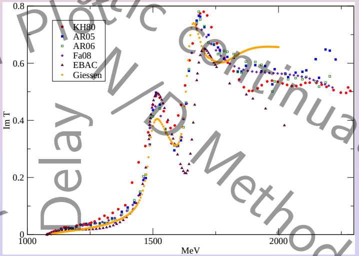

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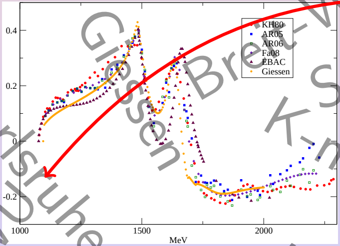

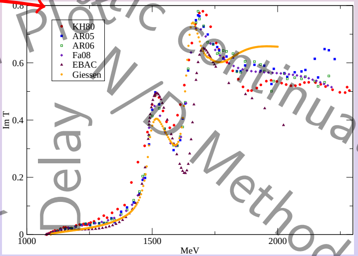

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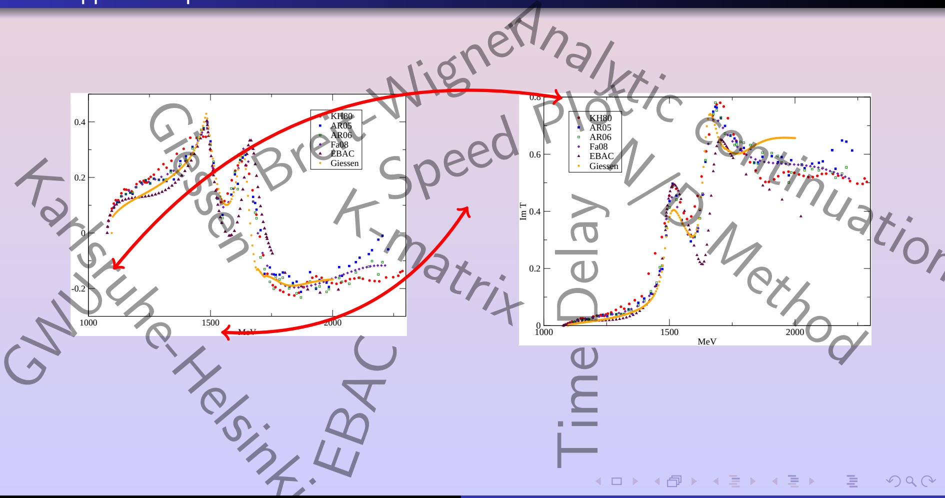

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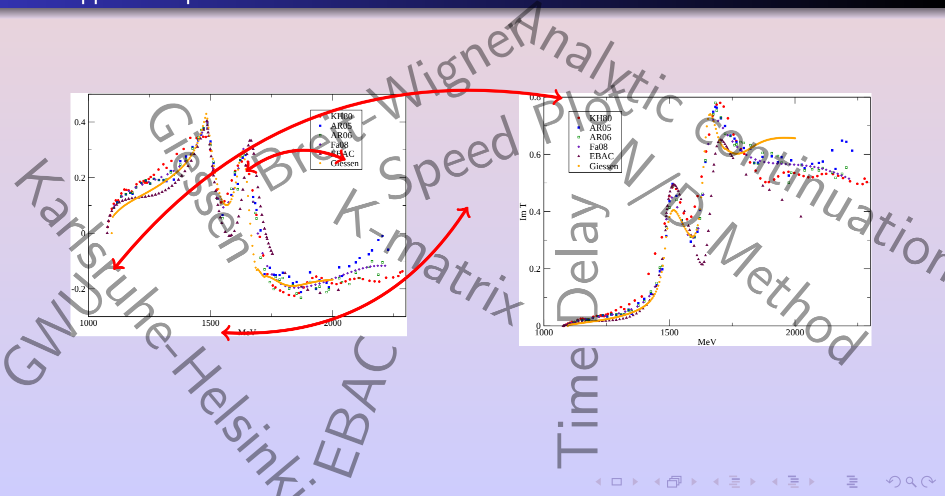

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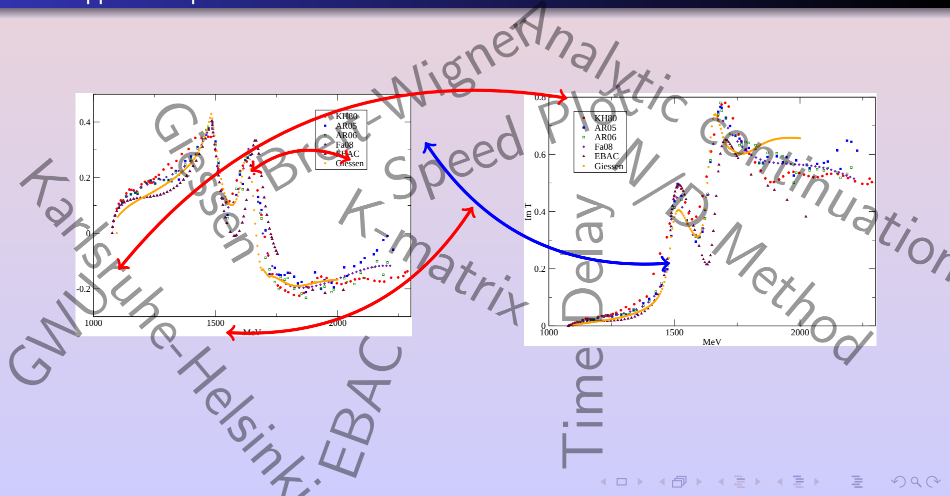

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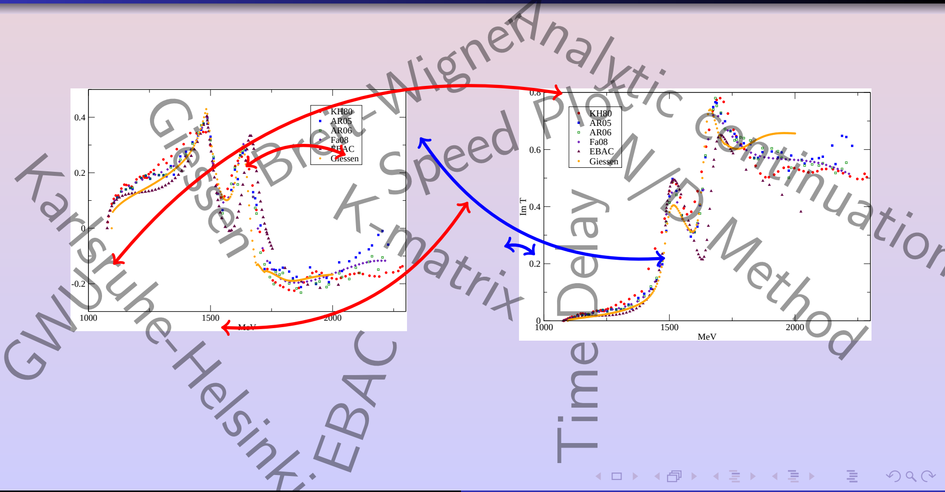

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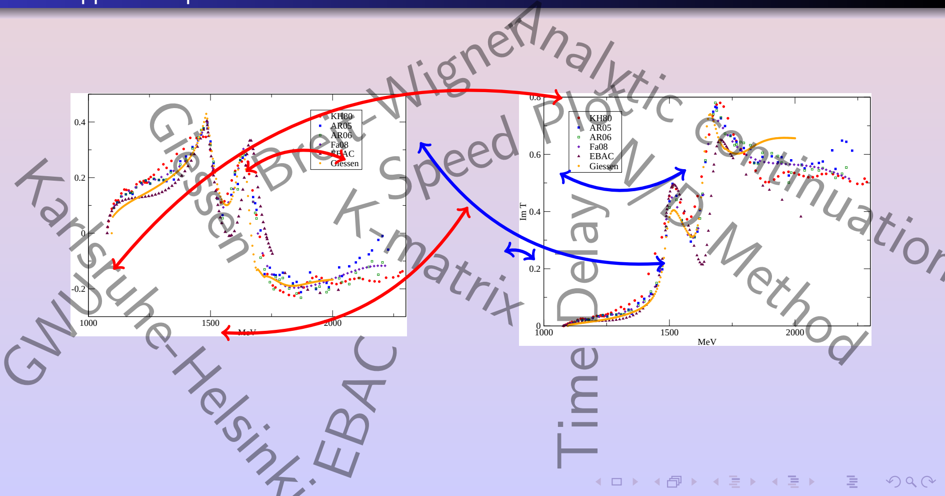

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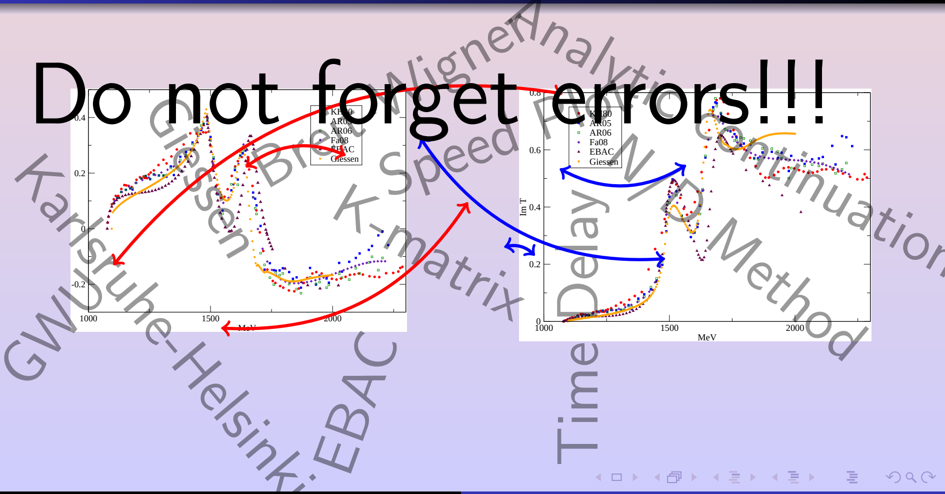

Comparation

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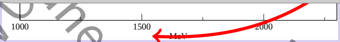
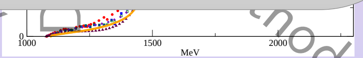
Messy, isn't it?





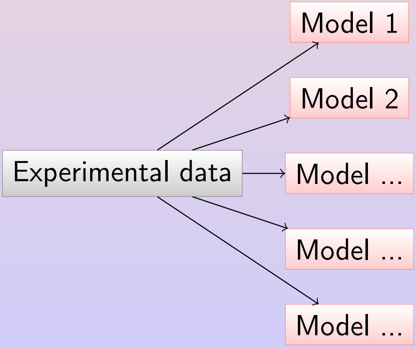
EBAC

Time

Resonance parameters

Experimental data

Resonance parameters



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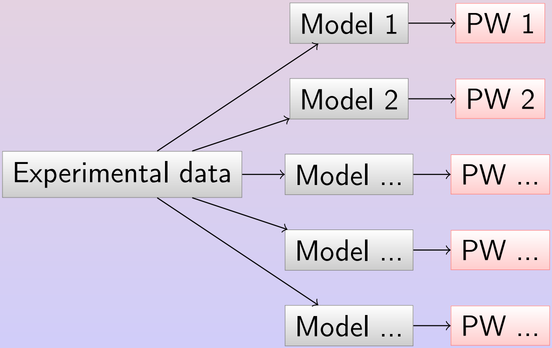

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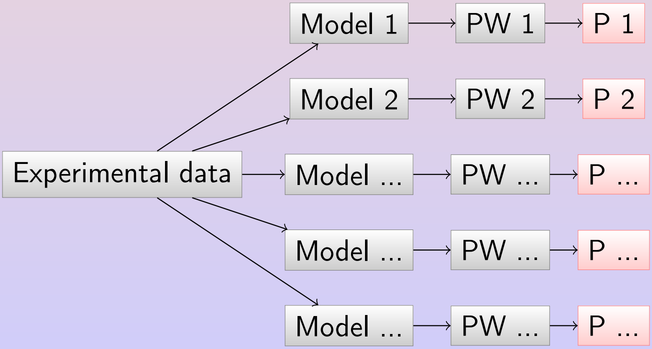

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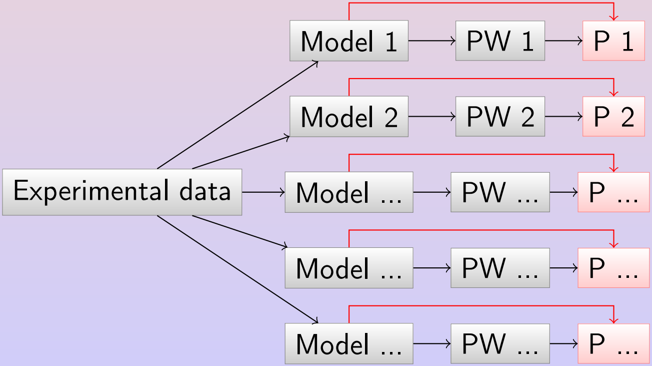

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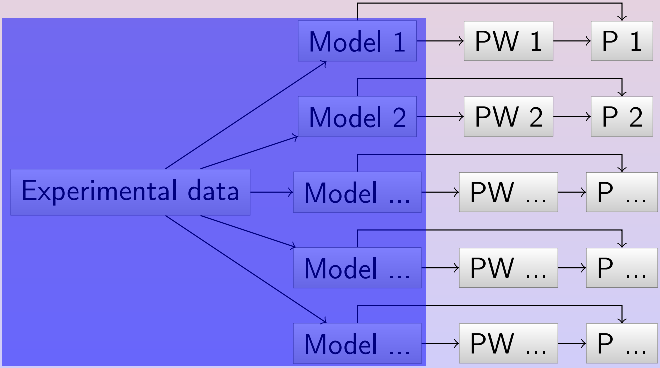

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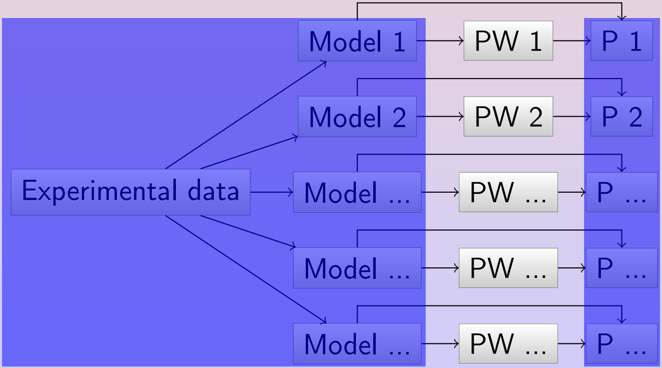

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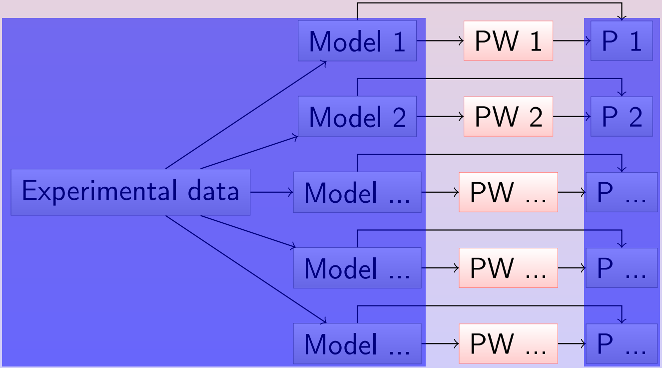

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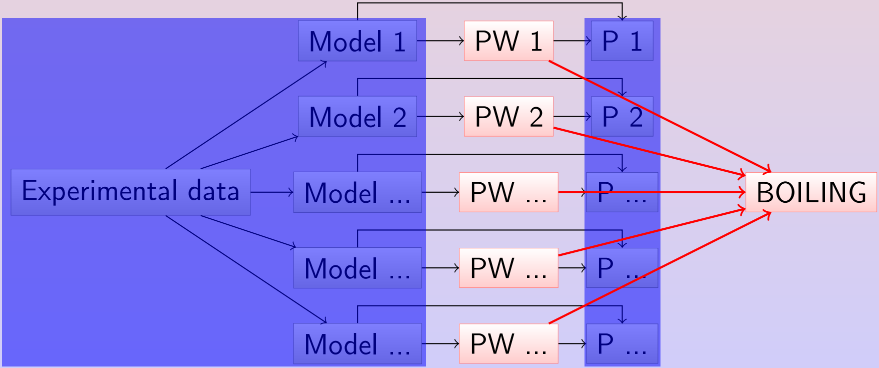

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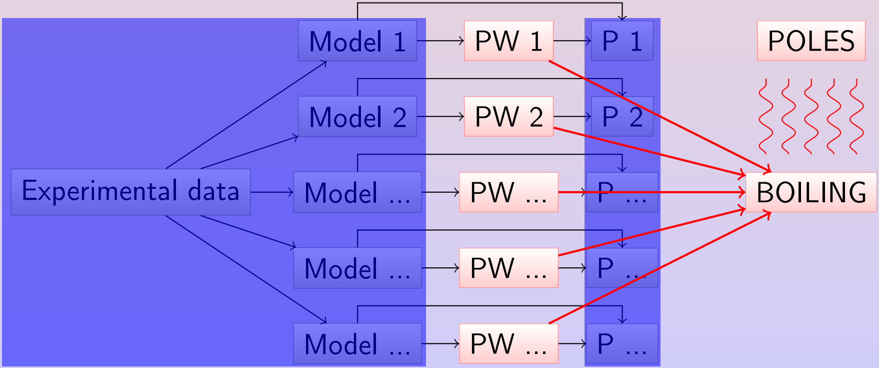
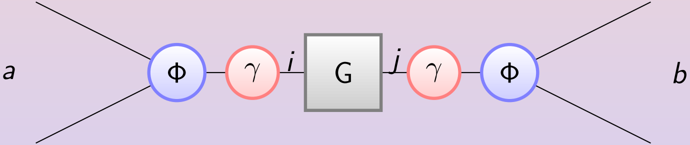


T - matrix



$$T_{ab} = \sum_{i,j=1}^{N} \sqrt{\Im m\ \phi_a}\gamma_{ai} G_{ij}\left(s\right)\gamma_{jb}\sqrt{\Im m\ \phi_b}$$

T - matrix

Something about all components of T - matrix in the CMB approach

$$T_{ab} = \sum_{i,j=1}^{N} \boxed{\Im m\Phi_a(s)^{1/2}} \gamma_{ai} G_{ij}(s) \gamma_{jb} \boxed{\Im m\Phi_b(s)^{1/2}}$$

- s - total center-of-mass energy squared
- a, b denote channels wich can be either
  - stable two particle sistem (πN or ηN)
  - quasi two particle state ($\pi\pi N$)
- i, j denote intermediate states (resonances) between states denoted with indices a and b

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$$T_{ab} = \sum_{i,j=1}^{N} f_a(s)\sqrt{\rho_a(s)}\gamma_{ai}G_{ij}(s)\gamma_{jb}\sqrt{\rho_b(s)}f_b(s)$$

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- $f_a(s)$ - form factor
- γ_{ai} - strenght constant
  - The strenght constant and form factor define the decay of the ith resonance into channel a
- $\rho_a(s)$ - phase space factor
- G_{ij} - dressed propagator

Parametrization

Form factor and phase space factor

form factor

$$f_a(s) = \left(\frac{q_a}{Q_1 + \sqrt{q_a^2 + Q_2^2}} \right)^{l_a}$$

phase space factor

$$\rho_a = \frac{q_a}{\sqrt{s}}$$

- Q_1 and Q_2 have to be defined for each channel
  - for $\pi N \rightarrow \pi N$, $Q_1 = Q_2 = m_\pi$,
  - for $\pi N \rightarrow \eta N$, $Q_1 = Q_2 = m_\eta$

- q_a is center-of-mass-momentum for channel a, defined as:

$$q_a = \sqrt{\frac{\left(s - (m_{\pi,\eta} + m_N)^2\right)\left(s - (m_{\pi,\eta} - m_N)^2\right)}{4s}}$$

Parametrization

Channel propagator

Imaginary part of the channel propagator

$$\Im m\, \phi_a(s) = f_a^2 \rho_a(s)$$

Real part of the channel propagator

Once suptracted dispersion relations

$$\phi_a = \frac{s - s_0}{\pi} \int_{s_{th}}^{\infty} \frac{\Im m\, \phi_a(s')}{(s' - s)(s' - s_0)} ds'$$

Parametrization
Channel propagator

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Extrapolation

Pietarinen's expansion

We also use Pietarinen's expansion

$$\varphi(s) = \sum_{n=0}^{N} c_n Z^n(s)$$

to extrapolate imaginary and real part of channel propagator. Function $Z(s)$ can be either

$$Z(s) = \frac{\alpha - \sqrt{s - s_0}}{\alpha + \sqrt{s - s_0}}$$

or

$$Z(s) = \frac{\alpha + \sqrt{s - s_0}}{\alpha - \sqrt{s - s_0}}$$

T - matrix again

3 channels and 3 poles

T-matrix element

$$T_{ab} = \sum_{1,j=1}^{N} \sqrt{\Im m\, \phi_a}\gamma_{ai} G_{ij} \gamma_{jb} \sqrt{\Im m\, \phi_b}$$

T-matrix

$$T = \sqrt{\Im m\, \Phi}\gamma^T G \gamma \sqrt{\Im m\, \Phi}$$

$$\overbrace{\underbrace{\begin{bmatrix} \pi\pi & \pi\eta & \pi\pi^2 \\ \eta\pi & \eta\eta & \eta\pi^2 \\ \pi^2\pi & \pi^2\eta & \pi^2\pi^2 \end{bmatrix}}}$$

$$\underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\, \Phi}} \underbrace{\begin{bmatrix} \pi\pi1 & \pi\pi2 & \pi\pi3 \\ \pi\eta1 & \pi\eta2 & \pi\eta3 \\ \pi\pi^2 1 & \pi\pi^2 2 & \pi\pi^2 3 \end{bmatrix}}_{\gamma^T} \underbrace{G}_{????????} \underbrace{\begin{bmatrix} 1\pi\pi & 1\pi\eta & 1\pi\pi^2 \\ 2\pi\pi & 2\pi\eta & 2\pi\pi^2 \\ 3\pi\pi & 3\pi\eta & 3\pi\pi^2 \end{bmatrix}}_{\gamma} \underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\, \Phi}}$$

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Examples

2 channels and 2 poles & 3 channels and 2 poles

$$\underbrace{\begin{bmatrix}\pi\pi & \pi\pi^{2}\\ \pi^{2}\pi & \pi^{2}\pi^{2}\end{bmatrix}}$$

$$\overbrace{\underbrace{\begin{bmatrix}\pi\pi & 0\\ 0 & \pi\pi^{2}\end{bmatrix}}_{\sqrt{\Im m\,\Phi}}\underbrace{\begin{bmatrix}\pi\pi 1 & \pi\pi 2\\ \pi\pi^{2}1 & \pi\pi^{2}2\end{bmatrix}}_{\gamma^{T}}\underbrace{G}_{????????}\underbrace{\begin{bmatrix}1\pi\pi & 1\pi\pi^{2}\\ 2\pi\pi & 2\pi\pi^{2}\end{bmatrix}}_{\gamma}\underbrace{\begin{bmatrix}\pi\pi & 0\\ 0 & \pi\pi^{2}\end{bmatrix}}_{\sqrt{\Im m\,\Phi}}}$$

$$\underbrace{\begin{bmatrix}\pi\pi & \pi\eta & \pi\pi^{2}\\ \eta\pi & \eta\eta & \eta\pi^{2}\\ \pi^{2}\pi & \pi^{2}\eta & \pi^{2}\pi^{2}\end{bmatrix}}$$

$$\overbrace{\underbrace{\begin{bmatrix}\pi\pi & 0 & 0\\ 0 & \pi\eta & 0\\ 0 & 0 & \pi\pi^{2}\end{bmatrix}}_{\sqrt{\Im m\,\Phi}}\underbrace{\begin{bmatrix}\pi\pi 1 & \pi\pi 2\\ \pi\eta 1 & \pi\eta 2\\ \pi\pi^{2}1 & \pi\pi^{2}2\end{bmatrix}}_{\gamma^{T}}\underbrace{G}_{????????}\underbrace{\begin{bmatrix}1\pi\pi & 1\pi\eta & 1\pi\pi^{2}\\ 2\pi\pi & 2\pi\eta & 2\pi\pi^{2}\end{bmatrix}}_{\gamma}\underbrace{\begin{bmatrix}\pi\pi & 0 & 0\\ 0 & \pi\eta & 0\\ 0 & 0 & \pi\pi^{2}\end{bmatrix}}_{\sqrt{\Im m\,\Phi}}}$$

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2 channels and 2 poles & 3 channels and 2 poles

$$\underbrace{\begin{bmatrix}\pi\pi & \pi\pi^2\\ \pi^2\pi & \pi^2\pi^2\end{bmatrix}}$$

$$\overbrace{\underbrace{\begin{bmatrix}\pi\pi & 0\\ 0 & \pi\pi^2\end{bmatrix}}_{\sqrt{\Im m\ \Phi}}\underbrace{\begin{bmatrix}\pi\pi 1 & \pi\pi 2\\ \pi\pi^2 1 & \pi\pi^2 2\end{bmatrix}}_{\gamma^T}\underbrace{G}_{????????}\underbrace{\begin{bmatrix}1\pi\pi & 1\pi\pi^2\\ 2\pi\pi & 2\pi\pi^2\end{bmatrix}}_{\gamma}\underbrace{\begin{bmatrix}\pi\pi & 0\\ 0 & \pi\pi^2\end{bmatrix}}_{\sqrt{\Im m\ \Phi}}}$$

$$\underbrace{\begin{bmatrix}\pi\pi & \pi\eta & \pi\pi^2\\ \eta\pi & \eta\eta & \eta\pi^2\\ \pi^2\pi & \pi^2\eta & \pi^2\pi^2\end{bmatrix}}$$

$$\overbrace{\underbrace{\begin{bmatrix}\pi\pi & 0 & 0\\ 0 & \pi\eta & 0\\ 0 & 0 & \pi\pi^2\end{bmatrix}}_{\sqrt{\Im m\ \Phi}}\underbrace{\begin{bmatrix}\pi\pi 1 & \pi\pi 2\\ \pi\eta 1 & \pi\eta 2\\ \pi\pi^2 1 & \pi\pi^2 2\end{bmatrix}}_{\gamma^T}\underbrace{G}_{????????}\underbrace{\begin{bmatrix}1\pi\pi & 1\pi\eta & 1\pi\pi^2\\ 2\pi\pi & 2\pi\eta & 2\pi\pi^2\end{bmatrix}}_{\gamma}\underbrace{\begin{bmatrix}\pi\pi & 0 & 0\\ 0 & \pi\eta & 0\\ 0 & 0 & \pi\pi^2\end{bmatrix}}_{\sqrt{\Im m\ \Phi}}}$$

Number of parameters
So far

$$\underbrace{\begin{bmatrix} \pi\pi & \pi\eta & \pi\pi^2 \\ \eta\pi & \eta\eta & \eta\pi^2 \\ \pi^2\pi & \pi^2\eta & \pi^2\pi^2 \end{bmatrix}}_{T}$$

$$\|$$

$$\overbrace{\underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\,\Phi}} \underbrace{\begin{bmatrix} \pi\pi 1 & \pi\pi 2 & \pi\pi 3 \\ \pi\eta 1 & \pi\eta 2 & \pi\eta 3 \\ \pi\pi^2 1 & \pi\pi^2 2 & \pi\pi^2 3 \end{bmatrix}}_{\gamma^T} \underbrace{G}_{????????} \underbrace{\begin{bmatrix} 1\pi\pi & 1\pi\eta & 1\pi\pi^2 \\ 2\pi\pi & 2\pi\eta & 2\pi\pi^2 \\ 3\pi\pi & 3\pi\eta & 3\pi\pi^2 \end{bmatrix}}_{\gamma} \underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\,\Phi}}}$$

As we can see in this example, we have nine parameters. Generaly the number of the paramaters are given by

$$N_C \times N_P$$

which is the dimension of γ matrices, where N_C is number of channels, and N_P is the number of poles included in fitting procedure.

Dressed propagator

Contains... & gives more parameters

Bare propagator

$$G^0_{ij} = \frac{\delta_{ij} e_i}{s - s_{0,i}}$$

Self energy term

$$\Sigma_{ij} = \sum_{c=1}^{M} \gamma_{ci} \Phi_c(s) \gamma_{cj}$$

Dressed propagator G is obtained by solving Dyson-Schwinger equation

$$G = G^0 + G^0 \Sigma G.$$

This equation can be solved by inverting a $N \times N$ matrix,

$$G = \begin{bmatrix} s - s_{0,1} - \Sigma_{11} & -\Sigma_{12} & -\Sigma_{13} \\ -\Sigma_{21} & s - s_{0,2} - \Sigma_{22} & -\Sigma_{23} \\ -\Sigma_{31} & -\Sigma_{32} & s - s_{0,3} - \Sigma_{33} \end{bmatrix}^{-1}$$

- where $s_{0,i}$ are bare poles
- So, finally we have $(N_C \times N_P) + N_P$ parameters.

T - matrix

After parametrization

$$\underbrace{\begin{bmatrix} \pi\pi & \pi\eta & \pi\pi^2 \\ \eta\pi & \eta\eta & \eta\pi^2 \\ \pi^2\pi & \pi^2\eta & \pi^2\pi^2 \end{bmatrix}}_{T}$$

$$\|$$

$$\overbrace{\underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\,\Phi}} \underbrace{\begin{bmatrix} \pi\pi1 & \pi\pi2 & \pi\pi3 \\ \pi\eta1 & \pi\eta2 & \pi\eta3 \\ \pi\pi^21 & \pi\pi^22 & \pi\pi^23 \end{bmatrix}}_{\gamma^T} \overbrace{\Downarrow\Downarrow\Downarrow\Downarrow\Downarrow\Downarrow}^{G} \underbrace{\begin{bmatrix} 1\pi\pi & 1\pi\eta & 1\pi\pi^2 \\ 2\pi\pi & 2\pi\eta & 2\pi\pi^2 \\ 3\pi\pi & 3\pi\eta & 3\pi\pi^2 \end{bmatrix}}_{\gamma} \underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\,\Phi}}}$$

$$\Downarrow$$

$$\begin{bmatrix} s - s_{0,1} - \Sigma_{11} & -\Sigma_{12} & -\Sigma_{13} \\ -\Sigma_{21} & s - s_{0,2} - \Sigma_{22} & -\Sigma_{23} \\ -\Sigma_{31} & -\Sigma_{32} & s - s_{0,3} - \Sigma_{33} \end{bmatrix}^{-1}$$

Fitting procedure

$$\underbrace{\begin{bmatrix} \pi\pi & \pi\eta & \pi\pi^2 \\ \eta\pi & \eta\eta & \eta\pi^2 \\ \pi^2\pi & \pi^2\eta & \pi^2\pi^2 \end{bmatrix}}_{T}$$

$$\|$$

$$\overbrace{\underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\ \Phi}} \underbrace{\begin{bmatrix} \pi\pi 1 & \pi\pi 2 & \pi\pi 3 \\ \pi\eta 1 & \pi\eta 2 & \pi\eta 3 \\ \pi\pi^2 1 & \pi\pi^2 2 & \pi\pi^2 3 \end{bmatrix}}_{\gamma^T} \overbrace{\downdownarrows\downdownarrows\downdownarrows\downdownarrows\downdownarrows\downdownarrows}^{G} \underbrace{\begin{bmatrix} 1\pi\pi & 1\pi\eta & 1\pi\pi^2 \\ 2\pi\pi & 2\pi\eta & 2\pi\pi^2 \\ 3\pi\pi & 3\pi\eta & 3\pi\pi^2 \end{bmatrix}}_{\gamma} \underbrace{\begin{bmatrix} \pi\pi & 0 & 0 \\ 0 & \pi\eta & 0 \\ 0 & 0 & \pi\pi^2 \end{bmatrix}}_{\sqrt{\Im m\ \Phi}}}$$

$$\downdownarrows$$

$$\begin{bmatrix} s - s_{0,1} - \Sigma_{11} & -\Sigma_{12} & -\Sigma_{13} \\ -\Sigma_{21} & s - s_{0,2} - \Sigma_{22} & -\Sigma_{23} \\ -\Sigma_{31} & -\Sigma_{32} & s - s_{0,3} - \Sigma_{33} \end{bmatrix}^{-1}$$

- Cyan $\rightarrow$ PWD or PWA
- Magenta $\rightarrow$ Theortically obtained function
- Red and blue $\rightarrow$ parameters to fit data

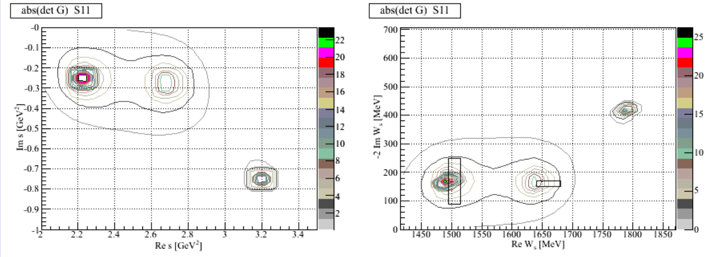
Dressed poles

Dressed poles can be obtained by solving an equation

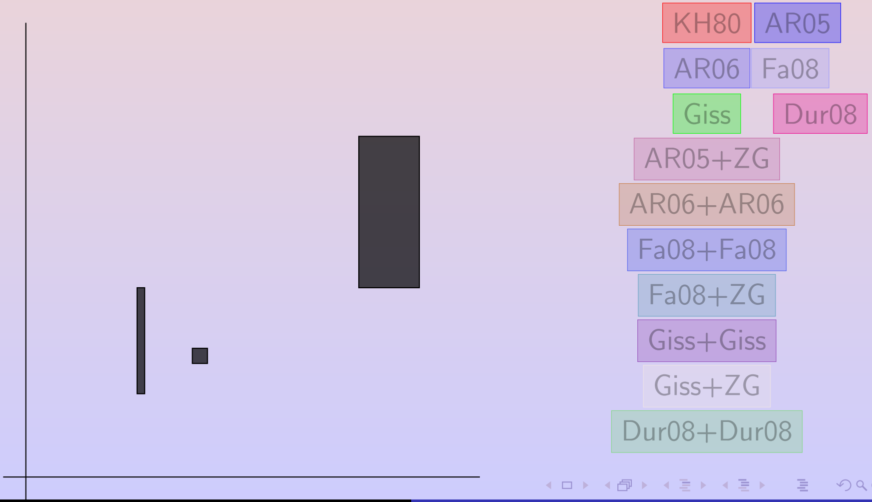
$$det(G^{-1}) = \begin{vmatrix} s - s_{0,1} - \Sigma_{11} & -\Sigma_{12} & -\Sigma_{13} \\ -\Sigma_{21} & s - s_{0,2} - \Sigma_{22} & -\Sigma_{23} \\ -\Sigma_{31} & -\Sigma_{32} & s - s_{0,3} - \Sigma_{33} \end{vmatrix} = 0$$

Example: S11 partial wave

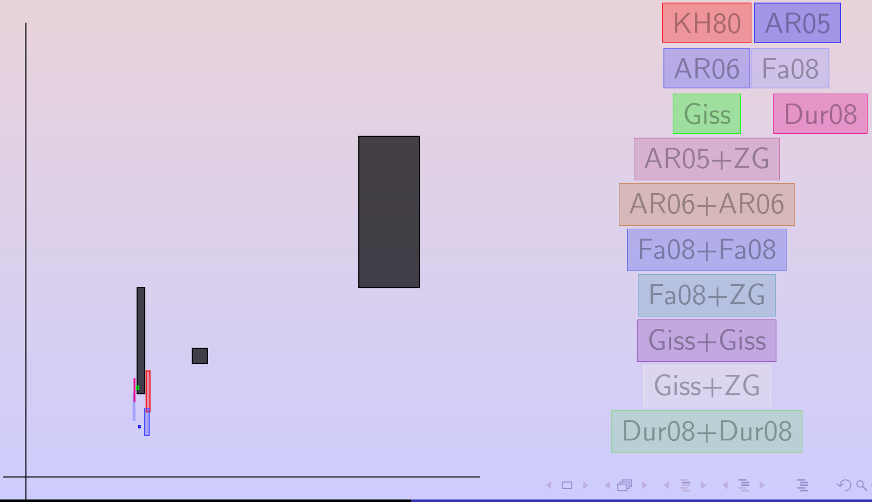
- 3 channels
- 3 poles
- Fa08 $\pi N \to \pi N$
- ZG98 $\pi N \to \eta N$



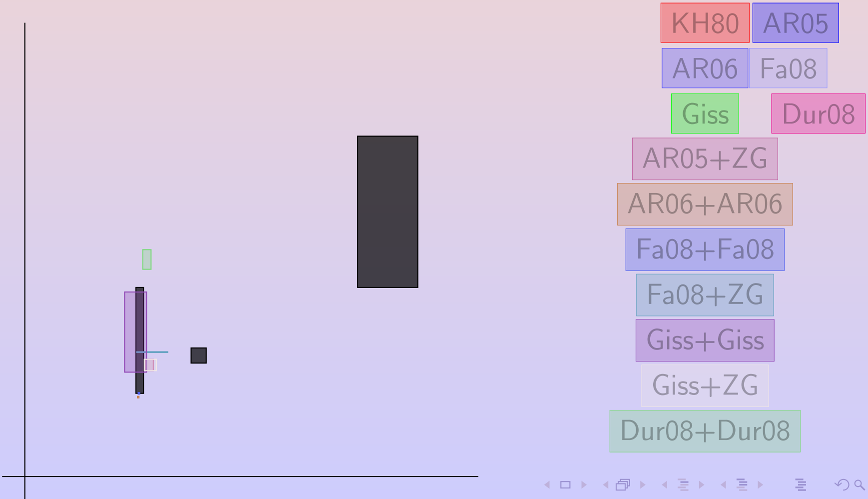
Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

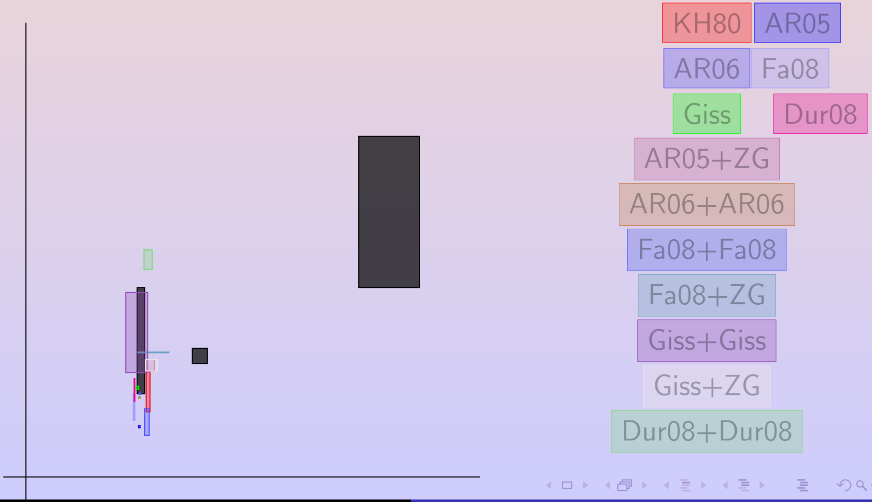
Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

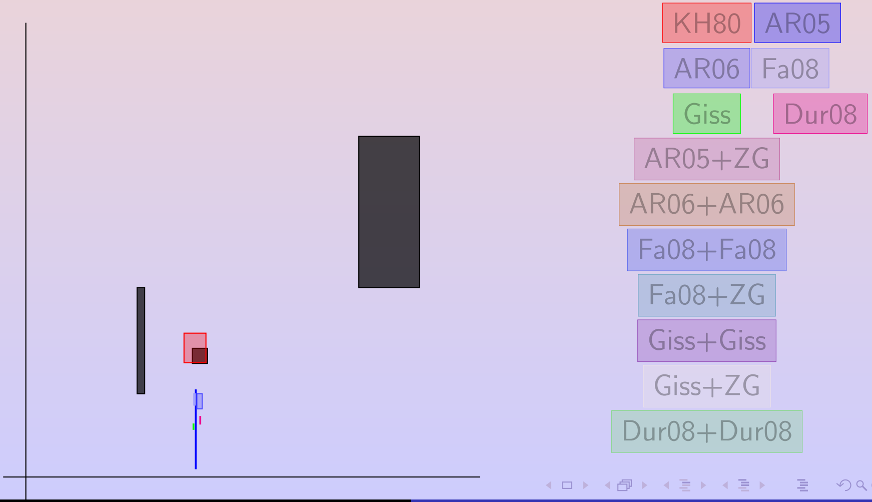
Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

Results


KH80
AR05
AR06
Fa08
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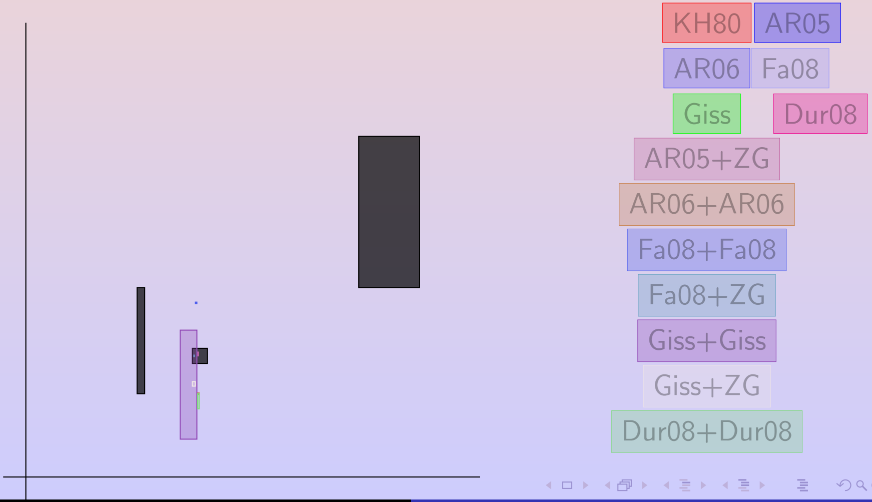
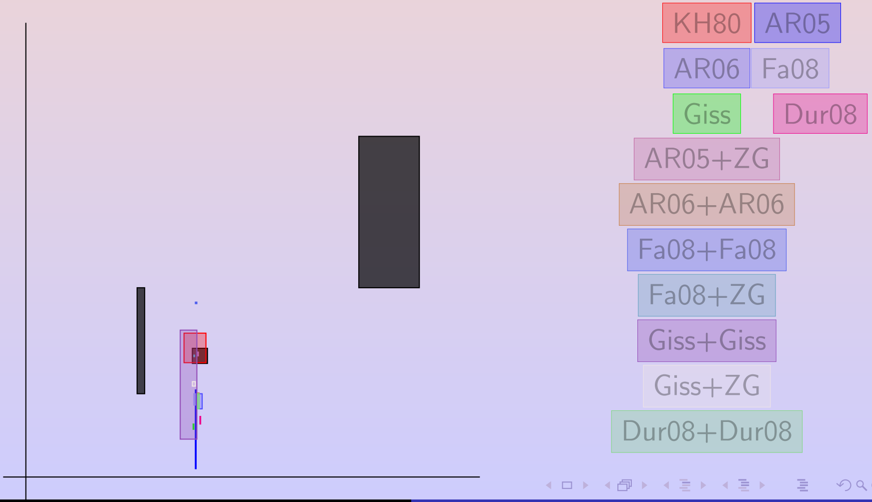
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

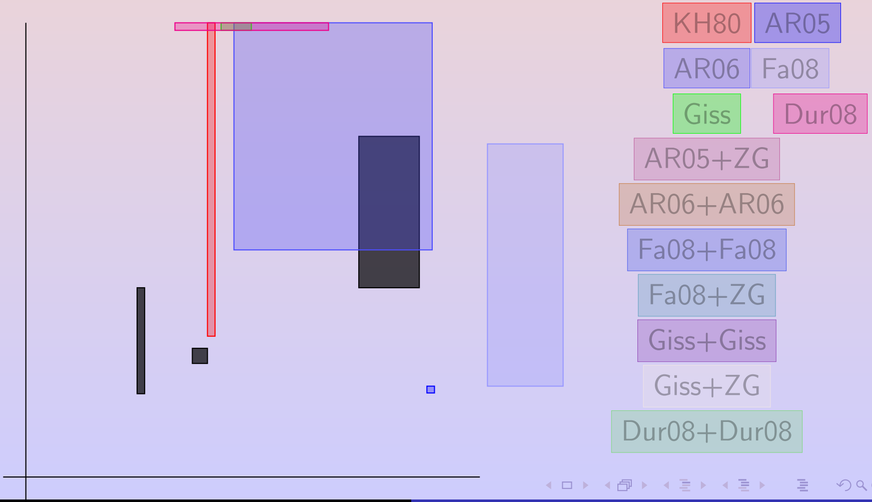
Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

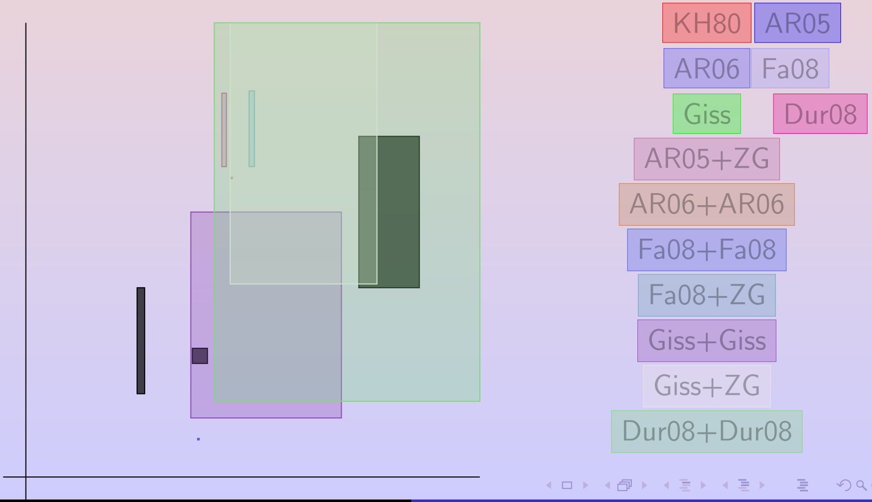
Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

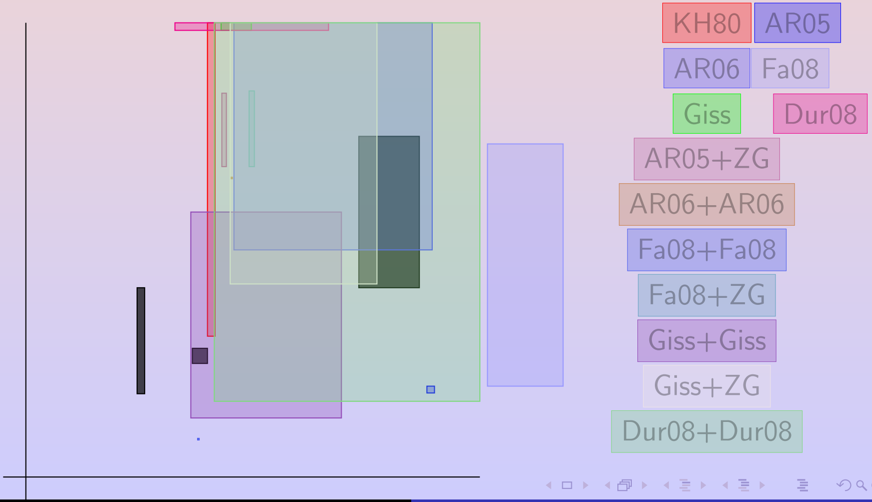
Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

Results


KH80
AR05
AR06
Fa08
Giss
Dur08
AR05+ZG
AR06+AR06
Fa08+Fa08
Fa08+ZG
Giss+Giss
Giss+ZG
Dur08+Dur08

Conclusions

- The first and the second pole position are stabile,
- Positions of the third pole (most of them are in beetwen 1700 MeV and 1900 MeV) indicate existance of the third pole somewhere about 1800 MeV.
- If we want the third pole to be stabile it is nescesary to include another channel in the fitting procedure.

Thank you !!!