JLab, 1 April 2002

MODERN HADRONIC RESONANCES THEORY

by

Norbert Ligterink

Department of Physics and Astronomy
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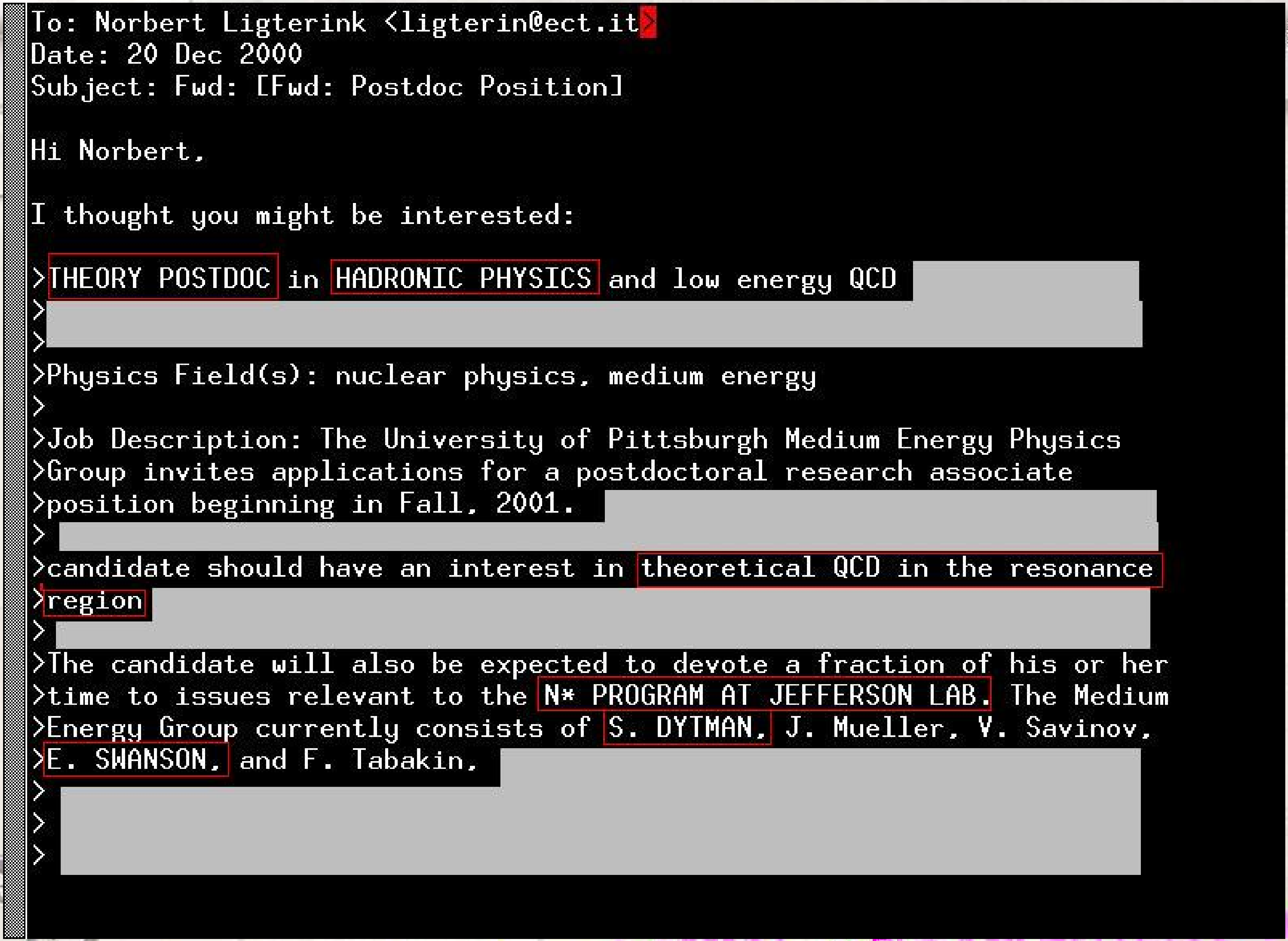
Pittsburgh

2, JLab



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To: Norbert Ligterink <ligterin@ect.it>
Date: 20 Dec 2000
Subject: Fwd: [Fwd: Postdoc Position]

Hi Norbert,

I thought you might be interested:

>THEORY POSTDOC in HADRONIC PHYSICS and low energy QCD [redacted]
>
>
>Physics Field(s): nuclear physics, medium energy
>
>Job Description: The University of Pittsburgh Medium Energy Physics
>Group invites applications for a postdoctoral research associate
>position beginning in Fall, 2001. [redacted]
>
>candidate should have an interest in theoretical QCD in the resonance
>region [redacted]
>
>The candidate will also be expected to devote a fraction of his or her
>time to issues relevant to the N* PROGRAM AT JEFFERSON LAB. The Medium
>Energy Group currently consists of S. DYTMAN, J. Mueller, V. Savinov,
>E. SWANSON, and F. Tabakin. [redacted]
>
>
>
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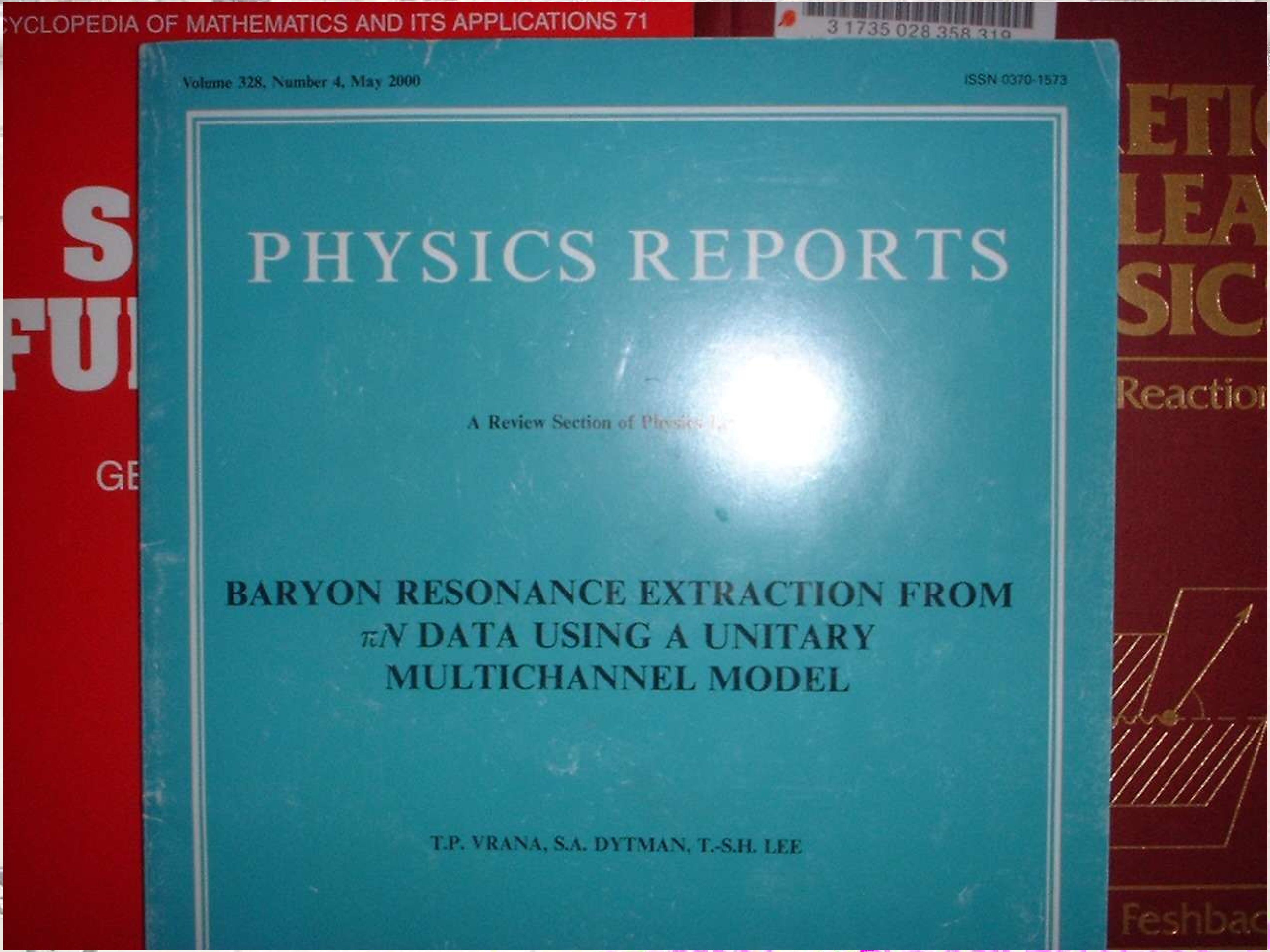

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PHYSICS REPORTS

A Review Section of Physics L

BARYON RESONANCE EXTRACTION FROM
πN DATA USING A UNITARY
MULTICHANNEL MODEL

T.P. VRANA, S.A. DYTMAN, T.-S.H. LEE

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$S_{11}(1535)$ confusion

FIT	Γ_{full}(MeV)	$bf_{\pi N}$	$A^p_{\frac{1}{2}}$	reaction
VPI(96)	105	0.31	60 ± 15	$\pi N \to \pi N$, $\gamma p \to \pi p$
Drechsel(99)	80	0.40*	67	$\gamma p \to \pi p$
Krusche(97)	212	0.45*	120	$\gamma p \to \eta p$
Sauermann(96)	162	0.41	102 ± 20	$\pi N \to \pi N, \gamma p \to \pi, \eta p$
Pitt-ANL(00)	126	0.34	87 ± 3	All
Feuster(99-00)	151-215	$\sim$ 0.31	91-106	All
PDG	100-250	0.35-0.55	90 ± 30	averaging

* uses PDG value

thanks to Steve Dytman

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the little page with the big statements

"we shall overcome" … "technical" … "food for mathematicians and philosophers" Not really! Extracting microscopic information

- Unstable states are hard to handle consistently in field theory (arrow-of-time, unitarity)
- One cannot postulate $m + i\Gamma$ without a microscopic model for the interaction and decay channels

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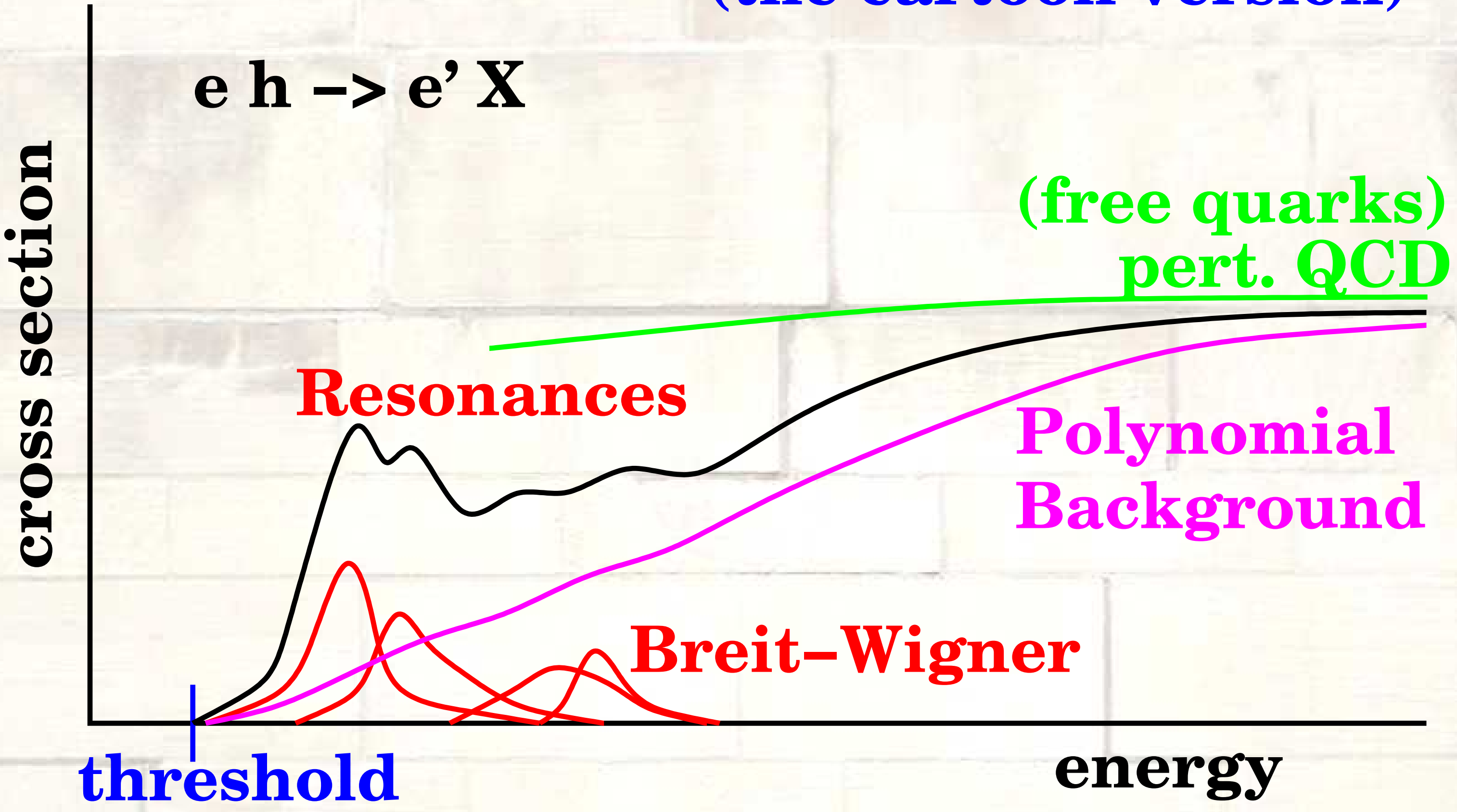
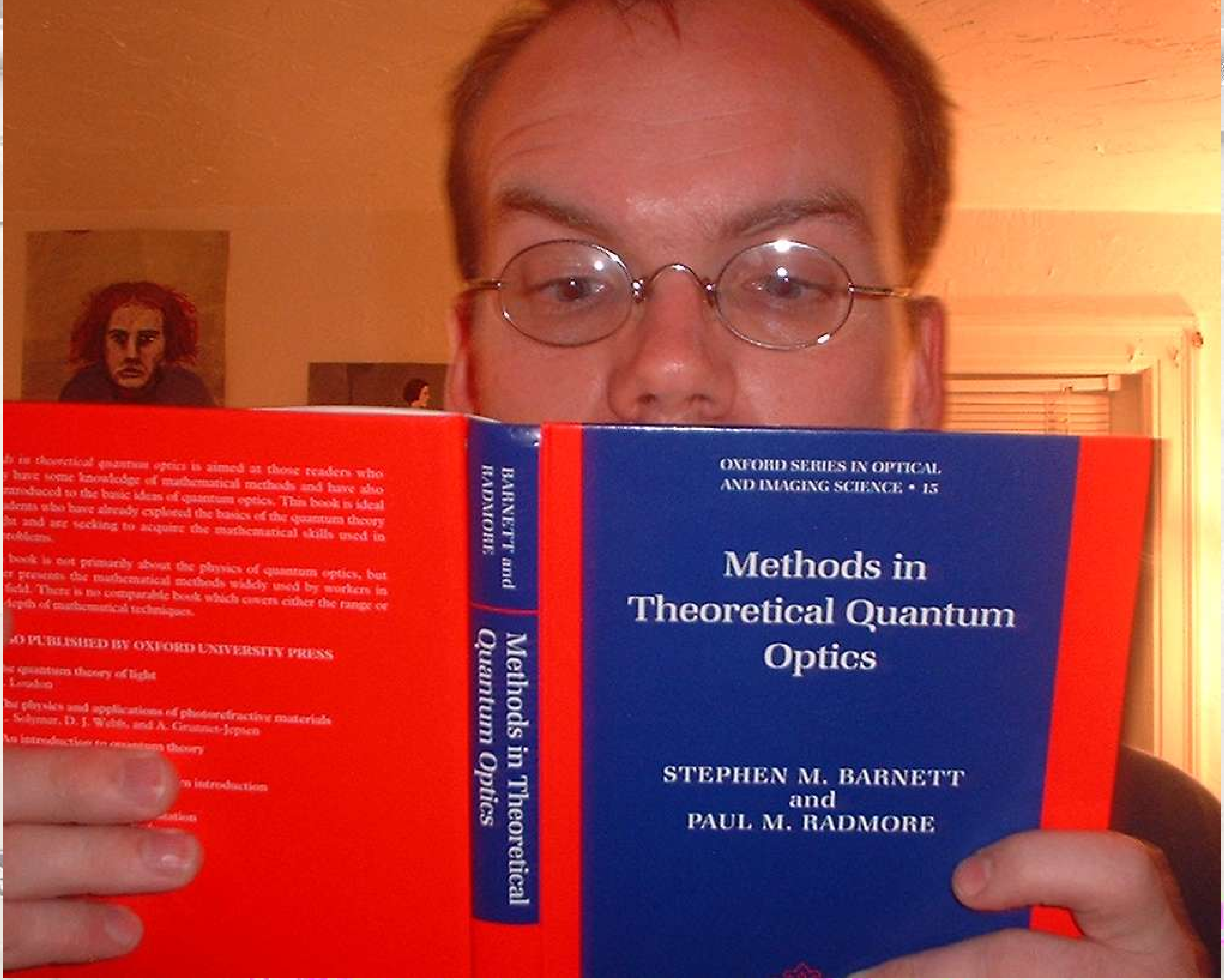
ELECTRO PROBE of HADRONIC PROCESSES

(the cartoon version)



Fit of the data with BWs+Polyn.?

***What did we learn?   *What do the parameters mean?**


OXFORD SERIES IN OPTICAL AND IMAGING SCIENCE • 15
Methods in Theoretical Quantum Optics
STEPHEN M. BARNETT and PAUL M. RADMORE
BARNETT and RADMORE
Methods in Theoretical Quantum Optics

nology

Hamiltonian: two discrete states a and b, one continuum ϵ.

$$
\begin{aligned}
H &= |a\rangle m_a \langle a| + |b\rangle m_b \langle b| + \int_0^1 d\epsilon |\epsilon\rangle \epsilon \langle \epsilon| \\
&\quad + \int_0^1 d\epsilon \; g\sqrt{\epsilon(1-\epsilon)}[|a\rangle\langle\epsilon| + |b\rangle\langle\epsilon| + |\epsilon\rangle\langle a| + |\epsilon\rangle\langle b|]
\end{aligned}
$$

where $|\epsilon\rangle \sim \int dk[\text{PS}]|\mathbf{k}\rangle$. Wave function (for energy ω : $0 < \omega < 1$):

$$|\omega\rangle = \alpha_a|a\rangle + \alpha_b|b\rangle + \int d\epsilon\beta(\epsilon)|\epsilon\rangle$$

$$\Rightarrow \quad \beta = \left(\frac{1}{\omega - \epsilon} + z(\omega)\delta(\omega-\epsilon)\right) g\sqrt{\epsilon(1-\epsilon)}(\alpha_a + \alpha_b)$$

Inserting β back gives $(\omega - H)\cdot\alpha = 0$, hence $\det[\omega - H] = 0$ yields z:

$$z(\omega) = \frac{1}{\omega(1-\omega)}\left(\left(\frac{g^2}{\omega - m_b} + \frac{g^2}{\omega - m_a}\right)^{-1} - (\omega - \frac{1}{2}) - \omega(1-\omega)\log\left|\frac{\omega}{1-\omega}\right|\right)$$

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Some properties

perturbative definition

$$\Gamma = |\langle a|H|\epsilon\rangle|^2 = g^2\epsilon(1-\epsilon)$$

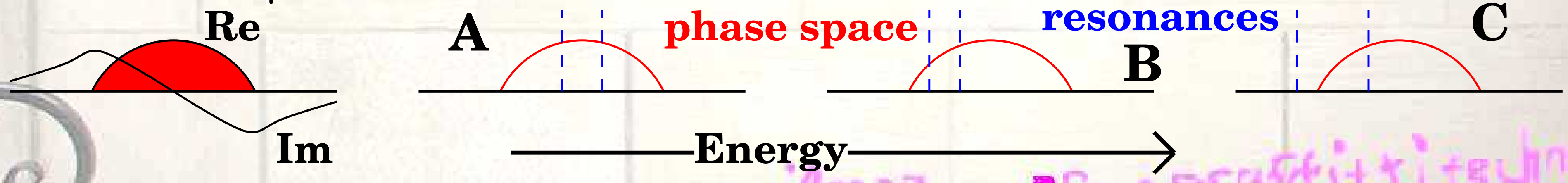
The phase shift

$$\delta_{\mathrm{r}} = \arctan\frac{-\pi}{z(\omega)}$$

Scattering amplitude

$$T = \frac{1}{z(\omega)+i\pi} \approx_{g\to 0} \frac{g^2\omega(1-\omega)}{(\omega-m_a)(\omega-m_b)/(2\omega-m_a-m_b)+i\pi g^2\omega(1-\omega)}$$

Some examples:



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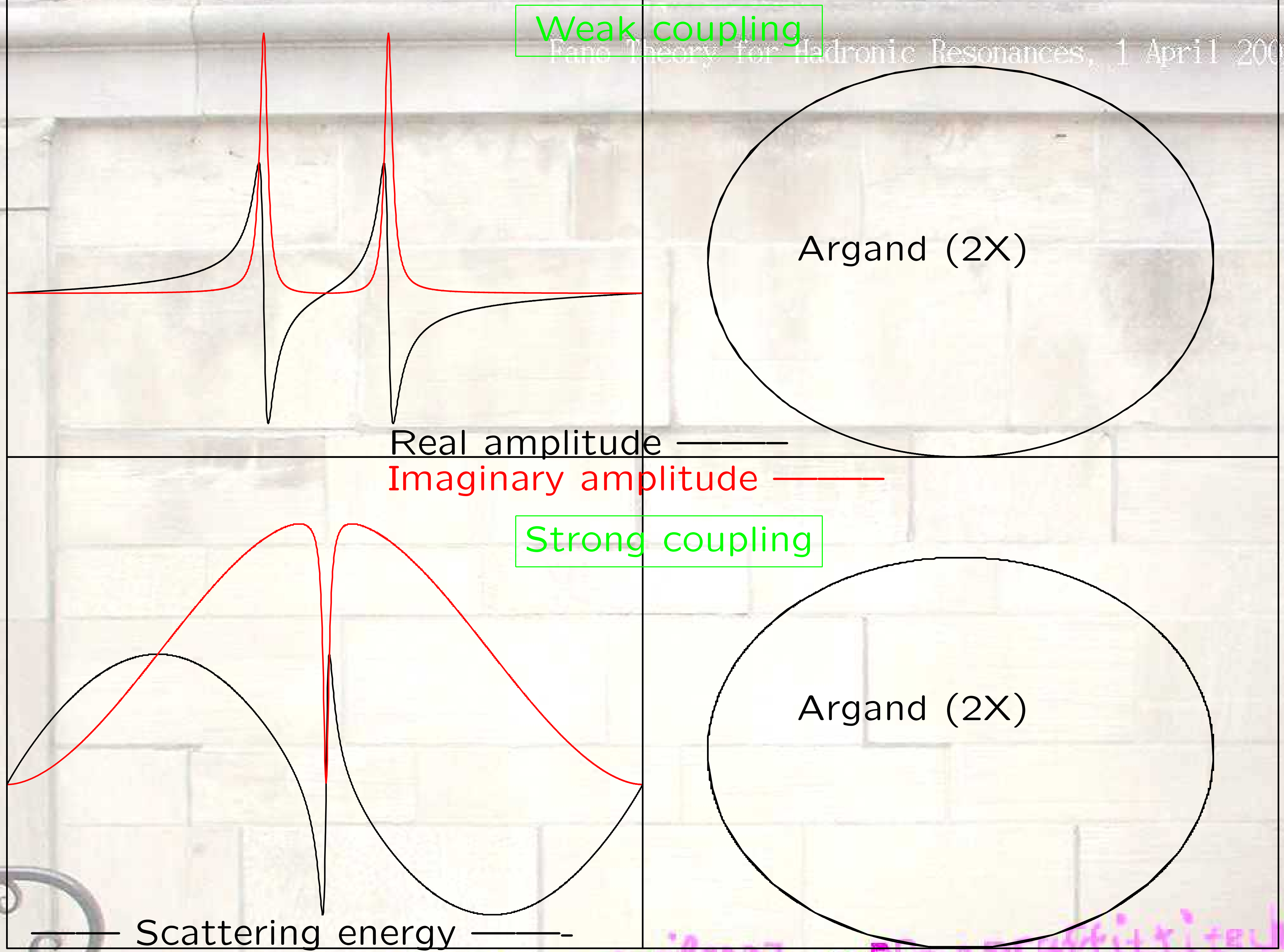

Weak coupling

Argand (2X)

Real amplitude ———

Imaginary amplitude ———

Strong coupling

Argand (2X)

—— Scattering energy ———-

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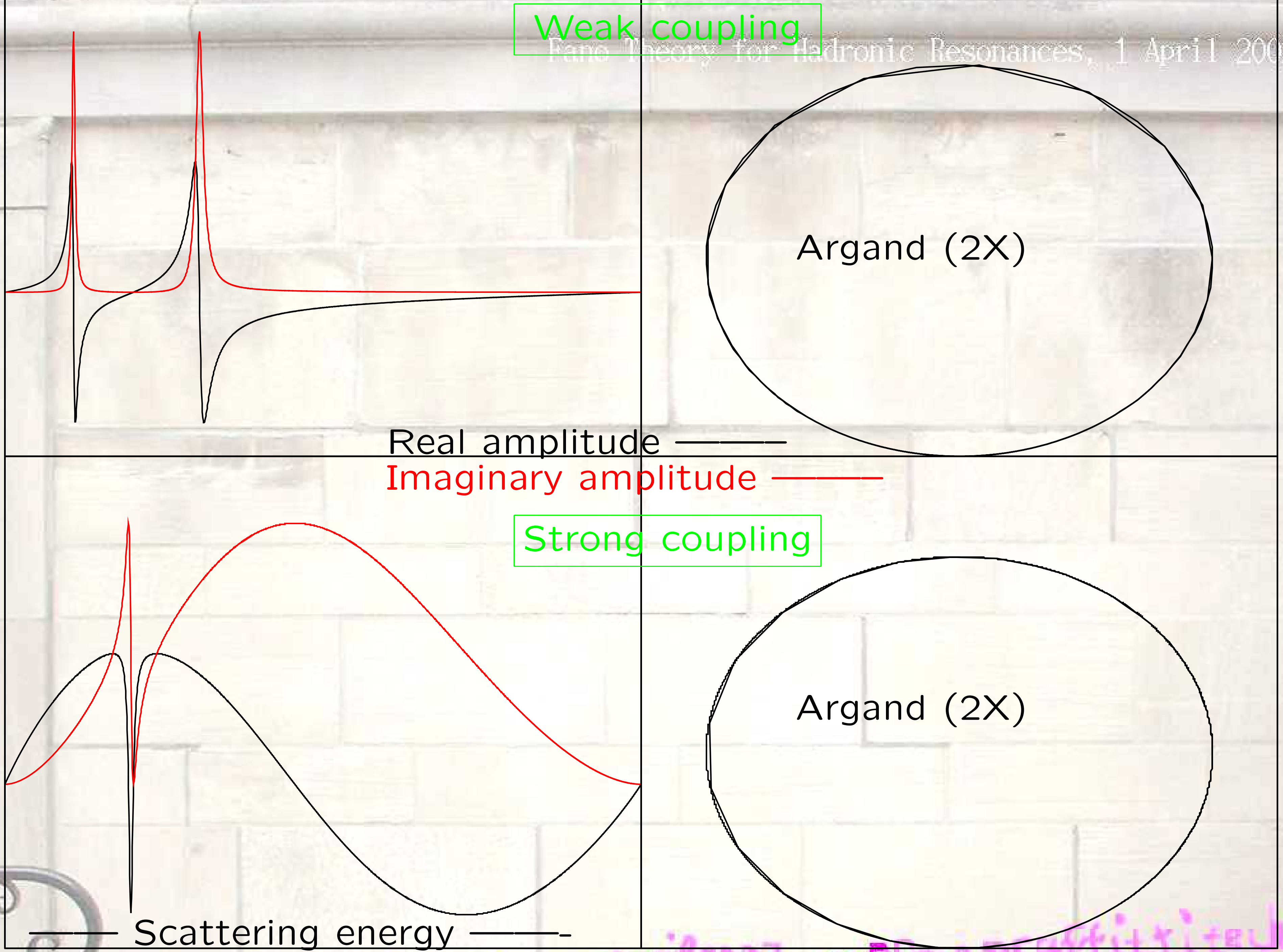

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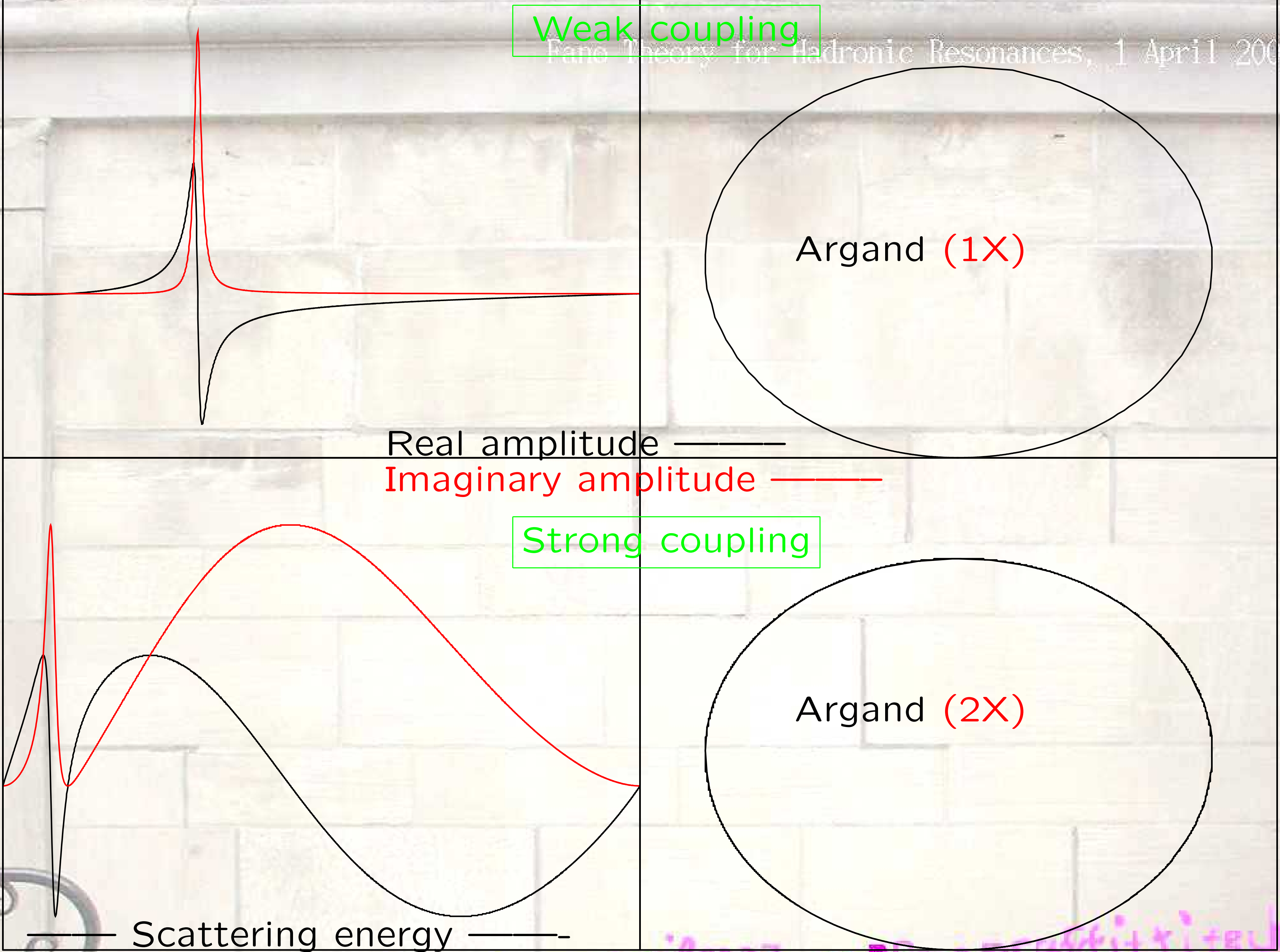

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T-Matrix / S-Matrix nothing new

$$V\frac{1}{E-H_0}V\frac{1}{E-H_0}V\frac{1}{E-H_0}V\frac{1}{E-H_0}V$$

Green's Function / Propagator / Resolvent

$$\frac{1}{E-H_0}V\frac{1}{E-H_0}V\frac{1}{E-H_0}V\frac{1}{E-H_0}$$

Eigenstates / Möller Operator

$$\frac{1}{E-H_0}V\frac{1}{E-H_0}V\frac{1}{E-H_0}V\frac{1}{E-H_0}V\phi_0$$

It all boils down to evaluating:

$$\sum_i^{N}\left(\frac{1}{E-H_0}V\right)^i$$

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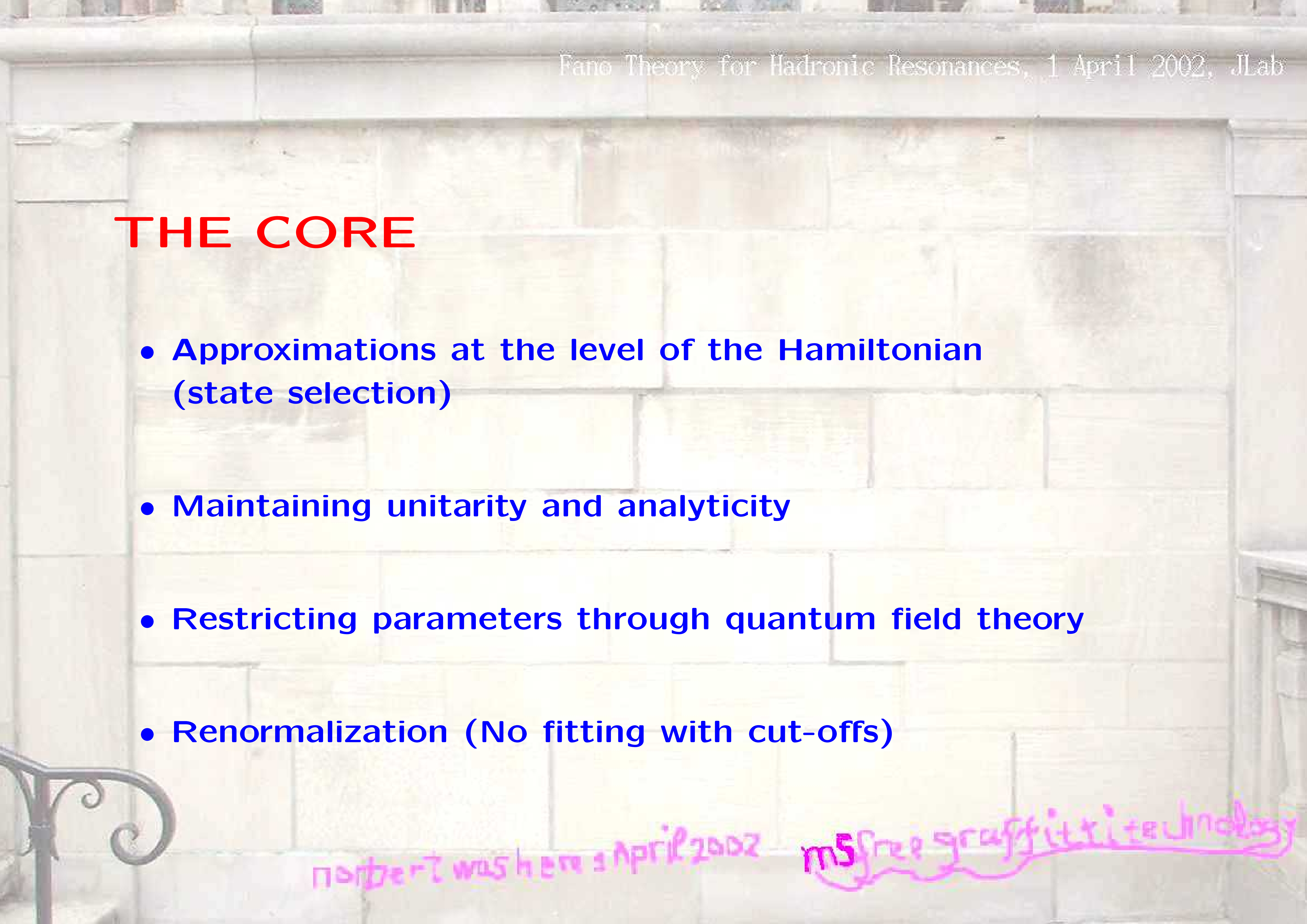
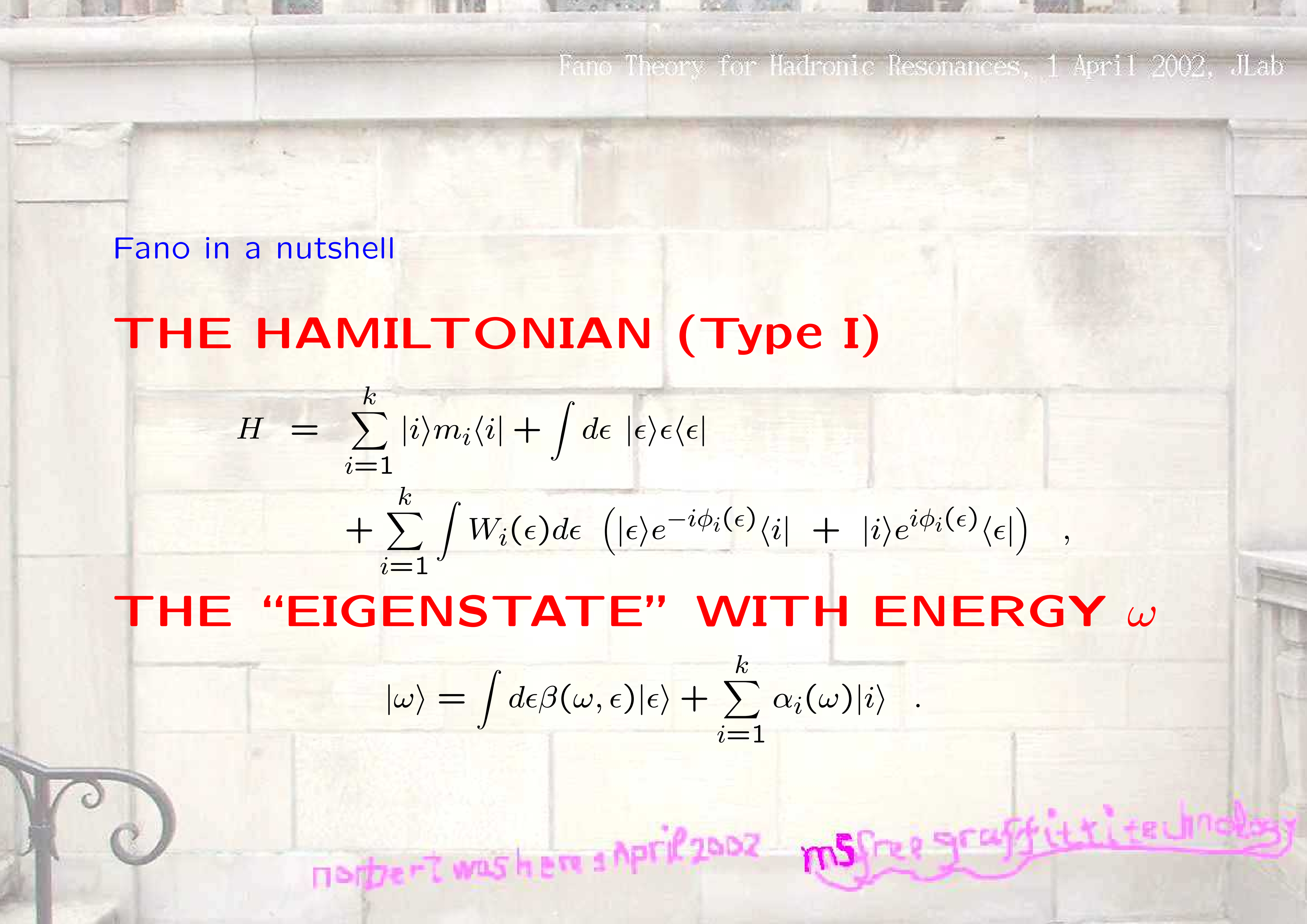
THE CORE

- **Approximations at the level of the Hamiltonian (state selection)**
- **Maintaining unitarity and analyticity**
- **Restricting parameters through quantum field theory**
- **Renormalization (No fitting with cut-offs)**





Fano in a nutshell

THE HAMILTONIAN (Type I)

$$H = \sum_{i=1}^{k} |i\rangle m_i \langle i| + \int d\epsilon \ |\epsilon\rangle \epsilon \langle \epsilon|$$

$$+ \sum_{i=1}^{k} \int W_i(\epsilon) d\epsilon \ \left(|\epsilon\rangle e^{-i\phi_i(\epsilon)} \langle i| \ + \ |i\rangle e^{i\phi_i(\epsilon)} \langle \epsilon| \right) \quad ,$$

THE “EIGENSTATE” WITH ENERGY ω

$$|\omega\rangle = \int d\epsilon \beta(\omega, \epsilon) |\epsilon\rangle + \sum_{i=1}^{k} \alpha_i(\omega) |i\rangle \quad .$$

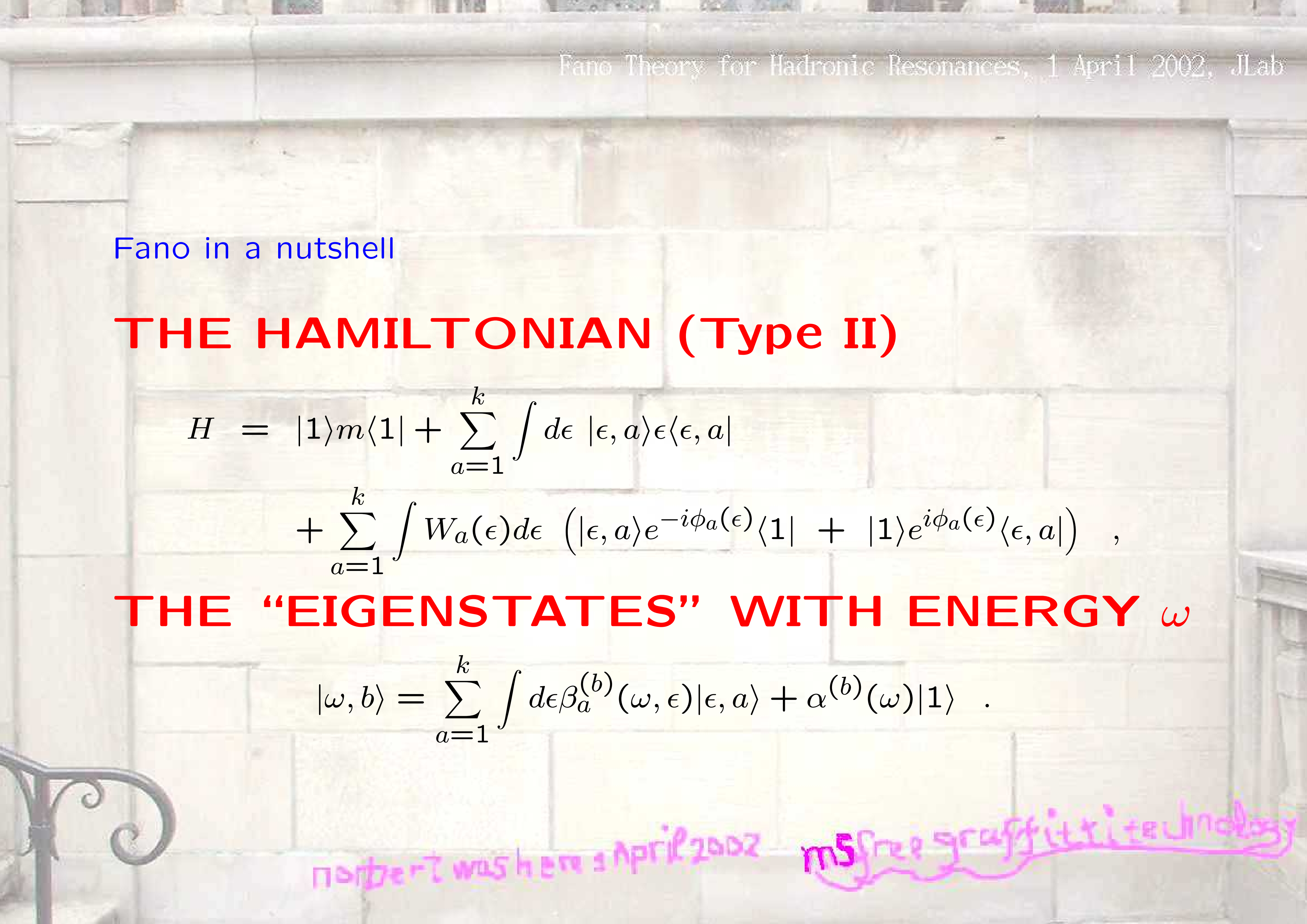
Fano in a nutshell

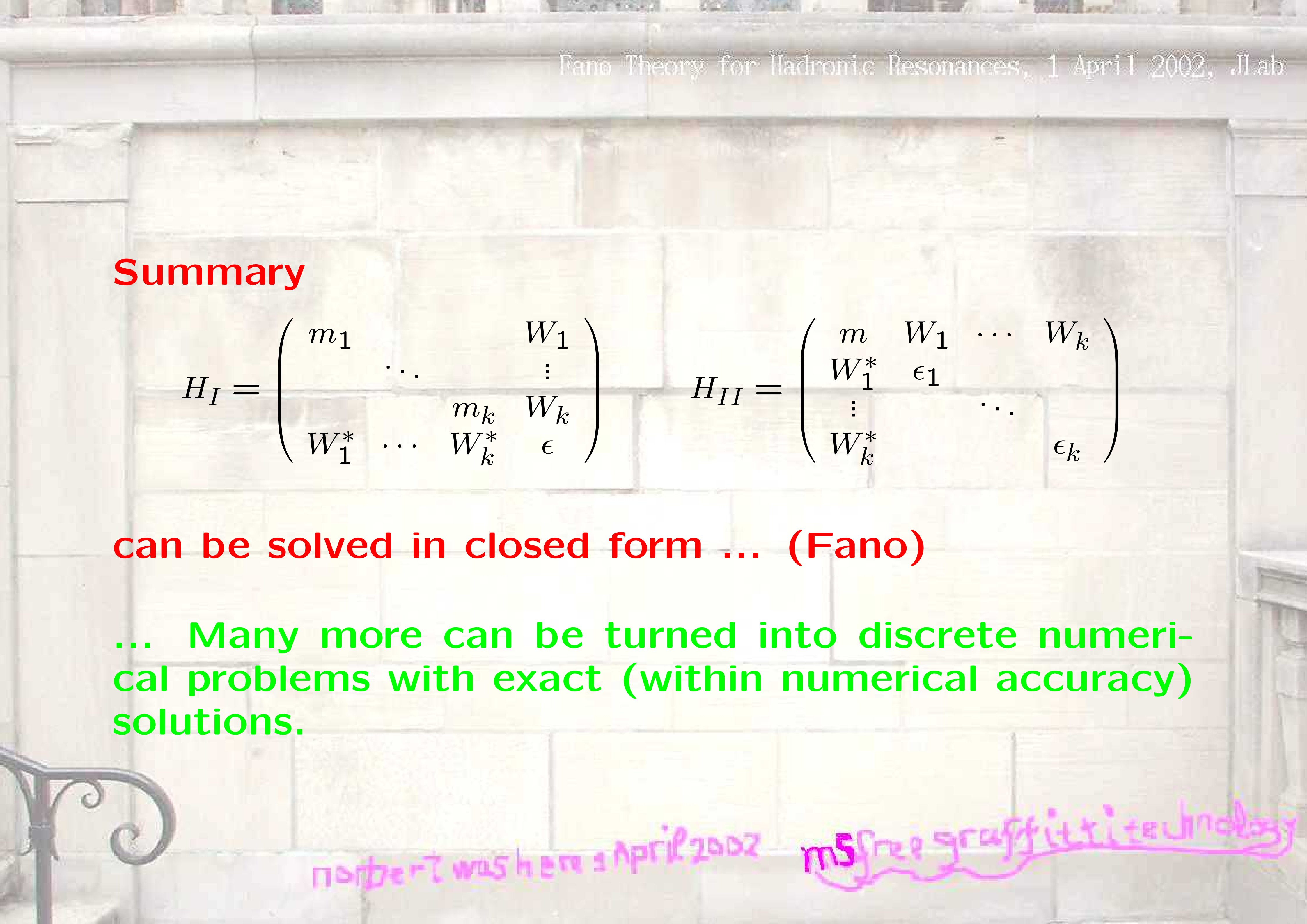
THE HAMILTONIAN (Type II)

$$
\begin{aligned}
H \; = \; & |1\rangle m \langle 1| + \sum_{a=1}^{k} \int d\epsilon \; |\epsilon, a\rangle \epsilon \langle \epsilon, a| \\
& + \sum_{a=1}^{k} \int W_a(\epsilon) d\epsilon \; \left(|\epsilon, a\rangle e^{-i\phi_a(\epsilon)} \langle 1| \; + \; |1\rangle e^{i\phi_a(\epsilon)} \langle \epsilon, a| \right) \quad ,
\end{aligned}
$$

THE “EIGENSTATES” WITH ENERGY ω

$$
|\omega, b\rangle = \sum_{a=1}^{k} \int d\epsilon \beta_a^{(b)}(\omega, \epsilon) |\epsilon, a\rangle + \alpha^{(b)}(\omega) |1\rangle \quad .
$$





Summary

$$H_I = \begin{pmatrix} m_1 & & & W_1 \\ & \ddots & & \vdots \\ & & m_k & W_k \\ W_1^* & \cdots & W_k^* & \epsilon \end{pmatrix} \qquad H_{II} = \begin{pmatrix} m & W_1 & \cdots & W_k \\ W_1^* & \epsilon_1 & & \\ \vdots & & \ddots & \\ W_k^* & & & \epsilon_k \end{pmatrix}$$

can be solved in closed form ... (Fano)

... Many more can be turned into discrete numerical problems with exact (within numerical accuracy) solutions.

Fano Type I where the free lunch went for dinner

$\beta(\omega,\epsilon)$ in terms of the α's:

$$\beta(\omega,\epsilon) = \left(\frac{1}{\omega-\epsilon} + z(\omega)\delta(\omega-\epsilon)\right)\sum_{i=1}^{k}\alpha_i(\omega)W_i(\epsilon)e^{-i\phi_i(\epsilon)}$$

For the consistency condition on $z(\omega)$ we define:

$$\begin{aligned} F_{ji}(\xi) &= W_i(\xi)W_j(\xi)e^{i(\phi_j(\xi)-\phi_i(\xi))} \\ \mathcal{F}_{ji}(\eta) &= \frac{1}{\pi}\int d\xi \frac{F_{ij}(\xi)}{\eta-\xi} \end{aligned}$$

$\mathcal{F}_{ji}$ is hermitian and yields the shifted, but real, energies of the discrete states:

$$z(\omega) = \left(\mathbf{W}^\dagger(\omega)\cdot\left((\omega-\epsilon)-\pi\mathcal{F}(\omega)\right)^{-1}\cdot\mathbf{W}(\omega)\right)^{-1}$$

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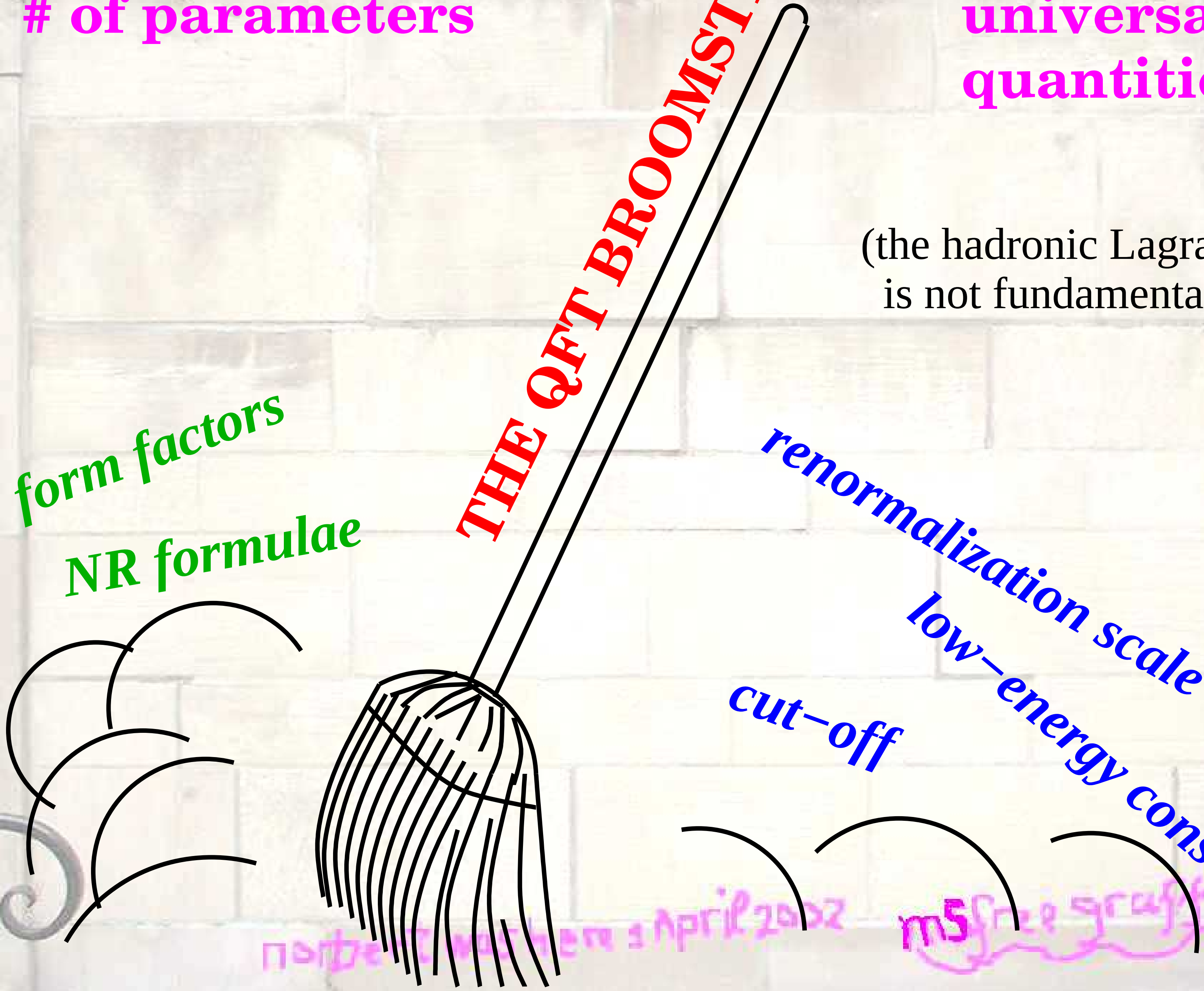
THE QFT BROOMSTICK

Restricting the # of parameters

Introducing universal quantities

(the hadronic Lagrangian is not fundamental!)



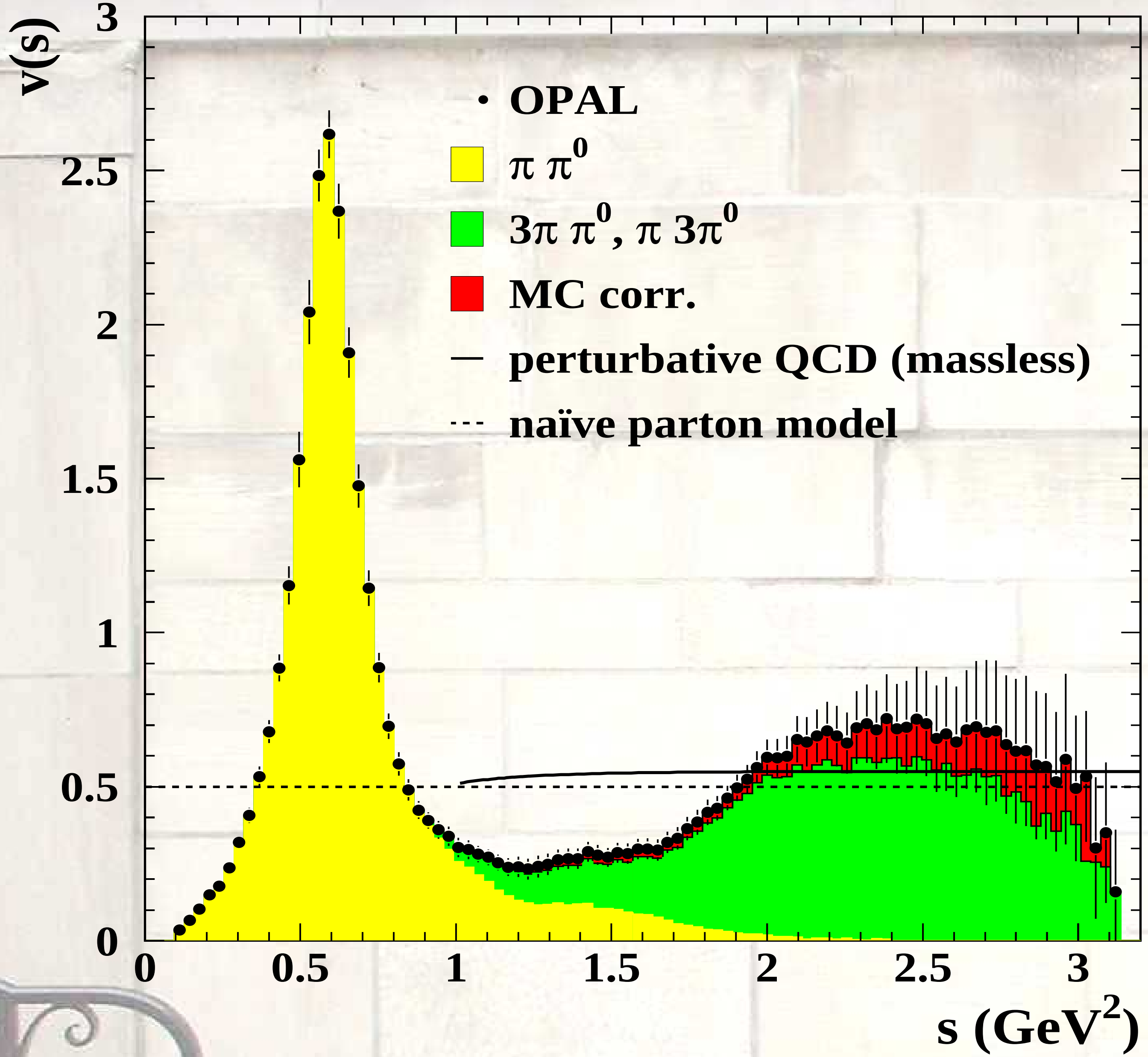
form factors

NR formulae

renormalization scale

low–energy constants

cut–off



OPAL (CERN) data

$\tau^- \rightarrow$ pions

rho meson peak + tail

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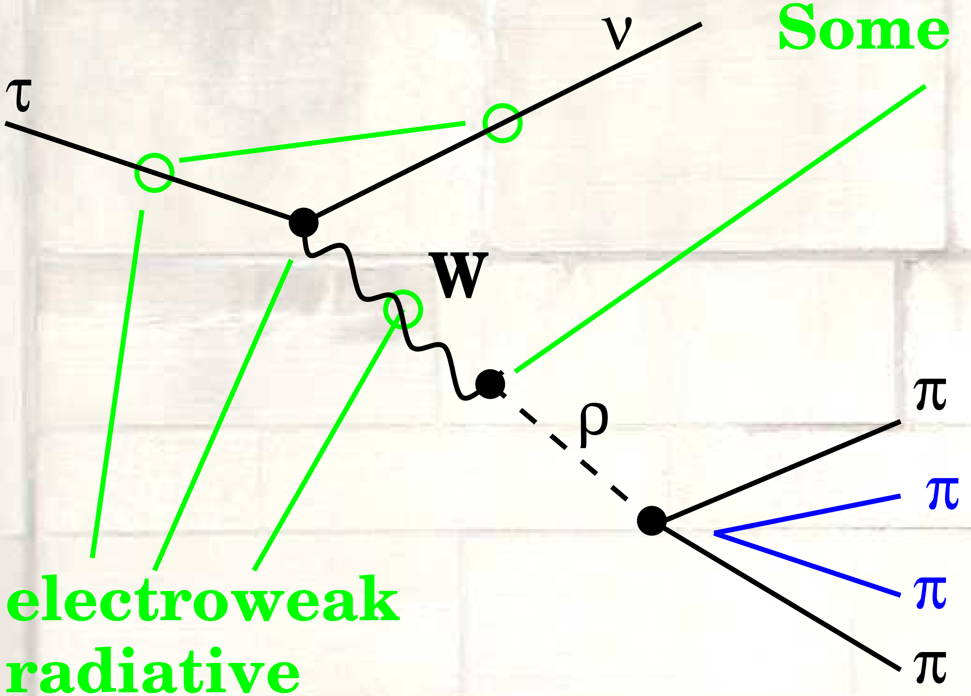
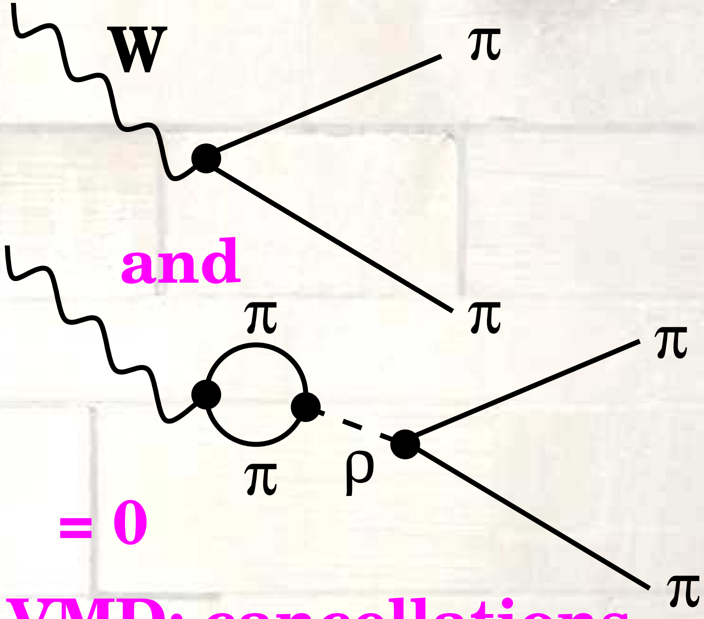
Hadronic tau–lepton decay:



Some QCD corrections

electroweak
radiative
corrections



and

= 0

VMD: cancellations

$g_{\gamma\pi\pi} = 1/g_{\rho\pi\pi}$

The Chiral Interpretation

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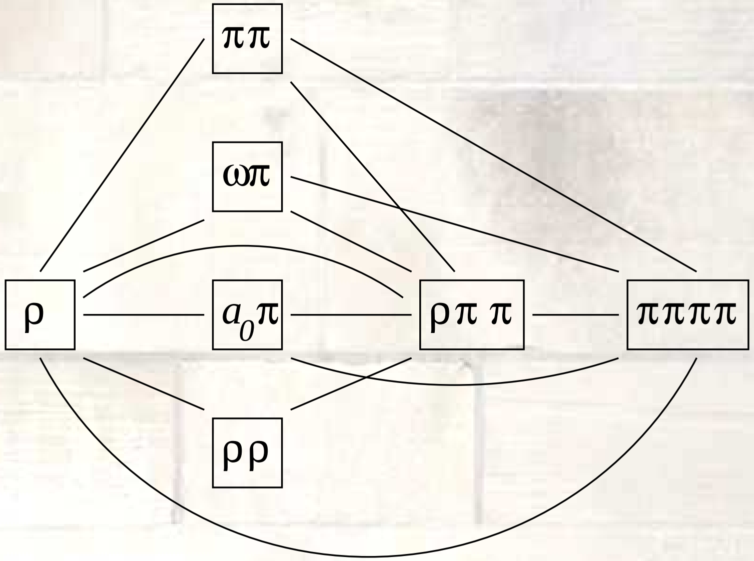
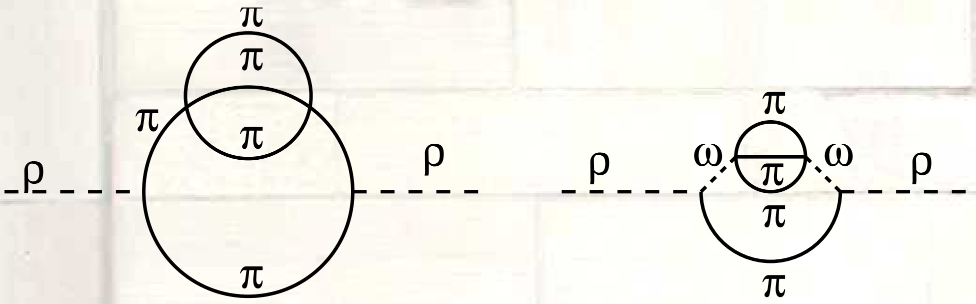
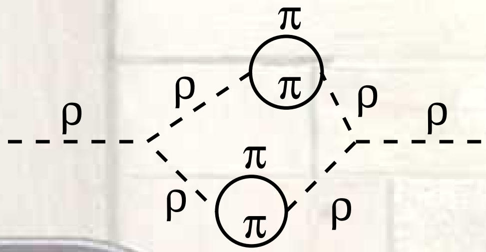
Many intermediate states

between ρ and $\pi\pi\pi\pi$







ET CETERA

ρ	770MeV	ρρ	1540MeV
ππ	279MeV	ρπ π	1049MeV
ωπ	922MeV	ππππ	558MeV
$a_0\pi$	1120MeV	ππππππ	837MeV

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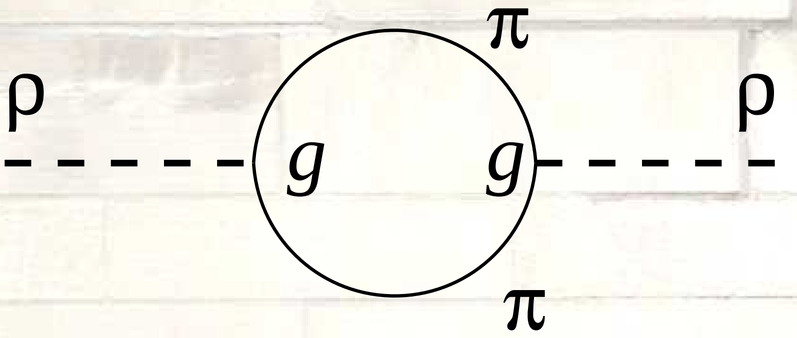
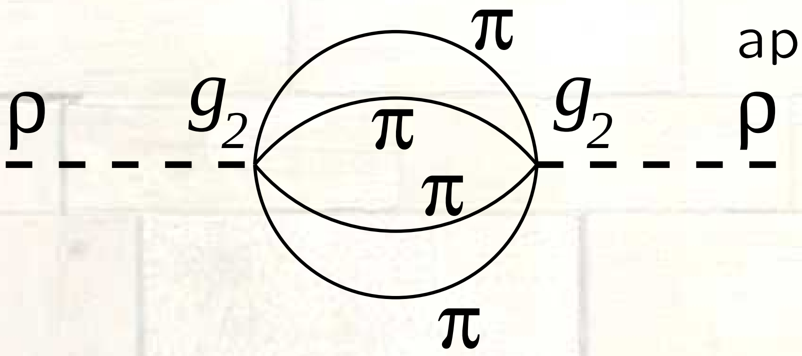
THE COUPLING FUNCTIONS W:

Follow from connection between the diagonal part of the field–theoretical self–energy and the corresponding quantity in Fano theory.





approximated by: $\propto (k^2)k^8 dk/\omega_\pi^2$

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COVARIANCE

adding the backward diagrams to the real part restores covariance:

$$\int d\epsilon \frac{f(\epsilon^2)}{\omega-\epsilon} + \int d\epsilon \frac{f(\epsilon^2)}{\omega-(2\omega+\epsilon)} = \int d\epsilon^2 \frac{f(\epsilon^2)}{\omega^2-\epsilon^2}$$

(Only in the real parts, because threshold $>$ 1800 MeV)

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Problems with multi-loop Feynman diagrams

Picking just one: Pseudo-thresholds

which turn up at succesive four-momentum integrations
(or as singularities in Feynman parameters)

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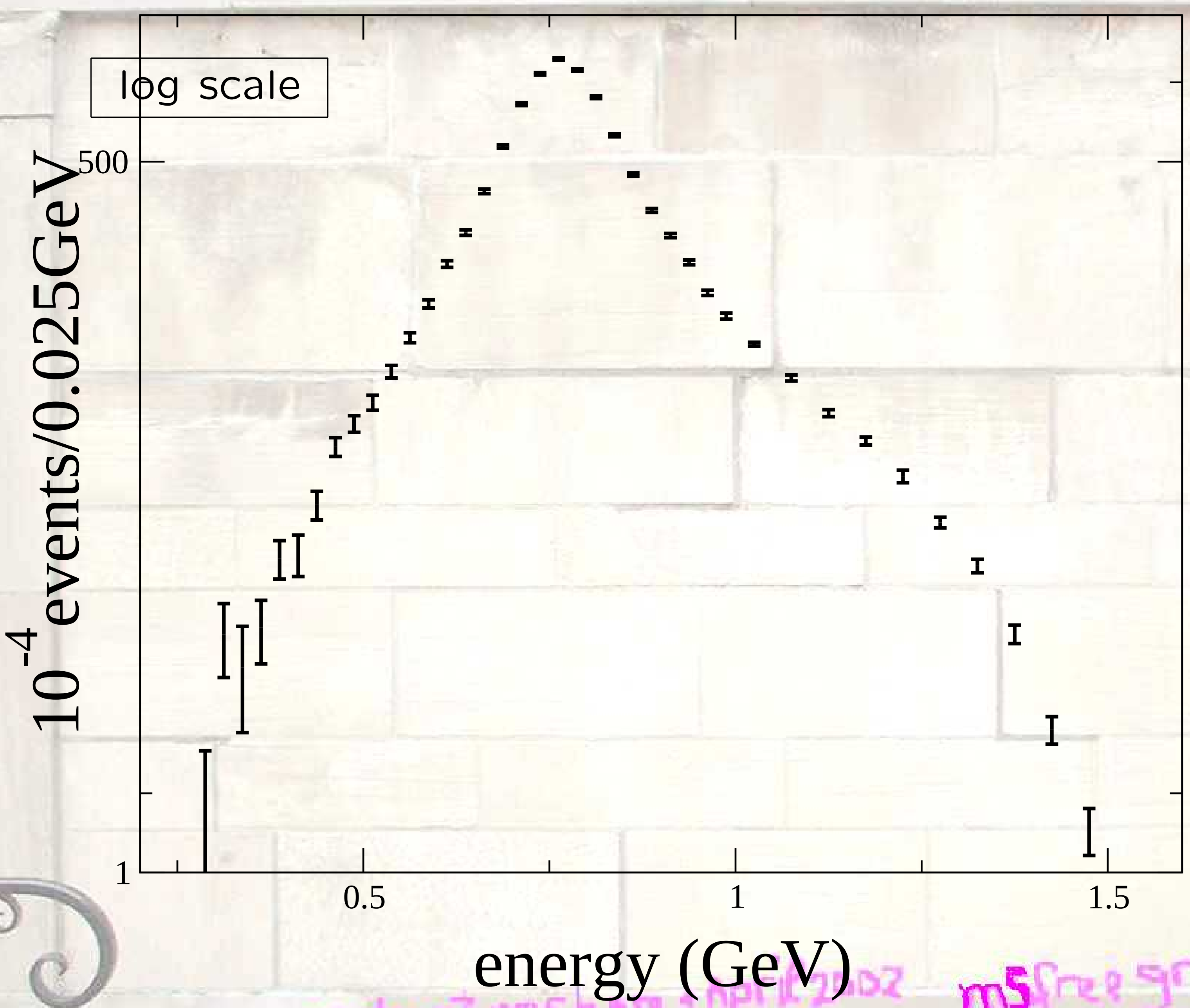
CLEO data + my fit



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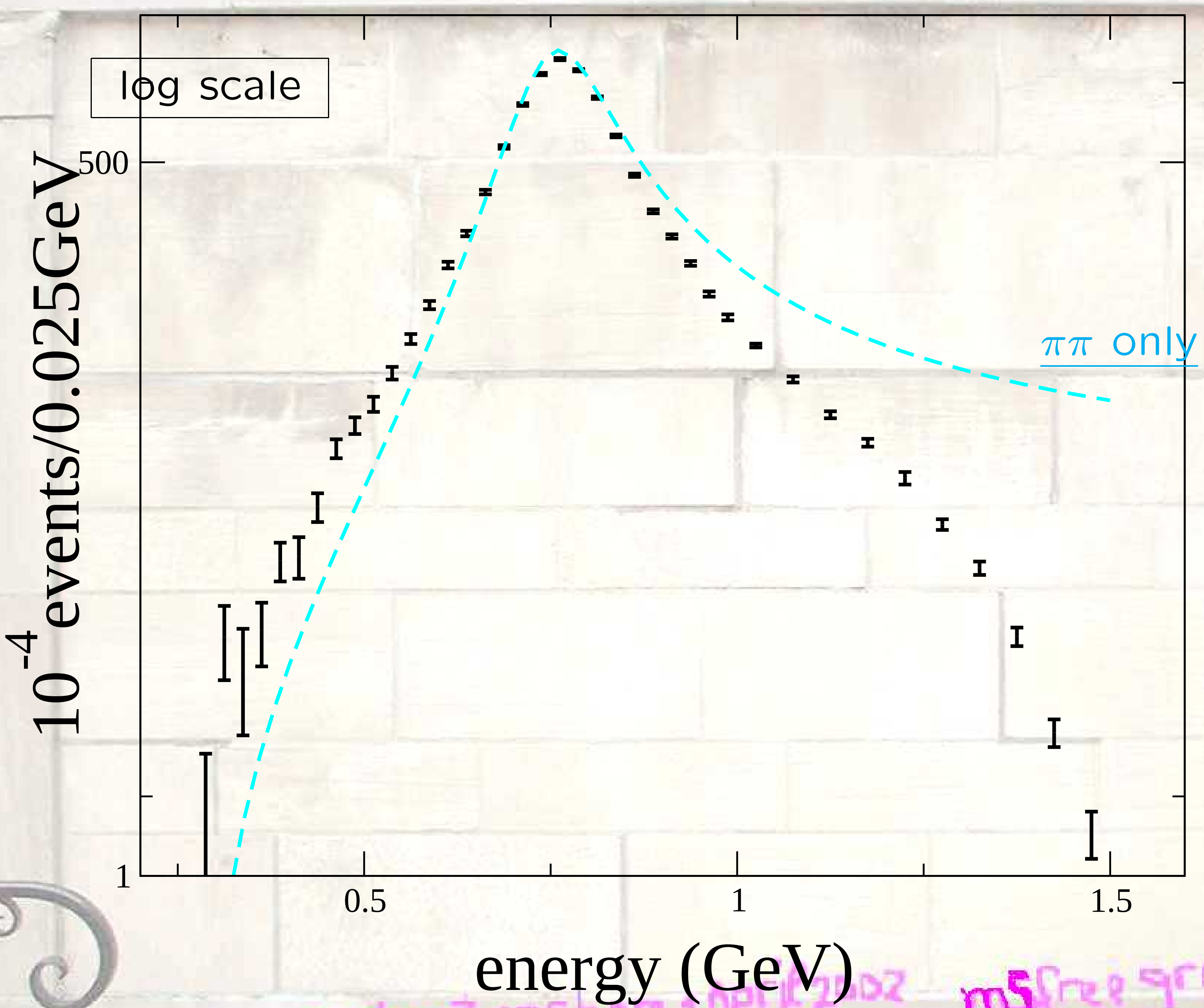

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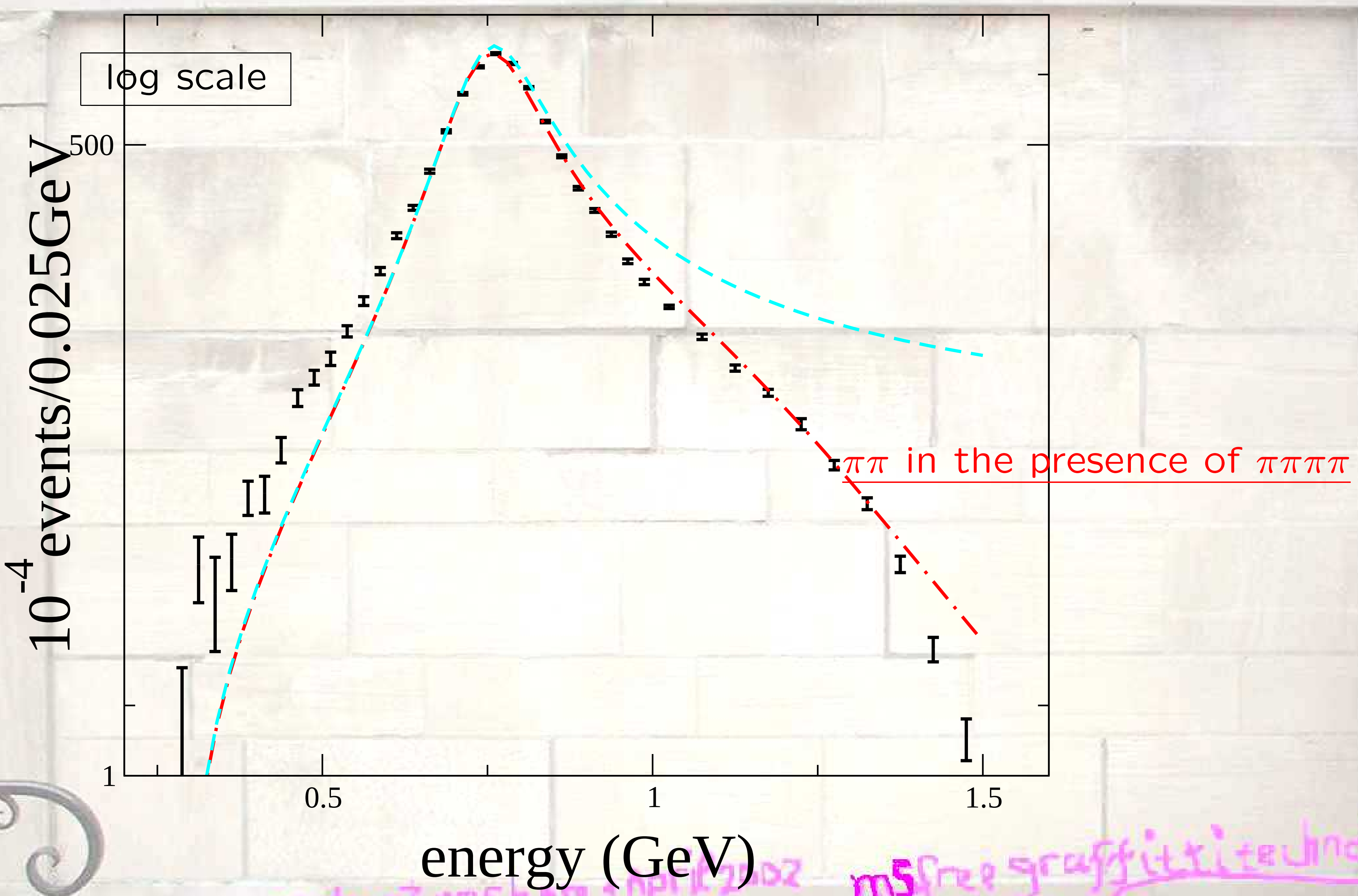
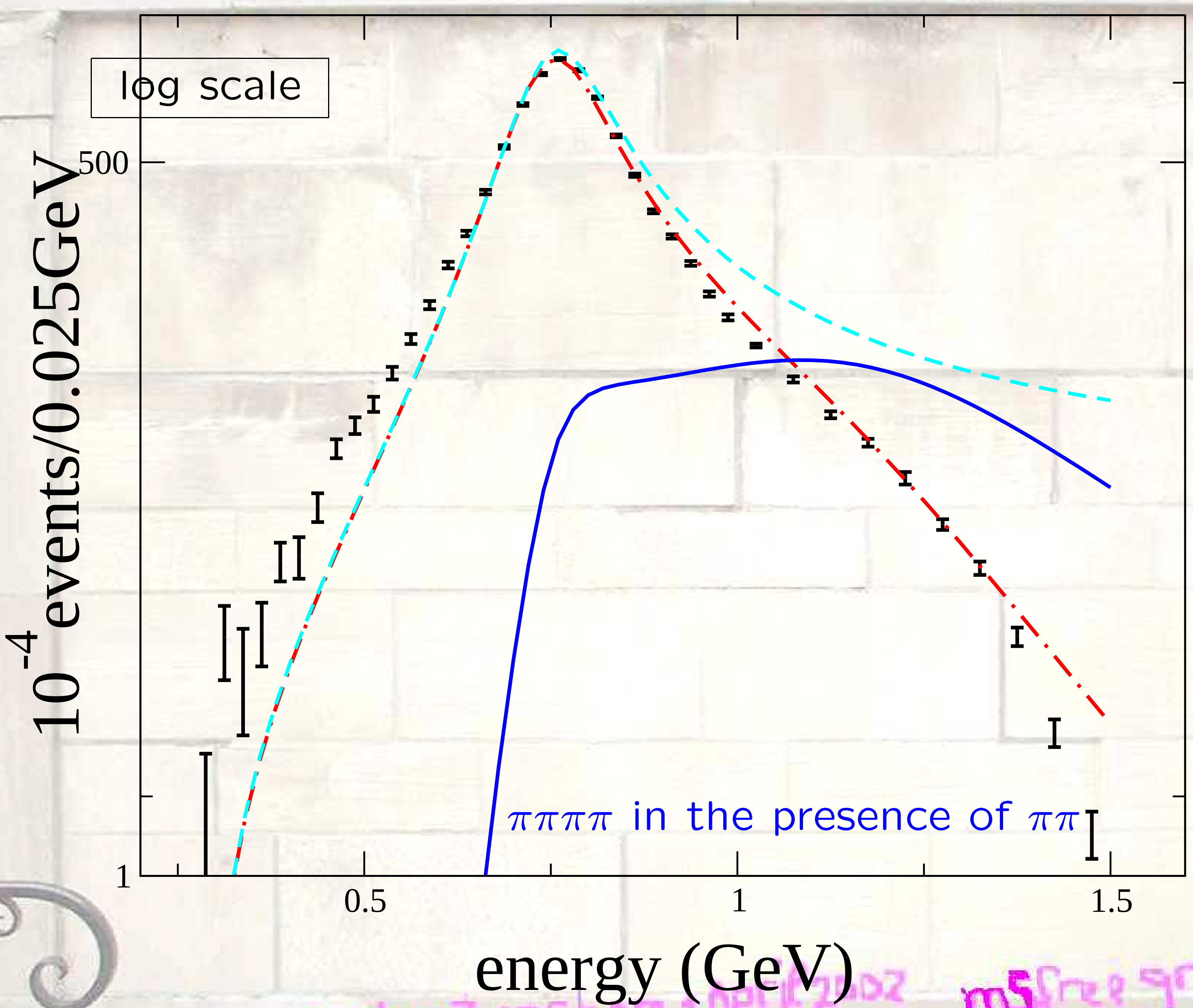
CLEO data + my fit



CLEO data + my fit



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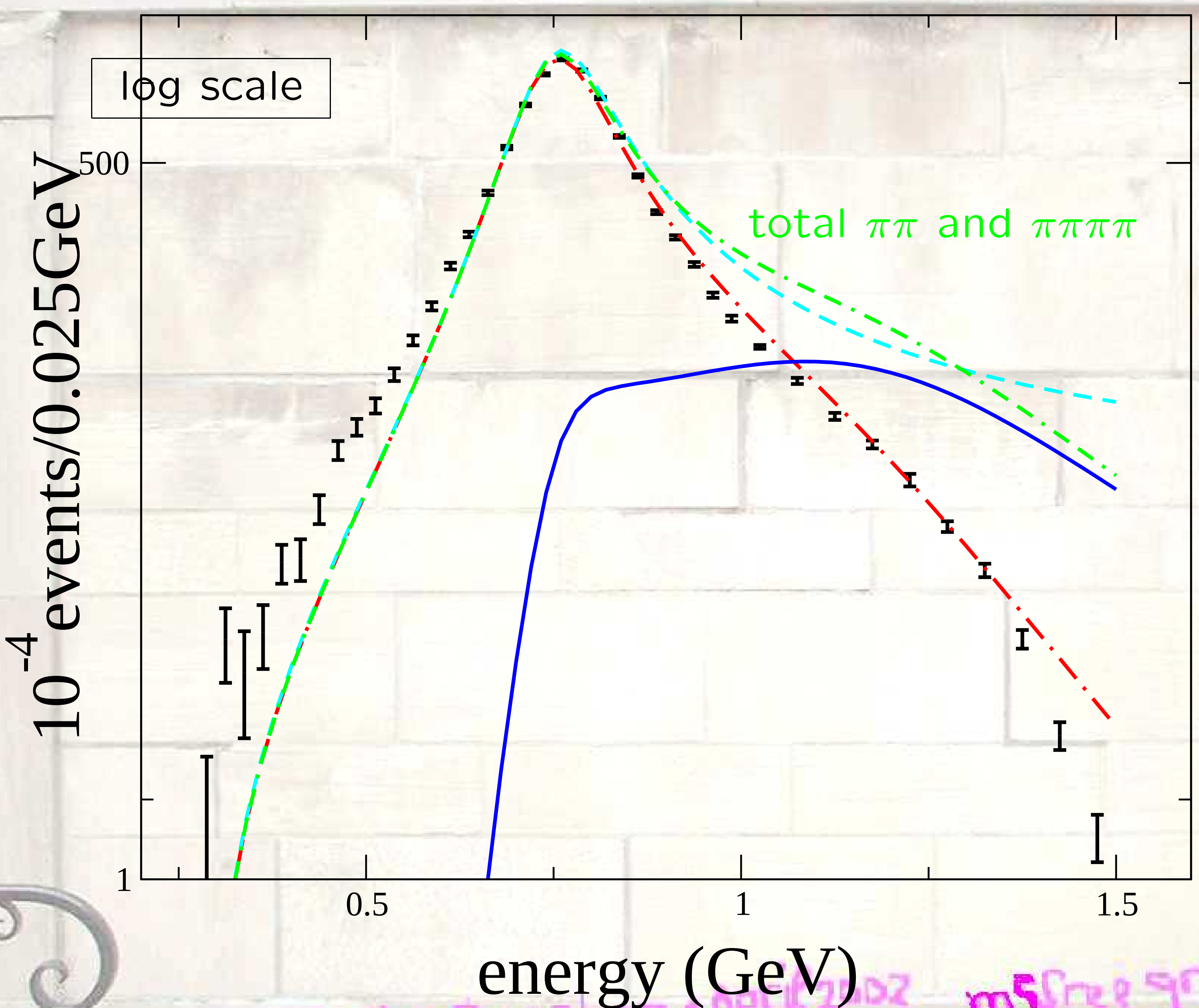

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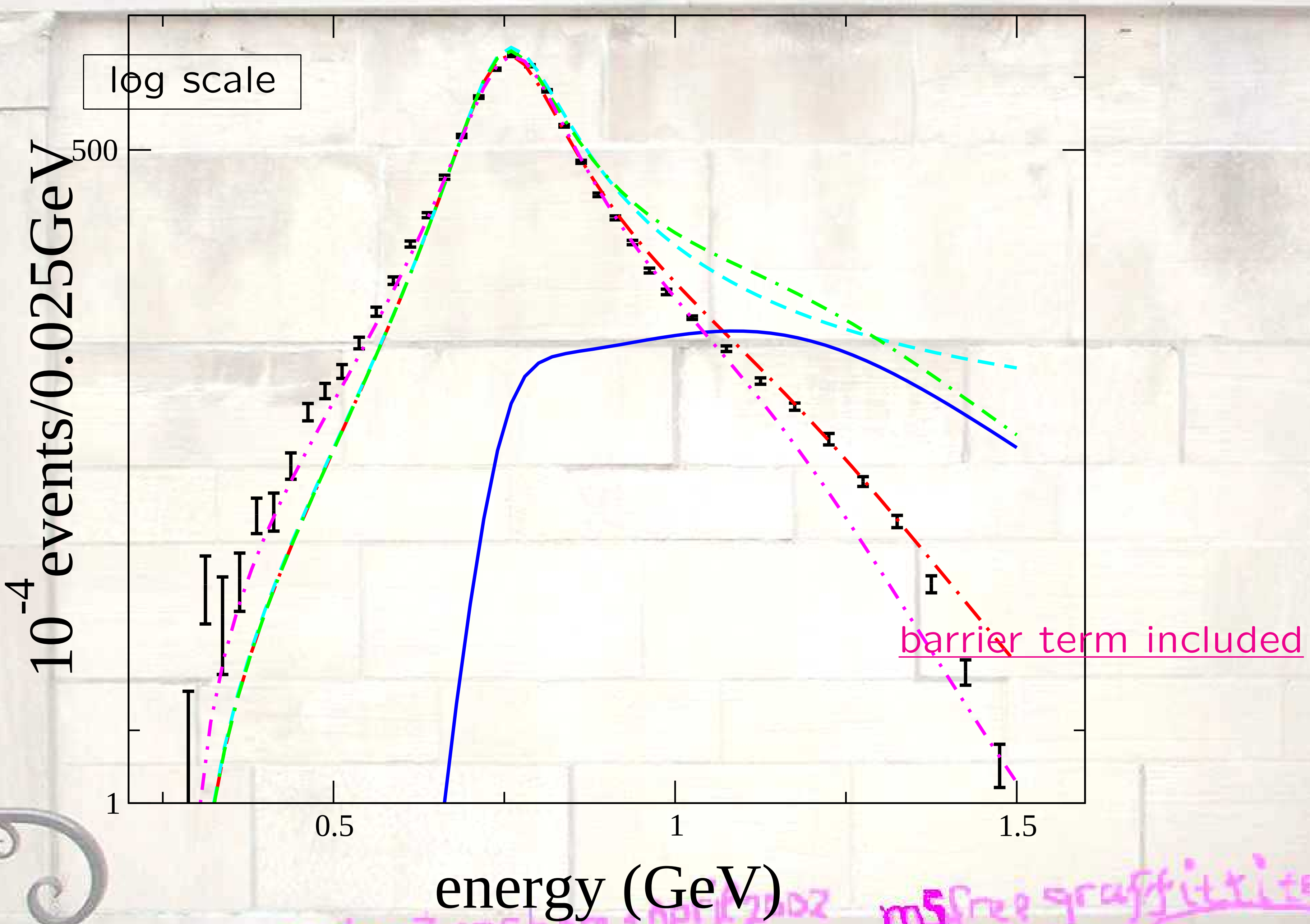

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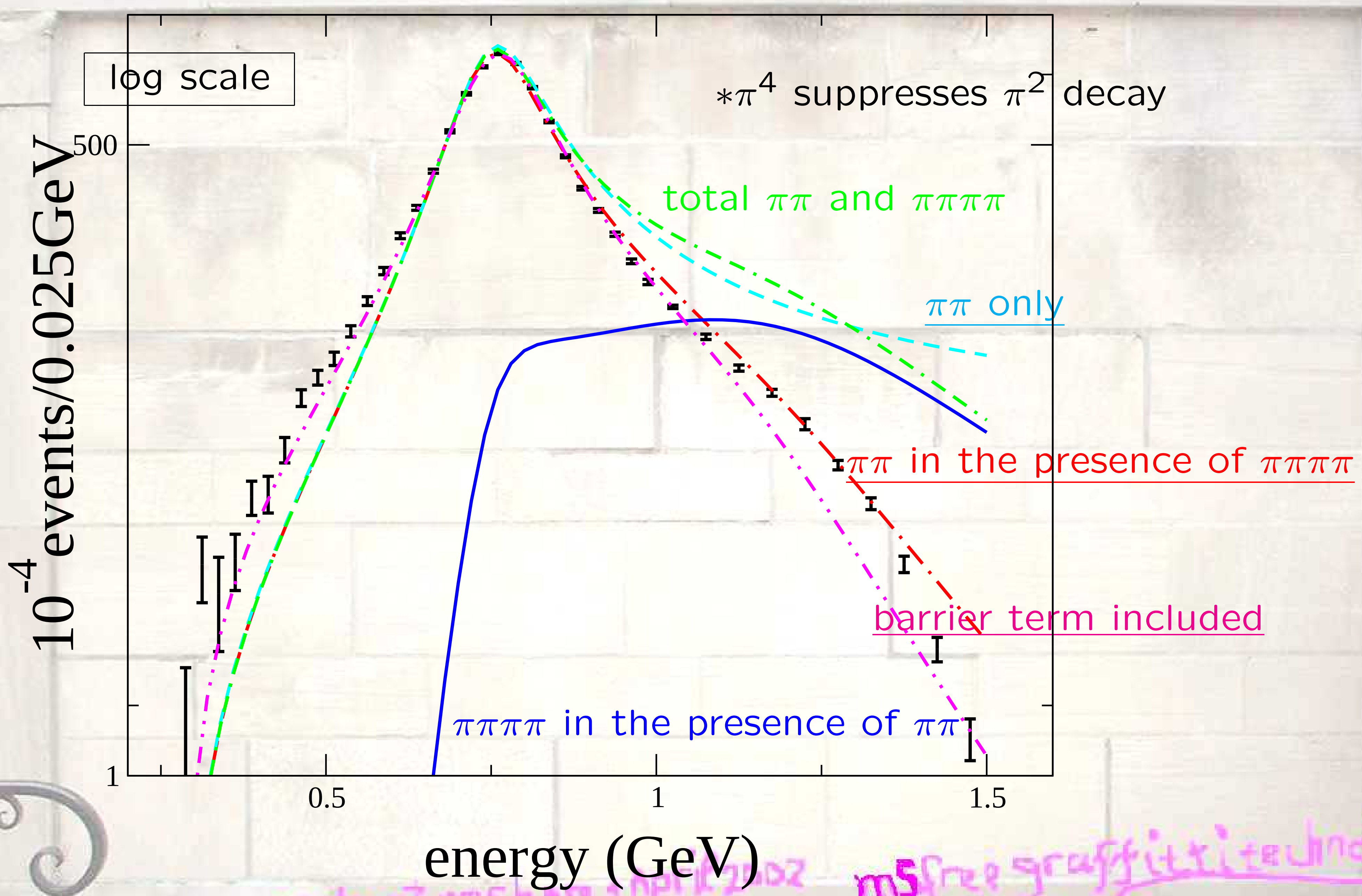
CLEO data + my fit

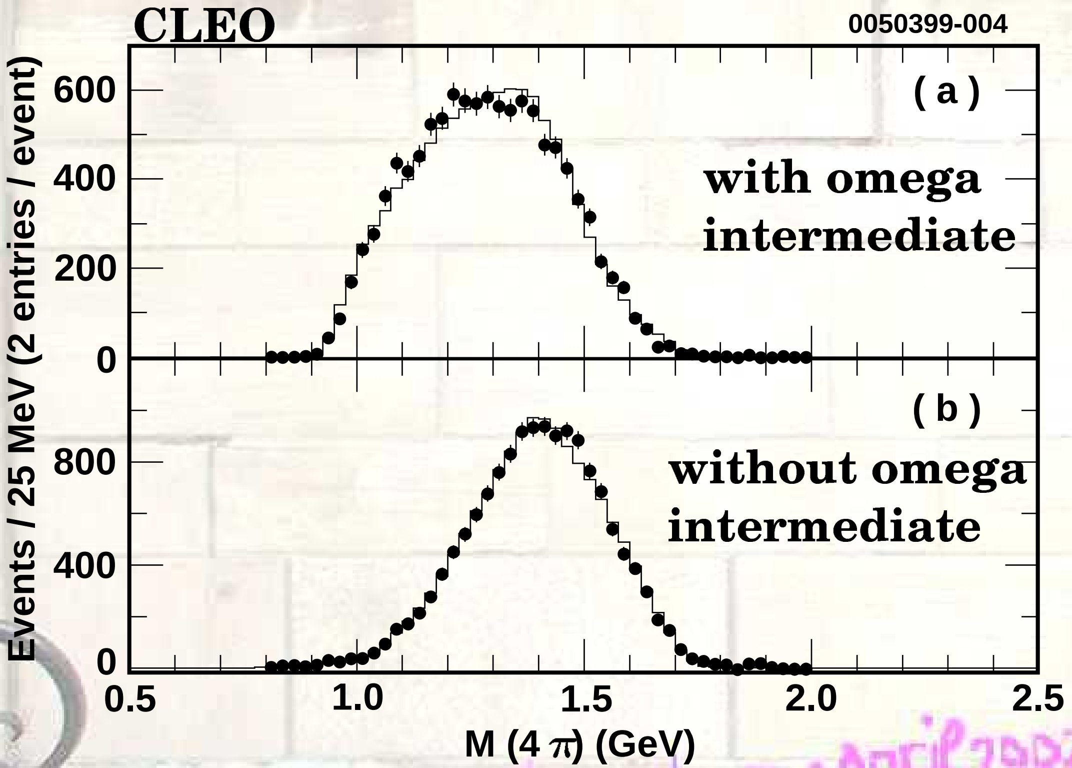
The underlined quantities compare with the data

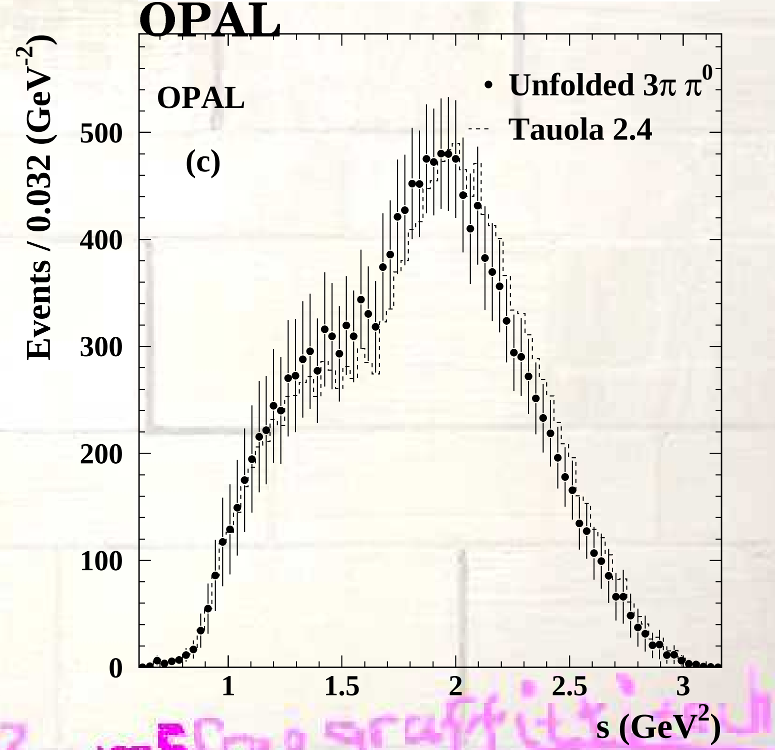


FOUR–PION DATA SUGGESTS A WEAKER THRESHOLD BEHAVIOR

OVERALL MAGNITUDE BELOW 1.2 GeV WITHIN 10% (from the inclusive data)

FROM 2–PION FIT





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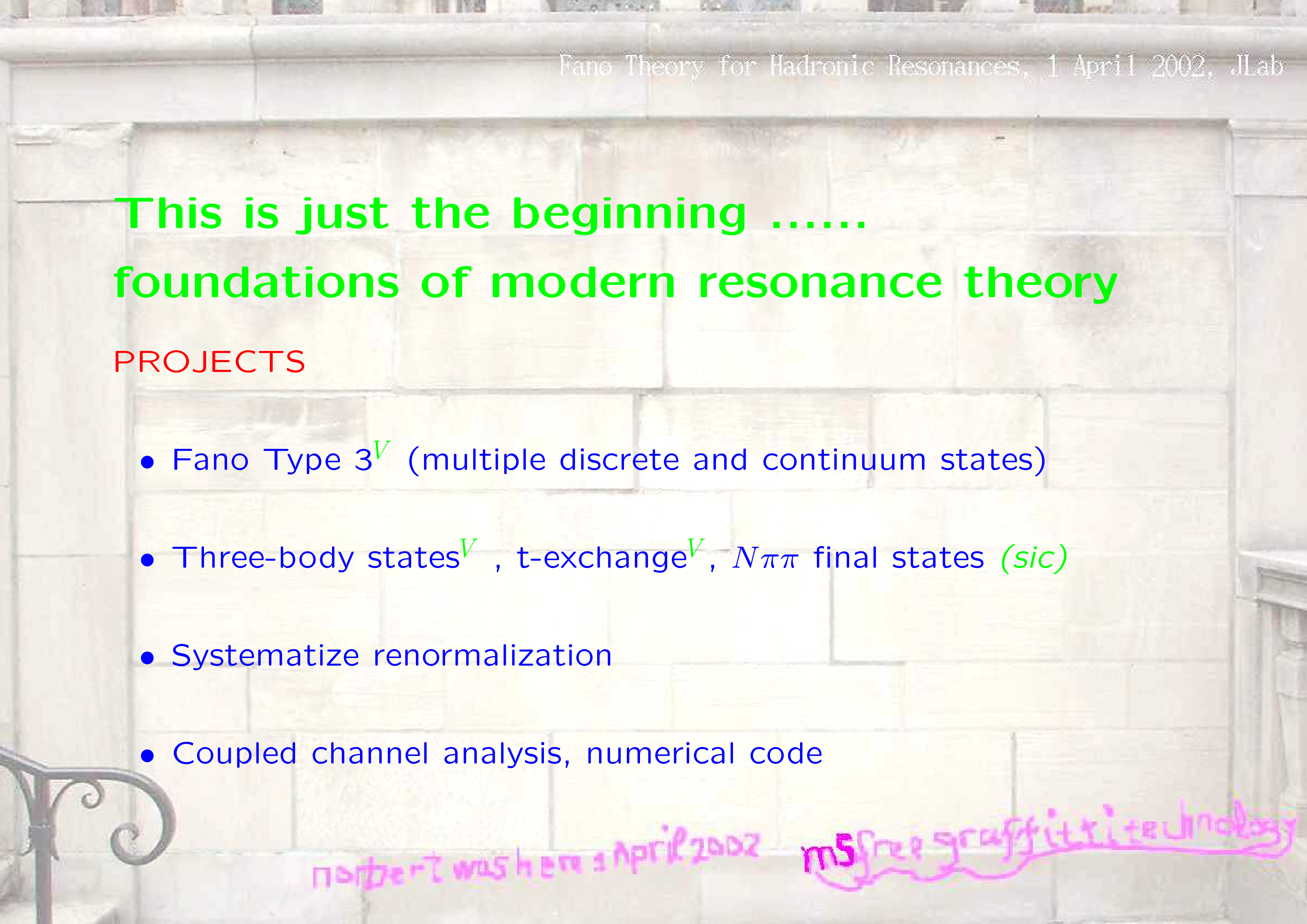
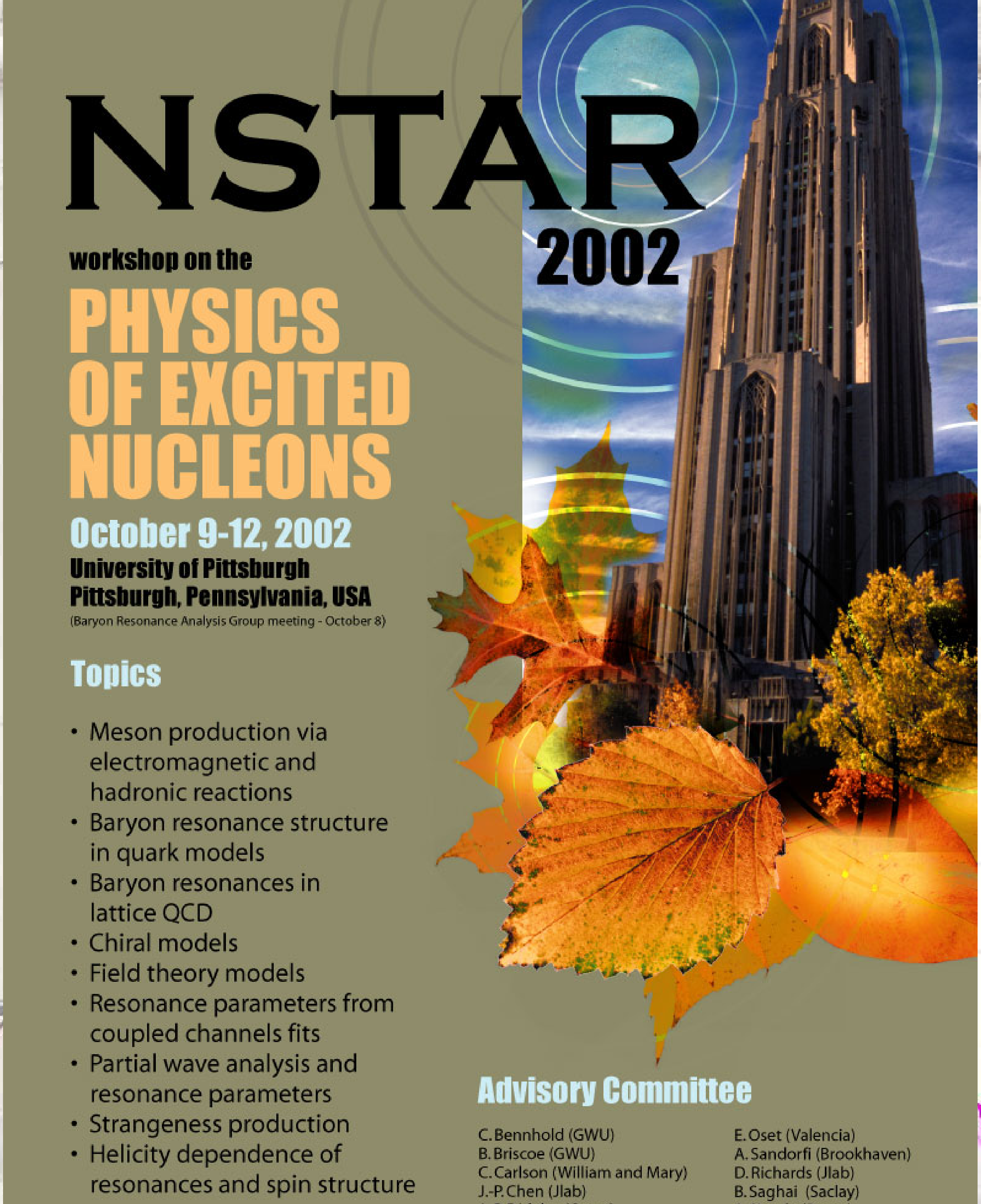
This is just the beginning ......

foundations of modern resonance theory

PROJECTS

- Fano Type 3^V (multiple discrete and continuum states)
- Three-body states^V , t-exchange^V, $N\pi\pi$ final states *(sic)*
- Systematize renormalization
- Coupled channel analysis, numerical code





NSTAR 2002

workshop on the

PHYSICS OF EXCITED NUCLEONS

October 9-12, 2002

University of Pittsburgh
Pittsburgh, Pennsylvania, USA
(Baryon Resonance Analysis Group meeting - October 8)

Topics

- Meson production via electromagnetic and hadronic reactions
- Baryon resonance structure in quark models
- Baryon resonances in lattice QCD
- Chiral models
- Field theory models
- Resonance parameters from coupled channels fits
- Partial wave analysis and resonance parameters
- Strangeness production
- Helicity dependence of resonances and spin structure

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