$\gamma\gamma \to \pi^0\pi^0$
& Light Scalars

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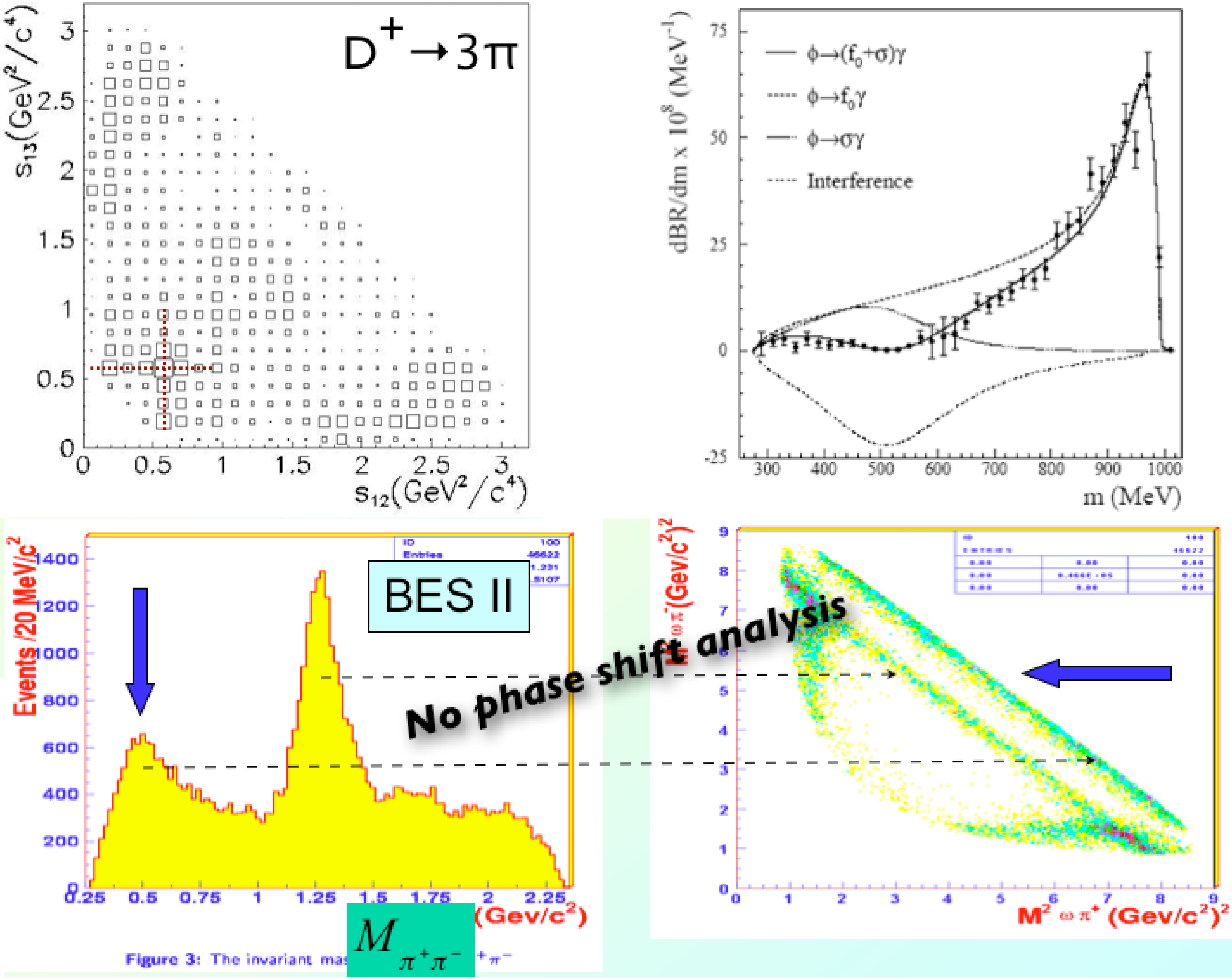
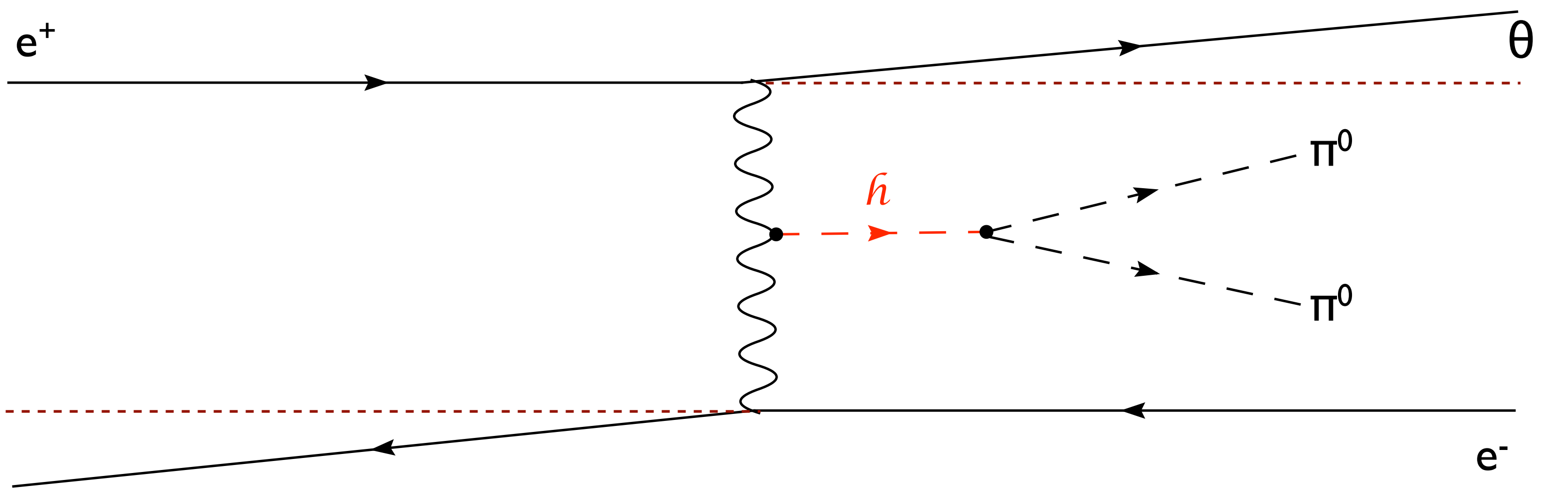


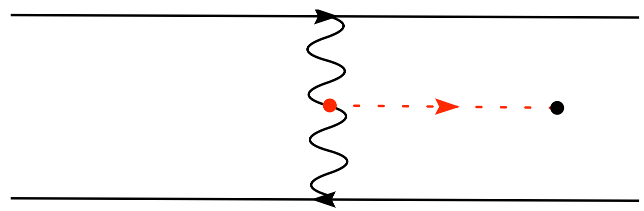
$D^+ \to 3\pi$
$s_{13}(GeV^2/c^4)$
$s_{12}(GeV^2/c^4)$
dBR/dm x 10^8 (MeV^{-1})
$\phi \to (f_0+\sigma)\gamma$
$\phi \to f_0\gamma$
$\phi \to \sigma\gamma$
Interference
m (MeV)
BES II
Events /20 MeV/c^2
(Gev/c^2)
$M_{\pi^+\pi^-}$
Figure 3: The invariant mas
No phase shift analysis
$M^2_{\omega\pi^+}$ (Gev/c^2)^2

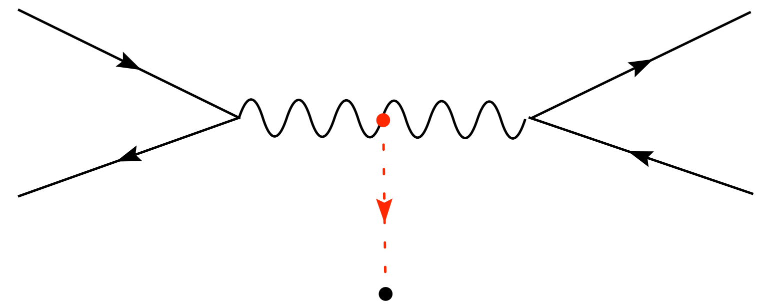
An e.m. probe for light scalars: Daphne run @ 1000 MeV



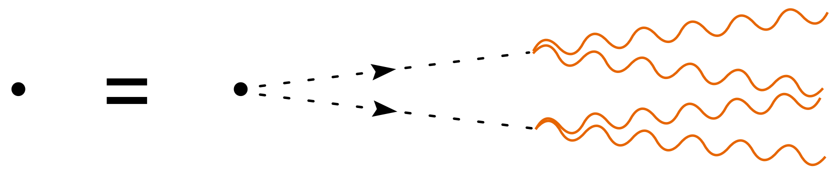
reduce the K backgrounds

The complete tree level process



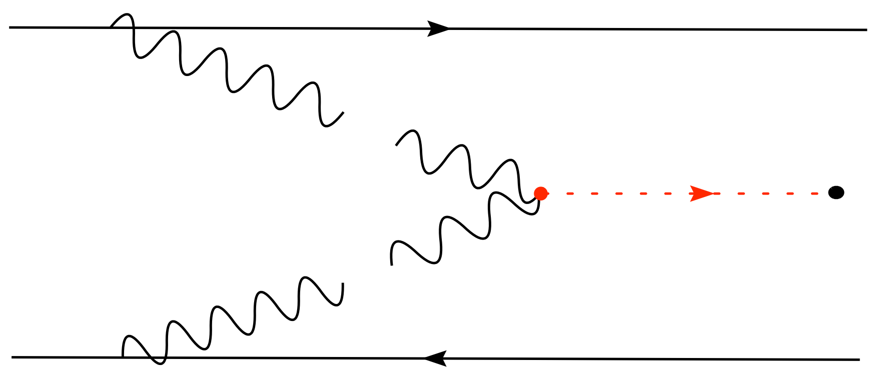


This accumulates a lot of xsect in the forward region



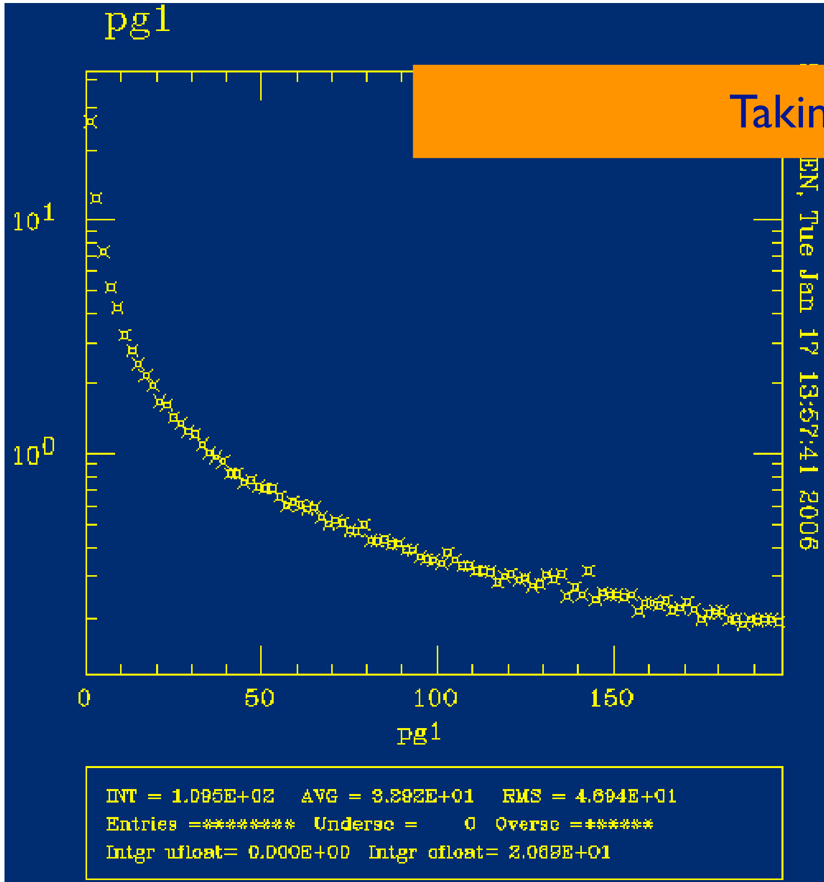
4-body phase space

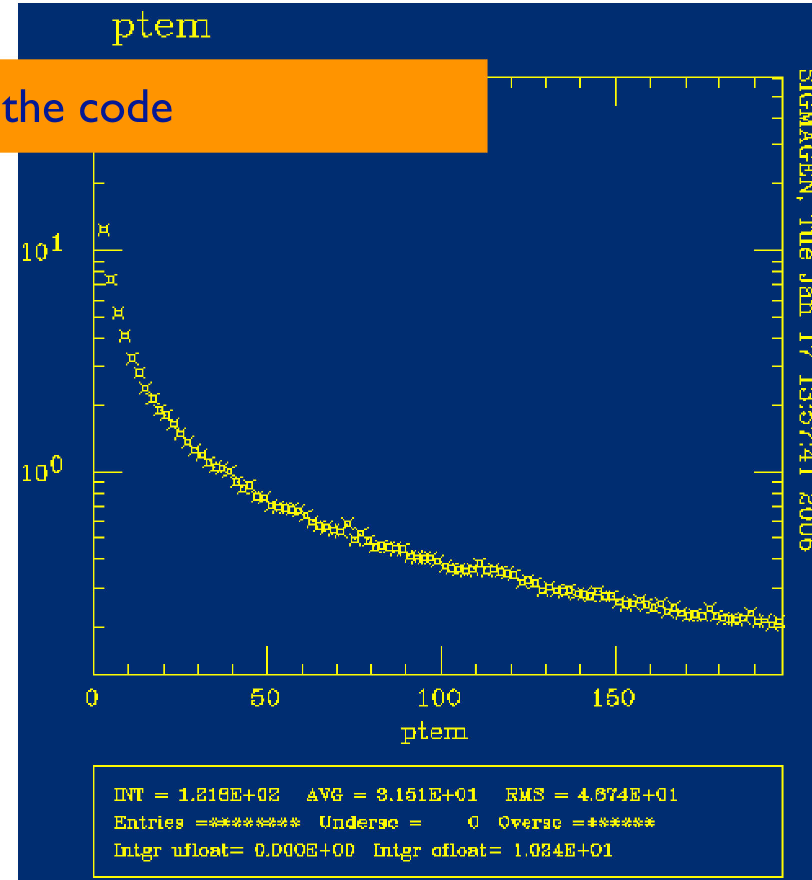
The W.W. approximation (see papers by G. Pancheri et al.)



Taking control of the code

Reasons to go beyond W.W.





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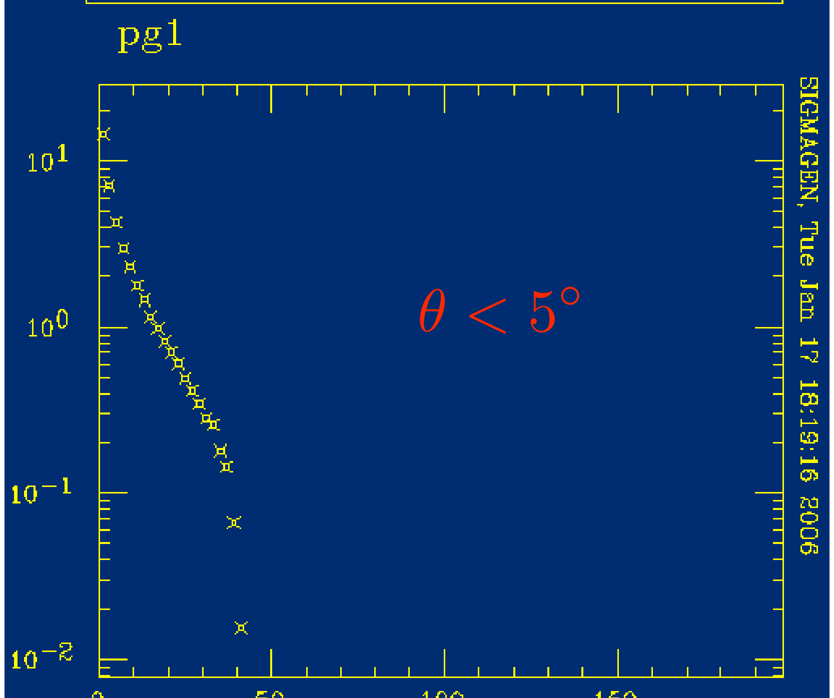

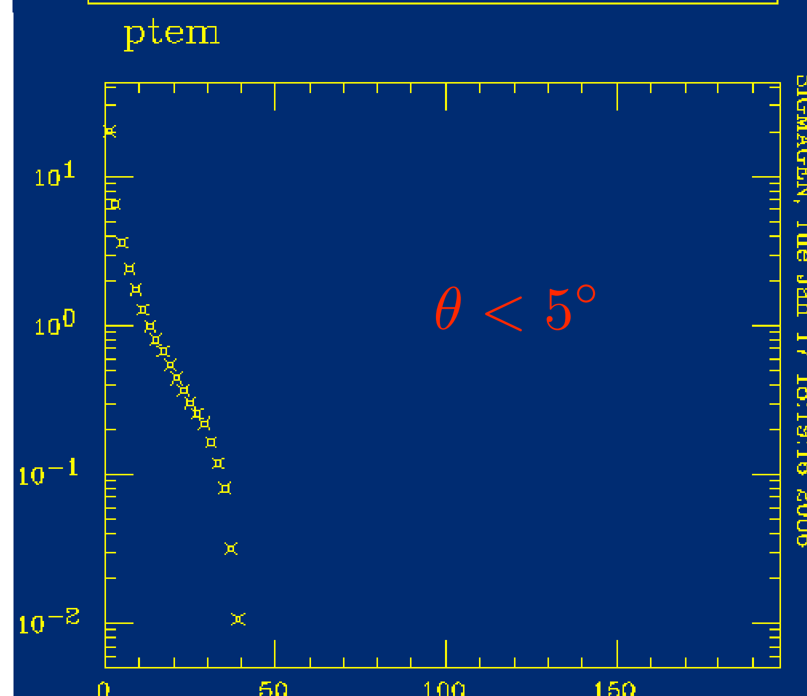

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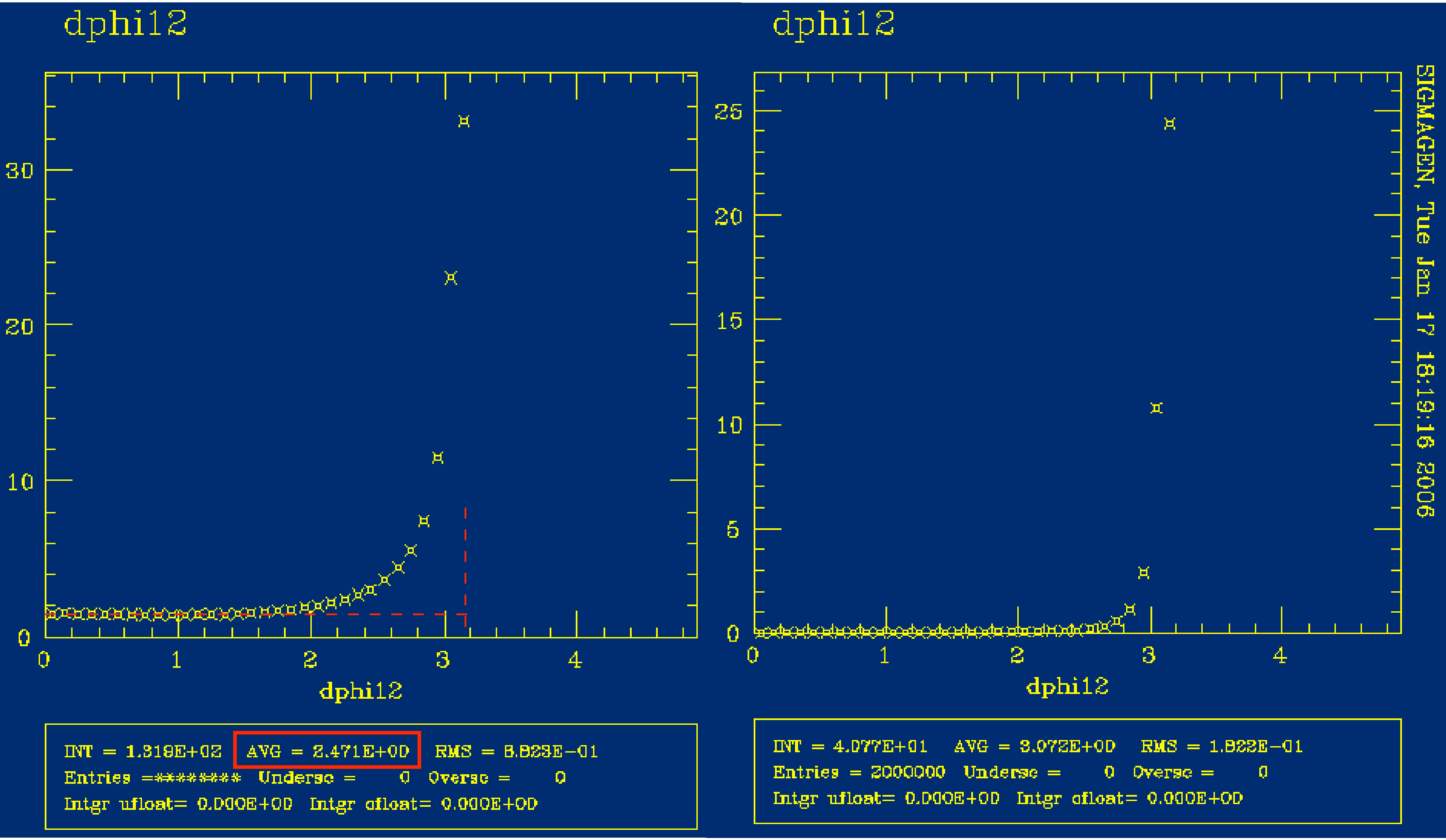
The angle between the two pions. A measure of the transverse $p_\perp$ boost of *h*.



Gell-Mann-Levy linear sigma model

$$\Sigma = \sigma \mathbf{1} + i\tau^a \pi^a$$

CCWZ non-linear realization of $SU(3)_L \otimes SU(3)_R$

$$\Sigma = \exp(2i\mathbf{\Pi}/f_\pi)$$

...no room for a **σ** field.
Is it an *effect* which can be described in chiral dynamics?

Mass and width of the lowest resonance in QCD

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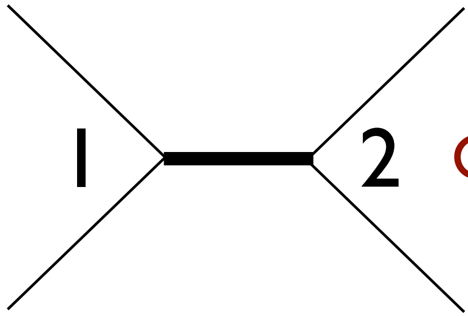
We demonstrate that near the threshold, the $\pi\pi$ scattering amplitude contains a pole with the quantum numbers of the vacuum – commonly referred to as the σ – and determine its mass and width within small uncertainties. Our derivation does not involve models or parametrizations, but relies on a straightforward calculation based on the Roy equation for the isoscalar S-wave.

...But it can be something else



Color interaction $\propto \sum_a T^a_{(1)} T^a_{(2)}$

$$T^a_{(1)} T^a_{(2)} = \frac{1}{2}\left(T^{a2} - T^a_{(1)}{}^2 - T^a_{(2)}{}^2\right)$$

The Casimir gives the 'size' of the color representation.
The color force is most attractive in the least colorful states.

$$\langle T^a_{(1)} T^a_{(2)} \rangle = \begin{cases} -2/3 \text{ in } \bar{\mathbf{3}} & -4/3 \text{ in } \mathbf{1} \\ 1/3 \text{ in } \mathbf{6} & 1/6 \text{ in } \mathbf{8} \end{cases}$$

qq	$q\bar{q}$

$$\langle\ \rangle = \frac{1}{\dim D_R}\mathrm{Sp}(\ )$$

$$\langle \sigma_{(1)} T^a_{(1)} \cdot \sigma_{(2)} T^a_{(2)} \rangle \propto \left(J(J+1) - \frac{3}{2}\right) \quad \begin{array}{l} \frac{1}{2}\otimes\frac{1}{2} \to 0 \\ \frac{1}{2}\otimes\frac{1}{2} \to 1 \end{array}$$

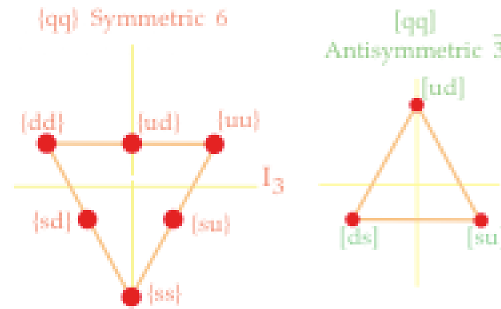
Baryons in the octet:

$\Lambda = ([ud]_{J=0}\, s)$; $\Sigma^0 = (\{ud\}_{J=1} s) \rightarrow \Lambda$ is lighter than Σ

With antisymmetry in color and spin and a common spatial configuration, Fermi statistics ⇒ $\bar{\mathbf{3}}_{\mathbf{f}}$

Good diquarks: $[qq]_{\bar{\mathbf{3}}_c,\mathbf{1}_s,\bar{\mathbf{3}}_f}$

Bad diquarks: $(qq)_{\bar{\mathbf{3}}_c,\mathbf{3}_s,\mathbf{6}_f}$

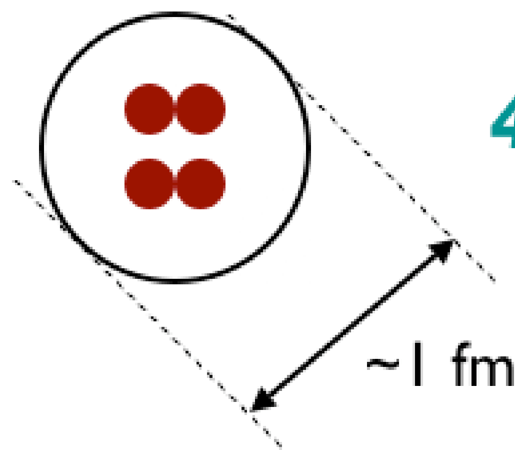


Cryptoexotics: [qq][q̄q̄] can explain for example the *non exotic structure of the light scalar meson nonet*.

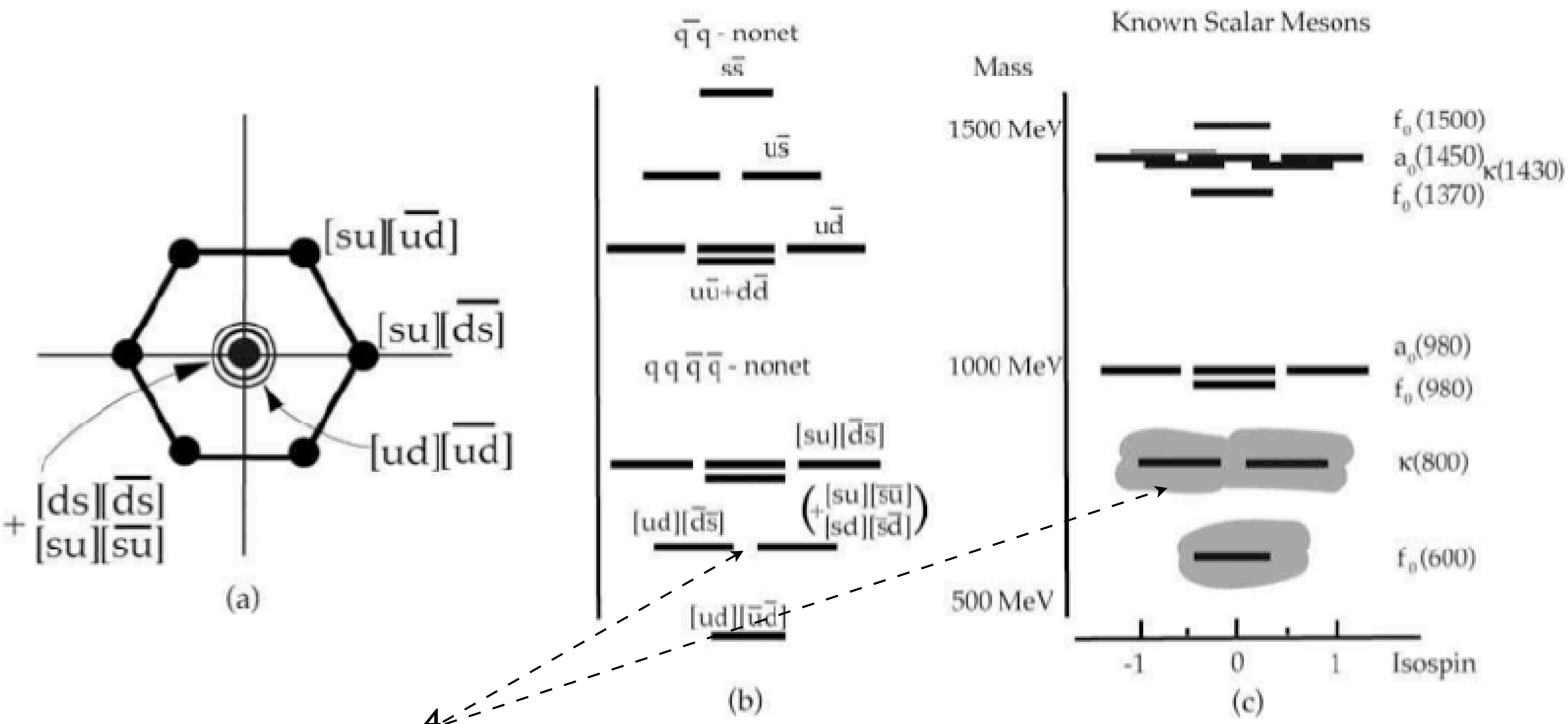
Indeed for flavor one has:

$$\mathbf{3} \otimes \bar{\mathbf{3}} = \mathbf{1} \oplus \mathbf{8}$$

with the same charges as for qqb



Light scalar mesons



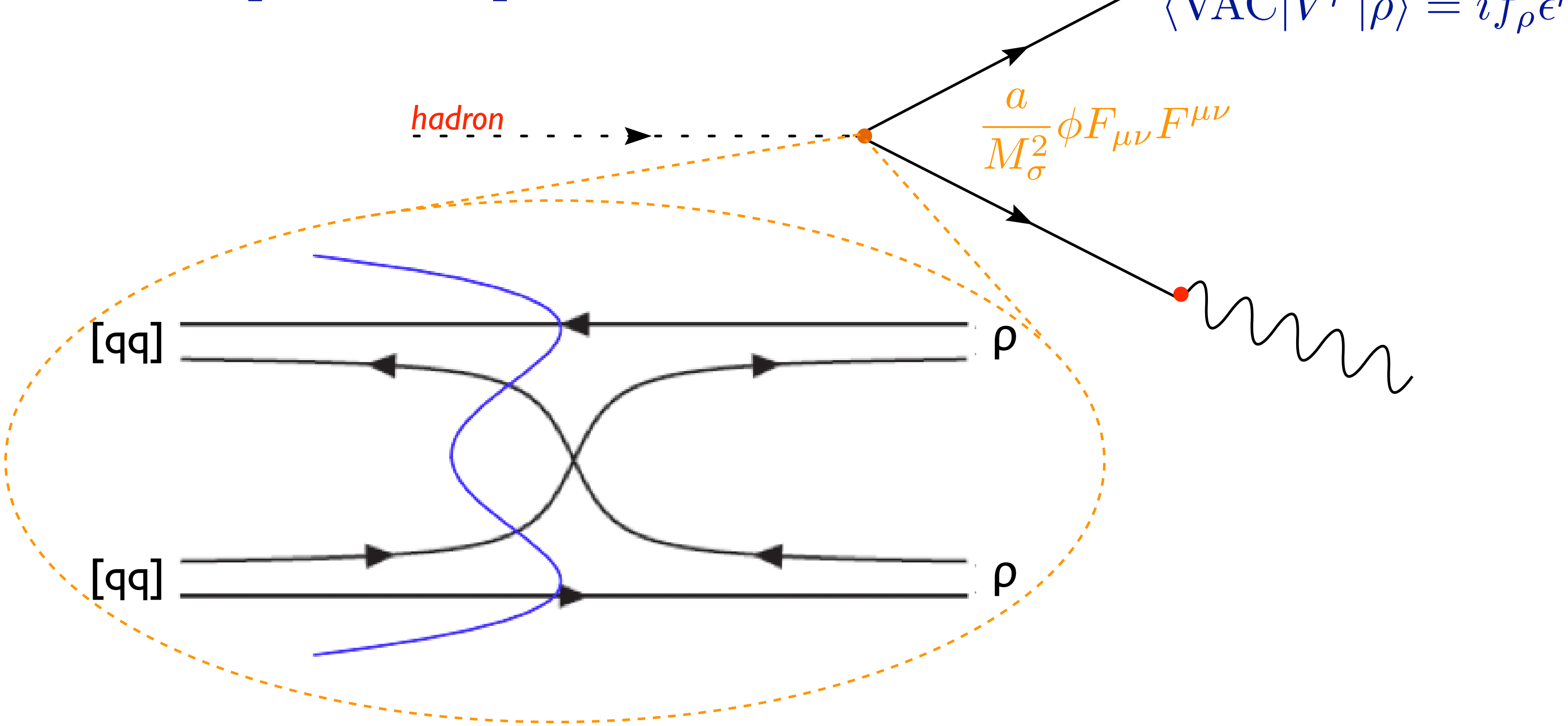
$$I_3 = \frac{1}{2}(n_u - n_d)$$

$$Y = \frac{1}{3}(n_u + n_d - 2n_s)$$

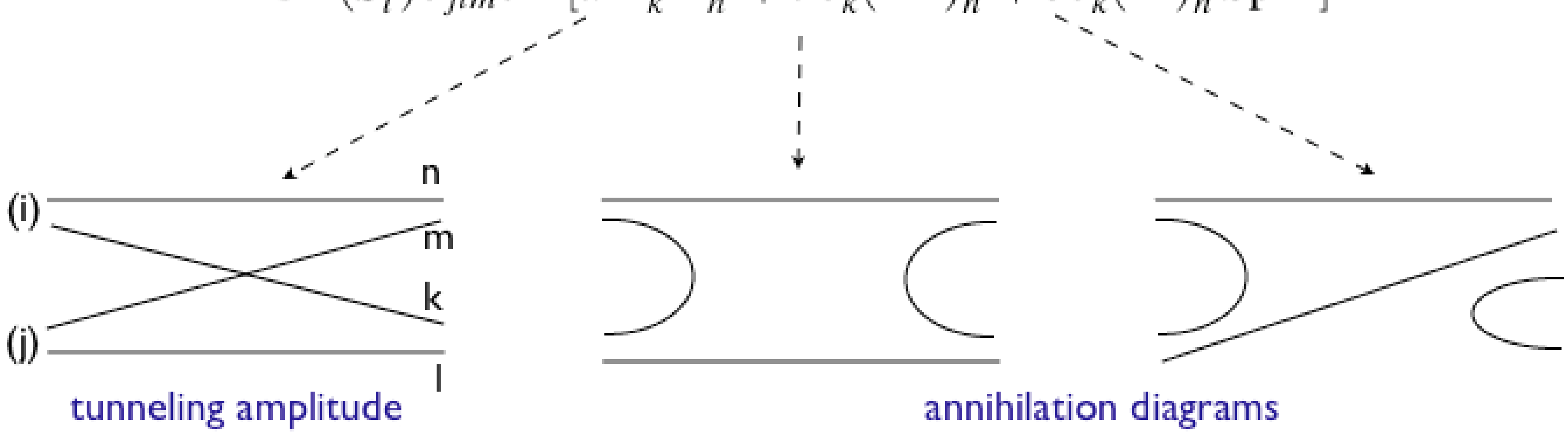
see e.g. R. L. Jaffe hep-ph/0409065

L. Maiani, F. Piccinini, A.D. Polosa and V. Riquer, Phys. Rev. Lett. **93**, 212002 (2004)

How the process is pictured



$$\mathcal{L} = (S_i^j)\varepsilon_{jlm}\varepsilon^{ikn}[aM_k^l M_n^m + b\delta_k^l (M^2)_n^m + c\delta_k^l (M)_n^m \mathrm{Sp}M]$$



$$p_+ + p_- = p_{\pi_0} + p_{\pi_0} + p'_+ + p'_-$$

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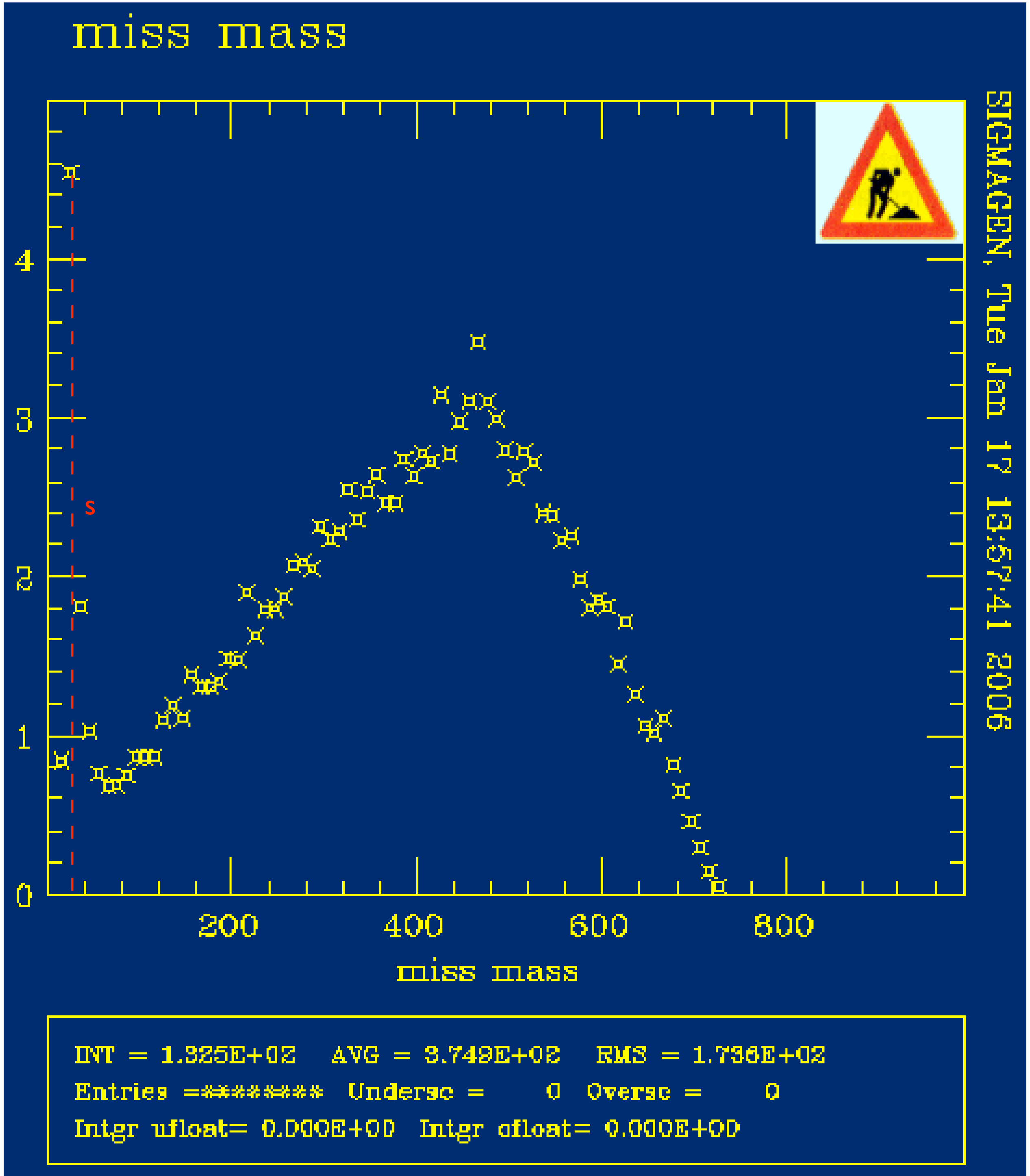
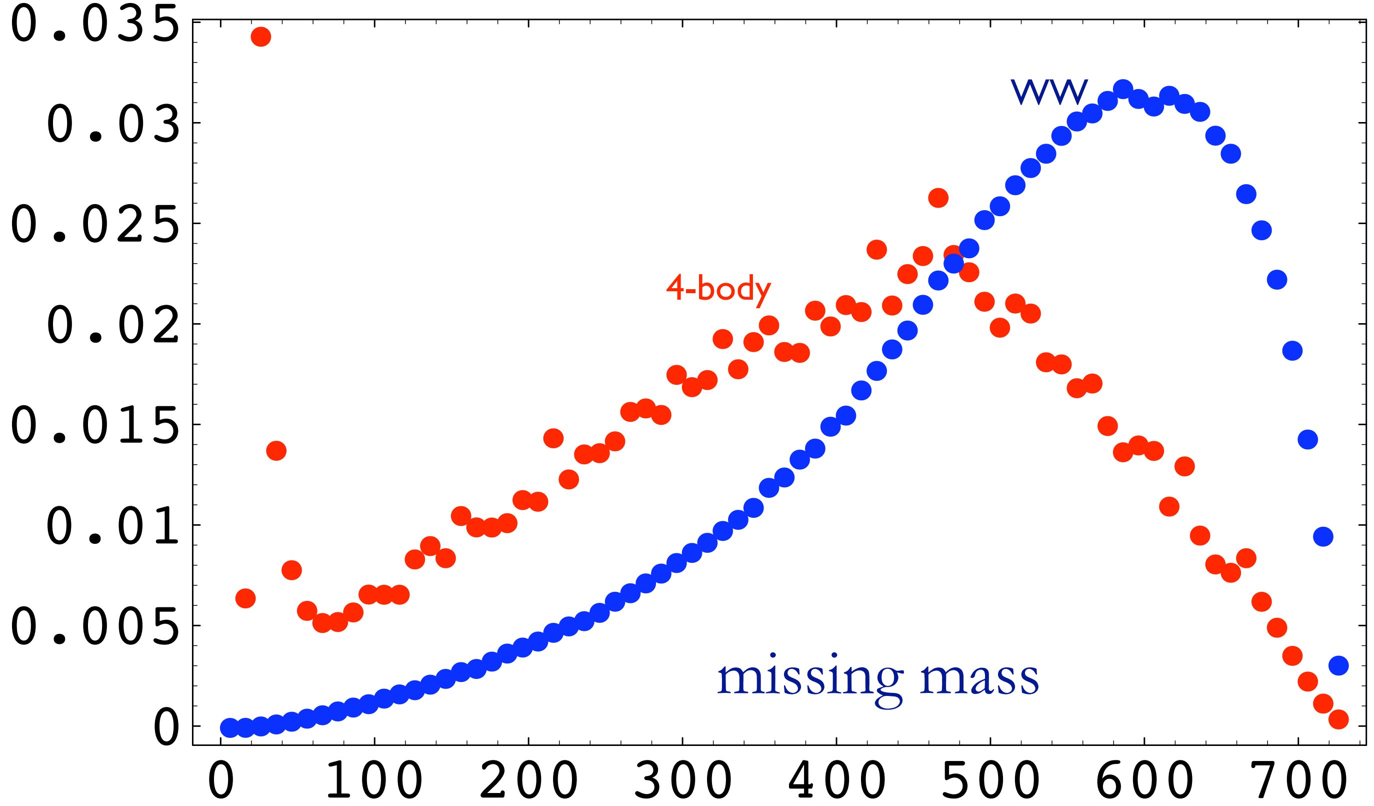
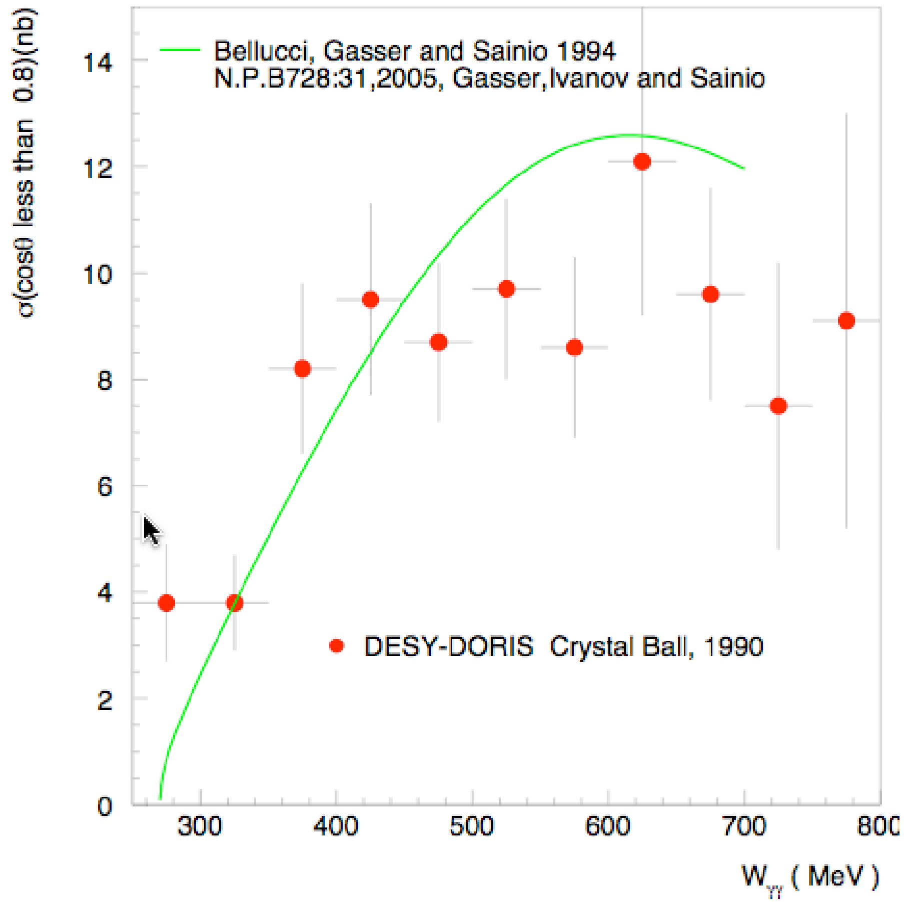


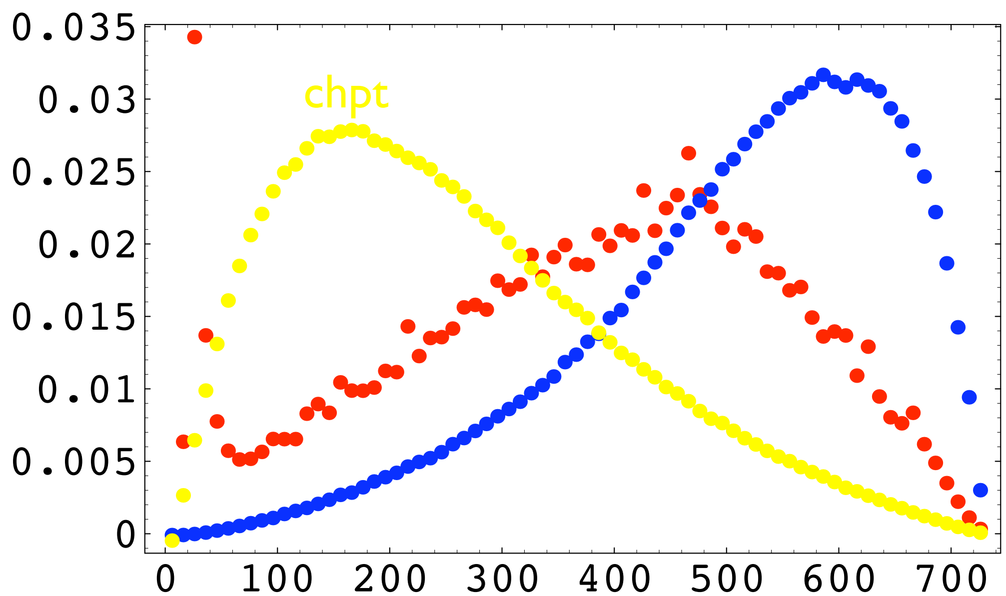
A comparison of the two



...to be smeared...

2-loop chpt -- $\gamma\gamma \to \pi^0\pi^0$





Backgrounds

$$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$$

Miss.mass. *peaks* on *0*. Smearing...

$$e^+e^- \to \eta e^+e^- \to \pi^0\pi^0\pi^0 e^+e^-$$

CM2 $$\sigma(\phi \to \eta\gamma) = 21.5 \text{ nb @ } \sqrt{s} = M_\phi$$

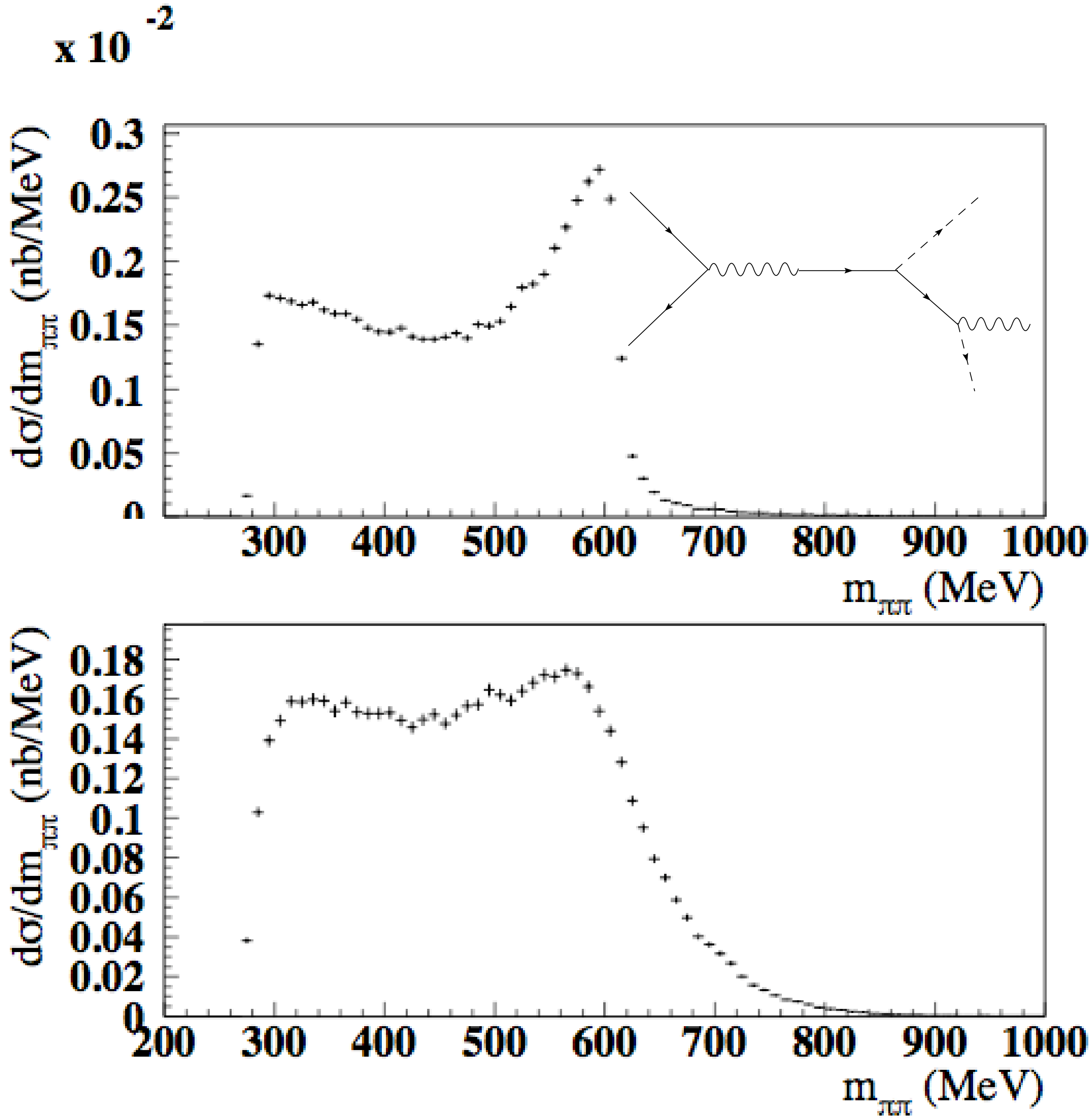
$$\sigma(\phi \to \eta\gamma) \sim 0.67 \text{ nb @ } \sqrt{s} = 1 \text{ GeV}$$

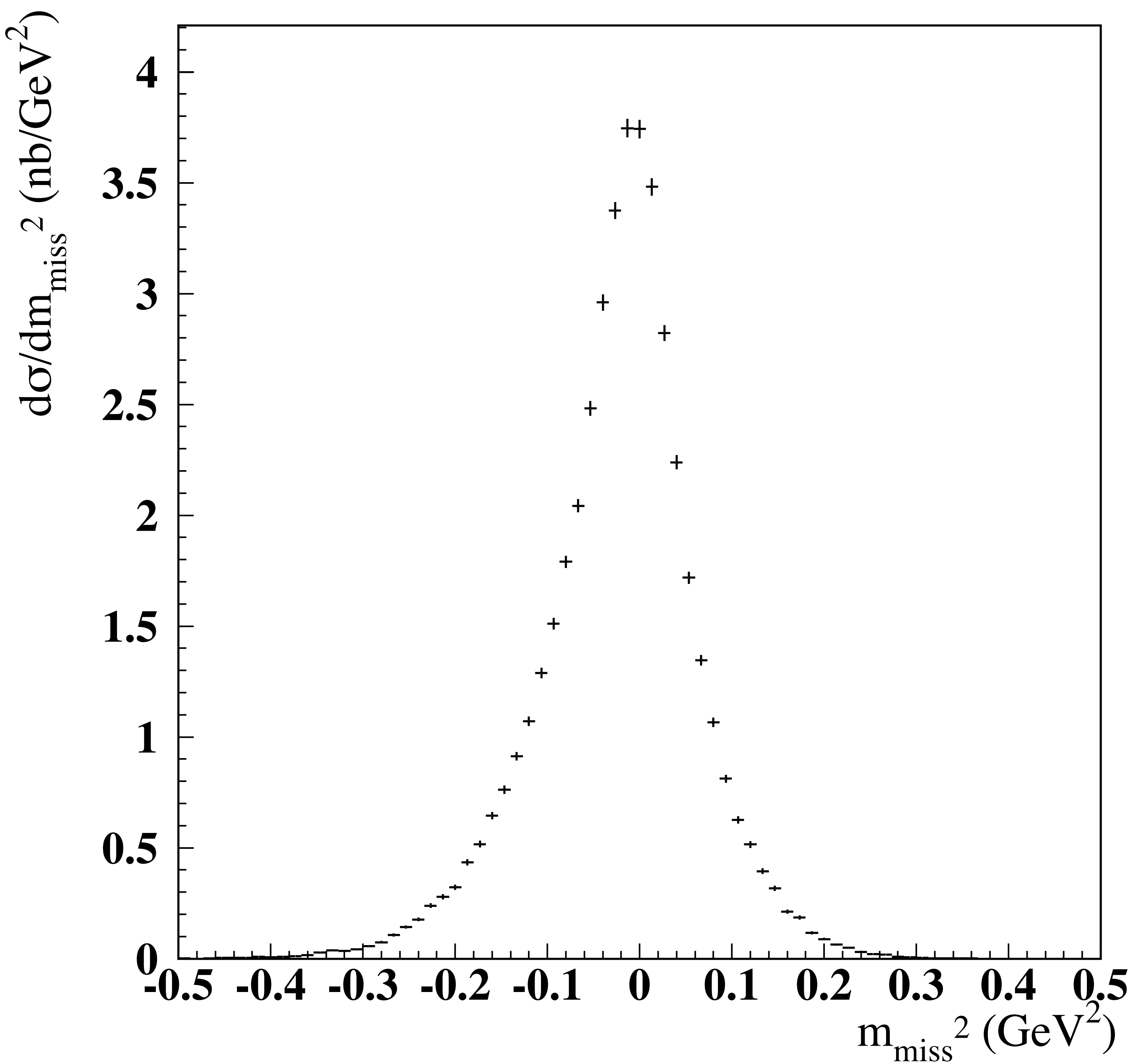
$$\sigma(\phi \to K_S K_L) \sim 1350 \text{ nb @ } \sqrt{s} = M_\phi$$

$$\sigma(\phi \to K_S K_L) \leq 12 \text{ nb @ } \sqrt{s} = 1 \text{ GeV}$$

KLOE $$\sigma(\phi \to \pi^0\pi^0\gamma) \sim 0.3 \text{ nb @ } \sqrt{s} = M_\phi$$

The only irreducible background in absence of tagging.




dσ/dm_miss^2 (nb/GeV^2)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
m_miss^2 (GeV^2)