

PHYSICS ISSUES AT DAΦNE 2

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Frascati 6 Novembre 2003

PHYSICS ISSUES AT DAΦNE 2

- NUCLEON FORM FACTORS (HE)
- KAON PHYSICS (HL)
- HYPERNUCLEAR SPECTROSCOPY (HL)
- HADRONIC CROSS SECTION (HL,HE)

HL = *HIGH LUMINOSITY*

HE = *HIGH ENERGY*

BARYONS FORM FACTORS

NUCLEON FORM FACTORS IN THE TIME LIKE REGION

Differential x-section:

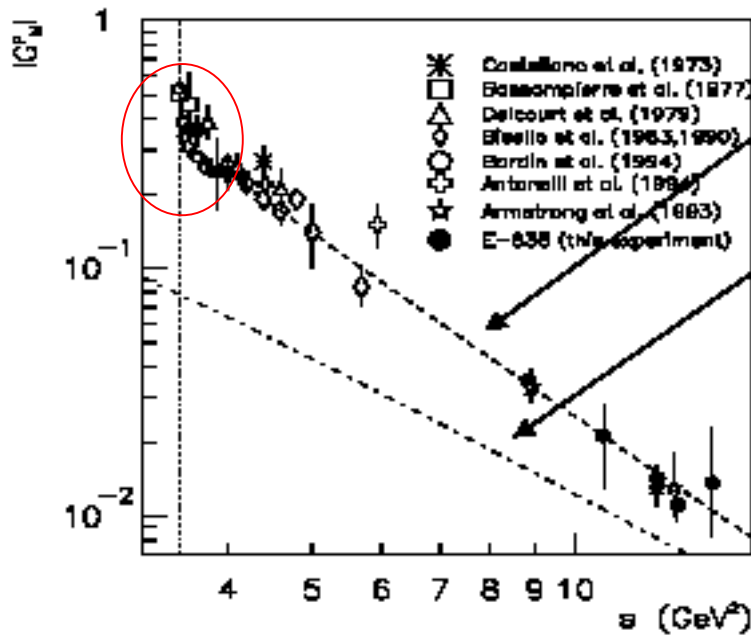
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4Q^2} \left[|G_M(Q^2)|^2 (1 + \cos^2 \theta^*) + \frac{4m_p^2}{Q^2} |G_E(Q^2)|^2 \sin^2 \theta^* \right]$$

G_E , G_M complex numbers, *need polarization of final state* to measure the relative phase

At large Q^2 , $G(Q^2) = G(-Q^2)$

If only valence quarks $G_M(n) = G_M(p) / 2$

PROTON FORM FACTOR

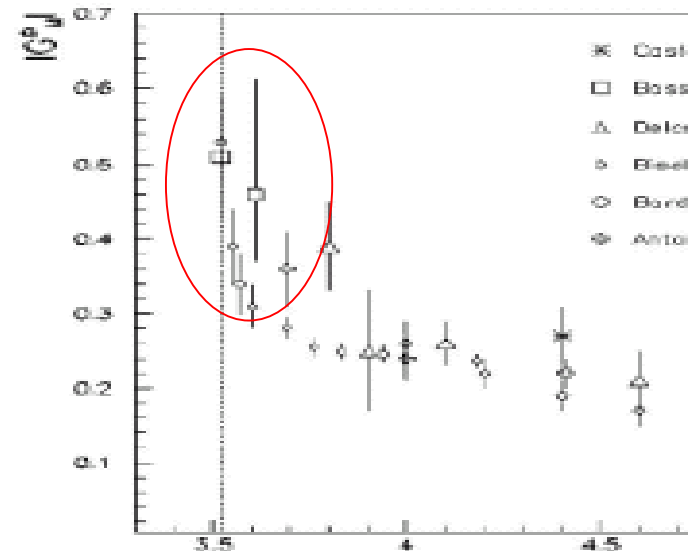


pQCD fit

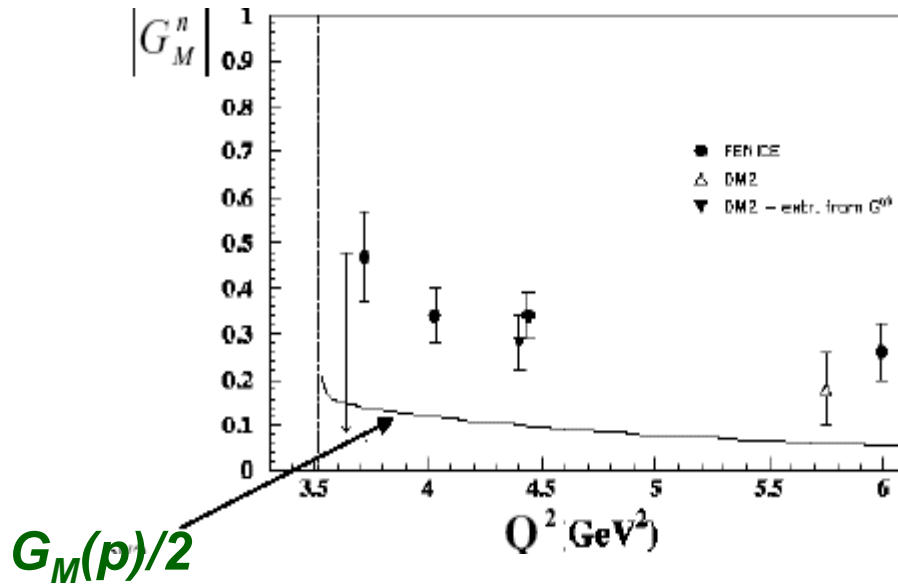
$$G(Q^2) = G(-Q^2)$$

factor 2 from naive prediction!

rapid fall just above threshold



NEUTRON FORM FACTOR



Data from FENICE only,

74 events, $\int L dt = 0.4 \text{ pb}^{-1}$

$G_M(n) > G_M(p) !$

Λ FORM FACTOR

*Only one existing measurement (DM2)
based on 4 events @ 2.4 GeV*

EVENT YIELDS

$$\sigma(e^+e^- \rightarrow NN) \sim 0.1 \div 1 \text{ nb}$$

400 ÷ 4000 events/day @ present luminosity

$$\sigma(e^+e^- \rightarrow \Lambda\Lambda) \sim 0.1 \text{ nb}$$

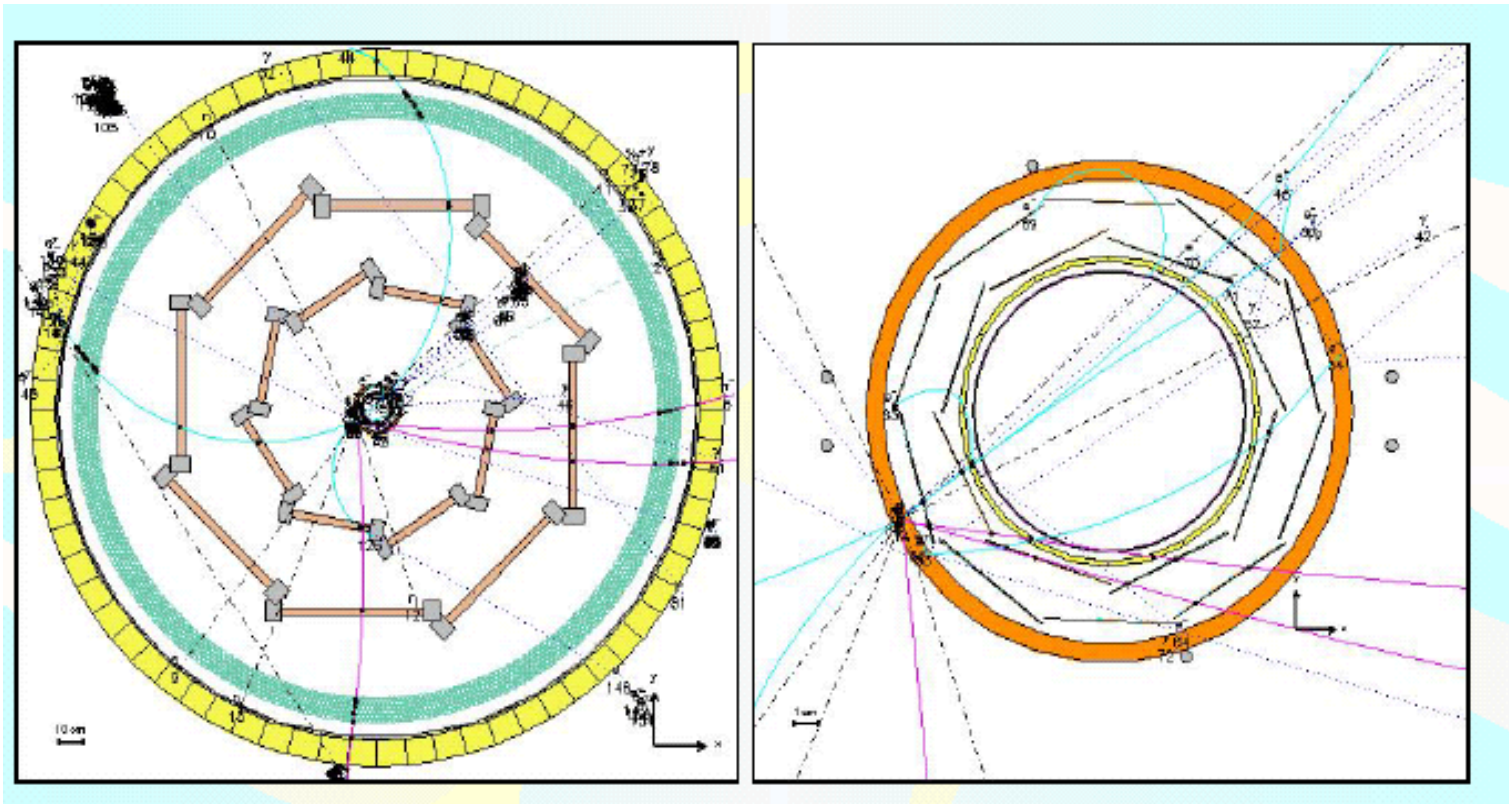
400 events/day @ present luminosity

FINUDA estimates efficiencies ranging between **(5 ÷ 40)%** for nucleons (no idea for Λ 's) (A. Filippi)

Major limitation of **FINUDA** present setup is limited angular acceptance (**KLOE** has full solid angle coverage)

FINUDA might measure **p polarization!** (A. Filippi)

FINUDA TYPICAL EVENT



$$e^+e^- \rightarrow n\bar{n}$$

$$\sqrt{s} = 1890 \text{ MeV}$$

A. Filippi

MY CONCLUSIONS ON BARYON F.F.

NUCLEON F.F. CAN BE MEASURED WITH UNPRECEDENTED PRECISION AT D2 AS LONG AS $L > \text{few } 10^{31}$

DISCRIMINATION BETWEEN NN AND $\gamma\gamma$ EVENTS (B/S ~ 4) BASED ON TIMING MIGHT RESULT VERY DIFFICULT DUE TO HIGH BUNCH X-ING RATE IN DAΦNE

**LAMBDA F.F. MEASUREMENT SHOULD BE PURSUED
→ $S > 2.4 \text{ GeV}$**

KAON PHYSICS

Rare K decays & Flavor Physics

The SM can be considered as the *renormalizable part* of an effective field theory, valid up to a (still undetermined) cut-off scale Λ :

$$\mathcal{L} = \mathcal{L}_{\text{gauge}}(A_i, \psi_i) + \mathcal{L}_{\text{Higgs}}(\phi, \psi_i, \mathbf{v}) + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \dots$$

Only 3 couplings

- simple
- tested with high precision

More than 15 coupl.

- complicated
- not very well known yet

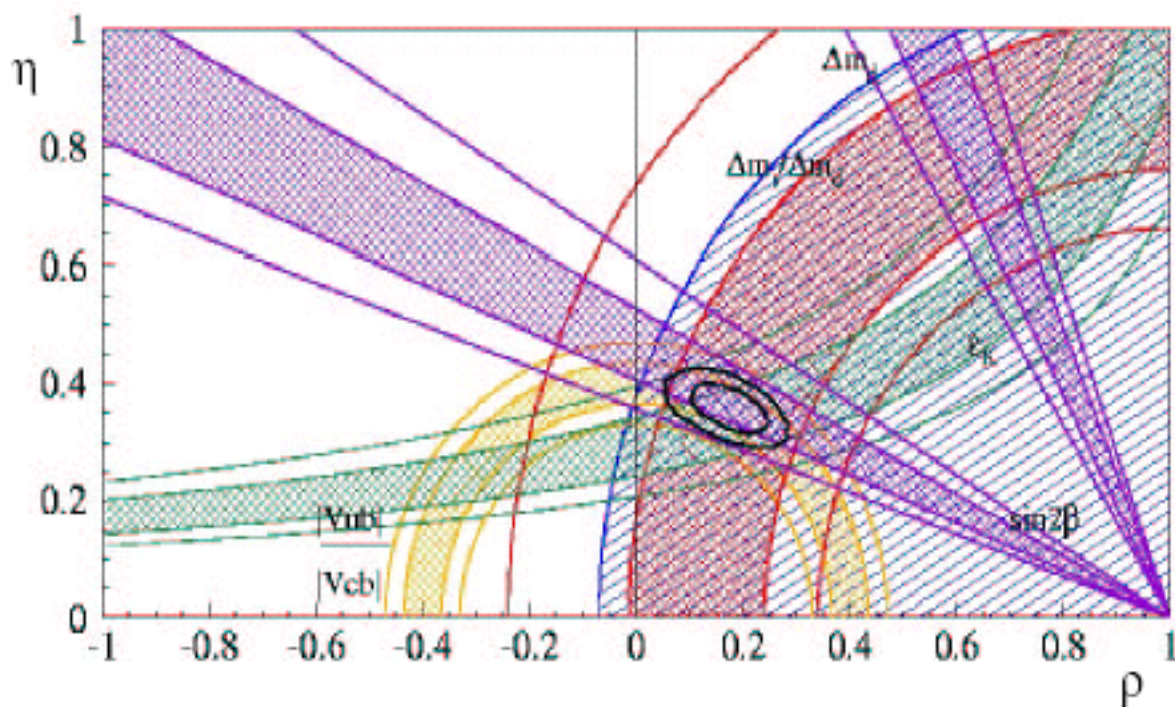
- 2 + ... Higgs Potential
 - 3 + ... Lepton's Yukawa coupl.
 - 10 Quark's Yukawa coupl.
- [FLAVOR PHYSICS]

Quark-flavor mixing is a key ingredient to understand the symmetry-breaking sector of the SM and, possibly, to provide an indirect indication about the value of Λ

➡ Rare decays

The Flavor Problem:

Available data on $\Delta F=2$ FCNC amplitudes (meson–antimeson mixing) already provides serious constraints on the scale of New Physics...



e.g.:

$K^0 - \bar{K}^0$ mixing



$\Lambda \gtrsim 100$ TeV

for $O^{(6)} \sim (\bar{s}d)^2$

much more severe than bounds on the scale of flavor-conserving operators from e.w. precision data

...while a natural stabilization of the Higgs potential $\Rightarrow \Lambda \sim 1$ TeV

After the recent precise data from B factories, it is more difficult [although not impossible...] to believe that this is an accident

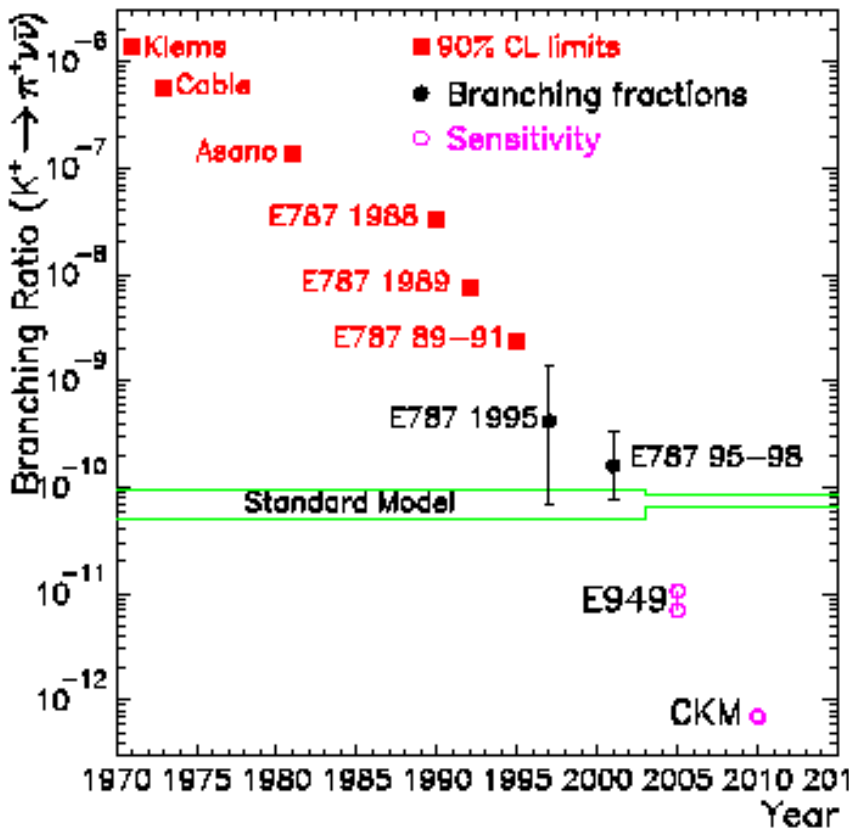
G. Isidori

G. Isidori

decreasing SM contrib. 

	$b \rightarrow s (\sim\lambda^2)$	$b \rightarrow d (\sim\lambda^3)$	$s \rightarrow d (\sim\lambda^5)$
$\Delta F=2$ box	ΔM_{Bs} $A_{CP}(B_s \rightarrow \psi\phi)$	ΔM_{Bd} $A_{CP}(B_d \rightarrow \psi K)$	$\Delta M_K, \epsilon_K$
$\Delta F=1$ 4-quark box	$B_d \rightarrow \phi K, B_d \rightarrow K\pi, \dots$	$B_d \rightarrow \pi\pi, B_d \rightarrow \rho\pi, \dots$	$\epsilon'/\epsilon, K \rightarrow 3\pi, \dots$
gluon penguin	$B_d \rightarrow X_s \gamma, B_d \rightarrow \phi K,$ $B_d \rightarrow K\pi, \dots$	$B_d \rightarrow X_d \gamma, B_d \rightarrow \pi\pi, \dots$	$\epsilon'/\epsilon, K_L \rightarrow \pi^0 \ell^+ \ell^-, \dots$
γ penguin	$B_d \rightarrow X_s \ell^+ \ell^-, B_d \rightarrow X_s \gamma$ $B_d \rightarrow \phi K, B_d \rightarrow K\pi, \dots$	$B_d \rightarrow X_d \ell^+ \ell^-, B_d \rightarrow X_d \gamma$ $B_d \rightarrow \pi\pi, \dots$	$\epsilon'/\epsilon, K_L \rightarrow \pi^0 \ell^+ \ell^-, \dots$
Z^0 penguin	$B_d \rightarrow X_s \ell^+ \ell^-, B_s \rightarrow \mu\mu$ $B_d \rightarrow \phi K, B_d \rightarrow K\pi, \dots$	$B_d \rightarrow X_d \ell^+ \ell^-, B_d \rightarrow \mu\mu$ $B_d \rightarrow \pi\pi, \dots$	$\epsilon'/\epsilon, K_L \rightarrow \pi^0 \ell^+ \ell^-,$ $K \rightarrow \pi\nu\nu, K \rightarrow \mu\mu, \dots$
H^0 penguin	$B_s \rightarrow \mu\mu$	$B_d \rightarrow \mu\mu$	$K_{L,S} \rightarrow \mu\mu$

 = Theoretical error < 10%



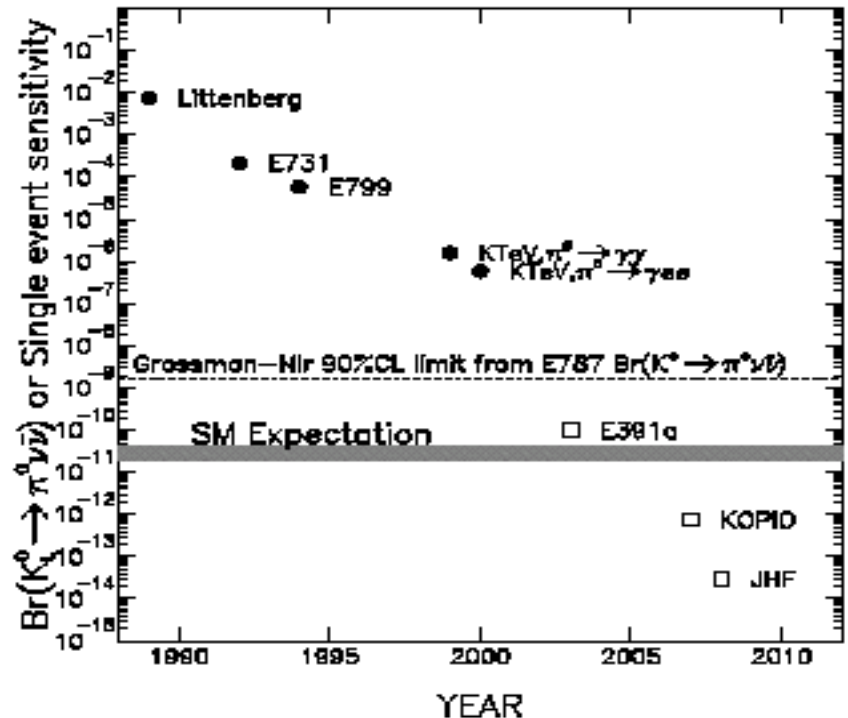
K⁺ → π⁺νν̄ history

E787: completed.

E949: 12 week run in 2002, can reach sensitivity goal of $\leq 10^{-11}$ when remaining 48 weeks of approved running is funded.

History of K_L⁰ → π⁰νν̄

D. Jaffe



Outlook for $K \rightarrow \pi \nu \bar{\nu}$ measurements

E787: completed

E949: Approved by DOE(1999), DOE halts HEP at AGS(2002), awaiting funding to continue

CKM: Stage I approval(2001), data taking in 2009(?)

KOPIO: Approved by NSF(2003), construction start in 2005

Stopped by DOE !



D. Jaffe

$K_L \Rightarrow \pi^0 \nu \nu$ at a Φ factory?

A Φ -factory is naturally suited for this search since:

- Kaons are tagged
- Kaons 4-momentum is known (reconstruction of decay kinematics allowed)
- Beam free of neutral baryons backg.

Production rate: 10^6 K_S - K_L pairs / pb⁻¹

1 year @ 10^{35} cm⁻²s⁻¹ : 10^{12} K_L produced

observed decays: $30 * \epsilon_{\text{tot}}$ / year (SM)

must be $\epsilon_{\text{tot}} \geq \sim 10\%$

F. Bossi

Conclusions

§ The search for $K_L \rightarrow \pi^0 \nu \nu$ requires luminosities of order $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

§ The **large x-ing angle** option, although fascinating, seems to present some major disadvantage in terms of tagging wrt to the conventional one

§ Beam related **backgrounds** have to be kept under control

§ Supplementary investigations needed on **photon detection efficiency**

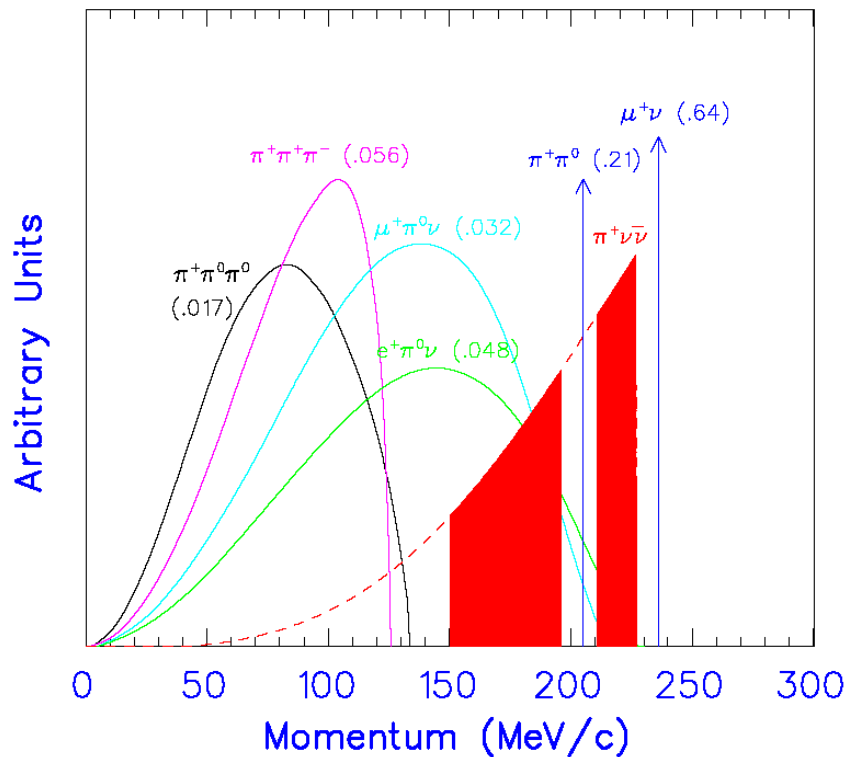
§ Tagging, trigger, and t_0 determination are an issue

Physics & Machine

Detector

CONCLUSIONS ON $K^\pm \rightarrow \pi^\pm \nu \bar{\nu}$ WITH KLOE

L. Passalacqua



A KLOE-like detector can probably reach a sound rejection factor to address $K^\pm \rightarrow \pi^\pm \nu \bar{\nu}$.

Minimum luminosity should be 10^{35} .

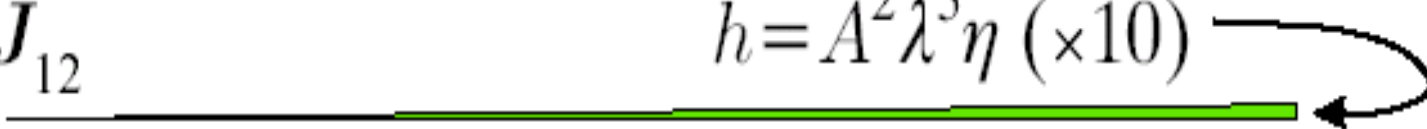
Should add a micro-vertex.

Should add a non- γ -destructive $\pi\mu$ separation system

$K^{\pm 0} \rightarrow \pi^{\pm 0} \nu \bar{\nu}$ cannot be measured

1. Cannot compete with hadron machines. KAMI: $4 - 7 \times 10^{13} K_L$ decays/y in detector. ϕ -factory @ $\mathcal{L}=10^{35} \text{ cm}^{-2} \text{ s}^{-1}$; $2 - 3 \times 10^{11} K_L$ dec/y.
2. E787 (2 ev) has collected $6 \times 10^{12} K^+$ decays. E949 should improve by a factor 5, but no AGS. CKM improve by another factor 10, but recently put on hold.
3. K^{\pm} experiments need strong pion ID or muon rejection. Efficiencies of few % are conceivable at higher p_{μ} . Still need $\mathcal{L} > 10^{36}$.
4. A new limit has little value. Must measure BR.

5. 8 years ago, I did believe $K \rightarrow \pi\nu\nu$ was fundamental. Today I do not think so.
6. Too bad

$$\mathbf{J}_{12} \quad h = A^2 \lambda^5 \eta (\times 10)$$

$$\lambda(1 - \lambda^2/2)$$

To get η need λ and A !

$$\delta(A^2 \lambda^5)/(A^2 \lambda^5) \sim 5.6\%, \text{ K. Schubert, LP03.}$$

Optimistic?

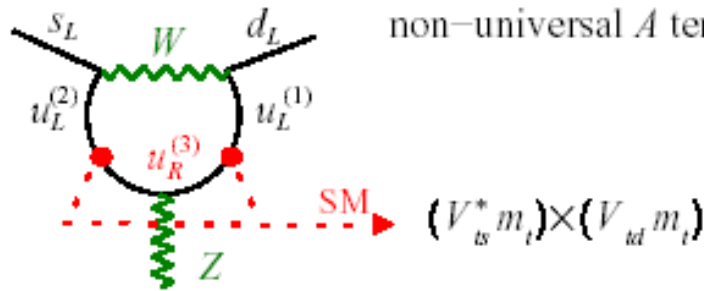
...but still remember

B) **Models with new sources of flavor mix.**
[the optimistic perspective]



large effects possible
[no λ^5 suppression]
in several specific
frameworks.

e.g.: MSSM with
non-universal A terms



Nir & Worah, '97
Buras, Silvestrini & Romanino, '97
Colangelo & G.I., '98

Model-independent bound:

$$\Gamma(K_L \rightarrow \pi^0 \nu \nu) < \Gamma(K^+ \rightarrow \pi^+ \nu \nu)$$

[Grossman & Nir, '97]

$B(K_L \rightarrow \pi^0 \nu \nu) < 1.8 \times 10^{-9}$ [90% C.L.]

Two orders of magnitudes above the SM: a wide unexplored
region of possible exciting new phenomena...

KLOE at DAΦNE2

- $\Delta S = \Delta Q$, use charge exchange, $K^+ \Rightarrow K^0$, $K^- \Rightarrow \bar{K}^0$ to tag strangeness.
- Use interference to measure $\Re\eta_{+-}\dots\Im\eta_{00}$, $\Im\delta$
- K_S , and K_L , leptonic asymmetry $\rightarrow \Re\delta$. This would be the first look at the Planck scale in particle physics.
- Push all modes to the limit, $\sim 10^{-(10-11)}$

Kaon interferometry: what can be measured

A . Di Domenico

Double differential time distribution:

$$I(f_1, t_1; f_2, t_2) = C_{12} \left\{ |\eta_1|^2 e^{-\Gamma_L t_1 - \Gamma_S t_2} + |\eta_2|^2 e^{-\Gamma_S t_1 - \Gamma_L t_2} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)(t_1 + t_2)/2} \cos[\Delta m(t_1 - t_2) + \phi_2 - \phi_1] \right\}$$

where $t_1(t_2)$ is the time of one (the other) kaon decay into f_1 (f_2) final state and:

$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | K_L \rangle / \langle f_i | K_S \rangle \quad C_{12} = \frac{N^2}{2} |\langle f_1 | K_S \rangle \langle f_2 | K_S \rangle|^2$$

$f_i = \pi^+\pi^-, \pi^0\pi^0, \pi l\nu, \pi^+\pi^-\pi^0, 3\pi^0, \pi^+\pi^-\gamma$..etc

characteristic interference term
at a ϕ -factory => interferometry

Integrating in $(t_1 + t_2)$ we get the time difference ($\Delta t = t_1 - t_2$) distribution (1-dim plot):

$$I(f_1, f_2; \Delta t \geq 0) = \frac{C_{12}}{\Gamma_S + \Gamma_L} \left[|\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right]$$

for $\Delta t < 0$ $\Delta t \rightarrow |\Delta t|$ and $1 \leftrightarrow 2$

From these distributions for various final states f_i we can measure the following quantities:

$$\Gamma_S, \Gamma_L, \Delta m, |\eta_i|, \arg(\eta_i) = \phi_i$$

Kaon interferometry: main observables

A . Di Domenico

mode

measured quantity

parameters

$$\phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^-$$

$$I(\pi^+ \pi^-, \pi^+ \pi^-; \Delta t)$$

$$\Delta m \quad (\Gamma_S \quad \Gamma_L)$$

$$\phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- \pi^0 \pi^0$$

$$A(\Delta t) = \frac{I(\pi^+ \pi^-, \pi^0 \pi^0; \Delta t > 0) - I(\pi^+ \pi^-, \pi^0 \pi^0; \Delta t < 0)}{I(\pi^+ \pi^-, \pi^0 \pi^0; \Delta t > 0) + I(\pi^+ \pi^-, \pi^0 \pi^0; \Delta t < 0)}$$

$$\Re\left(\frac{\varepsilon'}{\varepsilon}\right) \quad \Im\left(\frac{\varepsilon'}{\varepsilon}\right)$$

$$\phi \rightarrow K_S K_L \rightarrow \pi \ell \nu \quad \pi \ell \nu$$

$$A_{CPT}(\Delta t) = \frac{I(\pi^- e^+ \nu, \pi^+ e^- \bar{\nu}; \Delta t > 0) - I(\pi^- e^+ \nu, \pi^+ e^- \bar{\nu}; \Delta t < 0)}{I(\pi^- e^+ \nu, \pi^+ e^- \bar{\nu}; \Delta t > 0) + I(\pi^- e^+ \nu, \pi^+ e^- \bar{\nu}; \Delta t < 0)}$$

$$\Re \delta_K - \Re\left(\frac{d^*}{a}\right)$$

$$\Im \delta_K + \Im\left(\frac{c^*}{a}\right)$$

$$\phi \rightarrow K_S K_L \rightarrow \pi \pi \quad \pi \ell \nu$$

$$A(\Delta t) = \frac{I(\pi^- e^+ \nu, \pi^+ \pi^-; \Delta t) - I(\pi^+ e^- \bar{\nu}, \pi^+ \pi^-; \Delta t)}{I(\pi^- e^+ \nu, \pi^+ \pi^-; \Delta t) + I(\pi^+ e^- \bar{\nu}, \pi^+ \pi^-; \Delta t)}$$

$$\phi_{\pi\pi}$$

$$A_L = 2(\Re \varepsilon_K - \Re \delta_K + \Re b/a + \Re d^*/a)$$



A . Di Domenico

Fit including Δt resolution and efficiency effects + regeneration:

Γ_S, Γ_L fixed from PDG

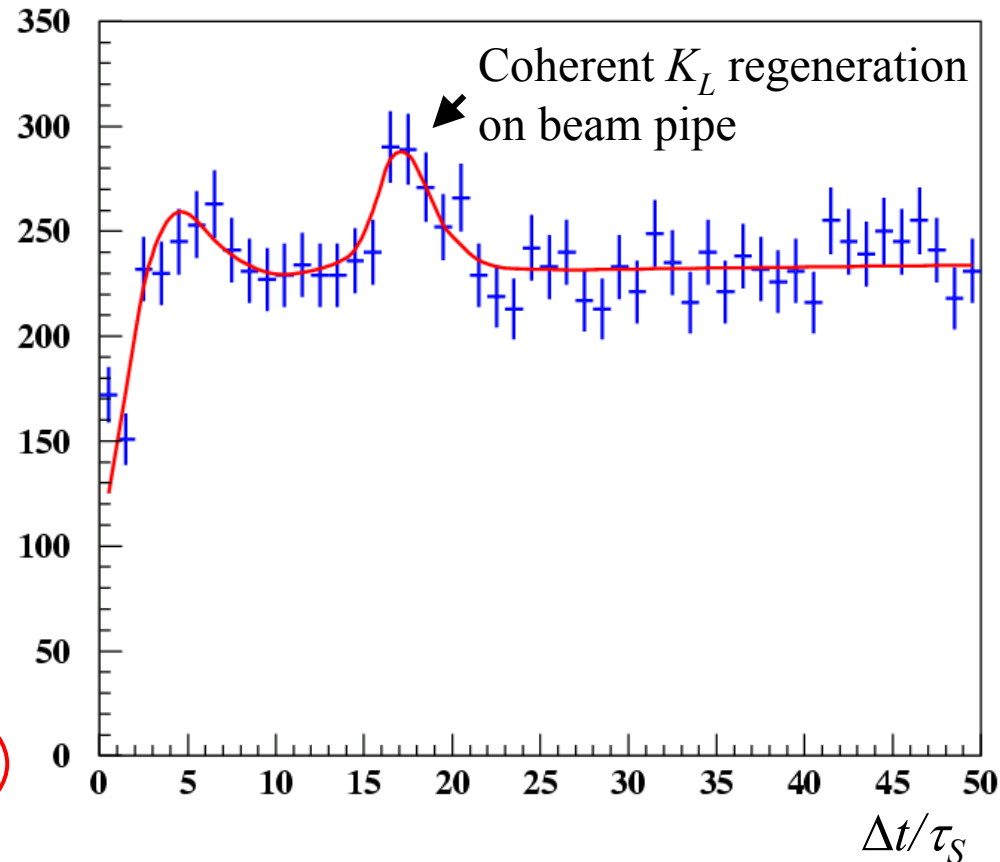
KLOE preliminary

340 pb^{-1} (2001 + 2002 data)

$$\Delta m = (5.64 \pm 0.37) \times 10^{11} \hbar \text{ s}^{-1}$$

$$\text{PDG '02: } (5.301 \pm 0.016) \times 10^{11} \hbar \text{ s}^{-1}$$

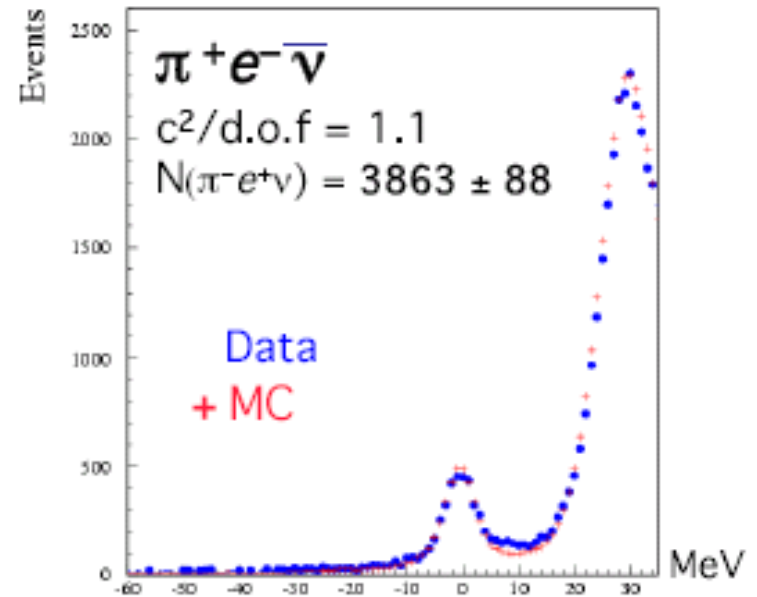
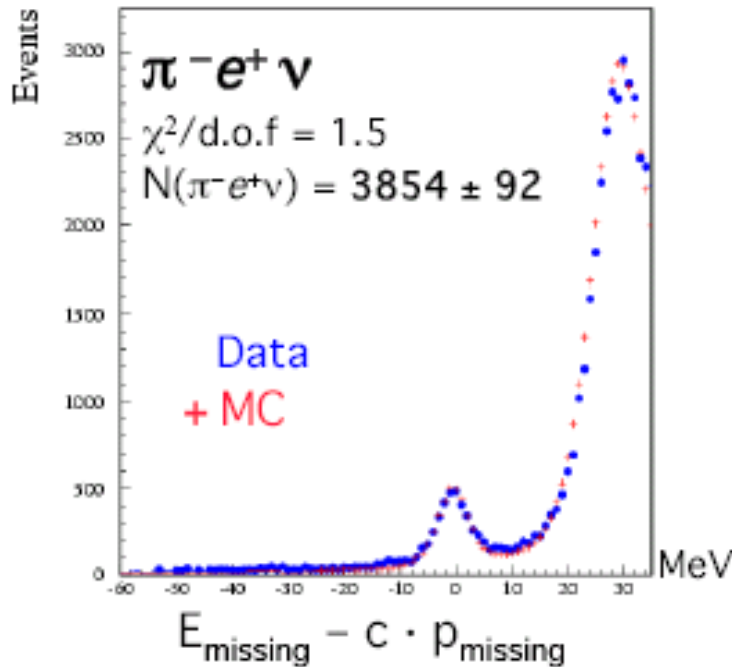
At a new ϕ -factory with 500 fb^{-1} :
 $\delta \Delta m \sim 0.009 \times 10^{11} \hbar \text{ s}^{-1}$



BR($K_S \rightarrow \pi e \nu$)



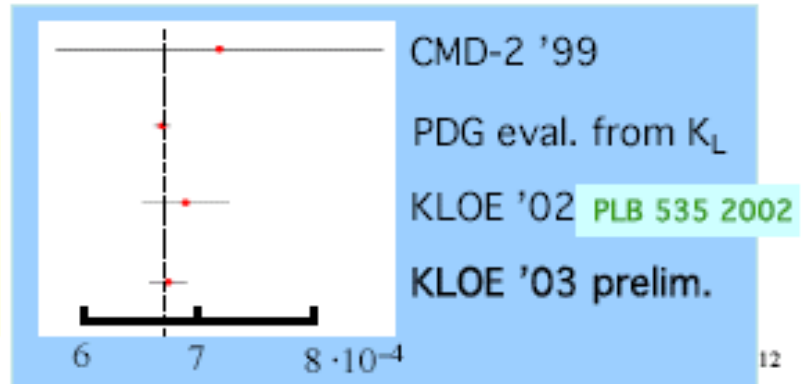
KLOE '03 preliminary result w/170 pb⁻¹ 2001 data



$$\text{BR}(\pi^- e^+ \nu) = (3.46 \pm 0.09 \pm 0.06) \cdot 10^{-4}$$

$$\text{BR}(\pi^+ e^- \bar{\nu}) = (3.33 \pm 0.08 \pm 0.05) \cdot 10^{-4}$$

$$\text{BR}(\pi^\mp e^\pm \nu) = (6.81 \pm 0.12 \pm 0.10) \cdot 10^{-4}$$



BR($K_S \rightarrow \pi e \nu$): charge asymmetry



Matrix elements of semil. decays

$$\langle \pi^- e^+ \nu | H_W | K^0 \rangle = a + b$$

$$\langle \pi^+ e^- \bar{\nu} | H_W | \bar{K}^0 \rangle = a^* - b^*$$

$$\langle \pi^+ e^- \bar{\nu} | H_W | K^0 \rangle = c + d$$

$$\langle \pi^- e^+ \nu | H_W | \bar{K}^0 \rangle = c^* - d^*$$

Charge asymmetry

$$A \equiv \frac{\Gamma(\pi^- e^+ \nu) - \Gamma(\pi^+ e^- \bar{\nu})}{\Gamma(\pi^- e^+ \nu) + \Gamma(\pi^+ e^- \bar{\nu})}$$

$$A_S = 2(\text{Re } \epsilon_K + \text{Re } \delta_K + \text{Re } b/a - \text{Re } d^*/a)$$

$$A_L = 2(\text{Re } \epsilon_K - \text{Re } \delta_K + \text{Re } b/a + \text{Re } d^*/a)$$

$A_S - A_L = 4\text{Re } \delta_K - 4\text{Re } d^*/a \neq 0$
implies CPT violation

~~C~~

~~CPT in
mixing~~

~~CPT in
decay~~

~~ΔS ΔQ
and CPT~~

KLOE preliminary

$$A_S = (19 \pm 17 \pm 6) \cdot 10^{-3}$$

First measurement of A_S !

Compare to A_L w.a.

$$A_L = (3.322 \pm 0.055) \cdot 10^{-3}$$

$$A_L = A_S = 2 \text{Re } \epsilon_K \text{ if CPT conserved}$$

CLEAR PL B444 1998 $\text{Re } \delta_K = (2.9 \pm 2.7) \cdot 10^{-4}$

The KAON system already provides the strongest upper bound on **CPT** conjugates states

$$\Delta M_K / M_K < 10^{-18}$$

To improve on this one should aim at measuring δ with a precision of $\sim 10^{-5}$ or better which implies $\sim 10^9 K_S$ semileptonic decays

@ $5 \cdot 10^{34}$ one gets $\sim 3 \cdot 10^8 K_S \rightarrow \pi e \nu$ decays/year
(and b.t.w. $\sim 1000 K_S \rightarrow 3\pi^0$ decays/year)

Efficiencies have to be applied but note that precision scales with $\sqrt{N_{ev}}$

Conclusions: detector upgrades @D2



- Just an exercise for future discussion/work
- If IR-D2 smaller, we can consider a compact inner vertex detector inside the Drift Chamber ($r=10-25\text{cm}$)
 - add z measurement !!! Helps pattern recognition
 - improves vertexing at IP and interferometry for all-track events like $K_L K_S \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ and $K_L K_S \rightarrow \pi e \nu \pi^+ \pi^-$
 - helps ID Kaon interactions (esp. Q-exch.) in the inner DC wall
 - if beam pipe were pure Be: big bonus for reconstruction
 - if pure Be sphere difficult \Rightarrow make a cylinder w/same radius
 - QCAL experience will be useful; can make new QCAL smaller
- Calorimeter: increasing readout granularity would improve clustering and enhance PID
- Current drift chamber upgrade w/new ADCs (enhances e/π but also) helps π/μ separation in K^0 decays

HYPERNUCLEAR SPECTROSCOPY

OPEN QUESTIONS

A. Feliciello

☛ (low-energy) ΛN ($\Lambda\Lambda$) interaction

- detailed knowledge of the **hypernuclear fine structure**
 - evaluation of the **spin dependent terms** of the ΛN interaction
- measurement of **angular distribution** and polarization of **γ -rays**
 - determination of **spin** and **parity** of **each** observed **level**

☛ Impurity nuclear physics

- measurement of transition probability **$B(E2)$**
 - information on the **size** and **deformation** of hypernuclei
 - measurement of nucleus **core shrinking** → **glue role** of Λ

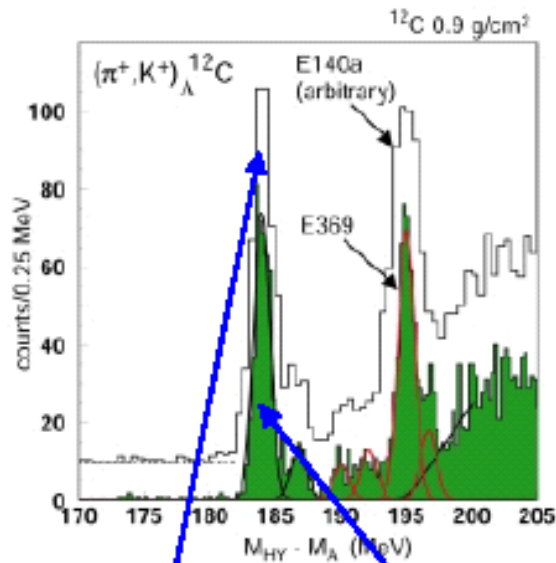
☛ Properties of hyperons in nuclear matter (medium effect)

- measurement of transition probability **$B(M1)$**
 - **g -factor** value for Λ in nuclear matter

FINUDA IS COMING!

A. Feliciello

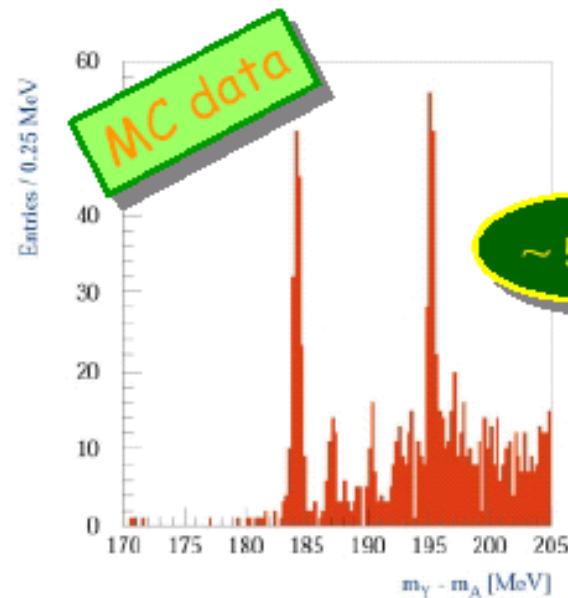
KEK data



$\Delta E = 1.9$ MeV FWHM

$\Delta E \sim 1.5$ MeV FWHM

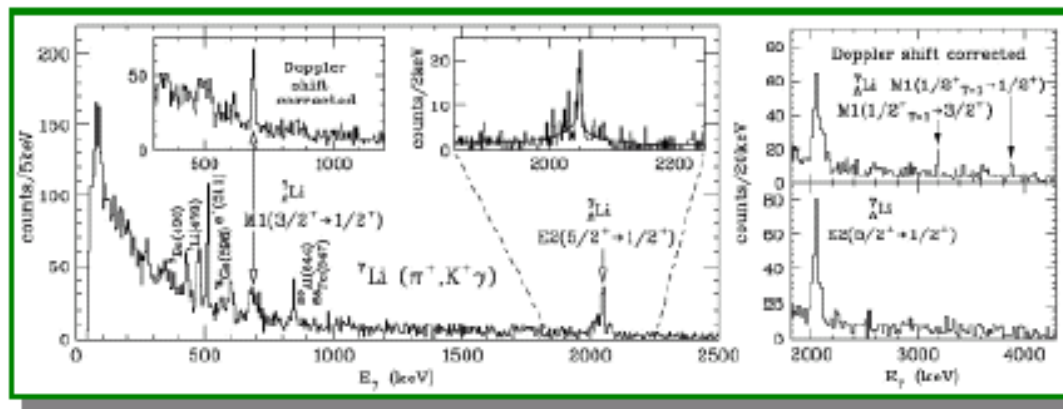
$\Delta E \sim 0.75$ MeV FWHM



$^{12}\text{C}(K_{stop}^-, \pi)_{\Lambda}^{12}\text{C}$

ONE STEP BEYOND: γ SPECTROSCOPY

KEK E419



Precise hypernuclear γ -spectroscopy has been established as new frontier in strangeness nuclear physics

NEED HIGH LUMINOSITY DUE TO LOW EVENT RATES (AND LOW DETECTOR EFFICIENCIES)

A. Feliciello

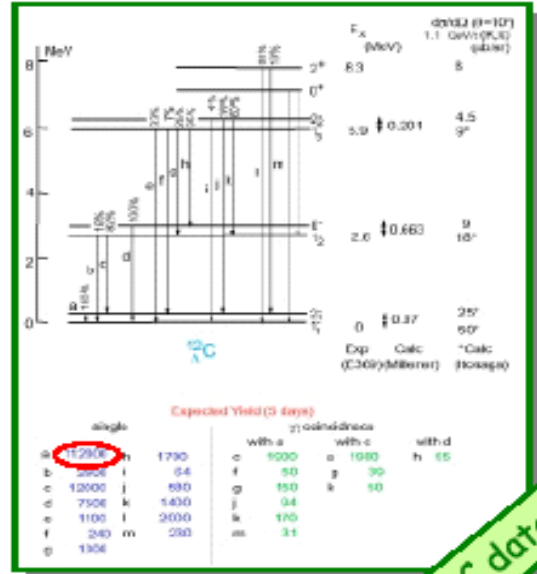
FINUDA WITH GERMANIUM DETECTOR

SLIGHTLY REDUCED DETECTOR ACCEPTANCE

@ $\mathcal{L} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ FINUDA can observe $\sim 1.6 \times 10^4 \text{ ev/h}$ from YN g.s.

- machine duty cycle: 75%
- spectrometer acceptance: 72%
- Ge acceptance: $\sim 30\%$
- ϵ_{Ge} : $\sim 30\%$

$\sim 1.87 \times 10^4 \text{ ev/d}$



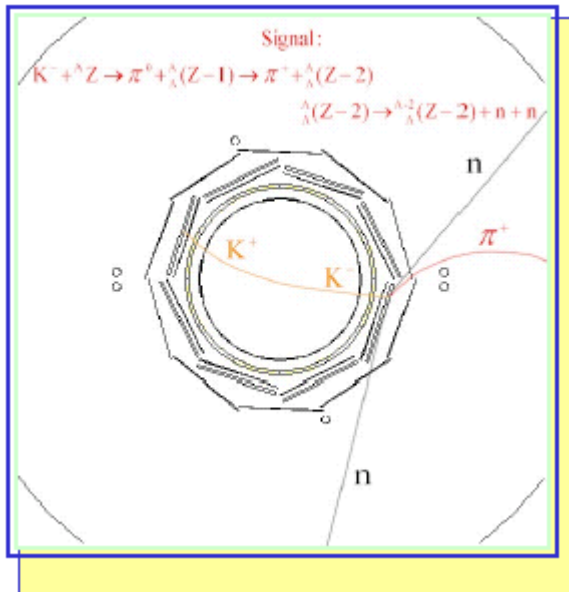
MC data

5 day data taking

$\sim 9.33 \times 10^4 \text{ ev}$

PRODUCTION OF NEUTRON RICH HYPERNUCLEI

V. Paticchio



- Search for the existence of neutron-rich hypernuclei
- Exotic nuclear matter, with extreme N/Z ratio (${}^7_{\Lambda}\text{H}$, ${}^6_{\Lambda}\text{H}$, ${}^{12}_{\Lambda}\text{Be}$)
- Study of mass distributions more extended than ordinary nucleus
- Study of the effect of Λ hyperon on neutron-halo
- Interest of astrophysics to explain various phenomena of high density matter in neutron-star

Typical counting rate with FINUDA @ 10^{34} : 130 ev/h

HADRONIC CROSS SECTION

Muon - Anomaly

Motivation: Determination of Hadronic Vacuum Polarization
 = High Precision Test of the Standard Model:

- Anomalous magnetic moment of the muon $a_\mu = (g-2)_\mu$
- Running Fine Structure Constant at Z^0 -mass $\alpha_{\text{QED}}(M_Z)$

Dirac-Theory: $(g - 2) = 0$

Quantum Corrections: $(g - 2) \neq 0$ due to corrections of:

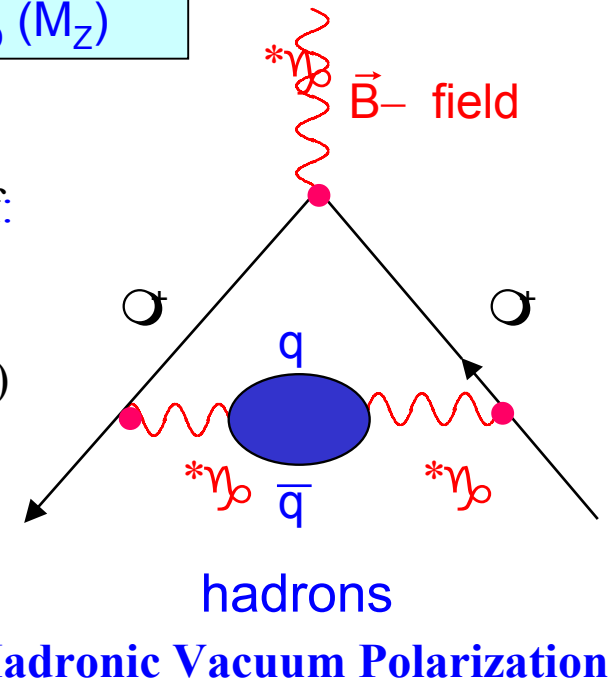
- electromagnetic Interaction
- weak Interaction
- strong Interaction (and maybe **NEW PHYSICS** ???)

$$a_\mu = (g_\mu - 2) / 2 = \frac{e^2}{4m_\mu} + \dots$$

$$a_\mu^{\text{theor}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{weak}} + a_\mu^{\text{new}}$$

2nd largest contrib., cannot be calculated in pQCD

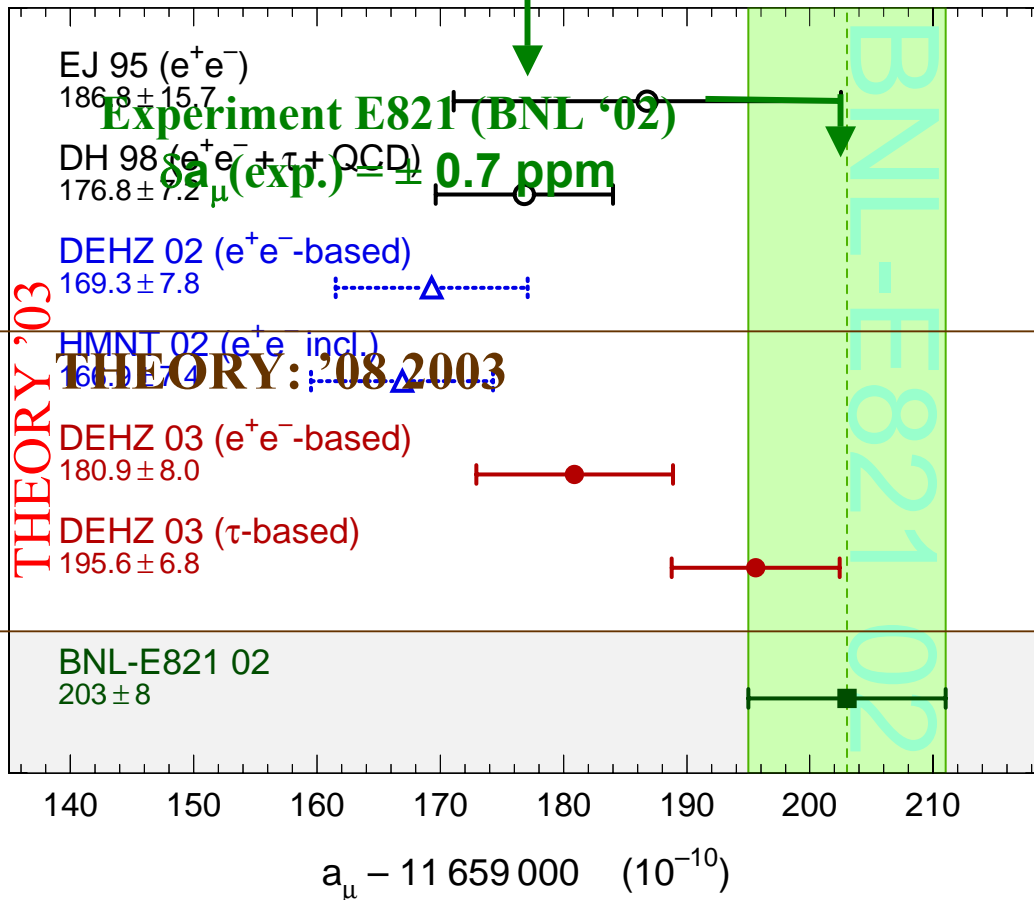
Error of hadronic contribution is dominating total Error !



Status: Muon - Anomaly

How to test the Standard Model?

Compare experimental Value with Theory - Prediction for Muon-Anomaly



New Data Input from:

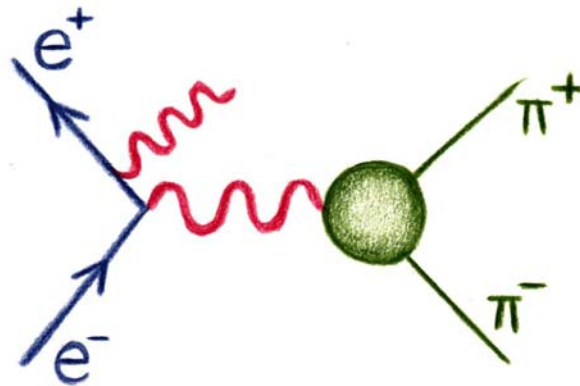
- a) **CMD-2** (Novosibirsk) in $\pi^+ \pi^-$ Channel: **0.6% Precision** < 1 GeV reanalysis of their data publ. '08/03
- b) τ -Data from **ALEPH, OPAL, CLEO**

- } Theory Evaluation using only $e^+ e^-$ - Data 2σ - Deviation
- } Theory Evaluation using only τ - Data: Agreement with Exp.

RADIATIVE RETURN @ KLOE & BABAR

S. Müller

Particle factories have the opportunity to measure the cross section $\sigma(e^+ e^- \rightarrow \text{hadrons})$ as a function of the hadronic c.m.s energy M^2_{hadrons} by using the radiative return.



$$M^2_{\text{hadr}} \frac{d\sigma(e^+ e^- \rightarrow \text{hadrons} + \gamma)}{dM^2_{\text{hadrons}}} = \sigma(e^+ e^- \rightarrow \text{hadrons}) H(M^2_{\text{hadr}}, \cos\theta_{\gamma \text{ min}})$$

This method is a **complementary approach** to the standard energy scan. It requires precise calculations of the radiator H .

→ EVA + Phokhara MC Generator

(S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999)

(H. Czyz, A. Grzelinska, J.H. Kühn, G. Rodrigo, hep-ph/0308312)

Preliminary KLOE value for $a_\mu \times 10^{10}$

$$a_\mu^{\pi\pi} \propto \int_{0.37}^{0.95} ds \sigma(e^+e^- \rightarrow \pi^+\pi^-) \cdot K(s)$$

In order to see how **KLOE data compares with existing e^+e^- data from CMD-2** we have integrated the bare cross section according to the dispersion integral in the energy range $0.37 < M_{\pi\pi}^2 < 0.93 \text{ GeV}^2$

KLOE:

$$a_\mu^{\pi\pi} = 378.4 \pm 0.8_{\text{stat}} \pm 4.9_{\text{syst}} \pm 4.5_{\text{theo}}$$

CMD-2:

$$a_\mu^{\pi\pi} = 378.6 \pm 2.7_{\text{stat}} \pm 2.3_{\text{syst}}$$

The two numbers are compatible given the systematic error, but **FSR corrections** must be refined with the **new version of Phokhara**

e^+e^- - versus τ - Data

Q^2/GeV^2

0.37:0.65

0.65:0.93

KLOE a_μ^{had}

309.4 ± 5.0

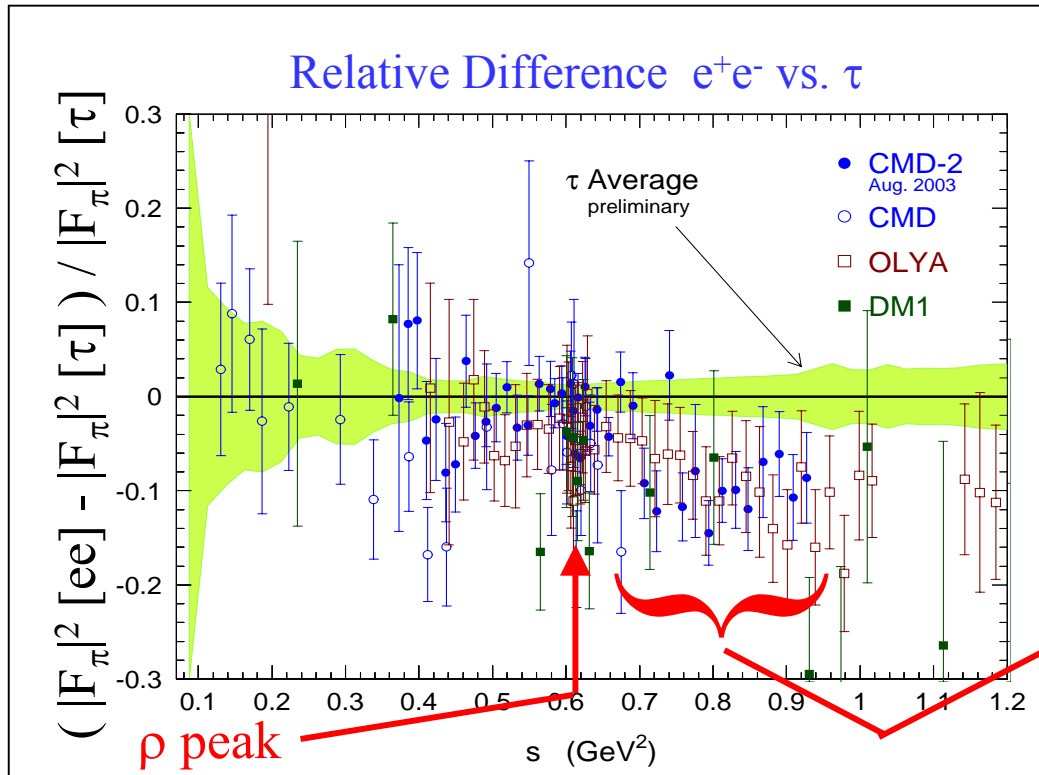
68.8 ± 1.0

CMD2 a_μ^{had}

308.5 ± 2.8

72.2 ± 0.7

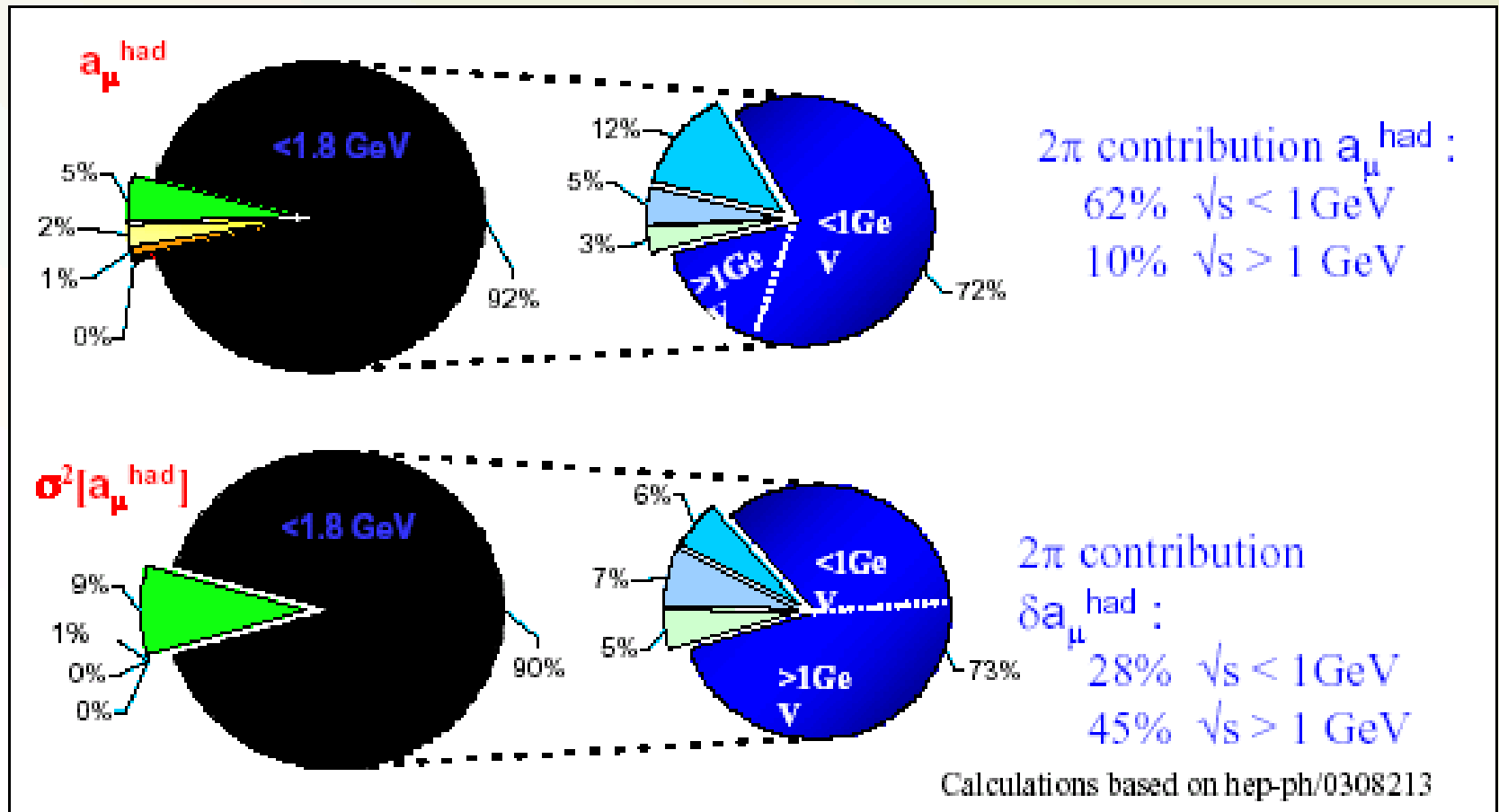
← *our interpolation*



KLOE data confirm the discrepancy between e^+e^- and τ data in the region above the ρ peak

In a large energy range above the ρ -peak τ -data is **systematically higher $\approx 10\% \dots 15\%$!**

S. Müller



A. Denig

- The **energy range 1 - 2 GeV is crucial** for an improvement on the theoretical knowledge of a_μ
- **2 - Pion - Channel $> 1\text{GeV}$** is now giving the **largest contribution** to the error of a_μ^{hadr}
- **3 - Pion - Channel** and even much **more 4 - Pion - Channel** are **poorly known** and need to be measured $> 1\text{ GeV}$
- **Actual / Future Measurements from:**
 - **BABAR:** Rad. Return all channels (**E. Solodov**)
 - **VEPP-2000:** Energy Scan all channels (**A. Sibidanov**)
 - **DAΦNE-2** *Energy Scan or Rad. Return ???*

A. Denig

Radiative Return vs. Energy Scan

Energy Scan seems the natural way of measuring hadronic cross sections, experience at DAΦNE has shown that the **Radiative Return** has to be considered as a **complementary approach**

Advantages:

- Data comes as a **by-product** of the standard program of the machine
- **Systematic errors** from Luminosity, \sqrt{s} , rad. corrections... **enter only once** and do not have to be studied for each point of s

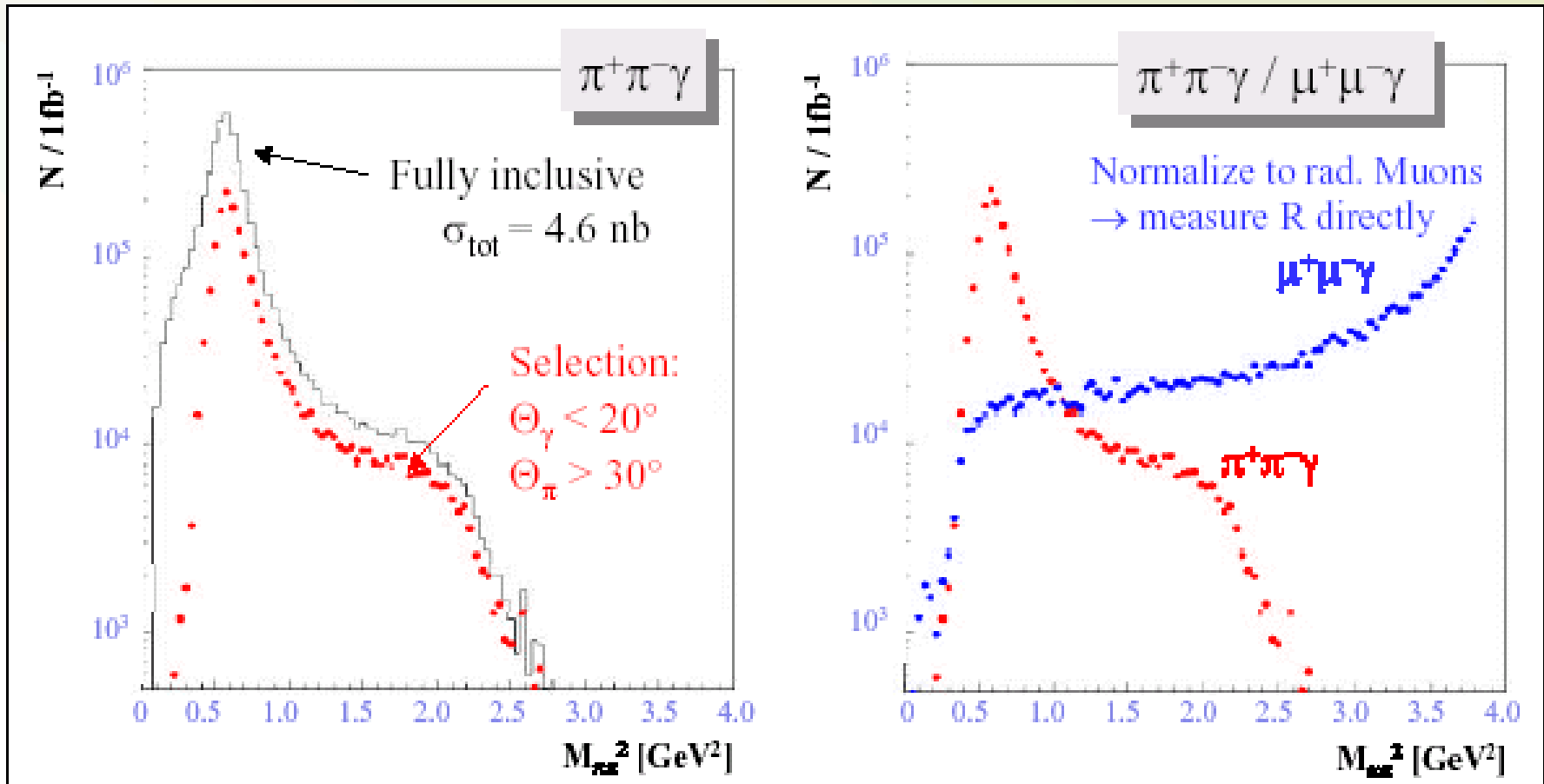
Disadvantages:

- Requires a **precise theoretical calculation** of the **Radiator Function**
- Requires **good suppression** (or understanding) of **Final State Radiation (FSR)**; the model of scalar QED used so far can be tested however by measuring the charge asymmetry
- Needs **high integrated Luminosity**; for 2-Pion-channel at DAΦNE-1 no problem, but might become critical for low hadr. cross-sections

A. Denig

Radiative Return $2\pi\gamma$ @ $\sqrt{s} = 2 \text{ GeV}$

- Preliminary MC Study with Event-Generator Phokhara vs 3.0
- Plotted are the Number of $\pi^+\pi^-\gamma$ events / 1 fb^{-1} (Bin width = 0.04 GeV^2)



CONCLUSIONS ON σ_{HAD}

- ❑ Right now **2.0 σ deviation** between theory and experiment for the anomalous magnetic moment of the muon \rightarrow **needs clarification !**
- ❑ For a future **improved evaluation of a_μ** the measurement of the **hadronic cross section in the energy range 1 - 2 GeV** with a precision $\mathcal{O}(1\%)$ is of great importance:
Goal to reach $\delta a_\mu^{\text{hadr}} \approx 2 \dots 3 \times 10^{-10}$
- ❑ **2 - Pion - Channel < 1 GeV** still very interesting in order to understand the $e^+e^- - \tau$ - puzzle (**energy scan as cross check?**)
- ⊖ **At DAΦNE - 2** the **radiative return** seems a **feasible option** if the energy of the machine cannot be tuned for an energy scan

A. Denig