Prospects on σ_{HAD} with KLOE-2 at DAFNE upgraded in energy

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LNF, 11 Giugno 2010

KLOE-2 High Energy program:

- running DAFNE up to 2.-2.5 GeV (and possibly below 1 GeV), with a luminosity ~10^{32} $cm^{-2}s^{-1}$ (~5 pb^{-1} per day⇔1 fb^{-1}/year, assuming 50% duty cycle).

Main Motivation:

Measurement of the (multi)hadronic cross section in the region 1-2 GeV at 1-2% (now 3-15%)⇒ Dramatic impact in the precision tests of the SM via $(g-2)_\mu$ and $\alpha_{em}(M_Z)$

Other motivations:

$\gamma\gamma$ physics above the ϕ, spectroscopy, exotics (light bosons), Baryon FF, etc…

References:
- KLOE-2 LoI: www.lnf.infn.it/lnfadmin/direzione/roadmap/LoIKLOE.pdf
- F.Ambrosino et al., EPJC50(2007)729
- Physics with KLOE2 experiment at the ϕ-factory, arXiv:1003.3868
- D. Babusci et al. "Proposal for taking data with the KLOE-2 detector at the DAFNE Collider upgraded in energy", LNF NOTE XXX

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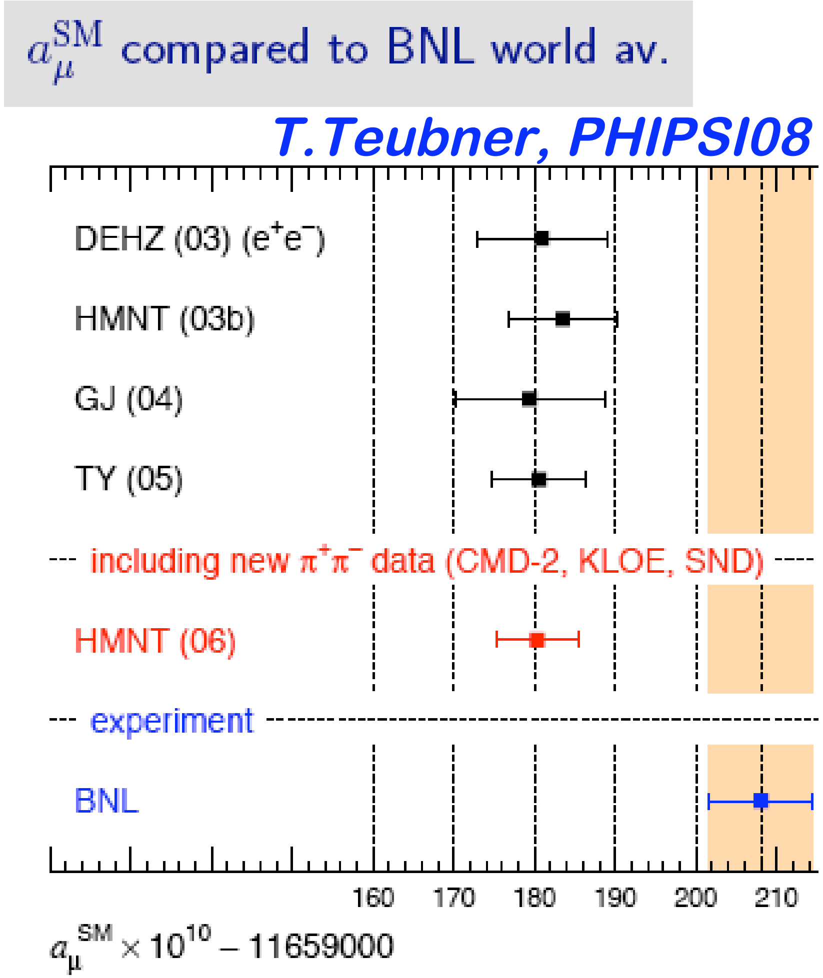
Muon Anomaly

$$a_\mu = \frac{(g_\mu - 2)}{2}$$

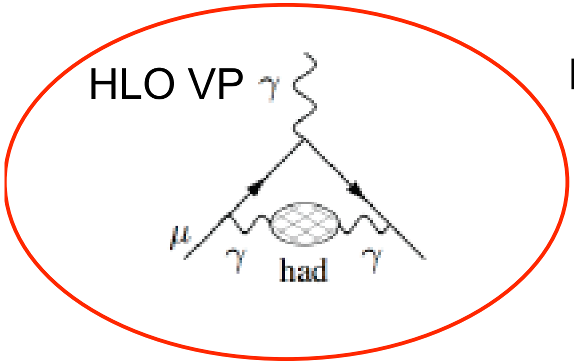
- Long established discrepancy (>3σ) between SM prediction and BNL E821 exp.

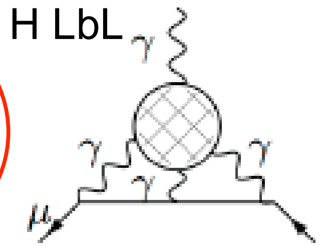
- Theoretical error δa_μ^{SM} ($\sim 6\times10^{-10}$) dominated by HLO VP ($4\div5\times10^{-10}$) and HLbL ($[2.5\div4]\times10^{-10}$)

- Experimental error $\delta a_\mu^{EXP} \sim 6\times10^{-10}$ (E821). Plan to reduce it to $1.5\ 10^{-10}$ by the new g-2 experiments at FNAL and J-PARC.



$$a_\mu^{EXP} - a_\mu^{TH} = (27.6 \pm 8.1)\cdot 10^{-10}, \ \sim 3.4\sigma$$





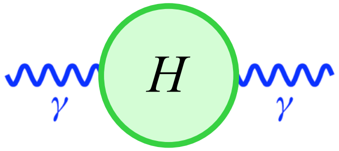
$a_\mu^{HLO} = (690.9\pm\mathbf{4.4})10^{-10}$
[Eidelman, TAU08]

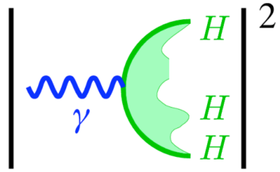
$\delta a_\mu^{HLO} \sim 0.7\%$

$a_\mu^{HLbL} = (10.5\pm2.6)10^{-10}$
[Prades, de Rafael & A. Vainshstein 08]
$(11 \pm4)10^{-10}$ (Jegerlehner, Nyffler)

a_μ^{HLO}:

L.O. Hadronic contribution to a_μ can be estimated by means of a dispersion integral:





$$a_\mu^{had} = \left(\frac{\alpha\ m\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds\, \frac{R(s)\,\hat{K}(s)}{s^2}$$

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to q\,\bar{q} \to hadrons)}{\sigma_{tot}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

$1 / s^2$ makes low energy contributions especially important:

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

in the range < 1 GeV contributes to 70% !

- K(s) = analytic kernel-function
- above sufficiently high energy value, typically 2…5 GeV, use *pQCD*

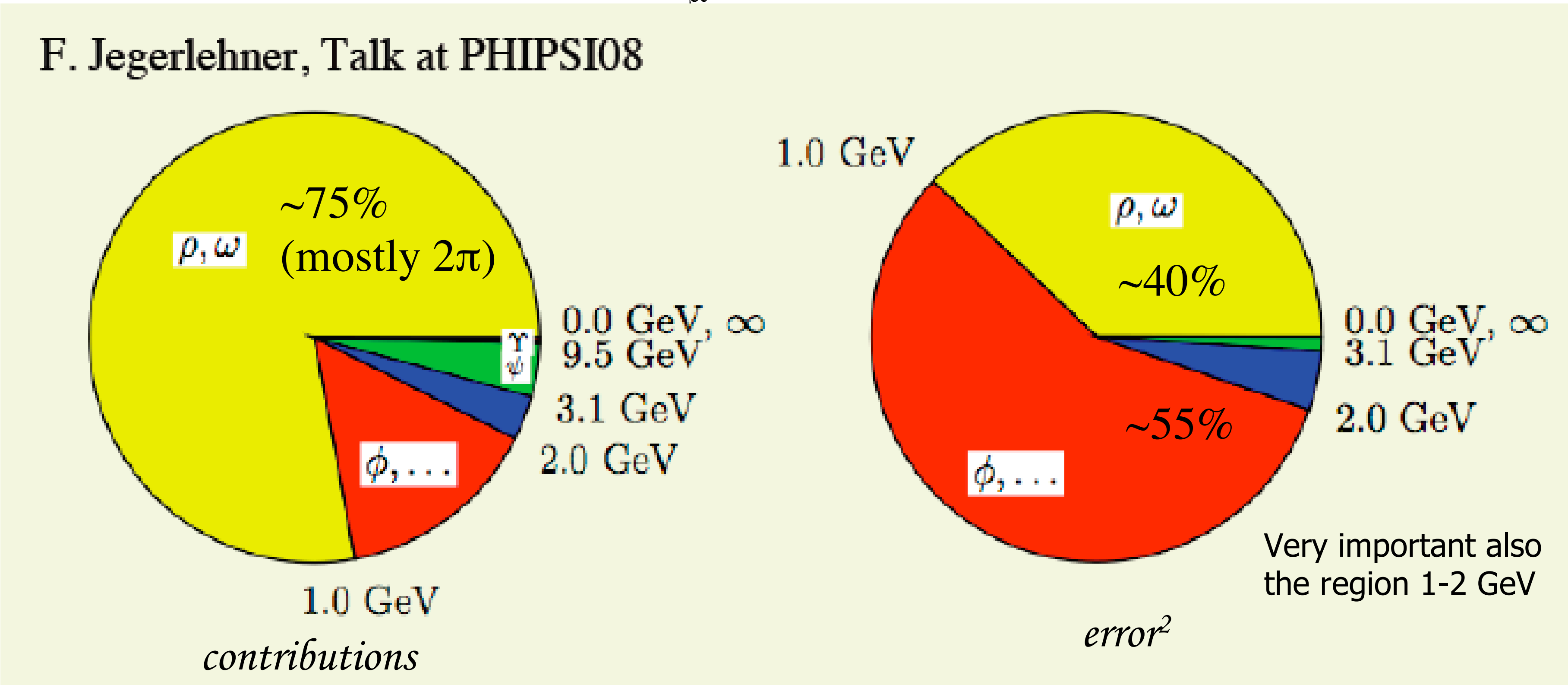
Input:

a) hadronic electron-positron cross section data

b) hadronic τ- decays, which can be used with the help of the CVC-theorem and an isospin rotation (plus isospin breaking corrections)

Dispersion Integral:

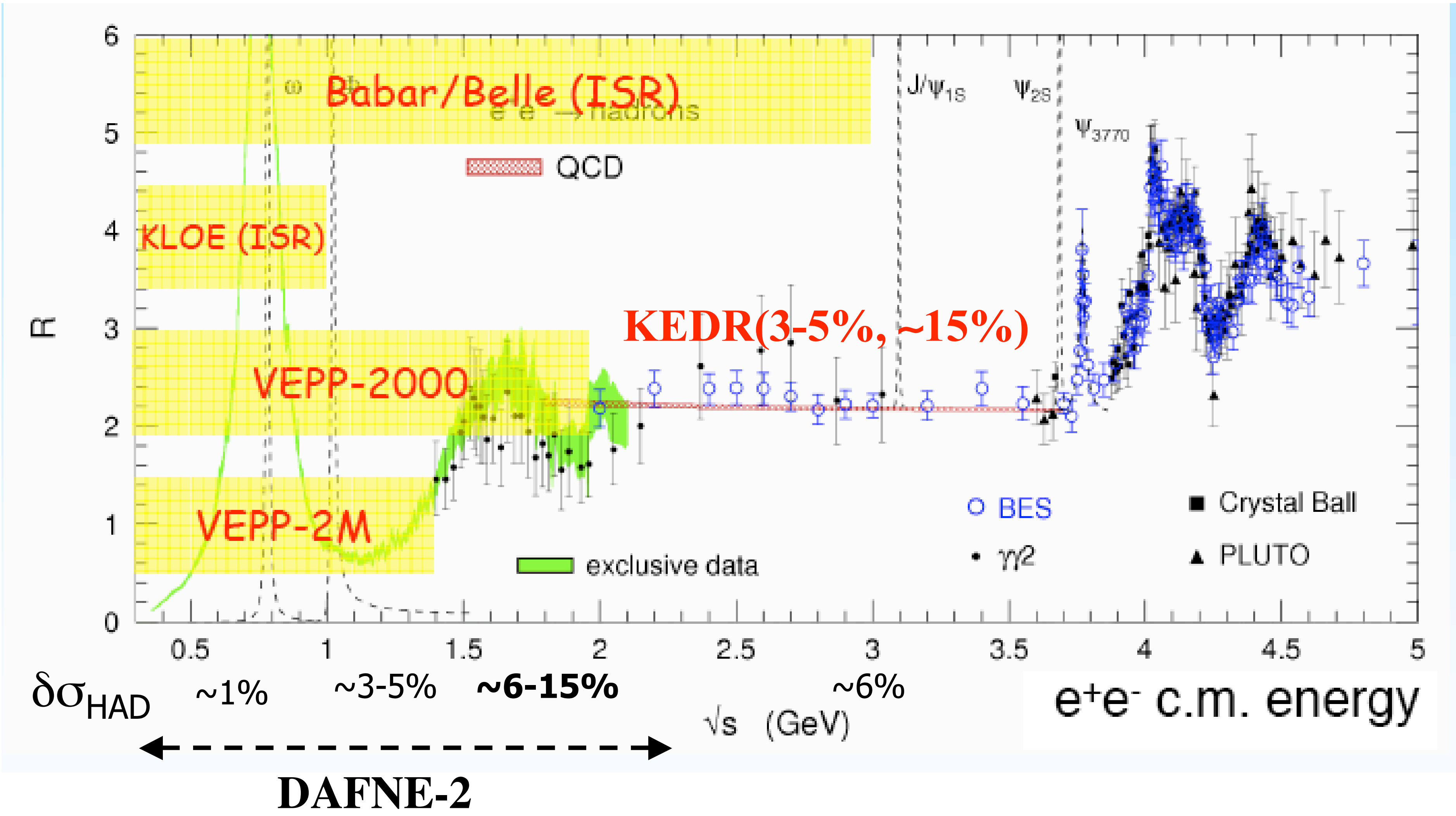
Contribution of different energy regions to the dispersion integral and the error to a_μ^{had}



Experimental errors on σ^{had} translate into theoretical uncertainty of a_μ^{had}!
→ Needs precision measurements!

$\delta a_\mu^{exp} \rightarrow 1.5\ 10^{-10} = 0.2\%$ on a_μ^{HLO}
New g-2 exp.

e^+e^- data: current and future/activities



Cross section data:

At low energies (< 2 GeV) only measurements of exclusive channels, two approaches:

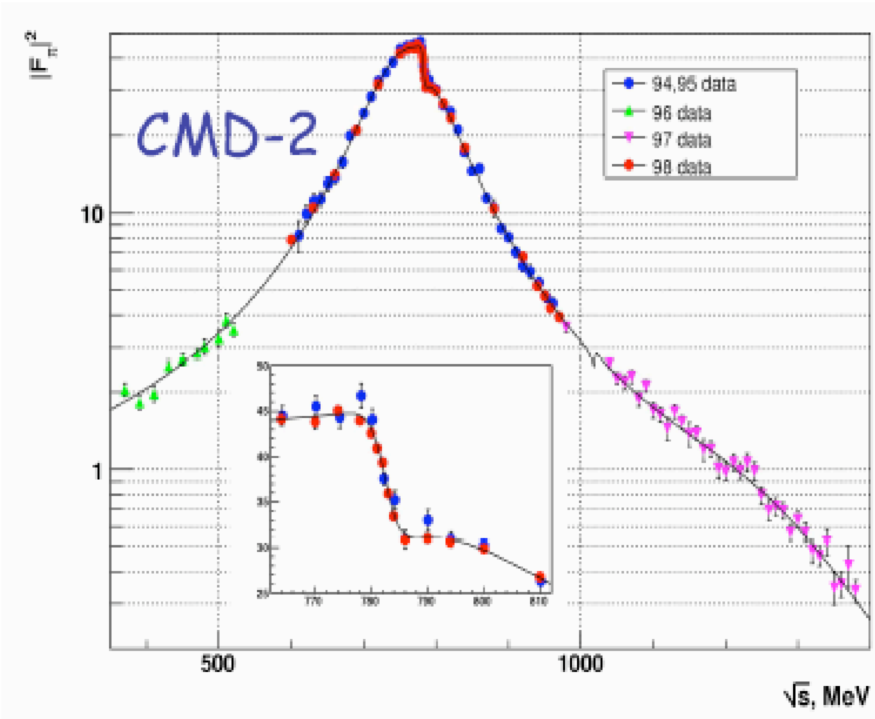
Energy scan (CMD2, SND):

- energy of colliding beams is changed to the desired value
- "direct" measurement of cross sections
- needs dedicated accelerator/physics program
- needs to measure luminosity and beam energy for every data point

Radiative return (KLOE, BABAR, BELLE):

- runs at fixed-energy machines (meson factories)
- use initial state radiation process to access lower lying energies or resonances
- data come as by-product of standard physics program
- requires precise theoretical calculation of the radiator function
- luminosity and beam energy enter only once for all energy points
- needs larger integrated luminosity

Pion form factor @ Novosibirsk (with energy scan)

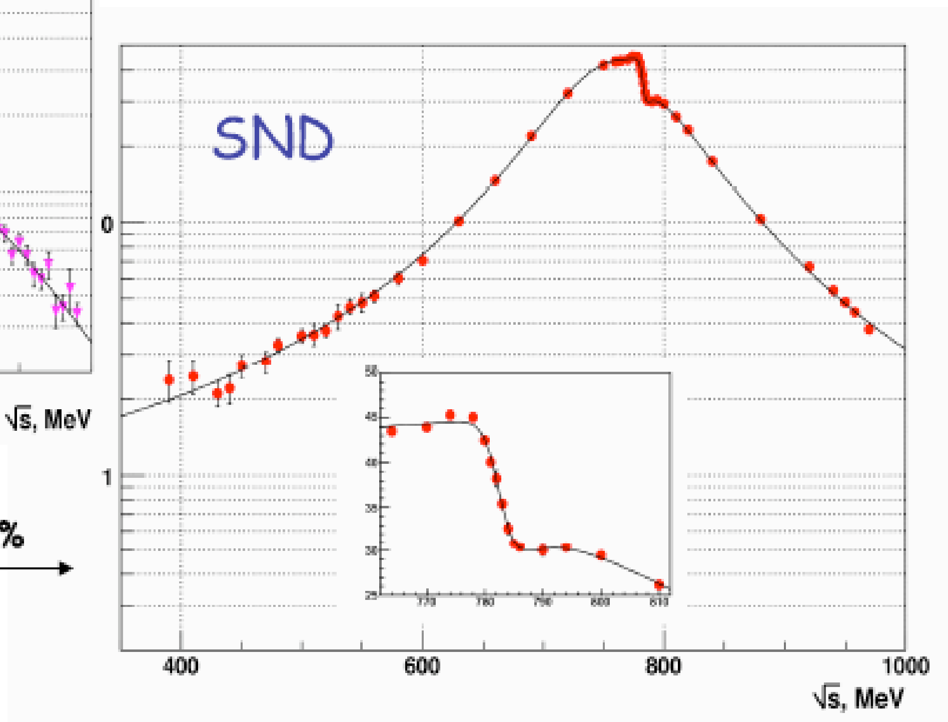


Systematic error

0.7% | 0.6% / 0.8% | 1.2-4.2%

CMD-2 ~ 9·10^5 ev.

SND ~ 8·10^5 ev.

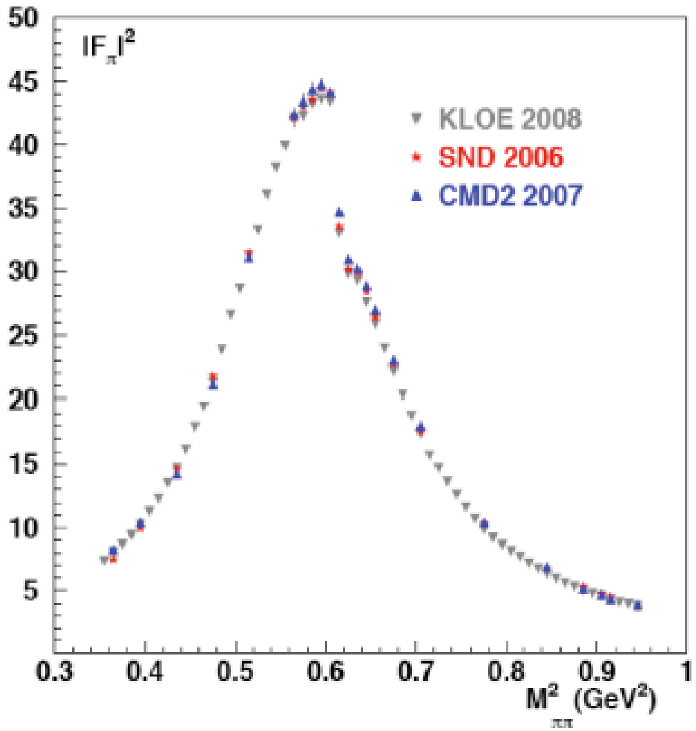


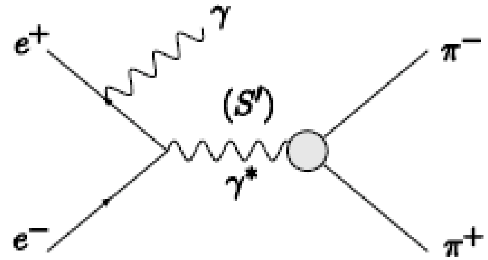
Systematic error

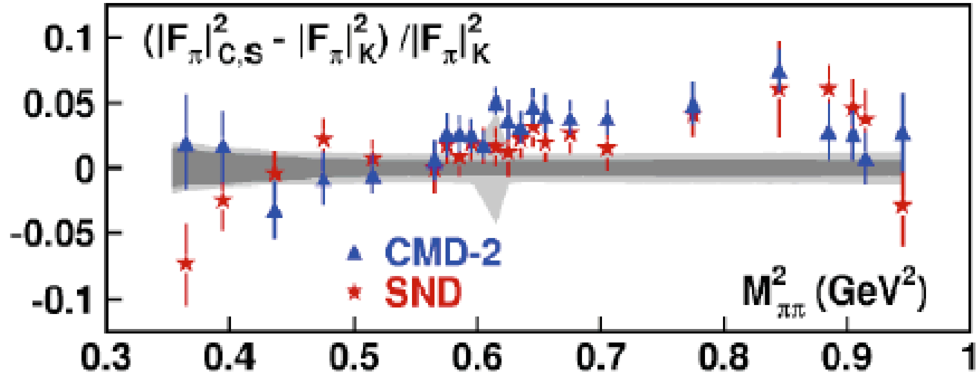
3.2% | 1.3% | 8

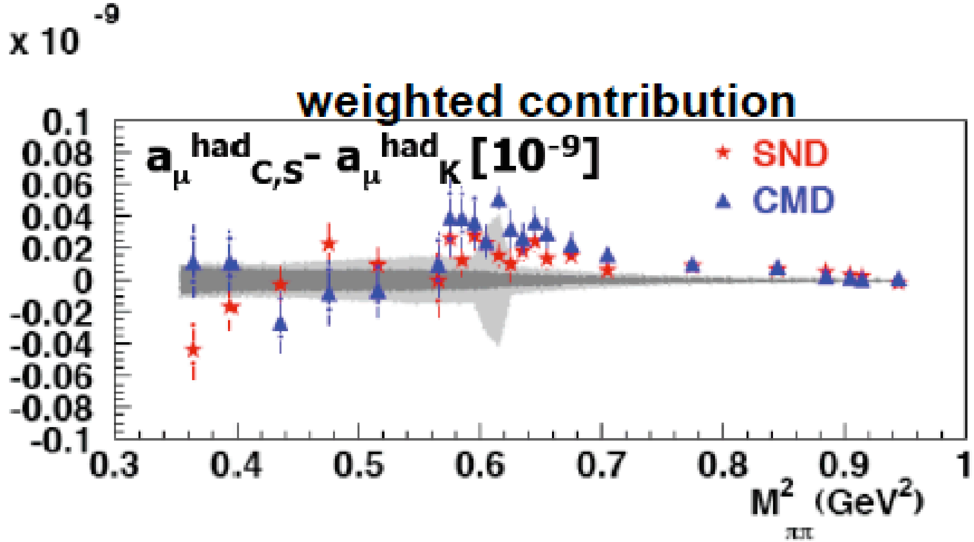
Good agreement between the two spectra

KLOE has pioneered use of ISR for a_μ









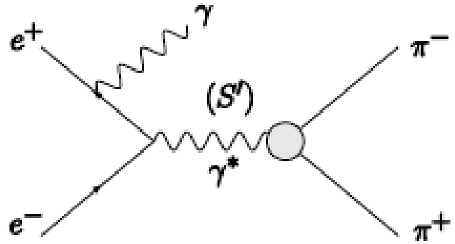
$$\sigma_{e^+e^-\to\pi^+\pi^-} = \frac{\pi\alpha^2}{3s}\beta_\pi^3|F_\pi|^2$$

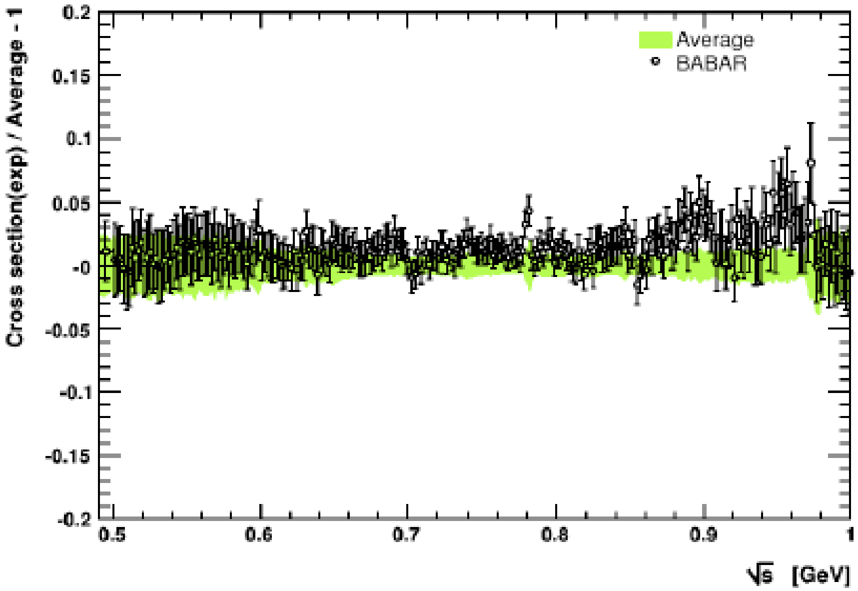
- Fantastic statistical precision
- KLOE agrees with direct CMD2 & SND

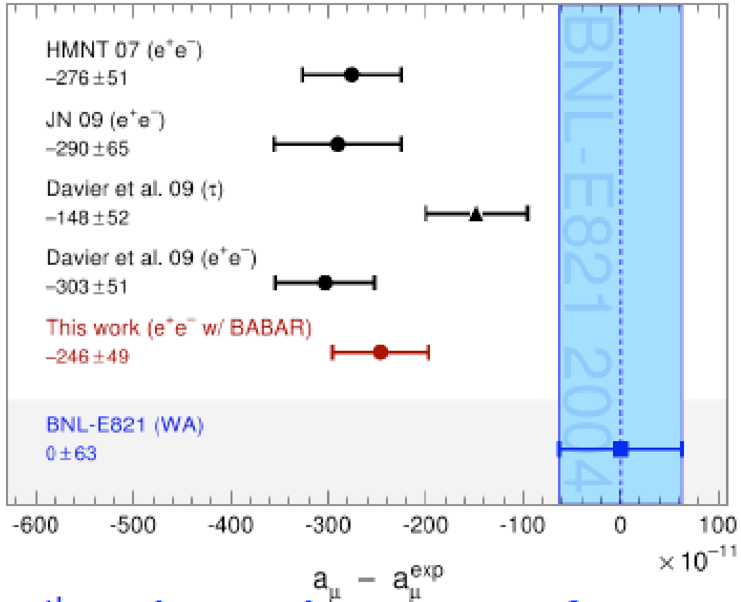
From C. Polly (FNAL)

New results from Babar! Also using ISR for a_μ

- Very interesting new result
- Only 2nd expt to use ISR for muon g-2 input







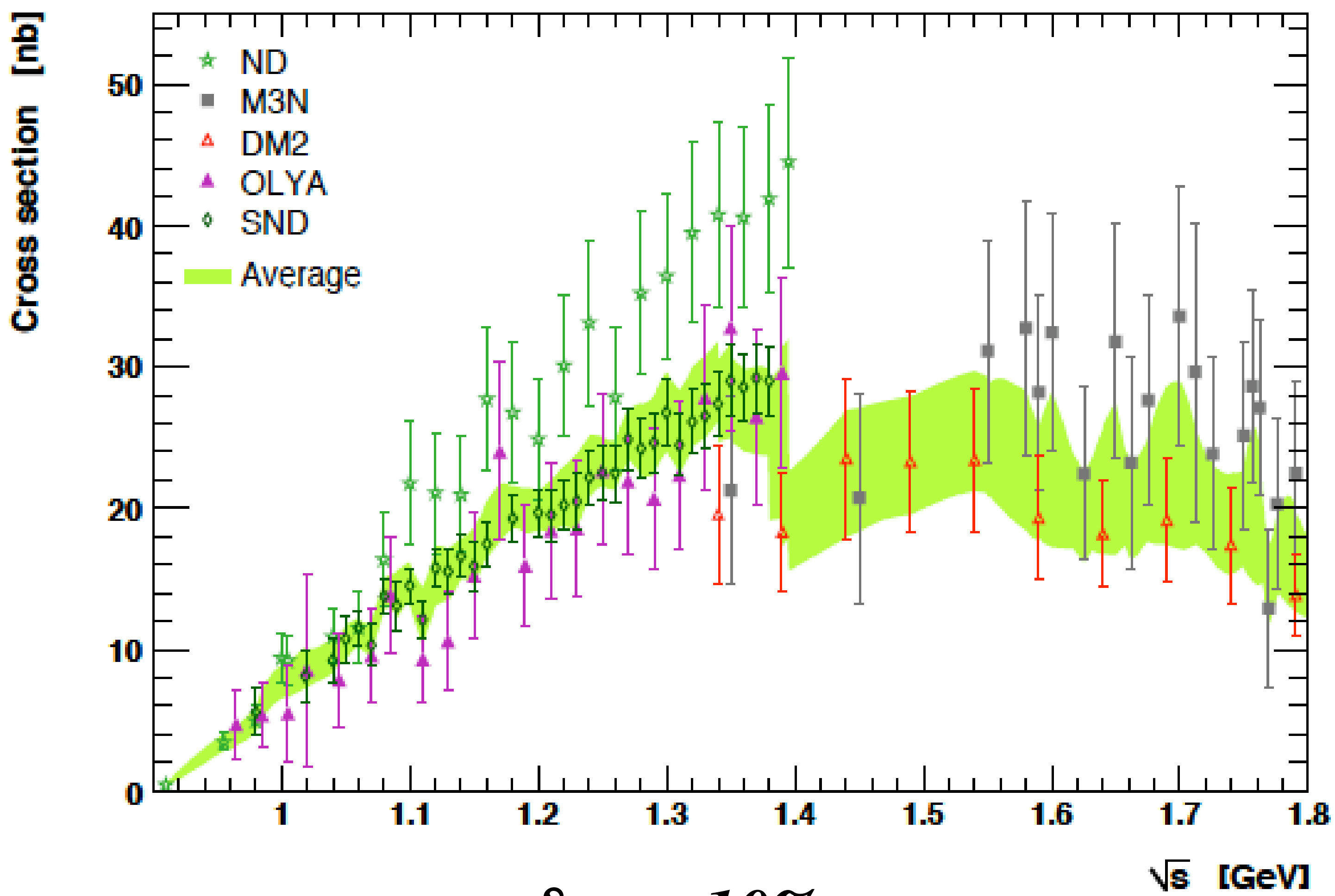
So now Babar had provided a 4th independent vote of confidence in theory…good, need that to extract new physics

$$a_\mu^{had} = 6955(41) \times 10^{-11}$$

From C. Polly (FNAL)

Above 1 GeV

Example: $\sigma(e^+e^- \rightarrow \pi^+\pi^-2\pi^o)$



$\delta\sigma_{sys}$~10%

DAFNE-2 can well improve this situation ($\rightarrow\delta\sigma_{HAD}$ ~ 2%)

Impact of DAFNE-2 on $(g\text{-}2)_\mu$

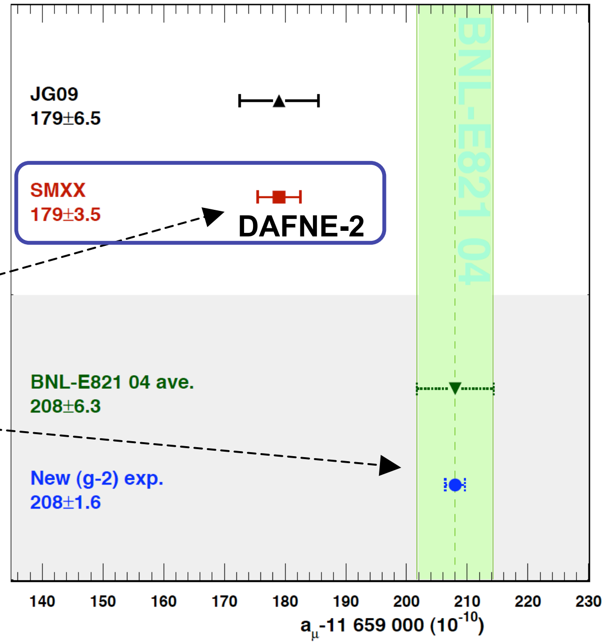
$a_\mu^{exp} - a_\mu^{theo,SM} = (27.7 \pm 8.4)10^{-10}$ (3.3σ) [Eidelman, TAU08]

$8.4 = \sim 5_{HLO} \oplus \sim 3_{HLbL} \oplus 6_{BNL}$

4 $\quad$ **2.6**$_{DAFNE\text{-}2}$ $\quad$ 2.5 $\quad$ $1.6_{NEW\ G\text{-}2}$

7-8σ

(if 27.7 will remain the same)



$\delta a_\mu^{HLO} = 5.3 = 3.3(\sqrt{s}<1GeV) \oplus 3.9(1<\sqrt{s}<2GeV) \oplus 1.2(\sqrt{s}>2GeV)$

$\delta a_\mu^{HLO} \rightarrow$ **2.6**$=1.9\ (\sqrt{s}<1GeV) \oplus$ **1.3 ($\sqrt{s}$<1GeV)** $\oplus 1.2(\sqrt{s}>2GeV)$

This means:

$\delta\sigma_{HAD}$ ~ 0.4% $\sqrt{s}$<1GeV (instead of 0.7% as now) *With ISR at 1 GeV*

$\delta\sigma_{HAD}$ ~ 2% 1<$\sqrt{s}$<2GeV (instead of 6% as now) *With Energy Scan 1-2 GeV*

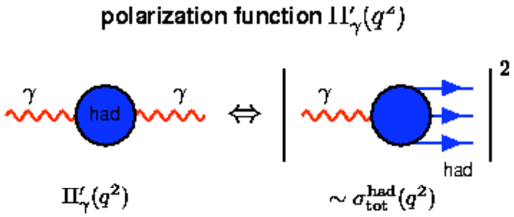
Possible at DAFNE-2!

Precise measurement of σ_{HAD} at low energies very important also for $\alpha_{em}(M_Z)$ (necessary for ILC) !!!

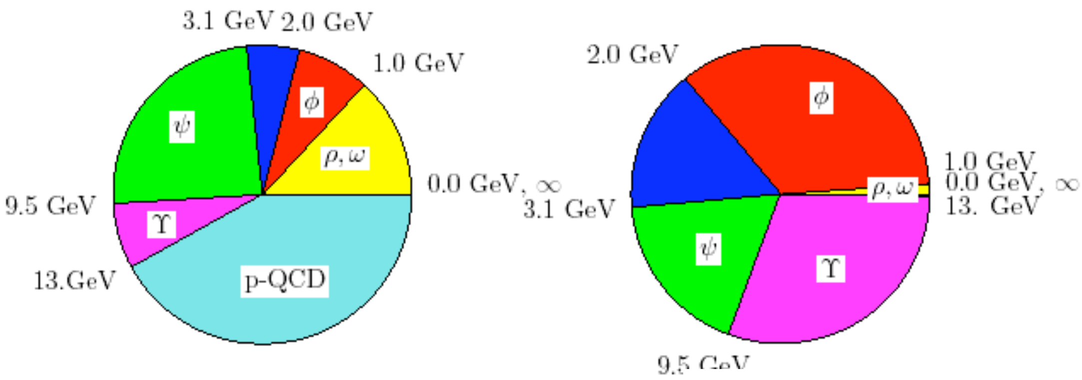
Effective fine structure constant $\alpha_{em}(M_Z)$

$$\alpha(M_Z) = \frac{\alpha(0)}{1 - \Delta\alpha(M_Z)}$$

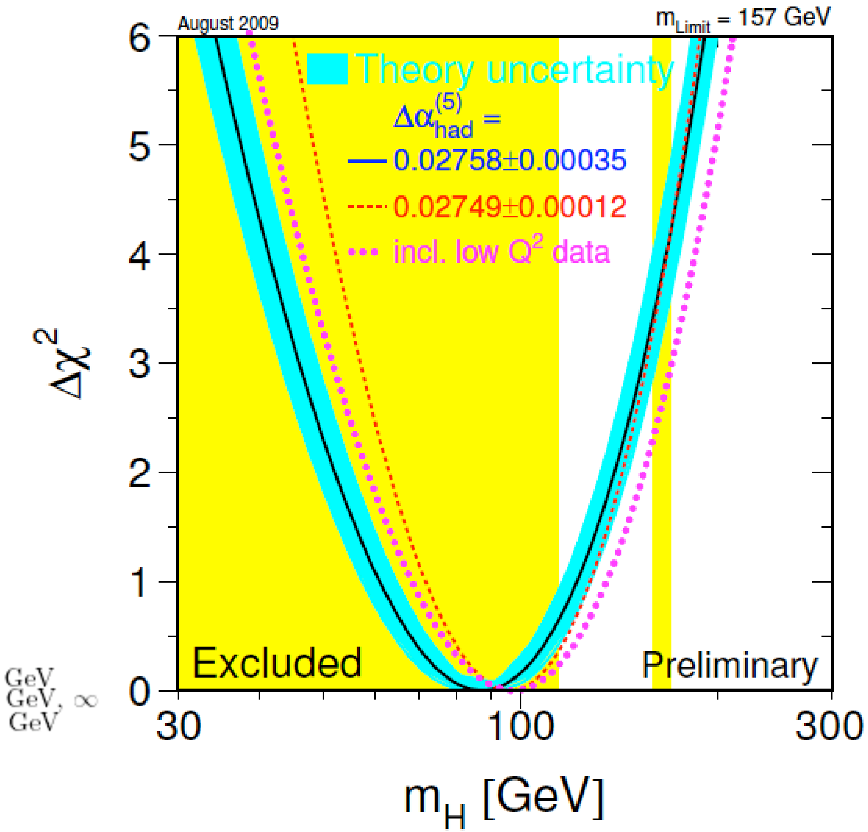
$\Delta\alpha = \Delta\alpha_l + \Delta\alpha^{(5)}_{had} + \Delta\alpha_{top}$



$$\Delta\alpha^{(5)}_{had}(M_Z^2) = -\frac{\alpha M_Z^2}{3\pi}\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s - M_Z^2 - i\varepsilon)}$$



$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $\delta^2\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$



$$\Delta\alpha^{(5)}_{had}(M_Z^2) = 0.027607 \pm 0.000225$$

$$\alpha^{-1}(M_Z^2) = 128.947 \pm 0.035$$

FJ08

$\delta\alpha(M_Z)/\alpha(M_Z) \sim 2 \div 7\times10^{-4} \rightarrow 5\times10^{-5}$ Requirement from ILC (6x improvement)

Which contributions on $\alpha_{em}(M_Z)$ from DAFNE-2?

The running fine structure constant $\alpha(E)$ via the Adler function

F. Jegerlehner[a b * c †]

Nucl.Phys.Proc.Suppl.181-182:135-140 2008

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[b]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstrasse 15, D-12489 Berlin, Germany

[c]Deutsches Elekronen-Synchrotron DESY, Platanenalle 6, D-15738 Zeuthen, Germany

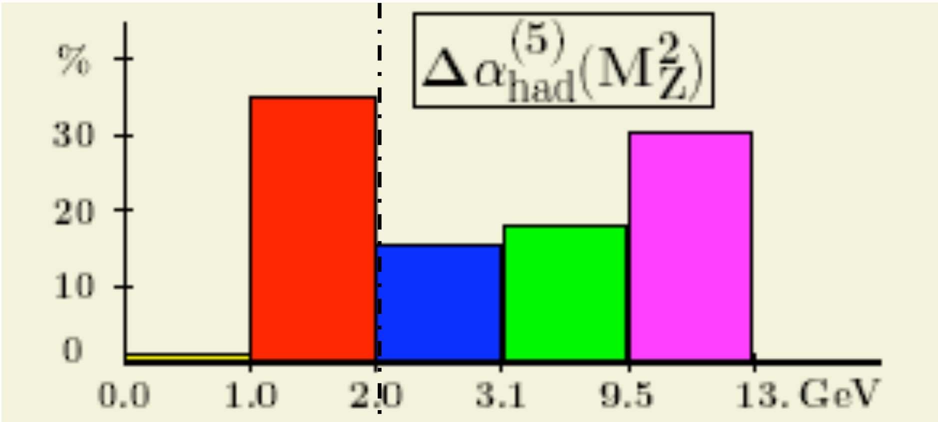
We present an up-to-date analysis for a precise determination of the effective fine structure constant and discuss the prospects for future improvements. We advocate to use a determination monitored by the Adler function which allows us to exploit perturbative QCD in an optimal well controlled way. Together with a long term program of hadronic cross section measurements at energies up to a few GeV, a determination of $\alpha(M_Z)$ at a precision comparable to the one of the Z mass M_Z should be feasible. Presently $\alpha(E)$ at $E > 1$ GeV is the least precisely known of the fundamental parameters of the SM. Since, in spite of substantial progress due to new BaBar exclusive data, the region 1.4 to 2.4 GeV remains the most problematic one a major step in the reduction of the uncertainties are expected from VEPP-2000 [1] and from a possible "high-energy" option DAFNE-2 at Frascati [2]. The up-to-date evaluation reads $\Delta\alpha^{(5)}_{\rm had}(M_Z^2) = 0.027515 \pm 0.000149$ or $\alpha^{-1}(M_Z^2) = 128.957 \pm 0.020$.

" In any case as we see from Fig. 4 by far the largest improvement factor will come from precise cross–section measurements in the region from 1.4 to 2.4 GeV. A unique challenge and chance for VEPP-2000 and DAFNE-2. "

Comparison of error profiles for $\alpha_{em}(M_Z)$

Direct integration of energy points

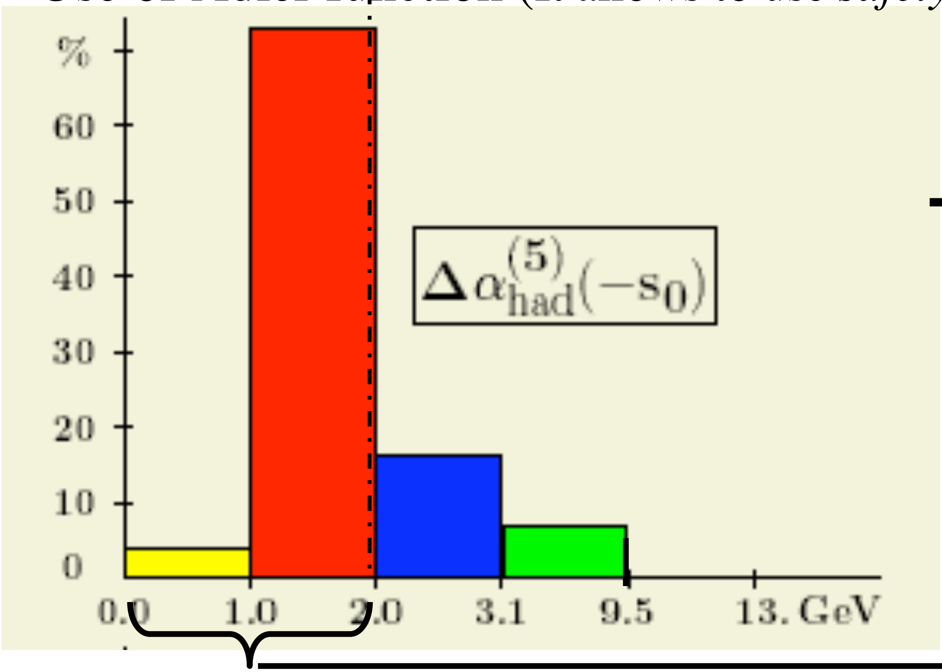
F. Jegerlehner, Nucl. Phys. B 181-182 (2008) 135



$\delta\sigma$ at 1% in the region **√s < 10 GeV**

⇒ improvement of ~**3** in $\delta\alpha(M_Z)$

Use of Adler function (It allows to use *safely* pQCD down to 2.5 GeV)



1% in the region 1<√s < 2.5 GeV

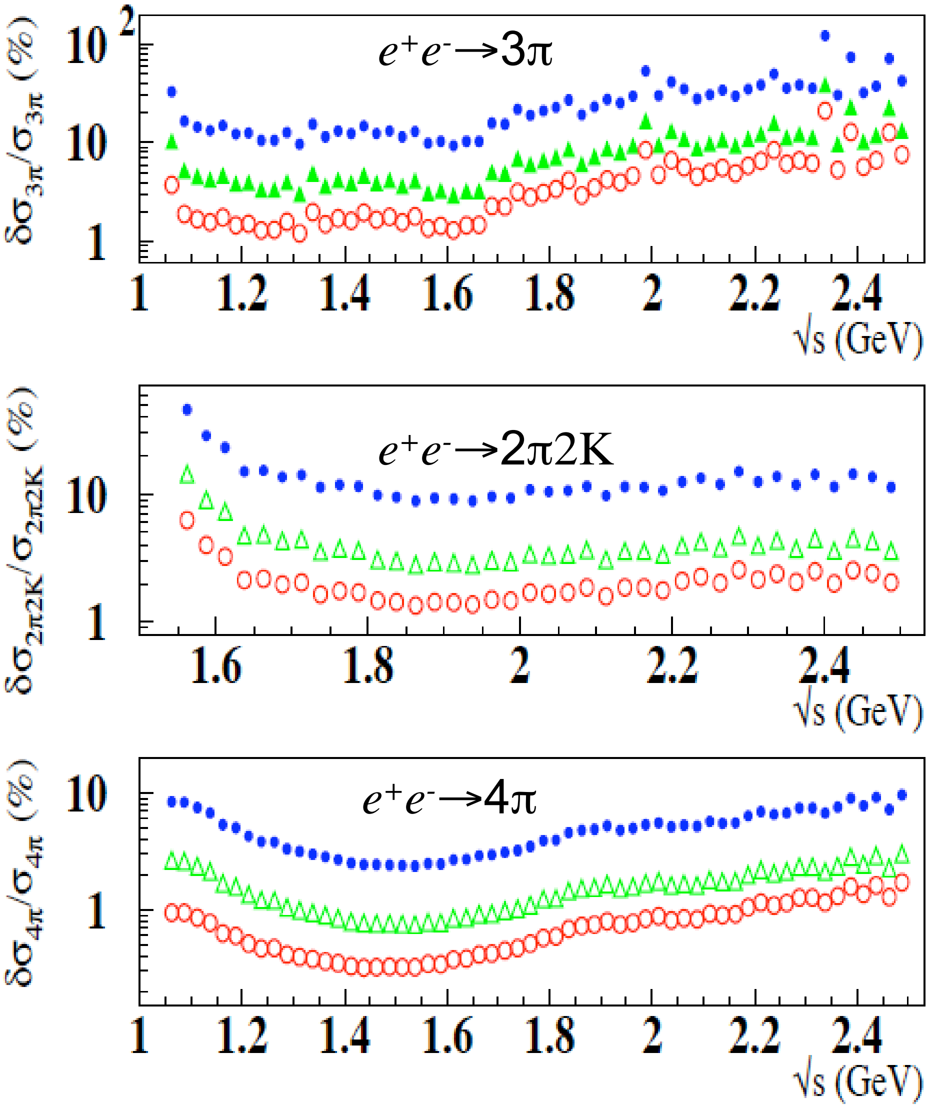
⇒ improvement of ~5 on $\delta\alpha(M_Z)$

$2m_\pi$<√s < 2 GeV

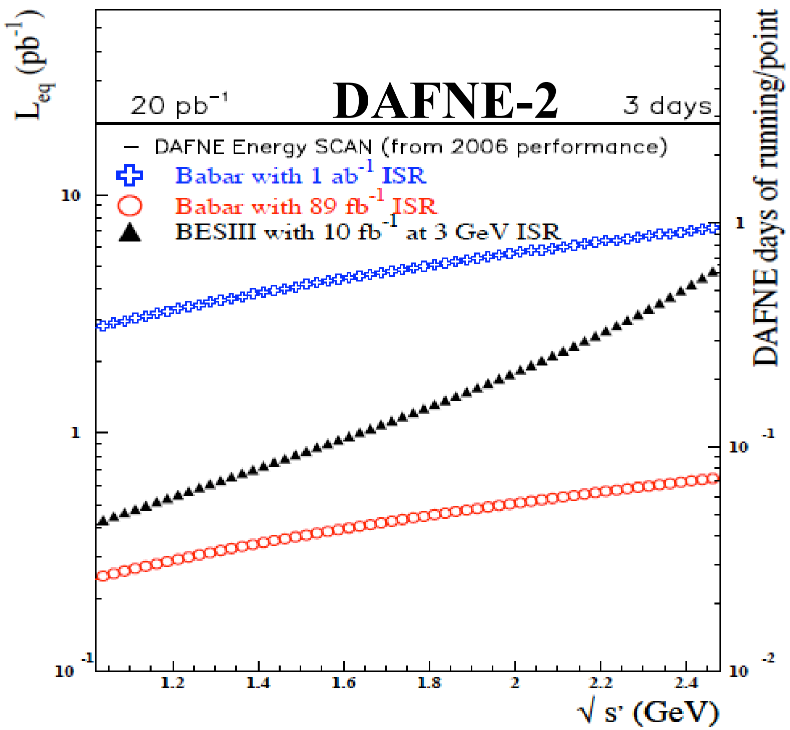
Extremely important:

- **80%** of $\delta\Delta\alpha^{(5)}_{had}$ (using Adler function)
- **95%** of δa_μ

Impact of DAFNE-2 on exclusive channels in the range [1-2.5] GeV with a scan (Statistics only)



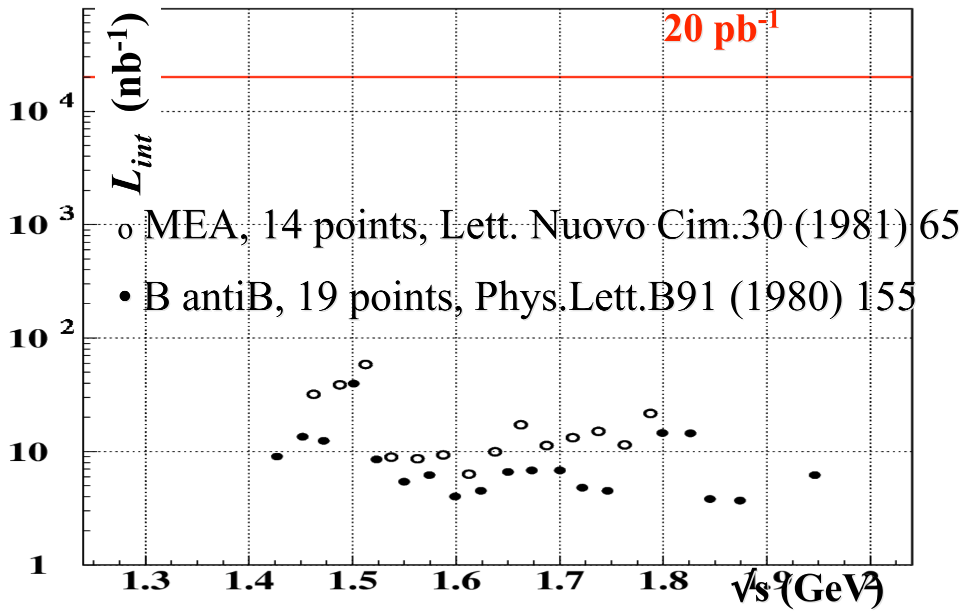
- **Published BaBar results: 89 fb^{-1} (ISR)**
- ▲ **"BaBar" × 10 (890 fb^{-1})**
- o **KLOE-2 energy scan: 20 pb^{-1}/point @ L= 10^{32} cm^{-2} s^{-1}, 25 MeV bin ⇒ 1 year data-taking**



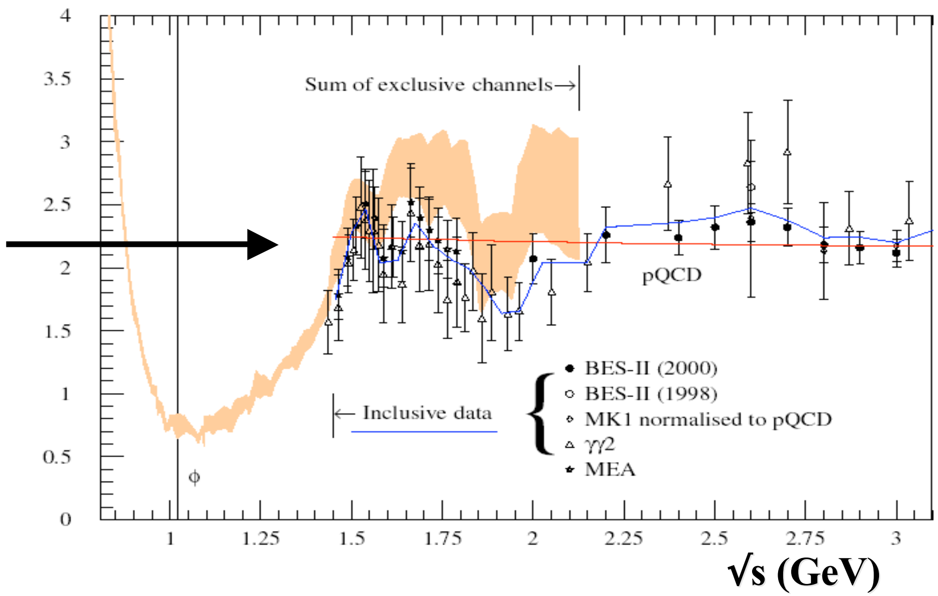
DAFNE-2 is **statistically** equivalent to 5÷10 ab^{-1} (Super)B-factory

Impact of DAFNE-2 on inclusive measurement

1) Most recent inclusive measurements: MEA and B antiB, with **total** integrated luminosity of **200 nb^{-1}** (one hour of data taking at 10^{32} cm^{-2} sec-1).**10% stat.+ 15% syst. Errors**

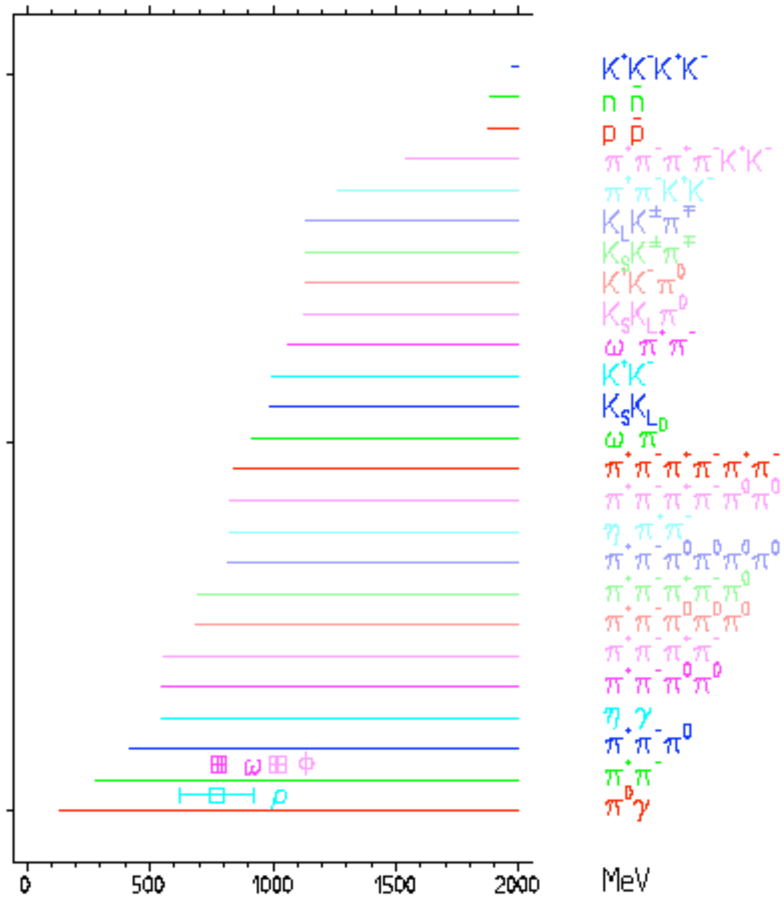


2) With 20 pb^{-1} per energy point (1year of data taking at 10^{32} cm^{-2} sec^{-1}) a **precise** comparison exclusive vs. inclusive can be carried out



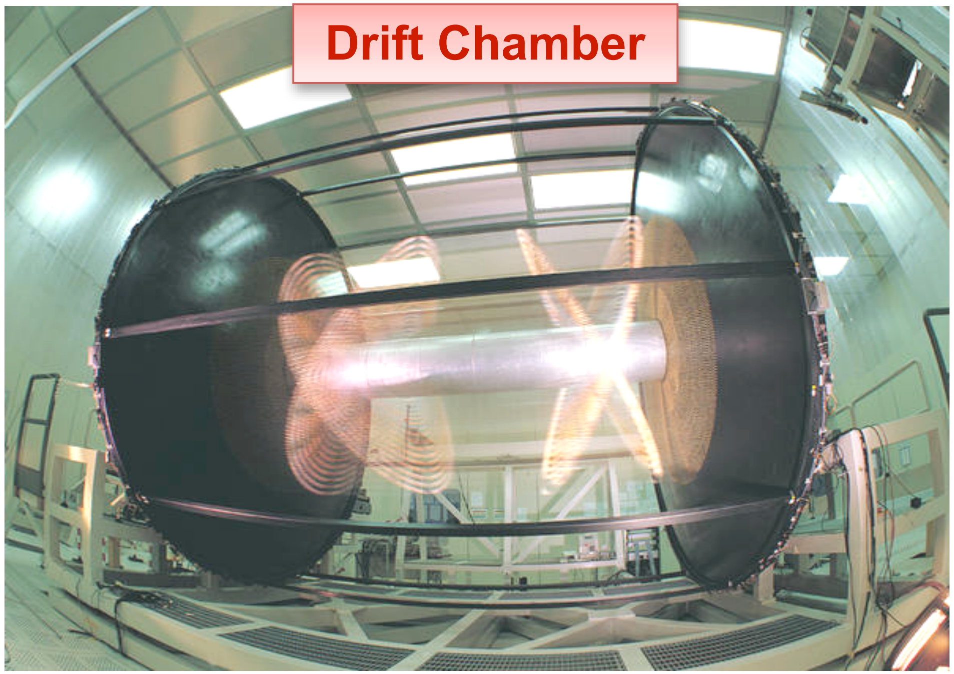
Can KLOE-2 measure σ_{HAD} with 1% error in the region 1-2 GeV?

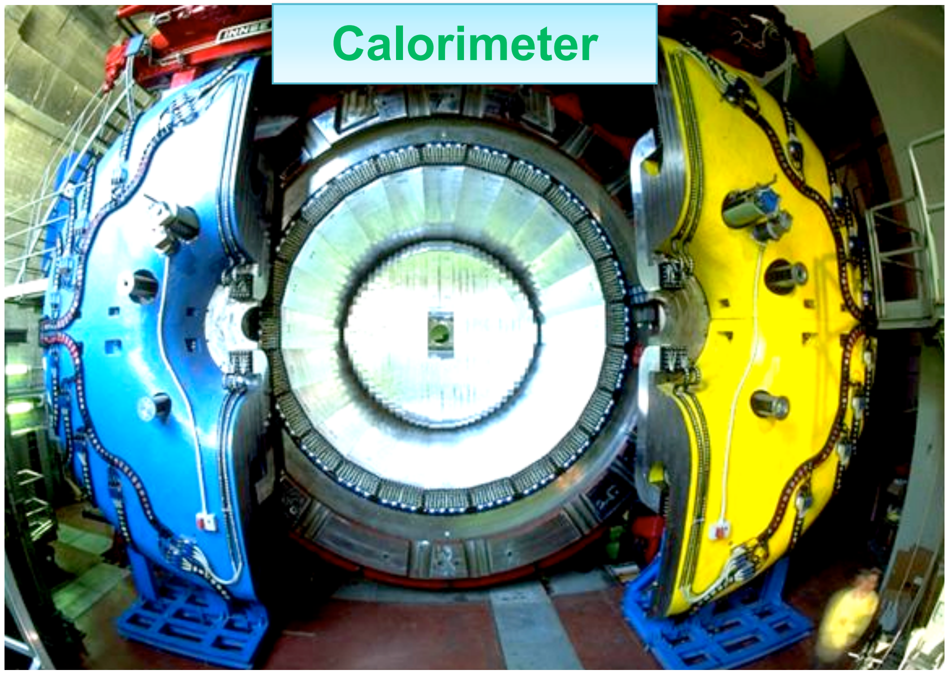
- Not easy task ⇒
- Statistics OK @ 10^{32}cm^{-2} sec^{-1} (scan)
- Systematics most likely under control, given the excellent performance of KLOE+inner tracker
- Precise determination of beam energy would help (using BS Compton)
- Exclusive vs inclusive?



KLOE-2 looks a perfect detector for these measurements, although a detailed Monte Carlo study must be done

From KLOE…





Multi-purpose detector optimized for K_L physics

- Huge, transparent Drift Chamber in 5.2 kGauss field of a SC coil
- Carbon fiber walls, 55000 stereo wires, 2 m radius, 4 m long, He/CO_2 gas mixture
- Momentum resolution: $\sigma(p_T)/p_T \sim 0.4\%$

- Pb-Scintillating Fiber Calorimeter with excellent timing performance
- 24 barrel modules, 4 m long and C-shaped End-Caps for 98% solid angle coverage
- Time resolution: $\sigma_T = 54\ \text{ps} / \sqrt{E(\text{GeV})} \oplus 50\ \text{ps}$
- Energy resolution: $\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$

…to KLOE-2…

Minimal detector upgrades:

- Tagger for γγ physics: to detect

  off-momentum $e^{\pm}$ from

  $$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$$

— LET: Low Energy Tagger (130-230 MeV)

calorimeters, LYSO + SiPM

— HET: High Energy Tagger (E > 400 MeV)

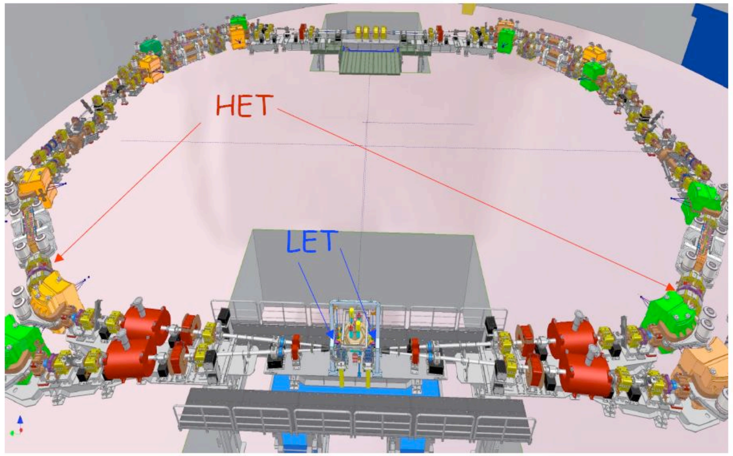
position sensitive detectors

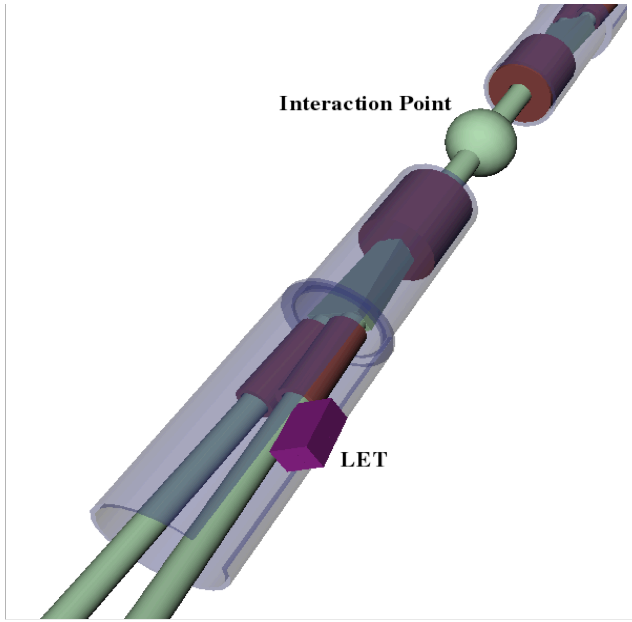
(strong energy-position correlation

⇒ use the DAΦNE magnets as $e^{\pm}$ spectrometer)

- Already funded by INFN

Approved ⇒ "roll-in": Summer 2010





…to KLOE-2…

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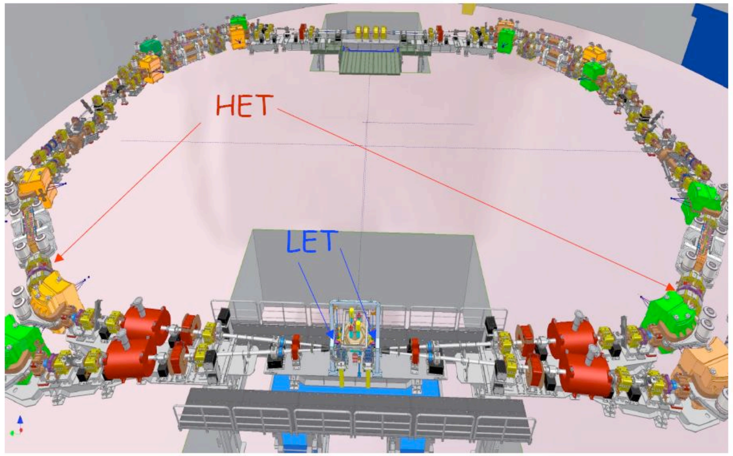
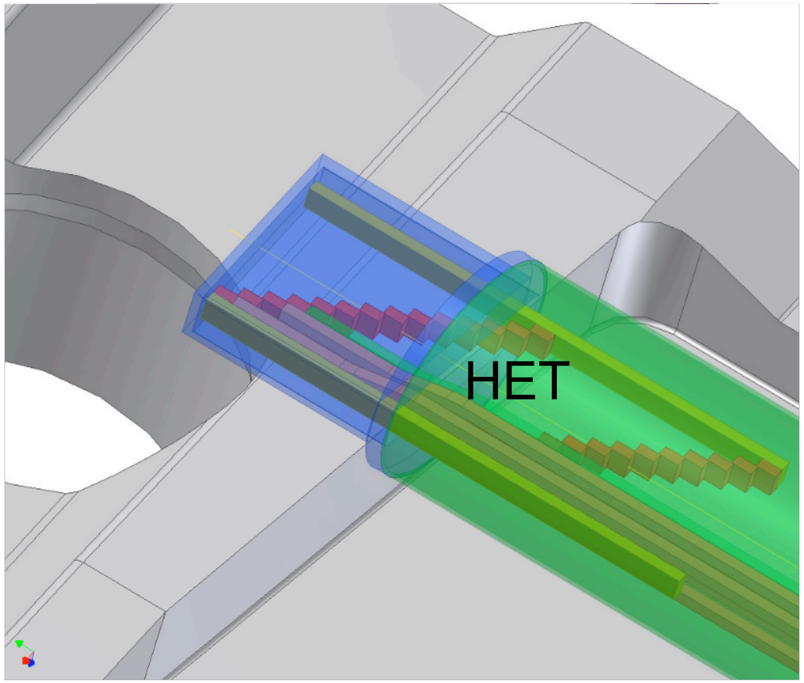


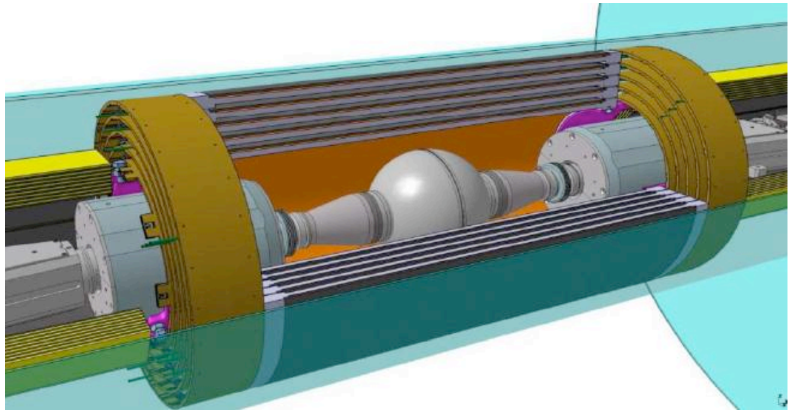


…to KLOE-2…

Major detector upgrade

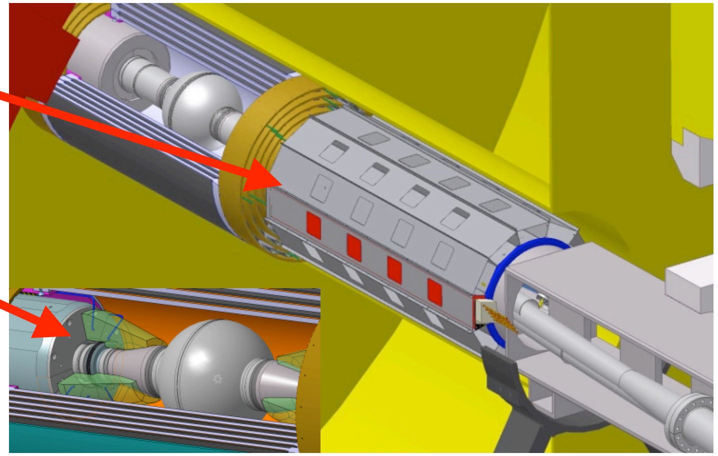
- Inner tracker (between the beam pipe and the DC): 4 layers of cylindrical triple GEM:

— improve vertex reconstruction near the IP



- QCALT: W + scint. tiles

  readout by SiPM via WLS fibers



- CCAL: LYSO crystals + APD; close to IP to increase acceptance for photons coming from the IP (min. angle: 21°→ 9°)
- Partially funded

  Time scale: installation in late 2011

Inner Tracker: the C-GEM project (novel technology developed at LNF)

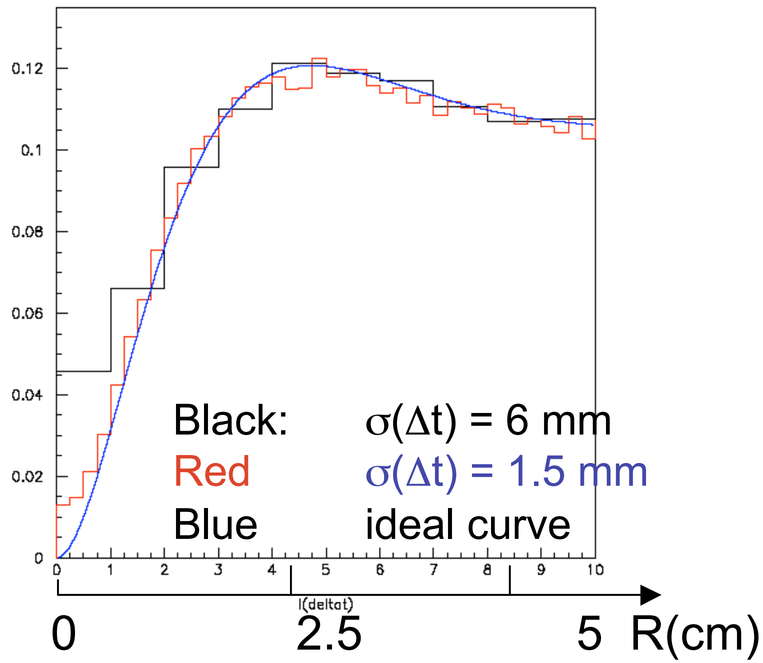
- Improve vertex reconstruction (of a factor 3 for $K_S \rightarrow \pi\,\pi$ from (present 6mm))
- Improve acceptance for low-Pt tracks
- Light material in order to minimize m.s. and γ absorbition

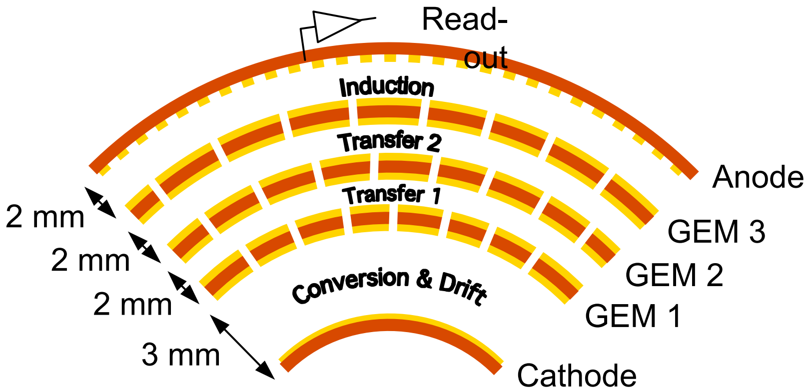
$\rightarrow$Cylindrical triple GEM

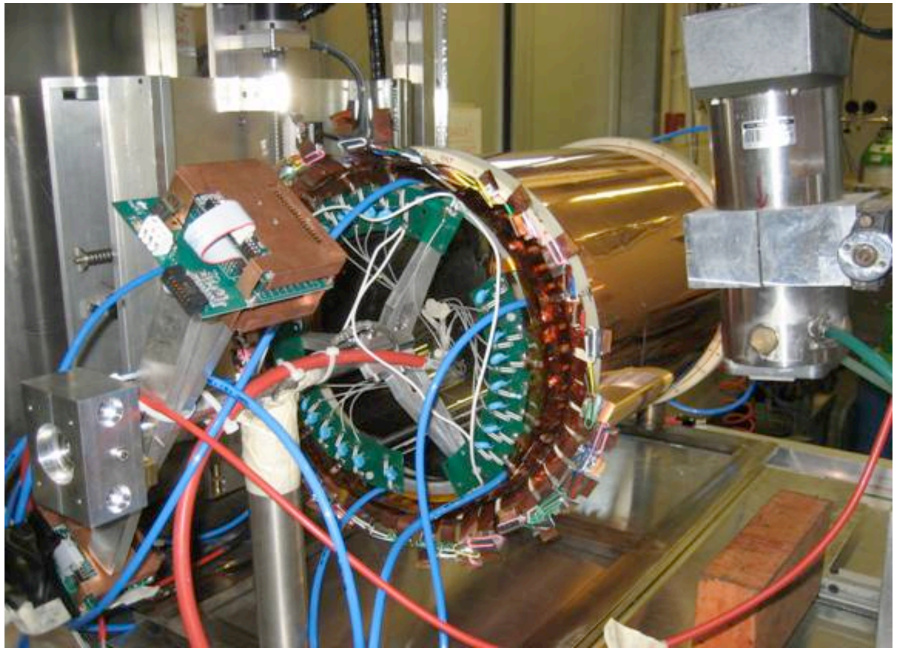
(G.Bencivenni et al.)

$\sigma(r\phi)$ = 200 μm

$\sigma(z)$ = 500 μm



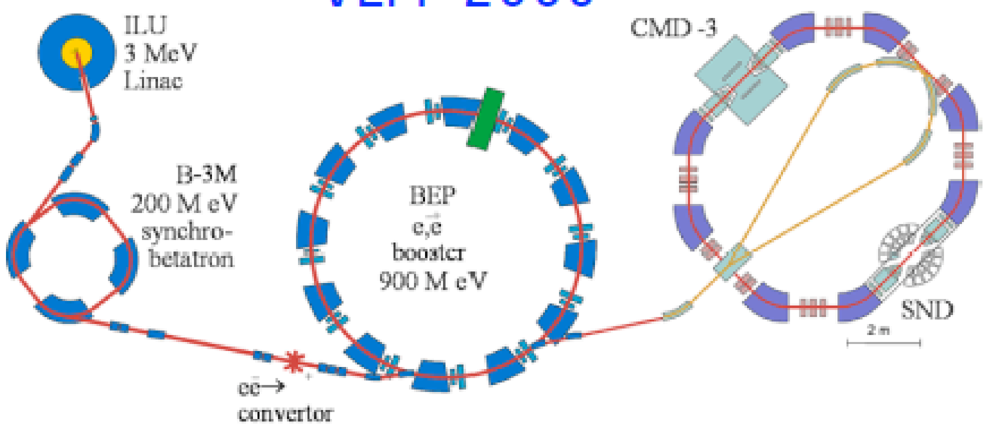




Very important also for multihadronic cross section!

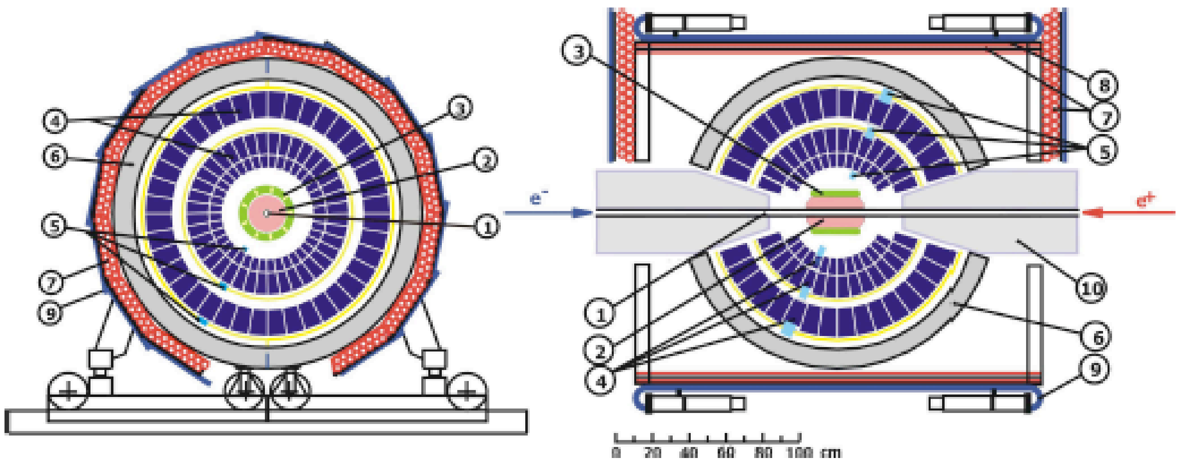
Comparison of DAFNE-2 with VEPP2000

VEPP-2000

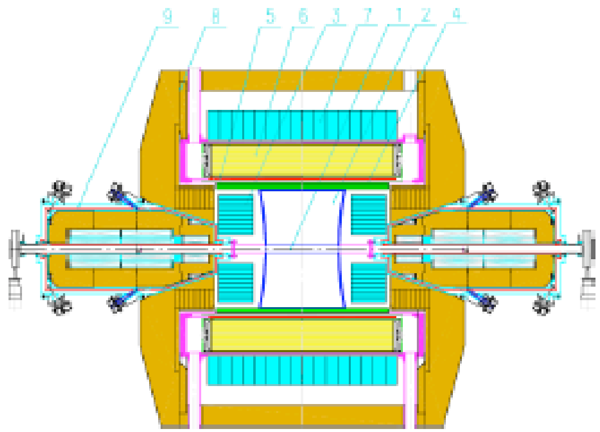


- Novosibirsk upgrades
  - Factor of 10-100 in stats, > 10 from luminosity alone
  - Energy extend range up to 2 GeV
  - Starting this year!!!
- More ISR results from KLOE & Babar, maybe Belle
- Note a 40% reduction in LOHVP will make HLBL the largest theory error

SND2000



CMD3



From C. Polly, at " Lattice QCD meets experiment", FNAL, 26 Apr 2010

From P. Lukin presentation at LNF, July 8 2010

Experimental requirements

- High detector hermeticity to provide good acceptance
- Good $e^{\pm}/\mu^{\pm}/\pi^{\pm}$ separation for two-body channels
- γ, $\pi^{\pm}(K^{\pm})$, $p(n)$ identification, reconstruction of $\pi^0, \eta, K_S^0, \Lambda$
- L=10^{31} cm^{-2} s^{-1}, ε =10%
- Broad resonances, $\Gamma \sim$ (150–300) MeV, possible Δ_{2E}=25 MeV
- At 2 GeV $\sigma_{\text{min}} \sim 0.2$ nb (K^+K^-, K_SK_L). Its 10% measurement $\Rightarrow$ 5 pb^{-1} per point. Most probable $(4\pi, 6\pi)$ processes have $\sigma \sim 5$ nb, at 5 pb^{-1} per point stat. precision $\sim 2\%$.
- At lower energies dominant channels have larger σ
- At 60 points from 1 to 2.5 GeV about 300 pb^{-1} needed – 1 year of continuous running

DAFNE-2 is 10 times better!

Conclusions

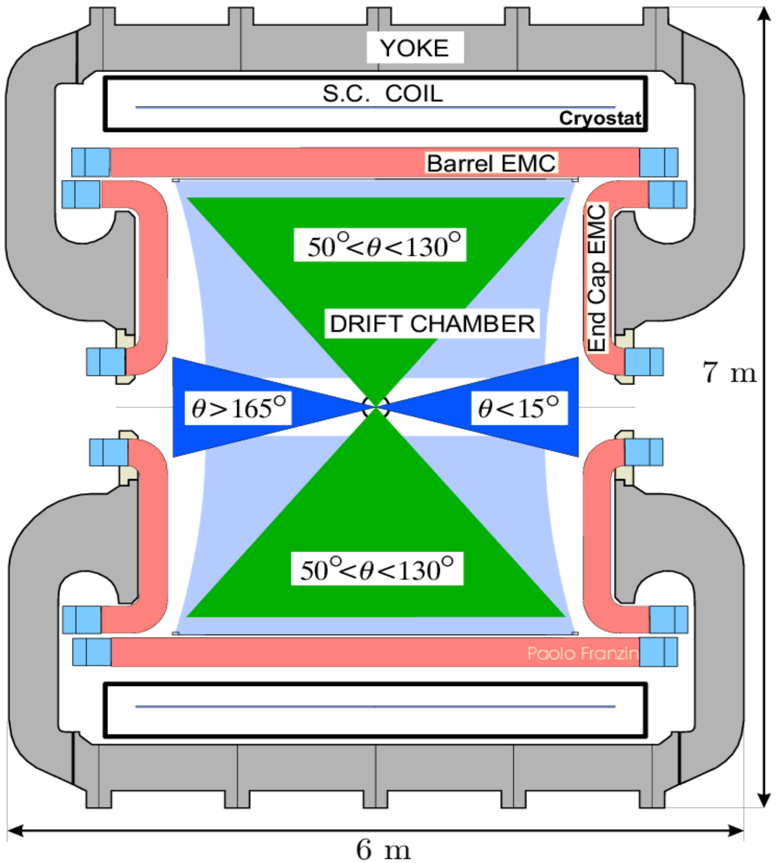
- Despite the recent progress, the region between 1 and 2.5 GeV is still poorly known (fractional accuracy~6%). KLOE-2 at DAFNE-2 can reduce this error at **1-2%**, which would have a dramatic impact on the precision tests of the SM via **$(g-2)_\mu$** and **$\alpha_{em}(M_{Z0})$**

- This region is also very relevant for other important physics topics (see Gino's presentation)

- DAFNE-2 at 10^{32} cm^{-1} sec^{-1} is statistically much better than direct competitors (VEPP-2000) and ISR at existing machines (BaBar, Belle, BESIII): an energy scan in the region 1-2.5 GeV would be equivalent to 5-10 ab^{-1} (Super)B-factories with ISR

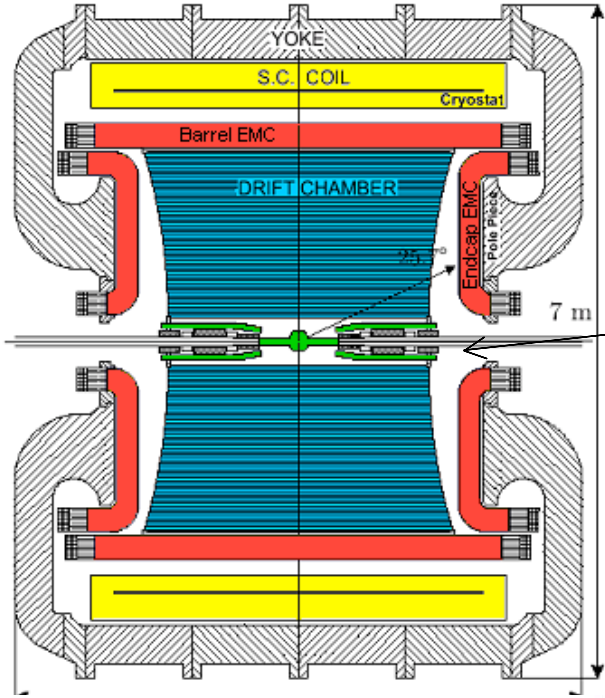
- KLOE-2 detector looks well suited for this program

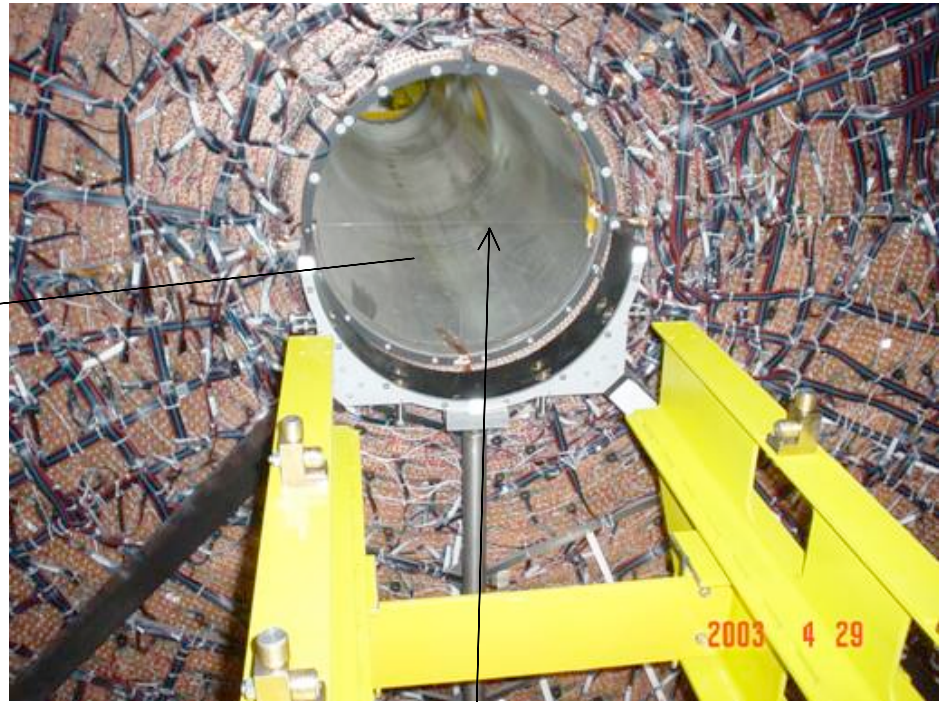
- This program can be done with a moderate upgrade of DAFNE (see Pantaleo's presentation)

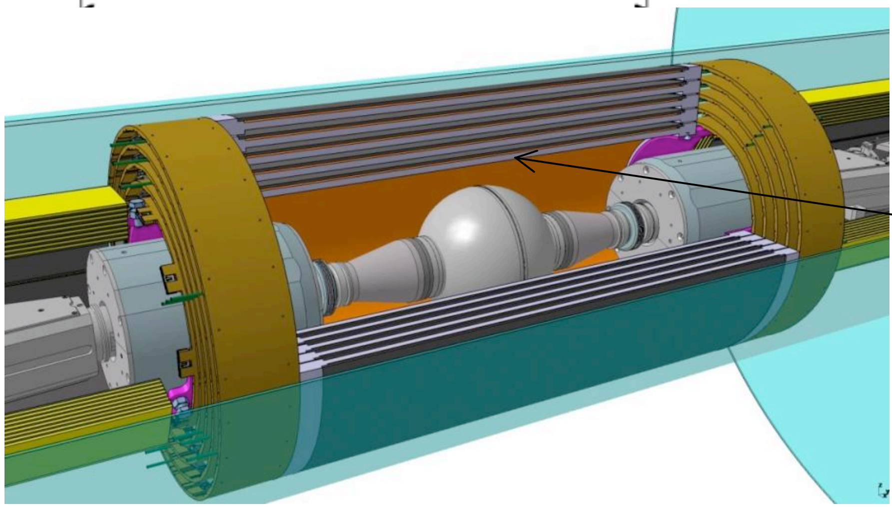


SPARE SLIDES

The Inner Tracker







IT to be inserted inside KLOE

- Inner radius **127 mm** (20 τ_s) to preserve K_L-K_s interference region
- Outer radius **215 mm** for safe installation inside the DC

σ_{HAD} < 1 GeV: CMD-2,SND,KLOE, BaBar

Current error: $\delta\sigma_{HAD}$ =0.7%

σ_{HAD} 1 - 2 GeV: CMD-2,SND, BaBar, Belle

Current error $\delta\sigma_{HAD}$ ~3-15%

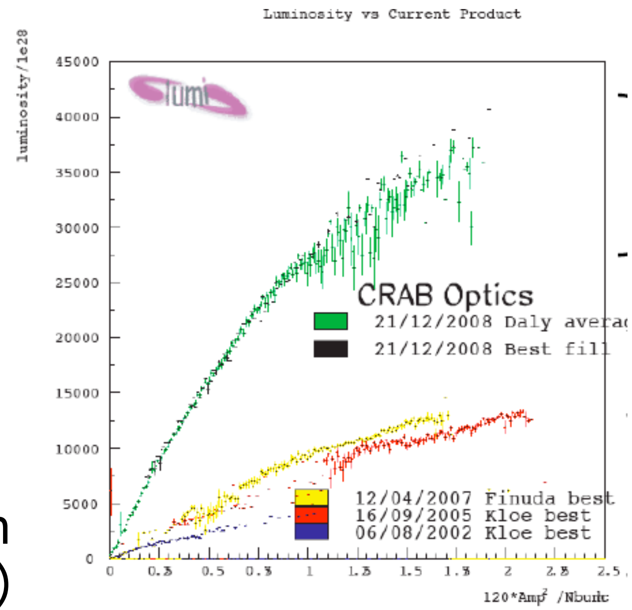
This is where DAFNE-2 can play an important role

How DAFNE-2 can improve the situation on (g-2)μ?

KLOE-2 at upgraded DAΦNE

Crabbed waist scheme at DAΦNE (P. Raimondi)

- increase L by a factor *O*(5)
- requires minor modifications
- relatively low cost



KLOE-2:

Extended KLOE physics program at DAFNE upgraded both in **luminosity** O(20 fb^{-1}) and **energy** ($2m_\pi<\sqrt{s}<2.4$ GeV)

Physics issues:

- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- γγ physics
- η,η', light scalar physics
- Search for new physics at O(1 GeV)
- Hadronic cross section at low energy

Detector upgrades:

- γγ tagging system (already funded)
- Inner tracker (partially funded)
- Calorimeters in forward directions (partially funded)
- Computing and networking upgrades

Already approved the first 3 years at ϕ peak (data taking will start soon)

DAFNE Energy upgrade scheme (P. Raimondi)

- Dafne injection scheme limits the beam energy to 540 MeV. An increase of this energy requires major changes, and seems not feasible.

  ⇒ The most reasonable solution is to inject in Dafne at the "nominal" energy of about 510MeV and then ramp the energy up to desired one

  The Quad's around the interaction region must be replaced by superconductive ones (now they are permanent)

  ⇒ In this way 1.4 GeV total energy can be reached.
- In order to achieve higher energy (2 GeV) the dipoles in the main rings must be replaced.
- Assuming $L \sim 10^{32}\ cm^{-2}\ s^{-1}$ and 50% duty cicle (due to ramping time) →$5 pb^{-1}$/day can be reached ($1 fb^{-1}$/year).
- Cost estimate: O(10) Meur (up to ~2 GeV)

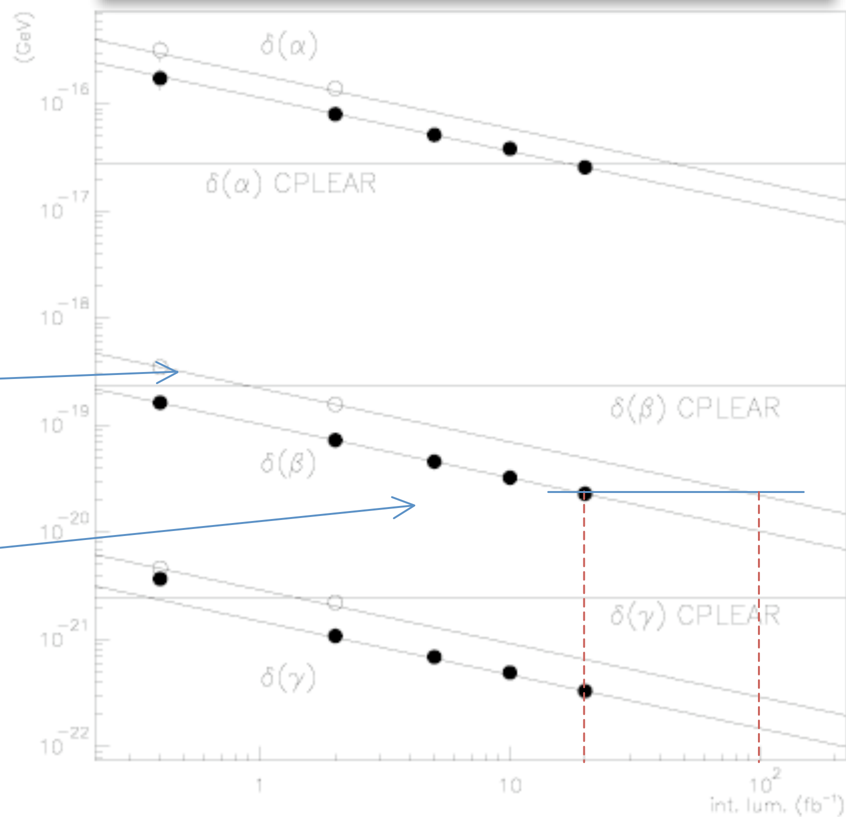
  Needs a detailed work

Need for an Inner Tracker

Simulation results for a π track from $K_S \to \pi\pi$

	Δx @pca	Δz @pca	Δp_x @pca	Δx @vertex
IT	0.6 mm	0.9 mm	1.2 MeV/c	1.9 mm
No IT	1.7 mm	2.2 mm	1.6 MeV/c	4.9 mm

Sensitivity on CPT violation parameters on K^0 interference (αβγ)



KLOE measurement ($\sigma_{\Delta t} = \tau_S$)

KLOE-2 prevision ($\sigma_{\Delta t} = 0.25\ \tau_S$)

Factor of 10 improvement of present error feasible with **20 fb^{-1}** (100 fb^{-1} needed witout IT)