# KLOE-2 news from CSN1

Erika De Lucia
on behalf of KLOE-2 Collaboration

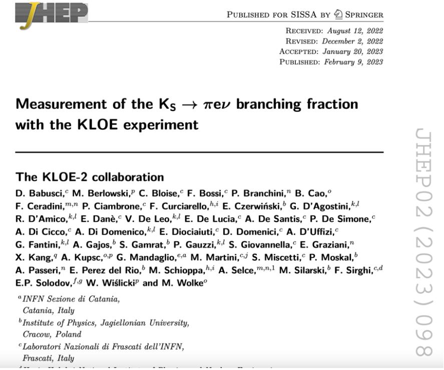
# KLOE-2 Achievements 2023

- Root Output for Data Preservation – KLOE-2 Data almost completed. Next KLOE-2 MC and then KLOE Data and MC

- New group from Liverpool joined KLOE-2 (G.Venanzoni + 2 Staff + 2 Postdoc + 2 PhD) Hadronic cross-section with ISR – Renewed interest after first results from g-2 @ FNAL & CMD-3 hadronic cross-section with energy scan

- Main 2023 physics results:

New measurement of BR($K_S \rightarrow \pi e \nu$) & f+(0) Vus


JHEP

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**Measurement of the $K_S \rightarrow \pi e \nu$ branching fraction with the KLOE experiment**

The KLOE-2 collaboration
D. Babusci,[c] M. Berlowski,[p] C. Bloise,[c] F. Bossi,[c] P. Branchini,[n] B. Cao,[o] F. Ceradini,[m,n] P. Ciambrone,[c] F. Curciarello,[h,i] E. Czerwiński,[b] G. D'Agostini,[k,l] R. D'Amico,[k,l] E. Danè,[c] V. De Leo,[k,l] E. De Lucia,[c] A. De Santis,[c] P. De Simone,[c] A. Di Cicco,[c] A. Di Domenico,[k,l] E. Diociaiuti,[c] D. Domenici,[c] A. D'Uffizi,[c] G. Fantini,[k,l] A. Gajos,[b] S. Gamrat,[b] P. Gauzzi,[k,l] S. Giovannella,[c] E. Graziani,[n] X. Kang,[q] A. Kupsc,[o,p] G. Mandaglio,[e,a] M. Martini,[c,j] S. Miscetti,[c] P. Moskal,[b] A. Passeri,[n] E. Perez del Rio,[b] M. Schioppa,[h,i] A. Selce,[m,n,1] M. Silarski,[b] F. Sirghi,[c,d] E.P. Solodov,[f,g] W. Wiślicki[p] and M. Wolke[o]
[a] INFN Sezione di Catania, Catania, Italy
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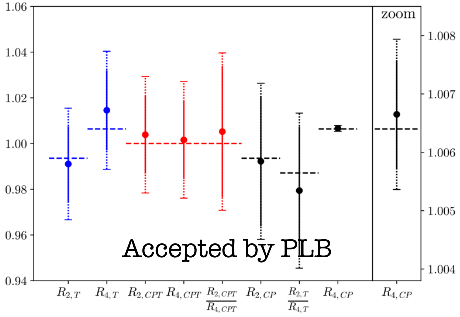
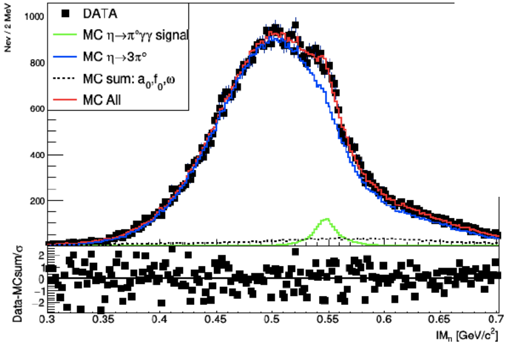
JHEP02(2023)098

Direct tests of T, CP, CPT symmetries in transitions of neutral K mesons with the KLOE experiment



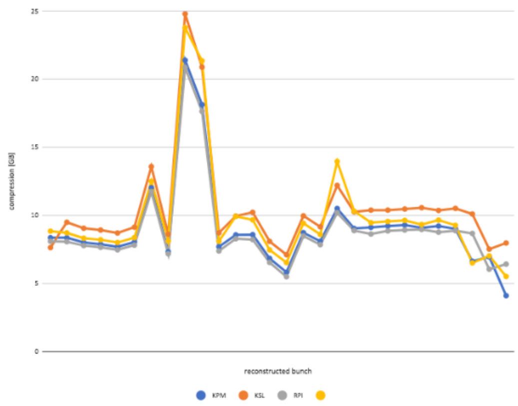

Final result on BR($\eta \rightarrow \pi 0 \gamma\gamma$) $\chi$PT golden mode



# ROOT output for Data Preservation

- Produzione di ROOT files quasi completata per i dati KLOE-2
- Mancano soltanto ~ 400 pb$^{-1}$ della stream dei K neutri
- Fattore di compressione, rapporto Datarec/ROOT ~ 8 (dipende dalle condizioni di run)

**Fattore di compressione: Datarec/ROOT size**




**Piano per la produzione di ROOT output:**

- Finire la produzione dei dati KLOE-2, comprese le stream UFO (min bias) e BHA (Bhabha)
- Produzione del MC KLOE-2 (test su ~ 300 pb$^{-1}$ effetuati)
- Produzione dei vecchi dati e MC (KLOE)
- L'idea e' di tenere tutti i files ROOT su disco per una migliore e piu' efficiente accessibilita'

# KLOE-2 Collaboration and Chart

- KLOE-2 is a small collaboration among Italian – Polish – Swedish and Russian research institutes & universities
  + New Liverpool group

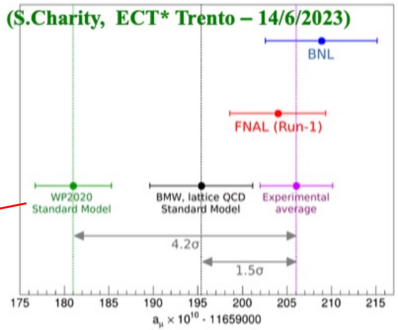
The KLOE-2 Collaboration

D. Babusci[c], M. Berlowski[p], C. Bloise[c], F. Bossi[c], P. Branchini[n], B. Cao[o], F. Ceradini[m,n], P. Ciambrone[c], F. Curciarello[h,i], E. Czerwiński[b], G. D'Agostini[k,ℓ], R. D'Amico[k,ℓ], E. Danè[c], V. De Leo[k,ℓ], E. De Lucia[c], A. De Santis[c], P. De Simone[c], A. Di Domenico[k,ℓ], E. Diociaiuti[c], D. Domenici[c], A. D'Uffizi[c], G. Fantini[k,ℓ], A. Gajos[b], S. Gamrat[b], P. Gauzzi[k,ℓ], S. Giovannella[c], E. Graziani[n], X. Kang[q], A. Kupsc[o,p], G. Mandaglio[e,a], M. Martini[c,j], S. Miscetti[c], P. Moskal[b], A. Passeri[n], E. Perez del Rio[b], M. Schioppa[h,i], A. Selce[m,n], M. Silarski[b], F. Sirghi[c,d], E. P. Solodov[f,g], W. Wiślicki[p], M. Wolke[o]

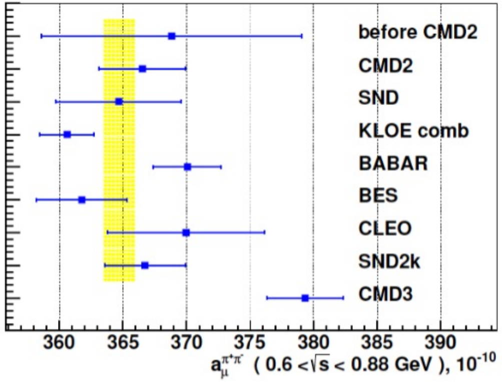
| | |
|---|---|
| Spokesman | A. Di Domenico (Sapienza Univ.) |
| Responsabile Nazionale | P. Gauzzi (LNF-INFN) |
| Analysis Board | P. Gauzzi (Sapienza Univ.-INFN)<br>A. Kupsc (Uppsala Univ.) |
| Kaon Physics WG | E. De Lucia (LNF-INFN)<br>E. Czerwinski (Jagiellonian Univ.) |
| Hadron Physics WG | G. Mandaglio (Univ. di Messina) |
| Offline WG | E. Perez del Rio (Jagiellonian Univ.)<br>P. Gauzzi (Sapienza Univ.) |
| Policy Board | S. Giovannella (LNF-INFN) |
| Institution Board | S. Miscetti (LNF-INFN) |

# New group from Liverpool joined KLOE-2

- **C'e' un rinnovato interesse per la misura della sezione d'urto adronica a energia < 1 GeV, dopo i primi risultati di g-2 @ FNAL, e dopo la misura recente di CMD-3 della sezione d'urto adronica, fatta con lo scan in energia**




Based on hadronic cross-section measurements




- **Nuovo gruppo di Liverpool e' entrato in KLOE-2 (G.Venanzoni + 2 Staff + 2 Postdocs + 2 Phd stud.)**

- **Scopo: misurare la sezione d'urto adronica ($e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$) al livello di qualche permille con tutta la statistica di KLOE**

# KLOE-2 Recent Papers & Ongoing Analysis

| | |
|---|---|
| Measurement of the KSe3 Branching Fraction with the KLOE experiment | **JHEP02(2023)098** |
| Direct test of T, CP, CPT Symmetries in Transitions of Neutral K mesons with the KLOE detector | **Accepted for publication on PLB** |
| $\chi$PT Golden mode – O($p^6$) dominates: BR($\eta \to \pi 0\ \gamma\gamma$) with 1.7 $fb^{-1}$ KLOE data | Draft ready<br>*Paper submission milestone 2024* |

- B-boson search: Upper limit on $B \to \pi 0\ \gamma$ using $\phi \to \eta\ \pi 0\ \gamma$ final state with KLOE data
- $\gamma^*\gamma^* \to \pi^0$ search with 3 $fb^{-1}$ KLOE-2 data *milestone 2023*
- $K_S \to 3\pi^0$ Upper limit on CP violating decay
- $e^+e^- \to \boldsymbol{\pi^+\pi^-\pi^0\gamma_{ISR}}$ : Br($\omega \to e+e-$) × Br($\omega \to \pi+\pi-\pi 0$) and cross-section @ $\omega$(782) for (g-2) Hadronic Vacuum Polarization
- First measurement ever of $\phi \to \eta\ \mu^+\ \mu^-$ Dalitz decay @EPS2023 *Final BR & TFF milestone 2024*
- «From future to past» effect in $\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ Evidence@EPS2023 *Preliminary milestone 2024*
- Charged Kaon mass – finalizing systematics

# KSe3 decay and $V_{us}$ extraction

- **Measurement of the $K_S \to \pi e \nu$ branching fraction with the KLOE experiment,**
  **⇒ JHEP02(2023)098**

- **Fit della distribuzione di $m^2_e$ ⇒ 49647 ± 316 eventi**

$$\boxed{Br(K_S \to \pi e \nu) = (7.211 \pm 0.046 \pm 0.052) \times 10^{-4}}$$

- **Combinato con la misura precedente**
  [~ 400 pb$^{-1}$, Br($K_S \to \pi e \nu$) = $(7.046 \pm 0.078_{stat} \pm 0.049_{syst}) \times 10^{-4}$ PLB636 (2006) 173]

$$\boxed{Br(K_S \to \pi e \nu) = (7.153 \pm 0.037 \pm 0.043) \times 10^{-4}}$$

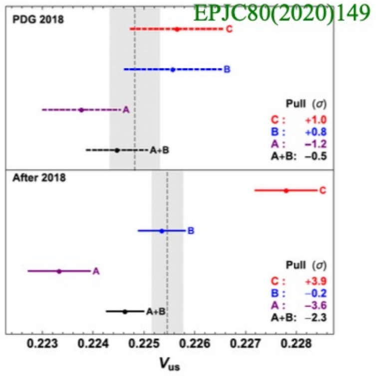
- **$V_{us}$ si ottiene da:**

$$Br(K_S \to \pi e \nu) = \frac{G_F^2 [f_+(0)|V_{us}|]^2}{192\pi^3} \tau_S m_K^5 I_K^\ell S_{EW} (1 + \delta_{EM}^{K\ell})$$

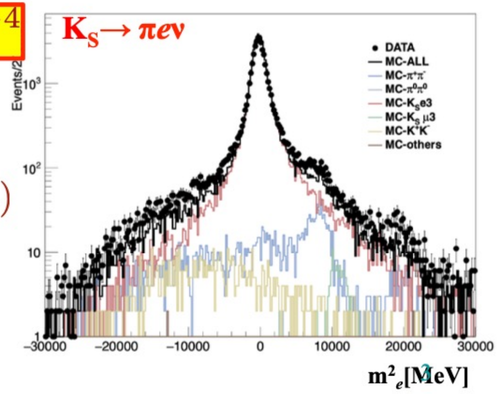
$$\boxed{f_+(0)\,|V_{us}| = 0.2170 \pm 0.0009}$$

**(incertezza = 0.4%)**

P.Gauzzi CSN1 - Milano



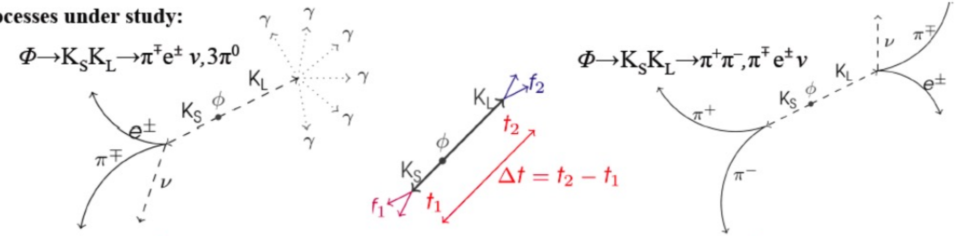

**Possibile deviazione dall'unitarieta' della prima riga della matrice CKM**
[EPJC80(2020)113, EPJC80(2020)149]



# Direct test of T, CP, CPT with Neutral K mesons

- **Primo test diretto con i K neutri, model independent**

**Processes under study:**




[J.Bernabeu, A.Di Domenico, P.Villanueva-Perez: NPB868(2013)102, JHEP1510(2015)139]

$$|i> = \frac{1}{\sqrt{2}}(|K^0>|\bar{K}^0> - |\bar{K}^0>|K^0>) = \frac{1}{\sqrt{2}}(|K_+>|K_-> - |K_->|K_+>)$$

- **$|K_->, |K_+>$ sono identificati dal decadimento dell'altro K in un autostato con CP = +1, −1 rispettivamente**

- **Osservabili ($\Delta t >> \tau_S$), sensibili a T, CPT e CP**

$$R_2^T(\Delta t) = \frac{P[K^0(0) \to K_-(\Delta t)]}{P[K_-(0) \to K^0(\Delta t)]} = \frac{I(\pi^+e^-\bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^-e^+\nu; \Delta t)} \times \frac{1}{D}$$

$$R_4^T(\Delta t) = \frac{P[\bar{K}^0(0) \to K_-(\Delta t)]}{P[K_-(0) \to \bar{K}^0(\Delta t)]} = \frac{I(\pi^-e^+\nu, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^+e^-\bar{\nu}; \Delta t)} \times \frac{1}{D}$$

$$R_2^{CPT}(\Delta t) = \frac{P[K^0(0) \to K_-(\Delta t)]}{P[K_-(0) \to \bar{K}^0(\Delta t)]} = \frac{I(\pi^+e^-\bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^+e^-\bar{\nu}; \Delta t)} \times \frac{1}{D},$$

$$R_4^{CPT}(\Delta t) = \frac{P[\bar{K}^0(0) \to K_-(\Delta t)]}{P[K_-(0) \to K^0(\Delta t)]} = \frac{I(\pi^-e^+\nu, 3\pi^0; \Delta t)}{I(\pi^+\pi^-, \pi^-e^+\nu; \Delta t)} \times \frac{1}{D}$$

$$R_{2,CP}^{exp}(\Delta t) \equiv \frac{I(\pi^+e^-\bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^-e^+\nu, 3\pi^0; \Delta t)}$$

$$R_{4,CP}^{exp}(\Delta t) \equiv \frac{I(\pi^+\pi^-, \pi^-e^+\nu; \Delta t)}{I(\pi^+\pi^-, \pi^+e^-\bar{\nu}; \Delta t)}$$

**Doppi rapporti:**

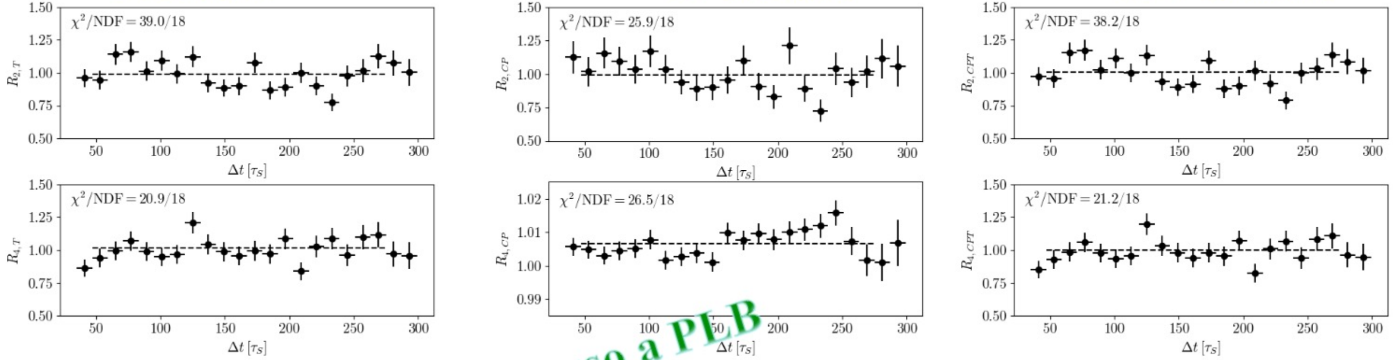
$$\frac{R_2^T}{R_4^T}(\Delta t) = \frac{I(3\pi^0, e^-)}{I(3\pi^0, e^+)}\frac{I(\pi^+\pi^-, e^-)}{I(\pi^+\pi^-, e^+)}$$

$$\frac{R_2^{CPT}}{R_4^{CPT}}(\Delta t) = \frac{I(3\pi^0, e^-)}{I(3\pi^0, e^+)}\frac{I(\pi^+\pi^-, e^+)}{I(\pi^+\pi^-, e^-)}$$

$$D = \frac{|<3\pi^0|T|K_->|^2}{|<\pi^+\pi^-|T|K_+>|^2}$$

# Direct test of T, CP, CPT with Neutral K mesons

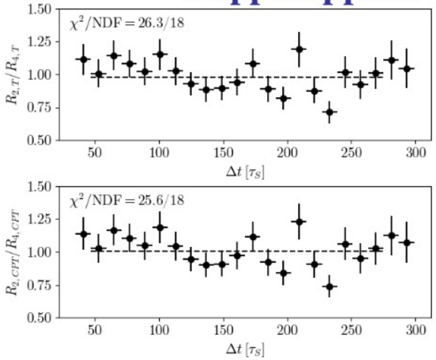
**T-sensitive** **CP-sensitive** **CPT-sensitive**

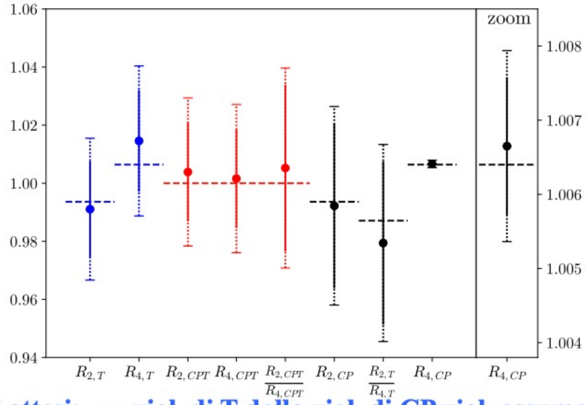



**Sottomesso a PLB**

**Dati analizzati: 1.7 fb$^{-1}$**

**Doppi rapporti**




**Valori attesi: ---- viol. di T dalla viol. di CP viol. assumendo CPT**
**---- dall'invarianza per CPT (rapporti =1)**
**---- viol. di CP dal PDG**

# $\eta \to \pi^0 \gamma\gamma$

$\eta\to\pi^0\gamma\gamma$ ($\phi\to\eta\gamma$): $\Rightarrow$ sensibile a $O(p^6)$ della ChPT

$O(p^2)$ nullo, $O(p^4)$ soppresso

Br = $(2.21 \pm 0.24 \pm 0.47)\times10^{-4}$ CB@AGS( 2008)

[PRC 78 (2008) 015206]

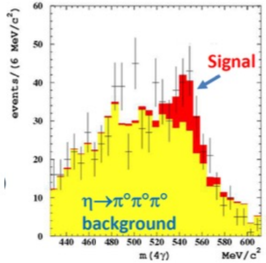
Br = $(2.52 \pm 0.25)\times10^{-4}$ CB@MAMI (2014) A2

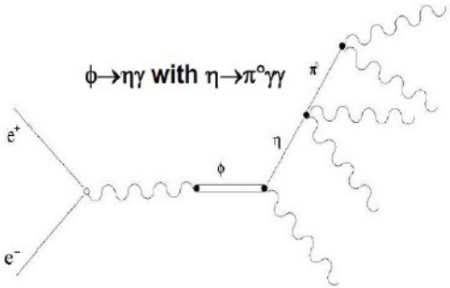
[PRC 90 (2014) 025206]

Vecchia misura di KLOE: $(0.84 \pm 0.27\pm 0.14)\times10^{-4}$

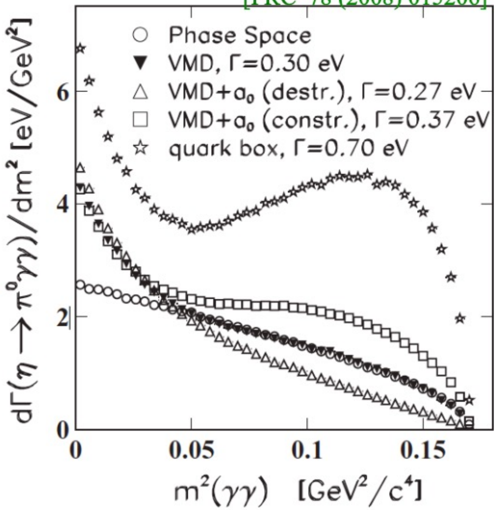
(L = 450 pb$^{-1}$ ~ 70 signal events)

[Acta Phys.Slov.56(2006)403]




[PRC 78 (2008) 015206]




La massa invariante dei due $\gamma$ non provenienti dal $\pi^0$ possono essere usati per test sui modelli teorici

CSN1 - Milano

# $\phi \rightarrow \eta\gamma$ with $\eta \rightarrow \pi^0\gamma\gamma$

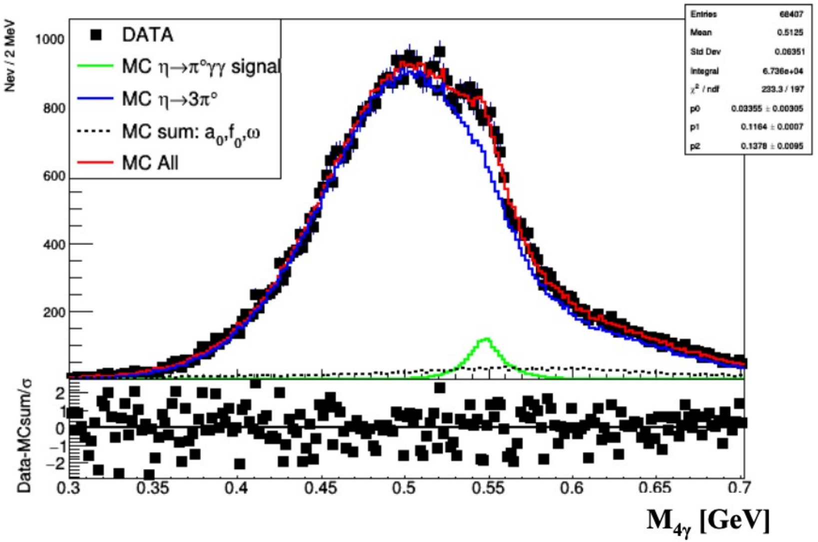
- $L = 1.7\ fb^{-1}$
- stato finale: 5 prompt $\gamma$
- Fondo: $\phi\rightarrow\eta\gamma$, $\eta\rightarrow3\pi^0$
  con merging o fotoni persi

- Fit a tre componenti, con le distribuzioni da MC

$\Rightarrow$ ~ 1200 eventi di segnale
(~ stessa statistica di Crystal Ball)

- Br in accordo con la nostra vecchia misura

- Differenza di ~ 4 $\sigma$
  con le misure precedenti




$$\mathrm{Br}(\eta\rightarrow\pi^0\gamma\gamma) = (0.99 \pm 0.11_{stat} \pm 0.24_{syst})\times10^{-4}$$

# KLOE-2 2024 Activities

- Data reconstruction and preservation
  - Root output production
  - Data Preservation completing the disaster recovery copy

- Paper submissions:
  - $\chi$PT Golden mode: $\eta \to \pi0\ \gamma\gamma$ (first paper draft ready and with internal referees)
  - Dark forces: Leptophobic B-boson search with $\phi \to \eta\ \pi0\ \gamma$ final state

- Complete ongoing analysis

- Continue with the newly started analysis: Hadronic cross-section with ISR & "From future to Past" effect

# Richieste 2024

| | Missioni [k€] | Consumo [k€] | Manutenzioni [k€] | Apparato [k€] | Totale [k€] |
|---|---|---|---|---|---|
| Richieste 2024 | 17 (1) | 23 (2) | 26 (3) +3(SJ) | 5 (SJ) (4) | 66 + 8(SJ) |
| Assegnazioni 2023 | 14 | 8.5 (5) | 26 | 5 (SJ) | 48.5 + 5(SJ) |

(1) Metabolismo (10 k€) piu' indiviso per conferenze, workshop, etc. (7 k€)
(2) 8 k€ metabolismo + 15 k€ per espansione spazio disco (250 TB solo dischi, l'infrastruttura gia' c'e' con varie slot libere) per nuova analisi della sezione d'urto adronica e produzione di ROOT files
(3) Manutenzione della Tape Library e del CISCO switch
(4) Eventuali sostituzioni di parti non piu' in manutenzione
(5) Metabolismo (8.5 k€); 10 k€ per espansione spazio disco anticipati a fine 2022

# Comments from the Referees

# Comments from the Referees

KLOE-2

Referee Report
e
Proposta Assegnazioni per il 2024

CSN1, Napoli, 11 settembre 2023

G. Cibinetto (FE) - B. - S. Giagu (RM1) - A. Perrotta (BO)
referee calcolo: B. Giacobbe (BO)

- Collaborazione ancora molto attiva nonostante un fisiologico calo di FTE
- Lo dimostrano le tante analisi in corso e le recenti pubblicazioni
    - Br($K_S \to \pi e \nu$) JHEP02(2023)098
    - Test diretto di T e CPT in decadimenti $\phi \to K_S K_L \to 3\pi^0\ \pi e \nu$, $\pi\pi\ \pi e \nu$ Accettato da PLB arXiv:2211.12377
- Importante attività di calcolo a LNF → processing e mantenimento infrastruttura (data storage e analisi) – per dettagli vedere presentazione di calcolo non-LHC di Benedetto
- Un nuovo gruppo è entrato in KLOE-2 (Liverpool) → misura della sezione d'urto adronica ($e^+e^- \to \pi^+\pi^-\gamma_{ISR}$) al livello di qualche permille con tutta la statistica di KLOE

# Comments from the Referees

## Richieste calcolo 2024

- CONSUMO: 250 TB disk per reprocessing, ntuples and analysis of sigma_hadronic (n.b. costo stimato **15 kEUR** invece dei 30 kEUR assumendo 120 EUR/TB)
  - **ANTICIPABILI al 2023**

OK

- MANUTENZIONI: Manutenzione nuova tape library: ***26 kEUR+~~3 kEUR SJ~~***
  - 26 kEUR ottenuti anche lo scorso anno
  - \+ 3 kEUR SJ (contingency)

OK 26 kEUR, non il SJ

- APPARATI: Manutenzione vecchia tape library : **5 kEUR SJ**
  - stesso ottenuto in 2023
  - Altri items possible manutenzione (il vecchio disk array, gli switch fibre channel, i vari server di tipo P6, P7 e P8 del cluster di KLOE, gli switch CISCO secondari che sono 5 x 24 porte, la libreria del disaster recovery, le telecamere per il controllo della sala e della temperatura, i PC di servizio, i server AFS che ancora manteniamo nel caso scoprissimo che manca qualcosa dalla migrazione da AFS a GPFS)

OK

# Comments from the Referees

## Totale proposte di assegnazione
## Confronto con anno precedente

| Totale Generale KLOE: | Richieste | | Richieste SJ | Proposta referees | | Proposta SJ |
|---|---|---|---|---|---|---|
| | 60 .5 | + | 8.0 | 57.5 | + | 5.0 |

| | MISSIONI | CONSUMO | INVENTARIO | MANUTENZ. | APPARATI | TOTALE |
|---|---|---|---|---|---|---|
| **Richiesta** | 13.0 | 21,5 | 0 | 26.0 + 3 sj | 0 + 5.0 sj | 60.5 + 8.0 sj |
| **Prop. ass.** | 11.0 | 21.5 | 0 | 26.0 | 0 + 5.0 sj | 57.5 + 5.0 sj |

| | MISSIONI | CONSUMO | INVENTARIO | MANUTENZ. | APPARATI | TOTALE |
|---|---|---|---|---|---|---|
| **Prop. 2024** | 11.0 | 21.5 | 0 | 26.0 | 5.0 | 62.5 |
| **Prop. 2023** | 15.0 | 19.5 | 0 | 26.0 | 5.0 | 63.5 |

**2024:** 4.0 FTE | **2023:** 5,3 FTE

Assegnati: 14.0

Assegnati: 8.5 per anticipo acquisto disco

CSN1 - 11/09/2023 KLOE2 referees 14

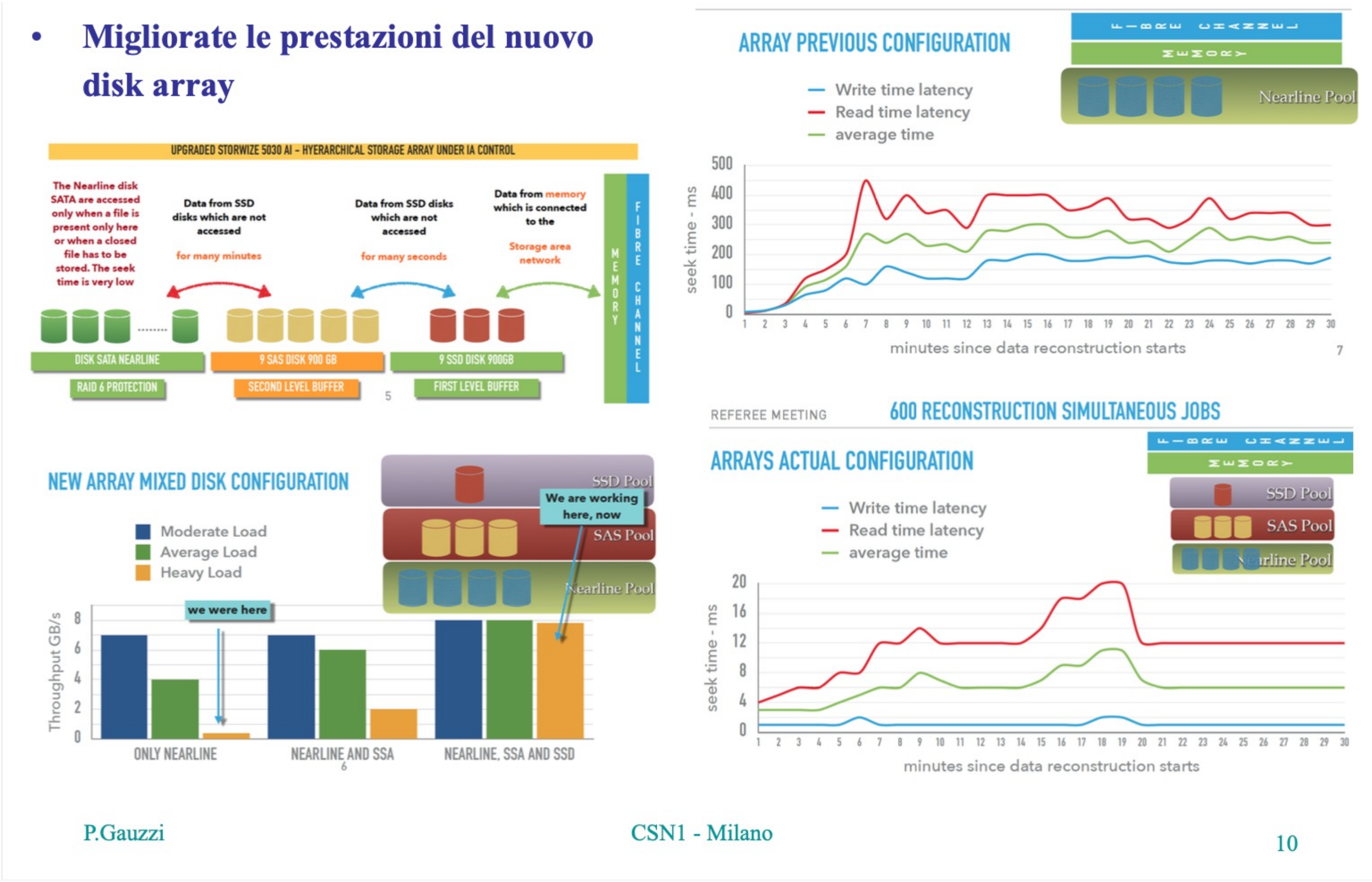
Sollevata in commissione dal resp. naz. Paolo Gauzzi la questione missioni per conferenze, non sufficienti nel 2023.

Il presidente ha detto che quando finiscono I soldi ci pensano i coordinatori locali di CSN1

- Conferenze: quelle degli anni precedenti riscalate al numero di FTE (rescaling non esatto, per consentire partecipazione a conferenze nonostante il numero di FTE in continua diminuzione)

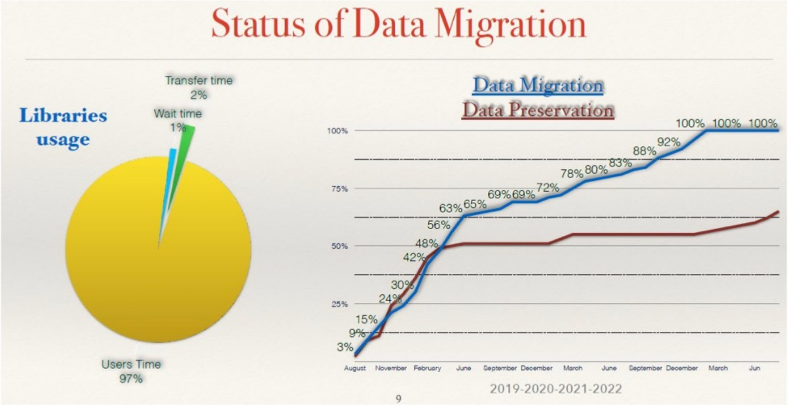
# Spare Slides

# KLOE-2 Computing



# Comments from the Referees

## KLOE:data migration



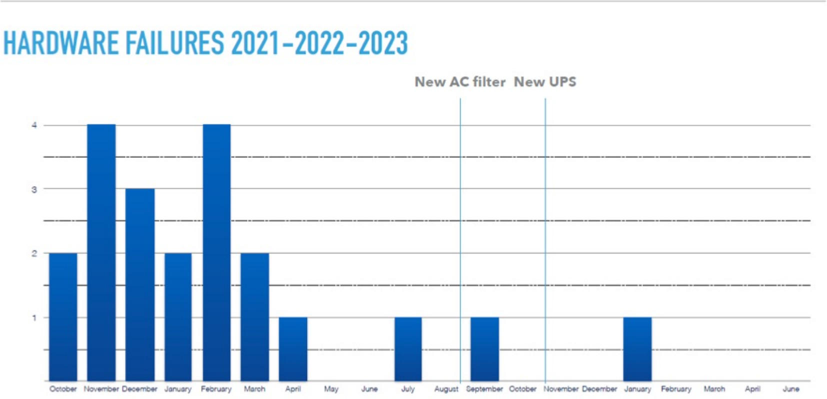

- Migration over but:
  - Crosscheck before switching off the old library, showed us a lot of RAW files duplication and some files not copied
  - Old library stopped working (request of SJ in 2023 to repair – was accepted)

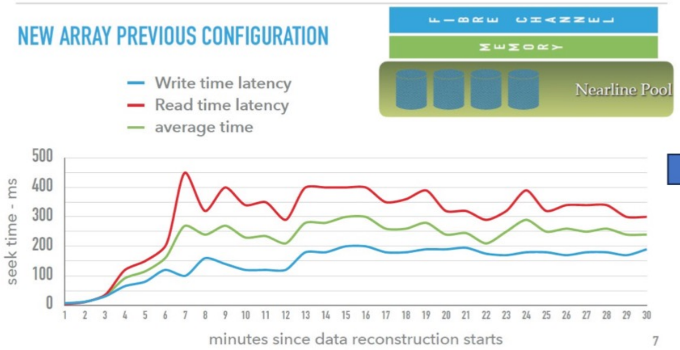
- Requests for CSN1 for old/new library maintenance - see next slide
- Additional request for disk space in Server LNF (CSN1) – see next slide

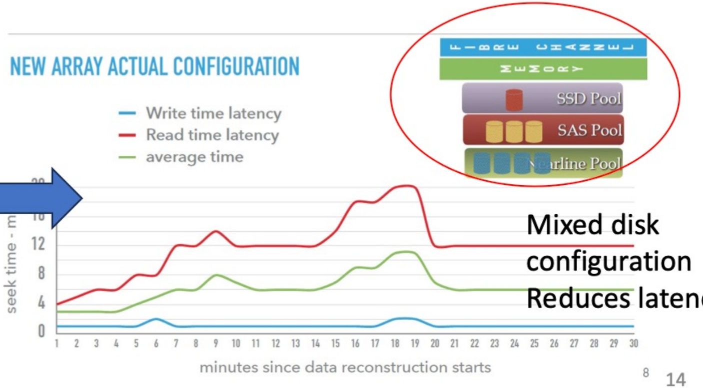
# Comments from the Referees

## KLOE: status

- Migration from old library to new library due to hardware failures




Mixed disk configuration
Reduces latencies

# Proposta di milestones 2024

| | | |
|---|---|---|
| * | 1) Sottomissione del lavoro su Br(eta->pi0 gamma gamma) | 29/6/2024 |
| * | 2) Risultato finale sul Br(phi->eta mu+mu-) e misura del fattore di forma di transizione | 31/12/2024 |
| | 3) Risultato premilinare sull'effetto "from future to past" in phi->KSKL->pi+pi-pi+pi- | 31/12/2024 |
| | 4) Produzione del ROOT output per il Monte Carlo di KLOE-2 | 30/6/2024 |
| | 5) Produzione del ROOT output per dati e Monte Carlo relativi alla prima presa dati | 31/12/2024 |

* riportate dal 2023

# $\sigma_{had}$, $e^+e^- \to \pi^+\pi^-\gamma_{ISR}$ – KLOE

## KLOE08: Small Angle ($\sqrt{s}$= 1020 MeV)

Systematic errors on $a_\mu^{\pi\pi}$:

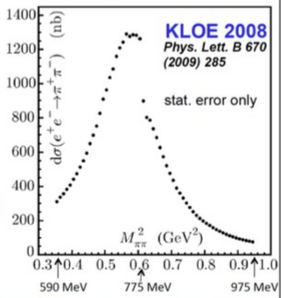
| | |
|---|---|
| Reconstruction Filter | negligible |
| Background | 0.3% |
| Trackmass/Miss. Mass | 0.2% |
| p/e-ID and TCA | negligible |
| Tracking | 0.3% |
| Trigger | 0.1% |
| Acceptance ($\theta_{\pi\pi}$) | 0.2% |
| Acceptance ($\theta_\pi$) | negligible |
| Unfolding | negligible |
| Software Trigger | 0.1% |
| $\sqrt{s}$ dep. Of H | 0.2% |
| Luminosity($0.1_{th} \oplus 0.3_{exp}$)% | 0.3% |

experimental fractional error on $a_\mu$ = 0.6 %

| | |
|---|---|
| FSR treatment | 0.3% |
| Radiator H | 0.5% |
| Vacuum polarization | 0.1% |

theoretical fractional error on $a_\mu$ = 0.6 %

$\sigma_{\pi\pi}$, undressed from VP, inclusive for FSR as function of $(M^0_{\pi\pi})^2$

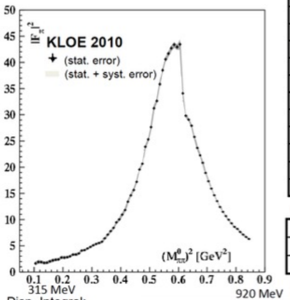



$a_\mu^{\pi\pi} = \int_{x1}^{x2} \sigma_{ee\to\pi\pi}(s) K(s) ds$

$a_\mu^{\pi\pi}(0.35\text{-}0.95 \text{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$

## KLOE10: Large Angle ($\sqrt{s}$= 1000 MeV)

*Phys. Lett. B 700 (2011) 102*




Disp. Integral:

$a_\mu^{\pi\pi} = \int_{x1}^{x2} \sigma_{ee\to\pi\pi}(s) K(s) ds$

Table of systematic errors on $a_\mu^{\pi\pi}(0.1\text{-}0.85 \text{ GeV}^2)$:

| | |
|---|---|
| Reconstruction Filter | negligible |
| Background | 0.5% |
| $f_0+\rho\pi$ | 0.4% |
| $\Omega$ cut | 0.2% |
| Trackmass | 0.5% |
| p/e-ID and TCA | negligible |
| Tracking | 0.3% |
| Trigger | 0.2% |
| Acceptance | 0.5% |
| Unfolding | negligible |
| Software Trigger | 0.1% |
| Luminosity($0.1_{th} \oplus 0.3_{exp}$)% | 0.3% |

experimental fractional error on $a_\mu$ = 1.0 %

| | |
|---|---|
| FSR treatment | 0.8% |
| Radiator H | 0.5% |
| Vacuum polarization | 0.1% |

theoretical fractional error on $a_\mu$ = 0.9 %

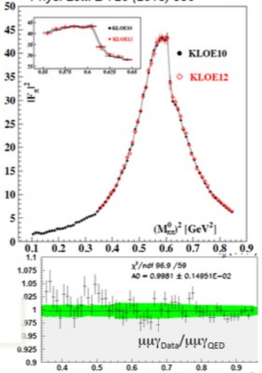
$a_\mu^{\pi\pi}(0.1\text{-}0.85 \text{ GeV}^2) = (478.5 \pm 2.0_{stat} \pm 5.0_{sys} \pm 4.5_{theo}) \cdot 10^{-10}$

0.4% 1.0% 0.9%

## KLOE12 result on $|F_\pi|^2$

| Syst. errors (%) | $\Delta^{\pi\pi}a_\mu$ ratio |
|---|---|
| Reconstruction Filter | negligible |
| Background subtraction | 0.6 |
| Trackmass | 0.2 |
| Particle ID | negligible |
| Tracking | 0.1 |
| Trigger | 0.1 |
| Unfolding | negligible |
| Acceptance ($\theta_{\pi\pi}$) | negligible |
| Acceptance ($\theta_\pi$) | negligible |
| Software Trigger (L3) | 0.1 |
| Luminosity | - |
| $\sqrt{s}$ dep. of $H$ | - |
| Total exp systematics | 0.7 |
| Vacuum Polarization | - |
| FSR treatment | 0.2 |
| Rad. function $H$ | - |
| Total theory systematics | 0.2 |
| Total systematic error | 0.7 |

*Phys. Lett. B 720 (2013) 336*

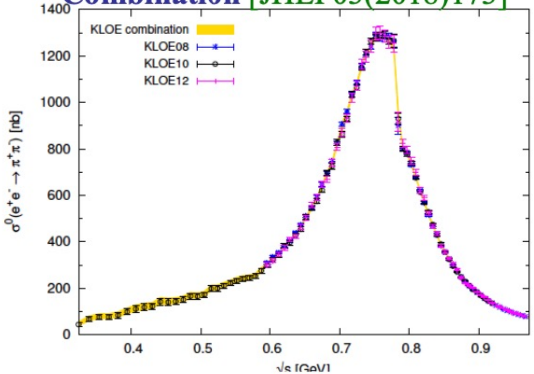



$a_\mu^{\pi\pi}(0.35\text{-}0.95\text{GeV}^2) =$

$(385.1 \pm 1.1_{stat} \pm 2.7_{sys+theo}) \cdot 10^{-10}$

**[L ~ 240 pb$^{-1}$]**

## Combination [JHEP03(2018)173]



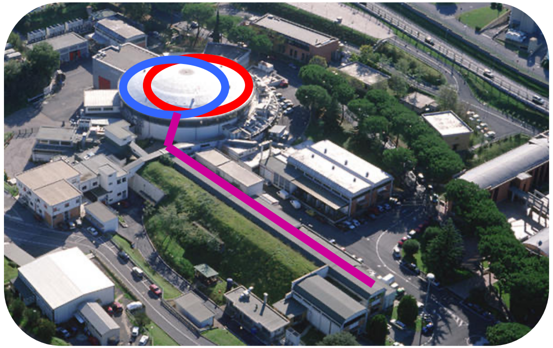



$a_\mu(0.35 – 0.85 \text{ GeV}^2)=(377.5 \pm 2.2)\times10^{-10}$

# DAφNE & KLOE-2

- DAφNE Frascati φ-factory: an $e^+e^-$ collider @ $\sqrt{s}$ =1019.4 MeV = $M_\varphi$ and with crab-waist sextuples configuration

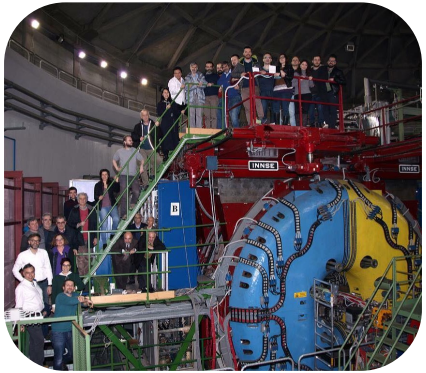
  Best performance in 2018:
  - $L_{peak} = 2.28 \times 10^{32}\ cm^{-2}s^{-1}$
  - $\int Ldt = 14.3\ pb^{-1}$/day delivered

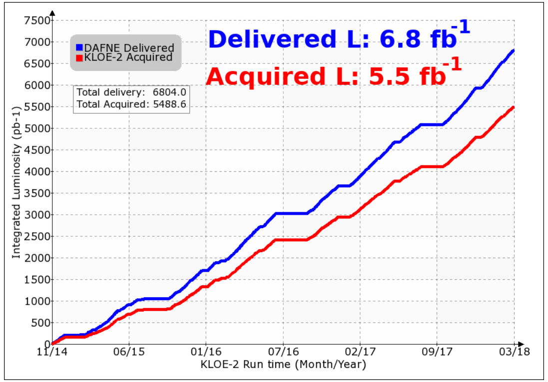


- KLOE-2 integrated 5.5 $fb^{-1}$ @ $\sqrt{s}=M_\varphi$ (2014-18)

Physics with the KLOE-2 experiment at the upgraded DAΦNE [EPJC 68 (2010)]

- Ks, η rare decays & hadron physics
- Interferometry & Symmetries
- Dark photon search

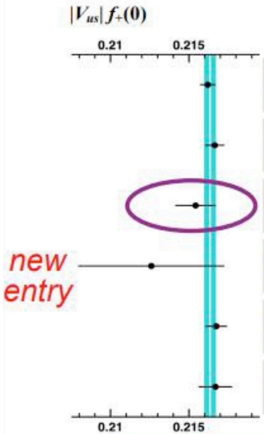





*KLOE+KLOE-2 data set largest sample ever collected at ϕ-meson peak*

# KSe3 decay and $V_{us}$ extraction

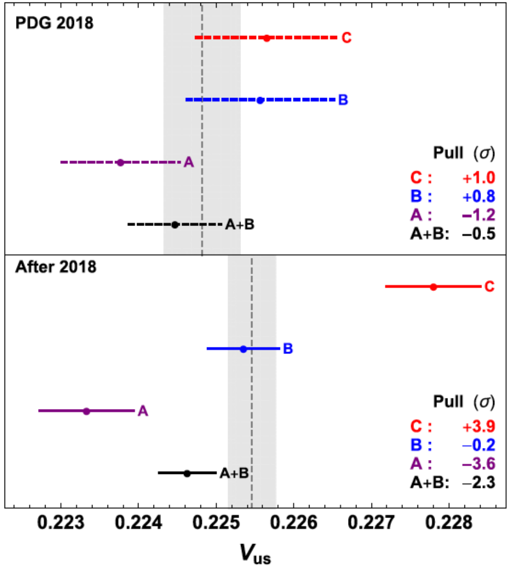
## $|V_{us}| f_+(0)$ from world data: Update




| | | % err | Approx. contrib. to % err from: BR | $\tau$ | $\Delta$ | Int |
|---|---|---|---|---|---|---|
| $K_L e3$ | 0.2162(5) | 0.23 | 0.09 | 0.20 | 0.02 | 0.05 |
| $K_L \mu 3$ | 0.2167(6) | 0.29 | 0.15 | 0.18 | 0.11 | 0.07 |
| $K_S e3$ | 0.2154(13) | 0.60 | 0.60 | 0.02 | 0.02 | 0.05 |
| $K_S \mu 3$ | 0.2126(47) | 2.2 | 2.2 | 0.02 | 0.11 | 0.07 |
| $K^\pm e3$ | 0.2167(7) | 0.32 | 0.27 | 0.06 | 0.17 | 0.05 |
| $K^\pm \mu 3$ | 0.2167(11) | 0.50 | 0.45 | 0.06 | 0.21 | 0.07 |

**Average: $|V_{us}| f_+(0) = 0.21635(38)$ $\chi^2/\text{ndf} = 2.14/5$ (83%)**

M.Moulson and E.Passemar @ CKM 2021




EPJC80(2020)149

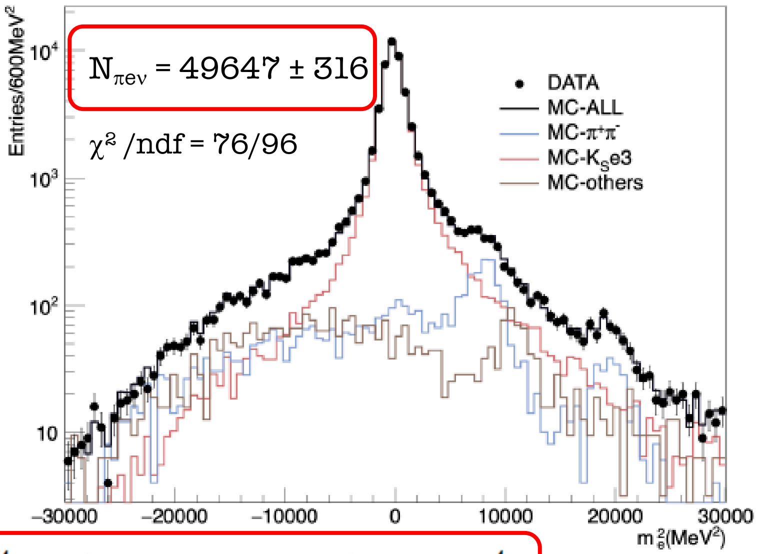
Possible deviation from unitarity of the CKM matrix 1st raw
[EPJC80(2020)113, EPJC80(2020)149]

- Unique possibility to select pure $K_S$ beam
- Present BR(KSe3) value dominated by the KLOE measurement with 0.4 fb$^{-1}$ [PLB 636 (2006) 173]

$\mathrm{BR}(K_S \to \pi e \nu) = (7.046 \pm 0.078 \pm 0.049) \times 10^{-4}$ 1.4% total uncertainty (1.1% stat ± 0.7% syst)

# The Results

- Sample selected with BDT and TOF
- Signal count from fit to $m_e^2$ distribution
  $m_e^2 = (E_{KS} - E_\pi - p_{miss})^2 - p_e^2$ ($E_{KS}$ and $p_{KS}$ from KL-crash)
- Previous KLOE result: 0.4 $fb^{-1}$ independent data sample
  [Phys. Lett. B 636 (2006) 173]
  $BR(K_S \to \pi e\nu) = (7.046 \pm 0.078 \pm 0.049) \times 10^{-4}$
  1.4% total uncertainty (1.1% stat ± 0.7% syst)




- New result with 1.63 $fb^{-1}$

$$\boxed{\mathcal{B}(K_S \to \pi e\nu) = (7.211 \pm 0.046_{\text{stat}} \pm 0.052_{\text{syst}}) \times 10^{-4} = (7.211 \pm 0.069) \times 10^{-4}}$$

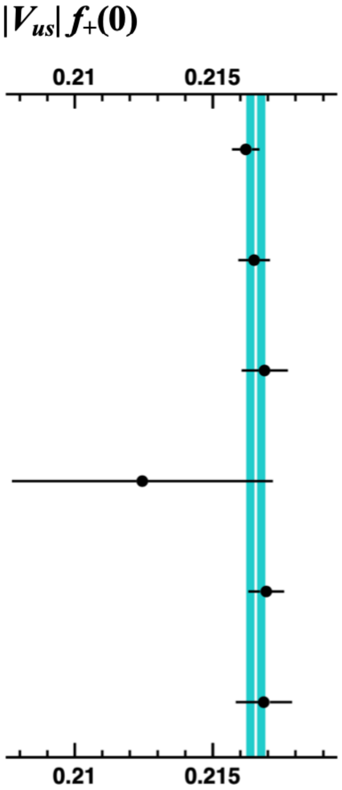
arXiv.2208.04872

- Combination accounting for correlations:

$$\boxed{\mathcal{B}(K_S \to \pi e\nu) = (7.153 \pm 0.037_{\text{stat}} \pm 0.043_{\text{syst}}) \times 10^{-4} = (7.153 \pm 0.057) \times 10^{-4}}$$

- Sizeable uncertainty reduction on: $\boxed{f_+(0)|V_{us}| = 0.2170 \pm 0.0009}$ 0.4% uncertainty

# $|V_{us}| f_+(0)$ from world data: 2022 update




| | | % err | BR | $\tau$ | $\Delta$ | Int |
|---|---|---|---|---|---|---|
| | | | Approx. contrib. to % err from: | | | |
| $K_L e3$ | **0.2162(5)** | **0.23** | 0.09 | 0.20 | 0.02 | 0.05 |
| $K_L \mu 3$ | **0.2165(6)** | **0.26** | 0.15 | 0.18 | 0.02 | 0.07 |
| $K_S e3$ | **0.2169(8)** | **0.39** | 0.38 | 0.02 | 0.02 | 0.05 |
| $K_S \mu 3$ | **0.2125(47)** | **2.2** | 2.2 | 0.02 | 0.02 | 0.08 |
| $K^{\pm} e3$ | **0.2169(6)** | **0.30** | 0.27 | 0.06 | 0.11 | 0.05 |
| $K^{\pm} \mu 3$ | **0.2168(10)** | **0.47** | 0.45 | 0.06 | 0.11 | 0.08 |

**Average: $|V_{us}| f_+(0)$ = 0.21656(35)** **$\chi^2$/ndf = 1.89/5 (86%)**

# $V_{us}$ from kaon decays: Summary

| | |
|---|---|
| $K_{\ell 3}$<br>$f_+(0) = 0.9698(17)$<br>$N_f = 2+1+1$ | $V_{us} = 0.22330(35)_{exp}(39)_{lat}(8)_{IB}$<br>$(53)_{tot} = 0.24\%$ |
| $K_{\mu 2}$<br>$f_K/f_\pi = 1.1978(22)$<br>$N_f = 2+1+1$ | $V_{us}/V_{ud} = 0.23108(23)_{exp}(42)_{lat}(16)_{IB}$<br>$(51)_{tot} = 0.22\%$ |

**First hint of an anomaly:** ***Without information from β decays***

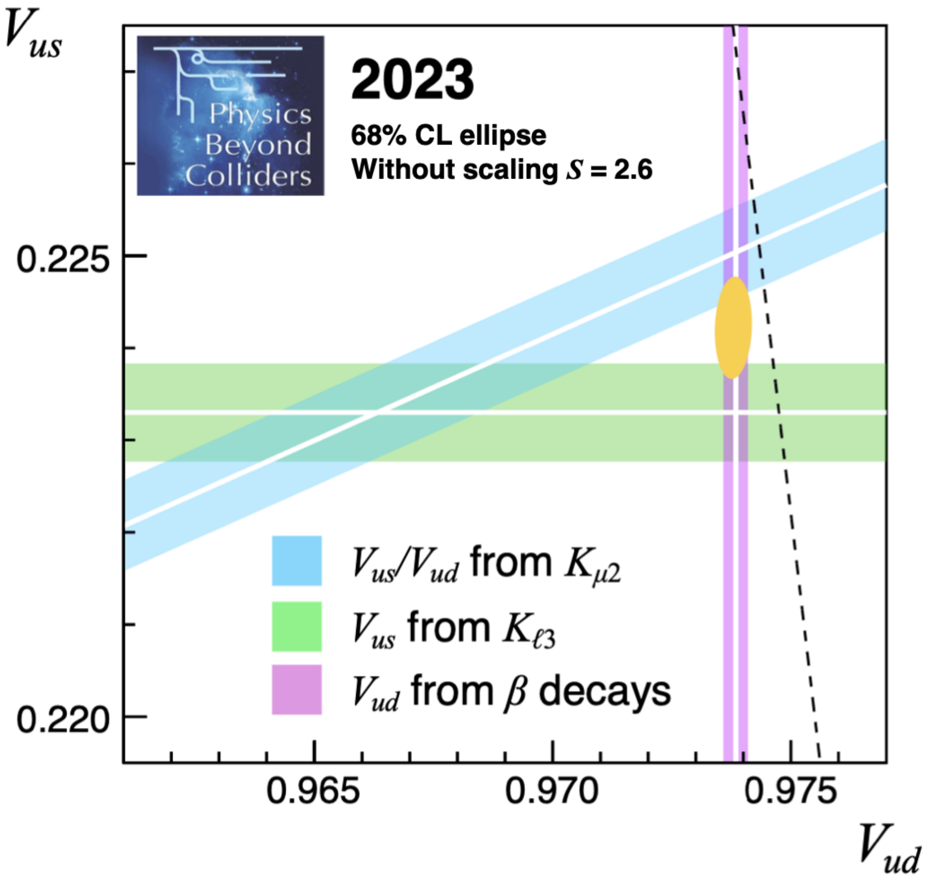
$$\Delta^{(3)}_{\mathrm{CKM}} = |V_{us}^{K\ell 3}|^2 \left[ \left( \frac{1}{|V_{us}/V_{ud}|^{K\mu 2}} \right)^2 + 1 \right] - 1$$

$\Delta^{(3)}_{\mathrm{CKM}} = -0.0164(63)$

$-2.6\sigma$

Need additional information to test consistency of $K_{\ell 3}$ and $K_{\mu 2}$

# Status of first-row unitarity




**Fit results, no constraint**

$V_{ud}$ = **0.97378(26)**

$V_{us}$ = **0.22422(36)**

$\chi^2$/ndf = 6.4/2 (4.1%)

$\Delta_{CKM}$ = **–0.0018(6)**

**–2.8$\sigma$**

With scale factor $S$ = 2.6

$V_{ud}$ = **0.9737(8)**

$V_{us}$ = **0.2242(10)**

# Status of first-row unitarity

| Experimental results from kaons | With $|V_{ud}|(\beta)$ and $N_f = 2+1+1$ lattice |
|---|---|
| $|V_{us}|\, f_+(0) = 0.21656(35)$ | $\Delta^{(1)}{}_{CKM} = -0.00176(56) = -3.1\sigma$ |
| $|V_{us}/V_{ud}| \times f_K/f_\pi = 0.27679(34)$ | $\Delta^{(2)}{}_{CKM} = -0.00098(58) = -1.7\sigma$ |

**Fit to both gives $\Delta_{CKM} = -2.8\sigma$ and $3.1\sigma$ evidence for right-handed currents**

**$K_{\mu 2}$ result shows better agreement with unitarity than $K_{\ell 3}$ result when $|V_{ud}|$ obtained from beta decays**

**New measurement of $K_{\mu 3}/K_{\mu 2}$ (e.g. from NA62) could be very helpful in distinguishing if origin of discrepancy is experimental**

- Other measurements of main $K$ BRs also very important!

**Precision in kaon sector strongly motivates further progress on $V_{ud}$, especially in theoretical calculation of radiative corrections!**

# First two generations: $|V_{ud}|$ and $|V_{us}|$ plane

→ $|V_{ud}|$ from nuclear transitions *R*fit: add theo. uncs. linearly

[Hardy, Towner '20]

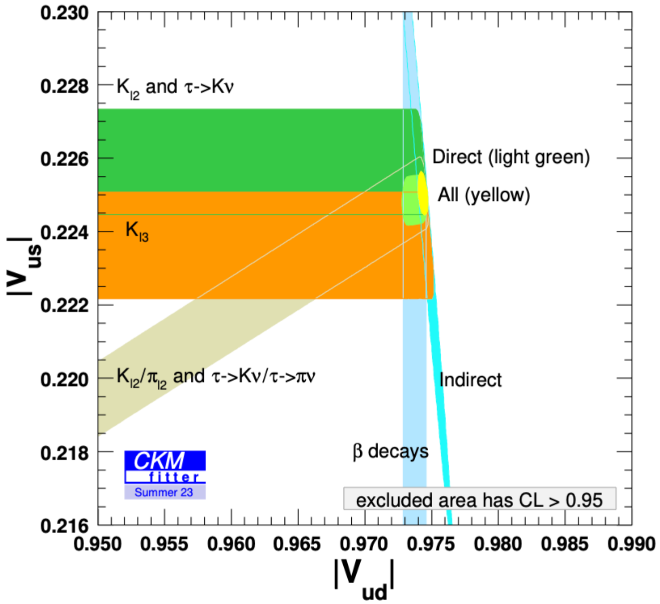
[See M. Gorshteyn on Thu @ 11h30]

→ $|V_{us}|$ from $K, \pi, \tau$ decays

[rad. correcs.: $\chi$PT, Cirigliano, Neufeld '11; R$\chi$T, Arroyo-U., Hernandez-T., Lopez-C., Roig, Rosell '21 '21]

[See M. Moulson on Wed @ 09h00]

→ Fair agreement among different classes of inputs, $K_{\ell 3}$ and $\tau_{K2}$ pulls of 2.2



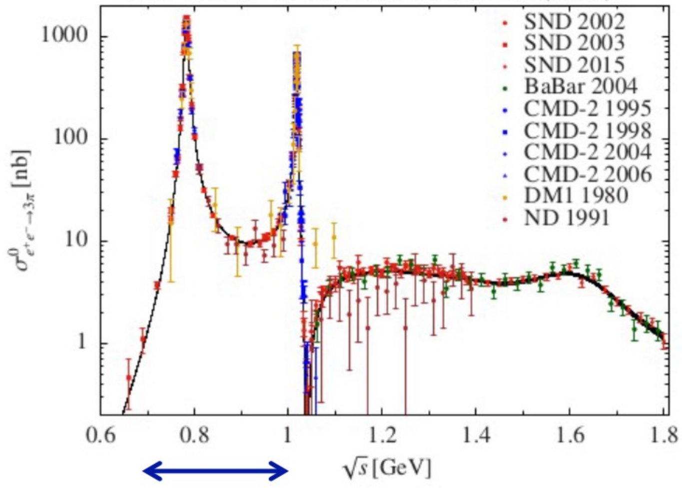

$|V_{ud}|$: ±0.006% [ind.], ±0.005% [comb.]

$|V_{us}|$: ±0.40% [ind.], ±0.10% [comb.]

# $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$

- $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ e' il secondo contributo alla polarizzazione del vuoto (HVP) per $(g\text{-}2)_\mu$ e alla sua incertezza

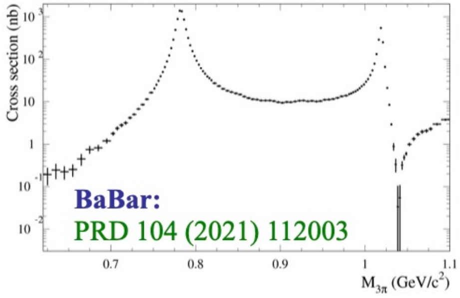
EPJ Web of Conferences **234**, 01006 (2020)




- La radiazione di stato iniziale (ISR) usata da KLOE e BaBar e' complementare allo scan in energia a $\sqrt{s} < M_\phi$ (SND e CMD-2)

**Obiettivi:**

- Misura della sezione d'urto nella regione dell'$\omega$(782)
- Misura del prodotto $Br(\omega \rightarrow e^+e^-) \times Br(\omega \rightarrow \pi^+\pi^-\pi^0)$



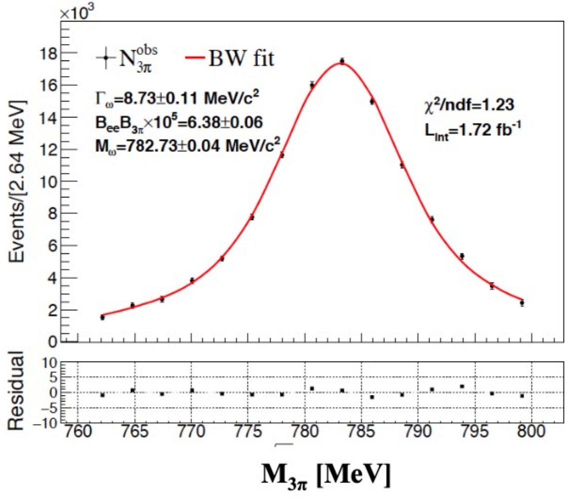
# $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$

- $L = 1.7\ fb^{-1}$

**Selezione:**

- Almeno 2 tracce con curvatura opposta
- 3 cluster neutri
- Fit cinematico

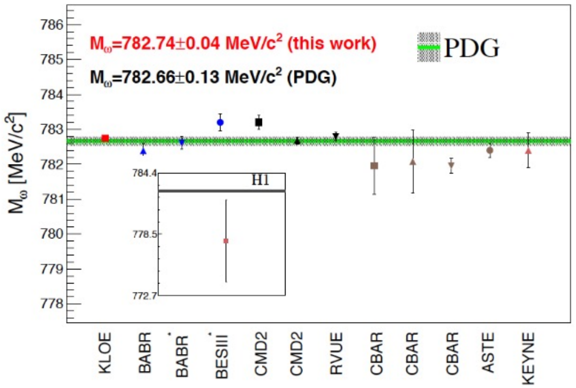
- Fit con una Breit-Wigner convoluta con la matrice di smearing
- Fattore di correzione per la ISR



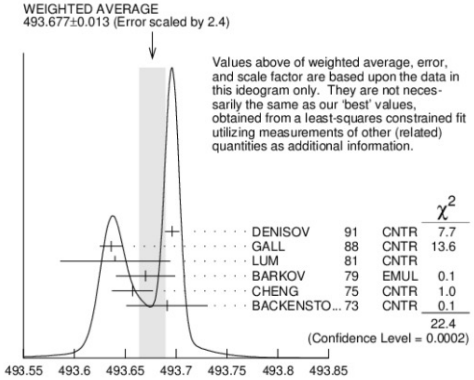

**Confronto con il PDG (solo incertezza stat. per KLOE):**

| | $M_\omega$ [MeV/c$^2$] | $\Gamma_\omega$ [MeV] | $\mathcal{B}_{ee}\times\mathcal{B}_{3\pi}$ [$10^{-5}$] |
|---|---|---|---|
| KLOE | $782.73 \pm 0.04$ | $8.73 \pm 0.11$ | $6.38 \pm 0.06$ |
| PDG | $782.66 \pm 0.13$ | $8.68 \pm 0.13$ | $6.60 \pm 0.16$ |

**BaBar:** $\mathcal{B}_{ee}\times\mathcal{B}_{3\pi} = (6.56 \pm 0.10) \times 10^{-5}$
[PRD 104 (2021) 112003]



# Massa del K carico

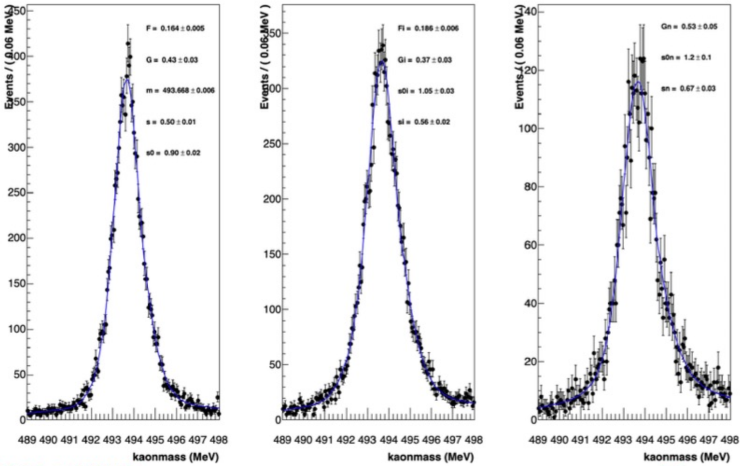



- Le misure fatte con i raggi X emessi da atomi kaonici mostrano qualche discrepanza

- I dati di KLOE possono fornire una misura di precisione con $K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$

- Studi col MC per trovare la miglior funzione per il fit della distribuzione

- Blind analysis sui dati aggiungendo un offset random al valore della massa

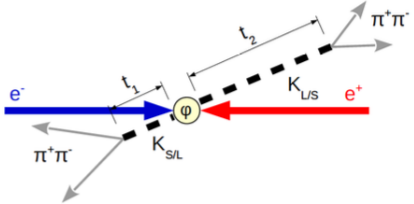


# "From future to past"

[J.Bernabeu, A.Di Domenico, PRD105(2022)116004 ]

- **Con il formalismo di Lee-Yang lo stato del secondo mesone, K(2) prima del decadimento si puo' scrivere come:**

$$\left|K^{(2)}(t=t_2)\right\rangle = \frac{N}{\sqrt{2}}\left\langle f_1\left|T\right|K_S\right\rangle e^{-i(\lambda_S+\lambda_L)t_1}\left(e^{-i\lambda_L\Delta t}\left|K_L\right\rangle - \eta_1 e^{-i\lambda_S\Delta t}\left|K_S\right\rangle\right)$$




$$\lambda_{S,L} = m_{S,L} - \frac{i}{2}\Gamma_{S,L}$$

$$\Delta t = t_2 - t_1 > 0$$

$$\Delta\Gamma = \Gamma_S - \Gamma_L$$

- **A t = $t_1$ il K(2) non puo' decadere nello stato $f_1$**

$$\left|K^{(2)}(t=t_1)\right\rangle = N_2\left(\left|K_L\right\rangle - \eta_1\left|K_S\right\rangle\right)$$

- $|\eta_1|e^{-\frac{1}{2}\Delta\Gamma\Delta t} << 1$ **a grandi Δt, K(2) e' sempre un $K_L$**

- **Con lo stesso formalismo lo stato del primo K, prima di decadere, e':**

$$\left|K^{(1)}(t=t_1)\right\rangle = \frac{N}{\sqrt{2}}\left\langle f_2\left|T\right|K_S\right\rangle\left(e^{-i\lambda_S t_1}\eta_2 e^{-i\lambda_L t_2}\left|K_S\right\rangle - e^{-i\lambda_L t_1}e^{-i\lambda_S t_2}\left|K_L\right\rangle\right)$$

$$\left|K^{(1)}(t=0)\right\rangle = N_1\left(\eta_2 e^{-i\lambda_L t_2}\left|K_S\right\rangle - e^{-i\lambda_S t_2}\left|K_L\right\rangle\right)$$

**a t=0 dipende dallo stato di decadimento futuro $f_2$, e anche dal tempo di decadimento futuro $t_2$**

- **A grandi Δt, K(1) e' un puro $K_S$**

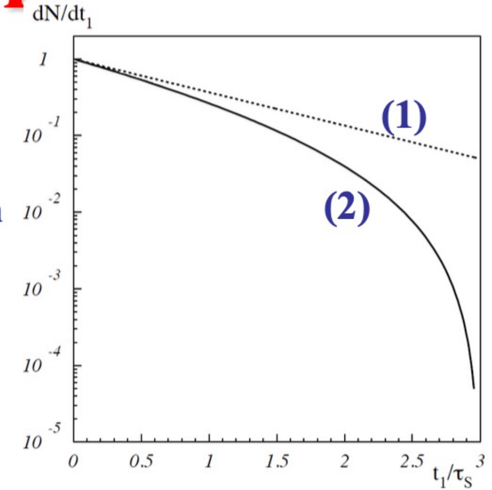
$$\frac{e^{-\frac{1}{2}\Delta\Gamma\Delta t}}{|\eta_2|} << 1$$

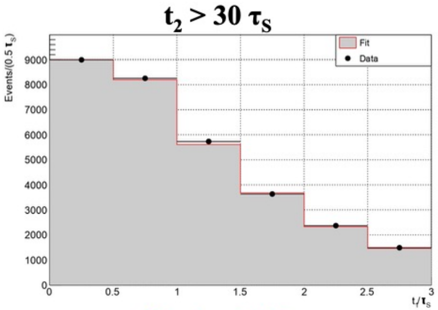
# “From future to past”

- L’effetto e’ osservabile misurando la rate di decadimento del $K^{(1)}$ in funzione di $t_1$
- Scegliendo $f_1 = f_2 = \pi^+\pi^-$ si massimizza l’effetto

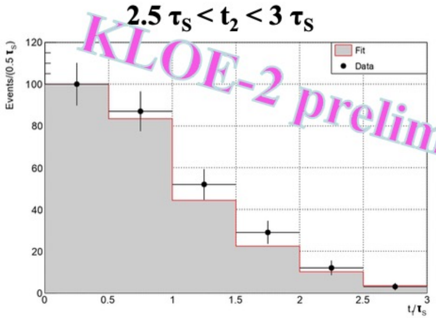
(1) Grandi $\Delta t$, “regione di decoerenza”, lo stato e’ $K_S$ con larghezza definita

(2) Piccoli $\Delta t$ (p.es. $t_2 = 3\ \tau_S$), “regione di interferenza”, la larghezza non e’ definita

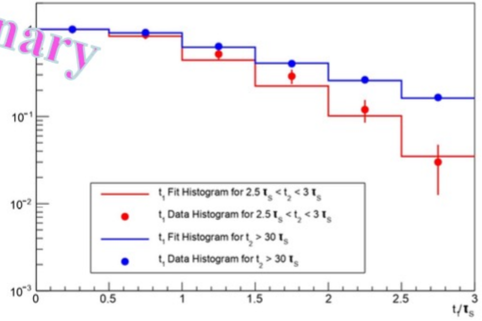



$\chi^2/\mathrm{dof} = 3.4/5$




$\chi^2/\mathrm{dof} = 2.0/5$

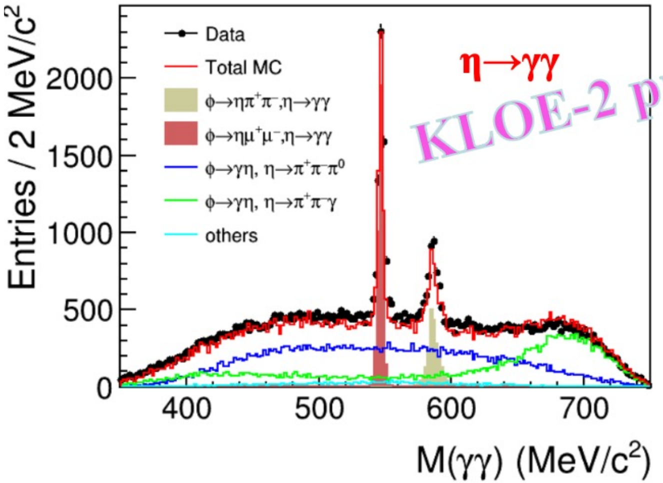



(normalizzazione al 1° bin)

# $\phi \to \eta\mu^+\mu^-$

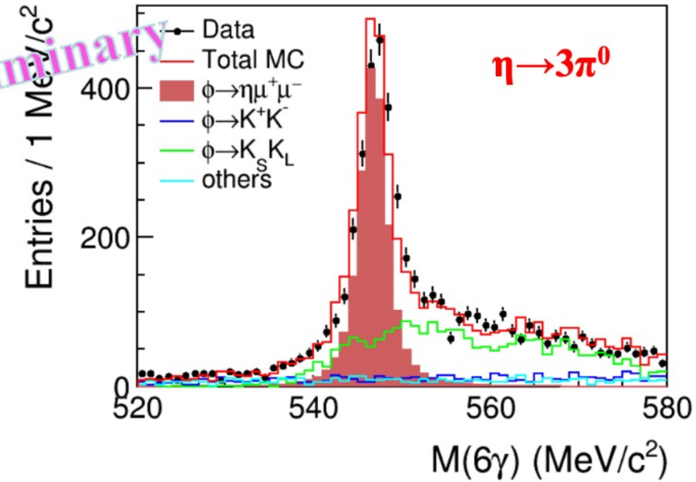
**Finora solo un limite superiore ⇒ $Br(\phi \to \eta\mu^+\mu^-) < 9.4 \times 10^{-6}$ @90% C.L.** [CMD-2, PLB501(2001)191]

- **L = 1.6 $fb^{-1}$**
- **2 tracce + 2 ($\eta \to \gamma\gamma$) o 6 ($\eta \to 3\pi^0$) fotoni prompt**
- **Fit cinematico con 6 o 10 constraints**
- **Taglio su $M(\gamma\mu^+\mu^-)$ per scartare $\phi \to \gamma\eta$, $\eta \to \gamma\pi^+\pi^-$**




**Fondo: $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\pi^0$, $\pi^+\pi^-\gamma$**

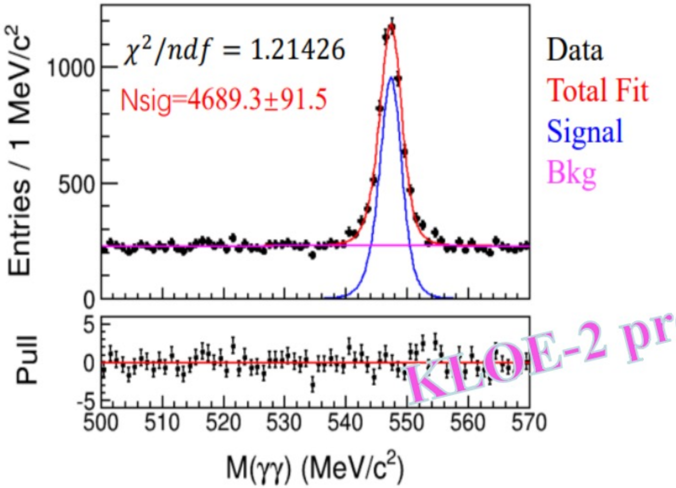
KLOE-2 preliminary



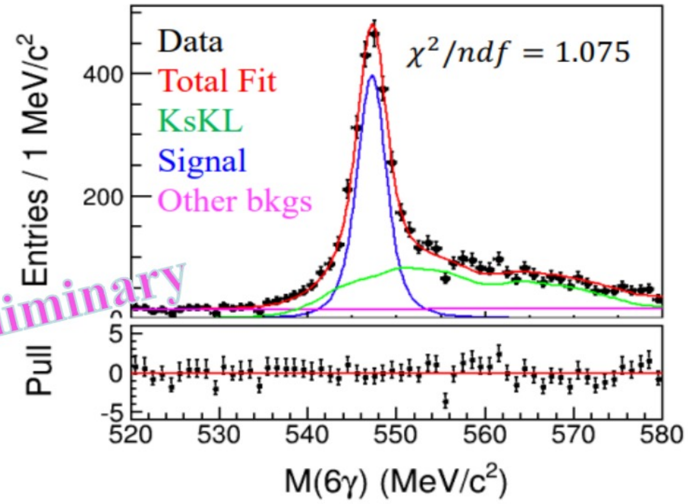

**Fondo: $\phi \to K_S K_L \to \pi^+\pi^-\pi^0\pi^0\pi^0$**

# $\phi \to \eta\mu^+\mu^-$

$\eta \to \gamma\gamma$




$\eta \to \pi^0\pi^0\pi^0$




$$Br(\phi \to \eta\mu^+\mu^-) = (5.65 \pm 0.11) \times 10^{-6}$$

$$Br(\phi \to \eta\mu^+\mu^-) = (5.76 \pm 0.19) \times 10^{-6}$$

Prima misura in assoluto

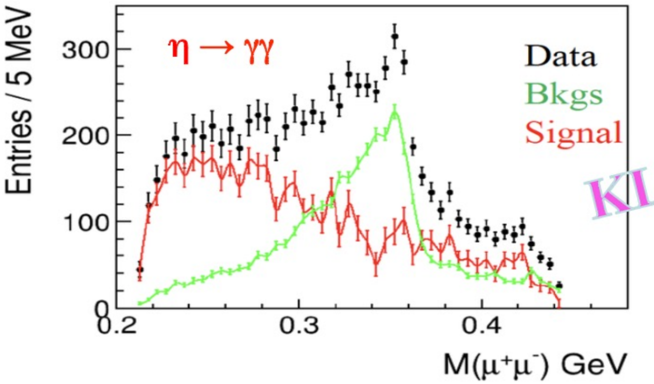
- **Solo incertezze statistiche**
- **In corso la stima delle sistematiche**

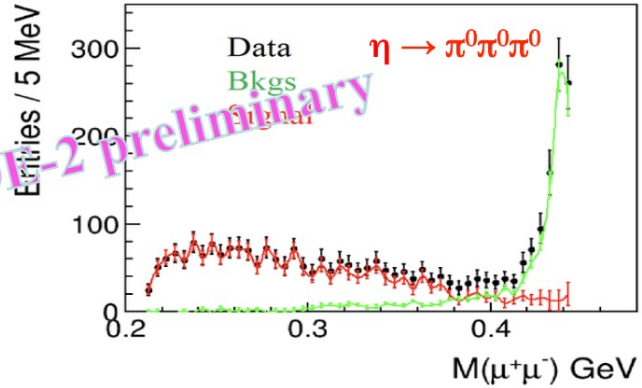
# $\phi \to \eta\mu^+\mu^-$

- **Il fattore di forma di transizione si estrae dalla distribuzione di $M_{\mu\mu}$**

$$\frac{1}{\Gamma(\phi \to \gamma\eta)}\frac{d\Gamma(\phi \to \eta\mu^+\mu^-)}{dq^2} = \left|F_{\phi\eta}(q^2)\right|^2 \times \frac{\alpha}{3\pi}\frac{1}{q^2}\sqrt{1-\frac{4M_\mu^2}{q^2}}\left(1+\frac{2M_\mu^2}{q^2}\right) \times \left[\left(1+\frac{q^2}{M_\phi^2-M_\eta^2}\right)^2 - \frac{4M_\phi^2 q^2}{\left(M_\phi^2-M_\eta^2\right)^2}\right]^{3/2}$$

- **Secondo la VDM:** $F(q^2) = \dfrac{1}{1-\frac{q^2}{\Lambda^2}} \quad \Lambda^{-2} = \left.\dfrac{dF}{dq^2}\right|_{q^2=0}$




$\Lambda^{-2} = (3.01 \pm 0.10)\ \mathrm{GeV}^{-2}$ $\qquad$ $\Lambda^{-2} = (2.90 \pm 0.20)\ \mathrm{GeV}^{-2}$

| | $\Lambda^{-2}$ [$\mathrm{GeV}^{-2}$] | |
|---|---|---|
| $\phi \to \eta e^+e^-$ | 1.28 ± 0.13 | *PLB742(2015)1* |
| $\phi \to \pi^0 e^+e^-$ | 2.02 ± 0.11 | *PLB757(2016)362* |

**Altri fattori di forma misurati da KLOE**