THE KLOE-2 EXPERIMENT

ANDREA SELCE

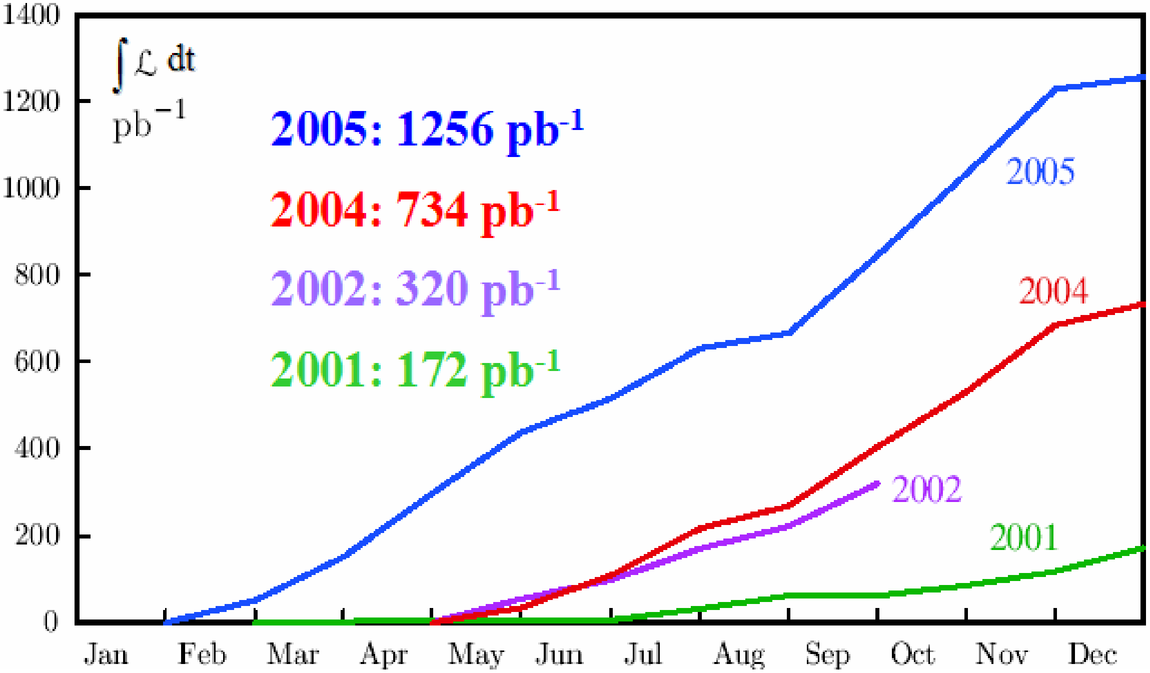
UNIVERSITA' & INFN ROMA TRE

on behalf of the KLOE-2 COLLABORATION

KLOE@DAΦNE

φ-FACTORY

- Collider $e^+ e^-$
- $\sqrt{s} = M(\phi) = 1019.4$ MeV



- KLOE ~2.5 fb^{-1} (2.0 @ $\sqrt{s}=M(\phi)$)
- KLOE-2 started 11/2014

KLOE-2 RUN IN PROGRESS

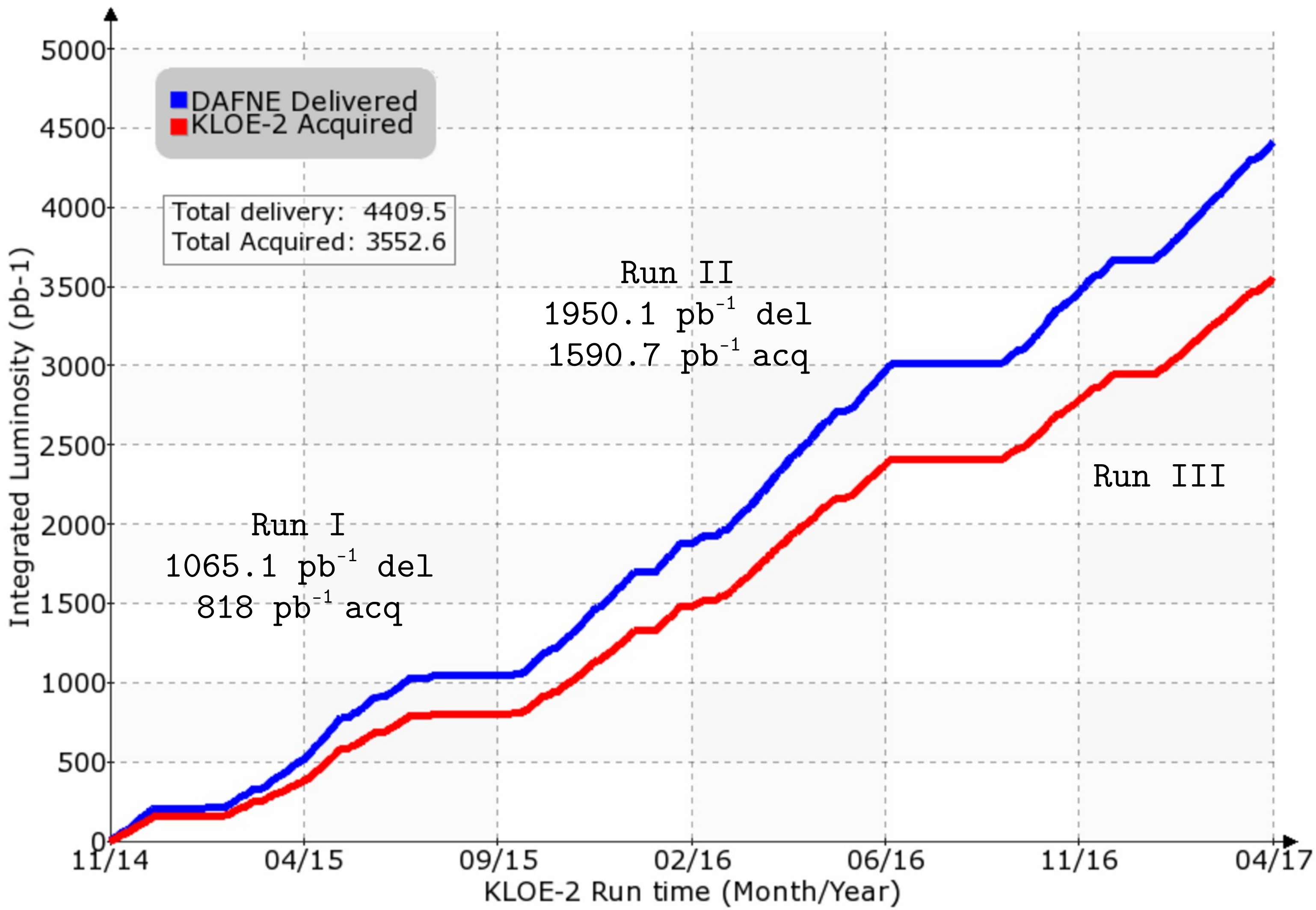
BEST Achievements in KLOE-2

Total delivery: 4351 pb^{-1}
Total acquired: 3505 pb^{-1}
Max instantaneous: $3.41 \times 10^{32} cm^{-2} s^{-1}$
Max hourly: 651.0 nb^{-1}
Max daily delivery: 13.4 pb^{-1}
Max daily acquired: 11.0 pb^{-1}
Max weekly delivered: 76.3 pb^{-1}
Max weekly acquired: 62.9 pb^{-1}

Goal

$\int L dt > 5 \; fb^{-1}$

Data taking till 31/03/2018



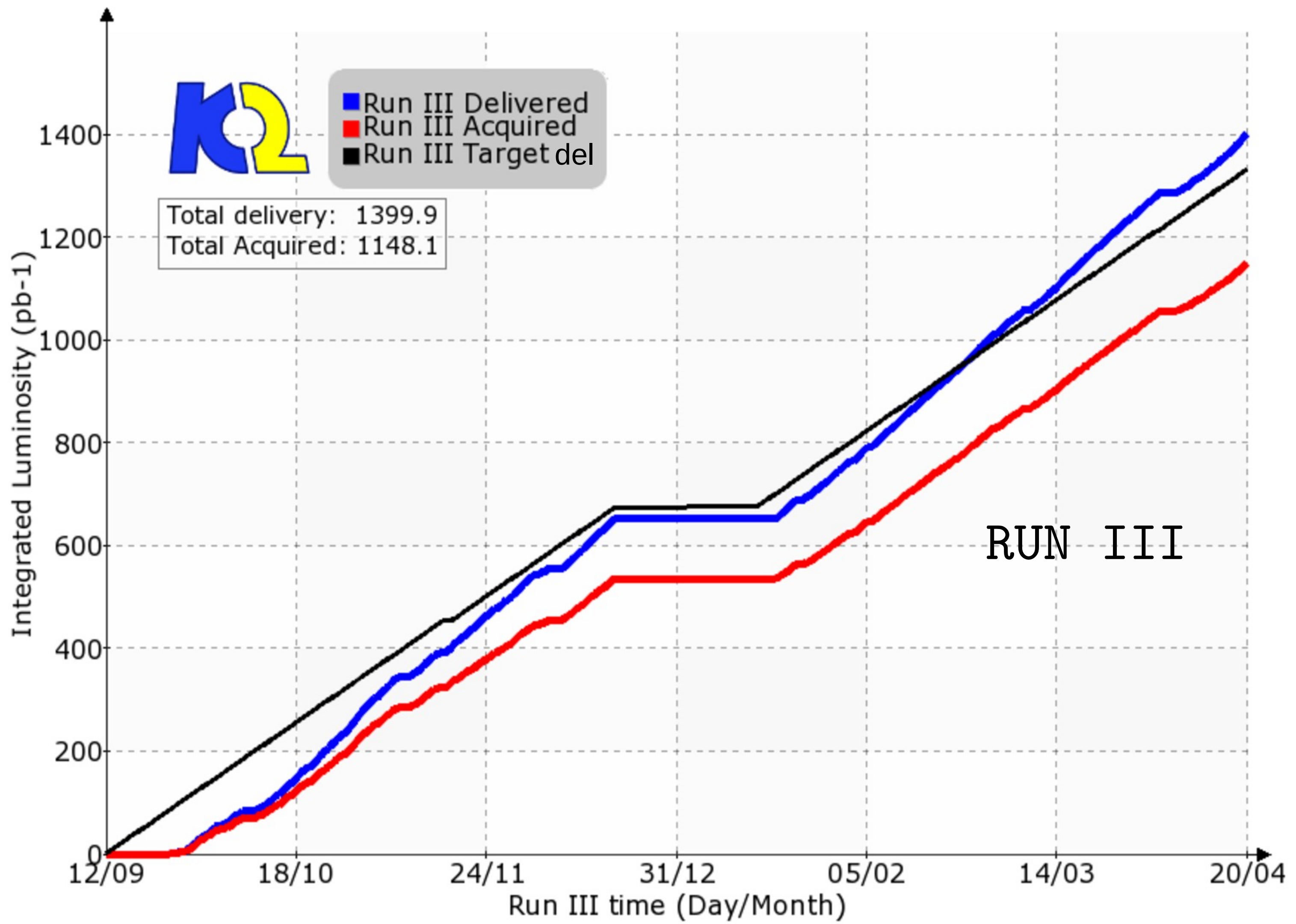
KLOE-2 RUN IN PROGRESS

BEST Achievements in KLOE-2

Total delivery: 4351 pb^{-1}
Total acquired: 3505 pb^{-1}
Max instantaneous: $3.41 \times 10^{32} cm^{-2} s^{-1}$
Max hourly: 651.0 nb^{-1}
Max daily delivery: 13.4 pb^{-1}
Max daily acquired: 11.0 pb^{-1}
Max weekly delivered: 76.3 pb^{-1}
Max weekly acquired: 62.9 pb^{-1}

Goal
$\int L dt > 5\ fb^{-1}$

Data taking till 31/03/2018



KLOE-2 TYPICAL DAY

Average values at run time:

$I^- \sim$ 1.2÷1.4 A

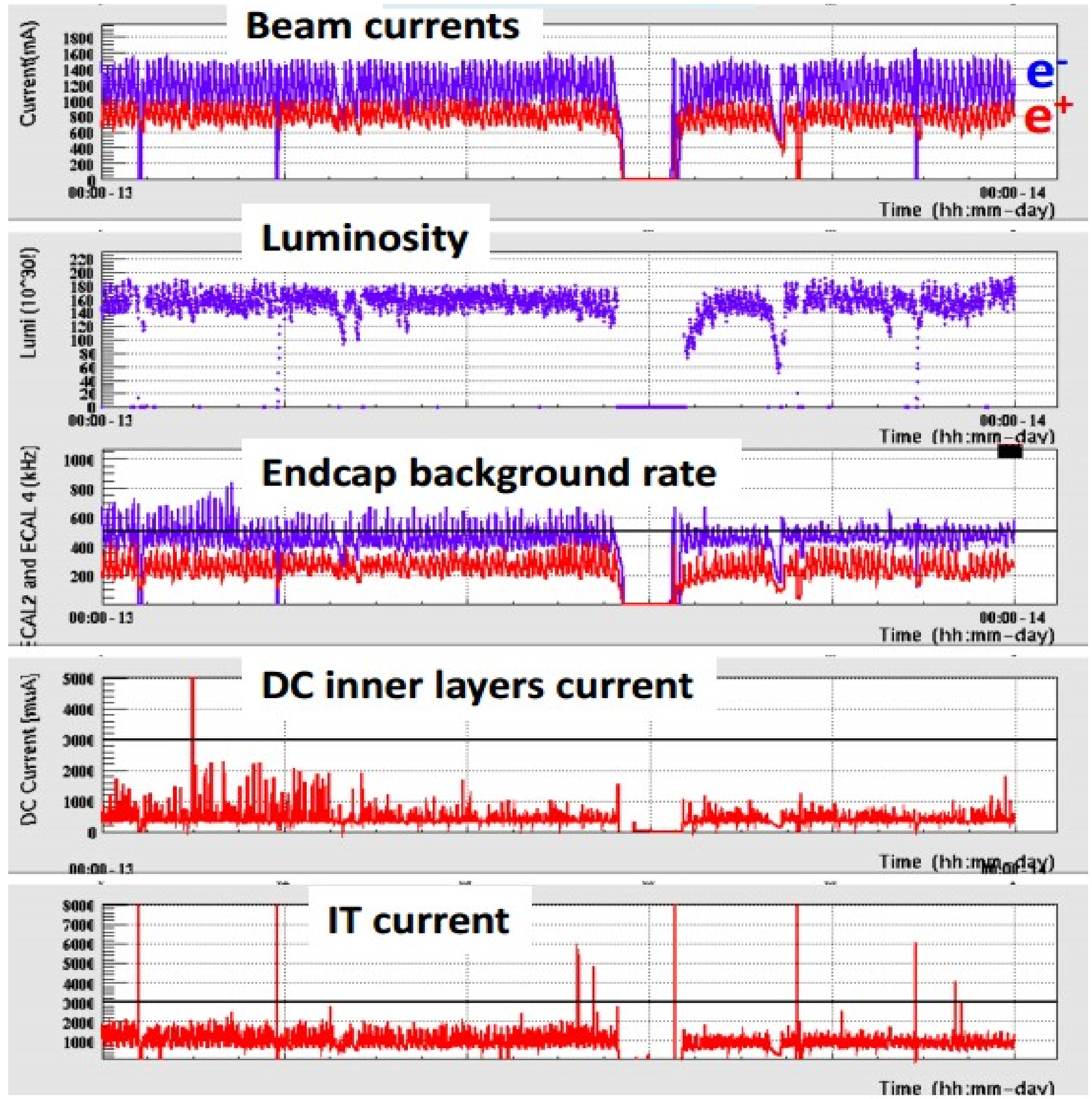
$I^+ \sim$ 0.7÷1.0 A

$\mathscr{L} \sim$ 1.4÷1.8 x10^{32} cm^{-2}s^{-1}

Higher background level than KLOE

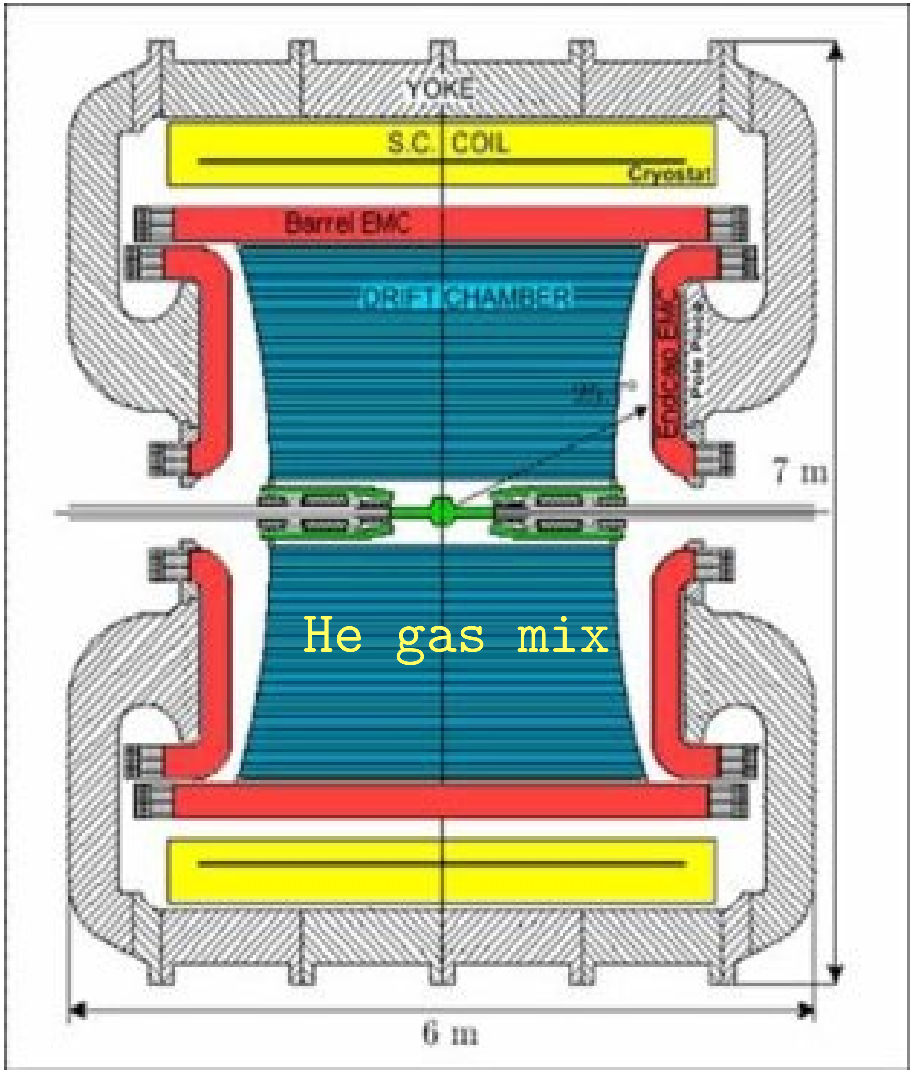
Constant monitoring on background level & feedback to DAFNE

- ECAP bkg-average < 500 kHz
- DC current < 3000 μA
- IT current < 3000 nA



KLOE-2 DETECTORS - DC

Superconducting coil, $B = 0.52$ T

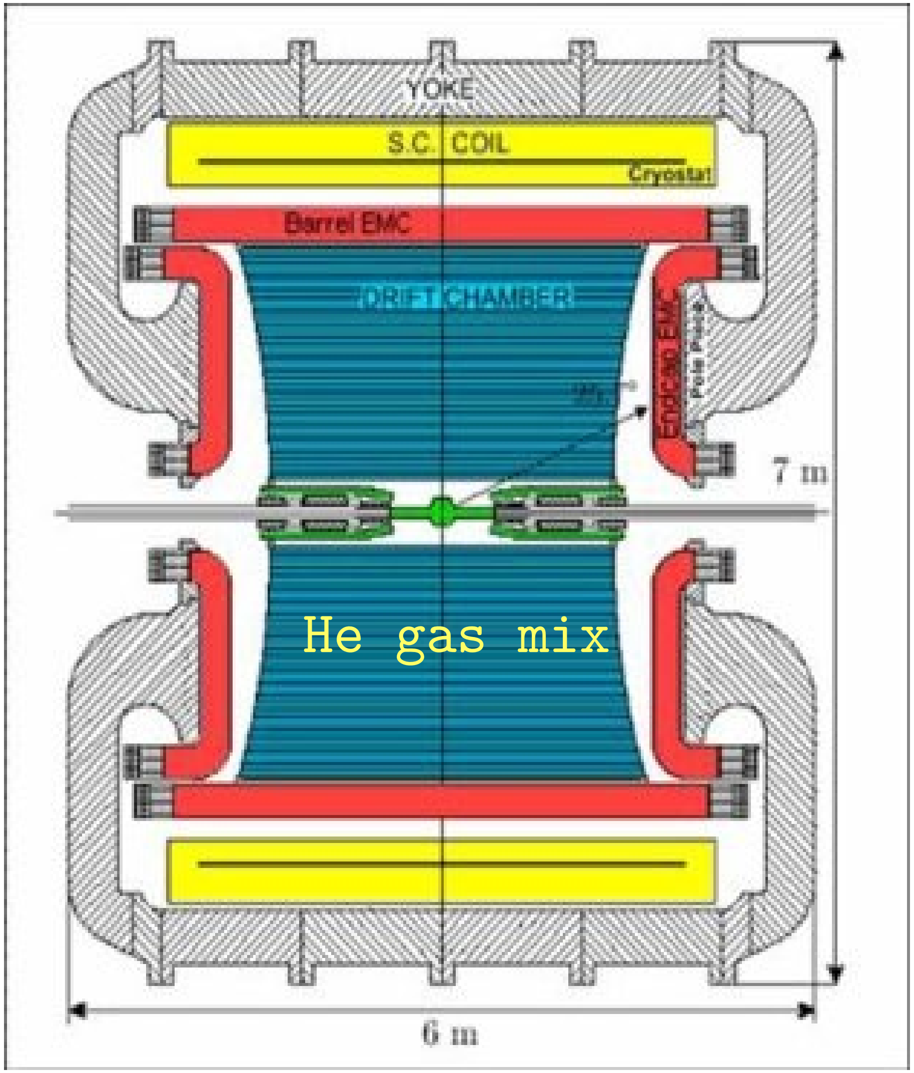


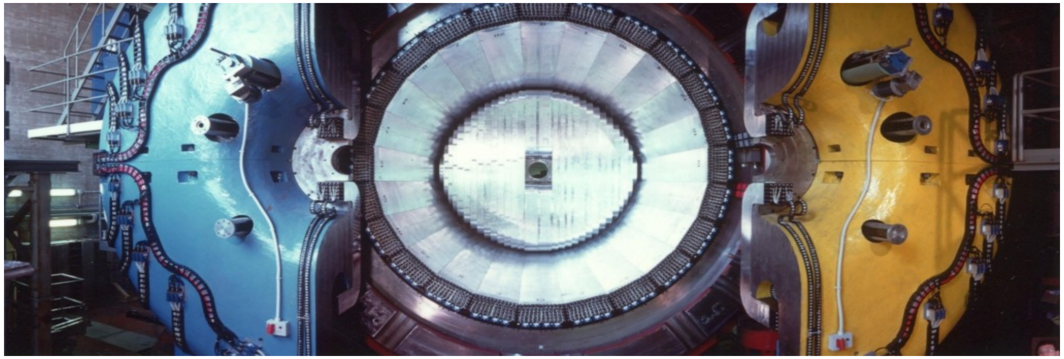
Full stereo geometry, 4m diameter
52140 total wires, 12582 sense wires

- $\sigma_p/p = 0.4\%$ (for $45^0 < \vartheta < 135^0$ tracks)
- $\sigma_{x,y} \approx 150$ μm, $\sigma_z \approx 2$ mm

KLOE-2 DETECTORS – EMC

Superconducting coil, B = 0.52 T



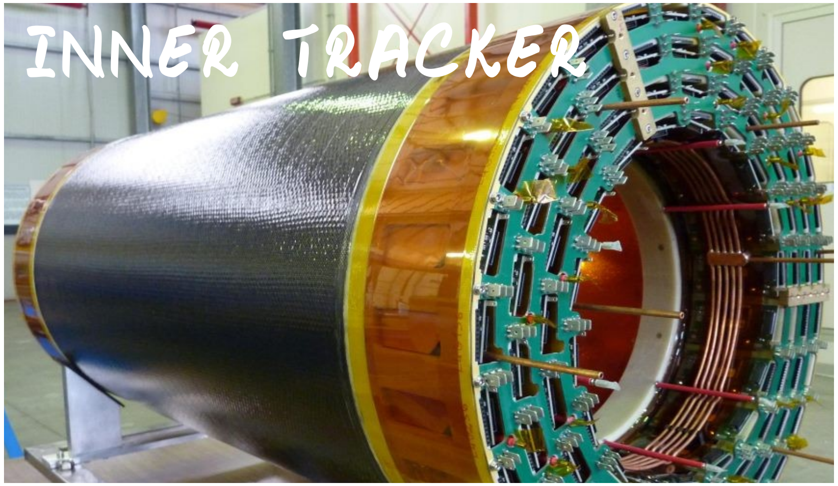


Pb-SciFi Calorimeter (15 X0 depth, 98% solid angle)

- $\sigma_E/E = 5.7\% / \sqrt{E(\mathrm{GeV})}$
- $\sigma_T = 54\ \mathrm{ps} / \sqrt{E(\mathrm{GeV})} \oplus 100\ \mathrm{ps}$

($\oplus$140 per Q=0)

KLOE-2 NEW DETECTORS

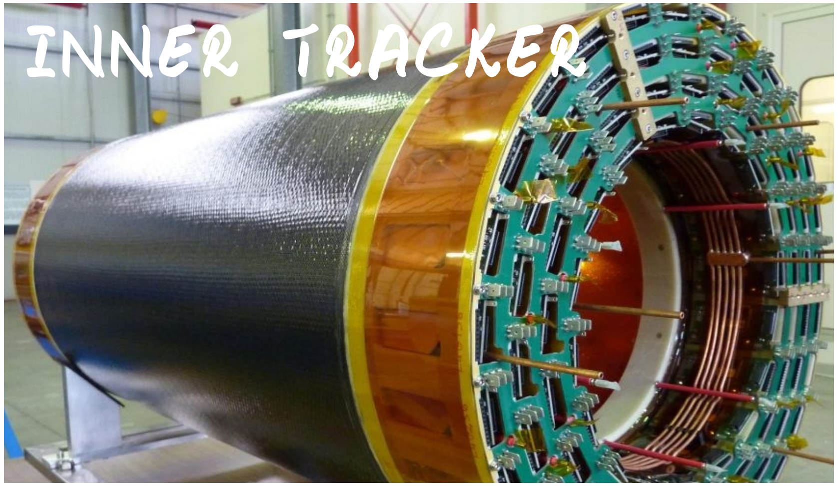


IMPROVE VERTEX AND TRACKING CLOSE TO IP

INNER TRACKER

- 4 layers of cylindrical triple GEM tracker

KLOE-2 NEW DETECTORS



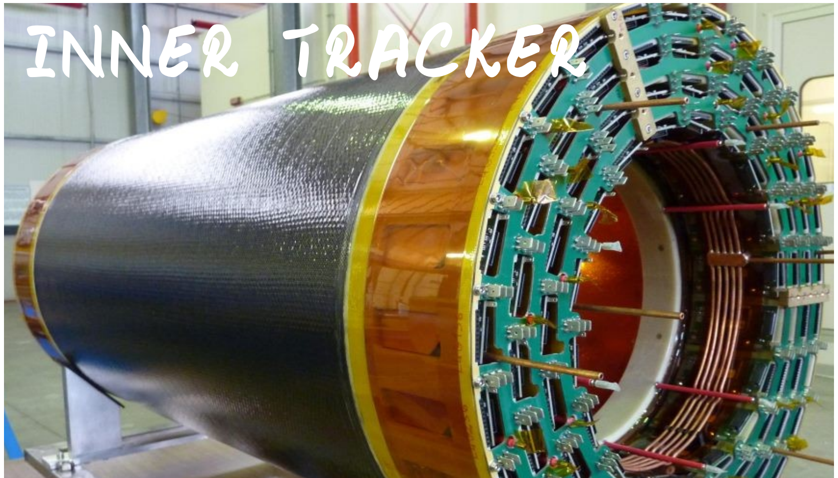
IMPROVE VERTEX AND TRACKING CLOSE TO IP

INNER TRACKER

- 4 layers of cylindrical triple GEM tracker

INCREASE CALORIMETER HERMETICITY

KLOE-2 NEW DETECTORS



IMPROVE VERTEX AND TRACKING CLOSE TO IP

INNER TRACKER

- 4 layers of cylindrical triple GEM tracker

INCREASE CALORIMETER HERMETICITY

QCALT

W + Scint. + WLS&SiPMs

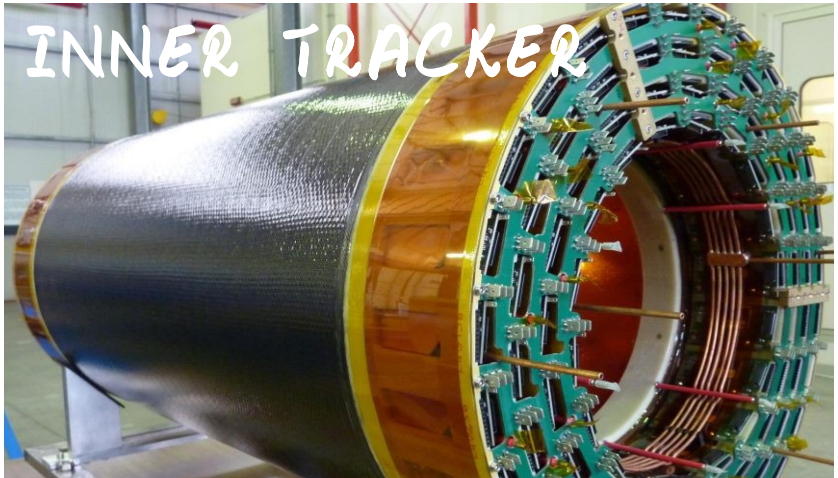
- 'Low-beta' quadrupole coverage

CCALT

LYSO+APDs

- Better photon/electron acceptance (20°-->10°)

KLOE-2 NEW DETECTORS



IMPROVE VERTEX AND TRACKING CLOSE TO IP

INNER TRACKER

- 4 layers of cylindrical triple GEM tracker

INCREASE CALORIMETER HERMETICITY

QCALT

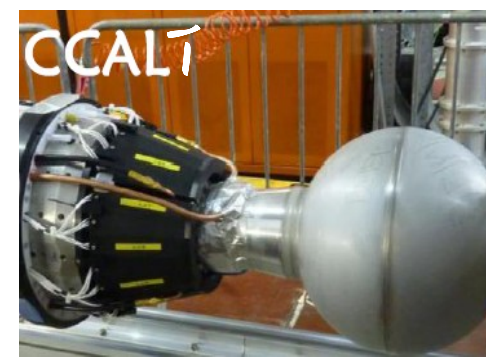
W + Scint. + WLS&SiPMs

- 'Low-beta' quadrupole coverage

CCALT

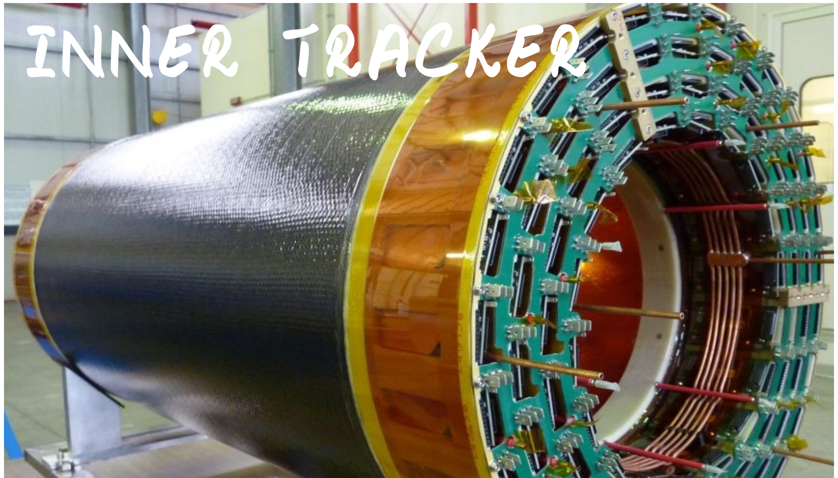
LYSO+APDs

- Better photon/electron acceptance (20°-->10°)



ADD $\gamma\gamma$ EVENTS TAGGING DETECTORS

KLOE-2 NEW DETECTORS



IMPROVE VERTEX AND TRACKING CLOSE TO IP

INNER TRACKER

- 4 layers of cylindrical triple GEM tracker

INCREASE CALORIMETER HERMETICITY

QCALT

W + Scint. + WLS&SiPMs

- 'Low-beta' quadrupole coverage

CCALT

LYSO+APDs

- Better photon/electron acceptance (20°-->10°)

ADD $\gamma\gamma$ EVENTS TAGGING DETECTORS

LET&HET

LYSO+SiPMs&Scint+PMTs

- e^+/e^- taggers for $\gamma\gamma$ physics

KLOE-2 INNER TRACKER

IMPROVE VERTEX AND TRACKING CLOSE TO IP

- INNER TRACKER
- 4 layers of cylindrical triple GEM tracker

KLOE-2 INNER TRACKER

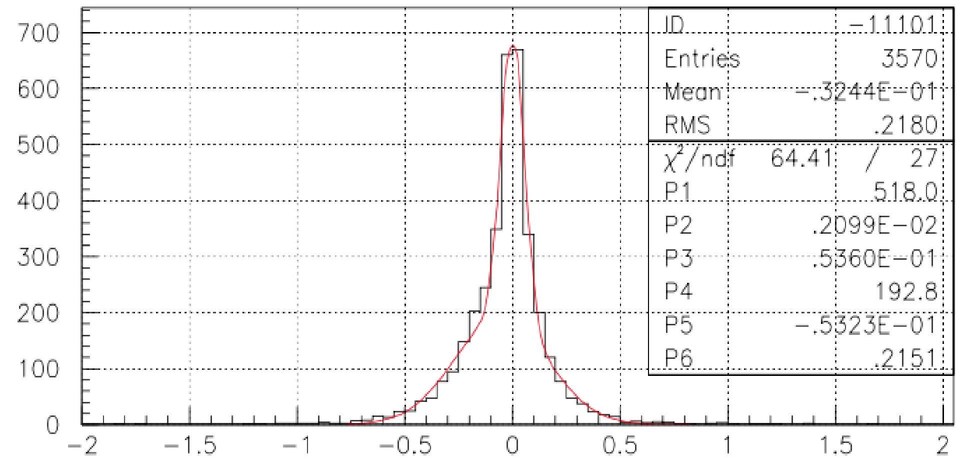
IMPROVE VERTEX AND TRACKING CLOSE TO IP

- $\phi \to \pi^+\pi^-\pi^0$ PCA

Narrow = 40%
Broad = 60%

$\text{sigma}_{\text{Narrow}}(\text{DC}) = 0.5$ mm
$\text{sigma}_{\text{Broad}}(\text{DC}) = 2.1$ mm

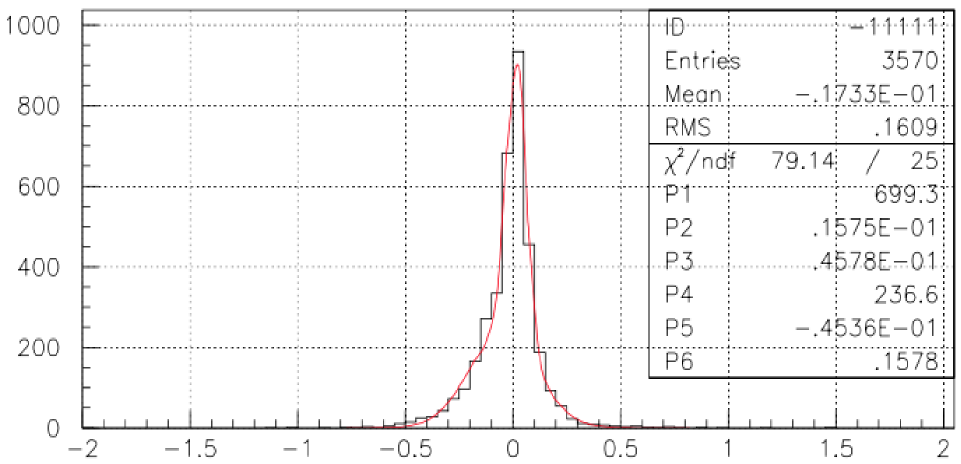
$\text{sigma}_{\text{PCA}}(\text{DC}) = 1.7$ mm



Narrow = 40%
Broad = 60%

$\text{sigma}_{\text{Narrow}}(\text{DC+IT}) = 0.4$ mm
$\text{sigma}_{\text{Broad}}(\text{DC+IT}) = 1.6$ mm

$\text{sigma}_{\text{PCA}}(\text{DC+IT}) = 1.1$ mm

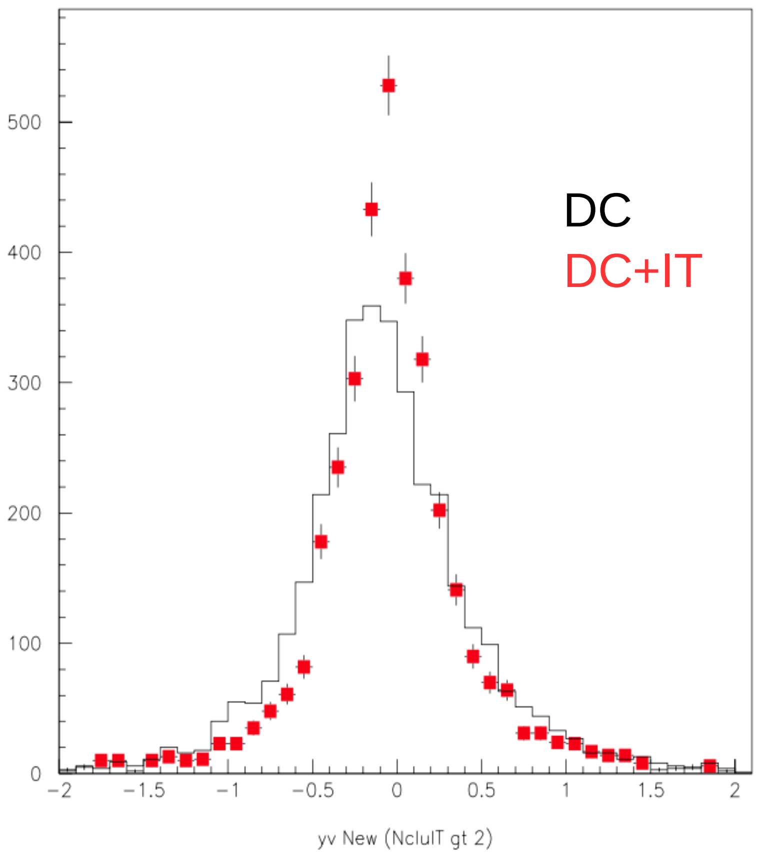


KLOE-2 INNER TRACKER

IMPROVE VERTEX AND TRACKING CLOSE TO IP

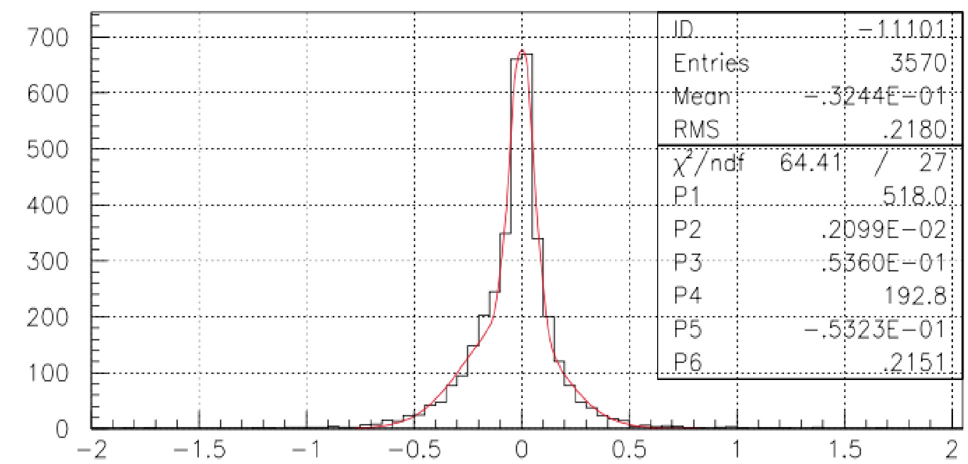
- $\phi \to \pi^+\pi^-\pi^0$ VTX

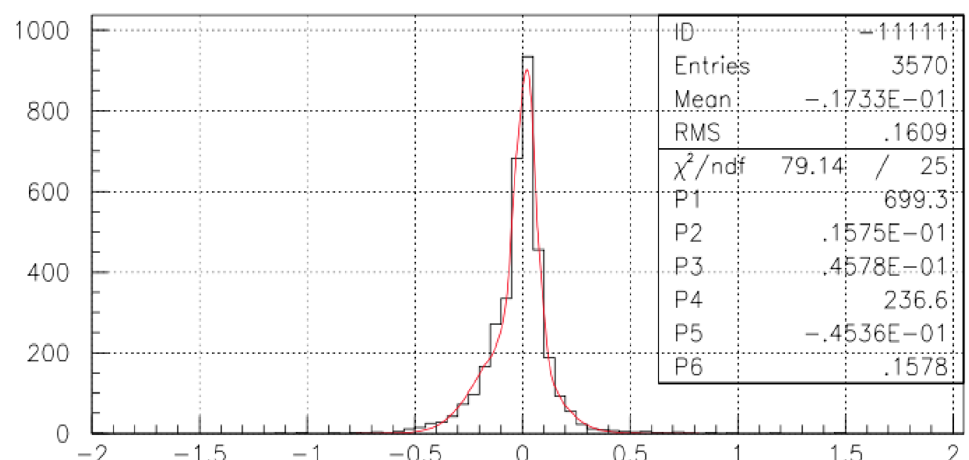
Measure directly vertex resolution with decay at IP



Y component due to smaller beam size (tens of μm)

- $\phi \to \pi^+\pi^-\pi^0$ PCA

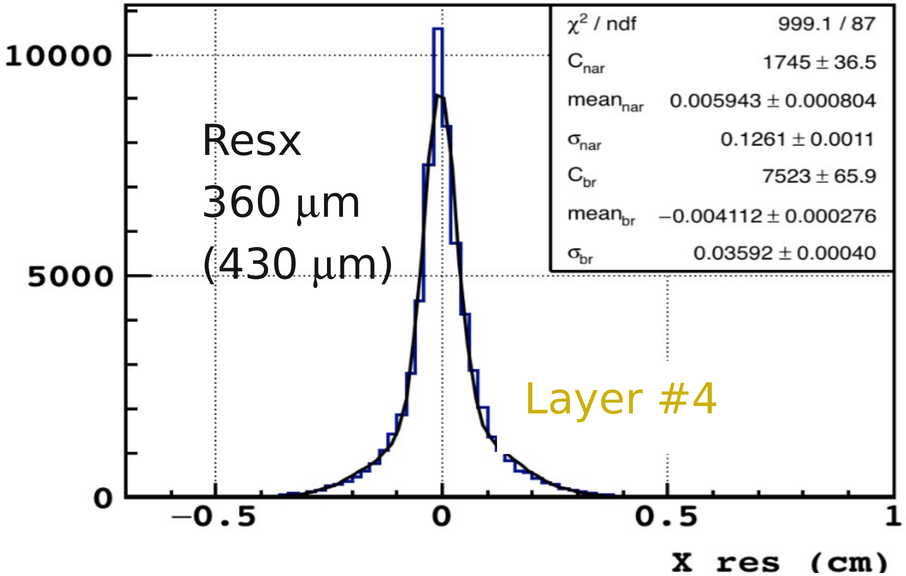


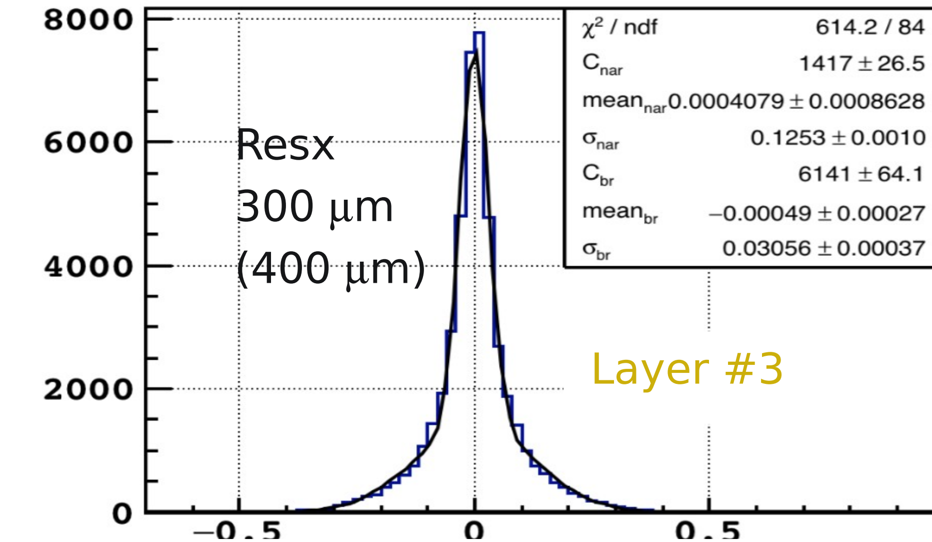


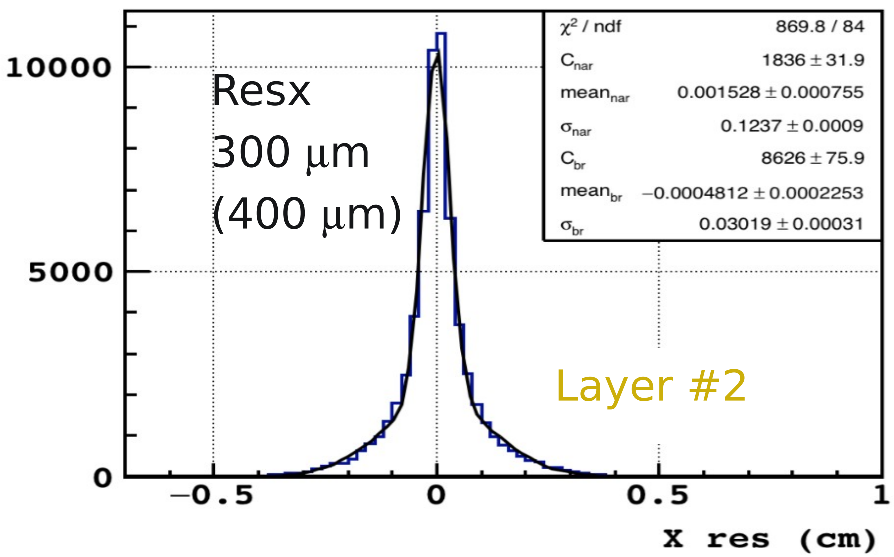
KLOE-2 INNER TRACKER

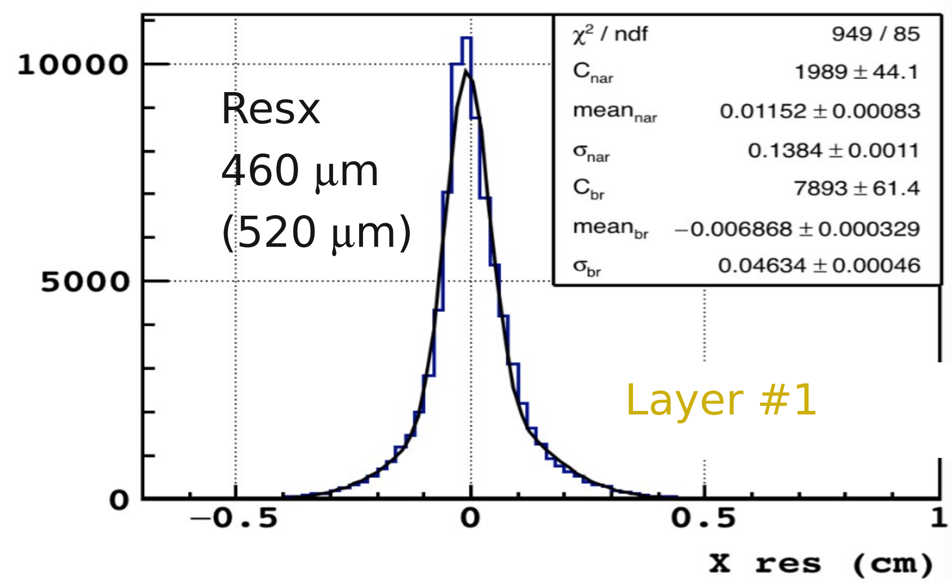
IMPROVE VERTEX AND TRACKING CLOSE TO IP

- NEW CALIBRATION (vs OLD): cosmics, B off



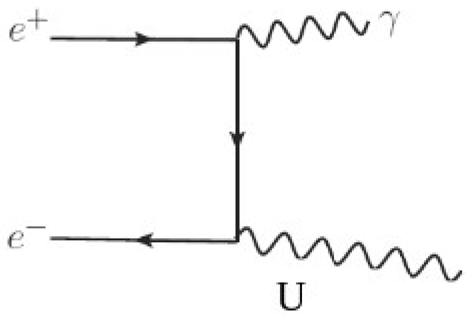






SINGLE PHOTON TRIGGER (SPT)

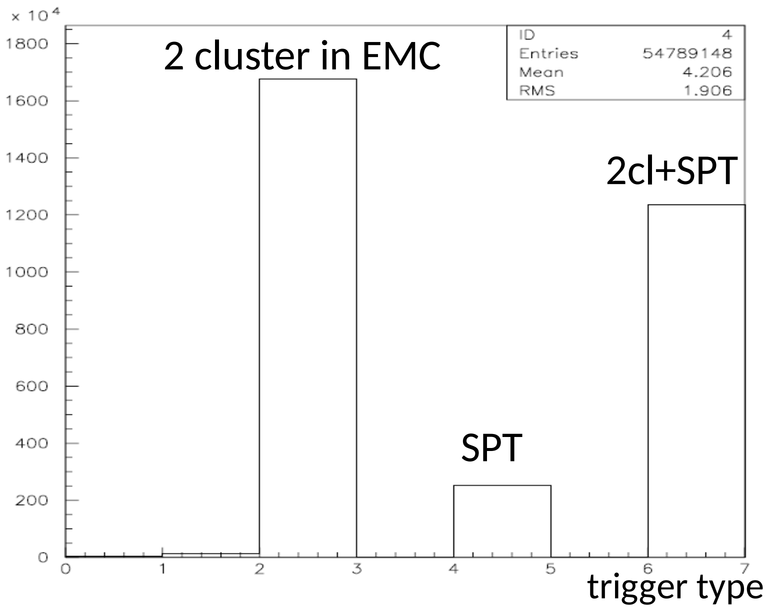
Single photon trigger crucial for search of dark mediator (U-boson) not decaying in the apparatus



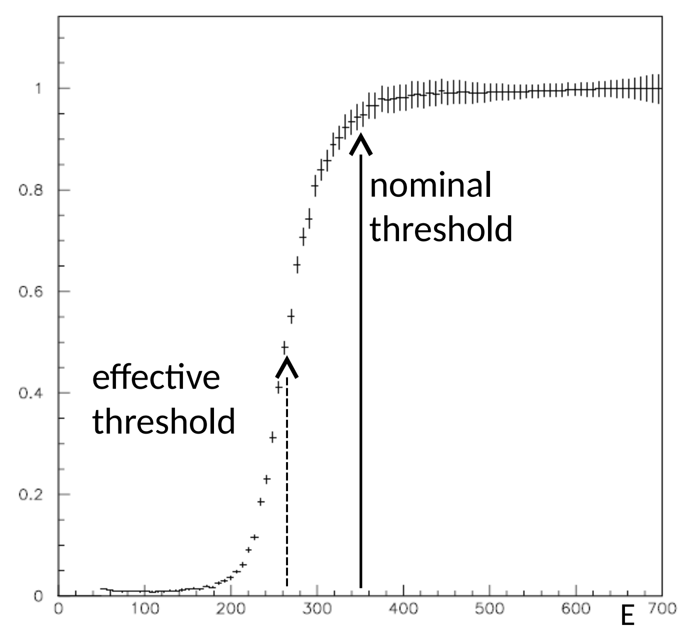
Barrel-only majority one, Bhabha nominal threshold (350 MeV)
→ exploring U boson mass below 600 MeV

Inserted permanently in the KLOE trigger logic since 28th November 2016

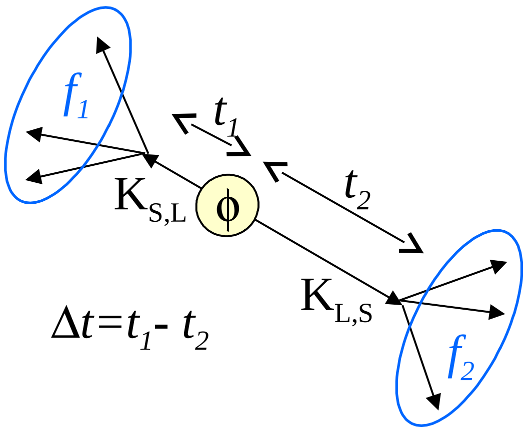
- SPT free running rate ~ 2.2 kHz
  SPT additional rate ~ 300 ÷ 350 Hz



- Efficiency studies on radiative bhabha events

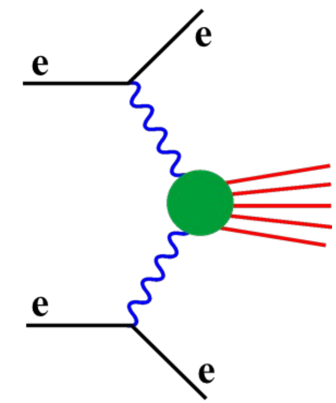


PHYSICS@KLOE-2

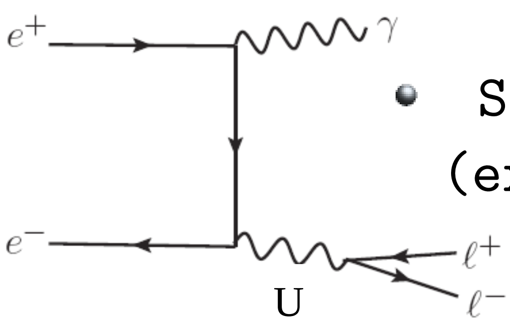


- Kaon Physics

- Discrete symmetries test

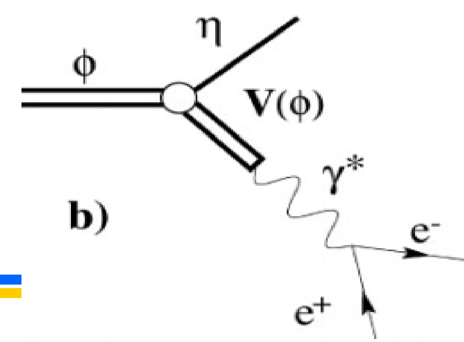


- $\gamma\gamma$ phisycs $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$, thanks to new tagger detectors



- Search of dark force mediator in various channels (ex: $e^+e^- \to U\gamma$; $e^+e^- \to U\gamma \to l^+l^-\gamma$)

- Hadronic physics below 1 GeV



RECENT KLOE-2 RESULTS

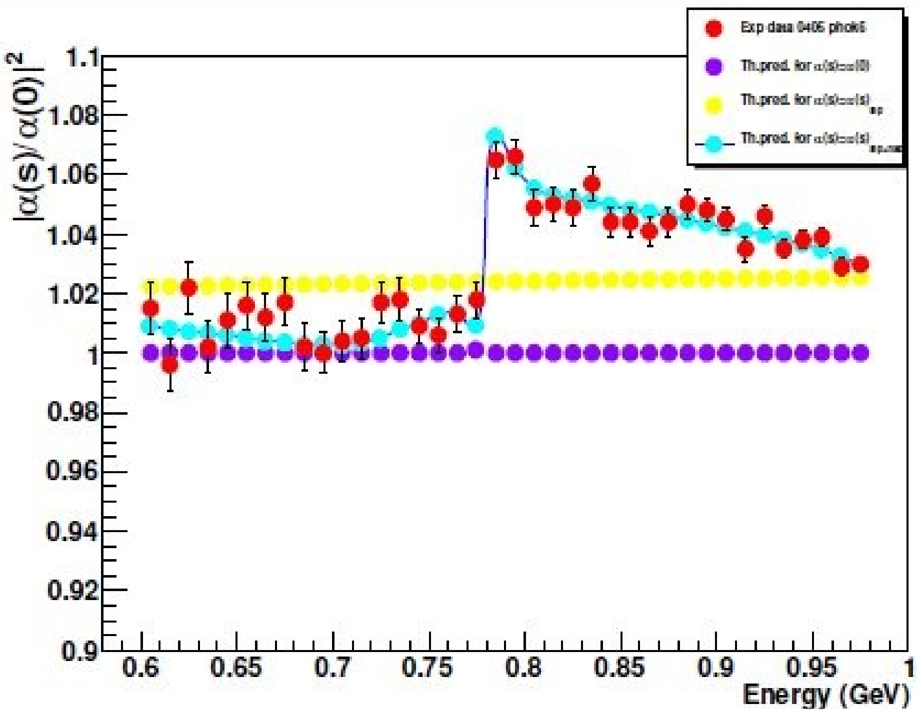
BR and Transition Form Factor of $\varphi \to \pi^0 e^+e^-$	PLB 757 (2016) 362
Dalitz plot analysis of $\eta \to \pi^+\pi^-\pi^0$	JHEP 1605 (2016) 019
Hadron Vacuum Polarization in $e^+e^- \to \mu^+\mu^-\gamma$ (*)	PLB 767 (2017) 485 (http://dx.doi.org/10.1016/j.physletb.2016.12.016)
U boson search in $e^+e^- \to U\gamma$, $U \to \pi^+\pi^-$	PLB 757 (2016) 356
U boson search: combined limit from $\mu\mu\gamma/\pi\pi\gamma$	In progress
BR of $\eta \to \pi^0\gamma\gamma$ χ_{pT} Golden mode	In progress
B boson search in $\phi \to \eta\pi^0 \gamma$	In progress
CPT test with $\varphi \to K_S K_L \to 3\pi^0\, \pi l \nu,\ \pi\pi\, \pi l \nu$	ΔT distributions ready (in progress)
BR and charge asymmetry in $K_S \to \pi e \nu$	Finalizing Systematics
BR in $K_S \to \pi^+ \pi^- \pi^0$	In progress

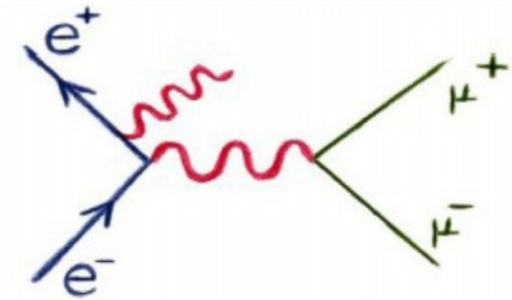
,

$\alpha_{QED}(s)$ below 1 GeV

Phys. Lett. B 767 (2017) 485-492

First measurement of the running of the effective $\alpha_{QED}(s)$ below 1 GeV





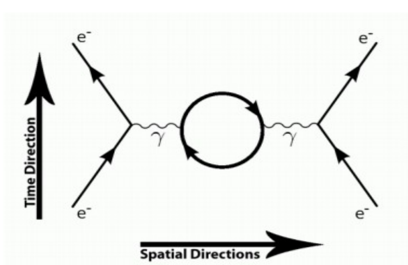
$$\left|\frac{\alpha_{QED}(s)}{\alpha_{QED}(0)}\right|^2 = \frac{\frac{d\sigma^{ISR}}{dM_{\mu\mu}}}{\frac{d\sigma^{MC}}{dM_{\mu\mu}}}$$

$\frac{d\sigma^{MC}}{dM_{\mu\mu}}$ with the VP contribution removed.

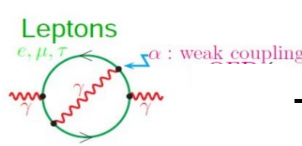
$$\left|\frac{\alpha(s)}{\alpha(0)}\right|^2 = |1/(1-\Delta\alpha(s))|^2$$

$$\Delta\alpha(s) = \Delta\alpha_{lep}(s) + \Delta\alpha_{had}(s)$$

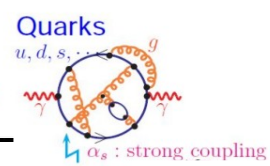
(we neglect the top contribution)



+



+



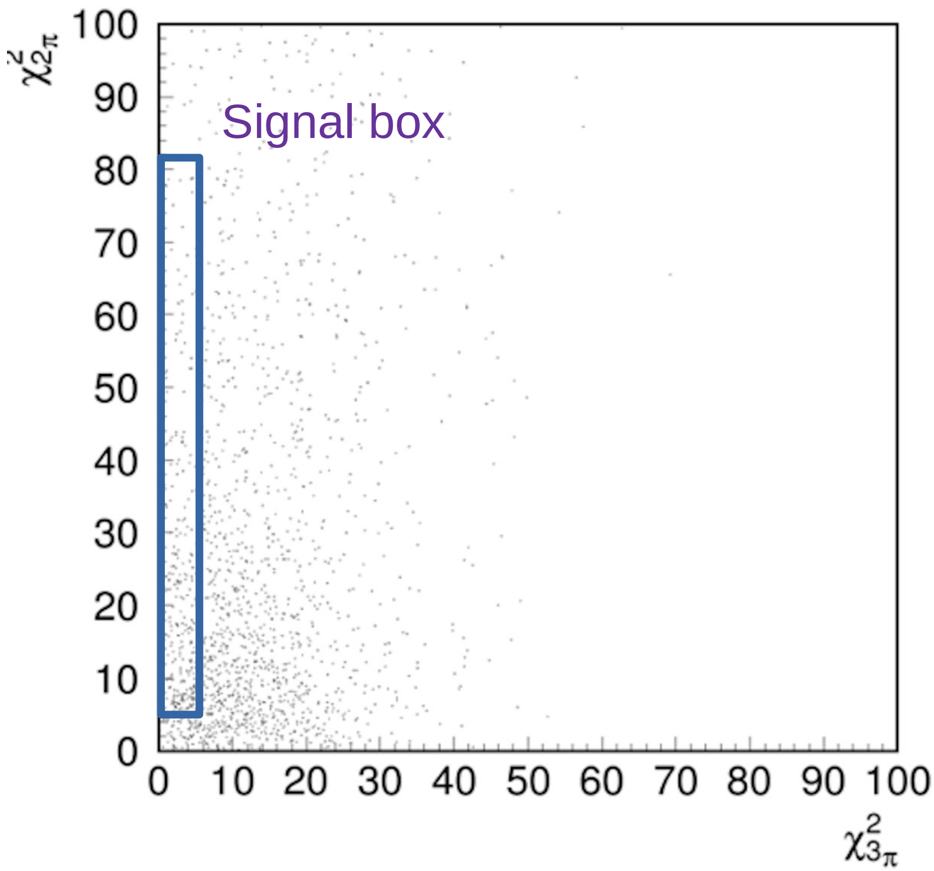
Hypothesis of only-leptonic contribution to $\alpha_{QED}(s)$ excluded at 6 sigmas

$K_S \to \pi^0\pi^0\pi^0$

Analyzing KLOE-2 new data
($224\ pb^{-1}$)

Direct search for the CP violating decay

Best KLOE upper limit:
$BR(K_S \to 3\pi^0) < 2.6 \times 10^{-8}$
with $1.7\ fb^{-1}$



KLOE-2:
Hardened selection criteria to cope with increase of background

$N_{obs}=0$ event selected as a signal
upper limit on $BR(K_S \to 3\pi^0) < 1.8 \times 10^{-7}$

SUMMARY

- KLOE-2 is currently taking data at the DAFNE collider
- All subdetectors are properly working
- Goal: $\int L dt > 5\ fb^{-1}$, until 31 March 2018
- Analyses ongoing on old and new data

SUMMARY

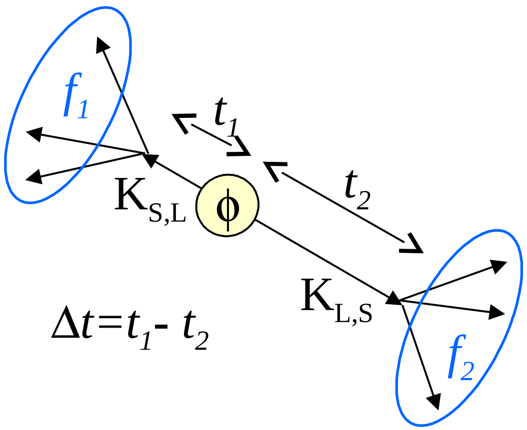
- KLOE-2 is currently taking data at the DAFNE collider
- All subdetectors are properly working
- Goal: $\int L dt > 5\ fb^{-1}$,until 31 March 2018
- Analyses ongoing on old and new data

THANK YOU FOR YOUR ATTENTION!!!

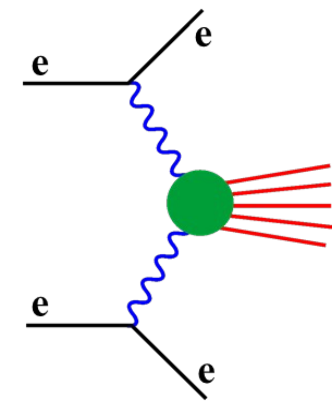
THANK YOU FOR YOUR ATTENTION

SPARES

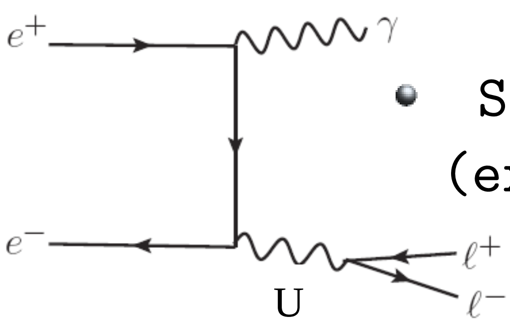
PHYSICS@KLOE-2



- Kaon Physics
- Discrete symmetries test

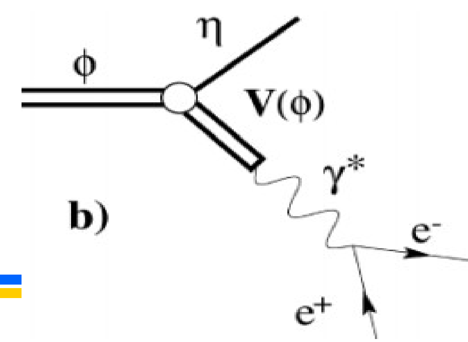


- $\gamma\gamma$ phisycs $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$, thanks to new tagger detectors



- Search of dark force mediator in various channels (ex: $e^+e^- \to U\gamma$; $e^+e^- \to U\gamma \to l^+l^-\gamma$)

- Hadronic physics below 1 GeV

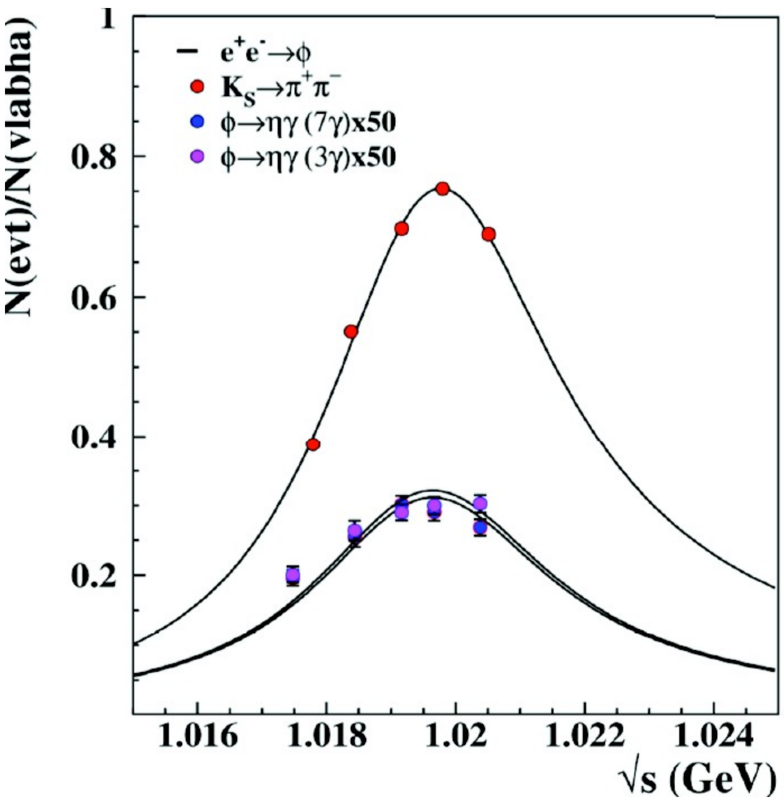


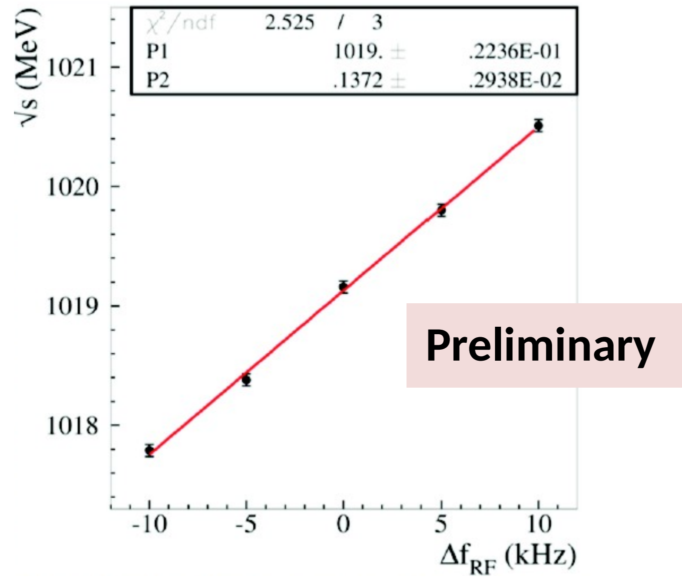
ENERGY SCAN

Scan performed by DAFNE shifting central RF:

Count events:

- $\phi \to K_S K_L$, with $K_S \to \pi^+\pi^-$
- $\phi \to \eta\gamma$, with $\eta \to \gamma\gamma$, $\eta \to 3\pi^0$





KLOE absolute $\sqrt{s}$ fine calibration: -240 keV

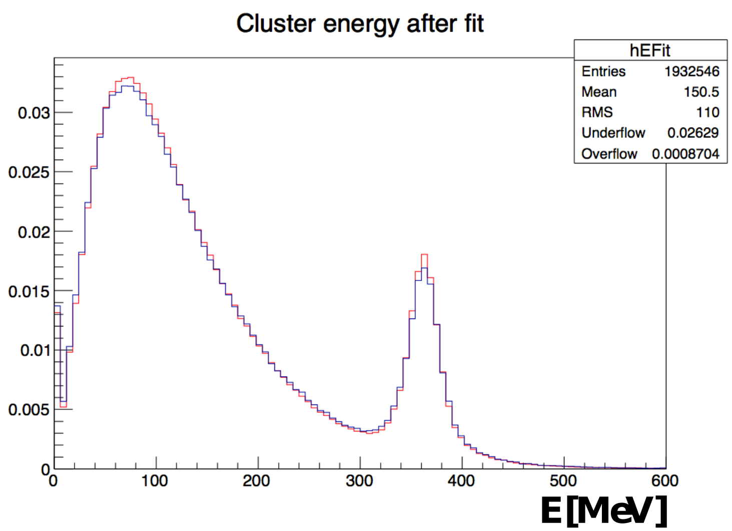
DAFNE $\sqrt{s}$ value shifted by +550 keV to run exactly on peak

Events normalized to large angle Bhabhas

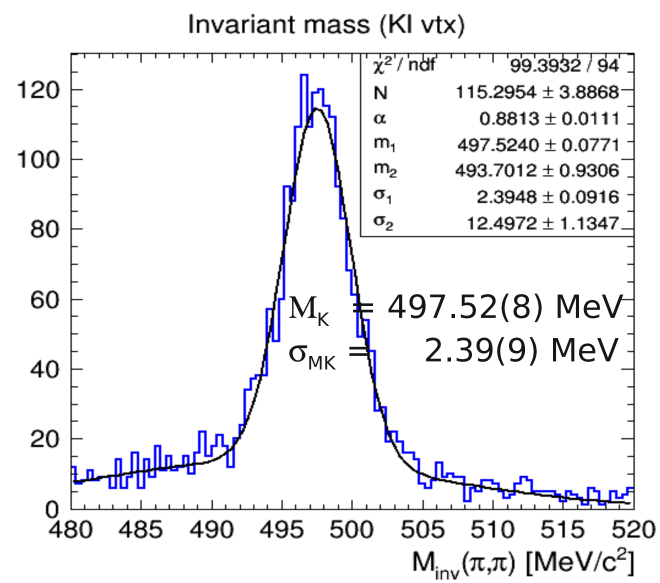
BENCHMARK CHANNELS

Analyses on benchmark channels show general agreement with KLOE data despite increase of background

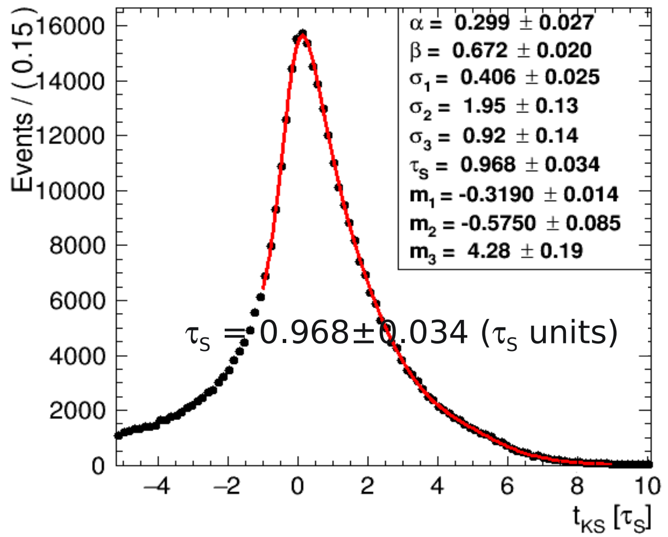
$\phi \to \eta\gamma$ with $\eta \to 3\pi^0$



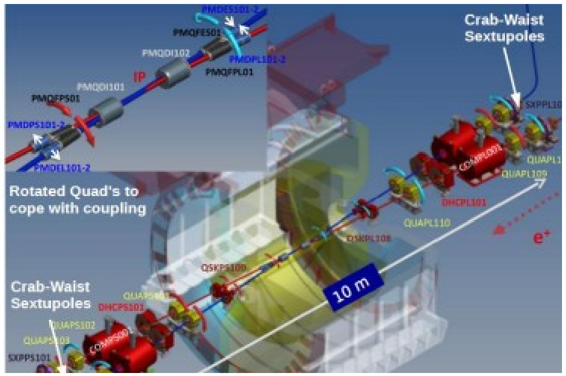
K_L inv mass with $K_L \to \pi^+\pi^-$



K_S lifetime with $K_S \to \pi^+\pi^-$

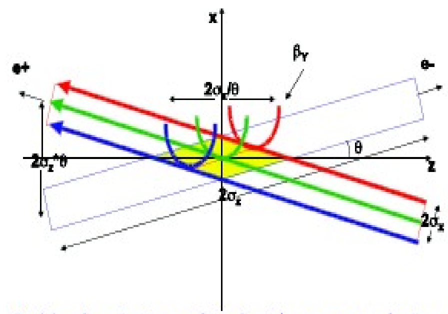


DAΦNE UPGRADE

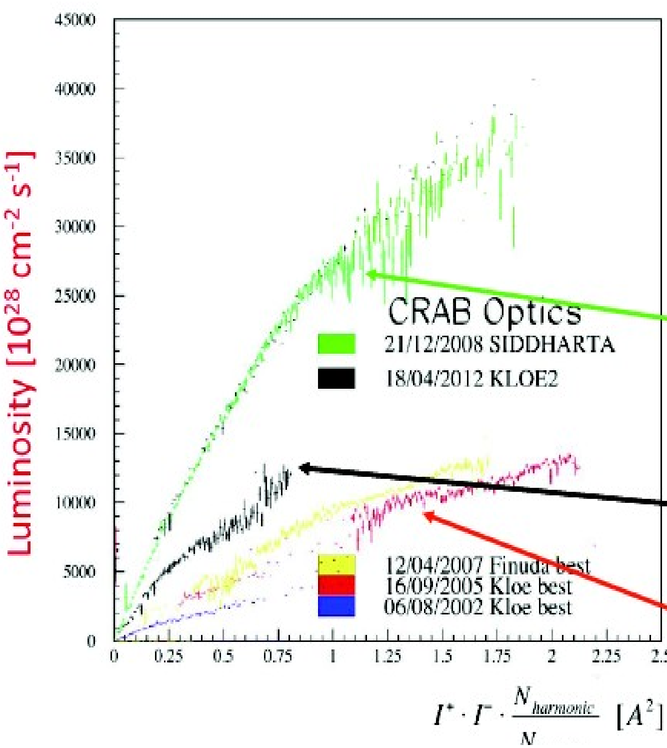


Crabbed waist scheme at DAΦNE

Crab Waist Scheme: beam crossing at large angle, sextuple correction



Crabbed waist is realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y



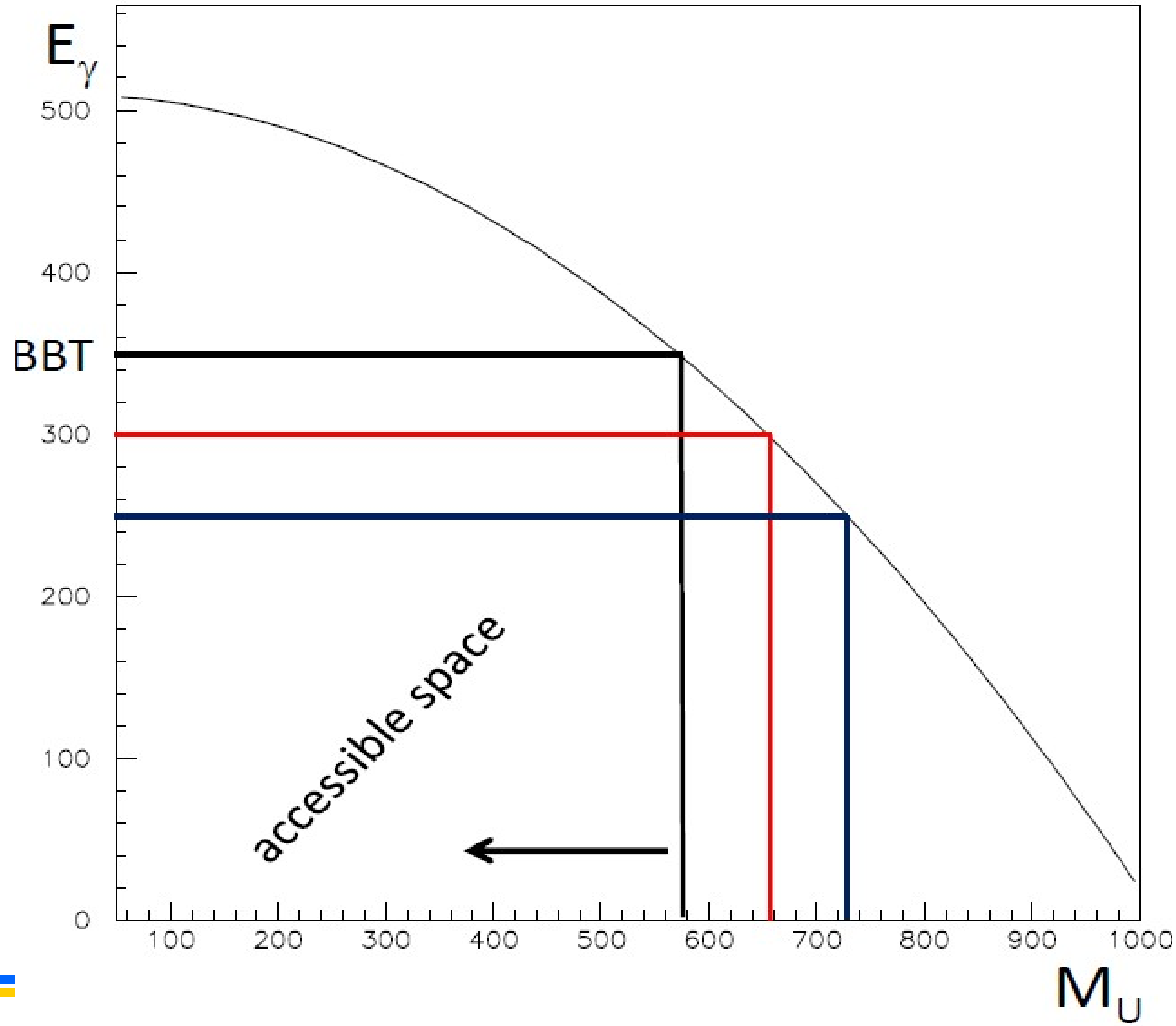
NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation SXTs

Present commissioning phase
New coll. scheme + KLOE det.

Old collision scheme

Implemented in DAFNE and tested in 2008 on SIDDARTHA experiment (no magnetic field)

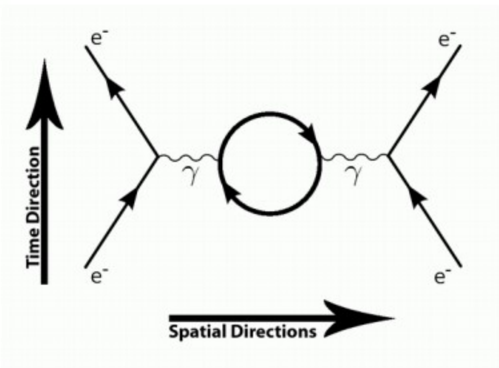
In KLOE B=0.52T require specific tuning and background control



E_γ
500
400
BBT
300
200
100
0
accessible space
100
200
300
400
500
600
700
800
900
1000
M_U

Physics Motivations

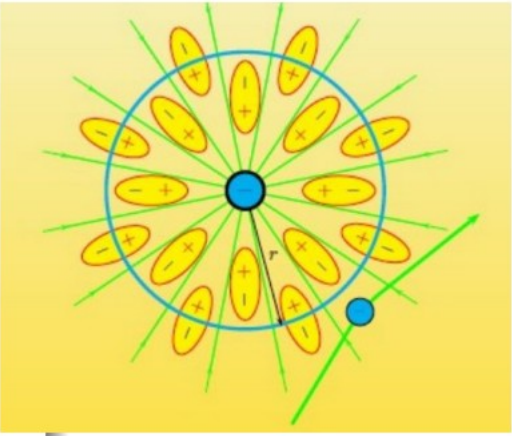
Knowledge of the QED coupling constant fundamental for testing the Standard Model

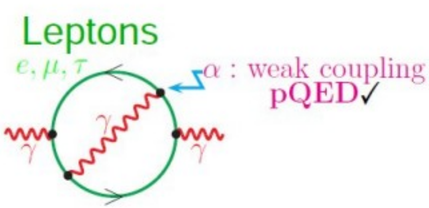


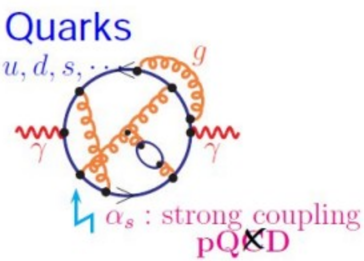
Modification of the QED coupling constant due to the Vacuum Polarization diagram:

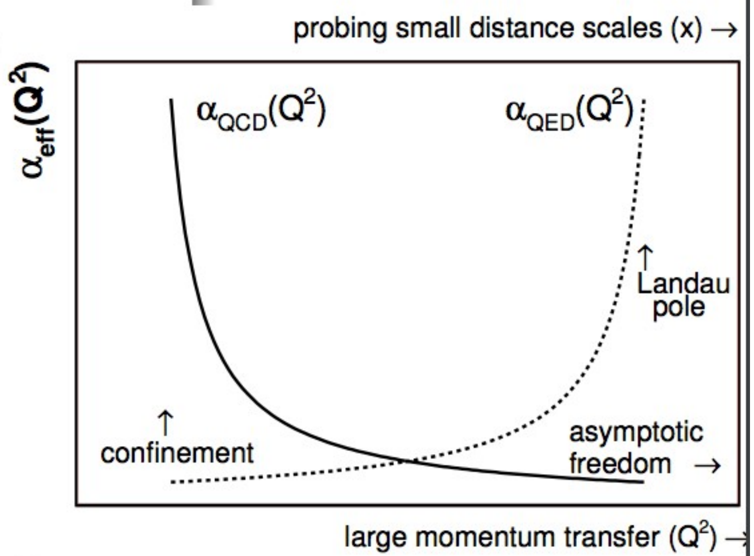
$$e^2 \to e^2(q^2) = \frac{e^2}{1+(\Pi'_\gamma(q^2)-\Pi'_\gamma(0))};$$

$$\alpha(q^2) = \frac{\alpha(0)}{1-\Delta\alpha(q^2)}$$





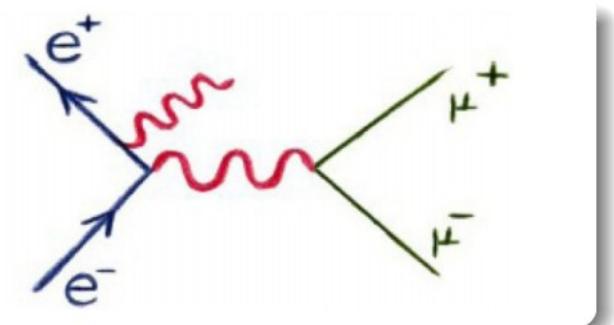




$$\Delta\alpha(q^2) = \Delta\alpha_{lep}(q^2) + \Delta\alpha_{had}(q^2)$$

No data in the low energy region

Analysis Method



$$\left|\frac{\alpha_{QED}(s)}{\alpha_{QED}(0)}\right|^2 = \frac{\frac{d\sigma^{ISR}}{dM_{\mu\mu}}}{\frac{d\sigma^{MC}}{dM_{\mu\mu}}}$$

where:

$$\frac{d\sigma^{ISR}}{dM_{\mu\mu}} = \frac{N_{obs} - N_{bkg}}{dM_{\mu\mu}} \frac{1}{\epsilon(\sqrt{s_\mu})L}$$

- $\theta_\gamma < 15^\circ$ $(\theta_\gamma > 165^\circ)$
- $0 < \theta_\mu < 180^\circ$

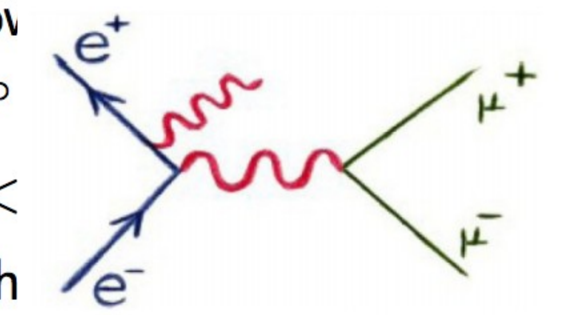
with FSR effects removed

$\frac{d\sigma^{MC}}{dM_{\mu\mu}}$ obtained from PHOKARA gen.

with the follov

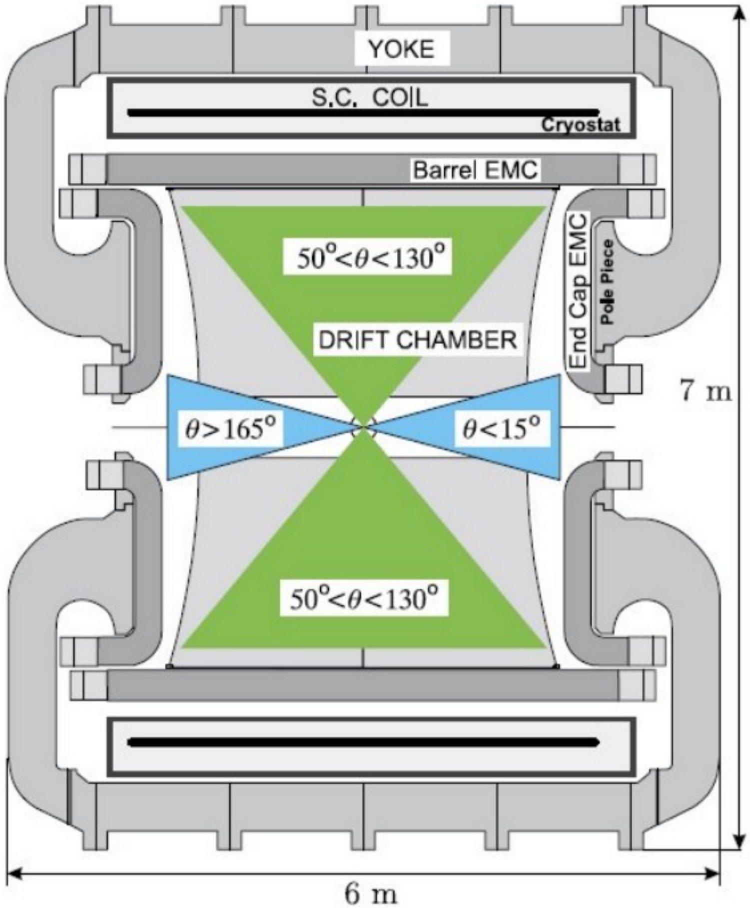
- $\theta_\gamma < 15^\circ$
- $0 < \theta_\mu <$

Inclusive of th



the VP contribution removed

Event selection: Small Angle (SA)



- Two tracks of opposite sign with

$$50^\circ < \theta < 130^\circ$$

- Photons (not detected) at small angles :

$$\theta < 15^\circ or\, \theta > 165^\circ$$

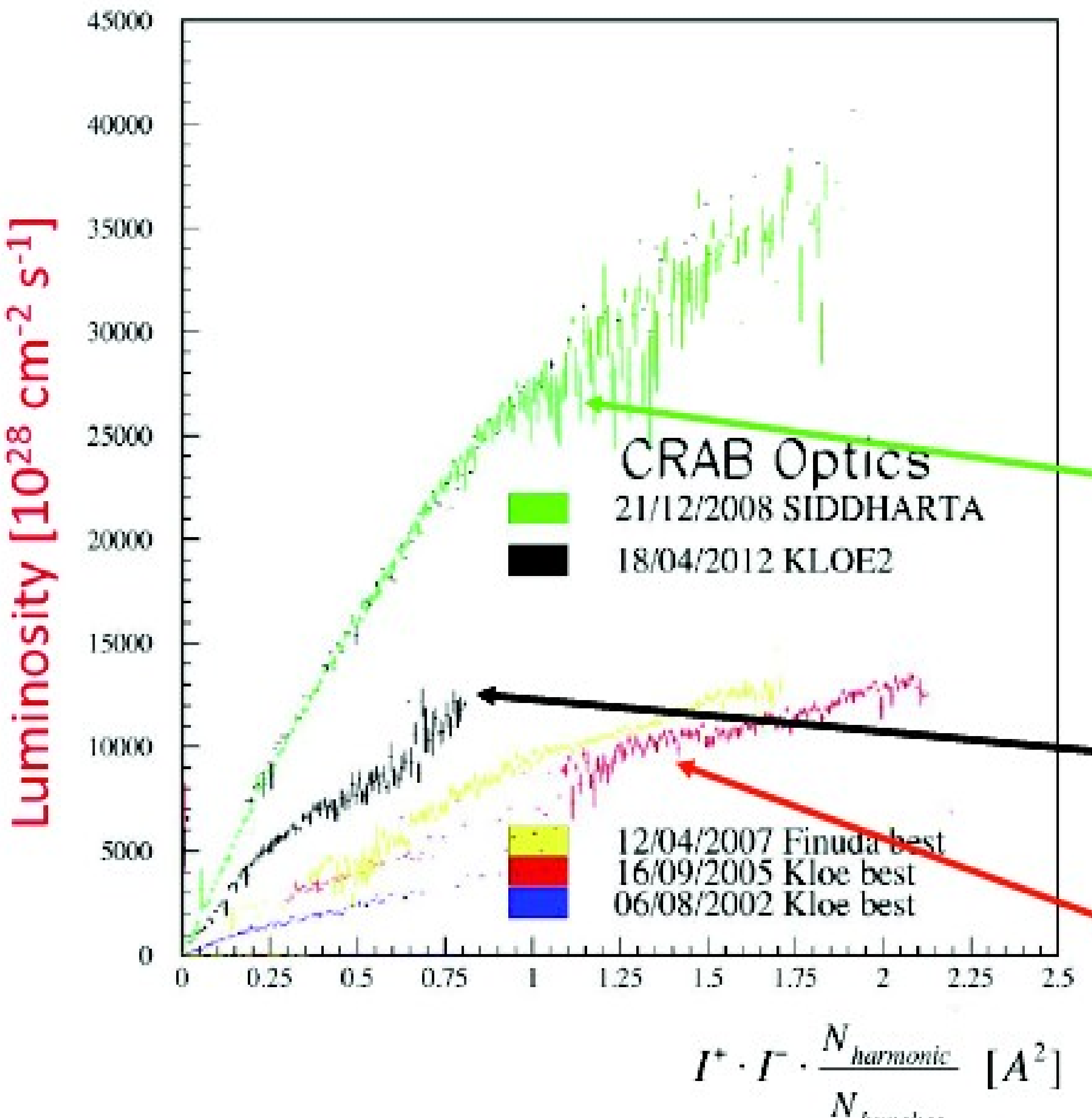
- Photon momentum from kinematics:

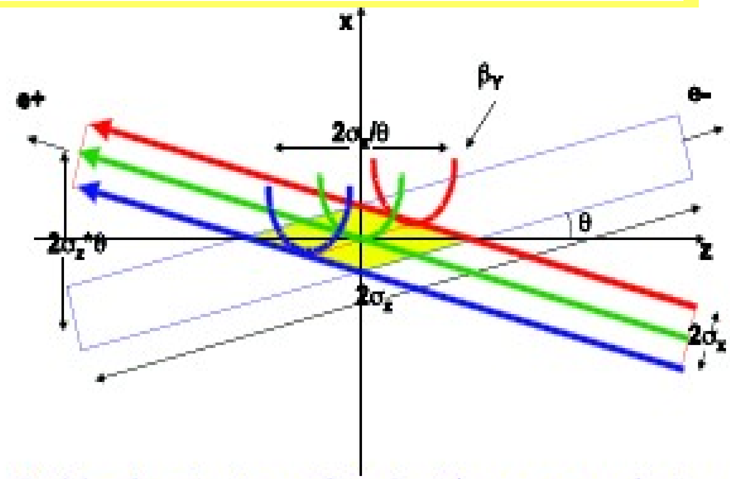
$$\vec{p_\gamma} \simeq \vec{p_{miss}} = -(\vec{p_+} + \vec{p_-})$$

- High statistics for ISR photons
- Very small contribution from FSR
- Reduced background contamination

Daϕne upgrade

Crabbed waist scheme at DAΦNE





Crabbed waist is realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y

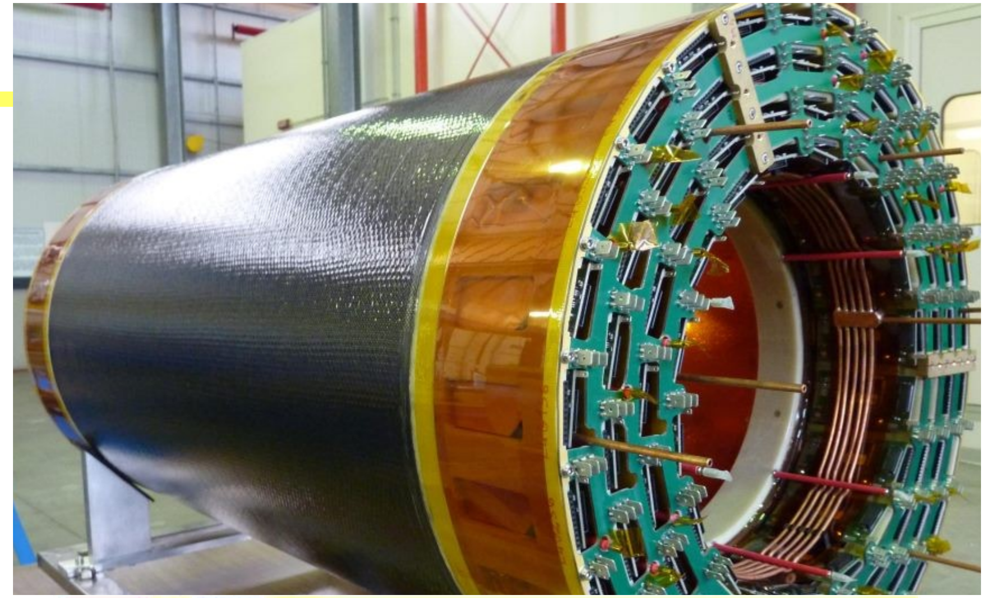
NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation SXTs

Present commissioning phase
New coll. scheme + KLOE det.

Old collision scheme

max. expected at KLOE-2 : L_{int} ~ 20 pb^{-1}/day x 200 dd/year = 4 fb^{-1} /year

DETECTOR UPGRADE: INNER TRACKER, QCALT, CCALT



INNER TRACKER

- 4 layers of cylindrical triple GEM
- Better vertex reconstruction near IP
- Larger acceptance for low p_t tracks

QCALT

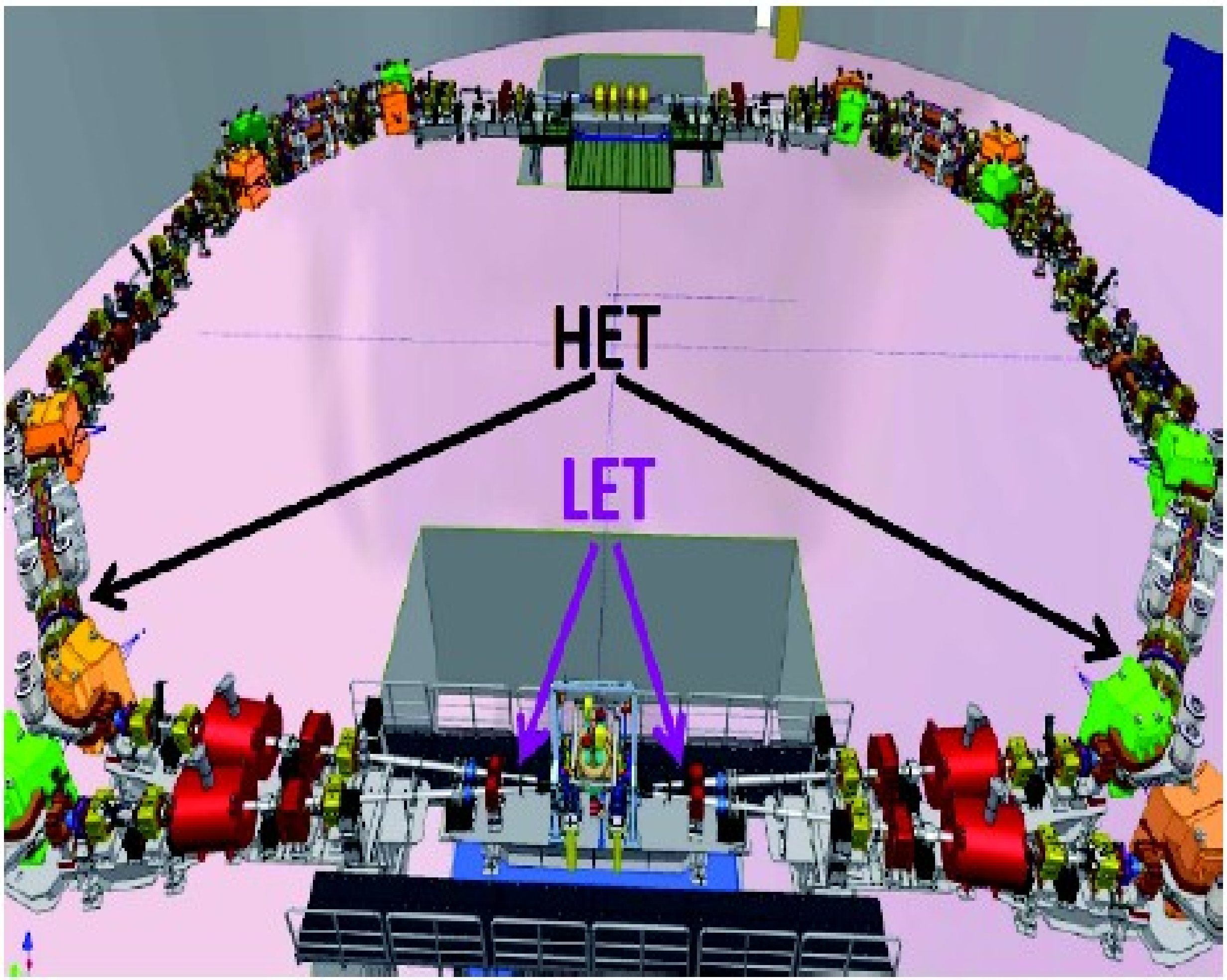
- W + scintillator tiles + SiPM/WLS
- Low-beta quadrupoles: coverage for K_L decays

CCALT

- LYSO + APD
- Increase acceptance for γ's from IP (21°→10°)

DETECTOR UPGRADE – HET&LET

Measurement of leptons momenta in $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$



LET: E_e ~ 160-230 MeV

- **Inside KLOE detector**
- **LYSO+SiPM**
- **σ_E<10% for E>150 MeV**

HET: E_e > 400 MeV

- **11 m from IP**
- **Scintillator hodoscopes**
- **σ_E ~ 2.5 MeV**
- **σ_T ~ 200 ps**

SPT SOURCE

Tnx2 E.Graziani

- Cosmics

Runs 87070 + 87071

SPT only trigger rate ≈ 60 Hz

'Special' cosmics is triggered by SPT: one hit over Bhabha threshold and no other trigger over LET threshold

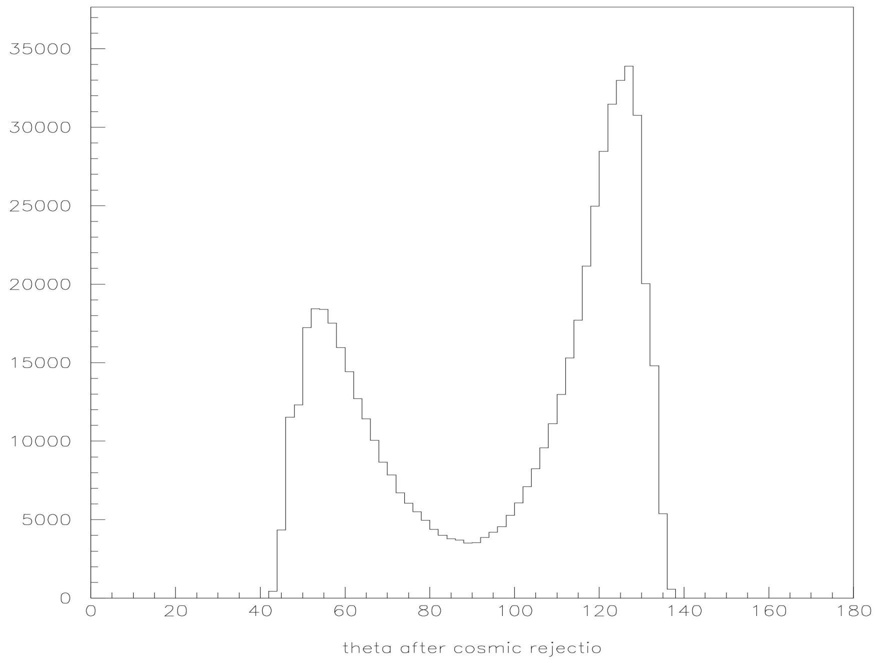
- Overfluctuate on upper sectors and underfluctuate on down one
- enter the barrel EMC almost horizontally
- stop inside the detector
- cross some cracks
- ...

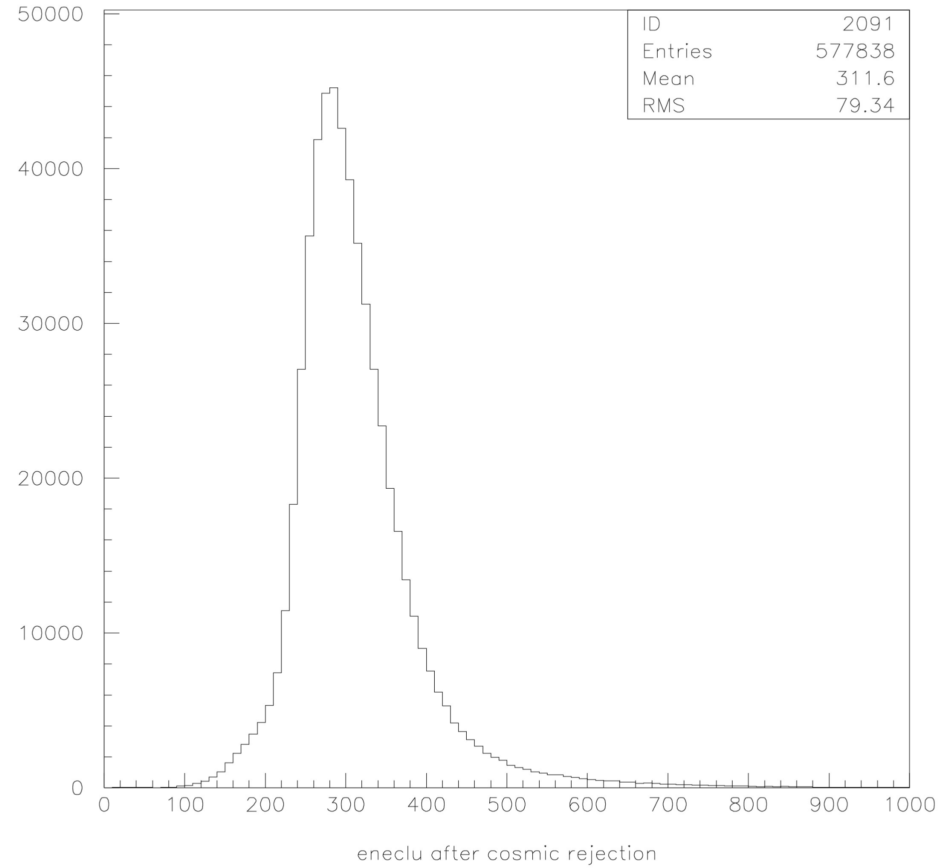
SPT SOURCE

- Machine background

Tnx2 E.Graziani

3 special runs (87452, 87453,87455) with non-colliding, longitudinally separated, beams.
Analysis in progress



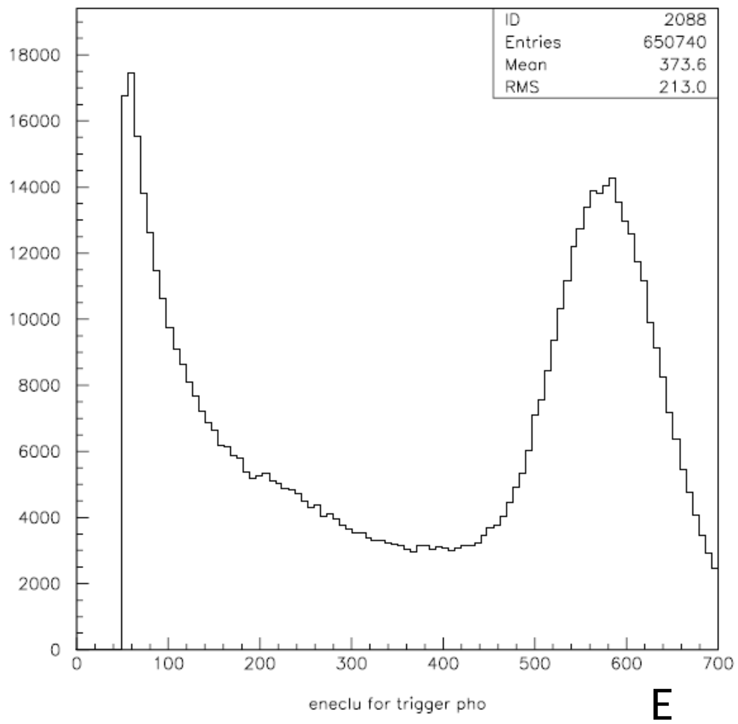


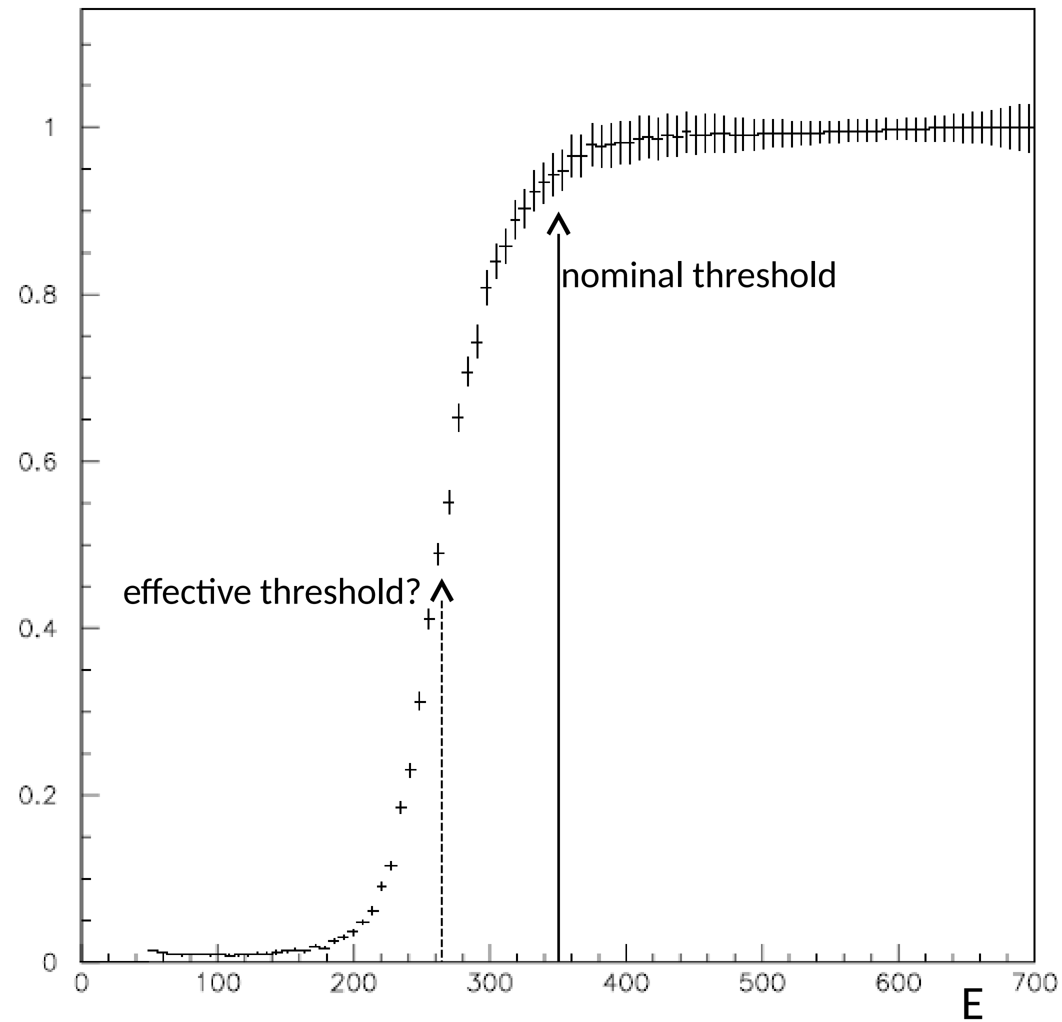
Within ~ 10 Hz, all the SPT 300 Hz trigger rate is explained by 60 Hz cosmics + machine background (Touschek, beam gas, etc...)

SPT EFFICIENCY

Barrel photon in L3BHA
(isolated clusters with no track association)

Bhabha trigger bit is set, as a function of the cluster energy





The effective (average) threshold seems to be consistently lower than the nominal one

Does not include calorimeter efficiency, cluster reconstruction efficiency, etc …

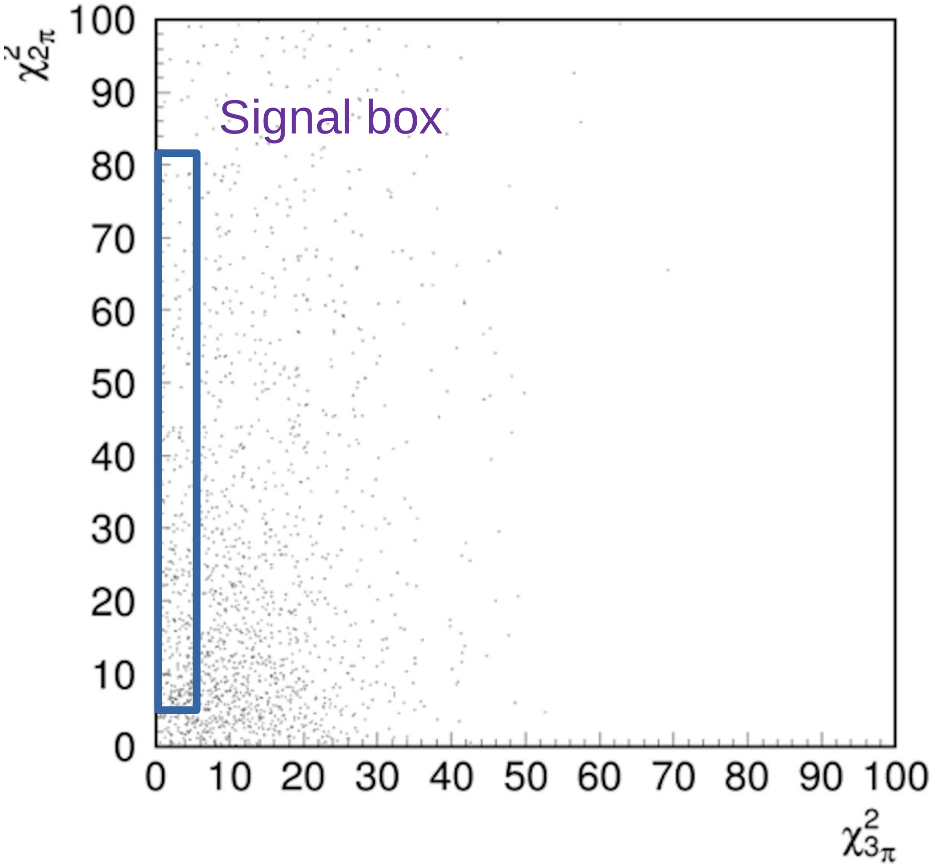
Tnx2 E.Graziani

$K_S \to \pi^0\pi^0\pi^0$

Analyzing KLOE-2 new data
(224 pb^{-1})

Direct search for the CP violating decay

Best KLOE upper limit:
$BR(K_S \to 3\pi^0) < 2.6 \times 10^{-8}$
with 1.7 fb^{-1}

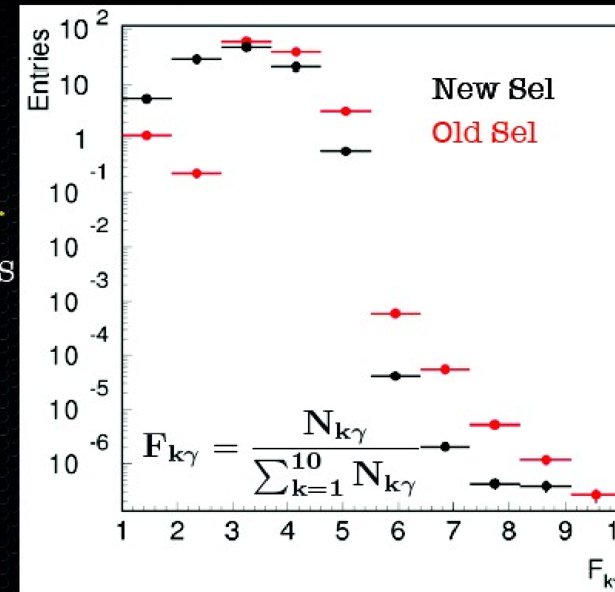


KLOE-2:
Hardened selection criteria to cope with increase of background

$N_{obs}=0$ event selected as a signal
upper limit on $BR(K_S \to 3\pi^0) < 1.8 \times 10^{-7}$

KLOE-2 Data Analysis: $K_S \to 3\pi^0$

- Analyzing KLOE-2 data
  - From 22 pb^{-1} @ Sep CSN1 to present 224 pb^{-1}
- $K_S \to 2\pi^0$ (4 prompt photons) used for normalization. Selection based on: 4-momentum conservation - K_S mass - Energy and timing for photons
- Hardened selection criteria to cope with increased background wrt KLOE run (>3 prompt γ + K_L-crash):



Old Selection	New Selection
○ K_L-crash: E>150 MeV, 0.2< β < 0.25	○ K_L-crash: E>150 MeV, 0.2< β < 0.25
○ prompt photons: E_{cl} > 7 MeV;	○ prompt photons: E_{cl} > 20 MeV;
$\lvert\cos\theta_{cl}\rvert \le 0.915$ and	$\lvert\cos\theta_{cl}\rvert \le 0.915$ and
$\lvert\Delta T_{cl}\rvert \le \mathrm{Min}(3.5\cdot\sigma_T(E_{cl}), 2\ \mathrm{ns})$	$\lvert\Delta T_{cl}\rvert \le \mathrm{Min}(3.0\cdot\sigma_T(E_{cl}), 2\ \mathrm{ns})$
Signal Efficiency 47%	Signal Efficiency 43%
	10x Background Rejection

Erika De Lucia - CSN1 Meeting - March 22nd 2017

21

K_L^0 DECAY MODES

	Mode			Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Semileptonic modes				
Γ_1	$\pi^{\pm} e^{\mp} \nu_e$ Called K^0_{e3}.		[a]	(40.55 ± 0.11) %	S=1.7
Γ_2	$\pi^{\pm} \mu^{\mp} \nu_\mu$ Called $K^0_{\mu 3}$.		[a]	(27.04 ± 0.07) %	S=1.1
Γ_3	$(\pi \mu \text{atom}) \nu$			$(1.05 \pm 0.11) \times 10^{-7}$	
Γ_4	$\pi^0 \pi^{\pm} e^{\mp} \nu$		[a]	$(5.20 \pm 0.11) \times 10^{-5}$	
Γ_5	$\pi^{\pm} e^{\mp} \nu e^+ e^-$		[a]	$(1.26 \pm 0.04) \times 10^{-5}$	
	Hadronic modes, including Charge conjugation×Parity Violating (*CPV*) modes				
Γ_6	$3\pi^0$			(19.52 ± 0.12) %	S=1.6
Γ_7	$\pi^+ \pi^- \pi^0$			(12.54 ± 0.05) %	
Γ_8	$\pi^+ \pi^-$	*CPV*	[b]	$(1.967 \pm 0.010) \times 10^{-3}$	S=1.5
Γ_9	$\pi^0 \pi^0$	*CPV*		$(8.64 \pm 0.06) \times 10^{-4}$	S=1.8
	Semileptonic modes with photons				
Γ_{10}	$\pi^{\pm} e^{\mp} \nu_e \gamma$		[a,c,d]	$(3.79 \pm 0.06) \times 10^{-3}$	
Γ_{11}	$\pi^{\pm} \mu^{\mp} \nu_\mu \gamma$			$(5.65 \pm 0.23) \times 10^{-4}$	
	Hadronic modes with photons or $\ell\overline{\ell}$ pairs				
Γ_{12}	$\pi^0 \pi^0 \gamma$			$< 2.43 \times 10^{-7}$	CL=90%
Γ_{13}	$\pi^+ \pi^- \gamma$		[c,d]	$(4.15 \pm 0.15) \times 10^{-5}$	S=2.8
Γ_{14}	$\pi^+ \pi^- \gamma (\text{DE})$			$(2.84 \pm 0.11) \times 10^{-5}$	S=2.0
Γ_{15}	$\pi^0 2\gamma$		[c]	$(1.273 \pm 0.033) \times 10^{-6}$	
Γ_{16}	$\pi^0 \gamma e^+ e^-$			$(1.62 \pm 0.17) \times 10^{-8}$	
	Other modes with photons or $\ell\overline{\ell}$ pairs				
Γ_{17}	2γ			$(5.47 \pm 0.04) \times 10^{-4}$	S=1.1
Γ_{18}	3γ			$< 7.4 \times 10^{-8}$	CL=90%
Γ_{19}	$e^+ e^- \gamma$			$(9.4 \pm 0.4) \times 10^{-6}$	S=2.0

K^0_S DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Hadronic modes			
Γ_1	$\pi^0\pi^0$		(30.69 ± 0.05) %	
Γ_2	$\pi^+\pi^-$		(69.20 ± 0.05) %	
Γ_3	$\pi^+\pi^-\pi^0$		$(3.5\ ^{+1.1}_{-0.9}) \times 10^{-7}$	
	Modes with photons or $\ell\bar{\ell}$ pairs			
Γ_4	$\pi^+\pi^-\gamma$	[a,b]	$(1.79\pm0.05) \times 10^{-3}$	
Γ_5	$\pi^+\pi^-e^+e^-$		$(4.79\pm0.15) \times 10^{-5}$	
Γ_6	$\pi^0\gamma\gamma$	[a]	$(4.9\ \pm1.8) \times 10^{-8}$	
Γ_7	$\gamma\gamma$		$(2.63\pm0.17) \times 10^{-6}$	S=3.0
	Semileptonic modes			
Γ_8	$\pi^\pm e^\mp \nu_e$	[c]	$(7.04\pm0.08) \times 10^{-4}$	
Γ_9	$\pi^\pm \mu^\mp \nu_\mu$	[c,d]	$(4.69\pm0.05) \times 10^{-4}$	
	***CP* violating (*CP*) and $\Delta S = 1$ weak neutral current (*S1*) modes**			
Γ_{10}	$3\pi^0$	*CP*	$< 2.6 \times 10^{-8}$	CL=90%
Γ_{11}	$\mu^+\mu^-$	*S1*	$< 9 \times 10^{-9}$	CL=90%
Γ_{12}	e^+e^-	*S1*	$< 9 \times 10^{-9}$	CL=90%
Γ_{13}	$\pi^0 e^+e^-$	*S1* [a]	$(3.0\ ^{+1.5}_{-1.2}) \times 10^{-9}$	
Γ_{14}	$\pi^0\mu^+\mu^-$	*S1*	$(2.9\ ^{+1.5}_{-1.2}) \times 10^{-9}$	