Status of KLOE-2

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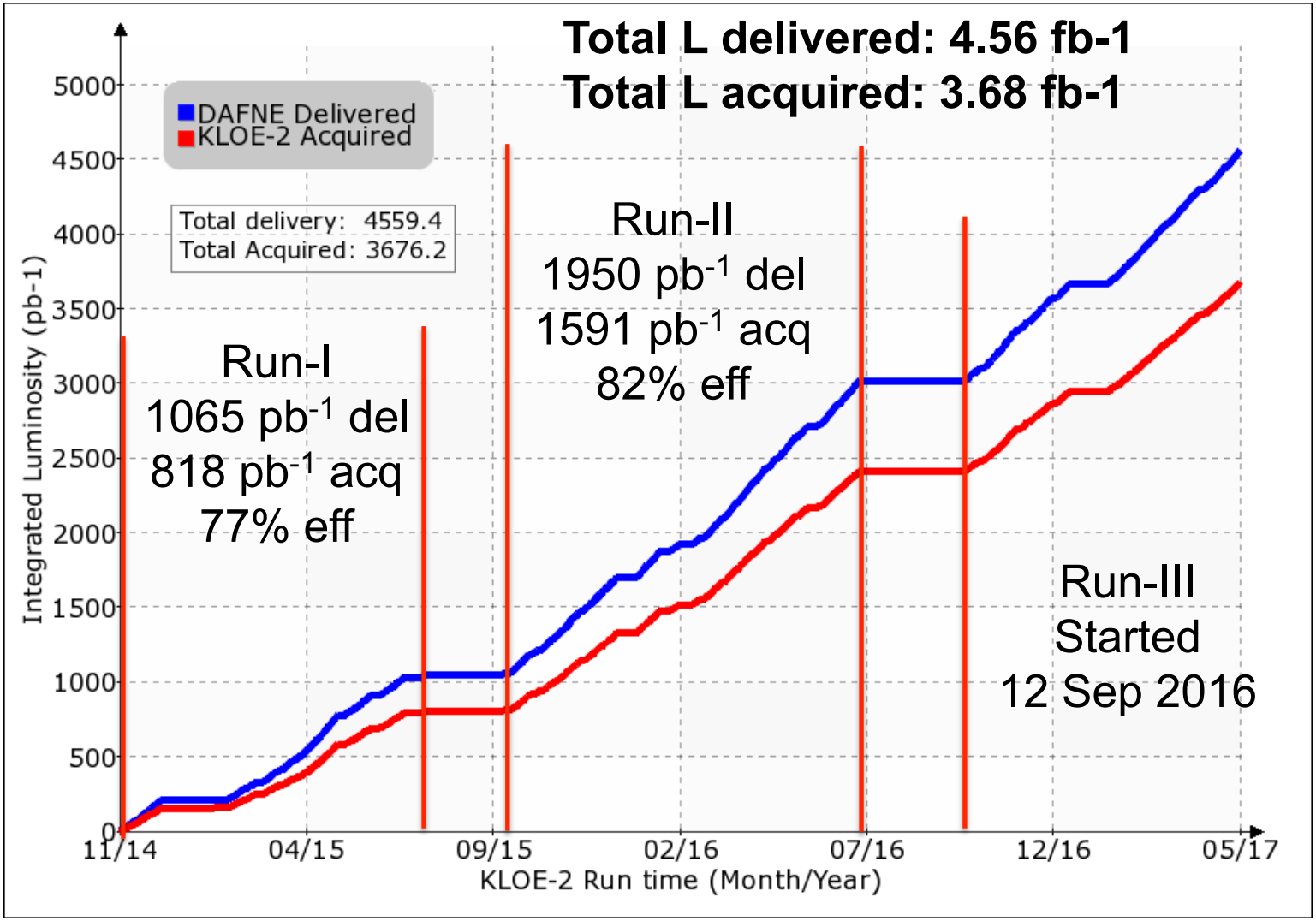
on behalf of the KLOE-2 collaboration

LNF Scientific Committee meeting
Frascati, 9 May 2017

A new artwork in the KLOE-2 control room

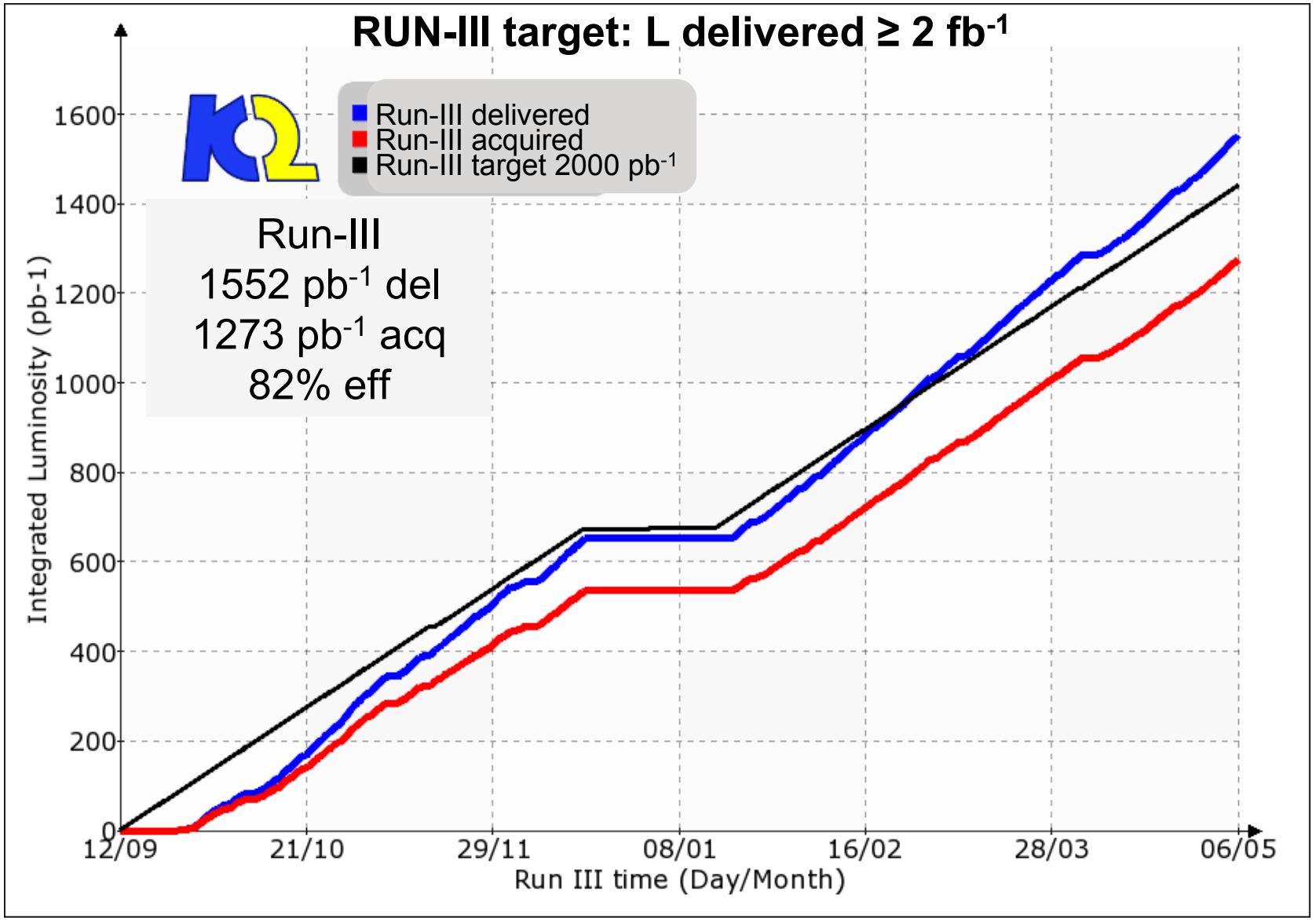
by artist Claudio Federici

Data Taking

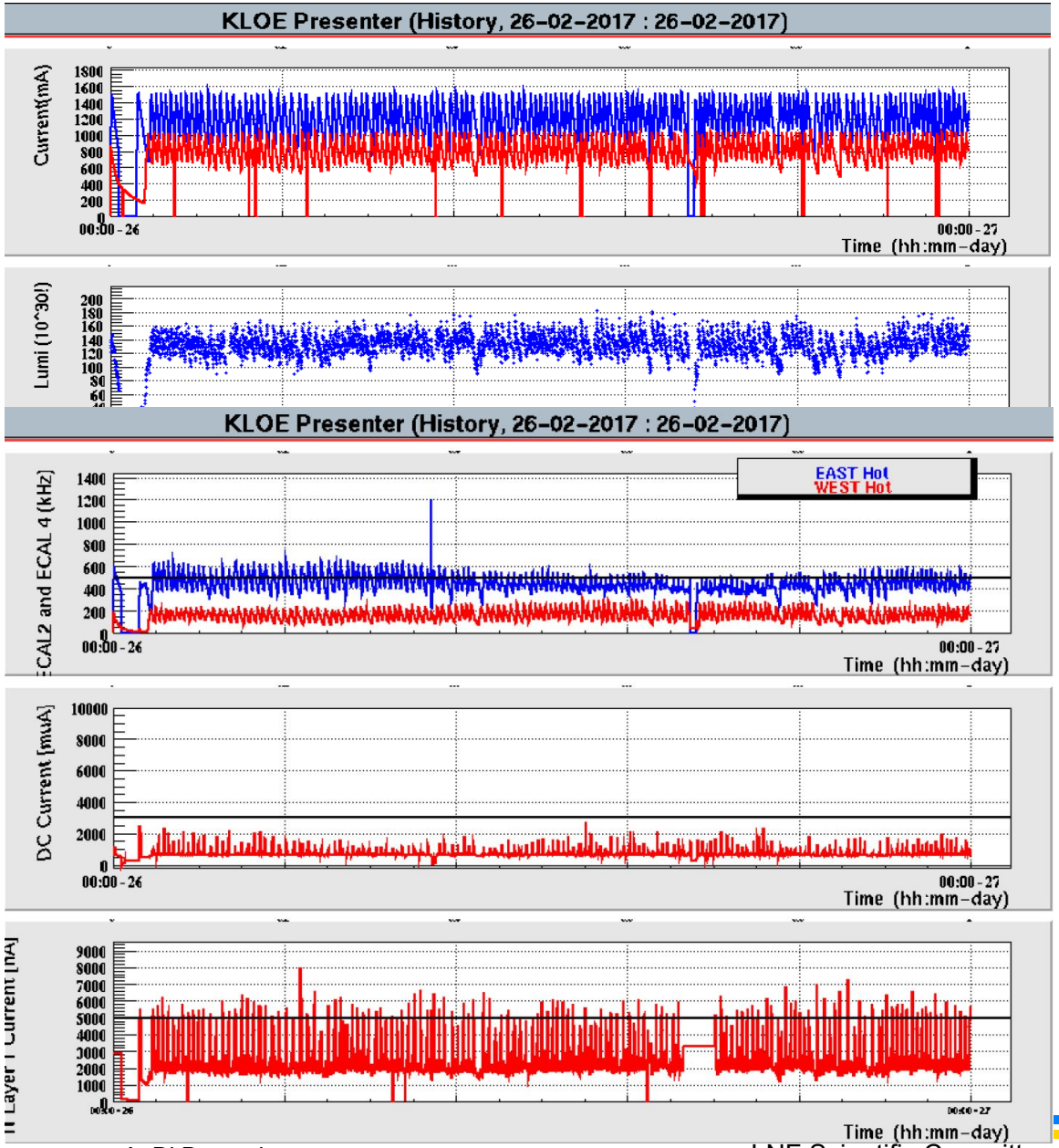


KLOE-2 goal: L acquired > 5 fb^{-1} => L delivered > ~ 6.2 fb-1

RUN-III detail



DAFNE performance



An example of good day in RUN-III (26 feb 2017)

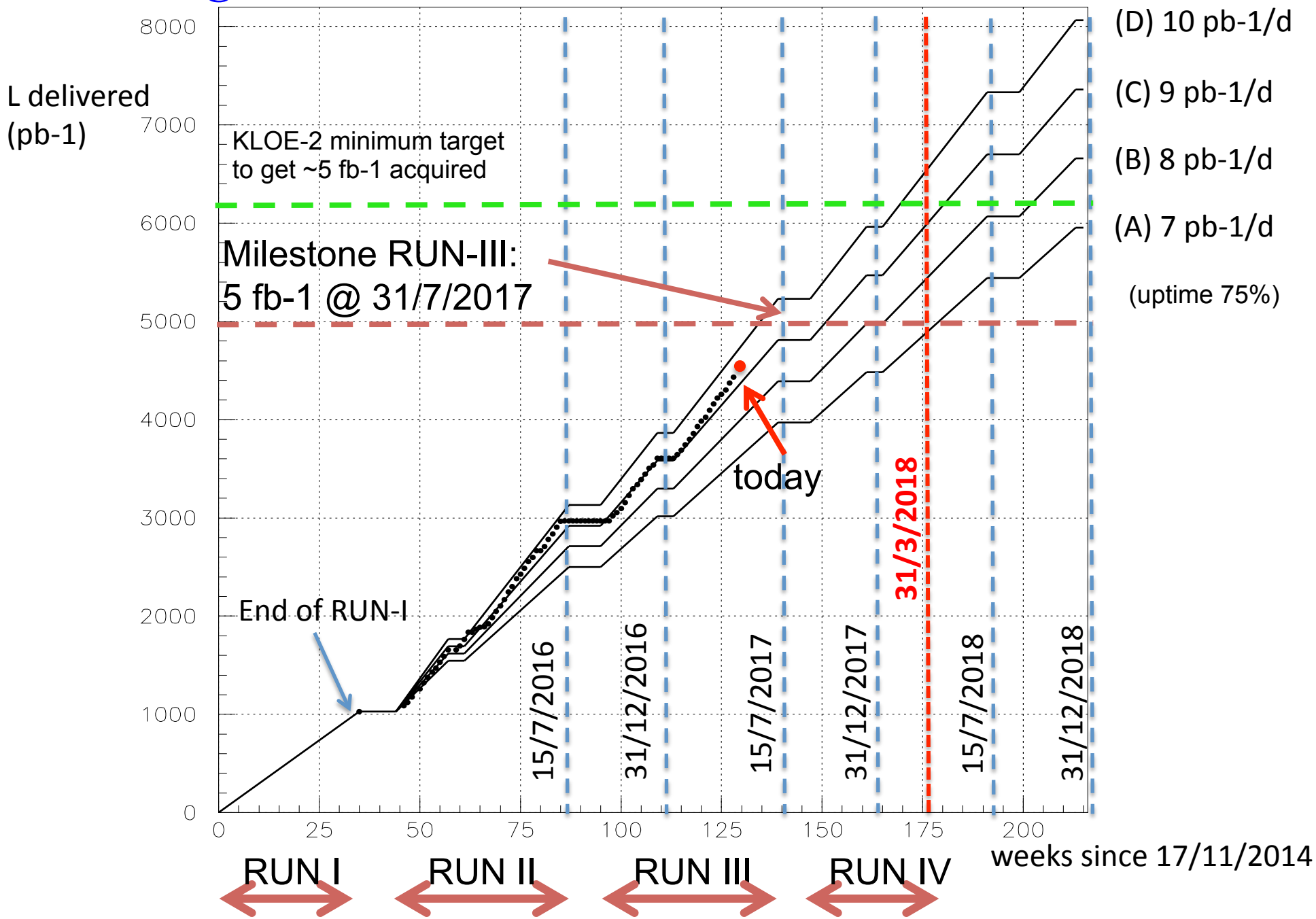
L delivered: ~11.1 pb^{-1}
L acquired: ~9.4 pb^{-1}

Hot End-caps counters
electrons < 500 kHz
positrons < 300 kHz

DC integrated current
mostly < 2 mA

IT layer 1 integrated current
mostly < 5 μA

Data Taking Plan



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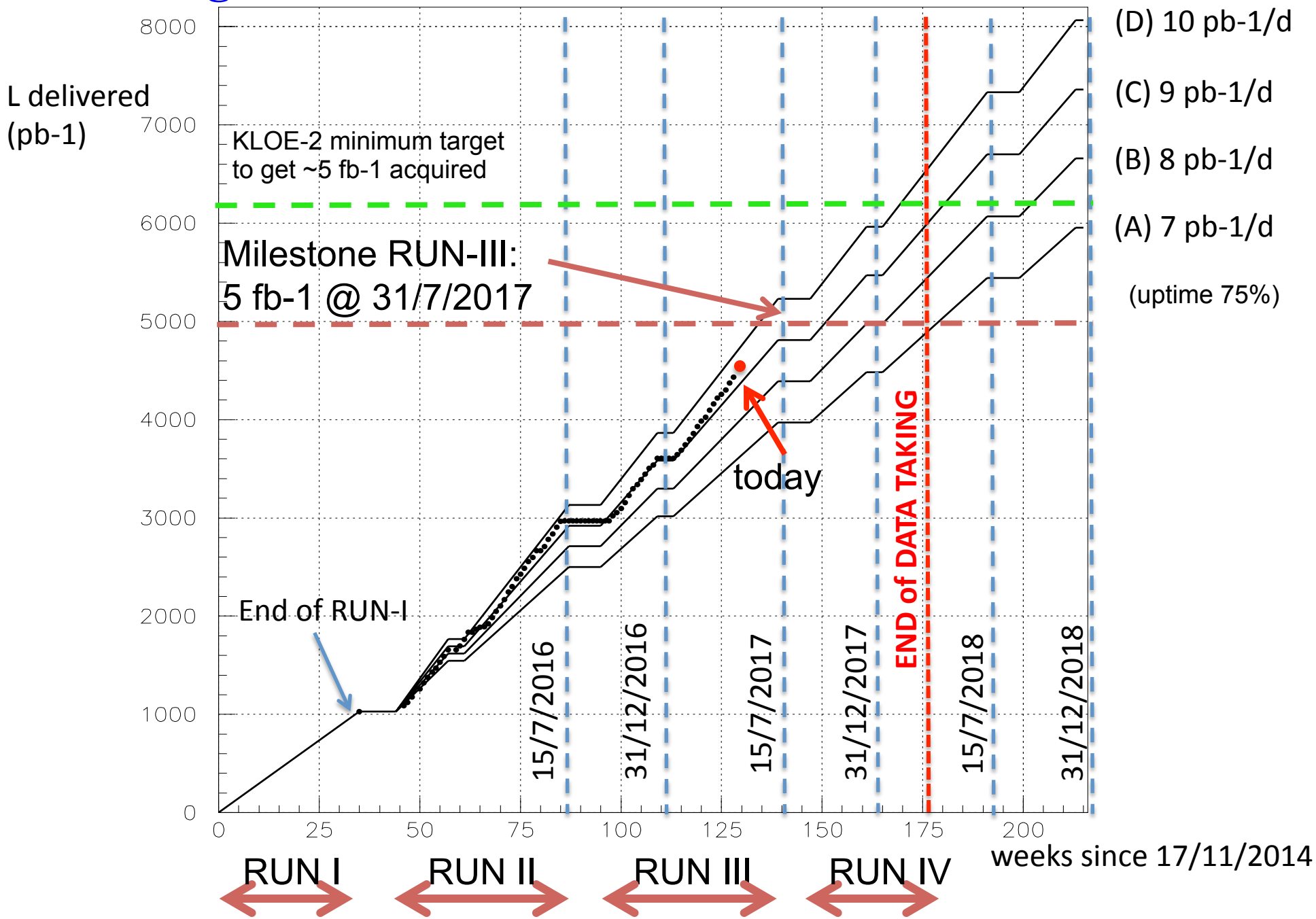
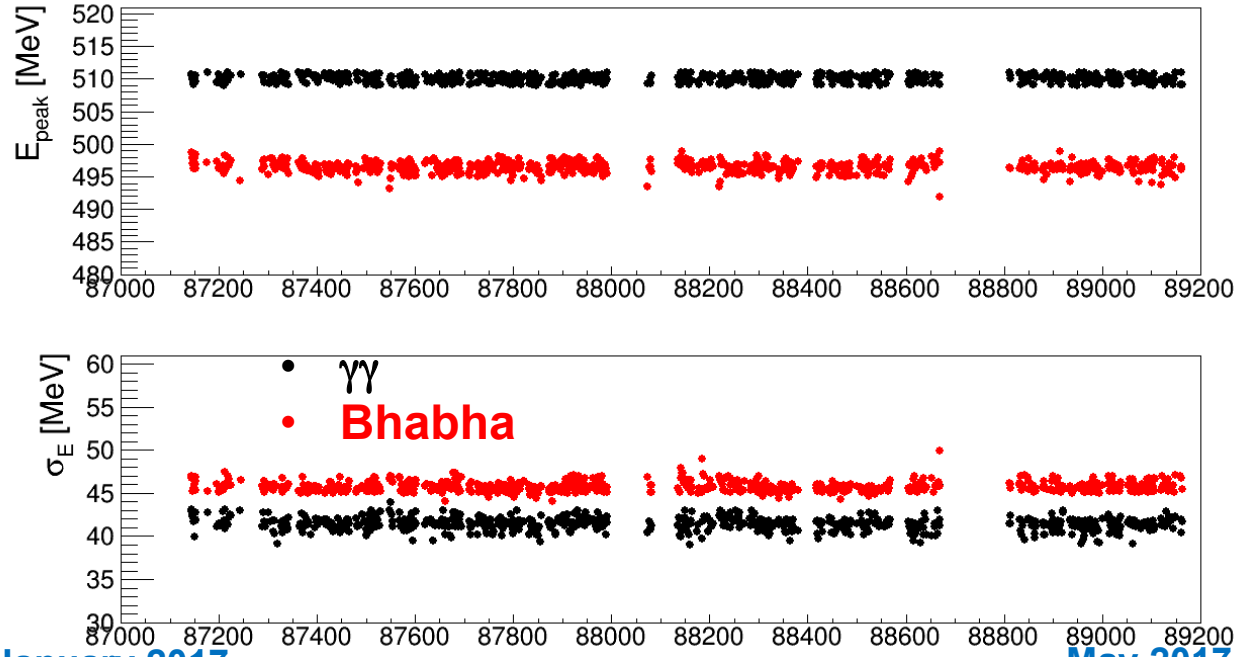


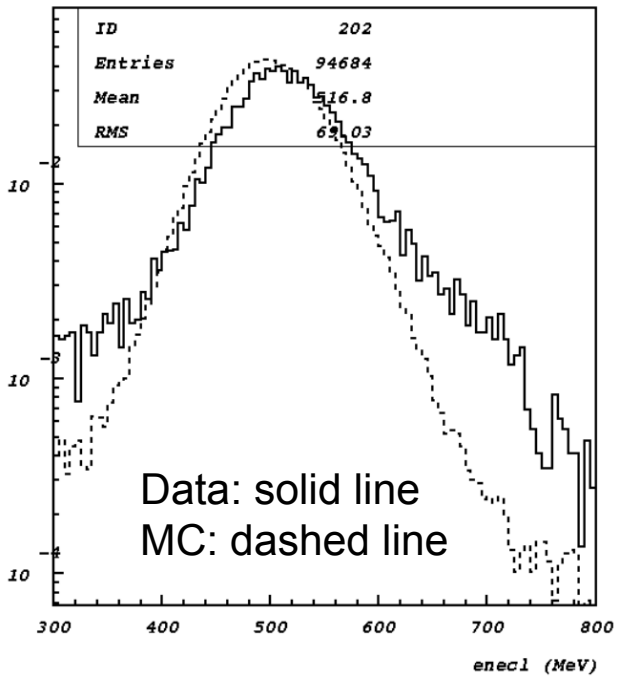
Detector Status

EMC calibration

- Improvement in the calibration procedure=>re-calibration of all data collected up to now
- Process parallelized; large part of the computing resources allocated for this reprocessing
- **~ 15000 runs successfully recalibrated in 4 days** Very good stability, improved Data/MC comparison for $e^+e^- \rightarrow \gamma\gamma$ events



with old EMC calibration



DC new TDCs

- We started using the TDC spares, the newly built TDC boards

Detector Status

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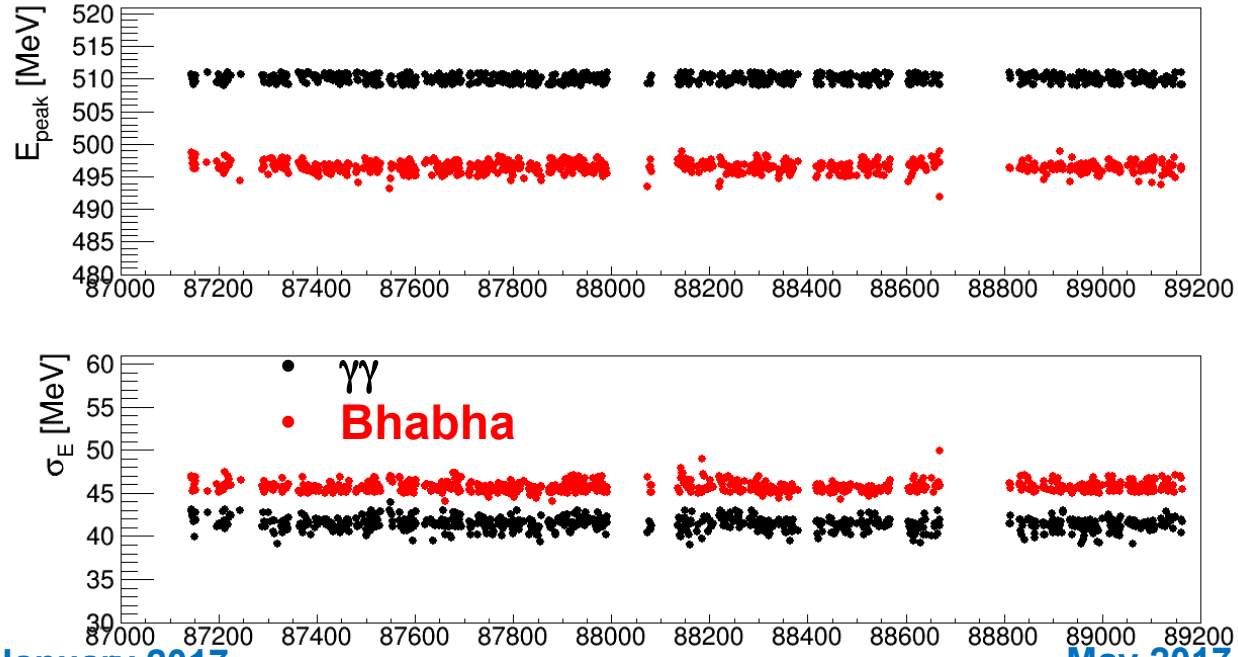
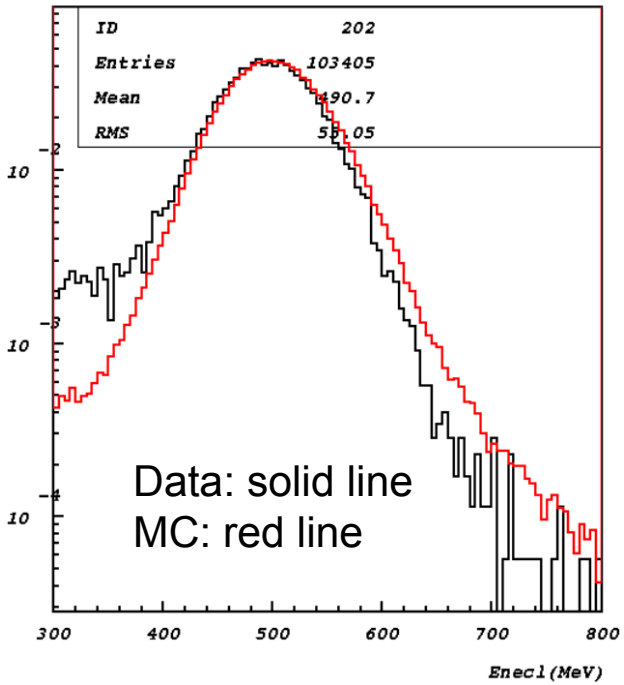


with new EMC calibration



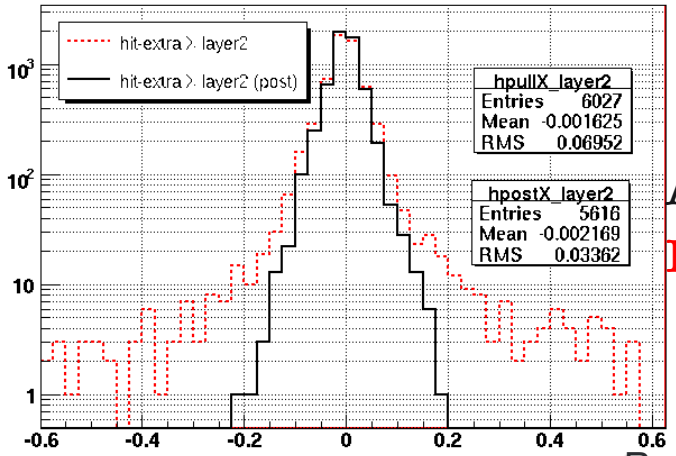
DC new TDCs

- We started using the TDC spares, the newly built TDC boards

Inner Tracker Status

- **IT+DC tracking performance**

  Residual distributions improvement



Layer #2

After Kalman

Before Kalman

- **Reconstruction with IT+DC tracking & official vertexing**

  Vertex finding specifically written for KLOE experiment: all cuts and procedures tuned for tracks reconstructed with DC

  IT+DC tracks treatment within Official vertexing more tricky than expected

  PCA & Vertex Improvement on $\phi \to \pi^+ \pi^- \pi^0$ and $K_S \to \pi^+\pi^-$ samples

  (see next slide)

- **Improving Alignment and Calibration**

  Refined calibration obtained for all layers with B-field OFF sample of cosmic muons

  Refined calibration obtained for all layers with B-field ON sample of cosmic muons
  Checked with Bhabha scattering events
  Presently inserting refined calibration in Kalman

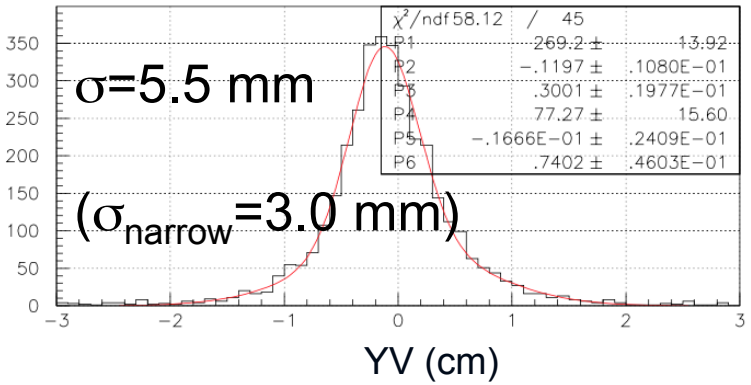
IT-DC integrated tracking and vertexing

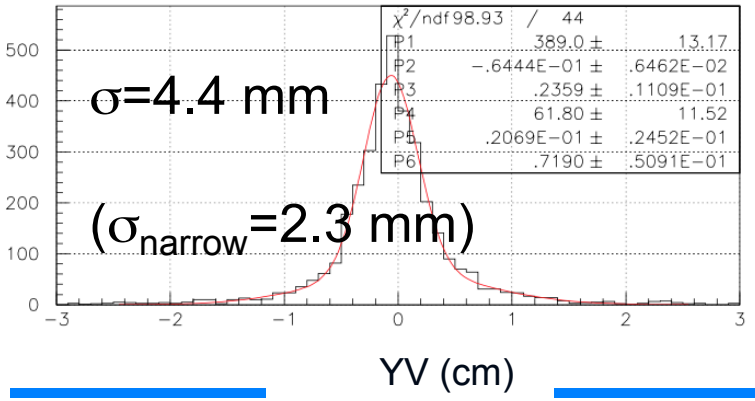
Using 1st Align & Calib parameters

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

Tracks from IP with pT > 100 MeV

Y-coordinate: vtx resolution
(negligible beam size)



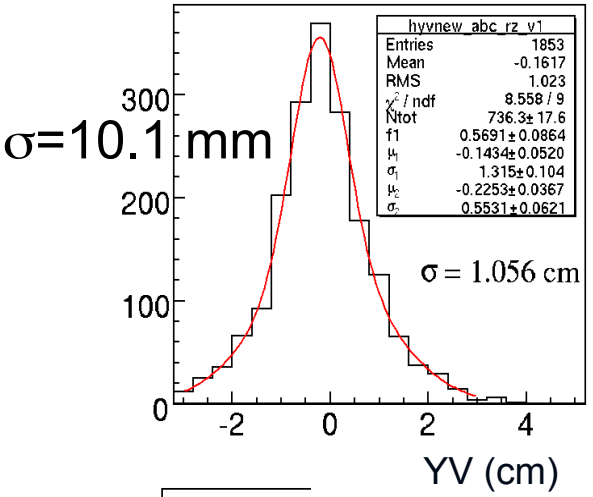


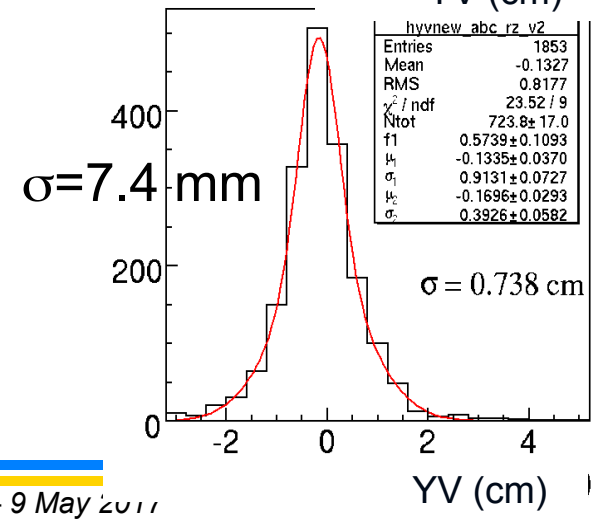
DC-only

IT+DC

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

Tracks from IP with pT> 10 MeV
Y coordinate: vtx resolution ⊕ Ks lifetime

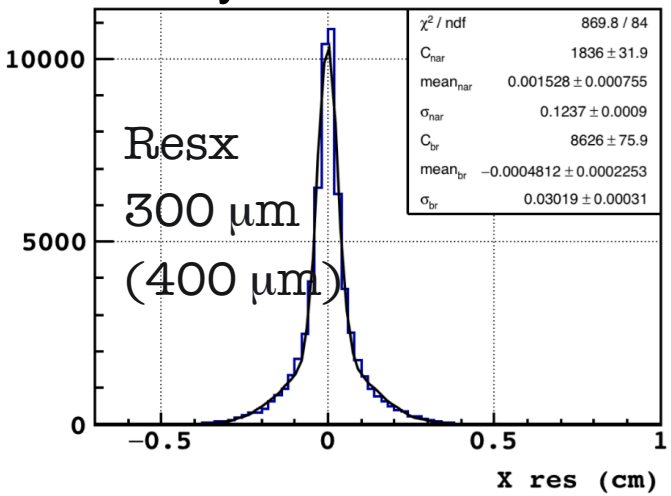




Improving IT calibration

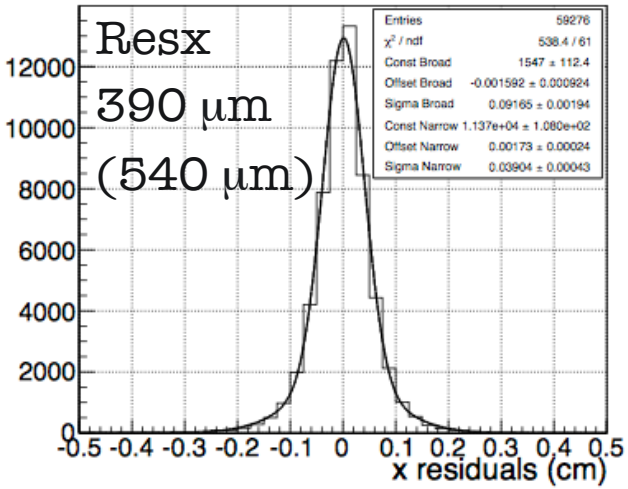
New improved Alignment and Calibration with:

cosmic-ray muons with B-field OFF



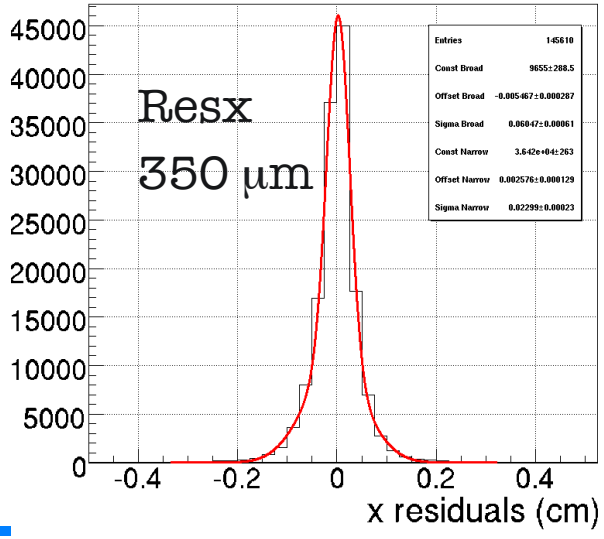
Layer #2

cosmic-ray muons with B-field ON



In (…) the 1st align and calib results

with Bhabha scattering events



Distributions well centered around zero

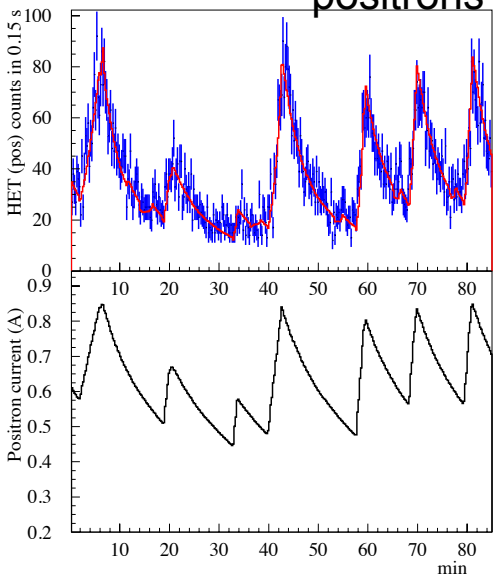
HET status and search for $\gamma\gamma \rightarrow \pi^0$ production events

- Installation of new discriminator boards (Jan17) to improve hardware efficiency (now ~100%)

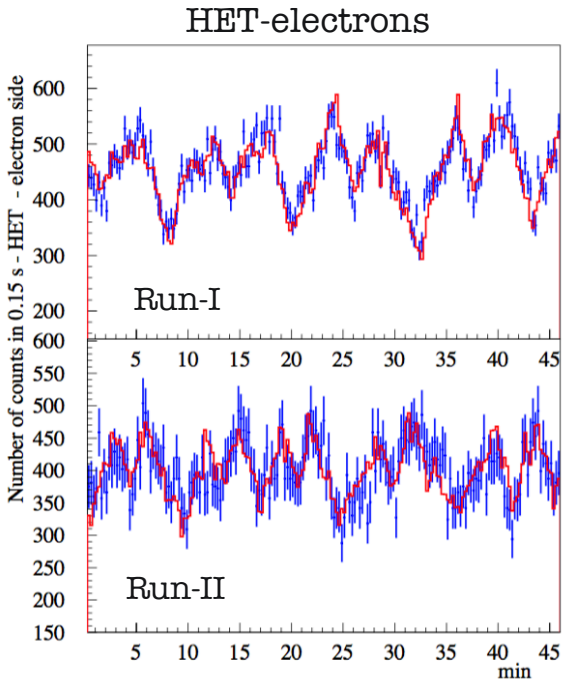
- Collisions clearly seen by rate increase and dependence on DAFNE Luminosity

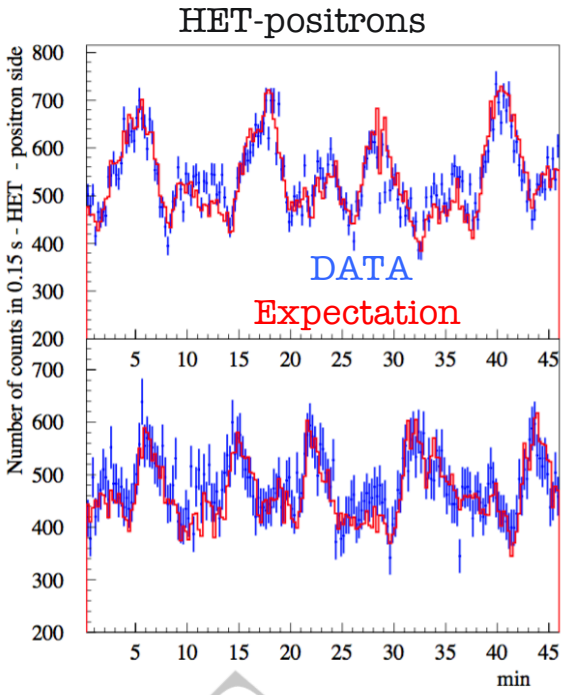
$$\text{HET-Rate} = \text{KLOE-Trigger-Rate} \times (\alpha_{ele/pos}\ \text{Luminosity} + \beta_{ele/pos}\ I^2_{ele/pos})$$

No Collisions



With Collisions

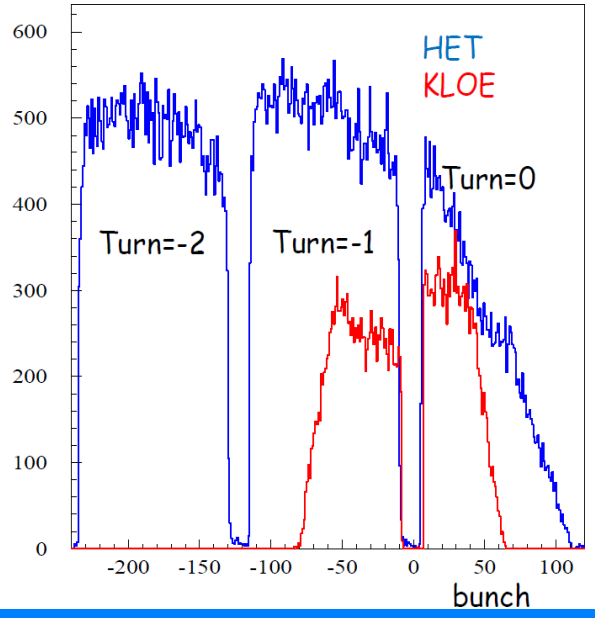


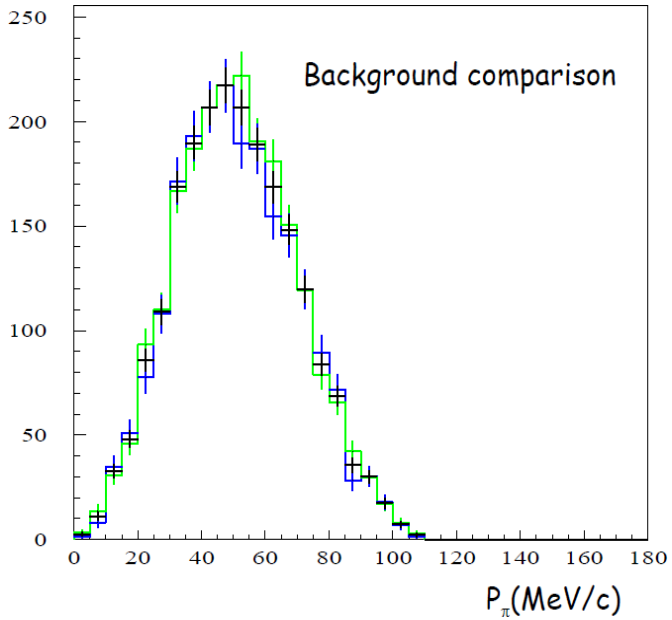


HET status and search for $\gamma\gamma \to \pi^0$ production events

- Pre-filtered single-π0 candidates (analysed a sample of L~550 pb^{-1})

- Analysis of Double-Arm and Single-Arm HET events
- Background evaluation directly from data
- Two independent evaluations of the background:
  - events matching bunch but not the right turn
  - $2<|\Delta T_{e+,e-}|<7$ and $\Delta T_{HET\text{-}KLOE} > 10$ bunches
- Background normalization in the $\Delta T\gamma\gamma$ signal free region



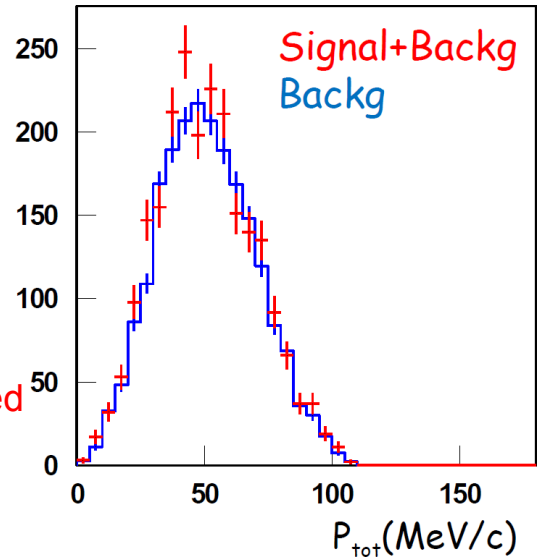


HET status and search for $\gamma\gamma \rightarrow \pi^0$ production events

Double-Arm Tagging

- coincidence between HET stations and in time with KLOE trigger
- 2 clusters in KLOE $E_{clu} < 300$ MeV associated with the same bunch with $|\Delta T_{KLOEclu-HET}| \leq 4$ bunches
- Kinematic cuts on E(γ), InvMass($\gamma\gamma$) cosθ($\gamma\gamma$) and P_{TOT}

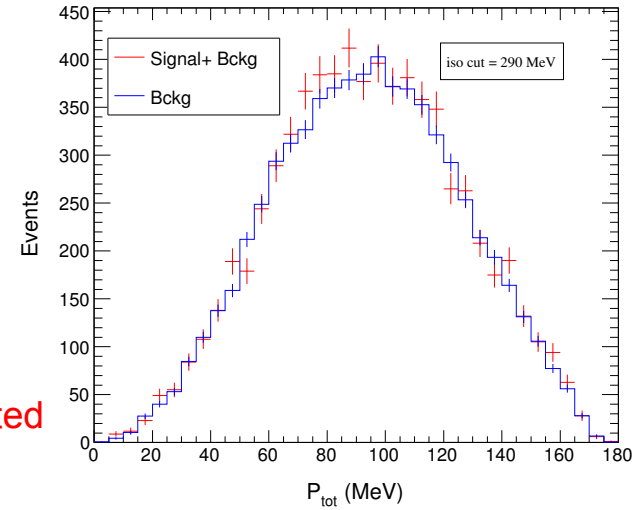
~600 expected signal events



Single-Arm Tagging

- HET ele/pos station in time with KLOE trigger
- 2 clusters in KLOE $20 < E_{clu} < 300$ MeV associated with the same bunch with $|\Delta T_{KLOEclu-HET}| \leq 4$ bunches
- Kinematic cuts on E(γ), InvMass($\gamma\gamma$) cosθ($\gamma\gamma$) and P_{TOT}
- Isolation cut to increase S/B ratio $E_{tot} - (E_{clu1} + E_{clu2}) < E_{isolation}$

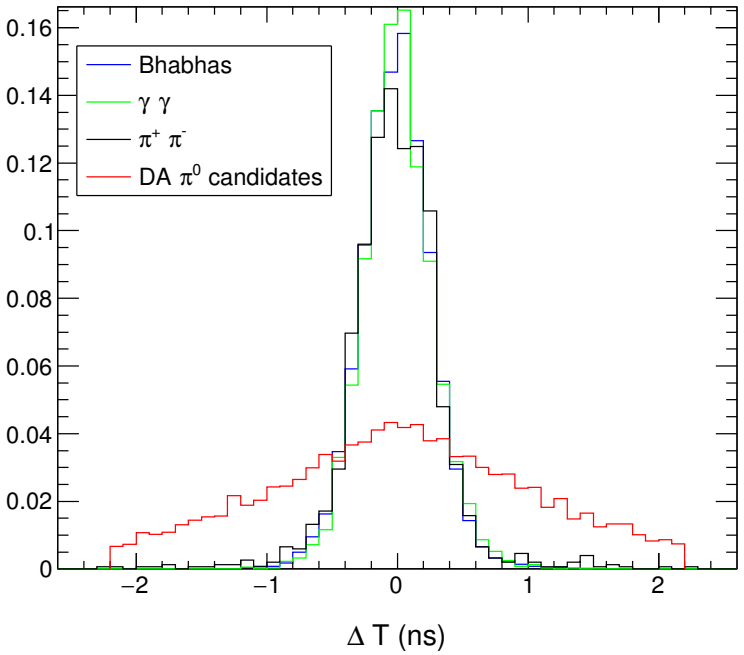
~3000/arm expected signal events



HET status and search for $\gamma\gamma \rightarrow \pi^0$ production events

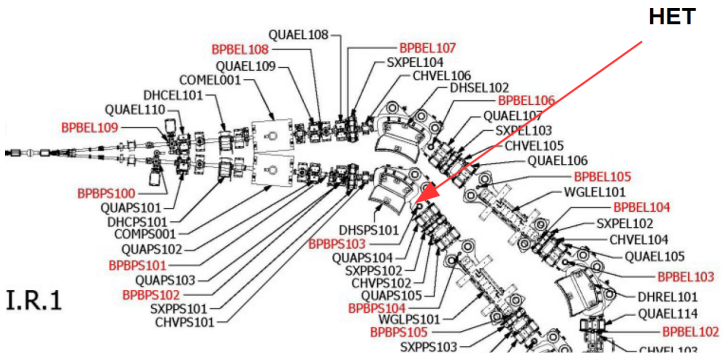
Complementary analysis approach

- search for single π^0 events with KLOE alone
- important cross check of HET response (TDCs decoding and electronics, etc..)
- Preliminary analysis of downscaled "unstreamed" events (ufo) excludes that the lack of π^0 signal events can be caused by time resolution effects.
- Full statistics analysis needs data reprocessing with a dedicated stream (in progress)



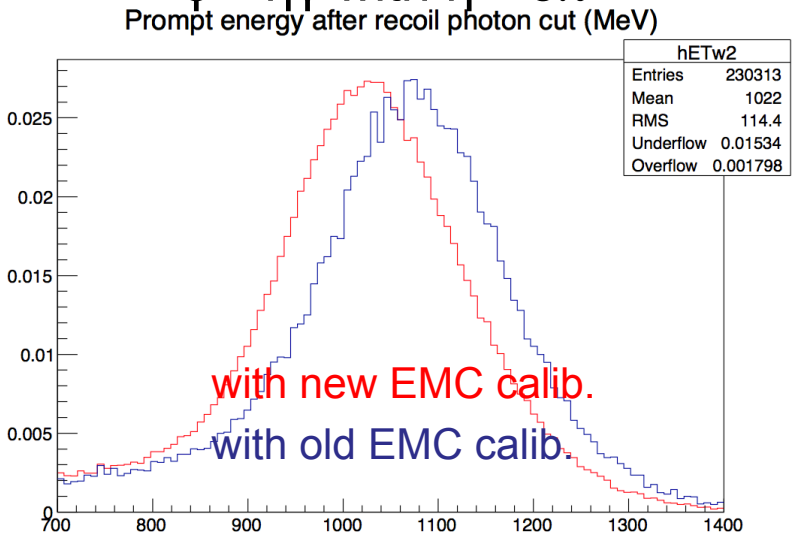
Simulation and energy acceptance studies

- A detailed study of the off-energy electrons and positrons transport along the machine lattice is in progress (collaboration with DAFNE), taking into account actual machine setup and measurements from beam position monitors in the machine layout.

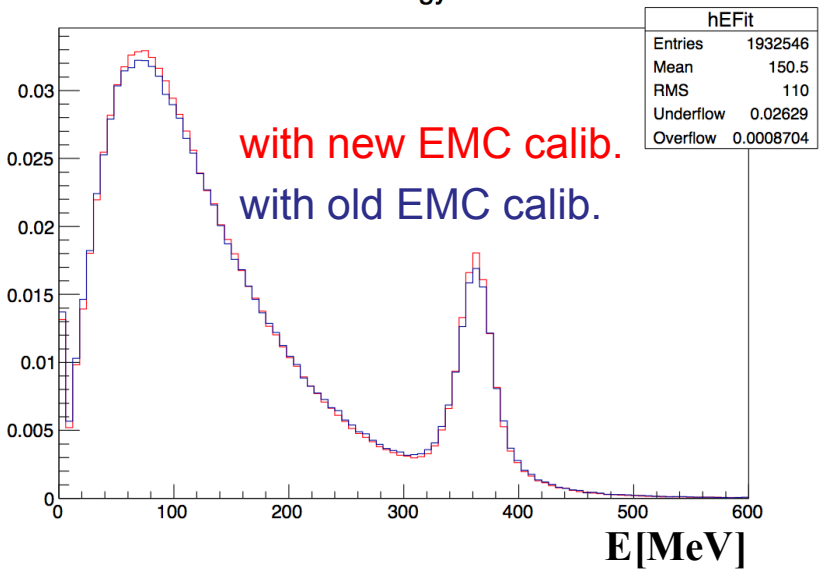


RUN-III Data quality benchmark analyses

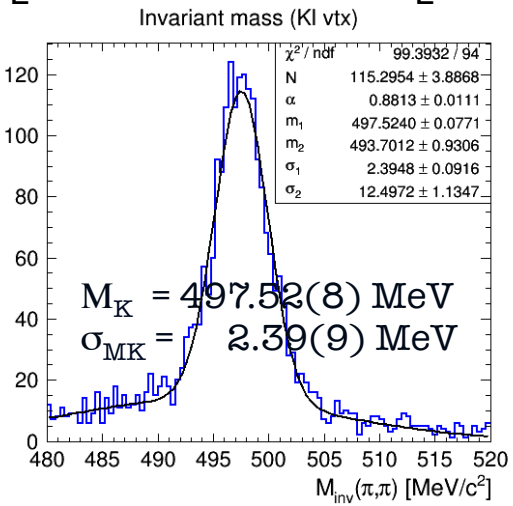
$\phi\to\eta\gamma$ with $\eta\to3\pi^0$



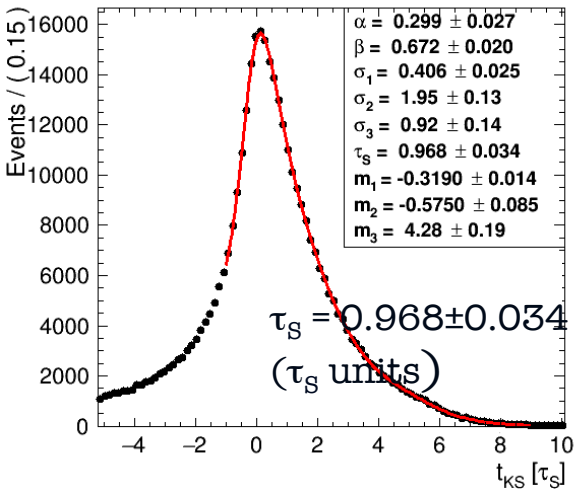
$\phi\to\eta\gamma$ with $\eta\to3\pi^0$



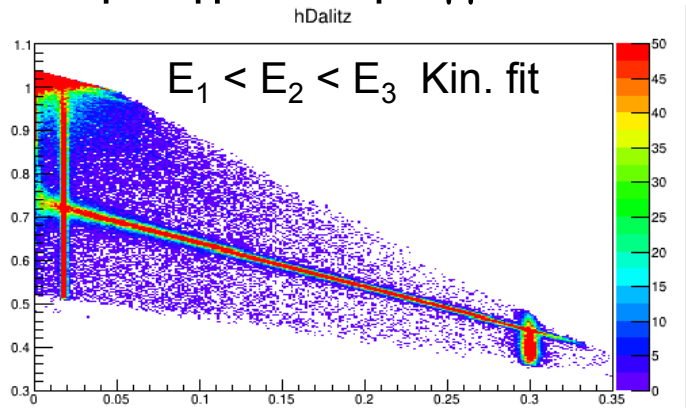
K_L inv mass with $K_L\to\pi^+\pi^-$



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



$\phi\to\eta\gamma$ with $\eta\to\gamma\gamma$



m^2_{23} vs m^2_{12} [GeV²]

$K_S \to 3\pi^0$ analysis on new data

- Analysis on new data: L ~ 300 pb^{-1}
- Need to harden the selection criteria to face the larger background wrt 2005 (~10 times more accidental clusters in trigger window).

  (old selection) (new selection)

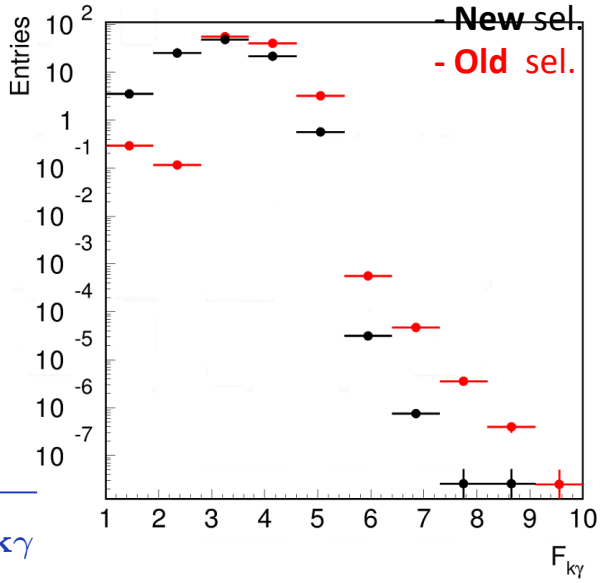
  - K_L crash: E>150 MeV, $0.2 < \beta < 0.225$
  - prompt γ's: $E_{cl} > 7$ MeV ⇒ $E_{cl} > 20$ MeV

    $|\cos\theta_{cl}| \le 0.915$

    $|t-r/c| \le \mathrm{Min}[3.5\cdot\sigma_T(E_{cl}), 2\ \mathrm{ns}]$ ⇒ $|t-r/c| \le \mathrm{Min}[3.0\cdot\sigma_T(E_{cl}), 2\ \mathrm{ns}]$

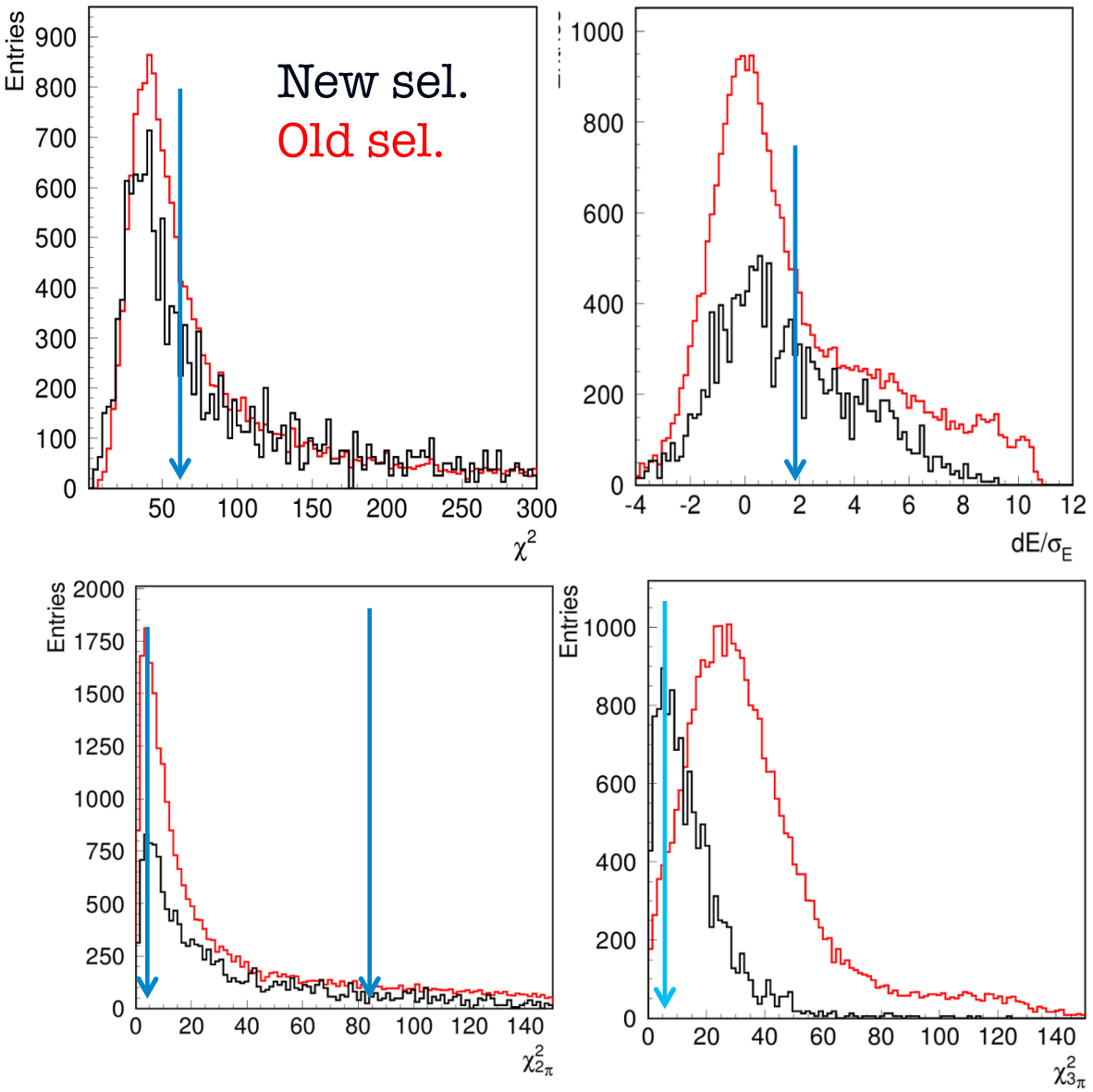
  - Efficiency for signal: 47% ⇒ 43%
  - 10 times better background rejection
- $K_S \to 2\pi^0$ used as normalization

$$F_{k\gamma} = \frac{N_{k\gamma}}{\sum_{k=1}^{10} N_{k\gamma}}$$

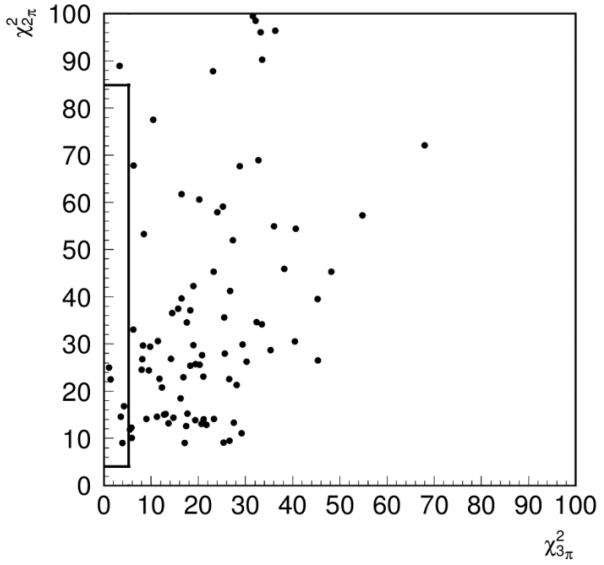


$K_S \rightarrow 3\pi^0$ analysis on new data

- **Hard K_L-crash:** cuts on the velocity of K_L and energy of the K_L cluster
- **$\Delta E/\sigma_E = (E_{Ks} - \Sigma E_\gamma)/\sigma_E$ cut:** Consistency of K_S reconstructed energy with four "best" γ clusters
- **Kinematic fit:** K_S mass, total 4-momentum conservation, consistency between the measured time and position of each cluster
- **Signal box definition:** $\chi^2_{2\pi}$: pairing of 4 out of 6 photons (π^0 masses, E_{Ks}, P_{Ks}, angle between π^0's) $\chi^2_{3\pi}$: pairing of 6 clusters with best π^0 mass estimates



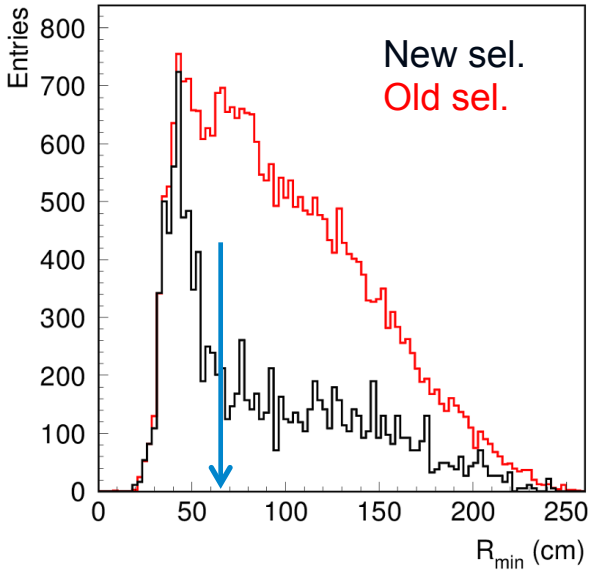
$K_S \to 3\pi^0$ analysis on new data



- R_{min} : minimum distance between clusters

$\chi^2_{fit} < 57.2$
$4.0 \leq \chi^2_{2\pi} \leq 84.9$
$R_{min} > 65$ cm

$\Delta E/\sigma_E \geq 1.8$
$\chi^2_{3\pi} \leq 5.2$



Track Veto → χ^2_{fit} → $\Delta E/\sigma_E$ → Sbox → R_{min} → counting

- With the old analysis chain and cuts we count N_{obs} = 1 event selected as a signal
- Taking into account the used statistics this translates to a very preliminary upper limit of $O(10^{-7})$
- KLOE results:

  BR($K_S \to 3\pi^0$) < 1.2 x 10^{-7} with 450 pb^{-1} [PLB 619 (2005) 61]

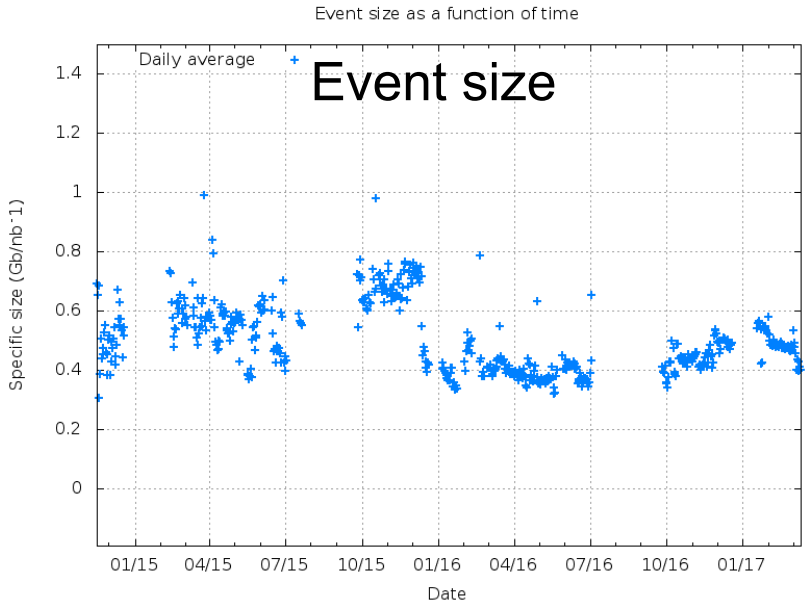
  BR($K_S \to 3\pi^0$) < 2.6 x 10^{-8} with 1.7 fb^{-1} [PLB 723 (2013) 54]

Data volume and reconstruction

Data Volume

- Reconstructed ~25% of the total luminosity
- Run-III consistent with expected 0.5 PB/fb^{-1}

	Run-I	Run-II	Run-III
L [fb^{-1}]	0.80	1.62	1.24
RAW [TB]	457	867	688
REC [pb^{-1}]	30	586	251



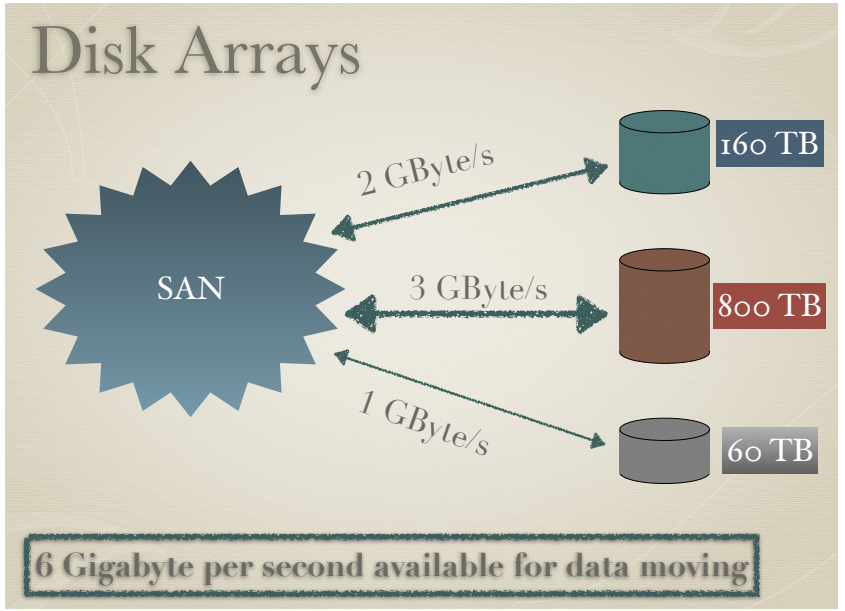
Reconstruction

- New version 2.0 of the DC-IT integrated tracking and vertexing successfully tested and working
- New event classification module for the $\gamma\gamma \rightarrow \pi^0$ analysis is ready and under test
- Implementation of a new stream for events collected by the Single Photon Trigger is ongoing
- New data handling scheme in operation (GPFS+Disk Array)
- Reconstruction rate ~10 pb-1/day OK to follow data taking (to increase reconstruction rate of previous runs and MC -> additional P8 machine planned)

Computing and storage

- New 300 Tape Cartridges (3PB)

- DataDirect 9900 Disk Array (from CNAF)
- Caching problems during heavy load => solved with a workaround (impossible to solve according to DD maintenance service)
- Speed test OK
- New data handling scheme is now in operation (GPFS+Disk Array)



- CPUs no longer show idle time or IO wait when busy with user programs.
- The SAN/GPFS architecture and the new disk array feed CPUs in a correct way, eventually saturating them.

```
Topas Monitor for host:fibm50
Fri Apr 28 11:49:52 2017   Interval:1

CPU      User% Kern% Wait% Idle%
Total     99.6   0.4   0.0   0.0
```

Publications

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
U boson search in $e^+e^- \to U\gamma$, $U \to \pi^+\pi^-$	PLB 757 (2016) 356
BR and charge asymmetry of $K_S \to \pi e \nu$ CP/CPT	Finalizing systematics
T/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 of $K_S \to \pi^+\pi^-\pi^0$	in progress
U boson search: combined limit from $\mu\mu\gamma/\pi\pi\gamma$	advanced stage
a_μ and pion FF: combined result	advanced stage
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
Improved UL of BR $K_S \to 3\pi^0$: CP/CPT (new K2 data)	started

Conclusions

- Data taking (RUN-III) is ongoing with KLOE-2 detector fully operational:
  Total L delivered up to now 4.6 fb^{-1}, acquired L~3.7 fb-1
- RUN-III milestone: L delivered 5 fb-1 for summer 2017
  in line with the minimum requirement of 6.2 fb^{-1} => L acquired ~5 fb^{-1} for end March 2018

- Results from IT+DC integrated tracking and vertexing using first align & Calib parameters with $\phi \rightarrow \pi^+\pi^-\pi^0$ and $K_S \rightarrow \pi^+\pi^-$ samples are encouraging
- Improved alignment & calibration parameters.

- Analyses of Double-arm and Single-arm HET tagged events show at the present stage no evidence of π^0 production. A complementary analysis approach to search for π^0 production with KLOE alone, and detailed beam transport studies are in progress.

- Data quality is continuously monitored with several benchmark analysis.
- The analysis to improve the limit on BR of $K_S \rightarrow 3\pi^0$ started: encouraging very preliminary results on 300 pb-1 of data.

- Data reconstruction with integrated IT+DC tracking and new data handling (GPFS+Disk Array) architecture is operative.

- We have a new artwork in the KLOE-2 control room!

SPARE SLIDES

KLOE-2 Physics

KAON Physics:

- CPT and QM tests with kaon interferometry
- Direct T and CPT tests using entanglement
- CP violation and CPT test:
  $K_S \to 3\pi^0$
  direct measurement of $\mathrm{Im}(\varepsilon'/\varepsilon)$ (lattice calc. improved)
- CKM Vus:
  K_S semileptonic decays and A_S (also CP and CPT test)
  $K\mu 3$ form factors, Kl3 radiative corrections
- χpT : $K_S \to \gamma\gamma$
- Search for rare K_S decays

Hadronic cross section

- Measurement of a_μ^{HLO} in the space-like region using Bhabha process
- ISR studies with 3π, 4π final states
- F_π with increased statistics

New proposal: running at $\sqrt{s}$ = 958 MeV

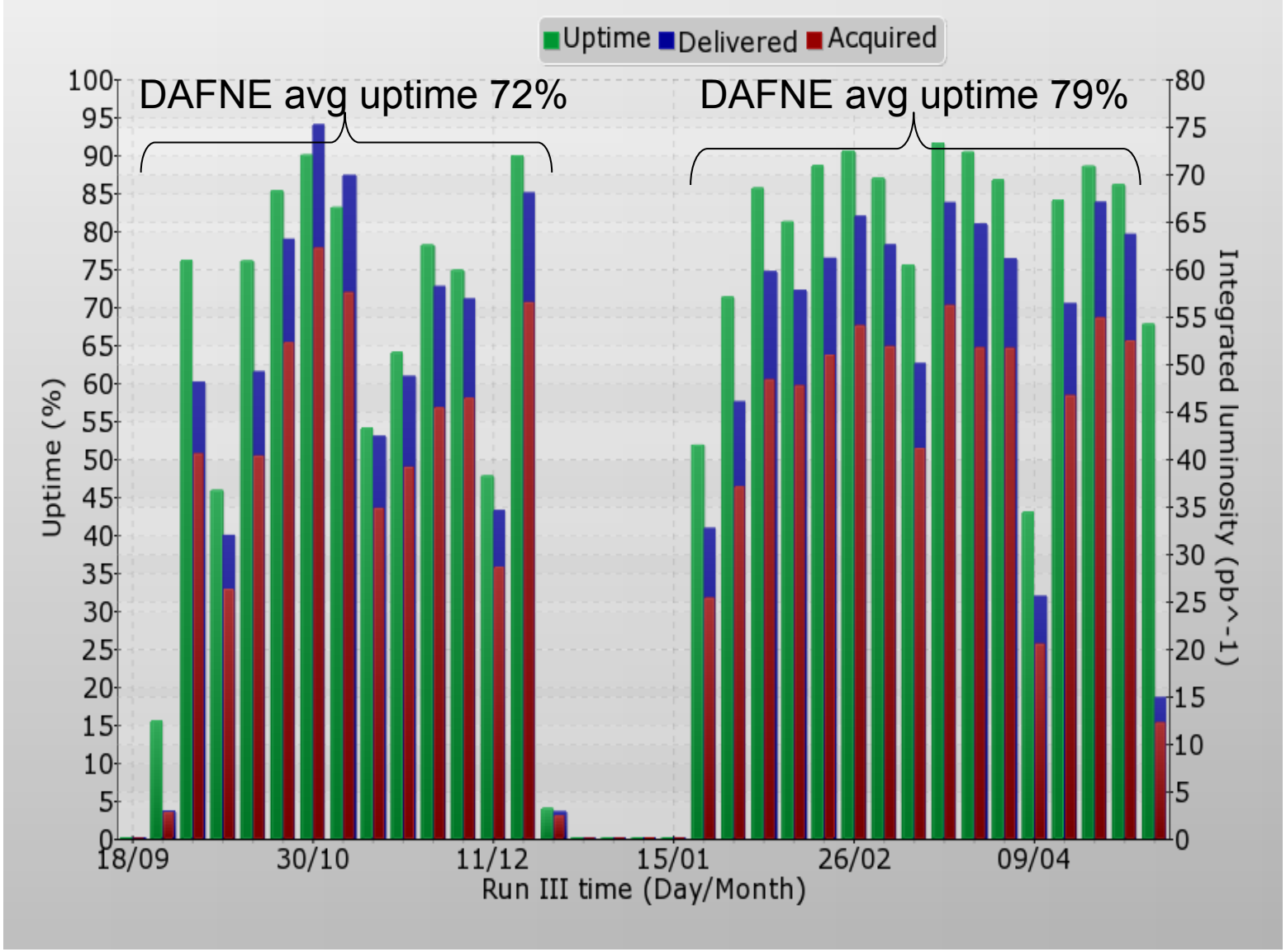
- Production of Non-Vector-Resonances (η') in e+e− annihilation (η' TFF)

Dark forces:

- Improve limits on:
  $U\gamma$ associate production
  $e^+e^- \to U\gamma \to \pi\pi\gamma, \mu\mu\gamma$
- Higgstrahlung
  $e^+e^- \to Uh' \to \mu^+\mu^-$ + miss. energy
- Leptophobic B boson search
  $\phi \to \eta B,\ B \to \pi^0\gamma,\ \eta \to \gamma\gamma$
  $\eta \to B\gamma,\ B \to \pi^0\gamma,\ \eta \to \pi^0\gamma\gamma$
- Search for U invisible decays

Light meson Physics:

- η decays, ω decays, TFF $\phi \to \eta e^+e^-$
- C,P,CP violation:
  improve limits on $\eta \to \gamma\gamma\gamma,\ \pi^+\pi^-,\ \pi^0\pi^0,\ \pi^0\pi^0\gamma$
- improve $\eta \to \pi^+\pi^-e^+e^-$
- χpT : $\eta \to \pi^0\gamma\gamma$
- Light scalar mesons: $\phi \to K_S K_S \gamma$
- $\gamma\gamma$ Physics: $\gamma\gamma \to \pi^0$ and π^0 TFF
- light-by-light scattering
- axion-like particles

(new wrt K2 program EPJC (2010) 68, 619)

RUN-III luminosity weekly detail