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NA48: direct ~~CP~~ in K^0 decays

- The NA48 collaboration::
  - Cagliari
  - Cambridge
  - CERN
  - Dubna
  - Edinburgh
  - Ferrara
  - Florence
  - Mainz
  - Orsay
  - Perugia
  - Pisa
  - Saclay
  - Siegen
  - Torino
  - Vienna
  - Warsaw

- This talk:
  - The method
  - Simultaneous K_L and K_S beams
  - The detector
  - Run '97
    - Liquid-Krypton calorimeter
    - K_S or K_L: proton tagging
    - Statistics
  - Data '97
    - Charged mode
    - Neutral mode
    - Other results: $K_L \to ee\gamma$, $ee\gamma\gamma$
  - Run '98
    - Upgrades and statistics
    - $K_L \to \pi^+\pi^-e^+e^-$
  - Summary, outlook

The Method

- Double ratio method

$$\mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right) = \frac{1}{6}\left\{1 - \frac{\Gamma\left(K_L \to \pi^0\pi^0\right)}{\Gamma\left(K_S \to \pi^0\pi^0\right)} \Big/ \frac{\Gamma\left(K_L \to \pi^+\pi^-\right)}{\Gamma\left(K_S \to \pi^+\pi^-\right)}\right\}$$

- Precision measurement of direct CP-violation
  - aims at a total error $\delta(\varepsilon'/\varepsilon) \leq 2 \cdot 10^{-4}$

- Minimal corrections required:
  - All decay modes are measured
    - simultaneously
    - from the same fiducial volume
    - with efficient and K_S-K_L blind trigger systems
    - by a magnetic spectrometer and Liquid-Krypton e.m. calorimeter
  - lifetime weighting yields the same longitudinal decay vertex distributions for K_L and K_S → acceptance(z_v) cancels out

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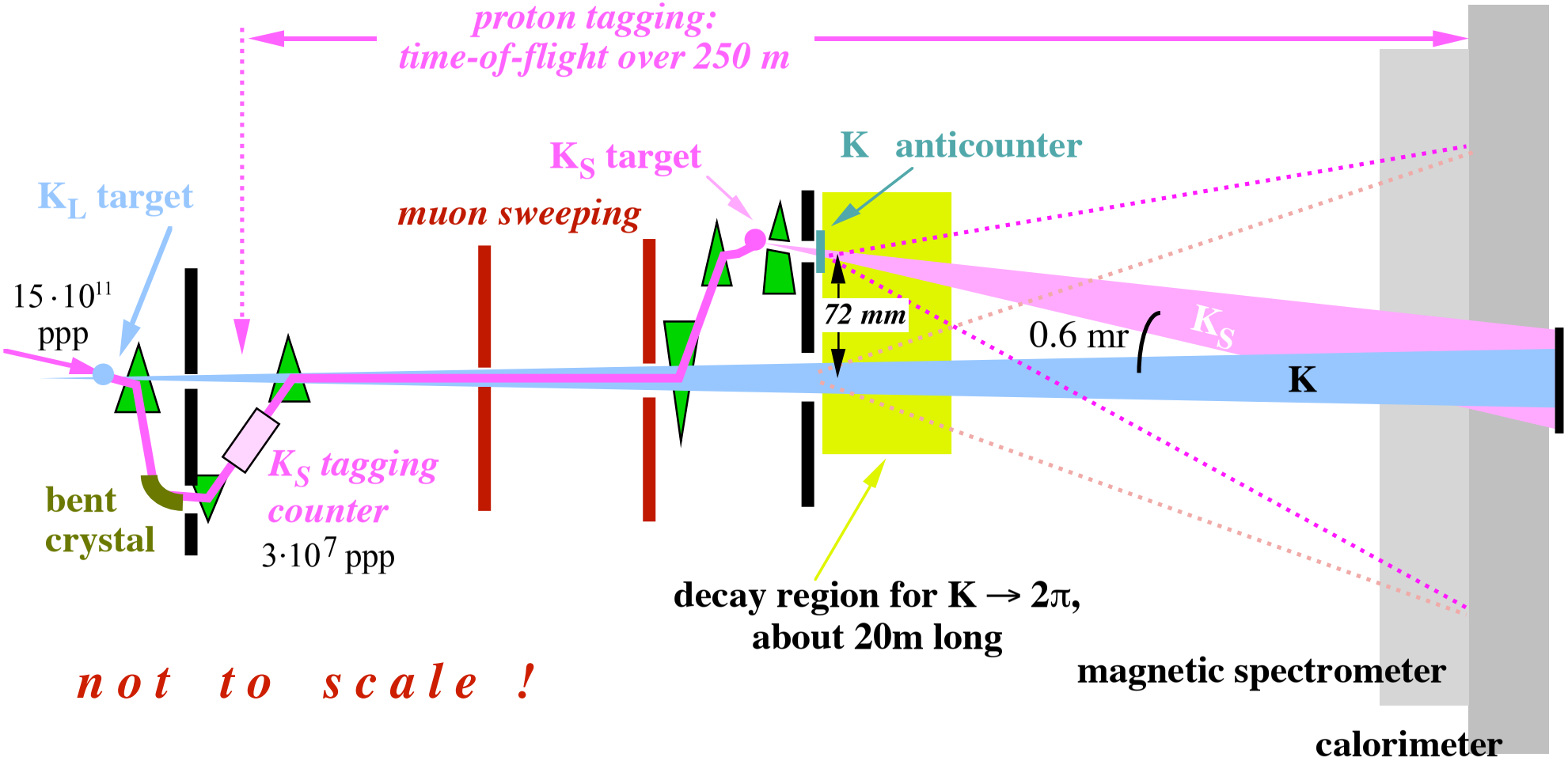
Simultaneous K_L and K_S Beams



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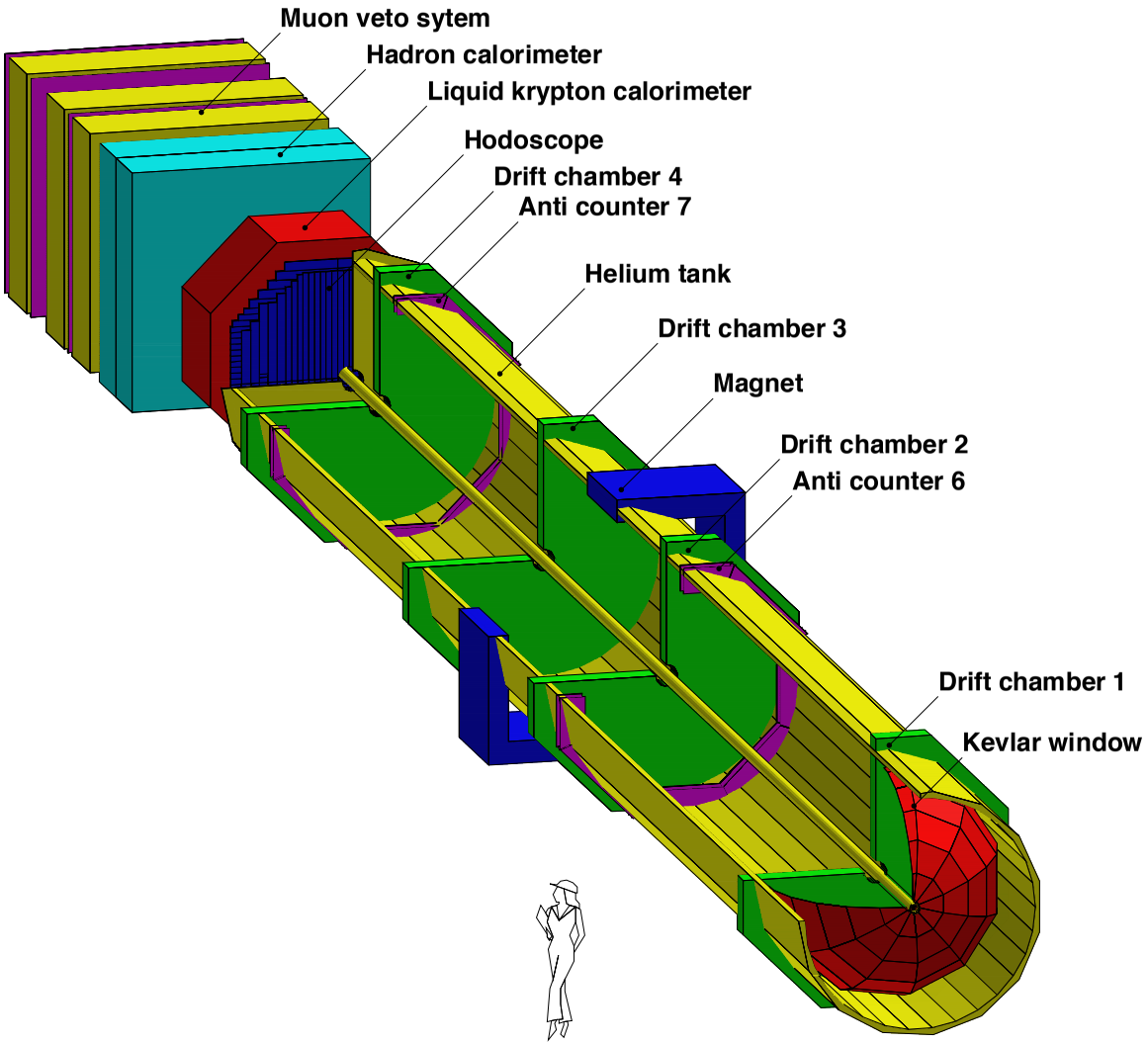
The Detector

- Proton tagging detector 250m upstream:
  - t_{TAG} with $\sigma_t < 200$ps
  - 1 GHz sampling, master clock
- Evacuated decay region
  - beam pipe through all detectors
- Scintillator hodoscope
  - t_{HOD} for charged mode
- Magnetic spectrometer for charged particles
  - four drift chambers in He
- Liquid-Krypton calorimeter for neutral particles
  - t_{LKR} for neutral mode



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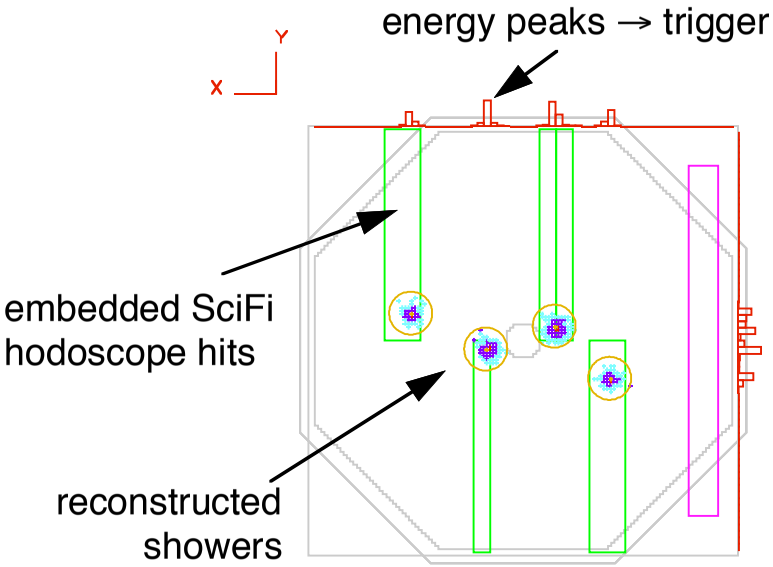
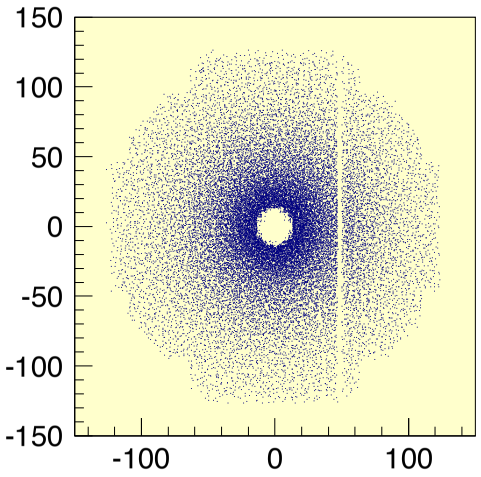
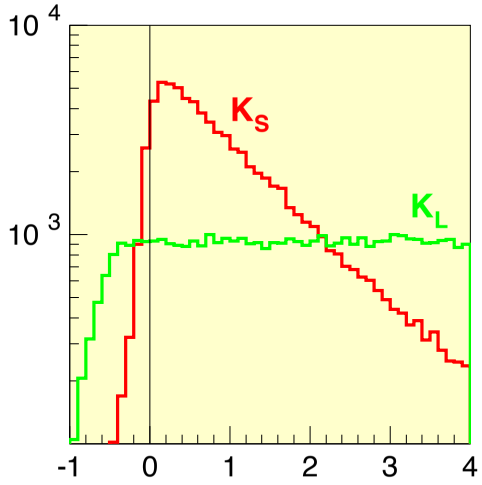
Run '97: Liquid-Krypton calorimeter

- 13,000 cells (2x2cm^2) read-out
- Stable operation at only 1.5 kV due to capacitor problems
  - 4 cm wide strip without high voltage
  - small space charge correction near the beam hole

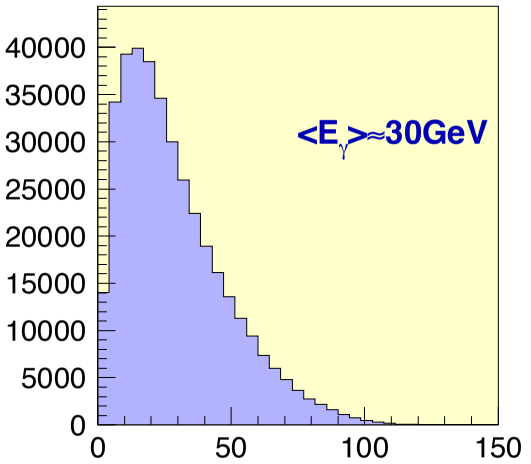




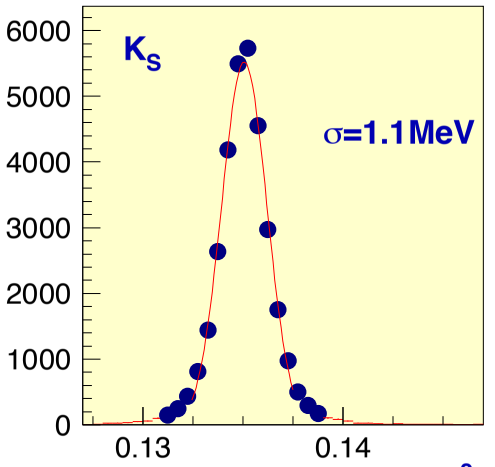
x/y LKR clusters for neutrals



cτ [<cτ$_{KS}$>]



Photon energy (4cluster events)



m$_{\gamma\gamma}$[GeV/c^2]

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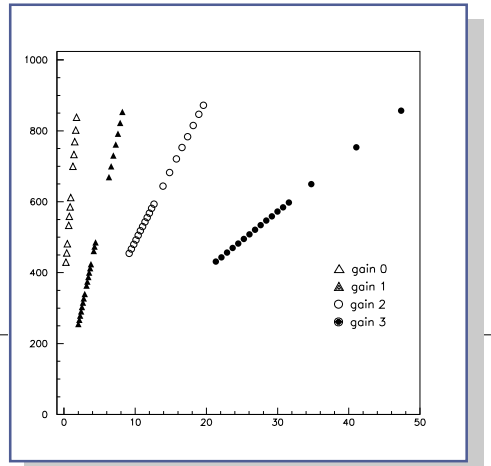
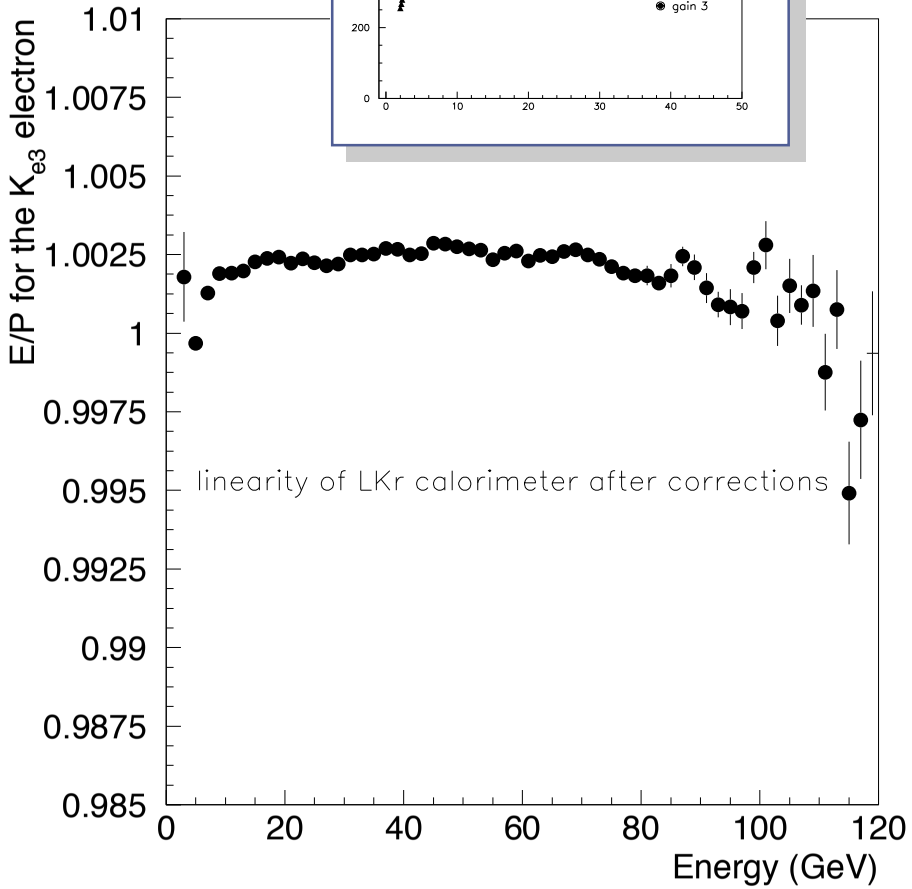
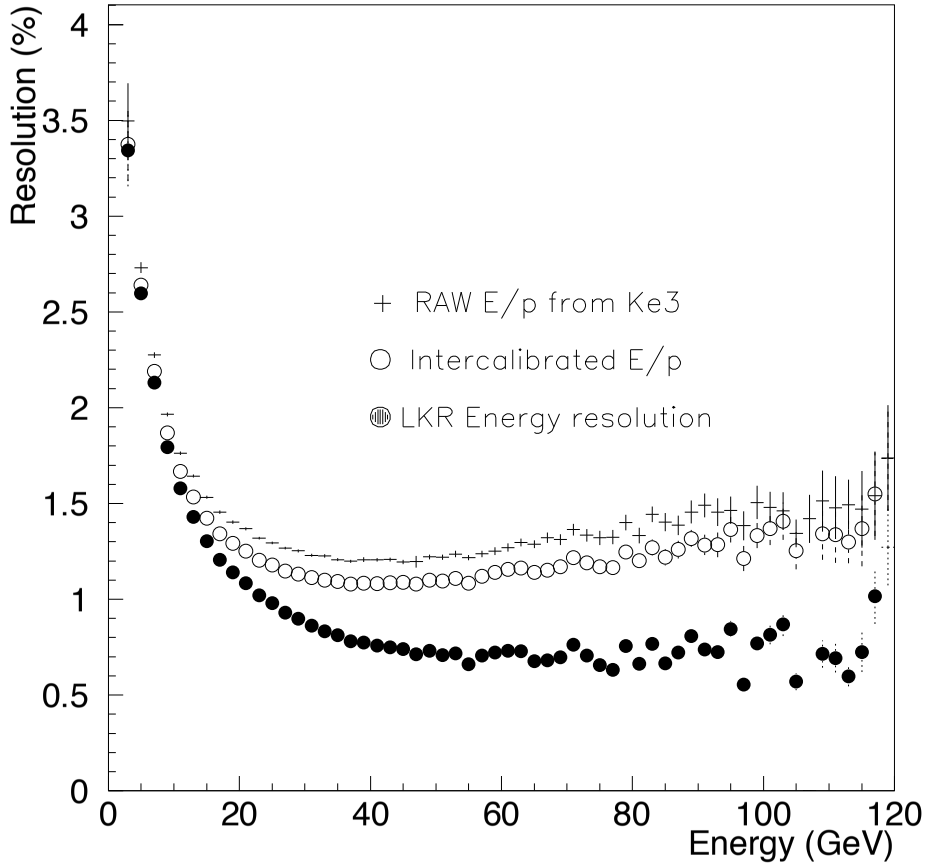
Run '97: LKr calorimeter calibrations

- LKr calorimeter: 4 fast-switched gain ranges, linear characteristics, stable over the run
- electronics calibration and K_{e3} corrections







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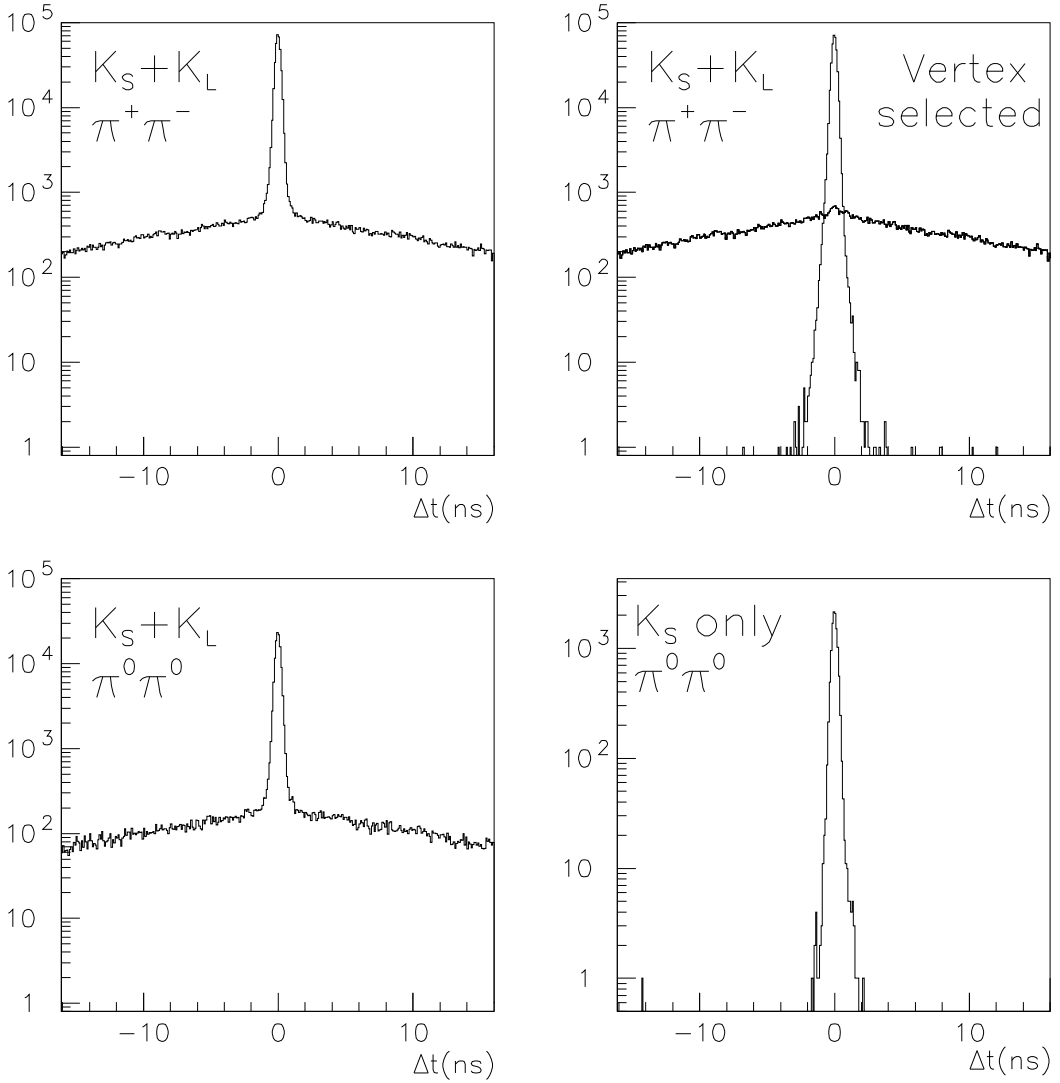
Run '97: K_S or K_L ?: proton tagging

- Δt = event time in detector minus proton time in tagger
  - neutrals: $\Delta t_N = t_{LKR} - t_{TAG}$
  - charged: $\Delta t_C = t_{HOD} - t_{TAG}$
- tagger doesn't know final states → can't fake ε'/ε
- K_S events have $|\Delta t| < 2$ns
  - Inefficiencies: few 10^{-4}
- K_L events have $|\Delta t| > 2$ns
  - accidental wrong $K_L \rightarrow K_S$ tags: ~11.5%, measured with high precision
- expect $\delta(\varepsilon'/\varepsilon) < 10^{-4}$ from tagging



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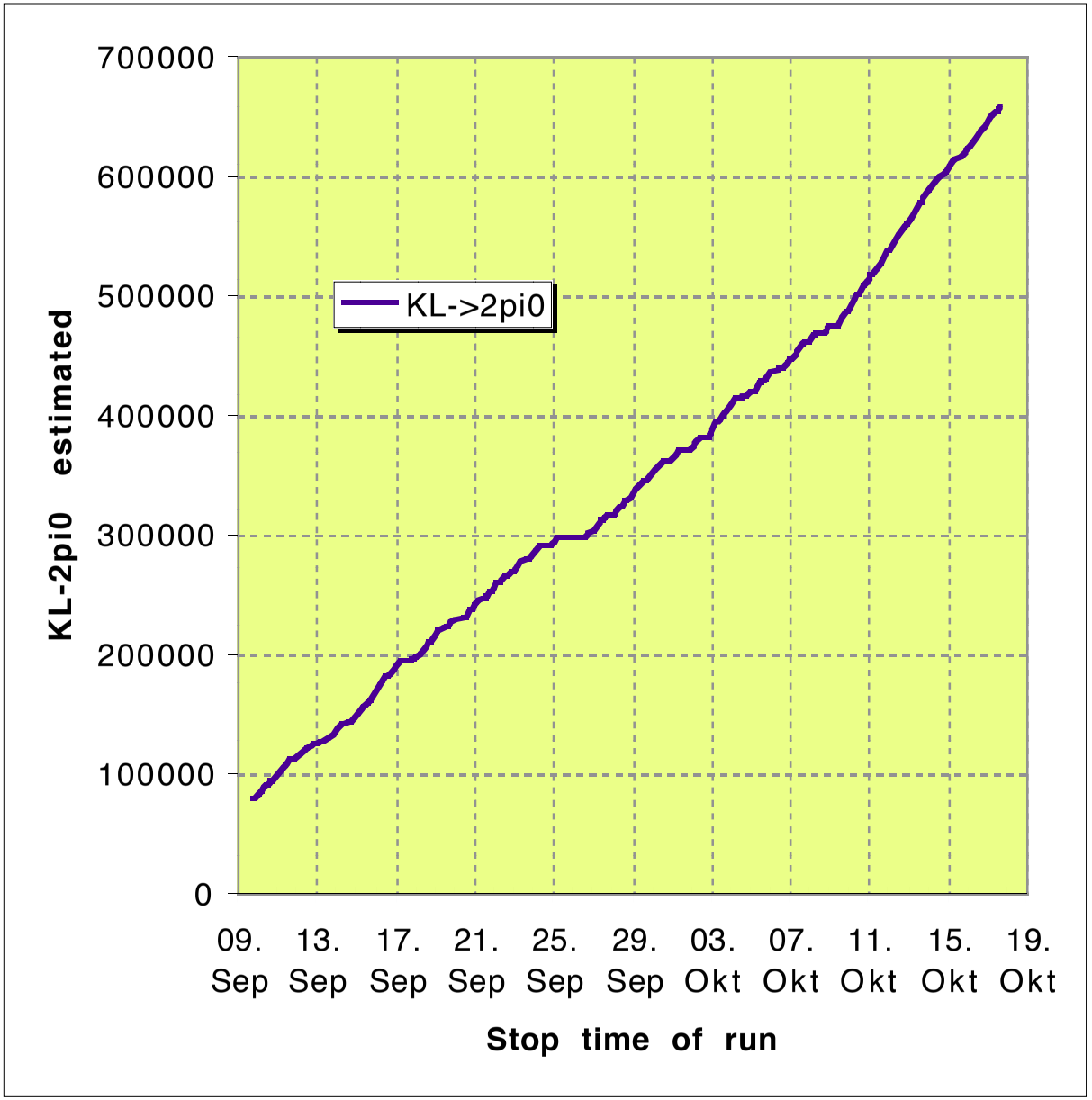
Run '97: statistics

- First physics run: Sep/Oct '97
  - 42 days of beam
  - 1.1 billion triggers
  - 25,000 GB
- 650,000 $K_L \rightarrow 2\pi^0$ events
  - energy: $70 < E_K < 170$ GeV
  - lifetime: $0 < \tau < 4\tau_s$
  - mistagging corrected
  - standard analysis cuts



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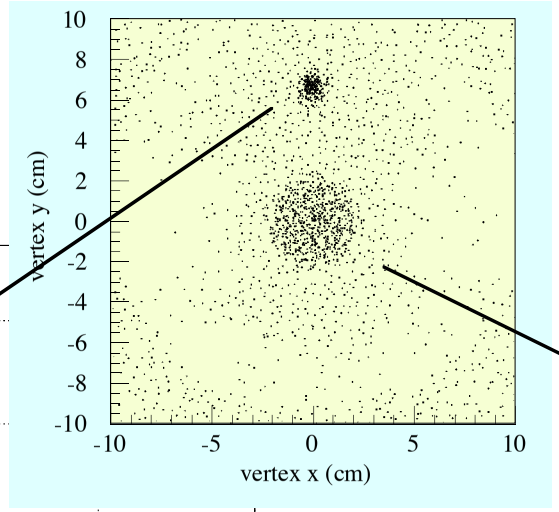
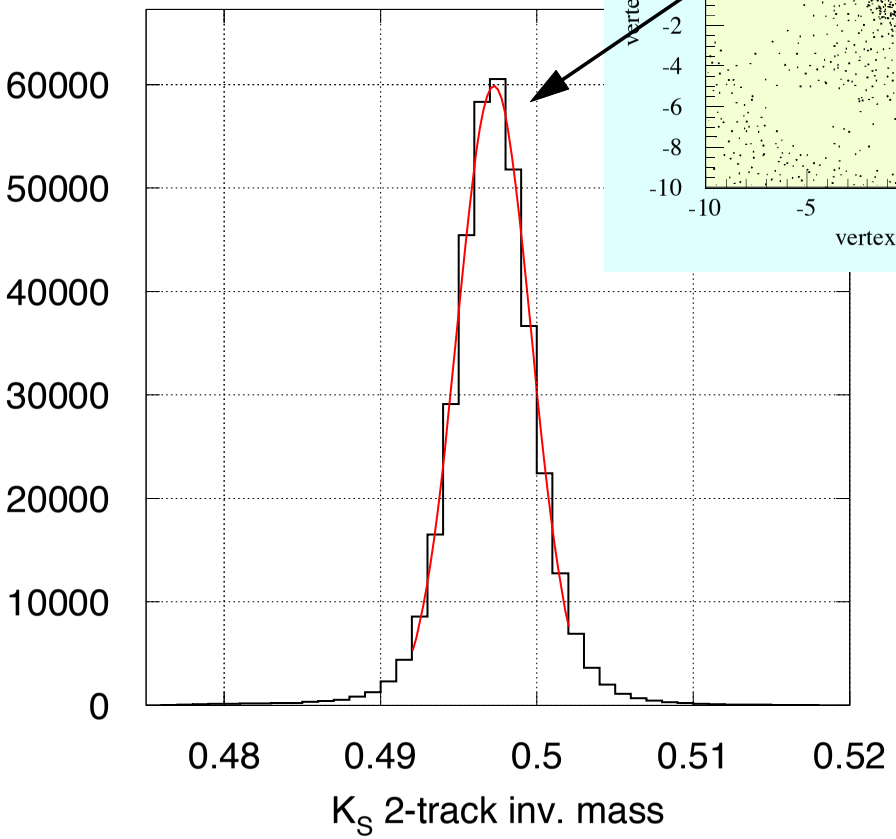
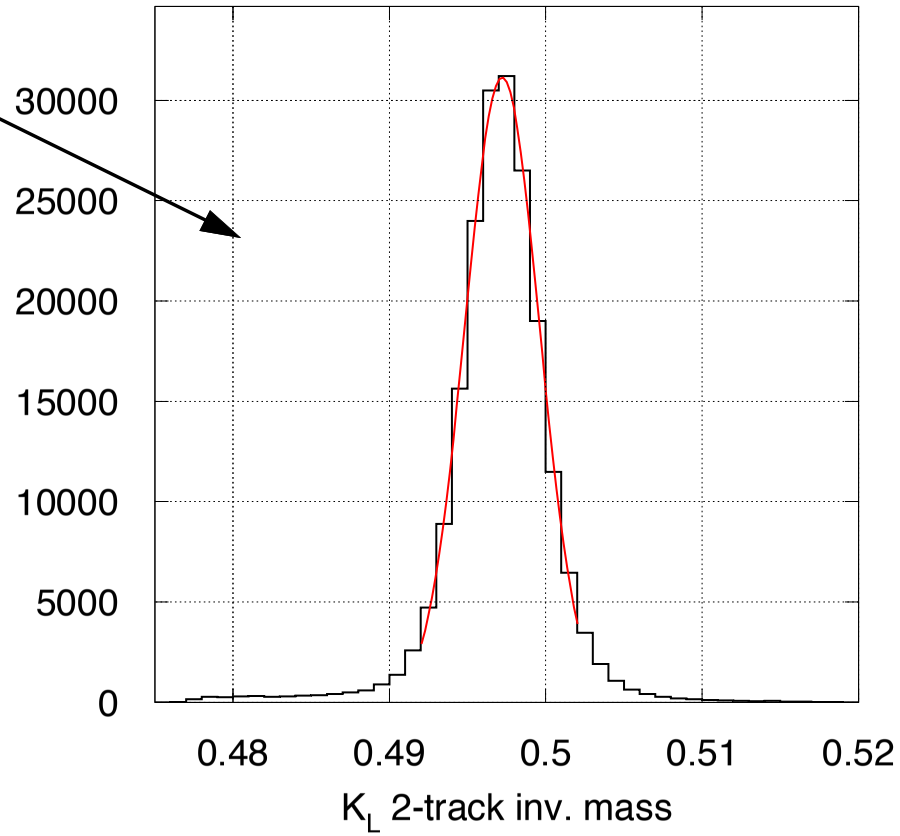
Data '97: charged mode

- x,y beam spots seen from 120 m







- invariant mass resolutions ≈ 2.5 MeV

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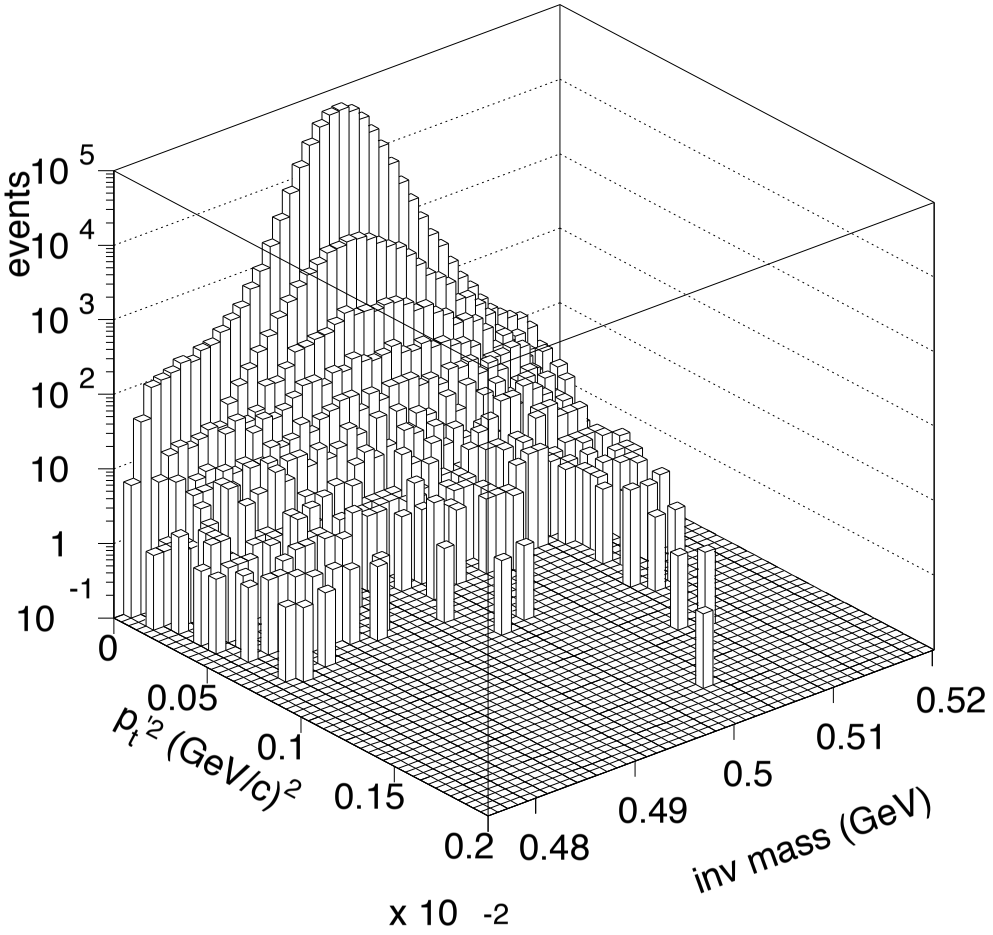
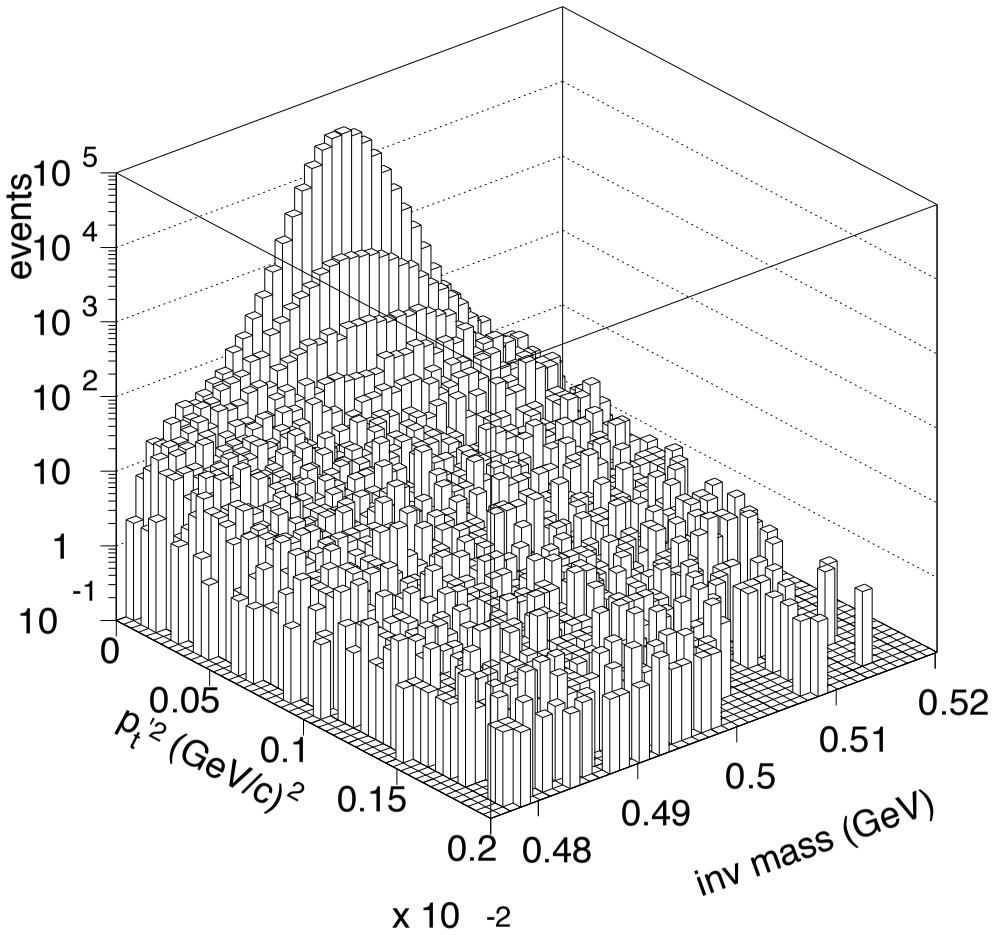
Data '97: charged mode

$K_S \rightarrow \pi^+\pi^-$ "all signal"



$K_L \rightarrow \pi^+\pi^-$ "signal + background"



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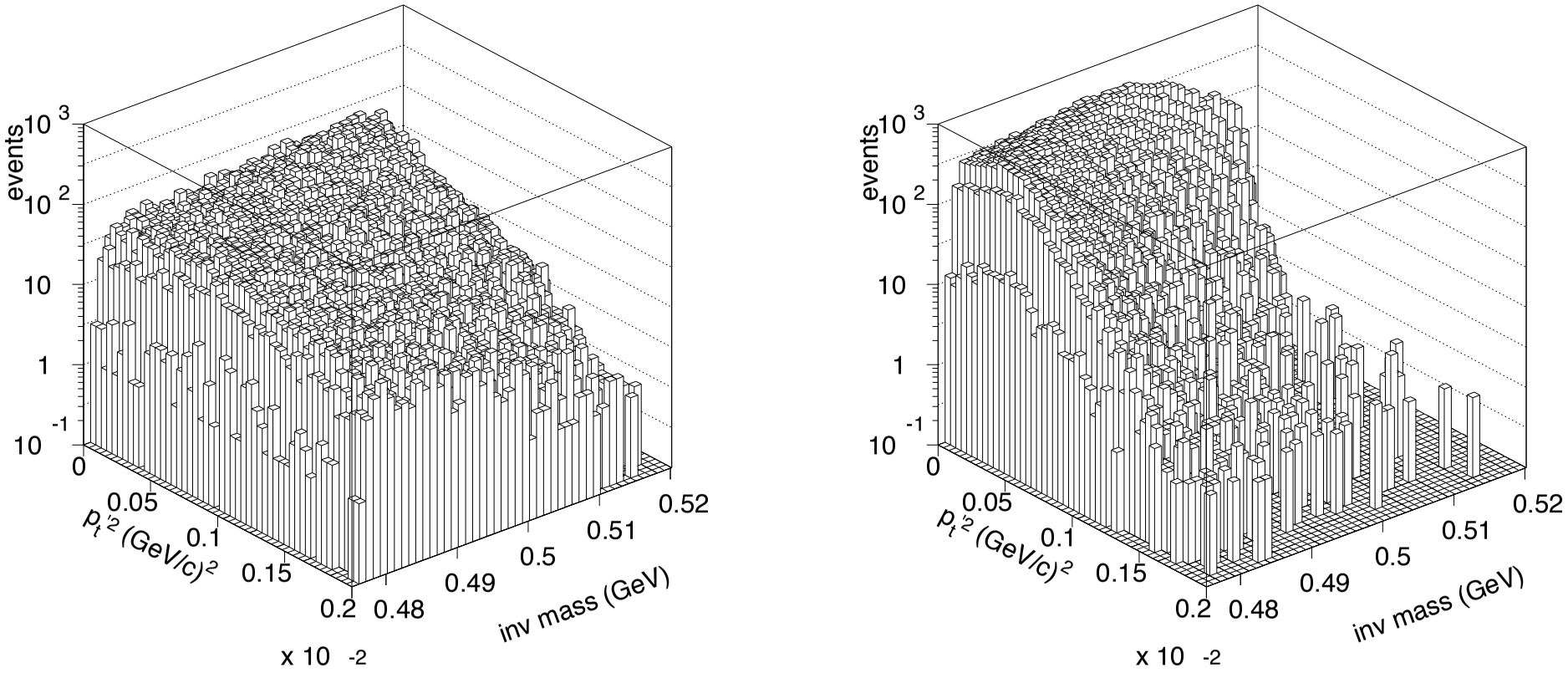
Data '97: charged mode

- obtain bkgd samples to study properties:
  - $K_L \to \pi e \nu$ "K_{e3}:" B/S=188 $K_L \to \pi \mu \nu$ "$K_{\mu 3}$:" B/S=135



- define control region in $\{p'^2_t, m_{\pi\pi}\}$, fit the data by $\alpha S(\pi\pi) + \alpha B(K_{e3}) + \gamma B(K_{\mu 3})$
  - functional form of subtracted background is taken from the data!

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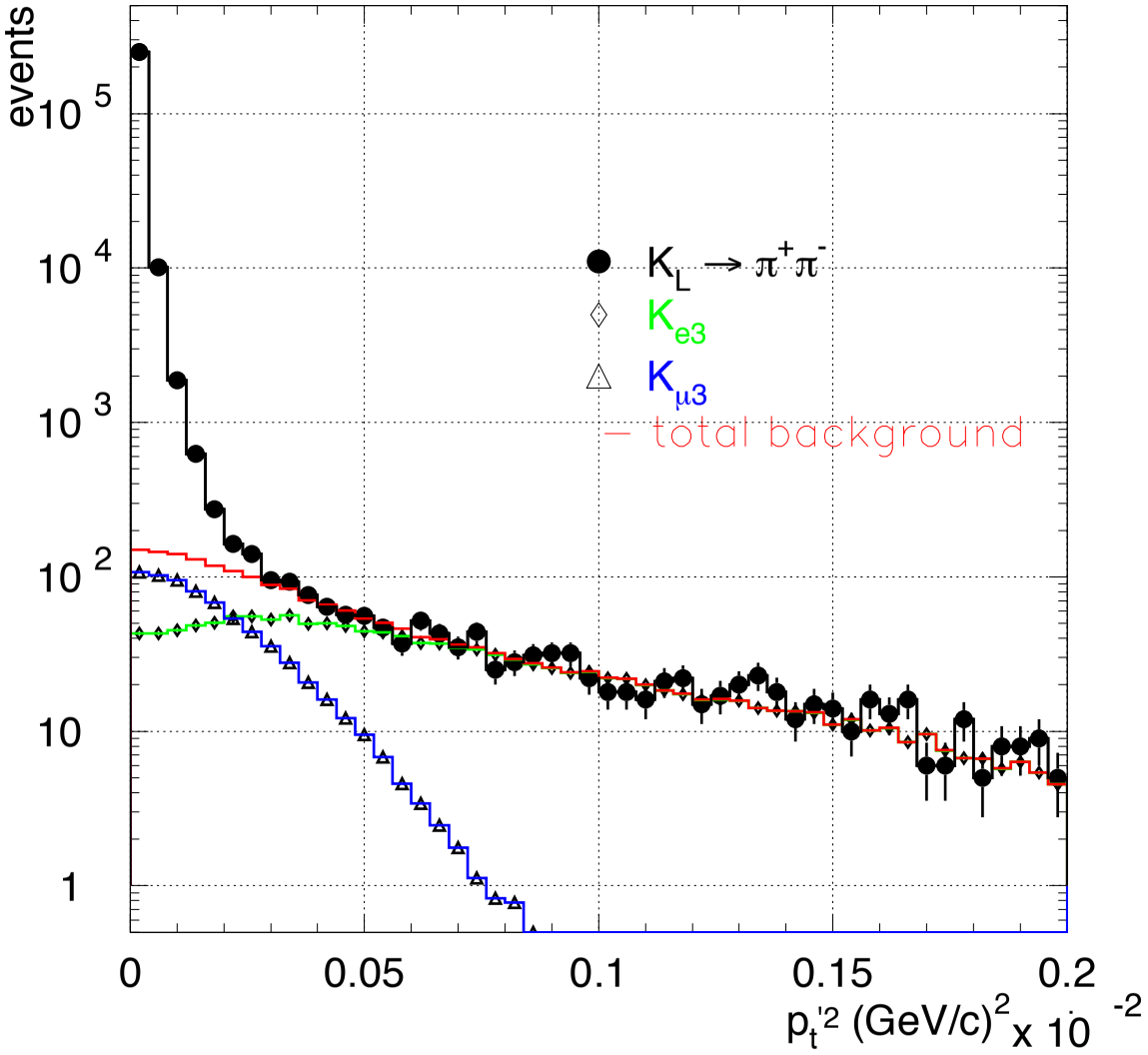
Data '97: charged mode

- Example:
  - control region:
    - $p'^2_t > 400$ (MeV/c)^2
    - $m_{\pi\pi} = m_K \pm 18$ MeV/c^2
  - plotted:
    - p'^2_t distribution of $K_L \to \pi^+\pi^-$ with K_{e3} and $K_{\mu 3}$ components for $m_{\pi\pi} = m_K \pm 7.5$ MeV/c^2
  - signal region:
    - $p'^2_t < 200$ (MeV/c)^2
    - $m_{\pi\pi} = m_K \pm 7.5$ MeV/c^2
  - numbers in signal region:
    - 264412 K_L
    - 230 ± 13 K_{e3}
    - 454 ± 89 $K_{\mu 3}$
  - background to be subtracted: $(2.6 \pm 0.4) \cdot 10^{-3}$

EXAMPLE
PRELIMINARY



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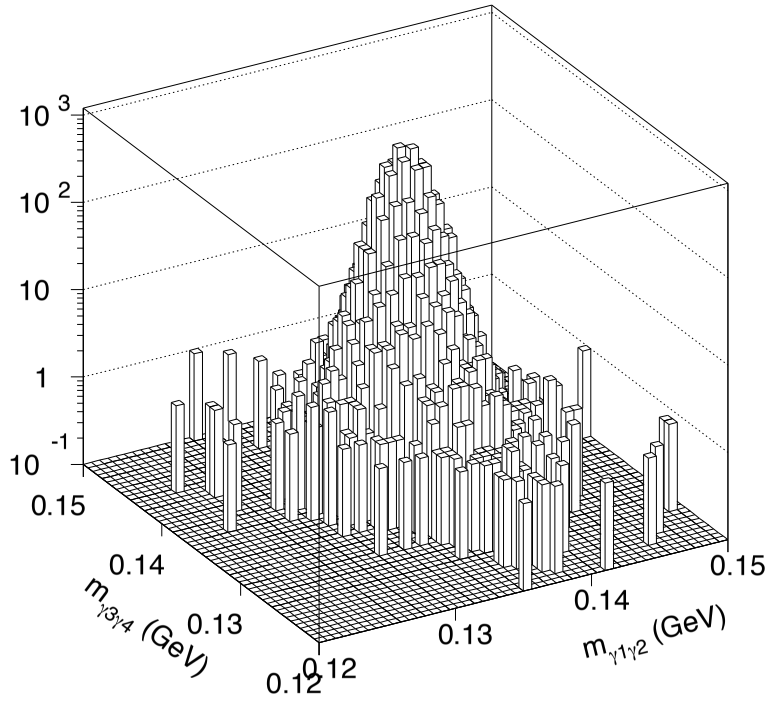
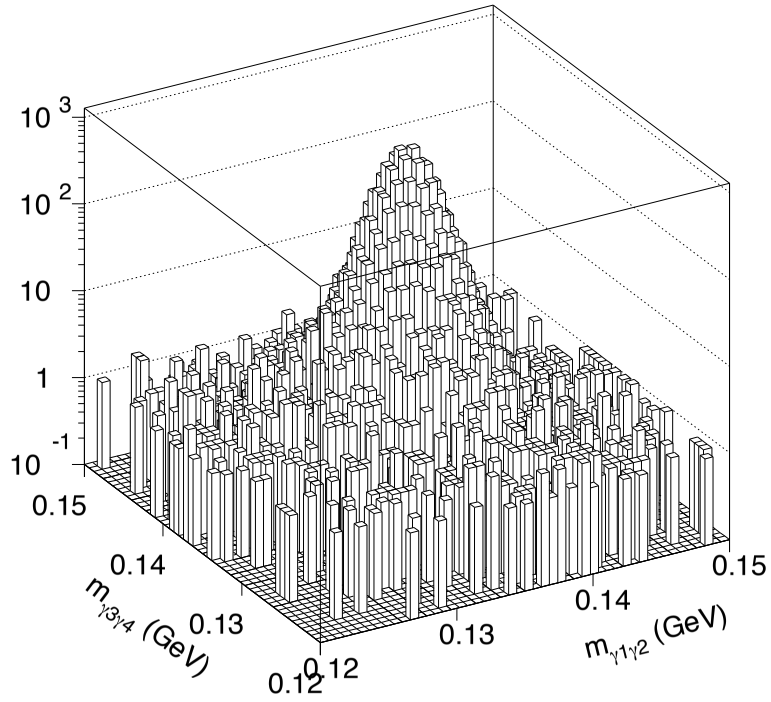
Data '97: neutral mode





- background to $K_L \rightarrow 2\pi^0 \rightarrow 4\gamma$ is $K_L \rightarrow 3\pi^0 \rightarrow 6\gamma$ with 2γ lost; B/S = 215
- suppress background: 4 clusters in time, energy centre-of-gravity
- impose m_K to find z_V, use z_V to find best χ^2 pairing of γ's to give $m_{\gamma\gamma}=m(\pi^0)$
- subtract background in elliptical χ^2-rings in the $m_{\gamma 1\gamma 2}$-$m_{\gamma 3\gamma 4}$ plane: R_{ell}

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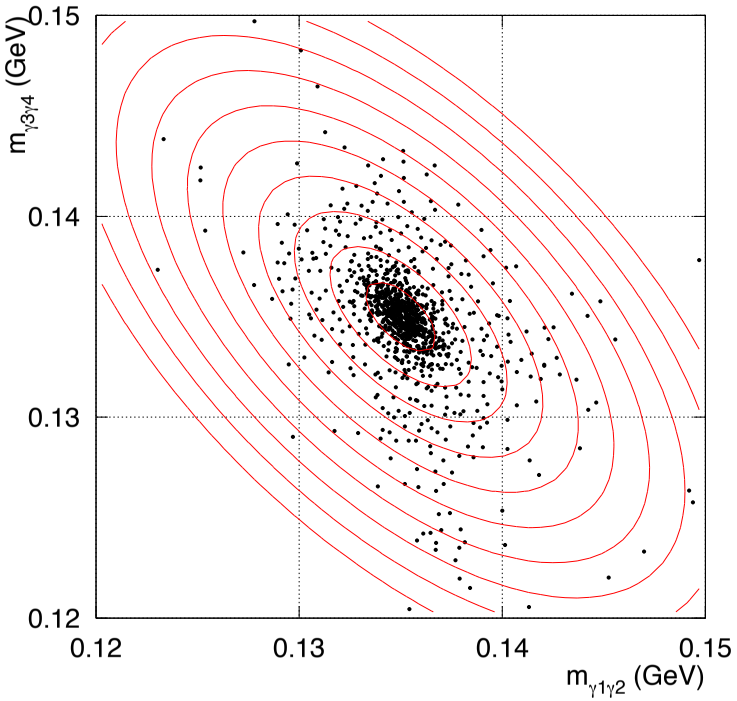
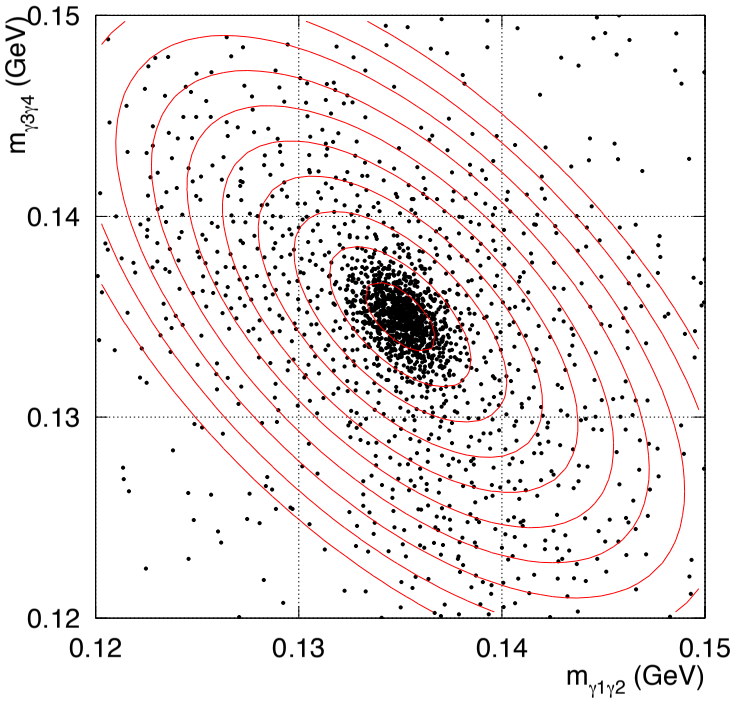
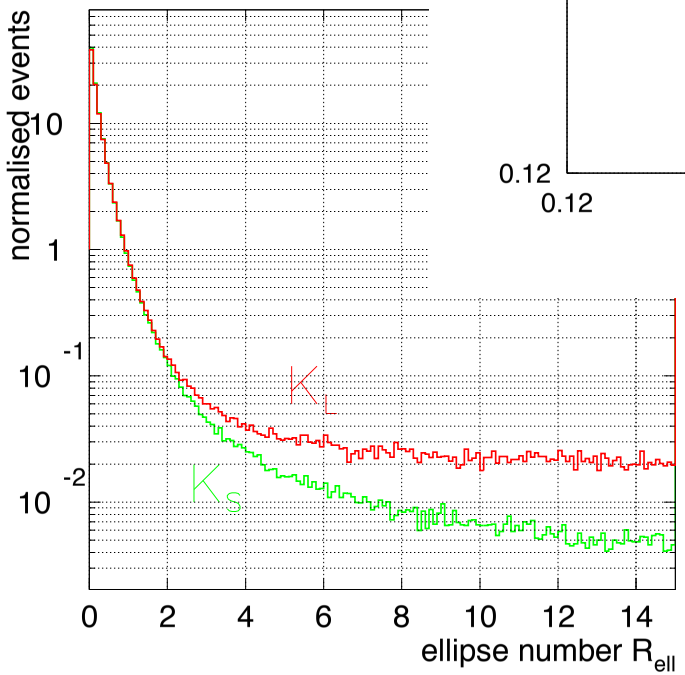
Data '97: neutral mode







- Background level to be subtracted: $3 \cdot 10^{-3}$ unweighted, $1 \cdot 10^{-3}$ weighted
  - $K_L \rightarrow 3\pi^0 \rightarrow$ "4γ" have large reconstructed z_V
  - the excellent energy, space and time resolution of the calorimeter pay off here

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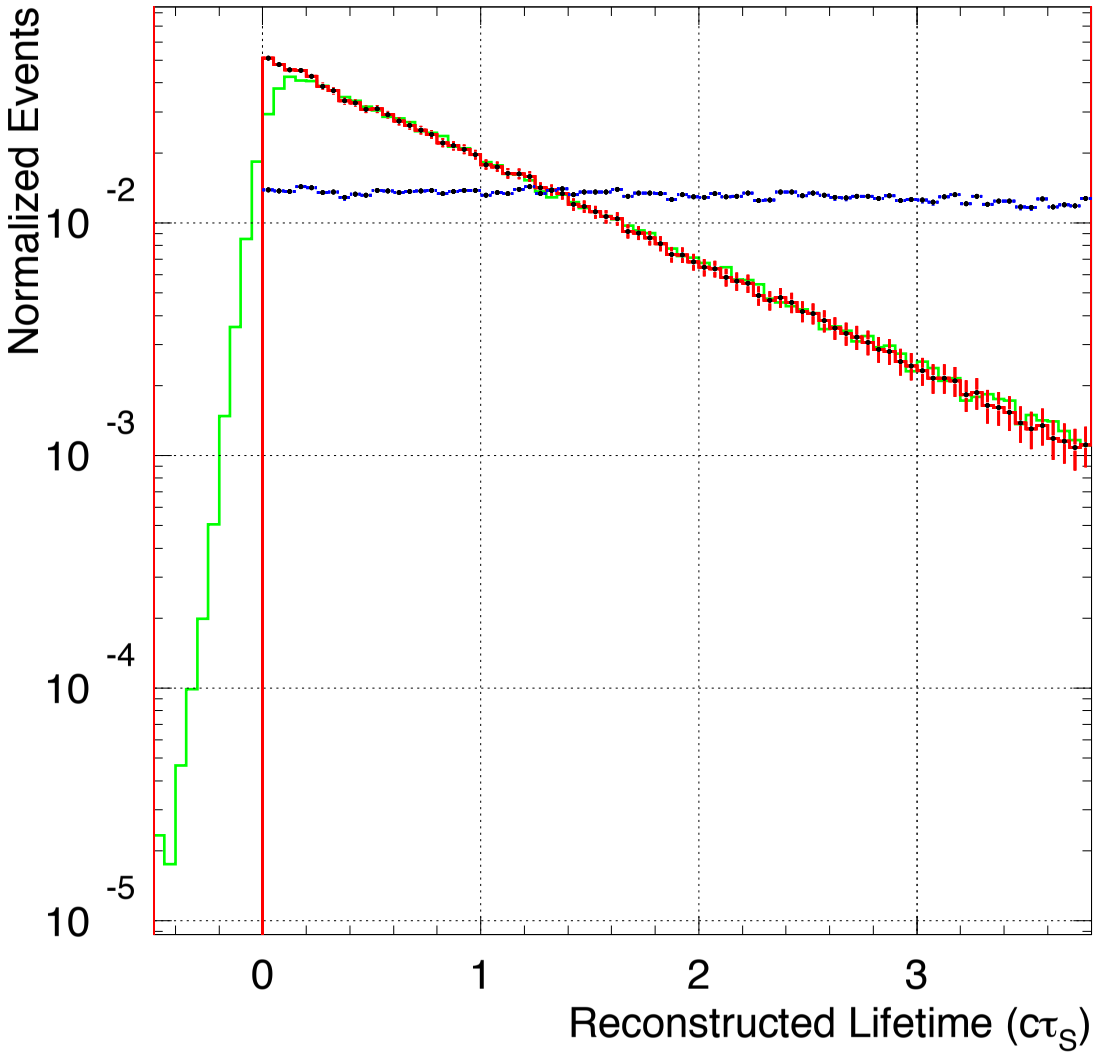
Data '97: lifetime weighting

- The statistical error of the '97 data will be (4 - 5)· 10^{-4} on ε'/ε
  - lifetime weighting makes the K_L vertex distribution identical to the K_S distribution
  - the effective fiducial volume will be ≈ 2 $c\tau_S$ long (10m at 100 GeV/c)
  - costs statistics...
  - the acceptances $A_{L,S}(z,p)$ as a function of the longitudinal decay position and momentum cancel out in z
  - $|A_L - A_S|$ may be a few per-mille on the double ratio depending on p



Data '97: ε' / ε

- Analysis of the '97 data is progressing while taking new data...
  - calibration ✔ reprocessing of 25TB ✔ re-selection of 'golden events' ✔
  - quality checking and compression of data in progress...
  - the data has good quality; so far all systematic uncertainties are at a very low level (very few 10^{-4} on ε'/ε) and are mostly of statistical nature

- Status: ✔✔✔ well advanced ✔✔ mid-way through ✔ started
  - trigger ✔✔ tagging ✔✔ energy scale ✔✔✔
  - linearity ✔✔✔ charged background ✔✔✔ neutral background ✔✔✔
  - acceptance ✔ accidental hits ✔

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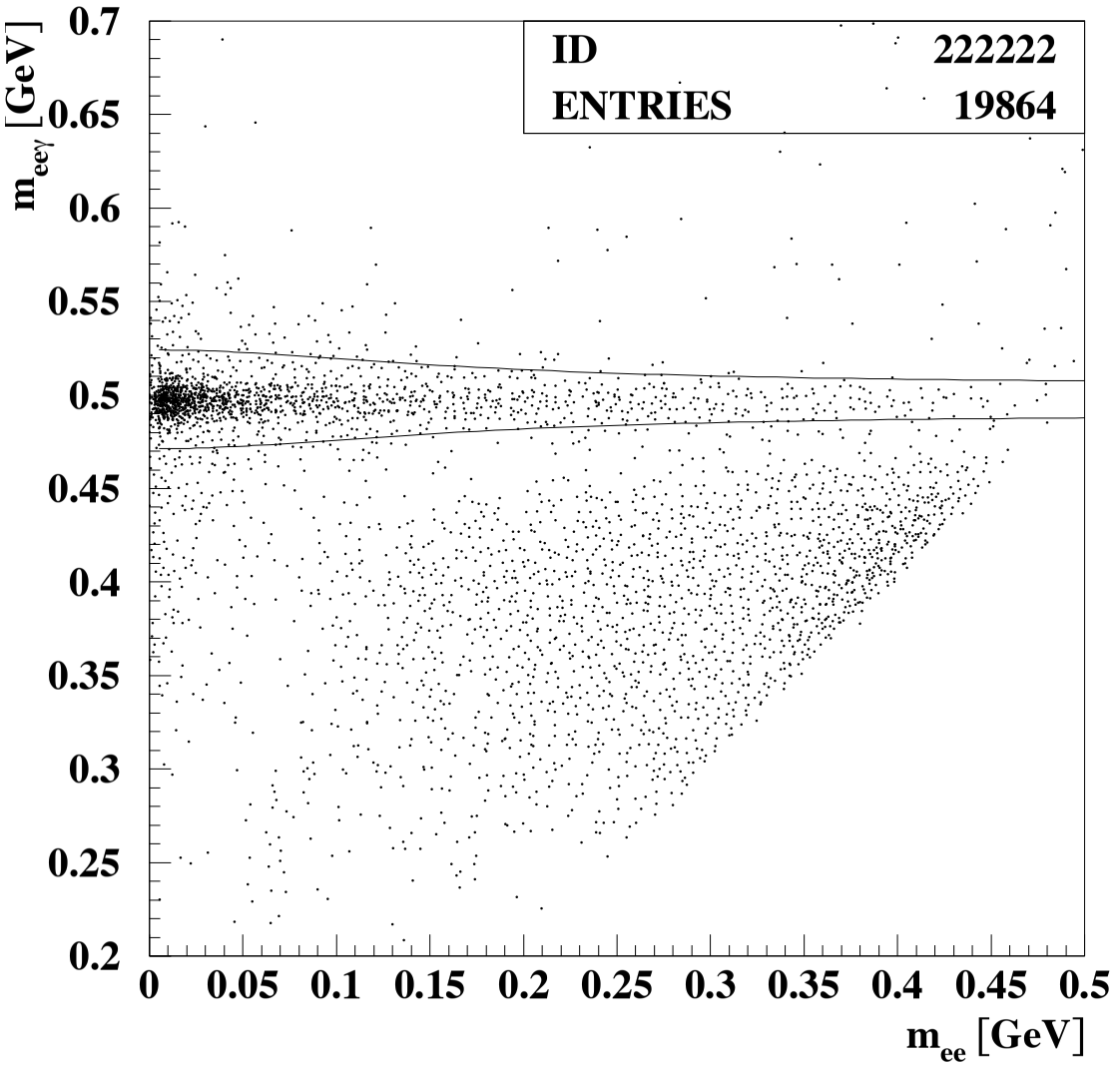
Data '97: $K_L \rightarrow ee\gamma$



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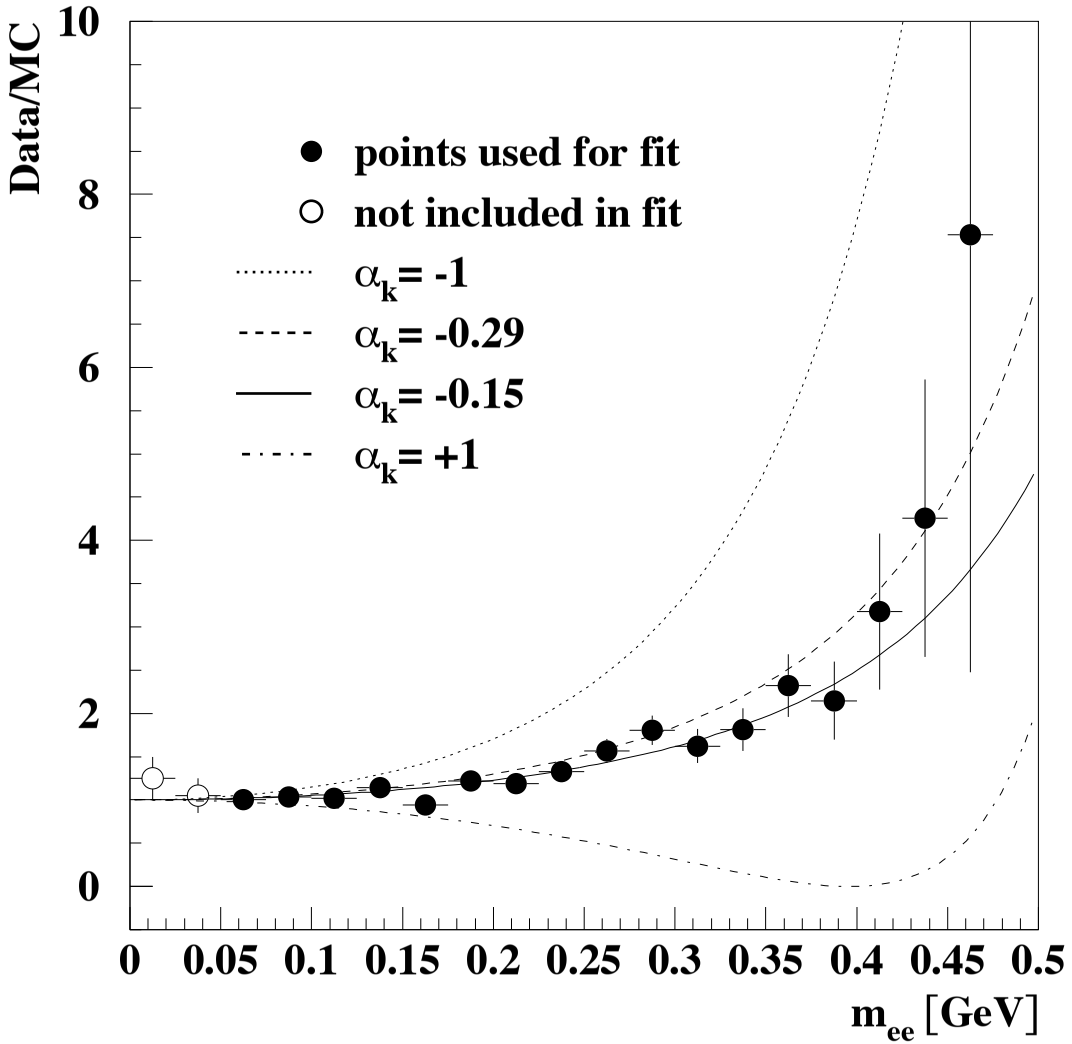
Data '97: $K_L \rightarrow ee\gamma$



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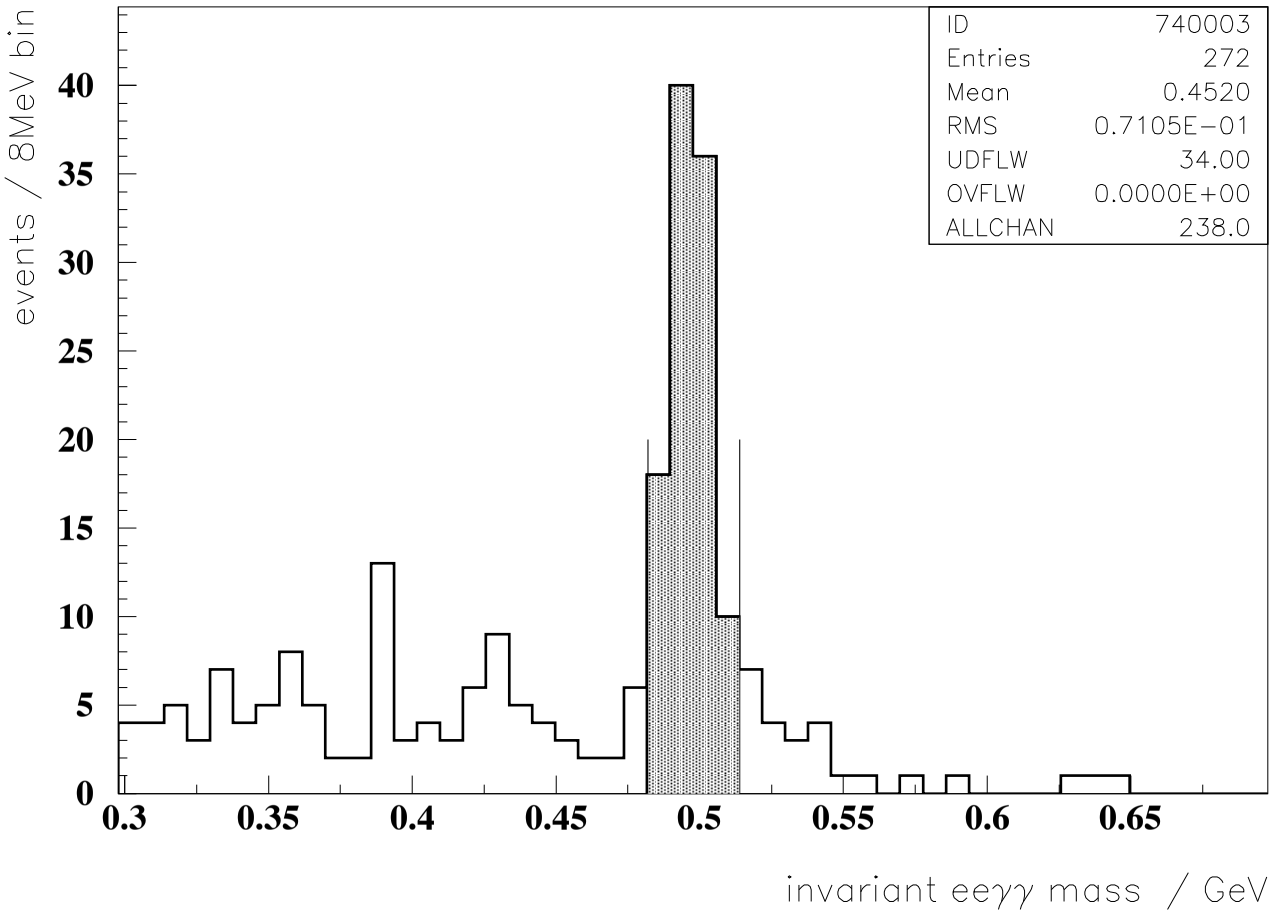
Data '97: $K_L \rightarrow ee\gamma\gamma$



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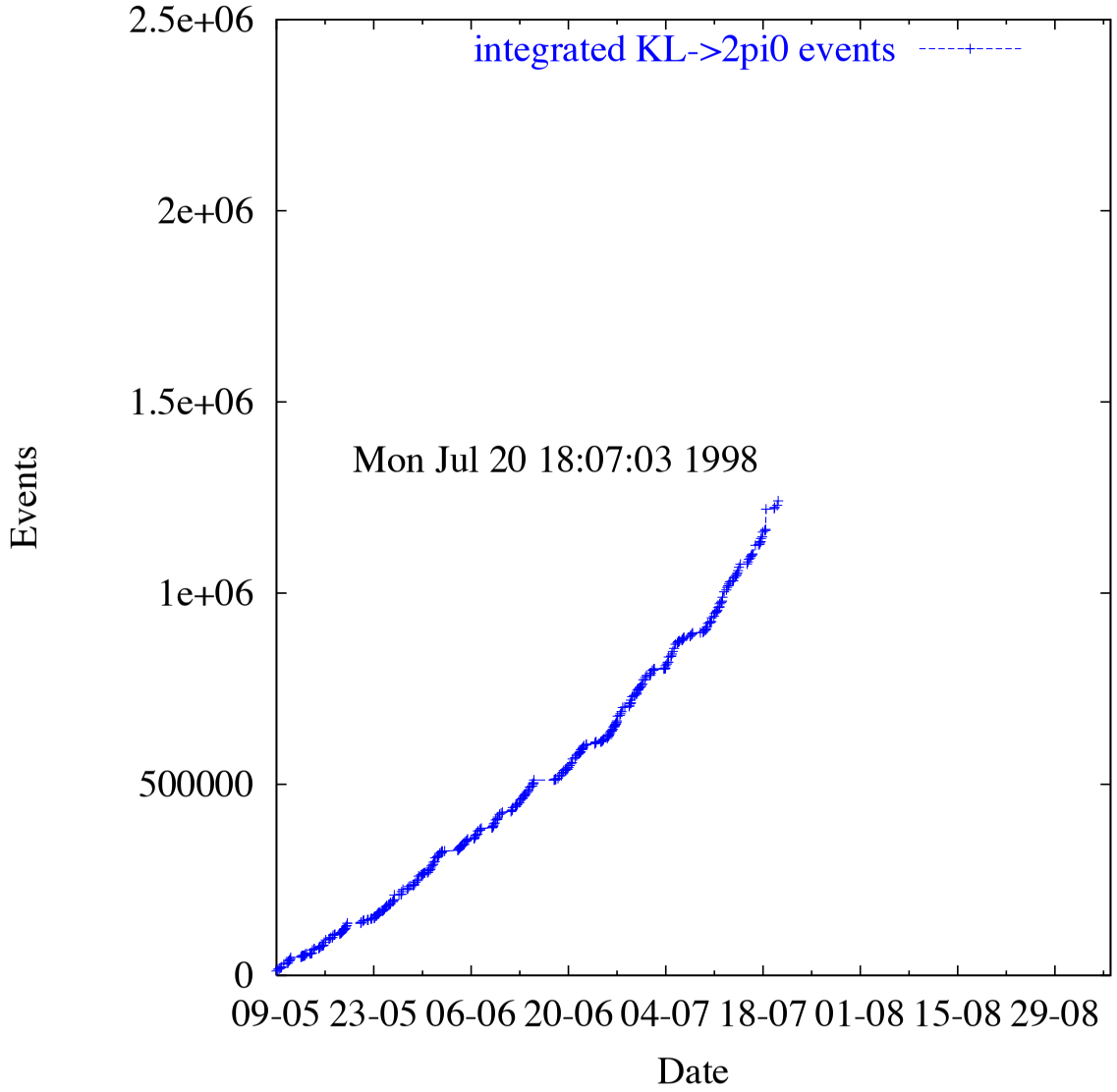
Run'98: upgrades and statistics

- Upgrades:
  - LKr calorimeter repaired successfully, all channels stable at 3 kV
  - faster $K \rightarrow \pi^+\pi^-$ online filter processors
  - data readout & event building by 26-unit 'pc farm'
  - fibre-optical link to computing centre at 20 MB/s sustained
  - carbon-fibre beam pipe
  - +50% beam intensity
- 1,300,000 $K_L \rightarrow 2\pi^0$ as of today
- >2,000,000 expected by 8-Sept-98



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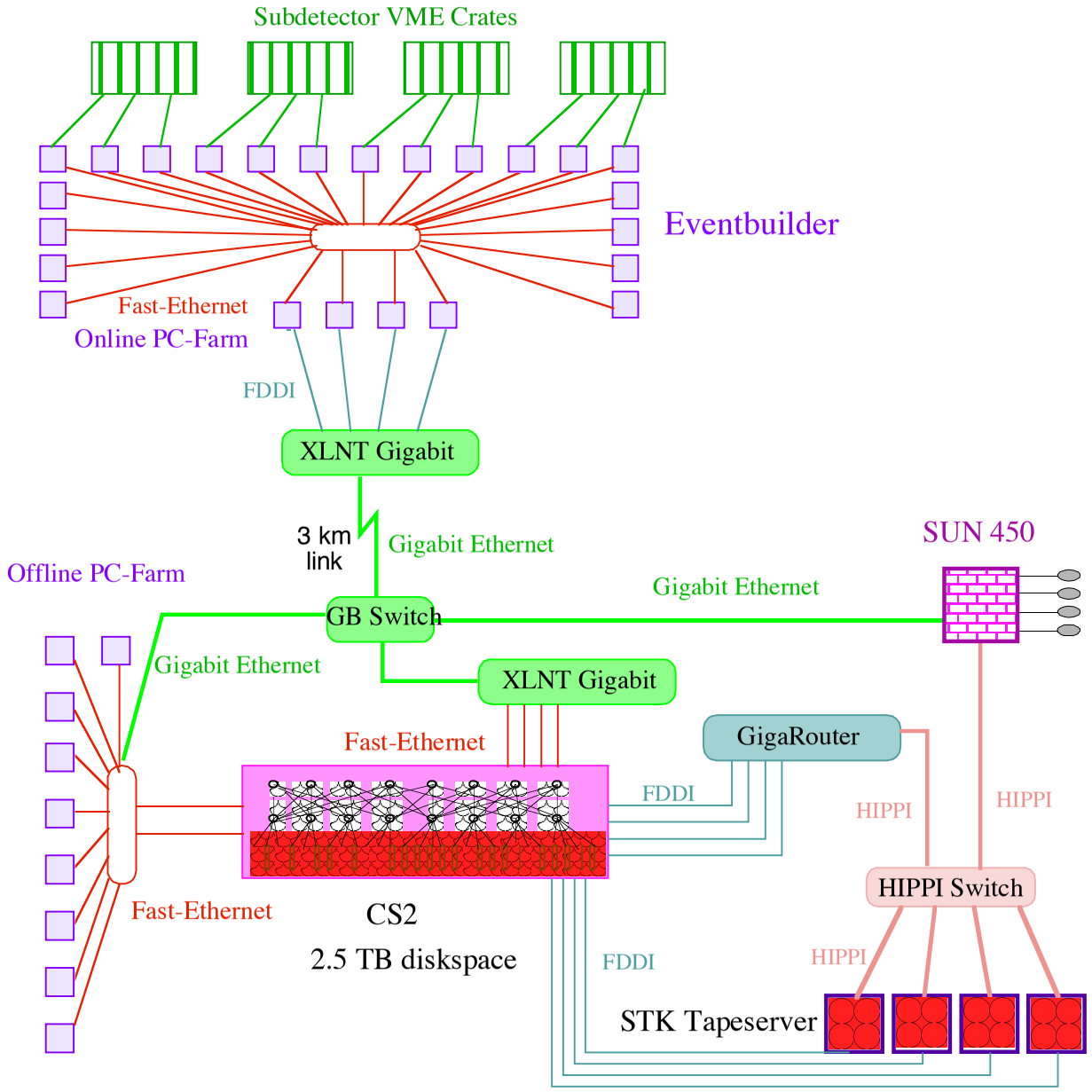
Run '98: Central Data Recording

- Hybrid system
  - Fibre-optical readout of front-end detectors into PCs
  - event building in PC farm
  - fibre-optical link to CERN computer centre
  - CS-2: 128 CPU parallel processors
  - I/O server and CPU server
- Typical burst data size is 250MB in 2.5s, to be recorded in 14s SPS cycle time
- Sustained aggregate throughput 20 MB/s



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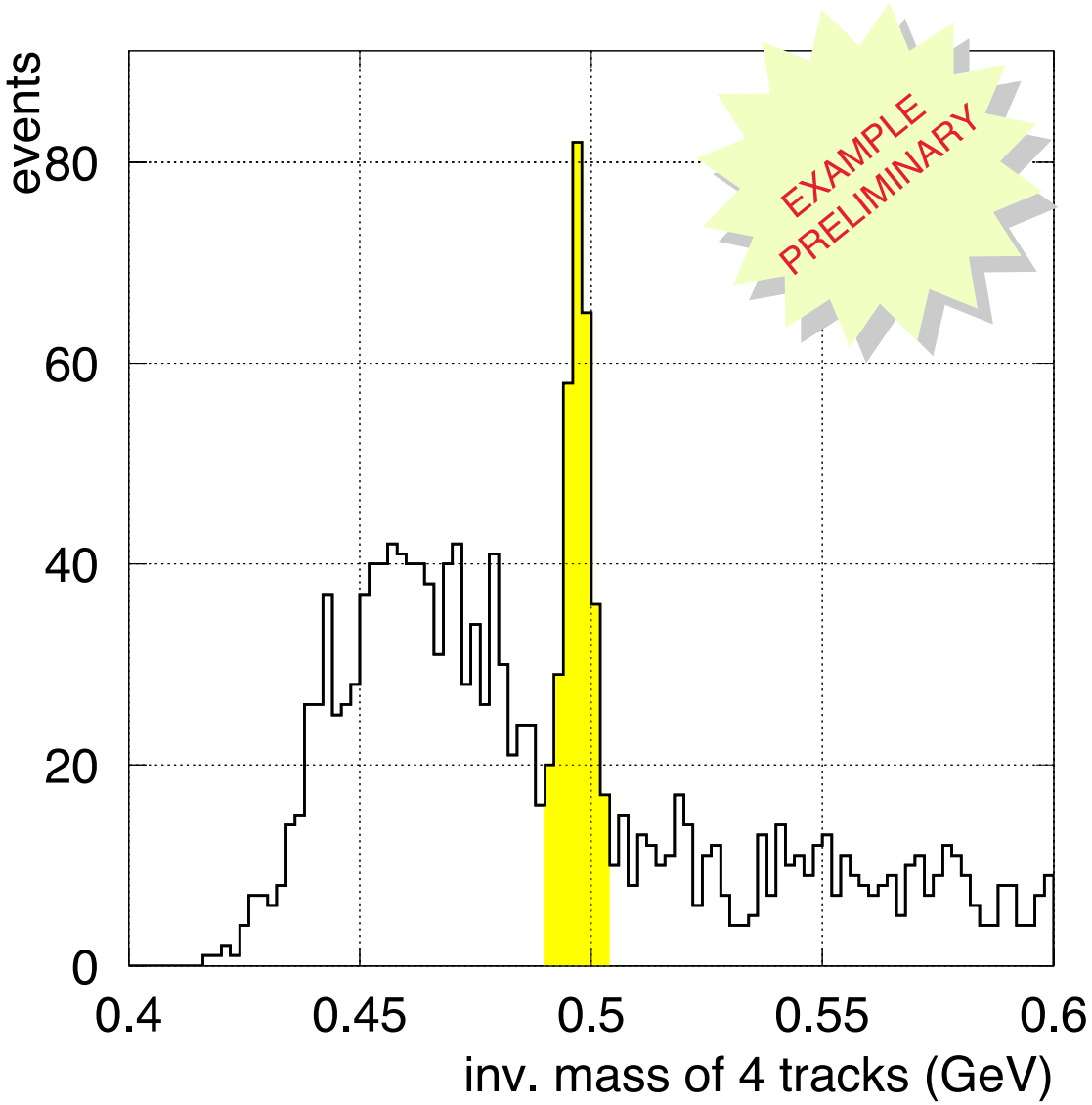
Run'98: $K_L \rightarrow \pi^+\pi^-e^+e^-$



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Summary and outlook

- The NA48 experiment is designed to perform a precision measurement of direct CP-violation with minimal corrections
- 1997 was a good success, first physics data
  - an in-depth analysis has revealed good data quality
- The statistical weight of the '97 data alone is comparable to the entire NA31 result
- We are taking data for >2 million new $K_L \rightarrow 2\pi^0$ events N O W
- Another 130 days of beam are booked for 1999
- We are confident to reach the goal of $\delta(\varepsilon'/\varepsilon) \leq 2 \cdot 10^{-4}$