# NA48/1: High sensitivity investigation of $K_S$ and neutral hyperon decays

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Cambridge, CERN, Chicago, Dubna, Edinburgh, Evanston, Ferrara, Firenze, Mainz, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Wien

Northwestern University (Evanston, IL) and
University of Chicago (Chicago, IL) are new Collaborating Institutes

- 87 Physicists and
- 17 PhD students

# NA48/1

- Unique Opportunity
  - Use NA48 detectors with modified beam line and upgraded read-out systems
  - More than 50 times the $K_S$ world statistics
- Proposal: December 1999; $3 \times 10^{10}$ $K_S$ (120 SPS days)
- Phase I: approved March, 2000
  - Run 45 days during the Y2K SPS run
  - Final states with only photons (charged spectrometer not available)
- Phase II: approved November 2000
  - Approved to significantly exceed proposal (e.g. $\times$ 2)
  - Took data during the SPS 2002 run

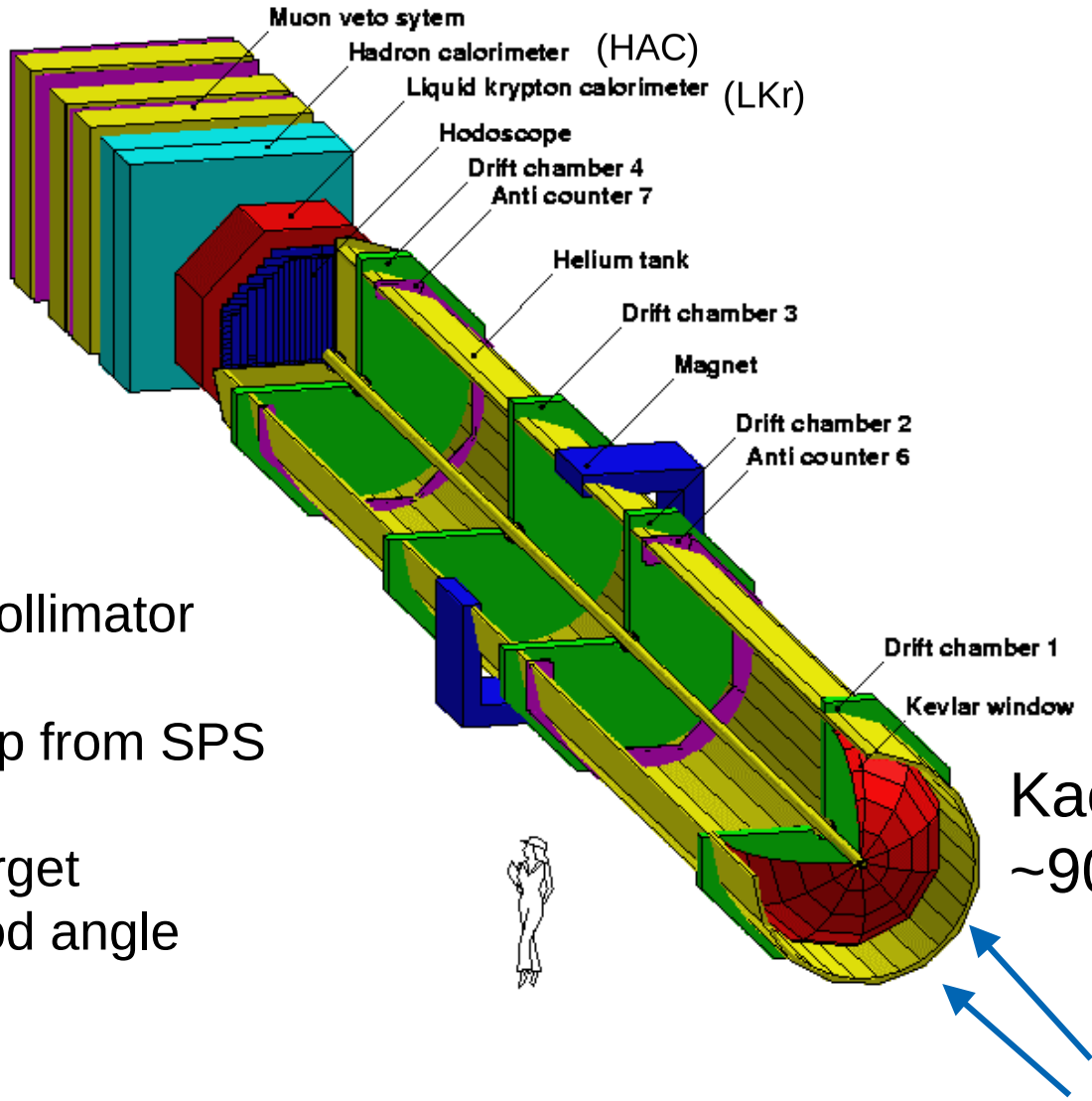
# NA48/1: $K_S$ Physics

| $K_S$ Decay Mode | PDG 2002 | Theory | NA48/1 expected (stat err)<br>Measured |
|---|---|---|---|
| Constraint the Indirect CP-Violation in $K_L$ Rare decays | | | |
| BR($K_S \to \pi^0 e^+ e^-$)x$10^{10}$ | <1400 NA48/1 test | 1-100 | ~4 (SES) |
| BR($K_S \to \pi^0 \mu^+ \mu^-$)x$10^{10}$ | - | 1-100 | ~ 2 (SES) |
| CP Violation, Test of CPT | | | |
| $3\pi^0$, Im($\eta_{000}$)x$10^2$<br>Im $\delta \times 10^5$ | -5 ± 12<br>-2.4 ± 5.0 | ~0<br>~0 | ± 1 (Y2K)<br>± 3 (Y2K) |
| $\pi^+\pi^-\pi^0$, Im $\eta_{+-0} \times 10^3$<br>CPC Re $\lambda \times 10^3$, Im $\lambda \times 10^3$ | -2 ± 9<br>28 ± 9, -10 ± 8 | ~0<br>- | ± 5<br>± 4, ± 4 |
| Ke3, BR $\times 10^4$<br>Re $\delta \times 10^4$ | 7.2 ± 1.4<br>~3 | -<br>0 | ± 0.1<br>- |
| $\pi^+\pi^-e^+e^-$ BR $\times 10^5$ asym.(%) | 4.5 ± 0.8 NA48 | -,~0 | ± 0.04, 0.2 |
| Chiral Perturbation theory | | | |
| BR($K_S \to \gamma\gamma$)x$10^6$<br>BR($K_S \to ee\gamma$)x$10^8$<br>BR($K_S \to \pi^0\gamma\gamma$)x$10^8$<br>BR($K_S \to \pi^0\pi^0\gamma\gamma$)x$10^9$ | 2.5 ± 0.4NA48/1 test<br>-<br>-<br>- | 2.1 O(p4)<br>3.4<br>3.8<br>5.0 | 2.78 ± 0.07(Y2K)<br>± 0.2<br>± 2 (Y2K)<br>1 (SES) |

# NA48/1: Neutral Hyperons

| Decay Model | PDG 2002 |
|---|---|
| β Decays ($V_{us}$) | |
| BR($\Xi^0 \to \Sigma^+ e^- \nu$)x$10^4$<br>g1/f1 | 2.7 ± 0.4 (KTeV, 187 evt.)<br>$1.27^{+0.21}_{-0.17}$ ± 0.05 (KTeV,487 evt) |
| BR($\Xi^0 \to \Sigma^+ \mu^- \nu$)x$10^4$ | <11 CL=90% |
| BR($\Lambda \to p e^- \nu$)x$10^4$ | 8.32± 0.14 |
| BR($\Lambda \to p \mu^- \nu$)x$10^4$ | 1.57 ± 0.35 (14 evt) |
| Radiative decays | |
| BR($\Xi^0 \to \Sigma^0 \gamma$)x$10^3$<br>BR($\Xi^0 \to \Lambda \gamma$)x$10^3$ | 3.33± 0.10<br>1.18± 0.30 |
| $\|\Delta S\| = 2$ | |
| BR($\Xi^0 \to p \pi^-$)x$10^5$ | <4 CL=90% |

# Detector




40 KHz $K_S$
6.2 m long collimator

~5 $\times$ $10^{10}$ ppp from SPS
400 GeV
40 cm Be target
4.2 mrad prod angle

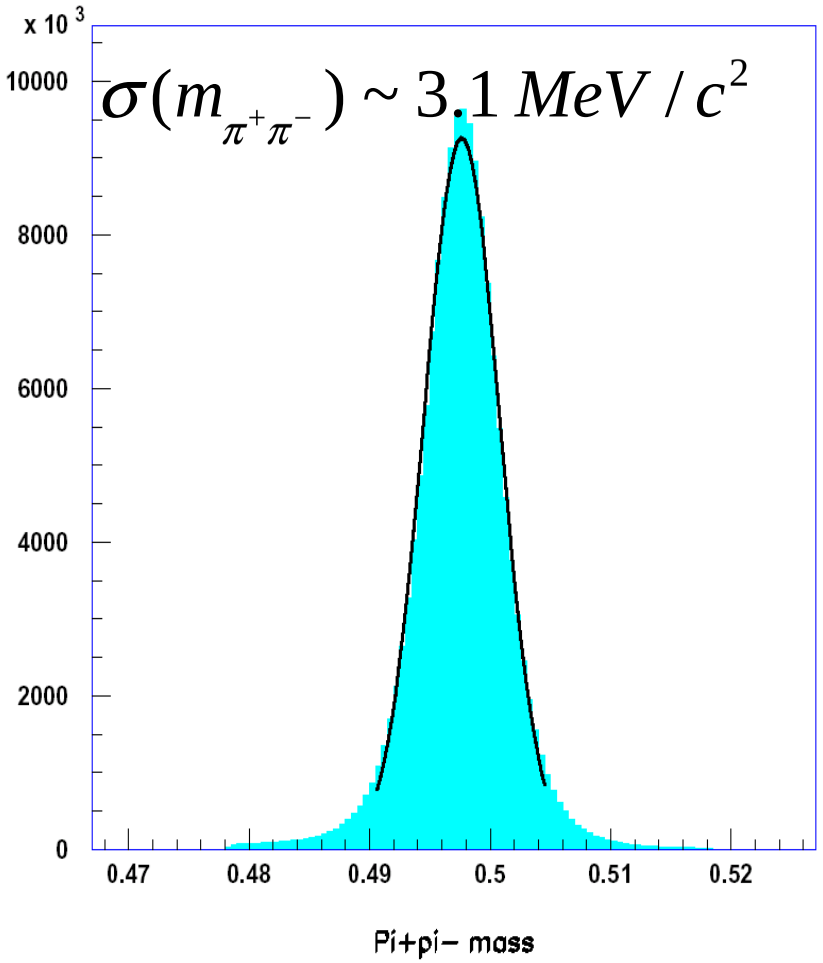
Kaons decay
~90m upstream

# RUN 2002

- Beam and Detectors
  - Added a photon converter downstream of Be target and a sweeping magnet after the defining collimator (× ~1.3)
  - Lowered drift chamber High Voltage by 50V (×~1.5)

    Trigger and read-out must match the flux that the detector can stand
- Trigger
  - Included photon vetoes in pre-trigger
  - Improved purity of hyperon triggers
  - Active Level III trigger (120 TB → 40 TB)
- Read-out
  - New drift chamber read-out
    - Removal of the dead time due to read out overflow (~30%)
  - Upgrade of the HAC read-out
  - Upgrade of LKr read-out (super-event r/o)
    - 30k → 50k event/burst (can take $K_S$, hyperons & control triggers!)

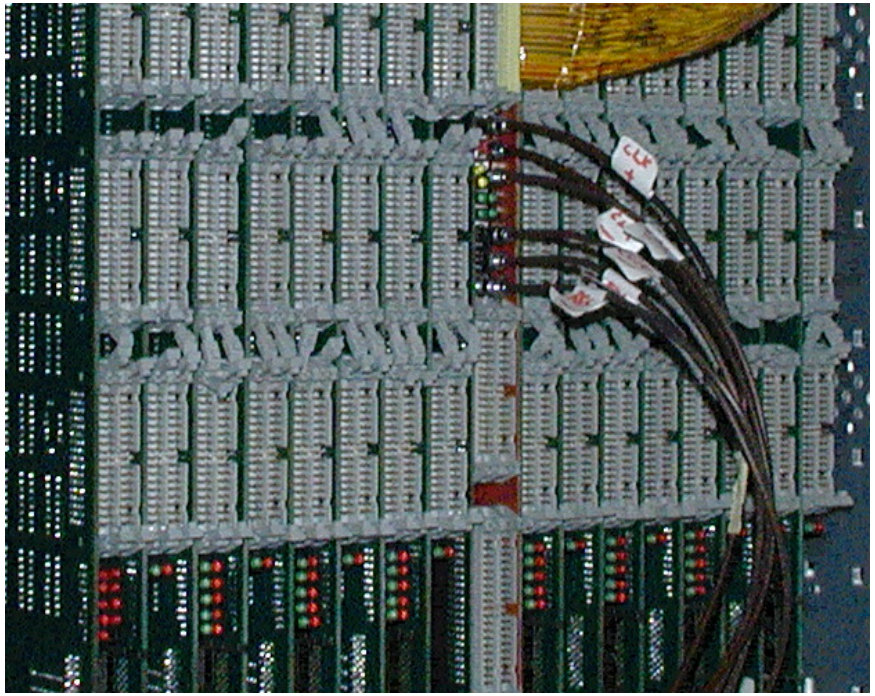
# Performance of the Spectrometer




- HV=2200 V (Ar 50%, Ethane 50%)
  - 2300 V during the ε'/ε era
  - 2250 V during the 2001 $K_S$ tests
- $\pi^+\pi^-$ mass resolution worsens from 2.5 to 3.1 MeV/$c^2$
- Good enough for rare decays
- Stable throughout the run

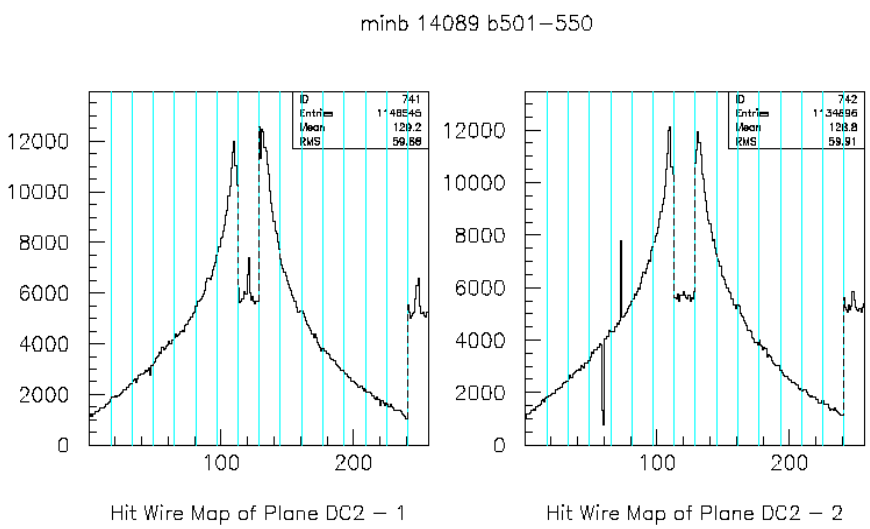
# New Drift chamber Read-out

- Designed around the F1 TDC chip
- Prototypes were beam tested in 2001
- For our application, the production TDC needed beam tuning
- The two lost weeks were compensated by 8 day extension of the SPS proton run



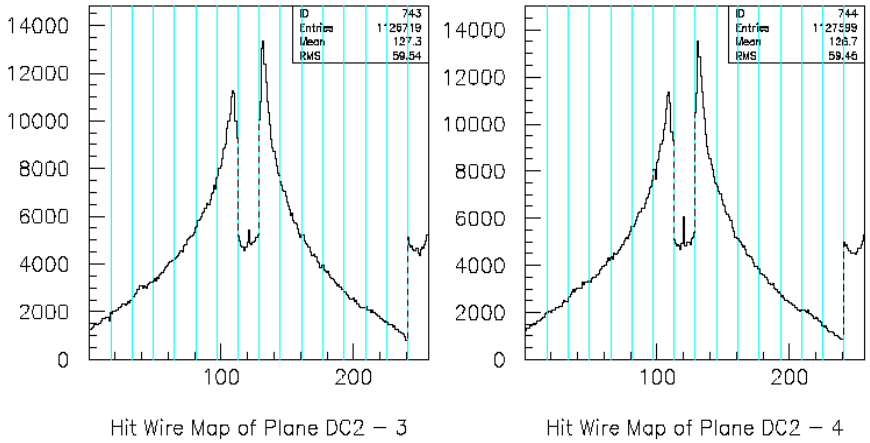
The new read out was instrumental to run at higher intensity

# Efficiency of drift chambers



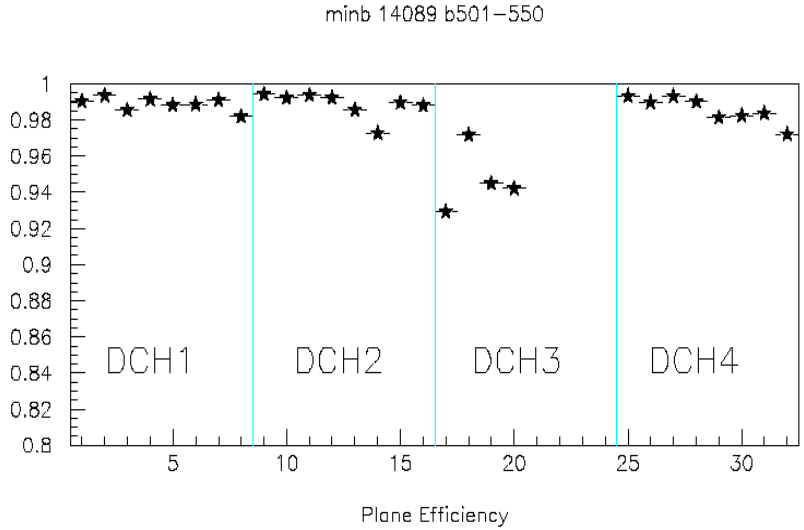


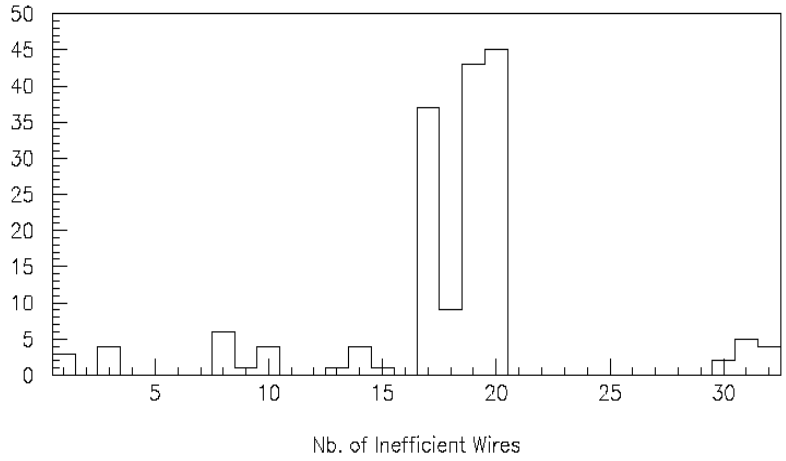






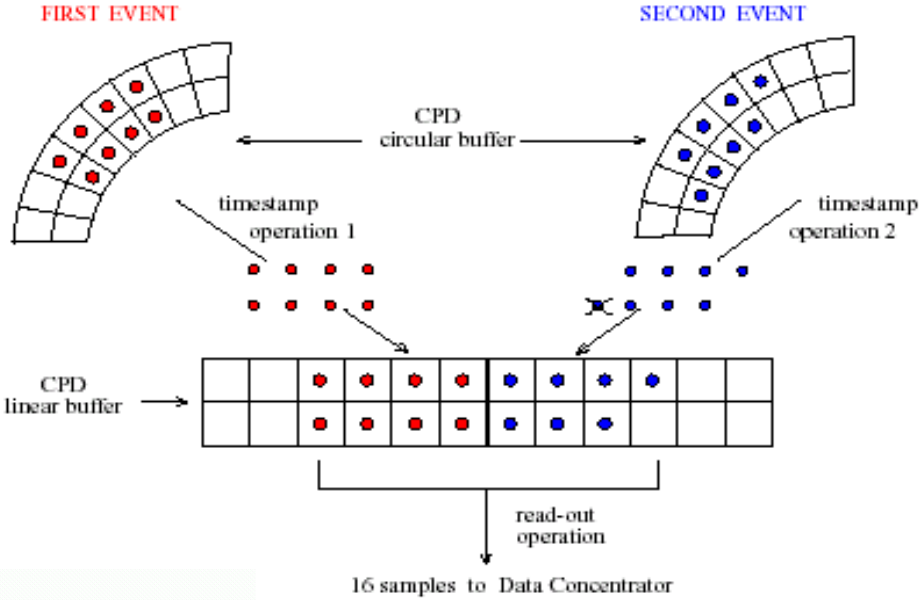


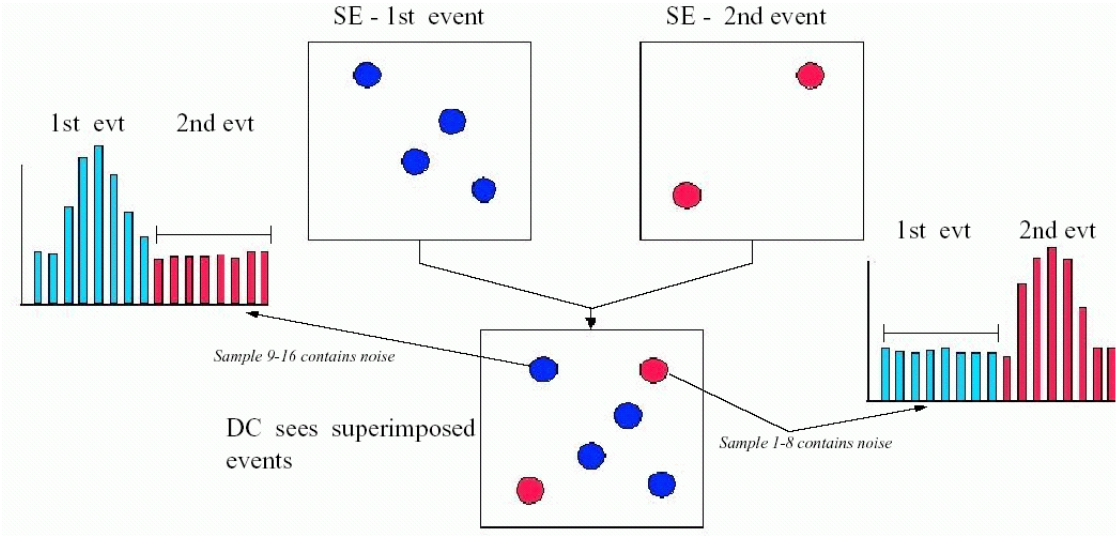


# Upgrade of the LKr read out

Bottle neck was the Data Concentrator (DC) clock

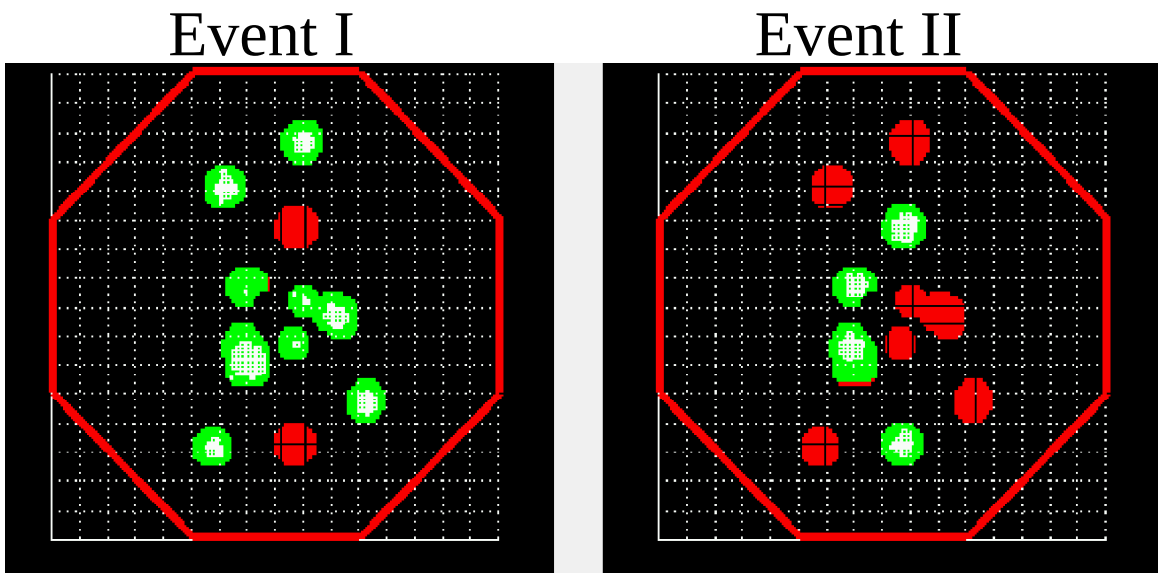


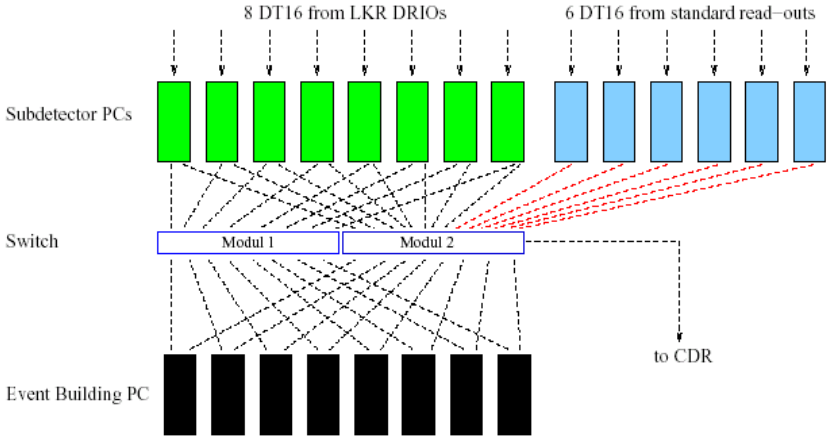




The bottle neck is bypassed
reading out two events as one

# LKr Super-Event (S-E) read out

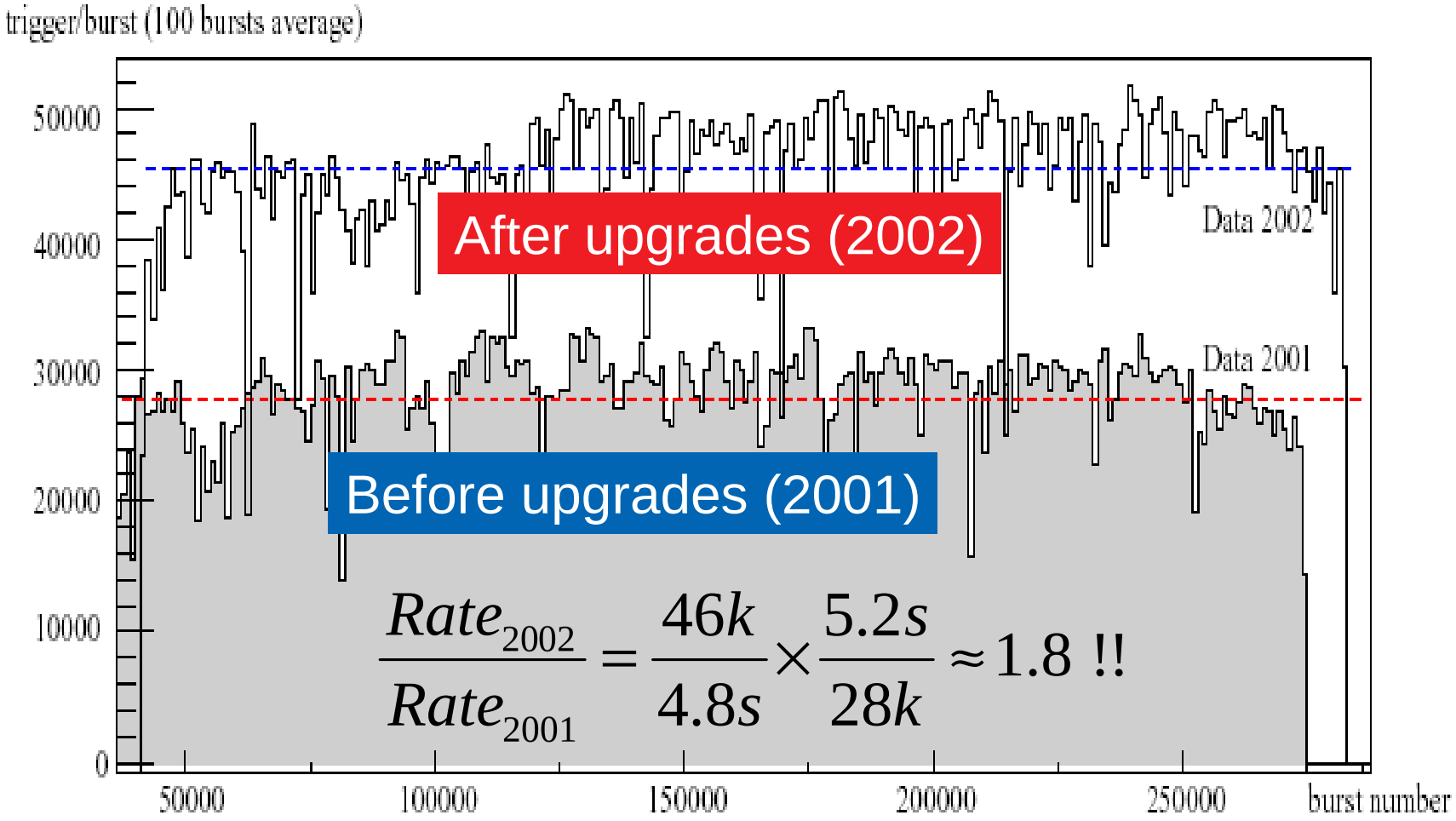
Dummy clusters created by S-E are passed to the event building PC farm




The PC farm performs the 2nd level zero suppression to remove the dummies: 40% reduction of data volume

# Improvement w.r.t. NA48



# RUN 2002: Schedule

**15-Oct-2002** — **2002 SPS Fixed Target Programme** — **Version 3.7**

Colour code: dark blue (dark shading) = not yet allocated ; yellow (light shading) = not allocatable or Machine Development

| | | P1A | P1B | P2A | P2B | P2C | | P3A |
|---|---|---|---|---|---|---|---|---|
| | | 23<br>27 May<br>19 Jun | 28<br>19 Jun<br>17 Jul | 28<br>17 Jul<br>14 Aug | 28<br>14 Aug<br>11 Sep | 7<br>11 Sep<br>18 Sep | | 10<br>9 Oct<br>19 Oct |
| T1 -X5 | SPS Setup 7 | CMOS 9 · ALICE SDD 14 | CMS ECAL 4 · ALICE Lumi 9 · TOTEM 7 · CMS ECAL 7 | 13 · CMS ECAL 5 · 2 · WCAL 7 | CMS Track 6 · TOTEM 13 · CMS Track 8 | 1 · 3 · 2 | Pb Setup 12 | |
| T1 -GIF | SPS Setup 7 | ATLAS MDT 7 · ALI MuonTr 9 · LHCb MUON 6 | CMS ECAL 4 · ATLAS TGC 9 · ATLAS RPC 7 · CMS ECAL 7 | CMS RPC 6 · LHCb MUON 7 · CMS ECAL 5 · ATLAS CSC 9 | ATLAS RPC 6 · ALI 5 · CMS RPC 7 · CMS DT 9 | 1 · 3 · 2 | Pb Setup 12 | |
| T1 -X7 | SPS Setup 7 | LHCb IT 9 · LHCb VELO 7 · Lb SPD/PS 6 | LHCb ECAL 6 · LHCb HCAL 7 · LHCb ECAL 7 · LHCb VELO 7 | 4 · LHCb HCAL 9 · LHCb ECAL 7 · 7 | LHCb CAL 6 · LHCb IT 7 · LHCb VELO 6 · RD42 8 | LHCb VELO 4 · 2 | Pb Setup 12 | |
| T2 -H2 | SPS Setup 7 | NA49 29 | CMS HCAL 6 · CMS Si/PX 15 | CREAM 6 | CMS-HCAL 55 | | Pb Setup 12 | NA49 9 |
| T2 -H4 | SPS Setup 7 | PAMELA 7 · GLAST 6 | LCal 6 · CALET 7 · ALICE SPD 14 | ACCESS 11 | CMS-ECAL 50 | | Pb Setup 12 | |
| T4 -H6 | SPS Setup 7 | ATLAS EMEC 16 · CERF 6 | ALICE ZDC 13 · KABES 7 · CERF 7 | AMS ECAL 13 · ALICE PHOS 14 | ATL-H/EMEC 34 | | Pb Setup 12 | |
| T4 -H8 | SPS Setup 7 | ATL SCT/PX 10 · ATL Tiles 6 · ATL Pixel 6 | ATL LAr 14 · ATL SCT 6 · ATL Pixel 7 | ATL Tiles 6 · ATL LAr 14 · ATL Muon 7 | ATL Tiles 6 · ATL SCT/PX 7 · ATL TRT 14 | ATLAS 6 | Pb Setup 12 | ALICE Lumi 5 · AMS 4 |
| T4 -P0 | SPS Setup 7 | NA60 23 | NA48/1 89 | | | | Pb Setup 12 | NA60 test 9 |
| T6 -M2 | SPS Setup 7 | | COMPASS 112 | | | | Pb Setup 12 | |

SPS/PS-Coordinator: Michael Hauschild
E-mail: SPS.Coordinator@cern.ch
phone: 73564 (ext. +41 22 767 3564)
mobile: 160143 (ext. +41 79 201 0143)

Heavy Ion running:
Oct 9 - Oct 19: Low energy Pb (30 + 20 GeV/A, 5 + 5 days)

# RUN 2002: Expectation

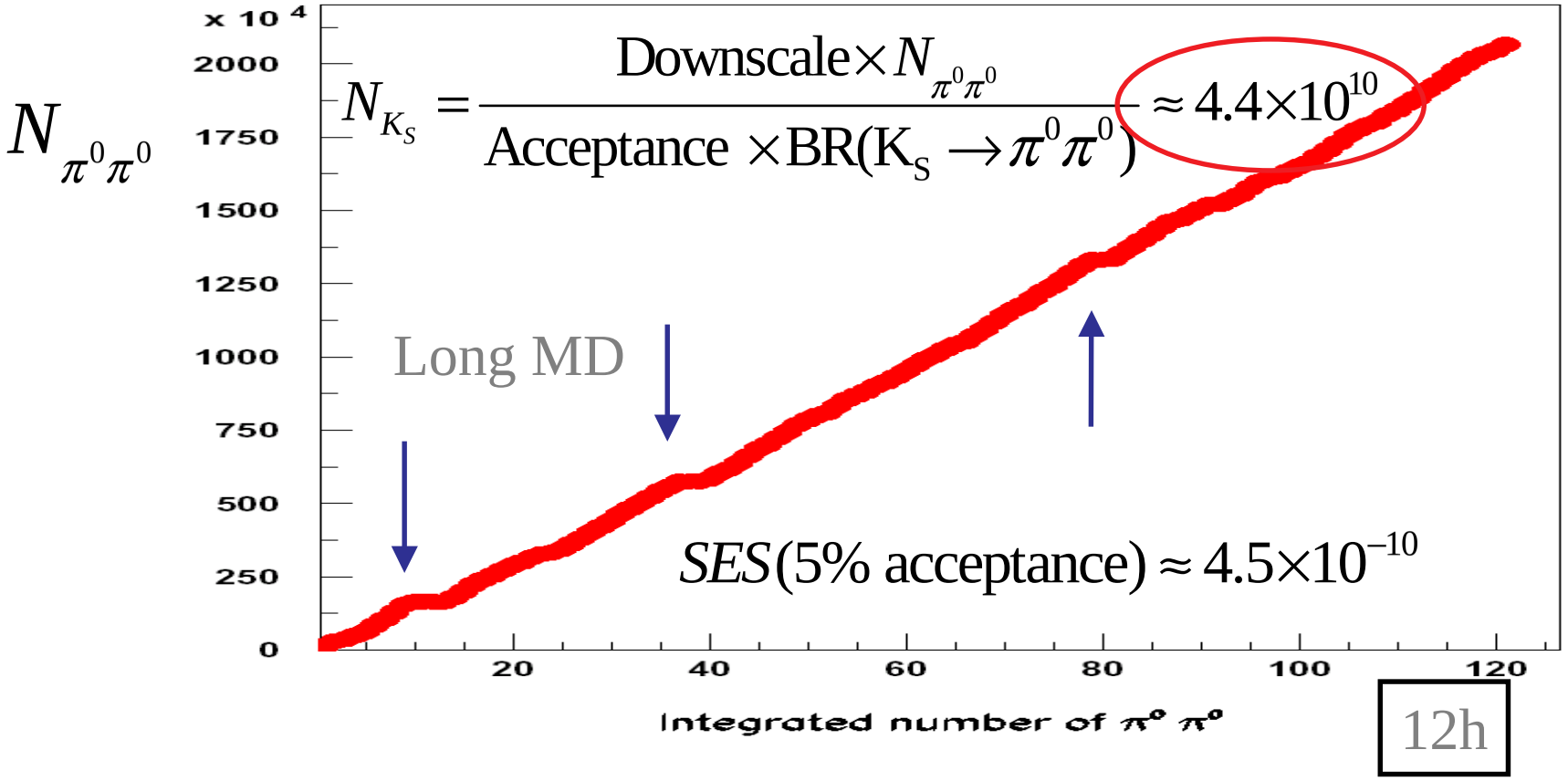
- 89 proton days scheduled, including 8 days extension (105 requested, equiv. to 120 day in proposal)
- SPS Flat top: 4.8 s/16.8 s (instead of 5.2 s as delivered in 2001 and expected)
- 89d/105d $\times$ 4.8s/5.2s = 78%
- Expectation:

  78% $\times$ proposal flux $\times$ 2 ~ 4.7 $10^{10}$ $K_S$

  (40-240 GeV)

# RUN 2002: Achieved

- Data taken at high intensity ($5\times10^{10}$ ppp) from July 18 onward
- Statistics collected before July 18 is not included in the figure



# RUN 2002: Data quality

- WHAT ABOUT DATA QUALITY?
- In the remaining time we address this point with a few examples
  - $K_S \rightarrow \pi^0 ee$
  - $\Xi^0 \rightarrow \Sigma^+ e^- \nu$
  - $\Xi^0 \rightarrow \Lambda\gamma$, $\Xi^0 \rightarrow \Sigma^0\gamma$

# RUN 2002: main motivation (kaons)

$$K_S \to \pi^0 e^+ e^-$$
$$K_S \to \pi^0 \mu^+ \mu^-$$

**Constrain Indirect CP Violation in $K_L \to \pi^0 ee(\mu\mu)$**

$$B(K_S \to \pi^0 e^+ e^-) \times 10^9 \approx 5.2 a_s^{\,2}$$

×330 lever arm

$$B(K_L \to \pi^0 e^+ e^-)_{CPV} \times 10^{12} \approx 15.3 a_s^{\,2} - 6.8 a_s \frac{\mathrm{Im}(\lambda_t)}{10^{-4}} + 2.8 \left( \frac{\mathrm{Im}(\lambda_t)}{10^{-4}} \right)^2$$

$$\lambda_t = V_{ts}^{*} V_{td}$$

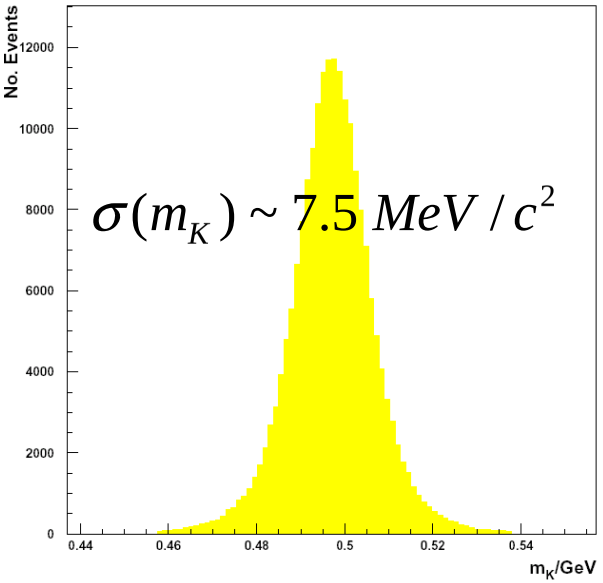
Theory does not usefully constraints $a_S$

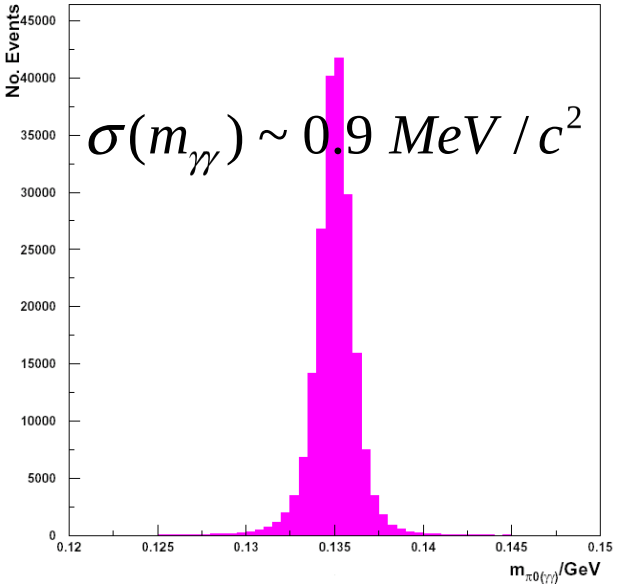
# Mass Resolution

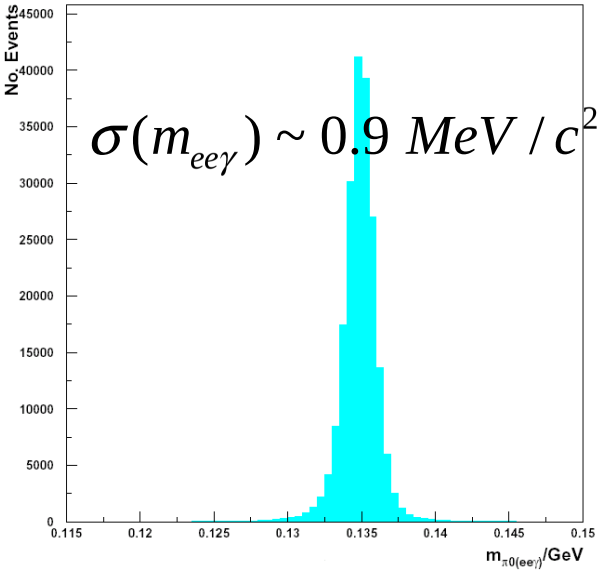
$$K_S \to \pi^0\pi^0_D \to ee\gamma$$
$$\downarrow$$
$$\gamma\ \gamma$$

This reaction represents well $K_S \to \pi^0 ee$ :

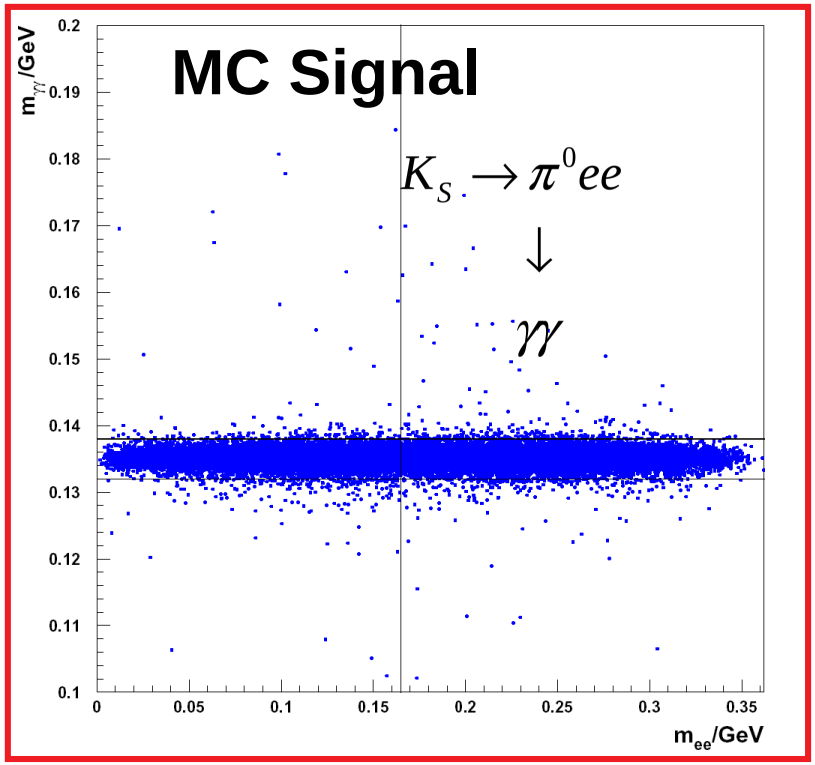
- 2e and photons
- same trigger

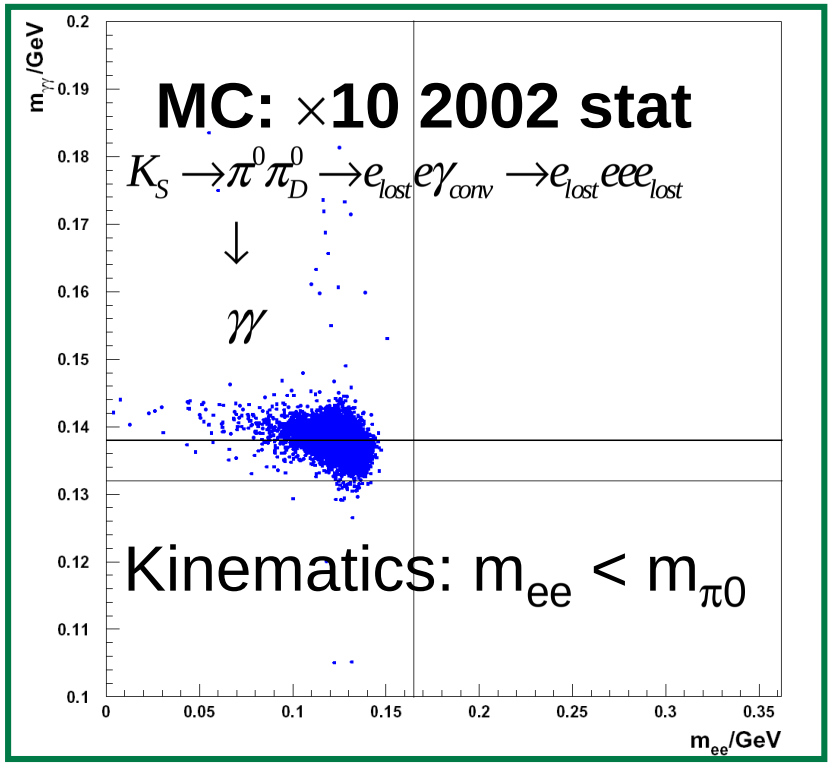


# Background studies: Examples



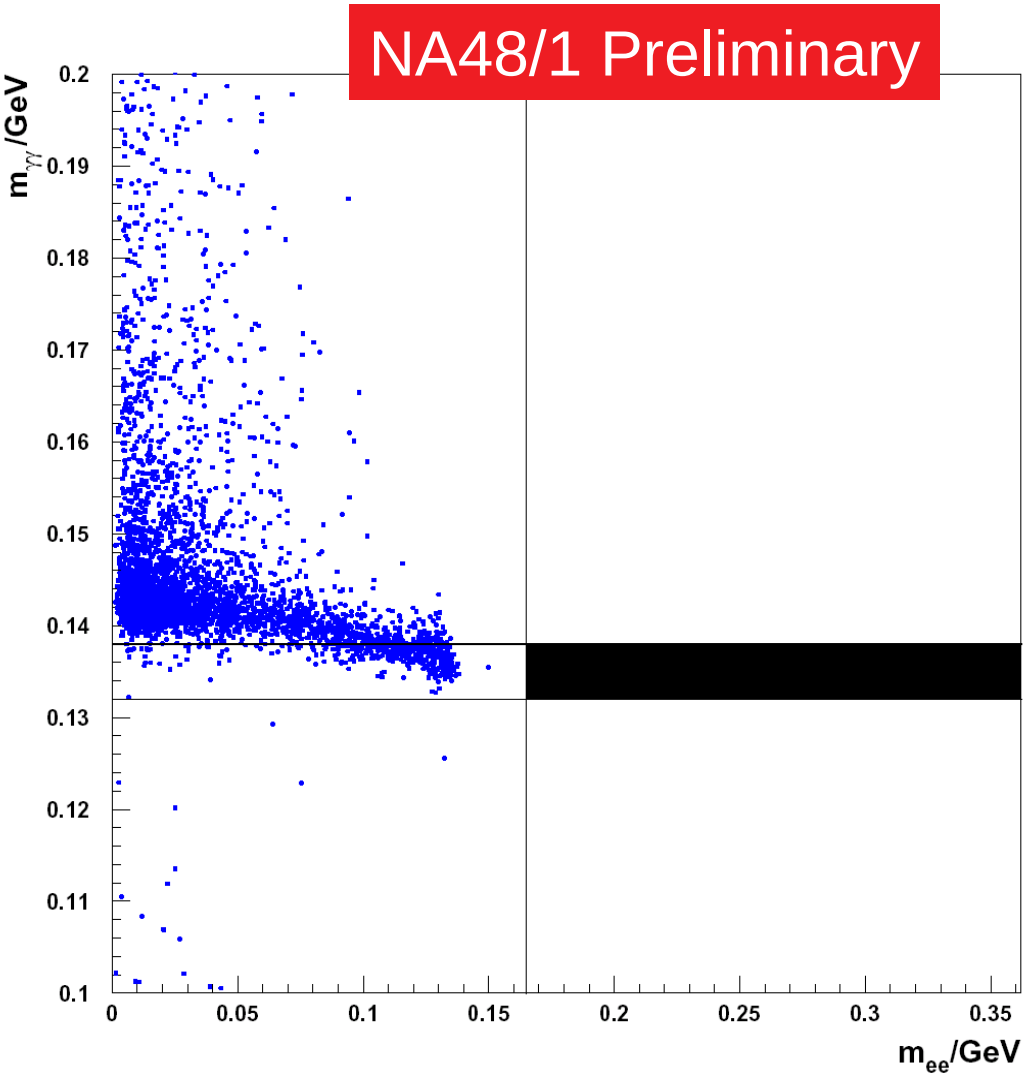

$K_S \to \pi^0_D \pi^0_D \to e_{lost} e\gamma$

$\downarrow$

$ee_{lost}\gamma$

Rejected by a $m_{e\gamma}$ $m_{e\gamma}$ cut around $m_{\pi 0}$

# Search for $K_S \rightarrow \pi^0 e^+e^-$



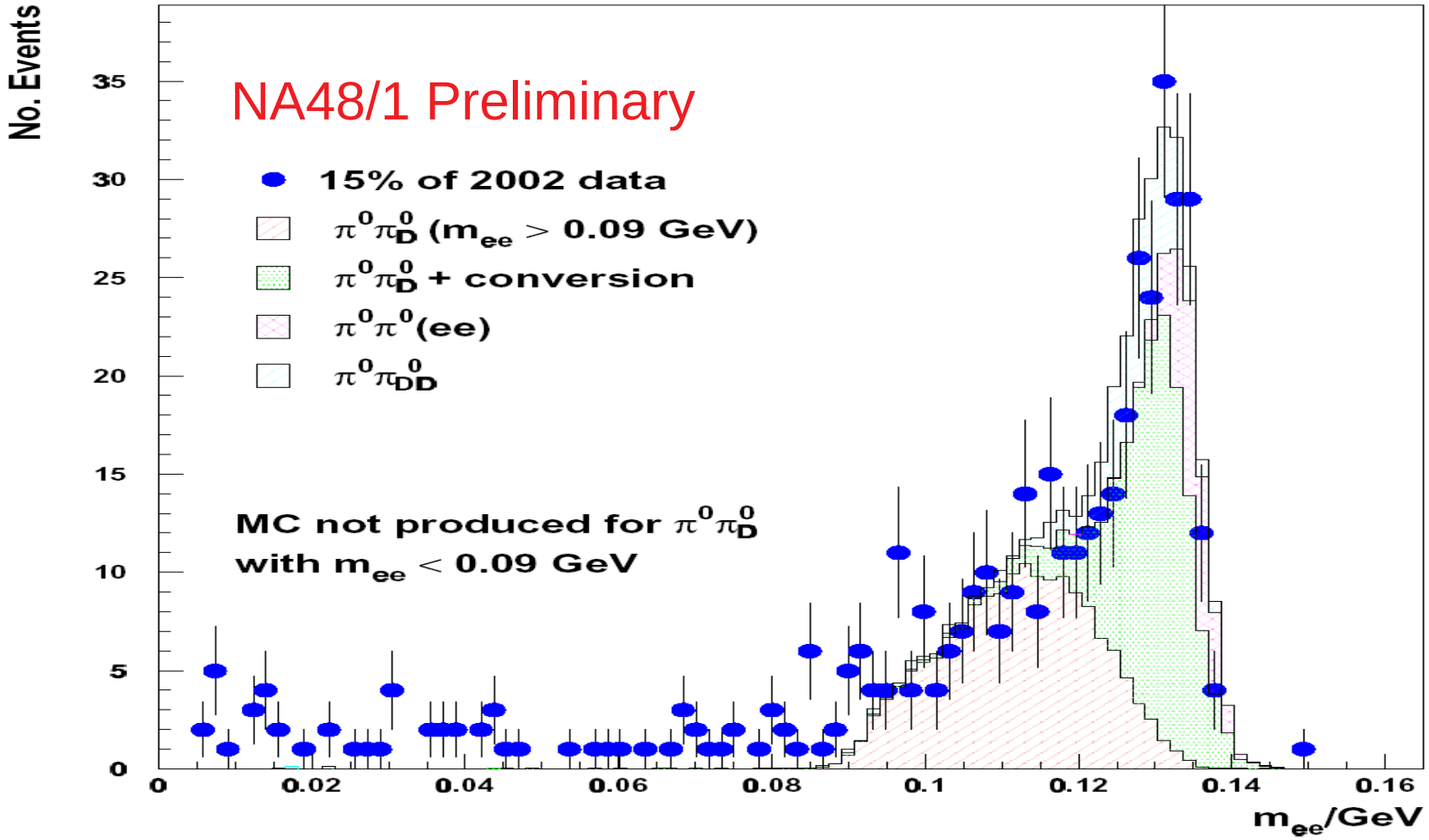

~15% 2002

Very clean

Signal region (black) and the cuts were defined a priori studying MC and test data

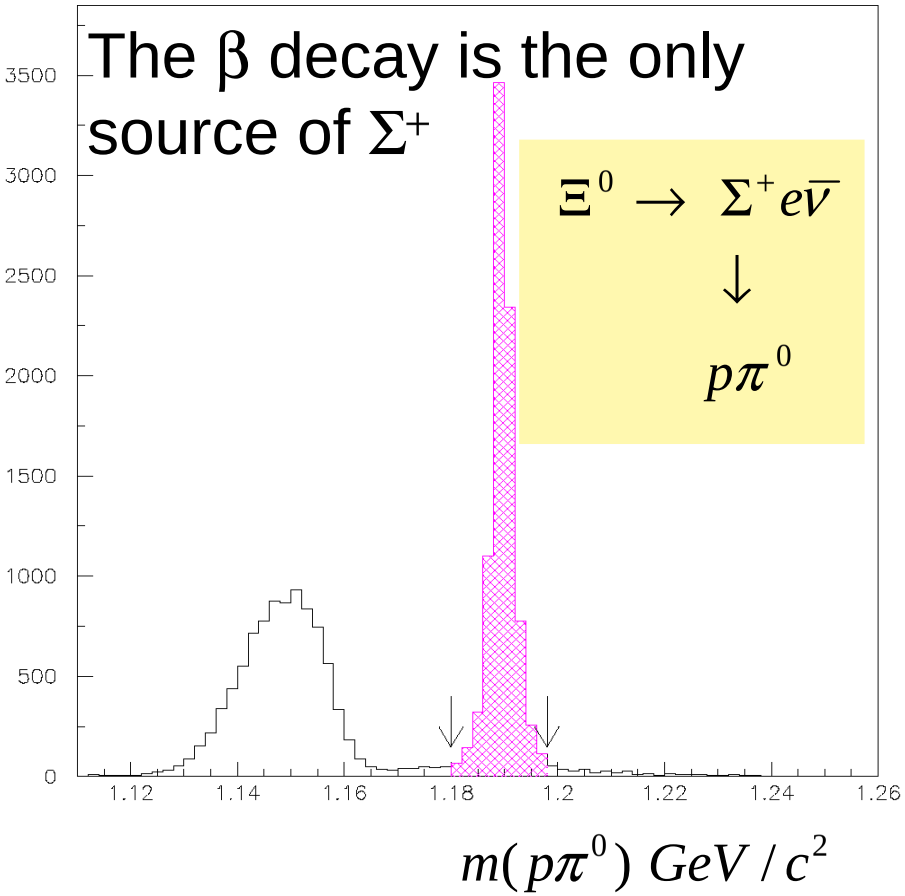
It may still be optimized for the 100% sample

# Data Montecarlo Comparison



# $\Xi^0 \to \Sigma^+ e^- \bar{\nu}$

## NA48/1 2002 Preliminary!




Study of the rate and of the form-factors to extract $V_{us}$

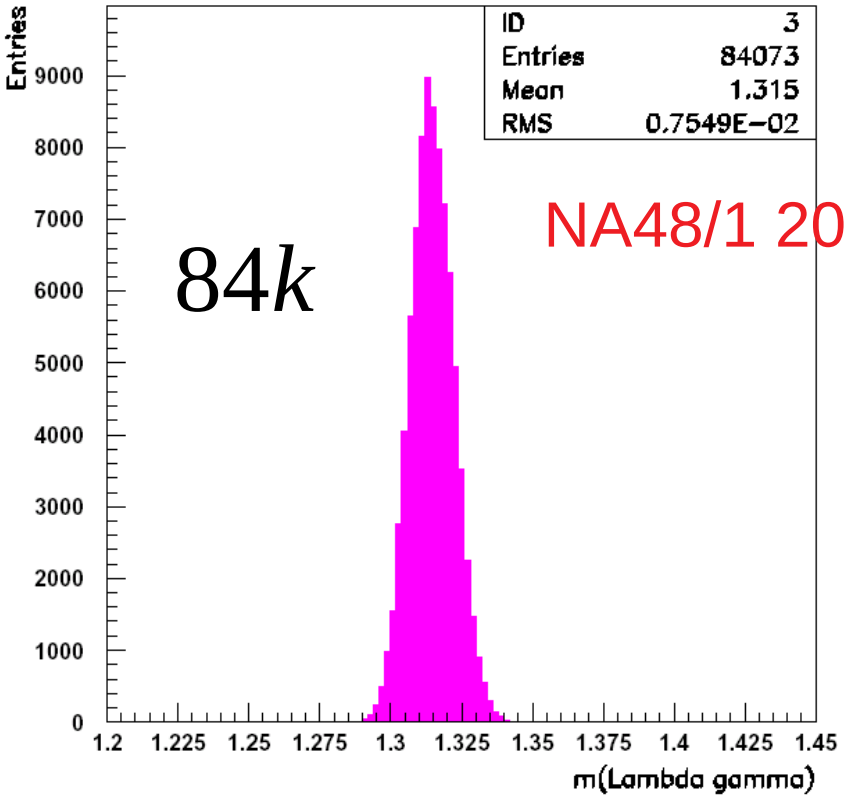
- Run 2002 not optimised for hyperons
- Clean sample, Signal/Back ~ 40
- ~9000 events after cuts
- Too early to predict precision on BR and form factor

Currently published sample:

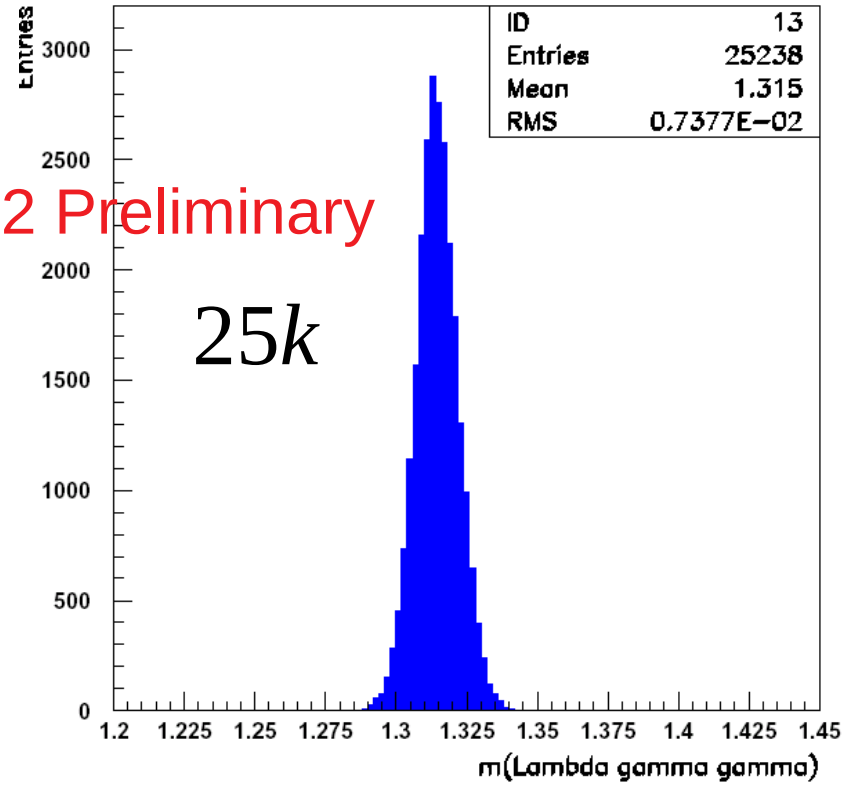
- Rate: 187 events (KTev)
- Form factor: 487 events (KTeV)

# $\Xi^0$ Radiative decays

Trigger downscale=4



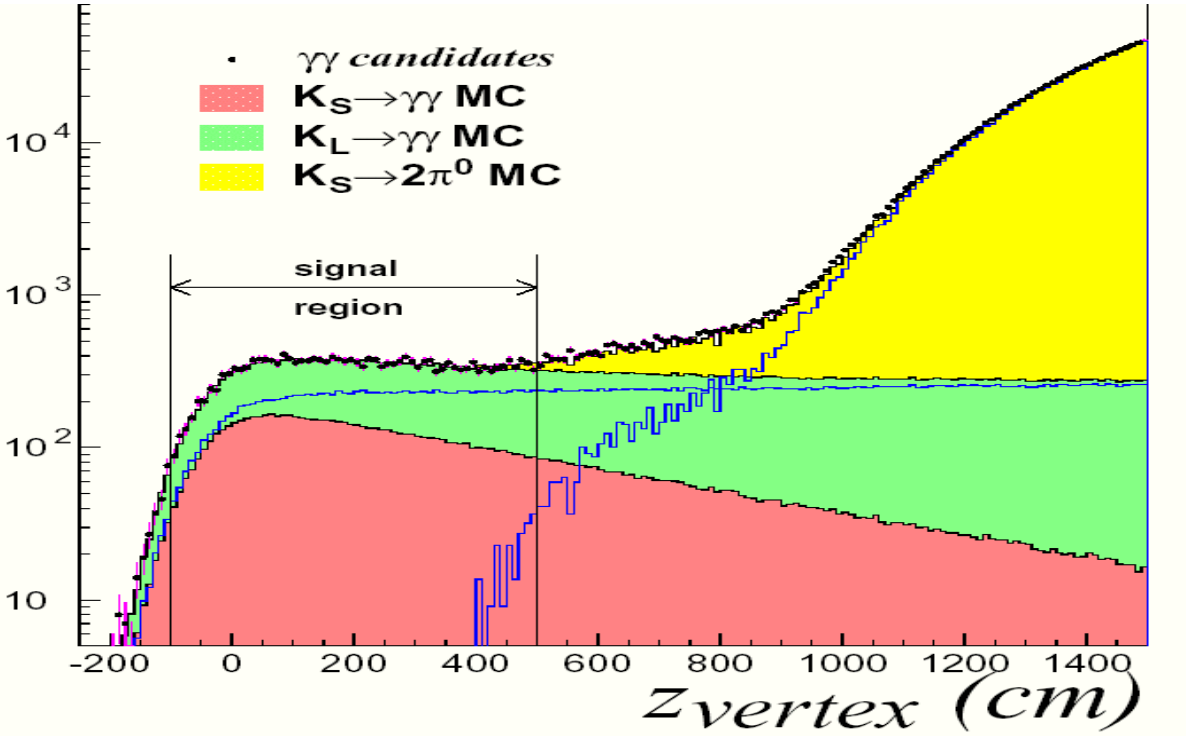

NA48/1 2002 Preliminary




$\Xi^0 \to \Lambda\gamma$

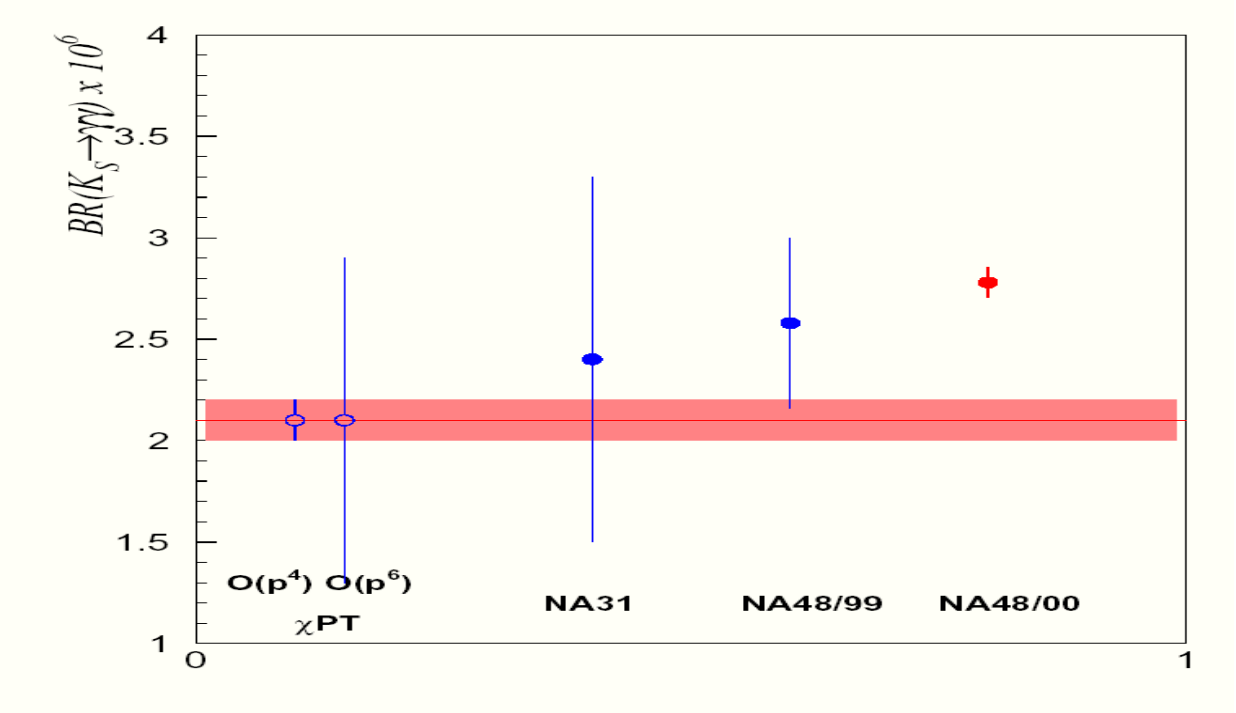
$\Xi^0 \to \Sigma^0\gamma \to (\Lambda\gamma)\gamma$

# Result from the 2000 data: $K_S \rightarrow \gamma\gamma$




- The $K_L \rightarrow \gamma\gamma$ component is precisely subtracted measuring the $K_L$ flux via $3\pi^0$ decays
- We measured the $K_L \rightarrow 2\gamma / K_L \rightarrow 3\pi^0$ ratio using a long neutral beam (Y2K NA48 $K_L$ sample accumulated for $\varepsilon'/\varepsilon$ studies)

# Result from the 2000 data: $K_S \to \gamma\gamma$




$$BR(K_S \to \gamma\gamma) = (2.78 \pm 0.06_{stat} \pm 0.04_{syst}) \times 10^{-6}$$

CERN-EP/2002-074

hep-ex/0210053

# Conclusions and outlook

- The proposed upgrades to the setup have been implemented
  - We increased the read-out rate by about 80% w.r.t NA48
  - The new drift chamber read-out has been commissioned and used
- During 2002 we collected a large sample of $K_S$ and neutral hyperon decays
  - We thank for the excellent performance of the CERN Accelerator Complex and for all the support we received from the CERN Management
- The priority now shifts to data re-processing and analysis
  - Preliminary analysis of the data looks promising
  - SES for $K_S \rightarrow \pi^0 e^+e^-$ seems in line with the expectations
  - Too early to forecast precision on hyperon physics
- The analysis of the Y2K data is advancing well
  - A precise result ($K_S \rightarrow \gamma\gamma$) is being published
  - More results should be available soon