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For ISTRA+ collaboration

Outline

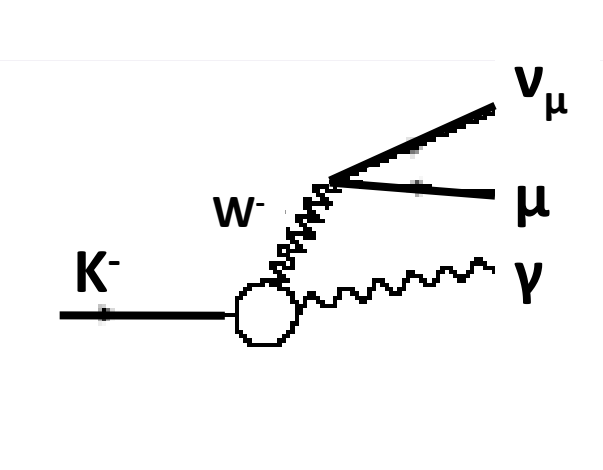
- $K \rightarrow \mu \nu \gamma$ decay
- ISTRA+ experiment
- Event selection
- Spectrum tuning
- Background rejection
- Signal extraction
- Spectrum fitting
- Results
- Conclusions

$K \to \mu \nu \gamma$ decay: introduction

- Motivation
- Differential decay rate
- F_V and F_A theoretical predictions
- Experiments

K→ μ ν γ decay: motivation

photon emitted from the vertex (SD or DE)



Probing electroweak structure of kaon

Testing predictions of ChPT, LFQM, …

K→μνγ theory: differential decay rate

$$\frac{d\Gamma_{K_{\mu\nu\gamma}}}{dxdy} = A_{IB} f_{IB}(x,y) + A_{SD}[(F_V + F_A)^2 f_{SD+}(x,y) + (F_V - F_A)^2 f_{SD-}(x,y)] - A_{INT}[(F_V + F_A) f_{INT+}(x,y) + (F_V - F_A) f_{INT-}(x,y)],$$

3 main terms:
IB – dominant
SD±, INT± - most interesting (→ F_v , F_A)

Kinematical variables:
x=2*E_γ(cm)/M_k
y=2*E_μ(cm)/M_k

$$f_{IB}(x,y) = \left[\frac{1-y+r}{x^2(x+y-1-r)}\right] \times \left[x^2 + 2(1-x)(1-r) - \frac{2xr(1-r)}{x+y-1-r}\right],$$
$$f_{SD+} = [x+y-1-r][(x+y-1)(1-x)-r],$$
$$f_{SD-} = [1-y+r][(1-x)(1-y)+r],$$
$$f_{INT+} = \left[\frac{1-y+r}{x(x+y-1-r)}\right][(1-x)(1-x-y)+r],$$
$$f_{INT-} = \left[\frac{1-y+r}{x(x+y-1-r)}\right][x^2-(1-x)(1-x-y)-r],$$

$$r = \left[\frac{M_\mu}{M_K}\right]^2,$$
$$A_{IB} = \Gamma_{K_{\mu 2}} \frac{\alpha}{2\pi} \frac{1}{(1-r)^2},$$
$$A_{SD} = \Gamma_{K_{\mu 2}} \frac{\alpha}{8\pi} \frac{1}{r(1-r)^2} \left[\frac{M_K}{F_K}\right]^2,$$
$$A_{INT} = \Gamma_{K_{\mu 2}} \frac{\alpha}{2\pi} \frac{1}{(1-r)^2} \frac{M_K}{F_K}.$$

K→μνγ theory: formfactors

ChPT $O(p^4)$	ChPT $O(p^6)$	LFQM
• $F_V + F_A = 0.137$ • $F_V - F_A = 0.055$	• $F_V + F_A = 0.116$ • $F_V - F_A = 0.048$	• $F_V + F_A = 0.142$ • $F_V - F_A = 0.070$

K→μνγ : main experimental results

experiment	collaboration	year	cuts	results
Barmin et al		1988	$P_\mu < 231.5$ MeV/c	BR(IB)
Demidov et al		1990	$P_\mu < 231.5$ MeV/c	BR(IB)
Akiba et al	E104 (KEK)	1985	$214.5 < P_\mu < 231.5$ MeV/c	BR(IB)
Adler et al	E787 (BNL)	2000	$P_\mu > 218.4$ MeV/c $E_\gamma > 90$ MeV	$\lvert F_V + F_A \rvert$, BR(SD+)

Formfactors:

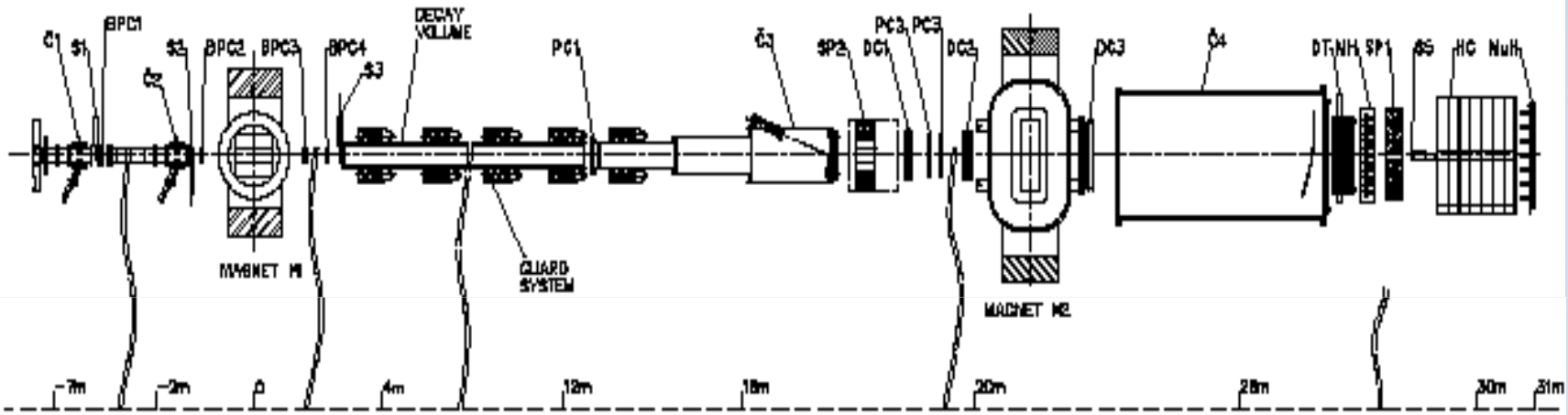
E787(BNL) Phys.Rev.Lett.85(2000)2256 (K→μνγ)

$|F_V+F_A|=0.165 \pm 0.013$; $-0.04<F_V-F_A<0.24$

E865(BNL) Phys.Rev.Lett.89(2002)061803 ($K\to e\nu e^+e^-$, $K\to\mu\nu e^+e^-$)

$F_V+F_A=0.147 \pm 0.026$; $F_V-F_A=0.077 \pm 0.028$

ISTRA+ setup



$p \sim -25$ GeV ; $\Delta p/p \sim 1.5\%$; $K^- \sim 3\%$; $I \sim 3 \cdot 10^6/1.9$ sec

$T_0 = S1 \cdot S2 \cdot S3 \cdot S4 \cdot C0 \cdot C1 \cdot C2 \cdot \overline{S5}$ (prescaled by a factor of ~10)	$T_1 = T_0 \cdot (\Sigma SP1 > MIP)$

C1-C4 – thresh. cherenkov counters; S1-S5 – scintillation counters; PC1-PC3 – proportional chambers; SP2 – veto calorimeter; SP1 – lead-glass calorimeter; DC – drift chambers; DT-drift tubes; MH – matrix scintilation godoscope

ISTRA+: from $\pi \to e \nu \gamma$ to $K \to \mu \nu \gamma$

1990

Study of $\pi \to e \nu \gamma$ decay: measuring F_V, $\gamma = F_V/F_A$, F_T

2003-2007

- High statistics study of the decays $K^- \to e^-(\mu^-)\nu\pi^0$
  K_{e3}: Phys. Lett. B589(2004)111 ; $K_{\mu 3}$: Phys. Lett. B581(2004)31
- Measurement of the Dalitz plot slopes for $K^- \to \pi^-\pi^0\pi^0$
  Phys. Lett. B567(2003)159 .
- Search for light pseudoscalar sgoldstino in $K^- \to \pi^-\pi^0 P$
  Phys.Lett.B602(2004)149-156.
- Precise measurement of Br for $K^- \to e\nu\pi^0$ Preliminary results
- Observation of the decay $K^- \to \mu^-\nu\pi^0\gamma$
- High statistics study of the decay $K^- \to e^-\nu\pi^0\gamma$

2009

Study of $K \to \mu \nu \gamma$ decay: measuring $F_V - F_A$

> 2009

ISTRA+ ⇒ OKA (see talk by Victor Kurshetsov)

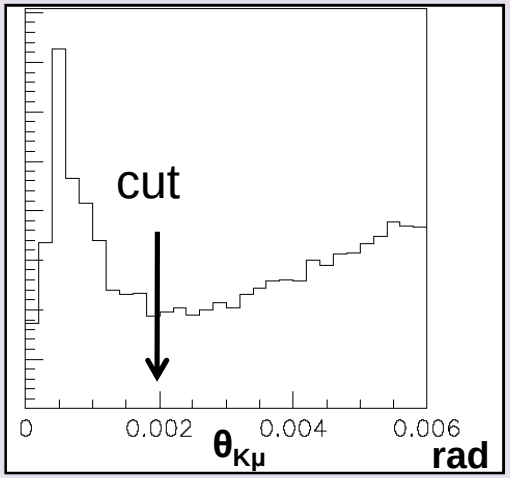
Event selection: strategy

- Track requirements
- Photon requirements
- Vertex requirements
- Particle ID

Event selection: track requirements

- Exactly one beam track in each projection
- Exactly one secondary track in each projection
- Secondary track is negatively charged
- track quality > 10^{-2} for each projection of beam track
- track quality > 0.1 for each projection of secondary track
- Angle between beam and secondary track > 2mrad

(suppression of undecayed particles)

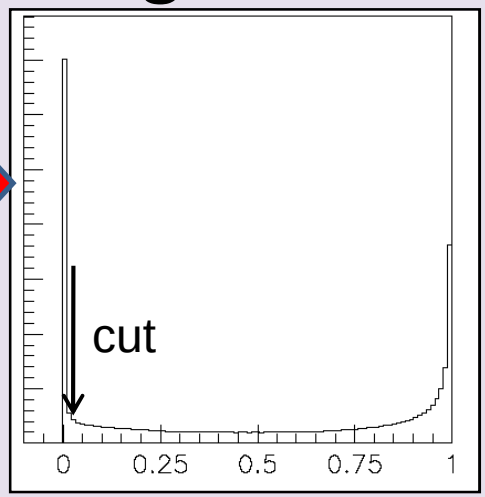


Event selection: photon requirements

- No photons in SP2 guard calorimeter
- No photons in GS

Event selection: vertex requirements

- -3 < x < 3 cm
- -2 < y < 6 cm
- 400 < z < 1600 cm
  (decay volume: 300-1200cm, SP2 guard calorimeter: z=1650cm)
- Vertex fit probability > 0.01



Event selection: particle ID

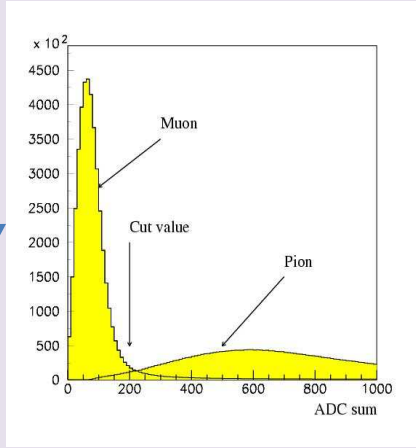
- **Photon**: shower in ECAL

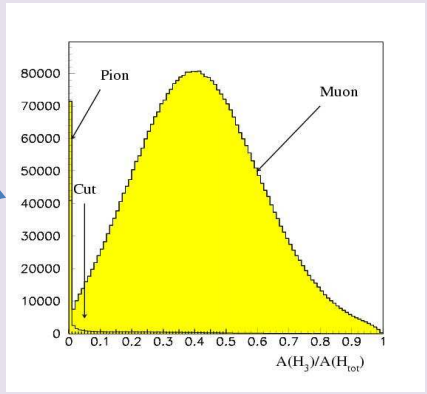
not associated with any track

- **Muon**:

1) ADC sum in HCAL < 200

2) relative energy deposition in last 3 layers of HCAL > 0.05





Spectrum tuning: strategy

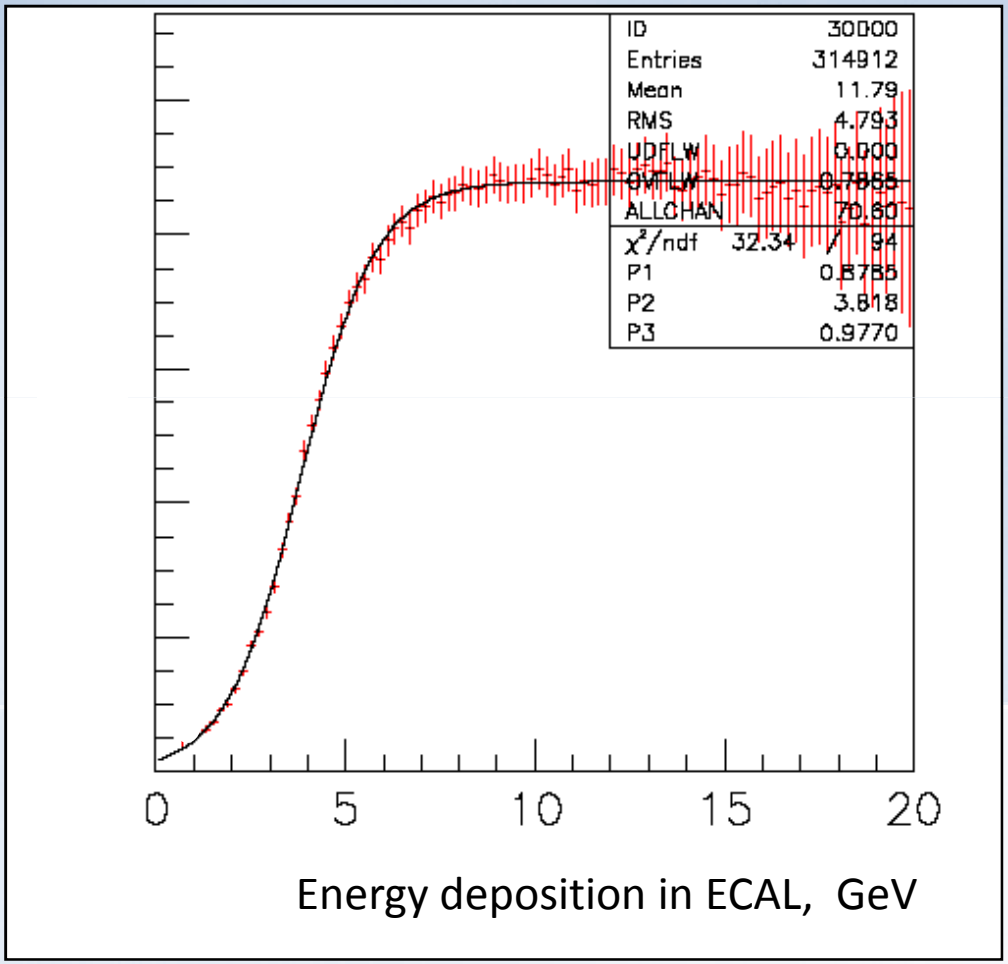
- Trigger efficiency for photon
- Muon momentum kinematical calibration
- Photon energy kinematical calibration

Trigger efficiency ε for photon

Data structure:
T_0 trigger: ~10%
$T_1 = T_0 \cdot (\sum ECAL > MIP)$: ~90%

Trigger efficiency:
$\varepsilon = T_0 * T_1 / T_0$

Data with T_1 are weighted by 1/ε



Kinematical calibration

- General idea: use of 2-body kinematics
- P_μ tuning: peaks in Kμ2 and Kπ2 must correspond to table values
- E_γ tuning: a peak in $E_{\pi 0}$ for Kπ2 selection must correspond to table value

Background rejection

- Main backgrounds
- Primary cuts
- Kinematical variables and signal observation

Background rejection

- Main background:
- $K \rightarrow \mu \nu \pi^0$ ($K\mu 3$)

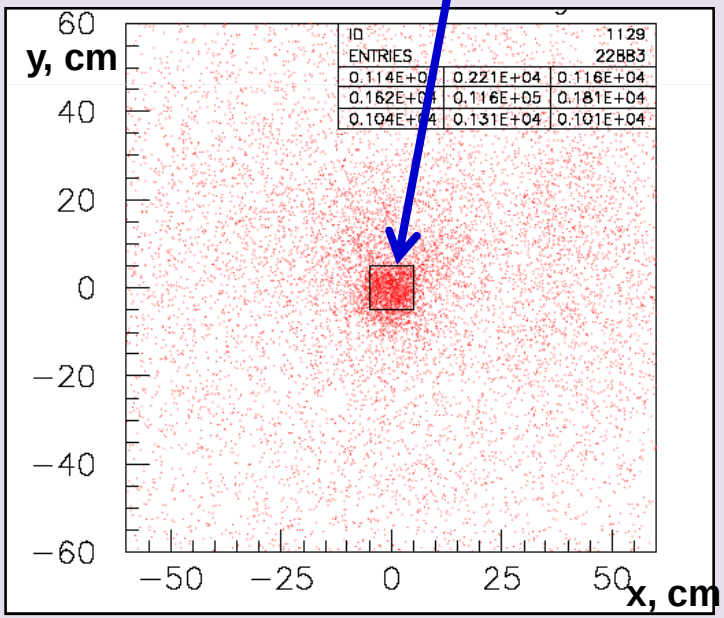
with 1 gamma lost (from $\pi^0 \rightarrow \gamma\gamma$)

- $K \rightarrow \pi \pi^0$ ($K\pi 2$)

with 1 gamma lost (from $\pi^0 \rightarrow \gamma\gamma$) and π misidentification

Background rejection: primary cuts

- Missing momentum in ECAL plane: central hole region is dominated by *Kπ2* and excluded
- Y-distance between muon and photon in ECAL plane: -20 < dy < 50 cm



Background rejection: kinematical variables

- Signal observation:

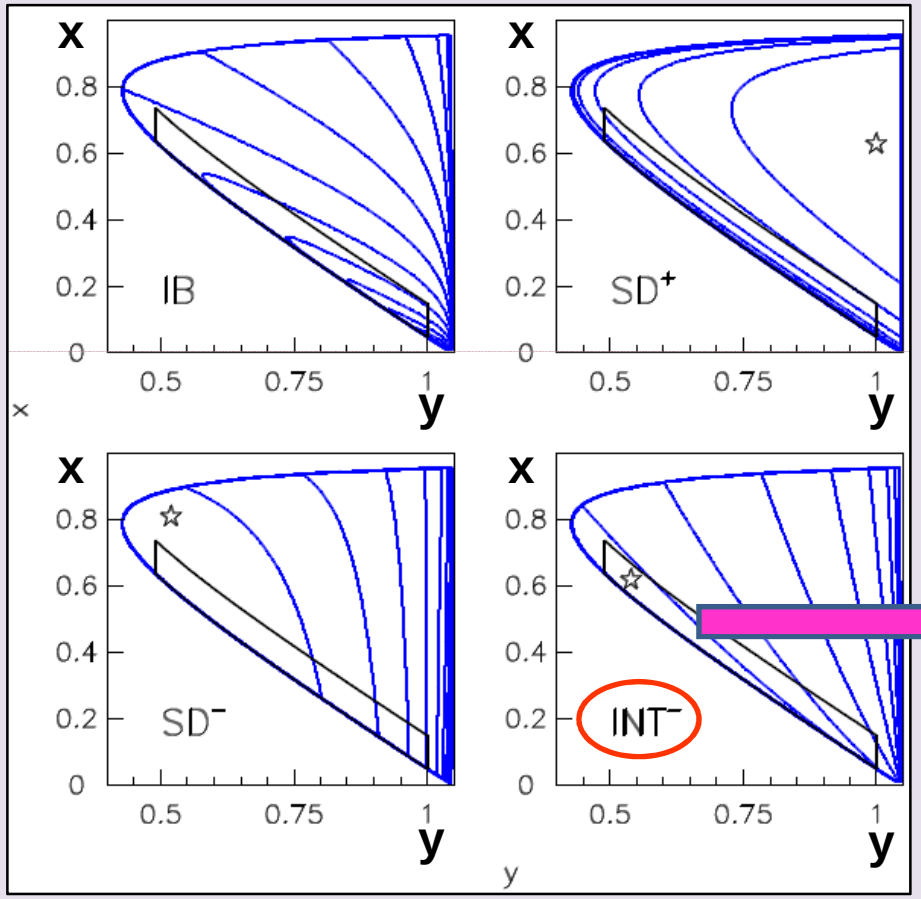
  $M(\mu\,\nu\,\gamma)=\sqrt{(P_\mu+P_\nu+P_\gamma)^2}$ where

  $\vec{p}_\nu=\vec{p}_K-\vec{p}_\mu-\vec{p}_\gamma$; $E_\nu=|\vec{p}_\nu|$

  $M(\mu\nu\gamma)$ peaks at M_K=0.494 GeV for signal

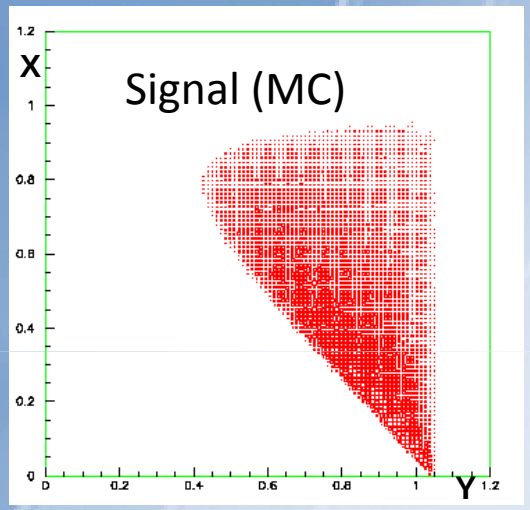
Background rejection procedure: scanning over (x,y) Dalits-plot and looking for a peak in $M(\mu\nu\gamma)$

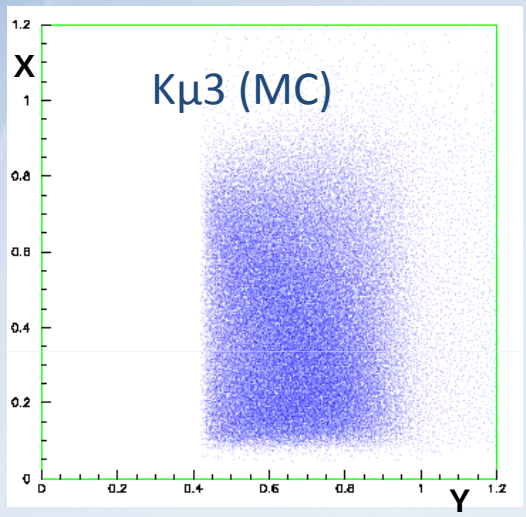
Background rejection: Dalits-plot plot signal

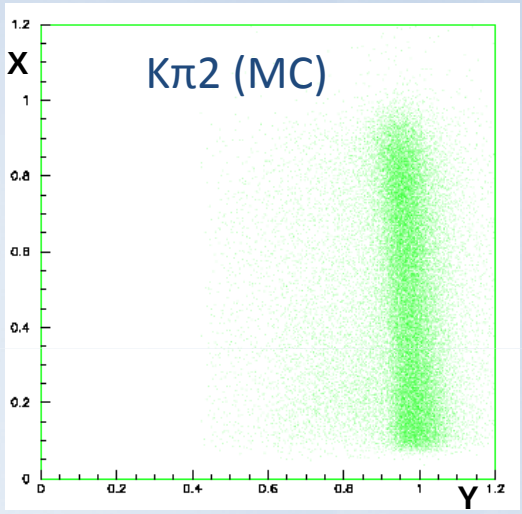


Our strategy:
Focusing on INT- region

Background rejection: (x,y) Dalits plot







Previous experiments: looking for signal near **y** kinematical border

ISTRA+: looking for signal near E_ν kinematical border

Signal extraction: strategy

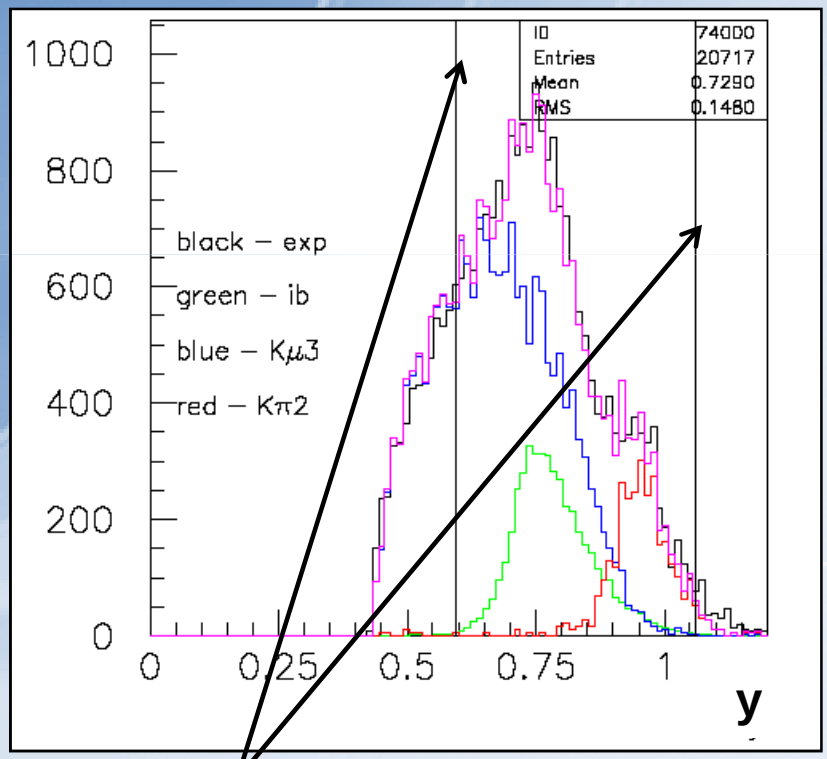
- X-stripes and distribution over y in x-stripes
- Cut on y in x-stripes
- M(μ ν γ) in xy-stripes

Signal extraction: X-stripes, distribution over y, cut on y

- (x,y) dalits-plot is divided into stripes with $\delta x=0.05$ width (x-stripes)
- A cut on y is put in each stripe (xy-stripe)
- Ratio $R=S/\sqrt{(S+B)}$ (S – number of INT- events, B – IB+background) is used for putting cut on y within a particular stripe
- Maximum of R corresponds to minimal error

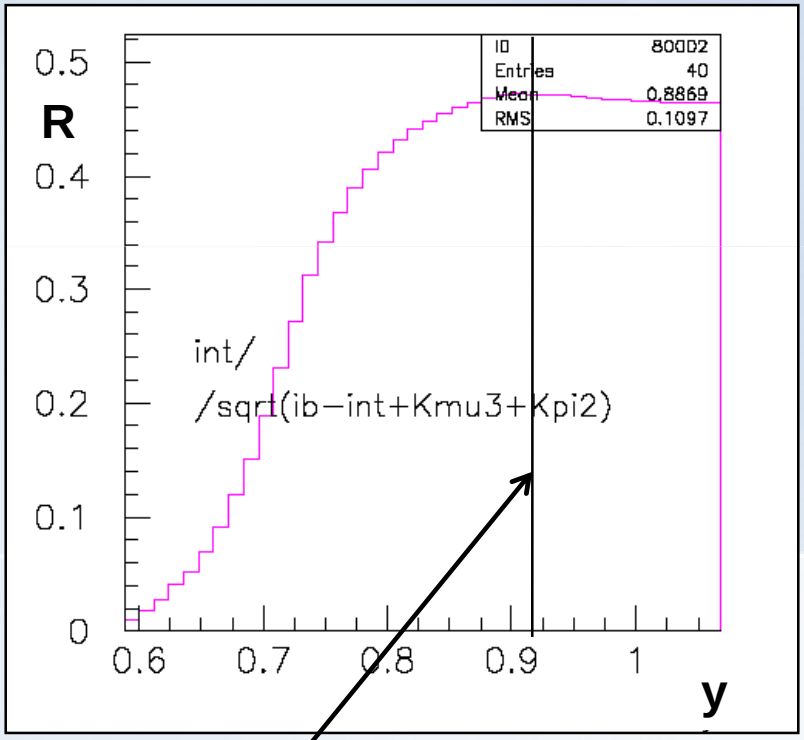
Signal extraction: X-stripes, distribution over y, cut on y

Y in x-stripe



Limits for R calculation

Ratio R in x-stripe

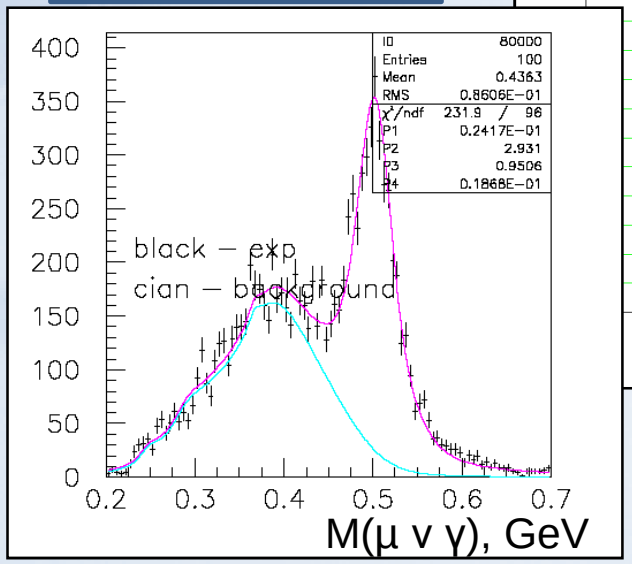


Putting upper cut on y

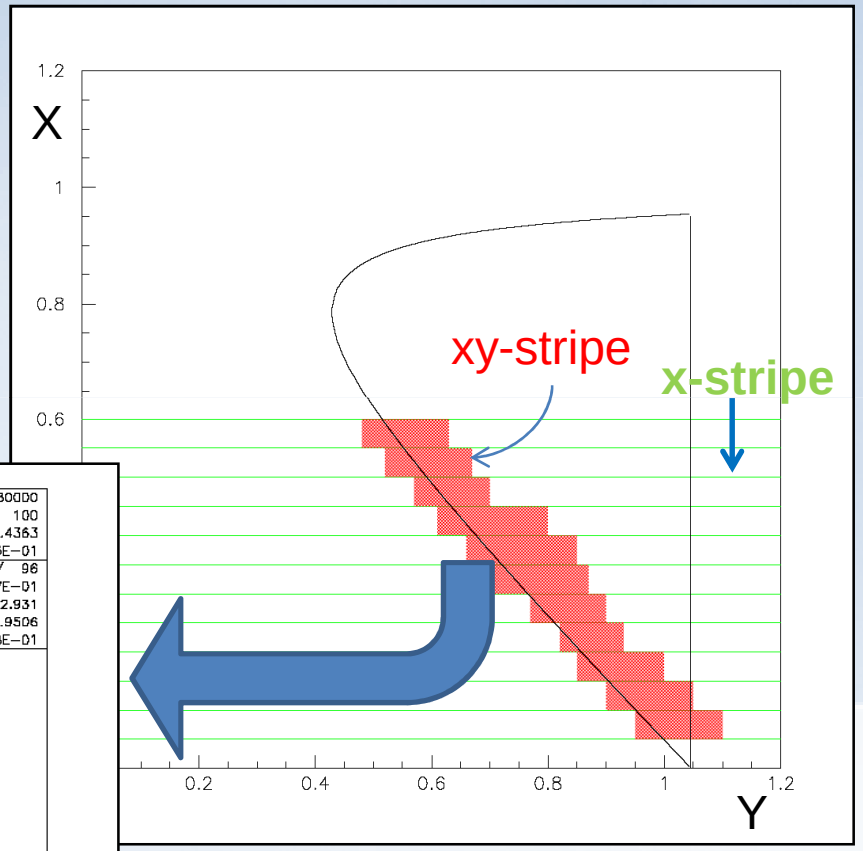
Signal extraction: fitting M(μ ν γ) in xy-stripes

~44000 events extracted

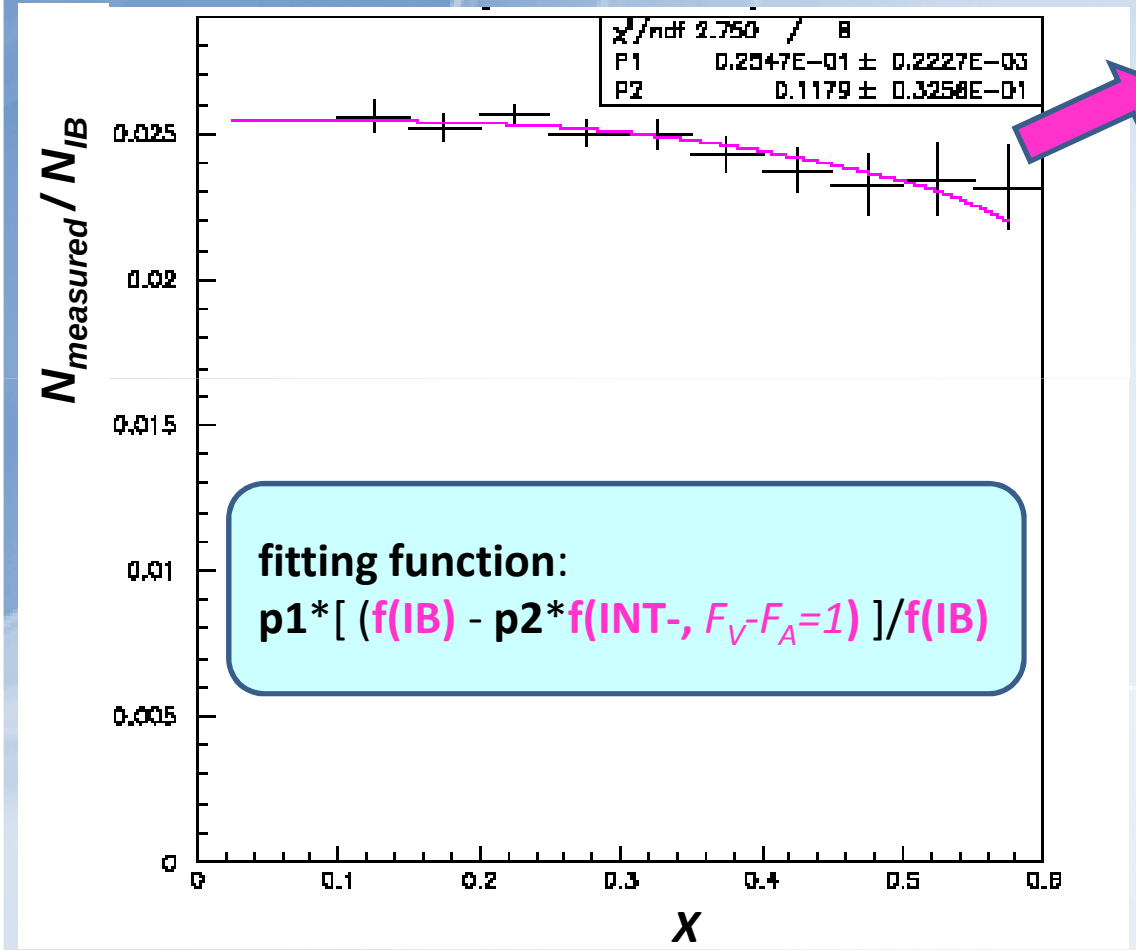
fitting M(μ ν γ) in xy-stripe



Signal and background shapes taken from MC



Spectrum fitting



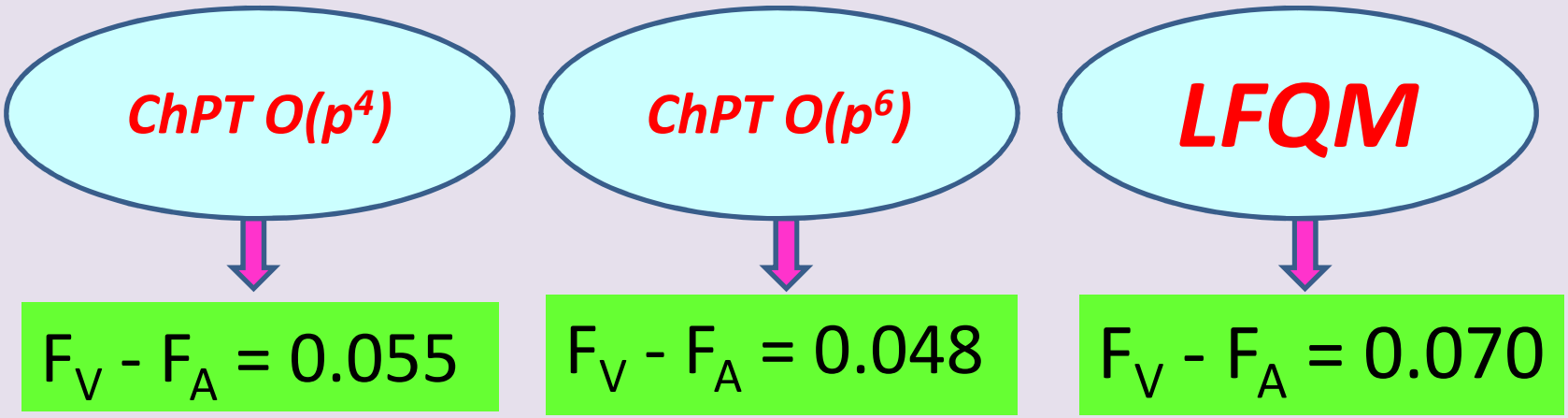
- N(IB) is taken from MC
- Negative sign of **INT-** clearly seen
- **~2%** effect of **INT-**

Preliminary result:

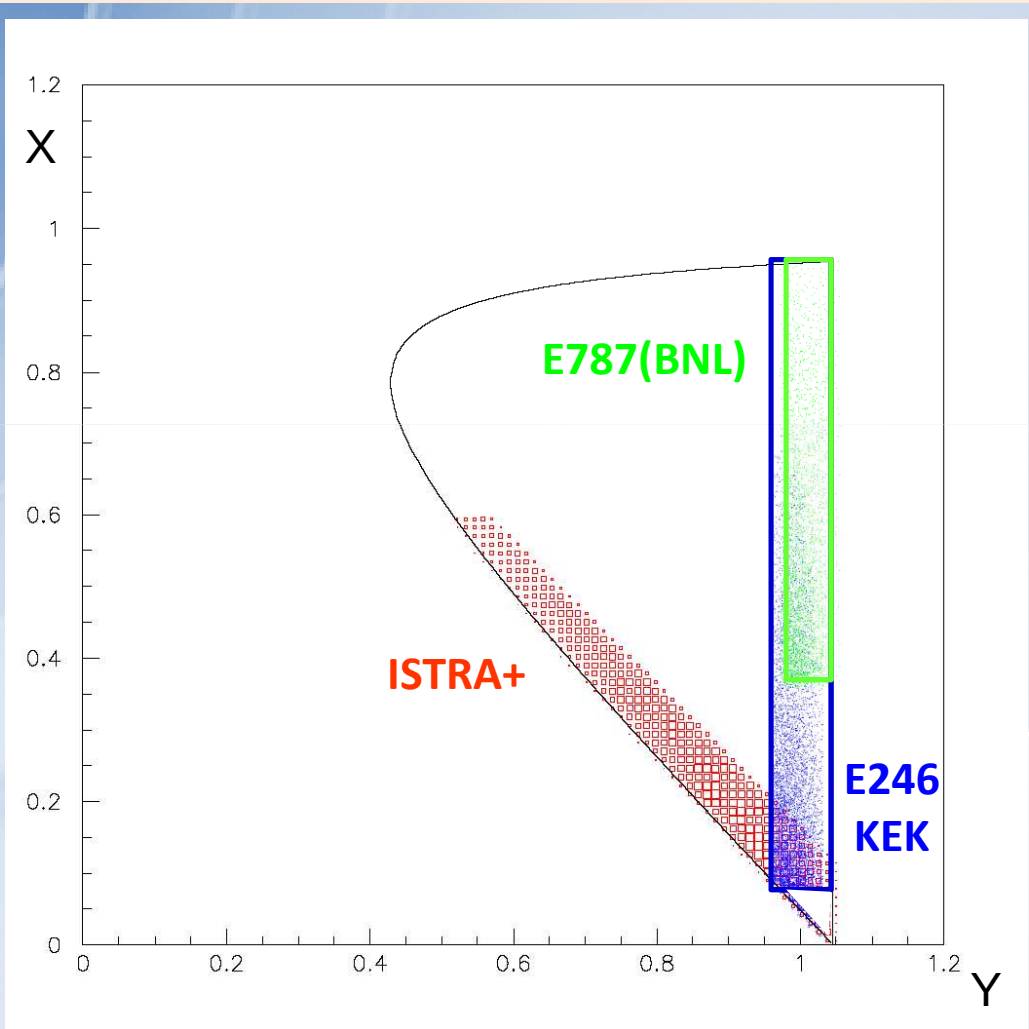
$F_V - F_A = 0.12 \pm 0.03 \pm 0.03$

F_V-F_A: comparison with theory

$F_V - F_A = 0.12 \pm 0.03(stat) \pm 0.03(syst)$



ISTRA+ kinematical region: complementary with previous experiments



ISTRA+ result: complementary with previous experiments

experiment	collaboration	year	cuts	results
Barmin et al		1988	$P_\mu < 231.5$ MeV/c	BR(IB)
Demidov et al		1990	$P_\mu < 231.5$ MeV/c	BR(IB)
Akiba et al	E104 (KEK)	1985	$214.5 < P_\mu < 231.5$ MeV/c	BR(IB)
Adler et al	E787 (BNL)	2000	$P_\mu > 218.4$ MeV/c $E_\gamma > 90$ MeV	$\lvert F_V + F_A \rvert$
Akimenko et al	**ISTRA+**	**2009**	**$E_\gamma < 148$ MeV (x<0.6)**	**$F_V - F_A$**

E787: 2800 events

ISTRA+: 44000 events

~15 times larger statistics

conclusion

- The K→ μ ν γ decay is observed at ISTRA+ setup in a new kinematical region
- The event number observed is 44K (the largest statistics in the world)
- First measurement of INT- term gives **F_V-F_A=0.12±0.03(stat)±0.03(syst)**
- The sign of INT- is negative
- The results are preliminary

To KAON09 organizers and participants

THANK YOU!!!