$D^0 \to K_S \pi^0$ and $D^0 \to K_L \pi^0$ decay rate asymmetry

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- **Decay rate asymmetry in $D^0 \to K_S\pi^0$ and $K_L\pi^0$, where does it come from?**
  - **D^0 decays occur through $\bar{K^0}\pi^0$(CF mode) and $K^0\pi^0$(DCS mode)**
    1. **The contributions reflect in the decay width expressions**
       $\Gamma_{D^0\to K_S\pi^0} = \frac{1}{2}\Gamma_{CF} - (\sqrt{\Gamma_{CF}}\sqrt{\Gamma_{DCS}}) cos(\delta_{CF} - \delta_{DCS}) + \frac{1}{2}\Gamma_{DCS}$
       $\Gamma_{D^0\to K_L\pi^0} = \frac{1}{2}\Gamma_{CF} + (\sqrt{\Gamma_{CF}}\sqrt{\Gamma_{DCS}}) cos(\delta_{CF} - \delta_{DCS}) + \frac{1}{2}\Gamma_{DCS}$
    2. **the asymmetry can then be written as**
       $A = \frac{(\Gamma_{D^0\to K_S\pi^0})-(\Gamma_{D^0\to K_L\pi^0})}{(\Gamma_{D^0\to K_S\pi^0})+(\Gamma_{D^0\to K_L\pi^0})} \simeq -2\sqrt{\frac{\Gamma_{DCS}}{\Gamma_{CF}}} cos(\delta_{CF} - \delta_{DCS}) \simeq tan^2\theta_c \simeq \mathcal{O}(5\%)$

- **Physics Motivation. refer [Physics Letters B 505(2001)94-106]**
  - **this asymmetry gives valuable information on $\delta = \delta_{CF} - \delta_{DCS}$**
    1. **δ is strong interaction phase diffeence between CF and DCS decay amplitudes**
    2. **in SU(3) invariance implies $\delta = 0$**
    3. **theoretical calculations for other δ's predicted values both in 1st and 2nd quadrant**
    4. **sign of experimentally obtained asymmetry can confirm which quadrant it should lie in**

- **Experimental Situation. Previous measurement at Belle in summer 2001**
  - $A = 0.06 \pm 0.05(stat) \pm 0.05(syst)$ **using** $23.6\ fb^{-1}$

Strategy for the Analysis

- **Central points of this analysis**
  - **Asymmetry is calibrated against reconstruction efficiencies from $D^0 \to (K_S\pi^-)\pi^+$ and $D^0 \to (K_L\pi^-)\pi^+$**
    1. $K^{*-}(K_S\pi^- \; or \; K_L\pi^-)$ **decays to $\bar{K}^0$ only,** $K_S\pi^- \; and \; K_L\pi^-$ **decay 1:1**
  - **The signal in all 4 decays is extracted by employing $D^{*+} \to D^0\pi^+_{slow}$**
    1. **since D^0 mass is used as constraint for K_L reconstruction**
    2. **signal for all 4 decays can be referred by either D^{*+} or $D^0 \to K_S\pi^0$ etc**
  - **For calibration purposes we assume factorizability of efficiencies (tested in MC)**
    1. $\epsilon^{D^{*+}}(p_1, p_2, \ldots) = \epsilon^1(p_1) \times \epsilon^2(p_2) \times \ldots$, **1,2 etc refer to the final state particles**
    2. **only K_S/K_L relative efficiency matters, taken from data in calibration modes**

- **All yields are measured in bins of K^0 momenta (p)**
  - **reduces bias due to K_L efficiency as it rapidly increases with momenta**
  - $A(p) = \frac{\eta^{rec}_{K_L\pi}(p) - r(p)\times\eta^{rec}_{K_S\pi}(p)}{\eta^{rec}_{K_L\pi}(p) + r(p)\times\eta^{rec}_{K_S\pi}(p)}$, **averaged over p**
    1. $\eta' s =$ **yields,** $r(p) \equiv \frac{\epsilon_{K_L\pi}(p)}{\epsilon_{K_S\pi}(p)} \equiv \frac{\epsilon_{K_L\pi\pi}(p)}{\epsilon_{K_S\pi\pi}(p)} = \frac{\eta^{rec}_{K_L\pi\pi}(p)}{\eta^{rec}_{K_S\pi\pi}(p)}$ **: (K_L/K_S) relative efficiency**

Data Sample used

- **100,000 Signal MC events for each mode produced by evtgen**
  - **generator $\to$ b20040727-1143 library**
    gsim $\to$ b20030807-1600 library
    analysis $\to$ b20040727-1143 library
  - $e^+e^- \to c\bar{c} \to frag \to D^{*+}, inclusive$ **by ' inclusive particle type ' in evtgen**
    1. **Produces atleast 1 D^{*+} in the event**
    2. **$D^{*+} \to D^0 \pi^+_{slow}$ and decay of $D^0 \to$ all 4 modes by 'user decay' table**
  - **charge conjugate modes not added yet**

Reconstruction, Event Selection and Fitting

- π^0 **from mdst-pi0**
- K_S **from mdst-vee2**
  - $dr > 0.25cm, d\phi < 0.1rad, dz < 1cm$
  - $0.486GeV < M_{K_S} < 0.510GeV$ **in** $D \to K_s\pi$
  - $0.491GeV < M_{K_S} < 0.504GeV$ **in** $D \to K_s\pi\pi$
- K_L **from mdst-klong**
  - **Detector gives only** K_L **direction**
  - M_{D^0} **and** M_{K_L} **is fixed to PDG value and kinematics is solved for** p_{K_L}
  - **This is a quadratic equation**
  - $\frac{-b-(\sqrt{b^2-4ac})}{2a}$ **is always +ve, currently chosen solution**
  - **A choice of the solutions is also being studied**
- K^{*-} **mass cuts**
  - **(0.752, 1.032) GeV in** K_L **mode, (0.750, 1.000) GeV in** K_S **mode**

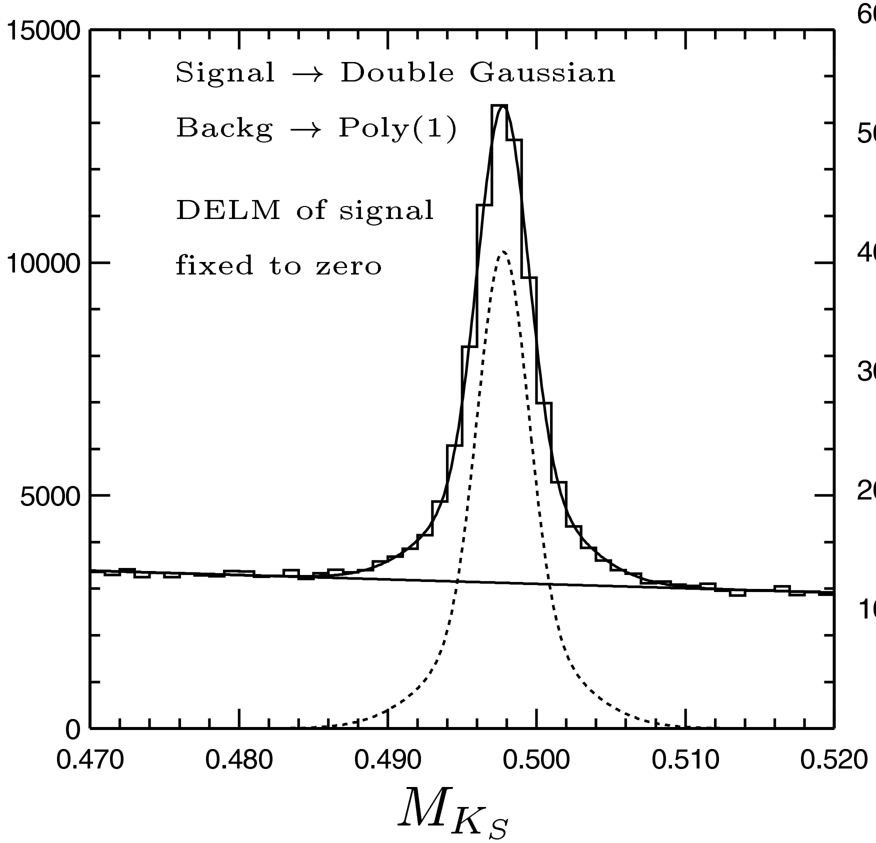
- D^0 **mass window cuts and constraints**
  - **(1.75, 1.90) GeV for $K_S\pi^0$ mode**
    (1.852, 1.878) GeV for $K_S\pi\pi$
    fixed to PDG value for K_L modes

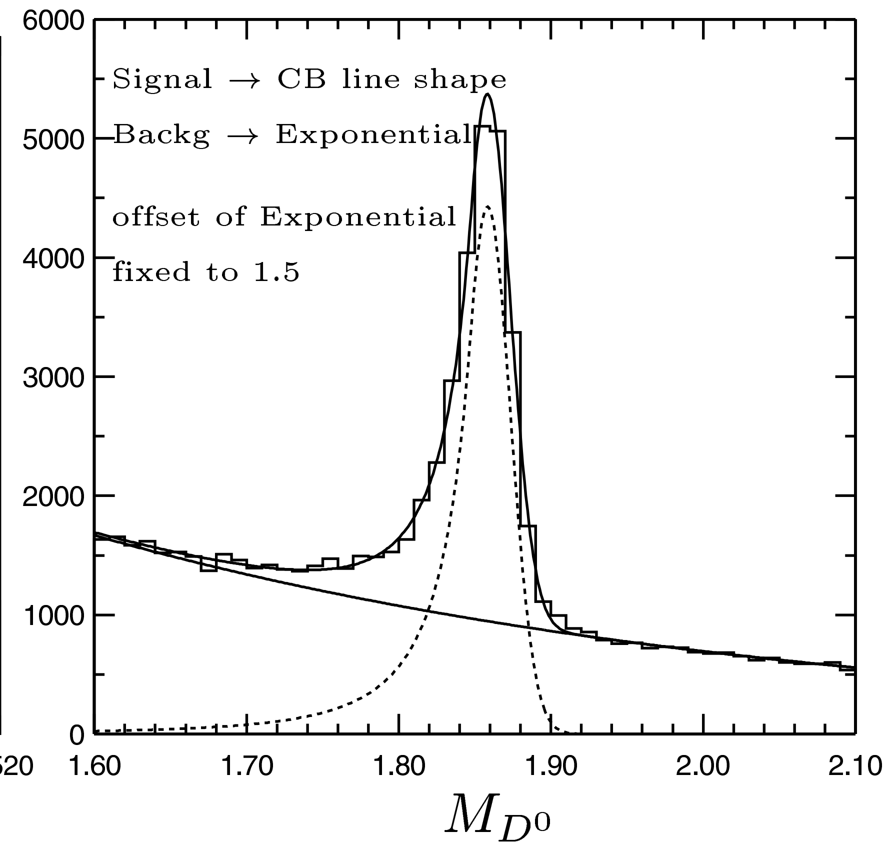
- D^{*+}
  - **3 σ cuts on $M_{D^{*+}}$ for K_L modes**
  - $0.144GeV < \delta M < 0.147GeV$ **for $D \to K_s\pi$ mode**

    $0.143geV < \delta M < 0.148GeV$ **for $D \to K_s\pi\pi$ mode**

    where $\delta M = M_{D^{*+}} - M_{D^0}$

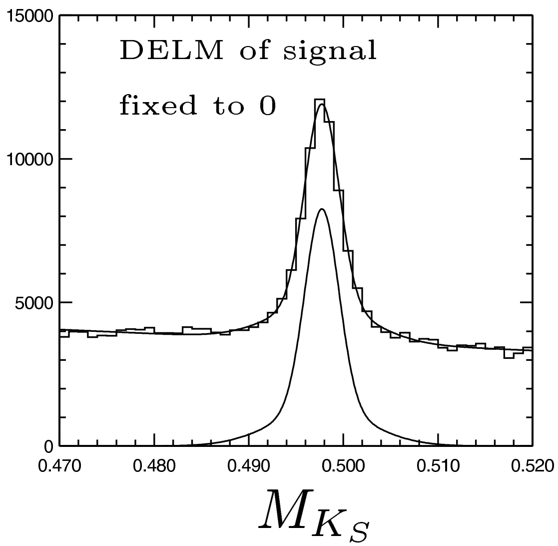
Reconstruction of $D^0 \to K_S\pi^0$



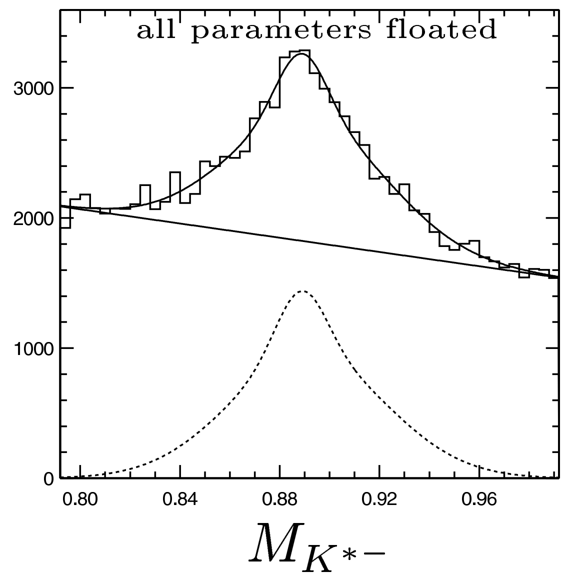


Reconstruction of $D^0 \to K_S\pi^+\pi^-$

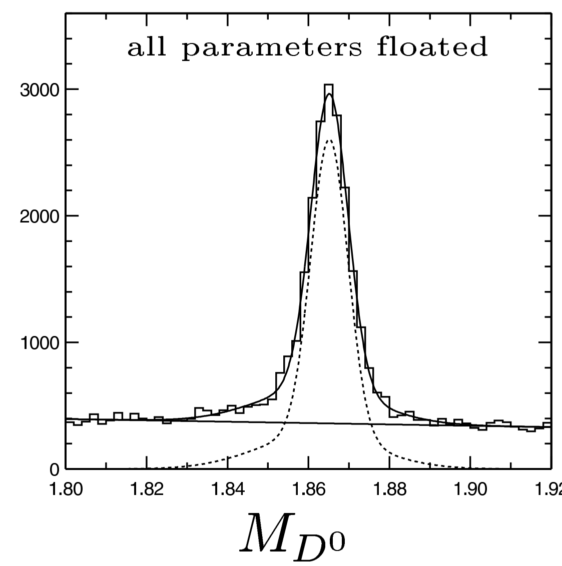
Signal → Double Gaussian
Backg → Poly(1)



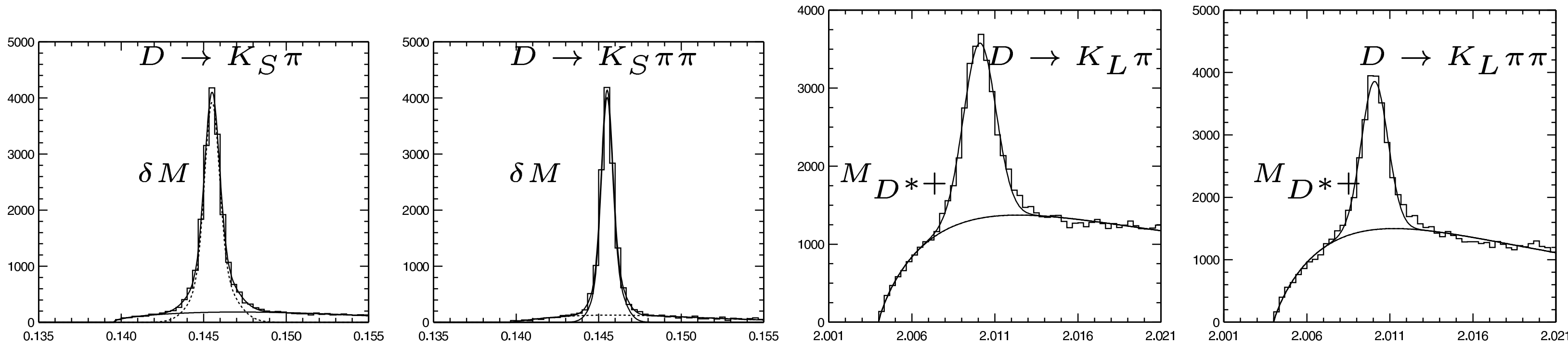
Signal → Double Gaussian
Backg → Poly(1)



Signal → Double Gaussian
Backg → Poly(1)



Signal shapes for 4-modes



- δM, Signal $\to$ Double Gaussian

  Backg $\to$ Threshold function : offset fixed to 0.1396 GeV(PDG)

- $M_{D^{*+}}$, Signal $\to$ Gaussian

  Backg $\to$ Threshold function : offset fixed to 2.004 GeV

- Threshold function :

  NORM*(X-OFFSET)**POWER*EXP(COEFF1*(X-OFFSET)+COEFF2*(X-OFFSET)**2)

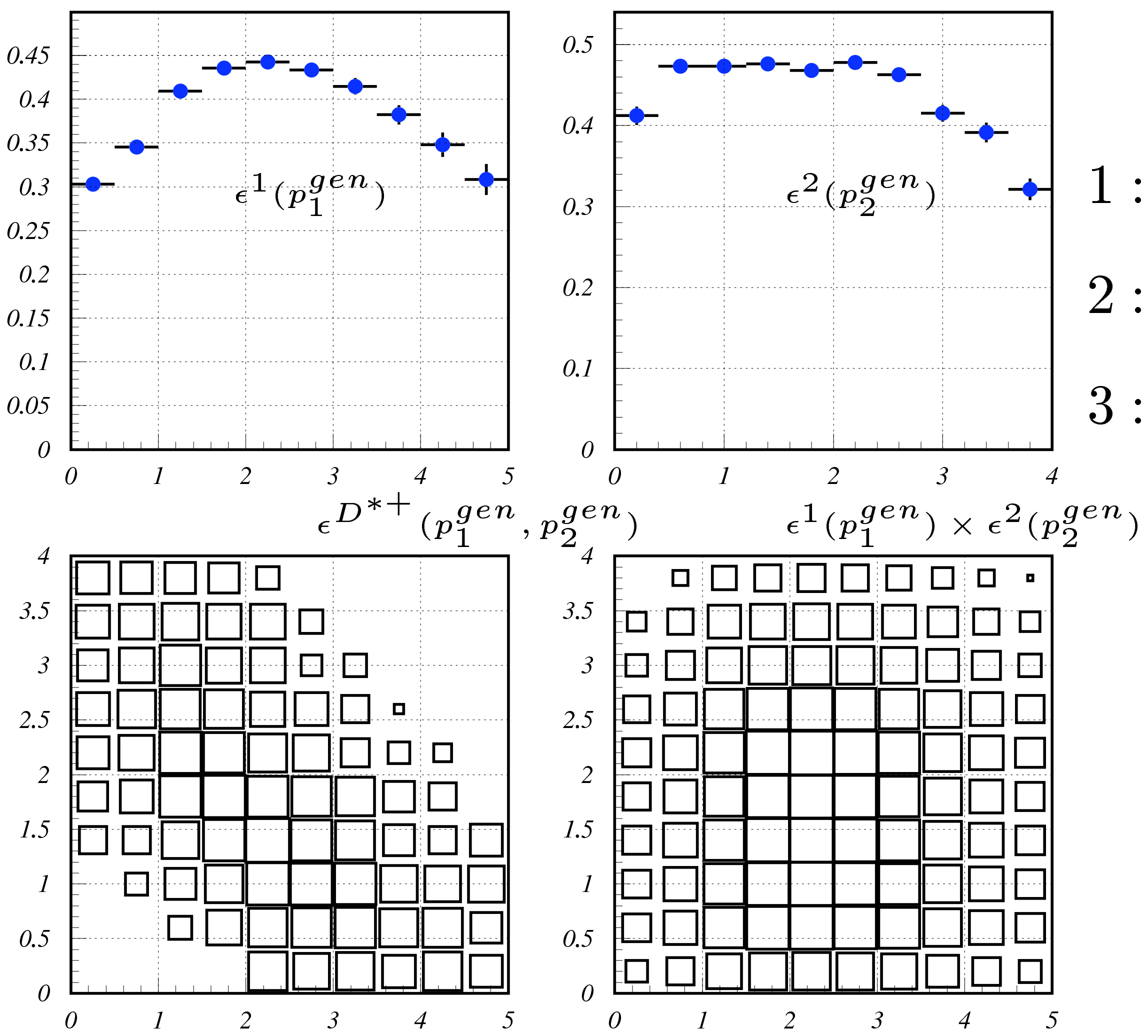
Reconstruction efficiencies and assumption of factorizability $\epsilon^{D^{*+}}(p_1, p_2, ...) = \epsilon^1(p_1) \times \epsilon^2(p_2) \times ...$

- **Efficiency study is done in momentum bins to validate factorizability assumption**
- To match reconstructed info with MC truth
  - get-hepevt() function is used for K_S, π^0 and angular cuts for K_L matching
- Plot the generated lab momenta
  - Count the matching number of events reconstructed in each bin
  - This gives 1d efficiencies as function of momenta eg $\epsilon^1(p_1)$ etc
- Scatter plot the generated lab momenta pair wise
  - Count the matching number of D^{*+} events reconstructed in each 2d bins
  - This gives efficiency of D^{*+} as function of 2 momenta eg $\epsilon^{D^{*+}}(p_1, p_2)$
- plot $\epsilon^1(p_1)$, $\epsilon^2(p_2)$, $\epsilon^{D^{*+}}(p_1, p_2)$ and $\epsilon^1(p_1) \times \epsilon^2(p_2)$
  - compare $\epsilon^{D^{*+}}(p_1, p_2)$ and $\epsilon^1(p_1) \times \epsilon^2(p_2)$

Ratio of $\epsilon^{D^{*+}}(p_1, p_2)$ to $\epsilon^1(p_1) \times \epsilon^2(p_2)$ should be flat

- **We'll see that for factorizability to hold good the above ratio should be flat**
- $\epsilon^{D^{*+}}(p_1, p_2, p_3) = N_3(p_3) \times \epsilon^{D^{*+}}(p_1, p_2)$
  - since p_3 is constrained by D^{*+} kinematics, here N_3 is some scale factor
  - this $\Longrightarrow \int \epsilon^{D^{*+}}(p_1, p_2, p_3)\, dp_3 = \int N_3(p_3)\, dp_3 \times \epsilon^{D^{*+}}(p_1, p_2)$
- Assume $\epsilon^{D^{*+}}(p_1, p_2, p_3) = \epsilon^1(p_1) \times \epsilon^2(p_2) \times \epsilon^3(p_3)$
  - this $\Longrightarrow \int \epsilon^{D^{*+}}(p_1, p_2, p_3)\, dp_3 = [\int \epsilon_3(p_3)\, dp_3] \times \epsilon^1(p_1) \times \epsilon^2(p_2)$
- From the above $\epsilon^{D^{*+}}(p_1, p_2) = \frac{\int \epsilon_3(p_3)\, dp_3}{\int N_3(p_3)\, dp_3} \times \epsilon^1(p_1) \times \epsilon^2(p_2)$
  - This means the ratio is flat

Factorizability in $D^0 \to K_S\pi^0$

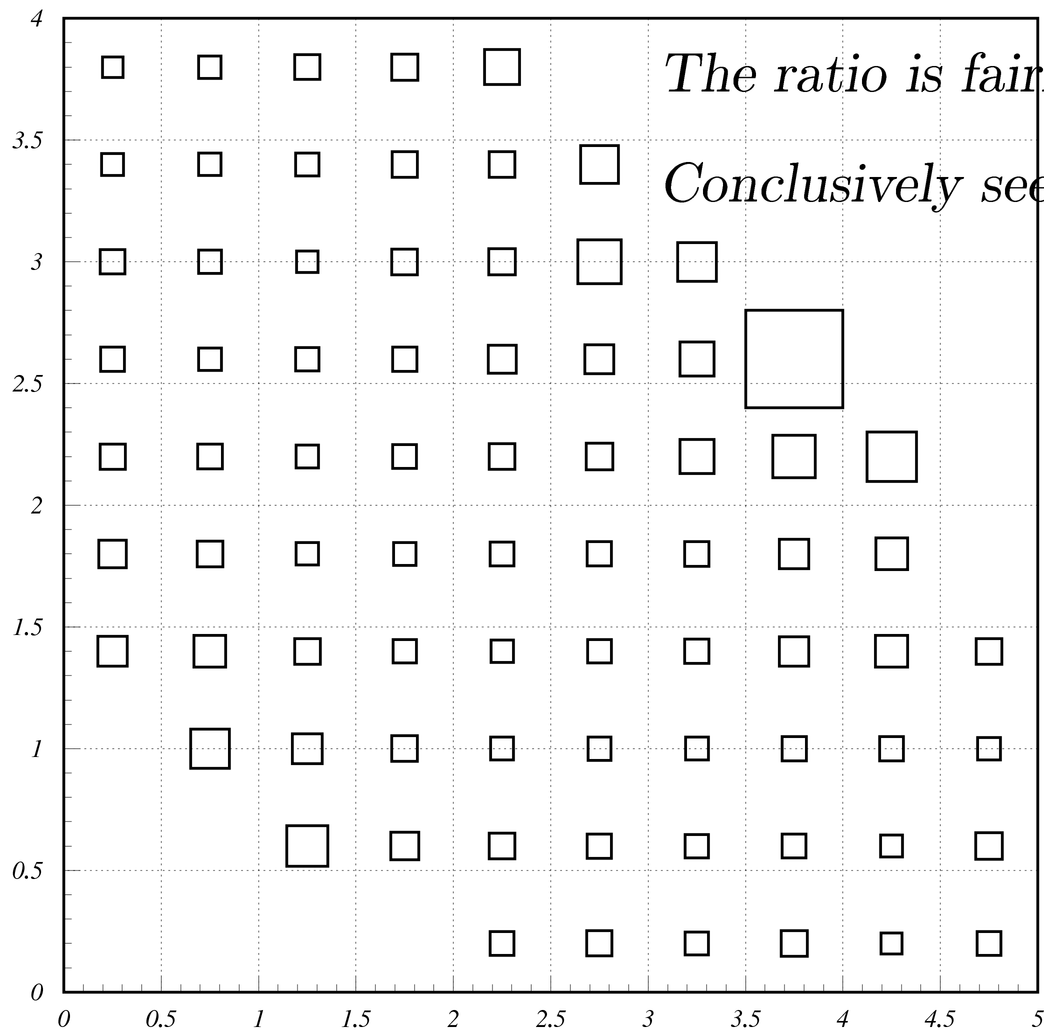


$1 : K_S$

$2 : \pi^0$

$3 : \pi^+_{slow}$

Ratio of $\epsilon^{D^{*+}}(p_1, p_2)$ and $\epsilon^1(p_1) \times \epsilon^2(p_2)$, in $D^0 \to K_S\pi^0$

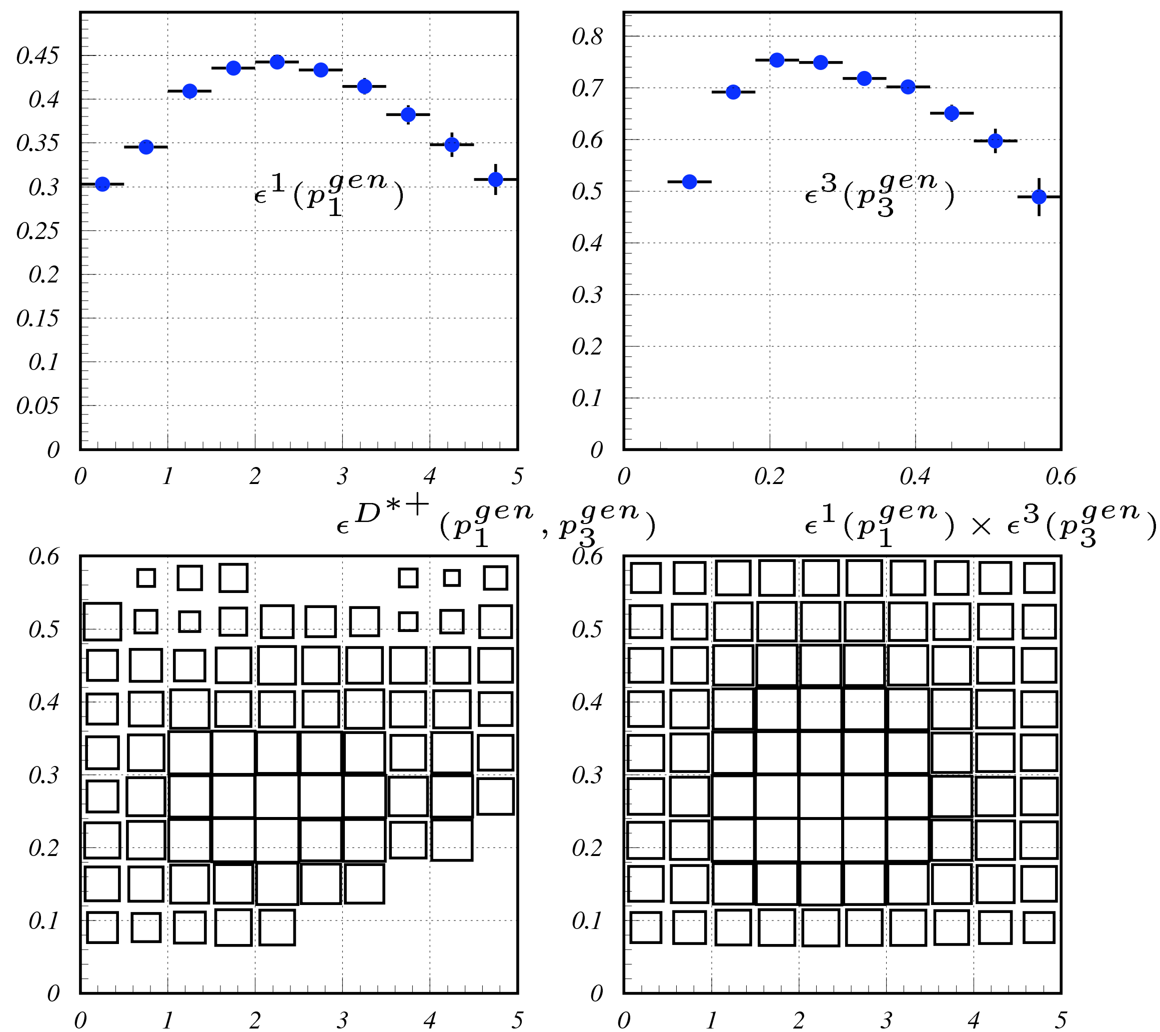


The ratio is fairly flat

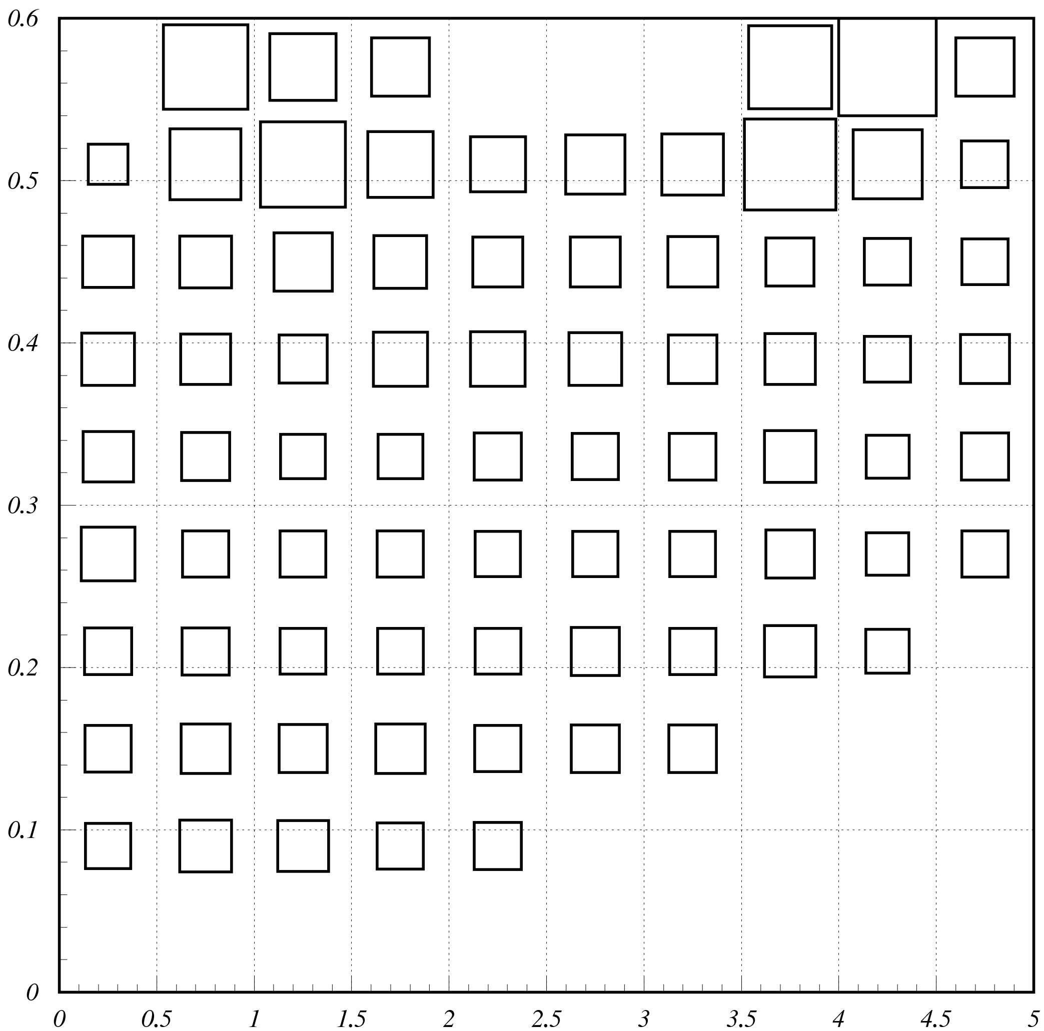
Conclusively seen that there is factorizability

Big squares only at boundary : region of low statistics

Factorizability in $D^0 \to K_S\pi^0$ continues....



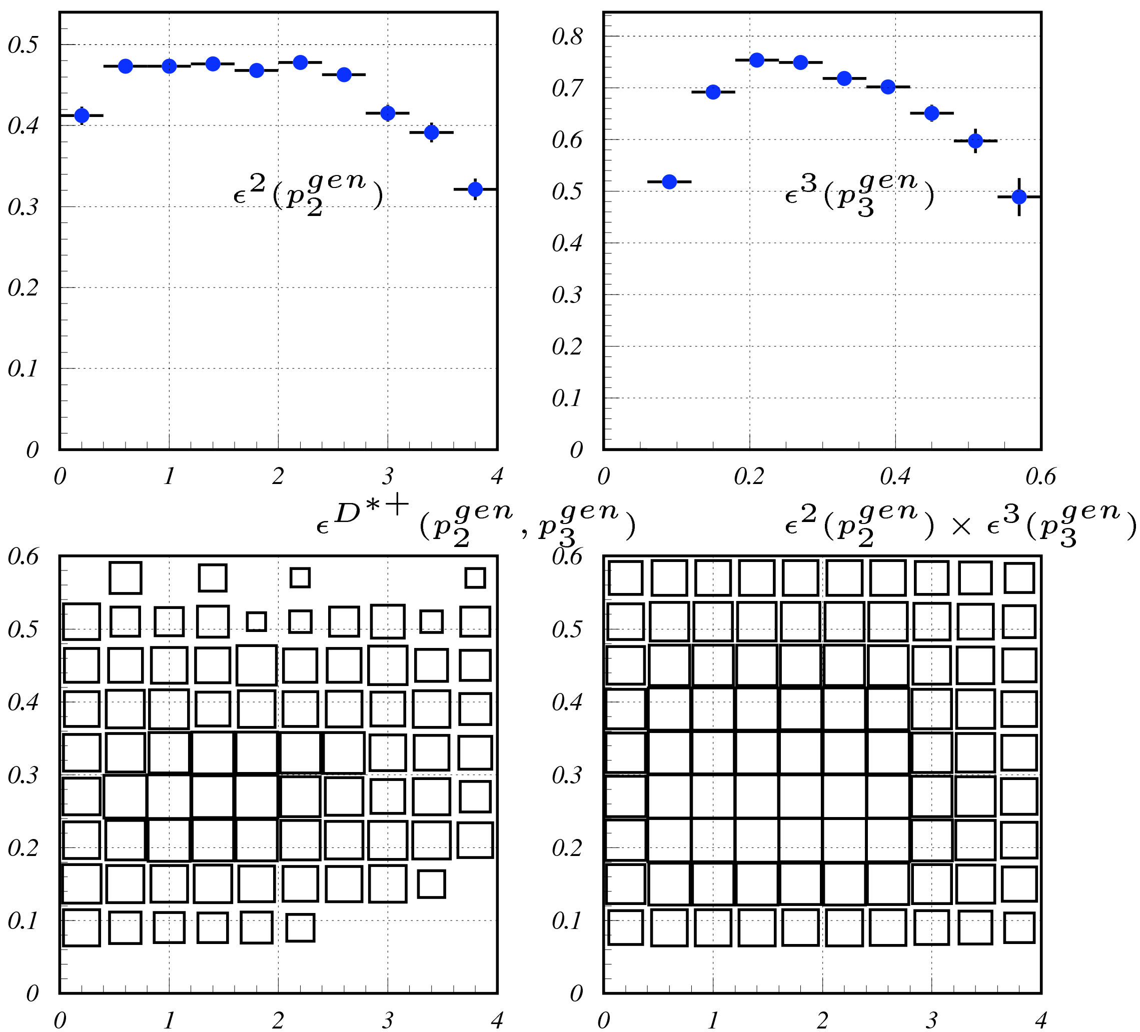
Ratio of $\epsilon^{D^{*+}}(p_1,p_3)$ and $\epsilon^1(p_1) \times \epsilon^3(p_3)$, in $D^0 \to K_S\pi^0$



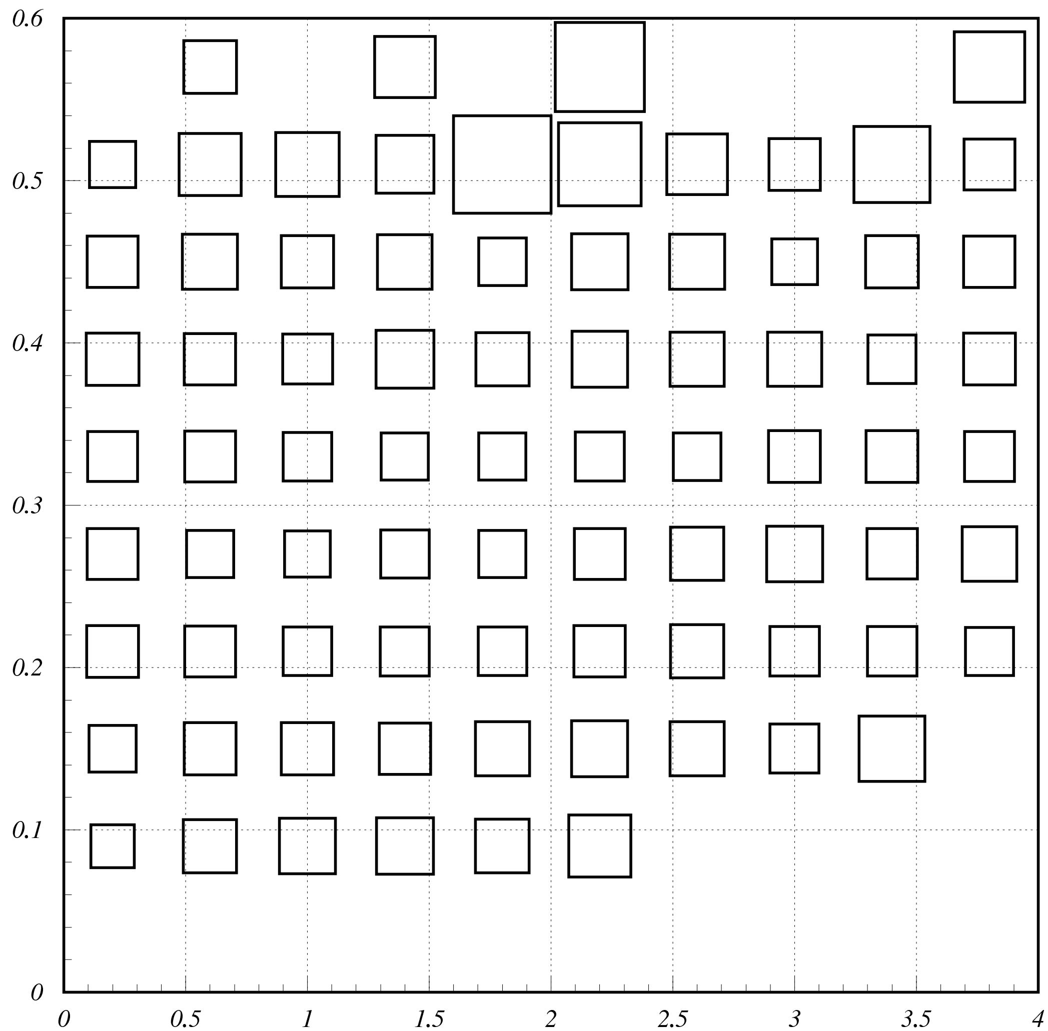
The ratio is fairly flat

Conclusively seen that there is factorizability

Factorizability in $D^0 \to K_S\pi^0$ continues....



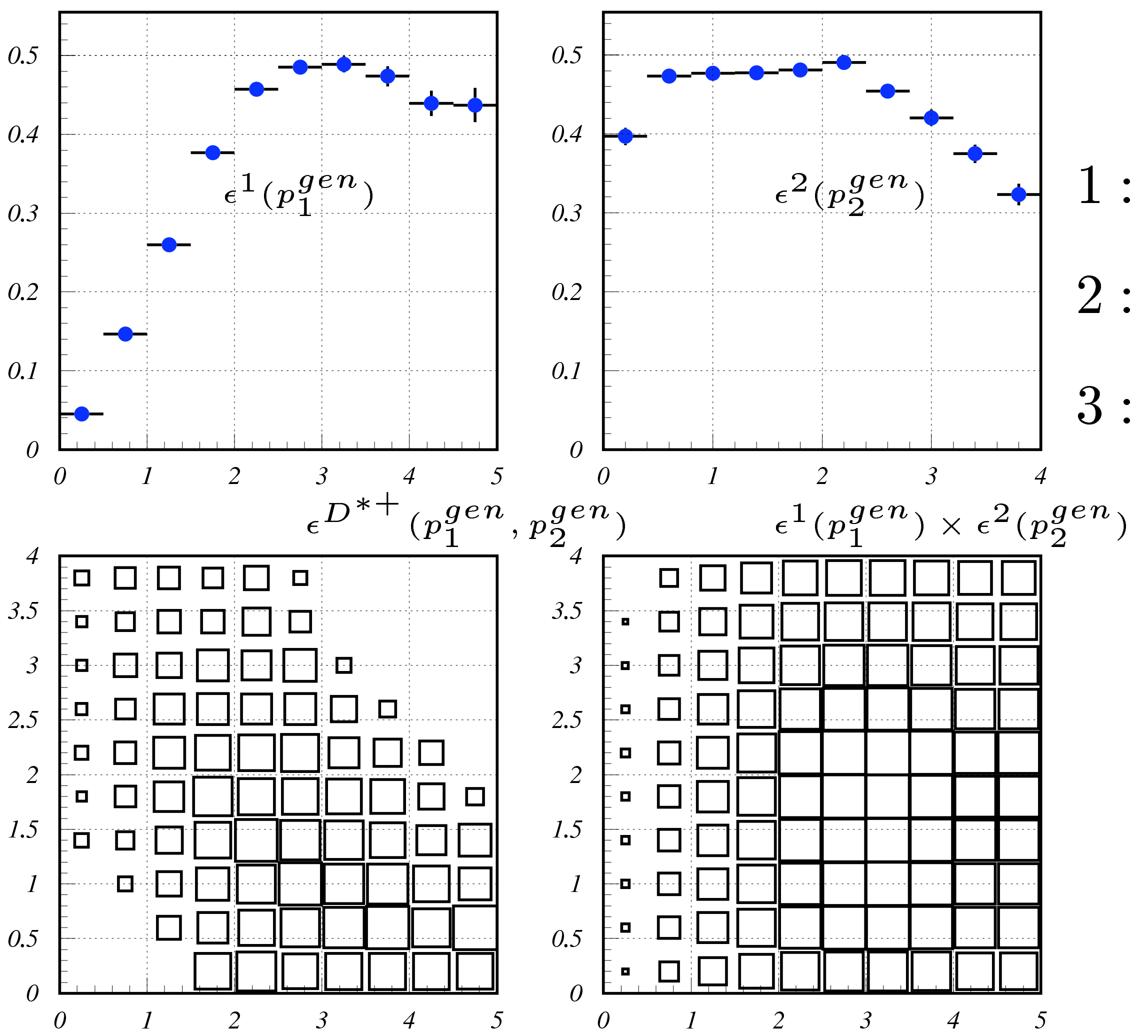
Ratio of $\epsilon^{D^{*+}}(p_2, p_3)$ and $\epsilon^2(p_2) \times \epsilon^3(p_3)$, in $D^0 \to K_S\pi^0$



The ratio is flat

There is factorizability

Factorizability in $D^0 \to K_L\pi^0$

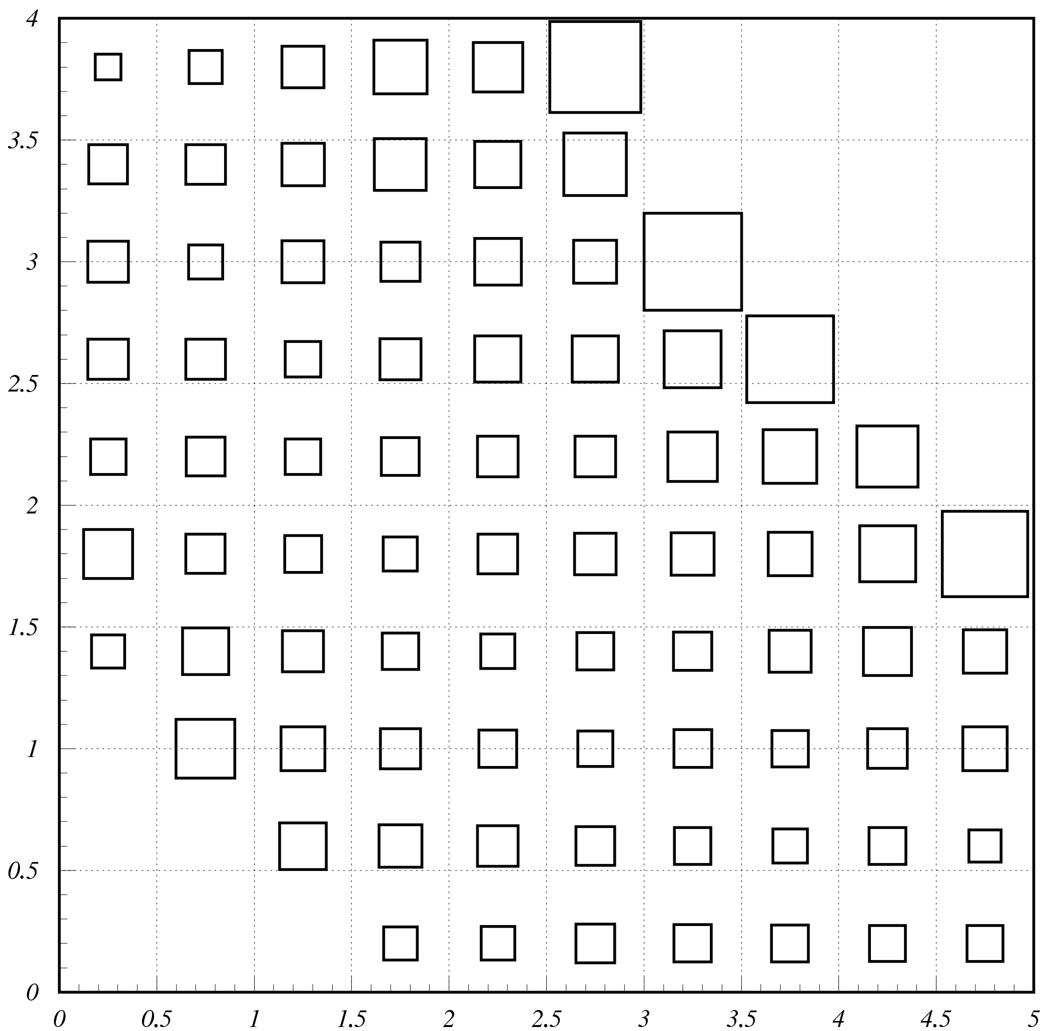


$1 : K_L$

$2 : \pi^0$

$3 : \pi^+_{slow}$

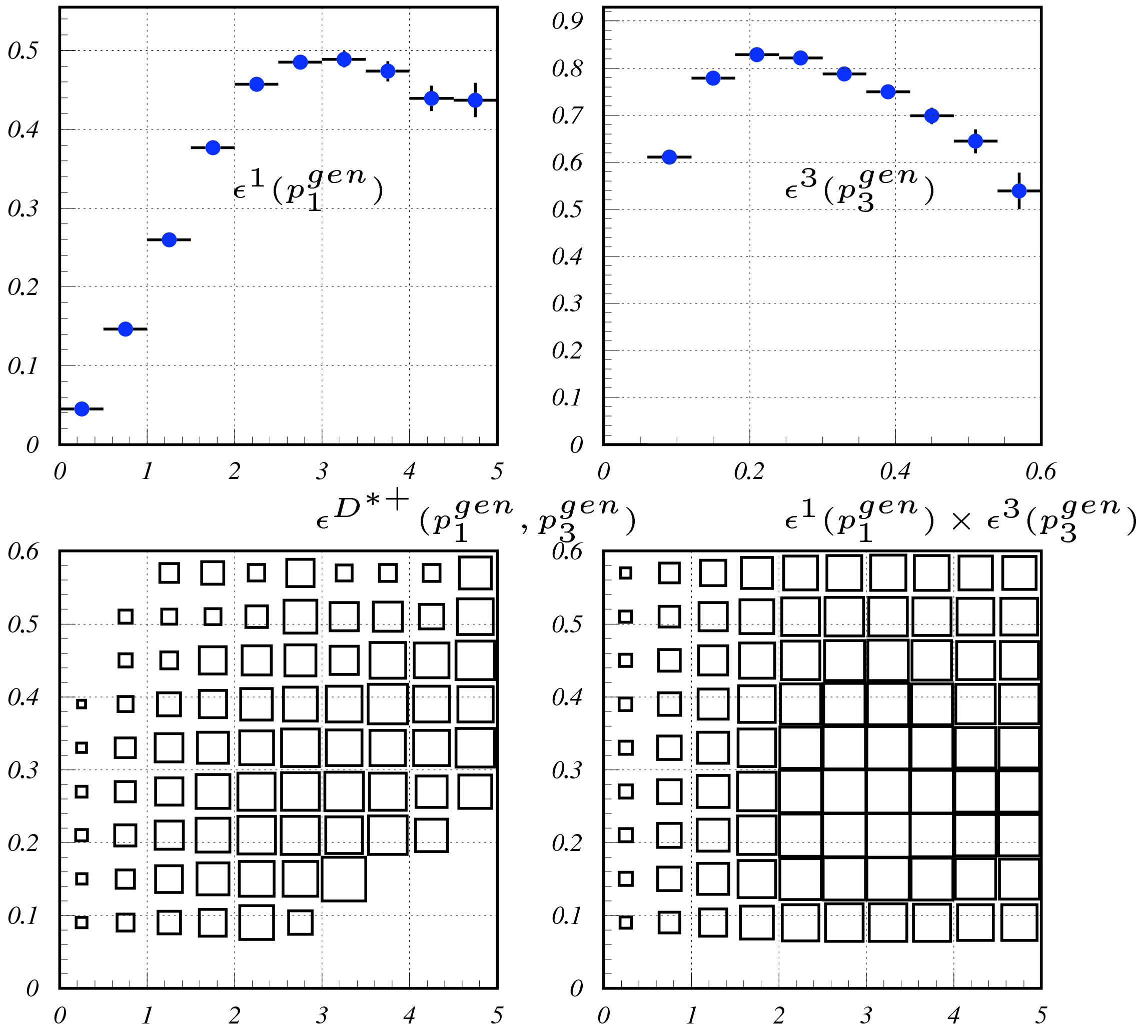
Ratio of $\epsilon^{D^{*+}}(p_1,p_2)$ and $\epsilon^1(p_1) \times \epsilon^2(p_2)$, in $D^0 \to K_L\pi^0$



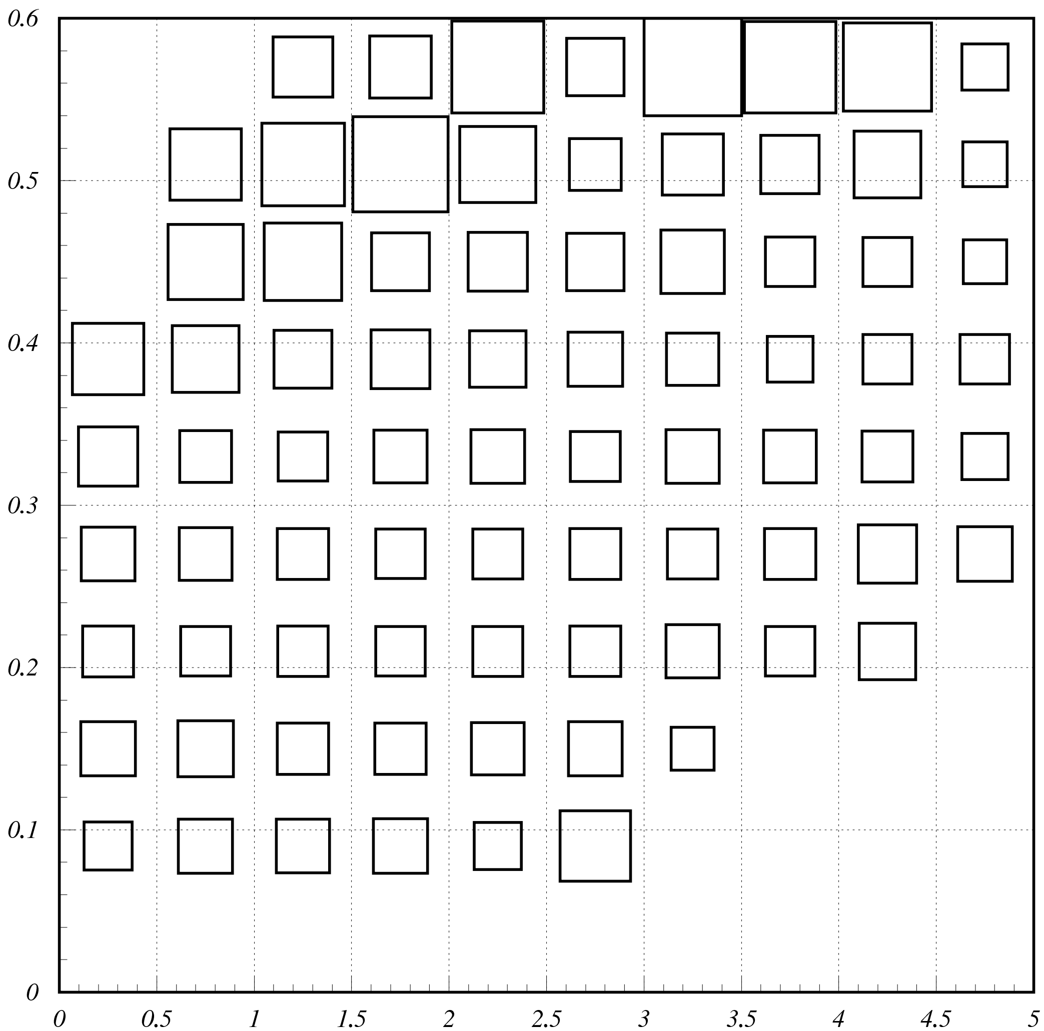
The ratio is flat

There is factorizability

Factorizability in $D^0 \to K_L\pi^0$ continues....



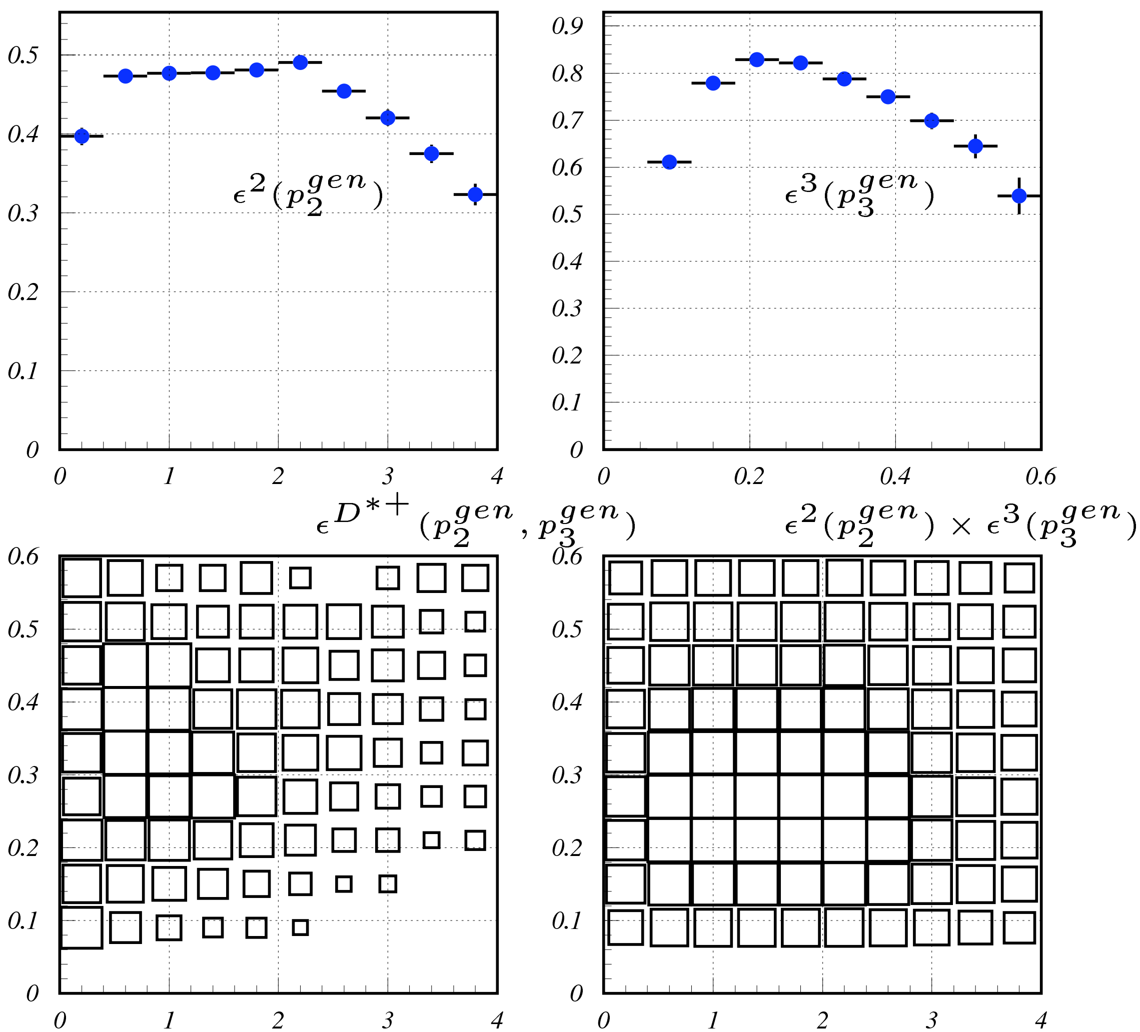
Ratio of $\epsilon^{D^{*+}}(p_1, p_3)$ and $\epsilon^1(p_1) \times \epsilon^3(p_3)$, in $D^0 \to K_L\pi^0$



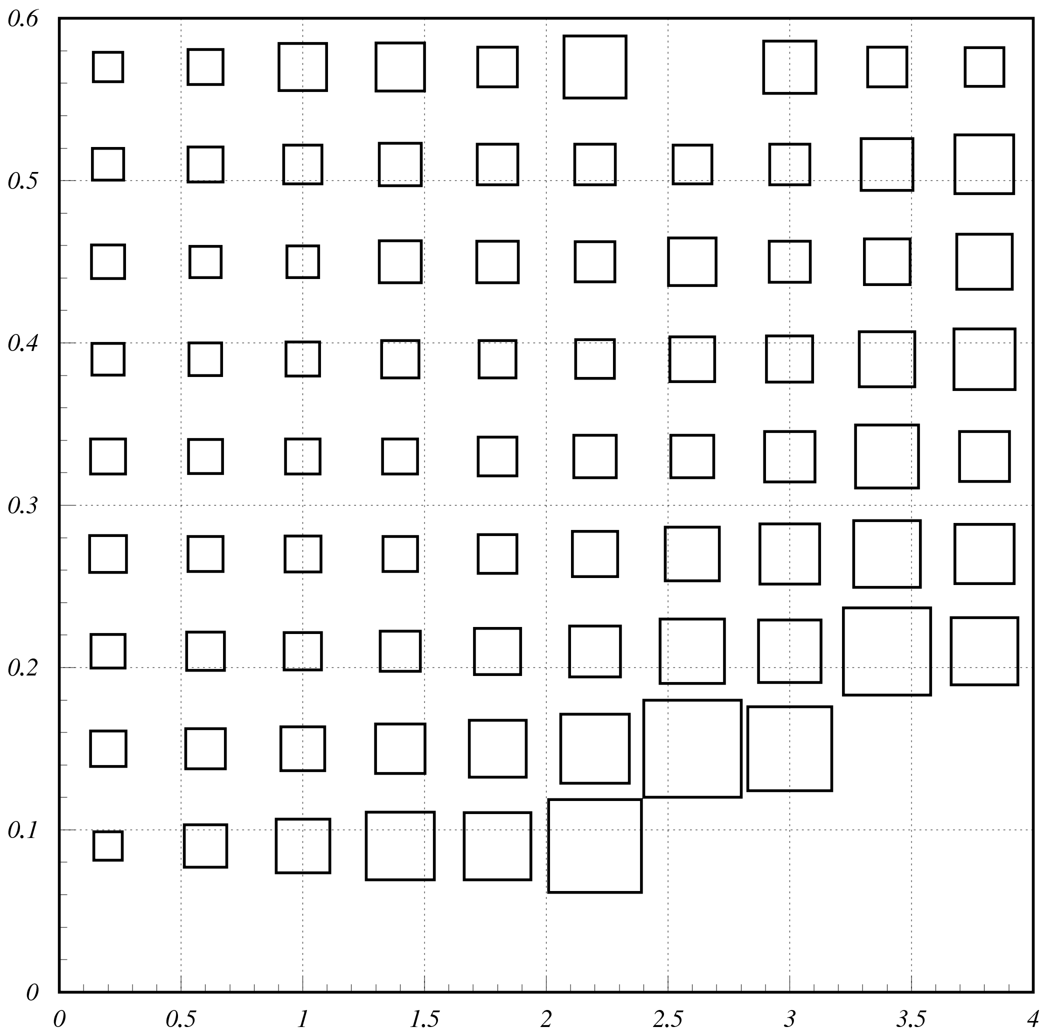
The ratio is flat

There is factorizability

Factorizability in $D^0 \to K_L\pi^0$ continues....



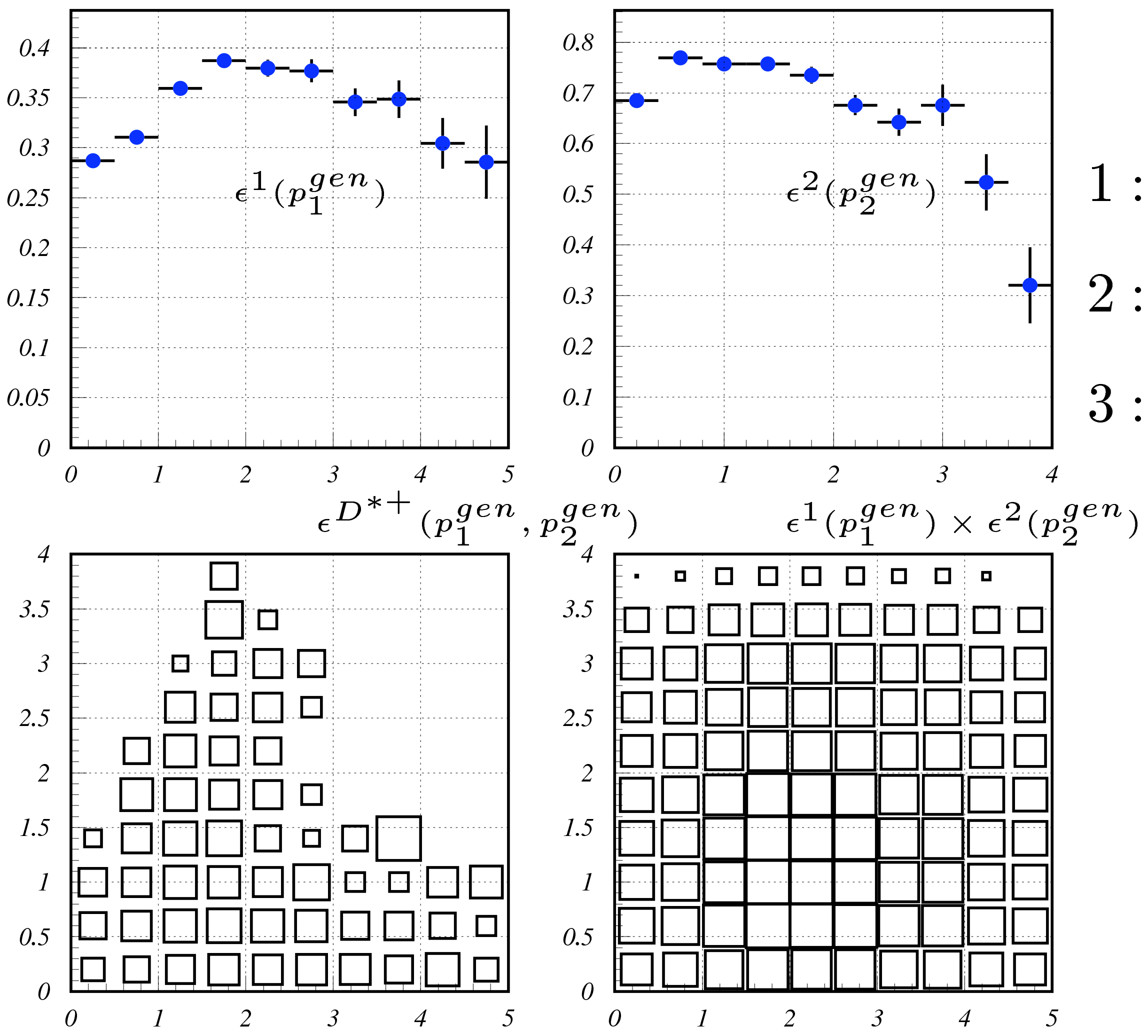
Ratio of $\epsilon^{D^{*+}}(p_2, p_3)$ and $\epsilon^2(p_2) \times \epsilon^3(p_3)$, in $D^0 \to K_L\pi^0$



The ratio is flat

There is factorizability

Factorizability in $D^0 \to K_S\pi^+\pi^-$, result shown partly, rest similar

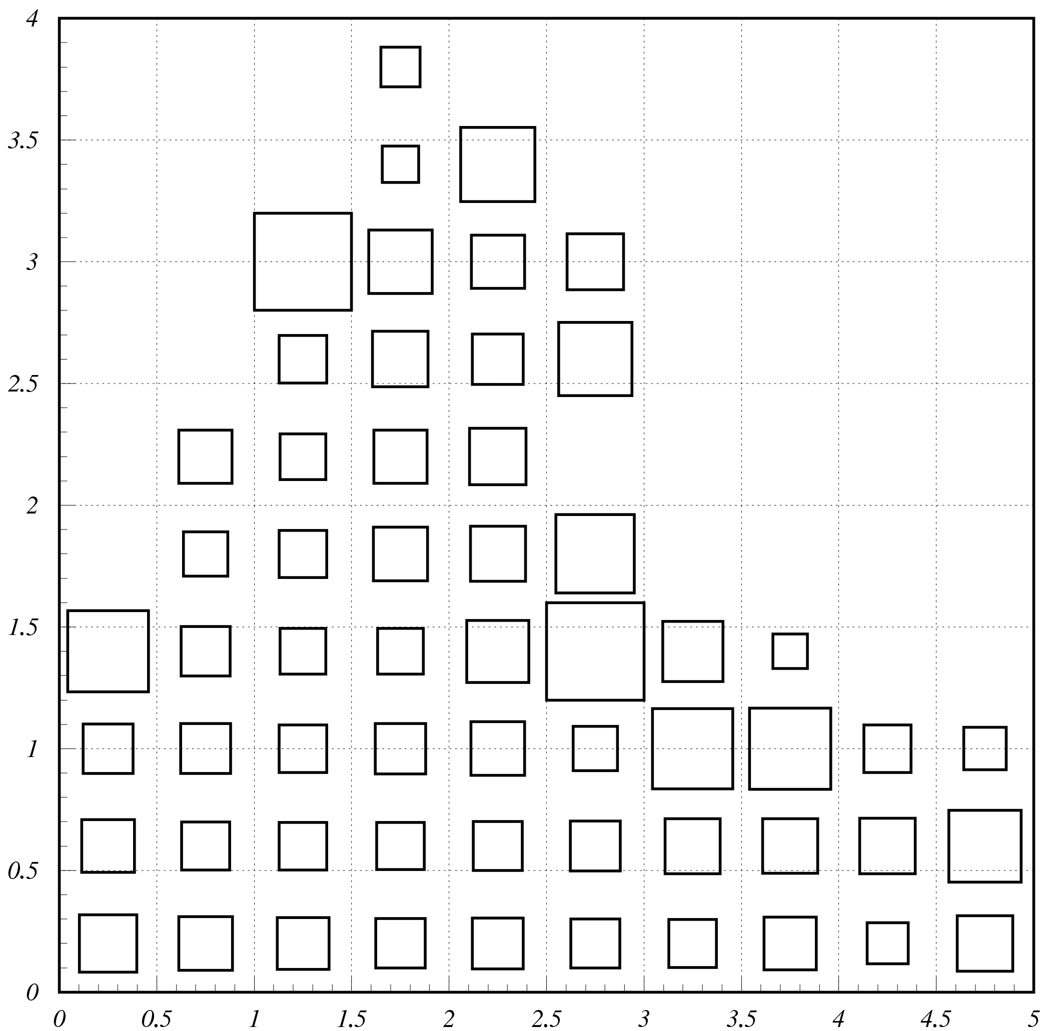


$1 : K_S$

$2 : \pi^-$

$3 : \pi^+_{slow}$

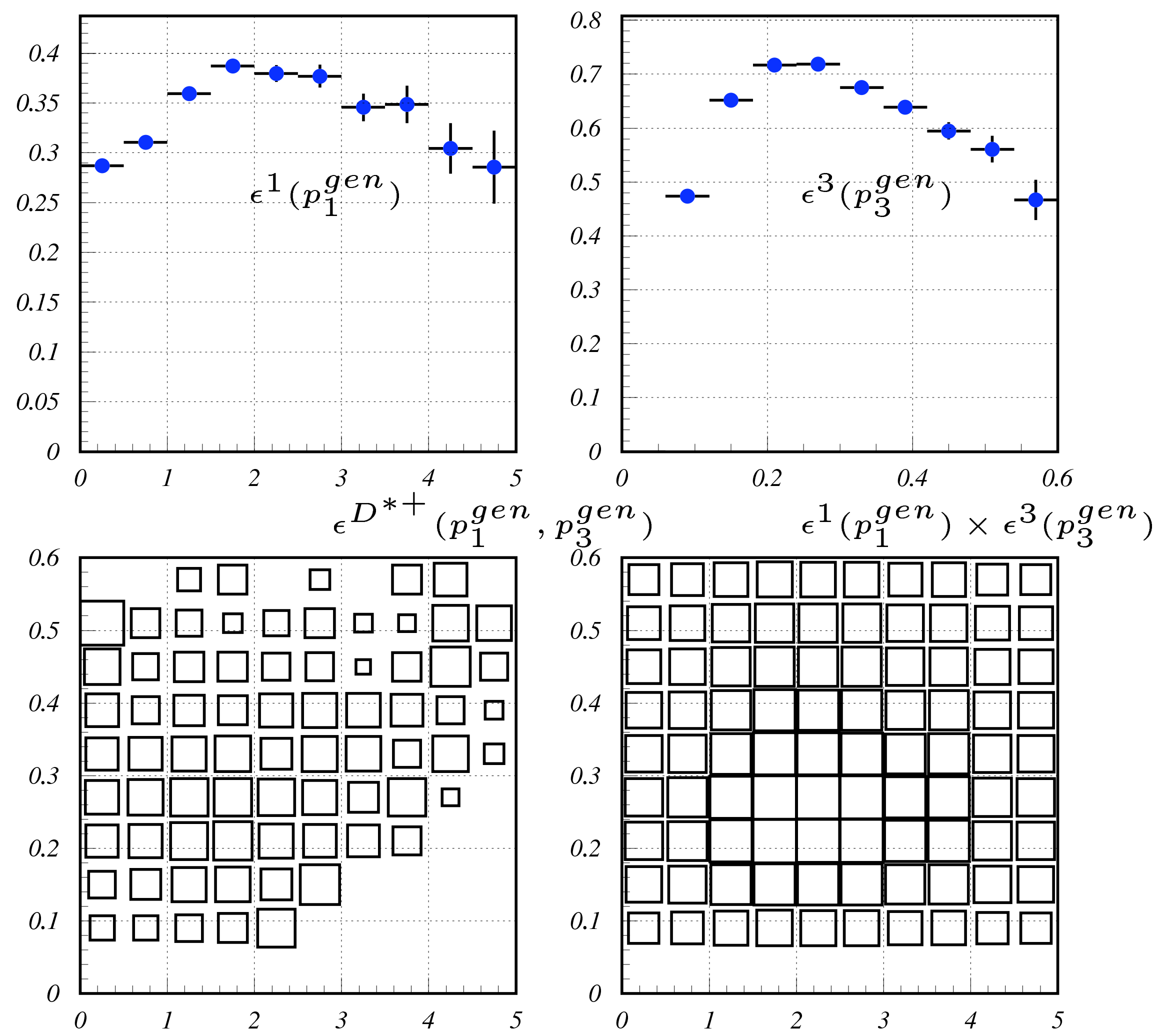
Ratio of $\epsilon^{D^{*+}}(p_1, p_2)$ and $\epsilon^1(p_1) \times \epsilon^2(p_2)$, in $D^0 \to K_S\pi^+\pi^-$



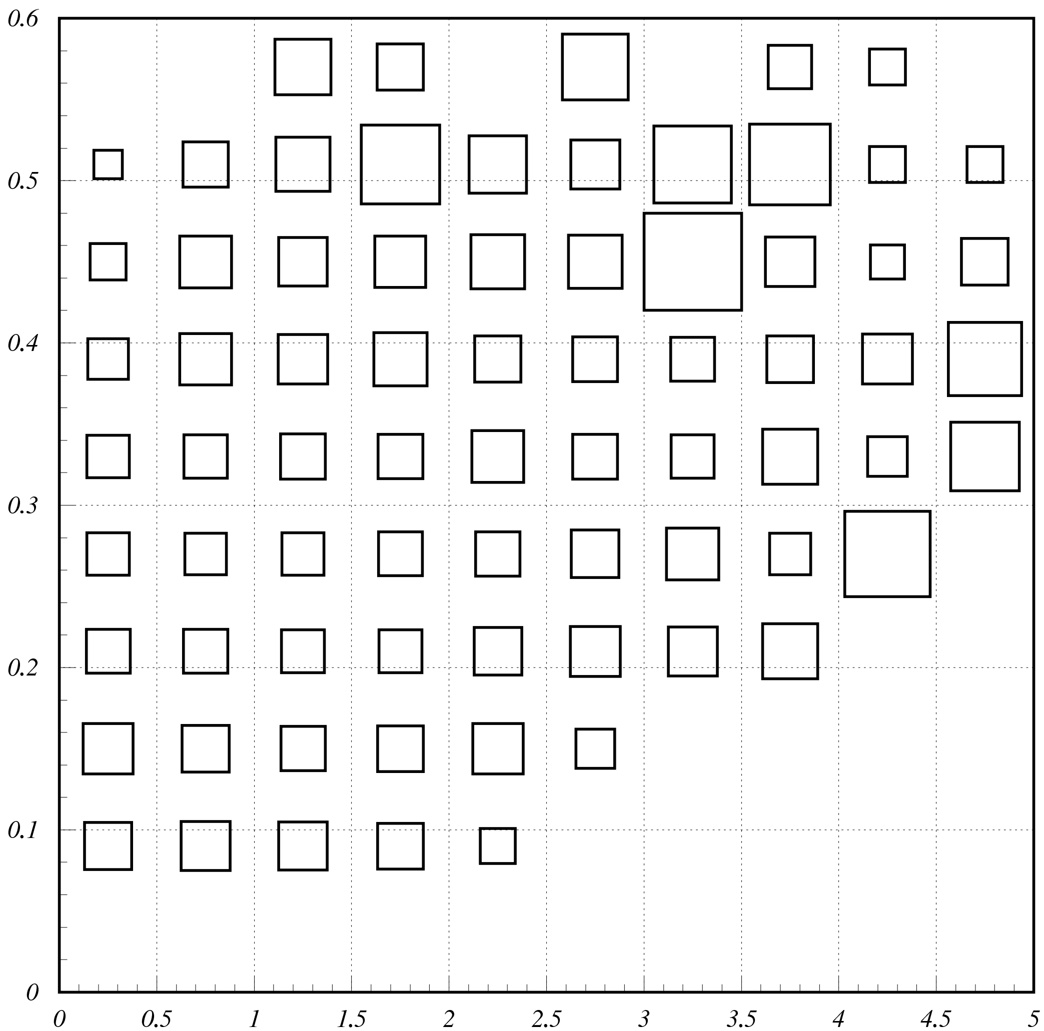
The ratio is flat

There is factorizability

Factorizability in $D^0 \to K_S\pi^+\pi^-$ continues....



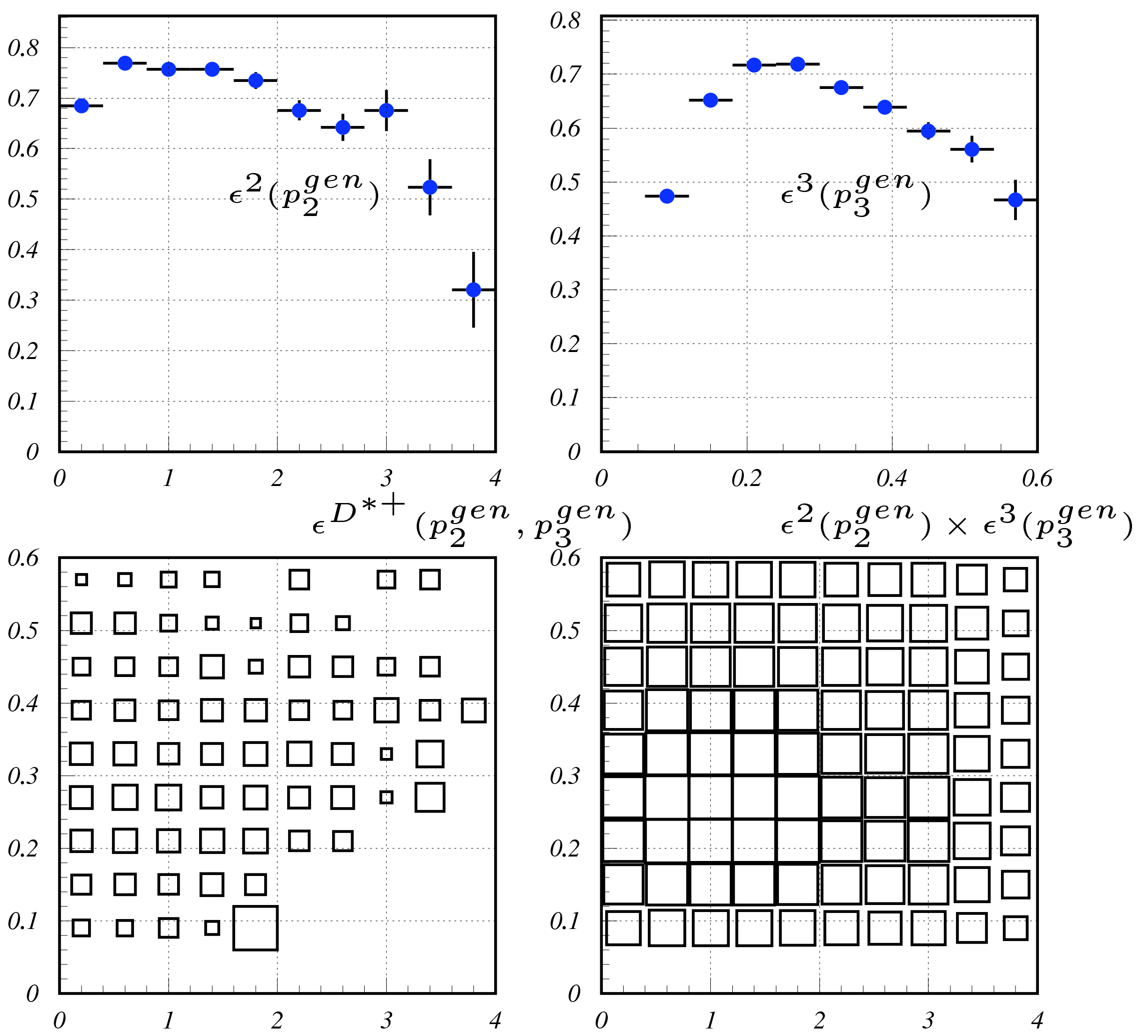
Ratio of $\epsilon^{D^{*+}}(p_1, p_3)$ and $\epsilon^1(p_1) \times \epsilon^3(p_3)$, in $D^0 \to K_S\pi^+\pi^-$



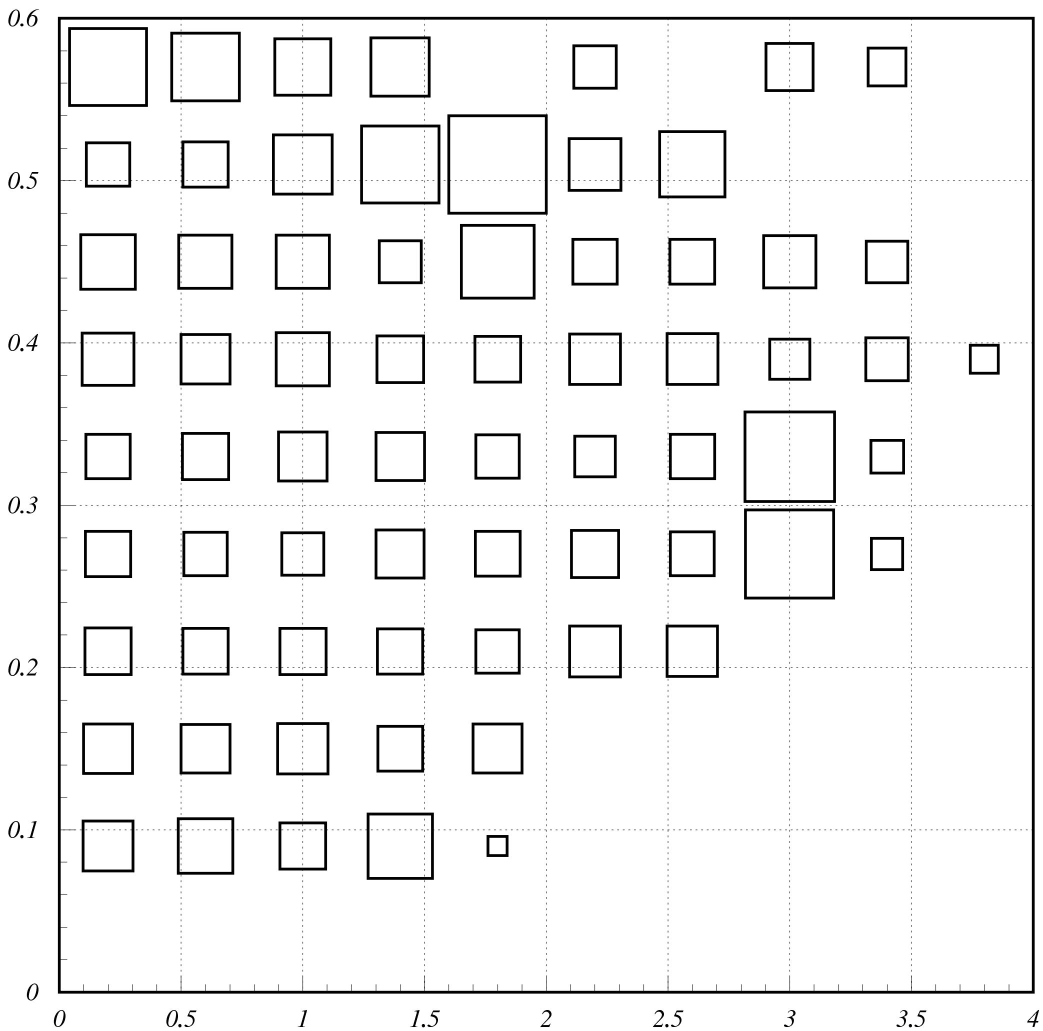
The ratio is flat

There is factorizability

Factorizability in $D^0 \to K_S\pi^+\pi^-$ continues....



Ratio of $\epsilon^{D^{*+}}(p_2,p_3)$ and $\epsilon^2(p_2) \times \epsilon^3(p_3)$, in $D^0 \to K_S\pi^+\pi^-$



The ratio is flat

There is factorizability

Future Course

- *Any improvements in efficiency study and fitting*
- *Add charge conjugate modes*
- *Skim and analyze small amount of data say exp(7+9+11+13),* $\int \alpha \, dt = 32.407 fb^{-1}$
  - **crosscheck with MC results. eg Signal and K^0 momentum spectra**
  - **preliminary asymmetry can be calculated as all quantities will be available**
  - **can compare with some of Roman's results previously carried out at Belle**
- *Background study*
- *Skim and analyze available data set*
- *Systematics study and Final asymmetry calculation*