Dalitz Analyses at CLEO-c

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Introduction

- **CESR-c/CLEO-c are in the beginning of the 1st year of experimental program [CLNS 01/1742, “Yellow book”].**
- **In ∼3 years we are going to collect the highest statistics of few fb^{-1} for** $\psi(3770) \to D\bar{D}$, $\psi(3686)$,
  $D_s\bar{D}_s$ **@ threshold and above** $4100 \le \sqrt{s} \le 5000$ MeV,
  J/ψ **decays.**
- **We plan extensive Dalitz plot analyses of** D, D_s, J/ψ, $\psi(3686)$ **decays.**
- **Pilot runs: Oct.2003 - Apr.2004,** $\mathcal{L} \simeq 60$ pb^{-1} **@** $\psi(3770)$**.**
- **Preliminary asset of this data sample for Dalitz analyses of D meson 3-body hadronic decays has been done.**
- **This talk is about: Preliminary look at statistics for Dalitz analyses of D meson decays at CLEO-c.**

Motivations

- **3-body K, π combinations represent a significant fraction of D meson decays. Not all of them are studied well.**
- **Rich set of intermediate states. With high statistics we may improve intermediate resonance parameters.**
- **Clean conditions to study scalars $f_0(980)$, $a_0(980)$ in coupled channels.**
- **Light scalars $f_0(600)$, κ ?**
- **Mixing and CP violation in charm decays are highly suppressed in the Standard Model. Good place to search for new physics.**
- **There is a room for CP asymmetry in SM: $A_{CP} \sim 10^{-3}$ for some of SCSD (in case of T+P interference), i.e. $D^0 \to \pi^+\pi^-\pi^0$, $D^+ \to K^+K^-\pi^+$.**

Comparison of CLEO-c and CLEO III

CLEO III	CLEO-c
Energy range, $\sqrt{s}$:	
$\sim$**10 GeV ($\Upsilon(nS)$, $n = 1, ..., 5$)**	J/ψ, $\psi(3686)$, $\psi(3770)$, $2m(D^{(*)}_{(s)}) \leq \sqrt{s} \leq$ **5 GeV**
D-meson production mechanism:	
$e^+e^- \to c\bar{c}(\text{continuum}) \to D^{(*)}_{(s)} + X$	$e^+e^- \to \psi(3770) \to D\bar{D}$
$e^+e^- \to \Upsilon(4S) \to B\bar{B} \to D^{(*)}_{(s)} + X$	
High multiplicity events,	**Clean $D\bar{D}$ pairs,**
D**-s are boosted**	D**-s almost at rest**
Tagging:	
$D^{*+} \to D^0\pi^+$, π^+**-tagging**	$D\bar{D}$, **one of D-s can be used as a tag**
Quantum coherence [1]:	$\psi(3770) \to D\bar{D}$, $C(D\bar{D}) = -1$, **opposite CP D-s**
	$e^+e^- \to \pi^0 D\bar{D}$, $C(D\bar{D}) = -1$, **opposite CP D-s**
	$\psi(4140) \to \gamma D\bar{D}$, $C(D\bar{D}) = +1$, **the same CP D-s**

[1] M. Gronau, Y. Grossman and J.L. Rosner, hep-ph/0103110

CLEO Experience in Dalitz Analyses

- $D^0 \to K^-\pi^+\pi^0$, **CLEO II, PR D v.63, 092001 (2001);** $\leftarrow$ **our formalism**
  PRL v.87, No.7, 071802 (2001) $\leftarrow$ **search for CP violation**
- $D^0 \to K^0_S\pi^+\pi^-$, **CLEO II.V, PRL 89, 251802 (2002), hep-ex/0207067;**
  Search for CP violation, accepted by PRD, hep-ex/0311033
- $D^0 \to K^0_S\eta\pi^0$, **CLEO II.V, PRL 93, 111801 (2004), hep-ex/0405011.**
  First direct observation of $a_0(980)$ in D meson decays.
- $D^0 \to \pi^+\pi^-\pi^0$, **CLEO II.V, preparing for publication (see i.e. Moriond 2003, hep-ex/0305006)**

Current Dalitz Analyses at CLEO

- $D^0 \to K^0_S \pi^0 \pi^0$, **CLEO II, III, c**
- $D^0 \to K^- K^+ \pi^0$, **CLEO III, c**
- $D^0 \to K^0_S \pi^+ \pi^-$ **versus CP tag, CLEO-c**
- $D^0 \to K^- \pi^+ \pi^0$, **CLEO-c, consistency check with CLEO II analysis**
- $D^+ \to K^- \pi^+ \pi^+$, $\pi^- \pi^+ \pi^+$, **CLEO-c, check for light scalars**
- **More modes for Dalitz plot analyses are considered below**

Considered modes

- **All possible 3-body K, π combinations.**
- **Few $K\eta\pi$ combinations.**
- **CF or SCS in most cases.**

Particle & Event selection

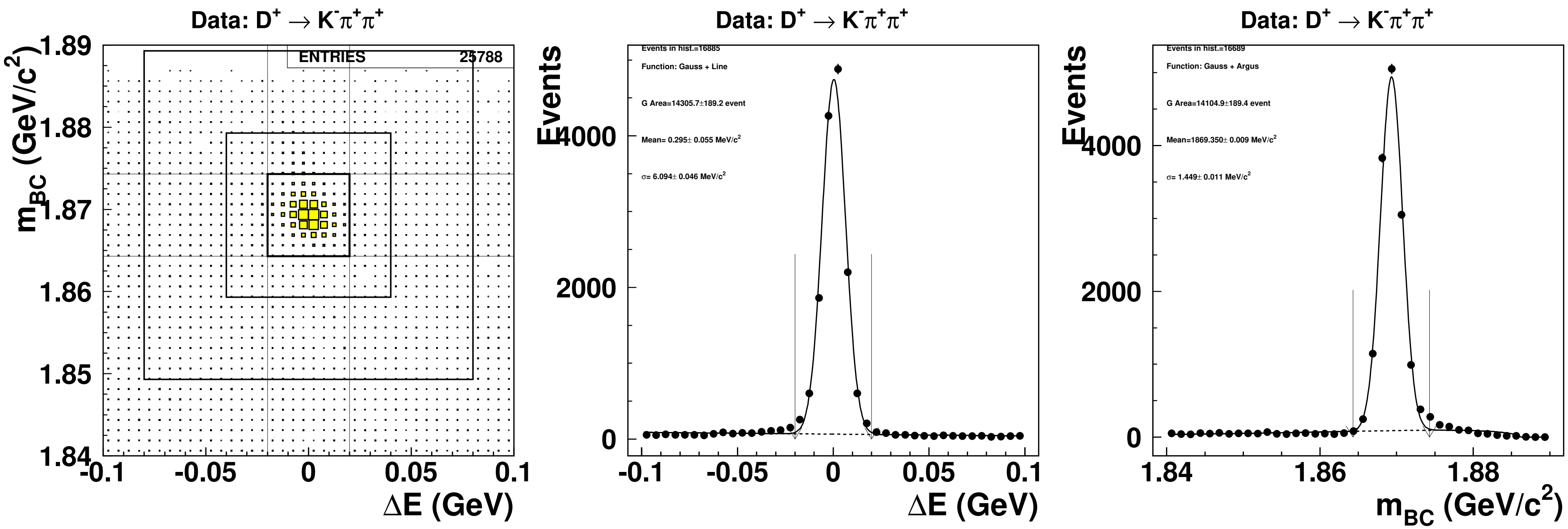
- **Use "DTag skim" [internal pub.: CLEO-c D Tagging for Summer 2004 Analyses].**
- **Particle selection algorithms:**
  - ▷ K/π **track selection:** $50\ \mathrm{MeV/c} \le \mathrm{p} \le 2000\ \mathrm{MeV/c}$, **"good" track fit quality, track origin is consistent with I.P. (excluding** π **tracks for** K_S^0 **vertices),** $|\cos\theta| < 0.93$
  - ▷ **Particle ID: combined RICH and dE/dx depending on track** p **and** $\cos\theta$
  - ▷ π^0 **and** η **selection:** $E_\gamma > 30\ \mathrm{MeV}$, **isolated shower using** E_9/E_{25} **threshold scheme, "good"** $m_{\gamma\gamma}$ **fit quality,** $|m_{\gamma\gamma} - m_{\pi^0(\eta)}| < 3\sigma_{\gamma\gamma}$
- **Variables for signal selection:**

$$\mathbf{\Delta E = E_{cand} - E_{beam}}$$

$$\mathbf{m_{BC} = \sqrt{E_{beam}^2 - p_{cand}^2}}$$

Yield estimate

- **A signal yield for each mode is estimated from the m_{BC} vs ΔE slices:**
  - ▷ m_{BC} **at** $|\Delta E| < 20$ MeV**: Gaussian (sig) + ARGUS function (bkg).**
  - ▷ ΔE **at** $|m_{BC} - m_D| < 5$ MeV/c^2**: Gaussian (sig) + linear function (bkg).**



- **It is shown that the yields obtained from two spectra are statisticly consistent.**

Yield estimate (cont.)

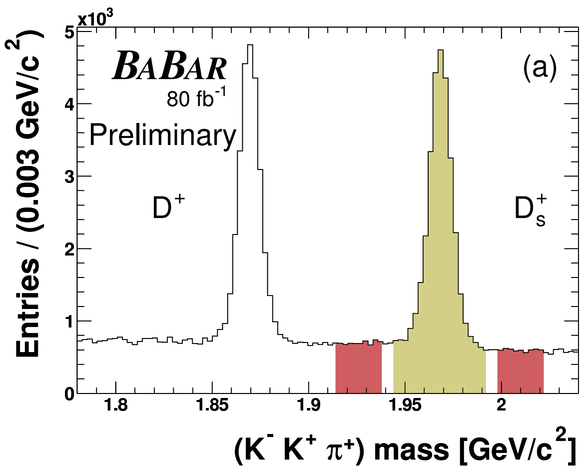
	D^0			D^+		
Mode	Final State	BR,%	Yield	Final State	BR,%	Yield
$\pi\pi\pi$	$\pi^0\pi^0\pi^0$	N/A	95	$\pi^+\pi^0\pi^0$	N/A	189?
	$\pi^+\pi^-\pi^0$	0.73(5)	1937	$\pi^+\pi^+\pi^-$	0.31(4)	714
$K\pi\pi$	$K_S\pi^0\pi^0$	∼1.8/2	537	$K_S\pi^+\pi^0$	9.7(3.0)/2	4134
	$K_S\pi^+\pi^-$	5.97(35)/2	4755	$K^-\pi^+\pi^+$	9.2(6)	14105
	$K^-\pi^+\pi^0$	13.0(8)	15887			
$KK\pi$	$K_SK\pi$	∼1/2	1174	$K_SK_S\pi^+$	∼2/4	398
	$K^-K^+\pi^0$	0.124(35)	258	$K_SK^+\pi^0$	N/A	151
	$K_SK_S\pi^0$	<0.059	228	$K^-K^+\pi^+$	0.89(8)	1162
KKK	$K_SK^+K^-$	1.03(10)/2	358	$K_SK_SK^+$	1.8(8)/4	66
	$K_SK_SK_S$	0.092(16)	32	$K^-K^+K^+$	N/A	∼0
$K\eta\pi$	$K_S^0\eta\pi^0$	∼0.5	94	$K_S^0\eta\pi^+$	N/A	89
	$K^-\eta\pi^+$	∼1	281			

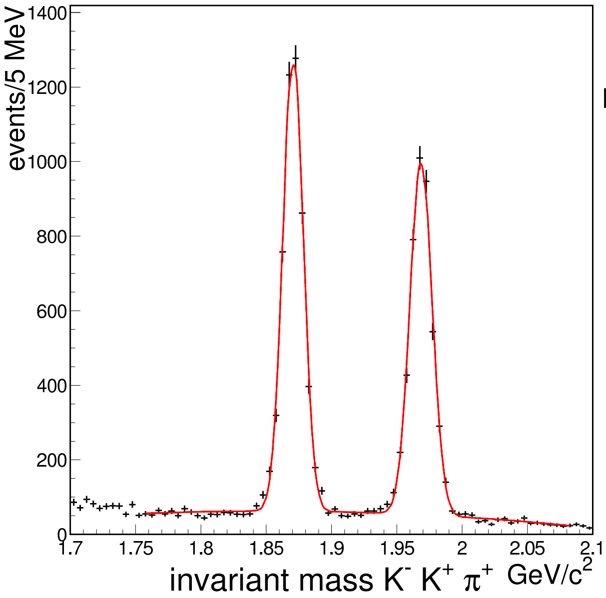
▷ **BLACK - preliminary estimate**

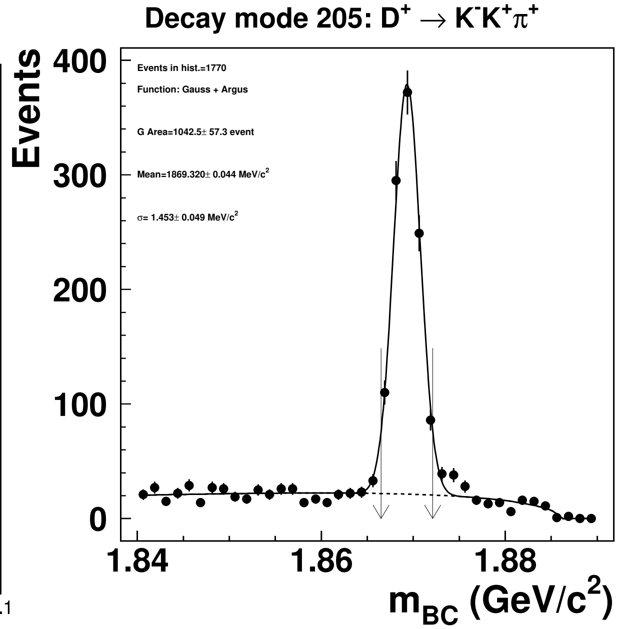
▷ **BLUE - VERY preliminary estimate (not all events were selected)**

Comparison of CLEO-c with other experiments

$D^+_{(s)} \to K^- K^+ \pi^+$ mass spectrum for
BaBar(hep-ex/0408136), FOCUS(E831)(hep-ex/0407014), and CLEO-c



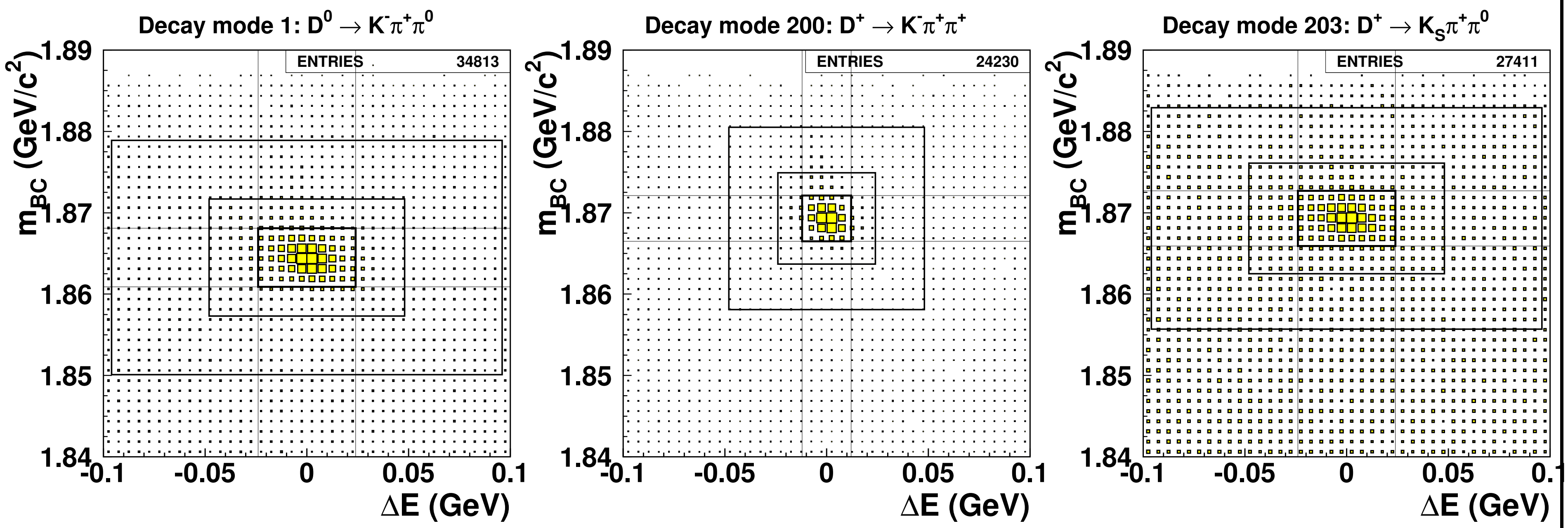




- **The 60/pb pilot runs with CLEO-c give comparable statistics**
- **Lower background**
- **The mass resolution is $\geq \times 4$ better.**

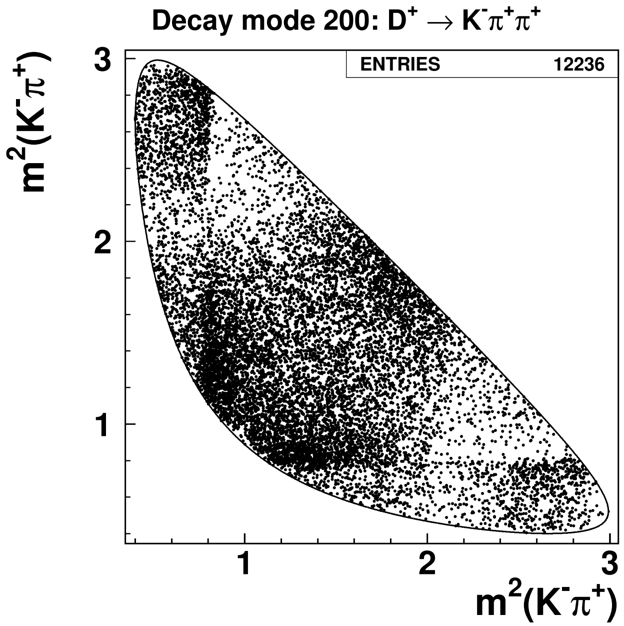
Event selection for Dalitz plot

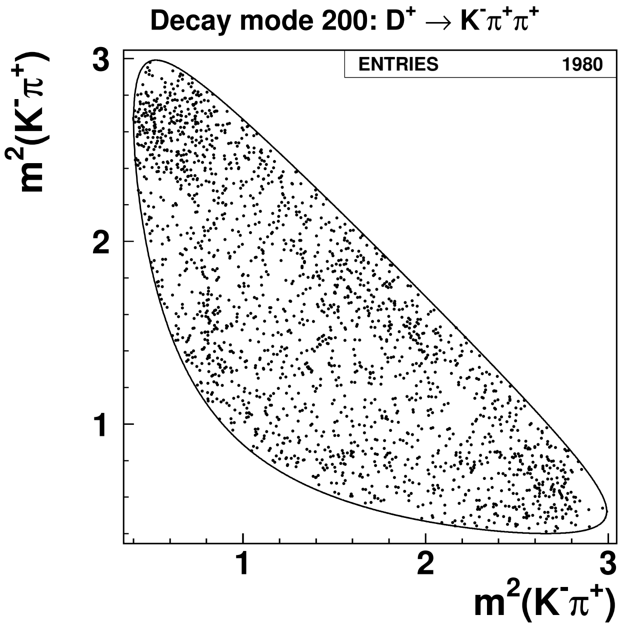
- **Signal region:** 2×2 **in terms of** $\sigma(m_{BC}) \times \sigma(\Delta E)$, **i.e.**
  $|m_{BC} - m_D| < 2\sigma(m_{BC})$,
  $|\Delta E| < 2\sigma(\Delta E)$,
- **Background region:** $8 \times 8 - 4 \times 4$ **in terms of** $\sigma(m_{BC}) \times \sigma(\Delta E)$.

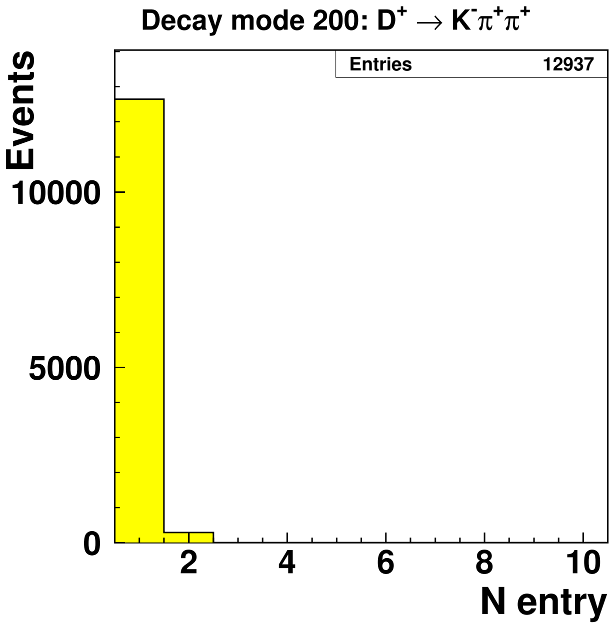


Event candidates for Dalitz plot $D^+ \to K^-\pi^+\pi^+$

- **Signal, Background, and the Number of entries per event:**







- **The first found combination per event only**
- **There is no $\pi^+\pi^+$ Bose symmetry for this plot**
- **The size of background box is $\times 12$ of signal box**

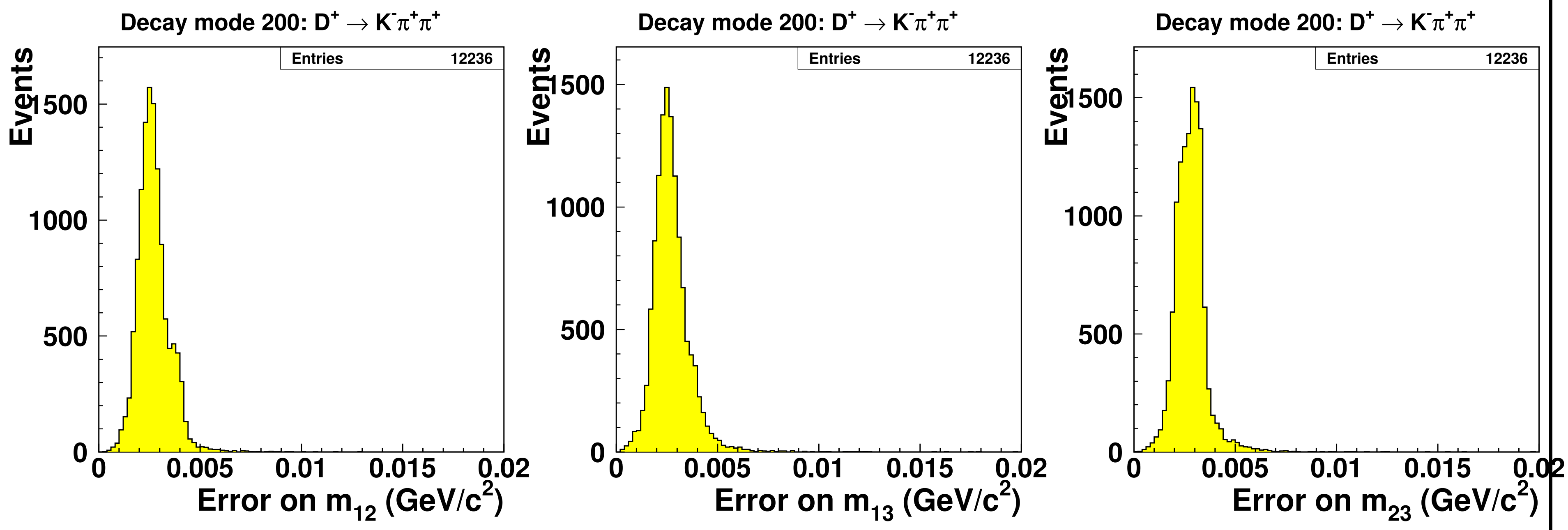
Modes with yield "significant" for DP Analysis

Modes with a signal yield ≥ 200 events / 60 pb^{-1}:

D^0			
Final State	Sig/Bkg box	$\sigma(m_{BC})$ / Cut, MeV/c^2	$\sigma(\Delta E)$ / Cut, MeV
$K^-\pi^+\pi^0$	13696/6915	1.88/1.9	11.8/12
$K_S\pi^+\pi^-$	3824/2848	1.46/1.5	6.11/6
$\pi^+\pi^-\pi^0$	2543/9540	1.84/1.8	12.6/12
$K_SK\pi$	987/1086	1.49/1.5	5.3/5
$K_S\pi^0\pi^0$	767/2098	2.4/2.5	15.7/16
$K_SK^+K^-$	296/143	1.61/1.6	4.2/4
$K^-\eta\pi^+$	337/968	2.2/2.2	7.9/8
$K^-K^+\pi^0$	307/1007	1.50/1.6	10.4/10
$K_SK_S\pi^0$	192/773	2.0/2.0	9.9/10
D^+			
$K^-\pi^+\pi^+$	12236/1980	1.43/1.4	6.02/6
$K_S\pi^+\pi^0$	3983/6538	1.71/1.7	12.3/12
$K^-K^+\pi^+$	1067/916	1.45/1.4	4.48/5
$\pi^+\pi^+\pi^-$	609/1200	1.37/1.4	6.6/7
$K_SK_S\pi^+$	327/732	1.45/1.4	5.41/5

Typical Errors on m_{12}, m_{13}, and m_{23}

Error on invariant mass is propagated from the track fit error matrix:



Preparing to global fits

- **Web based data access interface**
- **Dalitz data file format:**

```
http://www.lns.cornell.edu/ ... /dalitz.sig_mode200 :
---------------------------------------------------------------------------------


* Decay : D+  -> K   PI  PI
* Mode ID in DTag skim = 200
* Sig/Bkg/eff/Bmc (1/2/3/4) = 1
* Masses: m0 -> m1 m2 m3
* m0 = 1.8693000
* m1 = 0.4936770
* m2 = 0.1395700
* m3 = 0.1395700
* sigma(MBC), sigma(DeltaE) = 0.0014000 0.0060000
* N  m2_12    m2_13    m2_23    errm2_12 errm2_13 errm2_23 Charge D,1,2,3    MBC      DeltaE     Run Event
  1  0.492643 2.441234 0.890597 0.001415 0.011099 0.004345  1 -1  1  1  1.870771  0.010888 200979   654
  2  1.131868 1.895440 0.738138 0.004386 0.008098 0.003997 -1  1 -1 -1  1.870276 -0.004554 200979 10049
  3  2.807639 0.750044 0.226451 0.012928 0.004196 0.002874 -1  1 -1 -1  1.869671  0.001038 200979 17181
  4  1.399950 1.506813 0.859344 0.005296 0.006403 0.004358  1 -1  1  1  1.870348 -0.004309 200981   915
  5  1.362606 1.443486 0.997160 0.005546 0.006045 0.005128  1 -1  1  1  1.868591  0.008198 200981 21489

...
```

Unbinned Maximum Likelihood Fit

Notations: $D^0 \to P_1 P_2 P_3$: $x = m_{12}^2$, $y = m_{13}^2$, $z = m_{23}^2$.

Unbinned maximum likelihood fit: minimization of the function $\mathcal{F}$,

$$\mathcal{F} = -2 \sum_{\text{events}} \ln \mathcal{L}(+\chi^2)$$

where $\mathcal{L}$ is a p.d.f. for the event density on the DP.

In the perfect world of kinematics:

$$\mathcal{L} \propto d\Gamma = \frac{1}{(2\pi)^3} \frac{1}{32 m_{D^0}^3} \overline{|\mathcal{M}|^2} dx dy$$

In the real life:

$$\mathcal{L} = F \cdot G(m_{cand,D}) \cdot \frac{\varepsilon(x,y)|\mathcal{M}(x,y)|^2}{N_S} + (1-F) \cdot \frac{B(x,y)}{N_B}$$

$\otimes$ **smearing with resolution.**

Matrix element models

$D^0 \to RC \to ABC$, intermediate resonance(s) R of spin J

1. **Sum of Breit-Wigners (a.k.a. Isobar Model):**

$$\mathcal{M} = \mathbf{a_{NR} e^{i\varphi_{NR}}} + \sum_{\mathbf{R}} \mathbf{a_R e^{i\varphi_R}} \mathcal{A}_\mathbf{J}(\{\mathbf{A}, \mathbf{B}, \mathbf{C}\}|\mathbf{R}), \qquad \mathbf{a_{R_1} = 1}, \quad \varphi_{\mathbf{R_1}} = \mathbf{0}, \qquad (1)$$

2. **K-Matrix formalism (FOCUS):**
   The same as Isobar model, but the 2-body S wave (J=0) is expressed in terms of K-Matrix

3. **Other models:**
   - ▷ **Field theory motivated approach** based on N.N. Achasov et al. publications: PRD v.56, N7, 4084 (1997) (in stead of K-matrix), hep-ph/0405128 (better approach than Flatte), etc.
   - ▷ **CMB** nuclear physics model
     R.E. Cutkosky, et al., PR D 20, 2782-2803, 2804-2838, 2839-2853 (1979), T.P. Vrana, et al., Phys. Repts 328, 181 (2000), (nucl-th/9910012).
   - ▷ We need in unitarian, analytical or model independent matrix element parameterization.

Calculations on DP & Observables

$$Fit\ Fraction = \frac{\oint_{PS} |a_R \mathcal{A}_J(ABC|R)|^2 dDP}{\oint_{PS} |\sum_R a_R e^{i\varphi_R} \mathcal{A}_J(ABC|R)|^2 dDP}$$

Fit Fractions do not add up to 100% due to omitting the interference terms

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Integrated CP asymmetry:

$$A_{CP} = \oint_{PS} \frac{|\mathcal{M}_{D^0}|^2 - |\mathcal{M}_{\overline{D^0}}|^2}{|\mathcal{M}_{D^0}|^2 + |\mathcal{M}_{\overline{D^0}}|^2} dDP \Big/ \oint_{PS} dDP$$

Search for CP violation in amplitudes and phases:

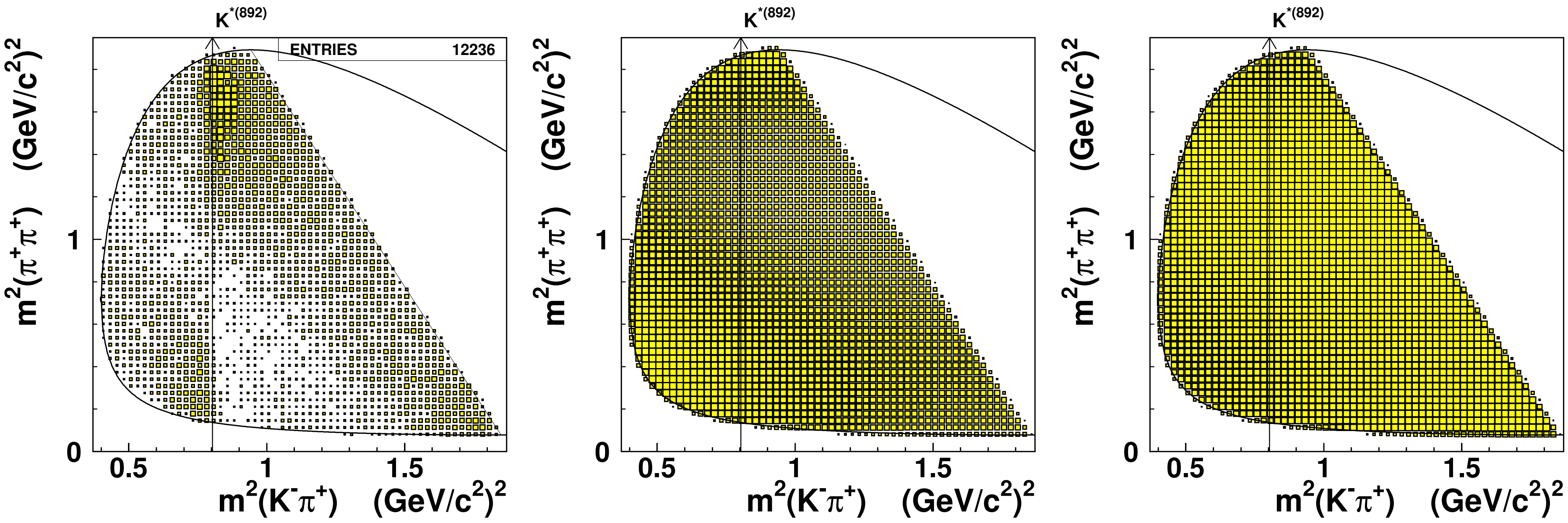
$a_r e^{i\varphi_r} \longrightarrow a_r e^{i\delta_r}\left(1 \pm \frac{b_r}{a_r} e^{\pm i\phi_r}\right)$, **where**

a_r **and** δ_r **- CP conserving parameters;**

b_r **and** ϕ_r **- CP violating parameters (difference between** $\mathbf{D^0}$ **and** $\overline{\mathbf{D^0}}$ **)**

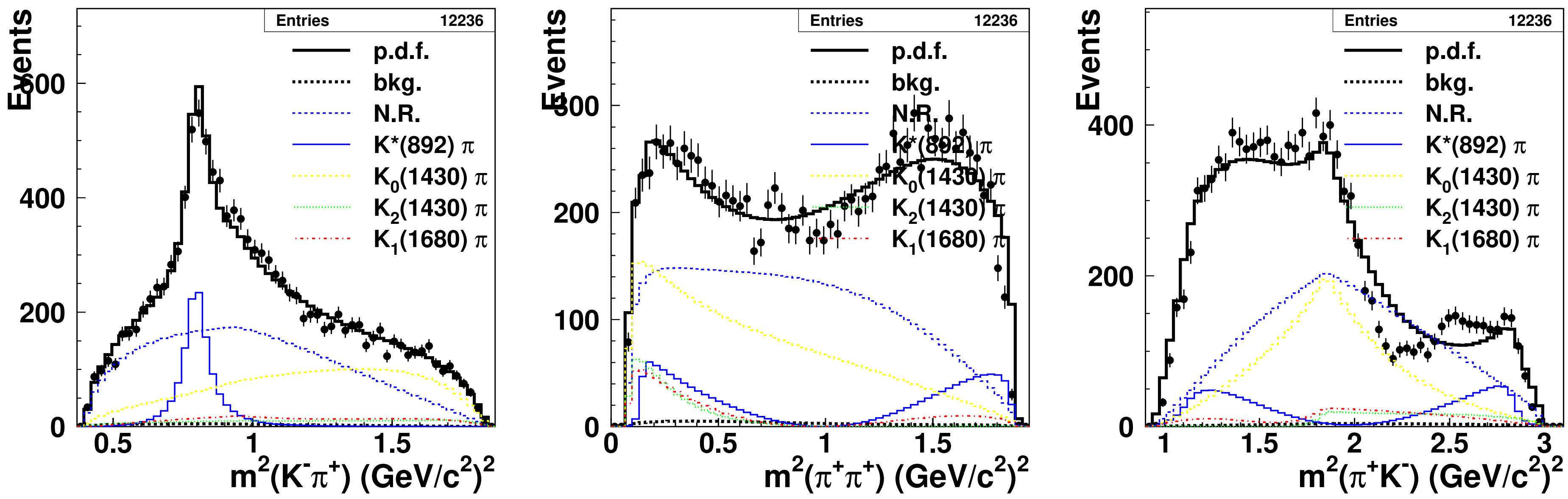
Preliminary Dalitz plot for $D^+ \to K^-\pi^+\pi^+$,

example of fits to background and efficiency



- $K^*(892)\pi^+$ is the only easy recognizable signal on this DP. Can you see the κ?
- Background is not uniform, but small ($\sim$1.4% in case of $D^+ \to K^-\pi^+\pi^+$).
- Efficiency (from the phase space MC) is uniform

Preliminary fit projections for $D^+ \to K^-\pi^+\pi^+$



- In present we work in the frame of isobar model.
- All well known low mass $K\pi$ resonances are included.
- Keep trying to get a consistent description of data.

Summary

- CESR-c/CLEO-c are successfully operating in the beginning of the 1st year of experimental program.
- We plan extensive Dalitz plot analyses of D, D_s, $\psi(3686)$, J/ψ decays as far as statistics is available.
- Preliminary asset of the pilot runs $\sim$60 pb^{-1} statistics for the Dalitz analyses of D meson 3-body hadronic decays has been done.
- Currently we are working on Dalitz plot fits of few D meson decays.
- New statistics will be added at $\psi(3770)$ in a few months.
- In a year we expect to present results of few Dalitz analyses.