PRODUCTION RATIOS OF D MESONS AT HERA

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Doktorandenseminar, 10.10.2001

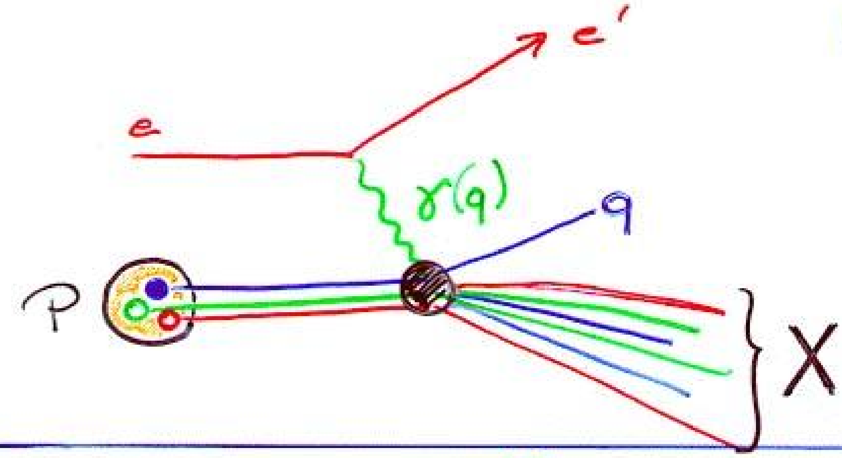
WHY IS IT INTERESTING?

HOW CAN THEY BE MEASURED?

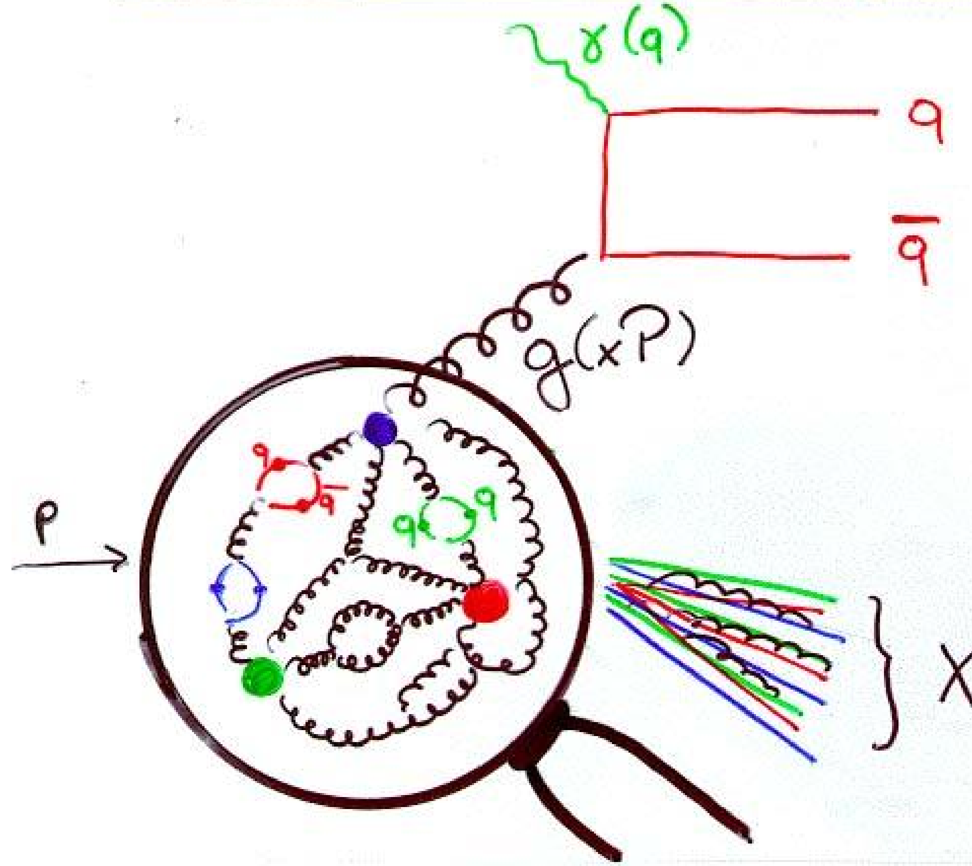
WHAT ARE THE RESULTS?

HERA: PROTON STRUCTURE

MAIN PHYSICAL GOAL OF HERA:
MEASUREMENT OF THE PROTON STRUCTUR F_2



@ small momentum transfer $Q^2 = -q^2$ one sees just the 3 valence quarks



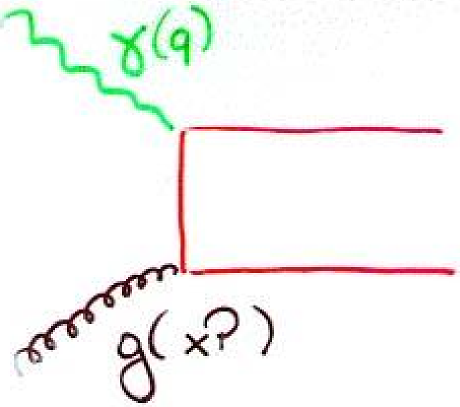
@ higher momentum transfer Q^2 $\hat{=}$ resolution one see the

SEA

of quarks & gluons inside the proton

CHARM & GLUON DENSITIES

BOSON GLUON FUSION (BGF)



$q = u, d, s, c, b$

$\bar{q} = \bar{u}, \bar{d}, \bar{s}, \bar{c}, \bar{b}$

process gives access to gluon density $f_{g/p}$
(part of total structure function)

BGF is main production mechanism for charm & beauty quarks @ HERA

charm density in proton F_2^c gives access to $f_{g/p}$!

for low values of x (small momenta) gluons are dominant inside proton

$f_{\gamma/p}$ is INTERESTING !

Charm Contribution to DIS: Ratio F_2^c/F_2

- Charm contribution F_2^c

  to proton structure function:

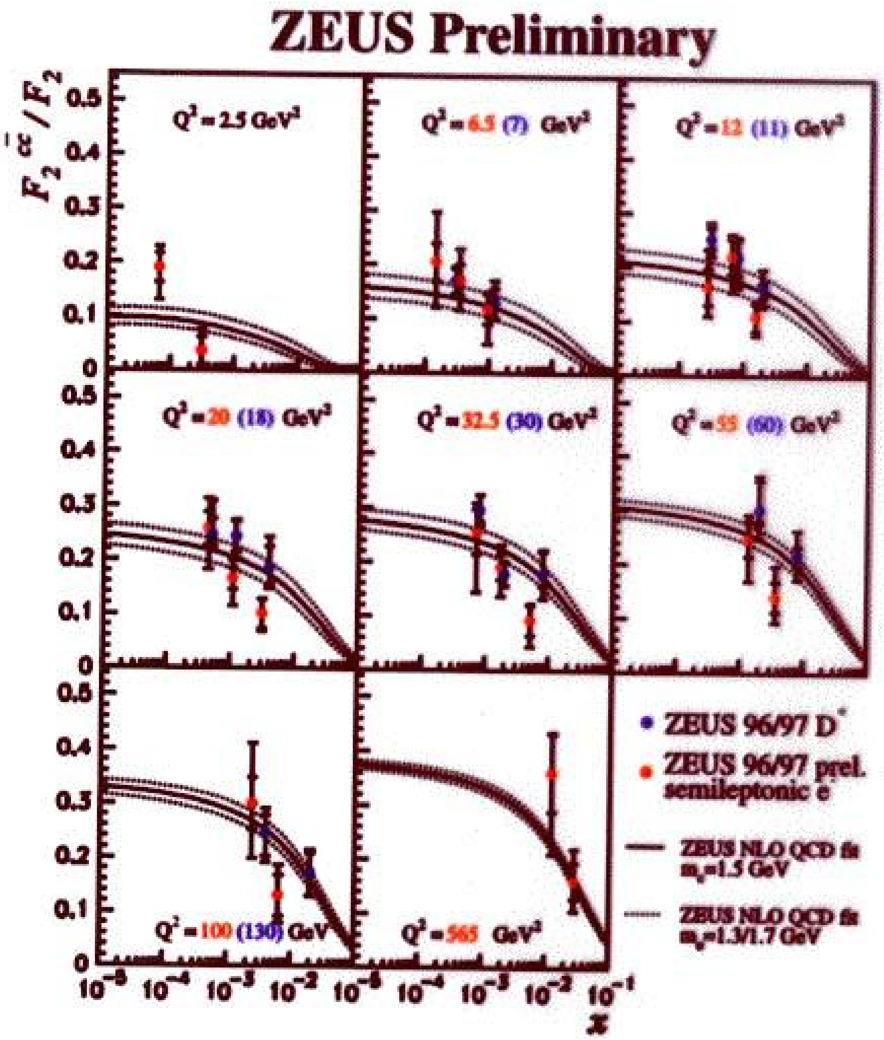
  $$\frac{d^2\sigma(ep\to cX)}{dx\,dQ^2}$$

  $$= \frac{2\pi\alpha}{xQ^4}(1+(1-y)^2)\cdot F_2^c(x,Q^2)$$

  DIS scaling variables:

  x_{Bjorken}, Q^2

→ F_2^c/F_2 is large at low x (where gluons dominate)



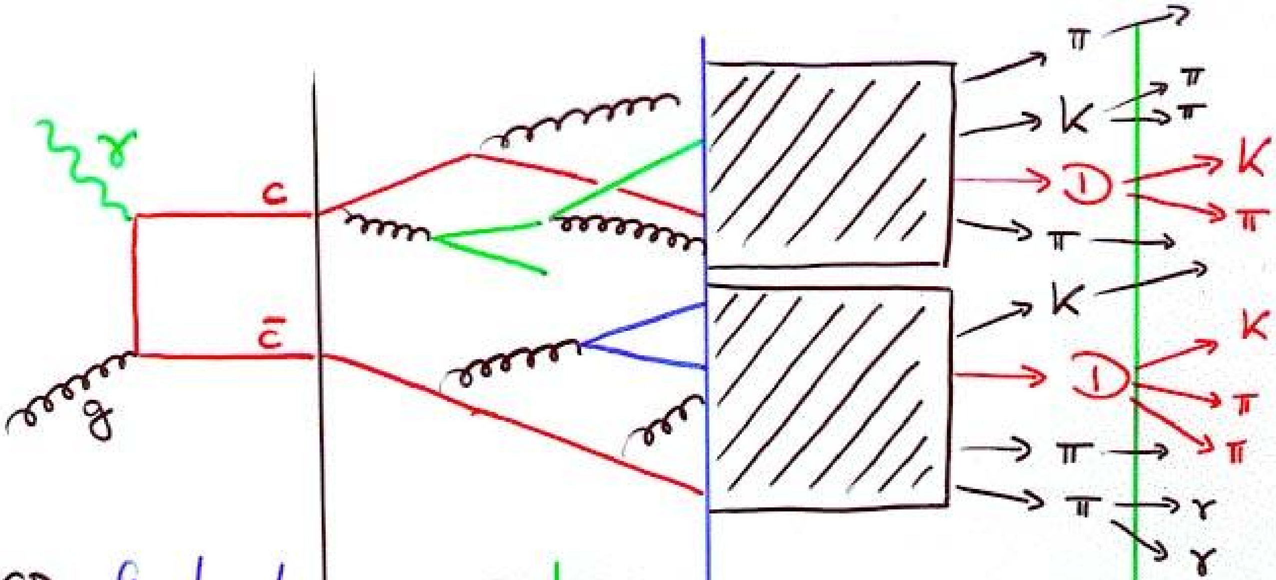
- D^* and semilept. data agree

MEASUREMENTS OF CHARM

Analyses via reconstruction of D mesons

TRANSITION $c \rightarrow D$?

$\Rightarrow$ FACTORISATION !



e.g.: pQCD: fixed order calculations make predictions

(short distances, free partons)

e.g. parton showers

(pQCD inspired)

CLEAN UP: FRAGMENTATION MODELS: soft, long distance (confinement) phenomenological!

e.g. Peterson, Lund Colour Dipol

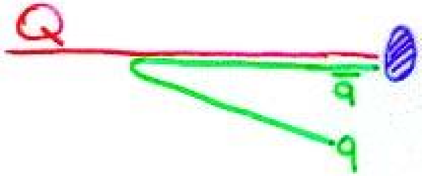
DETECTOR

UNDERSTAND IT ....

... TO STUDY THIS!

INGREDIANCES OF FRAGMENTATION

PETERSON MODEL FOR HEAVY QUARKS:



$H = (Q\bar{q})$

$$\frac{E_H}{E_Q} =: z \quad \text{engery fraction}$$

$\Rightarrow$ $D_Q^H(z) =$ Probability to find hadron H within $[z, z+dz]$

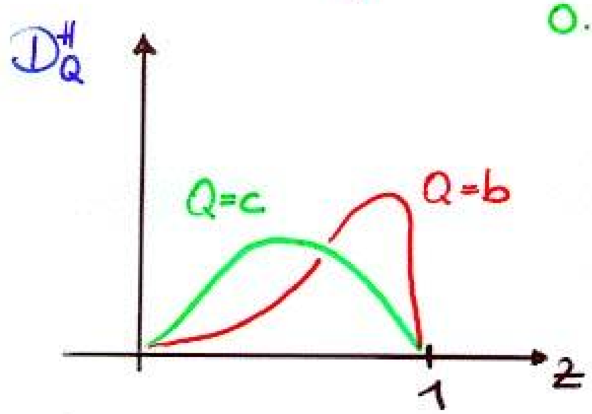
$$= \frac{1}{z}\left(1 - \frac{1}{z} - \frac{\varepsilon}{1-z}\right)^{-2}$$

ε = Peterson parameter describes "hardness" of fragment.

$\approx \frac{m_q^2}{m_Q^2} \approx$ 0.08 for charm, 0.008 for beauty } @ LEP

$\downarrow$

?? universal ??



BUT: @ HERA ep the proton remnant is an additional colour source !

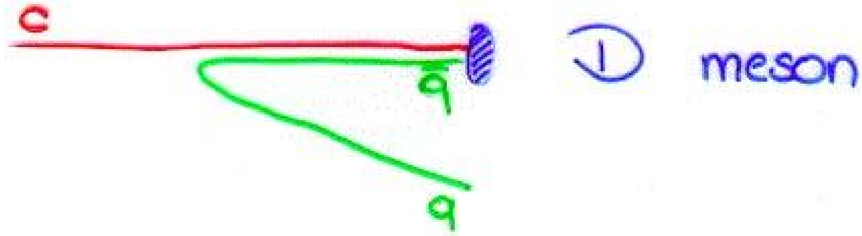
OTHER INGREDIANCES:

flavour mix : $u : d : s \approx 1 : 1 : 0.3$

spin mix : $PS : VM \approx 1 : 3$ (#states)

$\sim \exp(-m_Q^2)$

MEASUREMENT OF FRAGMENTATION



$$\underbrace{D^0 = (c\bar{u}),\quad D^+ = (c\bar{d}),\quad D_s^+ = (c\bar{s})}_{J^P = 0^-\ (PS)},\quad \underbrace{D^{*+} = (c\bar{d})}_{J^P = 1^-\ (VM)}$$

$D^0 : D^+ : D_s^+ \approx> u : d : s$

$D^+ : D^{*+} \approx> PS : VM$

$p_t(D) \approx>$ hardness ε

ADLO resuts (NIM A378, (1996) 101)

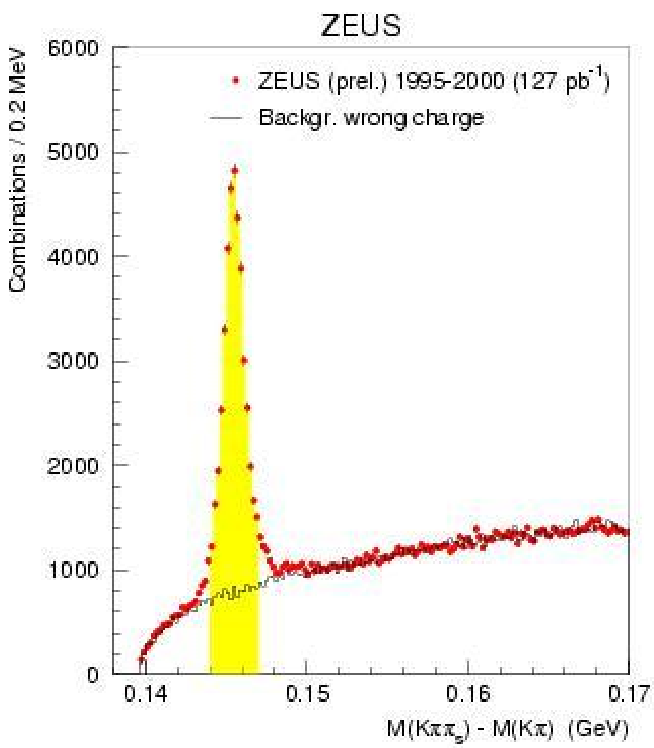
$f(c \rightarrow D^0) = 0.557 \pm 0.053$ (direct $+ (D^{*0} \rightarrow D^0)$ $+ (D^{*+} \rightarrow D^0)$)

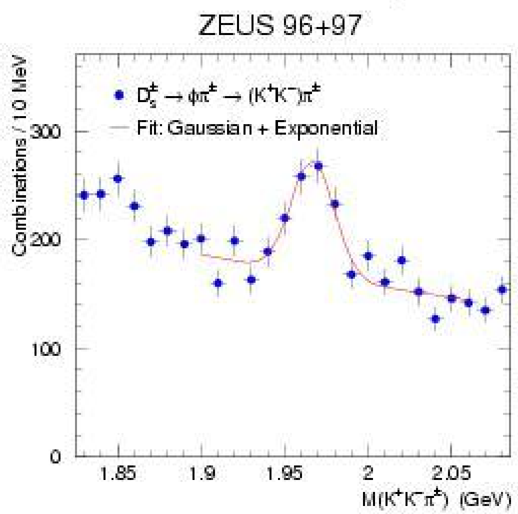
$f(c \rightarrow D^+) = 0.248 \pm 0.037$ (direct $+ (D^{*+} \rightarrow D^+)$)

$f(c \rightarrow D_s^+) = 0.12 \pm 0.03$ (direct $+ (D_s^* \rightarrow D_s)$)

$f(c \rightarrow D^{*+}) = 0.234 \pm 0.10$ (direct + higher excitations)

Charm Tagging and Universality of Charm Fragmentation





$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$ (+ c.c.)

$\Delta M = M(D^{*+}) - M(D^0) \sim m_\pi$

$P_\perp^{D^*} > 2\,\mathrm{GeV}$ and $-1.5 < \eta^{D^*} < 1.5$

In the yellow band under background:

$\boxed{N(D^{*\pm}) = 31350 \pm 240}$ Budapest, abstr. 497

Is $f(c \to D^{*+})$, measured in e^+e^-, the same for e^+p ?

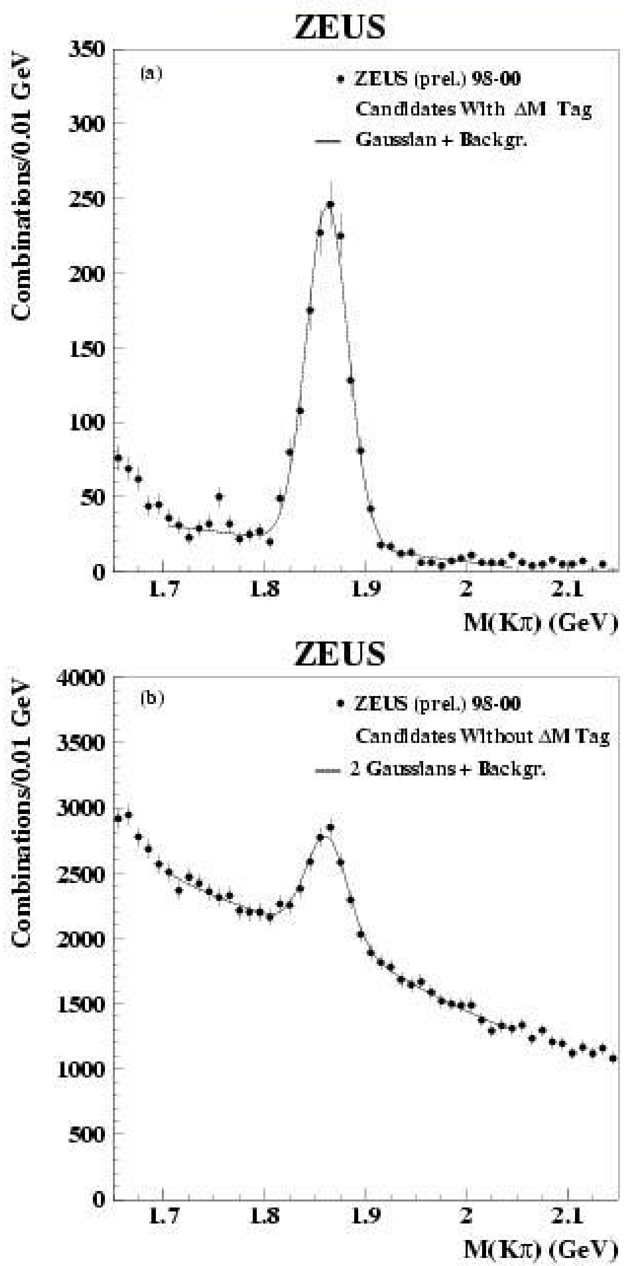
To answer measure other D mesons :

$D_s \to \phi\pi \to (K^-K^+)\pi$

	e^+p	e^+e^-
D_s/D^*	$0.41 \pm 0.07^{+0.03}_{-0.05}$	0.43 ± 0.04
γ_s	0.27 ± 0.05	0.26 ± 0.03

γ_s is the strangeness-suppression factor

Universality of Charm Fragmentation, P_v value



$D^{*\pm}$ and D^0 in PhP (Budapest, abstr. 501)

$$P_v = \frac{Vectro}{Vector+Pseudoscalar} = \frac{D^*}{D^*+D}$$

Assuming: a) $\sigma(D^{*0}) = \sigma(D^{*+})$

b) no sizable distortions from excited D mesons

$$P_v = (\sigma(D^0)/\sigma(D^{*+}) - B_{D^{*+}\to D^0\pi})^{-1}$$

Using : $N(D^0) = 5223 \pm 185$

$N(D^{*\pm}) = 1180 \pm 39$

$$\boxed{P_v = 0.546 \pm 0.045(\text{stat.}) \pm 0.028(\text{syst.})}$$

OPAL : $P_v = 0.57 \pm 0.05$

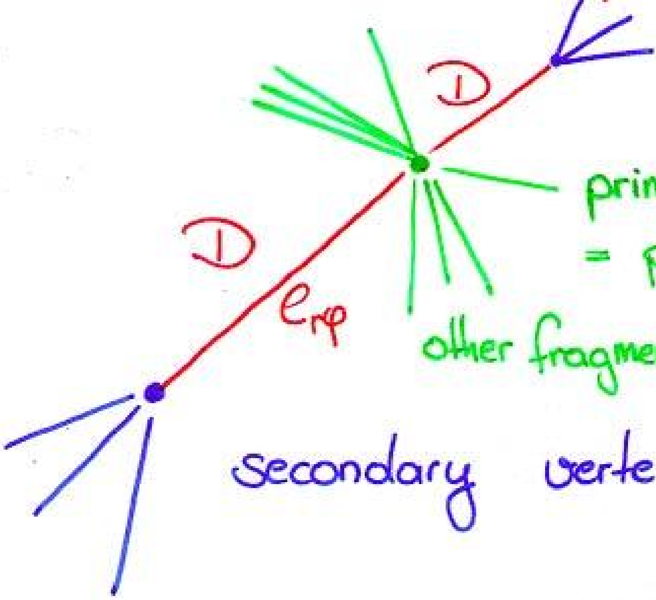
ALEPH : $P_v = 0.595 \pm 0.045$

Charm Fragmentation Fractions are Universal

ANALYSIS IDEA

- use finit life time of D mesons as criteria to suppress combinatorical background from uds (no or much larger life times)

⇒ reconstruct topology:



primary vertex of ep collision = production point

other fragmentation products

secondary vertex = decay point = intersect of decay particles

reconstruct $\underline{\text{decay length } \ell_{r\varphi}}$ (transversal projection)

$$\ell_{r\varphi} = \frac{p_t(D) \cdot t^*}{m(D)}$$

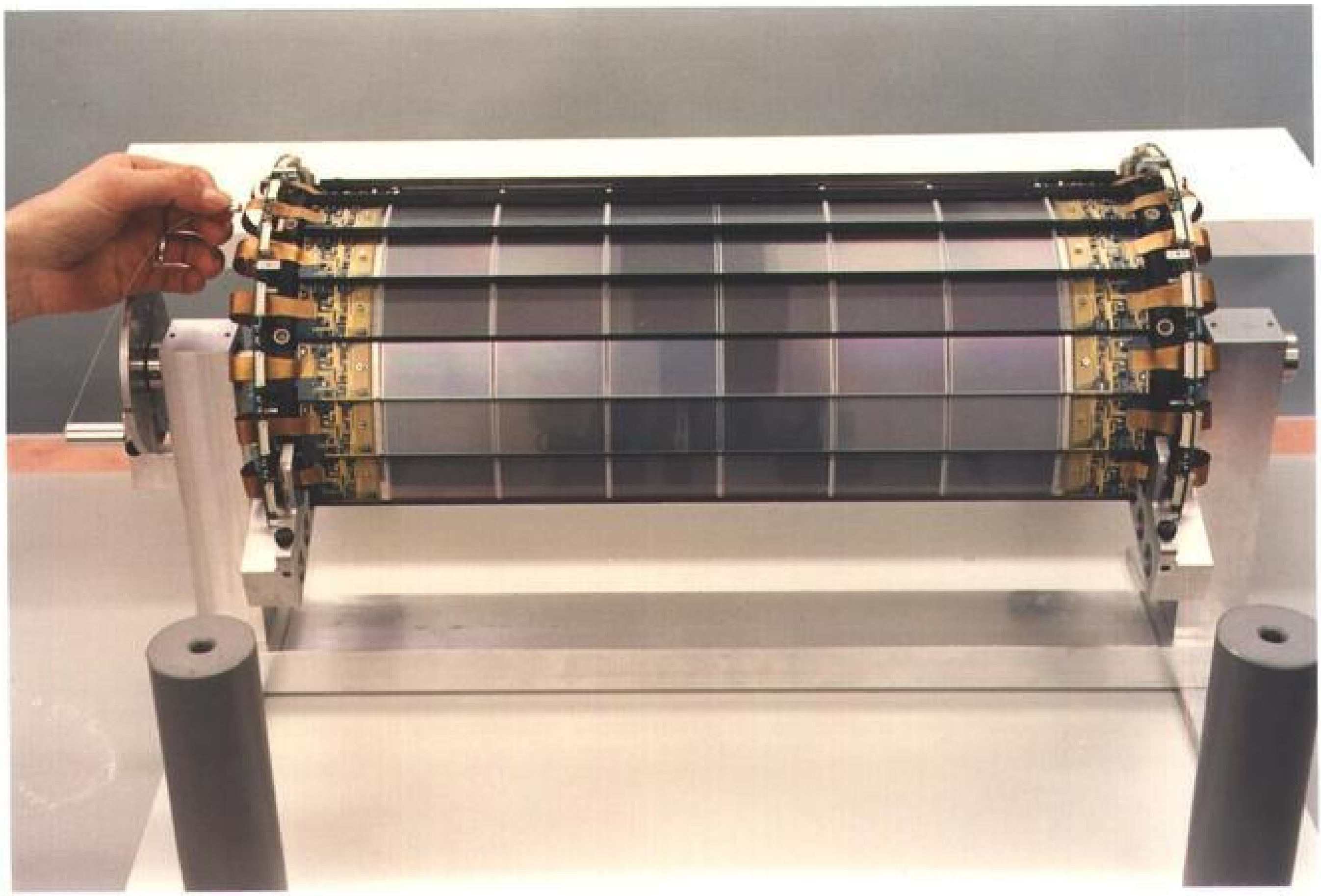
t^* = decay time in rest frame

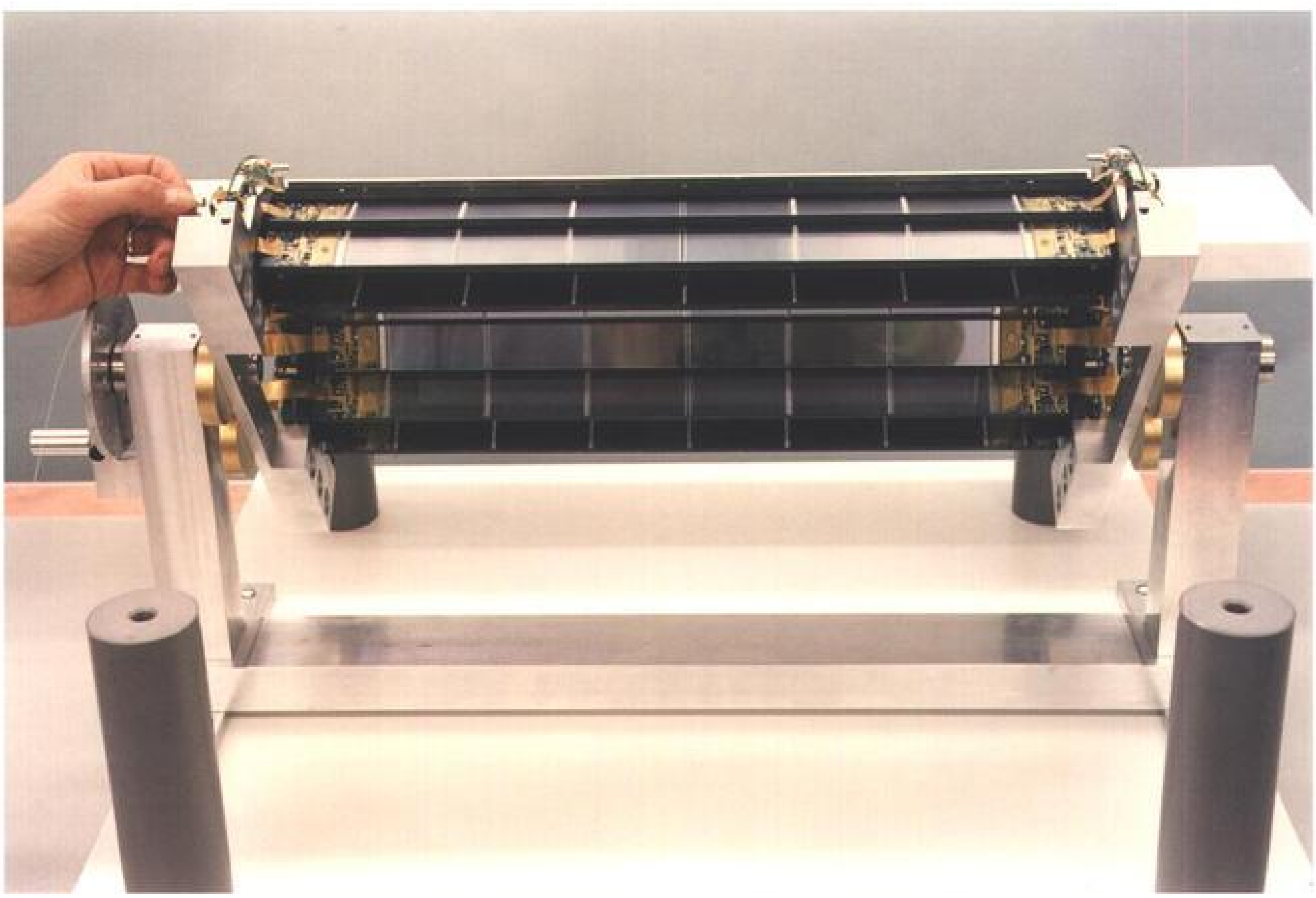
$$\#D(t) \propto \exp\left(-\frac{ct^*}{c\tau}\right)$$

$$\left.\begin{aligned} c\tau(D^0) &= 124\ \mu m \\ c\tau(D^+) &= 315\ \mu m \\ c\tau(D_s^+) &= 149\ \mu m \end{aligned}\right\}$$

need silicon detector

CST





Line of Argumentation

- $D^* \to D^0 \pi_s$, $D^0 \hookrightarrow K^- \pi^+$ can be reconstructed with the drift chamber (CJC) alone (Δm trick), apply life time tag D^0

  ⇒ serves as proof, that detector & vertexing efficiencies & dectector resolutions are well understood ! ($c\tau(D^0) = 124\,\mu m$)

- apply similar vertexing cuts in all decay channels

  ⇒ same systematic errors.

  main cut: decay length significance $l_{r\varphi}/\sigma_l$

- measure $\sigma(ep \to DX)$ in same region of P.S. & calculate ratios

  e.g. $\dfrac{\sigma(ep \to D^+ X)}{\sigma(ep \to D_s^+ X)}$ ⇒ u : s

  $\dfrac{\sigma(ep \to D^{*+} X)}{\sigma(ep \to D^+ X)}$ ⇒ VM : PS

  systematic errors cancel out (in 1st order)

- differential x-sections, e.g. $\dfrac{d\sigma(ep \to DX)}{dp_t}$, to test hardness

CHALLANGES FOR VERTEXING @ H1

- syncroton radiation of e ⇒ first silicon layer @ 6 cm
  ⇒ long leverage arm ($\sigma(\ell_{r\varphi}) \sim 150\,\mu m$)

- c production in ep @ threashold (low $p_t(D)$ in comparision to $E_c \sim 45$ GeV @ LEP)

  ⇒ multiple scattering dominates resolution @ low p_t

  $$\sigma^2(\ell_{r\varphi}) \approx \sigma^2_{intrinsic} + \left(\frac{\sigma^*(MS)}{p_t}\right)^2$$

  as cutting on $\ell_{r\varphi}/\sigma_\ell$ understanding of MS is CRUCIAL !

- bad S/N on z-side ⇒ $\varepsilon_{z\text{-hits}} \approx 86\%$
  c.f. $\varepsilon_{r\varphi\text{-hits}} \approx 98\%$

  (for vertexing: e.g. 3 decay tracks with 2 $r\varphi$+z hits each

  $$\Rightarrow \quad \varepsilon_{CST} = (\varepsilon_{r\varphi} \cdot \varepsilon_z)^6 \approx 35\%$$

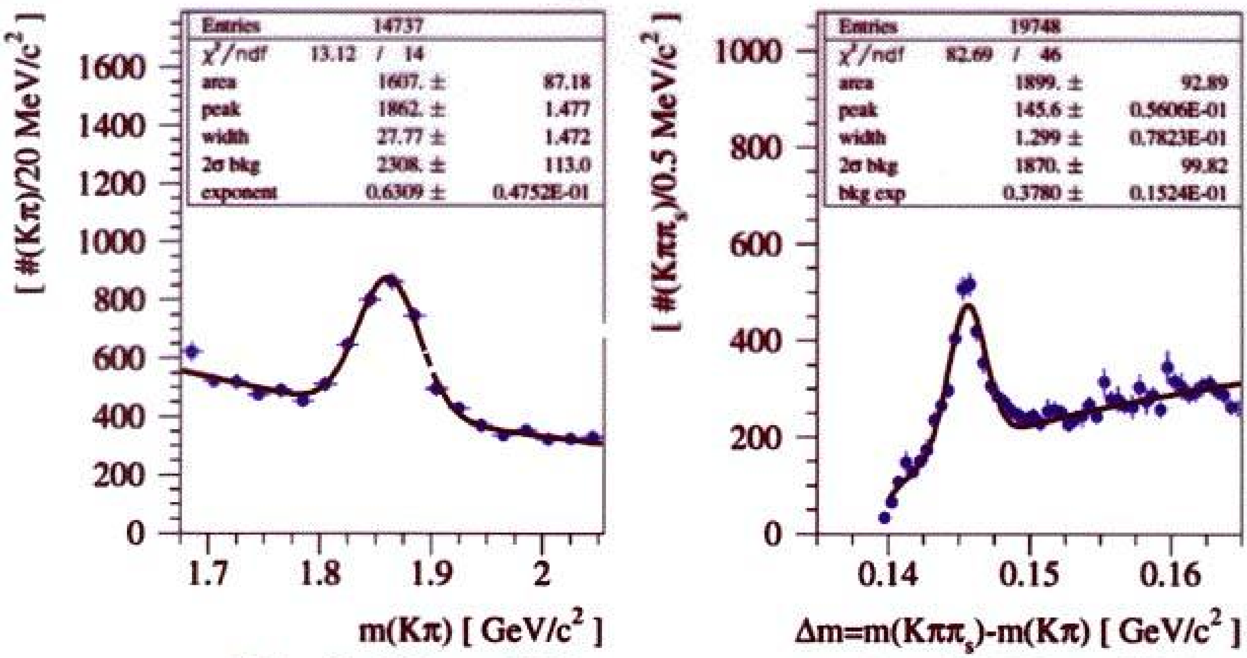
- linking to other detectors in z is difficult, as resolutions differ by orders:

  σ_z (drift chambe) ~ 2 cm

  σ_z (z - chambers) ~ 2 mm

  σ_z (silicon z-side) ~ 100 μm

$D^* \to D^0 \pi_s \to K\pi\pi_s$ (99b/00)



m(Kπ) with CJC cuts,ST61

Δm with CJC cuts,ST61

$D^* \to D^0 \pi_s$
$\hookrightarrow K^- \pi^+$

reconstructed with drift chamber alone, but inside CST acceptance and phase space region.

Δm - trick: $\Delta m = m(D^*) - m(D^0) = 0.146\ GeV/c^2$

$\approx m_\pi = 0.140\ GeV/c^2$

$\Rightarrow$ slow Pion,

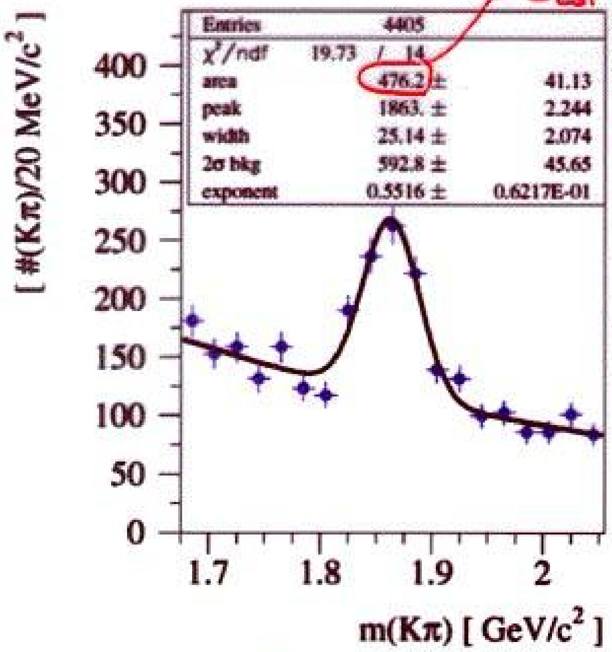
resolution of Δm good due to cancelations

$\Rightarrow$ good S/N ratio

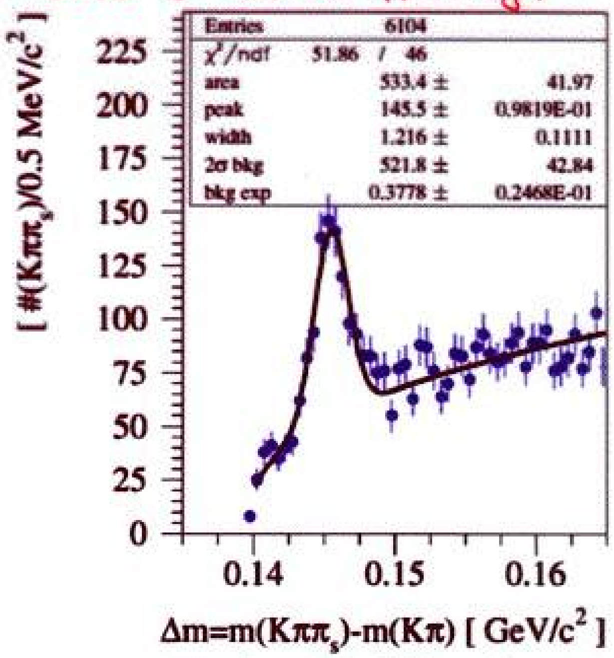
$D^* \to D^0 \pi_s$: $(K^-\pi^+)$ inside CST acceptance
$\hookrightarrow K^-\pi^+$ D^0 mass & decay vertex with full 3d CST info. $\left(\frac{2 r\varphi + 2z\text{-hits}}{\text{track}}\right)$

$D^* \to D^0\pi_s \to K\pi\pi_s$: l/σ_l cut (99b/00)

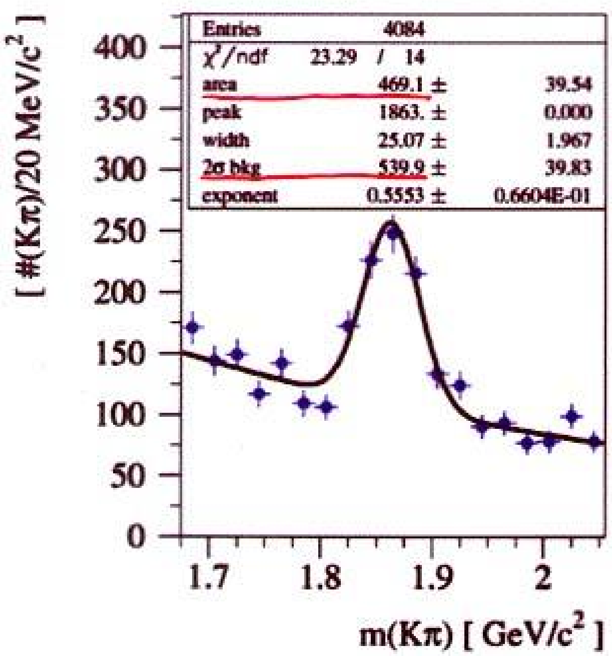
$\varepsilon_{CST} \approx 30\%$ (= detector efficiency)



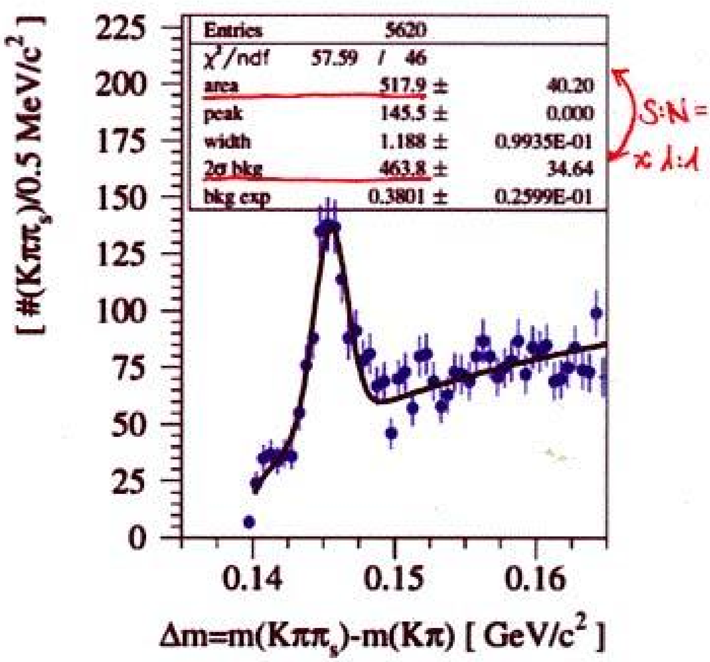
m(Kπ) with CST vertices



Δm with CST vertices



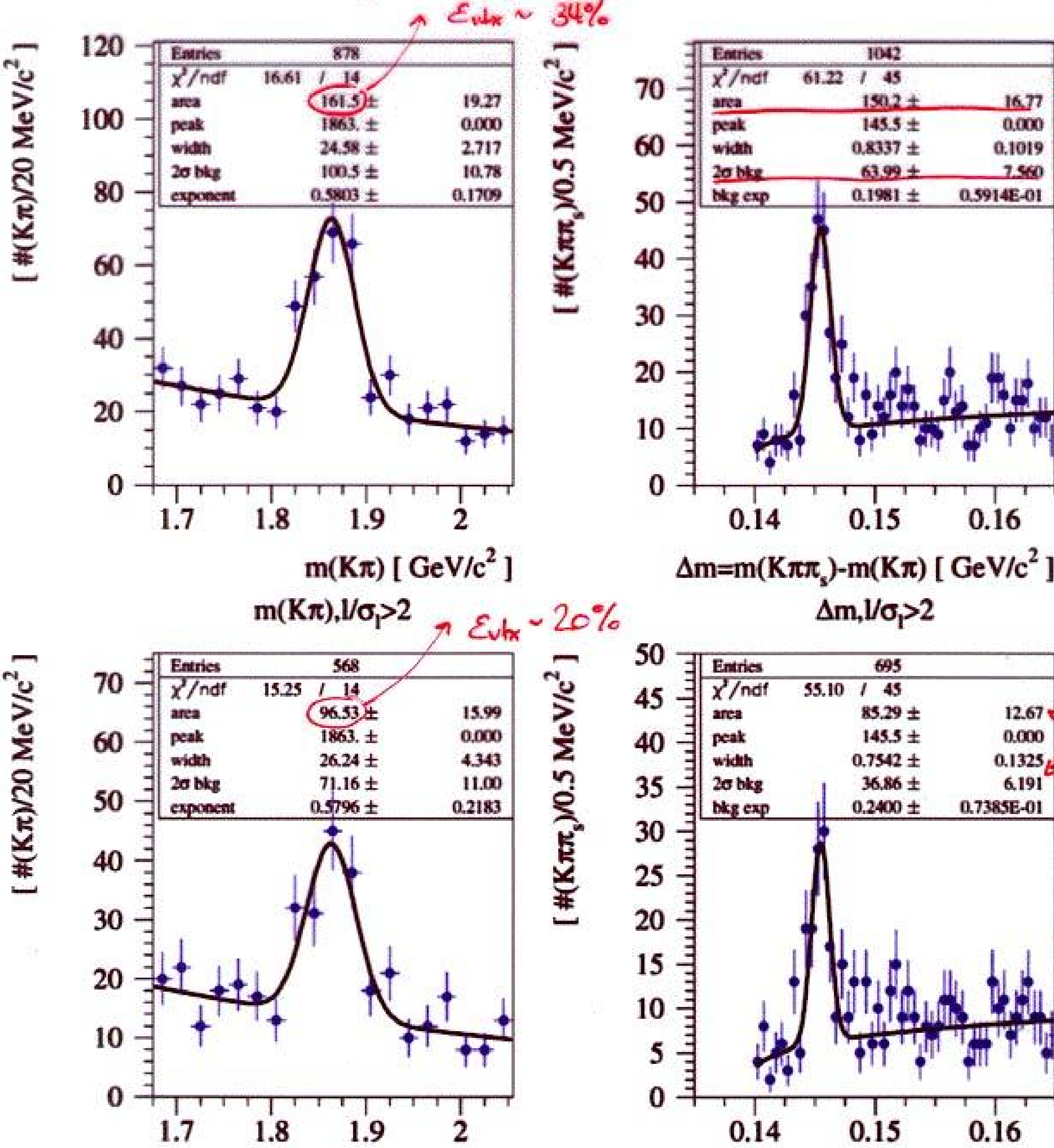
m(Kπ),l/σ_l>-3



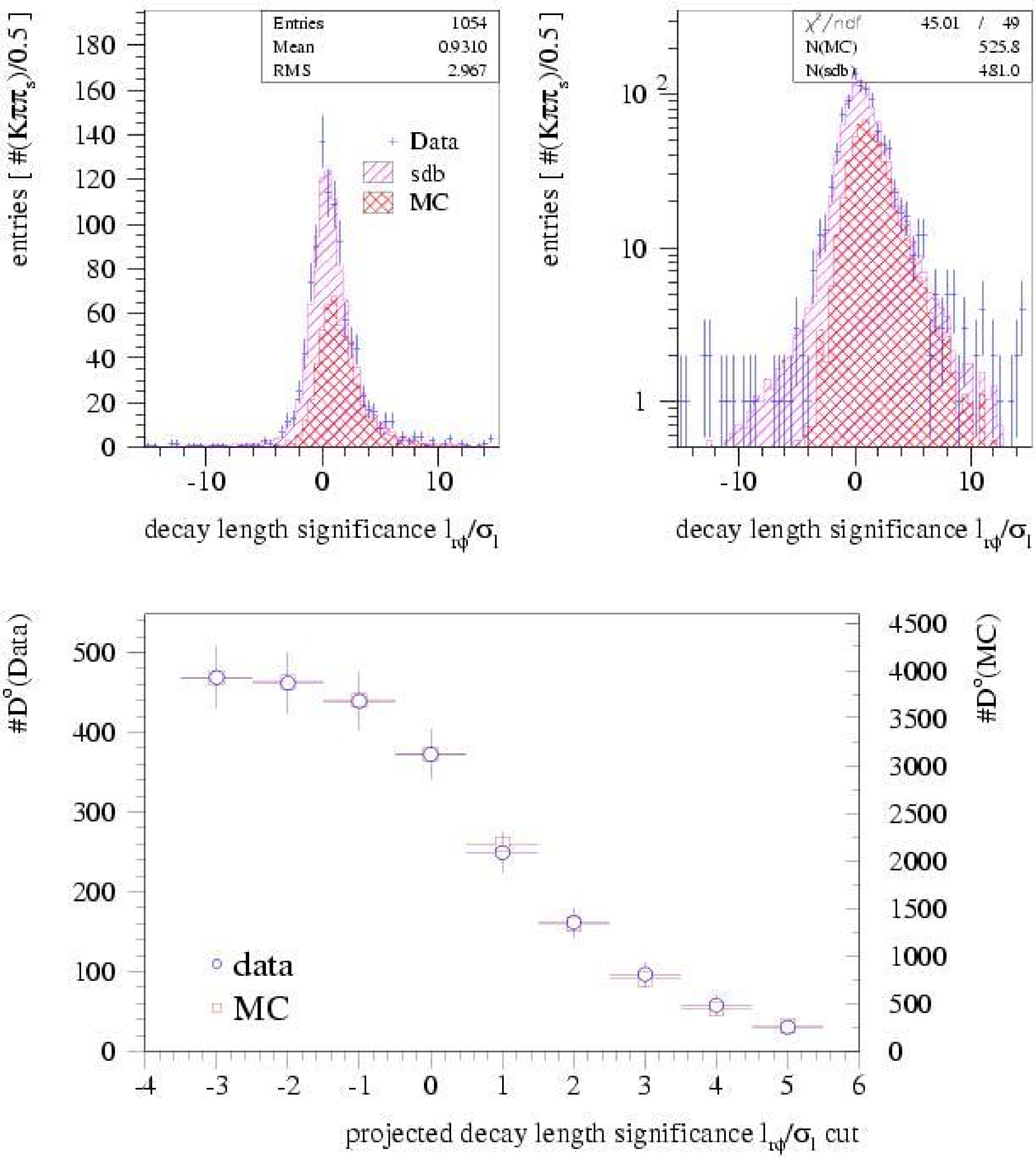
Δm,l/σ_l>-3

cut on decay length significance

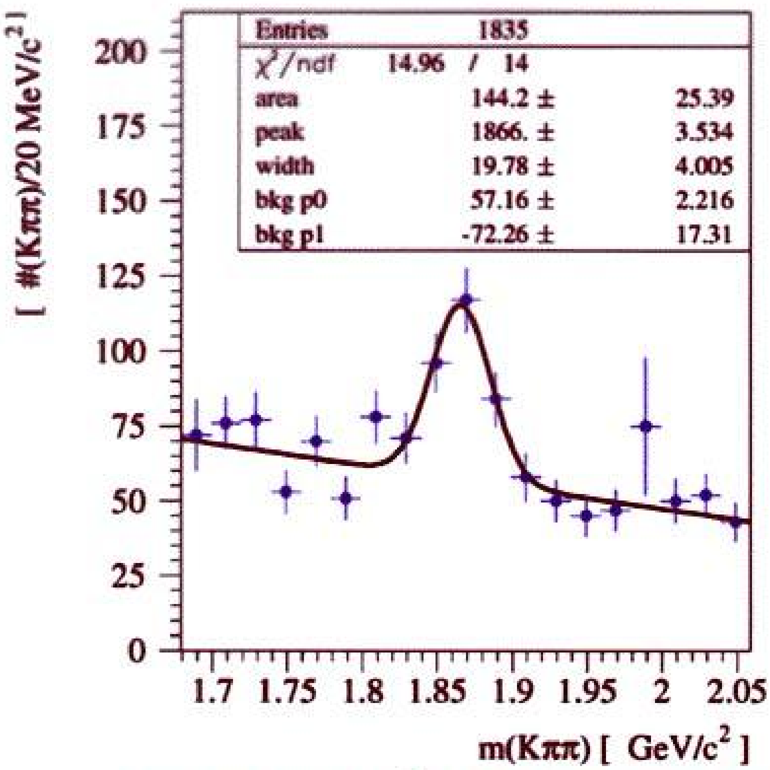
$D^* \to D^0 \pi_s \to K\pi\pi_s$: l/σ_l cut (99b/00)



$D^* \to D^o \pi_s \to K\pi\pi_s$: l/σ_l cut Data vs MC



$D^+ \to K^- \pi^+ \pi^+$ Decays with CST Life Time Tag



Invariant mass of $D^+ \to K\pi\pi$ decays after all cuts

D^+ reconstructed with full 3d CST information
(2 rφ & 2 z hits on each track)

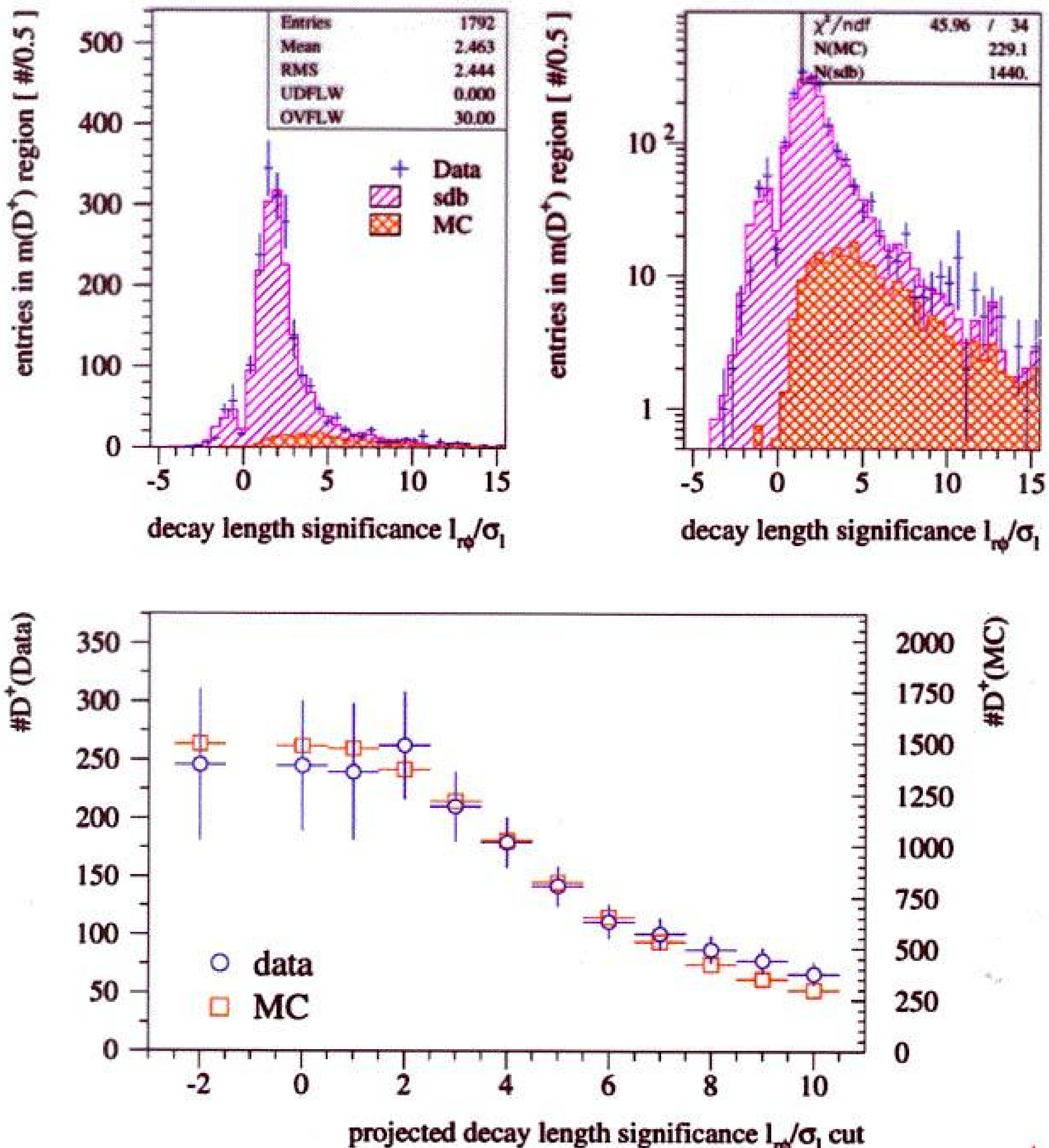
<u>METHOD:</u> do vertex fit & track-hit linking
is done simultaneously !

⇒ good tracks help others to get cor. links

⇒ 3d intersect more precise in r-φ (z helps !)

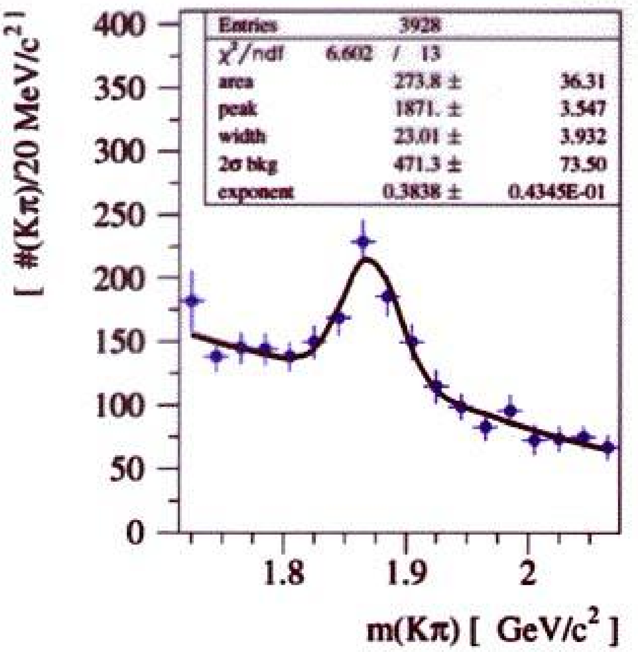
⇒ generally it's easier to measure directions
(pointing to same vtx) as offsets.

$D^+ \to K\pi\pi$: l/σ_l cut Data vs MC

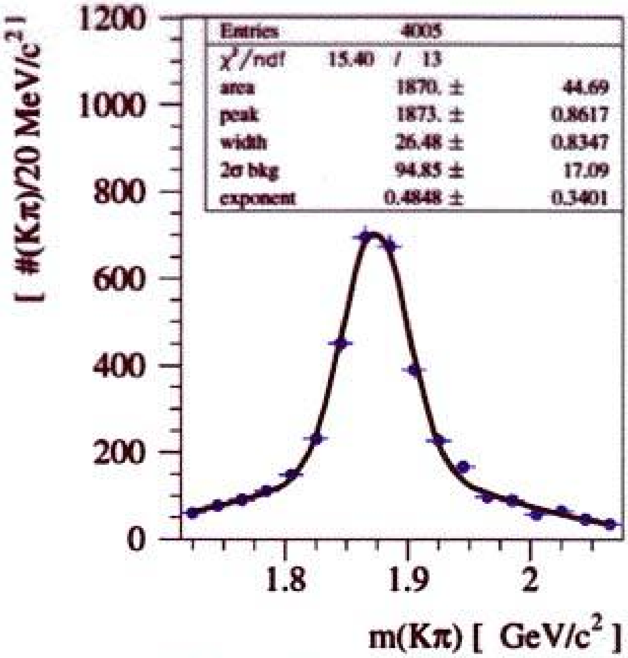


Efficiency biased as other vertexing cuts have to be applied to get a signal.

$D^0 \to K^-\pi^+$ Decays with CST Life Time Tag



Invariant mass of $D^0 \to K^-\pi^+$ decays



MC: both Kπ charge combination

D^0 reconstructed with same method as D^+.

special in this channel:

each real $D^0 \to K^- \pi^+$ decay has a partner with wrong assignment of $K\pi$, i.e. $\bar{D}^0 \to \pi^- K^+$

invariant mass approximatly the same !

<u>solution</u>: determine shape of wrong assigned combination and ratio between right & wrong assigned with MC and include it for data fits.

$D_s \to \phi\pi$
$\hookrightarrow K^+K^-$

applying same method as for D^+ & D^0 not possible!

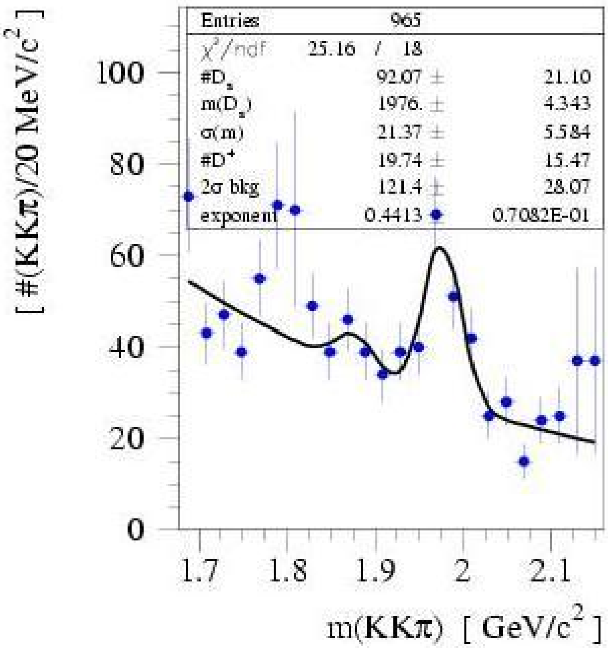
$$\left.\begin{array}{l} f(c\to D_s) : f(c\to D^+) = 1:2 \\ BR(D_s \to \underset{\hookrightarrow KK}{\phi\pi}) : BR(D^+ \to K\pi\pi) = 1:5 \\ c\tau(D^0) : c\tau(D^+) = 1:2 \end{array}\right\} \quad (\# D_s)_{3d} \approx \frac{1}{20}(\# D^+)_{3d} < 10!$$

⇒ use a 2d vertex fit (with directional constraint)
"gain" $(\varepsilon_{z\text{-hits}})^6$, don't require 2 r-φ hits on each track.

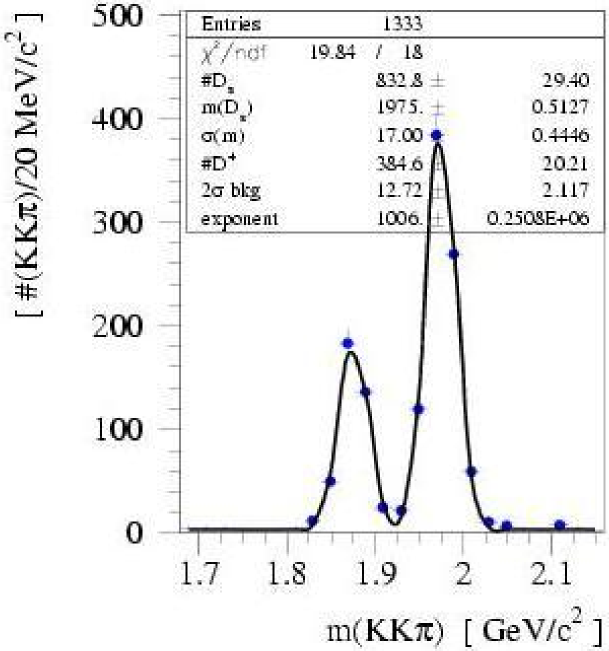
⇒ <u>problem with this approach:</u>

- today's calibration of H1's central tracking is not ideal, recalibration on the way....
- in 3d the CST dominates most measurements and therefore "saves" rest of tracking
- mass resolution in 2d case (w/o CST z-info) suffers under miscalibrations ⇒ bad S/N

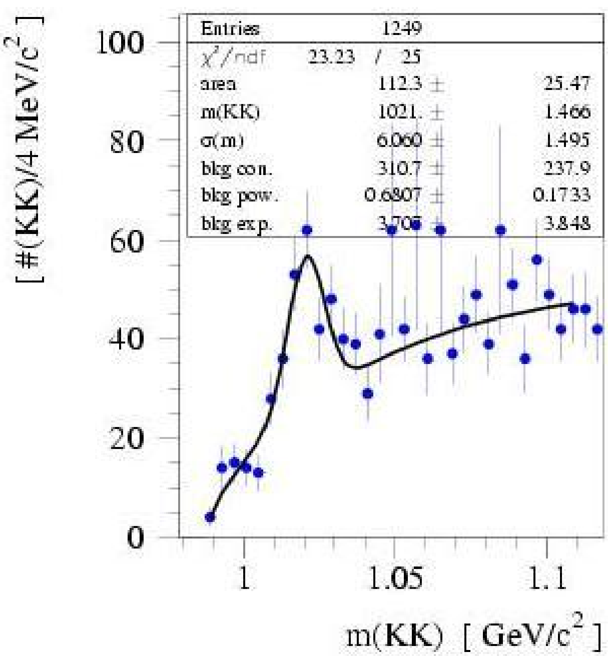
$D_s \rightarrow \Phi\pi \rightarrow KK\pi$ Data vs MC (99b/00)



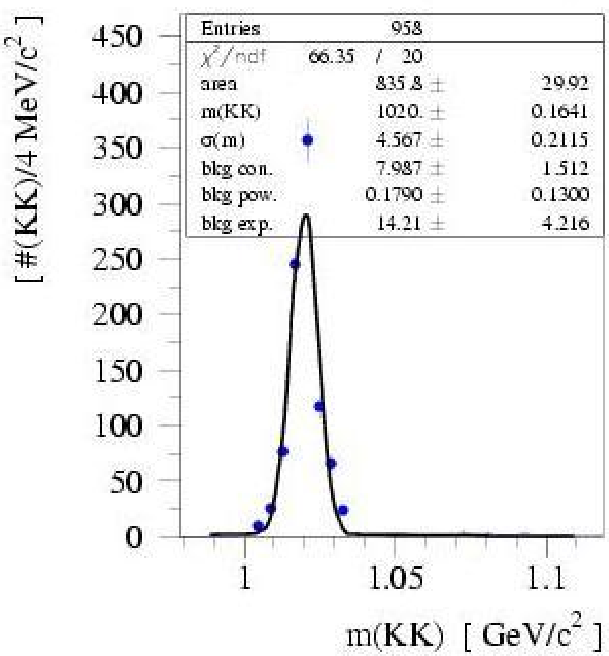
Data in ST 2/61



MC in ST 2/61 ($L_{mc}=10xL_{data}$)

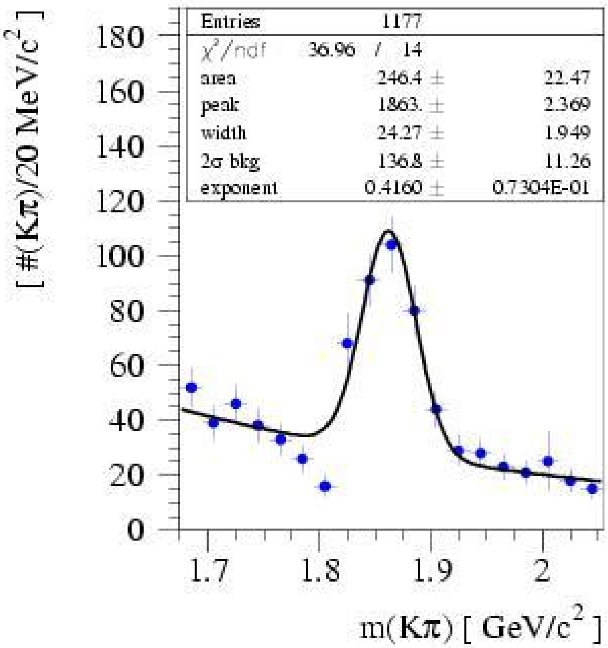


Data in ST 2/61

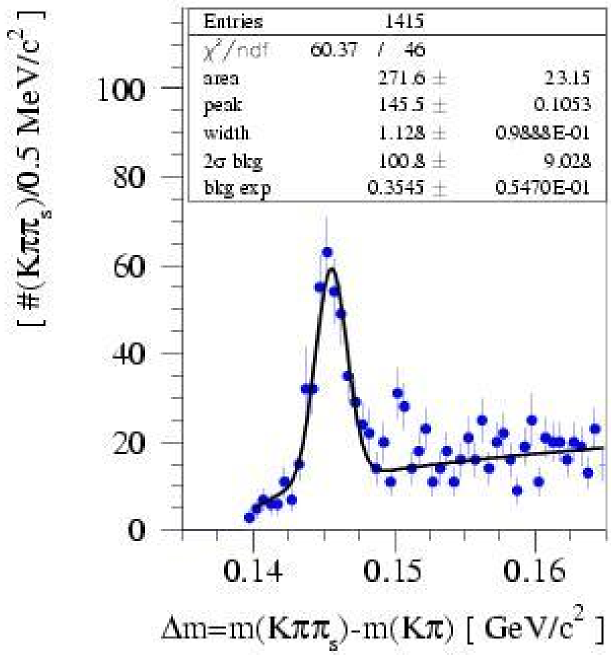


MC in ST 2/61 ($L_{mc}=10xL_{data}$)

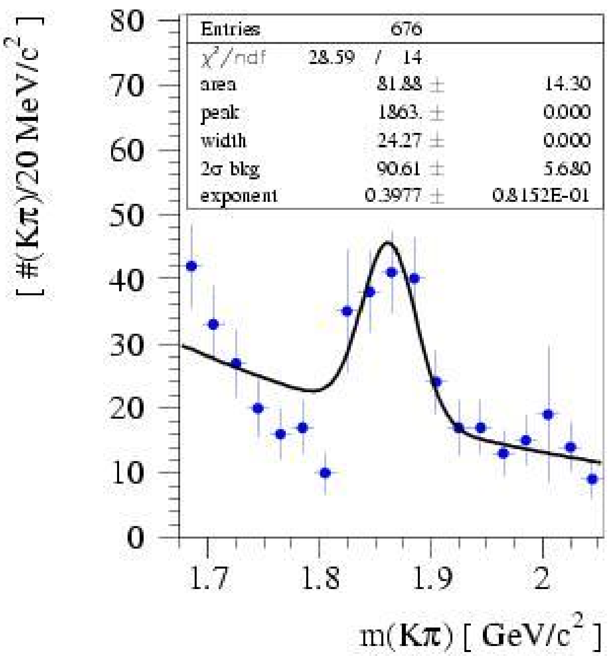
CST $D^* \to D^o \pi_s \to K\pi\pi_s$: $p_t(D^*)$-bins (99b/00)



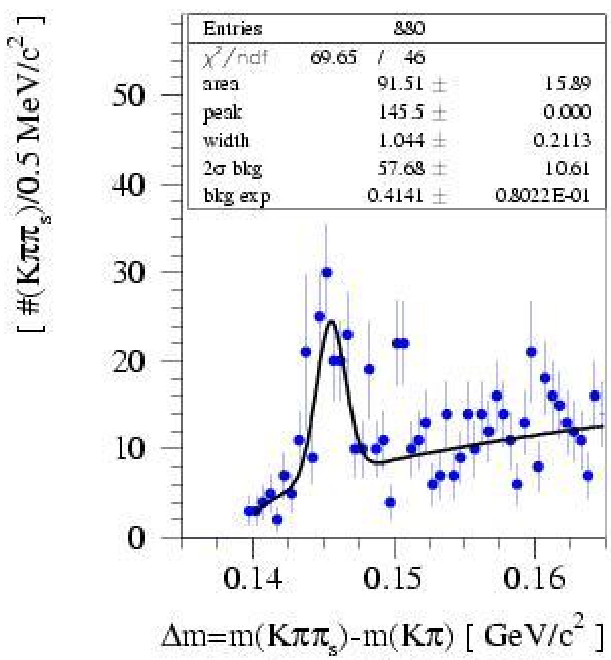
$m(K\pi)$,whole $p_t(D^*)$ range



Δm,whole $p_t(D^*)$ range

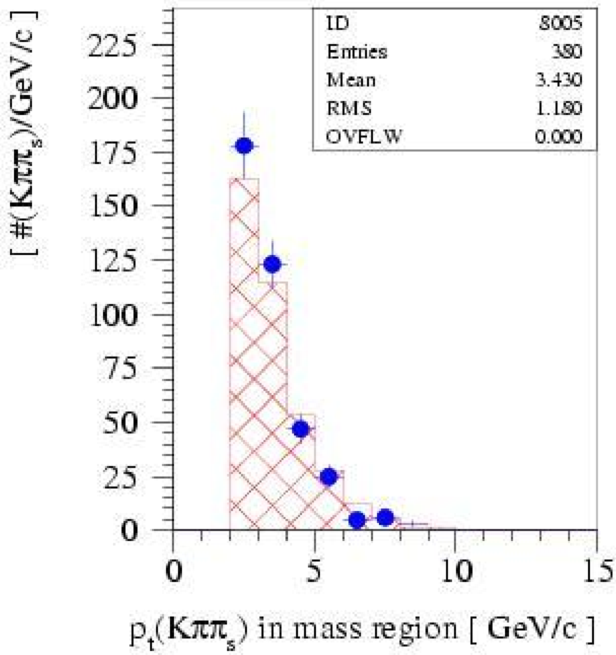


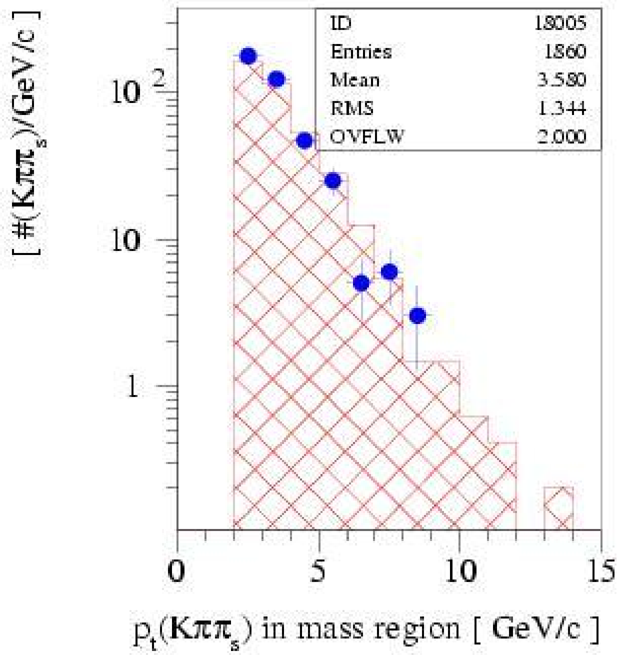
$m(K\pi)$,$p_t(D^*)$-bin [2,3]

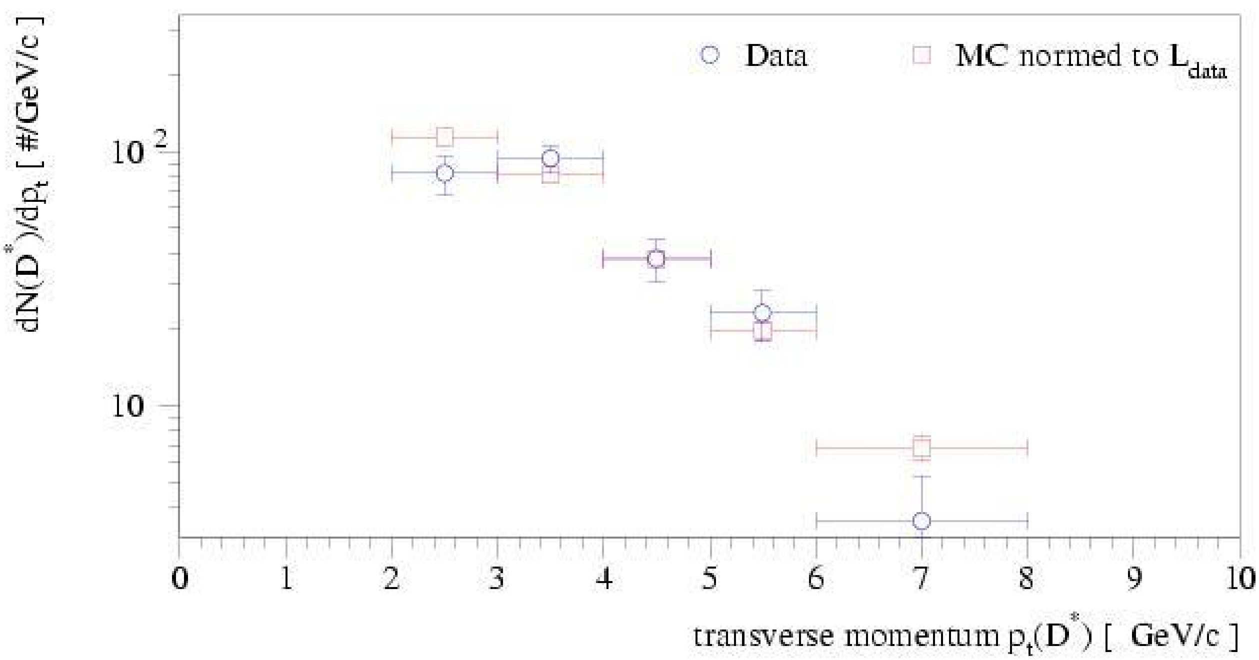


Δm,$p_t(D^*)$-bin [2,3]

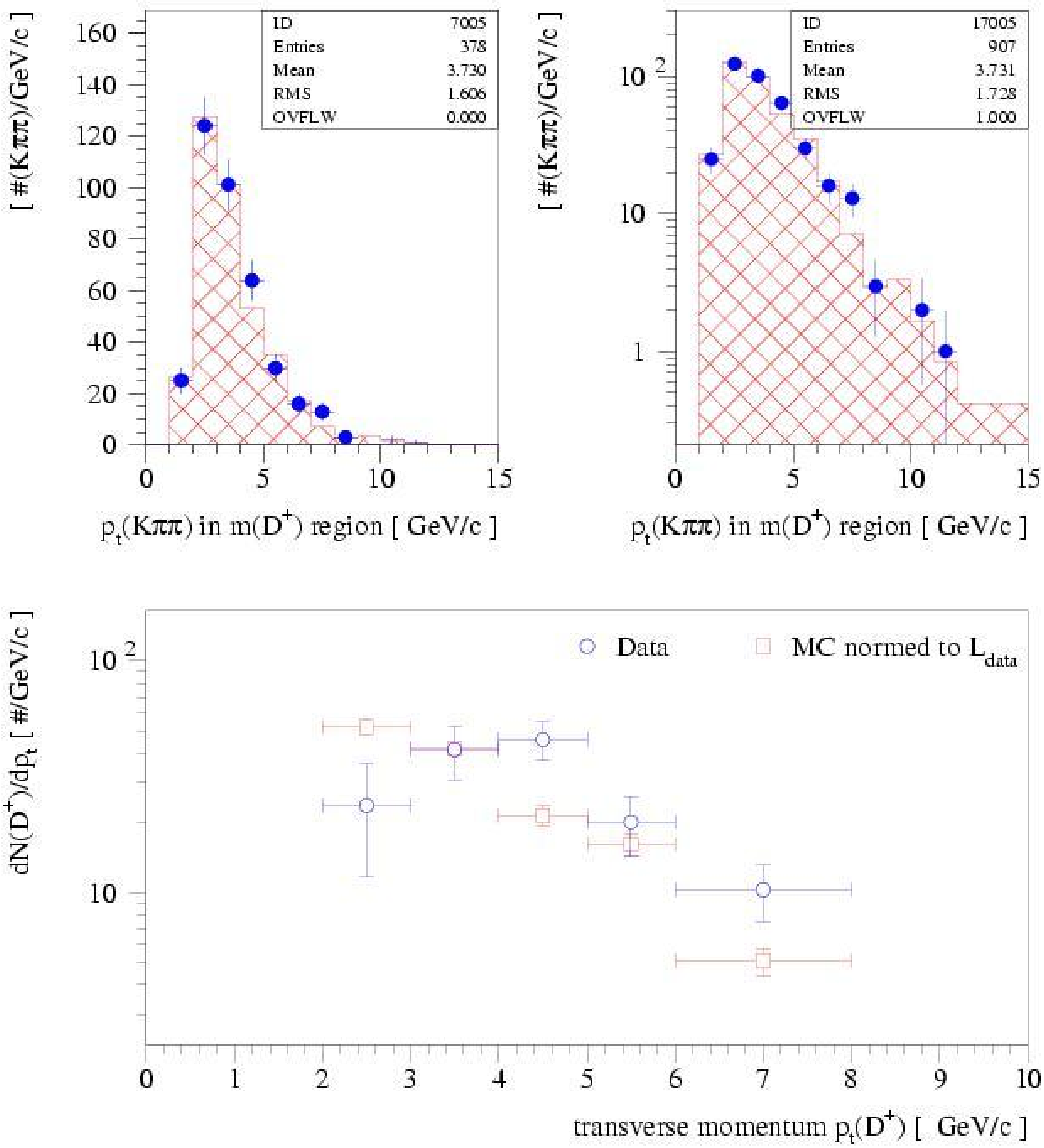
$p_t(D^*)$ Distribution: Data vs AROMA (CST)



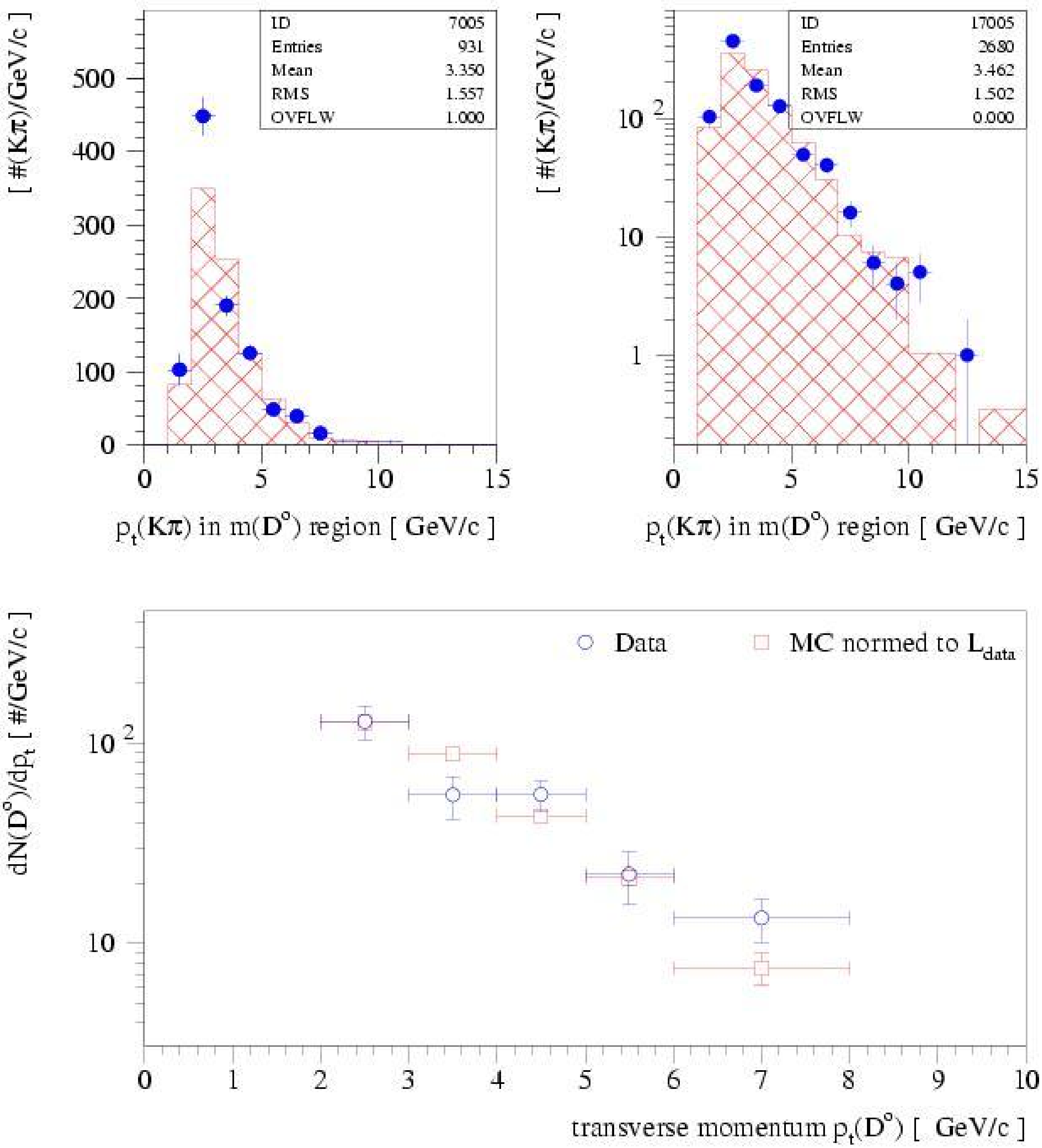




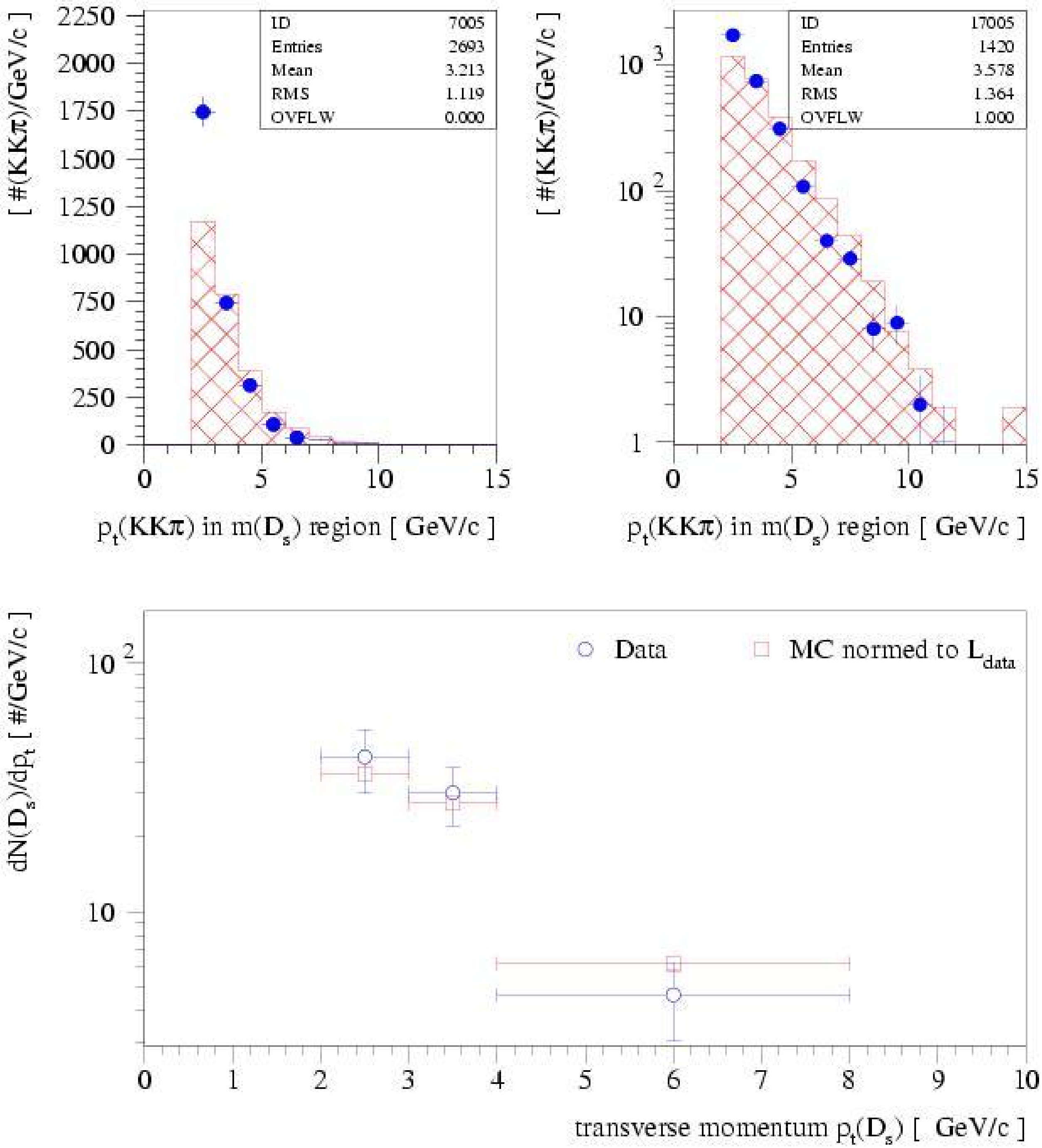
$p_t(D^+)$ Distribution: Data vs AROMA



$p_t(D^o)$ Distribution: Data vs AROMA



$p_t(D_s)$ Distribution: Data vs AROMA



FINAL RESULTS – – WHAT IS STILL MISSING ?

only $\left(\frac{A\varepsilon}{p}\right)_{det} \cdot \varepsilon_{vertexing}$ is missing !

for $\boxed{\sigma_{visible}(ep \rightarrow D^{+}X) = \sigma_{vis}(ep \rightarrow c\bar{c}X) \cdot 2f(c \rightarrow D^{+})}$

visible = $2\ \text{GeV}^2 \leq Q^2 \leq 100\ \text{GeV}^2$

$0.05 \leq y_B \leq 0.7$

$p_t(D) \geq 2\ \text{GeV/c}, \ |\eta^*(D)| < 1.5$

Acceptances $\quad \mathcal{A}_{geometrical} \cdot \mathcal{A}_{kinematic} =$

$0.55 \cdot 0.45 = 0.20$

Detector Efficiencies/Puritys $\quad \left(\varepsilon/p\right)_{det} \approx 0.20$

vertexing efficiency $\quad \varepsilon_{vtx} \approx 0.40$

$\left(A\varepsilon/p\right)_{det} \cdot \varepsilon_{vtx} \sim 1.5\%$

⇒ x-sections & ratios ☺

⊕ bin wise $\left(\frac{A\varepsilon}{p}\right)$ ⇒ differential x-sections

CONCLUSIONS:

- charm production at HERA is still interesting (e.g. F_2^c / F_2 at low x)
- therefore need understanding of fragmentation at ep collisions
- Vertex detector CST well understood
- vertexing methods now available & well understood.
- 1st D^+ x-section @ HERA (total & differential) ...... on the way ..... ;-)
- 1st differential x-section of direct D^0 @HERA .... on the way ..... ;-)
- LEP fragmentation parameters seem to describe HERA data