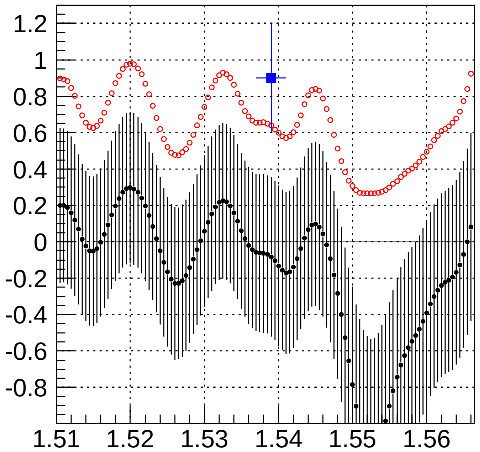
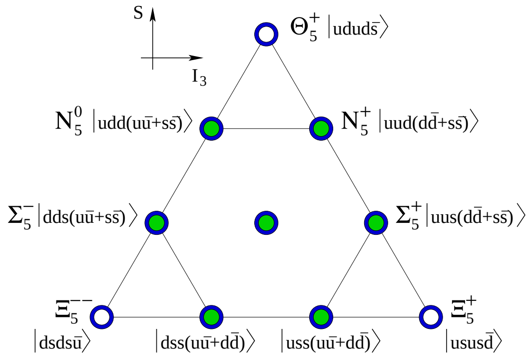
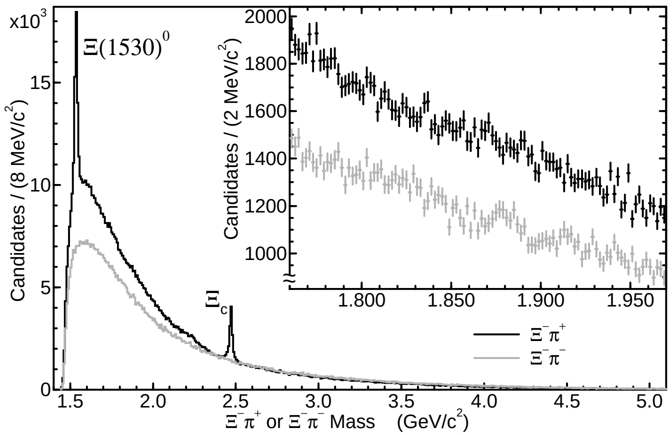
Searches for pentaquarks at the B-factories







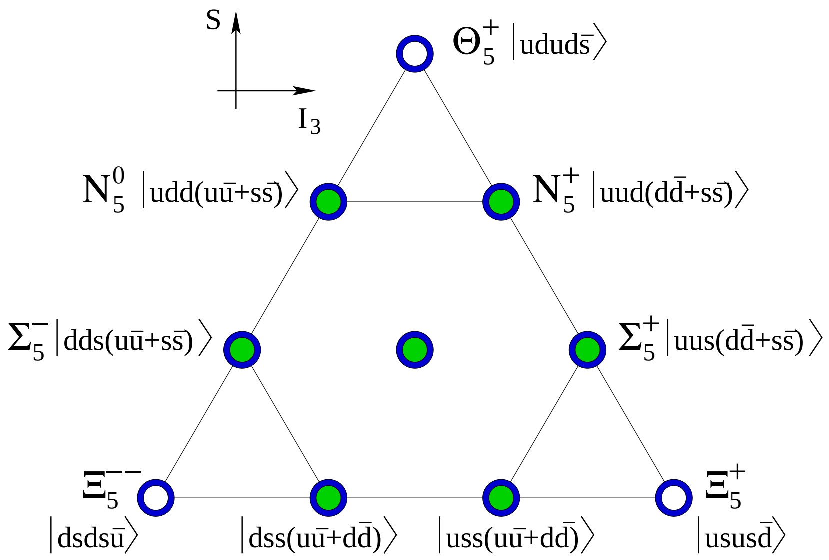
Bruce Yabsley (University of Sydney)

http://belle.kek.jp/~yabsley/

Charm 2006 International Workshop on Tau-Charm Physics
IHEP Beijing, 6th June 2006

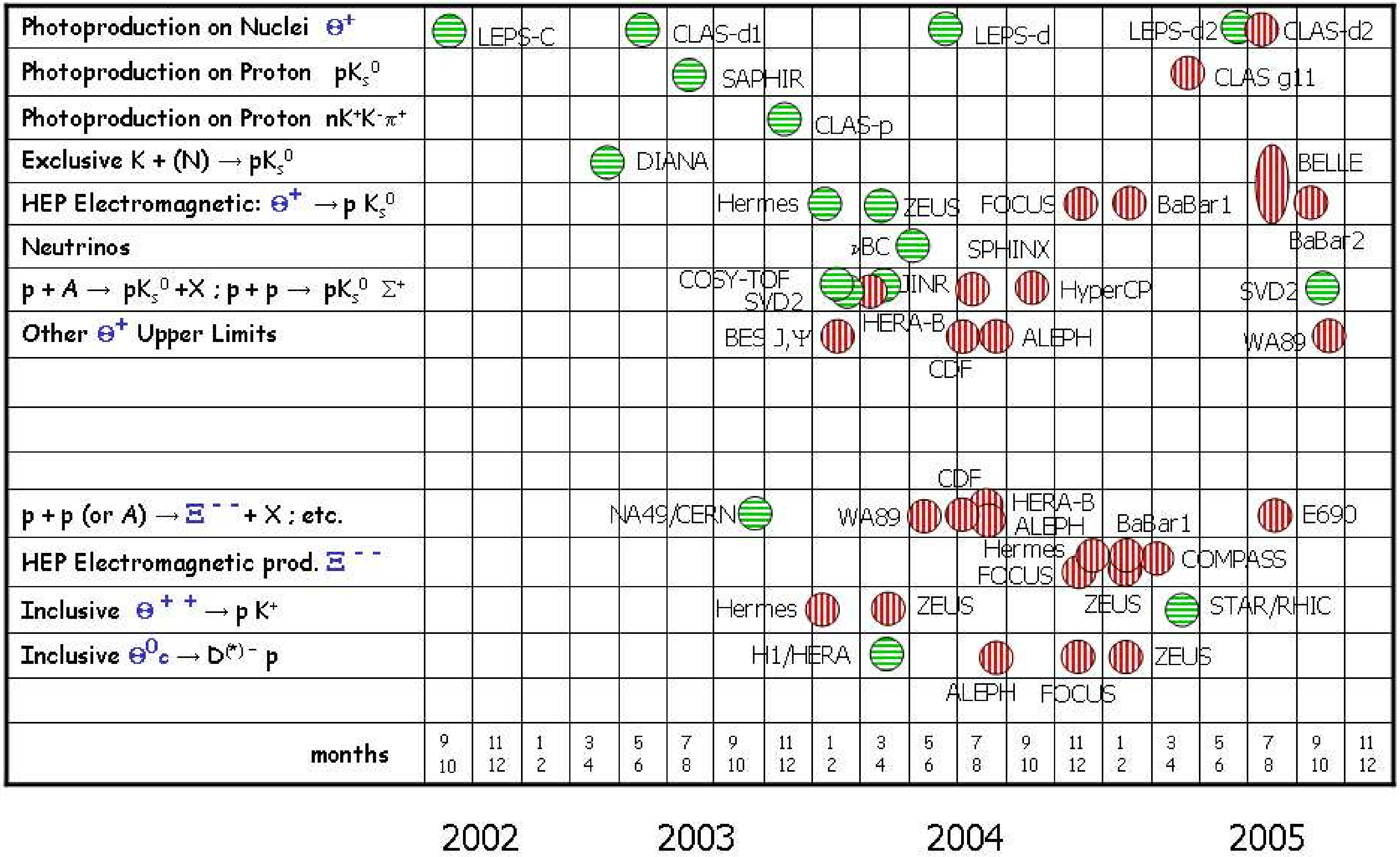
pentaquarks: a potted history . . .

- it is 'not obvious" that $q\bar{q}$ and $q\bar{q}q$ are the only bound states
- there have long been (negative) searches for pentaquarks $qqqq\bar{q}$
- interest revived by D. Diakonov, V. Petrov, M.Polyakov, *Z. Phys. A* **359**, 305 (1997) [not uncontroversial . . .]
- new states predicted in a $\overline{\mathbf{10}}$, $\mathbf{8}$, . . .
- narrow (!) Θ^+ seen by
  - LEPS: γC $\rightarrow$ (n)K$^+$K$^-$X
  - DIANA: K$^+$Xe $\rightarrow$ K^0_Sp X
  - "everyone" . . .
- $\Xi_5^{--,0} \rightarrow \Xi^-\pi^\mp$ seen in pp @ 160 GeV/c by NA49
- Θ_c^0 and other claims . . .



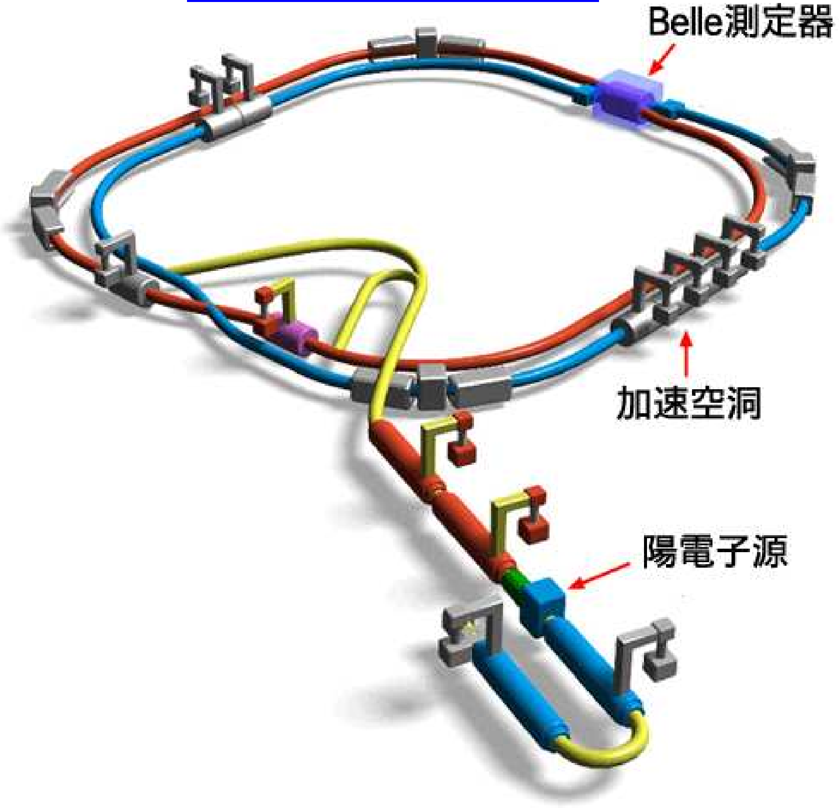
. . . and a contradictory picture

a bandwagon effect was clearly present (arXiv:nucl-ex/0512042)

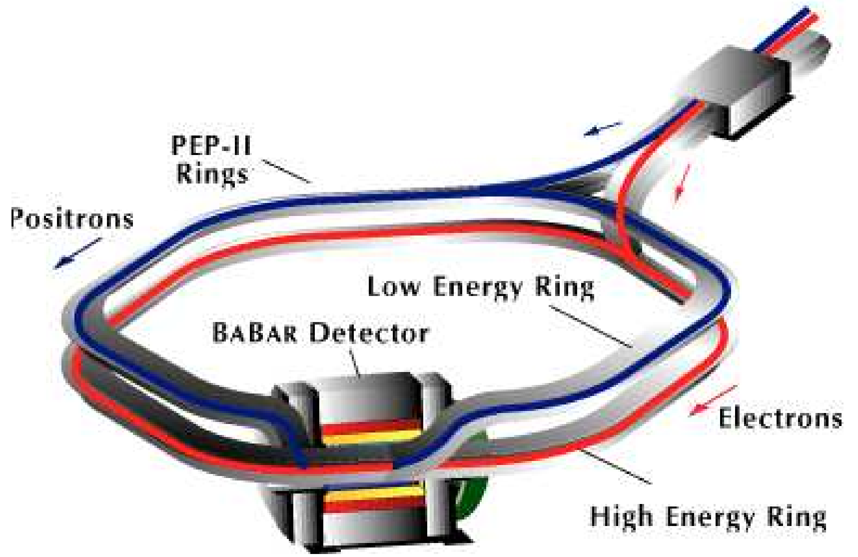


the B-factories: asymmetric e^+e^- @ $\sqrt{s} \approx M_{\Upsilon(4S)}$

KEKB / Belle



PEP-II / BaBar



$\mathcal{L} > 16\,\mathrm{nb}^{-1}/\mathrm{s}$ at peak

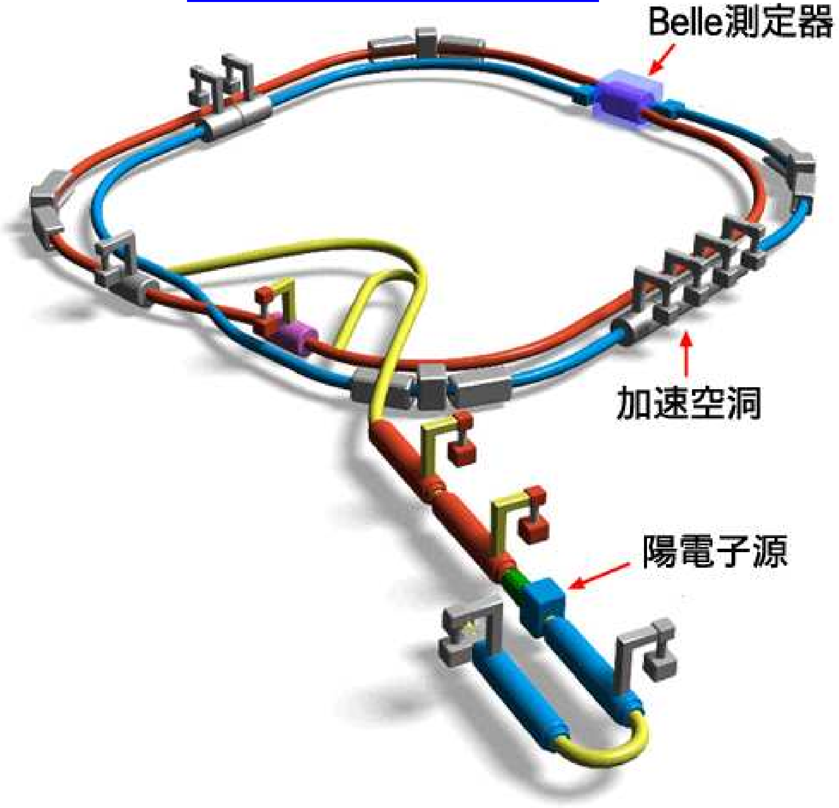
$\int \mathcal{L}\,\mathrm{d}t > 600\,\mathrm{fb}^{-1}$ on tape

$\mathcal{L} > 10\,\mathrm{nb}^{-1}/\mathrm{s}$ at peak

$\int \mathcal{L}\,\mathrm{d}t > 348\,\mathrm{fb}^{-1}$ on tape

high-acceptance solenoidal detectors (1.5 T), with good K/π & e, μ ID

KEKB / Belle



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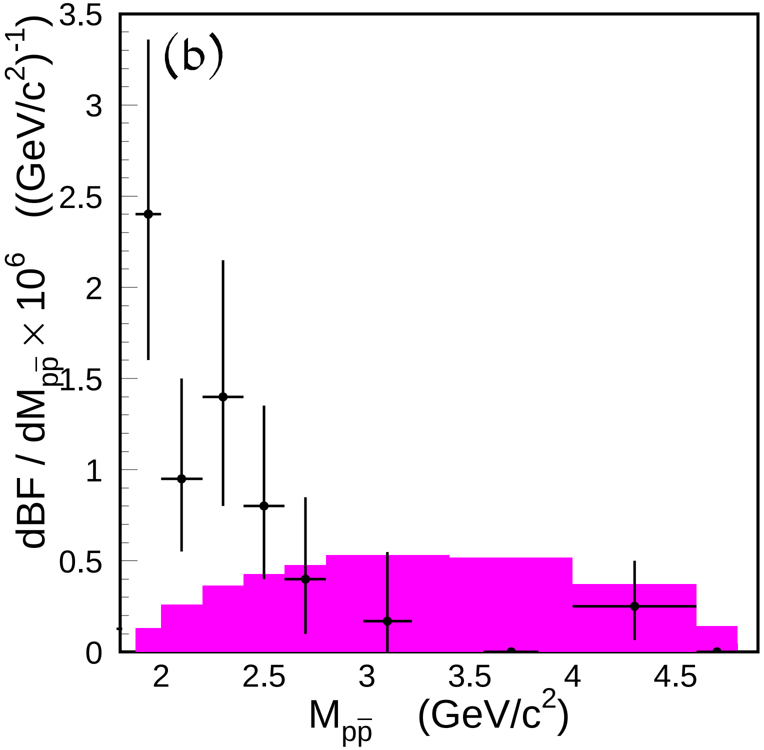
high-acceptance solenoidal detectors (1.5 T), with good K/π & e, μ ID

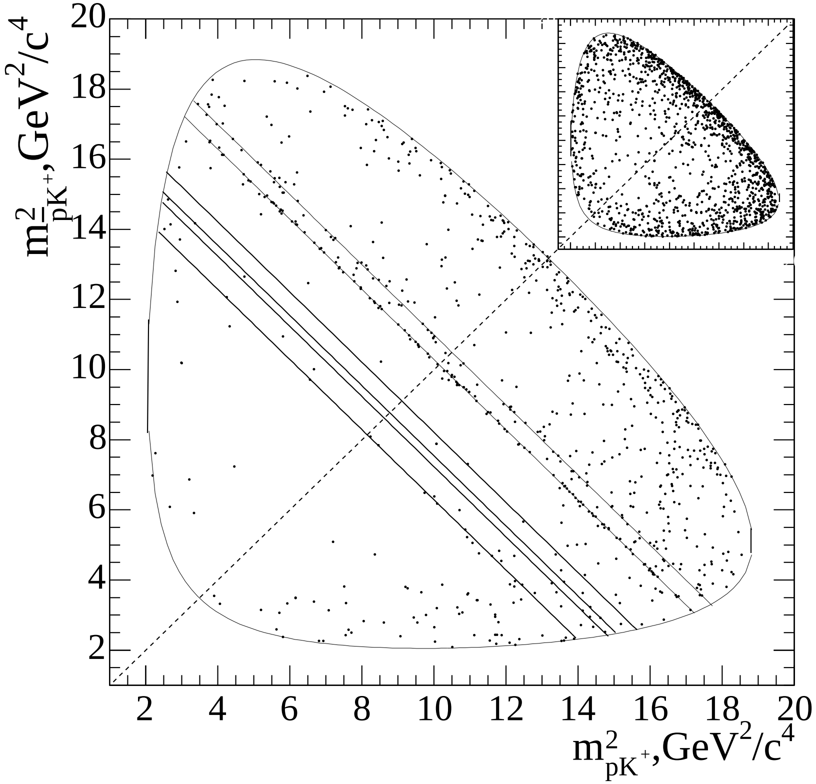
PQ @ Bfact (1): exclusive B-decays

while studying remarkable $B \to p\bar{p}K$ decay structure:

Belle: $B^0 \to p\bar{p}K^0_S$



BaBar: $B^+ \to p\bar{p}K^+$



low-$M(p\bar{p})$ enhancement

[*cf.* phase-space]

also seen in $p\bar{\Lambda}$

confirms the enhancement

N.B. charmonium vetoes needed

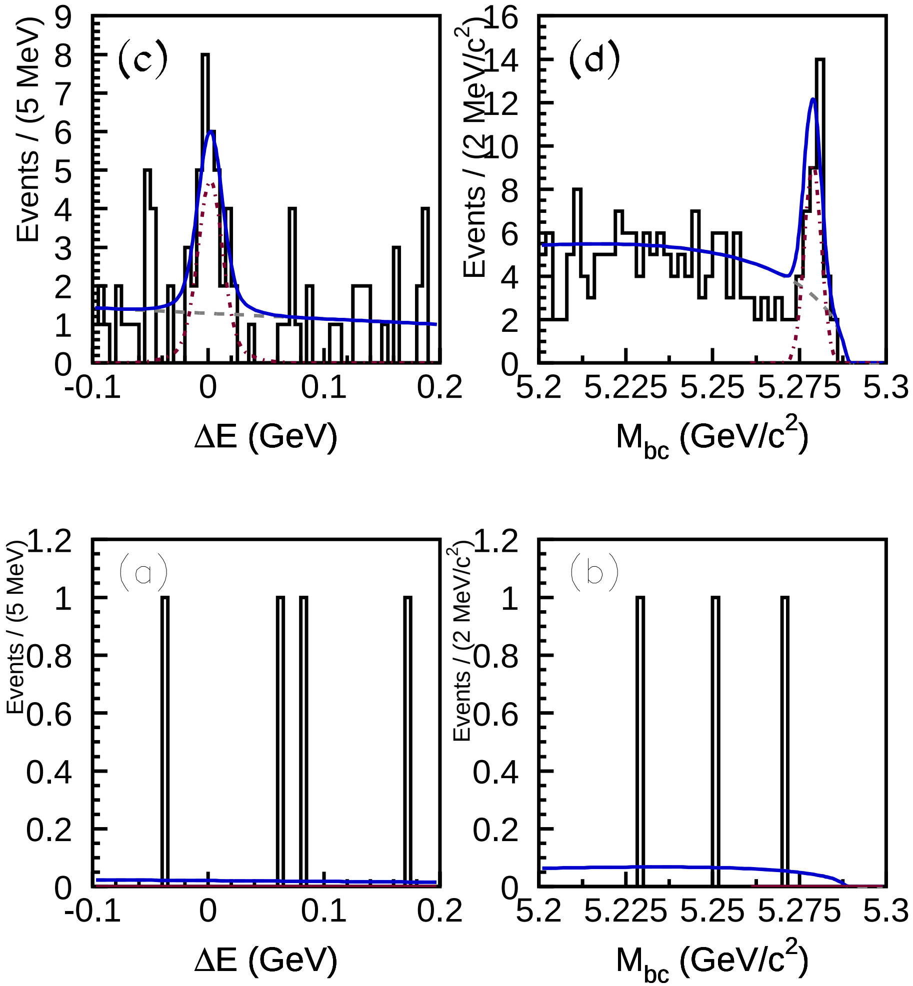
N.B. structure also in sideband

PQ @ Bfact (1): exclusive B-decays

Θ^+, $\Theta^{*++} \to$ pK

M.-Z. Wang *et al.* (Belle), *PLB* **617**, 141 (2005)

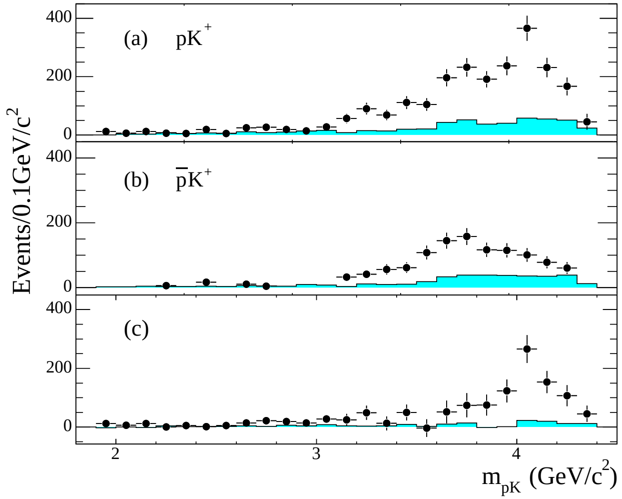
- standard skim, PID, $q\bar{q}$ suppression
- $B^+ \to p\bar{p}K^+$, $B^0 \to p\bar{p}K^0_S$, $p\bar{\Lambda}\pi^-$;
  $p\bar{p}K^0_S$ shown here $\longrightarrow$
- charmonium veto: reject if
  $M(p\bar{p}) \in (2.850, 3.128)$ GeV$/c^2$,
  $M(p\bar{p}) \in (3.315, 3.735)$ GeV$/c^2$
- UML fit in $M(p\bar{p})$ bins
- significant B-yield (all modes)
  for $M(p\bar{p}) < 2.85$ GeV$/c^2$
- nothing for $(1.53, 1.55)$ GeV$/c^2$
- $\mathcal{B}(B^0 \to \Theta^+\bar{p}) \times \mathcal{B}(\Theta^+ \to pK^0_S)$
  $< 2.3 \times 10^{-7}$ @ 90% C.L.
- for $\Theta^{*++} \to pK^+$: $< 0.9 \times 10^{-7}$



$\Theta^{*++} \to pK^+$

B. Aubert *et al.* (BaBar), *PRD* **72**, 051101 (2005)

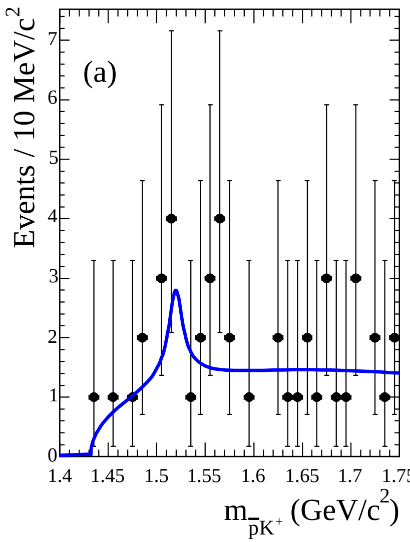
- comparable analysis method . . .
- . . . & low $M(p\bar{p})$ yield seen
- $dN/dM(pK^+) \neq dN/dM(\bar{p}K^+)$
  - favours fragmentation
  - associated $\bar{p}K^+$
  - also seen by Belle

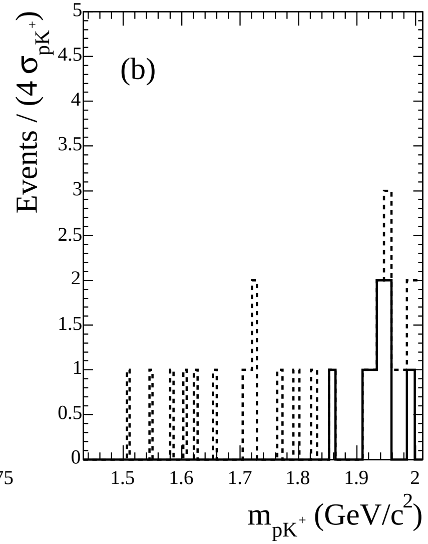


- 90% limits on other structure

– $\mathcal{B}(B^+ \to p\bar{\Lambda}(1520)) < 1.5 \times 10^{-6}$

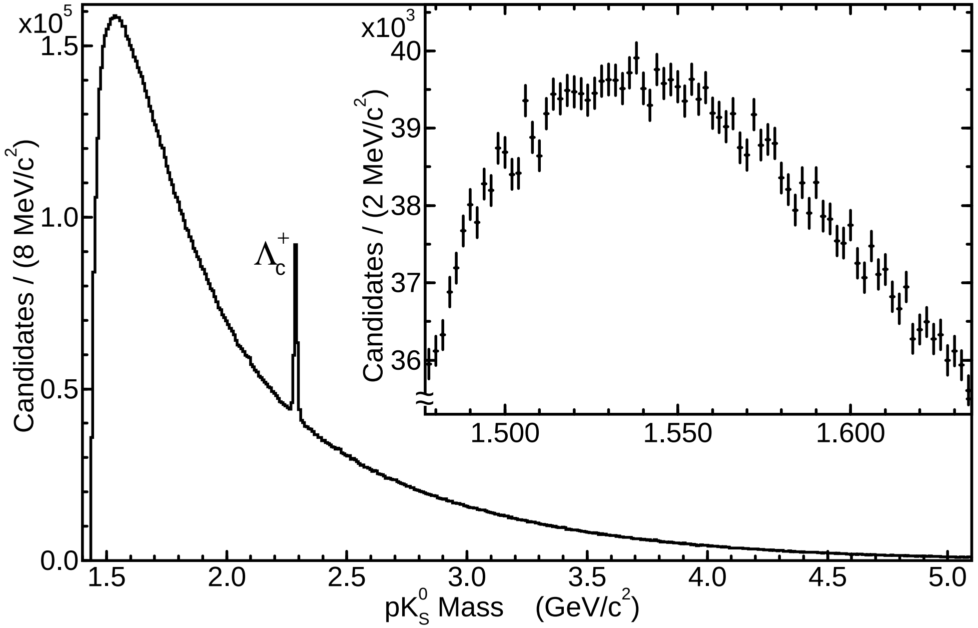
– $\mathcal{B}(B^+ \to \Theta^{*++}\bar{p}) \times$
$\mathcal{B}(\Theta^{*++} \to pK^+) < 0.9 \times 10^{-7}$
[*cf.* Belle!!]



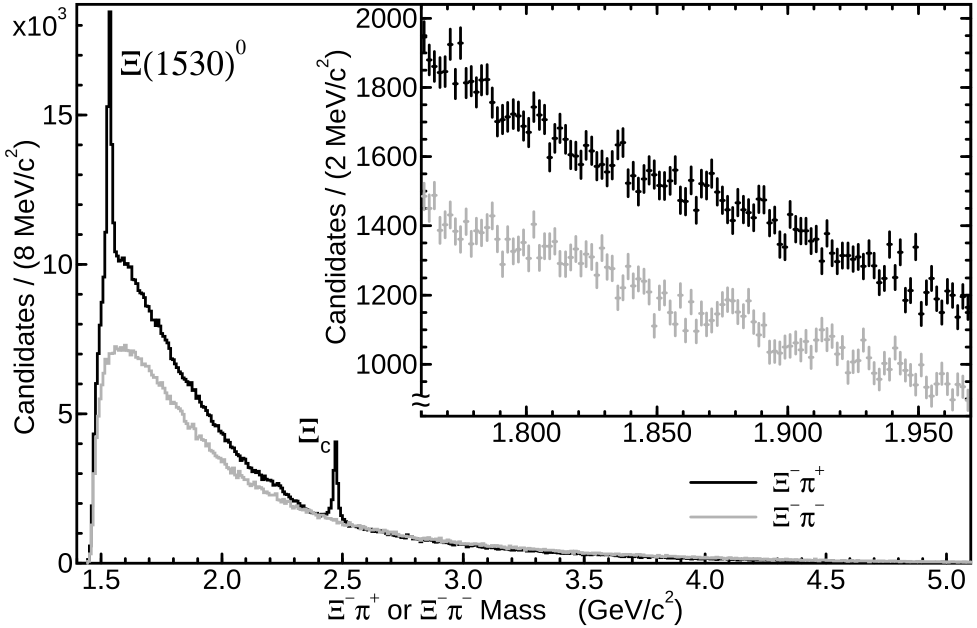


B. Aubert *et al.* (BaBar), *Phys. Rev. Lett.* **95**, 042002 (2005)

$\Theta(1540)^+ \to pK^0_S$



$\Xi_5(1860)^{0(--)} \to \Xi^-\pi^{+(-)}$



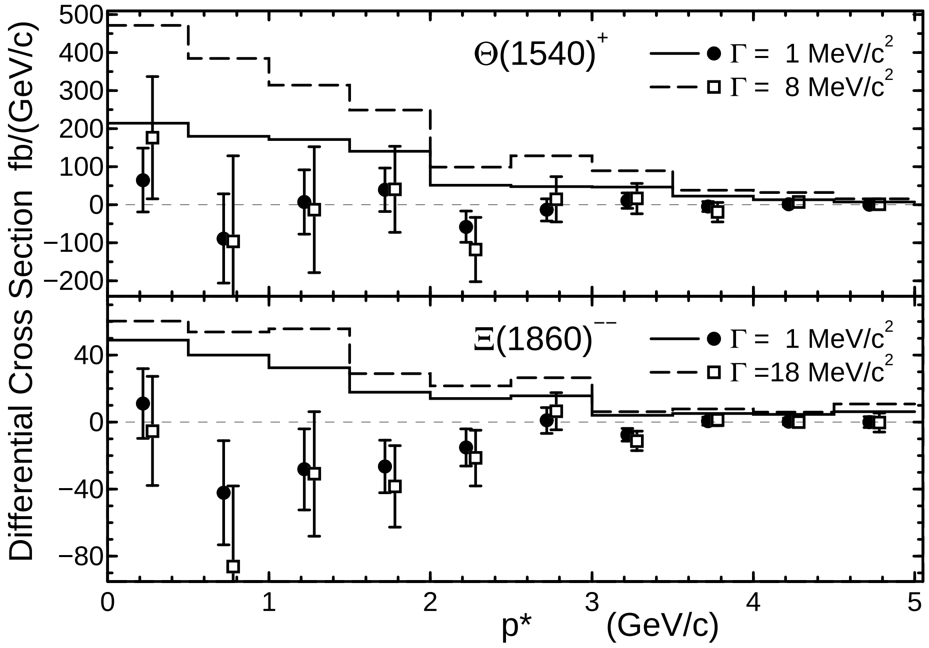
pK^0_S consistent with prod^n at IP

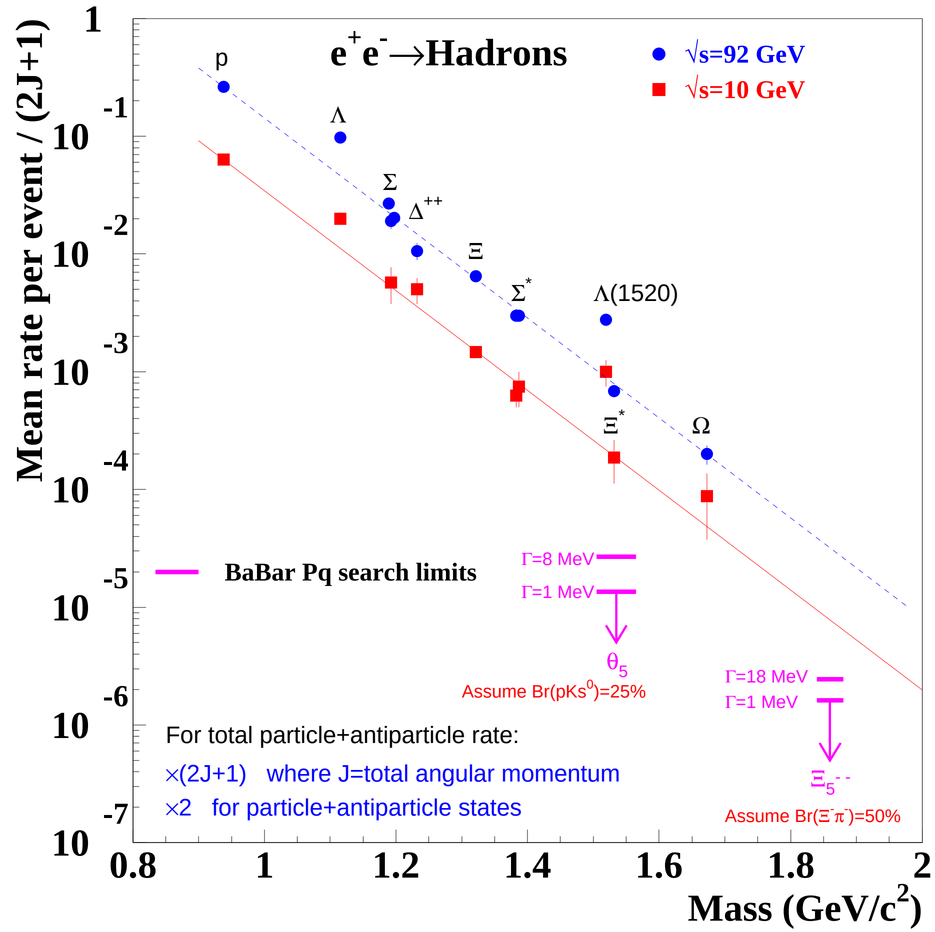
then binned in p^* and fitted . . .

$\Xi^- \to \Lambda\pi^-$; extra π^- track $\neq \Xi^-$

(note strong $\Xi(1530)^0$ and Ξ_c)

B. Aubert *et al.* (BaBar), *Phys. Rev. Lett.* **95**, 042002 (2005)





assume $\Gamma =$ "narrow" ("UL"):

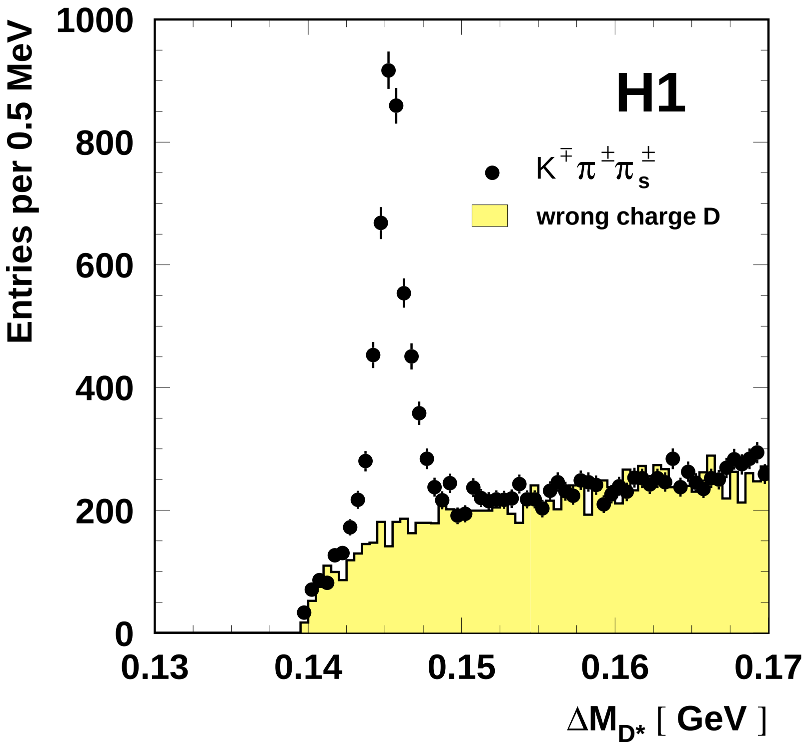
Θ^+: $< 5.0\,(11) \times 10^{-5}/q\bar{q}$ event

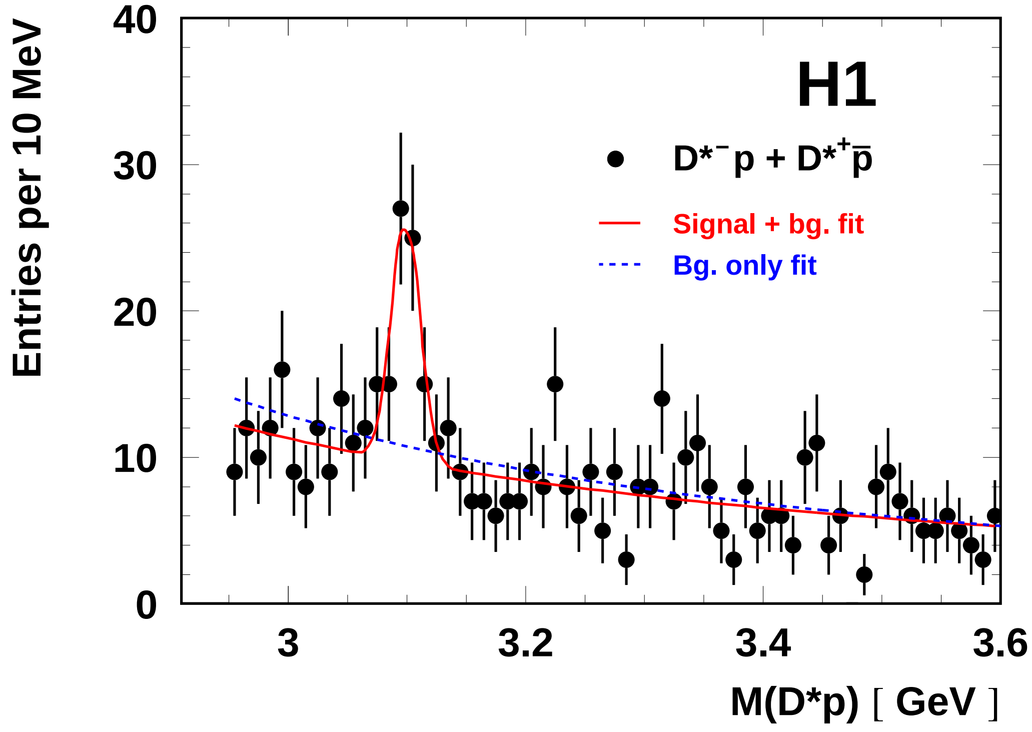
Ξ_5^{--}: $< 0.74\,(1.1) \times 10^{-5}/q\bar{q}$ event

factor 8 (for Θ^+) or 4 (for Ξ_5^{--}) below **8** or **10** baryon rates

$\Theta_c^0 \to D^{*-} p$

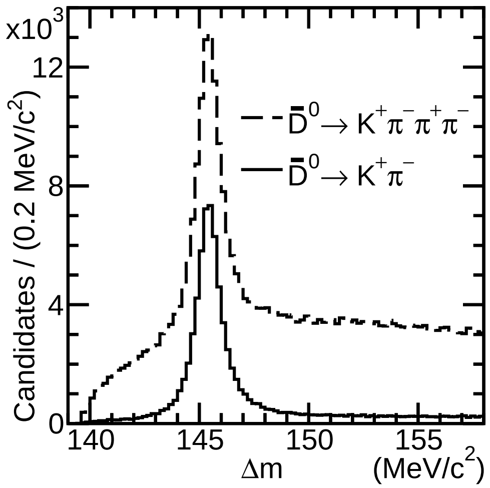
A. Aktas *et al.* (H1), *PLB* **588**, 17 (2004)

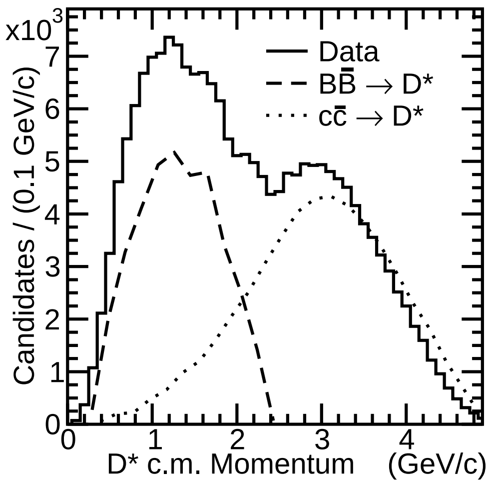




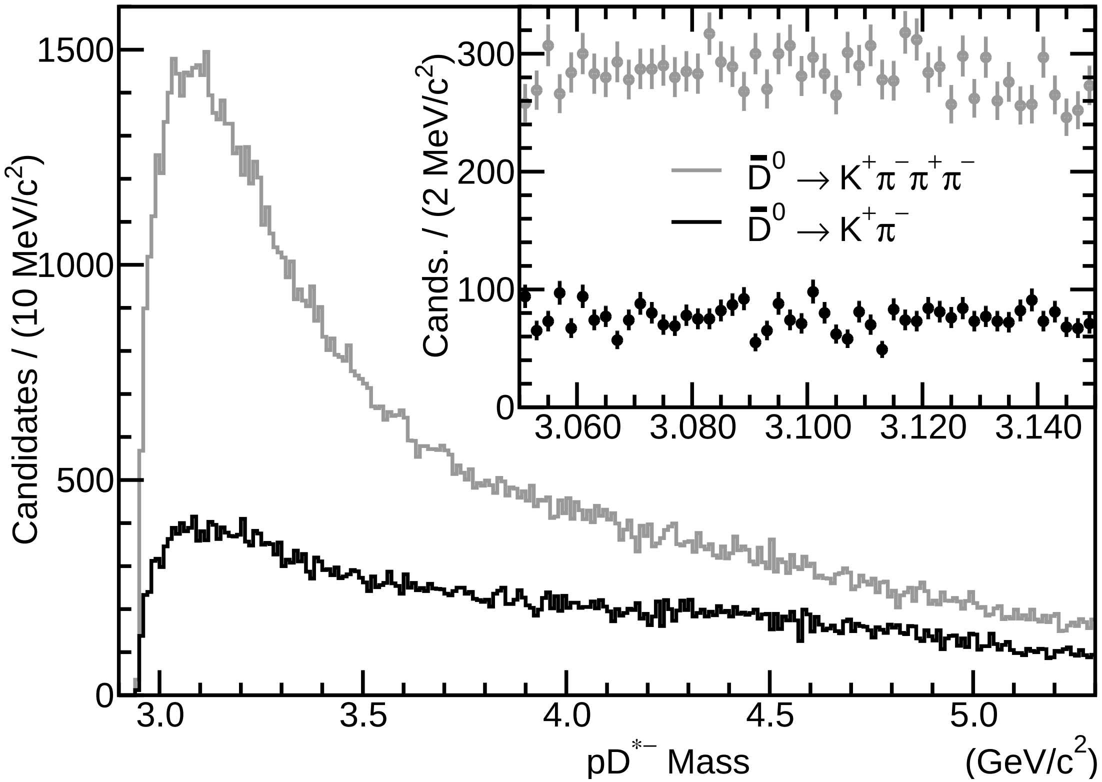
$\Theta_c^0 \to D^{*-}p$

B. Aubert *et al.* (BaBar), *PRD* **73**, 091101(R) (2006)





- vtx fits to $X \to pD^{*-}$ $[\to \pi^- \overline{D}^0\ [\to Kn\pi]\ ]$
- $\approx$ clean ($K3\pi$) & v.clean ($K\pi$) samples
- featureless pD^{*-} distributions

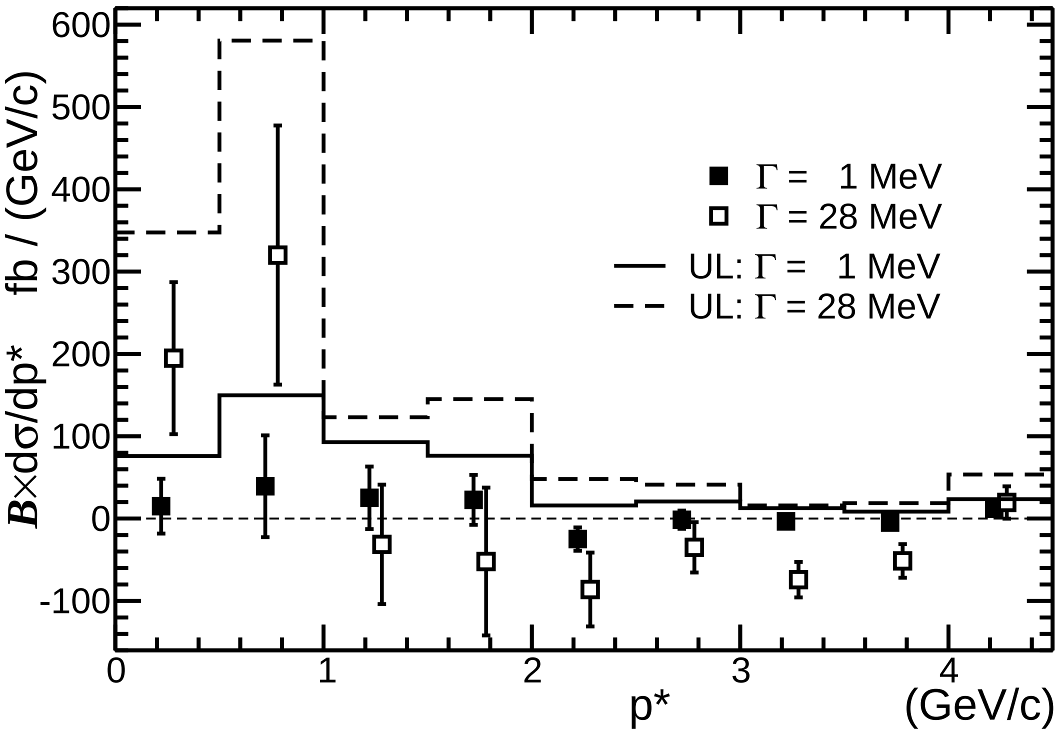


$\Theta_c^0 \to D^{*-} p$

B. Aubert *et al.* (BaBar), *PRD* **73**, 091101(R) (2006)

fit in bins of p^*; background higher at low p^* (per sideband)

- $\mathcal{B} \times \frac{d\sigma}{dp^*}$ & 95% limits for $\Gamma =$ "narrow" ("UL")
- integral less than 3.4 (8.8) $\times 10^{-5}/\, q\bar{q}$ event
- $\exists$ also $c\bar{c}$, $\Upsilon(4S)$ limits
- c-frag^n and B-decay samples 100× H1

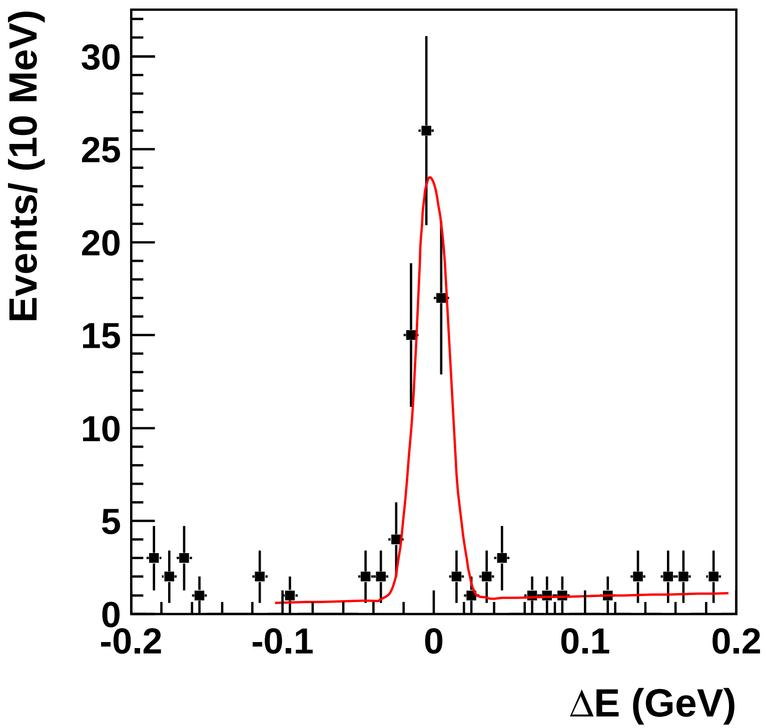


"[limit ≈ expected rate for normal charmed baryons]"

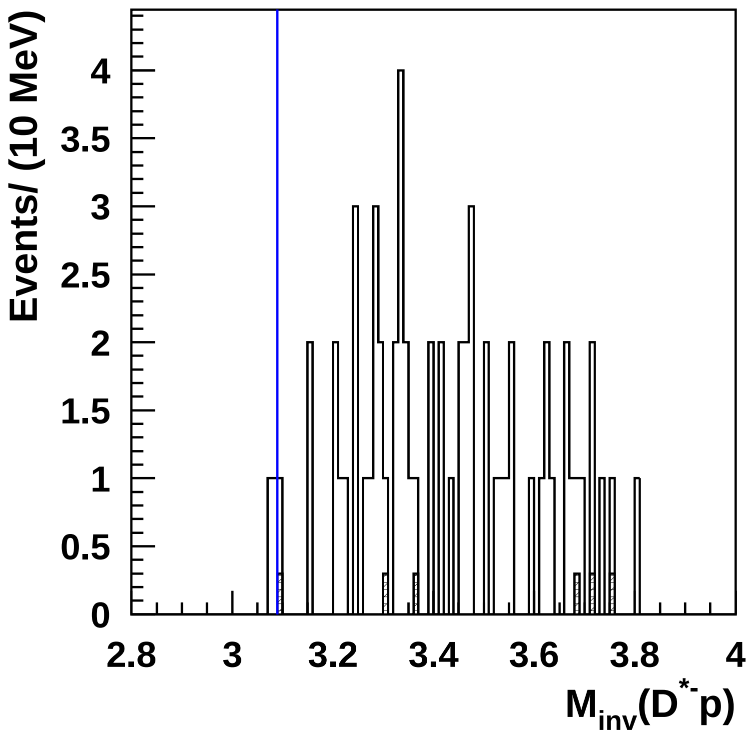
which we are now seeing in this mass range . . .

Belle: exclusive B-decays, arXiv:hep-ex/0411005 *conf. prelim.*

$B^0 \to D^{*-} p\bar{p}\pi^+$ yield



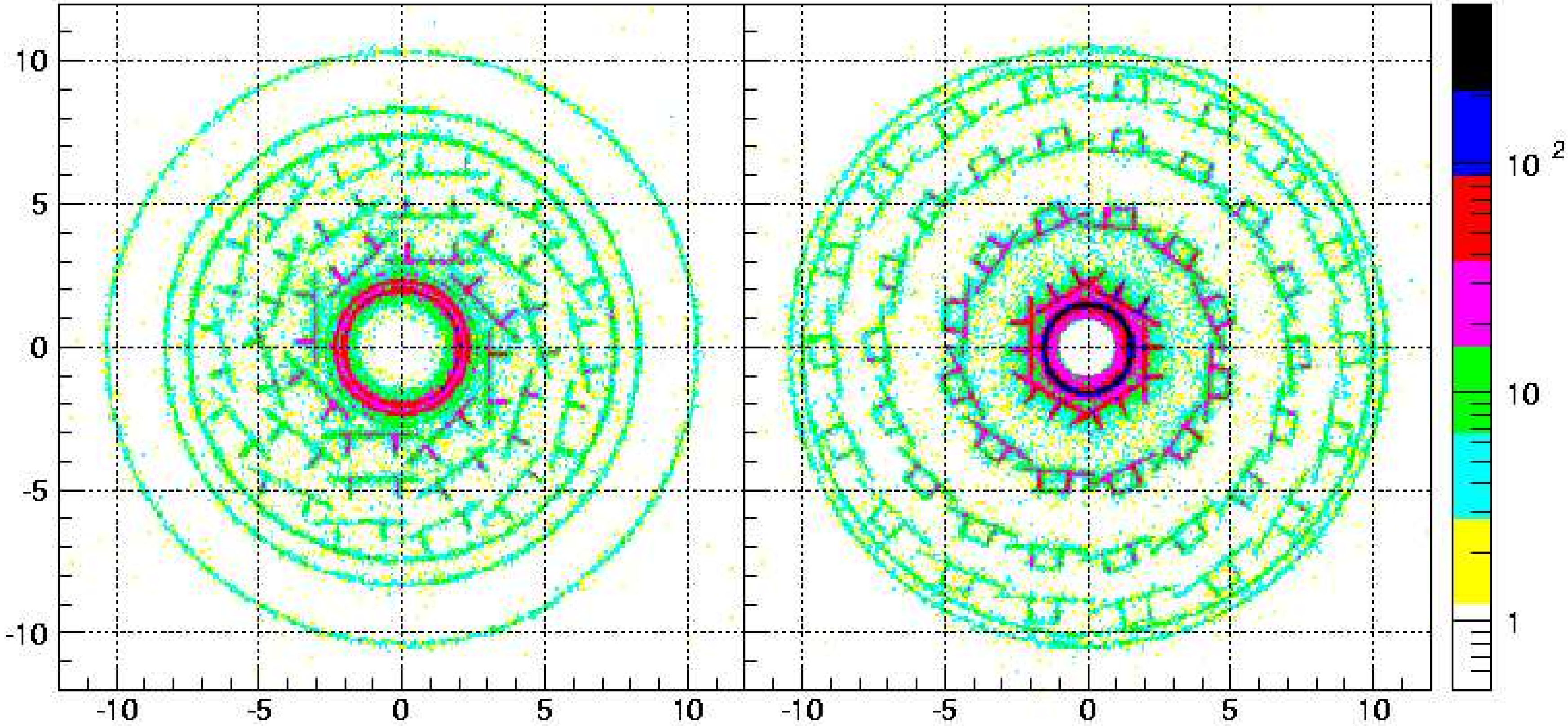
$M(D^{*-}p) \sim$ phase space



$$\frac{\mathcal{B}(B^0 \to \Theta_c^0 p\pi^+) \times \mathcal{B}(\Theta_c^0 \to D^{*-}p)}{\mathcal{B}(B^0 \to D^{*-}p\bar{p}\pi^+)} < 0.11 \text{ @ } 90\%; \ 0.012 \text{ for } D^- p$$

[$\Theta_c^+ \to \overline{D}{}^0 p$ also studied; limit < 0.059]

R. Mizuk *et al.* (Belle), *Phys. Lett. B* **632**, 173–180 (2006)

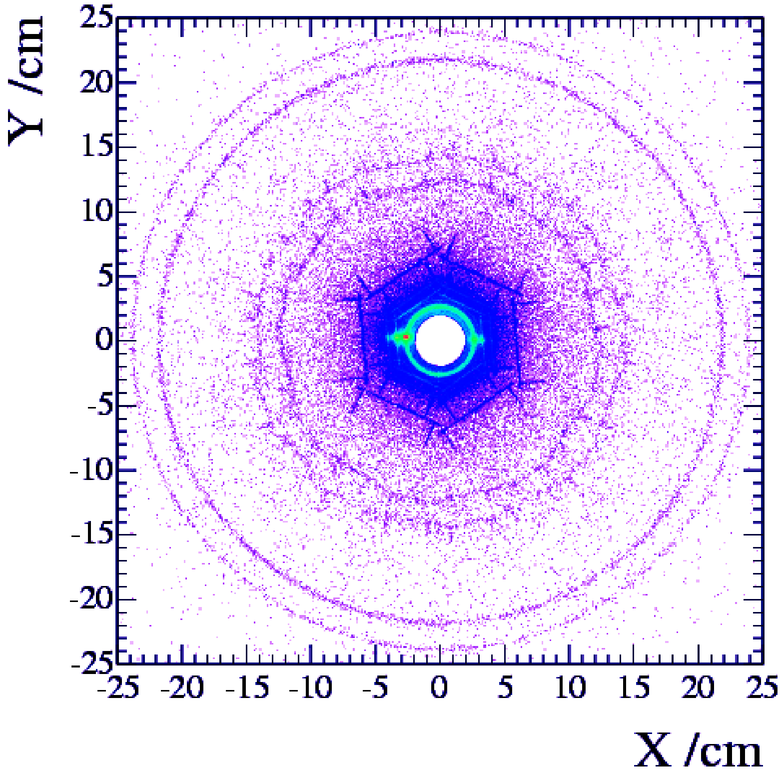


“tomography” of inner detector: pK^0_S vertices

$\Theta^+ \to pK^0_S$

BaBar conference prelim., *e.g.* `hep-ex/0510041`

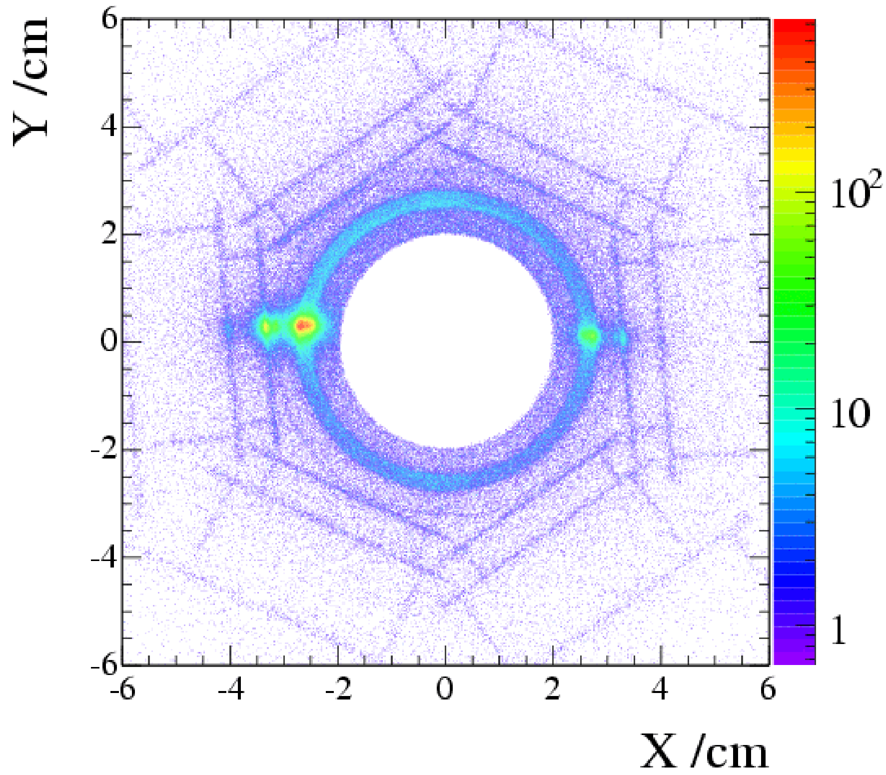
good pK^0_S at radii $> 2\,\text{cm}$



veto associated p, $\bar{p}$, d, t

no sign of the $\Theta(1540)^+$

e^-Be in beampipe



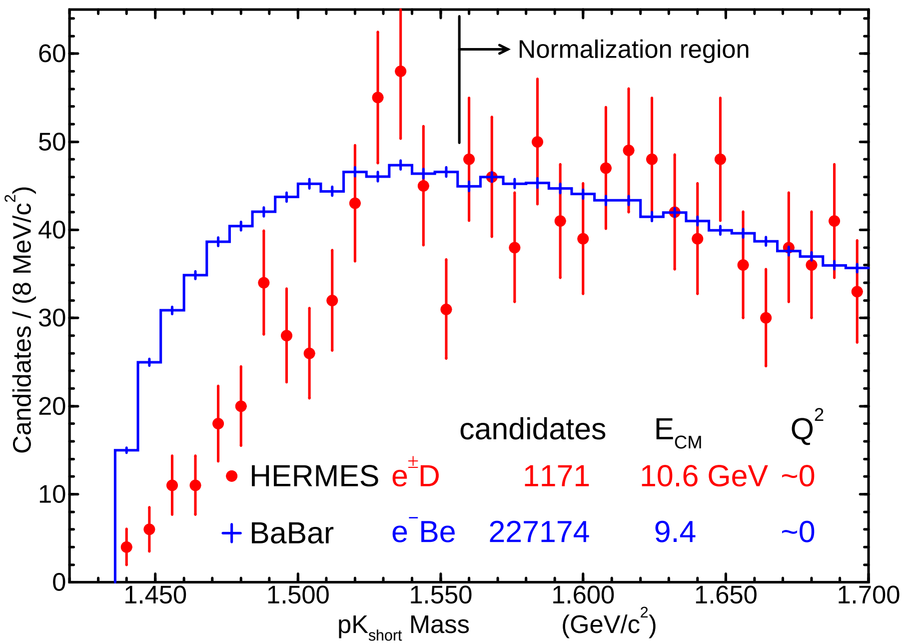
N.B. halo e^- flux unknown

compare final distributions . . .

$\Theta^+ \to pK^0_S$

BaBar conference prelim., *e.g.* hep-ex/0510041

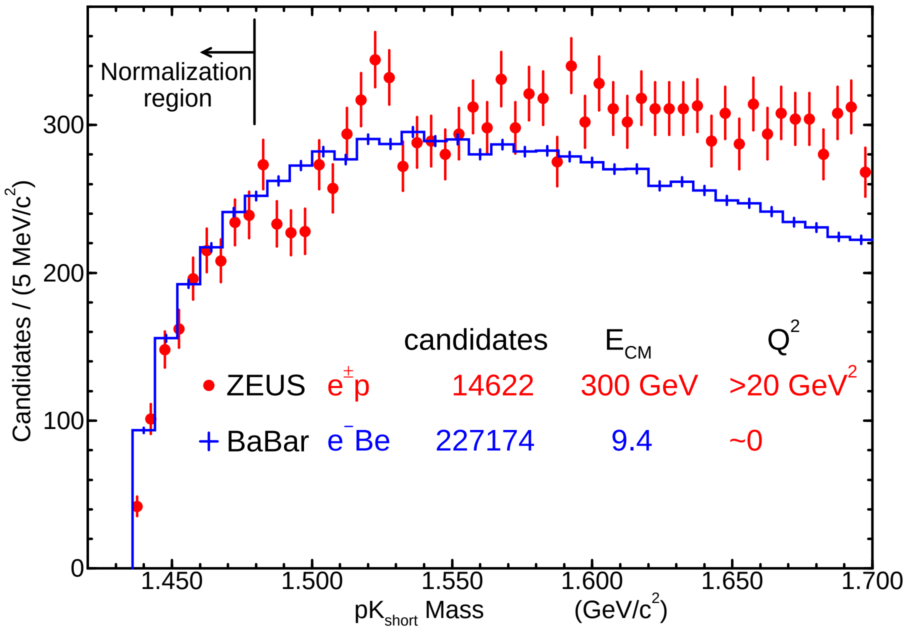
cf. HERMES $e^\pm D \to pK^0_S X$



$\sqrt{s}$, Q similar; $N \gg N_{\text{HERMES}}$

N.B. low-$M(pK^0_S)$ acceptance

cf. ZEUS $e^\pm \to pK^0_S X$



$\sqrt{s}$, Q v.different

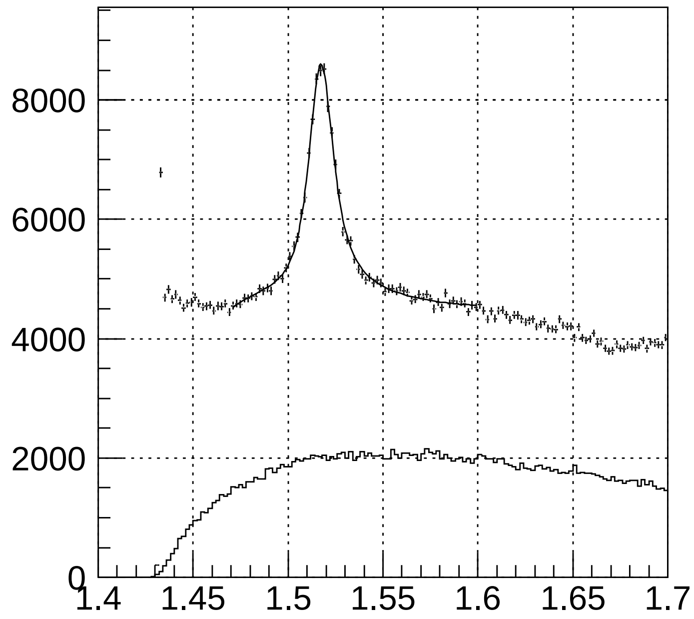
what can we say . . .

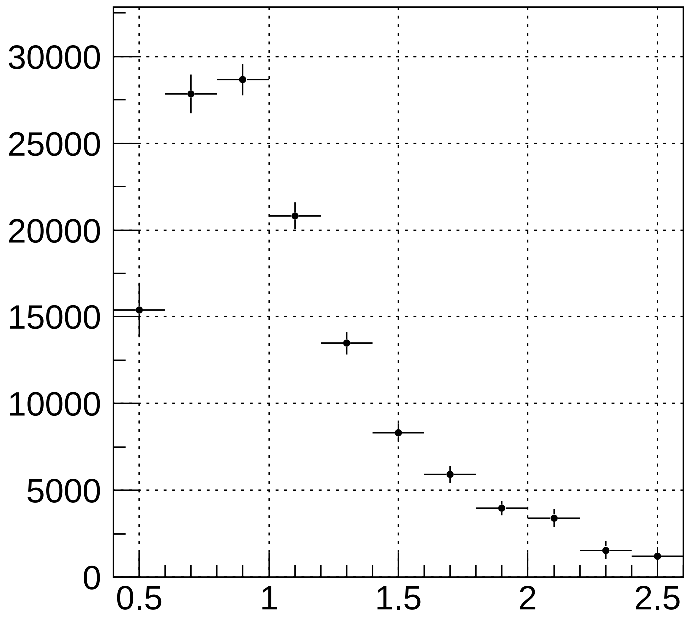
$\Theta^+ \to pK^0_S$

R. Mizuk *et al.* (Belle), *PLB* **632**, 173–180 (2006)

cf. $\Lambda(1520)^+ \to pK^-$; pK^0_S ...?

$p_\Lambda > 400\,\mathrm{MeV}/c$: **inelastic**





good Λ fit: $(4.1 \pm 0.1) \times 10^4$ ev.

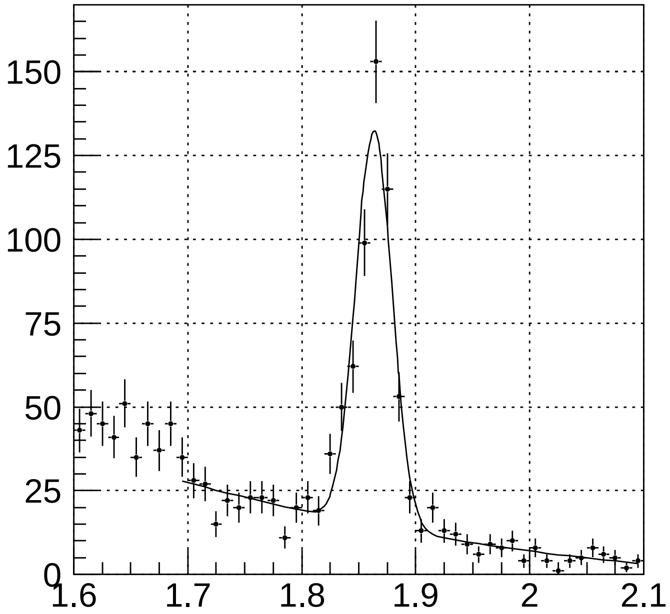
projectiles strange; mostly K

$\sigma(\Theta(1540)^+)/\sigma(\Lambda(1520)) < 2.5\%$ at 90%

$\Theta^+ \to pK^0_S$

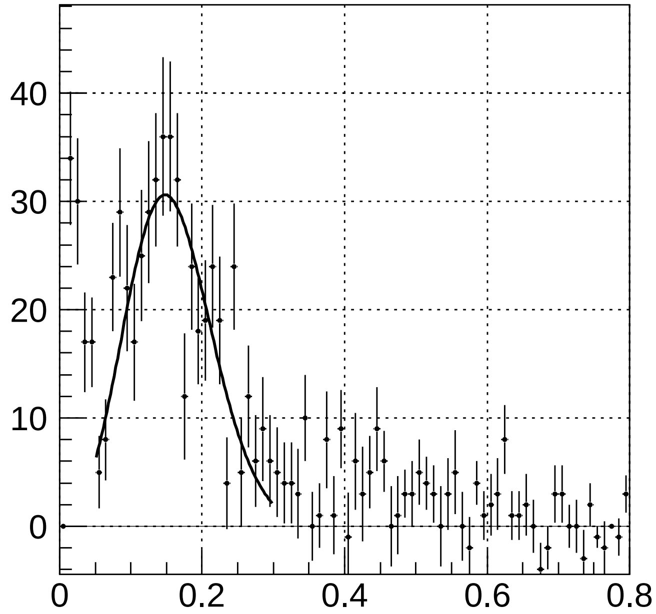
R. Mizuk *et al.* (Belle), *PLB* **632**, 173–180 (2006)

K^+ int^{ns}: $\overline{D}^0 \to K^+\pi^-$



obtain $\Phi^{K^+}_{D^*} \cdot \sigma^{el}$

Fermi momentum fit



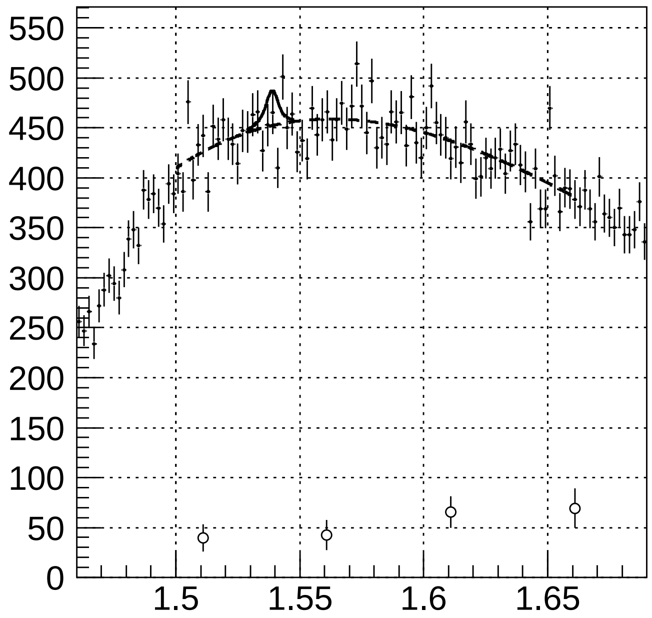
($\vec{p}_F$ used to solve $(\vec{p}, E)$)

given $\Phi^{K^+}/\Phi^{K^+}_{D^*}$, σ^{ch}/σ^{el}, $\epsilon_{pK^0_S}/\epsilon_{pK^+}$ . . .

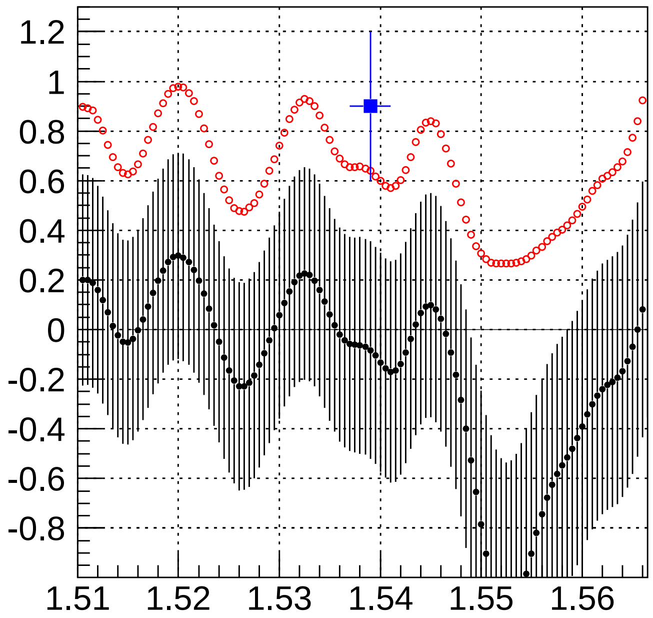
$\Theta^+ \to pK^0_S$

R. Mizuk *et al.* (Belle), *PLB* **632**, 173–180 (2006)

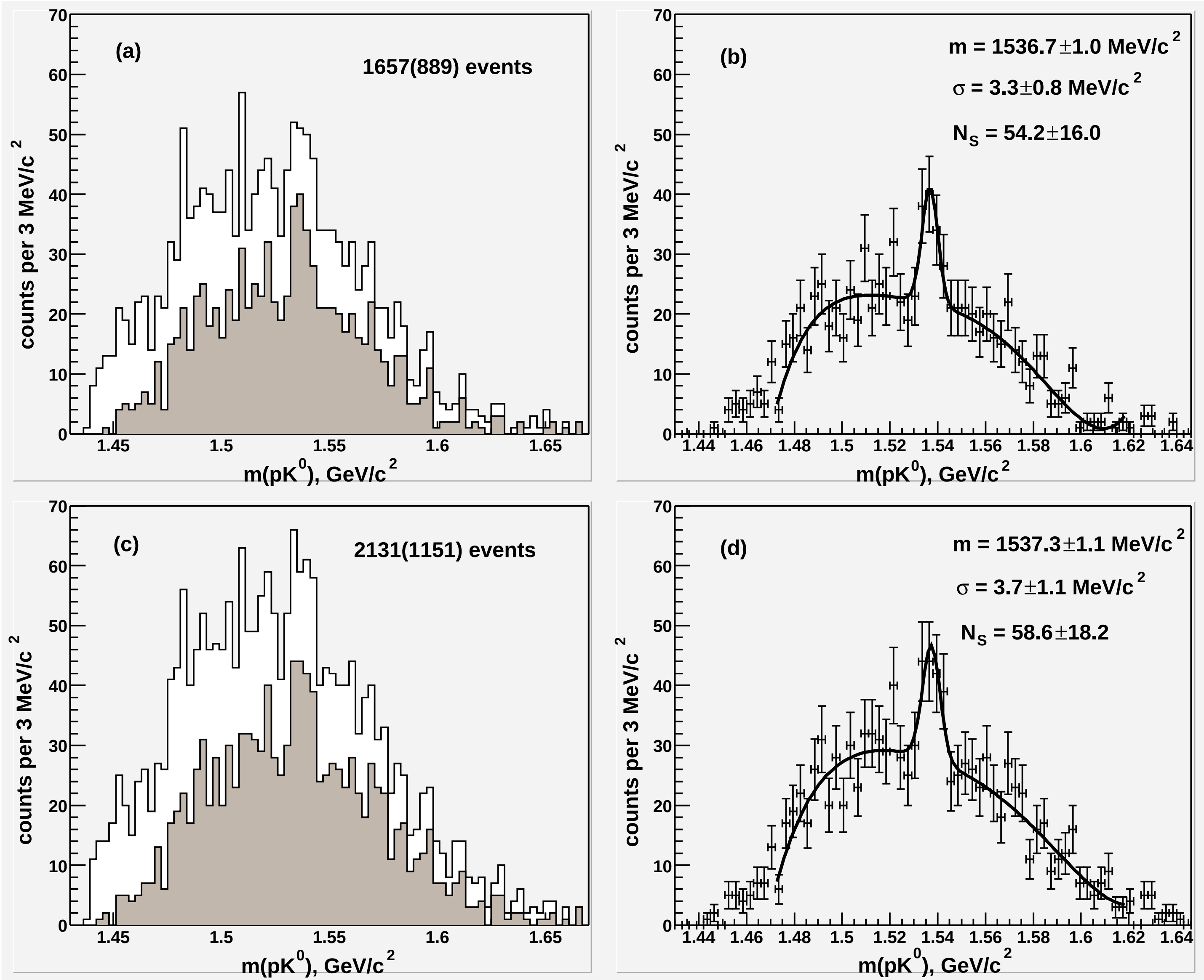
pK^0_S spectrum



yield and 90% UL: $f(M_{pK^0_S})$



limit on the width $\Gamma(K^+n \to \Theta^+ \to pK^0_S) < 0.64\,\mathrm{MeV}$



(a)
1657(889) events
counts per 3 MeV/c^2
m(pK^0), GeV/c^2
(b)
m = 1536.7±1.0 MeV/c^2
σ = 3.3±0.8 MeV/c^2
N$_S$ = 54.2±16.0
(c)
2131(1151) events
(d)
m = 1537.3±1.1 MeV/c^2
σ = 3.7±1.1 MeV/c^2
N$_S$ = 58.6±18.2

- the $\Theta(1540)^+$ and Θ^{*++} are not seen in $B \to p\overline{p}K$
  - $\mathcal{B}\left(B \to \Theta^{(*)}\overline{p}\right) \times \mathcal{B}\left(\Theta^{(*)} \to pK\right) < O(10^{-7})$
  - these decays are dominated by a low-$M(p\overline{p})$ amplitude
- inclusive e^+e^- prod^n rates for strange pentaquarks are low
  - $\sigma(\Theta^+) \lessapprox \frac{1}{8} \times \sigma(\mathbf{8}, \mathbf{10}, \text{baryons})$; $\sigma(\Xi_5^{--}) < \frac{1}{4} \times \sigma(\mathbf{8}, \mathbf{10})$
  - Ξ_5^- and Ξ_5^0 are not seen, but limits are weaker
- H1's charmed pentaquark $\Theta_c(3100)^0$ has not been seen
  - inclusive sample 100× H1: excludes hard c & B-decays
  - sensitivity ≈ expected rate for normal charmed baryon
- search in pK int^{ns} $\Longrightarrow$ any $\Theta^+(1540)$ must be narrow
  - inclusive rate low; $\Gamma(K^+n \to \Theta^+ \to pK^0_S) < 0.64\,\text{MeV}$
  - does not contradict the new DIANA claim