Evidence for a Narrow Exotic Anti-Charmed Baryon State

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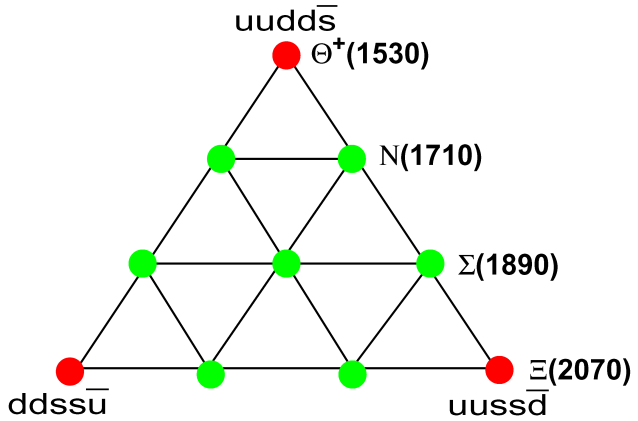
Motivation

- Recent discovery of strange pentaquark
- Narrow resonance in $K^{\pm}n$ or K_s^0p
- Mass around 1540 MeV
- Minimal quark content $uudd\bar{s}$
- Interpretation: pentaquark Θ^+



- What about exotics with charm?
- Good experimental signature for D*
- Search for signature in $D^{*-}\bar{p}$ and $D^{*+}p$ combinations …

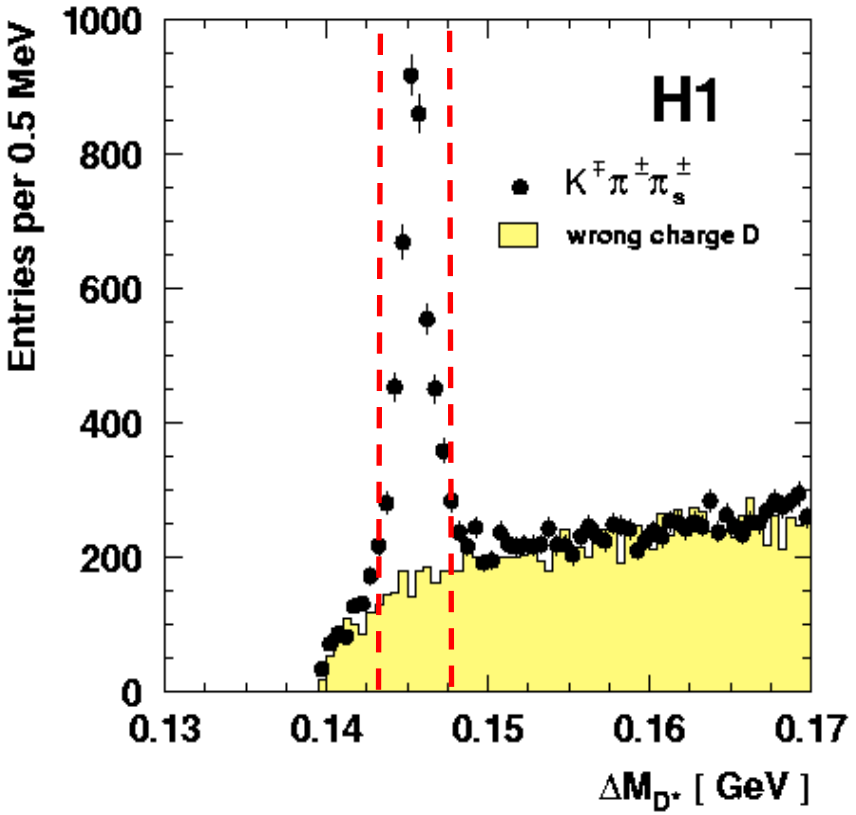
D* Signal Selection

- 1996-2000 data (L_{int} = 75 pb^{-1})
- DIS: 1 $GeV^2 < Q^2 < 100\ GeV^2$
  $0.05 < y < 0.7$
- $D^* \rightarrow D^0\pi_s \rightarrow (K\pi)\pi_s$
- $\Delta M(D^*)=m(K\pi\pi_s)-m(K\pi)$
- $p_t\,(D^*) > 1.5$ GeV
- $p_t\,(K) + p_t\,(\pi) > 2$ GeV

Modified cuts (with respect to F_2^c analysis) to improve S/B ratio:

- $-1.5 < |\eta\,(D^*)| < 1$
- Inelasticity $z\,(D^*) > 0.2$

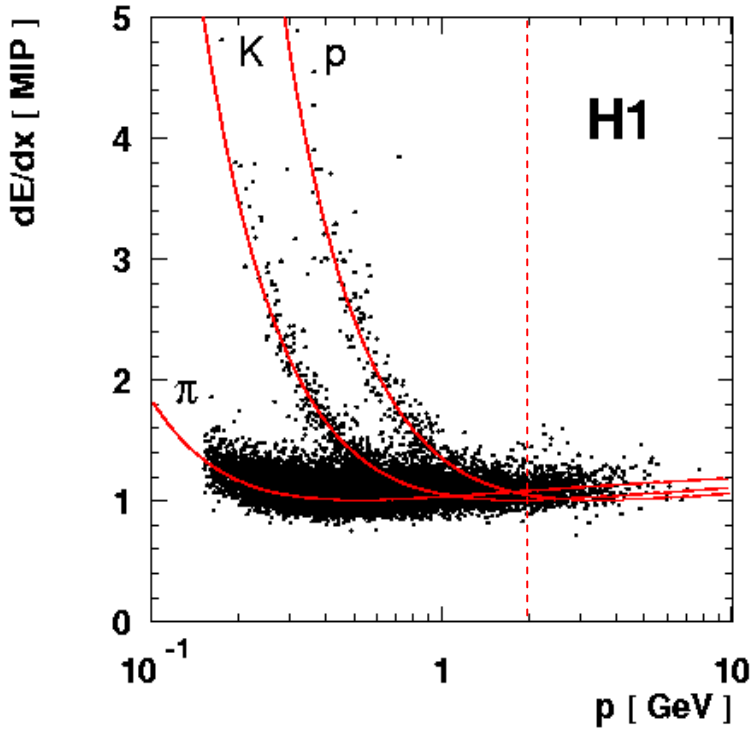
3400 D* in DIS



Proton Selection by dE/dx

- dE/dx-parameterization accurate to 3-5%
- 8% average resolution

- Normalized likelihood L based on measured dE/dx and expectations
- $L(\pi)+L(K)+L(p) = 1$

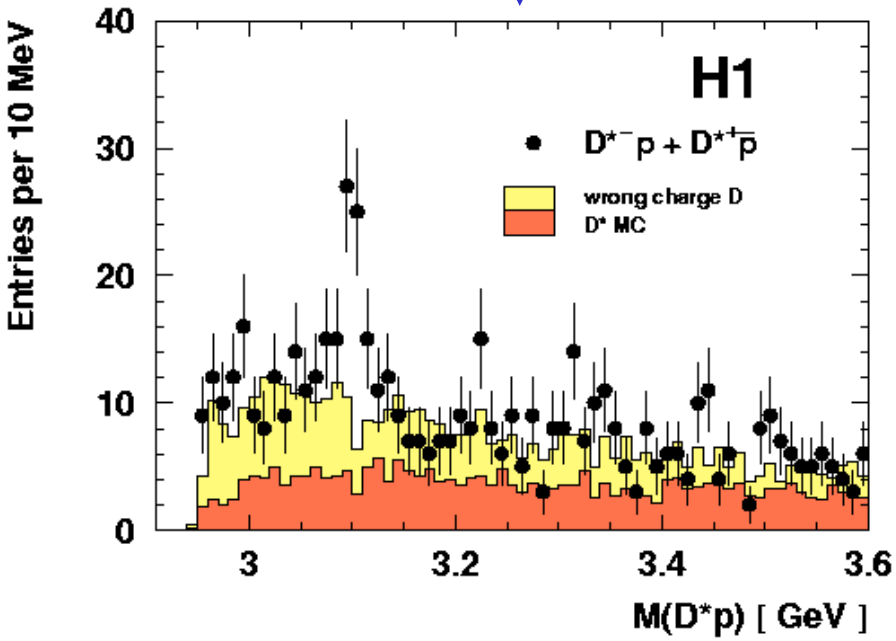


- Used for background rejection
- Proton selection:
  L(p)>0.3 for p(p)<2 GeV
  L(p)>0.1 for p(p)>2 GeV

$D^{*+}\bar{p}$ + cc in DIS

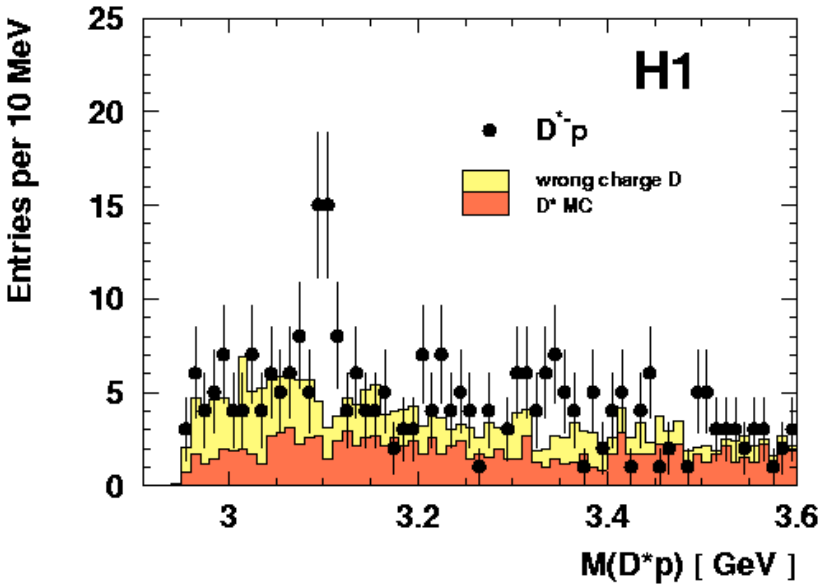
- Combination of D* and proton candidates
- To enhance resolution look at mass difference $m(K\pi\pi_s p)$-$m(K\pi\pi_s)$
- $M(D^*p) = m(K\pi\pi_s p)-m(K\pi\pi_s)+m(D^*)_{PDG}$

- Significant peak in opposite sign D*p
- No enhancement in wrong charge D
- No enhancement in D* MC (RAPGAP, CASCADE, HERWIG, Beauty MC)
- Total background well described by D* MC and wrong charge D from data



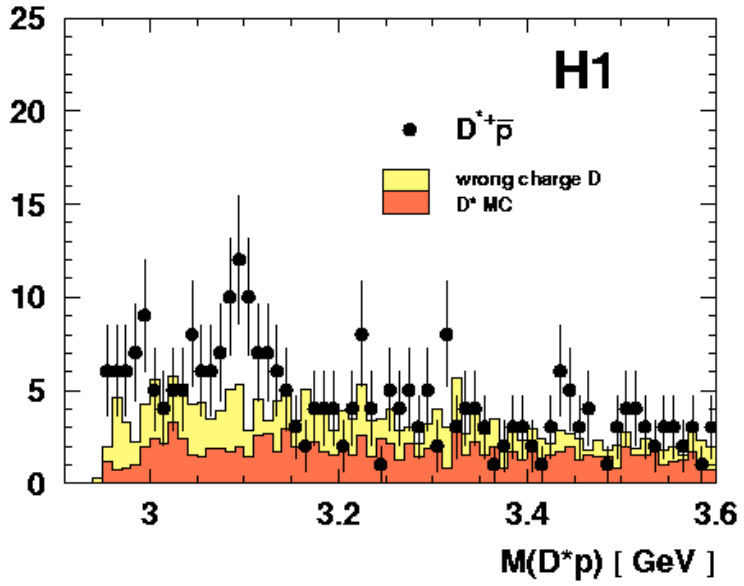
$D^{*-}p$ and $D^{*+}\bar{p}$

M (D*p) = 3.102 ± 0.003 GeV



25.8 ± 7.1 *Events*

M (D*p) = 3.096 ± 0.006 GeV



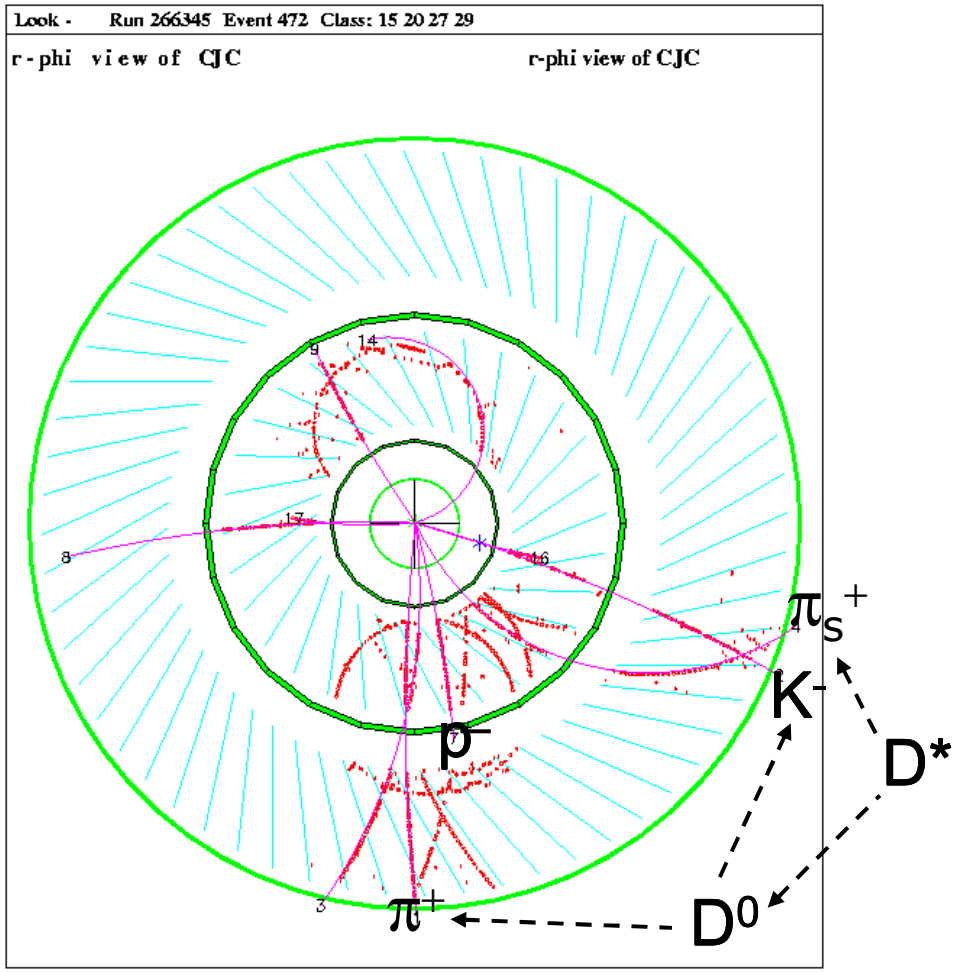
23.4 ± 8.6 *Events*

Signal of similar strength observed for both charge combinations at compatible M(D*p).

A Typical Event

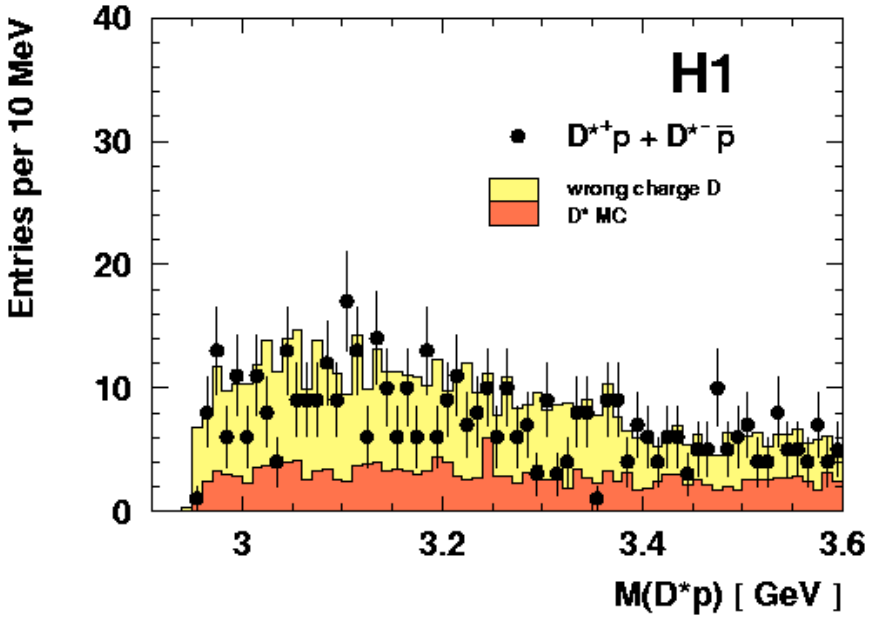
All events in the signal region have been scanned.

no anomalies observed e.g. split tracks, wrong reconstruction, …

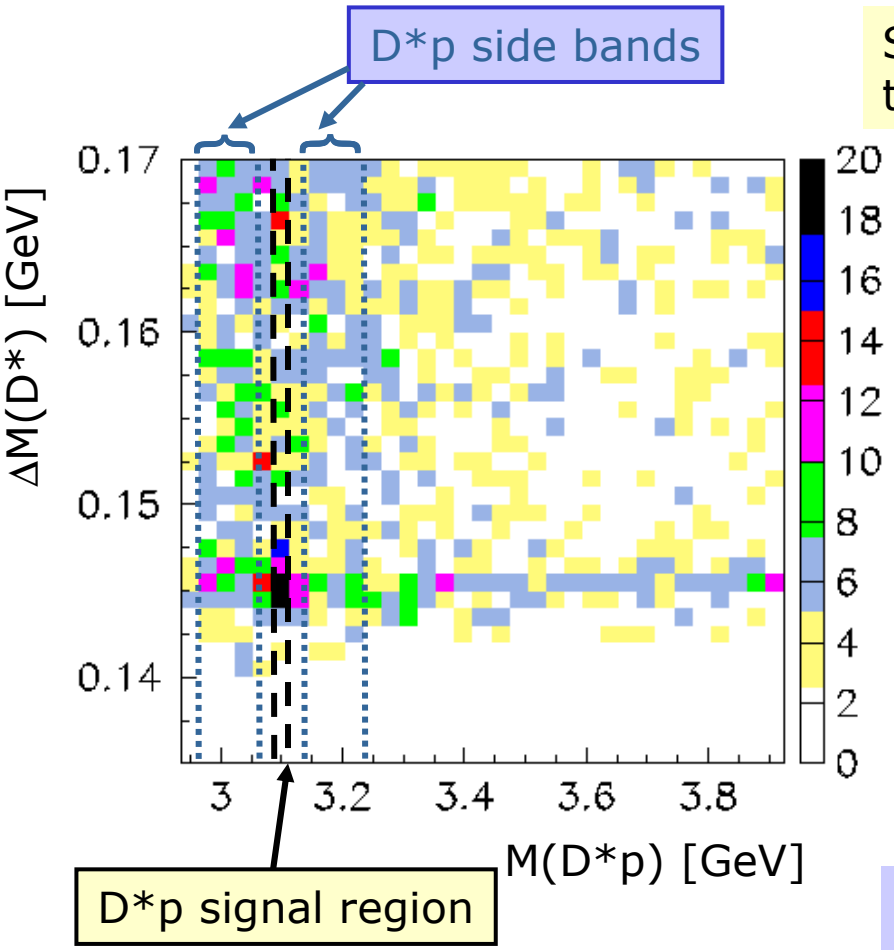


Like Sign $D^{*+}p$ + cc

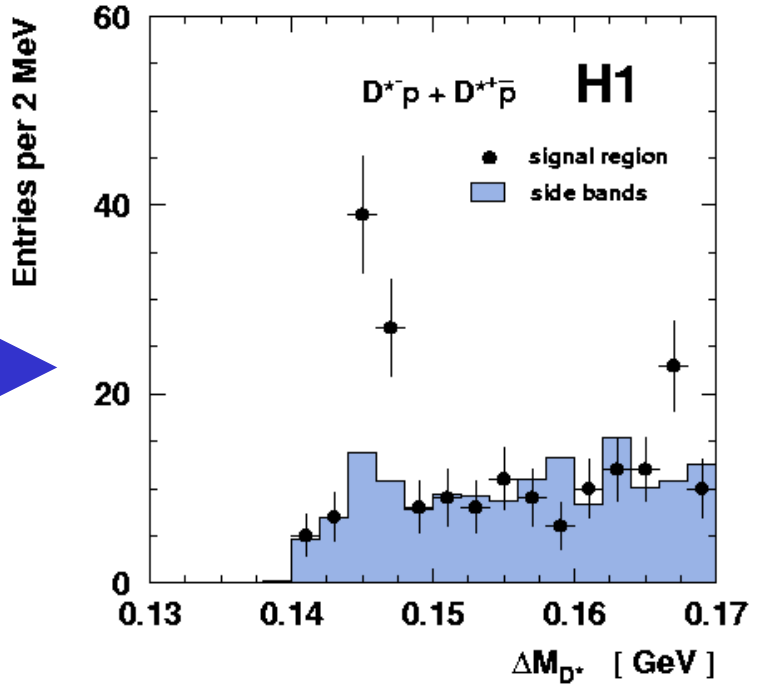
- No significant peak in like sign D*p
- Reasonably described by D* MC and wrong charged D from data



D* in Signal Region



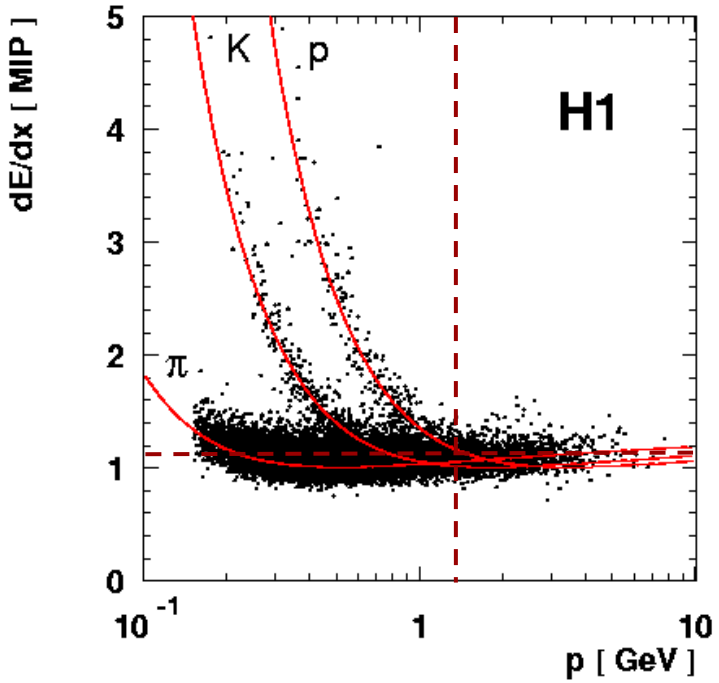
Side bands have been normalized to the width of the windows in M(D*p).

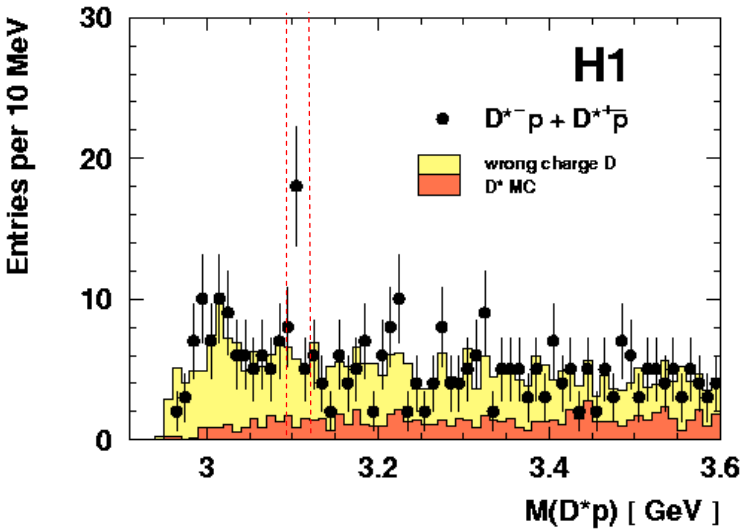


Richer yield of D* mesons in signal than in side bands.

Proton Identification

- dE/dx > 1.15 MIPS
- p(p) < 1.2 GeV
- L(p) > 0.5
- No cut on z(D*)
- No cut on $p_t(K)+p_t(\pi)$



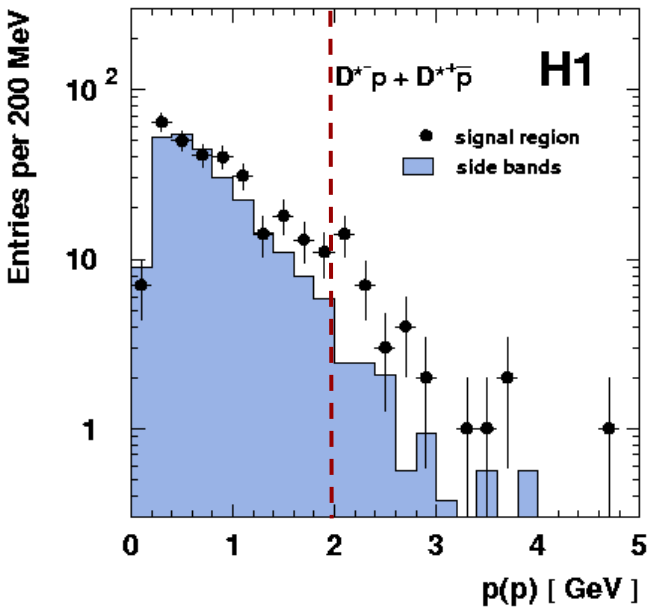


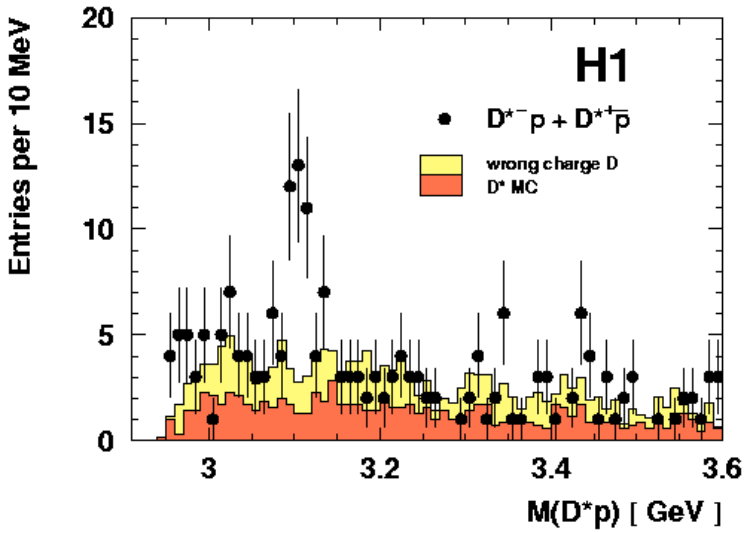
$$\langle L(p) \rangle = 0.92$$

Peak still visible.

Signal at large p(p)

No cut applied on proton likelihood.





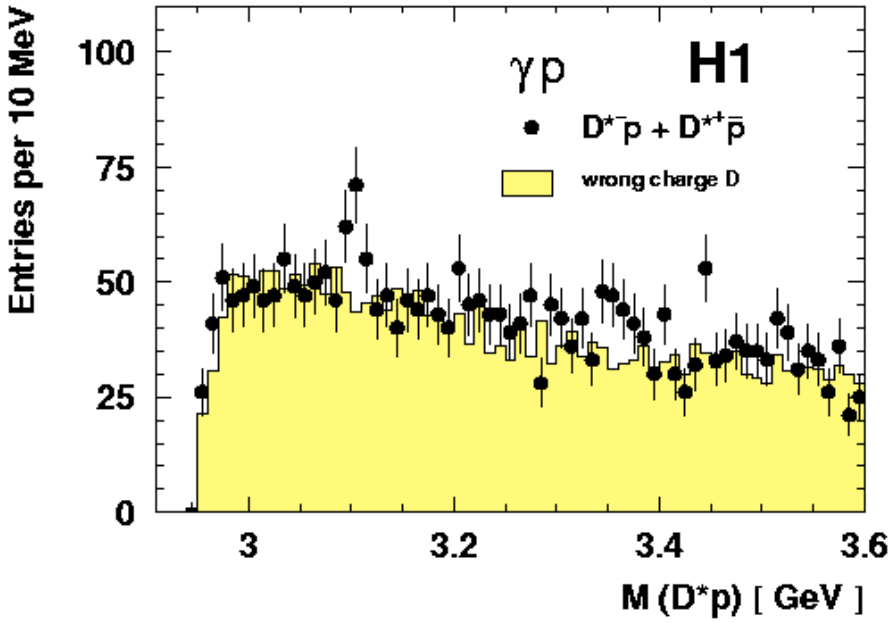
p(p) > 2GeV

- The momentum spectrum of the particles in the signal region is harder than in the M(D*p) side bands.
- Signal to background improves at larger proton momentum.

$D^{*-}\bar{p}$ + cc in photoproduction

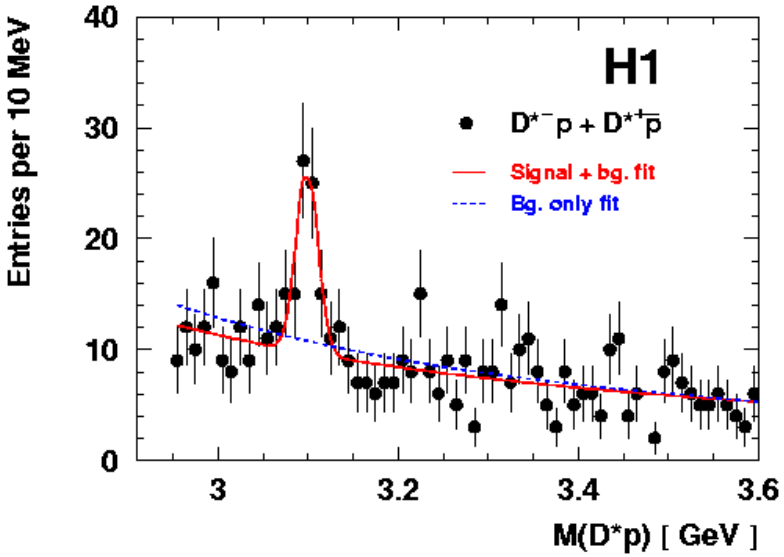
- 4900 D* in sample
- Peak also observed in photoproduction
- > 95% of background due to non-charm
- No enhancement in non-charm background
- Background well described by wrong charged D from data

$M(D^*p) = 3.103 \pm 0.004$ GeV



Photoproduction more difficult due to large non-charm background.

Significance estimation



- $N_s + N_b$ = 95 D*p candidates within 2σ
- N_s = 45.0 ± 2.8 from background + signal hypothesis
- Mass 3099 ±3 (stat.) ±5 (syst.) MeV
- Width 12 ± 3 (stat.) MeV
- N_b = 51.7 ± 2.7 from background only hypothesis

- Significance estimate based on the background only hypothesis

Background fluctuation probability **4×10^{-8} (Poisson) ≡ 5.4 σ (Gauss)**

- Use of different background functions as well as background model from data and MC
- Significance determined in a binning free method

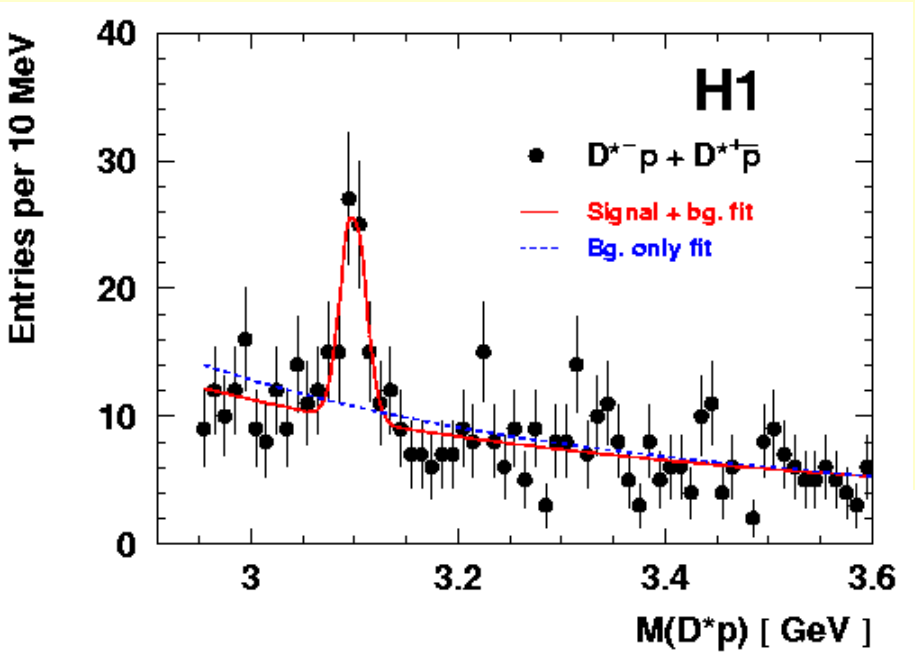
Conclusions

- **Narrow resonance** observed for $D^{*-}p$ and $D^{*+}\bar{p}$ in DIS
- **Mass of 3099± 3 (stat.) ± 5 (syst.) MeV**
- **Width** of the resonance is **12 ± 3 (stat.) MeV** consistent with the experimental resolution
- Significance of the signal is **5.4 σ**
- **Richer yield of D* mesons** and **harder momentum spectrum of the proton** candidates in M(D*p) signal region
- Many kinematical tests, all found to be only consistent with D*p hypothesis

- Interpretation as an **anti-charmed baryon** decaying to D*p
- Minimal quark content is **uudd$\bar{c}$**
- Candidate for a **charmed pentaquark** state

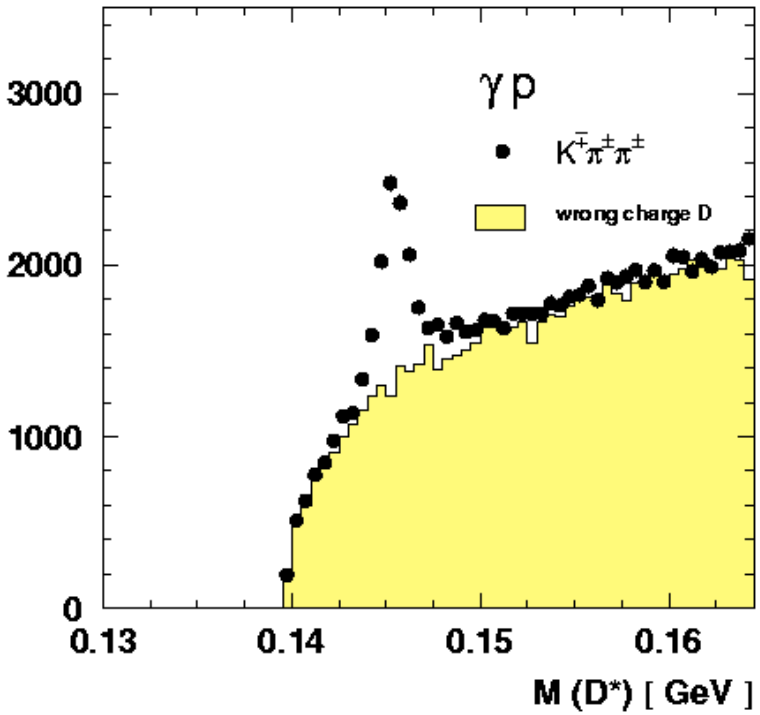
Evidence for a Narrow Anti-Charmed Baryon State

- **Narrow resonance** observed in opposite sign **D* proton** invariant mass combinations
- Mass: **3099 ± 3 (stat.) ± 5 (syst.) MeV**
- Width: **12 ± 3 (stat.) MeV**
- **Significance** of signal **5,4 σ**
- Interpretation as anti-charmed baryon with minimal quark content **$uudd\bar{c}$**
- Candidate for **charmed pentaquark state**

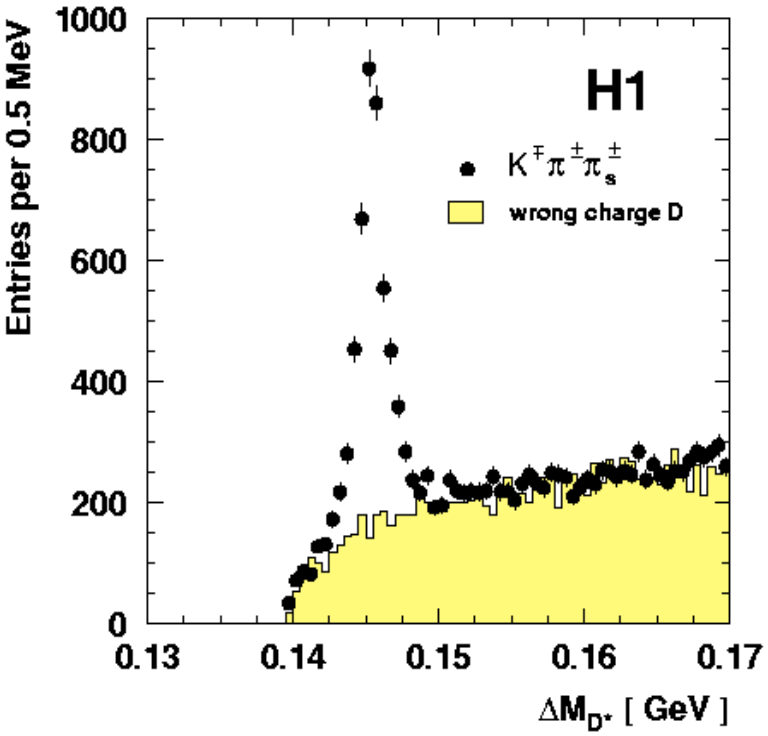


Both regimes equally well suited for the analysis ?

photoproduction



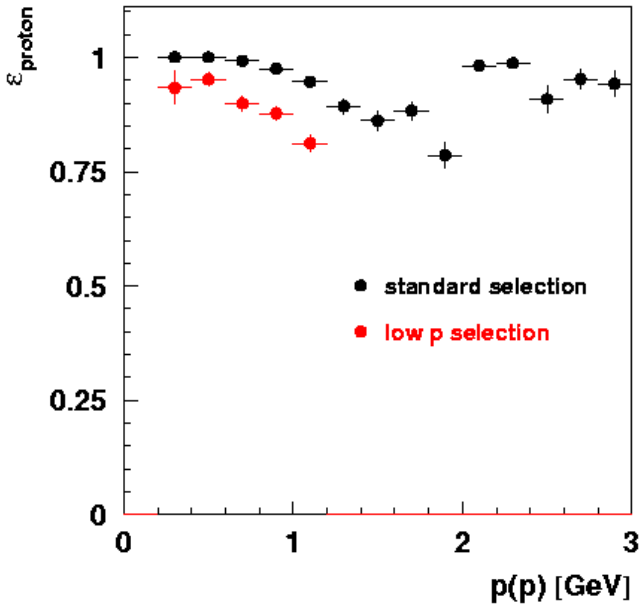
DIS



DIS much cleaner
→ base analysis on DIS
→ use photoproduction as cross check

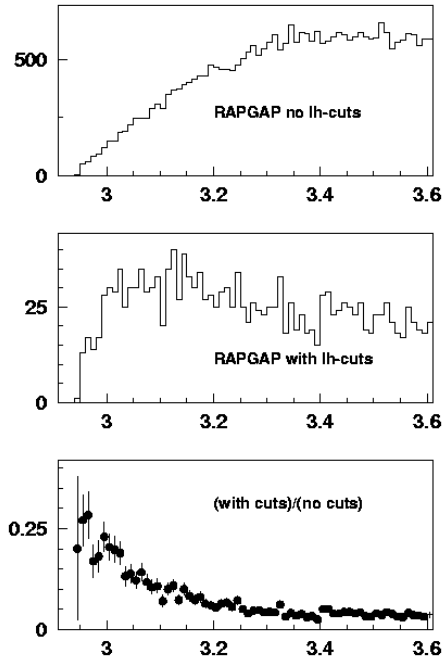
Does some acceptance effect fool us ?

proton efficiency



Good p efficiency

"pion survival probability"



M(D*p) [GeV]

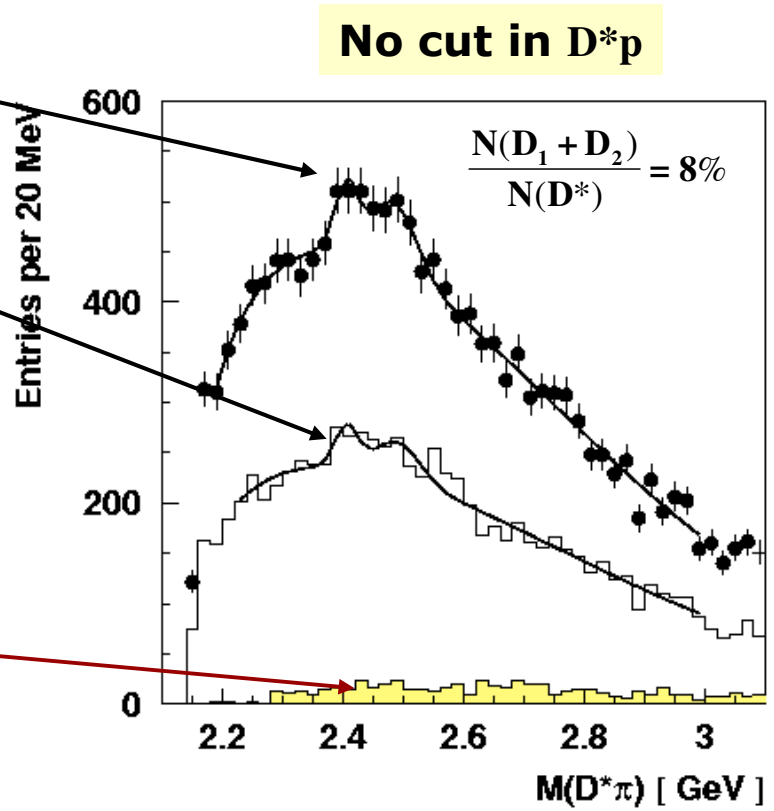
Smooth variation with M(D*p)
Shape reflects opening of phase space

Possible Background: $D_1(2420)/D_2(2460) \rightarrow D^*\pi$?

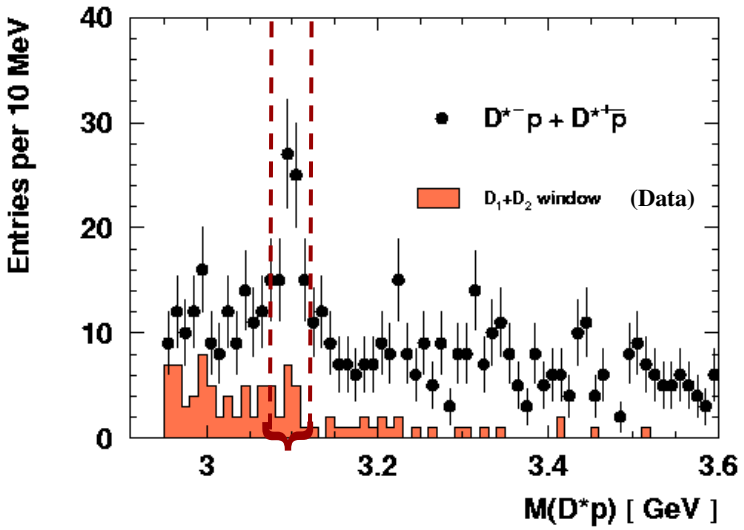
Loose D* cuts & pion selection

D* cuts of D*p & pion selection
$N(D_1+D_2)=276\pm70$

D* cuts of D*p & proton selection

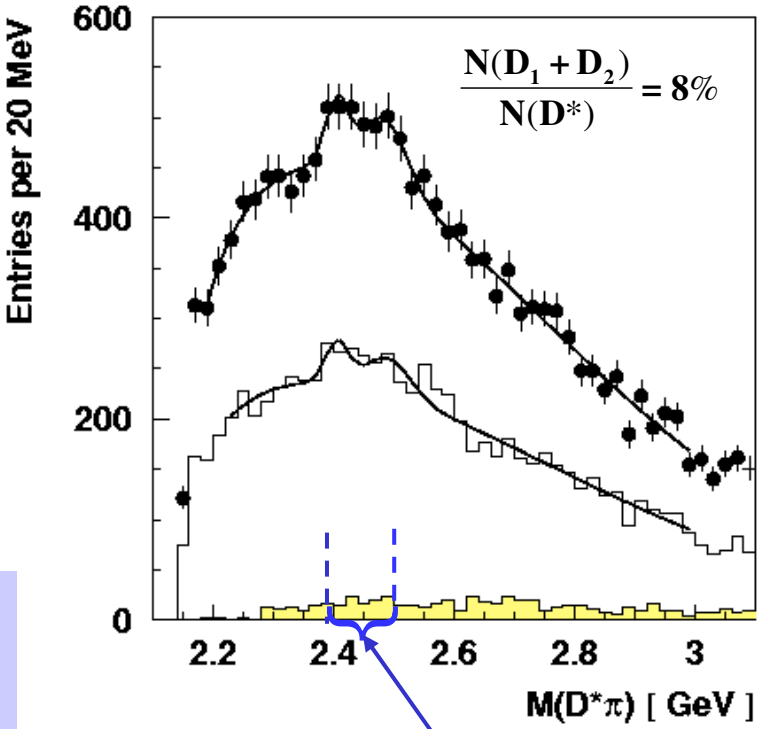


Possible Background: $D_1(2420)/D_2(2460) \rightarrow D^*\pi$?



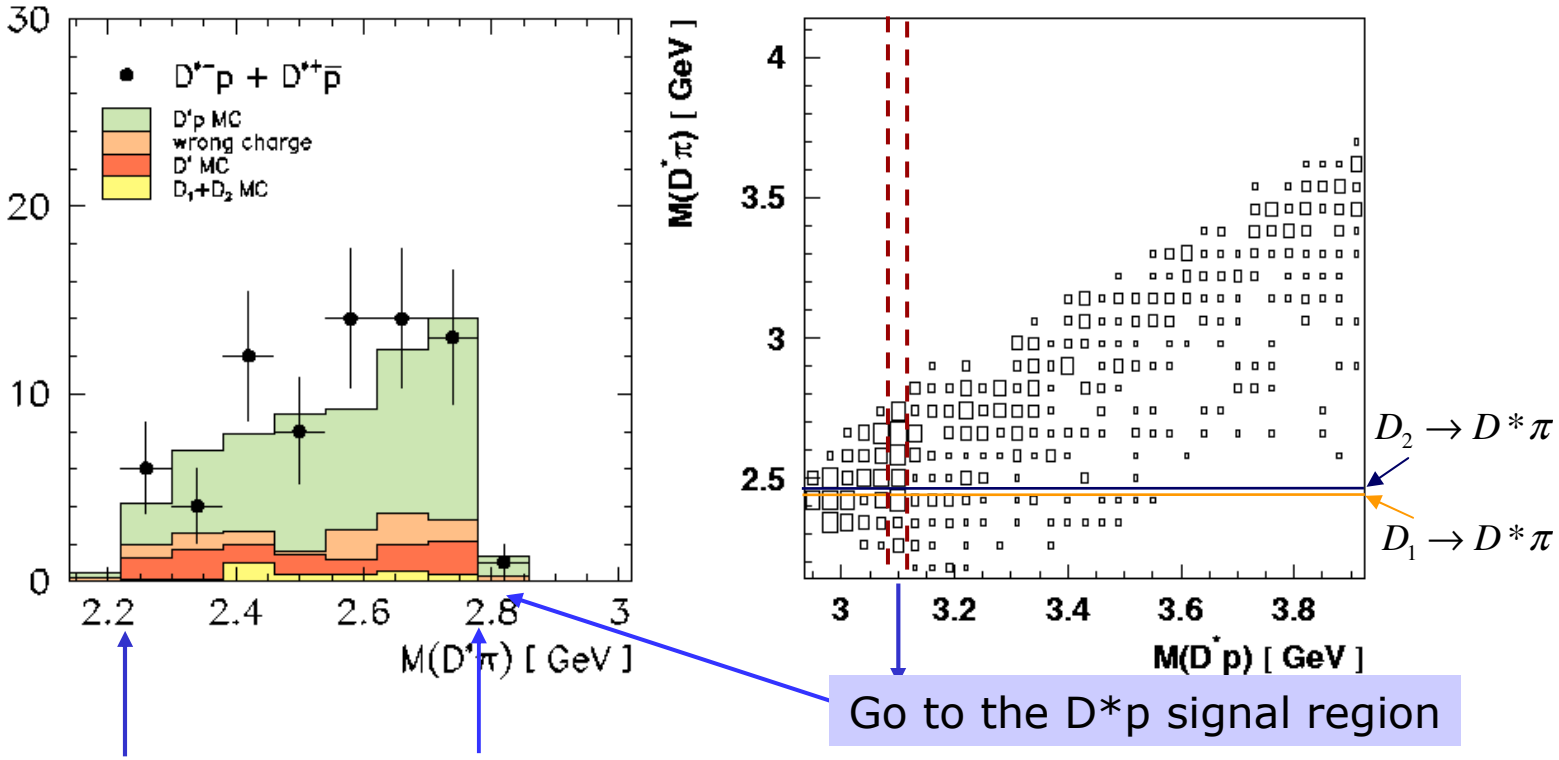
- Corrected for combinatorics
- N (D_1+D_2) = 3.5
  in D*p signal region from MC

No cut in D*p

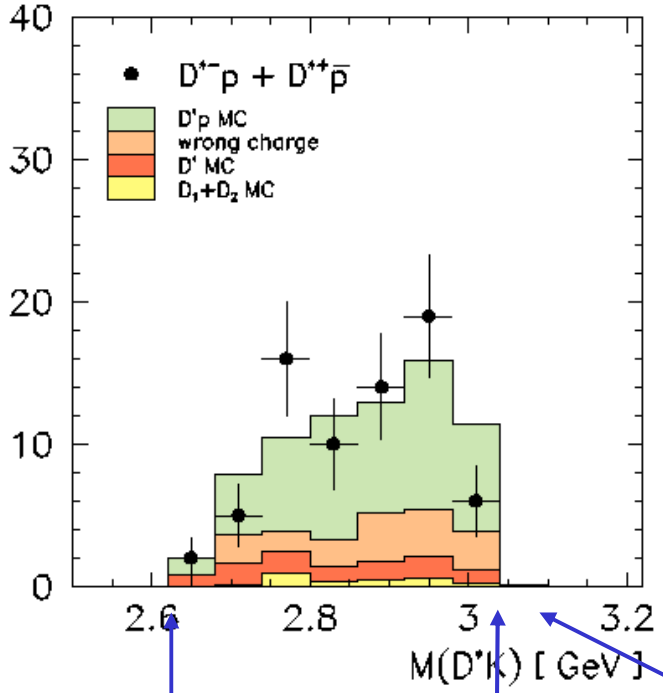


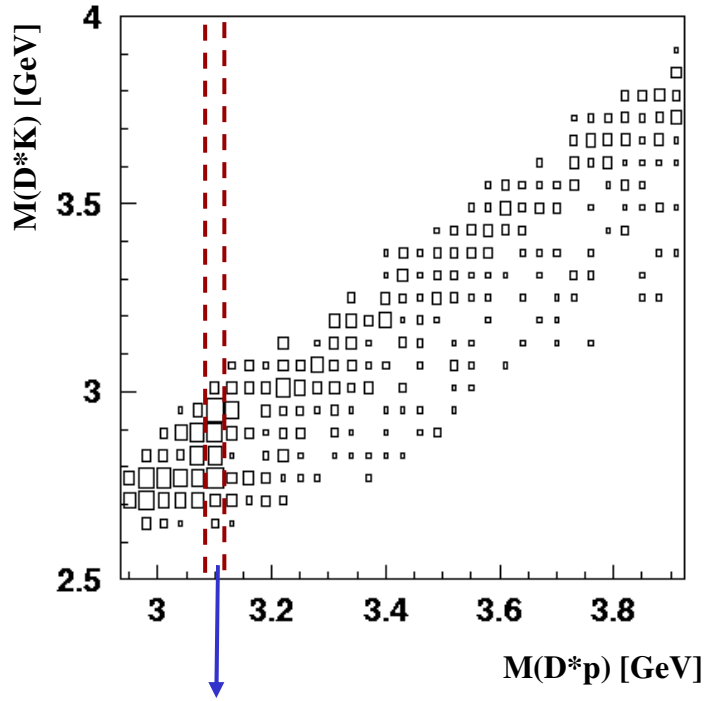
D_1, D_2 window

Signal due to D*π ?



Signal due to D*K ?



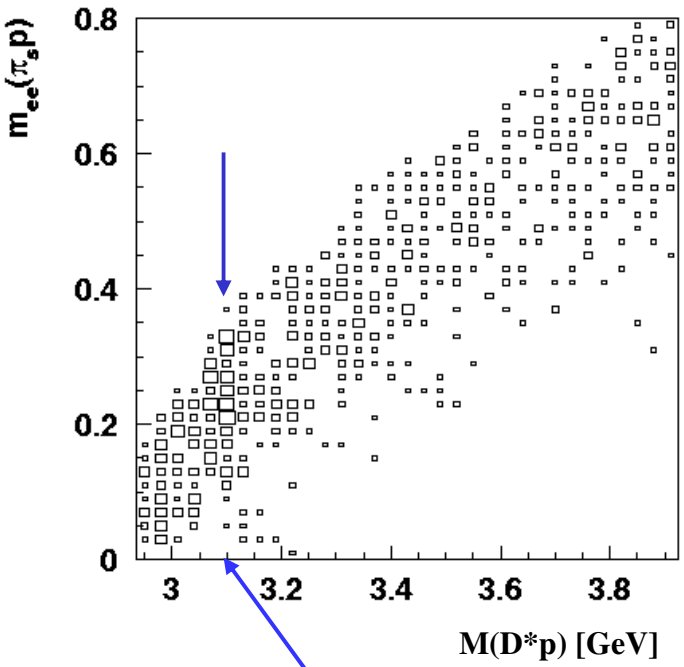


Go to the D*p signal region

Sign for X→D*p: available phase space in D*K completely used

Signal due to $D^{0*} \rightarrow D^0\gamma$?

- $D^0\gamma$ may be dangerous because of $\gamma \rightarrow e^+e^-$
- γ-conversion asymmetric in energy
- may be misinterpreted as π_s and proton
- $m_{ee}(\pi_s p)$ should peak at 0



No accumulation at zero

Lots of kinematic tests

- Checks for reflections from a signal in D*K mass distribution
- Checks for contributions from $D^{*0} \rightarrow D^0\gamma$ with γ-conversion, $D_1^0/D_2^{0*} \rightarrow D^*\pi$ and $D_{s1}/D_{sJ} \rightarrow D^0K$
- Checks for peak structures in all possible mass correlations with all possible mass hypotheses of the particles making the D* and the D*p system to search for real or fake resonances, e.g Λ^0, Δ^0, Δ^{++}, K^0_S, ϕ, f_2
- Checks for peak structures in all possible mass correlations among the proton candidate and the remaining charged particles of the event with all possible mass assignments to search for real or fake peaks

All tests are found to be only consistent with D*p hypothesis.