

# Pentaquarks @ SPD ?



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## Outline:

**Brief pentaquarks' story**

Interesting options for NICA

$(uuuu\bar{d}) = \Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$  with SPD?

**Summary**

# Brief pentaquarks' story, $\theta^+$ :

Diakonov, Petrov, Polyakov (hep-ph/9703373, Z.Phys. A359, 305 (1997))

Exotic Anti-Decuplet of Baryons: Prediction from Chiral Solitons

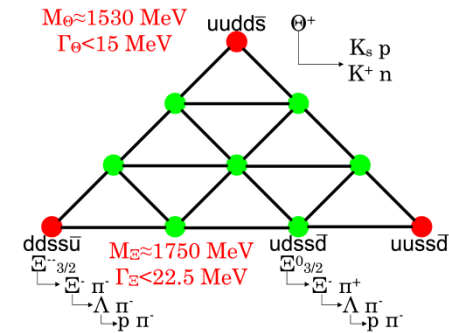
$\Theta(1540)^+$

2003: seen in exotic decay ( $\theta^+ \rightarrow \bar{K}^+ n$ ) by **LEPS, CLAS, SAPHIR**

non-exotic decay ( $\theta^+ \rightarrow K^0_s p$ ) seen by many exp's

Unseen by many exp's including **CLAS** with increased statistics

Current status of  $\theta^+$  : removed from PDG after 2006  
reputation below plinth



Attempts to explain differences between exp's:

Dementiev R.K., Phys. Atom. Nucl. 76 (2015) 301  
On the mechanism of  $\Theta^+$ -pentaquark production

phase-shift effects

Azimov, Goeke, Starkowsky , Phys.Rev.D76 (2007) 074013

An explanation why the Theta+ is seen in some experiments and not in others

short-term fluctuations of initial hadrons

“studies of the hadron remnants in hard processes”

at NICA?

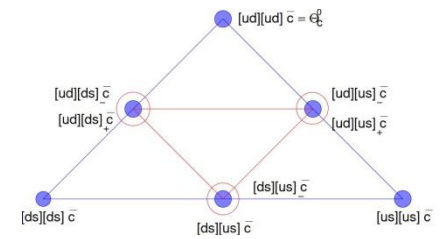
## Brief pentaquarks' story, $\Theta_c^0$ :

$$\Theta_c^0 = (\mathbf{ud})^2 \bar{\mathbf{c}}$$

Jaffe-Wilczek (hep-ph/0307341):  $m(\Theta_c^0) = 2710 \text{ MeV}$

Karliner-Lipkin (hep-ph/0307343):  $m(\Theta_c^0) = 2985 \pm 50 \text{ MeV}$

$$\Gamma(\Theta_c^0) \sim 21 \text{ MeV}$$



2004: seen in the decay  $(\Theta_c^0 \rightarrow D^{*-} p)$  with  $m(\Theta_c^0) = 3099 \text{ MeV}$  by only H1 @ HERA

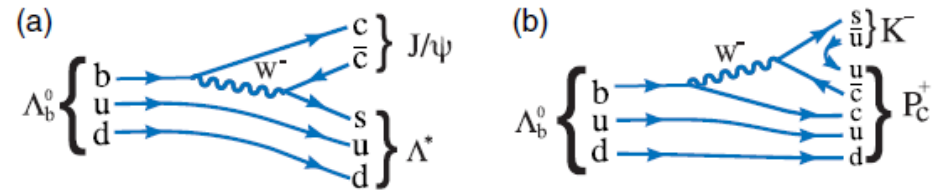
Unseen by many exp's including ZEUS @ HERA and H1 with increased statistics

Can be searched again in various decays:  $\Theta_c^0 \rightarrow \theta^+ \pi^-$ ,  $p K^0 \pi^-$ ,  $D^{(*)-} p$ , ...

at NICA?

# Brief pentaquarks' story, pentaquarks with hidden charm :

LHCb Collaboration  
PRL **115**, 072001 (2015)



Partially confirmed by D0, ATLAS

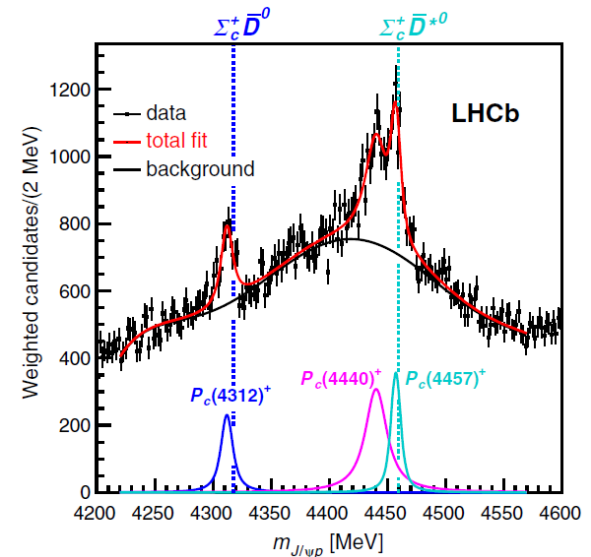
Not seen by GLueX → limits on branchings of decays to (J/ψ p)

Current status in PDG 2023:

$P_c(4312)^+$        $P_c(4440)^+$        $P_c(4457)^+$

$P_c(4380)^+$       Strange pentaquarks  
candidates are not yet in PDG

Most popular description – molecular states



Many phenomenological papers on pentaquarks  
with hidden charm, beauty and strangeness

at NICA?

# Interesting options for NICA :

Triply charged pentaquarks:  $(uuuu\bar{d}) = \Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$   
 $(uuuu\bar{s}) = \Delta_s^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) K^+$

Pentaquarks with hidden strangeness:  $(uuus\bar{s}) = P_s^{++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \phi (\rightarrow K^+ K^-)$   
 $(uuds\bar{s}) = P_s^+ \rightarrow p \phi (\rightarrow K^+ K^-)$   
 $(udds\bar{s}) = P_s^0 \rightarrow \Lambda^0 (\rightarrow p \pi^-) K_s^0 (\rightarrow \pi^+ \pi^-)$

Check for  $(udud\bar{s}) = \theta^+ : \theta^+ \rightarrow K_s^0 p, \theta^+ \rightarrow K^+ n (?)$

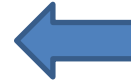
and with charm at NICA II :

Charmed pentaquarks:  $(uuuu\bar{c}) = \Delta_c^{++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \bar{D}^0 (\rightarrow K^+ \pi^-)$   
 $(uuud\bar{c}) = \Delta_c^+ \rightarrow \Delta^{++} (\rightarrow p \pi^+) D^- (\rightarrow K^+ \pi^- \pi^-)$   
Search for  $(udud\bar{c}) = \theta_c^0 \rightarrow \theta^+ \pi^-, p K^0 \pi^-, D^{(*)-} p, \dots$

Pentaquarks with hidden charm  $(uuuc\bar{c}) = P_c^{++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) J/\psi (\rightarrow \mu^+ \mu^-)$   
 $(uudc\bar{c}) = P_c^+ \rightarrow p J/\psi, \Lambda_c^+ (\rightarrow K^- p \pi^+) \bar{D}^0 (\rightarrow K^+ \pi^-)$   
 $(uddc\bar{c}) = P_c^0 \rightarrow \Lambda_c^+ (\rightarrow K^- p \pi^+) D^- (\rightarrow K^+ \pi^- \pi^-)$

# Interesting options for NICA :

Triply charged pentaquarks:  $(uuuu\bar{d}) = \Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$   
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# Can we register $(uuu\bar{d}) = \Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ with SPD?

Pythia 8.310, NNPDF40\_lo\_as\_01180

pp at  $\sqrt{s} = 4$  GeV and 10 GeV, SoftQCD:inelastic = on

## Simplified $\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ model

Gerasyuta, Kochkin (hep-ph/0310225, Int .J. Mod. Phys. E 15 (2006) 71-86

Relativistic five-quark equations and u, d- pentaquark spectroscopy

Table II. Low-lying  $\Delta$ - isobar pentaquark masses and contributions of subamplitudes  $BM$ ,  $D\bar{q}D$ ,  $Mqqq$  and  $Dqq\bar{q}$  to pentaquark amplitude in percentage of probability (diquark with  $J^P = 1^+$ ).

Fig. №	Meson $J^{PC}$	$J^P$	Mass, MeV	$A_1$ ( $BM$ )	$A_2$ ( $D\bar{q}D$ )	$A_3$ ( $Mqqq$ )	$A_4$ ( $Dqq\bar{q}$ )
4	$0^{++}$	$\frac{1}{2}^+, \frac{3}{2}^+$	1485(1600)	31.60	6.42	33.93	28.05
4	$1^{++}$	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$	1550(1750)	28.08	8.88	42.09	20.95
4	$2^{++}$	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$	1736(1920)	24.53	13.25	44.07	18.15
5	$2^{++}$	$\frac{7}{2}^+$	1950(1950)	24.99	-	75.01	-
5	$0^{-+}$	$\frac{1}{2}^-$	1453(1620)	38.13	-	61.87	-
5	$1^{--}$	$\frac{1}{2}^-, \frac{3}{2}^-$	1920(1940)	25.97	-	74.03	-

Parameters of model: quark mass  $m = 410$  MeV, cut-off parameter  $\Lambda = 20, 1$ ; gluon constant  $g = 0.417$ . Experimental mass values of  $\Delta$ - isobar pentaquarks are given in parentheses [12].

$(uuuu\bar{u})$

# Can we register $(uuu\bar{d}) = \Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ with SPD?

Pythia 8.310, NNPDF40\_lo\_as\_01180

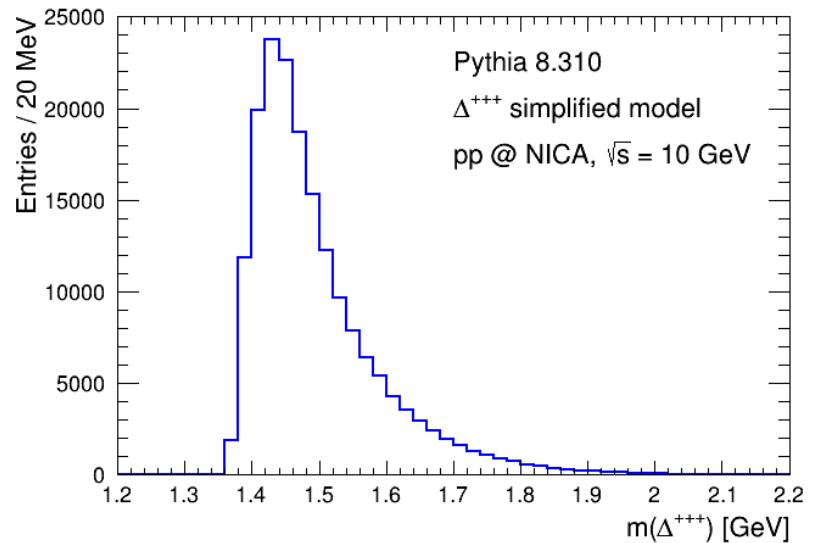
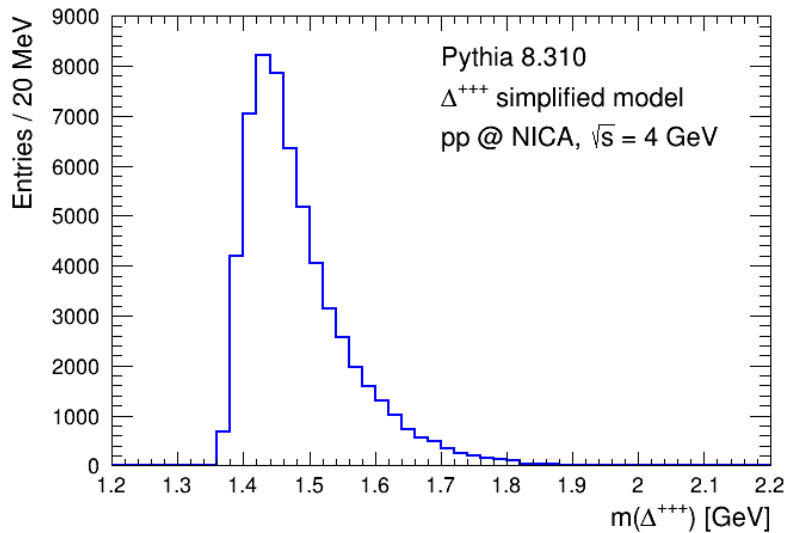
pp at  $\sqrt{s} = 4$  GeV and 10 GeV, SoftQCD:inelastic = on

## Simplified $\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ model

$m(\Delta^{+++}) = 1450$  MeV

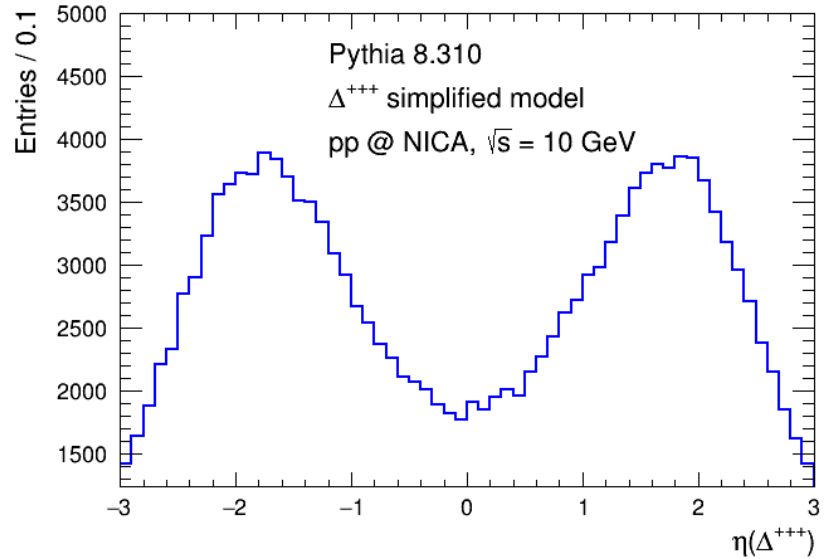
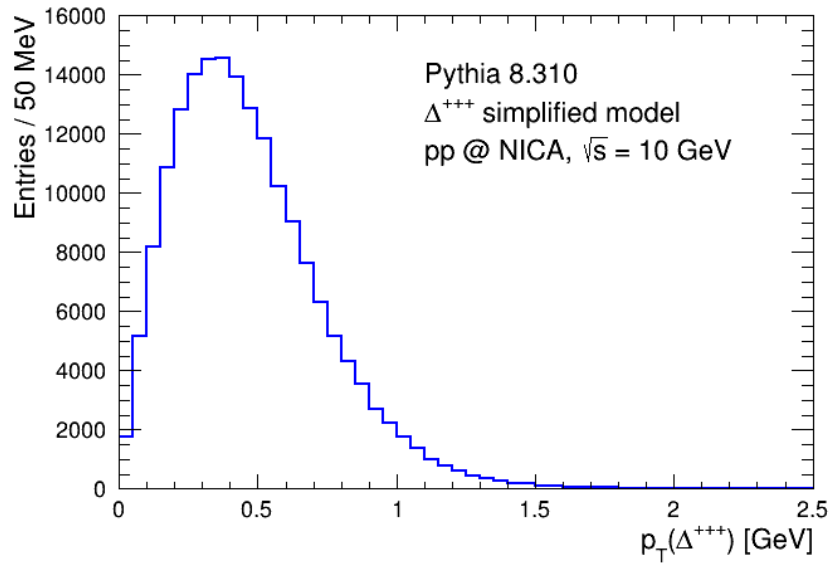
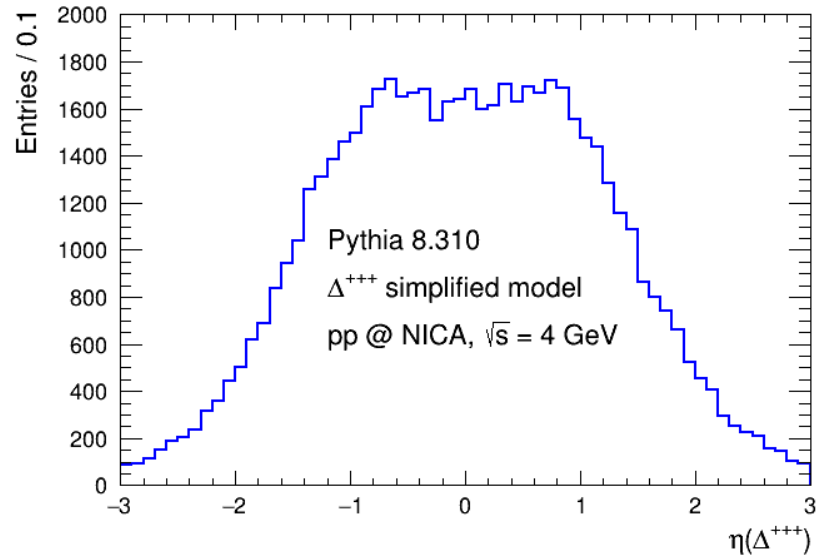
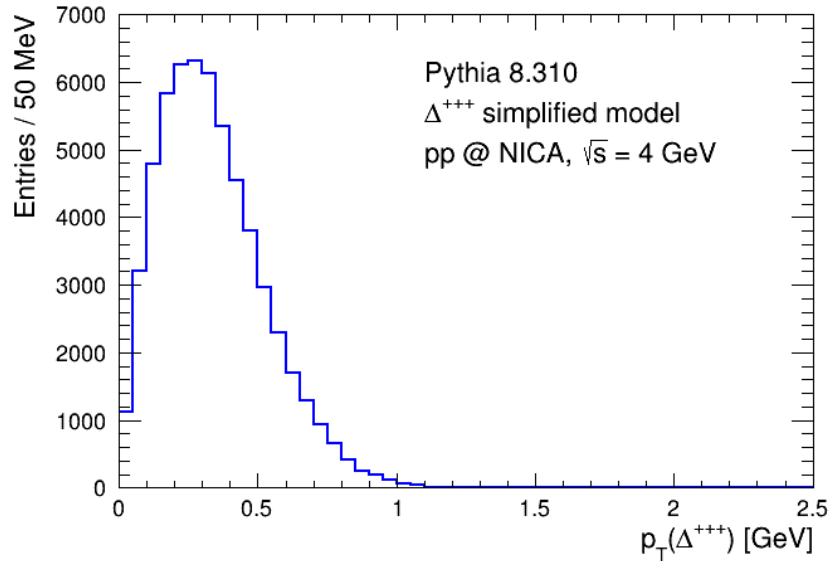
$\Gamma(\Delta^{+++}) = 150$  MeV      in comp. with  $\Gamma(\Delta^{++}) \sim 117$  MeV

produced in decays of heavy ( $\sim 2$  GeV)  $\Delta$ -like states





# $\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ kinematics

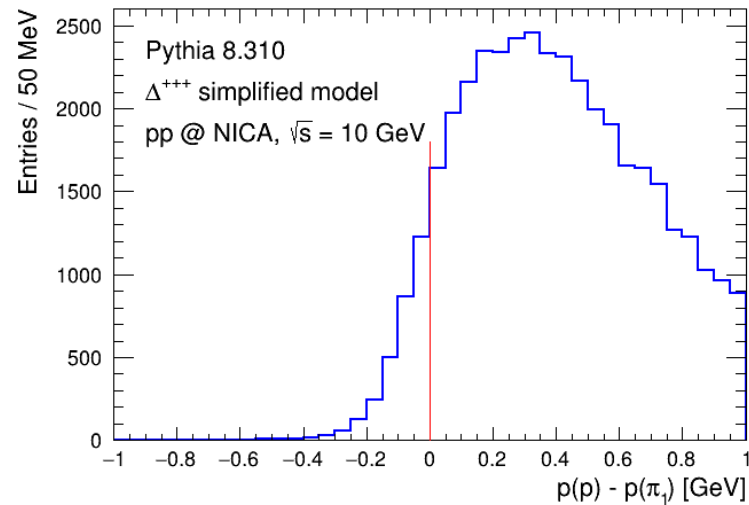
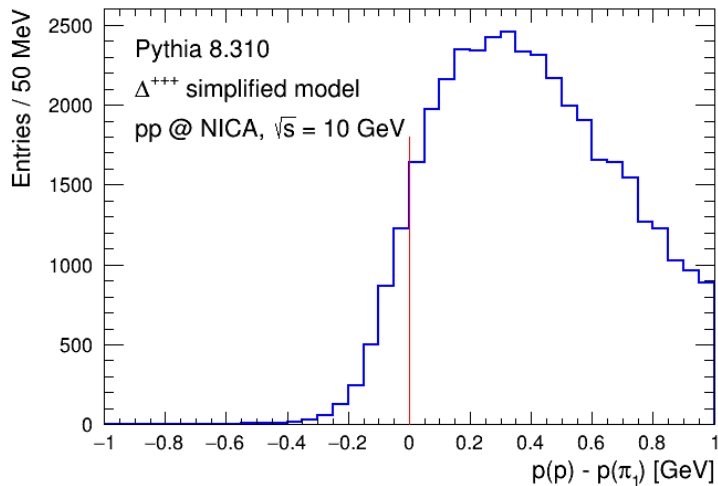
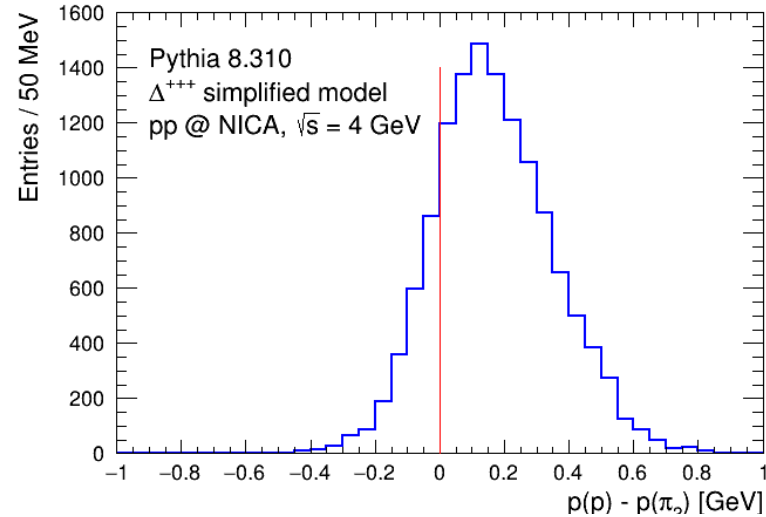
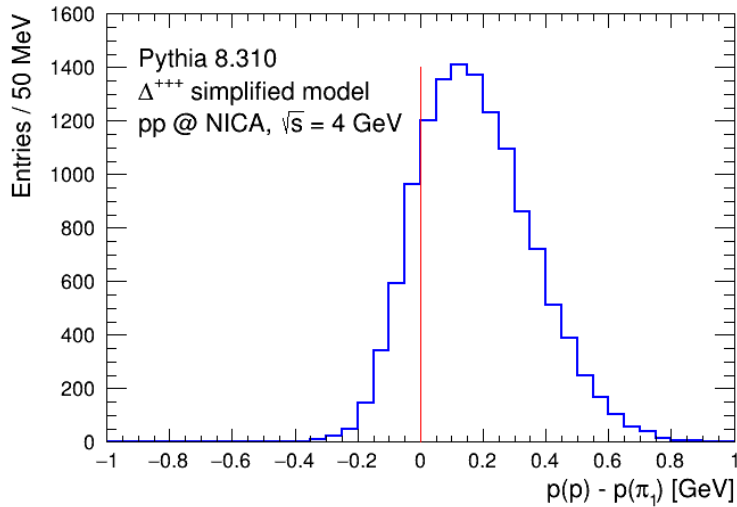


# $\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ tracks' acceptances

For all 3 tracks	$ \eta_{\text{track}}  < 2.5$ $\sqrt{s} =$ 4 / 10 GeV	$ \eta_{\text{track}}  < 2.0$ $\sqrt{s} =$ 4 / 10 GeV	$ \eta_{\text{track}}  < 1.5$ $\sqrt{s} =$ 4 / 10 GeV
$p_{T,\text{track}} > 100 \text{ MeV}$	54% / 51%	52% / 40%	45% / 25%
$p_{T,\text{track}} > 150 \text{ MeV}$	22% / 25%	22% / 21%	21% / 14%
$p_{T,\text{track}} > 200 \text{ MeV}$	6% / 9%	6% / 8%	6% / 5%

for further plots:  $p_{T,\text{track}} > 150 \text{ MeV}$  &&  $|\eta_{\text{track}}| < 2.5$

# $\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ , proton identification?

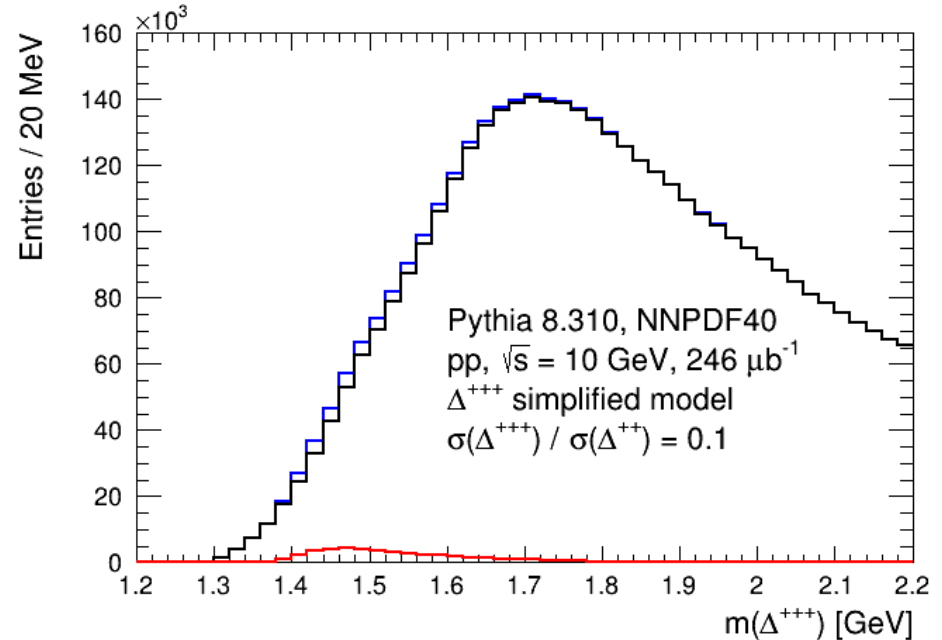
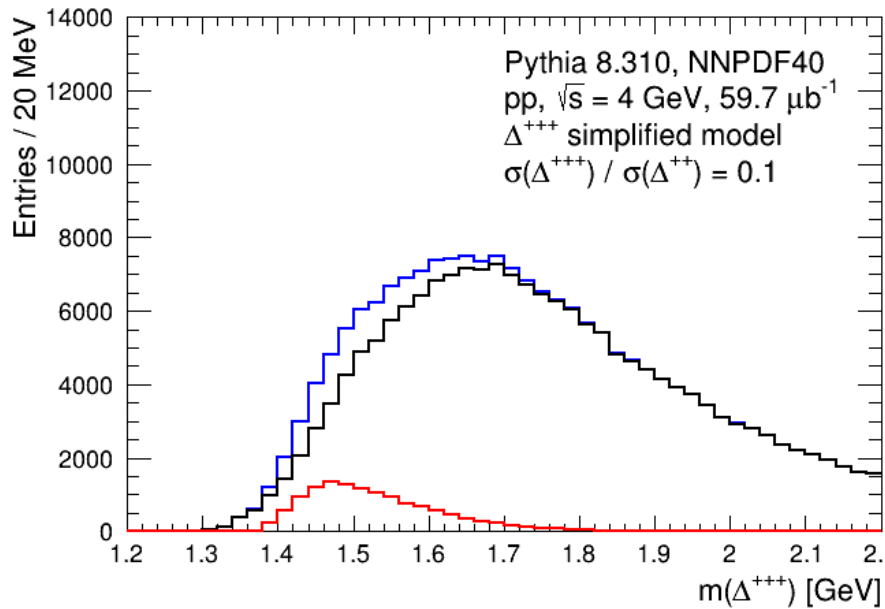


**proton is typically fastest track**  
**can be used in case of no PID**

$\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ , **reconstructed mass**

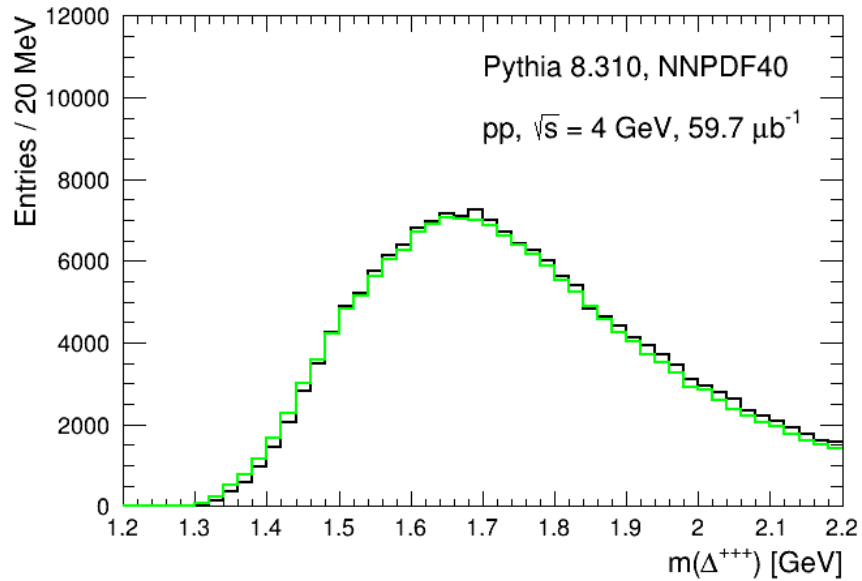
combine proton with two positively charged pions

require  $(1.14 < m(p \pi_1^+) < 1.32) \ || \ (1.14 < m(p \pi_2^+) < 1.32)$  (~97% eff.)

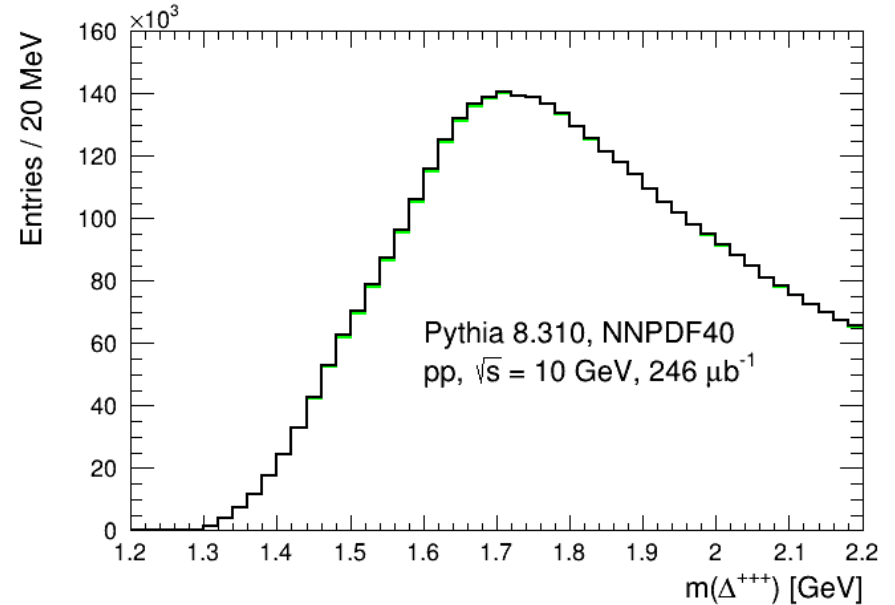


**data-driven background shape estimation is needed**

# $\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ , background shape



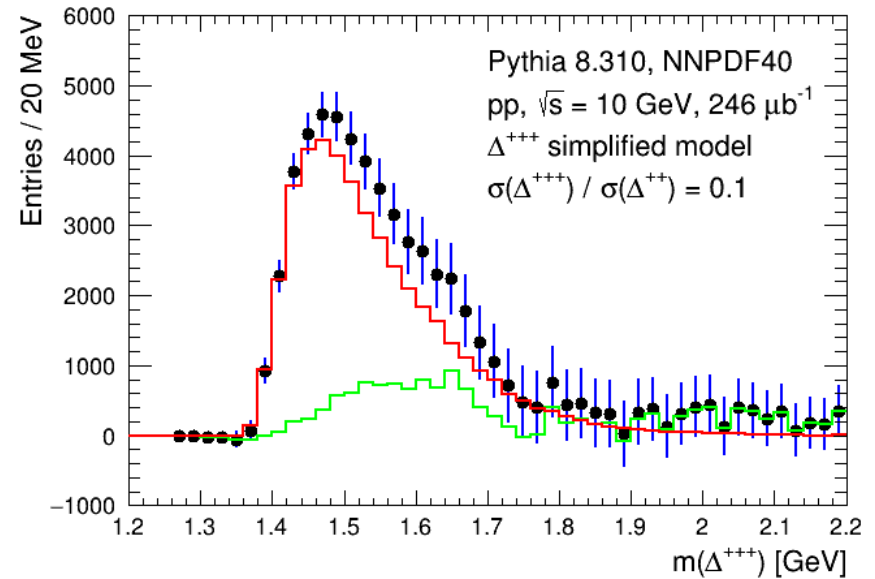
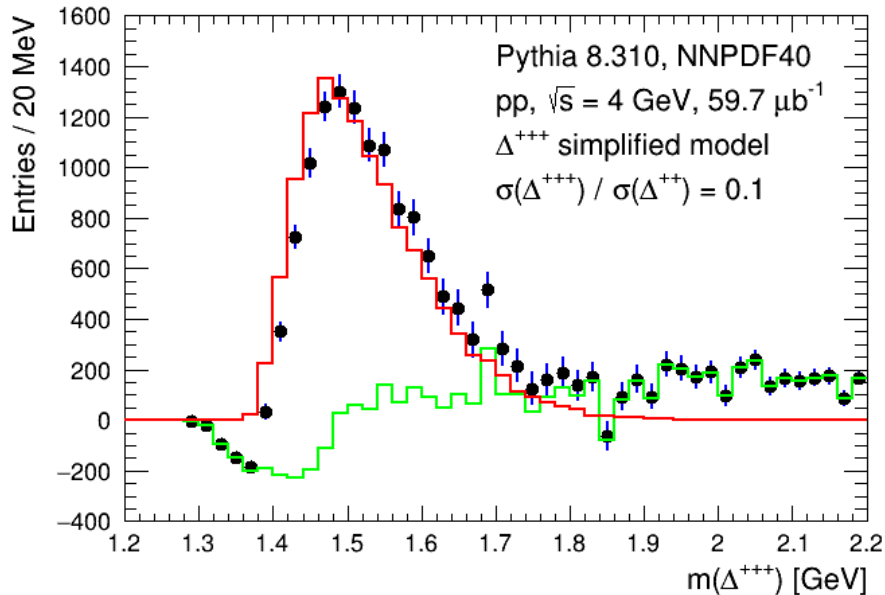
$p/\pi_1/\pi_2$  from another event



$p$  from another event

$\Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$ ,

**background-subtracted mass distribution**



$\sigma(\Delta^{+++})/\sigma(\Delta^{++}) = 10\%$

such large fraction looks like measurable

**careful background study is needed for 1%  
measurement or upper limit**

it can be a few overlapping  $\Delta^{+++}$  states

## Summary

There are interesting options for pentaquark measurements at NICA

$(uuuu\bar{d}) = \Delta^{+++} \rightarrow \Delta^{++} (\rightarrow p \pi^+) \pi^+$  can be searched with SPD :  
either an observation  
or a limit on  $\sigma(\Delta^{+++})/\sigma(\Delta^{++})$

# Backup