First studies on rare B → hh decays
Today – report primarily on B → p pbar

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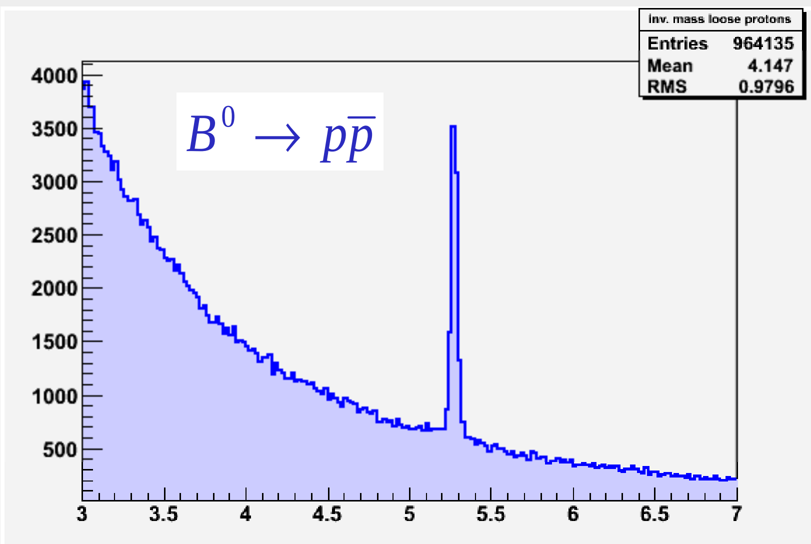
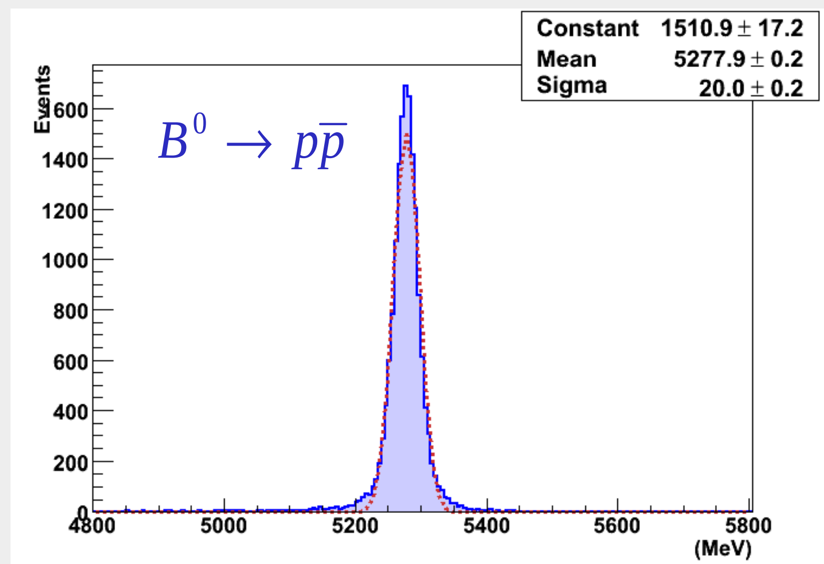
LHCb CP Measurements WG meeting, CERN, 15 April 2008





Outline

Motivations

- theory and experimental review of (rare) charmless baryonic B decays
- Brief reminder of Bd $\rightarrow$ KK and Bs $\rightarrow$ pp

First steps in the analysis of B $\rightarrow$ p pbar decays

- kinematics
- long tracks, “standard loose protons”

B $\rightarrow$ p pbar pre-selection: making of

- distributions of cut variables
- pre-selection cuts
- background and reduction factors

Theory review / B. R.s

Experimental review

Reminder from CP meeting 31/01/2008

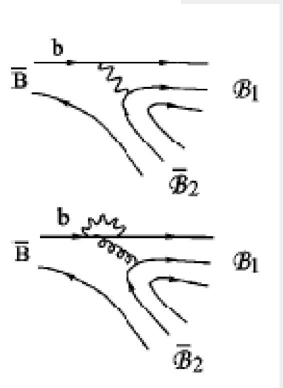
Charmless baryonic B decays: theoretical predictions

tree

penguin

	Ref [3]	Ref [7]	Ref [10]	Ref. [11] nonlocal	Ref. [11] local	This work
$\overline{B}^0 \to p\overline{p}$	4.2×10^{-6}	1.2×10^{-6}	7.0×10^{-6}	2.9×10^{-6}	2.7×10^{-5}	$1.1\times10^{-7\dagger}$
$\overline{B}^0 \to n\overline{n}$		3.5×10^{-7}	7.0×10^{-6}	2.9×10^{-6}	2.7×10^{-5}	$1.2\times10^{-7\dagger}$
$B^- \to n\overline{p}$		6.9×10^{-7}	1.7×10^{-5}	0	0	5.0×10^{-7}
$\overline{B}^0 \to \Lambda\overline{\Lambda}$			2×10^{-7}			$0^\dagger$
$B^- \to p\overline{\Delta}^{--}$	1.5×10^{-4}	2.9×10^{-7}	3.2×10^{-4}	2.4×10^{-6}	8.7×10^{-6}	1.4×10^{-6}
$\overline{B}^0 \to p\overline{\Delta}^-$		7×10^{-8}	1.0×10^{-4}	1.0×10^{-6}	4.0×10^{-6}	4.3×10^{-7}
$B^- \to n\overline{\Delta}^-$			1.1×10^{-4}	2.7×10^{-7}	1×10^{-7}	4.6×10^{-7}
$\overline{B}^0 \to n\overline{\Delta}^0$			1.0×10^{-4}	1.0×10^{-6}	4.0×10^{-6}	4.3×10^{-7}
$B^- \to \Lambda\overline{p}$		$\lesssim 3\times10^{-6}$				$2.2\times10^{-7\dagger}$
$\overline{B}^0 \to \Lambda\overline{n}$						$2.1\times10^{-7\dagger}$
$\overline{B}^0 \to \Sigma^+\overline{p}$		6×10^{-6}				$1.8\times10^{-8\dagger}$
$B^- \to \Sigma^0\overline{p}$		3×10^{-6}				$5.8\times10^{-8\dagger}$
$B^- \to \Sigma^+\overline{\Delta}^{--}$		6×10^{-6}				2.0×10^{-7}
$\overline{B}^0 \to \Sigma^+\overline{\Delta}^-$		6×10^{-6}				6.3×10^{-8}
$B^- \to \Sigma^-\overline{\Delta}^0$		2×10^{-6}				6.7×10^{-8}

Bag model & harmonic oscillator model disagree



Cheng & Yang, Phys Rev D 66 014020 (2002)

Theoretical predictions do not really agree

Reminder from CP meeting 31/01/2008

Charmless baryonic B decays: measurements (1/2)

Heavy Flavor Averaging Group
Aug. 2007

No 2-body decay discovered

Compilation of B^+ Baryonic Branching Fractions
All branching fractions are in units of 10^{-6}; limits are 90% CL

In PDG2006 | New since PDG2006 (preliminary) | New since PDG2006 (published)

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
286	$p\bar{p}\pi^+$	$3.1^{+0.8}_{-0.7}$	$1.69 \pm 0.29 \pm 0.26$ †	$1.68^{+0.26}_{-0.22} \pm 0.12$ ‡	< 160	$1.69^{+0.24}_{-0.22}$
289	$p\bar{p}K^+$	5.6 ± 1.0	$6.7 \pm 0.5 \pm 0.4$ †	$5.98^{+0.29}_{-0.27} \pm 0.39$ ‡		$6.24^{+0.39}_{-0.38}$
290	$\Theta^{++}\bar{p}$ *	< 0.091	< 0.09	< 0.091		< 0.09
291	$f_J(2221)K^+$ *	< 0.41		< 0.41		< 0.41
292	$p\bar{\Lambda}(1520)$	< 1.5	< 1.5			< 1.5
294	$p\bar{p}K^{*+}$	$10.3^{+3.6+1.3}_{-2.8-1.7}$	$5.3 \pm 1.5 \pm 1.3$ †	$10.3^{+3.6+1.3}_{-2.8-1.7}$ ‡		6.6 ± 1.7
–	$f_J(2221)K^{*+}$ *	New	< 0.77			< 0.77
295	$p\bar{\Lambda}$	< 0.49		< 0.32	< 1.5	< 0.32
–	$p\bar{\Lambda}\pi^0$	New		$3.00^{+0.61}_{-0.53} \pm 0.33$		$3.00^{+0.69}_{-0.62}$
–	$p\bar{\Sigma}(1385)^0$	New		< 0.47		< 0.47
–	$\Delta^+\bar{\Lambda}$	New		< 0.82		< 0.82
299	$\Lambda\bar{\Lambda}\pi^+$	< 2.8		< 2.8 ‡		< 2.8 ‡
300	$\Lambda\bar{\Lambda}K^+$	$2.9^{+0.9}_{-0.7} \pm 0.4$		$2.9^{+0.9}_{-0.7} \pm 0.4$ ‡		$2.9^{+1.0}_{-0.8}$
301	$\bar{\Delta}^0 p$	< 380		< 1.42	< 380	< 1.42
302	$\Delta^{++}\bar{p}$	< 150		< 0.14	< 150	< 0.14

Easy with LHCb?

§Di-baryon mass is less than 2.85 GeV/c^2; † Charmonium decays to $p\bar{p}$ have been statistically subtracted.
‡ The charmonium mass region has been vetoed. * Product BF - daughter BF taken to be 100%: $\Theta(1540)^{++} \to K^+ p$ (pentaquark candidate);

Reminder from CP meeting 31/01/2008

Charmless baryonic B decays: measurements (2/2)

No 2-body decay discovered

Heavy Flavor Averaging Group
Aug. 2007

Compilation of B^0 Baryonic Branching Fractions
All branching fractions are in units of 10^{-6}; limits are 90% CL

In PDG2006 | New since PDG2006 (preliminary) | New since PDG2006 (published)

RPP#	Mode	PDG2006 Avg.	BABAR	Belle	CLEO	New Avg.
266	$p\overline{p}$	< 0.27	< 0.27	< 0.11 *	< 1.4	< 0.11
268	$p\overline{p}K^0$	$2.1^{+0.6}_{-0.4}$	$3.0 \pm 0.5 \pm 0.3$ †	$2.40^{+0.64}_{-0.44} \pm 0.28$ ‡		$2.73^{+0.47}_{-0.42}$
269	$\Theta^+\overline{p}$ *	< 0.23	< 0.05	< 0.23		< 0.05
–	$f_J(2221)K^0$ *	New	< 0.45			< 0.45
270	$p\overline{p}K^{*0}$	< 7.6	$1.47 \pm 0.45 \pm 0.40$ †	< 7.6 ‡		1.5 ± 0.6
–	$f_J(2221)K^{*0}$ *	New	< 0.15			< 0.15
271	$p\overline{\Lambda}\pi^-$	2.6 ± 0.5	$3.30 \pm 0.53 \pm 0.31$	$3.23^{+0.33}_{-0.29} \pm 0.29$	< 13	$3.25^{+0.36}_{-0.34}$
–	$p\overline{\Sigma}(1385)^-$	New		< 0.26		< 0.26
–	$\Delta^0\overline{\Lambda}$	New		< 0.93		< 0.93
272	$p\overline{\Lambda}K^-$	< 0.82		< 0.82		< 0.82
273	$p\overline{\Sigma}^0\pi^-$	< 3.8		< 3.8		< 3.8
274	$\Lambda\overline{\Lambda}$	< 0.69		< 0.32	< 1.2	< 0.32

§Di-baryon mass is less than 2.85 GeV/c^2; † Charmonium decays to $p\bar{p}$ have been statistically subtracted. ‡ The charmonium mass region has been vetoed. * Product BF - daughter BF taken to be 100%; $\Theta(1540)^+ \to pK^0$ (pentaquark candidate).

Easy with LHCb?

* Belle collab., hep-ex/0703048v1

Reminder from CP meeting 31/01/2008

Charmless baryonic B decays in LHCb

- Several 3-body decays observed by BaBar and/or Belle; e.g. :

$$B^- \to p\overline{\Lambda}\pi^- \quad , \quad B^+ \to p\overline{p}\pi^+ \quad , \quad B^0 \to p\overline{p}K^0$$
$$B^+ \to p\overline{p}K^{*+} \quad , \quad B^+ \to \Lambda\overline{\Lambda}K^+ \quad , \quad B^+ \to p\overline{\Lambda}\gamma$$

  - Branching fractions ~10^{-6}

- But no 2-body decays yet discovered! At least at the level of 10^{-7}-ish …
- Note: calculations tricky and not all "schools" in agreement …

- Glasgow group wants to change this and exploit large LHCb samples "from day 1"
- Focus first on the easiest: 2-body proton- antiproton final state!

- Will also study rare B $\to$ hh decays
  - First studies done with DC04 data by Charlotte Newby (CERN-THESIS 2007-018)
  - Expect ~ 2000 $B_d \to KK$ and $B_s \to \pi\pi$ events per nominal year
    assuming branching ratios 10x smaller than $B_d \to \pi\pi$, etc.

Reminder from CP meeting 31/01/2008

First steps in the analysis of $B \to p\bar{p}$ decays

Software versions

- ❑ B-decay DSTs produced with Brunel v30r14
- ❑ b bbar inclusive DSTs produced with Brunel v30r14
- ❑ Minimum bias DSTs produced with Brunel v30r17

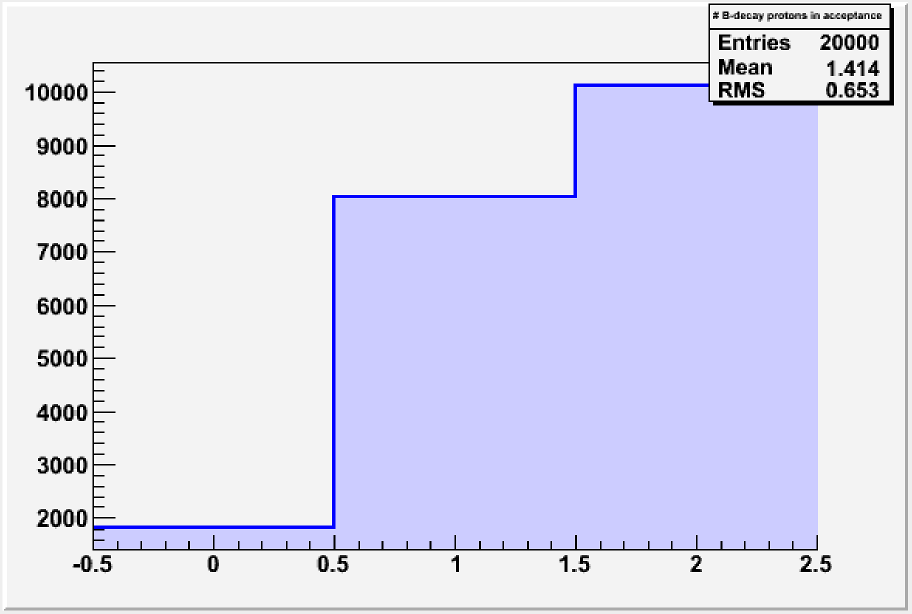
- ❑ All analyses done with DaVinci v19r11p1

❖ **Side remark:**

on signal samples

~ half of the events do not have

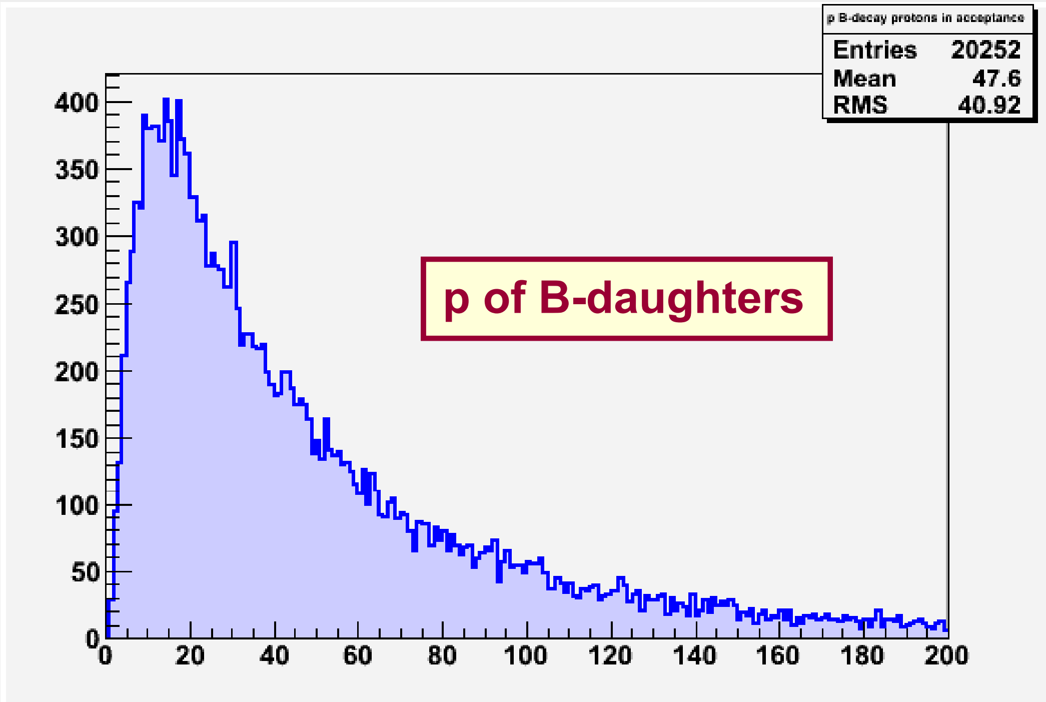
both B-daughters in the acceptance

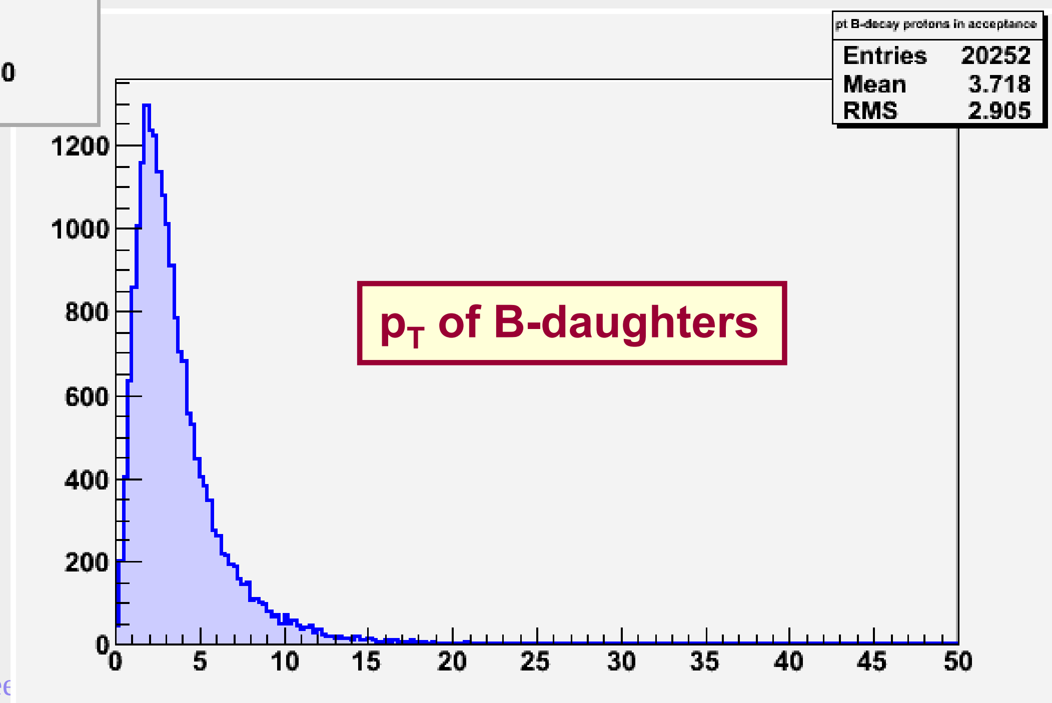


Kinematics of decay

Distributions for events with both MC B-daughter protons are in LHCb acceptance

MC-truth distributions when both protons in acceptance





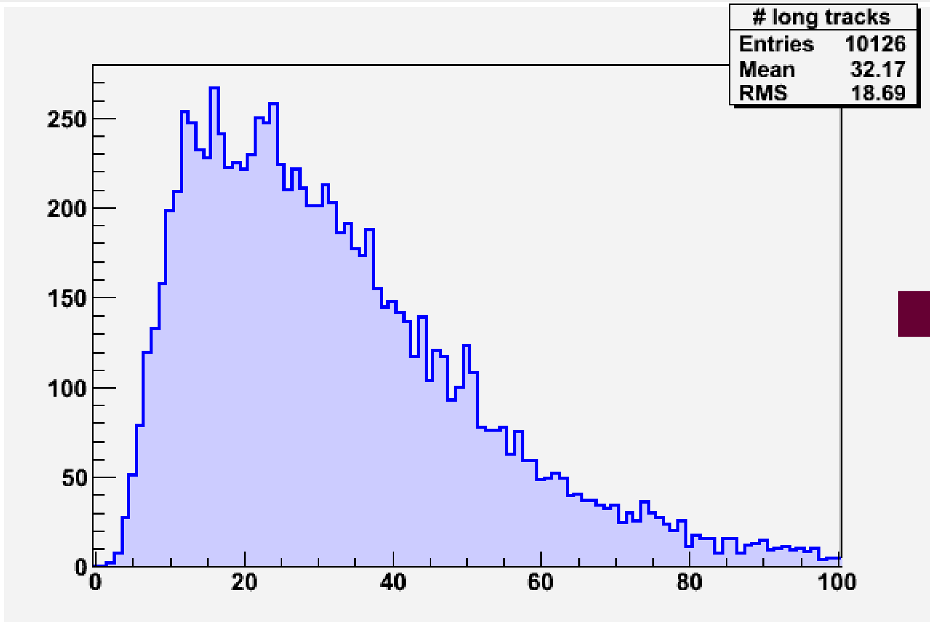
- High p and p_T spectrum

Long tracks

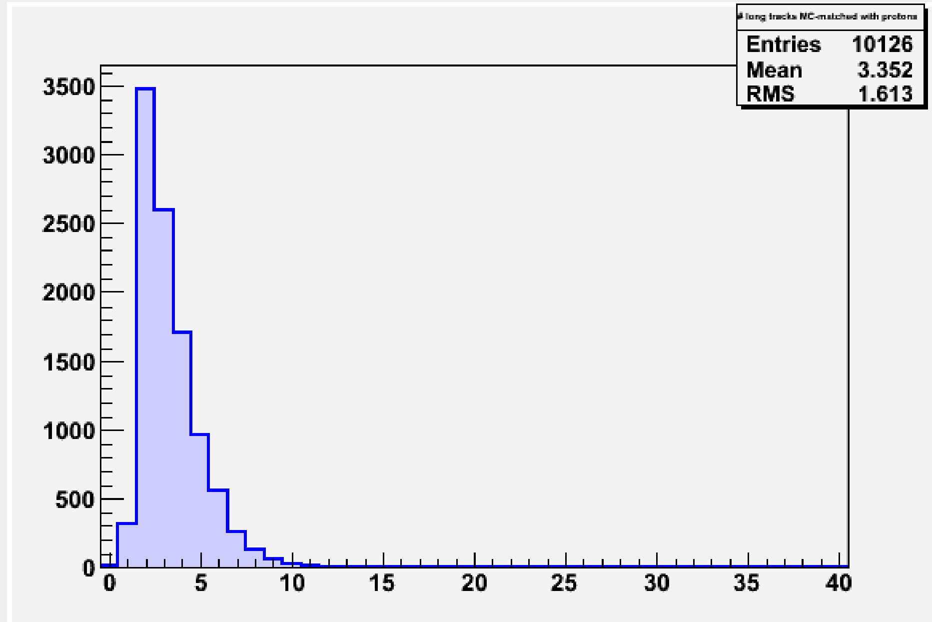
Distributions for events with both MC B-daughter protons are in LHCb acceptance

Input tracks: « long tracks »

All long tracks



Long tracks MC-matched to protons



- B signal sample contains ~ 32 long tracks per event
- On a B $\rightarrow$ p pbar sample just over 3 long tracks are real protons
- We should not have to deal with large combinatorics …

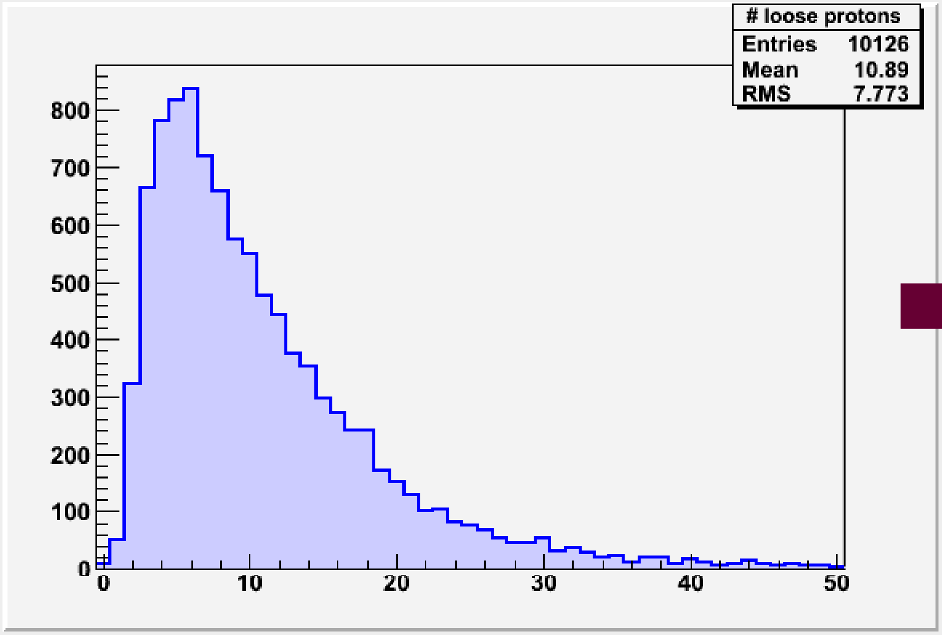
  … provided the PID is excellent ;-)

Standard loose protons

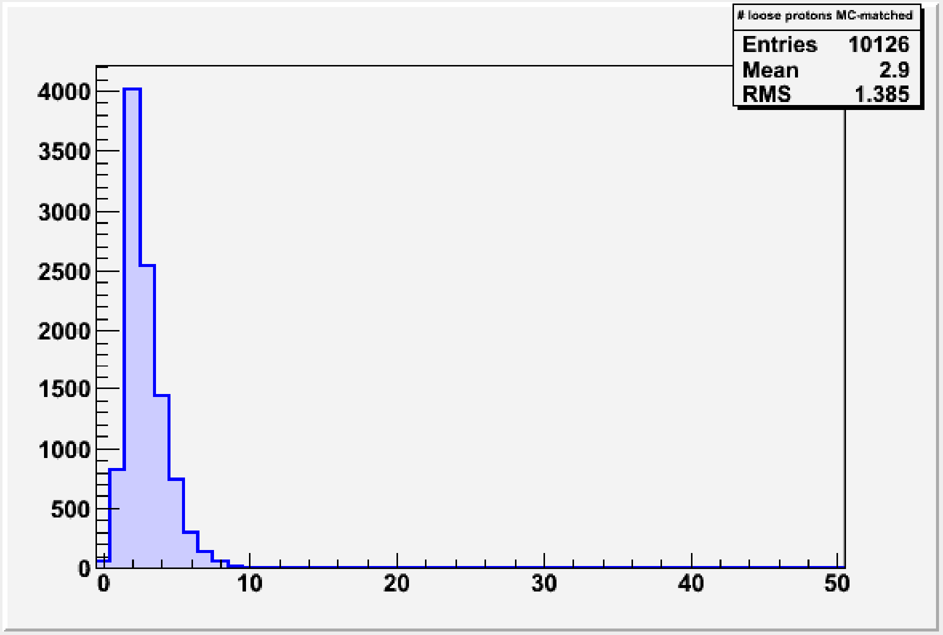
Distributions for events with both MC B-daughter protons are in LHCb acceptance

Input particles: « standard loose protons » (1/5)

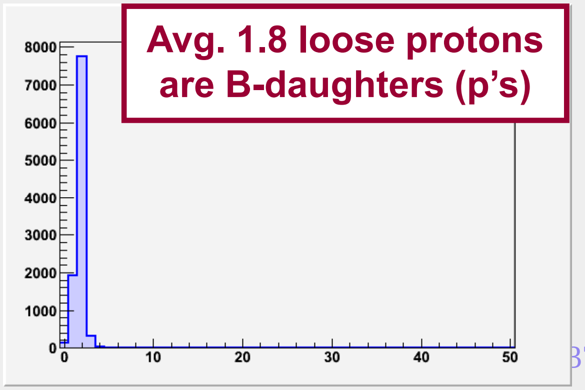
All loose protons



Loose protons MC-matched to protons



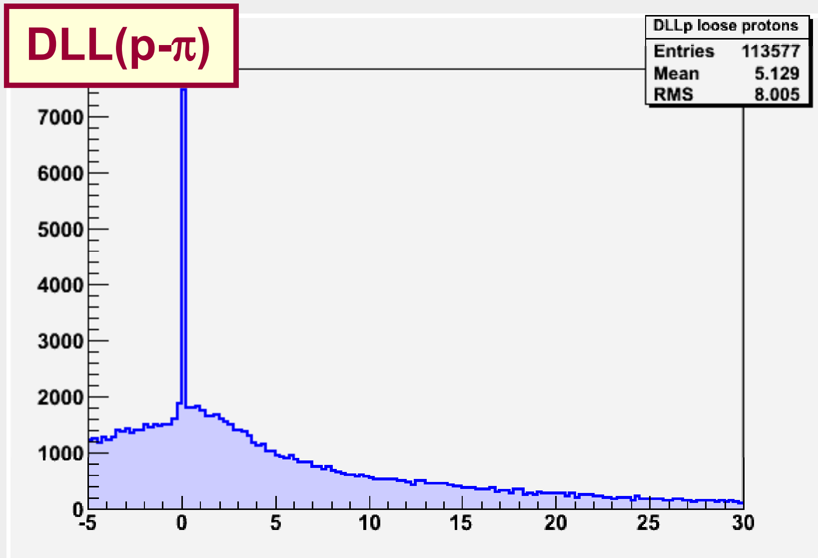
- On average, we start from ~ 3.4 long tracks that are real protons and the "standard loose" PID provides ~ 11 "standard loose protons"
- Only ~2.9 "standard loose protons" are real protons
- Proton PID inefficiencies account for the difference



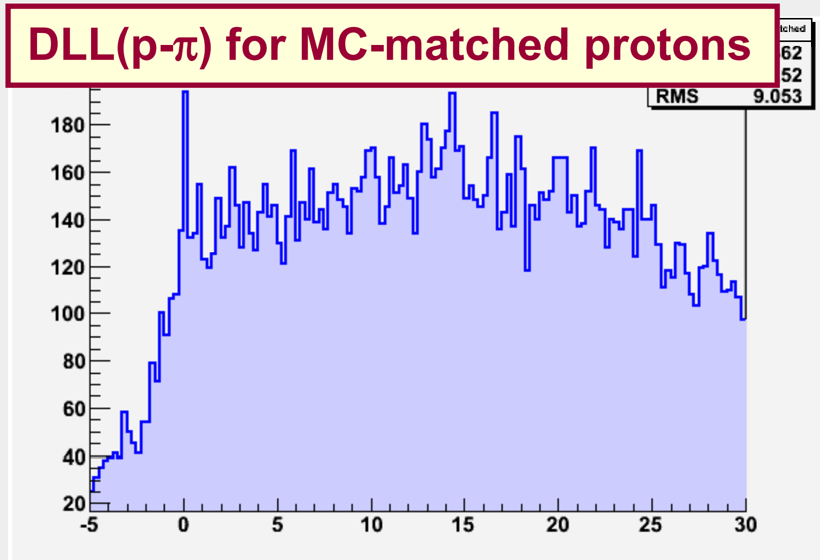
Avg. 1.8 loose protons are B-daughters (p's)

Input particles: « standard loose protons » (2/5)

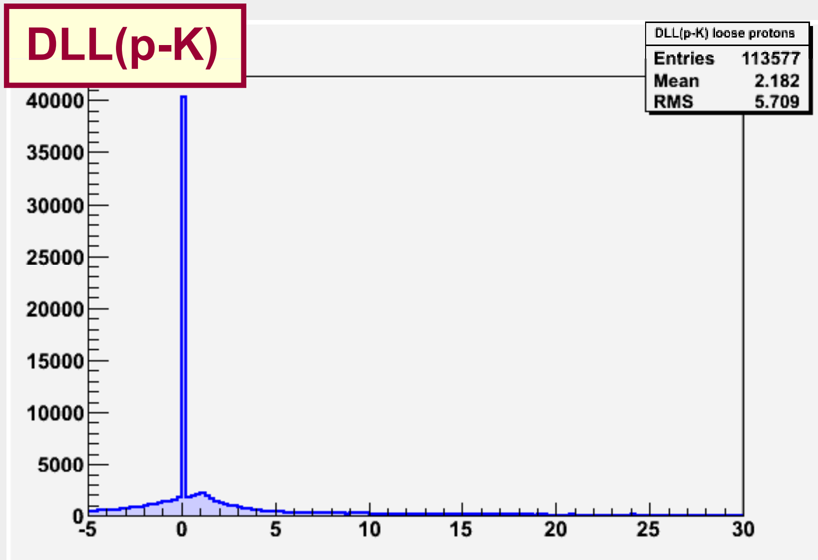
DLL(p-π)



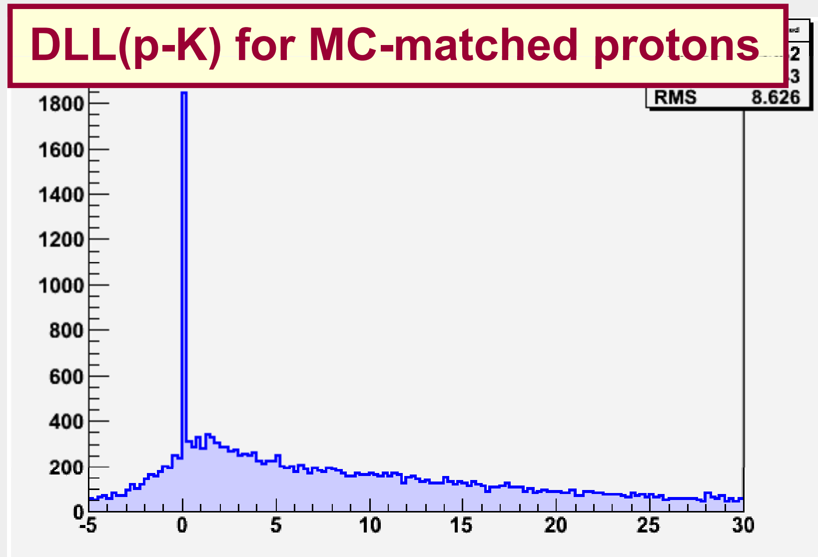
DLL(p-π) for MC-matched protons



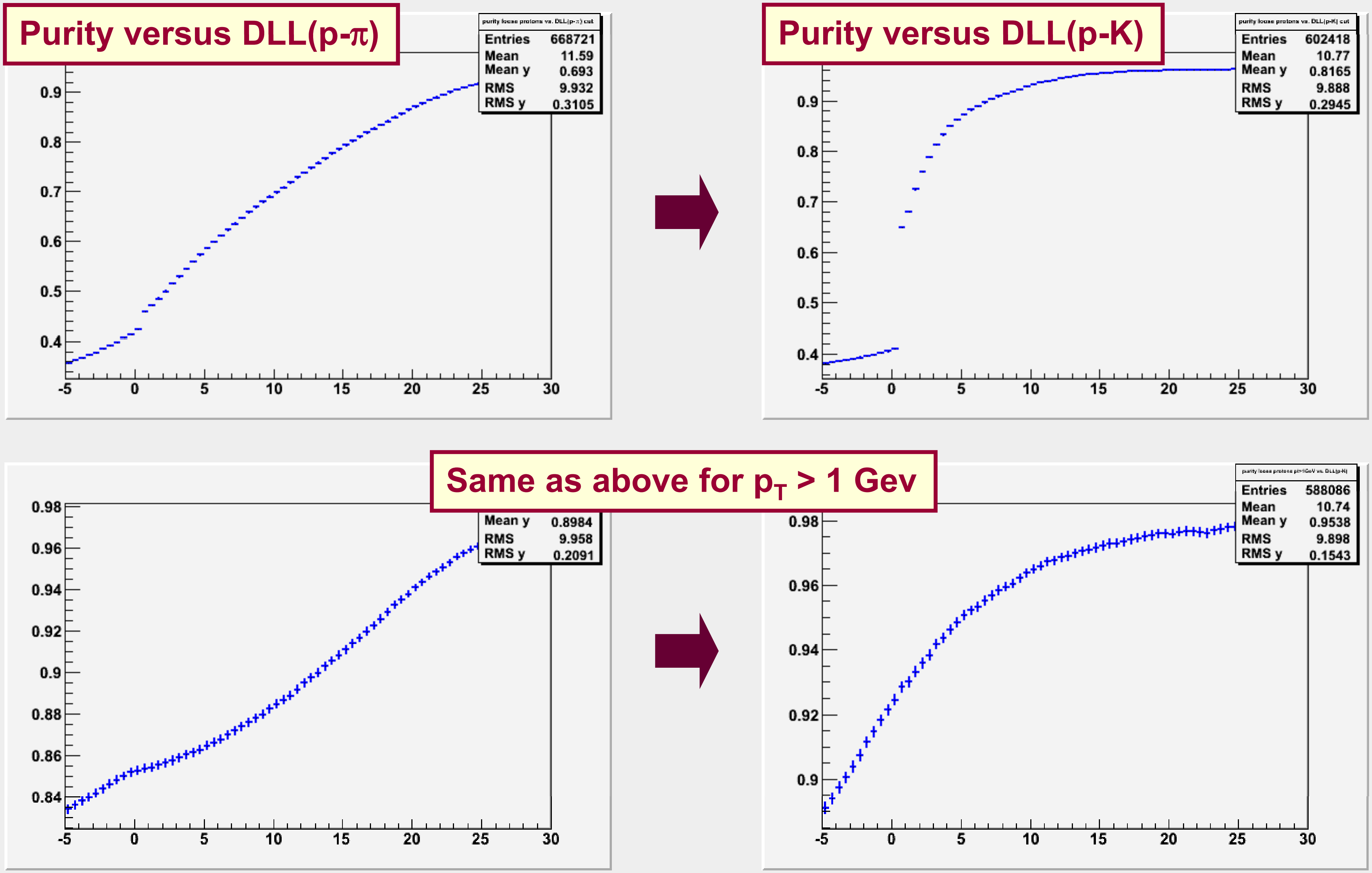
DLL(p-K)



DLL(p-K) for MC-matched protons

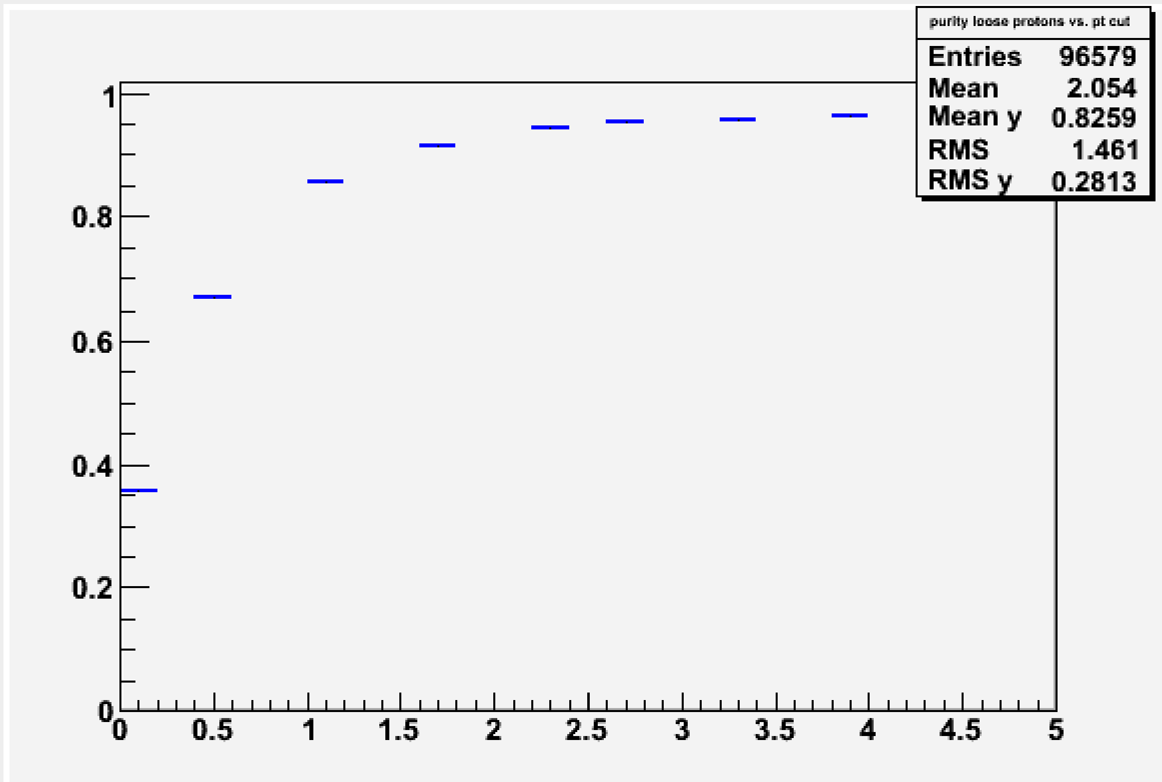


Input particles: « standard loose protons » (3/5)



Input particles: « standard loose protons » (4/5)

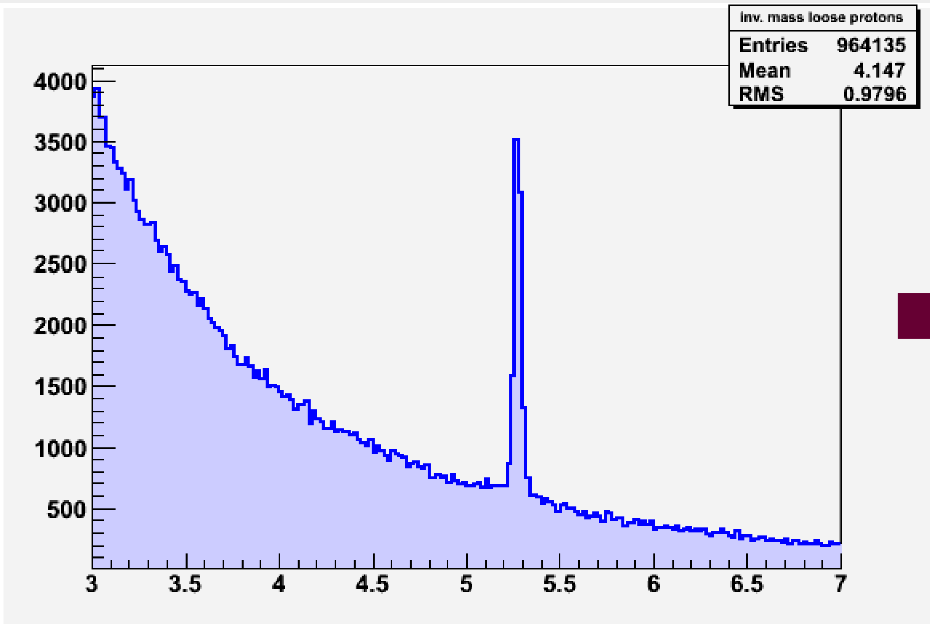
Purity loose protons versus p_T cut



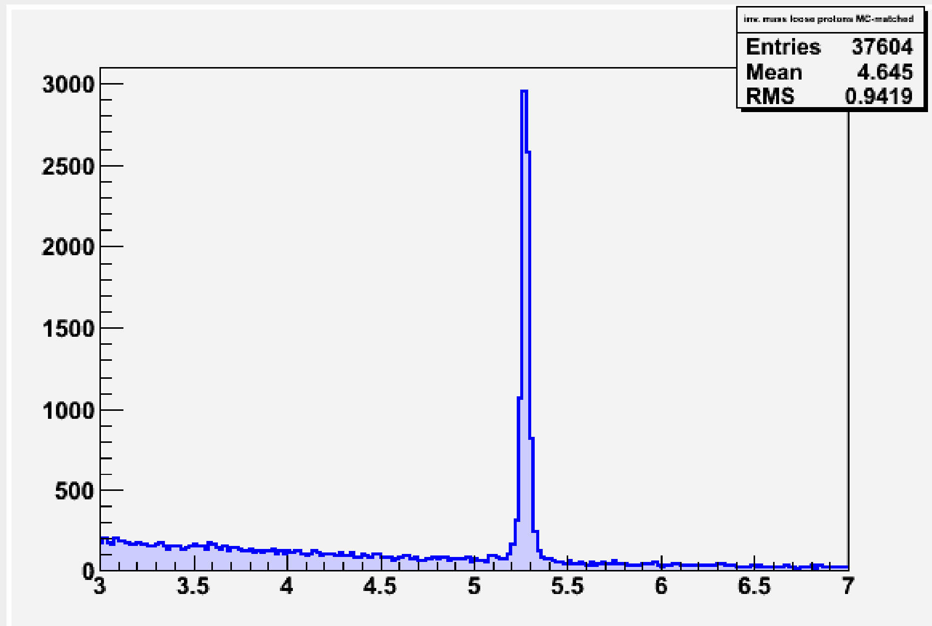
- **A p_T cut helps the PID**

Input particles: « standard loose protons » (5/5)

All loose protons



Loose protons MC-matched to protons



- ❑ **The B signal is indeed present even without any (pre-)selection**

  … on a signal sample ;-)

Pre-selection: making of

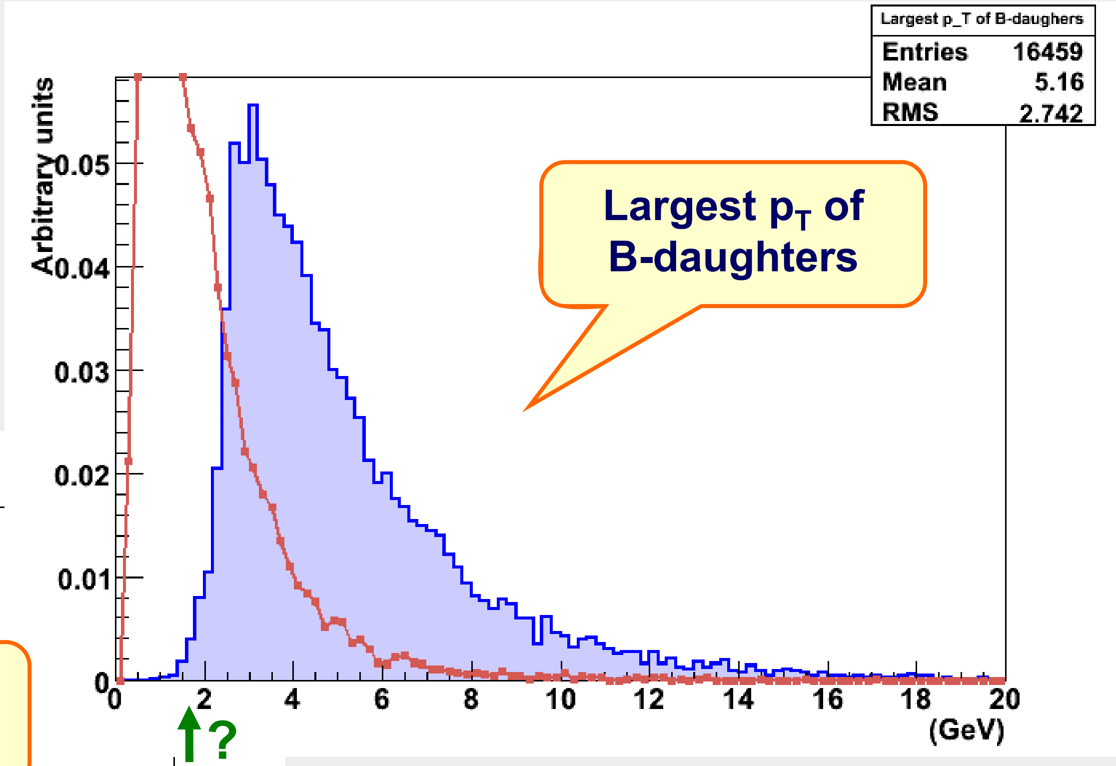
Towards a pre-selection …

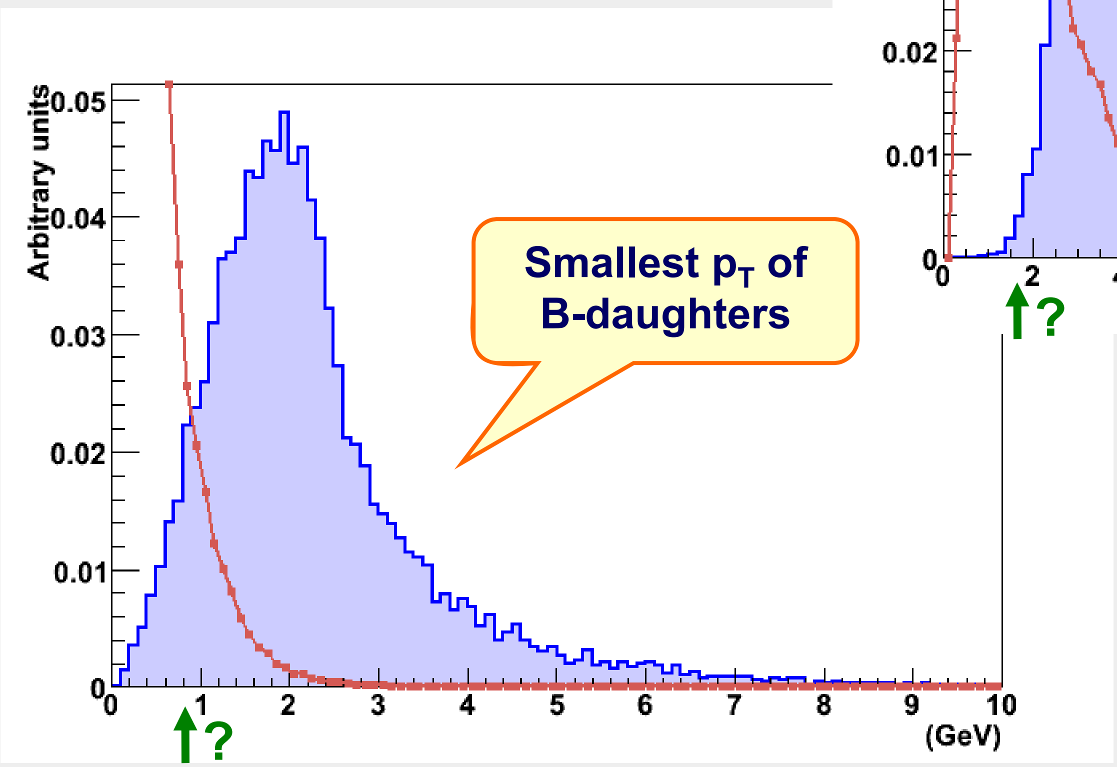
- What variables do we have at hand?

- Let's look at some distributions before any pre-selection …

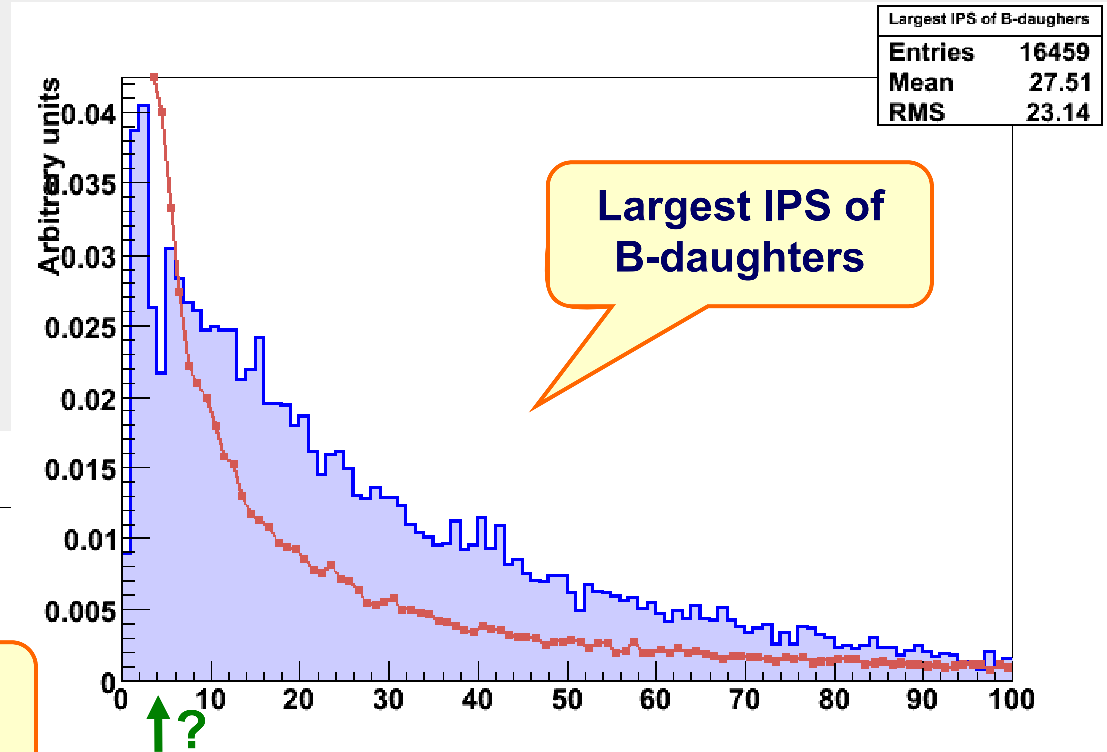
- **Well, nearly dummy cuts applied so as to be able to use the "DaVinci machinery" ;-) :**
  - "standard loose protons" are defined with $\Delta \ln \mathcal{L}_{p\pi} > -5$
  - minimum p_T of B-daughters > 100 MeV
  - B-candidate invariant mass within 2 GeV

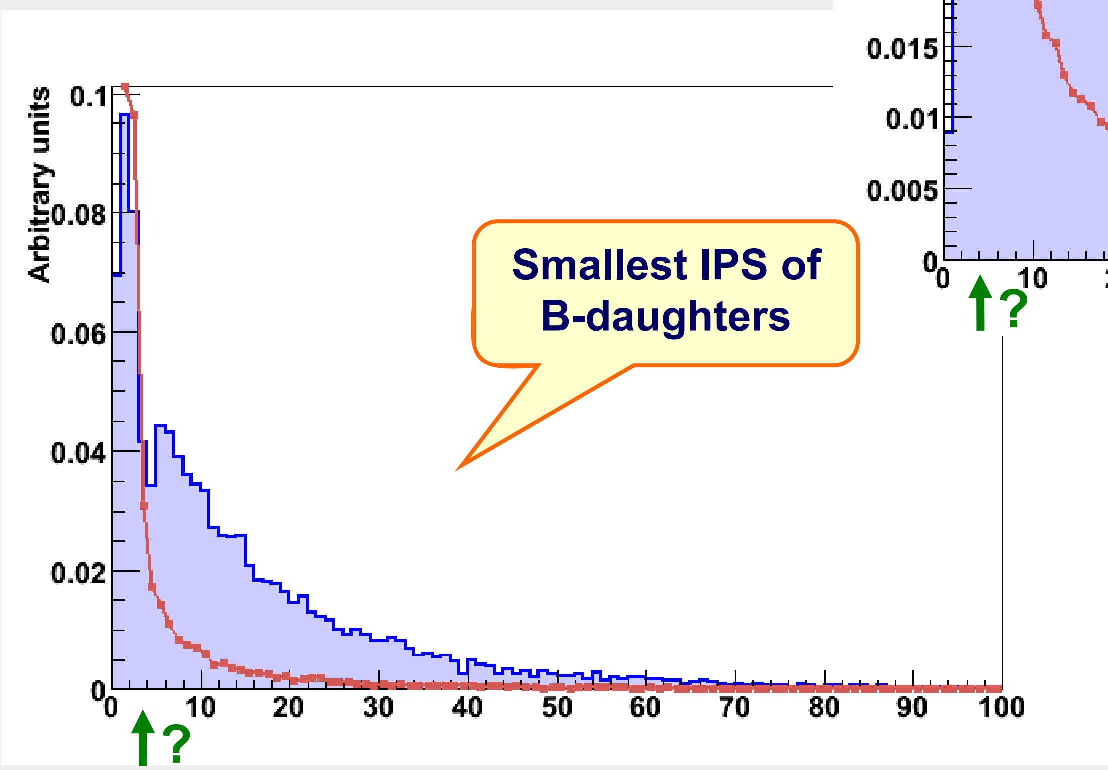
Distributions for signal and b-inclusive background (1/6)



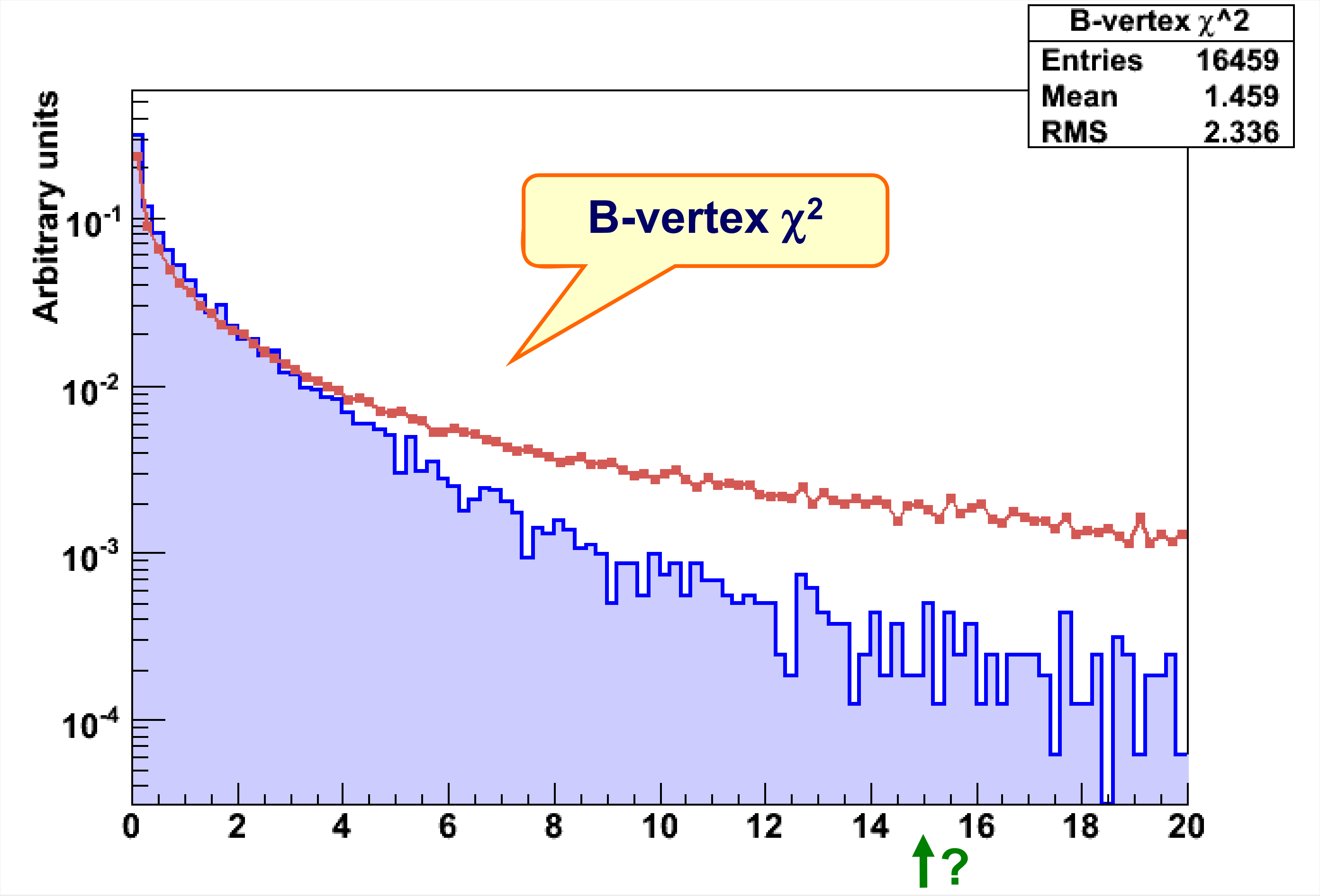


Distributions for signal and b-inclusive background (2/6)

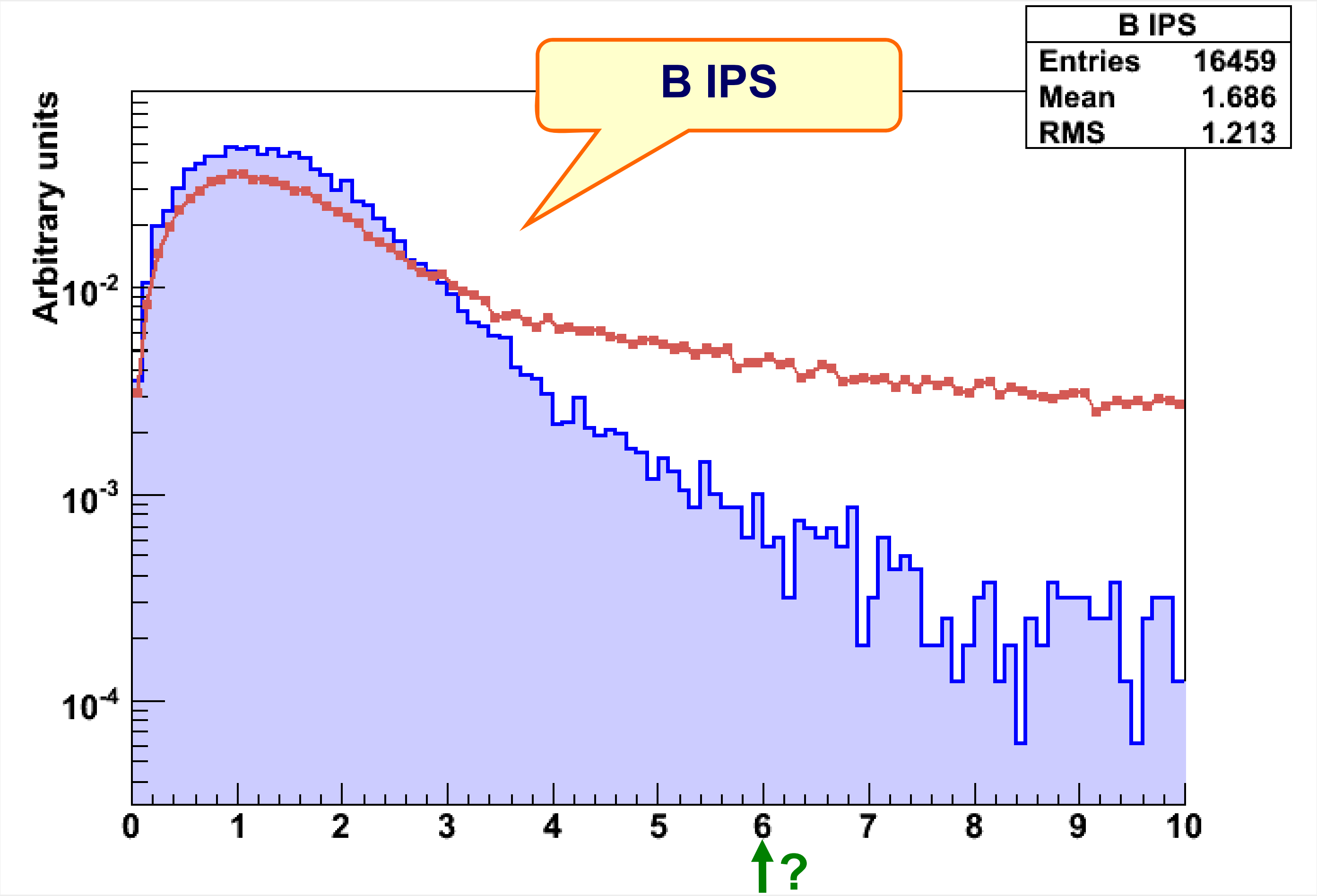




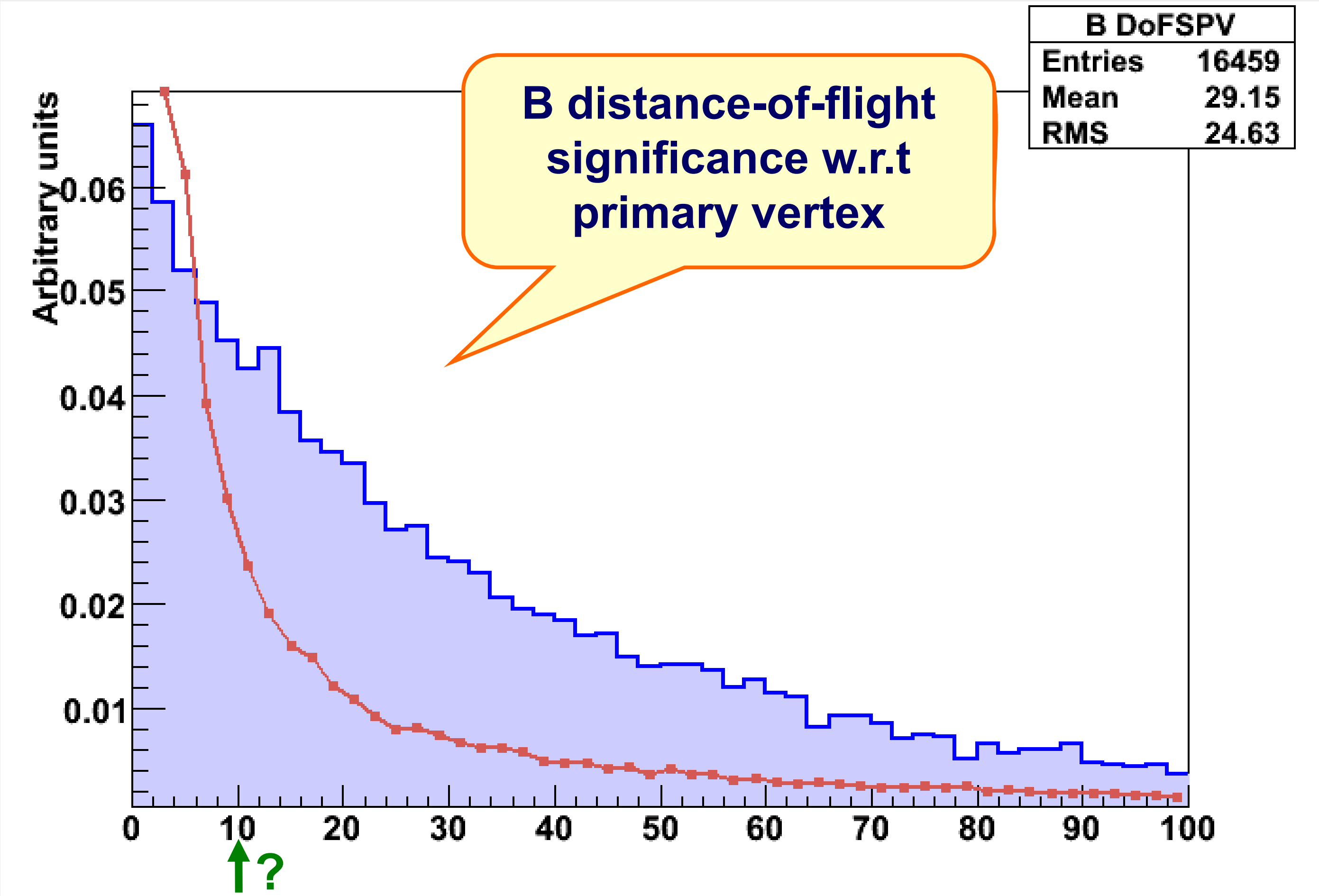
Distributions for signal and b-inclusive background (3/6)



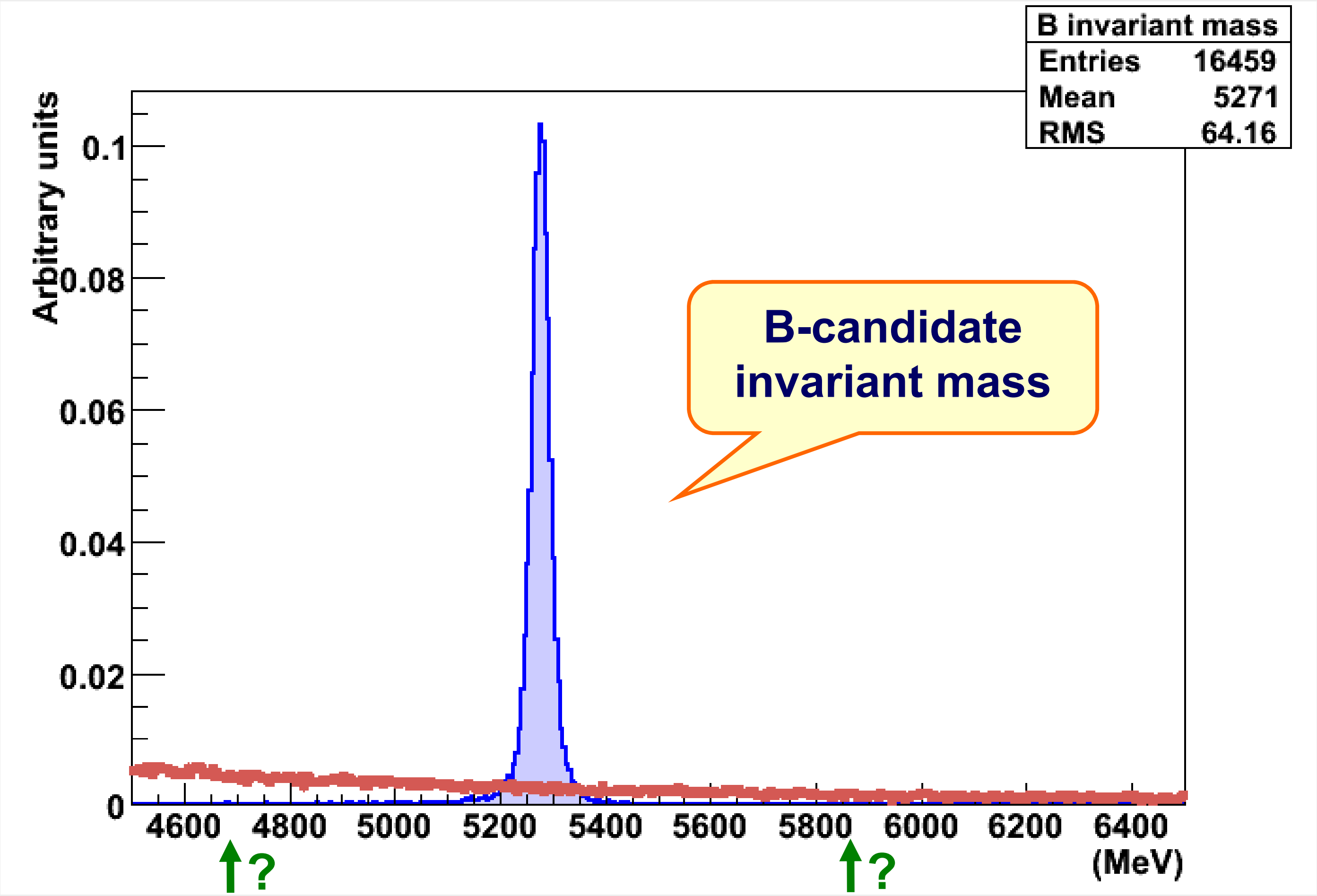
Distributions for signal and b-inclusive background (4/6)



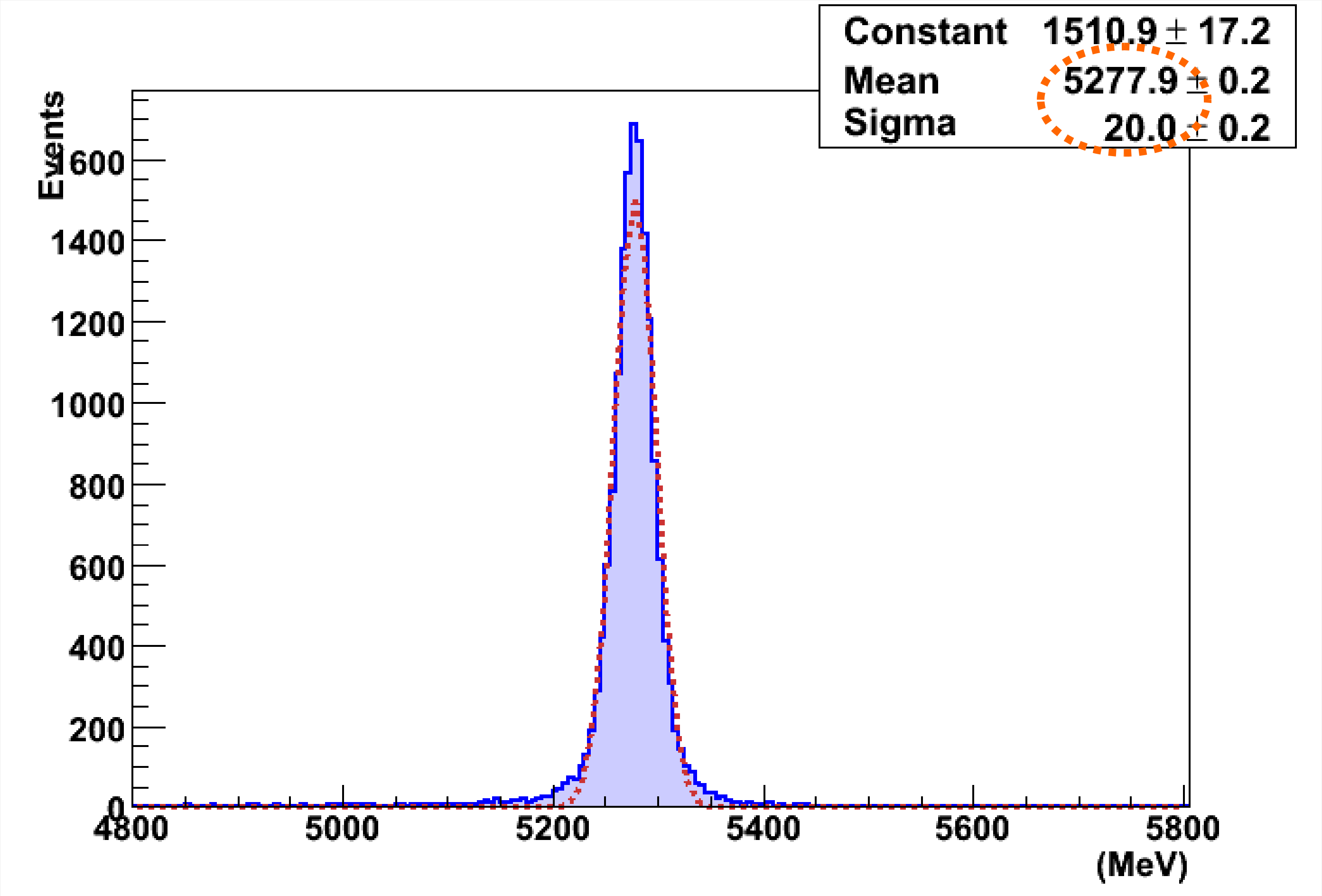
Distributions for signal and b-inclusive background (5/6)



Distributions for signal and b-inclusive background (6/6)



B invariant mass resolution on signal



- This is promising …

Pre-selection

Goal:

- Define a loose set of cuts for stripping
- Keep as much signal as possible while rejecting as much background as possible

“Optimisation”:

- Vary a few of the cuts considered and check reduction factor on a b-bbar inclusive background
- Cross-check reduction factor on signal
- First look at reduction factor on minimum bias

At the end:

- Better knowledge of possible/potential sources of background

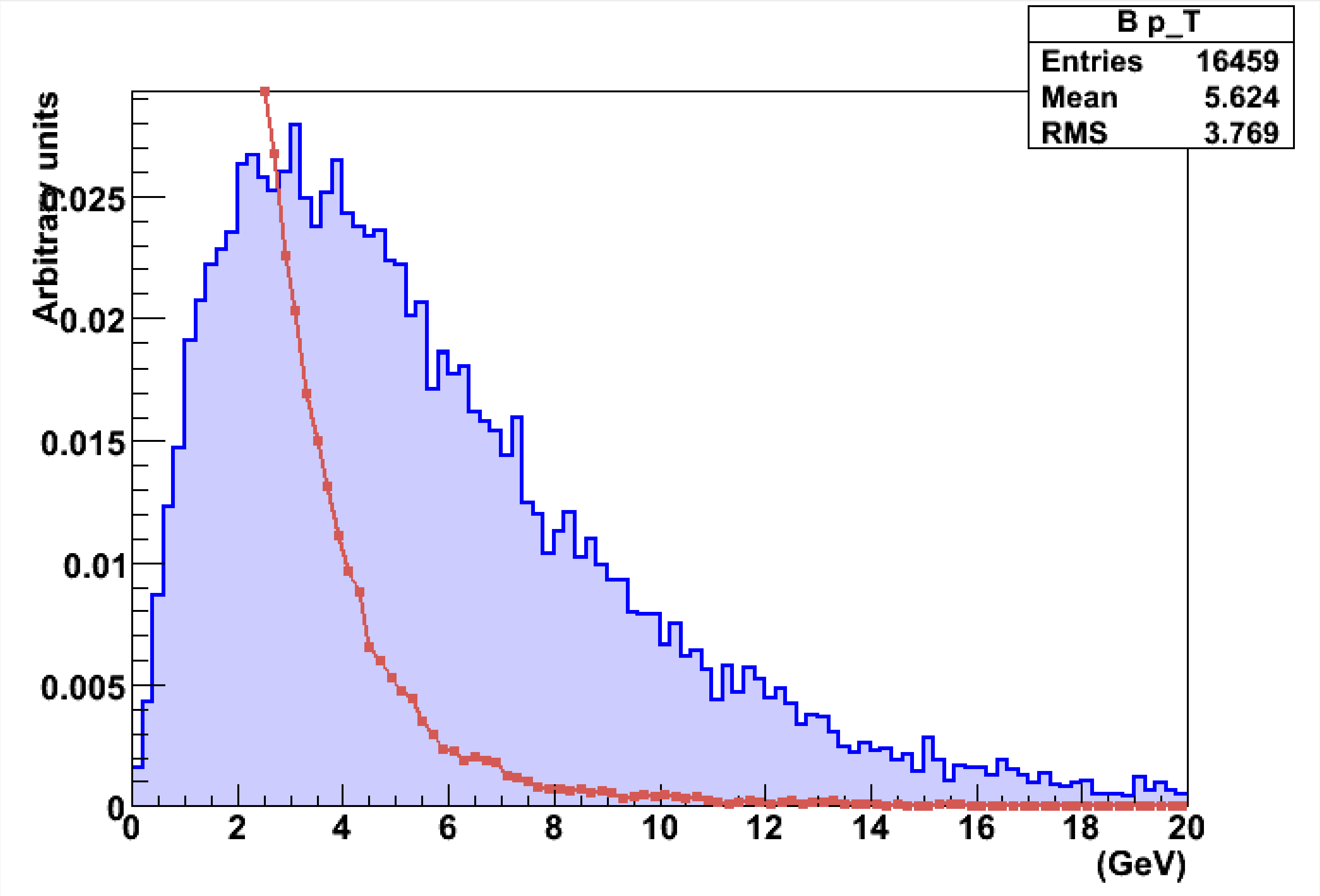
Pre-selection variables

Pre-selection cuts consist of various requirements:

- **Particle identification:**
  - p-π separation based on PID likelihood difference ($\Delta\ln\mathcal{L}_{p\pi}$)
- **Topological:**
  - clear separation of primary vertex and B-decay vertex
  - B-daughters impact parameter (IP) and B-decay length significance
- **Kinematic:**
  - minimal B-daughters transverse momentum
- **Vertexing:**
  - χ^2 of vertex fit to B-daughters
- **Mass:**
  - mass window cut on invariant mass of B-daughters

❖ **Other cuts possible but not considered: e.g. p_T of B, $\Delta\ln\mathcal{L}_{pK}$**

Example of cut not considered: p_T of B candidate



Pre-selection cuts

Cut variable	Cut value
B-mass window	± 600 MeV
min p_T of each B-daughter	800 MeV
min p_T of at least one B-daughter	1600 MeV
B-vertex χ^2	< 15
min IPS of each B-daughter	> 3.5
min IPS of at least one B-daughter	> 4.0
IPS of B-vertex	< 6
B flight distance significance	> 10

Backgrounds and reduction factors

Note: 40k samples in each case

Reduction factors:

- 3.5 on signal for ~2200 on b-bbar inclusive background
- No minimum bias event passed in a sample of 40k
  - clearly this needs to be checked on much larger a sample …
  - … keep fingers crossed …

Specific background :

- Looked at $B_s \rightarrow KK$, $B^0 \rightarrow KK$ and $\Lambda_b \rightarrow pK$:

  all contribute as background (main contributor is $\Lambda_b \rightarrow pK$)
- Note: Belle reports B-decay background to be negligible in their selection. They are dominated by $e^+e^- \rightarrow q$ qbar background
- We just started looking at background. Much more to be done …
  - e.g.: do we need to apply DLL cuts at pre-selection level?
  - look at channels such as $B \rightarrow hh$ with misid., 3-body B-decays with 2 protons in final state, $\Lambda_b \rightarrow p$+anything, etc.

Path towards a selection

Investigating TMVA for cut optimisation

Proof of principle only

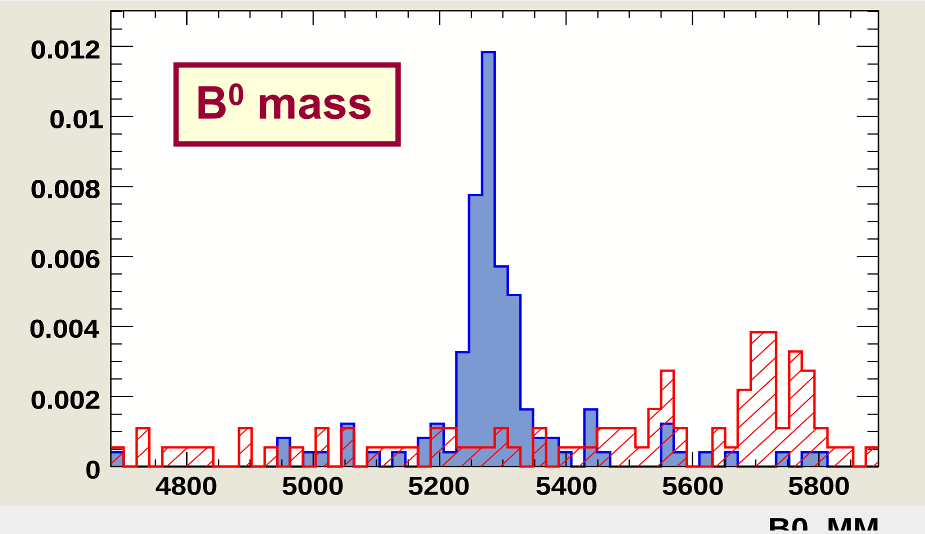
– arbitrary normalisation

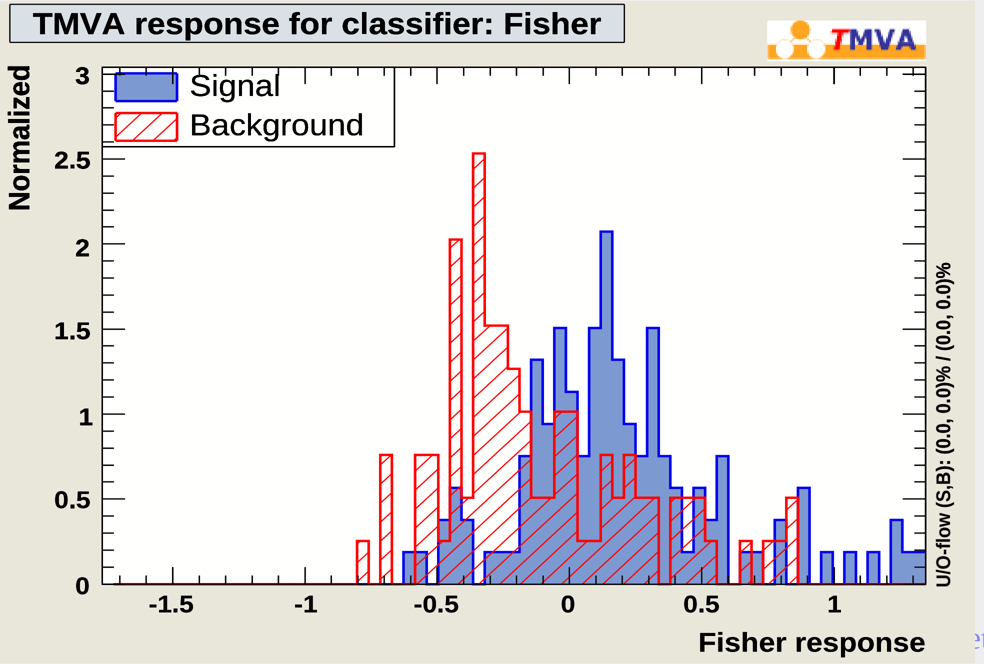
Trained with

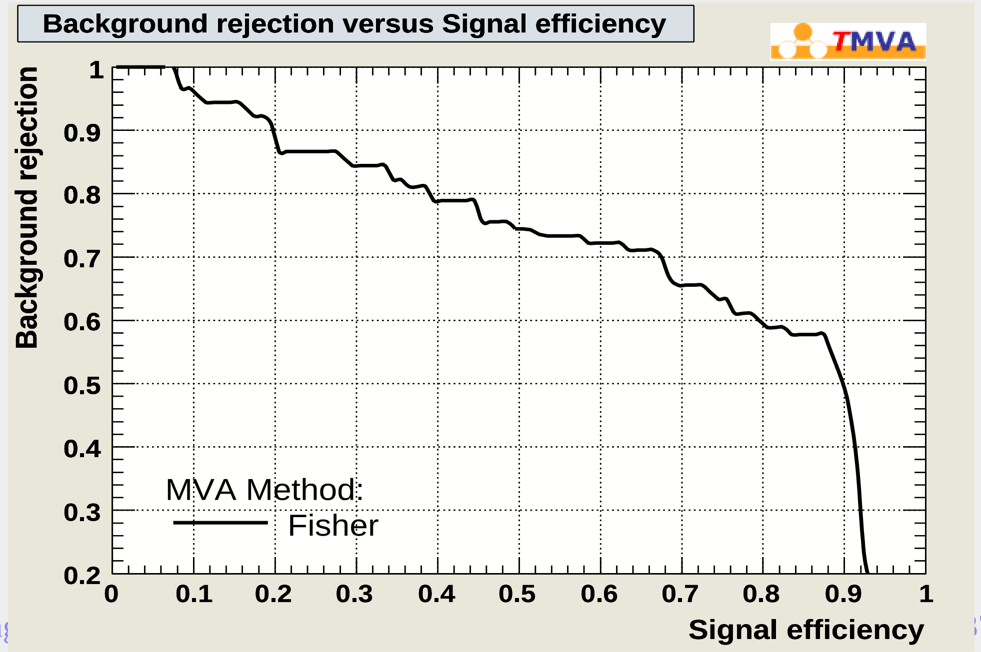
- samples: $B_S \to K^+K^-, B^0 \to K^+K^-, \Lambda_b \to pK^-$
- variables:

B^0 : mass, vertex χ^2, IPS , Flight distance signif.,

proton : p_T, IPS, proton ID







Conclusions and outlook (1/2)

- No 2-body baryonic charmless decays observed so far, e.g

$$B^0 \to p\bar{p} \quad , \quad B^0 \to \Lambda\bar{\Lambda} \quad , \quad B^+ \to p\bar{\Lambda}$$

- Theoretical calculations/predictions do not always agree
  - some limits already exclude certain models

- Focus for now on early measurement of $p\bar{p}$ mode: is easiest for LHCb
  - we could expect of order 1000-3000 events per nominal year?
  - first pre-selection is available and performance seems very reasonable

$\Rightarrow$ ***Possible observation by LHCb of first 2-body baryonic B decay***

- We could also look e.g. at Λ's … see the decays above …

Conclusions and outlook (2/2)

- Cross-check (stripping) pre-selection satisfies all requirements
- And release the agreed-upon pre-selection

- Work on a “final” selection starting from pre-selected events
  - use TMVA for the optimisation task

- Pay particular attention to protons particle identification
  - not very much studied so far since LHCb benchmark channels do not contain protons
  - Can anything be gained here?

- In parallel will start work on $B^0 \to KK$ and $B_s \to \pi\pi$