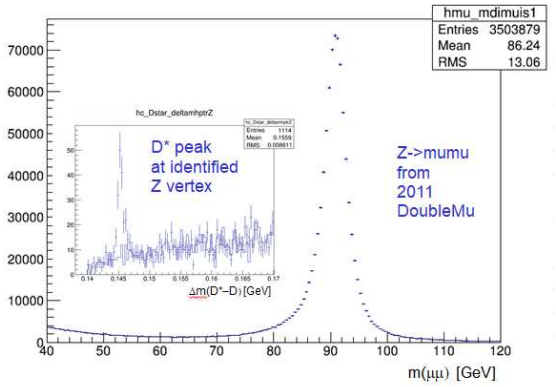
Prospects for Z+charm/beauty at Run 3

DESY QCD meeting, 26.03.2020

(update of talk at SMP-VJ meeting, 31. 1. 2020)

Achim Geiser, DESY Hamburg

+ contributions from N. Jomhari, J. Metwally



- **picking up a personal interest started several years ago**
- **building on earlier studies of inclusive charm/beauty and Drell-Yan, not about Z+jets** (but of course related to it)

Outline:

- **Why measure associated Z+charm/beauty production?**
- **A bit of history**
- **How to measure (associated Z+)charm/beauty production without jets?**
- **Why Run 3?**
- **Conclusions**

Why measure associated Z+charm/beauty production?

- QCD: expected total Z+cc cross section O(30%) of total Z cross section

expected total Z+bb cross section O(5%) of total Z cross section

-> measure total, single differential (p_T,y) and double differential (Z-b/c correlation) cross sections + compare with theory (and improve it!)

so far most measurements require b/c jets -> p_T>~20/30 GeV

most of the cross section is at much lower p_T -> do not require jets

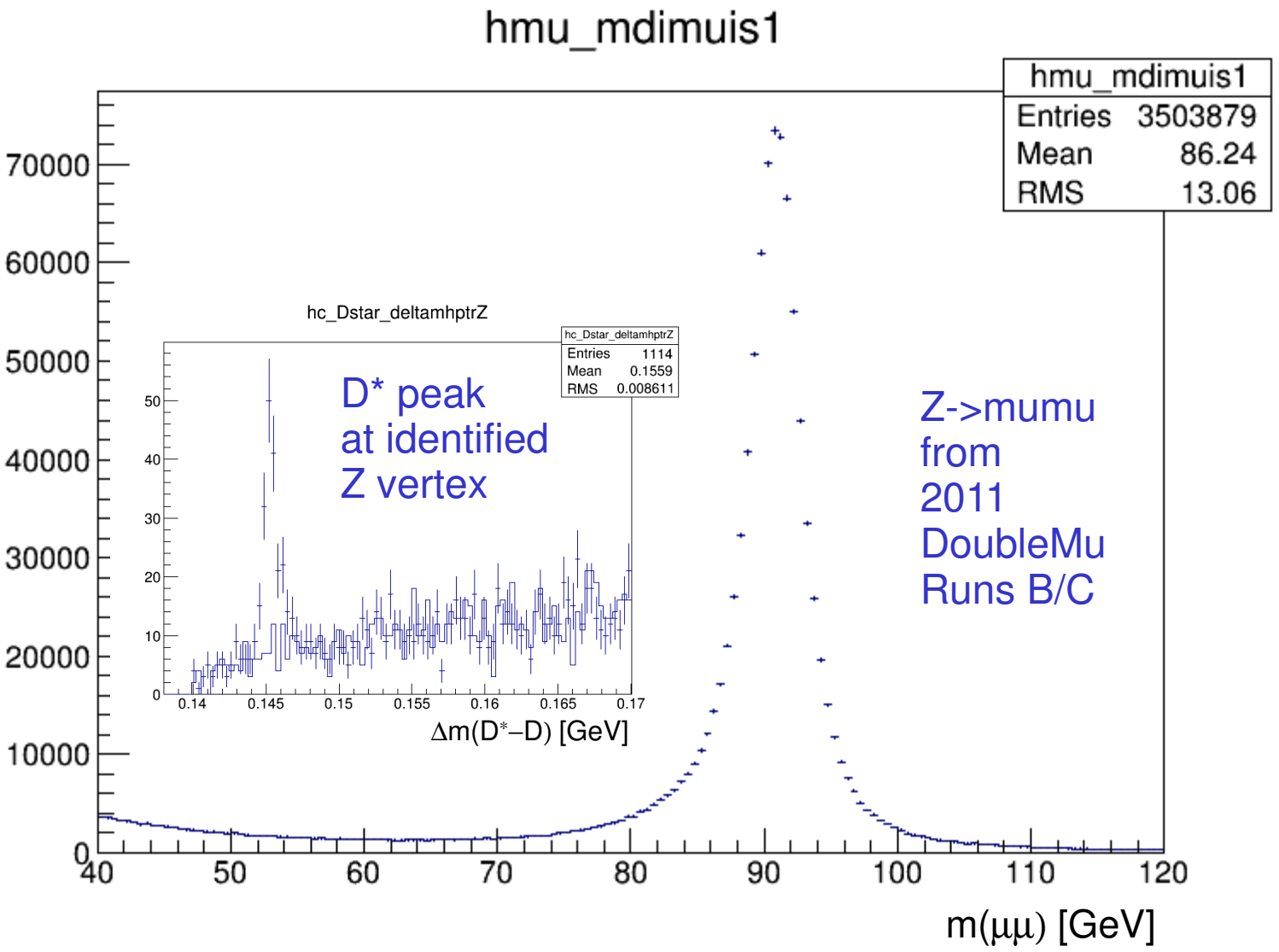
- W mass measurement:

one of largest systematic uncertainties of the ATLAS W mass result originates from the poorly known differences between the Z (template) and W (actual, but poorly measured) p_T distributions due to associated charm production near threshold

-> measurement of the differential cross section in both Z+charm and W+charm with lowest possible charm p_T threshold (O(1 GeV)) can help to reduce this uncertainty

- template for later H+charm/beauty analysis (c/b Yukawa couplings)

Example of older study: Z+charm @ 7 TeV



takes only few minutes to run sophisticated selection over 30 M events!
(full sample, from existing ntuples)

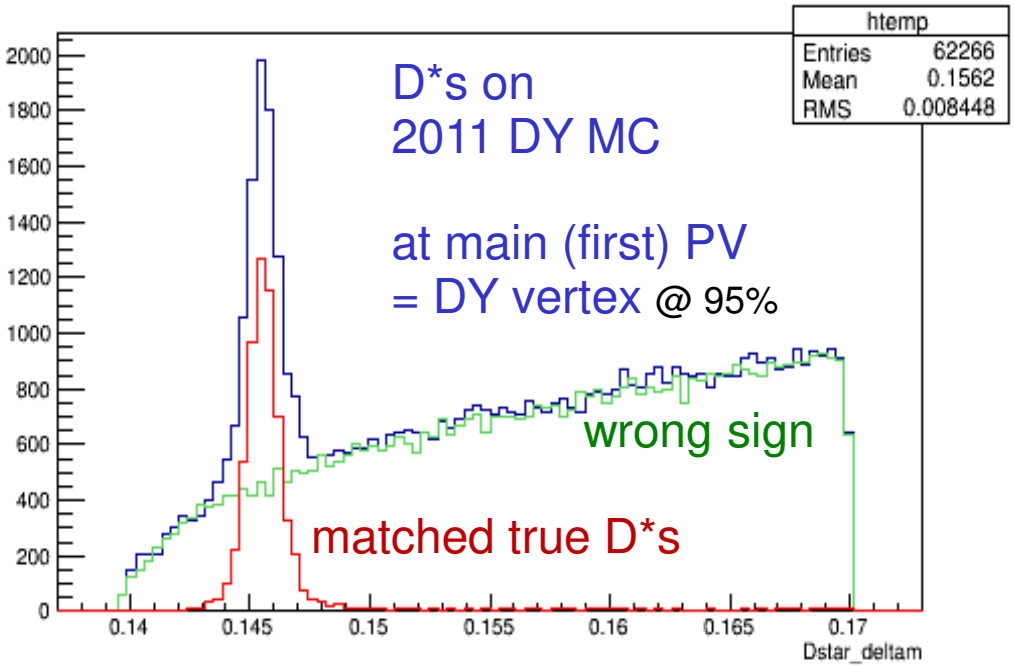
Goal:

extraction of total Z+charm cross section

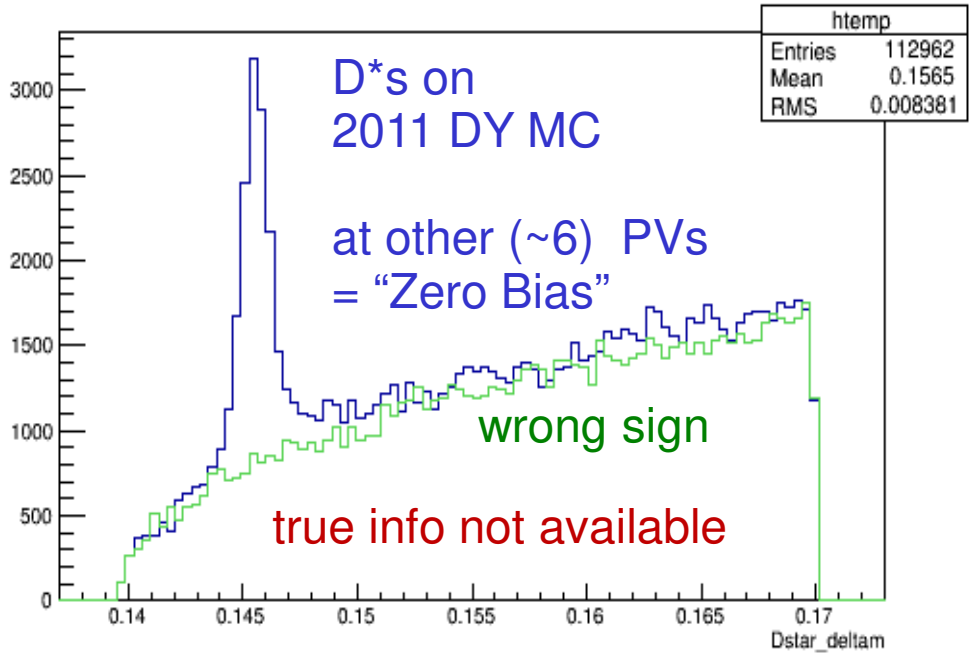
D* on 2011 DY MC, $m_{\mu\mu}$ >50 GeV:

"old" study:

- **D* p_T>3.5 GeV, no explicit eta cut**
- **separate main (DY) vertex and other primary vertices**

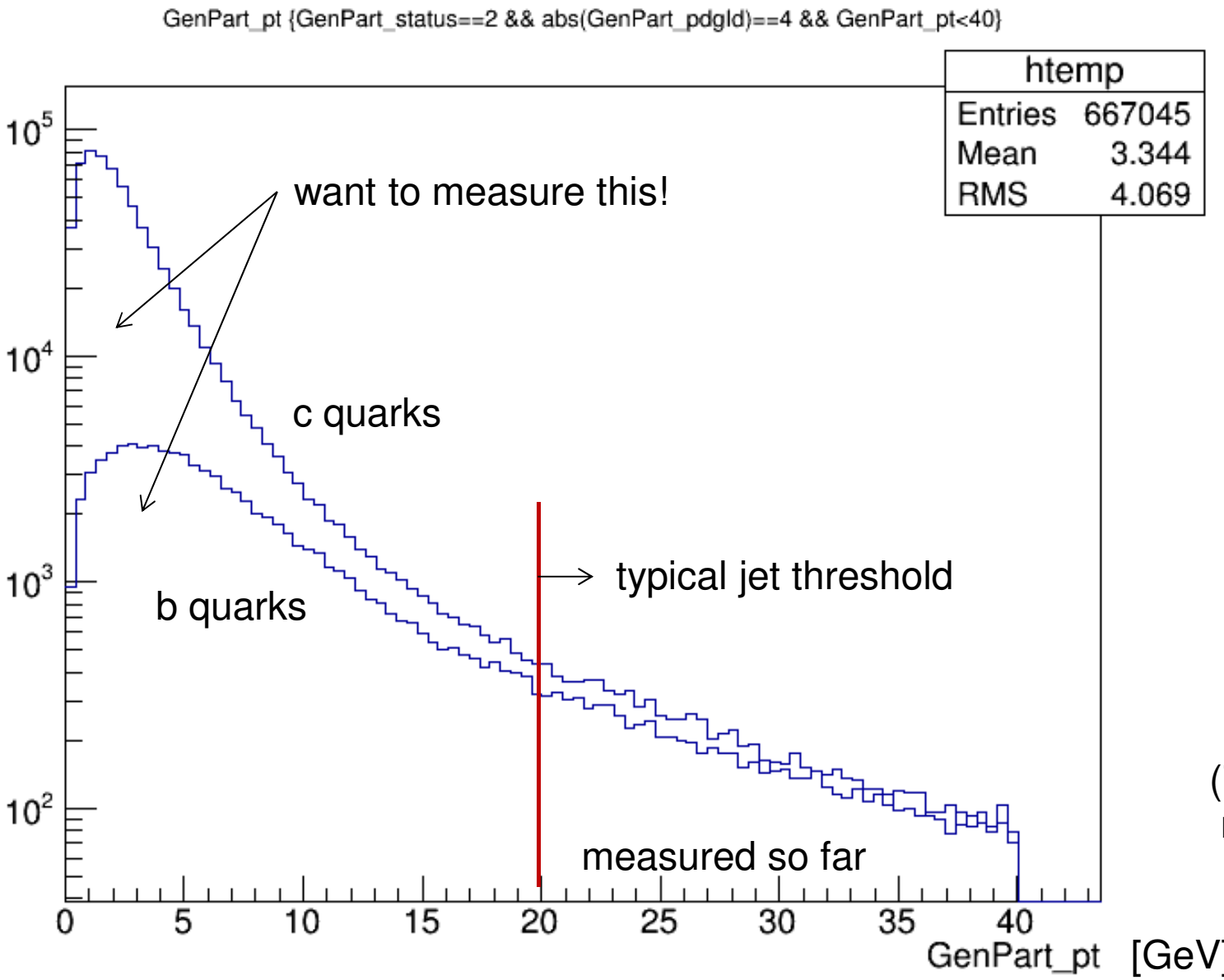


Δm(D*–D) [GeV]



Δm(D*–D) [GeV]

Charm and beauty quark p_T spectra in DY MC

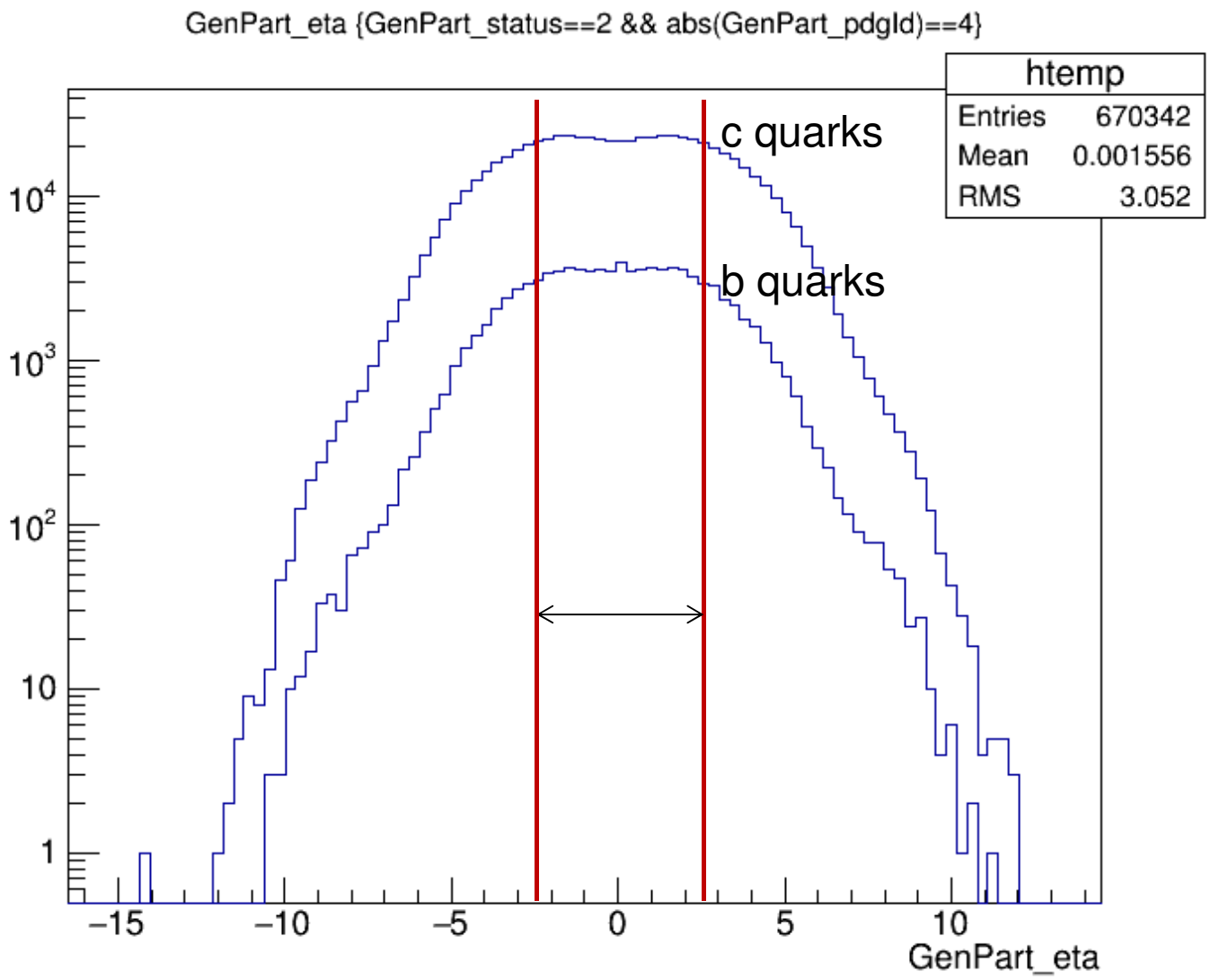


small subset of available MC (1M events)

PYTHIA:
peak cross sections ~ one (b) to two (c) orders of magnitude larger than at p_T=20 GeV

(7 TeV; 13 TeV not much different)

Charm and beauty quark eta spectra in DY MC

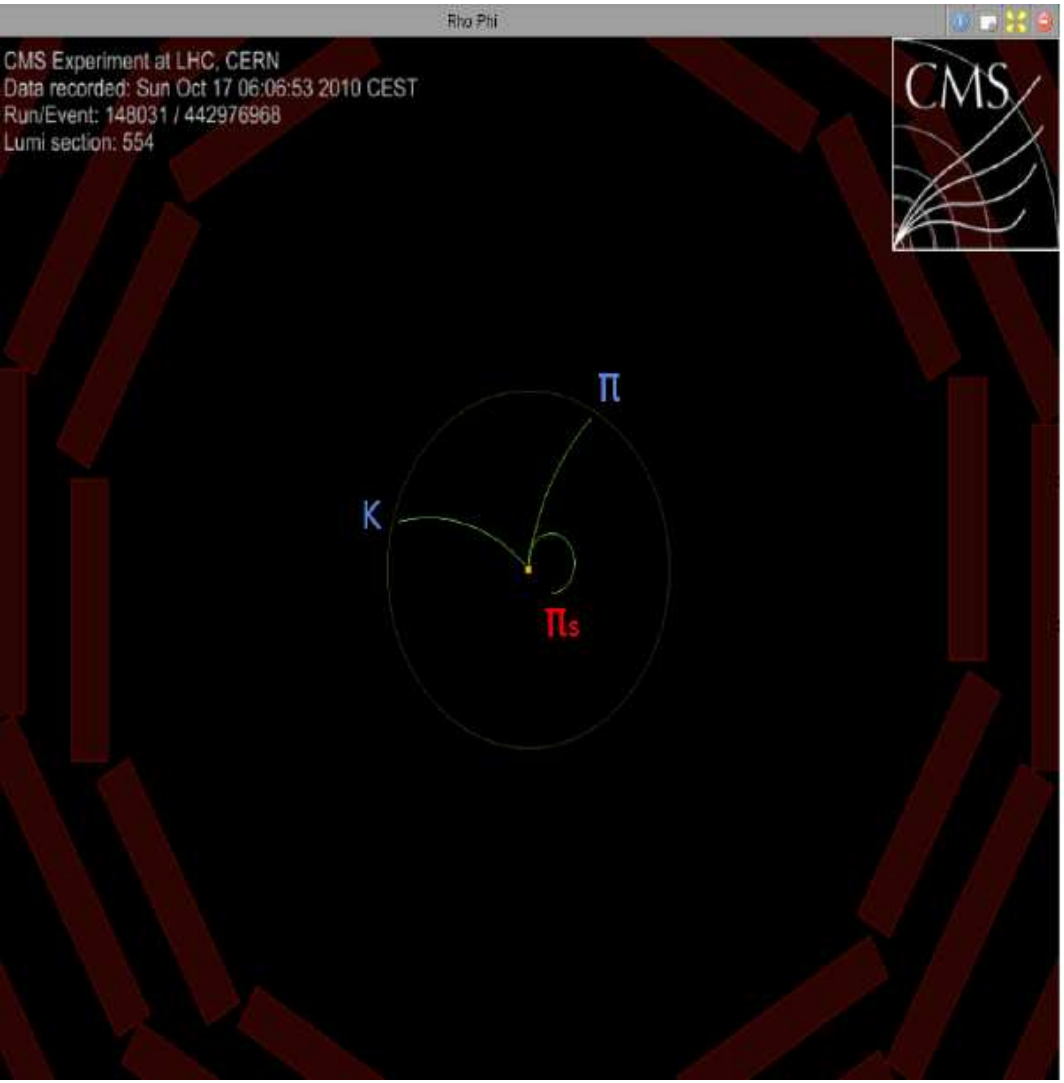


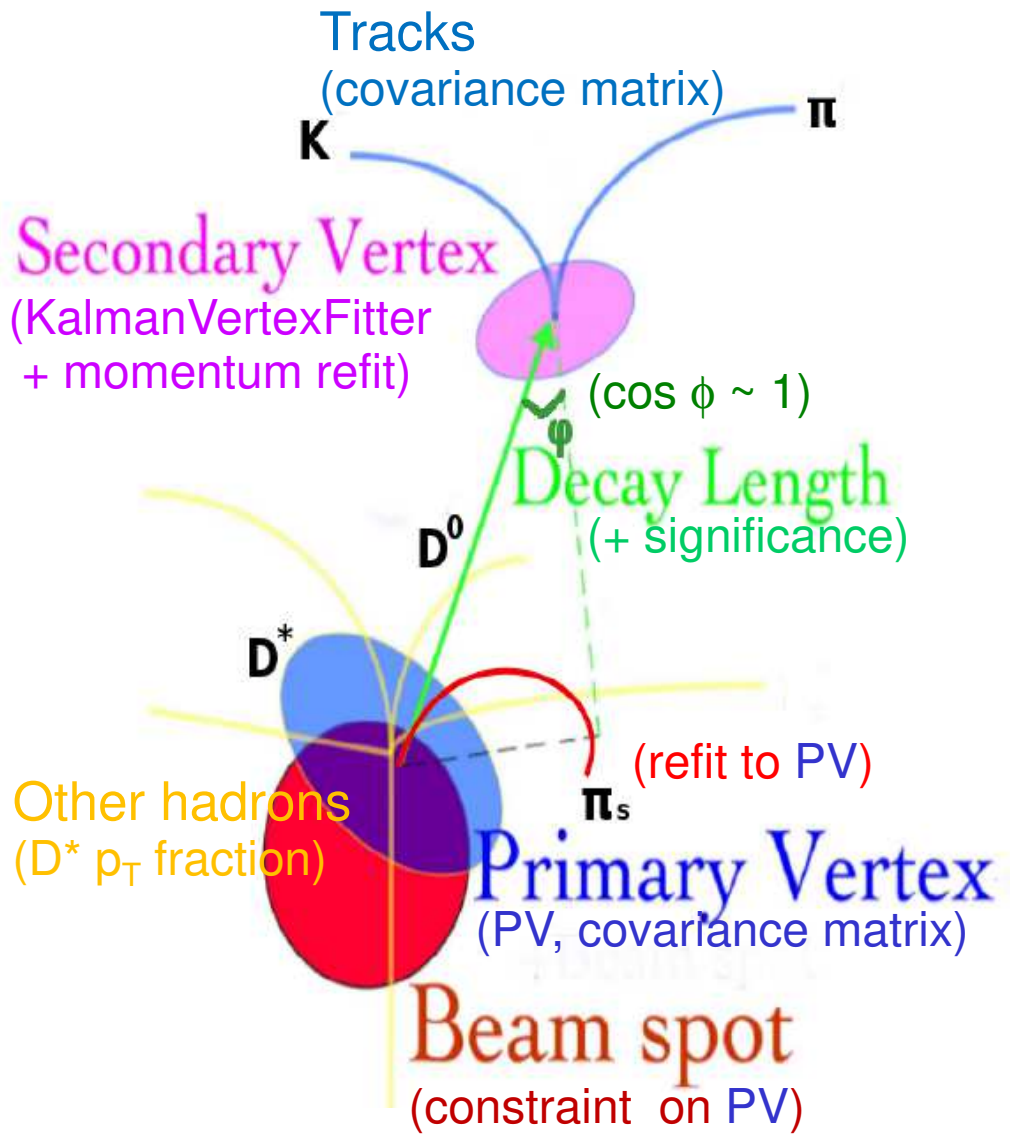
PYTHIA:
~50% are within measurable eta range of CMS

(7 TeV; 13 TeV not much different)

Prompt D^*->D^0 π_s, D^0->Kπ decay and reconstruction

N. Jomhari





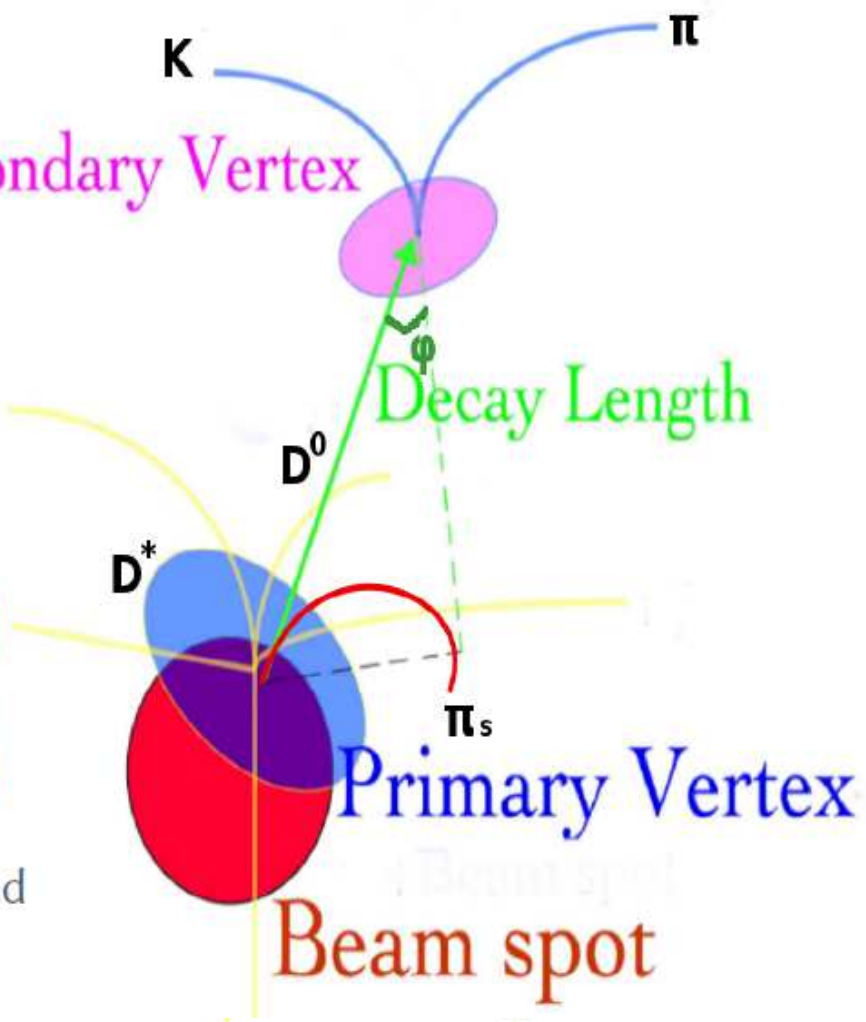
$D^{*\pm} \rightarrow D^0\pi^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$ selection

$$p_{Tfrac} = \frac{p_T \text{ of D meson}}{\sum p_T \text{ of all tracks}} \quad \text{at respective PV}$$

$$dl^{D^0}_{Sig} = \frac{dl^{D^0}}{dl^{D^0}_{err}}$$

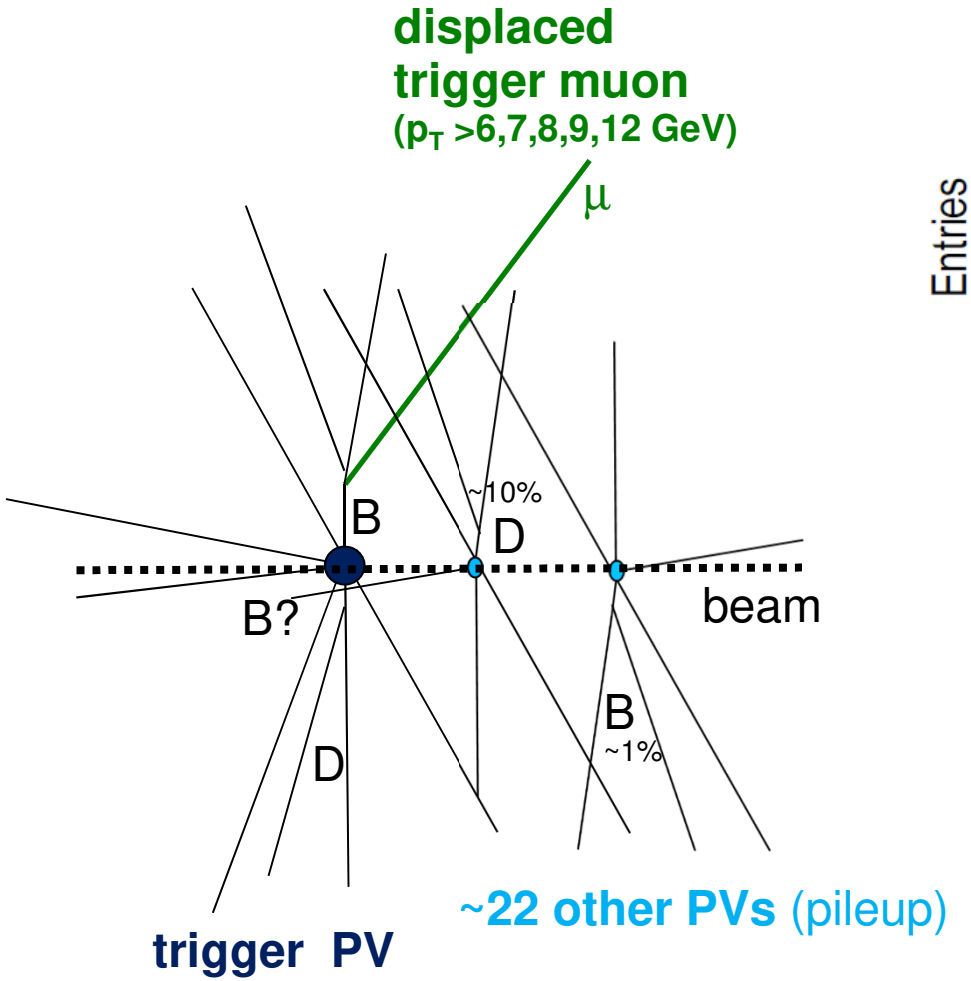
- Track p_T cut
  - $p_T^{K,\pi} > 0.5$ GeV, none for π_s
- D^0 mass cut
- Possible combination:
  - Right sign: $K^\mp\pi^\pm\pi_s^\pm$
  - Wrong sign: $K^\mp\pi^\mp\pi_s^\pm$ (combinatorial background)
- For higher p_T ($p_T^{D^*} > 3.5$ GeV):
  - ($dl^{D^0}_{Sig} > 0$ & $p^{D^*}_{Tfrac} > 0.15$ and $\cos\phi > 0.8$) or $dl^{D^0}_{Sig} > 2$
- For lower p_T ($p_T^{D^*} < 3.5$ GeV):
  - (($dl^{D^0}_{Sig} > 1.5$ & $p^{D^*}_{Tfrac} > 0.15$) or $dl^{D^0}_{Sig} > 3$ or ($dl^{D^0}_{Sig} > 2$ and $\cos\phi_{D^0} > 0.995$)) and $p^{D^0}_{Tfrac} > 0.1$ and $\cos\phi > 0.8$

optimized for low p_T charm

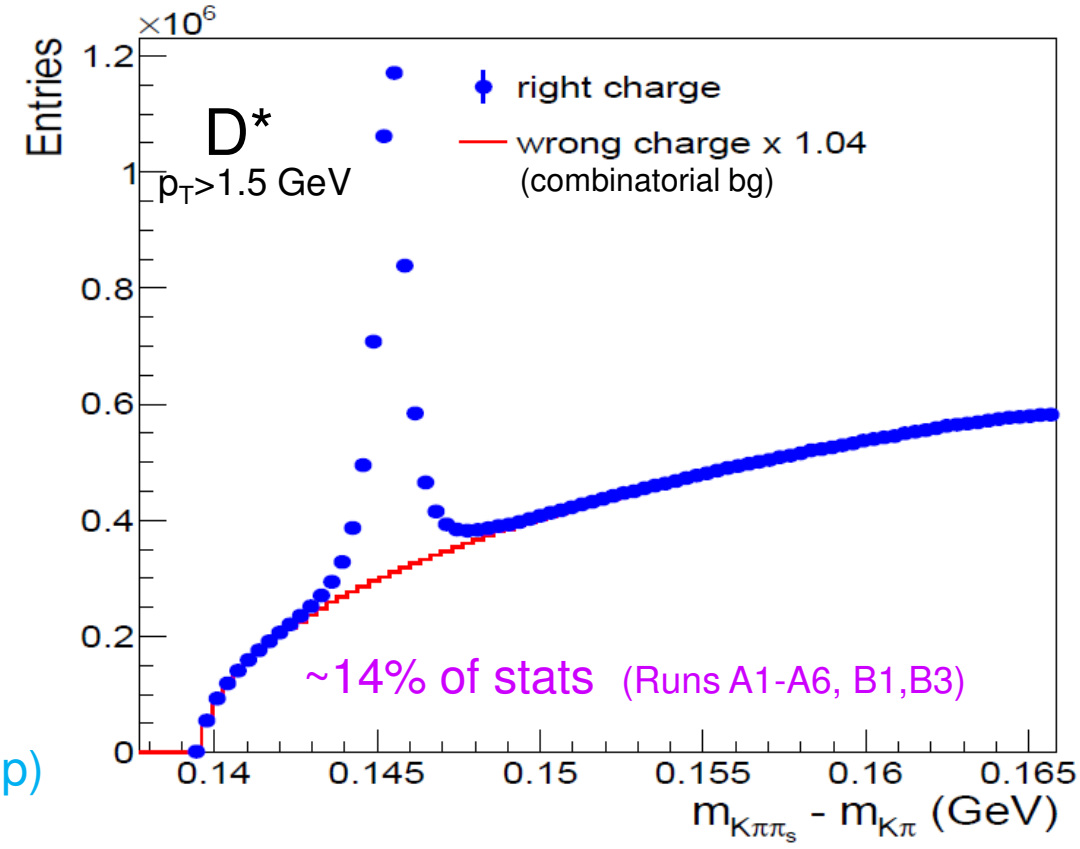


Example, B parking dataset: each B parking event has ~ 23 reconstructed pp collisions (primary vertices)

~12 billion events (trigger muons) **~270 billion reconstructed pp collisions** (primary vertices)



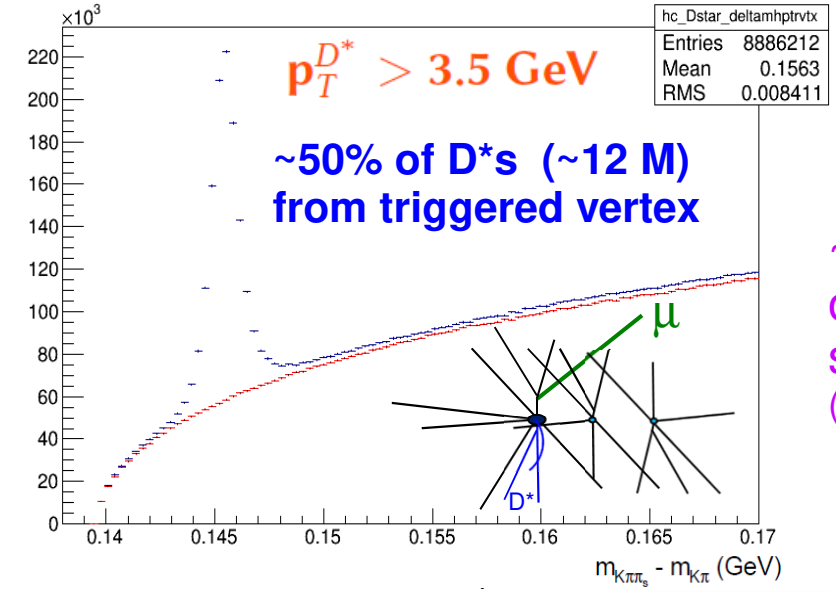
~24 million reconstructed true D*->(Kπ)π_s
(all tracks, all vertices) **D^0**

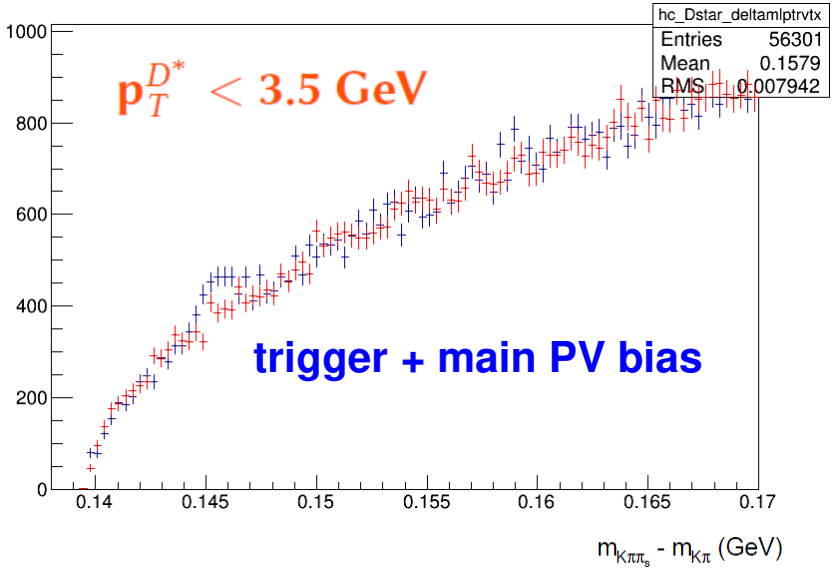


in general in this presentation for plots from B parking:
all numbers are given for expected total B Parking statistics (extrapolated)
all plots are for partial statistics (1% -> 14%)

D*s from main PV (~trigger mu) vs. other PVs (~pileup)

main PV (mainly b->μX, triggered)
total: **~12 B vertices**

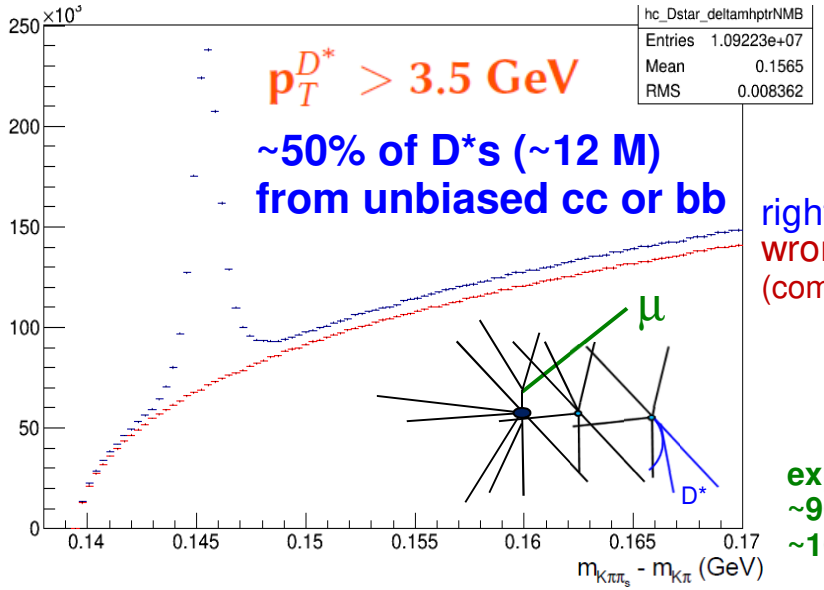




~7% of total statistics (70% Run A)

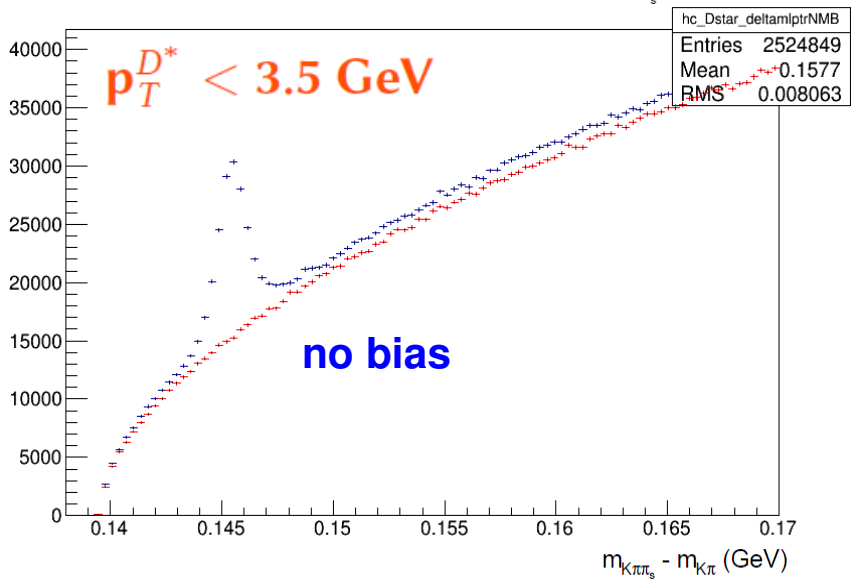
(no slow pion refit)

other PVs (mainly c from pileup)
~260 B vertices



right charge
wrong charge
(combinatorial)

expect
~90% ccbar
~10% bbbar



Comparison, pileup from B Parking <-> Zerobias

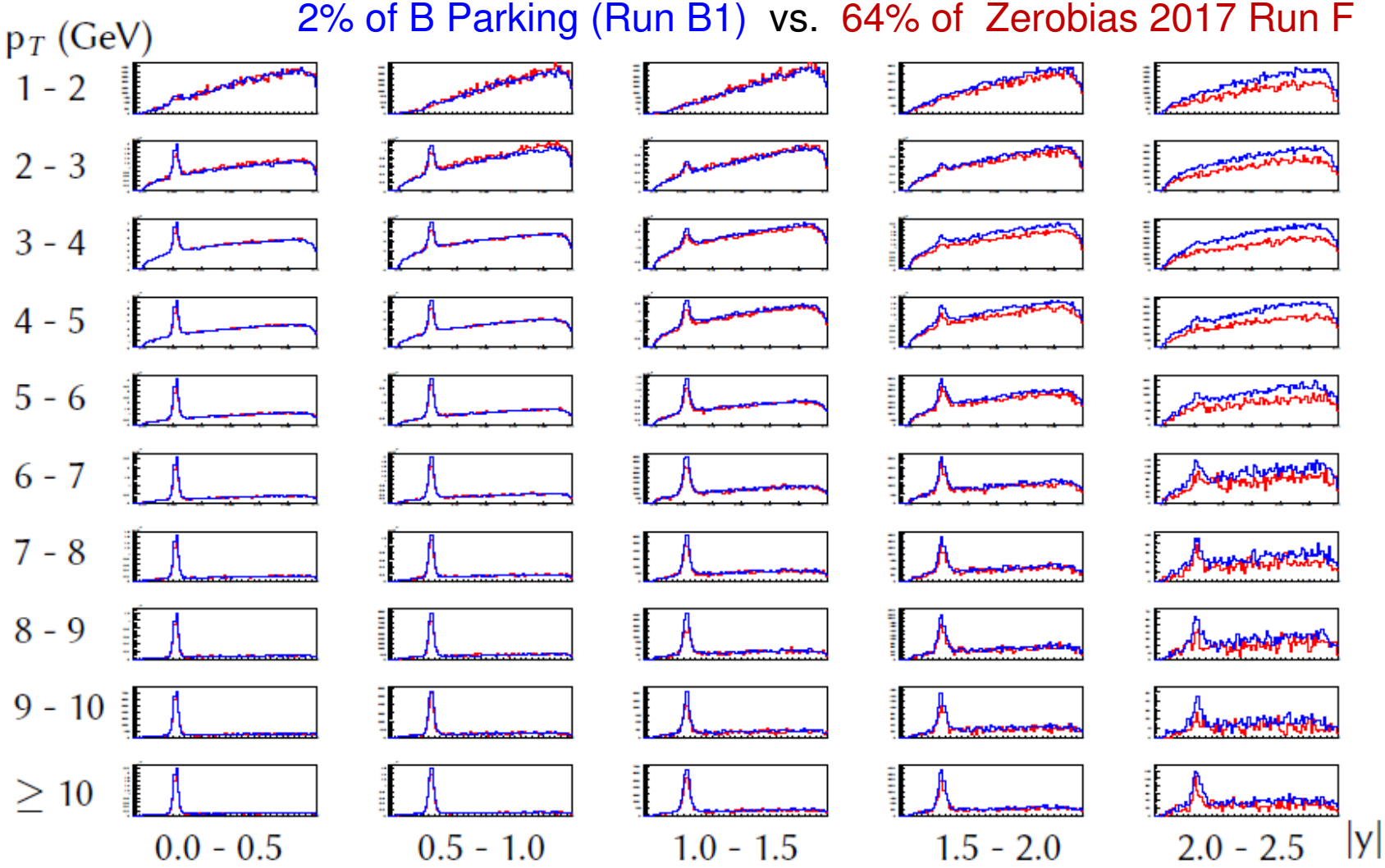
pileup: remove all PVs 1 cm around trigger muon (sometimes 3 cm depending on muon quality)

2% of B Parking (Run B1) vs. 64% of Zerobias 2017 Run F

D*->Kππ

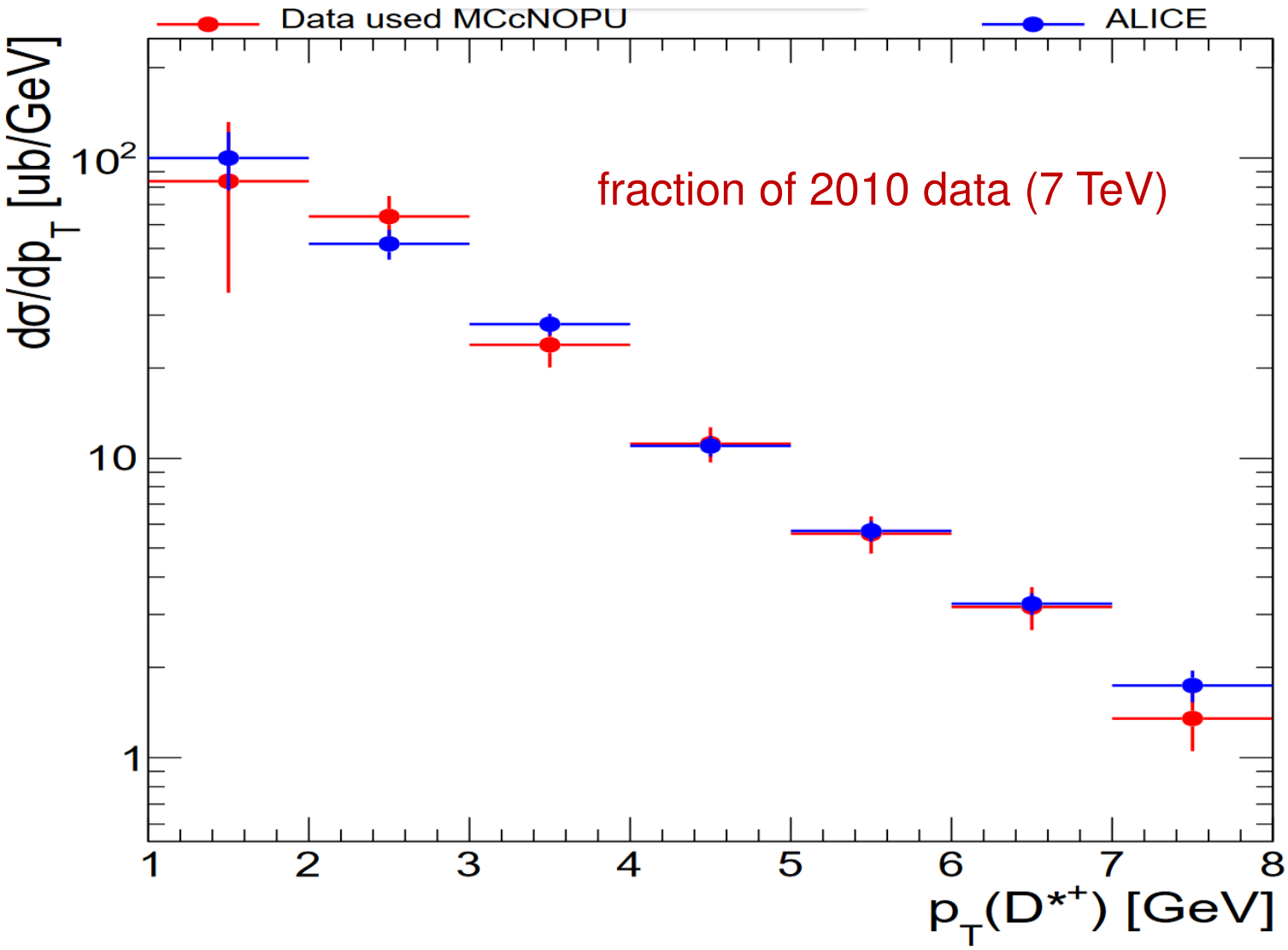
normalized to same effective luminosity (number of primary vertices)

more details in talk on D* reconstruction



results for inclusive charm from pileup in B Parking dataset consistent with results from ZeroBias dataset (similar PU)**, much more statistics**

Inclusive D* cross section in |y|<0.5, comparison to ALICE



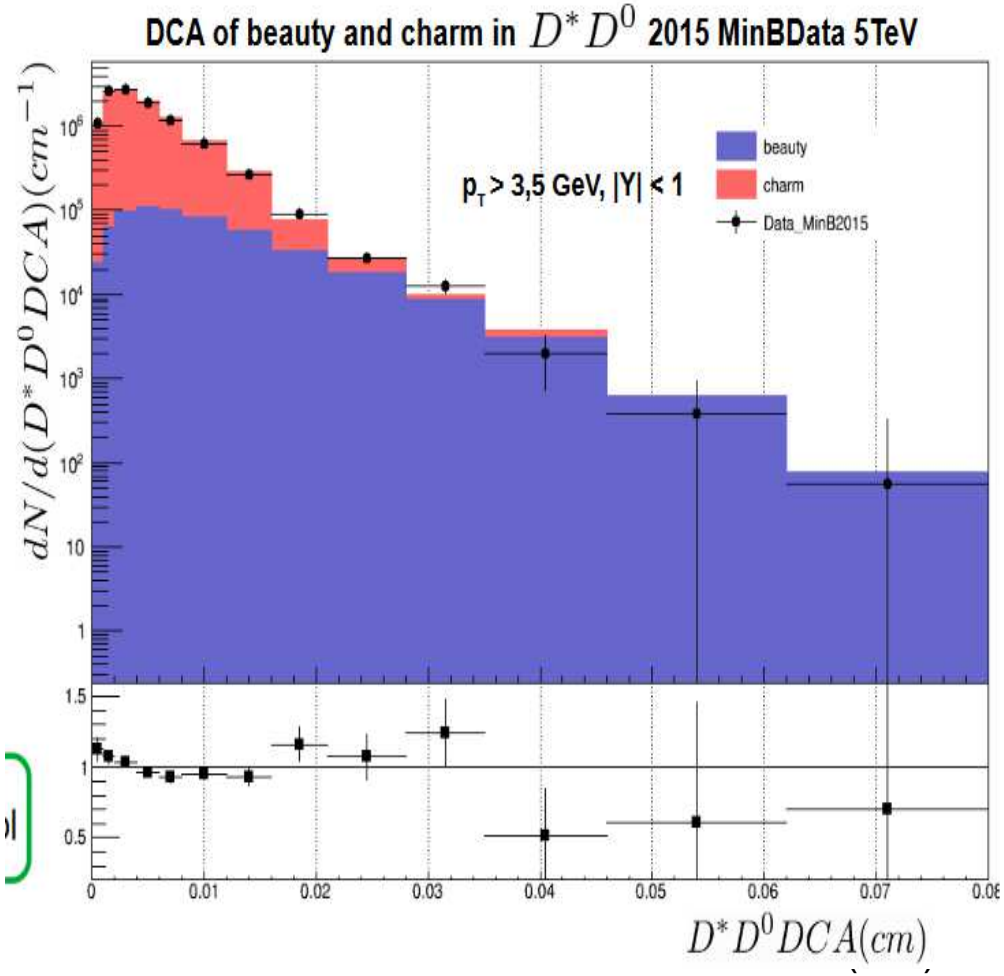
N. Jomhari

13 TeV data has three orders of magnitude more statistics!

2010 had best low p_T tracking (see backup), but statistics too low for Z+charm/beauty

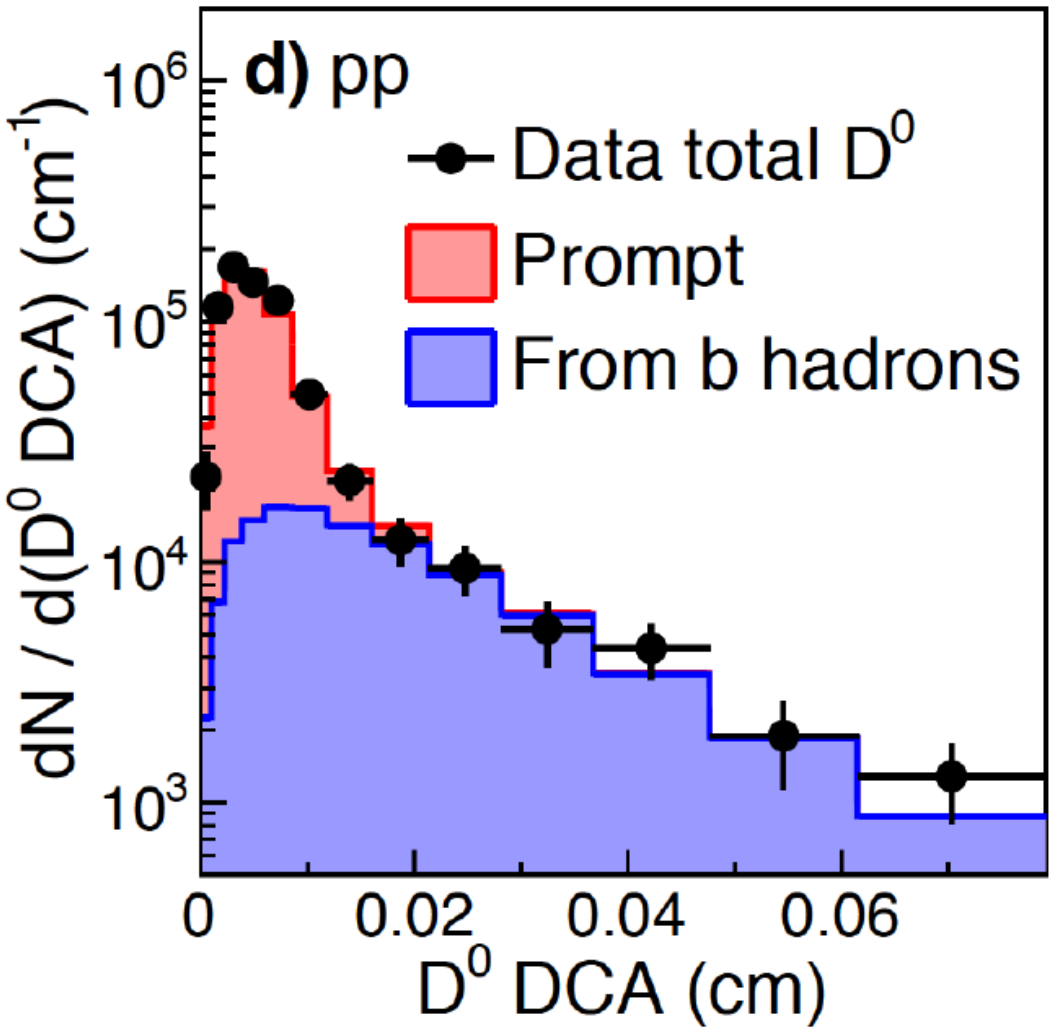
Charm-Beauty separation (5 TeV pp Minimum Bias, similar for 13 TeV)

D* p_T>3.5 GeV, |Y|<1 J. Metwally



~9% beauty, ~91% charm

benchmark: HIN-16-016, D^0 p_T>2, |Y|<1



beauty and charm can be separated statistically, but not on event-to-event basis

use same data to measure both (Z+) c and b cross sections

Why Run 3 ?

almost everything stated applies ~equally to Run 2 and Run 3 (or even Run 1)**, but**

- "new" pixel detector (from 2017 on) has better tracking coverage at low p_T (slow pion for D*) and large eta (see backup)

-> "effective" Run 3 luminosity > Run 2 luminosity

- Run 3 luminosity not so much larger -> go for "creative ideas" to do things differently -> this one of them

- "low" luminosity -> "low" pileup (compared to Run 4)

-> better performance of low p_T tracking,

well suited for "early days" Run 3 benchmark analysis

(possibly dedicated low p_T tracking pass like in 2010?) (see backup)

- aim for improvement of miniAOD for low p_T tracks

(currently need AOD for very low p_T end of spectrum, work ongoing)

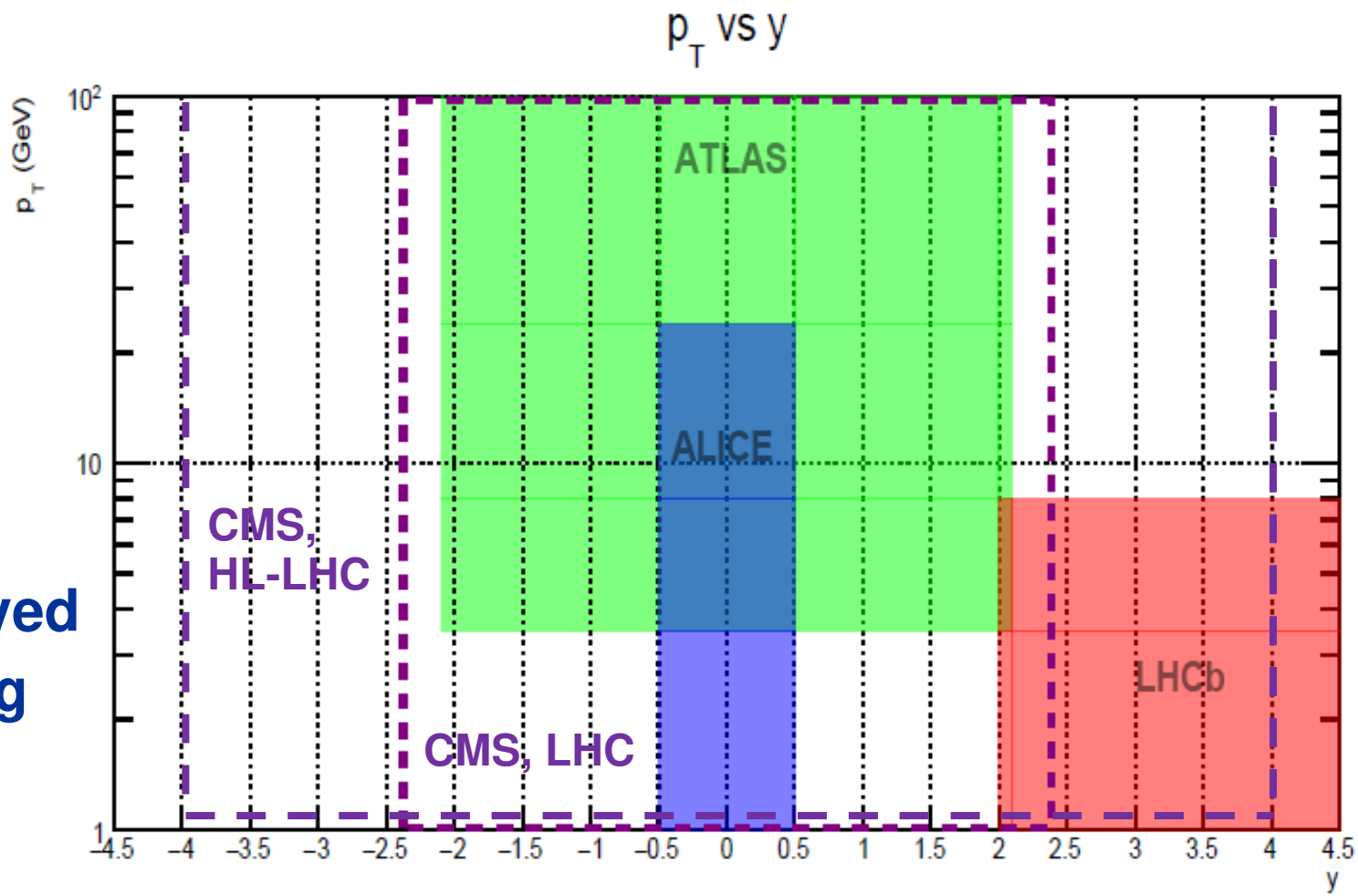
- aim for "associated" nanoAOD extension for D mesons (work ongoing)

-> eventually use nanoAOD

- aim for new master or PhD student to start later this year to be ready for Run 3 ("train" on Run 2)

Outlook for HL-LHC

kinematic acceptance for fully reconstructed D (D*) mesons



CMS@HL-LHC: strongly improved forward tracking acceptance

CMS can measure full charm/beauty phase space all by itself!

Study current performance as function of vertex multiplicity in order to extrapolate to HL-LHC performance

Conclusions

Low p_T end of associated Z+charm/beauty production has so far been barely exploited by any of the LHC experiments

-> satisfies criterion of "creative new analysis" for Run 3

-> improve understanding of QCD(+EW) for associated heavy flavour production
-> reduce uncertainties (both experimental and theoretical)
-> potentially improve W mass measurement
-> pave the way for later associated H+charm/beauty measurements
(marginal in Run 2/3, very interesting for High Lumi LHC!)

~1 out of 3 DY events is expected to contain charm or beauty!
-> inclusive (isolated) double and single lepton triggers
(with lowest possible threshold) will do the job

potential improvements for storage of tracking information in miniAOD and/or storage of D meson candidates in "nanoAOD extension" being investigated

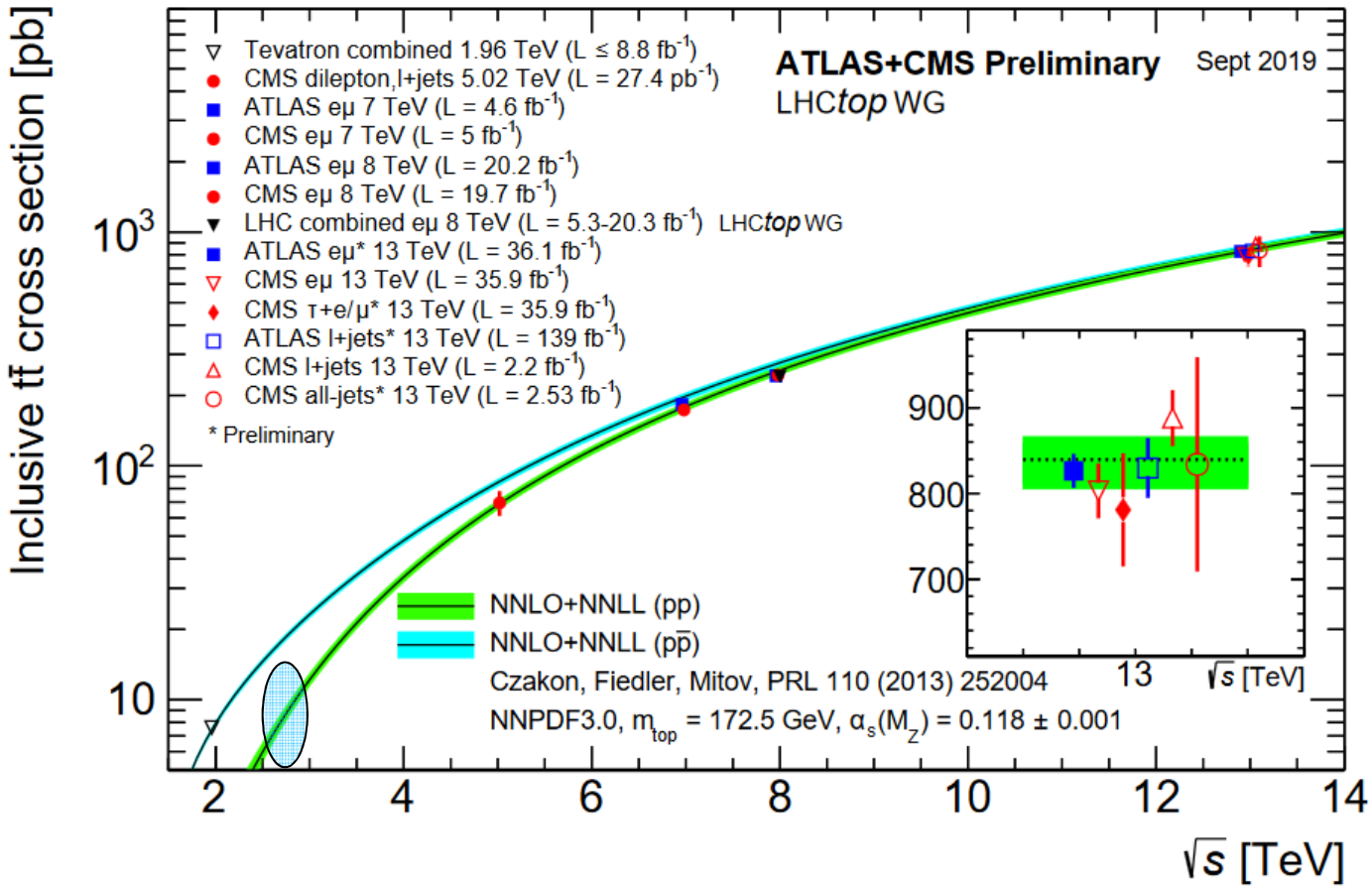
subject to person power availability, analysis can already be started on Run 2 (or even Run 1)

Backup

QCD teaser: measurements of total ttbar cross section

Measured at almost all available CMS energies (TOP PAG)

is there a corresponding official plot for Z?



produce the same

for charm and beauty (BPH, ongoing) and Z+c/Z+b (SMP) ?

(so far unmeasured at LHC; only strong extrapolations available)

7 TeV Run 1: why 2010 rather than 2011 ?

AN-18-284:

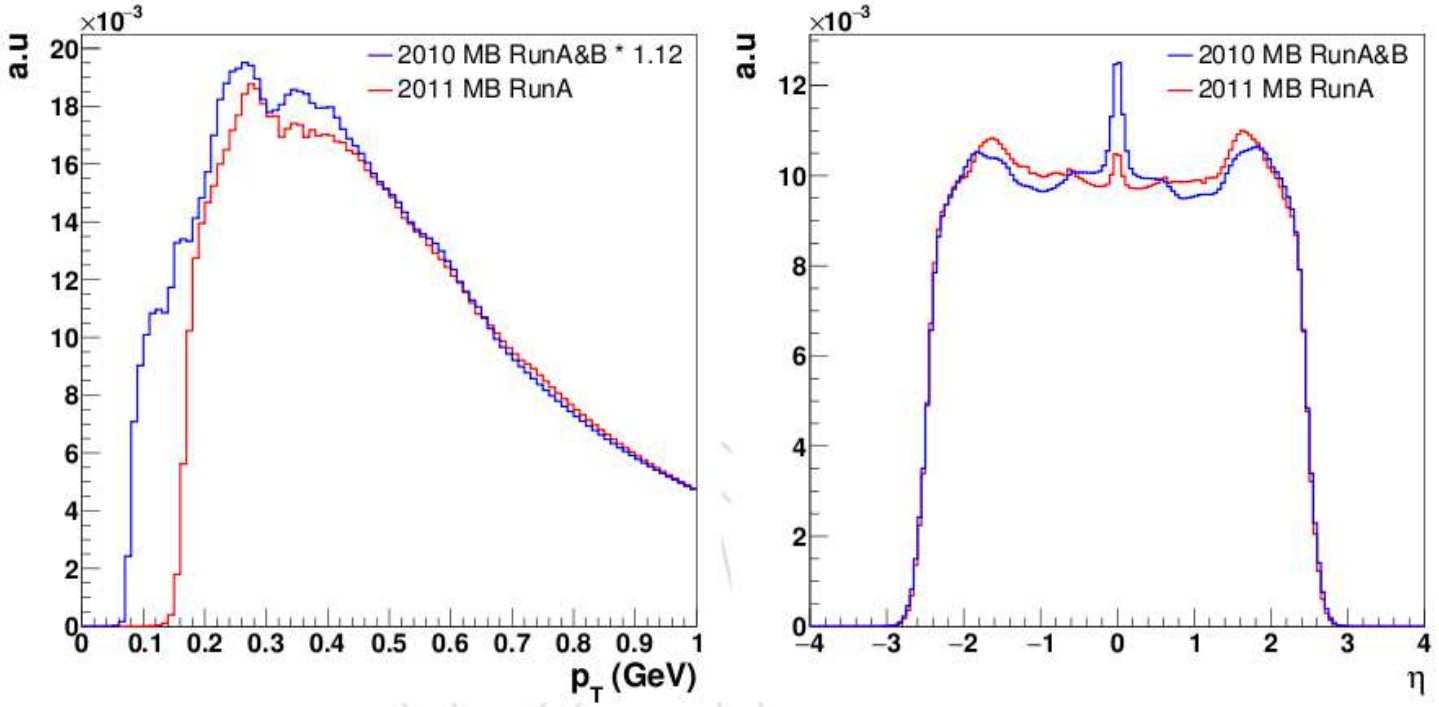


Figure 1: p_T and η distributions of MinimumBias tracks 2010 and 2011. The peak at $\eta = 0$ might be caused by low momentum loopers.

2011 has more statistics, but only 2010 allows decent access to very low p_T pions (< 200 MeV) needed for D* reconstruction in p_T ~ 1-3 GeV region (maximum of cross section)

MC available for 2010, no MC (yet) for 2011

13 TeV Run 2: why 2017/18 rather than 2015/16 ?

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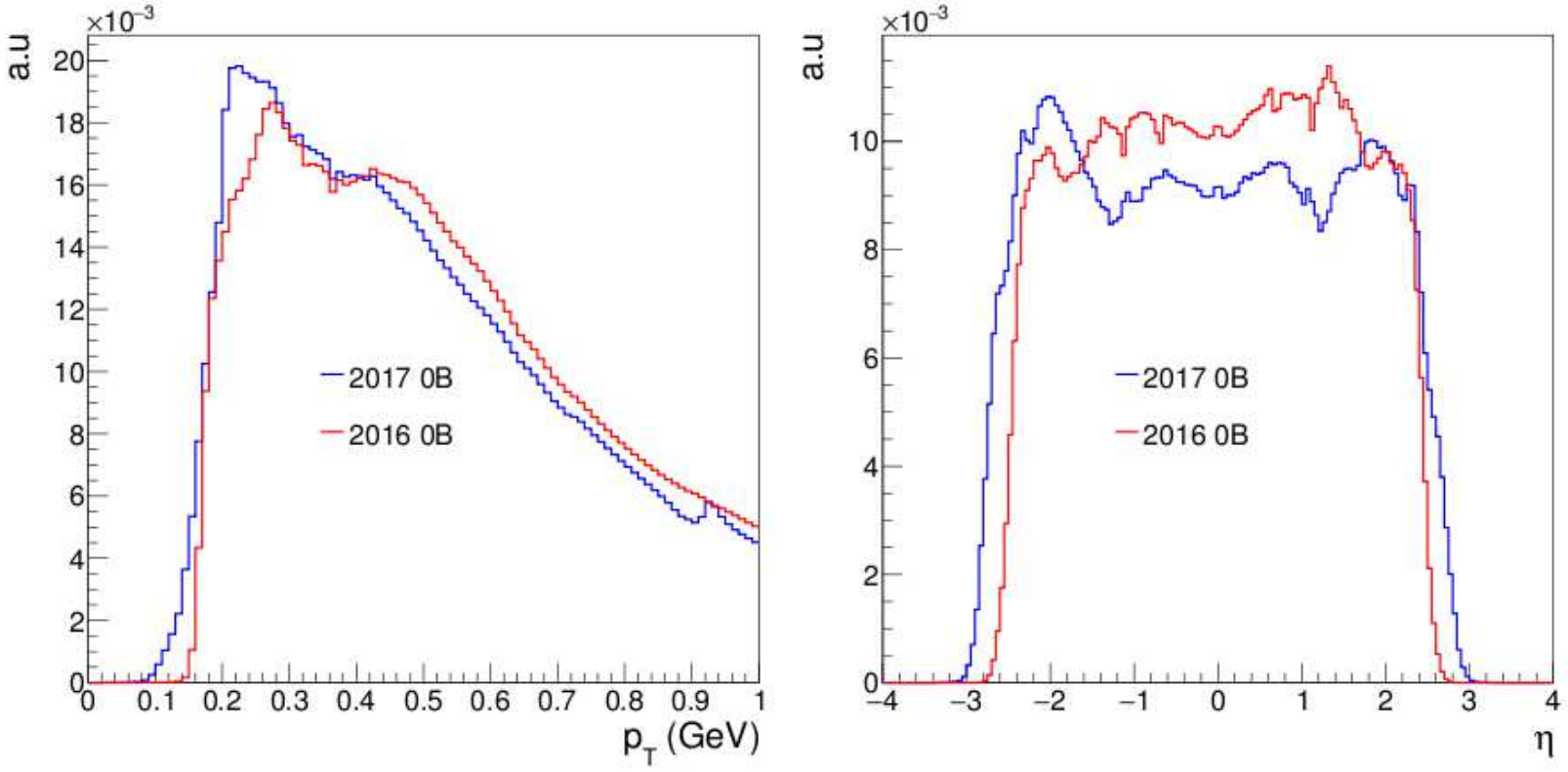


Figure 2: p_T and η distributions of ZeroBias tracks 2016 and 2017

-> 2017/18 better for low p_T D* measurement, better at large rapidities (new pixel detector), also more statistics:
From BParking (pileup) and 2017/18 Zerobias expect ~200 B pp collisions
(not today, BParking data crunching ongoing, Zerobias as soon as UL is completed)

-> fully complementary to ongoing almost completed 2016 data analysis (BPH-18-003)

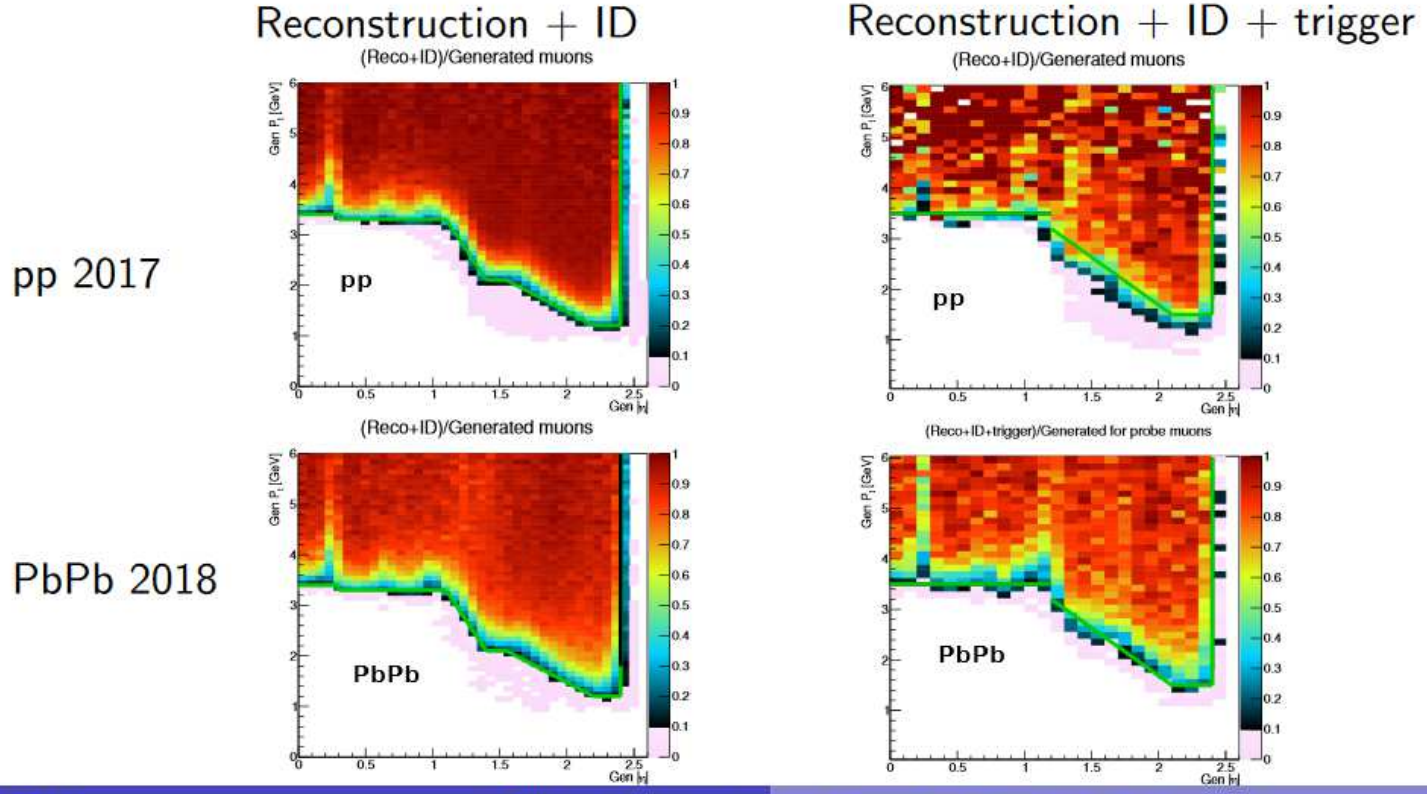
"Z" can be DY down to mass ~12 GeV -> $p_T(\mu)$ ~ 5 GeV

"stolen" from BPH presention G. Falmagne

Backup

2017-2018 data: new single muon acceptance cuts

- Single muon efficiency maps are obtained with $\frac{N_{reco}}{N_{gen}}$ for Reco+ID, and with a simplified tag-and-probe method for Reco+ID+trigger.
- Criterium for acceptance cuts: single muon efficiency $> 10\%$



27 / 24 Guillaume Falmagne B_c meson in pp and PbPb & J/ψ MC

CMS V+jet and V+b/c measurements

status at time of Lowx 17

	7 TeV	8 TeV	13 TeV
	CMS label, arXiv		
W+jet	SMP-12-023, 1406.7533 EWK-10-012, 1110.3226	SMP-14-023, 1610.04222	SMP-16-005 (PAS)
Z+jet	SMP-12-017, 1408.3104 EWK-10-012, 1110.3226	SMP-14-013, 1611.03844	SMP-15-010 (PAS)
W+c	SMP-12-002, 1310.1138		
Z+c		SMP-15-009 (PAS 07/2016)	
W+b	SMP-12-026, 1312.6608	SMP-14-020, 1608.07561	
Z+b	SMP-13-004, 1402.1581 EWK-11-015, 1310.1349 EWK-11-012, 1204.1643	SMP-14-010, 1611.06507	

CMS V+jet and V+b/c measurements

Update to current status (please correct if incomplete!)

	7 TeV	8 TeV	13 TeV
	CMS label, arXiv		
W+jet	SMP-12-023, 1406.7533 EWK-10-012, 1110.3226	SMP-14-023, 1610.04222	SMP-16-005, 1707.05979 SMP-17-011, 1711.02143
Z+jet	SMP-12-017, 1408.3104 EWK-10-012, 1110.3226	SMP-14-013, 1611.03844	SMP-15-010 (PAS) SMP-16-015, 1804.05252 SMP-19-009/010 (ongoing)
W+c	SMP-12-002, 1310.1138	SMP-18-013 (PAS)	SMP-17-014, 1811.10021
Z+c		SMP-15-009, 1711.02143	SMP-19-004, 2001.06899 SMP-19-011 (ongoing)
W+b	SMP-12-026, 1312.6608	SMP-14-020, 1608.07561	analysis in progress
Z+b	SMP-13-004, 1402.1581 EWK-11-015, 1310.1349 EWK-11-012, 1204.1643	SMP-14-010, 1611.06507	SMP-19-004, 2001.06899 + analysis in progress