Measurement of B mesons production at 13TeV with CMS

Students
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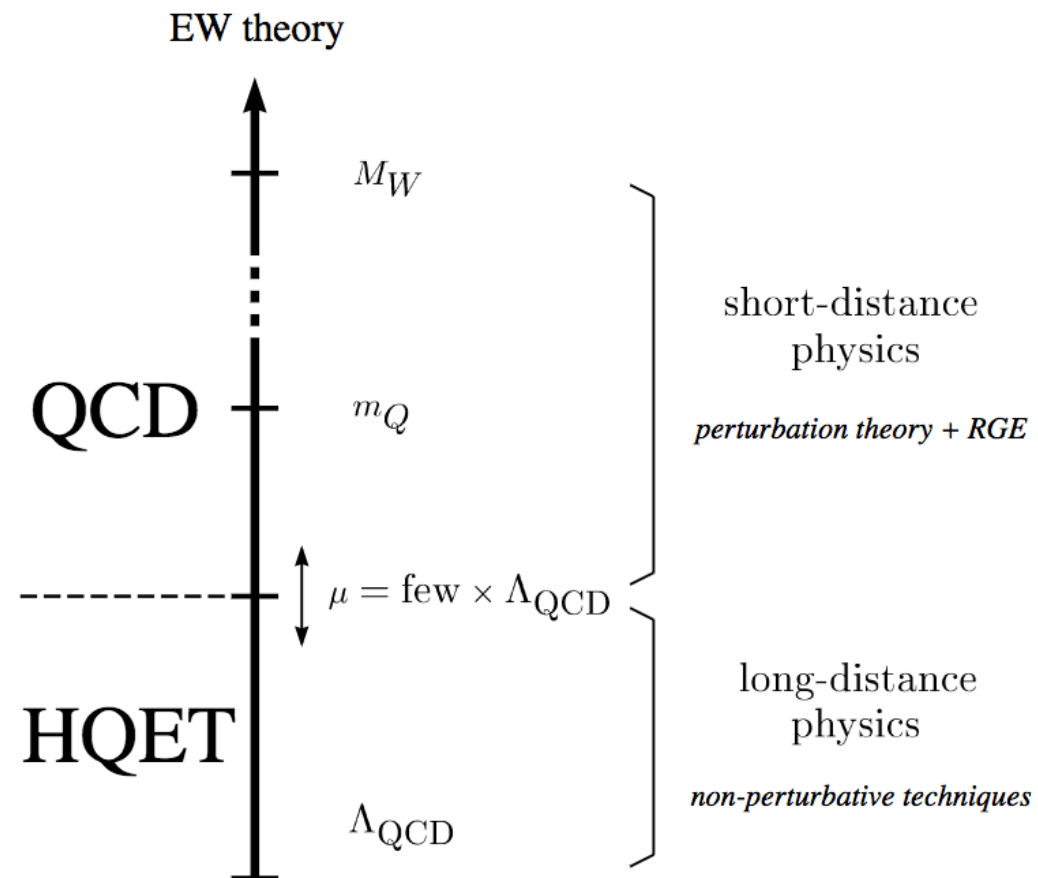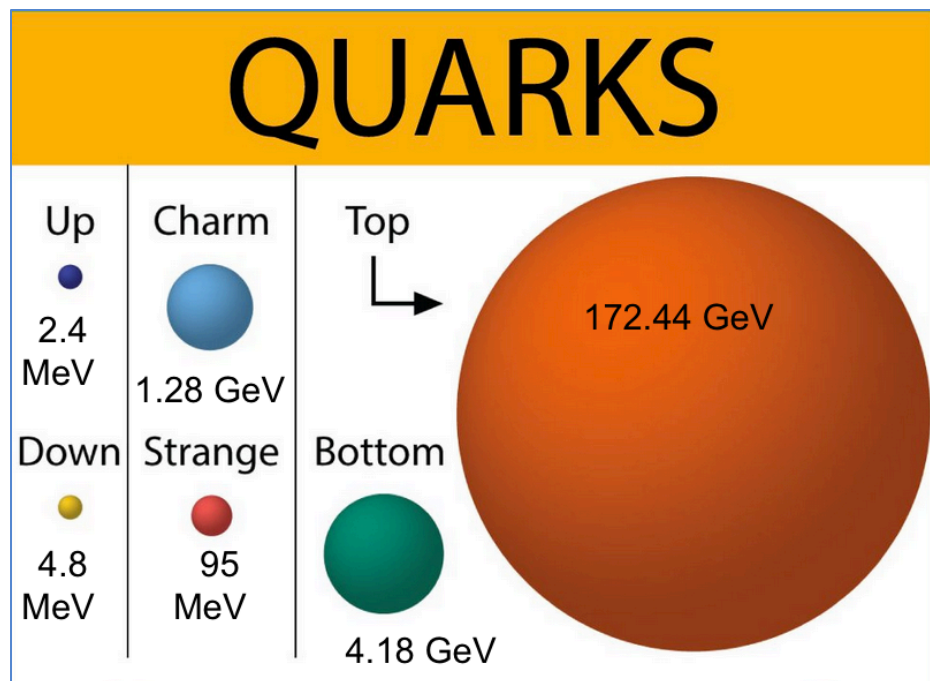**Bruno Alves** - IST, University of Lisbon

Supervisor
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Why study b production ?

- Understand Strong Force (QCD)
- Heavy Quark Effective Theory (HQET) range
- Heaviest Hadrons (recall top has very short lifetime, decays before it can hadronize)
- Reference baseline for rare decay searches

B decays

- $B^+ \rightarrow J/\psi \ K^+$ *(reference channel)*
- $B_s \rightarrow J/\psi \ \Phi$
- $B^0 \rightarrow J/\psi \ K^{*0} (\rightarrow K^{+/-} \pi^{-/+})$
- $B_c \rightarrow J/\psi \ \pi^+$

- Bc is the haviest meson with different quark flavors, b and c
- Heavier, shorter-lived, still poorly measured
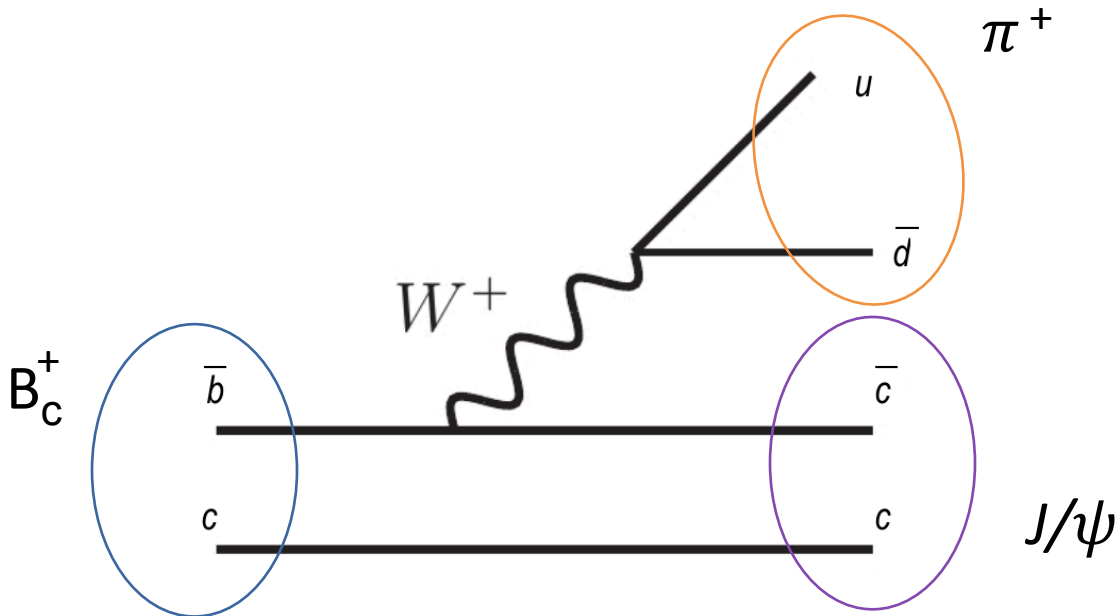
Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update

BOTTOM, CHARMED MESONS ($B = C = \pm 1$)

$B_c^+ = c\bar{b}, \ B_c^- = \bar{c}b, \quad$ similarly for B_c^*'s

B_c^+

$I(J^P) = 0(0^-)$
I, J, P need confirmation.
Quantum numbers shown are quark-model predictions.

Mass $m = 6274.9 \pm 0.8$ MeV
Mean life $\tau = (0.507 \pm 0.009) \times 10^{-12}$ s

B_c^- modes are charge conjugates of the modes below.

The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times B(\bar{b} \rightarrow B_c)$.

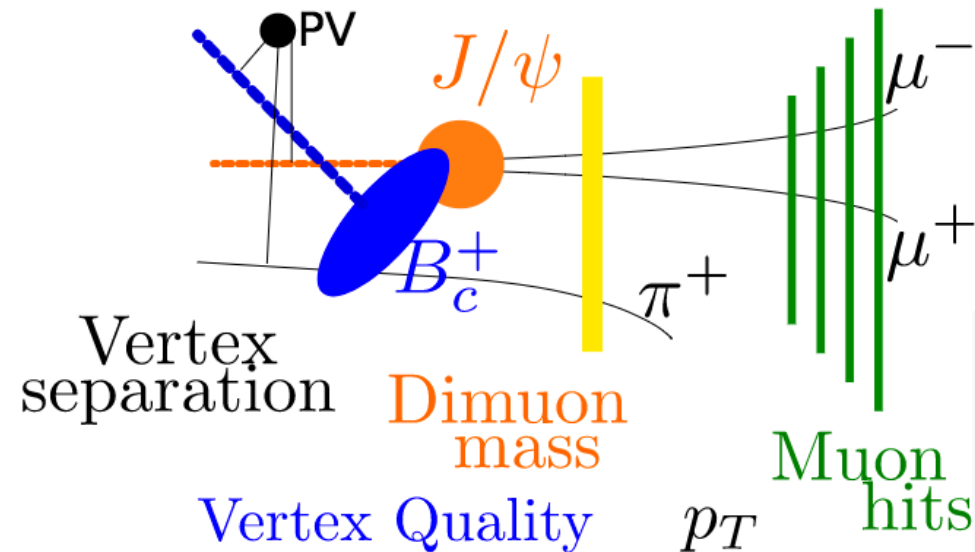| B_c^+ DECAY MODES $\times$ B($\bar{b} \rightarrow B_c$)	Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$J/\psi(1S)\ell^+\nu_\ell$ anything	$(5.2 \ ^{+2.4}_{-2.1}) \times 10^{-5}$			–
$J/\psi(1S)\pi^+$	seen			2371
$J/\psi(1S)K^+$	seen			2341
$J/\psi(1S)\pi^+\pi^+\pi^-$	seen			2350
$J/\psi(1S)a_1(1260)$	< 1.2	$\times 10^{-3}$	90%	2169
$J/\psi(1S)K^+K^-\pi^+$	seen			2203
$J/\psi(1S)\pi^+\pi^+\pi^+\pi^-\pi^-$	seen			2309
$\psi(2S)\pi^+$	seen			2052
$J/\psi(1S)D_s^+$	seen			1822

CMS Detector

General purpose detector at the LHC
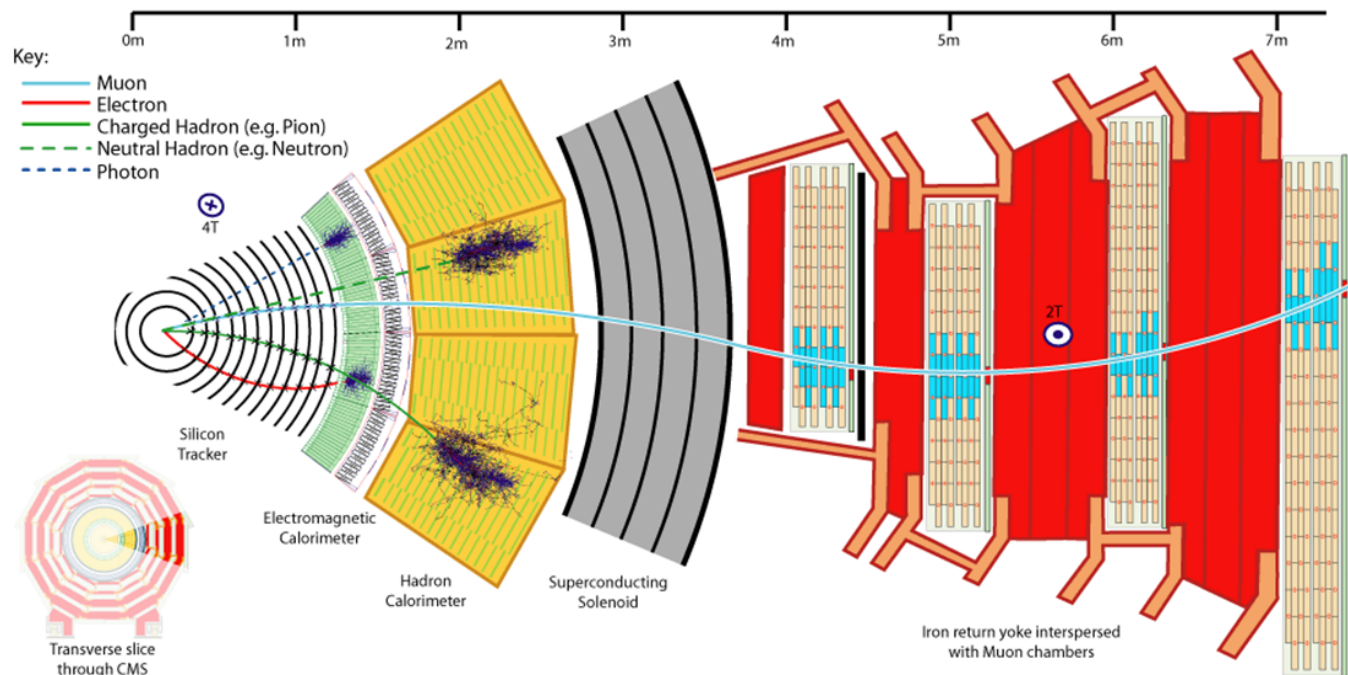
Most critical subdetectors for our analyses:
muon chambers (outer) and silicon detectors (inner)
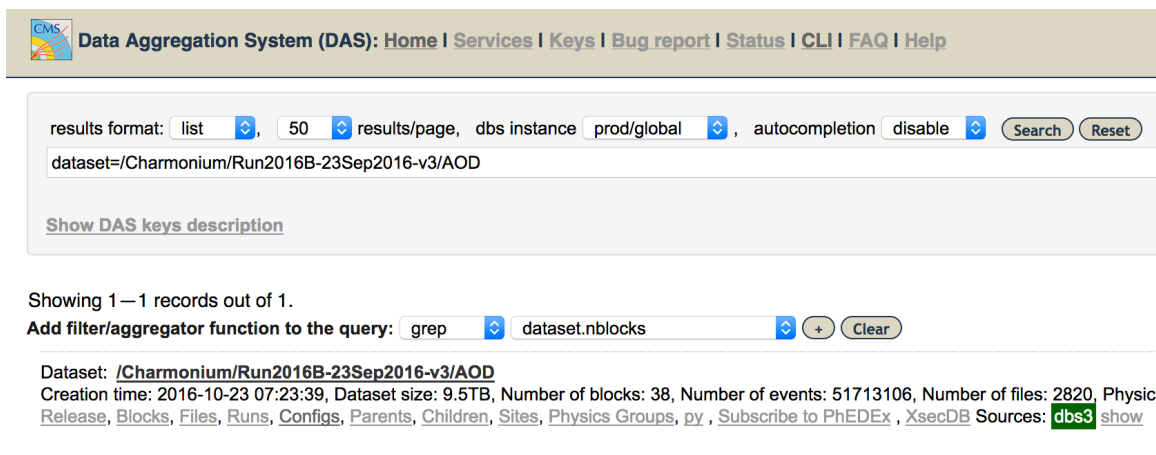
Elements of B reconstruction

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Data Processing

CMS and Datasets

Trigger: dedicated algorithm for Online selection

- Two muons from J/ψ decay
- Track from some vertex
- Decay vertex displacement

(HLT_DoubleMu4_JpsiTrk_Displaced)

pp collisions at 13TeV collected by CMS in 2016
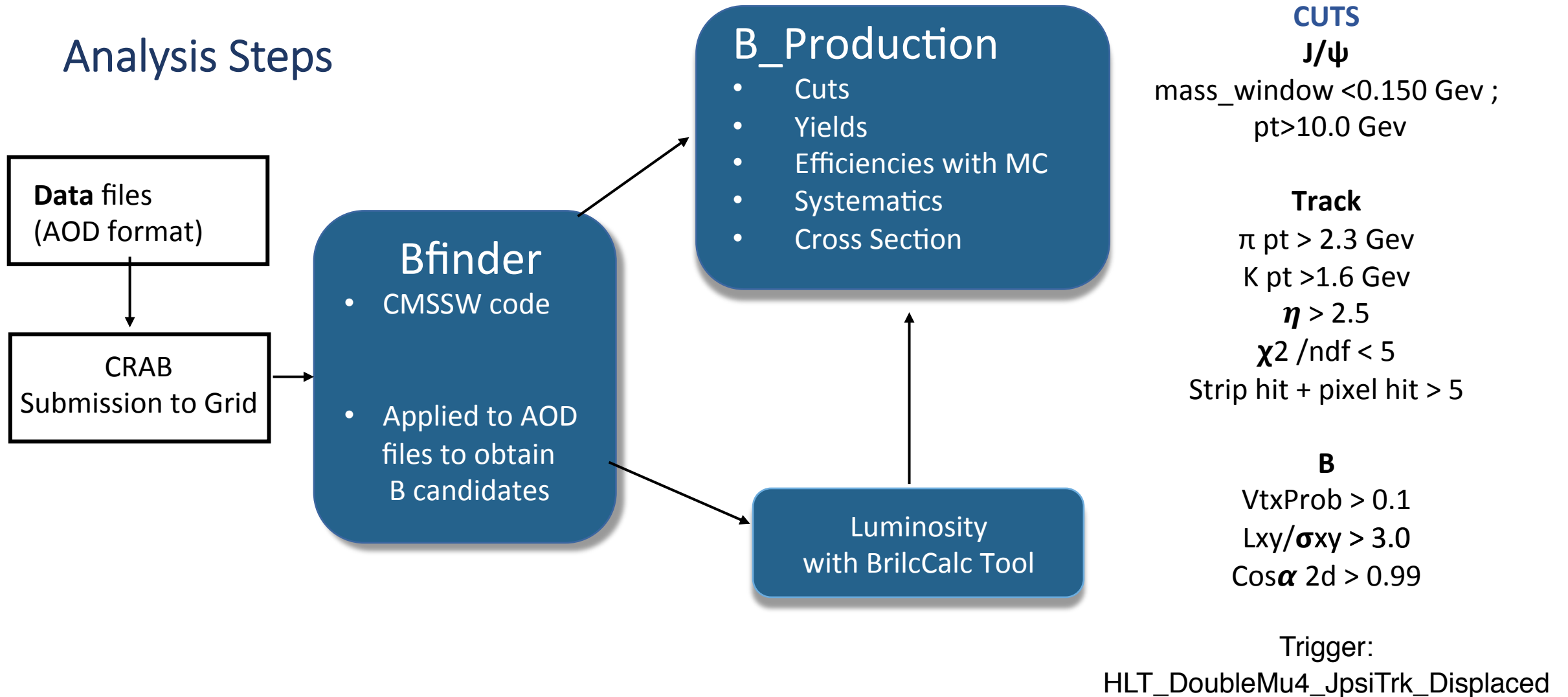
(23Sep2016 re-reco AOD)

Data processed:

Bc: Runs B, C, D ,E, F, G

B+,Bs,B0: Runs C, D, E, F, G(~81%)

CMSSW, CRAB/Grid, DAS, Bfinder, RooFit, etc

Analysis Steps

Data files
(AOD format)

↓

CRAB
Submission to Grid

→

Bfinder
- CMSSW code

- Applied to AOD files to obtain B candidates

B_Production
- Cuts
- Yields
- Efficiencies with MC
- Systematics
- Cross Section

Luminosity
with BrilcCalc Tool

CUTS

J/ψ
mass_window <0.150 Gev ;
pt>10.0 Gev

Track
π pt > 2.3 Gev
K pt >1.6 Gev
η > 2.5
$\chi 2$ /ndf < 5
Strip hit + pixel hit > 5

B
VtxProb > 0.1
Lxy/σxy > 3.0
Cosα 2d > 0.99

Trigger:
HLT_DoubleMu4_JpsiTrk_Displaced

Analysis

Mass fits (B$^+\to$ J/ψ K$^+$)

• Extendend unbinned maximum likelihood method (using RooFit)

Signal model:
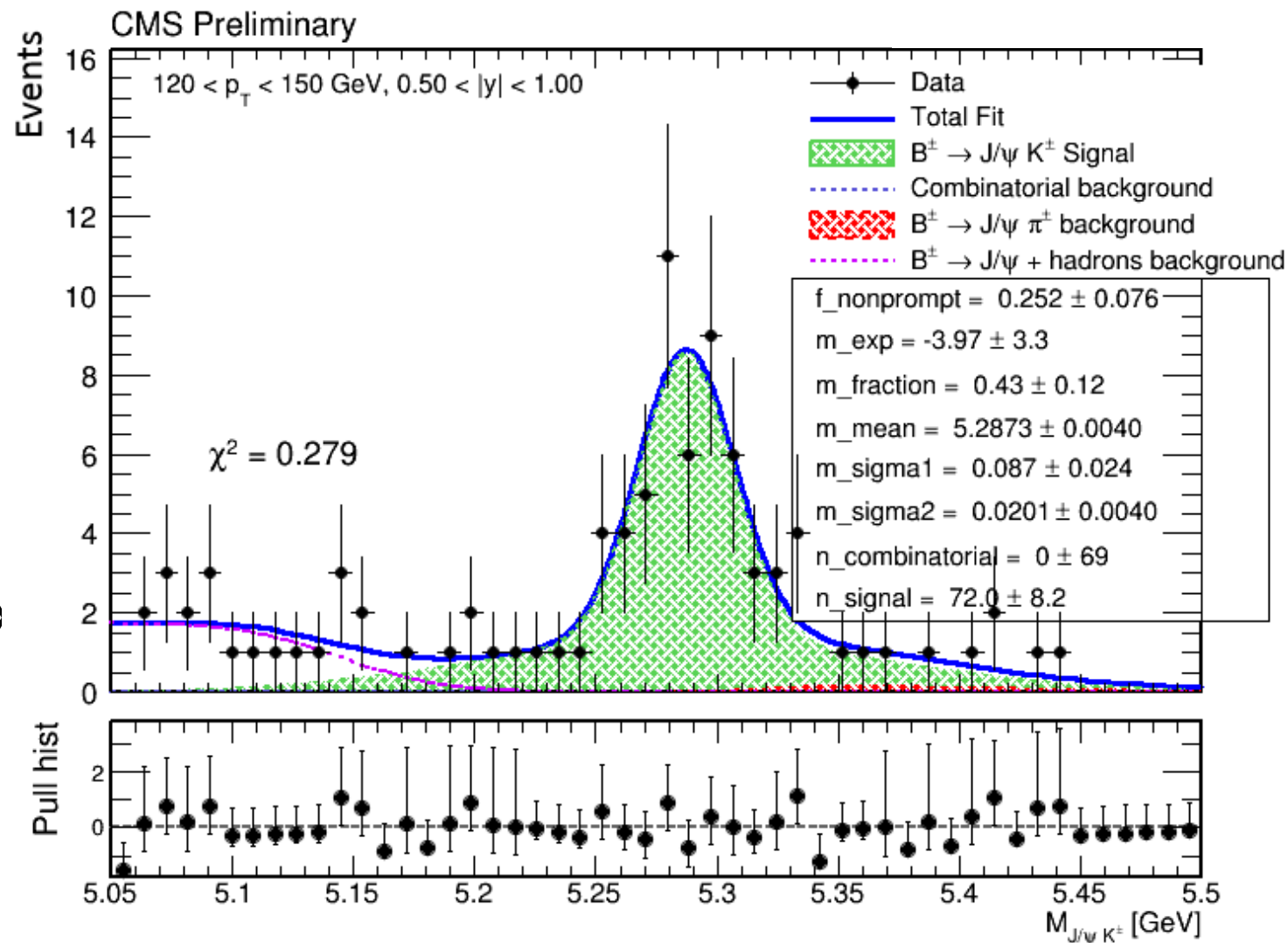   sum of two Gaussians
•Backgrounds
   Combinatorial: exponential
•. Physics backgrounds
   - partially reco'd decays (B$\to$ J/ψ)
   described by an error function
   - Cabibbo suppressed decay
•B+$\to$ J/ψ π+: sum of three Gaussians
•PDG Mass: 5279.31±0.15 MeV

CMS Preliminary

$120 < p_T < 150$ GeV, $0.50 < |y| < 1.00$

$\chi^2 = 0.279$

Data
Total Fit
B$^\pm\to$ J/ψ K$^\pm$ Signal
Combinatorial background
B$^\pm\to$ J/ψ $\pi^\pm$ background
B$^\pm\to$ J/ψ + hadrons background

f_nonprompt = 0.252 ± 0.076
m_exp = -3.97 ± 3.3
m_fraction = 0.43 ± 0.12
m_mean = 5.2873 ± 0.0040
m_sigma1 = 0.087 ± 0.024
m_sigma2 = 0.0201 ± 0.0040
n_combinatorial = 0 ± 69
n_signal = 72.0 ± 8.2
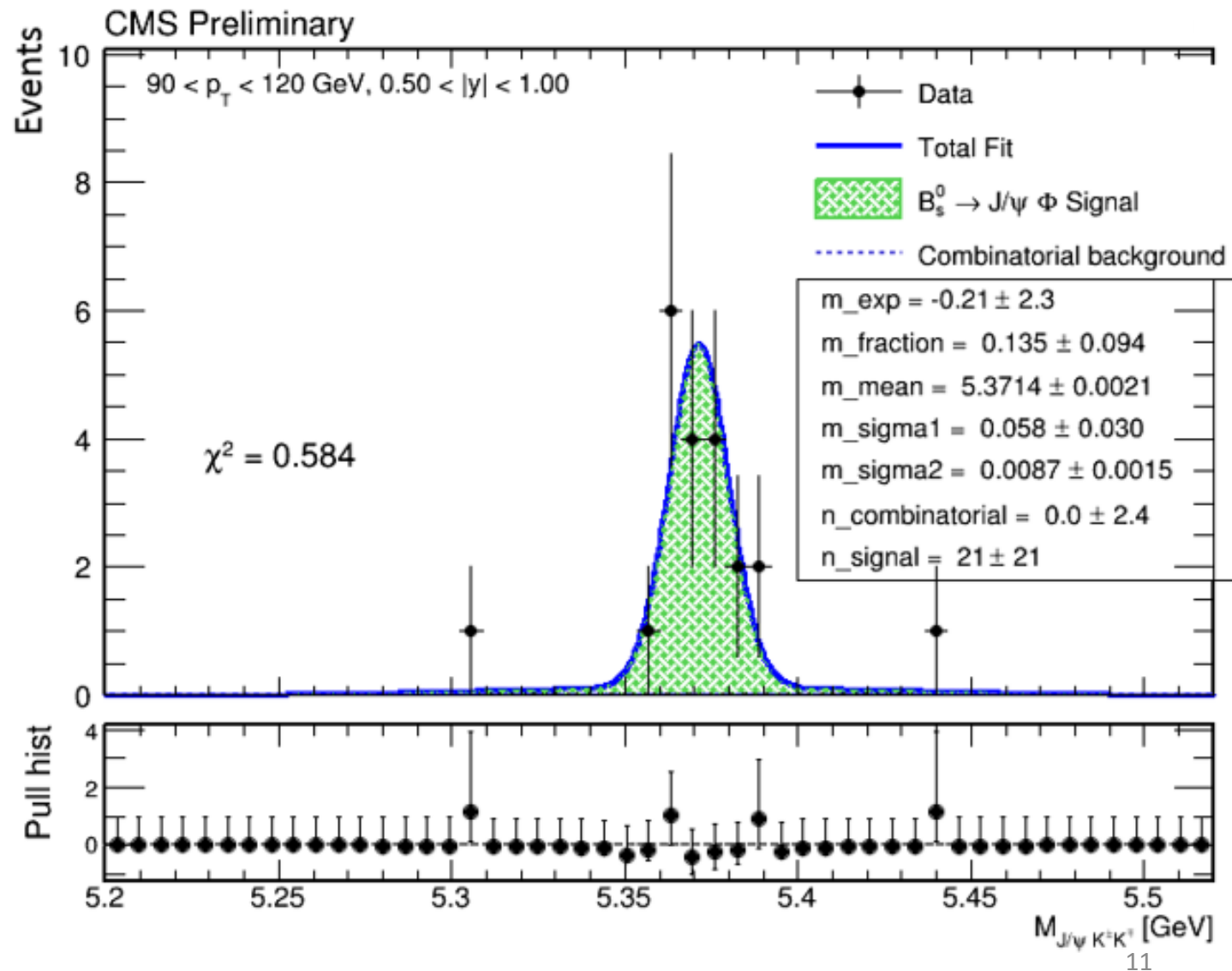
$M_{J/\psi\ K^\pm}$ [GeV]

Mass fits ($B^0 \rightarrow J/\psi\ K^{*0}\ (\rightarrow K^{+/-}\ \pi^{-/+})$)

- Signal:
  2 Gaussians
  "KPi Swap" (misreconstructed tracks)

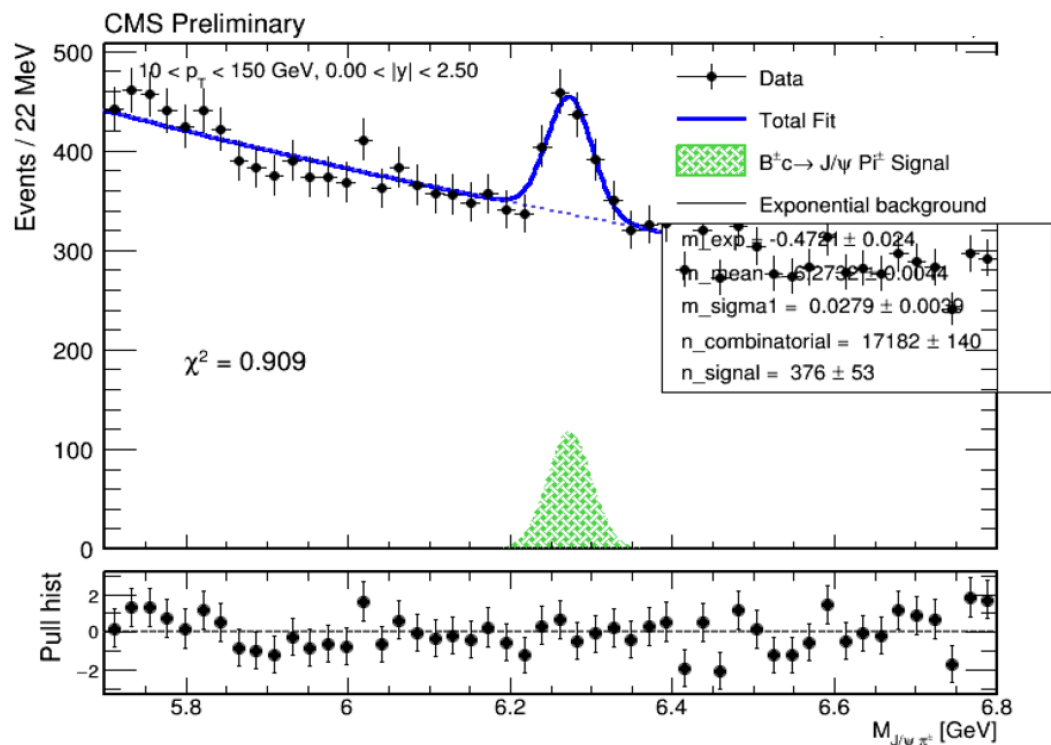- Combinatorial background:
  exponential

- PDG Mass: 5279.62±0.15 MeV
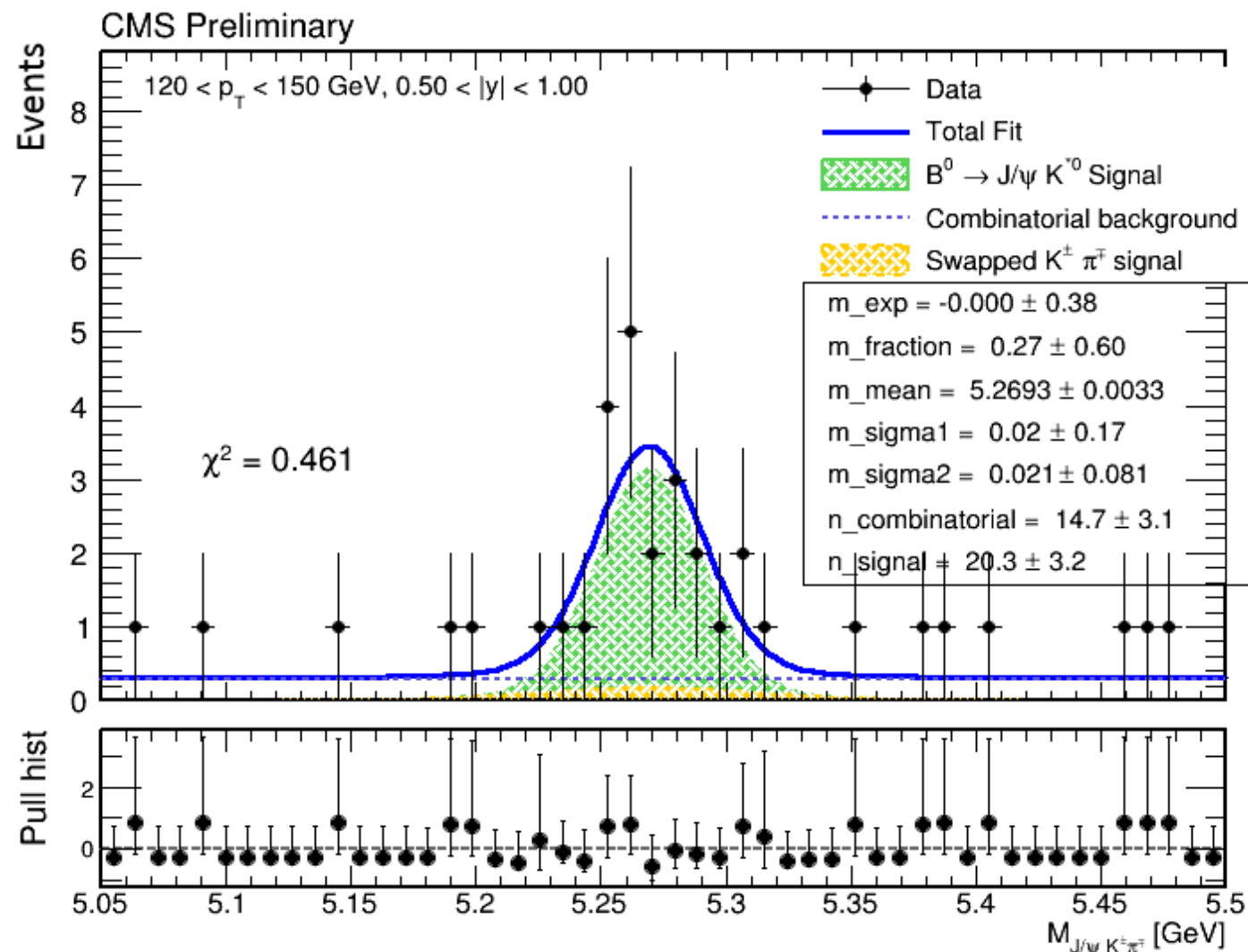
Mass fits (B$_s \rightarrow$ J/ψ Φ)

- Signal:
  2 Gaussians

- Combinatorial background:
  exponential

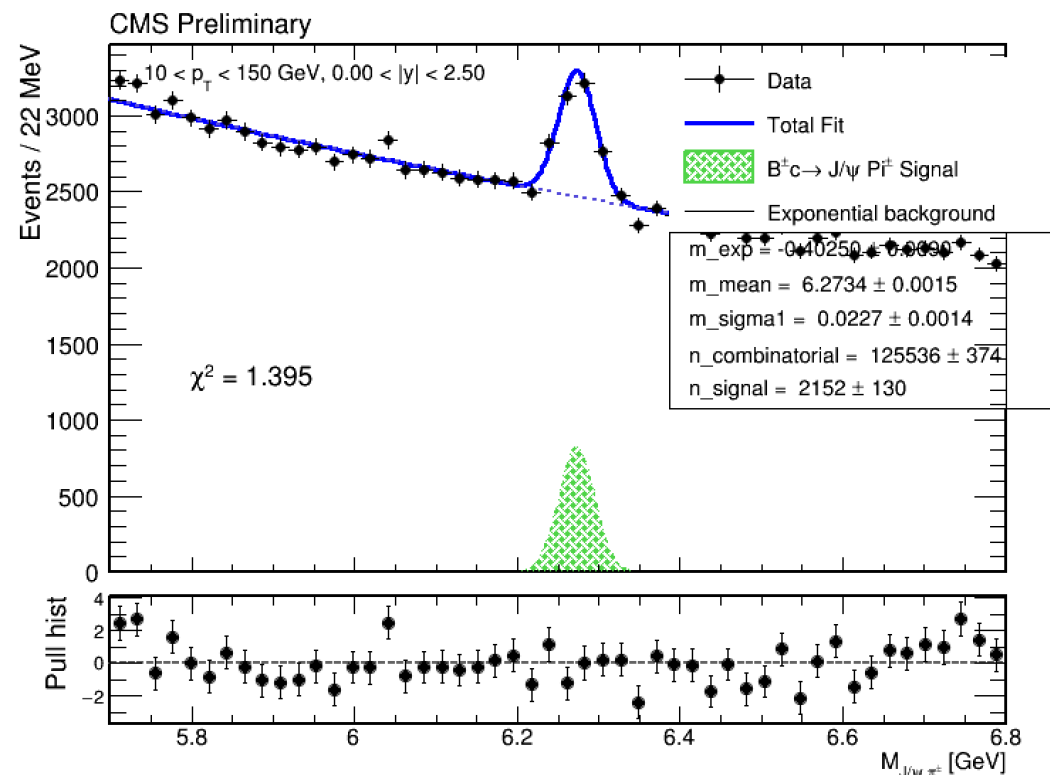- PDG Mass: 5366.82±0.22 MeV

Mass fits ($B_c^+ \to J/\psi \; \pi +$)

2015 13 TeV data

2016 13 TeV data

- Signal: • Combinatorial background:
  1 Gaussians   exponential

PDGMass: 62749±08 MeV

Increased ~10 times the signal yield wrt 2015

Results

Cross-section

Signal yield (from fit to data)

$$\sigma = \frac{N/\varepsilon}{A\,L}$$

Luminosity of our Dataset

$$\mathcal{B}_{J/\psi \to \mu^+\mu^-} \equiv \frac{N_{J/\psi \to \mu^+\mu^-}}{N_{J/\psi \to X}}$$

Selection Efficiency
(obtained from
MC simulation)

Acceptance of the detector
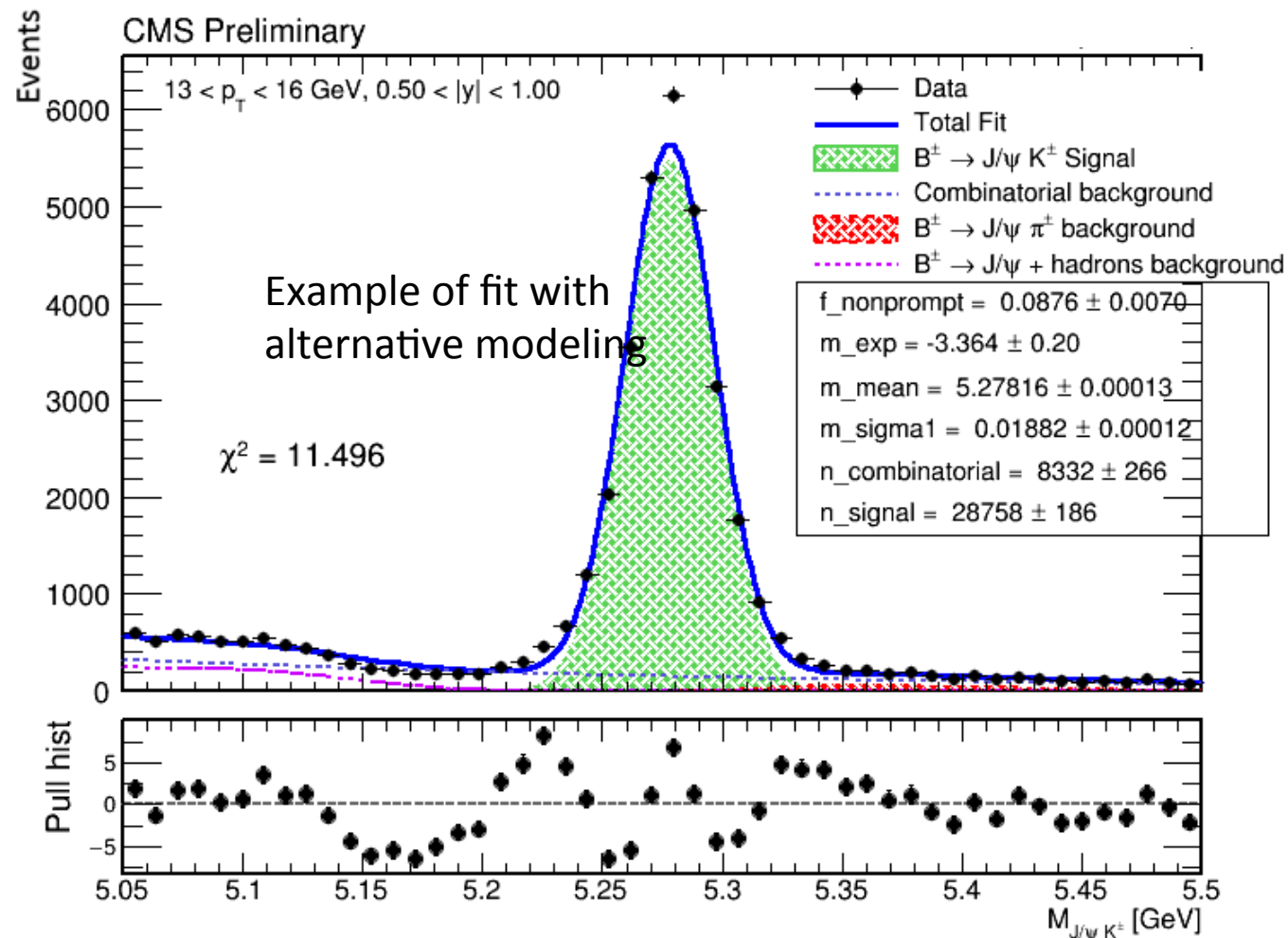
$$\frac{d\sigma(pp \to B_x X)}{dp_T^B} = \frac{n_{sig}(p_T^B)}{2\,A(p_T^B)\,\epsilon(p_T^B)\,\mathcal{B}\,\mathcal{L}\,\Delta p_T^B}$$

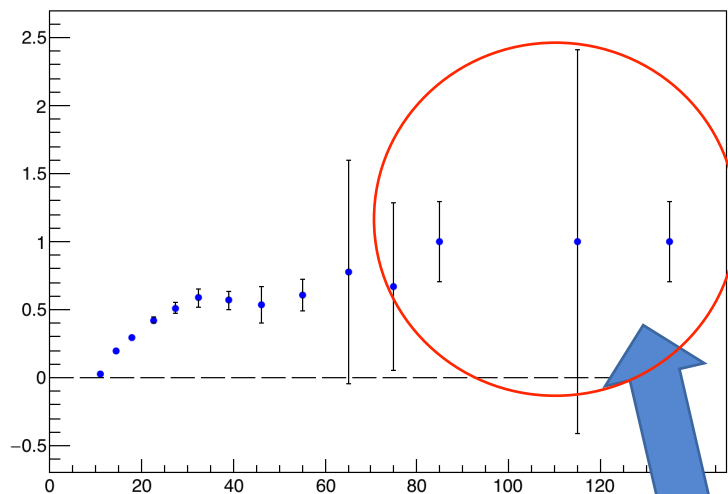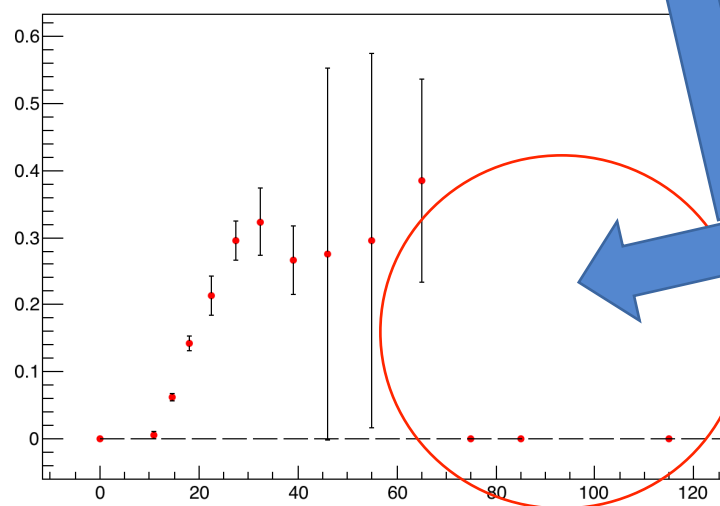$$\frac{d\sigma(pp \to B_x X)}{dy^B} = \frac{n_{sig}(|y^B|)}{2\,A(|y^B|)\,\epsilon(|y^B|)\,\mathcal{B}\,\mathcal{L}\,\Delta y^B}$$

Systematics

- Mass fits
  - Different fit models
  - Change mass window
- Luminosity (2.5%)
- Branching fractions (taken from PDG)
- Finite size of the simulated samples (efficiency)
- Charged particles reconstruction efficiency (3.9% per track)

Example of fit with alternative modeling

Efficiencies

Efficiency B+

Monte Carlo samples generated, simulating signal events

$$\mathcal{E}=\#MCCutAnalysis/\#MCTotal$$

Efficiency Bs

Differential measurements require larger MC samples For populating high pT region

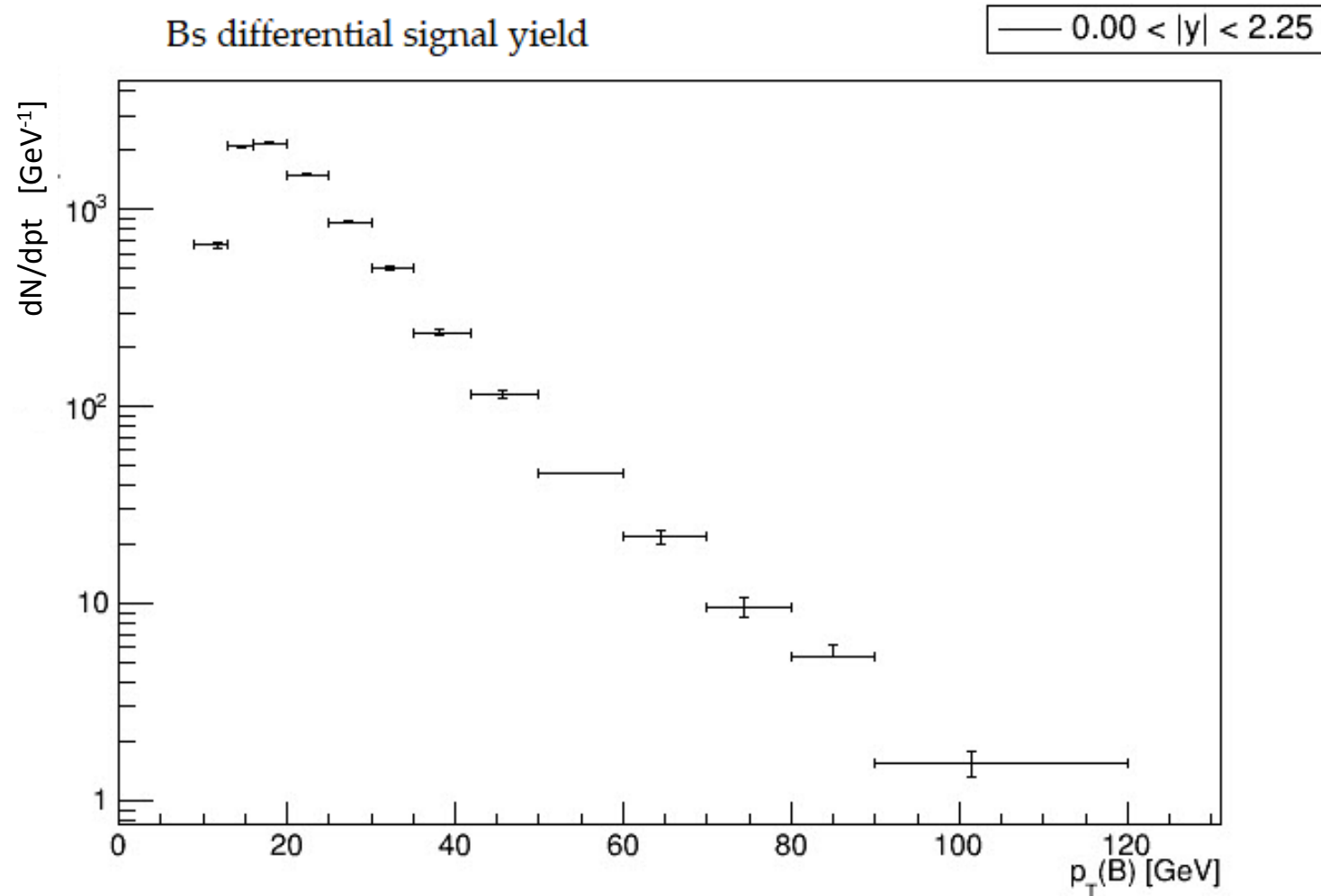**Signal efficiency obtained from fit to signal MC with and without selection applied**
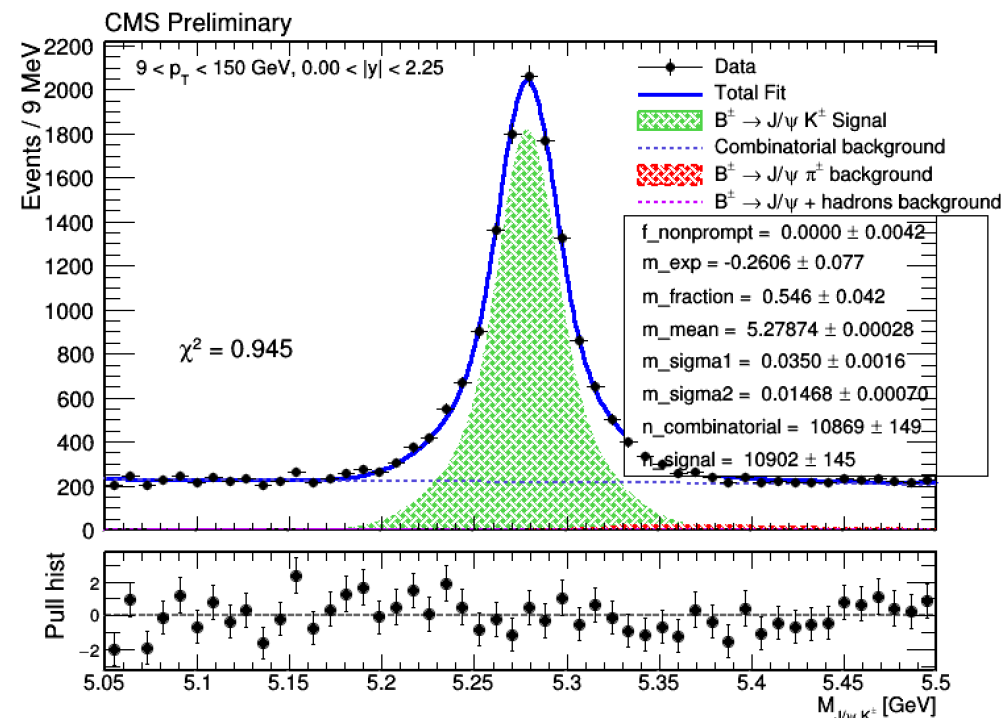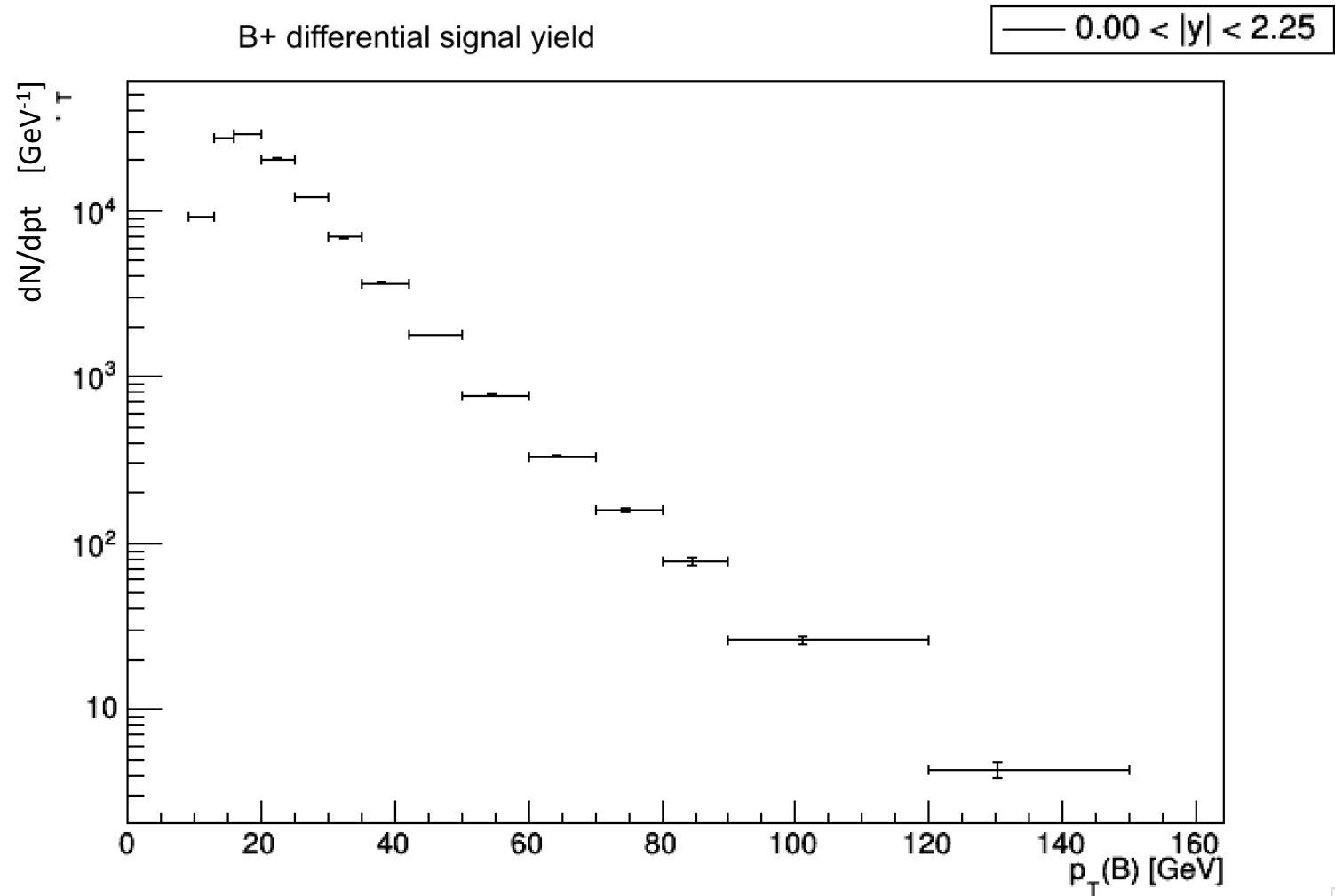

Totatal efficiency

B⁺ Eff. 18,63%   rel err 2,5%

Bₛ. Eff. 8,63%   rel err 3,6%

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Differential yield B$_s$

Differential yield B$^+$

Summary

- Carried out preliminary measurements of b hadron cross sections
  - first B production results with 2016 data at CMS
- Executed all analysis steps
  - from initial data (and MC) processing to final physics measurement
- Collected Run2 data allow data allows to reach above 100GeV for the ligher B mesons (B^+, B^0, B_s)
- First studies of B_c meson at CMS in Run2

Future work

- Selection optimization for B_c (MVA)
- Refine efficiency evaluation (using gen-level info)
- Produce MC samples for B_c and B^0 and increase production for B^+ and B_s
- Finalize systematics

Bored?
Don't forget the questions!

And the many, many, many presentations still to come...