

# Intrinsic Charm at LHCb

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on behalf of the LHCb Collaboration



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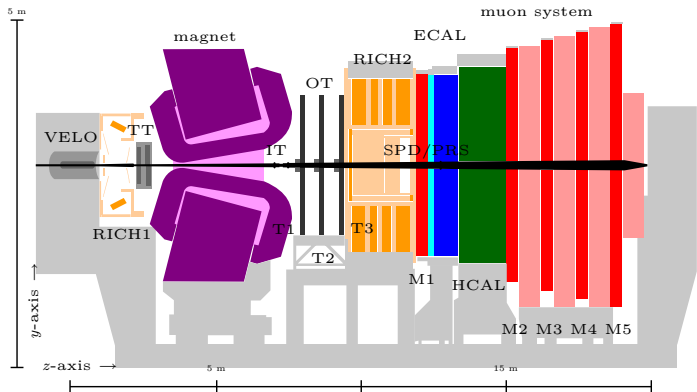
7TH WORKSHOP OF THE APS TOPICAL GROUP ON  
HADRONIC PHYSICS

# Overview

- detector overview
- intrinsic charm with  $Z + c$
- intrinsic charm using the **S**ystem for **M**easuring the **O**verlap with **G**as (SMOG)
- $J/\psi$  production in jets

## Detector

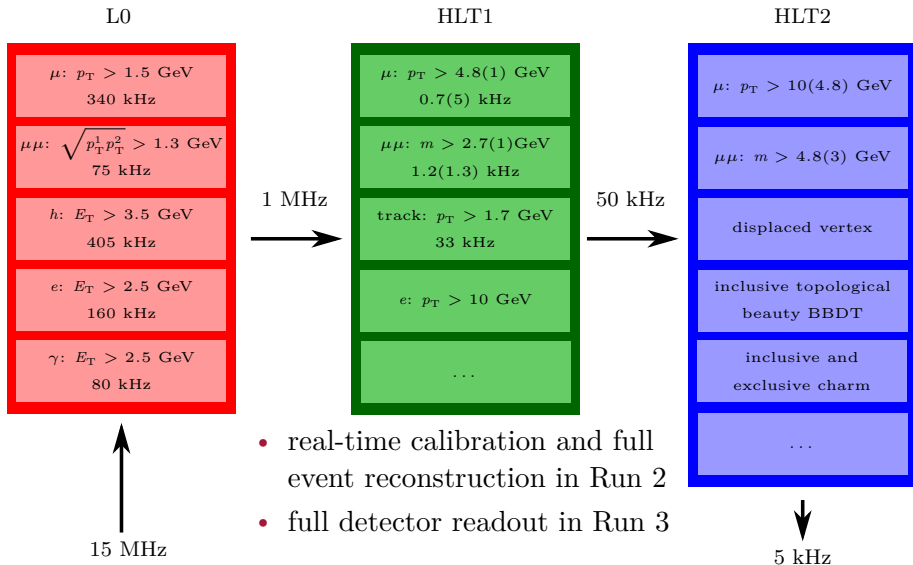
JINST 3 (2008) S08005



- fully instrumented between  $2 < \eta < 5$
- momentum resolution between 0.5% at 5 GeV to 1% at 200 GeV
- impact parameter resolution of 13 – 20  $\mu\text{m}$  for tracks
- secondary vertex precision of 0.01 – 0.05(0.1 – 0.3) mm in  $xy(z)$

## Trigger

JINST 8 (2013) P04022



- projected luminosity per run

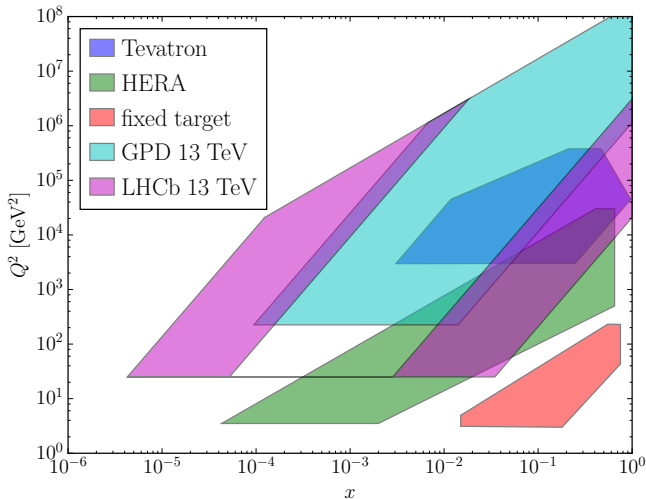
LHC era				HL-LHC era	
Run 1(a) 2011	Run 1(b) 2012	Run 2 2015 - 2019	Run 3 2021 - 2023	Run 4 2027 - 2029	Run 5 2031 - ?
1 fb <sup>-1</sup>	2 fb <sup>-1</sup>	5 fb <sup>-1</sup>	15 fb <sup>-1</sup>	23 fb <sup>-1</sup>	54 fb <sup>-1</sup>

- LHCb upgrade during LS 2
  - LHCb-PUB-2014-040**
  - replacement of readouts and photo-detectors for the RICHs
  - replacement of tracking detectors
  - full software trigger**, see **LHCb-TDR-016**
    - currently limited by hardware readout at 1 MHz
    - upgrade will read out entire detector at 40 MHz

# Intrinsic Charm with $Z + c$

Bjorken- $x$  Coverage

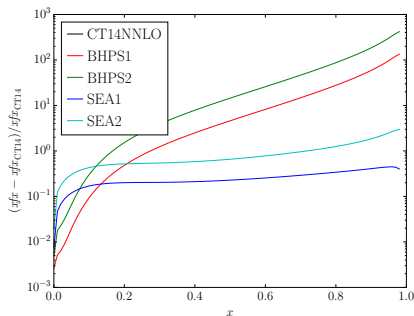
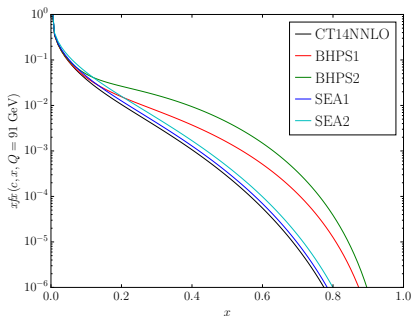
- parton distribution function (PDF) parameter space in  $Q^2$  and  $x$



## Intrinsic Charm PDFs

Phys. Rev. D **93**, no. 3,  
033006 (2016)

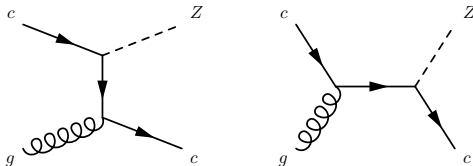
- consider two models from CT14
  - BHPS: valence-like via the light-cone picture of nucleon structure
  - SEA: sea-like assuming  $IC \propto [\bar{u}(x, Q_0) + \bar{d}(x, Q_0)]$  for  $Q_0 < m_c$
- two normalization points,  $\langle x \rangle_{IC} \equiv \int_0^1 x IC(x, m_c) dx$ 
  - 1:  $\langle x \rangle_{IC} = 0.6\%$
  - 2:  $\langle x \rangle_{IC} \approx 2\%$  (maximally allowed from global fit)



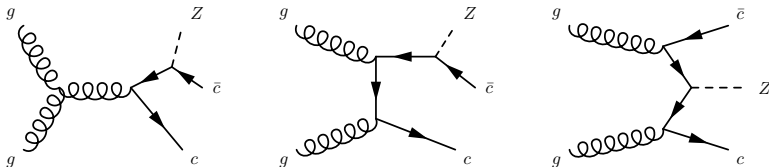


# Z Production with Charm

- measure ratio of  $Z + c$ -jet to  $Z$ +jet

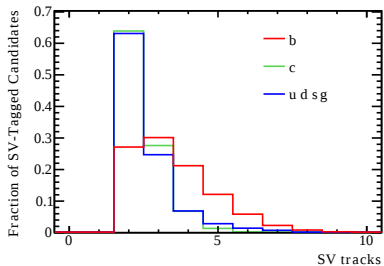
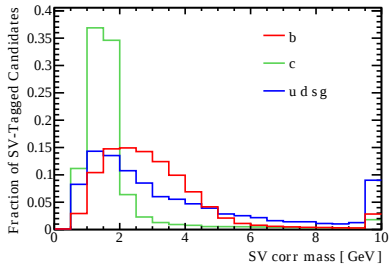
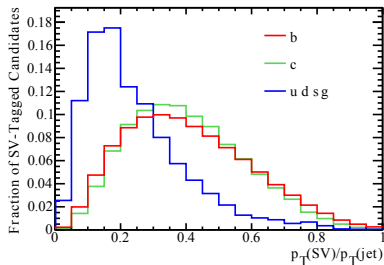


- not all  $Z + c$ -jet final states from intrinsic charm

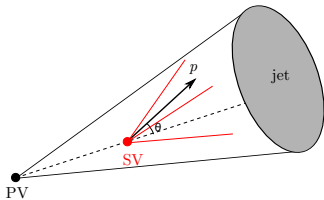


## Jet Tagging

JINST 10 (2015) P06013

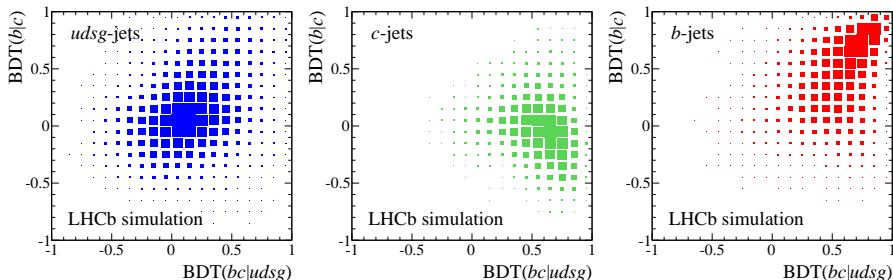


$$M_{\text{cor}} = \sqrt{M^2 + p^2 \sin^2 \theta + p \sin \theta}$$



## BDT Separation

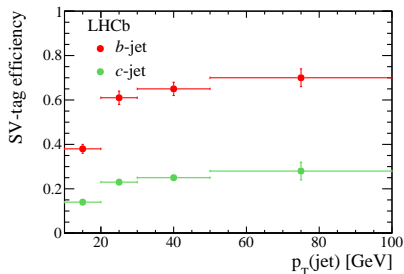
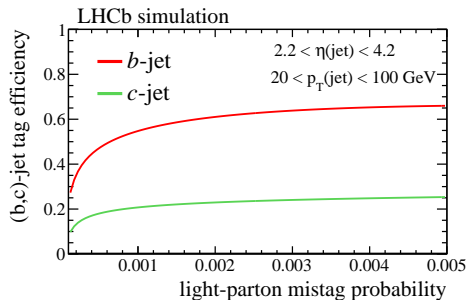
JINST 10 (2015) P06013



- $\text{BDT}(bc|udsg)$ :  $c$  and  $b$  as signal,  $udsg$  as background
- $\text{BDT}(b|c)$ :  $b$  as signal  $c$  as background
- fit 2-dimensional  $\text{BDT}(bc|udsg)$  versus  $\text{BDT}(b|c)$  distribution

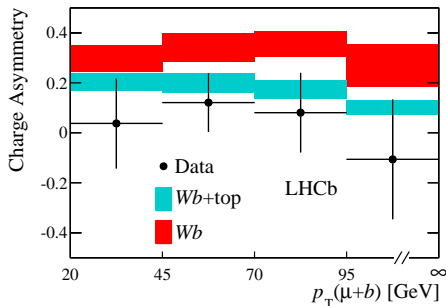
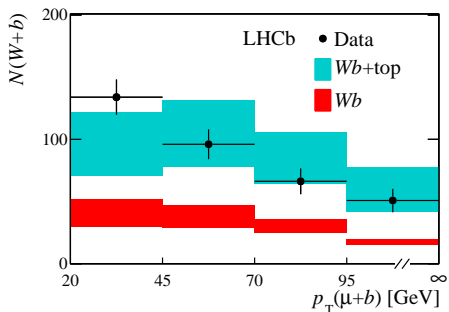
## Efficiencies

JINST 10 (2015) P06013



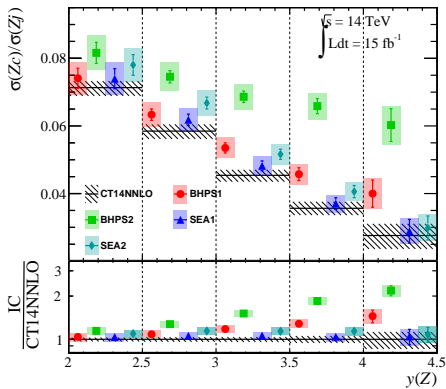
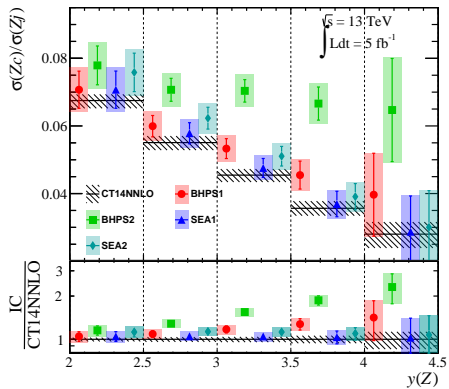
# Charm-Tagging Measurements

- JINST **10** (2015) P06013: validation of performance
- Phys. Rev. D **92** (2015):  $W + c$  and  $W + b$  measurement
- Phys. Rev. Lett. **115** (2015): first forward top measurement
- arXiv:1610.08142:  $t\bar{t}$  and  $W + Q\bar{Q}$



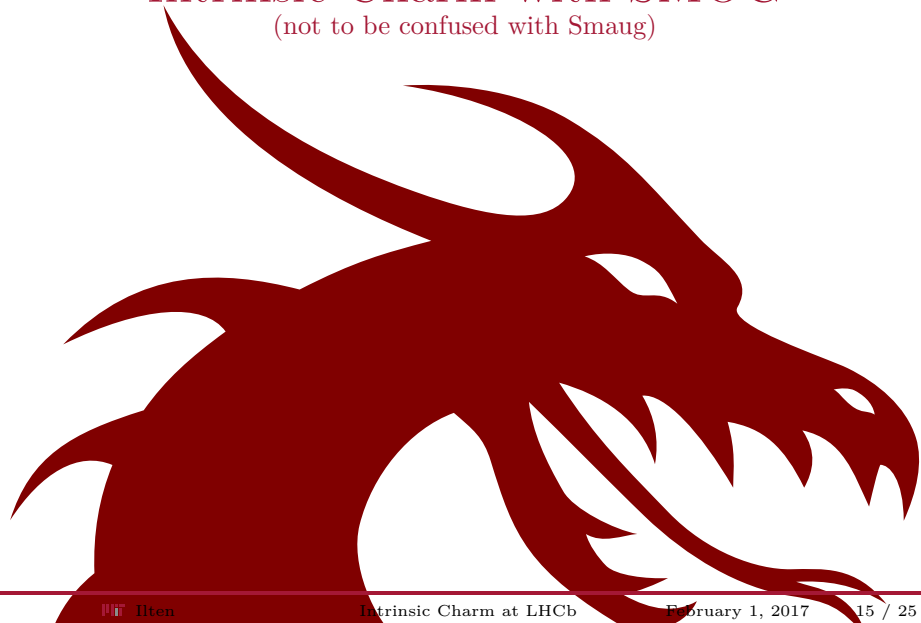
# Expected Sensitivity

Phys. Rev. D **93**, no. 7,  
074008 (2016)



# Intrinsic Charm with SMOG

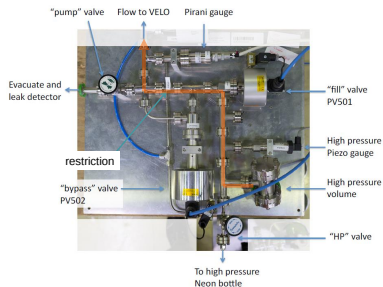
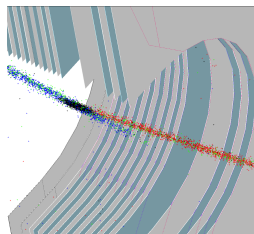
(not to be confused with Smaug)



## SMOG

JINST 9 P12005 (2014)

- used for precision luminosity measurements using beam gas imaging (uncertainty of 1.16%)
- at  $\sqrt{s} = 110$  GeV  
 $y = y_{\text{com}} + 4.77$

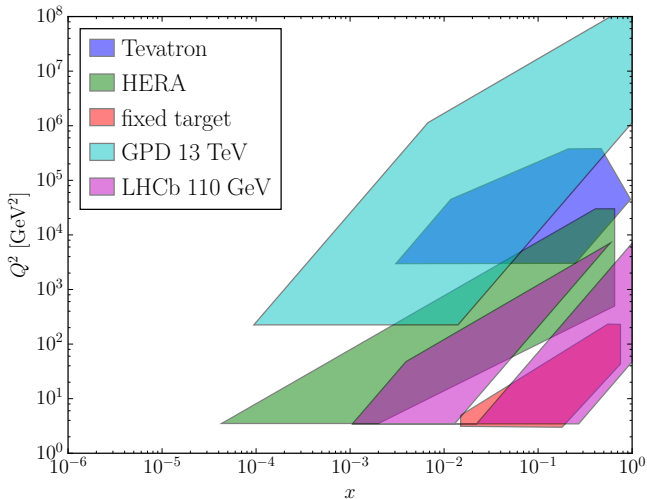


type	$\sqrt{s}$ [GeV]	year	time
<i>p</i> Ne	87	2012	30m
PbNe	54	2013	30m
<i>p</i> Ne	110	2015	12h
<i>p</i> He	110	2015	7h
<b><i>p</i>Ar</b>	<b>110</b>	<b>2015</b>	<b>20h</b>
<i>p</i> Ar	69	2015	11h
PbAr	69	2015	100h
<i>p</i> He	110	2016	20h
<i>p</i> He	87	2016	87h



# Bjorken- $x$ Coverage

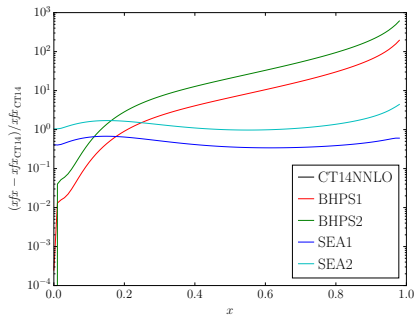
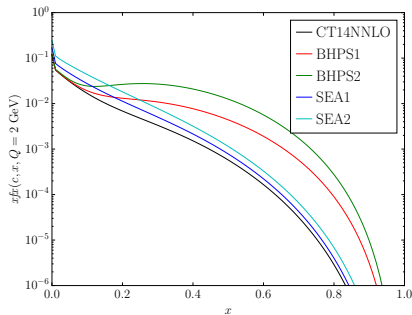
- parton distribution function (PDF) parameter space in  $Q^2$  and  $x$



## Intrinsic Charm PDFs

Phys. Rev. D **93**, no. 3,  
033006 (2016)

- test with open and hidden-charm production,  $Q$  of  $m(D)$

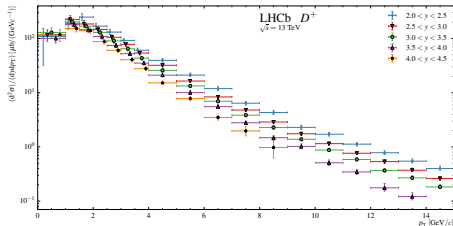
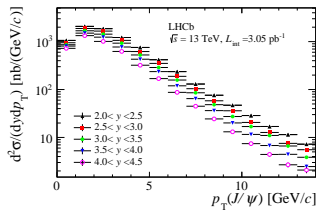
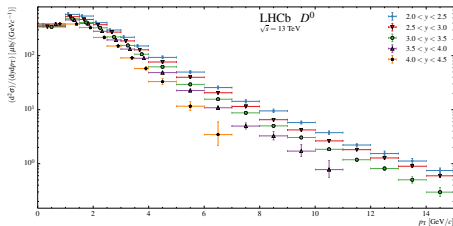


# Measurements

JHEP **1603**, 159 (2016)

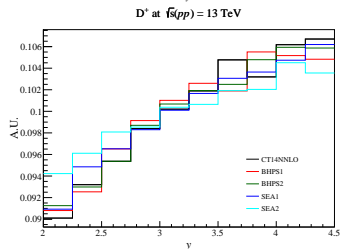
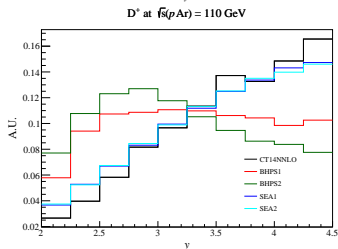
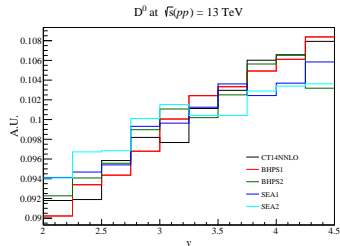
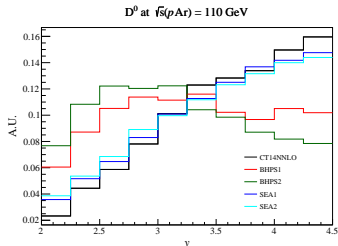
JHEP **1510**, 172 (2015)

- open and hidden-charm cross-sections with  $pp$  data
- use the  $J/\psi[\mu\mu]$ ,  $D^0[K^+\pi^-]$ , and  $D^+[K^+\pi^-\pi^+]$  channels



# Future Measurements

- same measurements but with  $p\text{He}$  and  $p\text{Ar}$  data
- rough predictions in LHCb acceptance from PYTHIA 8

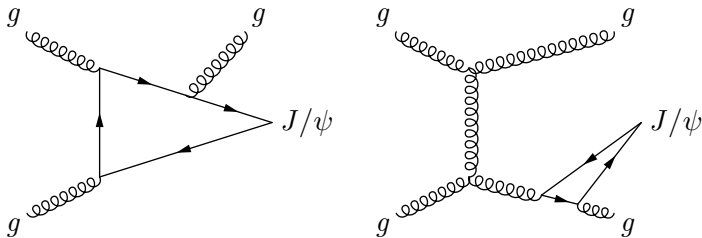


# $J/\psi$ Production in Jets

## Two Pictures

arXiv:1701.05116

- understanding prompt  $J/\psi$  critical for intrinsic charm
- prompt  $J/\psi$  calculated with non-relativistic QCD (NRQCD)
- two pictures on how NRQCD is used
  - NRQCD hard process, octet states showered with QCD splittings
  - shower with NRQCD splittings, match with hard process

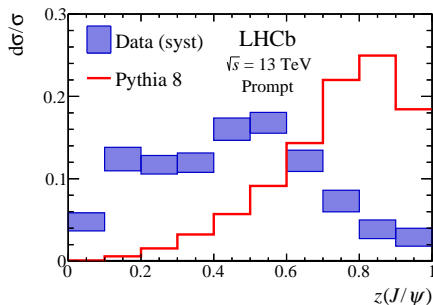
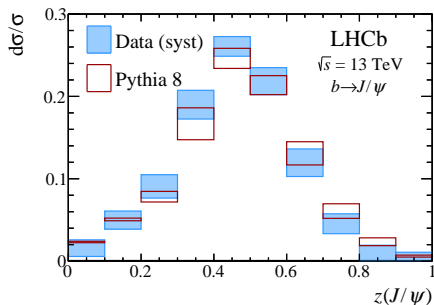


- utilize  $J/\psi$  trigger that writes out fully reconstructed event
- use jets with  $p_T > 20$  GeV which contain a  $J/\psi$

## Results

arXiv:1701.05116

- measure  $z \equiv p_T(J/\psi)/p_T(\text{jet})$
- separate into prompt and displaced contributions



- PYTHIA 8 implements the LO hard process picture
- not the end of the story, need different predictions

# Outlook



# Outlook

- forward detector with diverse datasets
- robust and efficient  $c(b)$ -tagging algorithm validated against data
- intrinsic charm studies underway both with  $pp$  and  $pA$
- rule out BHSP models at  $\langle x \rangle_{IC} \approx 1\%$  ... or demonstrate IC!

Thank you!

*I discover intrinsic charm where I wish and none dare resist.*  
- SMOG (if SMOG were Smaug)