LHCb status

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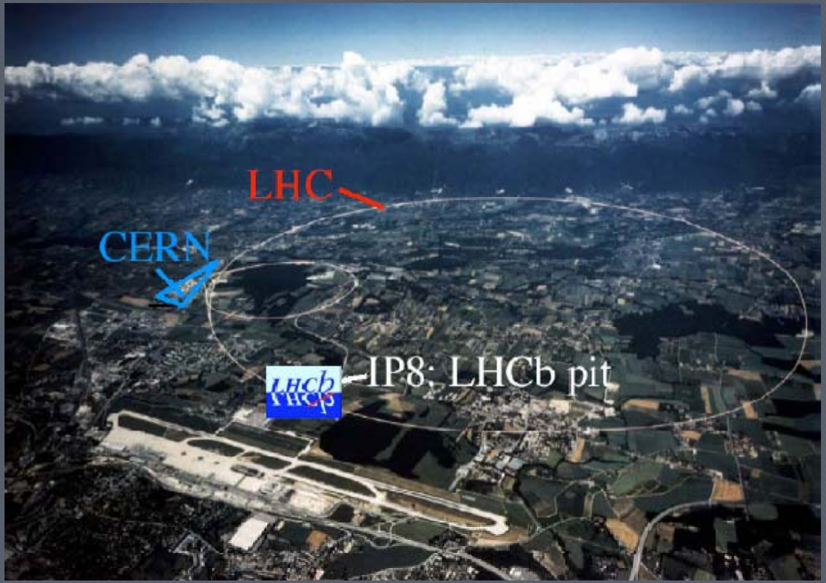
On behalf of the LHCb Collaboration

Conference on LHC First Data
December 12, 2010

laSalle
Universitat Ramon Llull

Outline

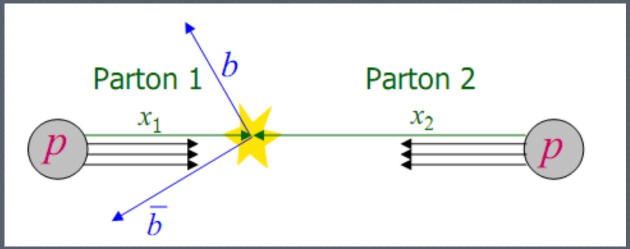
- LHCb experiment and detector
- 2010 run
- Status and performace of detector
- First results
- Expectations

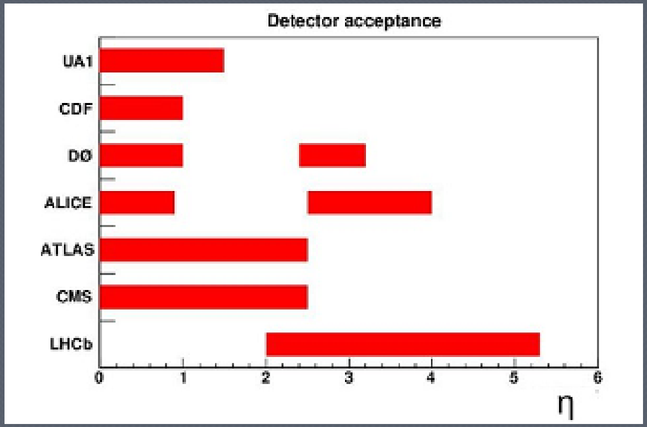


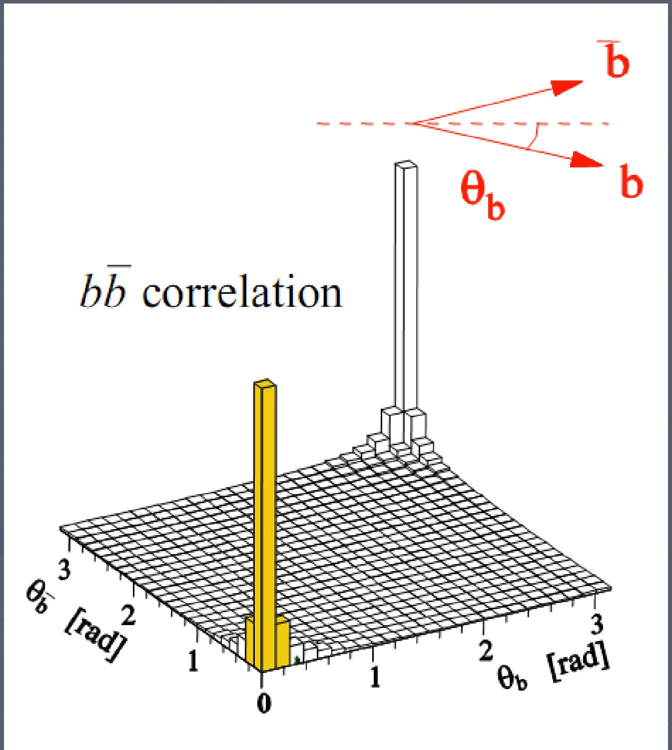
Experiment and detector

- Dedicated to B-physics
  - High precision study of CP violation and rare decays
- But also Charm, EW, Spectroscopy, …

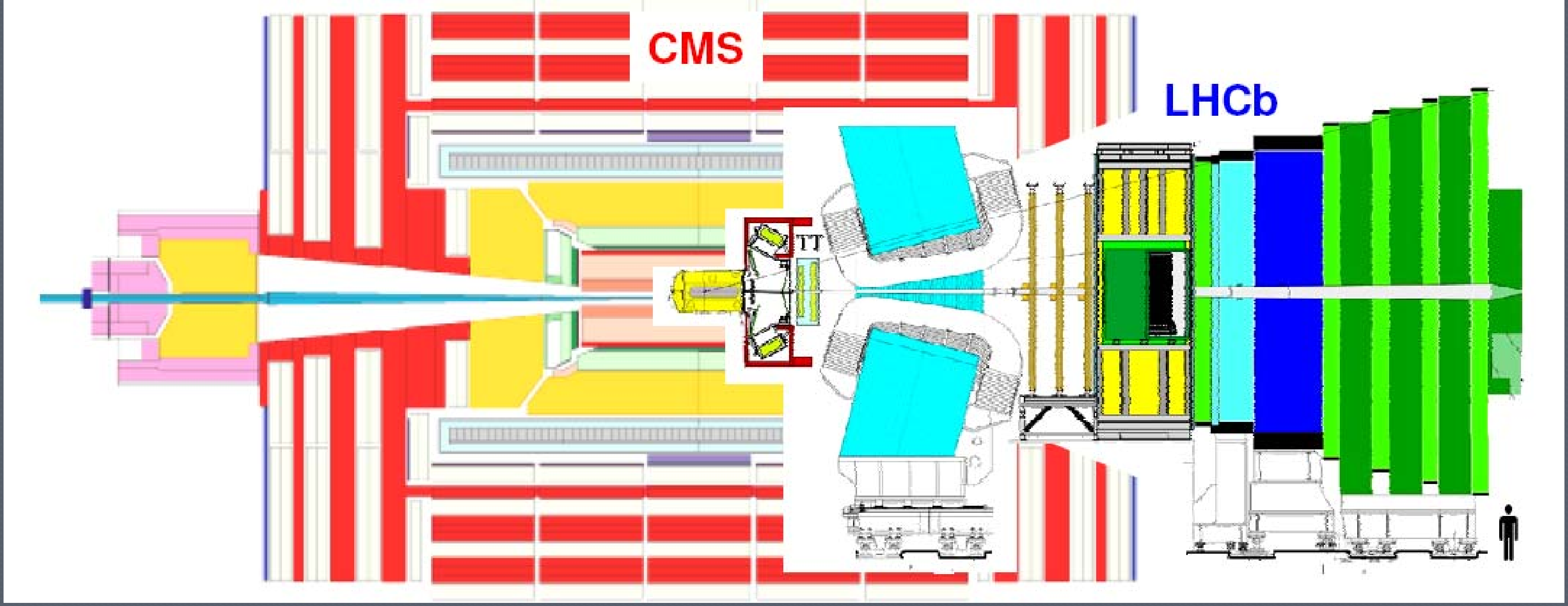
- Single arm forward spectrometer (15 mrad < θ < 300 (250) mrad)
  - Unique coverage in 2<η<5 for high energy pp collisions





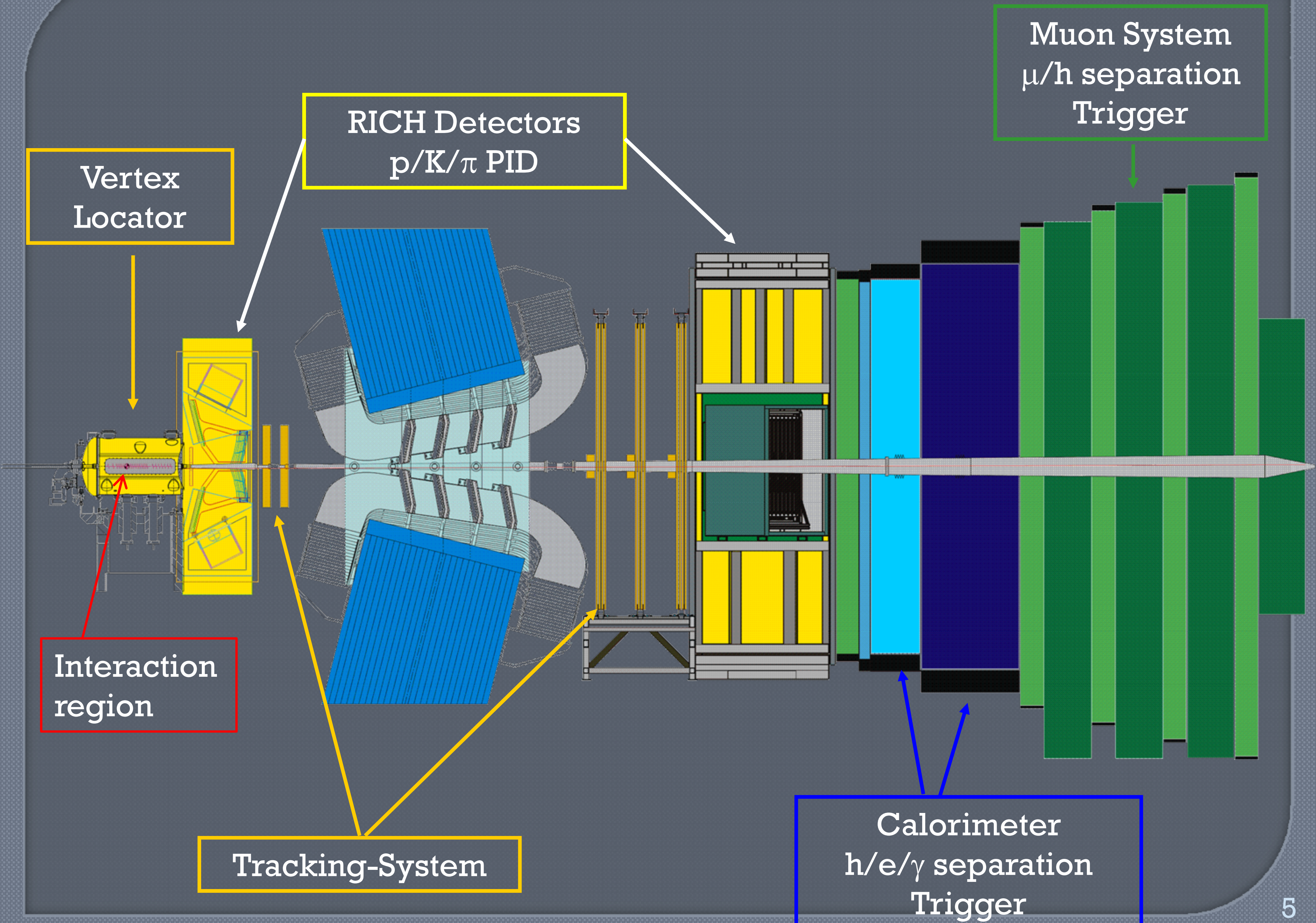


Comparison with "high-p_t" Detectors



ATLAS/CMS: $|\eta| < 2.5$ LHCb: $2 < \eta < 5$

LHCb is the only experiment fully instrumented in the forward direction


Muon System
μ/h separation
Trigger
RICH Detectors
p/K/π PID
Vertex
Locator
Interaction
region
Tracking-System
Calorimeter
h/e/γ separation
Trigger

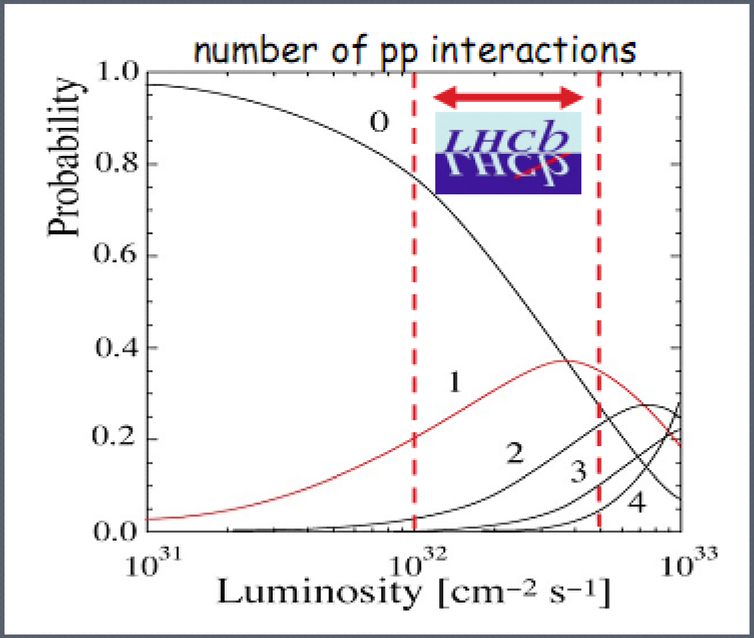
B physics

- Cross-section predictions (PYTHIA)
  $\sqrt{s}$ = 7, 10, 14 TeV
  $\sigma_{inel} \sim$ (0.89, 0.95, 1) × 80 mb
  $\sigma_{bb} \sim$ (0.44, 0.67, 1) × ~500 μb
  ~ 250 μb

- $B^{\pm}$, B^0, B_s, B_c, Λ_b…
  (40%, 40%, 10%, 10% from LEP)

- 10 x larger charm production

- Design $\mathcal{L} \sim 2{\cdot}10^{32}$ cm^{-2} s^{-1} (tuned)
  ~ 10^{12} bb events / year (2 fb^{-1})
  10 kHz bb-events in LHCb



Maximizes fraction of single interaction per bunch crossing

Some LHCb key measurements

+ CPV in Charm

CP Violation	
Mixing phase φ_s	$B_s \to J/\psi\phi$
CKM angle γ from loops	$B^0 \to \pi\pi$, $B_s \to KK$
CKM angle γ from trees	$B_s \to D_sK$, $B^0 \to D^0K^{*0}$, $B^+ \to D^0K^+$
Rare decays	
Angular analysis	$B^o \to K^{*o}\mu^+\mu^-$
Observation or BR limits	$B_s \to \mu^+\mu^-$
Radiative penguins in $b \to s\gamma$ transitions	$B_s \to \phi\gamma$, $B^0 \to K^{*0}\gamma$

For more details see the LHCb Roadmap document
http://arxiv.org/ftp/arxiv/papers/0912/0912.4179.pdf

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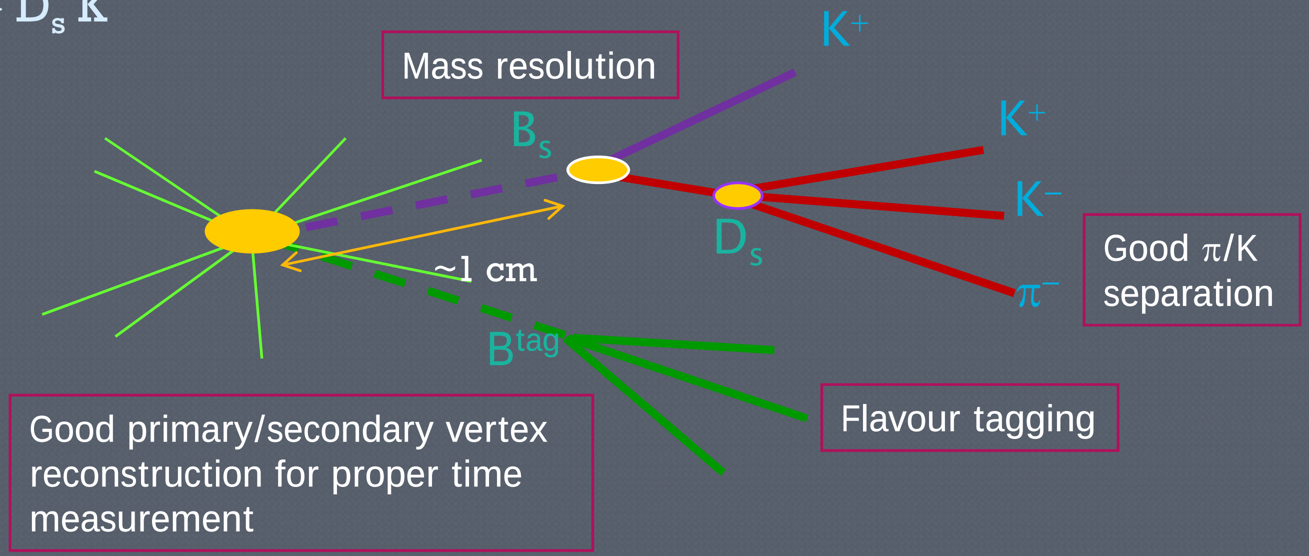
Themis Bowcock talk on Monday afternoon
"B physics with LHCb"

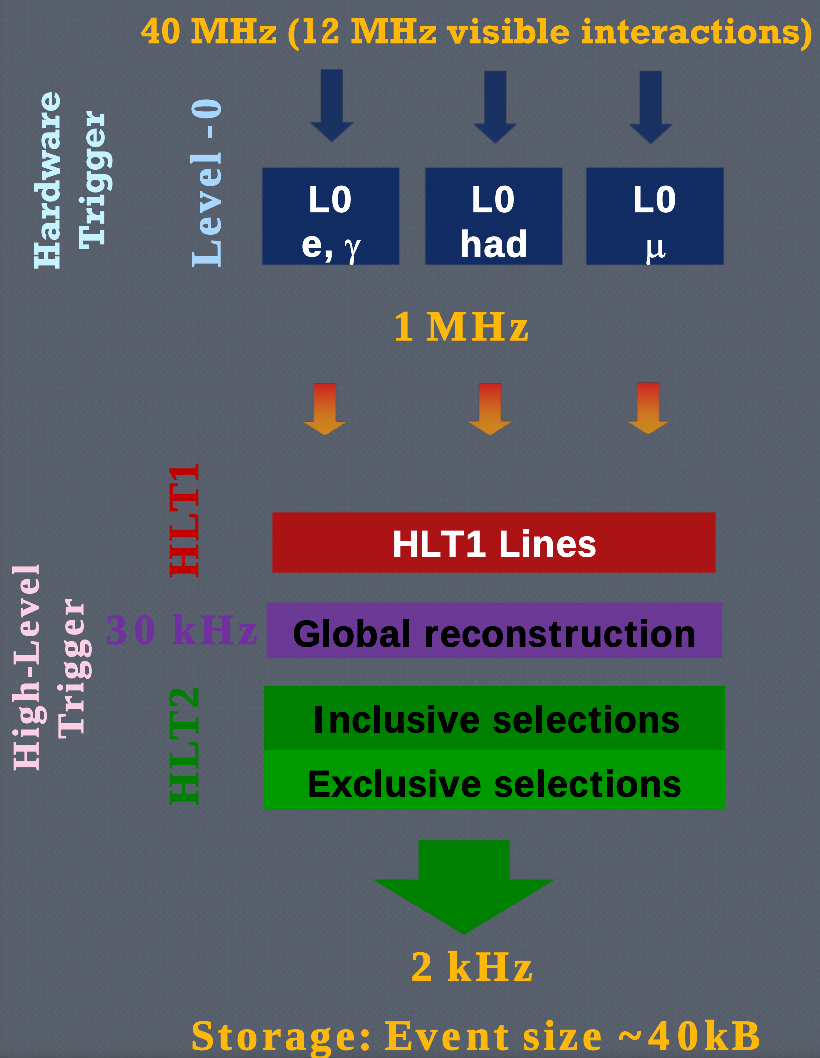
Experimental requirements

- Flexible and efficient trigger for both hadronic and leptonic final states
- Good Particle identification (PID)
- Excellent tracking and vertexing
  - Secondary vertex identification
  - Good momentum, mass and proper time resolutions

Example: $B_s \rightarrow D_s K$



LHCb trigger



Trigger is crucial as $\sigma_{bb}/\sigma_{inel} < 1\%$
B decays of interest typically have BR < 10^{-5}

Level-0 Hardware Trigger

high-p_T μ, e, γ, hadron candidates

Software High Level Trigger (HLT)

Farm of O(2000) multi-core processors

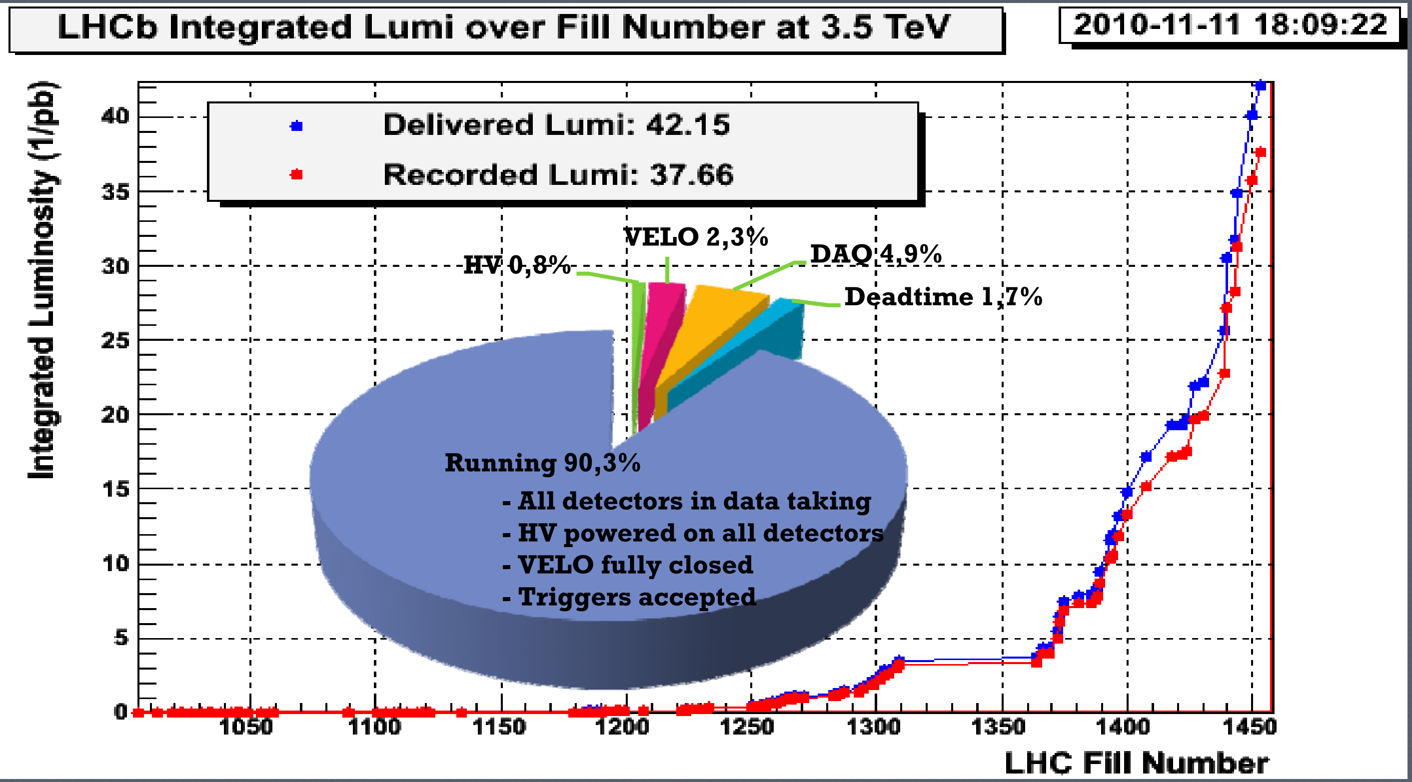
HLT1: Finds vertex in VELO, tracks with high IP and p_T

HLT2: Global event reconstruction + inclusive/exclusive selections.

2010 run

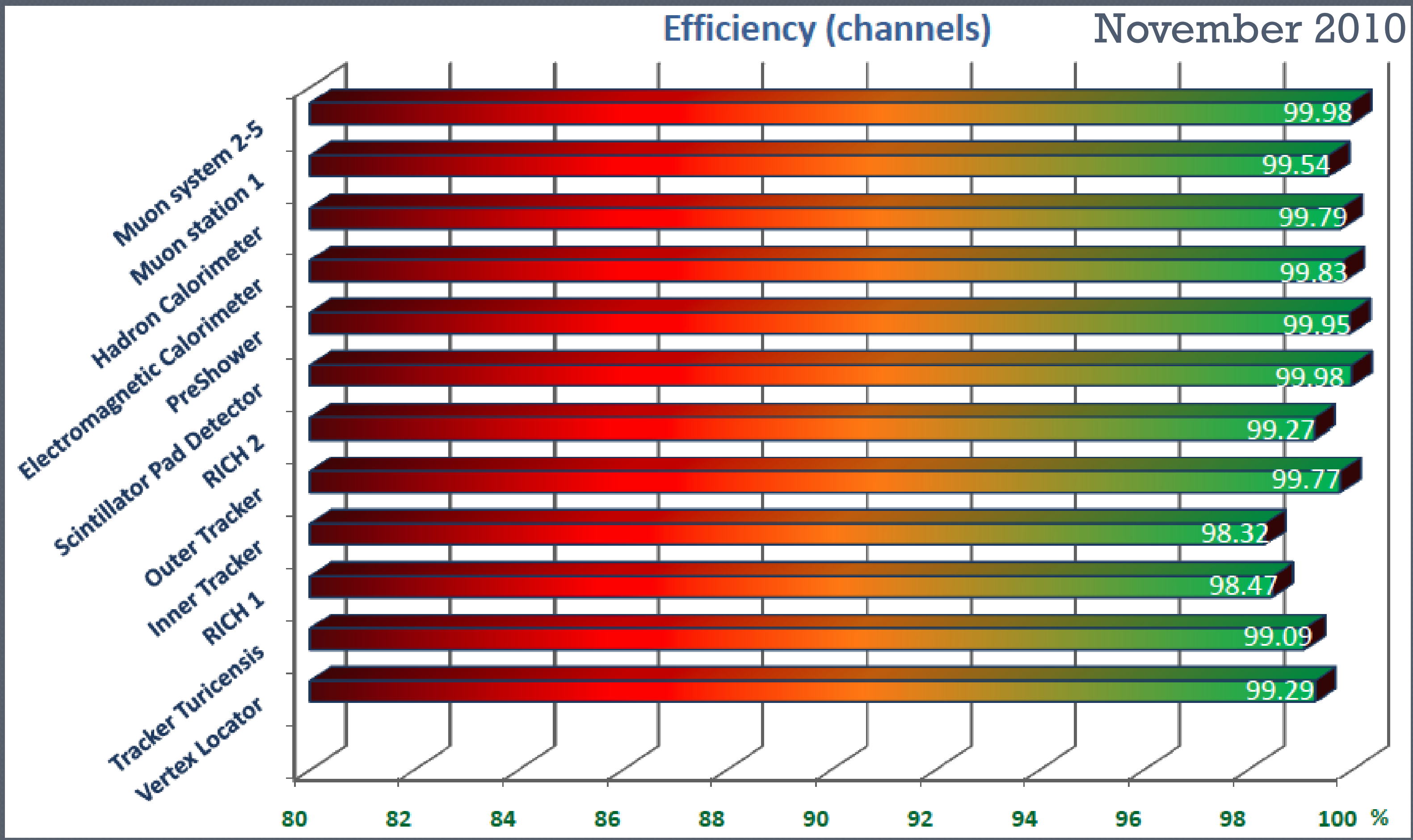
6.8 μb^{-1} at √s= 0.9 TeV in 2009
0.31 nb^{-1} at √s= 0.9 TeV in 2010
37.7 pb^{-1} at √s= 7 TeV in 2010
(~90% of delivered lumi)

From 30th March to 29th October



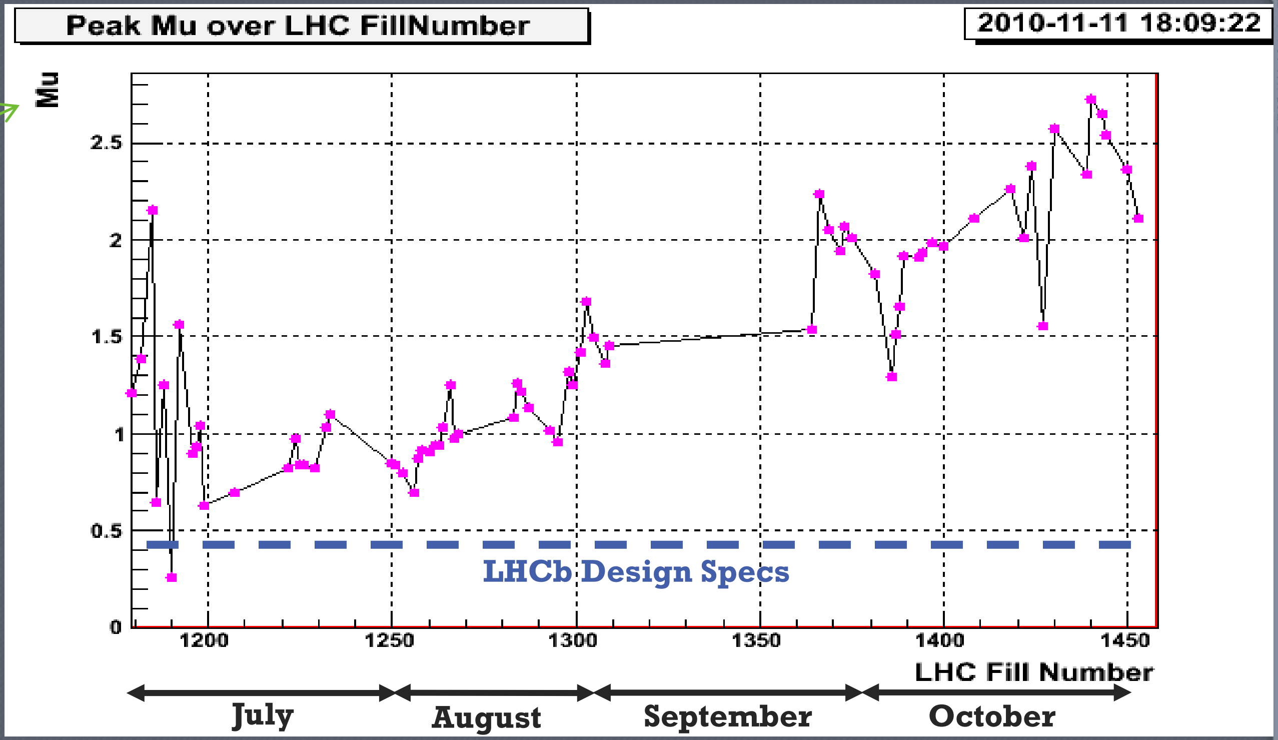
Last month

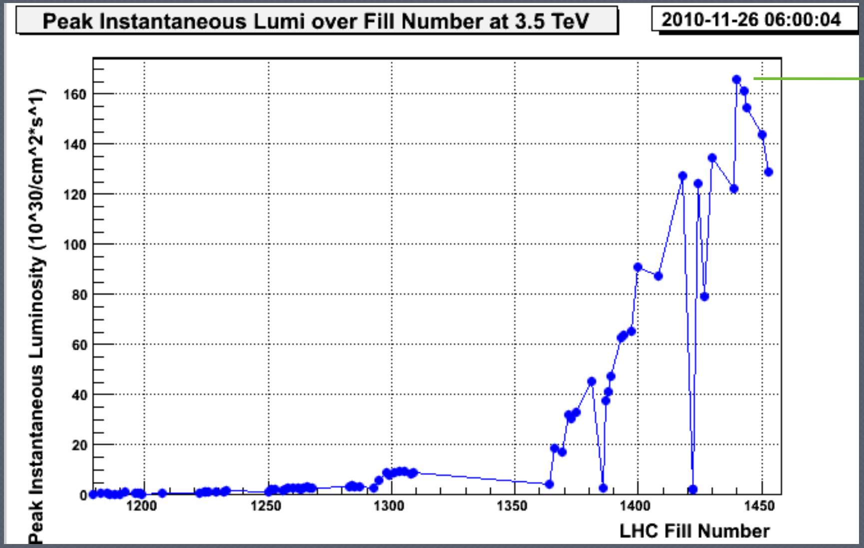
Status of the detector



The detector worked extremely well over the entire year!

Average number of visible interactions/crossing in LHCb acceptance (what we call μ)



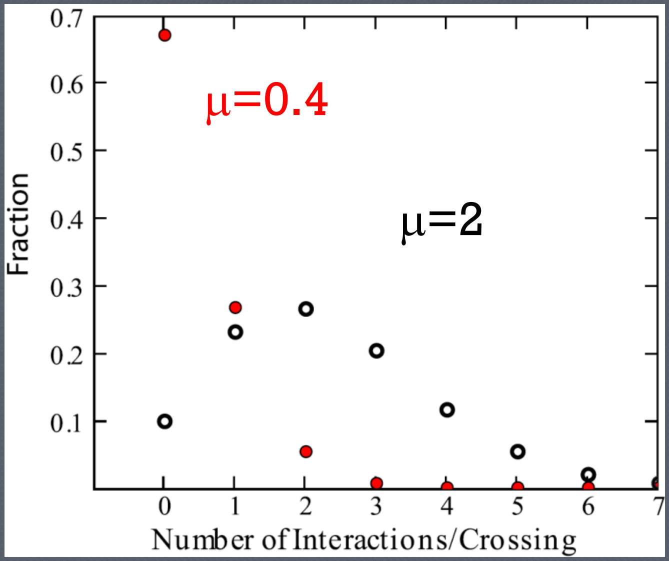


Instantaneous luminosity $1.6 \cdot 10^{32}\ cm^{-2}s^{-1}$

80% of design luminosity reached with 344 colliding bunches instead of 2622

Nominal

- $\sqrt{14}$ TeV
- L = $2\cdot10^{32}$ cm^{-2} s^{-1}
  - Defocus the beams
- 2622 colliding bunches
- β* = 10 m
  - Average 0.4 visible interactions/ bunch crossing
- Minimize the pile-up



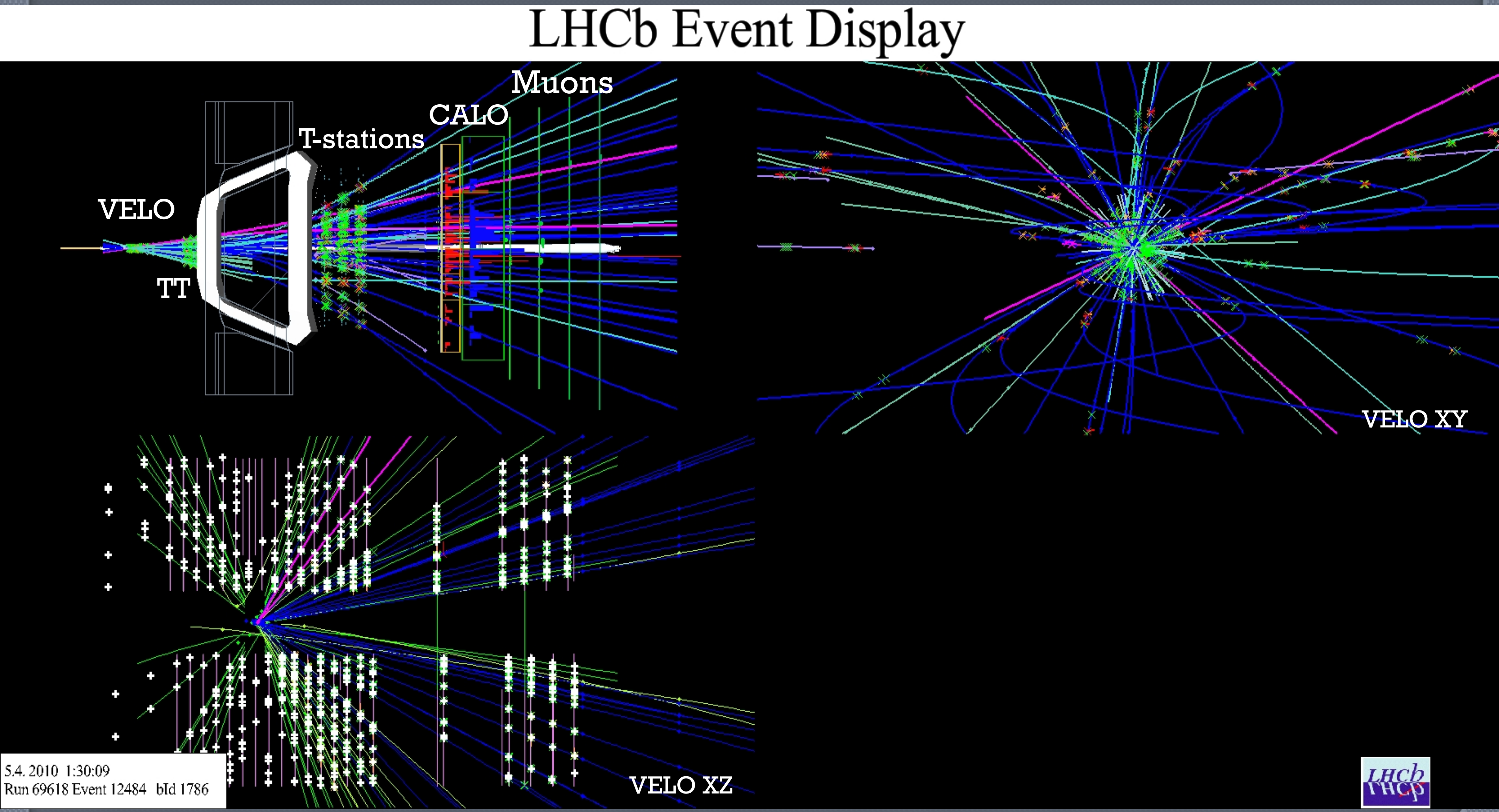
End of 2010

- $\sqrt{7}$ TeV
- $1.6\cdot10^{32}$ cm^{-2} s^{-1} has been reached
- Small number of bunches (344 max)
- β*~3.5 m
  - ~ 2 visible interactions/bunch crossing

- Trigger conditions rapidly evolving to accomodate increasing L

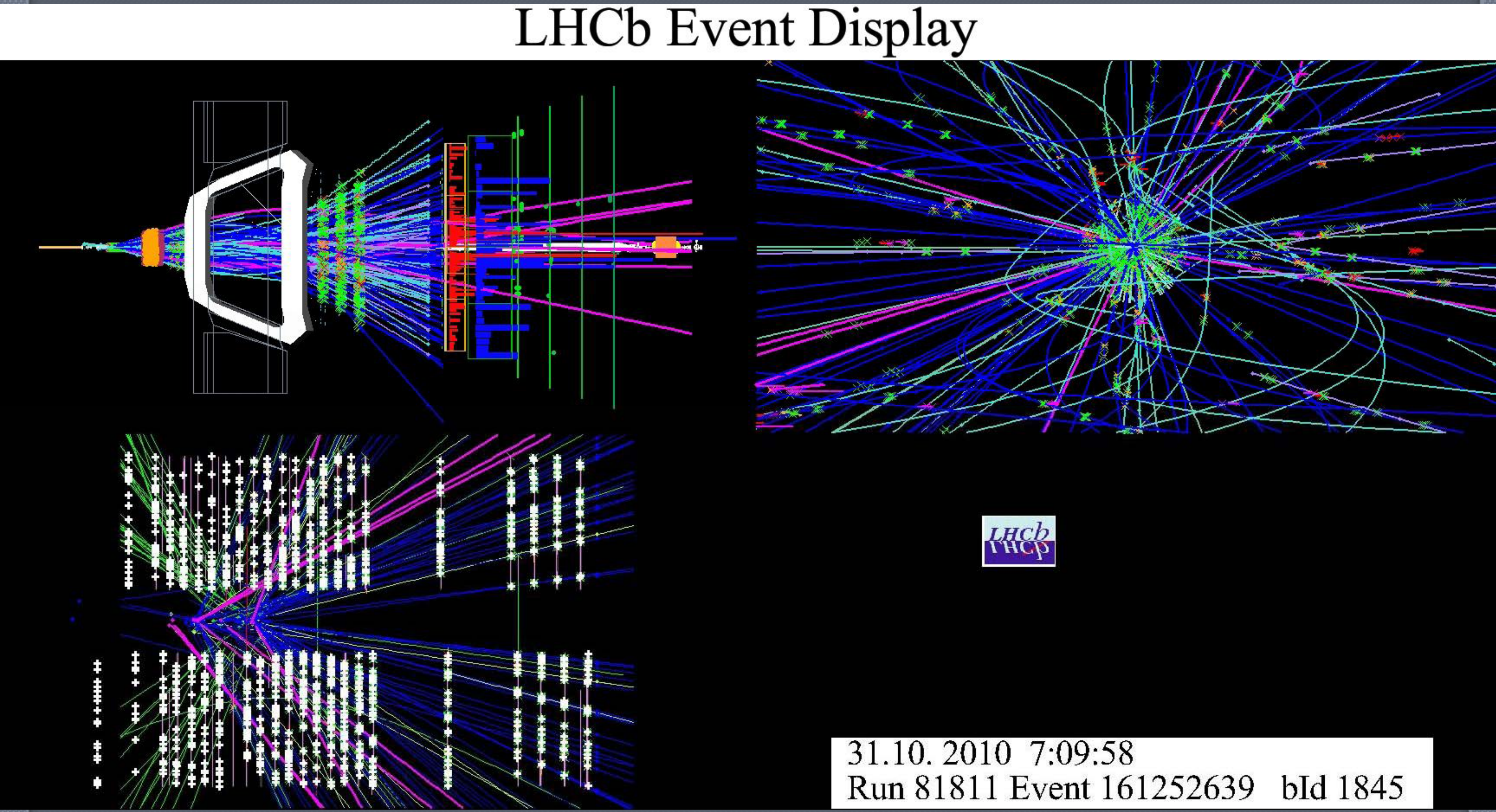
Despite running beyond design conditions, no problem of data quality in 2010

April 2010
Event with 1 interaction



October 2010

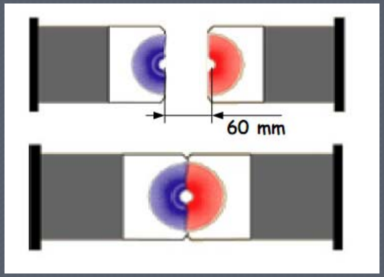
Several interactions



Performance-VELO

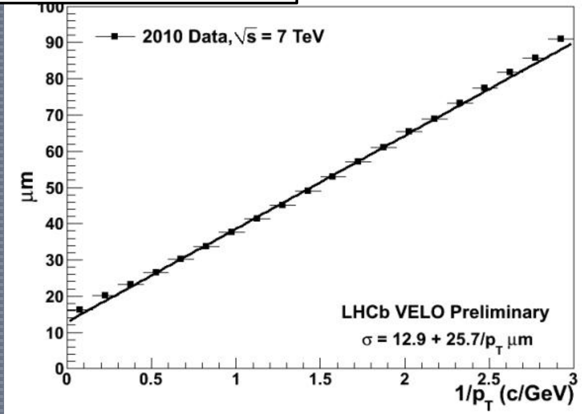
Vertex measurement
$\sigma(z)\sim$ 75 [150] μm for the Primary [Secondary] vertices
$\sigma(IP) \sim 13 + 26/p_T$ (GeV) μm
$\sigma(\tau)\sim$ 60 fs on b-hadrons decay times

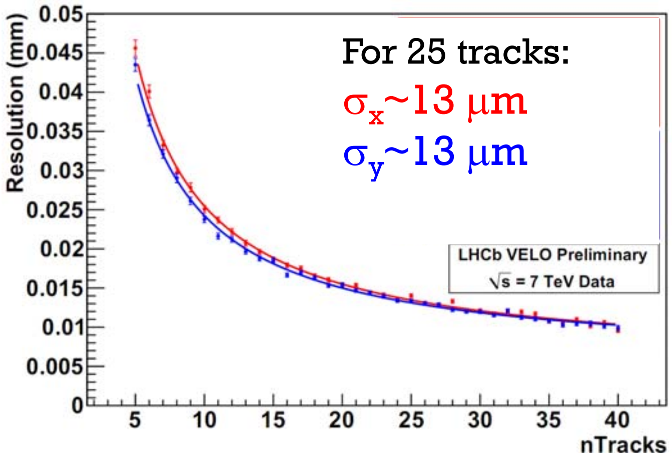
Silicon-strip detector
21 stations
Both Velo halves move at every fill

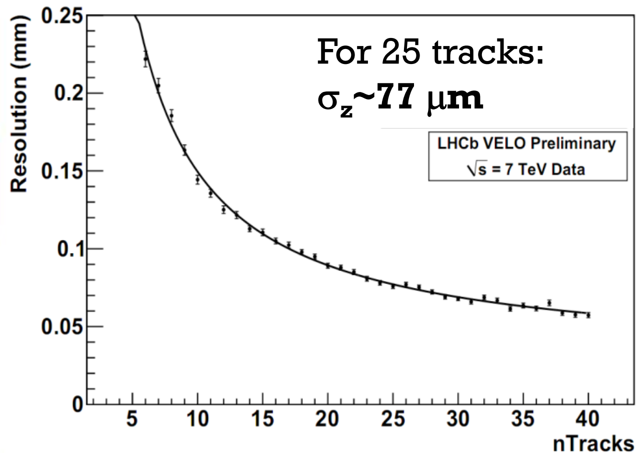


Nominal position of sensor: 8 mm to beam axis
Fill-to-fill variations < 5 μm
Hit resolution 4 μm

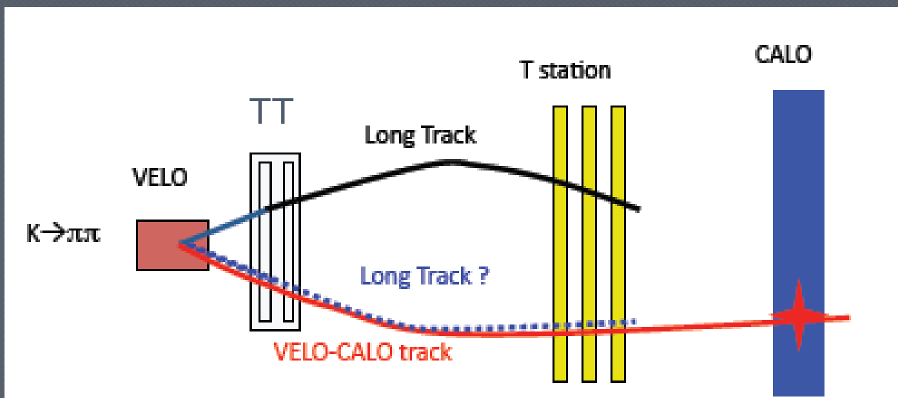
σ_x(IP) vs $1/p_T$



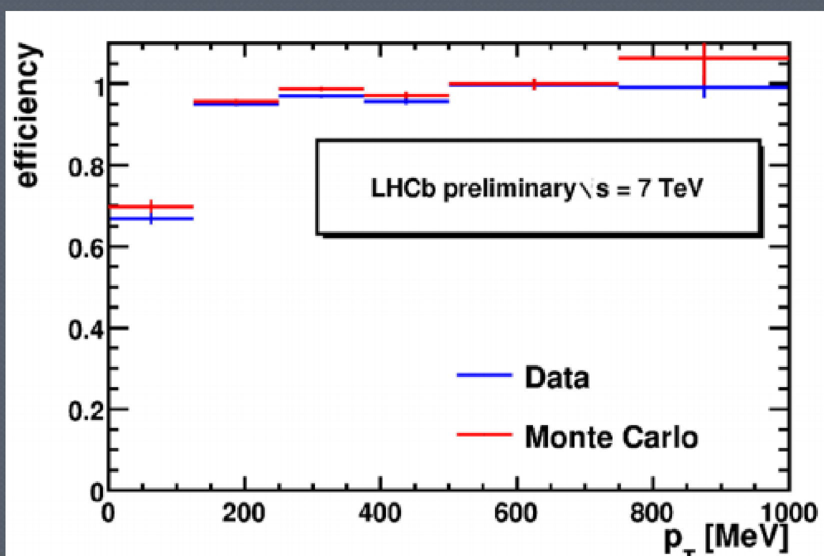


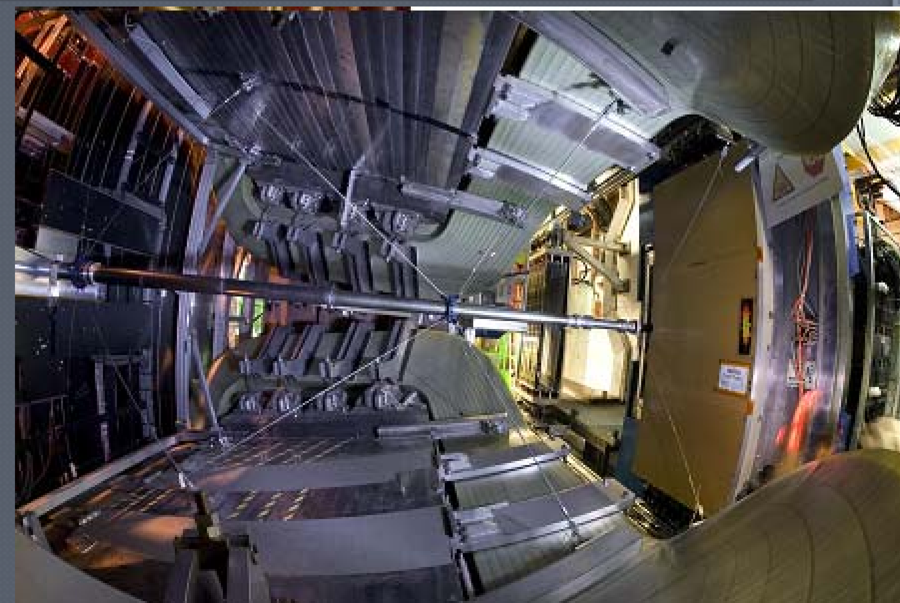


Tracking



$$\varepsilon = \frac{Tracks^{(VELO\,+\,IT/OT+CALO)}}{Tracks^{(VELO\,+\,CALO)}}$$



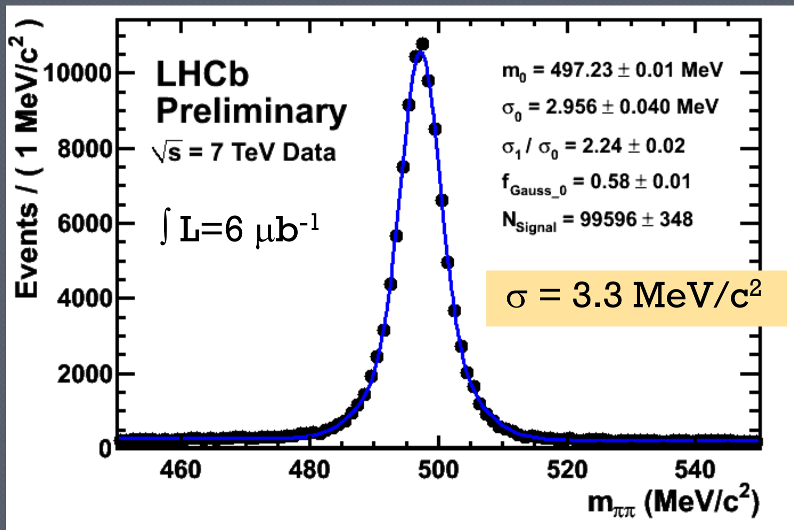


TT + IT (Silicon detectors)
+ OT (Straw Tubes)
4 Tm dipole magnet

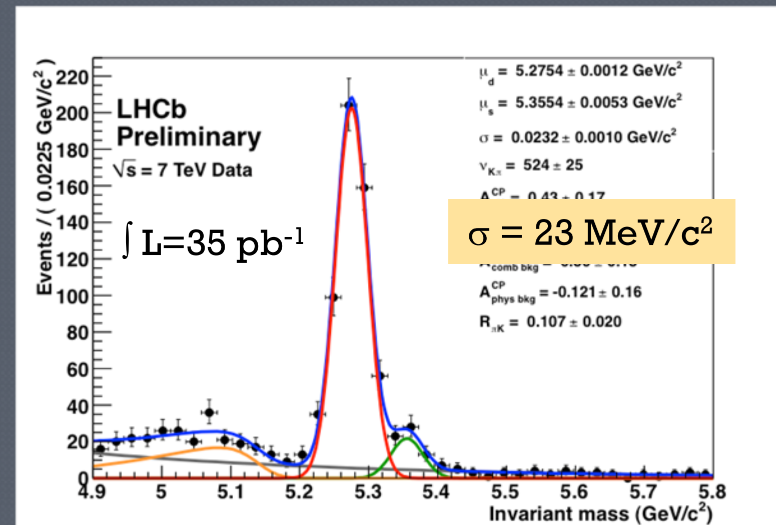
ε = 95% for p> 5 GeV
$\Delta p/p \sim 0.45\%$
σ(b-hadron mass)~11-25 MeV/c^2

Mass resolutions

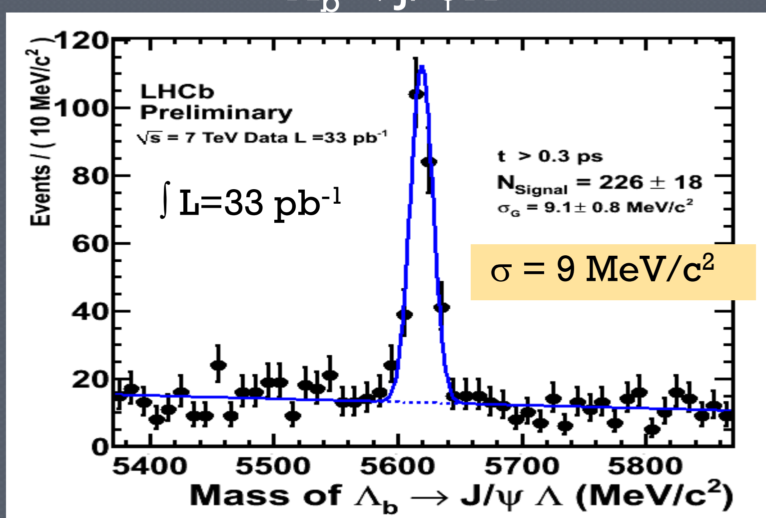
$K_s \rightarrow \pi\pi$



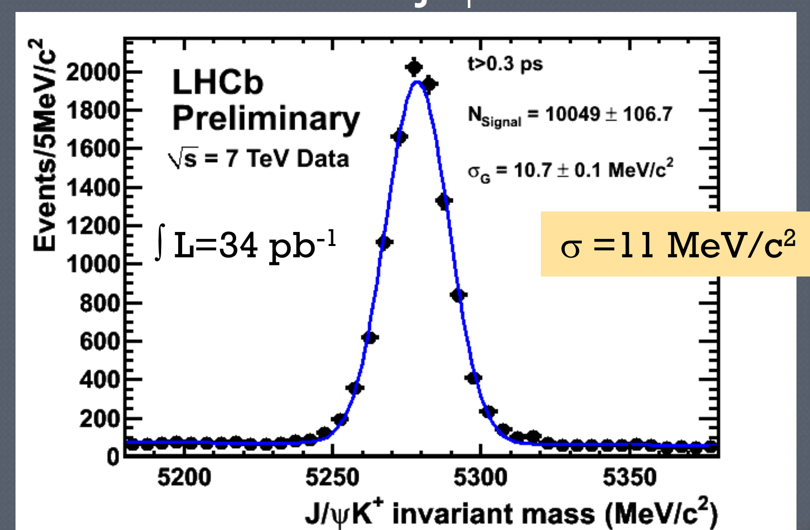
$B^0 \rightarrow K\pi$



$\Lambda_b \rightarrow J/\psi\Lambda$

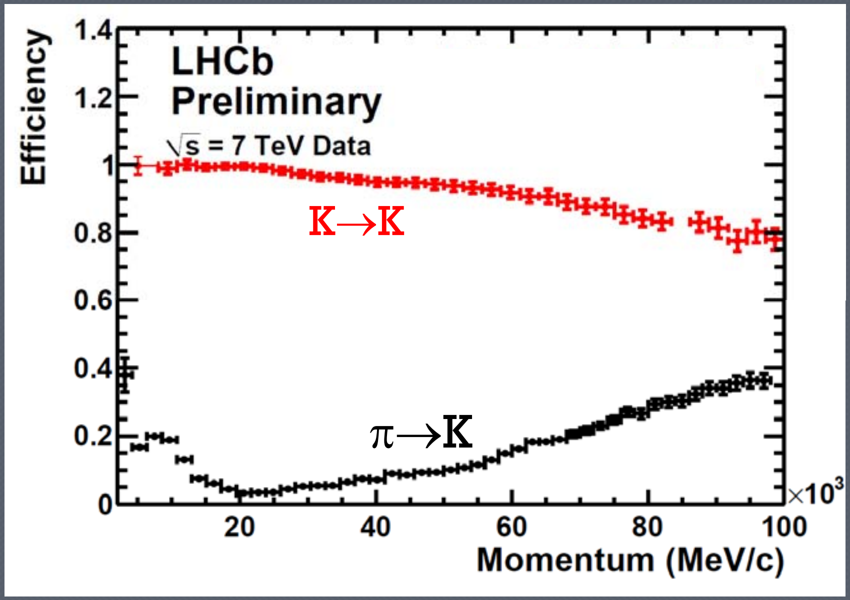


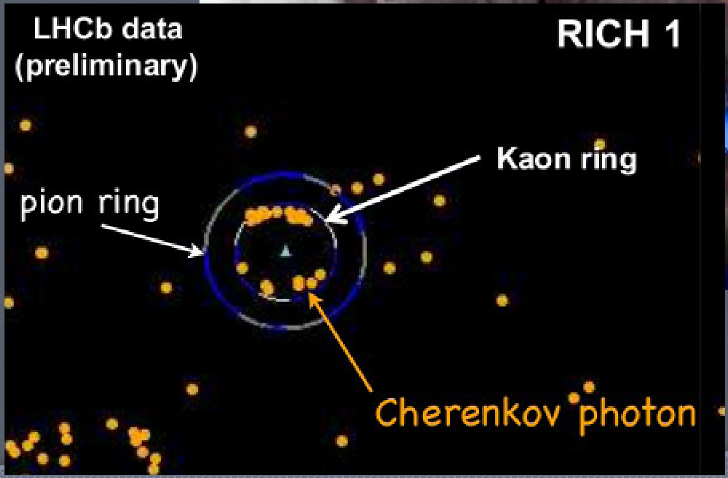
$B^+ \rightarrow J/\psi K^+$



RICHes

2 Ring Imaging CHerenkov detectors with 3 radiators
Momentum range of 2-100 GeV
Vital for good K/π/p discrimination

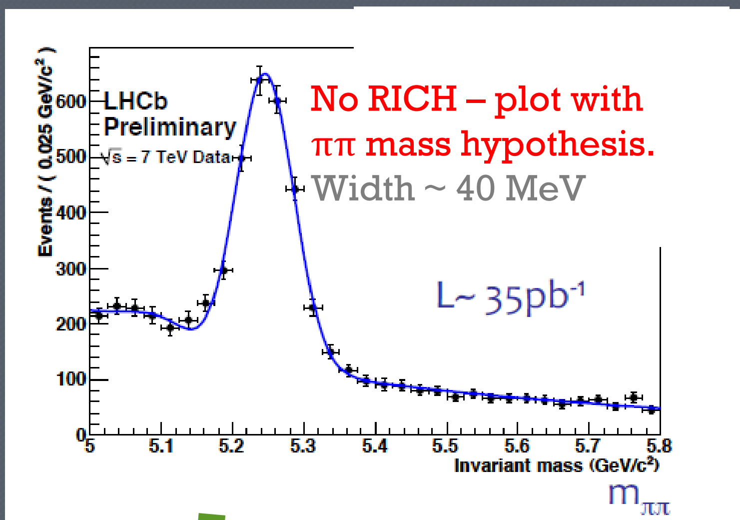




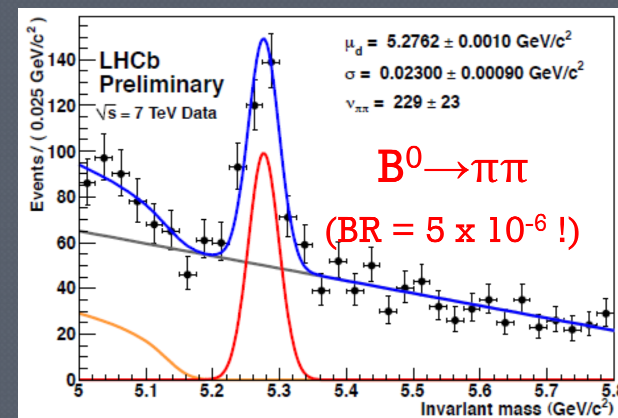
ε(K)~95% at 5% of π/K mis-id

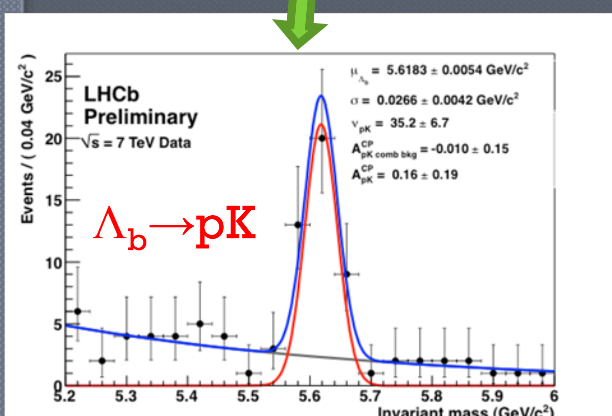
PID allows separation of topologically identical final states

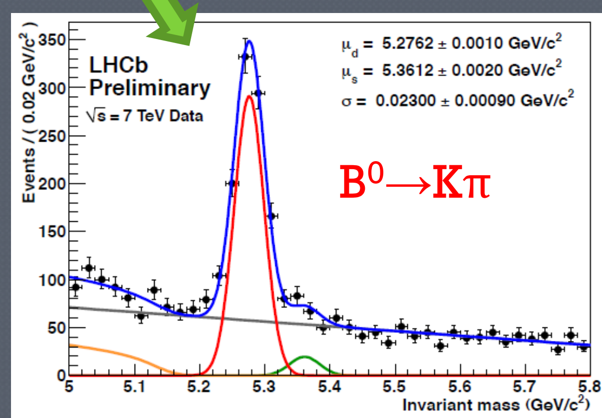
e.g. B→hh

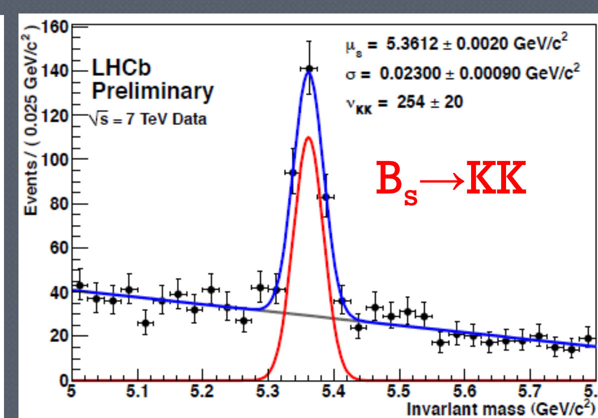


Deploy RICH
to isolate
each mode





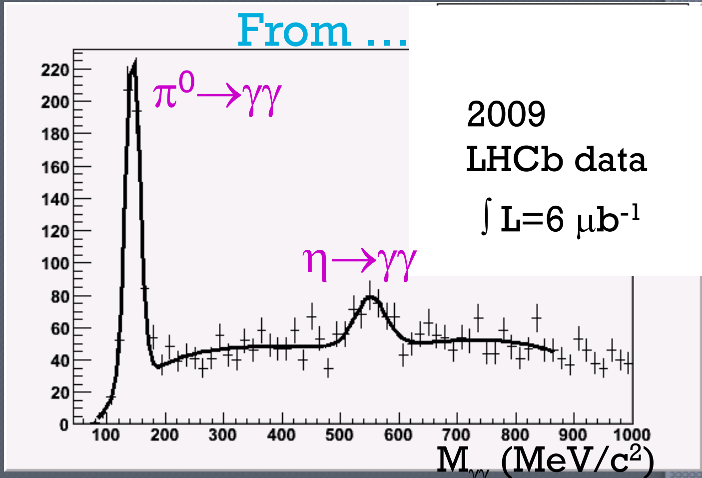


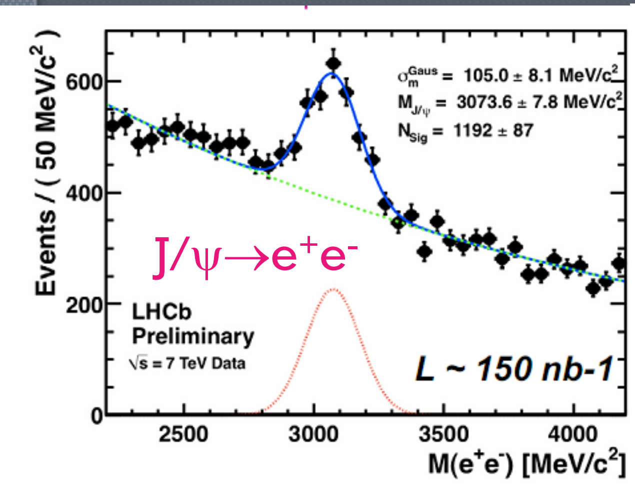


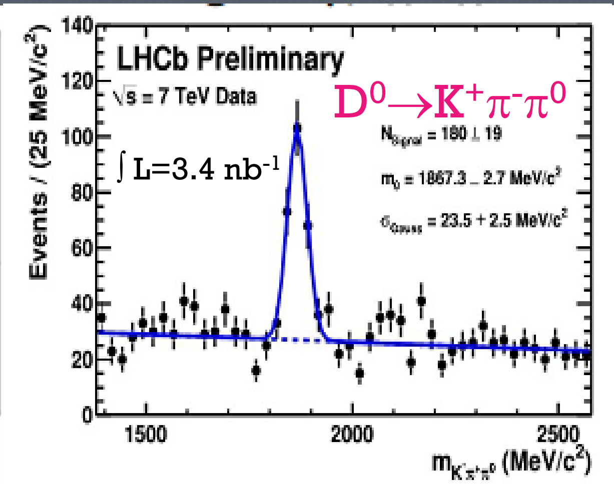
Calorimeters

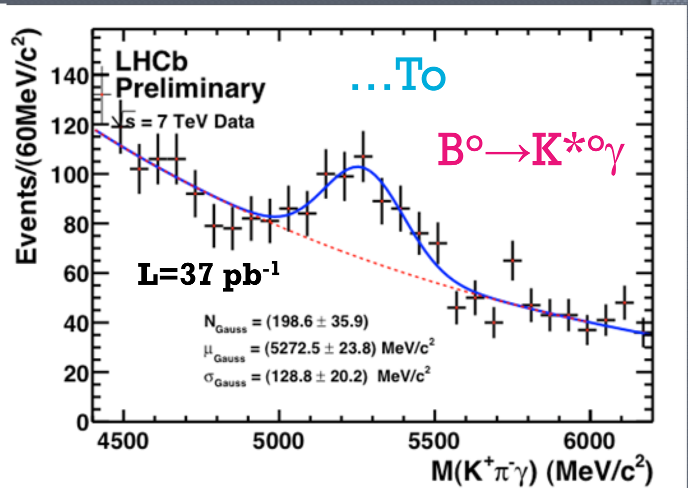
Pre-Shower, ECAL and HCAL
Essential role at L0 trigger
e/γ, h
and PID of e, γ, π^0

$\sigma/E \sim 9\%/\sqrt{E} \oplus 0.8\%$ (ECAL)
$\sigma/E \sim 69\%/\sqrt{E} \oplus 9\%$ (HCAL)

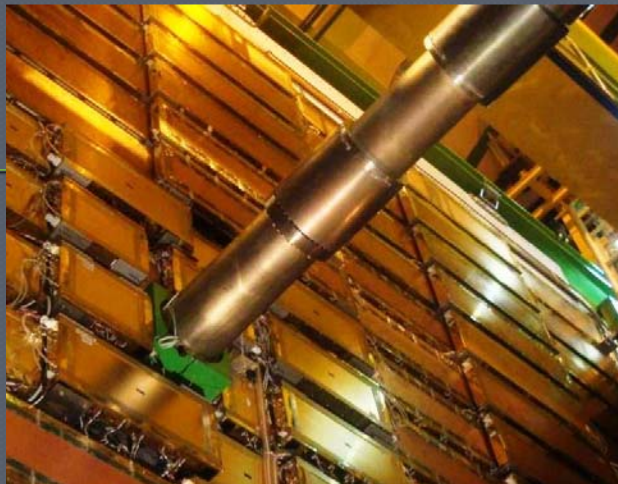






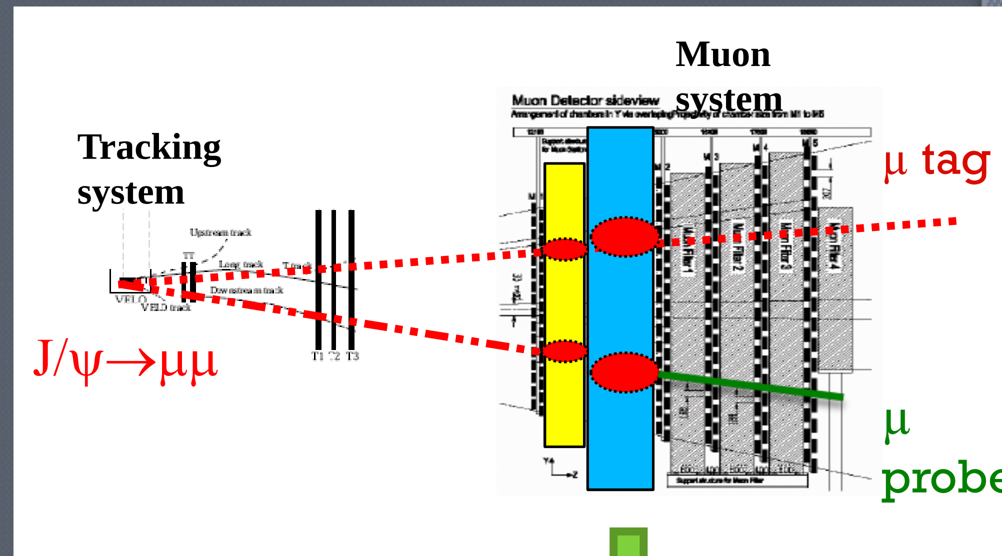


Muons



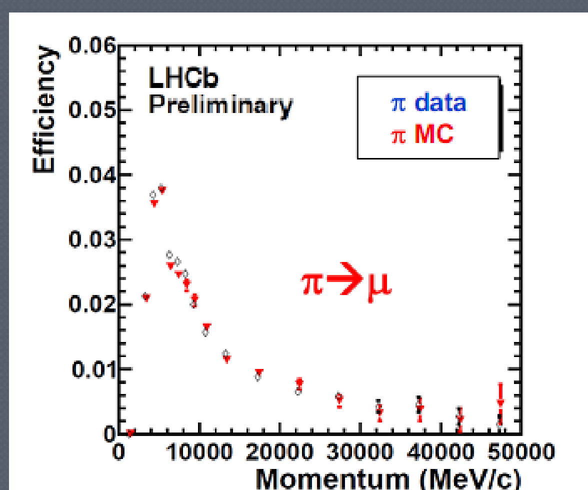
5 muon stations (MWPC)

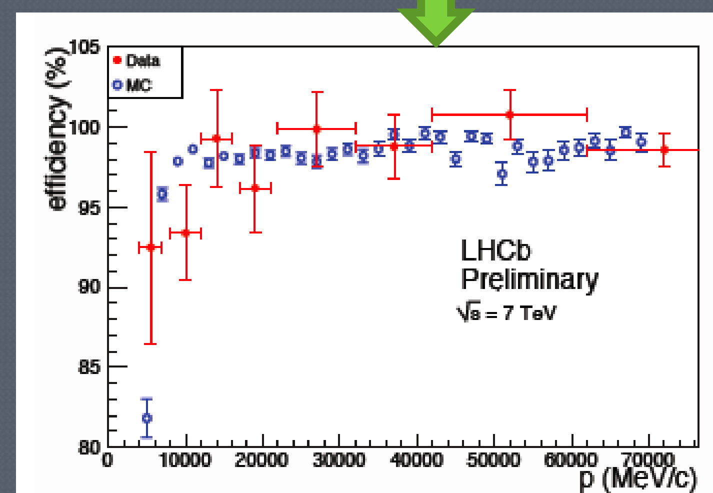
$\varepsilon(\mu)$>90% at <2% of π,K/μ mis-id for p>10 GeV/c

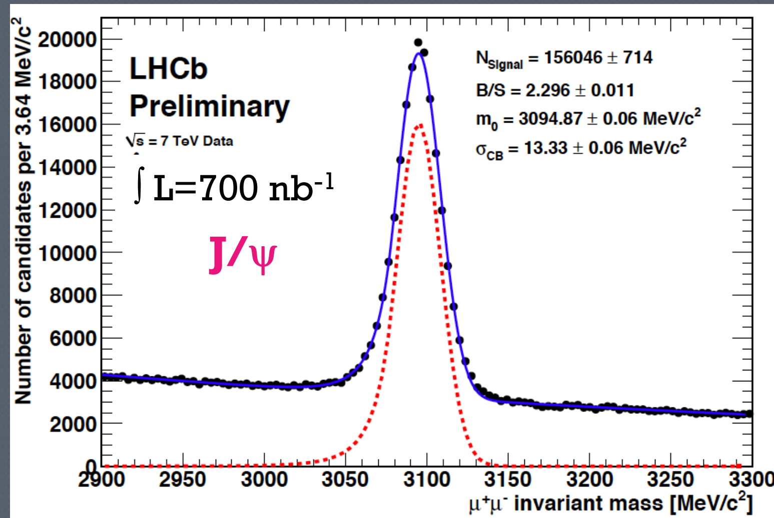


$\pi\rightarrow\mu$ mis-id from $K_s\rightarrow\pi\pi$

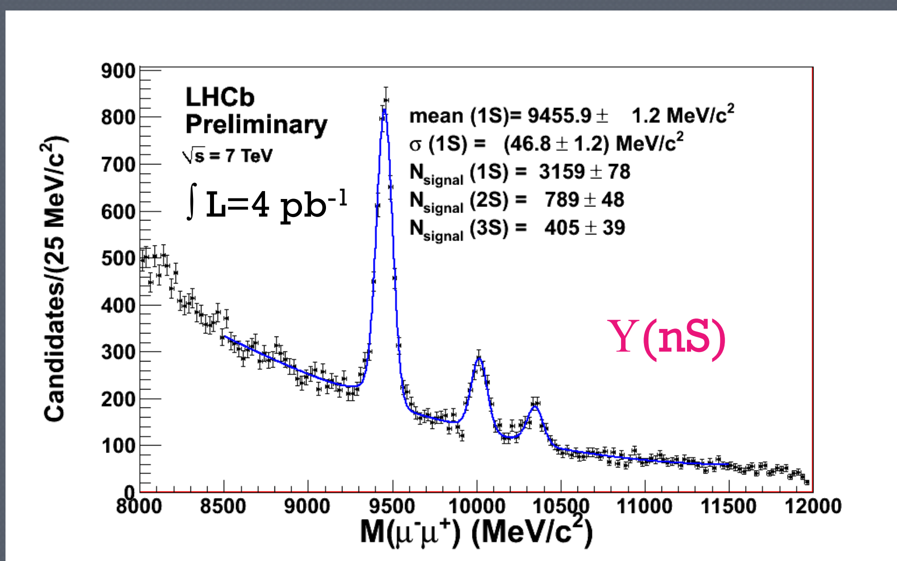
(K→μ mis-id from ϕ)



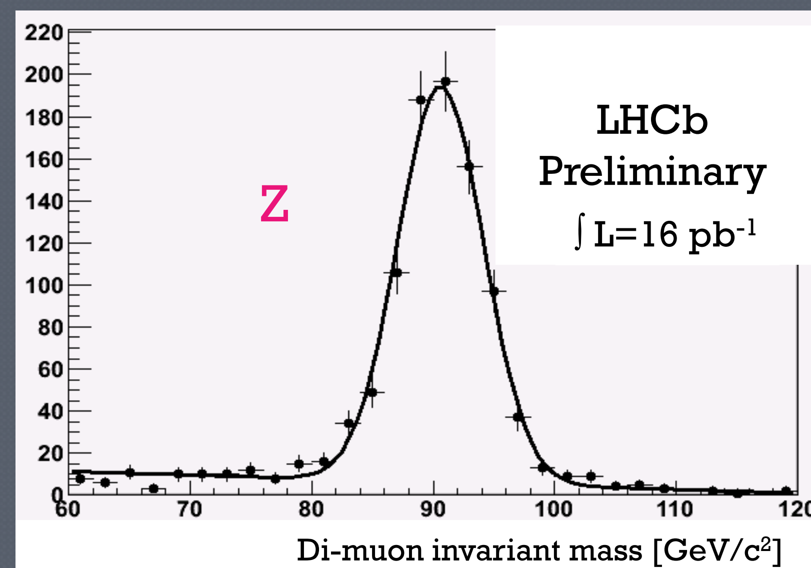




$\mathcal{O}$ (1 GeV/c^2)

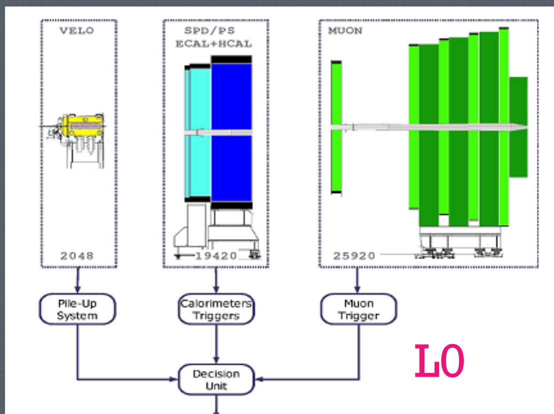


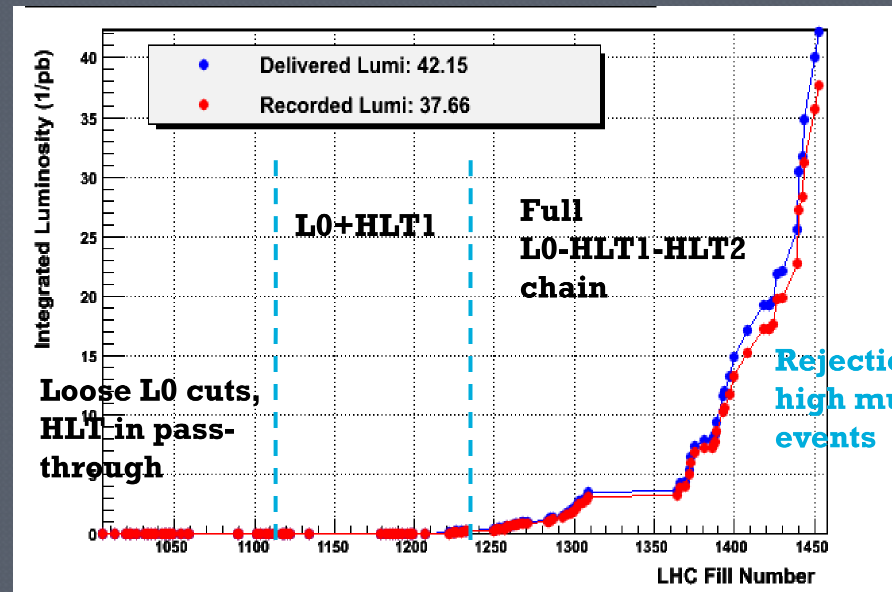
$\mathcal{O}$ (10 GeV/c^2)

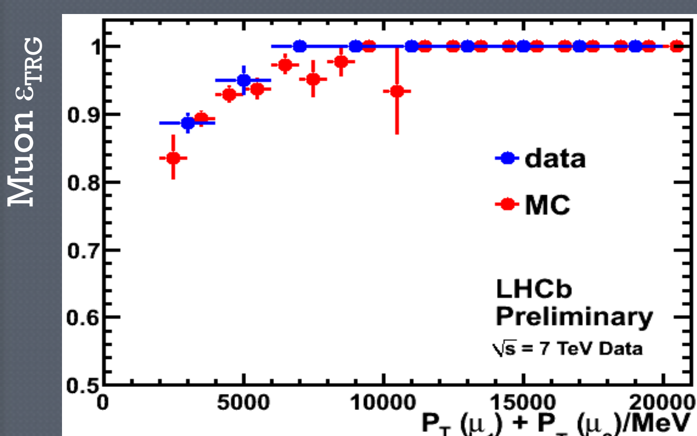


$\mathcal{O}$ (100 GeV/c^2)

Trigger



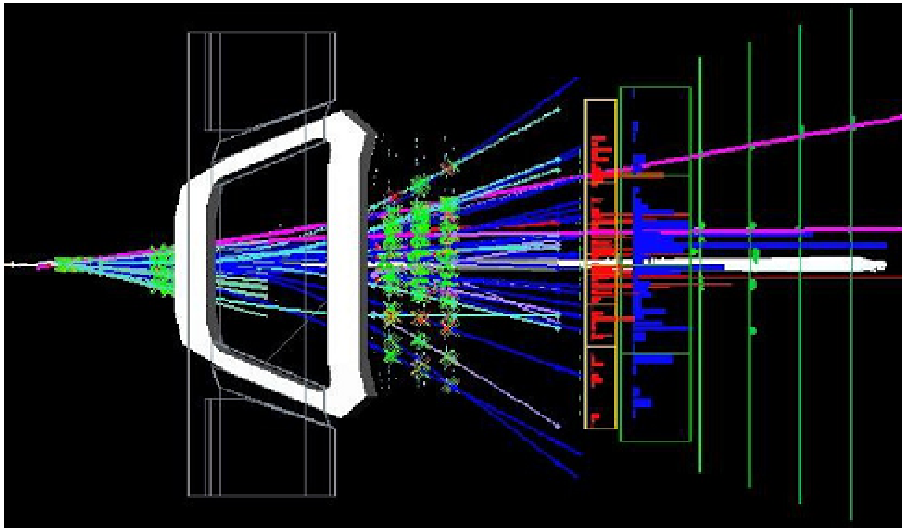


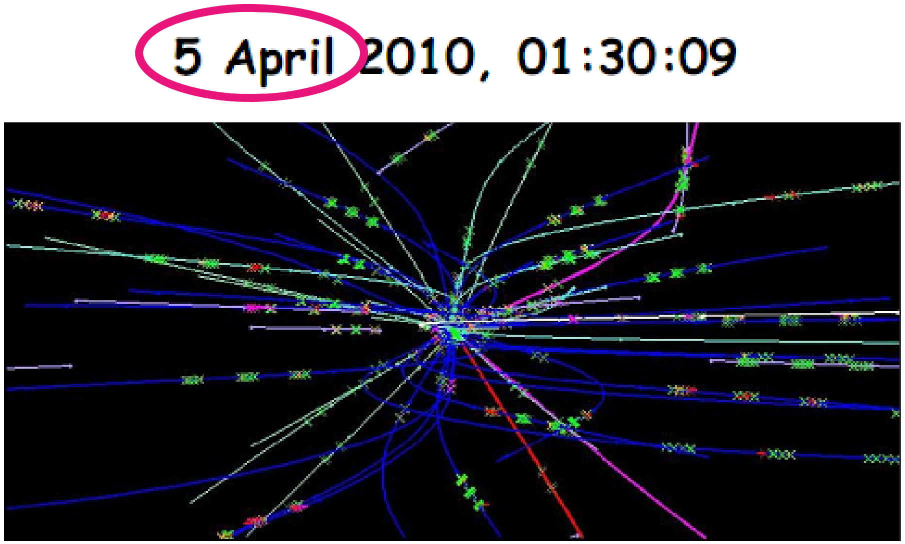


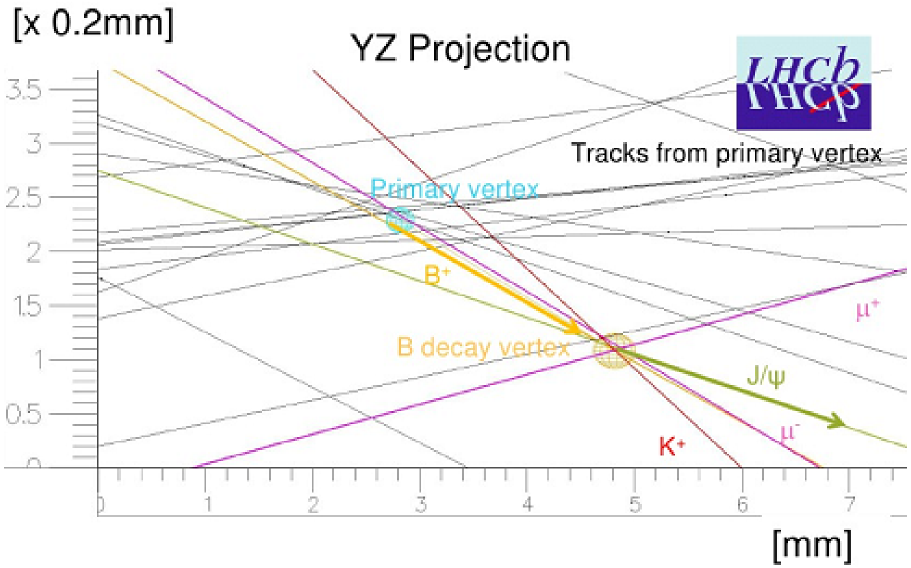
Trigger efficiencies L0xHLT1 determined on data using the tag-and-probe methods:

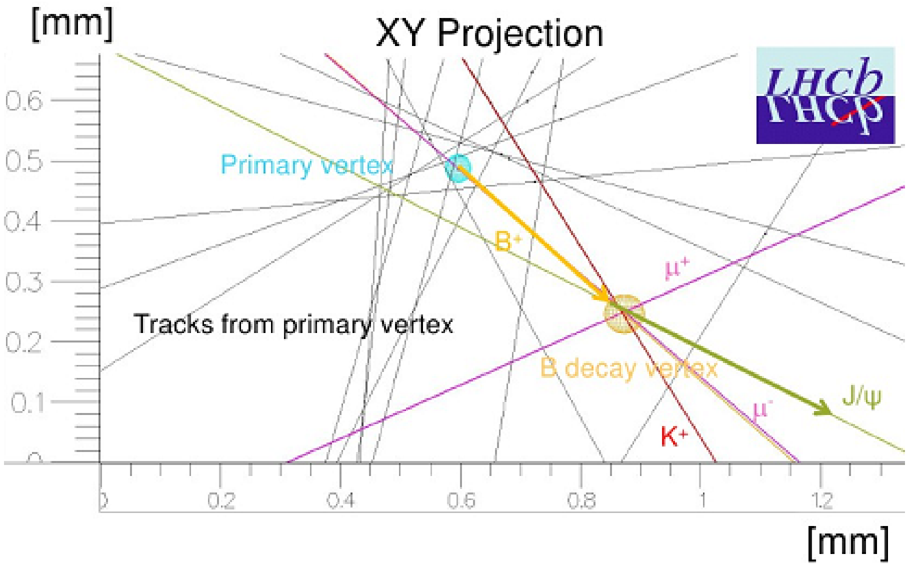
	Muon trigger (J/ψ)	Hadron trigger (D^0)
Data	94.9±0.2%	60±4%
MC	93.3±0.2%	66%

First $B^+ \to J/\psi\ K^+$ candidate









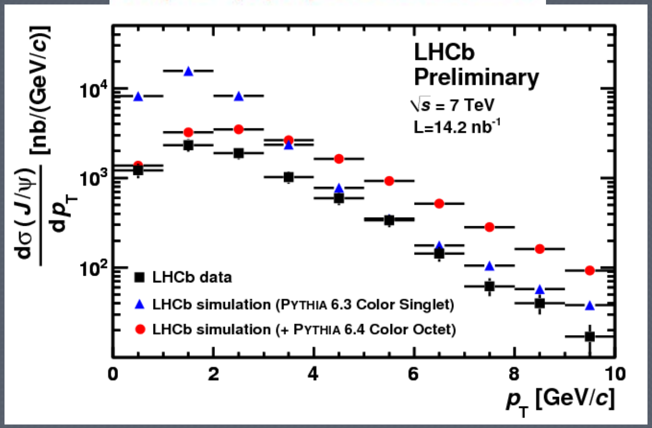
First results

- Physics reaches at LHCb with collected data include so far:
  - Inclusive distributions
  - Strangeness production
  - First Charm results
  - Onia (J/ψ, Υ, χ_c, …)
  - W, Z production
  - Jet studies
  - First b results

↓

Themis Bowcock talk
"B physics with LHCb"

$J/\psi \rightarrow \mu\mu$ production



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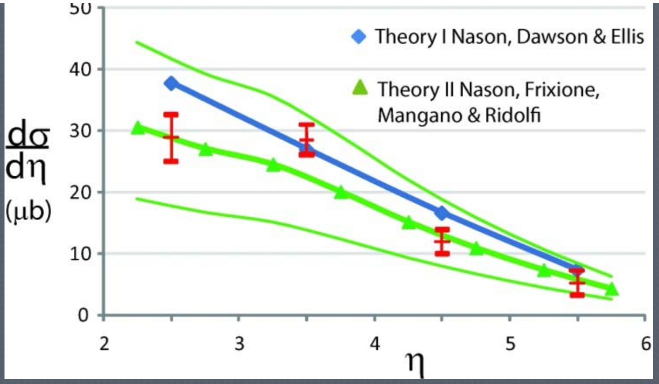
Beauty cross-section with $B \rightarrow D^0 \mu X$



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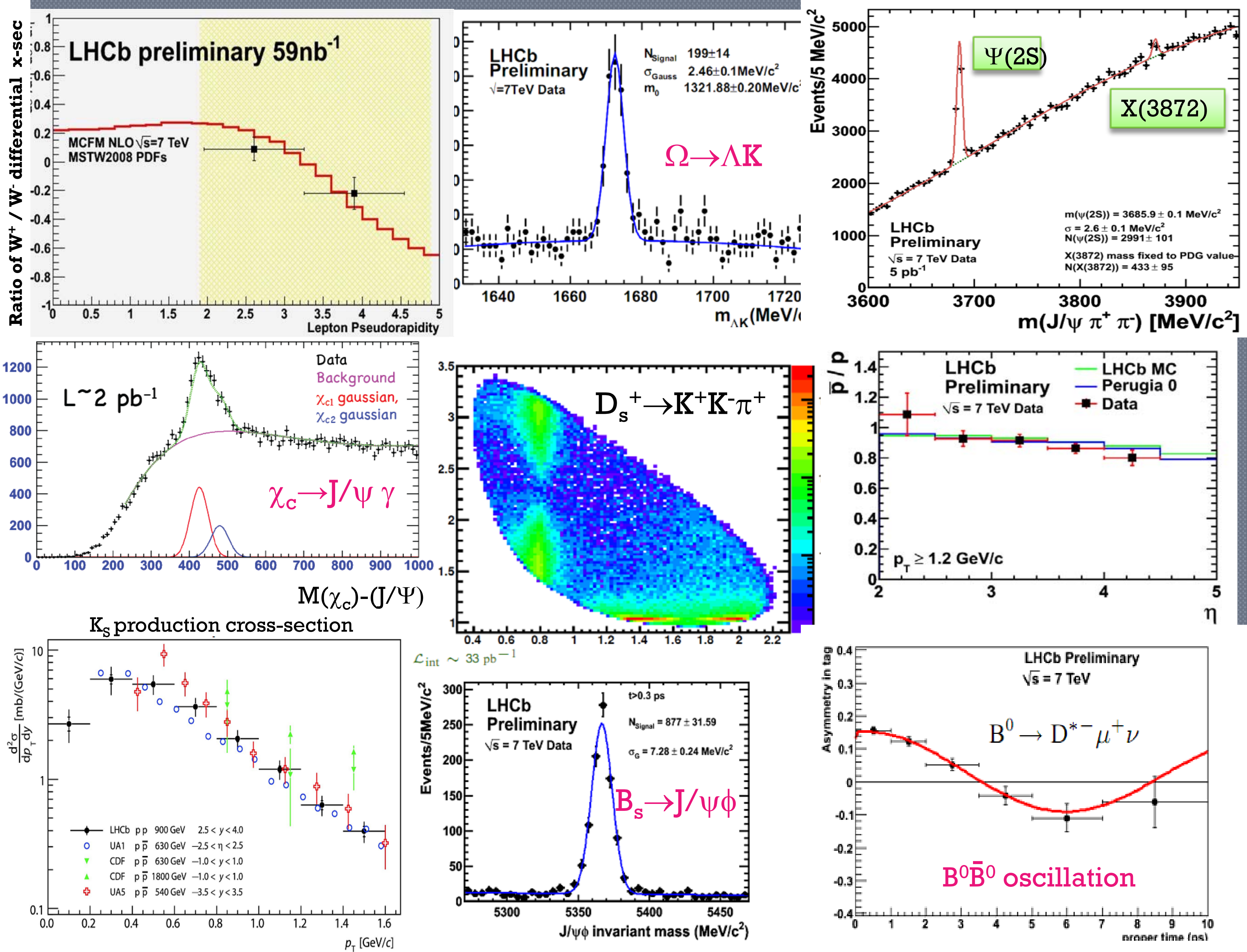


LHCb preliminary 59nb-1
MCFM NLO √s=7 TeV
MSTW2008 PDFs
Ratio of W+ / W- differential x-sec
Lepton Pseudorapidity
LHCb Preliminary
√=7TeV Data
N Signal 199±14
σ Gauss 2.46±0.1MeV/c2
m0 1321.88±0.20MeV/c2
Ω→ΛK
Ψ(2S)
X(3872)
Events/5 MeV/c2
m(ψ(2S)) = 3685.9 ± 0.1 MeV/c2
σ = 2.6 ± 0.1 MeV/c2
N(ψ(2S)) = 2991 ± 101
X(3872) mass fixed to PDG value
N(X(3872)) = 433 ± 95
LHCb Preliminary
√s = 7 TeV Data
5 pb-1
m(J/ψ π+ π-) [MeV/c2]
Data
Background
χc1 gaussian,
χc2 gaussian
L~2 pb-1
χc→J/ψ γ
M(χc)-(J/Ψ)
Ds+→K+K-π+
p̄ / p
LHCb Preliminary
LHCb MC
Perugia 0
Data
√s = 7 TeV Data
pT ≥ 1.2 GeV/c
η
KS production cross-section
d2σ/dpTdy [mb/(GeV/c)]
LHCb p p 900 GeV 2.5 < y < 4.0
UA1 p p̄ 630 GeV −2.5 < η < 2.5
CDF p p̄ 630 GeV −1.0 < y < 1.0
CDF p p̄ 1800 GeV −1.0 < y < 1.0
UA5 p p̄ 540 GeV −3.5 < y < 3.5
pT [GeV/c]
ℒint ~ 33 pb−1
LHCb Preliminary
√s = 7 TeV Data
t>0.3 ps
N Signal = 877 ± 31.59
σG = 7.28 ± 0.24 MeV/c2
Bs→J/ψφ
Events/5MeV/c2
J/ψφ invariant mass (MeV/c2)
LHCb Preliminary
√s = 7 TeV
B0 → D*− μ+ ν
Asymmetry in tag
B0B̄0 oscillation
proper time (ps)

LHCb physics results

Final results:

"Prompt K^0_S production in pp collisions at $\sqrt{s}$=0.9 TeV", PLB 693 (2010) 69

"Measurement of $\sigma(pp \rightarrow b\ \text{anti-}b\ X)$ at $\sqrt{s}$=7 TeV in the forward region", PLB 694 (2010) 209

Preliminary results:

"Prompt charm production in pp collisions in $\sqrt{s}$=7 TeV", LHCb-CONF-2010-013

"Measurements of B^0 mesons production cross-section in pp collisions at $\sqrt{s}$ = 7 TeV using $B^0 \rightarrow D^{*-}\mu^+\nu X$ decays", LHCb-CONF-2010-012

"Measurement of prompt Λ-bar/Λ and Λ-bar/K^0_S production ratios in inelastic non-diffractive pp collisions at $\sqrt{s}$ = 0.9 and 7 TeV", LHCb-CONF-2010-011

"Measurement of the J/Ψ production cross section at $\sqrt{s}$ = 7 TeV in LHCb", LHCb-CONF-2010-010

"Measurement of the p-bar/p ratio in LHCb at $\sqrt{s}$=900 GeV and 7 TeV", LHCb-CONF-2010-009

More coming soon!

2011 and beyond - expectations

- 2011
  - Ready to have detector, trigger and readout operating at 2-2.5 interations/bunch crossing at a maximum instantaneous luminosity around $3 \cdot 10^{32}$ $cm^{-2}s^{-1}$.
  - Expect to collect an integrated luminosity > **1 fb^{-1}** and perform full physics programme.
- "1st run"
  - Expect to collect up to **6 fb^{-1}**
- Upgrade
  - Expect to collect **50 fb^{-1}** (5 years at 10fb^{-1} /year)
  - Increase nominal luminosity to $L=10^{33}$ $cm^{-2}s^{-1}$
  - Detector read-out at 40 MHz.
    - Allows fully software based trigger.
    - Keep 20 kHz HLT output rate.
  - Phase-I (2016)
    - New FE-electronics for 40 MHz readout
    - Novel Velo pixel detector
    - RICH photon detectors replacement
    - New TT, IT tracking system

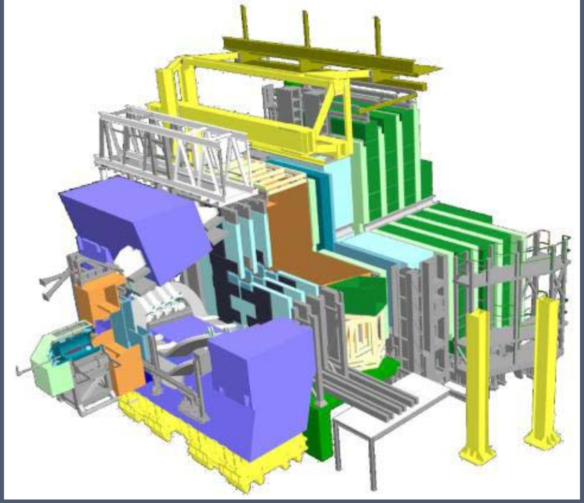
Upgraded Sensitivities (50 fb^{-1})	
Observable	Sensitivity
CPV($B_s \to \phi\phi$)	0.024
CPV($B_d \to \phi K_s$)	0.027-0.064
CPV($B_s \to J/\psi\phi$) ($2\beta_s$)	0.004
CPV($B_d \to J/\psi K_s$) (2β)	0.004-0.014
CPV($B \to DK$) (γ)	<1.4°
CPV($B_s \to D_s K$) (γ)	1.4-2.8°
$\mathcal{BR}$($B_s \to \mu^+\mu^-$)	~15% of SM
A_{FB}($B \to K^*\mu^+\mu^-$)	Zero to ±0.1GeV^2
$\sigma(\sin 2\psi)(B_s \to \phi\gamma)$	0.03
Charm mixing x'^2	$3x10^{-5}$
Charm mixing y'	$4x10^{-4}$
Charm CP y_{CP}	$2x10^{-4}$

Summary and Outlook

- Performance of detector and quality of data collected in 2010 are excellent.
  - About 38 pb^{-1} of useful data with an efficiency above 90%.
  - Performance close to expectation.
  - First important physics results emerging.
- Looking forward to a successful proton physics run in 2011, with an integrated luminosity >1 fb^{-1}.
  - With1-2 fb^{-1} of data we can make precise measurements in areas with great discovery potential.
  - Possible even though we run beyond our design conditions.
- Preparation for LHCb upgrade to collect data at 5-10 times higher luminosity is underway.


The End

Backup



LHCb Collaboration

Day of the 1st Collisions in 2010

751 participants
54 institutes
15 countries

Operation consecuence of high-μ

- Running with multiple interactions has implications on trigger, computing, reconstruction and analysis.

- Increases readout rate per bunch crossing.
  - This year only 344 crossings to look at, 3.5 MHz rate, "easy" to use L0 trigger to get to 1 MHz.
- Increases event size and storage rate.
  - @ μ~2.5 → 60 kB
- Number of tracks and event complexity.
- High particle flux. Ageing and detector stability.

- Adapted trigger settings to cope with increasing luminosity.
  - High priority to muon triggers
  - Reduction of hadron lines when needed
  - Rejection of very high multiplicity events (Global Event Cuts)
- Despite running beyond design conditions, no problem of data quality in 2010.
- Many physics channels do not gain significantly at high μ.

Agreement on the instantaneous luminosity the LHCb detector can handle

	μ	$\mathcal{L}$ [10^{32}cm-2s-1]
Vertex Locator	>3	5
Silicon Tracker	2.6	4.2 – 8.4 (HV?)
Outer Tracker	2-2.3	5 ok, but aging
RICHes	2.3-2.5 (CO_2)	No maximum
Calorimeter	2.5	5
Muon system	2.6	3 (7Tev)

Grid Usage

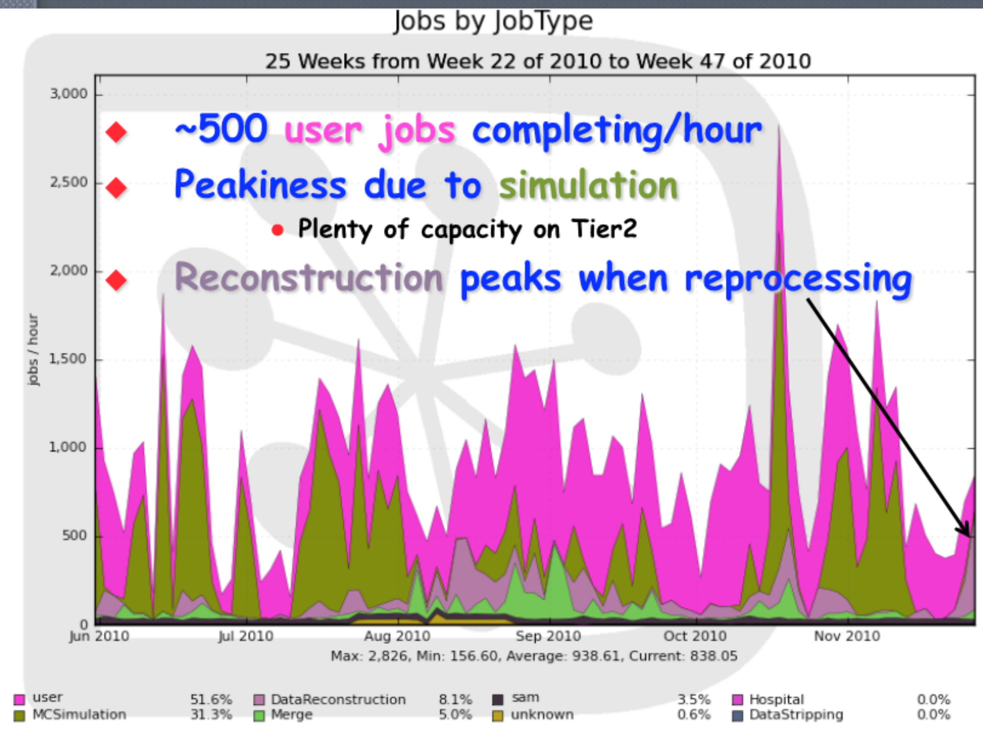
115 sites used
21 countries

CERN as Tier-0
6 Tier-1's
>100 Tier-2's

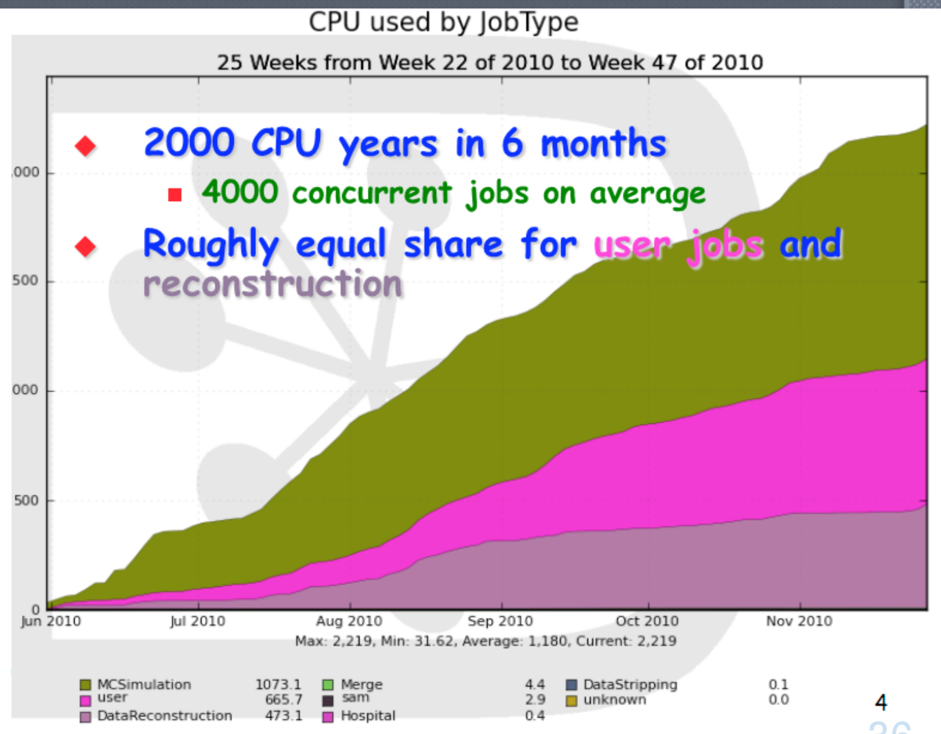
CERN and the Tier-1's: Reconstruction, Stripping and User analysis

Tier-2's: MC production

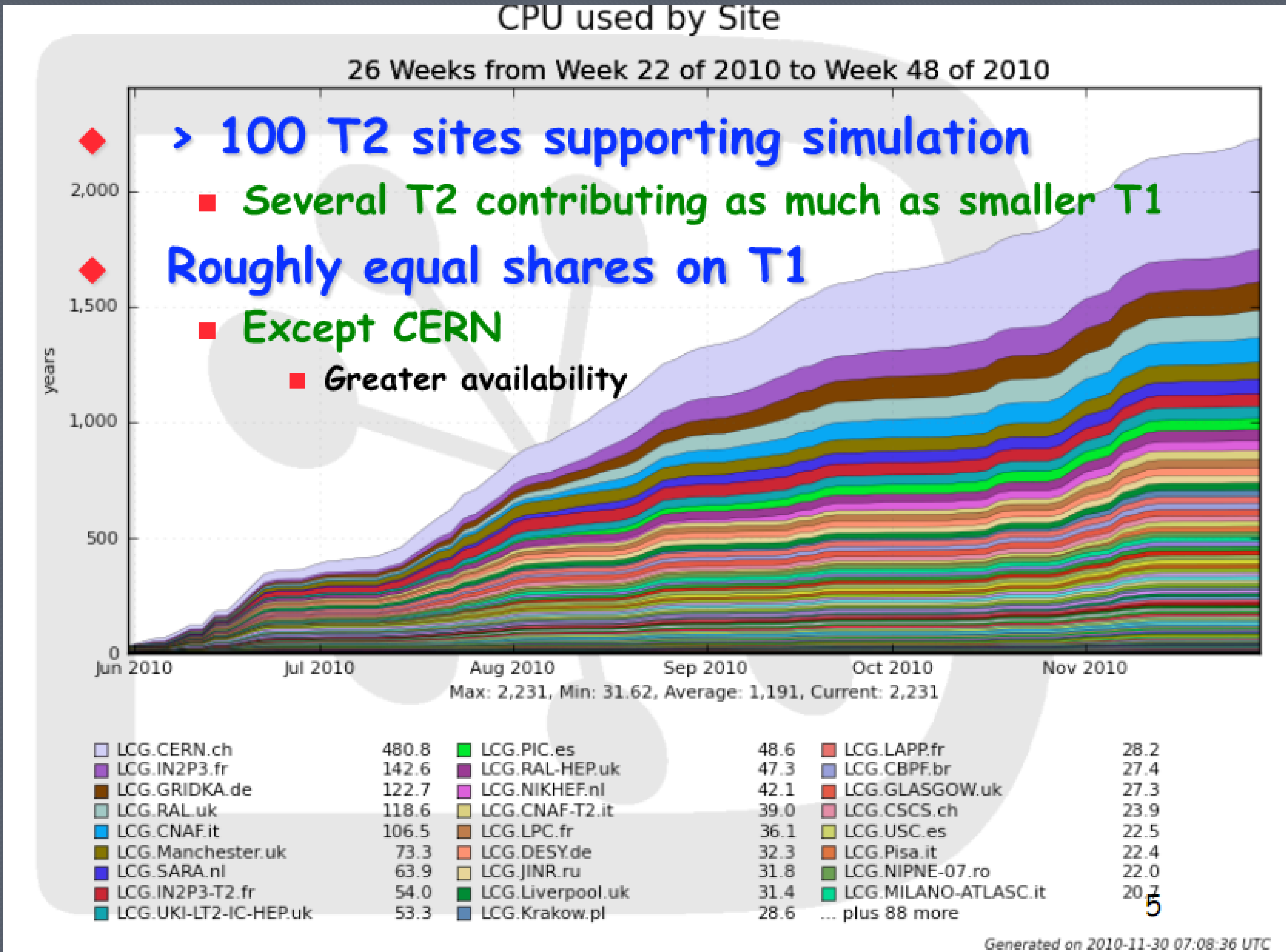
Finished jobs per hour, June to November



Cumulative CPU Usage



- > 100 T2 sites supporting simulation
  - Several T2 contributing as much as smaller T1
- Roughly equal shares on T1
  - Except CERN
    - Greater availability



Flavour tagging

Flavour tagging is the procedure which determines the flavour at production of the reconstructed B meson.

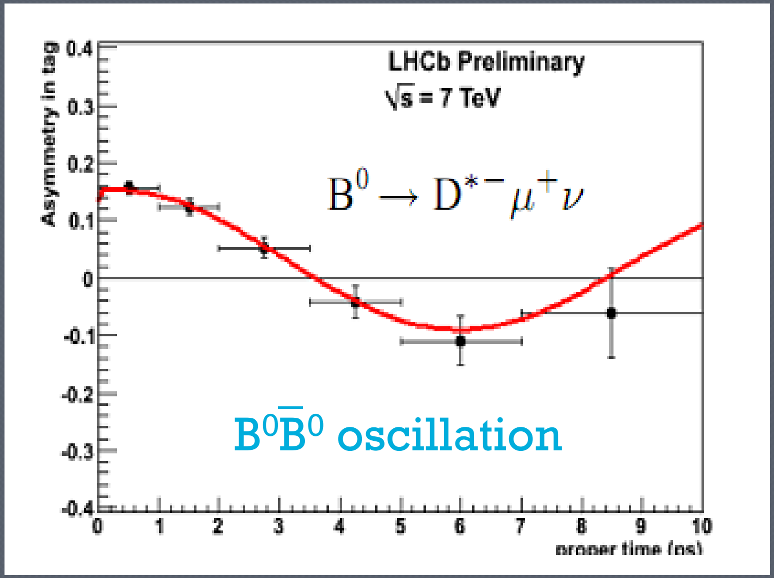
Taggers calibration on-going.
Opposite-Side (μ, e, K, Q_{vrtx}):

From the other B in the event

$\varepsilon_{tag} = 41.8 \pm 0.3\%$
$\omega = 39.8 \pm 0.6\%$
$\varepsilon_{eff} = 1.7 \pm 0.2\% = \varepsilon_{tag} \cdot D^2$

Still lower than the MC expectations ($\varepsilon_{eff} = 2.5\%$)

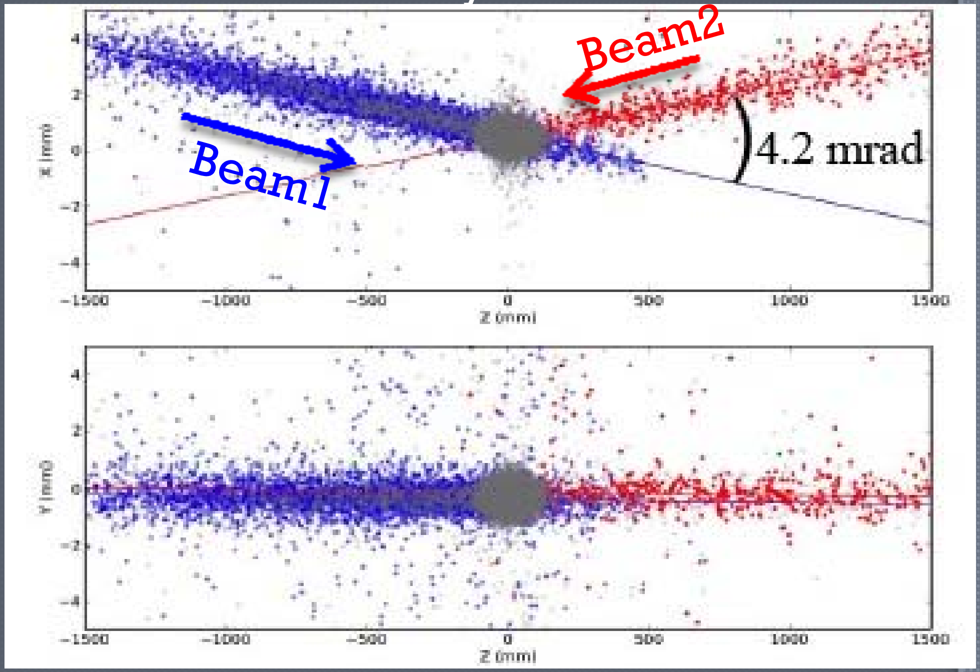
Same-Side tagger (hadron from fragmentation) should nearly double the tagging efficiency



Luminosity

- Cross sections normalized using Luminosity L
- L determined from:
  - Van der Meer scan
    - based on beam separation scans
  - Beam-gas imaging method (only possible @LHCb)
    - can run parasitically during physics running
    - non disruptive
    - → potentially smaller systematic

x-z and y-z vertices



Luminosity: $\mathcal{L} = n_1 \cdot n_2 \cdot f / \mathcal{A}_{eff}$

n:	protons/bunch
f:	collision frequency
$\mathcal{A}_{eff}$:	effective area calculated from beam size and position

→From LHC measurements

→ From VELO measurement of beam sizes, position and angles in beam-gas interactions

First results

B semi-leptonics

$B_s \to J/\Psi\varphi$ related

$B \to DX$

$B_s \to \mu\mu$

$B \to hh$

Charm mixing, CPV and rare decays

X(3872)

Onia

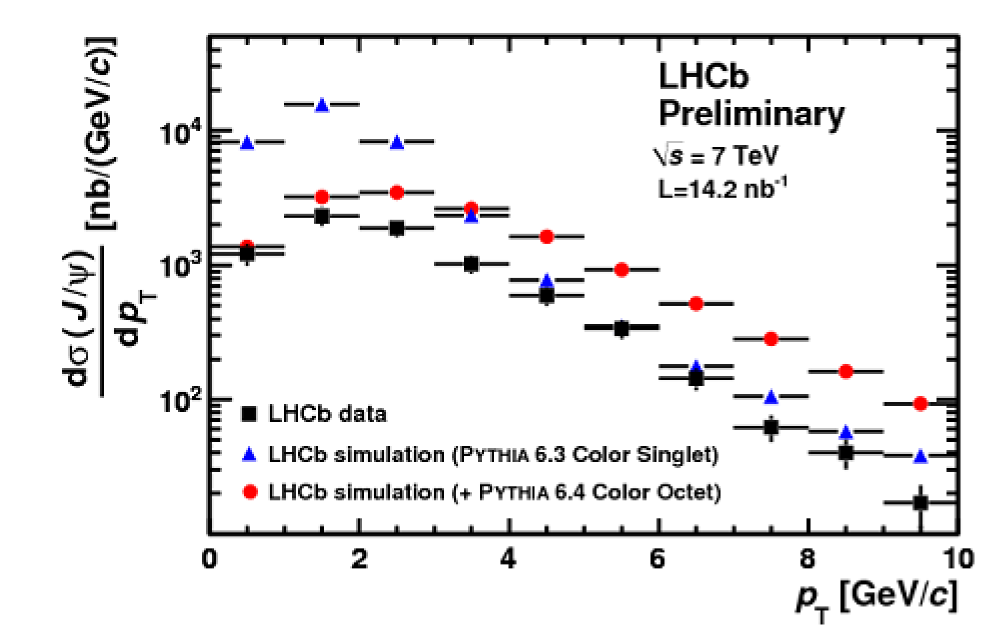
Exclusive J/Ψ production

Jet studies

W/Z production

Soft QCD

J/ψ→μμ production



Scale and shapes not well described by colour singlet nor by octet models→ new studies are coming.

~14 nb^{-1}

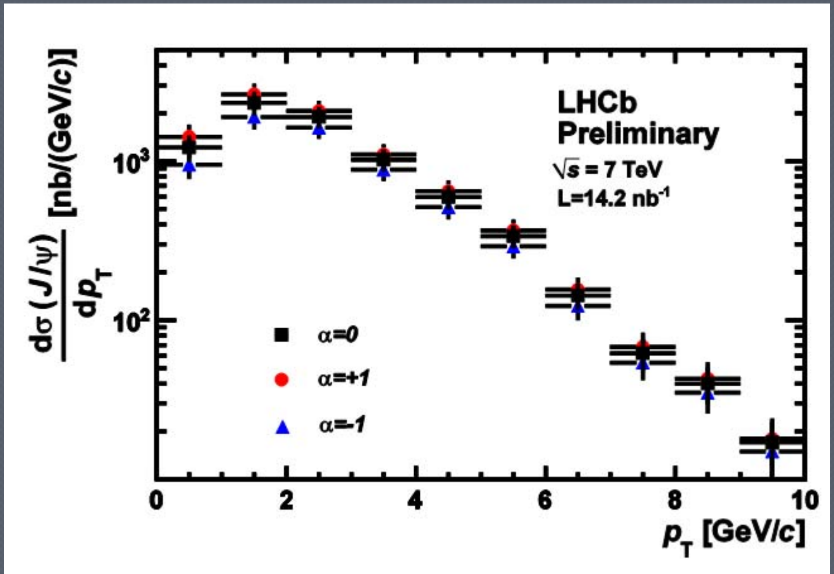
- Inclusive J/ψ production:

  $\sigma(2.5<y<4, p_T<10\ \mathrm{GeV/c}) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}\ \mu b$

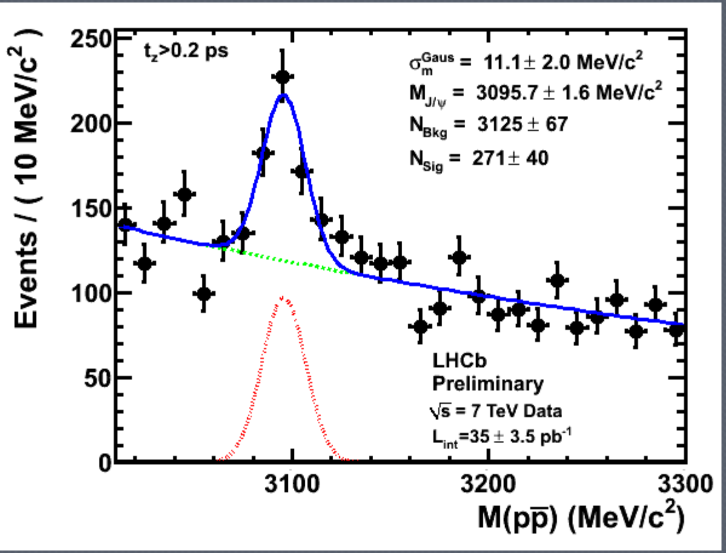
  polarization uncertainty

- J/ψ production from b:

  $\sigma(2.5<y<4, p_T<10\ \mathrm{GeV/c}) = 0.81 \pm 0.06 \pm 0.13\ \mu b$



No significant polarisation observed at LHCb with current data



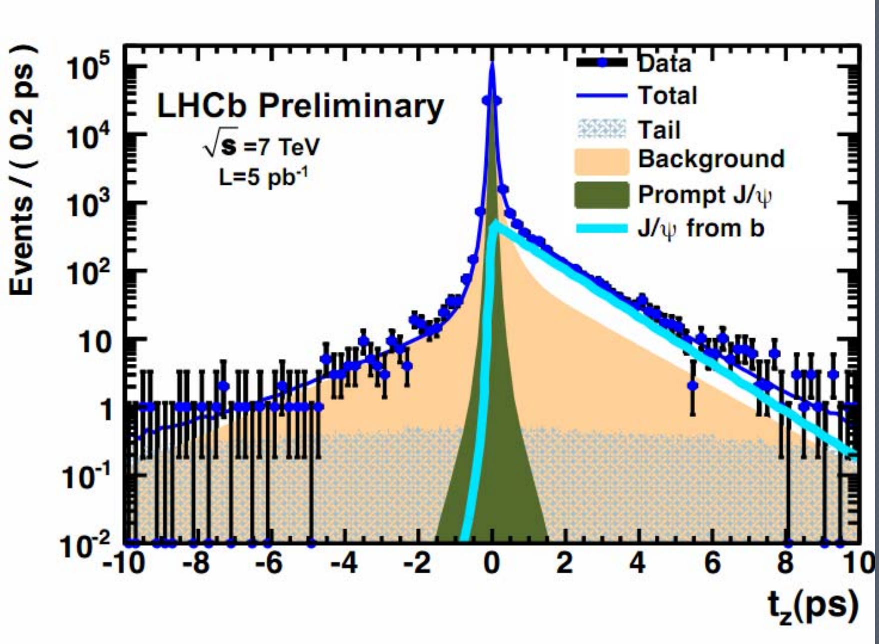
$J/\psi \rightarrow p\bar{p}$

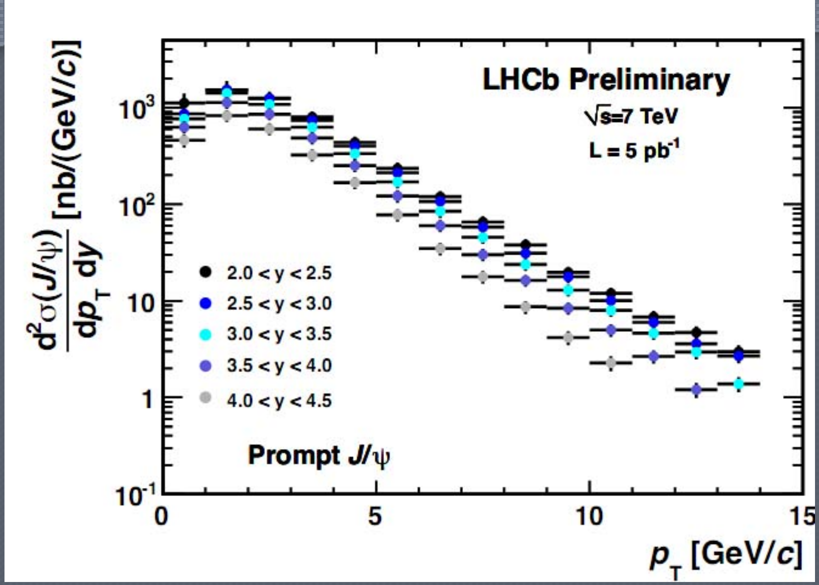
Measurement of prompt J/ψ and J/ψ from *b* Cross-Sections

underlying production mechanism is not yet understood.

Measure double-differential cross-section $d^2\sigma/(dy dp_T)$ of:

- **prompt J/ψ** (=direct and feed-down from χ_c),
- **J/ψ from *b***-hadron decays.

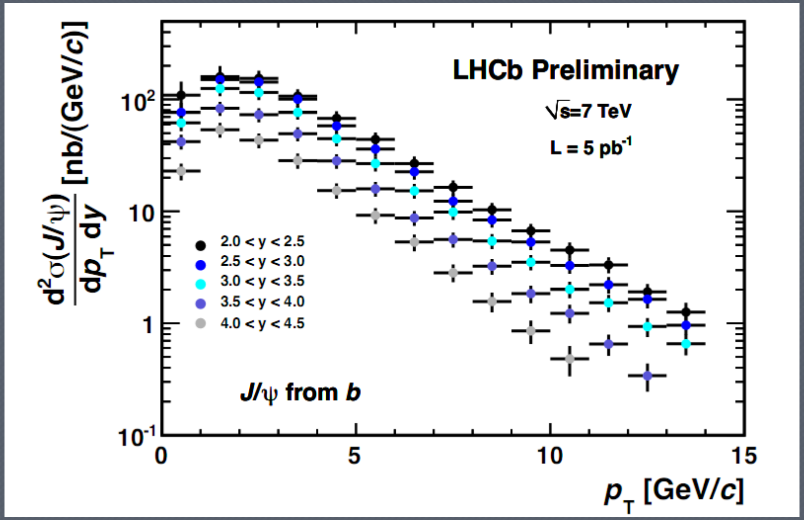




prompt J/ψ

$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

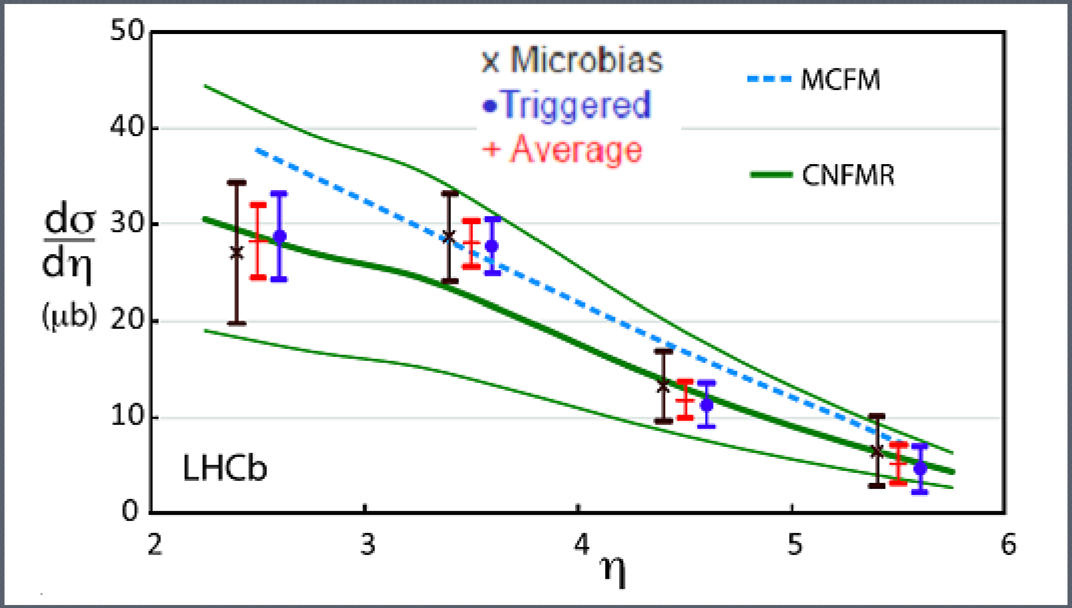
$$\sigma\,(\text{prompt } J/\psi,\, p_{\mathrm{T}} < 14\ \text{GeV}/c,\, 2 < y < 4.5) \;=\; 10.8 \pm 0.05 \pm 1.51^{+1.69}_{-2.25}\ \mu\text{b}$$



J/ψ from *b*

$$\sigma\,(J/\psi \text{ from } b,\, p_{\mathrm{T}} < 14\ \text{GeV}/c,\, 2 < y < 4.5) \;=\; 1.16 \pm 0.01 \pm 0.17\ \mu\text{b}$$

Beauty cross-section with B→$D^0\mu X$



Shapes and scales agree well with expectation. Validates QCD predictions at LHC energies

$\sigma(pp\rightarrow H_b X) = 75.3\pm5.4\pm13.0\ \mu b$ for $2<\eta<6$, any p_T, $\sqrt{s}=7$ TeV

Extrapolating to 4π with PYTHIA 6.4: **$\sigma(pp\rightarrow b\bar{b}X) = 284 \pm 20 \pm 49\ \mu b$**

Averaging with prel. result from b→J/ψ: **$\sigma(pp\rightarrow b\bar{b}X) = 292 \pm 15 \pm 43\ \mu b$**

Theory: MCFM 332 μb, NFMR 254 μb

b-hadron fractions

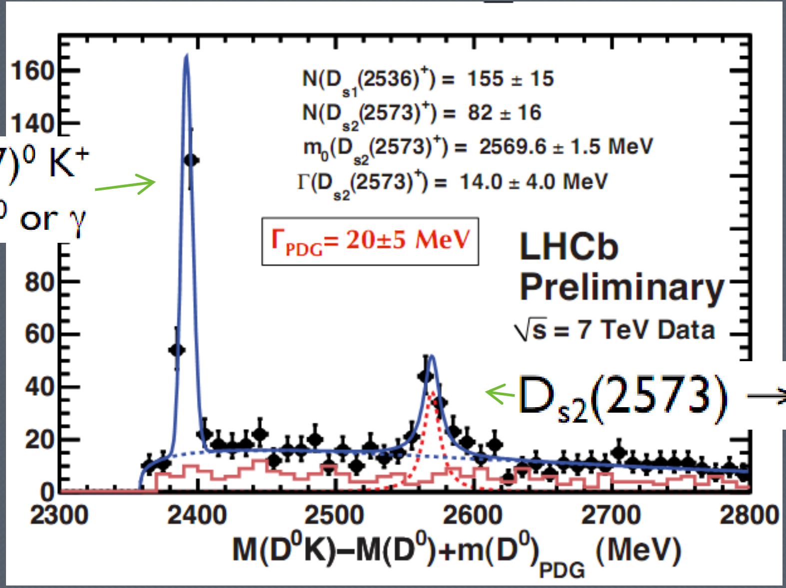
$f_s/(f_u+f_d) = 0.130 \pm 0.004(\text{stat.}) \pm 0.013(\text{sys.})$ [preliminary]

LEP: 0.129 ± 0.012

Tevatron: 0.18 ± 0.03

$B_s \rightarrow D^0 K^+ X \mu^- \nu$

$D_{s1}(2536) \rightarrow D^*(2007)^0 K^+$ missed π^0 or γ

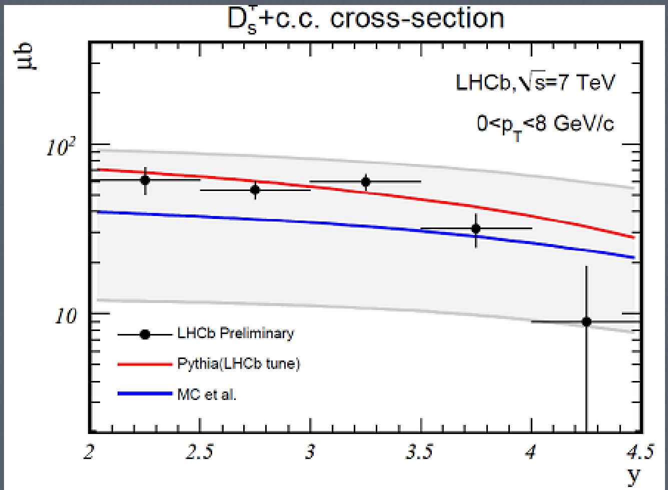


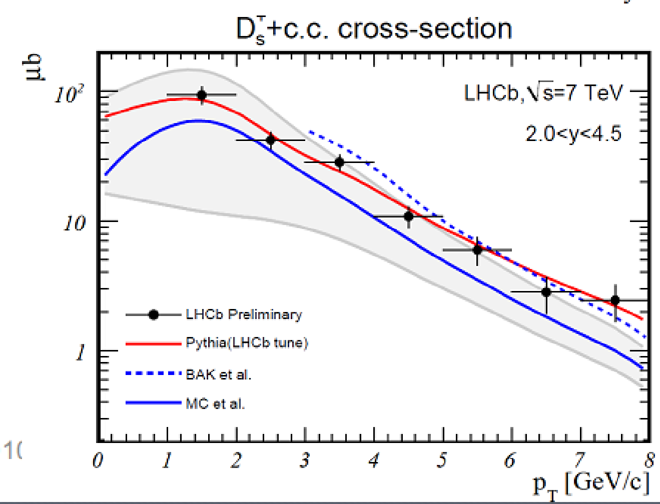
$D_{s2}(2573) \rightarrow D^0 K^+$

8.3 σ significance for $B_s \rightarrow D_{s2} \mu^- \nu$ mode.

Discovery!

Open charm cross-sections (D^*, D^0, D^+, D_s) @ $\sqrt{s}$ = 7 TeV





Combining $D^0/D^+/D^{*+}/D_s^+$

$\sigma(pp \to ccX)$ = 1234 ± 189 μb (pT< 8 GeV/c, 2<y<4.5)

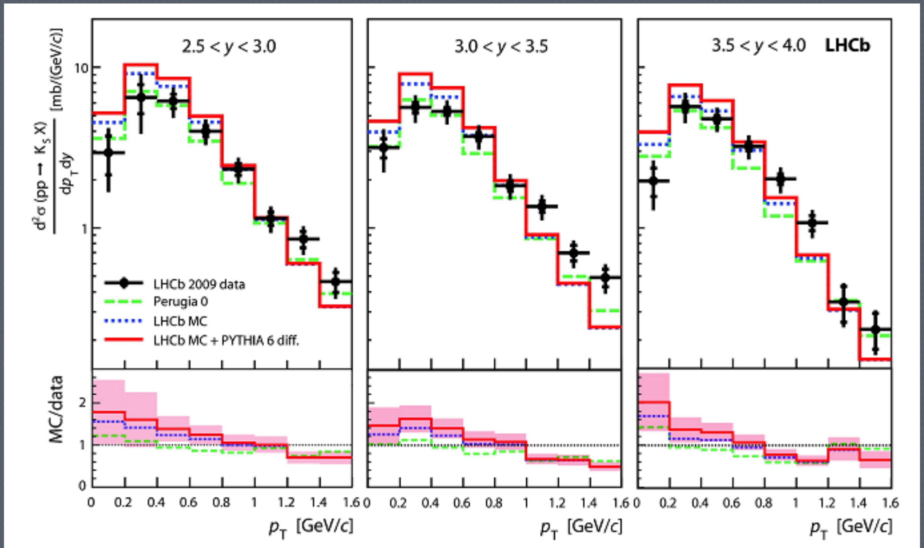
$\sigma(pp \to ccX)$ = 6100 ± 934 μb (full accept.)

Particle production multiplicities at LHCb

- K_S production cross section
- $\overline{\Lambda}/\Lambda$, $\overline{\Lambda}/K_S$ production ratios
- $\overline{p}/p$ production ratio
- Inclusive Φ cross section

Preliminary results compared to models indicate:
- Higher baryon transport
- Harder P_T spectra
- Underestimated strangeness production

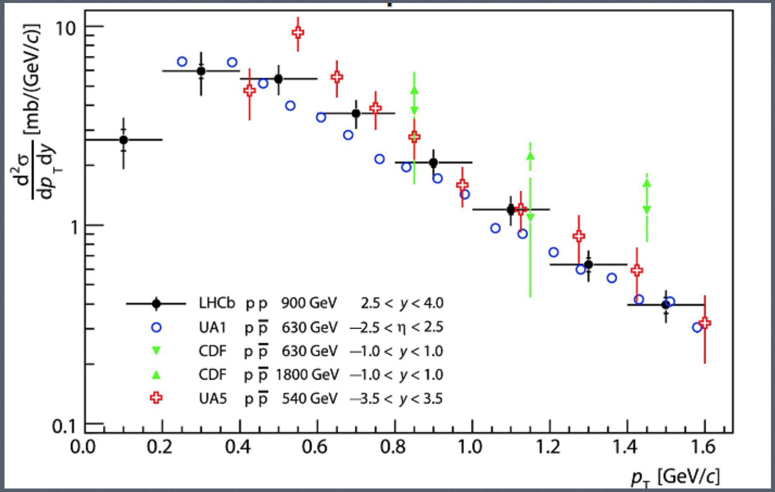
K_S production cross section



$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

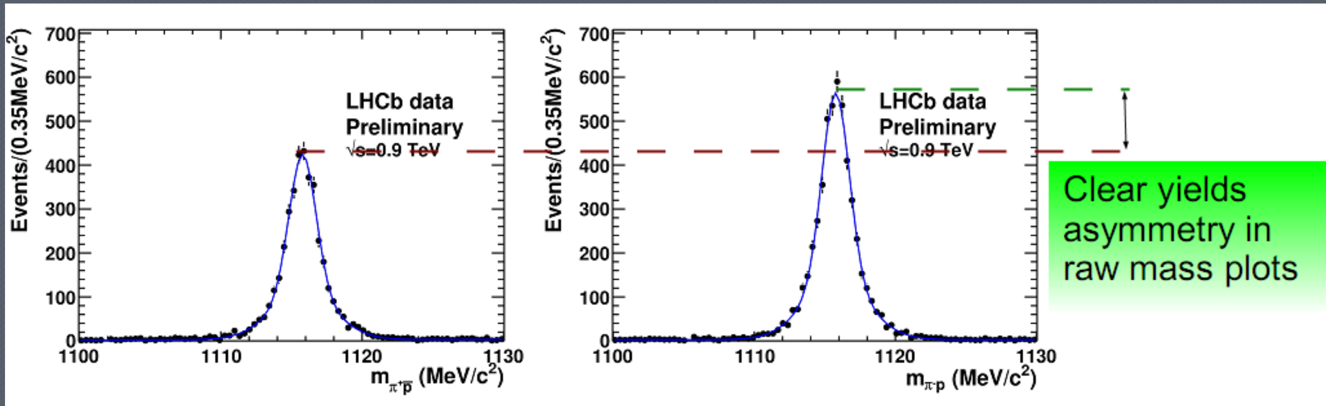
Good consistency with PYTHIA expectations
P_T spectra slightly harder

Published in: Phys. Lett. B 693 (2010) 69-80



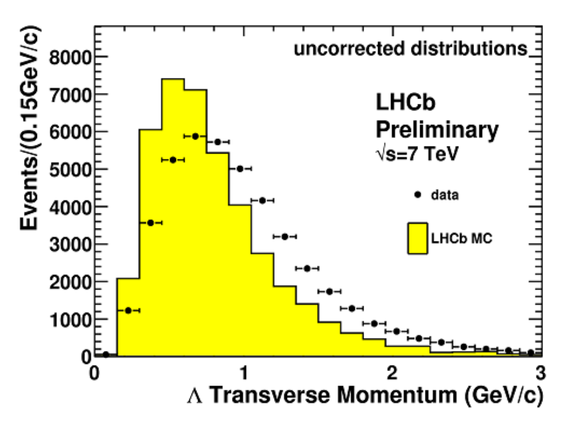
Unique measurement at high rapidity and low P_T

$\overline{\Lambda}/\Lambda$, $\overline{\Lambda}/K_S$ production ratios

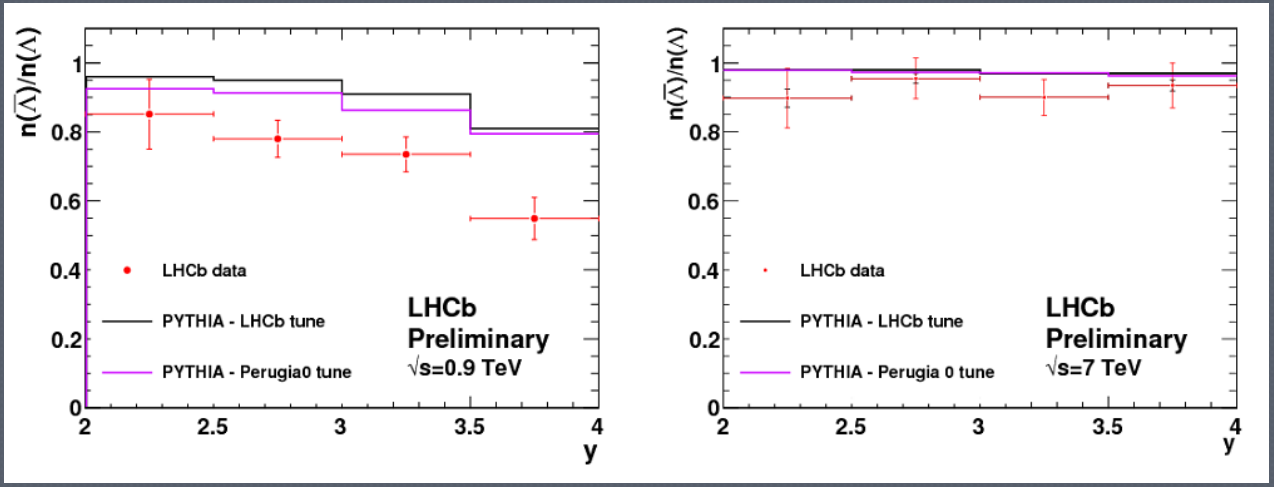


Clear yields asymmetry in raw mass plots

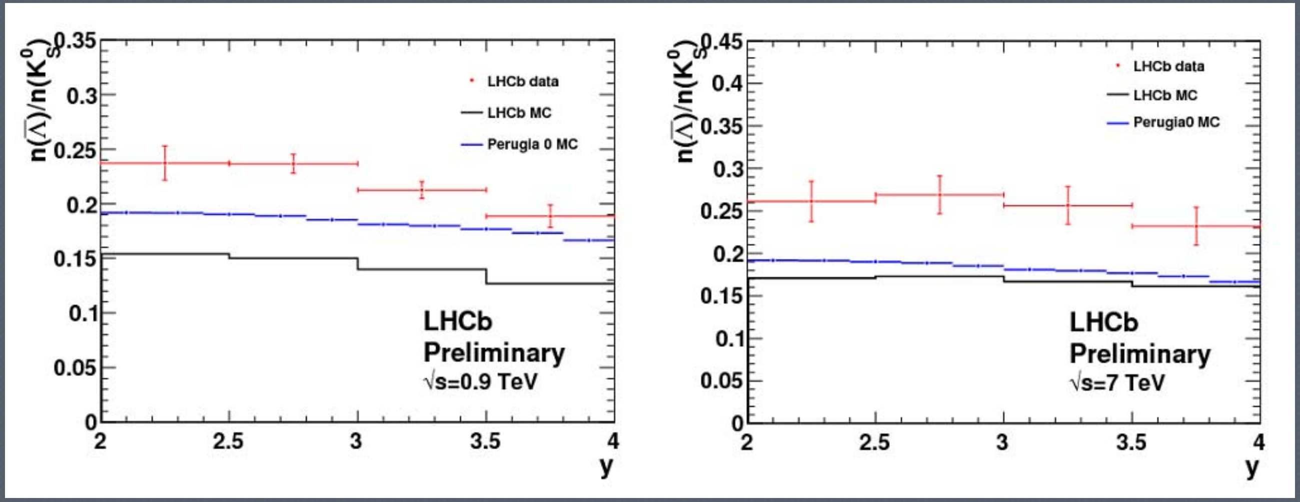
CERN-LHCb-CONF-2010-011



P_T spectra harder than predicted

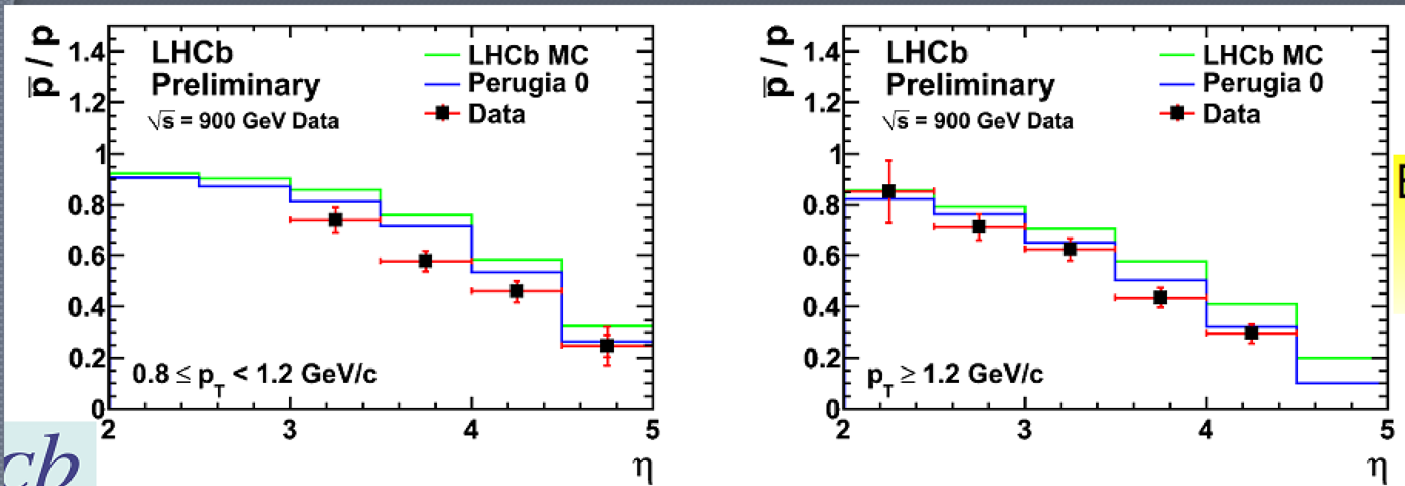


Baryon transport higher than predicted at 0.9 TeV



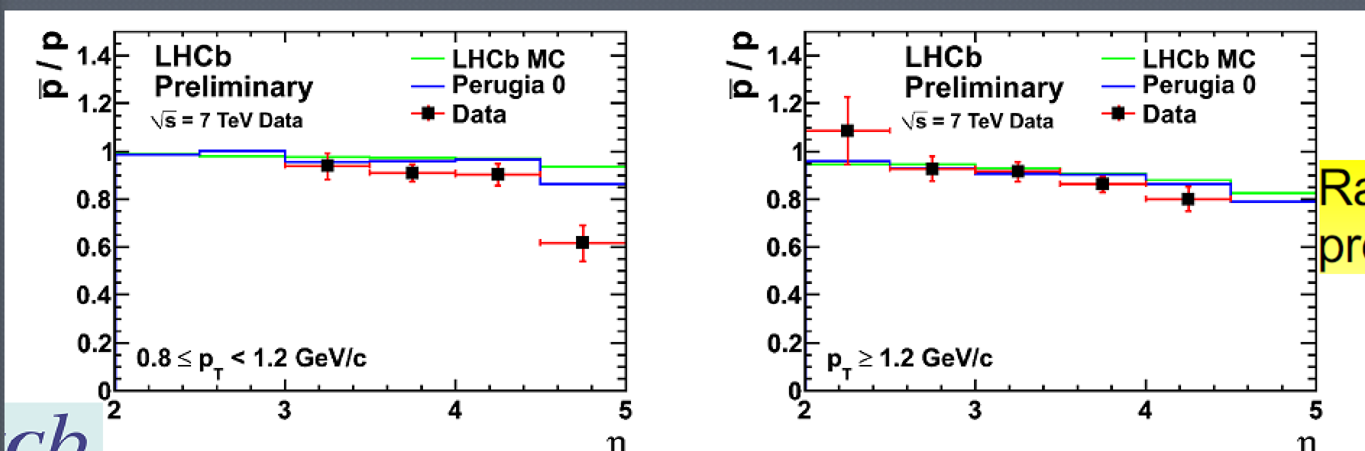
Baryon/Meson suppression lower than predicted

$\bar{p}/p$ production ratio



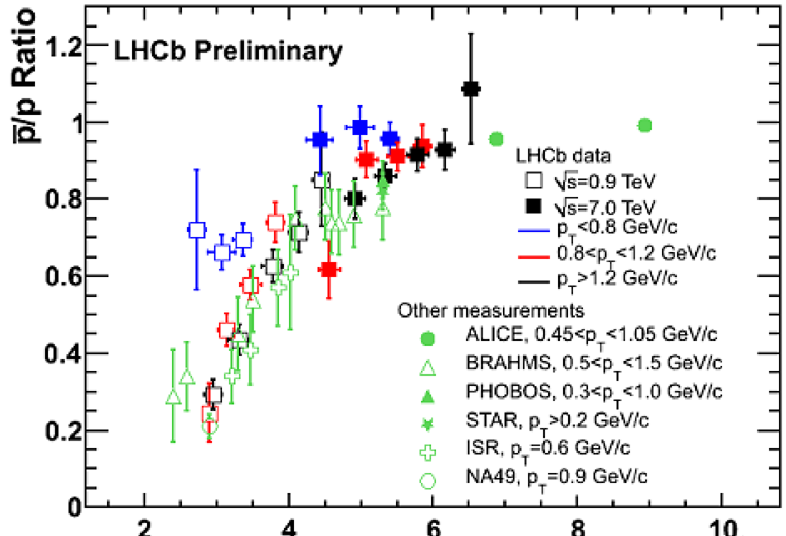
Baryon transport higher than predictions and consistent with $\bar{\Lambda}/\Lambda$

CERN-LHCb-CONF-2010-009



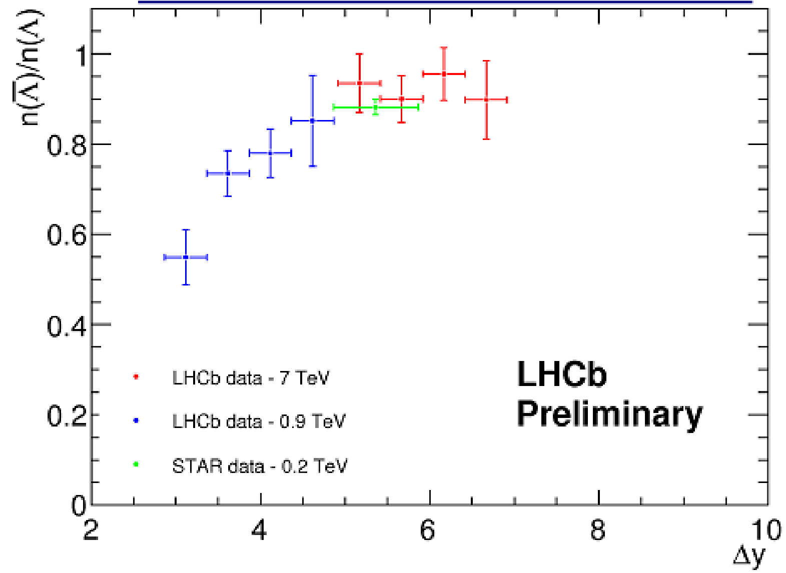
Ratios become flatter as predicted by models

CERN-LHCb-CONF-2010-009



Indications of P_T dependence

CERN-LHCb-CONF-2010-011

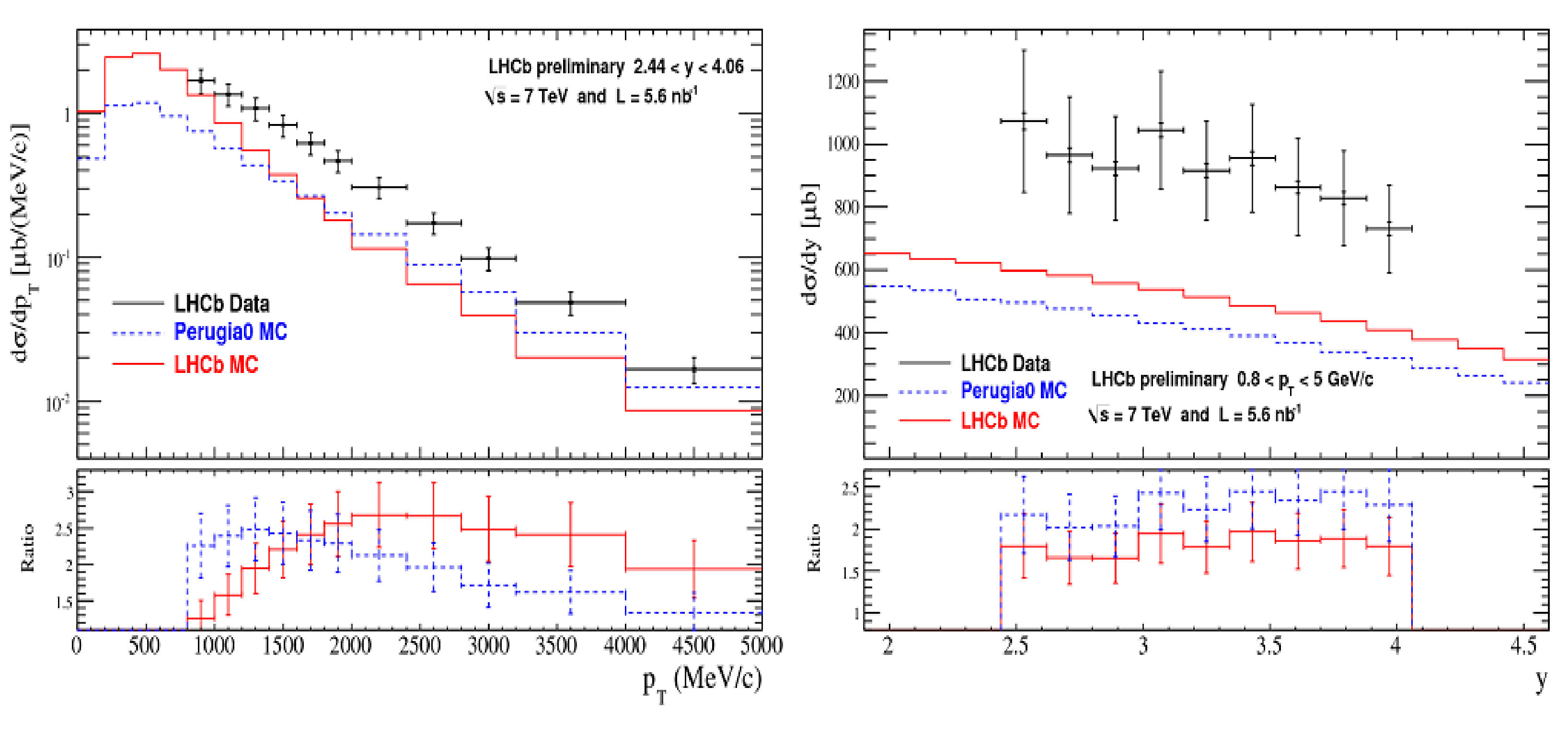


Summary

- prompt K^0_s absolute production cross section at $\sqrt{s}$ = 0.9TeV presented:
  - p_T spectra tend to be "harder" than PYTHIA predictions
  - extended measurement range to lower p_T and new y range
- prompt $\overline{\Lambda}$ / Λ ratio at $\sqrt{s}$ = 0.9TeV
  - tends to be lower than PYTHIA Perugia0 and LHCb tune, lower at larger y
- prompt $\overline{\Lambda}$ / Λ ratio at $\sqrt{s}$ = 7TeV
  - in fair agreement with PYTHIA LHCb tune, quite flat vs. y
- prompt $\overline{p}$ / p ratios at $\sqrt{s}$ = 0.9TeV and $\sqrt{s}$ = 7TeV
  - show similar energy dependence as Λ / Λ
- prompt $\overline{\Lambda}$ / K^0_s ratio at $\sqrt{s}$ = 0.9TeV and $\sqrt{s}$ = 7TeV
  - baryon suppression in hadronization is lower than predicted

Inclusive Φ cross section

Test QCD fragmentation models

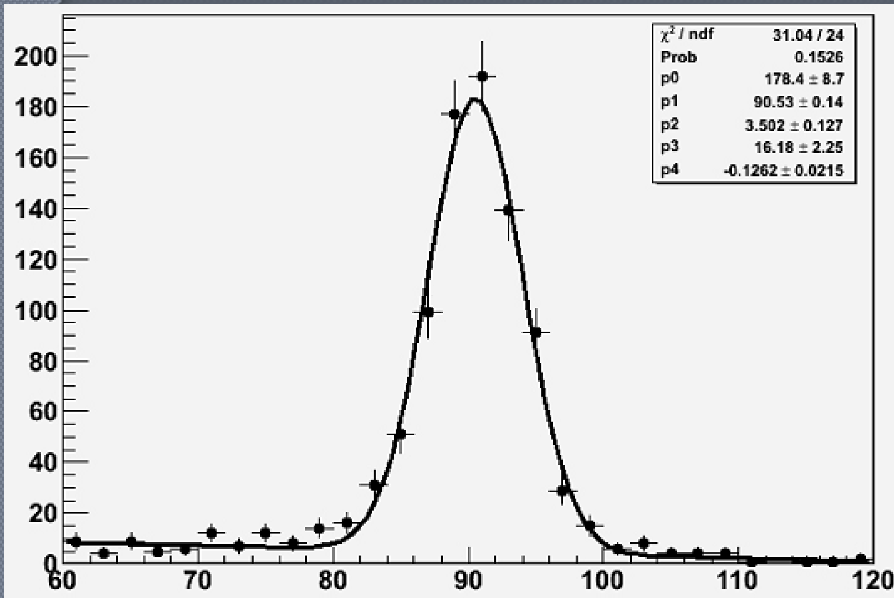


Both tunings underestimate Φ production in the measured kinematic range

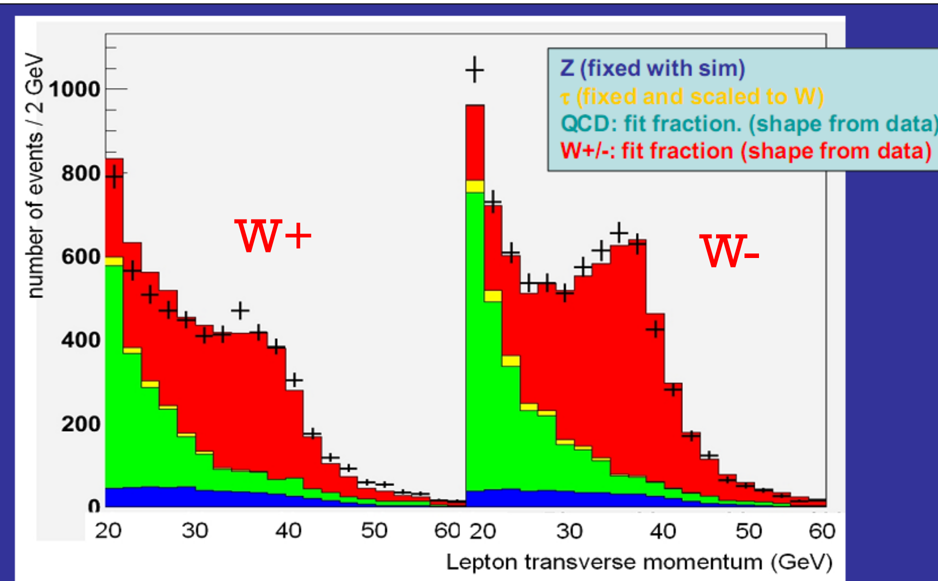
$$\sigma(pp \to \phi X) = (1493 \pm 12(\mathrm{stat}) \pm 12(\mathrm{syst}) \pm 209(\mathrm{syst}))\mu\mathrm{b}$$

$$y \in [2.44, 4.06] \qquad p_{\mathrm{T}} \in [0.8, 5.0]\ \mathrm{GeV/c}$$

W analysis

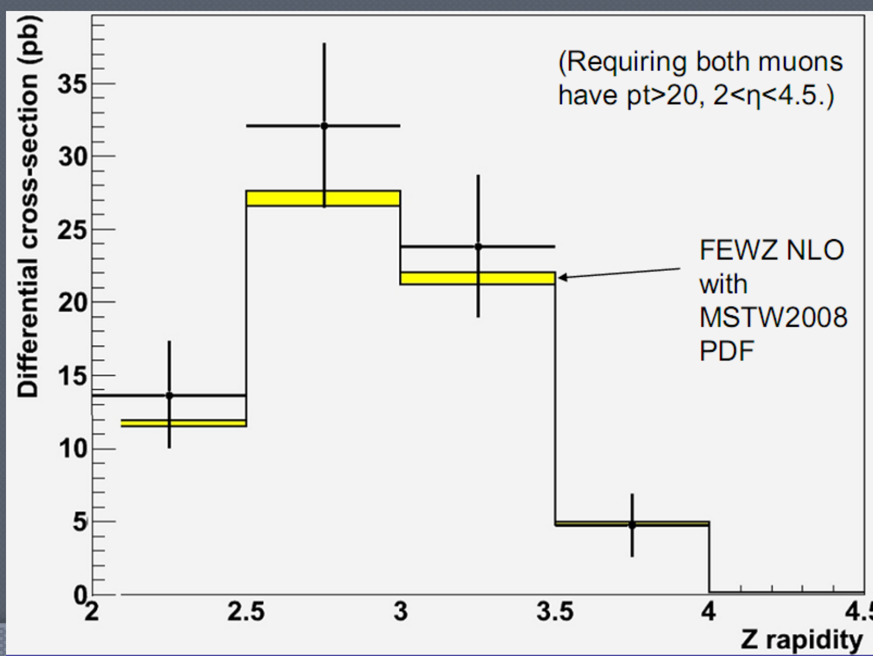


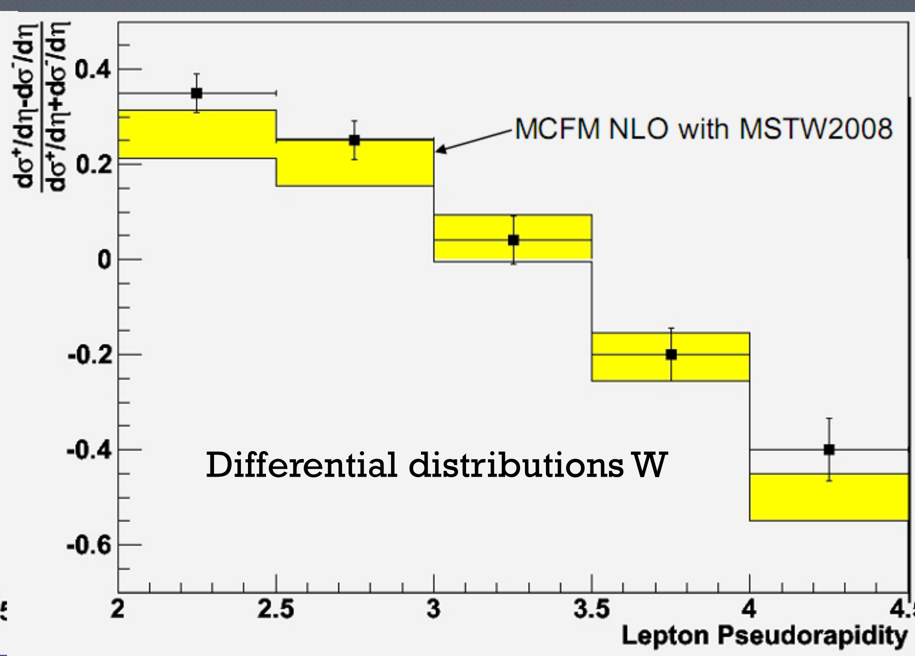
Z mass (GeV)



$$\sigma_{W\rightarrow\mu\nu}(\Delta\eta) = \frac{N^W_{tot} - N^W_{bkg}}{\epsilon_W L} \rightarrow \frac{N^W_{tot}}{L}\left(\frac{p_W}{\epsilon_W}\right)$$

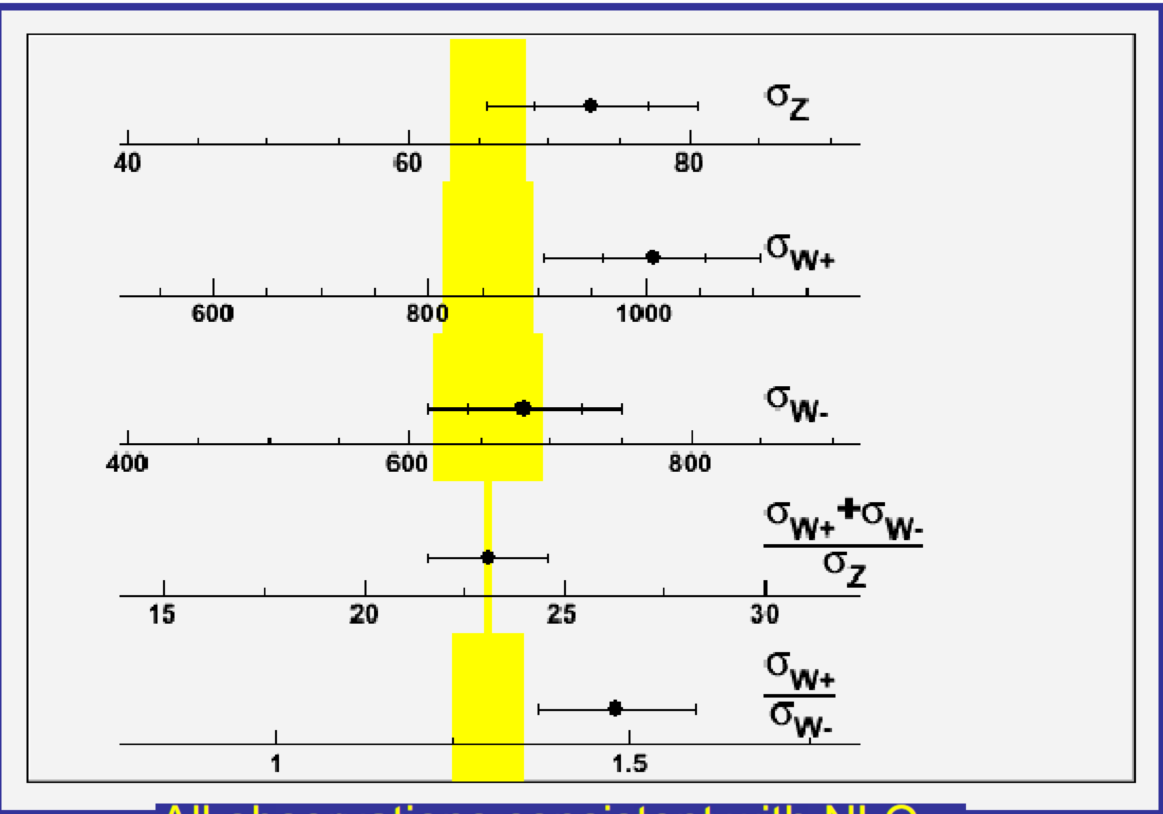
and all found from data.





W, Z cross-sections $2<\eta<4.5$

Generator	Order	PDF Set	Z	$W+$	$W-$	$(W^+ + W^-)/Z$	W^+/W^-
FEWZ	NLO	MSTW08NLO CTEQ66NLO NNPDF2.0	$65.7^{+2.9}_{2.5}$				
MCFM		MSTW08NLO CTEQ66NLO NNPDF2.0	$65.5^{+2.8}_{-2.5}$	855 ± 43	656 ± 39	23.1 ± 0.1	1.30 ± 0.05
FEWZ	NNLO	MSTW08NNLO					
Data			$73 \pm 4 \pm 7.5$	$1007 \pm 48 \pm 101$	$682 \pm 40 \pm 68$	23.1 ± 1.5	1.48 ± 0.11



All observations consistent with NLO theory