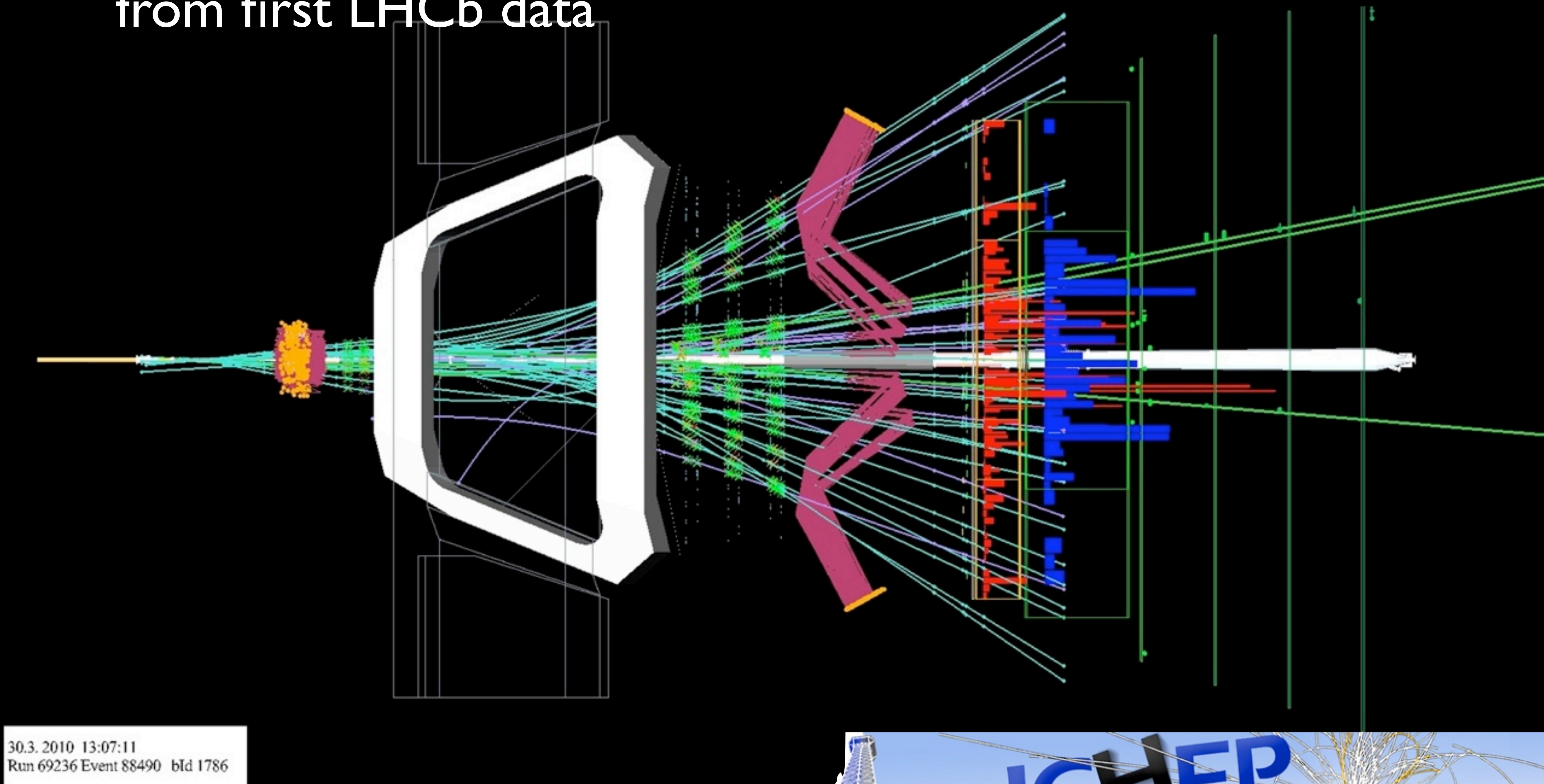
Prospects for CP violation in $B_s \rightarrow J/\psi\phi$
from first LHCb data

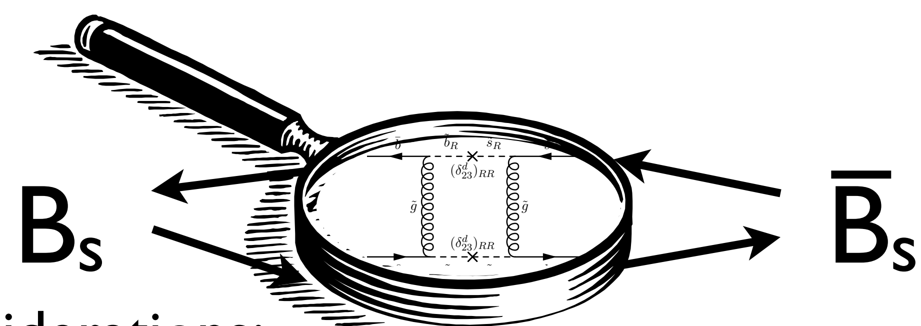


Gerhard Raven
on behalf of the LHCb collaboration

vrije Universiteit amsterdam NIKHEF LHCb

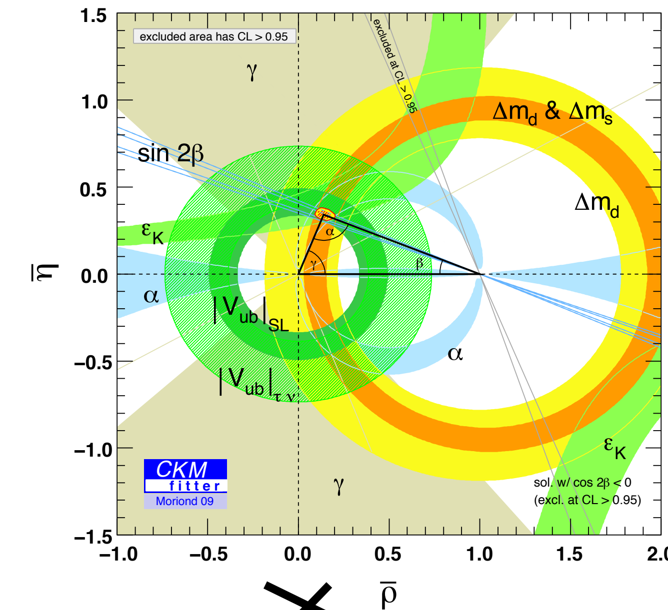
CP violation in $B_s \to J/\psi\phi$

- Interference between $B_s\,\bar{B}_s$ mixing and $b \to c(\bar{c}s)$ decay
- Compared to $B^0 \to J/\psi K_S$, assuming CKM is 'all there is':
  - frequency enhanced: $\Delta m_d = 0.5/\text{ps} \to \Delta m_s = 17.7/\text{ps}$
  - A_{CP} suppressed: $\sin(2\beta) = 0.69 \to \sin(\phi_s^{J/\psi}) = -0.04$
- But physics beyond SM could change this picture



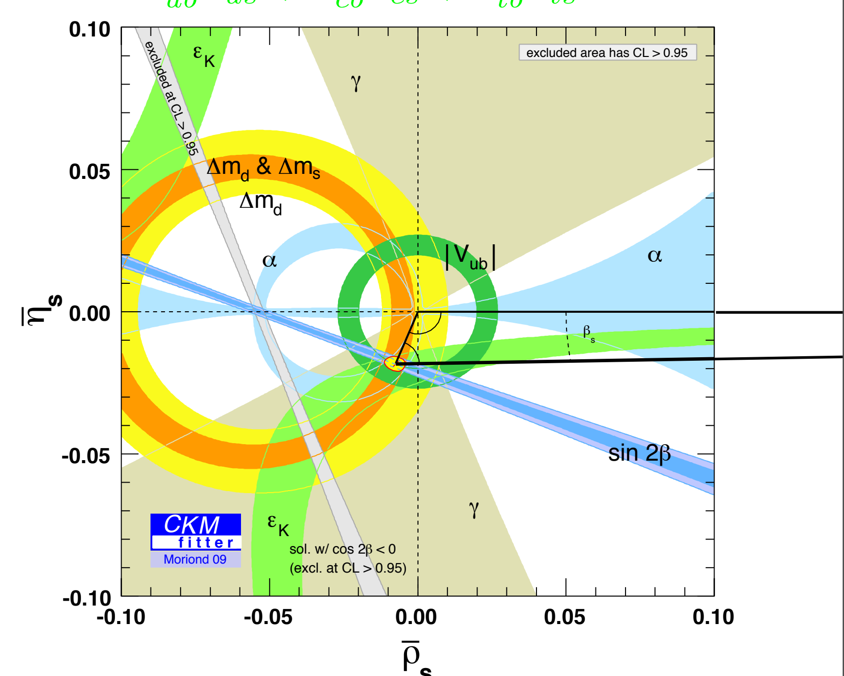
- Experimental considerations:
  - small Br ⇒ requires copious source of B_s mesons
  - fast oscillations ⇒ proper time resolution
  - CP asymmetry ⇒ flavor tagging
  - VV final state ⇒ angular analysis

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

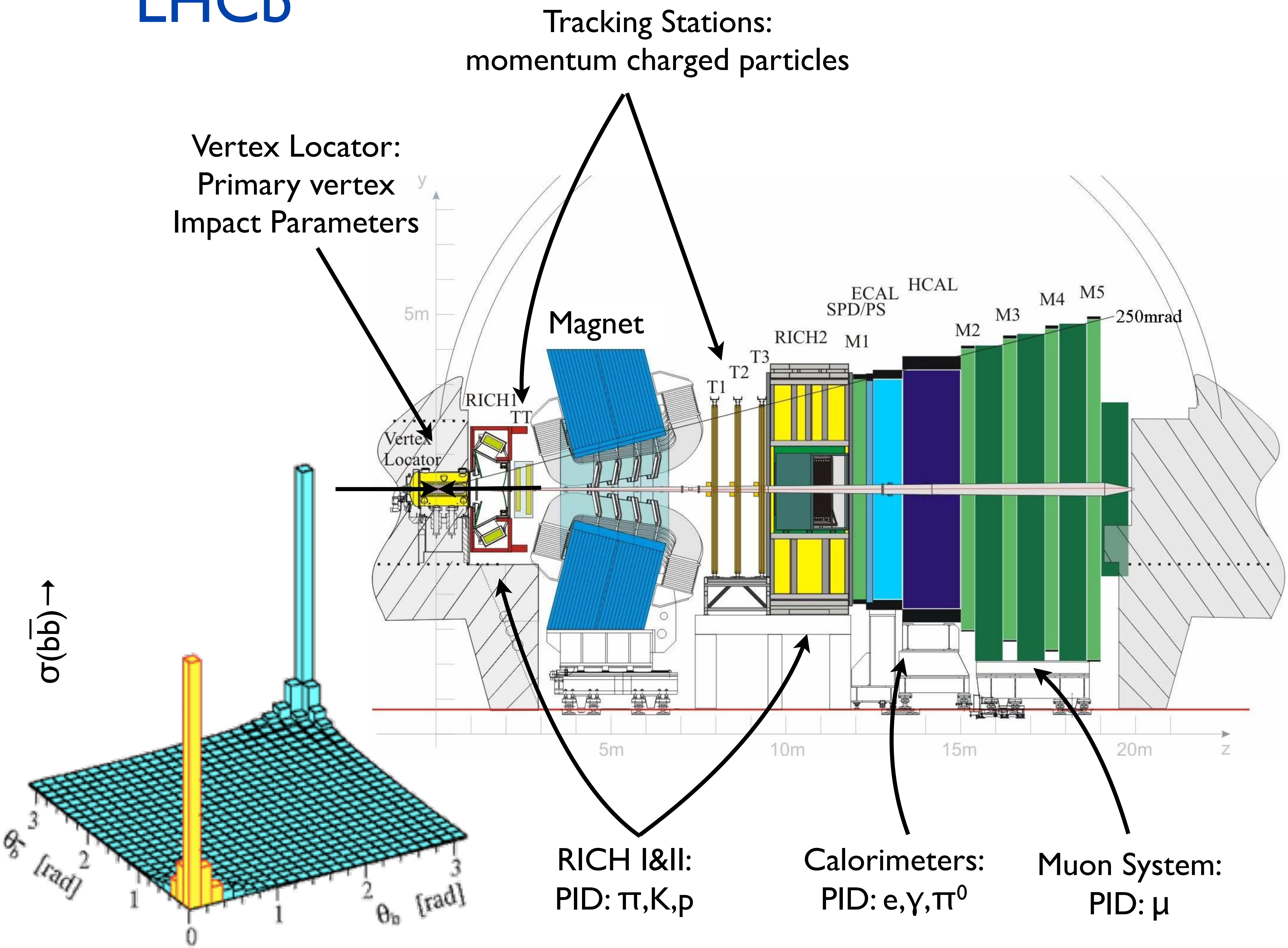


$$\times \frac{V_{us}V_{cd}}{V_{ud}V_{cs}} \approx -\lambda^2$$

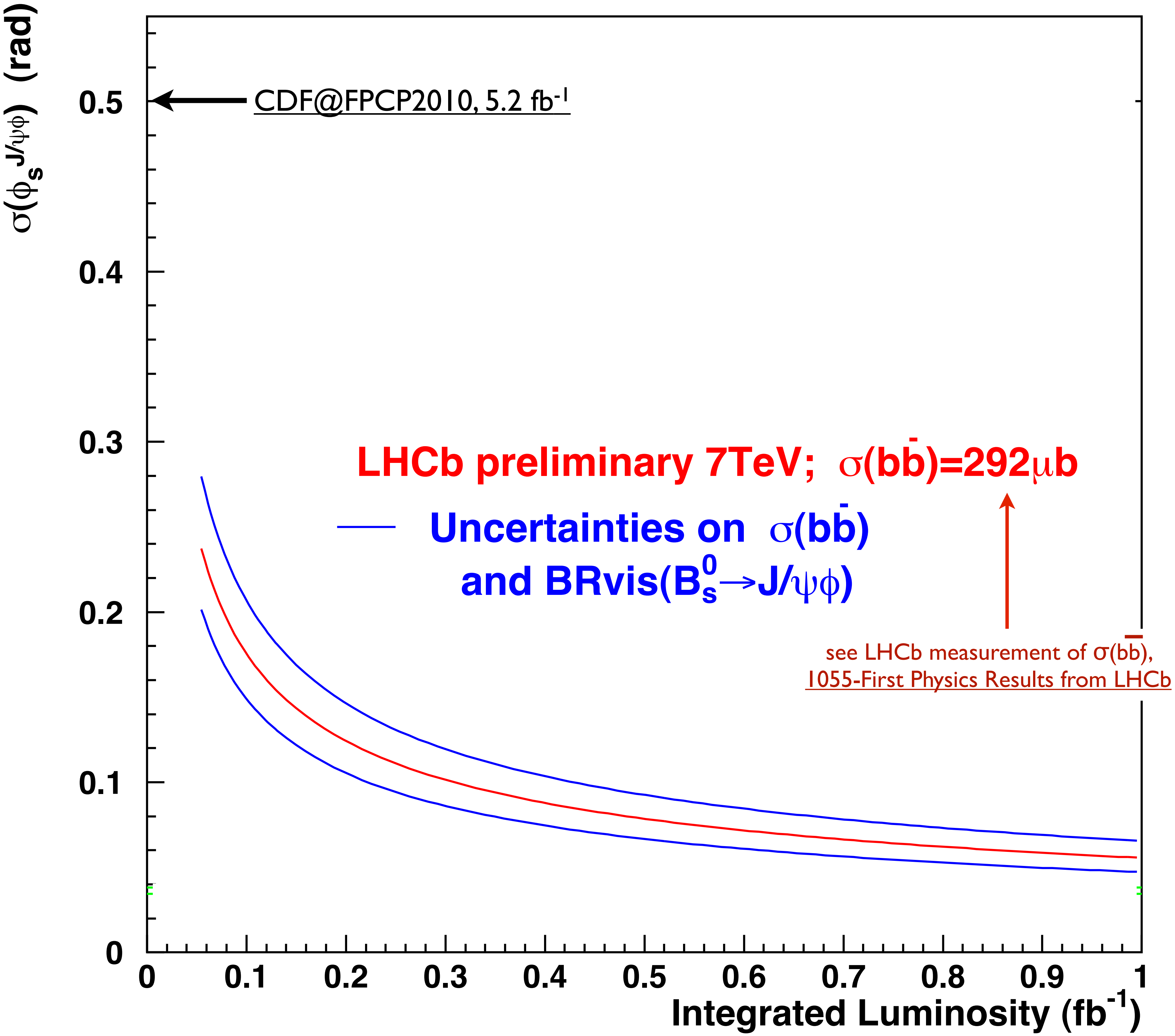
$$V_{ub}^* V_{us} + V_{cb}^* V_{cs} + V_{tb}^* V_{ts} = 0$$



LHCb


Tracking Stations:
momentum charged particles
Vertex Locator:
Primary vertex
Impact Parameters
Magnet
RICH I&II:
PID: π,K,p
Calorimeters:
PID: e,γ,π0
Muon System:
PID: μ
Vertex Locator
RICH1
TT
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
M3
M4
M5
250mrad
y
5m
10m
15m
20m
z
σ(bb̄)→
θb [rad]
0
1
2
3

LHCb Roadmap for $B_s \to J/\psi\varphi$

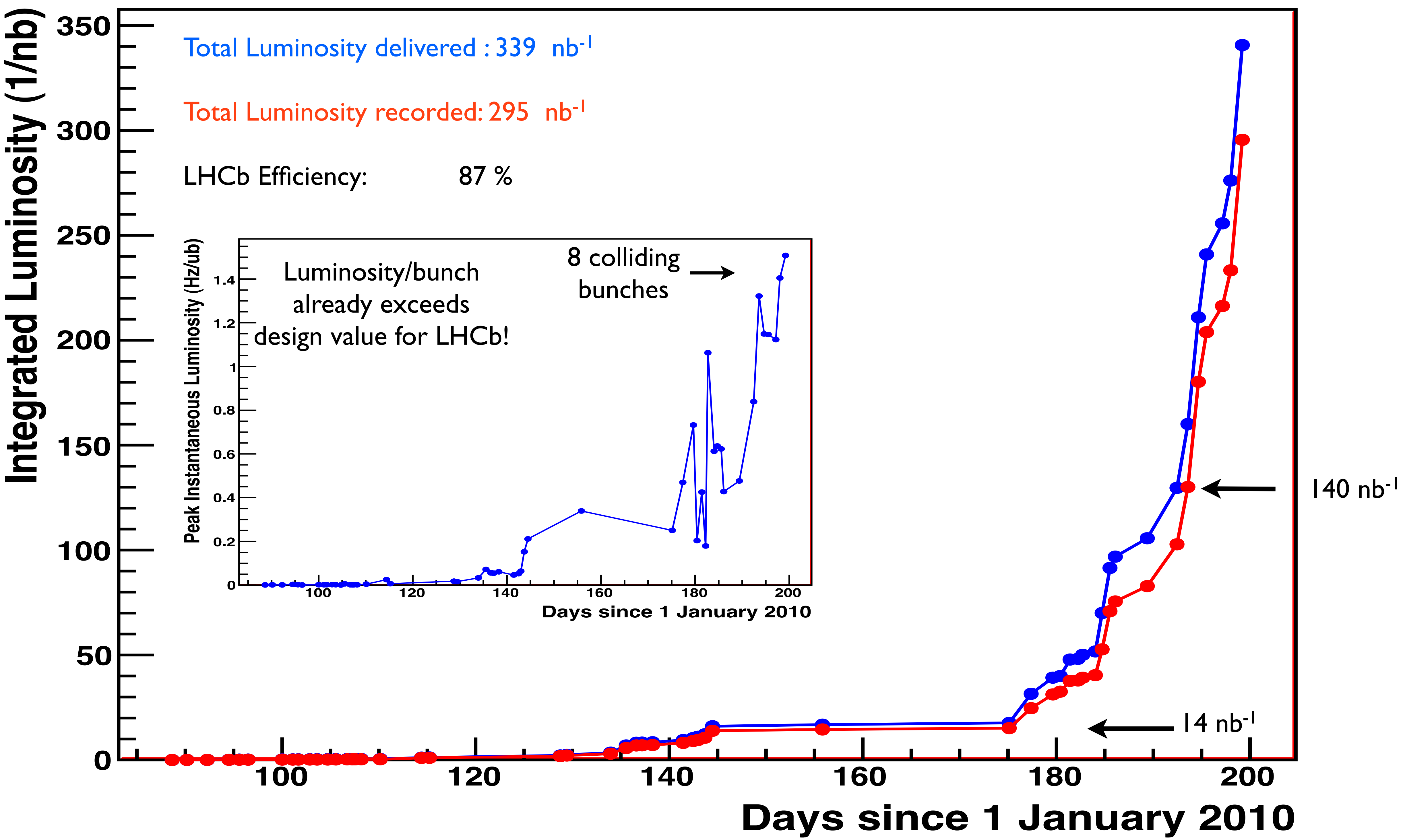


Expected sensitivity for
1) time-dependent,
2) three-angle,
3) flavor-tagged
analysis
at $\sqrt{s}$ = 7 TeV

Assuming MC performance:
35k events selected / fb^{-1}
$\langle\sigma_t\rangle$ = 0.038 ps
εD^2 = 6.2%

see arXiv:0912.4179v2 for more details, variations

Luminosity



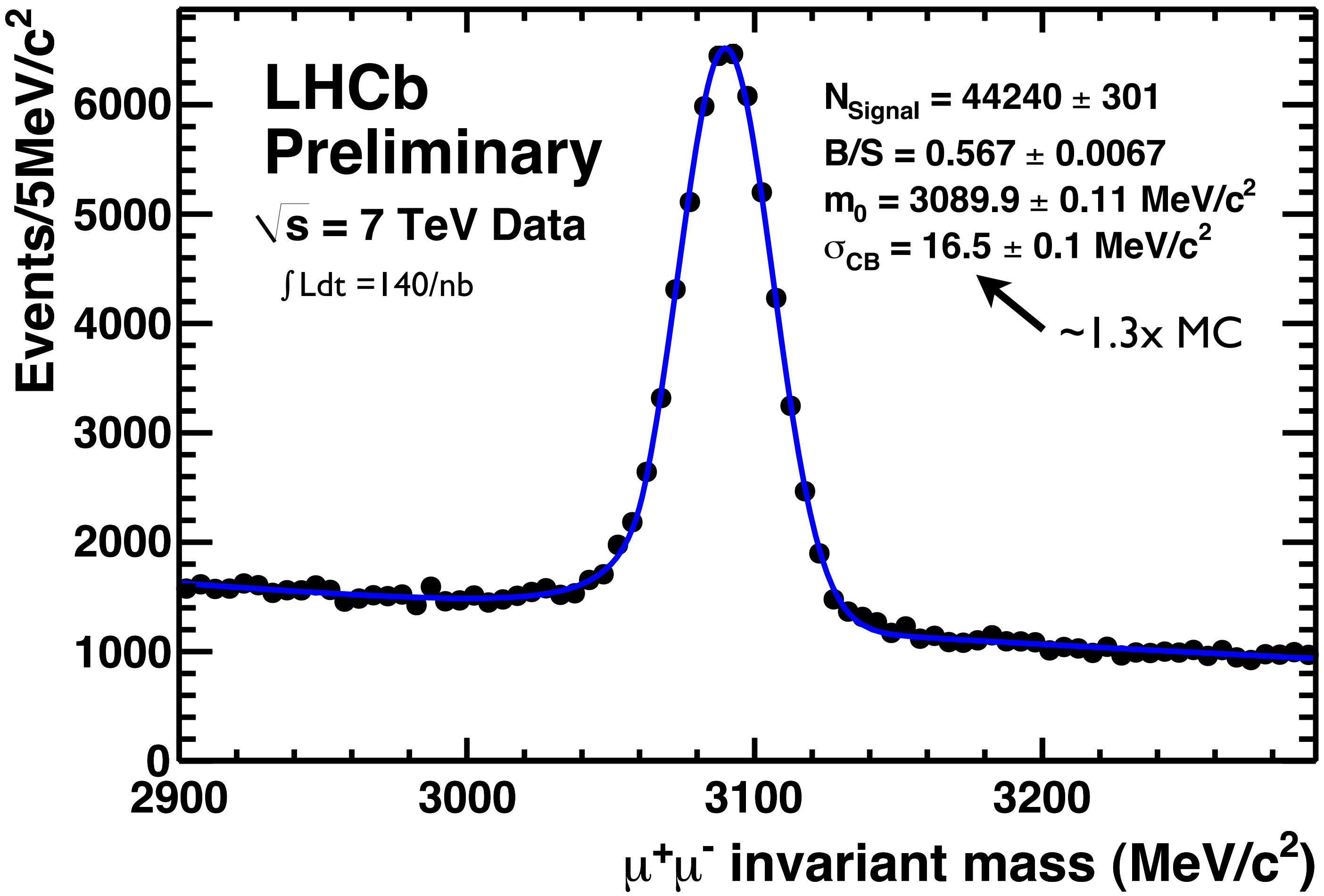
results shown: either 14 nb^{-1} or 140nb^{-1}

current projection: ~200 pb^{-1} end of 2010 → ~1 fb^{-1} end of 2011

J/ψ

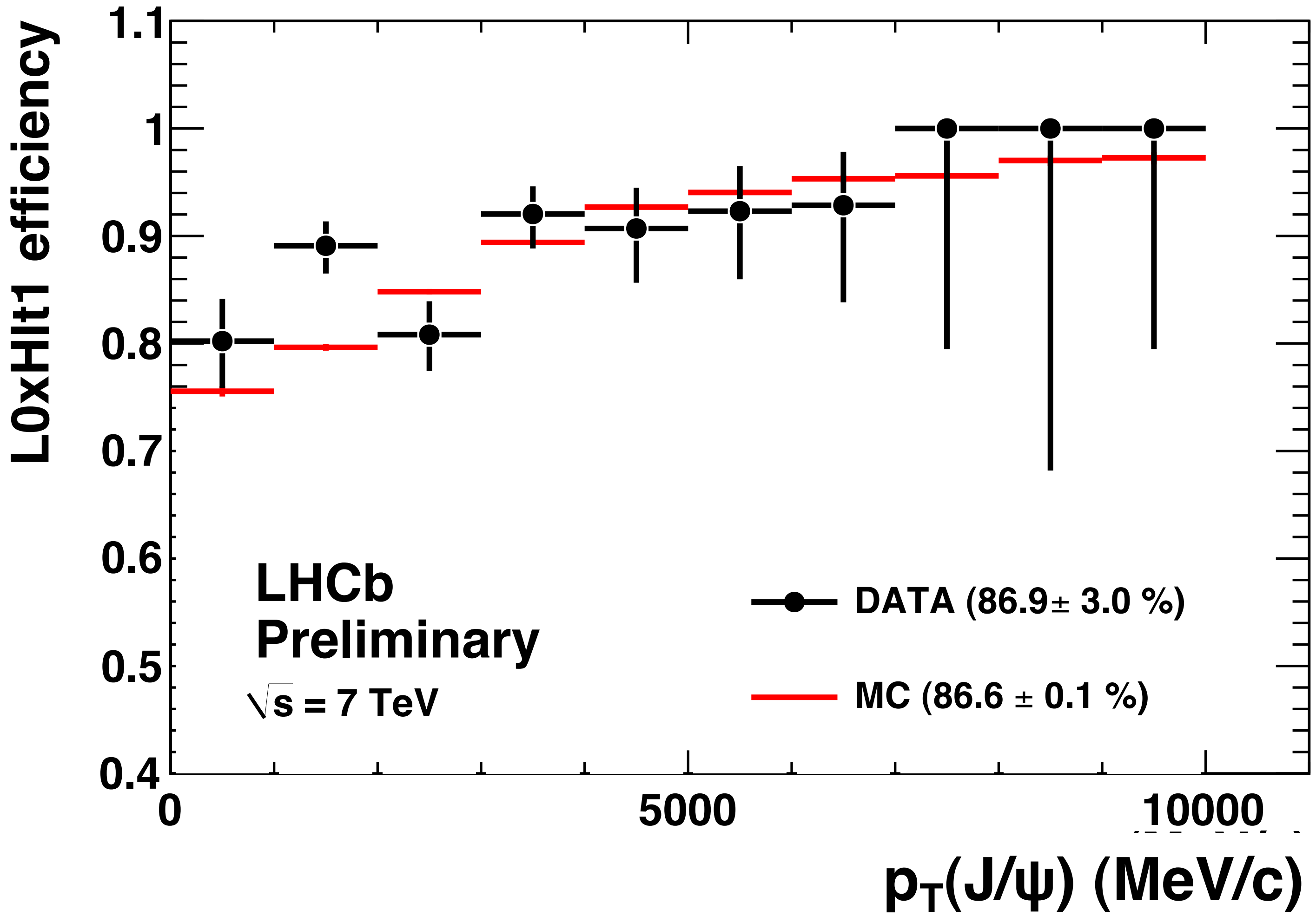
Spectrometer layout provides excellent momentum resolution

Alignment steadily improving:
221-Performance of the Tracking System at the LHCb Experiment



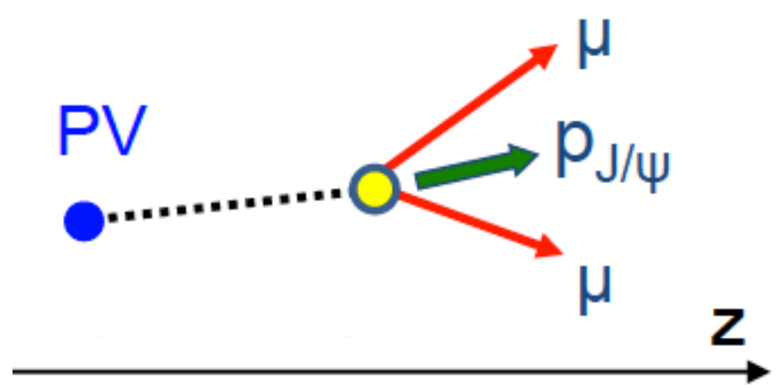
Forward detector geometry provides muon ID + trigger capabilities at low p_T

For more details on LHCb trigger, see 472-LHCb trigger system



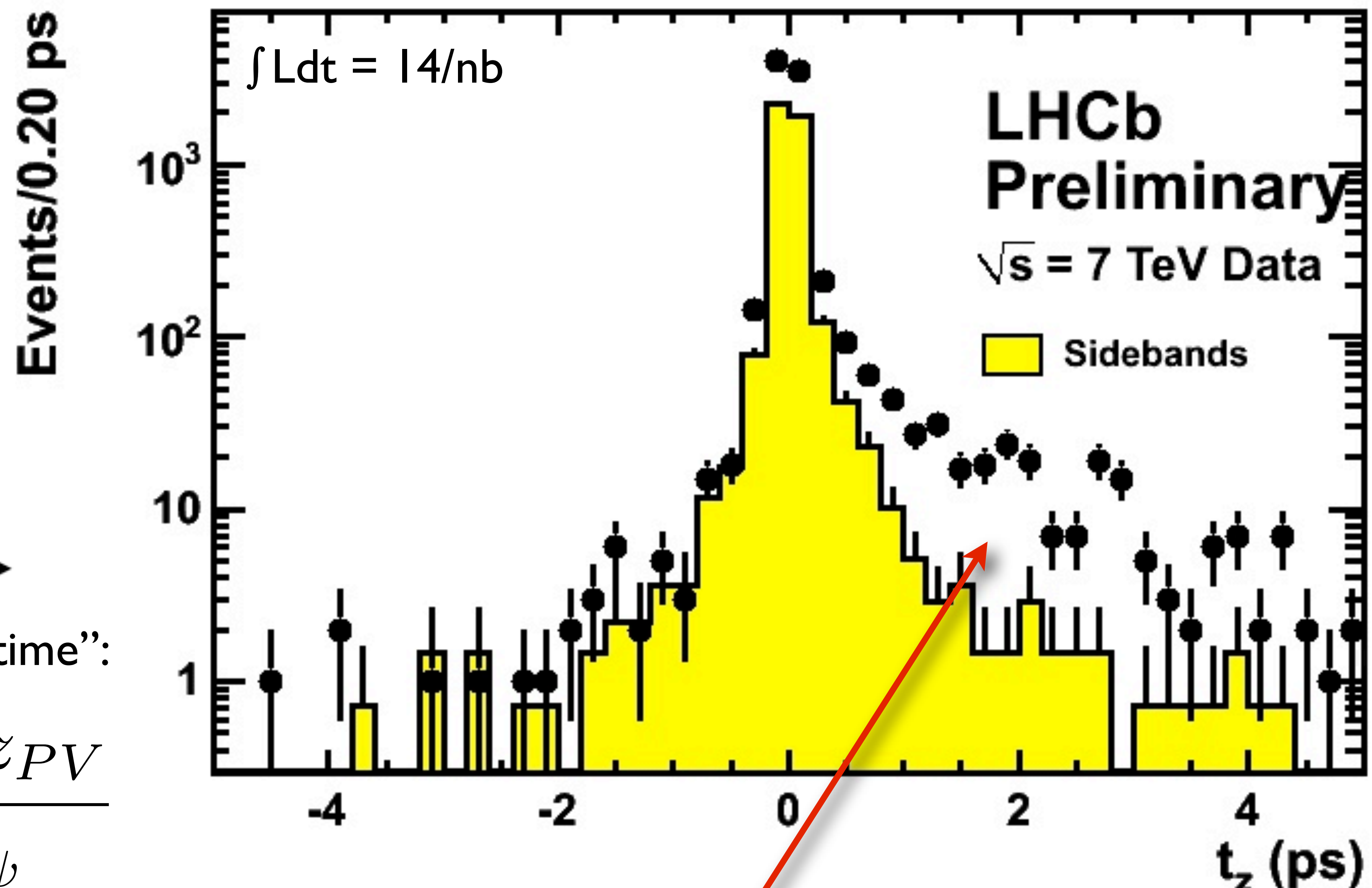
(Non-prompt) J/ψ

Utilize forward production:



to construct a "psuedo proper time":

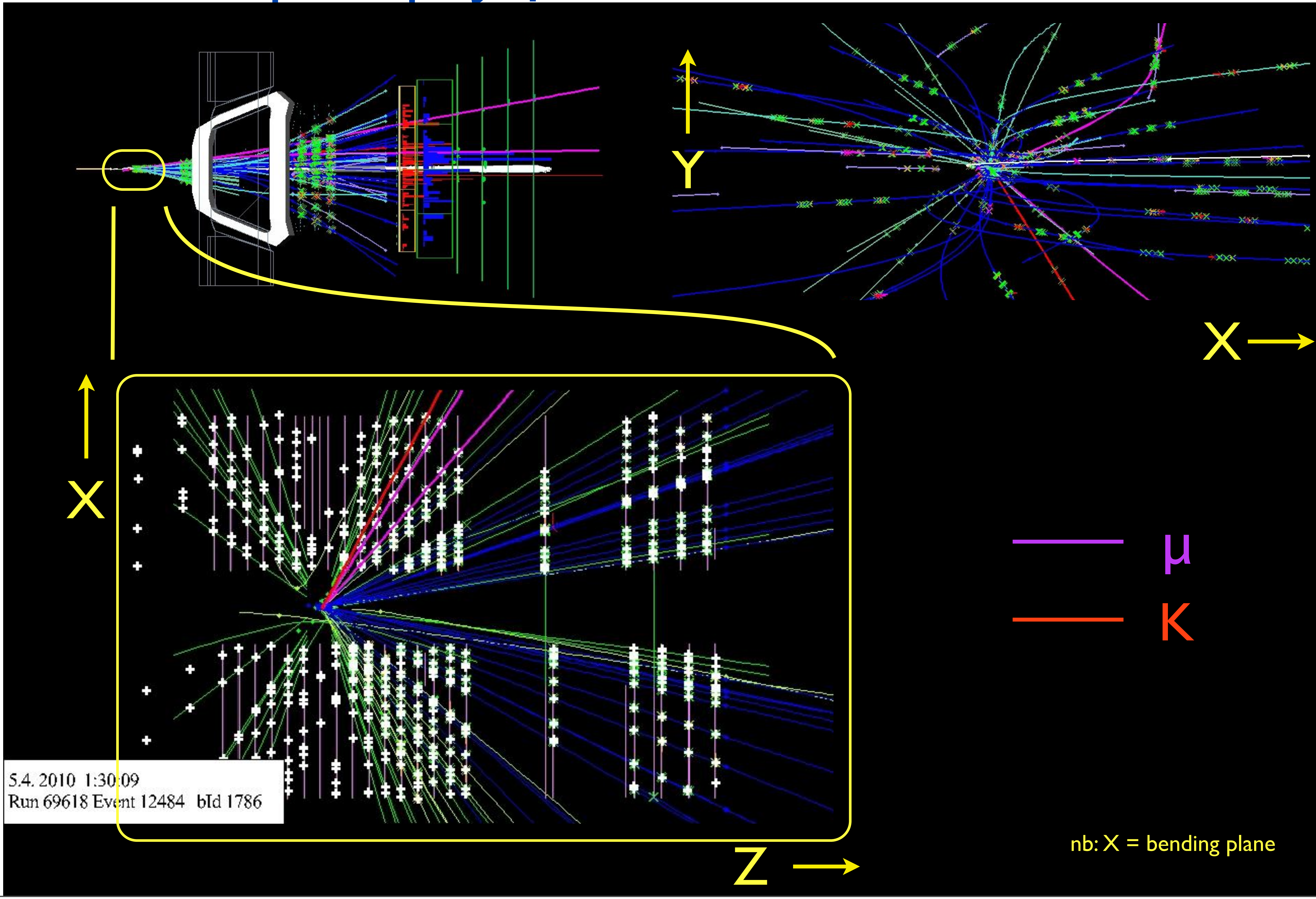
$$t_z = m_{J/\psi} \frac{z_{J/\psi} - z_{PV}}{p_{z,J/\psi}}$$



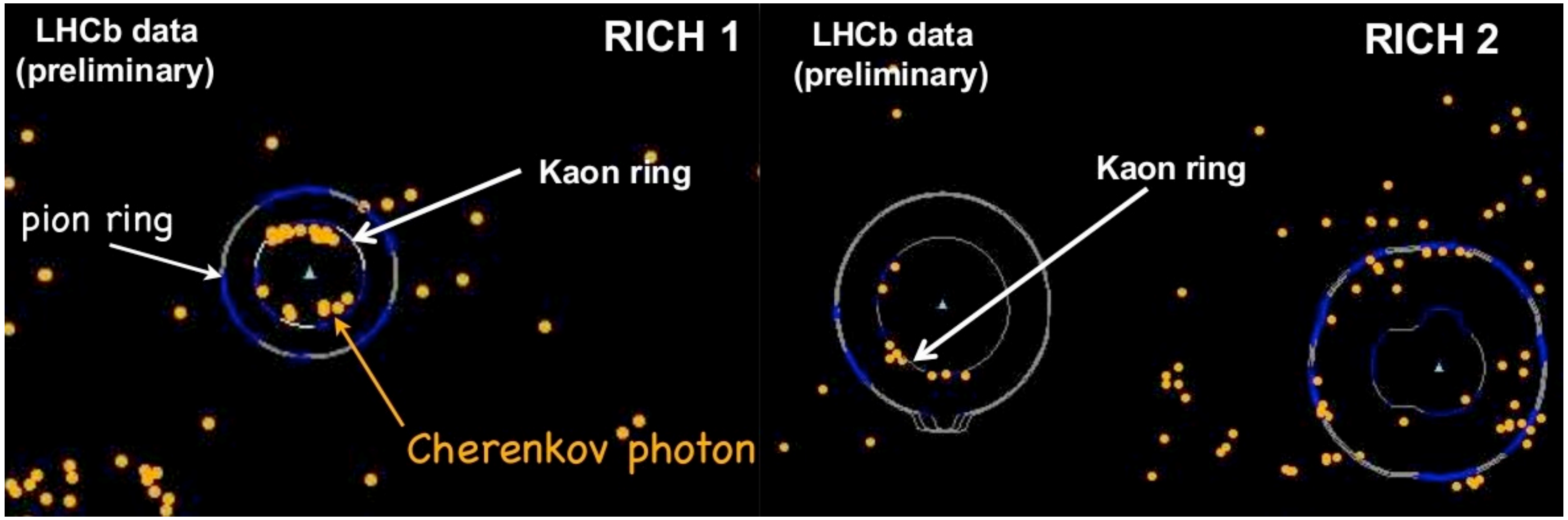
Clear evidence for non-prompt J/ψ

See 205-Prompt J/ψ and b→J/ψ X production in pp collisions at √s = 7 TeV

Non-prompt J/ψ



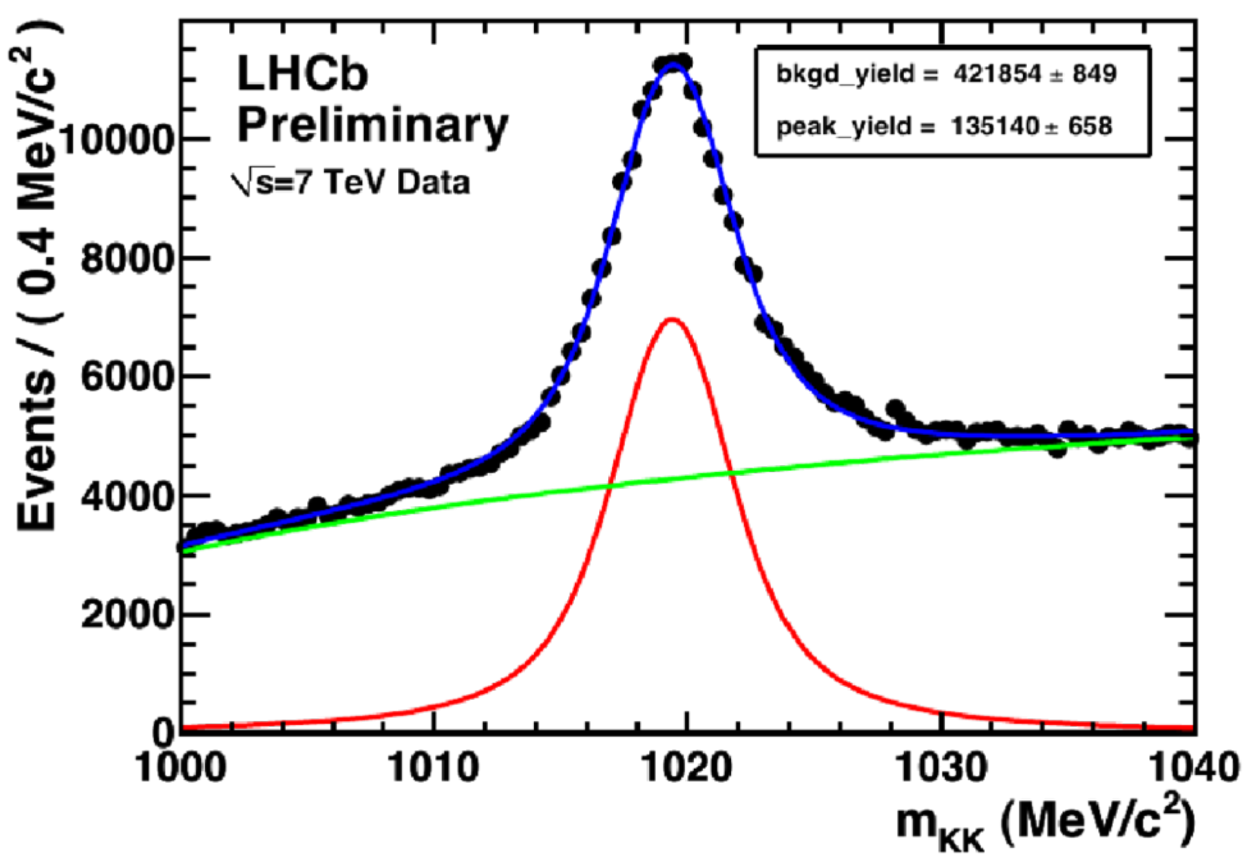
Kaon ID

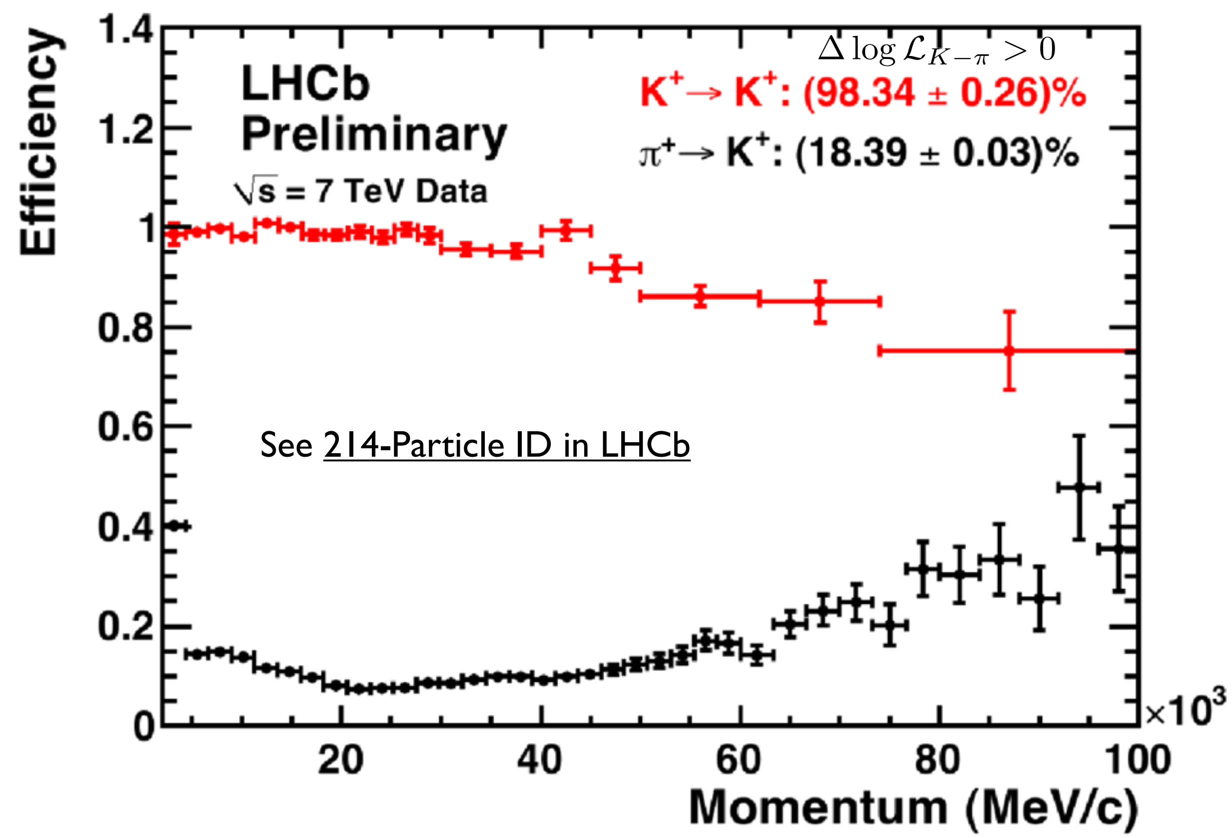


Crucial for flavor tagging.
$B_s \to J/\psi\varphi$ MC:

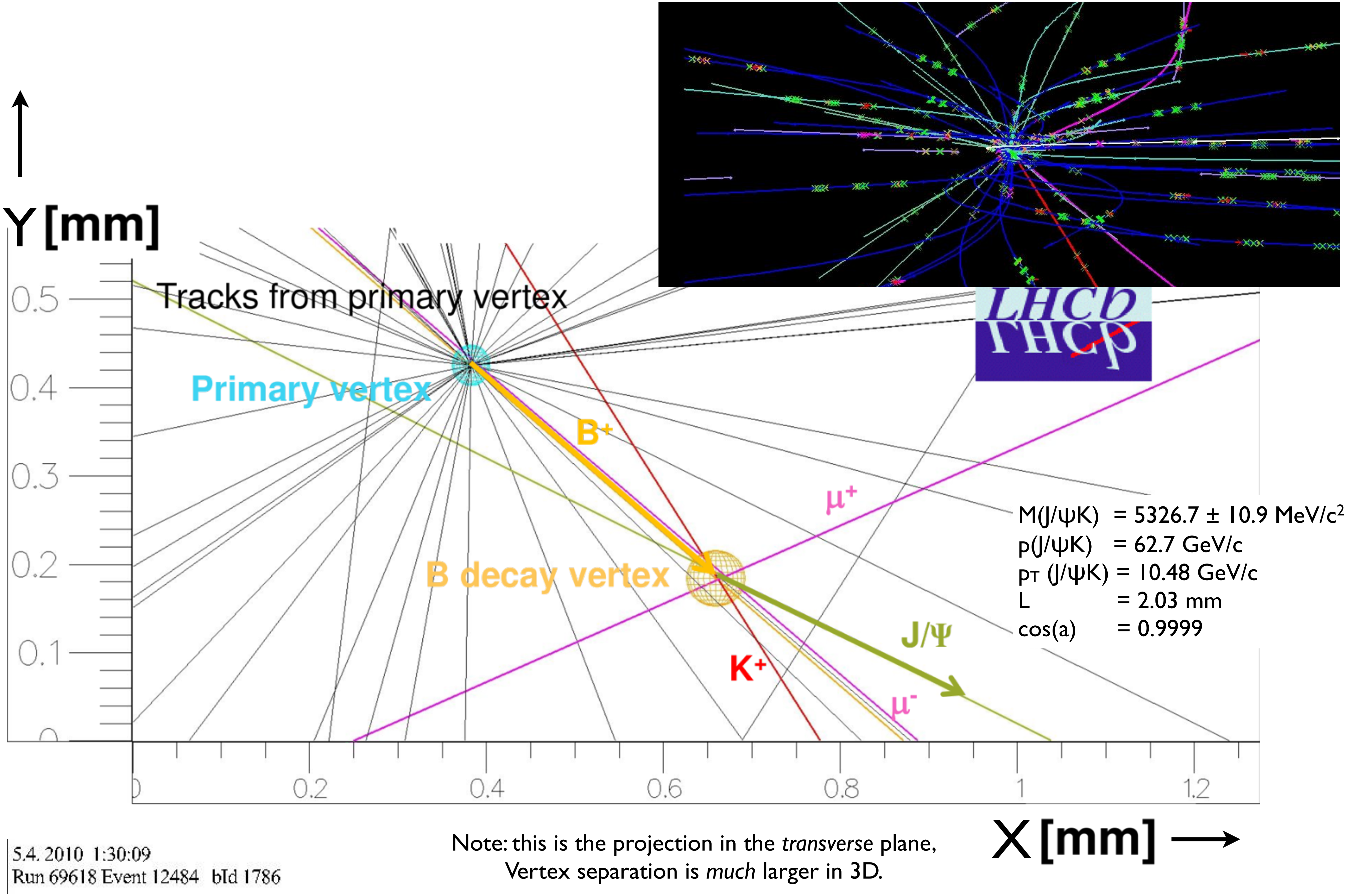
	$\varepsilon_{tag}(1-2\omega)^2$ %
μ	0.76 ± 0.05
e	0.38 ± 0.04
K_{opp}	1.25 ± 0.07
K_{same}	2.39 ± 0.10
Q_{vtx}	1.09 ± 0.07
Combined	Q_{opp} **$=3.32 \pm 0.11$**
Combined	Q_{all} **$=6.23 \pm 0.15$**

Use $\varphi \to K^+K^-$ where one leg is required to have RICH K-ID
⇒ use other leg as source of Kaons to determine K-ID efficiency





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

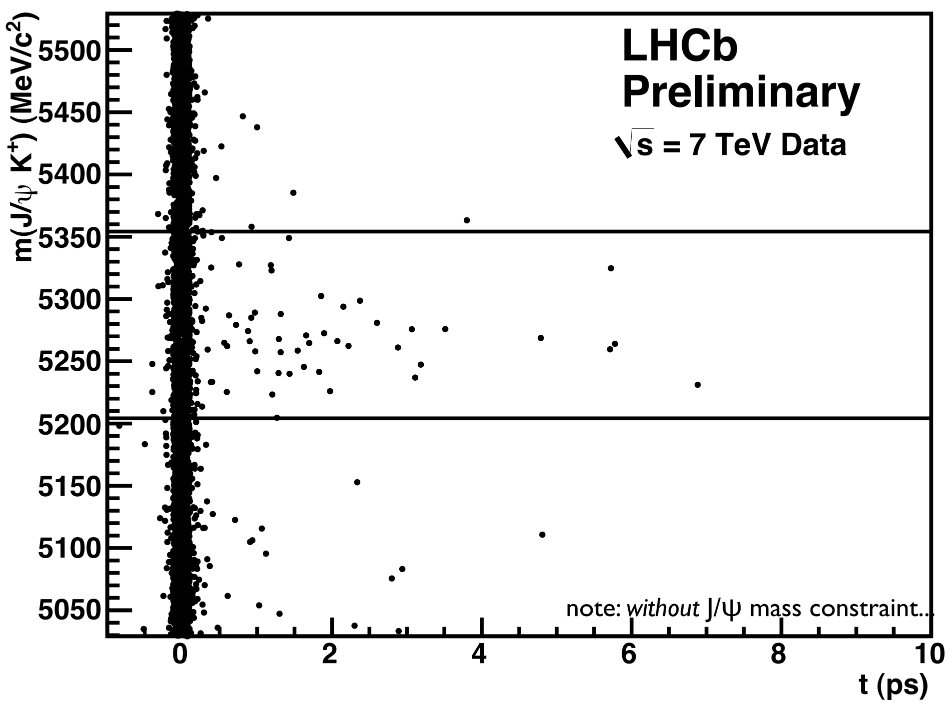


M(J/ψK) = 5326.7 ± 10.9 MeV/c^2
p(J/ψK) = 62.7 GeV/c
p_T (J/ψK) = 10.48 GeV/c
L = 2.03 mm
cos(a) = 0.9999

Note: this is the projection in the *transverse* plane,
Vertex separation is *much* larger in 3D.

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

$\int L dt = O(140/nb)$

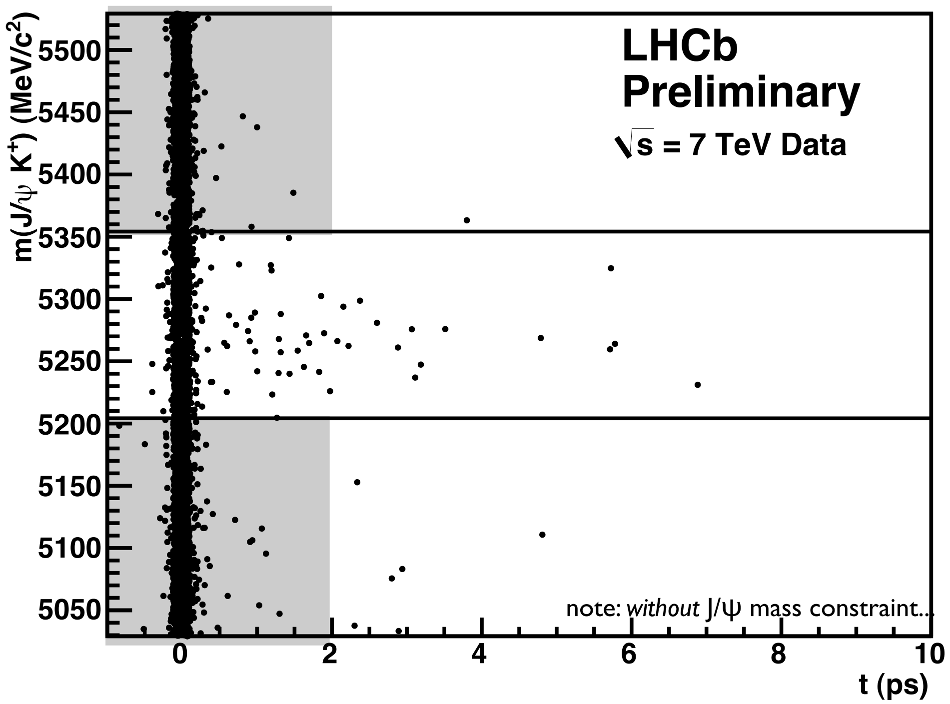


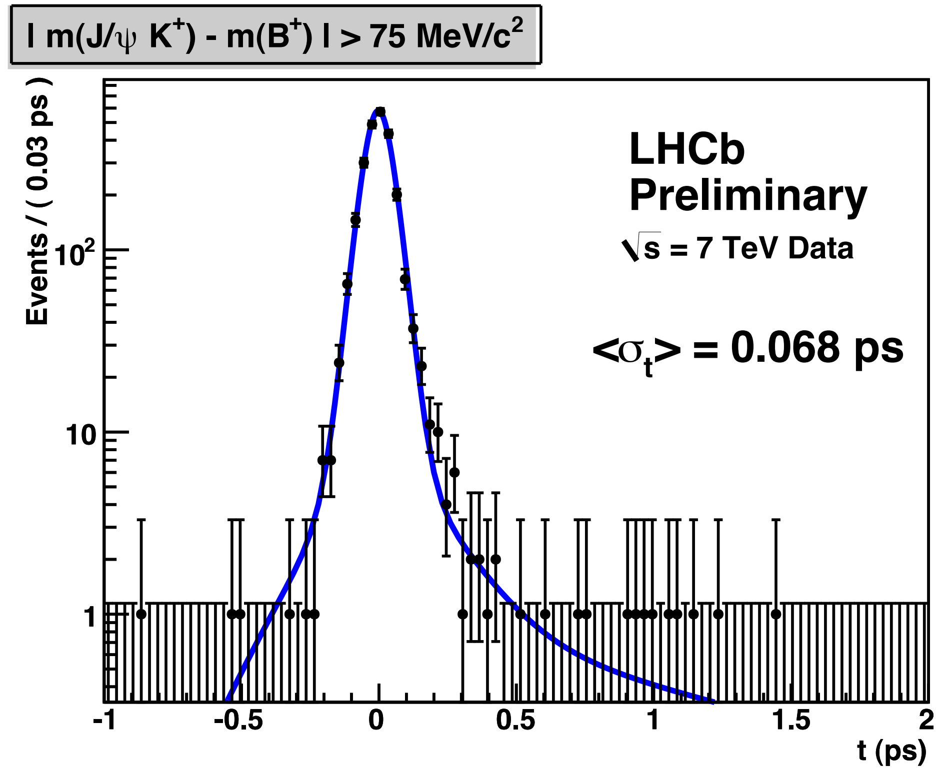
Unbinned likelihood fit of $m,t \,|\sigma_t$

Expected yield from MC: ~71 events (using LHCb value of $\sigma(b\bar{b})$)

$\int L dt = O(140/nb)$

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





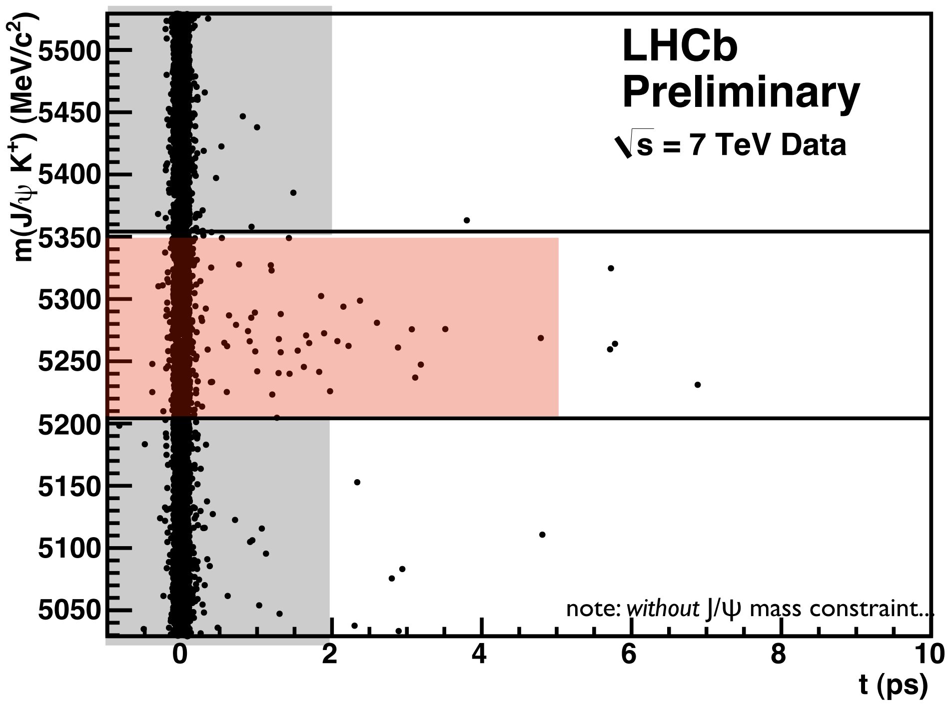
Unbinned likelihood fit of $m,t \,|\sigma_t$

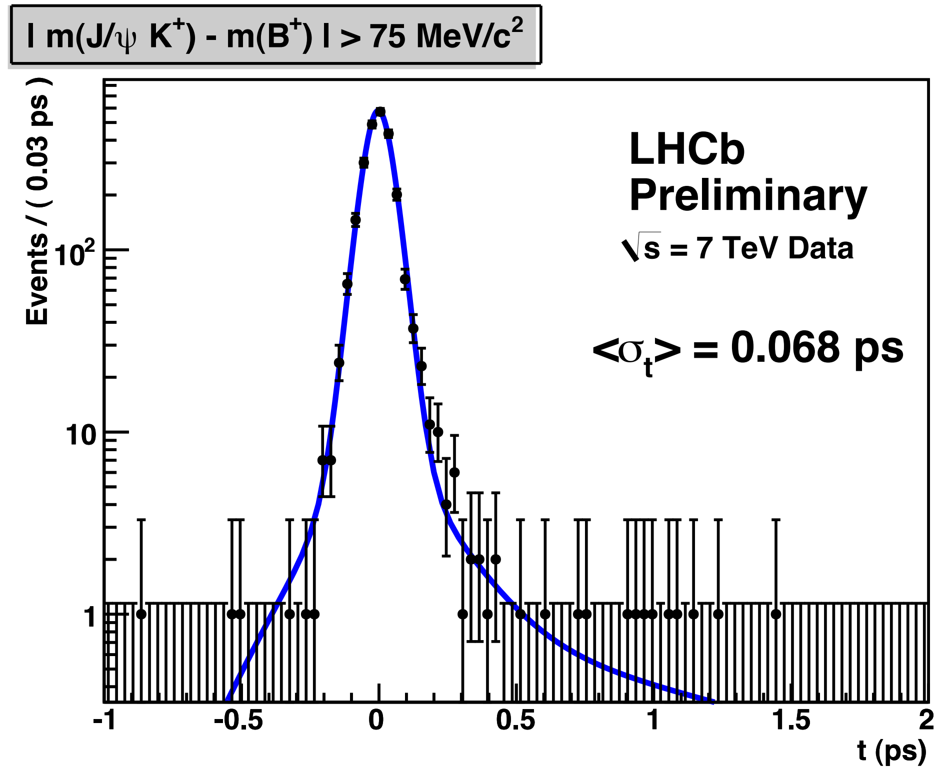
Expected yield from MC: ~71 events (using LHCb value of $\sigma(b\bar{b})$)

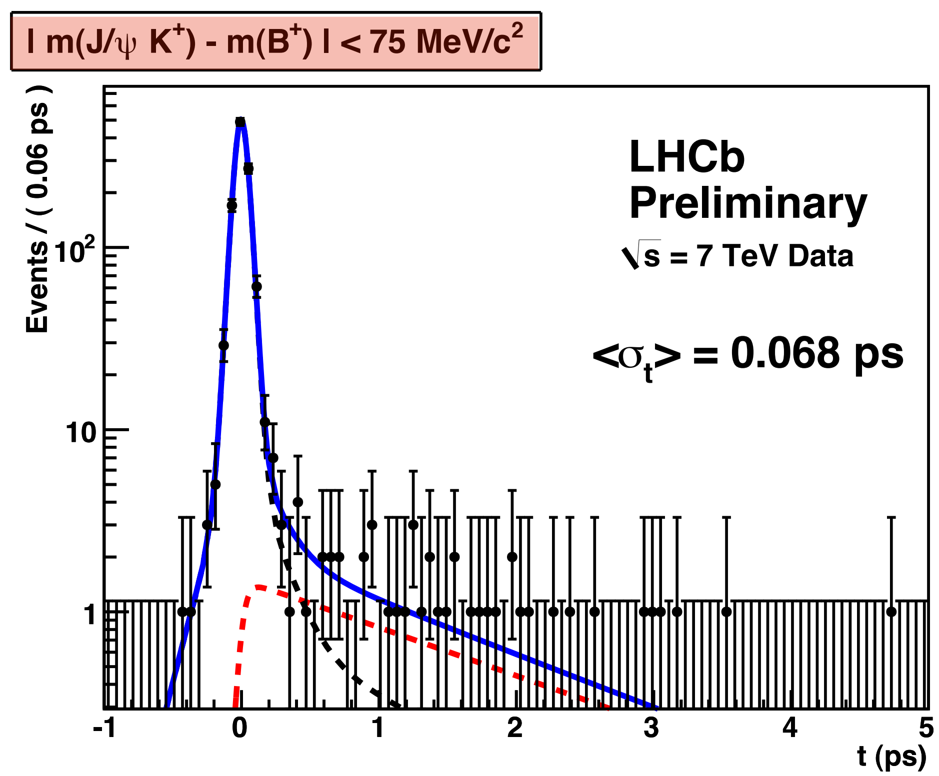
Proper time resolution: ~1.7x MC, but sufficient compared to $\Delta m_s \sim 17.7$/ps

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

$\int L dt = O(140/nb)$







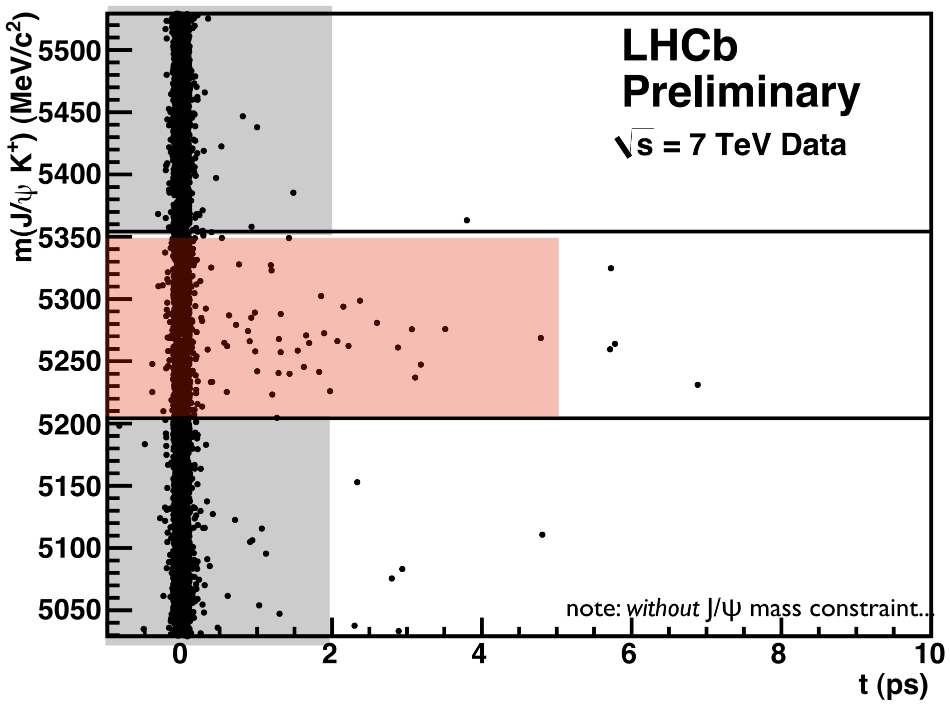
Unbinned likelihood fit of $m,t\,|\sigma_t$

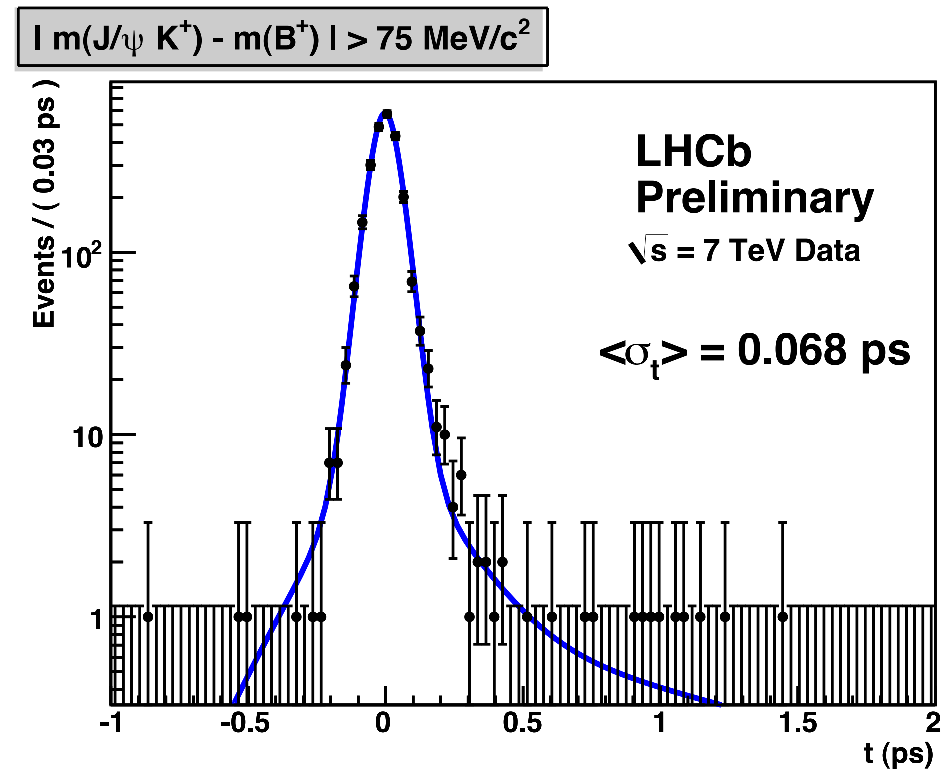
Expected yield from MC: ~71 events (using LHCb value of $\sigma(b\bar{b})$)

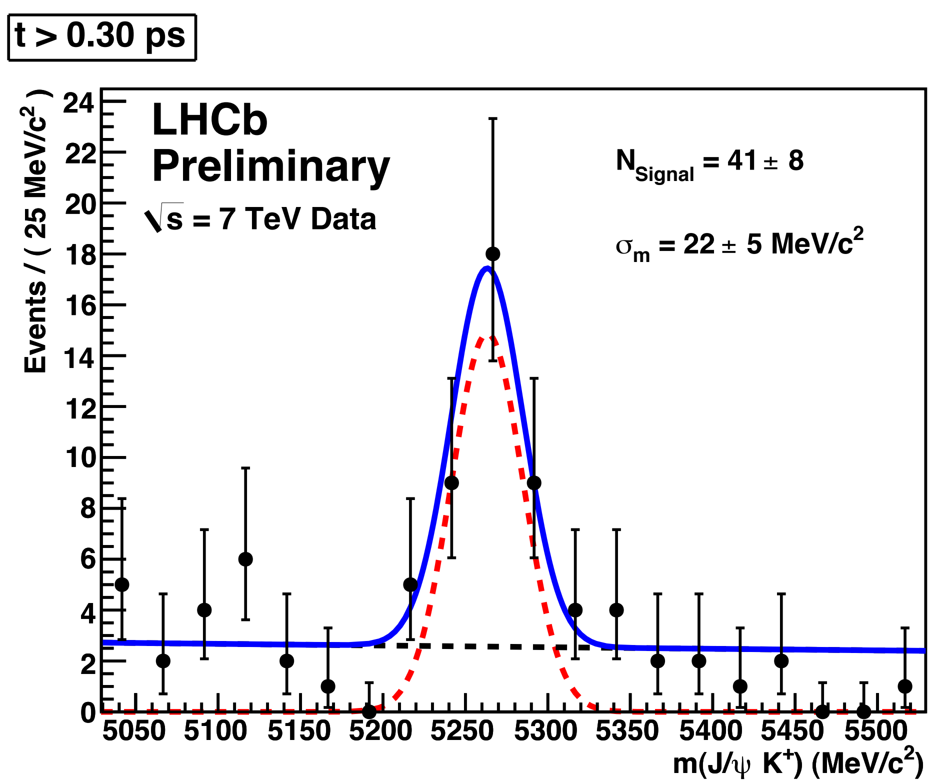
Proper time resolution: ~1.7x MC, but sufficient compared to Δm_s ~ 17.7/ps

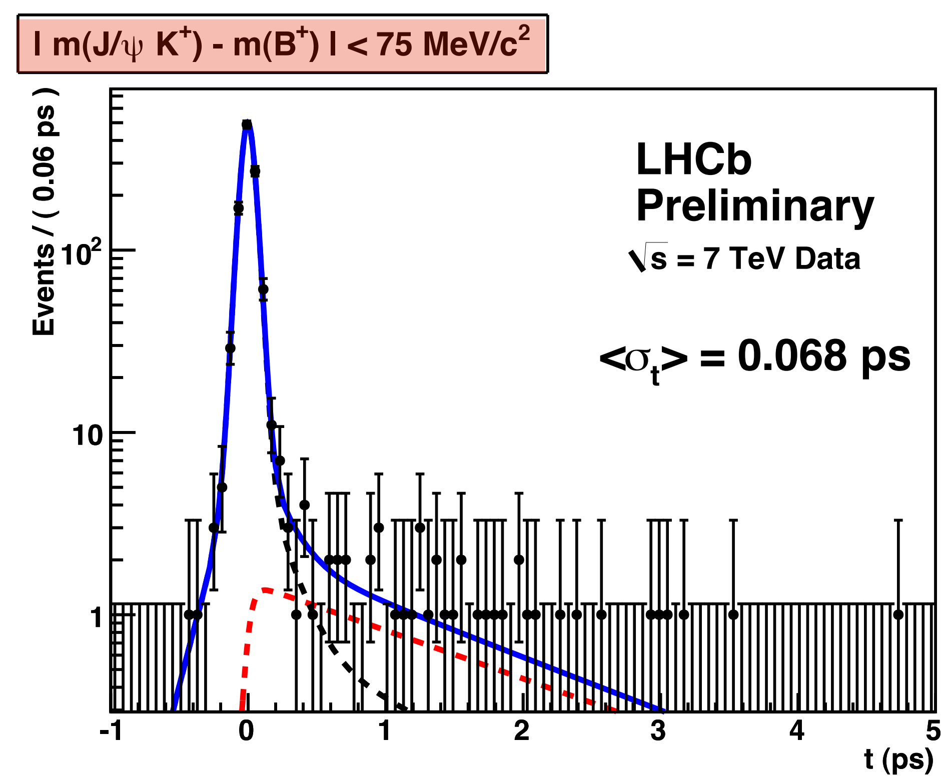
$B^+ \rightarrow J/\psi\ K^+$

$\int L dt = O(140/nb)$







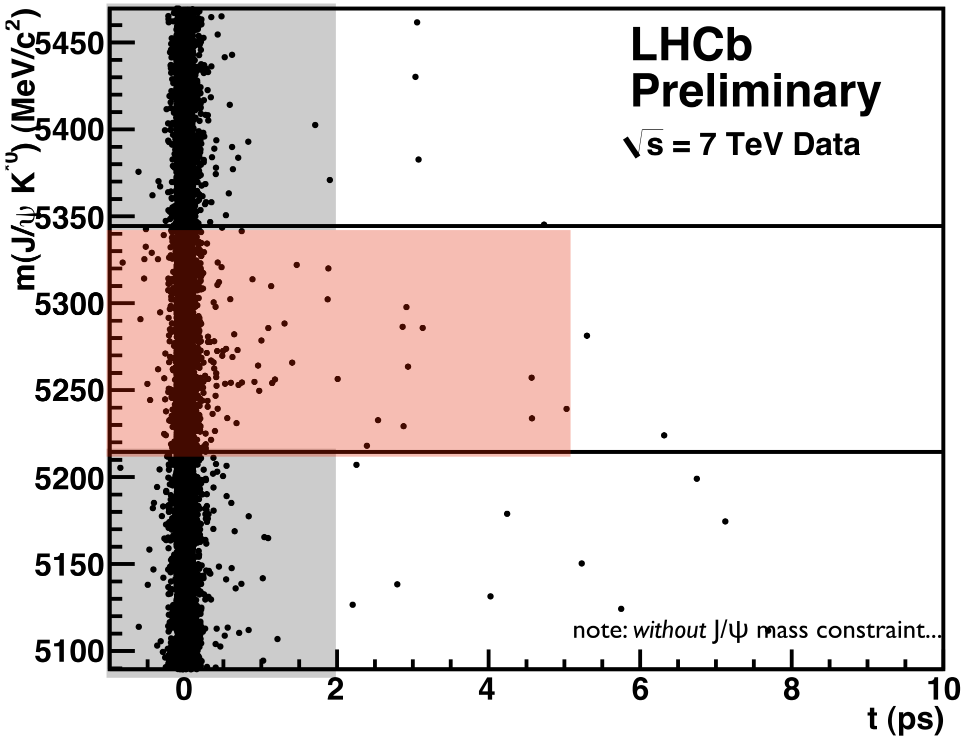


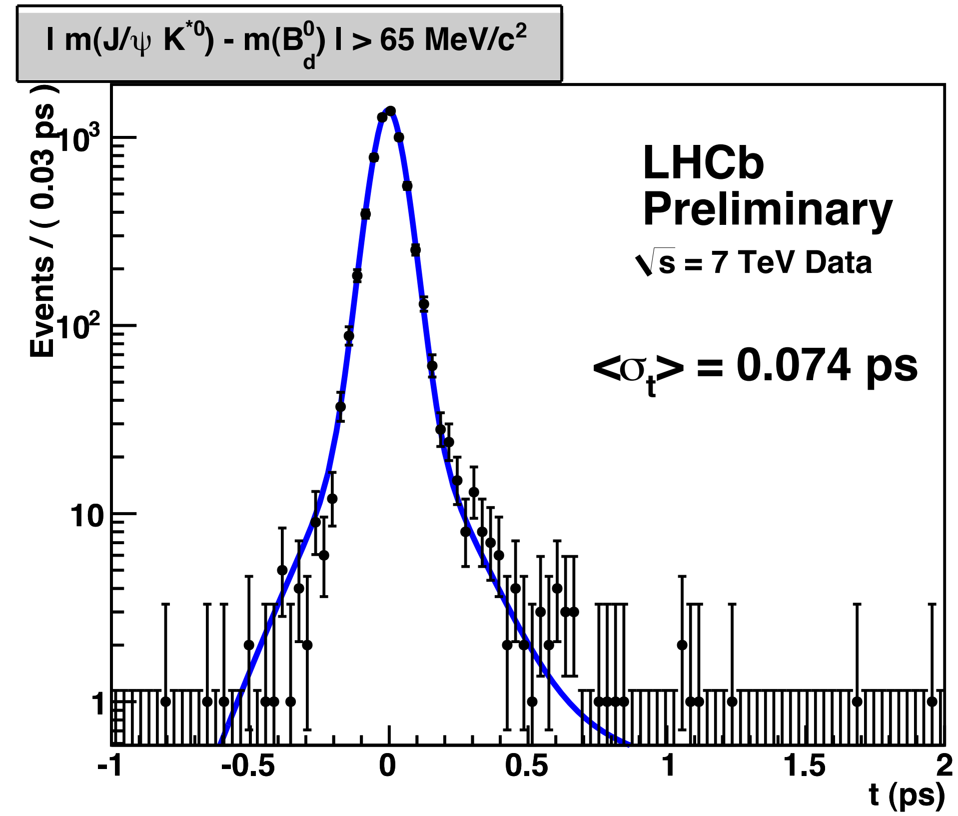
Unbinned likelihood fit of m,t $|\sigma_t$

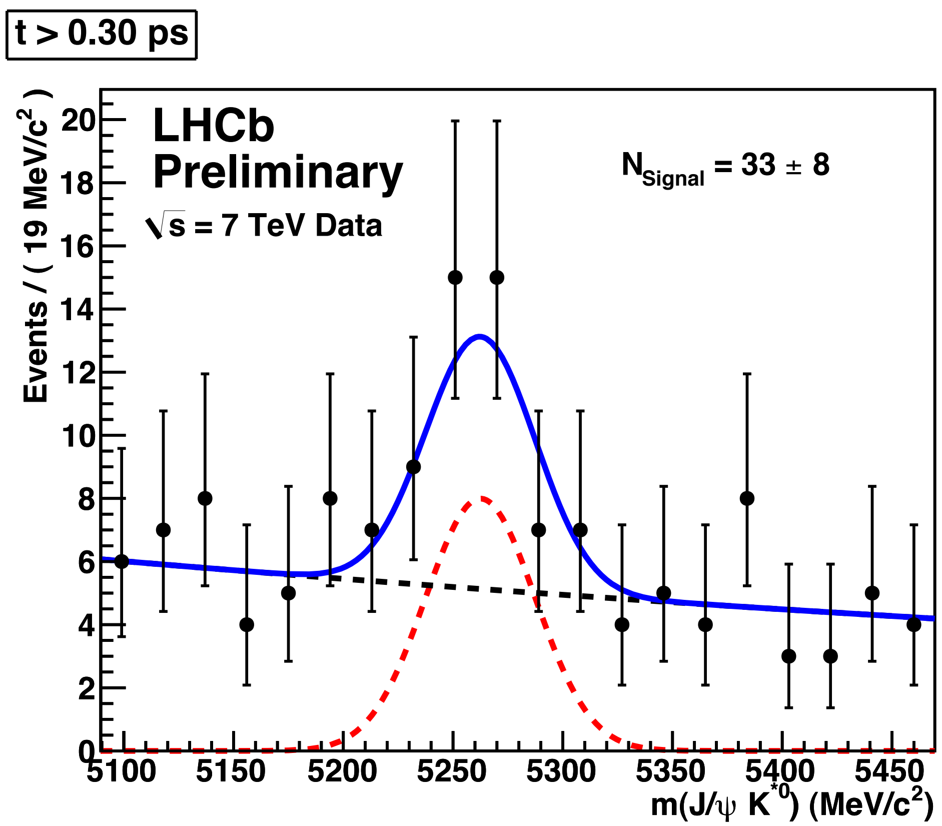
- Expected yield from MC: ~71 events (using LHCb value of $\sigma(b\bar{b})$)
- Proper time resolution: ~1.7x MC, but sufficient compared to Δm_s ~ 17.7/ps

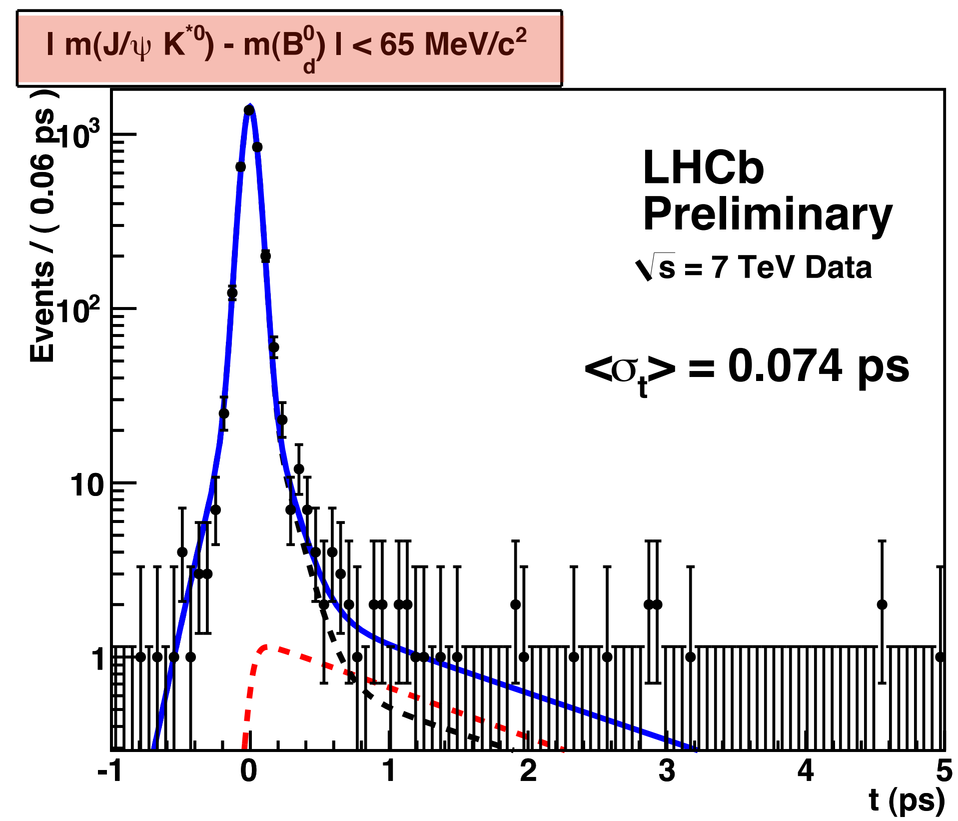
$\int Ldt = O(140/nb)$

$B^0 \to J/\psi K^{*0}$







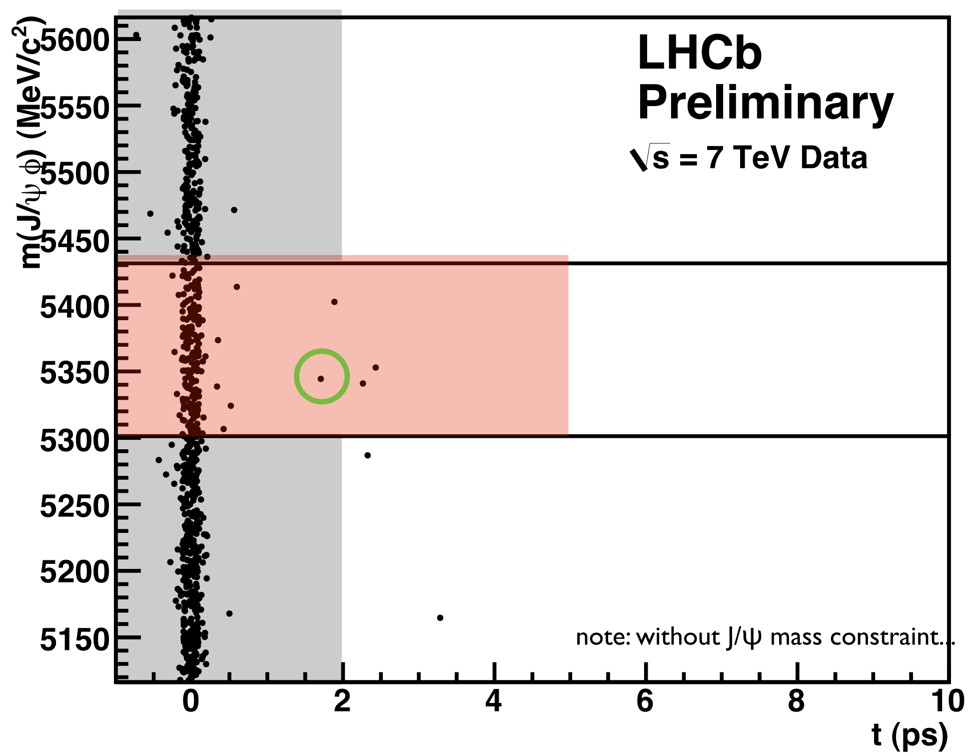


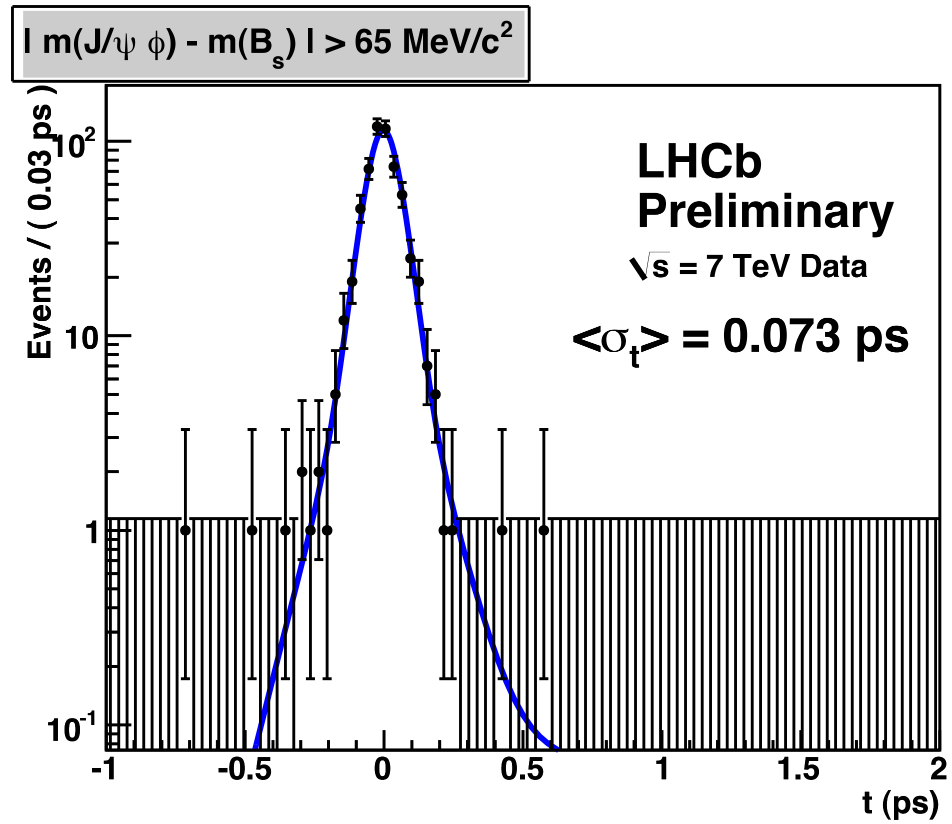
Unbinned likelihood fit of $m, t \,|\sigma_t$

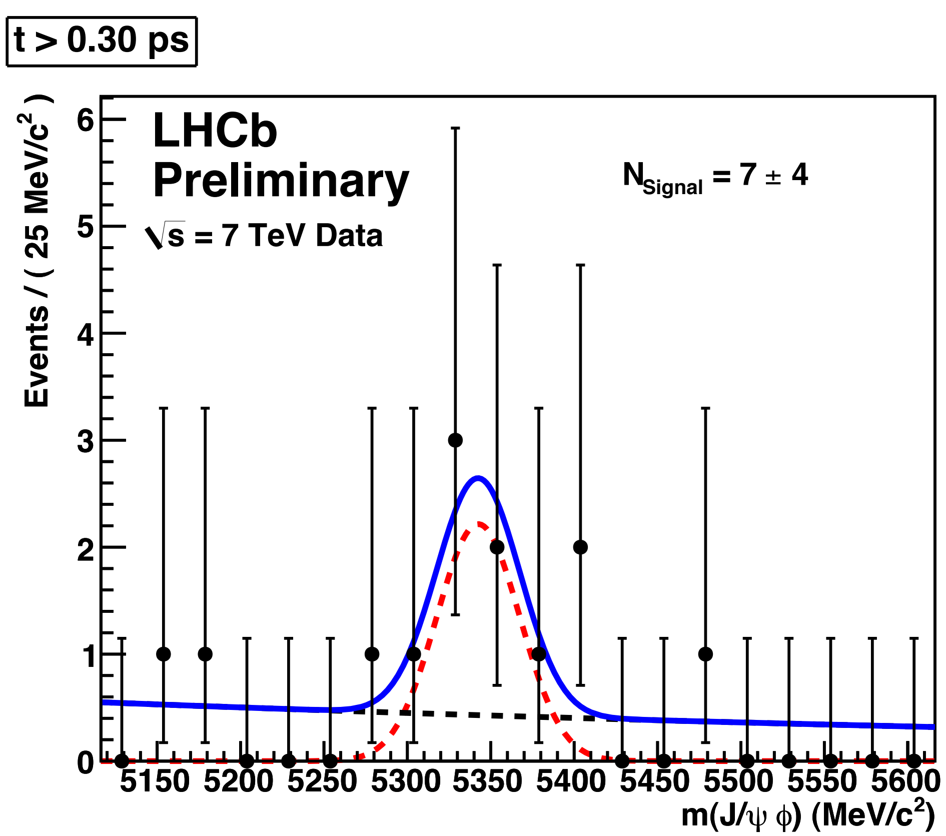
- Expected yield from MC: ~34 events (using LHCb value of $\sigma(b\bar{b})$)
- Proper time resolution: ~1.7x MC, but sufficient compared to Δm_s ~ 17.7/ps

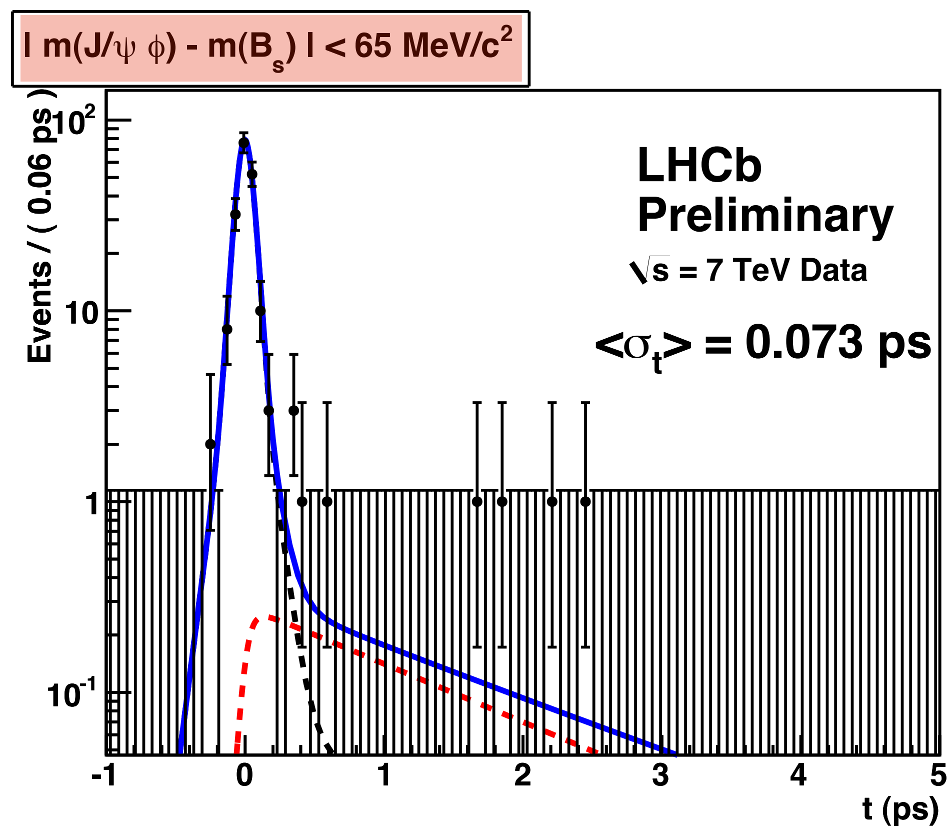
$B_s \rightarrow J/\psi\ \varphi$

$\int L dt = O(140/nb)$





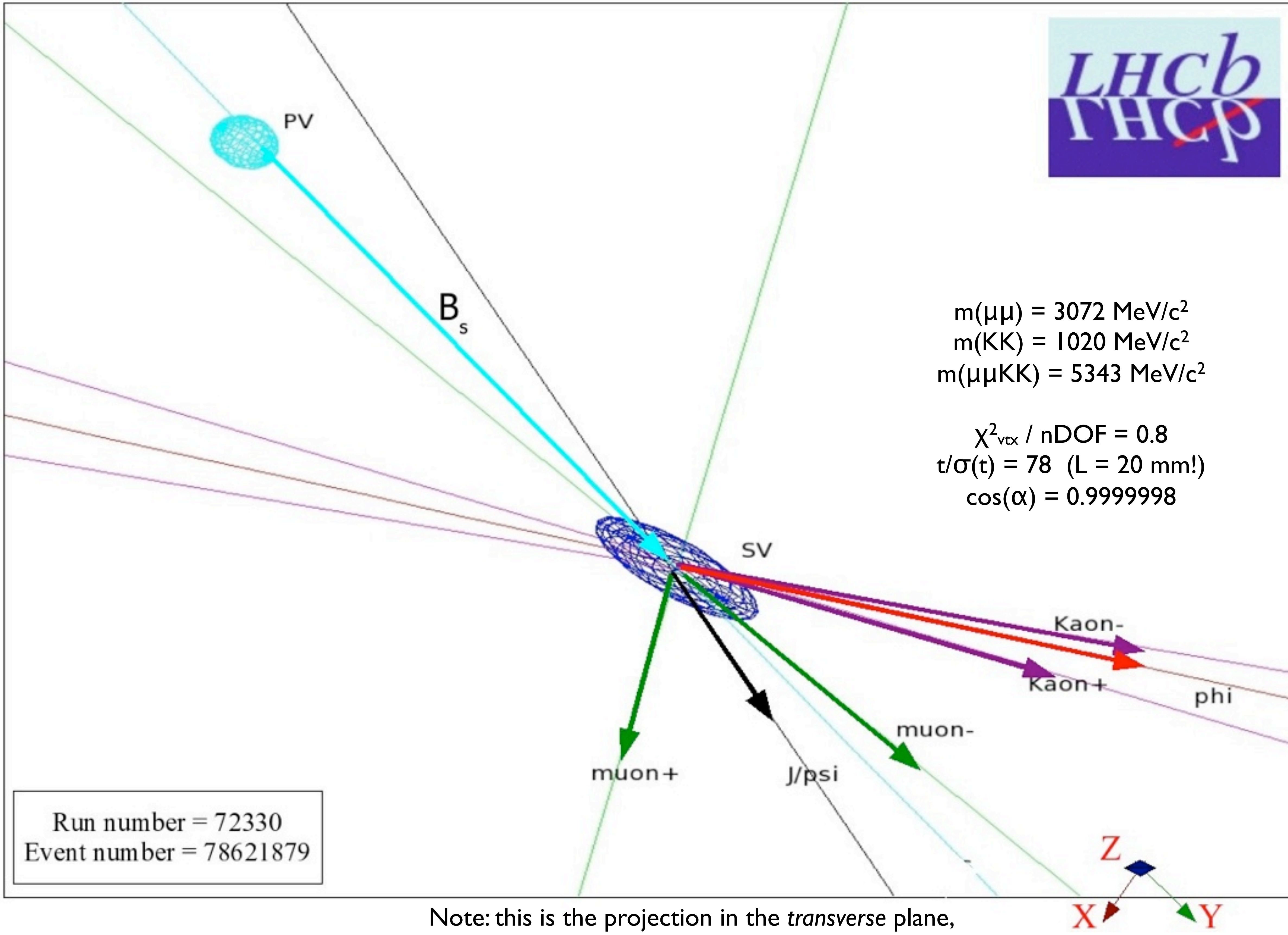




Not inconsistent with the MC expectation of ~7 events....

Resolution about 1.7x MC, but, once more, already sufficient compared to $\Delta m_s \sim 17.7$/ps

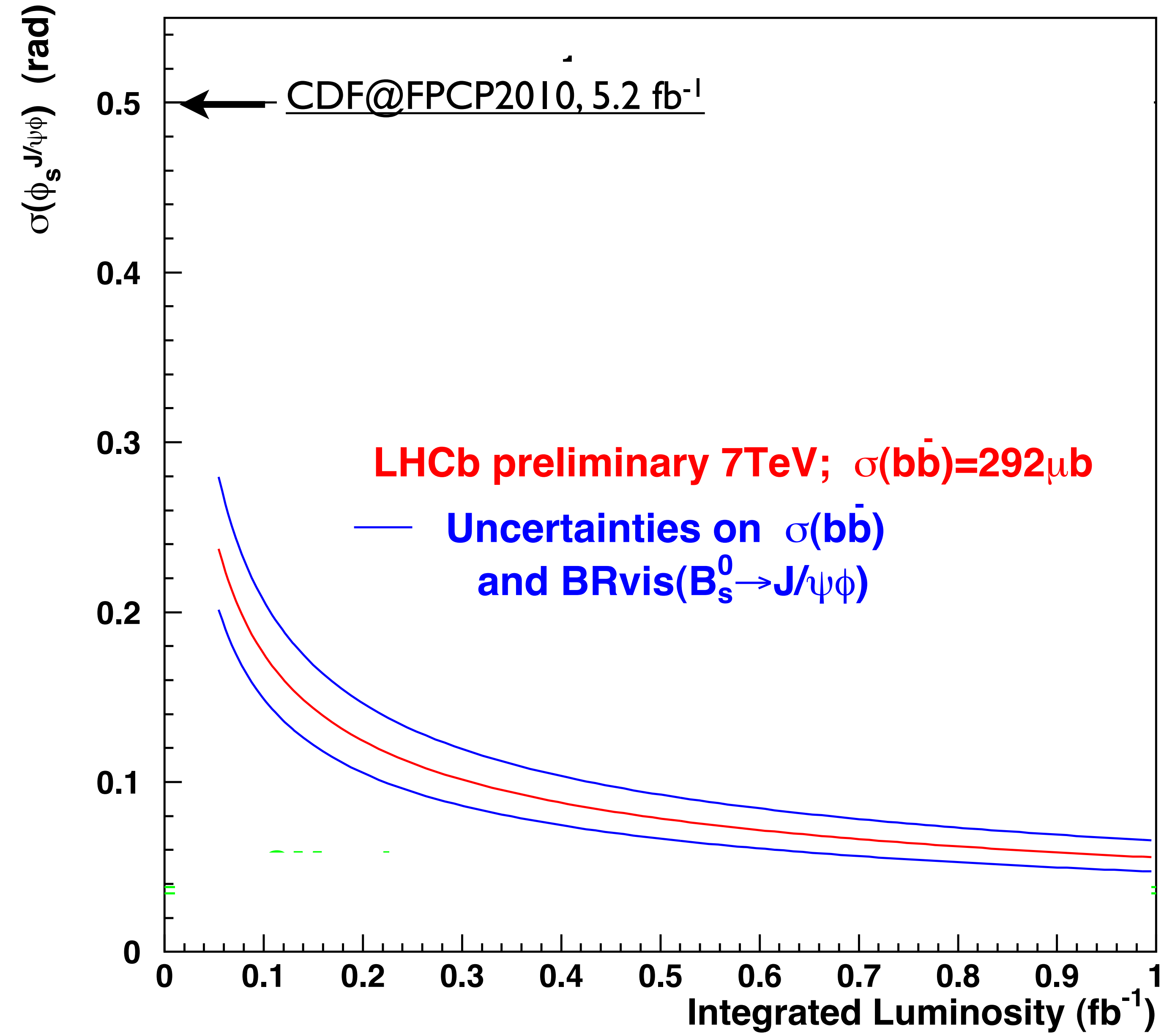
$B_s \rightarrow J/\psi\ \varphi$

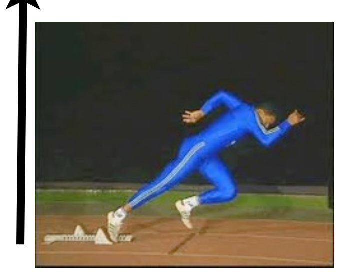


Note: this is the projection in the *transverse* plane,
Vertex separation is *much* larger in 3D.

Summary & Outlook

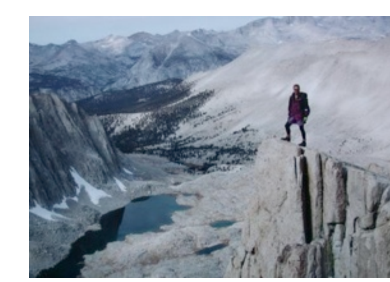
- LHCb fully operational
- Currently 295 nb^{-1} collected
- Hope for 0.2 fb^{-1} by end 2010, and 1 fb^{-1} by end of 2011
- In O(140 nb^{-1}) :
  - $N(B^+ \to J/\psi K^+) = 41 \pm 8$
  - $N(B^0 \to J/\psi K^{*0}) = 33 \pm 8$
  - $N(B_s \to J/\psi \varphi) = 7 \pm 4$
- Propertime resolution already sufficient for CP measurement
  - Alignment improving with more data
- Exciting & busy times ahead!





ICHEP'10

7±4 events

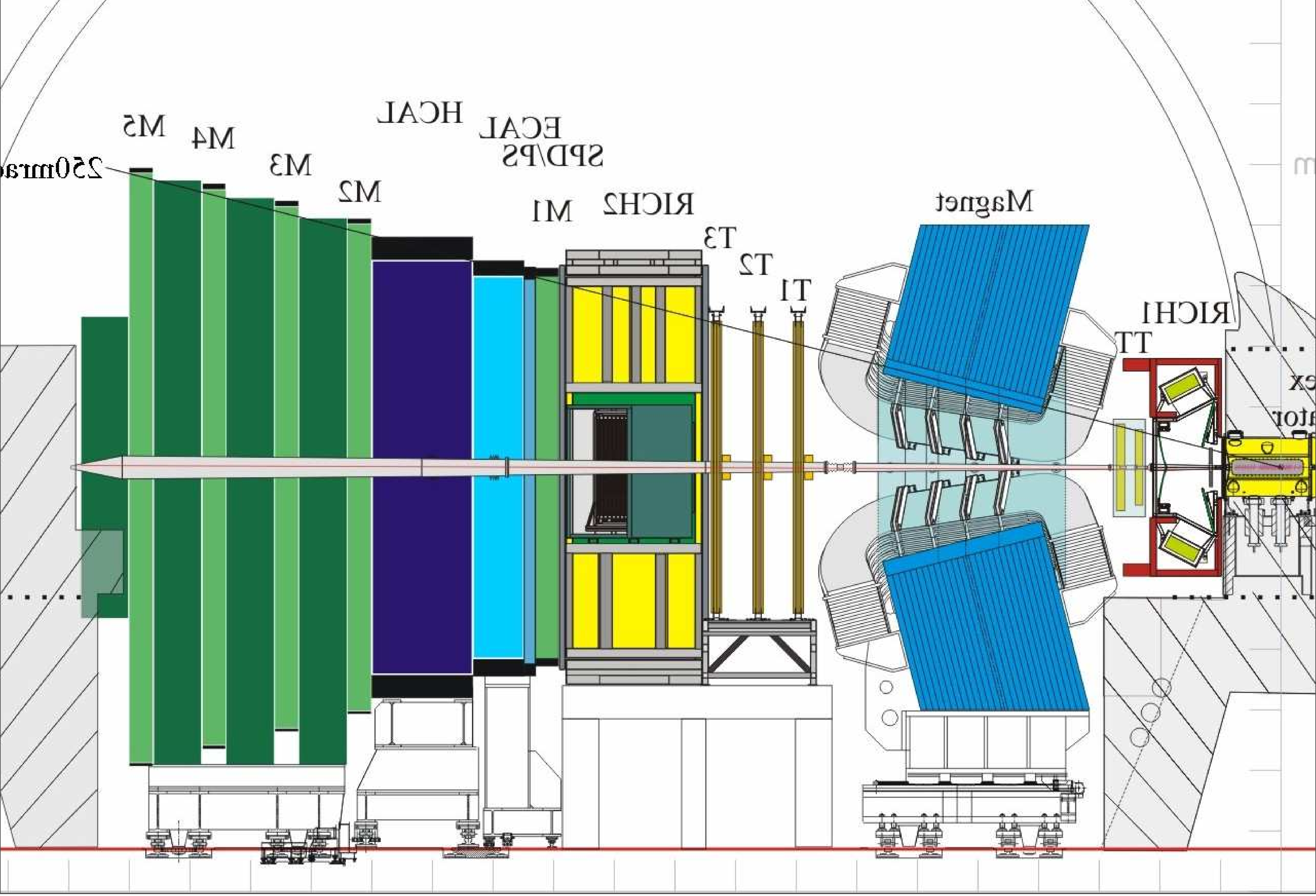


ICHEP'12?

35k events?

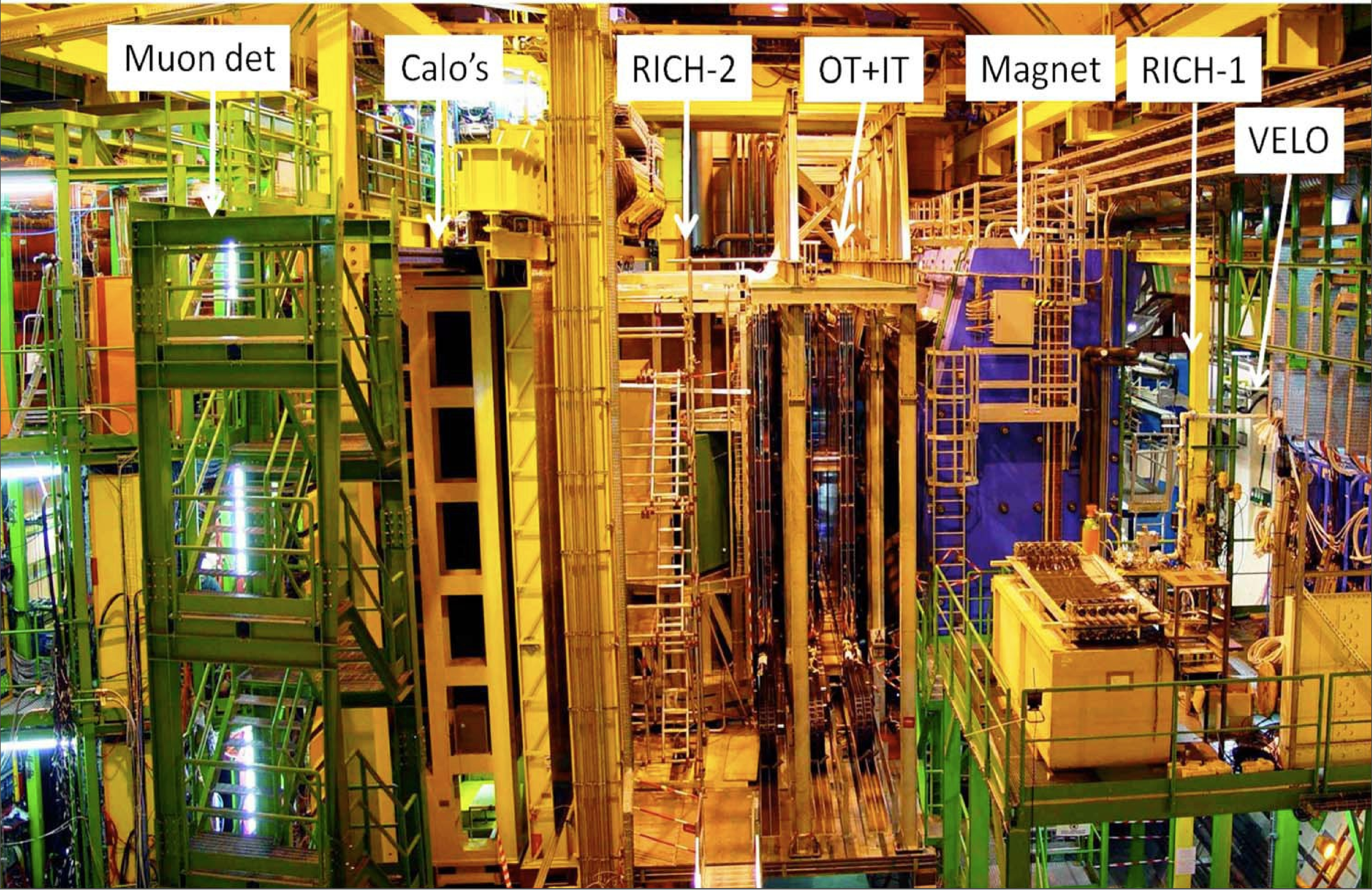
Backup

LHCb

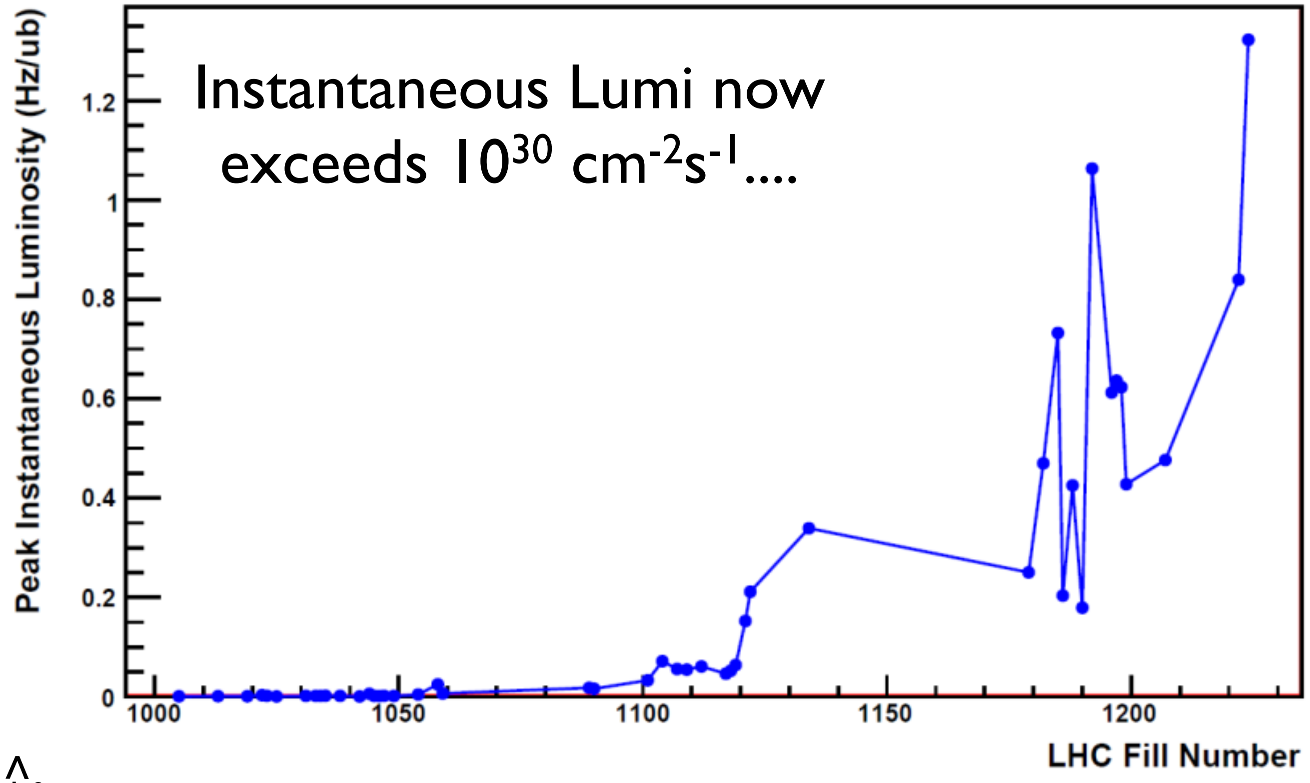


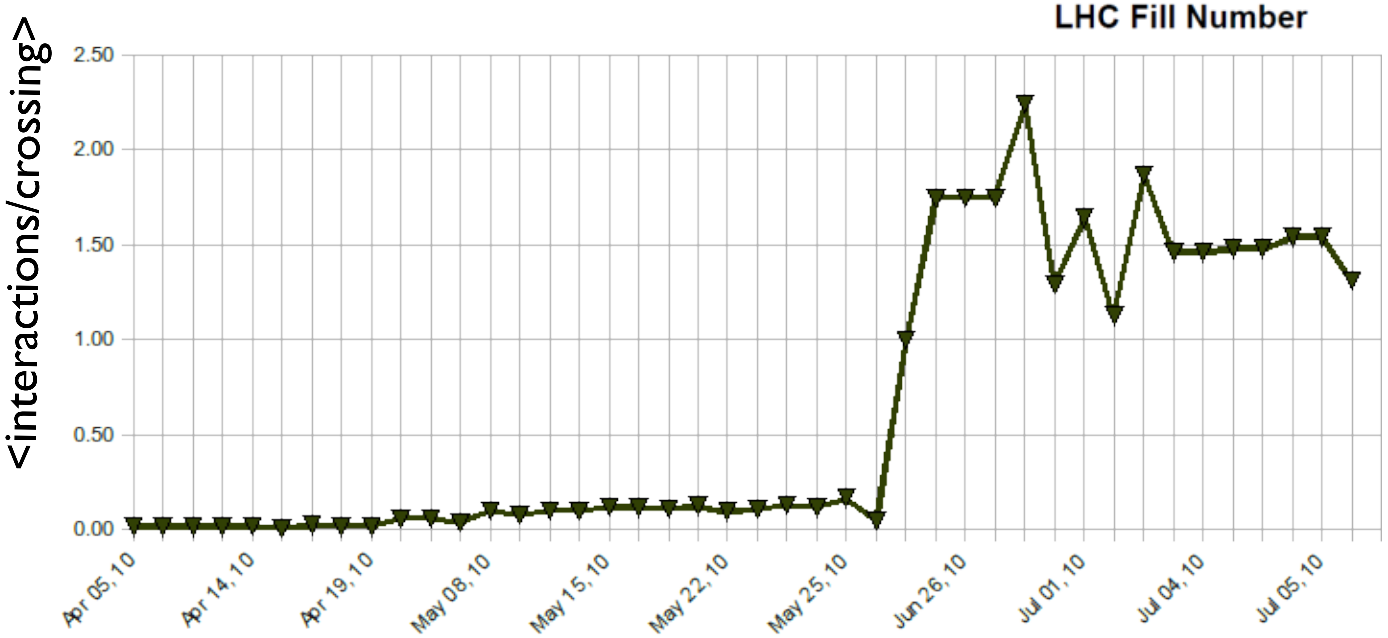
250mrad
M5
M4
M3
M2
HCAL
ECAL
SPD/PS
M1
RICH2
T3
T2
T1
Magnet
TT
RICH1

LHCb



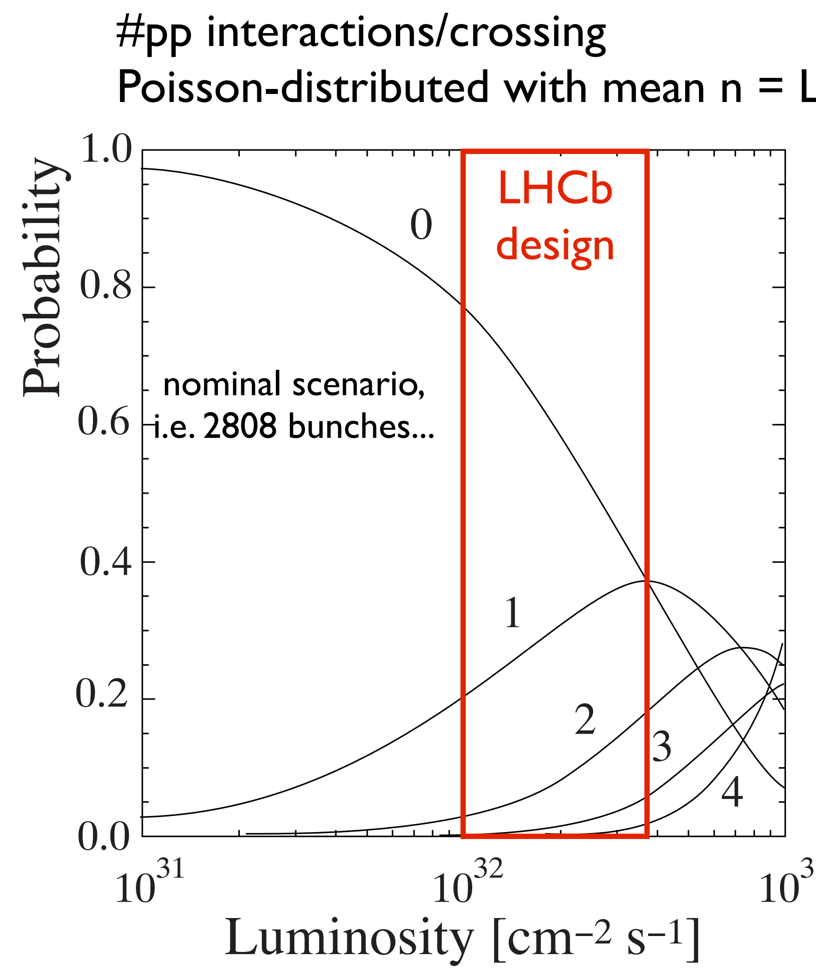
and pile-up!





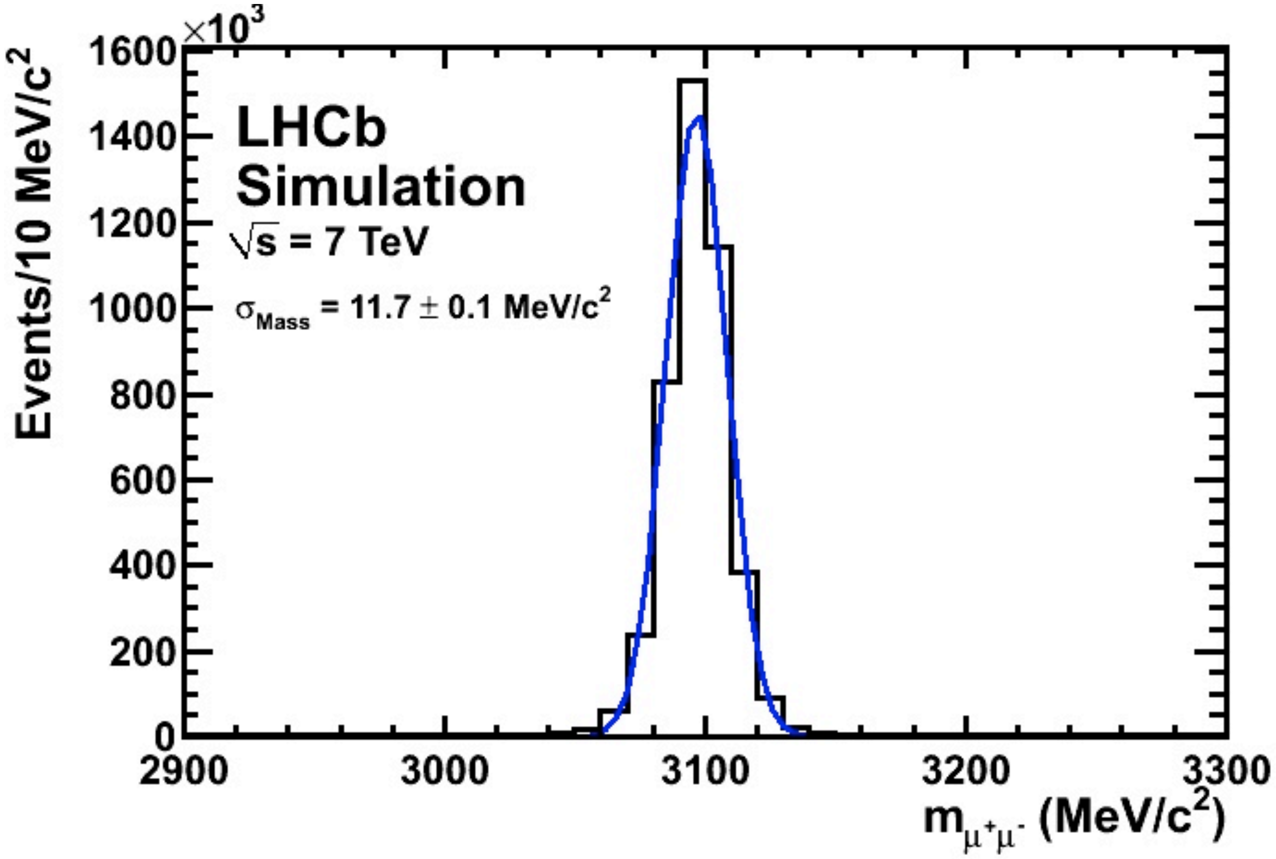
O(1%) of design luminosity....

.... but with only O(0.3%) of the # of bunches!

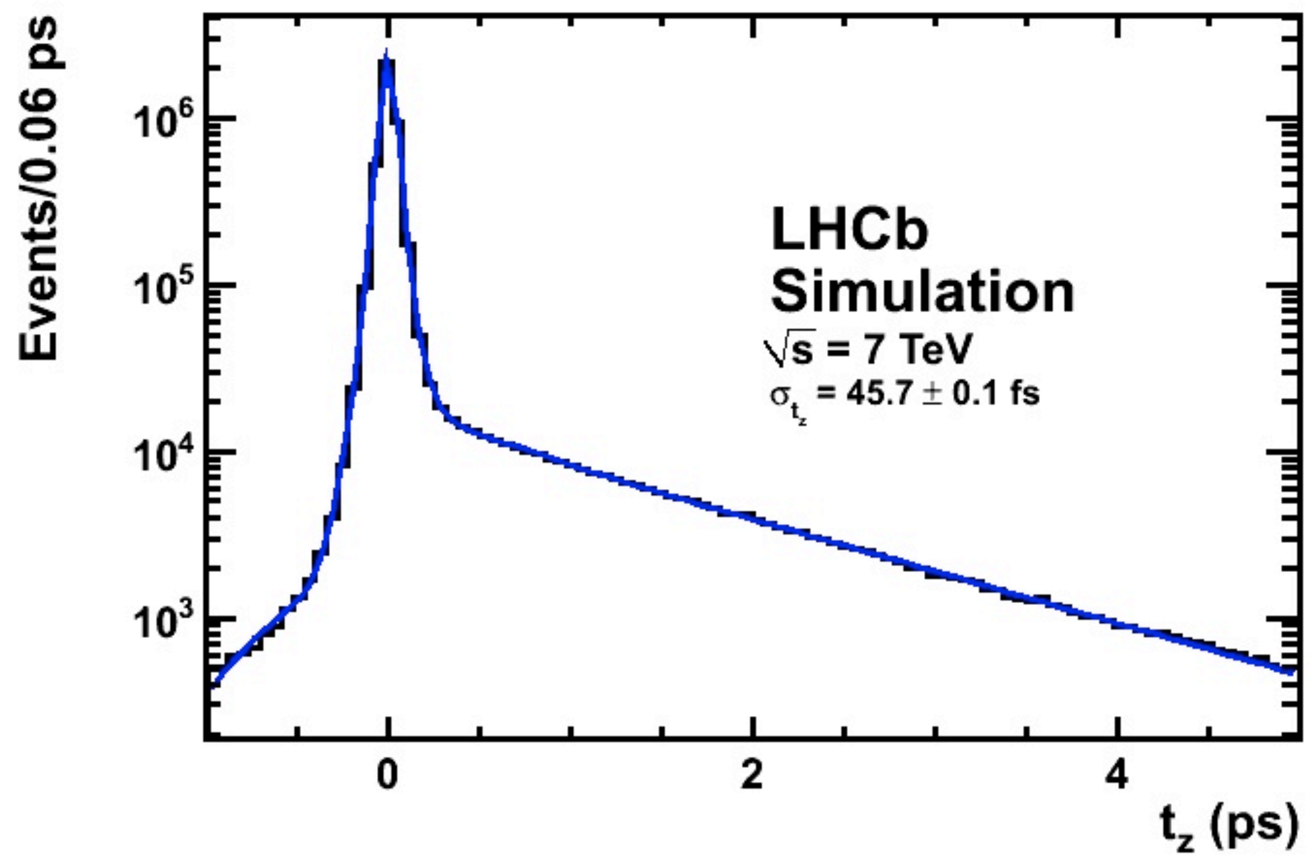


LHCb running (in this aspect) beyond the nominal scenario

Re-use experience from the ongoing LHCb upgrade planning!

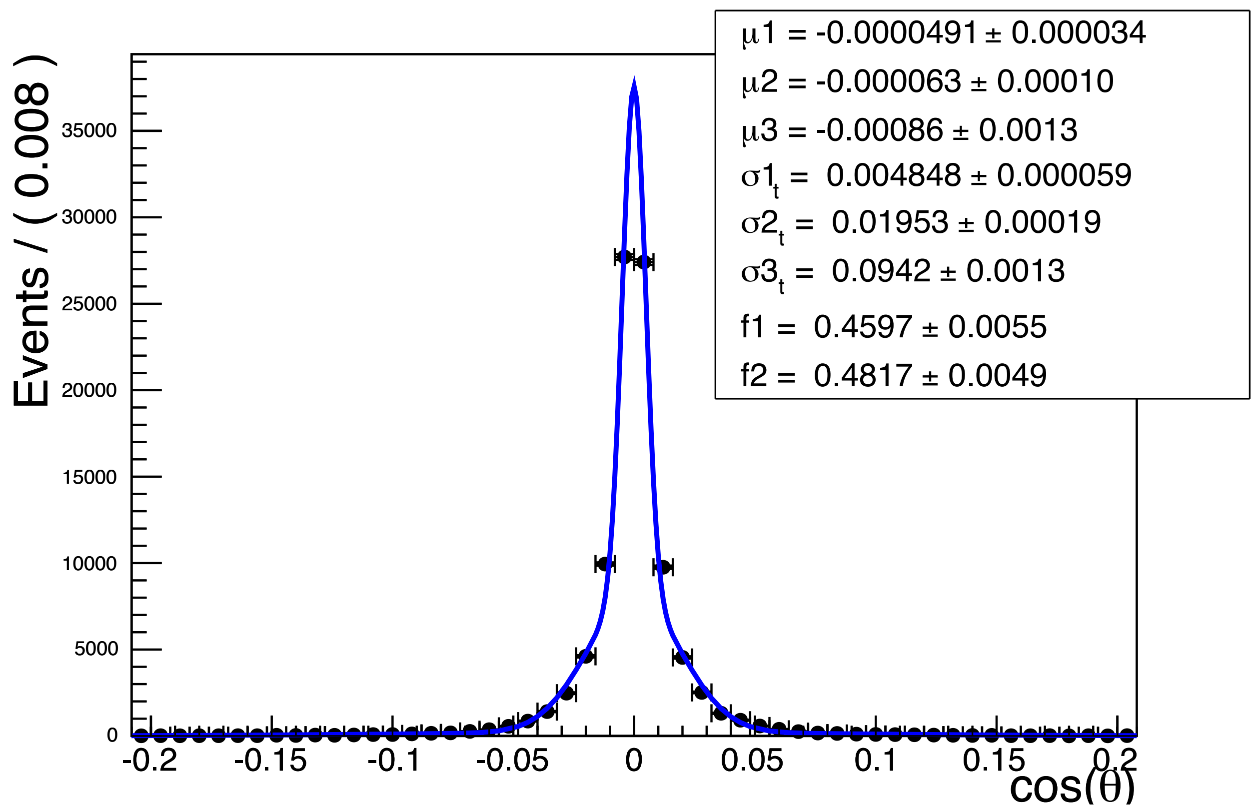


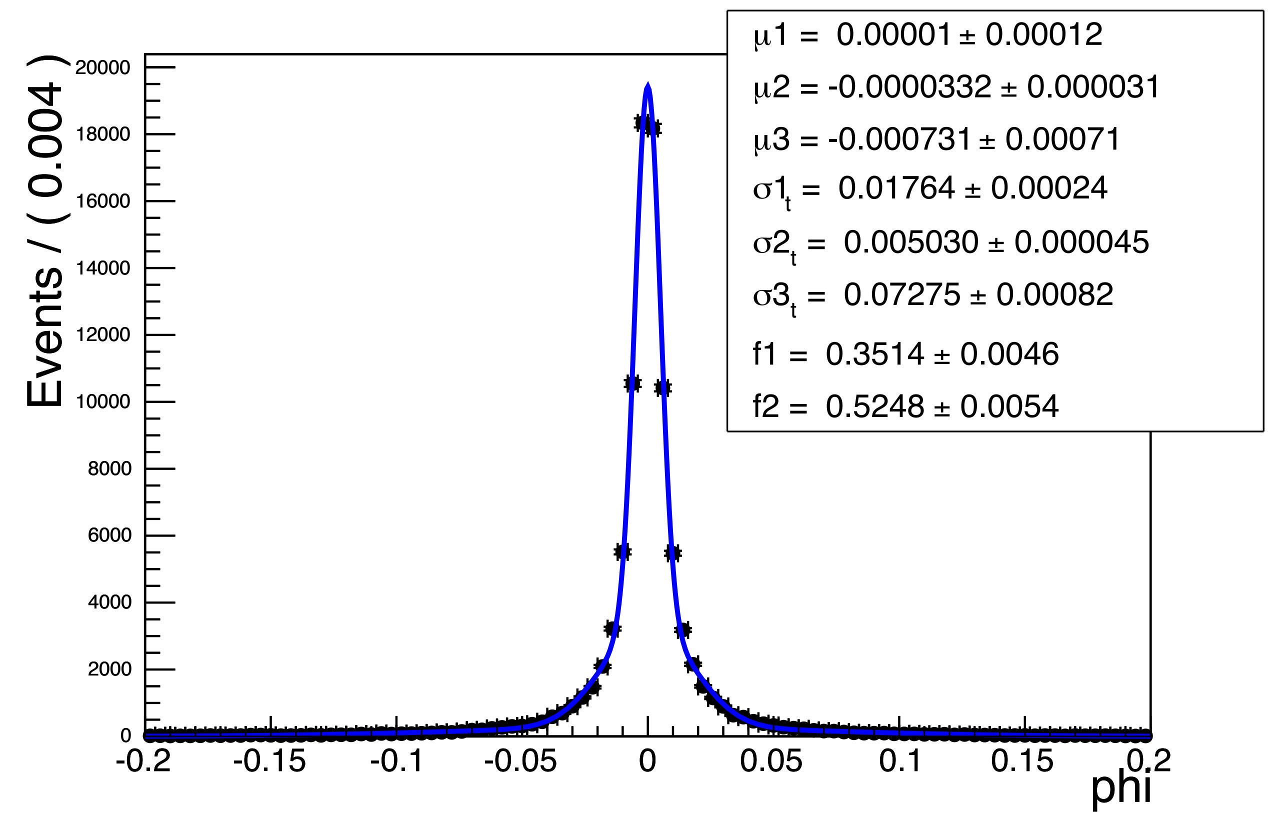
×10^3
Events/10 MeV/c^2
LHCb
Simulation
√s = 7 TeV
σ_Mass = 11.7 ± 0.1 MeV/c^2
m_μ+μ- (MeV/c^2)

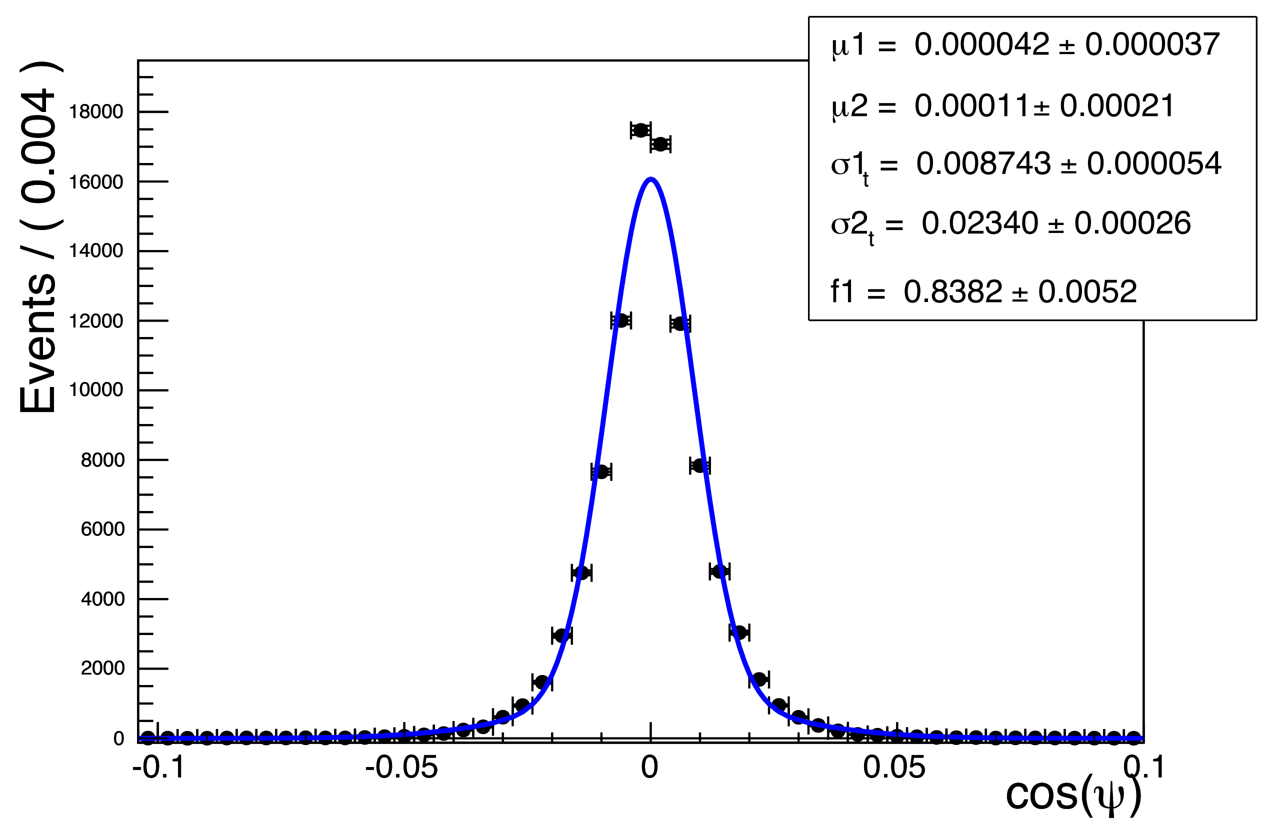


Events/0.06 ps
LHCb
Simulation
√s = 7 TeV
σ_tz = 45.7 ± 0.1 fs
t_z (ps)

$B_s \to J/\psi\varphi$ MC: angular resolution







57/ 77

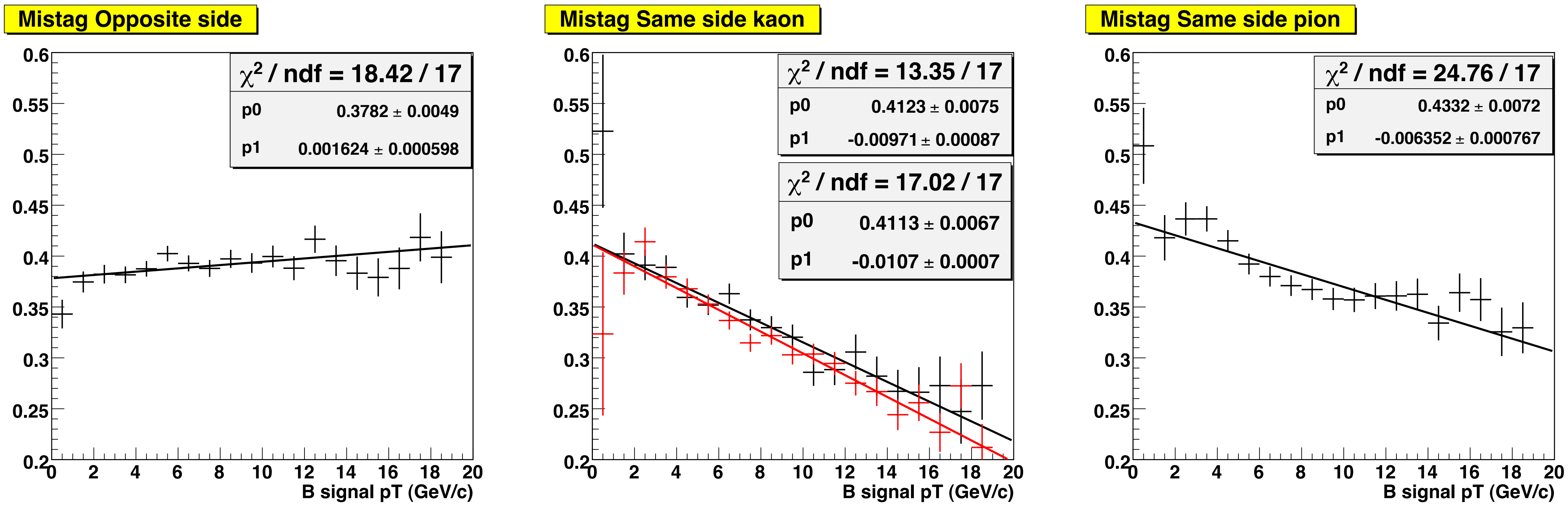


Figure 20: Mistag rate as a function of the B signal transverse momentum. Left: combination of all opposite side taggers in $B_s^0 \to J/\psi\phi$ events. Center: same side kaon tag in $B_s^0 \to J/\psi\phi$ events (black, upper box) and superimposed $B_s^0 \to D_s^-\pi^+$ events (red, lower box). Right: same side pion tag in $B^+ \to J/\psi K^+$ events.

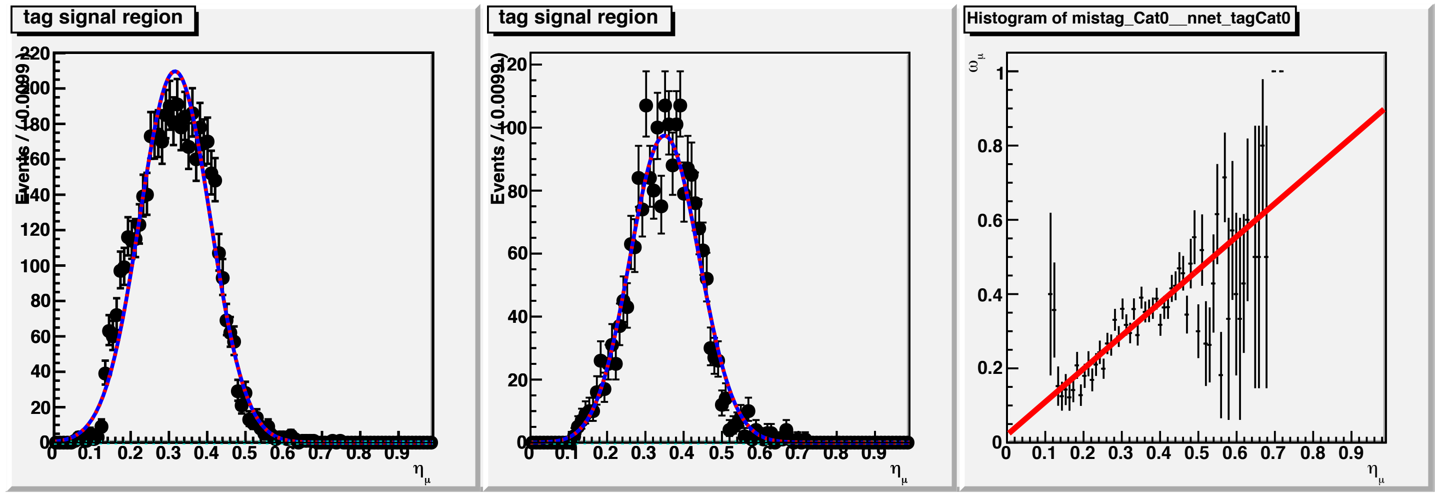


Figure 21: Mistag distribution for correctly (left) and wrongly (center) muon tagged $B^+ \to J/\psi(\mu\mu)K^+$ signal events. On the right the dependence of the measured mistag on the probability of mistag is represented. The best fit calibration curve $\omega_\mu(\eta_\mu) = p0_\mu + p1_\mu(\eta_\mu - \bar{\eta}_\mu)$ is superimposed.

$B_s^0 \rightarrow J/\psi(\mu\mu)\phi(KK)$			
	$\varepsilon_{tag}(1-2\omega)^2$ %	ε_{tag} %	ω %
Individual taggers			
μ	0.76 ± 0.05	5.77 ± 0.08	31.9 ± 0.6
e	0.38 ± 0.04	2.91 ± 0.06	32.0 ± 0.9
K_{opp}	1.25 ± 0.07	15.06 ± 0.12	35.6 ± 0.4
K_{same}	2.39 ± 0.10	26.37 ± 0.15	34.9 ± 0.3
Q_{vtx}	1.09 ± 0.07	44.35 ± 0.17	42.1 ± 0.2
Combination of opposite side taggers only			
cat#1	0.34 ± 0.04	28.18 ± 0.15	44.5 ± 0.3
cat#2	0.51 ± 0.04	6.89 ± 0.08	36.4 ± 0.6
cat#3	0.68 ± 0.05	4.79 ± 0.07	31.1 ± 0.7
cat#4	0.89 ± 0.05	3.57 ± 0.06	25.1 ± 0.8
cat#5	0.90 ± 0.05	2.18 ± 0.05	17.9 ± 0.9
Average	2.18 ± 0.10	45.61 ± 0.17	39.07 ± 0.24
Combined	$\mathbf{3.32 \pm 0.11}$	$\mathbf{45.61 \pm 0.17}$	$\mathbf{36.51 \pm 0.24}$
Combination of all taggers			
Average	4.45 ± 0.14	55.71 ± 0.17	35.88 ± 0.21
Combined	$\mathbf{6.23 \pm 0.15}$	$\mathbf{55.71 \pm 0.17}$	$\mathbf{33.27 \pm 0.21}$

Table 15: Results of flavour tagging obtained for $B_s^0 \rightarrow J/\psi\phi$ events passing Level-0, for the individual taggers and for their combination. Average: result from the global tagging decision for all events together. Combined: results after splitting into the 5 categories and summing the effective efficiencies. Uncertainties are statistical.

Semileptonic Asymmetry

$$\phi_s^{\rm SM} = 2\arg(V_{\rm ts}^* V_{\rm tb}) - 2\arg(V_{\rm cb} V_{\rm cs}^*) + \delta^{\rm Penguins} = -2\beta_{\rm s} + \delta^{\rm Penguins}$$

$$\phi_{\rm s} = \phi_s^{\rm SM} + \phi_{\rm s}^{\Delta}\,, \tag{1}$$

$$\Delta\Gamma_{\rm s} = 2|\Gamma_{12}^{\rm SM}|\cos(\phi_{\rm s12}^{\rm SM} + \phi_{\rm s}^{\Delta})\,, \tag{2}$$

$$a_{\rm fs} = \frac{|\Gamma_{12}^{\rm SM}|}{|M_{12}^{\rm SM}|}\,\frac{\sin(\phi_{\rm s12}^{\rm SM} + \phi_{\rm s}^{\Delta})}{|\Delta_{\rm s}|}\,. \tag{3}$$

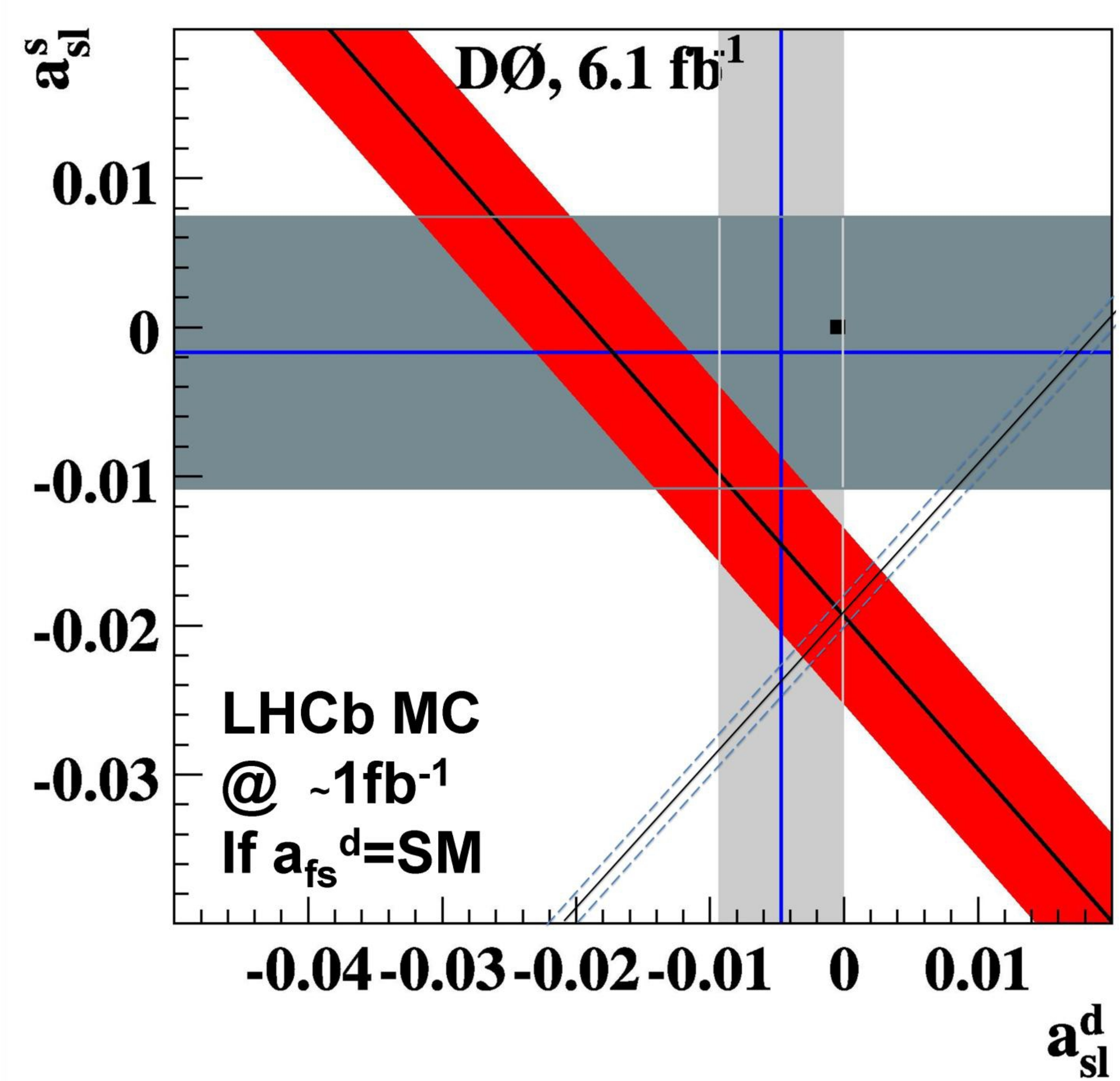
In the above equations, $a_{\rm fs}$ is the flavour specific asymmetry and

$$\phi_{\rm s12}^{\rm SM} = \arg\left(-\frac{M_{12}^{\rm SM}}{\Gamma_{12}^{\rm SM}}\right)\,. \tag{4}$$

In the Standard Model, $\phi_{\rm s12}^{\rm SM} = (3.40^{+1.32}_{-0.77}) \times 10^{-3}\,{\rm rad}$ while $2\beta_{\rm s} = (3.6 \pm 0.2) \times 10^{-2}\,{\rm rad}$.

Semileptonic Asymmetry

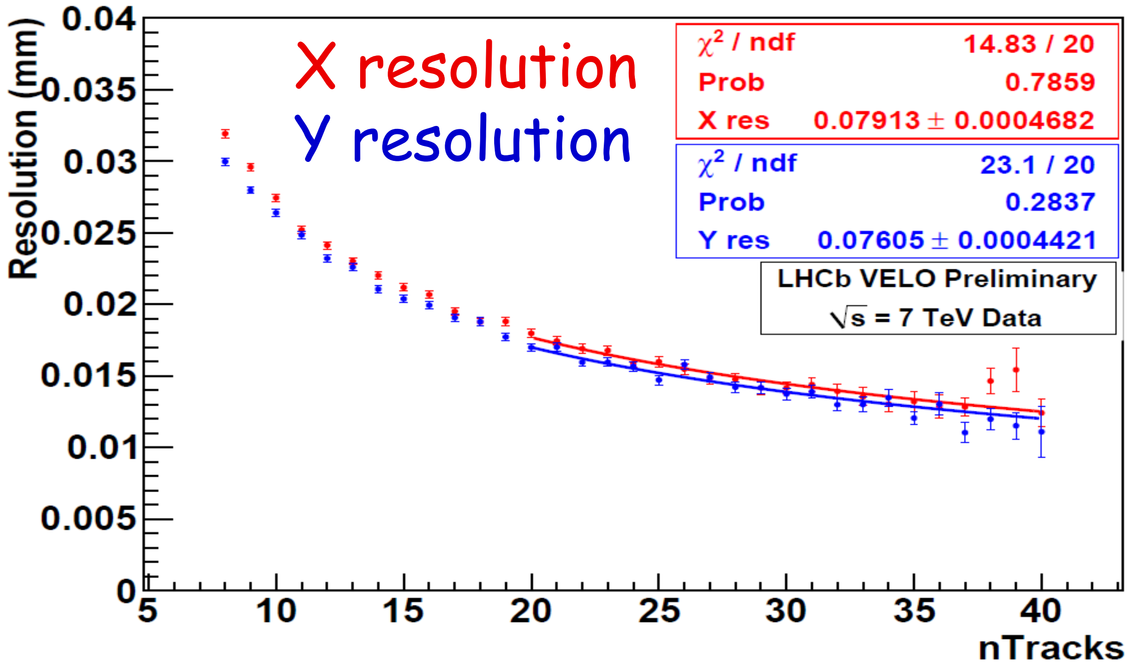
LHCb, 1 fb^{-1} [thesis R. Lambert]

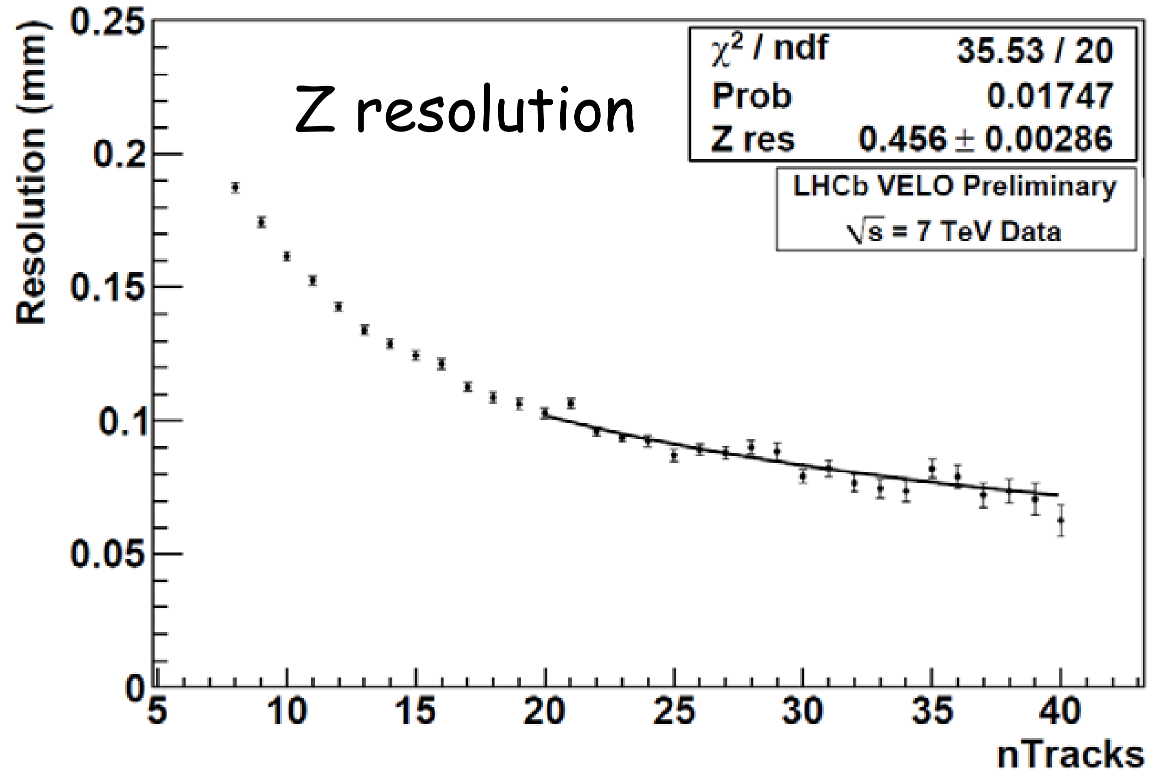


assumes A^b central value and no NP in B^0

PV resolution

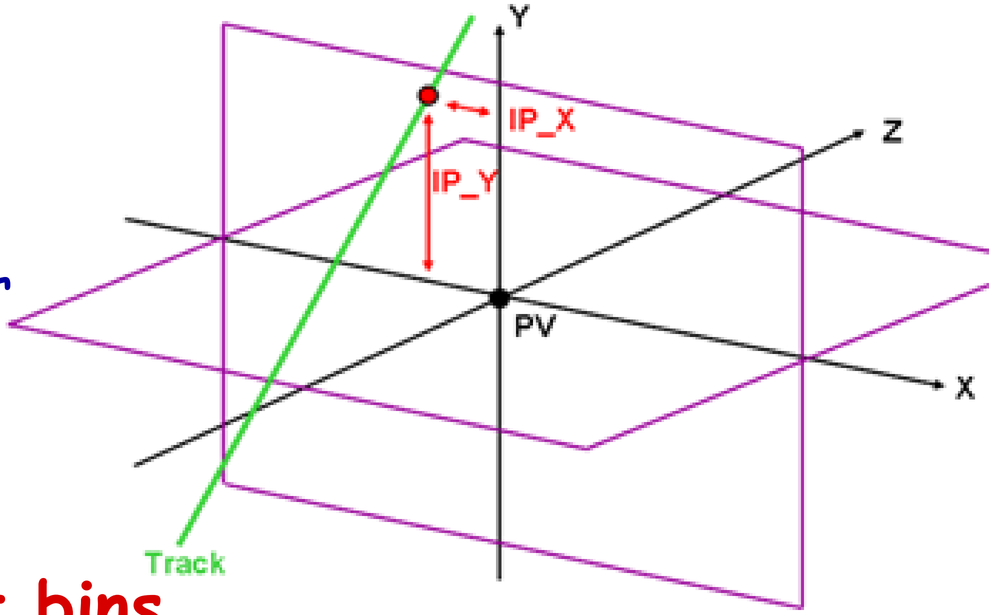
- Vertex resolution
  - Measure resolutions by randomly splitting track sample in two
  - Compare split vertices of equal multiplicity
  - Method validated with MC
- PV resolution (x,y,z) with 25 tracks:
  - **Data (15.8, 15.2, 91) μm**
  - MC (11.5, 11.3, 57) μm
- Room for improvement: alignment, material description



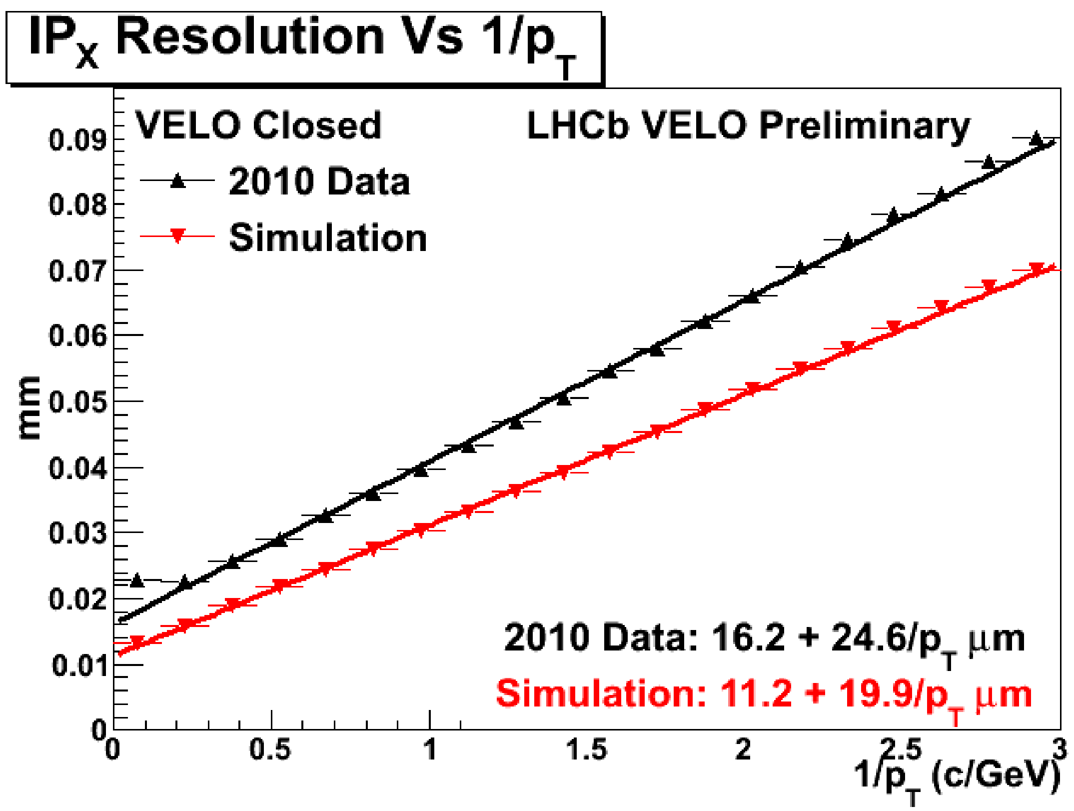


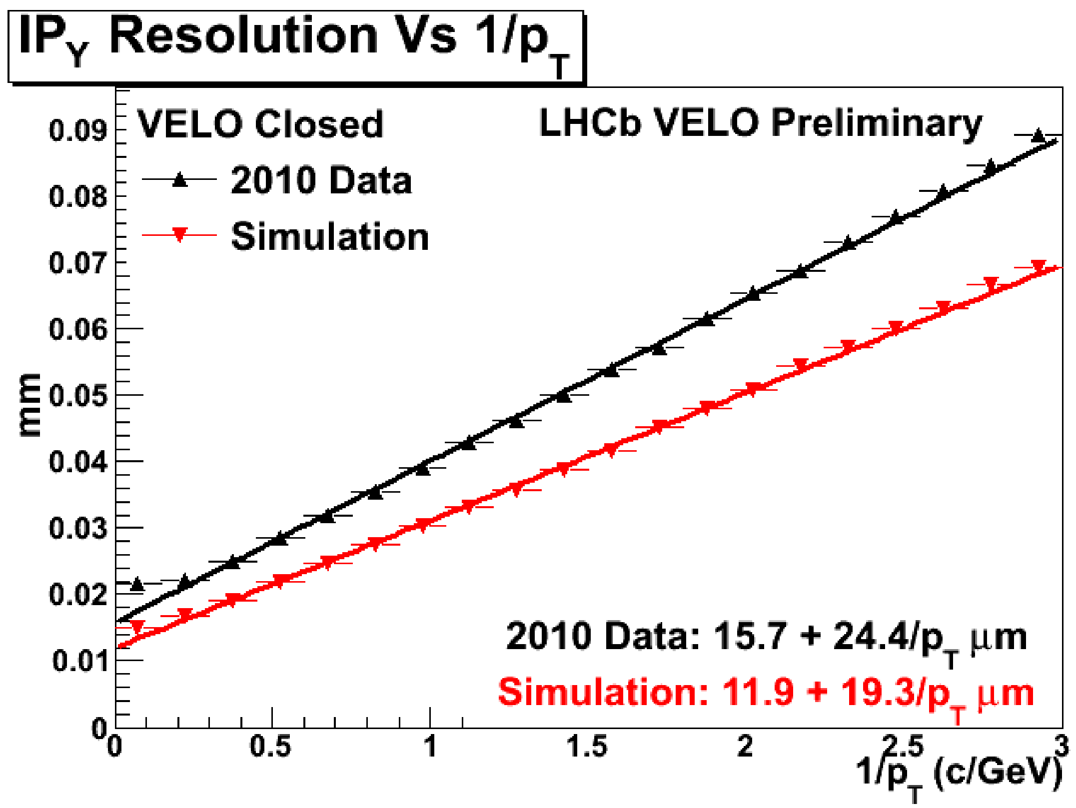
Impact Parameter resolution

- IP resolution:
  - Impact Parameter (IP) is defined as the closest distance of each track to the primary vertex:
  - Measure x and y component of impact parameter
  - Assume all tracks originate from primary interaction point
  - Measure resolution as spread of IP distribution



- **IP resolution up to 20 μm for the highest pt bins**
- Room for improvement: alignment, material description





LHCb Event Display