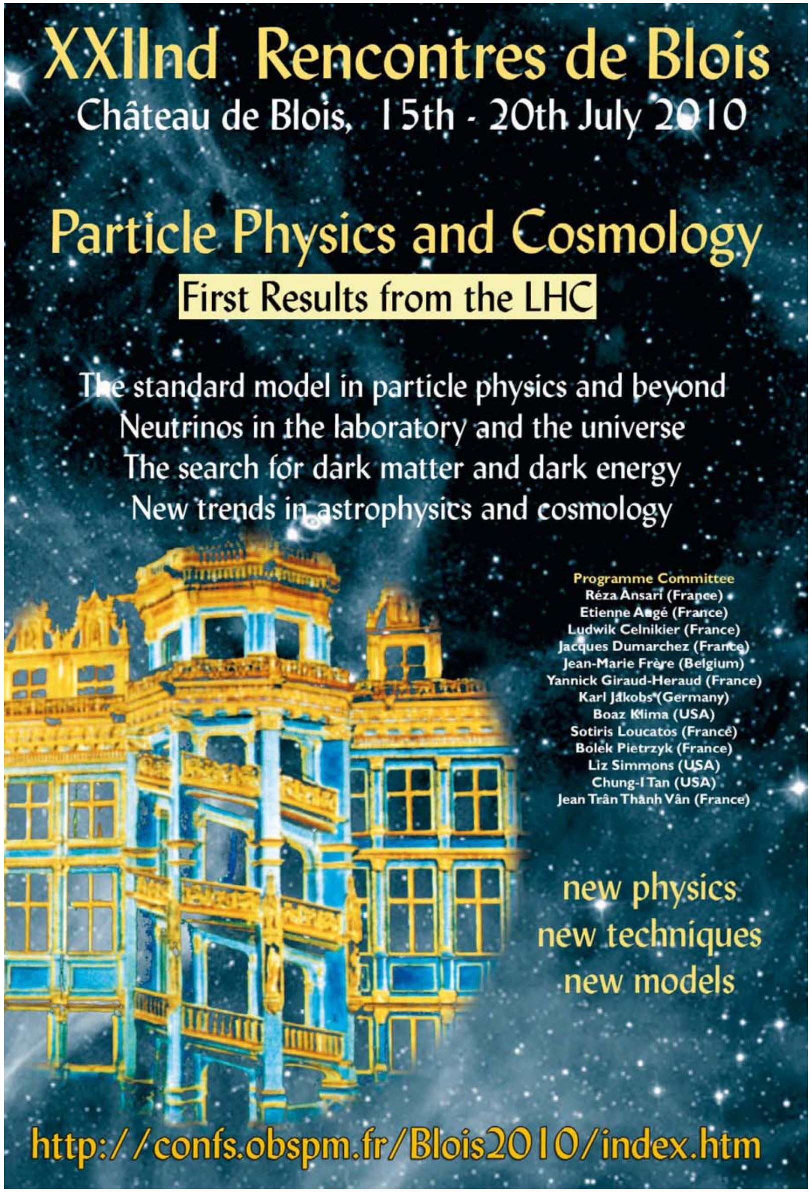
Recent results from LHCb (and prospects)



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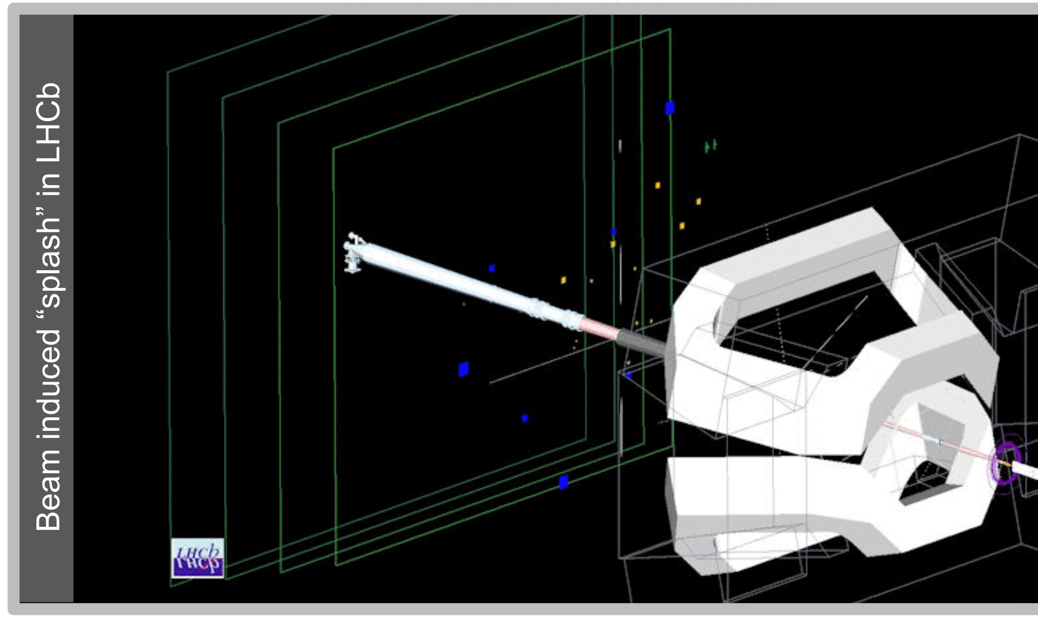


- Introduction and detector overview
- Preliminary results and ongoing analysis
- Outlook and prospects for 2010/2011

Andreas Schopper (CERN)

on behalf of the LHCb Collaboration

B Physics as a probe for New Physics

Standard Model (SM) cannot be the ultimate theory !

- SM could be a low-energy effective theory of a ***more fundamental theory at a higher energy scale***, probably in the TeV region → accessible at LHC !

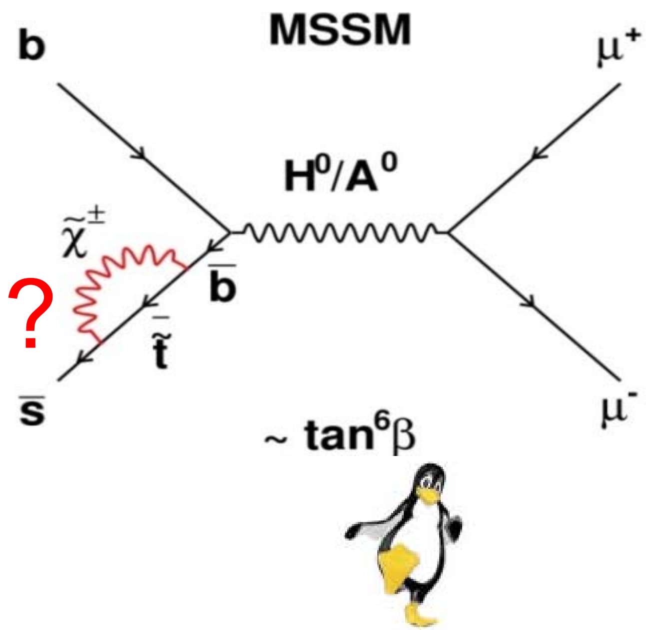
How can New Physics (NP) be discovered and studied ?

- NP models introduce ***new particles***, dynamics and/or symmetries at a higher energy scale, and these new particles could
  - ✓ be produced and observed ***as real particles*** at energy frontier machines like the LHC → detected by GPD (ATLAS & CMS)
  - ✓ appear ***as virtual particles*** in e.g. loop processes, leading to observable deviations from the pure SM expectations in flavour physics and CP violation → detected by LHCb in B decays

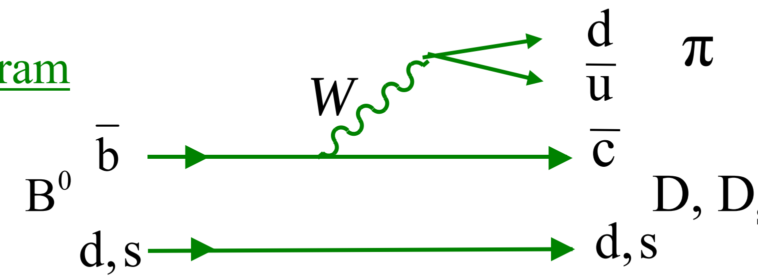
B decays in the Standard Model and beyond

virtual particles appear in loop mediated processes

$B_s \rightarrow \mu^+\mu^-$ "s-channel penguin"

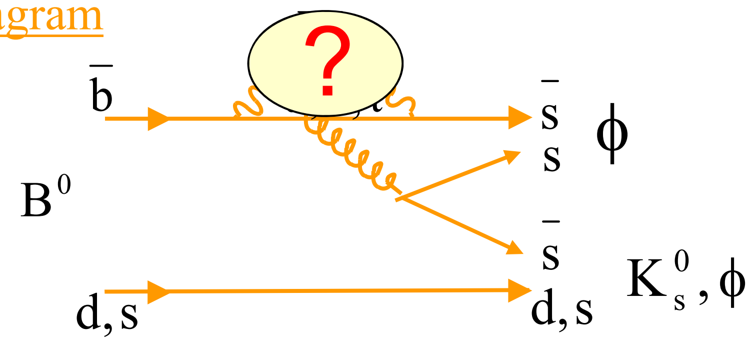


Tree diagram

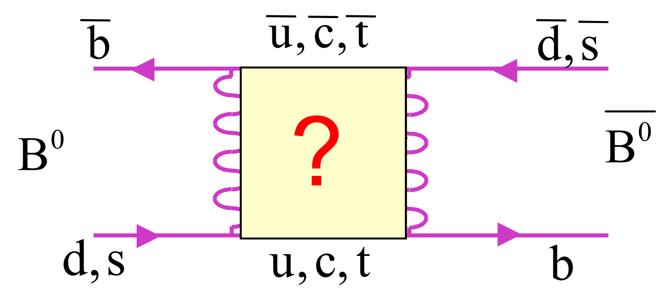


Penguin diagram

New Physics

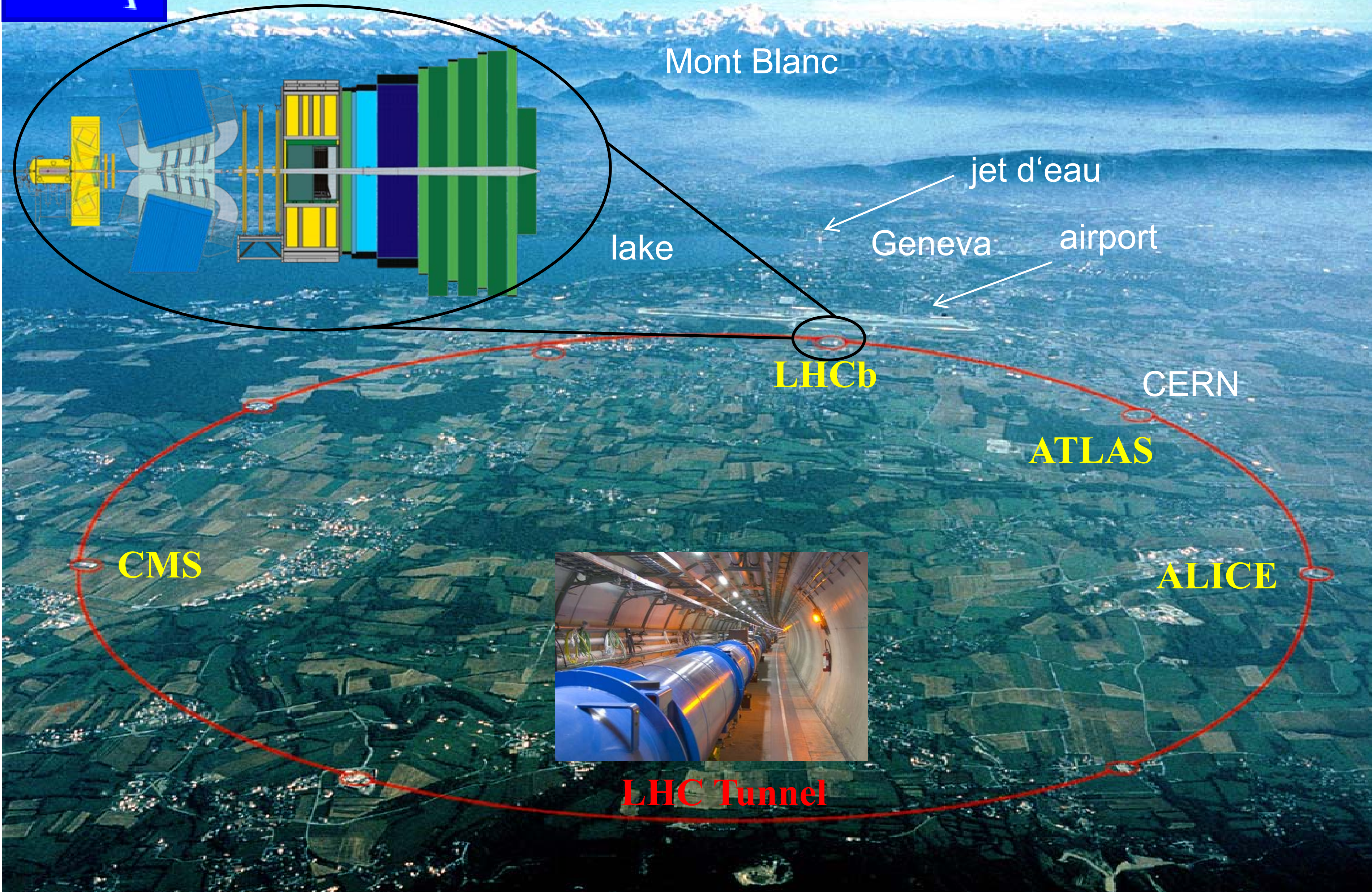


Box diagram

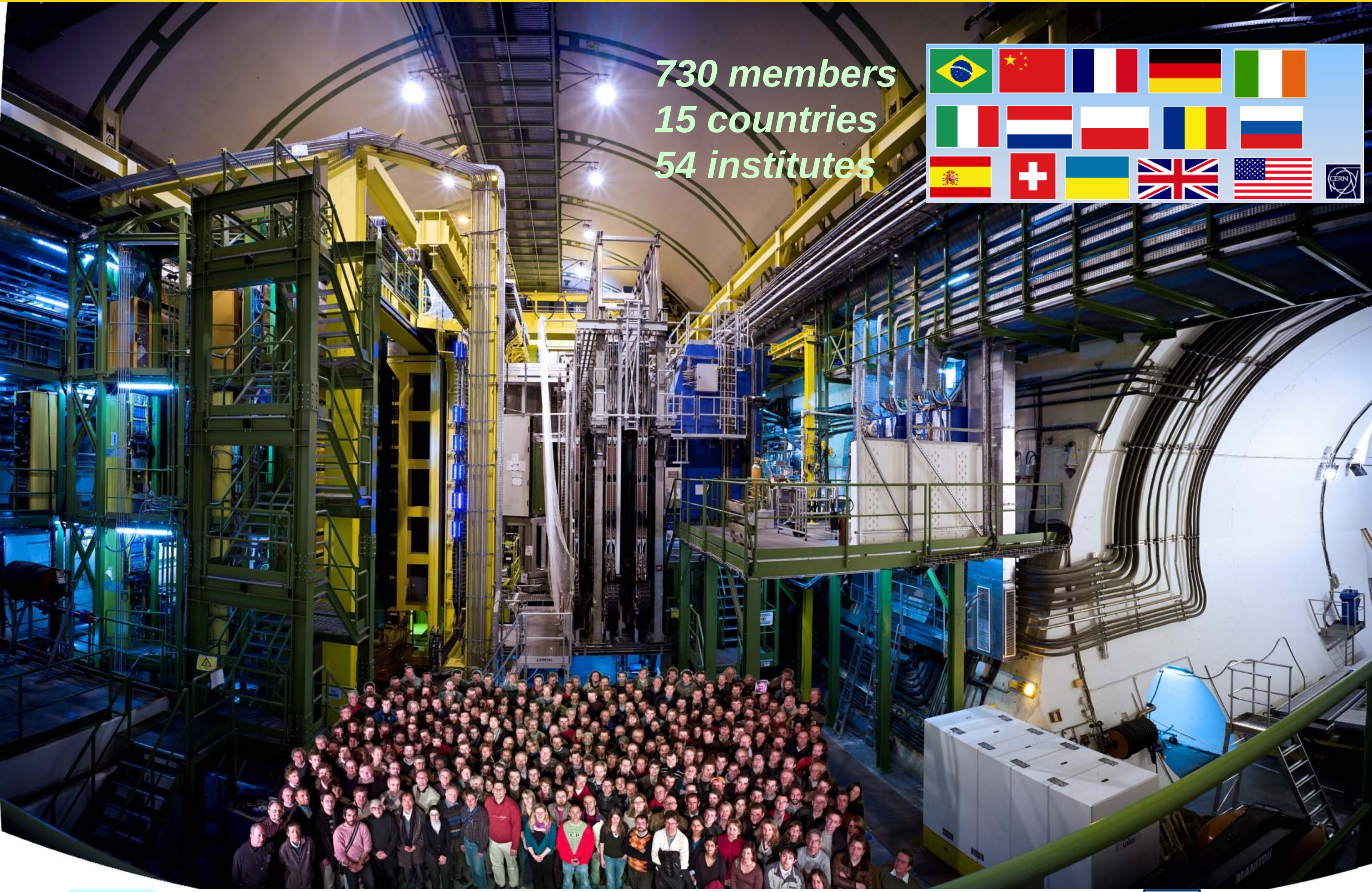


- ✓ Dominant decay process: "tree" b→c transition
- ✓ Very suppressed "tree" b→u transition
- ✓ FCNC: "penguin" b→s,d transition
- ✓ Flavour oscillations (b→t "box" diagram)

A dedicated B-Physics Experiment at the LHC

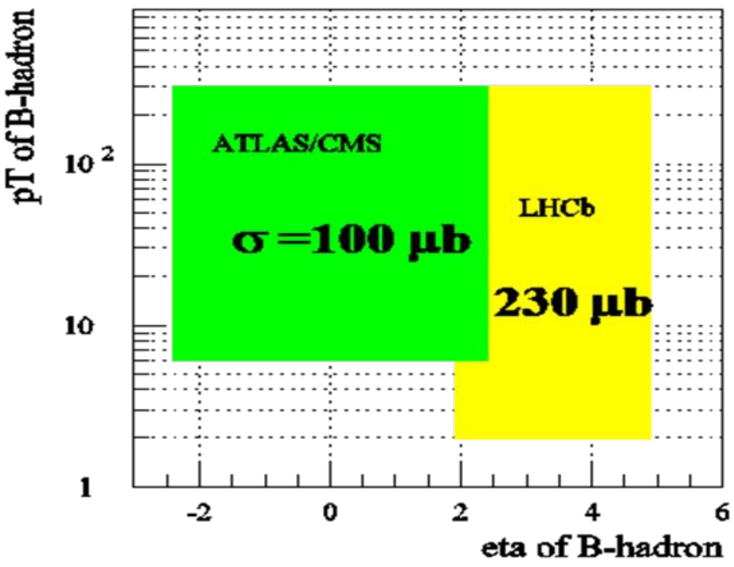


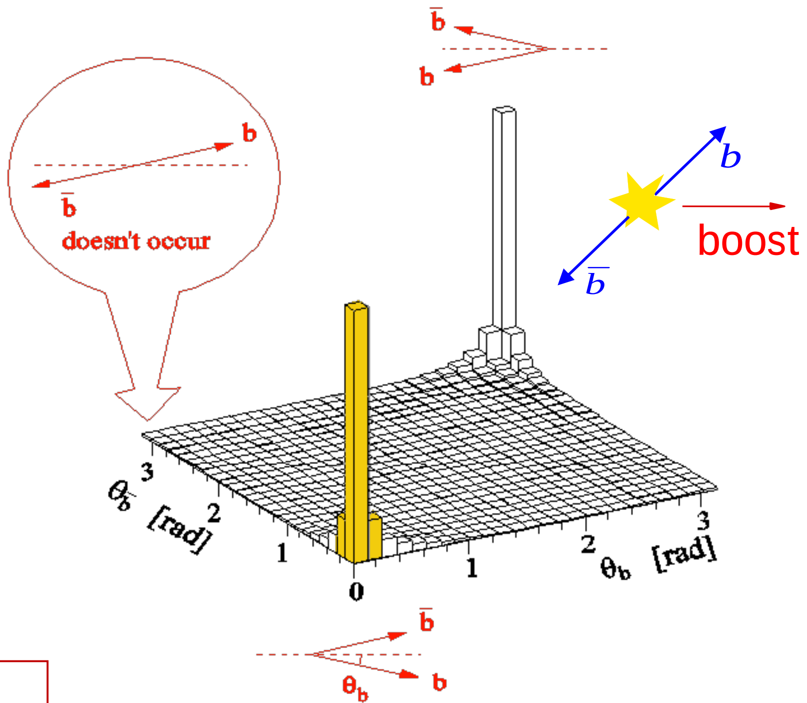
The LHCb Collaboration



B production in LHCb

- ✓ $b\bar{b}$ pair production correlated and sharply peaked forward-backward
  - ➢ forward geometry: 15-300 mrad, unique 5> η> 2 coverage
  - ➢ cross section of $b\bar{b}$ production in LHCb acceptance at $\sqrt{s}$=14 TeV: $\sigma_{bb} \sim 230$ μb
  - ➢ B^+ , B^0 , B_s , b-baryons , B_c
- ✓ LHCb limits luminosity to few 10^{32} $cm^{-2}s^{-1}$ instead of 10^{34} $cm^{-2}s^{-1}$ by not focusing the beam as much as ATLAS and CMS
  - ➢ maximizes probability of a single interaction per crossing
  - ➢ reach ~design luminosity in first year!





→ collect $2fb^{-1}$ per nominal year
→ ~ 10^{12} $b\bar{b}$ pairs produced per year

Requirements to detector performance

Triggering & selecting B's

✓ B's have a typical decay length of L~1cm in LHCb

➢ good vertex resolution

✓ B decay products have large transverse momentum (because of their high mass)

➢ select particles with high p_t that come from displaced vertex

Reconstructing B decays

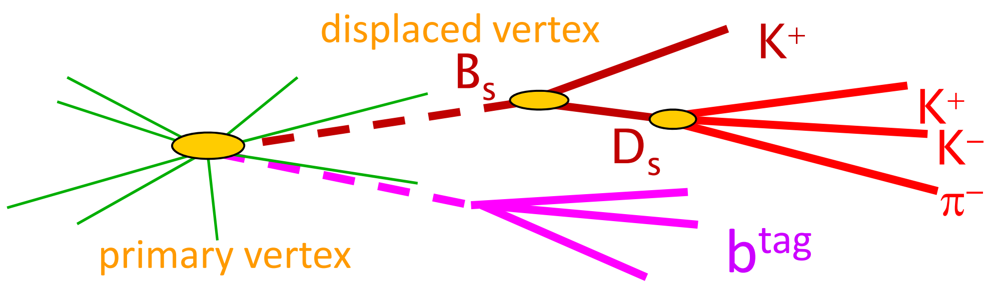
✓ Efficient background suppression

➢ good mass resolution

➢ particle identification

✓ Time resolved measurements for B_s decays

➢ good decay time resolution



example: $B_s \rightarrow D_s K$ decay

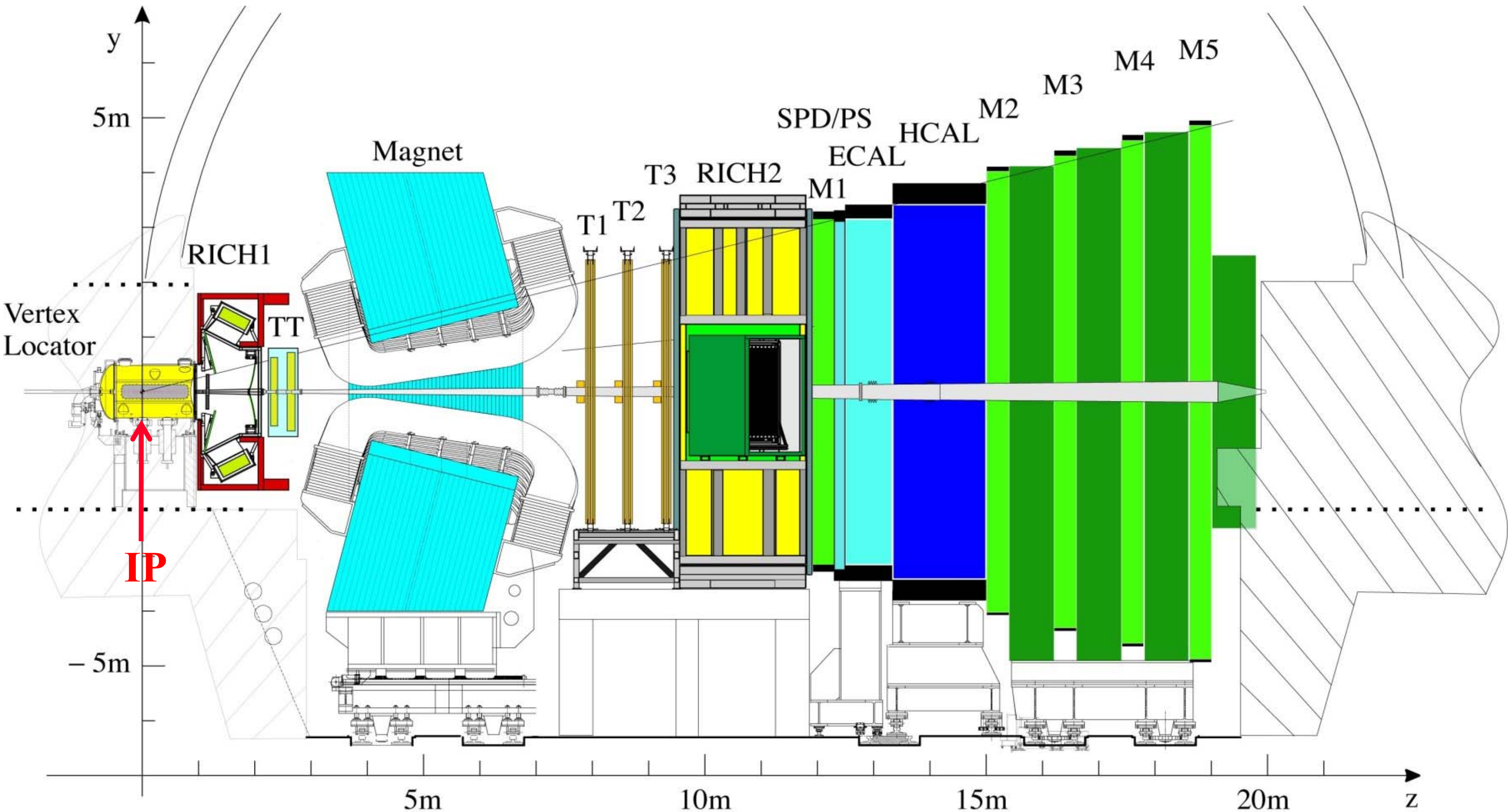
Tagging flavour of the B at production

✓ opposite side tagging of companion B (e.g. charge of the kaon in the b→ c→ s chain)

✓ same side tagging (e.g. charge of the kaon accompanying the B_s)

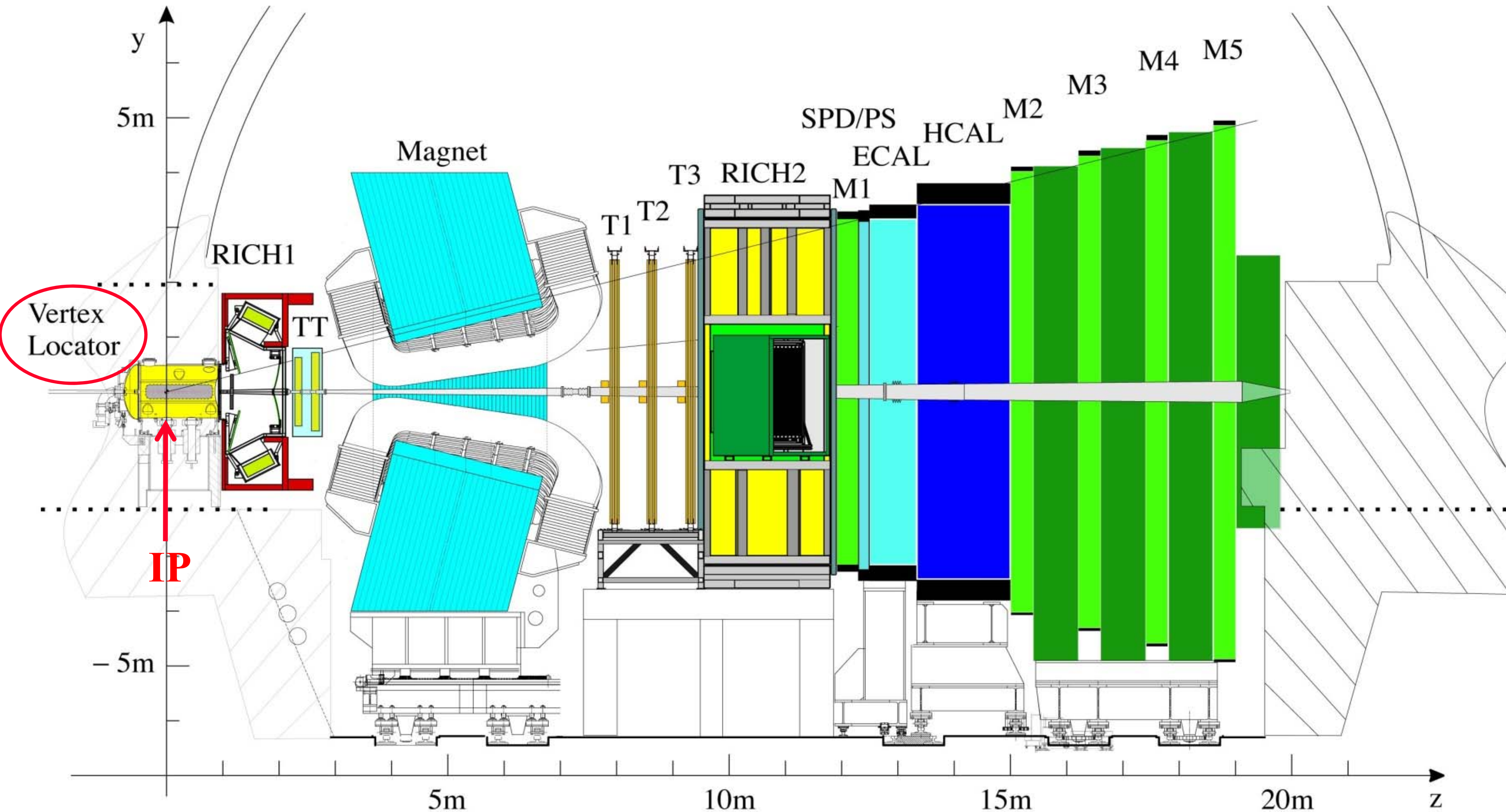
➢ particle identification

Overview of LHCb detector



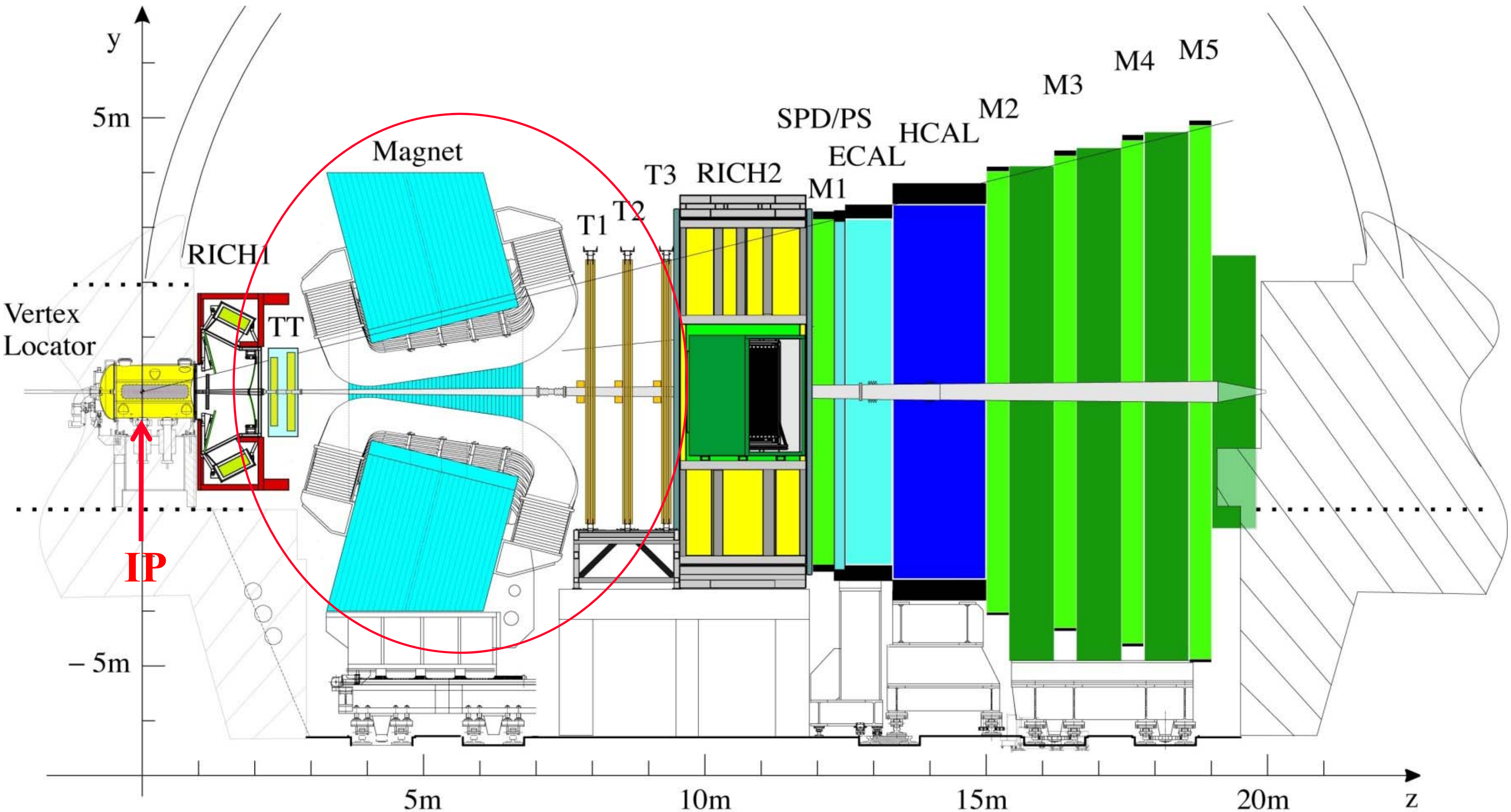
forward spectrometer specialized for B hadron reconstruction

Vertex locator



VELO: precise impact parameter and proper time resolution crucial for event selection and time dependent analysis

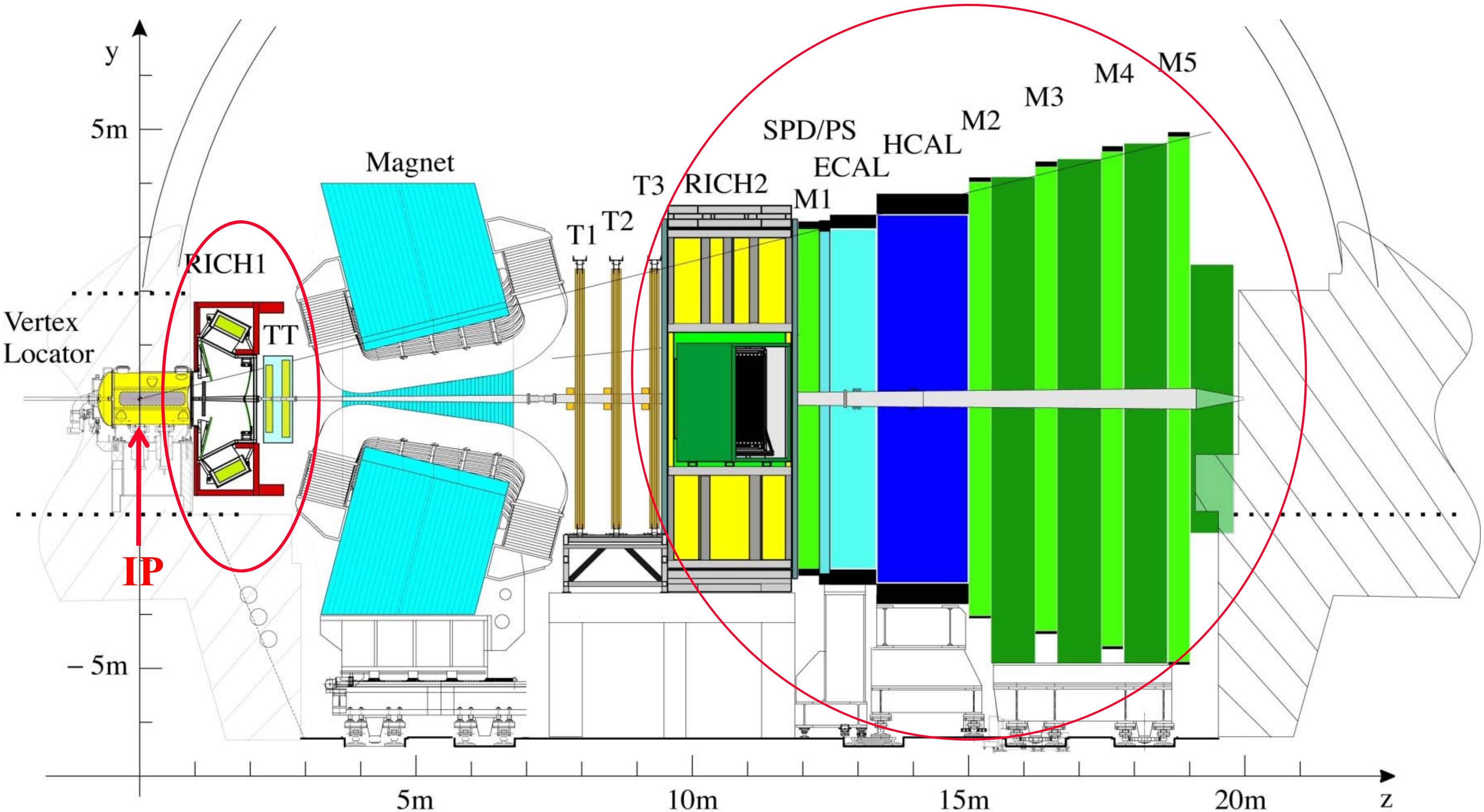
Tracking system



magnet & tracking stations: good momentum resolution → high mass resolution

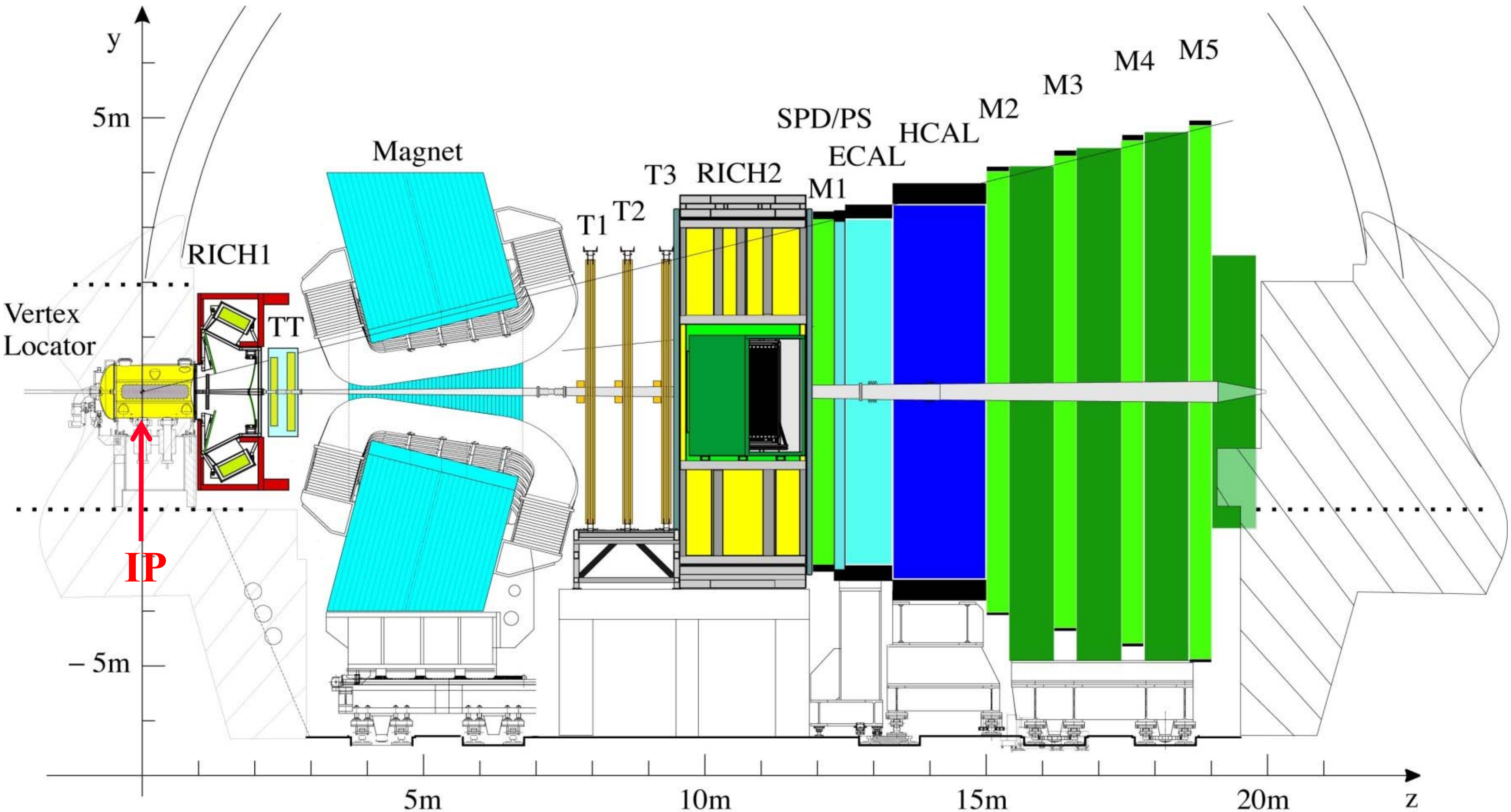
swap of B-field allows for test of detector asymmetry

Particle identification



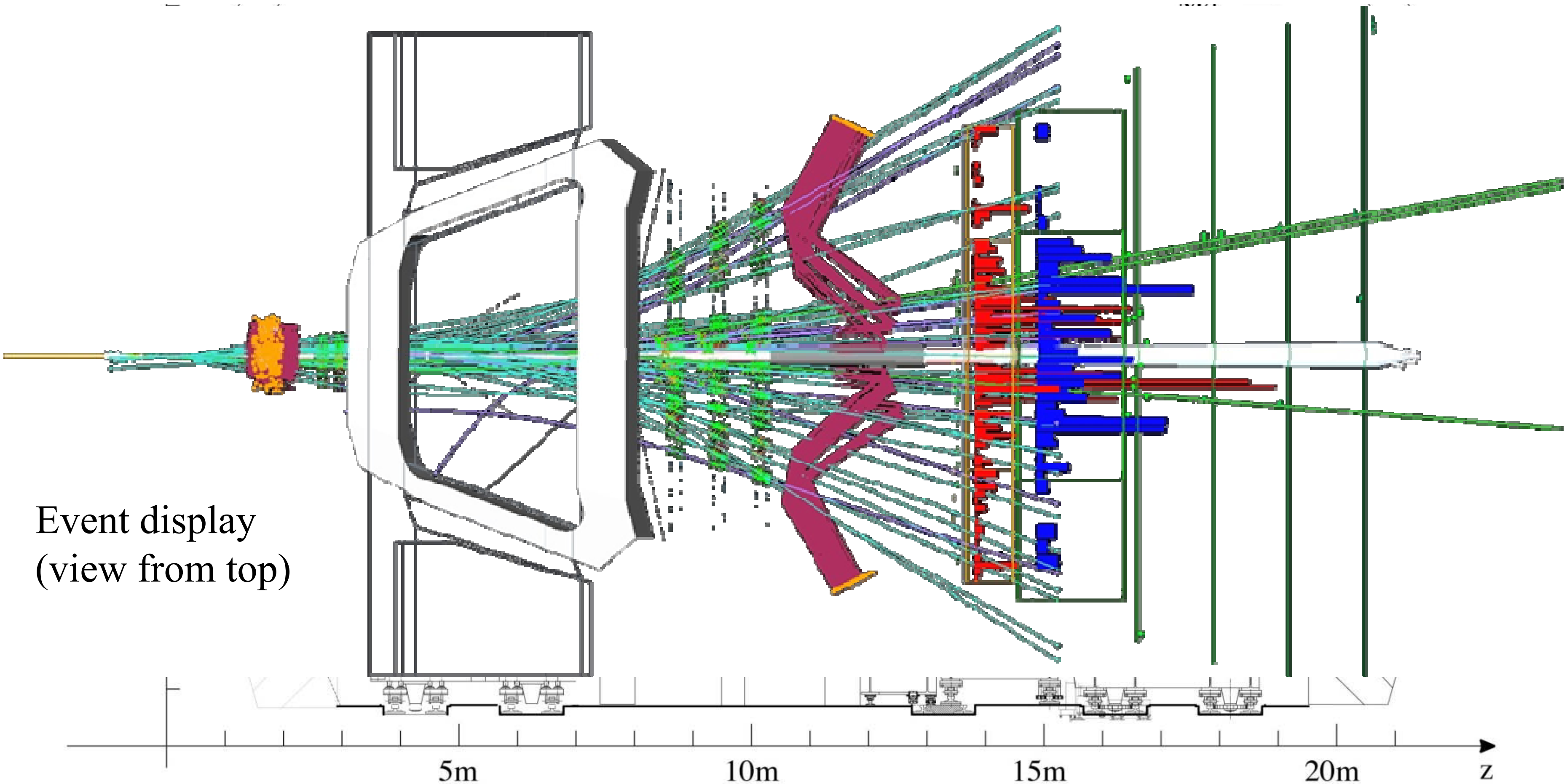
particle identification with RICHs, calorimeter and muon systems:
crucial for trigger, flavour tagging and B candidate selection

Trigger and data taking



+ dedicated hardware and software trigger to select interesting B events
+ large and clean data sets

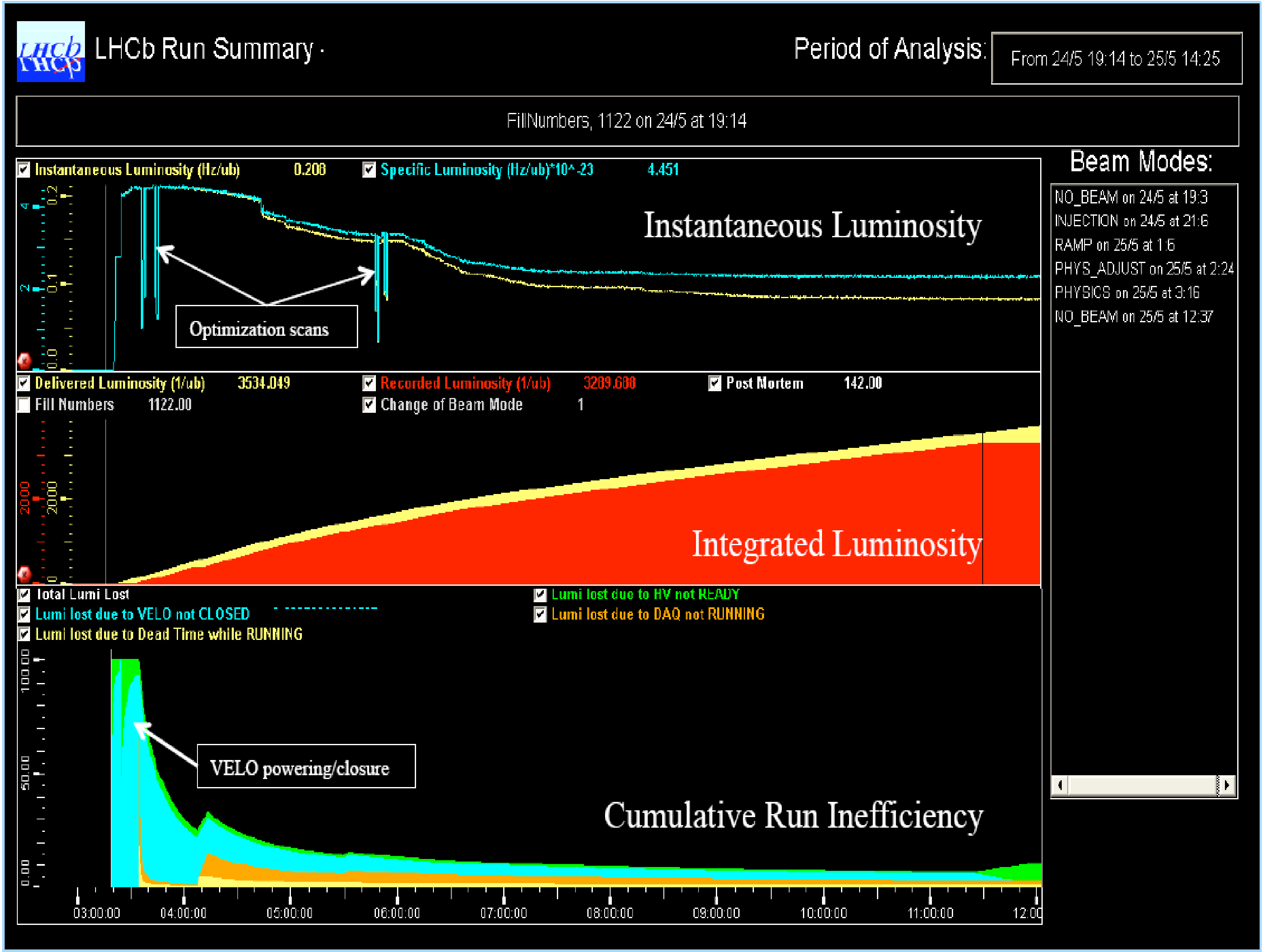
First pp collisions at √s = 7 TeV



Event display
(view from top)

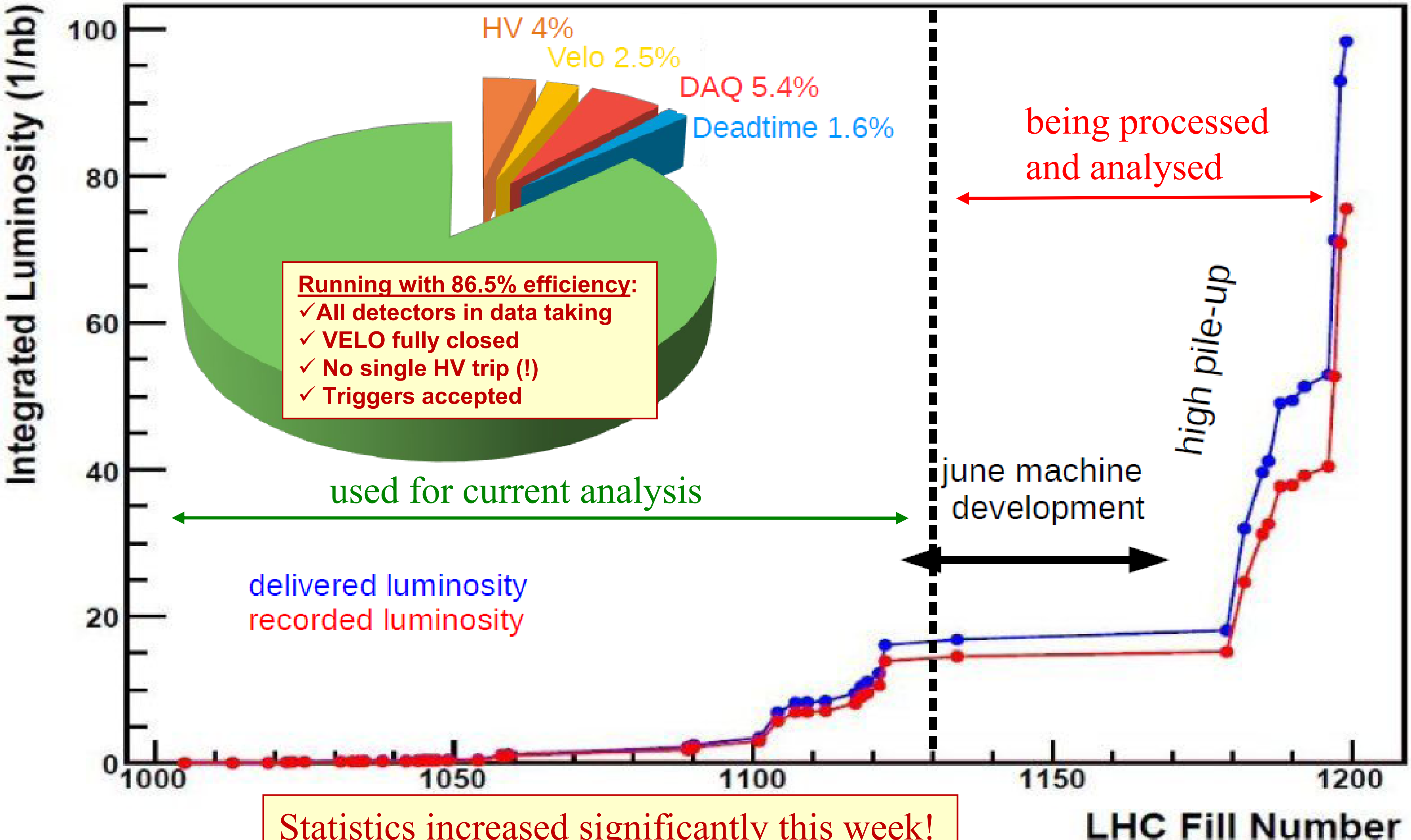
→ **Giacomo Graziani**

"Typical" data taking at LHCb



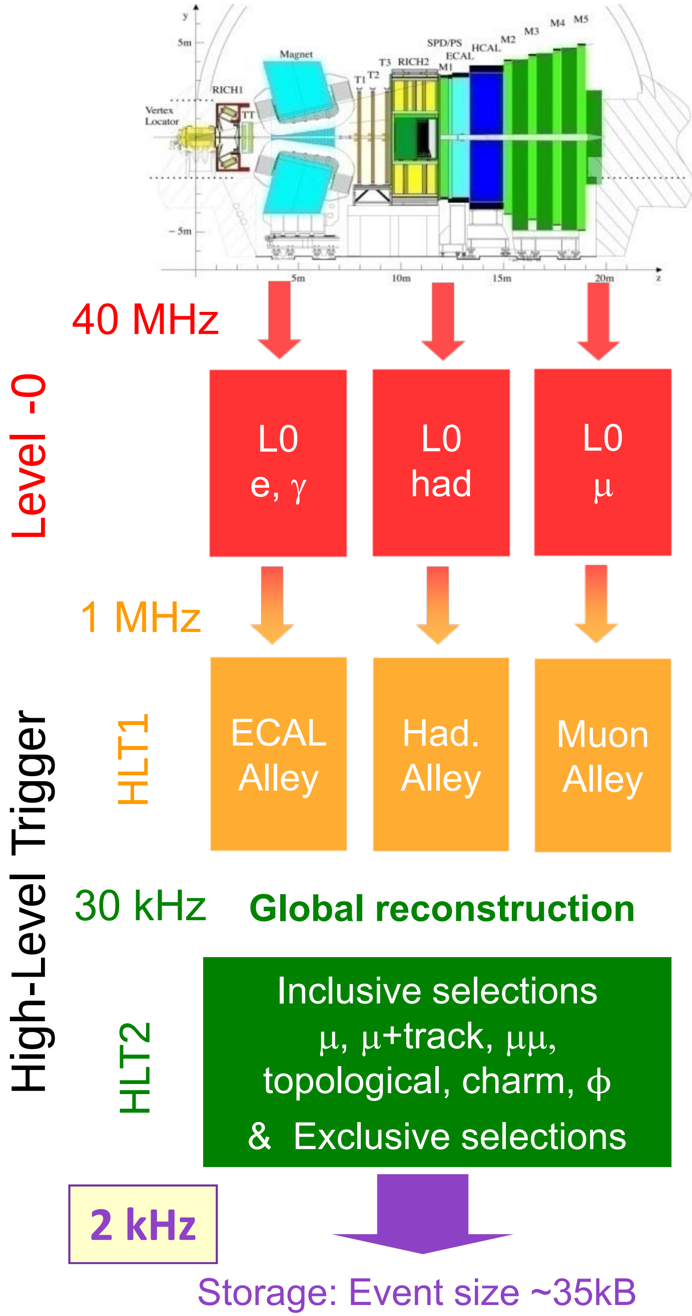
Accumulated statistics and data taking efficiency

When moving to crossing angle and 75 (150) ns bunch spacing we expect $L \sim 1\text{-}2 \cdot 10^{32}$ cm^{-2}s^{-1} with ~200 pb^{-1} in 2010 and ~1 fb^{-1} in 2011 (~1/2 of a nominal year for LHCb)



Statistics increased significantly this week!

LHCb trigger



Trigger is crucial:

- $\sigma_{b\bar{b}}$ is less than 1% of total inelastic cross section
- B decays of interest typically have BR < 10^{-5}

Customized Hardware Level Trigger (L0)

- random trigger
- high-p_t μ, e, γ and hadron candidates

Software High Level Trigger (HLT1&HLT2)

Farm with O(2000) multi-core processors

HLT1:

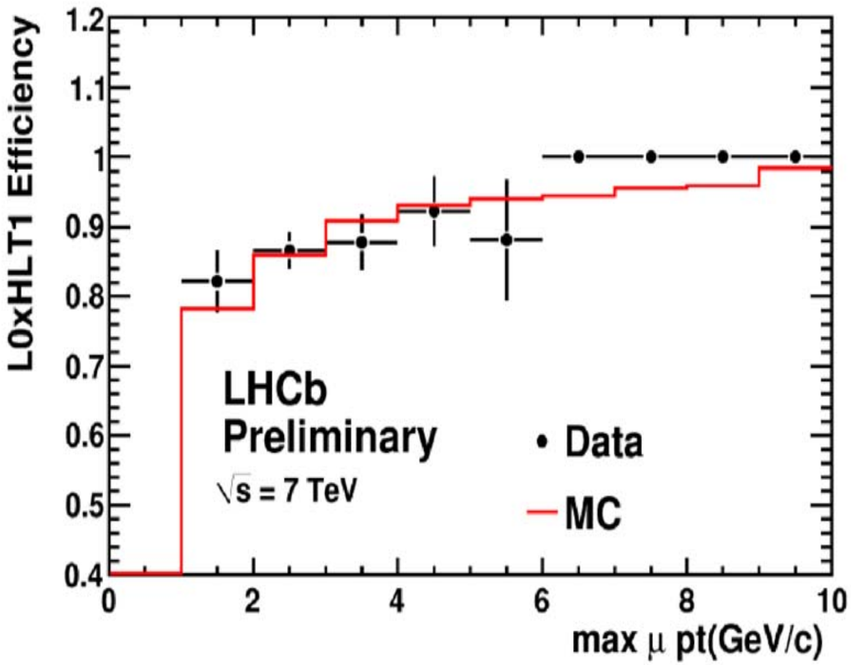
- minimum bias: no bias & micro bias (at least one track)
- c & b physics: L0 confirmation with more complete info, add impact parameter and lifetime cuts

HLT2:

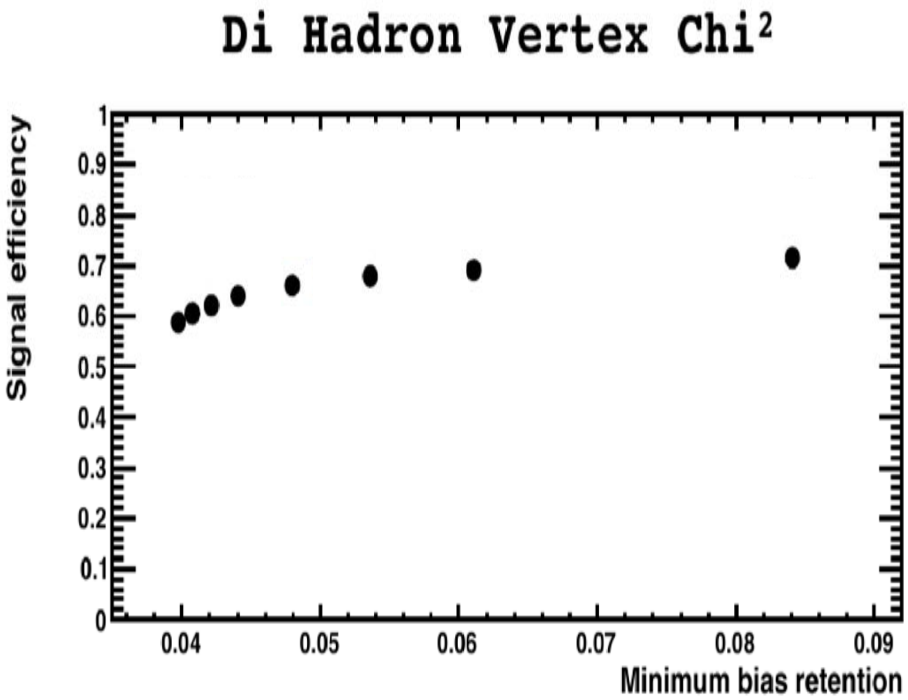
- inclusive and exclusive selections

LHCb trigger performance and strategy for 2010

L0 + HLT1 single-muon line
(tested on reconstructed J/ψ in MB sample)



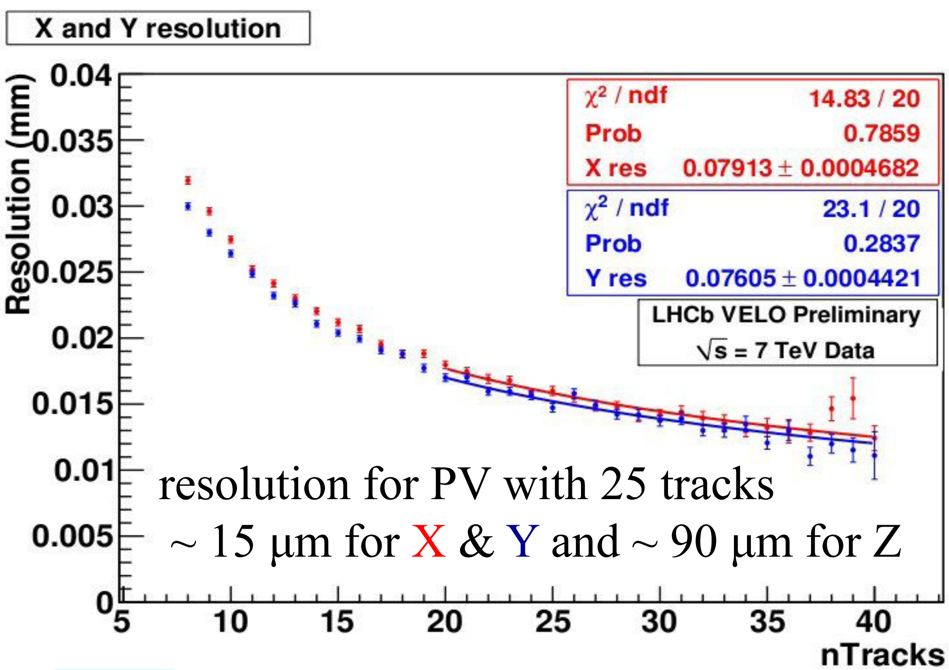
HLT1 di-hadron line
(tested on reconstructed charm in MB sample)

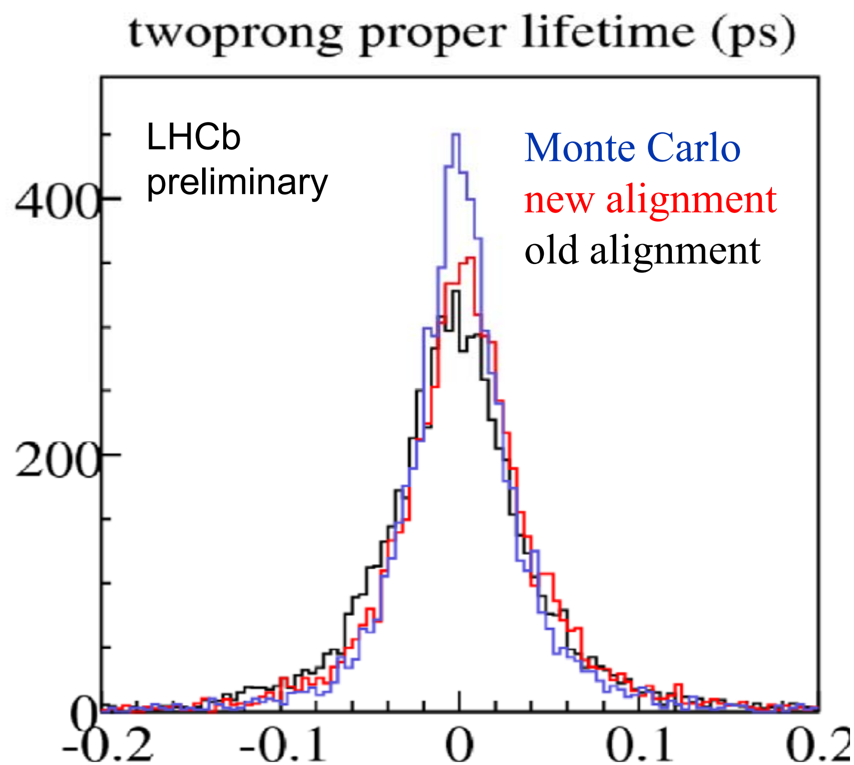


expected eff. (MC)	charm	hadr. B	lept. B
nominal L	~ 10%	~ 40%	~ 90%
low L (2010)	40–50%	75–80%	> 90%

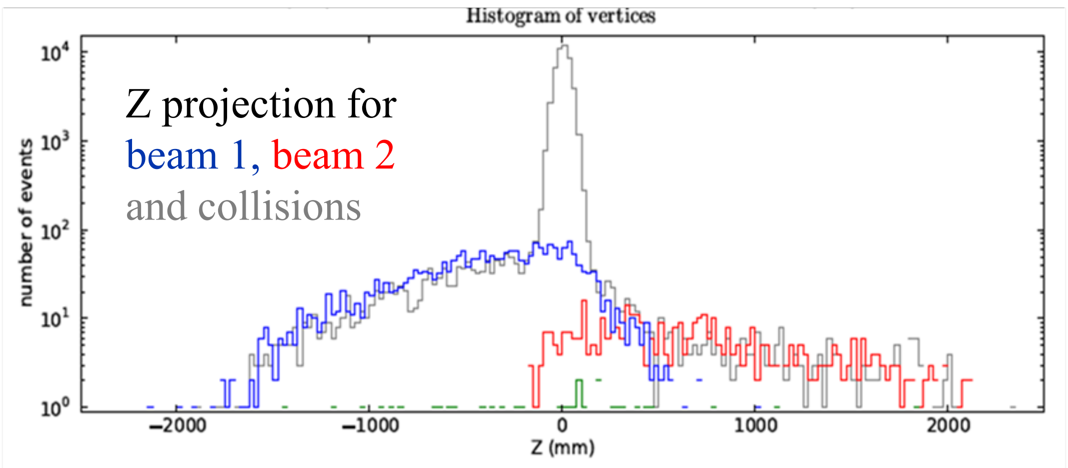
Vertexing performance

impact parameter resolution:
$\sigma(IPx) \sim 16.2 + 24.6/p_t$ µm
$\sigma(IPy) \sim 15.7 + 24.6/p_t$ µm

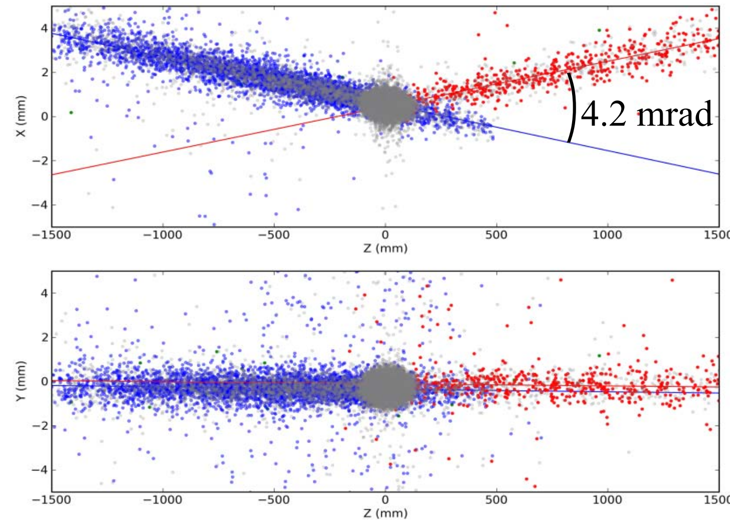


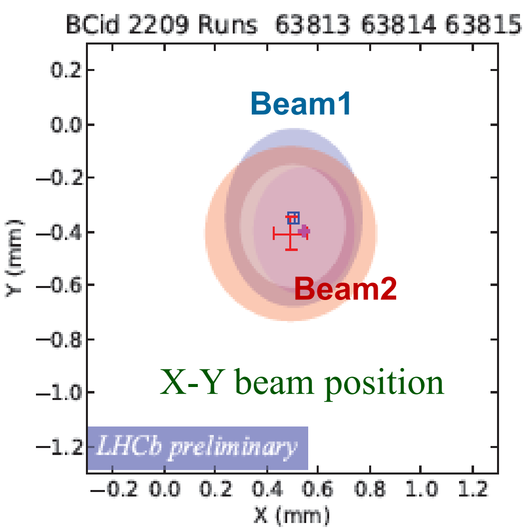


Luminosity measurement at $\sqrt{s} = 0.9$ TeV (2009 data)



X-Z & Y-Z vertices (before VdM scan)





Grey: beam-beam

White: beam-beam predicted from beam-gas

- get the bunch currents from machine measurements (BCT)
- measure (with VELO) beam sizes, positions and angles using beam-gas interactions

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

n: protons/bunch

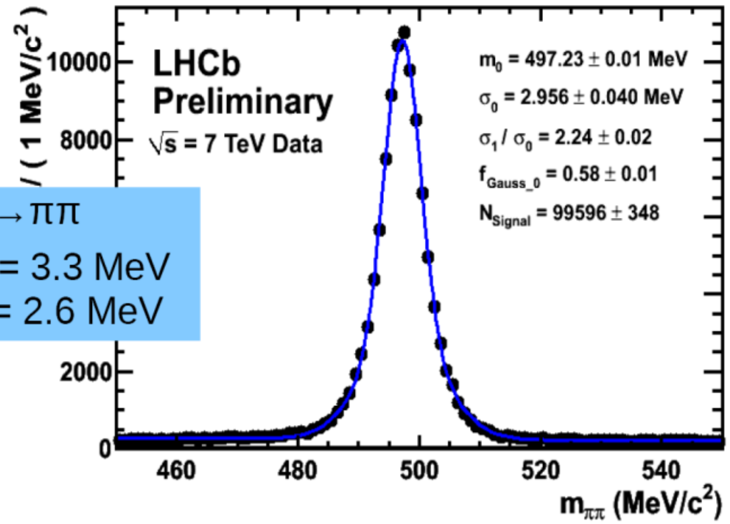
f: collision frequency

$\mathcal{A}_{eff}$: effective area calculated from beam size and position

$\mathcal{L} = (6.8 \quad 1.0)\ \mu b^{-1}$

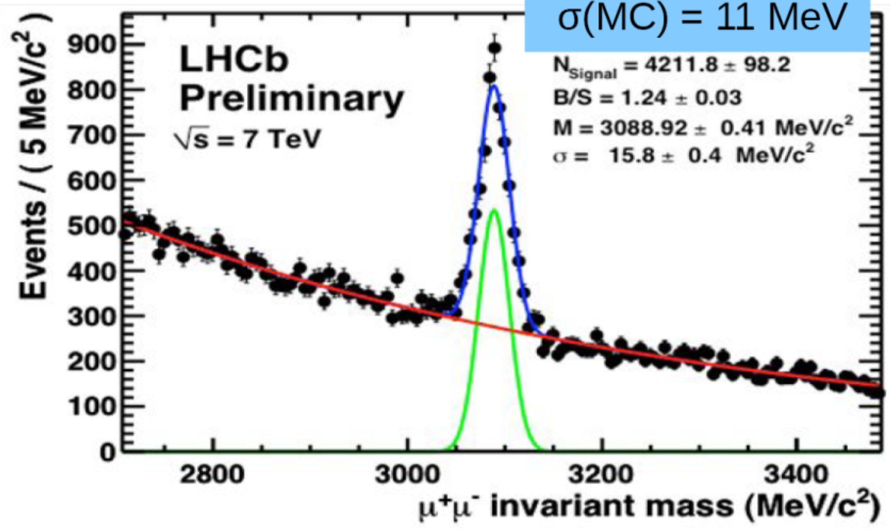
15% accuracy expected to improve to ~5% in 2010

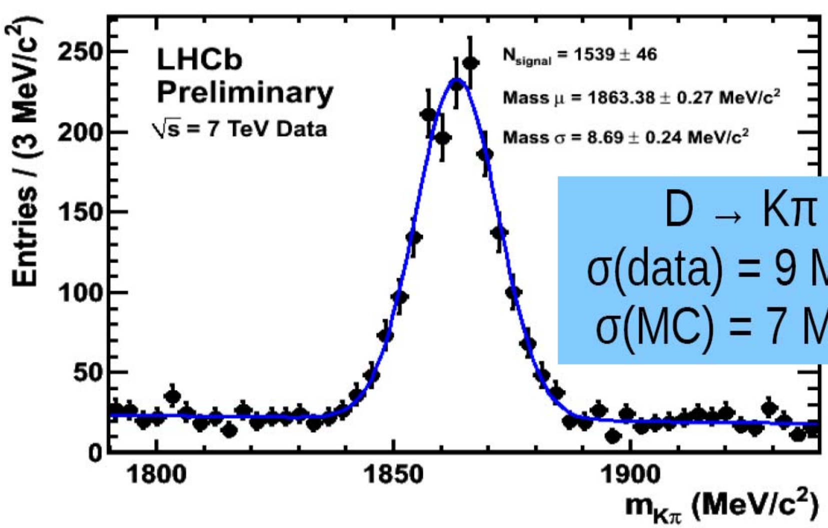
Tracking performance: invariant mass resolution



$K_s \to \pi\pi$
σ(data) = 3.3 MeV
σ(MC) = 2.6 MeV

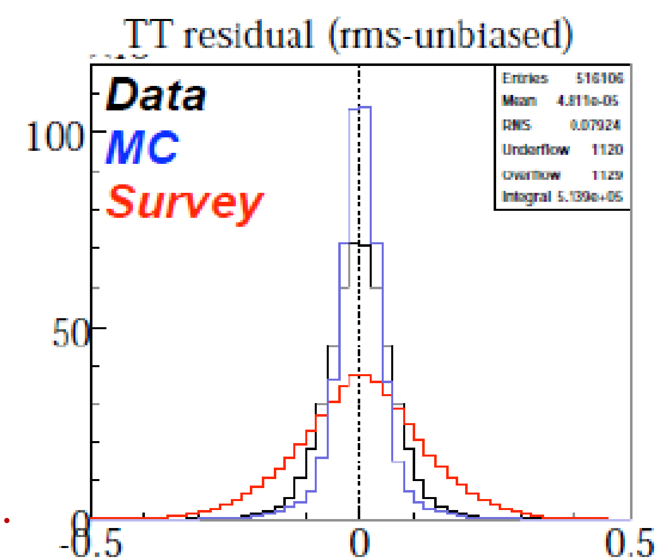
$J/\Psi \to \mu\mu$
σ(data) = 16 MeV
σ(MC) = 11 MeV





$D \to K\pi$
σ(data) = 9 MeV
σ(MC) = 7 MeV

still room for improvement…

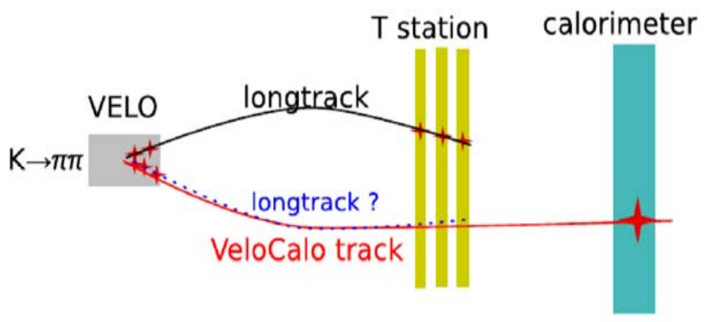


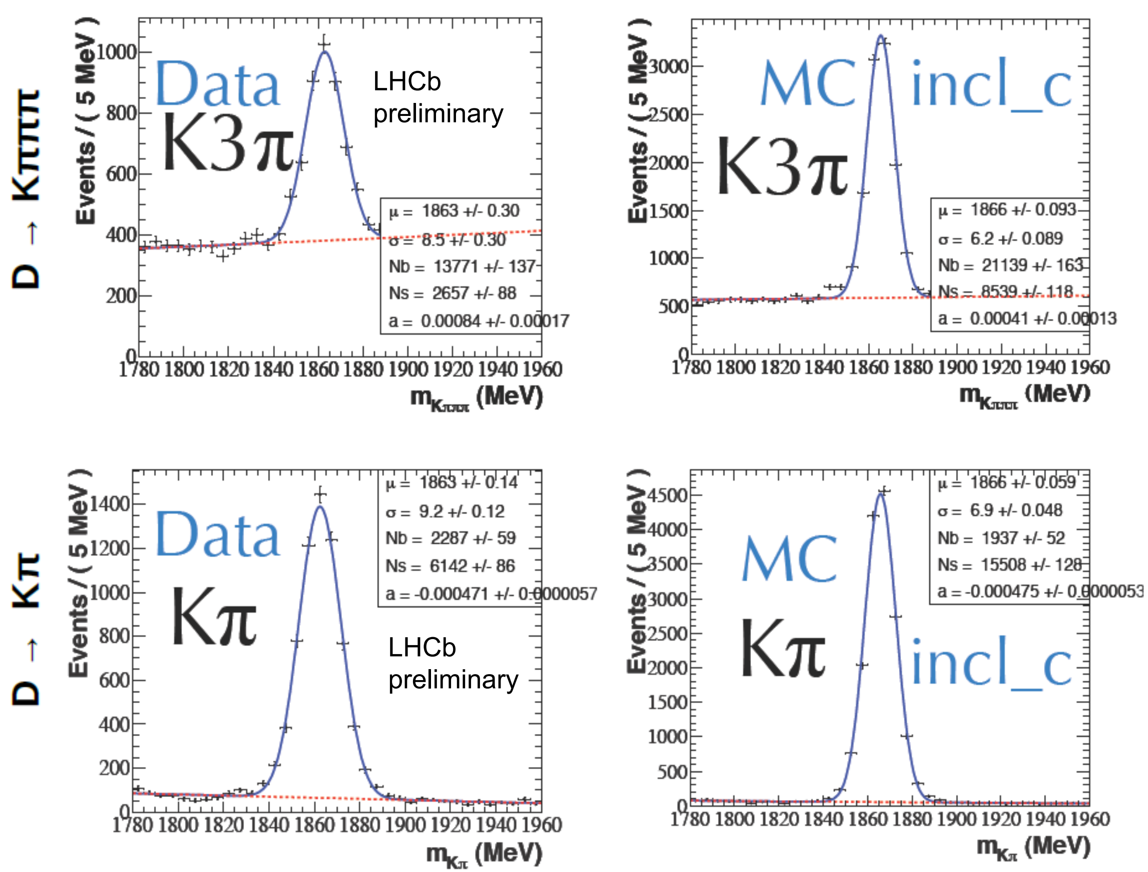
Tracking performance: efficiency

Currently known to ~2%

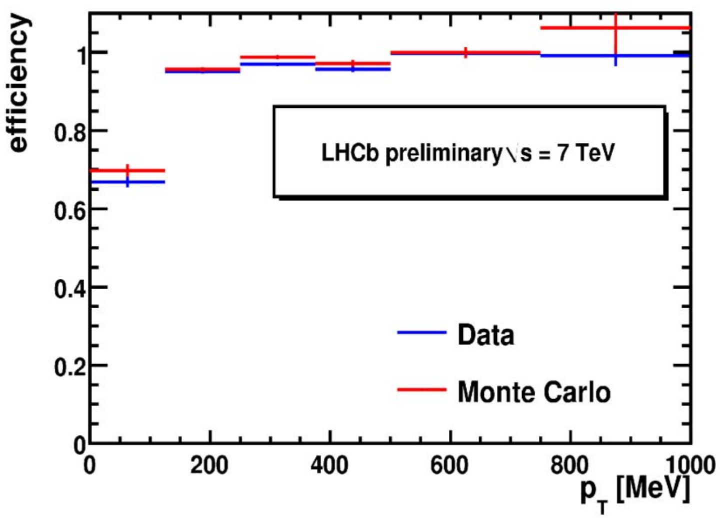
tag and probe method using K_s and J/Ψ

$\varepsilon(\text{track})^2 \sim N(K\pi\pi\pi)/N(K\pi) * BR(K\pi)/BR(K\pi\pi\pi)$



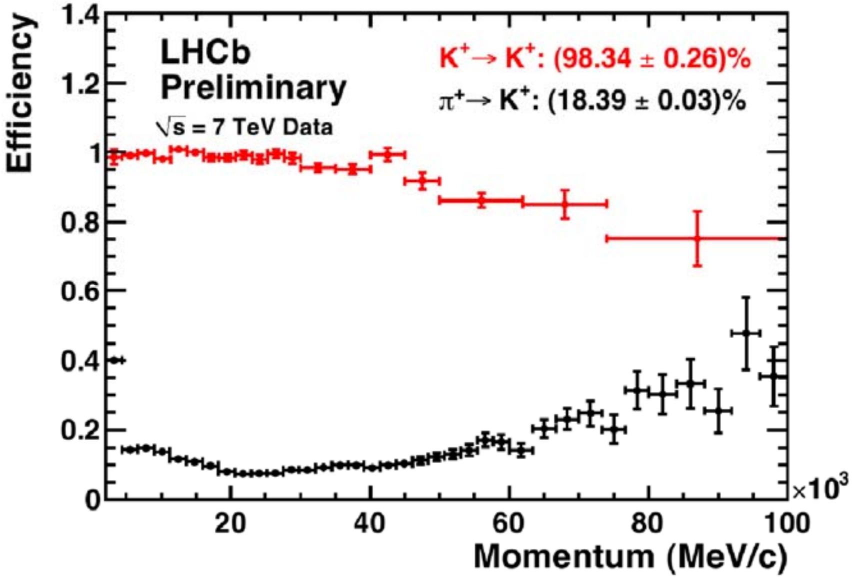


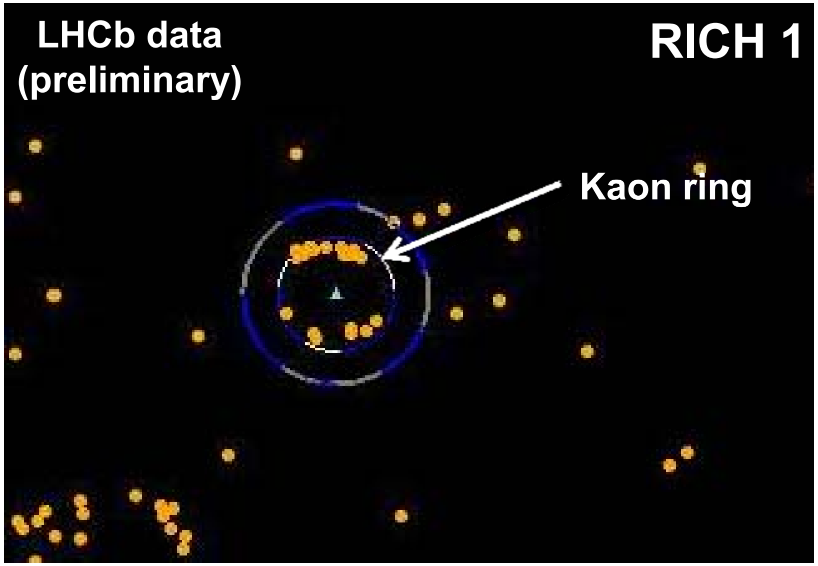
Tracking efficiency vs. p_t



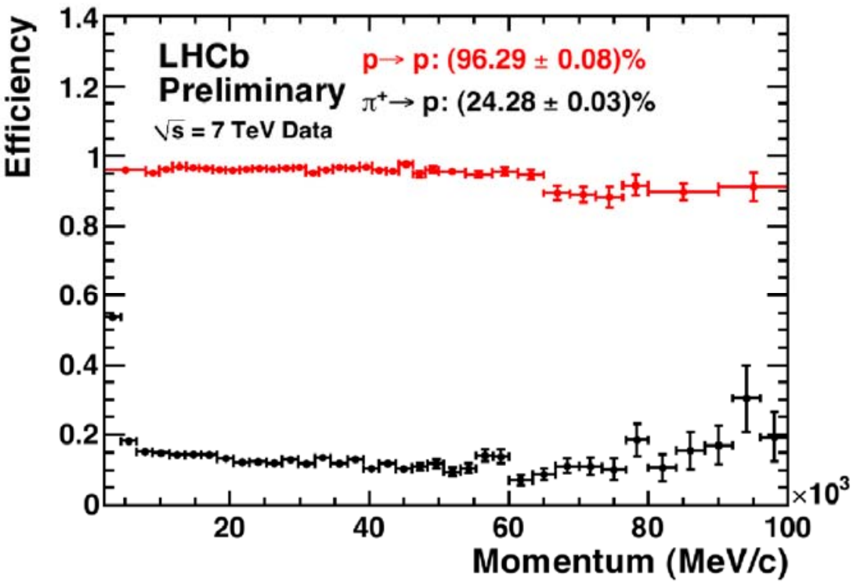
ε(Data) / ε(MC) = 0.975 ± 0.023

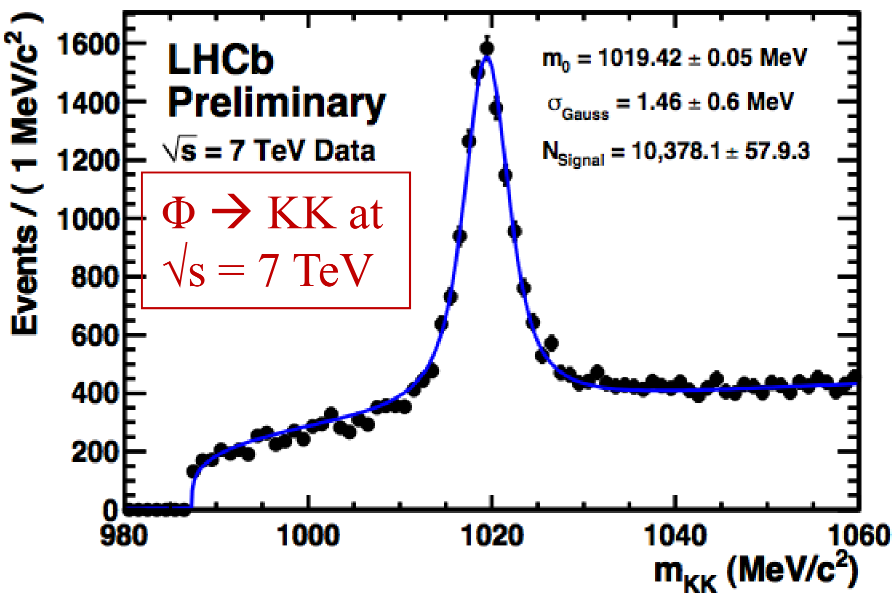
PID with RICH



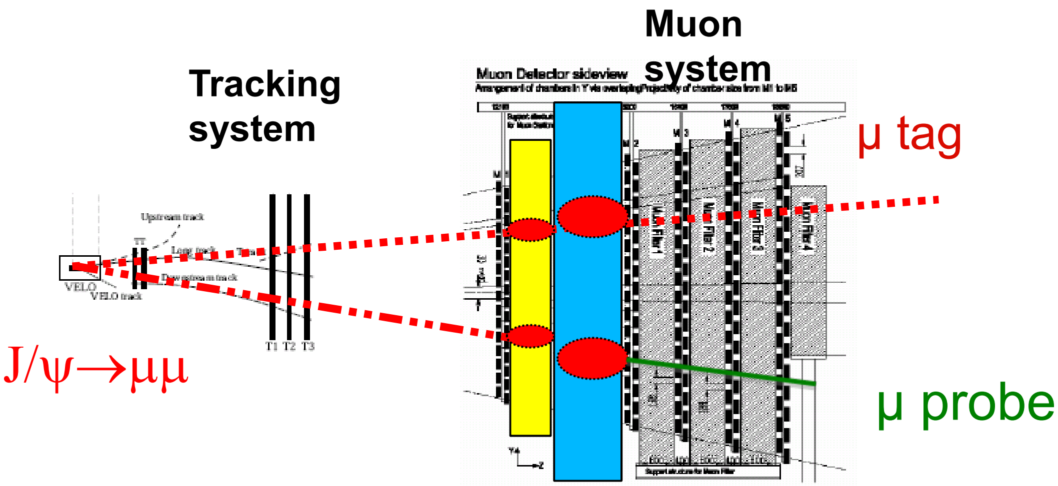


- Orange points → photon hits
- Continuous lines → expected distribution for each particle hypothesis (proton below threshold)



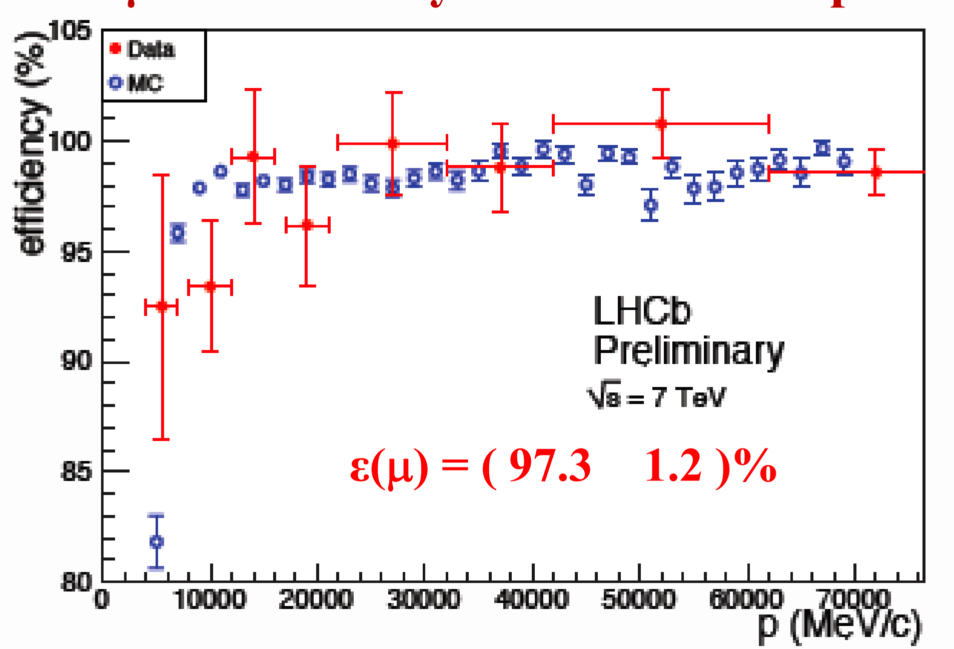


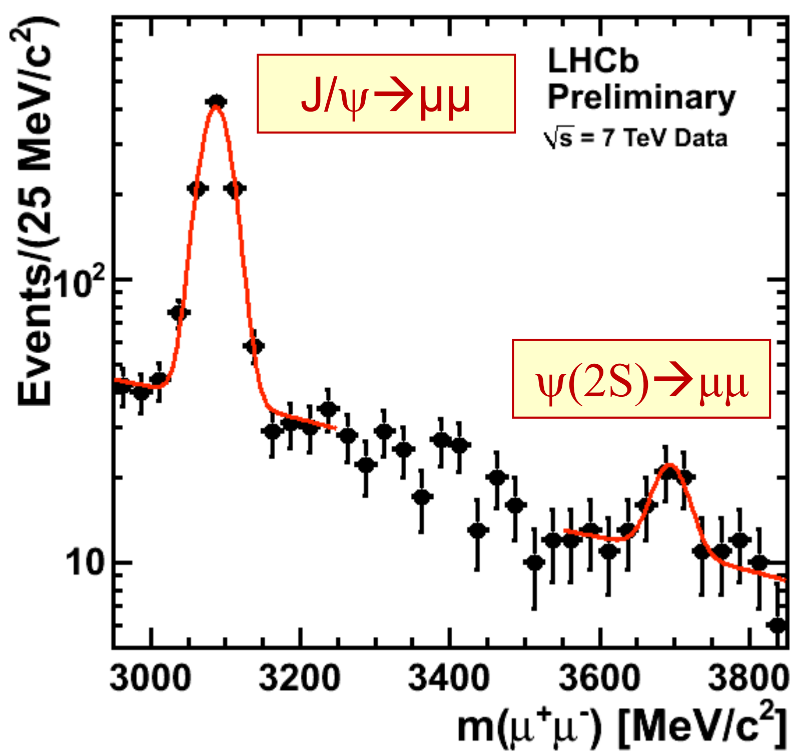
PID for muons



- ✓ achieved muon ID efficiency of >95% for p>6 GeV in 25 ns (5 stations), in good agreement with MC
- ✓ clean J/ψ sample using muon ID and pion mis-ID

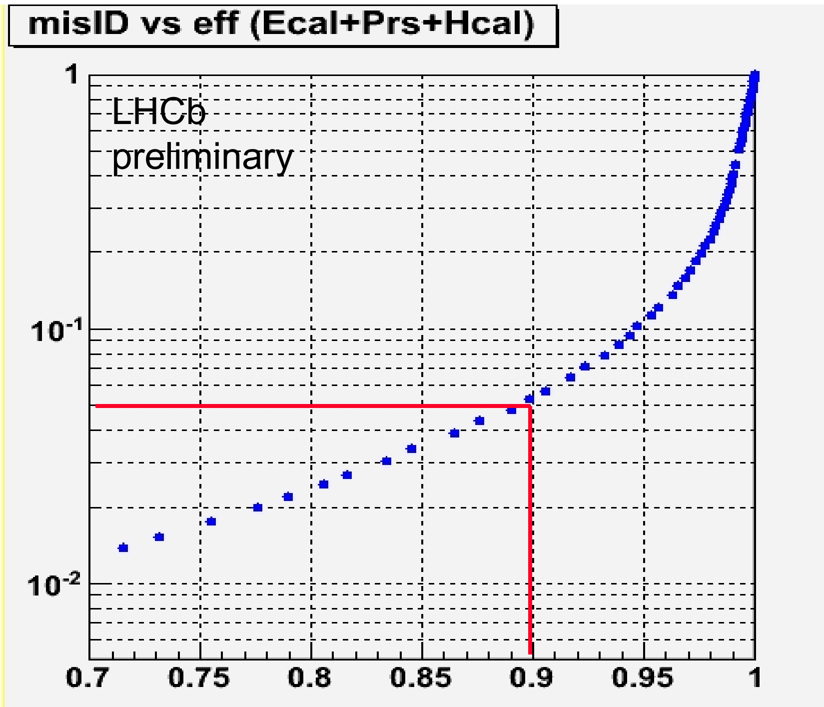
μ id. efficiency as a function of p



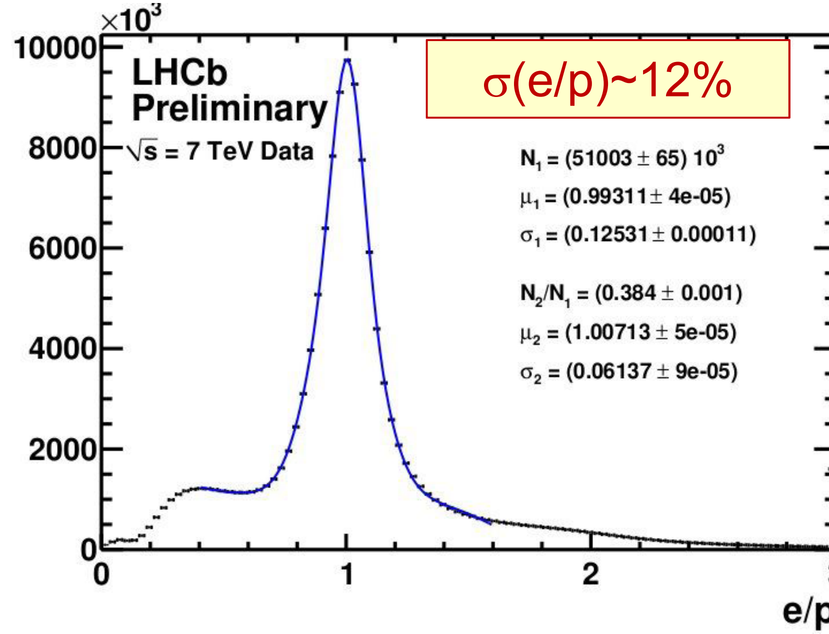


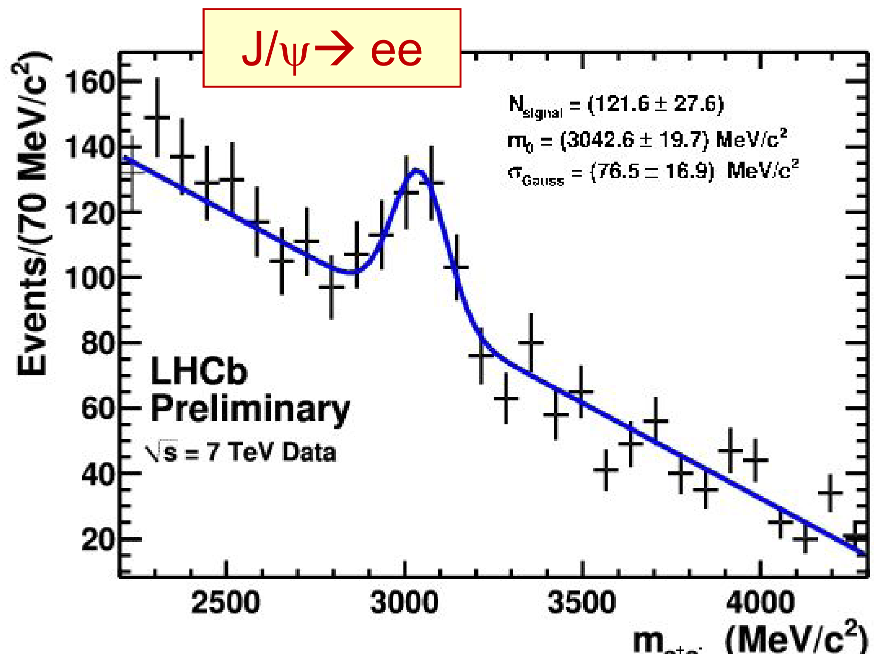
PID for electrons

misidentification rate vs. efficiency using converted photons



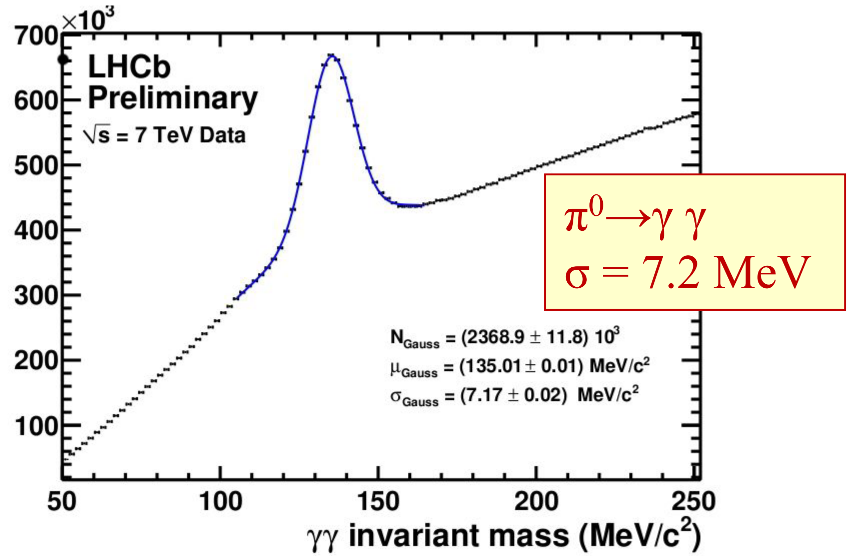
- ✓ 5 % mis-ID rate for 90 % efficiency
- ✓ 4.5 % in MC at same efficiency
- ➢ very good agreement!

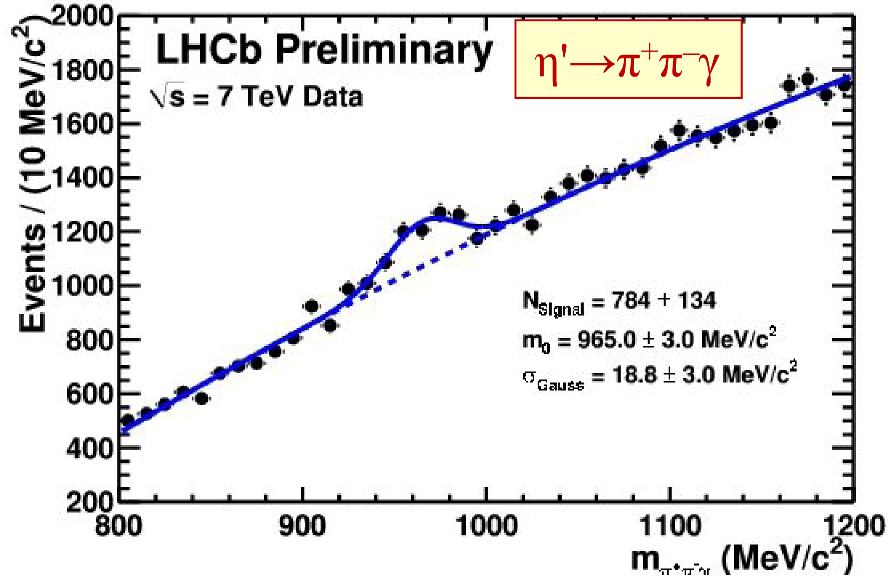


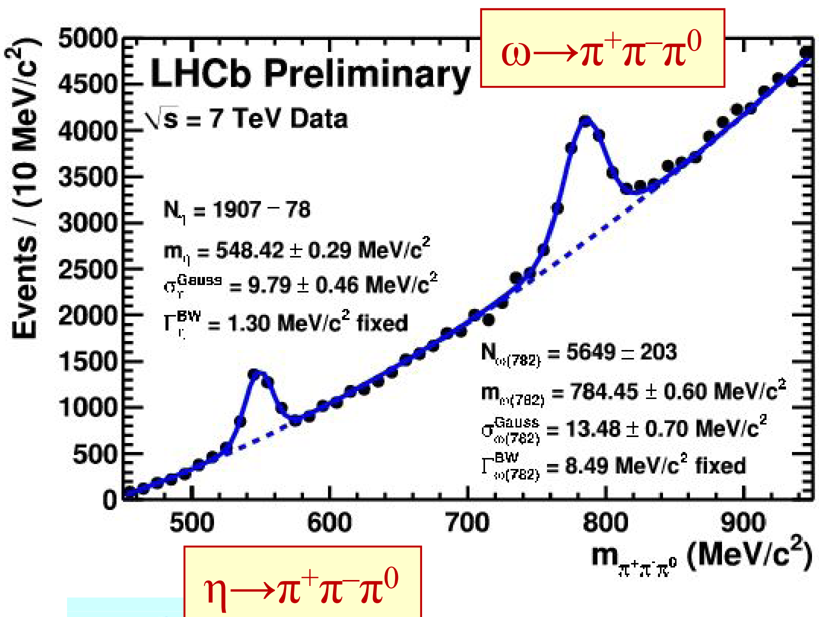


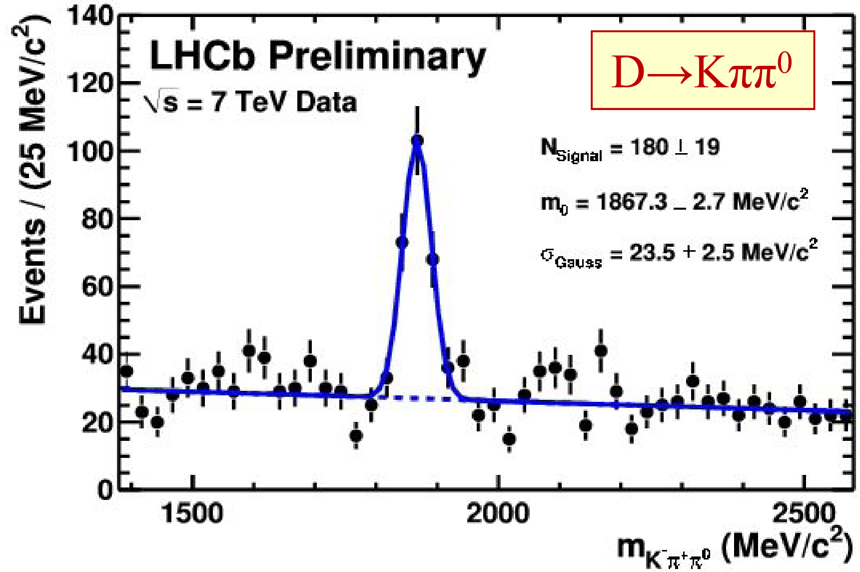
PID for neutrals

✓calorimeters calibrated to the ~2% level using first π^0 sample







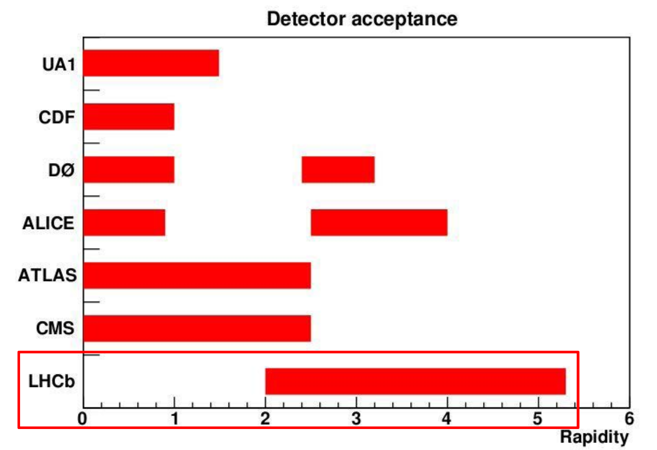


Preliminary results and outlook

Early physics results = cross section measurements & particle multiplicities/ratios

LHCb has a unique rapidity range of $2 < \eta < 5$ (crucial input to Event Simulation)

- charged particle multiplicities, kinematic distributions
- K_s cross section as function of p_T and η
- Λ / K_s and $\Lambda/\bar{\Lambda}$ ratios
- J/ψ cross-section (prompt & from b)
- D+ , D0 , D*, D_s production cross section
- $b\bar{b}$ cross section



- expectations for 2010 (0.2 fb^{-1}) and 2011 (1fb^{-1})

	σ(3.5+3.5TeV) [mbarn]	events in LHCb acceptance 2010	2011
total	100		
$b\bar{b}$	0.2	$40 \cdot 10^9$	$200 \cdot 10^9$
$c\bar{c}$	2	$400 \cdot 10^9$	$2 \cdot 10^{12}$

conservative estimates of cross-sections

- event yields for subset of bench-mark exclusive decays

	2010	2011
$J/\psi \to \mu^-\mu^-$ (prompt)	60M	300M
$B_s \to J/\psi\phi$	6k	30k
$B^0 \to K^{0*}\mu^+\mu^-$	300	1500
$B^0 \to K^+\pi^-$	11k	55k
$B_s \to K^+K^-$	4k	10k
$B_s \to \phi\gamma$	240	3k
$D^{*-} \to D(K^-\pi^+)\pi^-$ (WS)	10k	50k

comparable with total e^+e^- B-factory yield

LHCb will be competitive right from the start !

The "strange" outlook…
Prompt K_s production cross section at $\sqrt{s}$ = 0.9 TeV

Reconstruct $K_S \rightarrow \pi^+\pi^-$ pointing back to primary vertex (PV) in bins of p_t and rapidity y:

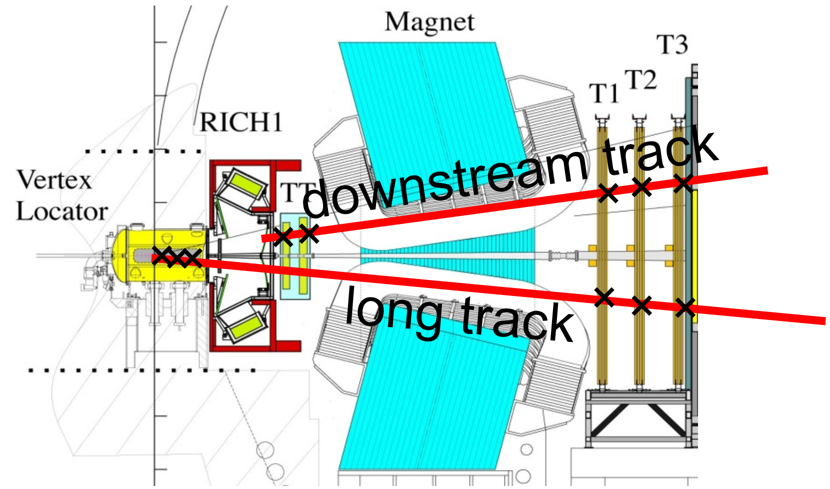
- ✓ beam-gas substracted,
- ✓ background-subtracted
- ✓ efficiency-corrected using MC tuned/reweighted to the data

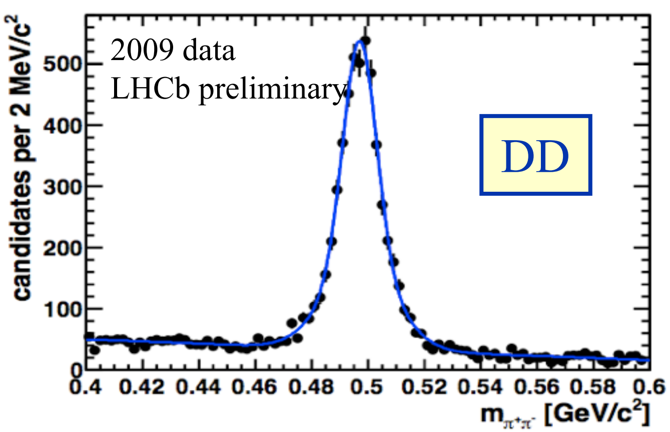
DD analysis:

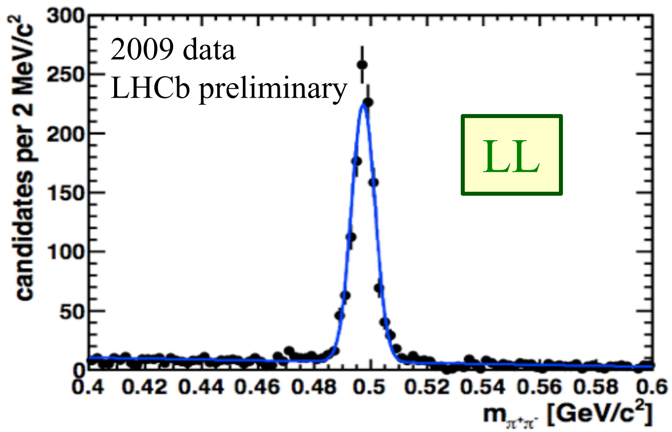
- ➢ use only downstream (D) tracks with hits in TT and T, ignore VELO info

LL analysis:

- ➢ use only long (L) tracks with VELO hits







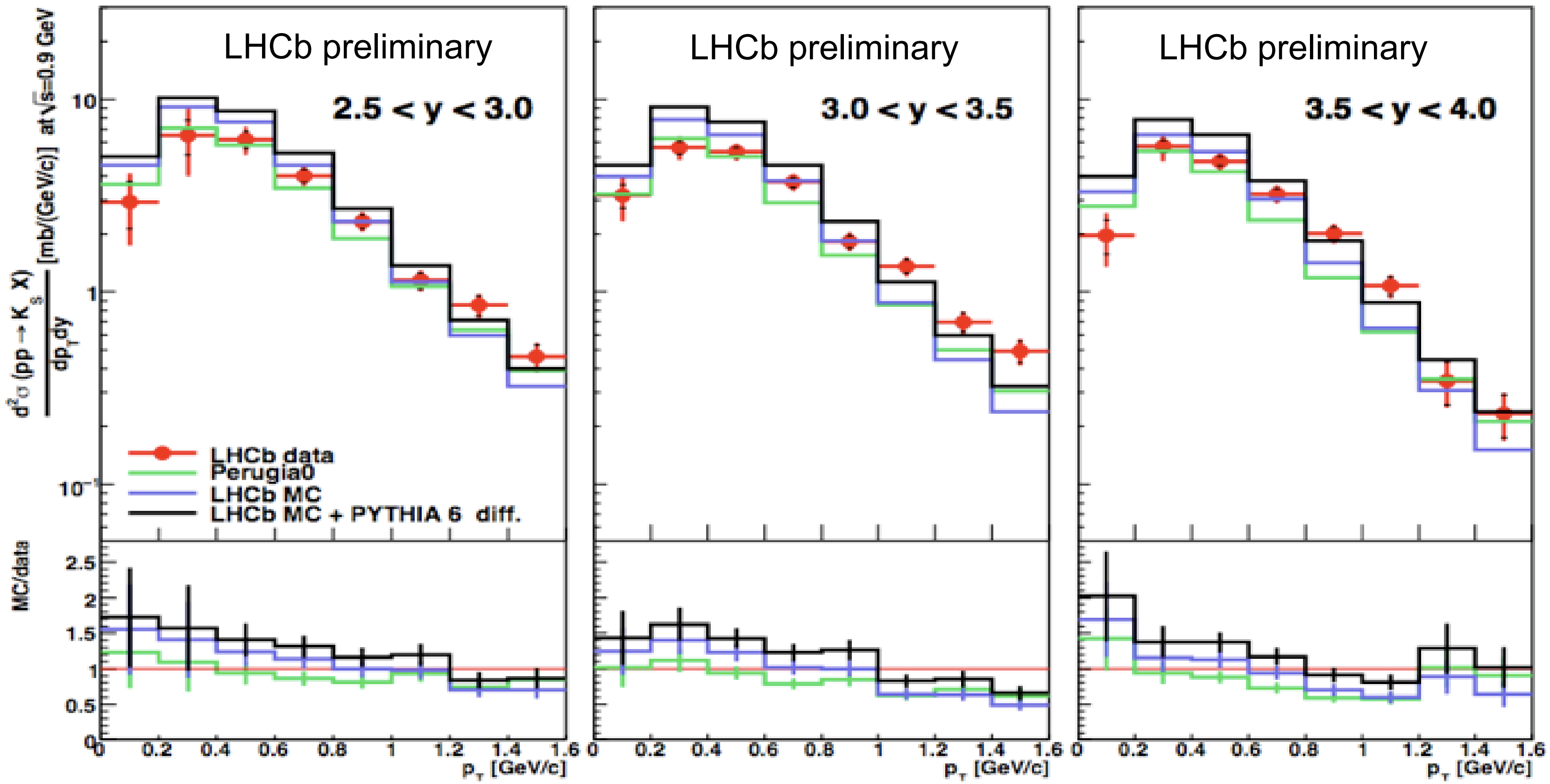
add luminosity measurement ...

Results of both analyses in agreement
→ take most precise result in each bin

→ **Sophie Redford**

Prompt K_S production in pp collisions at $\sqrt{s}$=0.9 TeV

- differential production cross section as function of the K_S transverse momentum and rapidity in the region $0.2 < p_T < 1.6$ GeV/c and $2.5 < y < 4.0$ in comparison with MC
- data tend to be harder in p_t than MC



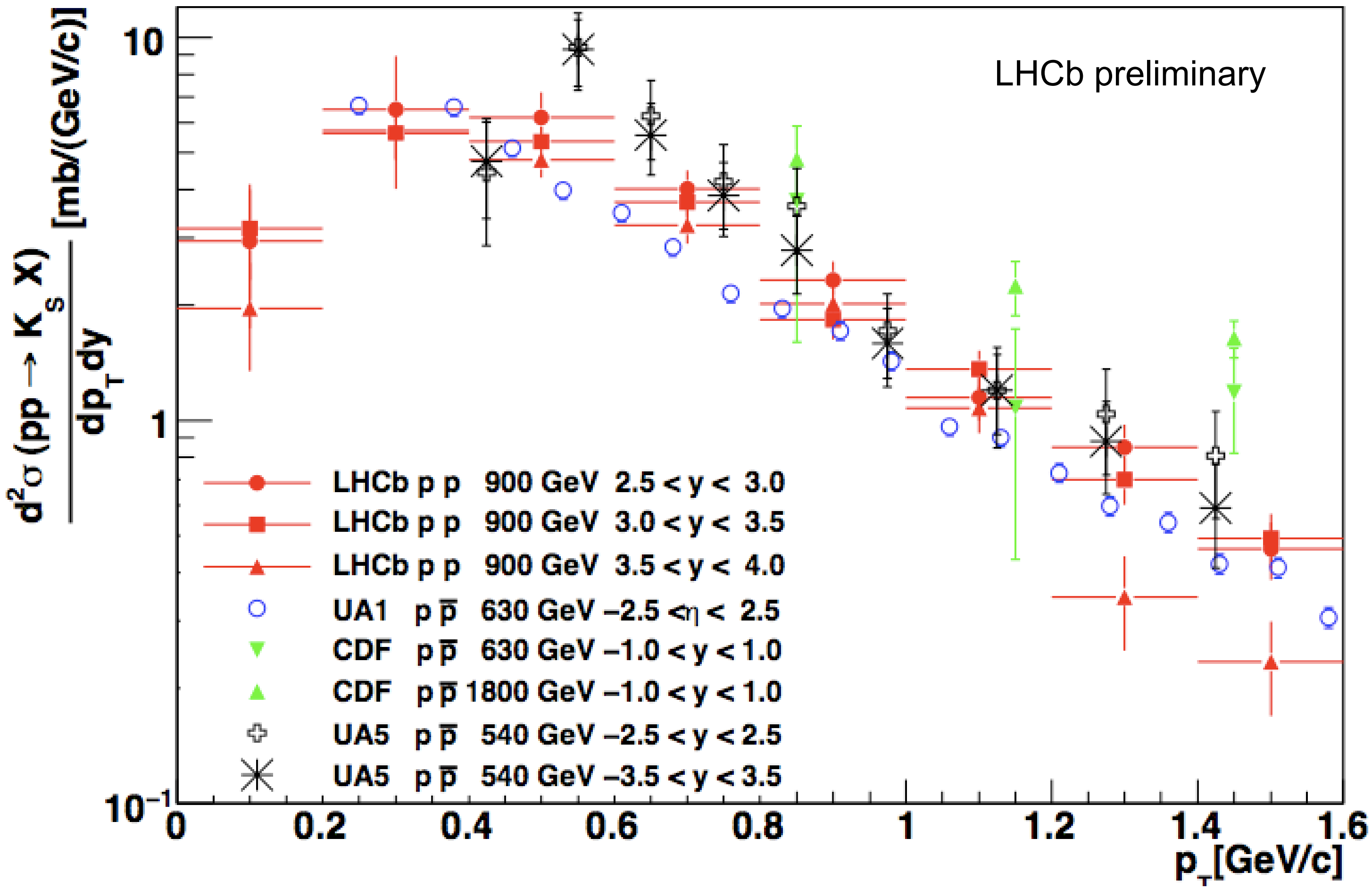
LHCb data - includes both diffractive and non-diffractive K_S production

Perugia0 - the "Perugia 0" settings, which exclude diffraction

LHCb MC - standard LHCb MC, with no diffractive processes

LHCb MC + PYTHIA 6 diff.- standard LHCb MC including soft diffraction

Prompt K_S production in pp collisions at $\sqrt{s}$=0.9 TeV



- steepening of p_t spectrum with increasing y
- more abundant production with increasing energy

(first publication under approval by the collaboration)

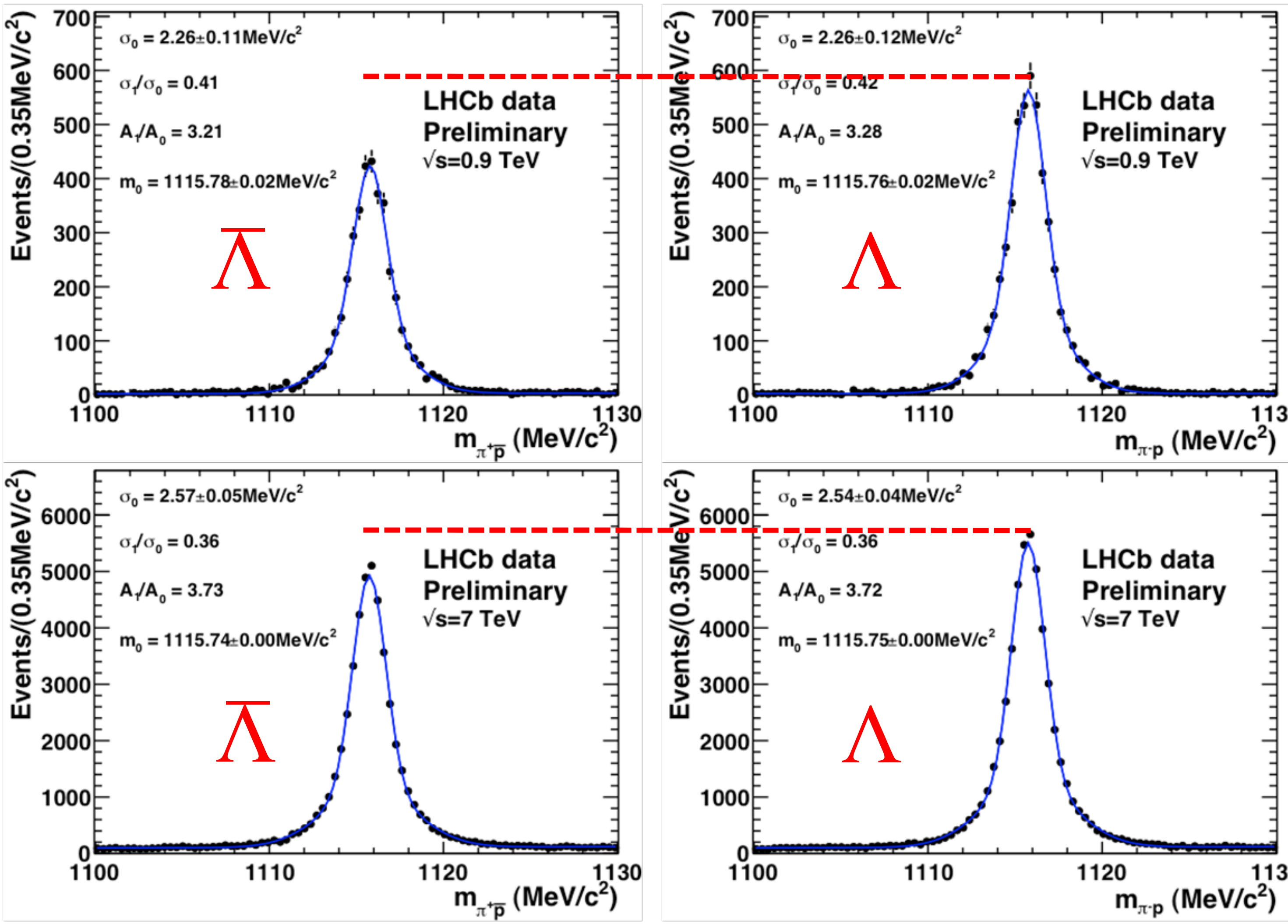
Prompt $\bar{\Lambda}$ and Λ production

→ valuable input to baryon number transport

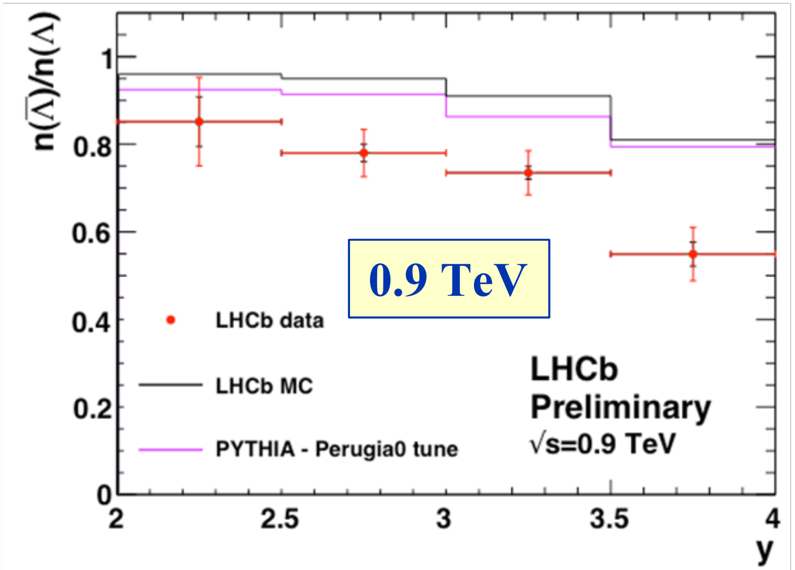
- ➢ use only long tracks in 2010 data recorded with "microbias" trigger → **Susanne Koblitz**

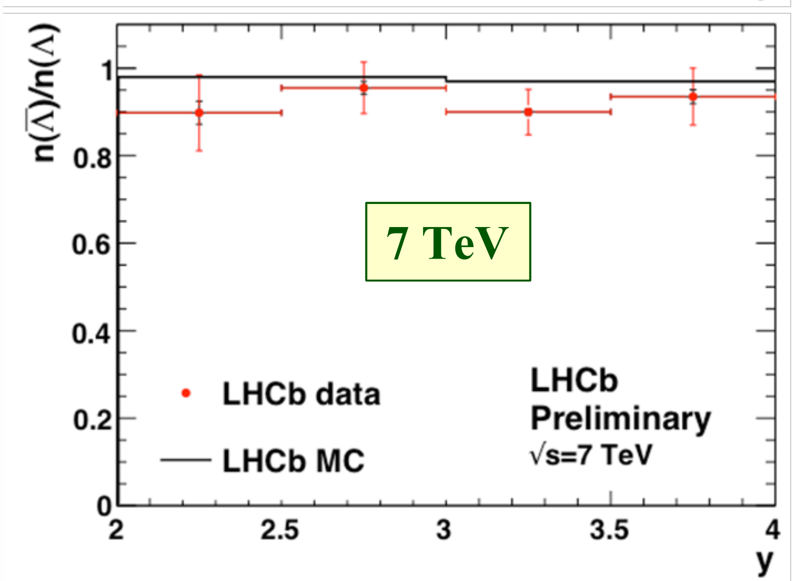
$\sqrt{s}$ = 0.9 TeV

$\sqrt{s}$ = 7 TeV



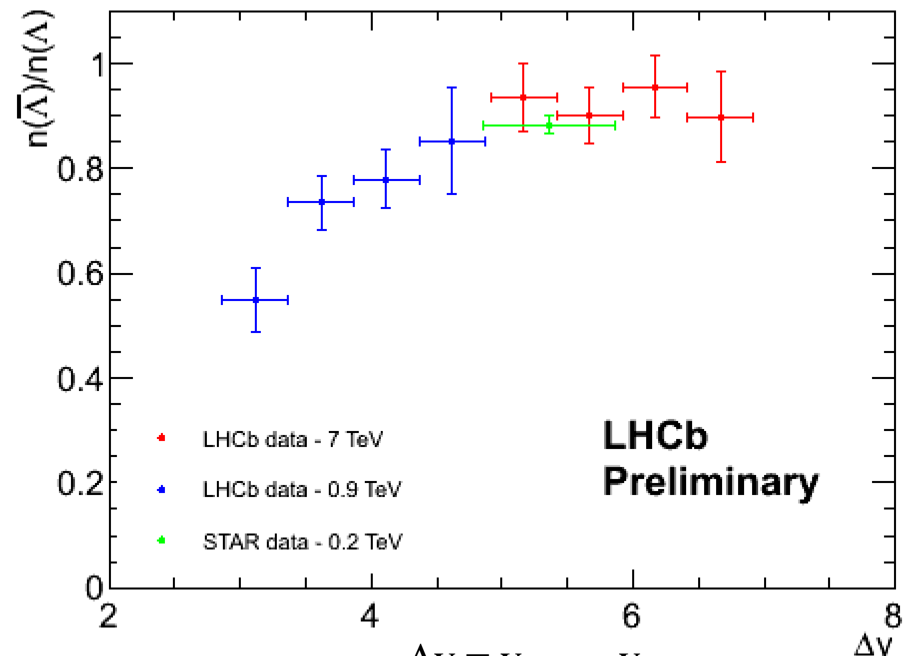
Prompt $\bar{\Lambda}$ and Λ production ratio





Efficiency corrected ratio, in rapidity bins:

- **at 0.9 TeV:**
  - ✓ ratio low, dropping with y
  - ✓ not reproduced by PYTHIA reference tunes
- **at 7 TeV:**
  - ✓ ratio larger, ~flat in y
  - ✓ prediction in fair agreement with MC



$\Delta y = y_{beam} - y$

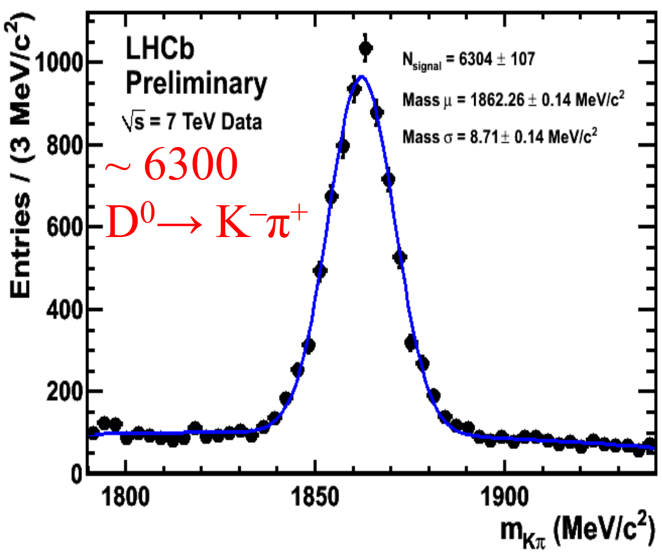
$y_{beam}(\sqrt{s} = 7\text{TeV}) \approx 8.3$

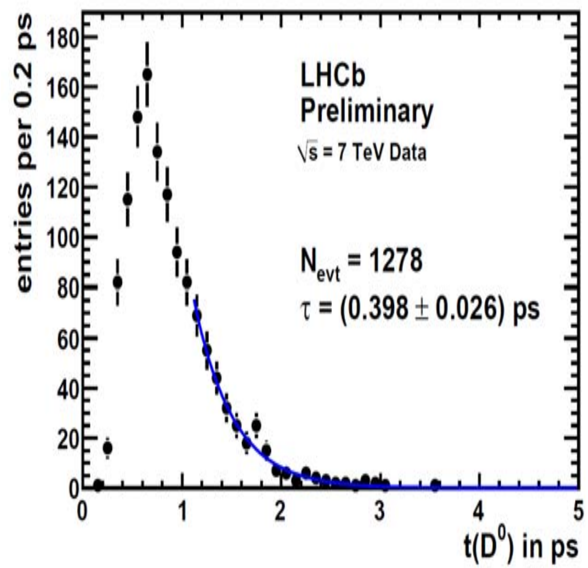
$y_{beam}(\sqrt{s} = 0.9\text{TeV}) \approx 6.6$

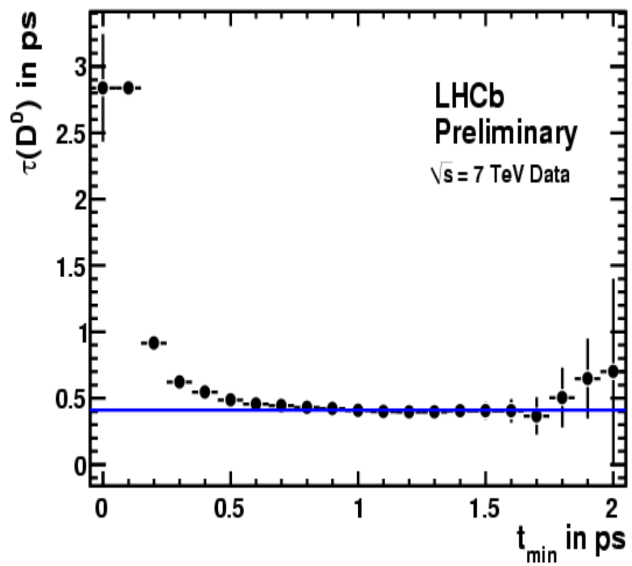
→ Λ/Ks and $\bar{p}/p$ to come (under approval by collaboration)

The “charming” outlook…
Untagged two-body D0 decays

in ~ 2.7 nb^{-1}





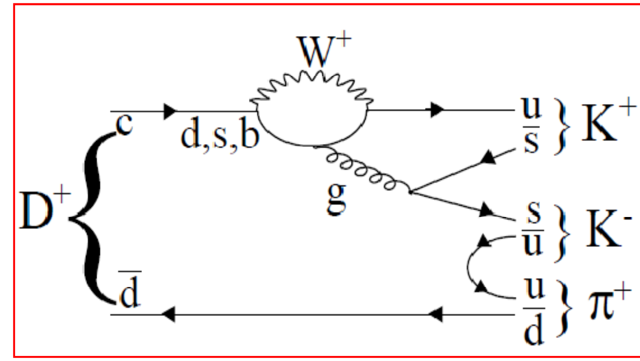


<u>Measure D^0 lifetime as a check:</u>

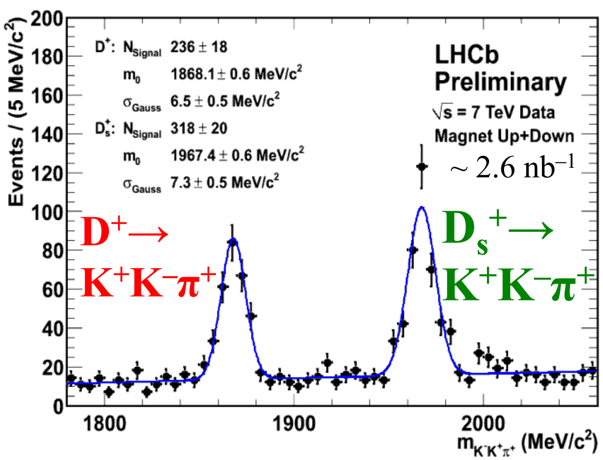
- make very pure $D^0 \to K^-\pi^+$ selection (S/B ~ 22)
- proper-time distribution with simple exponential
- use only tail, where efficiency is constant
  - ✓ $\tau(D^0)$ = 0.398   0.026 ps (6.5% stat. precision)
  - ✓ result does not depend on where the fit starts and agrees with the known D^0 lifetime of 0.4101   0.0015 ps

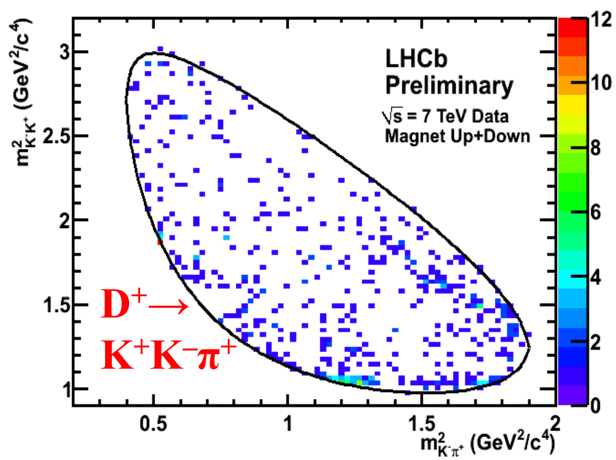
Direct CP violation studies in the charm sector

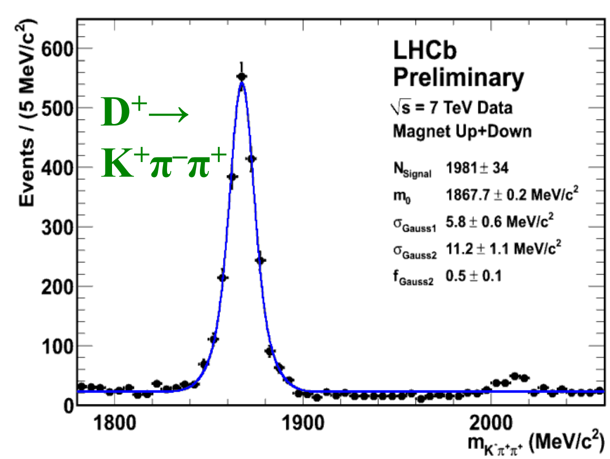
- interesting modes are:
  - ✓ single Cabibbo-suppressed decays where NP may enter in gluonic Penguin
  - ✓ 3-body decays, where Dalitz plot analysis allows for many local CP asymmetries to be probed



- $D^+ \rightarrow K^+K^-\pi^+$ is an excellent candidate:
  - ✓ use Cabibbo-favoured $D_s^+ \rightarrow K^+K^-\pi^+$ and $D^+ \rightarrow K^+\pi^-\pi^+$ decays as control channels

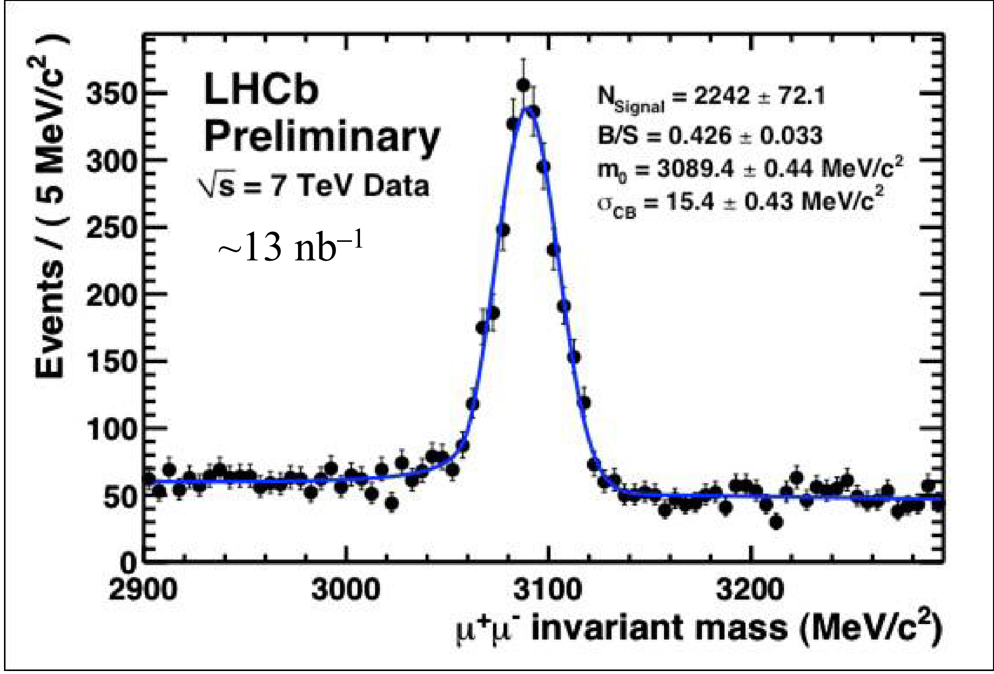






- expect several million events in 0.1 fb^{-1}
  (an order of magnitude more than B-factory samples)

J/ψ production: prompt and from b

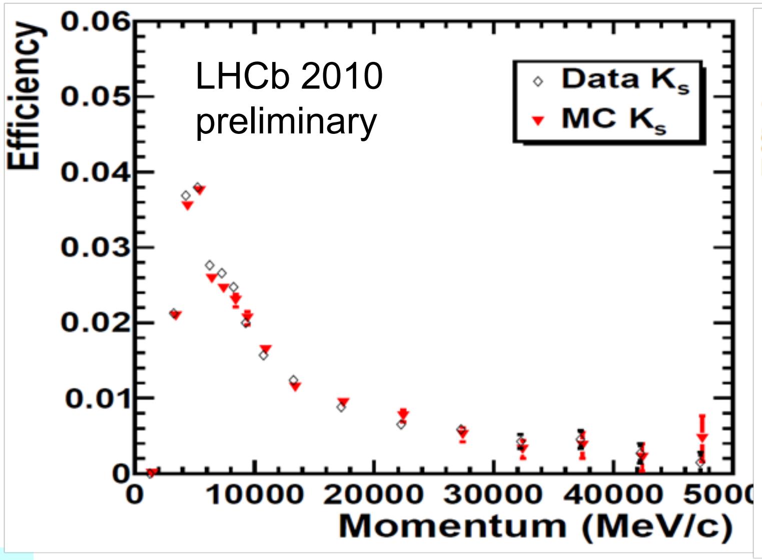


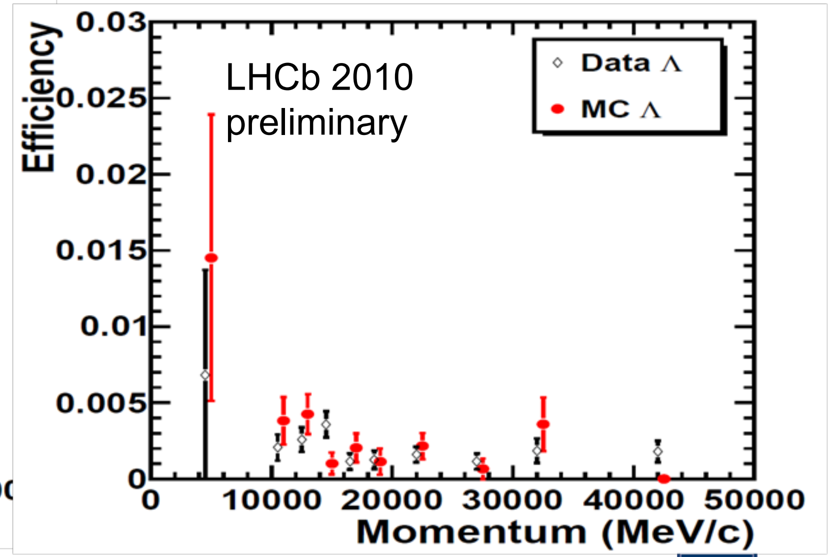
measure cross sections:
$d\sigma/dp_t$ (all J/ψ)
σ(prompt J/ψ)
σ(J/ψ from b)

μ - π and μ - p misidentification rates determined using large samples of $K_S \rightarrow \pi\pi$ and $\Lambda \rightarrow p\pi$ decays

π → μ dominated by decays in flight

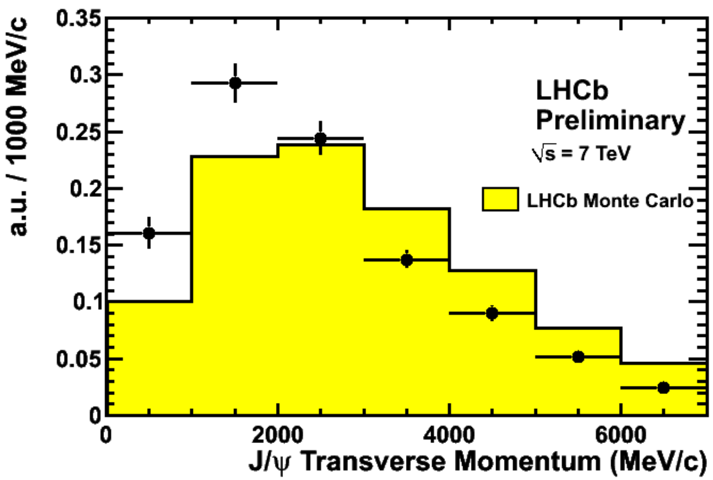
p → μ dominated by combinatorics in muon stations

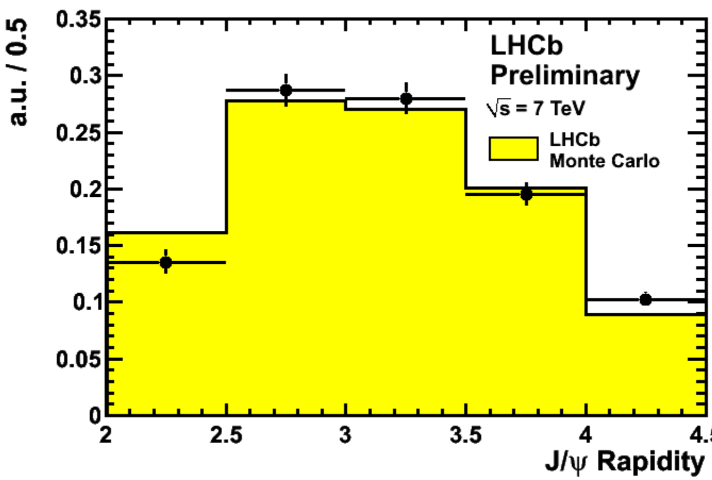




J/ψ production

- only statistical error
- no corrections (e.g. efficiency)





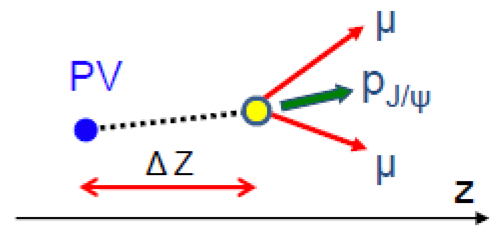
✓ p_t spectrum softer in data than MC

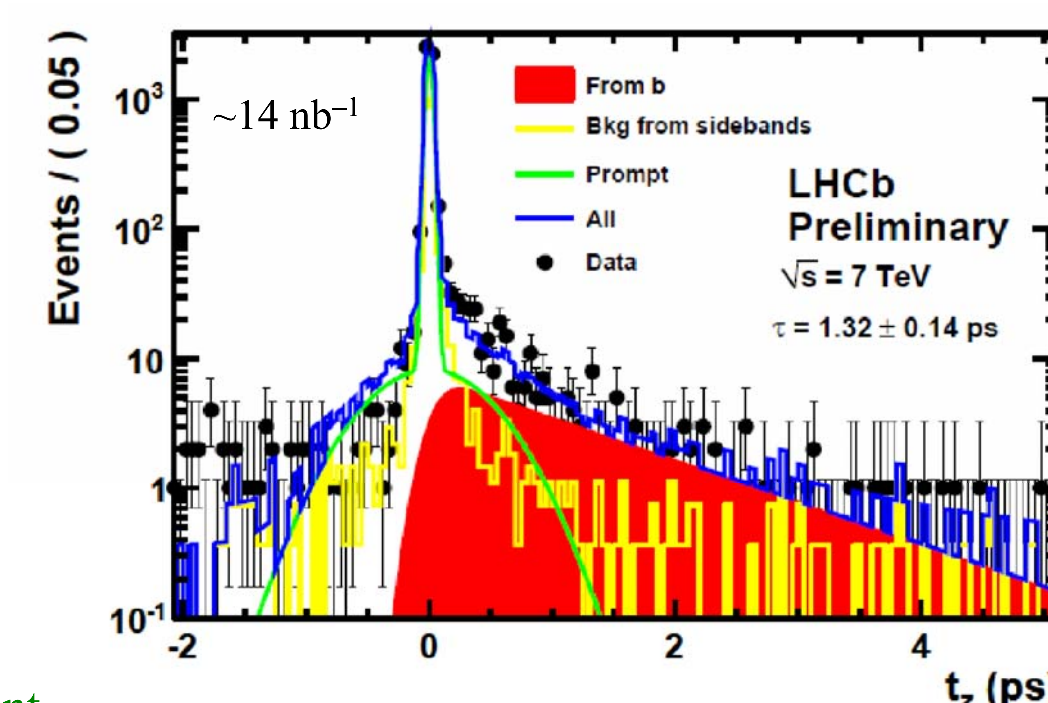
✓ rapidity distribution in good agreement

✓ b-events identified via detached vertex analysis

✓ combined fit to mass and pseudo proper-time t_z allows separation of prompt J/ψ and b → J/ψ components

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

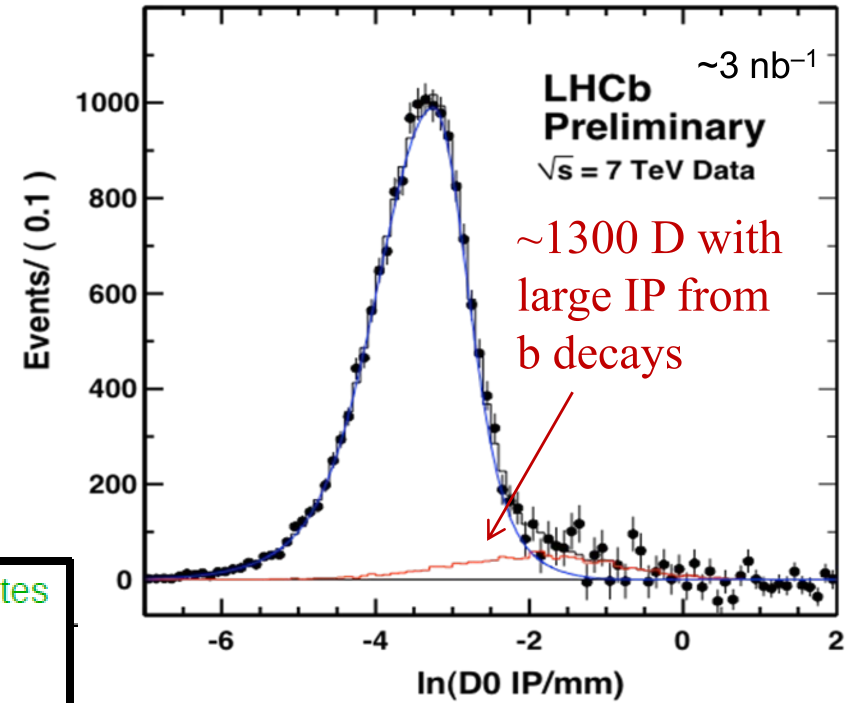




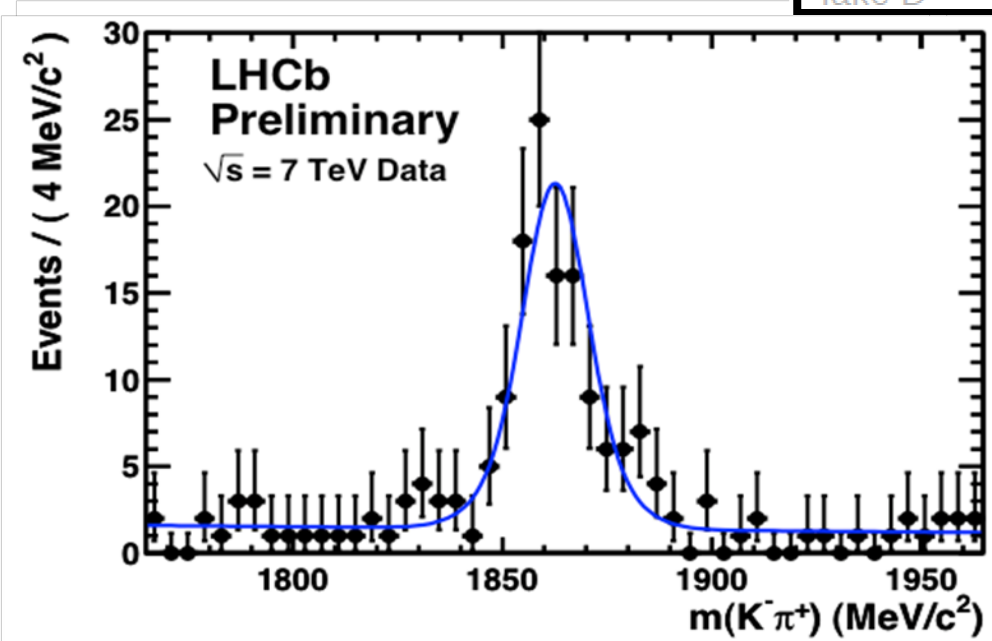
→ Cross section measurements under way!

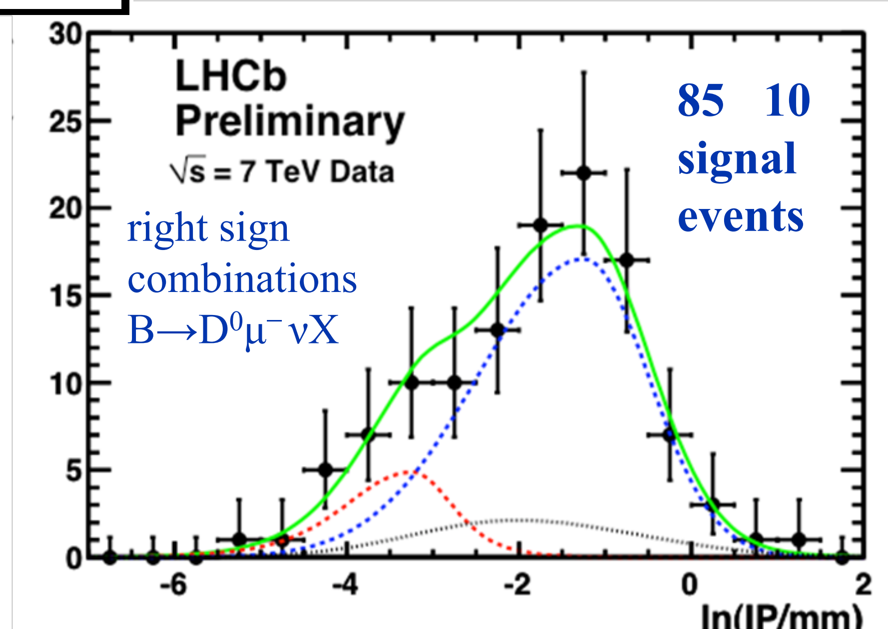
The "beautiful" outlook…
Looking for b hadrons

- ✓ select $D^0 \to K^-\pi^+$
- ✓ fit sideband-subtracted D^0 IP distribution
- ✓ combine D with μ
- ✓ form wrong sign combinations $B \to D\ \mu^+\nu X$
- ✓ form right sign combinations $B \to D\ \mu^-\nu X$



all D° candidates
prompt D°
D° from b
fake D°





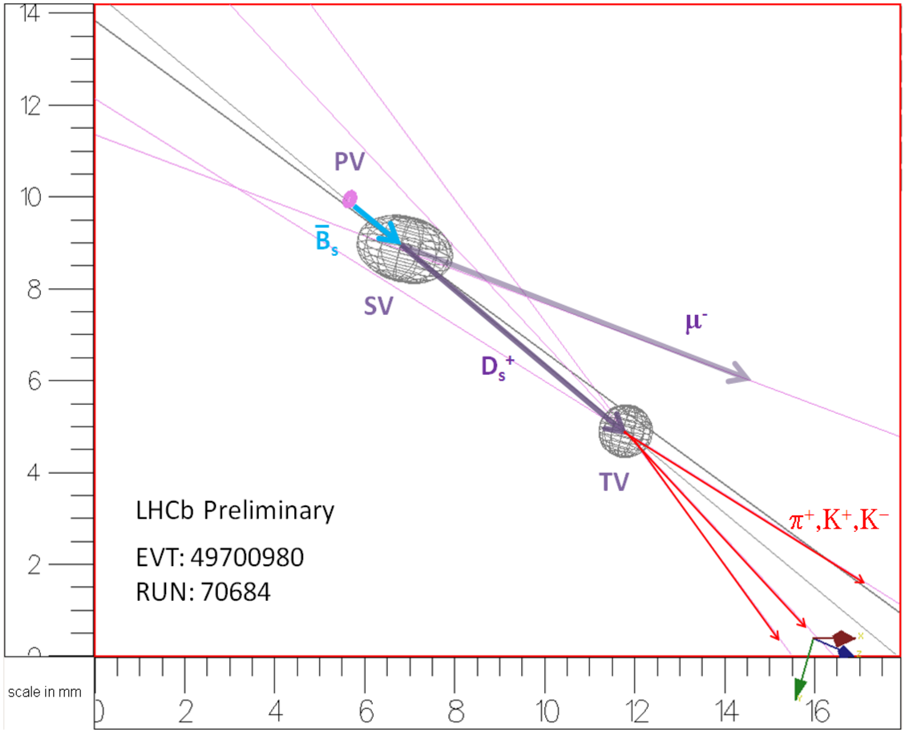
Semileptonic B-decays

Large branching fraction, suitable for early cross section measurement:

- with 100 nb^{-1}, expect 2.8k $B \to D^0\mu^-\nu X$ signal events with good purity
- measurement complementary to $b \to J/\psi$ result

$B_d \to D^-\mu^+\nu$ and $B_s \to D_s^-\mu^+\nu$ decays useful for:

- B_d and B_s oscillations (Δm_d and Δm_s), flavour tagging studies and calibration
- CP violation in B_d and B_s mixing:
  - ✓ measure $\Delta A_{fs} = (a_{fs}(B_s) - a_{fs}(B_d))/2$ where detector asymmetry will drop out if D^- and D_s^- decay to same $K^+K^-\pi^-$ final state



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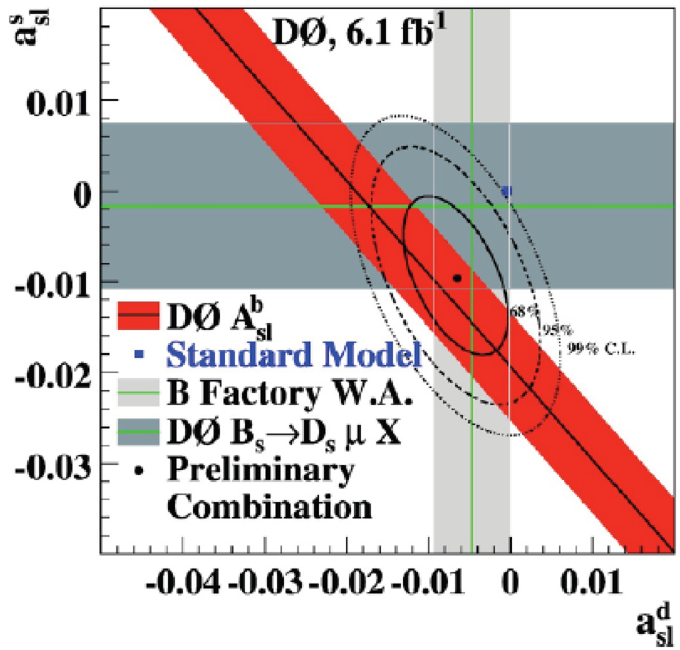
  - ✓ from MC study, assuming 0.1 fb^{-1} and $\sigma_{bb} = 500\ \mu b$, expect statistical precision on ΔA_{fs} of $2 \quad 10^{-3}$ similar to that of D0 on $A_{sl}^b \sim (a_{fs}(B_s) + a_{fs}(B_d))/2$

$$A_{sl}^b = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\,\%$$

$$A_{sl}^b\,(\text{SM}) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$



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Semileptonic B-decays

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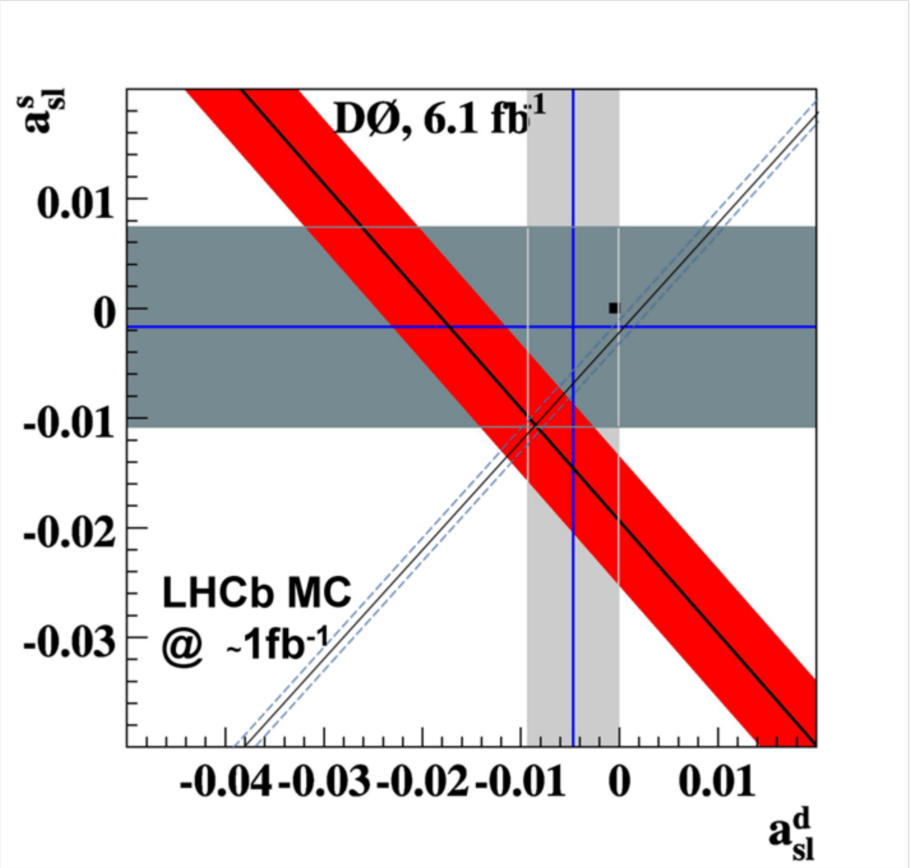
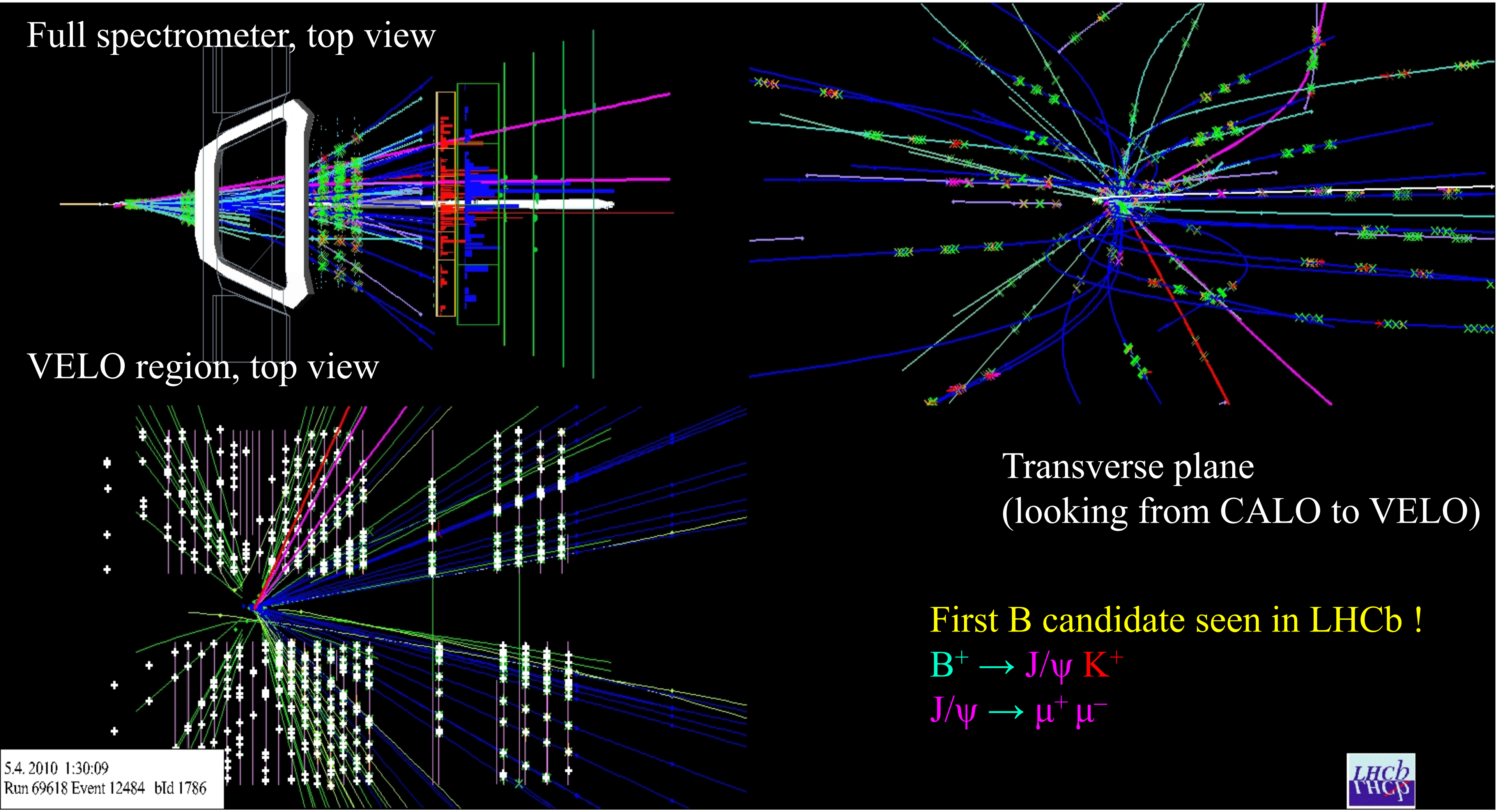
  - ✓ provide constraint "orthogonal" to recent D0 measurement of A_{sl}^b

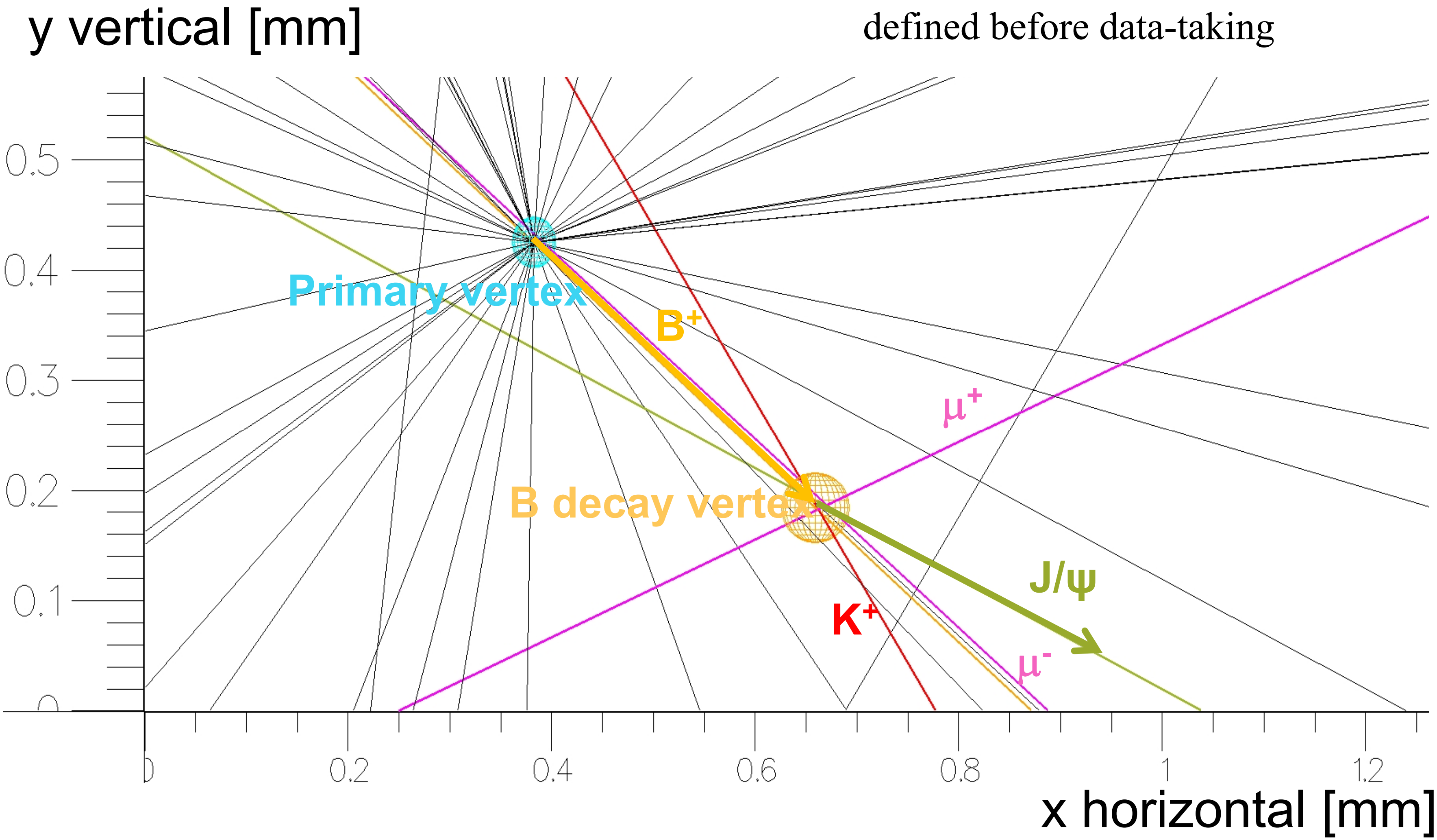


Fully reconstructed B decays



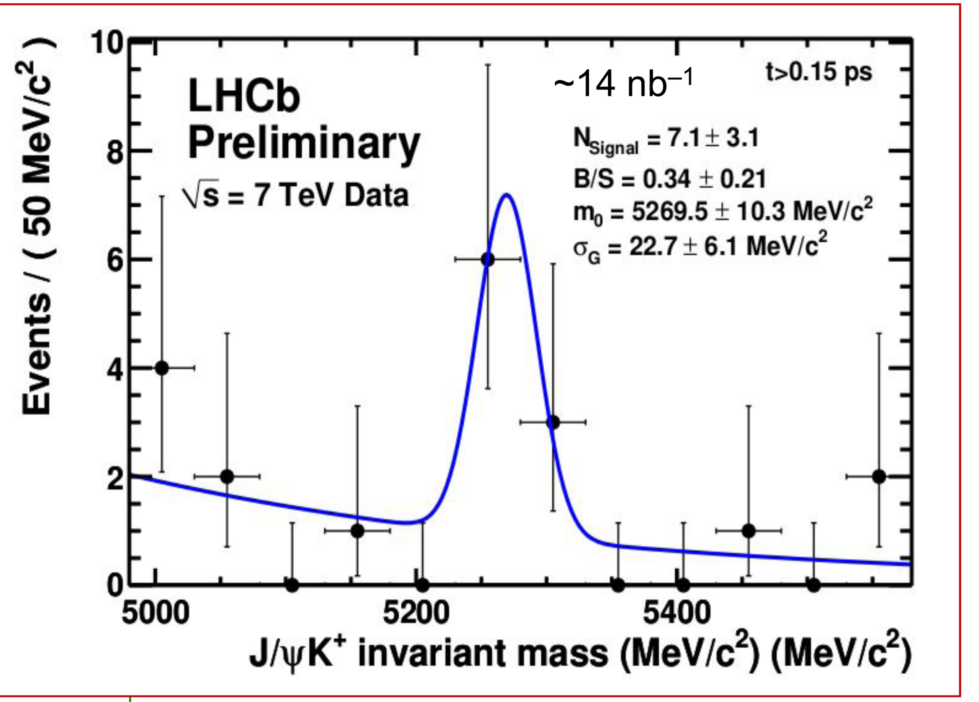
$B^+ \rightarrow J/\psi\ K^+$ candidate

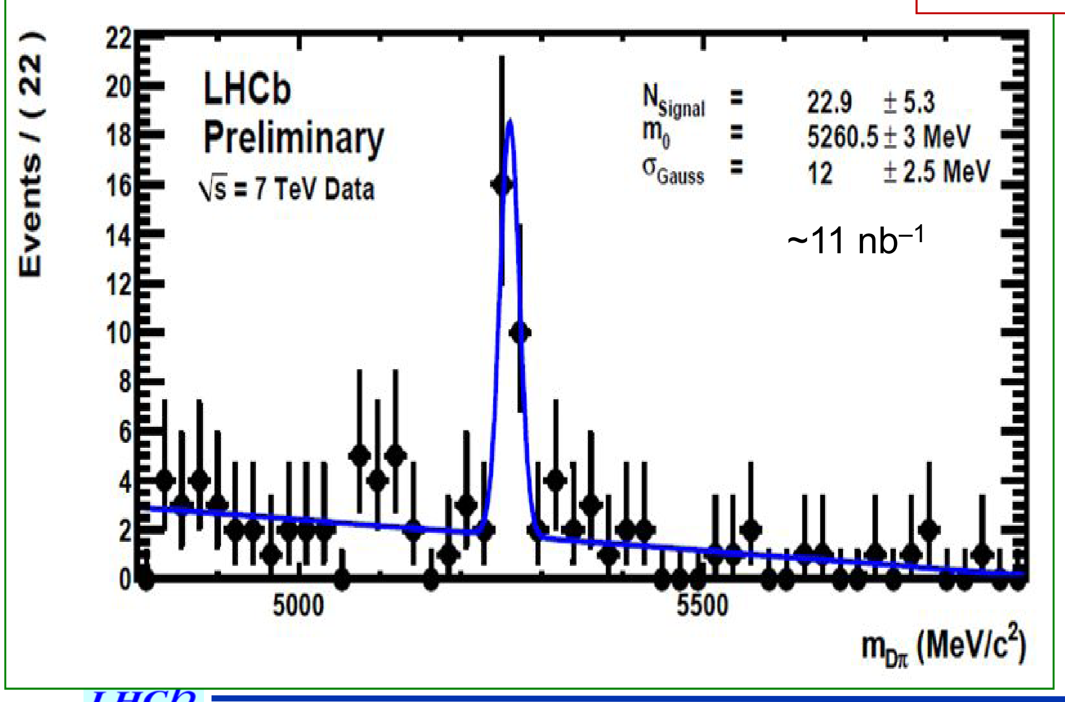
All observables far from cut values defined before data-taking



Fully reconstructed B signals

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





$B \rightarrow D\ \pi + B^+ \rightarrow D^+\ \pi$

~10 times more statistic collected
➔ B-physics to start soon!

Physics prospects with 2010/2011 data

Search for effects induced by New Physics in CP violation and Rare decays using the FCNC processes mediated by loop diagrams (box and penguin)

are New Physics already around the corner ?

LHCb key measurements

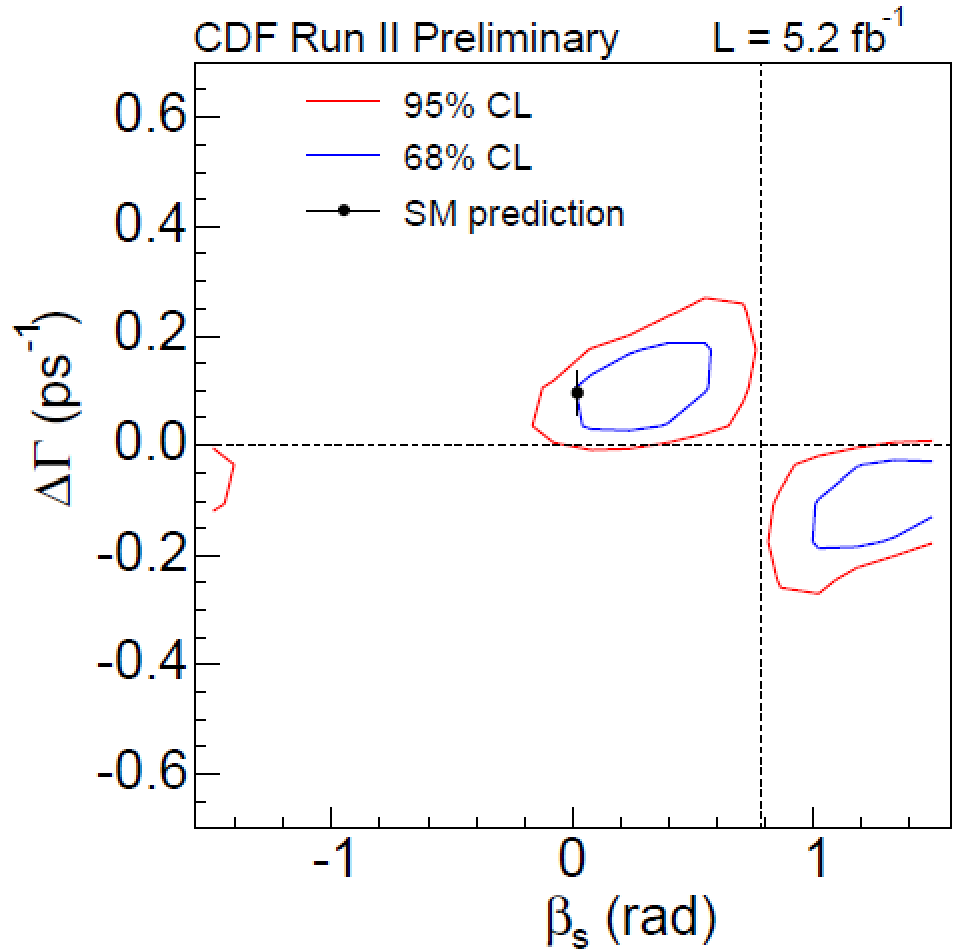
in CP–violation: → **Anton Poluektov**

- B_s-$\bar{B}_s$ mixing angle ϕ_s
- weak phase γ in trees
- weak phase γ in loops

in Rare Decays: → **Antonio Perez**

- branching ratio of $B_s \rightarrow \mu\mu$
- forward-backward asymmetry in $B \rightarrow K^*\mu\mu$
- polarization of photon in radiative penguin decays

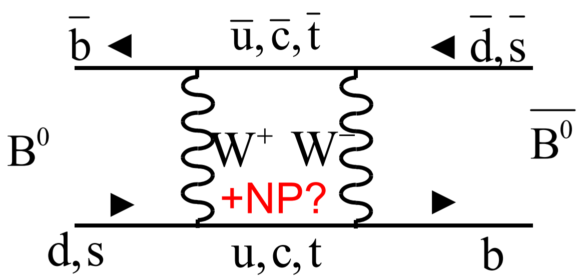
(early measurements in red)



B_s-$\bar{B}_s$ mixing phase ϕ_s in $B_s \to J/\psi(\mu\mu)\,\phi$

✓ Sensitive to New Physics effects in mixing

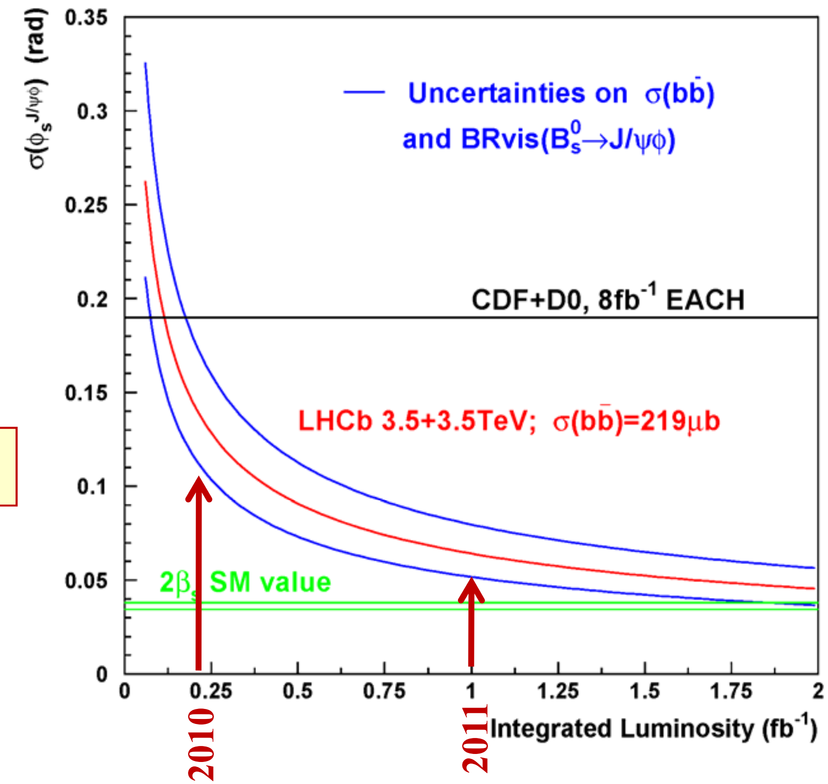
➢ $\phi_s = \phi_s(SM) + \phi_s(NP)$



➢ in SM: $\phi_s = -2\beta_s = -\arg(V_{ts}^2) = -0.036 \;\; 0.002$

✓ $J/\psi\phi$ is not a pure CP eigenstate (2 CP even, 1 CP odd amplitude)

➢ need to fit angular distributions of decay final states as function of proper time (requires very good proper-time resolution)

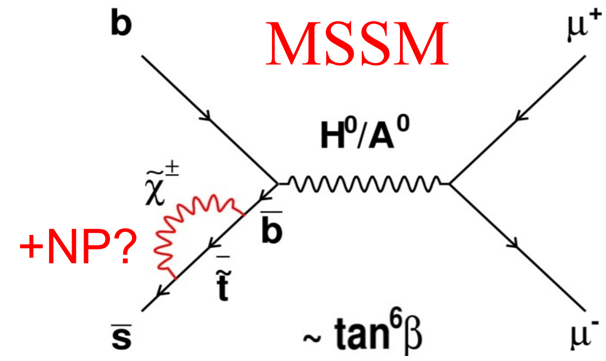


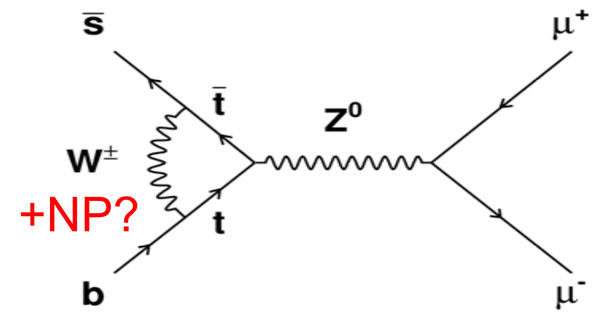
✓ with 2.8 fb^{-1} current combined Tevatron result ~2.1σ away from SM value

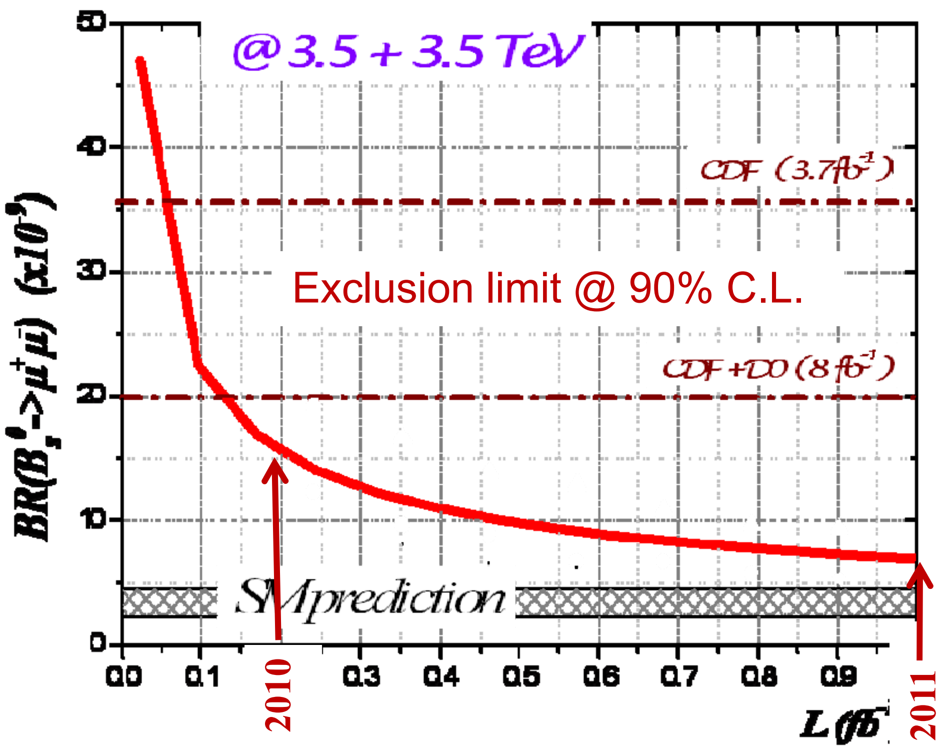
➢ hope to improve significance with LHCb's first year data

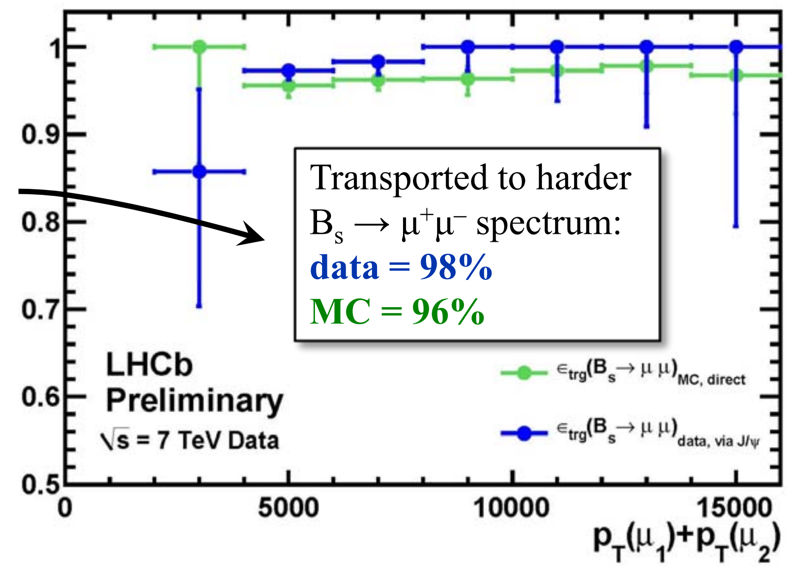
Branching ratio of rare decay $B_s \rightarrow \mu^+\mu^-$

- ✓ Very rare loop decay, sensitive to New Physics
- ✓ BR ~ 3.3×10^{-9} in SM, can be strongly enhanced in SUSY with scalar Higgs exchange
- ✓ Sensitive probe for MSSM with large tanβ: Br $(B_S\rightarrow\mu^+\mu^-)$ ~ $\tan\beta^6 / M_A^4$





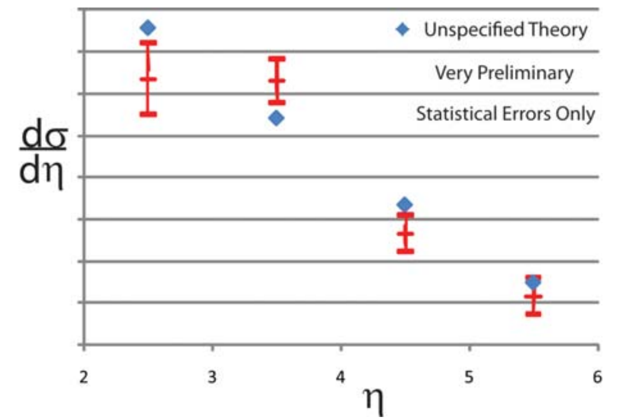




Summary

- LHCb is fully operational with a performance very close to “nominal”
  - ✓ profit from lower luminosity at start-up to by tuning the trigger for increased physics potential for minimum bias and charm physics
  - ✓ will deploy the core physics within next year with the first fb^{-1}

- Initial production measurements ongoing:
  - ✓ absolute K_S production cross section at 0.9 TeV
  - ✓ $\bar{\Lambda}/\Lambda$ production ratio at 0.9 and 7 TeV
  - ✓ to come very soon:
    - o $\bar{p}/p$ production ratio at 0.9 and 7 TeV
    - o open charm, prompt J/ψ, $b \to J/\psi$ and $\bar{b}/b$ cross sections



- Indirect New Physics searches at LHCb on the horizon:
  - ✓ several highly-sensitive physics observables in B and D sectors, accessible with data from 2010–2011 run
  - ✓ active preparation of analysis using existing calibration & control signals while looking forward to more statistics!

Don't miss the LHCb parallel session talks:

Parallel session on "LHC physics results":

- ✓ LHCb detector commissioning with first data
  → Giacomo Graziani (Firenze)
- ✓ Luminosity measurement and K-short production with first LHCb data
  → Sophie Redford (Oxford)
- ✓ LHCb particle identification performance and baryon/anti-baryon asymmetries
  → Susanne Koblitz (CERN)

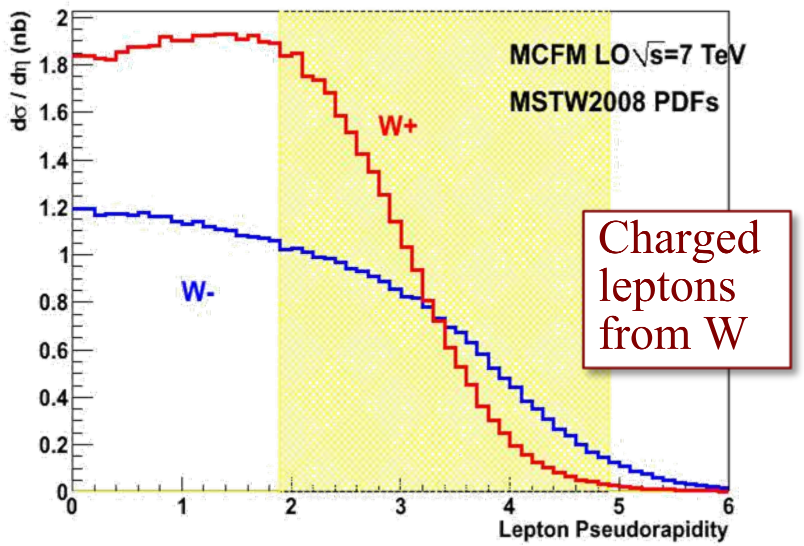
Parallel sessions on "QCD and Heavy Flavour Physics"

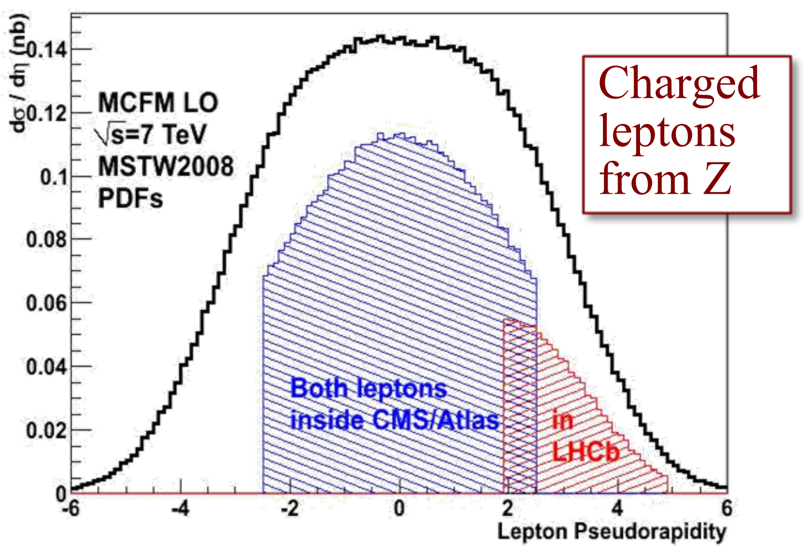
- ✓ LHCb physics prospects for CP violation measurements with 0.2 and 1 fb^{-1}
  → Anton Poluektov (Warwick)
- ✓ Search for rare decays at LHCb with 0.2 and 1 fb^{-1}
  → Antonio Maria Pérez-Calero Yzquierdo (Barcelona)

Back-up

Electroweak boson production

- LHCb coverage:
  - interesting pseudo-rapidity region where W^+/W^- ratio varies rapidly
  - small y overlap with ATLAS/CMS
  - unique area of (Q^2, x) plane
- Measurements of interest:
  - $Z^0/W^\pm$ ratio
    - precisely predicted (< 1%)
    - should aim at 1% measurement with 0.1 fb^{-1} → test SM
  - W^+/W^- ratio
    - sensitive to u/d ratio
  - W, Z production cross sections
    - can constrain PDFs, down to $\sim 6\times10^{-4}$ at $\sqrt{s}$= 7 TeV





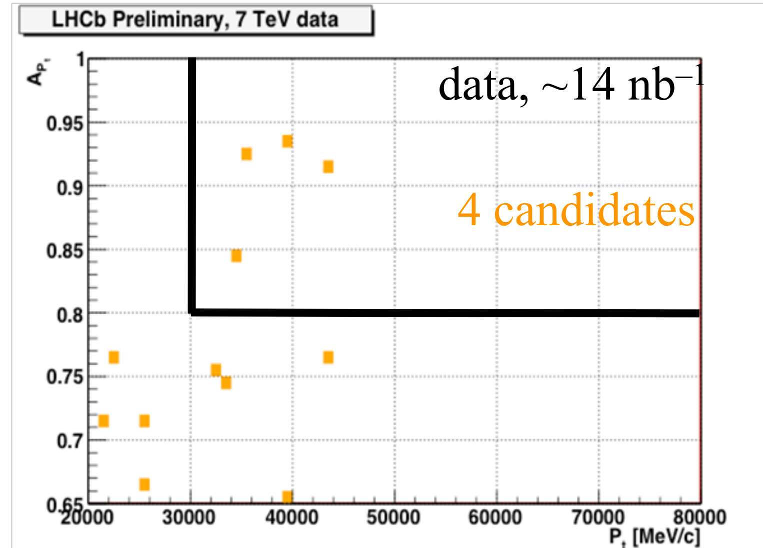
W → μν selection

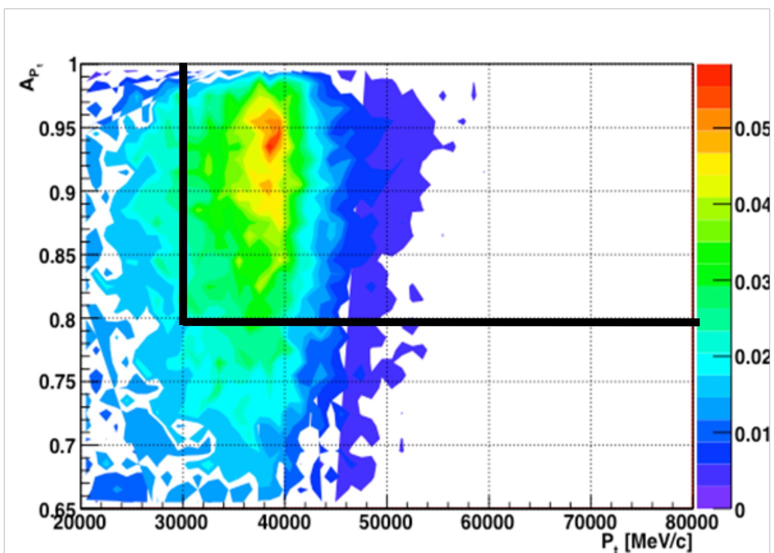
❑ Selection:

- good track (χ^2, $\sigma_p/_p$, …) identified as muon
- $p_T > 30$ GeV/c and $A_{pT} > 0.8$

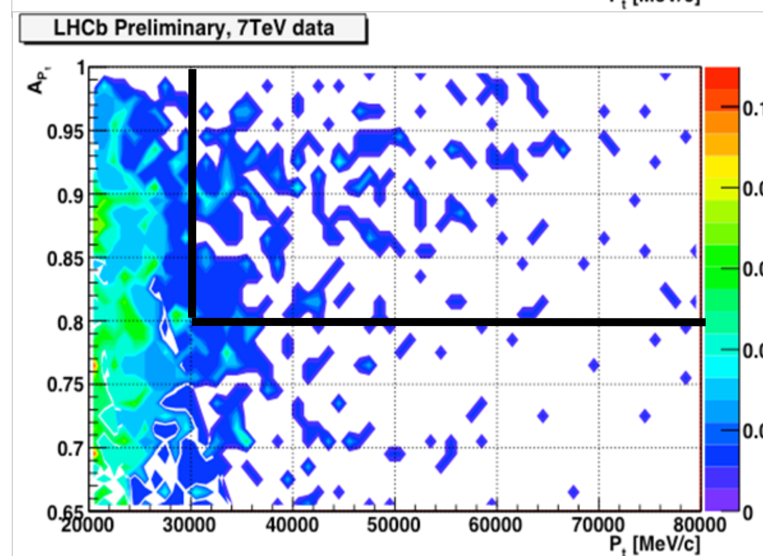
$$A_{pT} = \frac{p_T - p_T^{rest}}{p_T + p_T^{rest}}$$

p_T^{rest} = transverse momentum of vector sum of all charged tracks, excluding the selected track



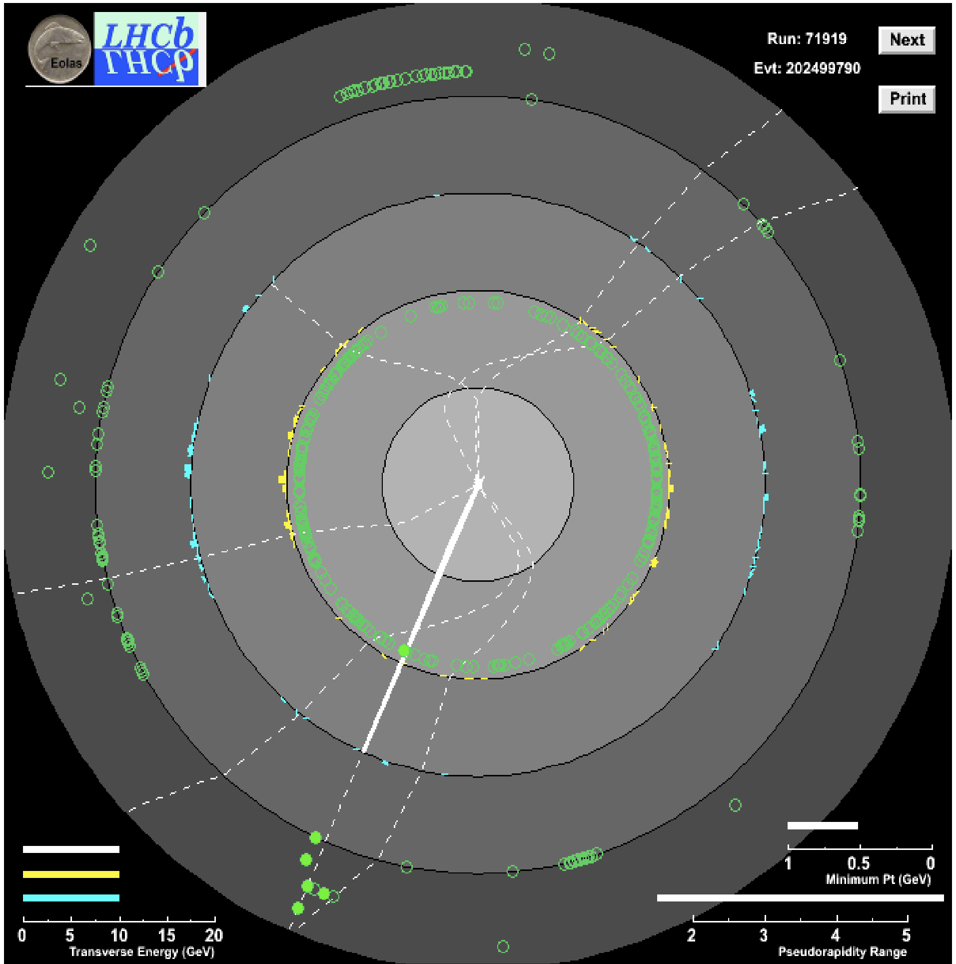


MC, W□ μν signal



data, ~8 nb^{-1}, without muID cut

$W^+ \rightarrow \mu^+\nu$ candidate

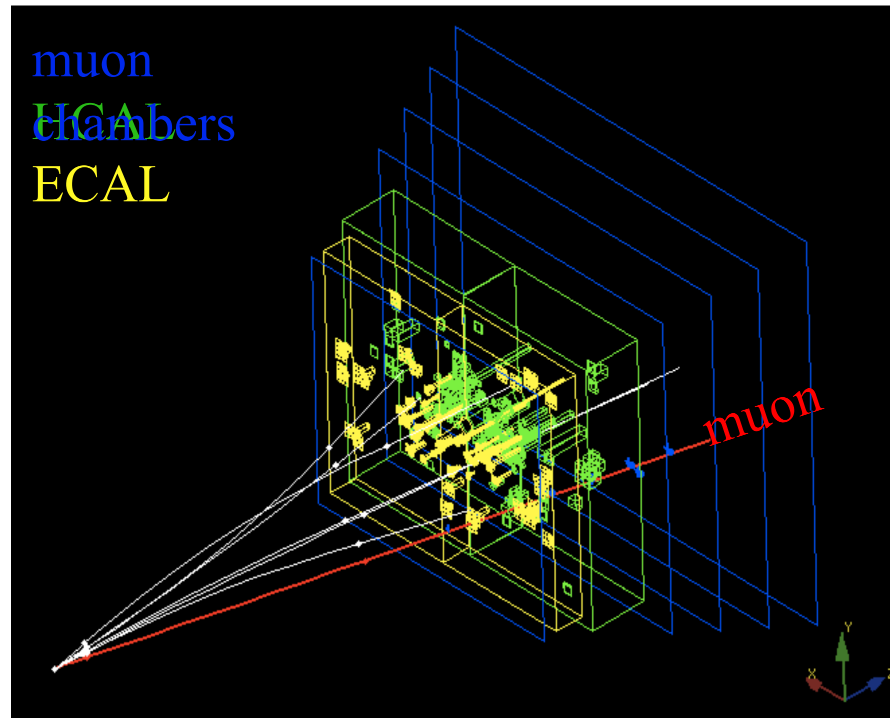


z–φ view

$\eta = 2.51$

$p_T = 35.4$ GeV/c

$A_{pT} = 0.92$



standard 3D view