Status of LHCb,c

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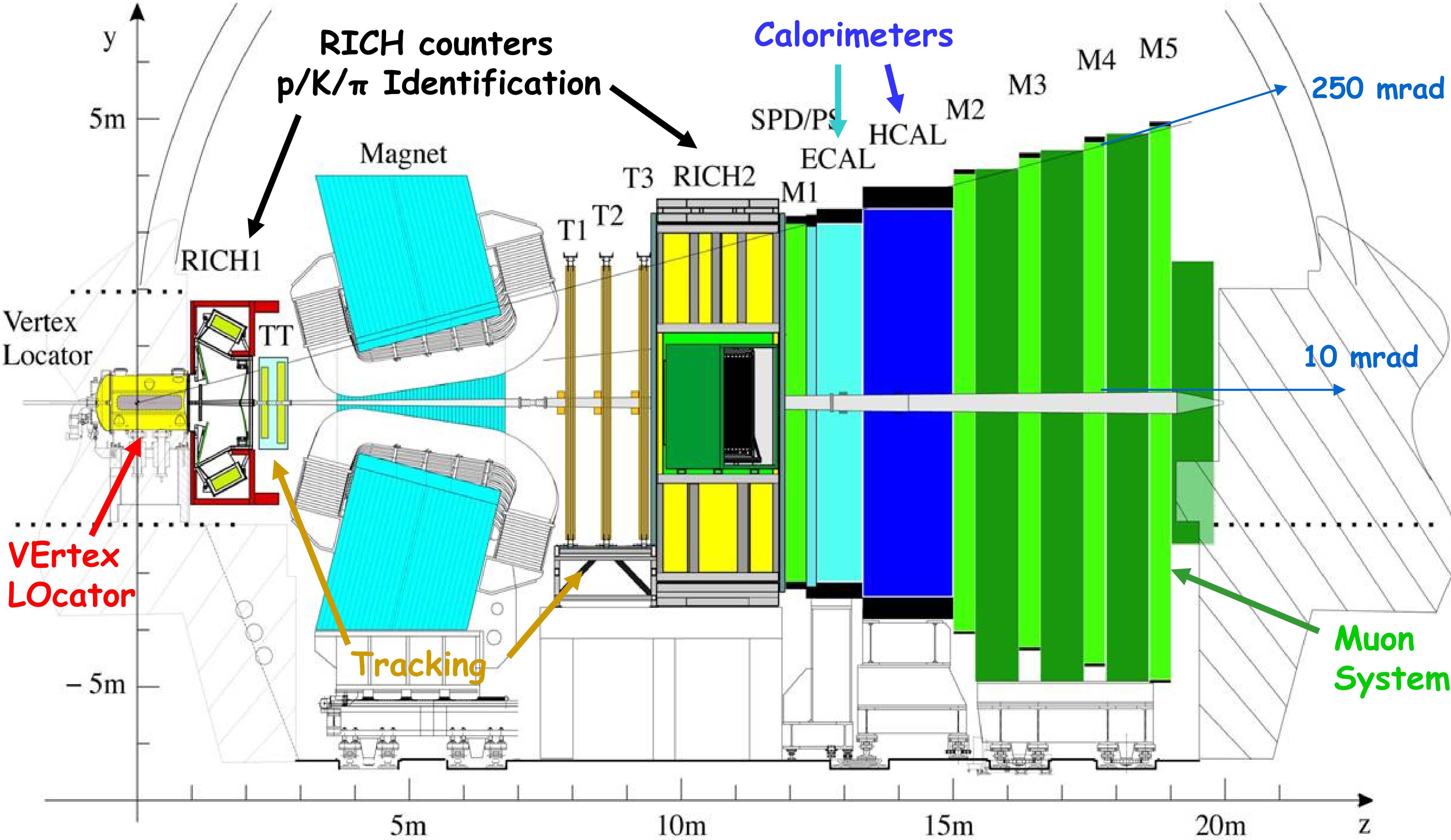
on behalf of the LHCb Collaboration

LHCb detector – single-arm forward spectrometer 10-250 mrad (V), 10-300 mrad (H)



Vertex reconstruction:
VELO

Kinematics:
Magnet
Tracker
Calorimeters

PID:
RICHs
Calorimeters
Muon Chambers

Trigger:
Muon Chambers
Calorimeters
Tracker

Hunt for both prompt charm & $b \to c$

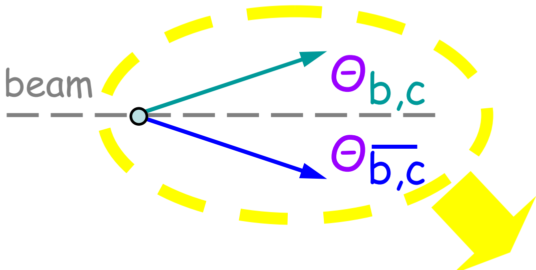
Correlated $Q\bar{Q}$-production, E_{CM}=14 TeV

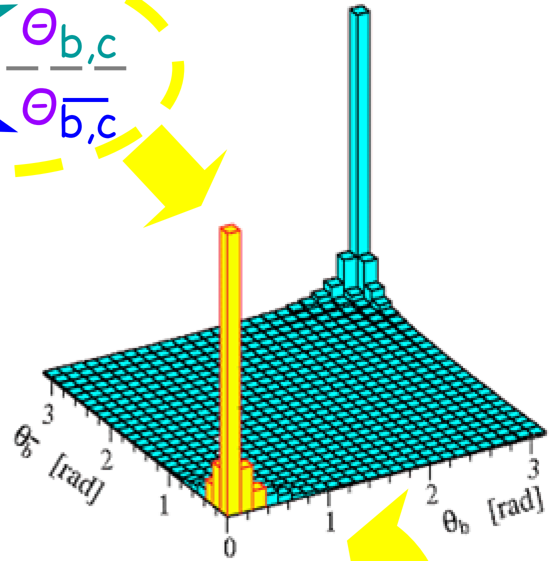
$\sigma_{inelastic}$ ~80 mb, σ_{cc} ~3 mb (~4%), σ_{bb} ~0.5 mb (~0.6%)

few x 10^{12} $c\bar{c}$ in 1 nominal year

1 LHCb year: 10^7 s, $\int Ldt$= 2 fb^{-1}

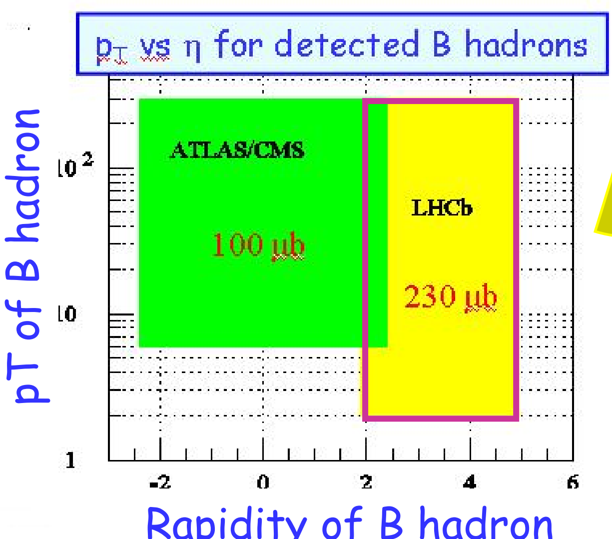
1st LHCb year: $\int Ldt$=~0.1 fb^{-1}

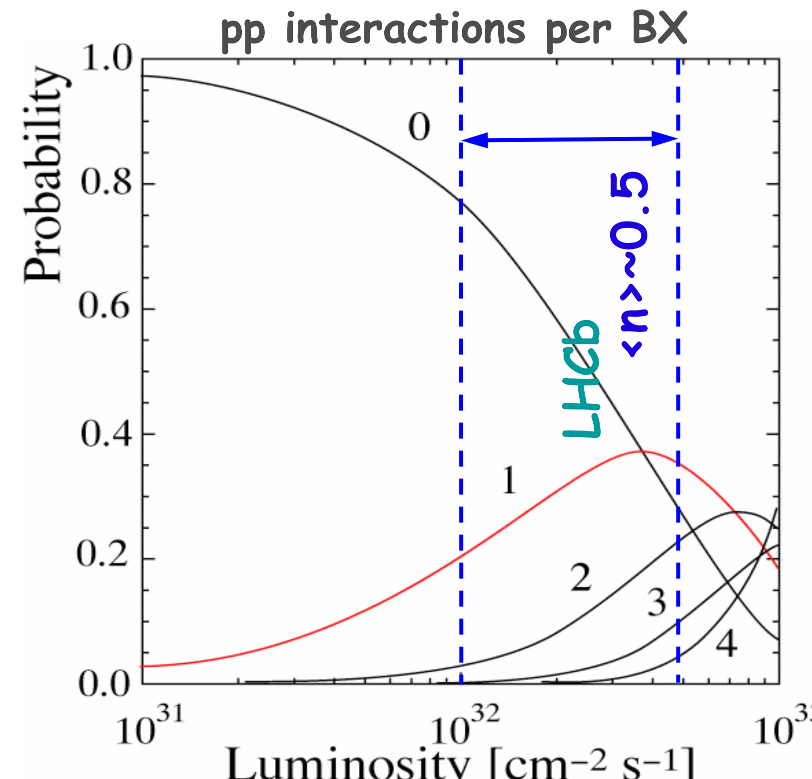




LHC Luminosity @ LHCb: 2-5 x 10^{32} $cm^{-2}s^{-1}$

(tuneable by defocusing beams)





Advantages of charm at LHCb …

- Precise **vertexing and tracking**
- **Particle ID**
- Access to large rapidity range
- STATISTICS

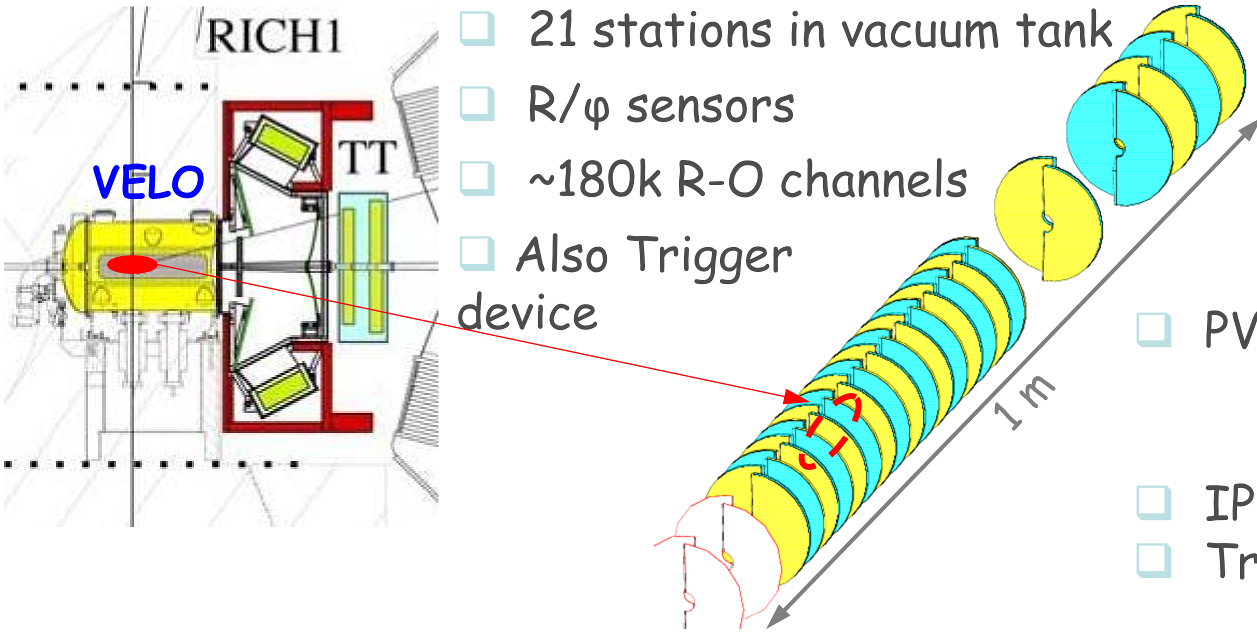
… still, working under …

- High multiplicities
- Forward geometry

  no full event reconstruction ensured
- Originally *b*-dedicated trigger

  difficult to optimize simultaneously for b-physics and prompt charm

Tracks and vertices: VErtex LOcator, Si TT and IT, straw OT

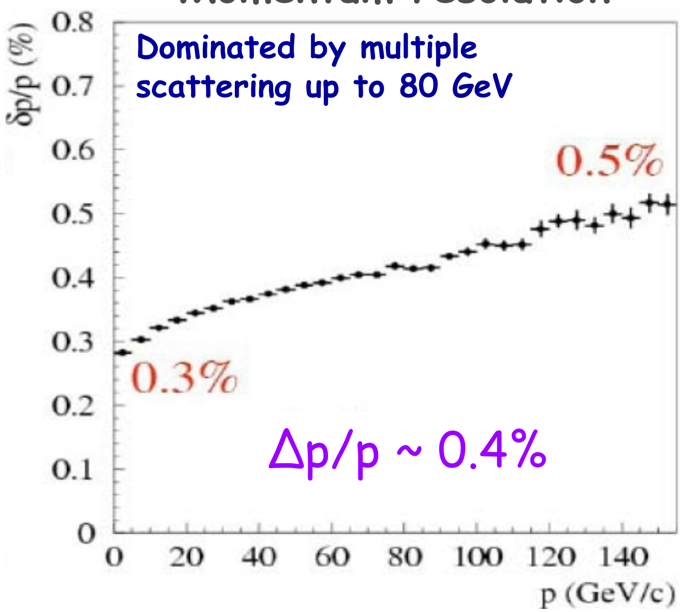


- 21 stations in vacuum tank
- R/φ sensors
- ~180k R-O channels
- Also Trigger device

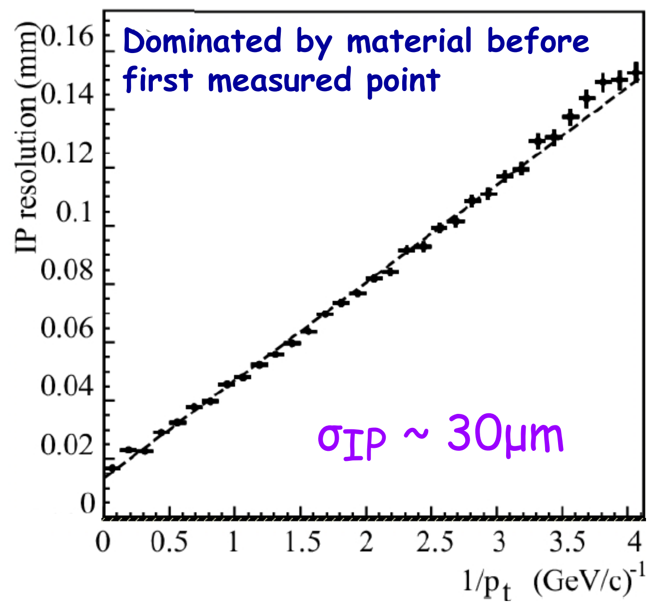
- Sensors sensitive area 8mm from beam line (30 mm during injection)

- PVx position resolution:
  x,y: ~ 8 μm
  z: ~ 44 μm
- IP precision: ~ 30 μm
- Track reconstruction ε~96%

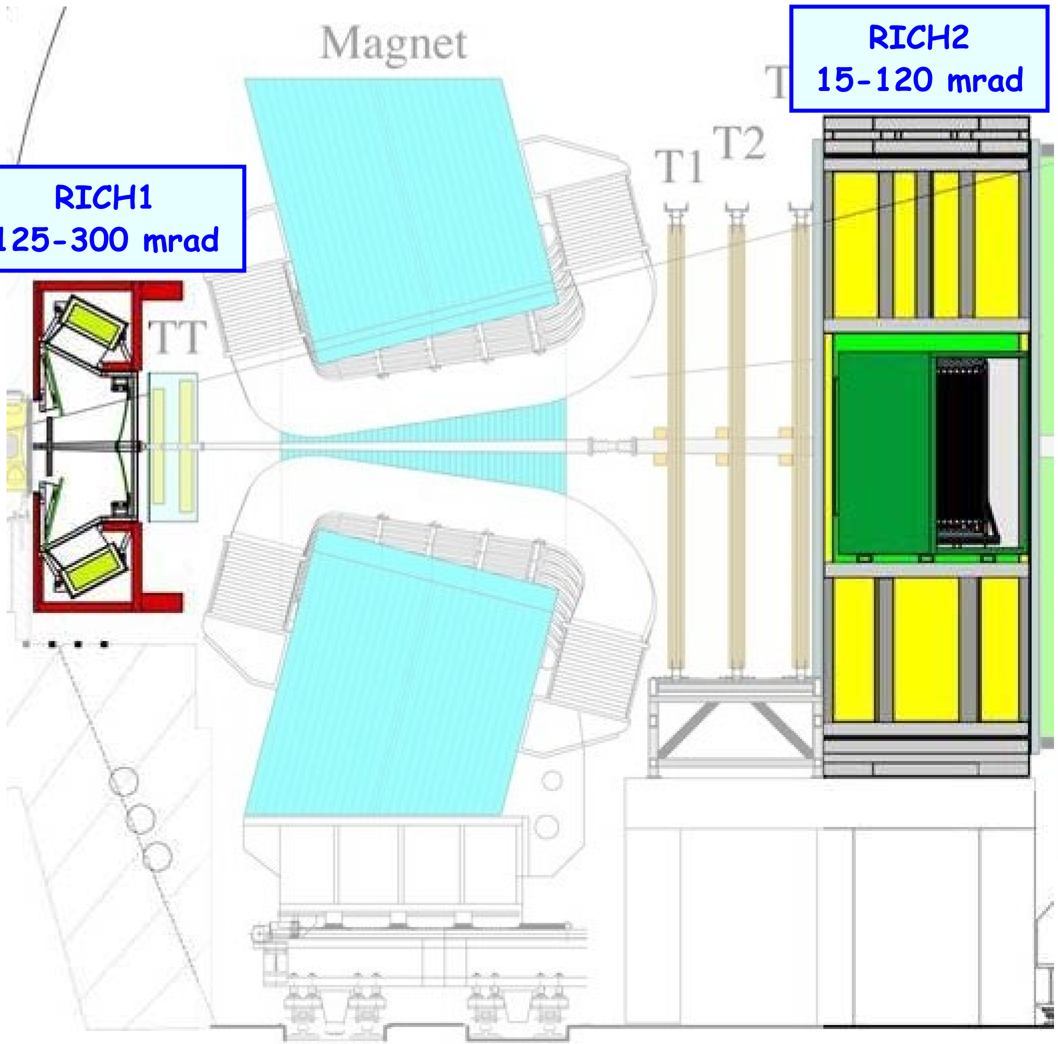
Momentum resolution

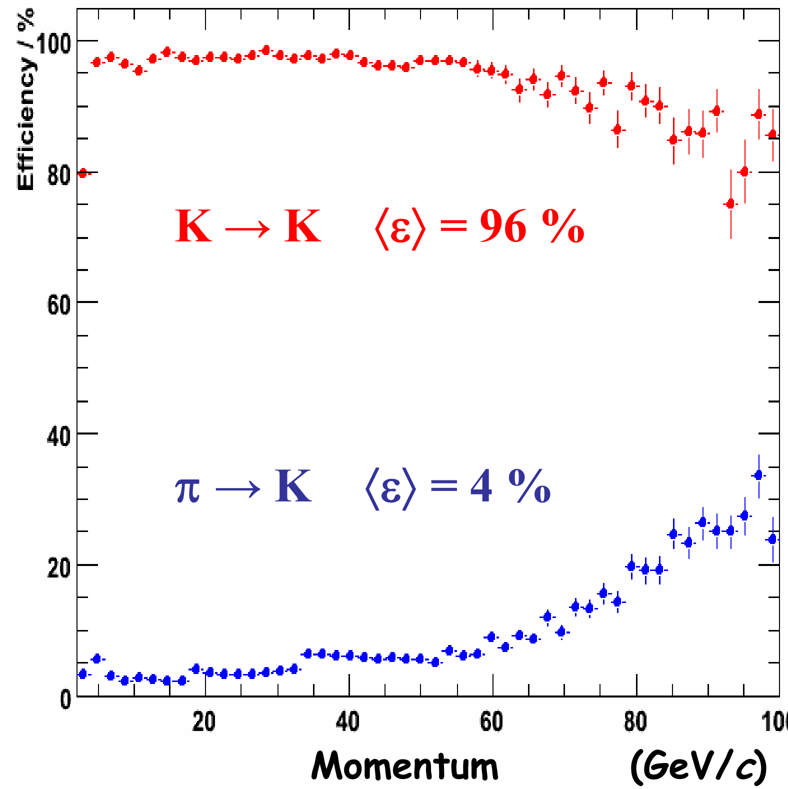


IP resolution



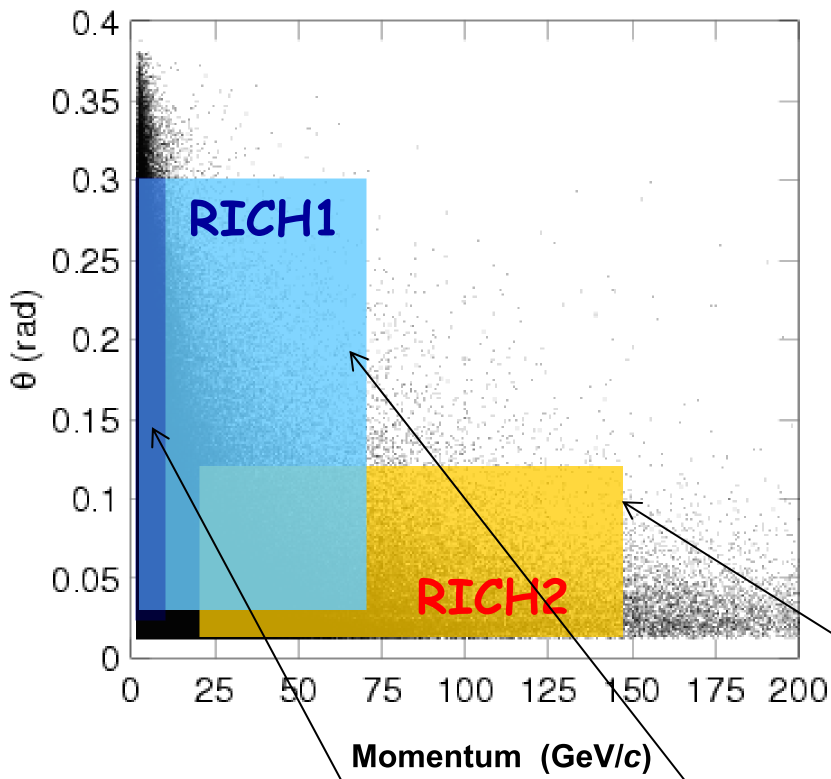
Particle ID: RICH system

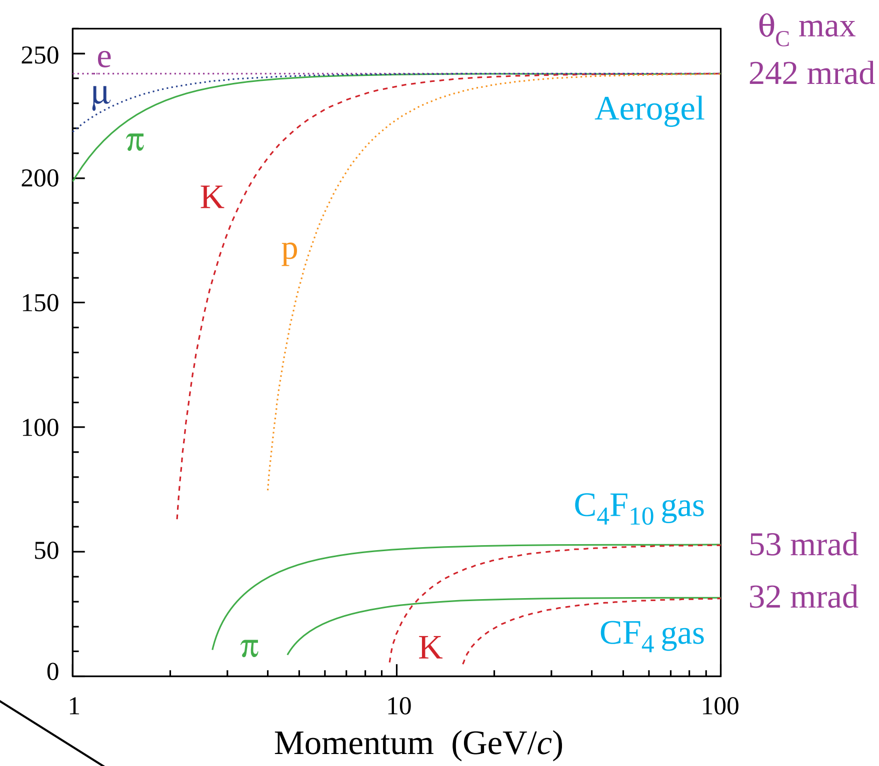




Excellent K/π separation for 2 GeV/c < p < 100 GeV/c

2 RICHs and 3 radiators to cover phase space





Silica Aerogel:
n=1.03
1-10 GeV/c

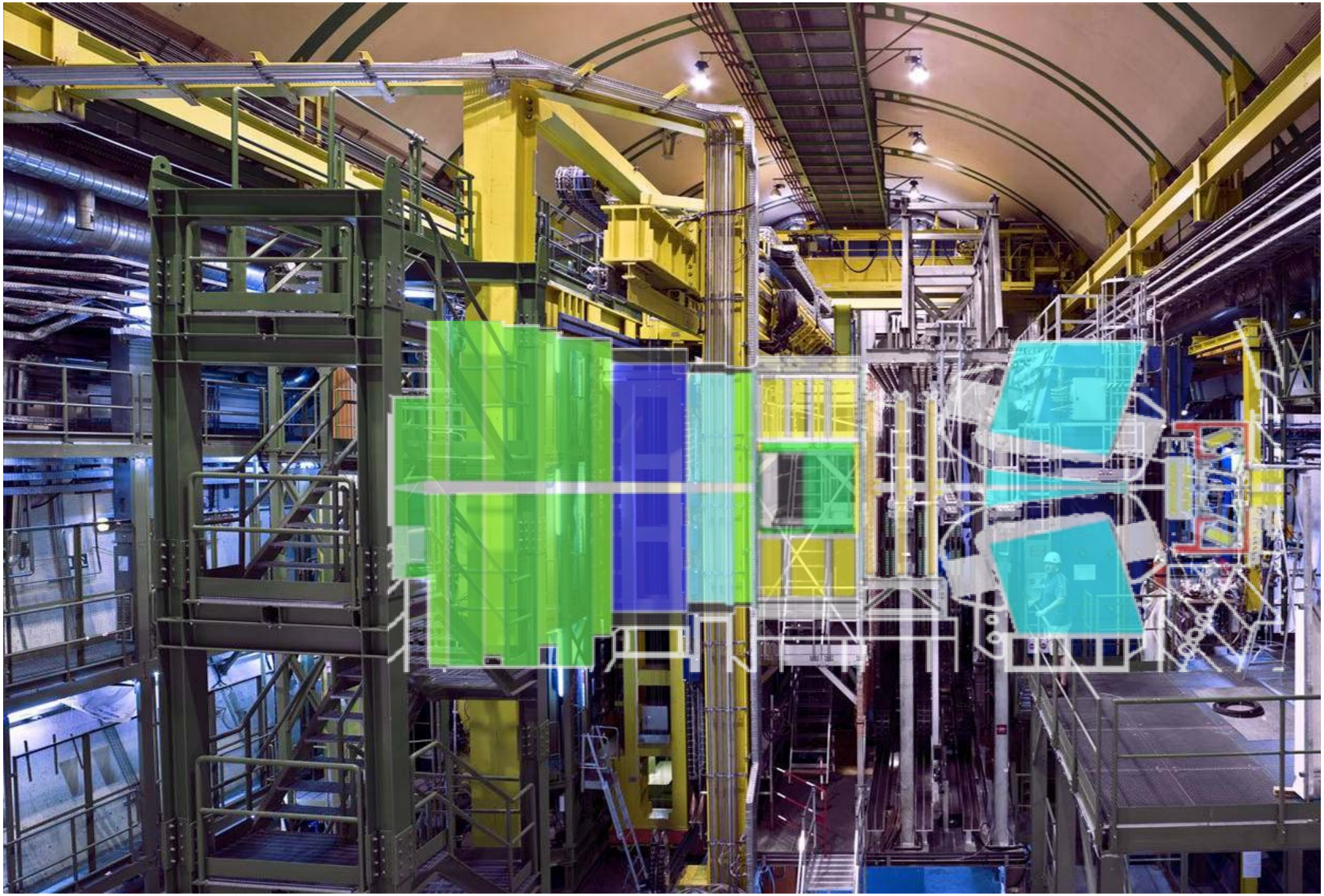
C_4F_{10}:
n=1.0014
Up to ~70 GeV/c

CF_4:
n=1.0005
Up to ~100 GeV/c

RICH1: 25-250 mrad vertical, 300 mrad horizontal

RICH2: 15-100 mrad vertical, 120 mrad horizontal

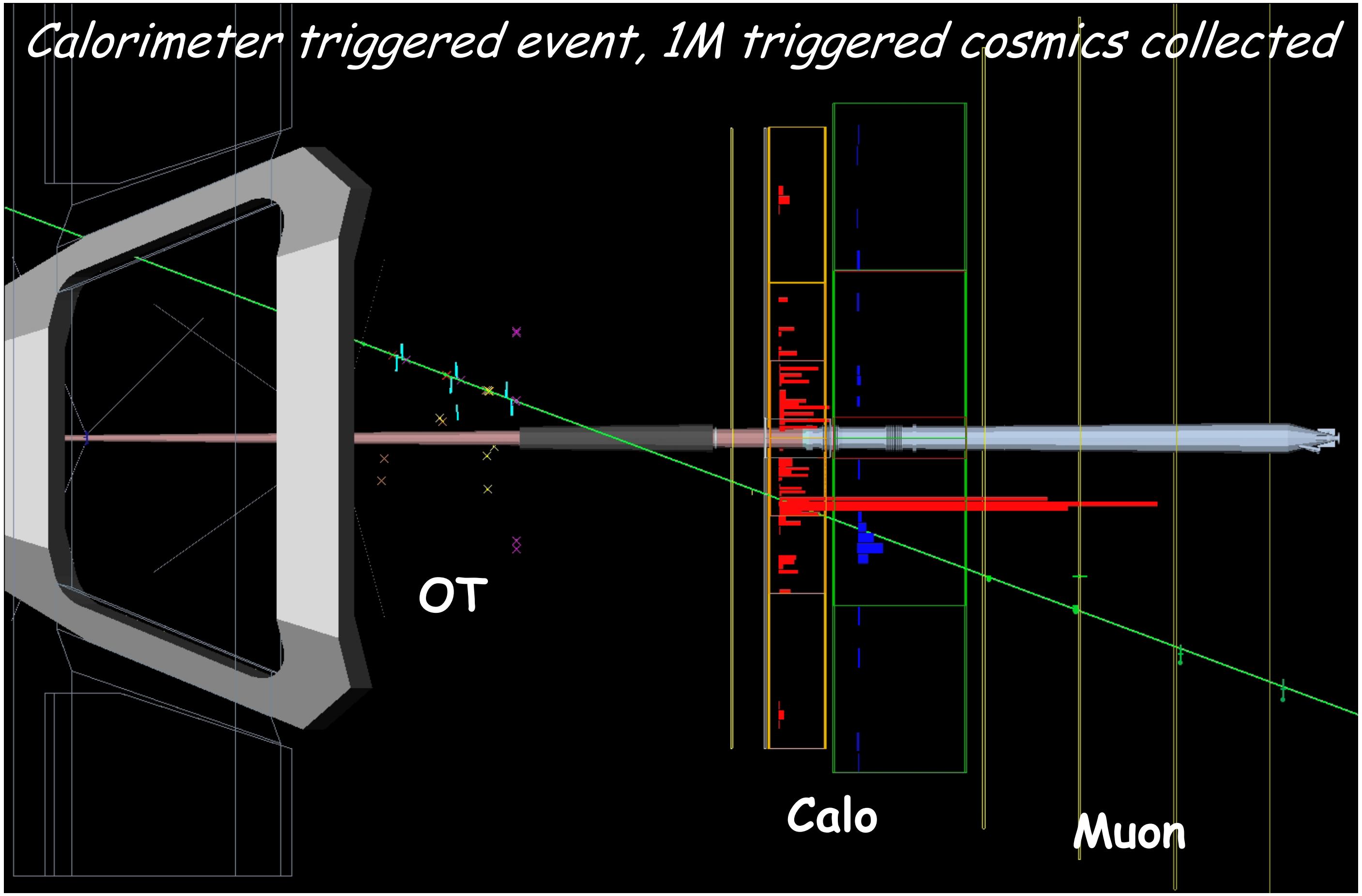
The experiment is fully installed, commissioning well advanced …



… no collisions yet ➔ cosmics + too short experience with LHC protons.

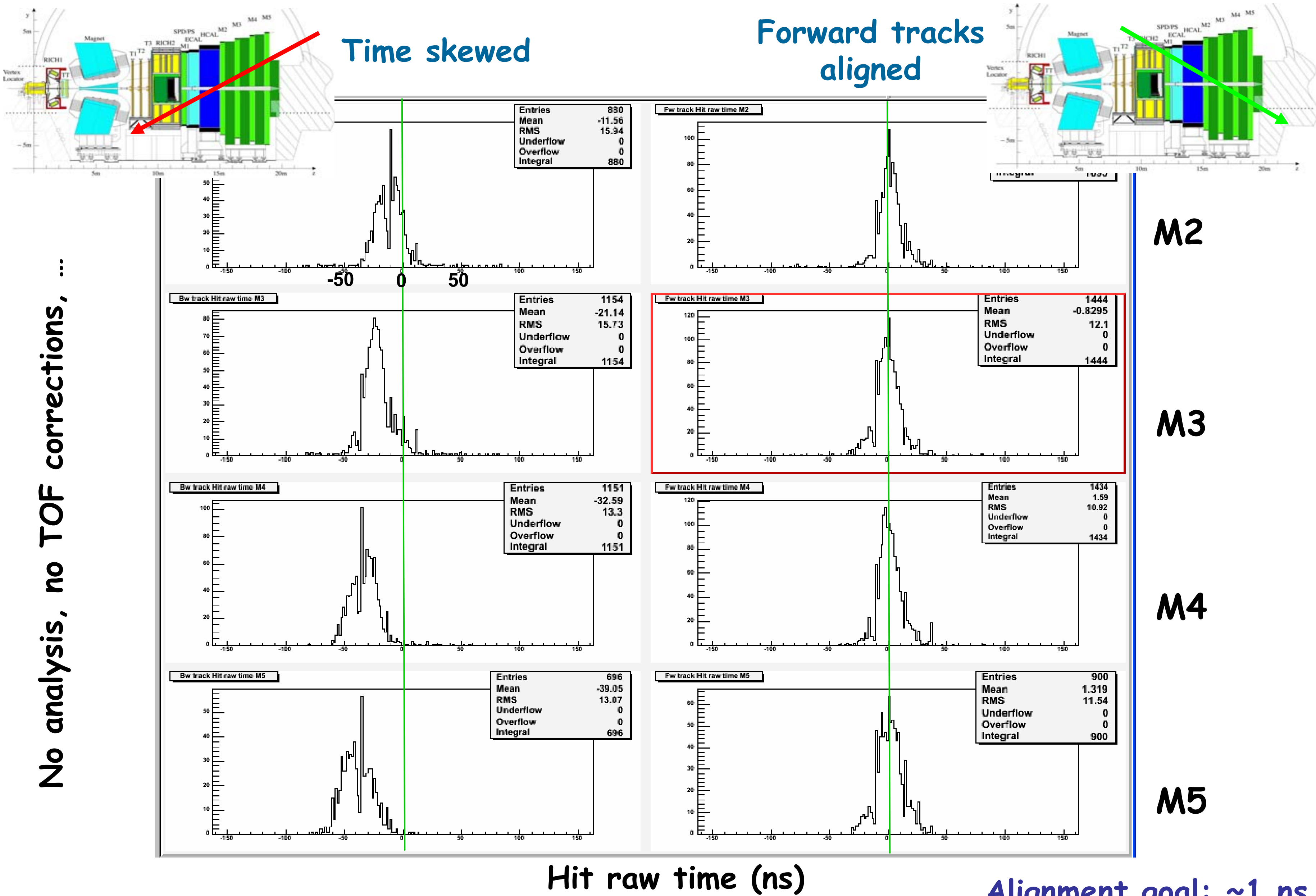
Cosmics for the tracking detectors

➔ Works for Outer Tracker (similar surface as the Calorimeter)
Marginal for Inner Tracker (small), Trigger Tracker (too far),
Vertex Locator (small and far)



Trigger with EM and H **calorimeters** with a high gain to see MIP
Muon trigger without spatial correlation (no pointing geometry) constraint
Readout of consecutive events ➔ time alignment, optimizing signal vs. spill-over

Time alignment of Muon stations with cosmics

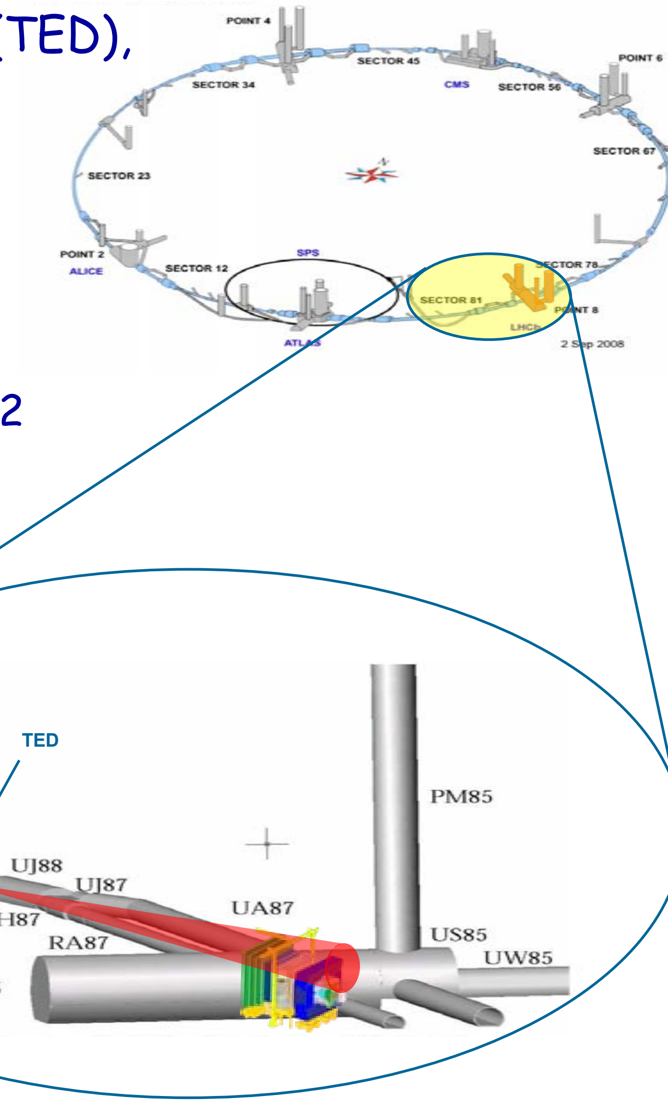


Alignment goal: ~1 ns

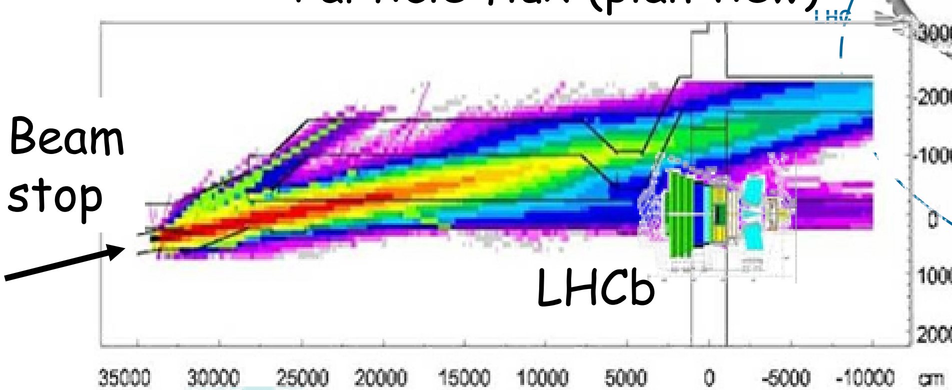
Sector tests : few x 10^9 p every 48 s

- Beam 2 dumped on injection line beam stopper (TED), i.e. 4m W, Cu, Al, graphite rod in a 1m diameter iron casing
- 340m before LHCb along Beam 2
- Wrong direction for LHCb
- High flux, centre of shower **O**(10) particles/cm^2
- VErtex LOcator **O**(0.1) particles/cm^2

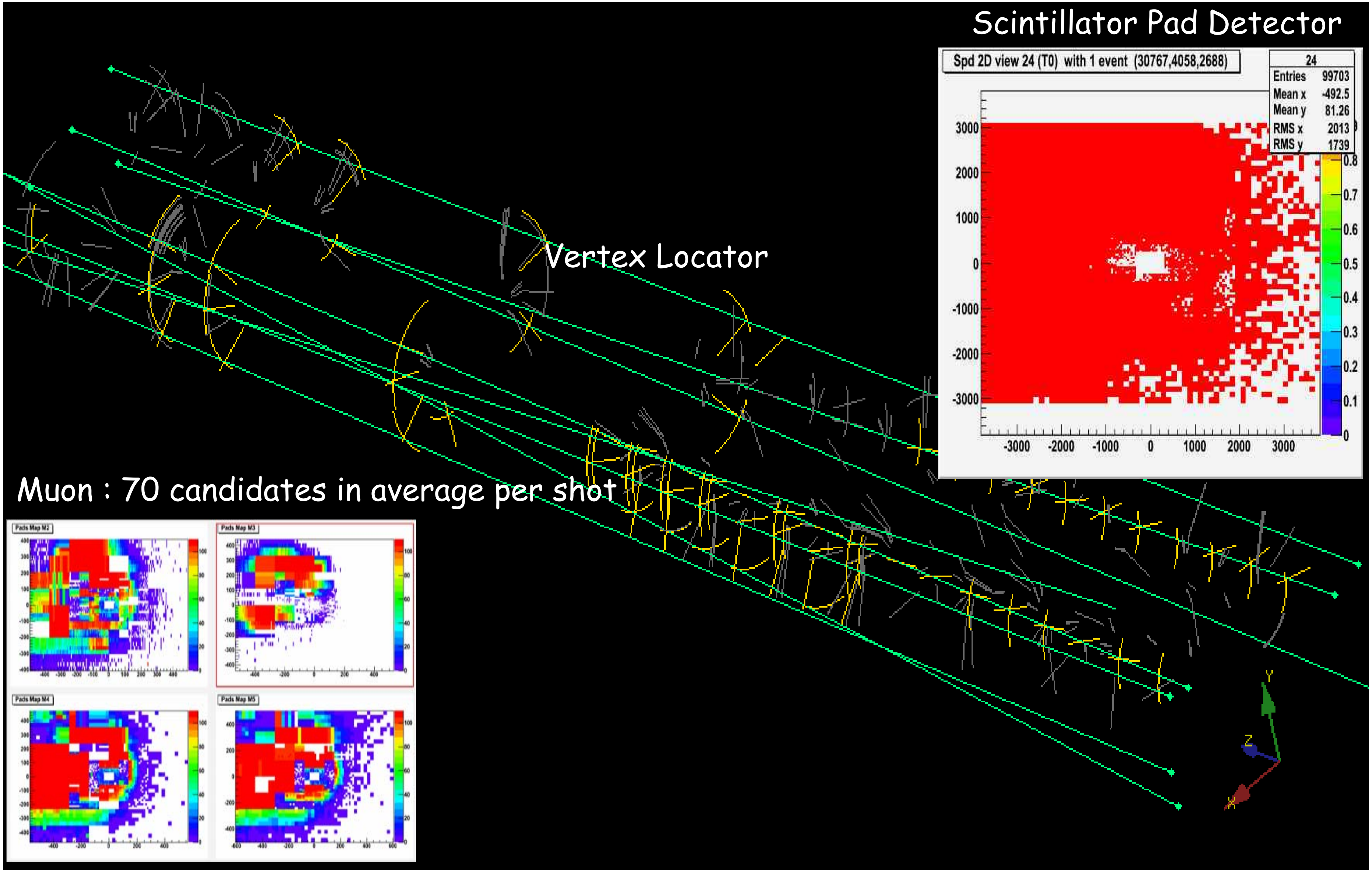
➔ ~700 VELO tracks per test



Particle flux (plan view)

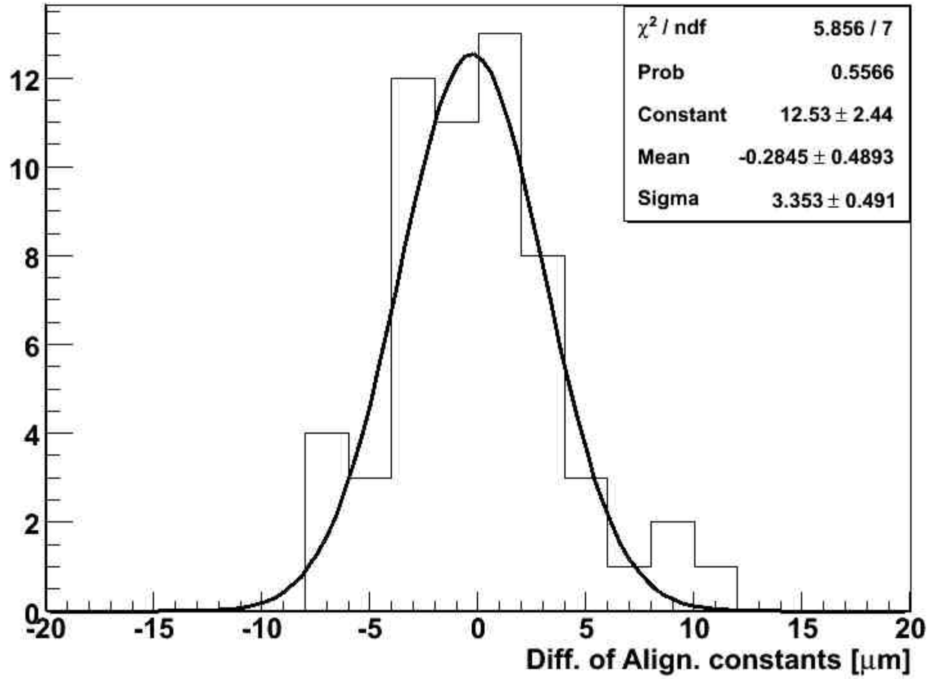


Sector test: VELO tracks in busy TED events

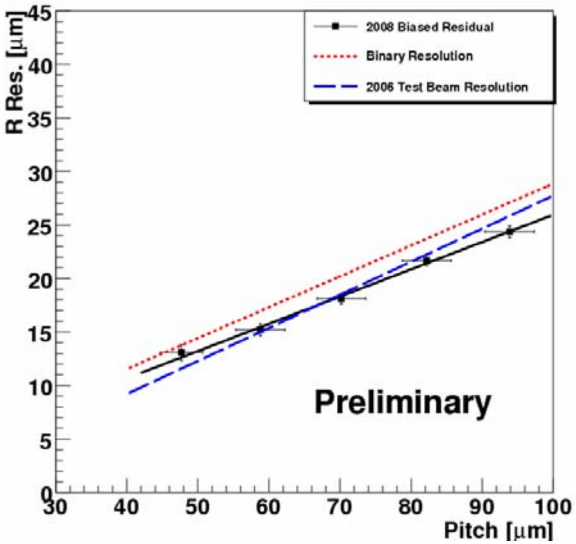


Sector test: VELO space alignment with the TED events

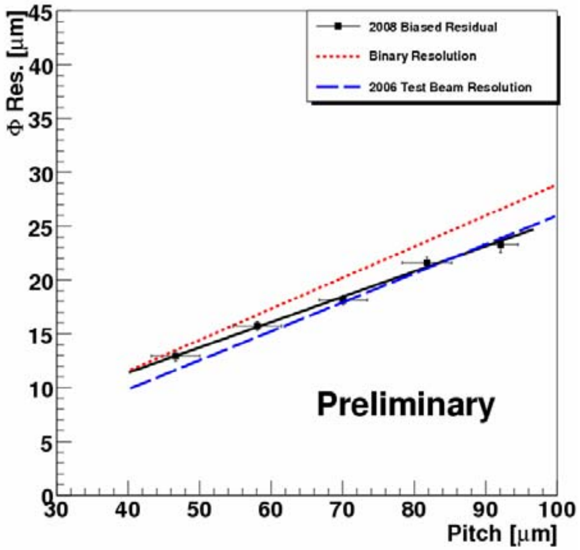
- The detector displacement from metrology usually is less than 10 μm
- Module alignment precision is about 3.4 μm for X and Y translation and 200 μrad for Z rotation



R residuals

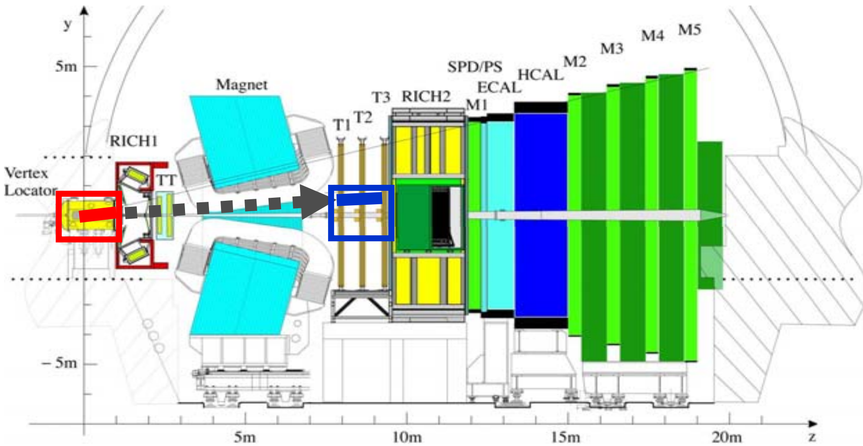


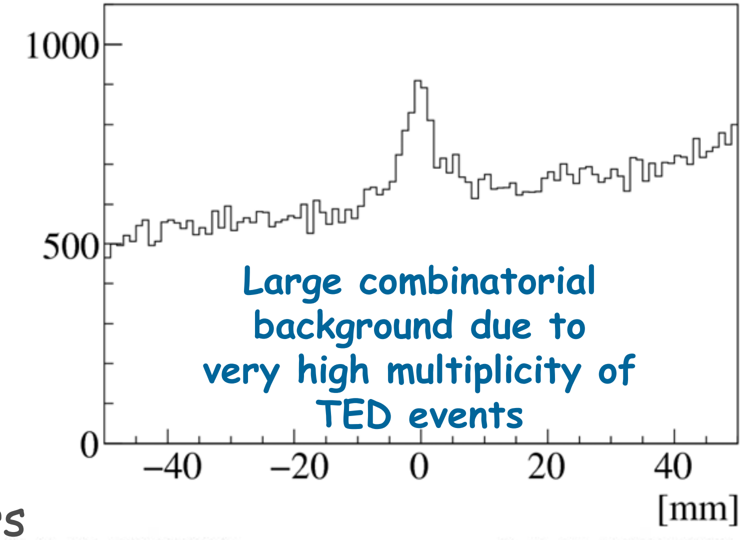
Φ residuals



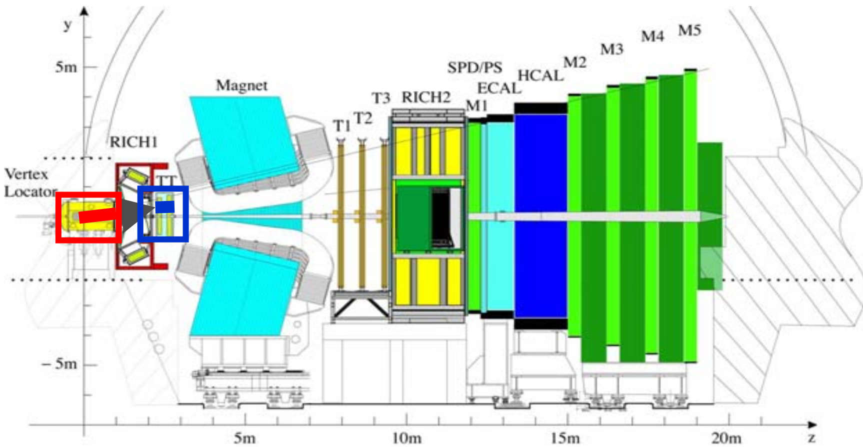
Sector test: using VELO tracks for IT, TT space alignment

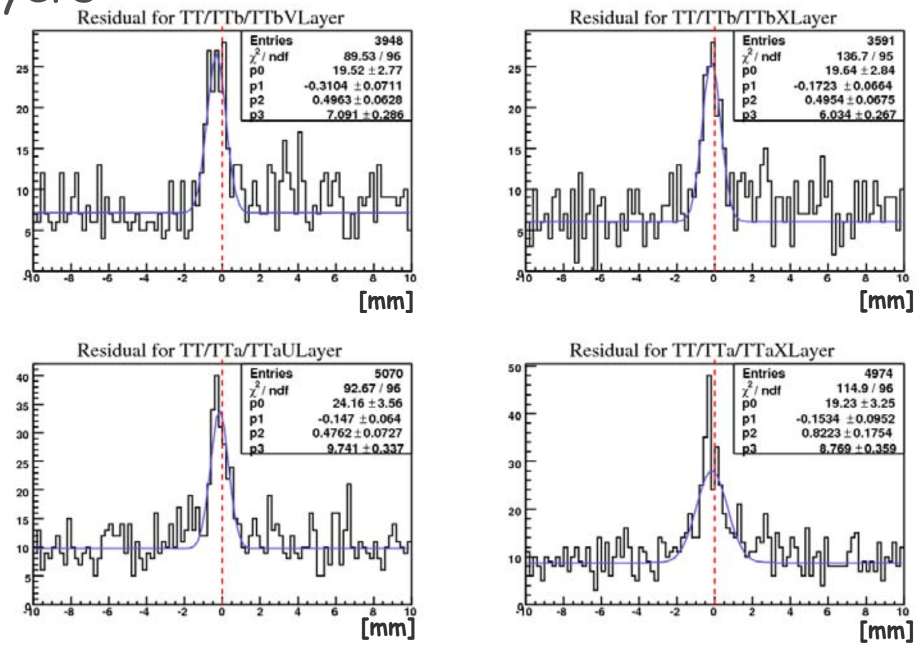
- Extrapolation of VELO tracks to IT (7m)



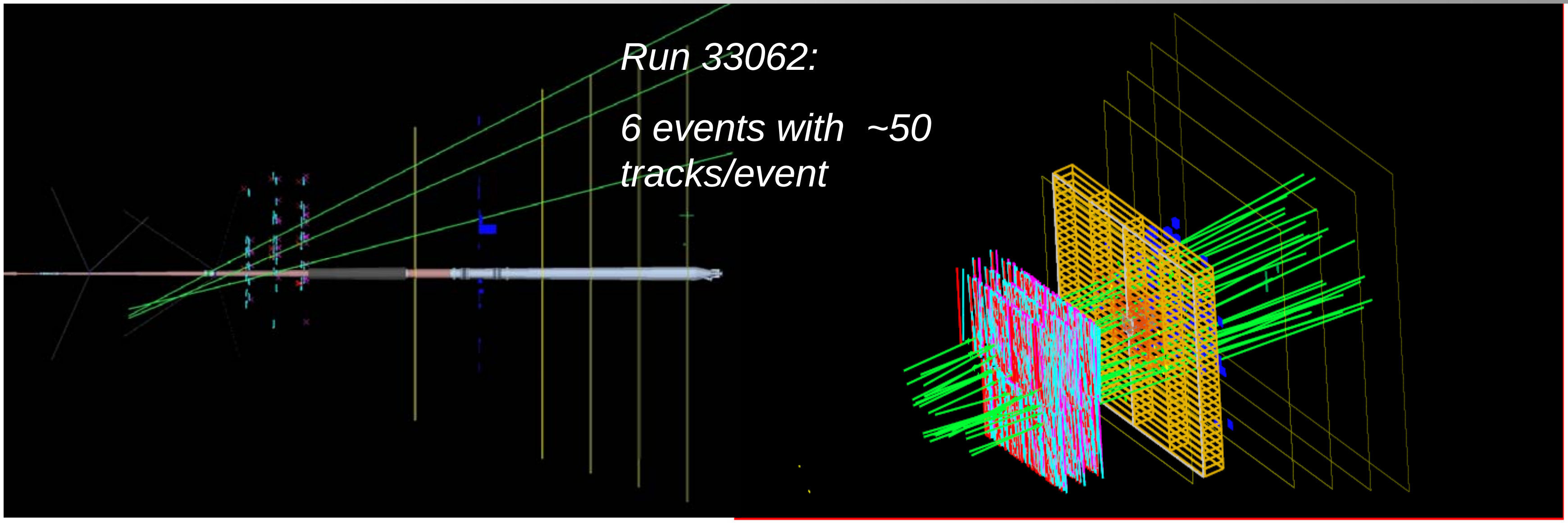


- Extrapolation of VELO tracks to TT layers
  - ➔ Within 300 μ of expected

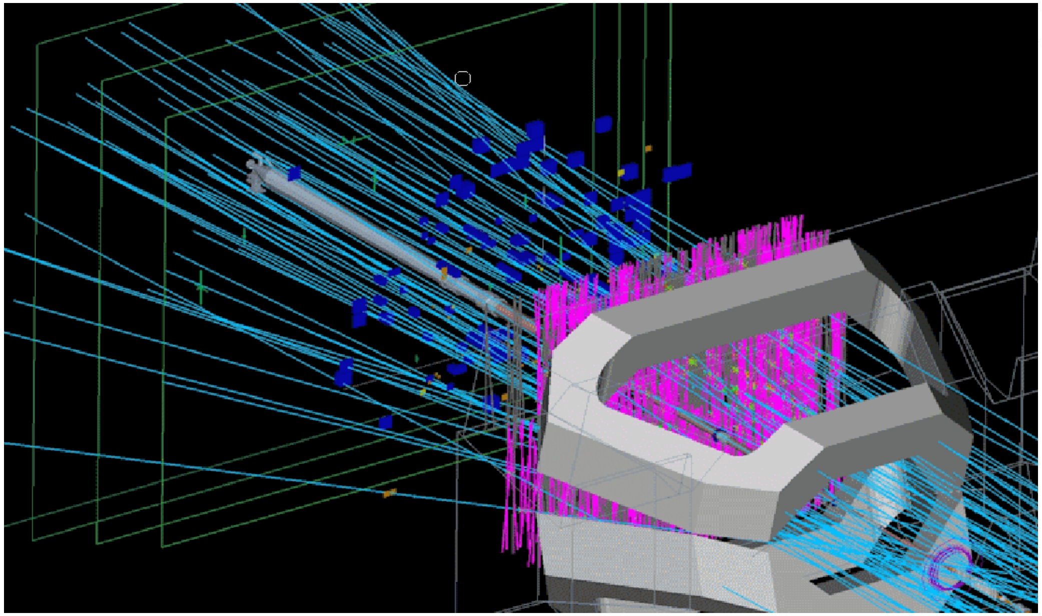


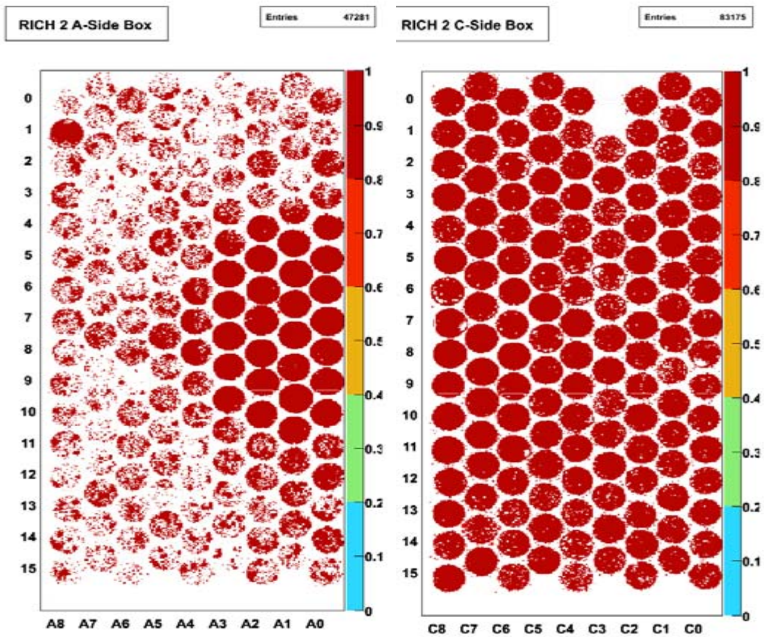


First beam on September 10: low multiplicities or splashes



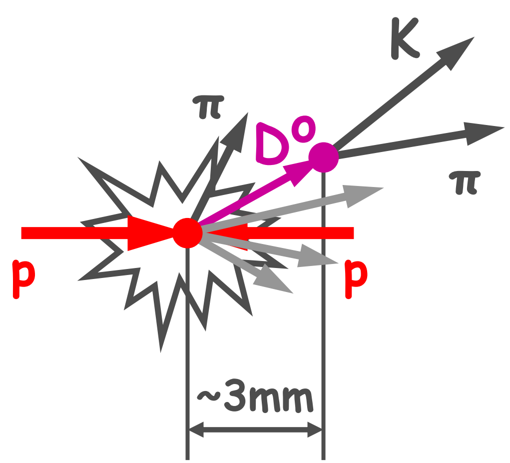
Beam 1 on collimator: busy tracker and RICH2 “photon blast”





140k hits / 200k total active area

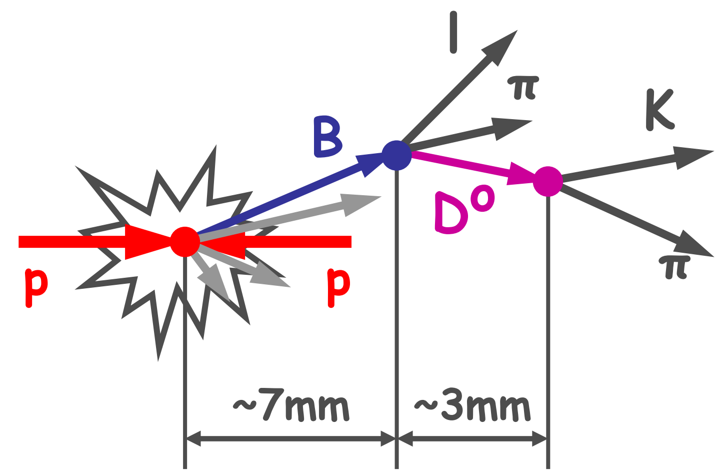
➔ Prompt charm : $c \rightarrow$ …



Order of magnitude higher wrt b-events
(generator suggests x7 at E_{CM}=14 TeV)

NB: D^+ travels ~1 cm !

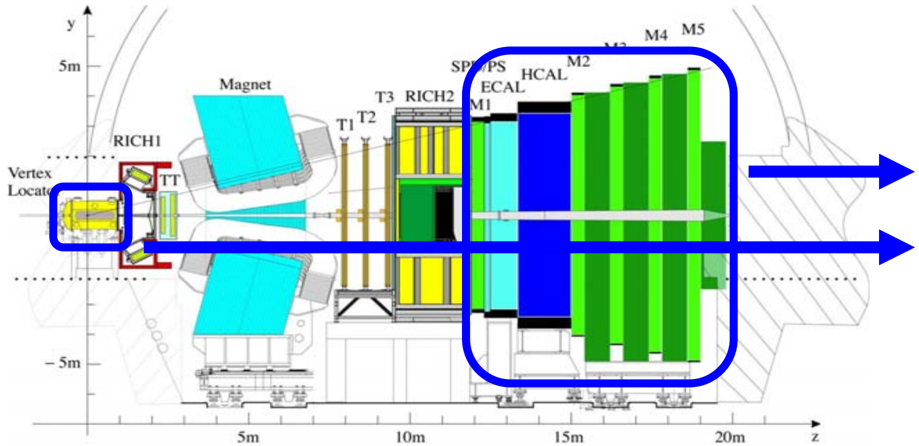
➔ LHCb optimised for *b*-physics
➔ Secondary charm : $b \rightarrow c \rightarrow$ …



x BR($B \rightarrow D^{*\pm}X$)~0.23
x BR($B \rightarrow D^0X$) ~0.63
x BR($B \rightarrow D^{\pm}X$) ~0.24

So far **complete** studies only for charm from b-decays → extrapolation to prompt charm

Crucial :
➔ **Vertex reconstruction**
➔ **Particle Id**
… **and TRIGGER**



10 MHz

L0 (hardware):
high p_T h, μ, μμ, $e^{\pm}$, γ, π^0 candidates
(optionally: veto busy events)

Fully synchr. (40 MHz), 4ms latency

1 MHz

HLT (PC farm, full event)

HLT1: confirms L0 candidate with tracker and VELO

HLT2: global event reconstruction, inclusive selections

~ 2 KHz

A plausible scenario

Output rate	Event type	Physics
200 Hz	Exclusive B candidates	B (core program)
600 Hz	High mass di-muons	J/ψ, b→J/ψX (unbiased)
300 Hz	D* candidates	Charm
900 Hz	Inclusive b (e.g., b → μ)	B (data mining)

➔ $D^{*\pm}$ sample, J/ψ sample, b→c→…

Expected $D^* \to D^0\pi$ samples

$D^{*\pm}$ trigger: $D^* \to D^0(hh)\,\pi$, **no RICH information**

➔ Sample for physics (after trigger and selection cuts) from b decays per 2 fb^{-1}

(Mixing and) CPV

- ➔ $D^0 \to K^-\pi^+$: 12.4M
- ➔ $D^0 \to K^-K^+$: 1.6M
- ➔ $D^0 \to \pi^-\pi^+$: 0.6M
- ➔ $D^0 \to K^+\pi^-$: 0.05M

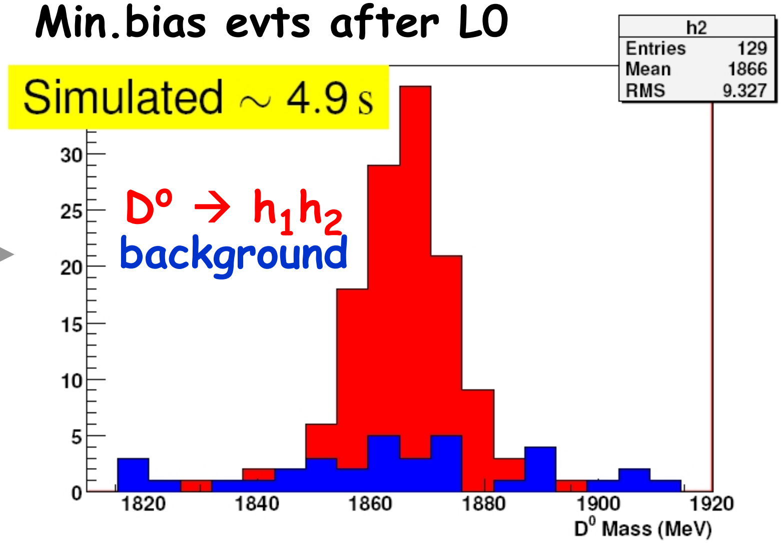
+ sample of prompt D mesons

- ➔ + $D^0 \to K_S\pi^+\pi^-$: ~20M ?
- ➔ + $D^0 \to K^+K^-\pi^+\pi^-$: ~few 100k ?

+ flavour tag from the D pion*

- ➔ + $D^+ \to K^+K^-\pi^+$: ~20M ?
- ➔ + ...

Min.bias evts after L0



2 fb^{-1} ➔
~18M triggered, selected flavour tagged KK

0.1 fb^{-1} ➔
~1M triggered, selected flavour tagged KK
~10M $K\pi$ events available for PID calibration

cf 0.11M KK events at BELLE with 540 fb^{-1}

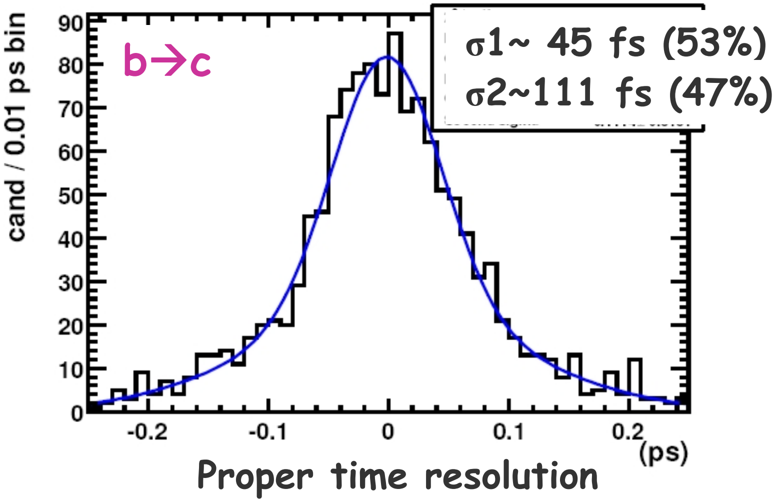
➔ **RICH calibration**

Below discussed only charm from b decays !

Mixing parameters from $D^0 \to K^+K^-$

- One of the most sensitive ways to access DD mixing

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1$$



- So far no single 5σ measurement
  E.g. Belle PRL 98 (2007) 211803 :
  y_{CP} = 1.31 ± 0.32 ± 0.25 %
- LHCb 2 fb^{-1} ($b \to c$): $y_{CP} \to \sigma_{stat}$ ~0.1%
  (prompt c): x 3 better ?
- LHCb 0.1 fb^{-1} (prompt c): $y_{CP} \to \sigma_{stat}$ ~0.15% ?

CPV from $D^0 \to K^+K^-$

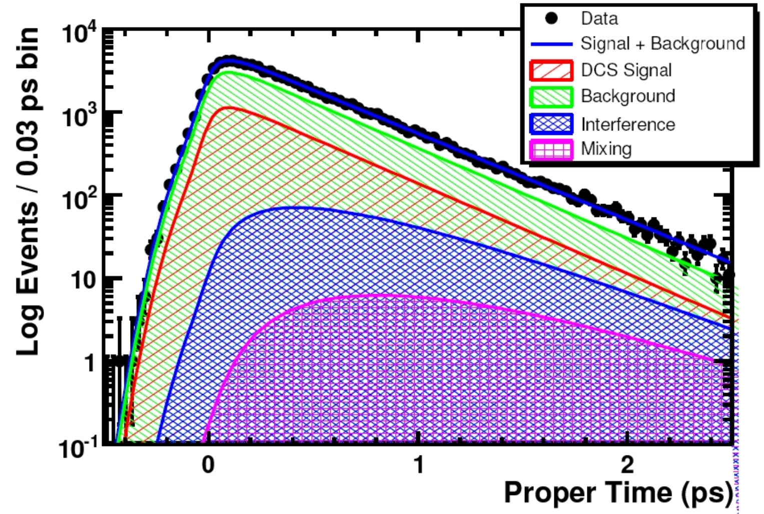
- CPV via A_Γ parameter:

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$

- $A_\Gamma \leq 10^{-3}$ in SM, up to 1% with NP
- HFAG 09: A_Γ ($D^0 \to K^+K^-$) = (-1.6 ± 2.3)x10^{-3}
- LHCb 2 fb^{-1} ($b \to c$): $A_\Gamma \to \sigma_{stat}$ ~1.1x10^{-3}
  (prompt c): x 3 better ?
- LHCb 0.1 fb^{-1} (prompt c): $A_\Gamma \to \sigma_{stat}$ ~1.6x10^{-3}

Mixing with the WS $D \to K\pi$

- Wrong sign: $dN_{ws}/dt \approx e^{-\Gamma t} \times \{ (x'^2+y'^2)/2 \cdot \Gamma^2 t^2/2 + D^2_{DCS} + D_{DCS} \cdot y' \cdot \Gamma t \}$
- Measures x'^2 and y'
- S/B ~ 0.4, input for the toy MC ➔
- LHCb 2 fb^{-1} ($b \to c$):
  - $x'^2 \to \sigma_{stat} \sim 1.4 \times 10^{-4}$
  - $y' \to \sigma_{stat} \sim 1.9 \times 10^{-3}$



cf:

Belle PRL 96 (2006) 151801 (400 fb^{-1}): $x'^2 = 0.018 \pm^{0.021}_{0.023}$ %

$y' = 0.06 \pm^{0.40}_{0.39}$ %

BABAR PRL 98 (2007) 211802 (384 fb^{-1}): $x'^2 = -0.022 \pm 0.030 \pm 0.021$ %

$y' = 0.97 \pm 0.44 \pm 0.31$ %

CDF PRL 100 (2008) 121802 (1.5 fb^{-1}): $x'^2 = -0.012 \pm 0.035$ %

$y' = 0.85 \pm 0.76$ %

CPV in $D^0 \to K^+K^-\pi^+\pi^-$ *Ongoing study*

- Also CSD decay, BR~10^{-3}, direct and indirect CPV ➔ Ikaros Bigi
- 4-body final state ➔ Additional observables: Dalitz analysis

CPV via T-odd correlations (*I.Bigi*)

$$\frac{d\Gamma}{d\phi} = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi.$$

T-odd angle Φ between the KK and $\pi\pi$ planes

$$A = \frac{\int_0^{\pi/2} d\phi \frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi \frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi \frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1 + \Gamma_2)}.$$

$A \neq 0$ can be caused by strong phases.

$$A_T^{CP} = \frac{1}{2}\left(A_T - \overline{A_T}\right) \propto \sin(\Phi_{weak}) \cos\left(\delta_{FSI,strong}\right)$$

Asymmetry of A for D and $\bar{D}$ ➔ true sign of T violation

➔ For $b \to D^* \to D^0 \to K^+K^-\pi^+\pi^-$: expect few x 10^5 x $\varepsilon_{trigger}$ with 2 fb^{-1} +prompt charm

BR for $D^0 \to K^+K^-\mu^+\mu^-$ *Ongoing study*

- $D_L \to K^+K^-\mu^+\mu^-$ - most direct analogue of $K_L \to \pi^+\pi^-e^+e^-$ ➔ Ikaros Bigi
- Can probe suppression mechanisms that can yield large A^T_{CP}
- BR~10^{-6}, for smaller BR, can be limited by decays in flight from $D^0 \to K^+K^-\pi^+\pi^-$

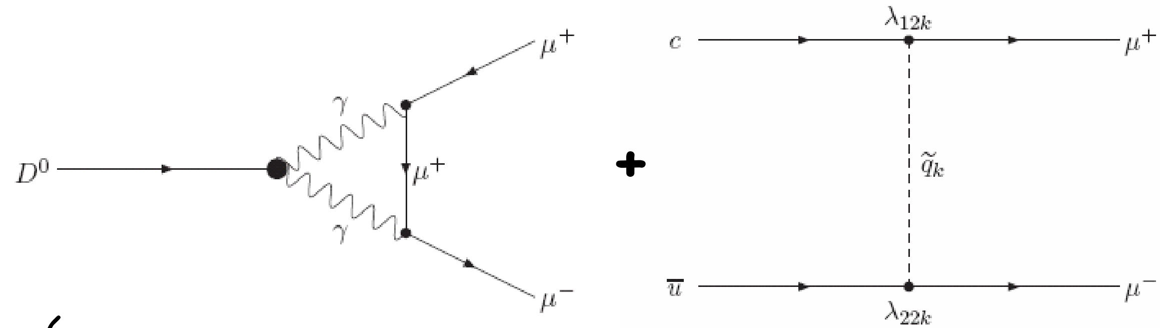
➔ For $b \to D^* \to D^0 \to K^+K^-\mu^+\mu^-$: expect few x 10^2 x $\varepsilon_{trigger}$ with 2 fb^{-1} +prompt charm

Rare decays

→ Alexey Petrov

D-decay	Comment	B topological analogue
$D^0 \to \mu\mu$	Sensitivity to some R-parity violating SUSY models, *G.Burdmann Phys.Rev. D66 (2002)*	$Bs \to \mu\mu$
$D^+ \to X^+ l^+ l^-$	Rate dominated by long distance resonance contribution at $m_{ll}=m_{\rho,\omega,\varphi}$ → measure m^2_{ll} spectrum at $m_{ll} \ll m_\rho$ and $m_{ll} \gg m_\varphi$	$B \to K^* l^+ l^-$
$D^0 \to V\gamma$	Long distance QCD » Up-type penguin	$B_{(S)} \to V\gamma$

$D^0 \to \mu\mu$



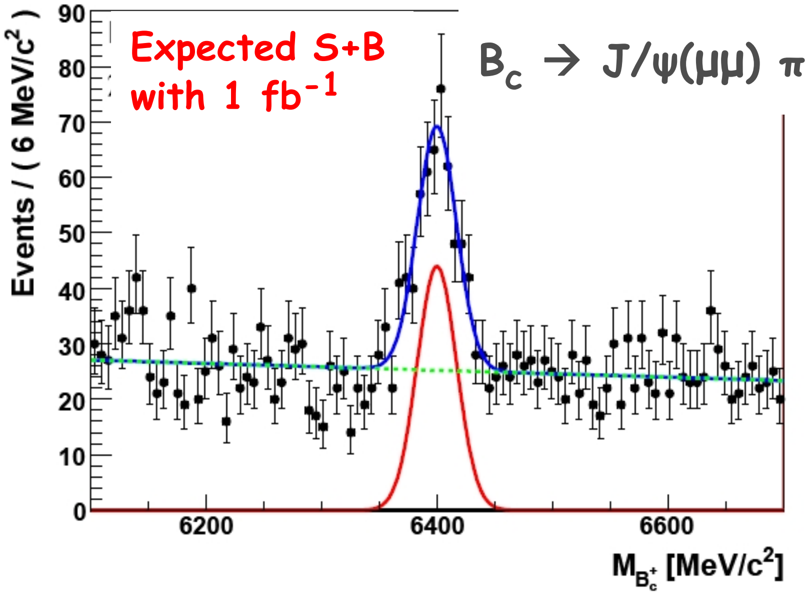
- $BR < 10^{-12}$ in SM, up to 10^{-6} with NP
- Best-to-date: CDF limit $BR < 4.7 \times 10^{-7}$ @90%CL with 360 pb^{-1}
- For $BR \sim 10^{-7}$ and **100 pb^{-1}** with **prompt** $D^0 \to \mu\mu$: >25 events

D_b^+: production, spectroscopy, mass, lifetime

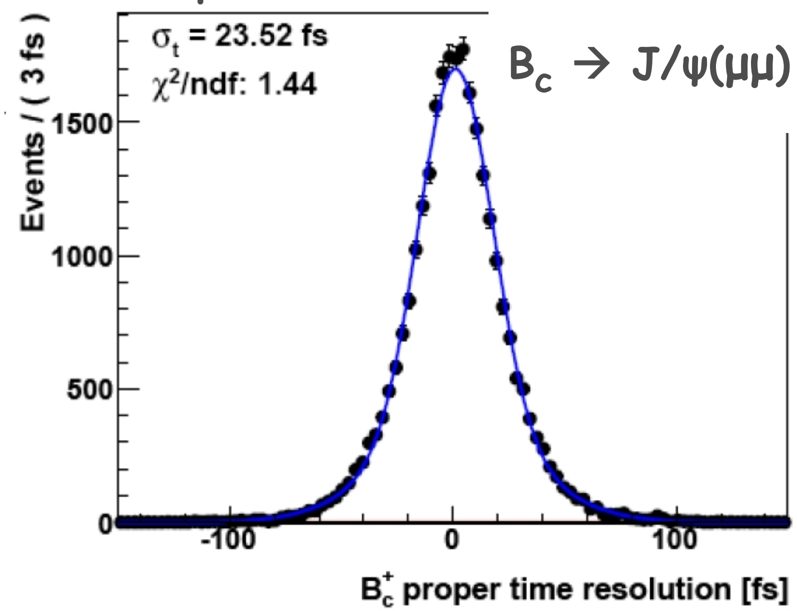
$\sigma(B_c^\pm) \sim 0.4\ \mu\text{b} \ @\ 14\ \text{TeV} \Rightarrow \sim 4 \times 10^8\ B_c^\pm/\text{fb}^{-1}$

$\sigma(B_c^\pm)_{\text{LHC}}/\sigma(B_c^\pm)_{\text{Tevatron}} \sim O(10)$

Mass resolution: σ~17 MeV/c^2



Proper time resolution: ~25 fs



With 1 fb^{-1}:

Mass measurement via $B_c \rightarrow J/\psi\pi$: ~310 events, $\sigma_{stat}(M)$ ~1.7 MeV/c^2

Best-to-date CDF: 108±15 events, M=6275.6±2.9±2.5 MeV/c^2 (2.4 fb^{-1})

Lifetime measurement via $B_c \rightarrow J/\psi\pi$: ~360 events, $\sigma_{stat}(\tau)$ ~0.027 ps

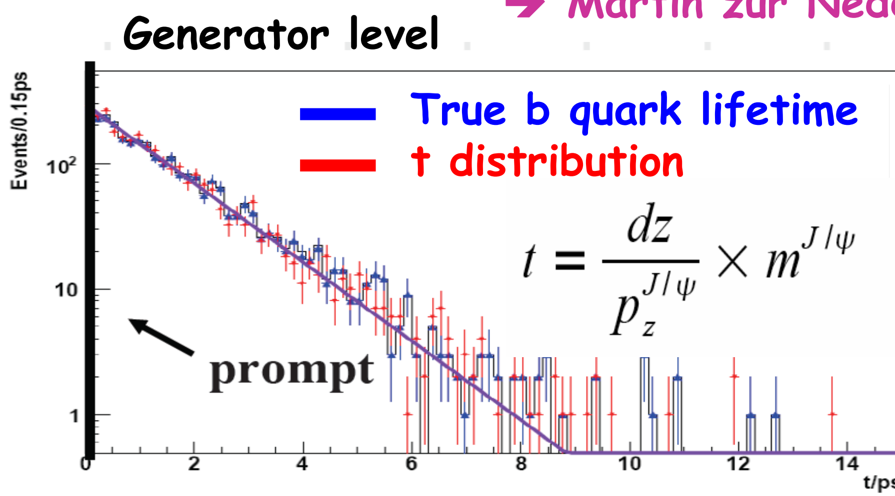
Best-to-date D0: 881±80 events, $\tau = 0.448^{+0.038}_{-0.036} \pm 0.032$ ps ($B_c \rightarrow J/\psi\mu X$, 1.3 fb^{-1})

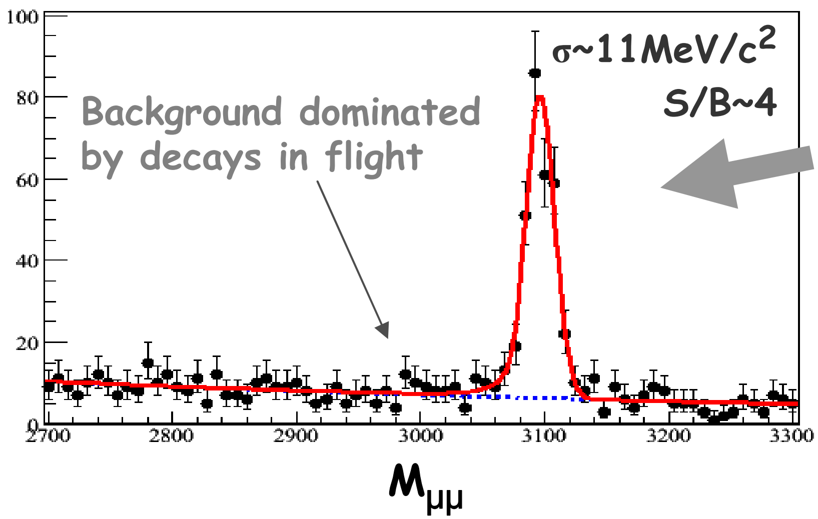
J/ψ, χ_c, … production

➔ Martin zur Nedden

- Unique (p_T,η) coverage
- Measure **prompt J/ψ** and **J/ψ from b-> J/ψ X** (BR = 1.16 ± 0.10 %) in bins of **η**, p_T and cosθ
- Luminosity measurement needed

  ➔ systematics





J/ψ signal (after L0) in 19M min bias evts [1.1 s of running @ nominal luminosity]

$\int Ldt$ ~5 pb^{-1} at E_{CM} = 8 TeV ➔ ~3.2M J/ψ

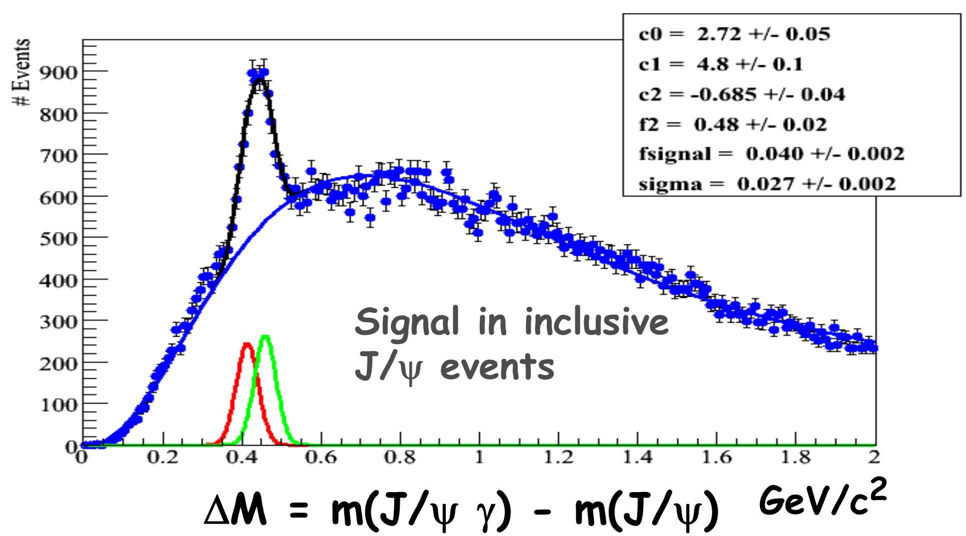
- ~30% **J/ψ** come **from** $\chi_{c1,2}$ [*Tevatron*]

➔ fraction of J/ψ from $\chi_{c1,2}$

➔ relative production $R\chi_c = \sigma(\chi_{c2})/\sigma(\chi_{c1})$

➔ σ_M ~ 27 MeV/c^2

cf $M(\chi_{c2})$-$M(\chi_{c1})$ = 55 MeV/c^2



Prompt production

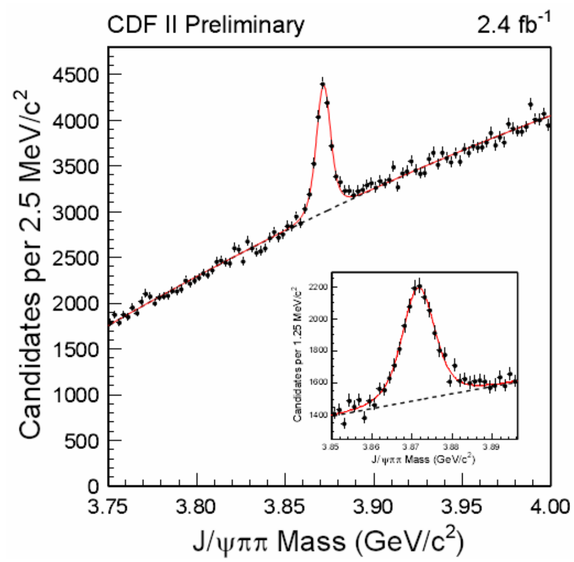
Ongoing study

Proof of power for hadron machine: **CDF**

LHCb : STATISTICS

Prompt production of X(3872) ~84% (at CDF)

Trigger on dimuons from primary vertex, with $m_{\mu\mu}$ around $m_{J/\psi}$ for X(3872),Y(4010),Y(4260) $\rightarrow J/\psi\pi\pi$, around $m_{\psi(2S)}$ for Y(4350),Y(4660) $\rightarrow \psi(2S)\pi\pi$



X,Y,Z from B decays

BR($B^+ \rightarrow K^+ X(3872) \rightarrow K^+ J/\psi\, \pi^+\pi^-$) ~ 8×10^{-6}

BR($B^0 \rightarrow J/\psi\, K^0_s \rightarrow J/\psi\, \pi^+\pi^-$) ~ 3×10^{-4}

Angular analysis to disentangle 1^{++} and 2^{-+}

➔ ~40 times less events for $B^+ \rightarrow K^+ X(3872)$ (~10k events/year)

Charged charmonium-like states from B decays

BR($\bar{B}^0 \rightarrow K^- Z^+(4430) \rightarrow K^- \psi(2S)\, \pi^+ \rightarrow K^- \mu^+ \mu^- \pi^+$) ~ 3×10^{-7}

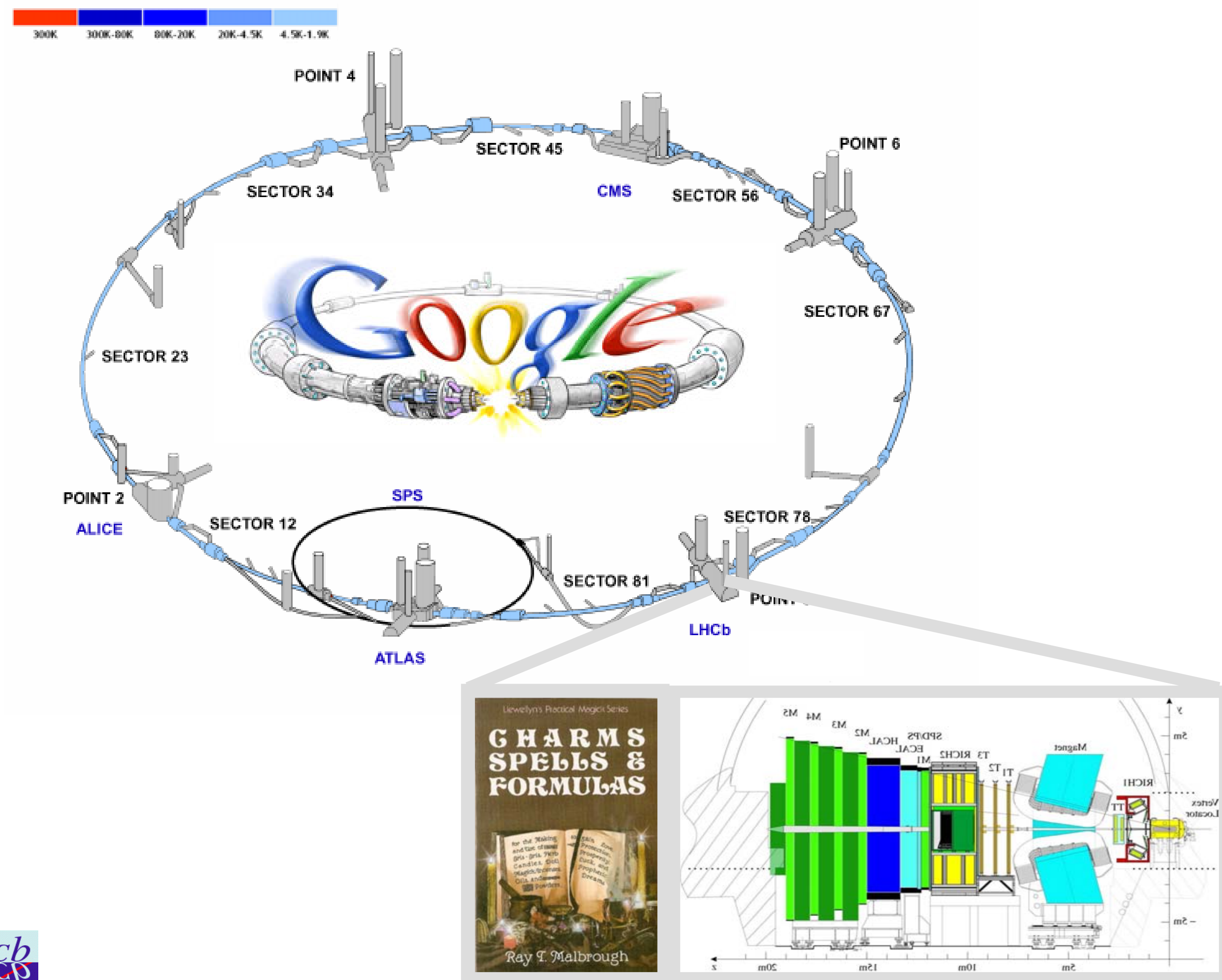
BR($B^0 \rightarrow J/\psi\, K^0_s \rightarrow J/\psi\, \pi^+\pi^- \rightarrow \mu^+ \mu^- \pi^+ \pi^-$) ~ 1.7×10^{-5}

➔ ~60 times less events for $B^+ \rightarrow K^- Z^+(4430)$ (~10k events/year)

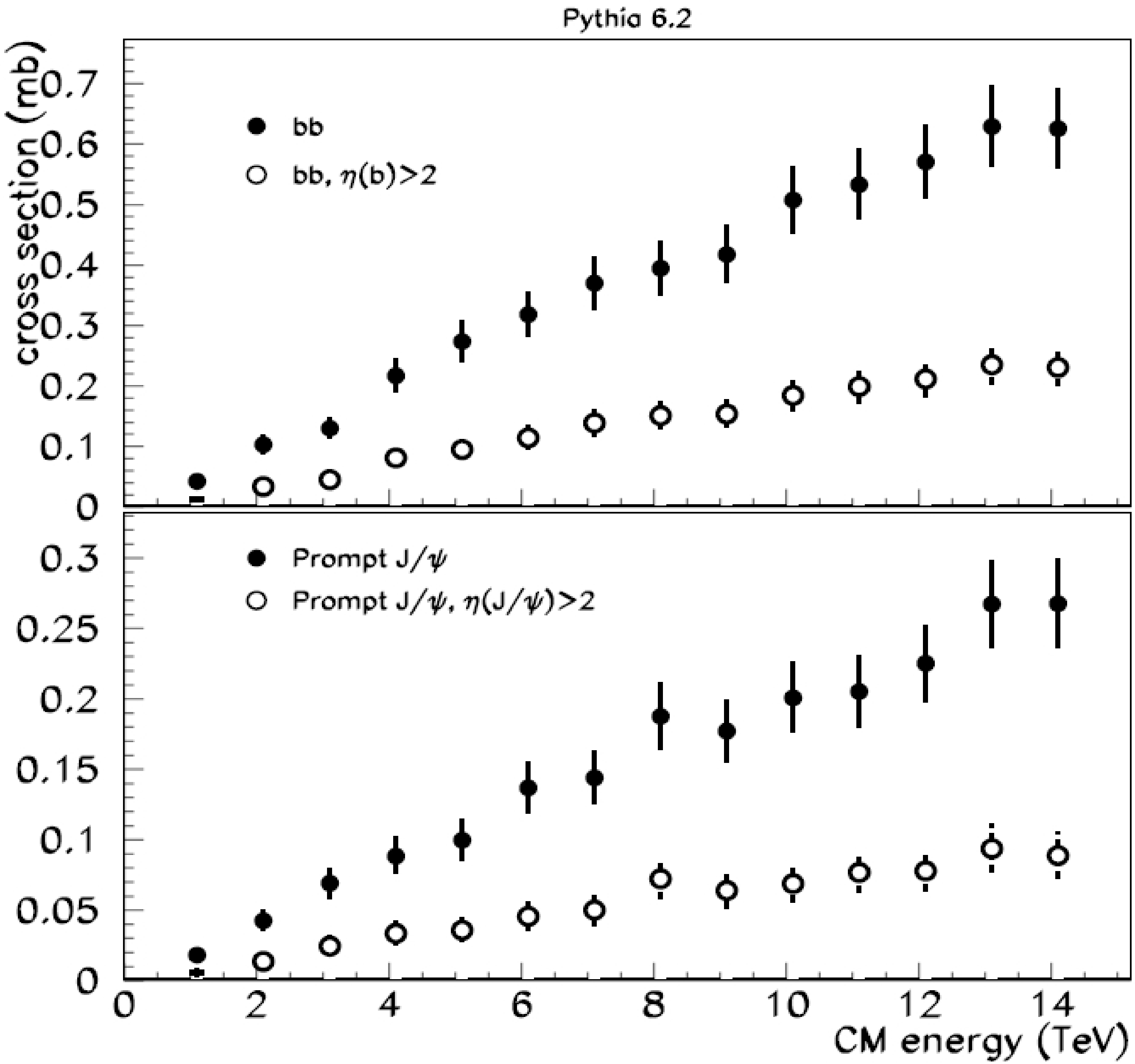
- 2009/2010 is expected to be machine-dependent
- Run at reduced CM energy (8-10 TeV ?)
- 50ns bunch scheme ➔ reduced spill-over
- Expect # of *pp* interactions / BX stable from the start-up onwards ➔ Lumi ~ #bunches
- **Fill ~2 kHz from day 1.**

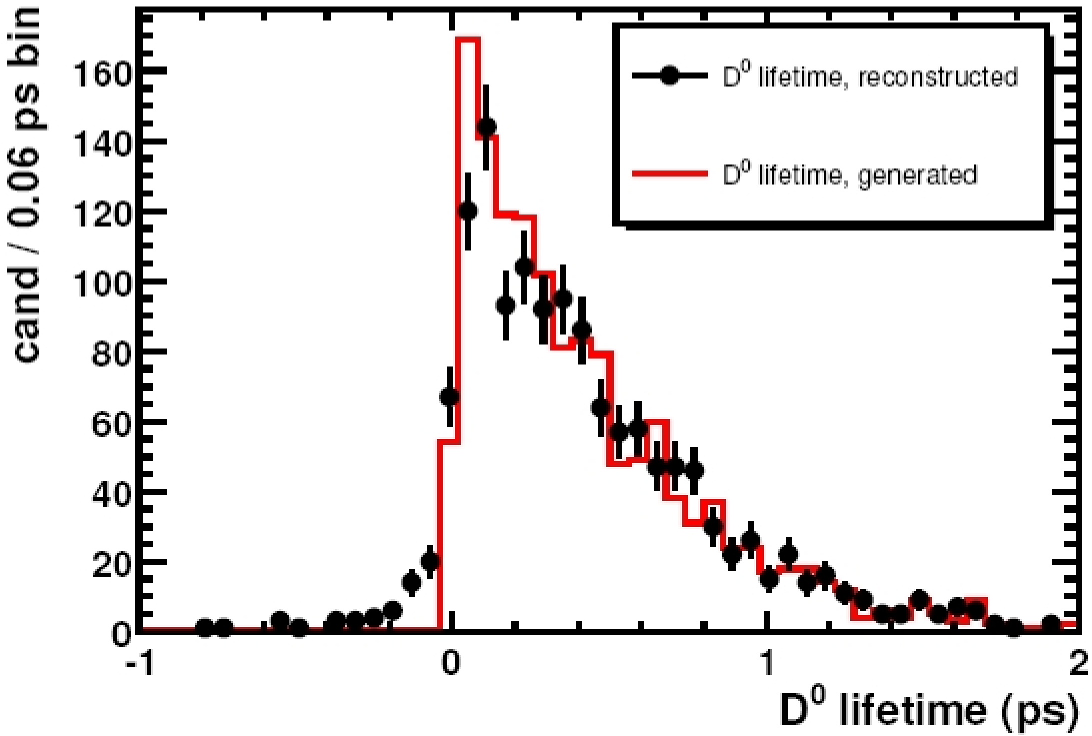
1. **Charm appetizer** Small # of bunches, min. bias running ➔ collect 2 x 10^8 events in ~100h ➔ unbiased events, MC tuning, flavour production (2k reconstructed J/ψ)
2. **Charm antipasti** More bunches ➔ Trigger focusing on J/ψ-containing events $\int Ldt \sim 5\ pb^{-1}$ ➔ ~3M J/ψ
   ➔ prompt vs. detached J/ψ; proper time resolution; prompt J/ψ cross-section; J/ψ polarization; $\chi_{c1,2}$, ψ(2S) production; X(3872); …
3. **Charm pasta** $\int Ldt \sim 100\ pb^{-1}$ ➔ "golden" time for charm studies, large number of signal events for majority of the channels
4. **Charm dessert** $\int Ldt \sim 2\ fb^{-1}$ → 2010/2011

We are looking forward to the LHC machine in blue again …



Back-up

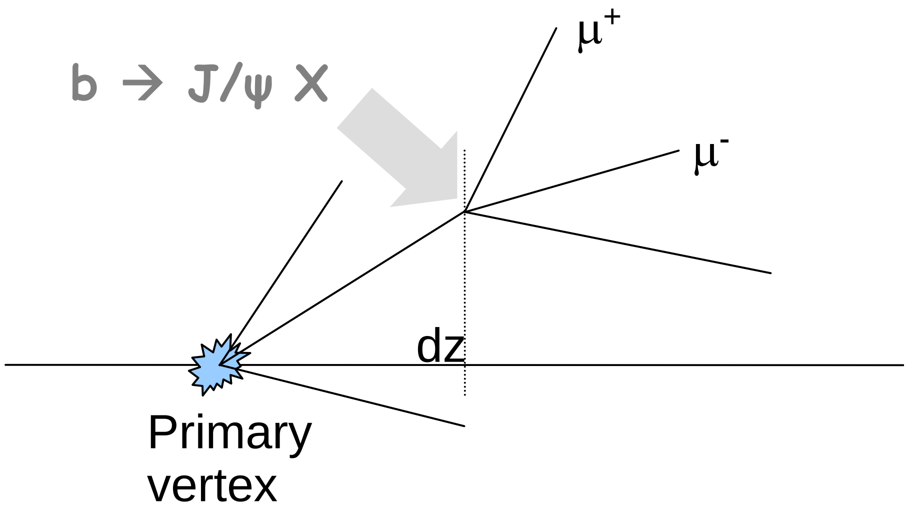

Pythia 6.2
cross section (mb)
bb
bb, η(b)>2
Prompt J/ψ
Prompt J/ψ, η(J/ψ)>2
CM energy (TeV)


cand / 0.06 ps bin
160
140
120
100
80
60
40
20
0
-1
0
1
2
D0 lifetime (ps)
D0 lifetime, reconstructed
D0 lifetime, generated

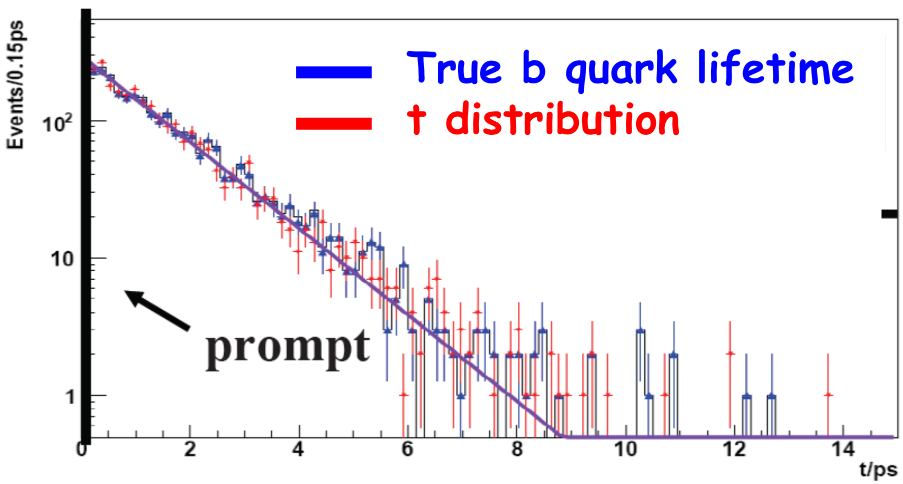
- New pseudo-rapidity region, up to ~6, unique (p_T,η) coverage
- Main problem: to distinguish A) prompt J/ψ and
  B) J/ψ from b-> J/ψ X (BR = 1.16 ± 0.10 %)
- Discriminating variable (simple approximation of b quark proper time):

$$t = \frac{dz}{p_z^{J/\psi}} \times m^{J/\psi}$$

- Measure A) and B) in bins of η, p_T and cosθ



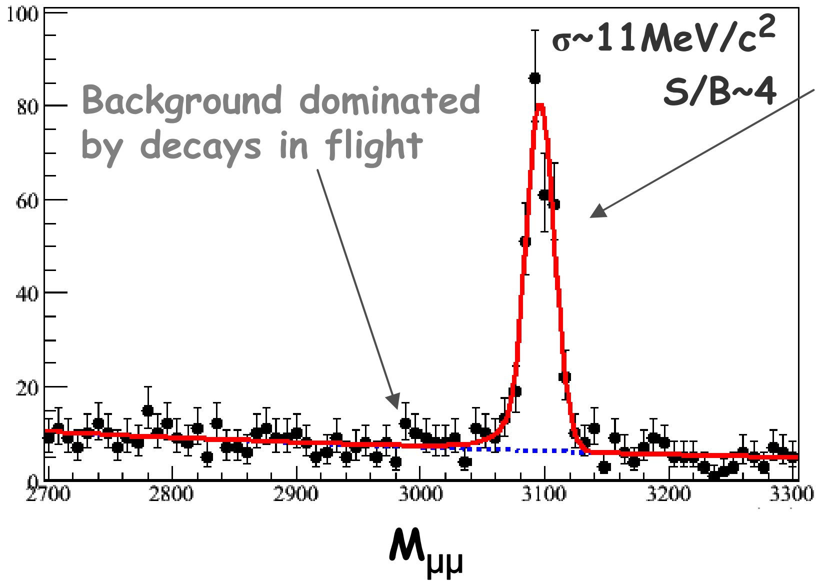
Generator level



- Luminosity measurement needed
  ➔ systematics (and also acceptance, polarization, BR, t model, …)

J/ψ production

- Two μuons (μ-π separation, ε~90%, mis-ID rate 1.4%) forming a common vertex
- For one track p_T > 1.5 GeV/c.



J/ψ signal (after L0) in 19M min bias evts [1.1 s of running @ nominal luminosity]

$\int L dt$ ~5 pb^{-1} at E_{CM} = 8 TeV ➔ ~3.2M J/ψ

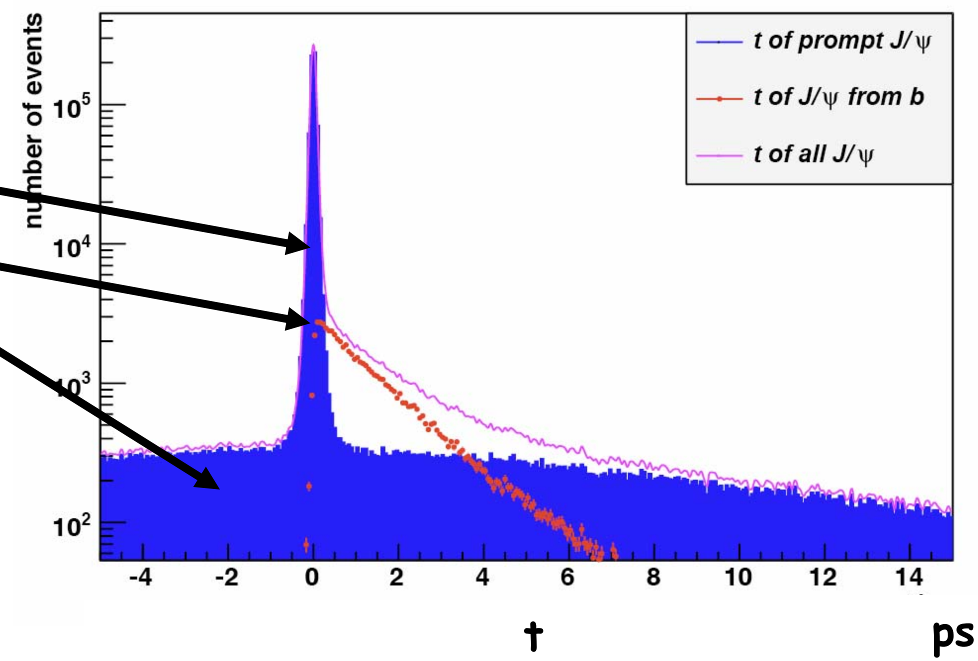
E.g. for 2<η<3: 40k with pT > 10 GeV/c
380k with 2 GeV/c < pT < 3 GeV/c

prompt J/ψ

J/ψ from b

Long tail due to association to wrong PVx [measure using the J/ψ Vx and the PVx in different event]

Prompt background [extract from mass sidebands]



χ_c production

~30% of J/ψ come from $\chi_{c1,2} \rightarrow J/\psi\ \gamma$ [*Tevatron*]

Important observables: ➔ fraction of J/ψ from $\chi_{c1,2}$,

➔ relative χc production $R\chi_c = \sigma(\chi_{c2}) / \sigma(\chi_{c1})$

J/ψ + photon, pt > 500 MeV

Signal modelled as two Gaussians

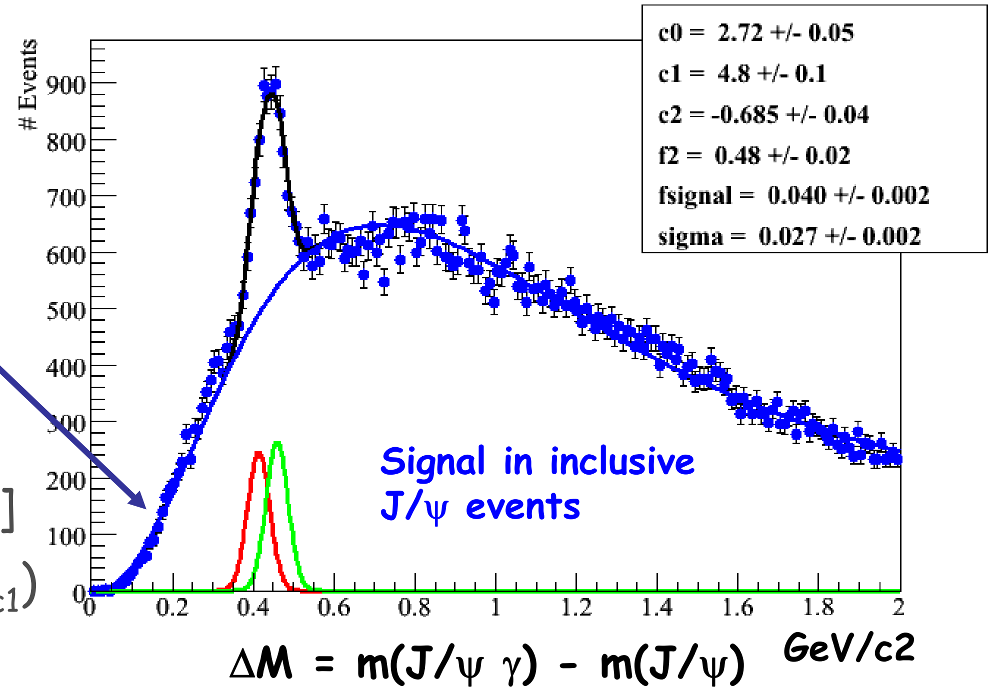
Background:

$$P(m) = (m - m_r)^{c0} \cdot exp(-c1 \cdot m - c2 \cdot m^2)$$

➔ σ_M ~ 27 MeV/c2

[cf $M(\chi_{c2})-M(\chi_{c1})$ = 55 MeV/c2]

➔ Some sensitivity to ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$



$\psi(2S)$ production and polarization

➔ Measurement of $\sigma(\psi(2S))/\sigma(J/\psi)$ very clean [most systematics cancel]