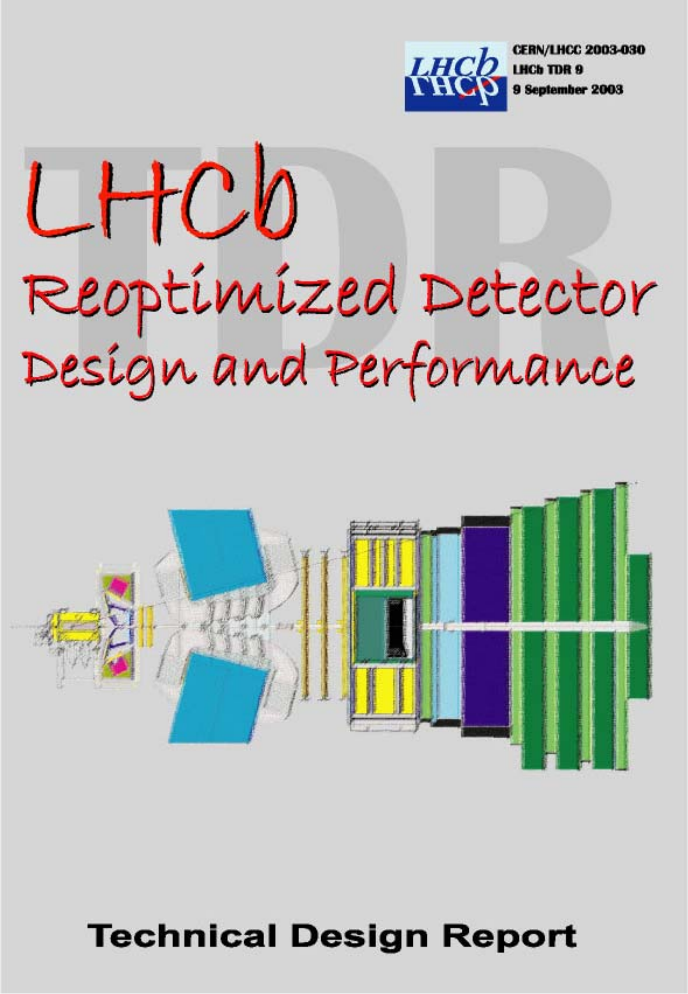
LHCb: Reoptimized Detector & Tracking Performance


CERN/LHCC 2003-030
LHCb TDR 9
9 September 2003

TDR

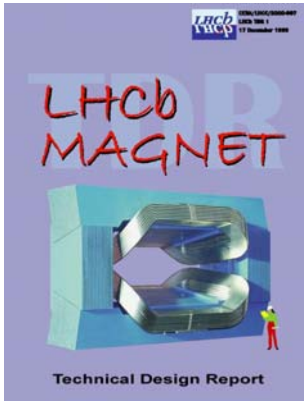
LHCb
Reoptimized Detector
Design and Performance

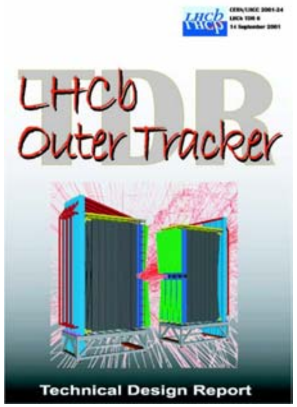
Technical Design Report

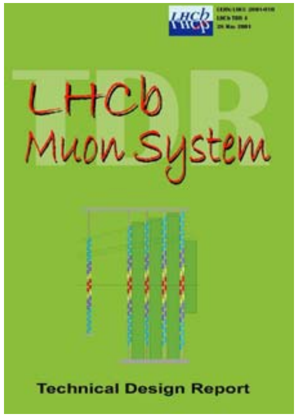
Gerhard Raven
NIKHEF and VU, Amsterdam
Representing
the LHCb collaboration

Beauty 2003,
Carnegie Mellon University,
Oct 14-18,
Pittsburgh, PA, USA

The LHCb collaboration has completed all the “detector” TDR’s







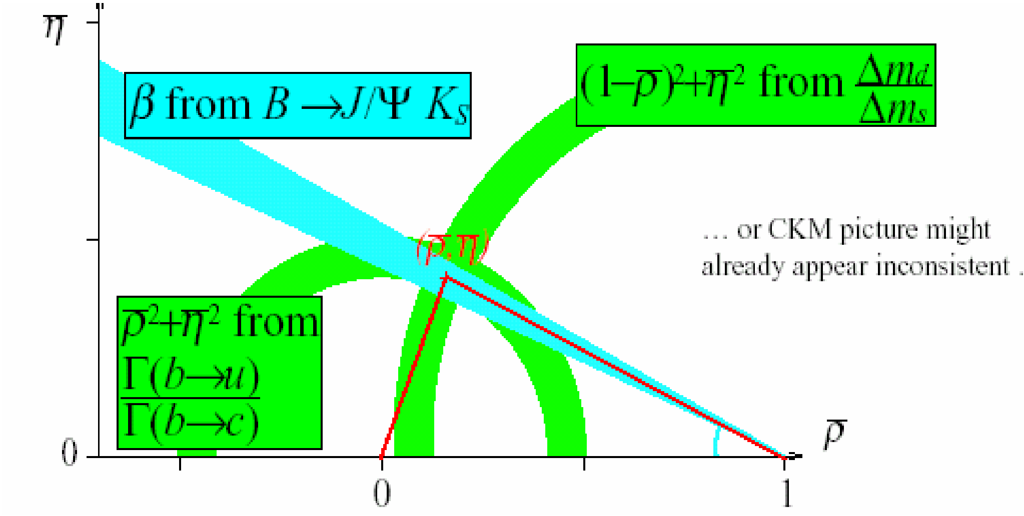
- Feb 1996: *LHCb* Letter of Intent
- Sep 1998: Technical Proposal approved
- 2000—2002:Technical Design Reports of all detector subsystems
- Sep 2003: LHCb re-optimization & Trigger TDRs
- Remaining: Computing TDR (next year)

B Physics in 2007

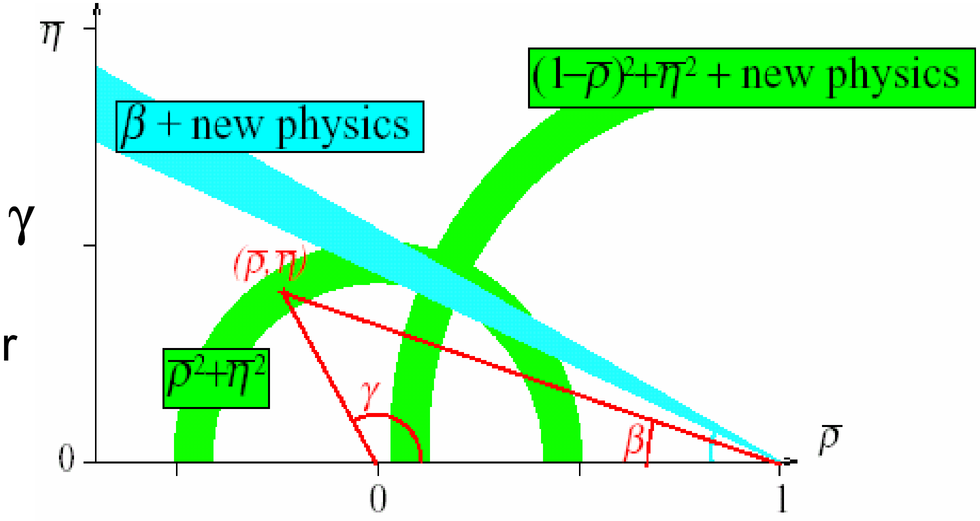
- Direct Measurement of angles:
  - $\sigma(\sin(2\beta)) \approx 0.03$ from $J/\psi\ K_s$ in B factories
  - Other angles not precisely known
- Knowledge of the sides of unitary triangle:

  (Dominated by theoretical uncertainties)
  - $\sigma(|V_{cb}|) \approx$ few % error
  - $\sigma(|V_{ub}|) \approx$ 5-10 % error
  - $\sigma(|V_{td}|/|V_{ts}|) \approx$ 5-10% error

    (assuming Δm_s observed)
- In case new physics is present in mixing, independent measurement of γ can reveal it…
- See Ulrich Uwer's talk on Saturday for 3 separate examples of the determination of γ at LHCb (2 of which require B_s mesons…)



… or CKM picture might already appear inconsistent .



B Physics @ LHC

$\sqrt{s}$	14 TeV
L	$2\text{x}10^{32}$ cm^{-2} s^{-1}
σ_{bb}	500 μb
σ_{inel} / $\sigma_{b\bar{b}}$	160

☺ Large $b\bar{b}$ production cross section:

10^{12} $b\bar{b}$/year at $2\text{x}10^{32}$ $\text{cm}^{-2}\text{s}^{-1}$

😐 Triggering is an issue

☺ All b hadrons are produced:

B_u (40%), B_d(40%), B_s(10%),

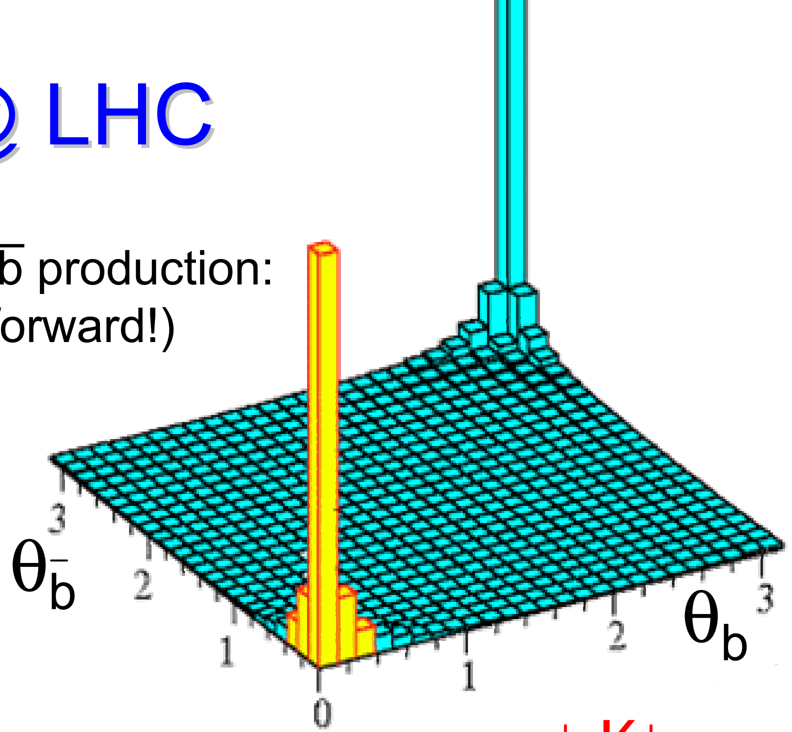
B_c and b-baryons (10%)

☺ Many tracks available for primary vertex

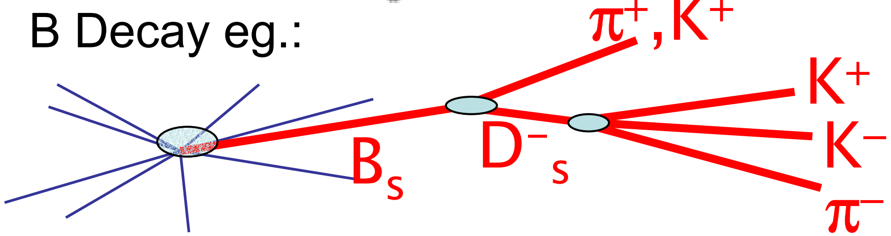
☹ Many particles not associated to b hadrons

☹ b hadrons are not coherent: mixing dilutes tagging

$b\bar{b}$ production:
(forward!)



B Decay eg.:



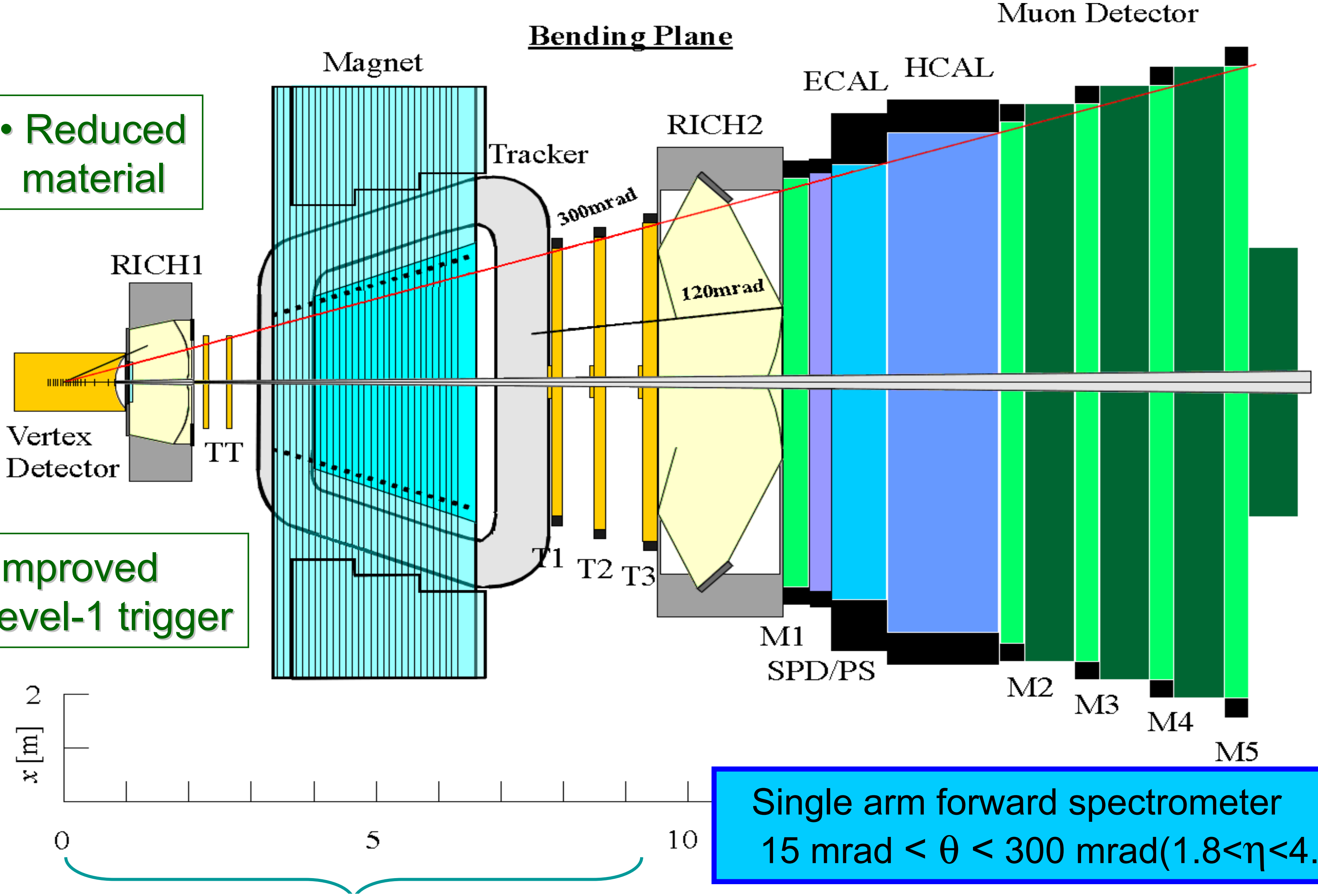
LHCb: Forward Spectrometer with:

- Efficient trigger and selection of many B meson decay final states
- Good tracking and Particle ID performance
- Excellent momentum and vertex resolution
- Adequate flavour tagging

Evolution since Technical Proposal

- Reduced material

- Improved level-1 trigger



Single arm forward spectrometer
15 mrad < θ < 300 mrad(1.8<η<4.9)

X_o:40%

20%→12%

Monte Carlo Generation

σ_{total} = 100 mb
$\sigma_{visible}$ = 65 mb

- pp interactions
  - Minimum bias events from PYTHIA 6.2
    - Hard QCD processes, single and double diffraction
    - Multiple parton interactions tuned to reproduced track multiplicities observed at SPS and Tevatron energies
  - bb events
    - Extracted from minimum bias sample

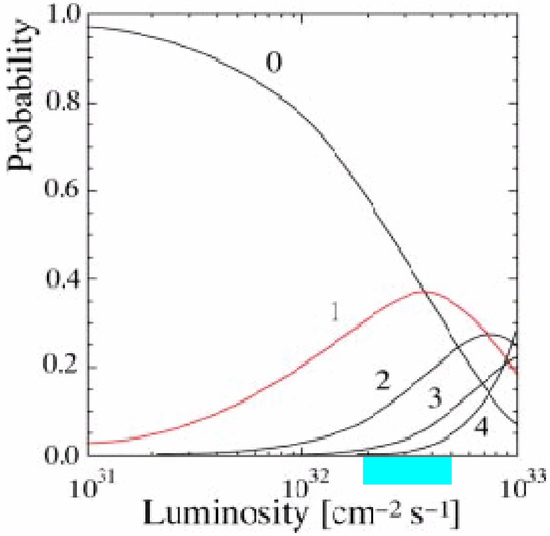
$\sigma_{bb}/\sigma_{visible}$ = 0.8%

- bunch crossings in LHCb
  - Size of luminous region
  - Simultaneous pp interactions ("*pileup*")
    - number of visible interactions n (in events with at least one) distributed according to $L = 2 \times 10^{32}\ \text{cm}^{-2}\ \text{s}^{-1}$, $\langle\nu\rangle$ = 30 MHz

$\sigma_x = \sigma_y$ = 70 μm, σ_z = 5 cm

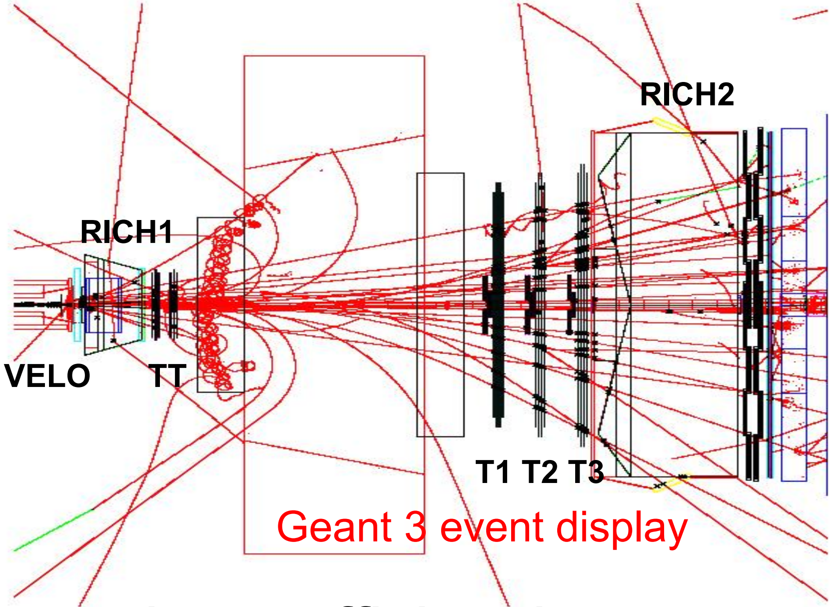
At least two tracks reconstructible in whole spectrometer

$\langle n\rangle_{\text{bb event}}$ = 1.42



Simulation and Reconstruction

- Full GEANT 3.2 simulation
  - Complete description from TDRs
- Detector response
  - Based on test-beam data (resolution, efficiency, noise, cross-talk)
  - *Spill-over* effects included (25 ns bunch spacing)

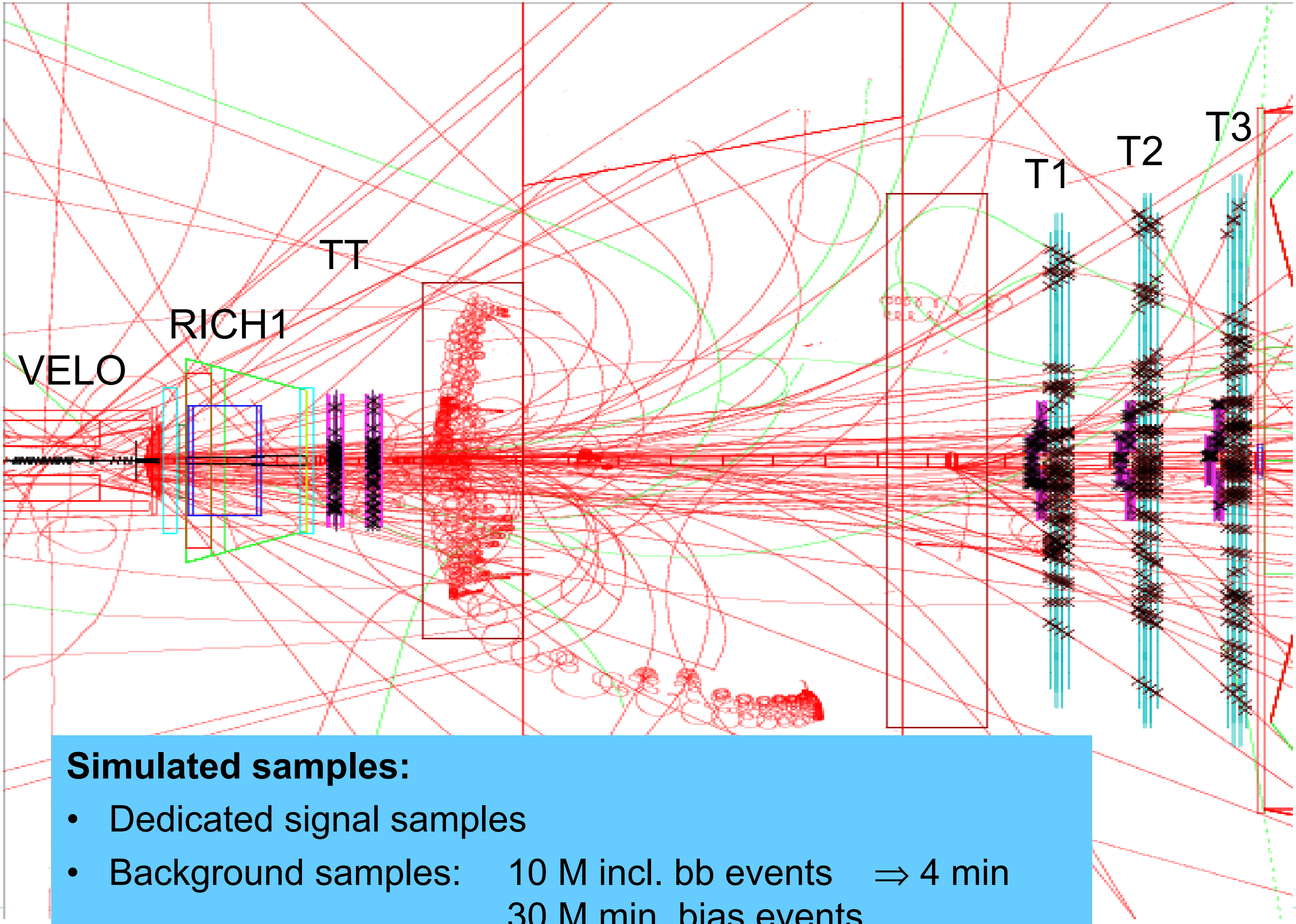


Geant 3 event display

- Trigger simulation
  - thresholds tuned to get maximal signal efficiencies at limited output rates of 1 MHz (L0) and 40 kHz (L1)
  - No full HLT simulation (yet)
- Offline reconstruction
  - Full pattern recognition (track finding, RICH reconstr. …)

No true MC info used anywhere!

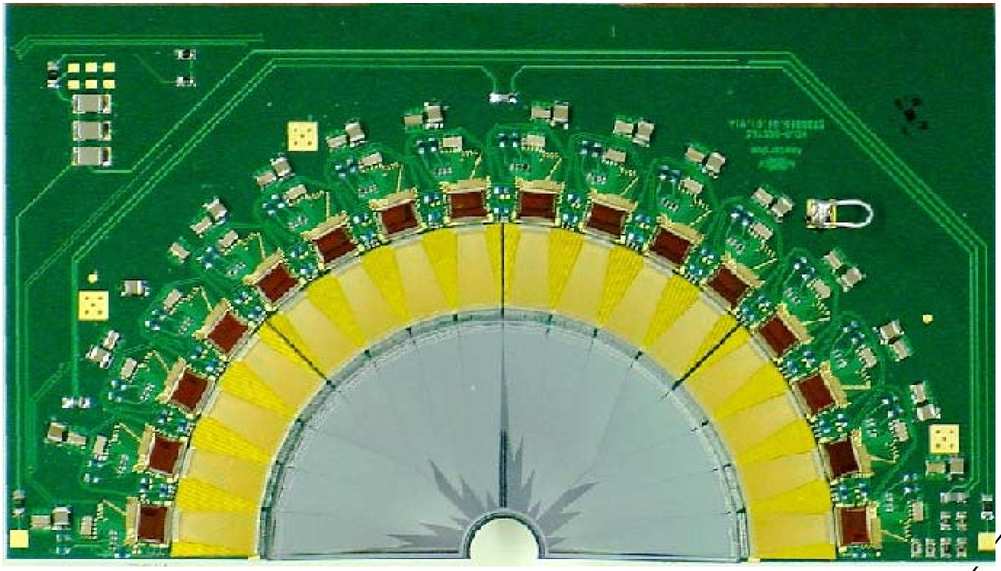
Simulation and Reconstruction

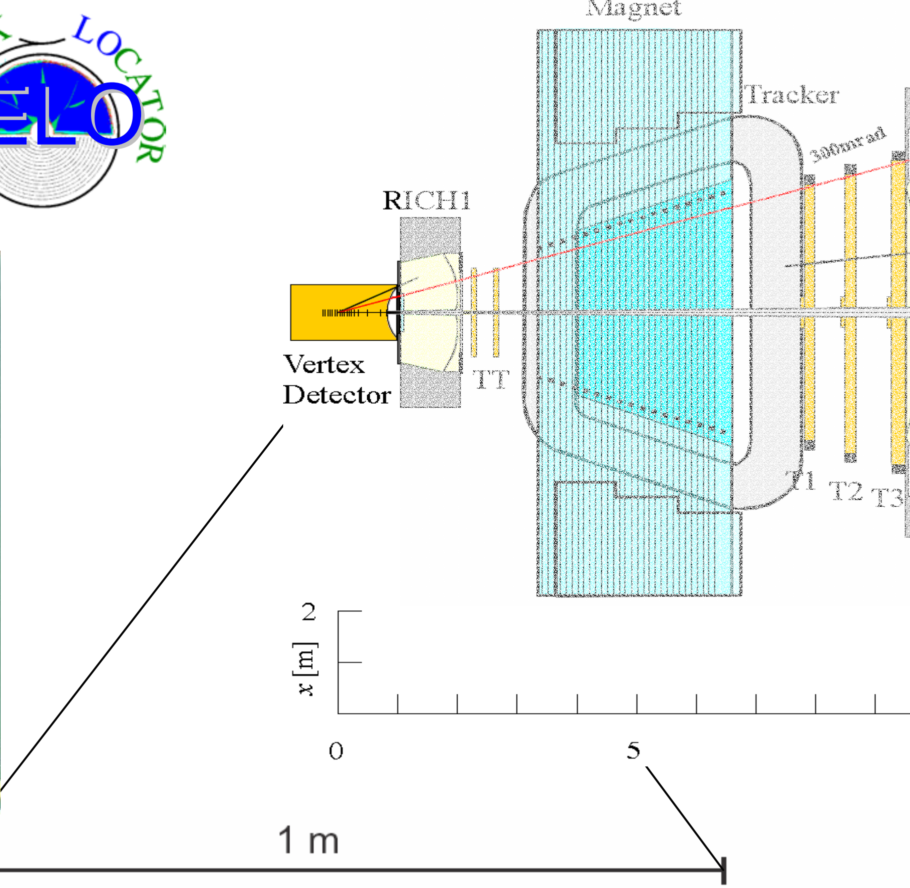


Simulated samples:

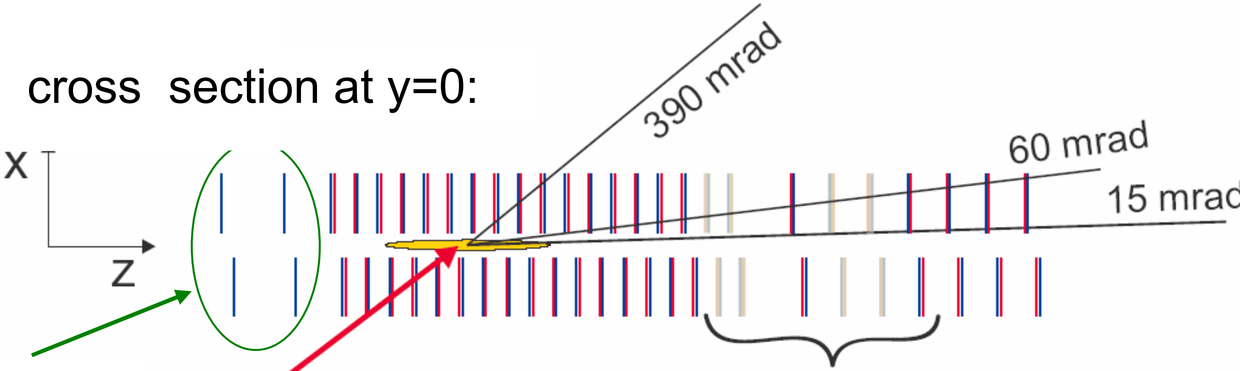
- Dedicated signal samples
- Background samples: 10 M incl. bb events ⇒ 4 min
  30 M min. bias events

Tracking Detectors: VELO





cross section at y=0:



Pile-Up Stations

Interaction Region
σ=5.3 cm

not required for LHCb acceptance coverage

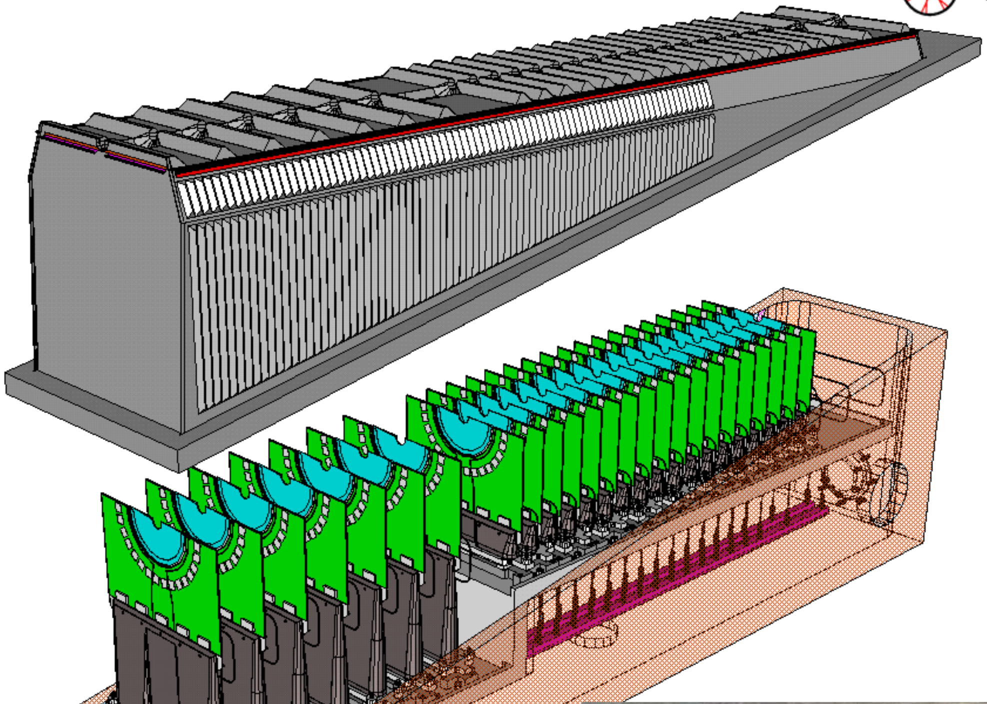
21 Stations, back-to-back

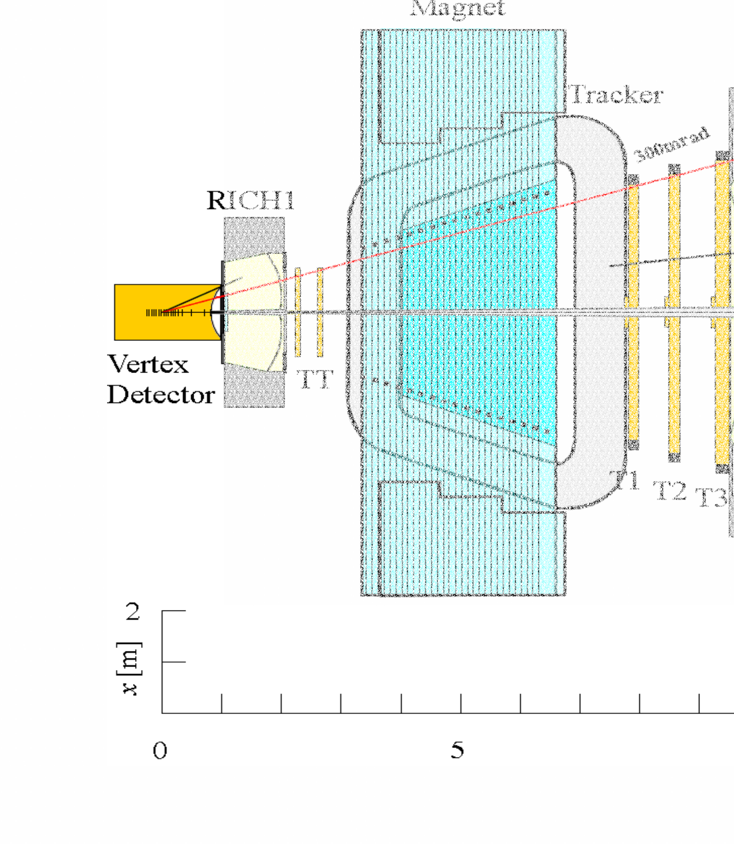
R and ϕ sensors

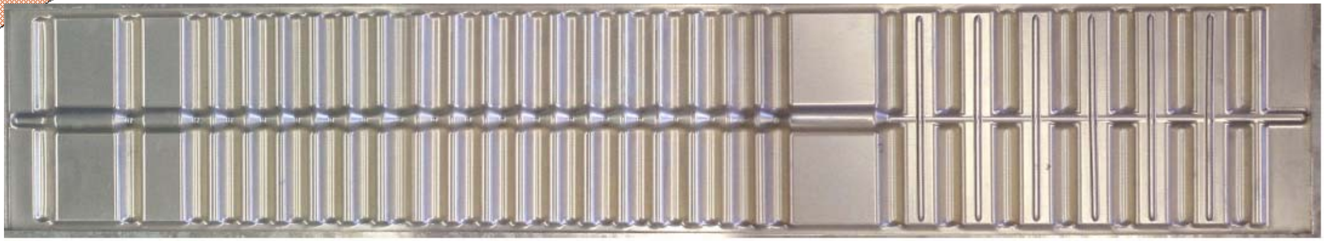
220 μm thin silicon

180K channels

Tracking Detectors:



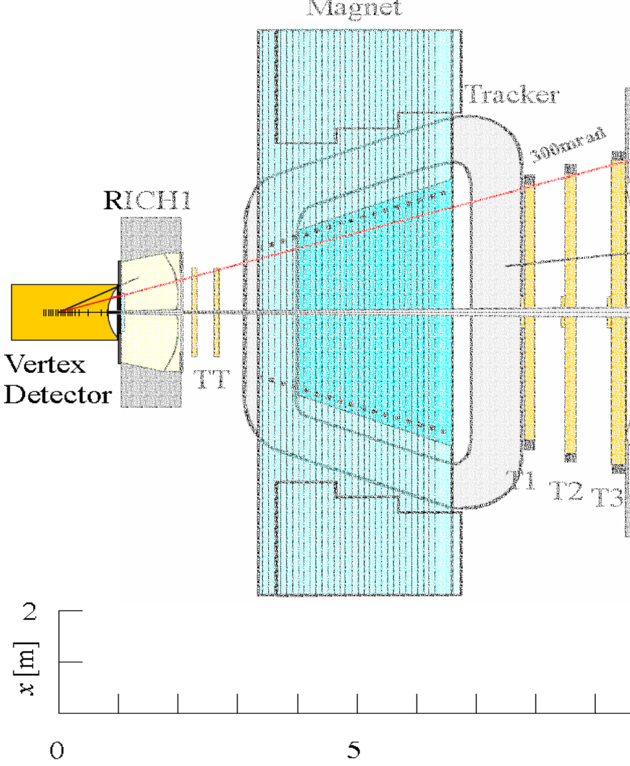


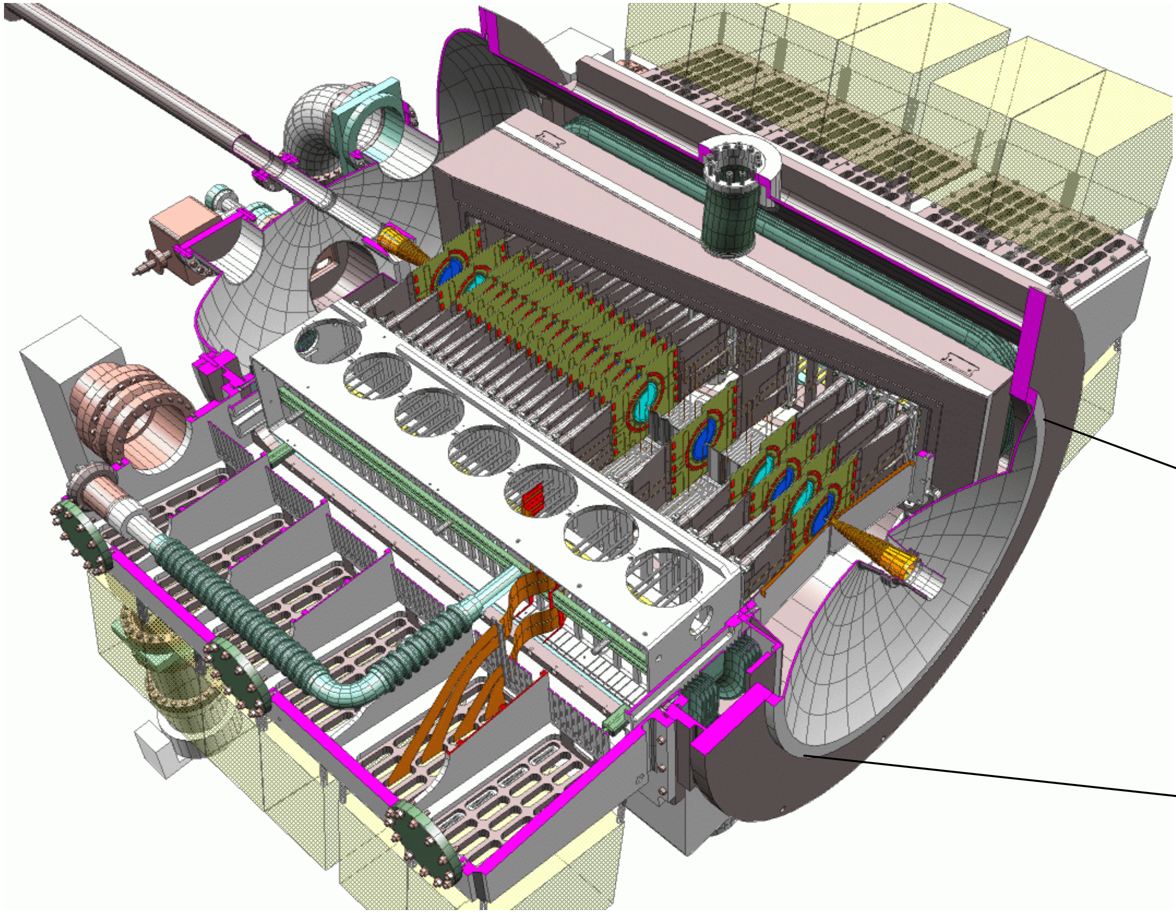


- Sensors are located in 2^{dary} vacuum
- Seperated from beams by RF foil (300 μm Al+3%Mg)
- Retractable during injection

Tracking Detectors:

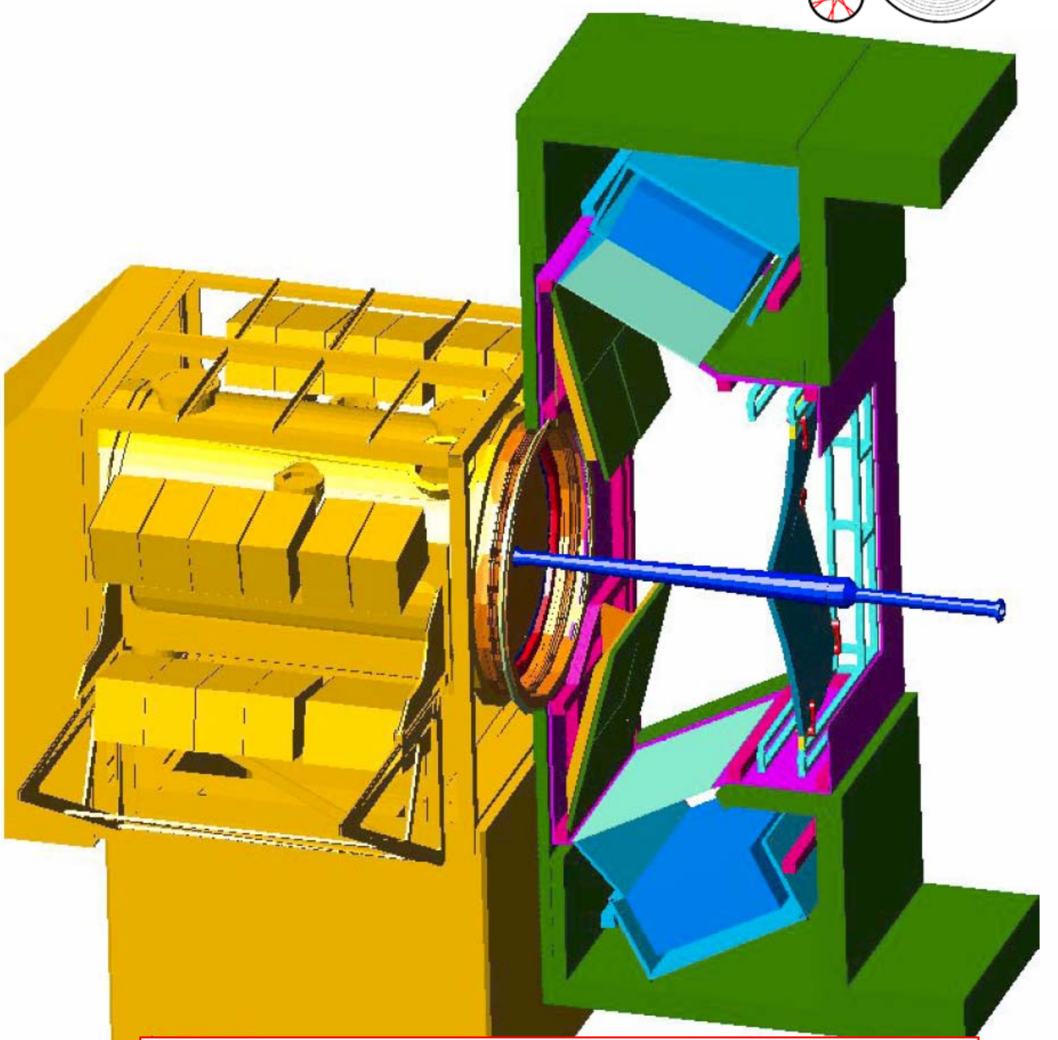
VELO is mounted on movable x-y tables
to stay (actively) centered around the beam

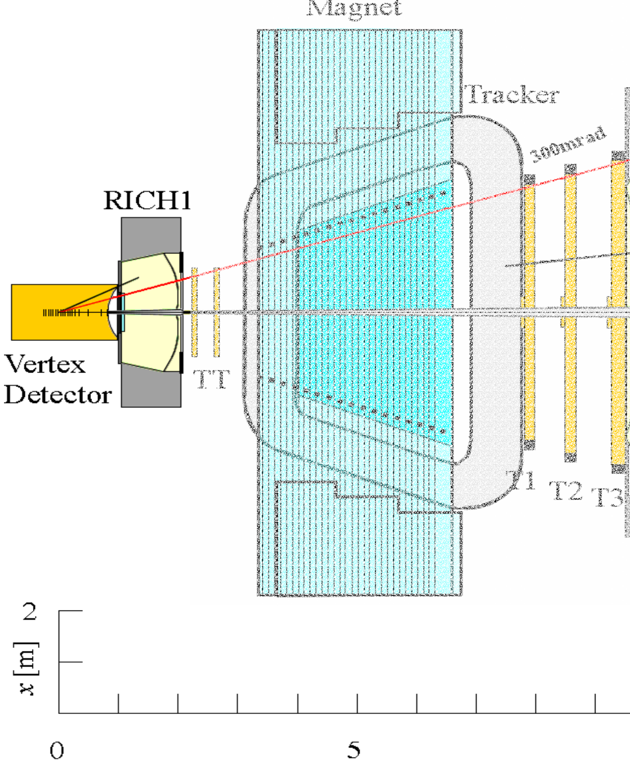




Al exit window

Tracking Detectors:



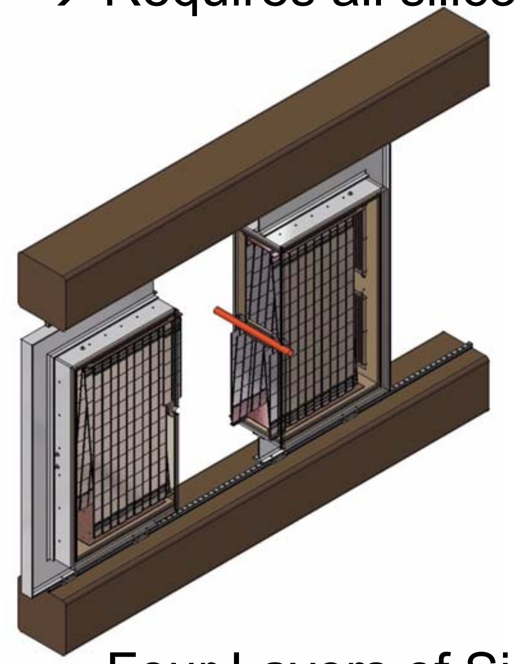



Al exit window

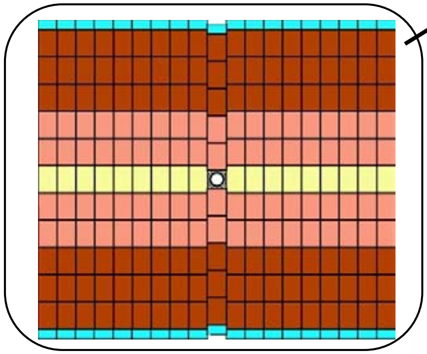
Exit window of VELO is also entry window of RICH-1

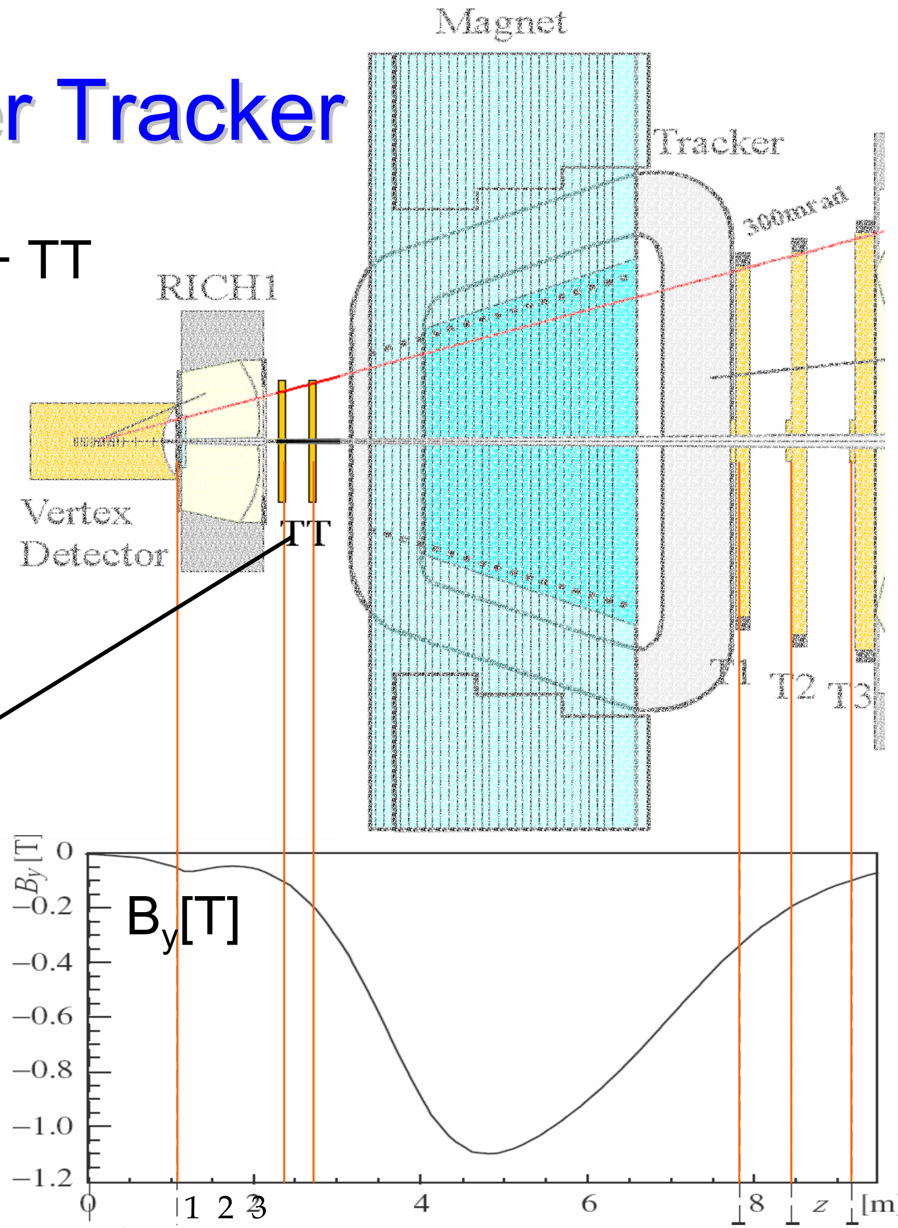
Tracking Detectors: Trigger Tracker

Magnet field (0.15 Tm) between VELO + TT
allows initial momentum estimate
of high IP tracks in Level-1 trigger
→ Field constraint by RICH1 shielding
→ Requires all silicon detector…



~1.4×1.2 m²

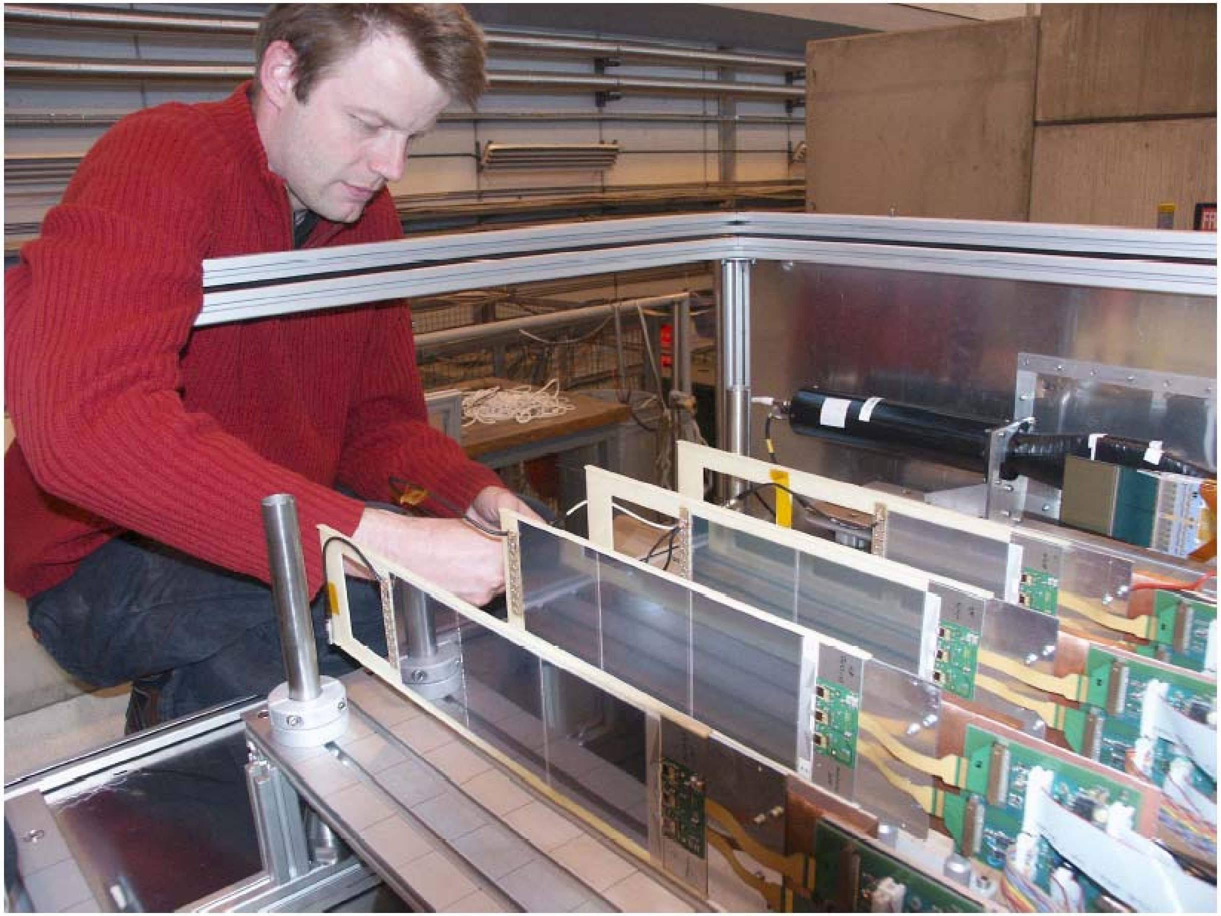


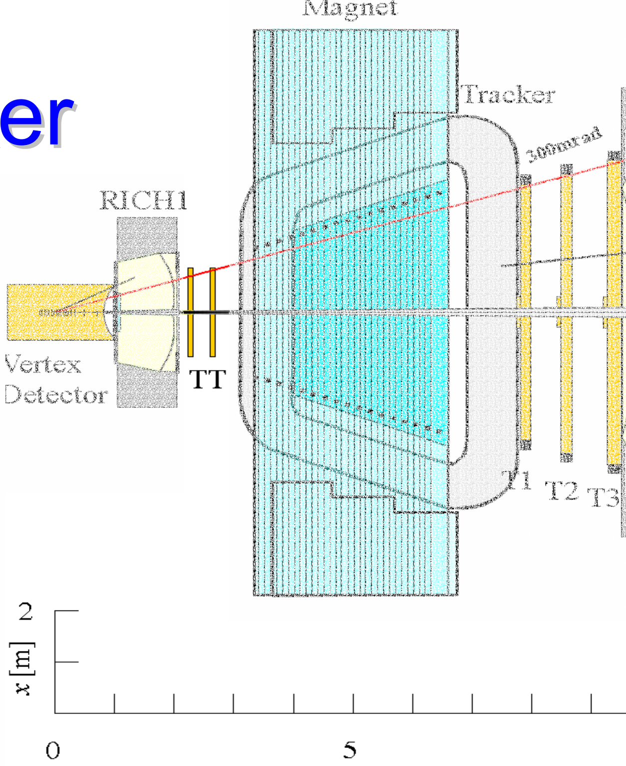


0.15 Tm

Four Layers of Si strip detectors
two stations: Vertical, +5° ; -5°, Vertical
Total area of Si: 8.3 m²

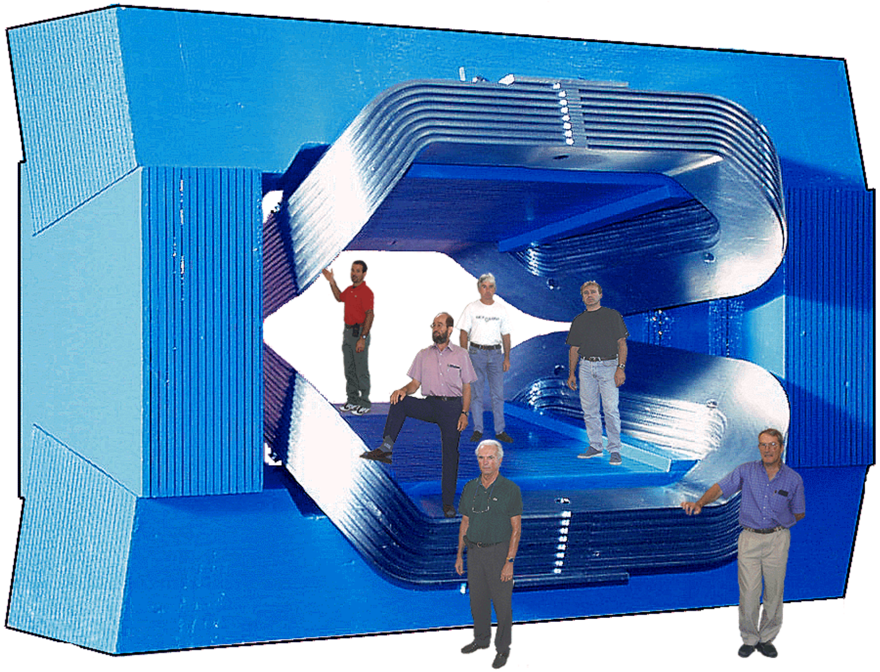
Tracking Detectors: Trigger Tracker

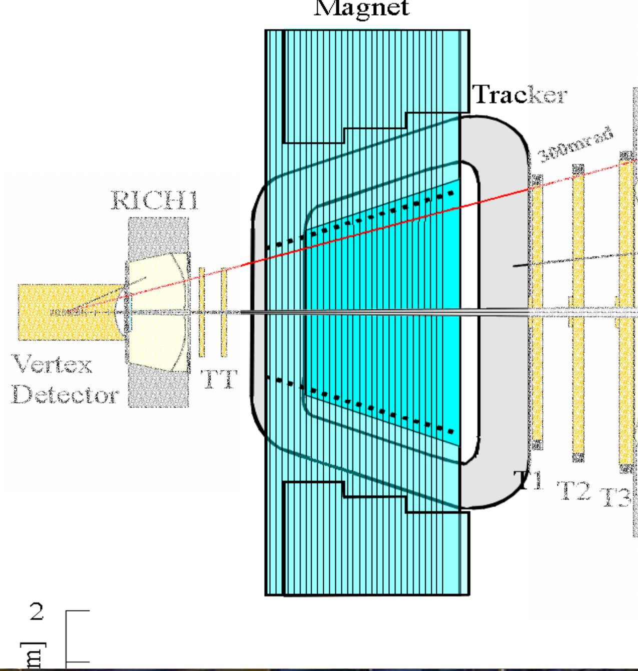




198 μm strip pitch, up to 30 cm long strips→410 μm thick
180K readout channels

Magnet



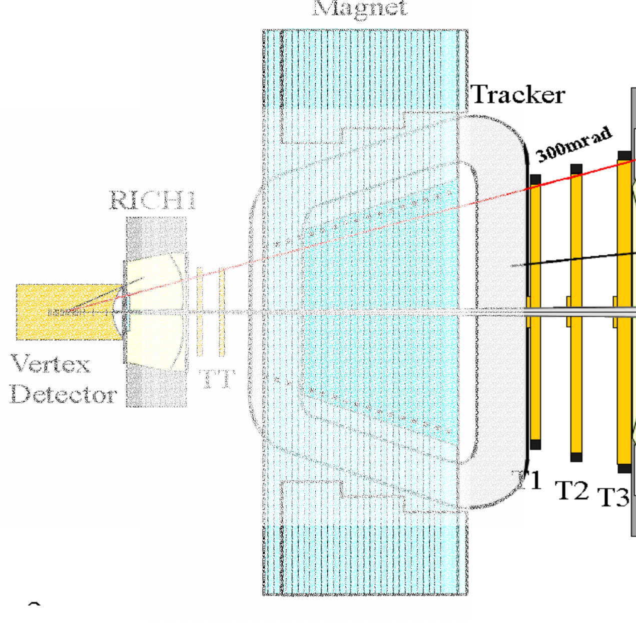


- dipole
- warm Al conductor
- 4 Tm integrated field
- 4.2 MW
- 1450 t yoke

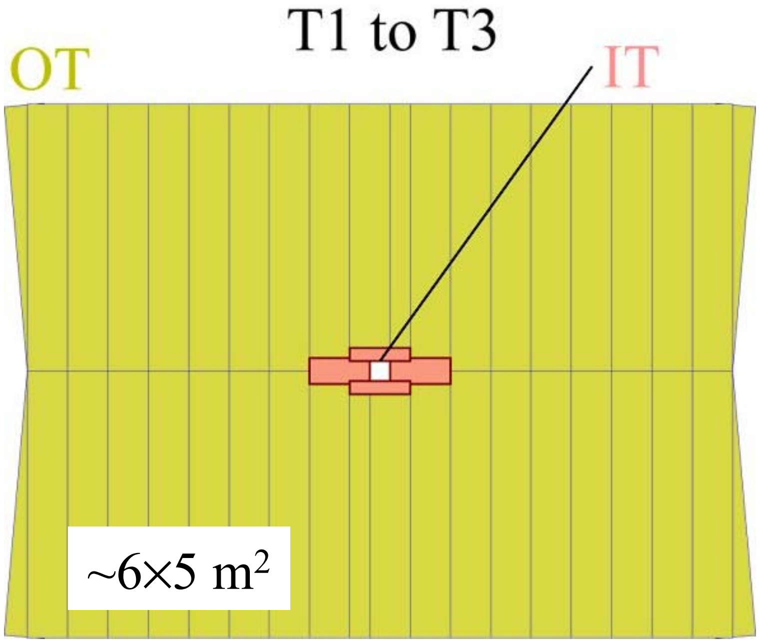
➢ All components delivered

➢ Underground assembly ongoing

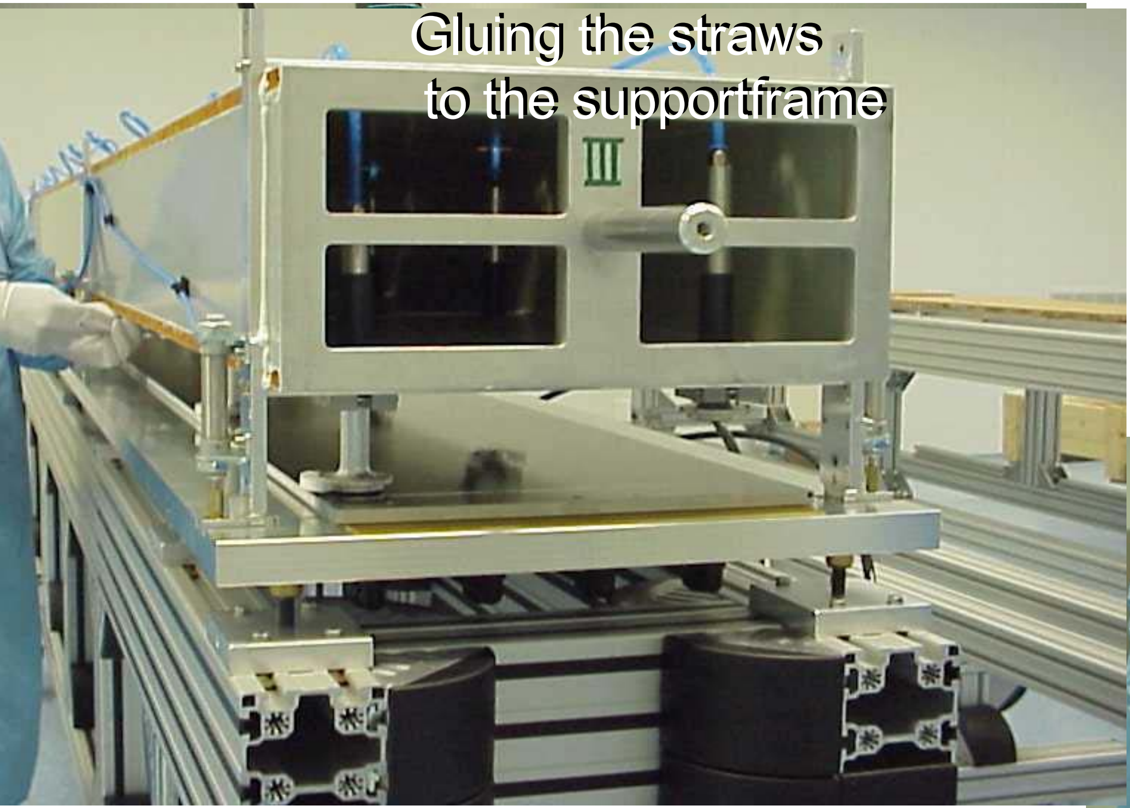
Tracking Detectors: T stations

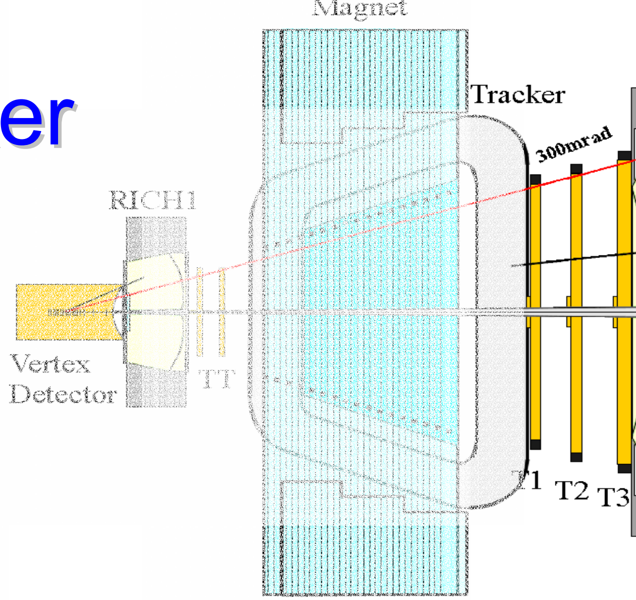


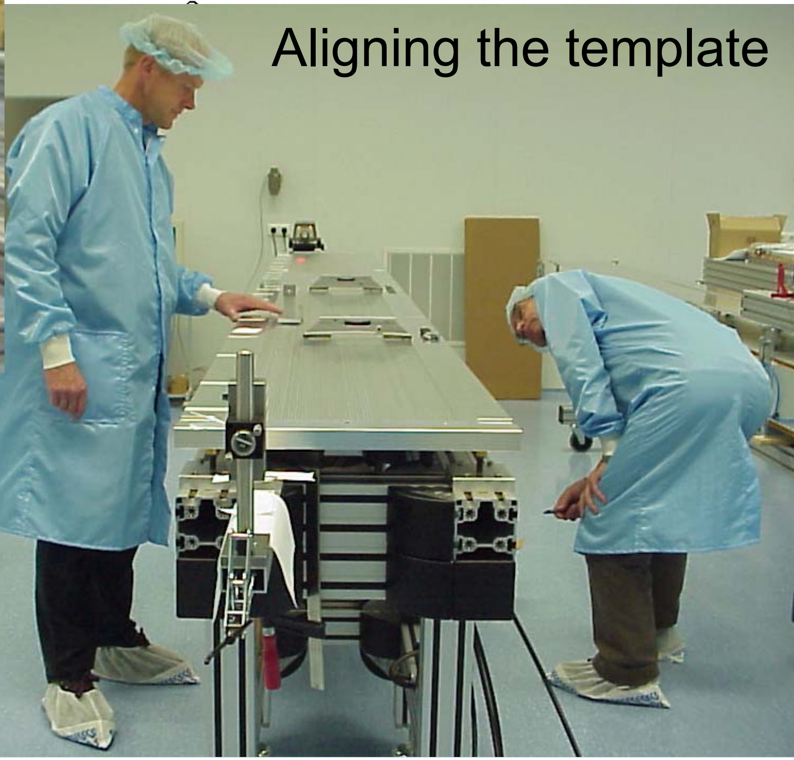
- Split into two systems
  - Inner and Outer Trackers
- particle fluences higher in equatorial plane (bending plane of magnet)
  - extend horizontal coverage of Inner Tracker
- Inner Tracker area
  - covers only 1.3% of sensitive overall tracker area
  - corresponds to 20% of all tracks within LHCb acceptance
  - Instrumented with silicon strip detectors
- Outer Tracker area
  - Large area
  - Instrumented with strawtube chambers



Tracking Detectors: Outer Tracker

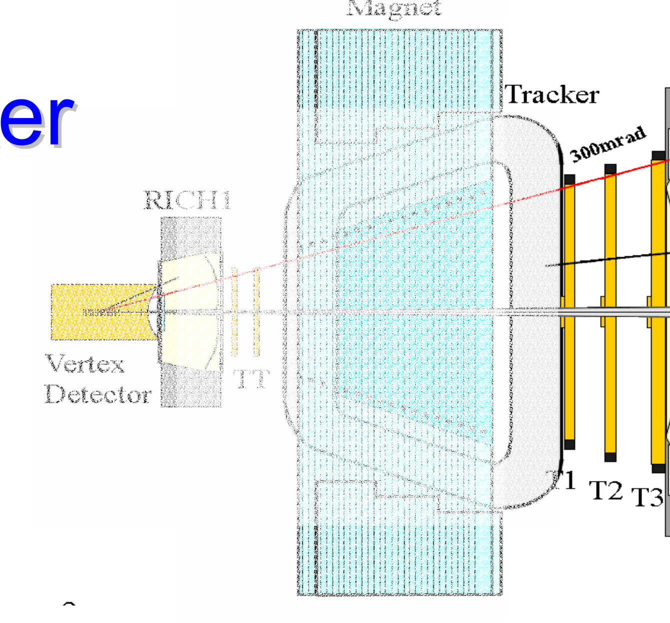

Gluing the straws
to the supportframe

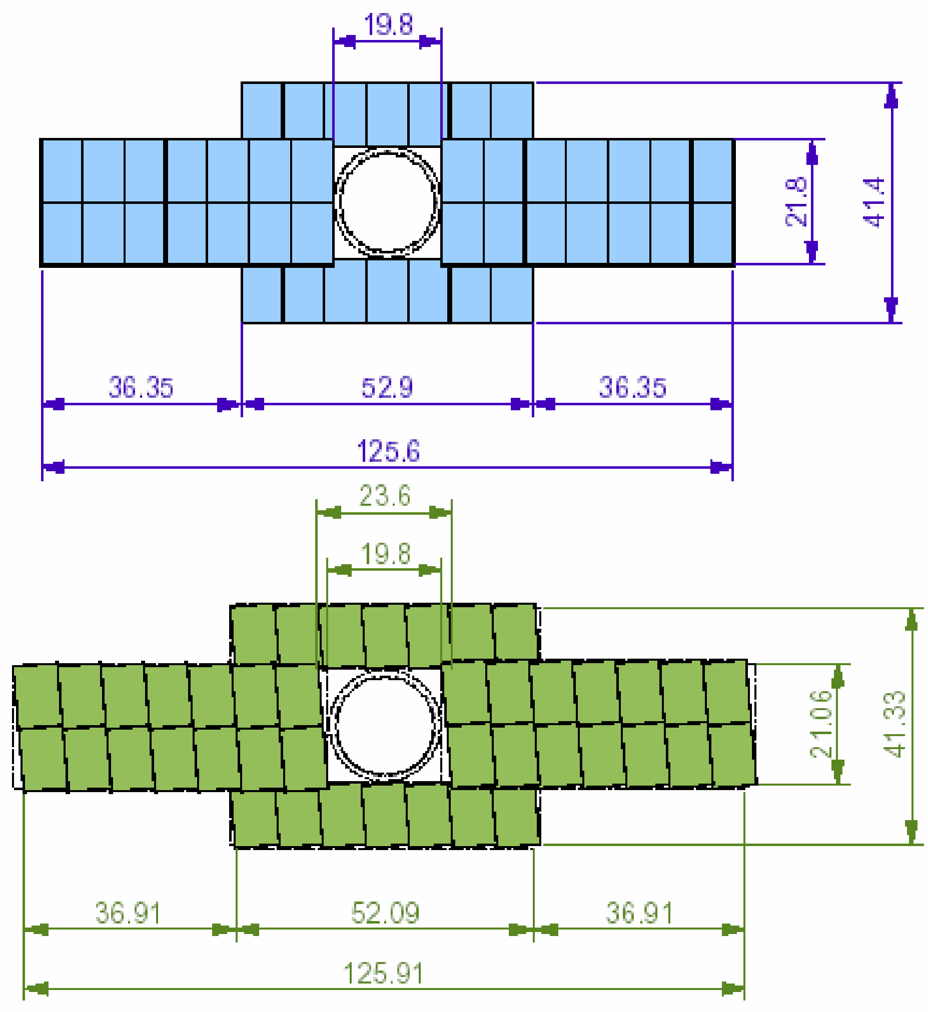



Aligning the template

- 3 stations with 4 double layers
- 5mm straw tubes
- 50k readout ch.

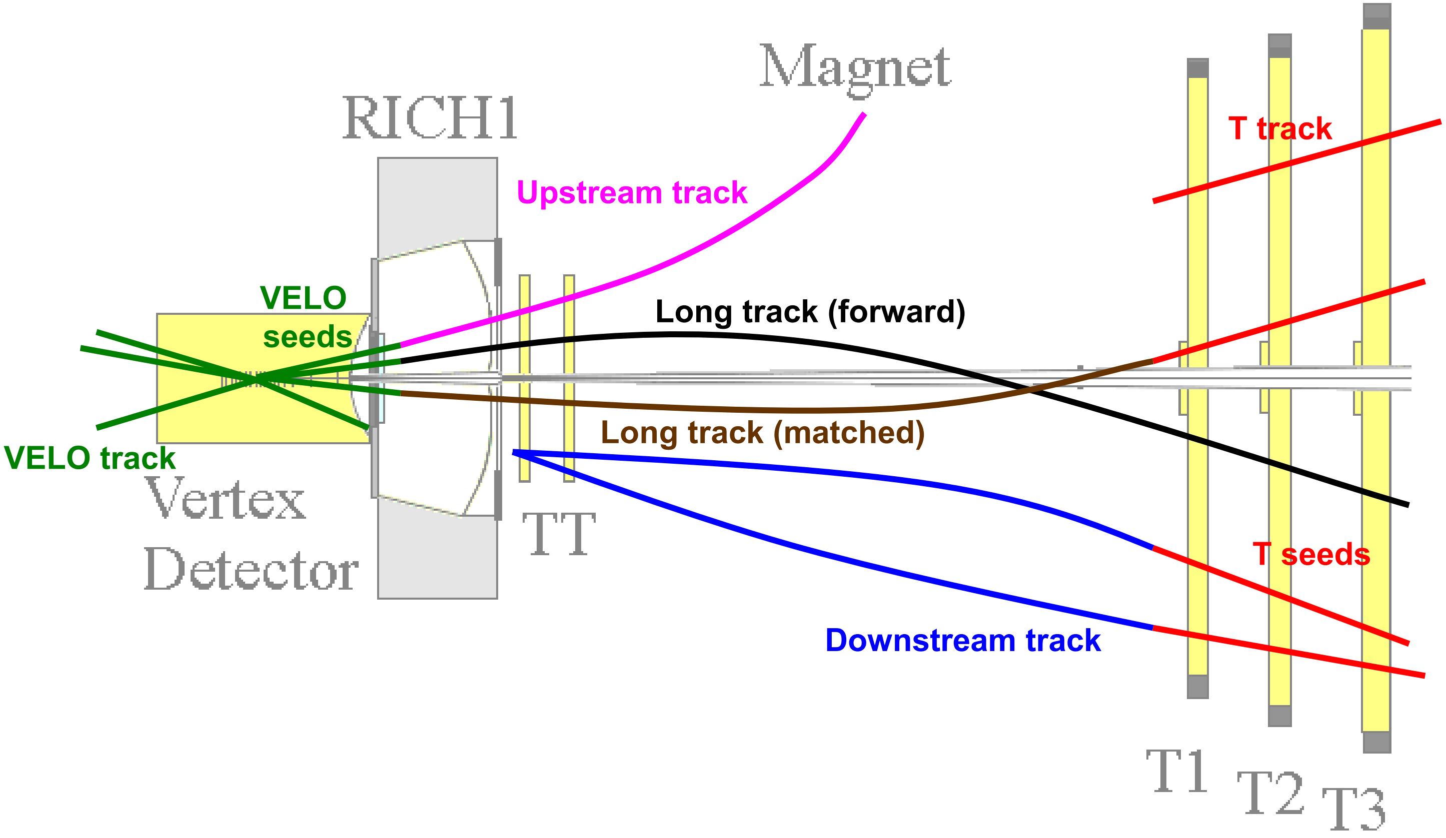
Tracking Detectors: Inner Tracker





- 3 stations with 4 layers each
- 320µm thin silicon
- 198µm readout pitch
- 130k readout ch.

Track finding strategy



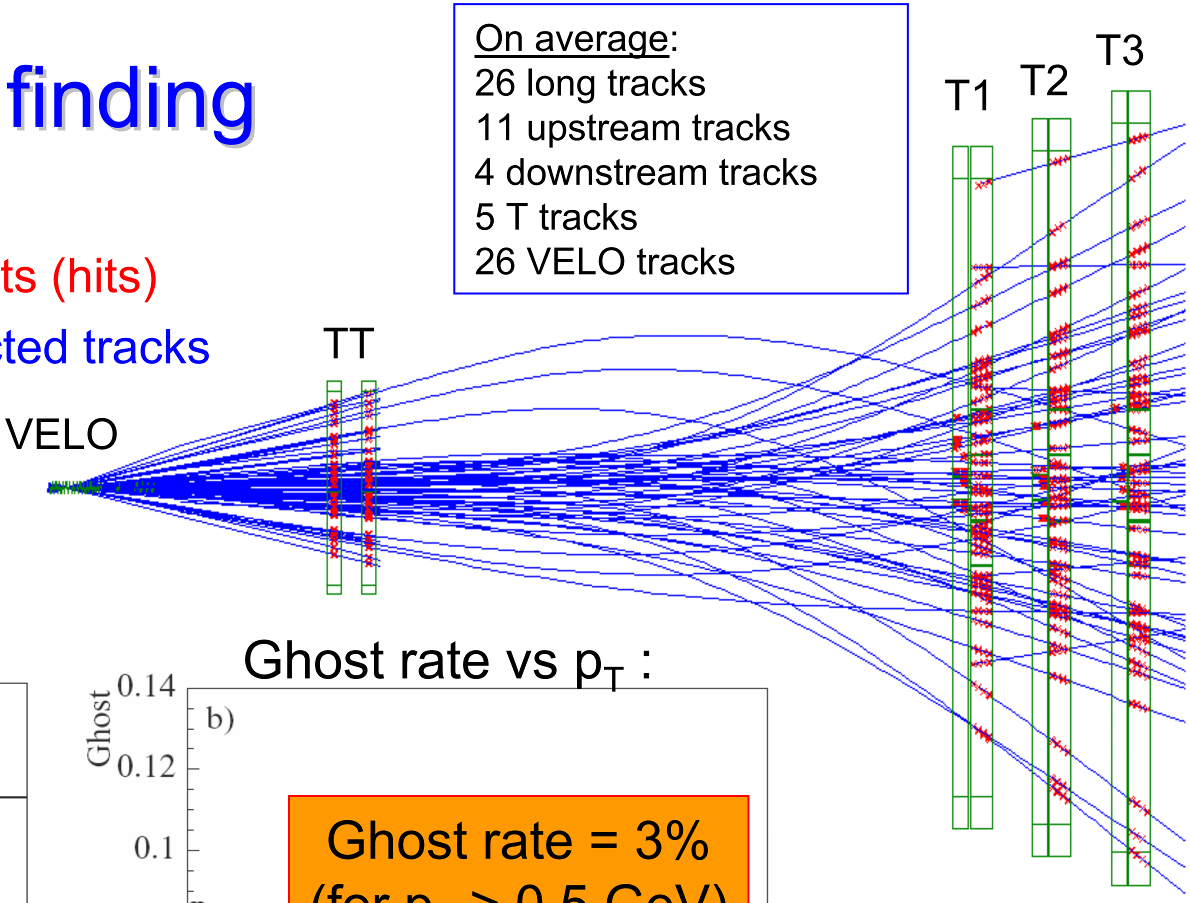
Long tracks	⇒	highest quality for physics (good IP & p resolution)
Downstream tracks	⇒	needed for efficient K_S finding (good p resolution)
Upstream tracks	⇒	lower p, worse p resolution, but useful for RICH1 pattern recognition
T tracks	⇒	useful for RICH2 pattern recognition
VELO tracks	⇒	useful for primary vertex reconstruction (good IP resolution)

Result of track finding

Typical event display:

Red = measurements (hits)

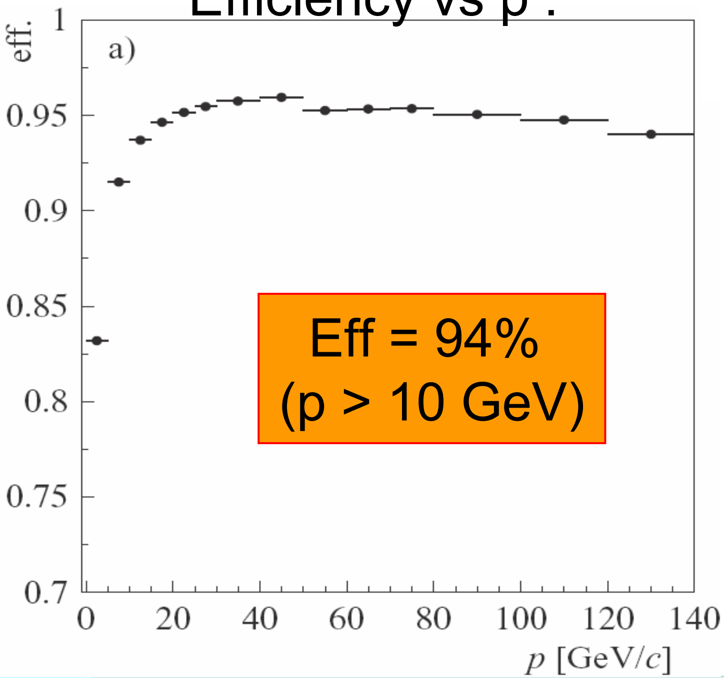
Blue = all reconstructed tracks



On average:
26 long tracks
11 upstream tracks
4 downstream tracks
5 T tracks
26 VELO tracks

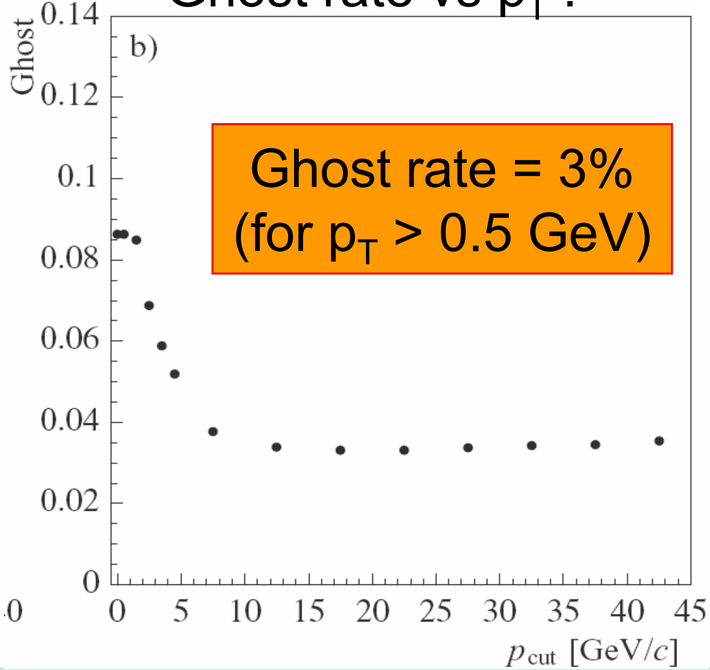
20–50 hits assigned to a long track:
98.7% correctly assigned

Efficiency vs p :



Eff = 94%
(p > 10 GeV)

Ghost rate vs p_T :

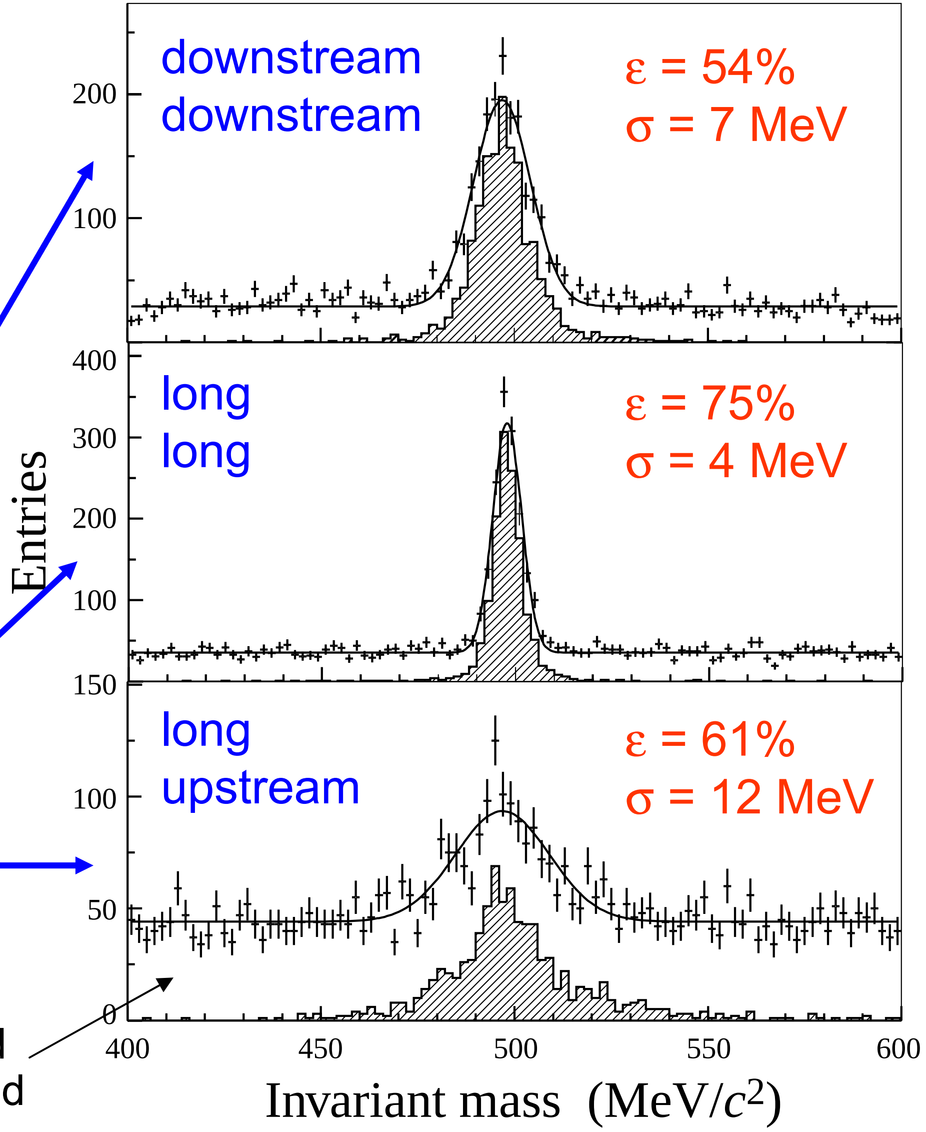


Ghost rate = 3%
(for p_T > 0.5 GeV)

Ghosts:
Negligible effect on
B decay reconstruction

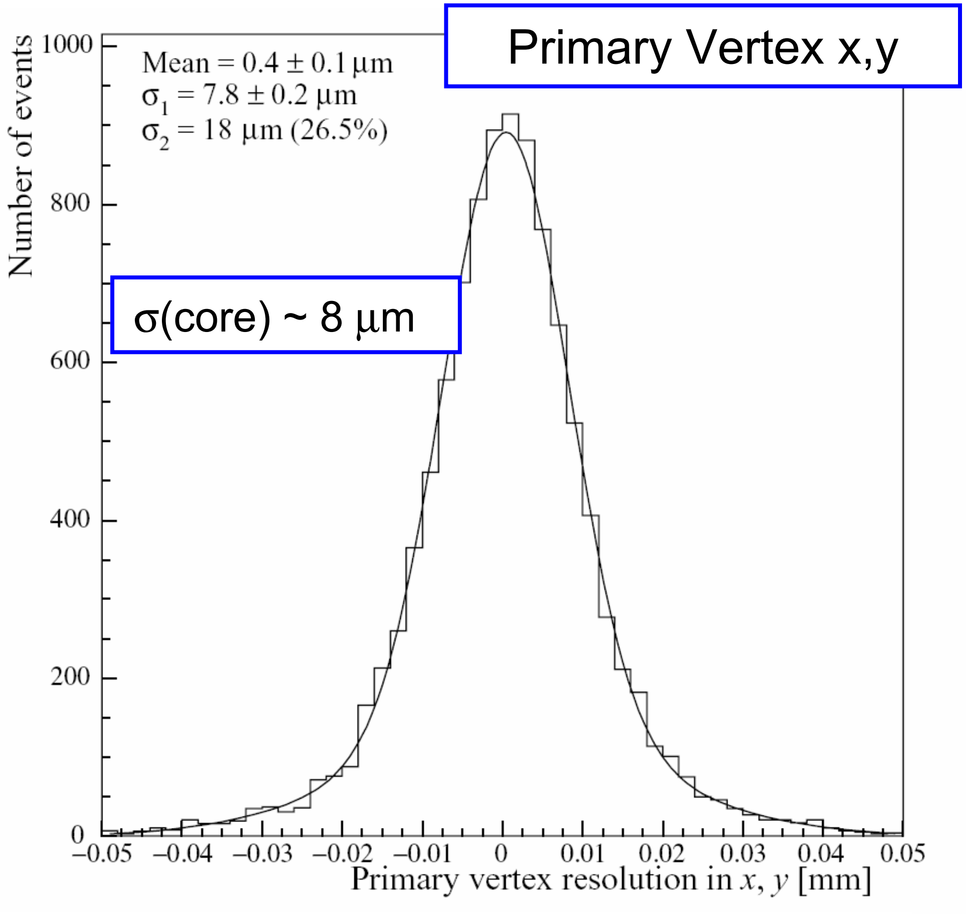
$K_S \rightarrow \pi^+\pi^-$ reconstruction

- K_S from $B^0 \rightarrow J/\psi\ K_S$
  - 25% decay after TT
    - Not reconstructed
  - 50% decay outside VELO but before TT
    - Use pairs of downstream tracks
  - 25% decay inside VELO
    - Use long and upstream tracks

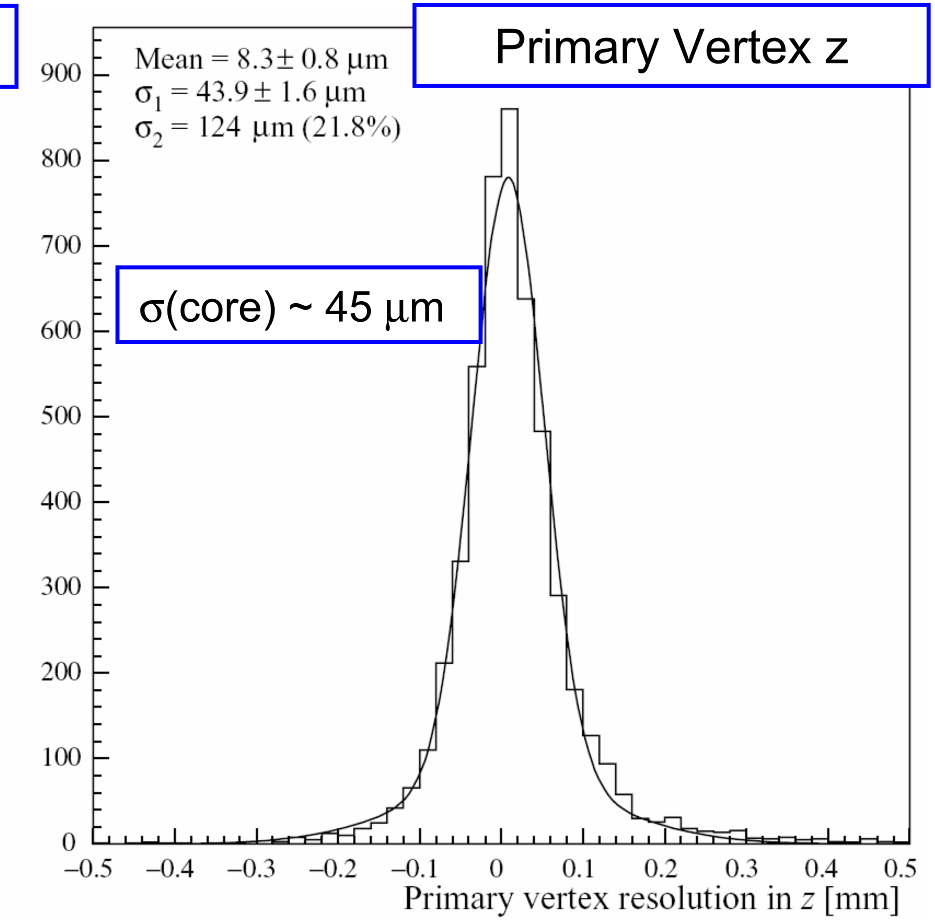


combinatorial background removed when K_S combined with J/ψ into a B^0 meson

Primary Vertex Reconstruction


Primary Vertex x,y

σ(core) ~ 8 μm

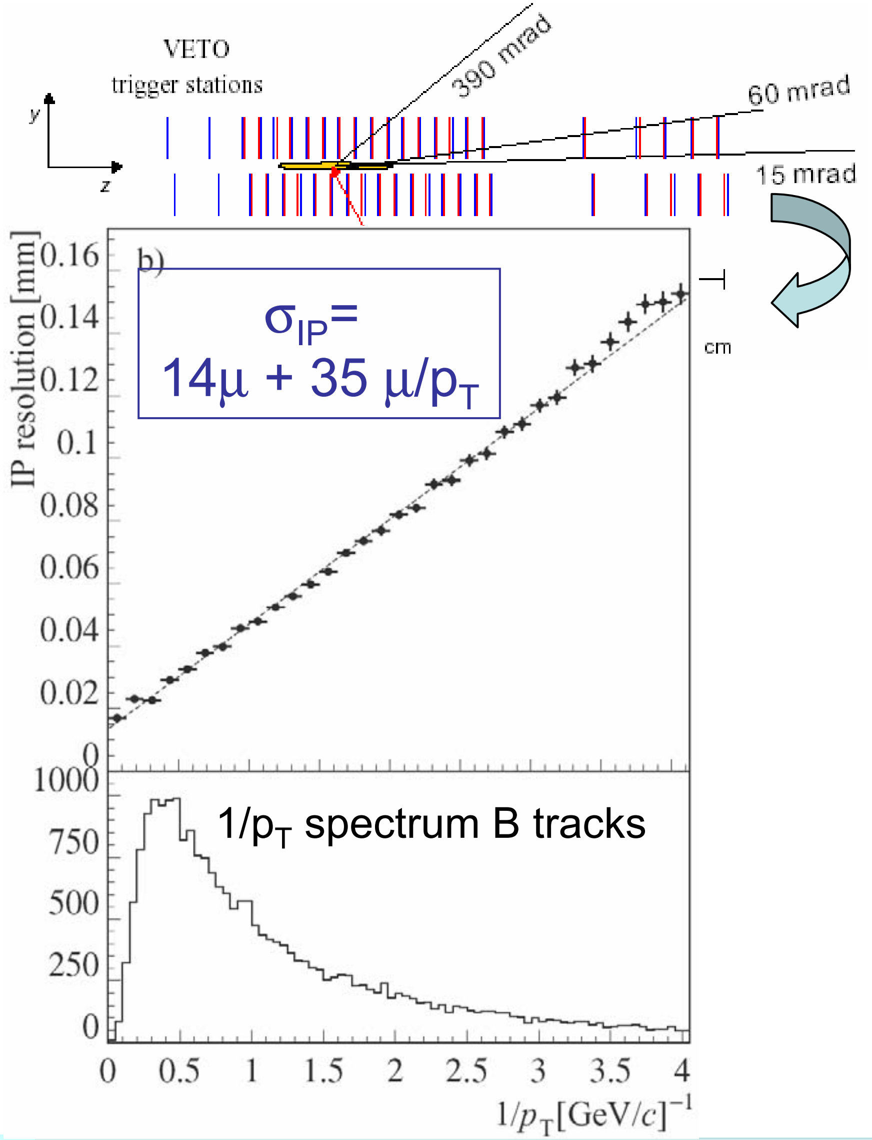

Primary Vertex z

σ(core) ~ 45 μm

- $b\bar{b}$ production vertex found in 98% of $b\bar{b}$ events
- Multiple primary vertices
  ⇒ use back-pointing of reconstructed B to find correct one

Track Resolution

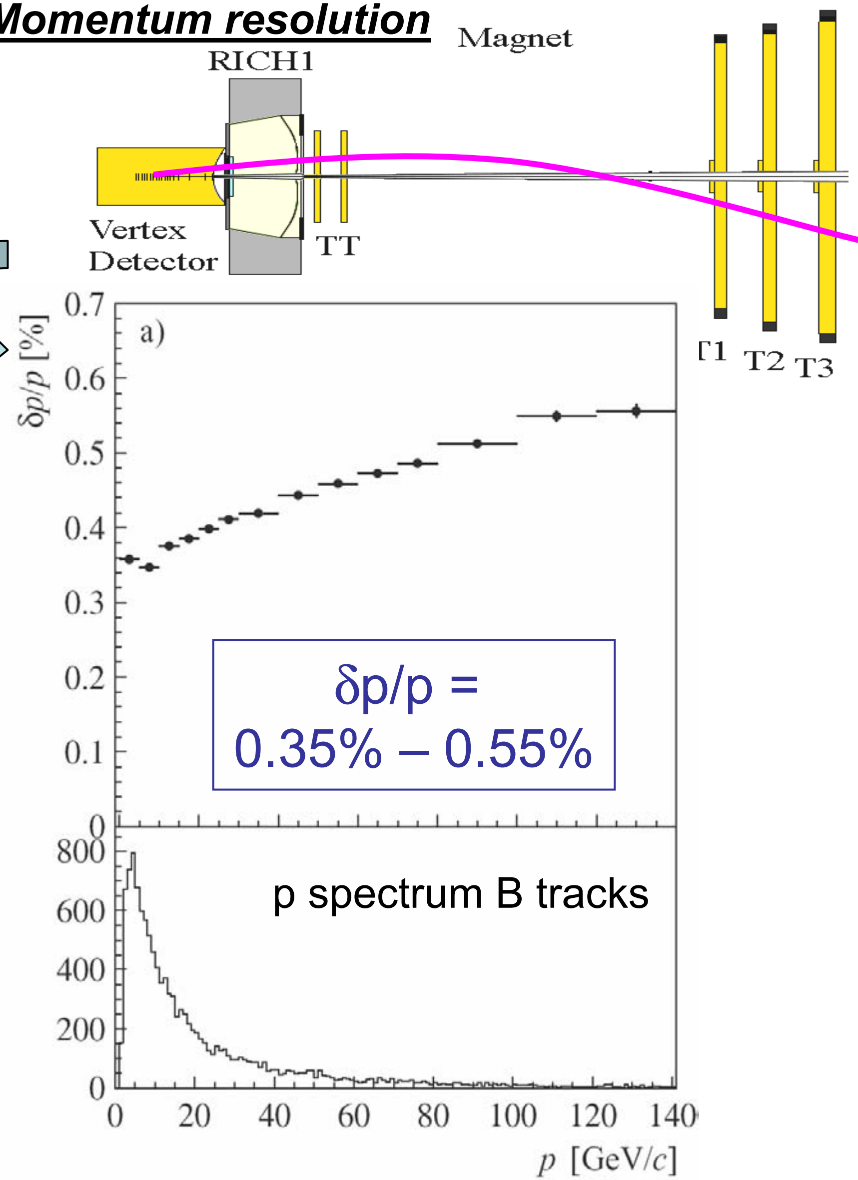
Impact parameter resolution



σ_{IP}= $14\mu + 35\ \mu/p_T$

$1/p_T$ spectrum B tracks

Momentum resolution

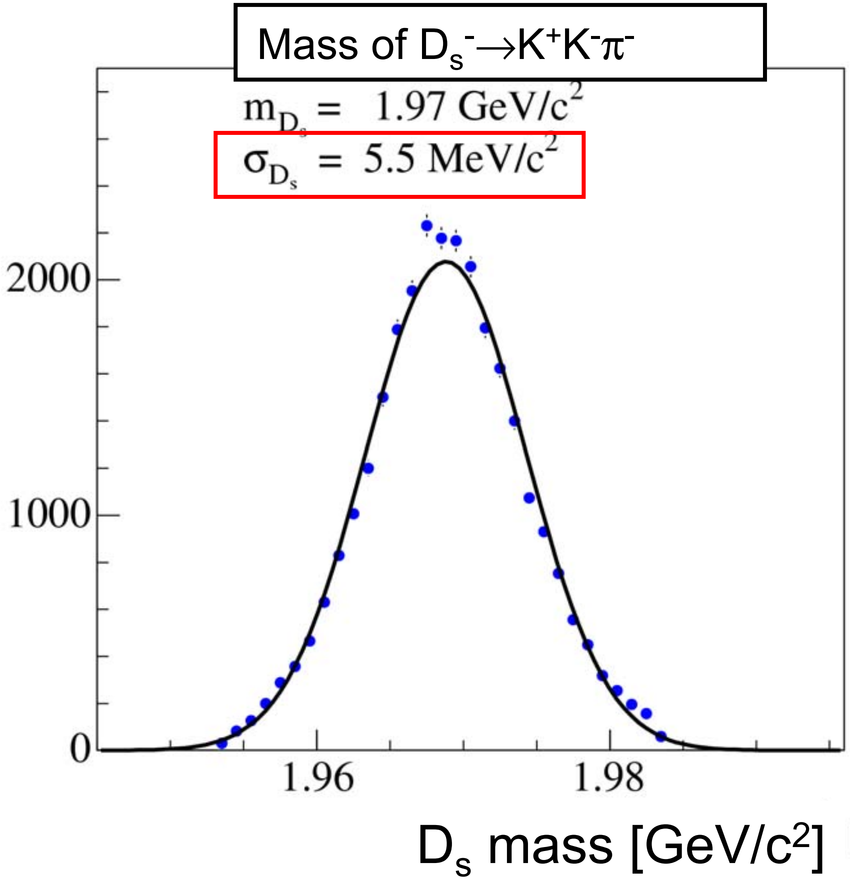


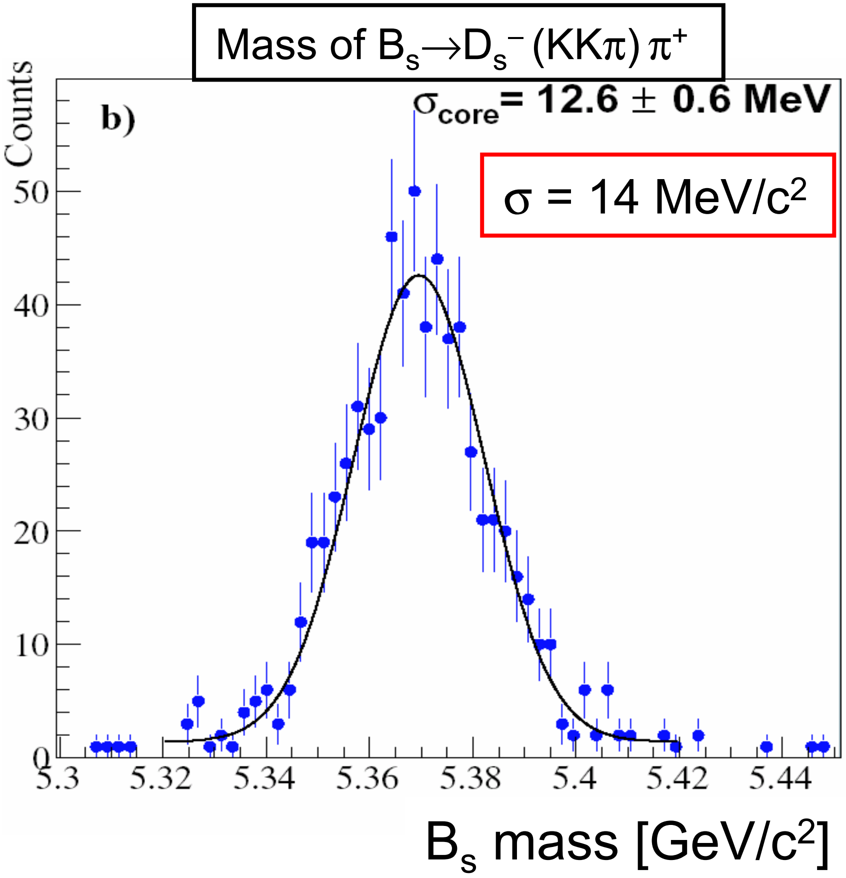
$\delta p/p$ = 0.35% – 0.55%

p spectrum B tracks

Mass Resolution

Need excellent momentum resolution to reject backgrounds by cutting on resonant masses, eg. $B_{(s)}$ mass, D_s mass, J/ψ mass





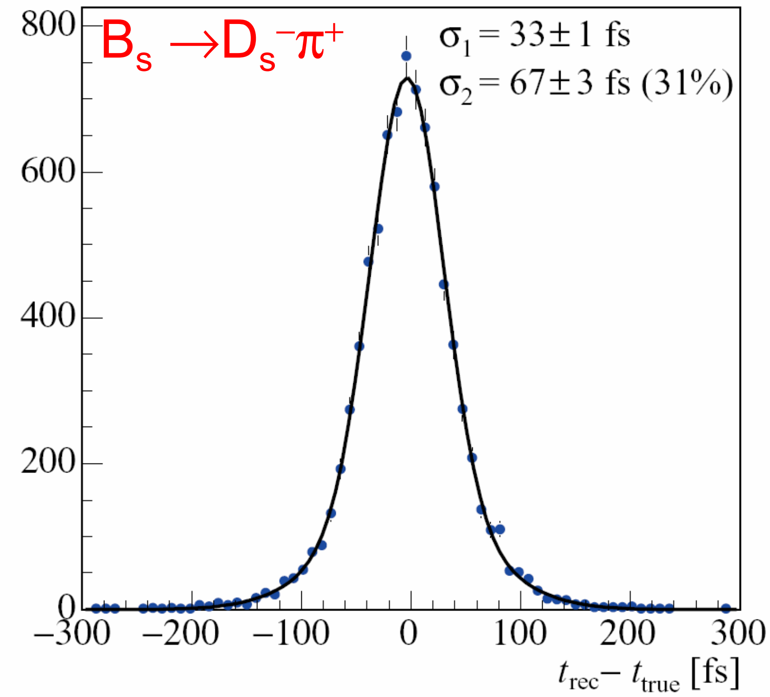
Proper time resolution

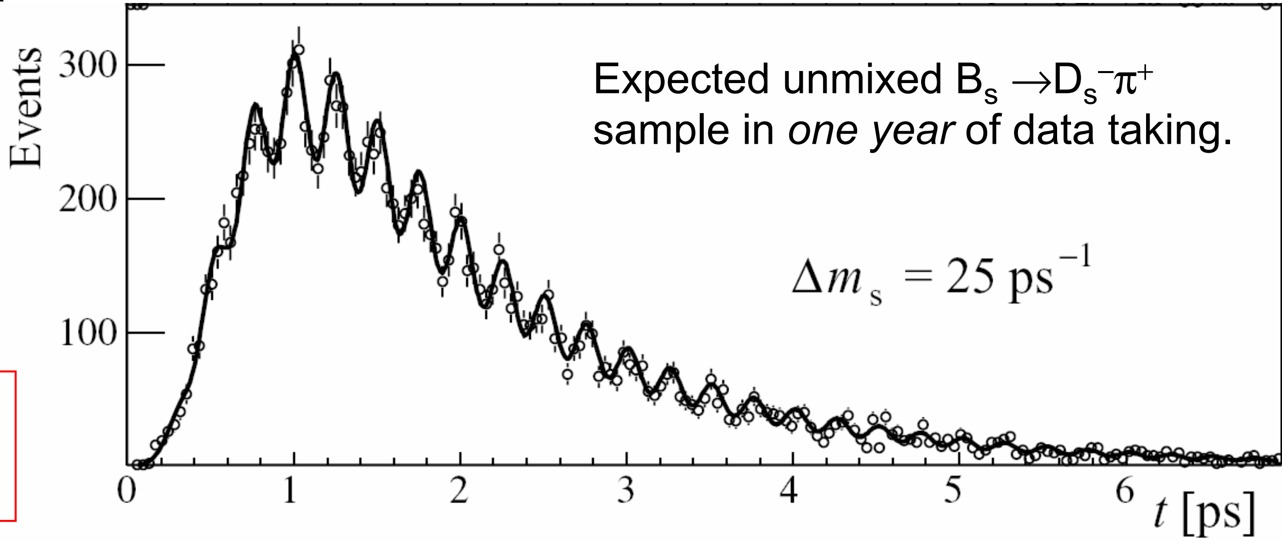
- Needed for the observation of CP asymmetries with B_s decays
- Use $B_s \rightarrow D_s^- \pi^+$
- If $\Delta m_s = 20\ \mathrm{ps}^{-1}$

$\sigma(\Delta m_s) = 0.011\ \mathrm{ps}^{-1}$

- Can observe >5σ oscillation signal if **$\Delta m_s < 68\ \mathrm{ps}^{-1}$** well beyond SM prediction

More physics examples:
Ulrich Uwer on Saturday



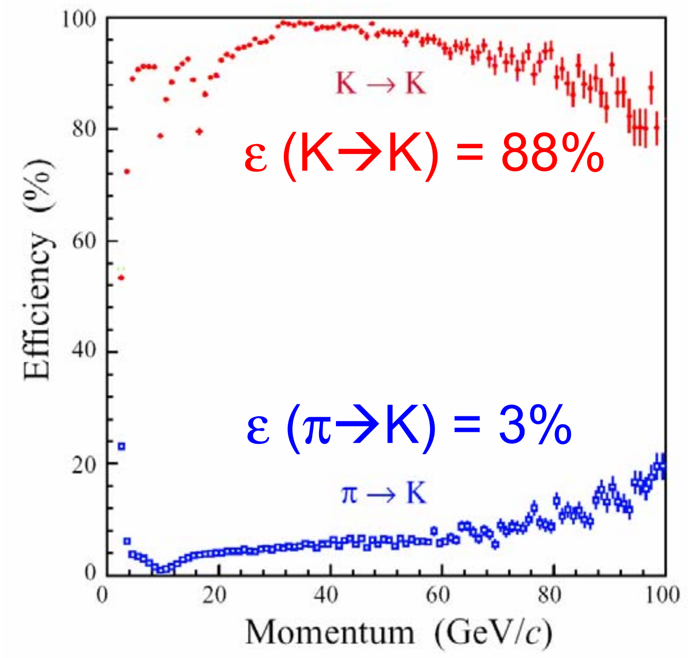


Expected unmixed $B_s \rightarrow D_s^- \pi^+$ sample in *one year* of data taking.

Particle ID

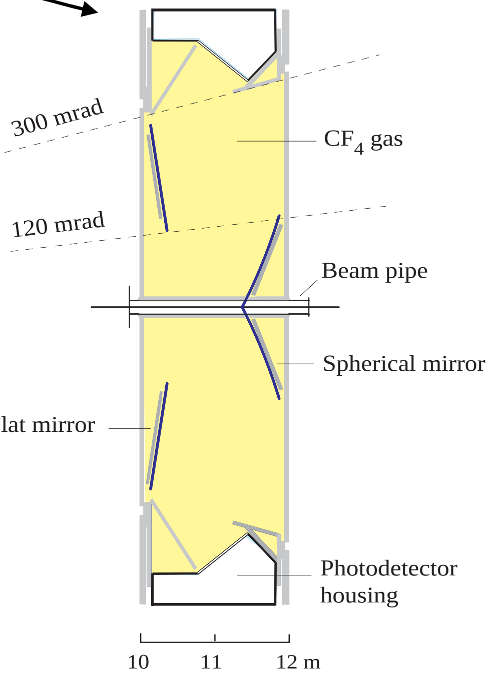
RICH 1

RICH 2



ε (K→K) = 88%

ε (π→K) = 3%



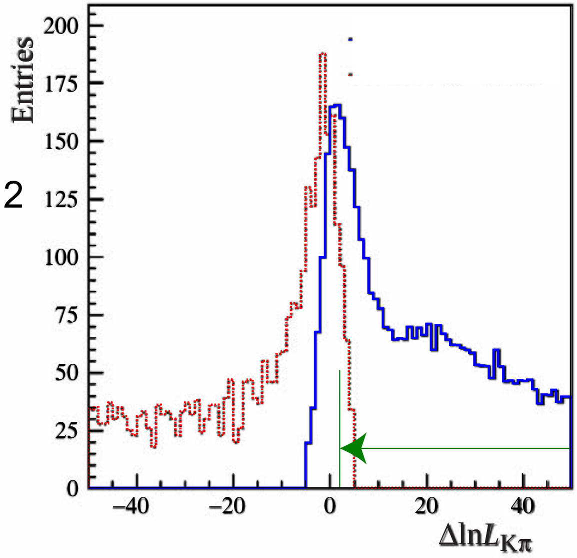
Example:

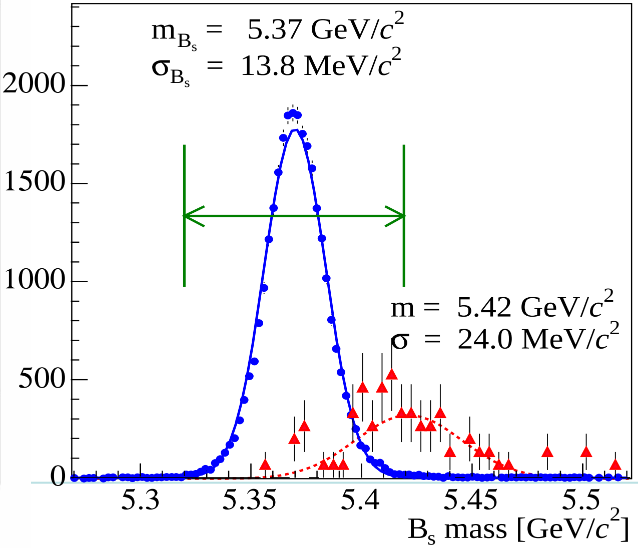
B_s→D_sK decays

BR($B_s \to D_s^- \pi^+$)/BR($B_s \to D_s^{\mp} K^{\pm}$) ~ 12

:

See next talk by
Marco Adinolfi
on the LHCb RICH





Trigger Strategy

40 MHz

Level-0:
p_T of
μ, e, h, γ

Calorimeter
Muon system
Pile-up system

1 MHz

Level-1:
Impact parameter
Rough p_T ~ 20%

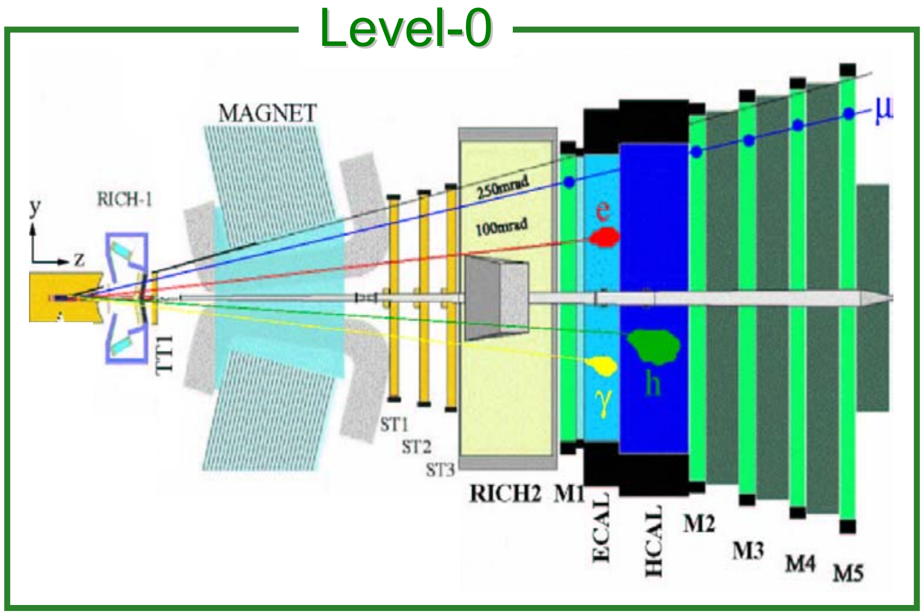
Vertex Locator
Trigger Tracker
Level 0 objects

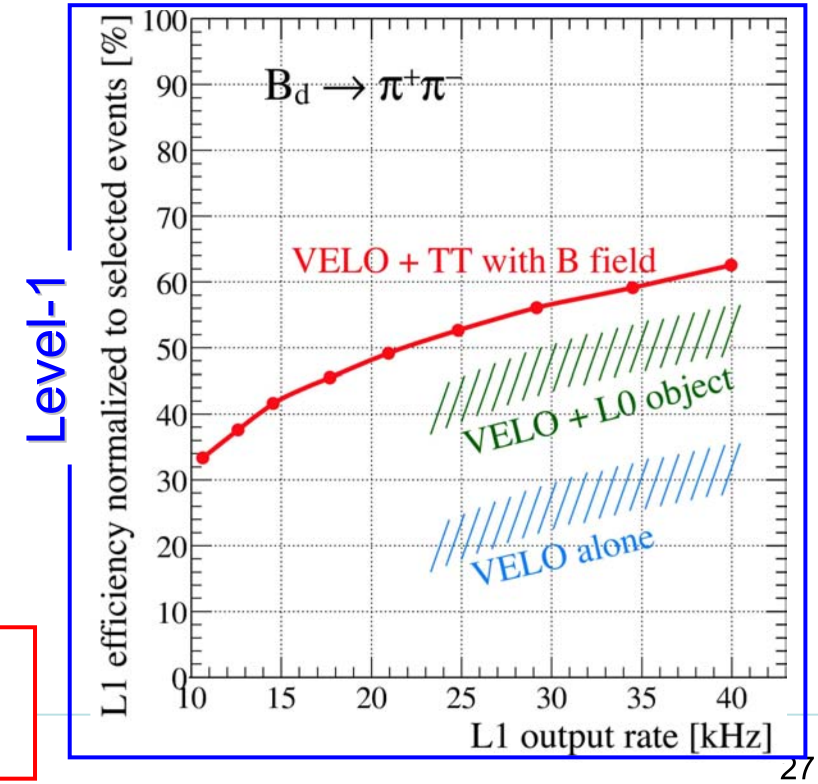
40 kHz

HLT:
Final state
reconstruction

Full detector
information

200 Hz output



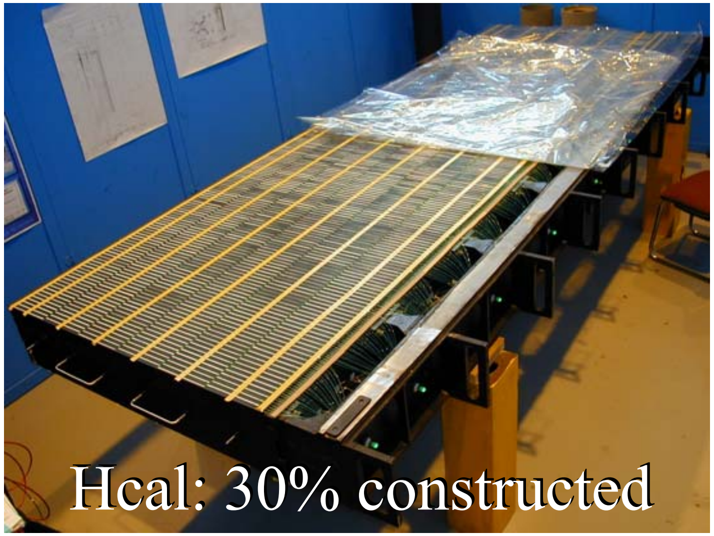


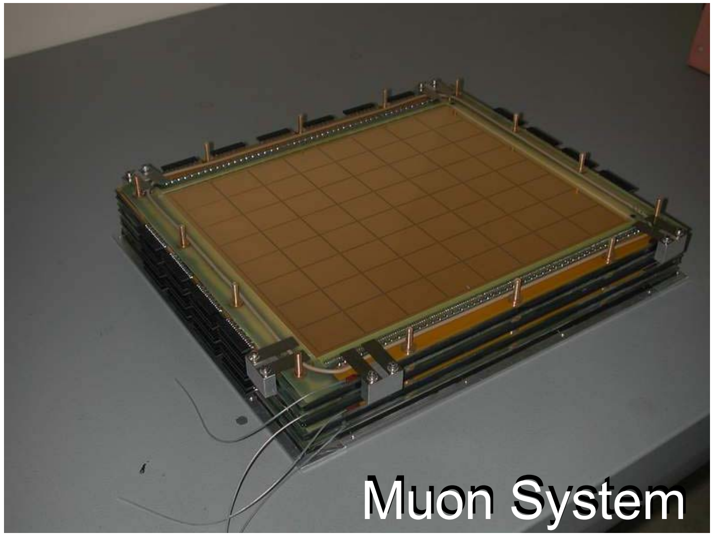
See talk by Olivier Callot on Friday on implementation and performance

Calorimeters and Muon System


Ecal: 100% constructed


Muon System


Hcal: 30% constructed


Muon System

See talk by Frédéric Machefert
on LHCb Calorimeters & Muon system (in ~22 minutes)

Conclusions

- LHC offers great potential for B physics from "day 1" LHC luminosity
- LHCb experiment has been reoptimized:
  - Less material in tracking volume
  - Improved Level1 trigger
- Realistic trigger simulation and full pattern recognition in place
- Tracking performance meets the requirements set by physics goals of the experiment
- LHC startup is now only 3.5 years away
  - Construction of the experiment is well underway

Backup

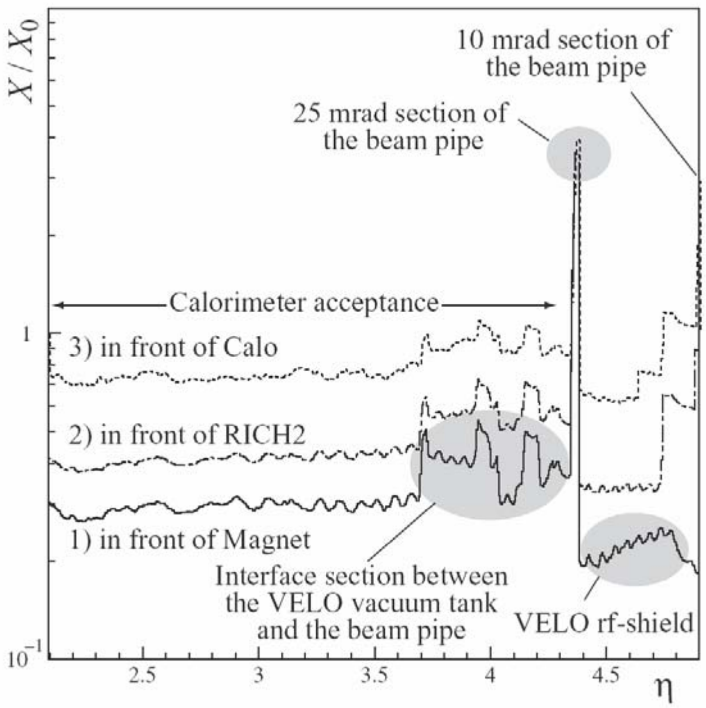


Figure 1.2: Material seen by a neutral particle from the nominal position of the primary vertex as a function of the pseudo-rapidity at three different z positions, averaged over the azimuthal angle.

Systematic Effects

Possible sources of systematic uncertainty in CP measurement:

- Asymmetry in $b\text{-}\bar{b}$ production rate
- Charge dependent detector efficiencies…
  - can bias tagging efficiencies
  - can fake CP asymmetries
- CP asymmetries in background process

Experimental handles:

- Use of control samples:
  - Calibrate $b\text{-}\bar{b}$ production rate
  - Determine tagging dilution from the data:

    e.g. B_s->$D_s\pi$ for B_s->D_sK, B->Kπ for B->$\pi\pi$, B->J/ψK* for B->J/ψK_s, etc
- Reversible B field in alternate runs
- Charge dependent efficiencies cancel in most B/$\bar{B}$ asymmetries
- Study CP asymmetry of backgrounds in B mass “sidebands”
- Perform simultaneous fits for specific background signals:

  e.g. B_s->$D_s\pi$ in B_s->D_sK , B_s->Kπ & B_s->KK, …