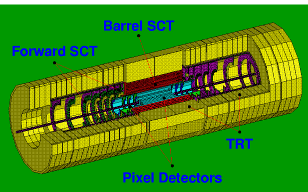
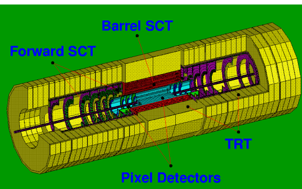


TDR talk - SJH

Additional transparencies from TDR not included in this file:

• $H \rightarrow b\bar{b}$	Fig 2-i
• $B_d \rightarrow J/\psi\ K^0$	Fig 2-iii
• Installation Schedule	Fig 1-10
• Milestones	Tab 1-3
• Cost	Tab 1-4

That makes 22+5=27 transparencies for 25 mins !!!!!!!



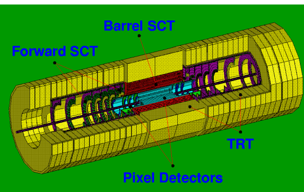
ATLAS Inner Detector

Performance and Conclusions

Stephen Haywood

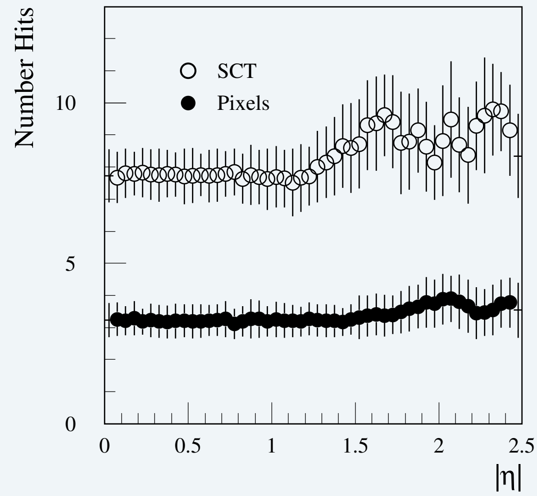
Simulation studies undertaken for Inner Detector (ID) TDR.

- Basic Performance (+ Alignment)
- Physics with the Inner Detector
- Schedule + Costing
- Conclusions

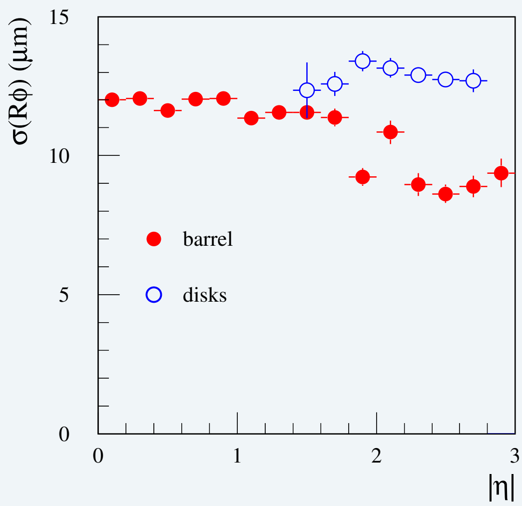


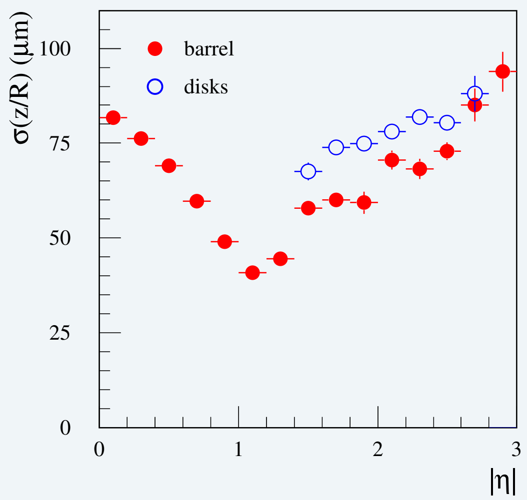
Pixels

Number of pixel hits ≥ 3



Resolutions

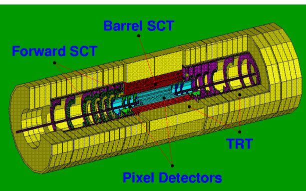




Occupancy per module

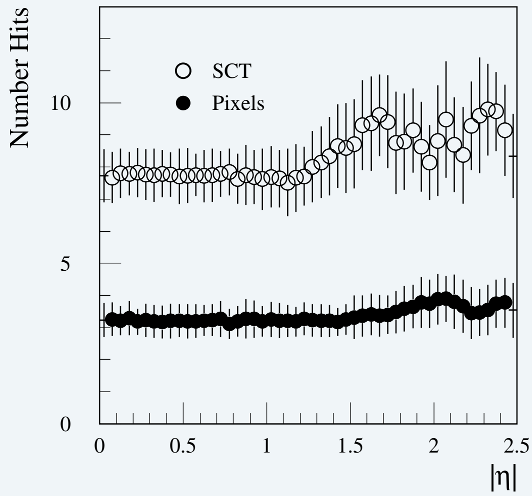
	Pile-up @ 10^{34}		b-jets	
	# hits	**Occ**	**#hits**	**Occ**
Barrel 0	27	4×10^{-4}	27	5×10^{-4}
Barrel 2	4	0.6×10^{-4}	19	3×10^{-4}

(Module 2×6 cm^2)

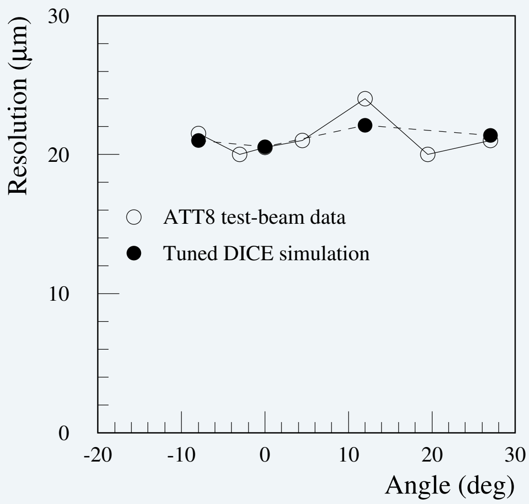


SCT

Number of ϕ + stereo hits ≥ 8



Resolution



Mean Cluster Width 1.2

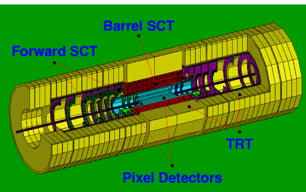
σ(strip) = 22 μm (pitch/$\sqrt{12}$)

$\sigma(R\phi)$ = 16 μm

$\sigma(z)$ = 580 μm

Occupancy per module

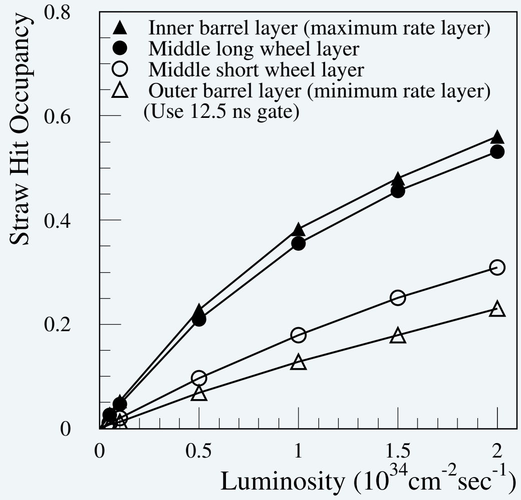
	Pile-up @ 10^{34}		b-jets	
	# hits	Occ (%)	#hits	Occ (%)
Barrel 1	5	0.6	27	1.7
Barrel 4	3	0.3	19	1.4



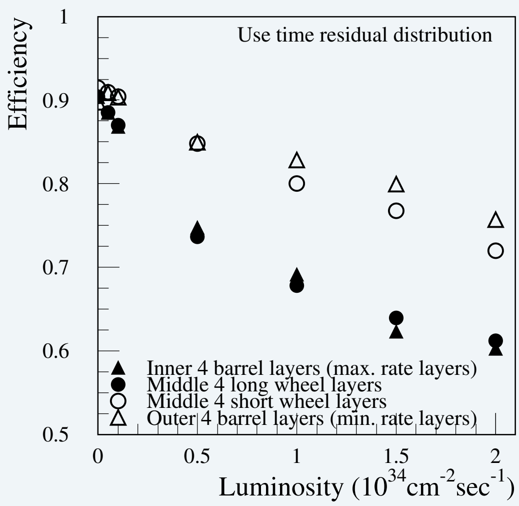
TRT

Occupancy

10 to 40% at 10^{34} cm^{-2}s^{-1}



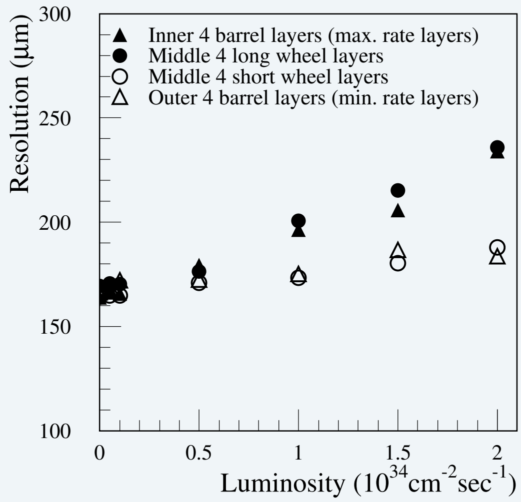
Nevertheless, PR works well because many hits



Efficiency

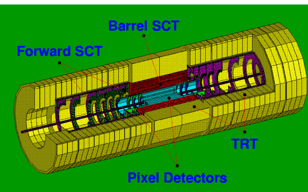
Drift time hits for high-p_T muon

within $\pm$ 2.5 σ



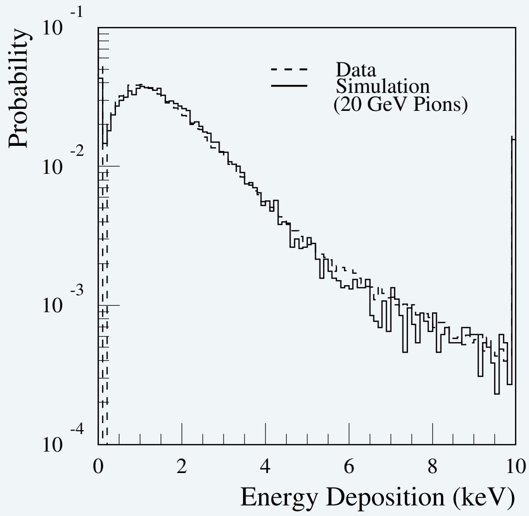
Resolution

At low luminosity: 170 µm

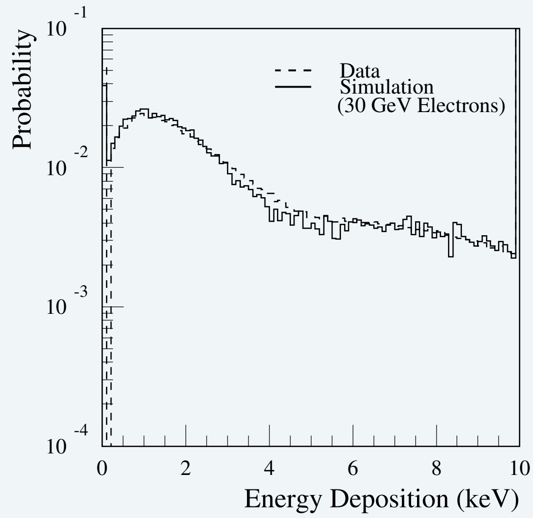


Transition Radiation

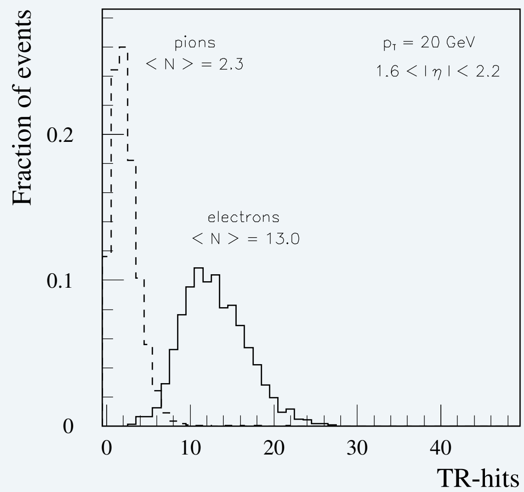
Pions

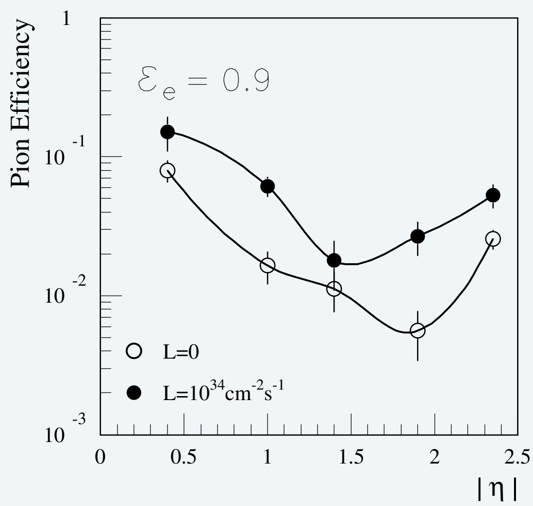


Electrons



High (TR) threshold at 7 keV

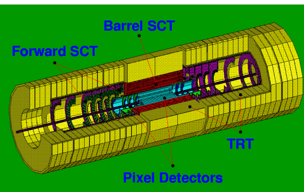




Eff(electron) = 90%

Rej(pion) = 10 - 1000 (low lumi)

= 6 - 60 (high lumi)



Alignment

Goal: Helix parameter resolutions degraded by < 20%

Alignment tolerances

	$\Delta R\phi$ (μm)	ΔR (μm)	Δz (μm)
Pix B-layer	7	10	20
Pix barrels	7	20	20
Pix disks	7	20	100
SCT barrels	12	100	50
SCT wheels	12	50	200

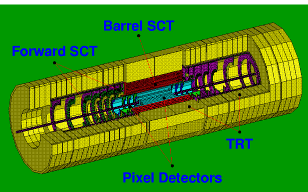
Need to follow alignment on short time-scales

Use all methods:

- Measure prototypes — ESPI[1]
- Initial survey — X-rays
- Run-time survey — FSI[2] + straightness monitors
- Run-time alignment — Tracks

Tracks: Record single muons $p_T > 6$ GeV at 100 - 1000 Hz.
In 24 hours, have enough tracks to align Tracker

1. Electronic SPeckle Interferometry
2. Frequency Scan Interferometry



Material

High rates and high occupancies

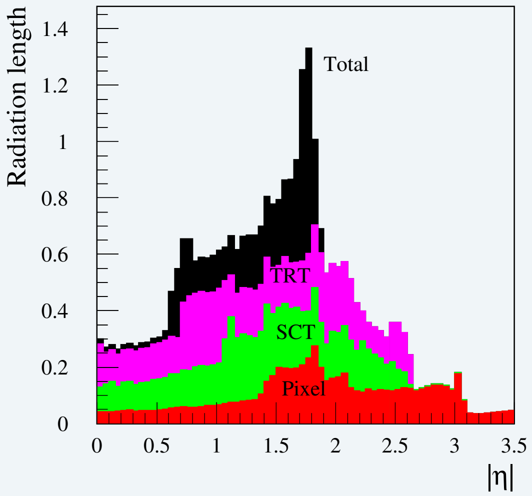
$\Rightarrow$ electronics on detector

$\Rightarrow$ power cables, r/o links, cooling etc in sensitive volume

High precision

$\Rightarrow$ mechanical stability

$\Rightarrow$ rigid support structure

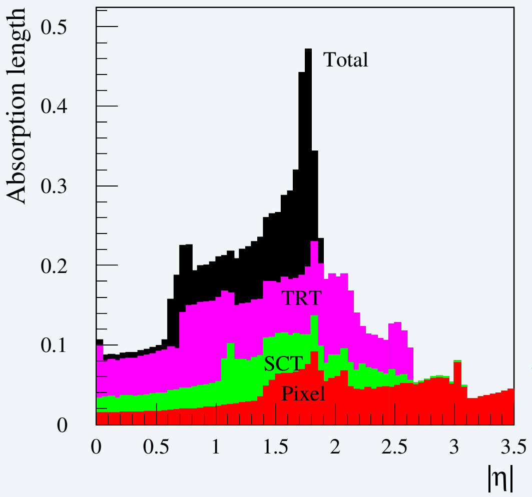


X_0

- multiple scattering
- secondaries $\pi^0 \rightarrow \gamma \rightarrow e^+e^-$
- $e^\pm$ bremsstrahlung
- γ conversions

Average (active, $|\eta|<2.5$) 43% X_0

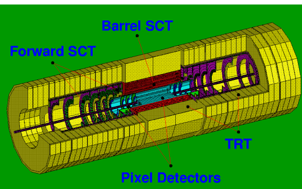
Total as used in Calo TDR



λ_{abs}

- π interactions
- secondaries

Average (active, $|\eta|<2.5$) 14% λ_{abs}



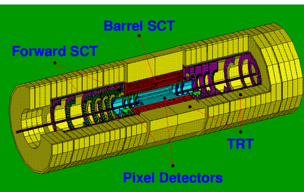
We are studying whether we can:

- maintain the same performance
- with reduced material.

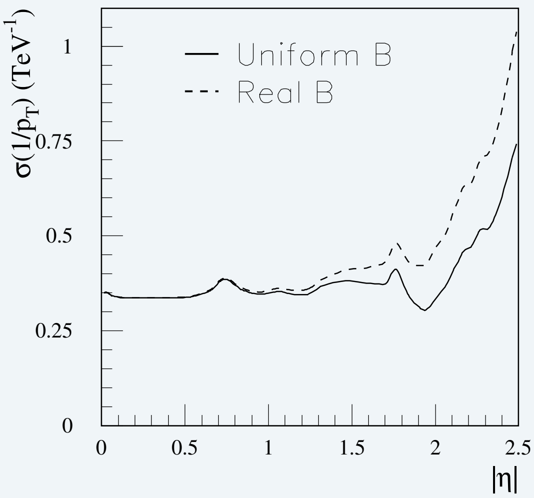
1. Detailed audit of material in current design
   Eg. reduce spike at $\eta = 1.7$ from patch panel with fewer connectors.
   Also aluminium ribbon power-cables, reduced monitoring etc.

2. Study layout with one layer removed.

This work does NOT affect the schedule or the system design.

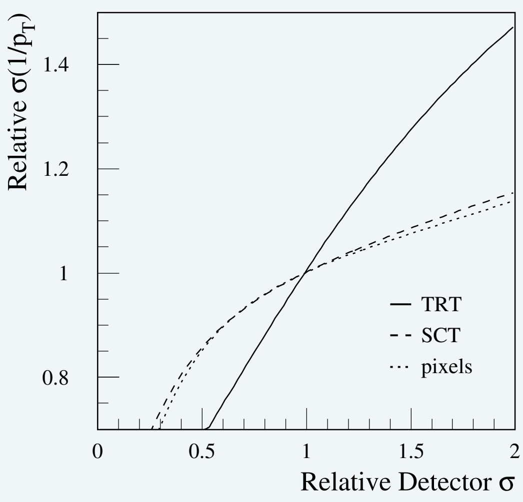


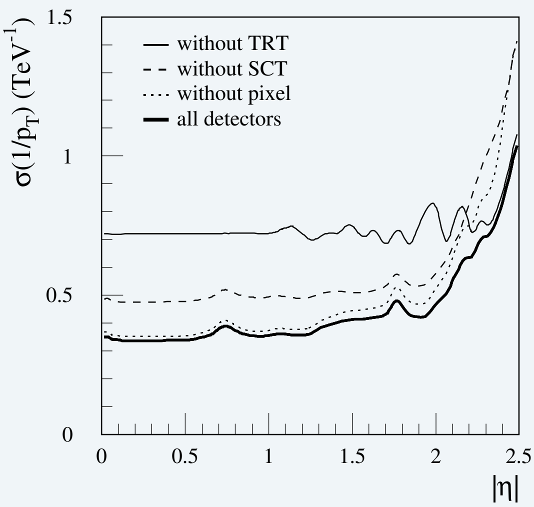
p_T Resolution



- **High p_T**
  $|\eta| < 2$: $\sigma(1/p_T) \approx 0.4$ TeV^{-1}
  $|\eta| = 2.5$: $\sigma(1/p_T) \approx 1.2$ TeV^{-1}
- **Low p_T**
  multiple-scattering $\Rightarrow$ 1.5%

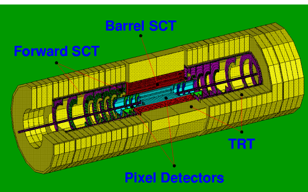
Sensitivity and Robustness



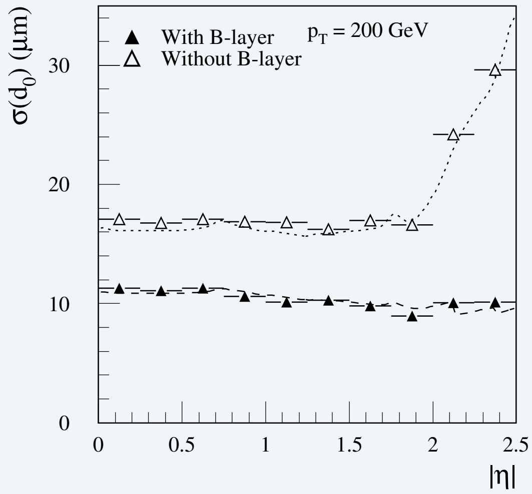


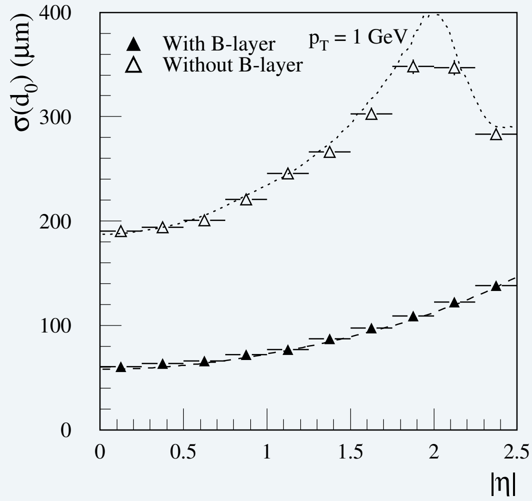
Probability for charge mis-measurement:

$p_T = 1$ TeV	< 2% for muons	and	< 5% for electrons
$p_T = 2$ TeV	< 12% for muons	and	< 13% for electrons

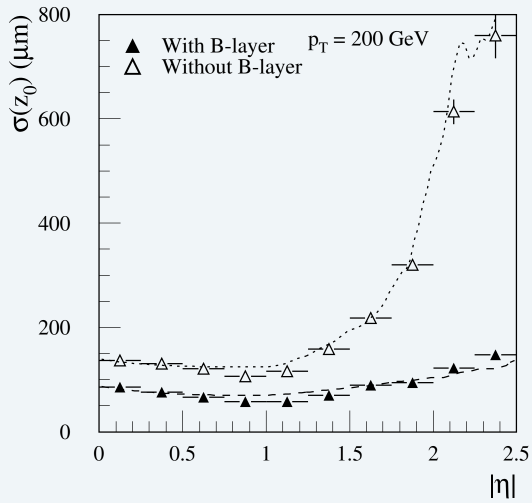


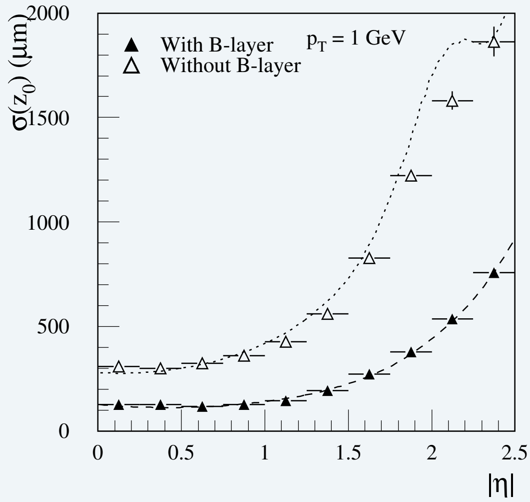
Impact Parameter Resolution



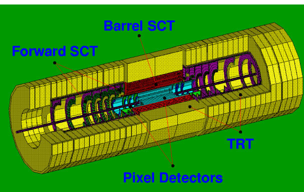


Transverse: $\sigma(d_0) \approx 11\ (1 \oplus 5.5/p_T\sqrt{\sin\theta})\ \mu m$





Longitudinal: $\sigma(z_0) \approx 70\ (1 \oplus 1.4/p_T\sqrt{\sin^3\theta})\ \mu m$



Pattern Recognition

We have used two different approaches:

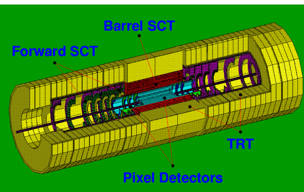
- **TRT → Precision** **xKalman**
- **Precision → TRT** **iPatRec, PixlRec**

Detailed comparison between xKalman and iPatRec for

1. Pattern recognition: Efficiencies and Fakes
2. Electron identification
3. b-tagging

Good agreement between programs ⇒

can study detector and physics rather than algorithms



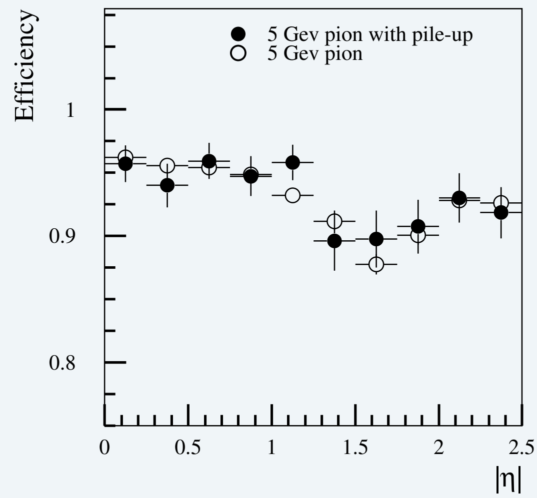
PR - Isolated Tracks

- 9 out of 11 precision hits (3 pixels + 2×4 strips)
- 2 out of 3 pixel hits, including B-layer
- $|d_0| < 1$ mm

Efficiency for muons > 99%

Pions p_T = 5 GeV

Tails $|d_0| > 3\sigma$ ~ 2%

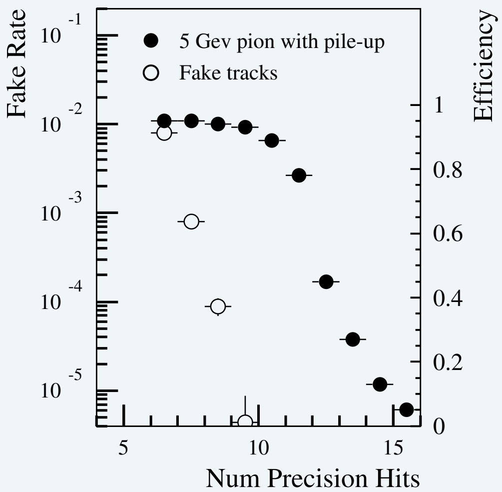


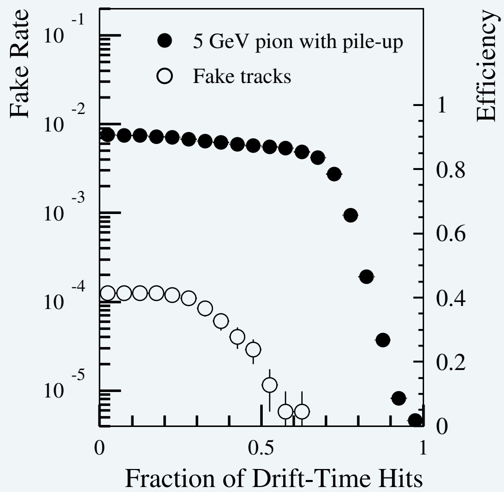
Fakes p_T > 2 GeV

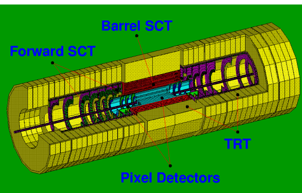
In ‘cone’ $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$

≥ 7 precision hits $\rightarrow$ 10^{-3}

Rate from pile-up 10^{-2}





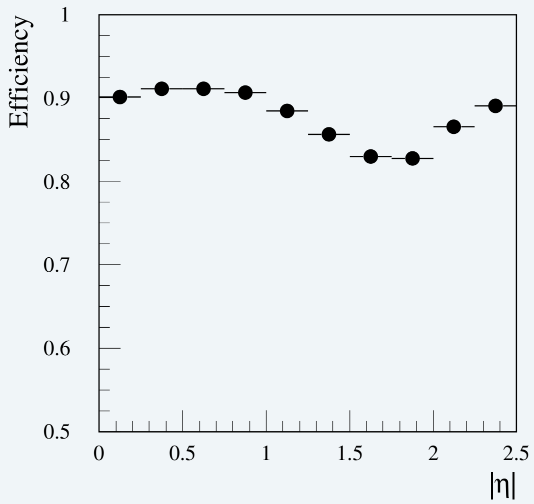


PR - 200 GeV Jets

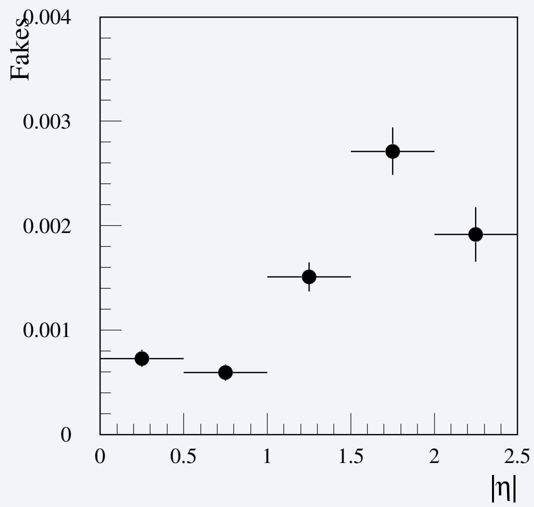
$H_{400} \rightarrow u\bar{u}$

Same cuts as for isolated tracks

Efficiency



Fakes



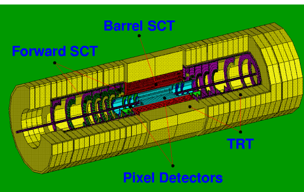
Detailed comparison of two different algorithms:

- Efficiency for primary particles 88.% - 86.%
- Fraction from secondaries 2.% - 2.%
- Fraction from fakes 0.1% - 0.2%

Tails in $|d_0|$:

- 2% of primaries $\rightarrow$ 70% of tails
- 30% of secondaries $\rightarrow$ 30% of tails

Of the secondaries, 30% originate after B-layer and pick up a wrong hit on B-layer



High-p_T Electrons

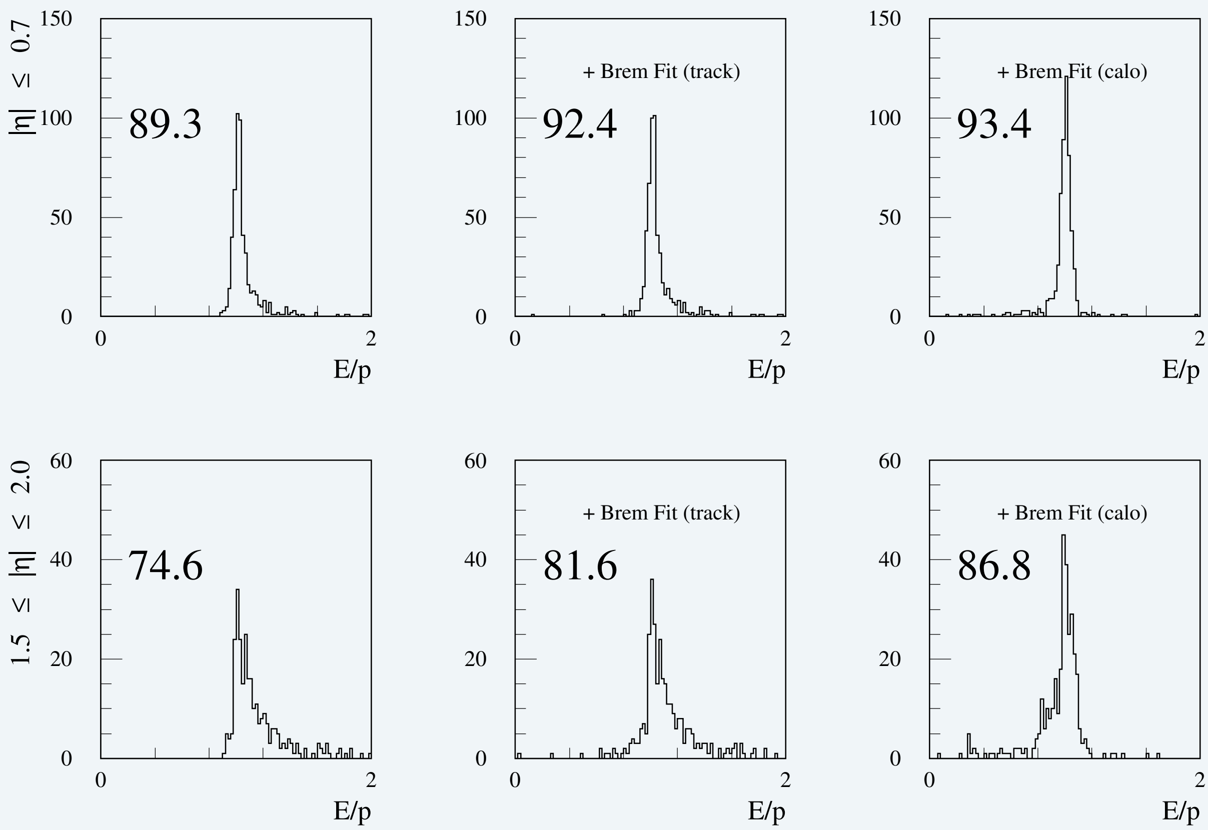
Consider electrons $p_T = 20$ GeV

Look after Calorimeter cuts with $E_T > 17$ GeV

- Verify charged track — remove γ
- Verify E(Ecal) ≈ p(ID) — remove $\pi^0/\pi^\pm$ overlap

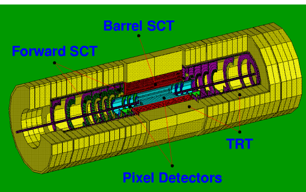
Correct electron for bremsstrahlung - use

- Kalman Filter to correct 'kink' (track)
- Ecal cluster position (calo)



Efficiencies for $0.7 < E/p < 1.4$ are given

ATLAS INNER DETECTOR



Efficiency for p_T = 20 GeV is 87% (75%) without (with) pile-up

QCD jet rejection (compare PR programs):

Calo		Track		E/p	
$\rightarrow$	150	$\rightarrow$	470 (620)	$\rightarrow$	2500 (2000)

TR rejection and removal of conversions $\rightarrow 4 \times 10^4$

Look at inclusive electron signature:

After E/p	Sig/Bgd ~ 1:3	(Bgd mainly hadrons)
After TR etc	Sig/Bgd ~ 6:1	(Sig mainly $b \rightarrow e$)

High-p_T Photons

Consider $H \rightarrow \gamma\gamma$

$Z \rightarrow e^+e^-$ background

For $m_H \approx m_Z$, must remove huge background from $Z \rightarrow e^+e^-$, where bremsstrahlung gives hard photons

Look for hits in ID

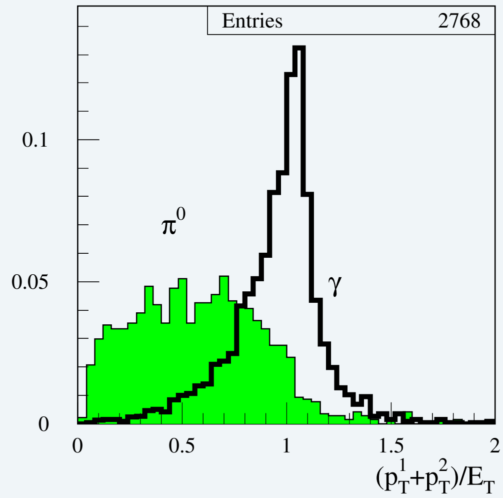
With rejection of 500 for *each* electron, obtain photon efficiency of 85% $\rightarrow S/B \approx 10$

π^0 backgrounds

Insist on reconstructed conversion:

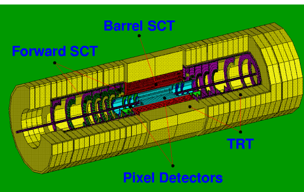
$$\pi^0 \rightarrow \gamma\, e{+}e{-} \qquad \text{vs} \qquad \gamma \rightarrow e{+}e{-}$$

Compare E(Calo) with p(conversion)



For photon efficiency of 90%

π^0 rejection of 3



$B_d \to J/\psi\ K^0$

$J/\psi \to e^+e^-$

Brem recovery with Kalman Filter (≈ 'kink' finding)

$\sigma(m)$ 71 MeV → 59 MeV

Use TR and vertexing to remove background

K^0

Can reconstruct $K^0 \to \pi^+\pi^-$

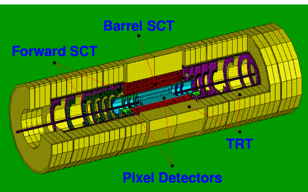
with 75% efficiency for $R_{decay} < 30$ cm and $\sigma(m) = 5$ MeV

B_d

J/ψ decay	$\sigma(m)$ (MeV)	$\sigma(R_{decay})$ (μm)
$\mu^+\mu^-$	19	64
e^+e^-	26	68

Primary Vertex

Decay	σ_x (μm)	σ_z(μm)
Min Bias	47	70
$H \to \gamma\gamma$	26	44
B	29	45



b-tagging

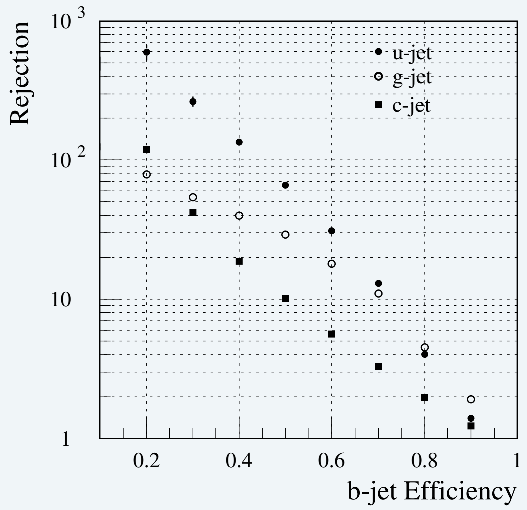
$H \rightarrow b\bar{b}$ vs $H \rightarrow u\bar{u}, c\bar{c}, gg$

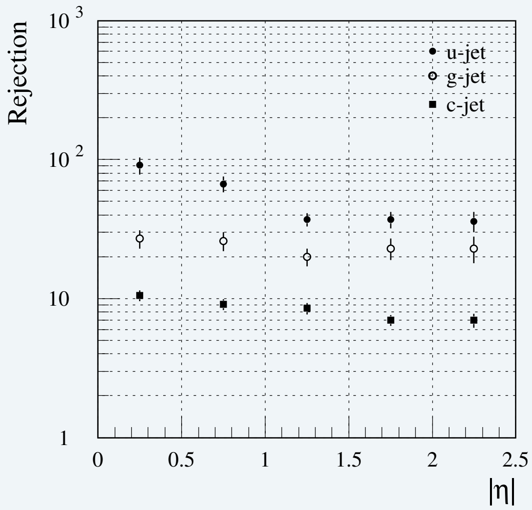
m_H = 400 GeV - ‘jet factory’

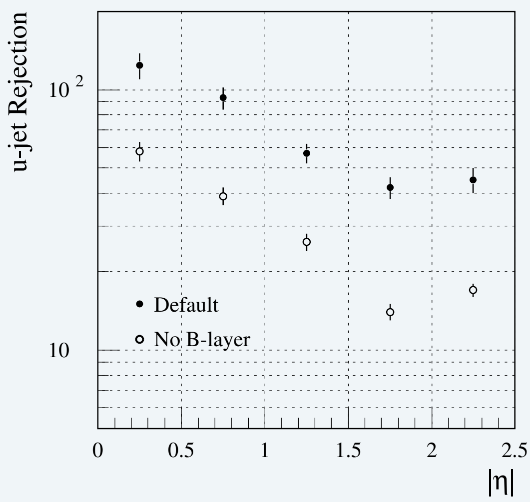
Use impact parameter

Likelihood method

B-layer essential





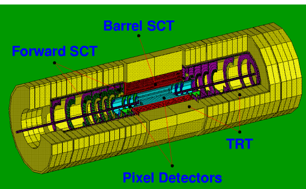


Rejection (1/efficiency) for b-tagging efficiency = 50%

m_H (GeV)	R_u	R_g	R_c
100	80 - 94	41 - 50	8 - 8
400	50 - 66	26 - 29	9 - 10

Still room for improvement:

Tag conversions, decays, use of z-information



u-jet rejection limited by

- photon conversions
- pion interactions

g-jet rejection limited by

- $Br(g \to c\bar{c}) = 6\%$ $m_H = 400$ GeV 4% $m_H = 100$ GeV
- $Br(g \to b\bar{b}) = 4\%$ 2%

c-jet rejection limited by

- c-quark lifetime

Soft lepton

Transition radiation, Ecal cuts and Matching to Ecal

$R_g \sim 100$ for b-tagging efficiency $\sim 50\% \times Br(b \to eX)$

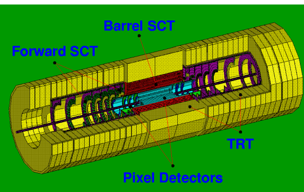
$H \to b\bar{b}$ (m_H = 100 GeV)

$pp \to WH$ with $H \to b\bar{b}$ 3×10^4 pb^{-1}

Tag	$S/\sqrt{B}$	S/B (%)
IP	2.4	1.8
IP + lepton	3.1	2.1

Room for improvement, some chance of measurement

... can combine with $H \to b\bar{b}$ from $pp \to t\bar{t}H$ and $H \to \gamma\gamma$



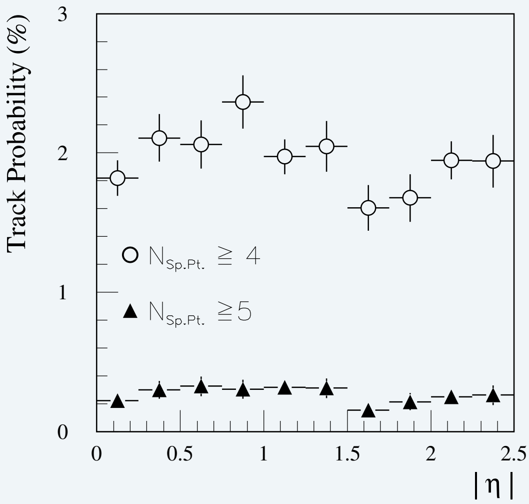
ID Level-2

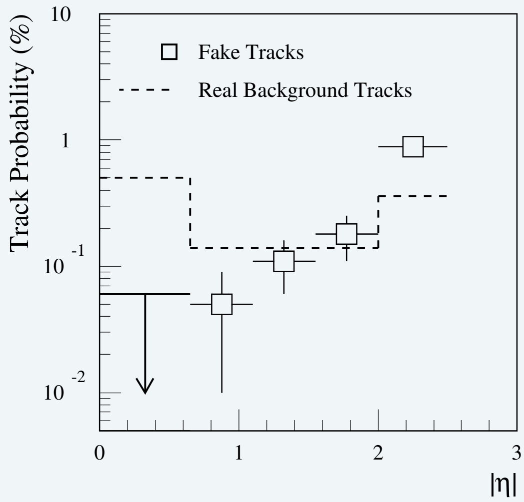
Precision and TRT both use histogramming method and fit

Fake rate in $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ at $10^{34}\ cm^{-2}s^{-1}$:

Precision $p_T > 7$ GeV
Eff(e_{20}) = 92%

TRT $p_T > 5$ GeV
Eff(e_{20}) = 85%





Rejection of jets:

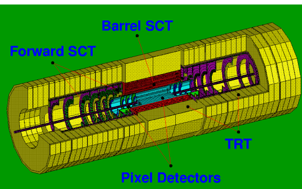
Look after Calorimeter Level-1 and Level-2 ($E_T > 17$ GeV)

Use ϕ and E/p match with EM calorimeter (Ecal)

	Eff(e_{30}) (%)	Rate (kHz)
Precision	95	1.4
TRT	91	1.5
Combined	88	0.7

Believe 700 Hz is acceptable

Can reduce rate by 2 with a 5 GeV increase in E_T cut (Ecal)



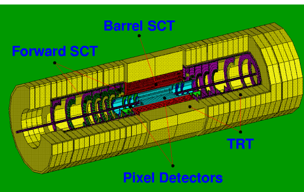
B-physics Trigger

For low luminosity

1. Find *all* tracks in TRT ($|\eta| \leq 2.5$)
2. Extrapolate to precision layers
3. Make cuts:
   - p_T cuts - low
   - mass cuts - loose
   - TR capability to identify $e^{\pm}$

Without efficiency loss at the analysis stage, can reduce rate below target of 800 Hz:

B decay	Trigger	Rate (Hz)
B_d	$J/\psi \to e^+e^-$	370
B_d	$B_d \to \pi\pi$	130
B_s	$D_s \to \phi\pi$	160



Conclusions

Based on detailed simulation, we have found:

- Combination of precision and continuous tracking is very robust
- Extra electron-id is a valuable tool for physics
- b-tagging performance is well understood

- Impact parameter resolution:
  $11\ (1 \oplus 5.5/p_T\sqrt{\sin\theta})\ \mu m$
- Isolated high-p_T muons ($p_T > 20$ GeV) with pile-up:
  Efficiency > 99%, Fakes << Pile-up
- Tracks in high-p_T jets ($p_T = 200$ GeV):
  Efficiency ≈ 88%, Fakes < 0.2%
- Inclusive high-p_T electrons ($p_T > 20$ GeV):
  Efficiency > 70%, S/B ≈ 6
- $H \to \gamma\gamma$ vs $Z \to ee$ ($m_H \approx m_Z$):
  Efficiency($H\to\gamma\gamma$) > $(0.85)^2$, S/B ≈ 10
- For 50% b-tagging efficiency, can obtain rejections (m_H=100 GeV) for u-, gluon-, c-jets: ≥ 80, ≥ 40, 8

The ATLAS Collaboration has demonstrated in the ID TDR that the current design for the Inner Detector satisfies the requirements for operation at the LHC and will be ready for physics in 2005.

We hope the LHCC will recommend approval for construction of the SCT and TRT systems.

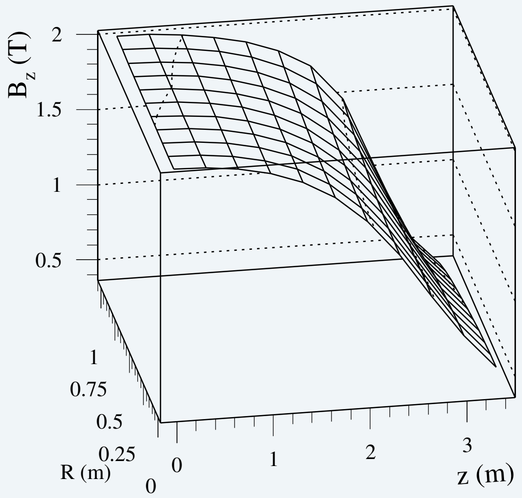
B Field

Coil between ID and EM calorimeter (Ecal)

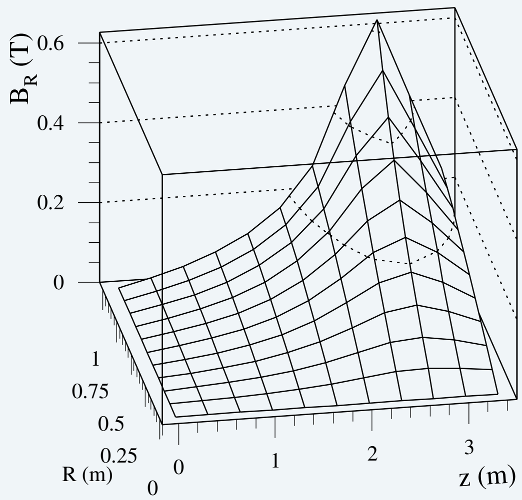
- Coil integrated into liquid argon (Ecal) barrel cryostat
- Want < 3 X_0 in front of Ecal

→ Half length: Coil = 270 cm cf ID = 340 cm

Longitudinal



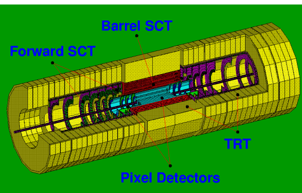
Radial



Simulation with uniform 2 T field

Anticipate difference is not significant except for $\sigma(1/p_T)$

ATLAS INNER DETECTOR

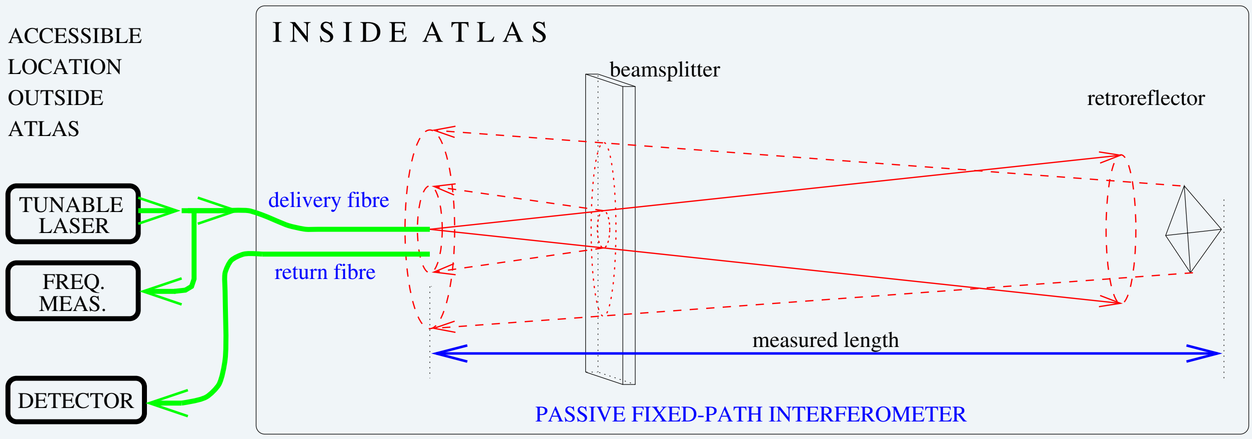


Frequency Scan Interferometry (FSI)

Two beam interferometry, no moving parts

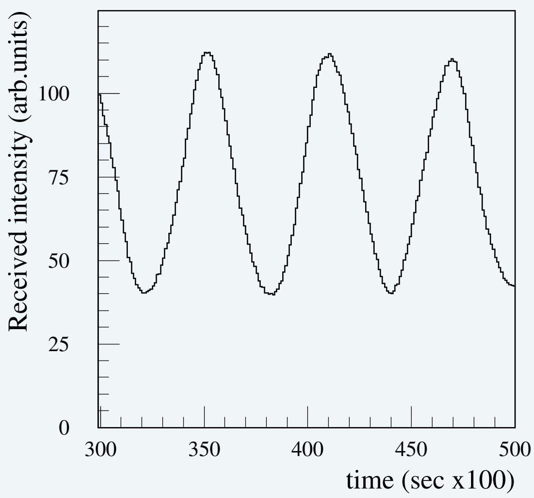
Network of length measurements:

$$L = n\,\lambda_1 = (n+\Delta n)\,\lambda_2$$



- $\Delta L \leq 1\ \mu m$
- No active parts on-detector
- On-detector parts are rad hard and low mass
- Small cost for extra measurements

In the Lab:



Pixels	$\Delta R\phi \leq 4\ \mu m$
SCT	$\Delta R\phi \leq 9\ \mu m$