Forward Tracking Detectors

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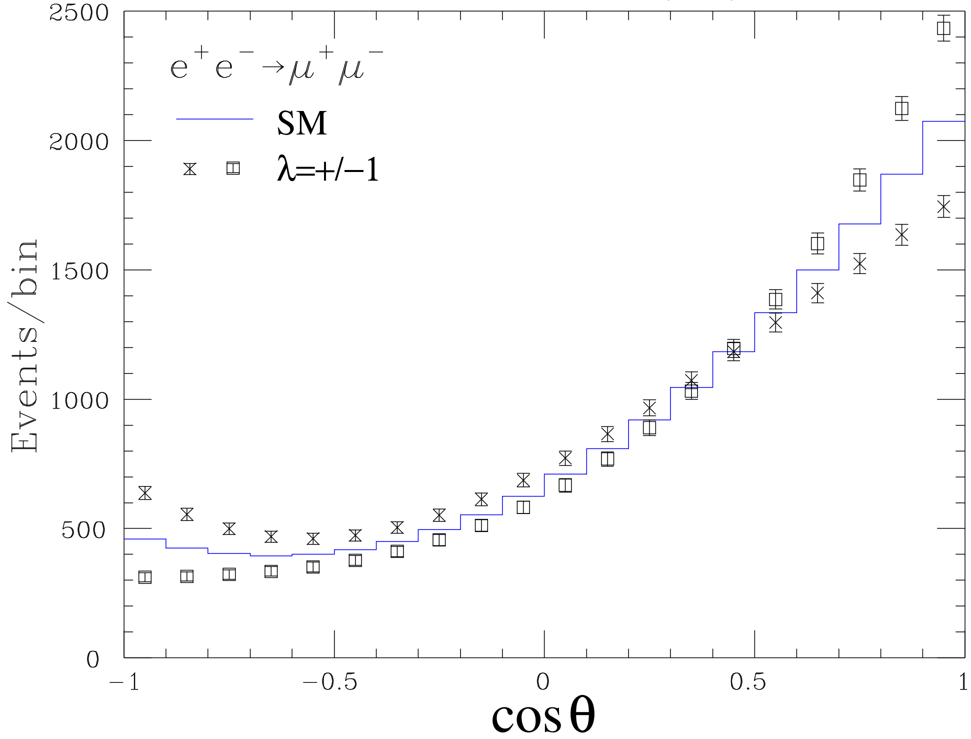
Disclaimer: This talk is meant to motivate forward tracking and to show possible problems and solutions. The TESLA-TDR detector ≈ LDC will be used over-proportionally for illustration.

Why forward tracking?

- Many processes at LC are peaked in the forward region like Bhabha scattering or W-pair production
- Fermion pair production has highest sensitivity to forward-backward asymmetry or to distinguish Z' effects from extra dimensions in the forward region

G^*-effects in $e^+e^- \rightarrow \mu^+\mu^-$



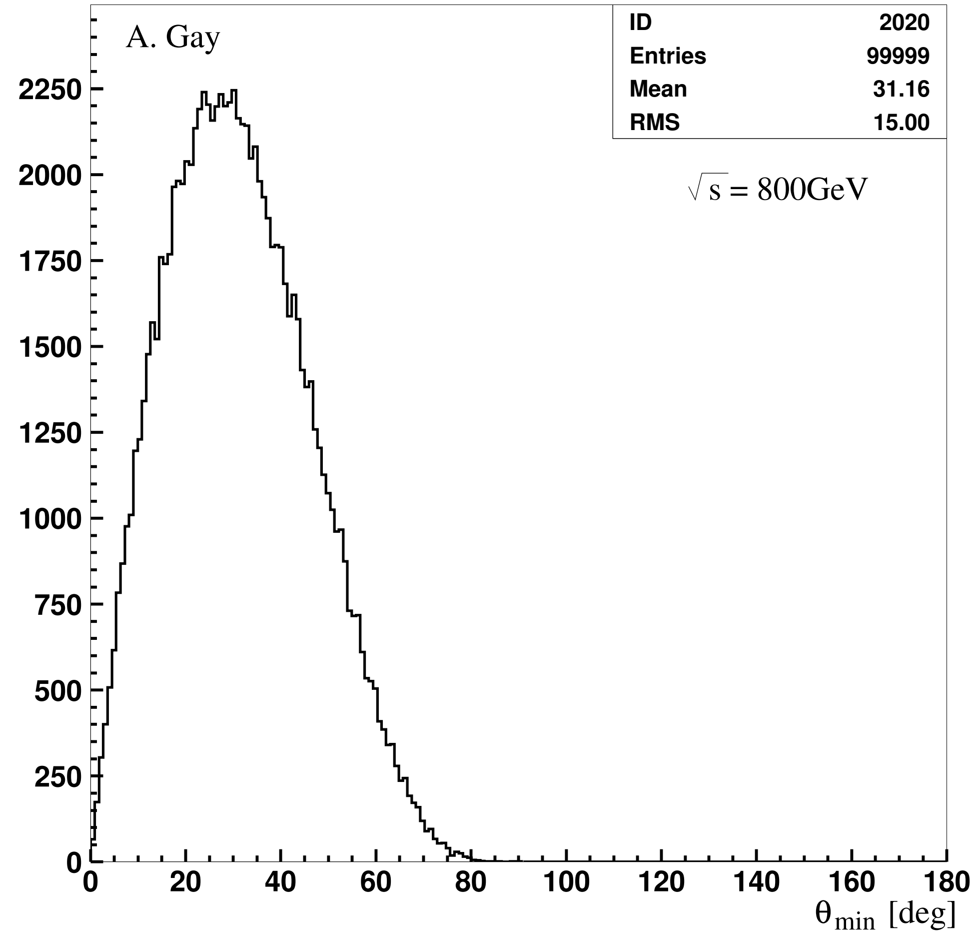
- W-pairs forward peaked with high momentum muons due to W-polarisation

➡ Good momentum resolution in the forward region is essential for charge determination and W suppression

Multi-jet final states

- At ILC many interesting processes have high jet multiplicity:
  $t\bar{t}$: 6 jets, ZHH: 6-10 jets, $t\bar{t}H$: 8-10 jets
- If the involved energies are not too far above threshold the jet directions are rather independent and flat in $\cos\theta$
- Even if the primary event is central there is a very high chance that at least one jet is forward
- Need full pflow coverage down to lowest possible angles

Minimum jet polar angle for $e^+e^- \to t\bar{t}$



Bhabha scattering

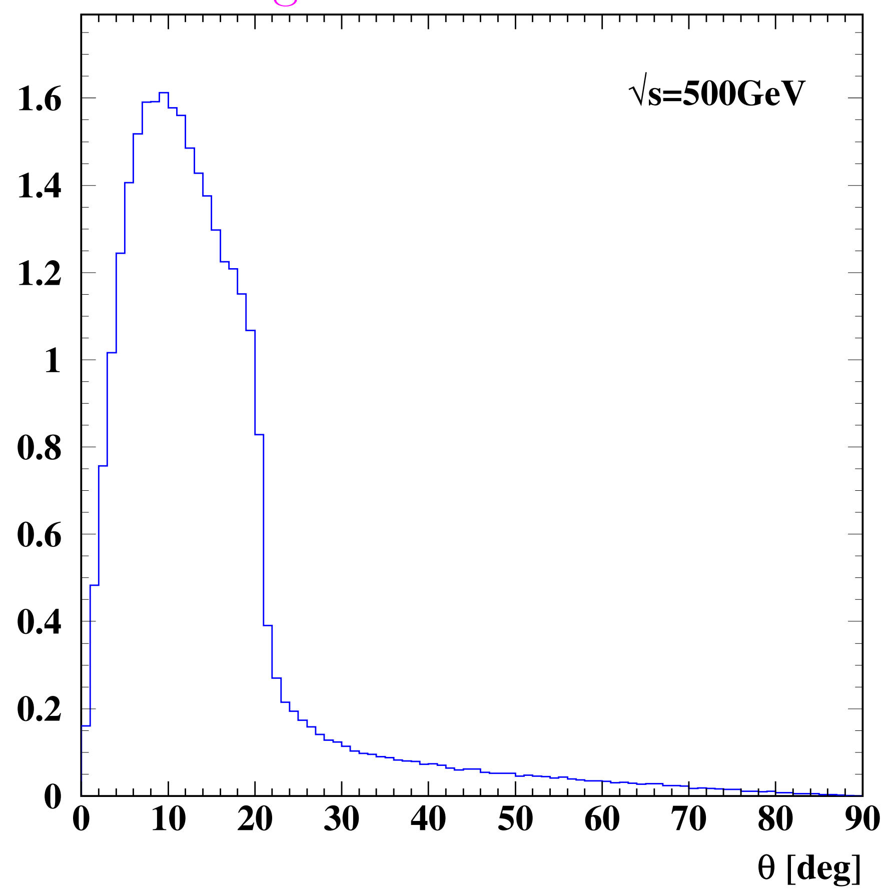
- ideal calibration process for the beam spectrum
- again strongly forward peaked ($d\sigma/d\theta \propto 1/\theta^3$)
- reconstruct $\sqrt{s'}$ of e^+e^- system from polar angles assuming energy momentum conservation and only one radiated photon
- want to measure beamstrahlung ($\mathcal{O}(10^{-2})$) and beam energy spread ($\mathcal{O}(10^{-3})$)
- $\sqrt{s'}$ error from angular reconstruction method: $\Delta\sqrt{s'}/\sqrt{s'} \approx \Delta\theta/\sin\theta$
  ➡ need $\Delta\theta < 10^{-4}$ in forward region
- electrons radiate in material and cylinders (e.g. TPC field cage) are crossed with small angles
  ➡ better assure angular resolution close to the IP

➡ good angular resolution close to the IP is key point for Bhabha

Radiative Return ($e^+e^- \to Z\gamma \to \ell^+\ell^-\gamma$)

- Ideal calibration process for the beam energy
- Due to large boost leptons are normally in the forward region
- The beam energy can be determined to $1.5 \cdot 10^{-4}$ using only polar angles
- It has been shown that the precision can be improved to $5 \cdot 10^{-5}$ with $\Delta \frac{1}{p_t} = 2 \cdot 10^{-5} / \mathrm{GeV}$ momentum resolution if the resolution is known apart from one free scale.

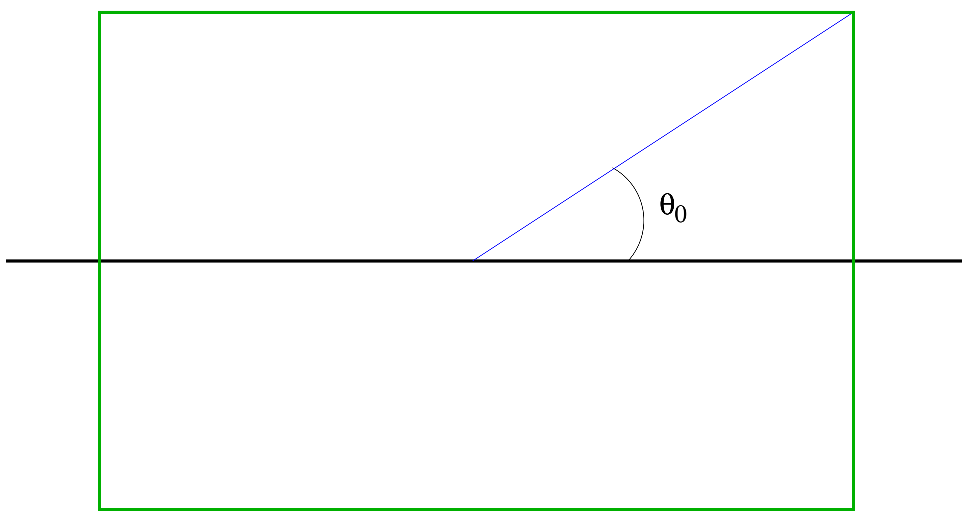
Minimum angle of radiative return events



General considerations

General scaling of momentum resolution: $\frac{\Delta p}{p} \propto \frac{p_t}{R^2}$
(Details depend on exact detector setup)

- Barrel region ($\theta > \theta_0$): $p_t = p \sin\theta$, $R = const.$
  $\Rightarrow \frac{\Delta p}{p} \propto p \sin\theta$
- Forward region ($\theta < \theta_0$): $p_t = p \sin\theta$, $R = l \tan\theta$
  $\Rightarrow \frac{\Delta p}{p} \propto p \sin\theta / \tan^2\theta \approx p/\tan\theta$



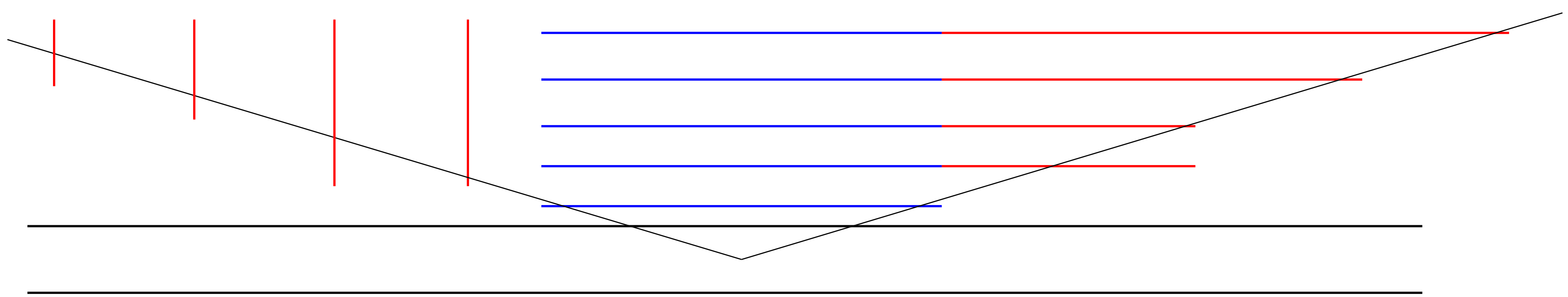
Possible layout:

Cylinders:

- need to be very long
- z-resolution decreases with angle

Disks:

- Less detector material
- Possibly better z resolution
- however material from barrel electronics and cables needs to be crossed



Background in the forward region

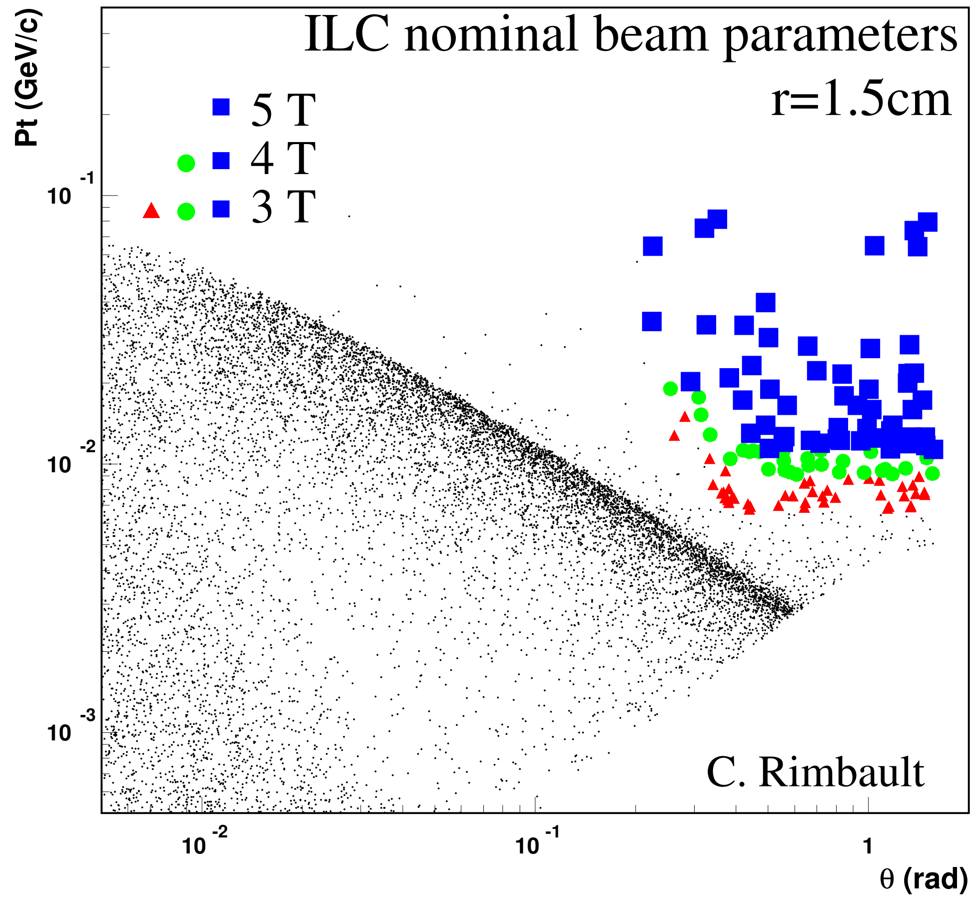
Pair background larger for smaller θ

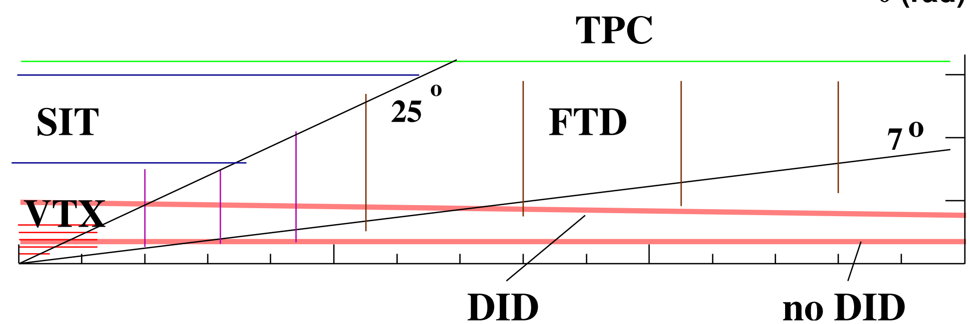
➠ Possibly many hits close to IP

Additional problem with large crossing angle (e.g. 20 mrad):

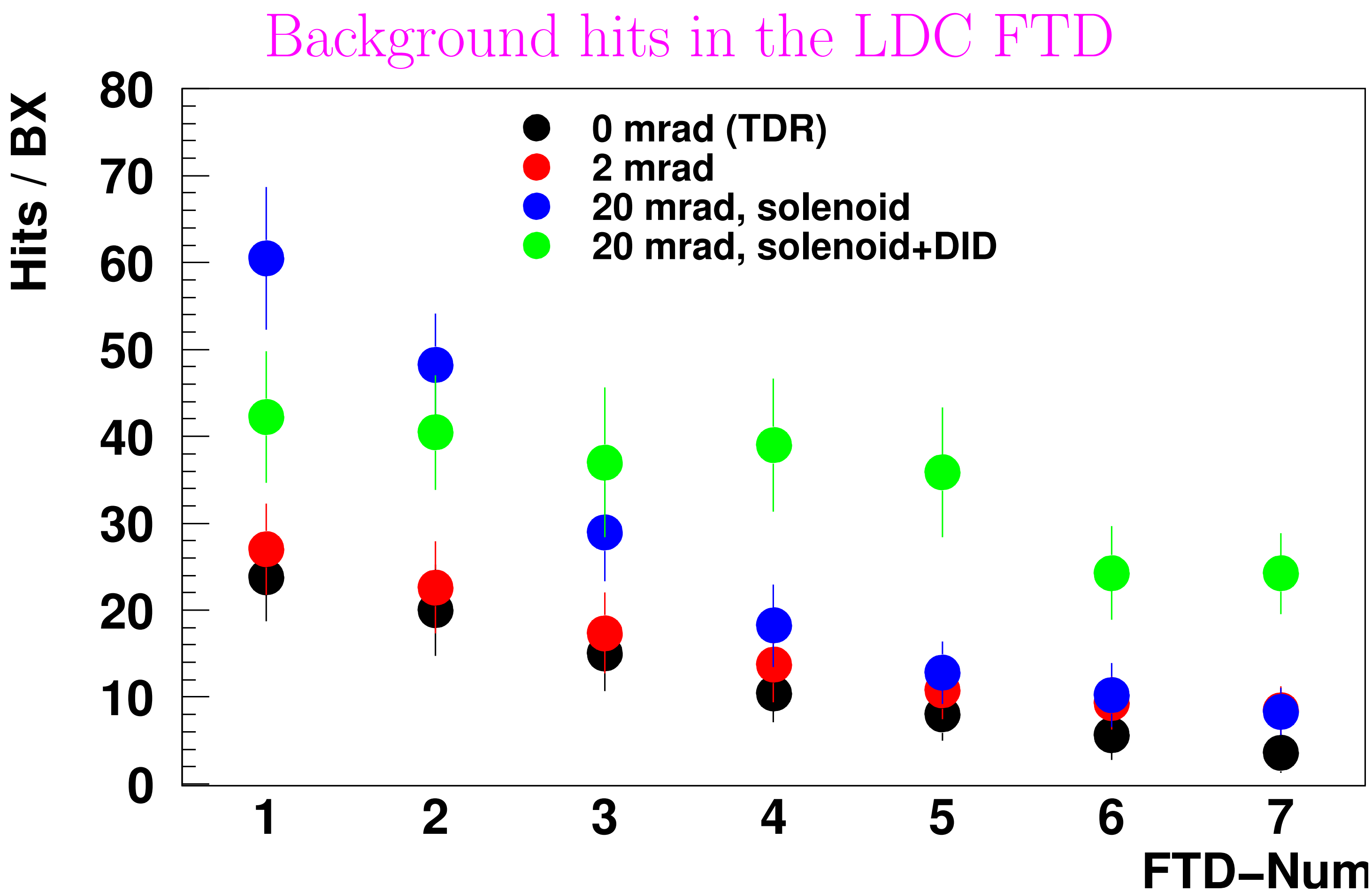
Backscattering Outgoing beamhole above inner detector radius ($\sim$ 3.5 cm)

- Ideal solenoid: The backscattering background is guided into the detector at constant radius by solenoid field
- With DID: The background from the outgoing hole is guided to even larger radii





In practise both components are relevant



The backscattered background has an $\mathcal{O}$(5m) longer way to the detector

➟ A $\mathcal{O}$(5ns) time resolution can suppress this background component in the crossing angle case.

Possible technologies close to IP

Pixels

- in general less sensitive to background and track density
- expensive
- two types:

  Vertex detector technology

  – very precise

  – very thin

  – slow (integration over $\sim$ 100 bx makes them background sensitive

  LHC type hybrid pixels

  – medium precision ($\sim (50 \times 400\mu\text{m}^2)/\sqrt{12}$)

  – relatively thick (ATLAS: $2\% X_0$)

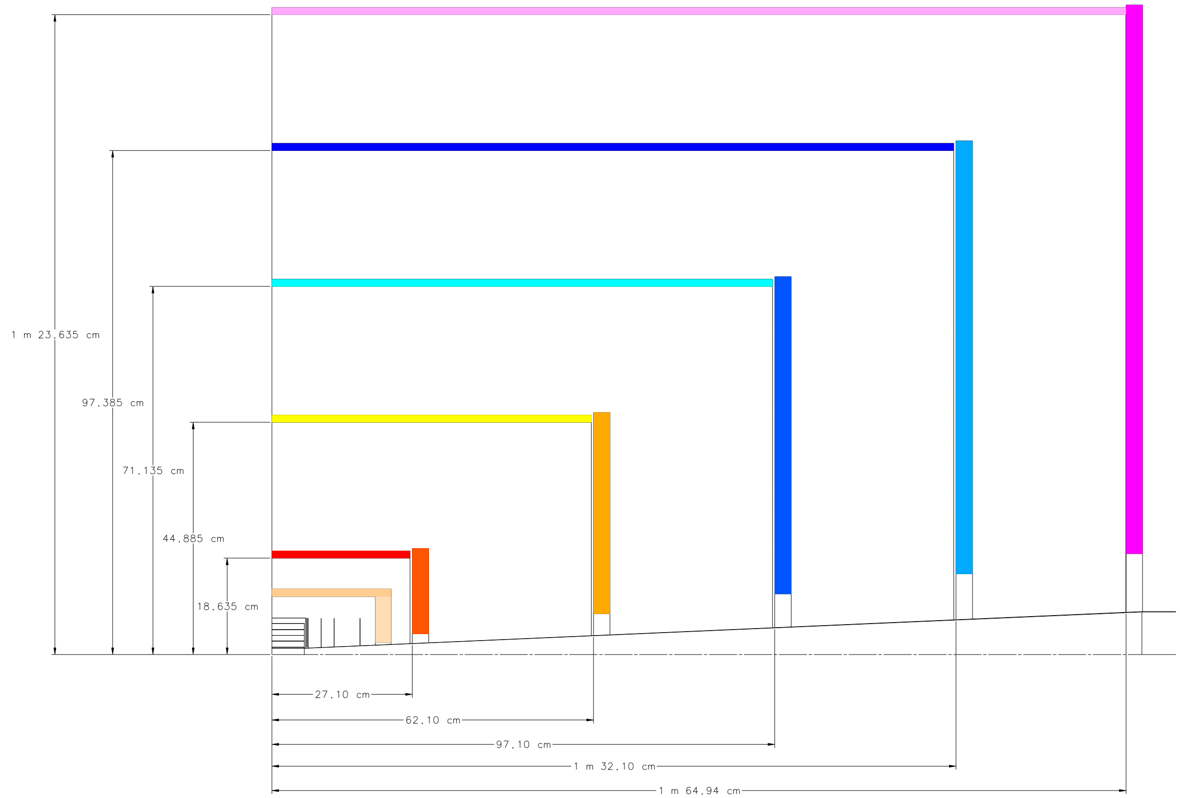
Silicon strips

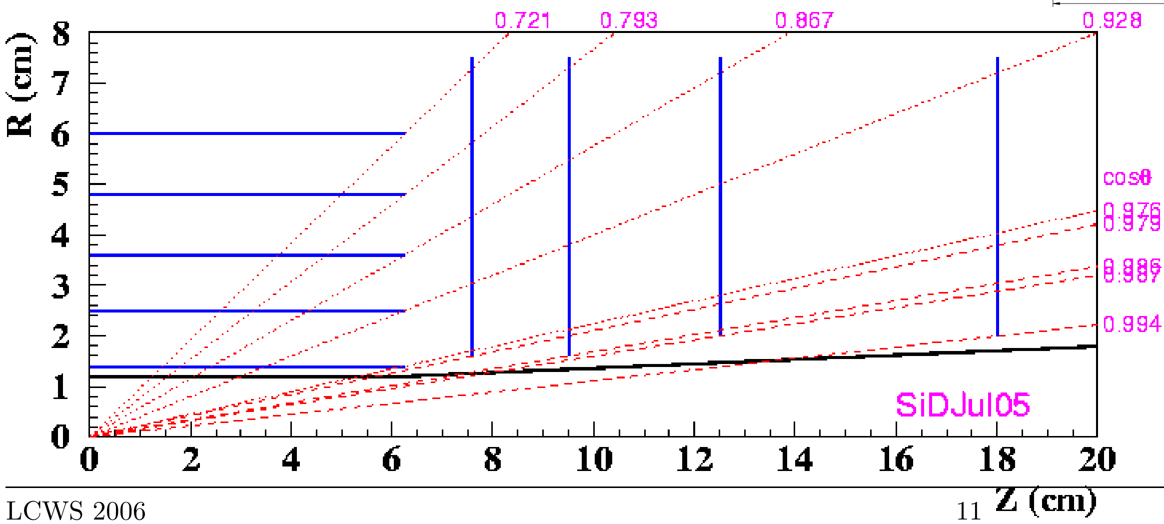
- precise
- relatively cheap
- sensitive to background and track density

Concrete implementation in the concepts

SID

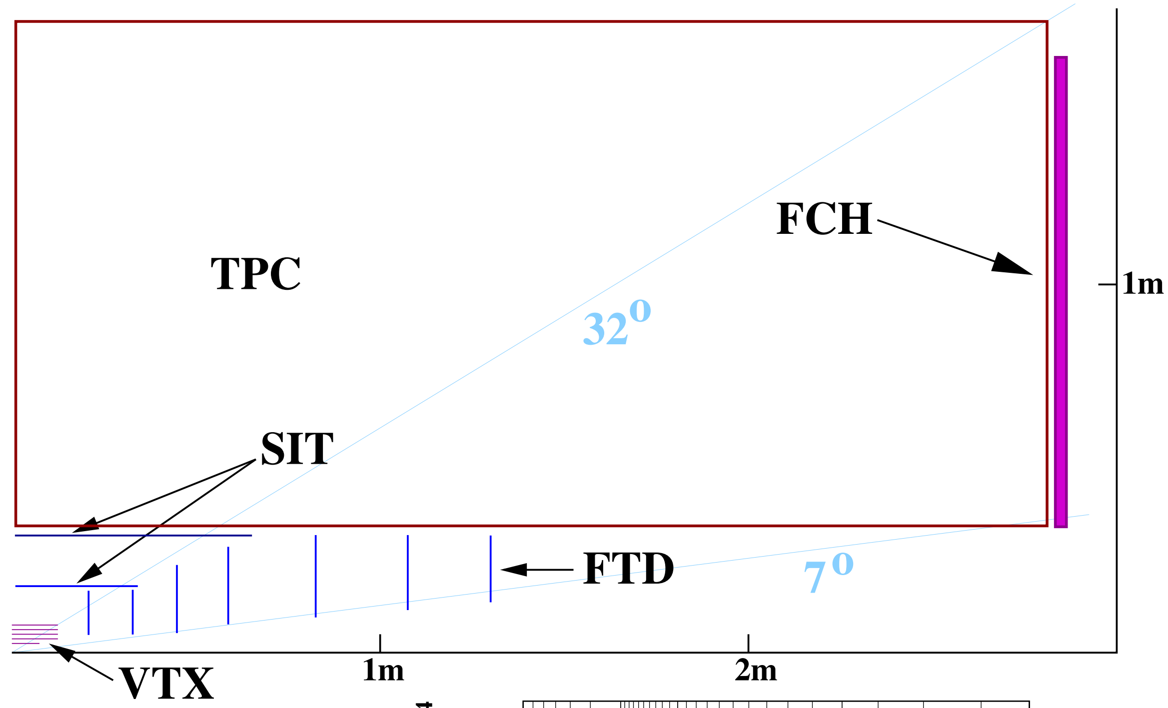
Vertex detector and main tracker separated in barrel cylinders and endcap tracks

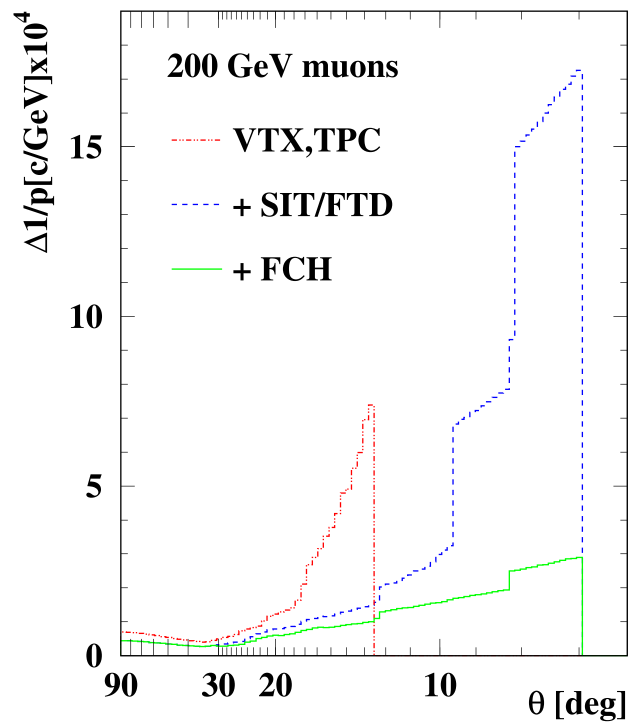




LDC

- Long TPC
- Vertex detector only cylinders
- Intermediate silicon with forward discs
- One plane behind TPC

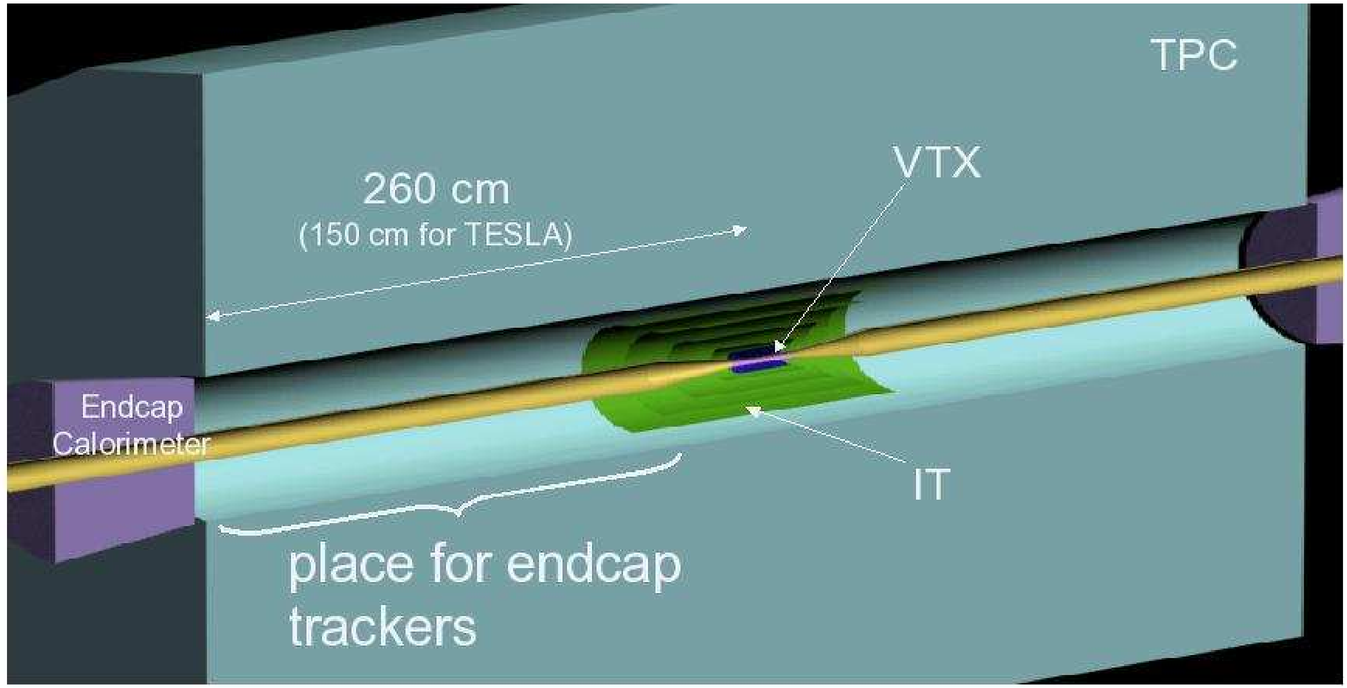


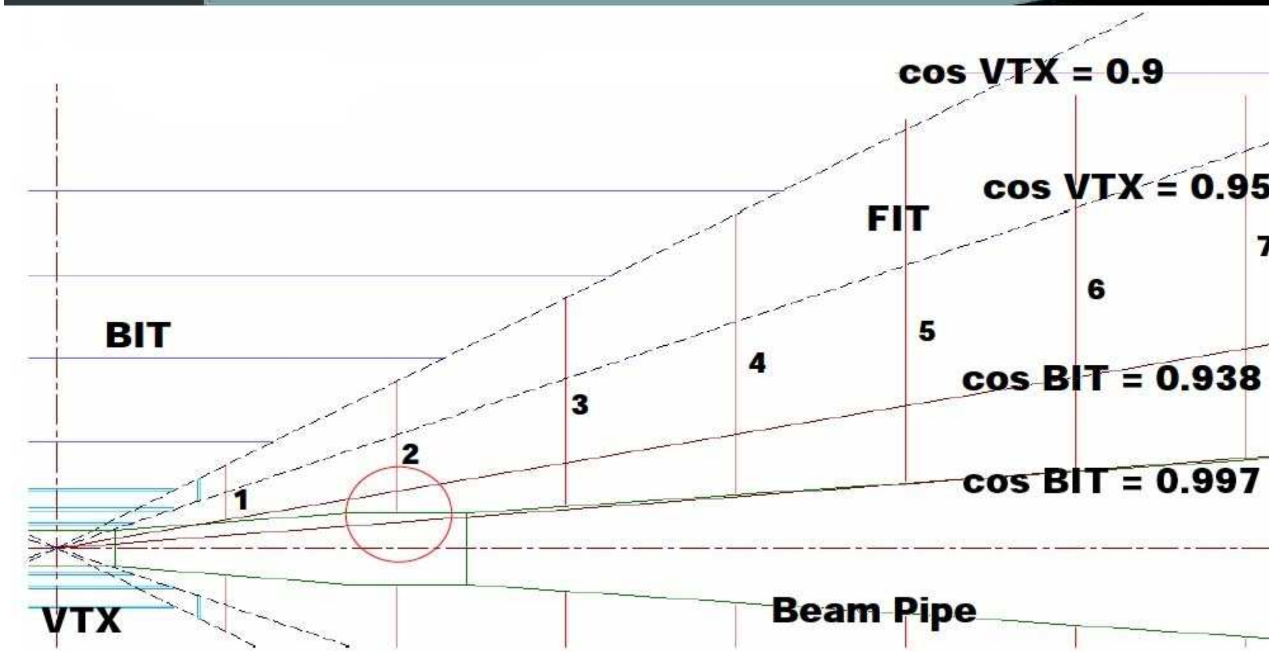


- At present hybrid solution of ATLAS type pixels (3 disks) and strips (4 disks)
- Vertex detector like disk under investigation
- FTD is mandatory
- FCH helps a lot a lowest possible angles

GLD

- Very similar to LDC
- No disk behind TPC (yet)

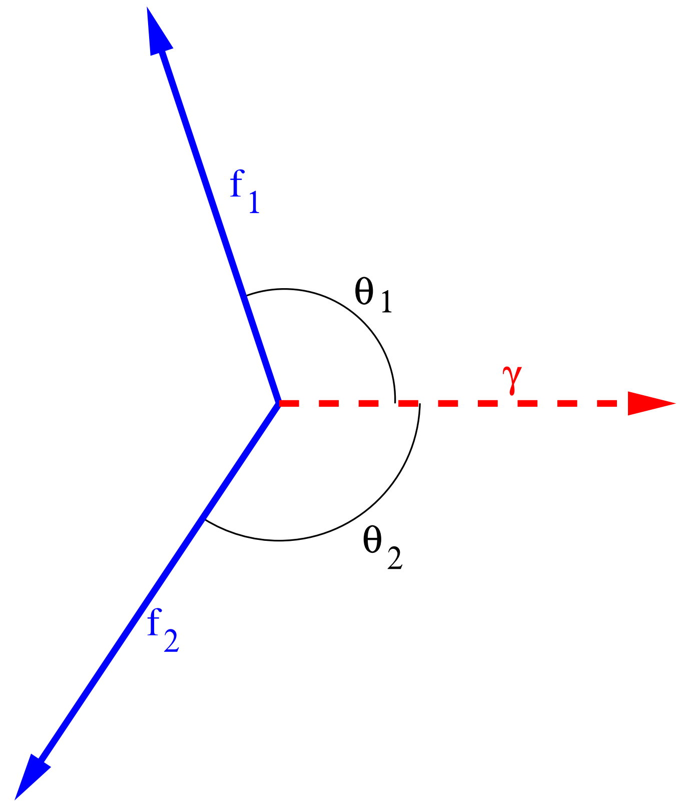




New challenge: systematics

Example: beam energy with radiative return

- Beam energy can be measured from angles and Z-mass constraint
- $\sqrt{s} = m_Z \sqrt{\frac{\sin\theta_1 + \sin\theta_2 - \sin(\theta_1+\theta_2)}{\sin\theta_1 + \sin\theta_2 + \sin(\theta_1+\theta_2)}}$
- Error from $100\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 350\,\mathrm{GeV}$: $\Delta\sqrt{s} = 50\,\mathrm{MeV}$
- Detector uncertainty: Aspect ratio (R/L) error systematically shifts θ



$$\Delta\left(\frac{\delta R}{\delta L}\right) = \delta\tan\theta = 10^{-4} \Rightarrow \Delta\sqrt{s} = 30\,\mathrm{MeV}$$

Need this precision in the detector aspect ratio

Can only be reached with a robust design that can be surveyed well before installation

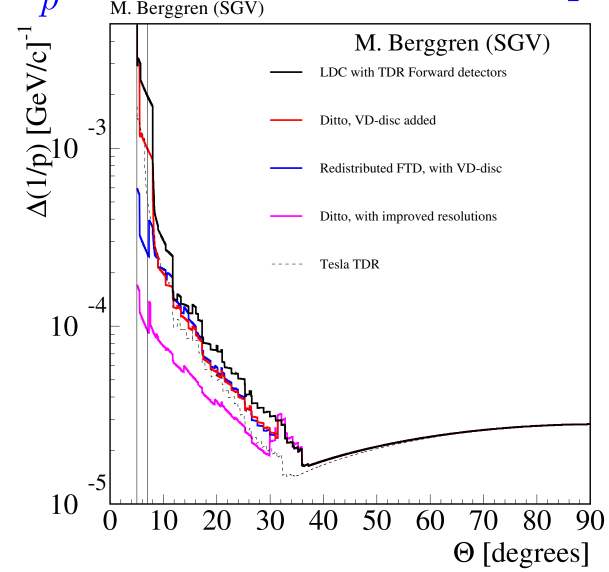
How to optimise the forward tracking

- (Partially conflicting) parameters: material, resolution, background tolerance, price
- Material might be critical for particle flow
- Background may prohibit vertex detector like disks
- Choice strips/pixels also determined by local track density
- Urgently need a pattern recognition program to answer these questions

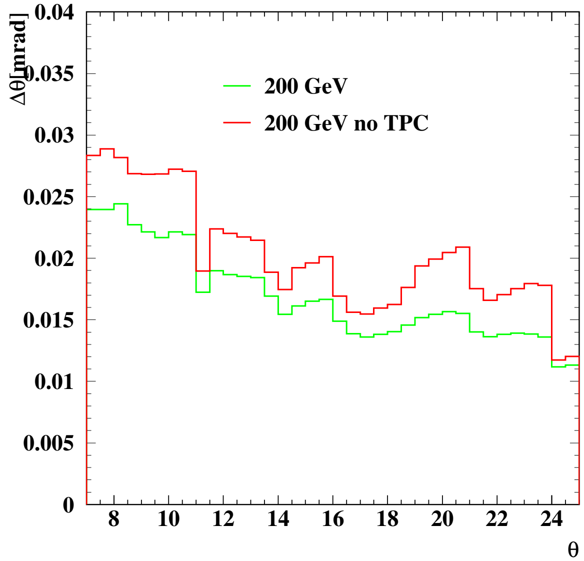
Performance (example LDC)

- $\Delta\frac{1}{p} = 2 \cdot 10^{-5} - 10^{-3}$ depending on angle and detector setup
- Polar angle resolution $20\,\mu$rad even with inner silicon only
- Sufficient to measure beamstrahlung and beamspread from Bhabha acolinearity

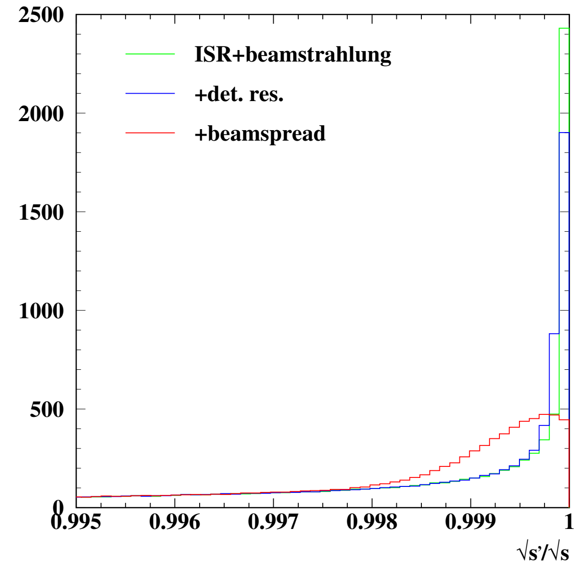
$\Delta\frac{1}{p}$ for different LDC setups



Polar angle resolution in forward region



$\sqrt{s'}$ spectra from Bhabha acolinearity



Conclusions

- Forward tracking needed for physics and calibration
- In principle under control, but needs optimisation
- Additional large effort on detector R&D seems not necessary
- However a reconstruction algorithm is urgently needed
- Forward tracking is certainly not the most important part of the detector but should also not be forgotten