Particle Identification for a Linear Collider Detector

Where are we, and where do we go from here? A North American perspective.

Worldwide Study on

Physics and Experiments with Future Linear e^+e^- Colliders

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Outline

- ✔ PID status in Europe and Japan?
- ✔ PID decision philosophies.
- ✔ What should PID groups do?
- ✔ Technology example
  - Ring Imaging Cerenkov technique
  - Compact implementation: DIRC
- ✔ A simple PID analysis
- ✔ Conclusions

PID studies in Europe & Japan?

- Has PID dropped below the event horizon in physics studies and overall detector optimisation?
- If so, is it for good reasons?

PID Development Philosophies

A Must identify key physics requiring PID.

B Plan for PID, we will use it if we have it.

In practice : $\Psi = \alpha\,\mathbf{A} + \beta\,\mathbf{B}$

In an ideal world: $\alpha \approx 1,\ \beta \approx 0$

Worldwide detector studies to date:

$\Rightarrow \quad \alpha >> \beta$ **??**

In the real world...

- Often, uses for PID not recognized until data is in hand.
- But also... some PID systems haven't earned their keep.
- *For such a unique facility we should at least **begin** with the goal to know everything about an event - not just the 3-vectors. There may be surprises (we hope so!).*
- Back to the real world… PID has a negative impact on tracking/calorimetry, so what we need now is

$$\alpha \approx \beta \approx \gamma_{other}$$

- This will allow a coherent design optimisation of the entire experiment.

What does this mean in practice?

- We need a much larger focus on PID - similar scale to tracking and calorimetry efforts.
- We need to keep searching for specific physics to justify PID explicitly - we may even find a “golden” mode
- The current PID groups are so small that they could not cover the phase space of LC physics, thoroughly and in reasonable time.
- The existing physics groups should be primed to address PID specific questions. The results carefully collated.

What *should* PID groups do?

- ✔ Select some particularly promising topics to provide practical examples for other groups.
- ✔ Provide the physics groups with guidelines on *plausible* PID technical capabilities and tradeoffs e.g. momentum range *vs.* space requirements.
- ✔ Provide PID code for simulation/reconstruction efforts.

Promising topics for PID

- Strange, charm, bottom tagging

$$e^+e^- \to t\bar{t} \to W^+bW^-\bar{b}$$

$$e^+e^- \to HA \to bbbb, bb\tau\tau$$

$$W^+ \to c\bar{s} \quad above \quad u\bar{d}$$

$$t \to W^+\bar{s}, \quad \Rightarrow V_{ts}$$

Asymmetries

- Multi-jet analysis - net flavor?
- Your favorite process here!

PID Interests in the US

- ✔ PID detector technologies review
- ✔ Top studies - discrimination from WW, new physics,
- ✔ $t \rightarrow Ws$, polarization? (*c.f.* M.Peskin)
- ✔ Flavor asymmetries: $A_{s,c,b}$
- ✔ Higgs - B tag
- ✔ Heavy, long-lived, charged particle
- ✔ Other SUSY

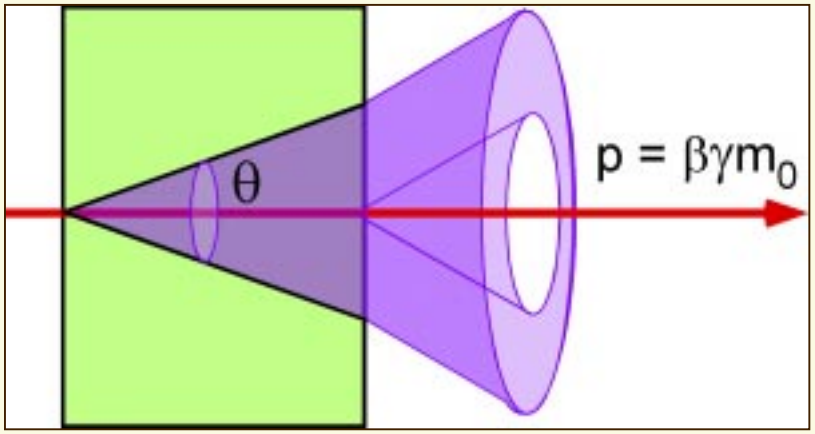
PID Technology Review

- What could we get for “free” i.e. from the tracking & calorimetry subsystems?
  - e.g. tracker dE/dx - *Next talk by H. Yamamoto*
- What could we get from a PID subsystem?
  - Transition Radiation Detector
  - Scintillator/Cerenkov Time-of-flight
  - Threshold Cerenkov
  - Ring imaging Cerenkov

Technology Example

Cerenkov Ring Imaging

$$\cos\theta = \frac{1}{\beta n}$$



$$\gamma_{threshold} = \left(1 - \frac{1}{n^2}\right)^{-1/2}$$

$$N_\gamma = N_0 L z^2 \sin^2\theta$$

In practice, need $\langle N_\gamma \rangle \approx 10$

Detection of Internally Reflected Cerenkov light

- ✔ Most compact (radially) Cerenkov device.
- ✔ BaBar DIRC
  - quartz radiator, refractive index n=1.474
  - radiator thickness, L=1.8 cm
  - radial extent including support structure, 8 cms

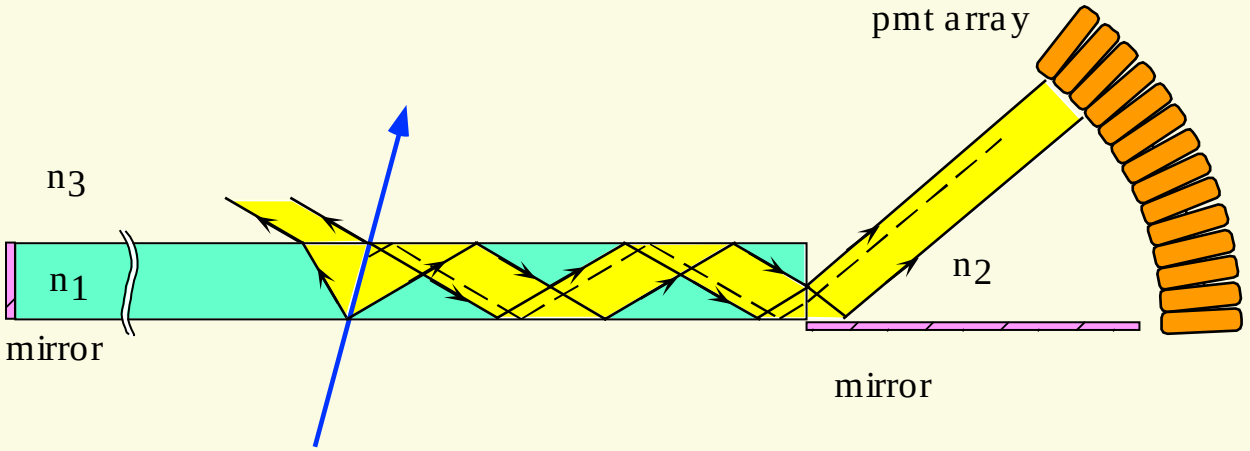
$$\beta_{threshold} = 0.68, \qquad \gamma_{threshold} = 1.36$$

$$\Rightarrow p_{threshold} = 0.92 m_{\mu,\pi,K,p}$$

$$N_{\gamma}(\beta \approx 1, normal, pmt) \approx 30$$

DIRC Principle

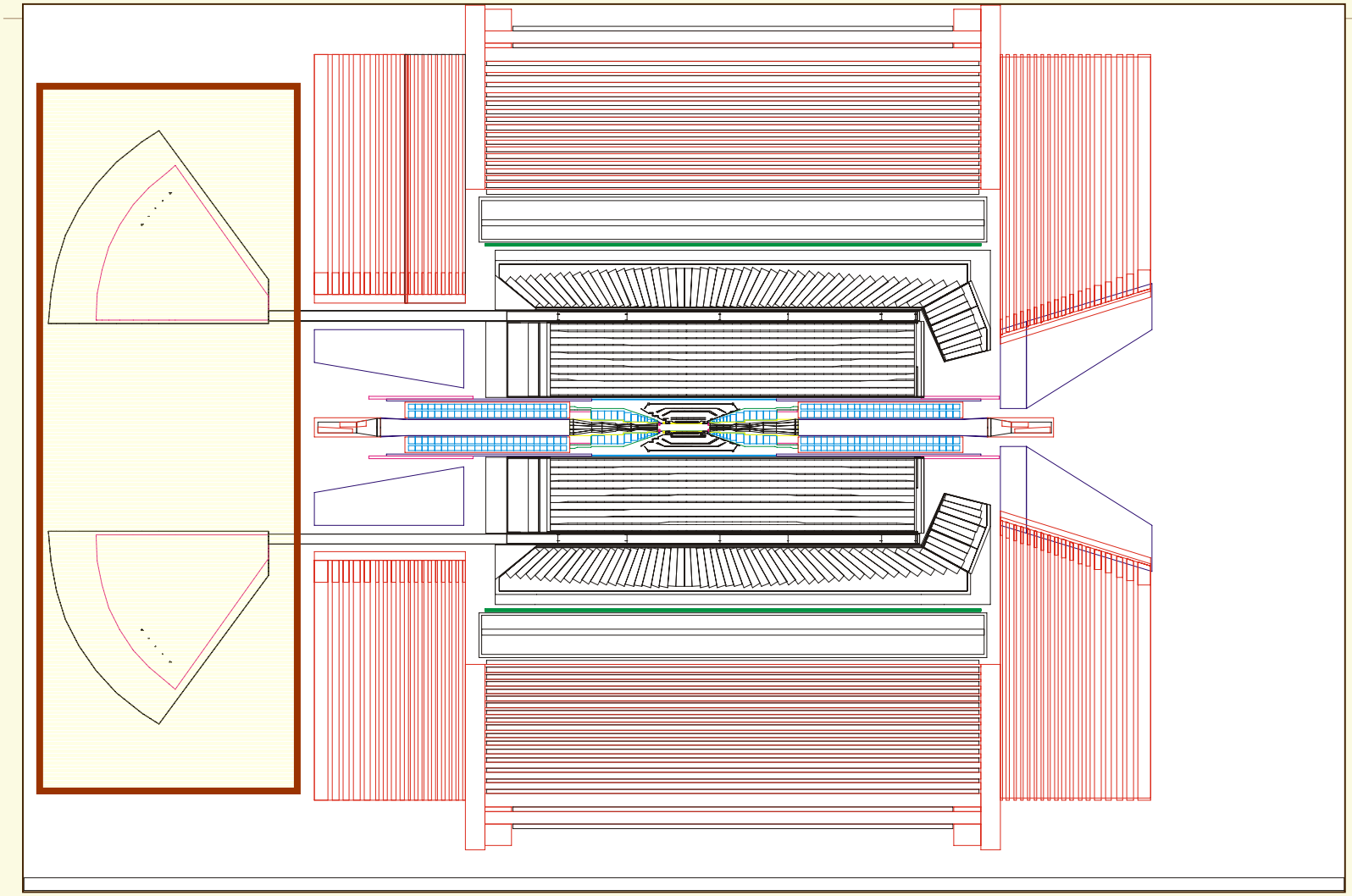
- Cerenkov light captured in a rectangular light guide
- single photon angle reconstruction



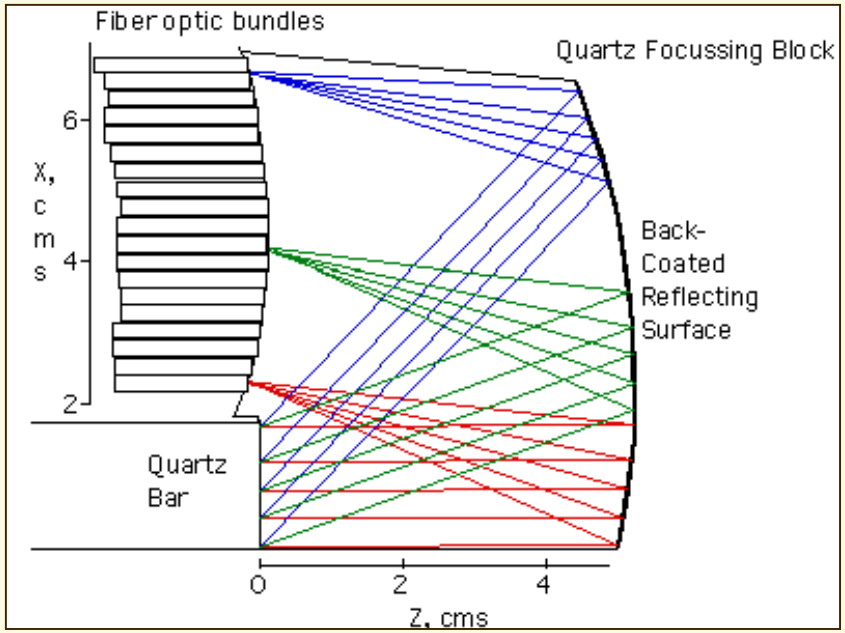
DIRC Advantages

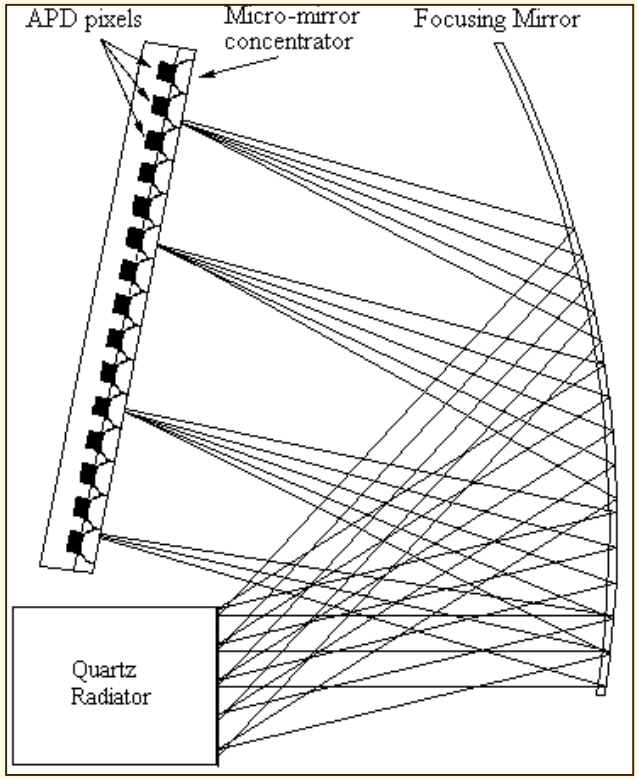
- ✔ *Compact (many photons/cm)*
- ✔ *Simple (monolithic, stable, solid radiator)*
- ✔ *Uniform (simple, homogeneous geometry)*
- ✔ *No active components in fiducial volume*
- ✔ *No gas system*
- ✔ *Acceptable mass close to calorimeter face*

BaBar DIRC



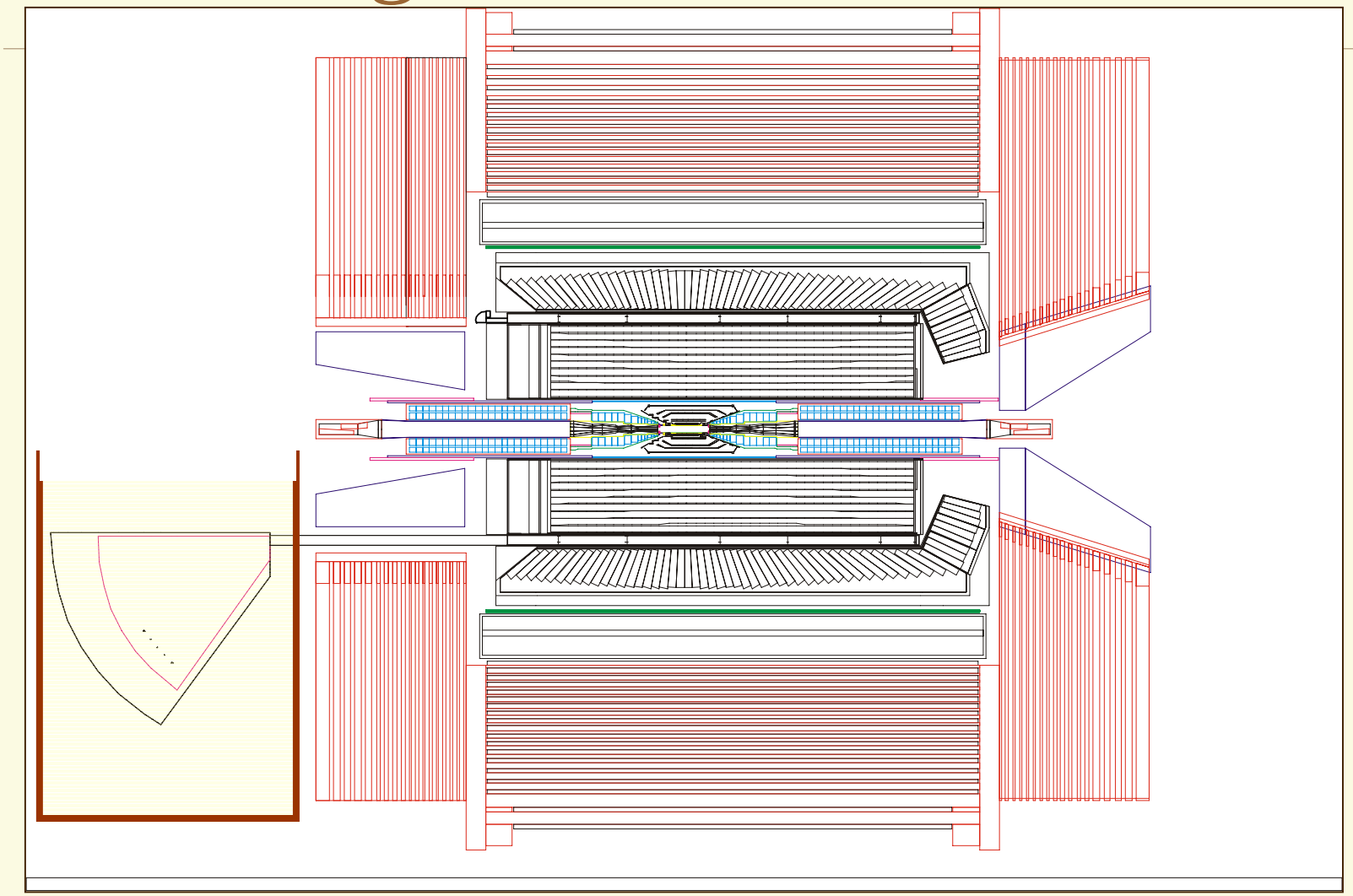
Focussing DIRC





- 1-axis/2-axis focussing (cylindrical/spherical)
- 1-axis focussing + timing (J-J. Veillet, M. Akatsu *et al*)

Focussing DIRC at BaBar



Photon Angular resolution

- Maximum momentum for separation by n_σ standard deviations

$$p_{\max} = \left(\frac{\beta^2 \Delta m^2 \beta_t \gamma_t N_\gamma^{1/2}}{2 n_\sigma \sigma_\theta} \right)^{1/2}$$

- For 3σ π-K separation in 18 mm quartz

$$p_{\max} = 0.14 \left(N_\gamma^{1/4} / \sigma_\theta^{1/2} \right)$$

- $p_{max} \approx 4$ GeV/c for BaBar-DIRC
  - double radiator thickness $\Rightarrow$ 20% increase in p_{max}
  - factor two better resolution $\Rightarrow$ 40% increase in p_{max}
- Limit for this technique 6-8 GeV/c

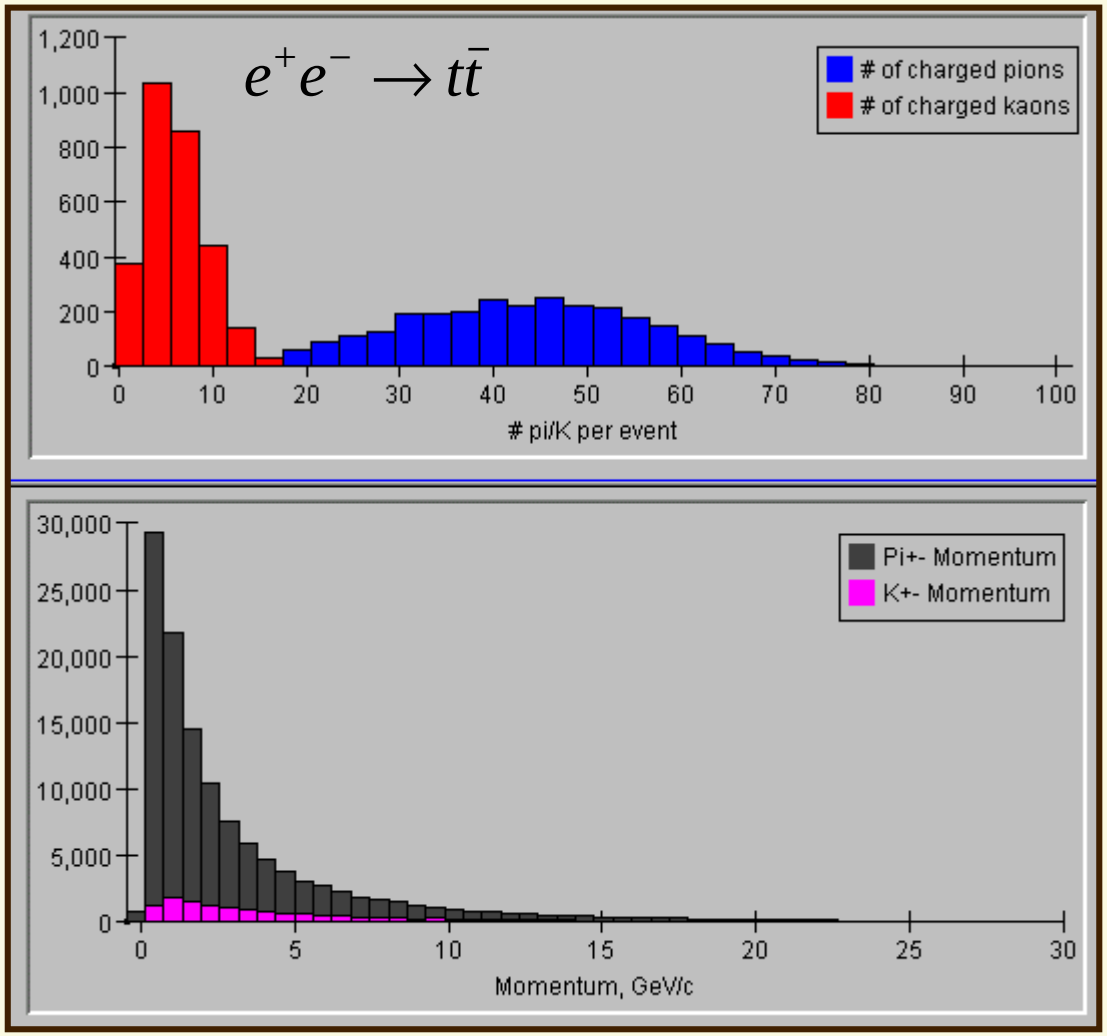
PID Subsystem impact

- ✔ Material in front of the calorimeter
  - – How much is tolerable? What is the spec.?
- ✔ Calorimeter cost *vs.* inner radius
- ✔ Track resolution (BL^2)
- ✔ ***The goal is the best LC physics***

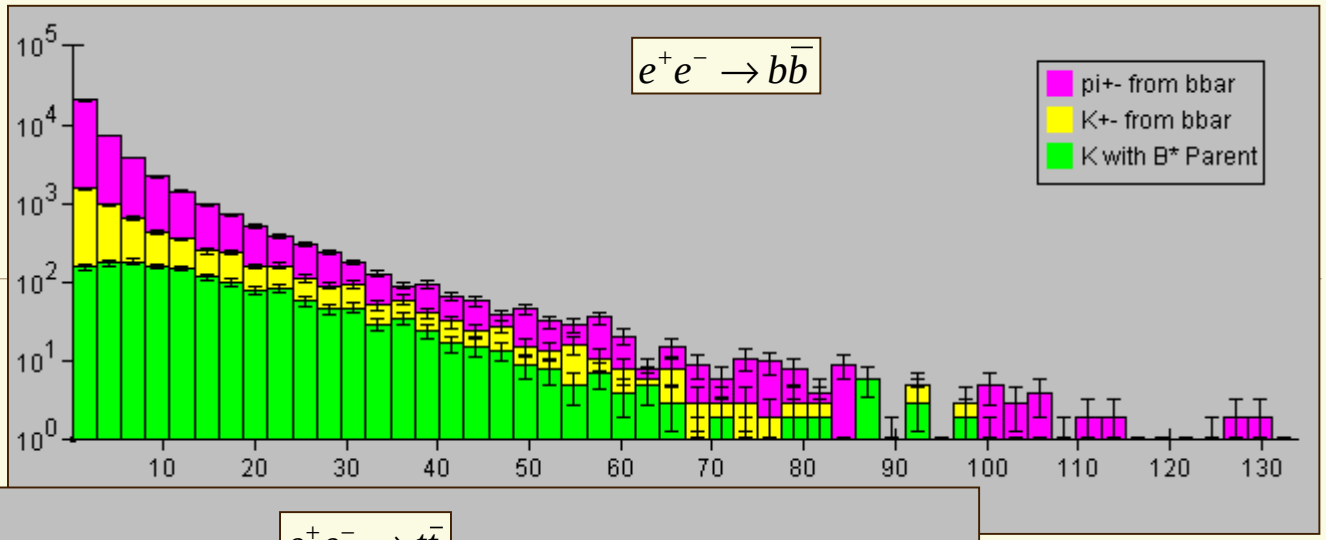
  ⇒ coherent design optimization of all subsystems

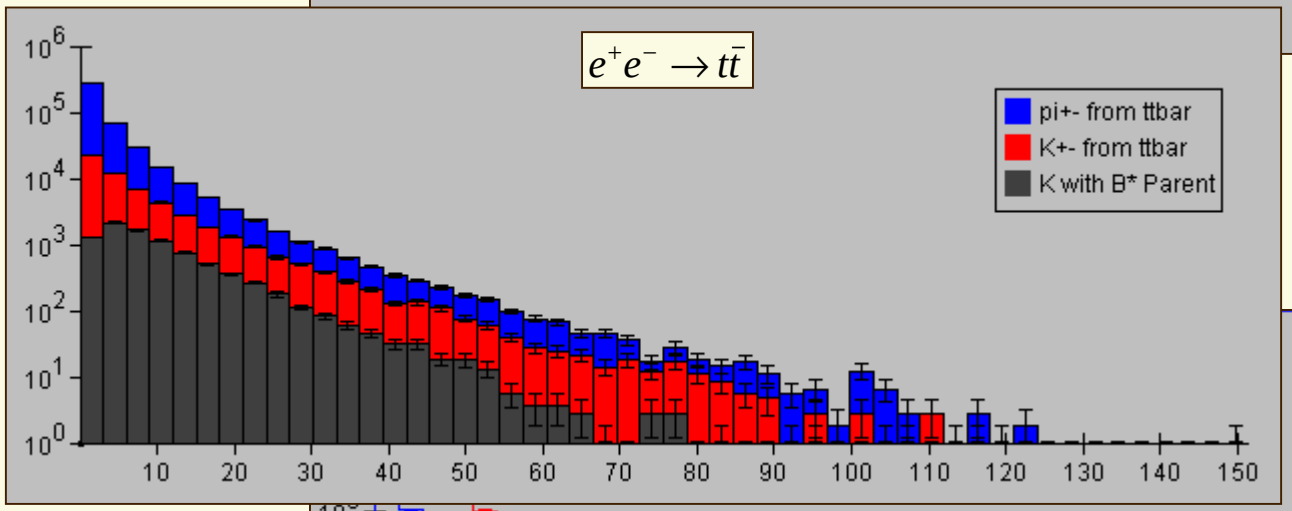
Is 0-6 GeV/c range useful?

Many π's & K's in this range but ...



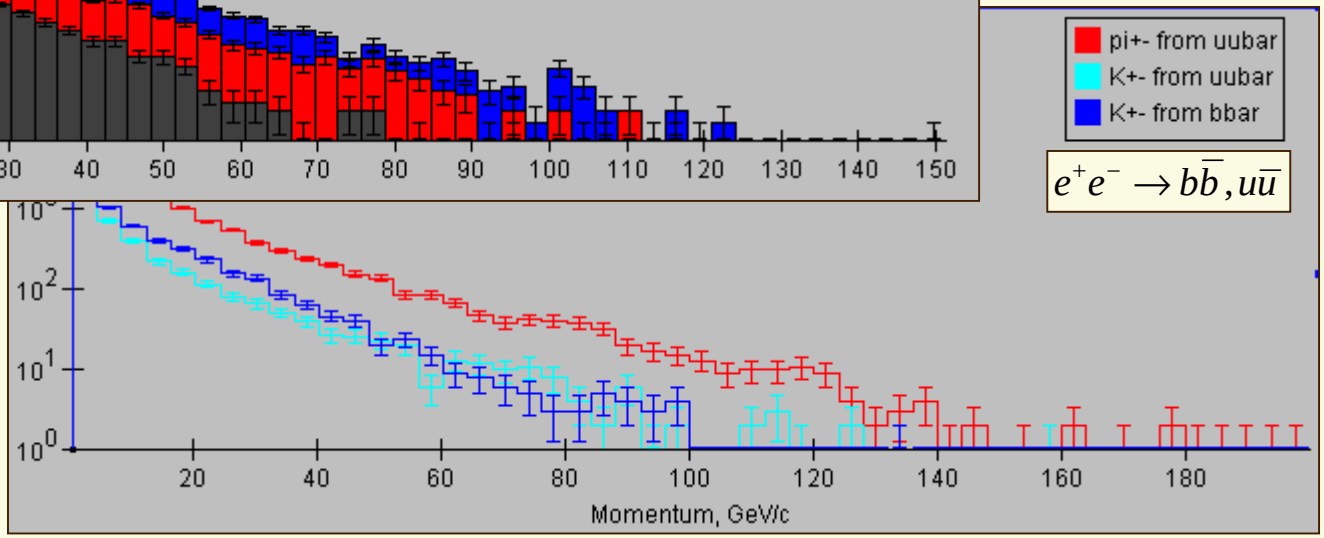
it doesn't...





…look...

…so good!



Conclusions...

- ✔ No obvious use for Kaon ID
  - conclusion reached by many preceding me
  - *prima facie* reason to neglect PID

- ✔ No ***obvious*** use for Kaon ID
  - most investigations have been at this simple level (or less)
  - some more sophisticated analyses point in the same direction? (T. Behnke *et al*)
  - the value of PID will be more subtle in more complex analyses e.g. in combination with vertexing

Conclusion

- PID has been neglected... but not without reason
- However...
  - most physics studies to-date relatively unsophisticated
  - current technologies may be inadequate,
    R&D may be needed with long lead time
  - emphasis on overall experiment design needs to be emphasized
- The Linear Collider will be a unique, multi-billion $/€/¥ facility so we had better make the most of it!
- Is a design report/proposal credible if these issues have not been addressed in detail?