Update on comparison of various PID performance predictions

J. Va'vra, SLAC

Content

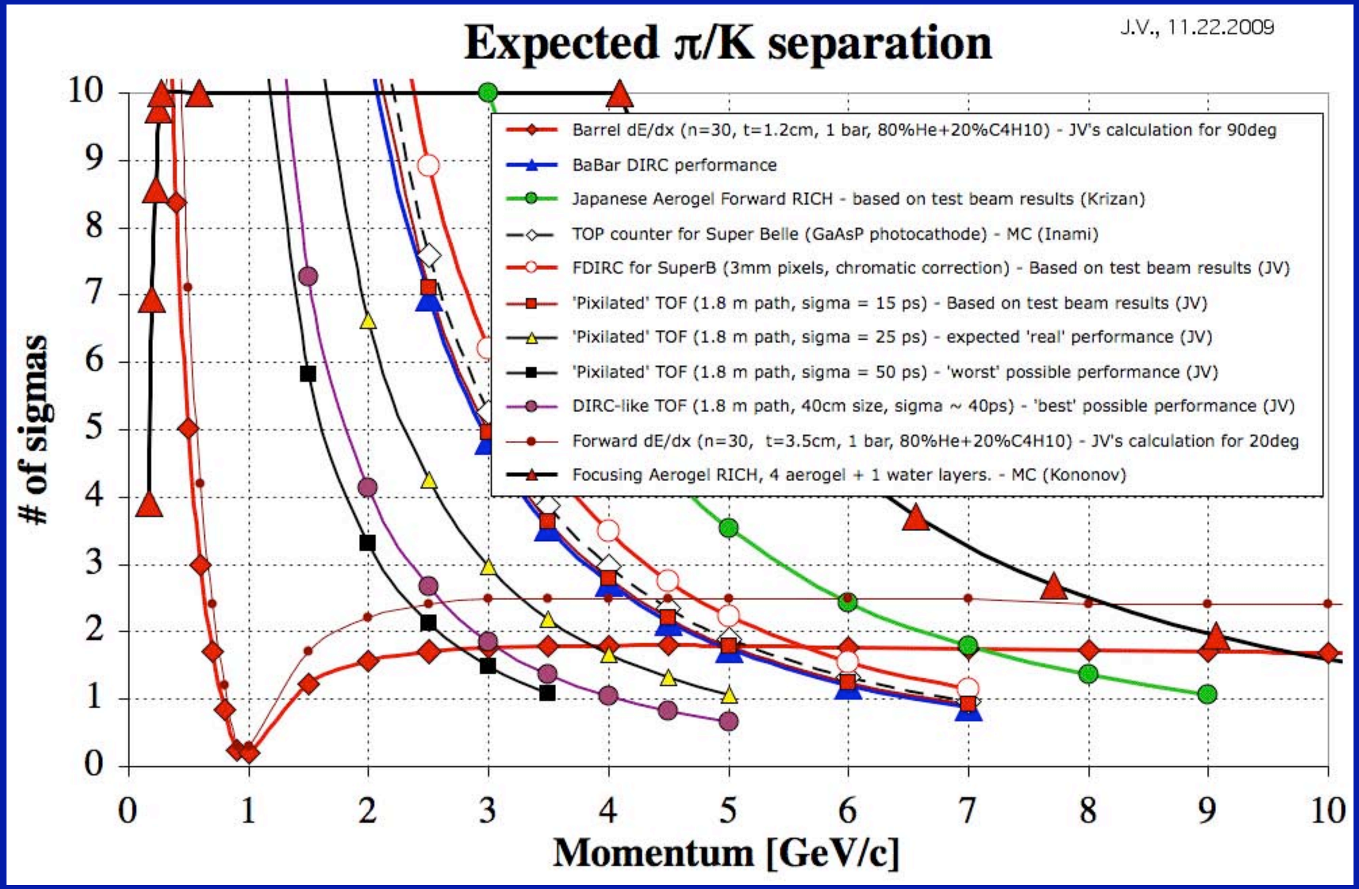
- Forward Aerogel RICH - MC simulation
- Forward dE/dx performance
- How is it all calculated ?

PID performance under "ideal" conditions

J. Va'vra, dE_dx = f(beta_gamma) study.xls spreadheet

Example of various Super-B PID designs:

Calculation done for flight path length = 1.8m

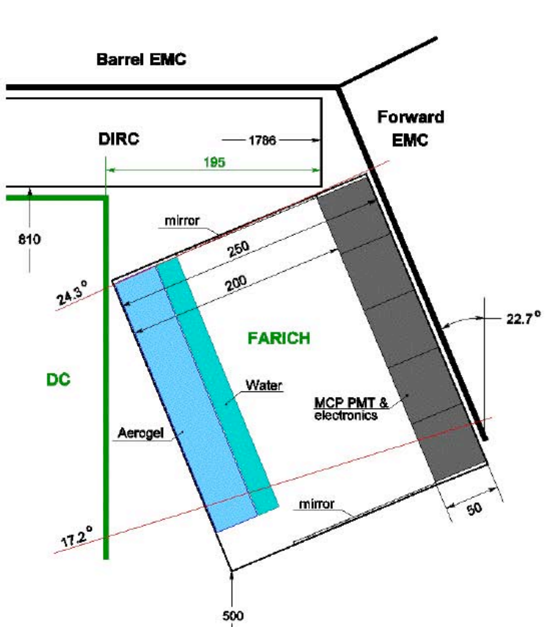


- **If a DIRC-like TOF would achieve σ ~ 50ps, it will be still useful up to ~ 2.5 GeV/c.**
- **Forward Aerogel RICH has superior PID performance compared to the TOF proposal, or any other scheme.**
- **Use my calculation of the dE/dx in the forward direction (a bit more pessimistic compared to Fastsim).**

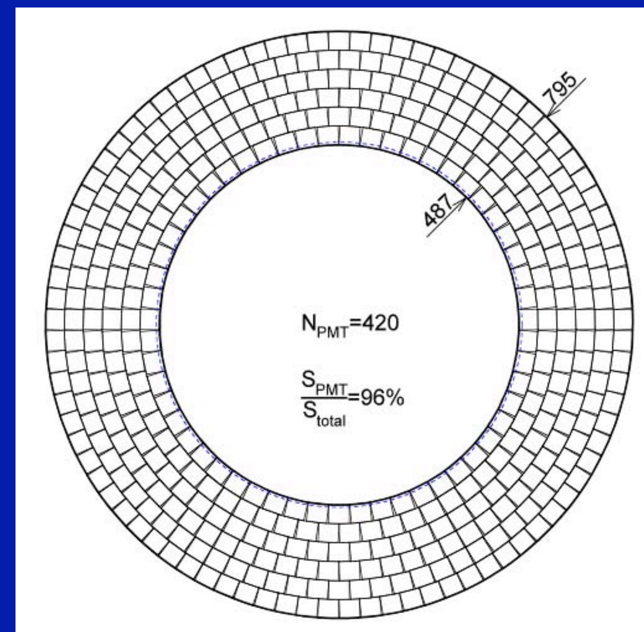
Novosibirsk forward Aerogel RICH

S. Kononov, E. Kravchenko and A. Onuchin, Novosibirsk

Kravchenko,SuperB wokshop, SLAC:



- Expansion gap 200 mm
- Burle MCP PMT with 3.2x3.2 mm pixels (16x16 matrix), photoelectron collection efficiency 70%, geometrical factor 85%
- 3-layer focusing aerogel, n_{max}=1.07, total thickness 30 mm
- Number of PMTs ~ 450
- Number of channels ~ 115000
- Amount of material, (X_0) = 3.5%(aerogel)+ 2.5%(water)+ 14%(MCP PMT)+8% (support, electronics, cables) ~ 28%

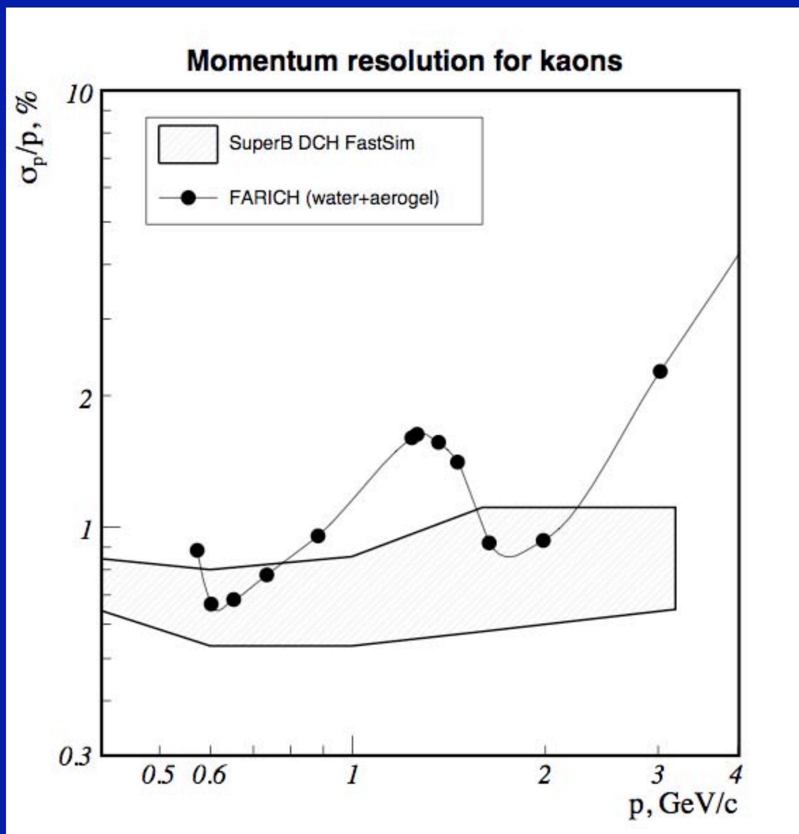


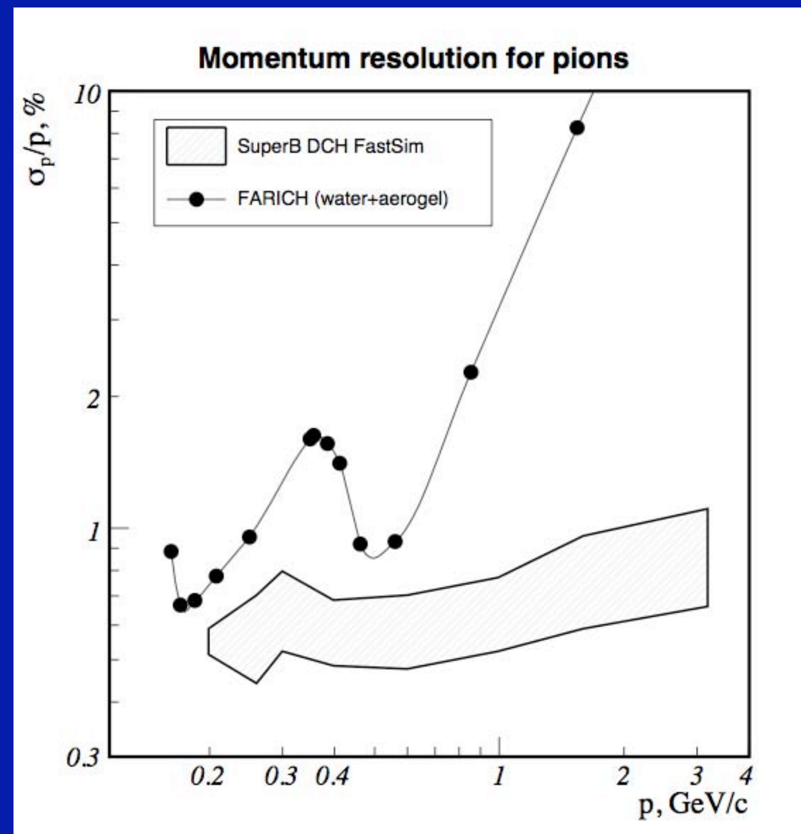
The latest plot assumes:

- **5-layer radiator: four aerogel layers and one layer of water.**
- **Add water, with higher n, to improve the low momentum PID capability.**
- **The system would use 450 Photonis MCP-PMTs with 10 micron holes.**

Aerogel RICH MC

S. Kononov, E. Kravchenko and A. Onuchin, Novosibirsk



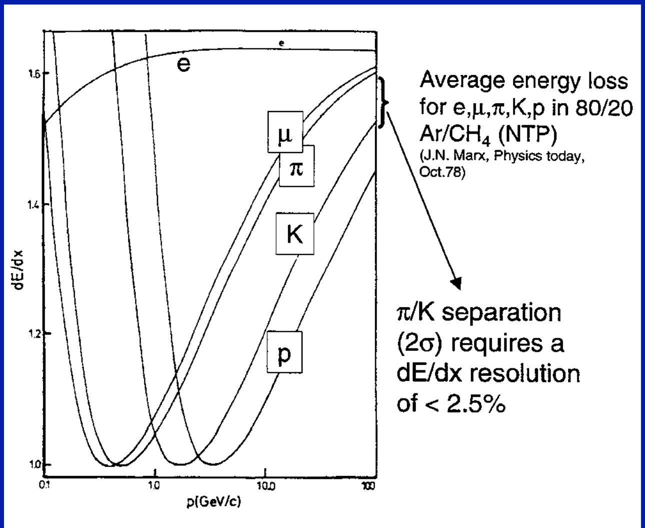


- **Forward Aerogel RICH is capable of measuring a momentum**
- **Momentum is measured by DCH**

dE/dx PID technique

$$N_\sigma = [dE/dx(m_1) - dE/dx(m_2)] / \sigma(dE/dx)$$

Bethe-Bloch were first to calculate it in 1930's



- **To predict dE/dx, one can use:**
  - **- Bethe - Bloch - Sternheimer calculation, or**
  - **- Landau - Sternheimer calculation, or**
  - **- Allison - Cobb Monte Carlo simulation, or**
  - **- Empirical curves based on fitting the data, such as in the book of Ronaldi-Bloom.**
- **To predict σ(dE/dx), one can use:**
  - **- Allison - Cobb Monte Carlo simulation, or**
  - **- Empirical curves based on fitting the data.**

Which model works best and is most useful ?

Prediction of dE/dx

J. Va'vra, Nucl. Instr. & Meth., A453(2000)262, and SLAC-PUB-8356, Jan. 2000, and dE_dx = f(beta_gamma) study.xls

Bethe-Bloch formula for dE/dx with Sternheimer parameterization of the density function:

$$\frac{dE}{dx} = -0.3071 \frac{Z}{A} \rho t \frac{1}{\beta^2} \left[\frac{1}{2} \ell n \frac{2 m_e c^2 \beta^2 \gamma^2 E_{cut}}{I^2} - \frac{\beta^2}{2} - \frac{\delta}{2} \right]$$

where

- Z is atomic number of medium,
- A is atomic mass of the medium,
- ρ is density of the medium,
- t is sample thickness,
- m_e is mass of electron,
- **I is mean excitation energy of the medium,**
- **E_{cut} is maximum kinetic energy which can be given to a free electron in a single collision,**
- **δ is density correction due to polarization of the medium.**

Sternheimer parametrization of density function δ:

$\delta = 0$ for $X = \ln \beta\gamma < X_0$

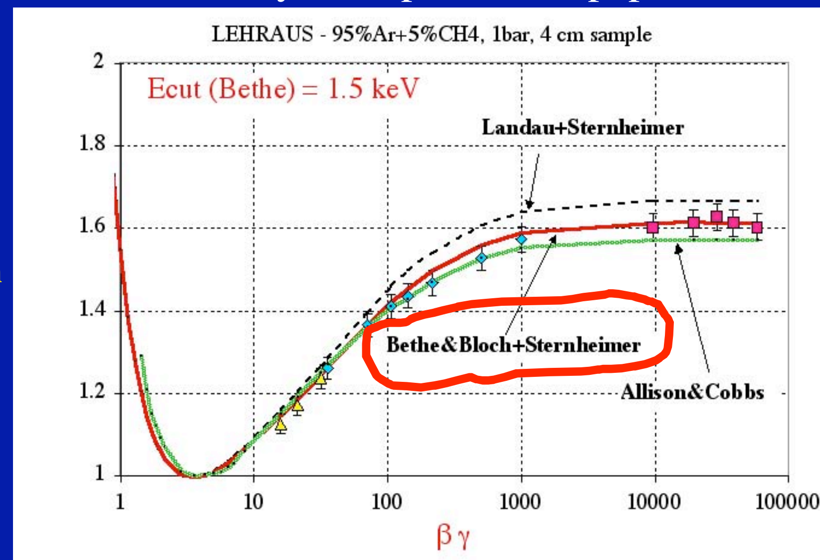
$\delta = 4.606(X - X_a) + \frac{4.606(X_a - X_0)}{(X_1 - X_0)^3}(X_1 - X)^3$ for $X_0 \le X < X_1$

$\delta = 4.606(X - X_a)$ for $X > X_1$

Electron density:
$n_{el} = N_A * Z * \rho / A$

Bloch found that the mean ionization potential can be approximated by:
$I \sim (10eV)*Z$

One of many examples in the paper:

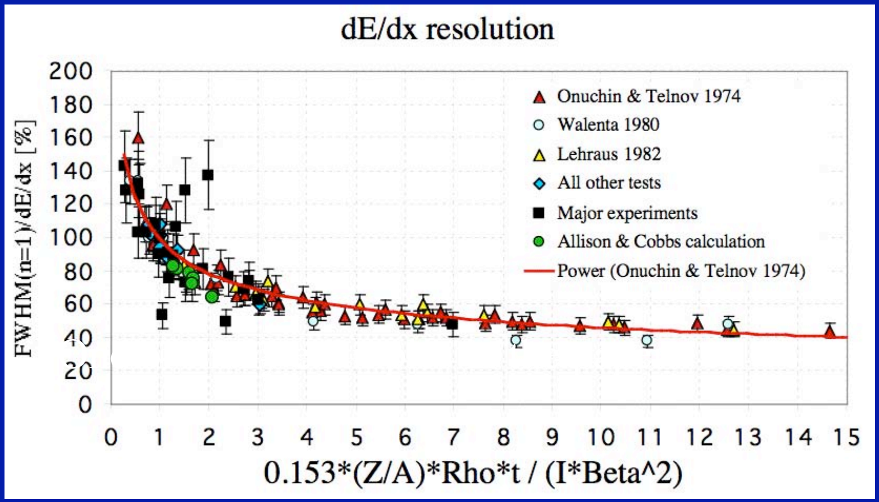


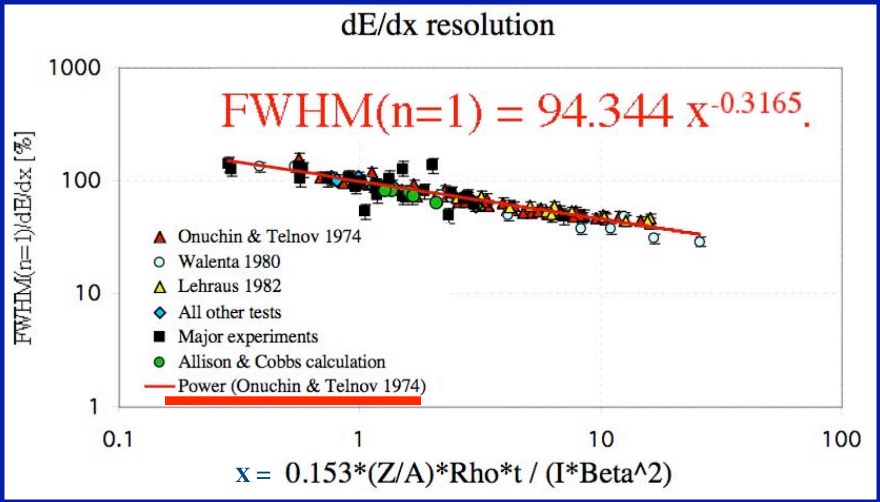
- **The density function parameterization is important to get an agreement in the relativistic part of the curve.**
- **Landau formula does not have E_{cut} cariable, and therefore does not do that well.**
- **Although Allison-Cobb MC method is a correct way to do it, I find that the Bethe-Bloch-Sternheimer parameterization is simple, practical and it works.**

Prediction of dE/dx resolution

J. Va'vra, Nucl. Instr. & Meth., A453(2000)262, and SLAC-PUB-8356, Jan. 2000, and dE_dx = f(beta_gamma) study.xls

Empirical formula for dE/dx resolution, i.e., σ(dE/dx) = f(electron density in the medium):





n - number of samples

Electron density:
$n_{el} = N_A * Z * \rho / A$

- **<u>Conclusion of the paper:</u>**
  dE/dx: a) Bethe-Bloch-Sternheimer formula works best.
  b) Allison - Cobb Monte Carlo agrees with data within ~3%.
  σ(dE/dx): Allison - Cobb prediction works well. However, I have found that the empirical fit is a fast and equally correct way to do it.

TOF PID technique

Principle is simple:

$$\Delta t = (L_{path}/c) * (1/\beta_1 - 1/\beta_2) = (L_{path}/c) * [\sqrt{(1+(m_1 c/p)^2)} - \sqrt{(1+(m_2 c/p)^2}] = \sim (L_{path} c/2p^2) * (m_1^2 - m_2^2)$$

Therefore expected particle separation:

$$N_\sigma = [(L_{path} c/2p^2) * (m_1^2 - m_2^2)] / \sigma_{Total}$$

where

$$\sigma_{Total} \sim \sqrt{[(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (\sigma_{Chromatic}/\sqrt{N_{pe}})^2 + \sigma^2_{Electronics} + \sigma^2_{Track} + \sigma^2_{T0}]}$$

$\sigma_{Electronics}$ - electronics contribution ~ 10 ps
$\sigma_{Chromatic}$ - chromatic term = f (photon path length) ~ 5-45 ps for path lengths 10-50 cm long
σ_{TTS} - transit time spread ~ 35 ps for the best MCP-PMT detectors
σ_{Track} - timing error due to track length L_{path} (poor tracking in the forward direction) ~ 5-10 ps
σ_{T0} - start time dominated by the SuperB crossing bunch length ~ 20-25 ps (?)

- **In the plot I consider:**

  a) <u>"Pixilated" TOF resolutions:</u> σ_{Total} ~ 15, 25 and 50 ps

  where 15 ps was obtained in the test beam and bench tests, 25 ps is probably the best one can do at SuperB, and 50 ps, if we screw up (?)

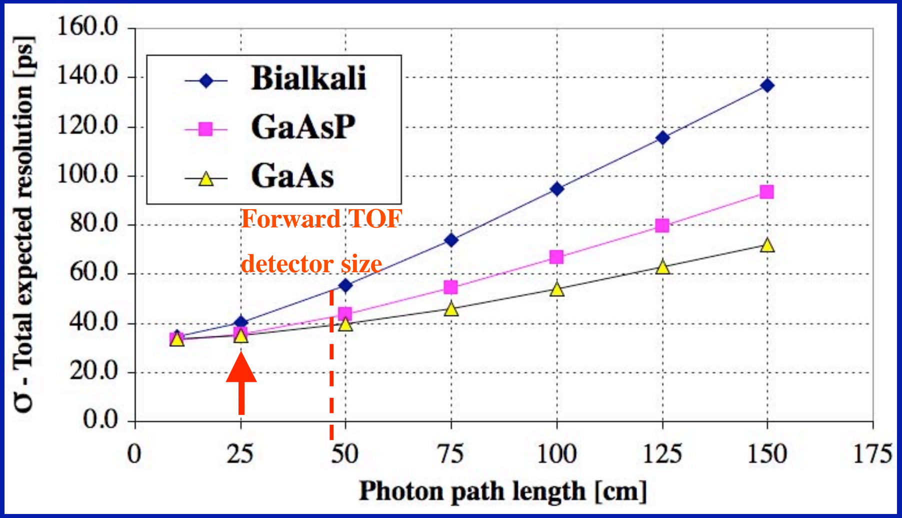
  b) <u>"DIRC-like" TOF resolution:</u> σ_{Total} ~ 40 ps.

"DIRC-like" TOF detector - simple

$$\sigma_{Total} \sim \sqrt{[\sigma^2_{Electronics} + (\sigma_{Chromatic} / \sqrt{(\varepsilon_{Geometrical\_loss} * N_{pe})})^2 + (\sigma_{TTS} / \sqrt{\varepsilon * N_{pe}})^2 + \sigma^2_{Track} + \sigma^2_{bar\ thickness} + \sigma^2_{detector\ coupling\ to\ bar} + \sigma^2_{to}]}$$

$\sigma_{Electronics}$ - electronics contribution ~ 10 ps
$\sigma_{Chromatic}$ - chromatic term = f (photon path length) ~ 40 ps for path lengths ~25 cm (Bialkali)
σ_{TTS} - transit time spread ~ 35 ps
σ_{Track} - timing error due to track length L_{path} (poor tracking in the forward direction) ~ 5-10 ps
$\sigma_{detector\ coupling\ to\ bar}$ - timing error due to detector coupling to the bar ~ 10 ps
$\sigma_{bar\ thickness}$ - timing error due to bar thickness ~ 12 ps
$\sigma_{t\ o}$ - start time dominated by the SuperB crossing bunch length ~ 25 ps
$\varepsilon_{Geometrical\_loss}$ - loss due to a geometrucal acceptance ("reject" bad photons) ~ 20%

Total expected final resolution:



- **Bialkali photocathode will give σ_{ave}~ 40 ps at best.**

RICH PID separation under "ideal" condition

N_σ = [$\theta_c (m_1)$ - $\theta_c (m_2)$] / $\sigma_{\theta c}$(tot) - separation in number of sigmas

- **In the plot I consider:**
  a) Calculate $\theta_c (m_1)$ - $\theta_c (m_2)$
  b) BaBar DIRC resolution: σ_{Total} ~ 2.4 mrads/track
  c) FDIRC resolution: Scale the performance by a ratio:
  $\sigma_{DIRC} / \sigma_{FDIRC}$ ~ 9.6 mrads/7.5 mrads ~ 1.28, i.e., assuming the FDIRC prototype test beam results with a chromatic corrections applied.
  d) TOP counter: This is a problem, as they update results every 2-3 months. In the plot I assume PID separation of 3 sigmas at 4 GeV/c and scale it from there. However, this is for the GaAsP photocathode, which is probably "unobtainium" because of the cost and difficulty to make it. For a multi-alkali photocathode the prediction will be worse, but do not know how much worse at the moment.

Plot again - caption separated