FDIRC optics with Mathematica

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Content

- The ray-tracing simulation with the Mathematica is employing a geometry similar to the FDIRC prototype, which was originally designed with the Vellum drafting program by a manual ray-tracing.
- Ray-tracing done in Mathematica in 3D (without Optica).
- FDIRC prototype - with spherical mirror, no wedge.
- FDIRC with a wedge and cylindrical mirror.
- Non-focusing DIRC with & without a wedge.
Focusing DIRC Prototype optics

- FDIRC prototype designed with a Vellum drafting program by ray-tracing.
- Keep similar dimension in the following simulation with the Mathematica.
- To find a true focal plane, throw a pair of two photons for each dip angle and find their intersect in 2D.
- Focal plane chosen so that 6mmx6mm pixels yield the same resolution as BaBar DIRC.
What is a detector surface with a spherical mirror & no wedge?

In the region, where the FDIRC prototype works ($z \sim -6$ cm), the calculated focal plane is close to a straight line. So a flat window solution for the FDIRC prototype was OK.

zbarstart = - barl; zbarend = 0;
Theta = (60 + Random[]*2*30 - 40)/(180/Pi); Phi = 90/(180/Pi);
Thetakc = 47.3/(180/Pi); Phic = 180/(180/Pi); Vary Phic
xm0 = 0; ym0 = 23.0; zm0 = -86.6; r = 2*(48.6); Choose r as one has in the FDIRC prototype Vellum study
a11 = 1; a22 = 1; a33 = 1; a12 = 0; a13 = 0; a23 = 0; a14 = - xm0; a24 = -ym0; a34 = - zm0; a44 = xm0*xm0 + ym0*ym0 + zm0*zm0 - r*r;

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FDIRC prototype: no wedge, spherical mirror, flat detector plane, $\theta_{\text{dip}} = 90^\circ$

Mirror equation: 

$$(x - x_{m0})^2 + (y - y_{m0})^2 + (z - z_{m0})^2 - r^2 = 0$$

$$a_{11}x^2 + a_{22}y^2 + a_{33}z^2 + 2a_{12}xy + 2a_{13}xz + 2a_{23}yz + 2a_{14}x + 2a_{24}y + 2a_{34}z + a_{44} = 0$$

$x_{m0} = 0; y_{m0} = 23.0; z_{m0} = -86.6; r = 2*(49.5);$  \(\leftarrow\) CRID mirror parameters

$$a_{11} = 1; a_{22} = 1; a_{33} = 1; a_{12} = 0; a_{13} = 0; a_{23} = 0.0; a_{14} = - x_{m0}; a_{24} = - y_{m0}; a_{34} = - z_{m0}; a_{44} = x_{m0}^2 + y_{m0}^2 + z_{m0}^2 - r^2;$$

- Detector plane in the bar coordinate system
- Because of the quartz rectangular block at the end of bar, we have only one Cherenkov image for this dip angle.
- Kaleidoscopic wiggles in image come from the bar rectangular structure.
FDIRC prototype: no wedge, spherical mirror, flat detector plane, vary $\theta_{\text{dip}}$

A flat detector plane located in the mirror’s focus:

- Keep a “detector image canvas” size constant for all pictures (no auto-scaling)

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Non-focusing DIRC: no wedge, no mirror, flat detector plane

A flat detector plane:

3 points defining the detector plane:

\[ P_1[0,0,0], P_2[\pm10, L\sqrt{2}, L\sqrt{2}], P_3[\pm10, -10, L\sqrt{2}, L\sqrt{2}] \]

\[ L = 45 \text{ cm} \]

\[ \theta_{\text{dip}} = 90^\circ \]

\[ \Delta y_f = y_f - 35.55 \]

Focal plane chosen so that 6mmx6mm pixels yield the same resolution as BaBar DIRC

Image is wider without a mirror.

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Add the wedge into FDIRC prototype simulation

- Add the wedge, while keeping other dimensions the same => getting crowded. Intended only for this particular study.
- The reason for adding the wedge: the real DIRC bar boxes have them presently.

Replace the spherical mirror with a cylindrical mirror

Replace the quartz block with the wedge
FDIRC: with wedge, cylindrical mirror, flat detector plane, $\theta_{\text{dip}} = 90 \degree$ & 85$\degree$

A flat detector plane located in the mirror’s focus:

$\theta_{\text{dip}} = 90 \degree$

Bounce from bottom wedge surface

$\theta_{\text{dip}} = 85 \degree$

Bounce from bar
Bounce from bottom wedge surface

Wedge:

$60 \degree$

79.0 mm

27.0 mm

30 \degree

6 mrad

$z = 0$

$z = z_{\text{wedge}} = 91.0 \text{ mm}$
FDIRC: with wedge, cylindrical mirror, flat detector plane, vary $\theta_{\text{dip}}$

A flat detector plane located in the mirror’s focus:

- **Wedge:**
  - Bounce from bottom wedge surface
  - Bounce from top wedge surface

- **Angles:**
  - $90^\circ$
  - $85^\circ$
  - $80^\circ$
  - $75^\circ$
  - $70^\circ$
  - $65^\circ$
  - $60^\circ$
  - $55^\circ$
  - $50^\circ$
Non-focusing DIRC: with wedge, no mirror, flat detector plane, $\theta_{\text{dip}} = 90^\circ$ & $85^\circ$

- $\theta_{\text{dip}} = 90^\circ$
  - Bounce from top wedge surface
  - Bounce from bottom wedge surface

- $\theta_{\text{dip}} = 85^\circ$
  - Bounce from top wedge surface
  - Bounce from bar

3 points defining the detector plane:
- $P_1 [0, 0, 63.6 \text{ cm} = 45 \text{ cm}/\cos(45^\circ)]$
- $P_2 [10, L/\sqrt{2}, L/\sqrt{2}]$
- $P_3 [-10, +10, L/\sqrt{2}, L/\sqrt{2}]$

Detector plane

Wedge

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Non-focusing DIRC: with wedge, no mirror, flat detector plane, vary $\theta_{\text{dip}}$

- Non-focusing DIRC with no mirror has a wider image, and a larger overall detector canvas size ($\sim 2x$)

$\Rightarrow$ need more pixels to cover the area
Images in BaBar DIRC
(wedge, no mirrors)

Bounce from top wedge surface
Bounce from bottom wedge surface
Conclusion

• We have developed a useful tool to study the optics.
• Cylindrical mirror requires a non-flat detector focal plane in principle, although a flat detector plane may be good enough approximation. One needs to quantify this.
• Non-focusing DIRC requires ~2x larger pixel area to cover compared to the FDIRC with a cylindrical mirror.
• The wedge does not seem to be too big obstacle even for the FDIRC.