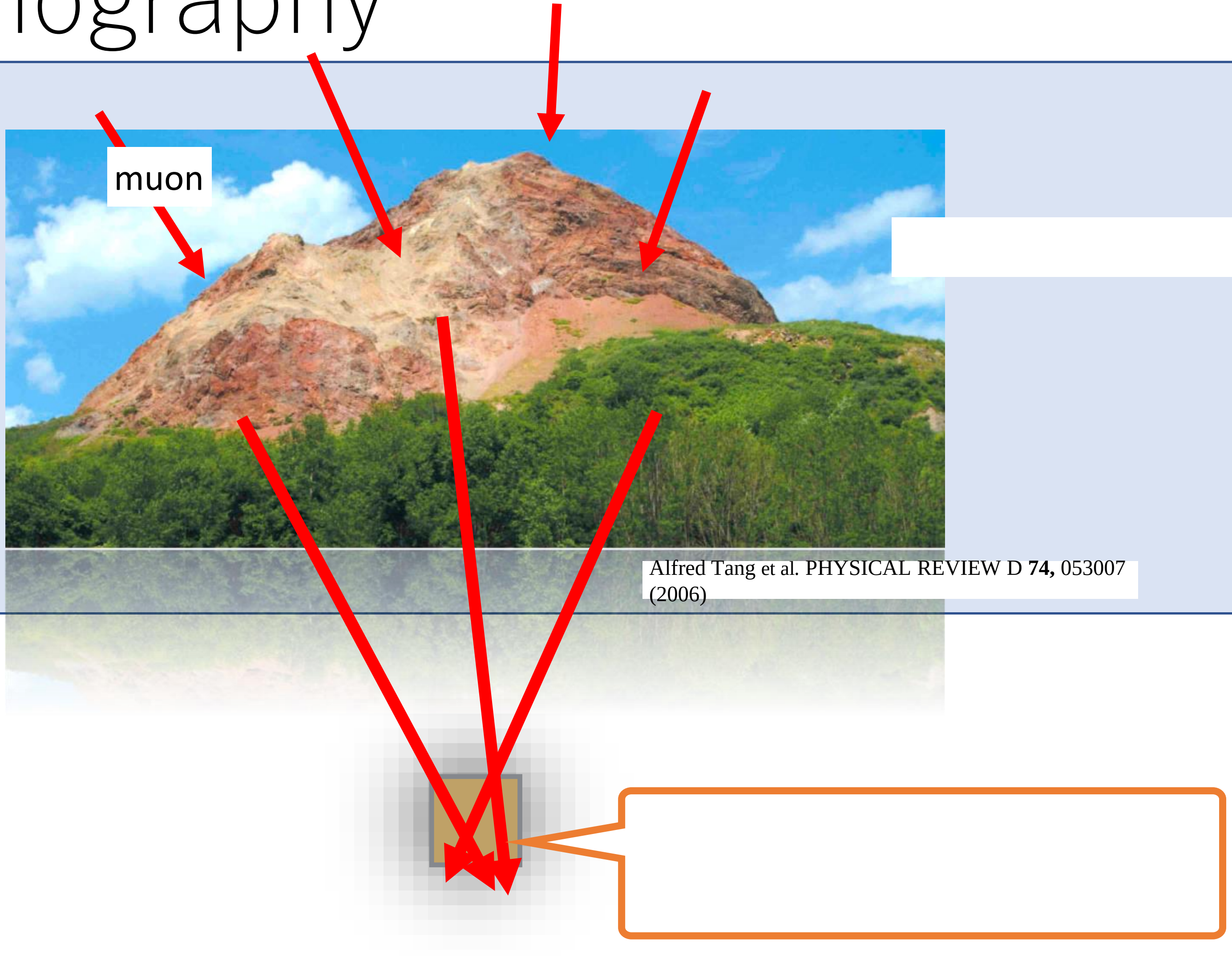
Development of Nuclear Emulsion for Cosmic Ray Radiography

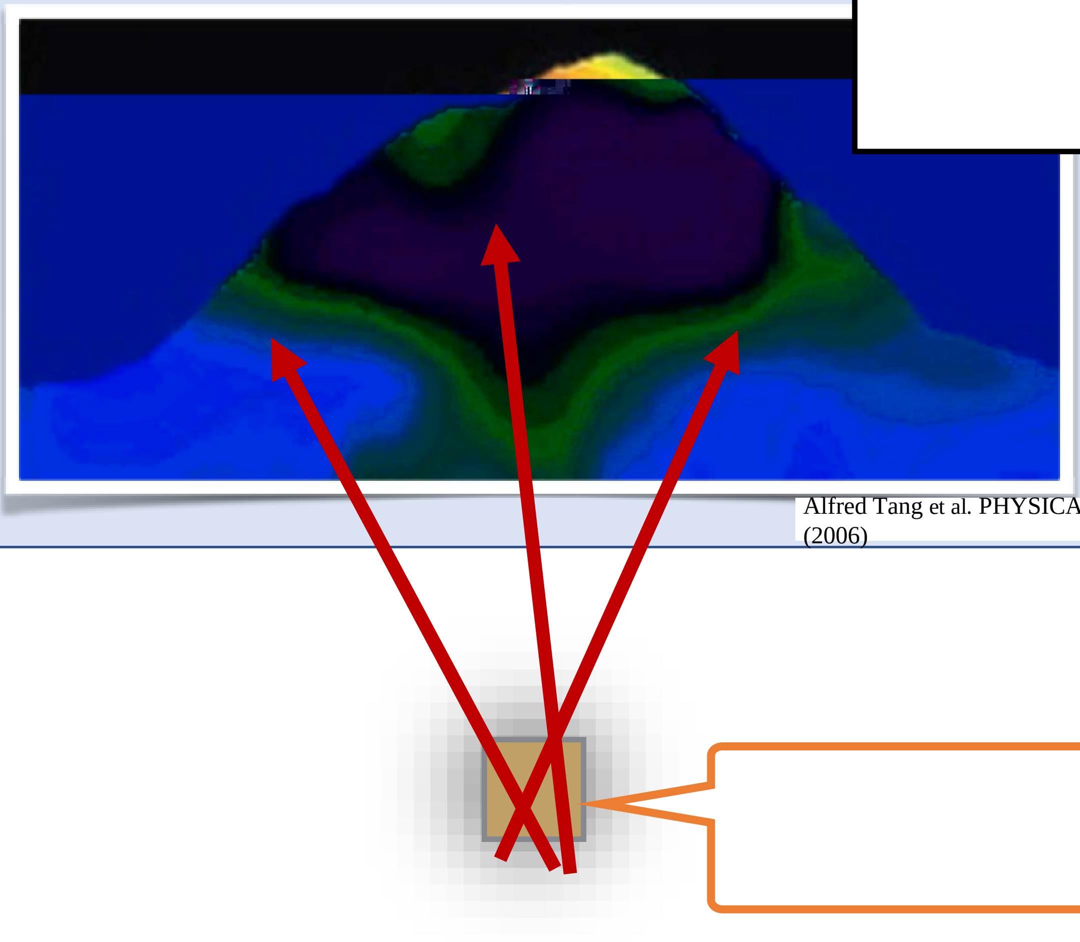
-Thick supporting base type emulsion-

Cosmic-Ray Radiography



Alfred Tang et al. PHYSICAL REVIEW D **74,** 053007 (2006)

Cosmic-Ray Radiography



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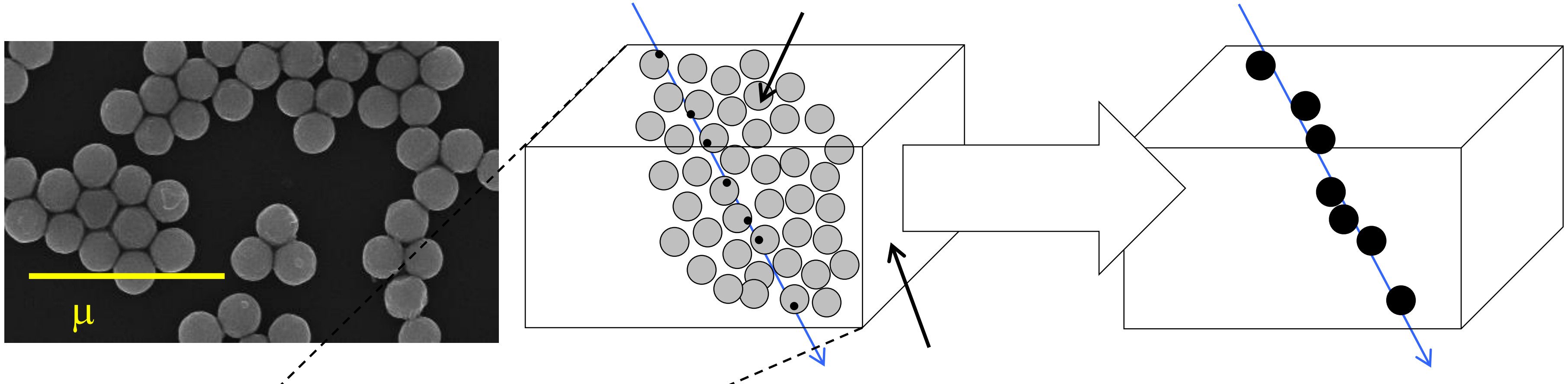
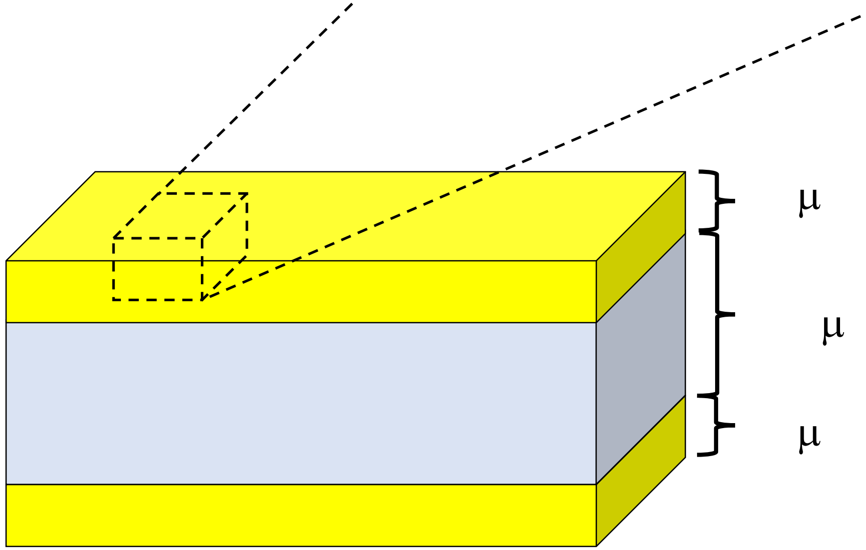
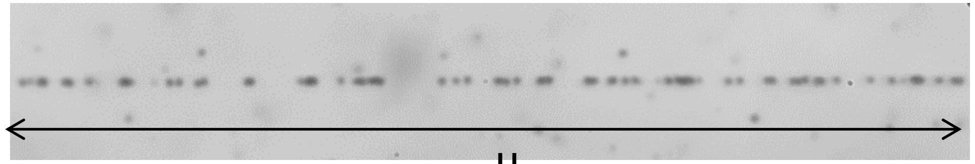
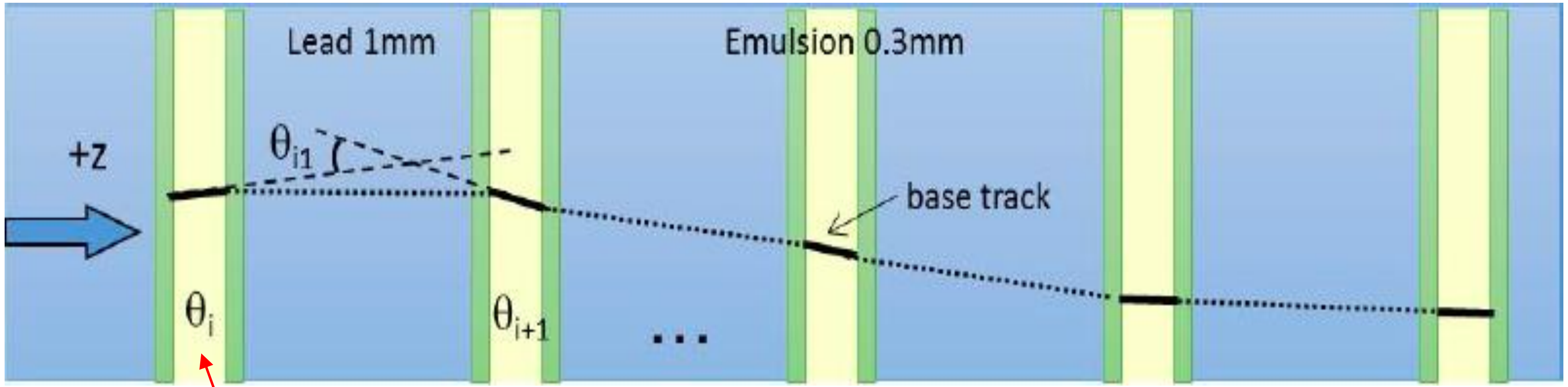
Structure of Nuclear Emulsion







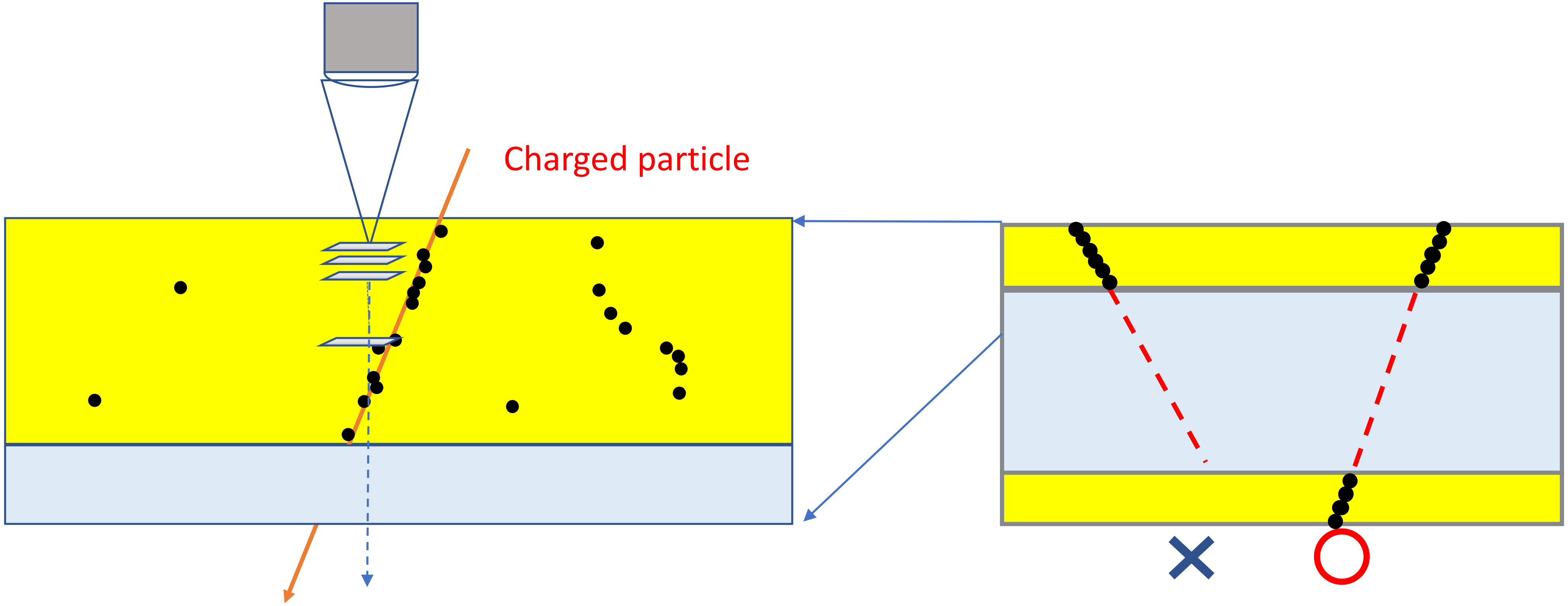
Emulsion Cloud Chamber(＝ECC)



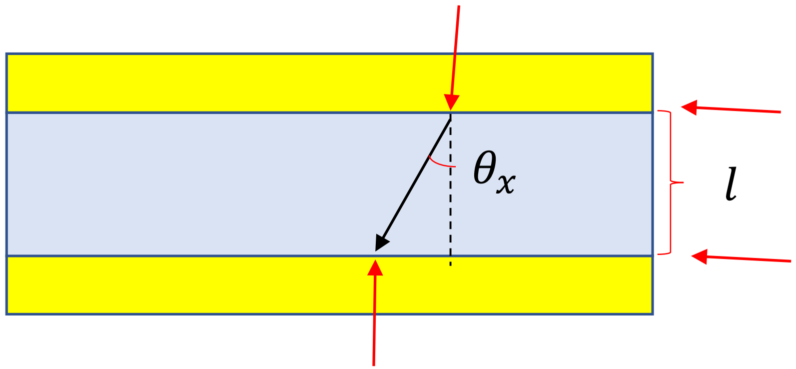
$$\theta_{scat} = \frac{13.6}{\beta cp} z \sqrt{\frac{x}{X_0}} \left\{ 1 + 0.038 \ln\left(\frac{x}{X_0}\right) \right\}$$

$$\theta_i = \sqrt{\theta_{scat}{}^2 + \delta\theta_i{}^2}$$

Detection Principle of Nuclear Emulsion



Definition of Angular Accuracy



$\boxed{\delta l = \sqrt{2}\delta z}$

$$\tan\theta_x = \frac{x_2 - x_1}{l}$$

$$\left(= \frac{x_2 - x_1}{z_2 - z_1} \right)$$

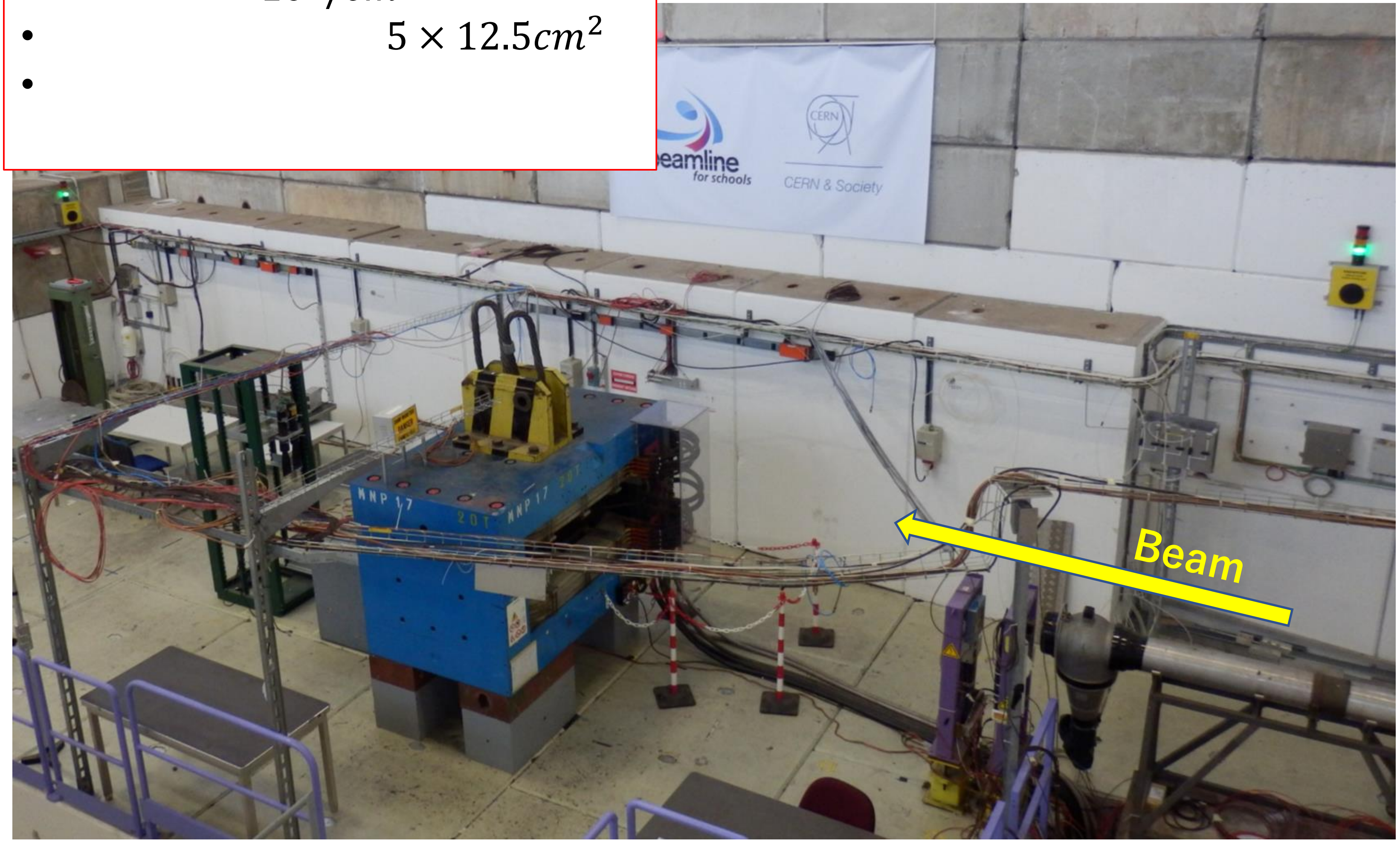
$$\delta \tan\theta_x = \sqrt{\frac{1}{l^2}\delta x^2 \times 2 + \left(\frac{x_2 - x_1}{l^2}\right)^2 \delta l^2}$$

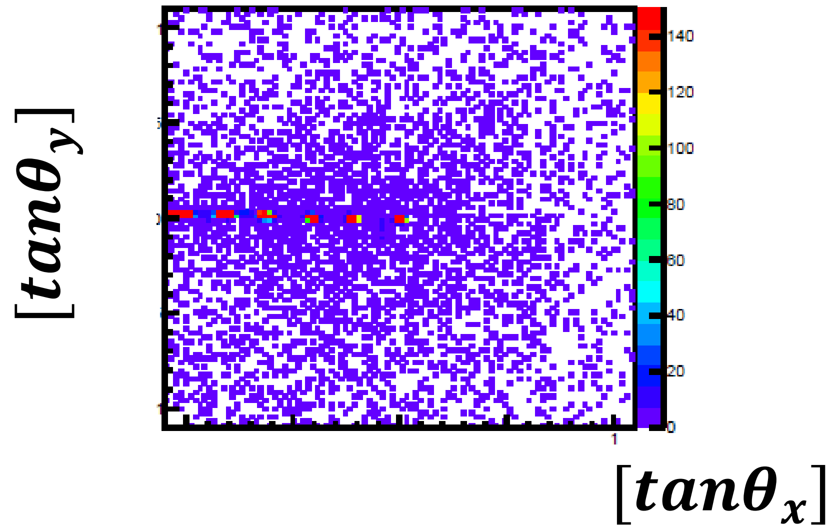
$$= \frac{\sqrt{2}}{l}\sqrt{\delta x^2 + \delta z^2 \times (\tan\theta_x)^2}$$

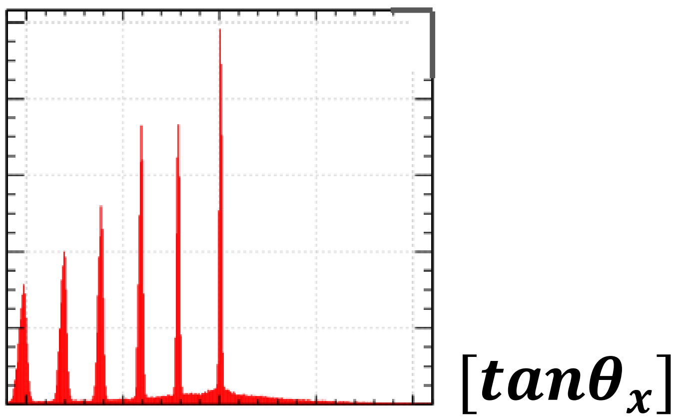
Base Candidates

Improvement of Angular Accuracy Test 1

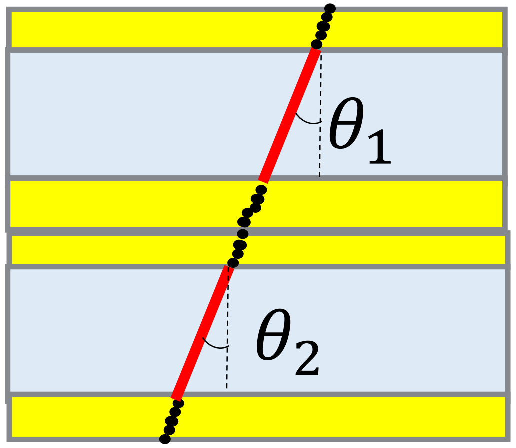
- –
-
- $10^3/cm^2$
- $5 \times 12.5cm^2$
-







Angular Accuracy of Vertical Tracks



-
-

1σ

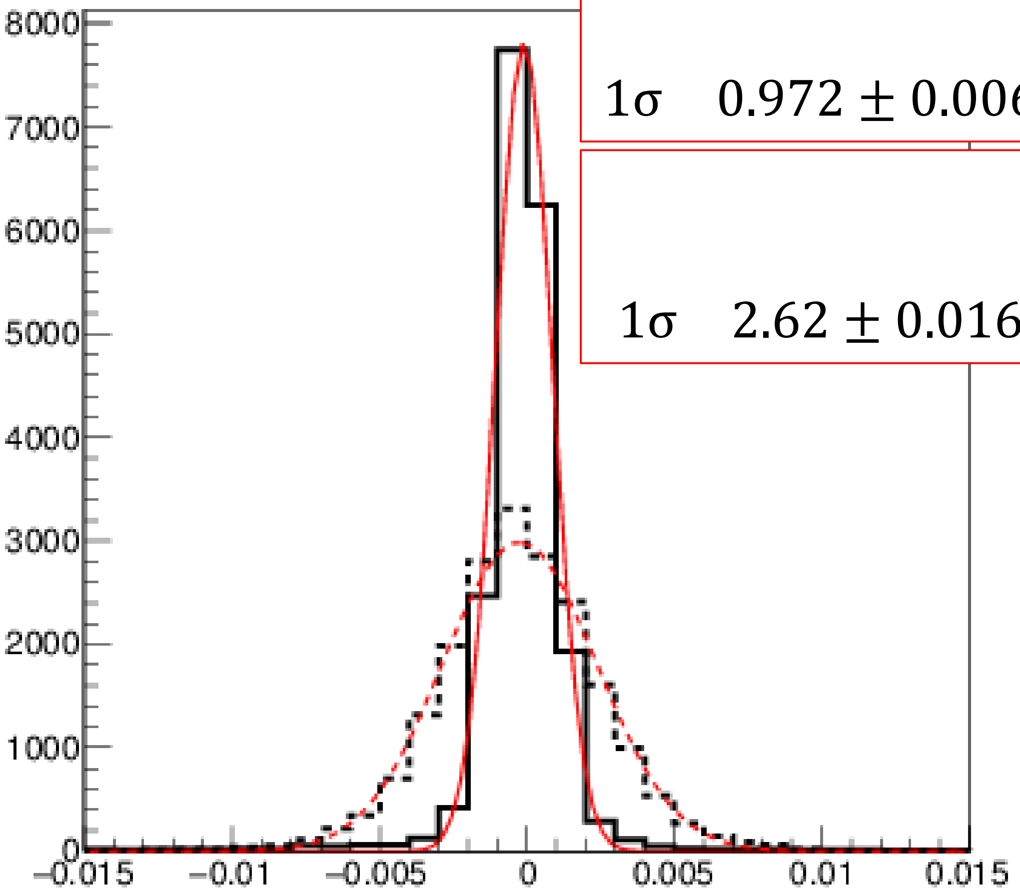
$tan\theta = 0.0 \pm 0.02$

$$\delta \tan \theta_x = \frac{\sqrt{2}}{l}\sqrt{\delta x^2 + \delta z^2 \times (\tan \theta_x)^2}$$

$tan\theta = 0.0$

$\delta \tan \theta_x = 0$

Angular Accuracy of Vertical Tracks
175μmPS・500μmCOP Emulsions



$1\sigma \quad 0.972 \pm 0.006 \times 10^{-3}$

$1\sigma \quad 2.62 \pm 0.016 \times 10^{-3}$

$[\sqrt{2} * \delta tan\theta_x]$

	175	500
	$2.62 \pm 0.016 \times 10^{-3}$	$0.972 \pm 0.006 \times 10^{-3}$

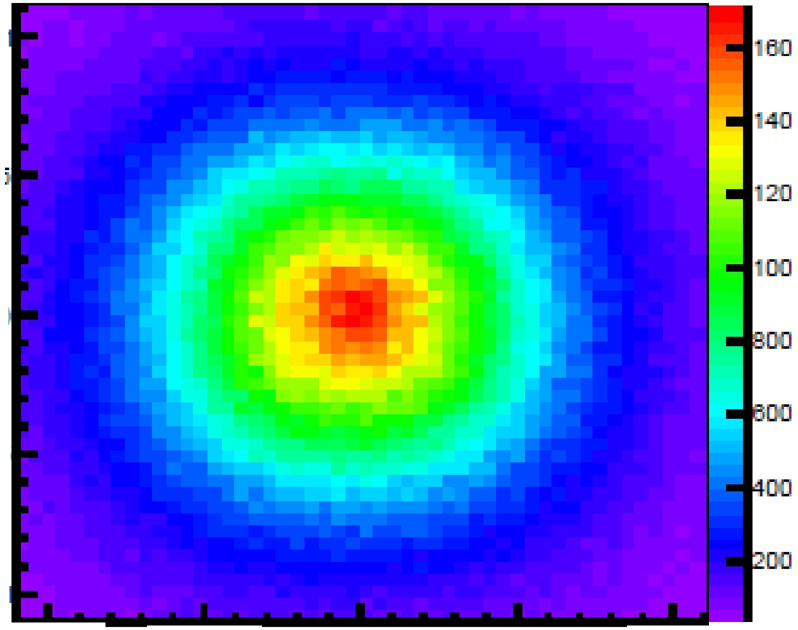
Ratio of base thickness $\dfrac{500\mu m}{175\mu m} = 2.86$

Ratio of angular accuracy $\dfrac{2.62 \times 10^{-3}}{0.972 \times 10^{-3}} = 2.70$

Improvement of Angular Accuracy Test 2

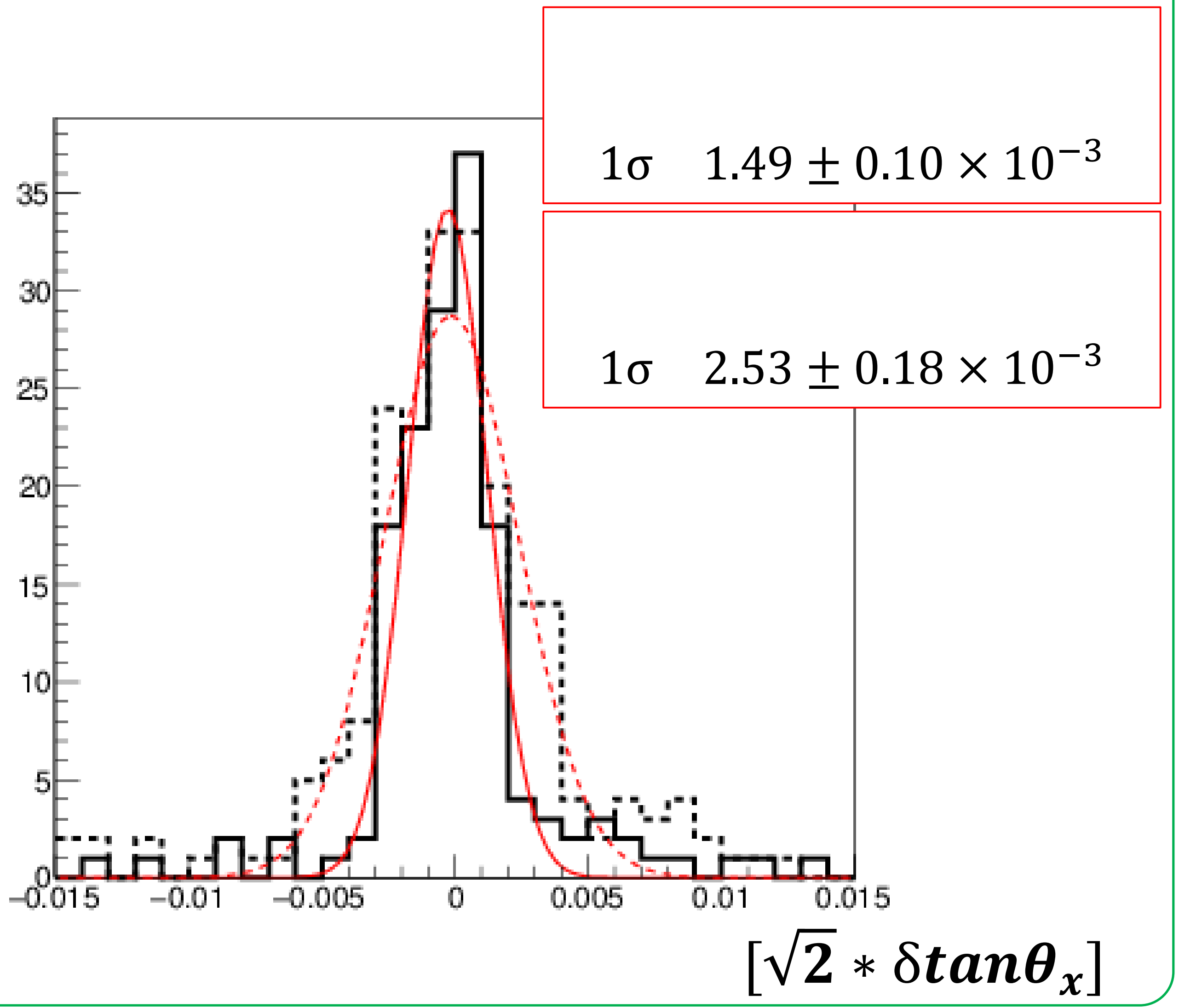
$-0.02 < tan\theta < 0.02$

$[tan\theta_y]$



$[tan\theta_x]$

Angular Accuracy of Vertical Tracks
175μmPS・300μmPC Emulsions



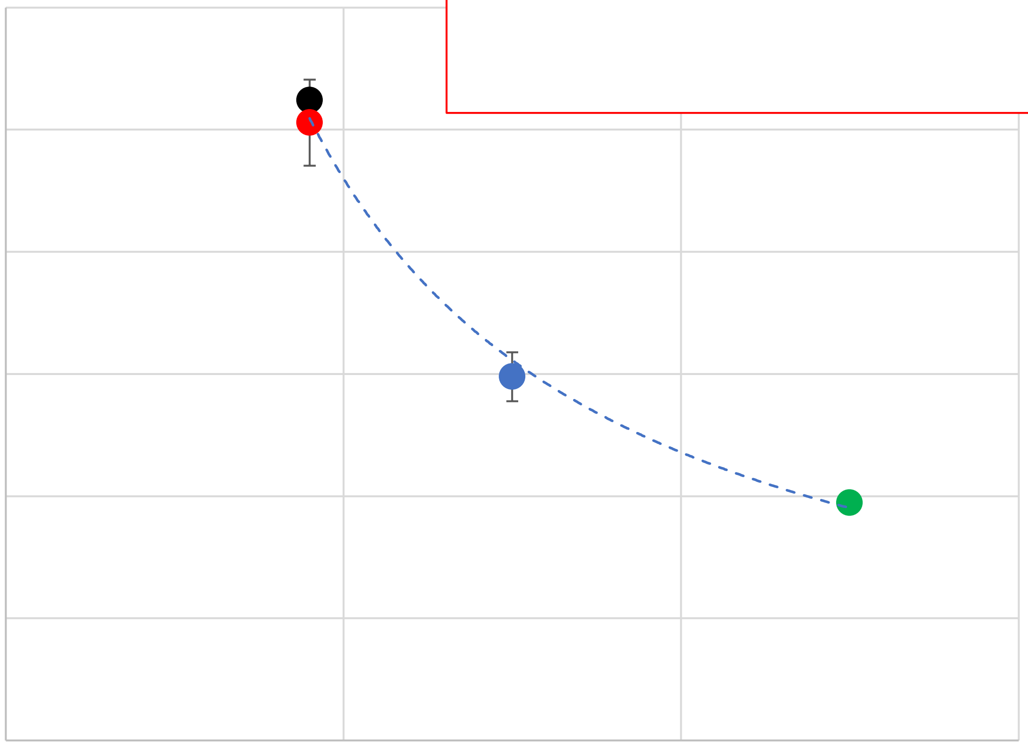
	175	300
	$2.53 \pm 0.18 \times 10^{-3}$	$1.49 \pm 0.10 \times 10^{-3}$

aito of base thickness $\frac{300\mu m}{175\mu m} = 1.71$

aito of angular accuracy $\frac{2.53\times10^{-3}}{1.49\times10^{-3}} = 1.70$

Summary of Angular Accuracy of Vertical Tracks

$[\sqrt{2} * \delta tan\theta_x \times 10^{-3}]$



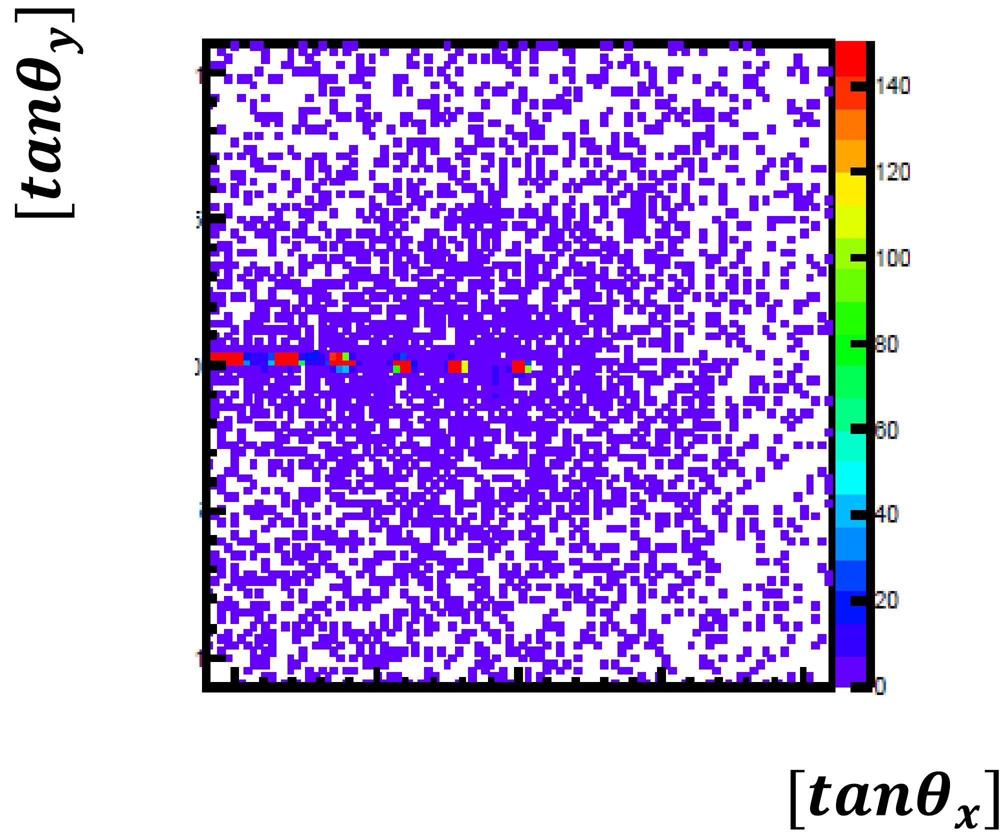
$\boldsymbol{Base\ thick}[\quad]$

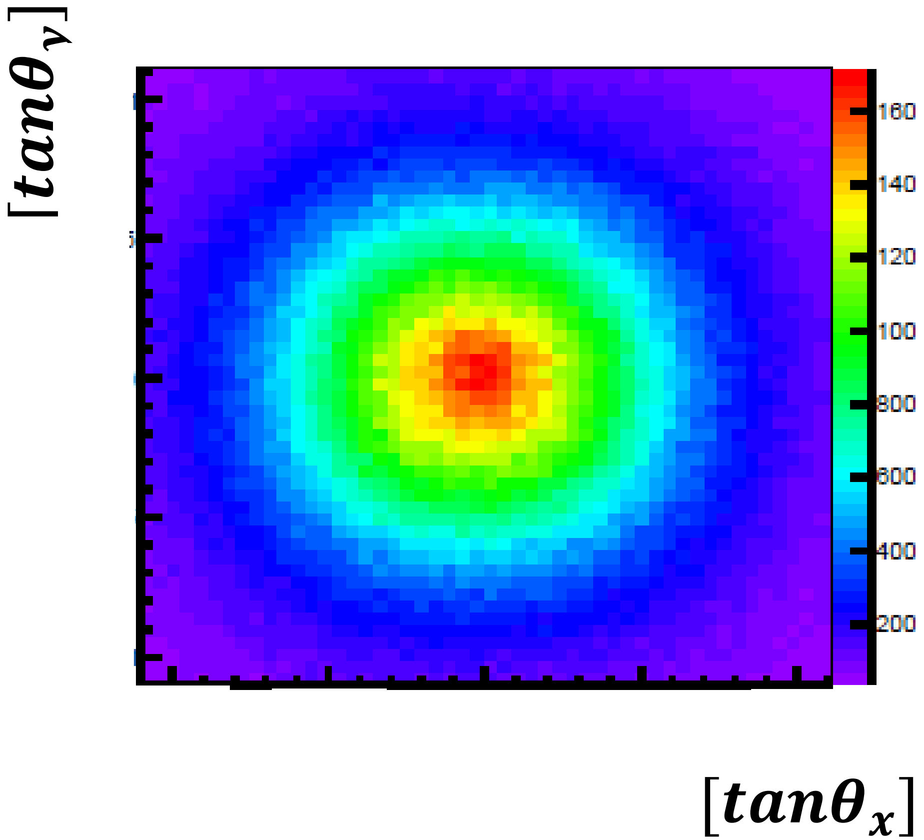
$$\delta \tan\theta_x = \frac{\sqrt{2}}{l}\sqrt{\delta x^2 + \quad \delta z^2 \times (\tan\theta_x)^2 = 0\}}$$

$$y = 7.75 \times 10^{-7} x^{-0.936}$$

δx

Angle Dependence of Angular Accuracy Test



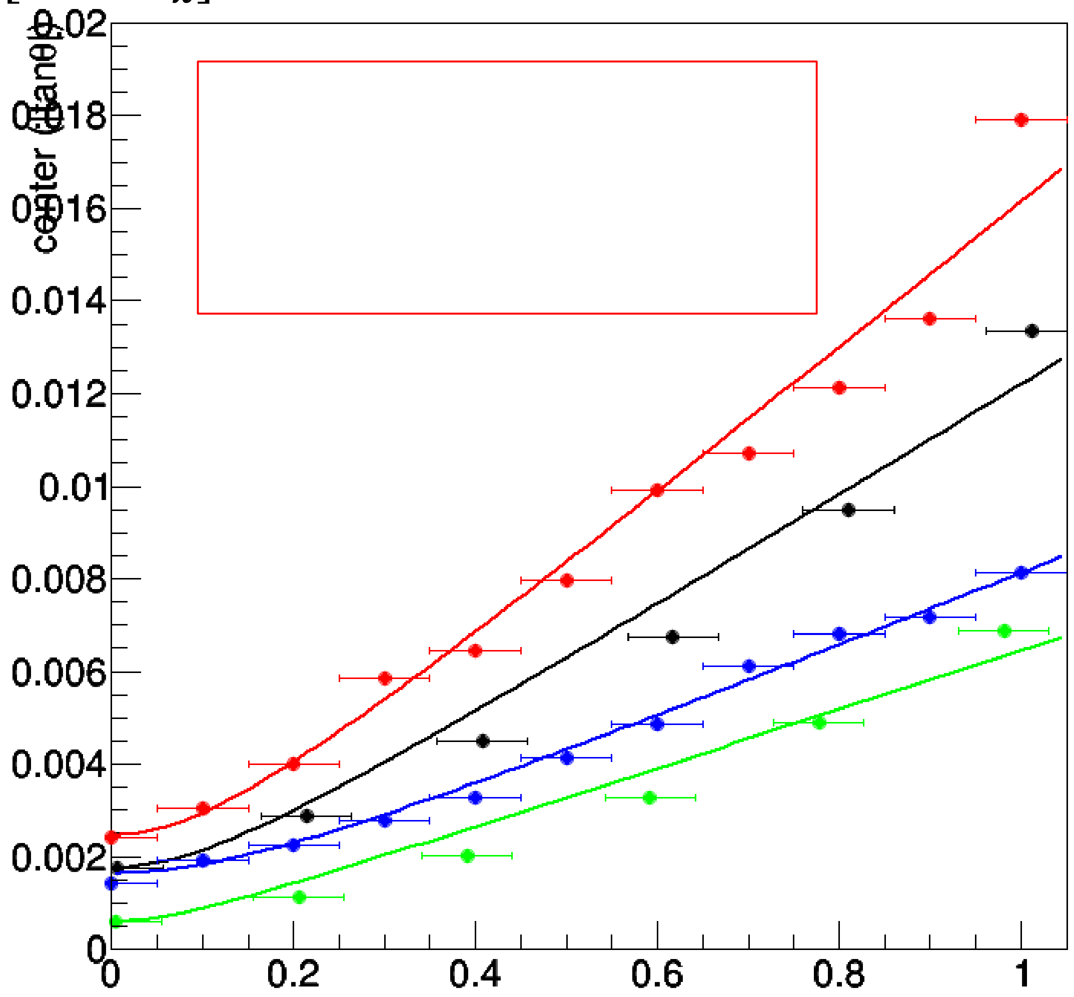


$tan\theta_x = 0.0, 0.2, 0.4 \ldots 1.0$
$tan\theta_y = 0.0$
$\pm tan\theta = 0.05$

$tan\theta_x = 0.0, 0.1, 0.2 \ldots 1.0$
$tan\theta_y = 0.0$
$\pm tan\theta = 0.05$

Angle Dependence of Angular Accuracy Test Result , Consideration

$[\delta tan\theta_x]$



$[tan\theta_x]$

Base Candidates (New Beam Test Samples)

	$5.0 \sim 8.3 \times 10^{-5}$	$5.0 \sim 9.0 \times 10^{-5}$	7×10^{-5}	6.8×10^{-5}	7.2×10^{-6}

Conclusion

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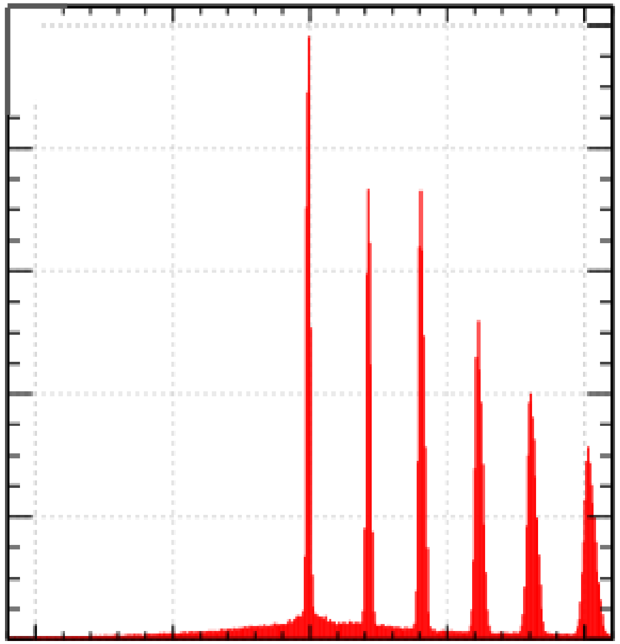
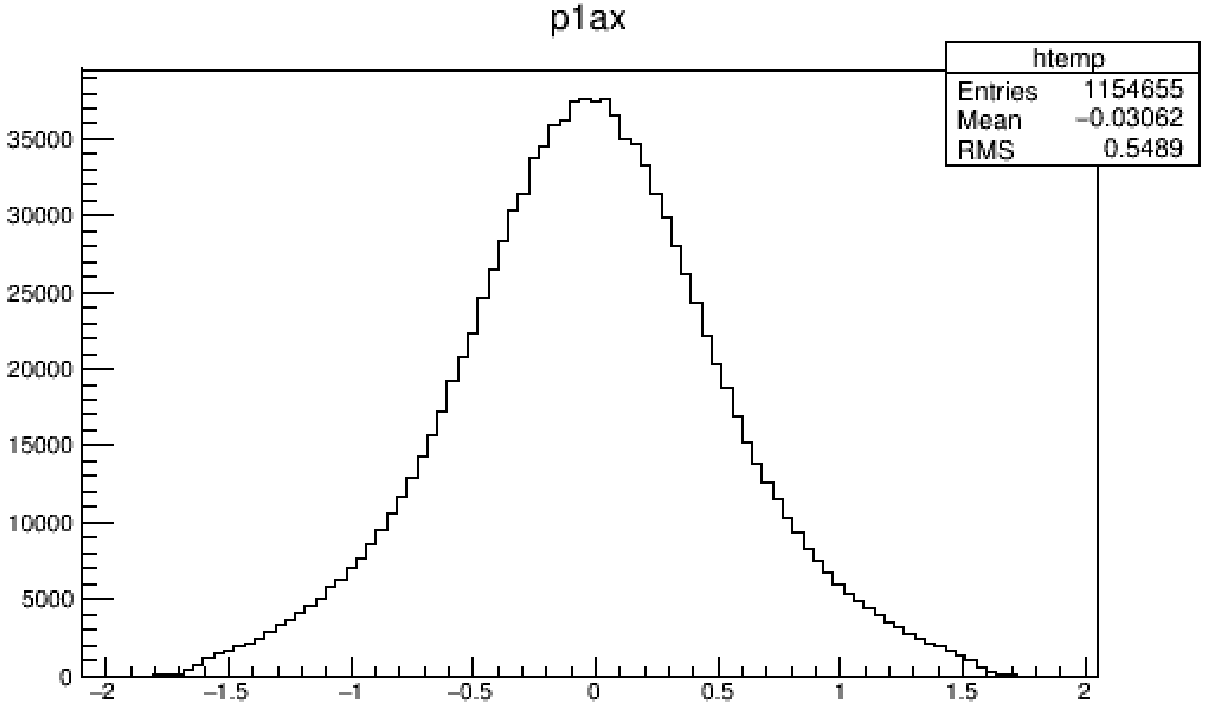
-
-

角度精度の角度依存性評価



$[\boldsymbol{tan\theta_x}]$

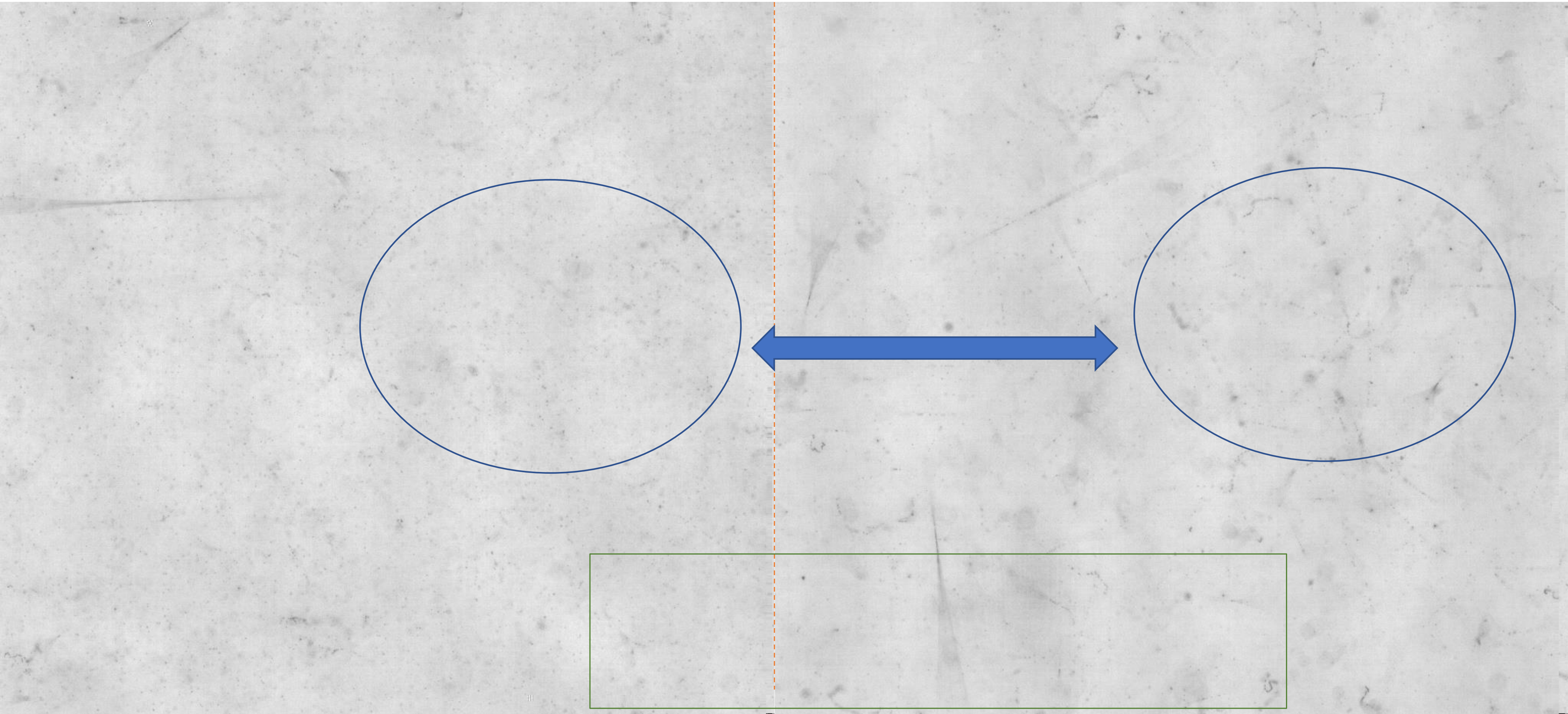


$[\boldsymbol{tan\theta_x}]$

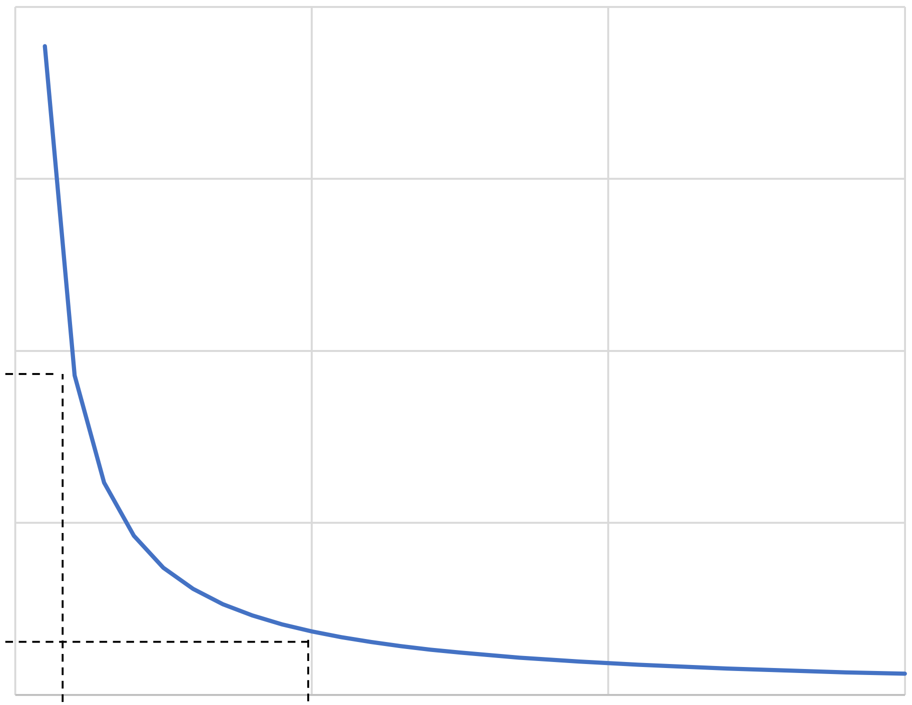
$tan\theta_x = 0.0, 0.2, 0.4 \dots 1.0$
$tan\theta_y = 0.0$

$tan\theta_x = 0.0, 0.1, 0.2 \dots 1.0$
$tan\theta_y = 0.0$

屈折率・副屈折率の違いによる見え方の差



散乱効果による画像のボケ



溶鉄10mを貫通したミューオンの散乱による画像ボケ