상대론적 고 에너지 중이온 충돌에서 제트입자와 관련된 **제동복사**

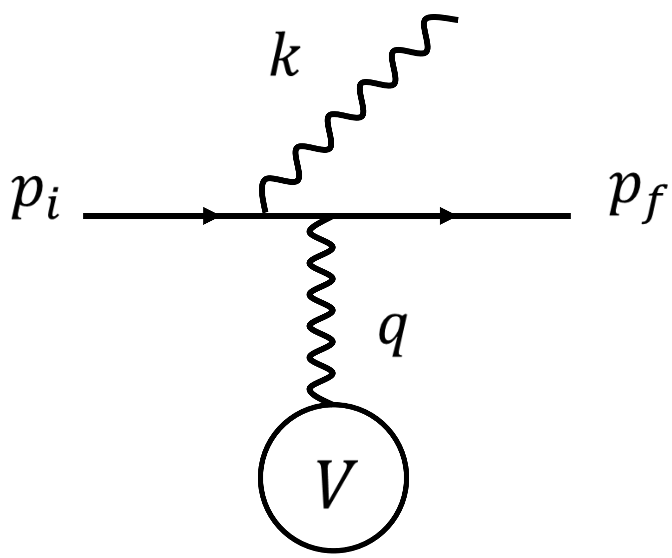
박가영

인하대학교

윤진희 교수님, 권민정 교수님

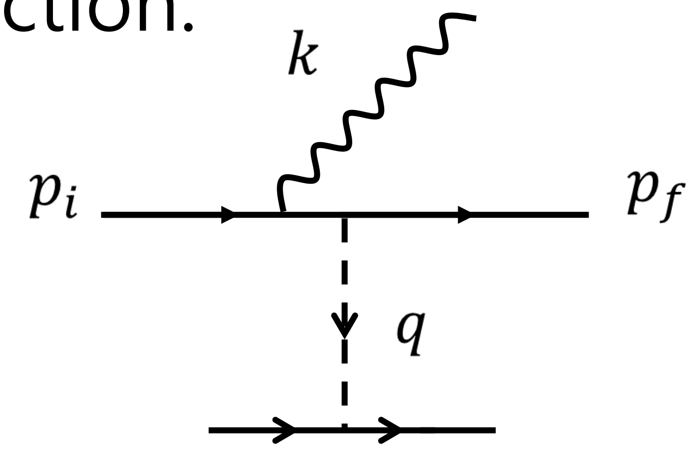
Motivation

- Bremsstrahlung is a major process losing energies while jet particles get through the medium.
- BUT it should be quite different from low energy potential scattering.

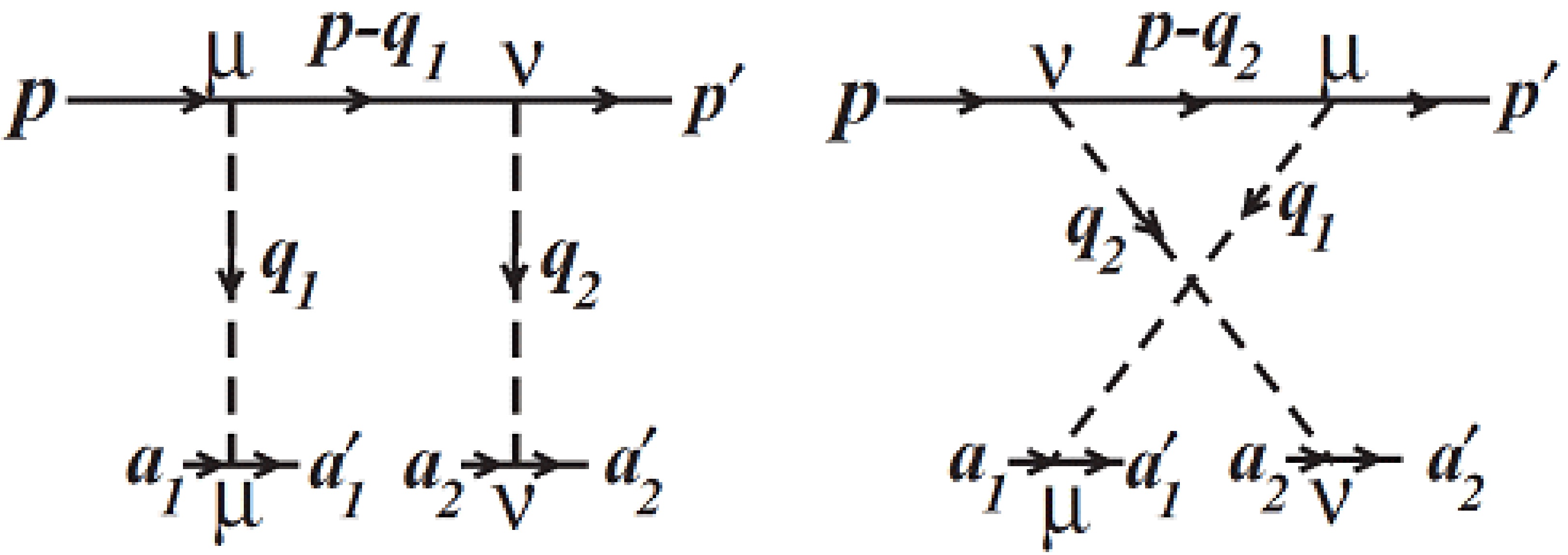


Motivation

- It is expected that in the high energy limit photons or gluons are emitted in the direction of the initial jet particles.
- Check the behavior of bremsstrahlung in relativistic heavy-ion collisions by calculating the cross section.



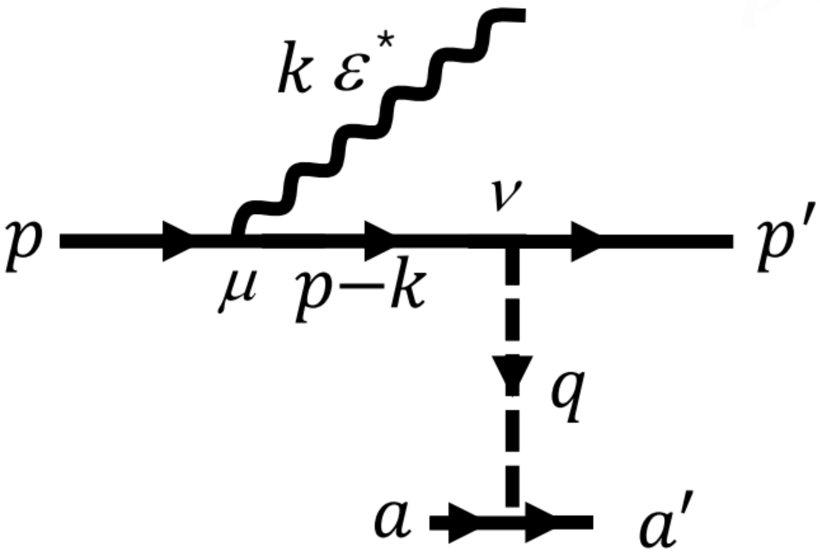
Model : Jet particle scattering in medium

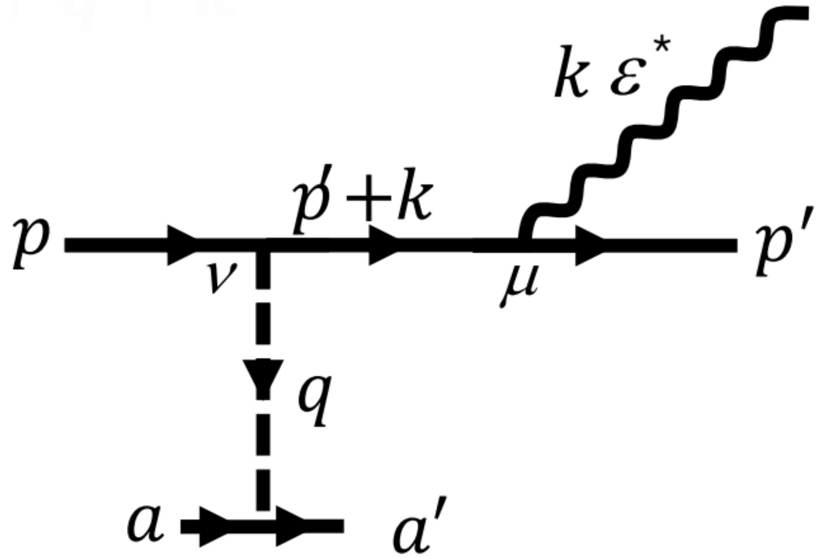


C. Y. Wong, Phys. Rev. C 85, 064909 (2012)

Two diagrams interfere to give the constructive behavior in the forward direction which results in the ridge correlation.

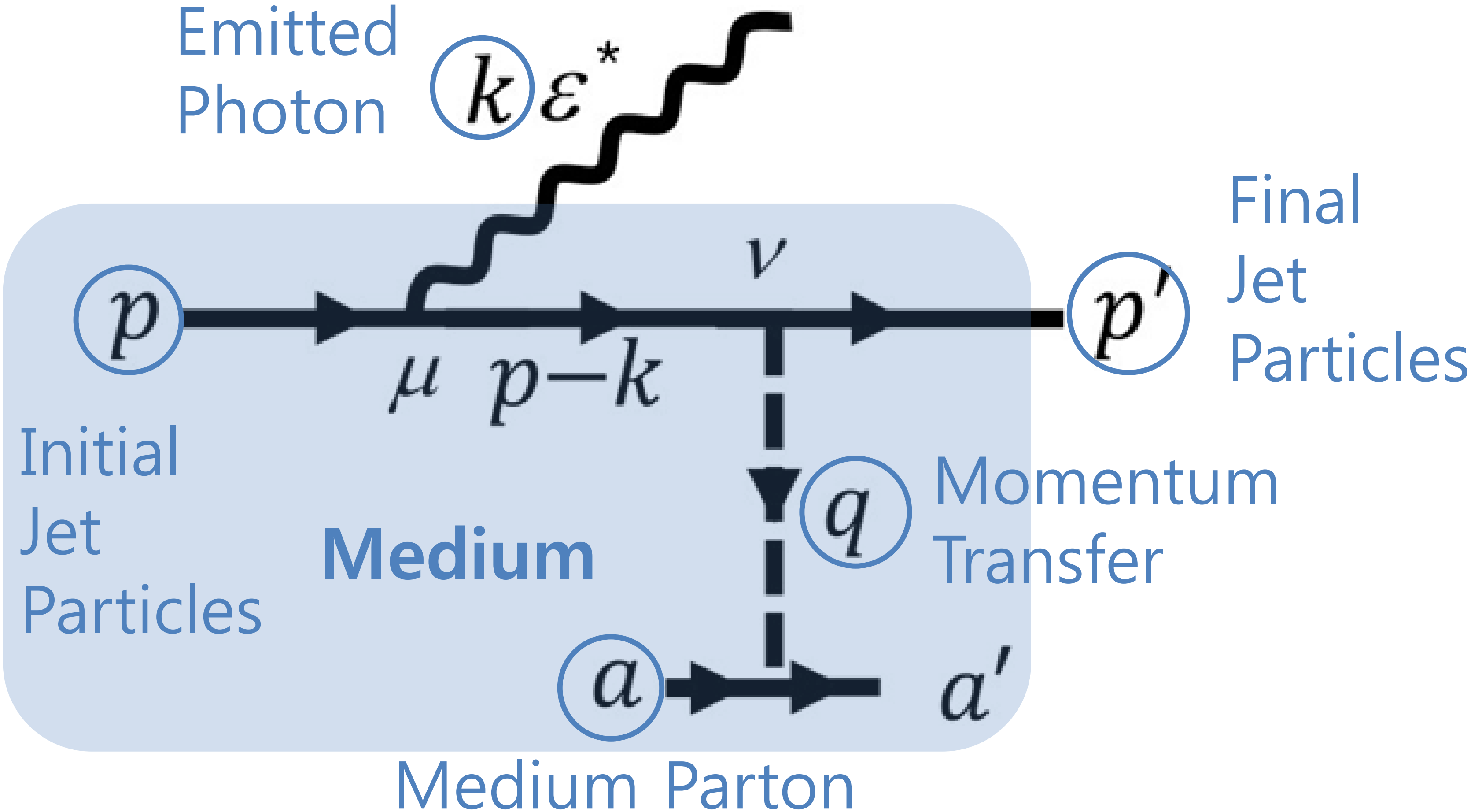
Bremsstrahlung of jet particle in medium



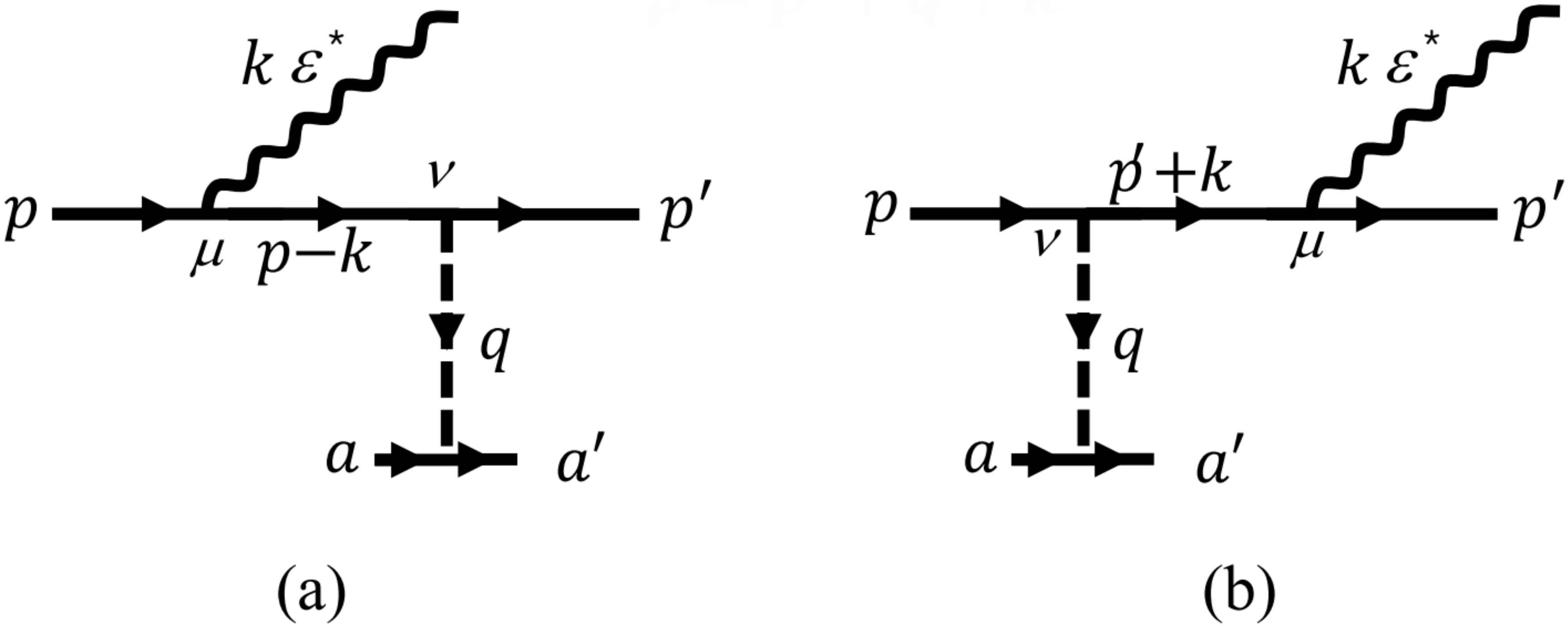


Interference term may play an important role in this process and give the forward peak.

Bremsstrahlung of jet particles



Amplitude for the Process



$$(a)\ M_a = -i\bar{u}(p')\Big((-ig\gamma^\nu)\frac{1}{q^2}\bar{u}(a')(-ig\gamma_\nu)u(a)\frac{i(\not{p}-\not{k}+m)}{(p-k)^2-m^2+i\epsilon}(-ig\gamma^\mu)\epsilon^*_\mu\Big)u(p)$$

$$(b)\ M_b = -i\bar{u}(p')\Big(\epsilon^*_\mu(-ig\gamma^\mu)\frac{i(\not{p}'+\not{k}+m)}{(p'+k)^2-m^2+i\epsilon}(-ig\gamma^\nu)\frac{1}{q^2}\bar{u}(a')(-ig\gamma_\nu)u(a)\Big)u(p)$$

Cross Section for the Process

$$d\sigma = \frac{1}{2(2\pi)^5}\frac{1}{v_p - \bar{v}}\frac{m_p}{p_0}\frac{m_a}{a_0}d\sigma'$$

$$d\sigma' = |M|^2\delta(p_0' + a_0' + k_0 - p_0 - a_0)\frac{m_p}{p_0'}\frac{m_a dq_z d\boldsymbol{q}_T}{a_0'}\frac{d^3k}{k_0}$$

$$M = M_a + M_b$$

Add them first before square them

and interference terms are expected to give the

forward peak.

Degree of Freedom

- Consider 5 particles → 20 degrees of freedom

- on mass shell condition : 5
- Energy momentum conservation : 4
- Set the direction of initial jet & medium parton
  to z axis : $p_x = p_y = 0$ & $a_x = a_y = 0$

- Left 7 degrees of freedom
  : p_0 , p'_0 , $\theta_{p'}$, $\varphi_{p'}$, k_0 , θ_k , φ_k

Degree of Freedom

Using on mass-shell condition

& $p - p' - k = q = a' - a$

- for initial medium

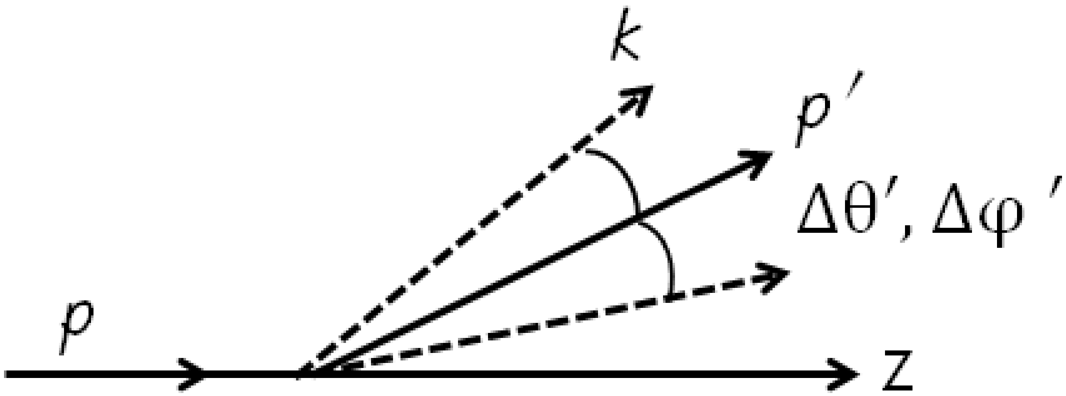
$$a_0^2 = a_3^2 + m_a^2$$

- for final medium

$$(a_0 + q_0)^2 = q_1^2 + q_2^2 + (a_3 + q_3)^2 + m_a^2$$

We have quadratic equation from two expression and solve it to get a_0 & a_3.

Angular Distribution of Cross Section



- Check the angular distribution of the cross section.
- Check the correlation

$$\Delta\theta' = \theta_{p'} - \theta_k \ \& \ \Delta\varphi' = \varphi_{p'} - \varphi_k$$

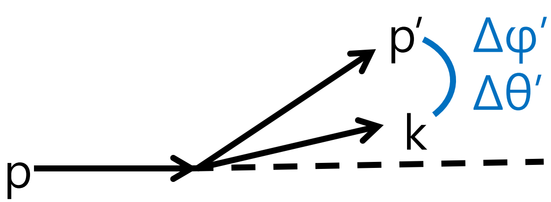
E_k Dependence of Cross Section

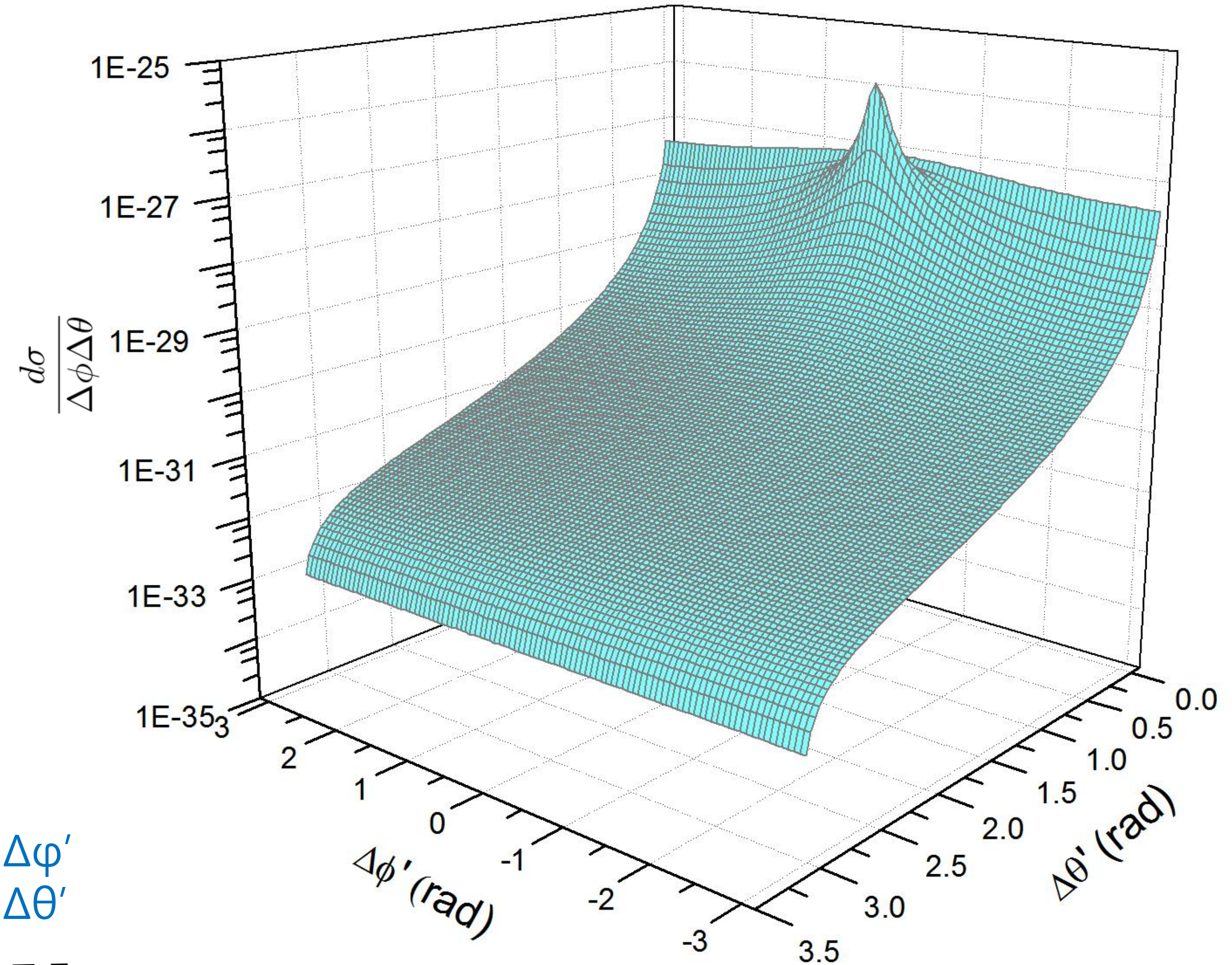
E_k dependence

p	10 GeV
p′	9 GeV
k	0.1 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	10 degree
φ_k	$0 \sim 2\pi$
θ_k	$0 \sim \pi$

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





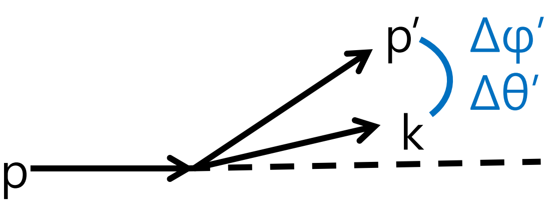
E_k Dependence of Cross Section

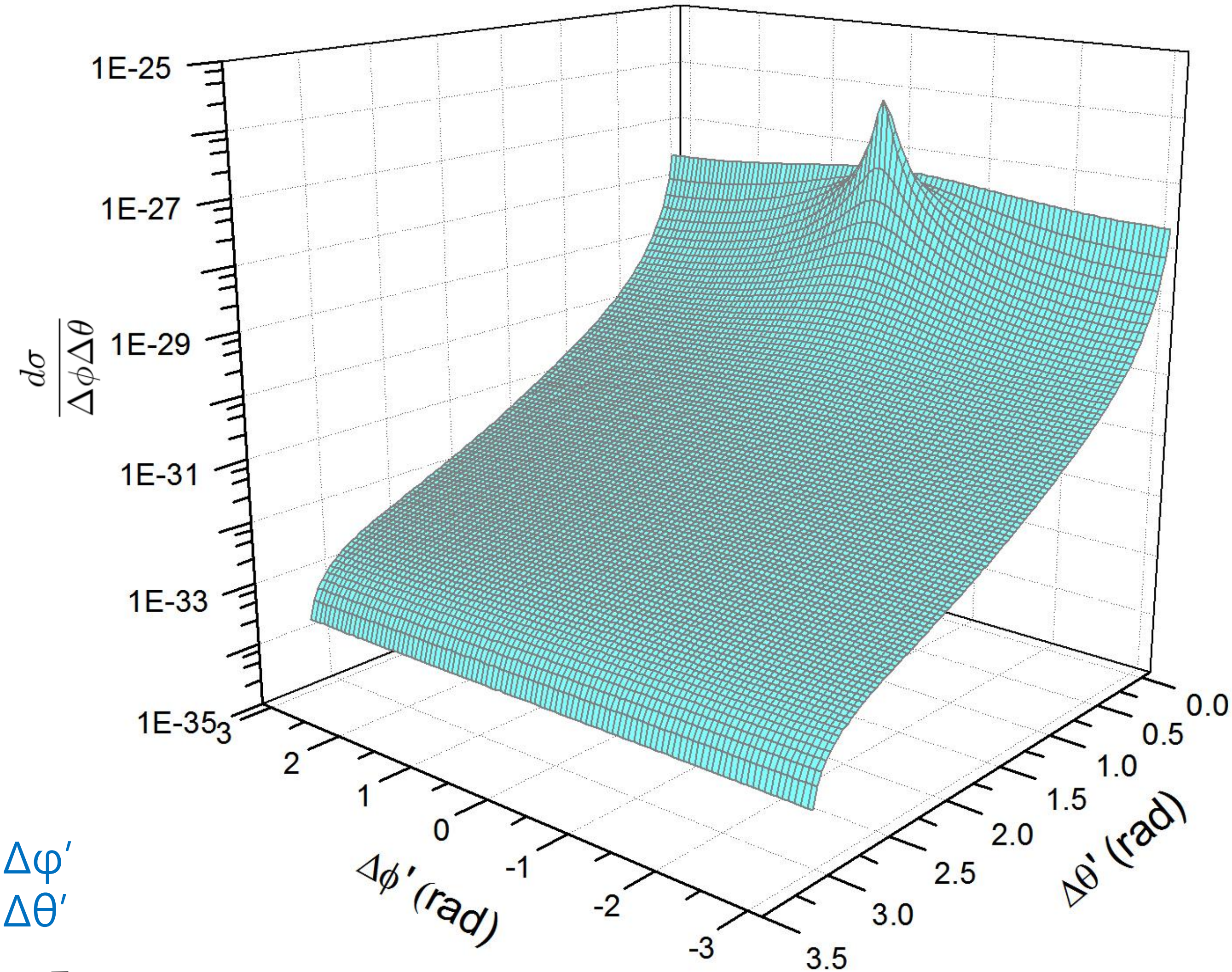
E_k dependence

p	10 GeV
p′	9 GeV
k	0.3 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	10 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$$\Delta\theta' = \theta_{p'} - \theta_k$$

$$\Delta\varphi' = \varphi_{p'} - \varphi_k$$





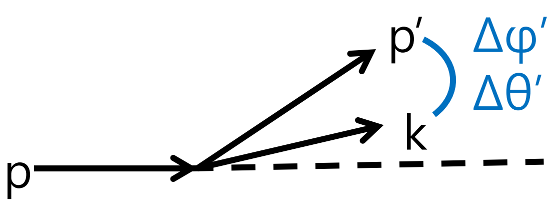
E_k Dependence of Cross Section

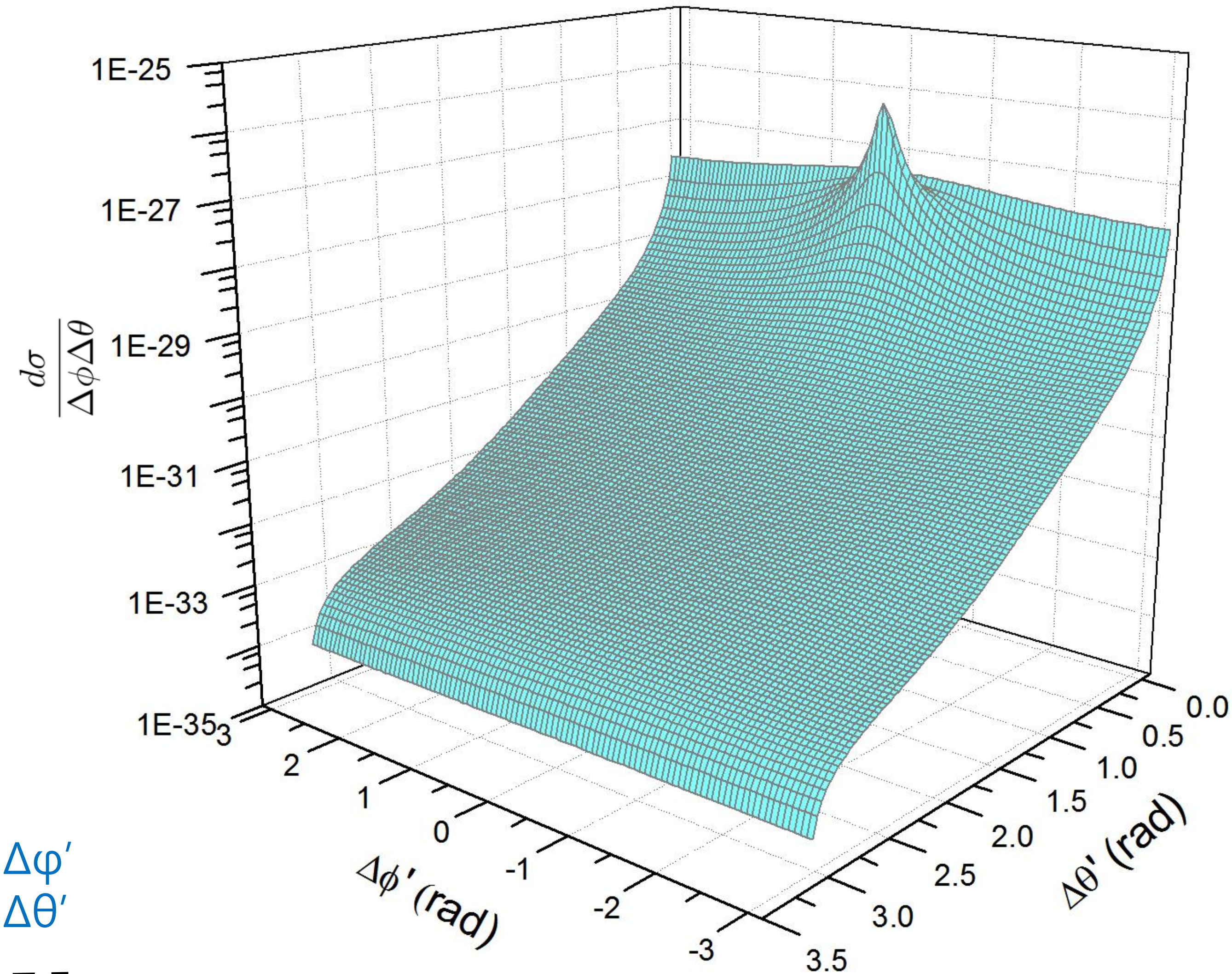
E_k dependence

p	10 GeV
p′	9 GeV
k	0.5 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	10 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





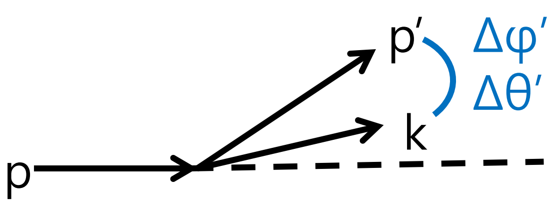
E_k Dependence of Cross Section

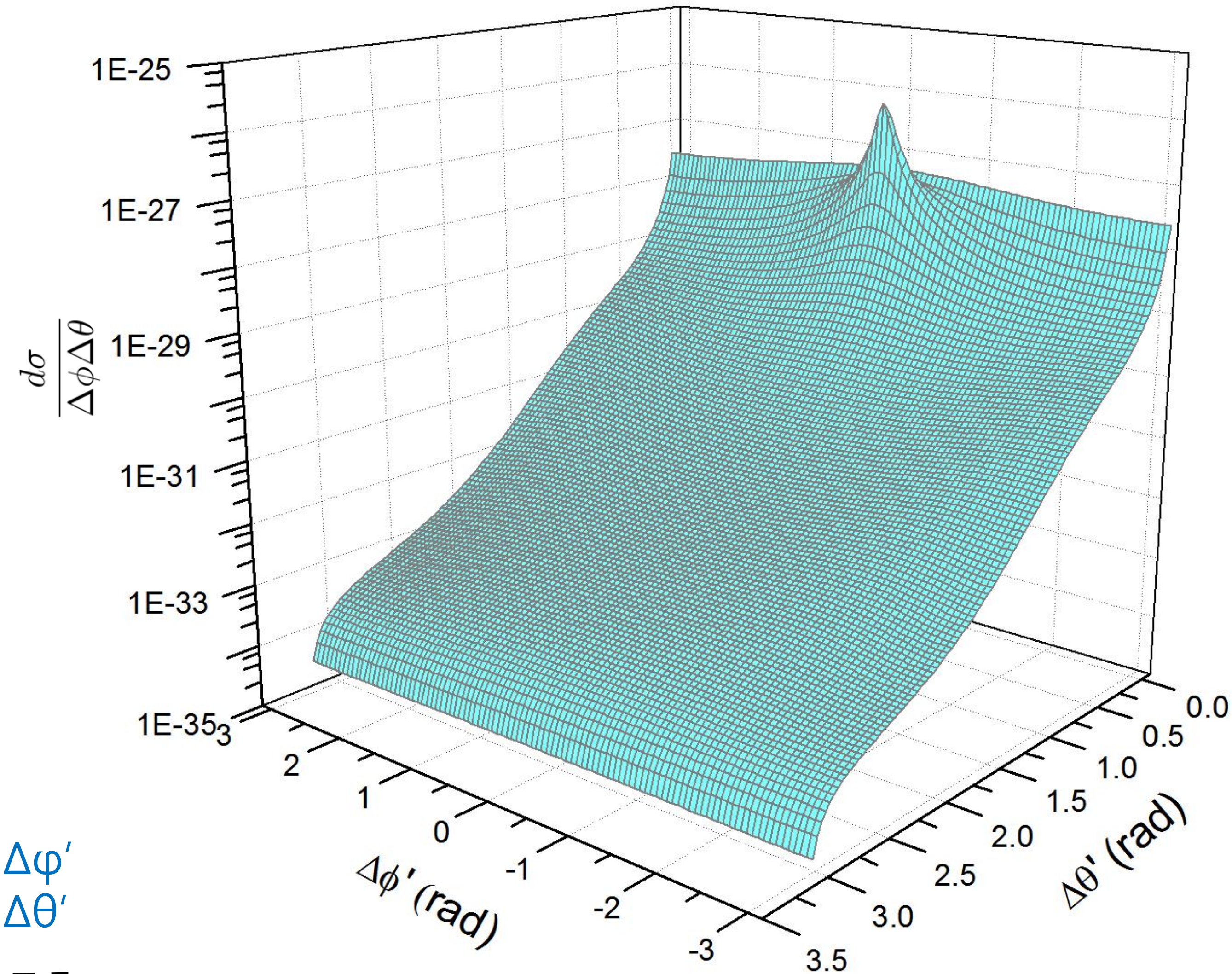
E_k dependence

p	10 GeV
p′	9 GeV
k	0.7 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	10 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





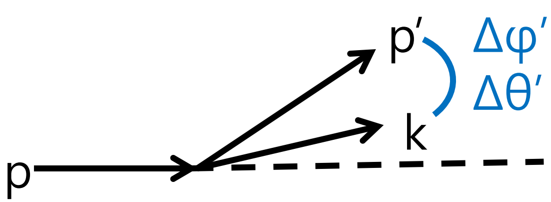
E_k Dependence of Cross Section

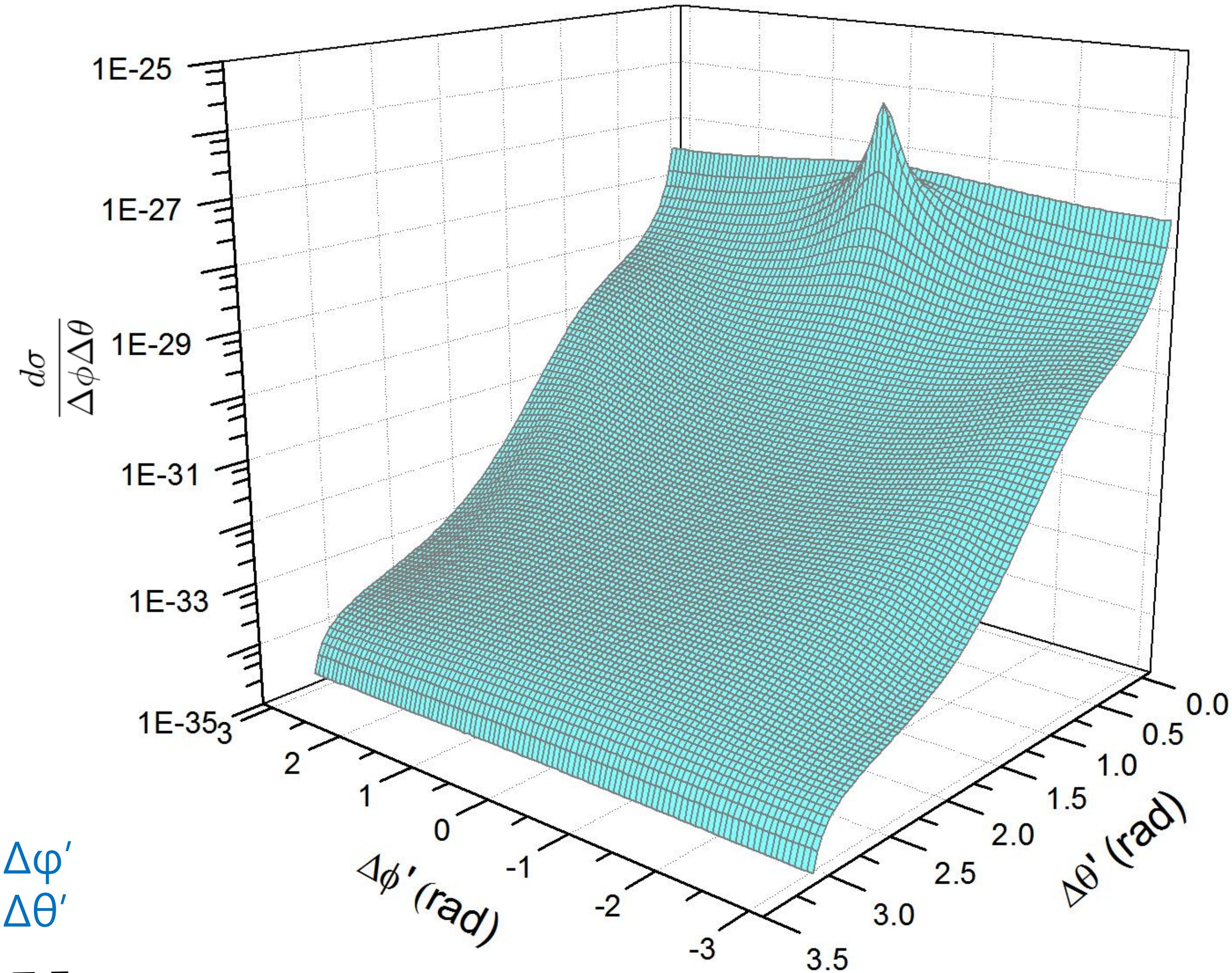
E_k dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	10 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





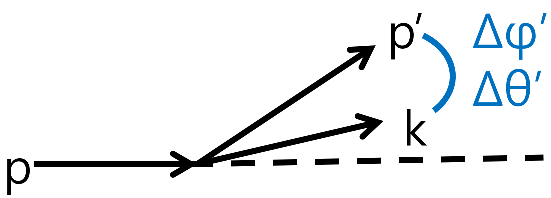
$\theta_{p'}$ Dependence of Cross Section

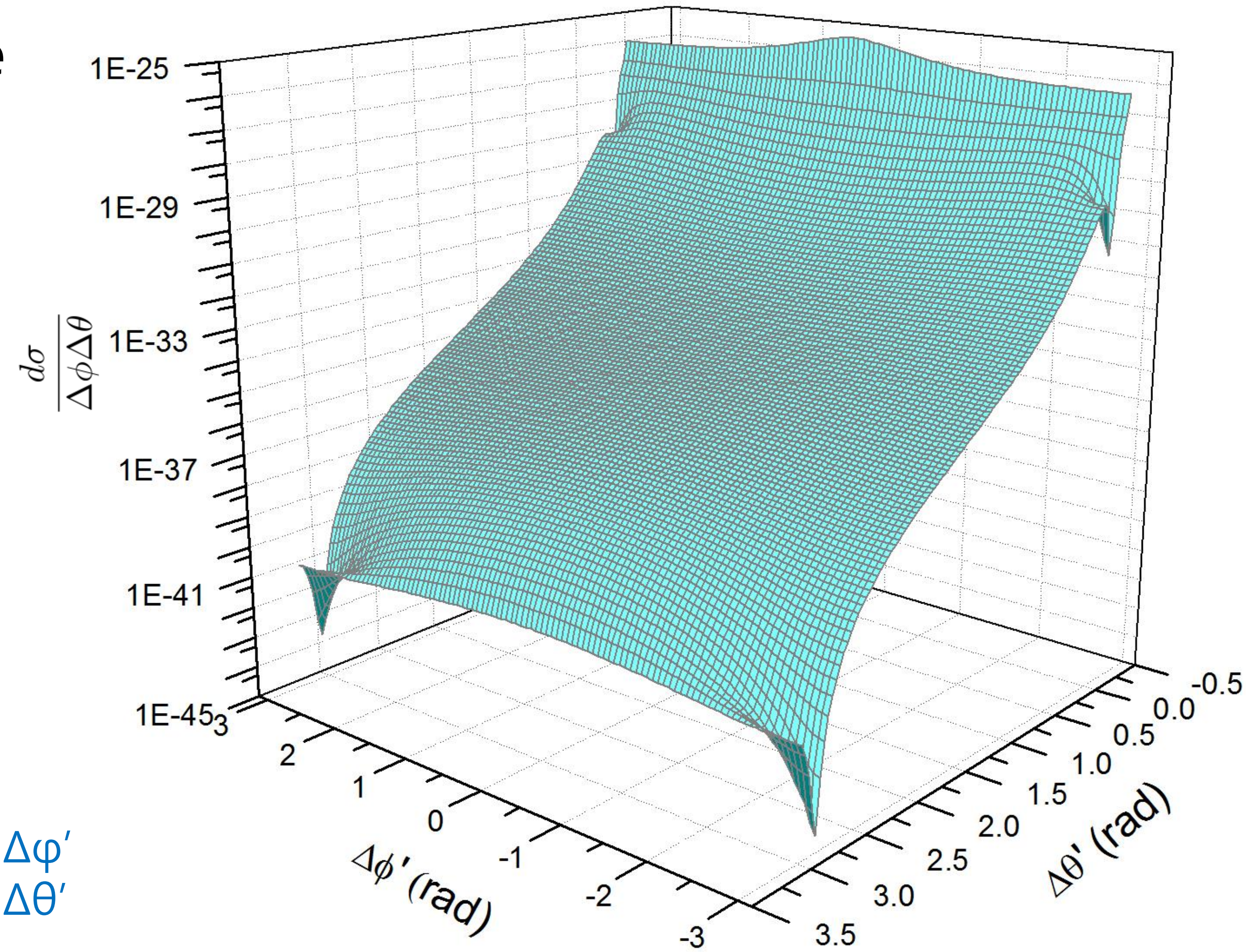
$\theta_{p'}$ dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





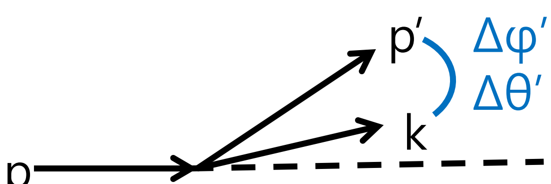
$\theta_{p'}$ Dependence of Cross Section

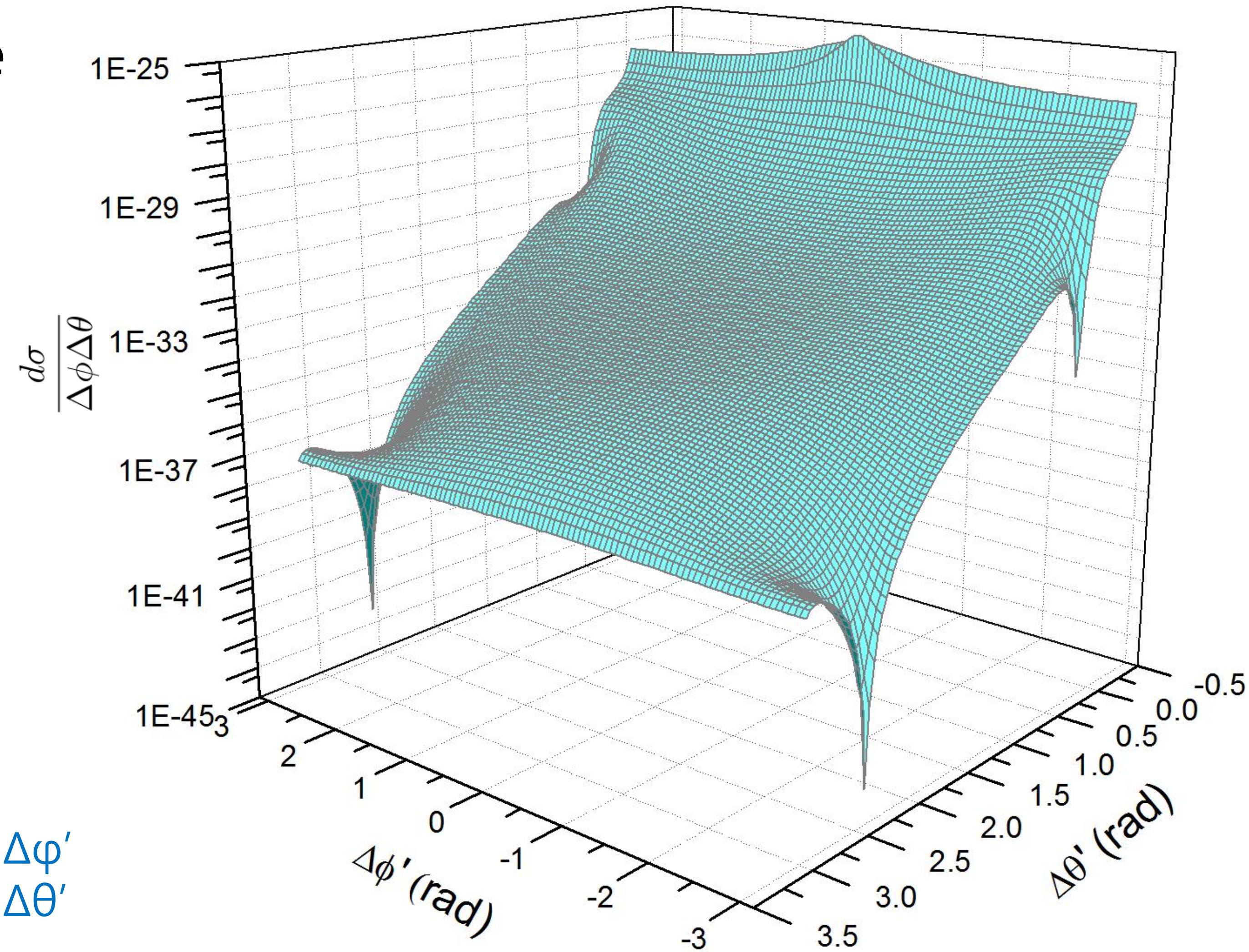
$\theta_{p'}$ dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	3 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





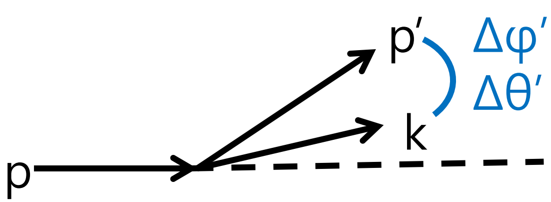
$\theta_{p'}$ Dependence of Cross Section

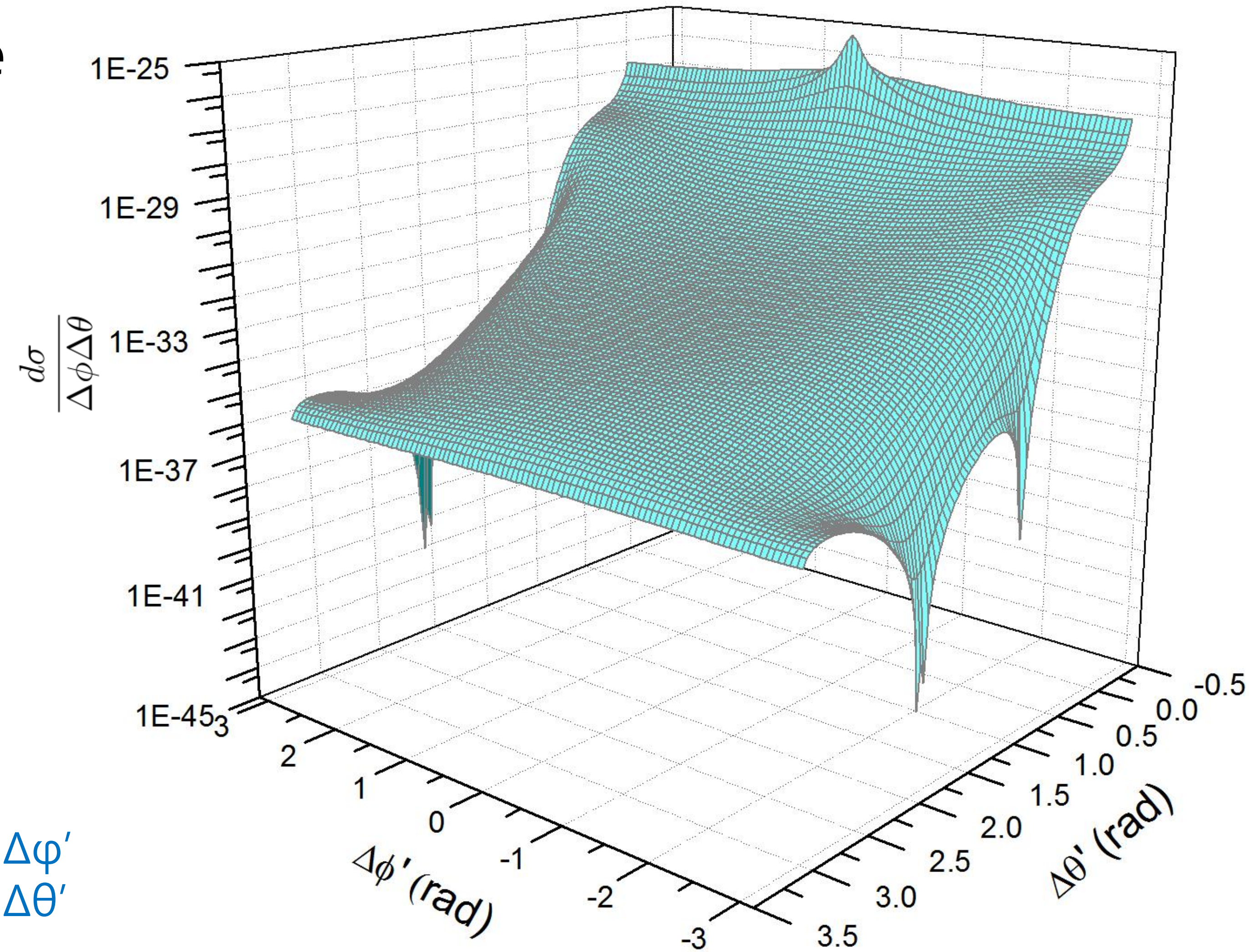
$\theta_{p'}$ dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	5 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$$\Delta\theta' = \theta_{p'} - \theta_k$$

$$\Delta\varphi' = \varphi_{p'} - \varphi_k$$





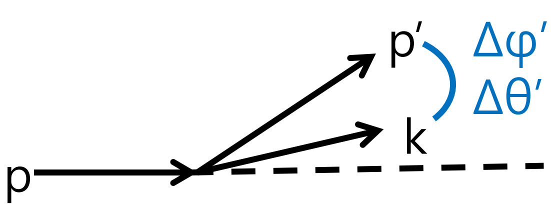
$\theta_{p'}$ Dependence of Cross Section

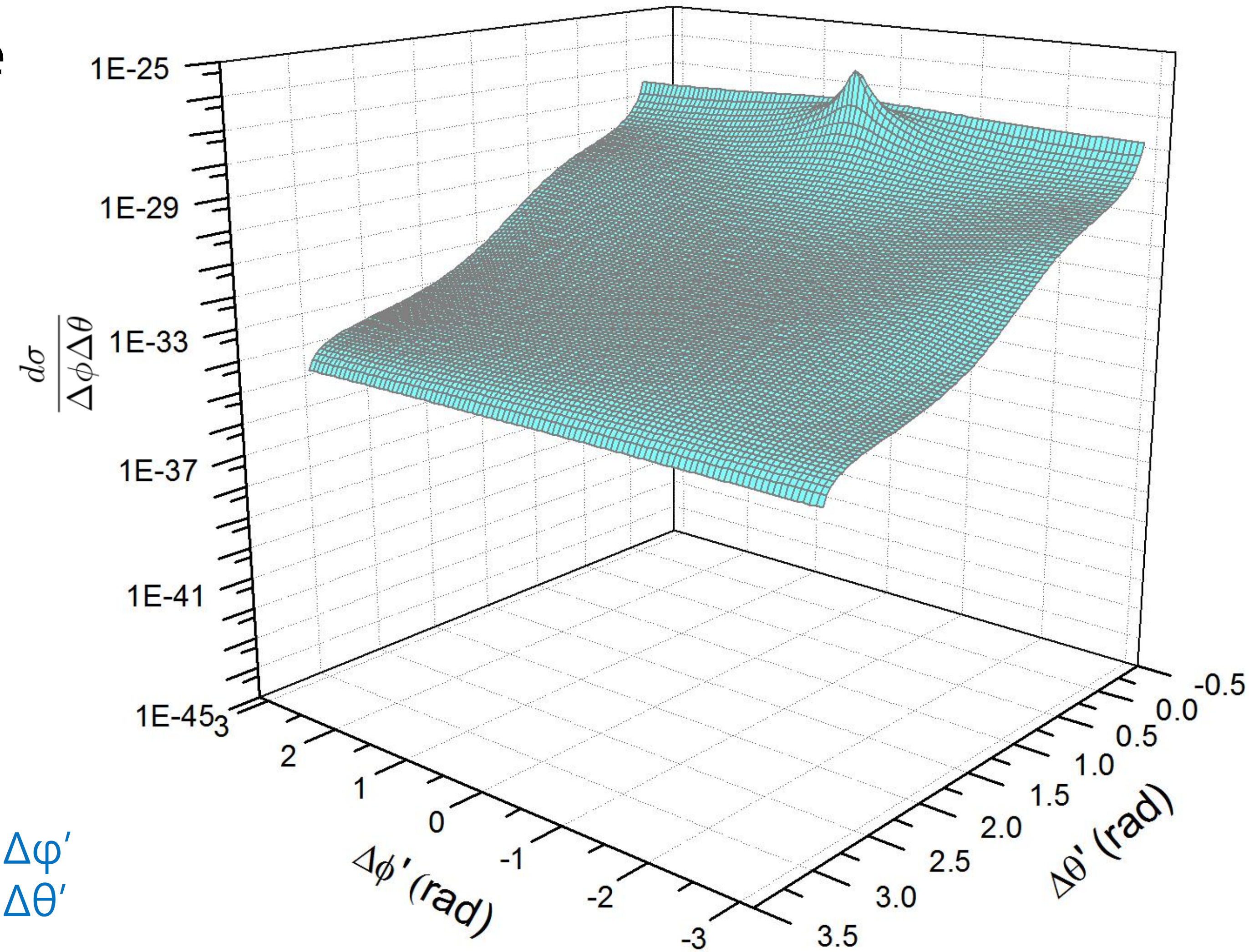
$\theta_{p'}$ dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	10 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





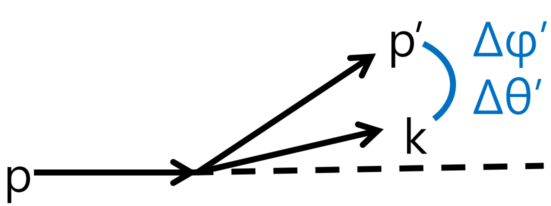
$\theta_{p'}$ Dependence of Cross Section

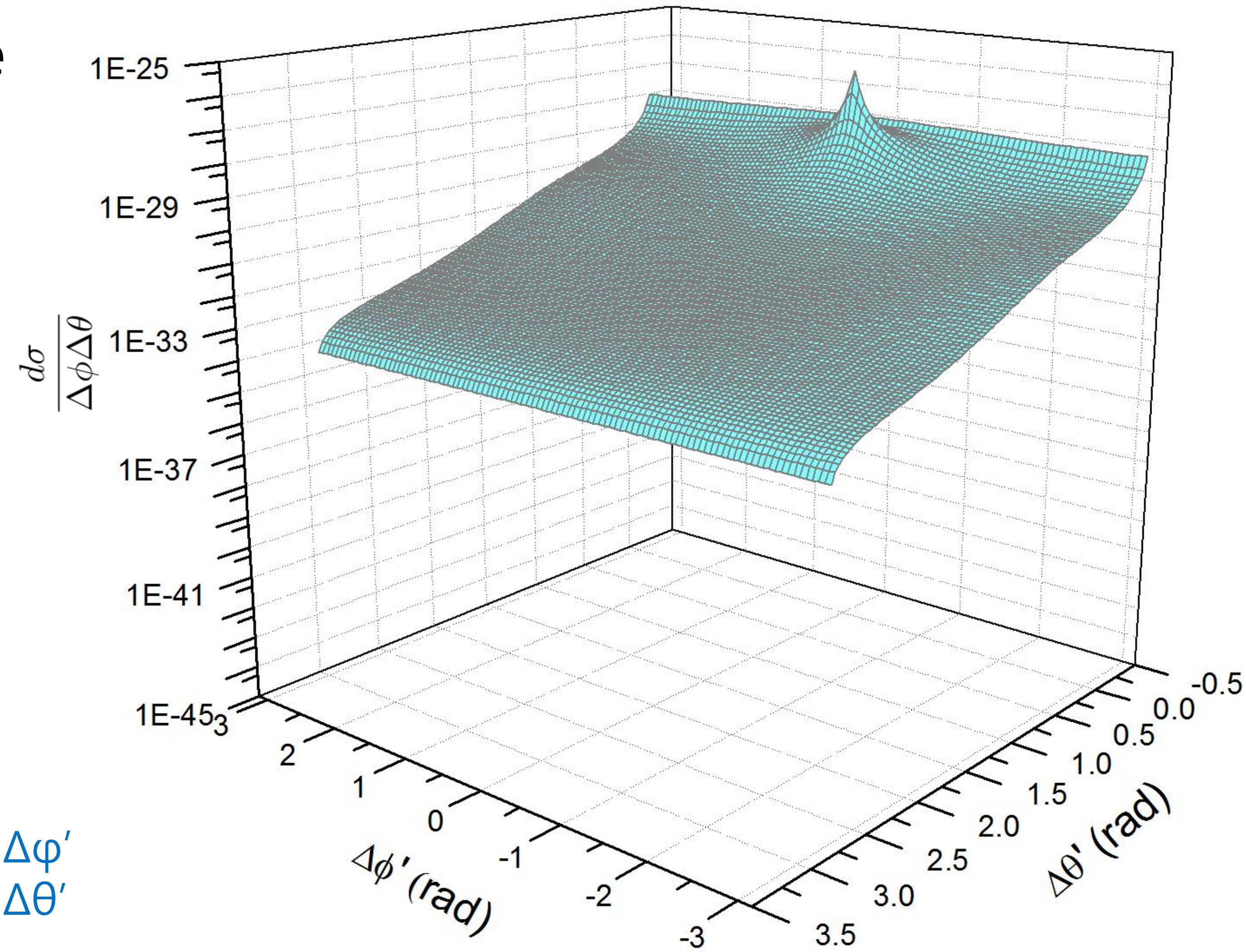
$\theta_{p'}$ dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	15 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





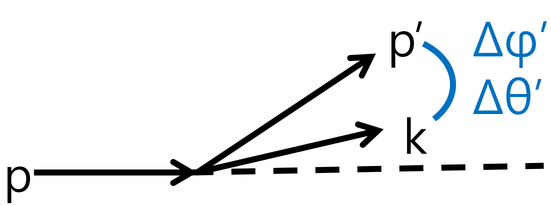
$\theta_{p'}$ Dependence of Cross Section

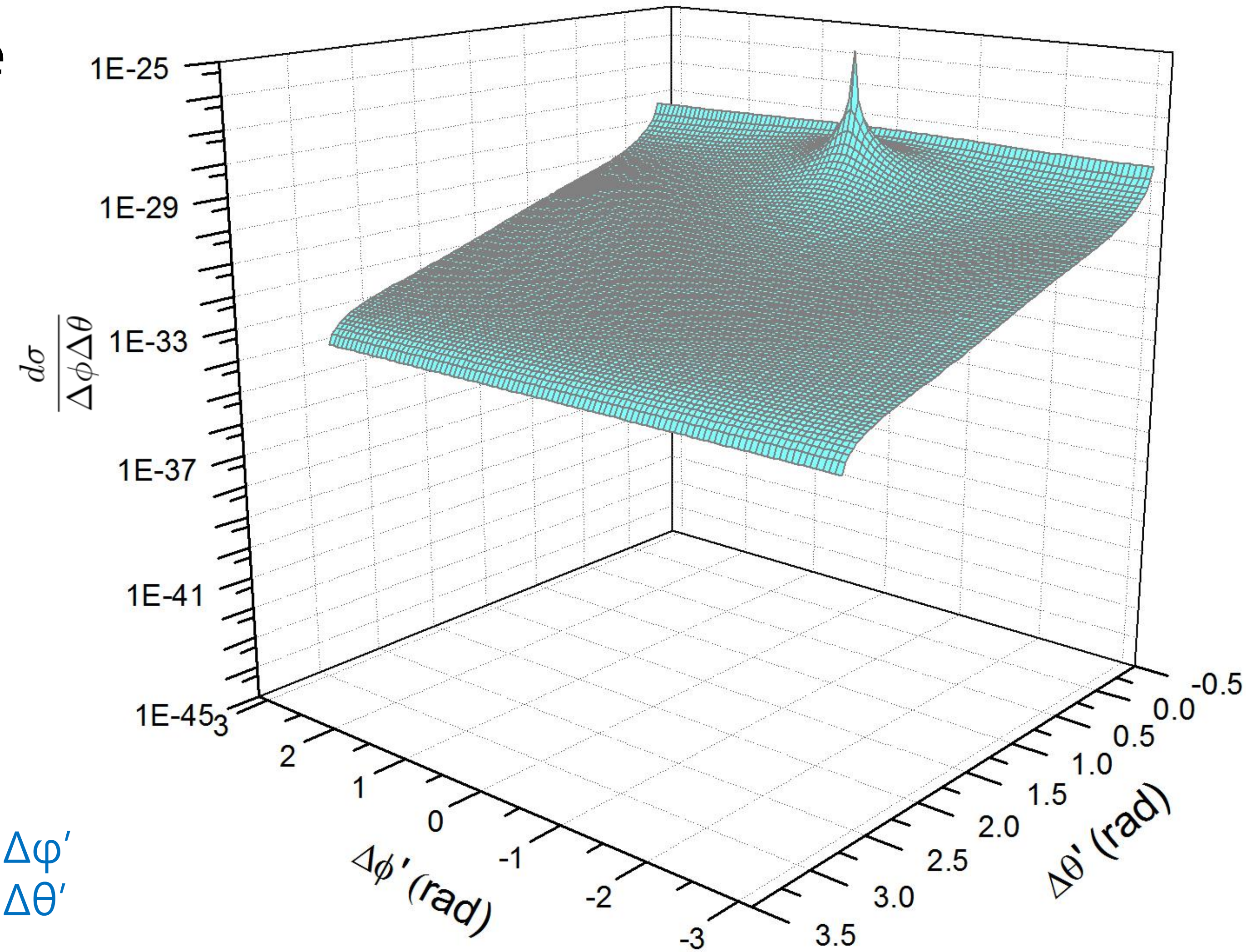
$\theta_{p'}$ dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	20 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





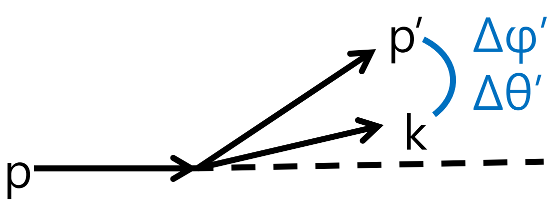
E_p Dependence of Cross Section

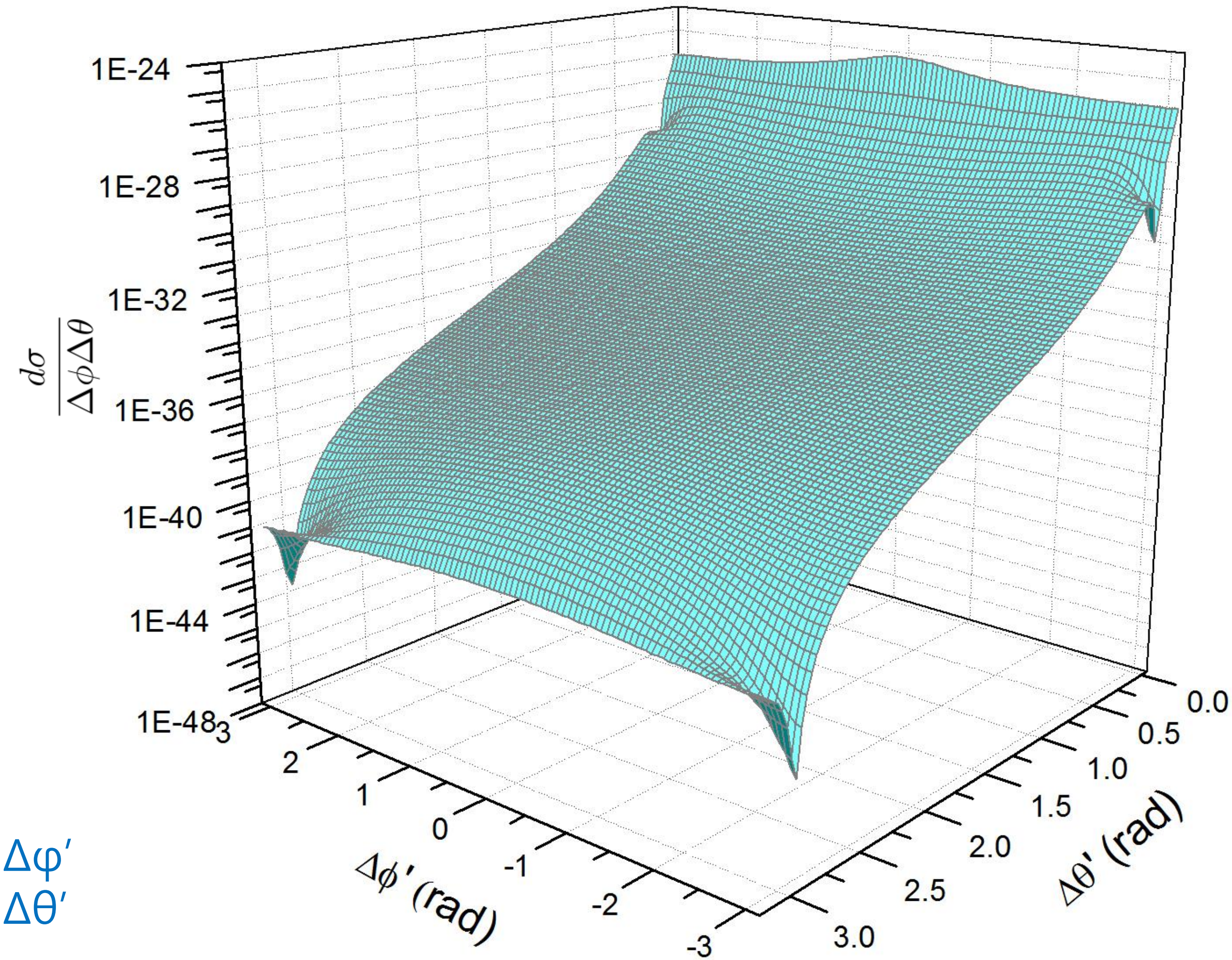
E_p dependence

p	10 GeV
p′	9 GeV
k	0.9 GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





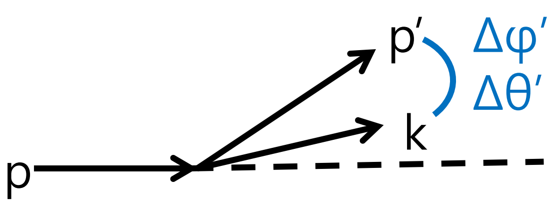
E_p Dependence of Cross Section

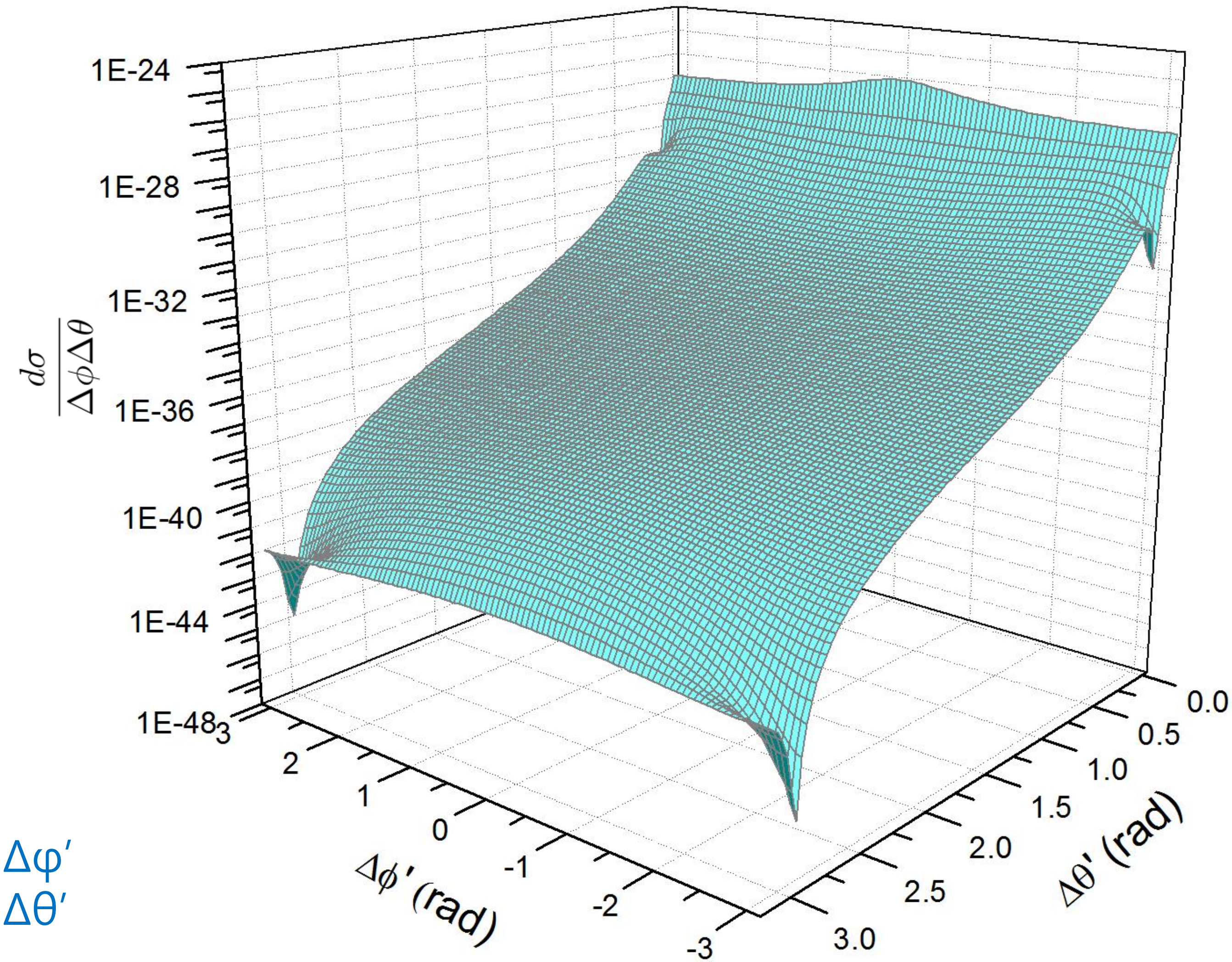
E_p dependence

p	20 GeV
p′	0.9 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





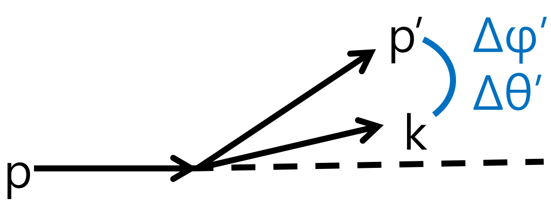
E_p Dependence of Cross Section

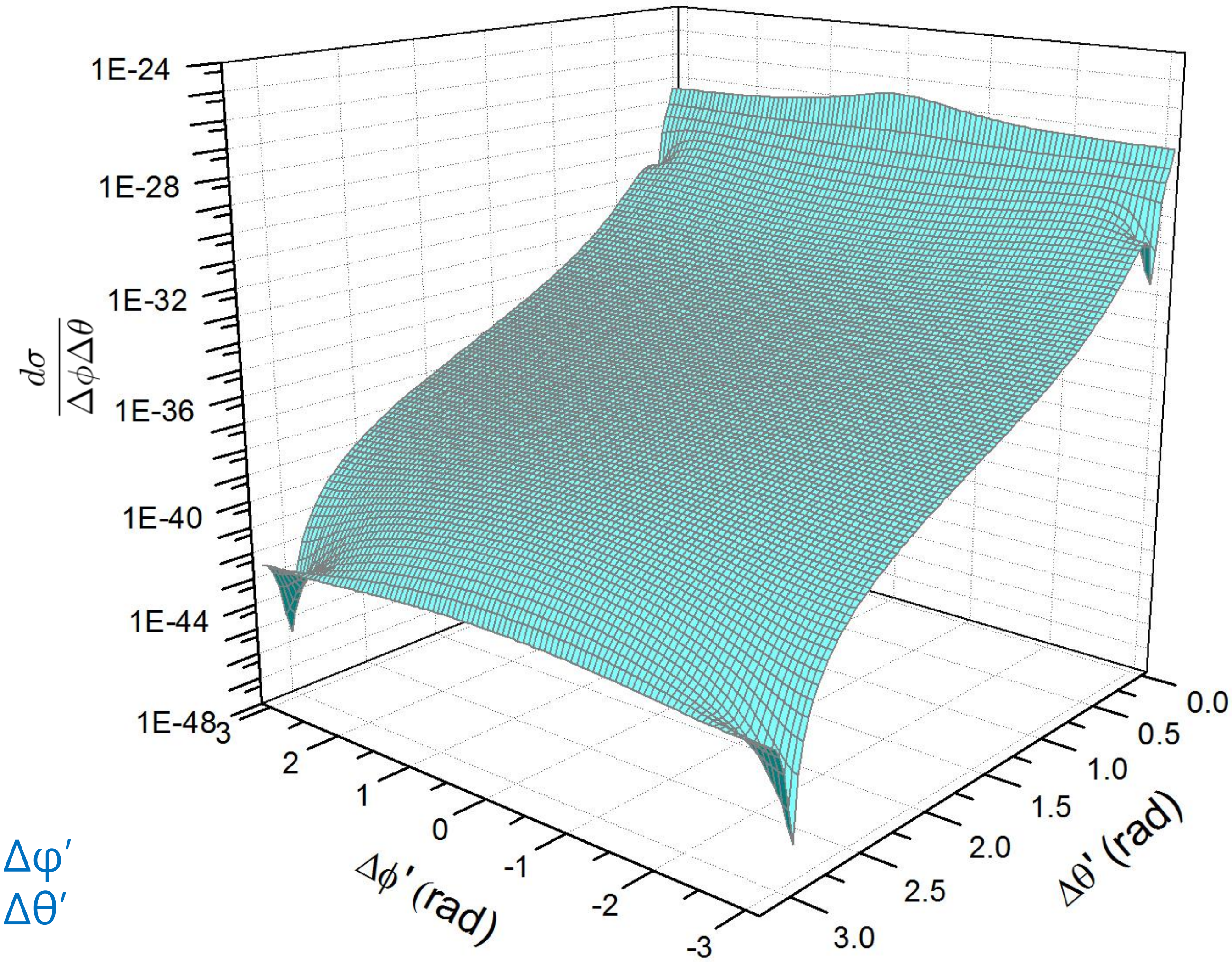
E_p dependence

p	30 GeV
p′	0.9 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$$\Delta\theta' = \theta_{p'} - \theta_k$$

$$\Delta\varphi' = \varphi_{p'} - \varphi_k$$





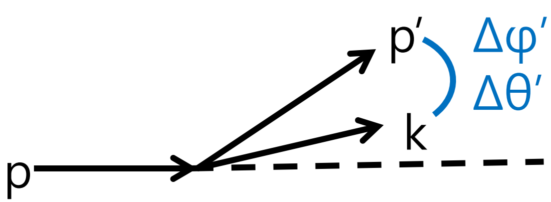
E_p Dependence of Cross Section

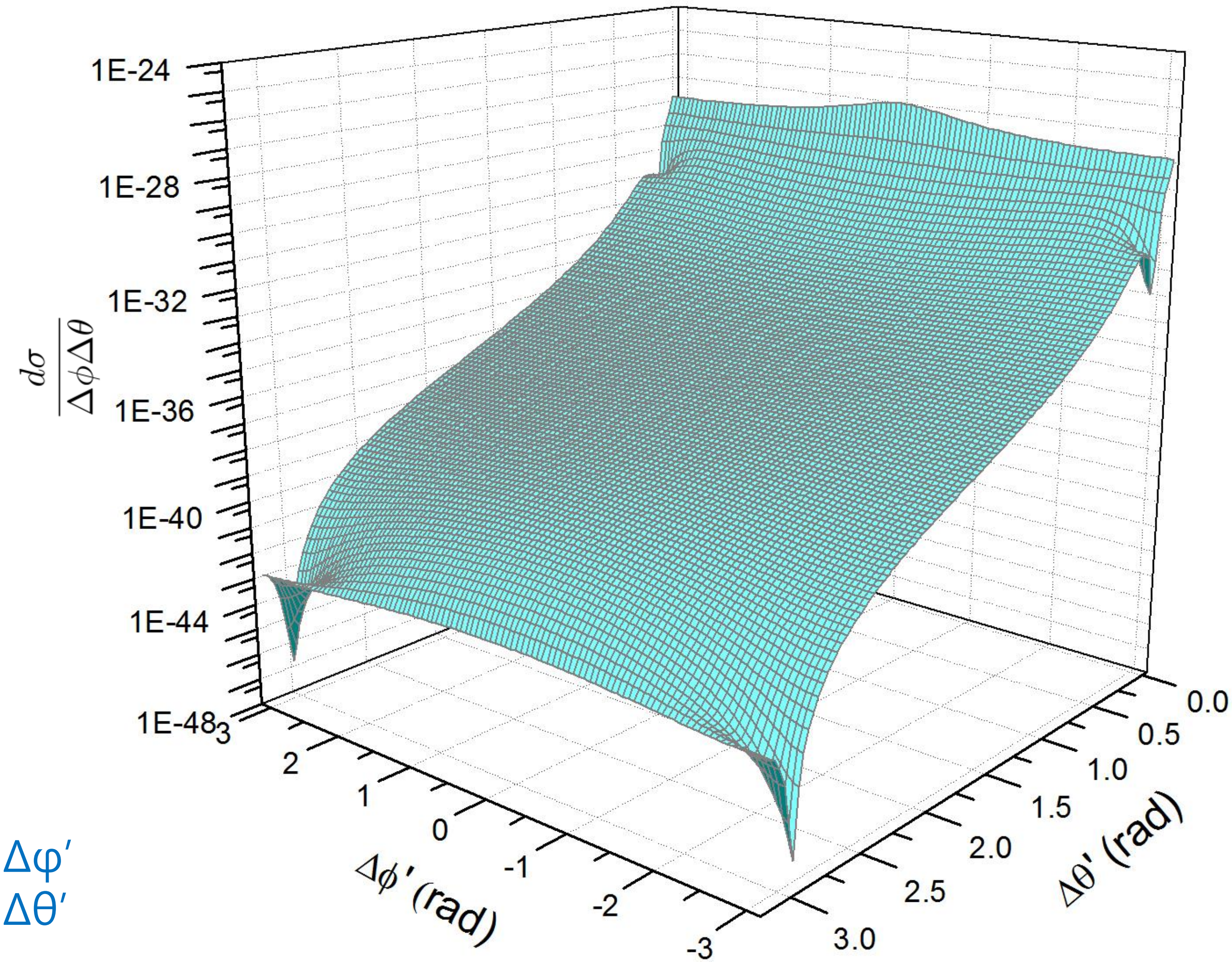
E_p dependence

p	40 GeV
p′	0.9 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





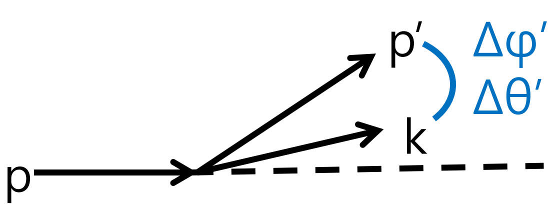
E_p Dependence of Cross Section

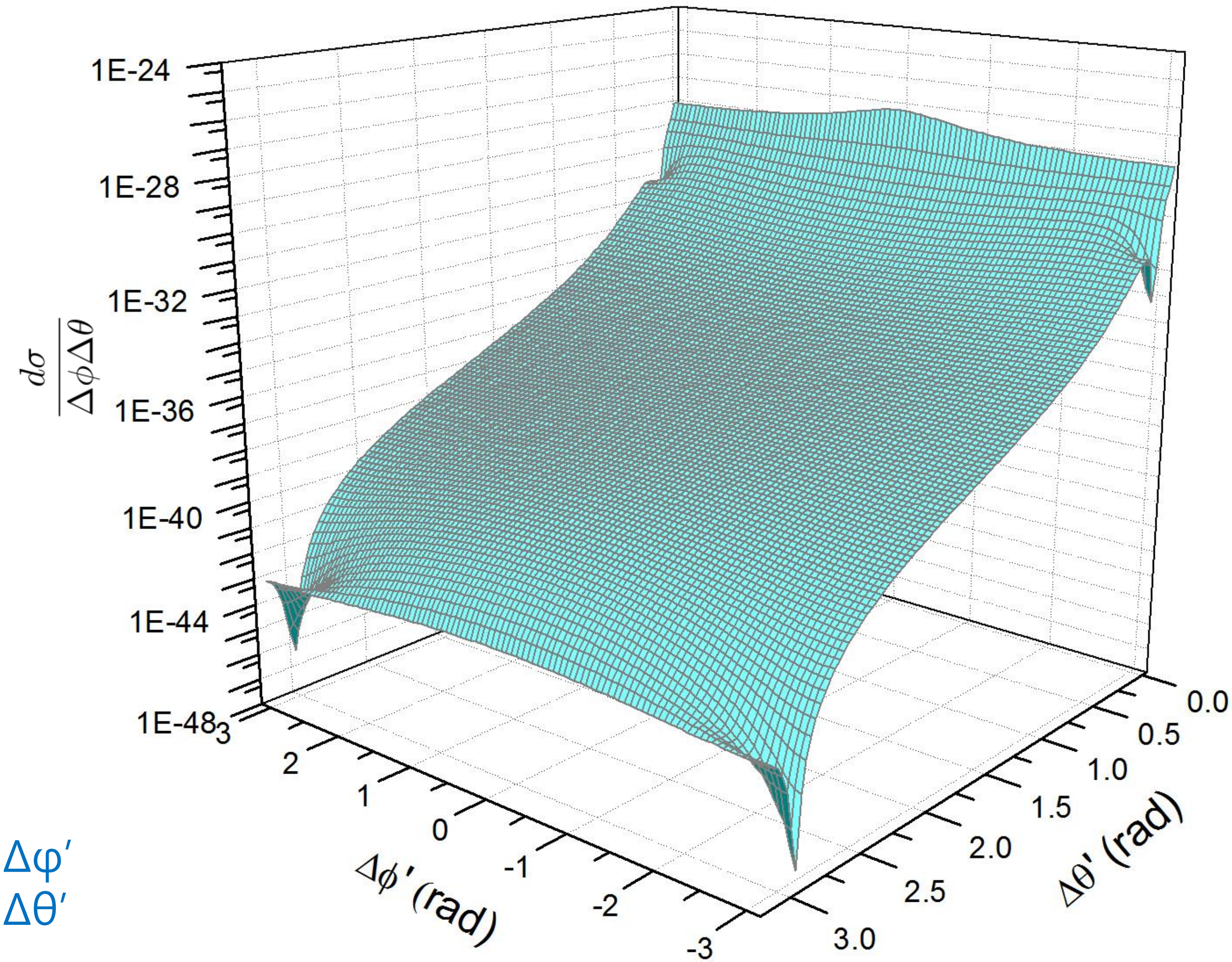
E_p dependence

p	50 GeV
p′	0.9 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





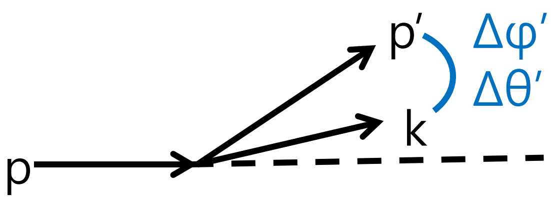
$E_{p'}$ Dependence of Cross Section

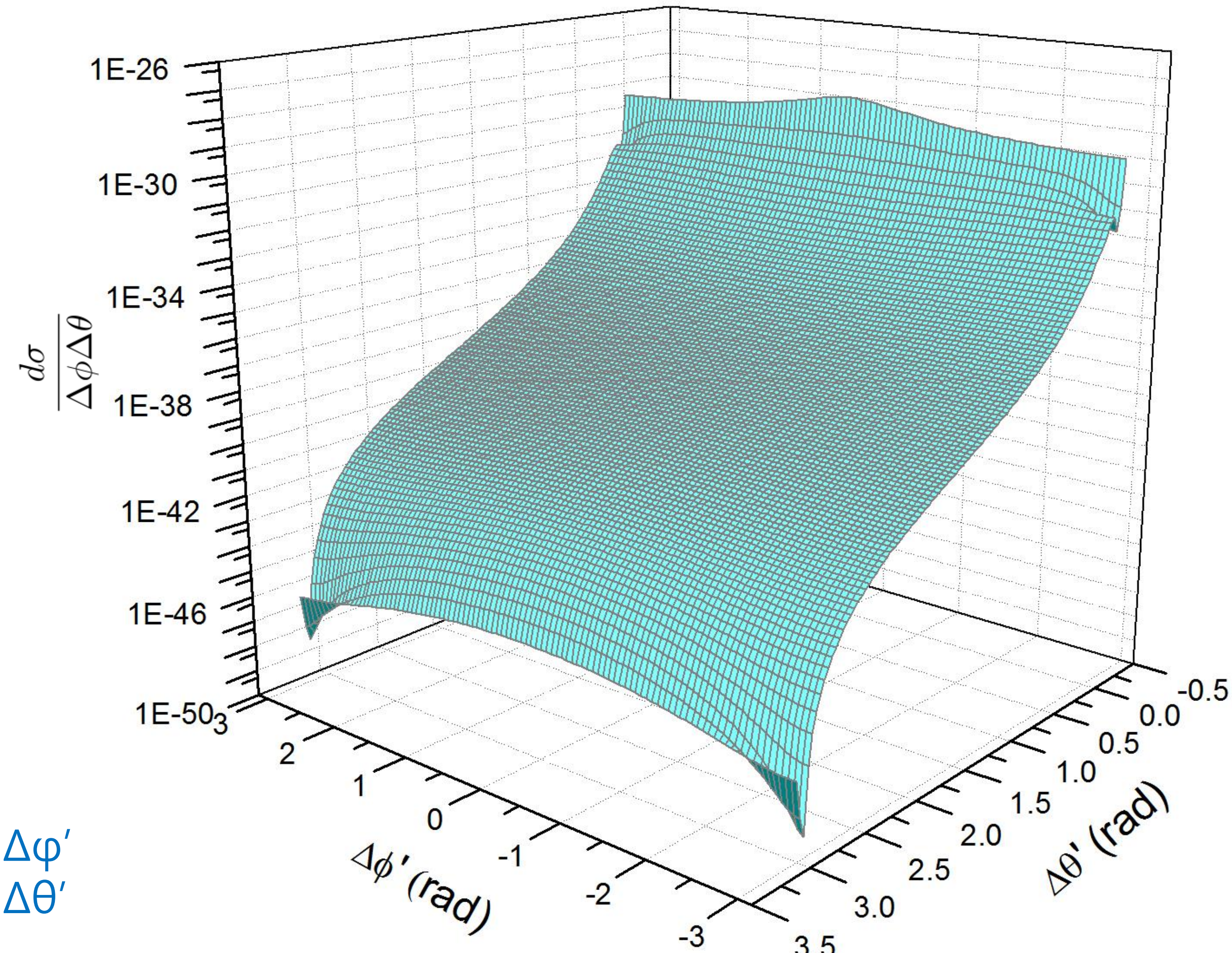
$E_{p'}$ dependence

p	50 GeV
p′	0.8 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





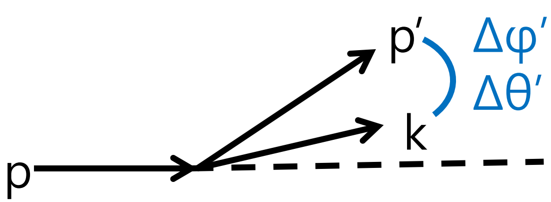
$E_{p'}$ Dependence of Cross Section

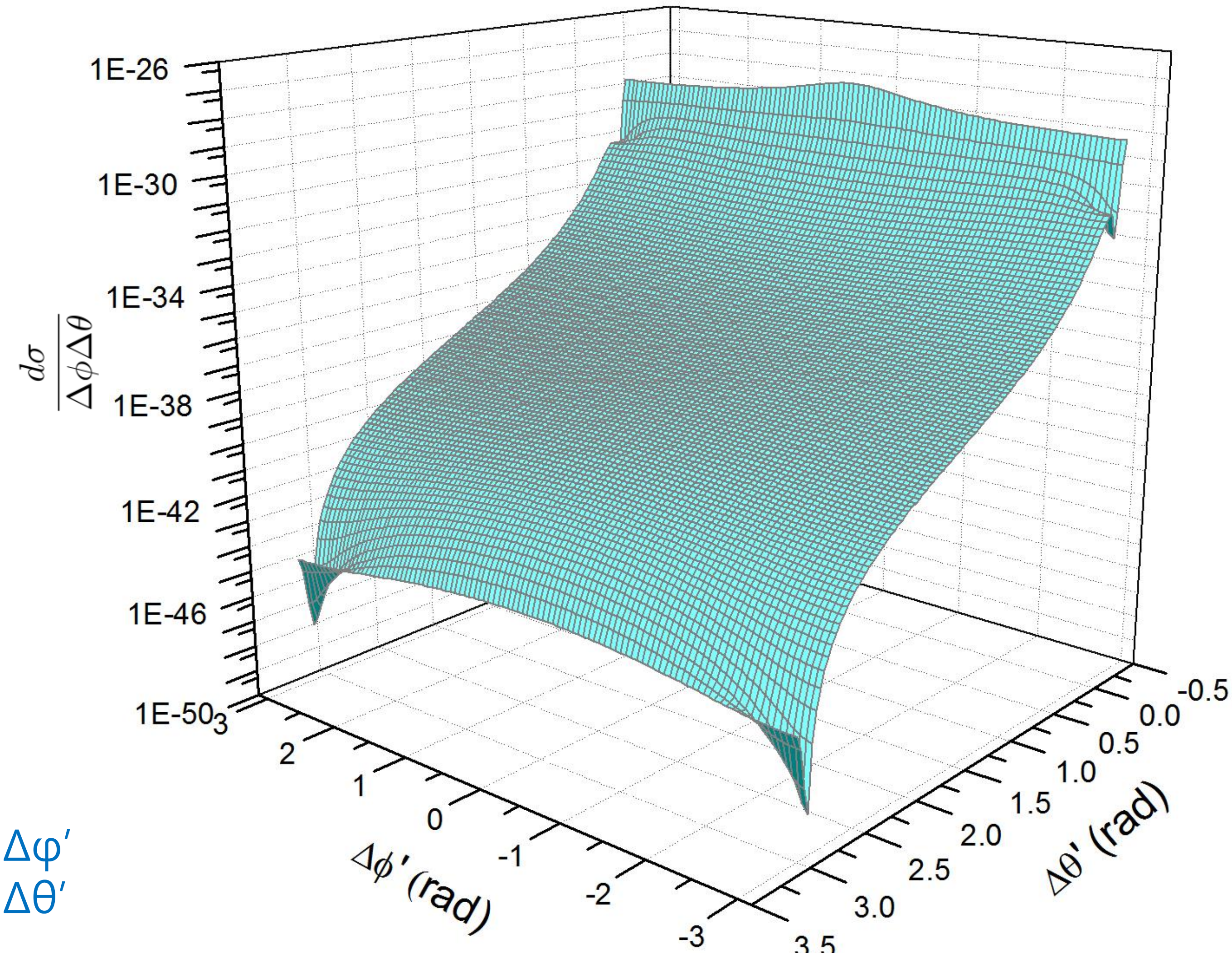
$E_{p'}$ dependence

p	50 GeV
p′	0.85 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$$\Delta\theta' = \theta_{p'} - \theta_k$$

$$\Delta\varphi' = \varphi_{p'} - \varphi_k$$





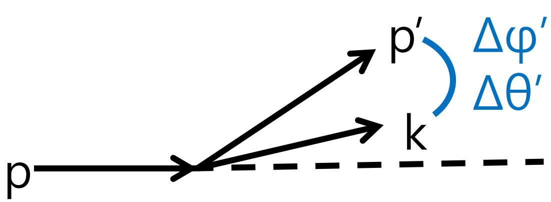
$E_{p'}$ Dependence of Cross Section

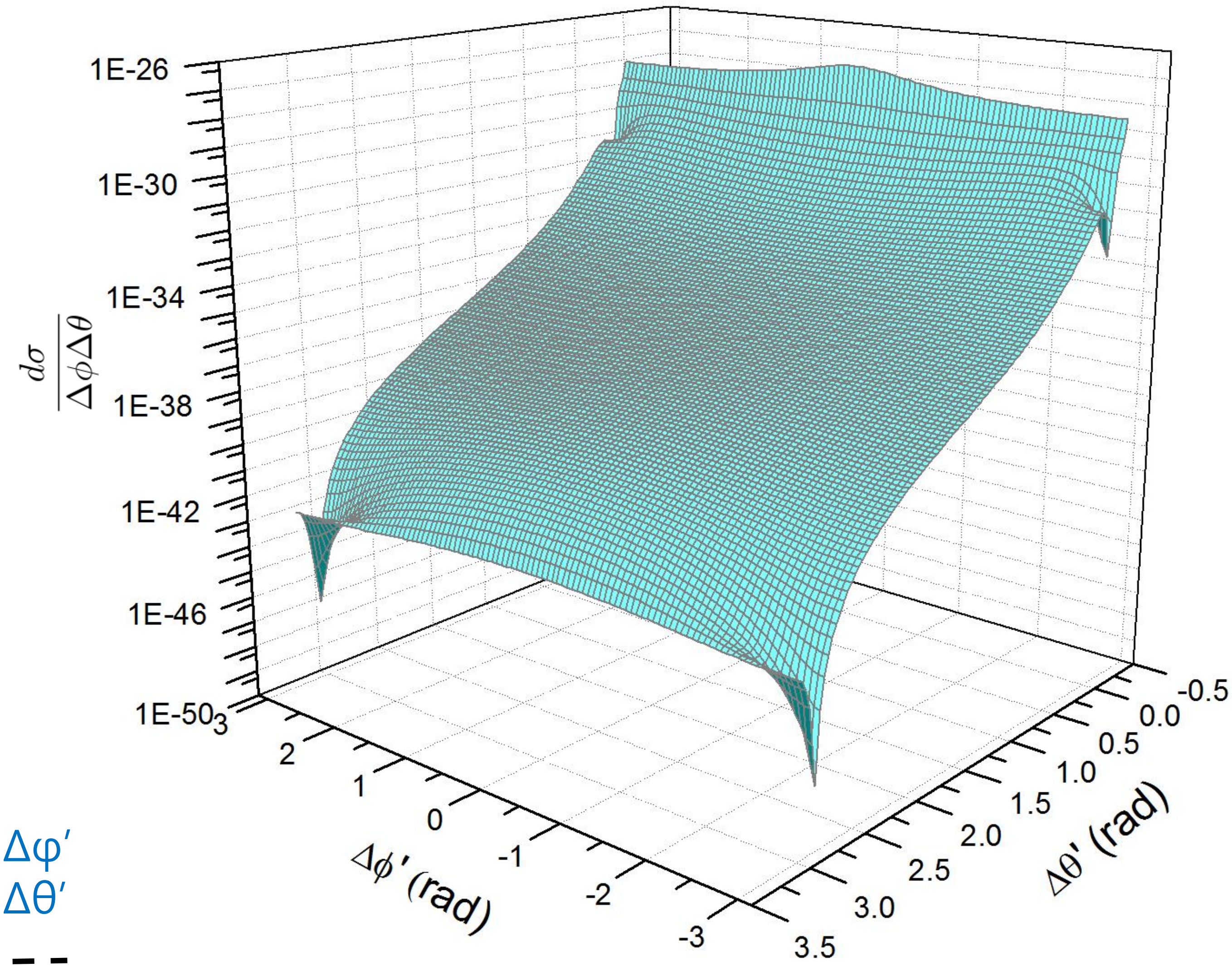
$E_{p'}$ dependence

p	50 GeV
p′	0.9 E_i GeV
k	0.9 (E_i – E_f)GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





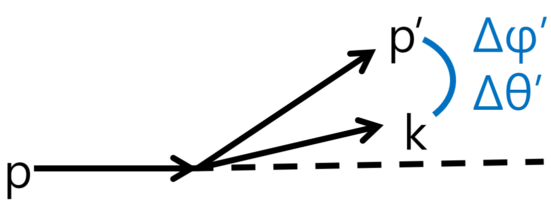
$E_{p'}$ Dependence of Cross Section

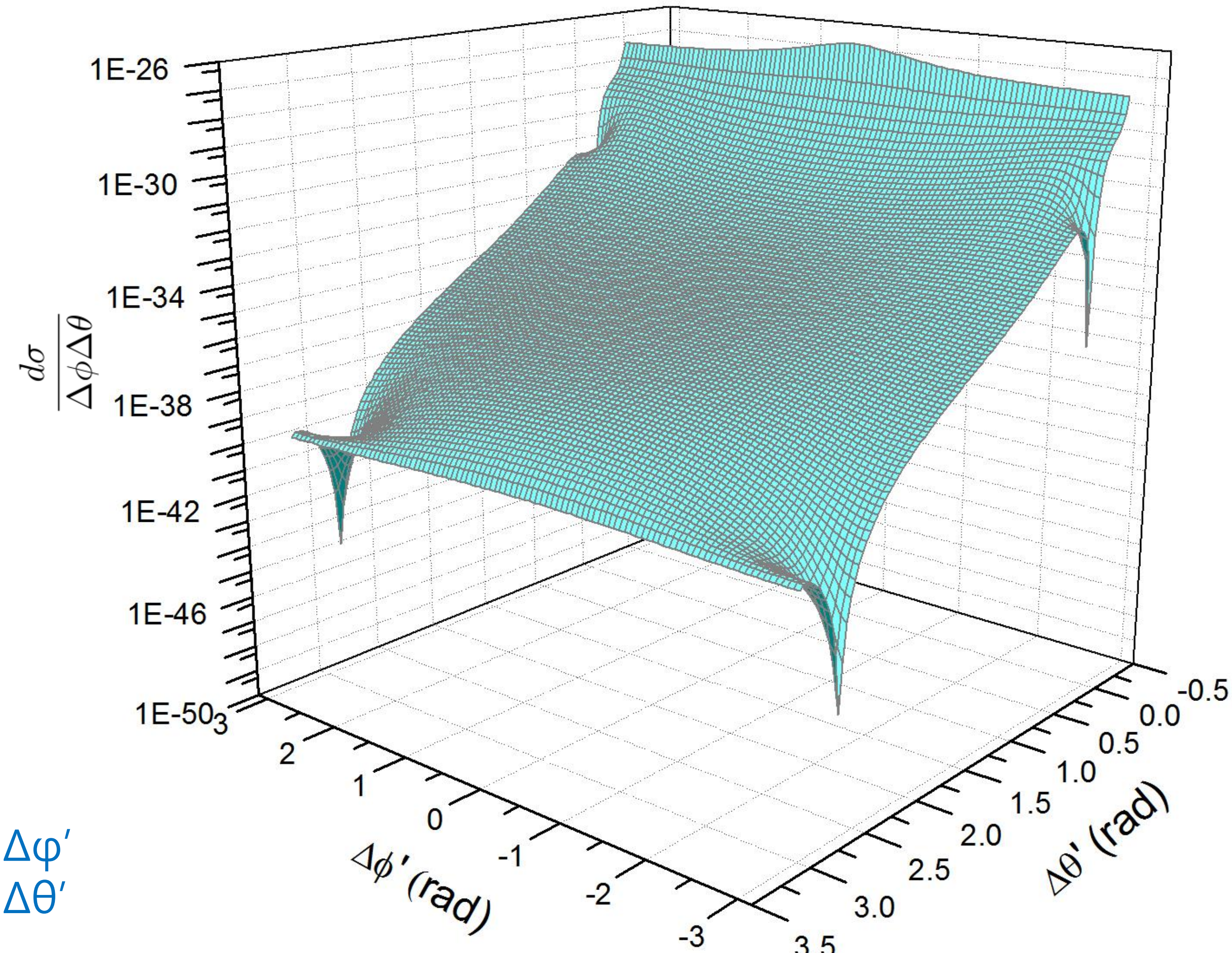
$E_{p'}$ dependence

p	50 GeV
p′	0.95 E_i GeV
k	0.9 $(E_i - E_f)$GeV
$\varphi_{p'}$	0 degree
$\theta_{p'}$	1 degree
φ_k	0 ~ 2π
θ_k	0 ~ π

$\Delta\theta' = \theta_{p'} - \theta_k$

$\Delta\varphi' = \varphi_{p'} - \varphi_k$





Summary

- Calculate the cross section of bremsstrahlung for jet particles in medium after the relativistic high energy heavy ion collision.
  - At given incident energy and p_T

- Show the angular distribution of cross section
  - check the correlation between p′ and k.

Outlook

- Need to include the momentum distribution of medium partons.

- Will check the correlation between medium parton a′ and p′ as a candidate process of the ridge correlation.

Motivation

- Bremsstrahlung is a major process losing energies while jet particles get through the medium.
- BUT it should be quite different from low energy potential scattering.