Measurement of Beam Luminosity with the ATLAS Pixel Detector

Yosuke Ashida
Kyoto University

Supervisor: H.Oide

CERN Summer Student Programme 2015
Student Session
13th August 2015

A Bit Self-Introduction

- I'm from Kyoto in Japan.

Yasaka shrine

Kinkaku-ji temple

- I like traveling and basketball.

@Supermarket in Geneva

@Building40

Outline

- Pixel Detector
- Beam Luminosity & van der Meer scan
- Events in LHC p-p collision
- Summary & Outlook

Introduction: LHC & ATLAS Experiment

Large Hadron Collider (LHC) …

It is the biggest particle collider around the world at CERN and the center of mass energy of collision is 13 TeV (world record!!).
A lot of people are doing many experiments with this collider.

ATLAS Experiment …

It is one of the experiments done at CERN.
They are searching for new physics (particles) by using LHC.

We Are Here !

My project is related to both of these!

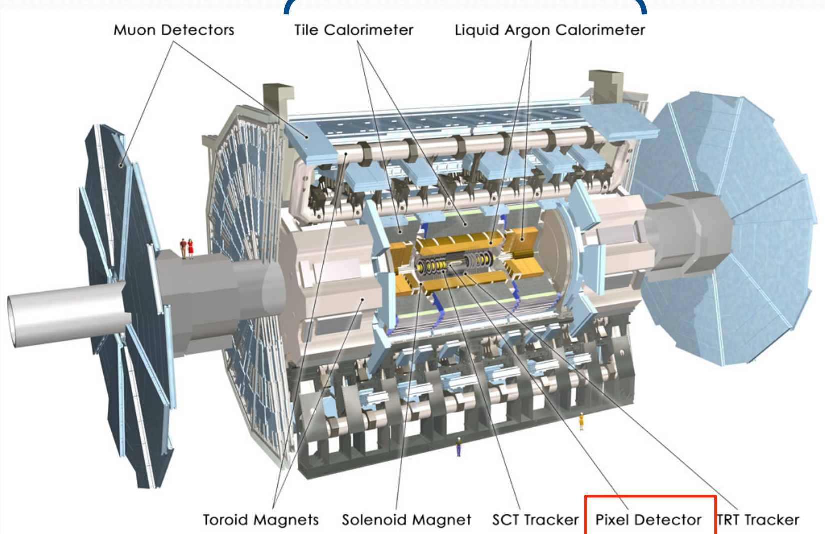
What's the Pixel Detector?

Pixel Detector …

- based on the minimum element = "pixel"
- innermost part of the ATLAS detector
- to reconstruct tracks of charged particles
- sensitive to track impact parameters and b-tagging

ATLAS Detector

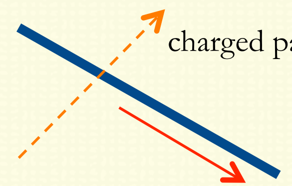
Calorimeters



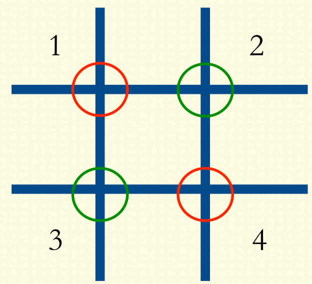
for bending charged particles

Inner Detector for tracking

In Silicon Strip Detector …

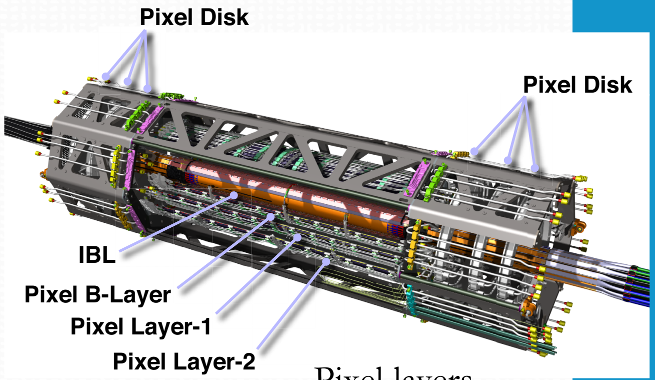


Basically, you can get only 1D information.



In this case, you can get 2D information.
But this has **the ghost hit problem**.

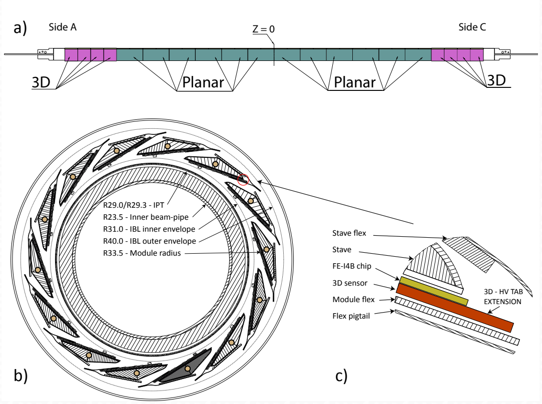
New Type of the Pixel



Pixel layers

There are four pixel layers in total.

The innermost "IBL" is the new-type pixel.
It has been equipped with ATLAS in LHC Run2.



pixel size of IBL is $50 \times 250\ \mu m^2$
(conventional pixel detectors: $50 \times 400\ \mu m^2$)

14 staves in ϕ -direction
32 chips in z-direction
radius = 33mm

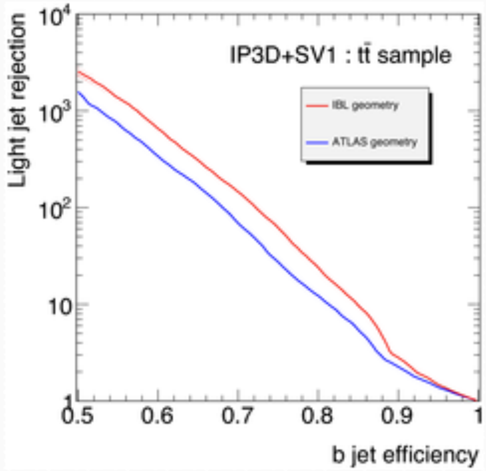
We can use IBL under higher luminosity $2.0 \times 10^{34}\ cm^{-2}\ s^{-1}$ in the near future.

IBL has better performance than the conventional pixel.

- resolution
- b-tagging

Contribution to $H \rightarrow b\bar{b}$ study

To measure this event is one of the most important works in LHC Run2. For this, high accuracy b-tagging is very important!



higher b-tagging ability of IBL

Ref: ATLAS TDR 019 Insertable B-Layer

Beam Luminosity

The performance of the particle collider is qualified by …

- **Energy** $(\sqrt{s} = 13\text{TeV @LHC})$
- **Luminosity**

LHC (original design) $\approx 1.0 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$

↓ Upgrade!

HL-LHC (2022-) Luminosity $\approx 5.0 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$

event rates = luminosity × cross section

We want more rates. (event rates)

We can't change this. This is determined by physics. (cross section)

Luminosity is so important especially in searching for rare events with the small production cross section!

How to Measure Luminosity

Luminosity (in two colliding beams):

$$\mathcal{L} = \frac{N_1 N_2 f N_b}{2\pi \sigma_x \sigma_y}$$

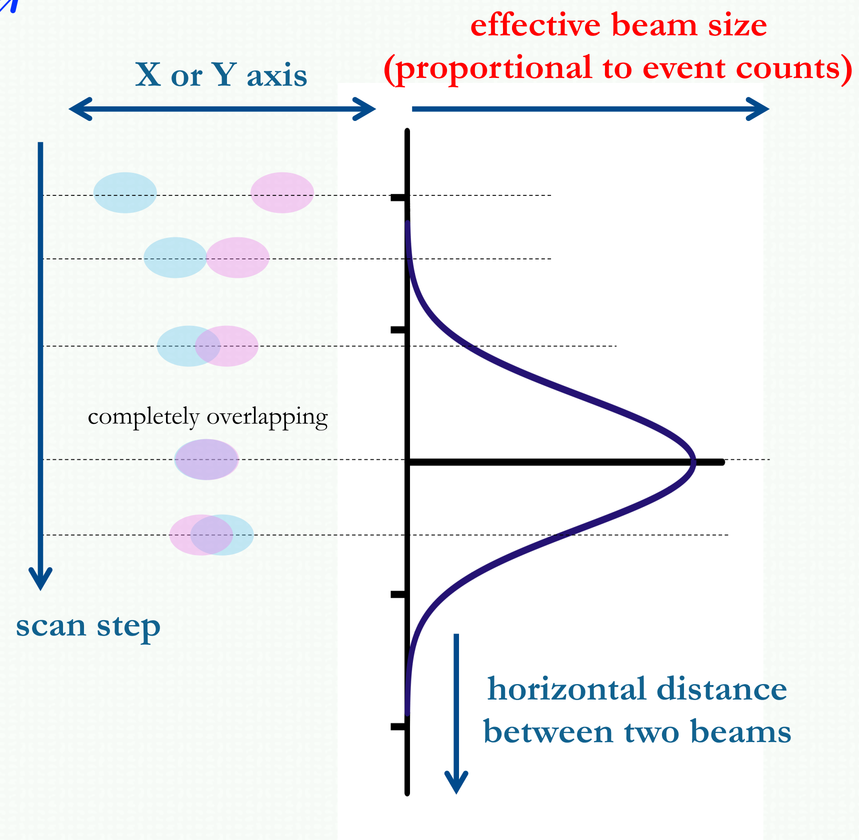
effective beam size

$N_{1,2}$: intensity of bunch (particles/bunch)
N_b : bunches/beam
f : revolution of frequency

These will be determined directly from the accelerator (machine parameters).

vdM scan will determine effective beam size by measuring event rates.

van der Meer scan



In this way, the only thing you have to do is to measure event rates.

The effective area of two beams is measured in-situ by sweeping one beam position horizontally with respect to the other beam.

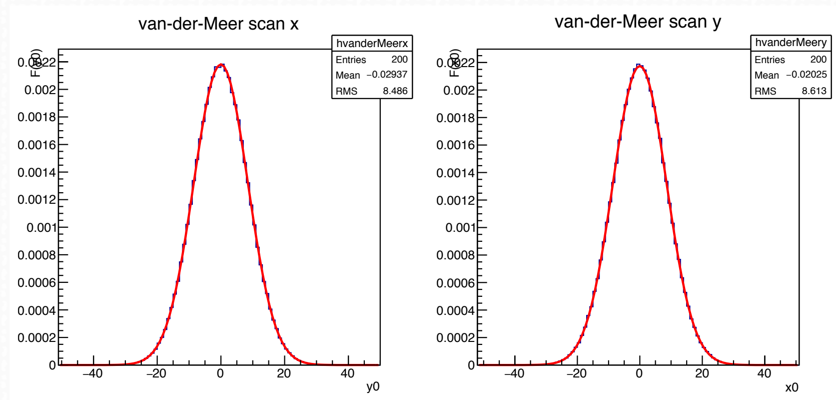
Ref: Concept of luminosity, W.Herr & B.Muratori

van der Meer scan simulation

I developed a toy 2D program to simulate the vdM scan in various beam shape configurations.

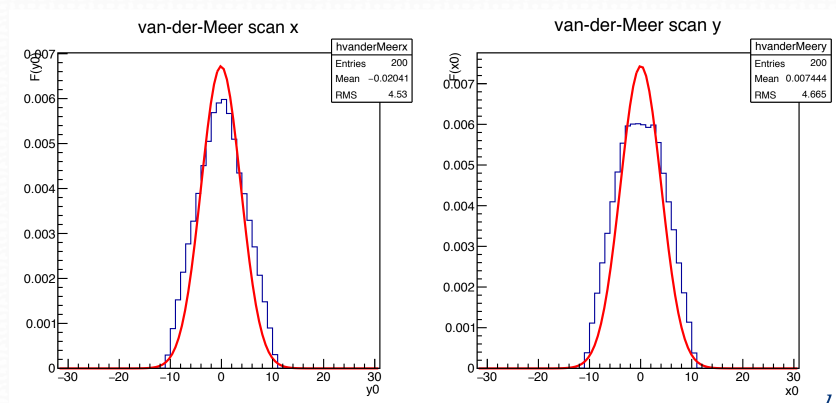
(e.g.)

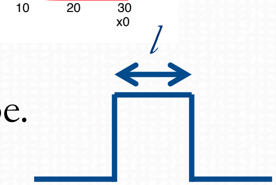
beam	direction	shape	size [μm]
1	x	Gaussian	$\sigma = 6.0$
1	y	Gaussian	$\sigma = 5.0$
2	x	Gaussian	$\sigma = 6.0$
2	y	Gaussian	$\sigma = 7.0$



vdM scan plot is the completely Gaussian when beam shape is Gaussian.

beam	direction	shape	size [μm]
1	x	Rectangular	$l = 10.0$
1	y	Rectangular	$l = 8.0$
2	x	Rectangular	$l = 12.0$
2	y	Rectangular	$l = 14.0$

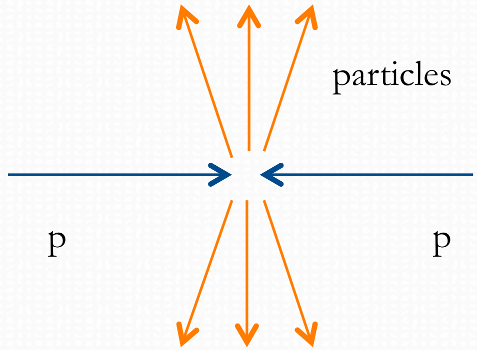


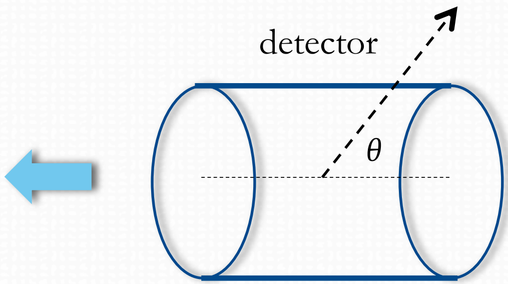


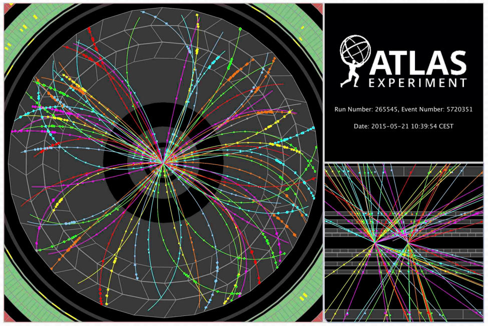
There is the deviation from Gaussian. vdM scan supposes Gaussian beam shape.

Events in LHC p-p collision

In p-p collision in center of mass frame…

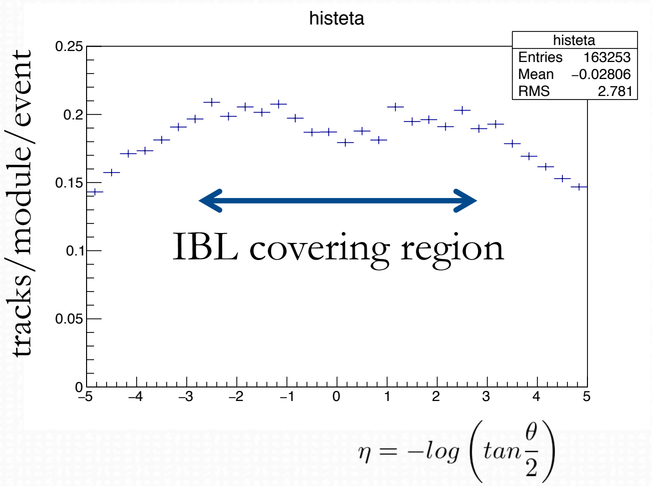


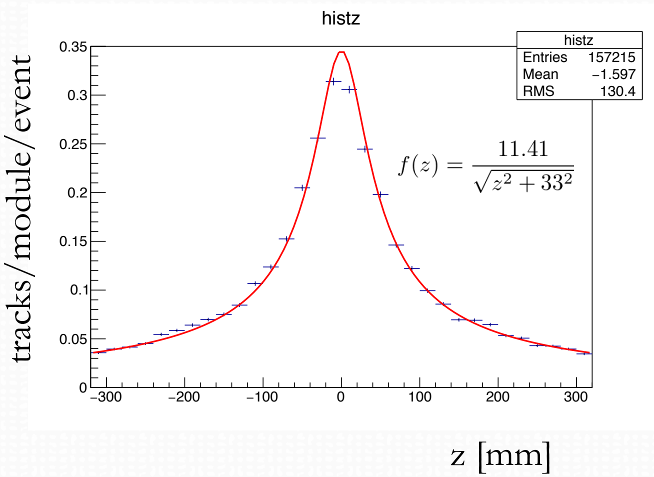




ATLAS event display

By using PYTHIA8 (event generation program), I computed hit events on IBL (I set IBL geometry in the program).





13th August 2015

Summary & Outlook

- With using the first term of the programme, I deepened understanding of the concept of vdM scan and the nature of p-p collisions, with developing toy simulations from scratch.

- In the latter half of the programme, I will focus on the real data taken with the ATLAS pixel detector for real measurement of luminosity.

END…

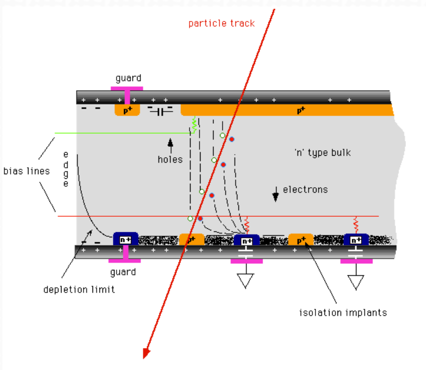
Thank you!!

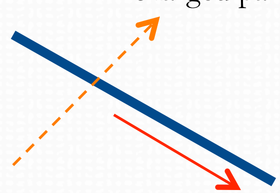
& Any Questions?

Back Up

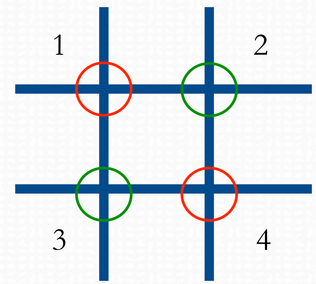
Comparison to Silicon Strip Detector

When identify the position by using Silicon Strip detectors, it is necessary to distribute them in reticular patterns.





Basically, you can get only 1D information.



In this case, you can get 2D information.
But this has **the ghost hit problem**.

We would get the same signal both in red & green hit cases!
(Red; hit on 1&4 simultaneously, Green; hit on 2&3 simultaneously)

There's no problem like this in the Pixel Detector, because it has the element structure ("pixel").
But for that, it must be small enough (pixel size < $1mm^2$).

Formalization of Luminosity

The performance of particle collider is qualified by …

- Energy $(\sqrt{s} = 13\text{TeV @LHC})$
- Luminosity

$$\mathcal{L} = \frac{1}{\sigma_p}\frac{dR}{dt}\ [\text{cm}^{-2}\text{s}^{-2}] \quad R : \text{number of event},\ \sigma_\text{p} : \text{cross section}$$

In the case of two colliding beams …

$$\mathcal{L} = \frac{N_1 N_2 f N_b}{2\pi\sqrt{\sigma_{1x}^2+\sigma_{2x}^2}\sqrt{\sigma_{1y}^2+\sigma_{2y}^2}}$$

LHC

$N_{1,2}$: intensity of bunch (particles/bunch) (1.15×10^{11})

N_b : bunches/beam (2808)

f : revolution of frequency (11.245 [kHz])

σ : standard deviation when beam profile considered to be Gaussian

Correctly, we have to take into accounts other effects such as crossing angle, offset, hourglass effect and so on …

Why is Luminosity so Important?

LHC Luminosity $\approx 1.0 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Upgrade!

HL-LHC (2022-) Luminosity

$\approx 5.0 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

High Luminosity LHC

The more luminosity you would get, the more events you can get!

So luminosity is very important especially in searching for rare events with the small production cross section!

We need higher luminosity for discovery of new particles!!

van der Meer scan in details

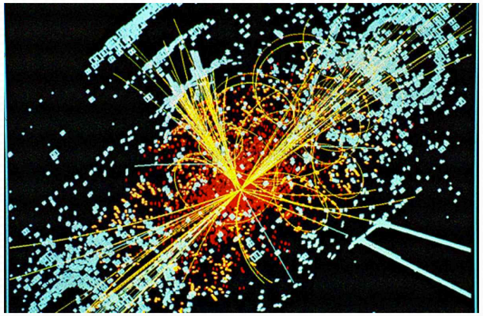
van der Meer scan …

1. Fix one of beam & move the other beam along x and y directions.
2. Measure the number of events at each point.
3. If you approximate beam profiles by Gaussian functions, you would get Gaussian in the position - number of events plots (two 1D plots along x and y axis).
4. Get standard deviation of the Gaussian functions.
5. You can calculate the beam luminosity by the formula described before.

$$\mathcal{L} = \frac{N_1 N_2 f N_b}{2\pi \sqrt{\sigma_{1x}^2 + \sigma_{2x}^2}\sqrt{\sigma_{1y}^2 + \sigma_{2y}^2}}$$

When counting event rates, we can use **pixel detectors**.

- for cross check by comparing other ways.
- to check the performance of pixel detectors.
- an independent way of luminosity measurement



13th August 2015