ALICE 2010 Luminosity Determination

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for the ALICE Collaboration

Jan. 13, 2011

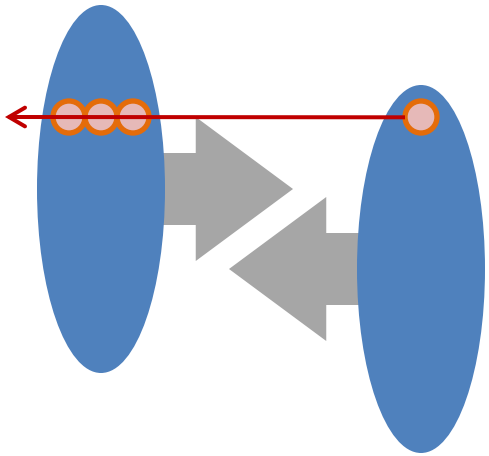
Requirements of c.s. normalization

- **In ALICE p+p measurements, absolute cross section determination of charm, beauty, J/Psi, Upsilon, jets, and all kinds of particle productions are essential for:**
  - QCD test
  - Reference for heavy ion collisions

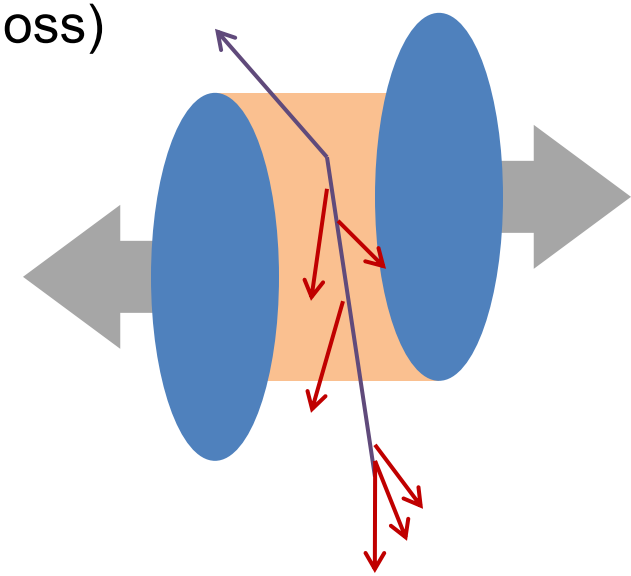
- **Strong interaction**
  - We aim at 10% accuracy
  - For perturbative productions, theoretical prediction has around 10-50% uncertainties
  - Experimental data systematic error except for cross section normalization depends on measurement:
    - J/Psi → lepton pair: below 10% is aiming
    - Heavy flavor (c, b decays) : 10% is marginal
  - Cross section uncertainty should not dominate

    → accuracy of 5 % for beam current is satisfactory

vdM Scan for Pb+Pb ?



- **Particle production cross sections in Pb+Pb is governed by many more factors**
  - Geometry
    - Pb+Pb is convolution of multiple N+N collisions
  - Nuclear modifications
    - PDF modification
    - Jet fragmentation modifications (parton energy loss)
    - Thermal equilibration



- **Electromagnetic interactions such as nuclear (mutual) dissociations**
  - total dissociation: 215 b at 2.76TeV Pb+Pb
    → Used as luminometer in Pb+Pb
  - Uncertainty is ~ 5%
  - Mutual dissociation: 6b

[*Pshenichnov et al., Phys. Rev.C 64 024903-1] and private communications*

p+p as Reference for Pb+Pb

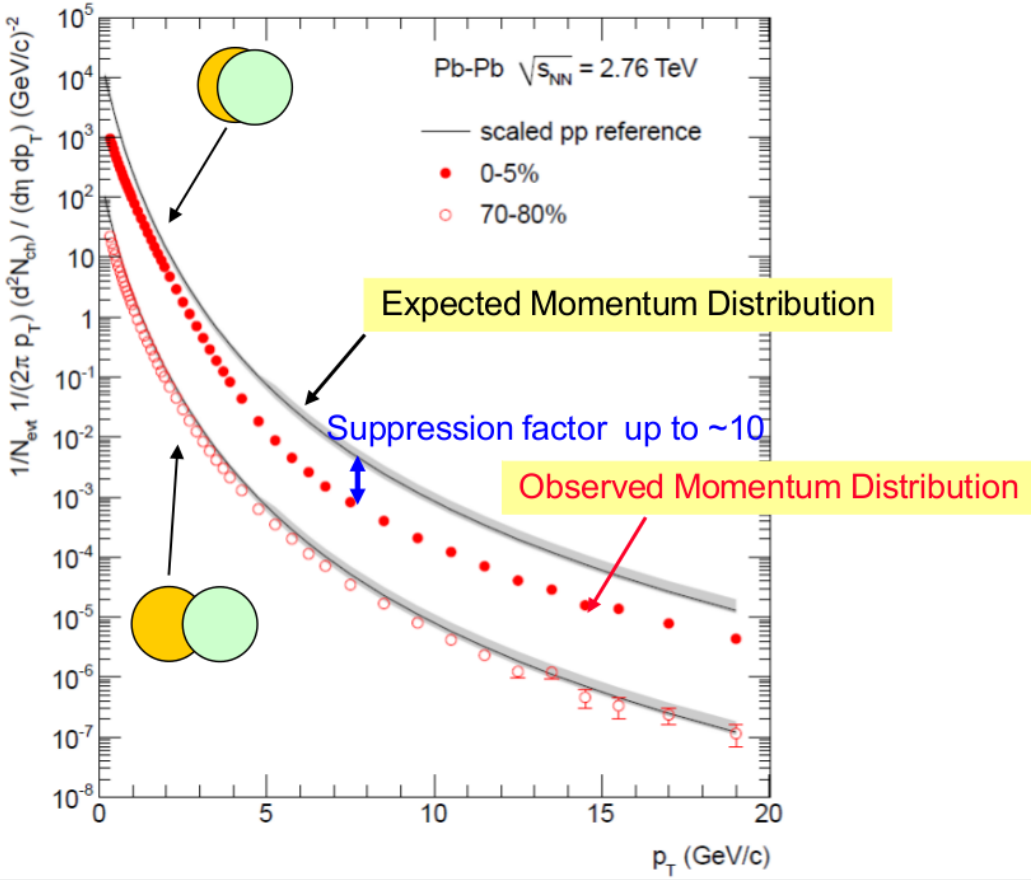
$$R_{AA}(p_T) = \frac{(1/N_{\mathrm{evt}})\, d^2N^{A+A}/dp_T\, d\eta}{\langle N_{\mathrm{binary}}\rangle/\sigma_{\mathrm{inel}}^{N+N})\, d^2\sigma^{N+N}/dp_T\, d\eta}$$

measured in Pb+Pb

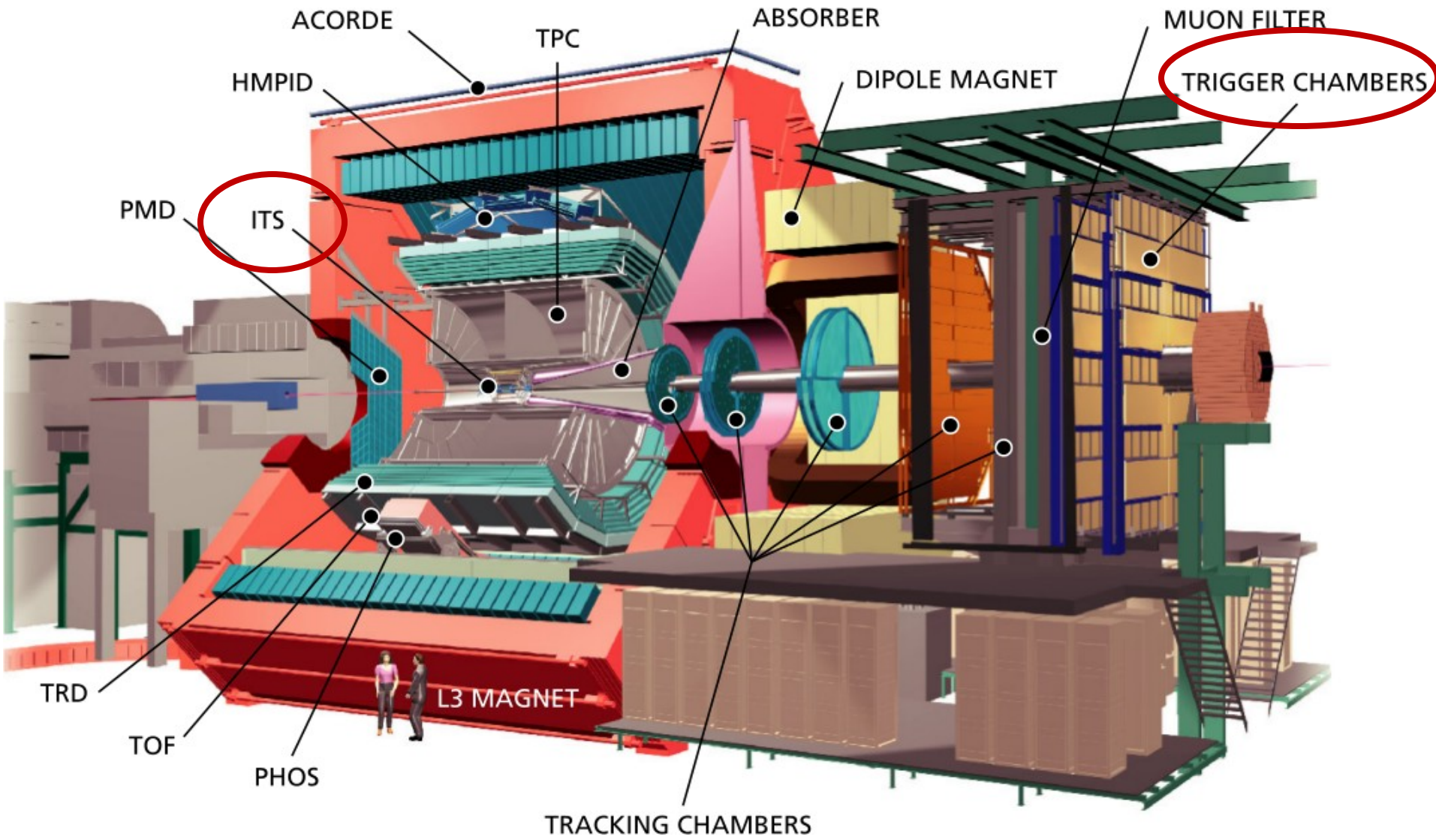
measured in p+p

T_{AA}

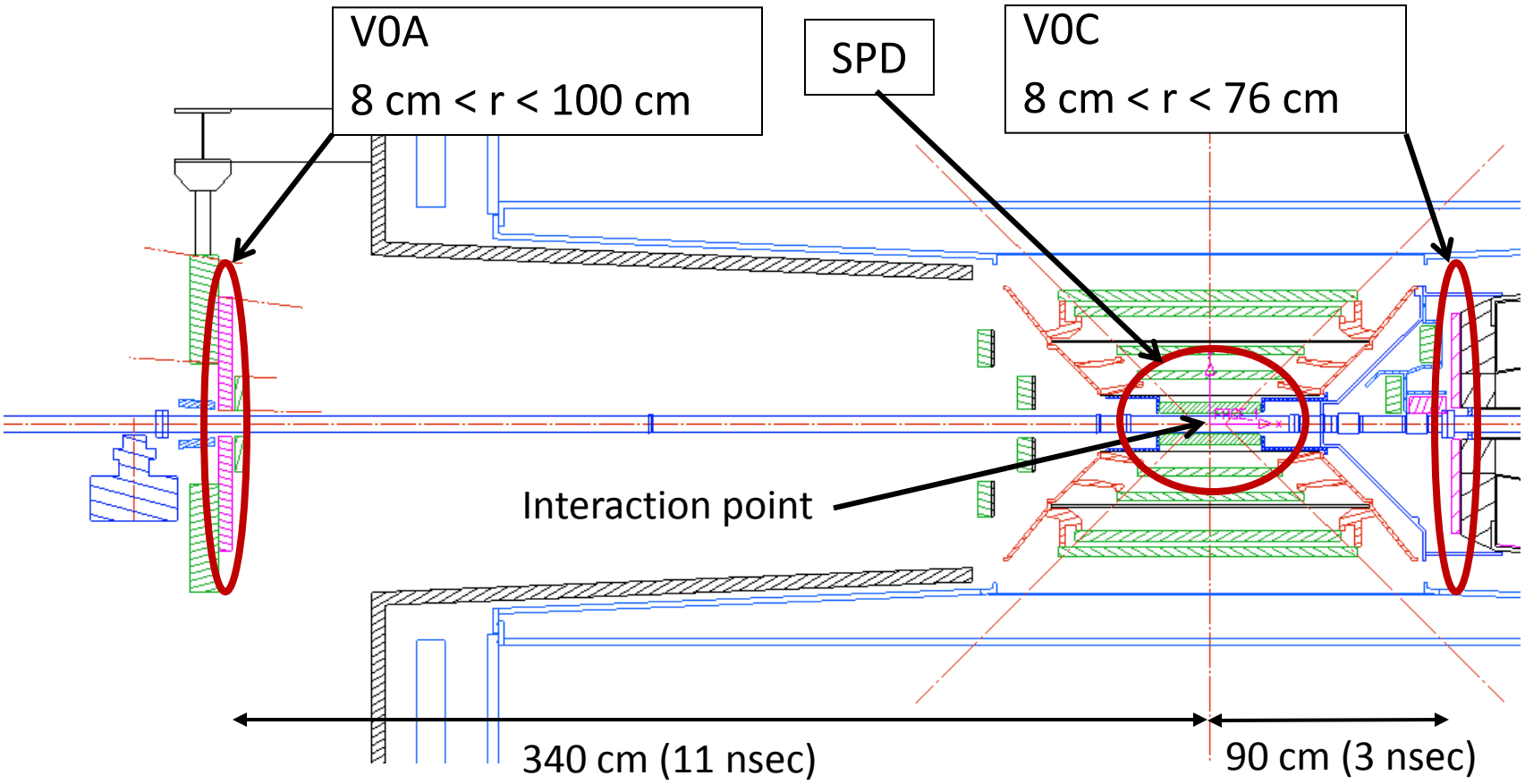
- Pb+Pb collision is modeled with multiple collisions of N+N → Nbinary times of binary collisions, and Npart of participating nucleons
- R_{AA} is one of the typical quantity for comparison
- Below 10 % precision is required for R_{AA} for most of the measurements
- Same p+p energy (2.76 TeV for example) is required especially at low momentum



Trigger Detector Used in ALICE



Pixel (SPD) and V0 Trigger



- V0s are asymmetrically placed close to IP
- Each detector has 32 channels scintillators with PMT readout
- V0 has after pulse → suppressed by veto or fill scheme
- SPD triggers if there is one particle hit in any of two layers

Trigger Setup for p+p Scans

- **V0** (forward scintillator paddles on both A/C-side) **η=2.8~5.1 and -1.7~-3.7**
  - ***CVBAND*** = V0A & V0C (at least one hit in both side)
  - ***CVBOR*** = V0A || V0C
  - ***CVBANOTC*** = V0A & !V0C, ***CVBCNOTA*** (exclusive hit) for pile-up check

- **Minimum Bias**
  - **CINT1** = CVBOR || SPD
  - **CINT5** = CVBOR

- **MTR** (RPC multi layer system for dimuon triggering in C-side) **η= -2.5 ~ -4.0**
  - ***CMUS1*** = SingleMuon & CINT1
  - ***CMUS5*** = SingleMuon & CVBOR

- All trigger counters count unity if there is activity every 25 ns
  (no dead-time but pile-up in 25 ns Is not distinguished)

p+p Scan History and Methods

	Scan-I	Scan-II
Date/Time	May 10, 2010	Oct. 15 (vdM), Oct. 29&30 (LSC)
vdM fill, scheme	1090, Single_2b_1_1_1	1422, Single_16b_3_1_12_allVdmB
Energy	7 TeV	7 TeV
Nominal bunch size	1.8 x 10^10	7.5 x 10^10
mu at head on	0.09	0.75
Crossing angle	internal (by dipole)	internal + external
Beta*	2.0 m	3.5 m
vdM method	2 beams moved to opposite One X and one Y scans +- 5 sigma	2 beams moved to opposite Two X and two Y scans, opposite directions +- 6 or 5 sigma
Length scale calib. methods	3 points for each X and Y Keep head-on	(see dedicated page next)
Measured triggers	VBAND	VBAND, CINT5 (VBOR), CMUS5, etc
ALICE vdM runs	119156	134780

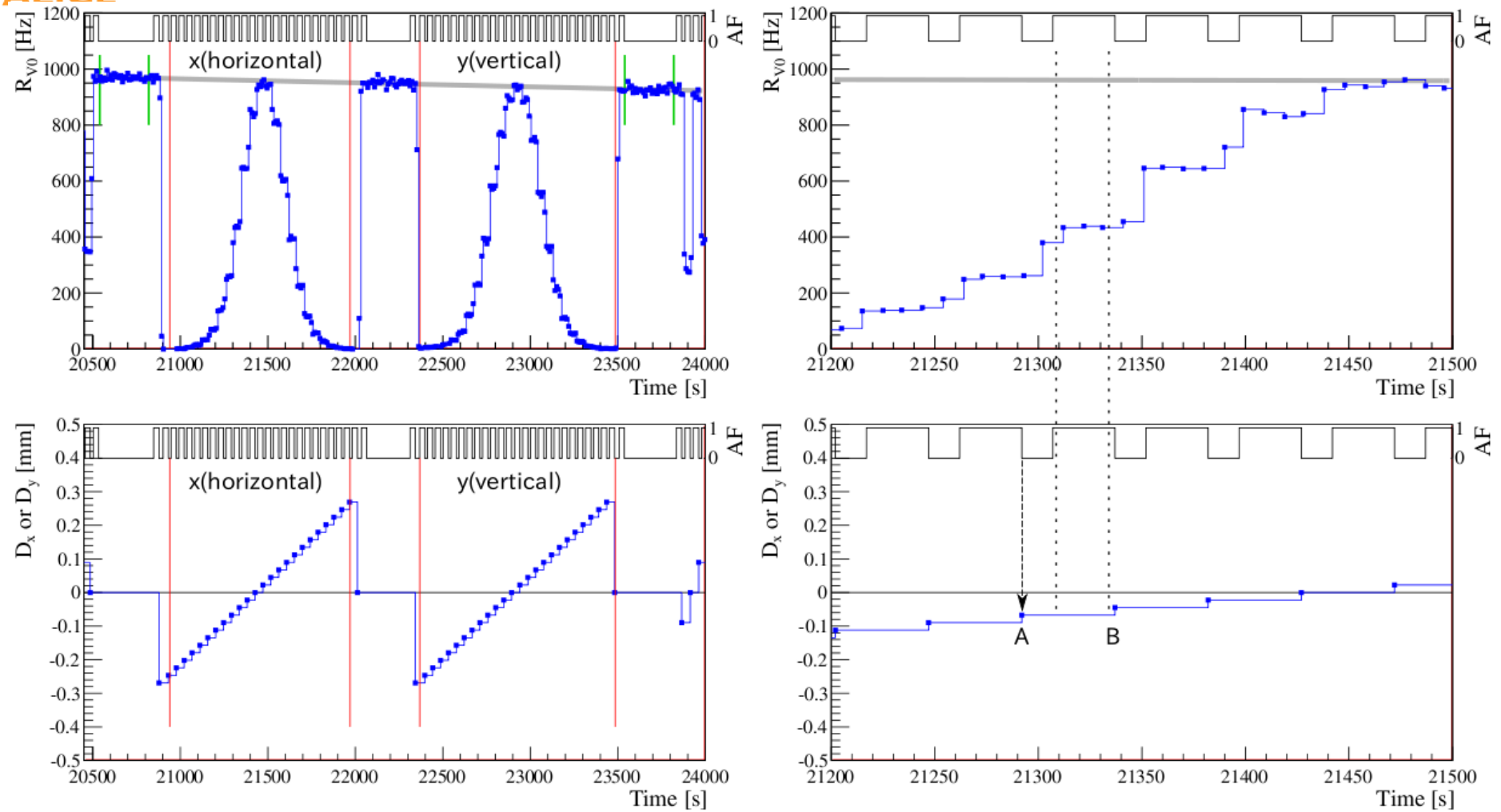
Length Scale Calib. in Oct.

- **Idea: keep 1 sigma separation between beams, and move together**
- **Tried in two pieces (Oct. 29 and Oct. 30)**

  - Oct. 29: Fill 1453
    - Horizontally we can not make 1 sigma (80 [μm]) separation for safety, thus kept at 3 sigma
    - Horizontal scan performed at +100, +50, 0, -50, -100 [μm]
    - Vertical: TCT BPM problem (postponed)

  - Oct. 30: Fill 1455 (Totem fill with Single_5b_5_1_1)
    - Vertical with separation of 80 um (determined with mini-scan)
    - Vertical scan performed at +160, +80, 0, -60, -160 [μm]
    - Horizontal again (to check) with horizontally 80 [μm] separation
    - Horizontal scan at 0 and -130 [μm] (not more with TCT limit)

Scan Method in Scan-I



- One scan for each X(horizontal) and Y(vertical) scans
- 1 kHz of moderate trigger rate
- Few % of luminosity decrease (gray straight line fit) observed

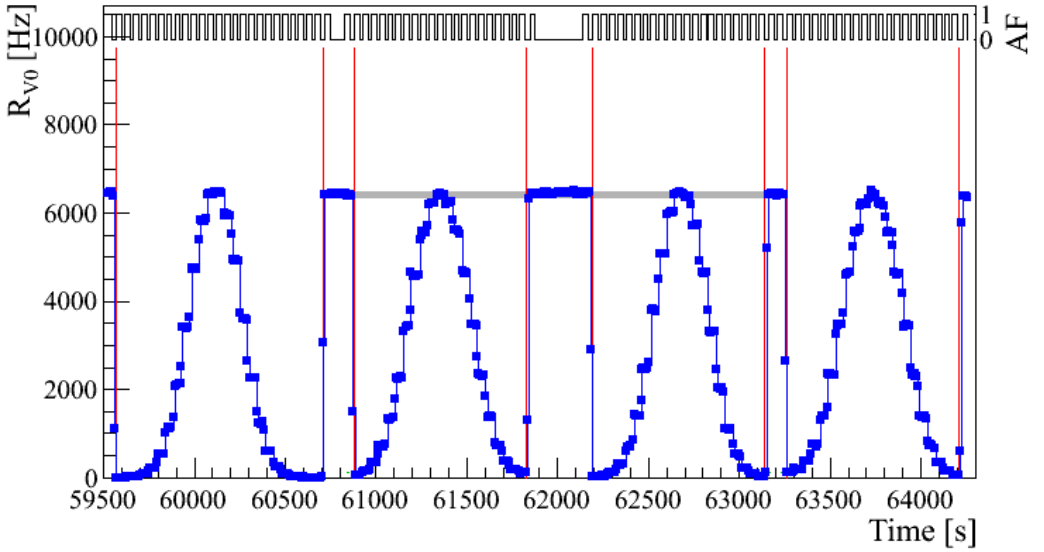
Scan Method in Scan-II

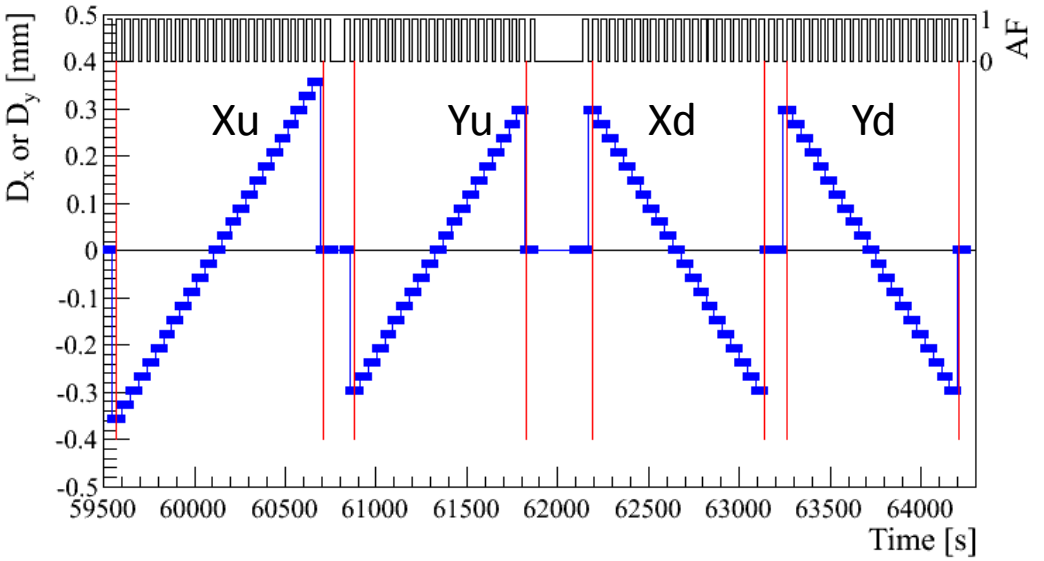
- **In the second scan in Oct, we had twice full scan**
  - Xu + Yu
  - Xd + Yd

  with different directions (u & d) for each X and Y

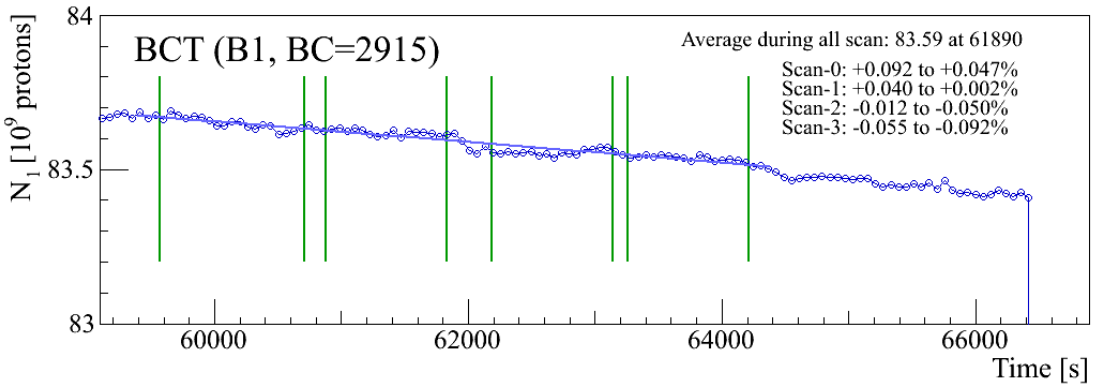
- **This is for systematic study → difference shown later**

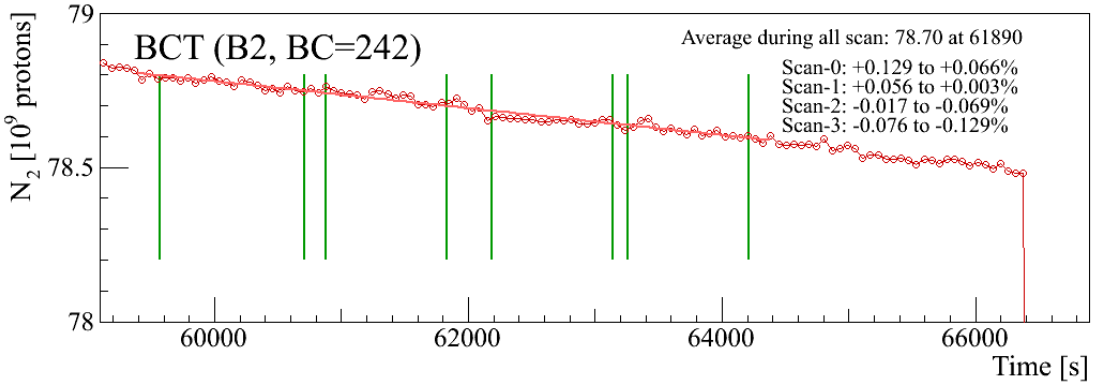
- **Negligibly small emittance grow observed (gray straight line fit)**





Bunch Intensity Change



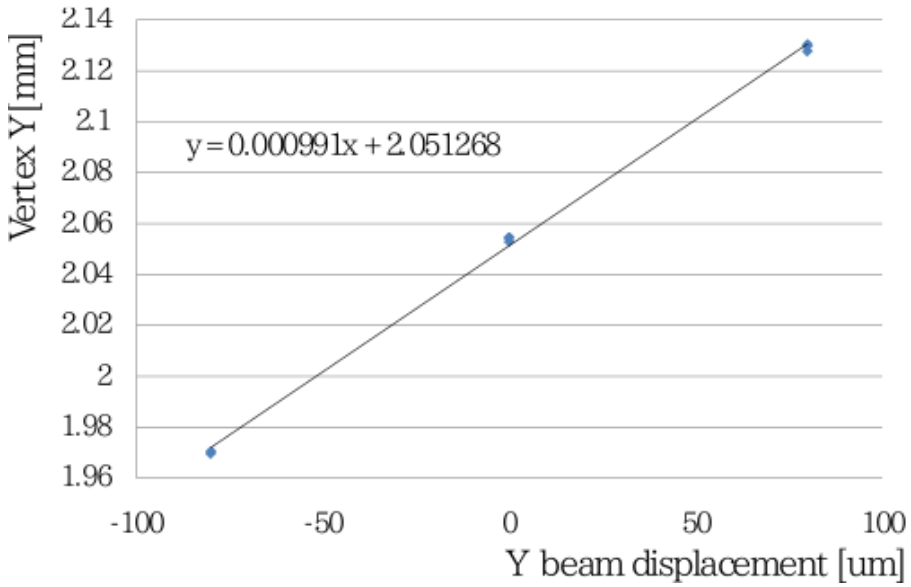


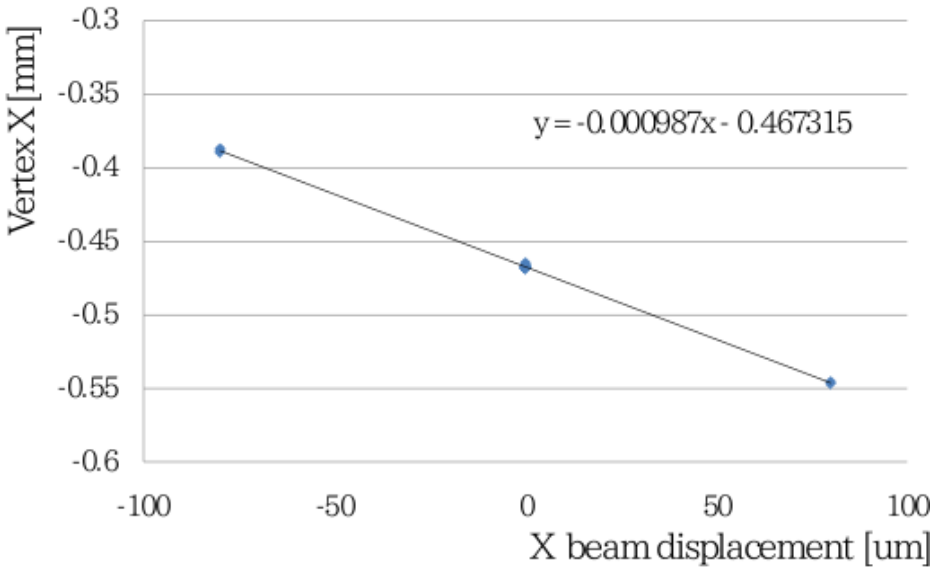
FBCT data during Scan-II in Oct.

- **The decrease over one period of scan set (X,Y) is as much as:**
  - Scan-I < 0.12%
  - Scan-II < 0.13%

  those are negligibly small
- **Correction for this is automatically done together with emittance grow corrections**

Length Scale Calibration





- **Straight line fit**

$$V_x = -0.987 \cdot D_x - 467.315 \ [\mu\mathrm{m}]$$
$$V_y = 0.991 \cdot D_y + 2051.268 \ [\mu\mathrm{m}]$$

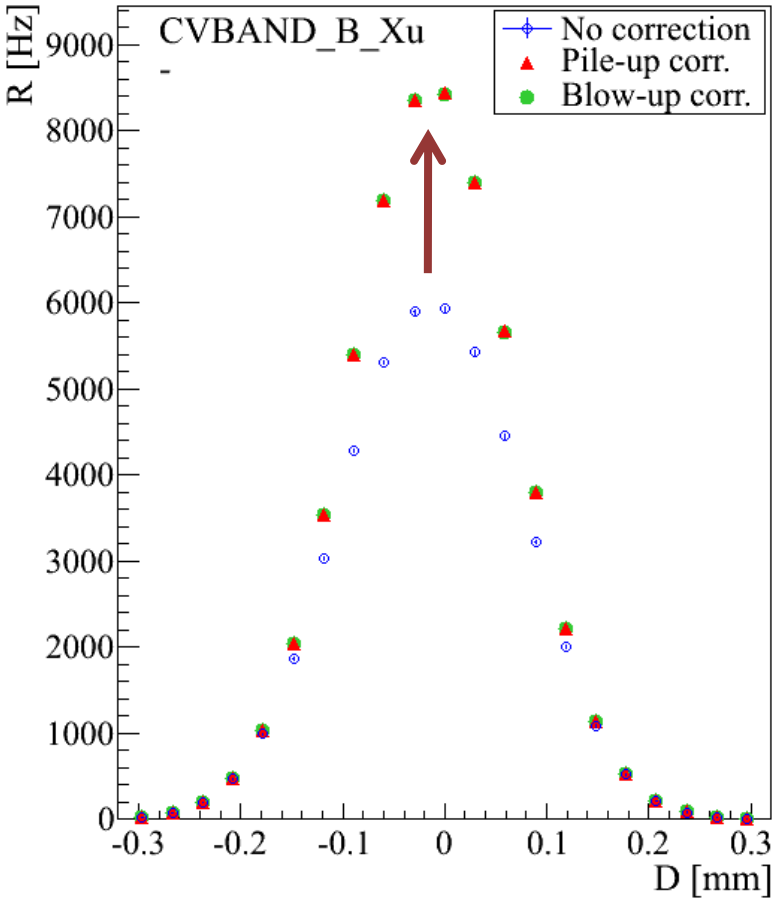
- **Effect to overall length scale for Scan-I is maximum 1.3% … small**
- **No actual correction applied but put as 2% systematic for the moment**
- **Scan-II results being analyzed and will come with more (5) points for each direction**

Pile-up Corrections

- ***Poissonian* treatment**

$$P_{int}(n;\mu) = \frac{e^{-\mu}\mu^n}{n!} \qquad P_{V0}(n;\mu) = \begin{cases} e^{-\mu} & (n=0) \\ 1-e^{-\mu} & (n=1) \\ 0 & (n \geq 2) \end{cases}$$

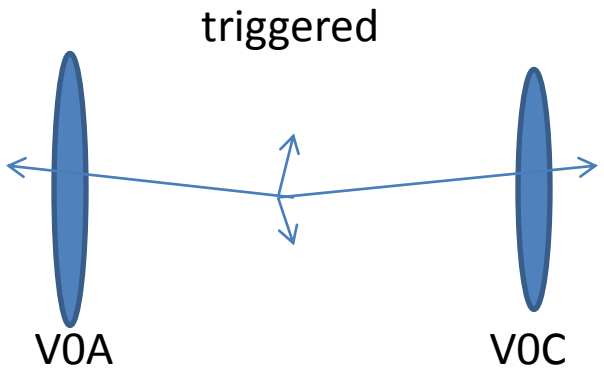
  - Then actual interaction rate and trigger rates are:
    - $R_{int} = \mu f$
    - $R_{trig} = (1-e^{-\mu}) f$
  - Correction factor is as much as 5% in Scan-I and 40% for Scan-II

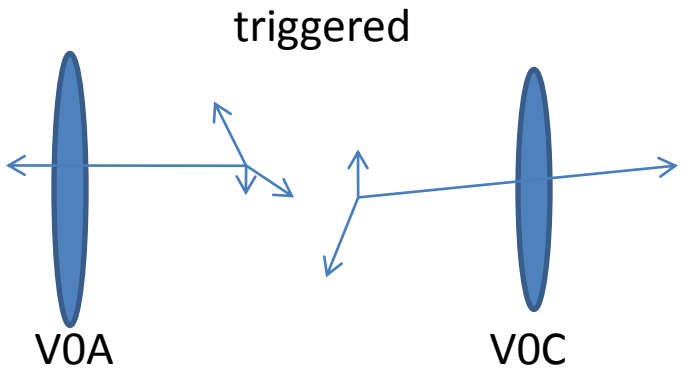


- **Pile-up of excluded events for multiplicity trigger such as CVBAND**
  - No poissonian treatment possible
  - Measured by excluded event triggers
    → next page

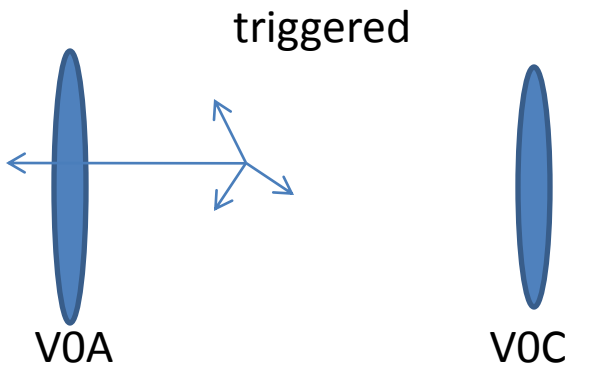
Pile-up of Excluded Events

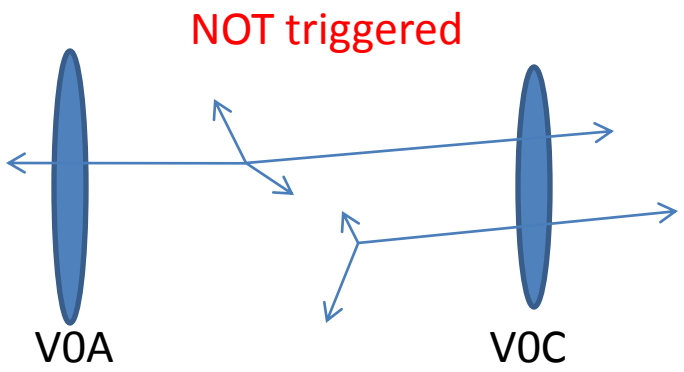
- **CVBAND (V0A & V0C) is a multiplicity trigger which triggers on pile-up of single-hit interactions**





- **We tested (A & !C) and (!A & C) triggers. This eliminates both above two cases and also one of the cases below**



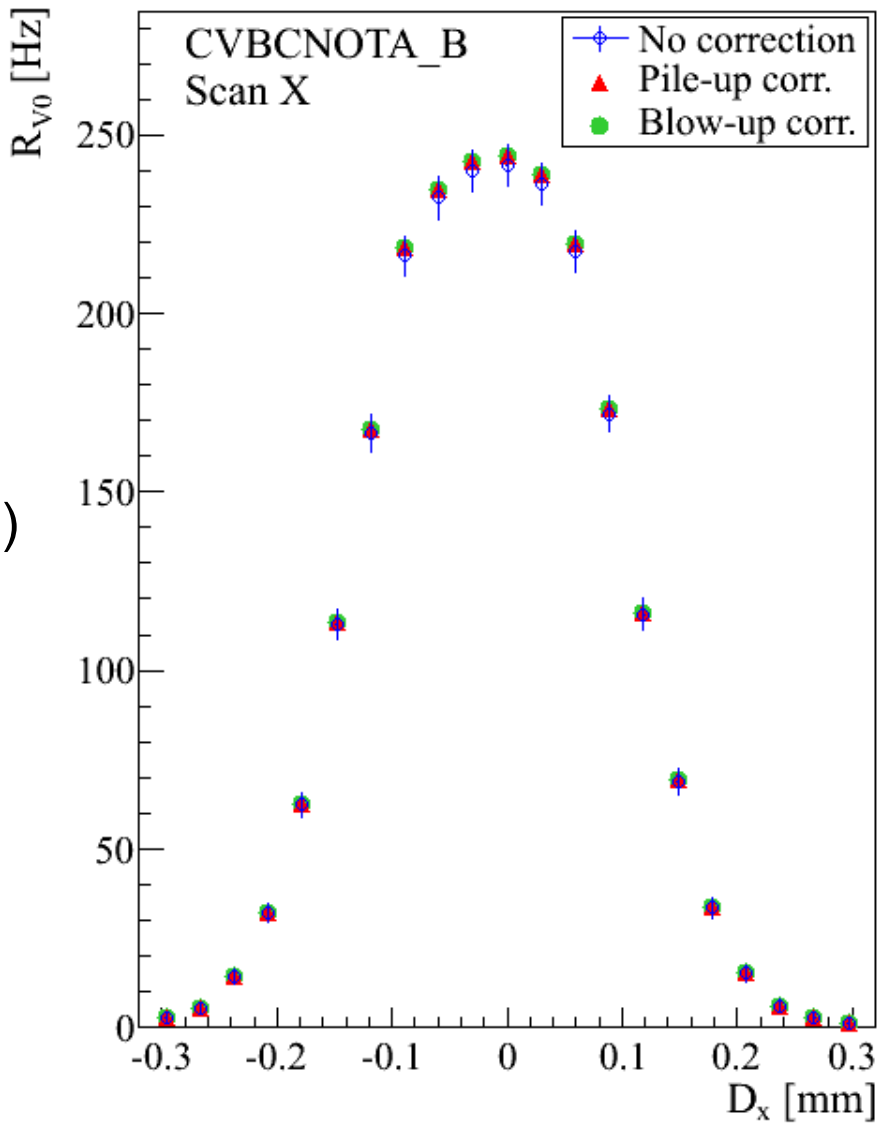


Pile-up of Excluded Events (II)

- **Not Gaussian**
  - Rejected due to pile-up from (normal) mutual hits

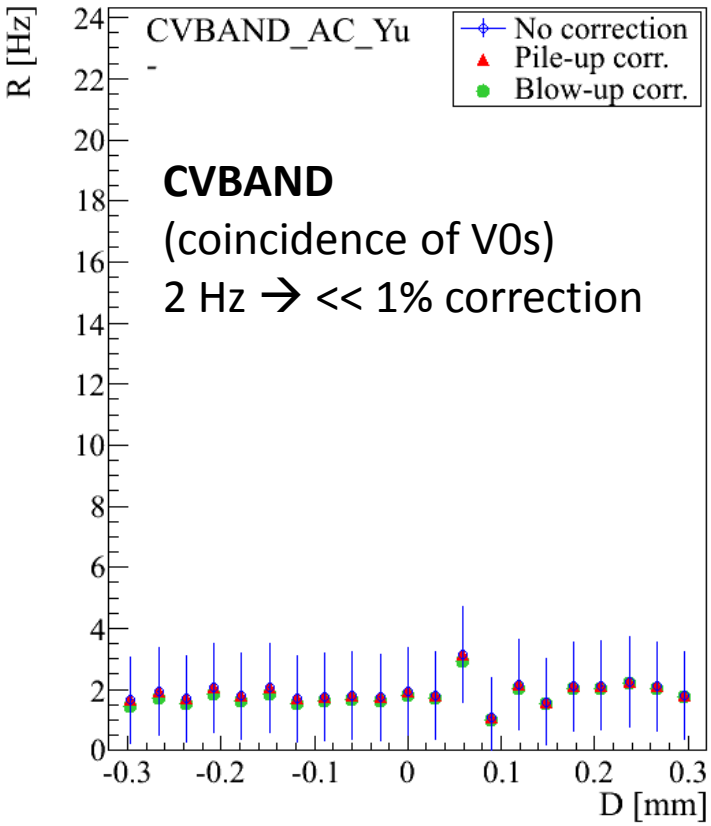
- **By looking at large sigma part, estimated top rate is:**
  380 Hz (for A) and 300 Hz (for C)
  → cross section ~ 3mb (A) and 2 mb (C)
  → μ is order of 0.04 (A) and 0.03

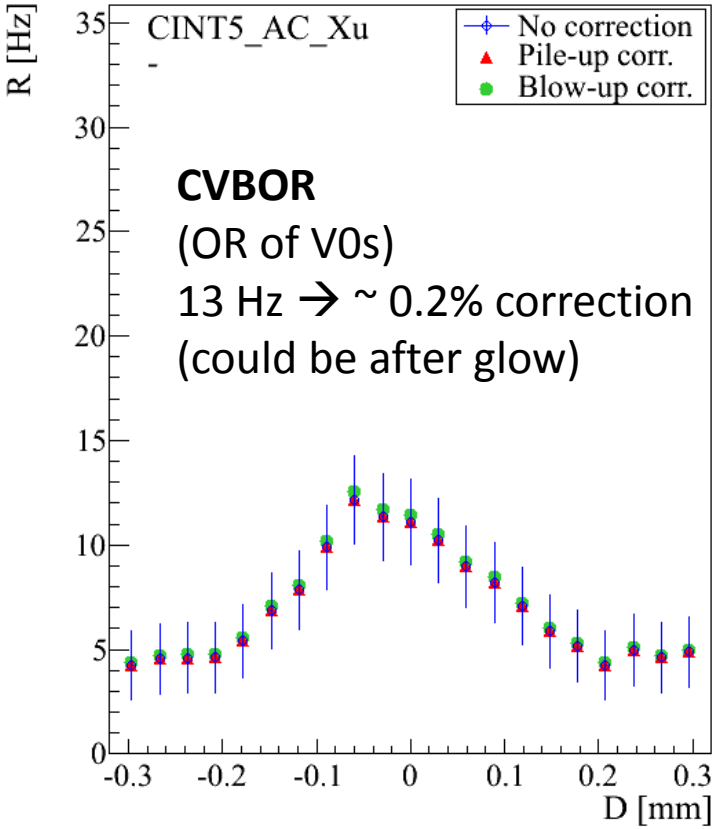
- **Corresponding μ for mutual happening**
  → 0.04x0.03 =1e-3
  → 10 Hz contribution to the main interactions (negligible)



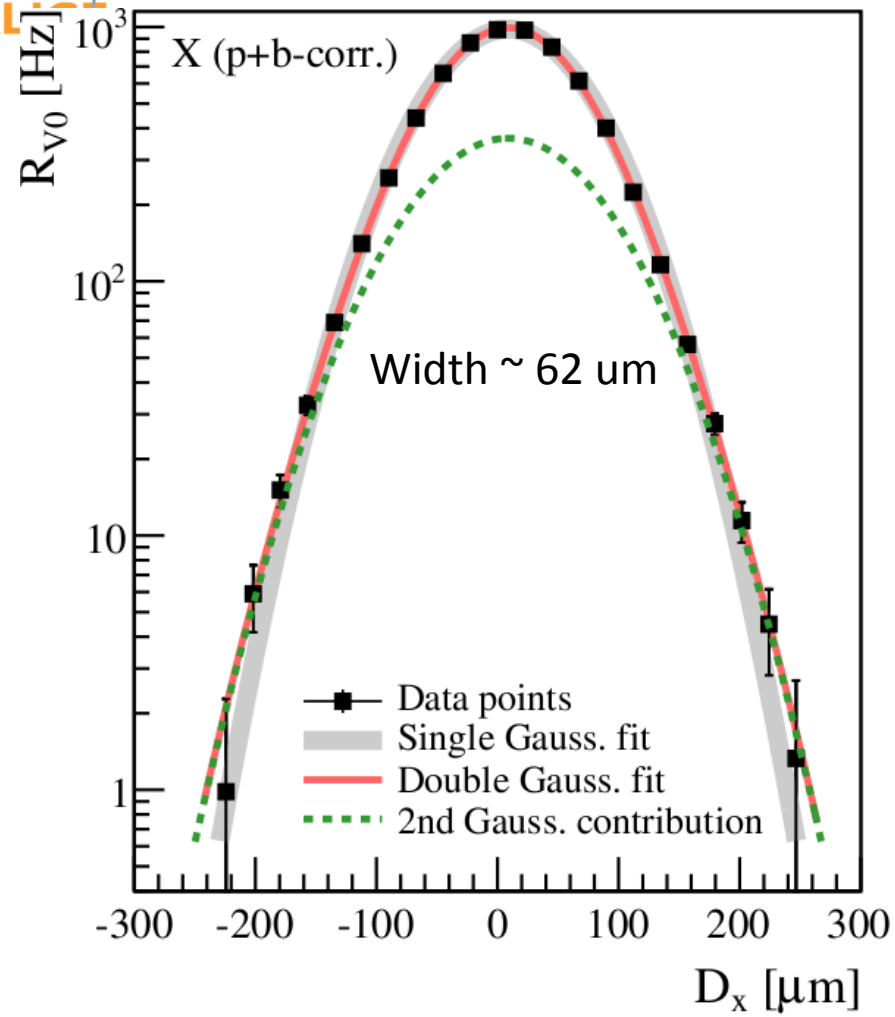
Background

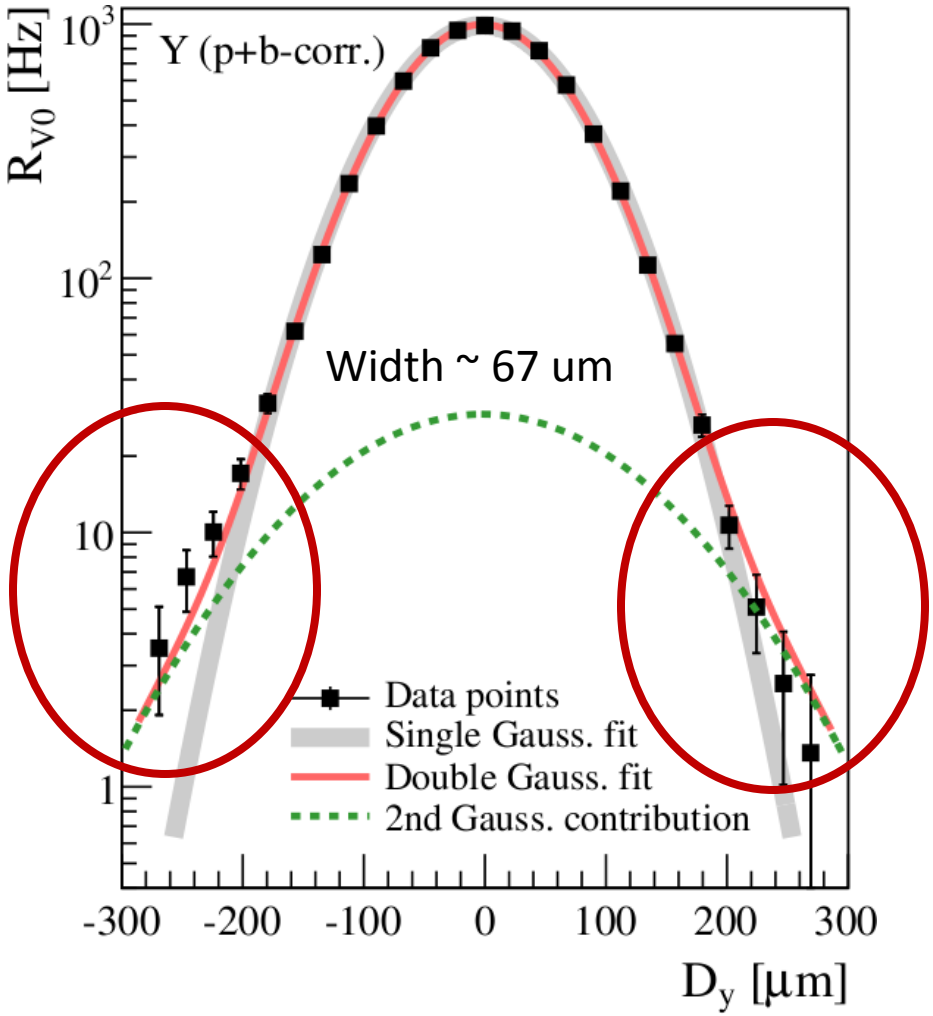
- Normally measurement was done by selecting only a “colliding” bunch pair
- Also it was checked by triggering on non-colliding bunches and empty bunches
- In the CVBAND (coincidence), nearly background free (<<1%)





Fitting Methods (Scan-I)



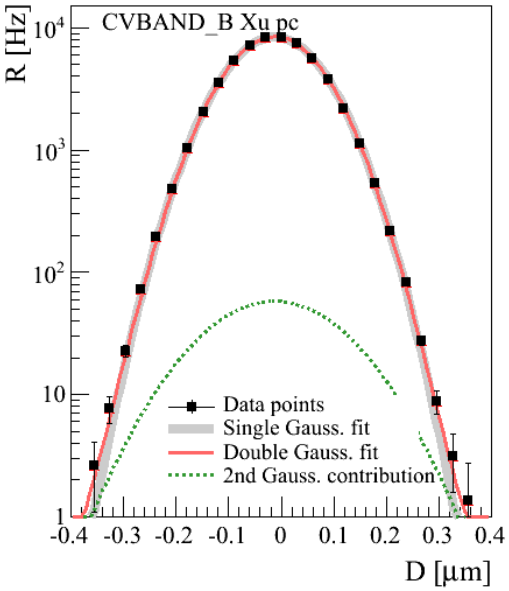


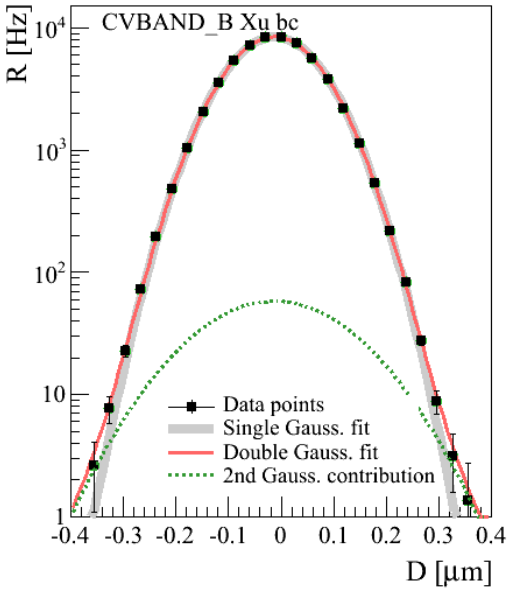
- Normal gaussian and double gaussian (g1+g2 with same center) were tested
- For Y-scan, tail needs double gaussian or even asymmetric gaussian

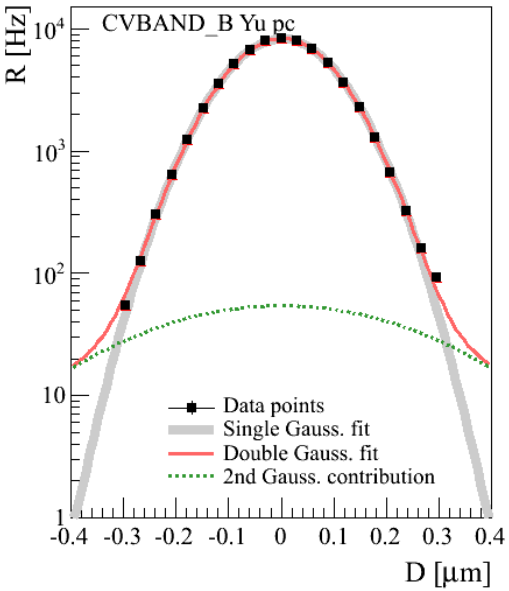
Fitting Methods (Scan-II)

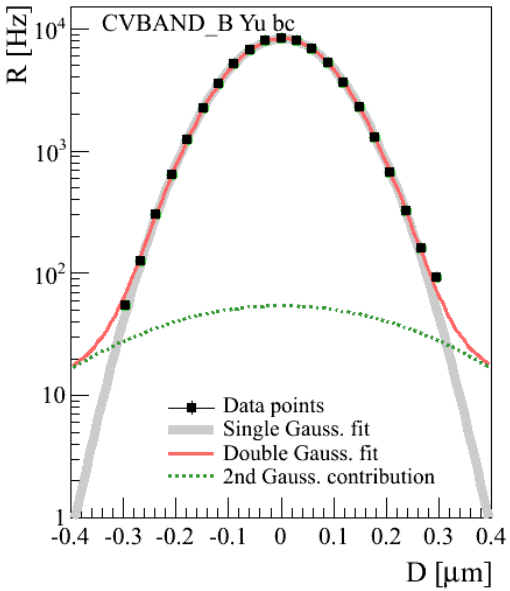
- In scan-II, it seems beams have less tail and less asymmetric
- No double-gaussian really required
- No change seen in results

- Typical gaussian fit width:
  - X: 81 μm
  - Y: 92 μm

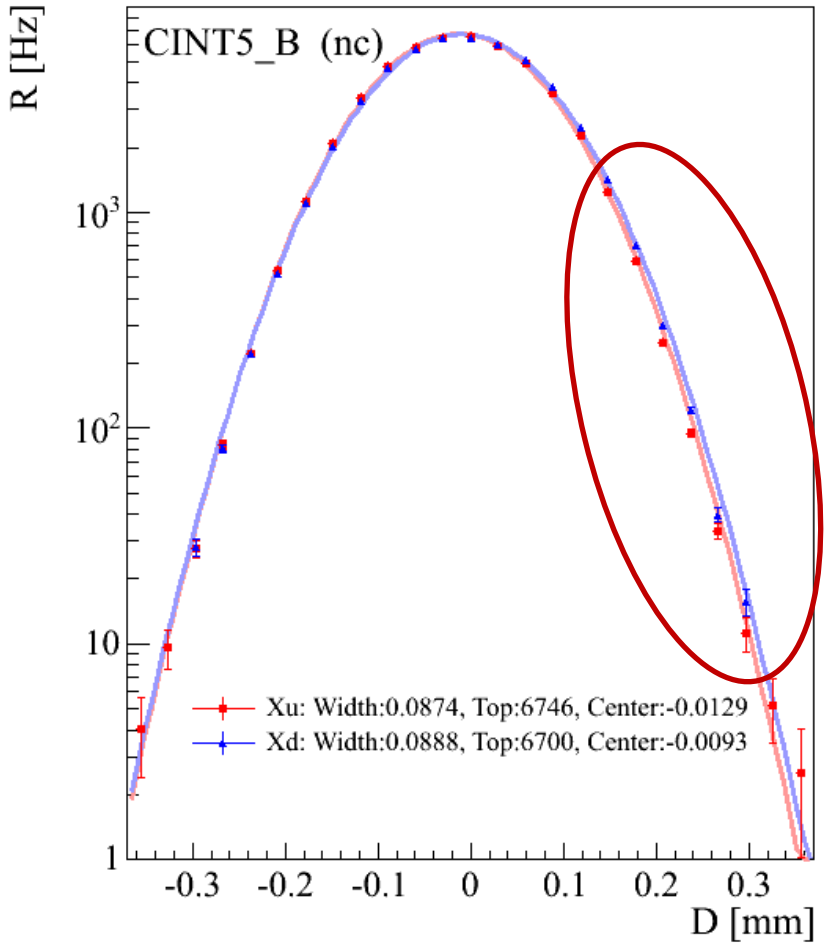


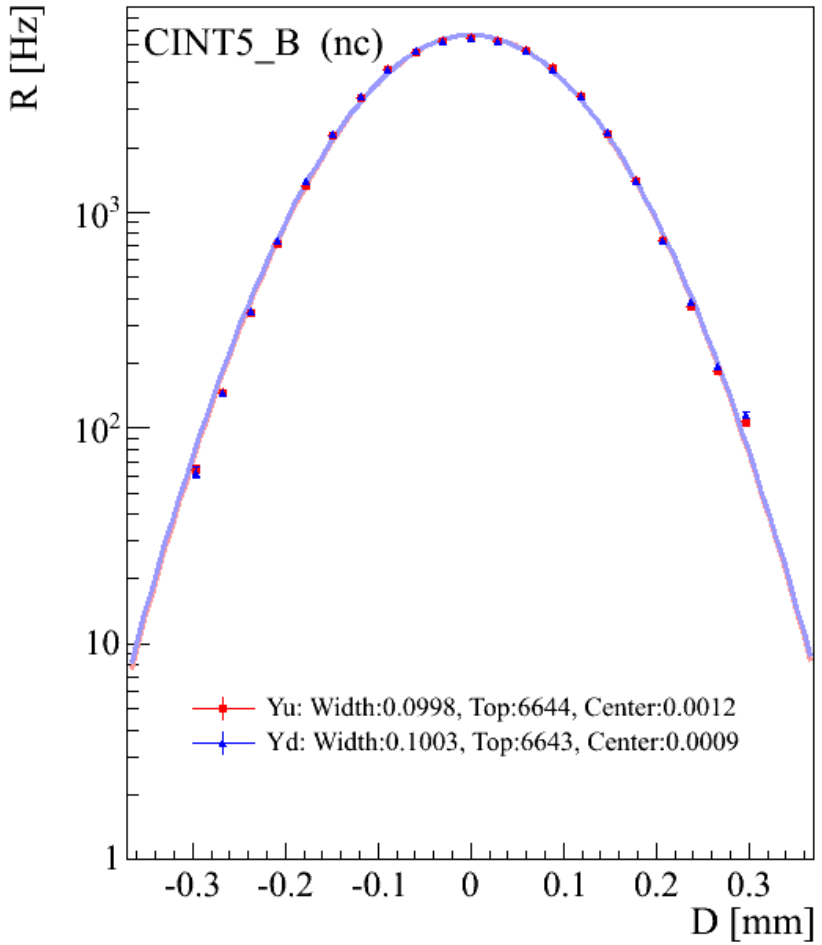






Scan-to-Scan in the same Fill





- There is slight systematic shift in scan directions
- Expected rate diff. due to emittance = 0.9% over scan range but largest change is > 15% at around +0.2mm sep. for X
- Width changes 1.6% for X scans and 0.5% for Y scans (2% syst.)

Cross Section Calculations

- Luminosity and cross section: $R_{\mathrm{V0}} = \sigma_{V0} \cdot L$
- With Gaussian approximation

$$L = \underbrace{k_b f_{rev}} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \underbrace{\rho_1(x,y)\rho_2(x,y)}dxdy \quad \rightarrow \quad \frac{k_b f_{rev} \overbrace{N_1 N_2}}{2\pi\sqrt{\underbrace{(\sigma_{1x}^2+\sigma_{2x}^2)(\sigma_{1y}^2+\sigma_{2y}^2)}}}$$

beam intensities

number of bunches and machine freq. | beam profiles | Gaussian shape approximation | beam sizes

- With scan data

$$R_{\mathrm{V0}}(D_x, D_y) = \underbrace{R_{\mathrm{V0}}(0,0)} \cdot \exp\left(-\frac{D_x^2}{2\sigma_{scan-x}^2}\right)\exp\left(-\frac{D_y^2}{2\sigma_{scan-y}^2}\right)$$

top rate

$$\begin{cases} \sigma_{scan-x} &= \sqrt{\sigma_{1x}^2+\sigma_{2x}^2} = \sqrt{2}\sigma_x \\ \sigma_{scan-y} &= \sqrt{\sigma_{1y}^2+\sigma_{2y}^2} = \sqrt{2}\sigma_y \end{cases}$$

- This was applied only for Gaussian fit results

Area and Numerical Sum Methods

- Fully take tail into account without gaussian assumption
- But one assumption: $\rho_{1,2}(x,y) = N_{1,2} p_x(x) p_y(y)$

$$\begin{aligned} R(D_x,0) &= \sigma_{V0} k_b f N_1 N_2 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p_x(x-D_x) p_y(y) p_x(x) p_y(y) dx dy \\ &= \sigma_{V0} k_b f N_1 N_2 Q_y \int_{-\infty}^{\infty} p_x(x-D_x) p_x(x) dx. \end{aligned}$$

- Consider sum of the scan area:

$$S_x = \int_{-\infty}^{\infty} R(D_x,0) dD_x = \sigma_{V0} k_b f N_1 N_2 Q_y \underbrace{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p_x(x-D_x) p_x(x) dx dD_x}_{=1}$$

where $\int_{-\infty}^{\infty} p_x^2(x) dx = Q_x, \quad \text{and} \quad \int_{-\infty}^{\infty} p_y^2(y) dy = Q_y$

$$\frac{R(0,0)}{S_x} = Q_x \quad \text{and} \quad \frac{R(0,0)}{S_y} = Q_y$$

thus $L(0,0) = \frac{R(0,0)}{\sigma_{V0}} = k_b f N_1 N_2 \frac{R^2(0,0)}{S_x S_y}$ $\qquad \sigma_{V0} = \frac{S_x S_y}{k_b f_{rev} \langle R(0,0) \rangle}$

In numerical sum methods $S_x = \sum_{i=1}^{n_x} R_{xi} \Delta_{xi} \quad \text{and} \quad S_y = \sum_{i=1}^{n_y} R_{yi} \Delta_{yi}$

Cross Section Results

- **Scan-I (preliminary)**

trigger class	Single Gaussian [mb]	Double Gaussian [mb]	numerical sum [mb]
VBAND	54.14 ± 0.37	53.79 ± (n.a.)	54.70 ± 0.56

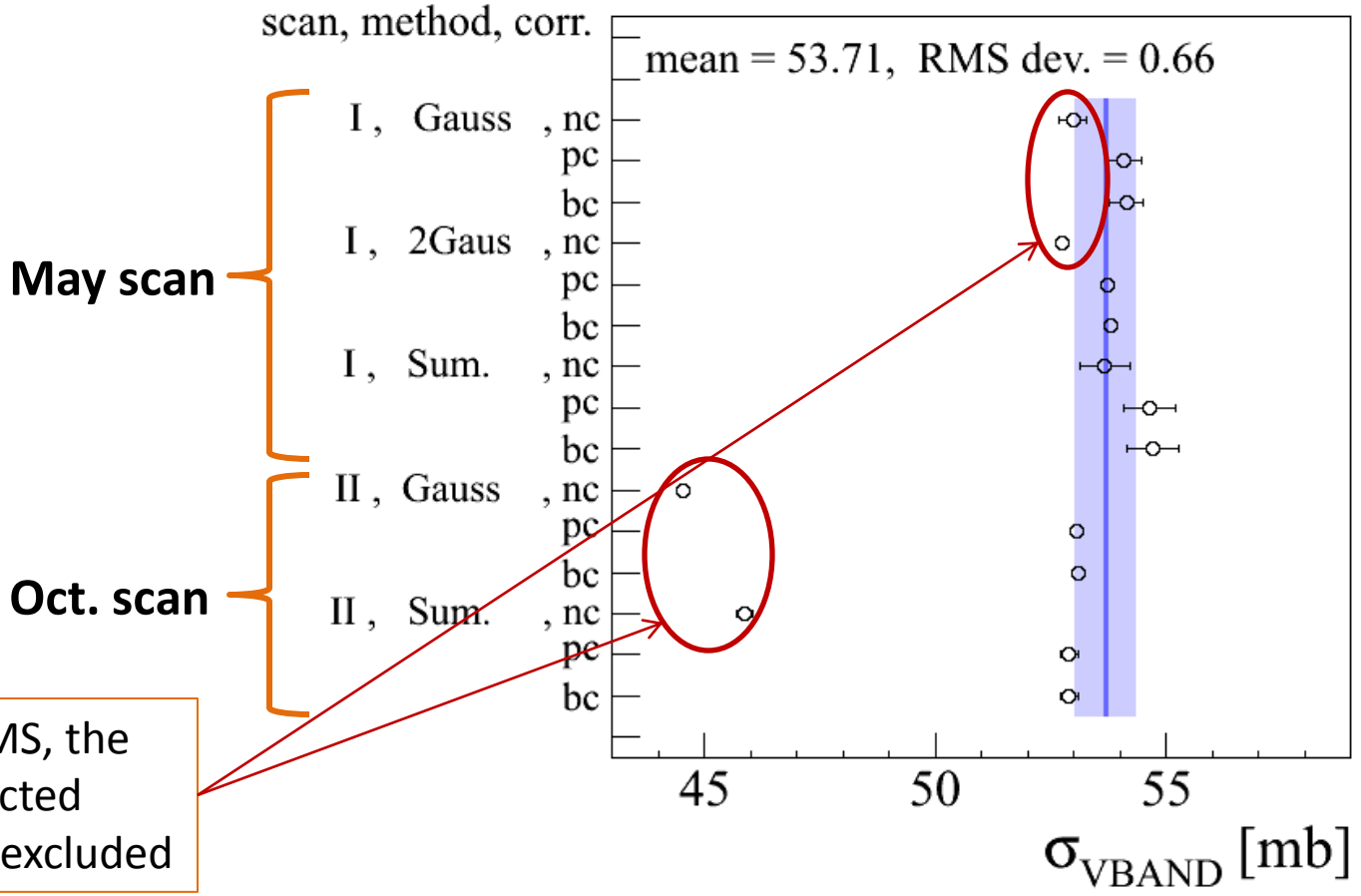
* Using last BCNWG (not published) results

- **Scan-II (preliminary)**

trigger class	Gaussian [mb]	numerical sum [mb]
VBAND	u: 53.09 ± 0.20 d: 53.93 ± 0.20 (+1.6%)	u: 52.90 ± 0.20 d: 53.51 ± 0.20 (+1.8%)
CINT5-B (VBOR)	u: 60.76 ± 0.32 d: 61.73 ± 0.37	u: 60.55 ± 0.22 d: 61.28 ±- 0.22
CMUS5	u: 0.77 ± 0.01 d: 0.76 ± 0.02	u: 0.77 ± 0.03 d: 0.75 ± 0.03

* u: first scan, d: next scan (go down). All data is pile-up and emittance grow corrected. All associated uncertainties are statistical. Xu has 6 sigma points, and Xd has 5 sigma points but that effect is not seen

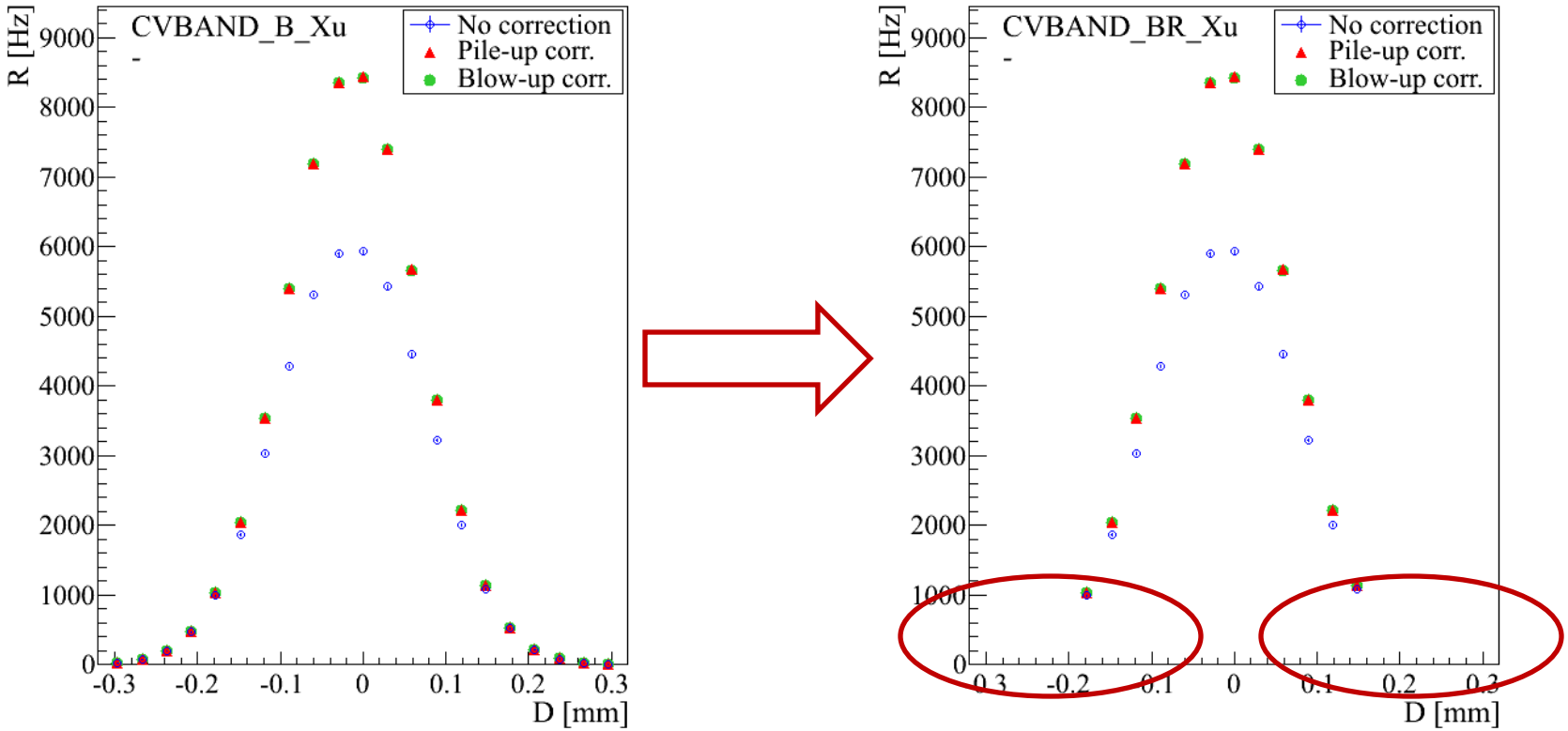
Scan-to-Scan Consistency



For mean and RMS, the non-pileup corrected points (nc) were excluded

- The May scan and Oct. scan are consistent within systematic errors but Oct. data gives >2.5% lower value than May.
- Reason why May "sum" method is high is probably due to taking all tail into account
- Emittance correction (difference from pc to bc) is negligible

Effect of Unmeasured Points

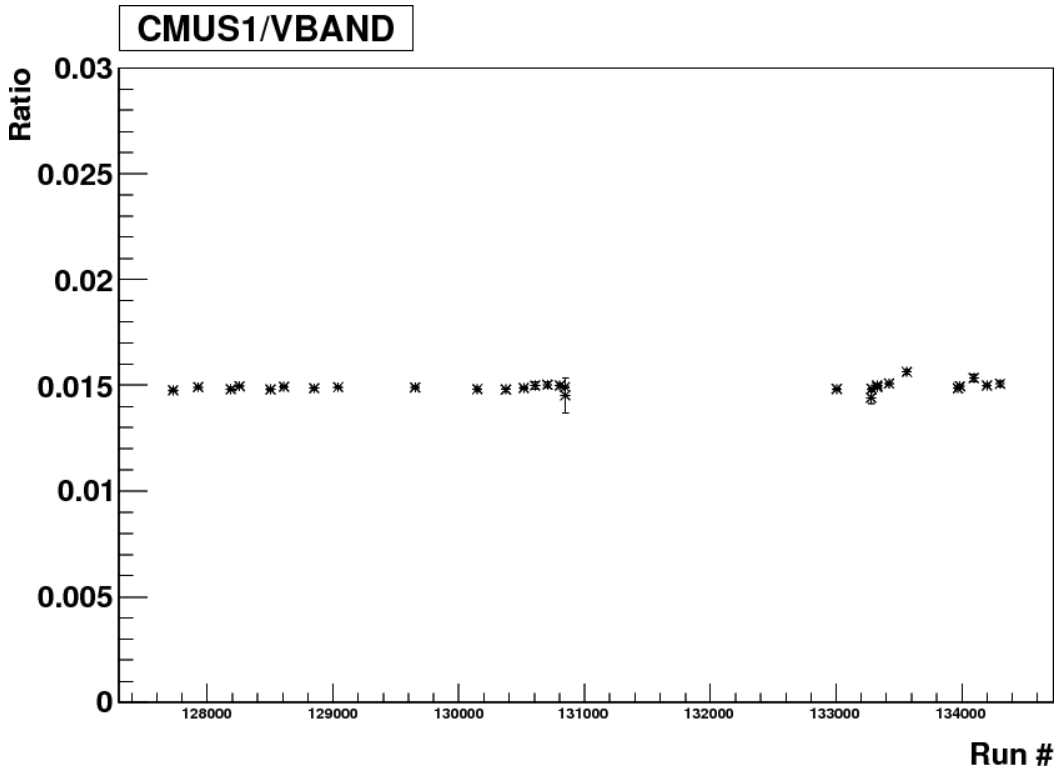


- Scan range of Xu and Xd was 6 sigma and 5 sigma, but no significant difference was seen but can we reduce more?
- Artificially reduce number of data points and see if result is stable
  - ~ 4 sigma instead of 6 sigma
- Gaussian fit results: changed from 53.09 to 52.75 mb (0.6% loss)
- Numerical sum results: changed from 52.90 to 50.34 mb (4.8% loss)

CMUS1/5 Estimation from Offline

- **In offline analysis**
  - CMUS1/ CVBAND trigger ratio shows 1.491%
  - CVBOR / CINT1 trigger ratio is 99.2%
    where CINT1 includes 0.8% more c.s. addition to CINT5 (CVBOR)

- **CMUS5 / VBAND (offline)**
  1.491% x 99.2% = 1.48%
- **From online vdM data:**
  CMUS5 / VBAND
  = 0.77 / 52.90 = 1.46%
  … good agreement



- **Point:**
  - Pile-up corrections are very different between those two triggers
  - CMUS5 has less than 1% correction while VBAND has 40% correction

Preliminary Systematic Uncertainties

item	Scan-I (May)	Scan-II (Oct.)	comment
Beam intensity (on product)	4.4%	<3%	new BCNWG value
Ghost charge	negligible	-	being analyzed for scan-II
Separation	2⊕2%	better	under analysis for Scan-II
Emittance grow and intensity	<1%	<1%	
Different fitting, methods	<1%	<1%	
Scan-to-scan (different fill)	---	<2.5%	discrepancy from May-Oct
Scan-to-scan (same fill)	---	<2%	
Rate and time window	<1%	<1%	
Background	<1%	<1%	
Noise	negligible	negligible	
Excluded process pile-up	negligible	negligible	

- **The largest uncertainty is the beam intensity**
- **Total uncertainty excluding beam intensity <4.5%**
- **The second largest is the separation calibration**

Summary and Outlook

- **Preliminary results of May scan and Oct. scan results were shown and cross section of ALICE triggers were measured**
- **Experiment effects and scan-to-scan reproducibility showed below 4.5% accuracy**
- **Still few analysis to be done (length scale for Scan-II etc)**
- **We would like to cross check the cross section values for defined kinematic with other experiment**
  - charged particle
    - eg. -0.9 < eta < 0.9 and pT>1 GeV/c
- **Offline analysis on going. One of the requested features for new scan from offline analysis is to have lower pile-up: order 10^10**