Relative Luminosity Measurement at PHENIX

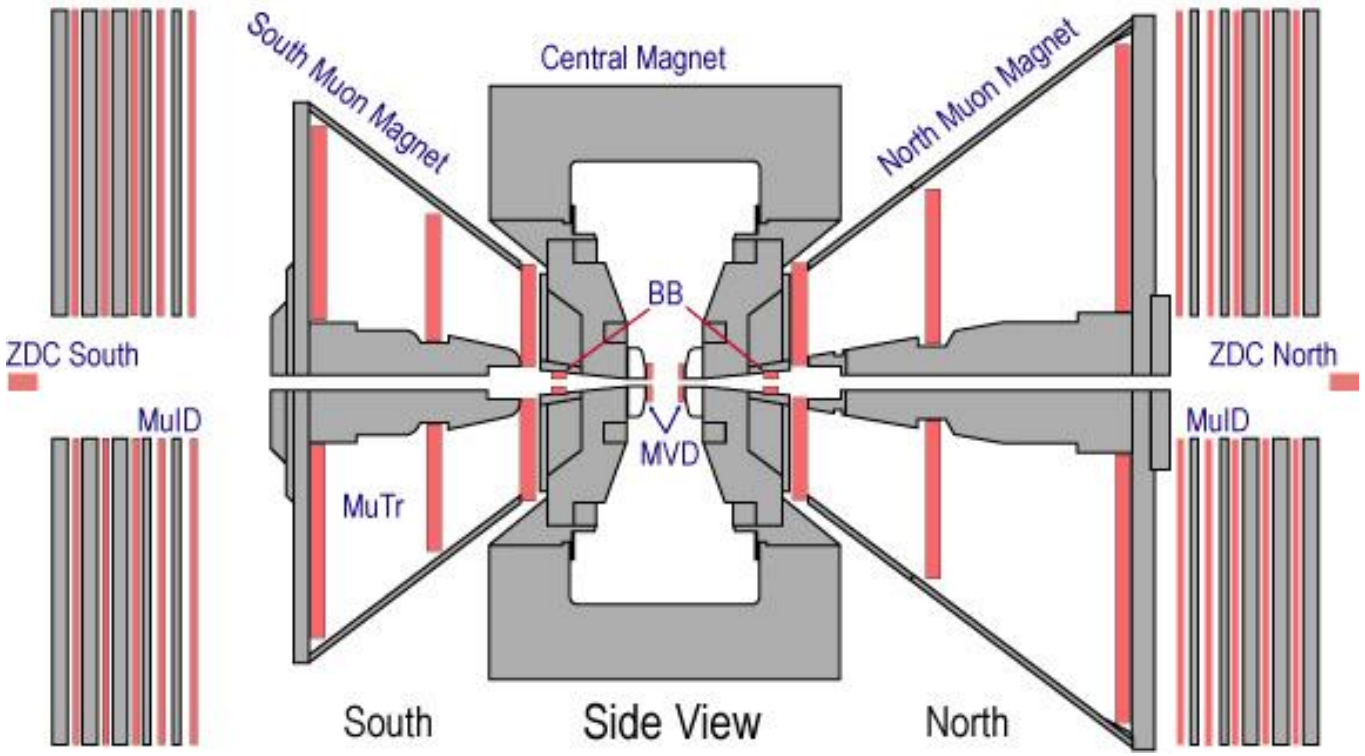
$$
\begin{aligned}
A_{LL} &= \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \\
&= \frac{1}{|\langle P_b P_y \rangle|} \cdot \frac{N_{++} - R \cdot N_{+-}}{N_{++} + R \cdot N_{+-}}; \quad R = \frac{L_{++}}{L_{+-}} \\
\frac{\partial A_{LL}}{\partial R} \delta R &\approx \frac{1}{2|\langle P_b P_y \rangle|} \delta R
\end{aligned}
$$

- To measure 1% asymmetry with $P_{beam} \approx 40\%$, need $\delta R < 10^{-3}$
- Higher polarization reduces sensitivity to uncertainty in R
- Order of magnitude requirement : $\delta R \leq \text{few} \times 10^{-4}$

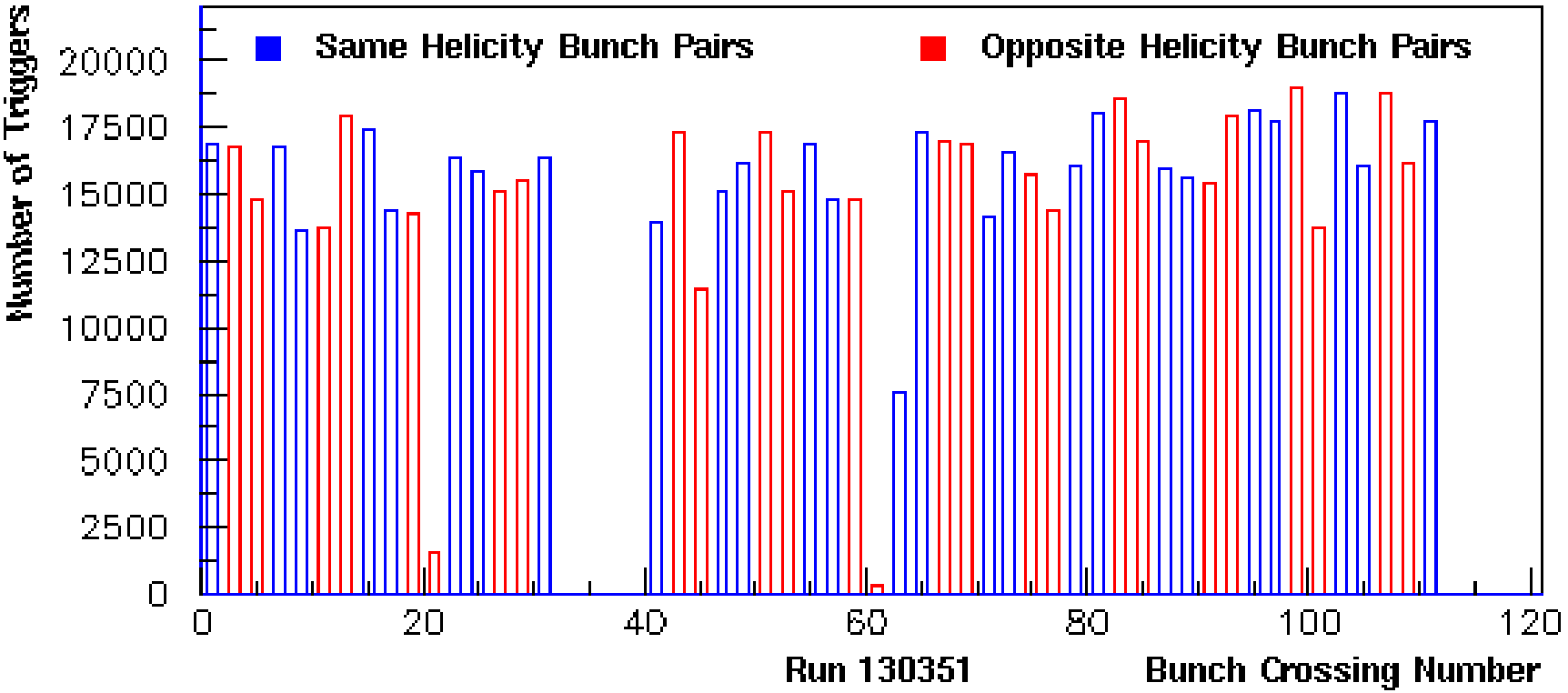
- How do measure relative luminosity?
- What are some of the difficulties we expect as $\mathcal{L}$ increases?
- What should we do? (Work in progress)

Relative Luminosity Measurement at PHENIX

- Located at ± 1.44 m from interaction point, cover $\Delta\phi = 2\pi,\ 3.0 \leq |\eta| \leq 3.9$
- Collisions defined by coincidence of signals in Beam-Beam Counters (BBCs)
- Average hit time is formed from PMTs in north and south BBC arms separately
- From difference of north and south BBC hit times can reconstruct z of vertex, require $|z| < 30$ cm
- Have separate scalers for each bunch pair to measure collison rate for different helicity combinations
- Measure R with scalers attached to this minimum-bias trigger, $R = \frac{BBC_{++} + BBC_{--}}{BBC_{+-} + BBC_{-+}}$



Relative Luminosity Measurement at PHENIX



- Ideally $R = 1$, blue and red bars identical in height
- Typical value of $|R - 1| \approx$ few percent in any run, 0.5% overall in Run 3
- Variation in bunch intensity develops at extraction and injection - can be improved by CAD
- In Run 3, $\delta R \approx \ 2.5 \times 10^{-4}$ (stat)
- Rate variation is one problem, another is due to different vertex distributions

Complications in Extracting R as Luminosity Increases

- In Run 4, probability of minimum-bias trigger/crossing ≈ 0.02
- Roughly 1 percent of all triggers contained a second pp collision
- In Run 5, $\approx$ 4 percent of all triggers may contain a second pp collision
- At design luminosity, we expect ≈ 1 pp collision/crossing $\Rightarrow$ 70 percent of all triggers may contain 2 or more pp collisions !

At least two complications will result :

(1) Scaler counting minimum-bias triggers only counts 0 or 1 pp interaction/crossing

$\Rightarrow$ we need to correct for possibility of multiple pp interactions/crossing

(2) With multiple pp interactions we are likely to :

(a) lose some events which should pass the vertex cut

(b) count some events which shouldn't pass the vertex cut

$\Rightarrow$ PHENIX will acquire a sensitivity to bunch longitudinal profiles

Complications in Extracting R as Luminosity Increases

Extracting R from a single-arm detector is relatively easy :

- Let μ=average number of pp interactions/crossing passing vertex cut
- Let ϵ=probability that we can detect a pp collision
- Let $\delta = 1 - \epsilon$=probability we miss a pp collision

Then the fraction of crossings with 0 triggers is :

$$\begin{aligned} P(0) &= \sum_{n=0}^{\infty} \frac{e^{-\mu}\mu^n}{n!}\delta^n \\ &= e^{-\mu}e^{\mu\delta}\sum_{n=0}^{\infty}\frac{e^{-\mu\delta}\left(\mu\delta\right)^n}{n!} \\ &= e^{-\mu\epsilon} \end{aligned}$$

$$\text{Then } \mu = -\log P(0)/\epsilon \quad \Rightarrow \quad R = \frac{\mu_{++}}{\mu_{+-}} = \frac{-\log P_{++}(0)/\epsilon}{-\log P_{+-}(0)/\epsilon}$$

$$R = \frac{\log P_{++}(0)}{\log P_{+-}(0)}$$

$\Rightarrow$ dependence on ϵ has dropped out

Complications in Extracting R as Luminosity Increases

How can we account for multiple pp interactions/crossing using the BBC trigger rate?

- Let μ=average number of pp interactions/crossing passing vertex cut
- Let ϵ=probability that one arm of BBC detects the collision
- Let $\delta = 1 - \epsilon$=probability one arm misses the collision

Now extract the fraction of beam crossings yielding a minimum-bias trigger :

$$\begin{aligned} P(1+) &= \sum_{n=1}^{\infty} \frac{e^{-\mu}\mu^n}{n!} \left(1-\delta^n\right)\left(1-\delta^n\right) \\ &= 1 - e^{-\mu(1-\delta)}\left(2 - e^{-\mu\delta(1-\delta)}\right) \\ &= 1 - e^{-\mu\epsilon}\left(2 - e^{-\mu\epsilon(1-\epsilon)}\right) \end{aligned}$$

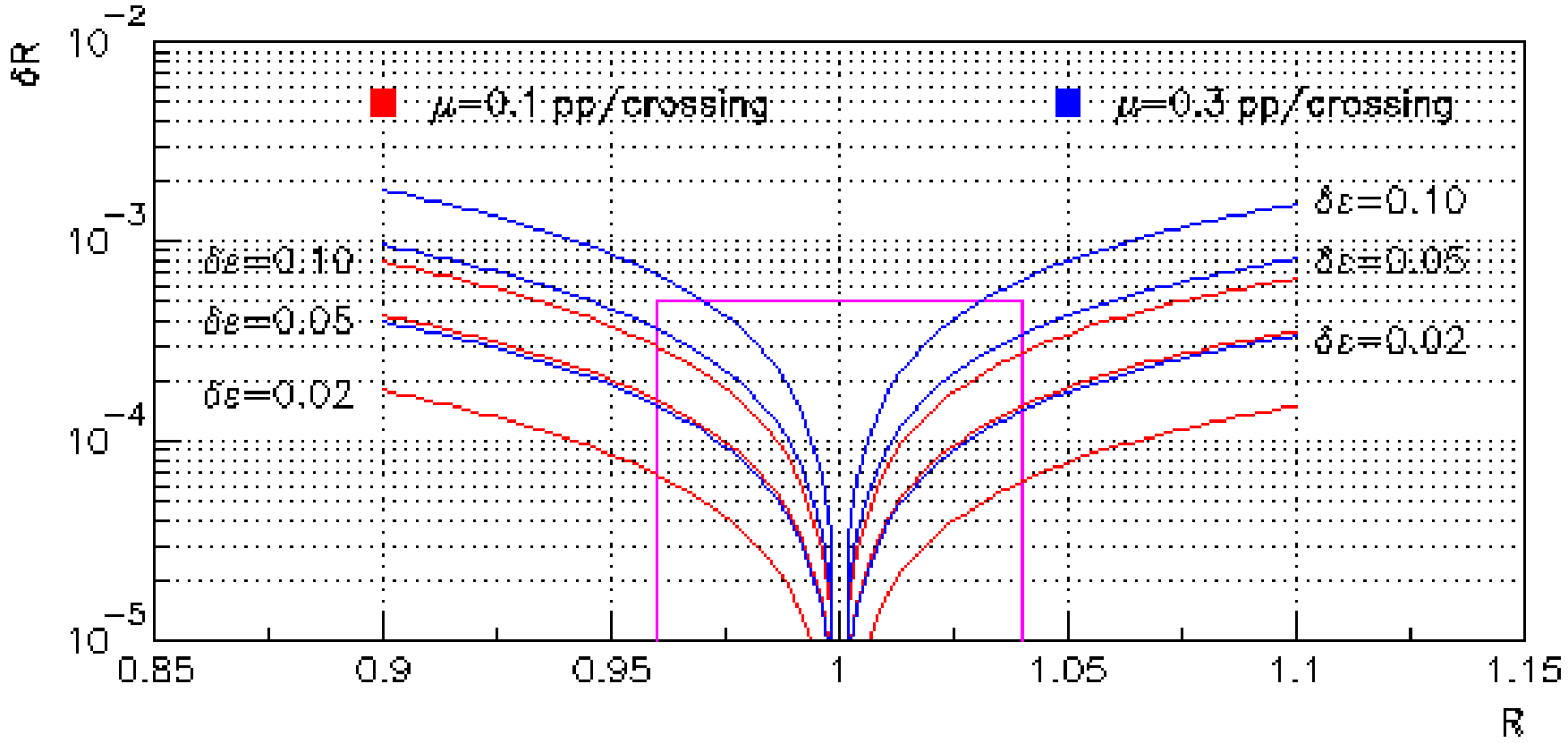
- We measure $P_{++}(1+)$ and $P_{+-}(1+)$, want to extract μ_{++} and μ_{+-}

$\Rightarrow$ Accuracy in extracting $R = \mu_{++}/\mu_{+-}$ depends on knowledge of ϵ (not true for single arm)

$\Rightarrow$ Minimum-bias trigger rate not simple function of luminosity

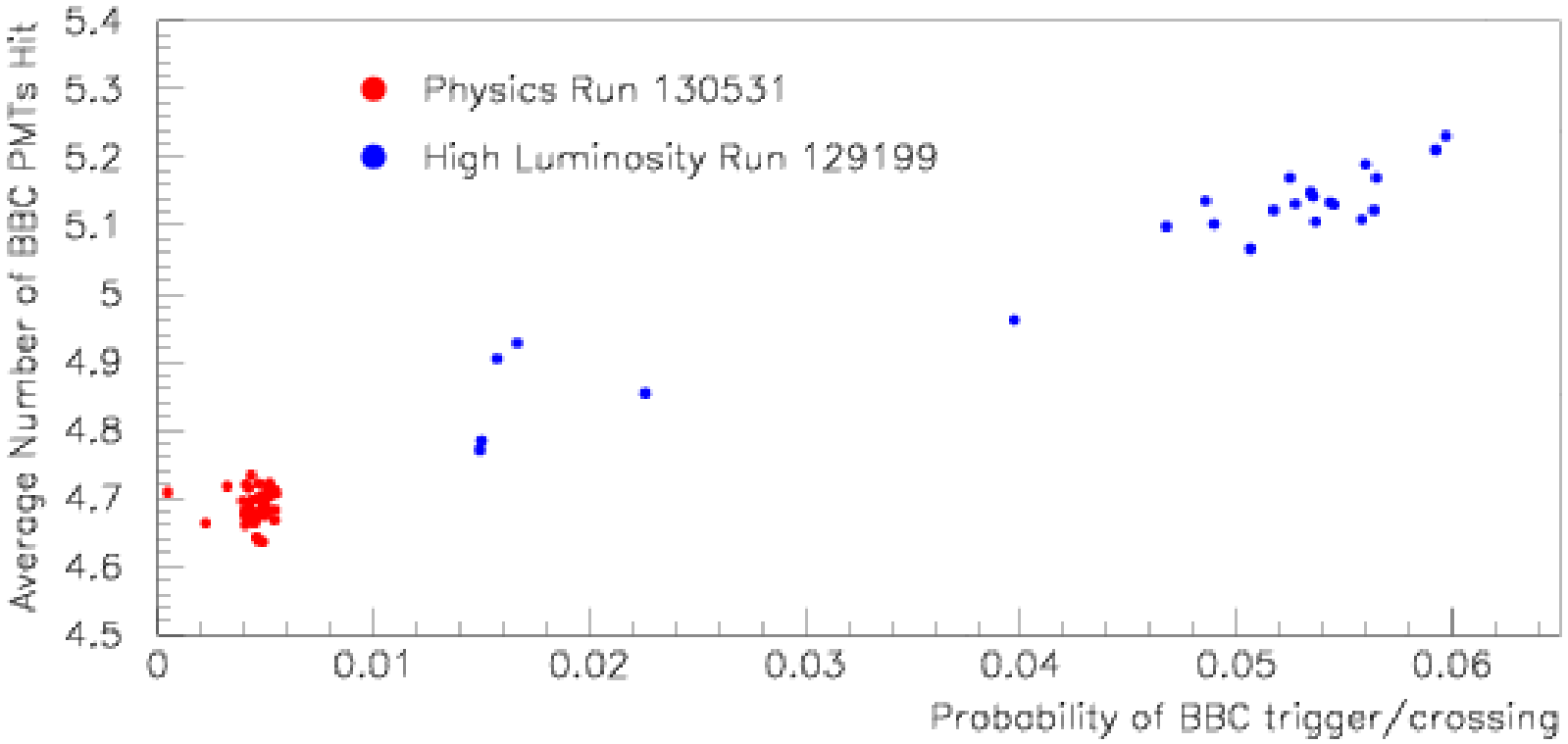
- Limits $\epsilon \longrightarrow 0$ or $\epsilon \longrightarrow 1$ reduce uncertainty on R due to uncertainty on ϵ

Complications in Extracting R as Luminosity Increases



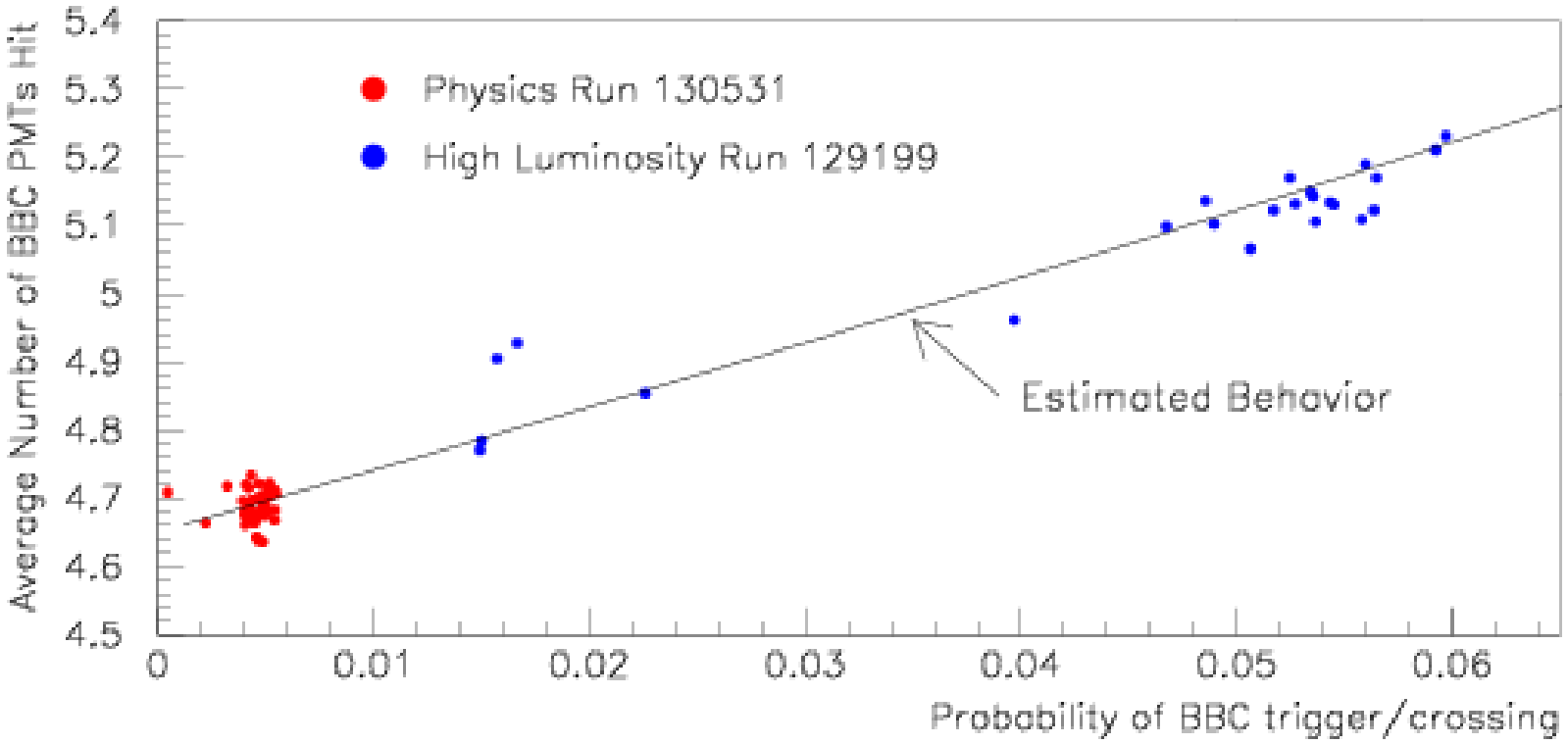
- What is our uncertainty δR on R given an uncertainty $\delta\epsilon$ on ϵ?
- δR increases as rate μ increases
- δR increases as uncertainty $\delta\epsilon$ on probability ϵ BBC detects a pp collision increases
- Perhaps recording BBC charge or tube multiplicity will decrease the uncertainty δR

Complications in Extracting R as Luminosity Increases



- As rate increases we will sometimes detect 2 pp interactions/crossing
- Average number of BBC PMTs hit in those cases will be double normal number
- Number of PMTs hit is sensitive to rate and probability ϵ BBC arm detects a collision
- $\epsilon \approx \sqrt{\sigma_{BBC}/\sigma_{PP}} \approx 0.73$

Complications in Extracting R as Luminosity Increases



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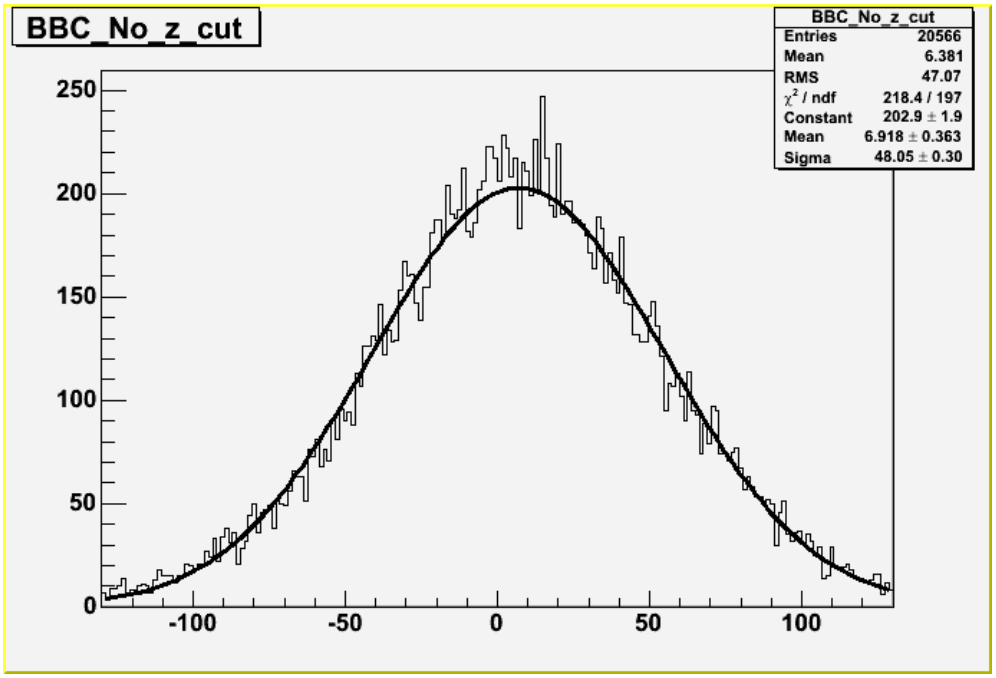
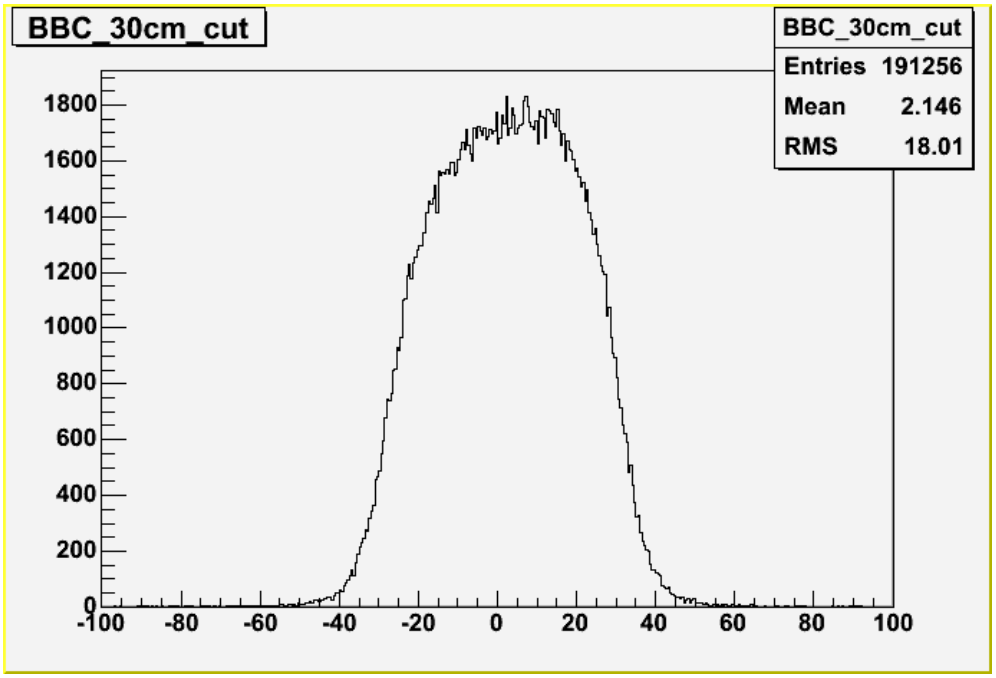
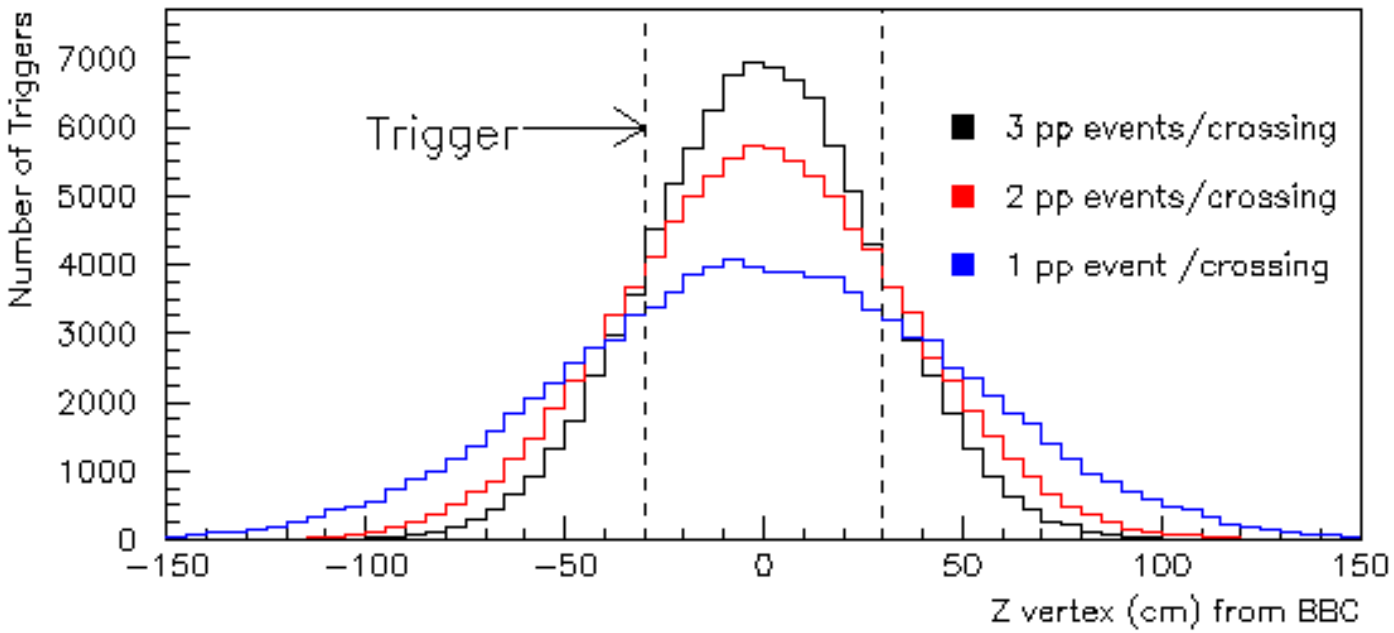
- Average number of BBC PMTs hit in those cases will be double normal number
- Number of PMTs hit is sensitive to rate and probability ϵ BBC arm detects a collision
- $\epsilon \approx \sqrt{\sigma_{BBC}/\sigma_{PP}} \approx 0.73$
- Could be luck, or possible handle on ϵ, correction for multiple pp interactions/crossing

Complications in Determining the Z Vertex with the BBC

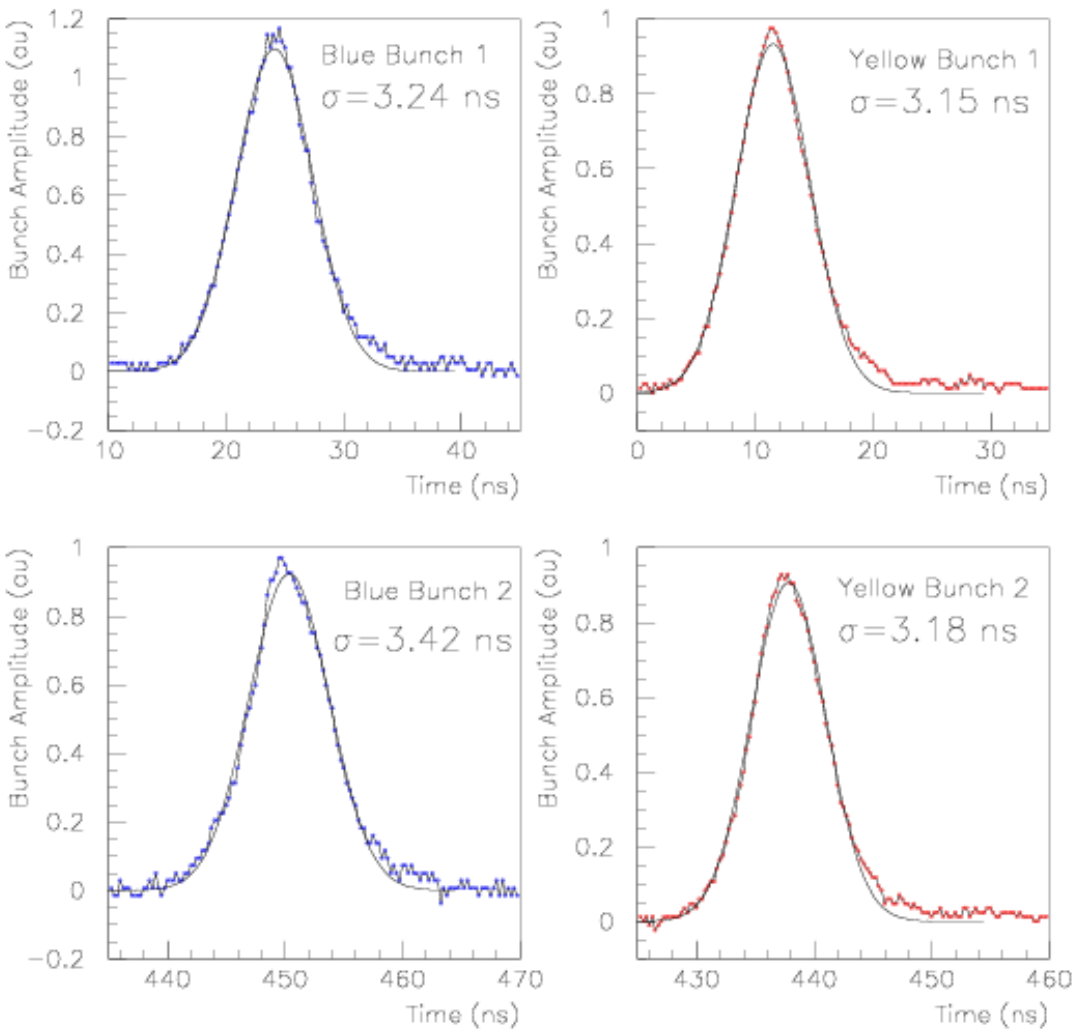






- We will need bunch longitudinal profiles
- Perhaps use Wall Current Monitor ?

Complications in Determining the Z Vertex with the BBC



- Wall current monitor samples profile in 0.25 nsec bins
- Wide bunches seem to correspond to wide vertex
- 1st pair : 47 cm; 2nd pair : 51 cm
- Still to do : predict vertex dist. from WCM
- Alternating between bunches $\longrightarrow$ 0.125 nsec bins $\longrightarrow$ improved vertex reconstruction
- To do : see if WCM data describes BBC,ZDC trigger rates and vertex distributions well enough for R

Possible Approaches to Determining Relative Luminosity

- From independent measurements of $\sigma_{pp}^{\text{inel+DD}}$ and vernier scan - can extract ϵ to $5-10\%$
  - With ϵ, can use BBC scaler data to extract R
  - Could output total charge in BBC PMTs or multiplicity to scalers
  - Can compare results to triggers formed from ZDC or ZDCN||S && opposite BBC arm
  - Need to correct scaler data for vertex shape as $\mathcal{L}$ increases !

    $\Rightarrow$ use wall current monitor to get bunch profiles and charge?
- Construct new small acceptance detector with vertexing ability, insensitivity to A_{LL} - Relative Luminosity Telescope (Wei Xie)
- Get spin flipper commissioned
- Try to reconstruct $\mathcal{L}$ from wall current monitor measurements of charge and bunch profiles
- Lots of ideas to try