Measurement of single spin asymmetries of PHENIX BBC with tagged very forward neutron in transeversely polarized pp collision at sqrt(s) = 200 GeV

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for the PHENIX collaboration

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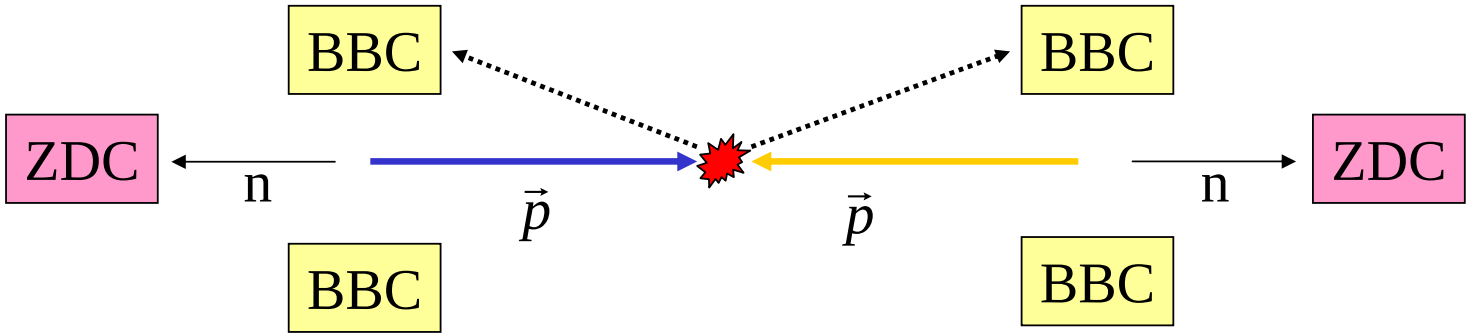
概要



超前方中性子を tag して、BBCで A_N を測定

Contents

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- RHIC spin **実験と** PHENIX detectors
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PHENIX collaboration

PHENIX

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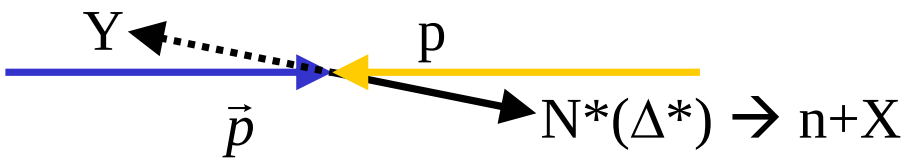
Motivation

- Transverse single spin asymmetry (A_N):
  - 高エネルギー pp 衝突のメカニズムの情報
- 前方でいくつか有限なA_Nの観測例：
  - FNAL E704 (π, sqrt(s) = 20 GeV)
  - STAR FPC (π^0, 200 GeV)
- LocalPol の測定 (sqrt(s) = 200 GeV)
  → 超前方の中性子に大きなA_N (～ −10%)
  – ポメロンだけの交換では説明できない
  – このメカニズムは？
- 超前方の中性子を捕まえたときに、
  他の粒子のA_Nを測定

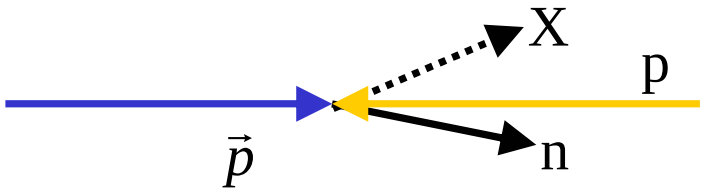
どんな process か？

- Diffractive-like



$A_N(X) < 0$, $A_N(Y) > 0$

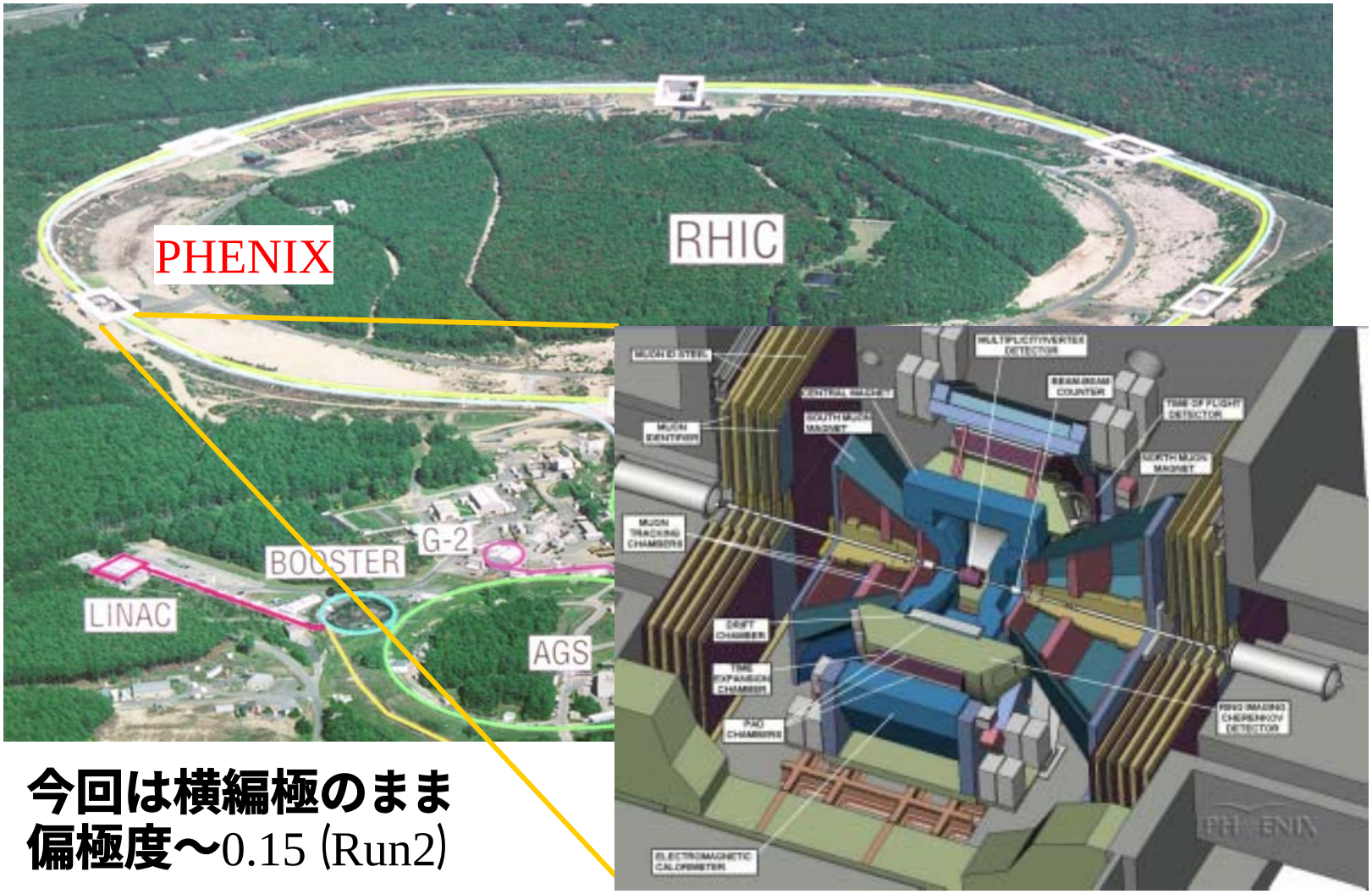
- kick-out/recoil



$A_N(X) > 0$, $A_N(Y)$?? [E704: $A_N(\pi^+) > 0$]

RHIC spin 実験

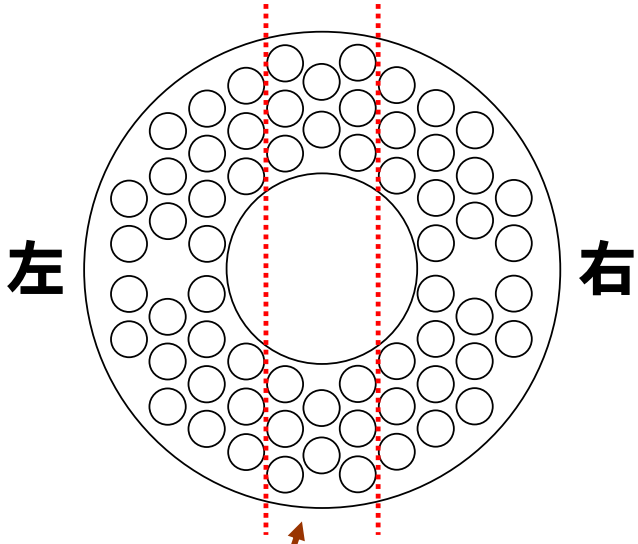
偏極陽子同士の collider

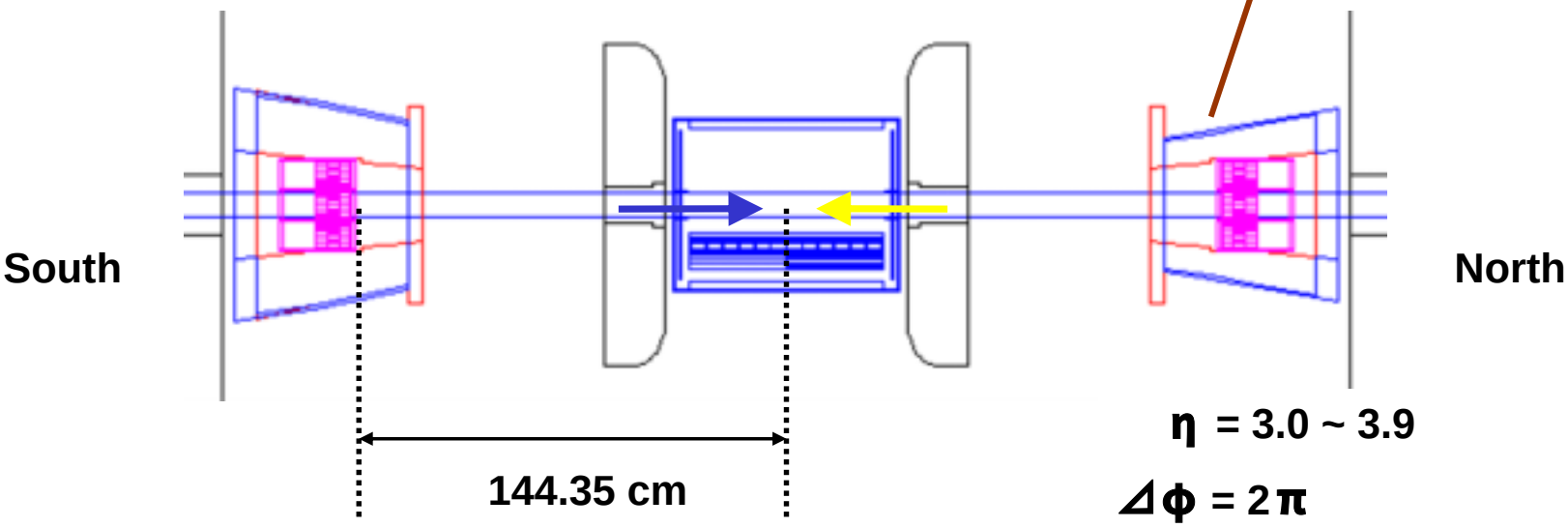


今回は横編極のまま
偏極度〜0.15 (Run2)

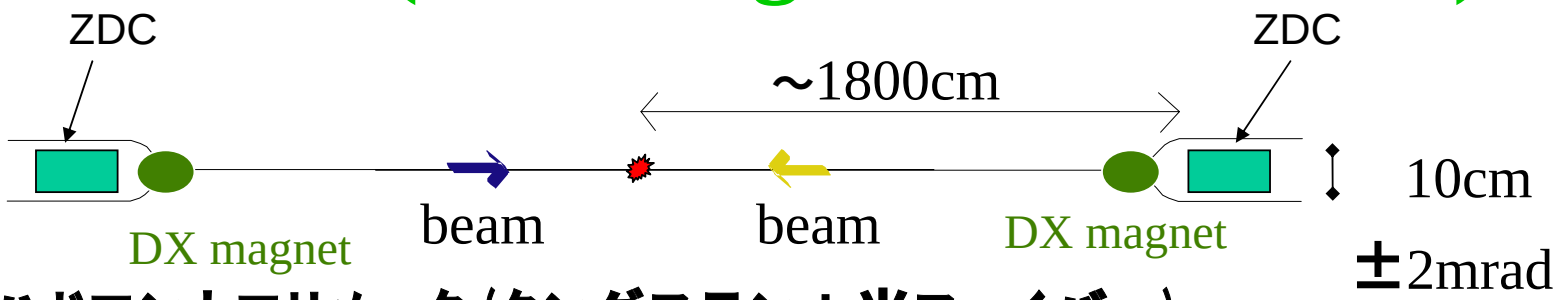
PHENIX BBC

- Quartz Cherenkov カウンター
  (n ~ 1.4, 厚さ ~ $1X_0$)
- 64 segments×2 (南北)
- 有限角補正：0.79
- 平均 multiplicity ~ 2
- 荷電粒子の inclusive 測定

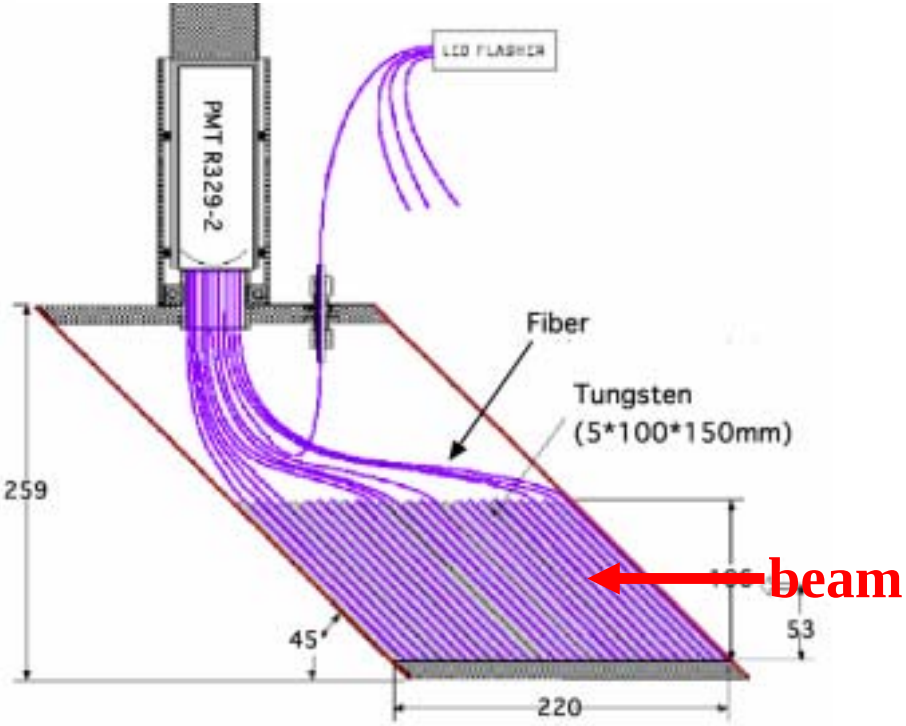


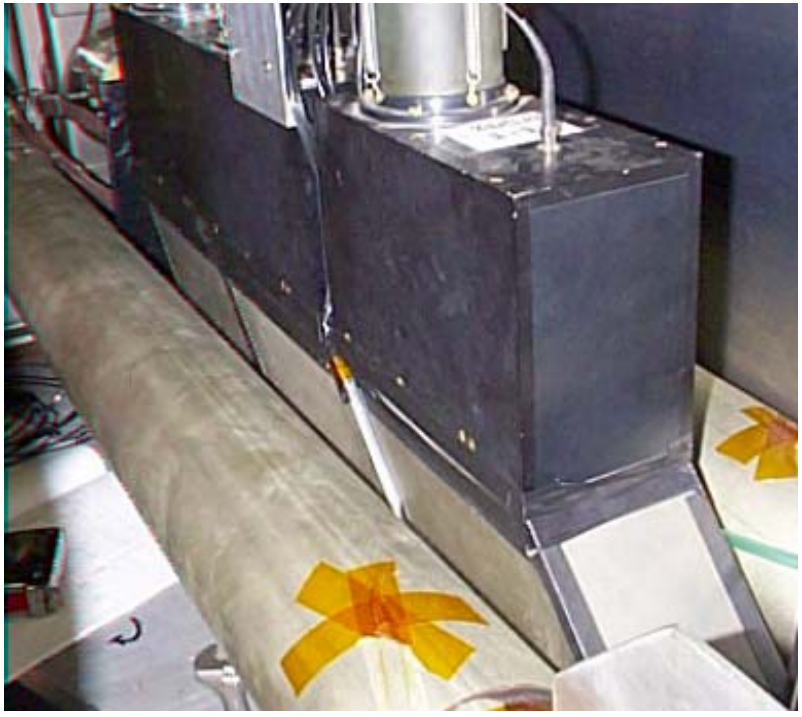


ZDC (Zero Degree Calorimeter)



ハドロンカロリメータ (タングステン＋光ファイバー)
3セグメント: 合計5.1λ_I, 149X_0





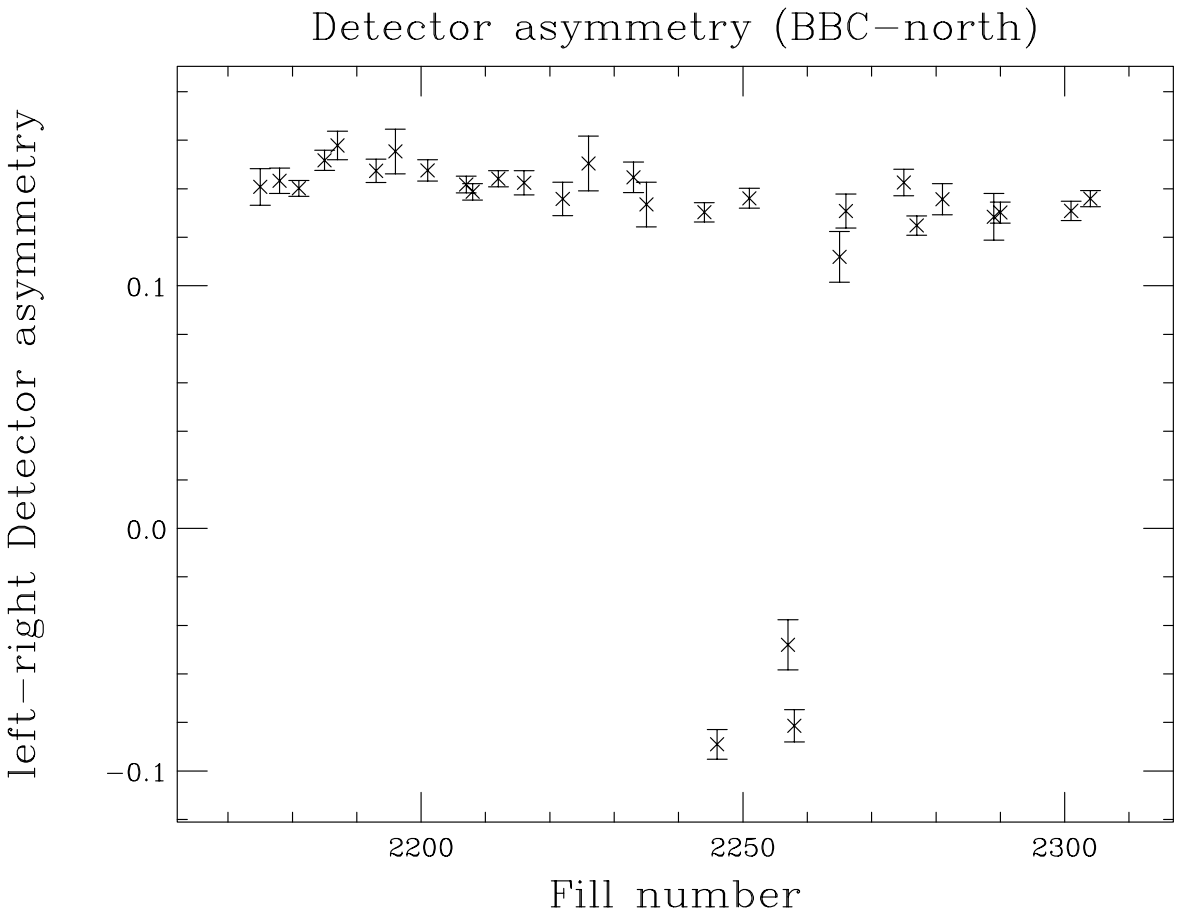
ZDC での n/γ 分離

- γ は最初のセグメントで止まる
  - 2つ目か3つ目のセグメントにヒット → 中性子
  - 最初のセグメントだけ → γ
- n/γ 比 ~ 1:1
- contamination（PYTHIA+GEANT simulation による）
  - 中性子: γがPMTの付近を通ったもの ～14%
    K_Lは2-3%程度
  - γ：中性子が 40%程度混入
- contamination に対して、A_N が変わらない場合、
  $A_N = 0$ の場合の2通りを解析してその中間を取る
  → systematic error を計算

解析条件

- 以下の組み合わせ (16通り)
  - ZDC south／north
  - ZDC neutron／γ
  - BBC south／north
  - 左右の asymmetry と上下の asymmetry
- そのそれぞれについて以下を計算
  - Detector asymmetry
  - Physics asymmetry for Blue beam
  - Physics asymmetry for Yellow beam
- 2つのチェック
  - 2つの独立な A_N の測定は consistent か？
  - 上下非対称性 (Parity を破る) は 0 か？

Detector asymmetry



stable for most fills

strange fills 2246, 2257, 2258

same tendency in other detector asymmetries

Include/exclude strange fills → systematic

結果 (PHENIX preliminary)

ZDC	n/γ	BBC	LR/TB	$A_B(10^{-2})$	$A_Y(10^{-2})$
south	n	south	LR	$0.86 \pm 0.88(0.79 \pm 0.92)$	$-4.44 \pm 0.65(-4.67 \pm 0.67)$
			TB	$-0.15 \pm 0.87(0.31 \pm 0.90)$	$1.25 \pm 0.63(1.36 \pm 0.65)$
		north	LR	$-0.06 \pm 0.97(-0.57 \pm 1.02)$	$2.44 \pm 0.72(2.88 \pm 0.74)$
			TB	$-0.41 \pm 0.98(-0.63 \pm 1.02)$	$1.04 \pm 0.72(1.18 \pm 0.73)$
	γ	south	LR	$0.73 \pm 0.63(0.96 \pm 0.66)$	$-1.64 \pm 0.47(-1.71 \pm 0.48)$
			TB	$0.29 \pm 0.63(0.08 \pm 0.67)$	$0.37 \pm 0.46(0.46 \pm 0.47)$
		north	LR	$0.22 \pm 0.69(-0.04 \pm 0.72)$	$-0.11 \pm 0.50(-0.12 \pm 0.51)$
			TB	$0.22 \pm 0.69(0.29 \pm 0.72)$	$-0.63 \pm 0.50(-0.55 \pm 0.51)$
north	n	south	LR	$1.86 \pm 0.80(1.74 \pm 0.84)$	$-0.68 \pm 0.58(-0.75 \pm 0.60)$
			TB	$-0.18 \pm 0.78(0.18 \pm 0.82)$	$0.94 \pm 0.58(1.00 \pm 0.59)$
		north	LR	$-4.06 \pm 0.75(-4.77 \pm 0.78)$	$-0.17 \pm 0.53(0.01 \pm 0.54)$
			TB	$0.01 \pm 0.73(-0.51 \pm 0.75)$	$0.60 \pm 0.53(0.86 \pm 0.54)$
	γ	south	LR	$0.40 \pm 0.78(0.73 \pm 0.82)$	$-0.56 \pm 0.57(-0.46 \pm 0.59)$
			TB	$-1.28 \pm 0.78(-1.50 \pm 0.82)$	$-0.59 \pm 0.57(-0.54 \pm 0.59)$
		north	LR	$-1.49 \pm 0.76(-2.15 \pm 0.79)$	$0.40 \pm 0.54(0.61 \pm 0.56)$
			TB	$-0.10 \pm 0.75(-0.21 \pm 0.77)$	$-0.87 \pm 0.54(-0.76 \pm 0.56)$

Table 3: Result of analyzing powers. Parenthsed values were obtained excluding fills 2246, 2257, and 2258. A_N^{CNI} was taken to be 0.0132. A correction for finite angle acceptance (0.788) was included. Underlines show that the values are significantly non-zero by more than 3σ.

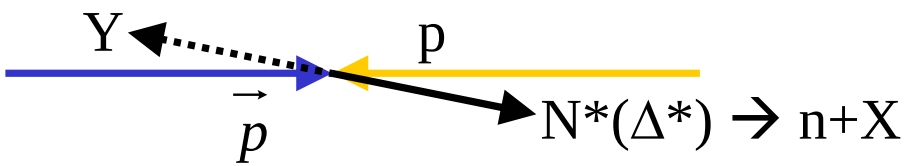
background **補正前**

non-zero values

- 前方の中性子、BBC も前方
  - $(-4.86 \pm 0.54 \pm 0.42) \times 10^{-2}$
  → 9σで有意!
- 前方 γ, 前方BBC
  - $(-1.72 \pm 0.40 \pm 0.12) \times 10^{-2}$ (background 補正前)
  - 中性子の contamination のせい？
- 前方中性子、後方BBC
  - $(2.46 \pm 0.59 \pm 0.21) \times 10^{-2}$
- 上下非対称、後方ZDCのデータはすべて0
  (cf. BBC 単独の測定では $A_N = (1.3 \pm 1.8) \times 10^{-3}$)
- 系統誤差には偏極度計のエラーは含まない
  (ZDCでの background の取り扱いと event の選び方によるもの)

議論

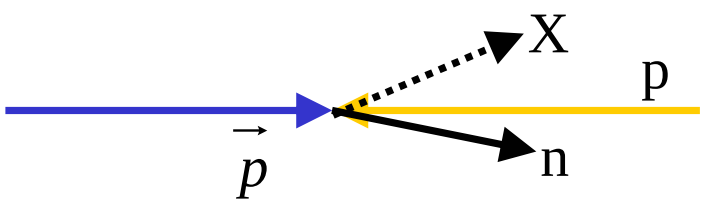
- Diffractive-like process



$A_N(X) < 0$, $A_N(Y) > 0$ → OK

ポメロン交換 ＋ spin flip amplitude (π,ρ, ... **交換**)

- kick-out/recoil picture



$A_N(X) > 0$, $A_N(Y)$?? → doesn't match

まとめと将来の展望

- 超前方の中性子を tag したときの BBC でのA_Nを求めた。
- 前方粒子に対しては、

$$A_N = (-4.86 \pm 0.54 \pm 0.42) \times 10^{-2} < 0$$

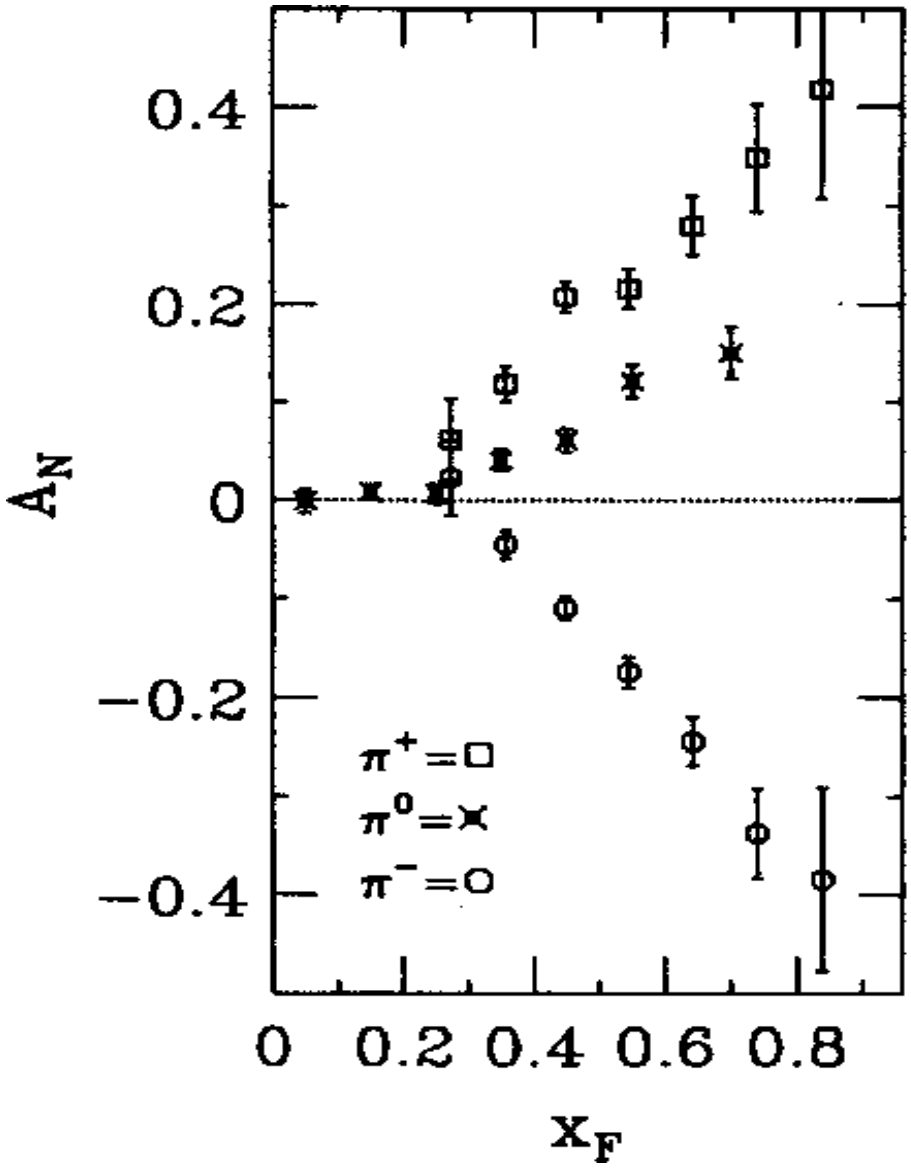
後方粒子に対しては

$$A_N = (2.46 \pm 0.59 \pm 0.21) \times 10^{-2} > 0$$

が得られた。

- これらは diffractive like な描像と定性的に一致
kickout/recoil 描像とは一致しない
- メカニズムの詳細を解明するにはきちんとした理論計算とより exclusive な測定が必要。

Supporting slides



FNAL E704

[PLB 264 (1991) 462]

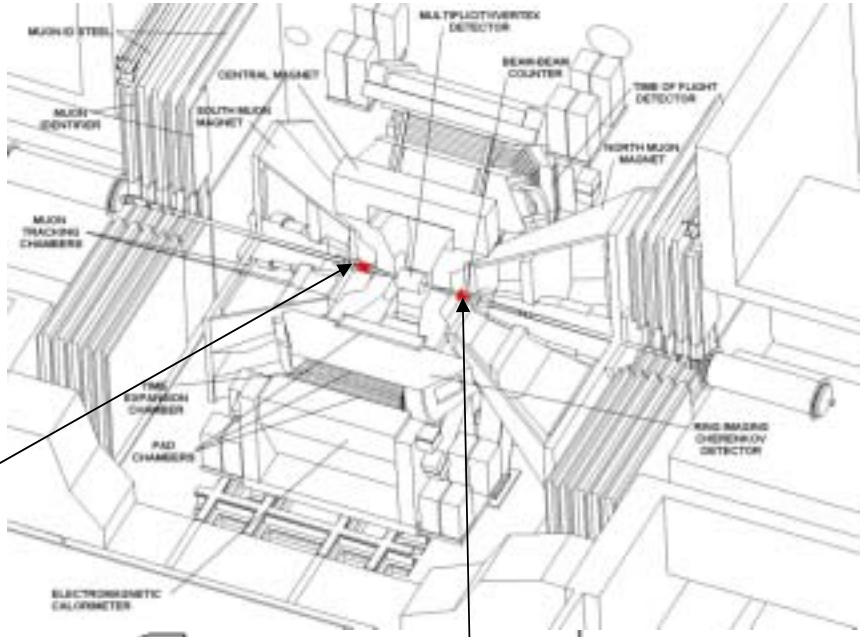
@ $s^{1/2} = 20$ GeV

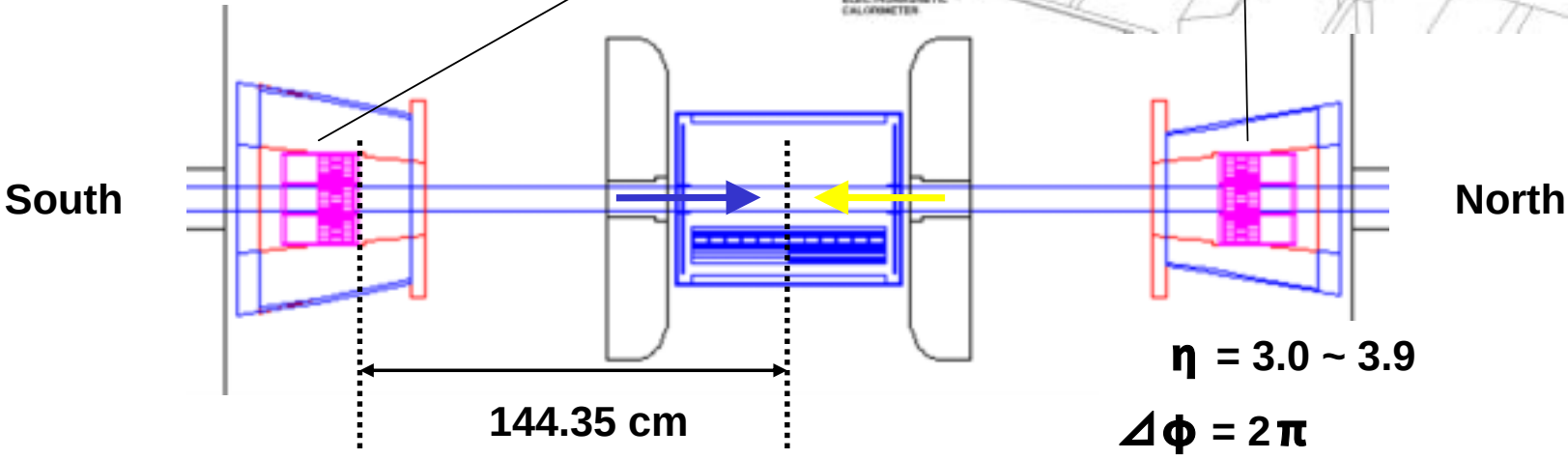
$(0.5 < p_t < 2.0$ GeV/c$)$

前方で大きな
A_Nを観測

PHENIX BBC

- Cherenkov counter (quartz, n~1.4)
- 64 segment **ずつ**
- PID**能力なし**

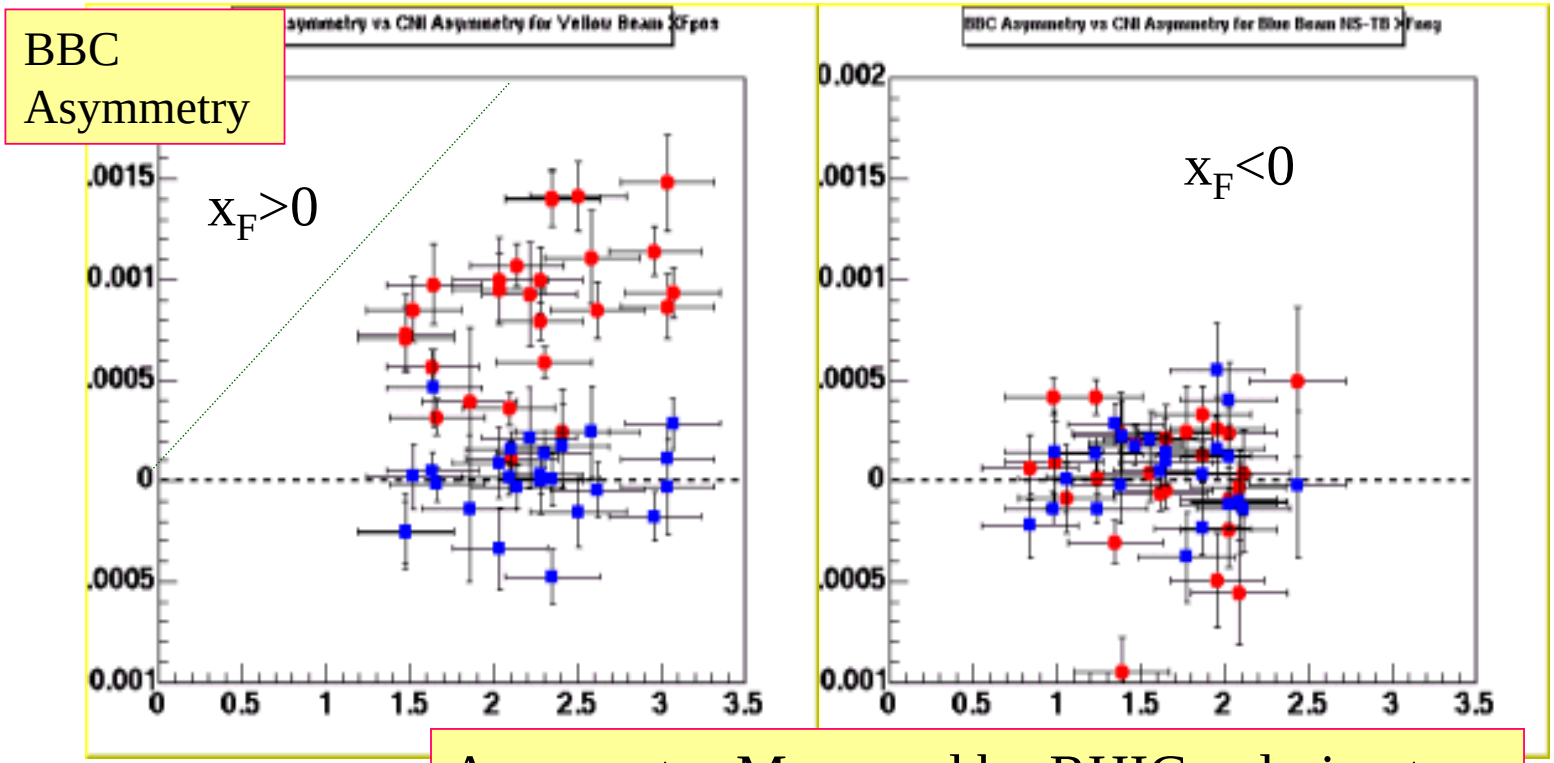




STAR BBC

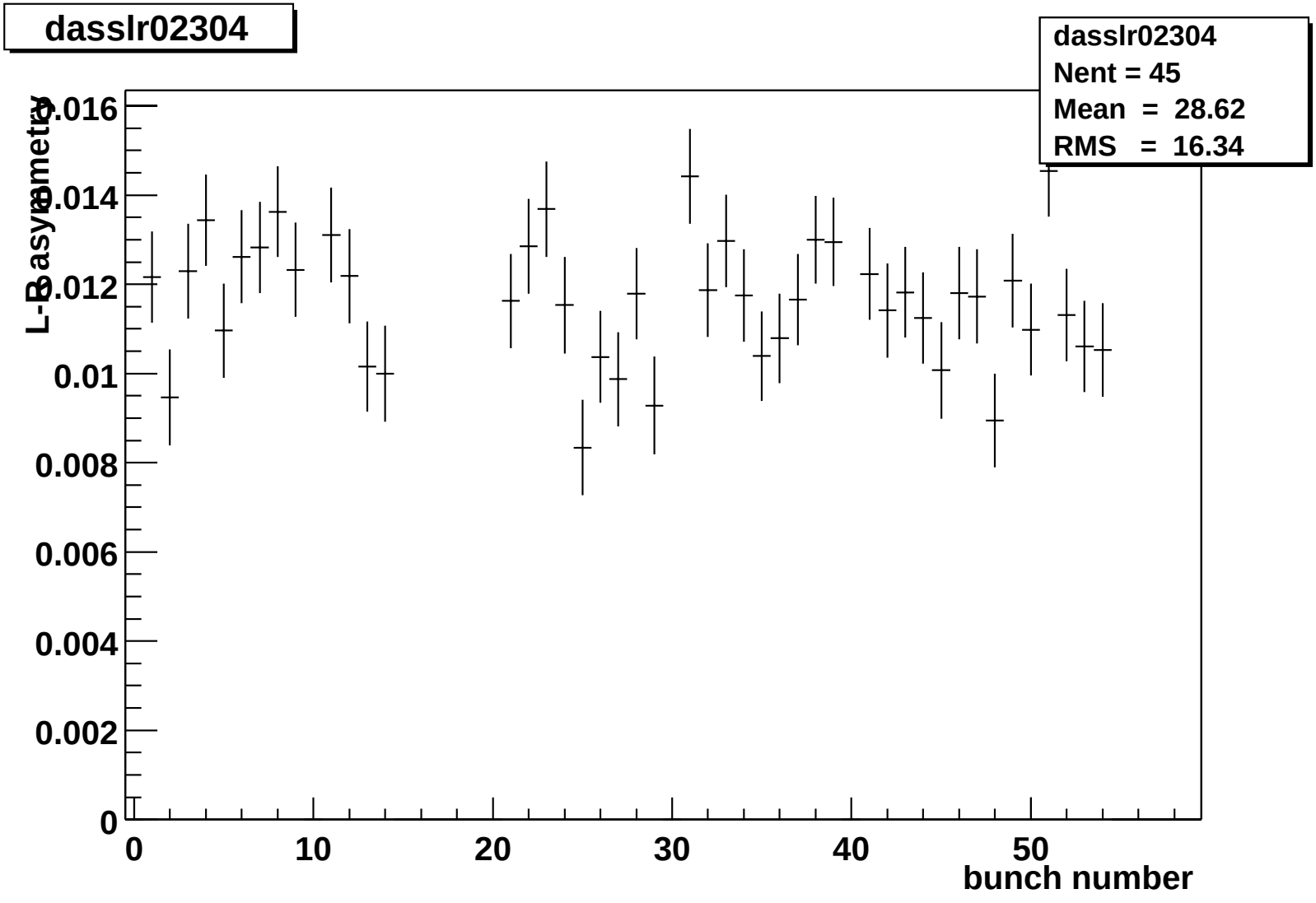
π^+ と π^- でキャンセルするために小さい?

(STAR preliminary @SPIN2002)



Asymmetry Measured by RHIC polarimeter

crossing by crossing LR asymmetry (fill 2304, north)



Coupling of A_B and A_Y

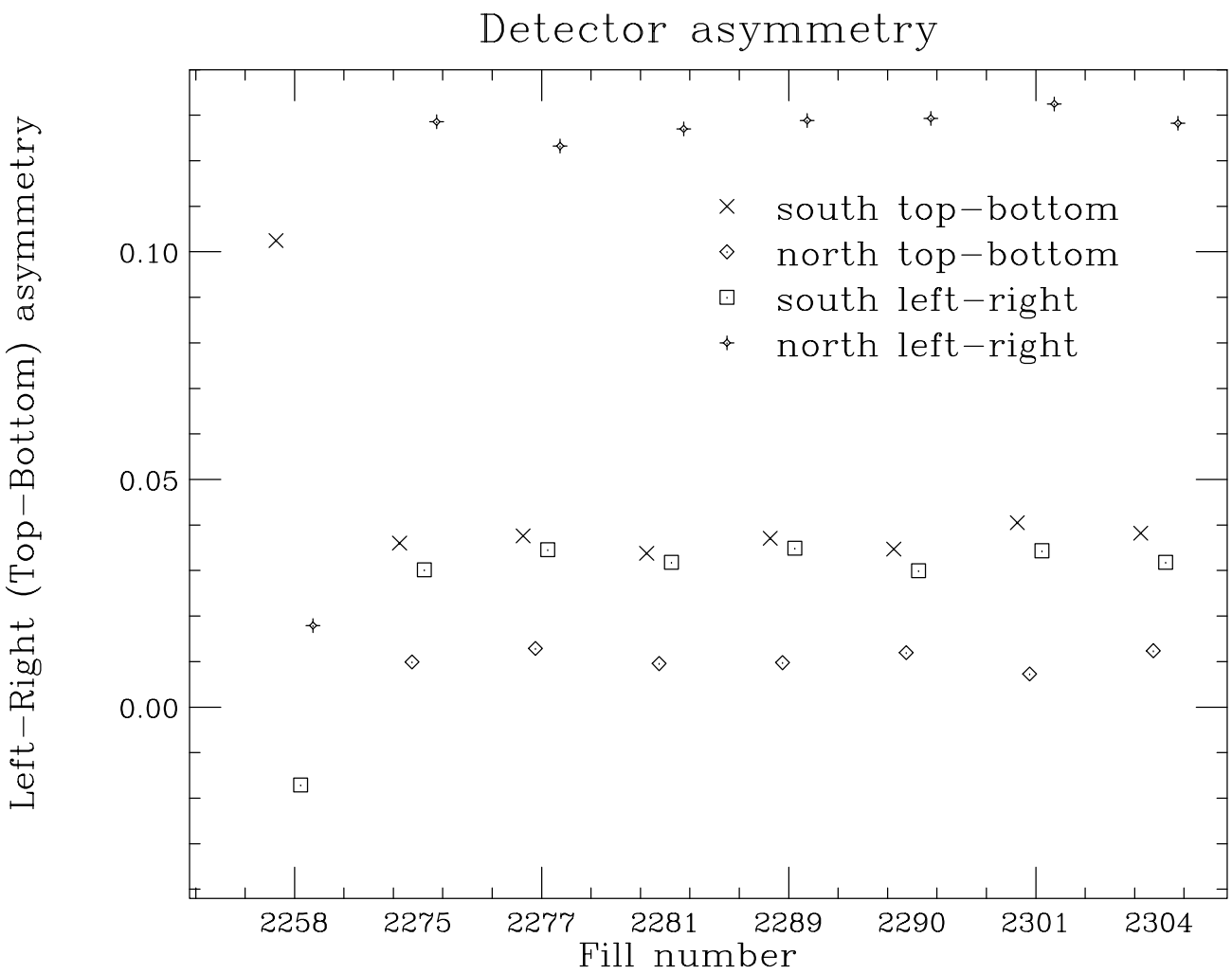
- ***M*** has off-diagonal elements (luminosity asymmetry)
  → A_B and A_Y couples
- Effects of off-diagonal elements (at leading order):

$$\Delta D \sim -(A_B\langle P_B\rangle + A_Y\langle P_Y\rangle)/\langle 1\rangle$$

$$\Delta A_B \sim -(D\langle P_B\rangle + A_Y\langle P_B P_Y\rangle)/\langle P_B^2\rangle$$

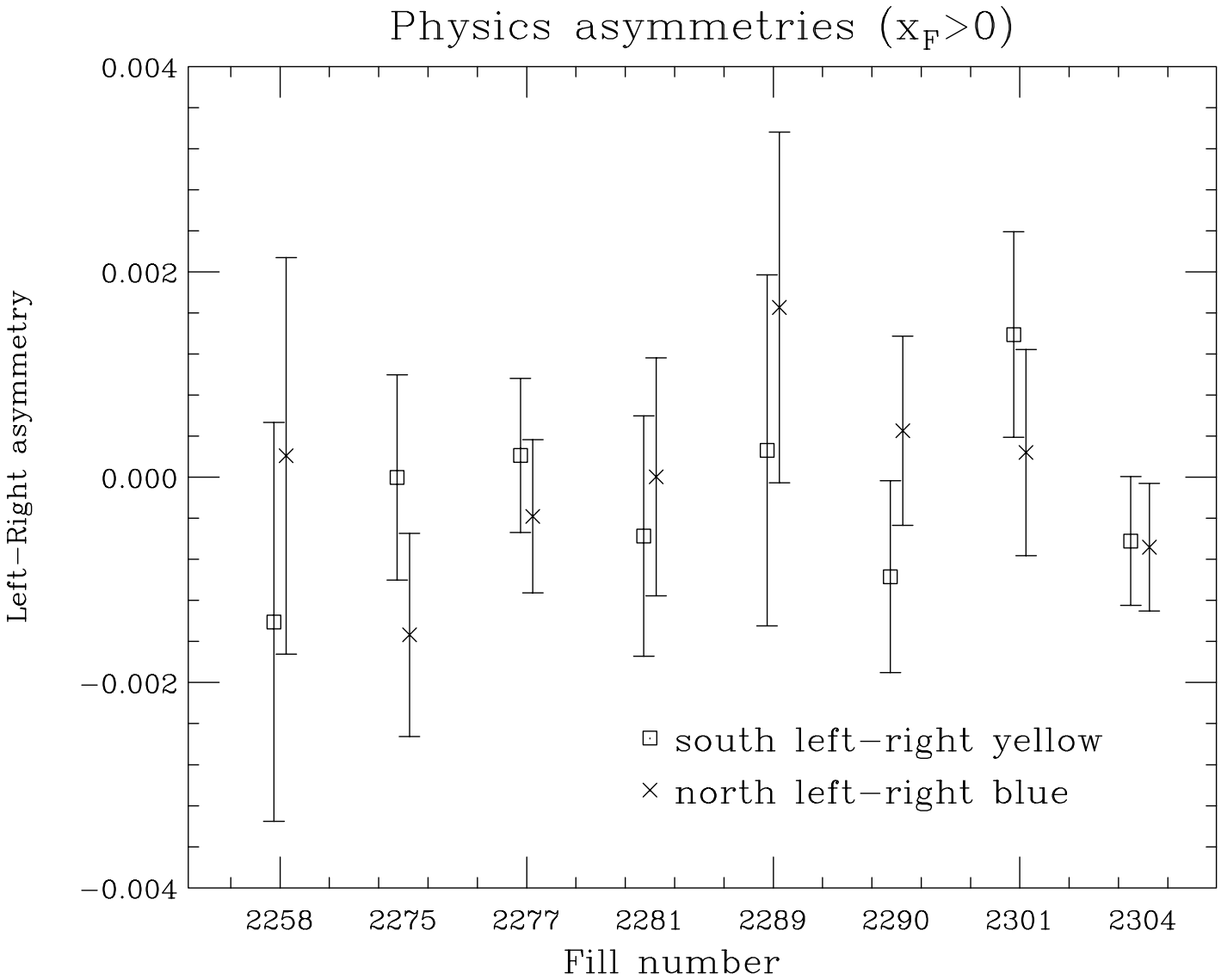
$$\Delta A_Y \sim -(D\langle P_Y\rangle + A_B\langle P_B P_Y\rangle)/\langle P_Y^2\rangle$$

  - second order
  - sqrt formula does not cancel terms such as $A_B\langle P_B P_Y\rangle$
- MC simulations tell the fitting method gives correct answers, while the sqrt formula does not.

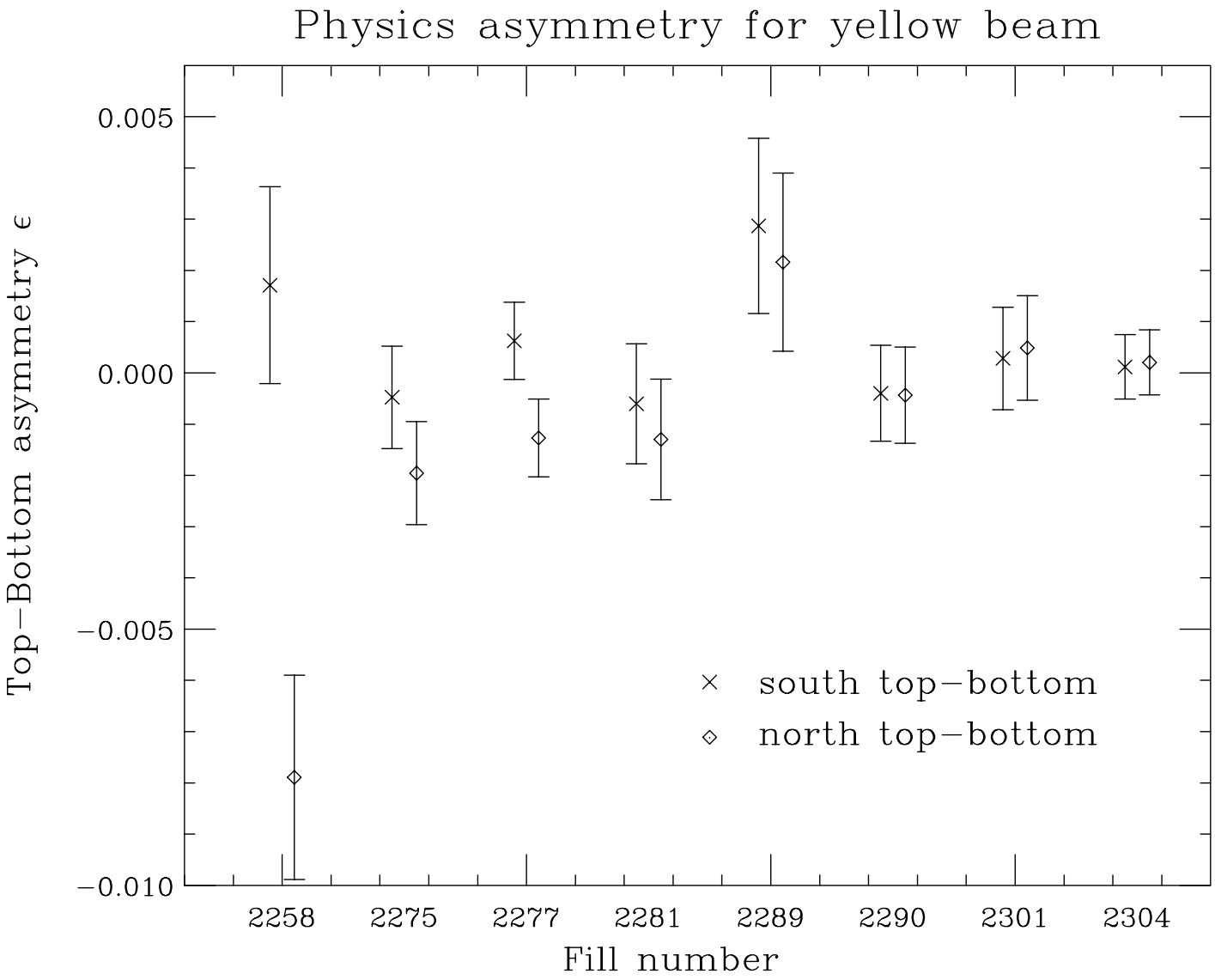


→ Detector asymmetry is resonably small

Check of ε_B(yellow)=ε_Y(blue)



Top-bottom asymmetry for exclusive counting



Systematic errors

- polarization measurement error:
  - unknown yet, but does not change $A/\delta A$.
  - ε is free from this. So, we show both A and ε.
- bunch-by-bunch polarization fluctuation:
  - effect is negligibly small for $A \sim 0$.
- Other systematic errors:
  - no evidence seen ($\chi^2/\mathrm{dof} \sim 1$)
  - probably negligible compared to statistical error.

  → We don't assign any systematic error other than coming from polarization measurement.

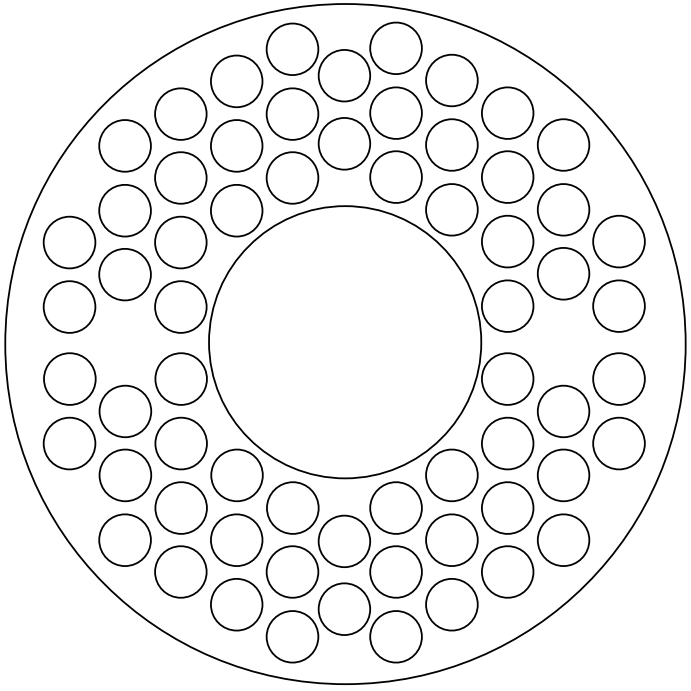
Comparison with sqrt formula

- In the present case, bunch fitting method gave the same result as sqrt formula down to $O(10^{-5})$
- Systematic deviation of sqrt formula
  - $\Delta A_B \sim A_Y \langle P_B P_Y \rangle / \langle P_B^2 \rangle$
  - $A_Y \sim 10^{-3}$
  - $\langle P_B P_Y \rangle / \langle P_B^2 \rangle \sim 10^{-2}$

  → $\Delta A_B \sim 10^{-5}$: small enough
- Systematic deviation of linear approximation.
  - $\Delta A_B / A_B$: $D(A_B P_B + A_Y P_Y) \sim 10^{-4}$

    i.e., $\Delta A_B \sim 10^{-3} \times 10^{-4} = 10^{-7}$

  → negligible

議論

- E704 との比較
  - π^+ と π^- では A_N の符号が反対.
  → BBC での測定では互いにキャンセル
  - x_f → 大で A_N → 大
  <=> BBC では x_f は測定していない。
  小さな x_f のイベントが dominate
  → 特に矛盾はない
- より前方の STAR BBC ($3.4 < \eta < 5.0$)では、
  $\varepsilon \sim 0.001$ ($A_N \sim 0.005$) が観測されたという
  preliminary な報告が SPIN2002 であった。
  → より前方では $N(\pi^+) > N(\pi^-)$ のためか？