p0 A_{LL} results from pp Run3:

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Nothing but Data

Data set

Data collected with high p_T photon trigger

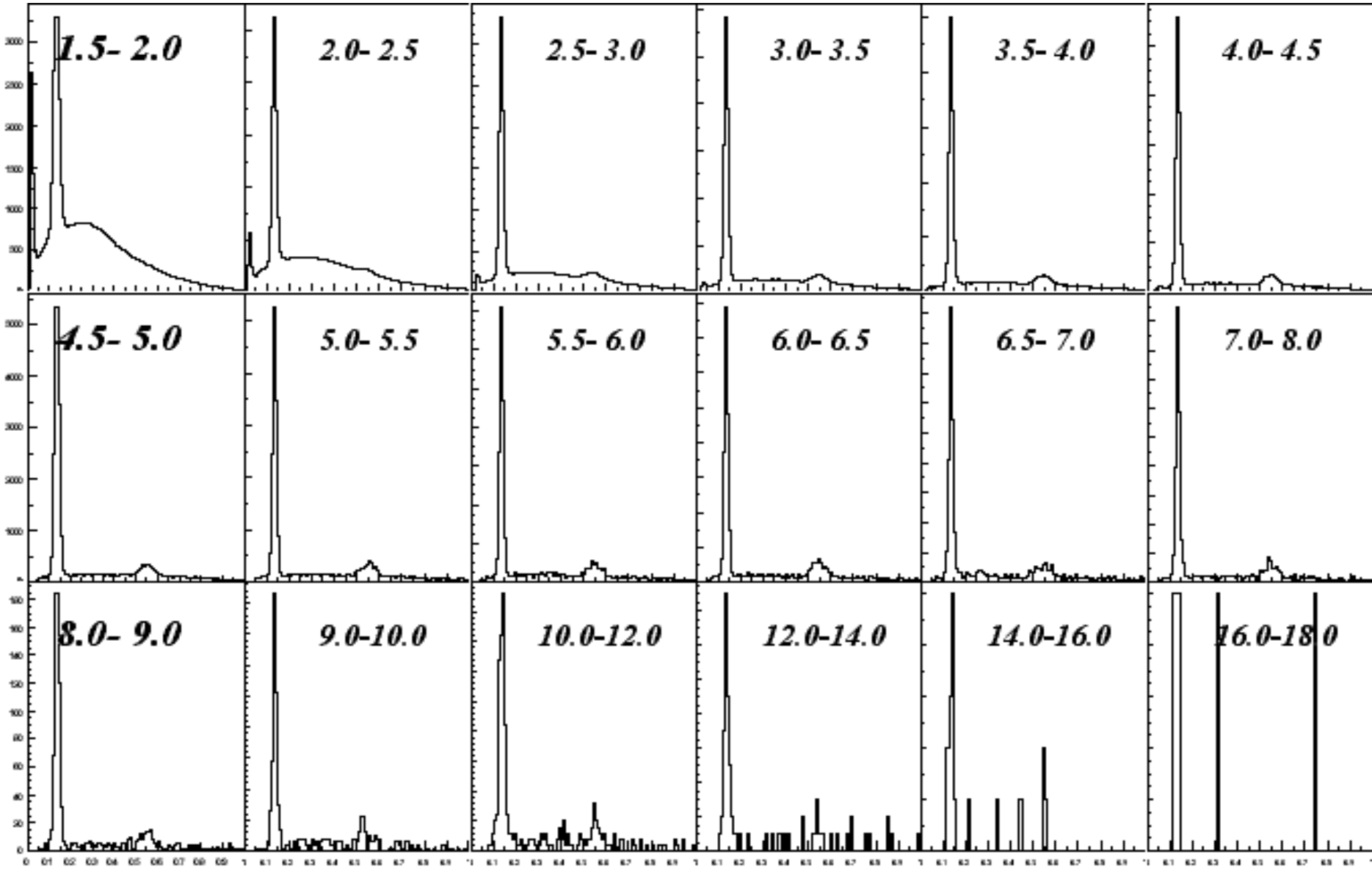
- Based on EMCal; Threshold ~1.4 GeV/c
- Rejection factor ~110
- Analyzed data sample: **42.7M events (~0.215 pb^{-1})**

  sqrt(<$P_b P_y$>)~26%

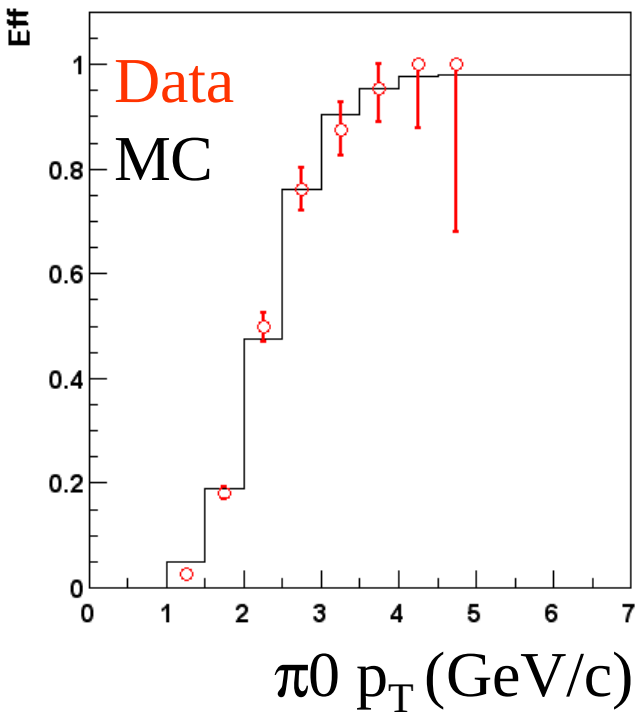
Minimum Bias data

- To obtain "unbiased" $\pi 0$ cross section at low p_T
- For high p_T photon trigger efficiency study

s_{p0}: Pi0 reconstruction



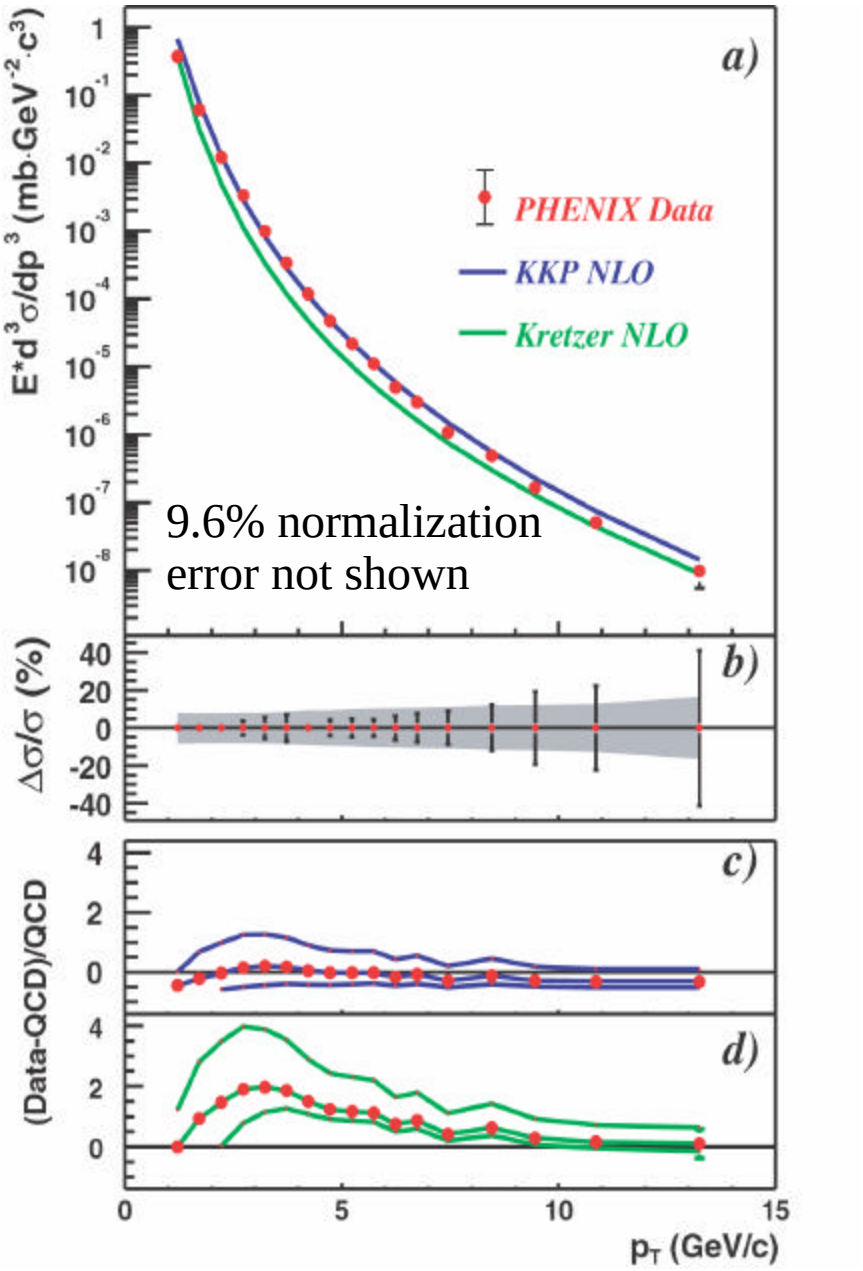
Photon trigger efficiency for p0



- ✓ Pi0 efficiency plateaus for p_T>4 GeV/c
- ✓ Limitted efficiency at p_T<4 GeV/c:
  - 1-2 GeV/c: 6%
  - 2-3 GeV/c: 60%
  - 3-4 GeV/c: 90%
  - 4-5 GeV/c: 95%
- ✓ Monte Carlo reproduces Data well

p0 Cross section

Run-2 results



- Results consistent with pQCD calculation
- Favours a larger gluon-to-pion FF (KKP)
- Run3 results reproduces Run2 results
  - ✓ Confirms the Run-3 data reliability and consistency
  - ✓ Run3 data reaches even higher p_Ts; results will be finalized soon

A_{LL}

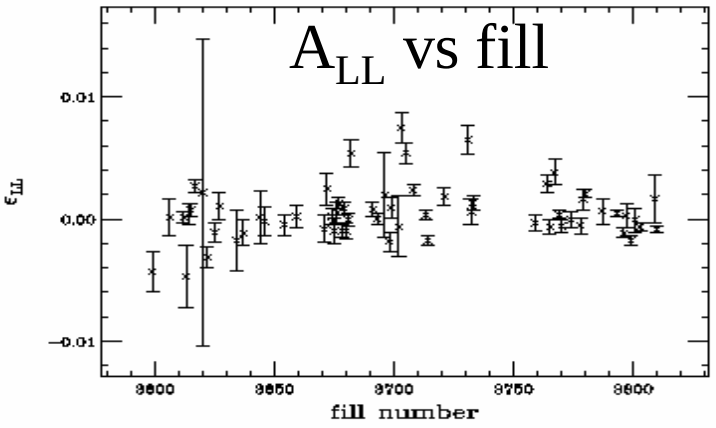
$$A_{LL} = \frac{s_{++} - s_{+-}}{s_{++} + s_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}$$

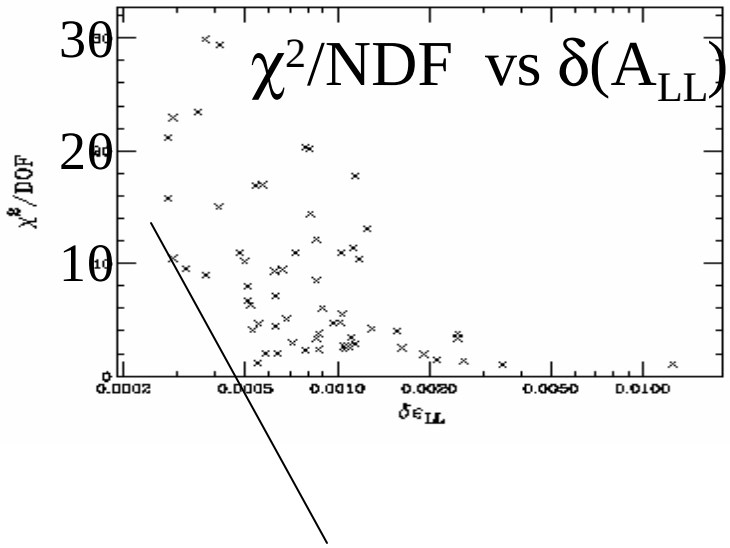
++ same helicity
+– opposite helicity

(L) Relative Luminosity
(P) Polarization
(N) Number of pi0s

Relative Luminosity

- Special GL1P scalers used
  - ✓ Counts live trigger in each bunch crossing
  - ✓ 4 inputs (detectors) – for syst. error study
- Systematic error study through comparison of counts from different detectors
  - look at ratio of 2 detector scalers crossing-by-crossing:
    - $a(i) = N_A(i)/N_B(i)$
  - Ratio should be the same for all crossings (constant) if:
    - $N_A(i) = L * e_A$ and $N_B(i) = L * e_B$
  - B is always the counts from the beam-beam counter (BBCLL1), A is one of the other scalers.
  - Fit this by the expected pattern:
    - $a(i) = C[1+A_{LL}P_1(i)P_2(i)]$
    - C, A_{LL} are the fitting parameters.
  - χ^2 is a very important check of systematic errors



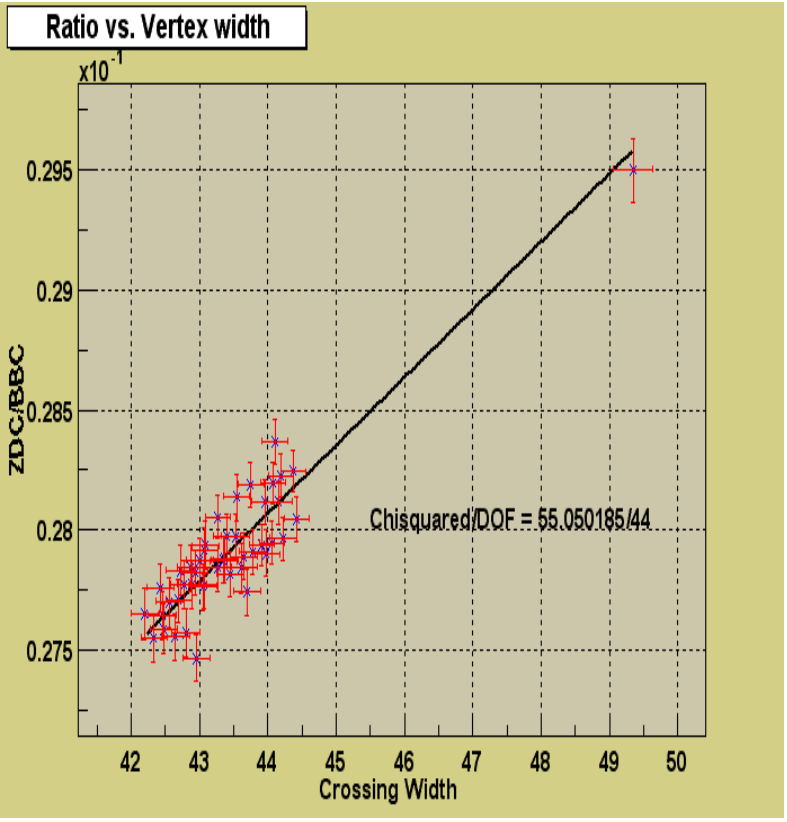


Not so good … so far, but …

Relative Luminosity

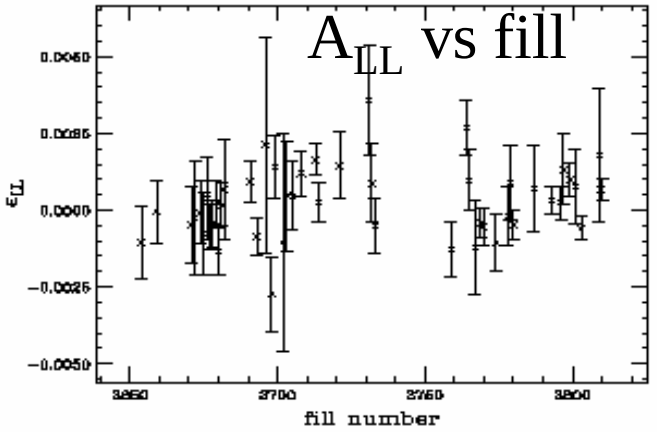
Vertex width affects
Rel. Lum. measurements

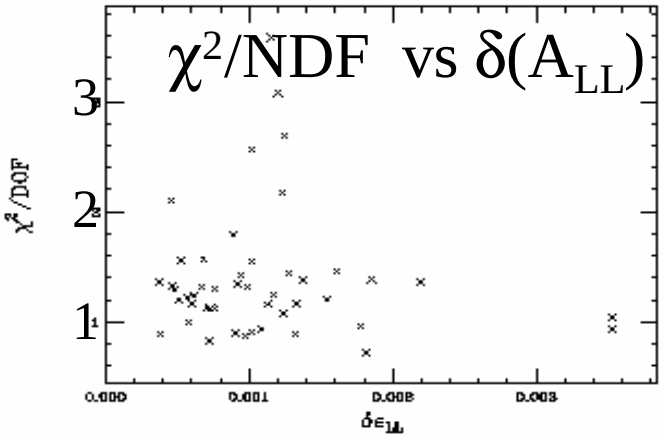
ZDC/BBC vs z-vertex width



⇒

After vertex correction





Now χ^2/NDF~1

Relative Luminosity: Results

Achieved relative luminosity precision $\delta R = 2.5 \cdot 10^{-4}$

- Pessimistic estimation limited by ZDC statistics (30 times less than BBC statistics used in Rel. Lum. measurements)

Rel. Lum. contribution for pi0 A_{LL} less than 0.2%

- For average beam polarizations of 26%

A_{LL} of BBC relative to ZDC consistent with 0

- Strong indication that both A_{LL}s are zero (very different kinematical regions)

Beam Polarization

Spin direction confirmation

- ✓ With Spin Rotators and PHENIX Local Polarimeter
- ✓ Confirmed

Long. component of the spin direction

- ✓ PHENIX Local Polarimeter

Absolute polarization scale

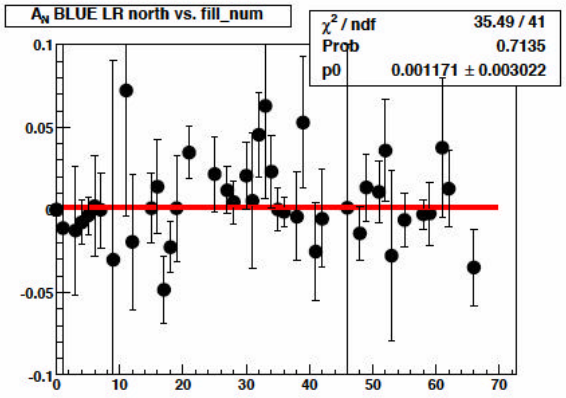
- ✓ With RHIC CNI polarimeter
- ✓ Estimated to be ~30%
- ✓ This error does not change the significance of non-zero A_{LL}, because it scales both value and error in the same way (but it does change the comparison to theory)

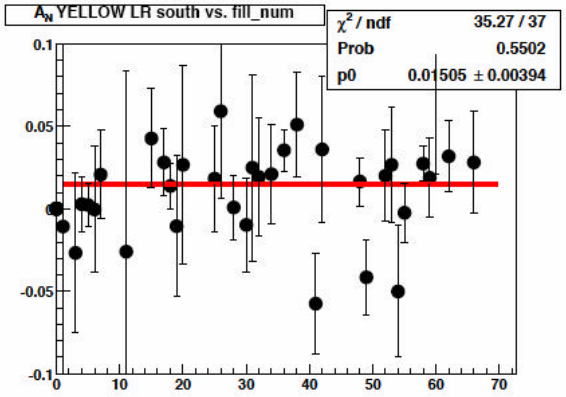
Spin Long. Component

$$S_L = \sqrt{1 - S_T^2}, \qquad S_T = \sqrt{S_{T-vertical}^2 + S_{T-radial}^2}$$

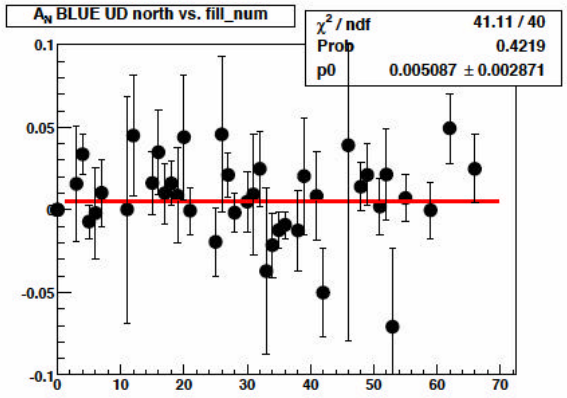
S_T is measured with PHENIX Local Polarimeter

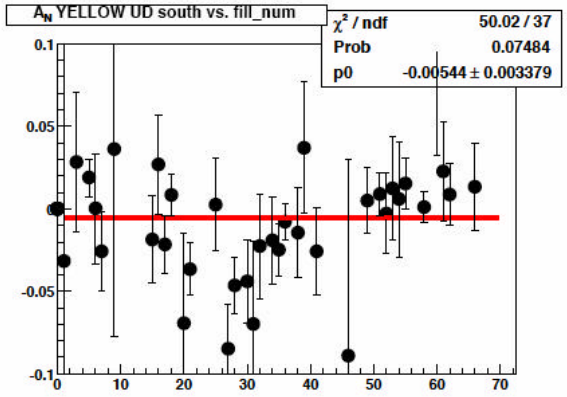
Left-Right asymmetry





Up-Down asymmetry

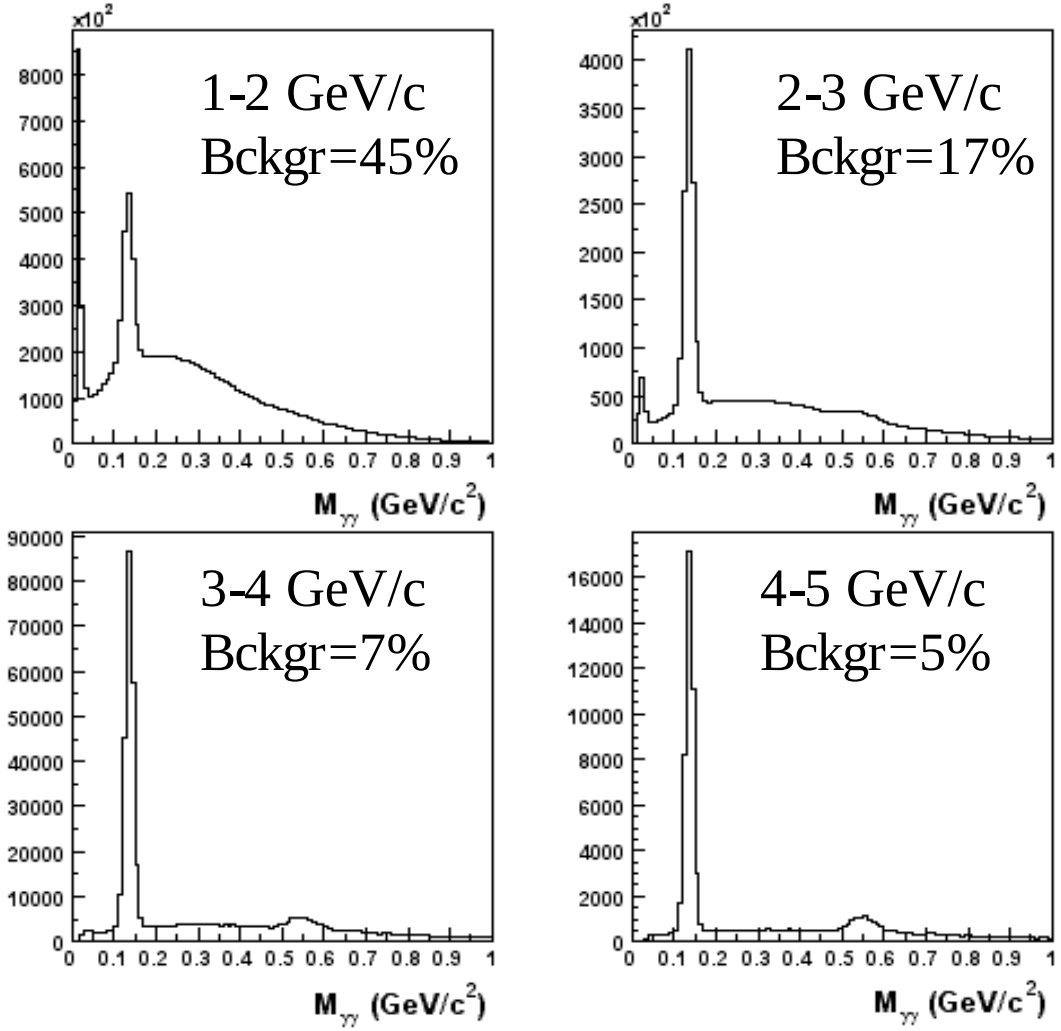




$$p_L(blue) = 99.3^{+0.5\ +0.0}_{-1.4\ -0.9}$$

$$p_L(yellow) = 97.4^{+1.3\ +0.1}_{-3.2\ -0.9}$$

A_{LL}: Pi0 reconstruction

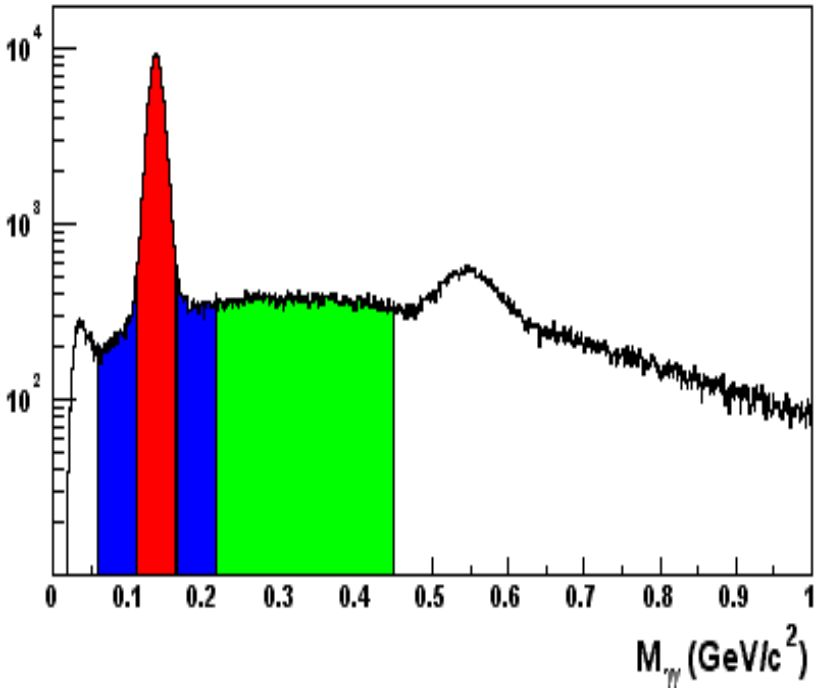


Results obtained for four pt bins from 1 to 5 GeV/c

Pi0 peak width varies from 12 to 9.5 MeV/c^2 from lowest to highest pt bins

Background contribution under pi0 peak for ±25 MeV/c^2 mass cut varies from 45% to 5% from lowest to highest pt bins

Pi0 counting for A_{LL}



N_{p0}:

±25 MeV/c² around *p0* peak (and also ±15 and ±35 MeV/c² for cross checks)

N_{bck1}:

Two 50 MeV/c² wide areas adjacent to *p0* peak

N_{bck2}:

250 MeV/c² wide area between *p0* and *h* peaks

$N_{\pi 0}$ and N_{bck} accumulated statistics

pt GeV/c	$N_{\pi 0}$ 15 MeV/c²	$N_{\pi 0}$ 25 MeV/c²	$N_{\pi 0}$ 35 MeV/c²	N_{bck1}	N_{bck2}
1-2	1278k	1777k	2129k	1470k	3478k
2-3	874k	1059k	1146k	335k	989k
3-4	176k	201k	208k	27k	83k
4-5	34k	38k	39k	3.9k	12k

A_{LL} measurements

$$A_{LL} = \frac{s_{++} - s_{+-}}{s_{++} + s_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}, \quad d_{A_{LL}} = \frac{1}{|P_B P_Y|} \frac{1}{\sqrt{N_{++} + N_{+-}}}$$

++ same helicity
+– opposite helicity

Luminosity approach

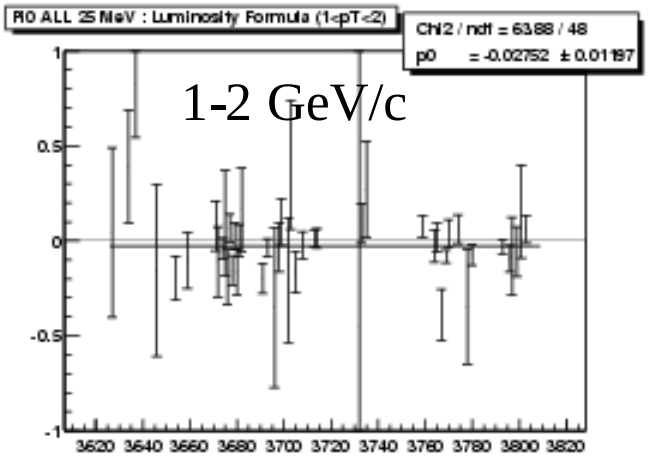
1. Collect *N* and *L* for ++ and +– configurations (sum over all crossings) and calculate A_{LL} for each fill
2. Average A_{LL} over fills; use χ^2/NDF to control fit quality; use "bunch shuffling" to check syst. errors

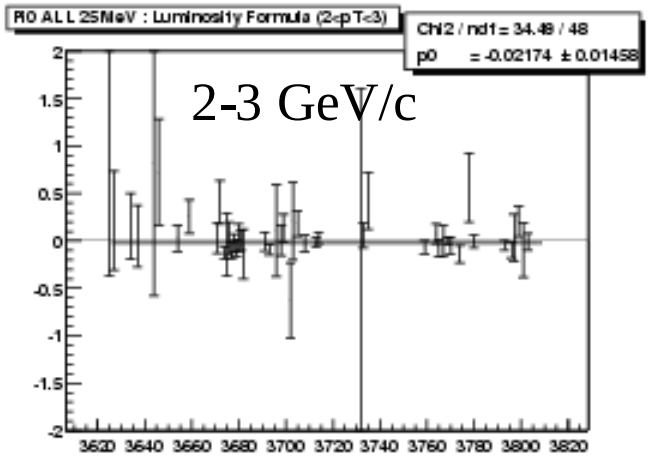
Bunch fitting approach (just for consistency check)

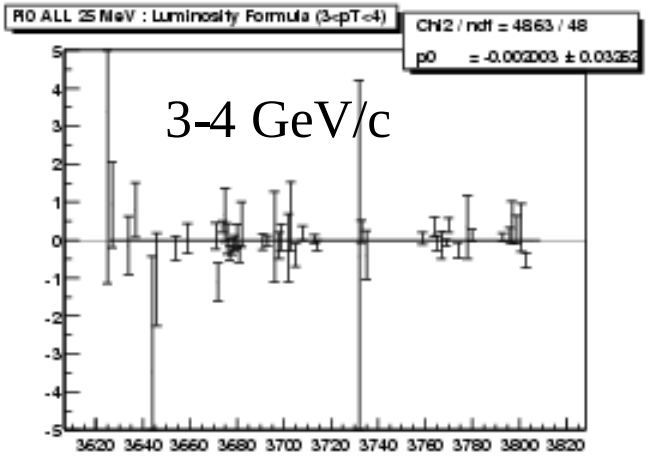
1. Collect *N* and *L* for each crossing *i* and fit A_{LL} from $N(i)/L(i)=C\{1+A_{LL}P_B(i)P_Y(i)\}$ for each fill; use χ^2/NDF to control fit quality
2. Average A_{LL} over fills ; use χ^2/NDF to control fit quality; use "bunch shuffling" to use bunch shuffling to check syst. errors

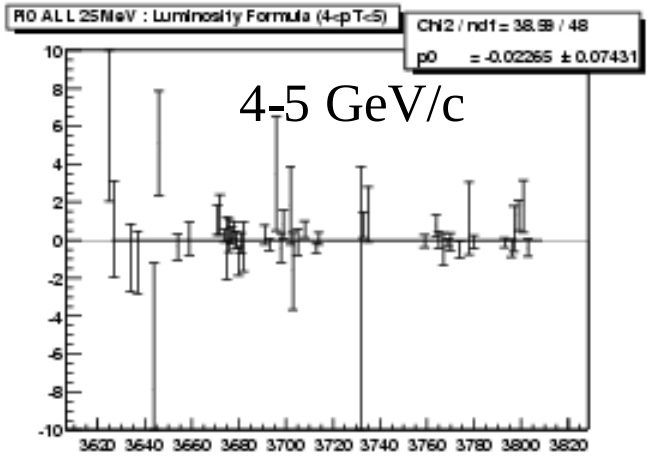
Luminosity approach

A_{LL} averaged over fills









1-2 GeV/c

A_{LL} = -2.8%±1.2%

χ^2/ndf = 64/48

2-3 GeV/c

A_{LL} = -2.2%±1.5%

χ^2/ndf = 34/48

3-4 GeV/c

A_{LL} = -0.2%±3.3%

χ^2/ndf = 49/48

4-5 GeV/c

A_{LL} = -2.3%±7.4%

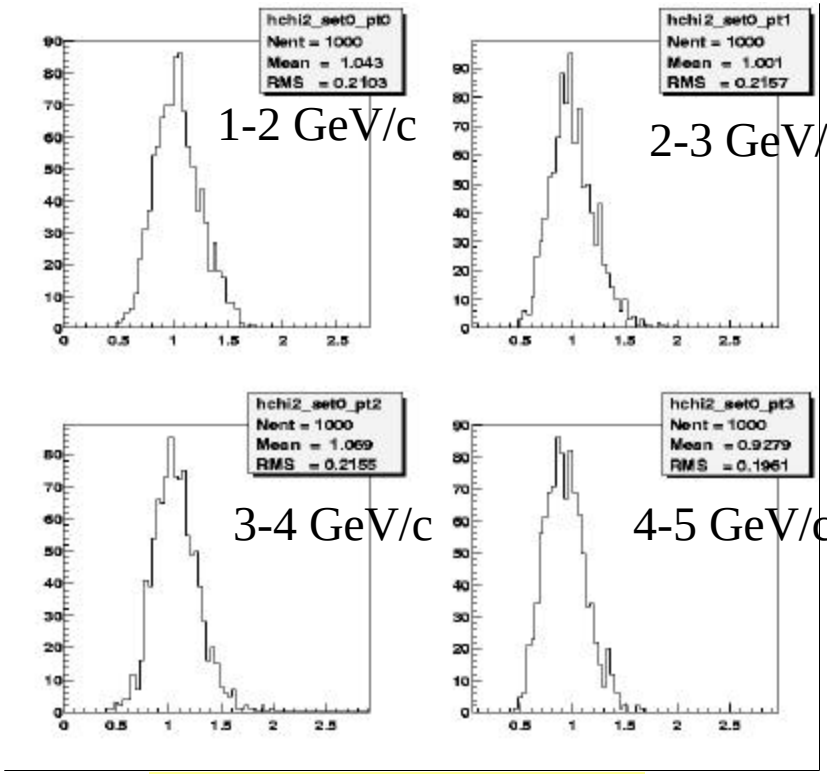
χ^2/ndf = 39/48

Bunch shuffling

to check for syst. errors

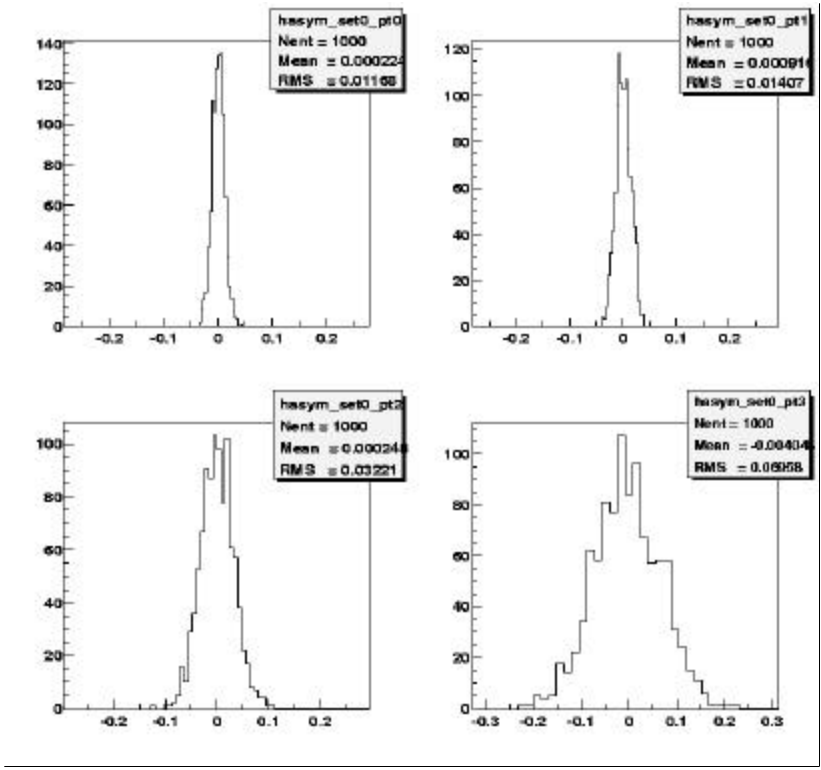
Bunch shuffling = Randomly assigns helicity for each crossing

χ^2/NDF



All $<\chi^2/NDF>$ are ~1

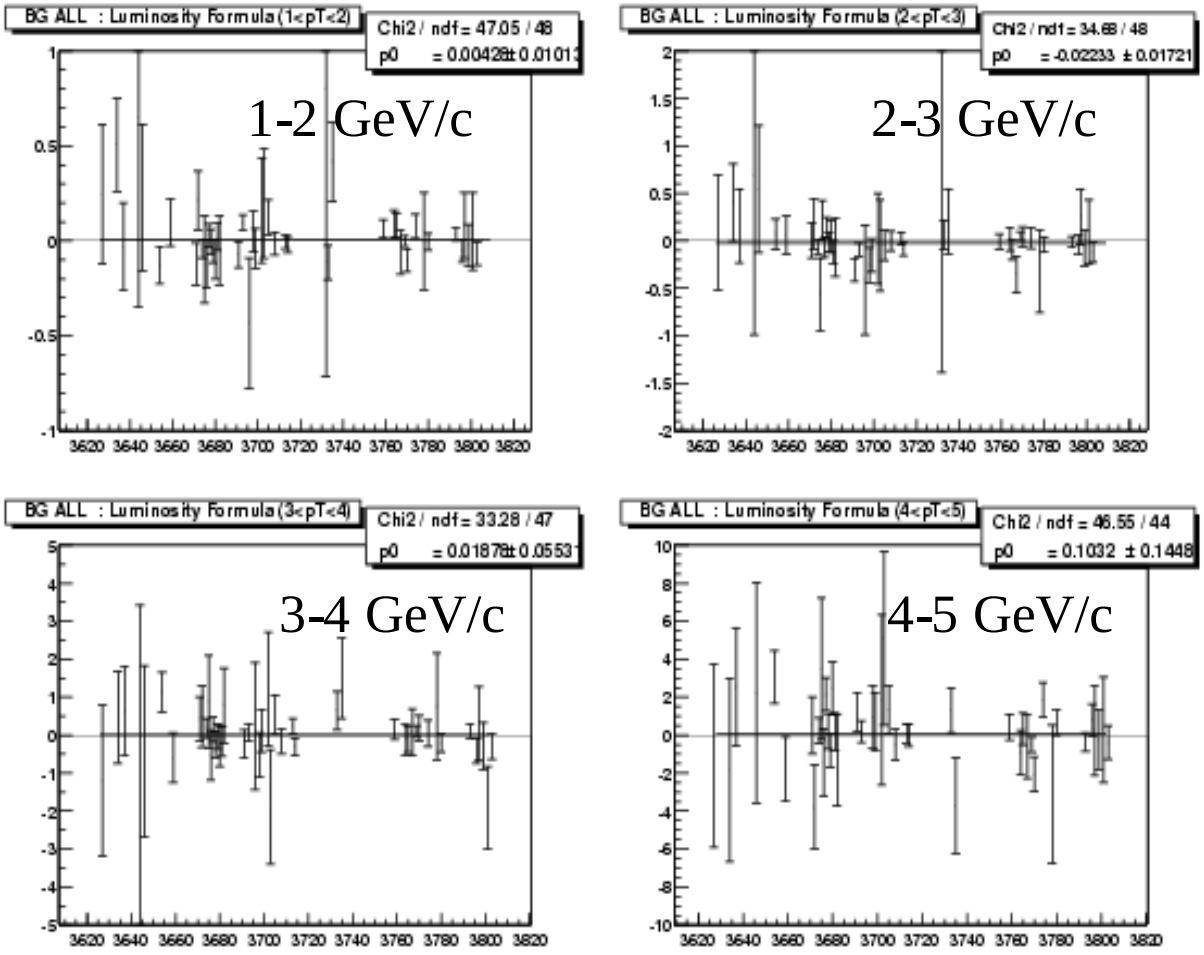
A_{LL}



Widths are consistent with obtained errors $\delta(A_{LL})$

Luminosity approach: background

A_{LL} averaged over fills



1-2 GeV/c

A_{LL} = 0.4%±1.0%

χ^2/ndf = 47/48

$\langle\chi^2/ndf\rangle$ = 48/48

2-3 GeV/c

A_{LL} = -2.2%±1.7%

χ^2/ndf = 35/48

$\langle\chi^2/ndf\rangle$ = 50/48

3-4 GeV/c

A_{LL} = 1.9%±5.5%

χ^2/ndf = 33/47

$\langle\chi^2/ndf\rangle$ = 45/47

4-5 GeV/c

A_{LL} = 10%±14%

χ^2/ndf = 47/44

$\langle\chi^2/ndf\rangle$ = 41/44

A_{LL} results

A_{LL} (%) and $<\chi^2/NDF>$

pt GeV/c	$N_{\pi 0}$ 15 MeV/c^2	$N_{\pi 0}$ 25 MeV/c^2	$N_{\pi 0}$ 35 MeV/c^2	N_{bck1}	N_{bck2}
1-2	-2.3±1.4 1.02	-2.8±1.2 1.04	-2.4±1.1 1.03	-0.6±1.4 0.99	0.4±1.0 0.99
2-3	-2.7±1.6 0.99	-2.2±1.5 1.01	-2.2±1.4 1.03	-3.5±2.7 1.01	-2.2±1.7 1.05
3-4	-1.7±3.5 1.08	-0.2±3.3 1.07	-0.1±3.2 1.06	9.4±9.2 0.96	1.9±5.5 0.95
4-5	-1.4±7.9 0.99	-2.3±7.4 0.90	-1.3±7.3 0.93	38±24 0.94	10±14 0.94

A_{LL} results: plots

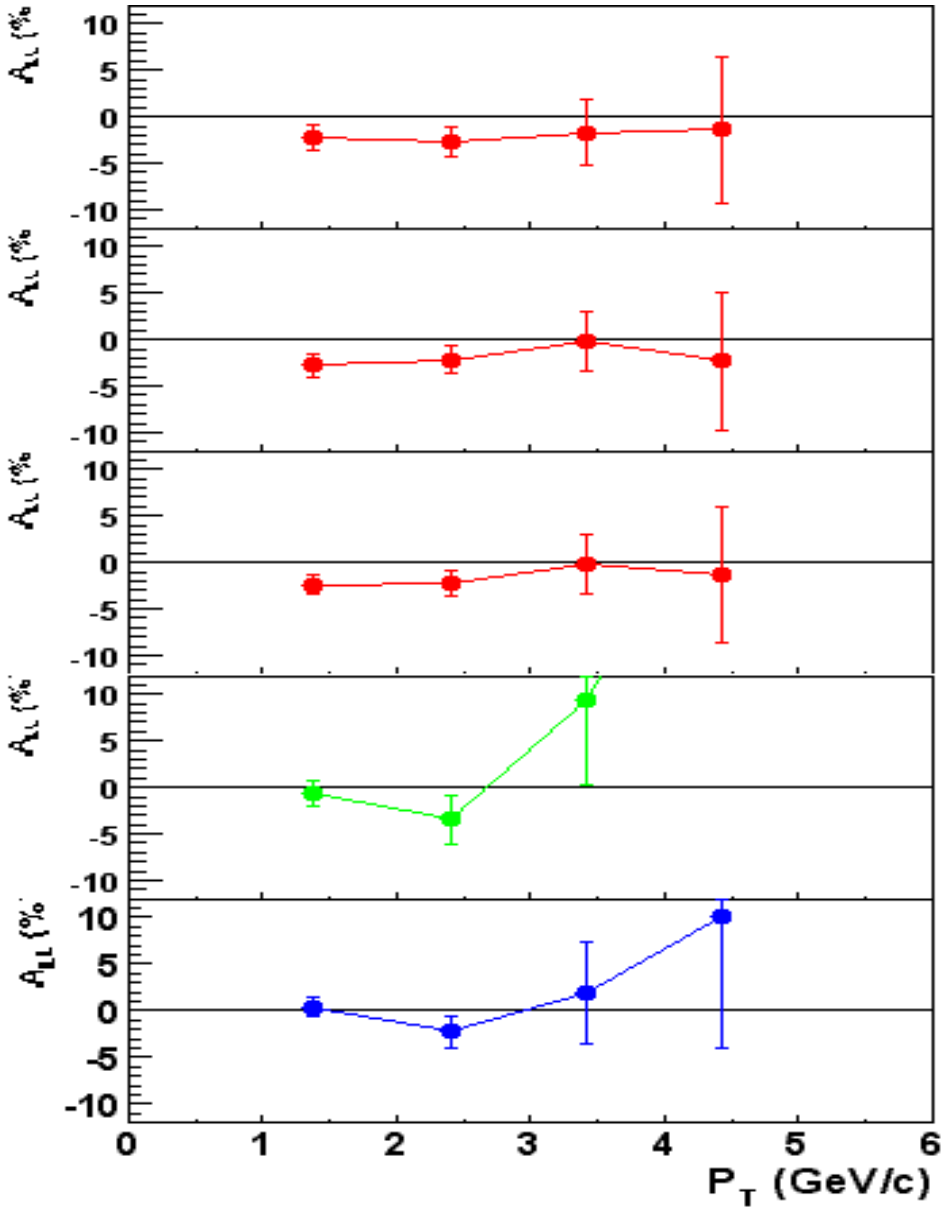
$N_{\pi 0}$ 15 MeV/c^2

$N_{\pi 0}$ 25 MeV/c^2

$N_{\pi 0}$ 35 MeV/c^2

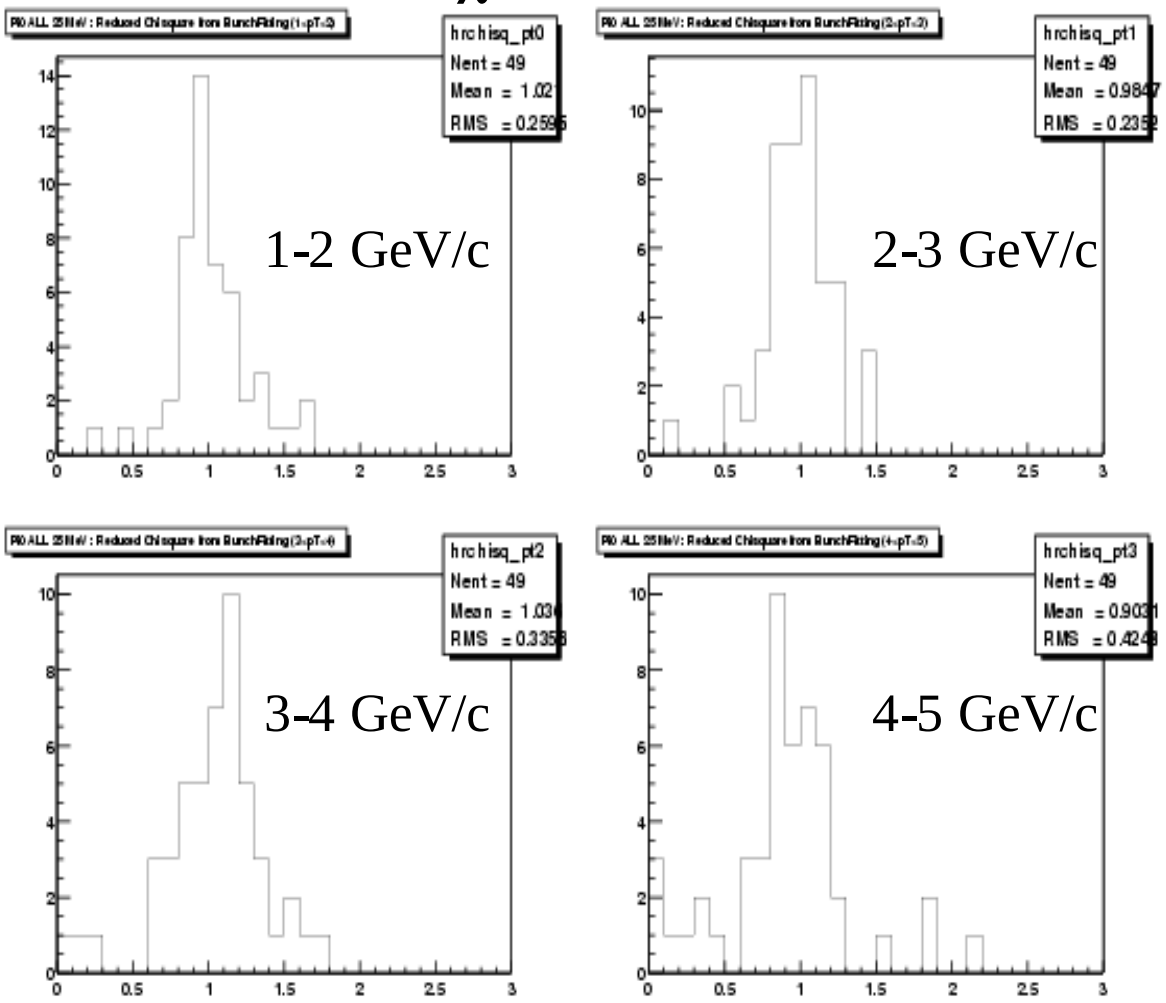
Bck1

Bck2



Bunch fitting approach

χ^2/NDF

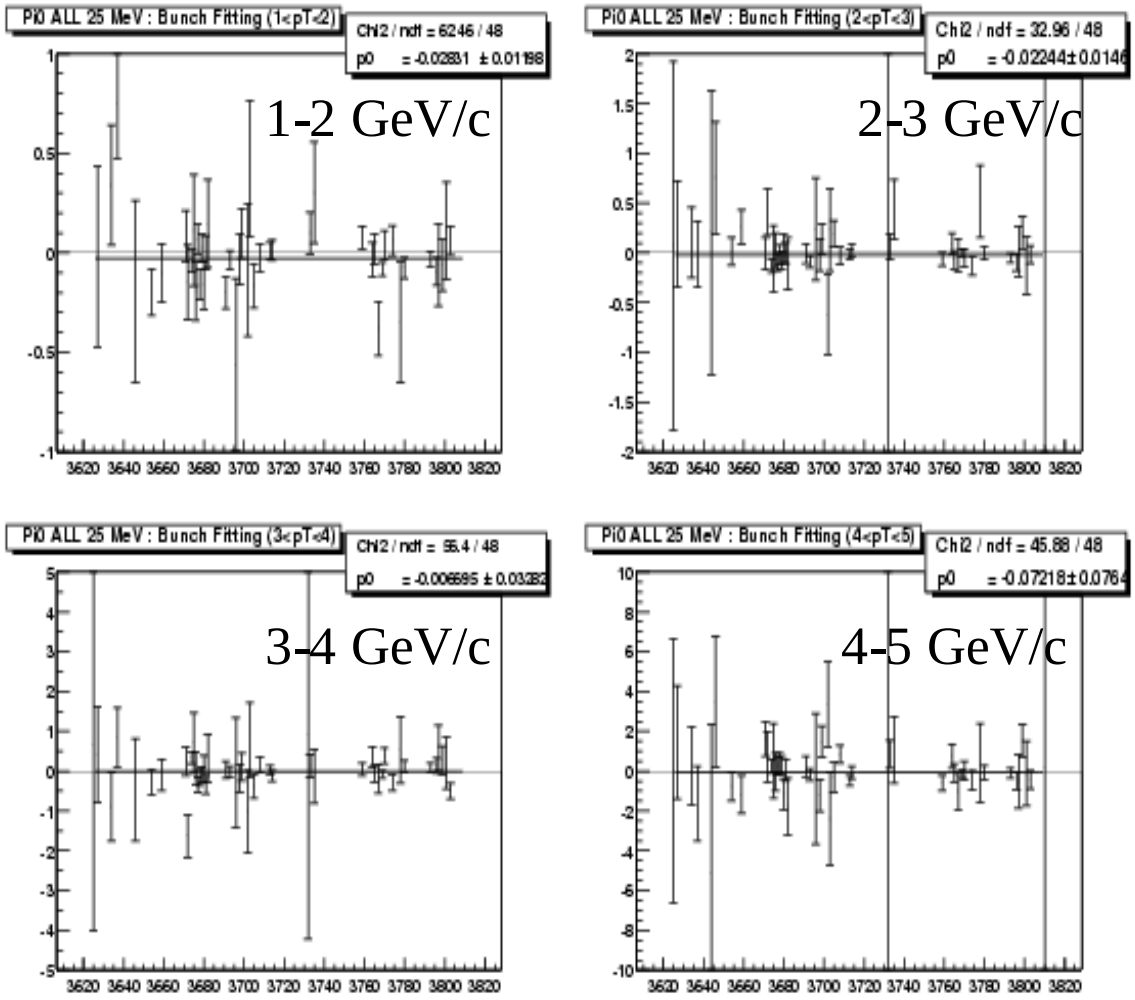


χ^2/NDF from bunch fitting for each fill

All χ^2/NDF ~ 1 => no problem seen within fills

A_{LL} from bunch fitting

A_{LL} averaged over fills



1-2 GeV/c

A_{LL}= -2.8%±1.2%

χ^2/ndf = 62/48

$\langle\chi^2/ndf\rangle$ = 51/48

2-3 GeV/c

A_{LL}= -2.2%±1.5%

χ^2/ndf = 35/48

$\langle\chi^2/ndf\rangle$ = 48/48

3-4 GeV/c

A_{LL}= -0.7%±3.3%

χ^2/ndf = 56/48

$\langle\chi^2/ndf\rangle$ = 56/48

4-5 GeV/c

A_{LL}= -7.2%±7.6%

χ^2/ndf = 46/48

$\langle\chi^2/ndf\rangle$ = 56/48

Luminosity vs bunch fitting

pt GeV/c	$N_{\pi 0}$ Bunch fit	$N_{\pi 0}$ Luminosity
1-2	-2.8±1.2 1.06	-2.8±1.2 1.04
2-3	-2.2±1.5 0.99	-2.2±1.5 1.01
3-4	-0.7±3.3 1.17	-0.2±3.3 1.07
4-5	-7.2±7.6 1.17	-2.3±7.4 0.90

- ✓ Results are identical at lower pt bins
- ✓ Results start deviate at higher pt bins
- ✓ Pure statistical effect: too low statistics in each crossings to be used in bunch fitting
- ✓ Confirmed from simple MC: deviations may be comparable to stat. error

We use luminosity approach for final A_{LL} for all pt bins

Checks

PID check

pt GeV/c	$N_{\pi 0}$ noPID	$N_{\pi 0}$ PID
1-2	-3.1±1.0	-2.8±1.2
2-3	-1.9±1.4	-2.2±1.5
3-4	-0.4±3.2	-0.2±3.3
4-5	-3.9±7.3	-2.3±7.4

PID = Shower profile cut

The same results

++ vs −− and +− vs −+

pt GeV/c	++ vs − −	+ − vs −+
1-2	0.7±1.7	-1.3±1.7
2-3	0.2±2.1	0.5±2.1
3-4	6.1±4.6	-2.7±4.6
4-5	-8.6±10.5	-6.7±10.4

Consistent with 0 within 1.5σ

A_L check for yellow beam

$$A_{LL} = \frac{s_+ - s_-}{s_+ + s_-} = -\frac{1}{|P|}\frac{N_+/L_+ - N_-/L_-}{N_+/L_+ + N_-/L_-}$$

A_L (%)

pt GeV/c	$N_{\pi 0}$ 15 MeV/c^2	$N_{\pi 0}$ 25 MeV/c^2	$N_{\pi 0}$ 35 MeV/c^2	N_{bck1}	N_{bck2}
1-2	0.1±0.4	-0.02±0.3	-0.04±0.3	0.2±0.4	0.00±0.3
2-3	0.1±0.4	-0.03±0.4	-0.01±0.4	0.2±0.7	0.2±0.5
3-4	0.7±0.9	1.1±0.9	0.8±0.9	-3.3±2.5	-1.0±1.5
4-5	-0.1±2.1	0.4±2.0	0.8±2.0	2.0±6.4	5.0±3.9

All are zeros within 1.5σ except

A_L check for blue beam

$$A_{LL} = \frac{s_+ - s_-}{s_+ + s_-} = -\frac{1}{|P|}\frac{N_+/L_+ - N_-/L_-}{N_+/L_+ + N_-/L_-}$$

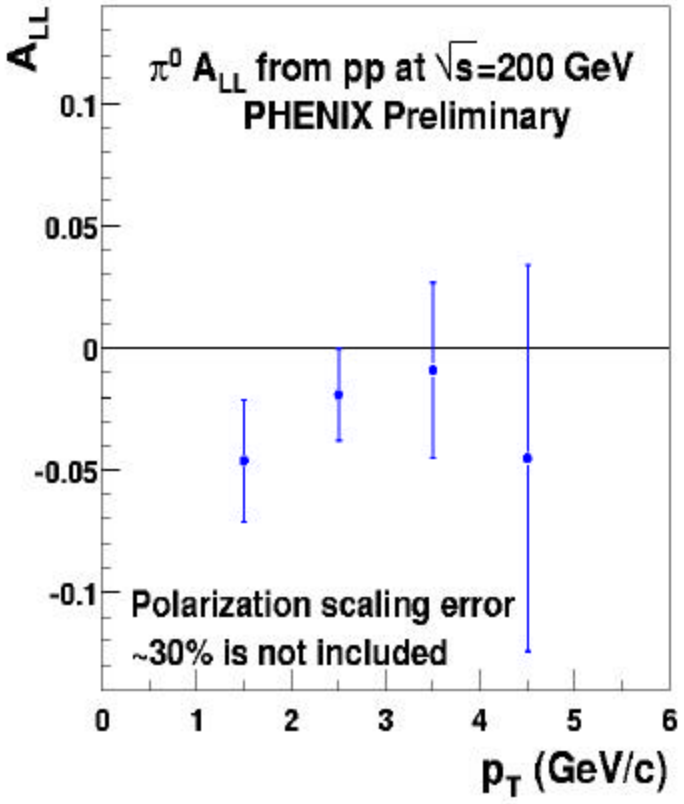
A_L (%)

pt GeV/c	$N_{\pi 0}$ 15 MeV/c^2	$N_{\pi 0}$ 25 MeV/c^2	$N_{\pi 0}$ 35 MeV/c^2	N_{bck1}	N_{bck2}
1-2	-0.06±0.4	0.06±0.3	0.00±0.3	-0.2±0.4	-0.02±0.3
2-3	0.1±0.4	0.00±0.4	0.2±0.4	0.9±0.7	0.01±0.5
3-4	0.4±0.9	0.6±0.9	0.6±0.8	-0.4±2.4	-3.6±1.5
4-5	-2.4±2.1	-1.6±2.0	-1.6±1.9	-1.1±6.2	1.3±3.8

All are zeros within 1.5σ, except

p^0 A_{LL} from pp at 200 GeV

p_T GeV/c	$A_{LL}^{p\ 0+bck}$ (r_{bck})	A_{LL}^{bck}	$A_{LL}^{p\ 0}$ (Background subtracted)
1-2	-0.028±0.012 (45%)	-0.006±0.014	-0.046±0.025
2-3	-0.022±0.015 (17%)	-0.035±0.027	-0.019±0.019
3-4	-0.002±0.033 (7%)	0.094±0.092	-0.009±0.036
4-5	-0.023±0.074 (5%)	0.38±0.24	-0.045±0.079



Polarization scaling error *dP/P* ~30%: is not included

- ✓ Analyzing power A_N(100 GeV) = A_N(22GeV) is assumed
- ✓ *dP/P*~30%: combined stat. and syst. error for A_N(22GeV) (AGS E950)

Summary

First Pi0 A_{LL} results from long. polarized pp collisions with average beam polarizations of 26% presented

- ✓ Results presented in four p_T bins in the range 1-5 GeV/c
- ✓ A_{LL} sensitivity in the lowest p_T bin (1-2 GeV/c) is 1.2%
- ✓ 2.5σ (1.5 σ) effect seen at 1-2 GeV/c (2-3 GeV/c) bin