Single high $\mathrm{p}_\perp$ μ Physics from PHENIX

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Abstract

The PHENIX muon system took its first data during the 2001-2002 run of RHIC. The experiment recorded 1.06×10^8 events in AuAu collisions and 3.0×10^8 events in pp collisions at integrated luminosities of $45\,\mu\mathrm{b}^{-1}$ and $0.2\,\mathrm{pb}^{-1}$ respectively at a cm energy of $200\,\mathrm{GeV}$. High $p_\perp$ muon production via heavy flavor decay in high energy pp collisions is sensitive to both G and ΔG nucleon structure functions and address the so called "spin crisis of the nucleon". Understanding free nucleon structure is relevant in gauging nuclear medium effects on parton distributions as well. Preliminary PHENIX data for high $\mathrm{p}_\perp$ single muons will be presented. In addition, a description will be given of the technique for extracting the heavy flavor component of the muon $p_\perp$ spectrum.

Talk Outline:

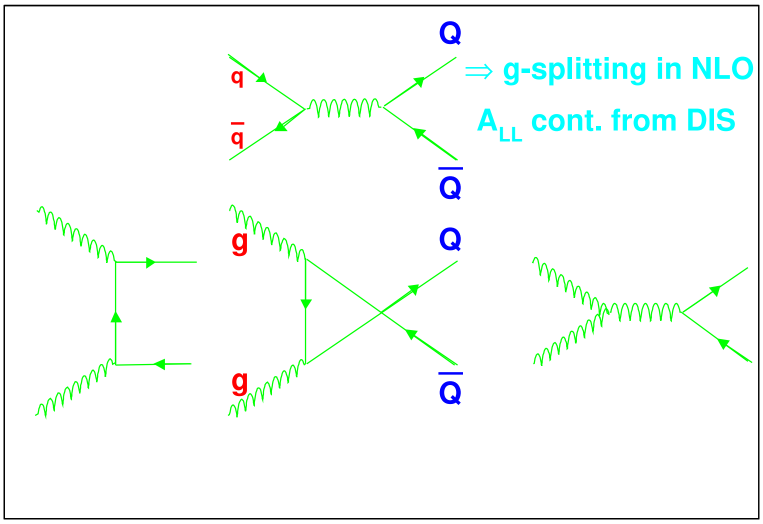
- Physics issues addressed by high $\mathrm{p}_\perp$ μs in HI and pp collisions
- Details of pp collision physics -
  heavy flavor production sensitive to gluons in the initial state
- Overview of PHENIX experiment &
  RHIC polarized proton facility
- Extracting the Heavy Flavor signal from background
  in PHENIX muon arms

Single μ Physics - Heavy Flavor Production

At sufficiently high $p_\perp$ the single muon spectrum is dominated by semileptonic decays of D and B mesons.

W production only near kinematic limit at $\sqrt{s} = 200\,\mathrm{GeV}$

Heavy Flavor production has high sensitivity to gluon dynamics - in LO:



Gluon dynamics of interest in:

HI collisions- QGP signature

1. $\sigma_{HeavyFlavor}$ serves as a baseline for J/Ψ suppression
2. thermalization of gluons? & thermalization time of QGP
3. study $c\bar{c}$ correlations for evidence of QGP

pA collisions- Gluon shadowing and EMC effect

pp collisions- polarized pp

1. Measure $\triangle G$ to address spin crisis of nucleon
2. NLO G measurement at $\sqrt{s} = 200\,\mathrm{GeV}$
3. Baseline for $\sigma_{HeavyFlavor}$ in HI collisions - binary scaling

Bit O' Background - A_{LL}

Theoretical Perspective:

Measuring polarizied gluon S.F. in nucleon is important in understanding violation of Ellis-Jaffe sum rule in DIS

Complements sea quark studies in high energy W boson and Drell-Yan production, as well as strange sea measurements via parity violation in polarized elastic $\mathbf{ep}$ scattering.

For Heavy Flavor production $\triangle G$ can be obtained via measurement of A_{LL},

$$A_{LL} = \frac{\int dx_1 dx_2 \triangle G(x_1, Q^2) \triangle G(x_2, Q^2) \hat{a}_{12} d\hat{\sigma}_{12}}{\int dx_1 dx_2 G(x_1, Q^2) G(x_2, Q^2) d\hat{\sigma}_{12}}$$

$\hat{a}_{12}$ is the constituent analyzing power – pQCD calculable

- in LO $\hat{a}_{12} = +1$ at threshold and $\hat{a}_{12} \to -1$ as $Q^2, \mathrm{p}_\perp^2 \to \infty$
- Some papers indicate NLO corections involving $2 \to 3$ processes tend to cancel $\hat{a}_{12}$ in LO for heavy flavor production, but not for $jet + jet$ and $\gamma + jet$ production.
- γg fusion process in DIS at a high energy polarized $\mathbf{ep}$ collider also directly sensitive to $\triangle G$

So $b\bar{b}$ production may not have greatest sensitivity to $\triangle G$ in pp collisions.

But, PHENIX has a robust muon system that's gathering data and pQCD is verified by the consistency of different data sets. Studying Heavy Flavor production will be useful.

A_{LL} cont...

Experimental Perspective:

$$A_{LL} = \frac{1}{P^2} \times \frac{\sigma_{++} - R\sigma_{+-}}{\sigma_{++} + R\sigma_{+-}}$$

To get σ_{++} and σ_{+-} one needs a high energy proton-proton collider with longitudinally polarized bunches, (RHIC).

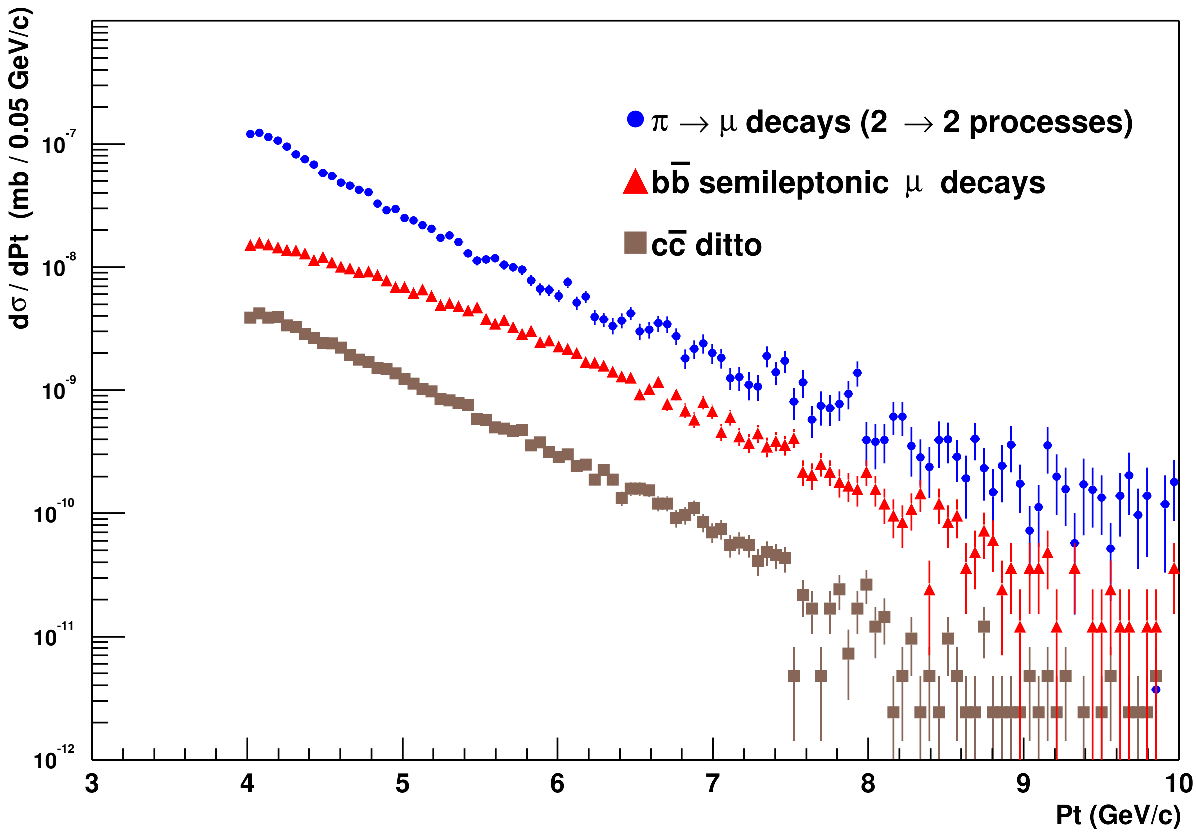
P: Beam polarization, assumed equal for all bunches; $< 5\%$ systematic with polarized hydrogen gas jet target in RHIC

1. Measure RHIC beam polarization at full energy non-invasively with known analyzing power - 2004.
2. Currently use CNI polarimeters at injection energy with poorly known analyzing power.

R: RELATIVE bunch luminosity. Uncertainty can be made sufficiently small by averaging over different bunch fill patterns during a run

- Need $70\,\%$ polarization for canonical $32\,\mathrm{pb}^{-1}$ run to achieve required A_{LL} sensitivity - 2004?
- But since little is known about $\triangle G$ even sign of $\triangle G$ and $\triangle G$ "large or small" type measurements are relevant for early RHIC runs.
- G measurements at $\sqrt{s} = 200\,\mathrm{GeV}$ are important also to confirm that NLO predictions are consistent with UA1 and Tevatron data. Actual luminosity becomes important; dominant systematic uncertainty for 2001 Run at $30\,\%$
  Work In Progress

PYTHIA Predictions - pessimistic

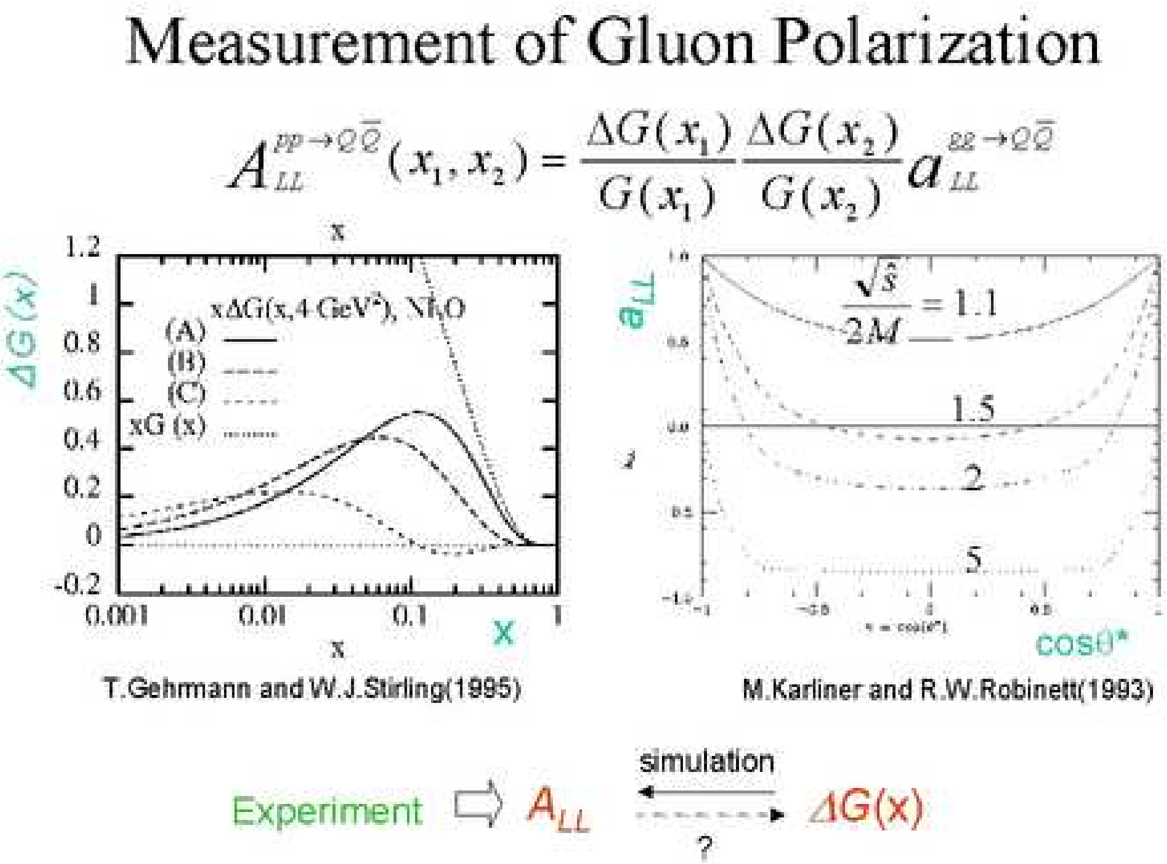


Default parameters and Structure Functions (“soft” G)

NOTE: $b\bar{b}$ μ spectrum is shallower as predicted by pQCD and decay kinematics near threshold.

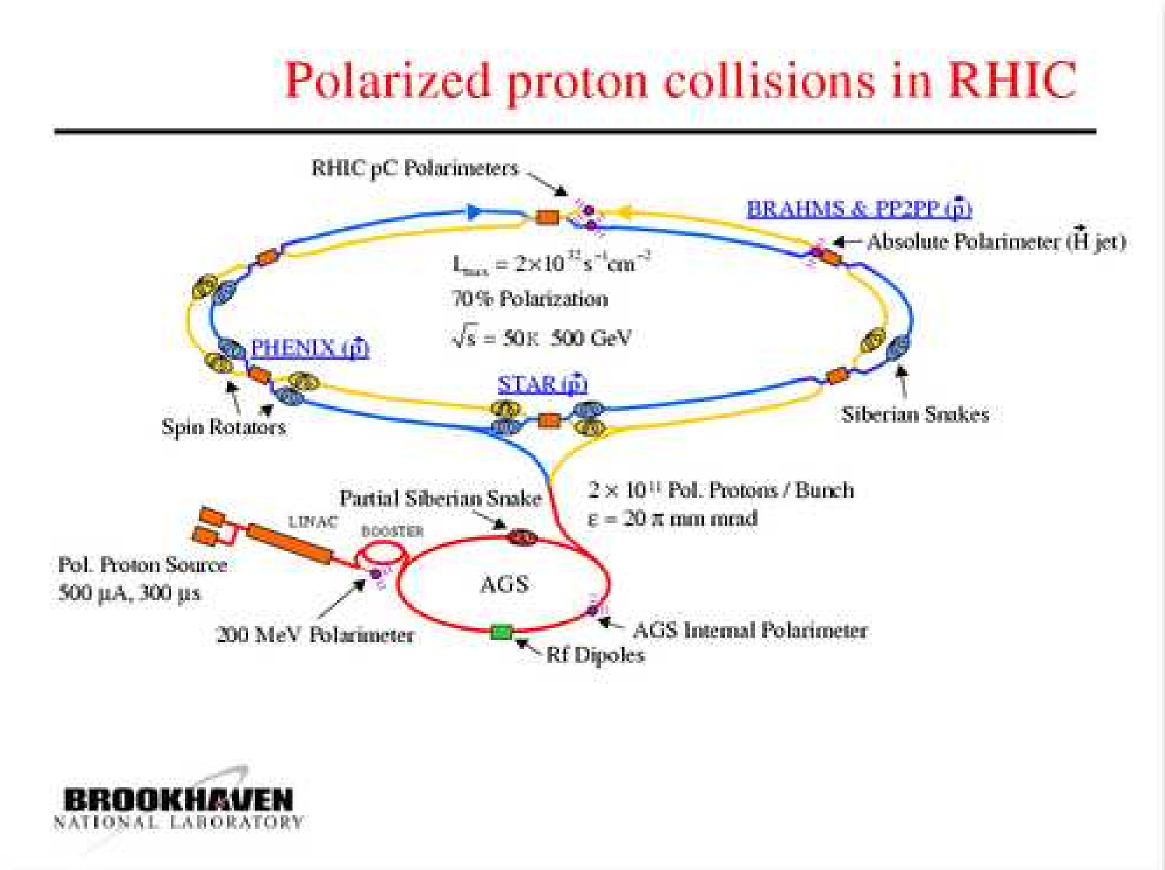
In this scenario $S/B \simeq 0.5$ at $\mathrm{p}_\perp > 5\,\mathrm{GeV/c}$ so...
$32\,\mathrm{pb}^{-1}$ run should yield 3300 heavy flavor events with $\mathrm{p}_\perp > 5\,\mathrm{GeV/c}$ or $4\,\%$ sensitivity.

$\triangle G(x)$ Sensitivity



- Maximum $\triangle G$ sensitivity at $x \sim 0.1$ which corresponds to $b\bar{b}$ production at $\mathrm{p}_\perp \approx 5\,\mathrm{GeV/c}$ for $\sqrt{s} = 200\,\mathrm{GeV}$
- 4% sensitivity for σ_{tot} implies about 8% sensitivity on A_{LL} $(\delta A_{LL} \sim 1/P^2 \times 1/\sqrt{N})$
- so for $32\,\mathrm{pb}^{-1}$ and $\hat{a}_{LL} \sim 1$ we might distinguish "hard" and "soft" $\triangle G$, sign of $\triangle G$
- larger physics cross section and/or luminosity increase needed.

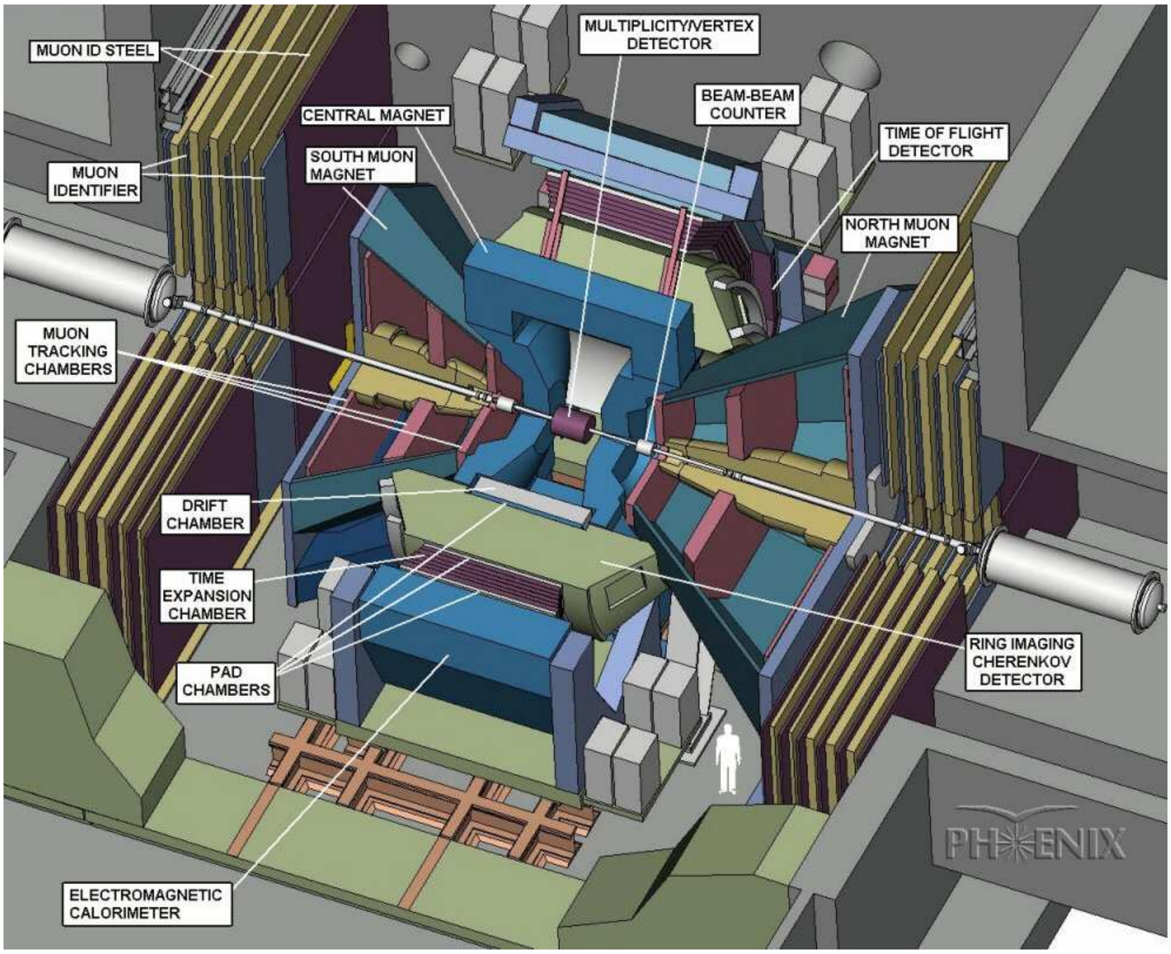
RHIC – Polarized pp



RHIC is actually 2 separate superconducting synchrotron rings with counterrotating beams.

- "DX" magnets force beams of 110 bunches to collide at itersection regions
- Special magnets for polarized $\mathbf{pp}$
    1. Siberian Snakes - maintain beam polarization
    2. Spin Rotators - beams are transversely polarized, but spins can be made longitudinal at intersection regions (needed for A_{LL})

PHENIX



Only South arm installed for 2001 run. For current run both arms are operational.

Data from MuId, MuTr and Bbc systems essential for single muon studies.

Brass nosecones and steel pole faces of central magnet filter out high energy hadrons.

BUT... light meson decays to muons between nosecones form an irreducible background at hardware level!

Key Hardware Parameters

MuId:

1. 5 layers of $20, 10, 10, 20, 20\,\mathrm{cm}$ thick steel plate with panels of proportional drift tubes sandwiched in between.
2. drift tube panels composed of an X and Y oriented pair of "2-packs" per layer
3. MuId Road hit resolution is thus $4\,\mathrm{cm} \times 4\,\mathrm{cm}/12$
4. MuId π rejection factor is 2.5×10^{-4} at $3\,\mathrm{GeV/c}$; rising to $\sim\ 10^{-3}$ for momenta in the range $10 - 20\,\mathrm{GeV/c}$
5. μ are triggered by quadrants

MuTr: Cathode Strip Chambers

1. 3 stations of chambers with 3 gaps in 1st 2 stations and 2 gaps in 3rd
2. 2 cathode planes per gap: 1 plane w/ strips $\perp$ beam (bend plane), the other with stereo strips at $0, 7, \mathrm{or} 12\,\mathrm{deg}$ w.r.t. 1st plane
3. $100\,\mu m$ hit resolution in bend plane
4. nominal J/Ψ mass resolution $150\,\mathrm{MeV/c^2}$

BBC: Beam-Beam Counters to obtain z-vertex

1. $2\,\mathrm{cm}$ z-vertex resolution
2. trigger efficiency in pp collisions $\simeq 50\%$

2001 Run Data Summary

- $0.15\mathrm{pb}^{-1}$ $\mathbf{pp}$ integrated luminosity
- $P \simeq 20\,\%$ and transverse only so no A_{LL} for today
- Separate Heavy Flavor signal from background for $\sigma_{HeavyFlavor}$

Breakdown of μ data

Trigger type	Number of events
Minimum bias	196×10^6
Single μ	34×10^6
di-μ	4.8×10^6

Data Cuts:

MuId: 1 μ in trigger quadrant, no ghosts, good road reconstruction quality w/ < 3 hits per panel

MuTr: > 12 hits on track, χ^2 cut, does not share too many hits with another track

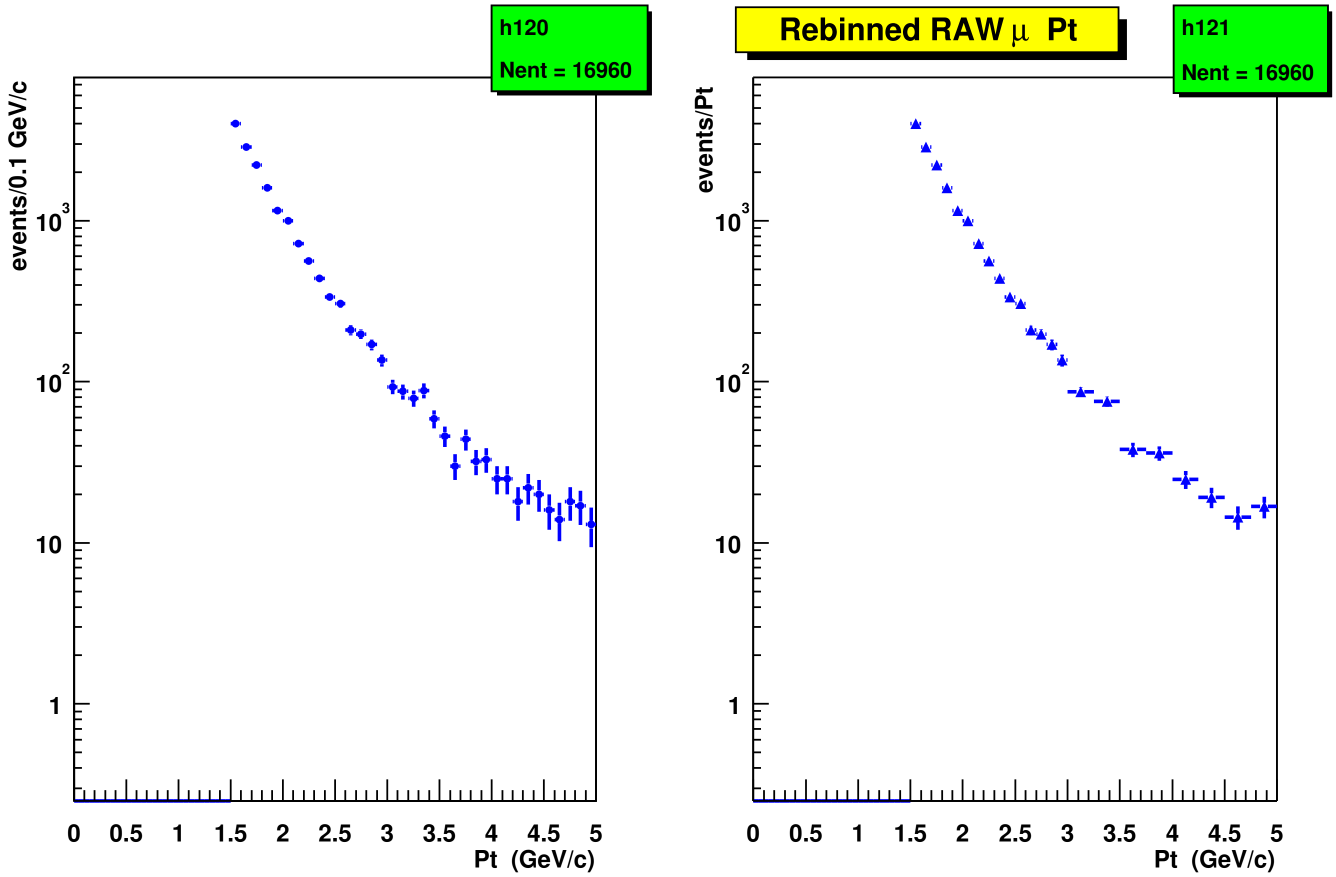
Matching: Matching angle $< 40^o$, matching distance w/in $10\,\mathrm{cm}$, and μ prob. 1

z-vertex: $\mathrm{BbcZ} > -20.0\,\mathrm{cm}$ and $\mathrm{BbcZ} < 40.0\,\mathrm{cm}$

kinematics: $\mathrm{p}_\perp > 1.5\,\mathrm{GeV/c}$ and $P > 2.5\,\mathrm{GeV/c}$

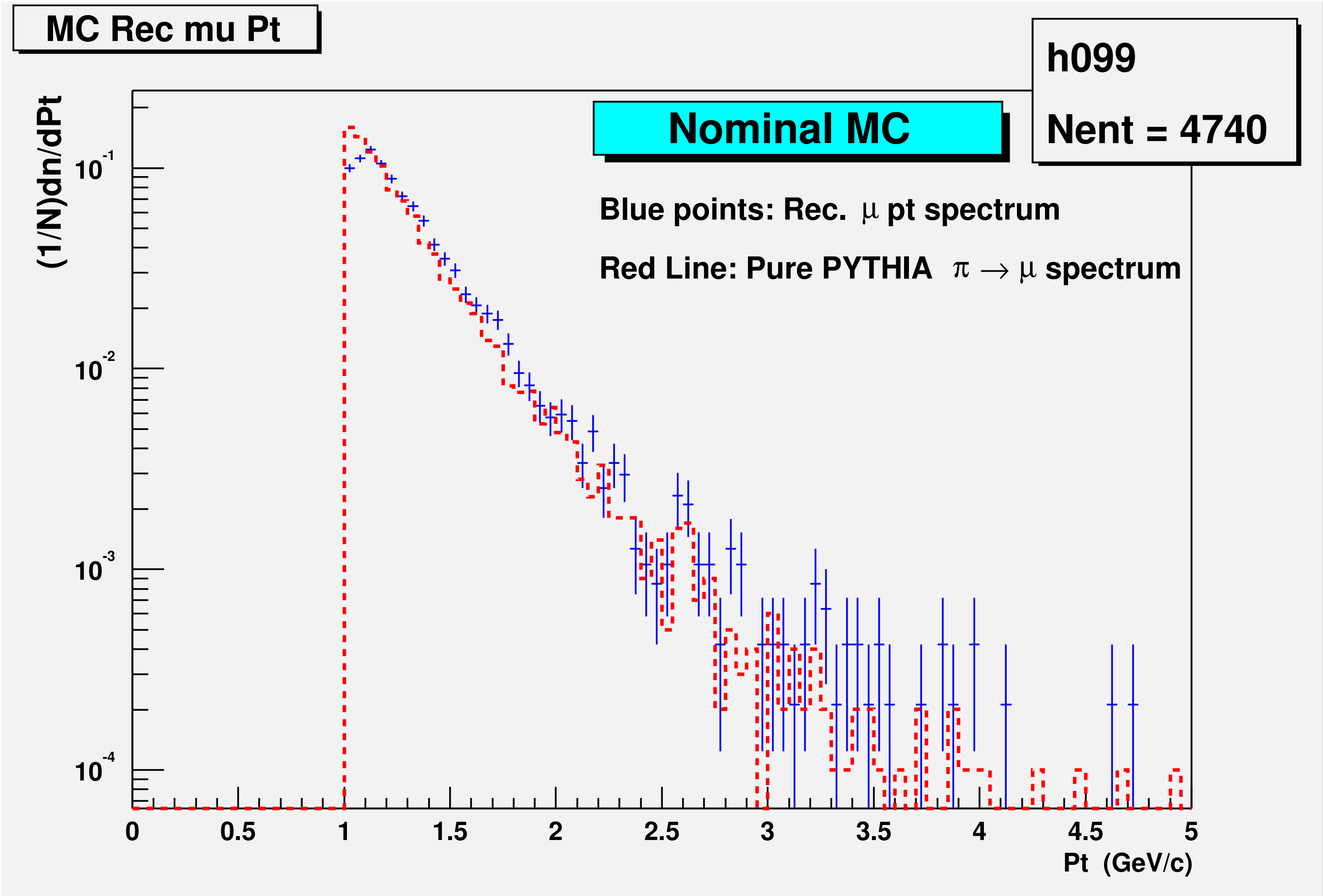
After Cuts ONLY 17K single μ events remain...

Raw μ $\mathrm{p}_\perp$ Spectrum



- Raw & Uncorrected spectra
- uniformly binned (Left), rebinned to reduce fluctuations (Right)
- 242 events above $5\,\mathrm{GeV/c}$ in $\mathrm{p}_\perp$

Spectrum Distortion - Systematics



- No observable distortion in $p_\perp$spectrum from NOMINAL detector/reconstructor. Low $p_\perp$dip due to energy loss.
- Nominal hit resolution achieved ($180\,\mathrm{MeV/c}$ width for J/ψ)
- Significant loss of acceptance in 2001 run from HV and electronics failure - TO BE Investigated with realistic MC
- Need more stats to match data!

The HF Background

2 SOURCES:

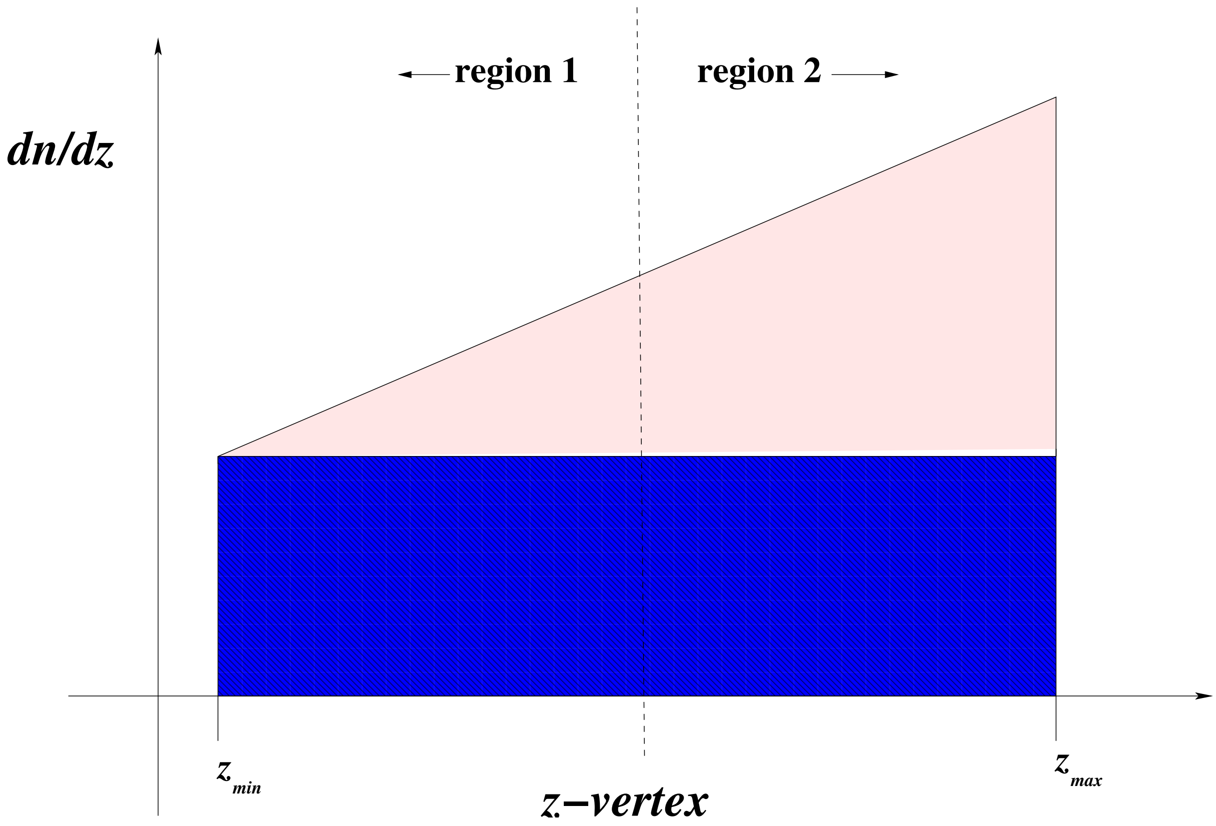
- $\pi^{\pm}, K^{\pm} \rightarrow \mu^{\pm}\nu$ Decays
  1. in fiducial volume between nosecones, "free decays"
  2. in nosecone/magnet steel absorber material - attenuated by λ_I
- $\pi^{\pm}, K^{\pm}$ Punchthru's - high momentum hadrons that penetrate to last layer of MuId

Determine Background from DATA:

1. Use z-vertex distribution to get decay spectrum between nosecones
2. Use Monte Carlo (model independent) to determine decay contribution in absorber
   a) Use simple decay MC to determine total $\pi^{\pm}, K^{\pm}$ production
   b) K/π ratio is fixed by other experimental data
3. Use total $\pi^{\pm}, K^{\pm}$ production spectrum to obtain Punchthru component using known MuId response
4. Add the 3 background spectra and subtract from data to obtain signal

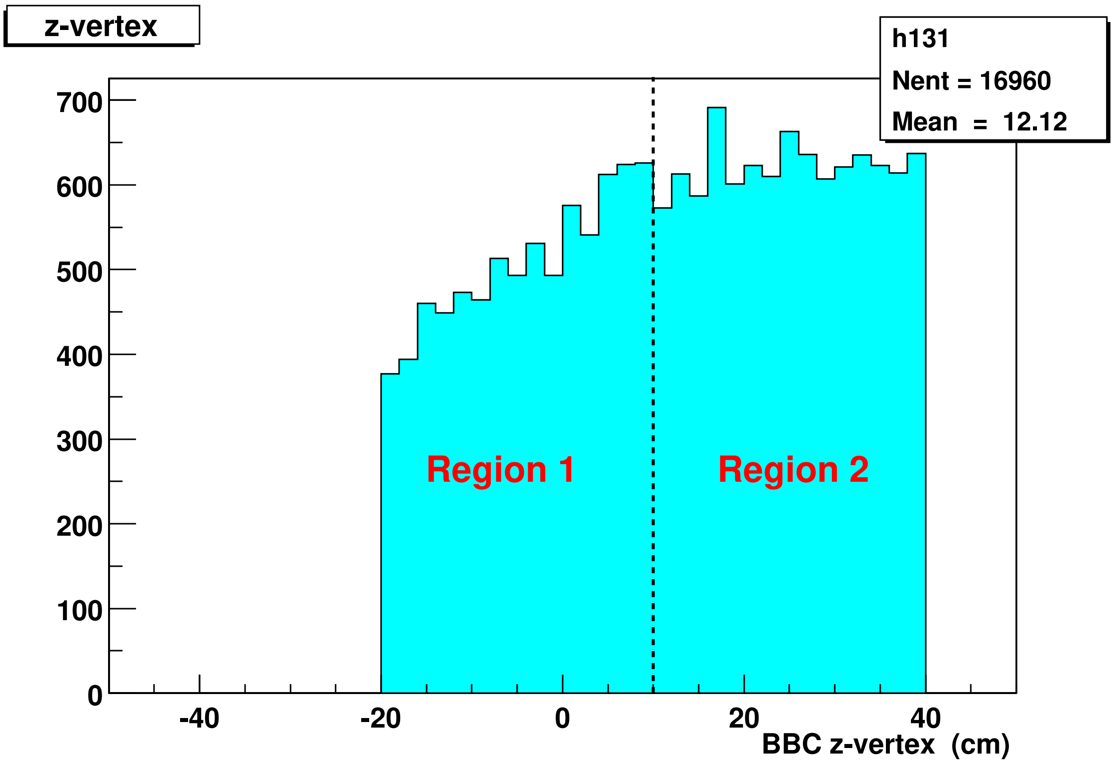
Today's Focus: free decay spectrum

Z-Vertex Studies - Cartoon



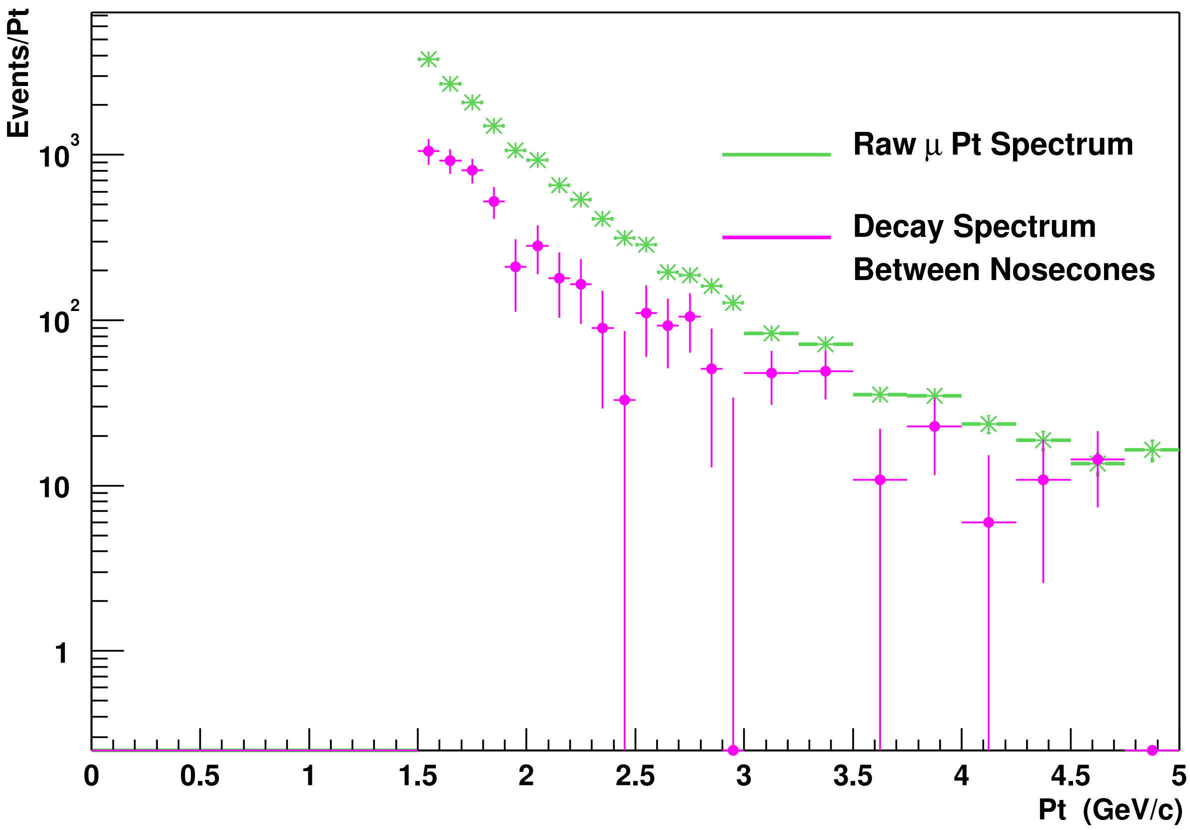
- Red Part - Z dependent and *a priori* contains all and only the component from free decays of light mesons. Expected shape is actually $\sim (1 - exp(-\alpha z))$.
- Blue Part - Z independent containing Signal, Punchthru and absorber decay components
- SUBTRACT Region 1 from 2 and apply geometric scale factor to obtain spectrum of decays between nosecones...
- $z_{MAX} - z_{MIN}$ is the distance between the nosecones

Z-Vertex Studies - DATA



- Raw z-vertex distribution from beam-beam counter data $\sigma = 2\,\mathrm{cm}$
- uniform z-acceptance: cut in pseudorapidity, η, applied to data
- fiducial cut at $z = -20\,\mathrm{cm}$ so all tracks impinge on South nosecone
- Subtract Region 1 from Region 2. Apply geometric scale factor, based on MATHEMATICAL FORM of z-vertex dist. to get "free" decay spectrum. Includes extrapolation to South nosecone at $-40\,\mathrm{cm}$

“Free” Decay Background



1. RAW “Free” decay $p_\perp$spectrum only
2. BUT 2 other background components will have to be studied before Heavy Flavor production can be confirmed!
3. NEED to fit/extrapolate decay spectrum to estimate high $p_\perp$backgound because spectrum is only 2σ from 0 above $4\,\mathrm{GeV/c}$

SUMMARY

Current Status:

- Light meson decay background between the nosecones not responsible for observed $\mathrm{p}_\perp$spectrum?
- So maybe σ_{TOT} measurement for Heavy Flavor is possible...

To Do:

- Quantify all background components and obtain SIGNAL spectrum - at least estimate σ_{TOT} for "Blue Book" running
- Apply acceptance/trigger corrections and normalization for heavy flavor σ_{TOT}
- Study $\mathrm{p}_\perp$spectrum shape and systematics with actual acceptance
- Systematic error study