Measurement of muon tagged open heavy flavor production in Pb+Pb collisions at 2.76 TeV with ATLAS

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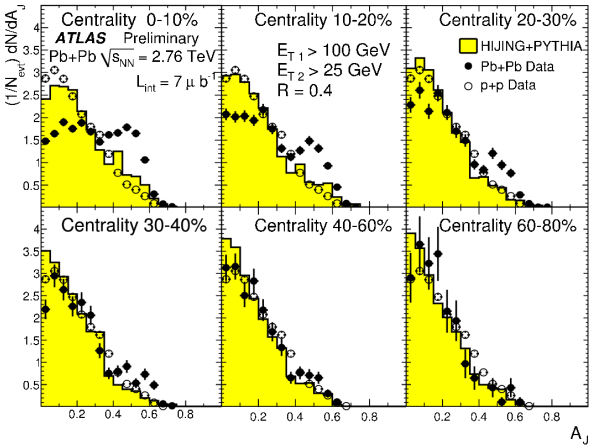
Heavy flavor suppression at RHIC and the LHC



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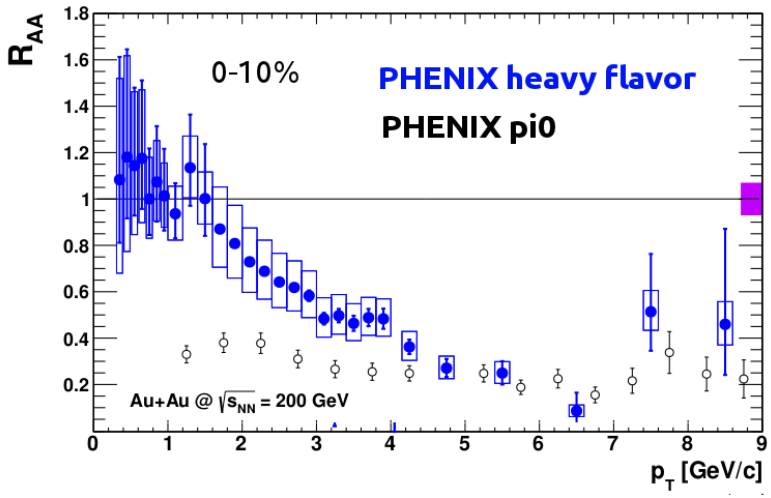

PRC **84**, 044905 (2011)

PRL **101**, 232301 (2008)

- Heavy quark measurements complement light quark/gluon dominated measurements (jets, leading hadrons):

  $\Rightarrow$ larger mass, different formation time, etc.

  $\Rightarrow$ essential for full picture of jet quenching

- RHIC experiments indicate that heavy quarks are suppressed at the same level as light q/g ... what about the LHC?

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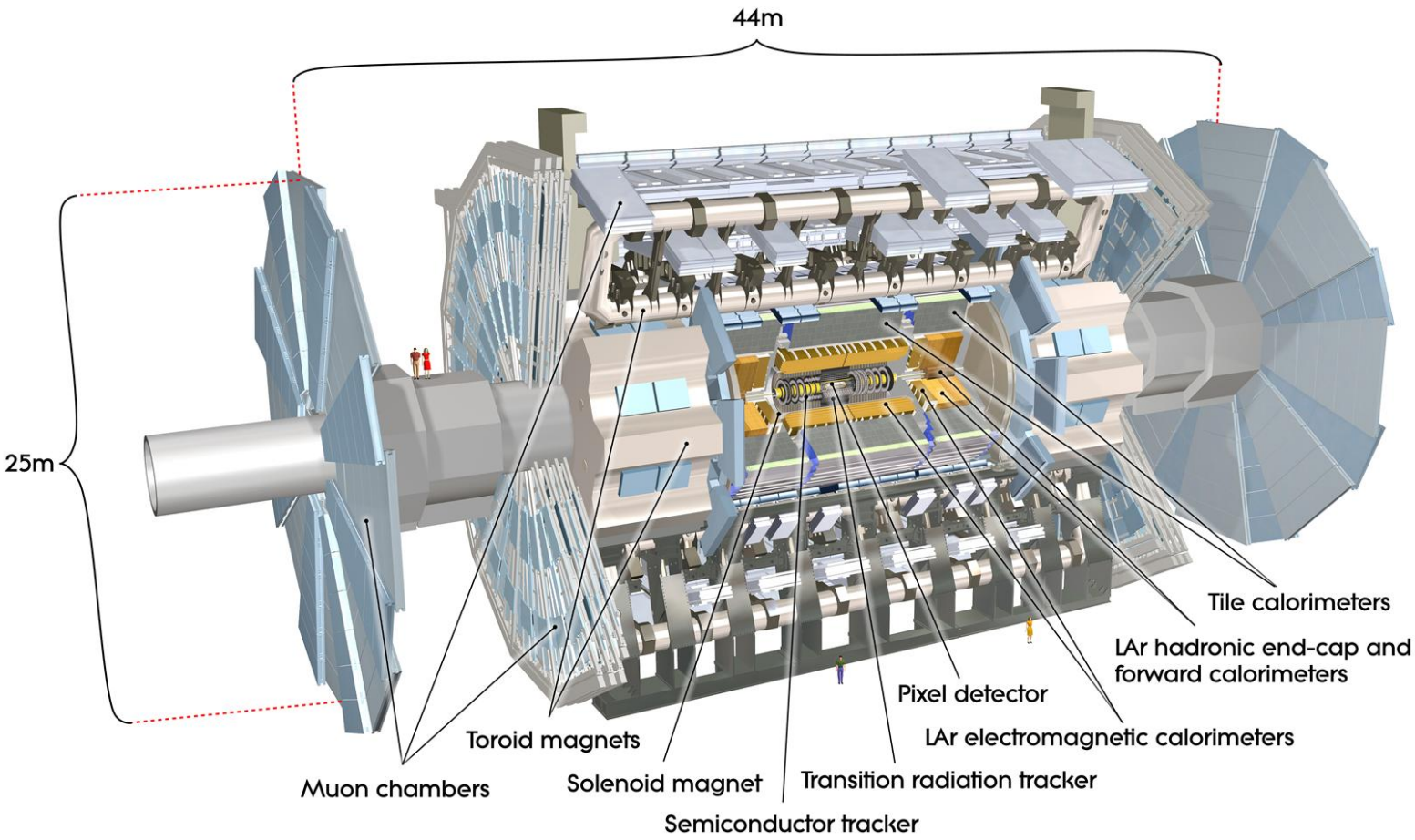
ATLAS detector



- $\mu^{\pm}$ **reconstruction**: silicon pixel detectors/silicon microstrip detectors/straw tube tracker (ID), muon spectrometer (MS)
- **centrality determination**: forward calorimeters (FCal)

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Data & event selection

- Data: 2010 Pb+Pb 2.76 TeV, $\int \mathcal{L} = 7\ \mu b^{-1}$

  $\Rightarrow$ all data taken Minimum Bias, 53×10^6 events analyzed

- Event selection:

  $\Rightarrow$ timing, ZDC coincidence + primary vertex requirements
  $\Rightarrow$ sample $98 \pm 2\%$ of Pb+Pb cross-section

- $\mu^{\pm}$ selection:

  $\Rightarrow$ $|\eta| < 1.05$ (inner detector + muon spectrometer)
  $\Rightarrow$ $p_{\mathrm{T}} > 4$ GeV (good reconstruction efficiency)
  $\Rightarrow$ $p_{\mathrm{T}} < 14$ GeV (statistics, $< 1\%$ $W^{\pm}$ contribution)

- Monte Carlo:

  $\Rightarrow$ 5×10^6 `PYTHIA` dijets with $\hat{p}_{\mathrm{T}} = 17$-$280$ GeV + overlay with 1×10^6 `HIJING` Pb+Pb events

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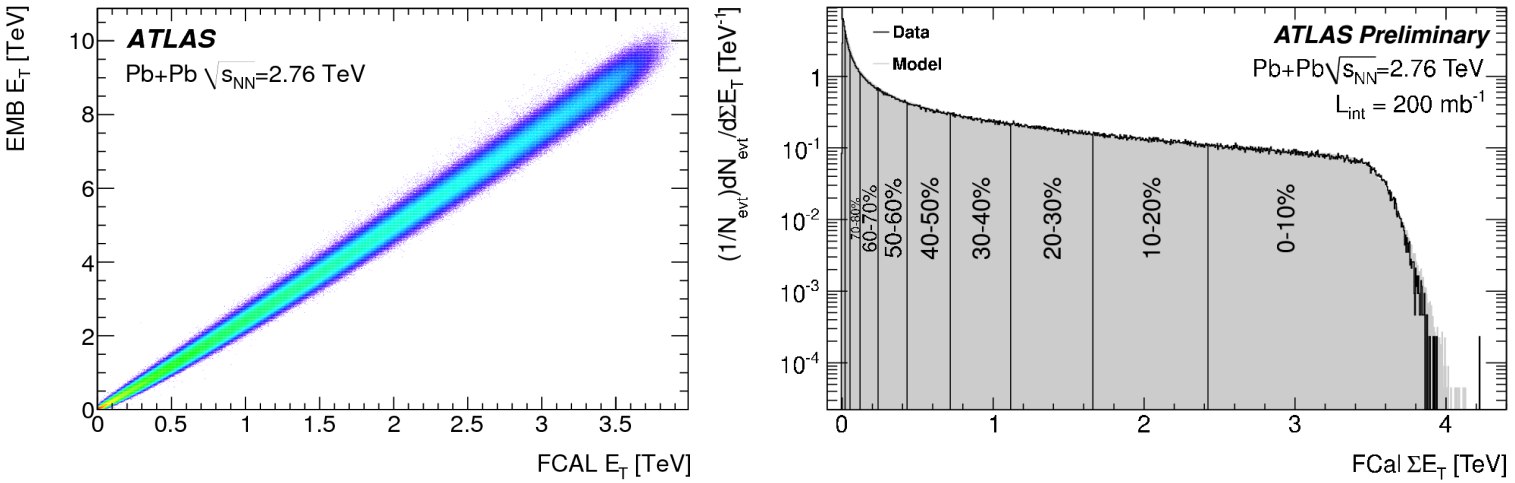
Centrality determination in ATLAS



- $\Sigma E_{\mathrm{T}}^{\mathrm{FCal}}$ used to categorize centrality
  - $\Rightarrow$ $3.2 < |\eta| < 4.9$, far removed from mid-rapidity physics
  - $\Rightarrow$ good agreement between data and Glauber + p+p simulation
- This analysis: 0-10%, 10-20%, 20-40%, 40-60%, 60-80%
  - $\Rightarrow$ 60-80% used as common reference (expect small hot nuclear matter effects)

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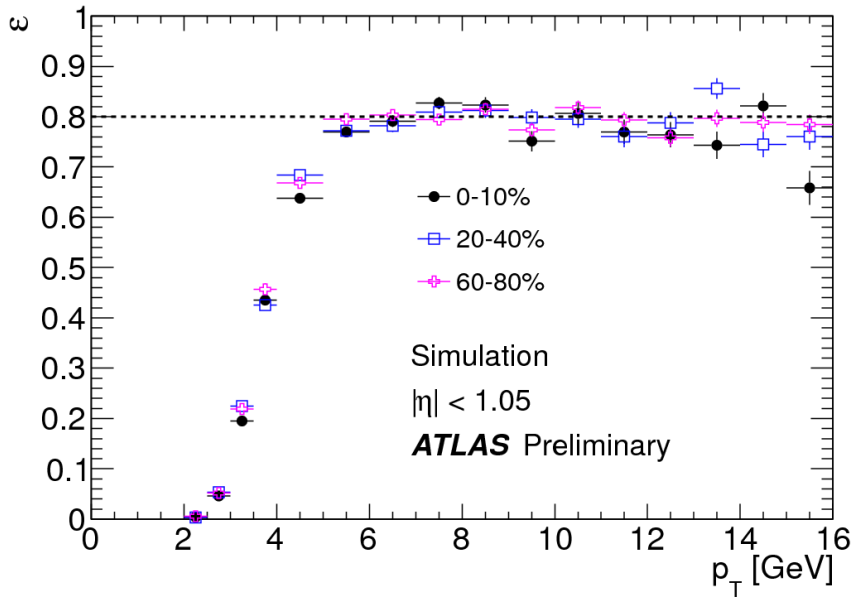
Reconstructing $\mu^{\pm}$'s



p_T [GeV]	Centrality [%]				
	0–10	10–20	20–40	40–60	60–80
4–5	49k	36k	43k	17k	4.7k
5–6	19k	15k	18k	7.4k	2.0k
6–7	8.6k	6.5k	8.2k	3.4k	0.93k
7–8	4.1k	3.1k	3.9k	1.6k	0.46k
8–9	2.2k	1.7k	2.1k	0.78k	0.21k
9–10	1.2k	0.93k	1.1k	0.46k	0.13k
10–14	1.7k	1.31k	1.5k	0.62k	0.15k

number of reconstructed $\mu^{\pm}$

- Reconstruction efficiency for $\mu^{\pm}$ from semi-leptonic *b*- or *c*-decays:

  $\Rightarrow$ centrality-independent above $p_{\mathrm{T}} > 5$ GeV ($\epsilon_{plateau} = 80 \pm 2\%$)

  $\Rightarrow$ weak centrality dependence for $p_{\mathrm{T}} \in$ 4-5 GeV

(More information on ATLAS $\mu^{\pm}/e^{\pm}$ reco in p+p: PLB **707** (2012), 438458)

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Heavy flavor extraction: template definition

Discriminant #1 (expected momentum loss while moving through calorimeters):

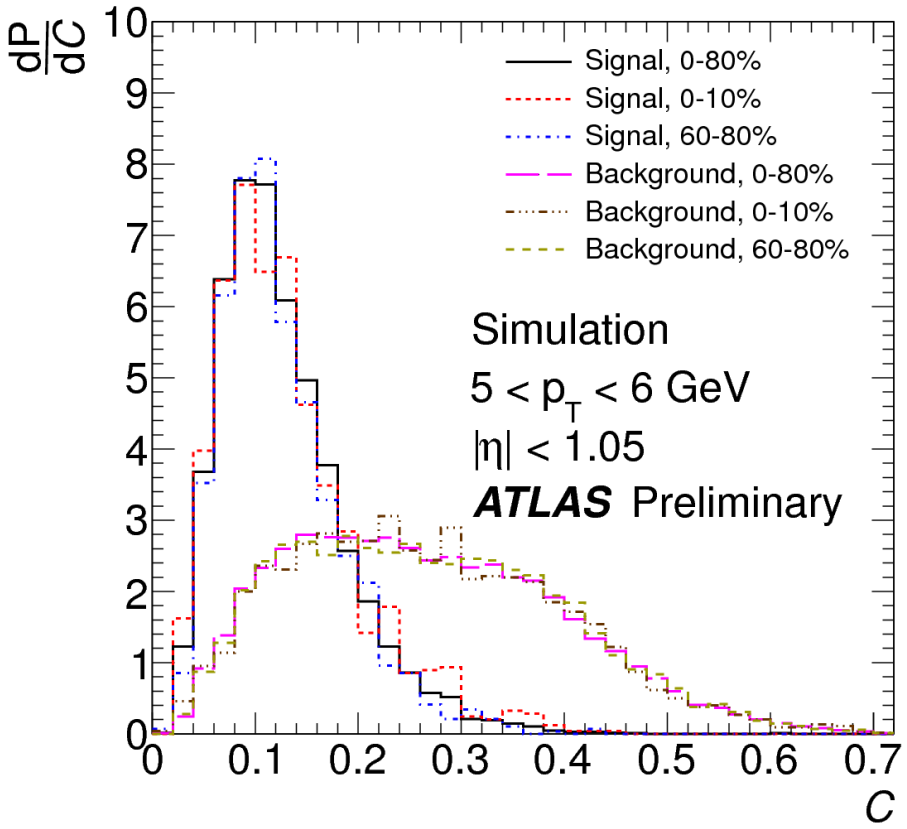
$$\Delta p_{loss} = p_{ID} - p_{MS} - p_{param}^{MC}$$

Discriminant #2 (angular deflection in inner detector):

$$s_i = q\frac{\Delta\phi_i}{\phi_i^{msc}}$$

$$S = \frac{1}{\sqrt{n}}\left(\Sigma_1^j s_i - \Sigma_{j+1}^k s_i\right)$$

Composite: $C = \left|\frac{\Delta p_{loss}}{p_{ID}}\right| + 0.07 \cdot S$



- Composite discriminant from $\mu^{\pm}$ momentum loss (#1) and scattering angle (#2):

  $\Rightarrow$ heavy quark signal well-separated from $\pi^{\pm}/K^{\pm}$ background

  $\Rightarrow$ no centrality dependence

  $\Rightarrow$ increasing separation with muon p_{T}

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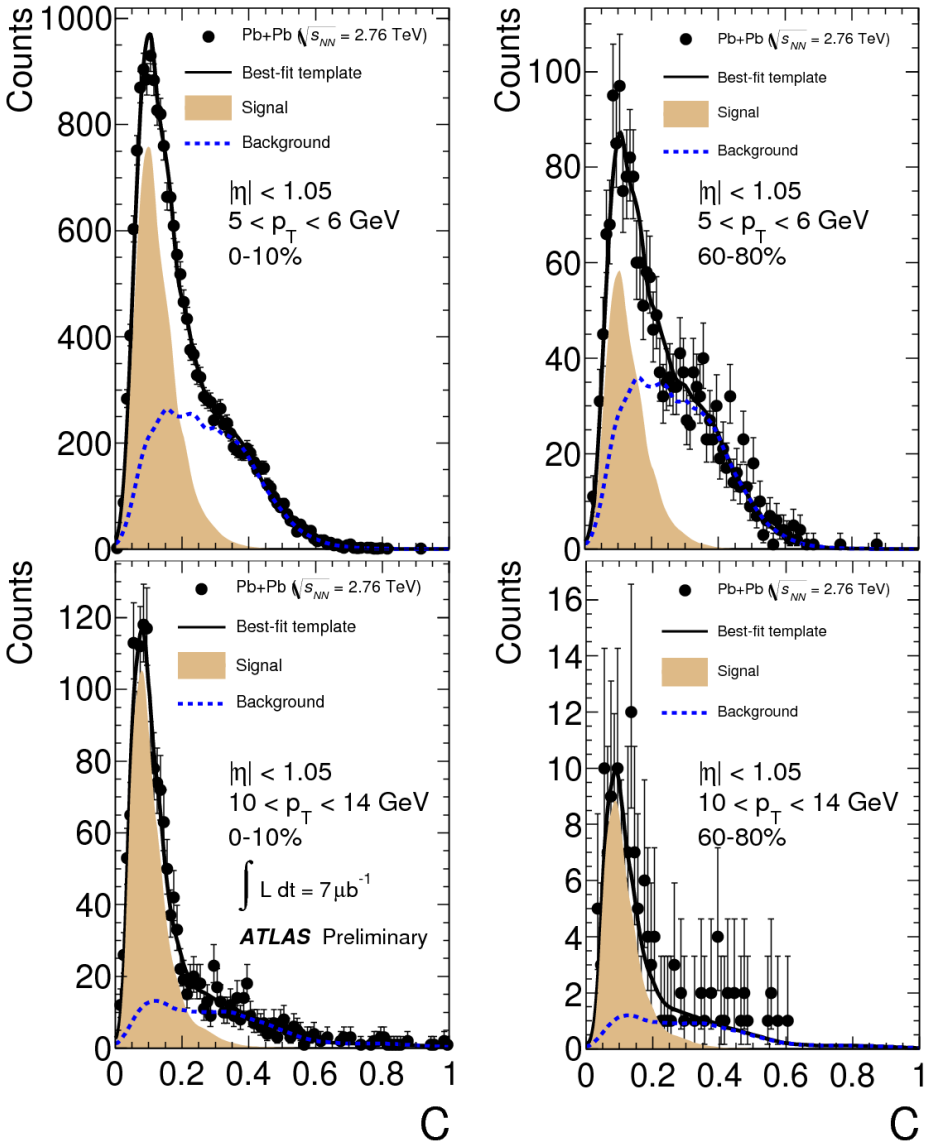
Heavy flavor extraction: template fitting

Composite fit:

$$\frac{dP}{dC} = f_s \left.\frac{dP}{dC}\right|_S + (1-f_s) \left.\frac{dP}{dC}\right|_B$$

- Limited data adaptation allows template to:
  - shift
  - stretch
  - smear
- Extract heavy flavor component from inclusive $\mu^{\pm}$ yield
- Toy MC re-sampling to determine systematic uncertainty



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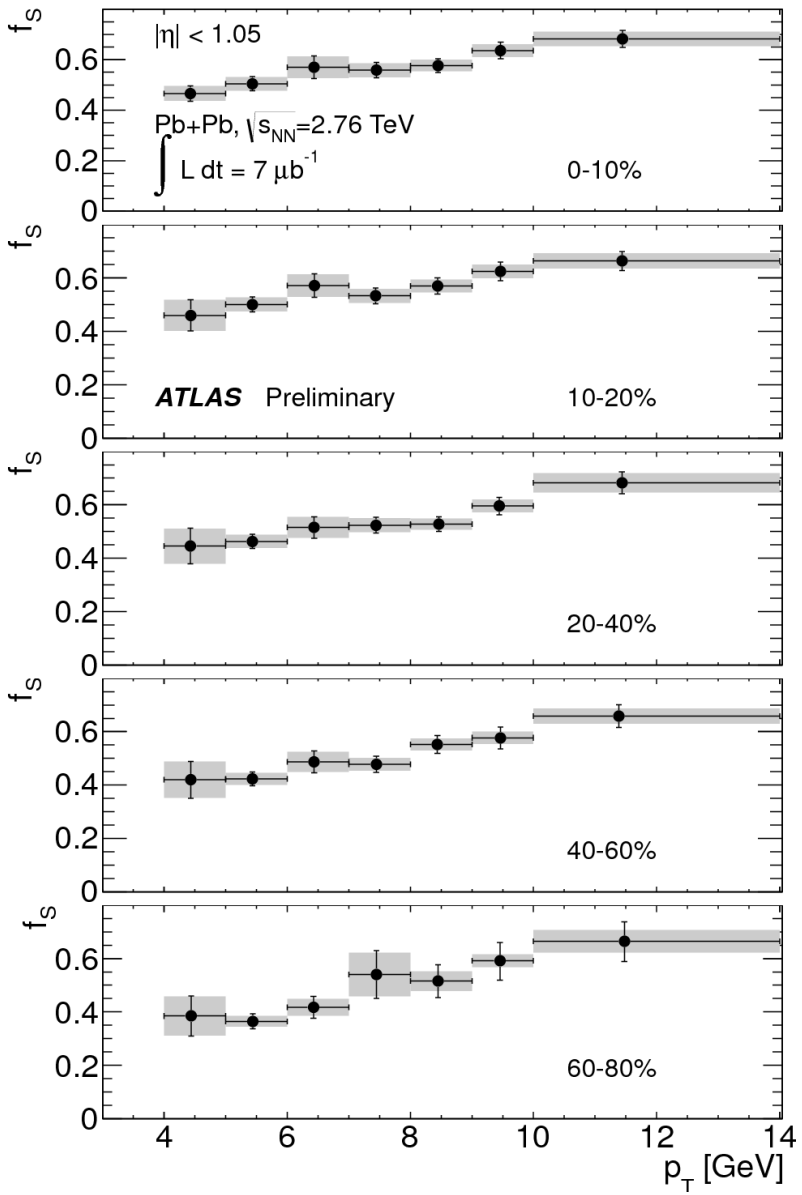
Heavy flavor extraction: signal fraction



Fraction of heavy flavor $\mu^{\pm}$ is *higher* in central events!

. . . hint that open heavy flavor is *less* suppressed than inclusive hadrons. . .

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Systematic uncertainty overview

Centrality [%]	p_T [GeV]	Uncertainty [%]				
		dP/dC	Fit	K/π	ε	Total
0-10	4–5	4	0	5	3	7
	7–8	5	0.5	0.5	2	5.5
	10–14	4	1	1	2	5
60-80	4–5	18	1	5	3	19
	7–8	14	5	0.5	2	15
	10–14	4	4	2	2	6

- "dP/dC":

  $\Rightarrow$ possible centrality dependence in signal/background templates

- "Fit":

  $\Rightarrow$ use $C < C_{cut}$ as alternate signal extraction method

  $\Rightarrow$ restrict shift/stretch/smear template distortion

- "π/K":

  $\Rightarrow$ separately double π/K contribution in background template

- "ϵ":

  $\Rightarrow$ $\mu^{\pm}$ reconstruction efficiency uncertainty

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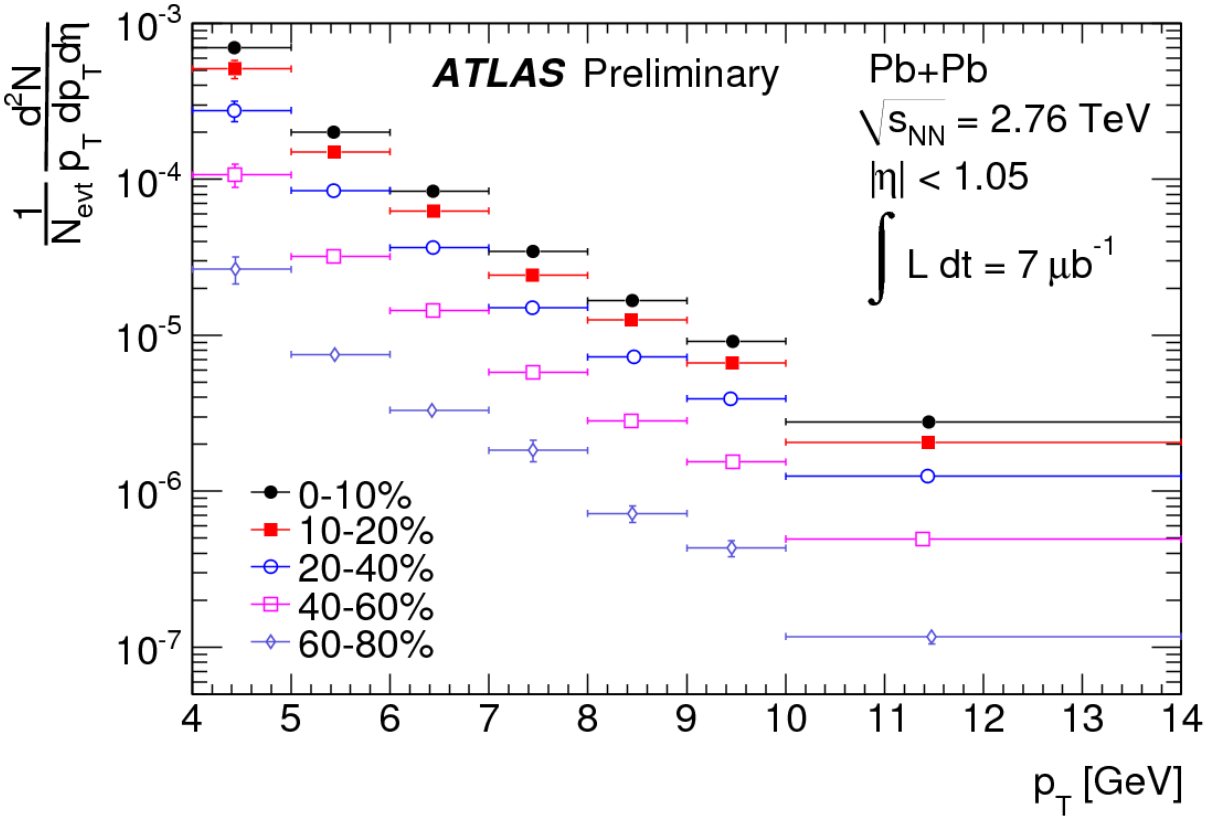
Results: yields from heavy flavor decays



- Invariant yields of muons from heavy flavor:

$$R_{CP}^{cent} = \frac{(1/N_{\rm evt}^{cent})(dN^{cent}/dp_{\rm T})}{R_{\rm coll}^{cent}(1/N_{\rm evt}^{60-80\%})(dN^{60-80\%}/dp_{\rm T})} \qquad (1)$$

- $R_{\rm coll}$: ratio of # binary collisions between central and peripheral

  $\Rightarrow$ 56.7 $\pm$ 6.2 (0-10%), 34.9 $\pm$ 3.5 (10-20%),16.7 $\pm$ 1.5 (20-40%), 4.9 $\pm$ 0.2 (40-60%)

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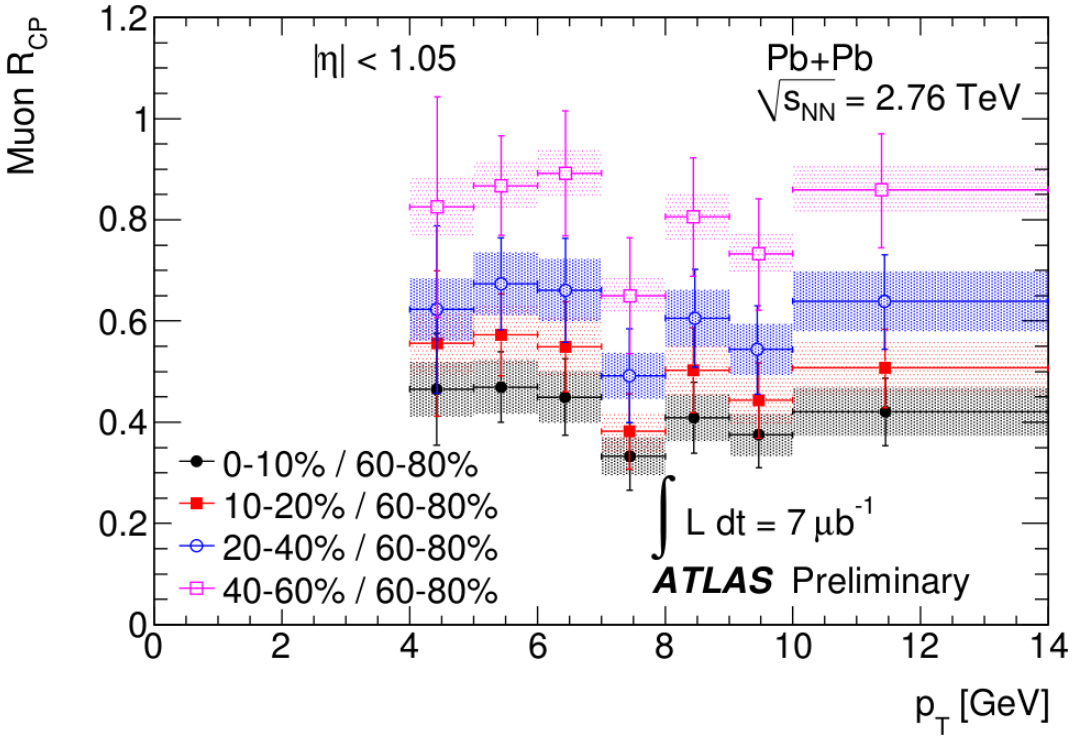
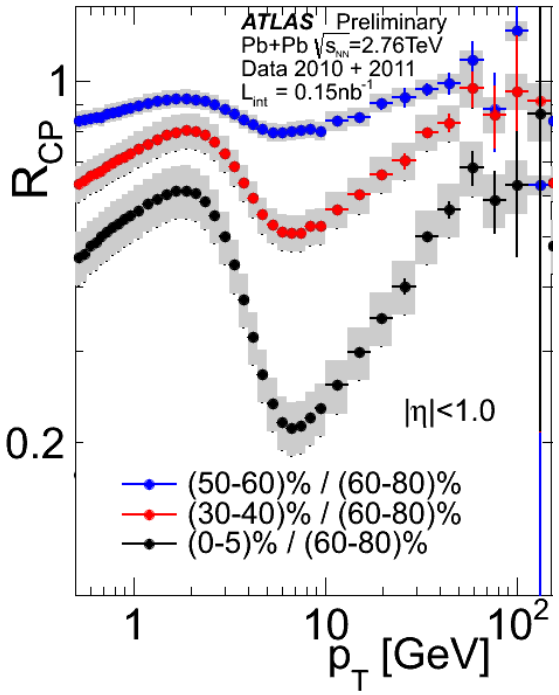
Results: $R_{\mathrm{CP}}(p_{\mathrm{T}})$ from heavy flavor decays





- Corr. syst. (shaded boxes) and uncorr. syst. + stat. (bars)
- Systematic suppression with centrality (~ 0.45 for 0-10%/60-80%)
- No p_{T} dependence, even as bottom overtakes charm!

  $\Rightarrow$ different suppression than in single hadron R_{CP}

  $\Rightarrow$ (ATLAS-CONF-2012-120, **P. Balek, Parallel 5C, 5/16**)

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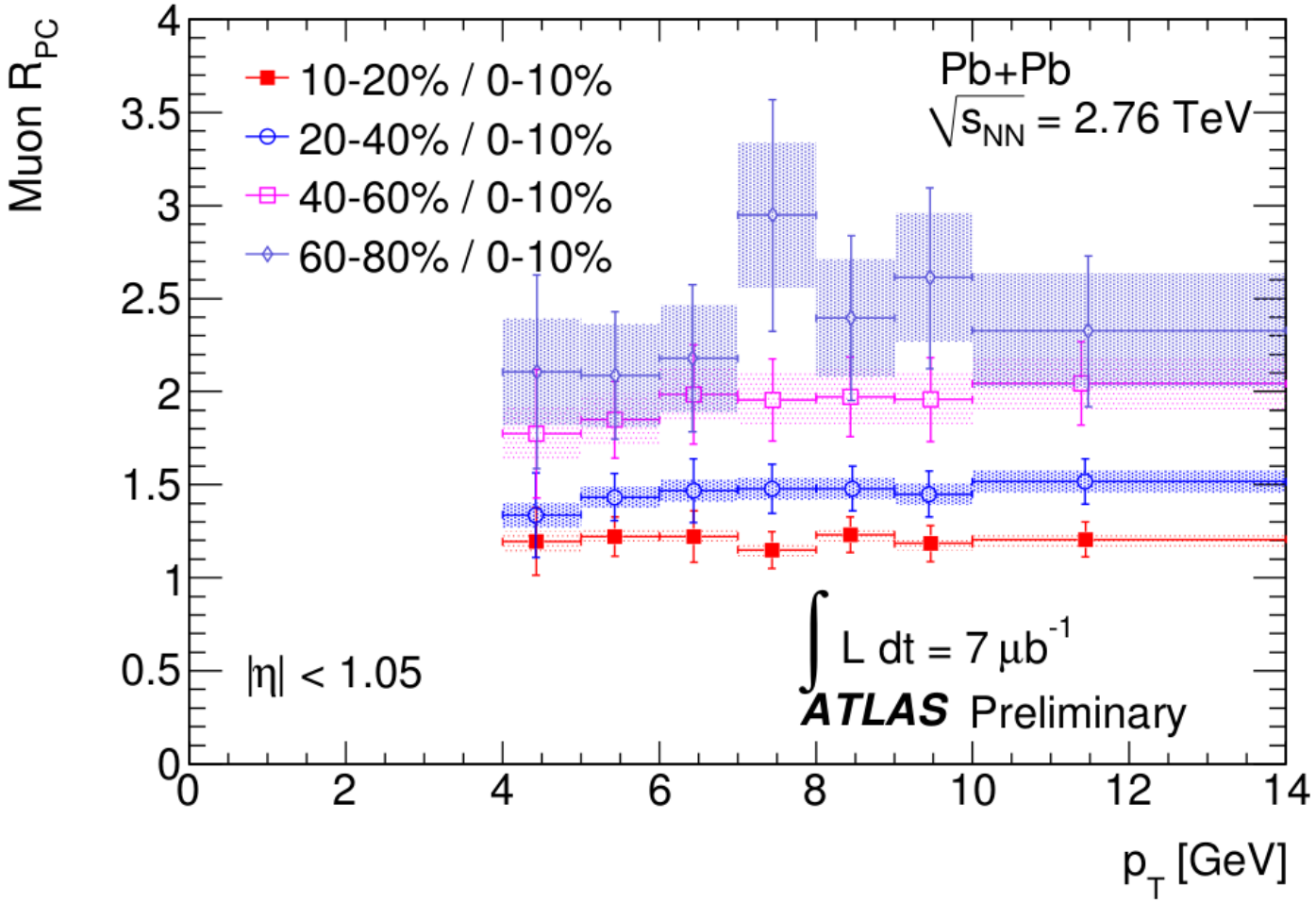
Results: $R_{\mathrm{PC}}(p_{\mathrm{T}})$ from heavy flavor decays



- R_{PC} uses 0-10% central bin as reference:

  $\Rightarrow$ does not suffer from statistical fluctuations and large systematic uncertainties in peripheral reference

- Better gauge of p_{T} dependence.

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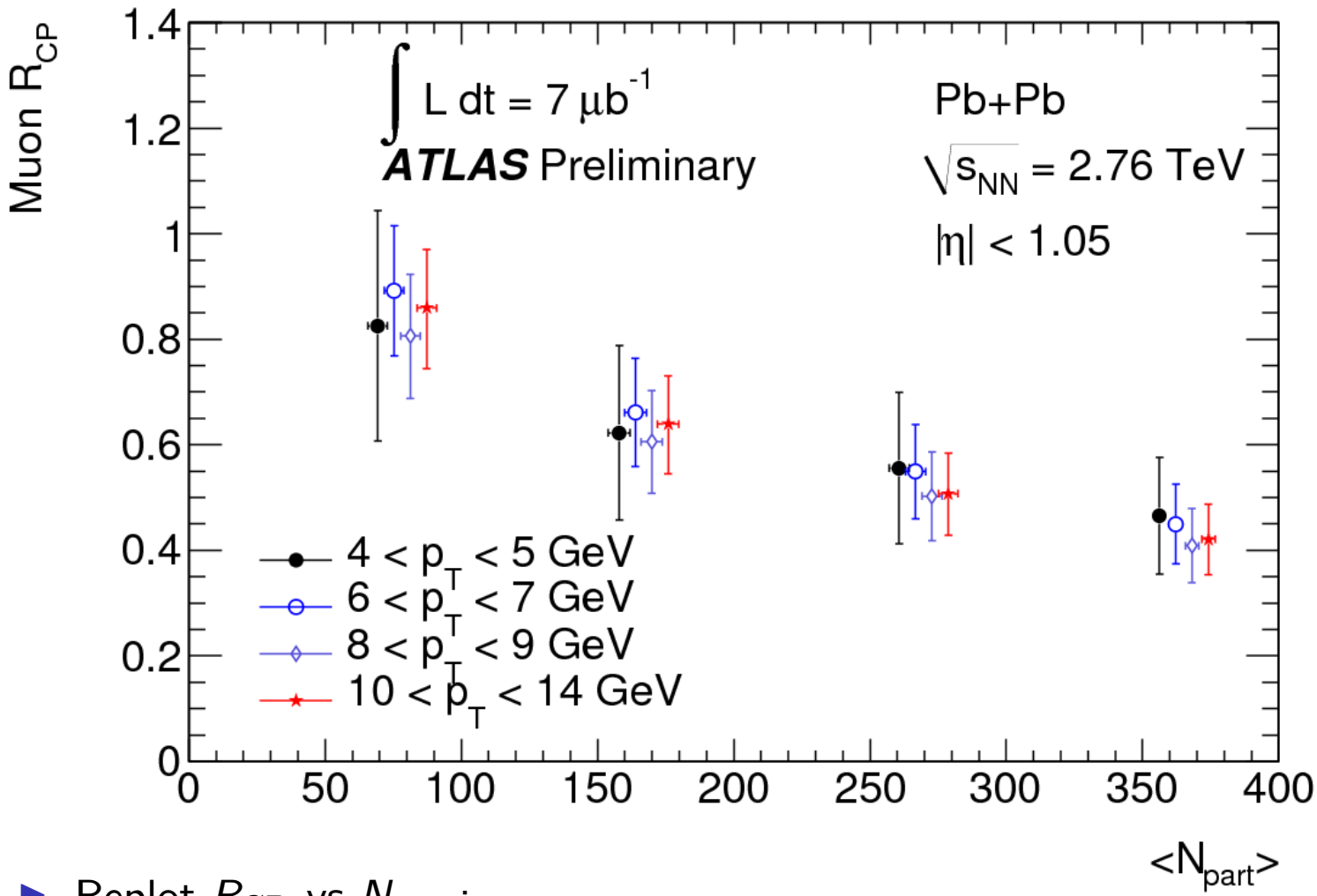
Results: $R_{\mathrm{CP}}(N_{\mathrm{part}})$ from heavy flavor decays



- Replot R_{CP} vs N_{part}:
  - $\Rightarrow$ suppression evolves smoothly with centrality.
  - $\Rightarrow$ similar N_{part} dependence at all p_{T}.

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Conclusion

- ATLAS has measured muon yields from heavy quark decays in Pb+Pb collisions.
  - $\Rightarrow$ 4 GeV $< p_{\mathrm{T}} <$ 14 GeV and $|\eta| < 1.05$
  - $\Rightarrow$ template fitting method to extract heavy quark signal from π/K background
- R_{CP} indicates factor of $\gtrsim 2$ suppression
  - $\Rightarrow$ flat with p_{T} (as charm/bottom ratio evolves)
  - $\Rightarrow$ smooth with centrality
- Distinct suppression pattern from ATLAS charged hadron R_{CP}!
  - $\Rightarrow$ indication that heavy flavor behaves differently at the LHC than at RHIC

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