First physics simulation for AFTER@LHC

Barbara Trzeciak
Czech Technical University in Prague

M. Anselmino (Torino), R. Arnarldi (Torino), S.J. Brodsky (SLAC), V. Chambert (IPN), J.P. Didelez (IPN), B. Genolini (IPN), E.G. Ferreiro (USC), F. Fleuret (LLR), Y. Gao (Tsinghua), C. Hadjidakis (IPN), J.P. Lansberg (IPN), C. Lorcé (IPN), L. Massacrier (LAL), R. Mikkelsen (Aarhus), A. Rakotozafindrabe (CEA), P. Rosier (IPN), I. Schienbein (LPSC), E. Scomparin (Torino), B. Trzeciak (CTU), U.I. Uggerhøj (Aarhus), R. Ulrich (Karlsruhe), Z. Yang (Tsinghua)

AFTER@LHC week
17-21 November, 2014
CERN

esf evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

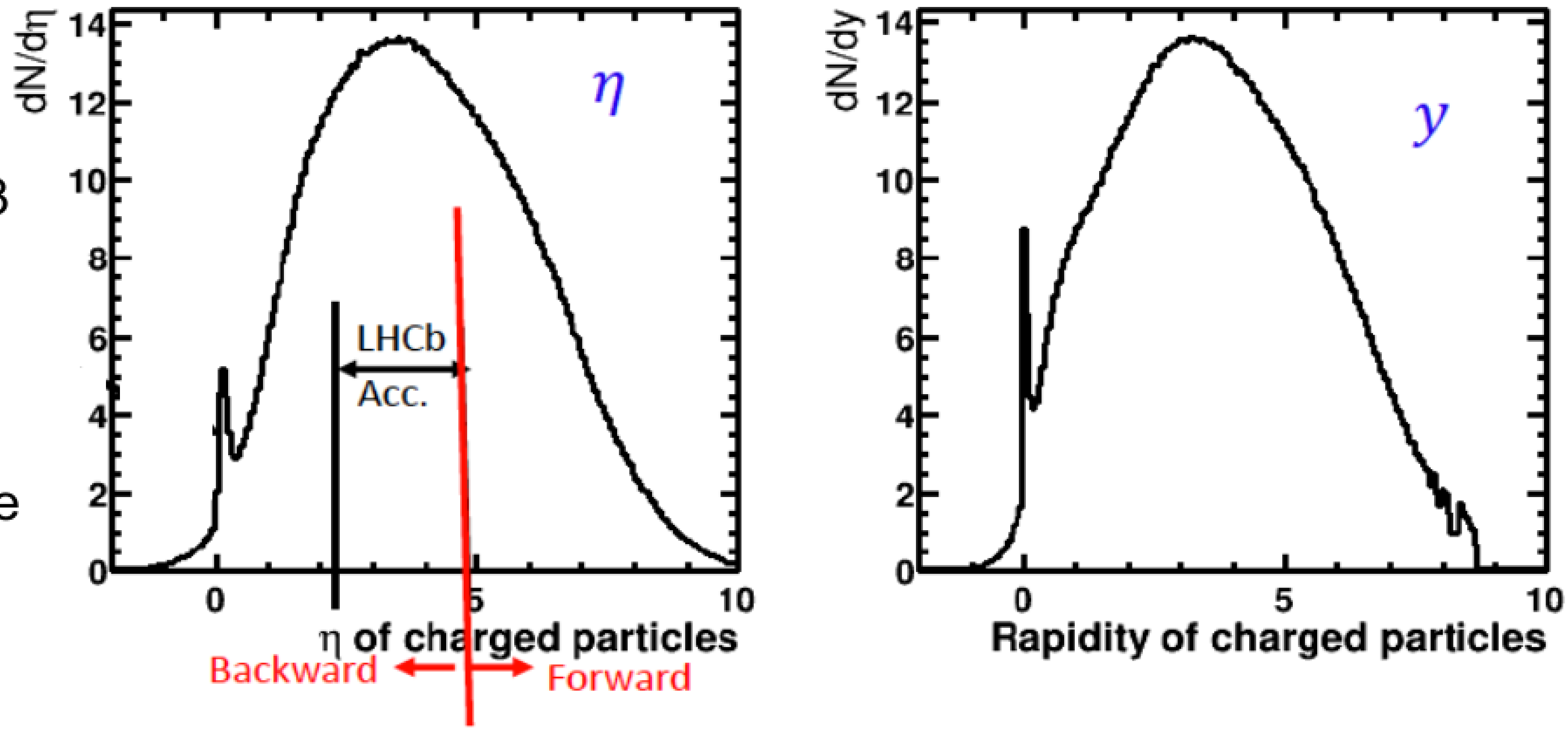
7 TeV proton beam on a Pb target $\sqrt{s_{NN}}$ = 115 GeV

- ✓ Full LHCb simulation and standard reconstruction

- ✓ HIJING simulations (v. 1.383bs.2)
- ✓ 10 000 events generated without pile-up

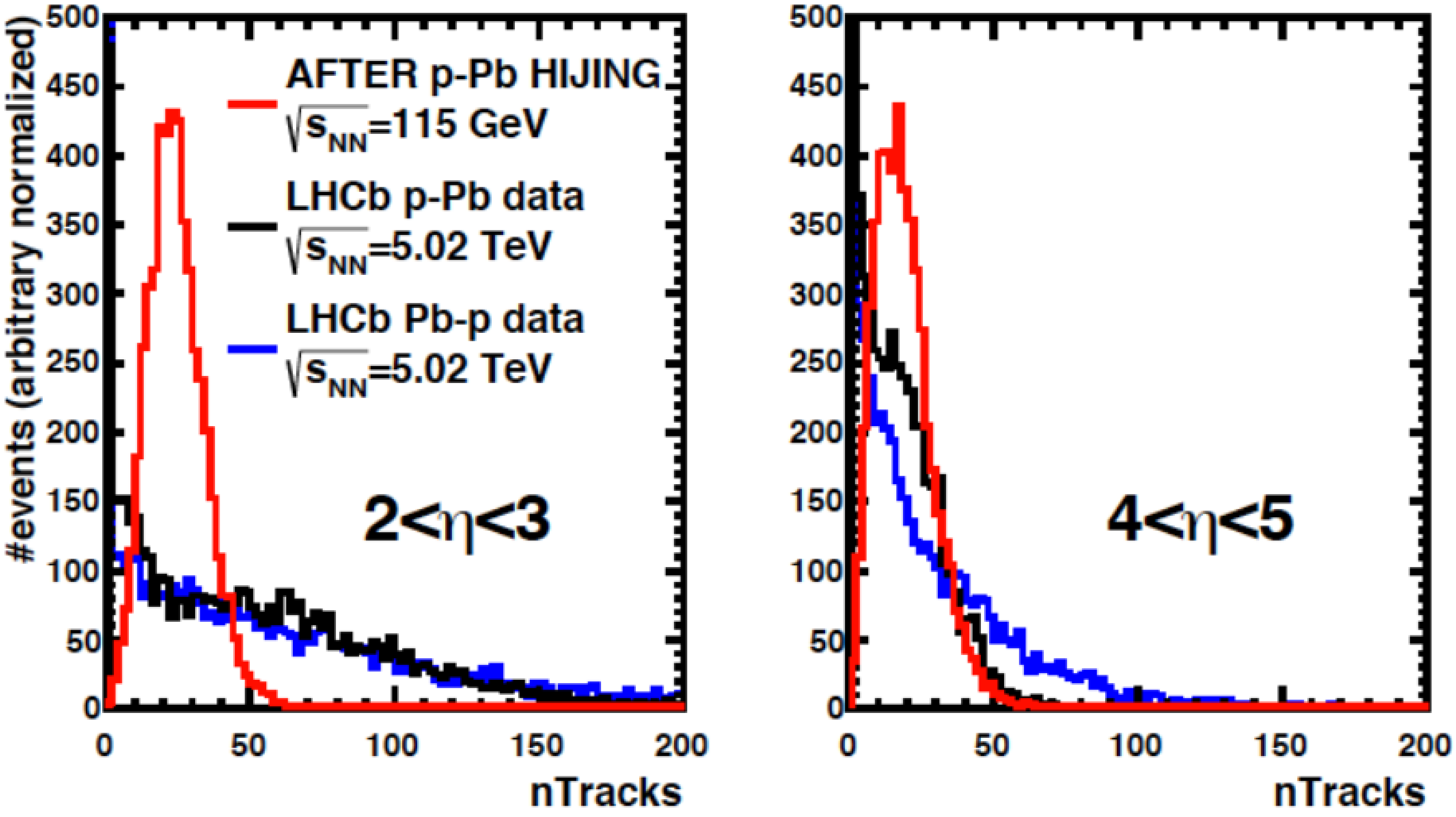
Z. Yang, AFTER workshop les Houches, January 2014

dN/dη ~ 13 Generated charged particles in LHCb acceptance



7 TeV proton beam on a Pb target $\sqrt{s_{NN}}$ = 115 GeV

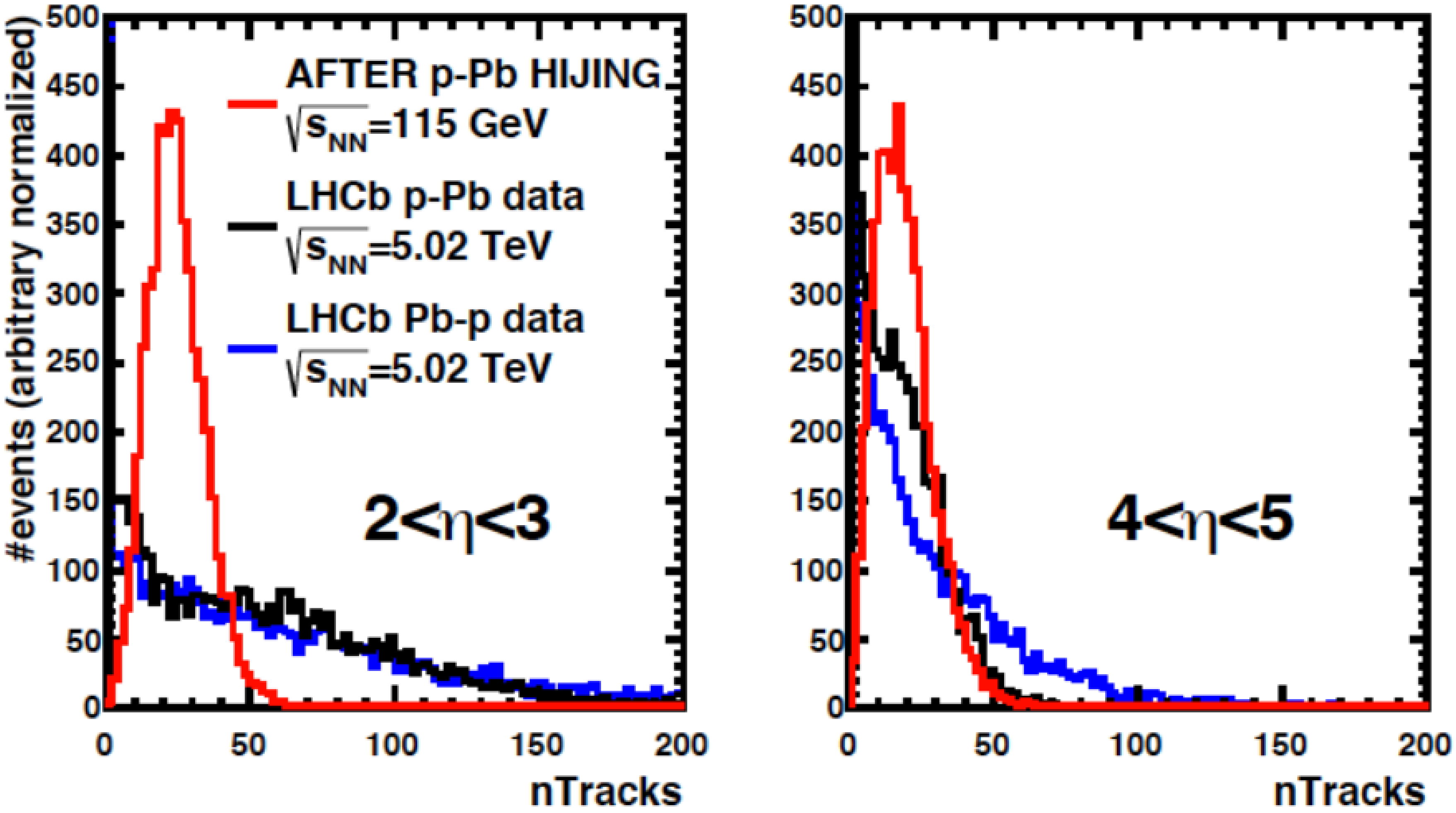
Z. Yang, AFTER workshop les Houches, January 2014



- ✓ HIJING simulations of number of tracks for a fixed target mode at $\sqrt{s_{NN}}$ = 115 GeV using LHCb-like detector compared to LHCb measurement at a collider mode at $\sqrt{s_{NN}}$ = 5.02 TeV

7 TeV proton beam on a Pb target $\sqrt{s}_{NN}$ = 115 GeV

Z. Yang, AFTER workshop les Houches, January 2014



- ✓ Probability of high track multiplicity is lower in the fixed target mode than in the collider mode, at LHCb acceptance 2 < η < 5
    - more discussion on Wednesday morning
- ✓ Boost should not be an issue – no problem for LHCb-like detector to cope with seen multiplicity

Expected quarkonium yield

pp@√s = 115 GeV

Target	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} $= A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} $=A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Liq. D_2	24	9.6 10^8	1.9 10^6
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^7 1.4 10^9	1.8 10^5 7.2 10^6
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^5	1.2 10^3

1 m H_2 target

- ✓ 1000 times more statistics than at RHIC (@200 GeV)
- ✓ Comparable statistics to LHCb

Detailed study of quarkonium production

Expected quarkonium yield

pA@$\sqrt{s_{NN}}$ = 115 GeV

Target	A	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} =$A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1cm Be	9	0.62	1.1 10^8	2.2 10^5
1cm Cu	64	0.42	5.3 10^8	1.1 10^6
1cm W	185	0.31	1.1 10^9	2.3 10^6
1cm Pb	207	0.16	6.7 10^8	1.3 10^6
LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^7	7.5 10^4
RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^6	5.9 10^3
RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^4	18

1 cm Pb target

- ✓ 100 times more statistics than at RHIC (dAu@200 GeV)
- ✓ Comparable statistics to LHCb

Detailed study of quarkonium production and nuclear effects

Expected quarkonium yield

PbA@$\sqrt{s_{NN}}$ = 115 GeV

Target	A.B	$\int\mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = AB$\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} =AB$\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	**800**	**3.4 10^6**	**6.9 10^3**
1cm Be	207.9	**25**	**9.1 10^5**	**1.9 10^3**
1cm Cu	207.64	**17**	**4.3 10^6**	**0.9 10^3**
1cm W	207.185	**13**	**9.7 10^6**	**1.9 10^4**
1cm Pb	207.207	**7**	**5.7 10^6**	**1.1 10^4**
LHC PbPb 5.5 TeV	207.207	**0.5**	**7.3 10^6**	**3.6 10^4**
RHIC AuAu 200GeV	198.198	**2.8**	**4.4 10^6**	**1.1 10^4**
RHIC AuAu 62GeV	198.198	**0.13**	**4.0 10^4**	**61**

1 cm Pb target

- ✓ Similar statistics than at RHIC @200 GeV
- ✓ 2 order of magnitude larger that at RHIC @62 GeV

Detailed study of quarkonium states

Quarkonia simulations with PYTHIA, pp at √s = 115 GeV

- PYTHIA 8.185
- Fast simulations with LHCb reconstruction parameters

✓ *Requirements:*

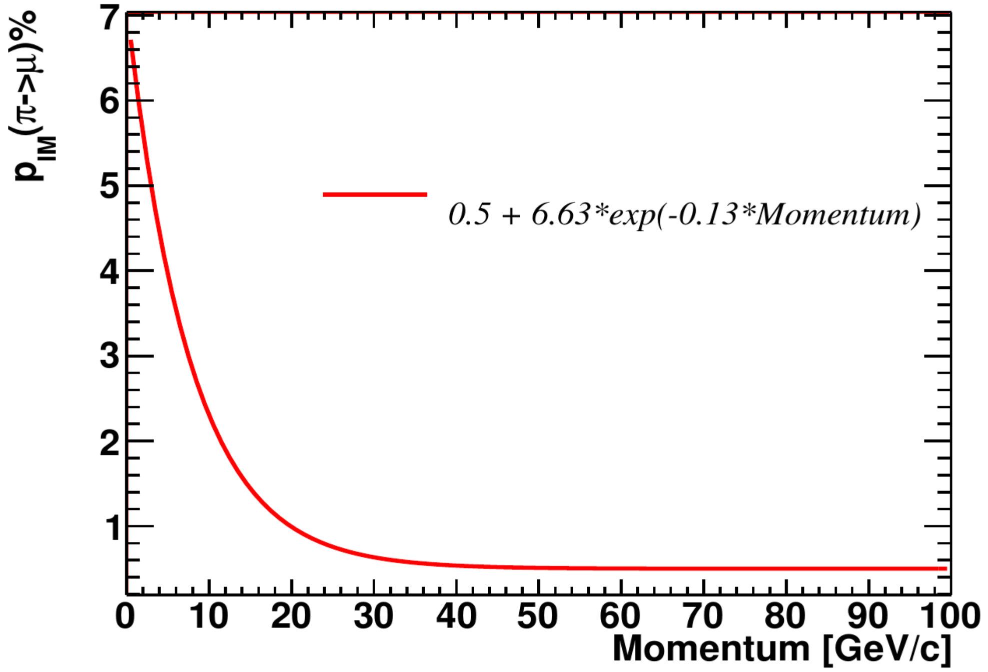
- Momentum resolution: $\Delta p/p = 0.5\%$
- Energy resolution: $\Delta E/\sqrt{E} = 10\%$
- μ identification efficiency: 98%

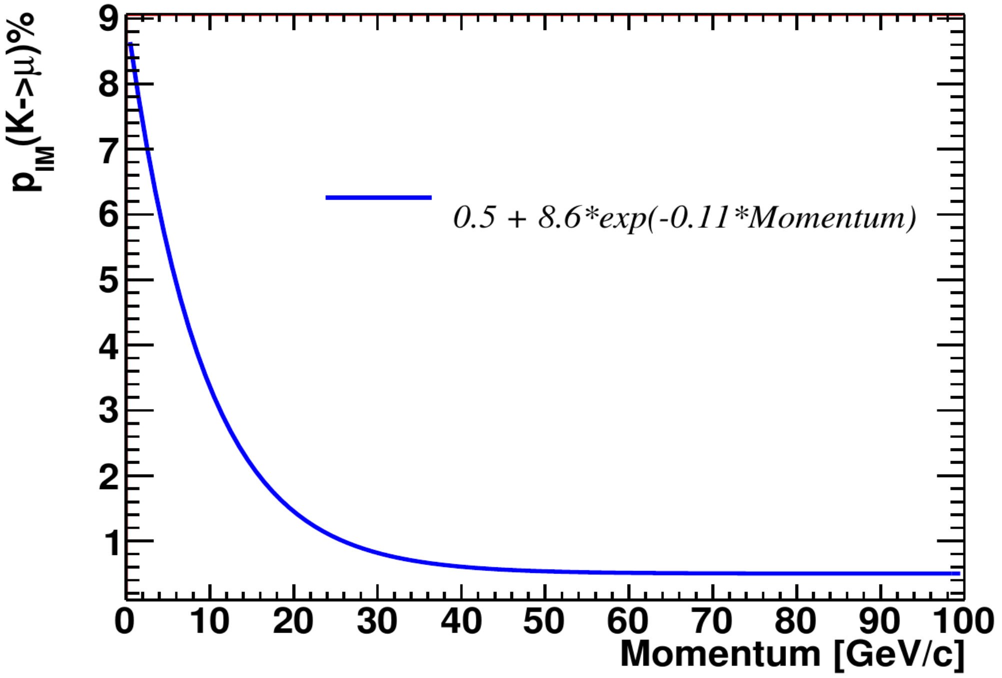
✓ *Single μ cuts:*

- $2 < \eta_\mu < 5$
- $p_T^\mu > 0.7$ GeV/c

✓ *μ misidentification (with π or K):*

- If π/K decays before 12m (LHCb calorimeter) it is rejected by tracking
- If decays after 12m misidentification probability is applied – see plots



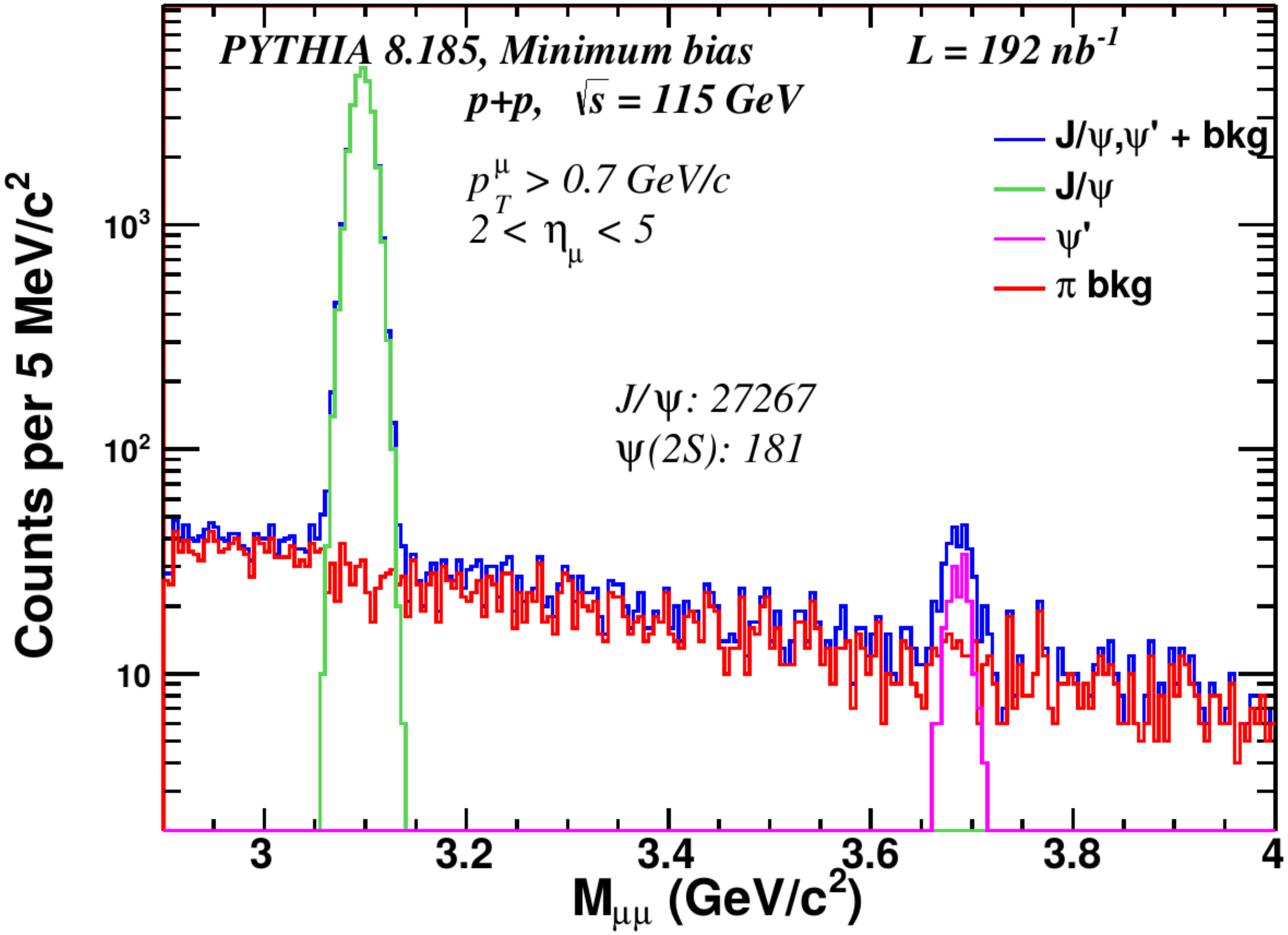


F. Achilli et al, arXiv:1306.0249

ψ signal simulation with full background

$J/\psi \rightarrow \mu^+ \mu^-$

- $\int L = 192\ nb^{-1}$, **1.5 minute of data taking with 1m H_2 target**

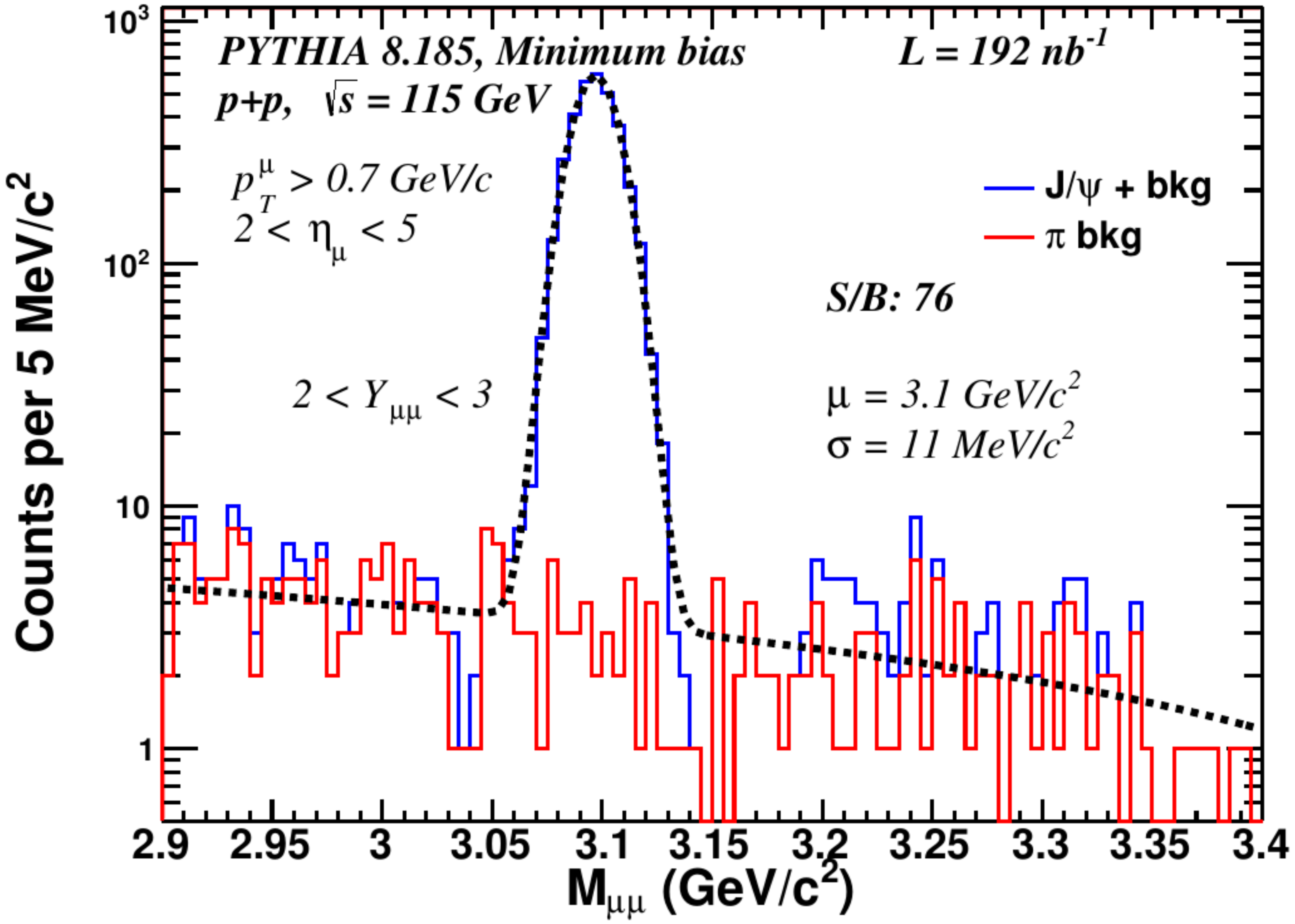


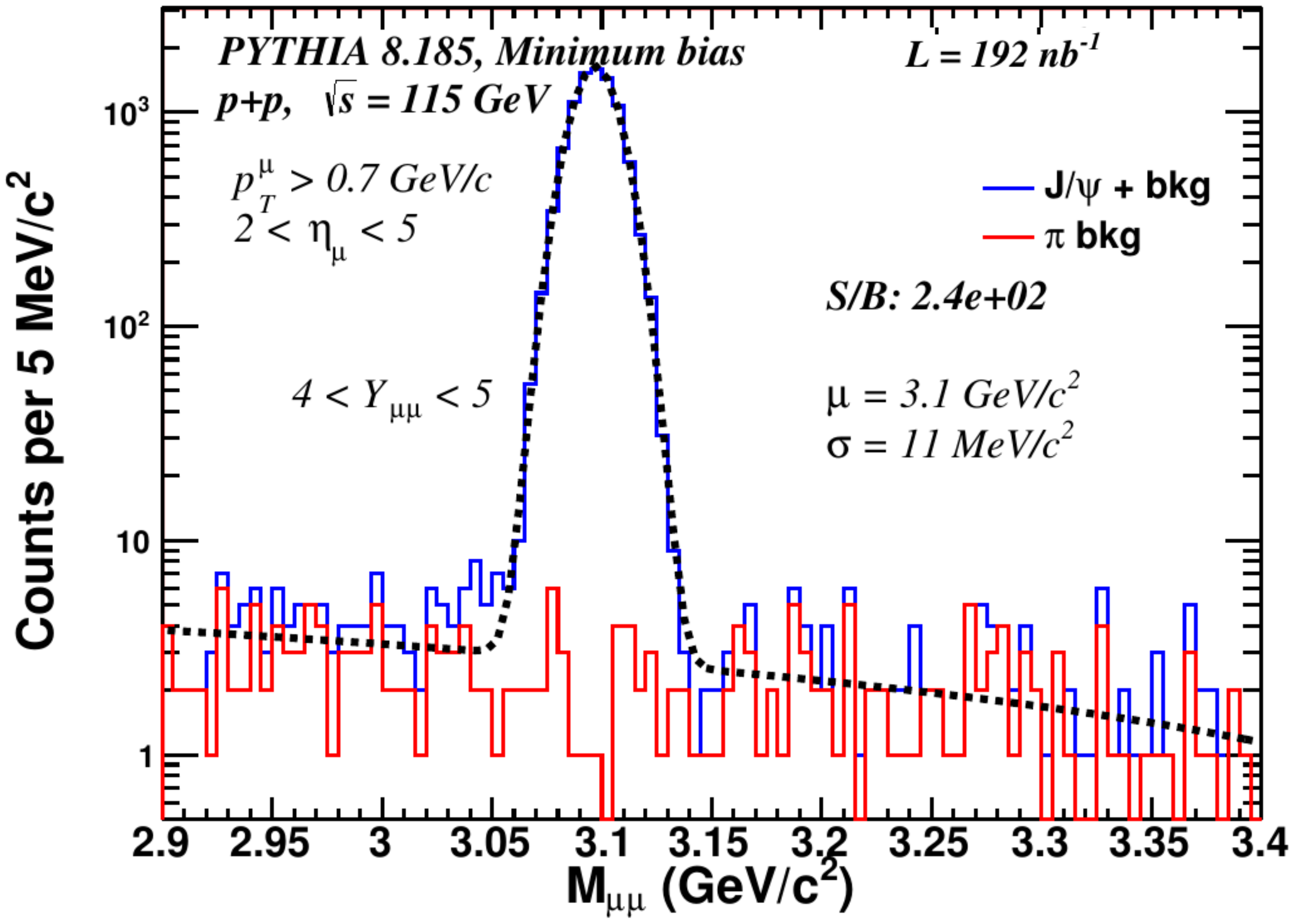
- Dominant source of background is from misidentified π
- ψ(2S) to J/ψ ratio should be 4 times higher - "PYTHIA output needs to be checked"

J/ψ signal simulation with full background, y bins

$J/\psi \rightarrow \mu^+ \mu^-$

- $\int L = 192\ nb^{-1}$, **1.5 minute of data taking with 1m H_2 target**





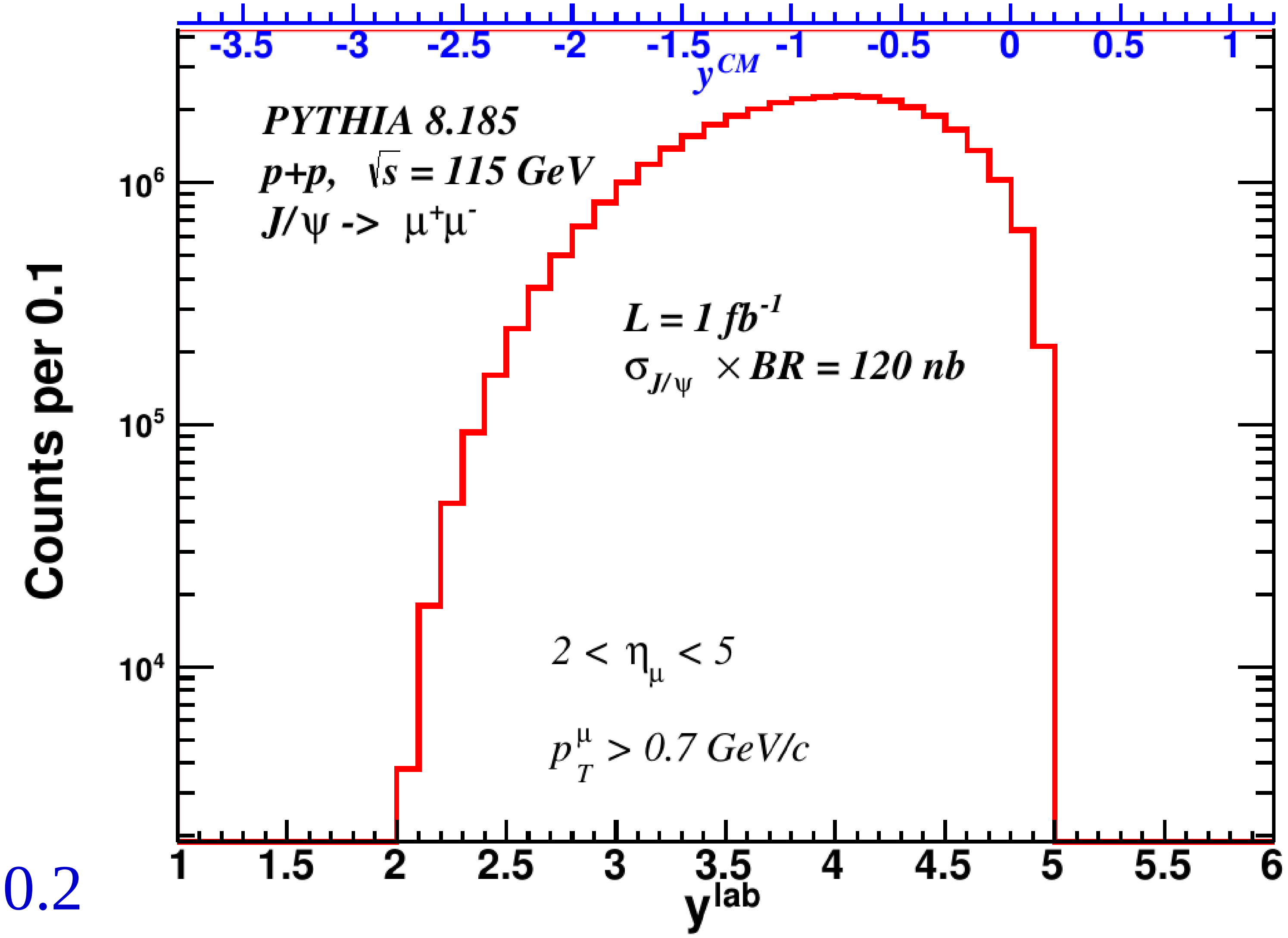
- Excellent J/ψ signal
- Most background is combinatorial (μ not coming from J/ψ decay)

J/ψ acceptance

$J/\psi \rightarrow \mu^+ \mu^-$

Pure signal

- $\int L = 1\ fb^{-1}$, **2 weeks of data taking with 1m H_2 target**



J/ψ y range:

- $2 < y_{lab} < 5$
- $-2.8 < y_{CMS} < 0.2$

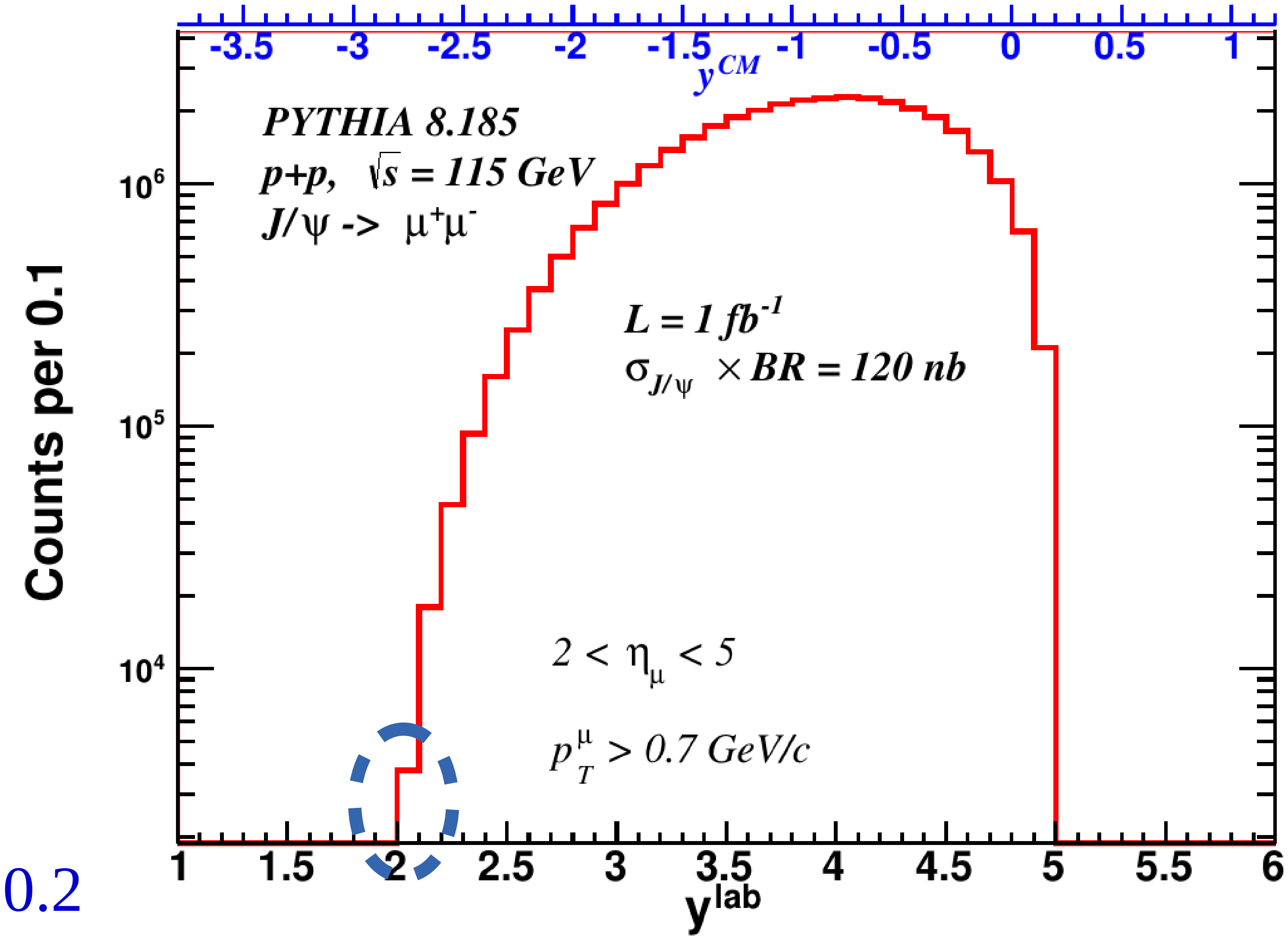
- J/ψ rapidity range limited only by cuts on μ ($2 < \eta_\mu < 5$)

J/ψ acceptance

$J/\psi \rightarrow \mu^+ \mu^-$

Pure signal

- $\int L = 1$ fb^{-1} , **2 weeks of data taking with 1m H_2 target**



J/ψ y range:

- $2 < y_{lab} < 5$
- $-2.8 < y_{CMS} < 0.2$

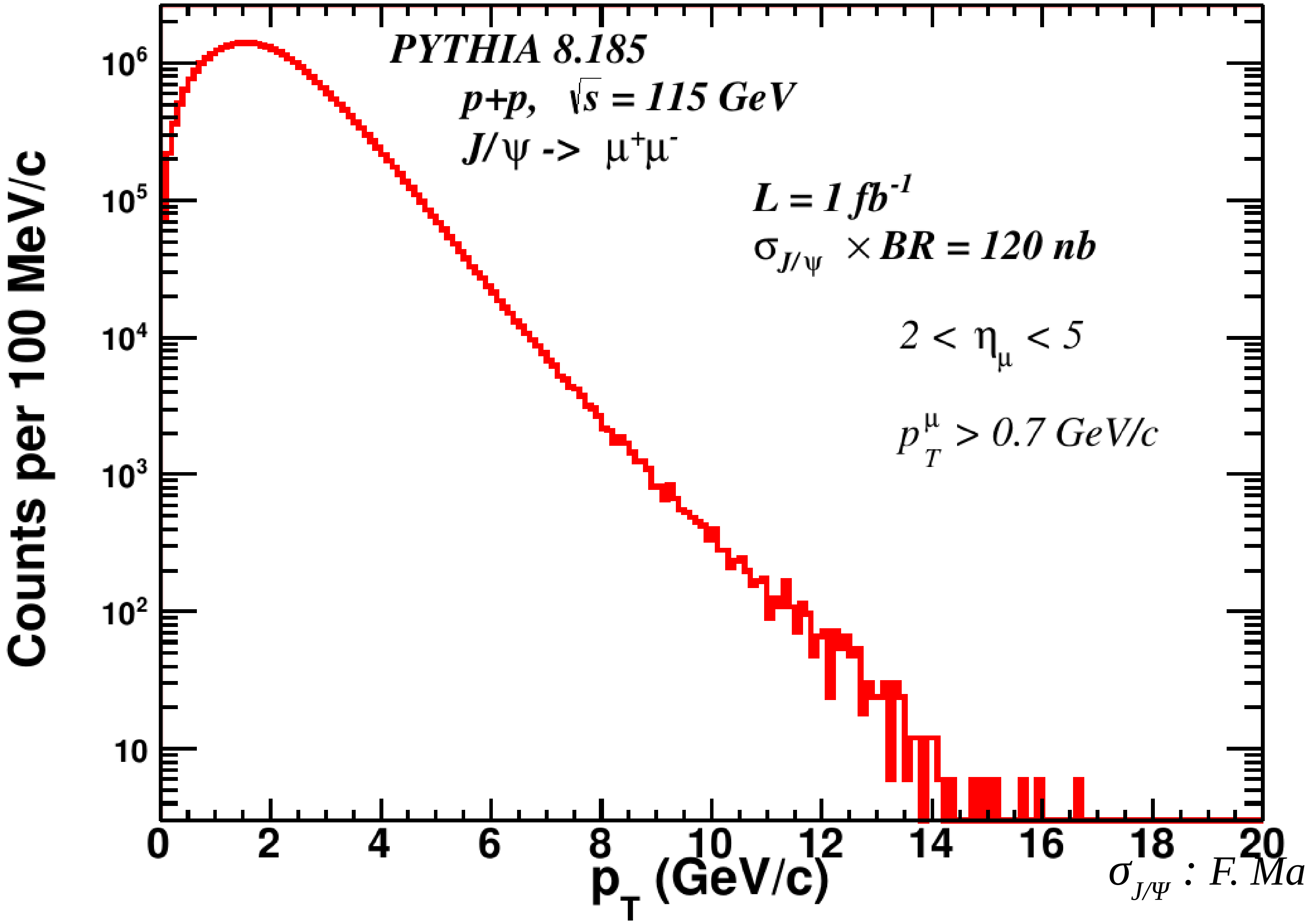
- J/ψ rapidity range limited only by cuts on μ ($2 < \eta_\mu < 5$)
- With larger acceptance detector can get wider J/ψ rapidity range

J/ψ p_T spectrum

$J/\psi \rightarrow \mu^+ \mu^-$

Pure signal

- $\int L = 1\ fb^{-1}$, **2 weeks of data taking with 1m H_2 target**



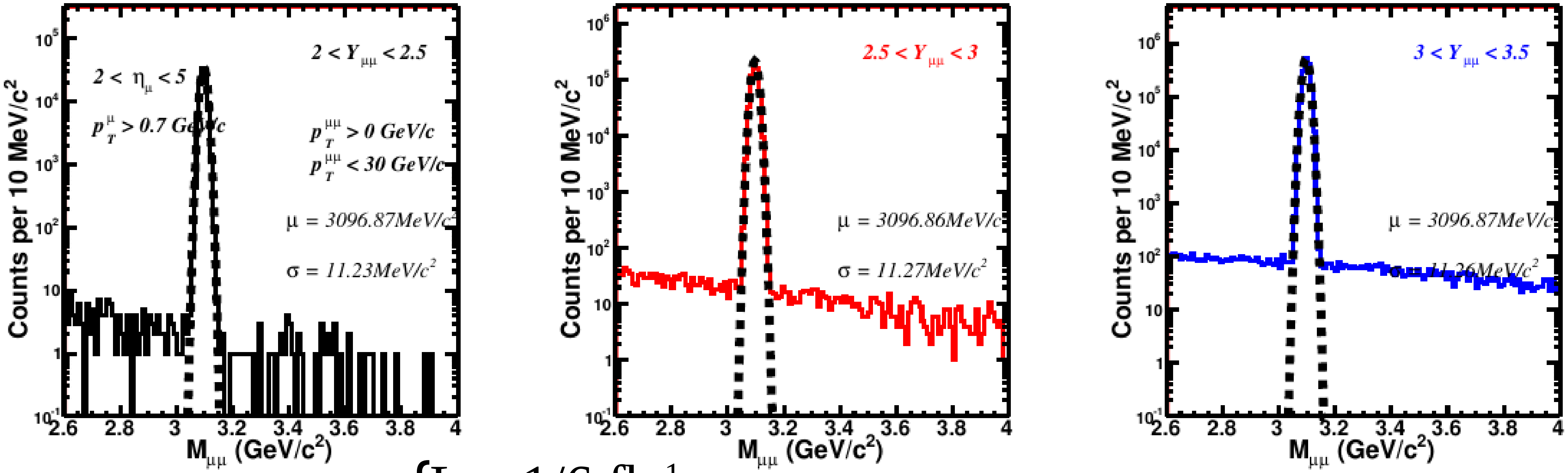
$\sigma_{J/\psi}$: F. Maltoni et al. PLB 638 (2006) 202

- Can easily reach $p_T = 15$ GeV/c for J/ψ with a year of data taking (20 fb^{-1})
- This corresponds to $x_T = 0.25$
- Equivalent p_T reach to RHIC @500 GeV
- The same p_T reach expected for pA

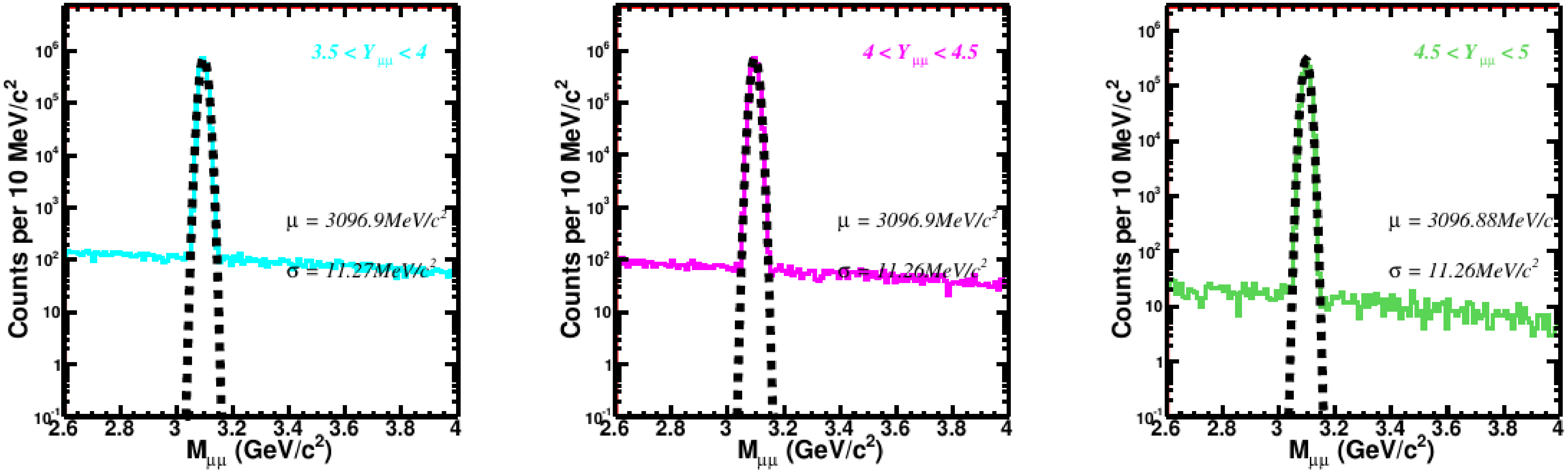
J/ψ signal in y bins

J/ψ → μ⁺ μ⁻

Pure signal



$\int L = 1/6\ \text{fb}^{-1}$



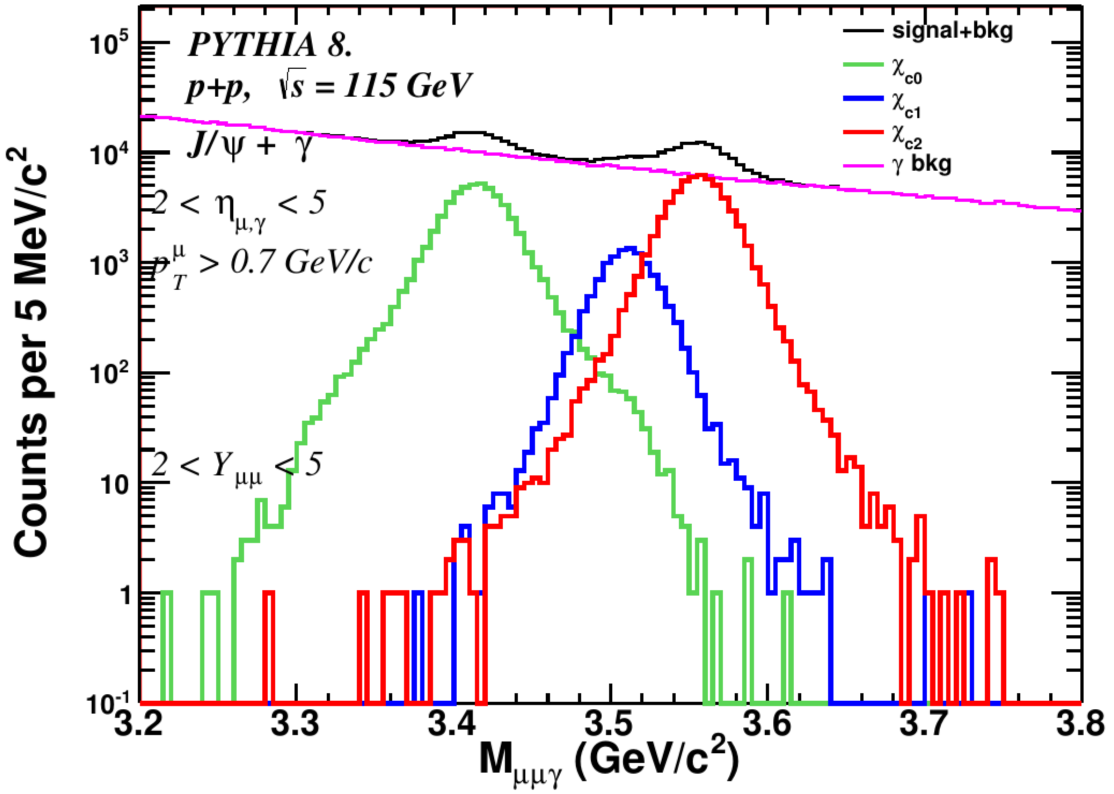
- Significant J/ψ signals for each rapidity bin

χ_c simulations – PYTHIA inputs

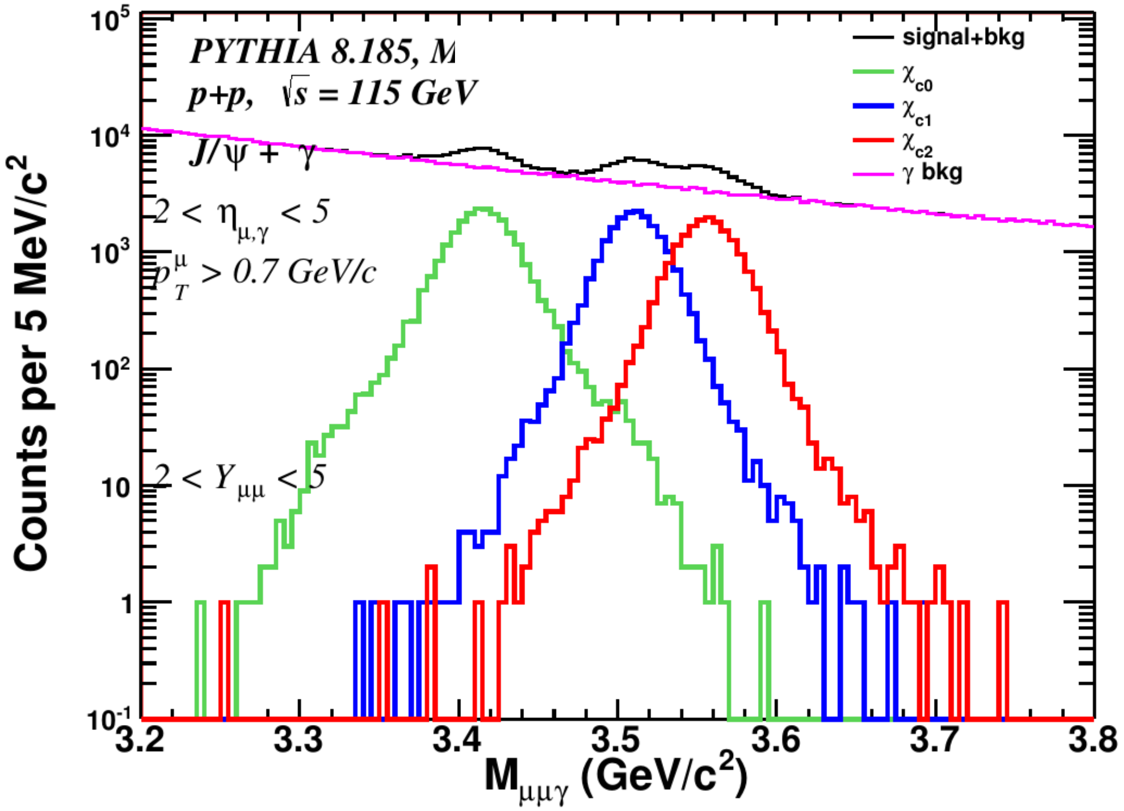
$\chi_C \rightarrow J/\psi\,\gamma \rightarrow \mu^+ \mu^- \gamma$

Pure signal

singlet



octet



Long-distance matrix elements:

Charmonium:O(3PJ)[3P0(1)] (default = 0.05,0.05,0.05; minimum = 0.0)

Charmonium:O(3PJ)[3S1(8)] (default = 0.0031,0.0031,0.0031; minimum = 0.0)

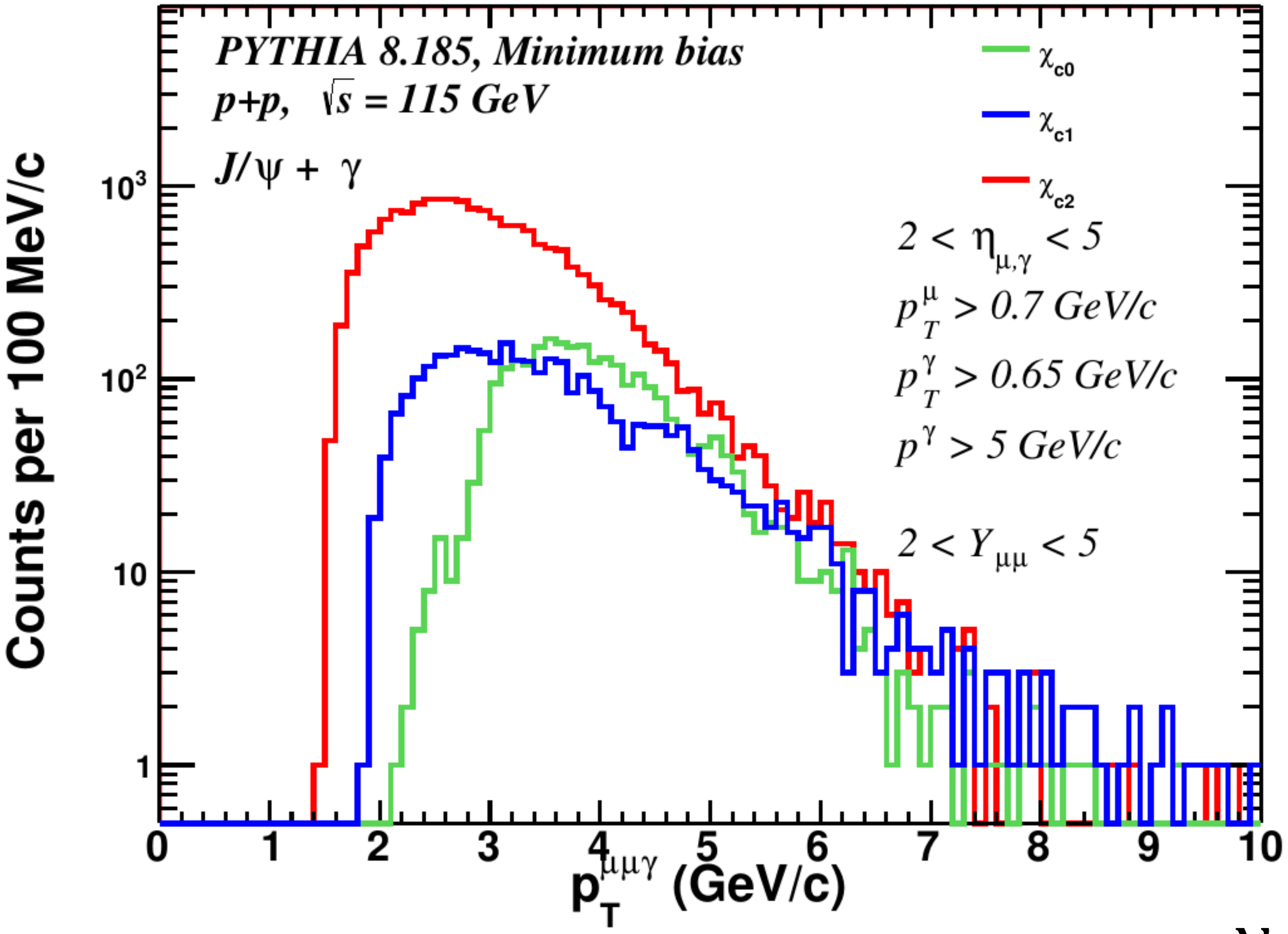
Need to check PYTHIA rates versus low-energy and low-p_T data !!!

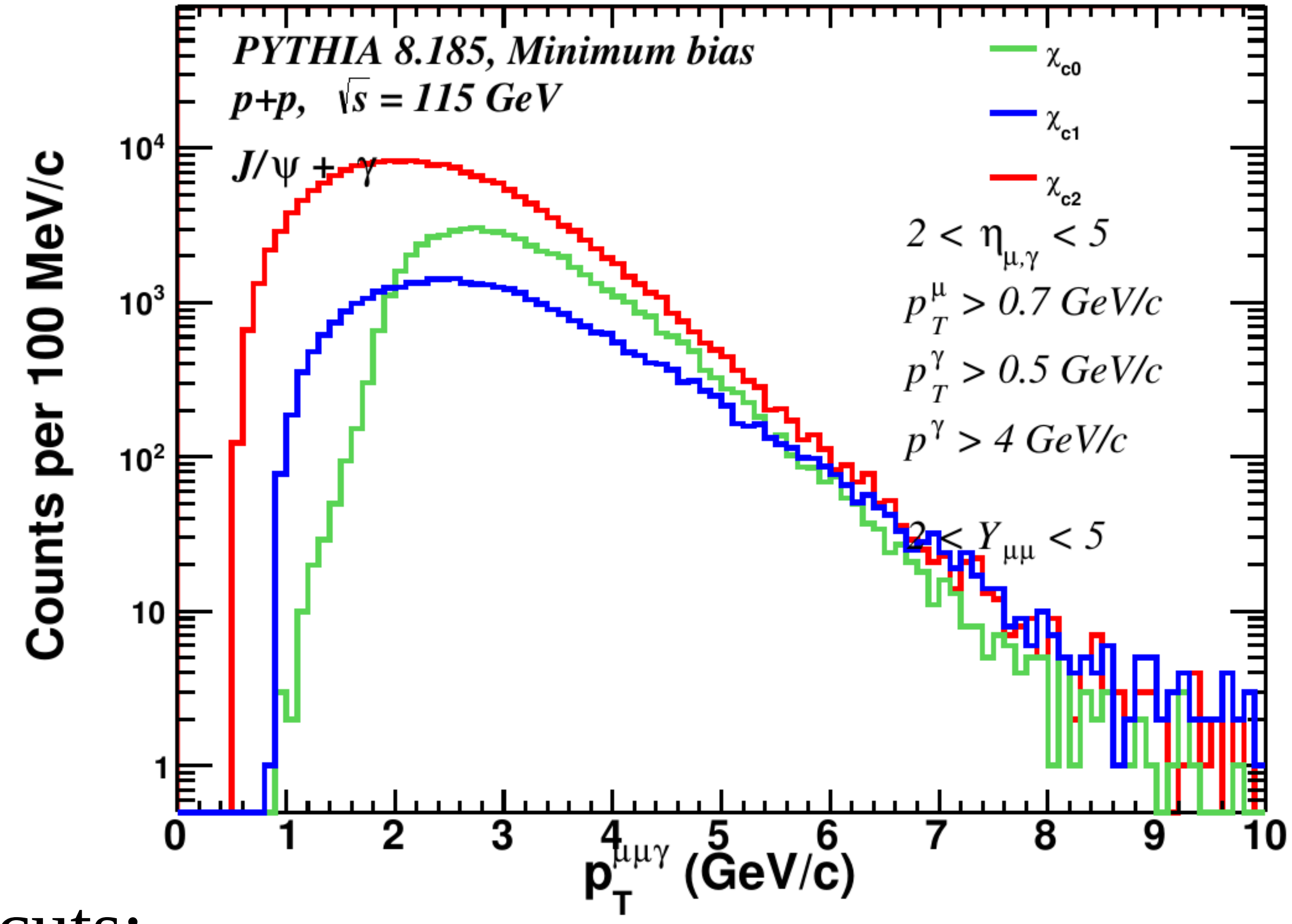
χ_c simulations

Pure signal

$\chi_C \rightarrow J/\psi\, \gamma \rightarrow \mu^+ \mu^- \gamma$

- χ_C p_T reach for different γ cuts





γ cuts:

$p_T > 0.65$ GeV/c, $p > 5$ GeV/c

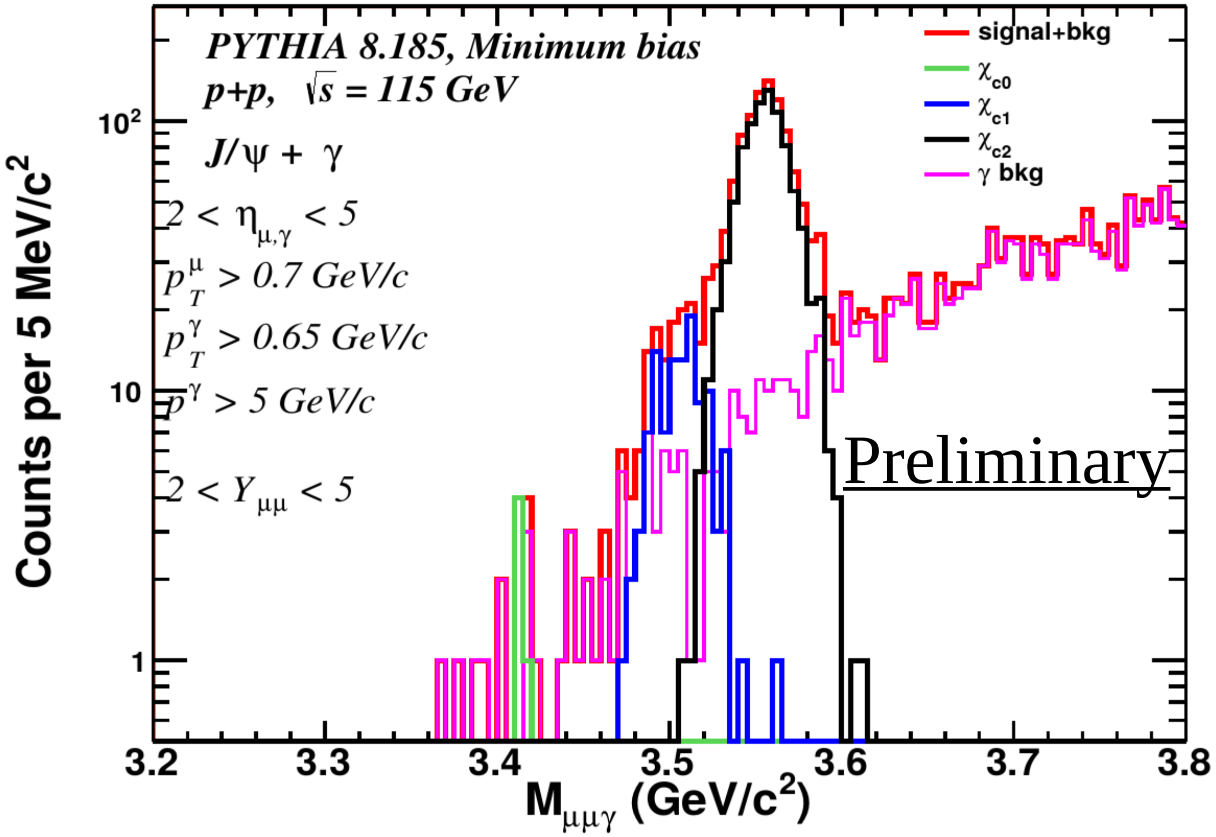
$p_T > 0.5$ GeV/c, $p > 4$ GeV/c

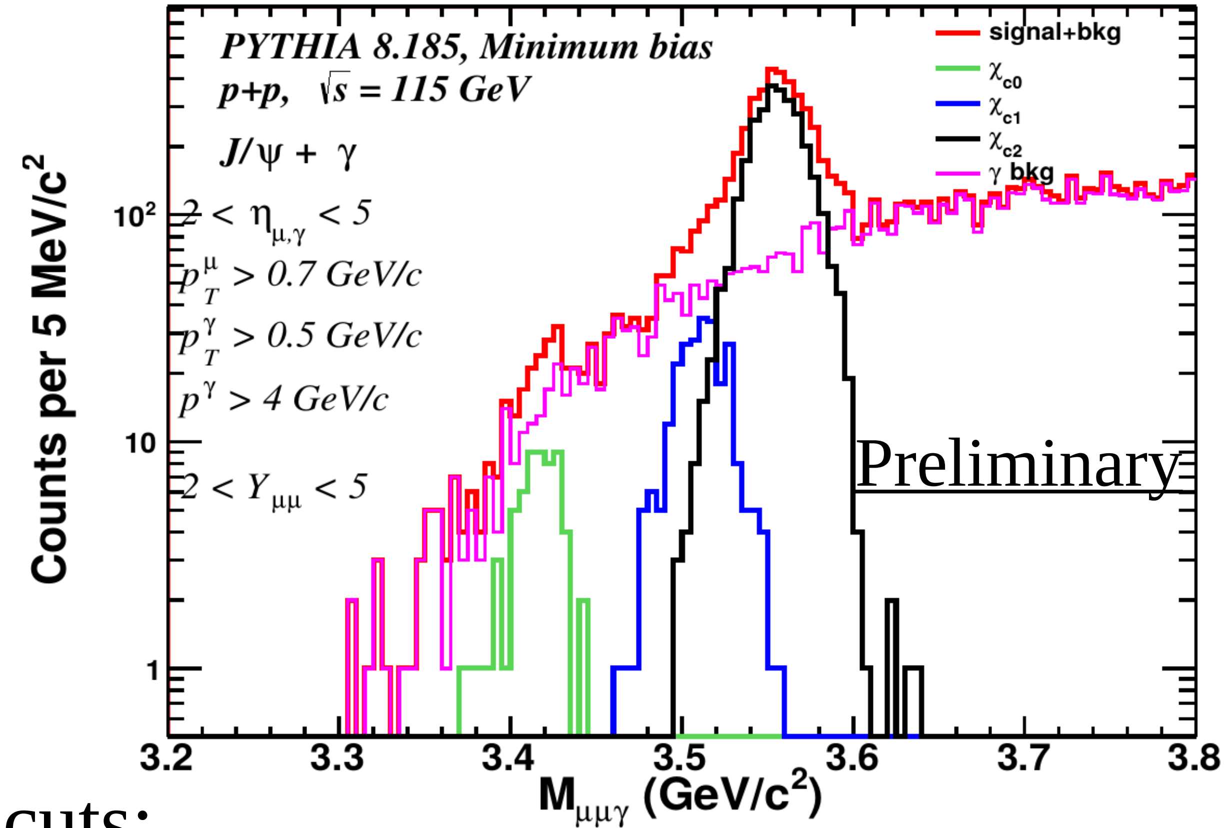
- Need to go down with γ cuts in order to reach $p_T = 0$ for χ_C

χ_c simulations with full background

$\chi_C \rightarrow J/\psi\,\gamma \rightarrow \mu^+ \mu^- \gamma$

- $\int L = 192\ \mathrm{nb}^{-1}$ - **1.5 minute of data taking with 1m H_2 target**
- Preliminary studies – need (i) to check signal normalization from PYTHIA, (ii) to study γ isolation, identification and misidentification, χ_{C1}, χ_{C2} signal extraction, (iii) to increase statistics
  - **Lowering cuts on γ - aim to get low p_T χ_C**





γ cuts:

$p_T > 0.65$ GeV/c, $p > 5$ GeV/c

$p_T > 0.5$ GeV/c, $p > 4$ GeV/c

Summary

- LHCb HIJING simulations for pPb@115 GeV
  - ➔ Track multiplicity study – LHCb-like detector should cope with the expected multiplicities without any difficulties
- First simulations using PYHIA for pp@115 GeV, focusing on quarkonia
  - ➔ Fast simulations with LHCb requirements
  - ➔ Significant J/ψ signal in whole available y range, up to high p_T
  - ➔ χ_C simulations ongoing, but some issues:
    - ➔ Ratios of χ_C states: one needs to cross-check PYHIA cross sections
    - ➔ How far down in χ_C p_T we can go

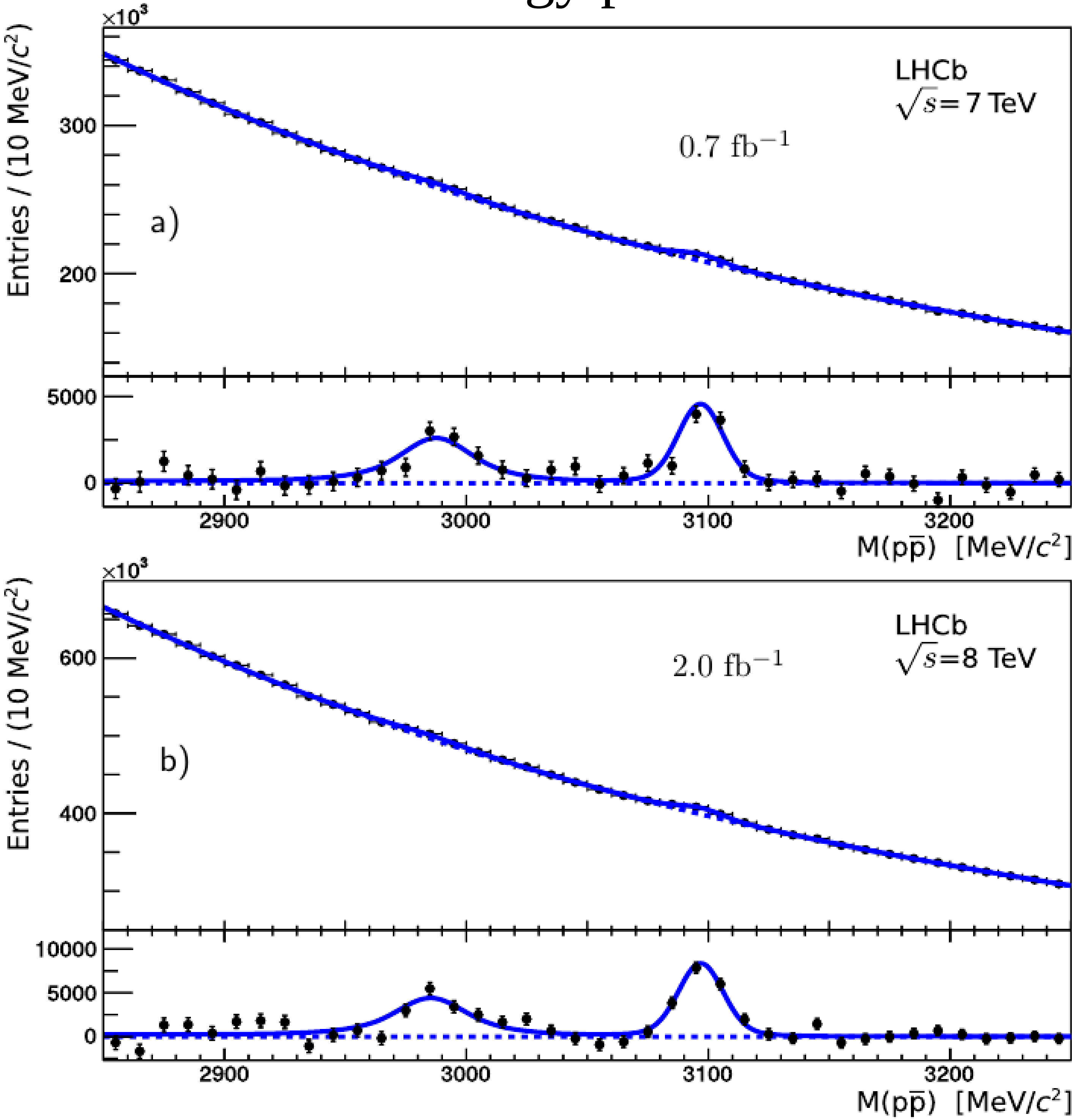
- Development of a simulation framework for AFTER

Prospects

$\eta_c(1S) \rightarrow p\overline{p}$

LHCb: arXiv:1409.3612

- Avoid problem with reconstruction of radiative decays with low-energy photons



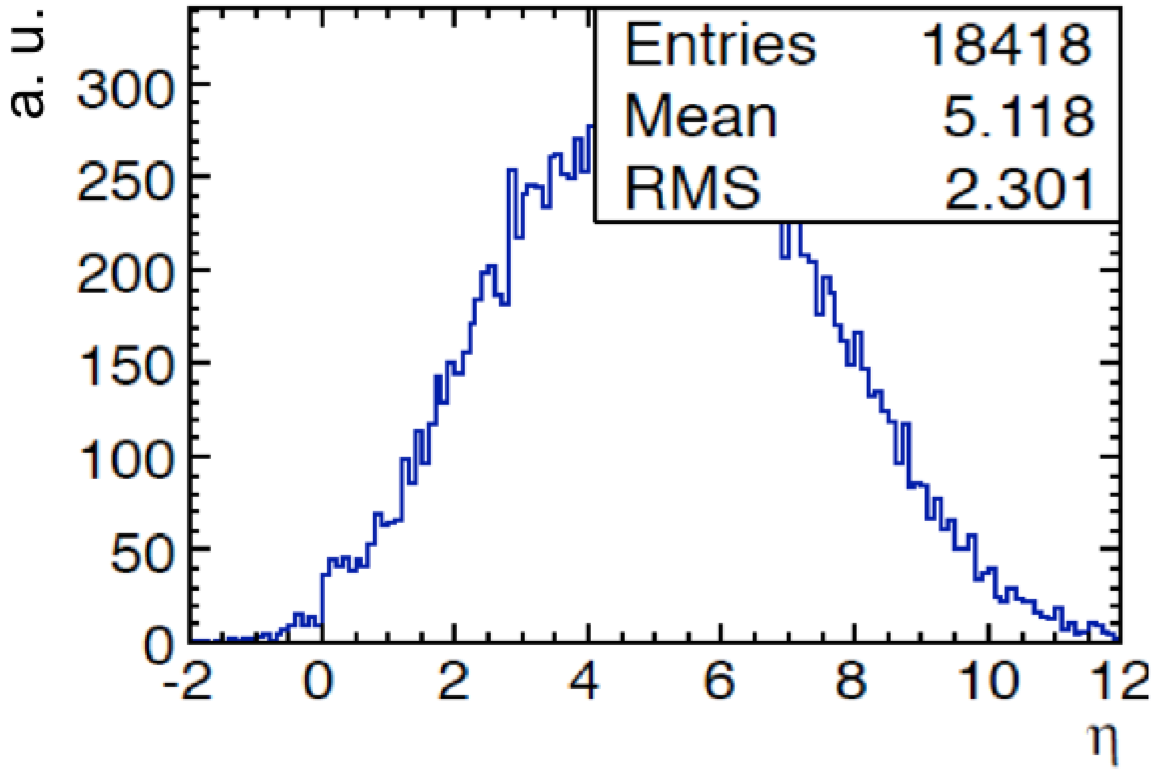
Proton-antiproton invariant mass spectrum with η_C(1S) and J/ψ signal, for candidates originating from a primary vertex.

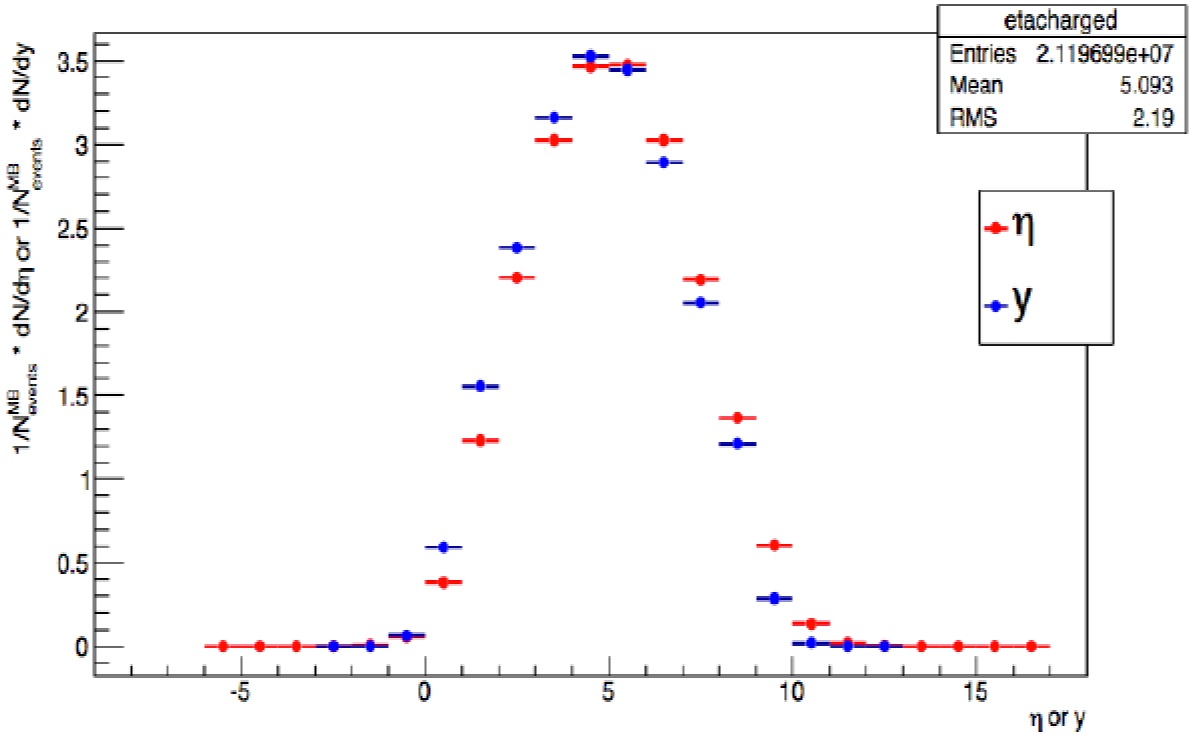
BACKUP

Minimum-bias simulations for pp at √s = 115 GeV

Multiplicity distributions vs η/y

AFTER workshop les Houches, January 2014
AFTER simulation group





EPOS 1.6.5

generated events: 1000

$dN_{ch}/d\eta\ |_{\eta = 0}\ \sim 3$

PYTHIA 8.170

generated events: 1M

$dN_{ch}/d\eta\ |_{\eta = 0}\ \sim 3.5$

Rapidity shift: $\Delta y = \tan^{-1}\beta \approx 4.8$
$y_{CM} = 0 \rightarrow y_{lab} \approx 4.8$

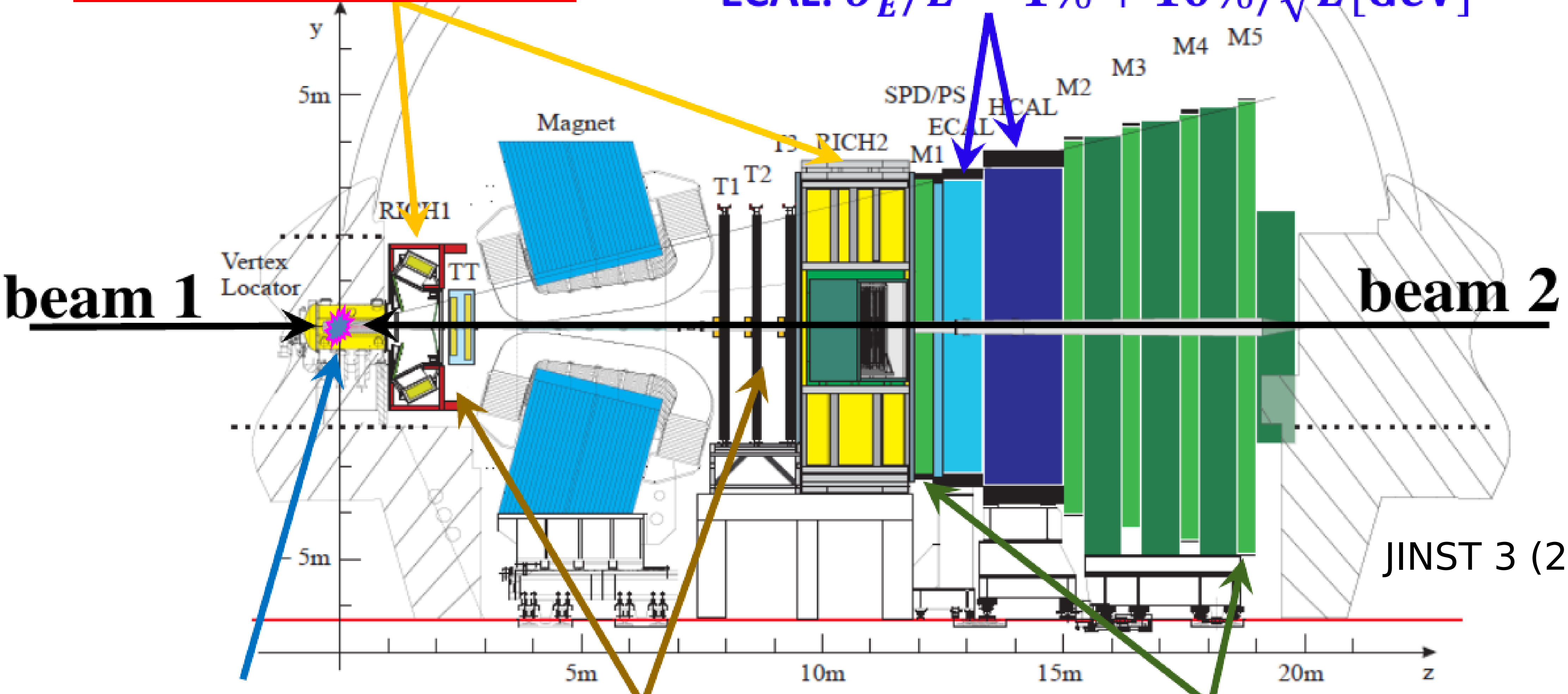
“LHCb-like” simulations

- ✓ LHCb acceptance, resolutions, cuts taken for AFTER simulations

Pseudorapidity acceptance
$2 < \eta < 5$

RICH1 & RICH2
$\epsilon(K \to K) \sim 95\%$
$\pi \to K$ **mis-id:** $\sim 5\%$

Calorimeters
ECAL: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\mathrm{GeV}]}$



VELO
$\sigma_{\mathrm{IP}} \sim 20$ **µm**
for high-p_{T} **tracks**

Tracking System
$\Delta p/p = 0.4\%@5$ **GeV/**c
to $0.6\%@100$ **GeV/**c

Muon System
$\epsilon(\mu \to \mu) \sim 97\%$
$\pi \to \mu$ **mis-id:** $1 \sim 3\%$

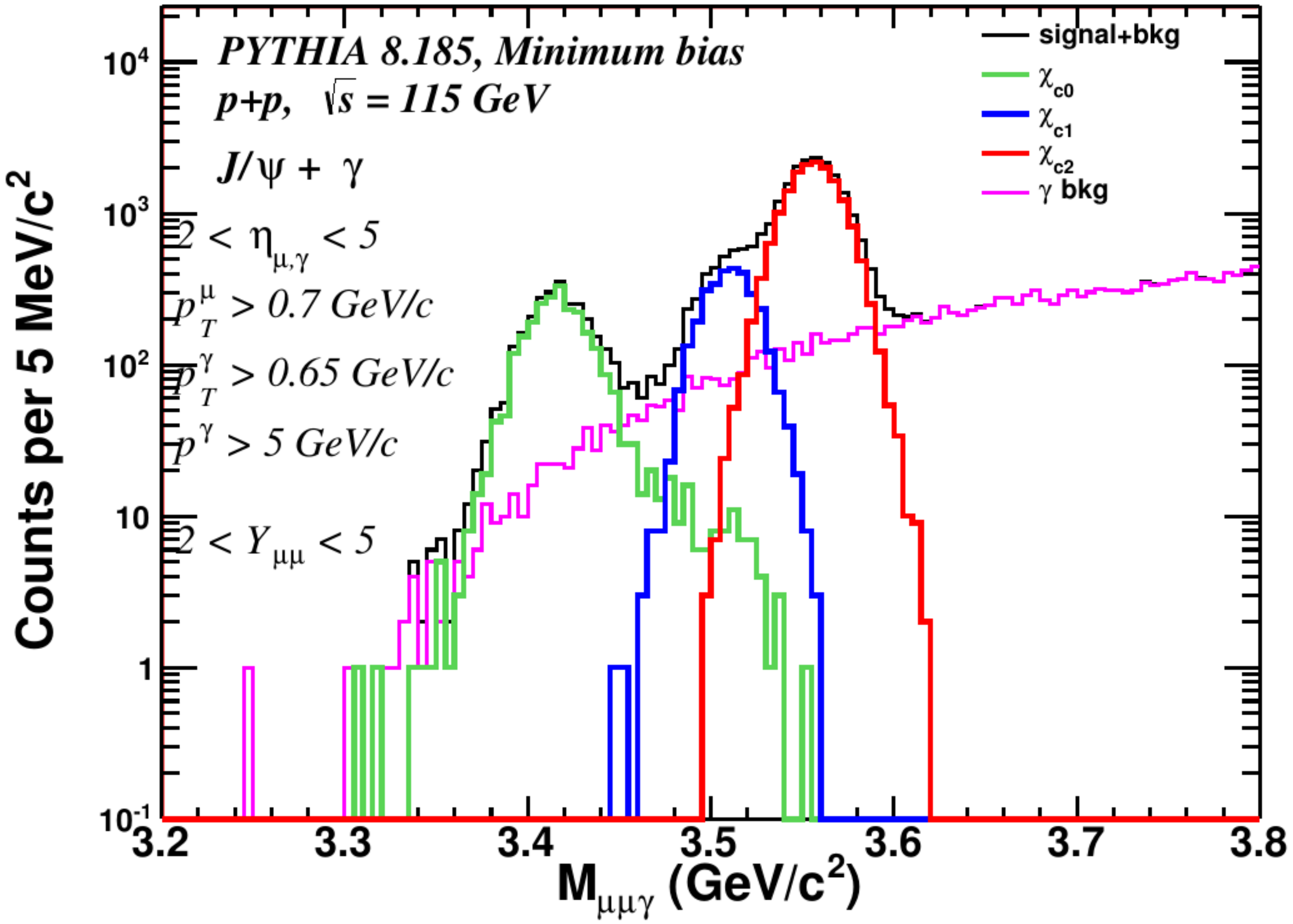
JINST 3 (2008) S08005

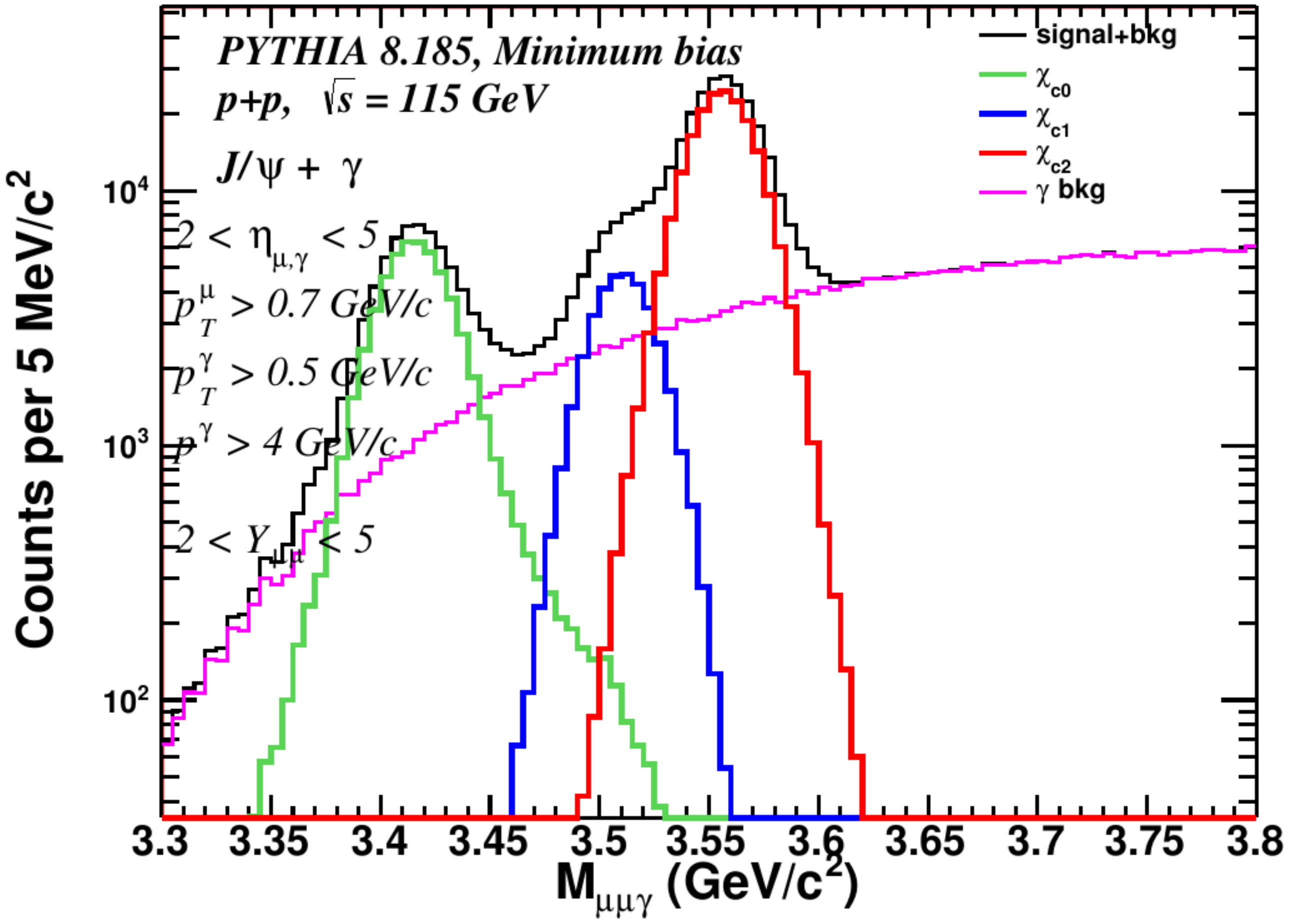
χ_c simulations

$$\chi_C \rightarrow J/\psi\,\gamma \rightarrow \mu^+ \mu^- \gamma$$

Pure signal

singlet





- γ cuts:
  - $p_T > 0.65$ GeV/c
  - $p > 5$ GeV/c
  - $p_T > 0.5$ GeV/c
  - $p > 4$ GeV/c