Z’ discrimination @27TeV (In case discovery @14TeV)

Clement Helsens, Michele Selvaggi CERN-EP
Michelangelo Mangano CERN-TH
Thomas Rizzo SLAC-TH

Outline

- Context of the study
- Discovery reach @14/27TeV
  - Analysis context
- Discrimination @27TeV
  - Pheno like analysis
  - Detector like analysis
- Summary

Context of the study

- At the very end of HL-LHC
  - Some significant excess in the di-lepton channel is seen
  - What would be HE-LHC model discrimination capabilities?
- Consider benchmark narrow resonances Z’
  - Coupling only to SM particles
  - Models: SSM, LRM, I, χ, ψ, η
  - References: arXiv:1403.5465 , arXiv:1308.2738

Discovery reach @14TeV

- 14TeV HL-LHC with $3ab^{-1}$
- Using the present ATLAS and CMS 13TeV results
- Estimate by extrapolation at 14TeV the significance reach of several models

For the following consider 6TeV Z' for HE-LHC model discrimination

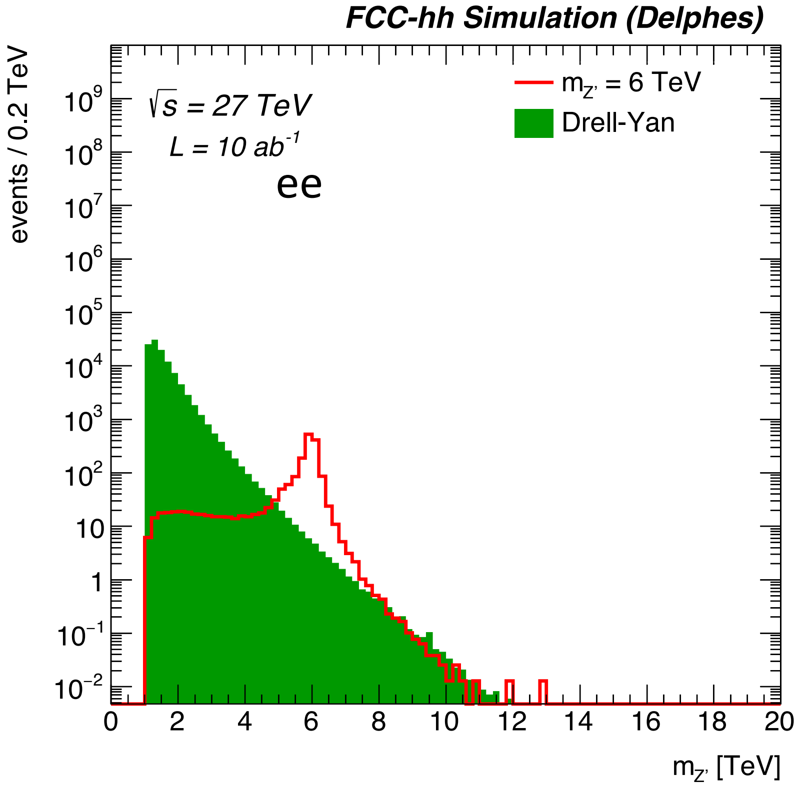
Mass reach in TeV with $3ab^{-1}$ @ $\sqrt{s}$=14TeV

Model	95% CL	3σ	5σ
SSM	6.62	6.09	5.62
LRM	6.39	5.85	5.39
ψ	6.10	5.55	5.07
χ	6.22	5.68	5.26
η	6.15	5.59	5.16
I	5.98	5.45	5.05

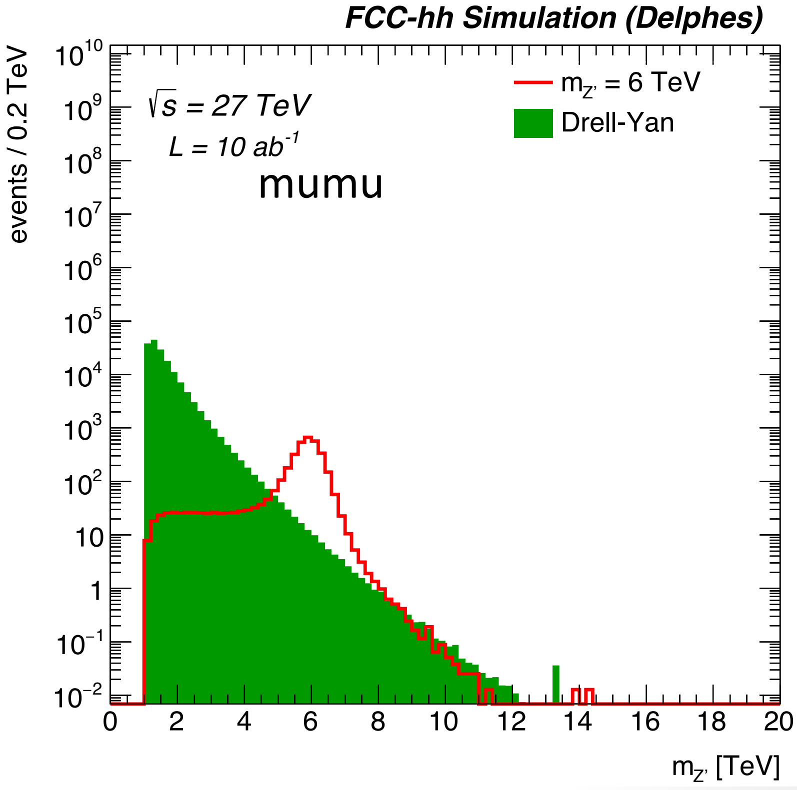
Z'->ll 27 TeV (detector like)

- Drell-Yan generated with MG5
  - In bins of HT
  - K-factor of 2 to account for N^xLO corrections
- Signals generated with Pythia8
  - Using the same couplings as pheno like analysis
  - Also consider Z' interference with Drell-Yan
- Selection for limits and discovery:
  - Two same flavor leptons p_T>500GeV, $|\eta|<4$
  - m_{ll} > 1TeV
- Selection for model discrimination
  - $|\eta|<2.5$ and $|\eta|<4$
  - $m_{Z'}$ within 200GeV of the Z' mass

process	yield (10.0 ab-1)
m_{Z} = 6 TeV	1796.1
Drell-Yan	108465.9



process	yield (10.0 ab-1)
m_{Z} = 6 TeV	3561.9
Drell-Yan	163201.3

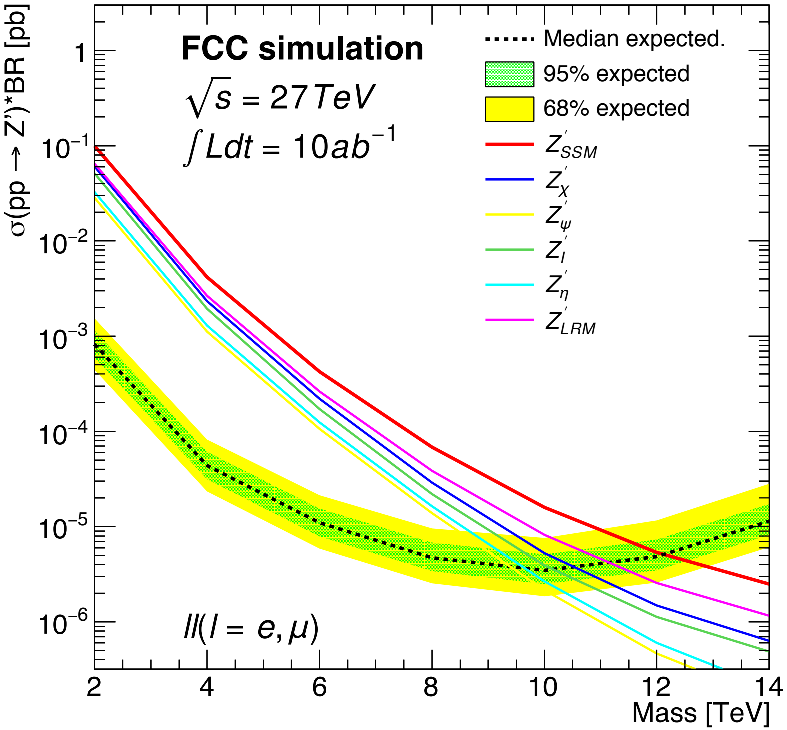


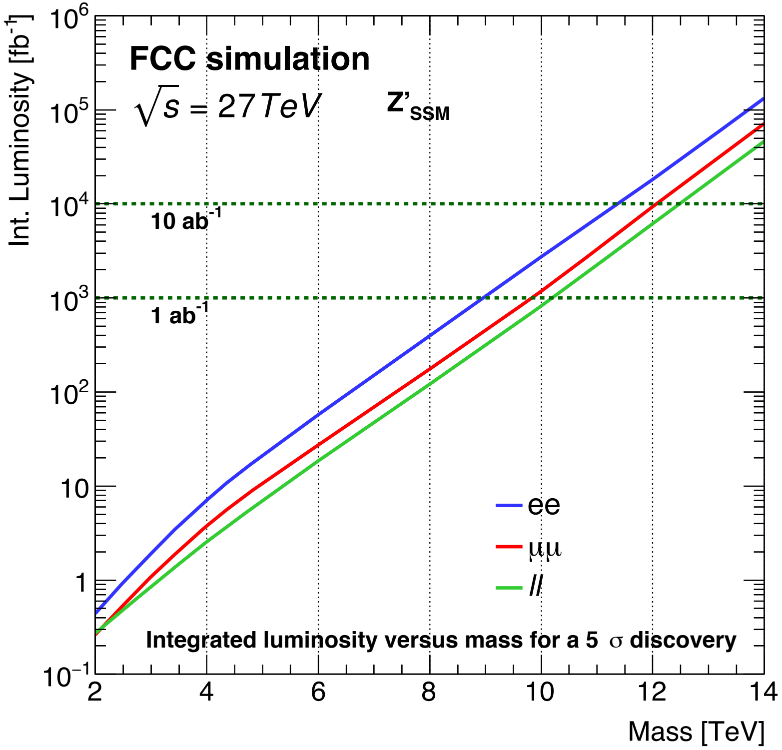
Z'->ll 27TeV

Better standalone results for di-muon channel due to electron isolation not tuned

Reach exclusion 9-12TeV

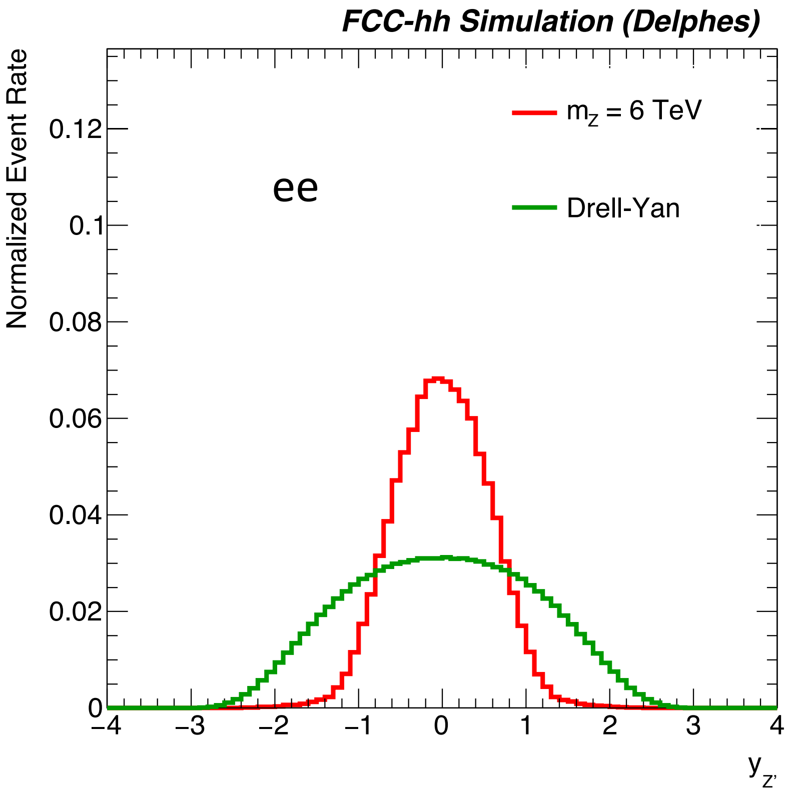
Discovery reach up to 13TeV

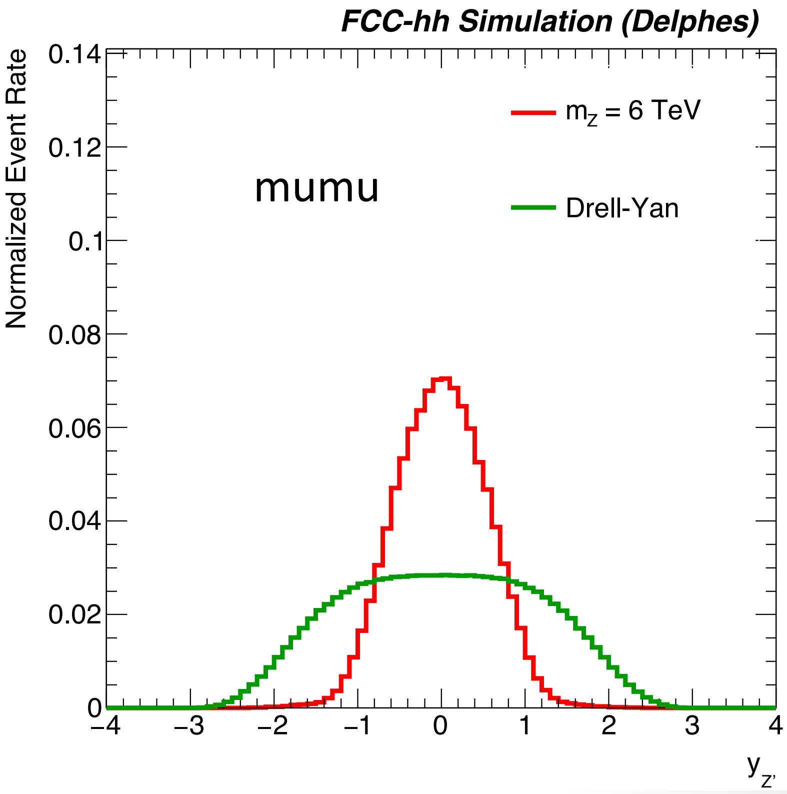




Z'->ll 27TeV

Z' rapidity distribution





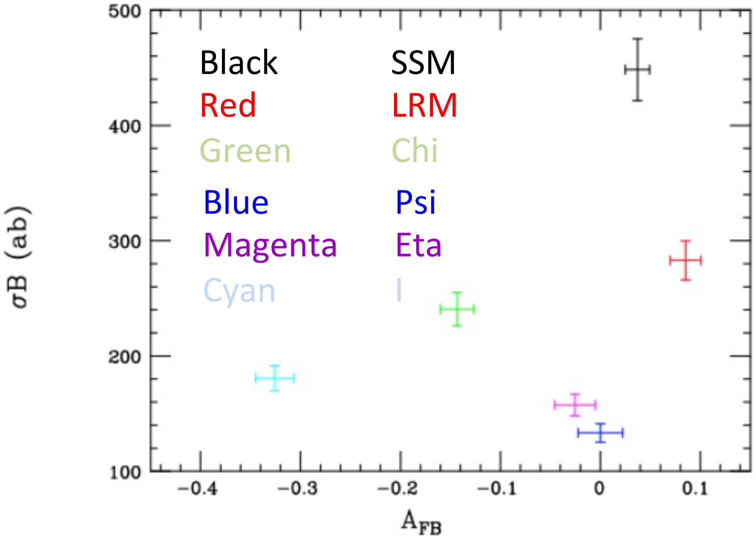
27TeV discrimination pheno

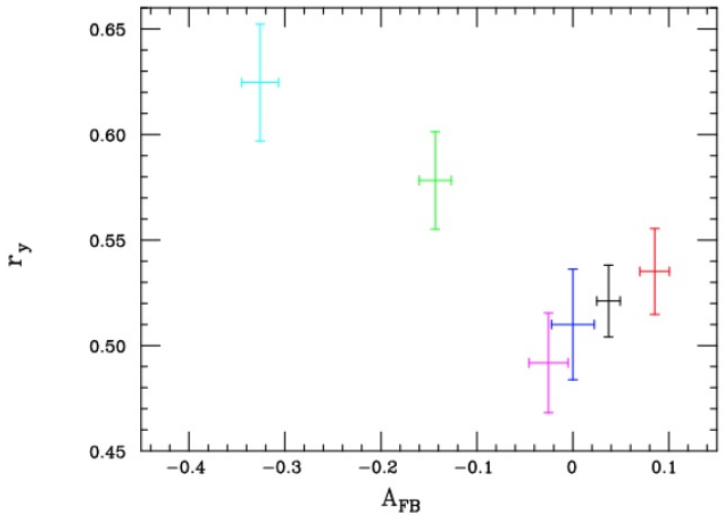
- 6TeV Z'
- Variables considered $\sigma_{Z'}$, A_{FB}, r_y
- In most cases, good for model discrimination

$$\frac{d\sigma}{d\cos\theta^*} = C\left[\frac{3}{8}(1+\cos^2\theta^*) + A_{FB}\cos\theta^*\right]$$

$$r_y = \frac{\int_{-y_1}^{y_1} \frac{d\sigma}{dy}\, dy}{\left[\int_{y_1}^{Y} + \int_{-Y}^{-y_1} \frac{d\sigma}{dy}\, dy\right]}.$$

y_1= 0.5, Y=2.5





Variable definitions A_{FB} (Detector level)

- Tried two definitions at detector level
  - $A_{FB} = A_C = (N(\Delta|y|>0) - N(\Delta|y|<0))/(N(\Delta|y|>0) + N(\Delta|y|<0))$
  - $\Delta|y|=|y_l|-|y_{lbar}|$
  - $A_{FB} = (\sigma_F - \sigma_B)/(\sigma_F + \sigma_B)$
  - With σ_F =N(Cosθ*cs)>0 and σ_B =N(Cosθ*cs)<0
  - With Cosθ*cs = $\frac{Q_z}{|Q_z|}\frac{2(P_1^+P_2^- - P_1^-P_2^+)}{|Q|\sqrt{Q^2+Q_T^2}}$,

model	A_{FB} Δ|y|	A_{FB} cosθ
SSM	0.0329	0.0330
ETA	-0.0295	-0.0285
CHI	-0.1220	-0.1232
LRM	0.0831	0.0836
PSI	-0.0079	-0.0074
I	-0.2582	-0.2593

Both definition are equivalent, use A_{FB} from cosθ in the following
Get similar values as pheno analysis

Variable definitions r_y

- $R_y = N(|y_{z'}|<x)/N(x<|y_{z'}|<y)$
- From pheno study x=0.5 and y=2.5

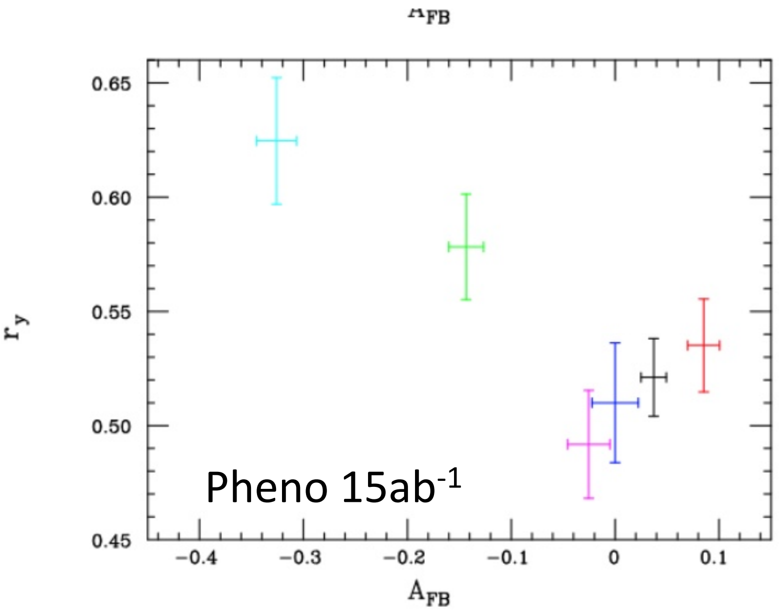
At detector level get closer values if x=0.25, but not yet understood why can't reproduce pheno values

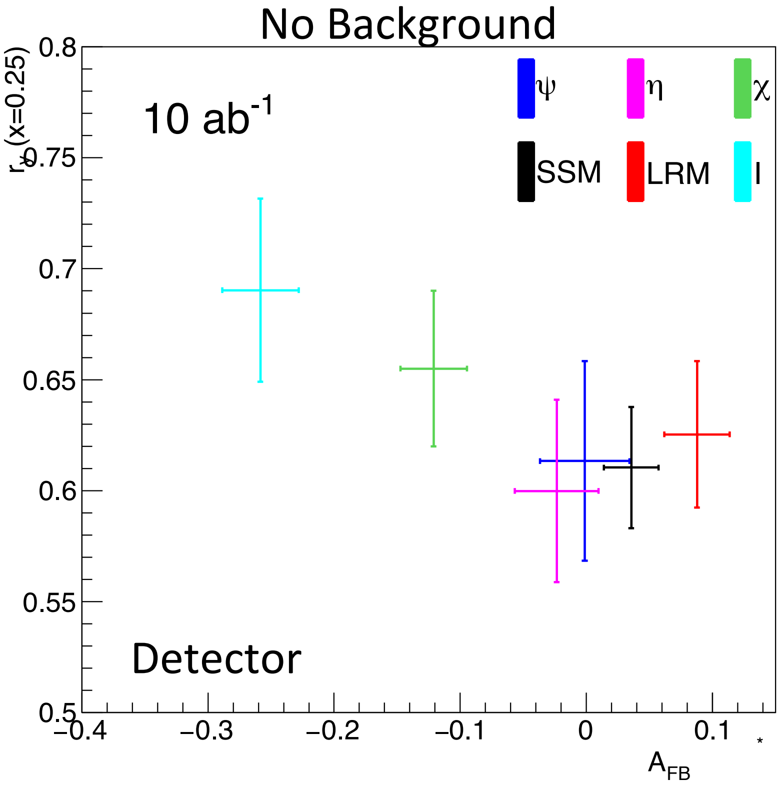
Model	x=0.5, y=2.5	x=0.25, y=2.5
SSM	2.186	0.6096
ETA	2.143	0.5983
CHI	2.424	0.6533
LRM	2.258	0.6241
PSI	2.19	0.6112
I	2.62	0.6876

Possible explanations that will be checked:

- Shower effects
- gq production mode
- Selection
- PDFs

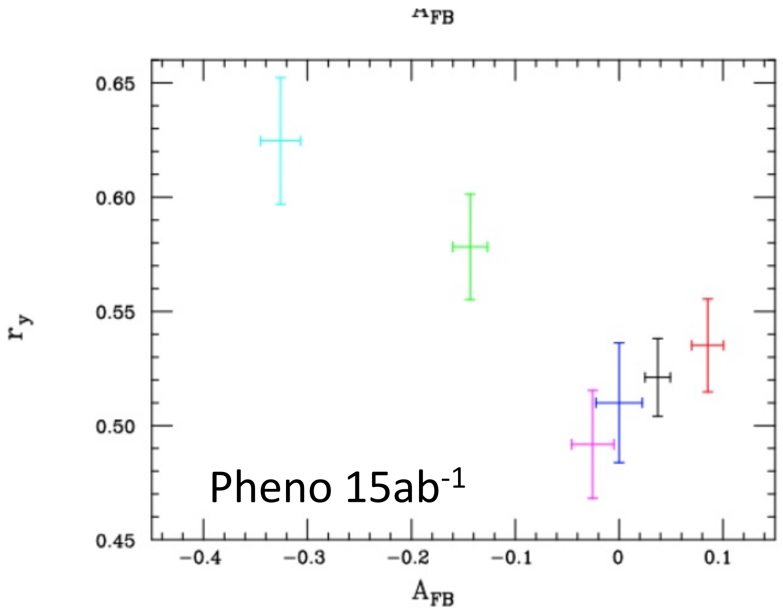
27TeV model discrimination

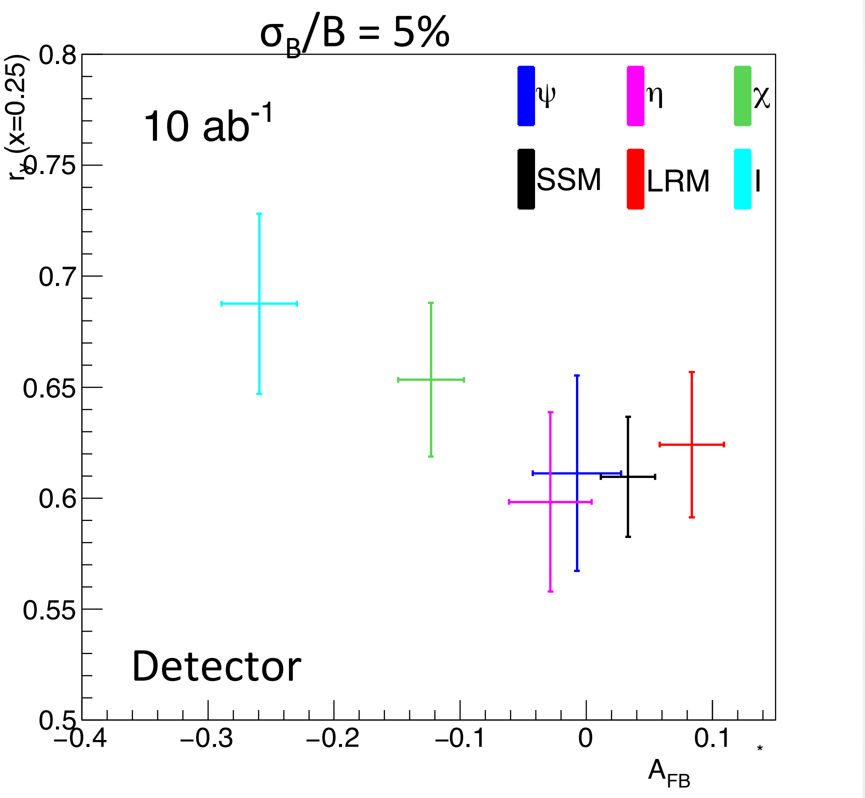




27TeV model discrimination

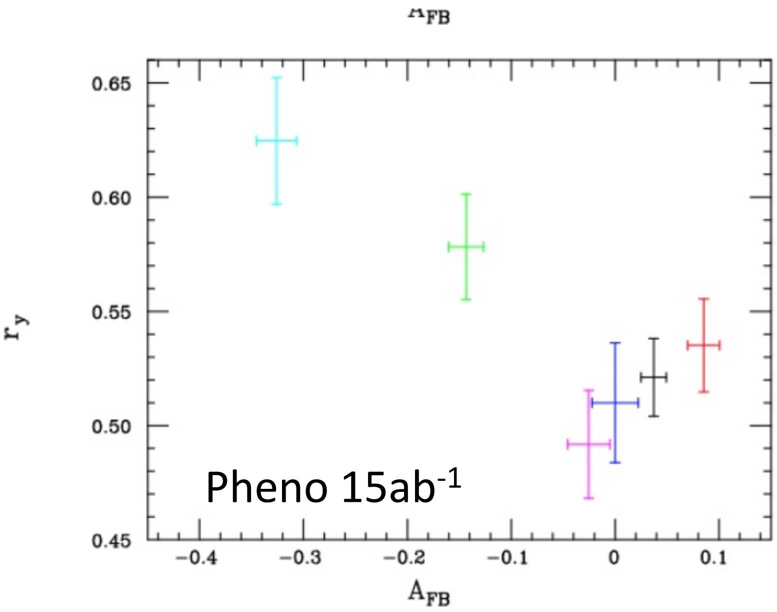
Tiny background under the peak
-> very small effect of adding σ_B/B

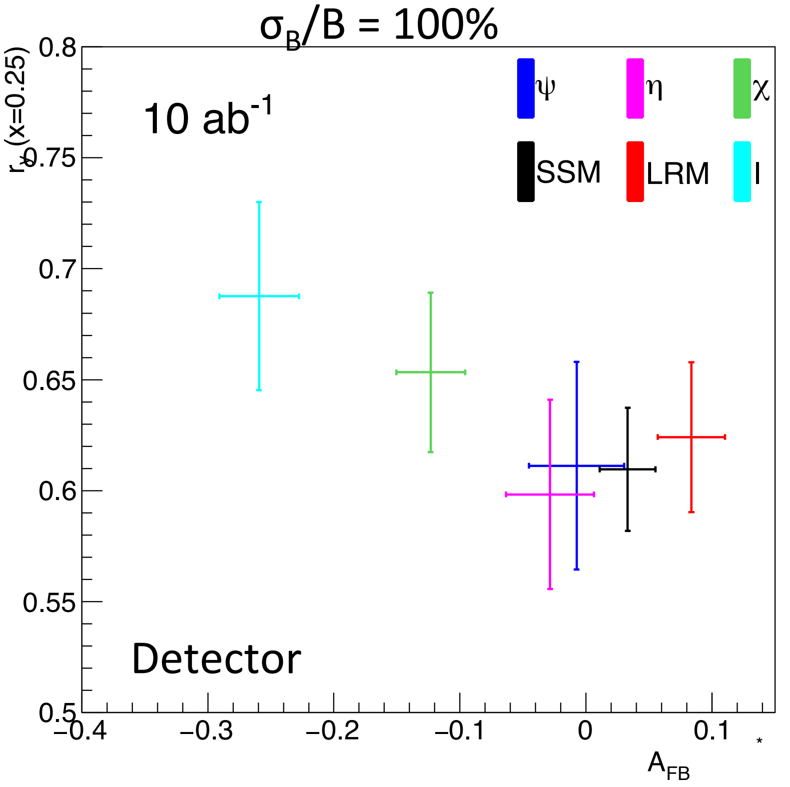




27TeV model discrimination

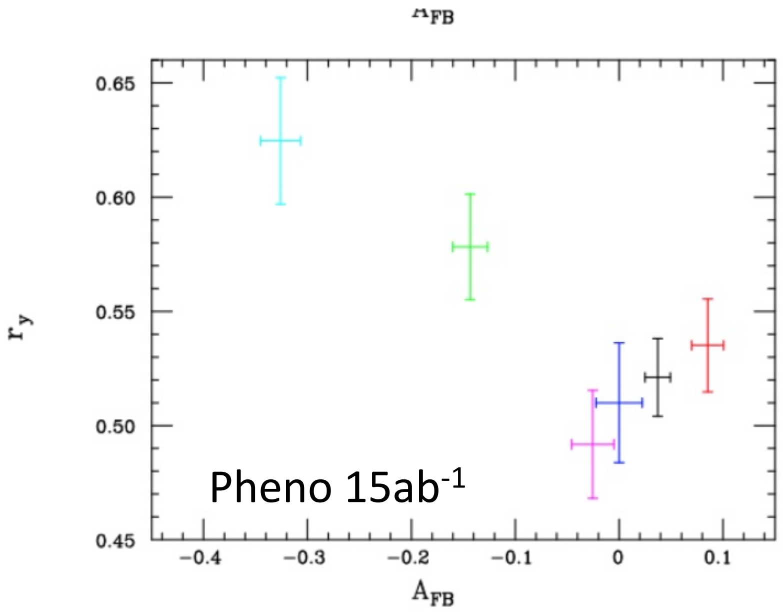
Tiny background under the peak
-> very small effect if very large σ_B/B

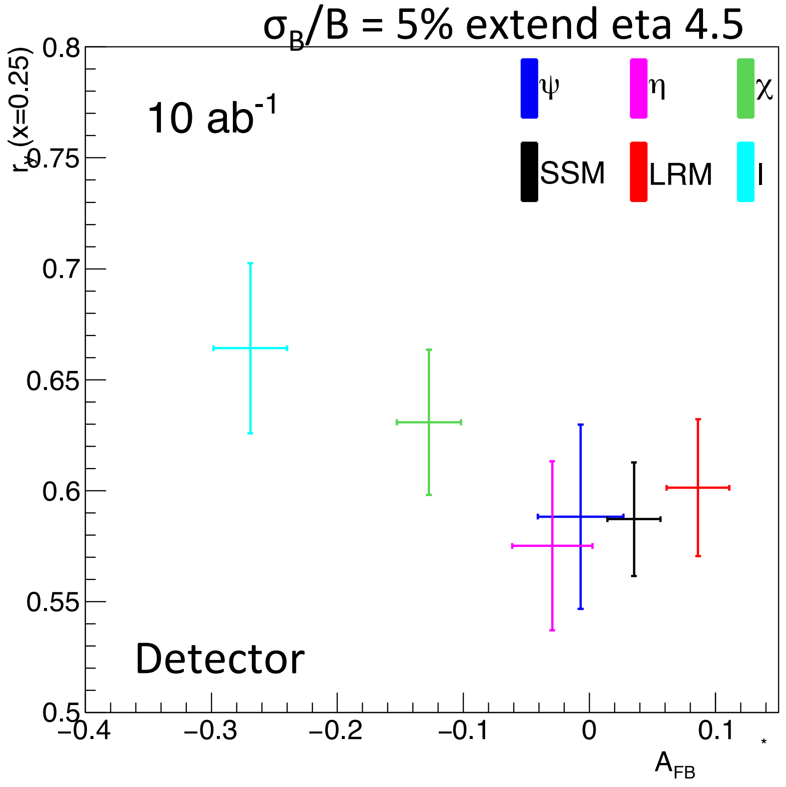




27TeV model discrimination

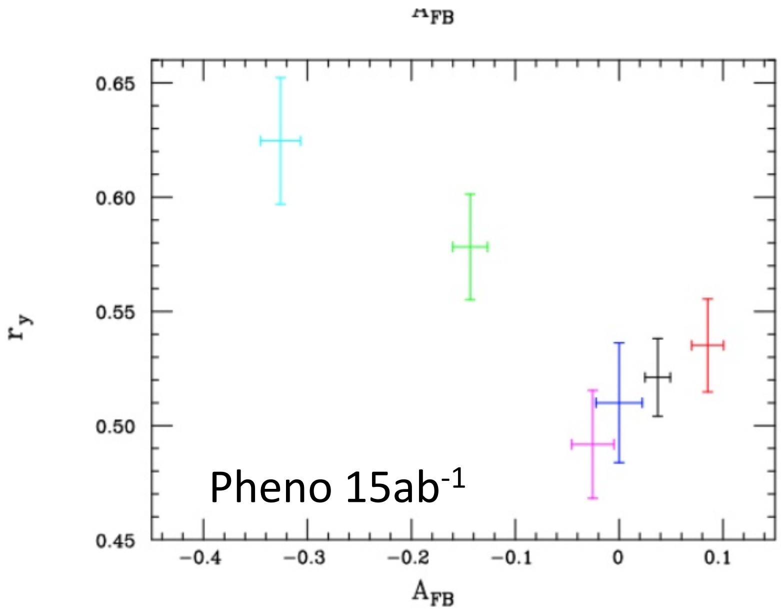
Changing fiducial acceptance does not improve the discrimination

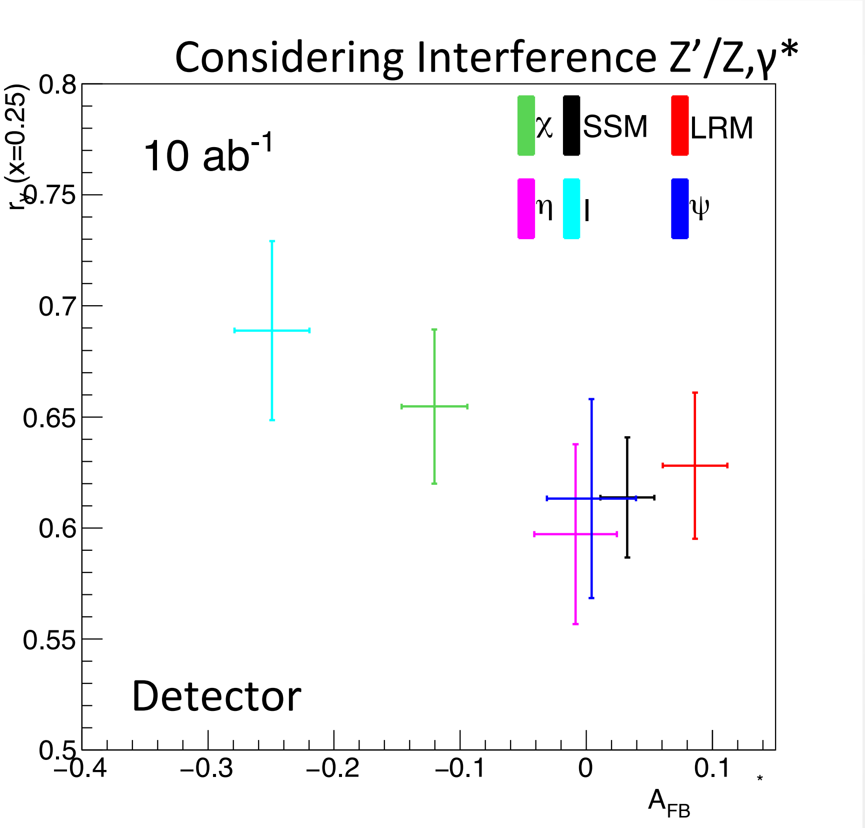




27TeV model discrimination

As relatively narrow resonances are considered, small effect observed if interference with Drell-Yan considered





27TeV model discrimination

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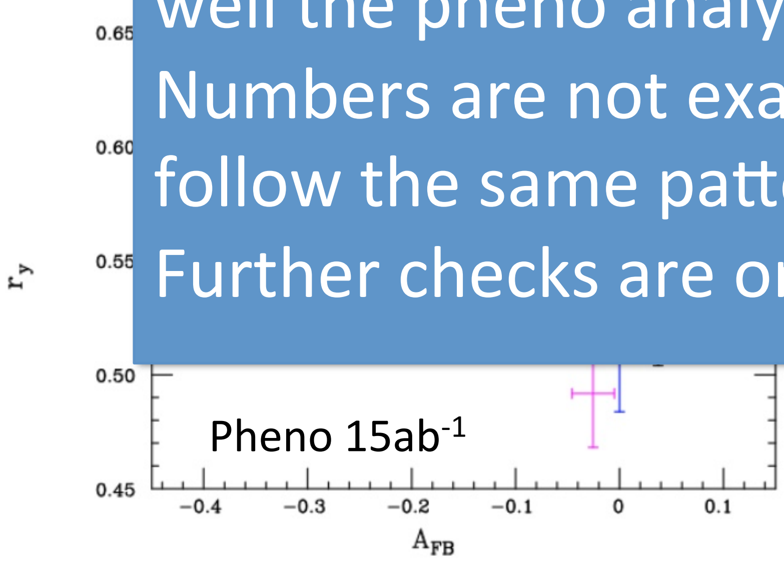
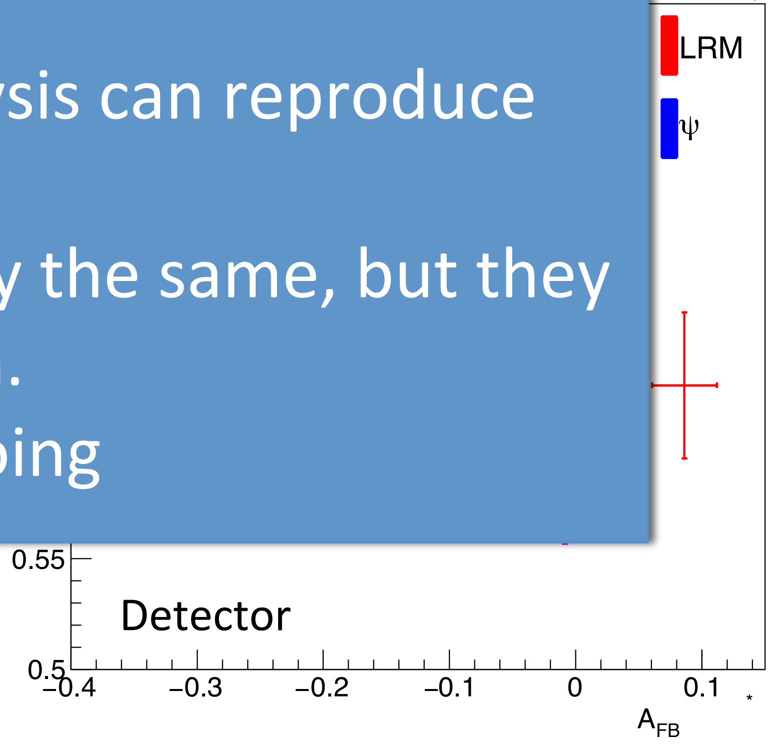
Considering Interference Z'/Z,γ*

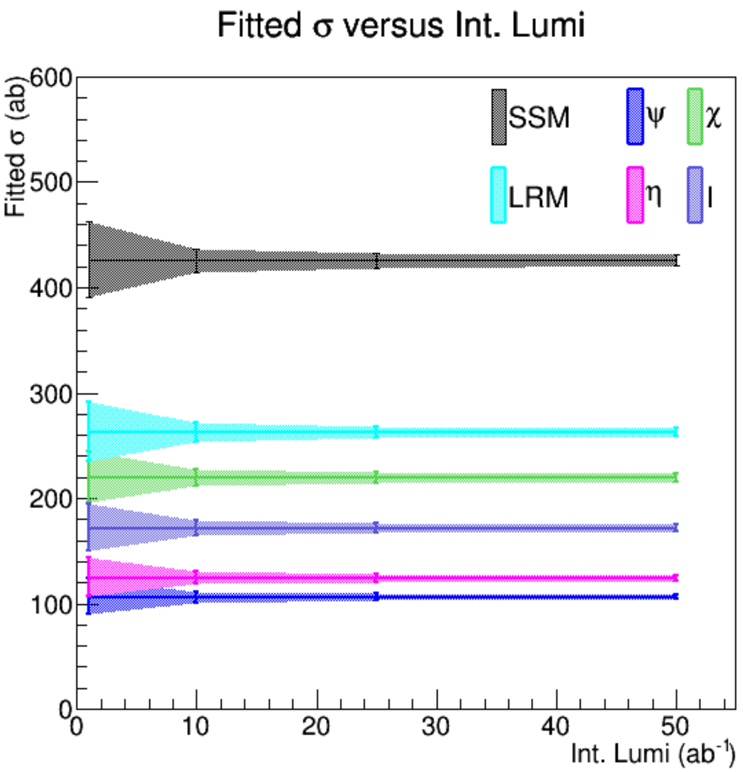




The detector level analysis can reproduce well the pheno analysis.
Numbers are not exactly the same, but they follow the same pattern.
Further checks are ongoing

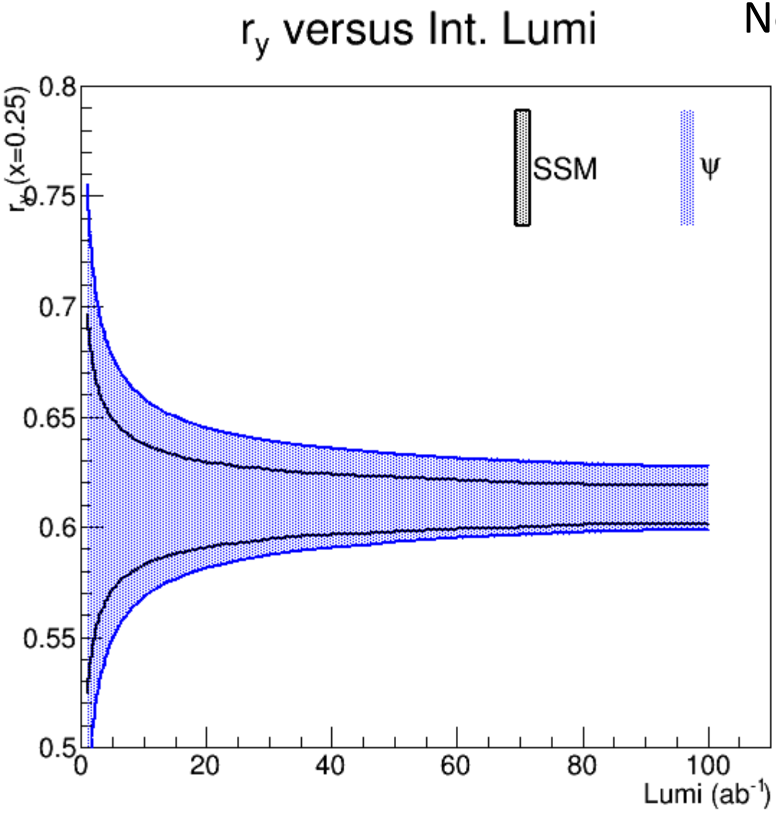
Fitting the μ value of signal

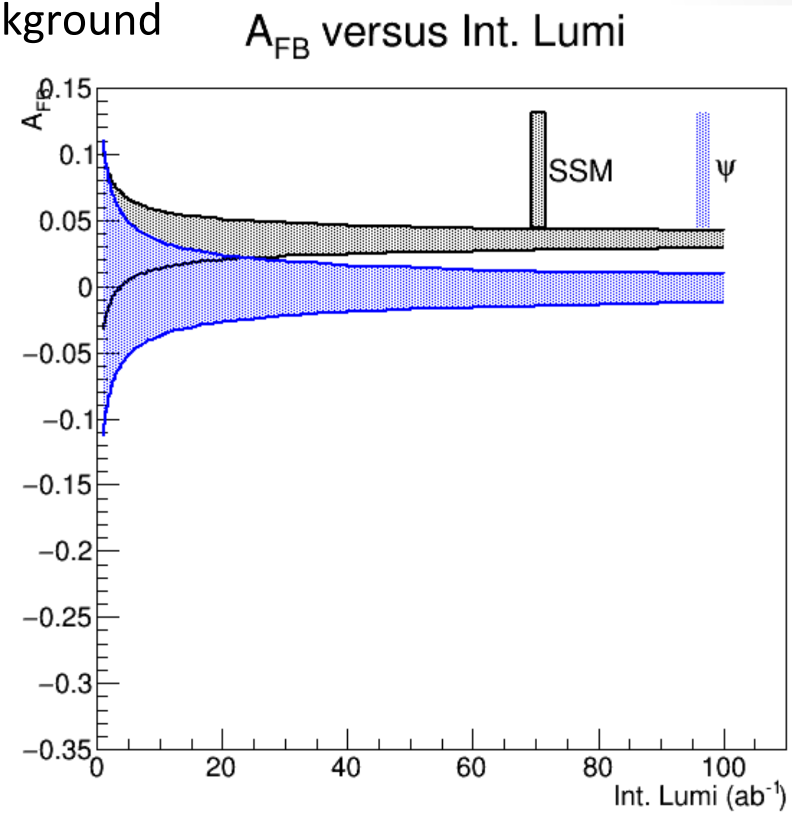
- In profile likelihood fit the signal μ value in the analysis
- The background under the mass peak is so tiny that it does not influence the μ value + there is a lot of side-bands
- From cross-section fit it seems that the model discrimination is already good enough
- But need angular variables in order to get rid of the couplings to quarks and also possible other decays mode



R_y, A_{FB} versus lumi SSM/PSI

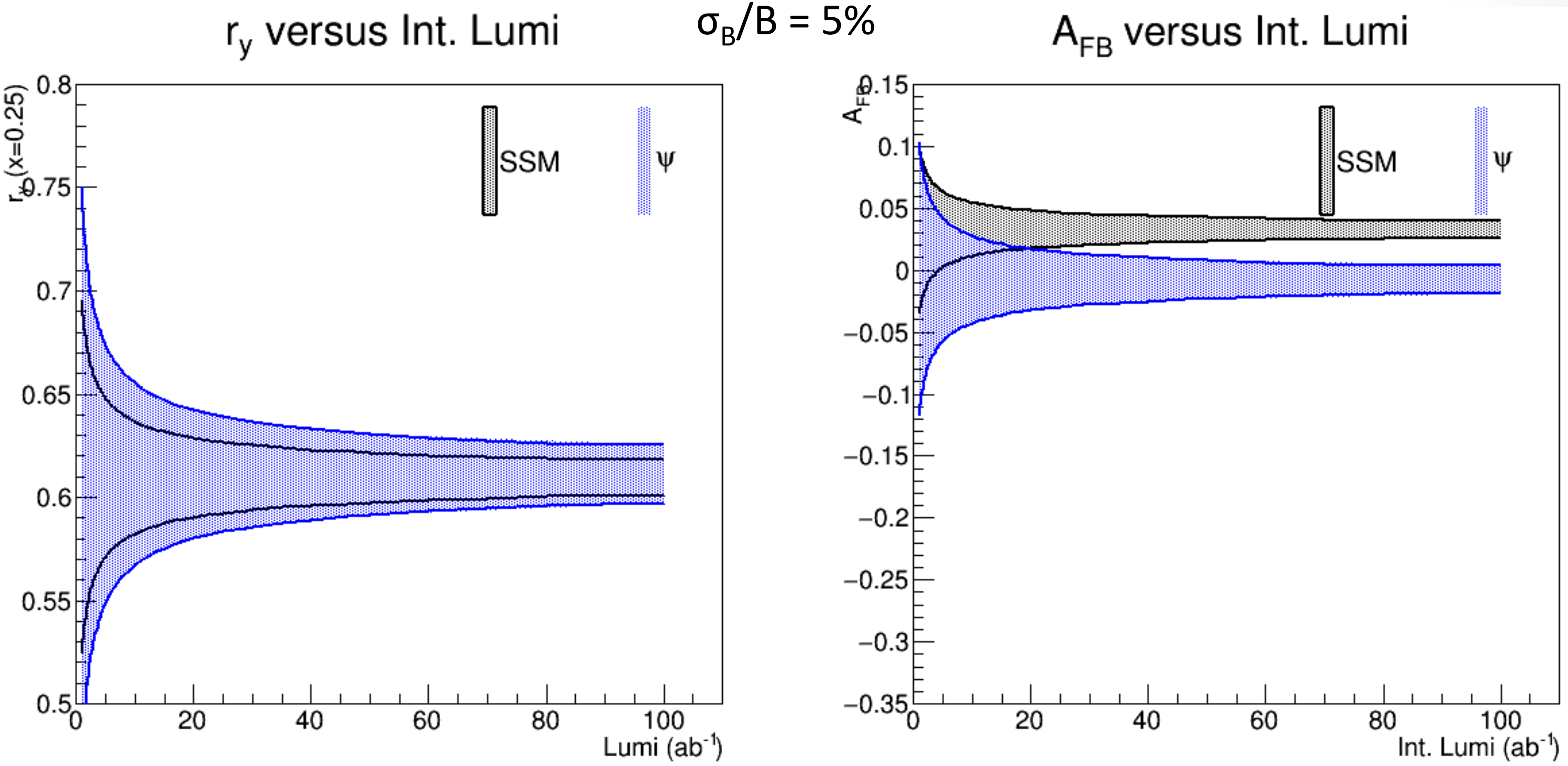
No background





R_y, A_{FB} versus lumi SSM/PSI

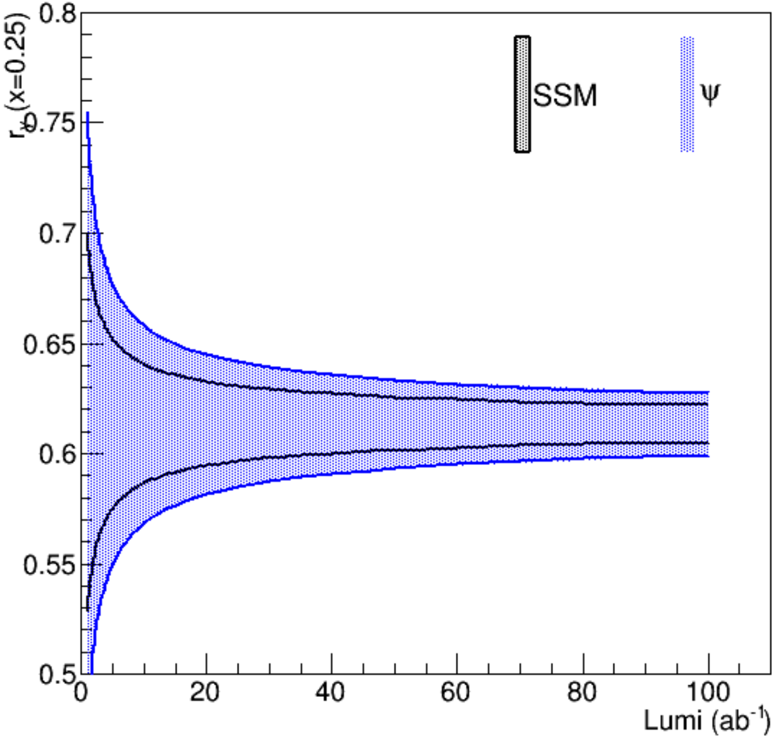
$\sigma_B/B = 5\%$



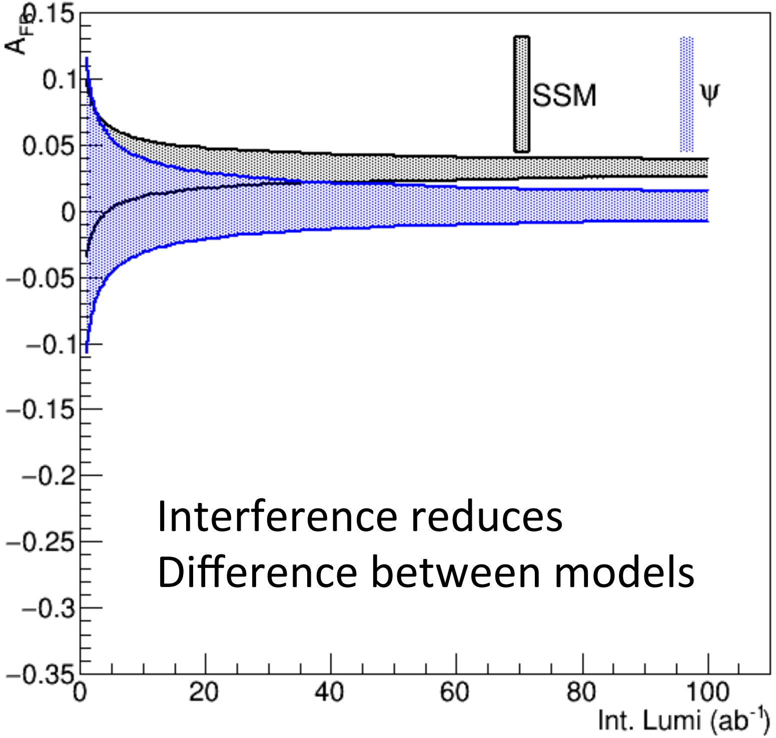
R_y, A_{FB} versus lumi SSM/PSI

r_y versus Int. Lumi

Interference Z'/Z,γ*



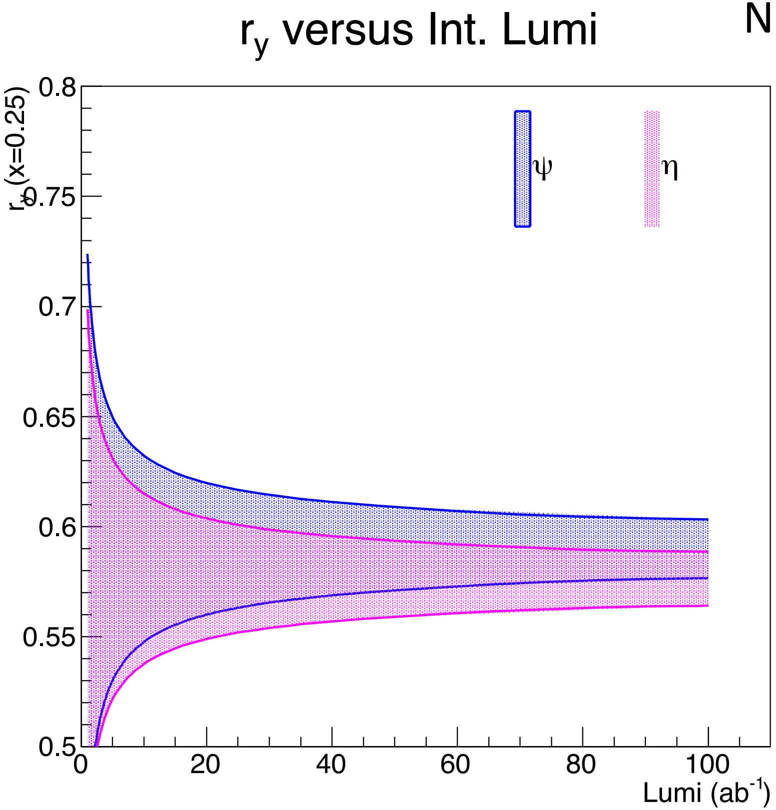
A_{FB} versus Int. Lumi

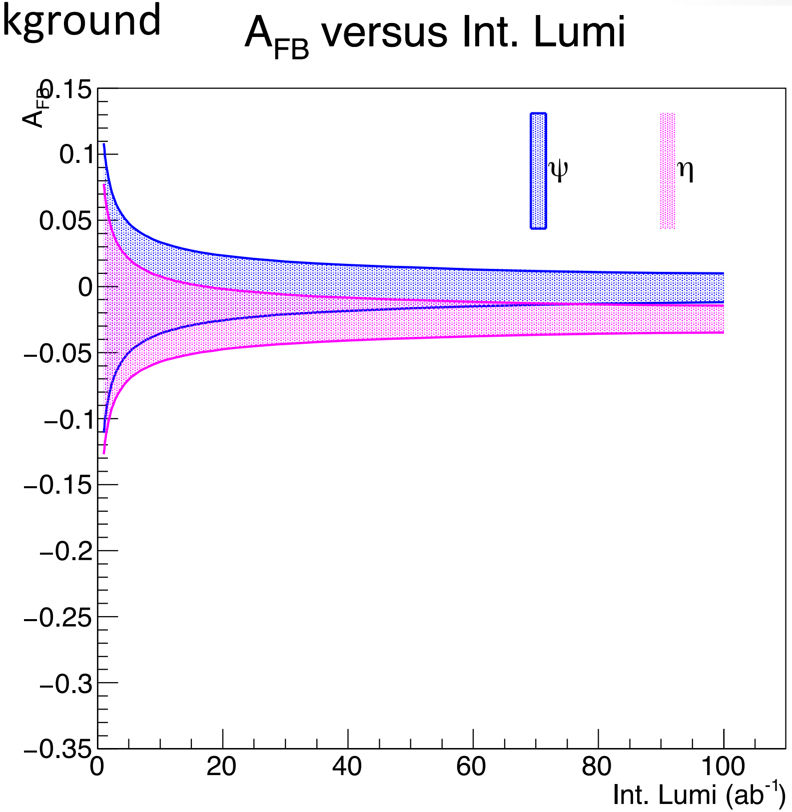


Interference reduces
Difference between models

R_y, A_{FB} versus lumi SSM/PSI

No background





R_y, A_{FB} versus lumi SSM/PSI

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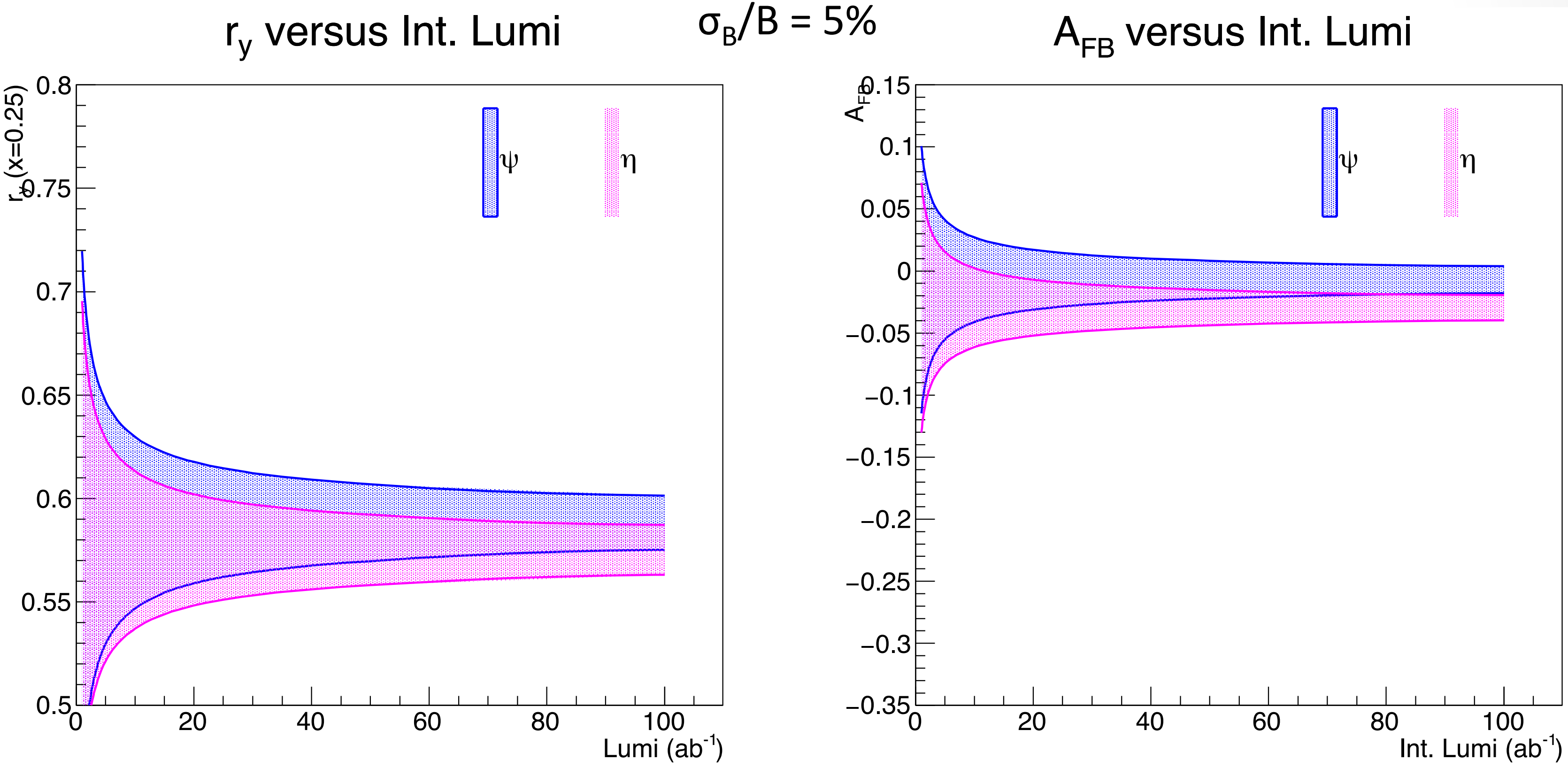
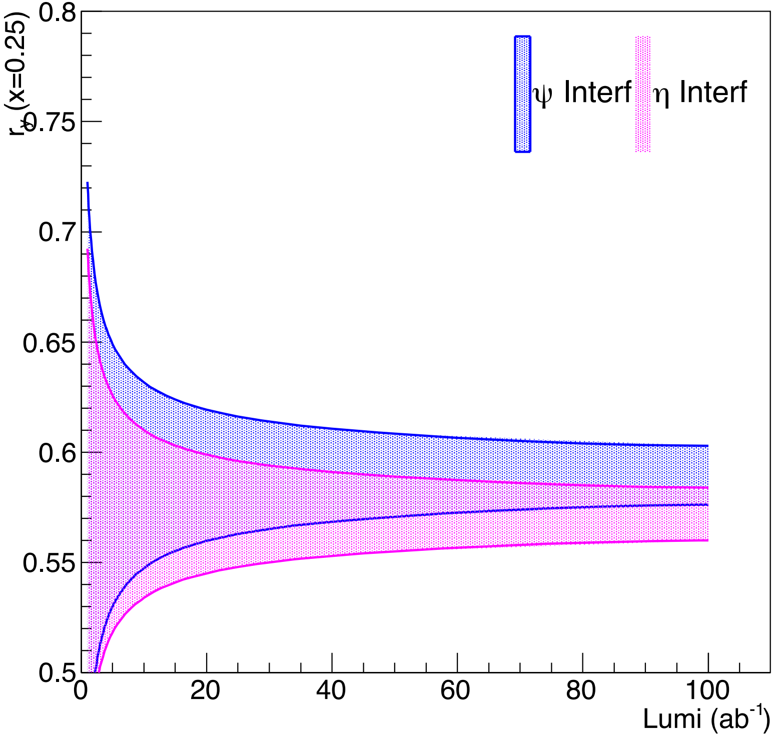


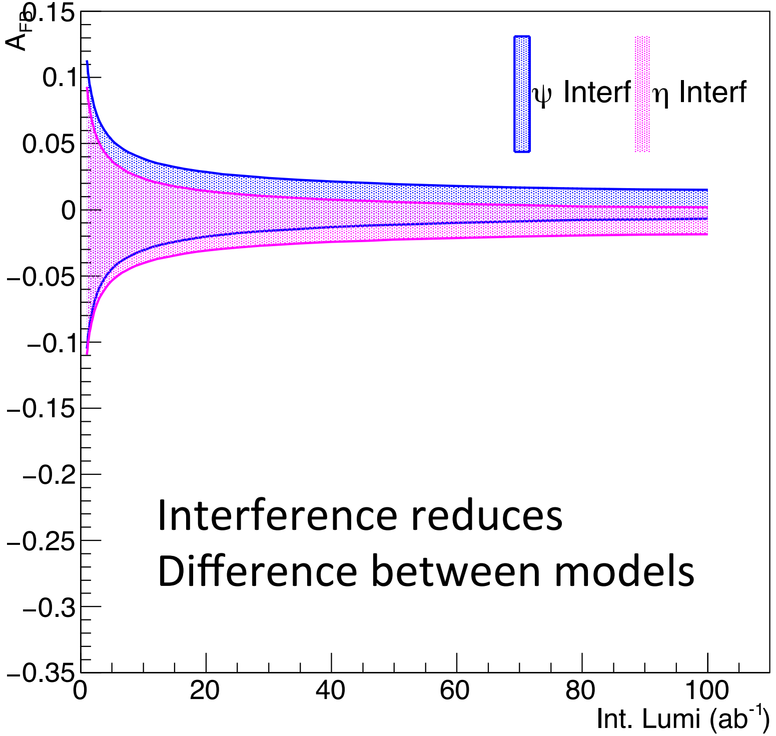
R_y, A_{FB} versus lumi SSM/PSI

Interference Z'/Z,γ*

r_y versus Int. Lumi



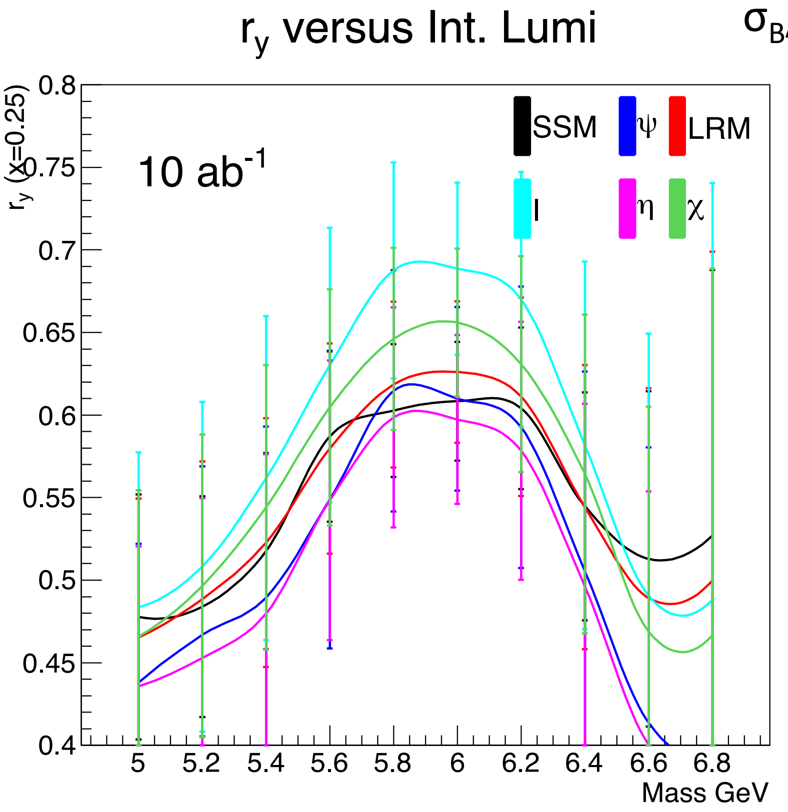
A_{FB} versus Int. Lumi

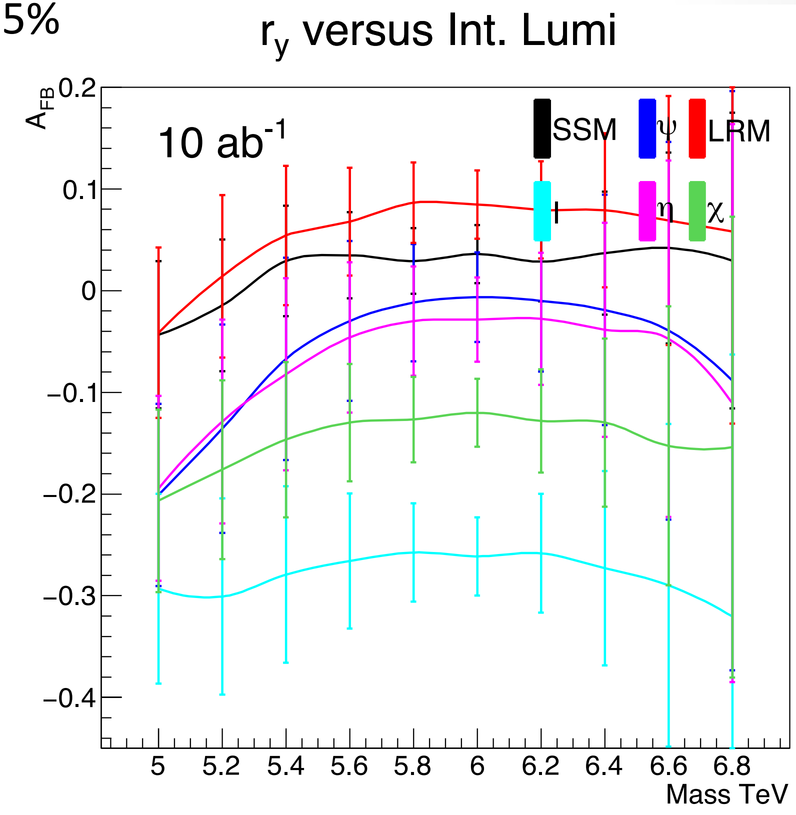


Interference reduces
Difference between models

A_{FB} R_y vs mass (in 200GeV mass bins)

$\sigma_B/B = 5\%$





A_{FB} R_y vs mass (in 200GeV mass bins)

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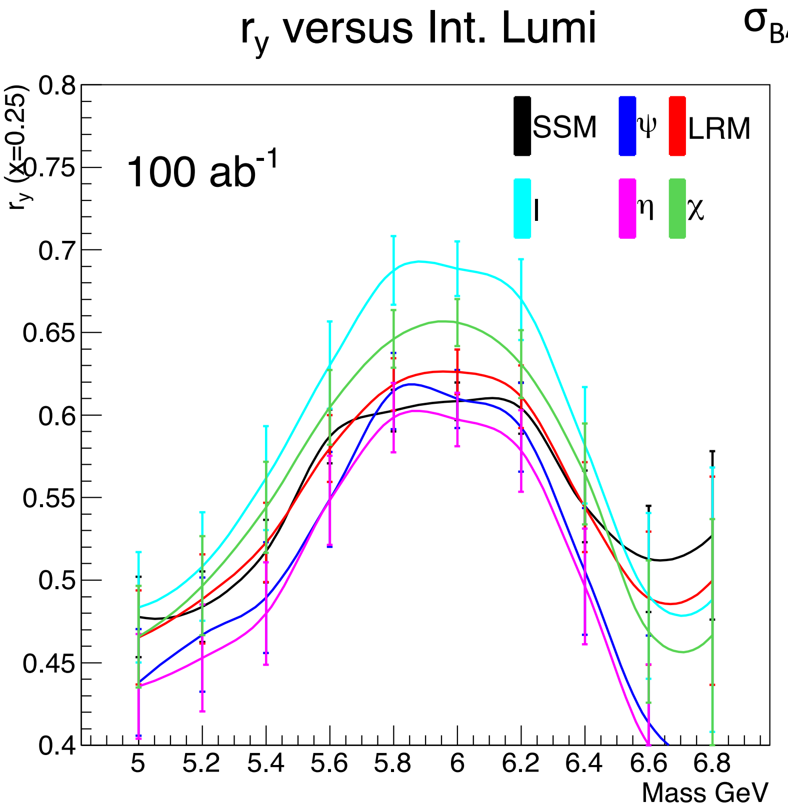
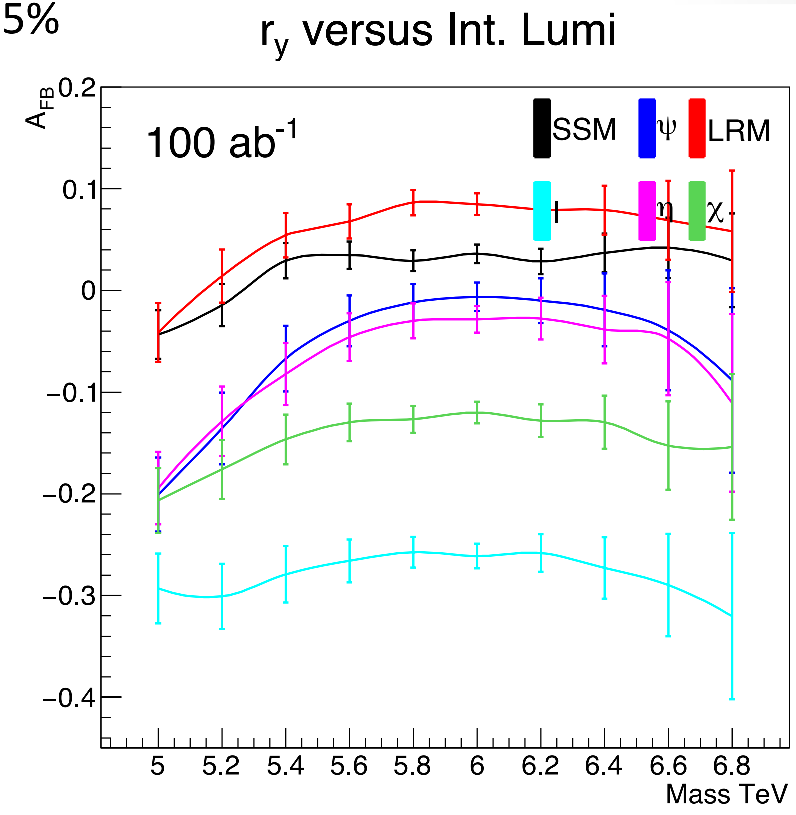
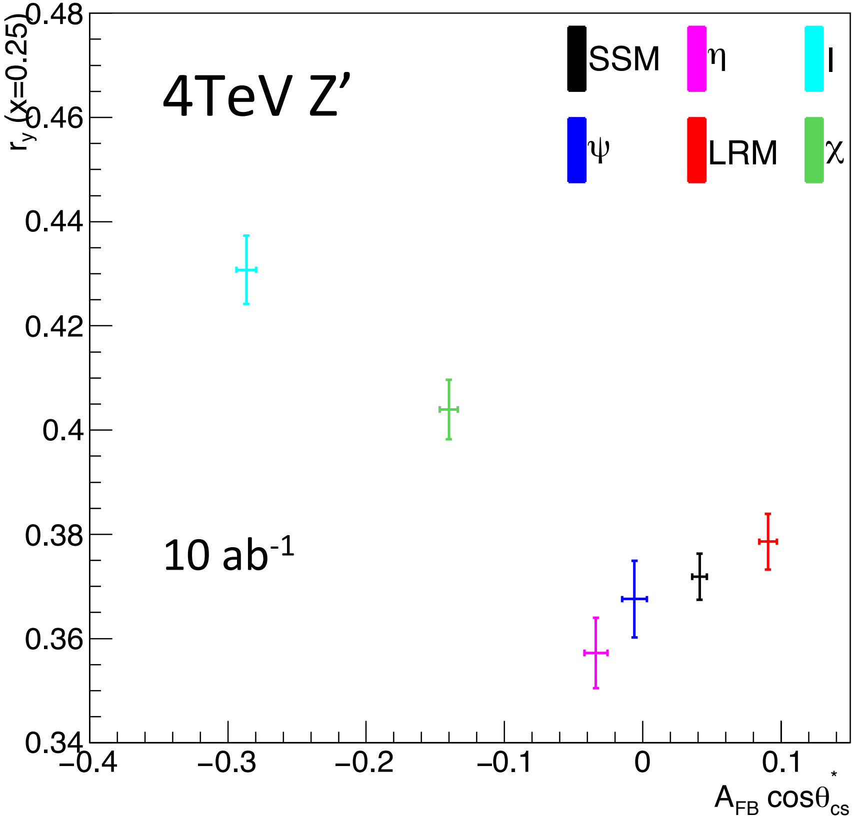
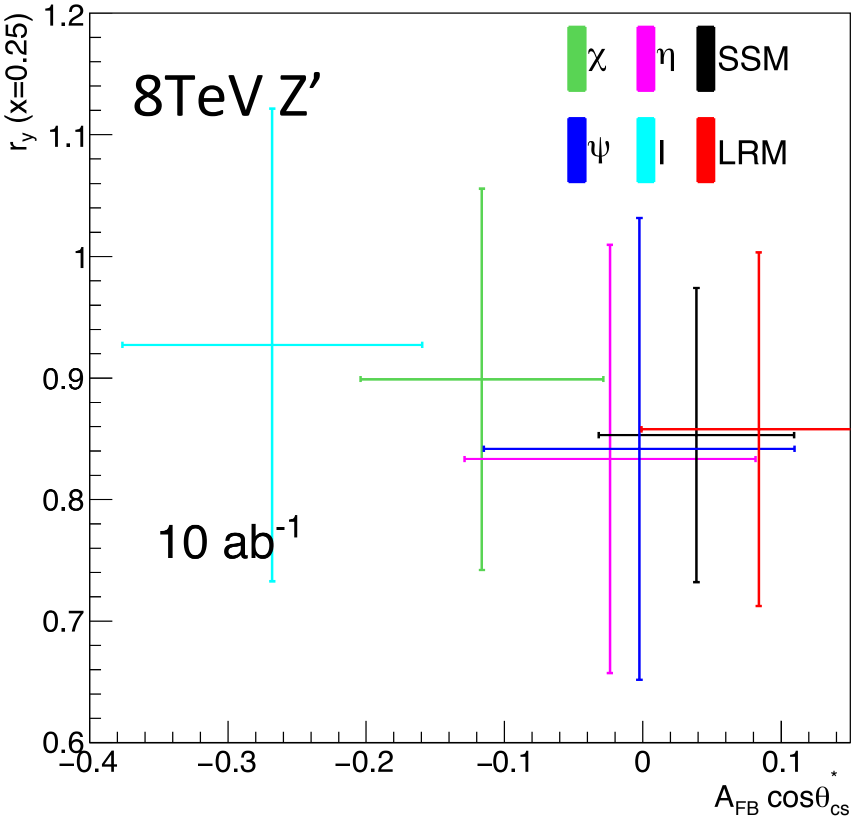




Heavier/lighter Z’





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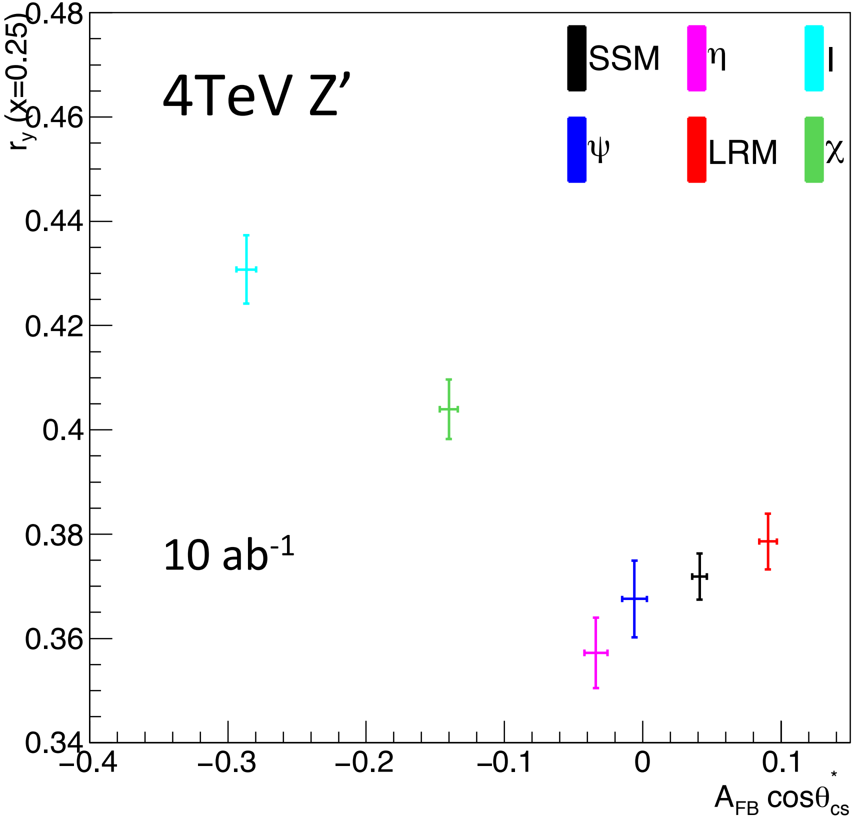
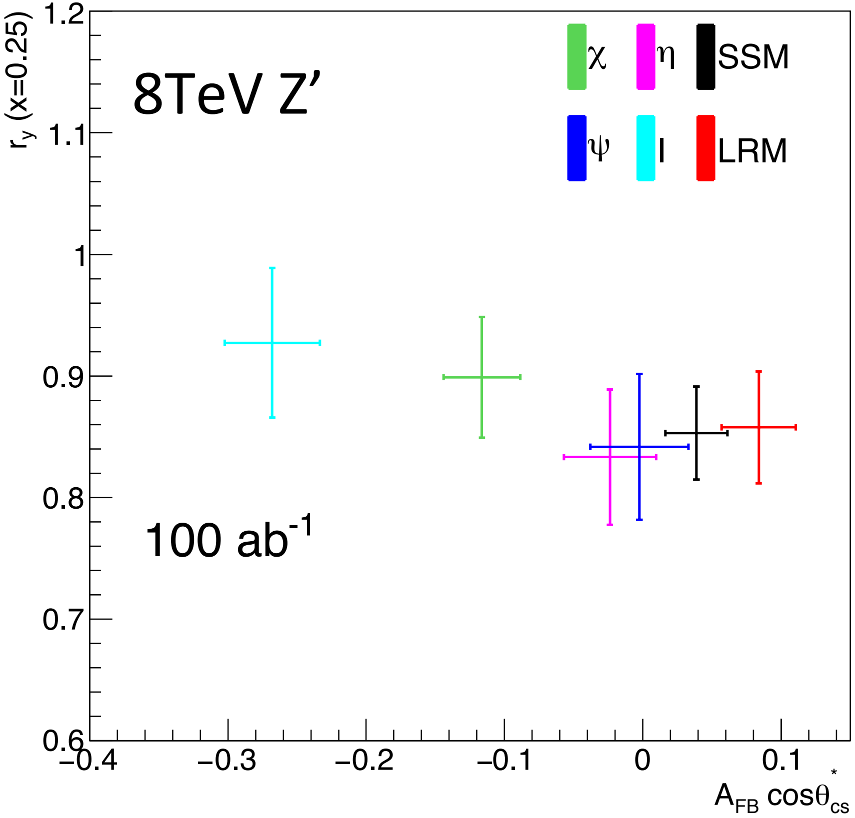




Conclusions

- Presented a study on Z' discrimination at 27TeV in case of a discovery at HL-LHC
- Apart from a possible near degeneracy in models ψ,η, a reasonable Z' model separation can be achieved
- Systematics error on the background estimate don't play a role
- In narrow width the interference with Drell-Yan is negligible
- Increasing lepton acceptance from 2.5 to 4.5 does not help discrimination
- Need to continue the study and estimate the effect of PDF on the observables
- If Z' > 6TeV Model discrimination will be much harder if only $10ab^{-1}$ is collected
- Other resonances analysis are being re-done from 100 to 27TeV for the YR
- Will start to document all of this in the overleaf document

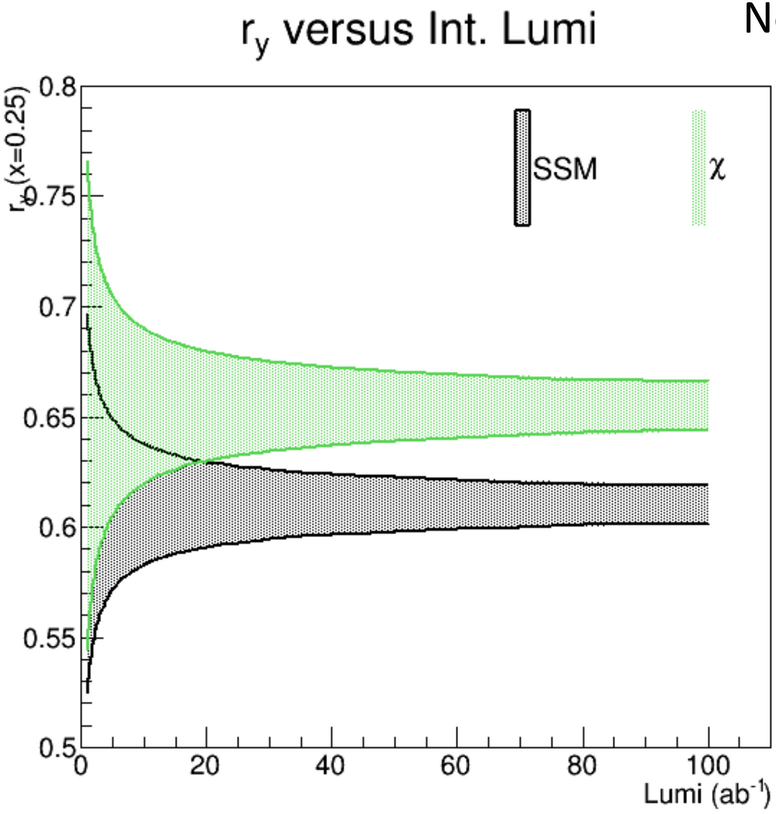
Bonus

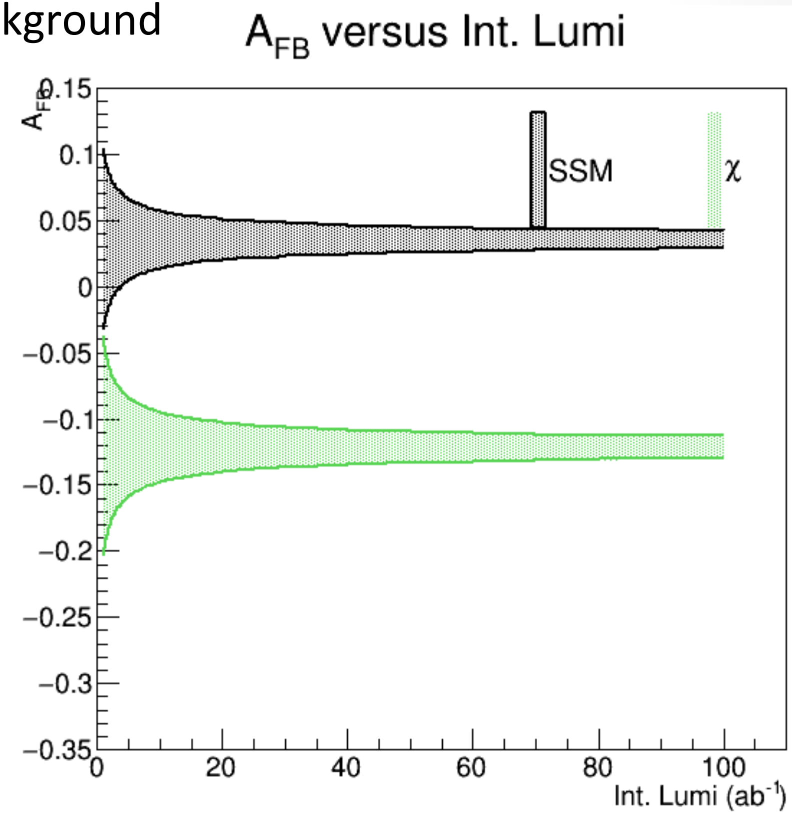
Couplings

	v-d	a-d	v-u	a-u	v-e	a-e	v-nue	a-nue
SSM	-0.6933	-1	0.3866	1	-0.08	-1	1	1
LRM	-0.9435	0.7348	0.5261	-0.7348	-0.1088	0.7348	0.3129	0.3129
PSI	0	0.5055	0	0.5055	0	0.5055	0.2527	0.2527
CHI	-0.7831	0.3916	0	-0.3916	0.7832	0.3916	0.5873	0.5873
ETA	0.4795	0.1598	0	0.6394	-0.4795	0.1598	-0.1598	-0.1598
I	-0.6191	0.6191	0	0	0.6191	0.6191	0.6191	0.6191

R_y, A_{FB} versus lumi SSM/CHI

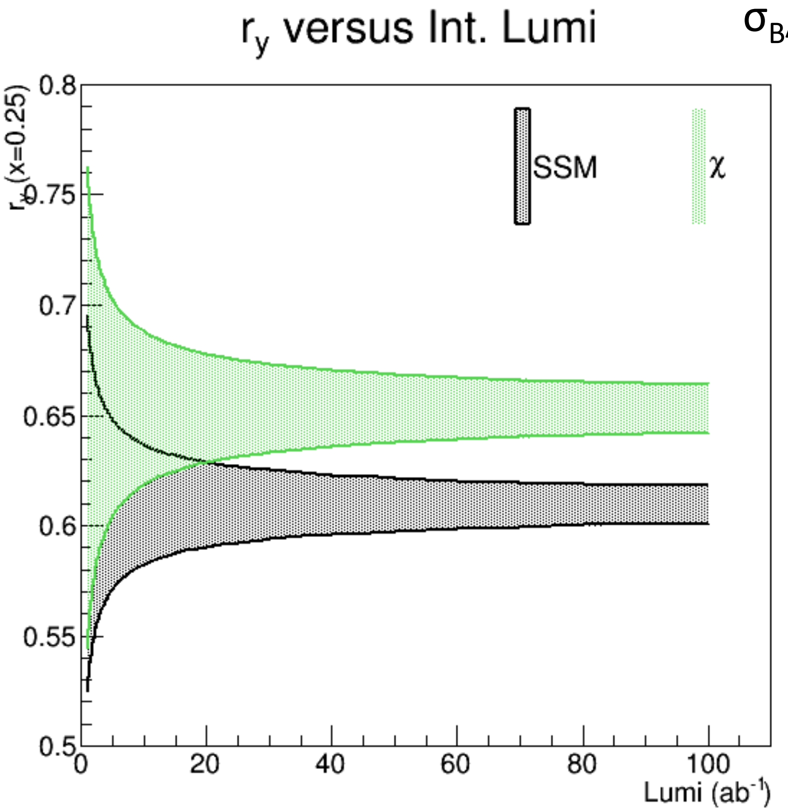
No background

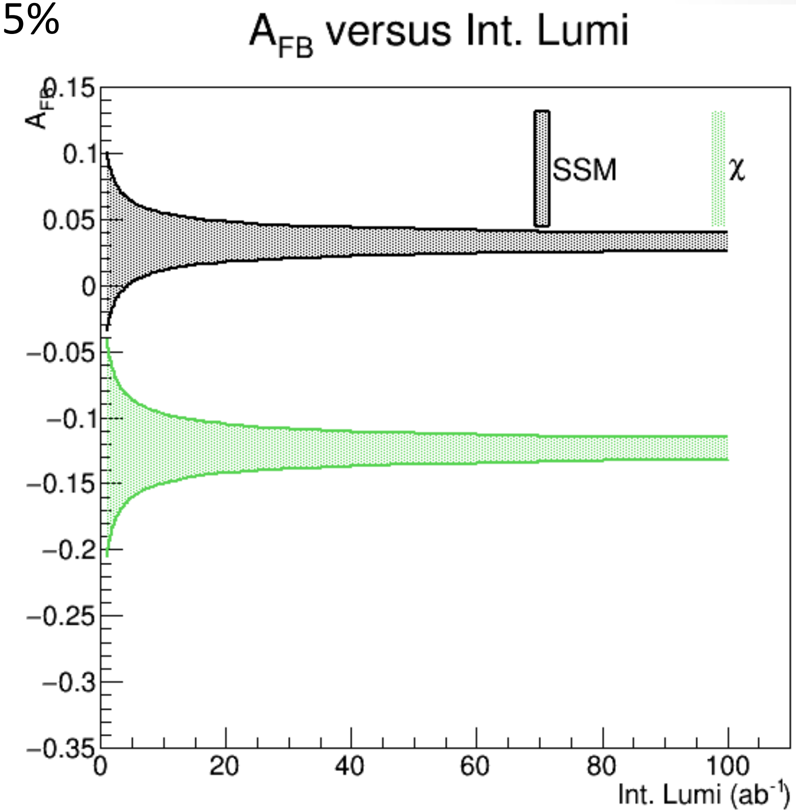




R_y, A_{FB} versus lumi SSM/CHI

$\sigma_B/B = 5\%$

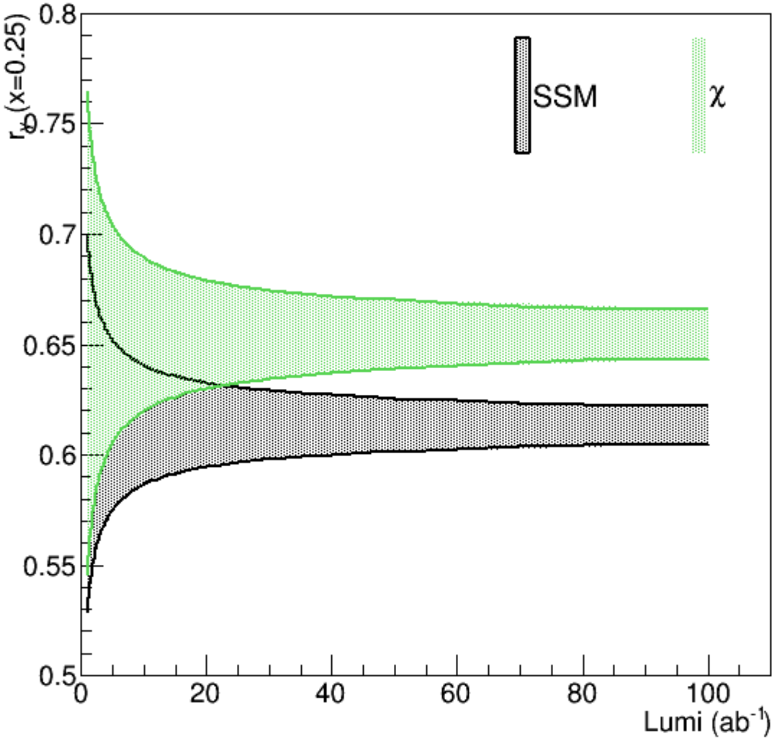




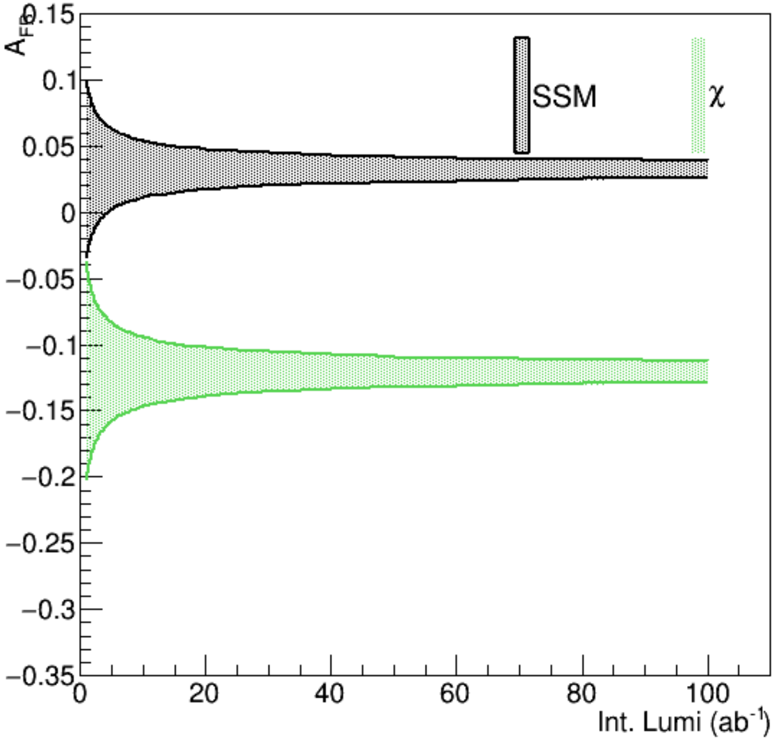
R_y, A_{FB} versus lumi SSM/CHI

Interference Z'/Z,γ*

r_y versus Int. Lumi

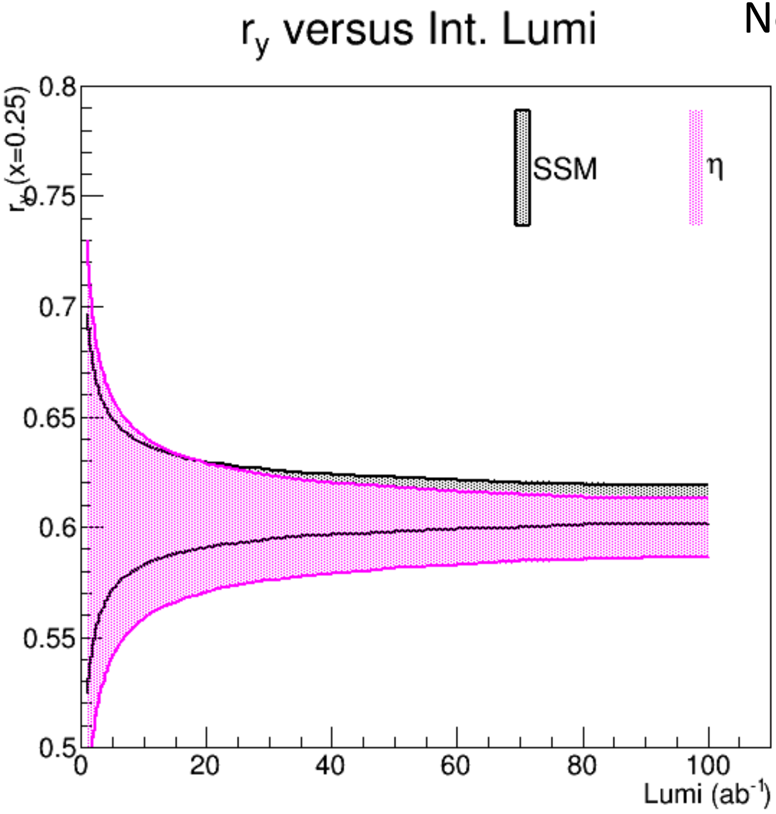


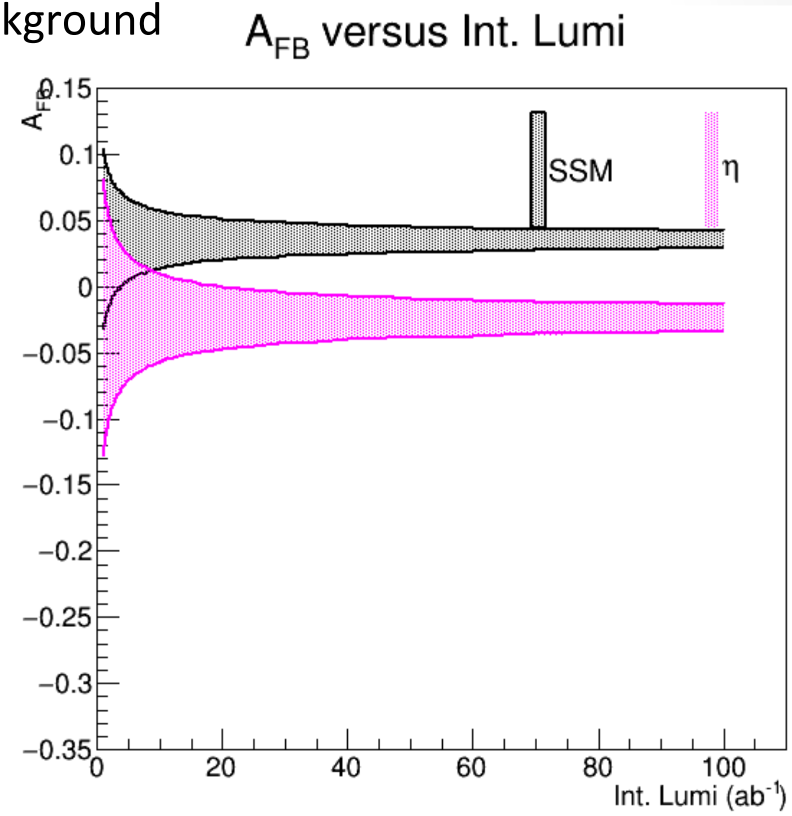
A_{FB} versus Int. Lumi



R_y, A_{FB} versus lumi SSM/ETA

No background





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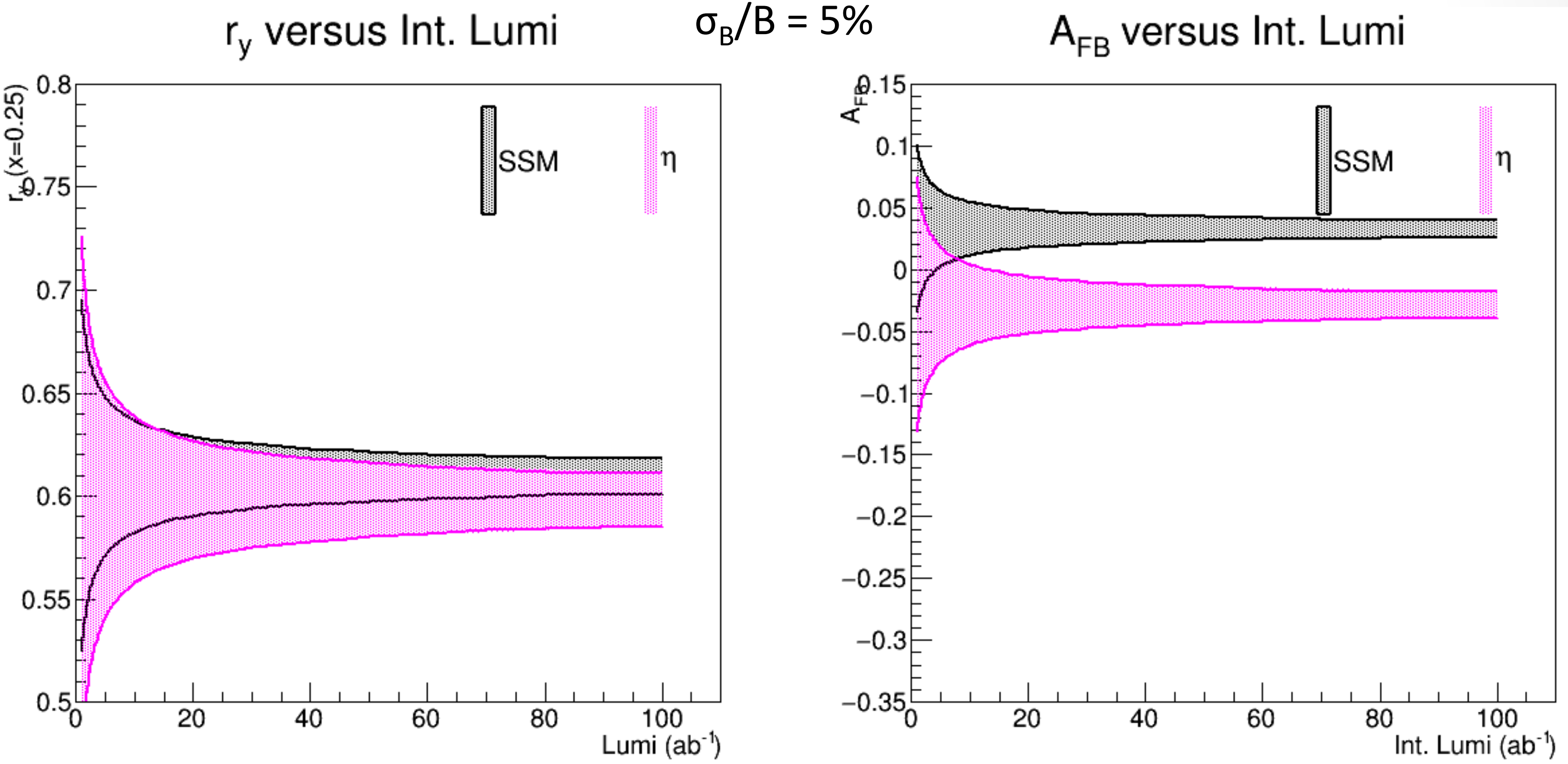
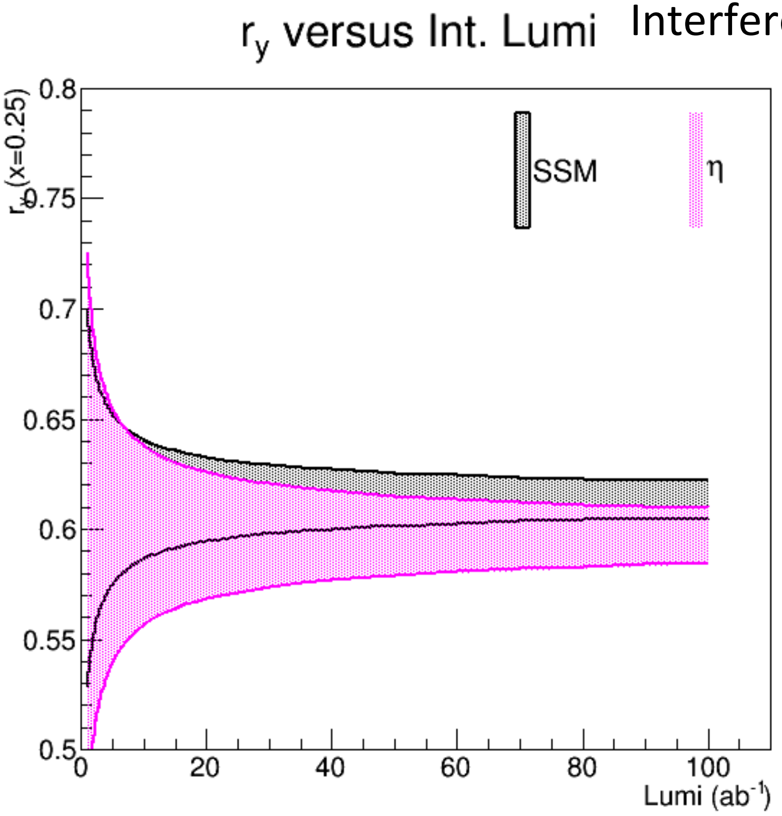
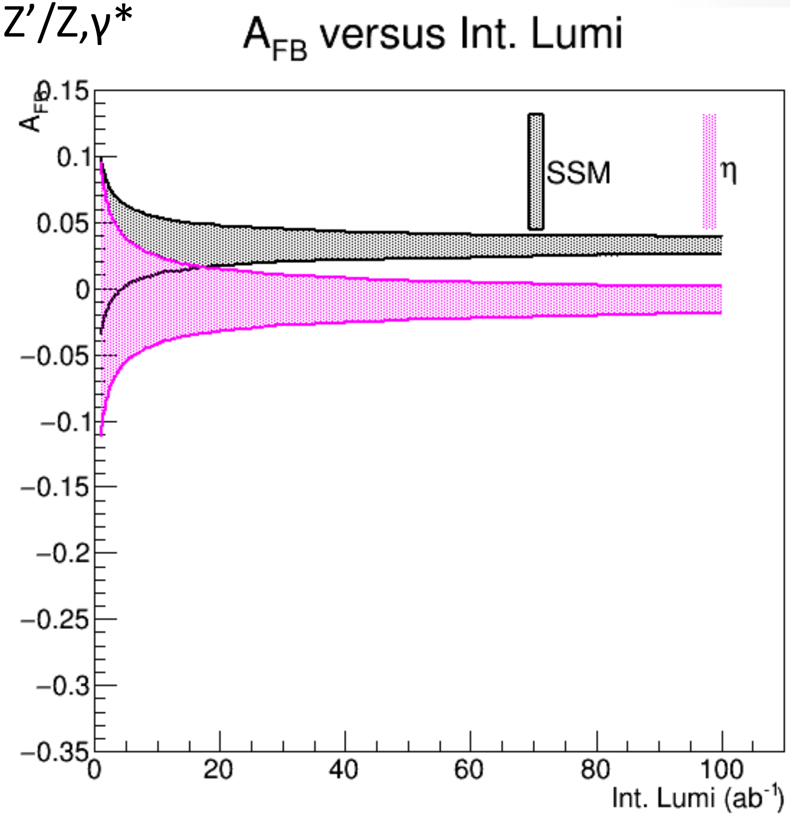


R_y, A_{FB} versus lumi SSM/ETA

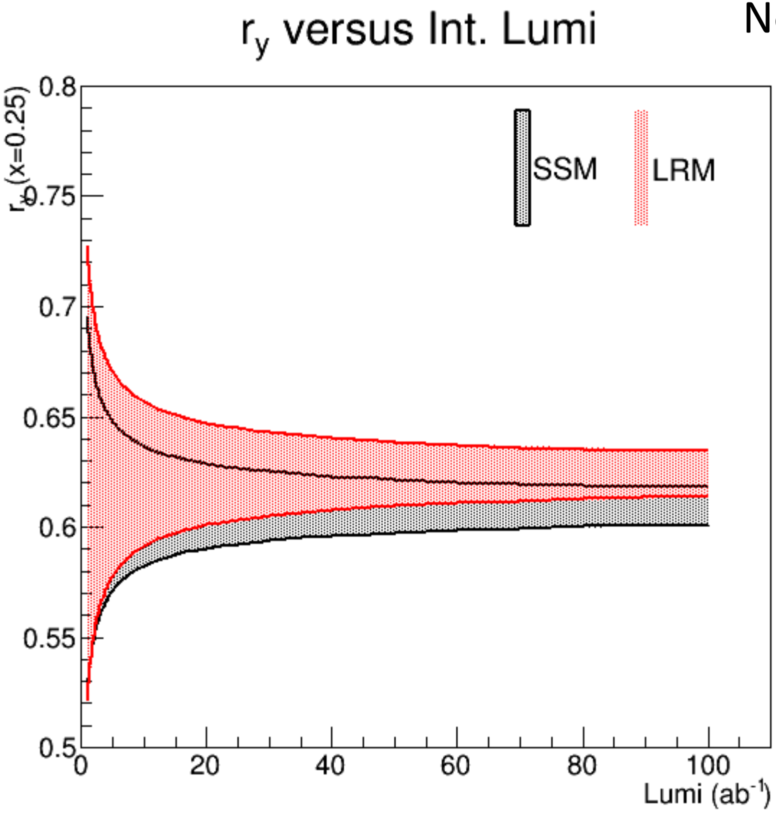
Interference Z'/Z,γ*

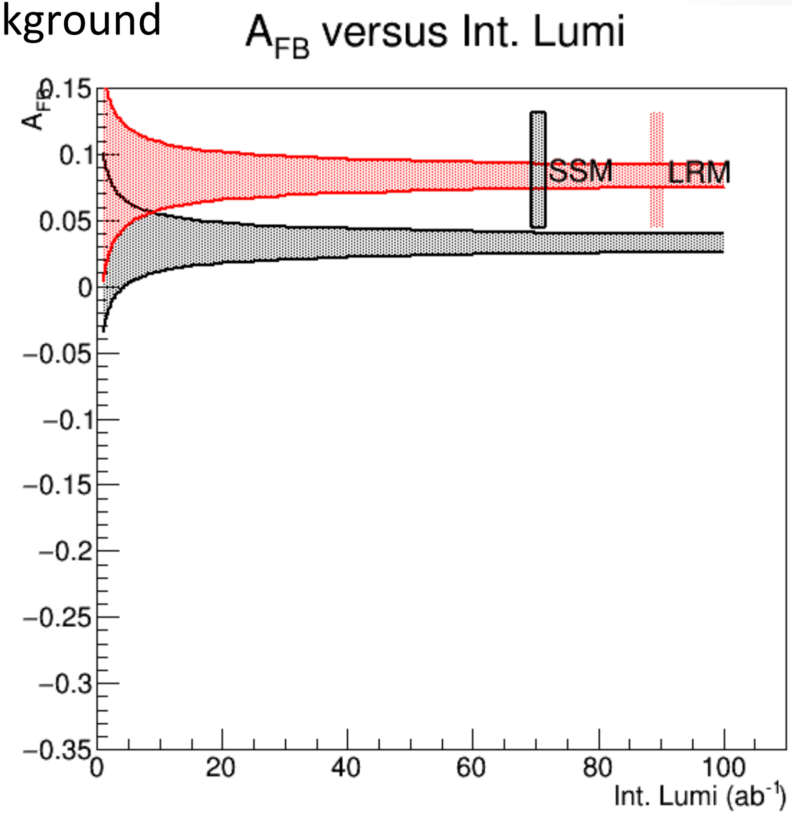




R_y, A_{FB} versus lumi SSM/LRM

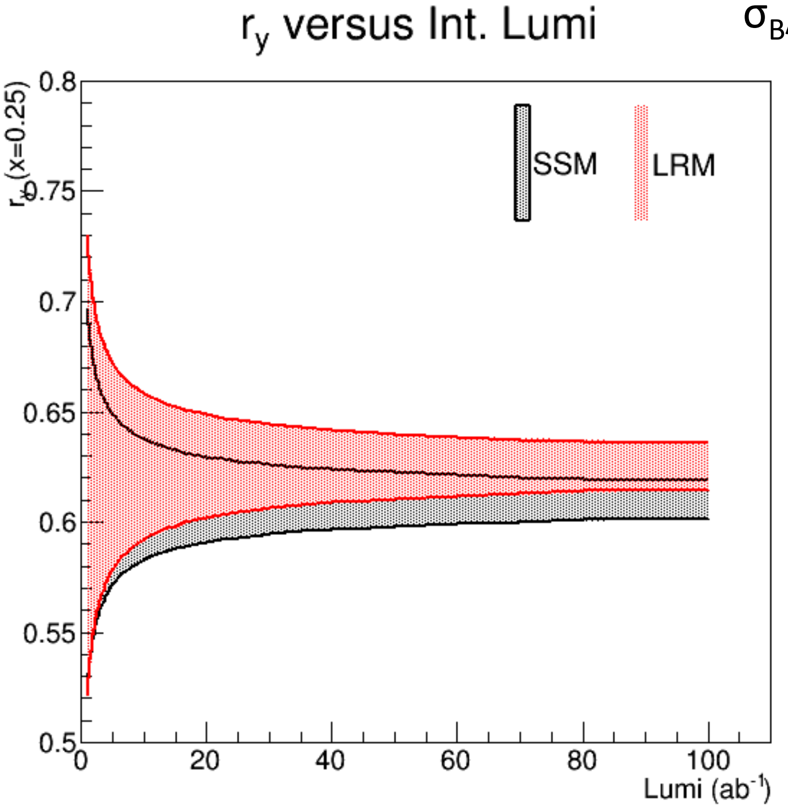
No background

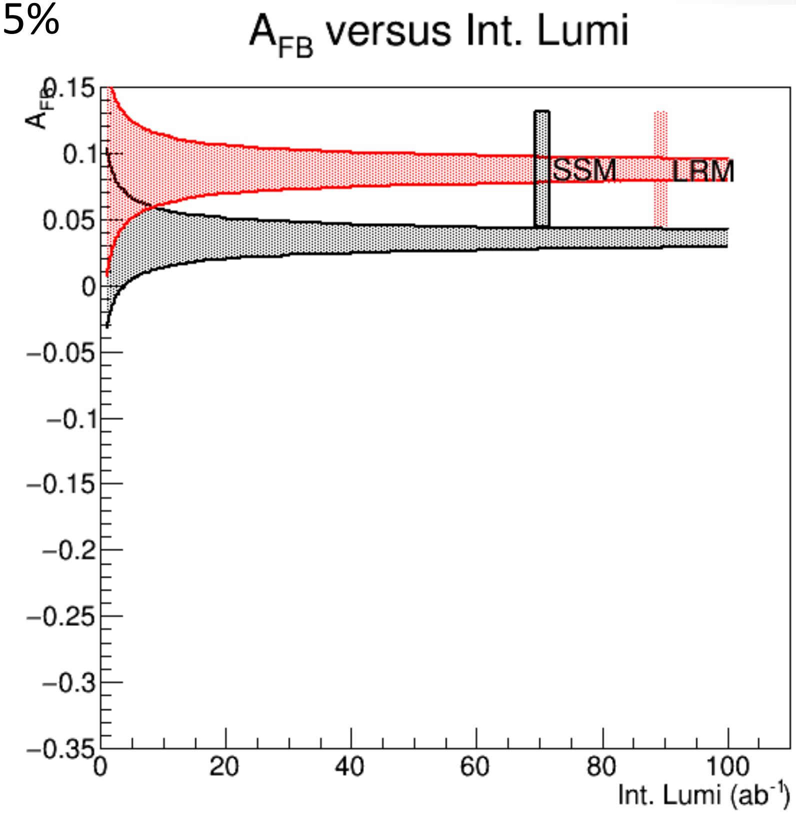




R_y, A_{FB} versus lumi SSM/LRM

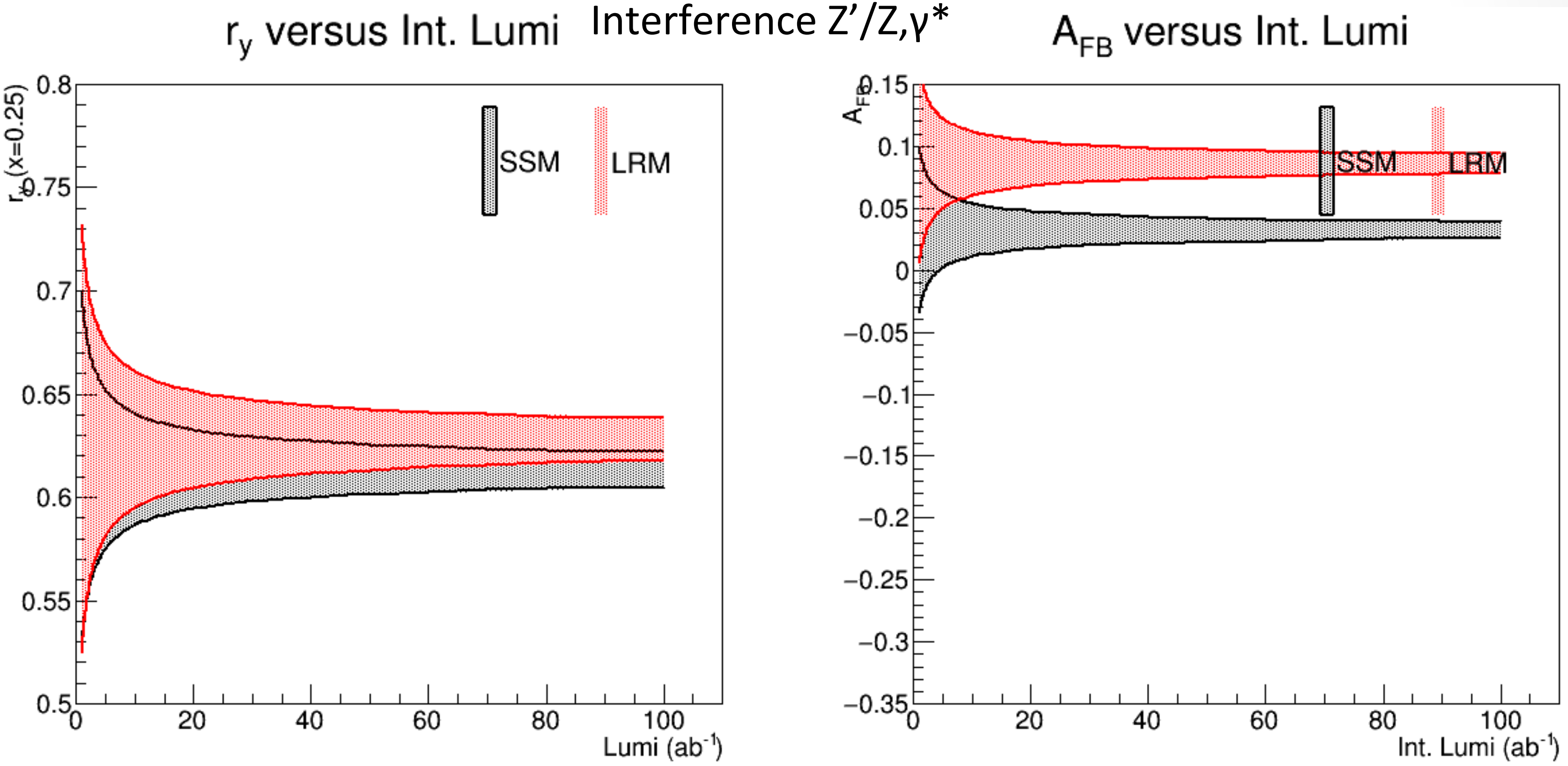
$\sigma_B/B = 5\%$





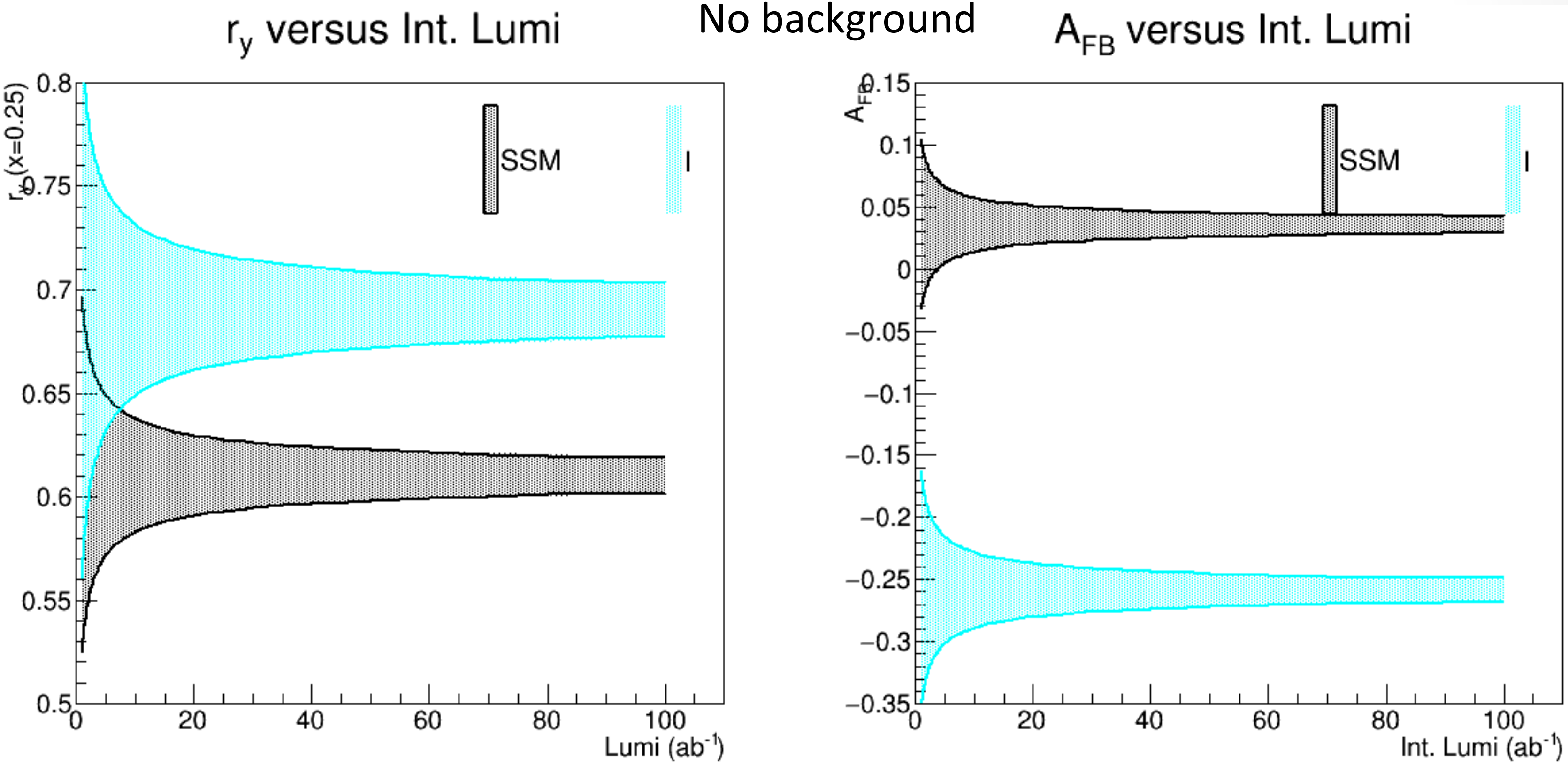
R_y, A_{FB} versus lumi SSM/LRM

Interference Z'/Z,γ*



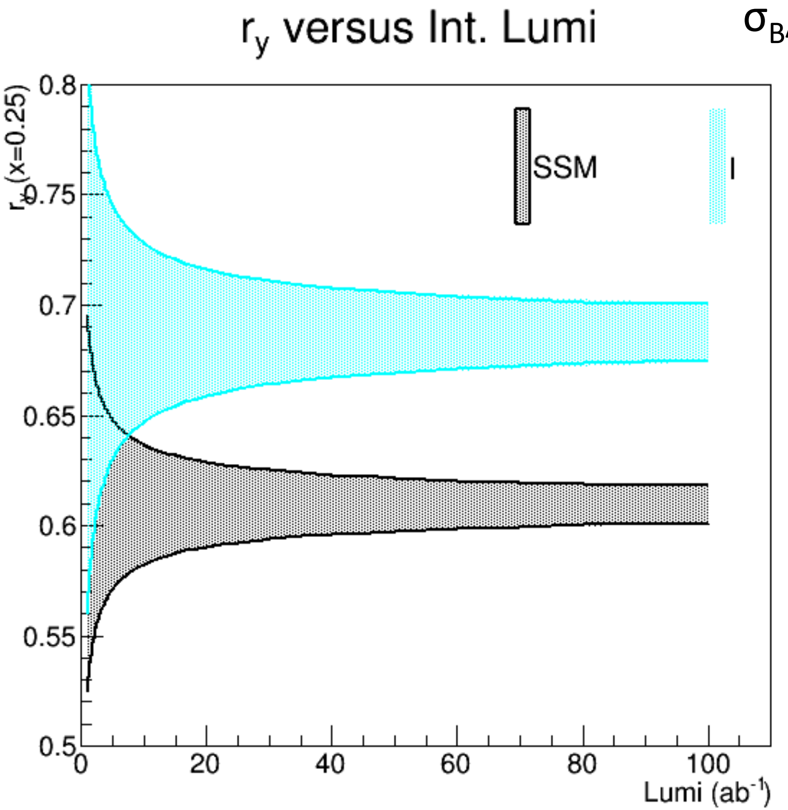
R_y, A_{FB} versus lumi SSM/I

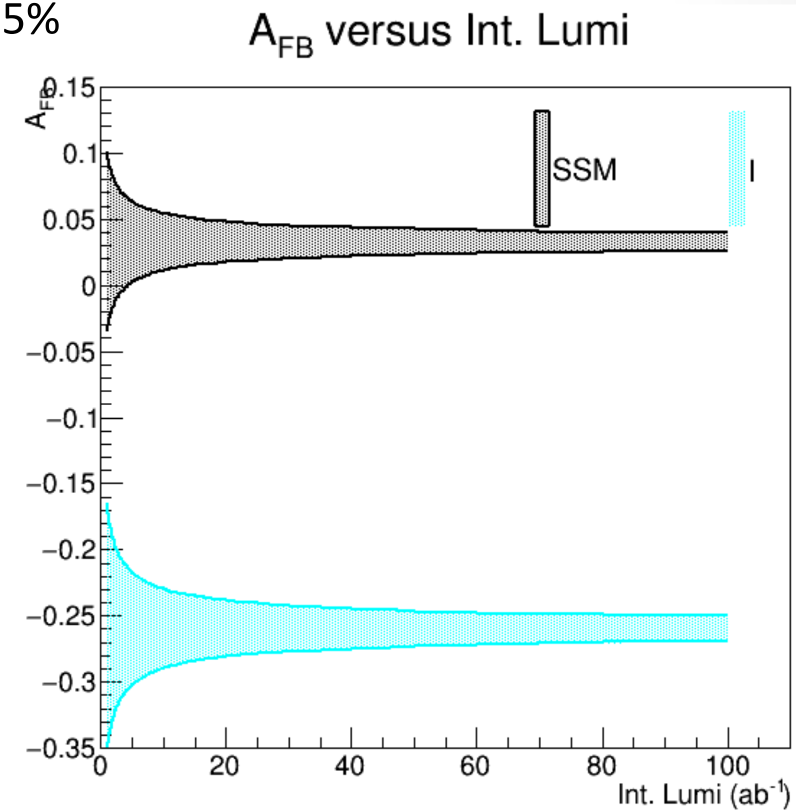
No background



R_y, A_{FB} versus lumi SSM/I

$\sigma_B/B = 5\%$





R_y, A_{FB} versus lumi SSM/I

Interference Z'/Z,γ*