

WG5 - Heavy flavour: Summary

Takashi Hachiya, Mark Owen, Karim Trabelsi

DIS2018, Kobe, Japan

Heavy Flavour

- 6 sessions + joint sessions with WGs 1, 3 & 4, covering:
 - Top quark physics
 - Quarkonia
 - Hadron spectroscopy
 - Heavy flavour in heavy ions
 - Other heavy-flavour studies

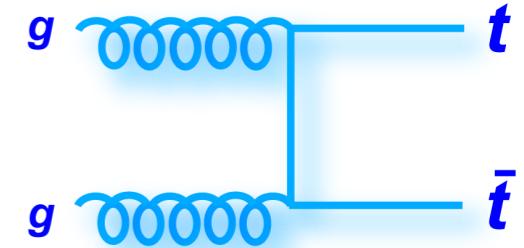
Heavy Flavour

- 6 sessions + joint sessions with WGs 1, 3 & 4, covering:
 - Top quark physics
 - Quarkonia
 - Hadron spectroscopy
 - Heavy flavour in heavy ions
 - Other heavy-flavour studies
- 37 talks
~20 minutes to summarise

Have to be selective!

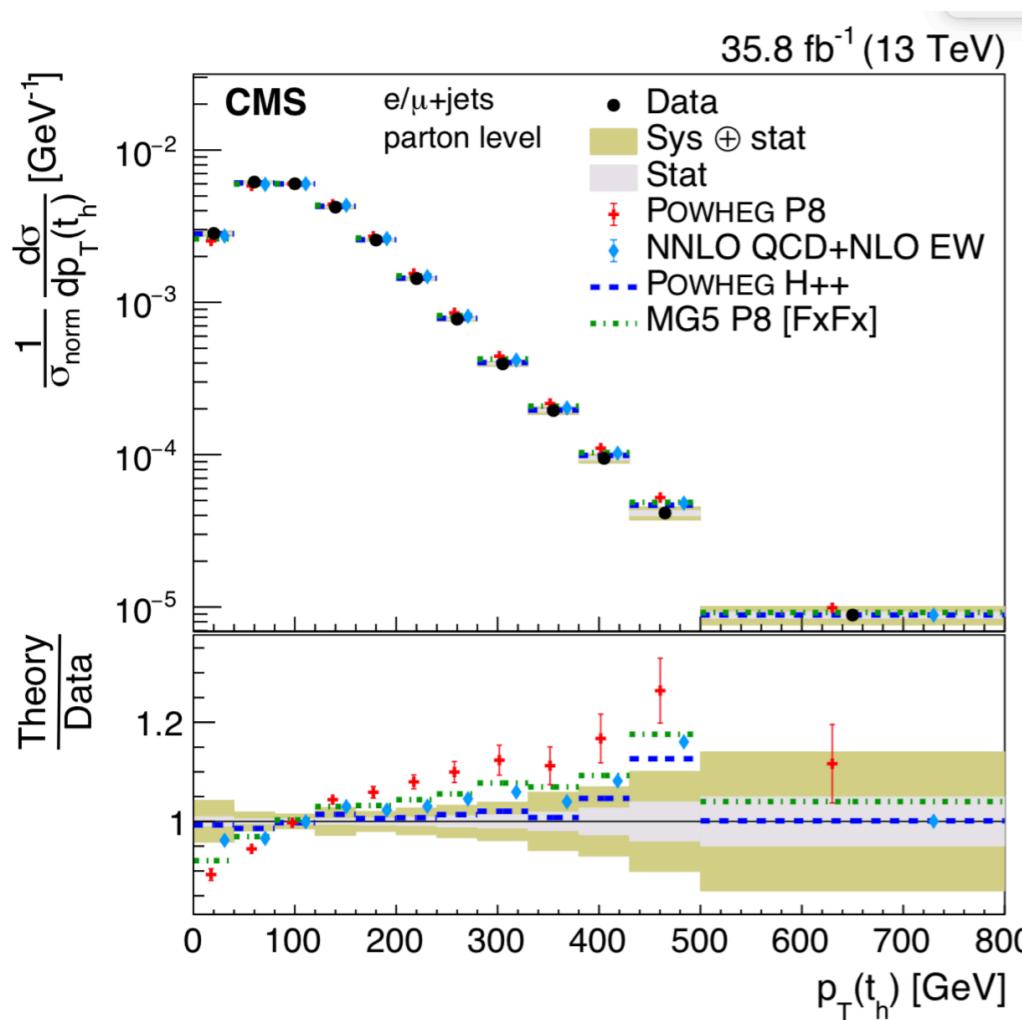
Top quark physics

Top pair-production



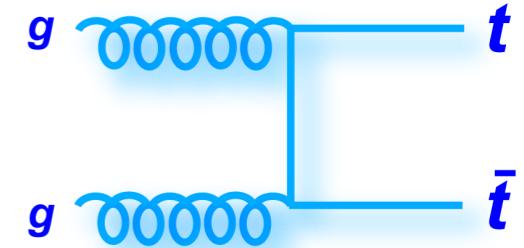
(Differential)
measurement of $\sigma_{t\bar{t}}$

- provides a **stringent test of QCD calculations** with heavy quarks
- **sensitive to potential new physics**



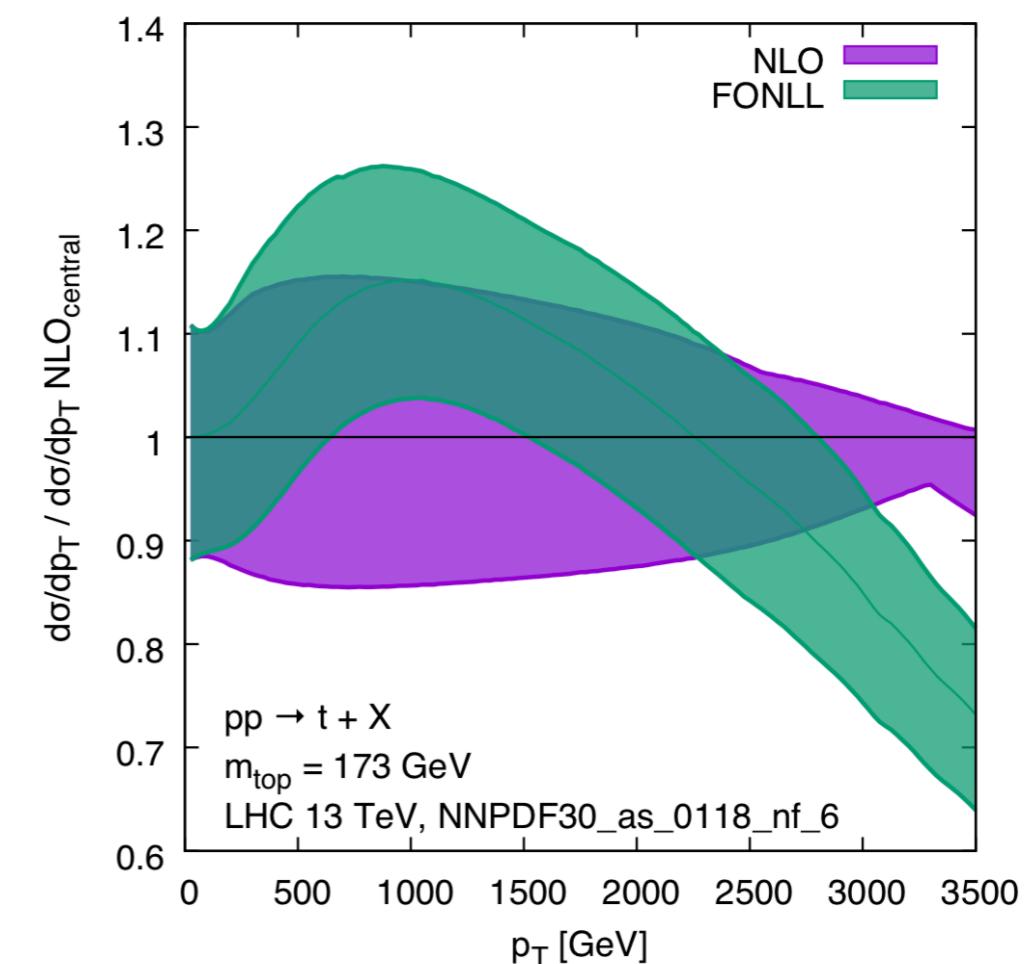
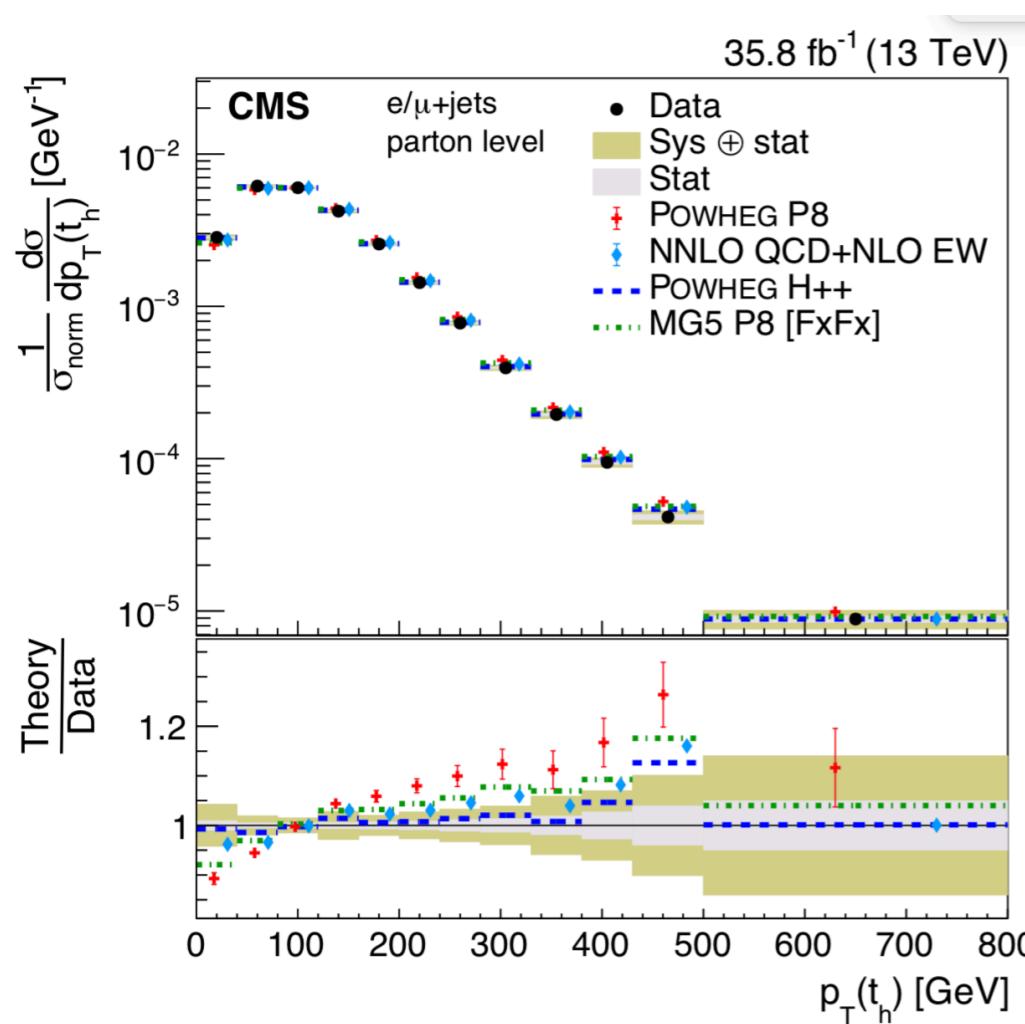
Bartos, Tsinikos, Cacciari, Roh

Top pair-production



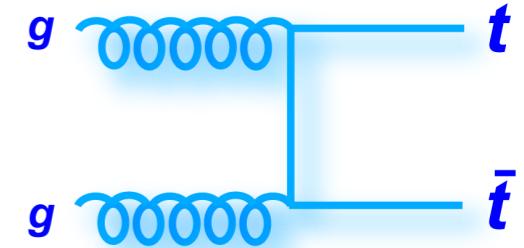
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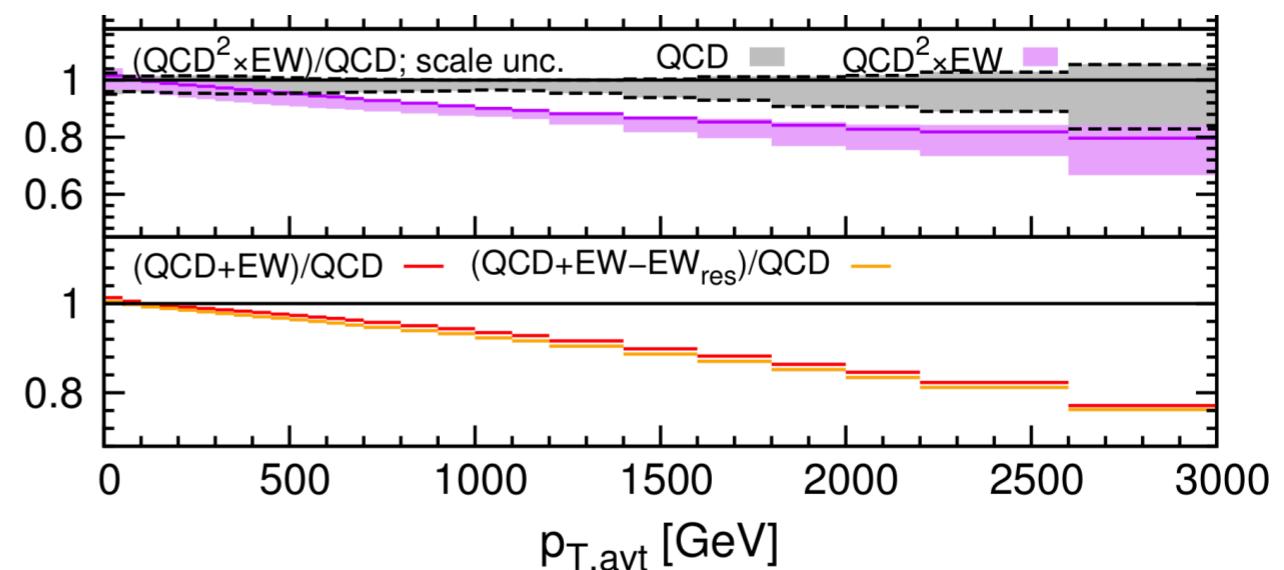
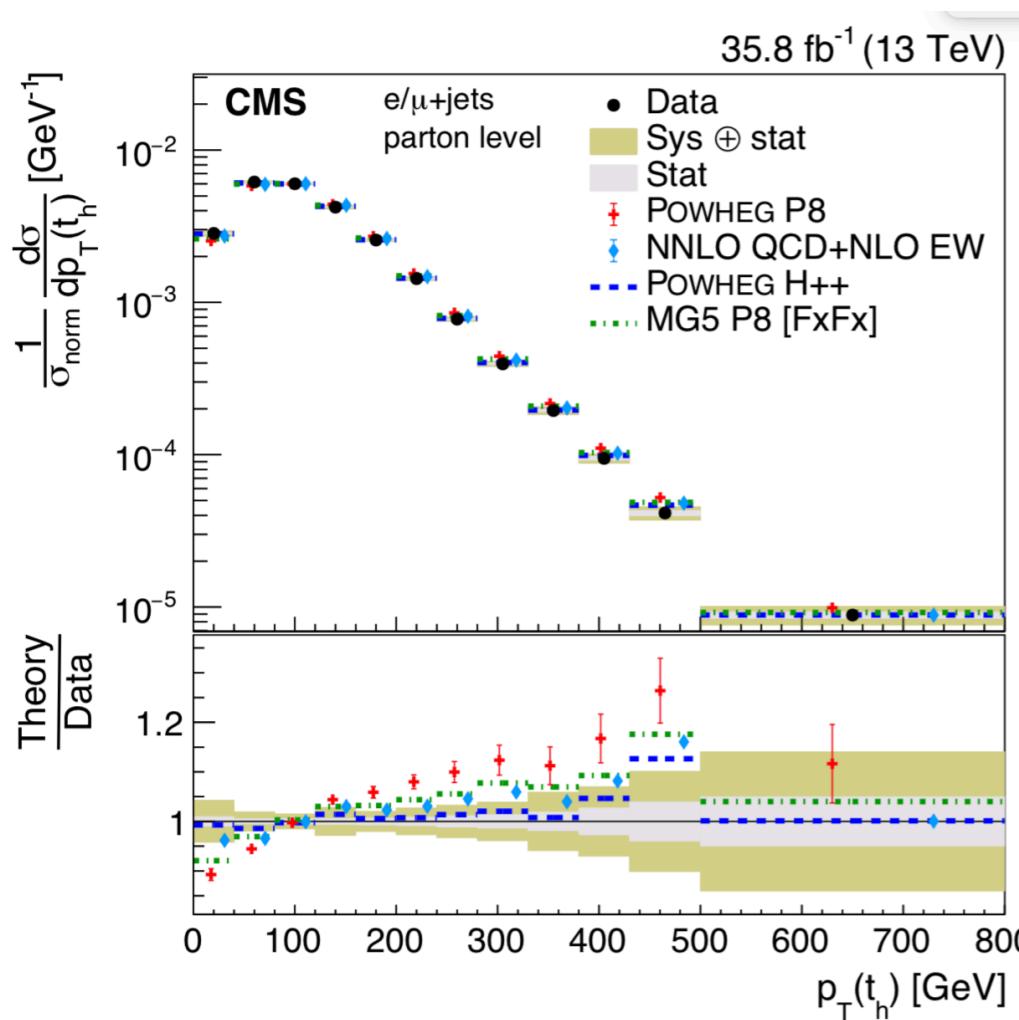
Bartos, Tsinikos, Cacciari, Roh

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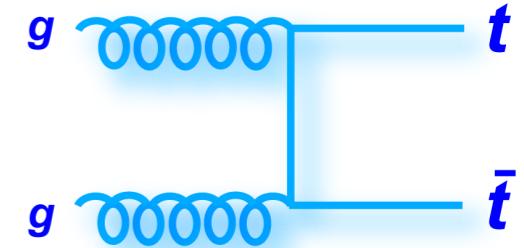
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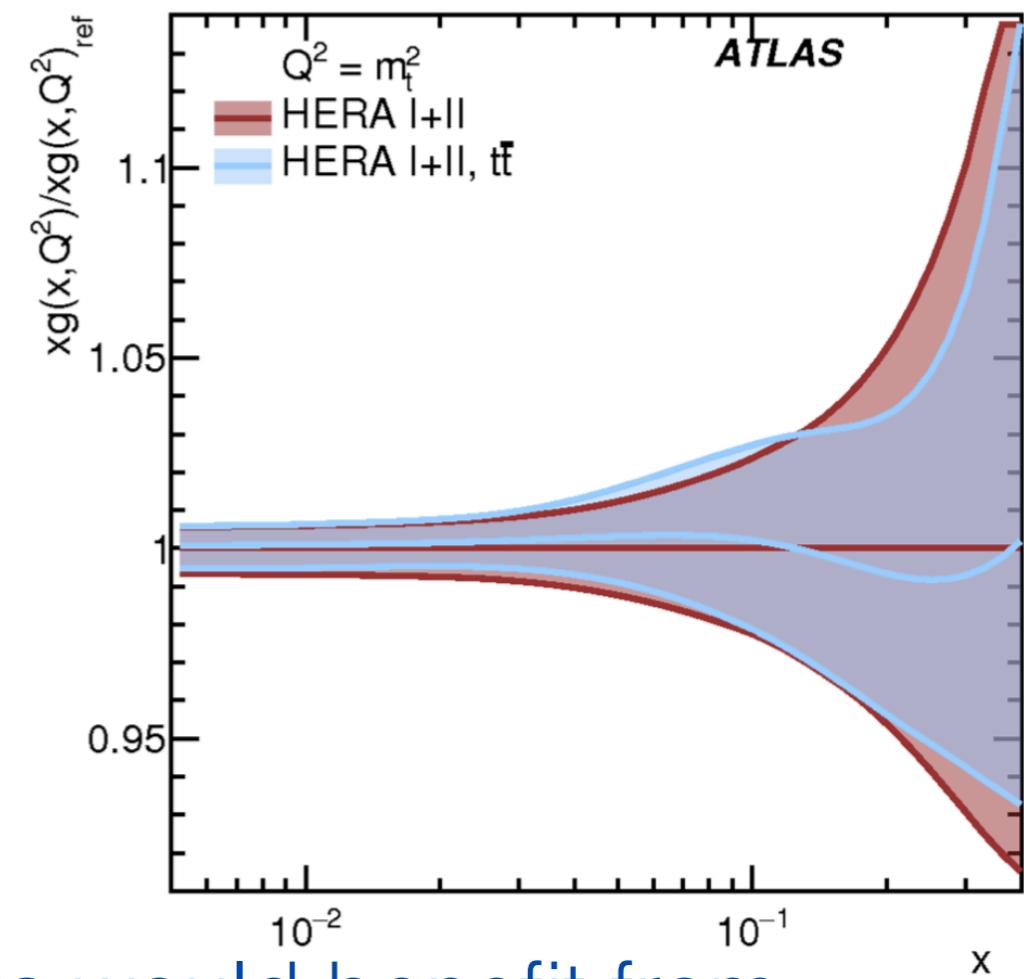
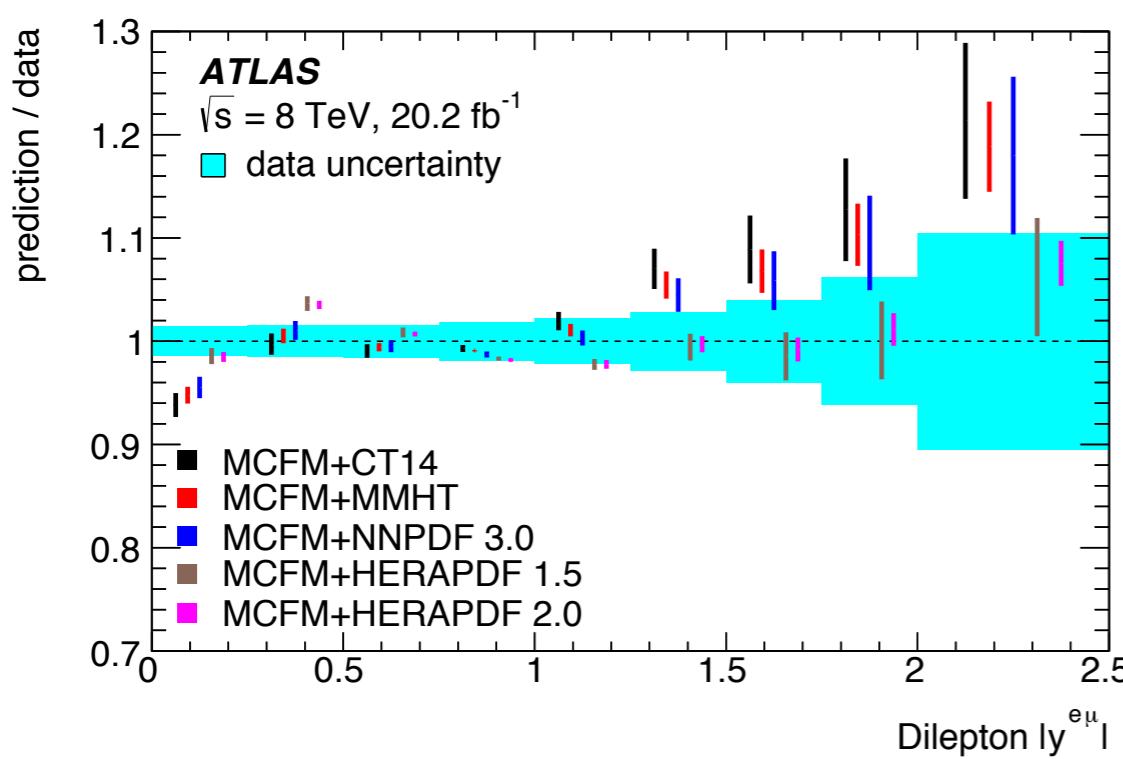
- NLO+PS QCD not enough to describe the data.
- NNLO QCD improves the agreement, NLO EW not negligible.

Bartos, Tsinikos, Cacciari, Roh

Top pair-production



- Top data being used to constrain PDFs:

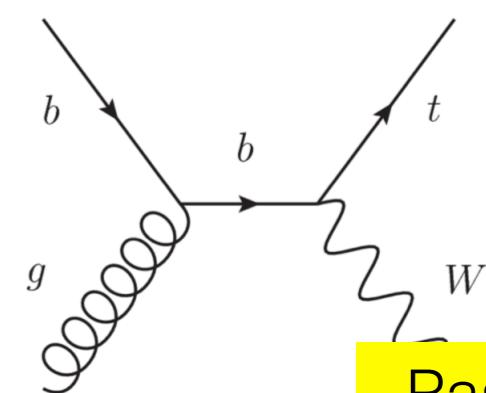
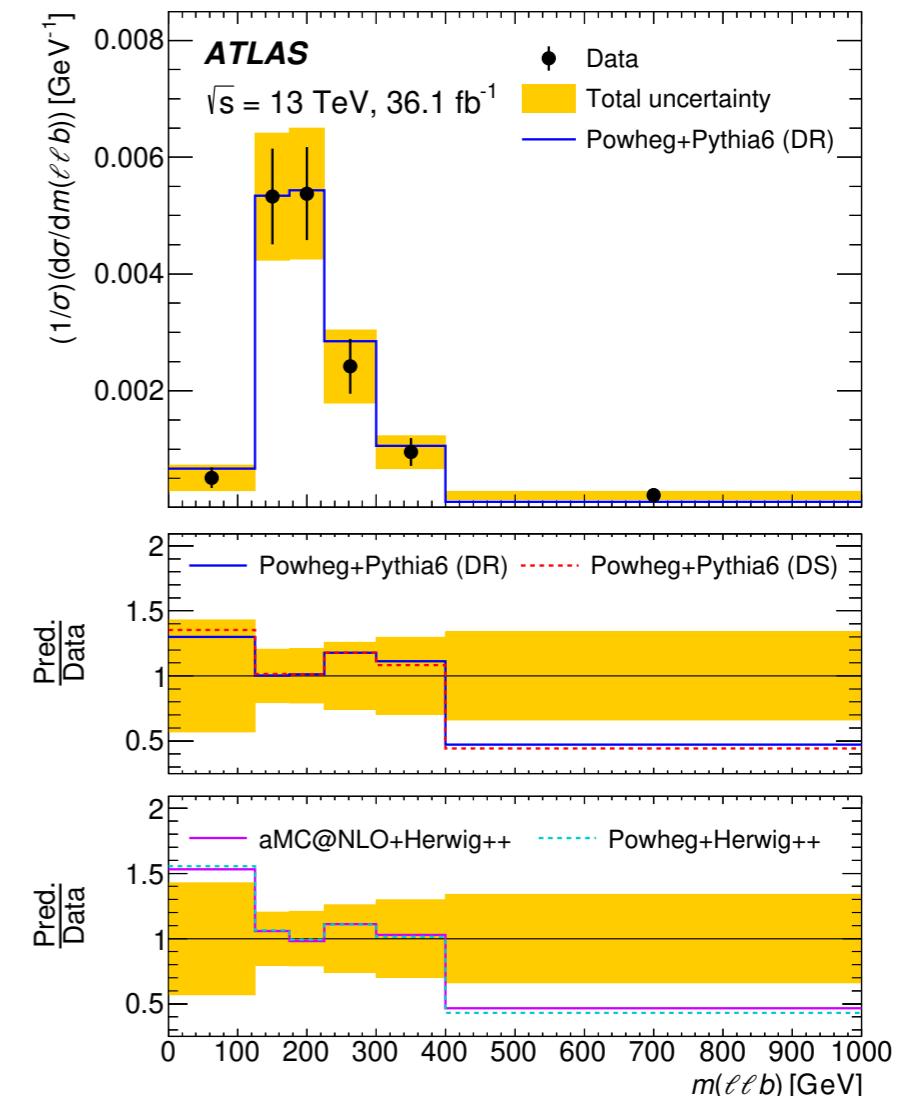
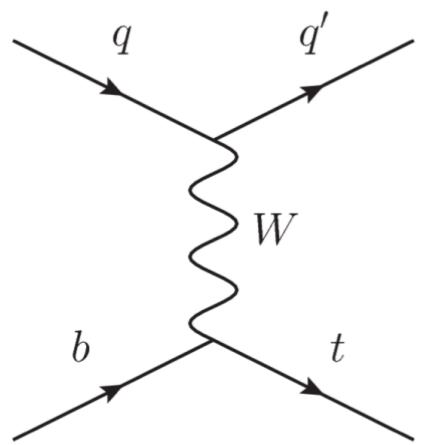
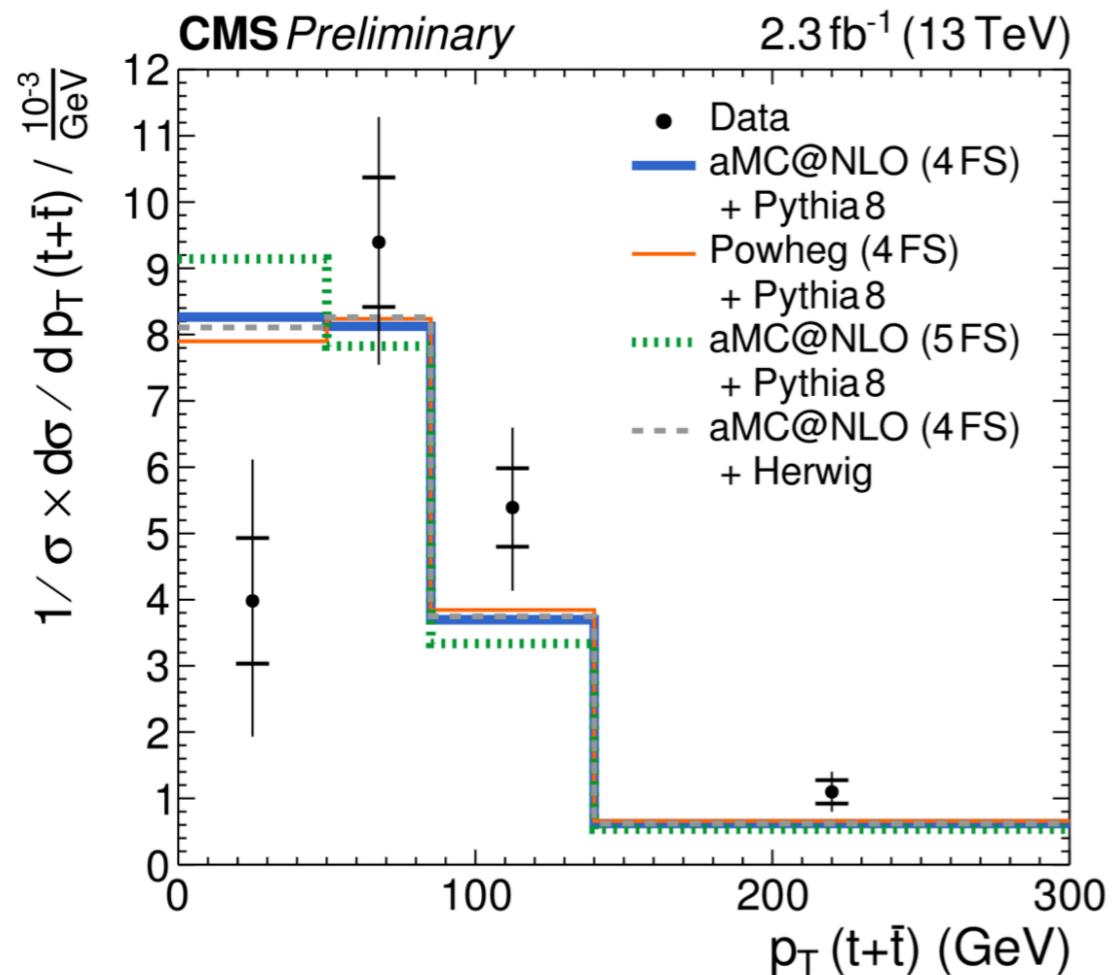


- Extractions from differential data would benefit from NNLO calculation including stable tops.

Bartos, Navarro

Single-top production

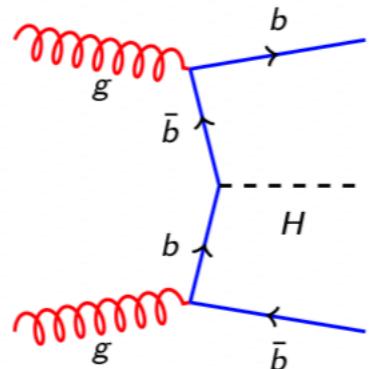
- As for ttbar, now look differentially:



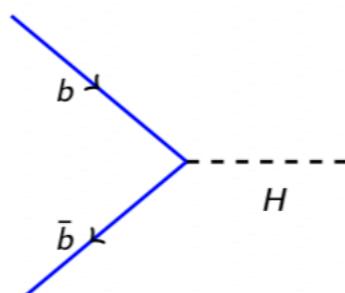
Pastor, Roh

4 & 5 Flavour schemes

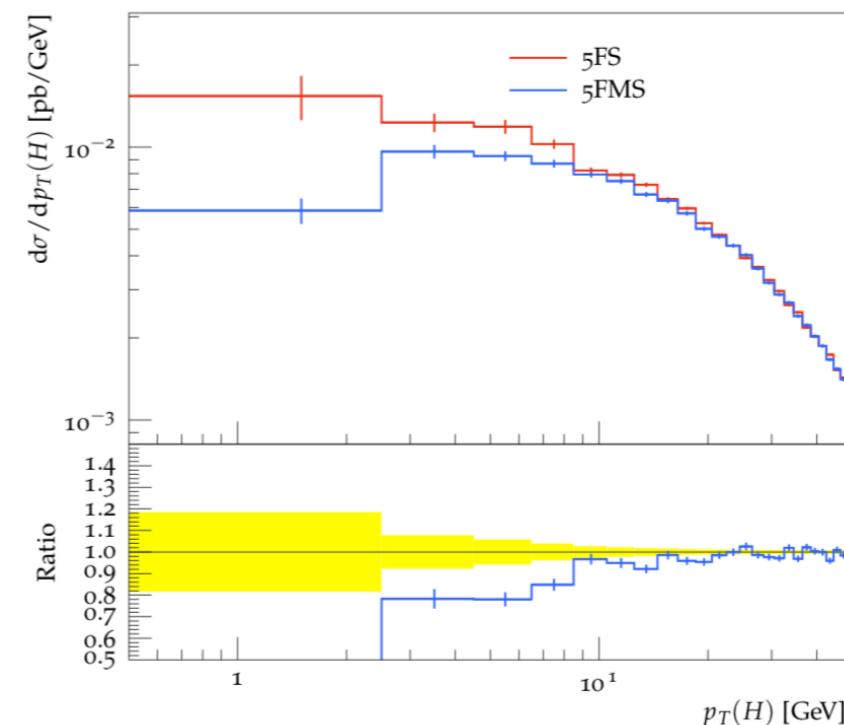
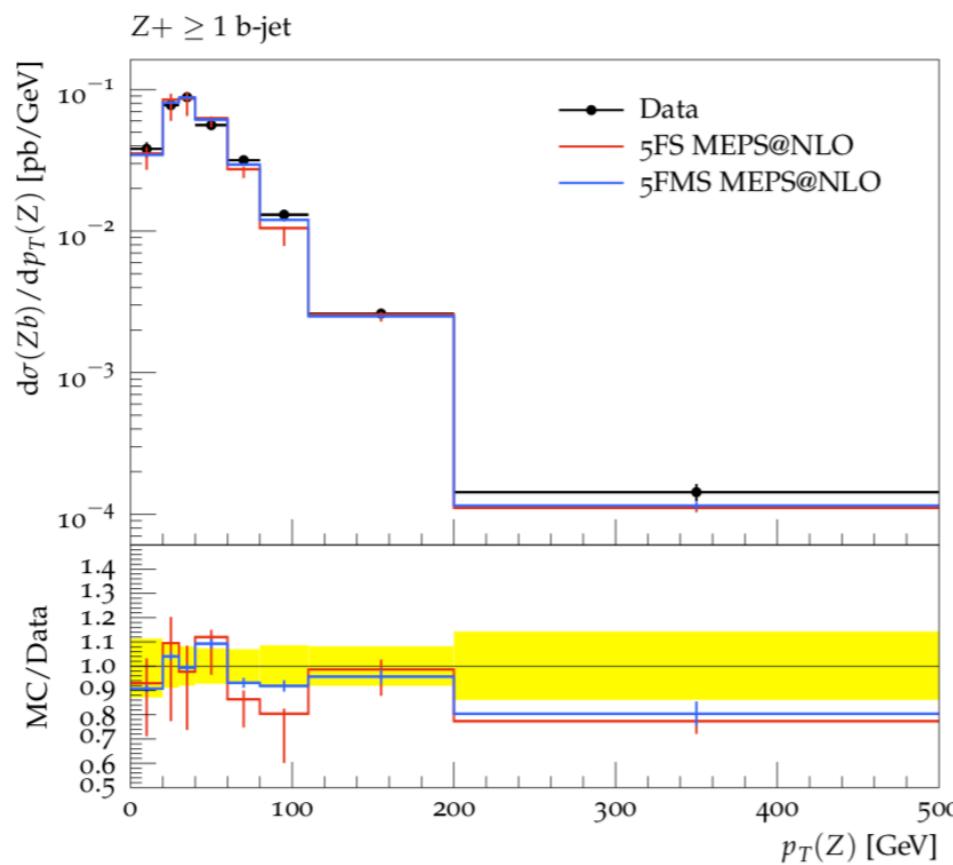
4F Scheme:



5F Scheme:



- Improve 5F scheme by including (approx.) mass effects.

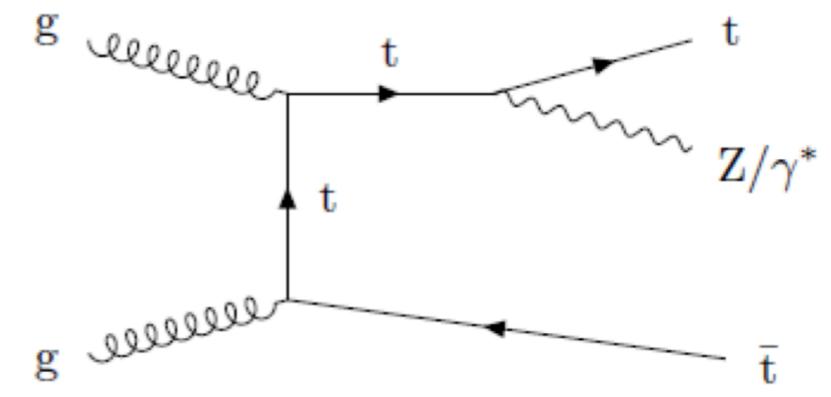
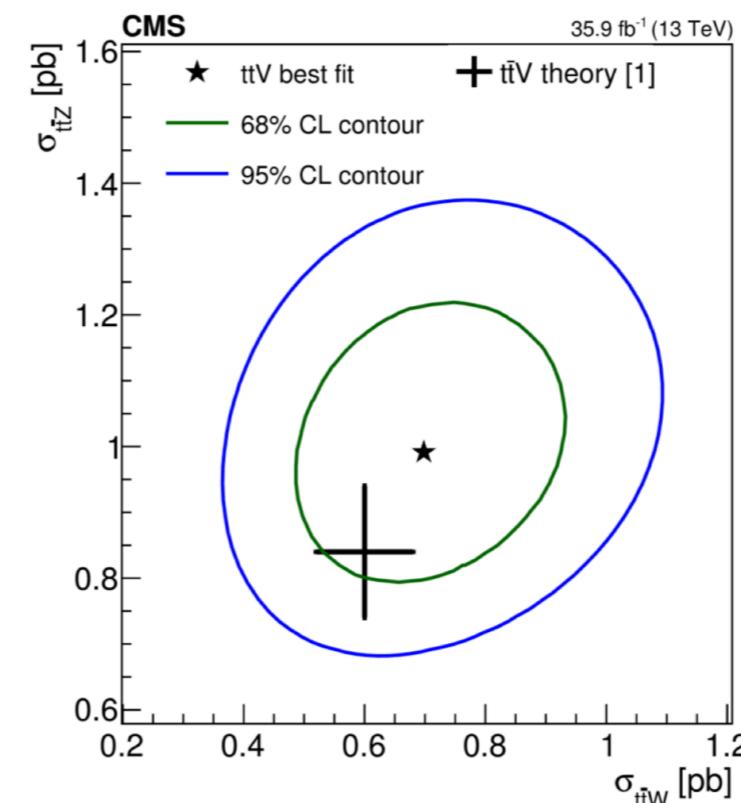
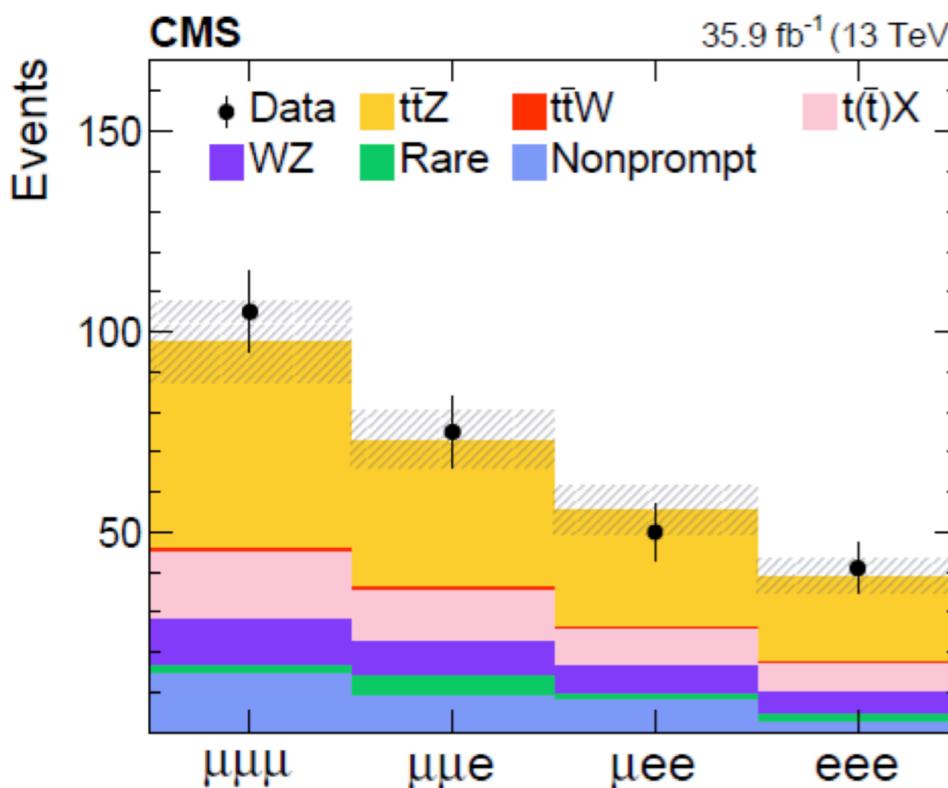


- Interesting to look at single top?

Napoletano

Top + friends

- Many possibilities at LHC for top + X:



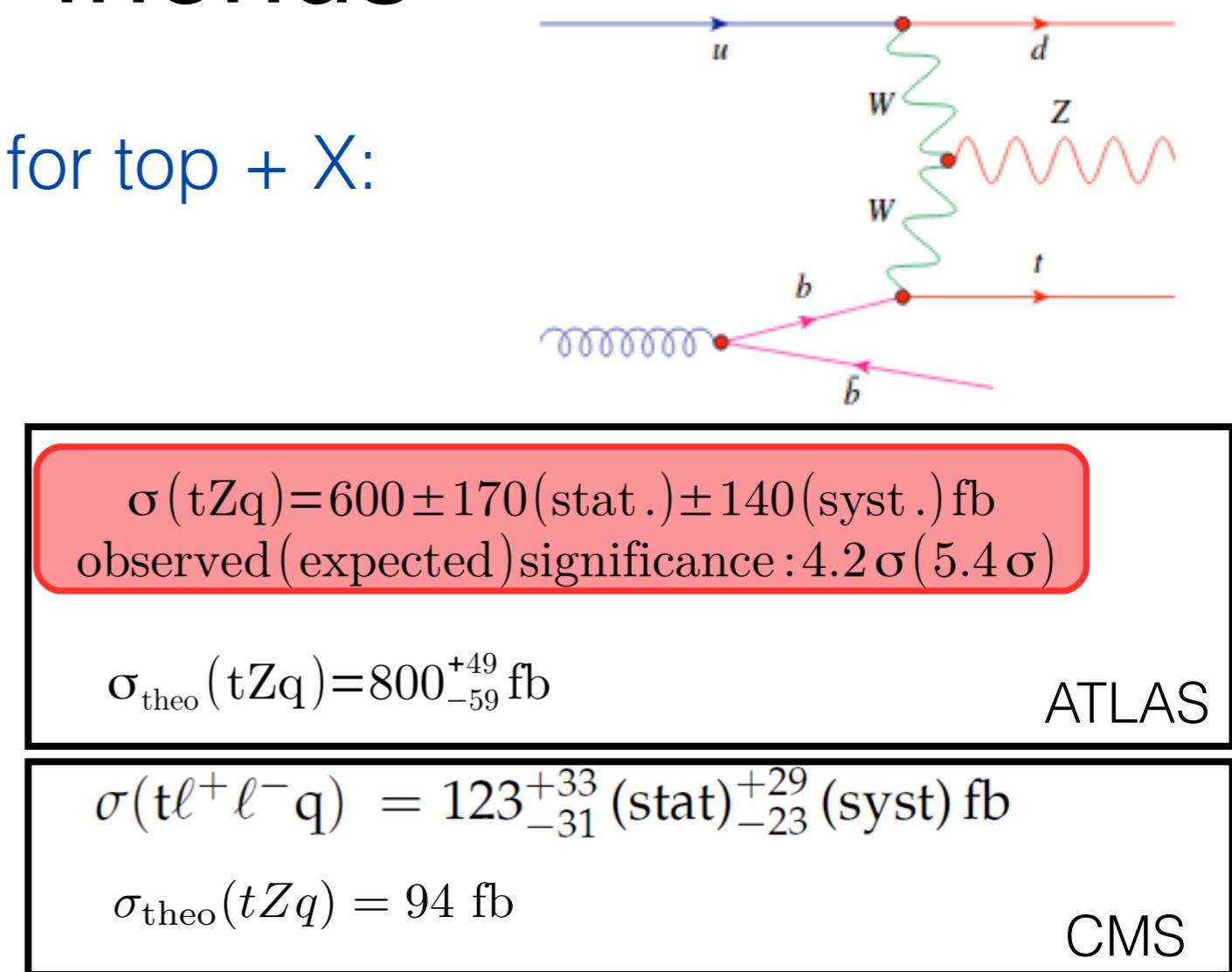
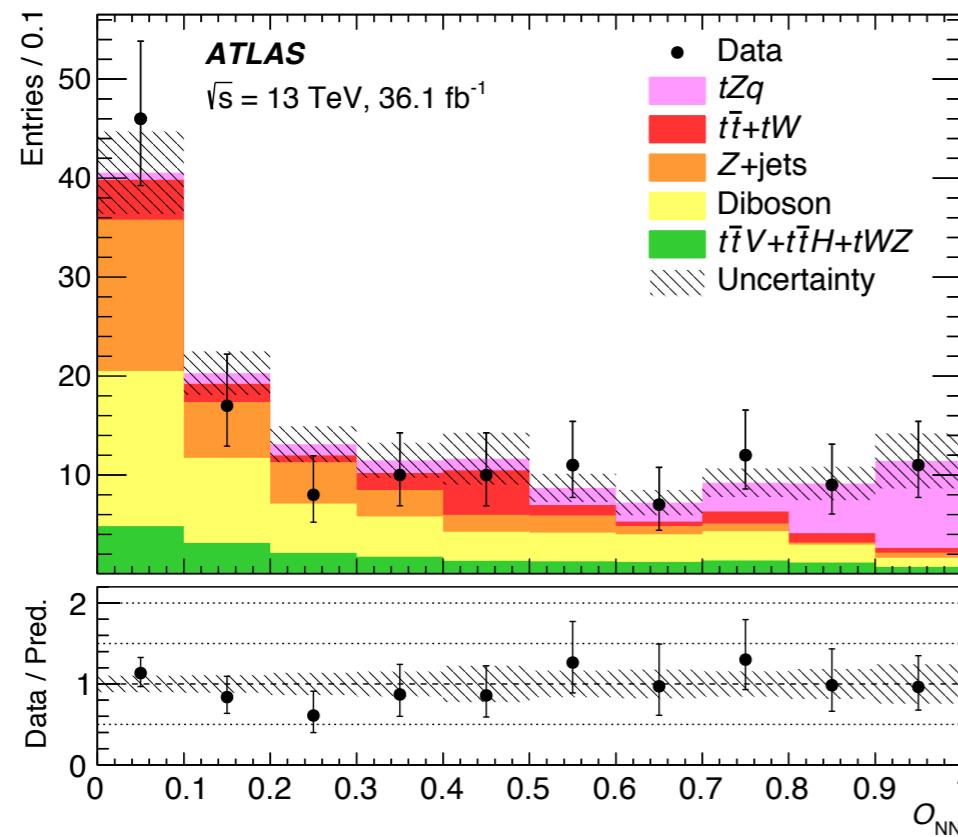
$$\sigma(\text{stat}) \sim \sigma(\text{syst})$$

- Next round of measurements need to tackle systematics.

Choi, Ahmed

Top + friends

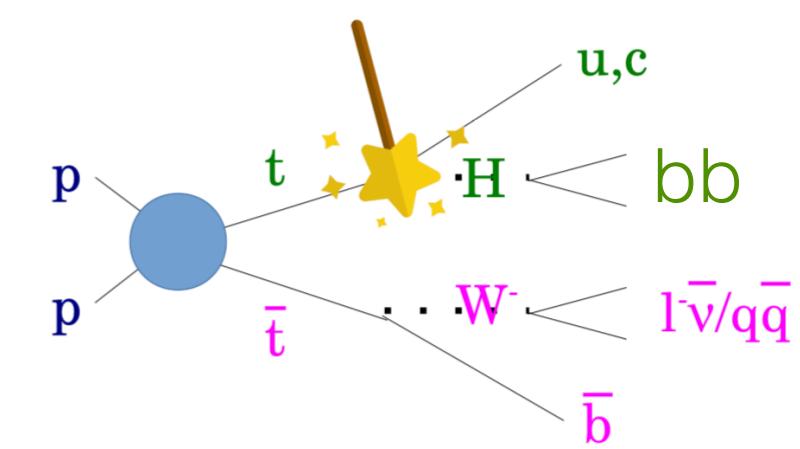
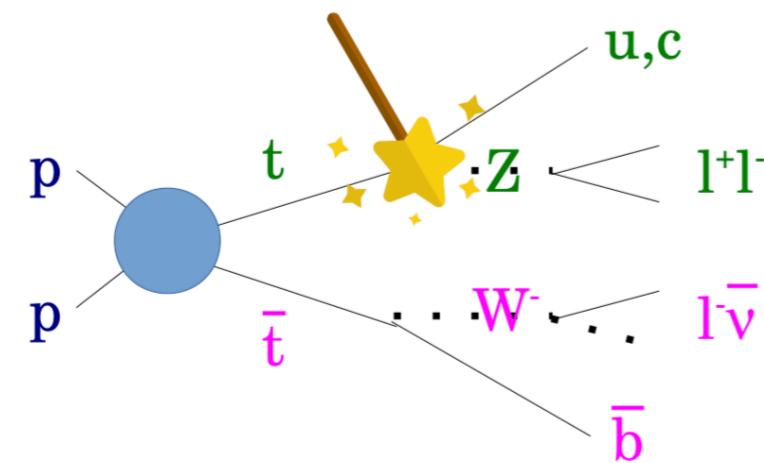
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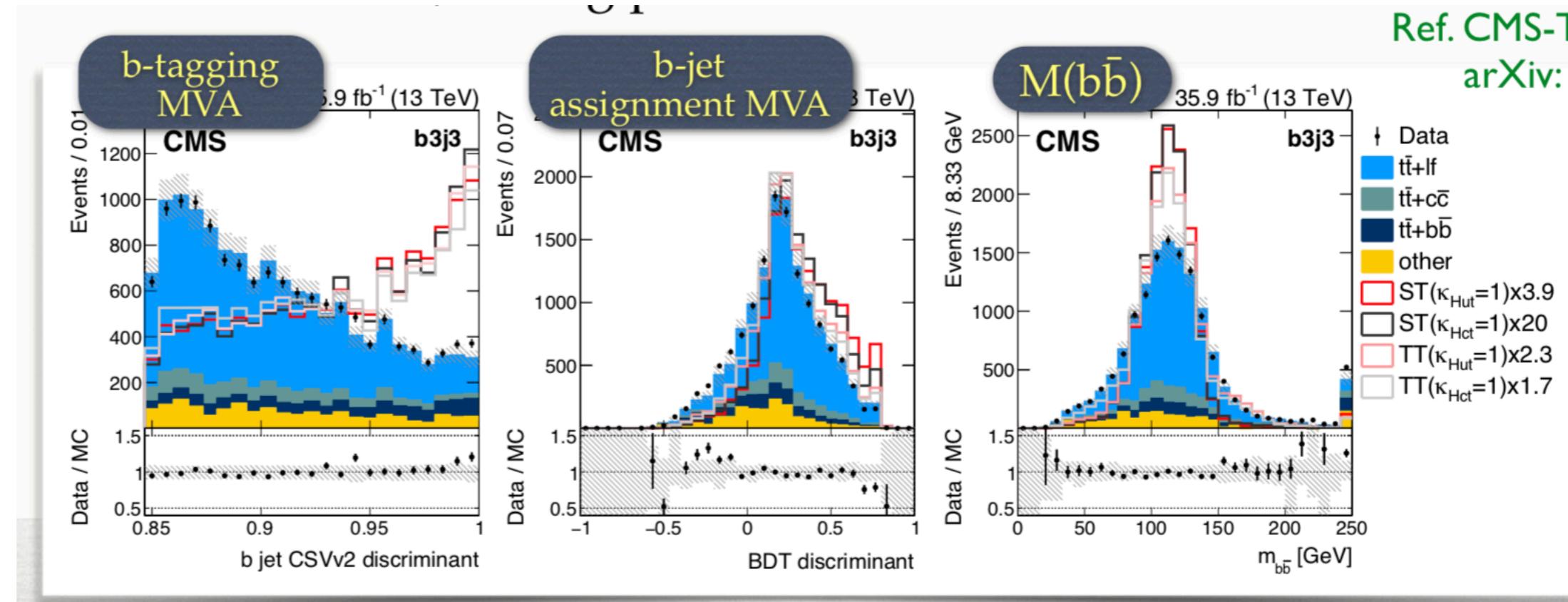
Evidence in both experiments for tZq process.

Choi, Pastor

Rare top decays



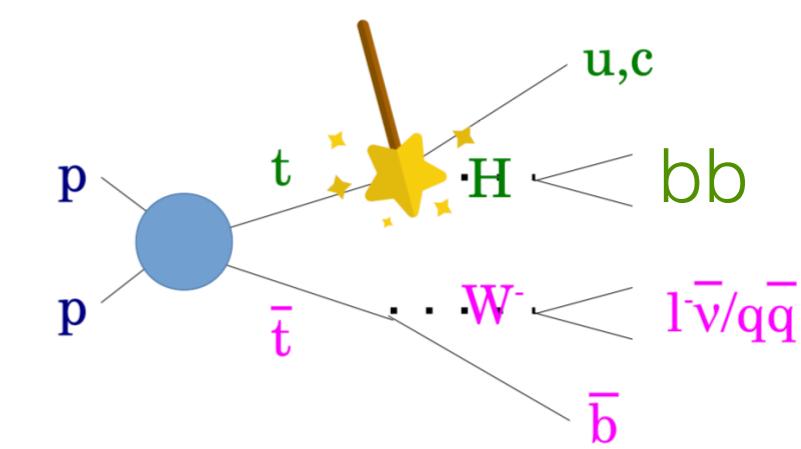
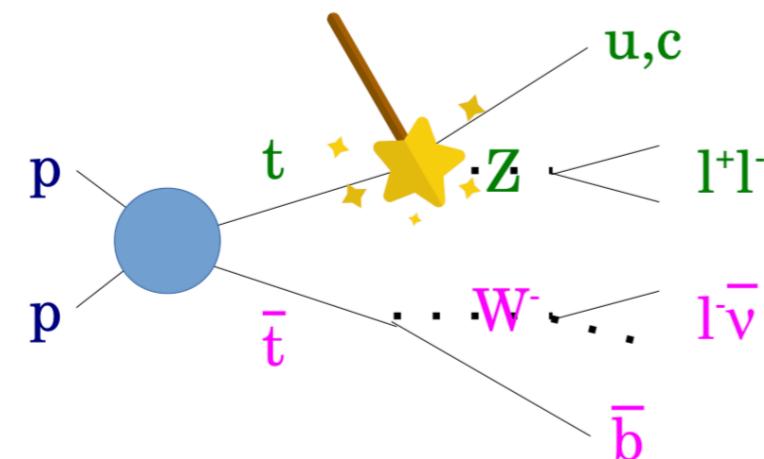
- FCNC/H decays heavily suppressed in SM \rightarrow place for NP?



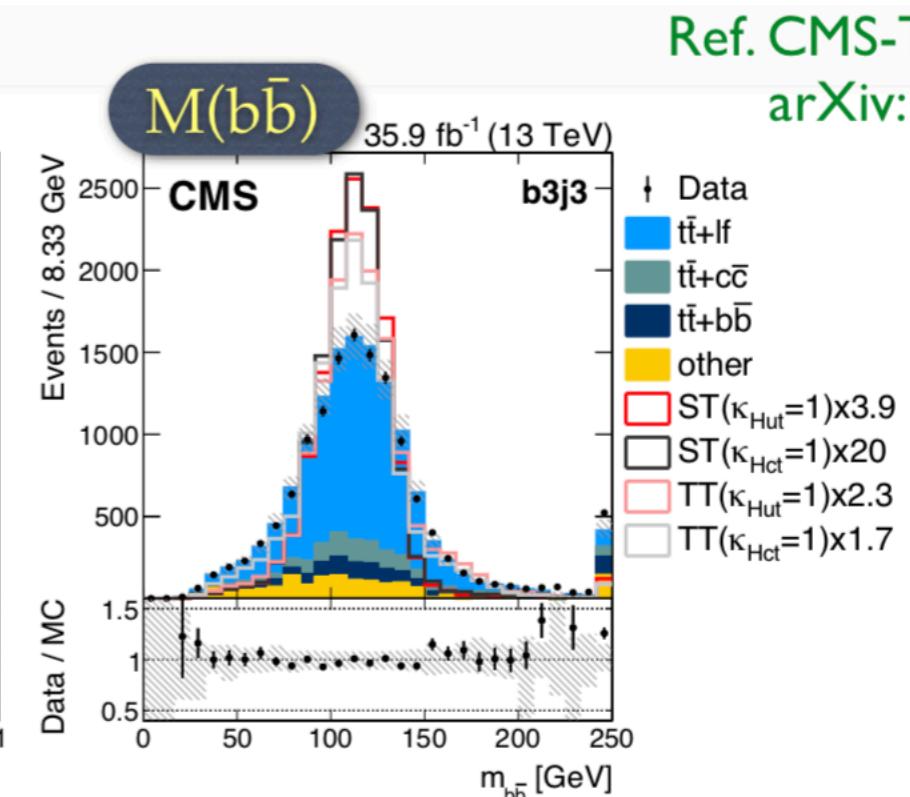
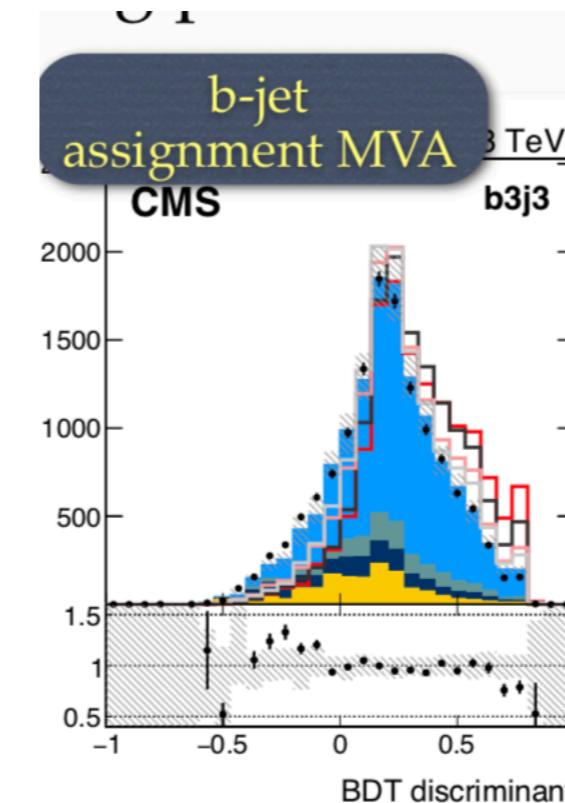
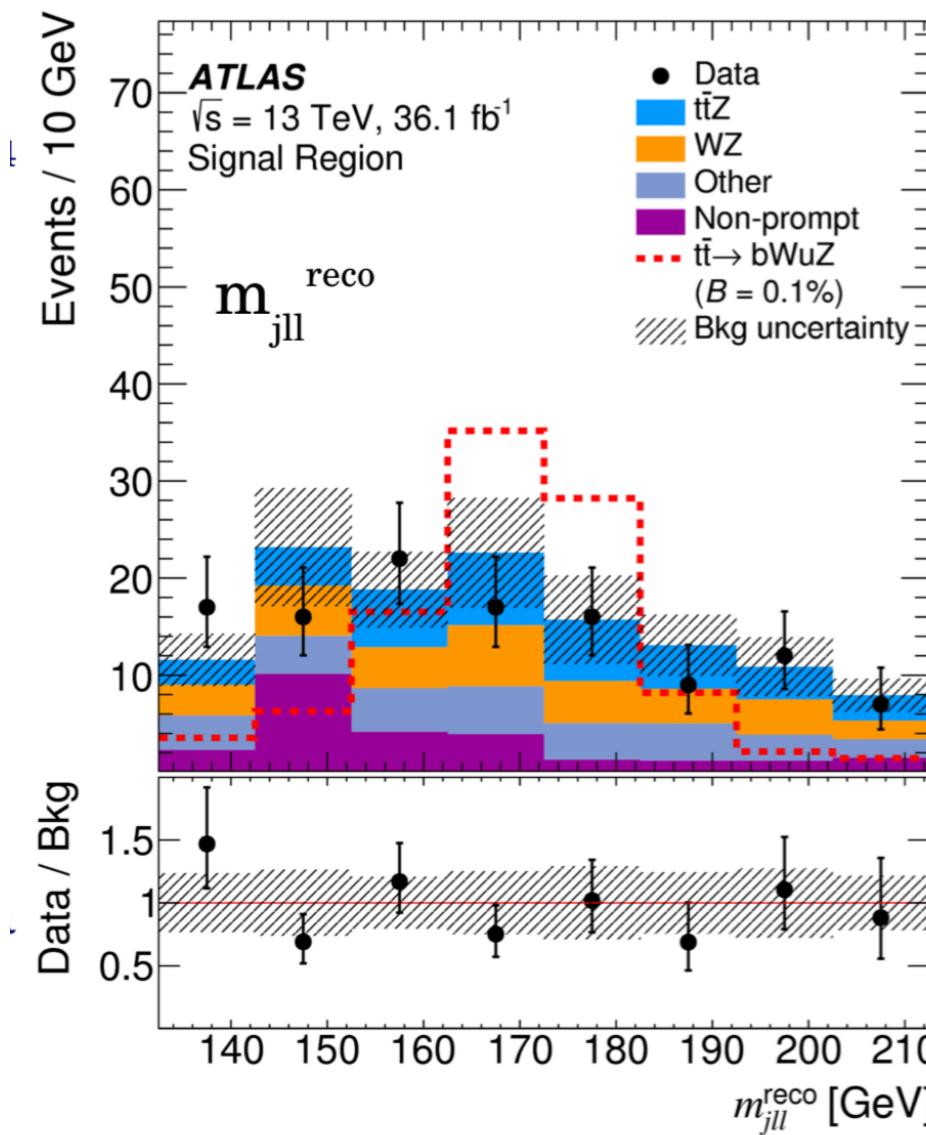
Channel	Observed limit
$B(t \rightarrow cH)$	$<0.47\%$
$B(t \rightarrow uH)$	$<0.47\%$

Kluth, Chen

Rare top decays



- FCNC/H decays heavily suppressed in SM \rightarrow place for NP?

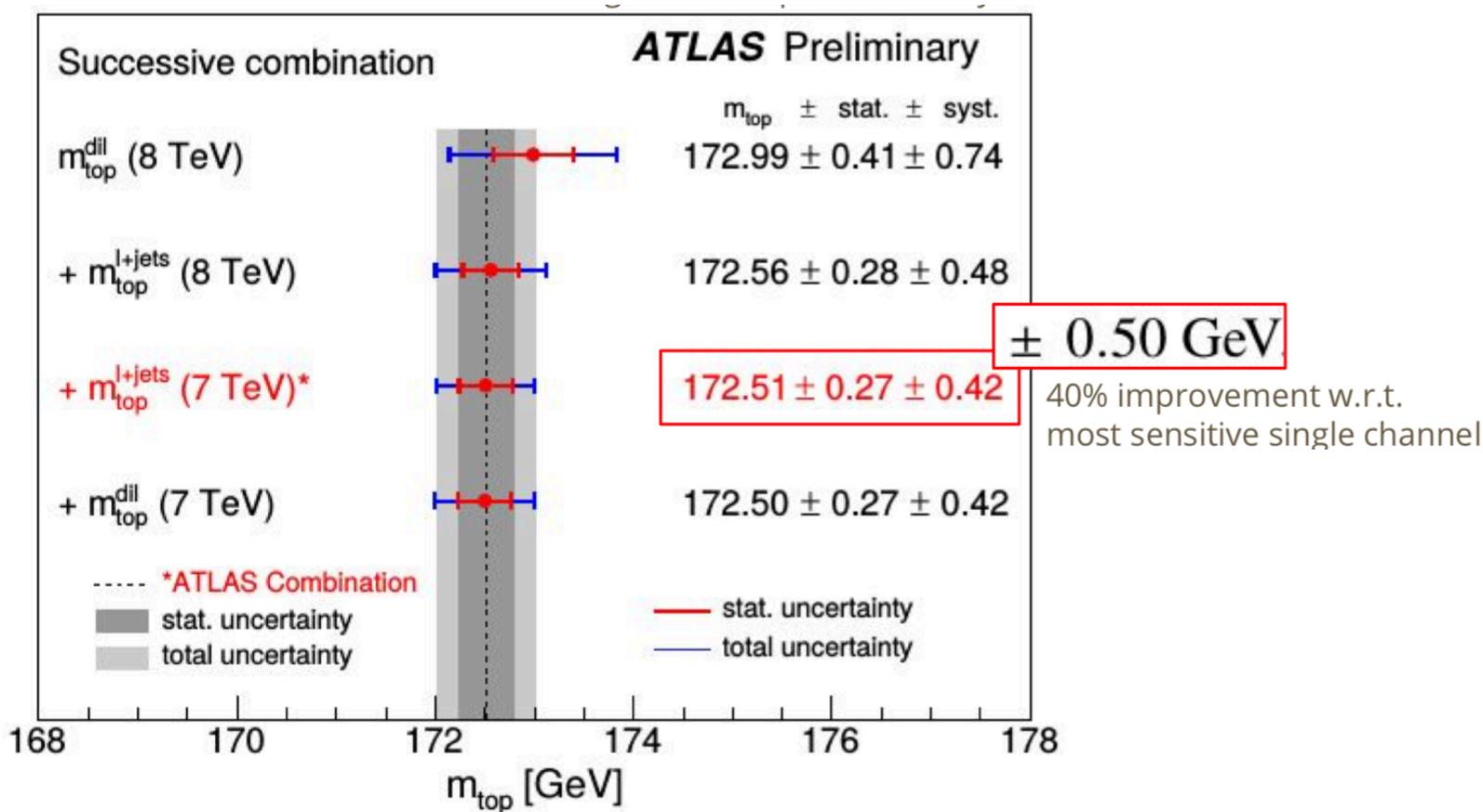
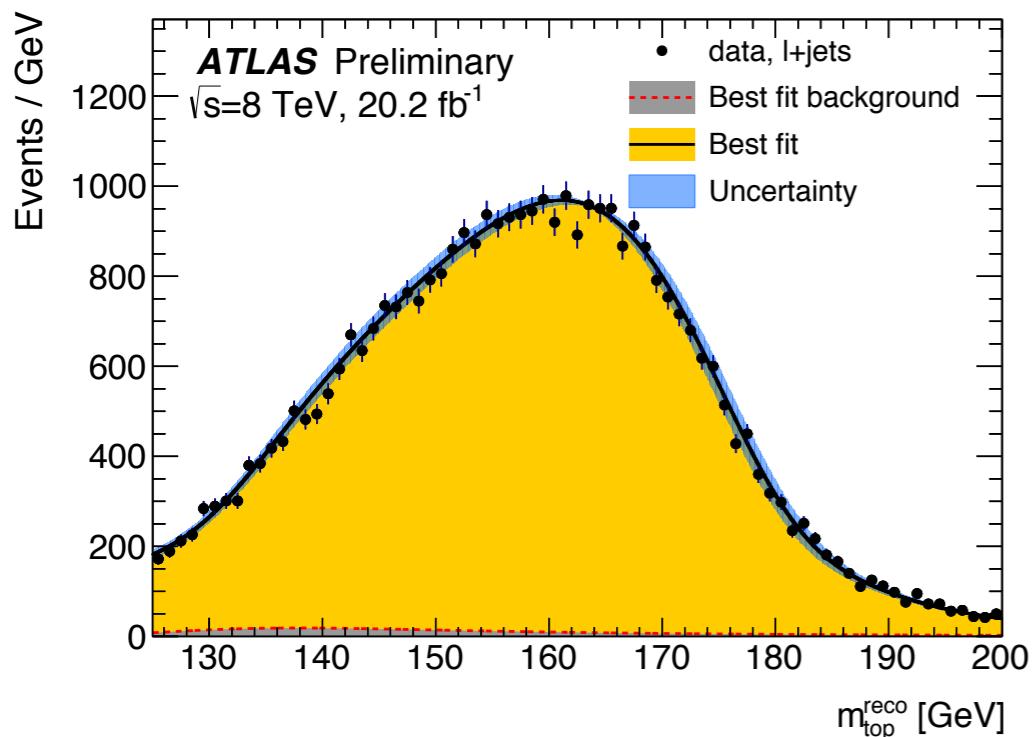


$\text{BR}(t \rightarrow uZ) < 1.7 \cdot 10^{-4}$ (95% CL)
 $\text{BR}(t \rightarrow cZ) < 2.4 \cdot 10^{-4}$

Channel	Observed limit
$B(t \rightarrow cH)$	$< 0.47\%$
$B(t \rightarrow uH)$	$< 0.47\%$

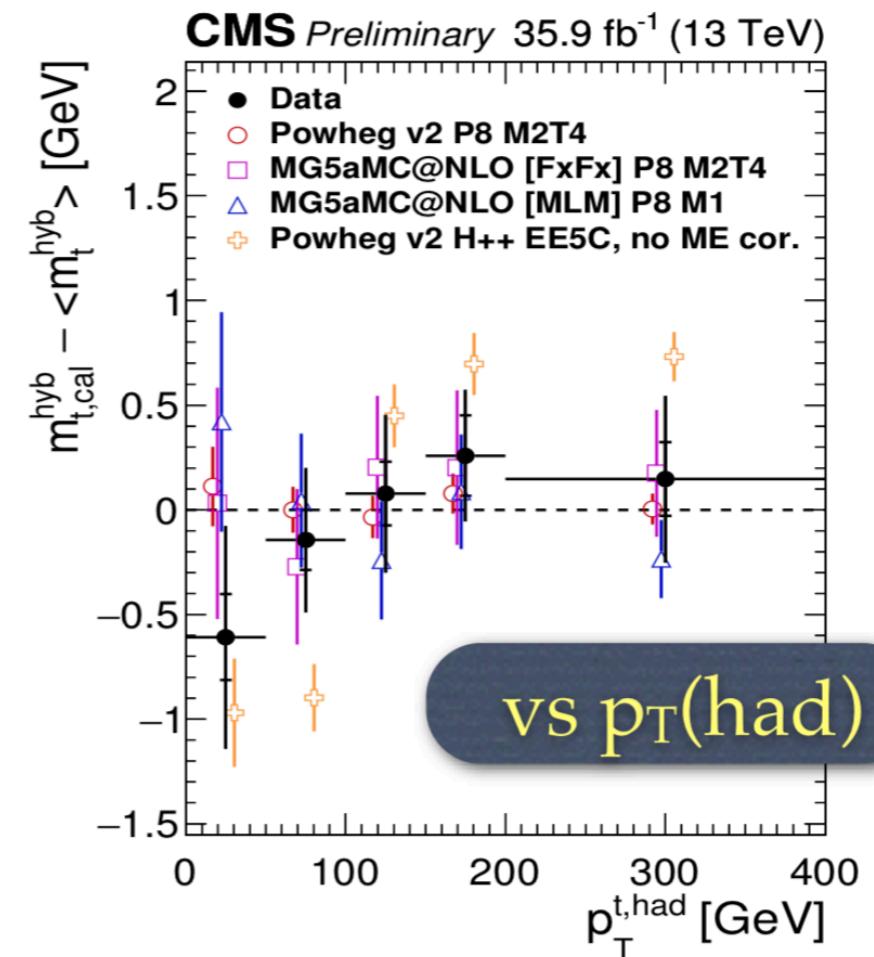
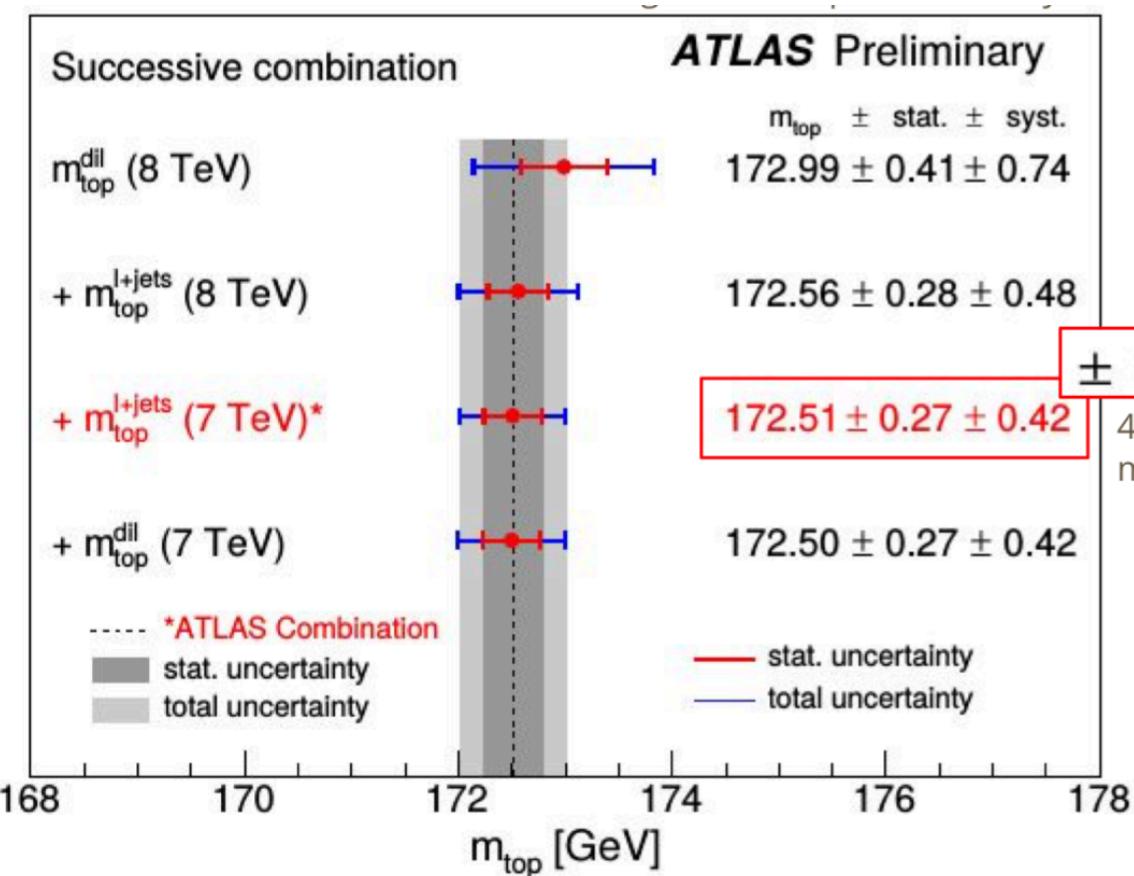
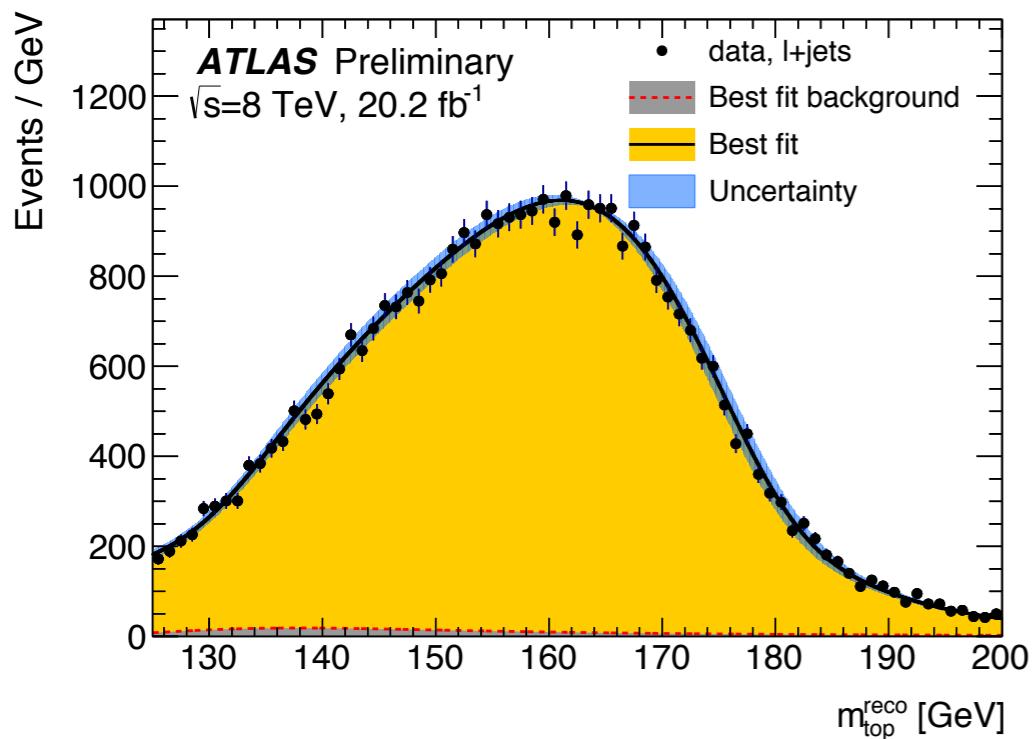
Kluth, Chen

Top Mass



Chen, Jezo, Pinamonti

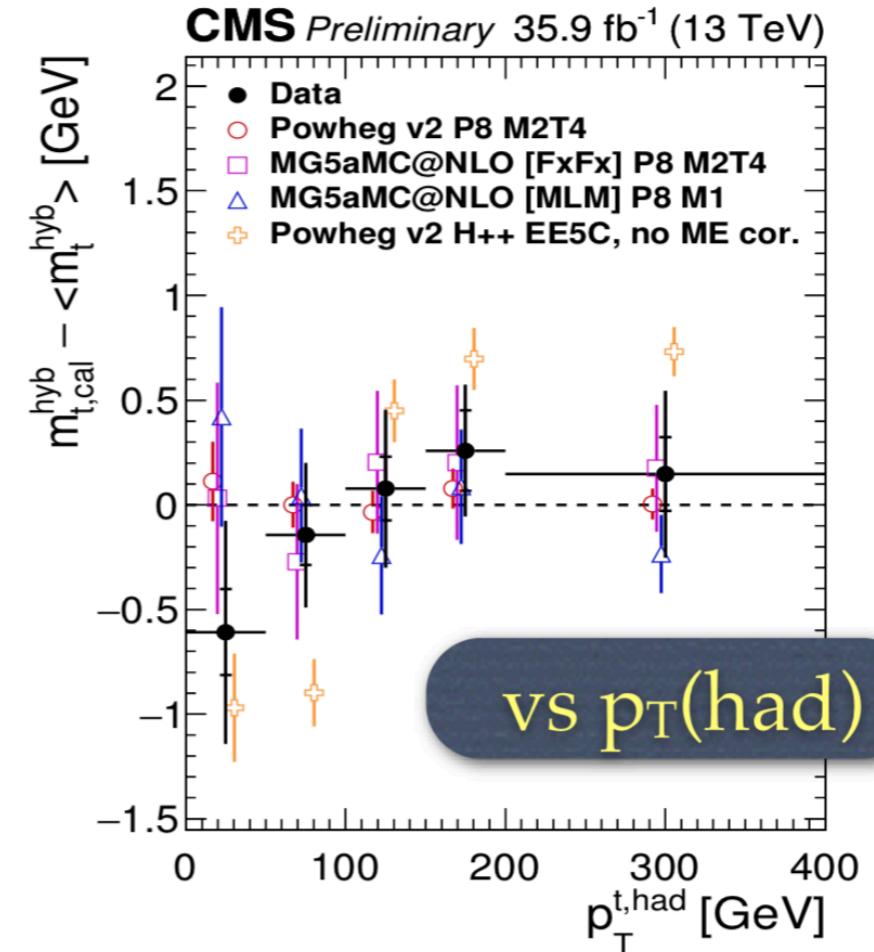
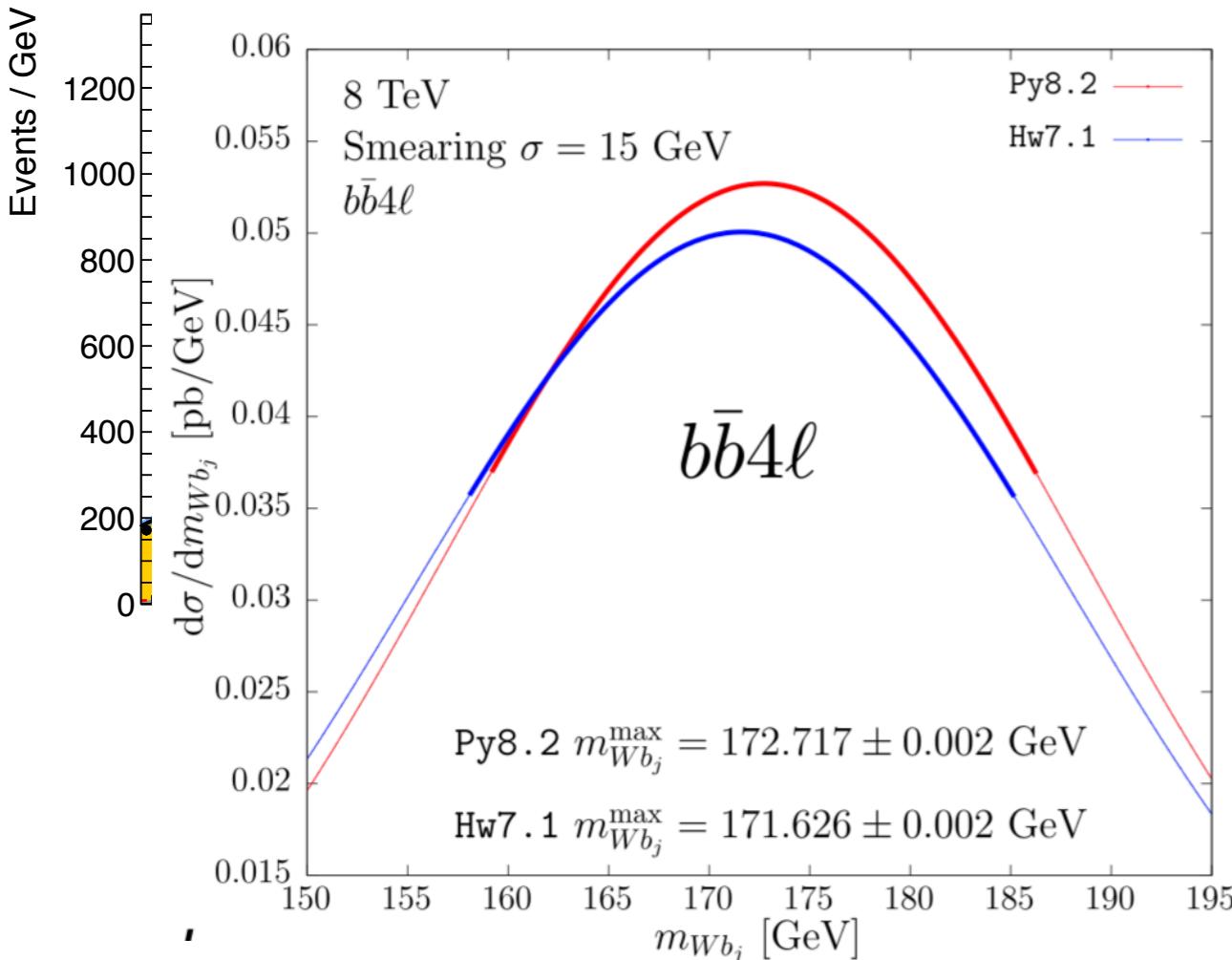
Top Mass



$M_{\text{t}} = 172.25 \pm 0.08 \text{ (stat+JSF)} \pm 0.62 \text{ (syst) GeV}$
 $\text{JSF} = 0.996 \pm 0.001 \pm 0.008$

Chen, Jezo, Pinamonti

Top Mass



Pheno study: 1 GeV difference when changing PS for ‘best’ NLO generator.
To be further studied.

**M_t = 172.25 ± 0.08 (stat+JSF)
± 0.62 (syst) GeV**
JSF = 0.996 ± 0.001 ± 0.008

Chen, Jezo, Pinamonti

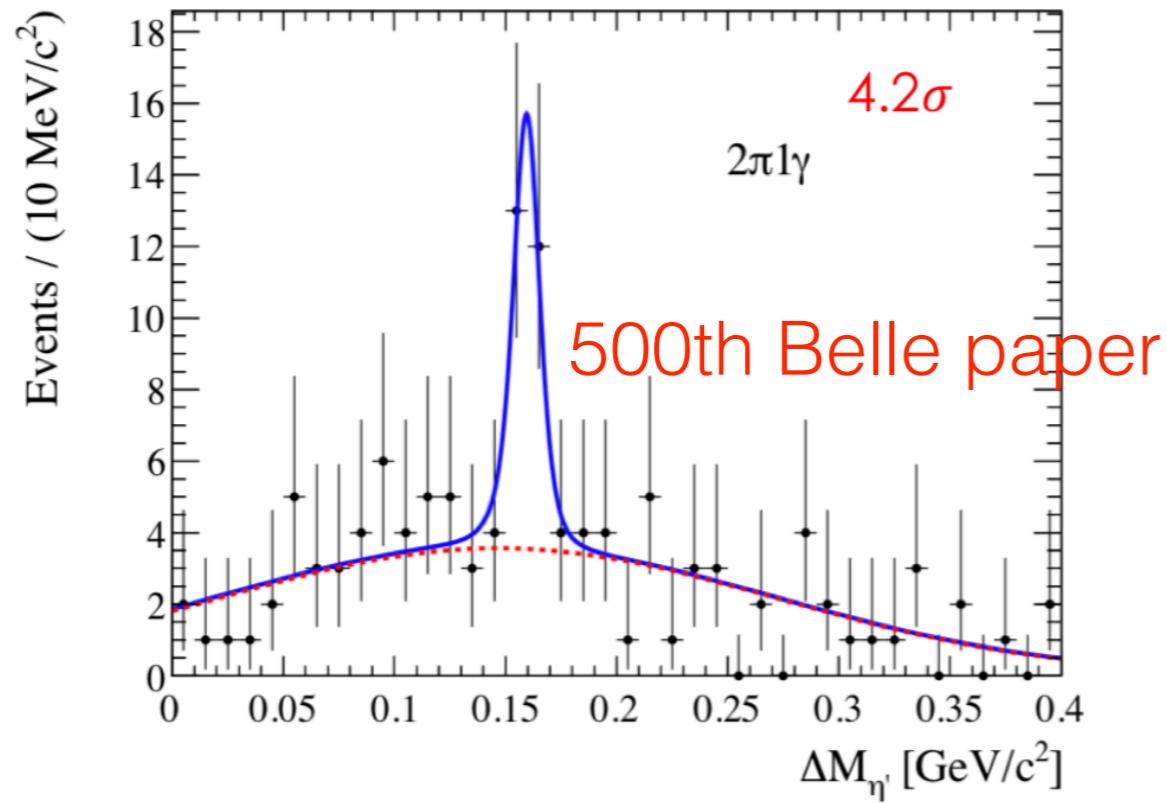
Quarkonia

Quarkonia

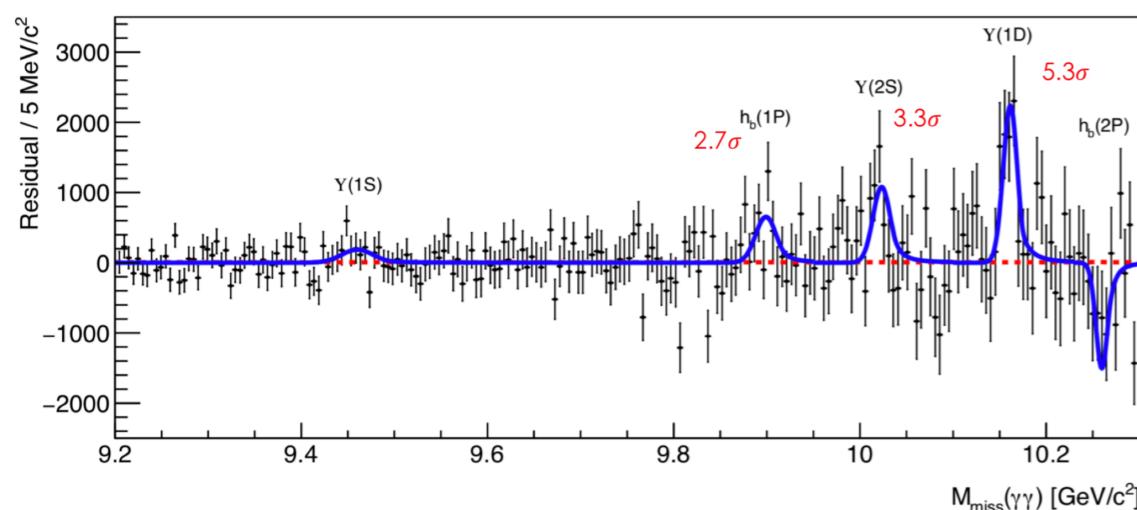
Quarkonium physics is complex and extensive
& MO is not an expert

Bottomium

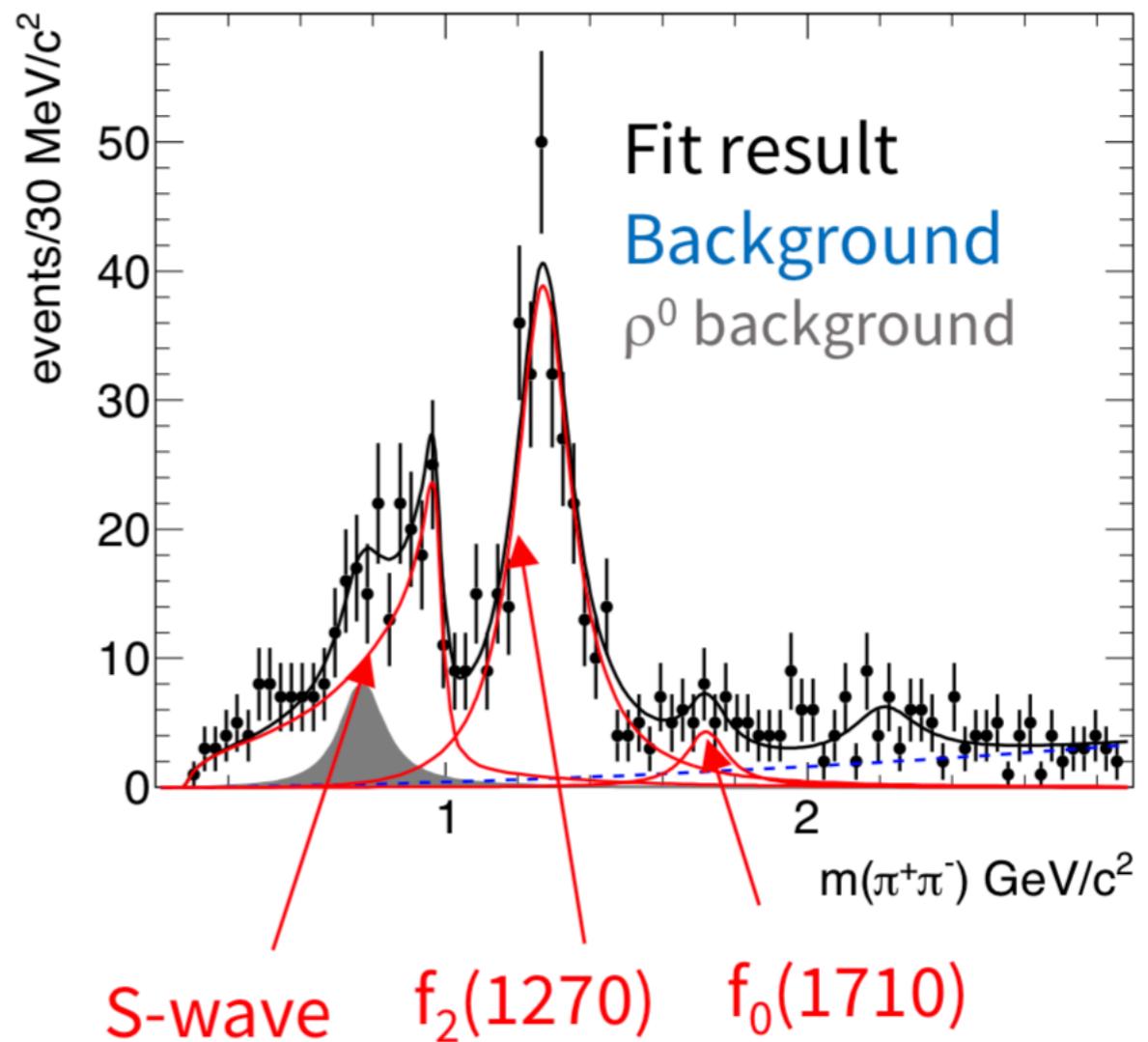
First observation of $\Upsilon(4s) \rightarrow \eta' \Upsilon(1s)$



First observation of $\Upsilon(5s) \rightarrow \eta \Upsilon(1d)$



$\Upsilon(2S)/\Upsilon(3S) \rightarrow (\pi_s^+ \pi_s^-) \Upsilon(1S) \rightarrow (\pi_s^+ \pi_s^-)(\gamma \pi^+ \pi^-)$



Jia, Robbe

The Belle II bottomonium program

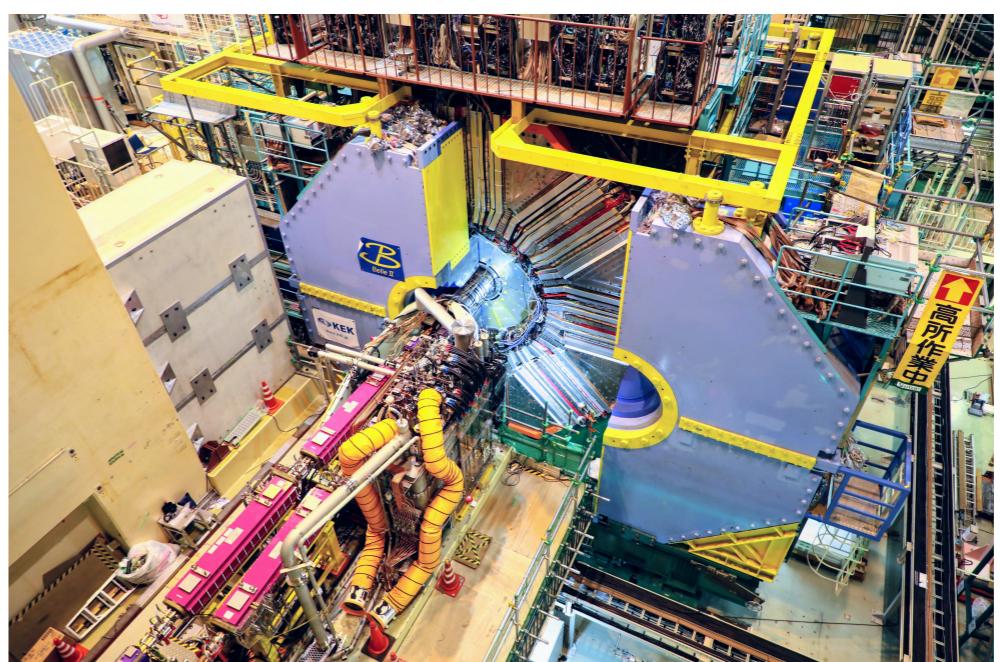
Current samples in fb^{-1} (millions of events)

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII	-	-	300 (1200)	5×10^4 (5.4×10^4)	1000 (300)	100+400(scan)	3.6%

- Narrow states spectroscopy ($\Upsilon(1D)$, $\chi_b(nP)...$)
- Exotica as virtual contributions to transitions
- Precision NRQCD test
- New Physics (DM / light higgs)
- Missing hadronic and radiative transitions
- Baryon physics (inc. correlations)
- Anti-nuclei production (with DM applications)
- Gluon fragmentation
- Inclusive charmonium production and $D\bar{D}$ correlations
- LFV and LUV in $\Upsilon(nS)$ decays

- B_s physics
- Exotica discovery
- Precision Z_b mass measurement
- Missing hadronic and radiative transitions
- Light meson spectroscopy in transitions

1.6% for
bottomonium only

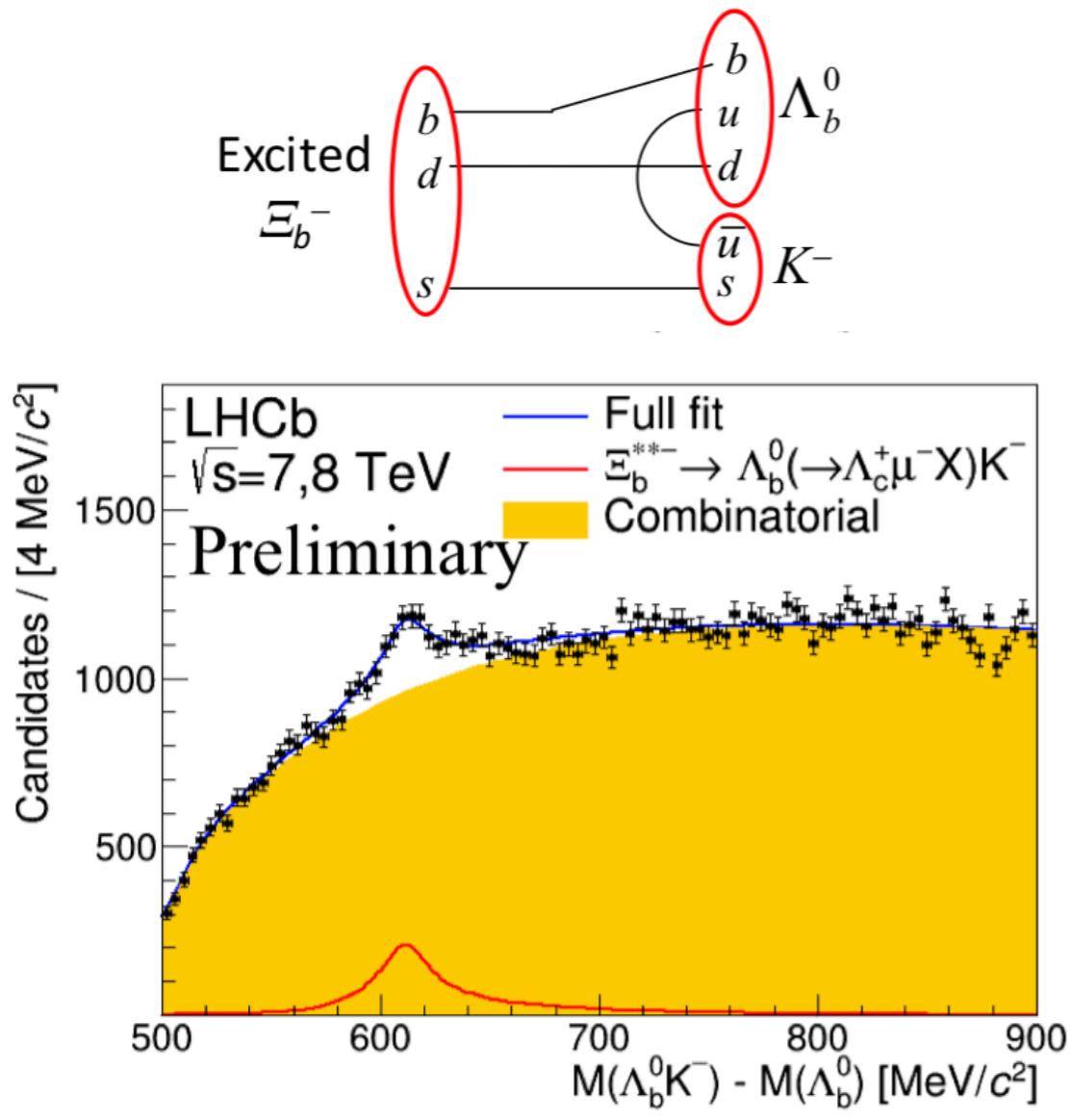


Commissioning run this year, 1st physics run next year

Tamponi

Hadron spectroscopy

Observation of Ξ particles

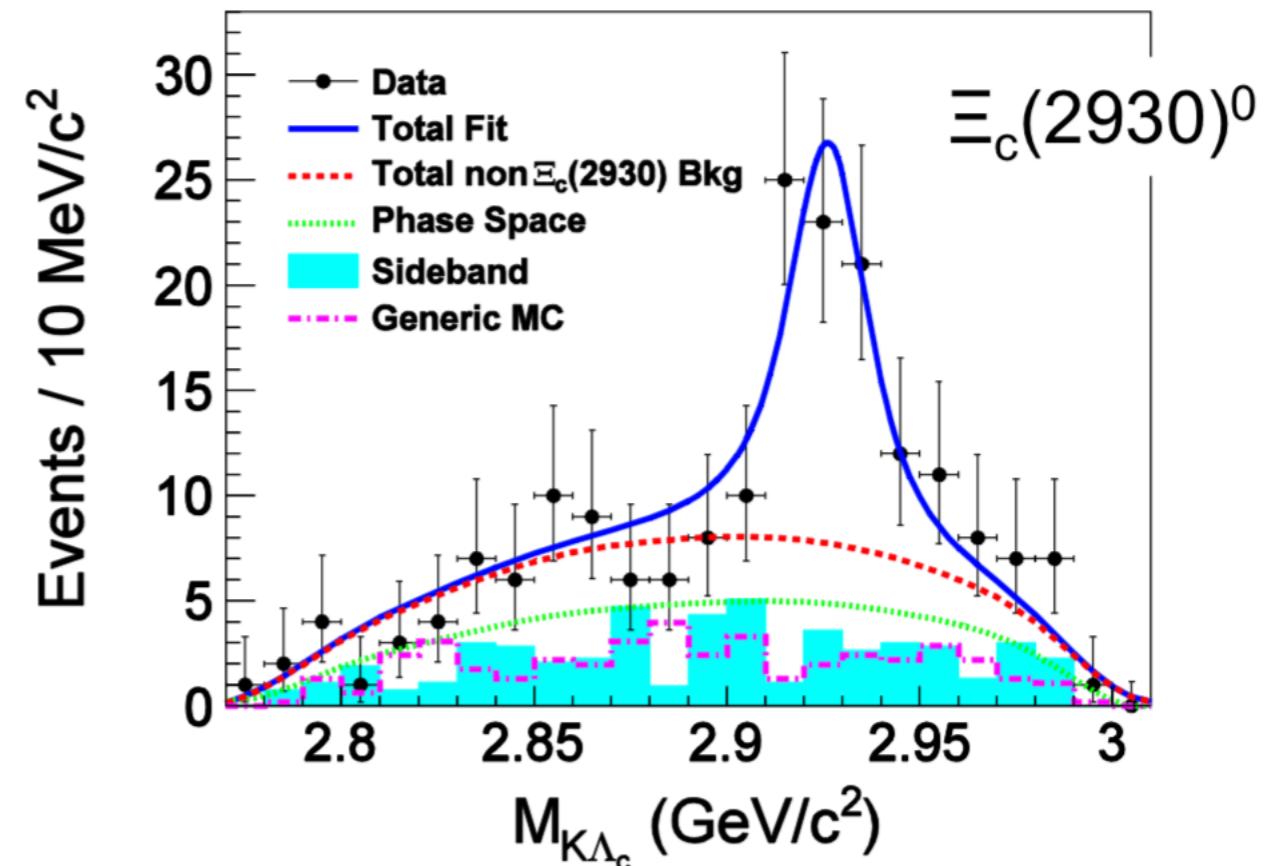


>5 σ in 3 channels

$$M(\Xi_b^{**-}) = 6226.9 \pm 2.0 \text{ (stat)} \pm 0.3 \text{ (syst)} \pm 0.2(\Lambda_b^0) \text{ MeV}/c^2$$

Sumihama, Zhang

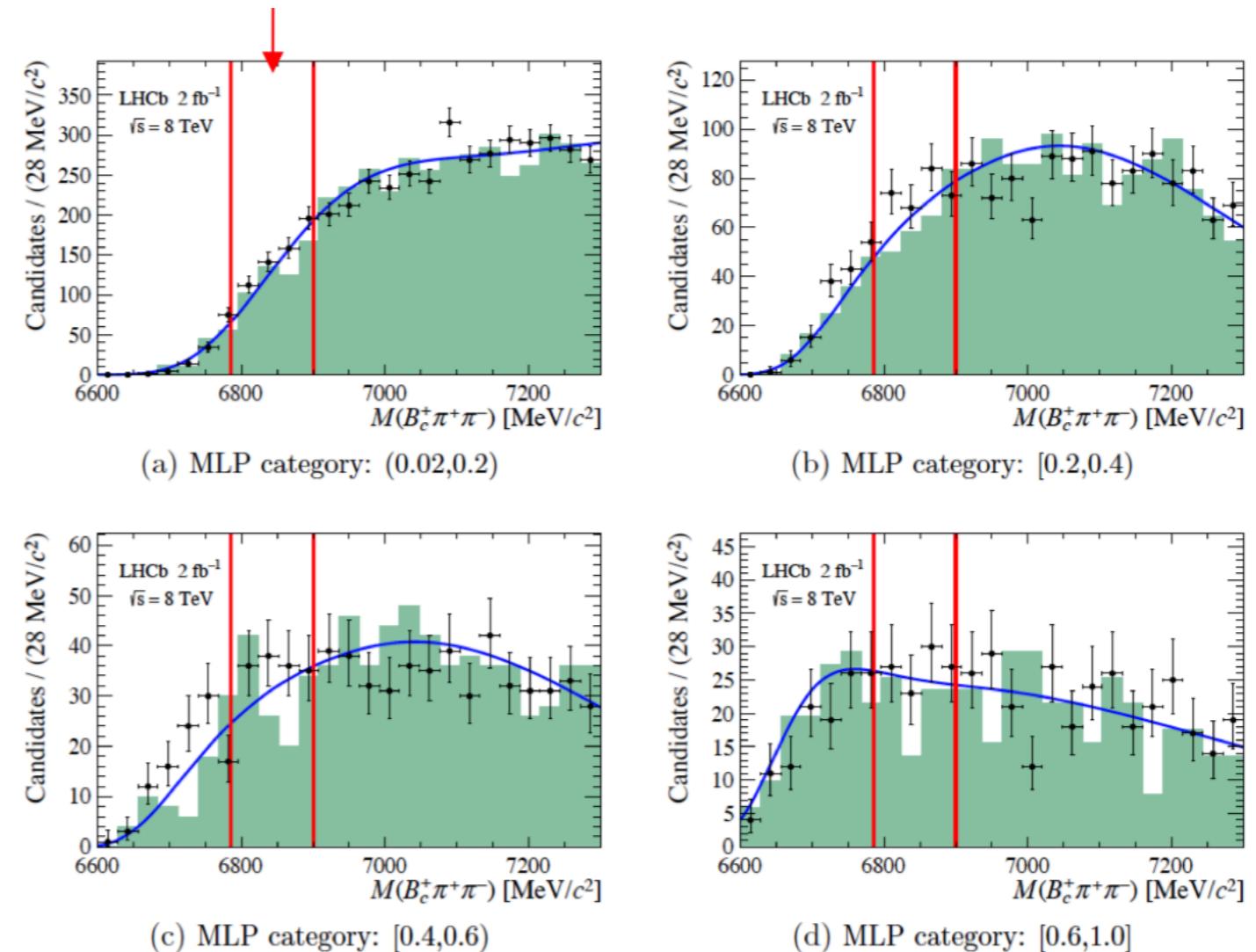
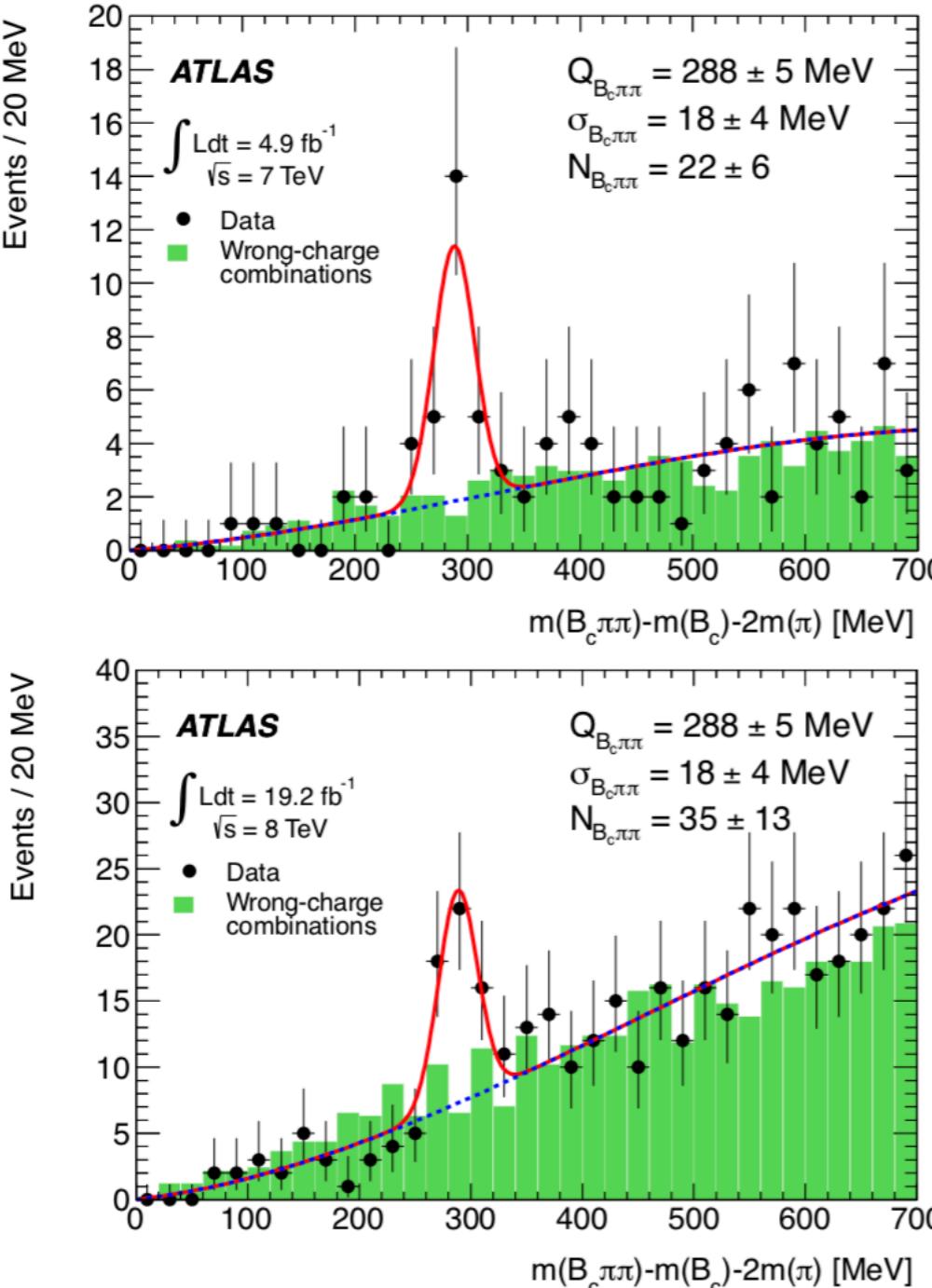
$$B \rightarrow \Xi_c(2930)^0 \bar{\Lambda}_c^-, \Xi_c(2930)^0 \rightarrow \Lambda_c^+ K^-$$



Previous evidence from BaBar
5.1 σ from Belle

	Mass (MeV/c ²)	Width (MeV)
BaBar	$2931 \pm 3 \pm 5$	$36 \pm 7 \pm 11$
Belle	$2928.9 \pm 3.0^{+0.8}_{-12.0}$	$19.5 \pm 8.4^{+5.4}_{-7.9}$

$B_c^{(*)+}(2S) \rightarrow B_c^{(*)+} \pi^+ \pi^-$

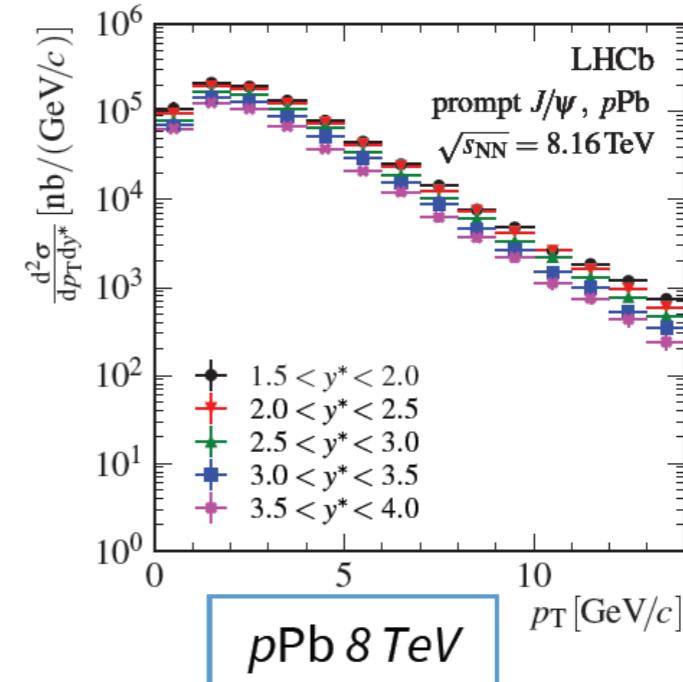
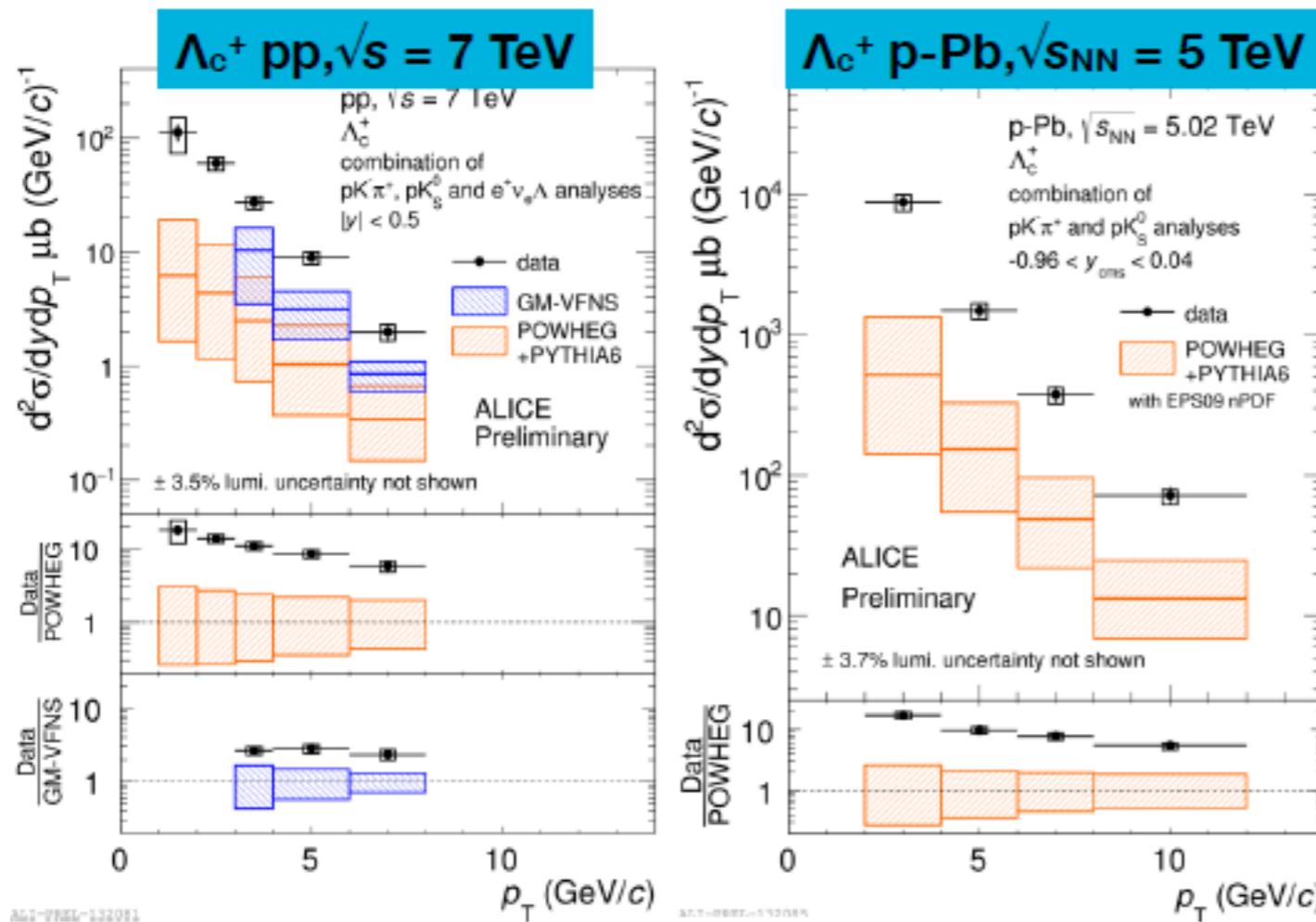


5.2 σ at ATLAS
 No sign at LHCb

'Tension' between the results -> lets see more data.

Heavy flavour in heavy ions

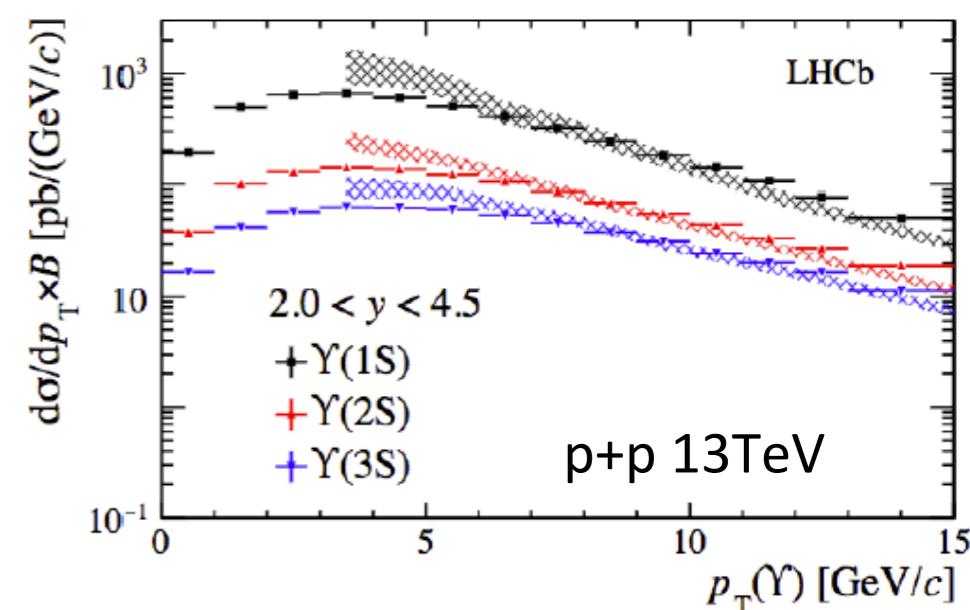
Bottom & charm in p+p and p+Pb at ALICE & LHCb



Comparison with recent theoretical computations based on NRQCD [Yu, Bin, Lu-Ping, Jian-Xiong CPC39 (2017) 12] shows good agreement.

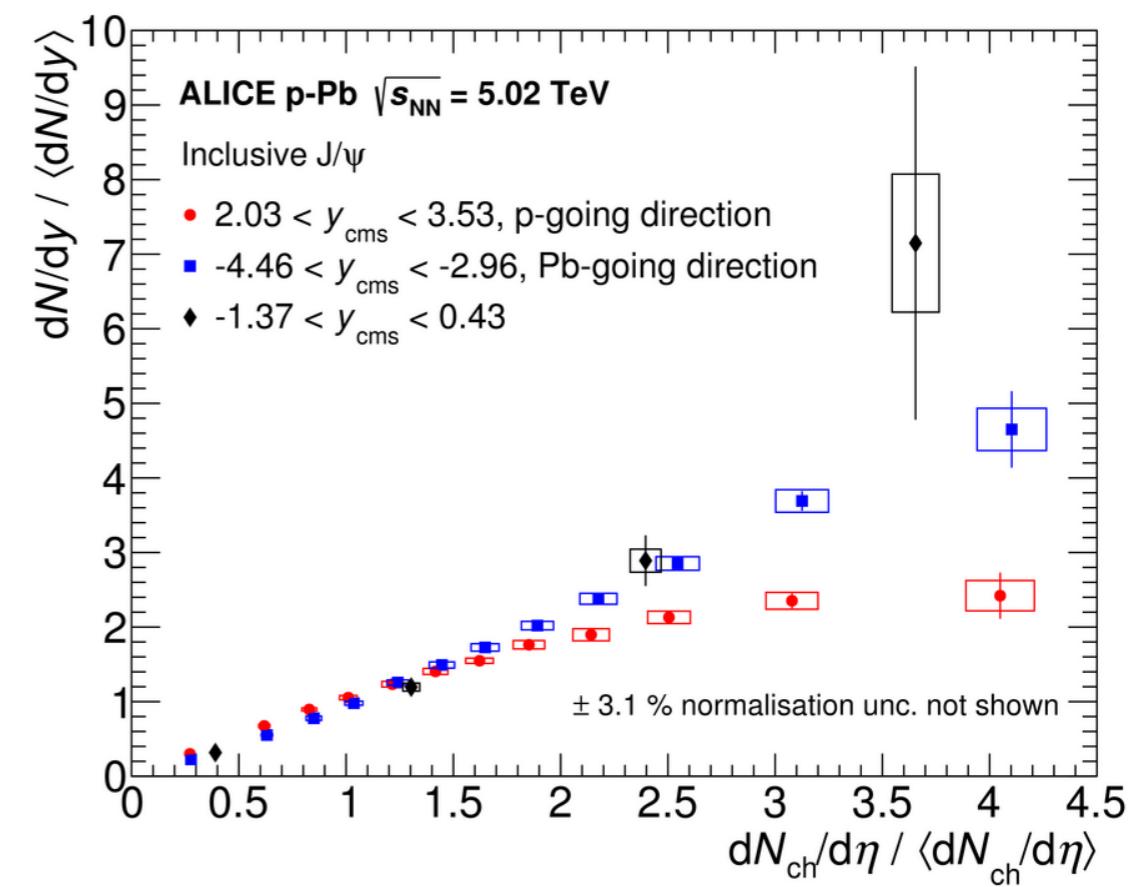
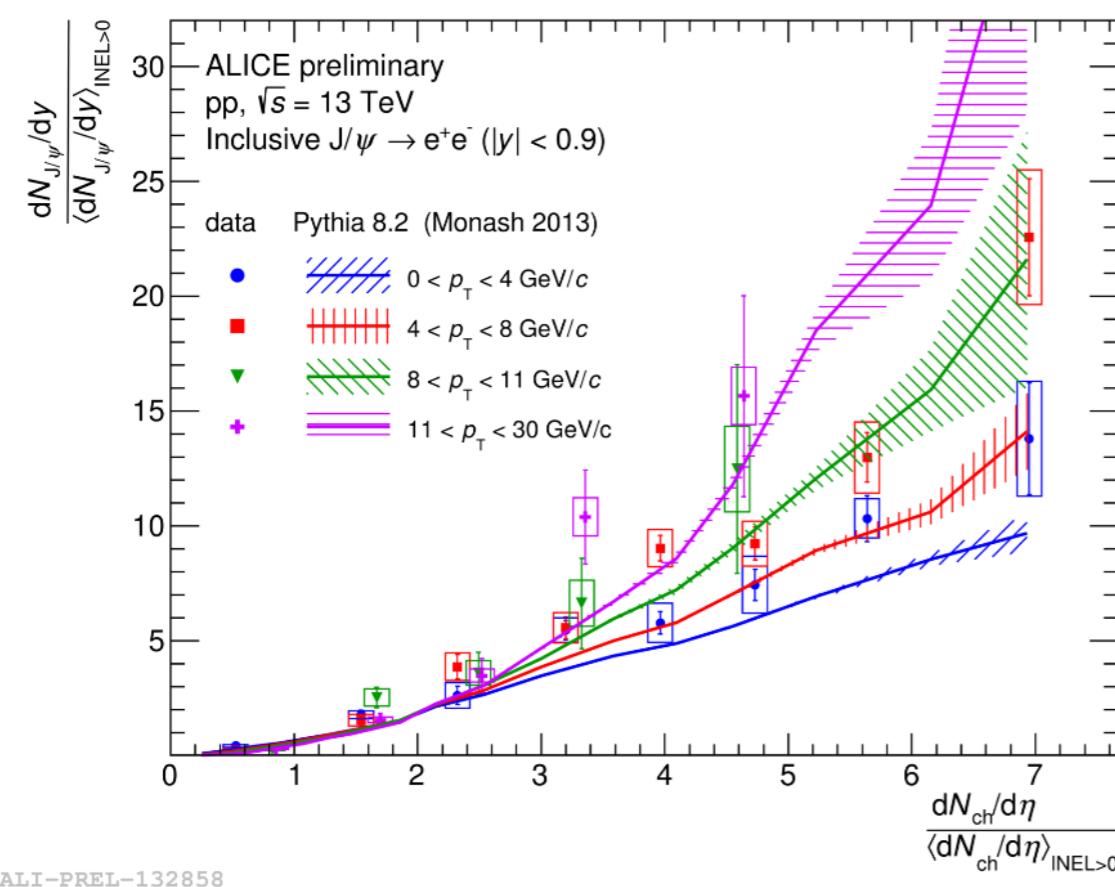
[LHCb-PAPER-2018-002]

- P+p and p+A provides baseline to study QGP in A+A collisions
- Study hadronization
- First measurement of Λ_c^+ and Ξ_c^0



J/Ψ vs multiplicity in p+p and p+Pb

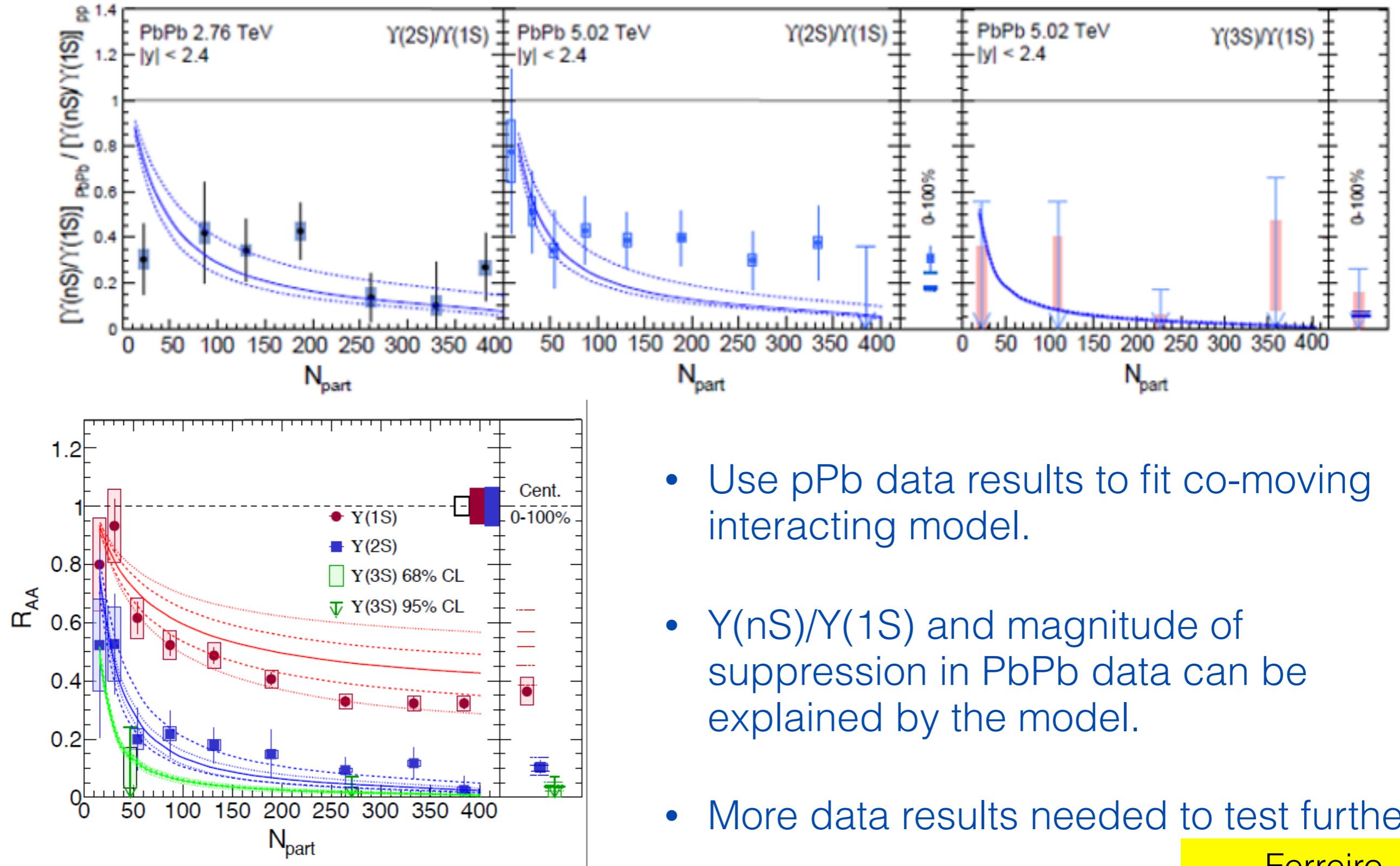
The measurement of quarkonium production as a function of event multiplicity allows one to study the [interplay between hard and soft scale of QCD](#)



- Increase qualitatively reproduced by models (need MPI).
- Indication of saturation for p-going J/Ψ.

Gagliardi

Suppression of $\Upsilon(nS)/\Upsilon(1S)$

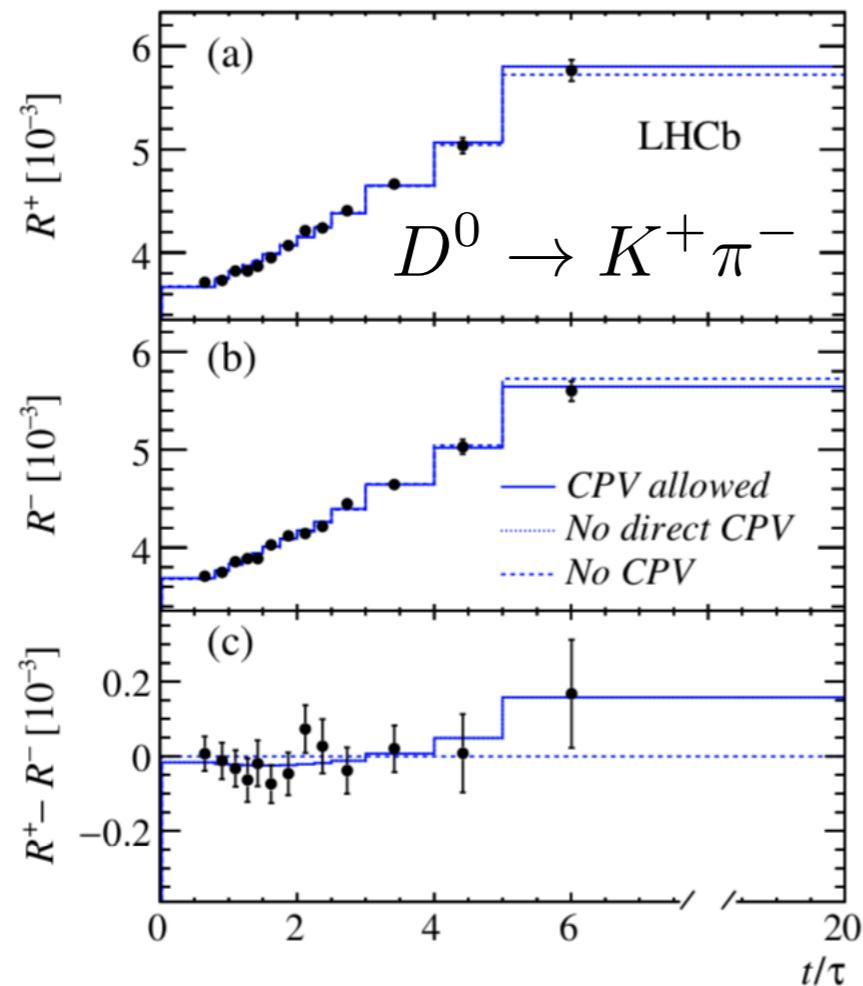


Ferreiro

Other heavy flavour studies

NP in Heavy Flavour - CP violation

CP violation in D-mixing



$$A_{CP}^{\text{Dir}} = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-} = (-0.1 \pm 9.1) \times 10^{-3}$$

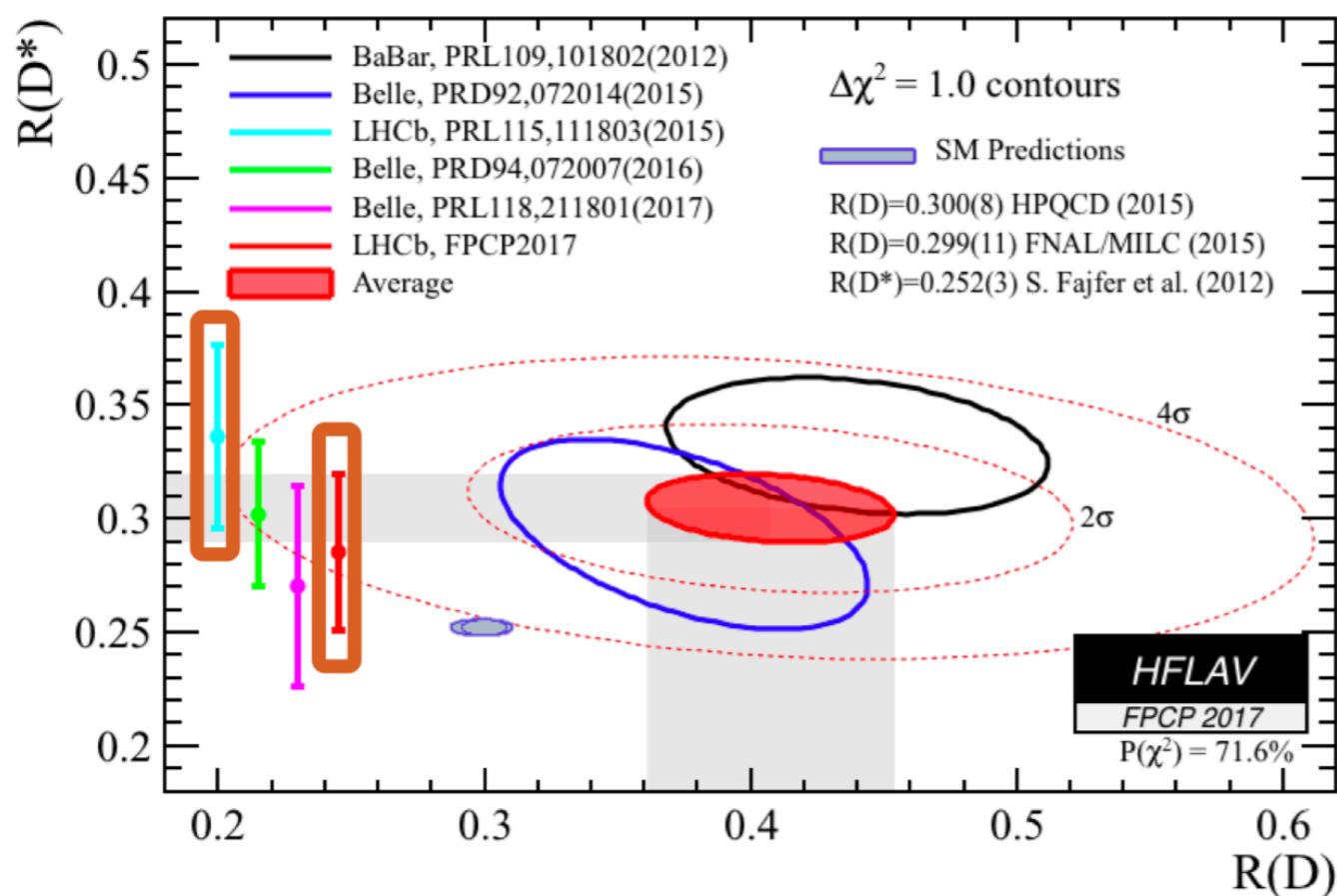
No evidence for CPV (direct or indirect)

Dean

NP in Heavy Flavour - Lepton flavour universality

$$R(D^{(*)}) \equiv \frac{\text{BR}(\bar{B}^0 \rightarrow D^{(*)+} \tau^- \bar{\nu}_\tau)}{\text{BR}(\bar{B}^0 \rightarrow D^{(*)+} \mu^- \bar{\nu}_\mu)}$$

$$R(D^*) = 0.286 \pm 0.019 \text{ (stat)} \pm 0.025 \text{ (syst)} \pm 0.021 \text{ (ext)}$$

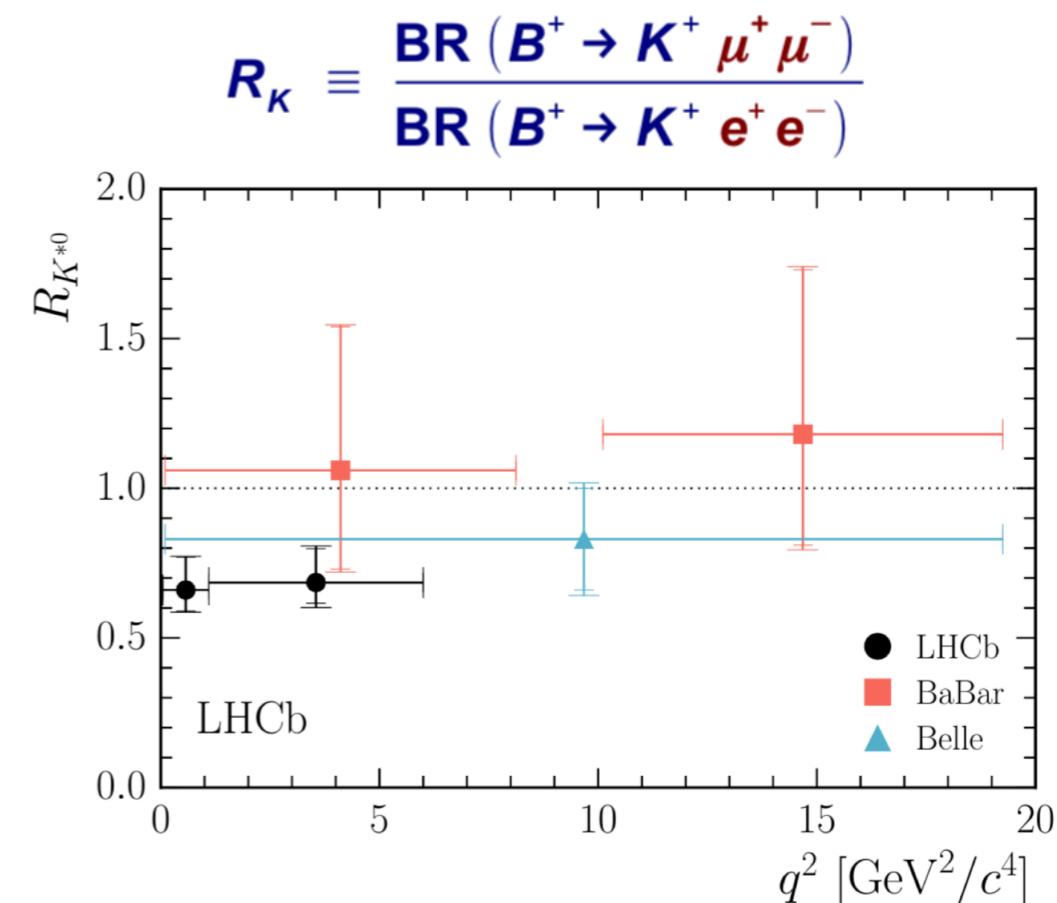
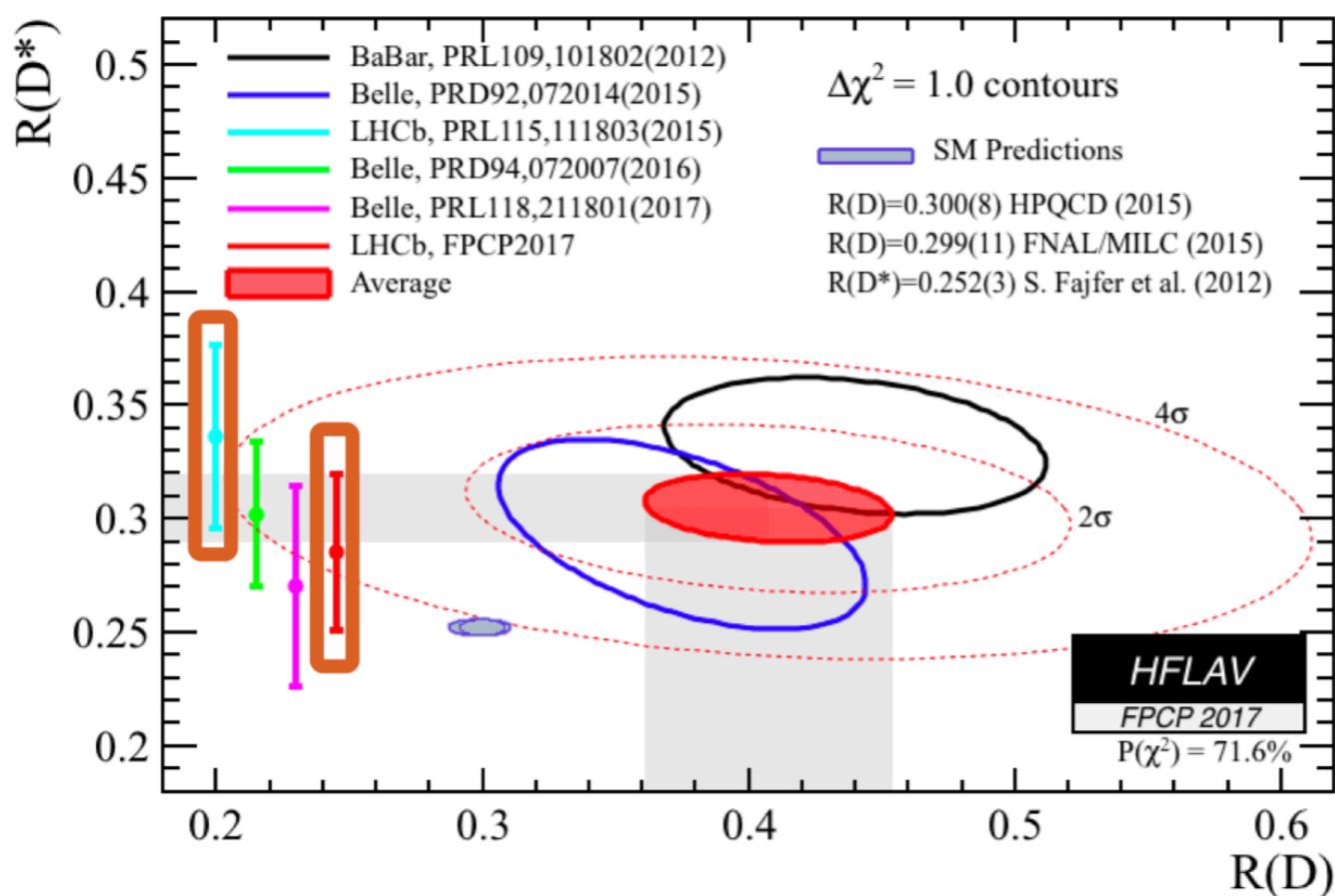


Campoverde, Santelj, Steinkamp

NP in Heavy Flavour - Lepton flavour universality

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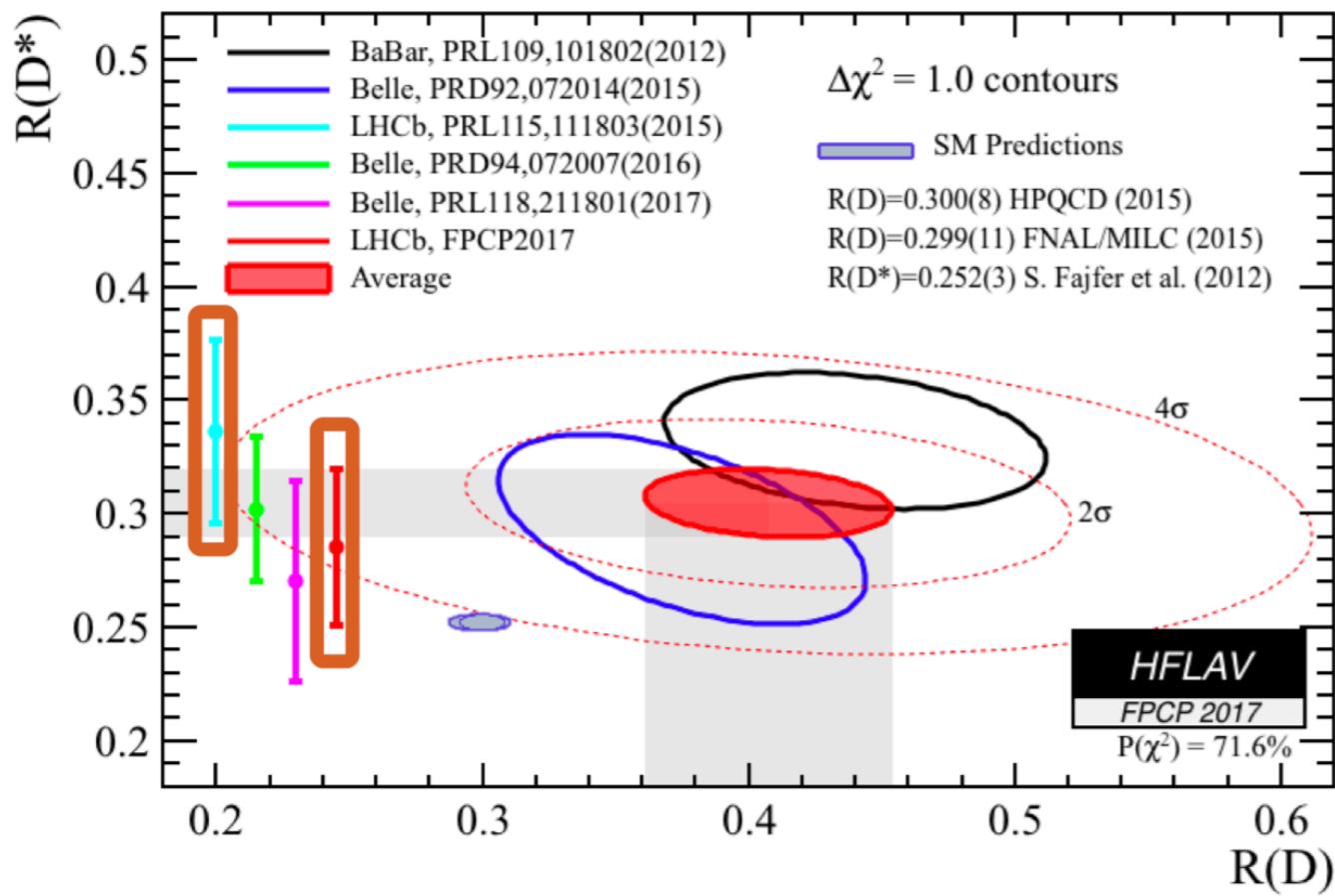


Campoverde, Santelj, Steinkamp

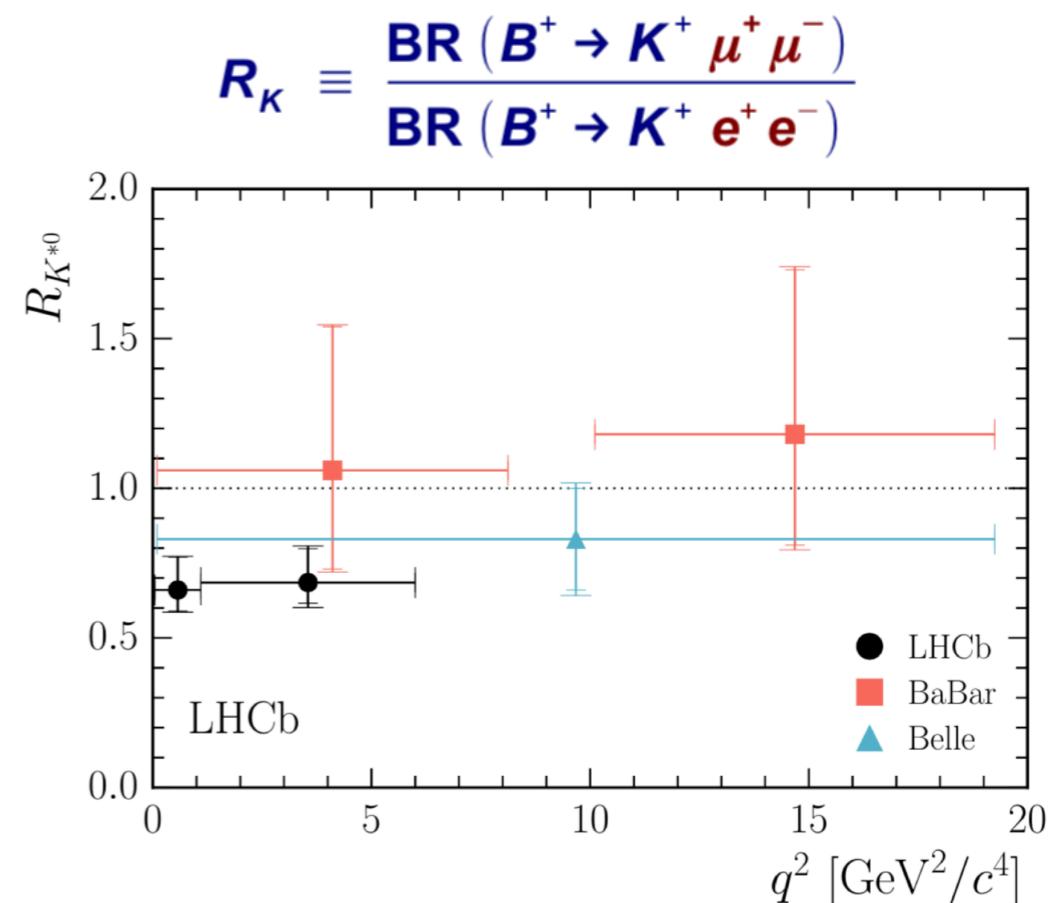
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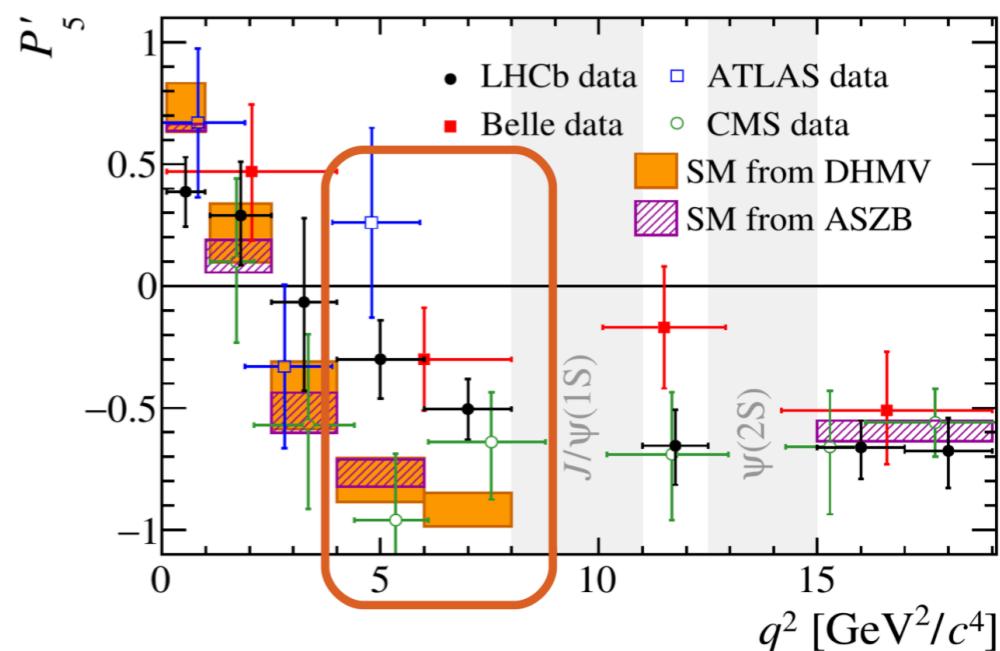
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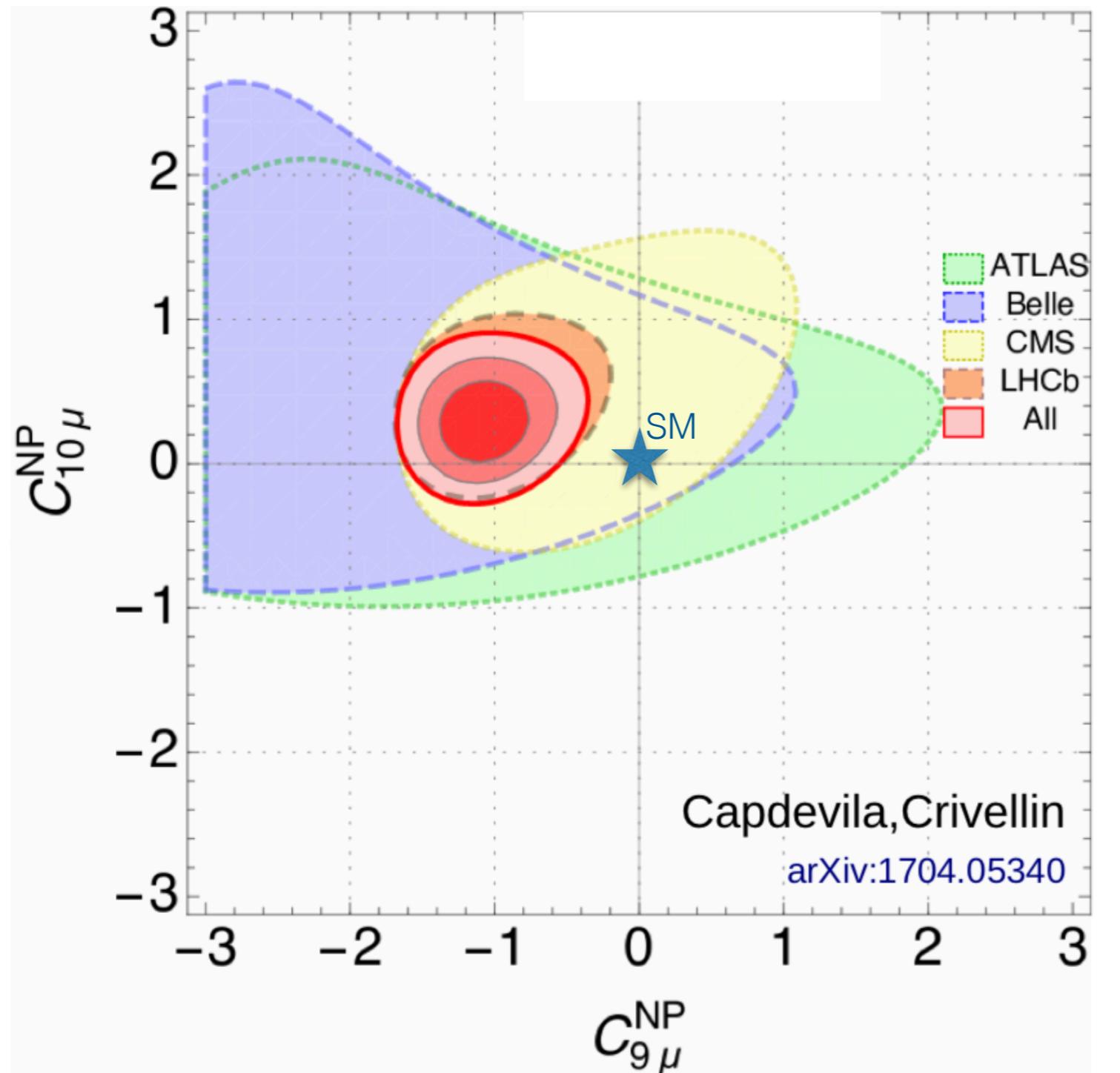
Campoverde, Santelj, Steinkamp



Angular analysis of $B \rightarrow K^* \ell^+ \ell^-$

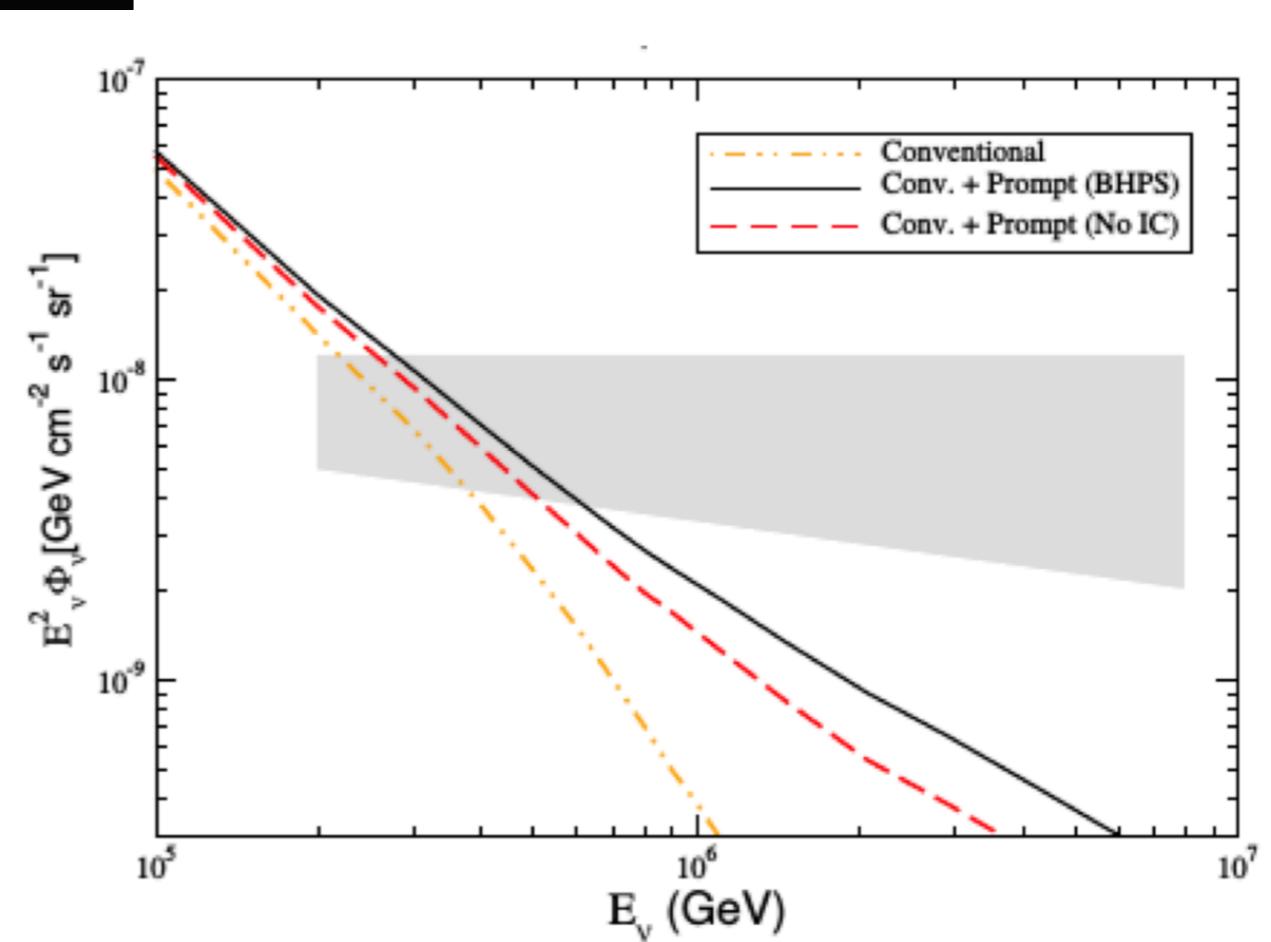
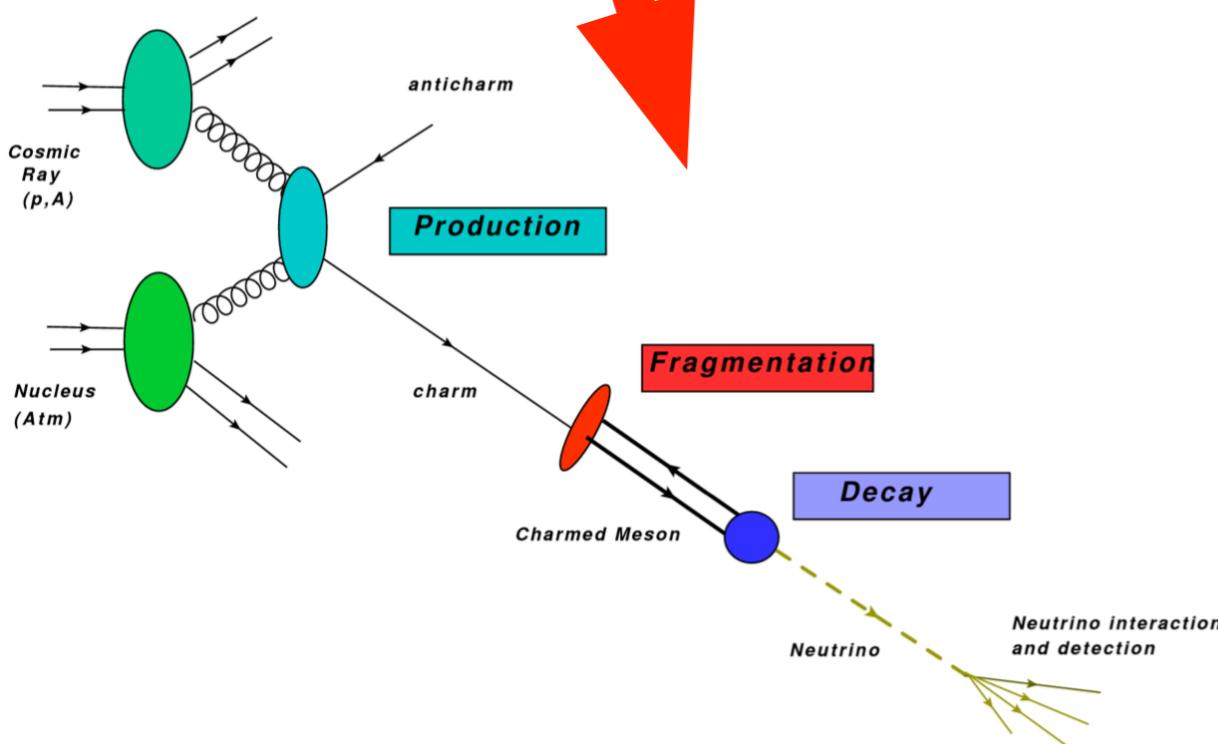
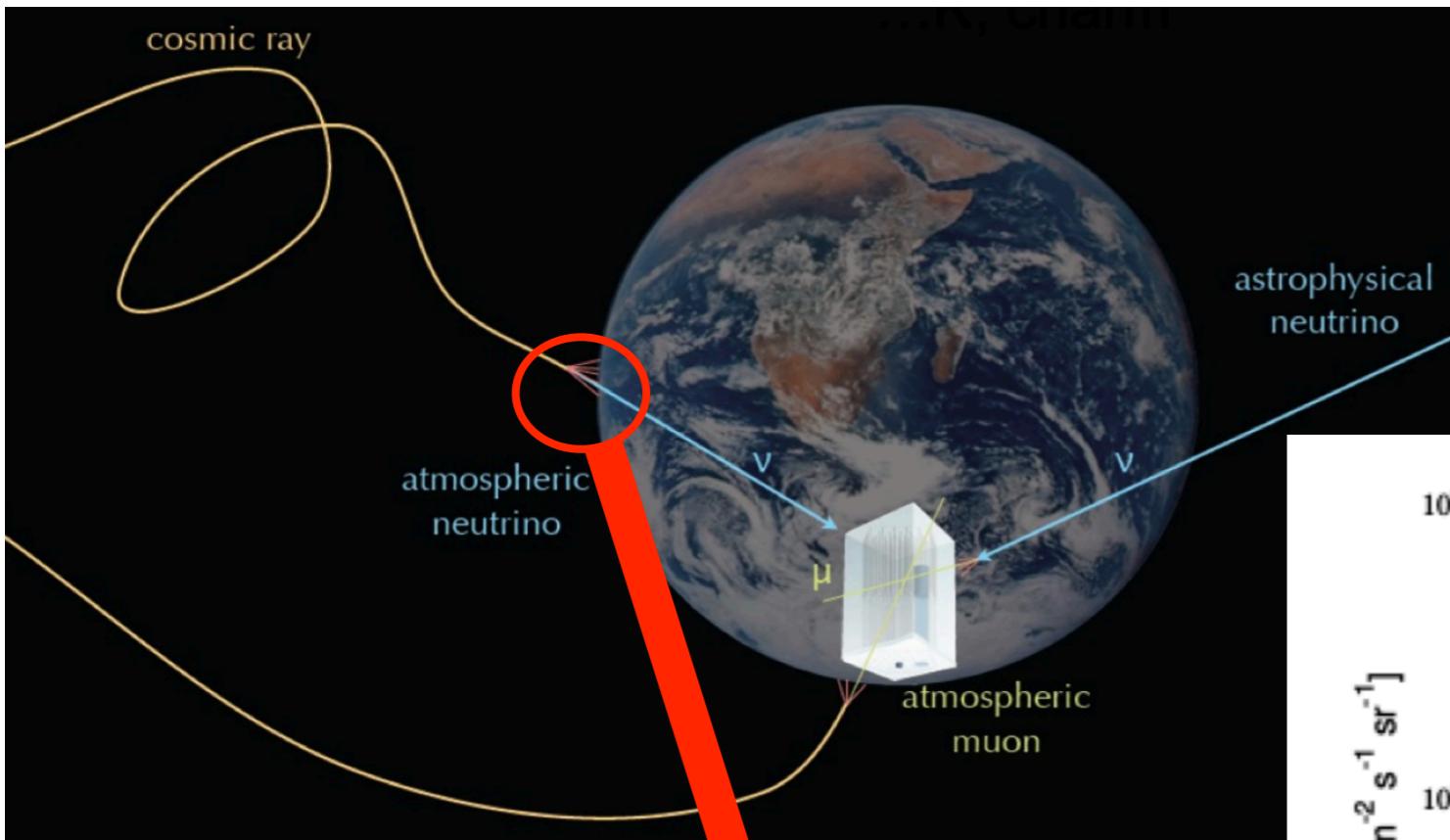


NP in Heavy Flavour - Lepton flavour universality



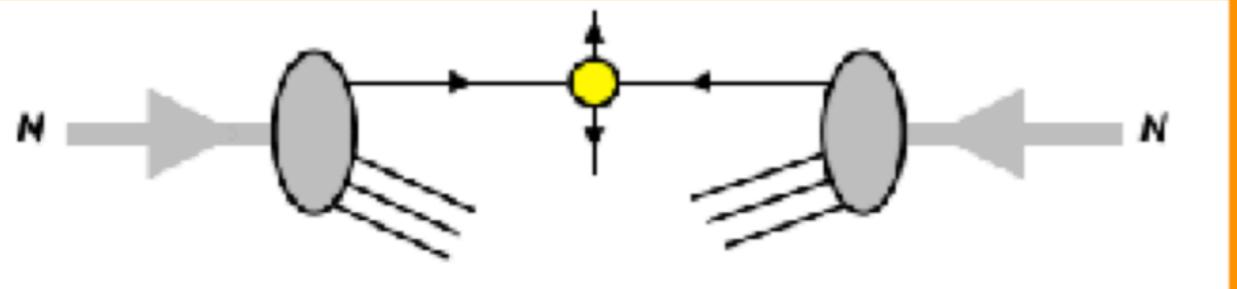
Looking forward to
new results, both
from LHCb &
Belle-2

Charm in the atmosphere

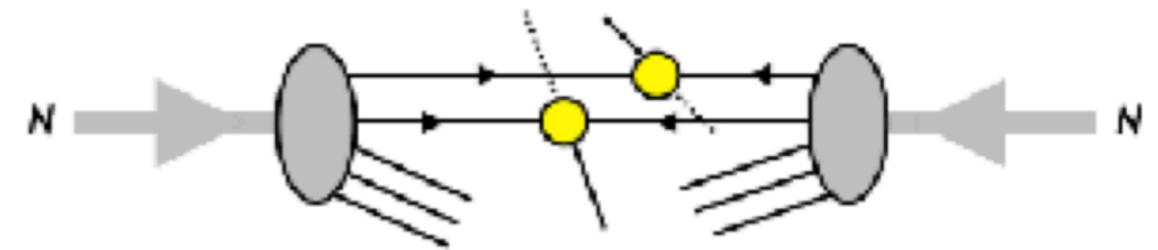


Gonçalves

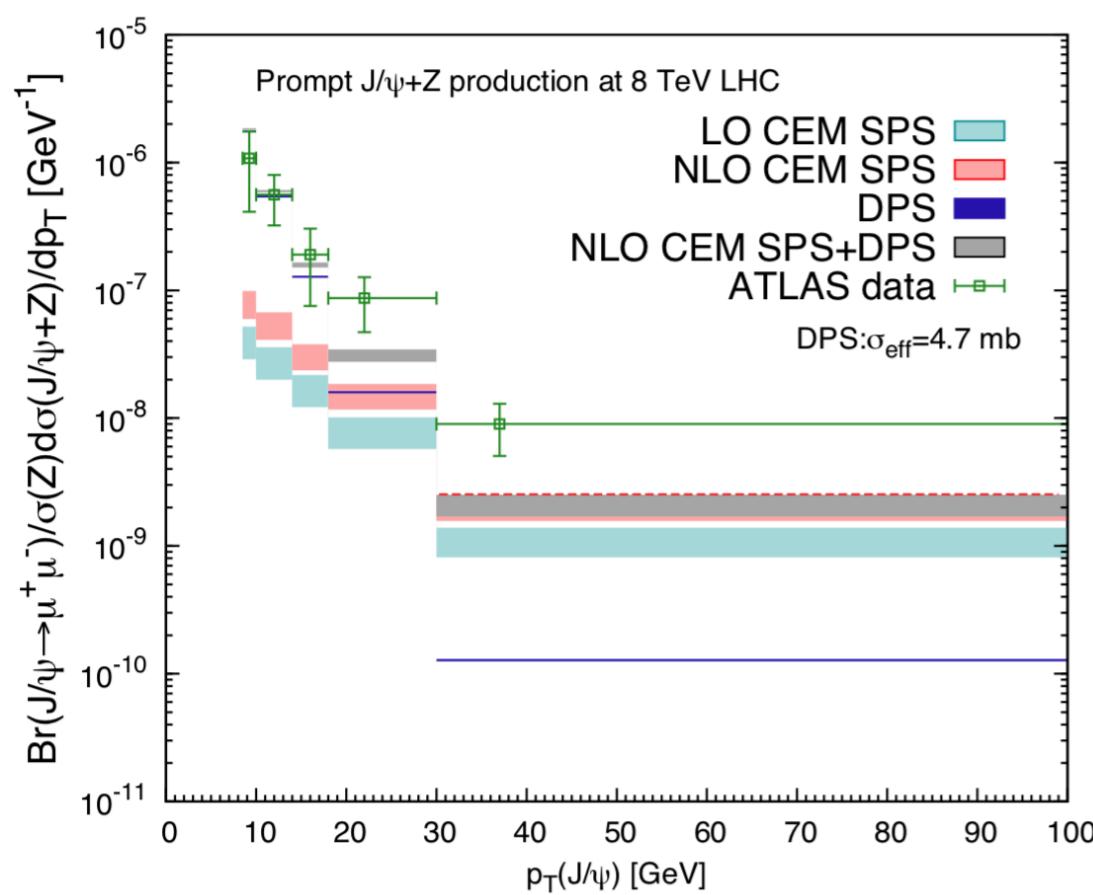
Double-parton scattering



Single Parton Scattering (SPS)

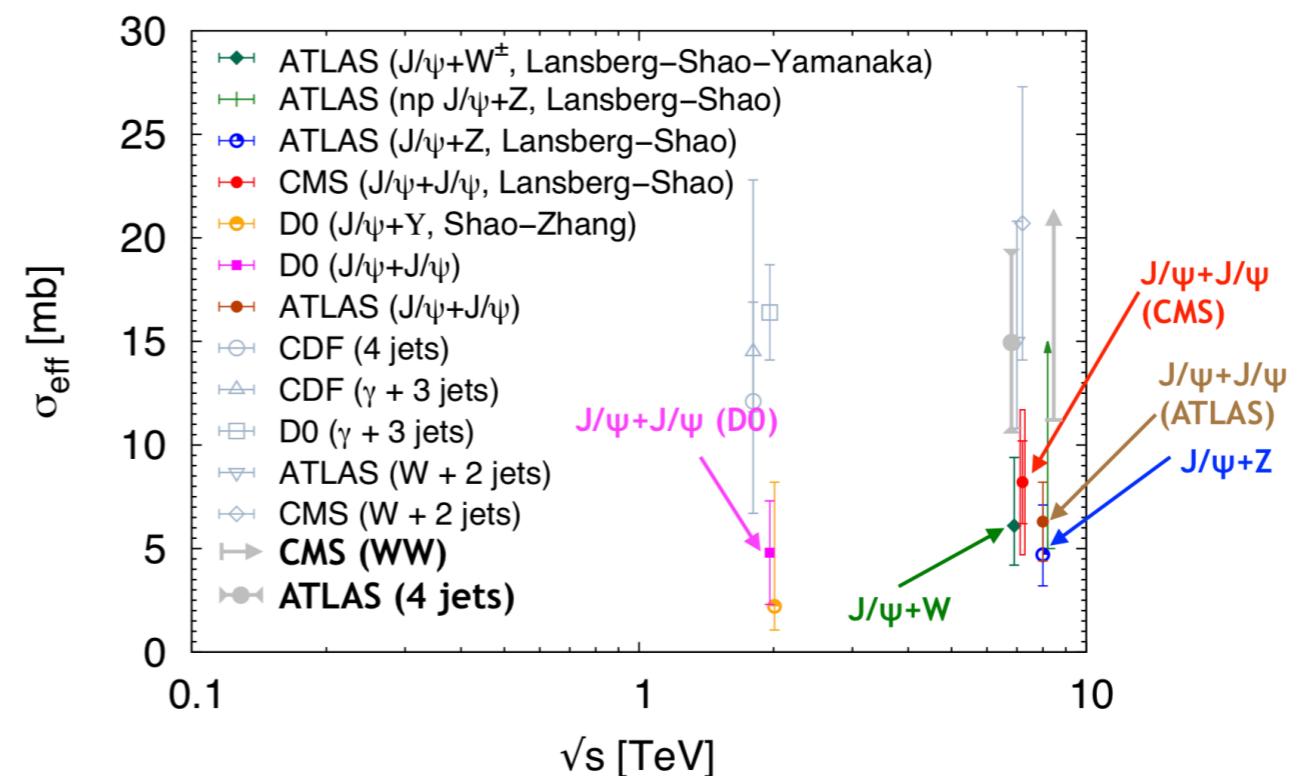
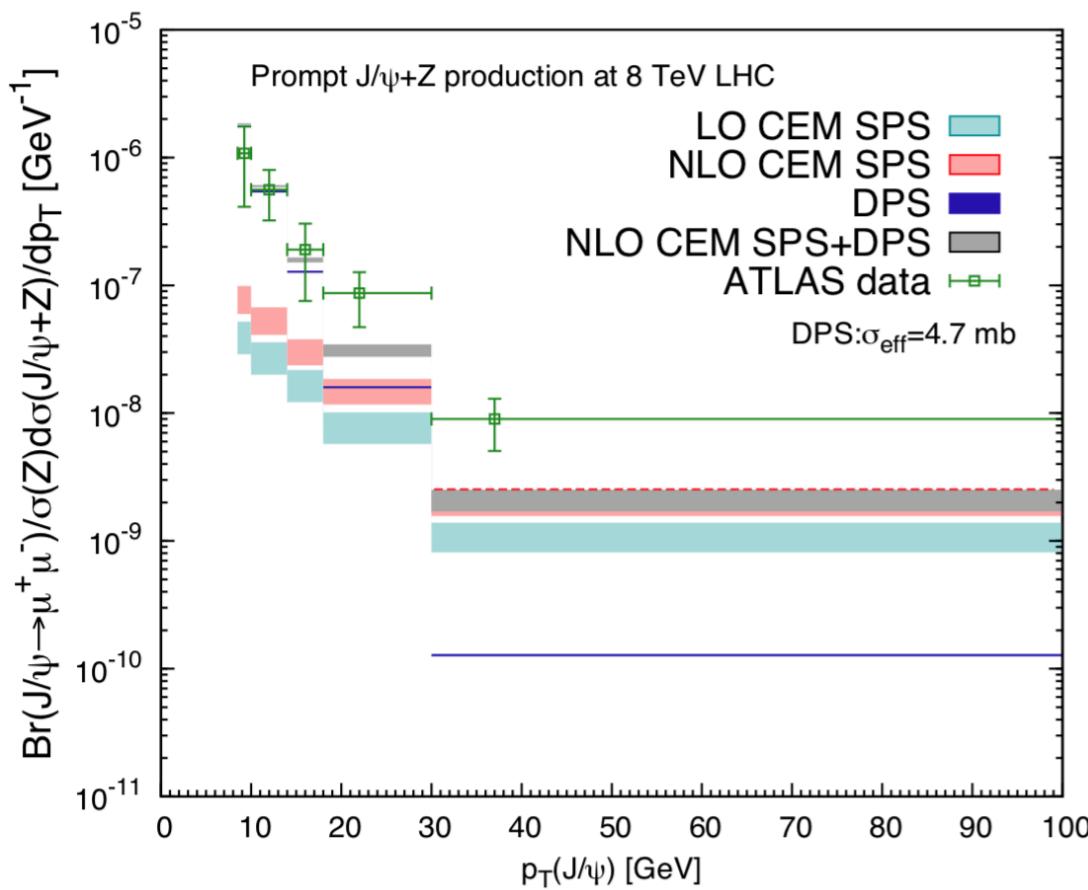
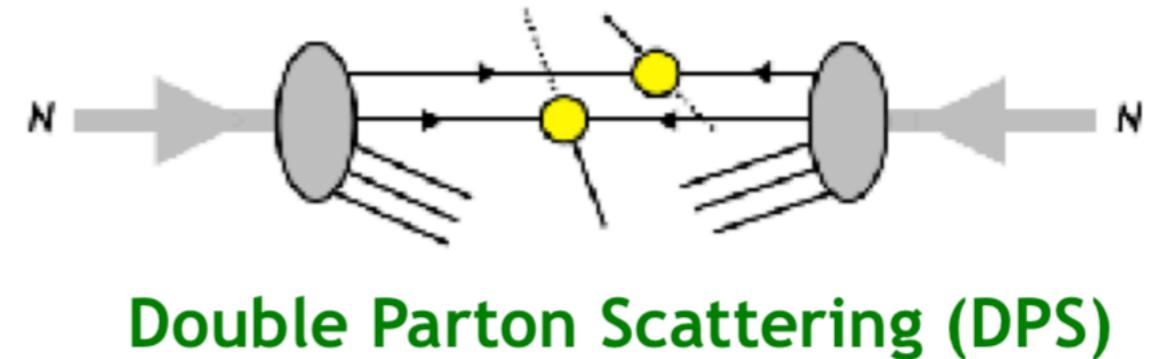
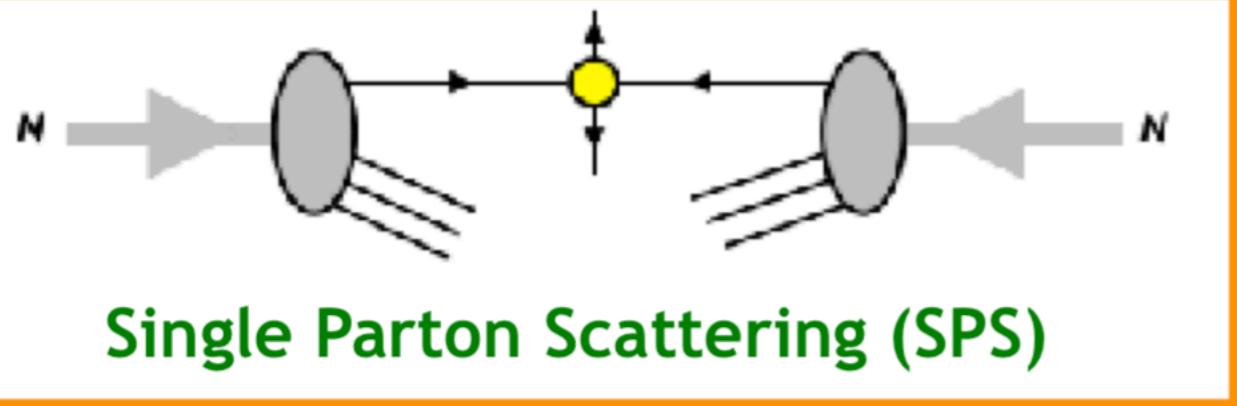


Double Parton Scattering (DPS)



Yamanaka

Double-parton scattering

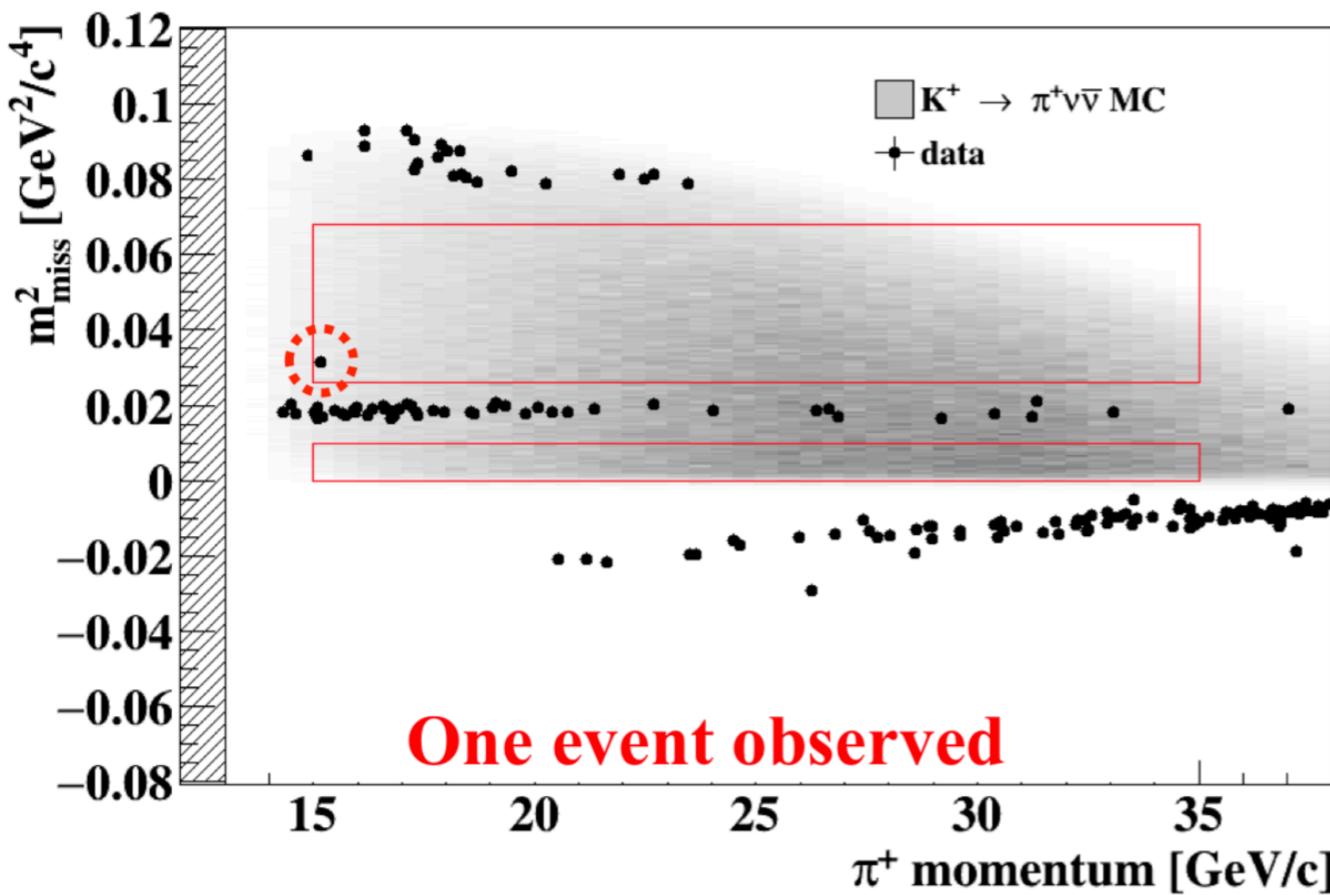


Uncertainties are large -> look at larger LHC datasets

Yamanaka

Kaons & neutrinos

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: first NA62 results



$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 11 \times 10^{-10} \text{ @ 90% CL}$$

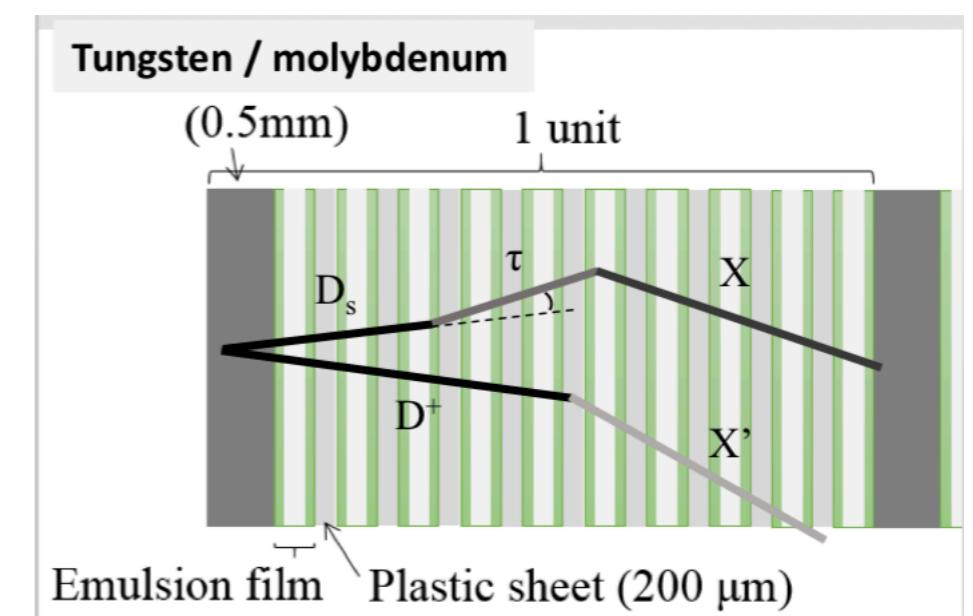
Massarotti, Sato

Improving DONuT

$$\sigma_{\nu \tau}^{\text{const}} = 7.5(0.335n^{1.52}) \times 10^{-40} \text{ cm}^2 \text{ GeV}^{-1}$$

improve to 0.1

Systematic uncertainties	
D_s differential cross section (x_F dependence)	~0.5!?
Charm production cross section	0.17
Decay branching ratio	0.23
Target atomic mass effects (A dependence)	0.14



Summary

- “Don’t summarise a summary”.
- Thanks to the speakers & my co-conveners.
- Thanks to the organisers for a great conference.

