LHCb precision EW physics

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CERN

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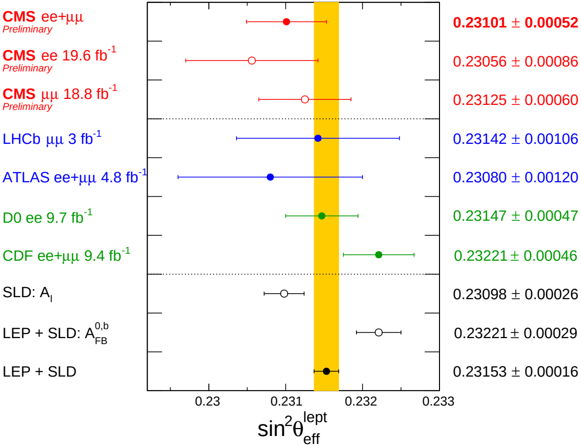
First…a look at $\sin^2\theta_{\text{eff}}^{\text{lept}}$

- In 2015 LHCb produced the most precise LHC determination of $\sin^2\theta_{\text{eff}}^{\text{lept}}$[1]
- Recently beaten by CMS, which [I assume] the previous talk told us about[2]
- LHCb has less lumi…but we are more sensitive per fb^{-1}

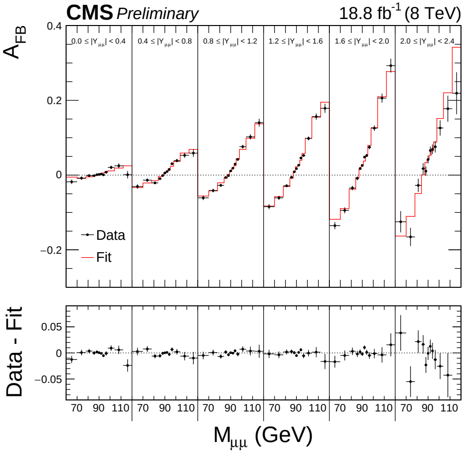


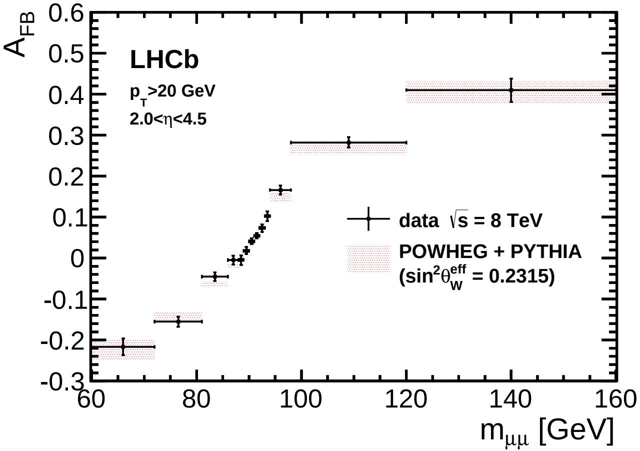
[1] LHCb collaboration, "Measurement of the forward-backward asymmetry in $Z/\gamma^* \to \mu^+\mu^-$ decays and determination of the effective weak mixing angle", JHEP **11**, 190 (2015), arXiv:1509.07645

[2] CMS collaboration, "Measurement of the weak mixing angle with the forward-backward asymmetry of Drell-Yan events at 8 TeV", CDS (2017)

Reminder...why is this a good measurement for LHCb

At high Z^0 rapidity the assumed q direction is more likely to be accurate $\Longrightarrow$ less dilution





Larger asymmetries in LHCb acceptance

What's the outlook for $\sin^2\theta_{\text{eff}}^{\text{lept}}$ at LHCb?

- The full Run 1 + 2 LHCb dataset should have $\sim 5\times$ the Run 1 statistics
- $\sqrt{N}$ scaling for the statistical uncertainty $\implies \sim 0.00033$ with these data
- For reference, this is $\mathcal{O}(20\,\%)$ lower than each Tevatron measurement
- LHCb upgrade in LS2 $\implies \sim 20\times$ Run 1 statistics by the end of Run 3 (2023)
- $\sqrt{N}$ gives a statistical uncertainty of < 0.00020 at this point, competitive with LEP

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So LHCb has/will have interesting statistical sensitivity

(and that's before we consider any improved statistical techniques)

Previous slide: just statistical, just scaling with expected yields

- Use the event weighting technique[1] $\Longrightarrow$ 20 % reduction in σ_{stat}?
- Bin in Z^0 rapidity as well as $m_{\mu^+\mu^-}$
- Expect experimental systematics, *e.g.* momentum scale to also come down as we integrate more luminosity

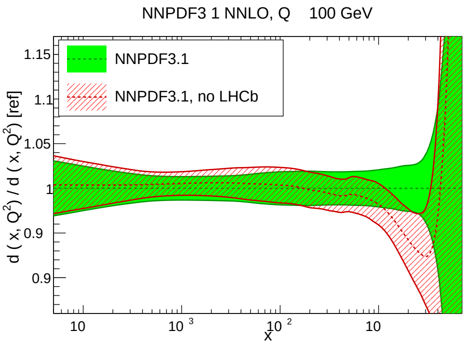
Source of uncertainty	$\sqrt{s} = 7\,\text{TeV}$	$\sqrt{s} = 8\,\text{TeV}$
curvature/momentum scale	0.0102	0.0050
data/simulation mass resolution	0.0032	0.0025
unfolding parameter	0.0033	0.0009
unfolding bias	0.0025	0.0025

Experimental systematics (LHCb Run 1)

[1] A. Bodek, "A simple event weighting technique for optimizing the measurement of the forward-backward asymmetry of Drell-Yan dilepton pairs at hadron colliders", Eur. Phys. J. **C67**, 321–334 (2010), arXiv:0911.2850

What about the theoretical uncertainties?

- The Run 1 result used NNPDF23, now NNPDF31 is available
- This includes **much** more LHCb data...which has a big impact[1]



Uncertainty	average $\Delta\lvert A_{FB}^{pred}\rvert$
PDF	0.0062
scale	0.0040
α_s	0.0030
FSR	0.0016

Theory uncertainties (LHCb Run 1)

- Use NNLO codes if scale uncertainties are a problem
- We can also explore PDF weighting techniques

[1] NNPDF collaboration, "Parton distributions from high-precision collider data", (2017), arXiv:1706.00428

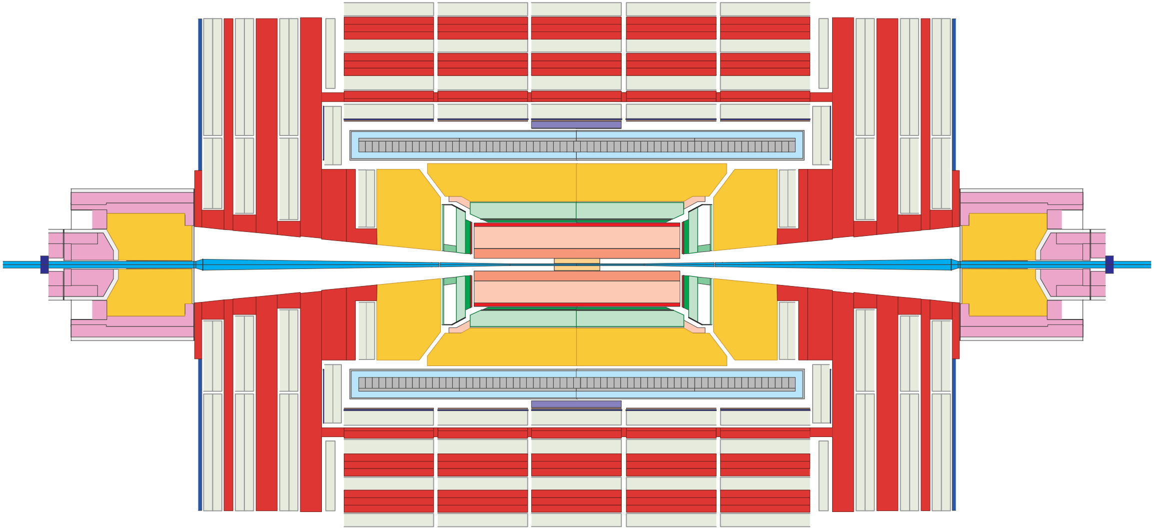
- LHCb should have interesting sensitivity to $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ with the dataset collected up to 2018, statistics competitive with LEP by 2023 or so
- Experimental systematics shouldn't be a showstopper, though plenty of work needed...
- If the theoretical uncertainties were trivial we wouldn't all be here!
- I'll come back to what supporting measurements LHCb can/should make at the end
- First...on to m_{W}

m_W @ LHCb

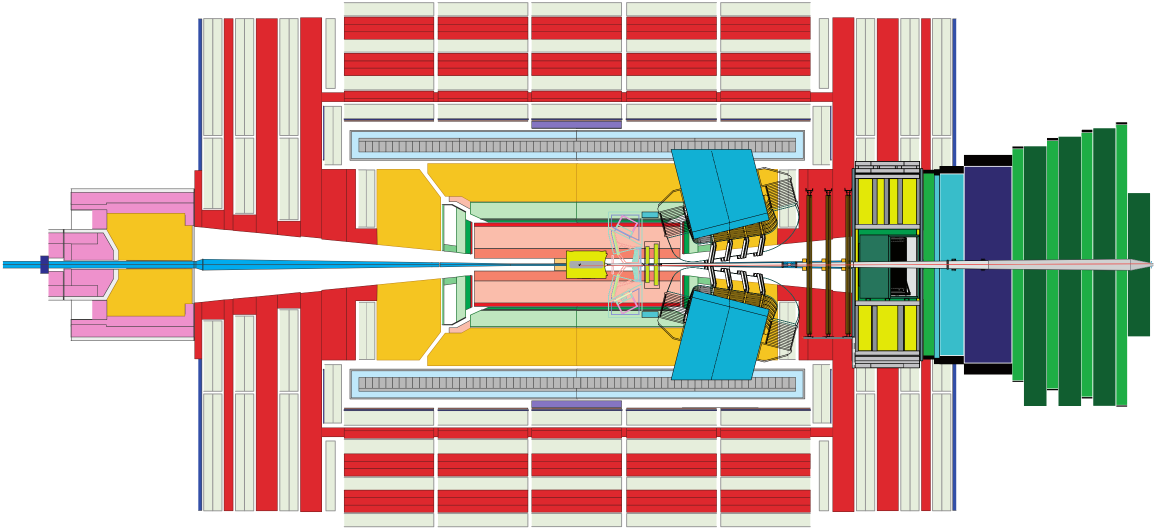
Why measure m_W at LHCb?

- Is it even possible..?
  Restricted acceptance, no missing p_T, worse purity, low luminosity, ...
- Even so, why bother..?
  Unique forward acceptance **complements** GPDs, probes different physics
- You may remember Mika's talk at the last m_W workshop [link]

Getting close to 4π AKA complementarity...

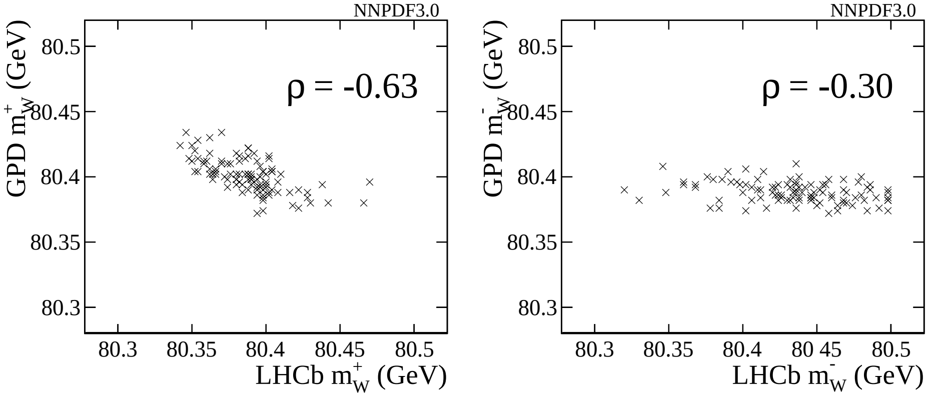


Getting close to 4π AKA complementarity...



How does that help us?

- Has been shown[1] that (assuming a $\mu^\pm$ p_T based measurement) the PDF uncertainties are anti-correlated between central and forward m_W measurements



[1] G. Bozzi, L. Citelli, M. Vesterinen, and A. Vicini, "Prospects for improving the LHC W boson mass measurement with forward muons", Eur. Phys. J. **C75**, 601 (2015), arXiv:1508.06954

What does that mean?

- LHCb could improve the LHC average uncertainty by $\mathcal{O}(30\,\%)$

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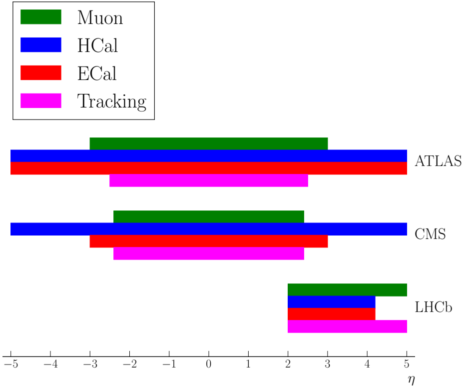
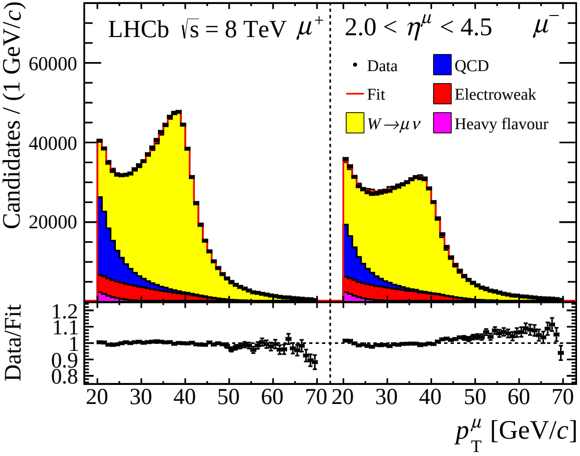
- Clear that we need to carefully coordinate the different LHC experiments to exploit our complementarity



- Only muons, only p_T
- Aim to go straight to the full Run 1 + 2 dataset $\implies$ simultaneously analyse $\sqrt{s} = 7,\ 8,\ 13\,\text{TeV}$
- LHCb's luminosity levelling means these data are rather homogeneous. The largest dataset (13 TeV) has the lowest pile-up
- Limited "LHCb visible" recoil information?

- Expect to have $\mathcal{O}(10M)$ $W^{\pm}$ decays in Run 1 + Run 2 dataset
- Expect $\mathcal{O}(10\,\mathrm{MeV}/c^2)$ statistical uncertainty on m_W using this sample
- Purity seen here is **without** recoil information $\longrightarrow$
- "LHCb visible" recoil may help

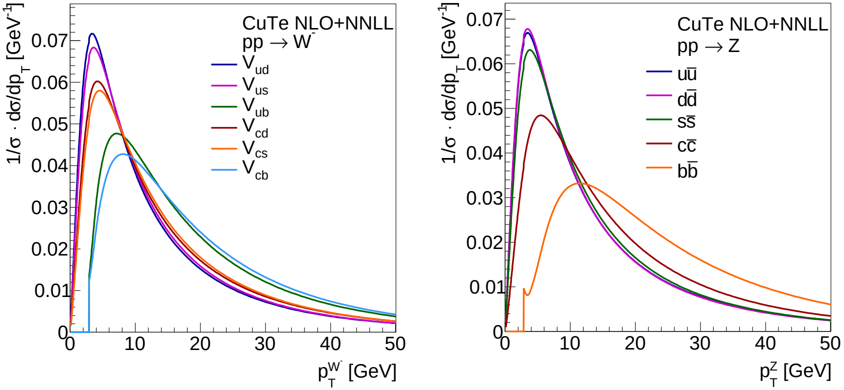


LHCb $W \rightarrow \mu$ cross-section[1]

[1] LHCb collaboration, "Measurement of forward W and Z boson production in pp collisions at $\sqrt{s} = 8$ TeV ", JHEP **01**, 155 (2015), arXiv:1511.08039

$W^{\pm}$ p_{T} spectrum modelling

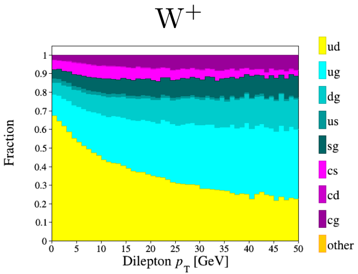
- We will produce whatever measurements of our $\mathcal{O}(1M)$ $Z^0/\gamma^* \to \mu^+\mu^-$ are needed...but translation from Z^0 to $W^{\pm}$ is still non-trivial. *e.g.* heavy flavour effects[1]

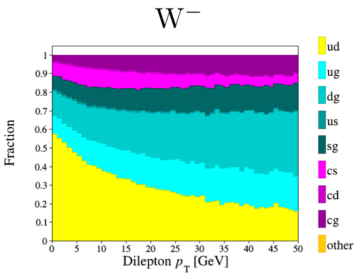


[1] ATLAS collaboration, "Studies of theoretical uncertainties on the measurement of the mass of the W boson at the LHC", CDS (2014)

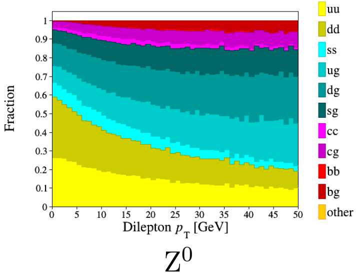
$W^{\pm}$ p_T spectrum modelling – forward has its advantages?

- Powheg+Pythia
- GPD acceptance

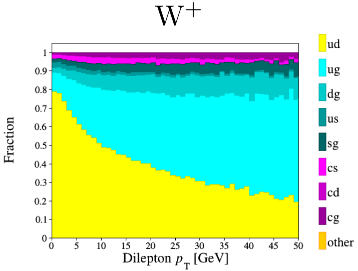


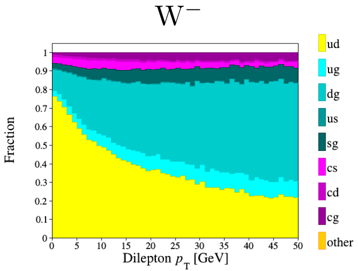


Light qq
Light qg
Charm
Beauty



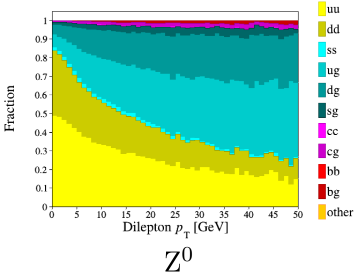
$W^{\pm}$ p_T spectrum modelling – forward has its advantages?





- LHCb acceptance
- Valence-enhanced
- Heavy flavour suppressed
- Not shown, but p_T spectrum is also a bit softer

Light qq
Light qg
Charm
Beauty



Gauge boson kinematic modelling at high rapidity

- Clear that for both m_{W} and $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ we will need the theory tools to describe our Z^0/γ^* data very well
- Important to validate all state-of-the-art MC codes (shower, NLO-matched-shower, NNLL analytic resummed) in our unique acceptance...expect surprises!
- We also need **input from our theory friends**:

  How can we tailor our Z^0/γ^* measurements to help with tuning/development?

- Some data are already published at $\sqrt{s} = 7, 8, 13$ TeV. We'll try to add $\sqrt{s} = 5$ TeV
- Plan to produce at least $\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}$ and/or $\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*}$ for Z^0/γ^* in bins of $m_{\mu^+\mu^-}$ and rapidity, and measure Z^0 angular coefficients
- Theorists' input here is valuable. What should we do **now** to reduce theory and PDF uncertainties in our m_{W} and $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ measurements?
- Everything with our full Z^0 sample, finest binning we can manage

Conclusions

- We've already made plenty of precision EW measurements, more are in the pipeline...
- Our unique kinematic coverage and running conditions have their advantages
- LHCb is definitely not "just" a flavour physics experiment
- Highly complementary to ATLAS and CMS, particularly important when trying to improve systematics...

Backup

Table 5 The uncertainties on different LHC averages for m_W. The separate experimental and PDF uncertainties are listed, as are the weights that minimise the total uncertainty.

Scenario	Experiments	δm_W (MeV) Tot	Exp	PDF	α
Default	2×GPD + LHCb	9.0	4.7	7.7	$(0.30, 0.44, 0.22, 0.04)$
Default	1×GPD + LHCb	10.1	6.5	7.7	$(0.31, 0.40, 0.25, 0.04)$
Default	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
PDF4LHC(3-sets)	2×GPD + LHCb	13.6	4.8	12.7	$(0.43, 0.41, 0.12, 0.04)$
PDF4LHC(3-sets)	1×GPD + LHCb	14.6	7.3	12.7	$(0.43, 0.40, 0.12, 0.04)$
PDF4LHC(3-sets)	2×GPD	17.7	5.5	16.9	$(0.50, 0.50, 0, 0)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	2×GPD + LHCb	8.7	4.0	7.7	$(0.31, 0.41, 0.24, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	1×GPD + LHCb	9.8	5.9	7.9	$(0.31, 0.37, 0.28, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\rm exp}^{\rm GPD} = 0$	2×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\rm exp}^{\rm GPD} = 0$	1×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\rm exp}^{\rm GPD} = 0$	2×GPD	10.5	0.1	10.5	$(0.26, 0.74, 0, 0)$
$\delta_{\rm PDF} = 0$	2×GPD + LHCb	4.6	4.6	0.0	$(0.34, 0.34, 0.22, 0.10)$
$\delta_{\rm PDF} = 0$	1×GPD + LHCb	5.8	5.8	0.0	$(0.23, 0.23, 0.37, 0.17)$
$\delta_{\rm PDF} = 0$	2×GPD	5.5	5.5	0.0	$(0.50, 0.50, 0, 0)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	2×GPD + LHCb	9.6	5.6	7.7	$(0.29, 0.50, 0.17, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	1×GPD + LHCb	10.8	7.6	7.7	$(0.30, 0.46, 0.20, 0.05)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	2×GPD + LHCb	11.2	7.9	8.0	$(0.32, 0.35, 0.29, 0.04)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	1×GPD + LHCb	13.9	10.5	9.0	$(0.31, 0.26, 0.37, 0.05)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	2×GPD	15.6	11.5	10.6	$(0.32, 0.68, 0, 0)$
$\delta_{\rm PDF} \times 2$	2×GPD + LHCb	16.0	4.7	15.3	$(0.30, 0.45, 0.21, 0.04)$
$\delta_{\rm PDF} \times 2$	1×GPD + LHCb	16.7	6.7	15.3	$(0.30, 0.44, 0.22, 0.04)$
$\delta_{\rm PDF} \times 2$	2×GPD	21.7	5.9	20.9	$(0.27, 0.73, 0, 0)$