Probing the structure of weak interactions

<u>D.Zakoucky</u>, P.Alfaurt, V.Araujo-Escalona, P.Ascher, D.Atanasov, B.Blank, L.Daudin, X.Fléchard, M.Gerbaux, J.Giovinazzo, S.Grévy, T. Kurtukian-Nieto, E.Liénard, G.Quéméner, M.Roche, N.Severijns, S.Vanlangendonck, M.Versteegen

Experimental project **WISArD**
(**W**eak-**I**nteraction **S**tudies with ^{32}**Ar D**ecay)
online at ISOLDE/CERN

Study structure of weak interactions : search for 'forbidden' Scalar & Tensor components by precise measurements of sensitive correlations in low-energy beta-decays

CENBG Bordeaux   KU Leuven   ISOLDE,CERN   LPC Caen   NPI Rez

Motivation, sensitive variables

Standard model of electro-weak interactions: **V-A character of interaction**

C_V=1, C_A=-1.27, C_V'=C_V & C_A'=C_A, C_S=C_S'=C_T=C_T'=C_P=C_P'=0 No Scalar or Tensor

But experimental limits for $|C_T^{(\prime)}/C_A|$ and $|C_S^{(\prime)}/C_V|$ only at the % level (After 60 years of efforts !!!)

β-ν correlations in β-decay - **a** parameter (sensitive to both **Scalar**, **Tensor** interaction)

can simultaneously study both "forbidden interactions" – Scalar in Fermi decays, Tensor in Gamow-Teller decays

study **recoil nuclei** instead of **neutrinos -** measurement of the shape of p-spectrum from **β-delayed proton decay** (WISArD)

High-energy and low-energy experiments are complementary :

experimental upper limits for $|C_S/C_V|$ & $|C_T/C_A|$ are currently at the % level (n & nuclear β-decay)

- extending the limit to ‰ level allows to increase lower limits on possible new bosons whose exchange could create possible Scalar or Tensor-type interactions (mass ~ 2.5 TeV)

$$C_i \propto \frac{M_W^2}{M_{new}^2}$$

Decay rate for non polarized nuclei

$$dW = dW_0\left(1 + a\frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e}\right)$$

$$a_F \cong 1 - \frac{|C_S|^2 + |C_S'|^2}{|C_V|^2} \quad \text{=1 SM}$$

$$a_{GT} \cong -\frac{1}{3}\left[1 - \frac{|C_T|^2 + |C_T'|^2}{|C_A|^2}\right] \quad \text{= -1/3 SM}$$

β-ν correlation coefficient

$$b_F \cong Re\,\frac{C_S + C_S'}{C_V}$$

$$b_{GT} \cong Re\,\frac{C_T + C_T'}{C_A} \quad \text{= 0 SM}$$

Fierz interference term

Best measurements:
a_F ~ 0.45%,
a_{GT} ~1%

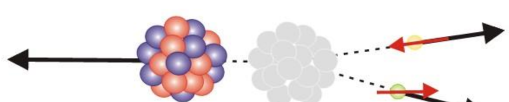
WISArD: measuring $\tilde{a}$, sensitive to both a & b

$$\tilde{a} \approx \frac{a}{1 + b\langle m_e / E_e\rangle}$$

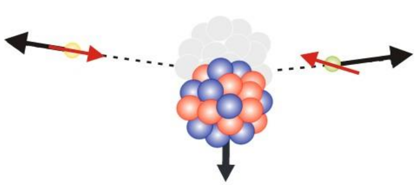
measuring **recoil nucleus energy**⇒ ratio Scalar/Vector

F decay $\tilde{a}_F$ limits Scalar, GT $\tilde{a}_{GT}$ limits Tensor

Vector interaction (SM)
High energy of recoil nucleus,
moving opposite to emitted particles

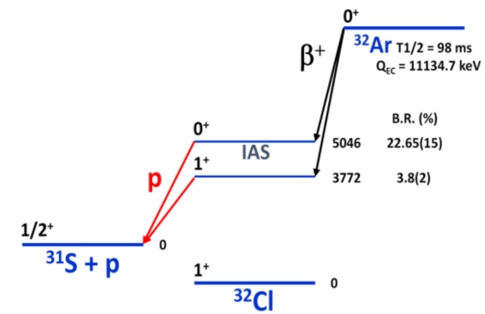


Scalar interaction (beyondSM)
Very small energy of recoil nucleus



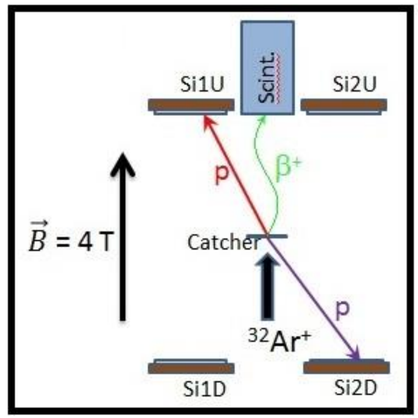
WISArD (Weak-Interaction Studies with ^{32}Ar Decay) experiment

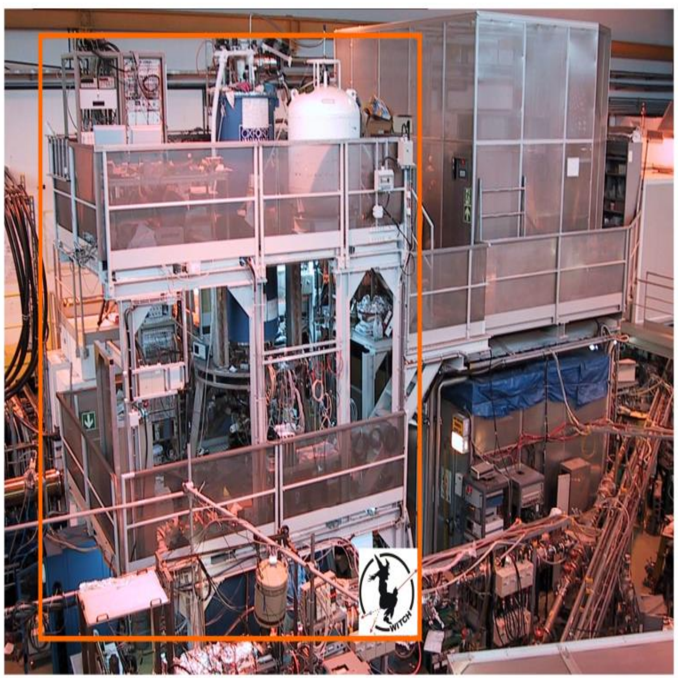
WISArD – measuring β-delayed proton decay of ^{32}Ar
in β-p coincidence measurement we measure the proton energy shift for same & opposite β emission directions which is a linear function of $\tilde{a}$

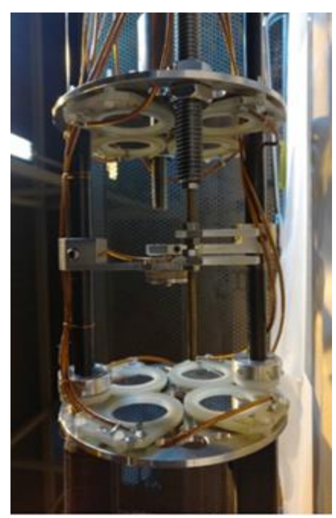


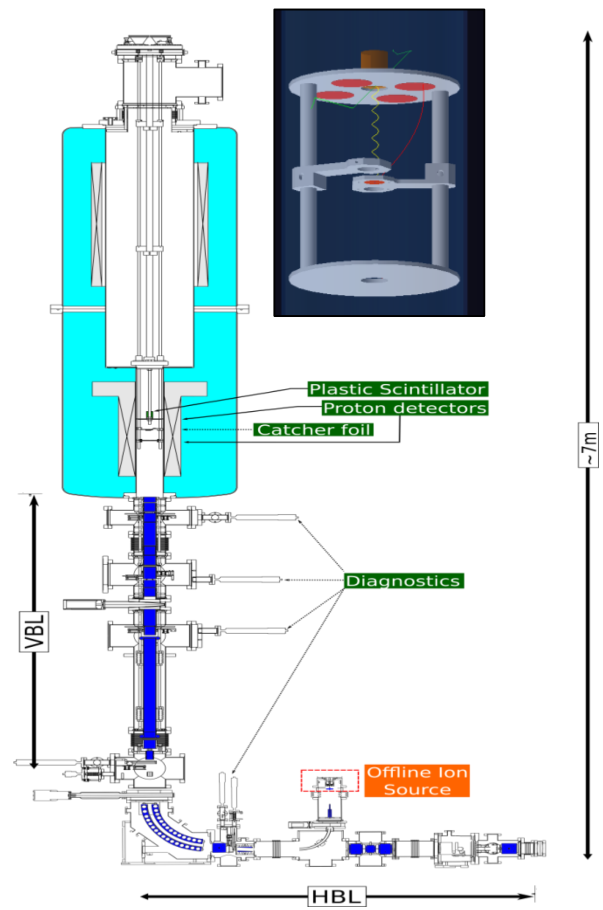
- Super-allowed Fermi β-decay ^{32}Ar→ ^{32}Cl to Isobaric Analog State is promptly followed (Γ~20eV ⇔ $T_{1/2}$~10^{-17}s) by the proton decay ^{32}Cl → ^{31}Si
- Protons are emitted from the moving nucleus ^{32}Cl recoiling after previous β-decay ⇒ proton energy is Doppler shifted: high recoil energy, Vector interaction, *a* = 1 ; low recoil energy, Scalar, *a* = -1

- ^{32}Ar ions implanted into the catcher mylar foil
- Positrons from the β-decay detected by the narrow forward detector placed on axis
- Protons from the subsequent p-decay of ^{32}Cl detected by arrays of Si detectors in forward (UP) and backward (DOWN) direction off axis
- Whole setup in the **magnetic field 4T** (up to 9T)) → spiraling positrons cannot reach the proton detectors placed off axis ⇒ **no summing p+e, no distortions of p-peaks**





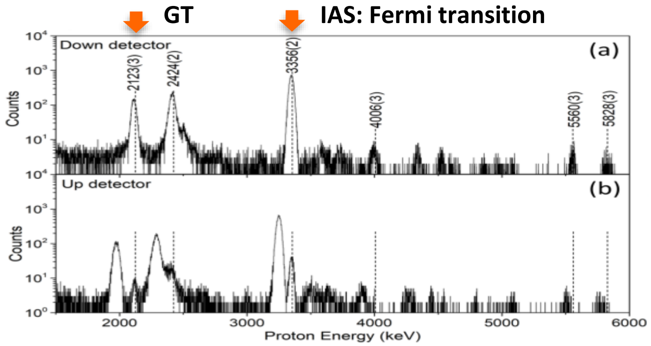




Results, outlook

WISArD online proof-of-principle experiment

Nov 2018, latest run before the CERN shutdown
- readily available beta and proton detectors
- ~ 1700 pps of ^{32}Ar instead of 3000 nominal
- ~ 35h of beamtime



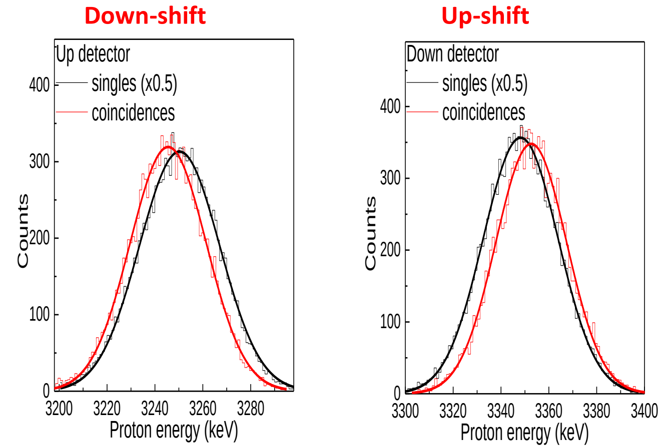
Current precision, outlook:

Systematic error budget (in ‰) :

	Source	Uncertainty	$\Delta\tilde{a}_{\beta\nu}(10^{-3})$
background	false coinc.	8%	< 1
proton	detector calibration	0.2%	2
	detector position	1 mm	< 1
	source position	3 mm	3
	source radius	3 mm	1
	B field homogeneity	1%	< 1
	silicon dead layer	0.3 μm	5
	mylar thickness	0.15 μm	3
positron	detector backscattering	15%	2
	catcher backscattering	15%	21
	threshold	12 keV	8
total			24

-unknown detectors DL
-source profile poorly known
→upgrade of p-detectors
can be easily reduced by factor *x ~10*

→Must be reduced by factor >20
thinner catcher → *x ~10 improvement*
dedicated BS measurements→ *x ~3-5 improvement*



Typical resolution ~35 keV FWHM

Statistical error reduction below 1 ‰
- production + transmission + time (ISOLDE, beamlines upgrade, 2weeks beamtime)
  → x ~50 in decay statistics
- dedicated detection setup (higher p-resolution, higher solid angle, lower beta threshold)
  → x ~5 in sensitivity

$\Delta E_F = 4.49(3)$keV, $\Delta E_{GT} = 3.05(9)$keV

$$\tilde{a}_F = 1.01(3)_{\rm stat}(2)_{\rm syst}$$

$$\tilde{a}_{GT} = -0.22(9)_{\rm stat}(2)_{\rm syst}$$

⇒ achievable **~0.9 ‰ (F), ~1.4 ‰ (GT)**

V. Araujo-Escalona et al, PRC 101 055501 (2020)

Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo

ICTEA
Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias

CMS

30-07-2020

ICHEP 2020

Latest single top differential cross section measurements at CMS

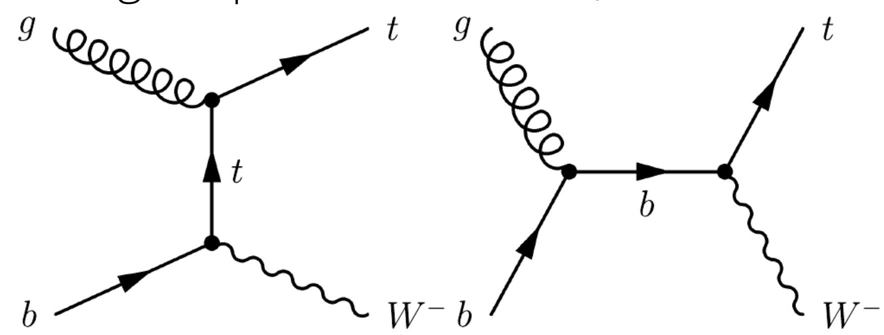
Víctor Rodríguez Bouza (on behalf of the CMS Collaboration)

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

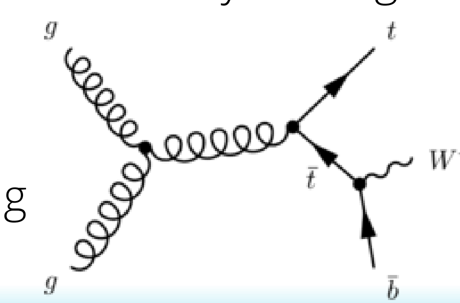
Partially publicly funded by Ministerio de Ciencia e Innovación (Gobierno de España), *through the* "Ayudas para contratos predoctorales para la formación de doctores 2019" *program.*

Introduction

- The CMS' latest measurement of single top differential cross sections has been done on the tW process with 2016 data using dilepton final states (CMS-PAS-TOP-19-003).



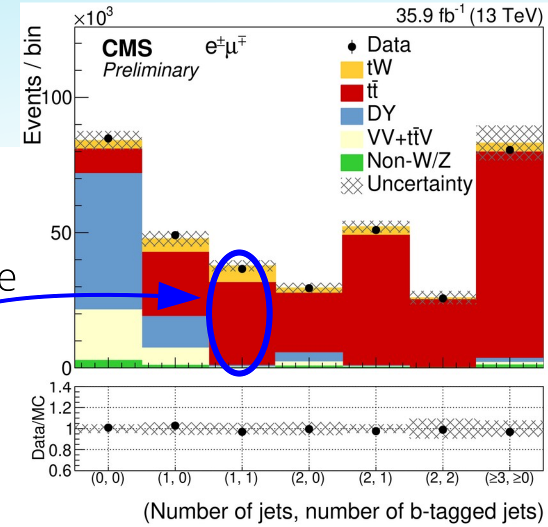
- Main challenge: **background** *largely* **dominates signal**, being the most important $t\bar{t}$.
- This is a consequence of its similarity with the most important way of producing top quarks at p-p collisions: pair production. Actually, at NLO, **they interfere**. In order to resolve both processes' definitions, and avoid double counting issues, two approaches (JHEP 07 (2008) 029) are used to obtain the tW simulation samples.
  - Diagram Removal (**DR**): we remove Feynman diagrams that might present two on-shell tops (also called *double resonant*).
  - Diagram Subtraction (**DS**): we remove locally the pair-production contribution by adding an artificial term in the calculation.

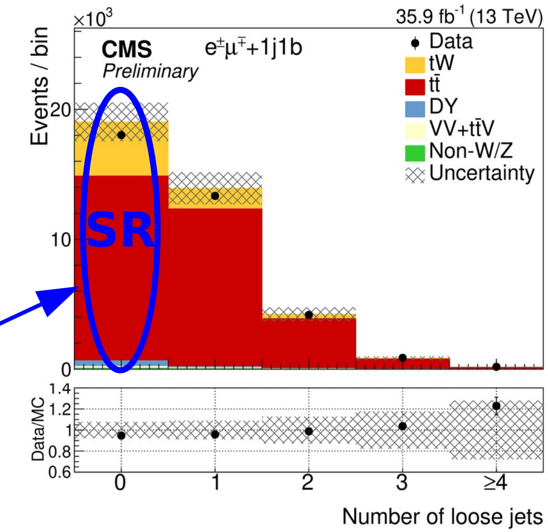


- The differential cross sections are measured as a function of the leading lepton p_T, jet p_T, $\Delta\varphi(e^{\pm},\mu^{\mp})$, $p_Z(e^{\pm},\mu^{\mp}, j)$, $m(e^{\pm},\mu^{\mp}, j)$ and $m_T(e^{\pm},\mu^{\mp}, j, p_T^{miss})$.

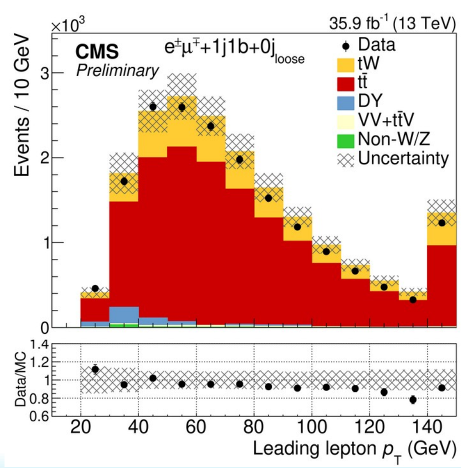
Methodology

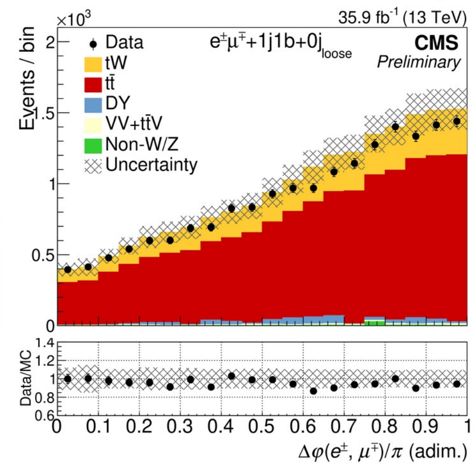
- The analysis is performed using the **complete 2016 dataset** (35.9 fb^{-1}).
- The **trigger strategy** uses a combination of single and double triggers to maximise efficiency.
- **Event selection**
  - At least two identified leptons.
  - One of them must fulfil $p_T > 25$ GeV.
  - The two first (in terms of p_T) must have opposite charge…
  - … and be an electron and a muon (eμ channel)…
  - …whose invariant mass satisfy m(e, μ) > 20 GeV.
  - Exactly 1 jet ($p_T > 30$ GeV) that must be b-tagged.
  - Exactly zero loose jets (jets with 20 GeV < p_T < 30 GeV).





- Signal is extracted by subtracting background to data.
- Afterwards, unfolding (implemented using `TUnfold`: JINST 7 (2012) T10003) is done to an equivalent fiducial region at particle level. The result is normalised to the fiducial cross section.



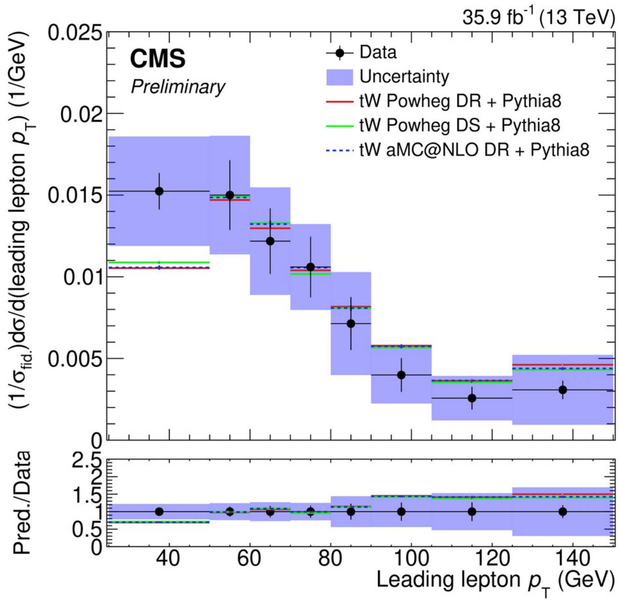


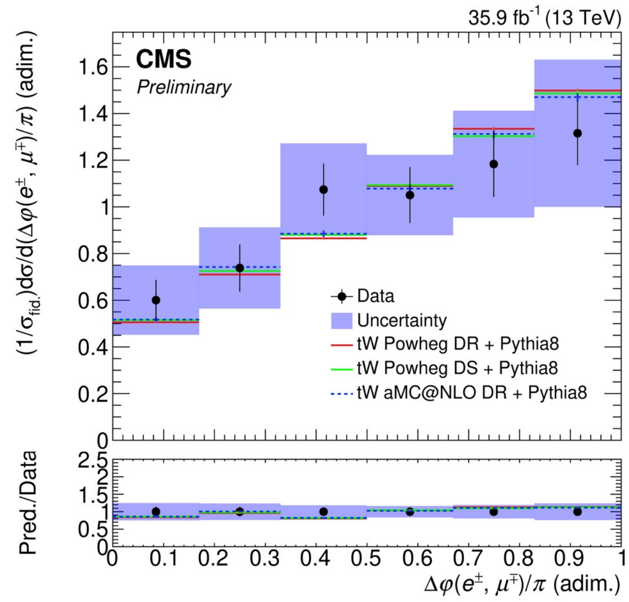
Result & discussion

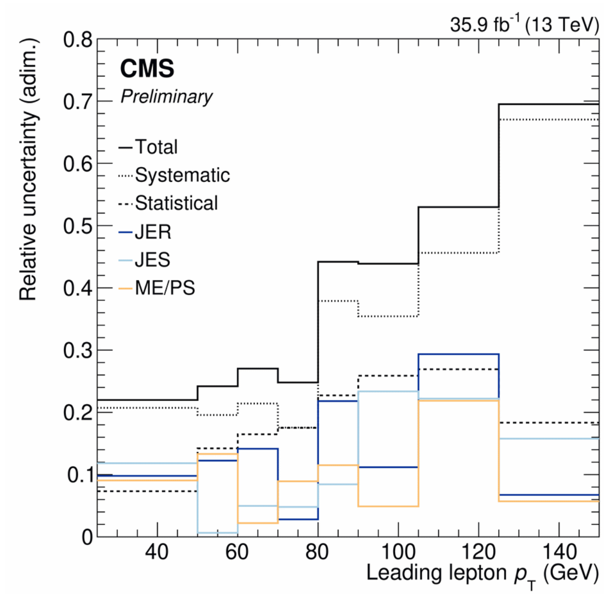
- **Agreement** between data and expectations (with the two generators, `POWHEG` and `MADGRAPH5_aMC@NLO`) is **fairly good**.

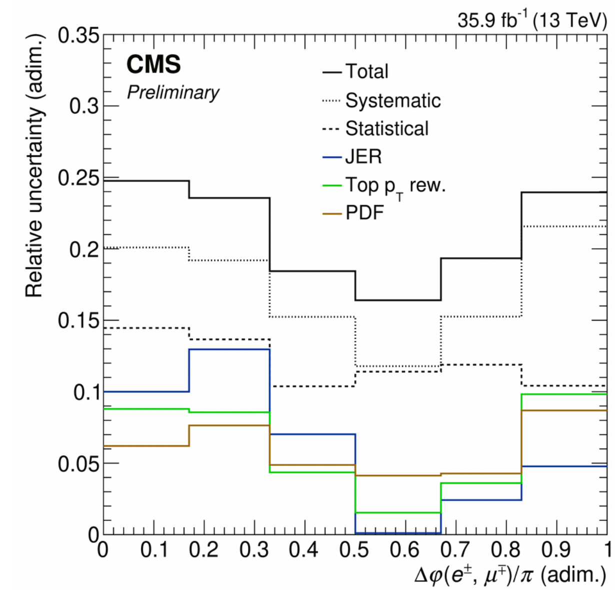
- Analysis **largely dominated by systematic sources of uncertainties**, whose main origin is the overwhelming **background**.
  - Main sources: jet–related uncs. (e.g. JES, JER) and modeling (e.g. ME/PS matching).
  - Depending on the bin and distribution, varying from ~15-40% (bulk of distributions) up to ~25-100% in the tails.

- In addition, the result shows **compatible agreement** for the DR and DS schemes of the signal process.









Extraction of CKM matrix elements in the single-top *t*-channel events at 13 TeV with CMS

ICHEP2020: 40^{th} International Conference on High Energy Physics

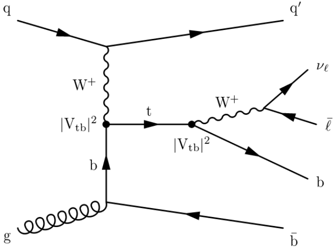
A. De Iorio

on behalf of the CMS Collaboration

Prague, 28 July – 6 August 2020

Single-top quark process

The top quark can be singly produced via electroweak interaction.



– light jets (high pseudorapidity)
– missing energy from ν
– isolated lepton
– b-jet from top quark
– b-jet from gluon splitting

Requirements: 2 or 3 jets (1 or 2 b jet)

- The single top *t*-channel production process is particularly indicated to measure the Cabibbo-Kobayashi-Maskawa elements $|\mathrm{V_{tb}}|^2$, $|\mathrm{V_{ts}}|^2$, and $|\mathrm{V_{td}}|^2$.
- The cross section and branching fraction can be written as:

$$\sigma_{t-\mathrm{ch.,b}}\mathcal{B}(\mathsf{t} \to \mathsf{Wb}) + \sigma_{t-\mathrm{ch.,b}}\mathcal{B}(\mathsf{t} \to \mathsf{Wd,s}) + \sigma_{t-\mathrm{ch.,s,d}}\mathcal{B}(\mathsf{t} \to \mathsf{Wb}) + \mathcal{O}(|V_{\mathrm{td,s}}|^4)$$

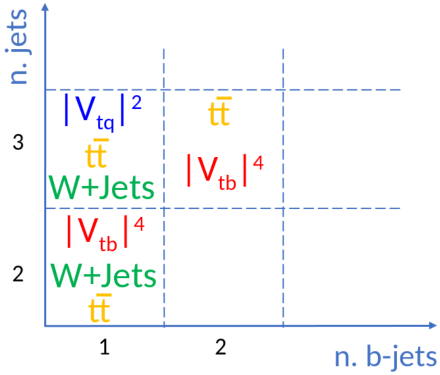
where:

$$\sigma_{t-\mathrm{ch.,q}} \propto |\mathrm{V_{tq}}|^2 \qquad \mathcal{B}(\mathsf{t} \to \mathsf{Wq}) = |\mathrm{V_{tq}}|^2 \widetilde{\Gamma_{\mathsf{q}}} \Gamma_{\mathrm{top}}$$

Analysis strategy

Several irreducible backgrounds $\rightarrow$ control regions

- 2-jets–1-tag rich in *t*-channel $|V_{tb}|^4$; main backgrounds: $W+\text{jets}$ and $t\bar{t}$
- 3-jets–1-tag rich in *t*-channel $|V_{tq}|^2$; main bkgs: $W+\text{jets}$ and $t\bar{t}$
- 3-jets–2-tags pure in $|V_{tb}|^4$; main bkg: $t\bar{t}$



QCD discrimination:

- Shape obtained from data (from region with anti-isolated lepton)
- Depleted by requiring W boson transverse mass $> 50\ \text{GeV}$

Signal to background discrimination:

- Several kinematic variables
- Use of Boosted Decision Trees discriminator
- simultaneous fit is performed: 6 categories (2 lepton flavour x 3 regions)

Results

The absolute values of CKM matrix elements are extracted from the fit results[1]:

SM scenario:
$|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2 = 1$

Results:

$$|V_{tb}|^2 > 0.970$$
$$|V_{ts}|^2 + |V_{td}|^2 < 0.057$$

BSM model 1:
$|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2 \neq 1$

Results:

$$|V_{tb}|^2 = 0.988 \pm 0.051$$
$$|V_{ts}|^2 + |V_{td}|^2 = 0.06 \pm 0.06$$

BSM model 2:
Γ_t allowed to vary due to decay in new particles

$$|V_{tb}|^2 = 0.988 \pm 0.024$$
$$|V_{ts}|^2 + |V_{td}|^2 = 0.06 \pm 0.06$$
$$\frac{\Gamma_t^{obs}}{\Gamma_t} = 0.99 \pm 0.42$$

No deviations observed from the SM

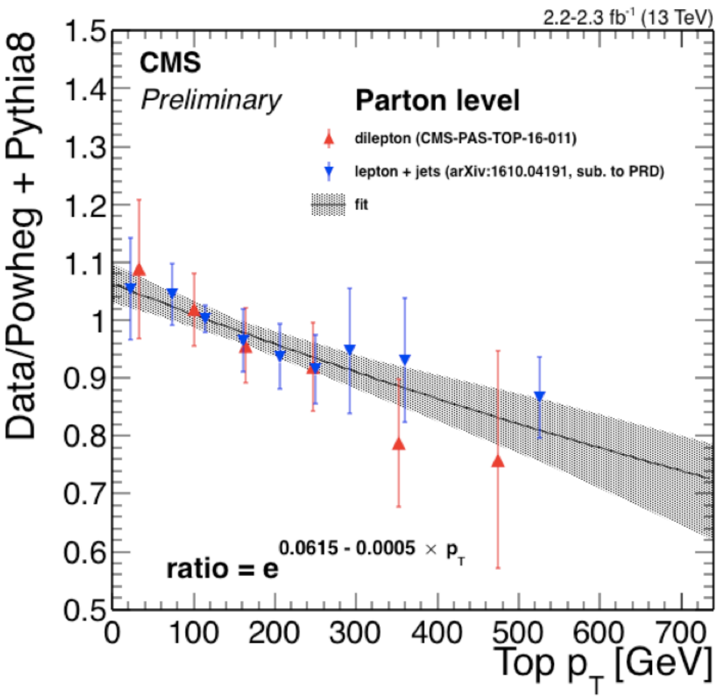
The results are more precise than the last measurement of $|V_{tb}|$ performed by CMS[2] and than the ATLAS and CMS combination at $\sqrt{s} = 7 - 8$ TeV [3]

Measurement of differential tt production cross sections for high-pTtop quarks with CMS at 13 TeV

ICHEP 2020

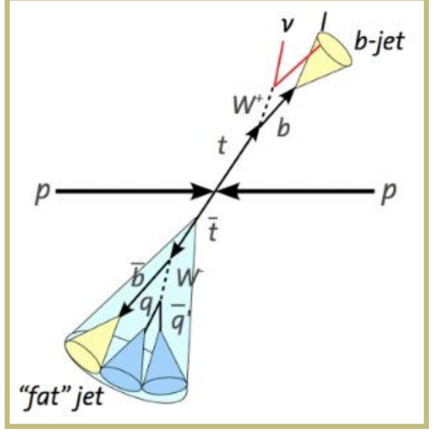
Ioannis Papakrivopoulos on behalf of the CMS Collaboration

Introduction / Motivation



Explore the kinematic regions beyond the reach of the resolve analyses (p_t> 400 GeV)

- Provide precision in that region
- Sensitivity to new physics
- Test for perturbative QCD



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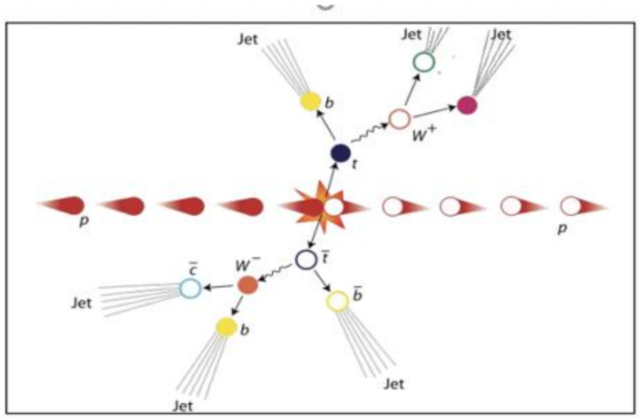
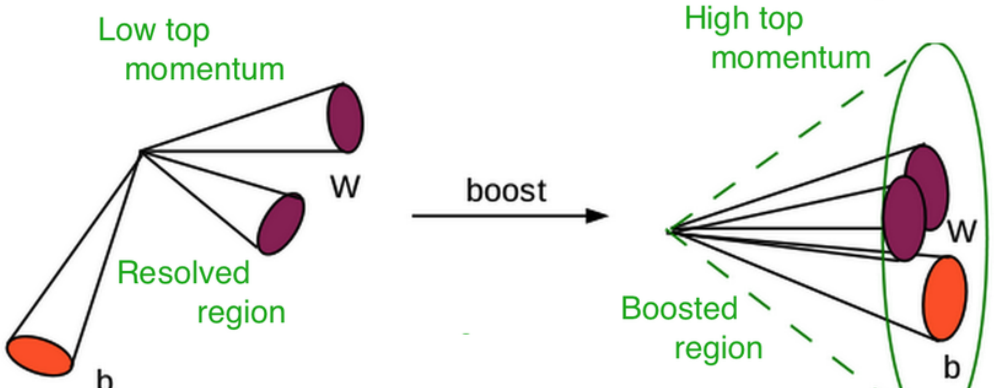


Two distinct final states:

- l + jets (boosted hadronically decaying top quark and resolved leptonically decaying top quark)
- Hadronic (both boosted top quarks decaying hadronically)

Compatible results with other analyses

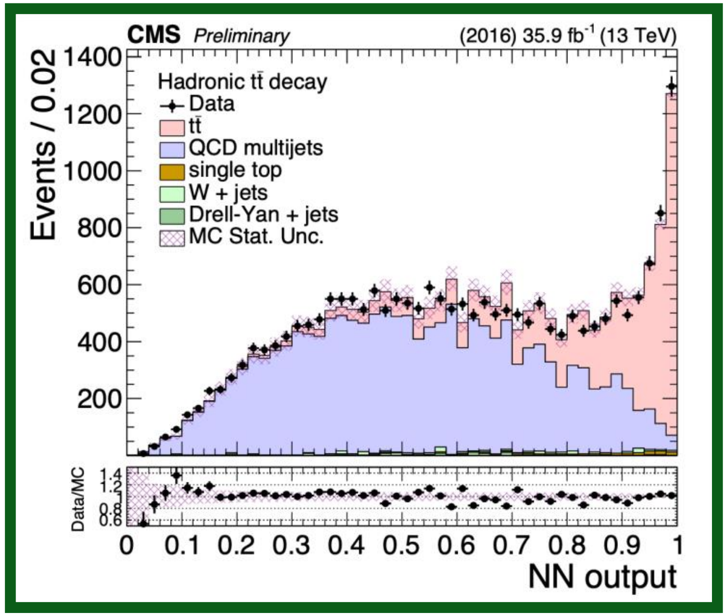


$p_T \sim 2M_t/R$ ~ 400 GeV

Object selection / reconstruction

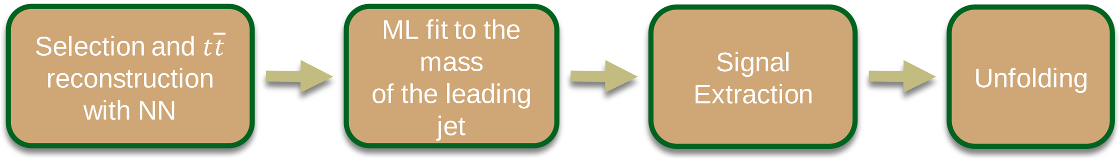
Hadronic channel:

- Trigger selects two AK8 (anti-kt, R=0.8) jets and b-tagging @ HLT level
- Two AK8 (anti-kt, R=0.8) jets with pt > 400 GeV
- ttbar event tagging with NN using jet substructure variables as inputs



- Selection split in categories based on the b-tagging requirements. 2b Signal Region (SR) 0b Control Region (CR)

Data driven background suppression. QCD shape taken from CR, while QCD yield is estimated by a ML fit to the mass of the leading jet.

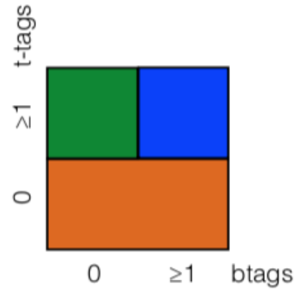


l + jets channel:

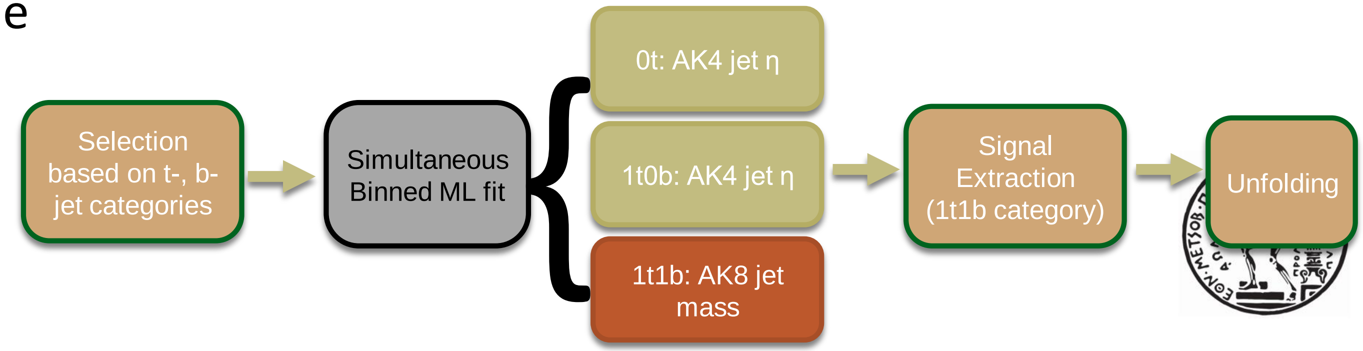
- Final state a lepton + b jet + MET + t jet
- Trigger selects a single lepton and two small R jets

Selection:

- Exactly 1 lepton e/μ ≥ 1 small R jet (anti-kt, R = 0.4, leptonic top decay)
- ≥ 1 large R jet (anti-kt, R = 0.8, hadronic top decay)
- E_T^{Miss}
- b tagging AK4 jet, medium WP
- t tagging → AK8 jet, 105 < m_{top} < 220 GeV, subjetiness τ_{32} < 0.81, No b tagging → better acceptance
- Categories 0t, 1t0b 1t1b

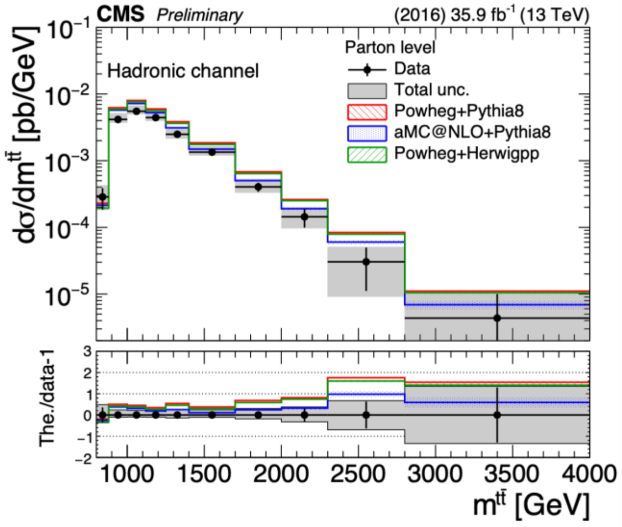


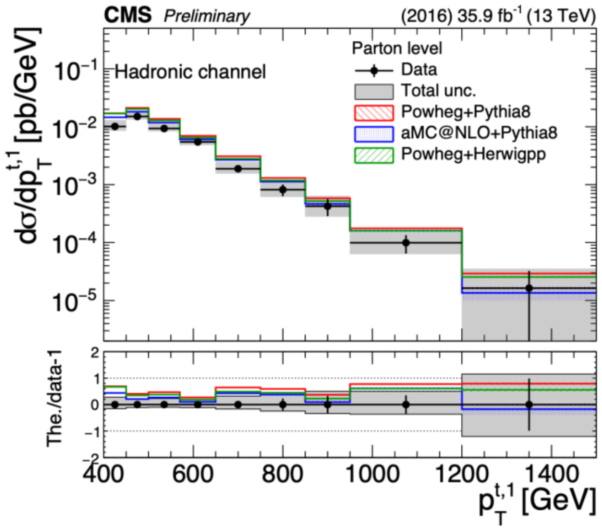
QCD estimated from simultaneous fit in the 3 categories in a QCD dominated sideband (invert lepton isolation).



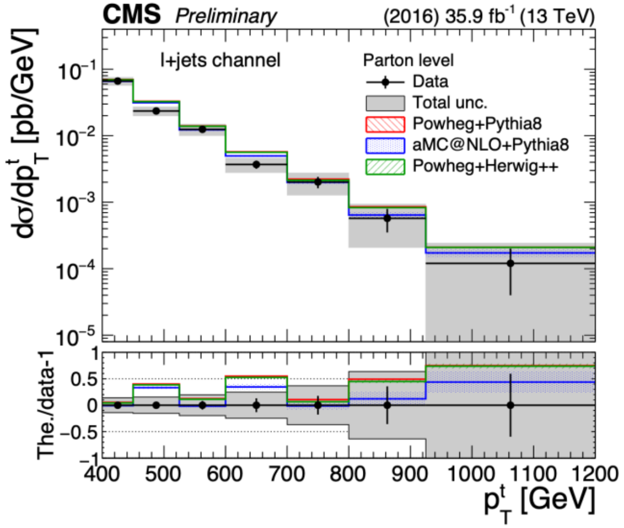
Hadronic channel

l+ jets channel





Absolute



Results

Results using unfolding with simple matrix inversion without regularization for both channels

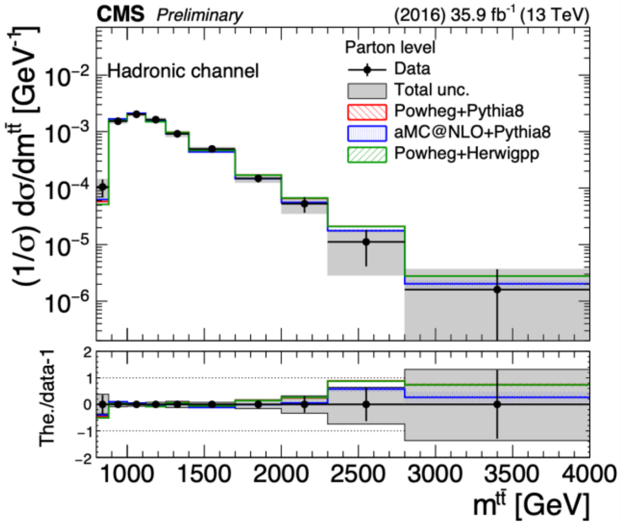
Hadronic:

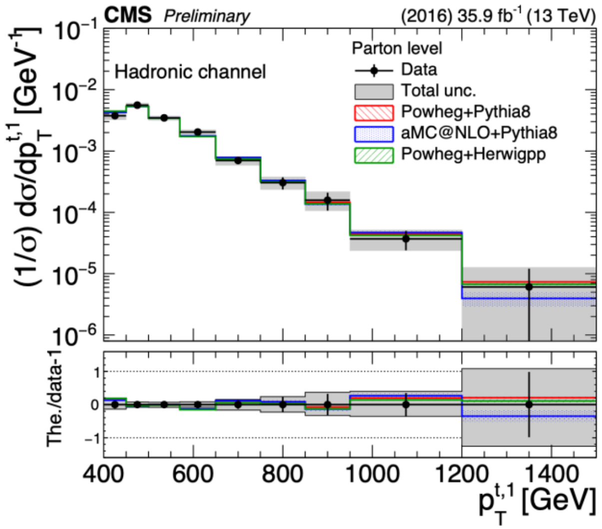
- Shapes overall compatible with theory
- Overall shift of 35% in the total cross section

l + jets:

- Differential distributions generally well described
- All models over predict the absolute cross section

More data is needed in order to enhance the statistical significance and investigate the severity of this discrepancy.





Normalized