Karlsruhe Institute of Technology

Single top in CMS

Results · new developments · modelling aspects

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Top Quarks Physics Day at TU Munich, August 11, 2014

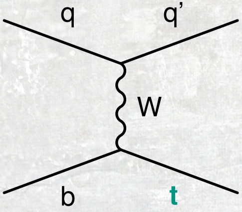
Content

1. Single top – experimental results in t, s and tW
2. The Higgs in Single top
3. Modelling aspects of t-channel

Guideline

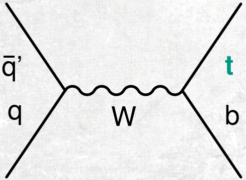
1. Single top – experimental results in t, s and tW
2. The Higgs in Single top
3. Modelling aspects of t-channel

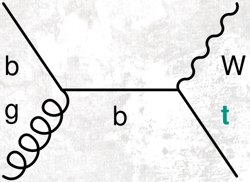
Production mechanisms



t-channel

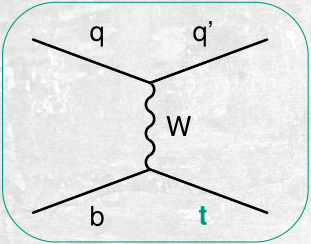
s-channel





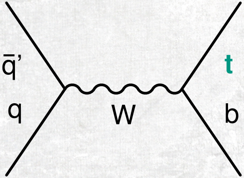
tW-channel

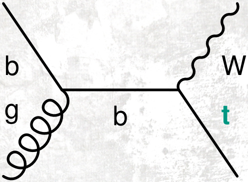
Production mechanisms



t-channel

s-channel

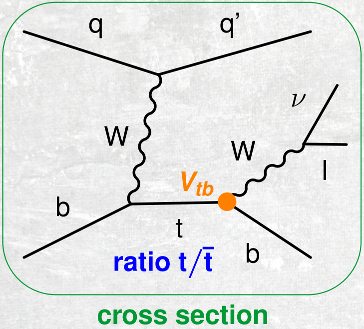




tW-channel

Single top *t*-channel topology

t-channel has largest cross section of all production modes



Experimental signature:

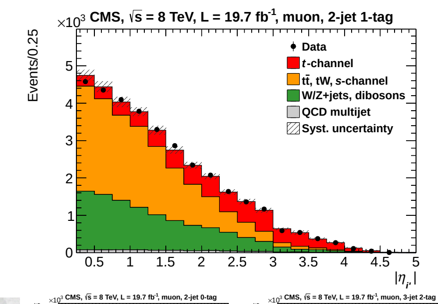
- light quark jet with large $|\eta_{j'}|$
- isolated lepton (*e* or μ)
- missing transverse energy
- central high-p_T b-jet
- (extra b-jet, broad $|\eta|$, low-p_T)

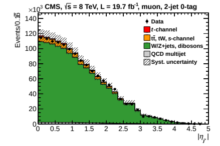
Main backgrounds:

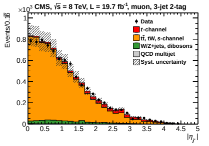
- W+jets, top pairs, QCD multi-jets

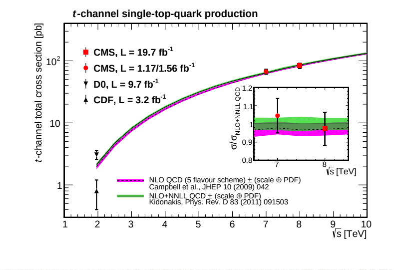
t-channel: results at 8 TeV JHEP 06 (2014) 090

- Template analysis in $|\eta_{j'}|$
- Fit to $|\eta_{j'}|$ shape in signal enriched region ($130 < m_{\text{top}} < 220\,\text{GeV}$)
- Shape of W+jets and $t\bar{t}$ derived from data in sidebands









Measured 8 TeV cross section:

$$\sigma_{t\text{-ch.}} = 83.6 \pm 2.3\,(\text{stat.}) \pm 7.4\,(\text{syst.})\,\text{pb}$$

Theory says*: $83.9^{+0.8}_{-0.3}$ pb

Extraction of $|V_{tb}| = \sqrt{\sigma_{t\text{-ch.}}/\sigma^{\text{theo}}_{t\text{-ch.}}}$
(assuming $\mathcal{B}(t \to bW) = 1$)

$$V_{tb} = 0.979 \pm 0.045\,(\text{exp.}) \pm 0.016\,(\text{theo.})$$

Combination of **8 and 7 TeV** data gives:

$$V_{tb} = 0.998 \pm 0.038\,(\text{exp.}) \pm 0.016\,(\text{theo.})$$

* NNLO QCD, arXiv:1404.7116, Brucherseifer, Caola, Melnikov

t-channel: R-ratios JHEP 06 (2014) 090

Fit to $|\eta_{j'}|$ by lepton charge reveals asymmetry in t/$\bar{\text{t}}$ production due to different u- and d-quark-PDFs:

$$\sigma_{\text{top}} = 53.8 \pm 1.5\,(\text{stat.}) \pm 4.4\,(\text{syst.})\,\text{pb}$$

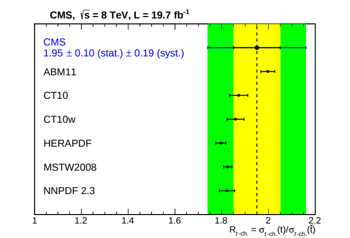
$$\sigma_{\text{anti-top}} = 27.6 \pm 1.3\,(\text{stat.}) \pm 3.7\,(\text{syst.})\,\text{pb}$$

Cross section **ratios**:

$$R_{8/7} \equiv \sigma_{8\,\text{TeV}}/\sigma_{7\,\text{TeV}} = 1.14 \pm 0.08\,(\text{stat.}) \pm 0.12\,(\text{syst.})$$

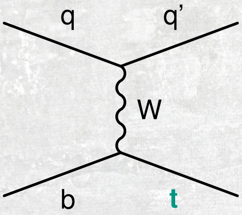
$$R_{t\text{-chan.}} \equiv \sigma_{\text{top}}/\sigma_{\text{anti-top}} = 1.95 \pm 0.10\,(\text{stat.}) \pm 0.19\,(\text{syst.})$$

Comparing with predictions of **different PDF sets**:



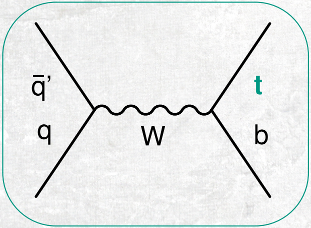
Main uncertainties: PDF and signal modelling ($\sim 6\%$)

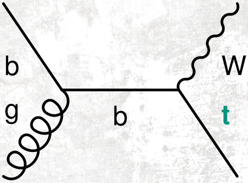
Production mechanisms



t-channel

s-channel

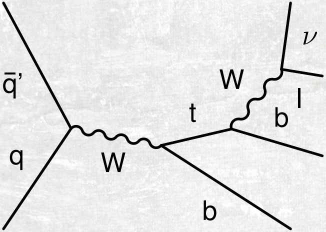




tW-channel

Single top *s*-channel topology

s-channel has smallest cross section of all production modes at LHC



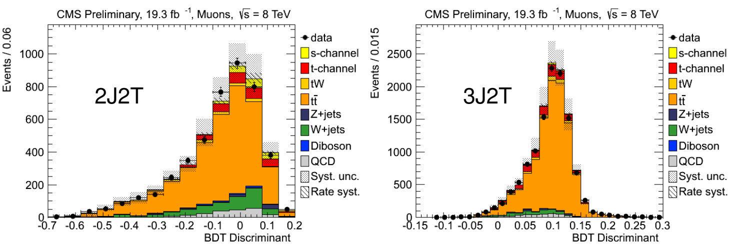
Experimental signature:

- isolated, high-p_T lepton (e or μ)
- missing transverse energy
- central high-p_T b-jet
- second b-jet, recoiling against top

Main backgrounds:

- W+jets, top pairs, QCD multi-jets

Single top *s*: results at 8 TeV CMS TOP PAS-13-009



Analysis strategy:

- Data-driven QCD template
- maximum-likelihood fit to BDT distribution to extract signal (in both signal and control region)

Measured **cross section**:

$\sigma_{s\text{-chan.}} = 6.2 \pm 5.4\,(\text{exp.}) \pm 5.9\,(\text{theo.})$ pb   Theory says*: 5.55 ± 0.08 (scale) $\pm$ 0.21 (PDF) pb

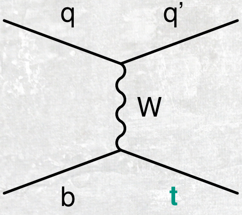
Upper limit on cross-section (95% C.L.):

$\sigma_{s\text{-chan.}} < 11.5$ pb at 95% C.L.

Main uncertainties: $t\bar{t}$ ren. and fact. scales ($\sim$ 80%) $\rightarrow$ can be improved with NLO generators; jet energy scale ($\sim$ 50%)

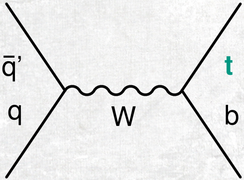
* approx. NNLO Phys. Rev. D 81, 054028 (2010), N. Kidonakis

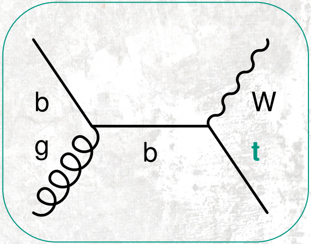
Production mechanisms



t-channel

s-channel

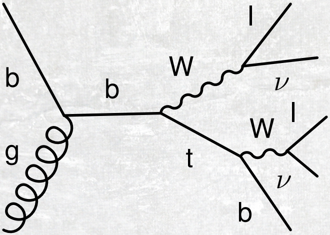




tW-channel

Single top *tW*-channel topology

tW-channel accessible at LHC for the first time!



Experimental signature:

- dilepton topology: two isolated leptons (ee, $\mu\mu$ or $e\mu$)
- missing transverse energy
- one b-jet from top decay

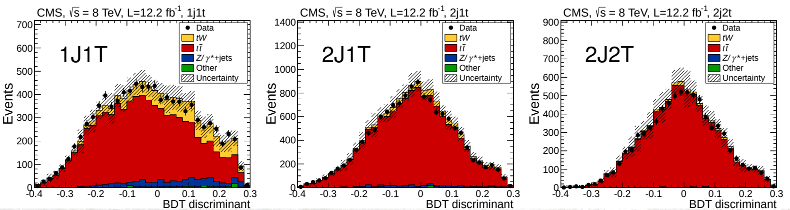
Main backgrounds:

- top pairs, Z+jets

N.B.: DR scheme is used for the analysis; any differences w.r.t. to DS scheme included in syst. unc.'s

tW-channel: results at 8 TeV PRL 112 (2014) 231802

First observation of tW production!



- Handle of background: get normalization for Z+jets in control region with inverting mass veto on m_{ll}; using variables discriminating against top pairs in BDT
- Signal extraction by fit to BDT discriminant in signal and control regions

Expected significance $5.4 \pm 1.4\sigma$, **observed significance** 6.1

Measured **cross section**:

$\sigma_{tW\text{-chan.}} = 23.4 \pm 5.4$ pb Theory says*: 22.2 ± 0.6 (scale) ± 1.4 (PDF) pb

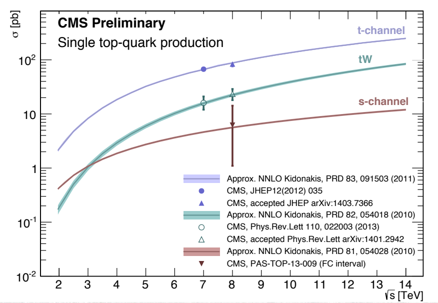
V_{tb} estimate:

$V_{tb} = 1.03 \pm 0.12\,(\text{exp.}) \pm 0.04\,(\text{theo.})$

Main uncertainties: ME/PS matching threshold ($\sim 14\%$), ren. and fact. scales ($\sim 12\%$); top mass ($\sim 9\%$)

* approx. NNLO, arXiv:1205.3453, N. Kidonakis

Measurements summary and plans



- Observation and measurement of *t*- and *tW*-chan.
- Upper limit on *s*-chan.
- Charge asymmetry in t/t̄ production

- Differential, fiducial measurements
- Reduce syst. uncertainties by moving to NLO tt̄ generators; combine 7+8 TeV data
- Constrain PDF models

Guideline

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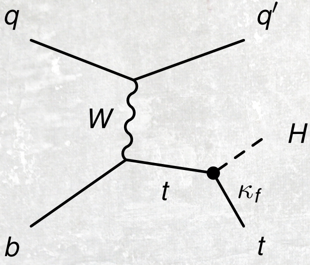
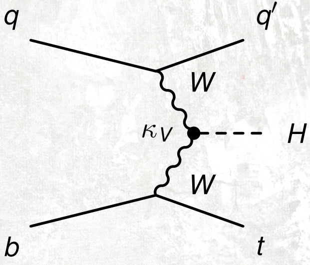
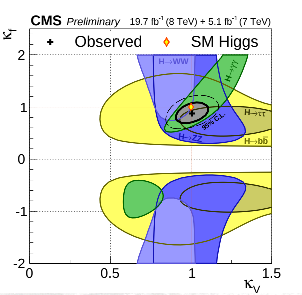
Introduction to tHq



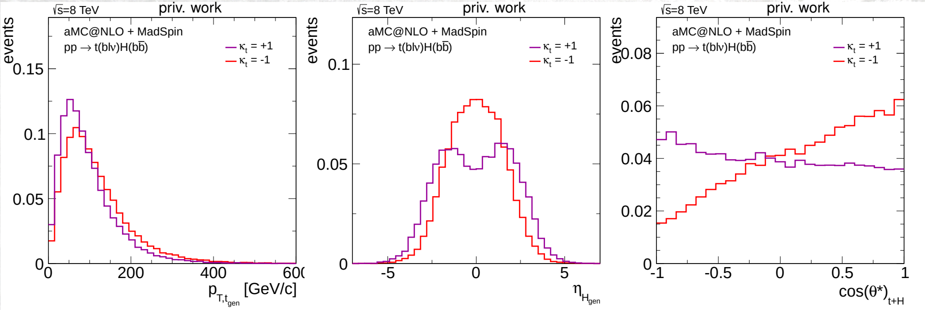


- Destructive interference for SM case because of $\mathcal{A} \propto (\kappa_V - \kappa_f) \rightarrow \sigma = 18.3\,\text{fb}$
- For the BSM case of $\kappa_f = -1$: enhanced cross section $\rightarrow \sigma = 233.8\,\text{fb}$
- Farina et al. show in `arXiv:1211.3736` that $\kappa_f = -1$ can be constrained with pp $\rightarrow$ tHq. Looking for H $\rightarrow$ b$\bar{\text{b}}$ and $\kappa_f = -1$!



Generator studies: different models

- What is actually different for the two cases of different coupling signs?
- Well, the cross section. But also in terms of distributions? ...
- Comparing SM case $\kappa_t = +1$ to anomalous coupling $\kappa_t = -1$ (generated with aMC@NLO)



Analysis strategy

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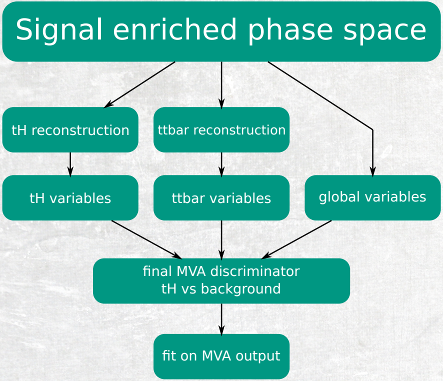
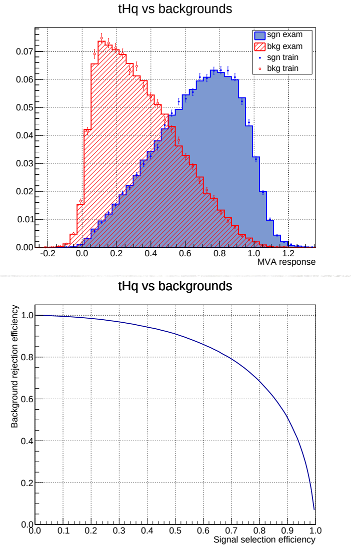
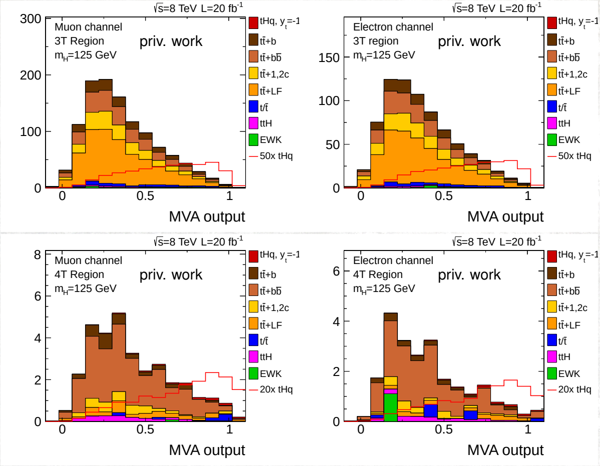




Signal enriched phase space:

- one isolated lepton (e,μ)
- 3 or 4 b-tagged jets
- $\geq$ 4 or $\geq$ 5 jets in total

Signal extraction



Simultaneous fit to MVA discriminator distribution in 3T and 4T regions

Expected upper limit of $\sim 5 \times \sigma_{y_t=-1}$. Combination with H $\rightarrow \tau\tau$, H $\rightarrow \gamma\gamma$, H $\rightarrow$ WW to narrow down window of $y_t = -1$ scenario

Main systematics: ren./fact. scales, $t\bar{t}$ +heavy flavor content

Guideline

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QCD description – leading order diagrams

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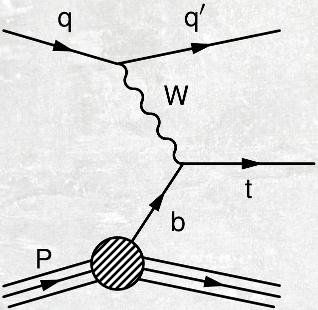
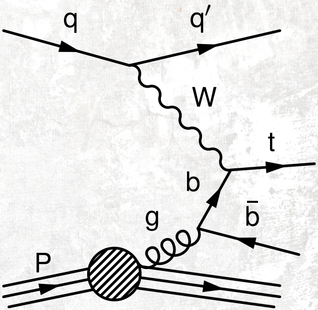
Five-flavor scheme ($2 \rightarrow 2$)



- b quark inside proton ($m_b = 0$) with dedicated b-PDF
- add. b jet comes from backwards-evolution in parton shower ($\sim$ LO accuracy)

Four-flavor scheme ($2 \rightarrow 3$)

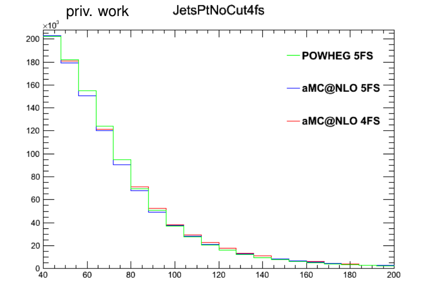


- $gb\bar{b}$ vertex already present in matrix element
- gives NLO accuracy in description of add. b quark

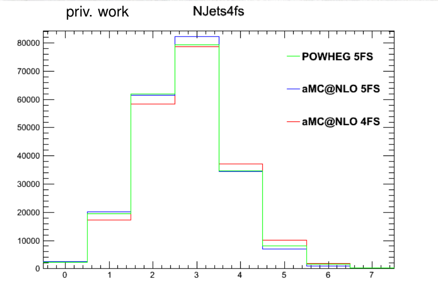
Current status

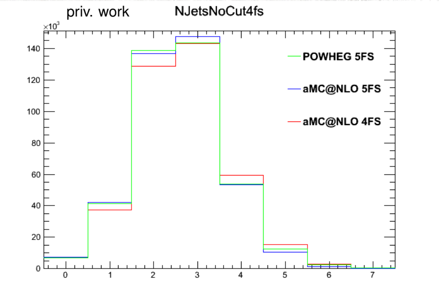
- Until now, CMS was/is using Powheg $2 \rightarrow 2$ for the single-top t-channel.
- We'll be stuying also event generation in the 4FS with aMC@NLO
  - NLO evolution of MadGraph5 $\rightarrow$ vast array of processes possible!
  - complete automation of NLO QCD correction calculations
  - makes use of new LHE_v2 format

4FS vs. 5FS



- Comparing 5FS Powheg sample to 4/5FS aMC@NLO (hadr. w/Pythia8)
- Good agreement between 5FSs
- As expected, FS differences for NJet





LO vs. NLO

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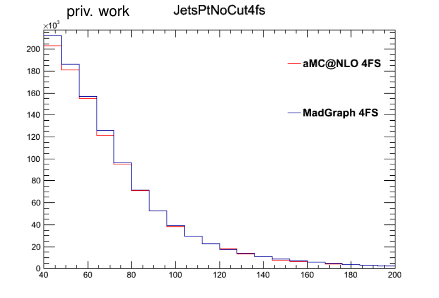
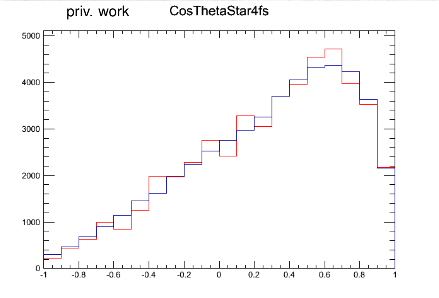
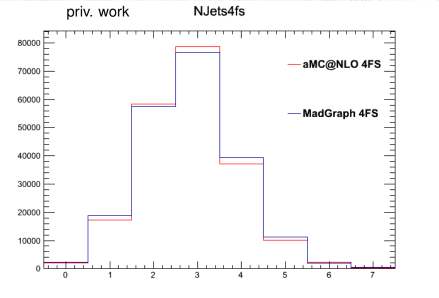


- Comparing MadGraph5 LO to aMC@NLO NLO sample (hadr. w/Pythia8)
- Good agreement between LO/NLO





LHE_v2 weights in single-top

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Studying scale variations in new format of LHE files with single-top *t*-chan. (aMC@NLO)

- Produce 400k events with $\mu = 4\sqrt{p_\mathrm{T}^2(b) + m^2(b)}$, 4FS, CT10f4
  - Access nominal event weight as well as the weight information for $\mu_\mathrm{F} = \mu_\mathrm{R} = 0.5\mu$ and 2μ

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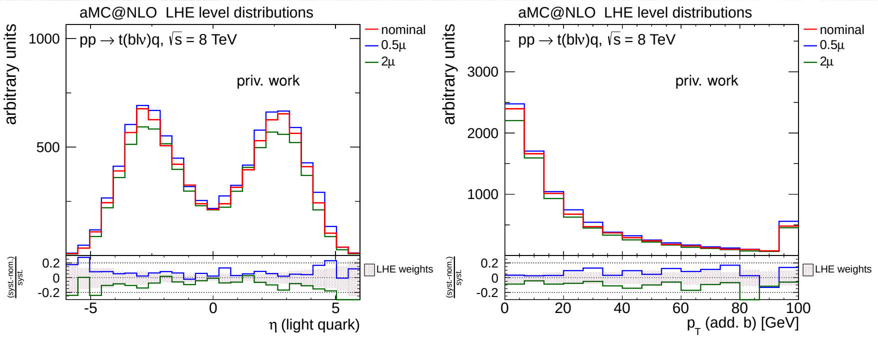
- Compare the distributions with samples which have the 0.5μ and 2μ as their nominal scale

LHE level distributions



Summary

· Measurements in single top field are in good agreement with (approx.) NNLO calculations; established t-channel, observed tW-channel, constrained s-channel

· High luminosities and large amounts of data bring new, interesting searches within reach (single top +Higgs)

· Single top (in particular t-channel) is a perfect playground for studies with new NLO MC generators

· Deliberate choices need to be made for modelling of t-channel and its uncertainties → currently big effort in studying and exploiting new tools & features