

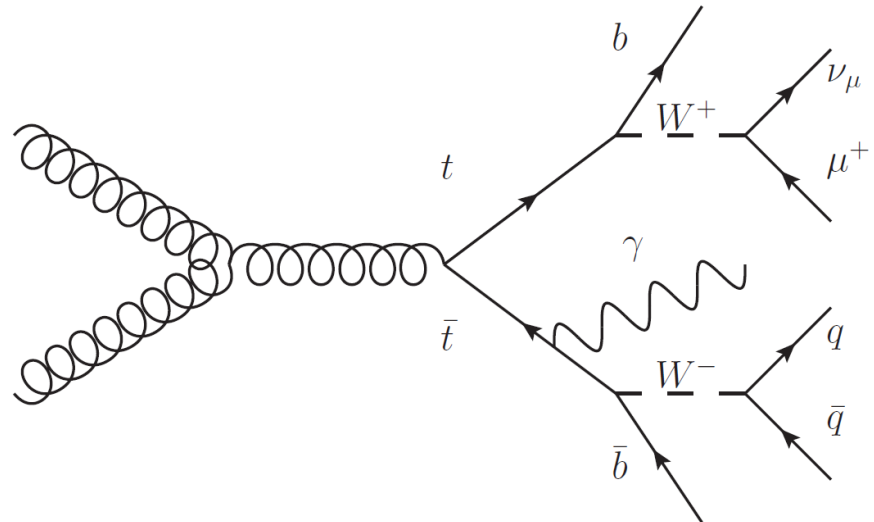
Probing the top-quark photon vertex with the CMS detector

DPG-Wuppertal
T21.2

09.03.2015

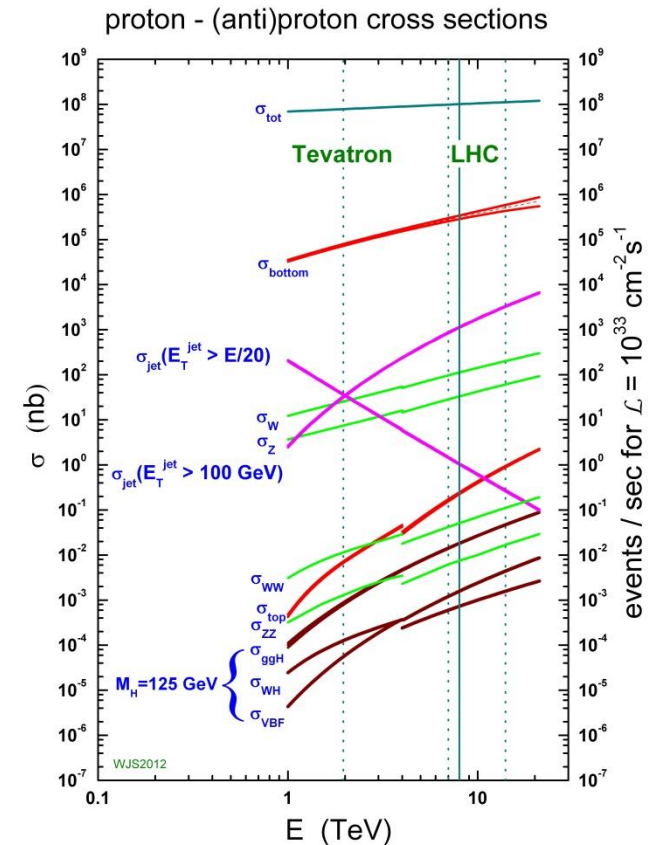
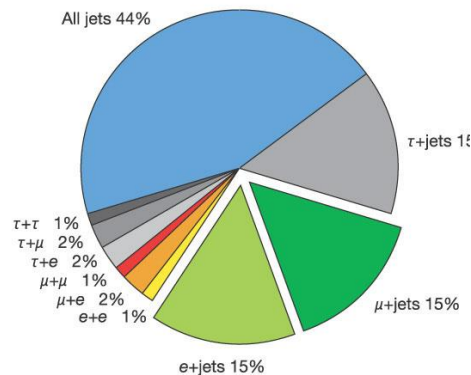
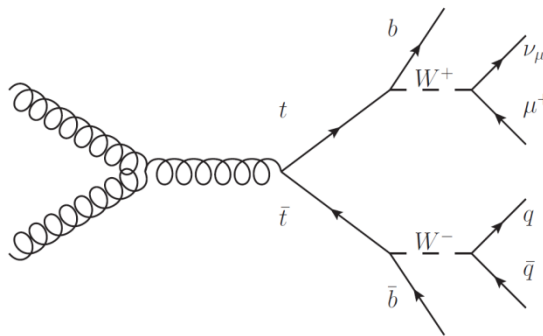
Till Arndt

DESY Hamburg



The Top Quark

- $m_t = 173 \pm 1 \text{ GeV}$
 - Short lifetime, no hadronization
 - Direct measurement of coupling
- $\sigma_{t\bar{t}, 8\text{TeV}}^{CMS} = 227 \pm 15 \text{ pb}$ CMS-PAS-TOP-12-007
 - About 4.5 million events (2012)
 - LHC: gluon-gluon fusion ($\sim 80 \%$)
- This analysis: $\mu + \text{jets}$



The Top-Photon Vertex

- $\mathcal{L}_{t\bar{t}\gamma} = -eQ_t\bar{t}\gamma^\mu t A_\mu - e\bar{t}\frac{i\sigma^{\mu\nu}}{m_t}(d_V^\gamma + id_A^\gamma\gamma_5)tA_\mu$

- First term: SM

- Second term: Loop corrections

- Cross section CMS-PAS-TOP-13-011

- $\sigma_{t\bar{t}\gamma}^{CMS} = 2.4 \pm 0.2(\text{stat.}) \pm 0.6(\text{syst.}) \text{ pb}$

- Fiducial phase space:

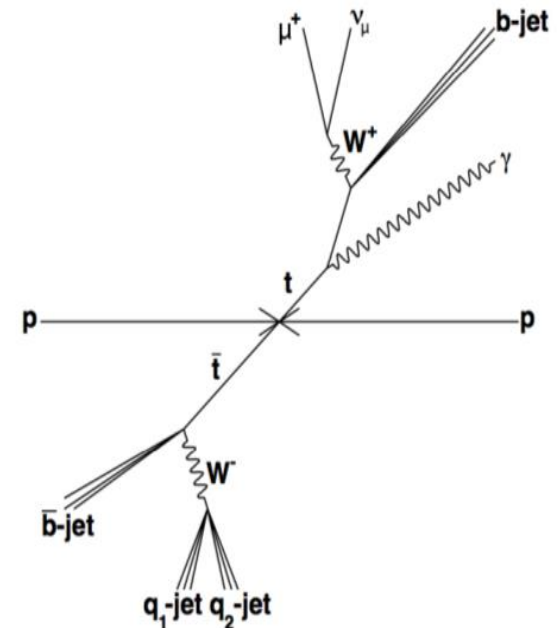
- $P_T(\gamma) > 20 \text{ GeV}, \Delta R(\gamma, b) > 0.1$

- This analysis:

- Improve cross section

- » Data-driven template fit

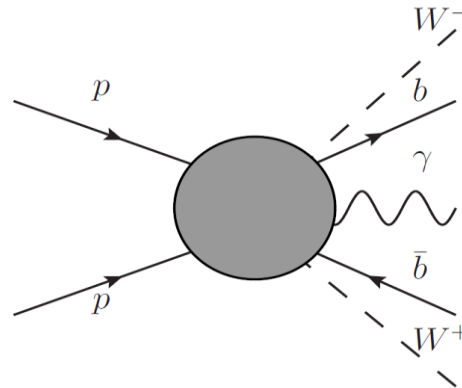
- » New simulation strategy



Cross Section Measurement

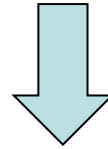
- 2012 data:
 - $\mathcal{L}_{int} = 19.7 \text{ fb}^{-1}$
 - $\sqrt{s} = 8 \text{ TeV}$

- Simulation: $2 \rightarrow 5$
 - WHIZARD

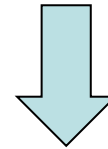


- Photon fakes
 - Mainly pions and jets
- Ratio: Reduced Systematics

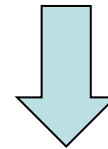
Preselection:
Semi-muonic $t\bar{t}$



Selection:
Prompt Photon



Template Fit



Result: $R = \frac{\sigma_{t\bar{t}\gamma}}{\sigma_{t\bar{t}}}$

■ Preselection: Semi-muonic top-pair events

- Exactly one muon
- Four high energetic jets
- No electron

» Events: $N^{presel} = 256,665$

» Purity: $\pi_{t\bar{t}} = 84.3\%$

■ Selection: One prompt photon candidate

- At least one high energetic photon
- Contained shower
- Isolated against neutral hadrons and photons

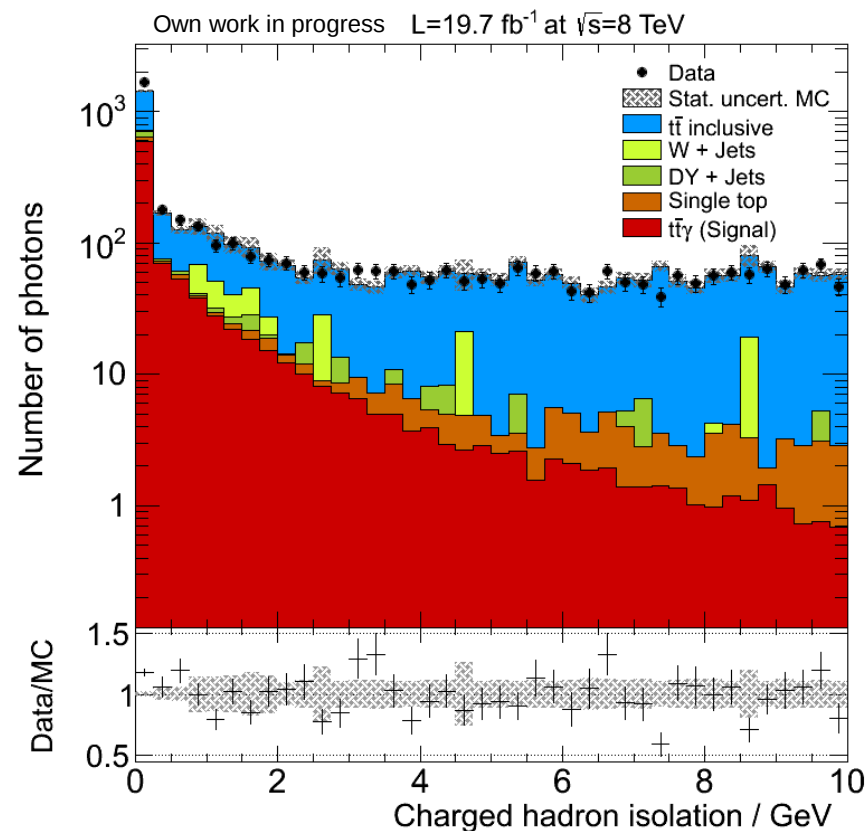
» Events: $N^{sel} = 7836$

» Purity: $\pi_{t\bar{t}\gamma} = 66.7\%$

» Efficiency : $\epsilon_{\gamma} = 62.9\%$

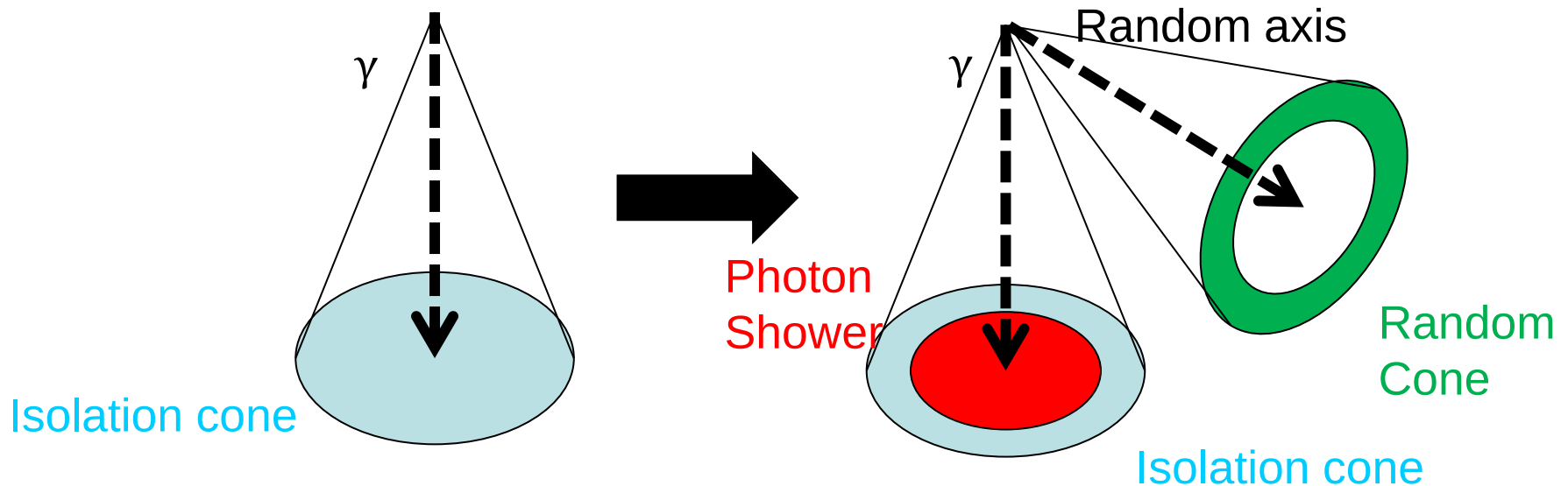
The Template Fit

- Discriminating variable:
 - Charged hadron isolation
 - » Good against jets
- Two Templates for real and fake photons
 - Signal: Next slide
 - Fake: Combined Sideband
 - » Both data-driven
- Closure Test for validation
 - Different pile-up simulations
 - » Up to 300 ns OOT PU



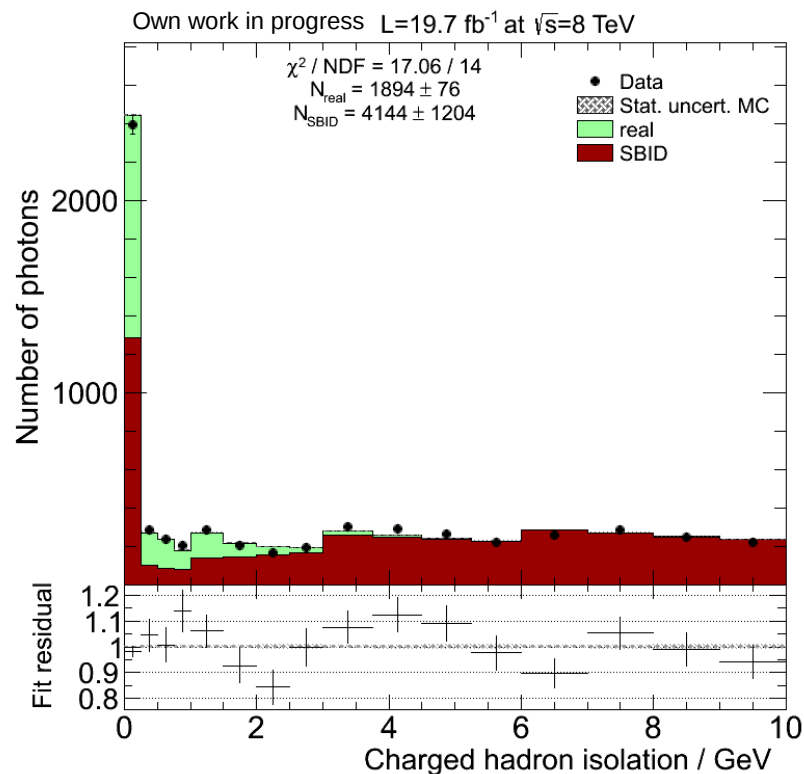
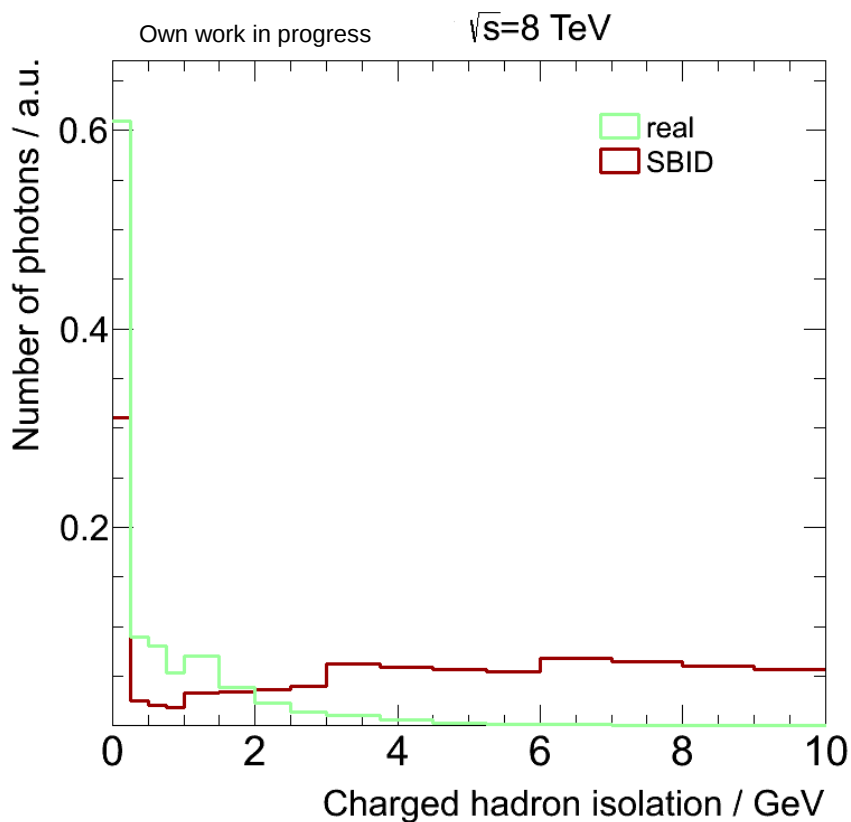
Signal Template: Random-Cone Isolation

JHEP, 1201, 133



- New random axis around existing photon
- Check isolation of new axis
- Remove impact of original photon from new axis
- Calculate charged hadron isolation around new axis
- Possible in data and simulation

The Real Photon Content



- Signal, background template provide separation
- Result : $N_{\text{real}} = 1894 \pm 76$

■ R-ratio:

$$R \equiv \frac{\sigma_{t\bar{t}\gamma}}{\sigma_{t\bar{t}}} = \frac{N_{t\bar{t}\gamma}^{sig}}{\epsilon_{\gamma}^{vis} \epsilon_{\gamma} N^{presel} \pi_{t\bar{t}}}$$

■ Result for R:

$$R^{vis} = (0.93 \pm 0.04_{stat} \pm 0.17_{sys}) \times 10^{-2}$$

■ Result, this analysis:

$$\sigma_{t\bar{t}\gamma} = 2.6 \pm 0.1_{stat} \pm 0.5_{sys} \text{ pb}$$

■ Theory M. Schulze, private communication

$$\sigma_{t\bar{t}\gamma} = 1.8 \pm 0.5 \text{ pb}$$

Source	Uncertainty (%)	
	R^{vis}	$\sigma_{t\bar{t}\gamma}$
Statistical	4.1	4.1
Systematic	18.2	19.4
Individual contributions:		
pileup	0.4	0.3
out-of-time pileup	8.2	8.2
σ_{sig}	9.0	9.0
σ_{bkg}	1.4	1.4
shower./hadr.	3.0	3.0
generator	13.0	13.0
top-quark p_T	0.5	0.3
b-tag	0.3	0.3
JEC	1.9	1.7
JER	0.3	0.4
Total	18.7	19.8

Conclusion and Outlook

■ Top pair + photon cross section

→ Improvement of previous CMS result

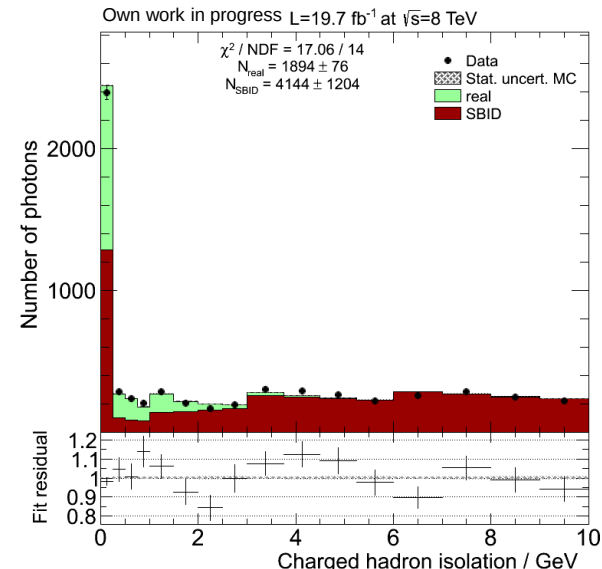
→ Systematically dominated

» New simulation strategy

» Data driven top pair yield

» New templates for OOT pile-up

→ Combination with other channels



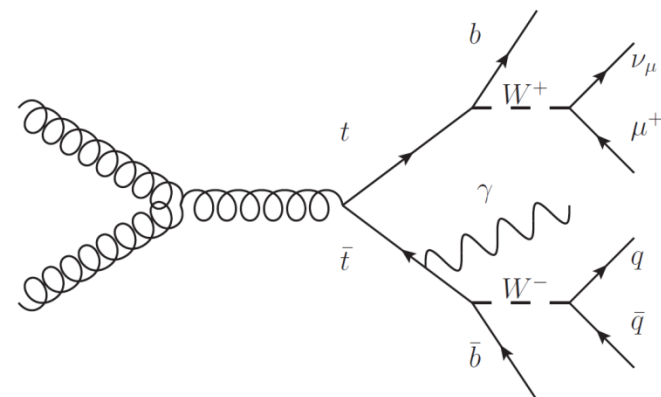
■ New factorized simulation strategy

→ $pp \rightarrow t\bar{t}\gamma, t \rightarrow bx, \bar{t} \rightarrow \bar{b}x$

$pp \rightarrow t\bar{t}, t \rightarrow bx\gamma, \bar{t} \rightarrow \bar{b}x$

$pp \rightarrow t\bar{t}, t \rightarrow bx, \bar{t} \rightarrow \bar{b}x\gamma$

→ Validated for WHIZARD and MADGRAPH



Thank You for the Attention

Backup

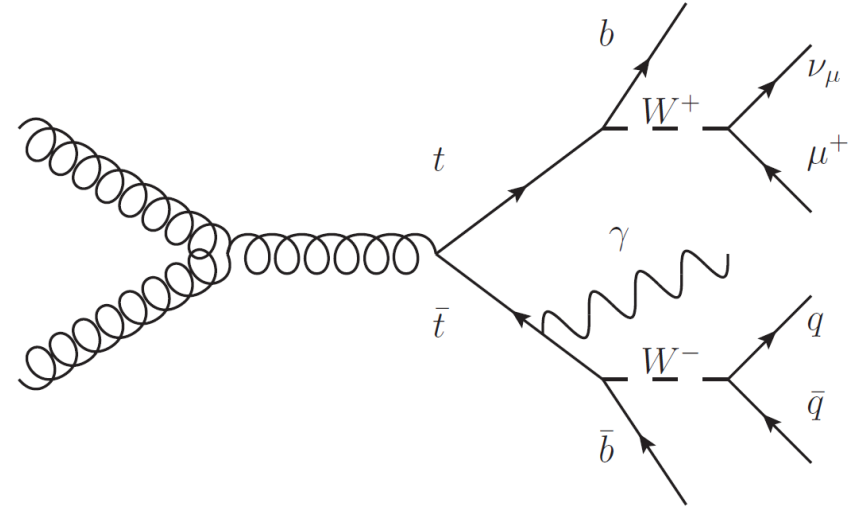
- $2 \rightarrow 7$, with factorization:

$$pp \rightarrow t\bar{t}\gamma, t \rightarrow bx, \bar{t} \rightarrow \bar{b}x$$

$$pp \rightarrow t\bar{t}, t \rightarrow bx\gamma, \bar{t} \rightarrow \bar{b}x$$

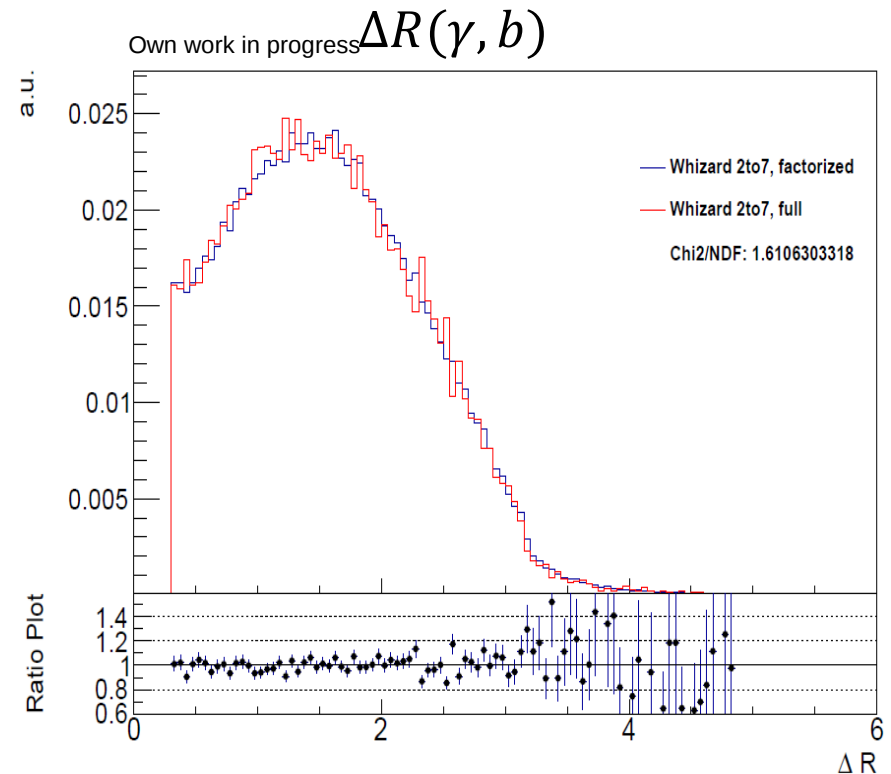
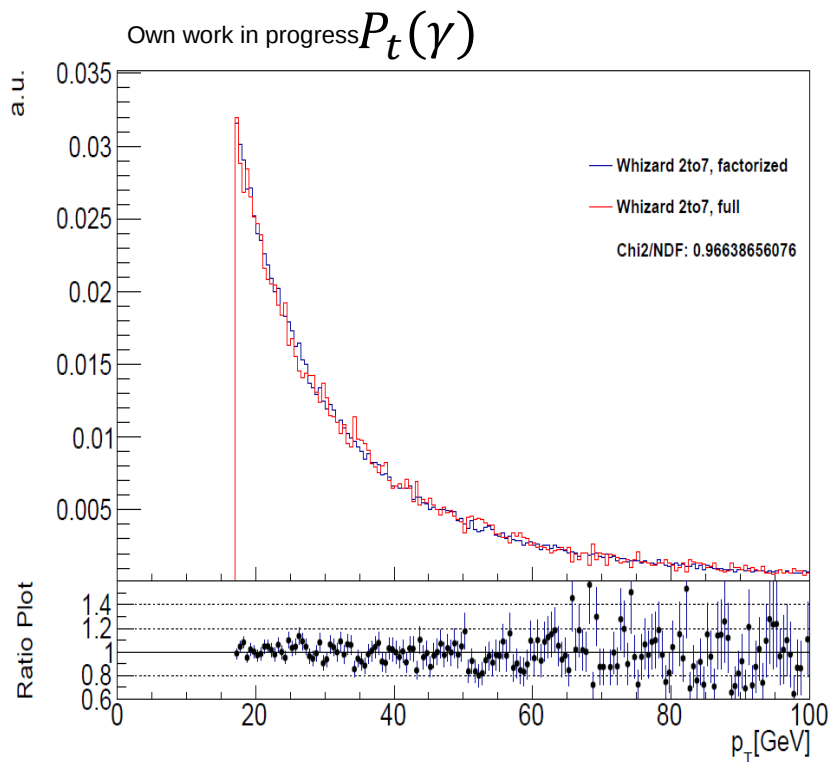
$$pp \rightarrow t\bar{t}, t \rightarrow bx, \bar{t} \rightarrow \bar{b}x\gamma$$

x : leptons or quarks



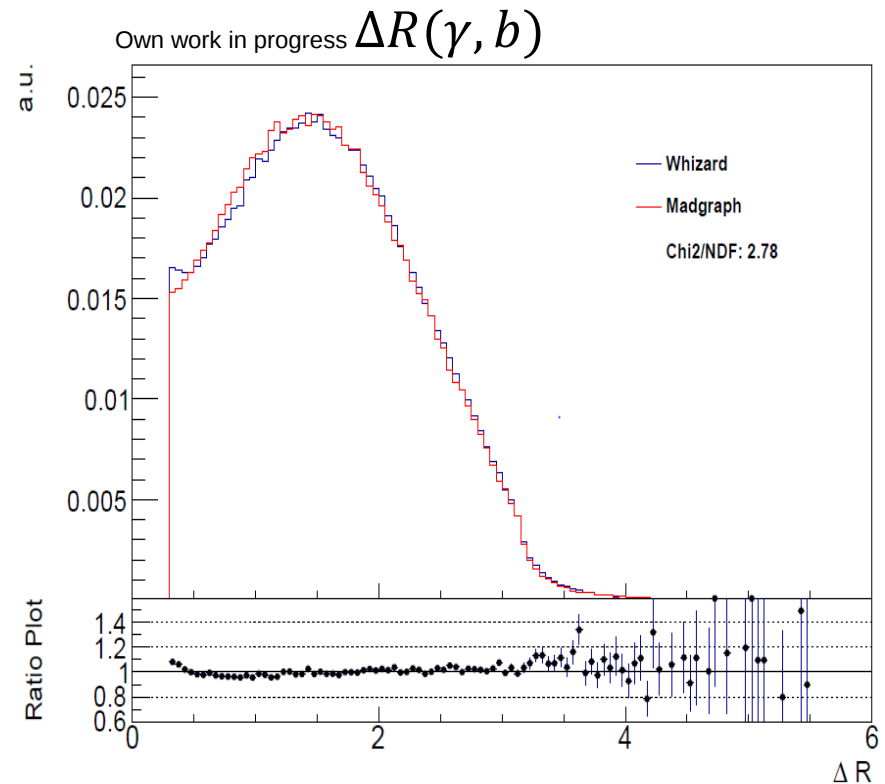
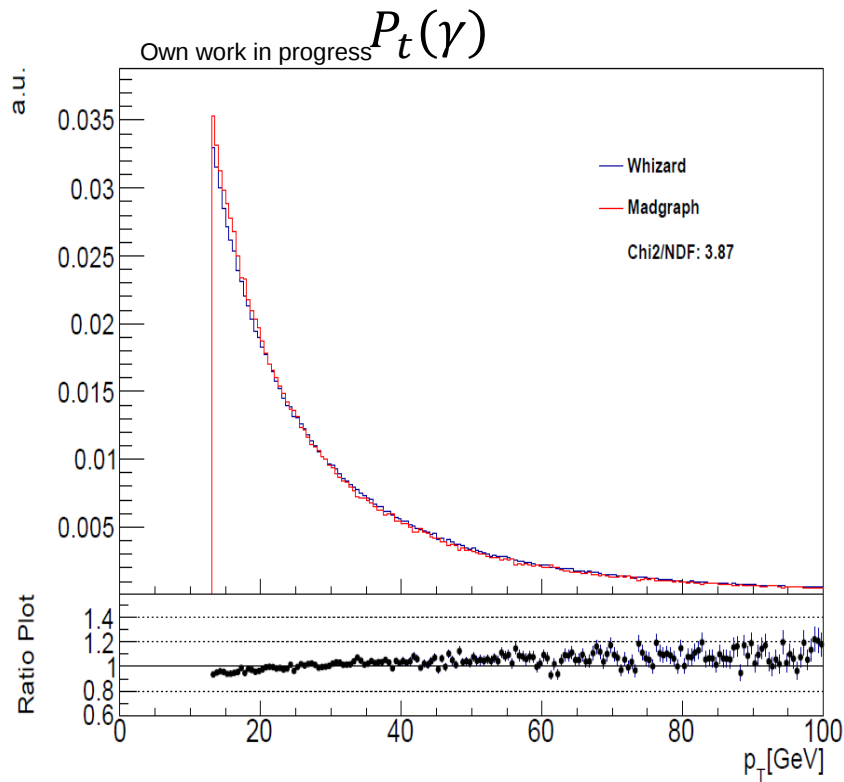
- Compromise between computation time and physics
- Final state particles close to the physics process
- Not all interferences included

Full vs. Factorized



- Full $2 \rightarrow 7$ simulation compared to factorized simu.
- Both samples simulated with WHIZARD generator
- Agreement for relevant phase space

WHIZARD vs. MADGRAPH



- LO generators, factorized simulation
- Agreement for relevant phase space
- Anomalous couplings investigated with WHIZARD

- Trigger: HLT_IsoMu24_2p1
 - $P_t > 24 \text{ GeV}$ $|\eta| < 2.1$
- Exactly one muon
 - $P_t > 26 \text{ GeV}$ $I_{rel}(0.4) < 0.12$
 - Veto: $P_t > 10 \text{ GeV}$ $|\eta| < 2.5$ $I_{rel}(0.4) < 0.20$
 - Electron veto: $P_t > 20 \text{ GeV}$ $|\eta| < 2.5$ $I_{rel}(0.3) < 0.15$
- Primary vertex
 - $\Delta z < 24 \text{ cm}$ $\Delta \rho < 2 \text{ cm}$
- Jets
 - $P_t > 55, 45, 35, 20 \text{ GeV}$ $|\eta| < 2.5$
- Btag
 - $CVSM > 0.679$

- Fiducialization

$$\rightarrow E_T(\gamma) > 25 \text{ GeV} \quad |\eta| < 1.4442 \quad \Delta R(\gamma, \mu \setminus j) > 0.7$$

- Electron veto

- $H/E: \frac{E_{HCAL}}{E_{ECAL}} < 5 \%$

- Shower shape

$$\rightarrow \sigma_{i\eta i\eta} < 0.012$$

- Neutral hadron isolation

$$\rightarrow I_{neu.had.} < 3.5 \text{ GeV} + 0.04 \cdot E_T(\gamma)$$

- Photon Isolation

$$\rightarrow I_{pho.} < 1.3 \text{ GeV} + 0.005 \cdot E_T(\gamma)$$