The XXII International Workshop
High Energy Physics and Quantum Field Theory

Single top quark production in heavy ion collisions at the LHC.

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Heavy ion collisions and top quark

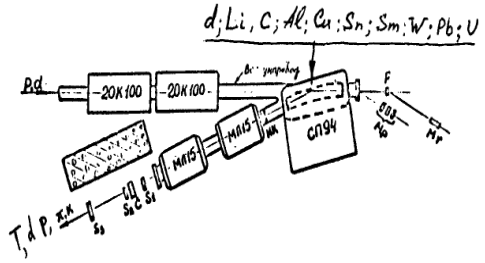
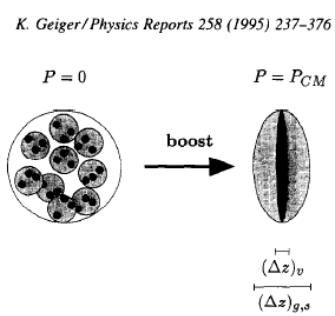
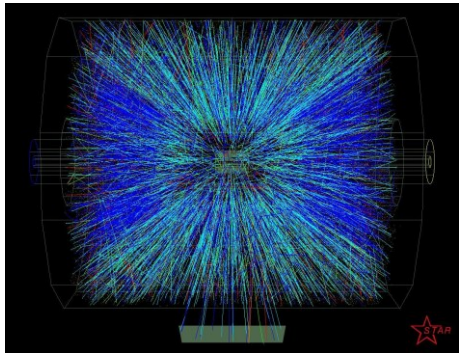
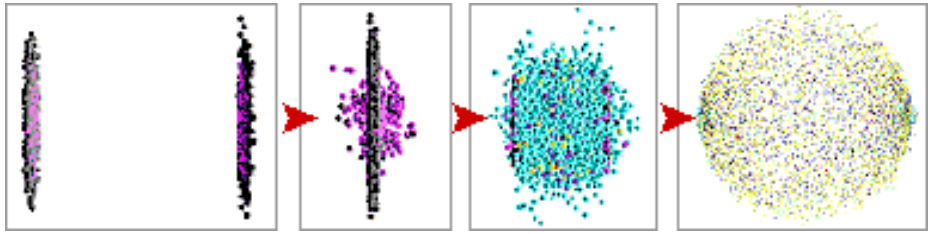


Fig. 2 Experimental layout

A.M. Baldin ,"Heavy Ion Interactions at High Energies", report at AIP Conf. Proc. 26, 621 (1975)







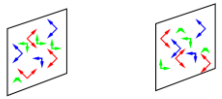
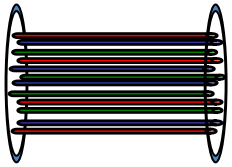
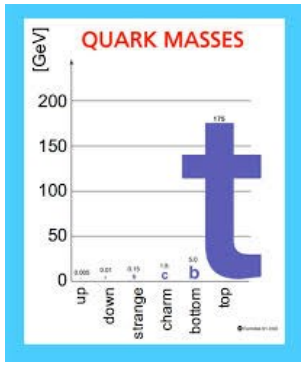


Fig. 16: The collision of two sheets of coloured glass

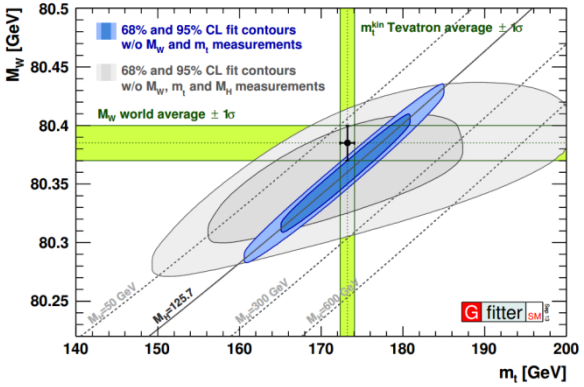


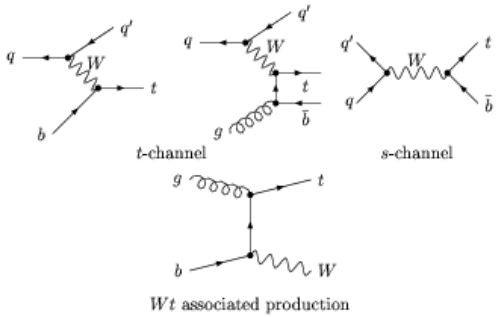


$172.2 \pm 0.1(stat.) \pm 0.7(syst.)\ GeV$ (CMS)

Higgs boson coupling 1

Life time $(10^{-25}\ s)$is less then hadronization time $(10^{-24}\ s)$





Heavy ion collisions and top quark
What is already done?

Smearing and decreasing mean and maximum values of invariant mass distributions of three jets from top quark decay (one b-jet and two jets from W-boson) and dijets from W-boson decay in PbPb collisions as compared with pp interactions are predicted for top anti-top pair production[*].

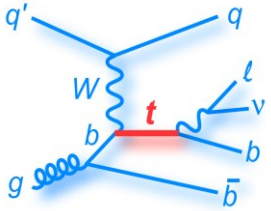
* L.Bhattacharya, K.Ghosh, K.Huitu, arXiv:1210.0116 [hep-ph], (2012).

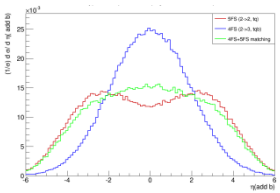
Single and pair top-quark production cross sections in p-Pb and Pb-Pb collisions at the energies of LHC and Future Circular Collider (FCC) have been estimated with next-to-leading-order perturbative QCD calculations including nuclear parton distribution functions[**].

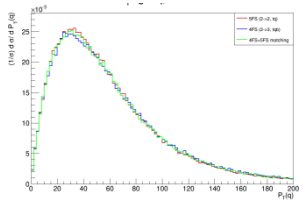
**D.d'Enterria, K.Krajczar, H.Paukkunen, Phys. Lett. B 746, 64 (2015).

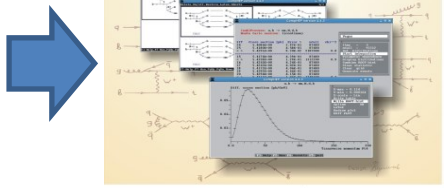
Monte Carlo modelling, General scheme

- **Signal events for single top quark production and decay –**
  CompHEP v4.5 + MCFM v6.8



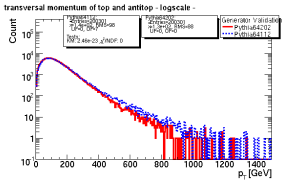


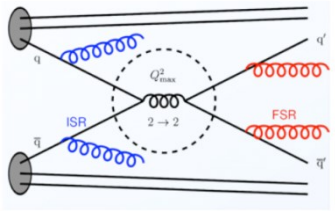




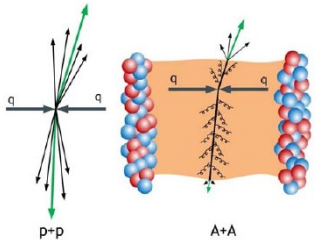
+ **MCFM**

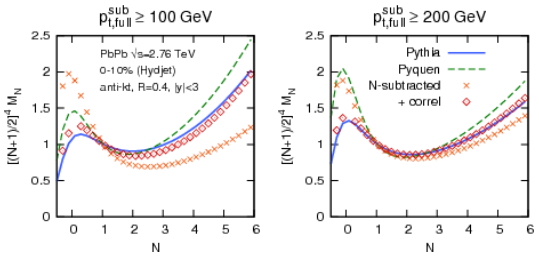
- **Hadronisation and fragmentation –**
  Pythia v6.4





- **Nuclear medium effects – PYQUEN v1.5**





PYQUEN

Monte Carlo modelling scenarios

General modelling

CompHEP v4.5 + MCFM v6.8
MSTW2008 NNLO PDF
MC event of single top quark production with lepton decay

	EPS09	PYQUEN
(1) pp	-	-
(2) PbPb	+	-
(3) PbPb + PYQUEN	+	+

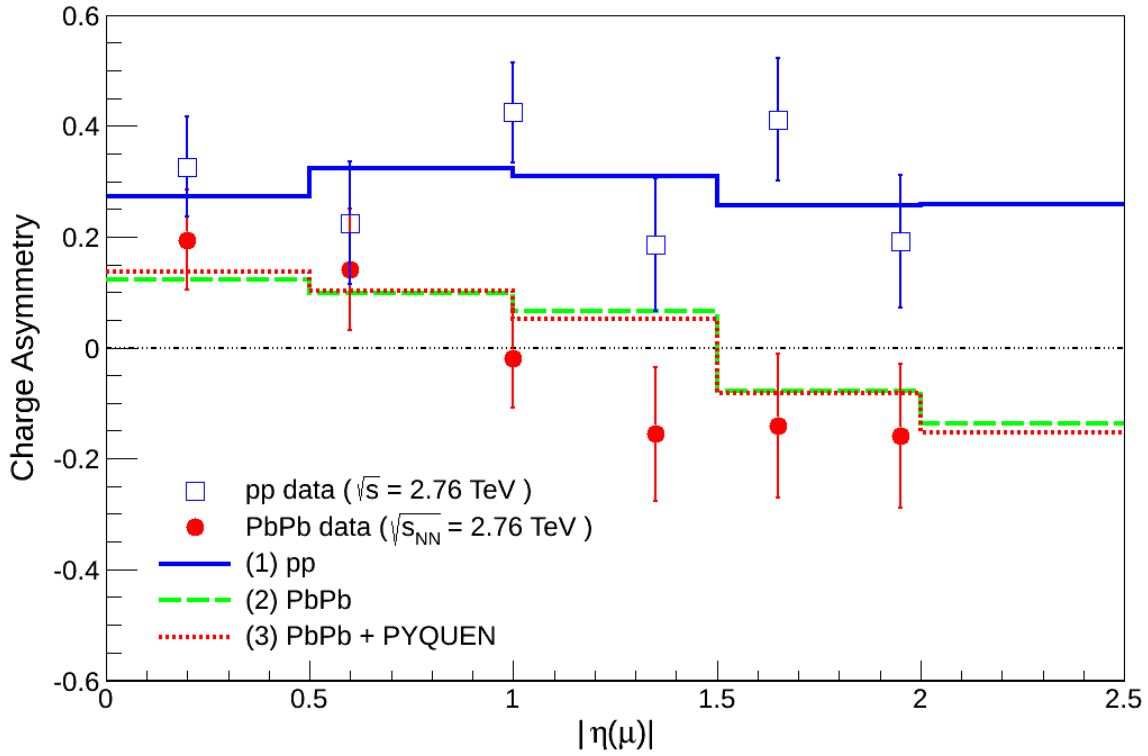
Well-studied process

Initial state effects

Final state effects

*** EPS 09 NLO – nuclear parton distribution functions (PDF)**

Test of the Monte Carlo modelling



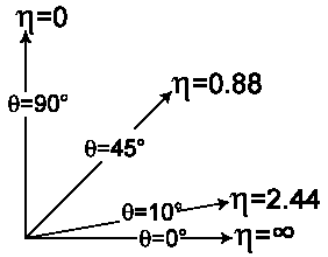
Agreement with experimental data on W-production cross section and rapidity dependence of W+,W- charge asymmetry
$(N_{W+} - N_{W-})/(N_{W+} + N_{W-})$
pp(blue open squares) and PbPb(red-filled circles)$\sqrt{s} = 2.76$ [*].

* S. Chatrchyan, et al. (CMS Collaboration), Phys. Lett. B 715, 66 (2012)

Modelling of the single top quark production

Realistic geometrical acceptance and kinematic cuts for CMS and ATLAS

Light quark jet	$\mid \eta \mid < 5$
b-quark jet	$\mid \eta \mid < 2.5$
Leptons (e, mu)	$\mid \eta \mid < 2.5$
Pseudorapidity	$\eta = -\ln[\tan(\theta/2)]$
Lepton transverse momentum	$p_{\mathrm{T}}^{\mathrm{l}} > 20\ \mathrm{GeV}/c$
Jet transverse momentum	$E_{\mathrm{T}}^{\mathrm{jet}} > 20\ \mathrm{GeV}$
Efficiency of kinematic acceptance	$\frac{N_{pass}}{N_{total}} \sim 65\%$
b-tagging efficiency	$\frac{\epsilon \times N_{1bjet} + (1-(1-\epsilon)^2) \times N_{2bjet}}{N_{1bjet} + N_{2bjet}} \sim 52\%$ $\epsilon = 0.5$
Total efficiency	$\sim 31 - 35\%$.



Results

Cross section and event rate estimation

Single top quark production cross section

$$\sigma_{PbPb} = \sigma_{pp} * Br(W \to l\nu_l) * TotalEff * A^2$$

$$\sigma_{pp} = 38.6pb$$

$$Br(W \to l\nu_l) = \frac{2}{9}$$

$$TotalEff \sim 35\%$$

$$\mathrm{A} = 208$$

$$\sigma_{PbPb} \sim 0.13\mu b$$

Event rate

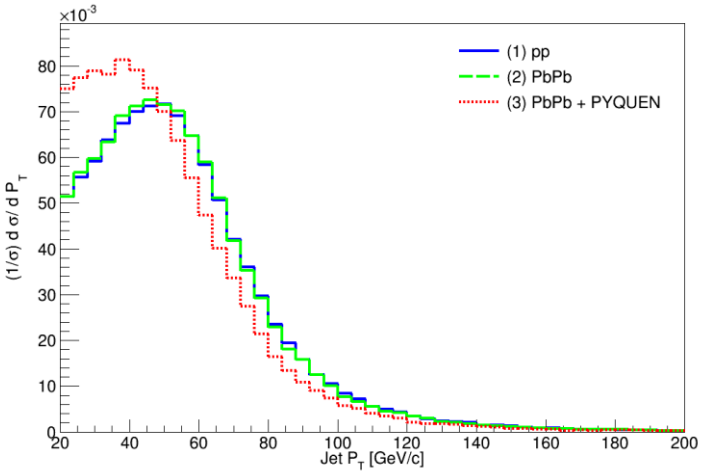
$$T = 10^6 \ \mathrm{s}$$

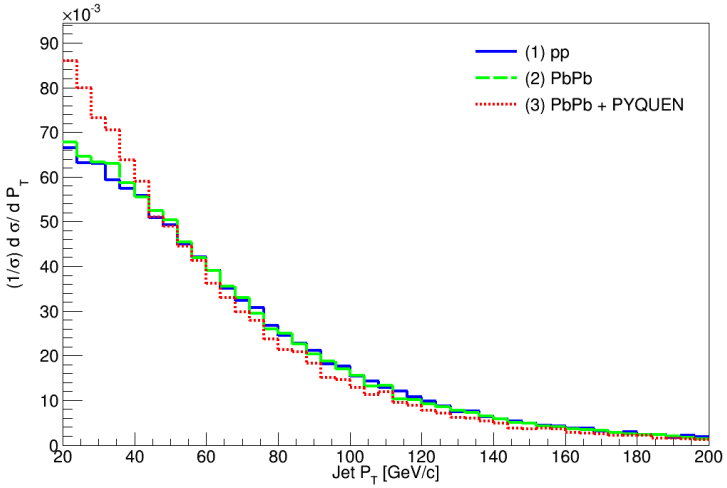
$$L = 10^{27} \ \mathrm{cm^{-2}s^{-1}}$$

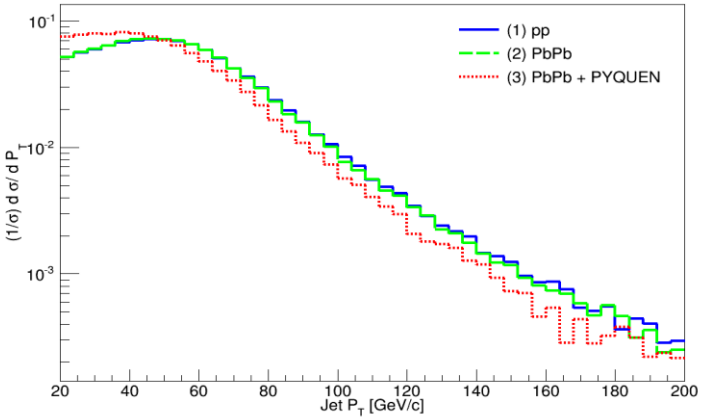
$$N_{\mathrm{ev}} = T\sigma_{\mathrm{PbPb}}L \sim 130 \iff 1\mathrm{nb}^{-1}$$

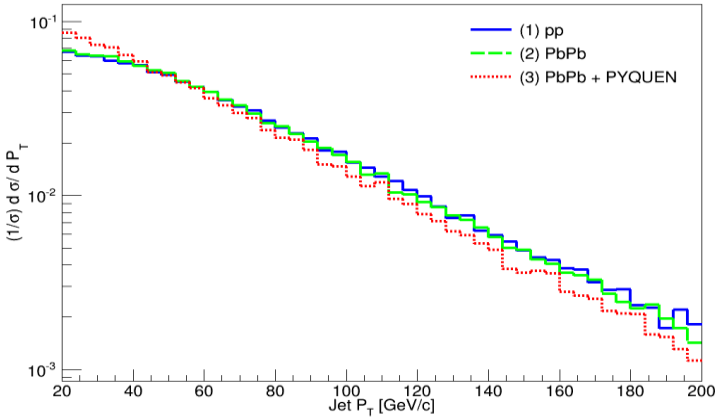
130 events rate in a one month PbPb run, up to 1300 events per month at HL-LHC?

Kinematic distributions.
pT distributions of b-jet and light quark jet



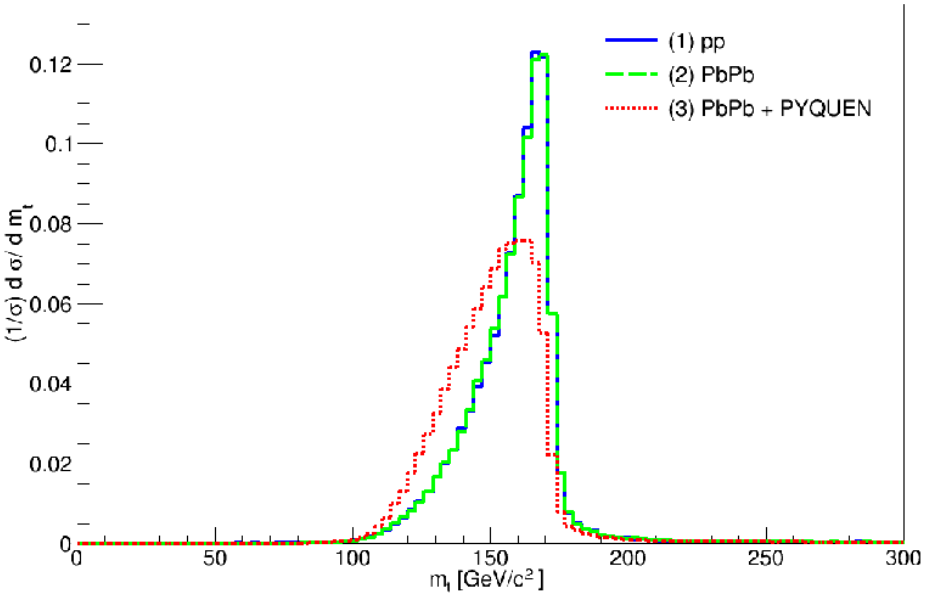






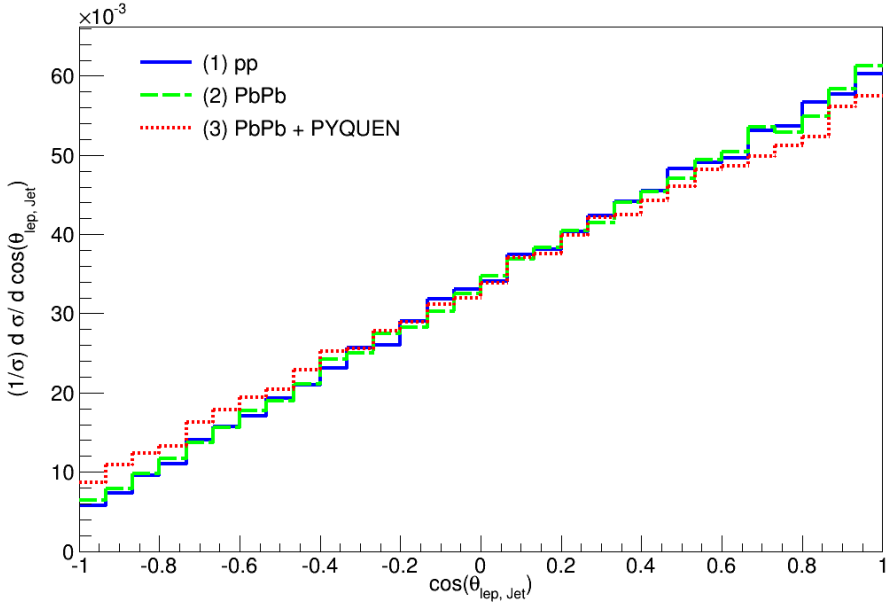
b-jet (left column) light quark jet (right column)
Linear scale (top row) logarithmic scale (bottom row)

Kinematic distributions.
Invariant top mass, cos(lep&light jet)

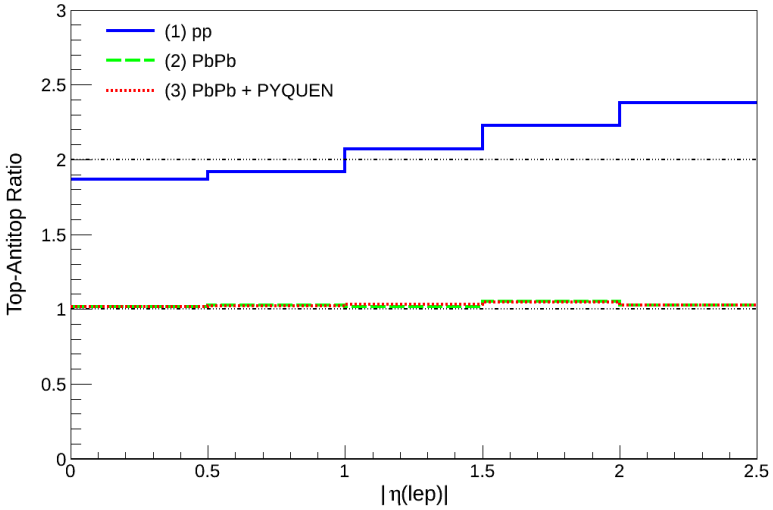


The invariant mass distributions of W-boson and b-jet from top quark decays

Cosine of angle between lepton from top decay and jet from light quark associated with the top in top quark rest frame.

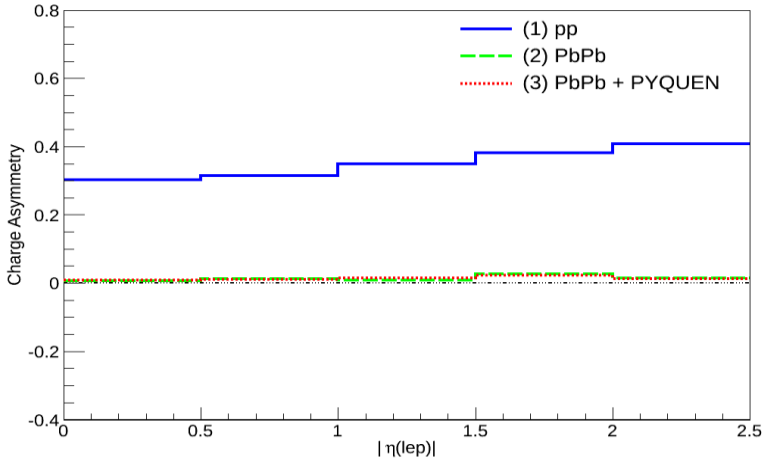


Top anti-top asymmetries



Top/anti-top ratio

$$\frac{N_t}{N_{\bar{t}}}$$



Charge asymmetry

$$\frac{(N_t - N_{\bar{t}})}{(N_t + N_{\bar{t}})}$$

Conclusions

- Single top quark production has a large enough cross section and visible event rate for the nominal LHC luminosities and is open to study in PbPb collisions.
- Smearing and decreasing mean and maximum values of the invariant mass distribution of W-boson and b-jet from top quark decays
- Significant softening the transverse momentum spectrum of jets associated with top quark and shifting its peak from the half mass of W-boson.
- Disappearance of charge asymmetry of single top quark production
- Cosine of angle taken in the top rest frame between the lepton from the top decay and the momentum of jet from light quark produced in association with the top is only slightly affected and may be used for separation single top signal from backgrounds in future

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Thank you for your attention!