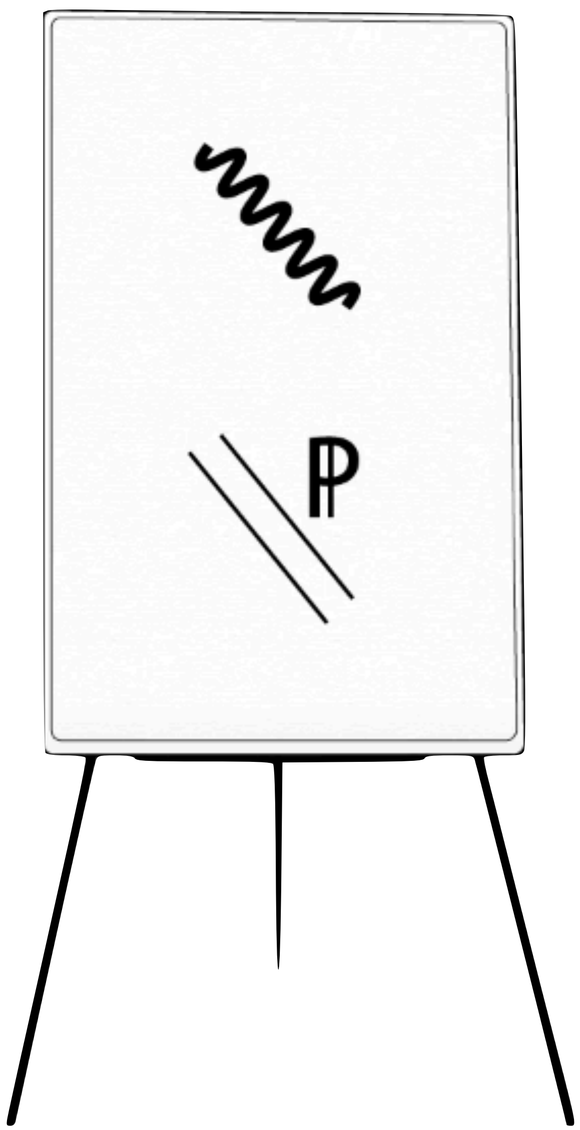
DIFFRACTIVE TOP PHYSICS

at the

LHC

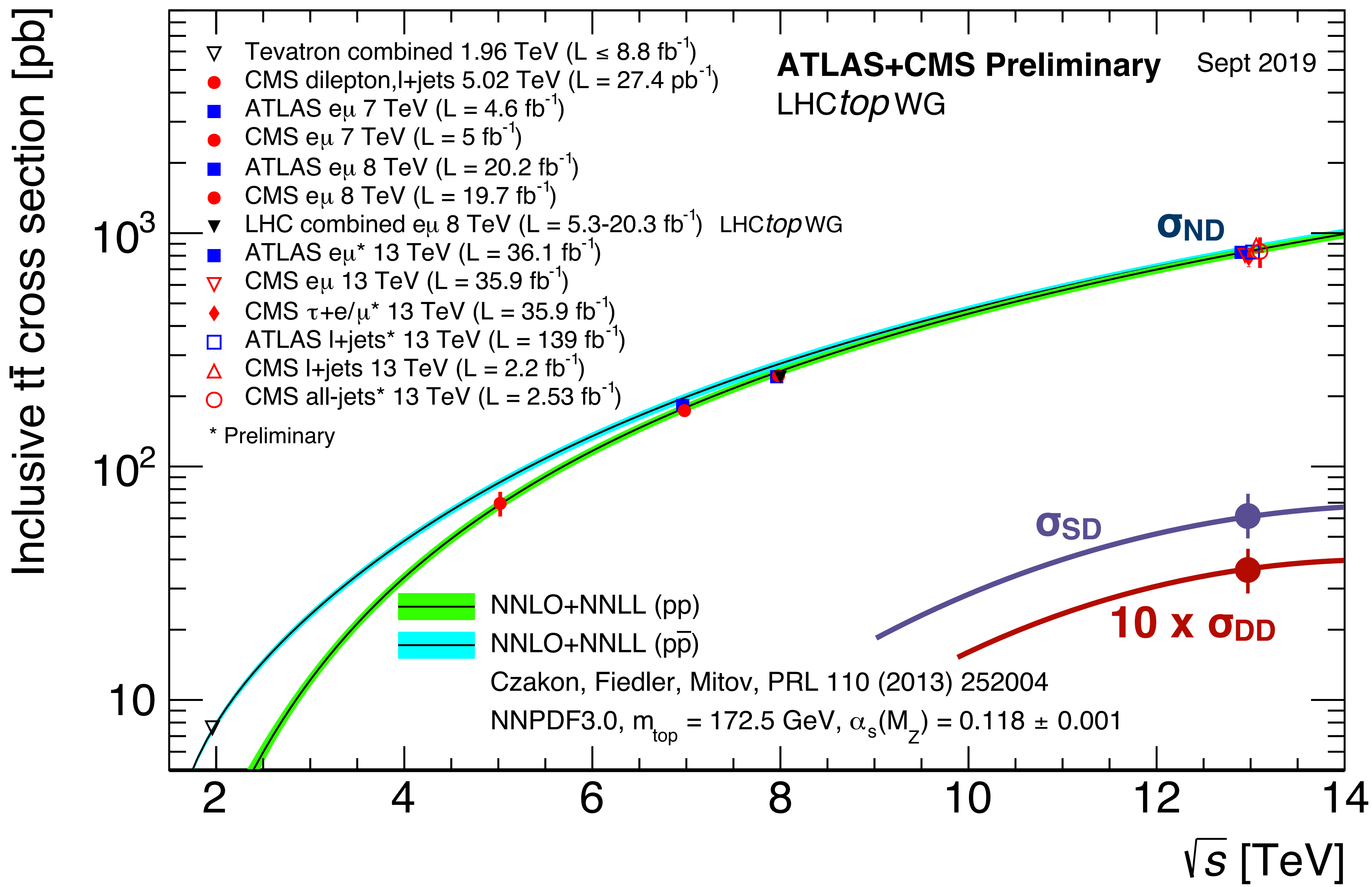


YouTube summary

Jay Howarth

Elastic Physics

- **The Aim: To discover semi-elastic production of $t\bar{t}$ and other SM processes.**

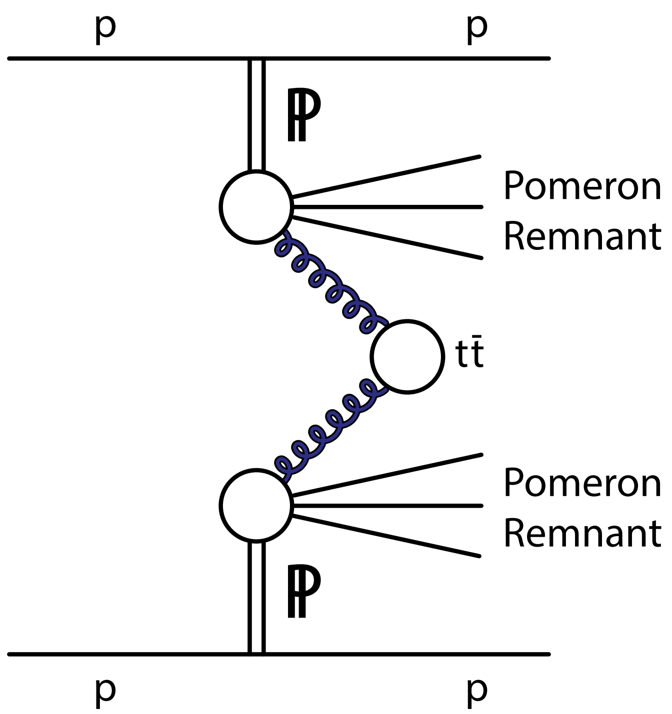


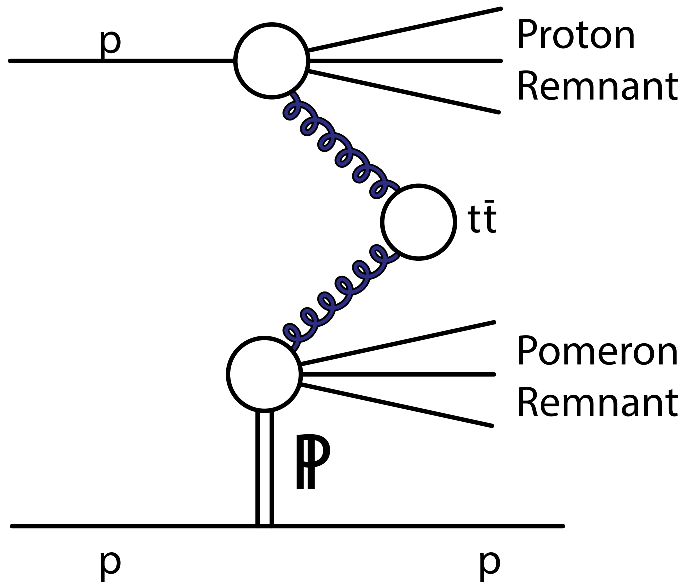
Elastic Physics

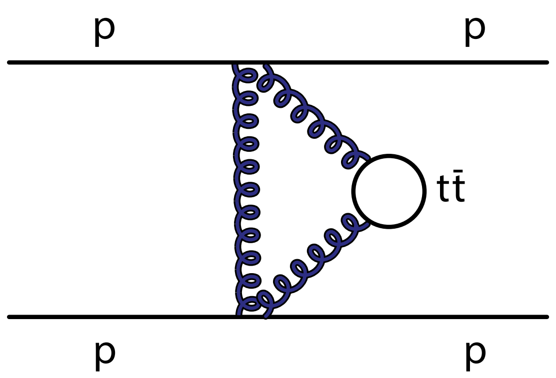
- Elastic collisions are where at least one proton remains intact.
- Different processes that can contribute to this:

Elastic Physics

- **Elastic collisions are where <u>at least one</u> proton remain intact.**
- **Different processes that can contribute to this:**
  - ➡ Diffractive Events



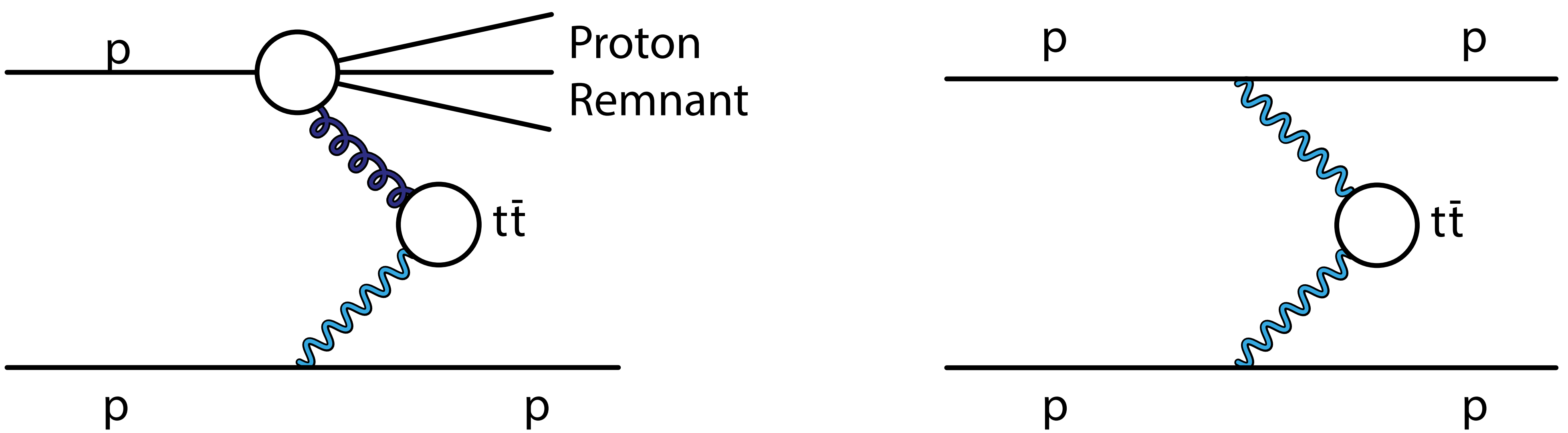




- **Diffractive means that "QCD" is the dominant force involved.**

Elastic Physics

- **Elastic collisions are where <u>at least one</u> proton remain intact.**
- **Different processes that can contribute to this:**
  - ➡ Diffractive Events
  - ➡ Photo-induced Events



- **Photo-induced events are the dominant process.**

Elastic Physics

- **Elastic collisions are where <u>at least one</u> proton remain intact.**
- **Different processes that can contribute to this:**
  - ➡ Diffractive Events
  - ➡ Photo-induced Events

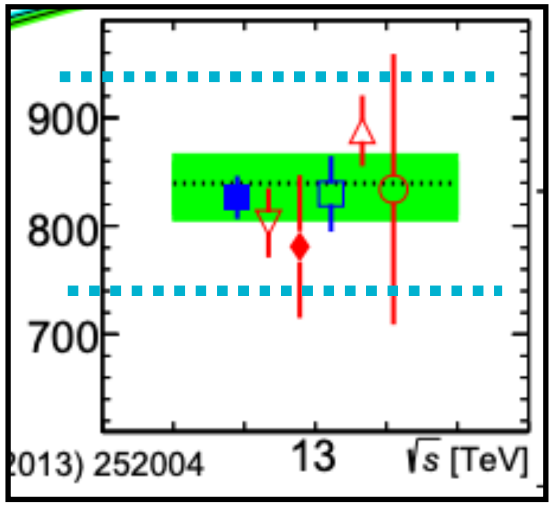
- **Why are they interesting?**

Elastic Physics

- **Elastic collisions are where <u>at least one</u> proton remain intact.**
- **Different processes that can contribute to this:**
  - ➡ Diffractive Events
  - ➡ Photo-induced Events

- **Why are they interesting?**
  1. Total cross-sections have ~100pb contribution from events containing Pomerons/Photons from protons (~6pb from elastic).

LHCTopWG



This is contained in the gluon PDF but relies on indirect measurements to constrain.

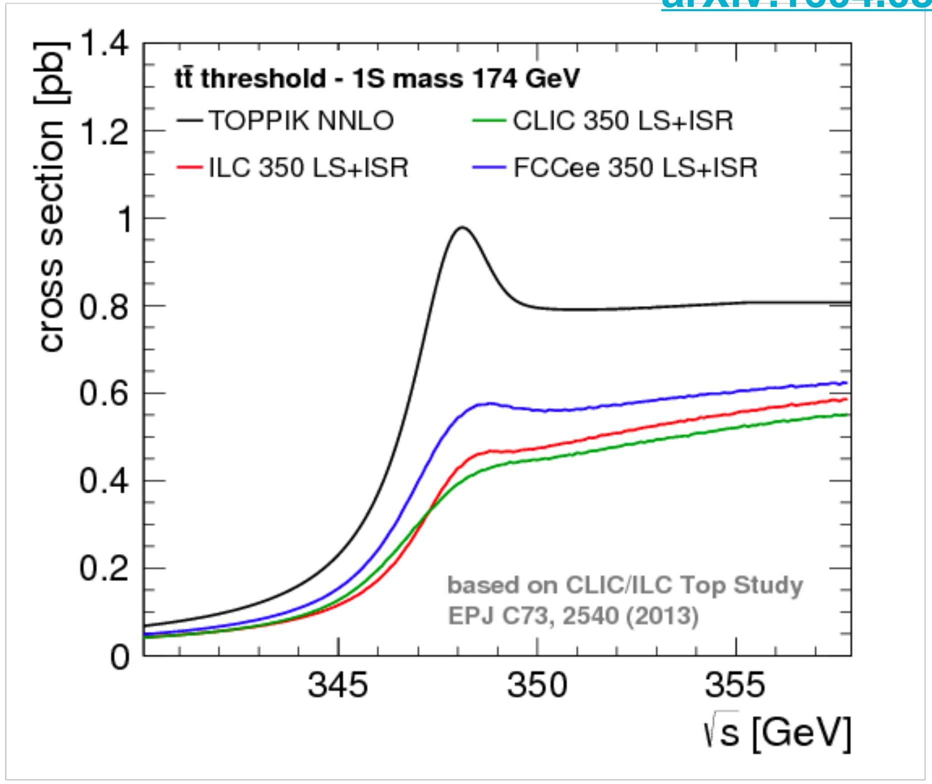
Elastic Physics

- **Elastic collisions are where <u>at least one</u> proton remain intact.**
- **Different processes that can contribute to this:**
  - ➡ Diffractive Events
  - ➡ Photo-induced Events

- **Why are they interesting?**

  2. Forward protons provide unique access to the initial state. In the most extreme case, once can probe the $t\bar{t}$ mass threshold at lepton-collider precision (without ISR uncertainties).

arXiv:1604.08122

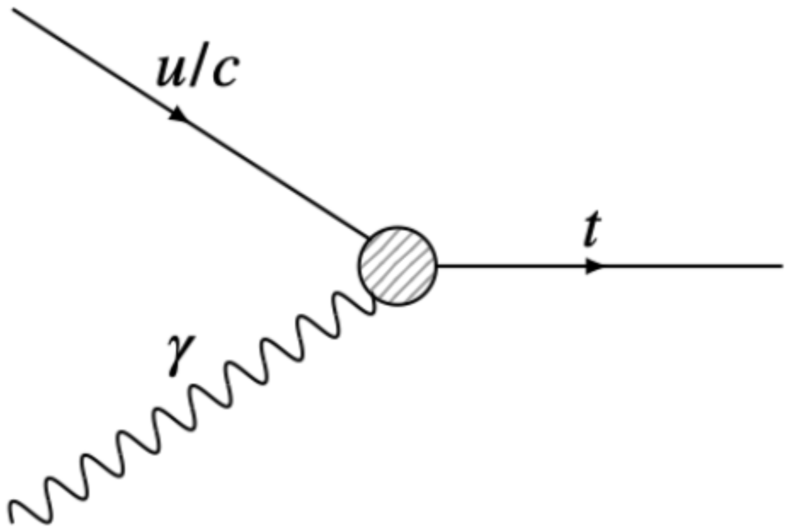


Elastic Physics

- **Elastic collisions are where at least one proton remain intact.**
- **Different processes that can contribute to this:**
  - ➡ Diffractive Events
  - ➡ Photo-induced Events

- **Why are they interesting?**
  3. They have the potential to probe the top-gamma coupling at higher precision than tqγ and ttγ and to search for BSM contributions to FCNC(t→u/c) via photons.

arXiv:2008.04249

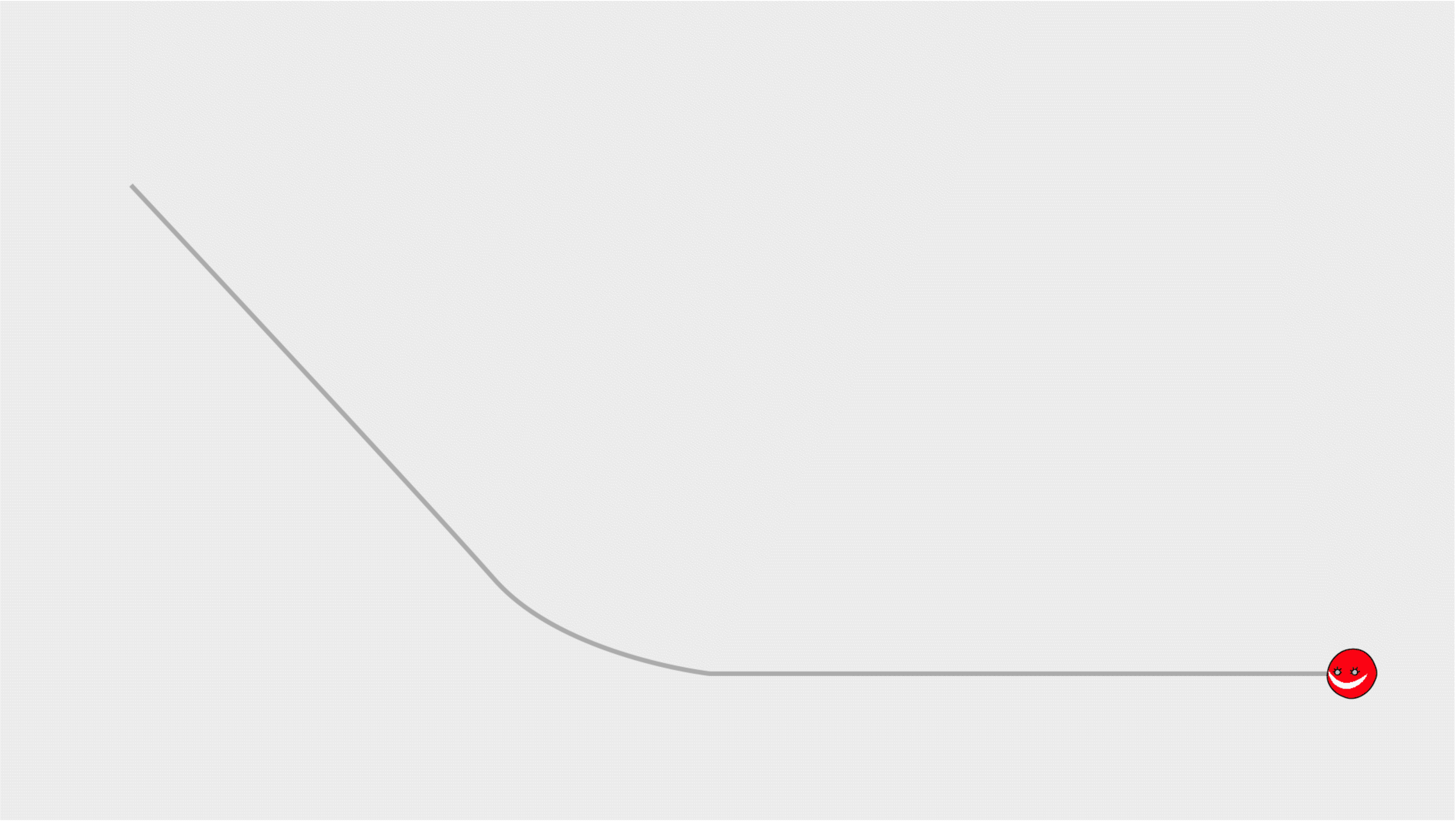


Inelastic Background

- Cross-section for inelastic $t\bar{t}$ production is many orders of magnitude higher than for (semi)elastic $t\bar{t}$.

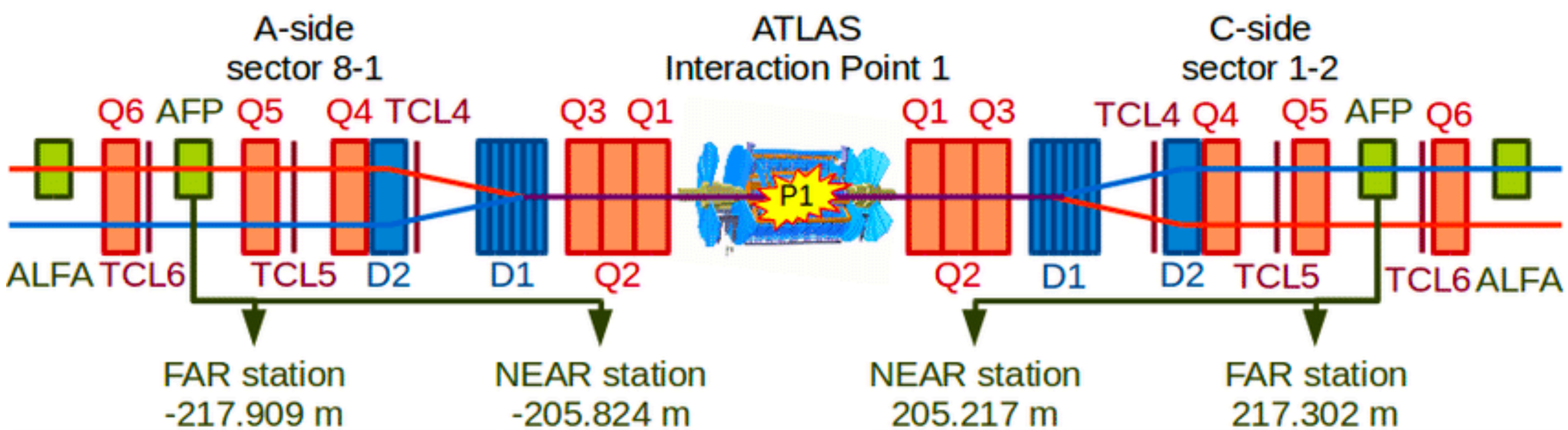
- How can we suppress it?
  ➡ By "tagging" the intact forward proton

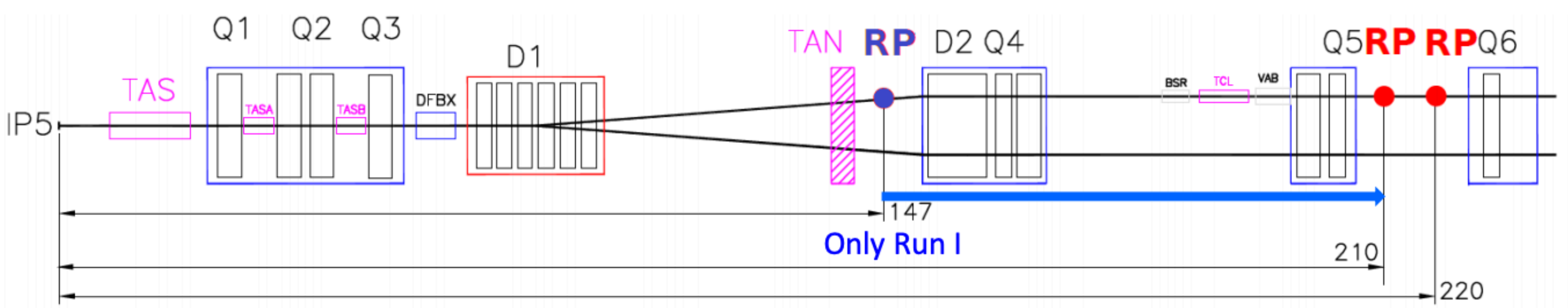
Forward Proton Tags



Forward Roman Pots

- ATLAS AFP and TOTEM (CMS) positioned on Roman Pots at ~200m





- Horizontal stations are the most relevant for low β* (standard runs).
- Vertical stations (e.g. ATLAS ALFA) use high β* runs to measure total cross-section.

Ingredient List

$$\sigma_{in}(t\bar{t}) = \frac{N_{events}}{\mathscr{L} \cdot A_{AFP} \cdot A_{central} \cdot \epsilon_{ff} \cdot S_p}$$

$\mathscr{L}$ = integrated luminosity

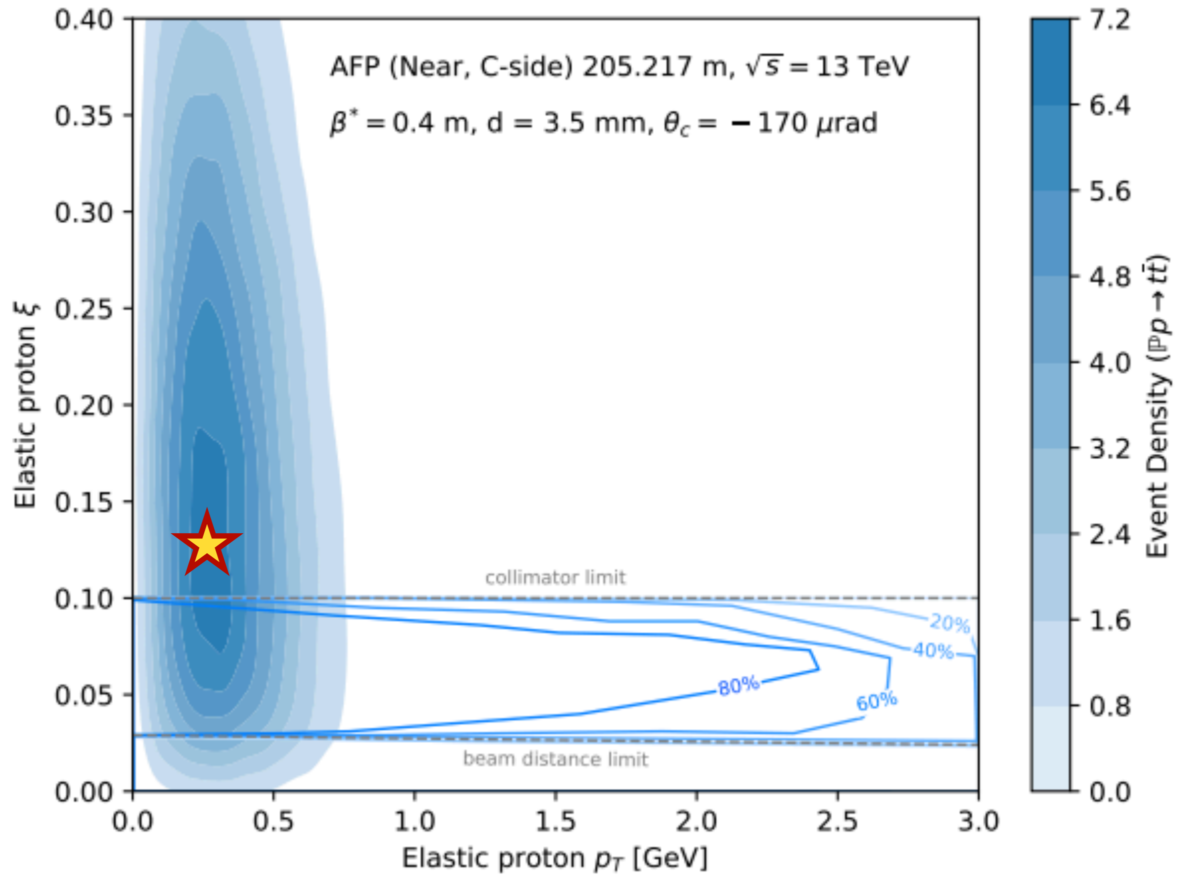
A_{AFP} = AFP acceptance

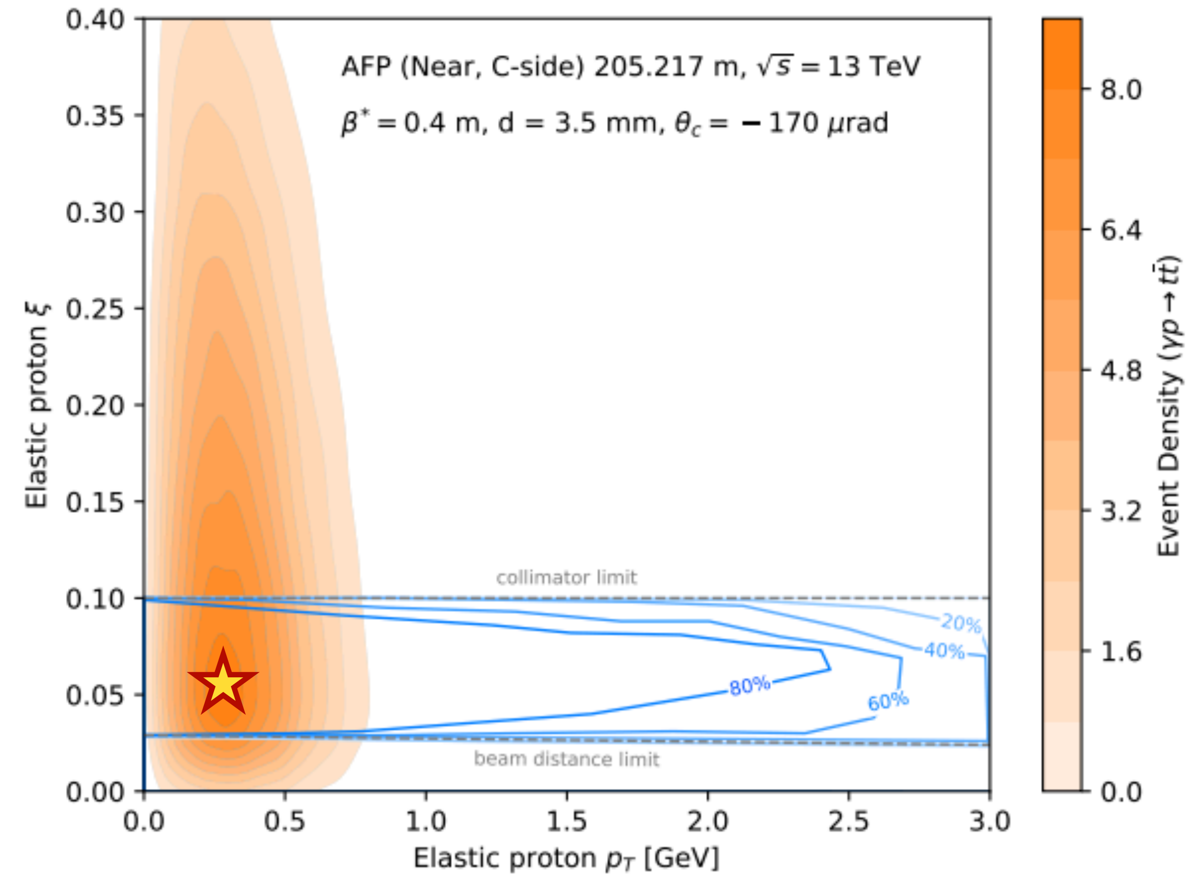
$A_{central}$ = central ATLAS acceptance

ϵ_{ff} = selection efficiency

S_p = survival probability of the proton

AFP acceptance



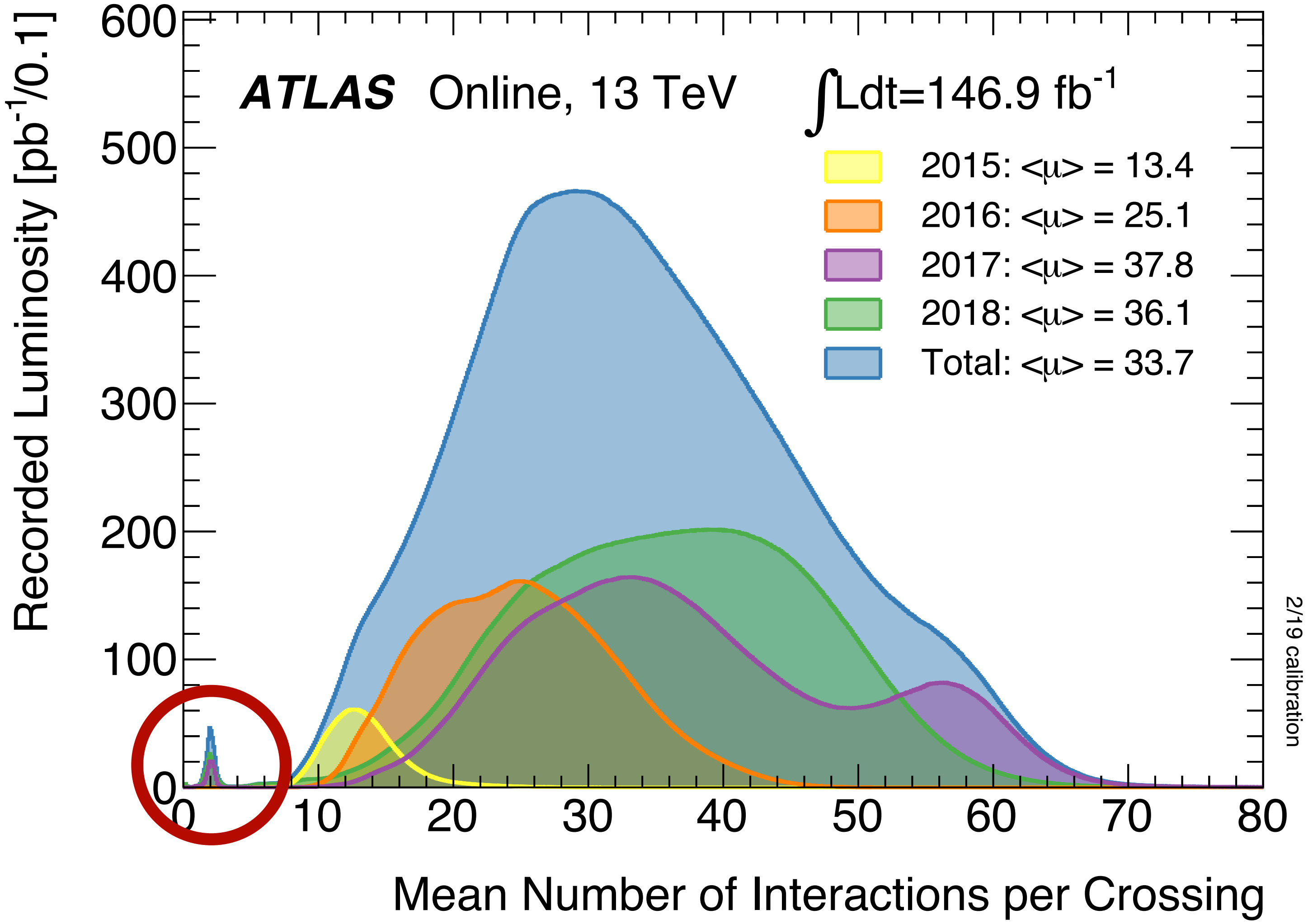


- **The AFP position and collimator position strongly effect the acceptance of the AFP detectors for $t\bar{t}$.**
  - Photon processes 30% Acceptance
  - Pomeron processes 20% Acceptance

Integrated Luminosity

- **High pileup saturates the forward detectors with protons** (timing detectors only help for fully elastic).

- **Low pileup data doesn't have this problem** (but lower integrated lumi).



- **LHC delivered ~350pb^{-1} of low μ data** (with standard β*).

- **145pb^{-1} of this recorded by ATLAS AFP.**

Predictions from MC

- **Two ways to model Pomerons:**
  ➡ **As resolved objects** (with their own PDFs, based on HERA data)
  ➡ **As a "peturbative" ladder of gluons** (Durham model, only for high scales)

- **Photons are modelled with a simple photon flux** (pretty common across all MC generators)**.**

- **Matrix Elements only available at LO QCD and QED for these processes.**
  ➡ Not likely to improve in the short term, need to use these measurements to increase interest!

- **All generators using resolved PDF approach for pomerons for hard diffraction.**

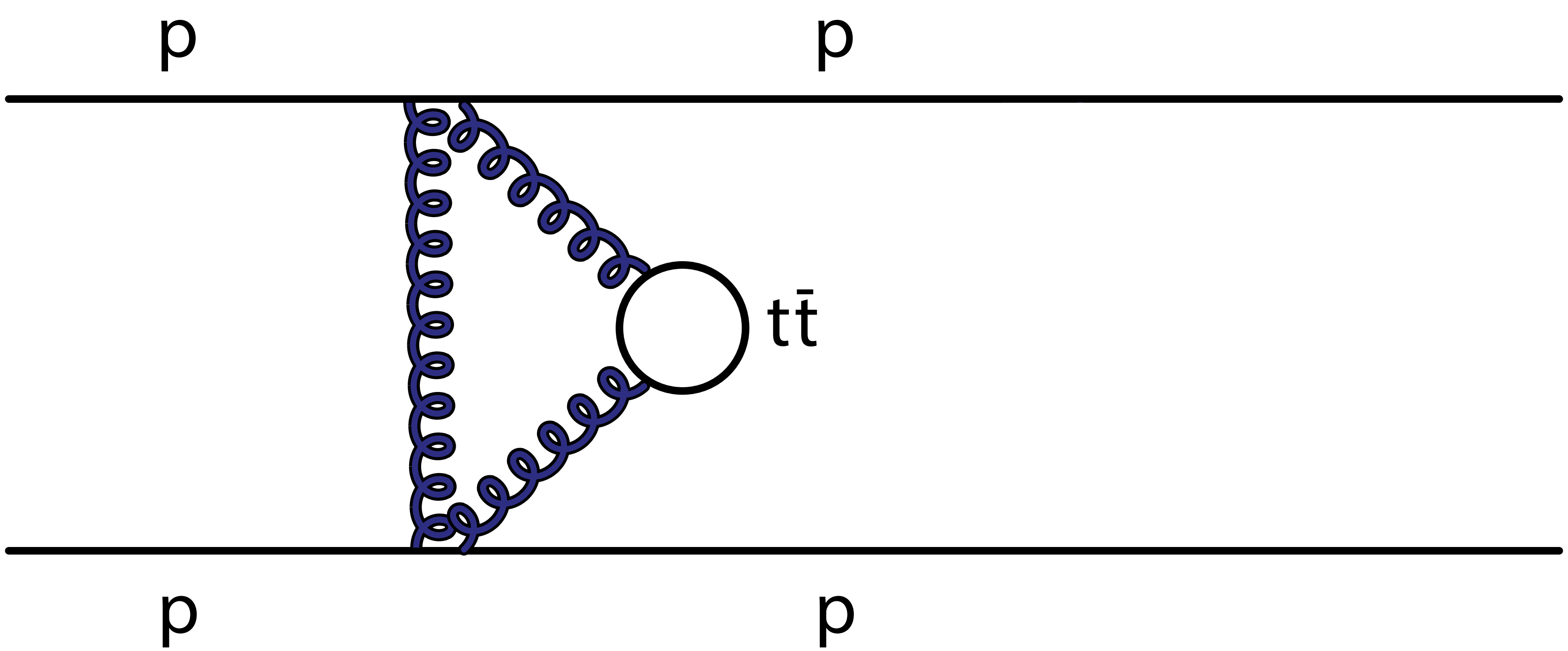
Cross-sections

- **Numbers from arxiv (proposal paper)**

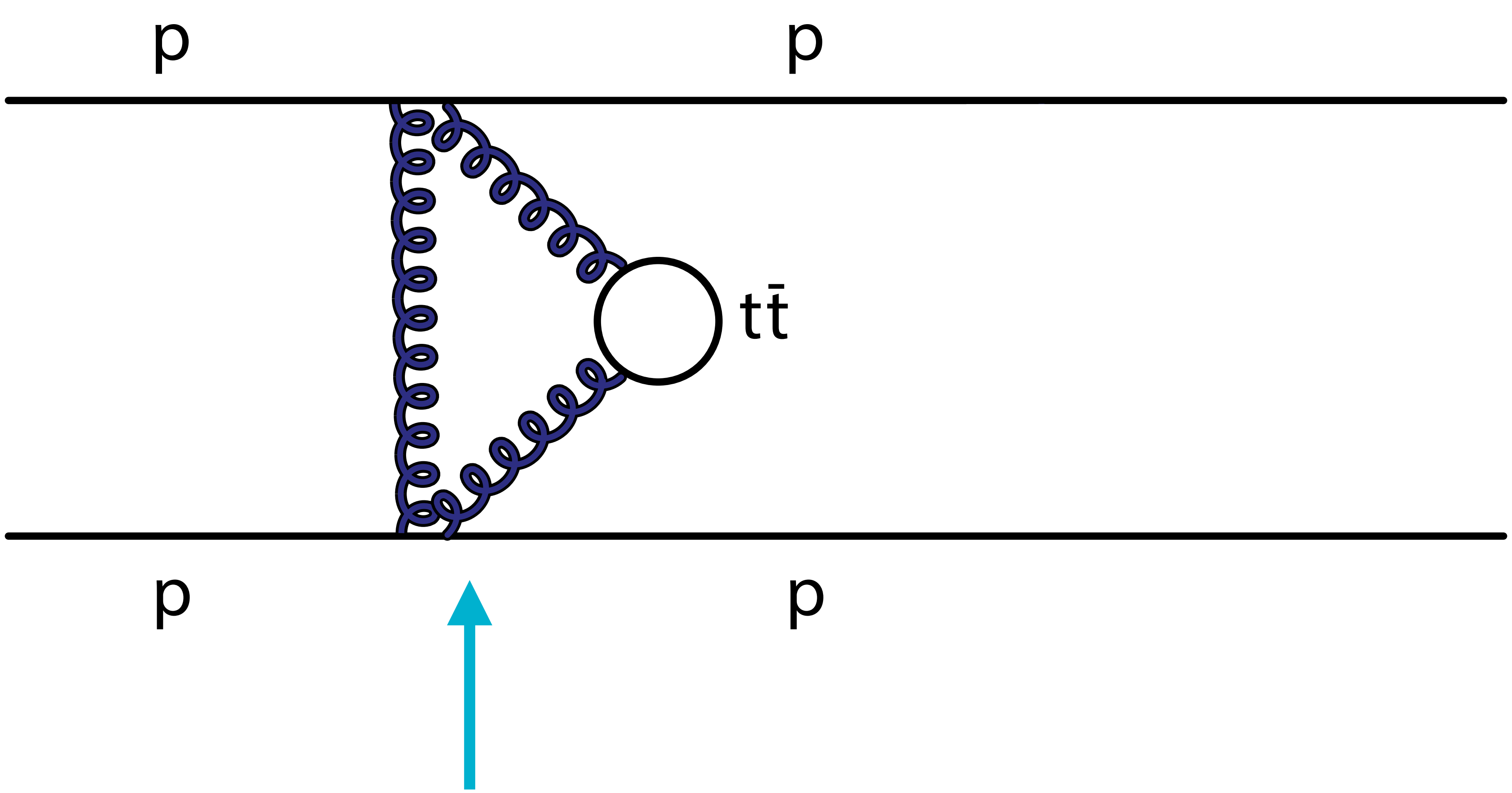
Generator Setting	$\sigma_{(p\mathbb{P}\to t\bar{t})}$ [pb]	$\sigma_{(\gamma p\to t\bar{t})}$ [pb]	$\sigma_{(\gamma\mathbb{P}\to t\bar{t})}$ [pb]	$\sigma_{(\mathbb{P}\mathbb{P}\to t\bar{t})}$ [pb]	$\sigma_{(\gamma\gamma\to t\bar{t})}$ [pb]
SuperChic					
(sfaci = false)	–	–	–	$1.73(1)\cdot 10^{-3}$	$2.77(2)\cdot 10^{-4}$
MadGraph	–	1.23	–	–	$3.33\cdot 10^{-4}$
PYTHIA (MPI: unchecked)	90.5(1)	1.45	$1.26(6)\cdot 10^{-1}$	–	$4.56(2)\cdot 10^{-4}$
FPMC[7]	–	–	$5.2\cdot 10^{-2}$	$2.84\cdot 10^{-2}$	$3.4\cdot 10^{-4}$

- **Pythia:** Can model all processes except fully diffractive.
- **MadGraph**: Anything with photons, nothing with Pomerons.
- **SuperChic:** Central exclusive only (photons or Pomerons).
- **FPMC**: Anything fully elastic (not just central exclusive).
  - ➡ No one generator can do everything!
  - ➡ All $t\bar{t}$ ME are at LO precision only.

Proton Survival Probability

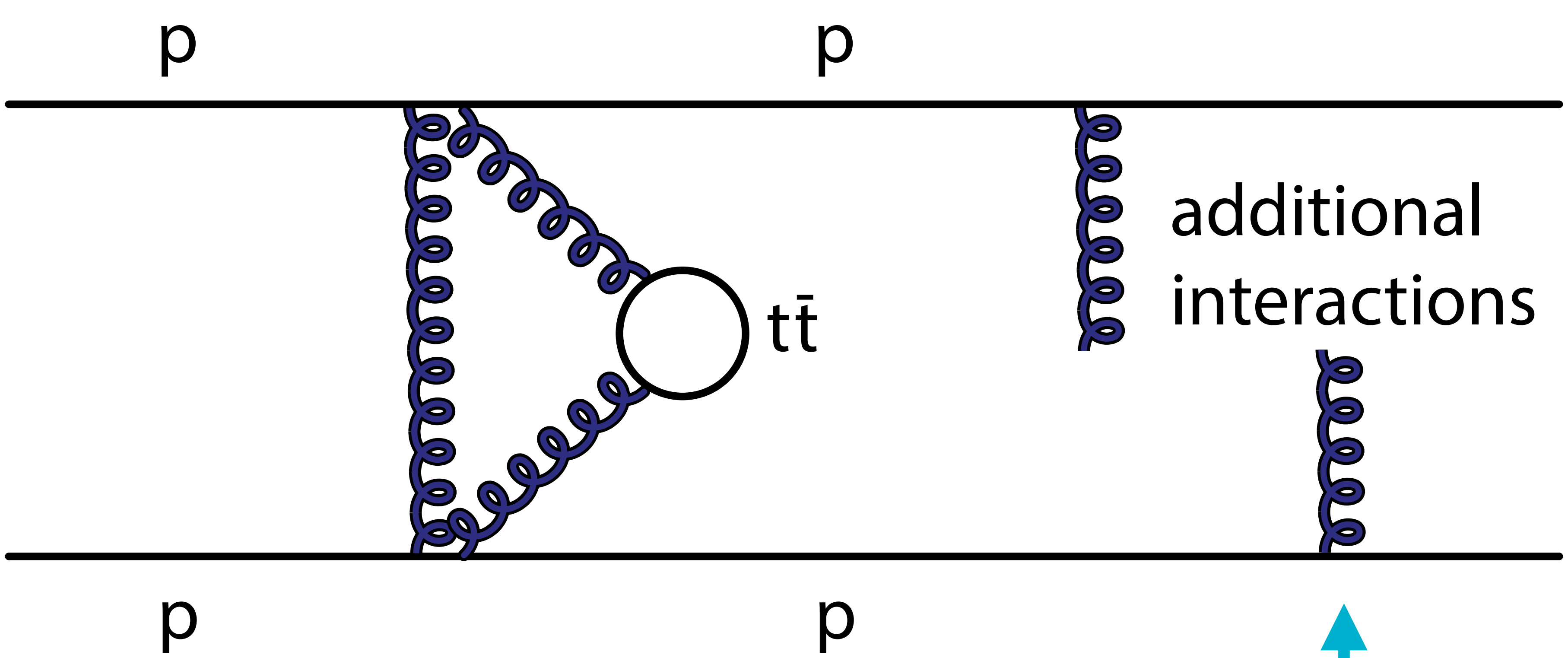


Proton Survival Probability



After this has happened, both protons are intact.

Proton Survival Probability



How likely is it that the protons continue to interact? (and hence, dissociate)

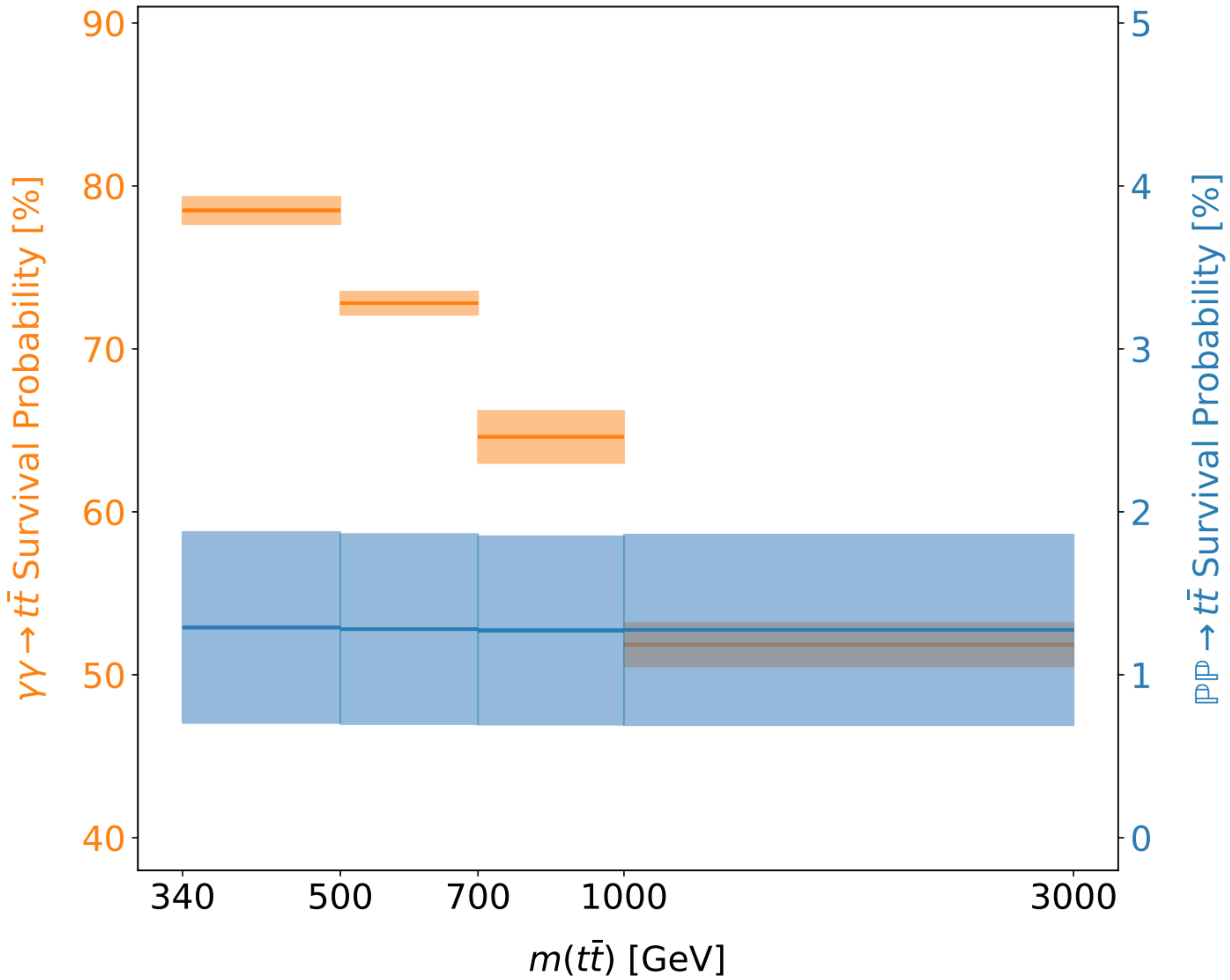
Cross-sections

- **Numbers from [arxiv (proposal paper)]**

Generator Setting		$\sigma_{(p\mathbb{P}\to t\bar{t})}$ [pb]	$\sigma_{(\gamma p\to t\bar{t})}$ [pb]	$\sigma_{(\gamma\mathbb{P}\to t\bar{t})}$ [pb]	$\sigma_{(\mathbb{P}\mathbb{P}\to t\bar{t})}$ [pb]	$\sigma_{(\gamma\gamma\to t\bar{t})}$ [pb]
SuperChic	(isurv = 1)	–	–	–	$1.22(1)\cdot 10^{-5}$	$2.05(2)\cdot 10^{-4}$
	(isurv = 2)	–	–	–	$3.21(2)\cdot 10^{-5}$	$2.06(1)\cdot 10^{-4}$
	(isurv = 3)	–	–	–	$2.05(1)\cdot 10^{-5}$	$2.05(1)\cdot 10^{-4}$
	(isurv = 4)	–	–	–	$1.59(1)\cdot 10^{-5}$	$2.06(1)\cdot 10^{-4}$
	(sfaci = false)	–	–	–	$1.73(1)\cdot 10^{-3}$	$2.77(2)\cdot 10^{-4}$
MadGraph		–	1.23	–	–	$3.33\cdot 10^{-4}$
PYTHIA	(MPI: unchecked)	90.5(1)	1.45	$1.26(6)\cdot 10^{-1}$	–	$4.56(2)\cdot 10^{-4}$
	(MPI: checked)	5.14(5)	1.46	$1.27(6)\cdot 10^{-1}$	–	$4.57(2)\cdot 10^{-4}$
FPMC[7]		–	–	$5.2\cdot 10^{-2}$	$2.84\cdot 10^{-2}$	$3.4\cdot 10^{-4}$

- **Pythia:** Can approximate effect by checking for MPI
- **SuperChic:** Can do a more sophisticated eikonal model, but only for central exclusive events.

Cross-sections



- **Survival probability higher for photon interactions than pomerons because the EW interactions are longer range than QCD** (lower probability of subsequent interactions)**.**

Central Selection

- **We need to consider all $t\bar{t}$ decay modes and standard** (though low μ allows us to use slightly looser selections)

- **All channels:** $p_T(\ell, j) > 25\ GeV,\ |\eta(\ell, j)| < 2.5$ (p$_T$ could go as low as 20 GeV with a decent trigger menu in Run3)

- **Using public performance estimates from ATLAS. All selections require at least 1 forward proton tag.**

- **Dilepton:**
  - ➡ 2 OS leptons (e or μ)
  - ➡ At least 1 b-tagged jet (85% WP)
- **L+jets**:
  - ➡ 1 lepton (e or μ)
  - ➡ 2 b-tagged jets (no req on light jets)
- **All Hadronic**:
  - ➡ 4 non-tagged jets
  - ➡ 2 b-tagged jets

$$A^{dilep}_{central} = 2\,\%$$

$$A^{ljets}_{central} = 20\,\%$$

$$A^{ljets}_{central} = 5\,\%$$

Ingredient List

$$\sigma_{in}(t\bar{t}) = \frac{N_{events}}{\mathscr{L} \cdot A_{AFP} \cdot A_{central} \cdot \epsilon_{ff} \cdot S_p}$$

$\mathscr{L}$ = **145 pb^{-1}**

A_{AFP} = **0.3 (0.4)** depending on process

$A_{central}$ = **5% - 20%** depending on channel

ϵ_{ff} = (folded into above)

S_p = **0.03 (0.8)** depending on process

Expectations

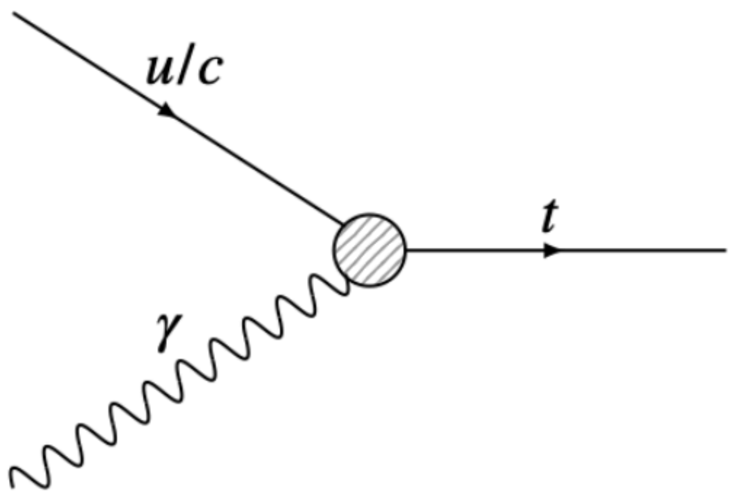
- **Rough estimate of selectable events for a single experiment** (ATLAS, thought CMS would be similar)
- **Based on loose channel selections and low pileup data:**

Process	100 pb^{-1}	300 pb^{-1}	1 fb^{-1}
$\gamma\gamma \to t\bar{t}$	$9 \cdot 10^{-4}$	$2.7 \cdot 10^{-3}$	$9 \cdot 10^{-3}$
$\mathbb{P}\mathbb{P} \to t\bar{t}$	$6 \cdot 10^{-5}$	$1.7 \cdot 10^{-4}$	$6 \cdot 10^{-4}$
$\gamma\mathbb{P} \to t\bar{t}$	$1.6 \cdot 10^{-1}$	$4.9 \cdot 10^{-1}$	1.6
$\gamma p \to t\bar{t}$	9.4 ± 0.3	30 ± 1	94 ± 3
$p\mathbb{P} \to t\bar{t}$	15 ± 2	40 ± 7	150 ± 20
Total	24 ± 2	70 ± 7	240 ± 20

- **We have 145 pb^{-1} of low-μ data in 2017, should be enough to get evidence of semi-elastic production.**

New Physics

- **Semi-elastic process can also be used to set limits on new physics:**



Operator	0.1 fb^{-1}	0.3 fb^{-1}	1.0 fb^{-1}	ATLAS [28]
$\lvert C_{uW}^{(13)*} + C_{uB}^{(13)*} \rvert$	< 0.23	< 0.13	< 0.07	< 0.19
$\lvert C_{uW}^{(23)*} + C_{uB}^{(23)*} \rvert$	< 0.35	< 0.20	< 0.11	< 0.52
$\mathrm{BR}(t \to u\gamma)[10^{-5}]$	< 4.05	< 1.35	< 0.39	< 2.8
$\mathrm{BR}(t \to c\gamma)[10^{-5}]$	< 9.80	< 3.20	< 0.97	< 22

$\ell^{\pm}\nu_l b \;+\; p_{tag}$ ← doesn't exists in the SM, sizeable with FCNC.

$\ell^{\pm}\nu_l j \;+\; p_{tag}$ ← does exists in the SM, suppressed by b-tagging.

- **Limits with 2017 data could be (much) better than existing ATLAS and CMS limits.**

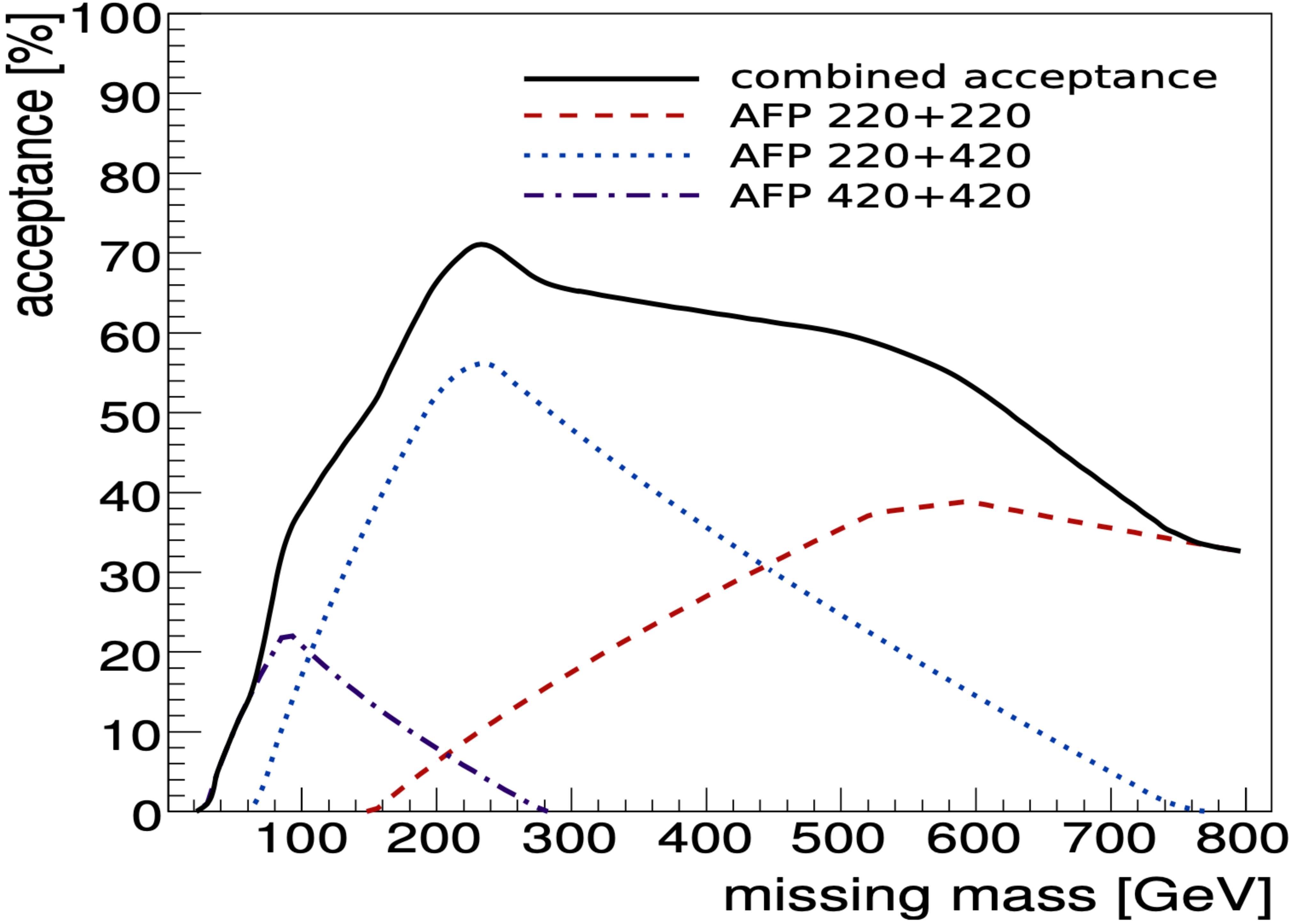
Conclusions

- **This is a new, niche area of top physics, probing the proton at the highest scales:**
  ➡ If you're looking for high-visibility and novelty, this is for you!

- **Should be possible to observe process in existing Run2 data and maybe set competitive FCNC limits.**

- **Very possible to set world-leading FCNC limits given optimisation of Run3 running and sufficient person power.**

Backup


acceptance [%]
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
800
missing mass [GeV]
combined acceptance
AFP 220+220
AFP 220+420
AFP 420+420