Particle Physics II
(LPHY2133)

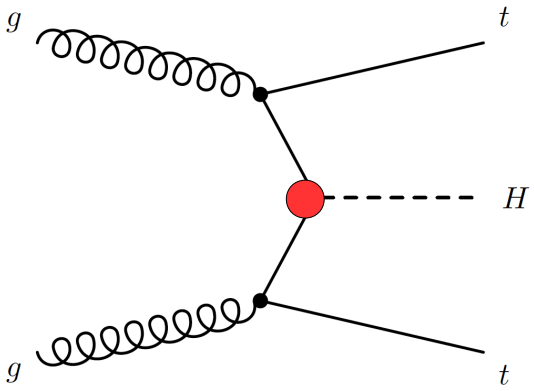
Andrea Giammanco, UCL

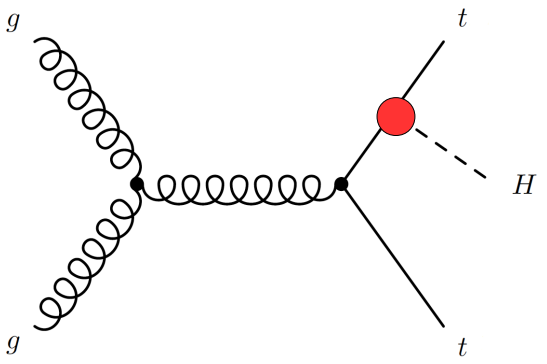
Section 7.a

Another approach to "top+Higgs"

Sensitivity to y_t or $|y_t|$?

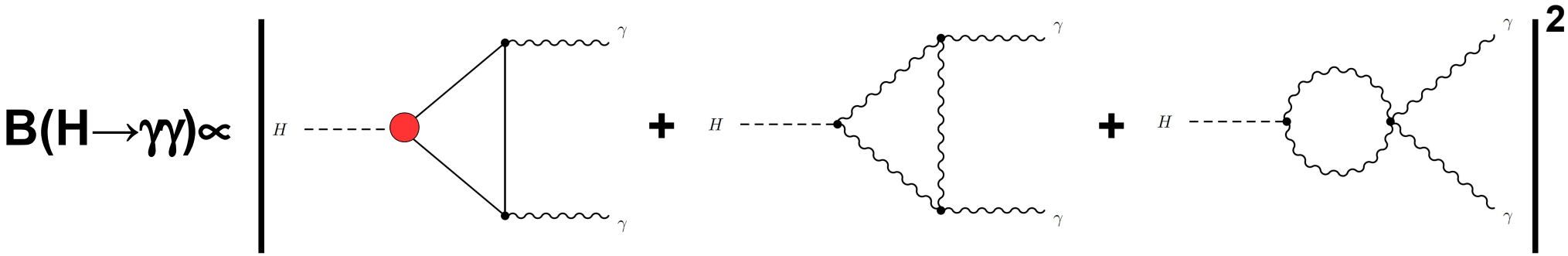
$$\sigma(t\bar{t}H) \propto \left| \right. \quad + \quad + \ldots \left. \right|^2 \propto |y_t|^2$$





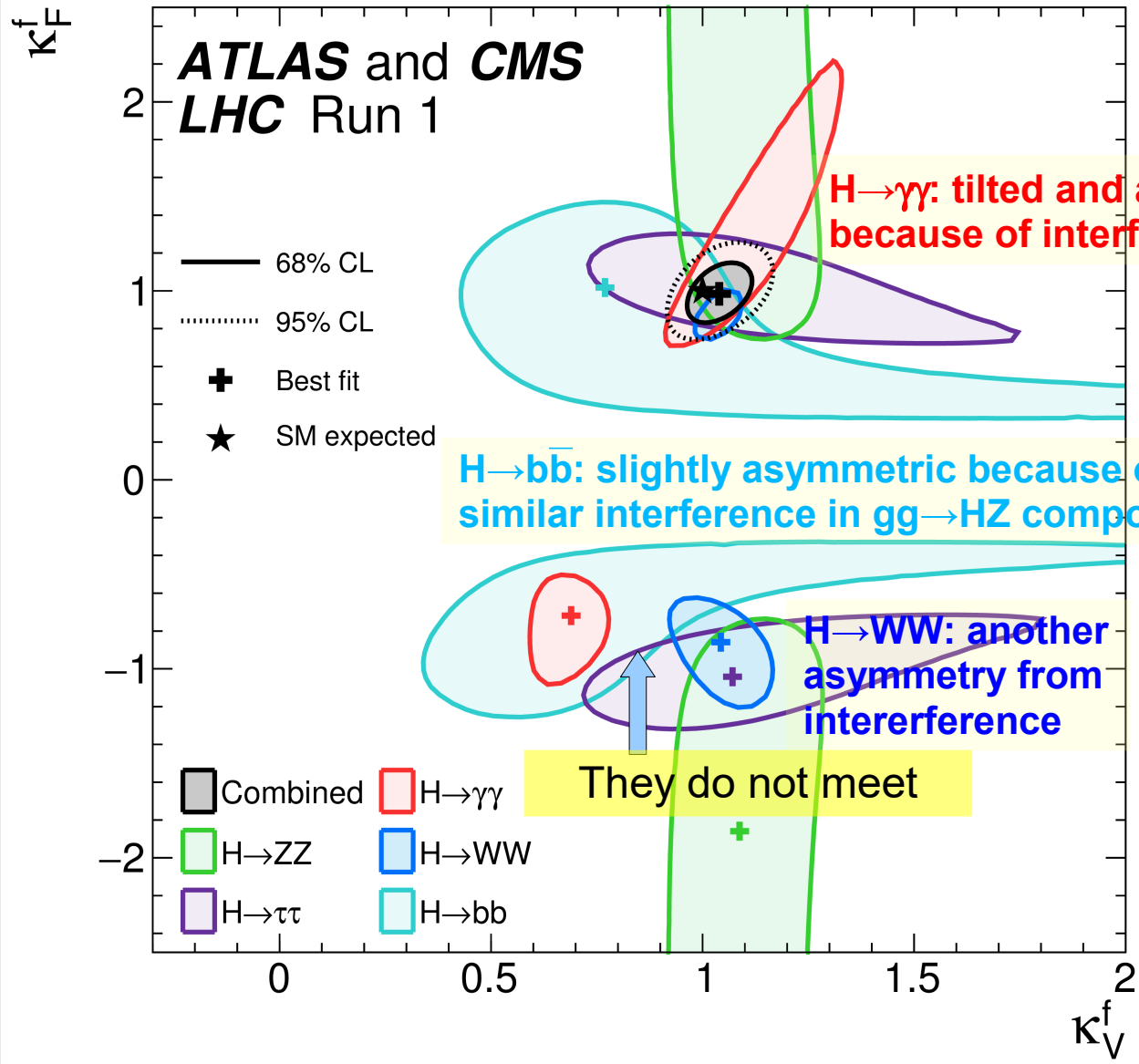
- The cross section of $t\bar{t}H$ is only sensitive to $|y_t|$
- The global phase of all the couplings has no effect on any observable, what matters here s the relative one between y_t and the Higgs coupling to gauge bosons ($g_{W,Z}$)
- In the SM, these phases are aligned and so we don't care; we write y_t as short-hand for $|y_t|$
- "Wrong sign" would cause non-renormalizable divergences, hence it would prove that some new physics is fixing them

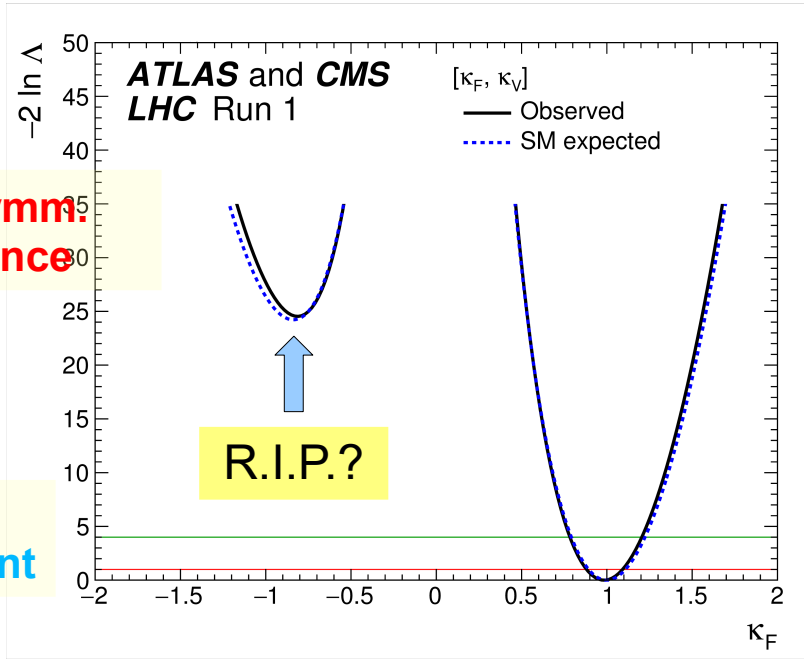
Use interference



- This branching ratio has both a quadratic and a linear term in y_t, the latter coming from interference
- Fermion loops and boson loops have amplitudes of opposite sign → destructive interference in SM
- Swapping the sign of y_t makes interference constructive, and BR enhanced by 2.4 times

The case is closed?

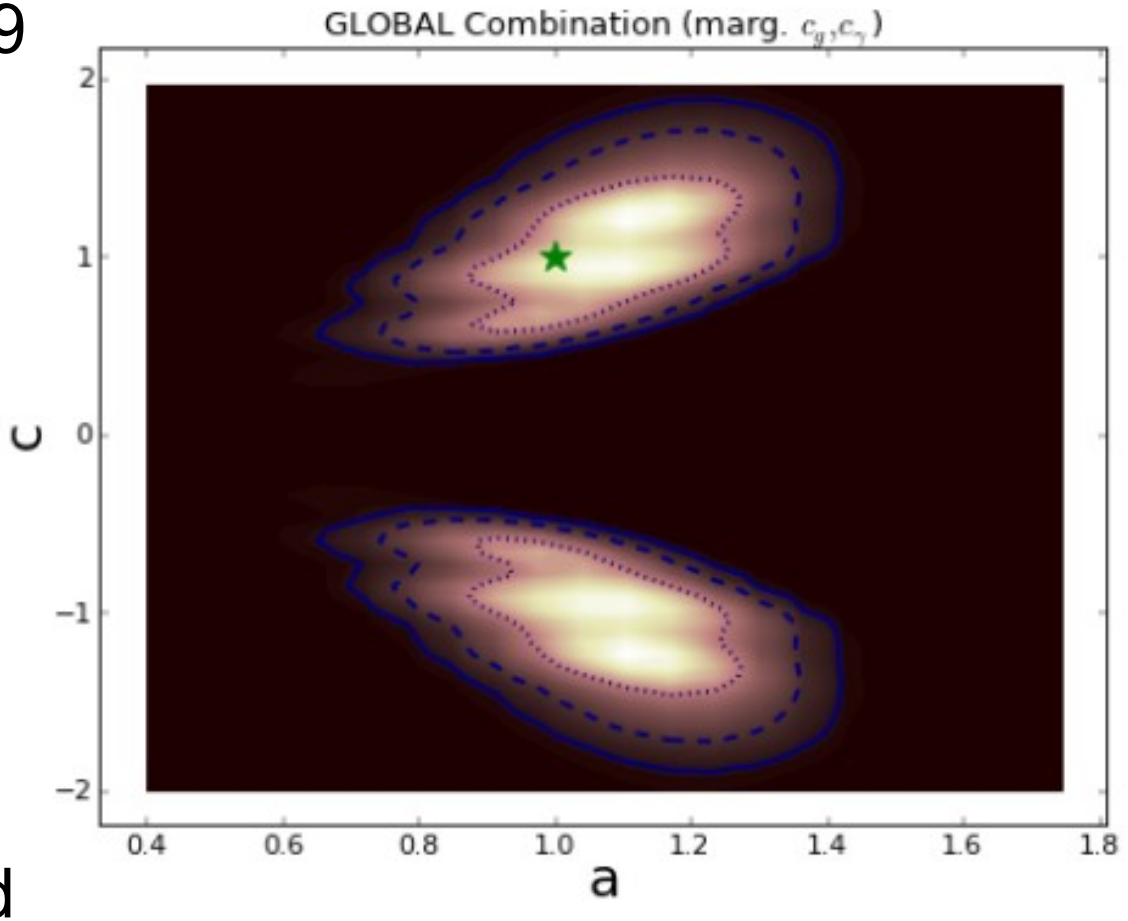




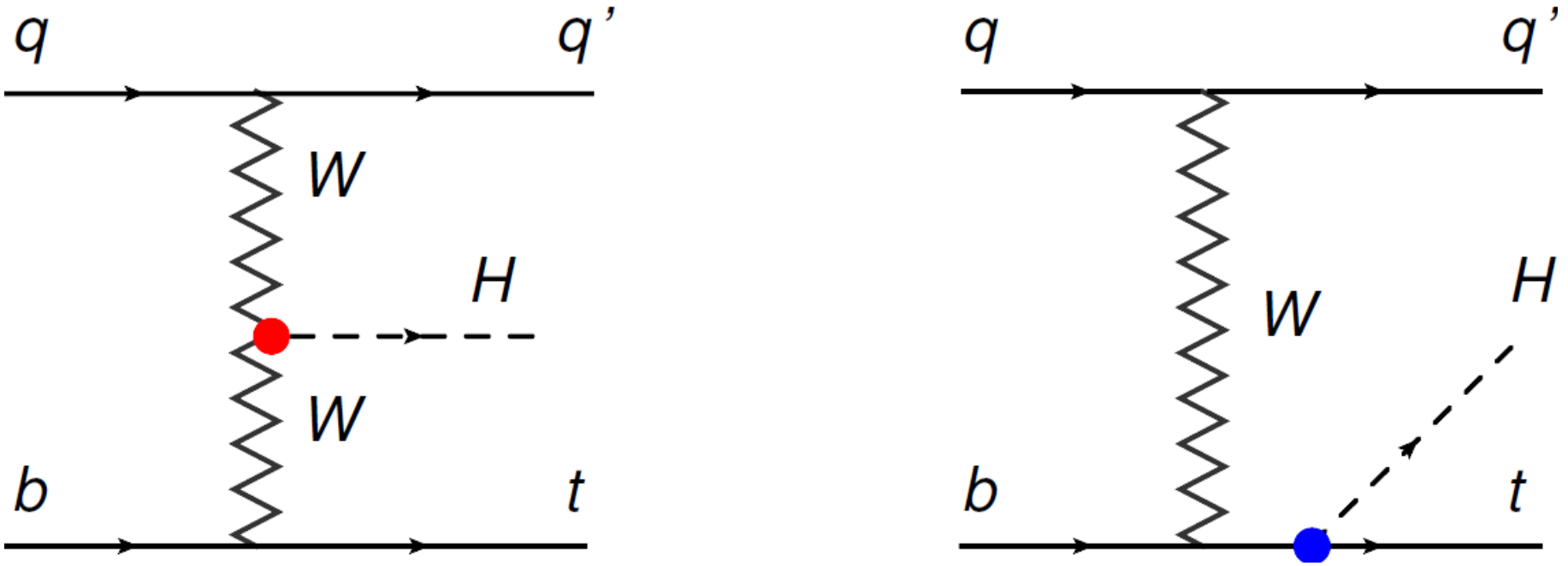
Assumption: no BSM in loops

Remove that assumption and...

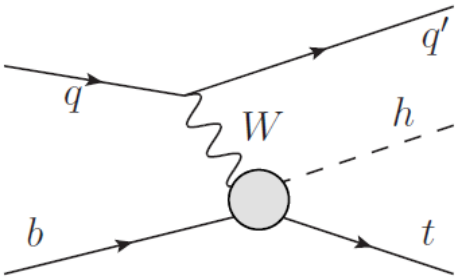
- J.Ellis, T.You, JHEP 06 (2013) 103, arXiv:1303.3879
  - Based on home-made combination of CMS, ATLAS, and Tevatron (not up to date, but here it doesn't matter)
- Here *a,c* have similar meaning as k_V, k_F
- In the plot reproduced here, BSM contributions are allowed in ggH and Hγγ loops and marginalised, and **the minima are degenerate**



Looking for a better "interferometer"



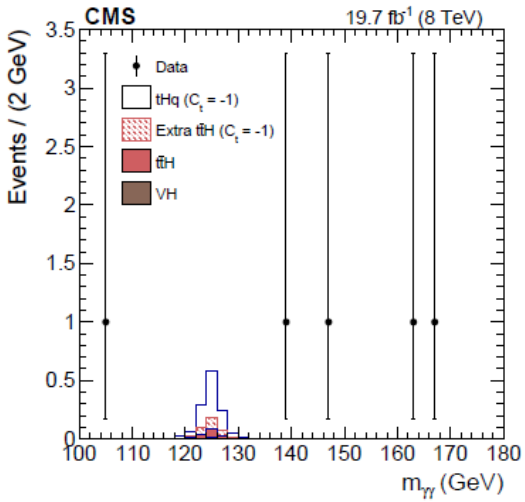
- In tHq production, accidentally strong cancellation in the SM
- Hence, strong enhancement (~13x) if the relative sign between HWW and Htt couplings turns out to be negative



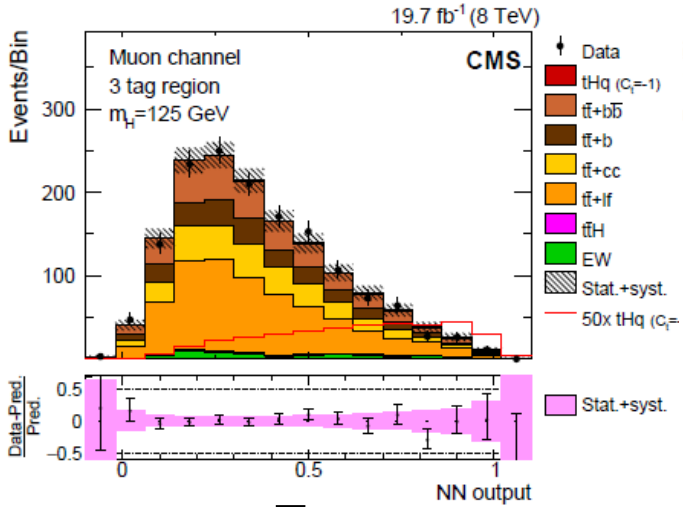
tH: Run-1 analyses

CMS coll., JHEP 06 (2016) 177

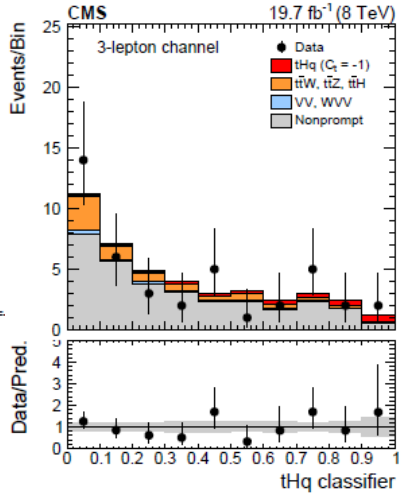
- Search was performed in $\gamma\gamma$, $b\bar{b}$, multi-lepton, $\tau\tau$ decays
- Common features:
  - Top quark always assumed to decay leptonically
  - Pseudorapidity of "recoil quark" (q') is a good discriminant
  - Exploiting dominance of top over anti-top in signal
  - Analyses optimized for y_t=-1



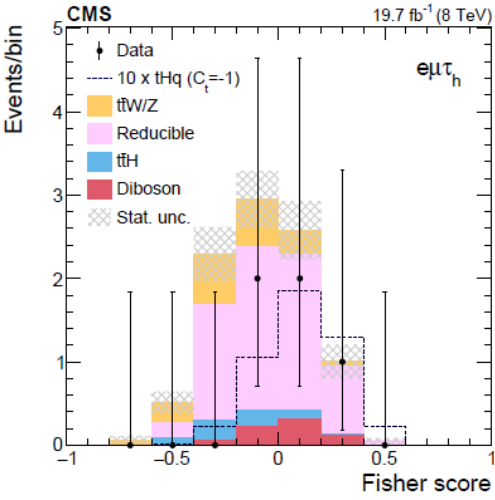
$\gamma\gamma$



$b\bar{b}$



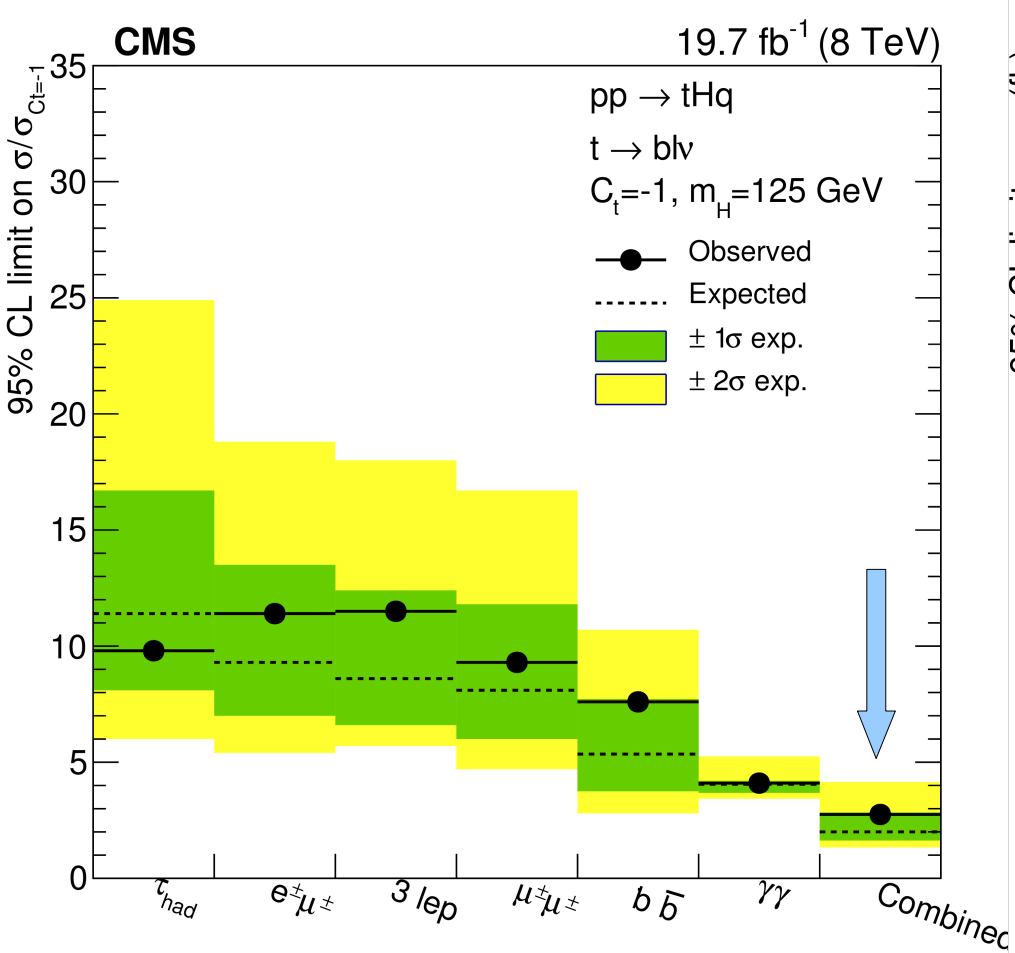
multi-lepton

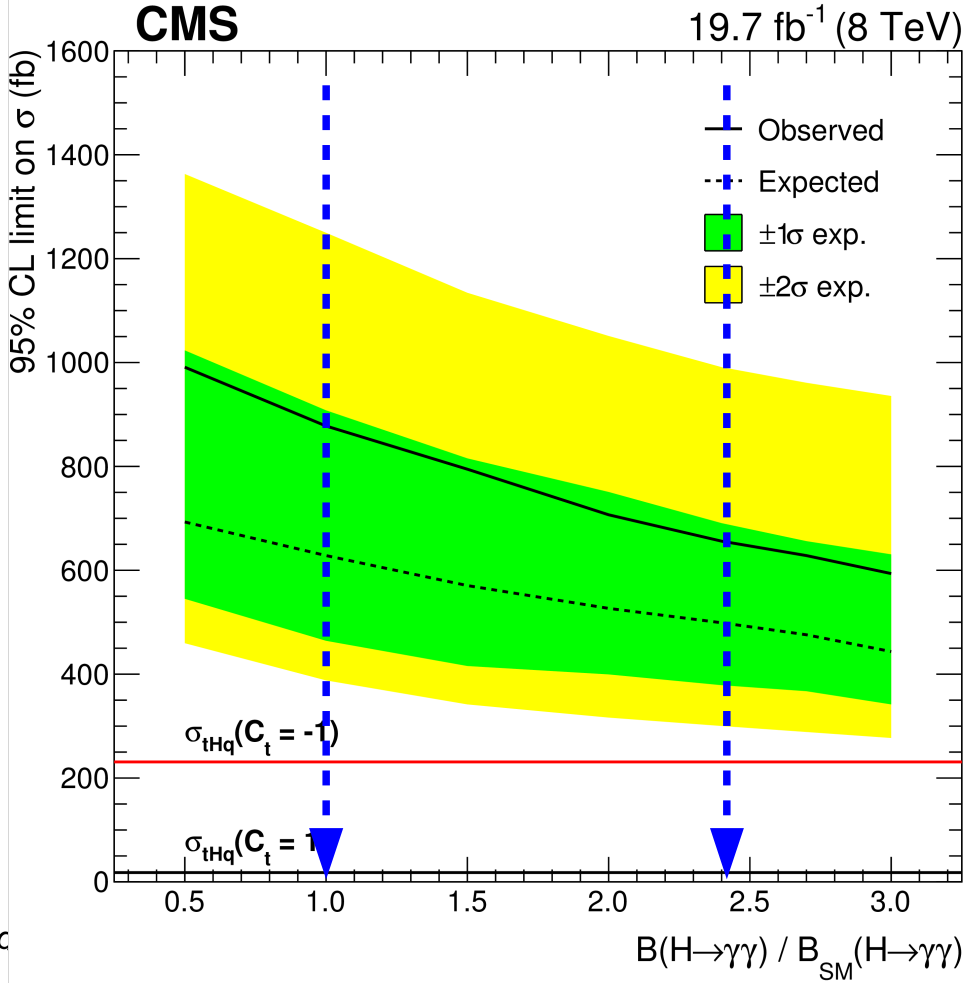


$\tau\tau$

tH: Run-1 combination

CMS coll., JHEP 06 (2016) 177





Observed (expected) limit: 2.8 (2.0) times the expectation for y_t=-1

This plot assumes B(H→γγ) = 2.4xSM

This plot is agnostic about B(H→γγ)

Exam

- It will be on 23/06 (not 20/06) starting at 14:00
- Format:
  - Written "review" report of <10 pages in pdf format including pictures, references, etc., by 16/06
  - Oral exam (not a presentation!) on 23/06
  - Bonus if you do well at the mid-term evaluation next week
  - Bonus (up to 2 points in total) for the problem-solving evaluations during K.P.'s lectures

The written report

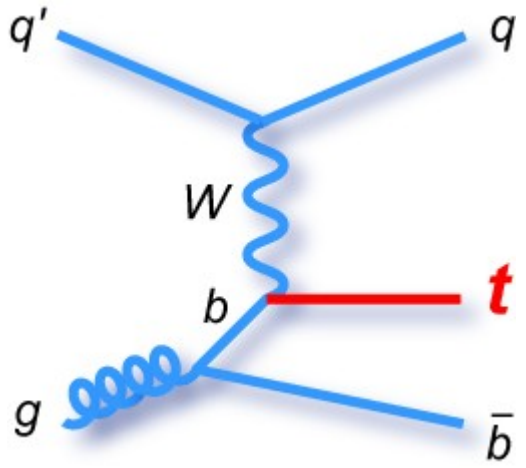
- Topics:
  - Muon collider: physics motivations
  - Muon collider: experimental challenges
  - New acceleration techniques
  - Dark matter searches (choose one type)
  - Free subject (but very well motivated)
- Purpose:
  - A short overview of the subject (in English or French)
- Structure:
  - Introduction: motivation + stating a "problem" + wider context
  - Present status of their studies and their relevance
  - Outlook: next steps and longer-term perspectives

Section 7.b

Other topics (possible *memoires*)

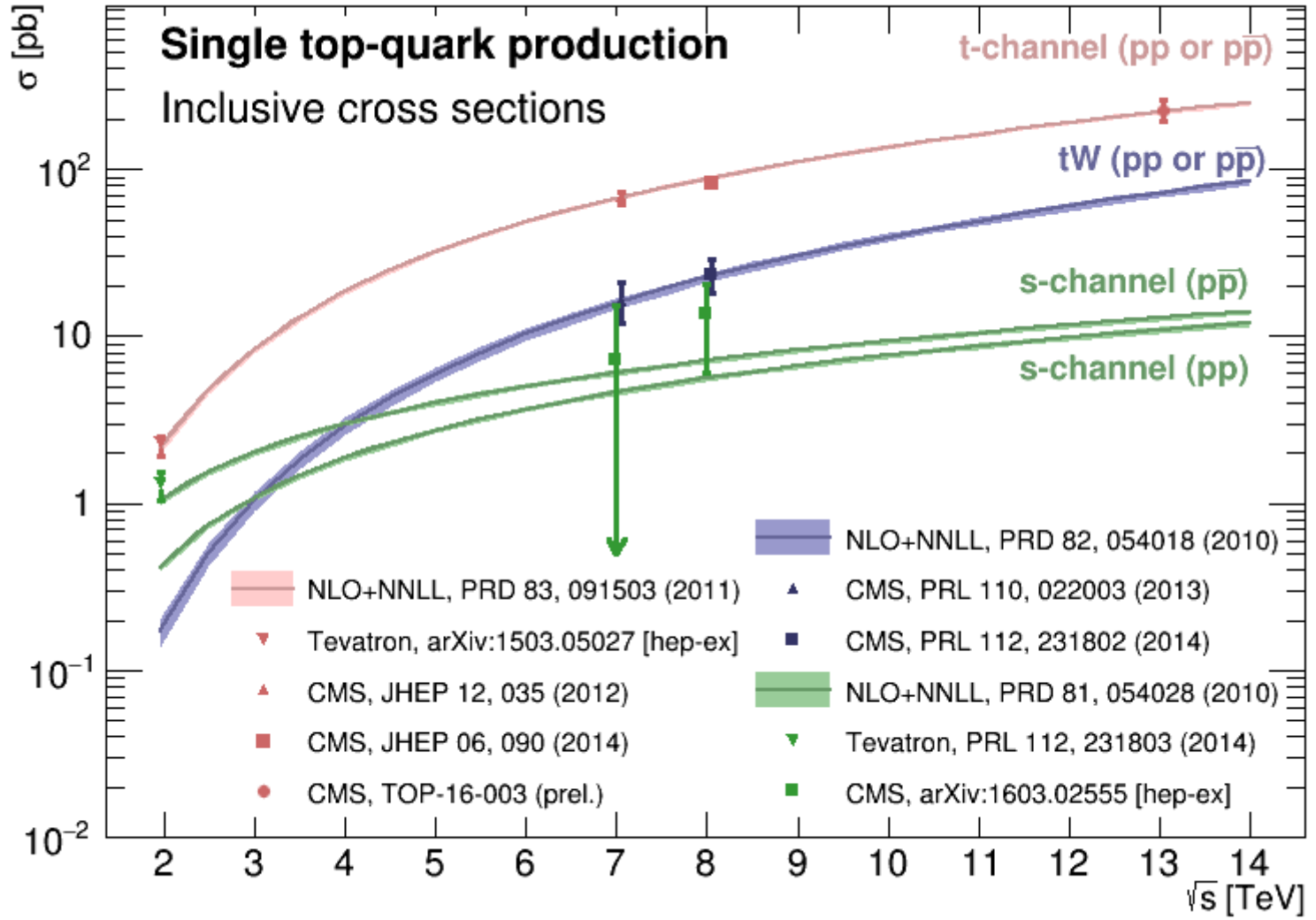
(Restricted to what is relevant to my interests right now; many more cutting-edge research topics available at CP3, both in experiments and theory)

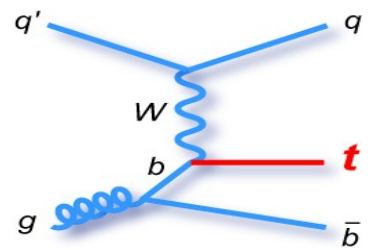
Single top

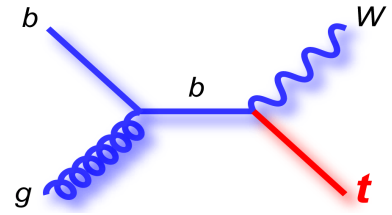


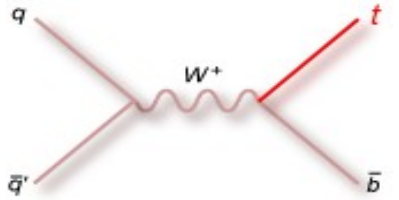
Reading material: I collected my knowledge of the subject in
„Single top quark production at the LHC“,
Reviews in Physics 1 (2016) 1-12

Single top


Single top-quark production
Inclusive cross sections
σ [pb]
t-channel (pp or p$\bar{p}$)
tW (pp or p$\bar{p}$)
s-channel (p$\bar{p}$)
s-channel (pp)
NLO+NNLL, PRD 83, 091503 (2011)
Tevatron, arXiv:1503.05027 [hep-ex]
CMS, JHEP 12, 035 (2012)
CMS, JHEP 06, 090 (2014)
CMS, TOP-16-003 (prel.)
NLO+NNLL, PRD 82, 054018 (2010)
CMS, PRL 110, 022003 (2013)
CMS, PRL 112, 231802 (2014)
NLO+NNLL, PRD 81, 054028 (2010)
Tevatron, PRL 112, 231803 (2014)
CMS, arXiv:1603.02555 [hep-ex]
10^2
10
1
10^{-1}
10^{-2}
2 3 4 5 6 7 8 9 10 11 12 13 14
$\sqrt{s}$ [TeV]

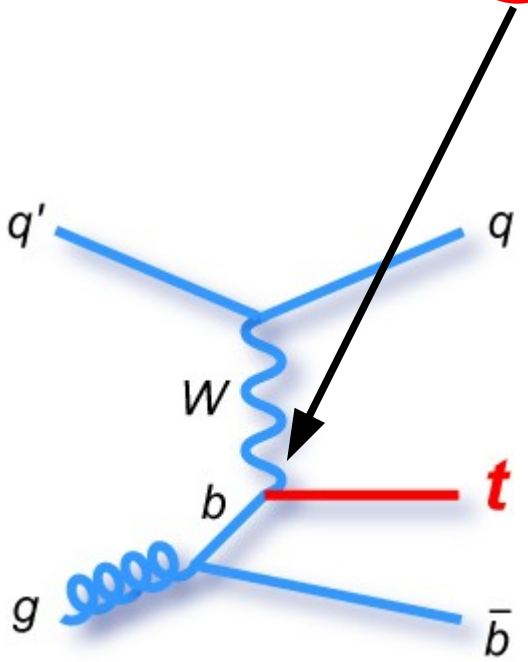

q'
q
W
b
t
g
$\bar{b}$


b
W
b
g
t


q
t
W+
$\bar{q}'$
$\bar{b}$

Single top and V_{tb}

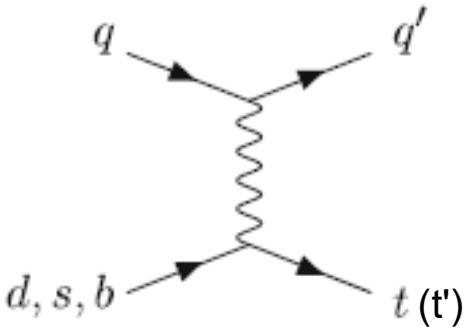
$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix}$$

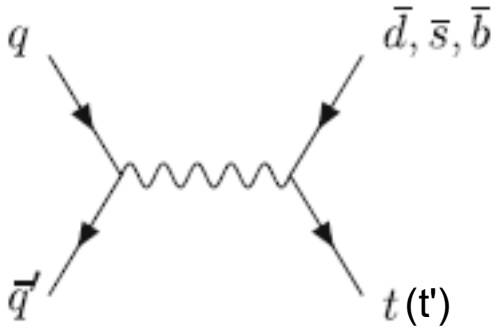


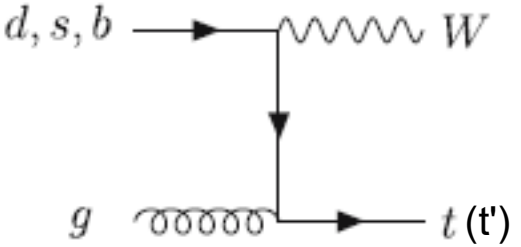
- CKM matrix is **unitary**, meaning that:
  - Any two rows/columns are orthogonal
  - Scalar product of a row/column by its conjugate = **1**; if less ⇒ new quarks exist
- 1st and 2nd rows very precisely known:
  - $|V_{ud}|$: from $0^+ \rightarrow 0^+$ β decays
  - $|V_{us}|$: from semileptonic K decays; $|V_{ci}|$ (i=d,s): from D, D_s decays
  - $|V_{cd}|$ also from $\nu d \rightarrow \mu^- c$
  - $|V_{ib}|$ (i=u,c): from B decays
- Single top cross section $\propto |V_{tb}|^2$ if one assumes $|V_{tb}|^2 >> |V_{ti}|^2$ (i=d,s)

Single top and V_{tx} (x=d,s,b)

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix} .$$



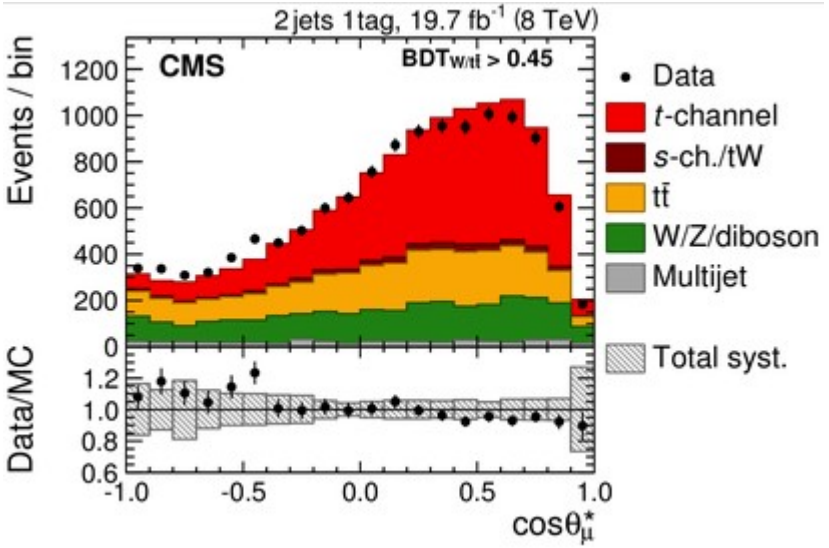




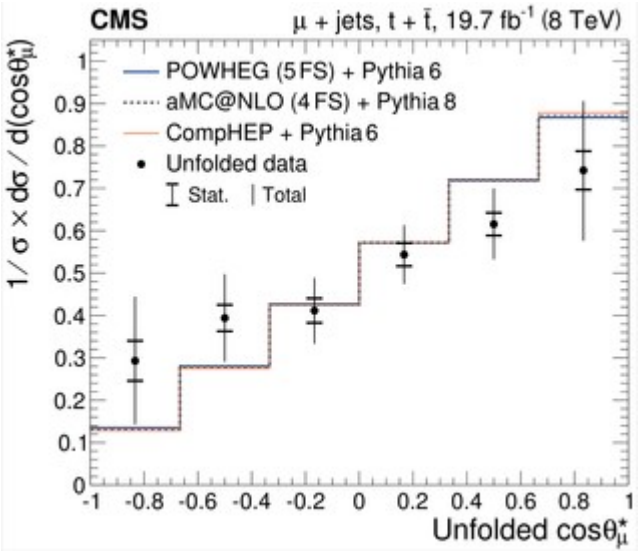
First proposal on how to do it right: J.Alwall et al, hep-ph/0607115
Follow-up: H.Lacker et al, arXiv:1202.4694 [hep-ph]
Possible *memoire*: MC study using MadGraph and Delphes, to show which possible kinematic variables are most promising

Single top unfolded

Raw data:



Unfolded data:

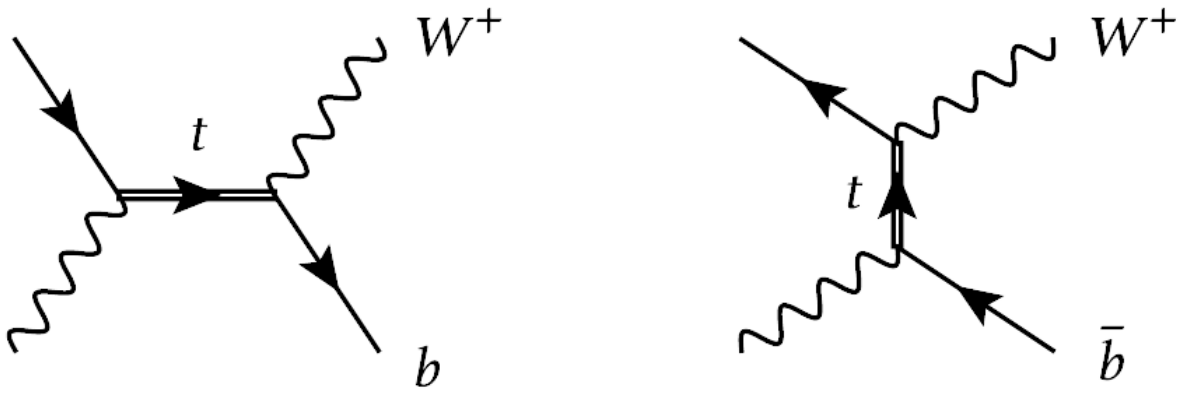


Unfolding methods and pitfalls: reading material at [1] [2] [3] [4]

Possible *memoire*: implement alternative unfolding methods, and compare their relative pros and cons.
Co-tutoring by my PhD student Matthias Komm.

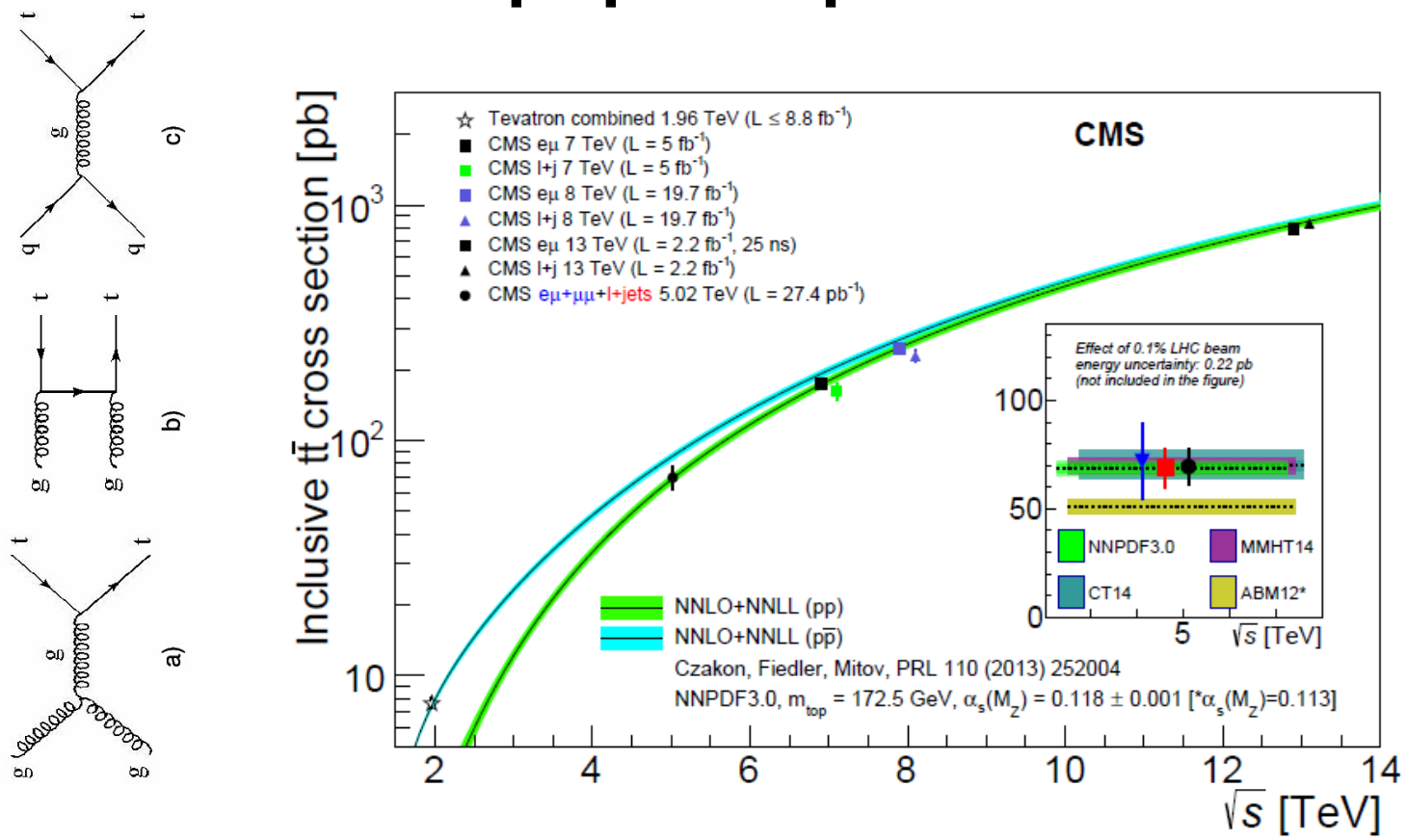
Measuring the width of the top resonance using single top

Recent theory paper: arXiv:1702.06996 [hep-ph]
Basic idea: measure the total width of the top quark resonance (precisely predicted by the SM, but never directly measured yet) by comparing two single-top processes:



Possible *memoire*: perform MC study using MadGraph and Delphes, checking whether the proposed strategy is realistic.
Theory support by F.Maltoni and his postdocs / PhD students.

Top pair production



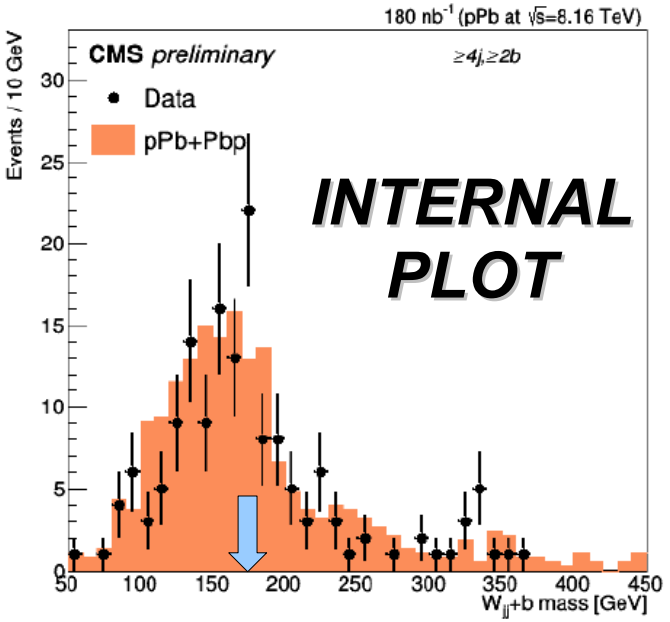
Possible *memoire*: extract the top mass from a fit to this curve.
Challenge: treating all systematics and their correlations correctly.
Even more challenging: also use single top curves simultaneously?

Top production in Heavy Ion collisions

In principle top quarks can also be studied in Heavy Ion collisions (runs of one month per year at LHC.)

Some long-term motivation nicely explained here; in short: position of the mass peaks (W and t) may be shifted or deformed by the *Quark Gluon Plasma* and other *hot nuclear matter* effects, in ways that are different from any other experimental method.

First step: first top quark observation in p-Pb.

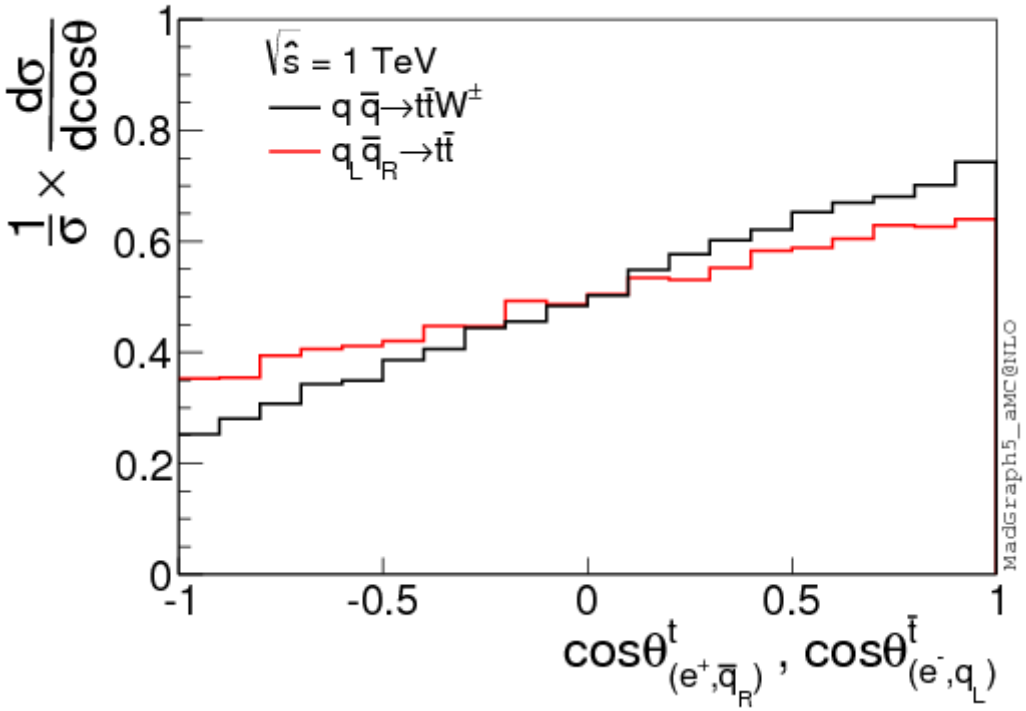


Possible *memoire*: study the perspectives of this analysis with future data for p-Pb and Pb-Pb collisions at larger center-of-mass energies. Co-tutoring by my PhD student Georgios Krintiras.

Other LHC topics

(all with theory support by Maltoni's group)

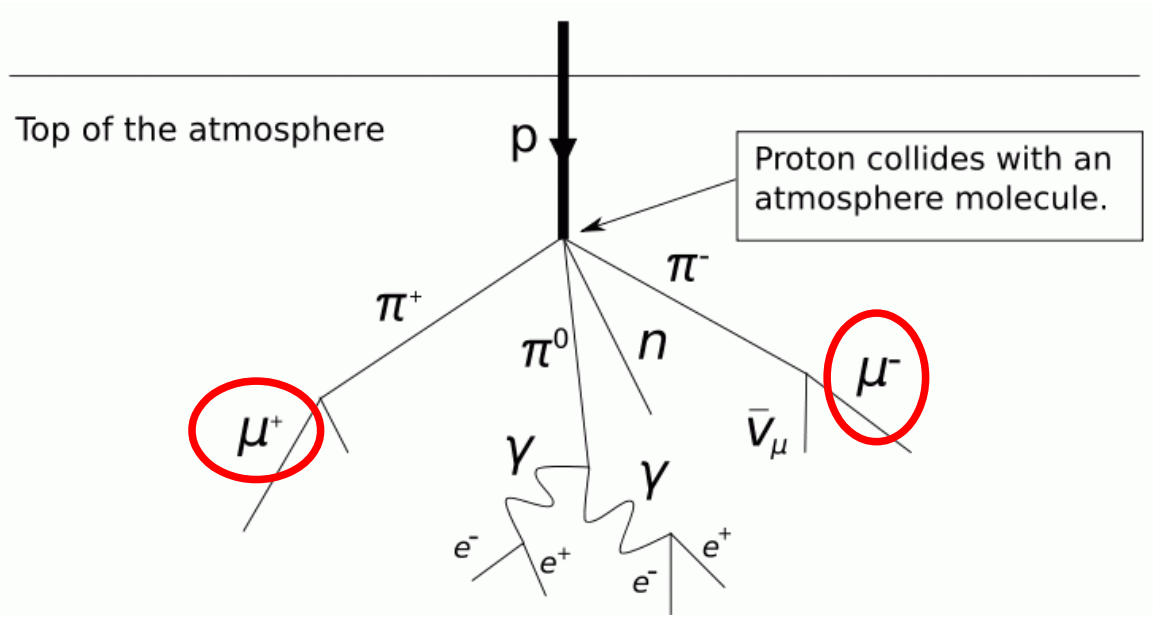
- Single top and Higgs
  - We are involved in $\gamma\gamma$, where interference happens twice (production and decay)
  - Possible *memoire*: extrapolation to future data
  - Co-tutoring by Hamed Bakhshiansohi (post-doc)
- Angular asymmetries in $t\bar{t}W$
  - Very sensitive (indirectly) to many forms of new physics
  - Possible *memoire*: extrapolation to future data
  - Co-tutoring by Pieter David (post-doc)



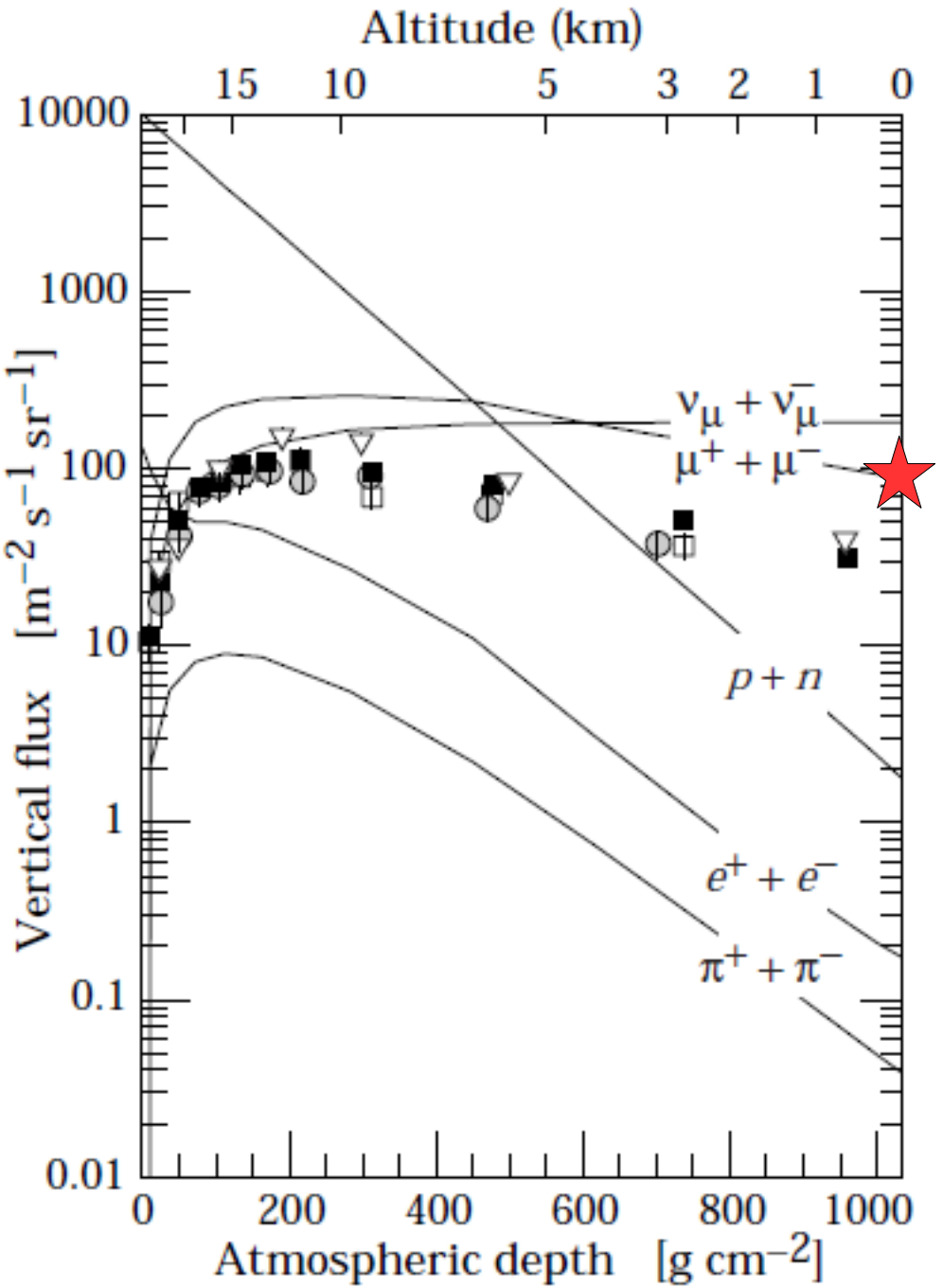
Plot from the ttW theory reference:
Maltoni, Mangano, Tsikinos, Zaro,
arXiv:1406.3262 [hep-ph]
(CMS analysis is ongoing)

Muography

- Cosmic rays give a free and abundant flux of energetic particles
- At sea level, almost only muons survive from the „cosmic showers“
- Muons are very penetrating particles (remember why?)
- Can be used for „radiography“ of very large structures



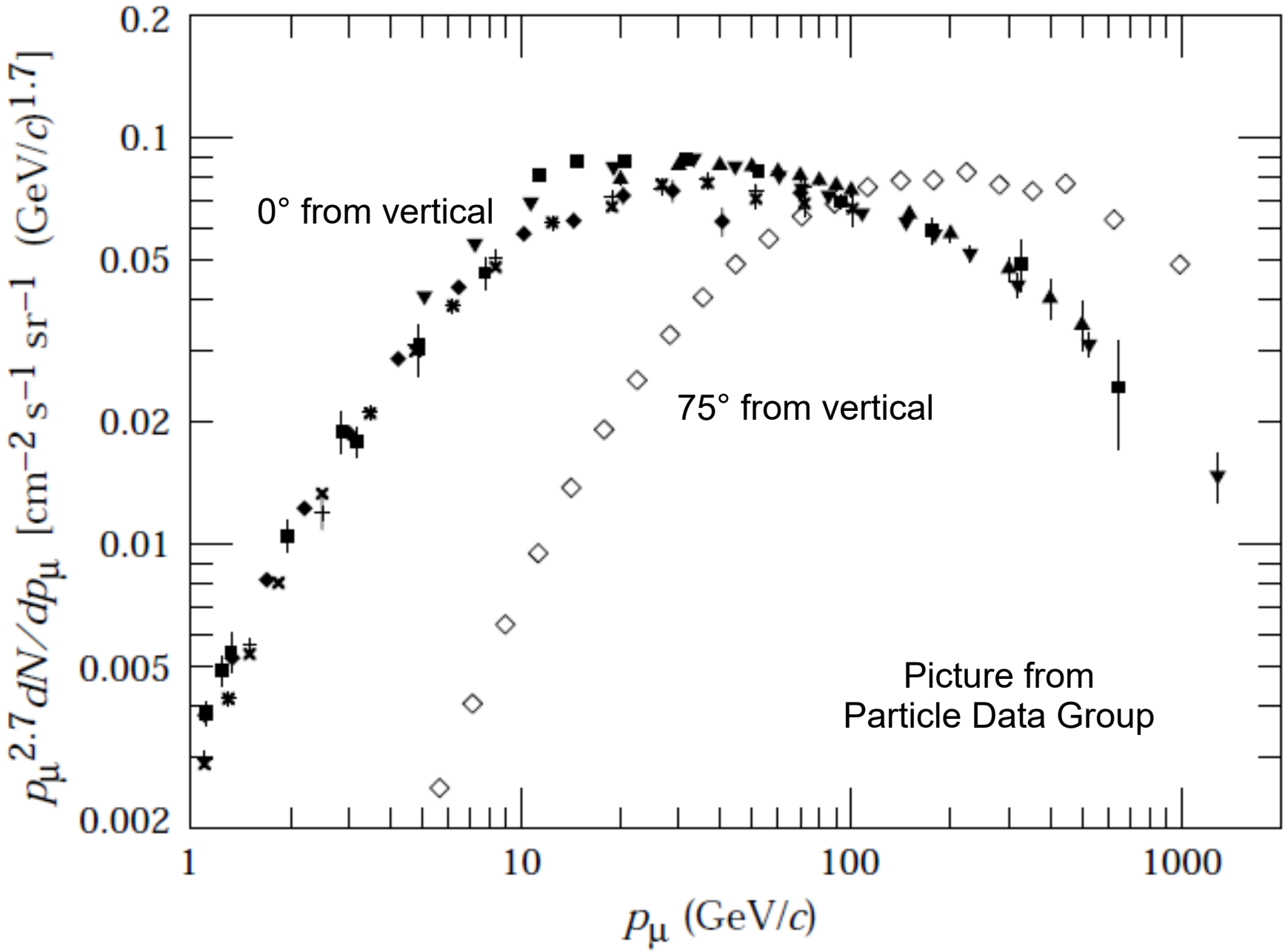
(Picture from wikipedia)



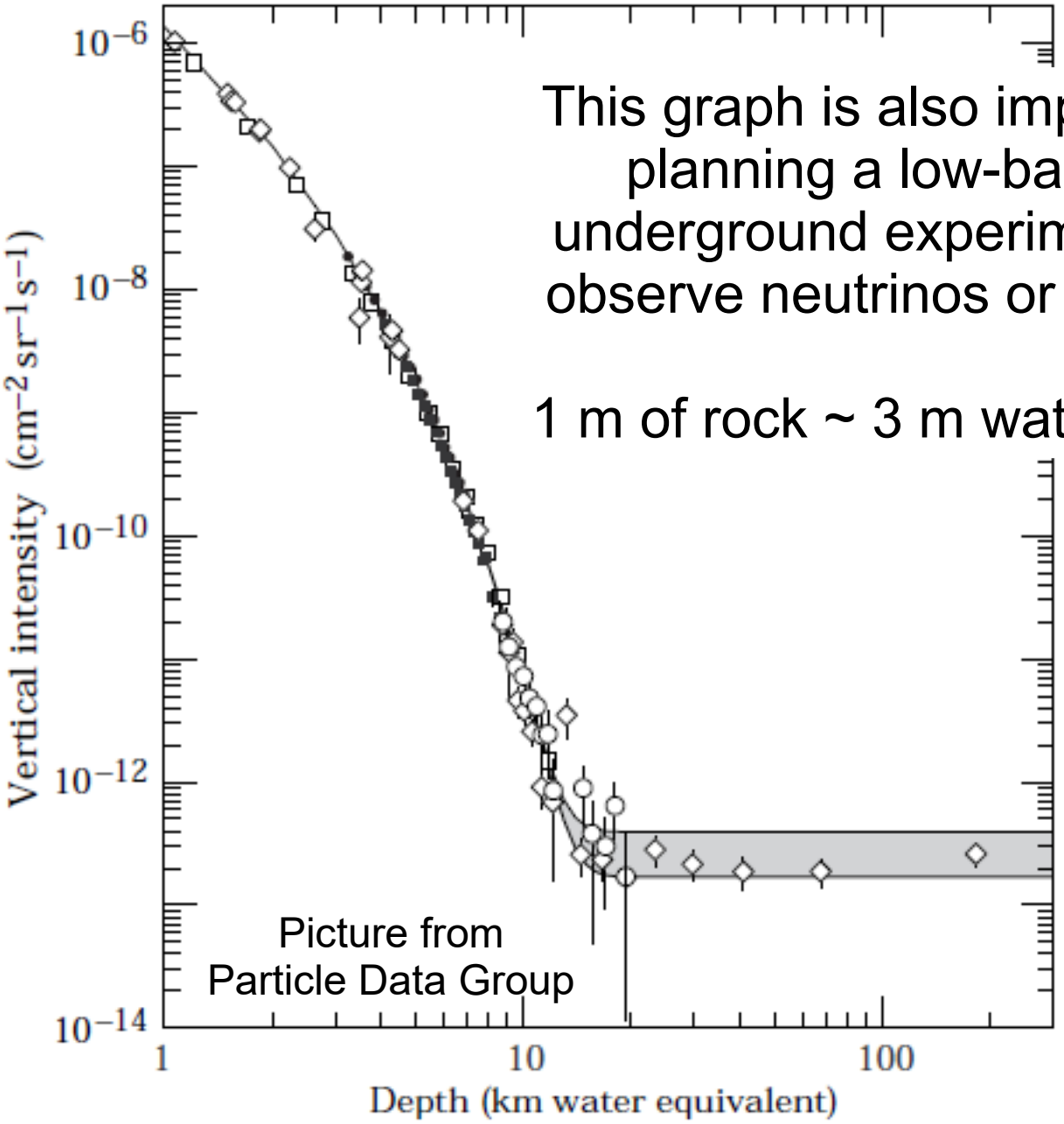
At ground level, the visible flux is dominated by muons

Picture from Particle Data Group (link)

All curves are for E>1 GeV; points are experimental measurements for negative muons



Question: how do you explain the difference?

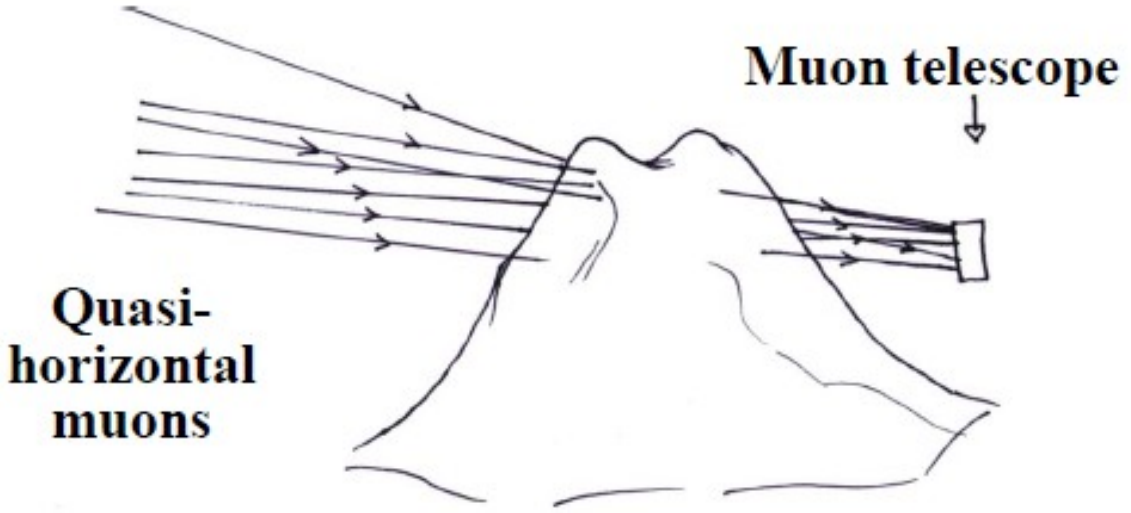


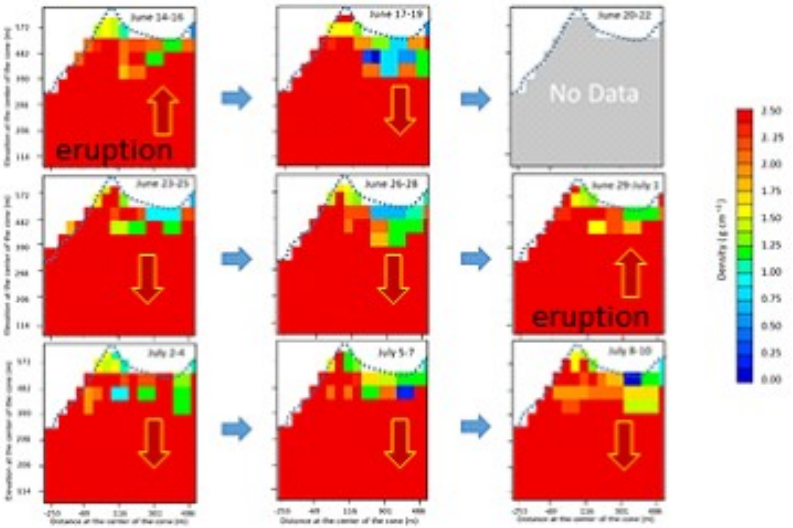
This graph is also important when planning a low-background underground experiment (e.g., to observe neutrinos or dark matter)

1 m of rock ~ 3 m water equivalent

Digression: explain the shape above 10 km w.e.

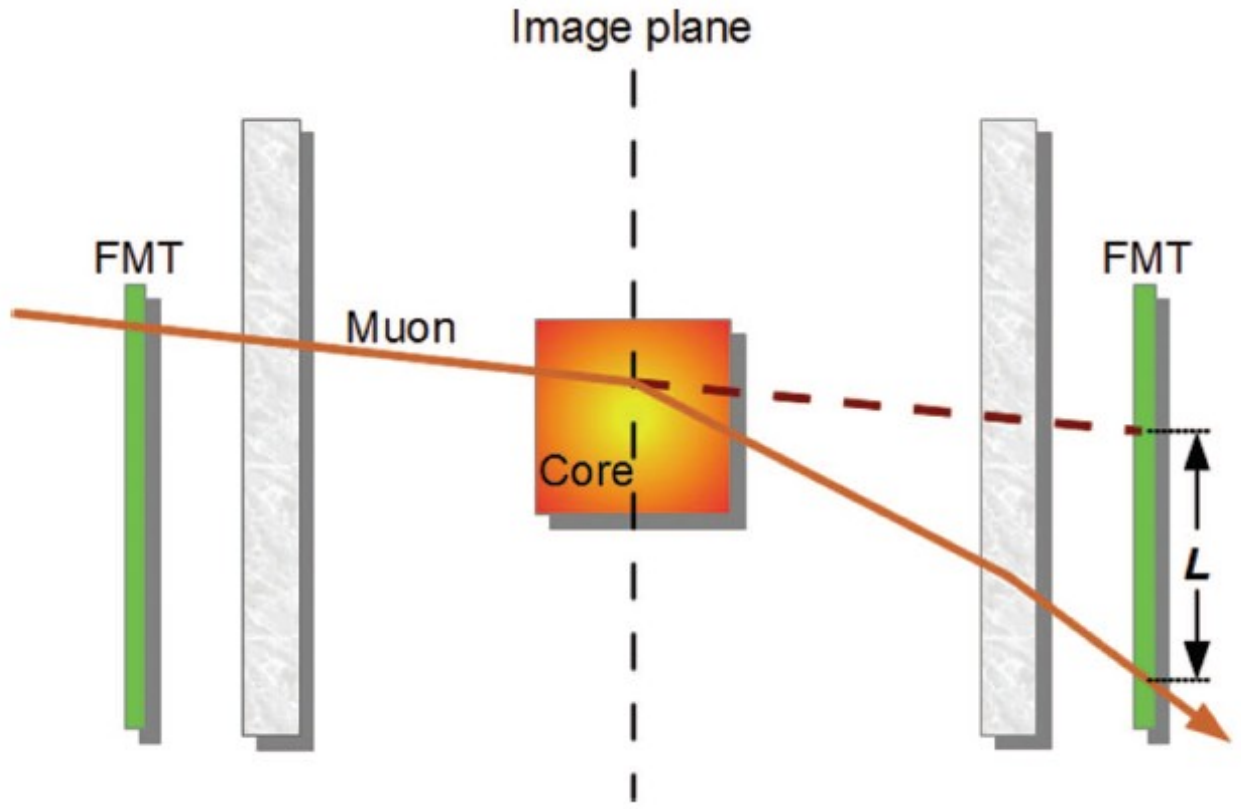
Absorption method
(application to volcano radiography)





- Basic idea: just like normal radiography, with μ instead of X-rays
- Static studies: useful for volcanologists
- Time-dependent studies (monitoring): useful for Civil Protection and volcanologists
- Mixed phys/geo groups are active in Japan, Italy, France
- **Possible *memoires***: many aspects of analysis of data from Vesuvius and Stromboli in collaboration with University of Naples

Scattering method
(application to nuclear reactor monitoring)



- Exploits multiple scattering in high-Z materials (like nuclear reactor fuel, to monitor at a distance)
- Used in Japan for the Fukushima reactor after the earthquake
- **Possible *memoire***: simulation studies to further develop the idea, in collaboration with Gent University and Tokyo U.

Questions?