Hitchhikers

A guide to survive with early results of LHC RUN II
~ Long term prospects ~

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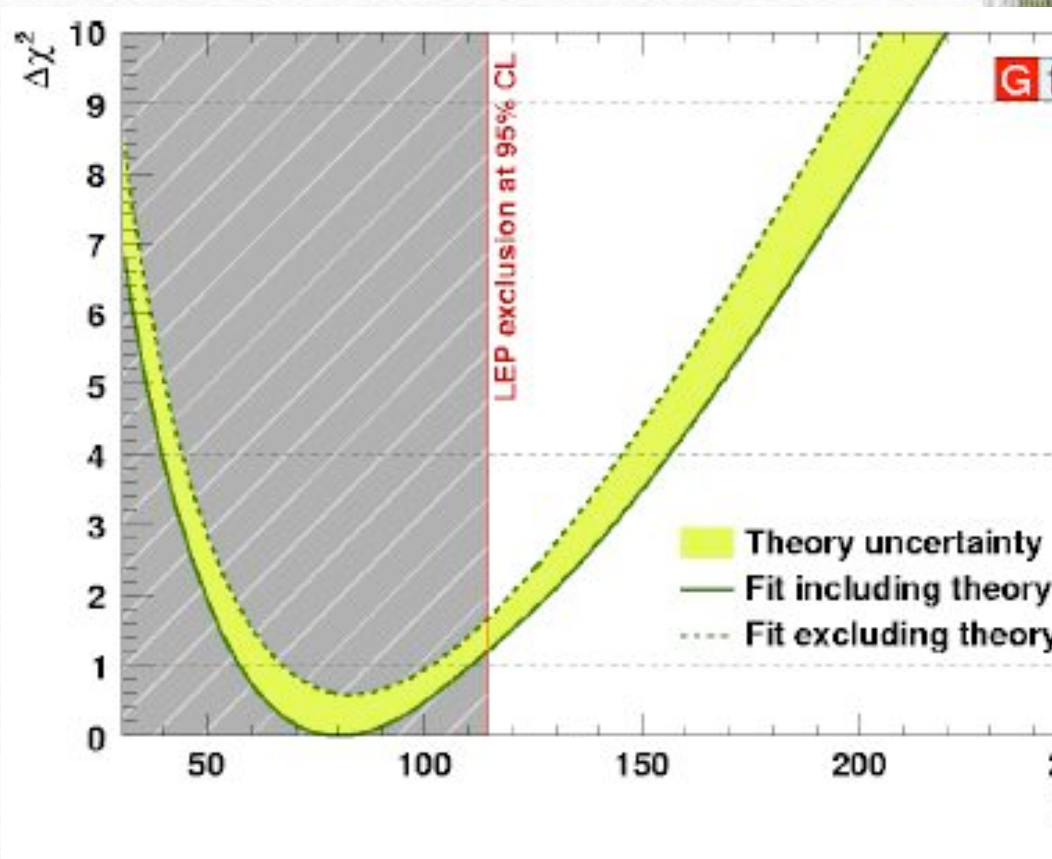
Particle physics has been

- ….. answering big questions
- and has been **allowed to exist** because it can answer remaining big questions (such as origin of symmetry breaking, charge, gauge interaction, dark matter,
- this talk
  - What particle physics have done in the past
  - What LHC is doing right now
  - Thinking about future

1. History

Looking back LEP era
EW precision



- No deviation of standard model. **Field Theory win. Light higgs boson was suggested.**
- People started to believe SUSY and thought **neutralino** as standard dark matter candidate.
- Technicolor became difficult and people have left to **effective theory: Little Higgs model/composite model:** Higgs boson is NG boson of some global symmetry **without specifying** the origin of symmetry breaking
- **Important Lessons** have been learned from this approach
  - top sector need to be enlarged → **top partner**
  - Z2 symmetry separating new sector from SM sector → TeV scale new physics **(stable spin 1 particle as dark matter)**

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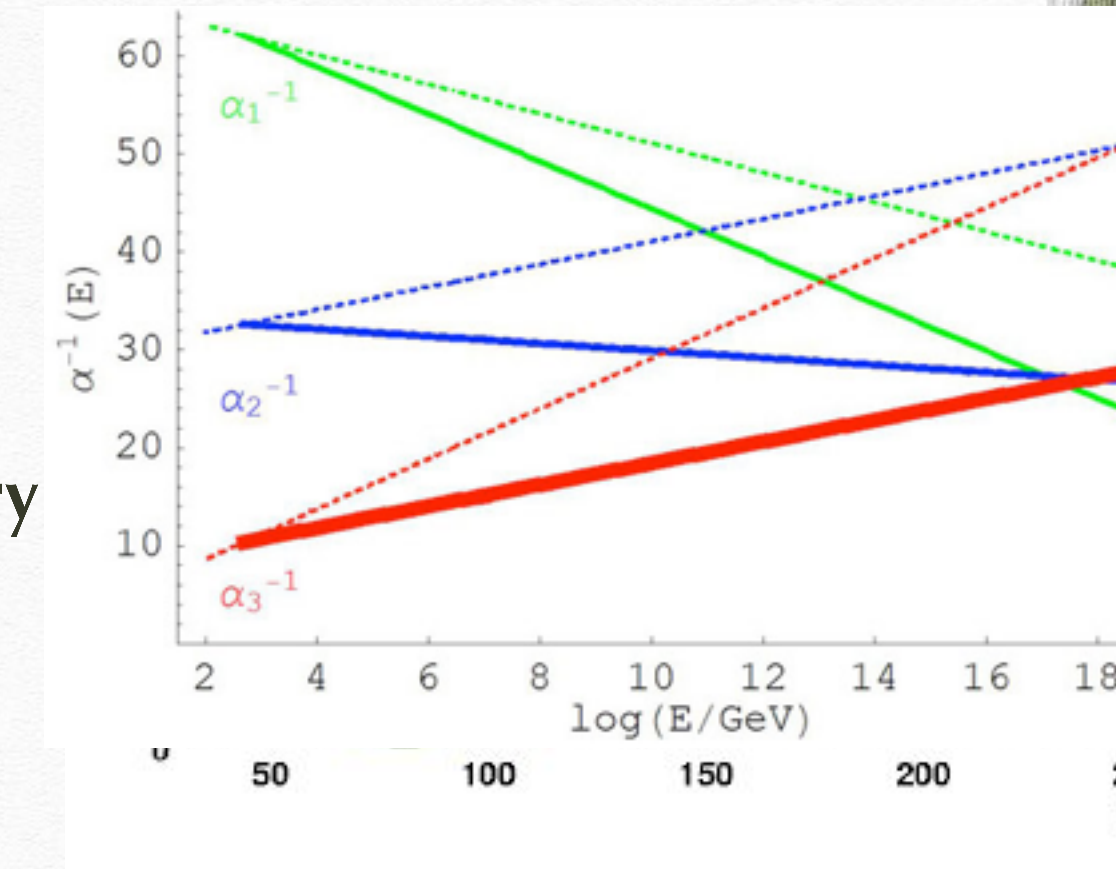

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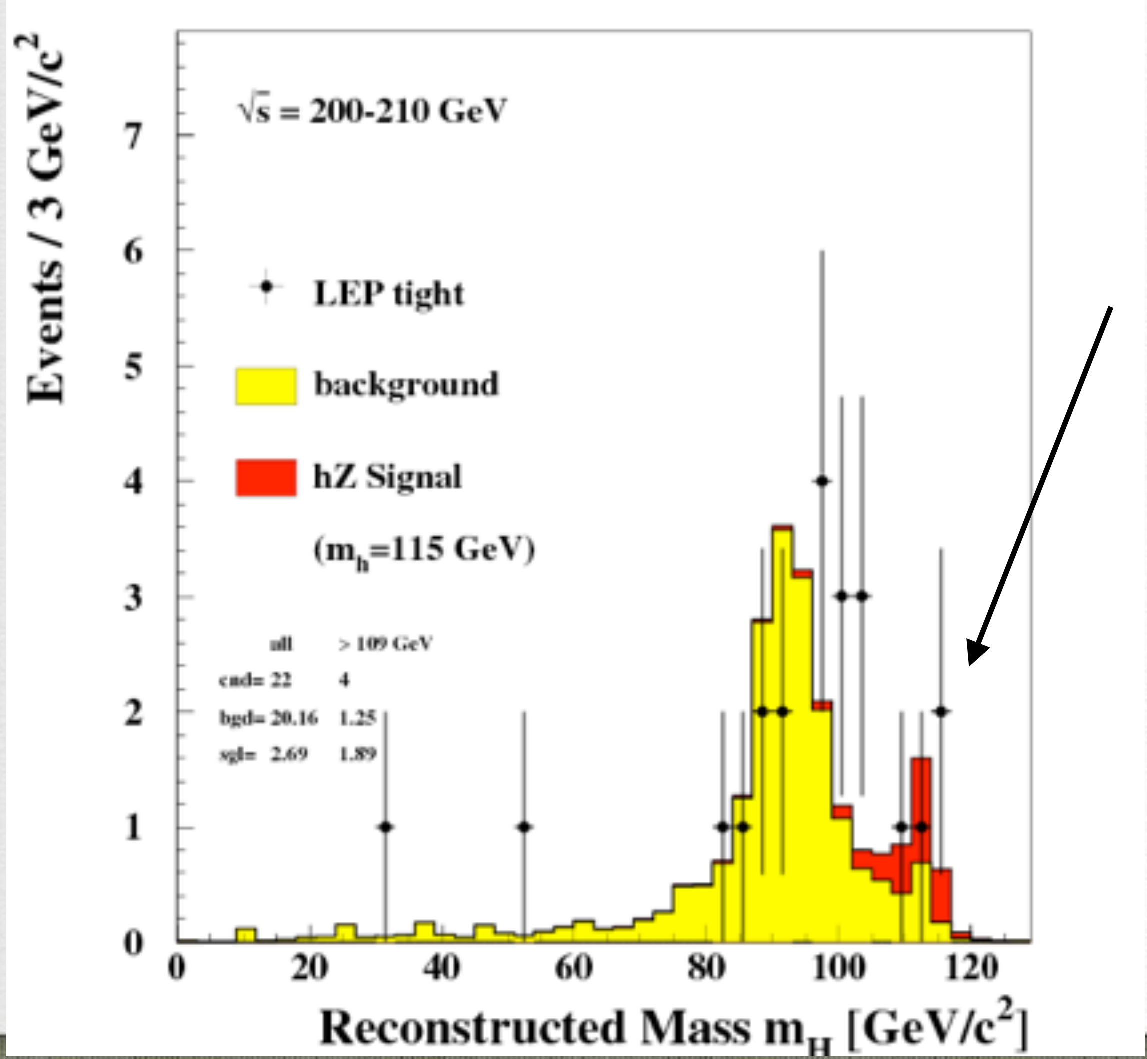
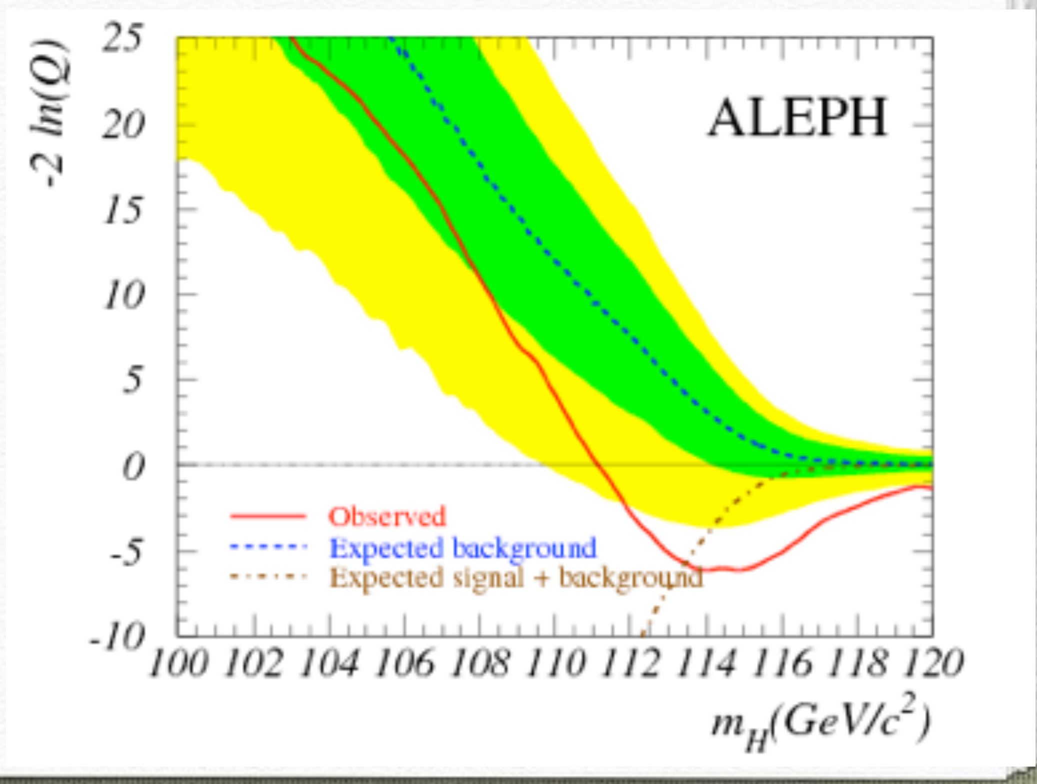
LEP is Demolished for LHC

The 115 GeV Higgs Odyssey John Ellis (CERN) 2000 (at that time we were planning to start LHC at 2005)

On his way home from Troy, Odysseus had arrived within reach of Ithaca when a great storm blew up. He was swept away, and only several years later was he able to return to reclaim his rights from the rapacious suitors, with the aid of his son Telemachus. Some wonder whether this epic is repeating itself, if the Higgs weighs 115 GeV. If so, are CMS and ATLAS cast in the role of Telemachus? In this paper, I first discuss how close to Ithaca LEP may have been,…



This peak was interpreted and argued very loudly at that time.We learned lots about "global significance" since then



What Odyssey had been doing **for 12years:** role of Model building

2years (budget) + 2 (delay)+ 2(He) was added

- **SUSY**
- Gauge Mediation: **Low energy SUSY breaking,** and gravitino dark matter (spin 3/2, Late decay, connection to BBN)
- Anomaly Mediation :**suppressed gaugino mass,** wino dark matter, moduli decay
- Little Hierarchy argument ,natural SUSY?

- **Extra dim**

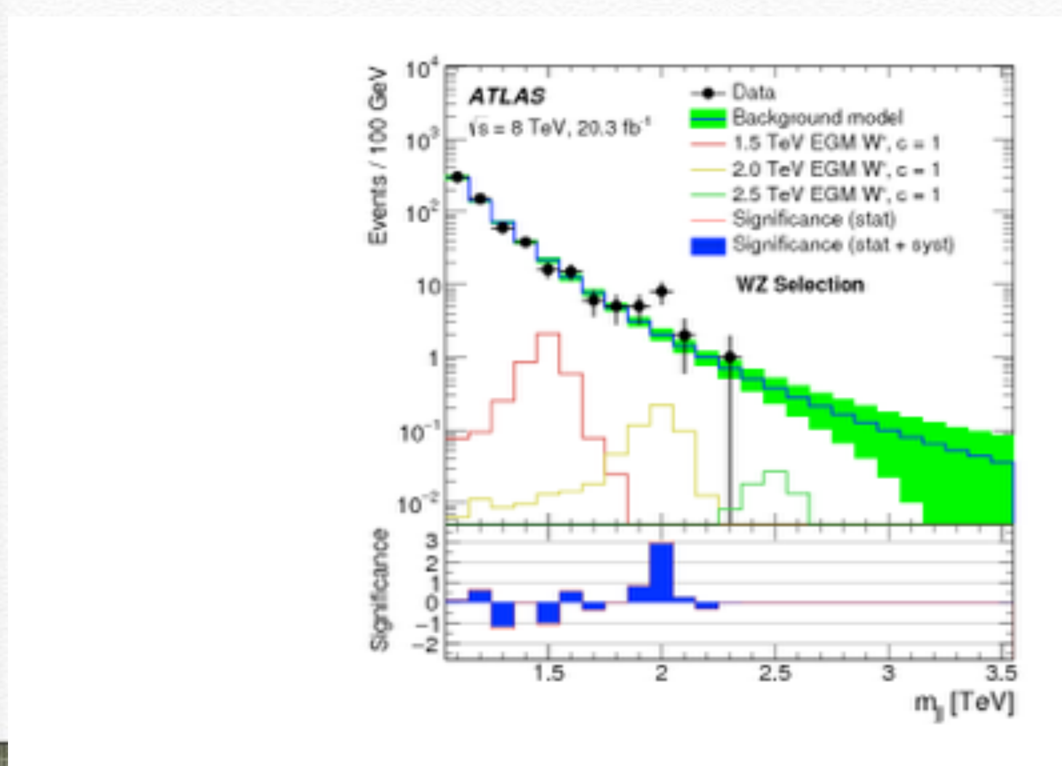
- Warped Extra dimension(1998, 1999) Planck scale → EW scale. Yukawa coupling can have geometrical meaning, U(1) gauge boson KK dark matter

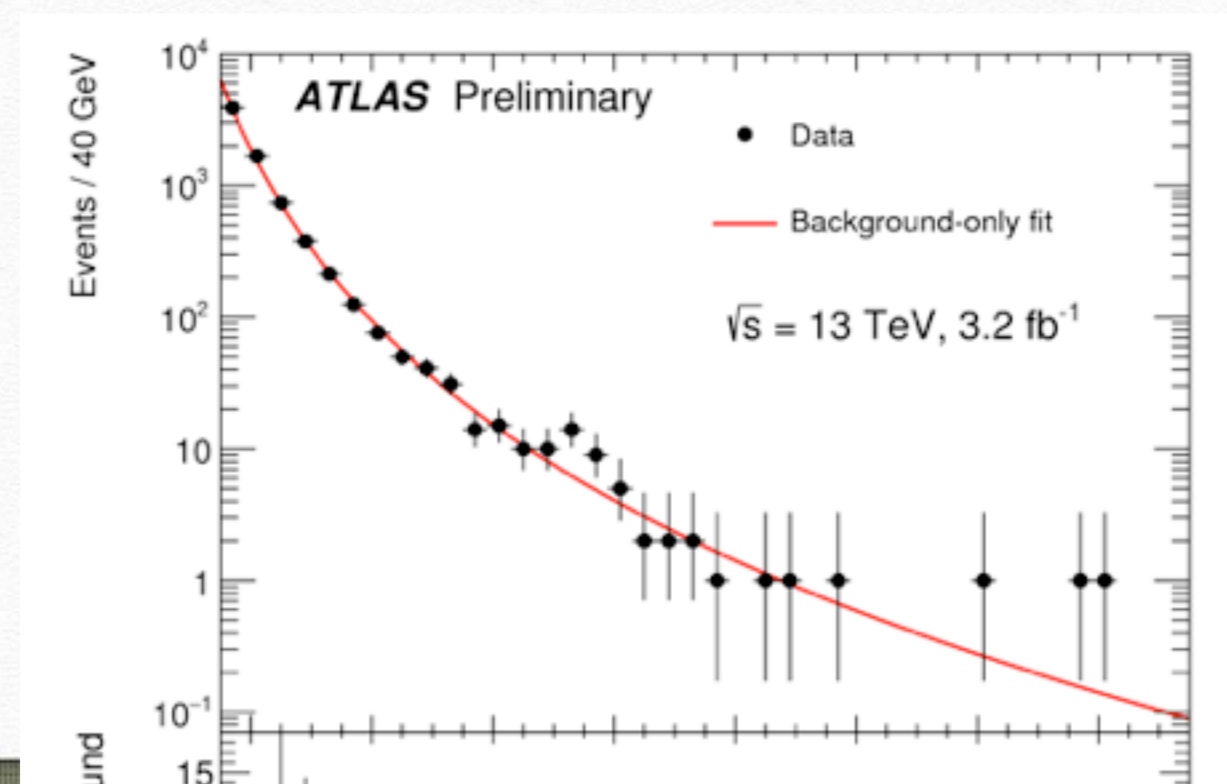
- **Composite**

- Little Higgs models (2001) & Minimal composite models

What LHC have done so far

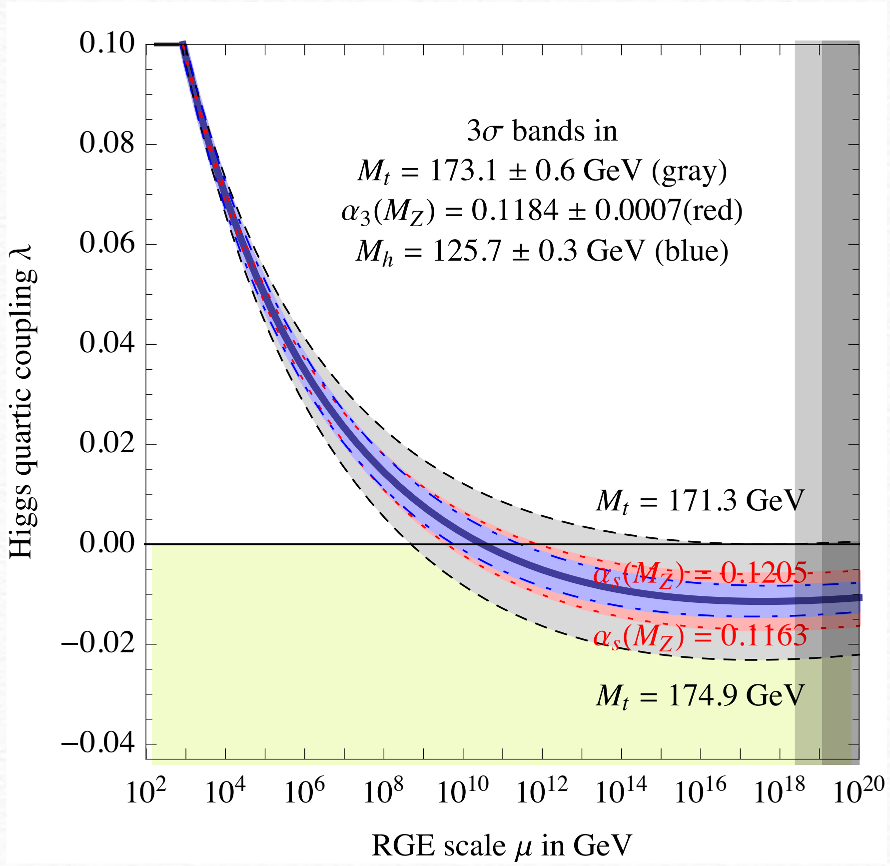
- finding SM Higgs boson at 125GeV
- not finding SUSY ~TeV range tension with naturalness
- not finding any top partner <TeV range
- Finding **"mostly harmless"** peaks and excesses





2.Higgs and SUSY

Higgs boson in SM



Recent Cosmological issues:

Kearney, Yoo, Zurek Physical Review D91 123537

probability of ***Higgs field falls in unstable region during the inflation*** can be significant.

potential danger developing anti-de Sitter patches

Recent follow up paper 1607.00381 East et al

Espinosa, Giudice, Morgante, Riotto,Senatore Strumia, Tetradis JHEP 1509(2015) 174

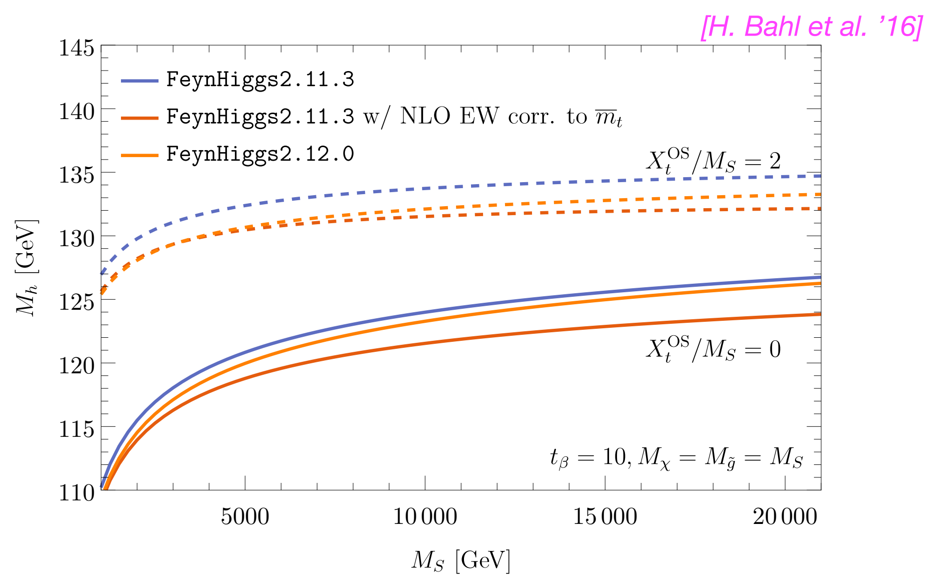
lower limit to reheating temperature depending on the Higgs coupling to gravy and Habble constant during the inflation.

Very high scale SUSY vs Future collider reaches

How heavy it can be ?

Higgs mass correction is challenged by large log

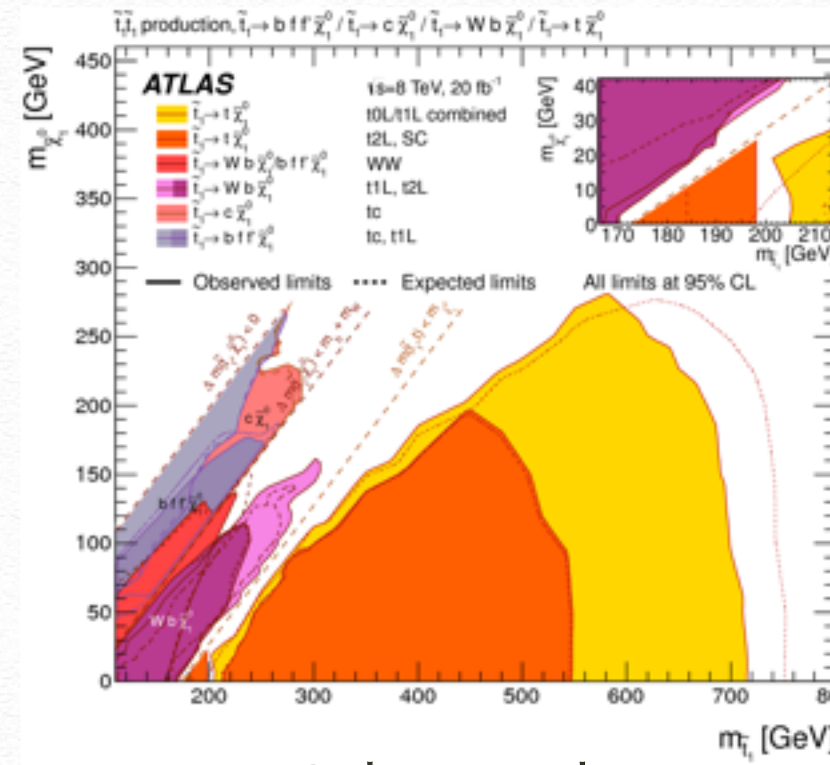
Numerical impact of new contributions



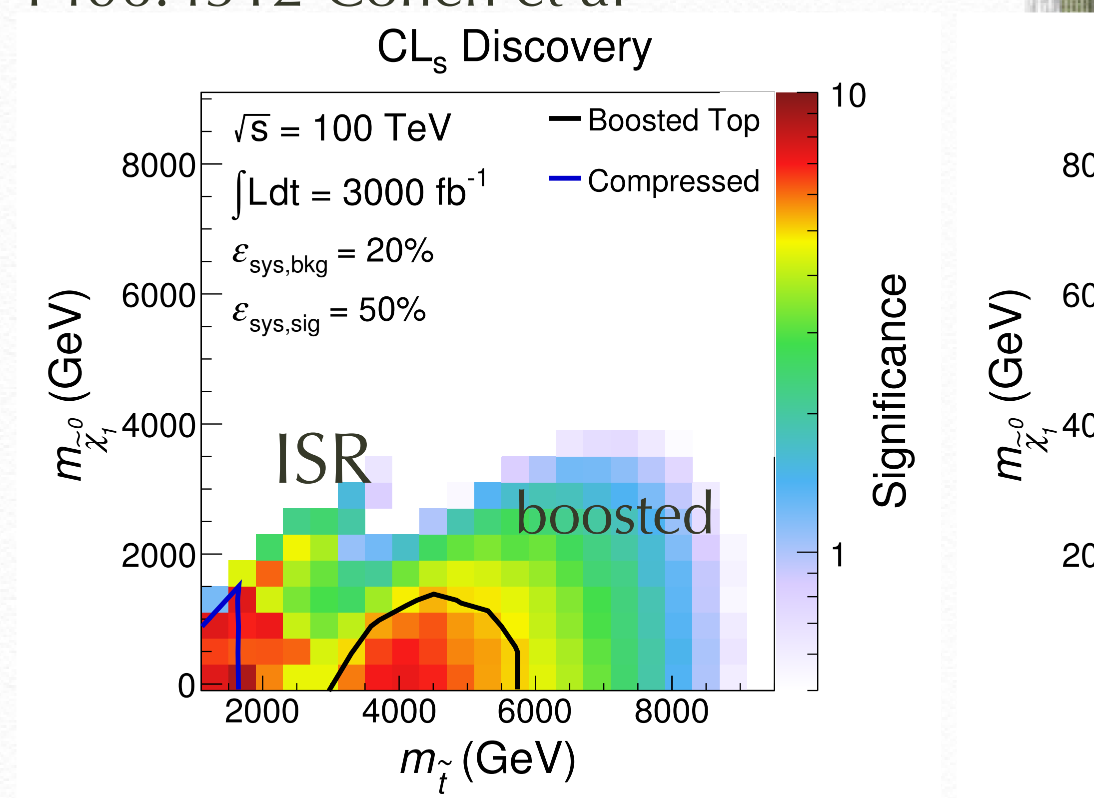
⇒ Main contribution from electroweak contributions to the running top mass

Higher-order SUSY Higgs, Georg Weiglein, SUSY 2016, Melbourne, 07 / 2016 31

How light it can be?

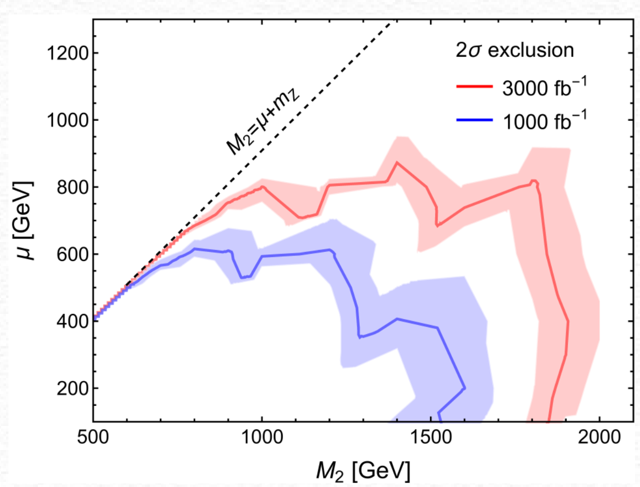


1406.4512 Cohen et al

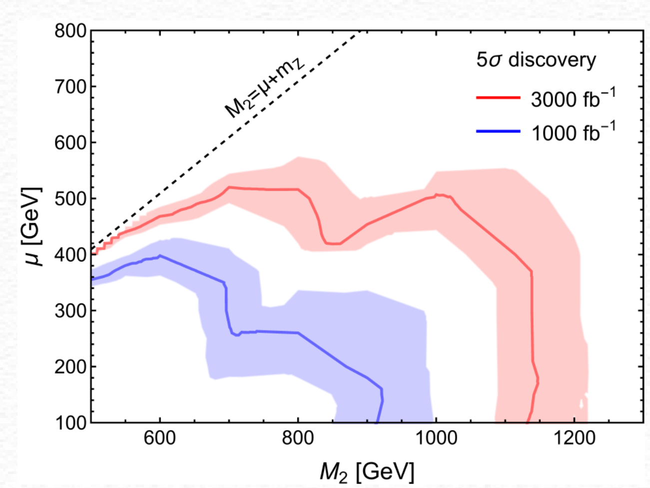


How far we can reach?

1410.1532 Acharya et al



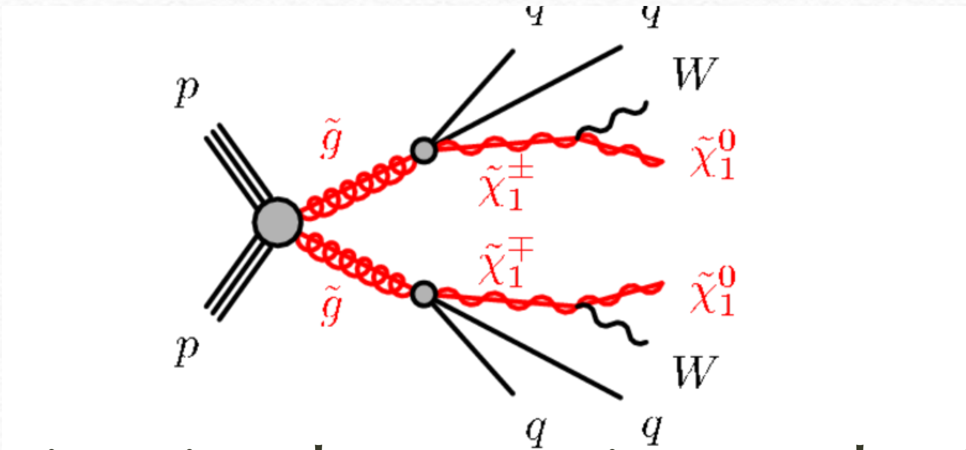
(a)

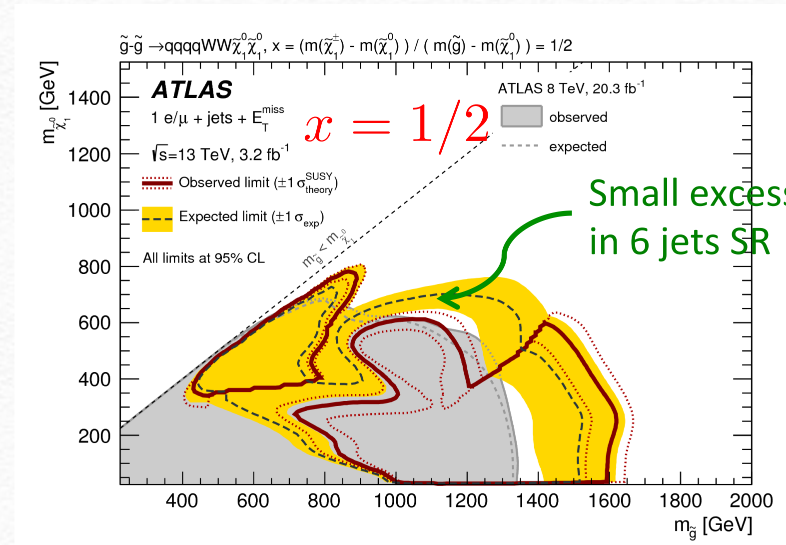


(b)

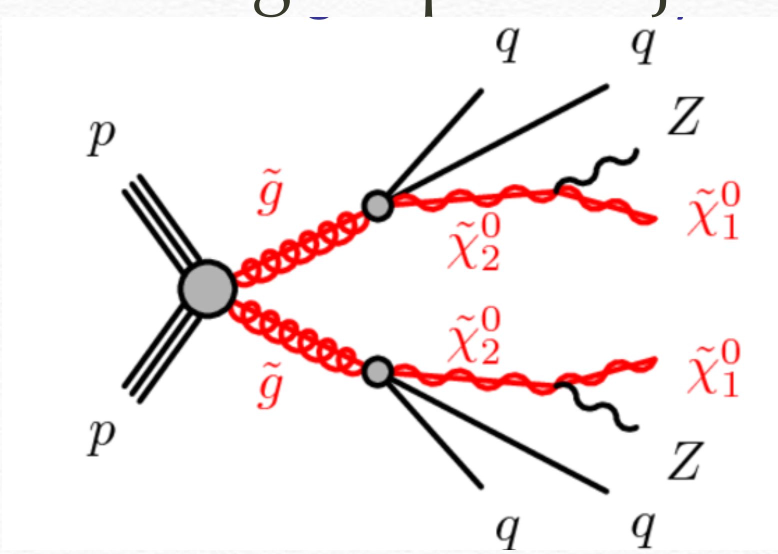
Any SUSY sign at 13TeV
(plots with the largest expect vs observed deviations)

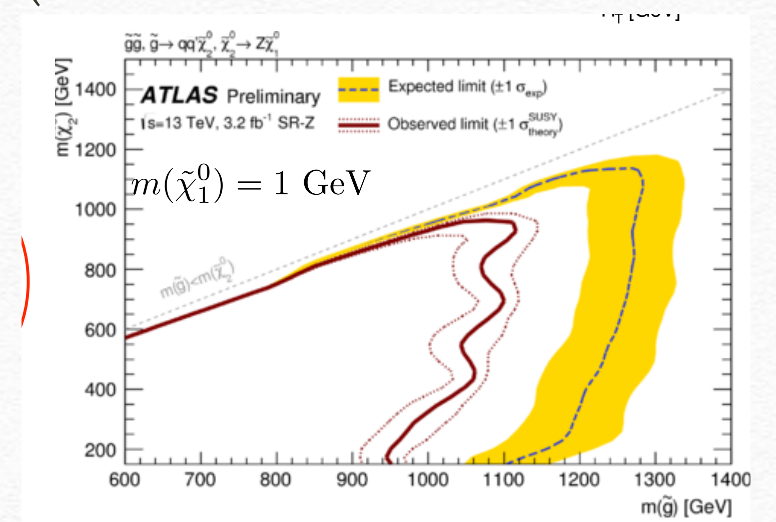
1 lepton + jets + missing ET



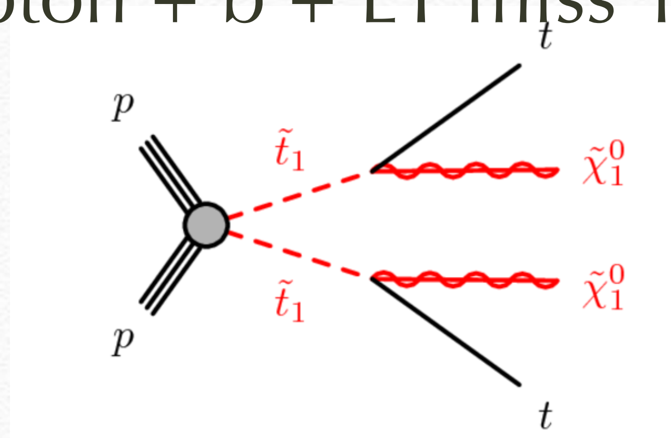


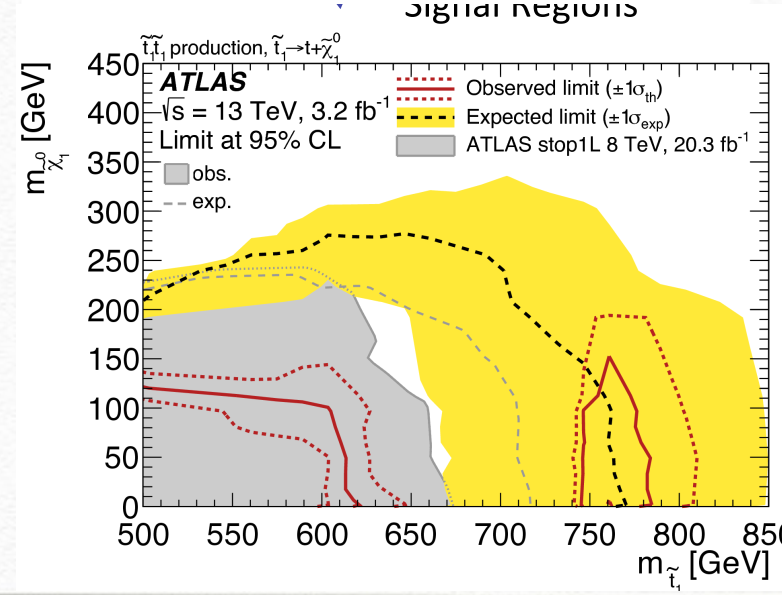
opposite sign leptons jets and missing ET(ATLAS-CONF-2015-082





one lepton + b + ET miss 1603.03903





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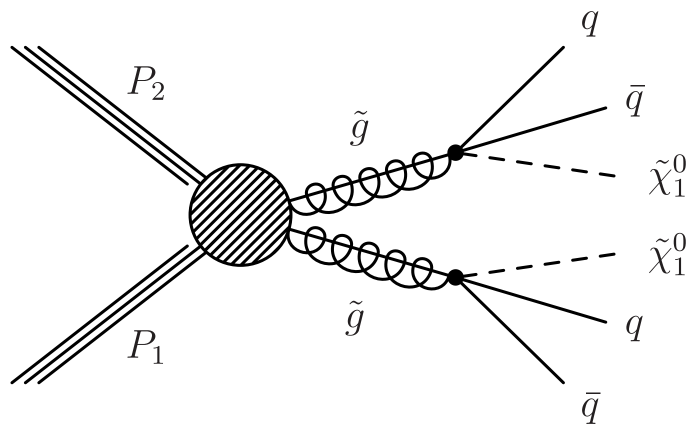

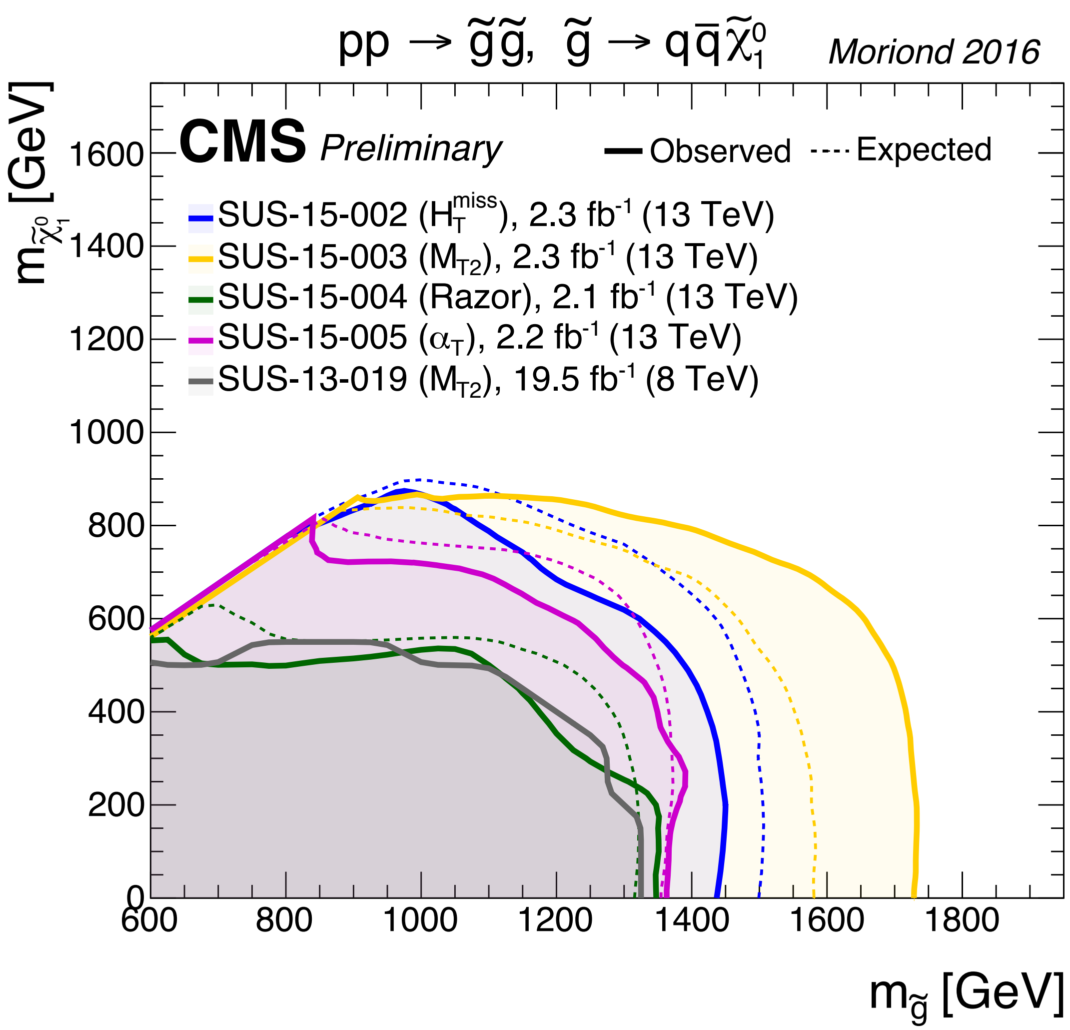

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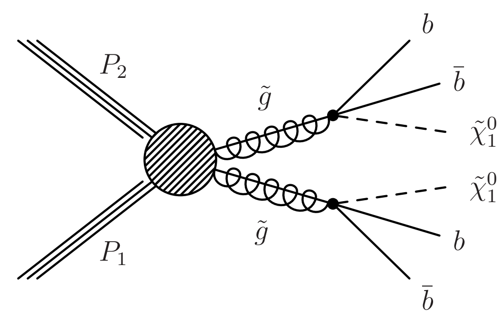

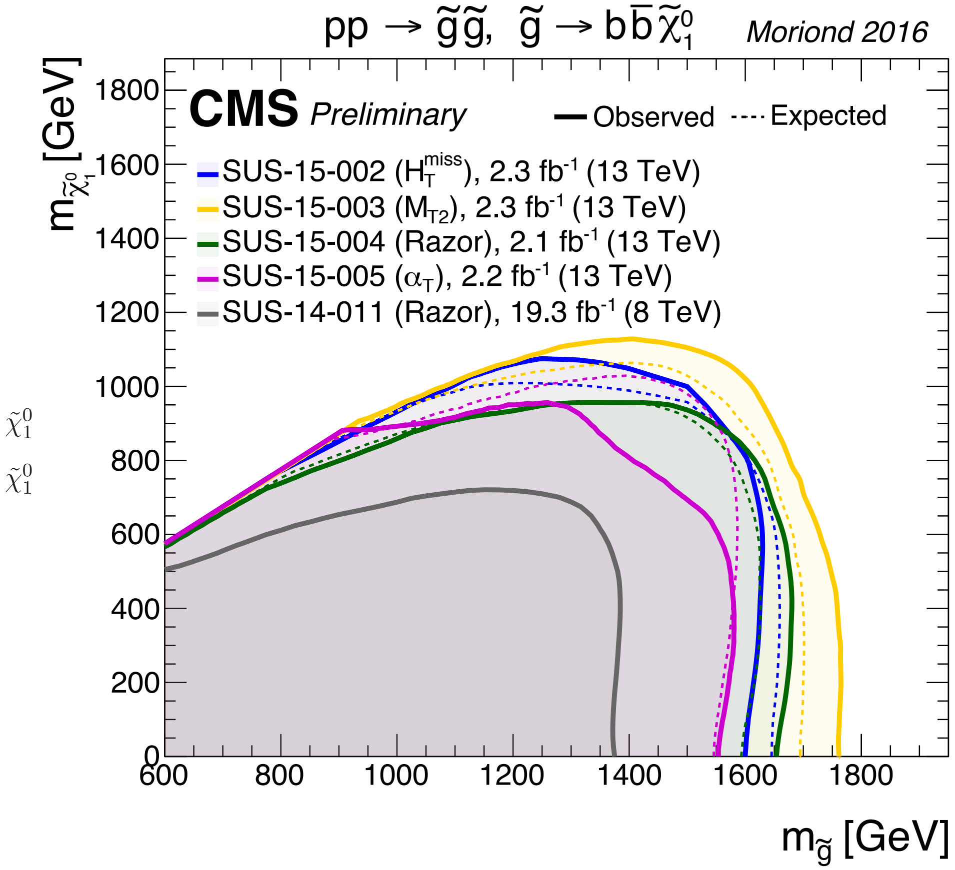

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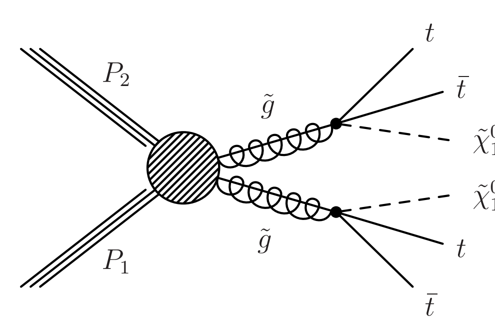
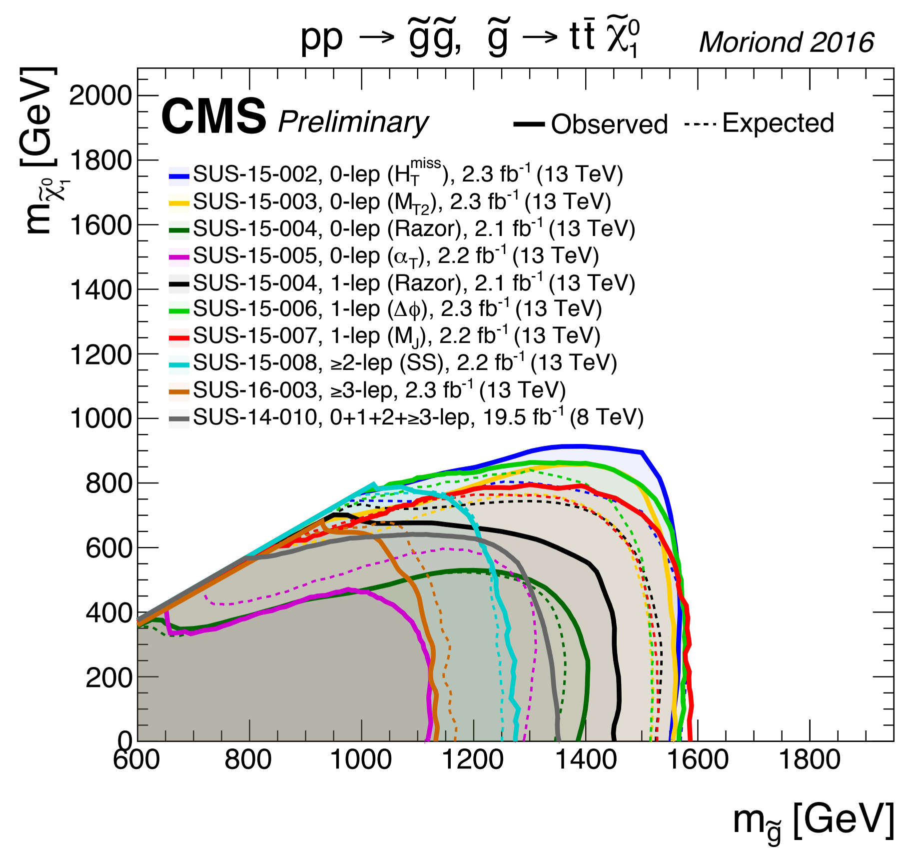




https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

background modeling at 13TeV

proton → u, d(harder) , g(soft, but many)
leading order gg→tt(large color factor)) NLO qg→qtt(largest among luminosity) **so, only at NNLO scale dependence being canceled at last**

Physics process	Generator	Cross-section normalisation	PDF set	Parton shower	Tune
$W(\to \ell\nu)$ + jets	Sherpa 2.1.1	NNLO	CT10	Sherpa	Sherpa default
$Z/\gamma^*(\to \ell\bar{\ell})$ + jets	Sherpa 2.1.1	NNLO	CT10	Sherpa	Sherpa default
γ + jets	Sherpa 2.1.1	LO	CT10	Sherpa	Sherpa default
$t\bar{t}$	Powheg-Box v2	NNLO+NNLL	CT10	Pythia 6.428	Perugia2012
Single top (t-channel)	Powheg-Box v1	NLO	CT10f4	Pythia 6.428	Perugia2012
Single top (s- and Wt-channel)	Powheg-Box v2	NLO	CT10	Pythia 6.428	Perugia2012
$t\bar{t} + W/Z/WW$	Madgraph 5.2.2.2	NLO	NNPDF2.3LO	Pythia 8.186	A14
WW, WZ, ZZ	Sherpa 2.1.1	NLO	CT10	Sherpa	Sherpa default
Multi-jet	Pythia 8.186	LO	NNPDF2.3LO	Pythia 8.186	A14

on going progress on reducing the theoretical uncertainty on the backgrounc

uncertainties are the result of the control region statistical uncertainties and the systematic uncertainties entering a specific control region. In brackets, uncertainties are given relative to the expected total background yield, also presented in the Table. Empty cells (indicated by a '-') correspond to uncertainties lower than 1 per mil.

statistics in CR improve these

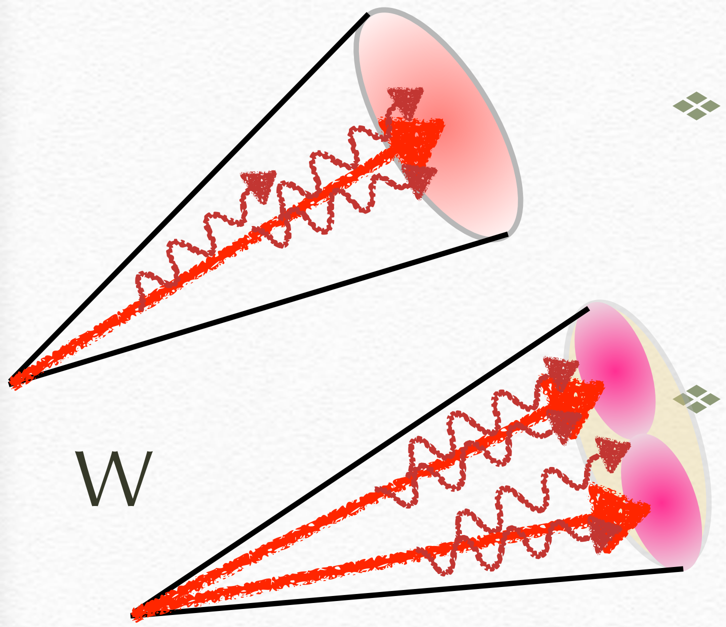
Channel	**2jl**	**2jm**	**2jt**	**4jt**	**5j**	**6jm**	**6jt**
Total bkg	283	191	23	4.6	13.2	6.9	4.2
Total bkg unc.	±24 [8%]	±21 [11%]	±4 [17%]	±1.1 [24%]	±2.2 [17%]	±1.5 [22%]	±1.2 [29%]
MC statistics	–	±2.3 [1%]	±0.5 [2%]	±0.31 [7%]	±0.5 [4%]	±0.4 [6%]	±0.32 [8%]
$\Delta\mu_{Z+\mathrm{jets}}$	±7 [2%]	±6 [3%]	±2.5 [11%]	±0.7 [15%]	±1.0 [8%]	±0.8 [12%]	±0.7 [17%]
$\Delta\mu_{W+\mathrm{jets}}$	±10 [4%]	±8 [4%]	±1.2 [5%]	±0.5 [11%]	±1.1 [8%]	±0.7 [10%]	±0.5 [12%]
$\Delta\mu$ Top	±1.8 [1%]	±2.0 [1%]	±0.23 [1%]	±0.26 [6%]	±0.4 [3%]	±0.24 [3%]	±0.22 [5%]
$\Delta\mu_{\mathrm{Multi-jet}}$	±0.05 [0%]	±0.09 [0%]	±0.1 [0%]	–	–	–	–
CRγ corr. factor	±11 [4%]	±7 [4%]	±1.0 [4%]	±0.17 [4%]	±0.4 [3%]	±0.21 [3%]	±0.15 [4%]
Theory Z	±8 [3%]	±4 [2%]	±2.4 [10%]	±0.6 [13%]	±0.6 [5%]	±0.5 [7%]	±0.6 [14%]
Theory W	±2.9 [1%]	±2.5 [1%]	±0.5 [2%]	±0.29 [6%]	±0.7 [5%]	±0.5 [7%]	±0.4 [10%]
Theory top	±2.1 [1%]	±2.1 [1%]	±0.28 [1%]	±0.12 [3%]	±0.8 [6%]	±0.4 [6%]	±0.13 [3%]
Theory diboson	±15 [5%]	±15 [8%]	±1.0 [4%]	–	±1.0 [8%]	–	–
Jet/$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.7 [0%]	±0.6 [0%]	±0.09 [0%]	±0.1 [2%]	±0.4 [3%]	±0.21 [3%]	±0.19 [5%]

3. Mostly Hamlesses

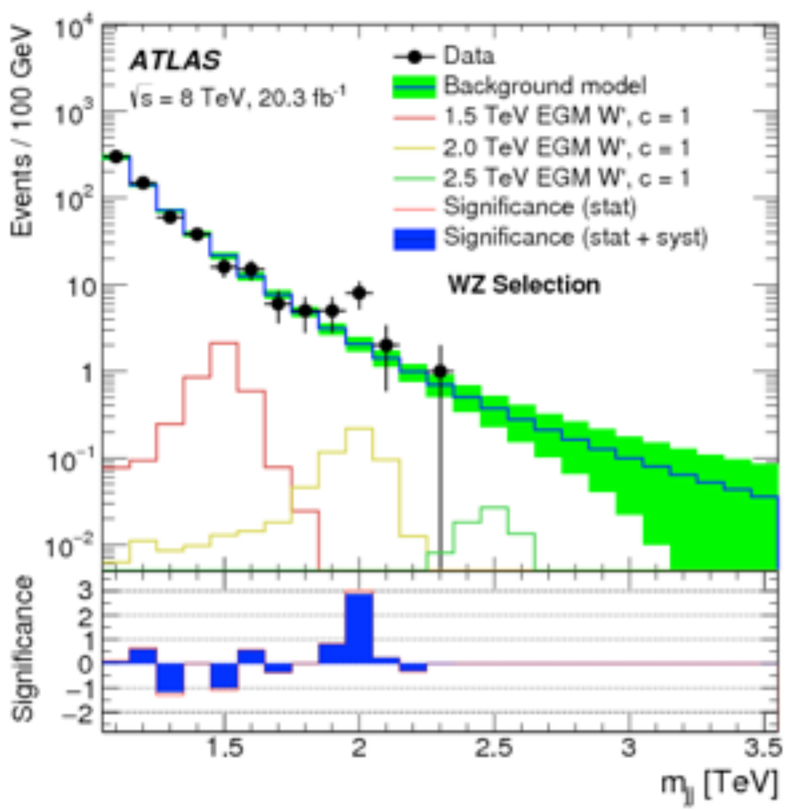
2TeV Gauge bosons and subjet analysis

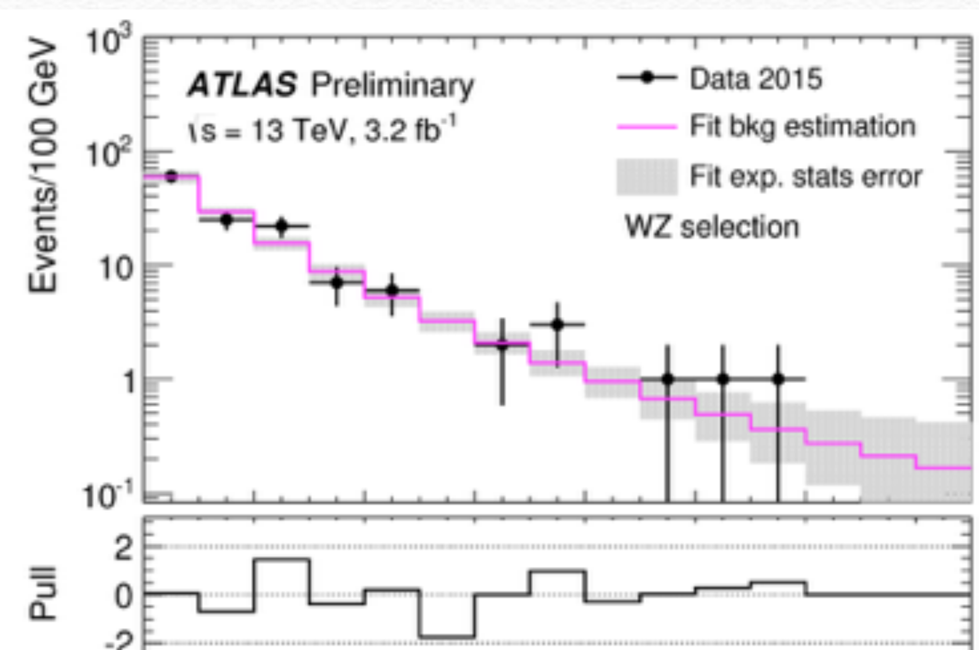
quark/gluion

W

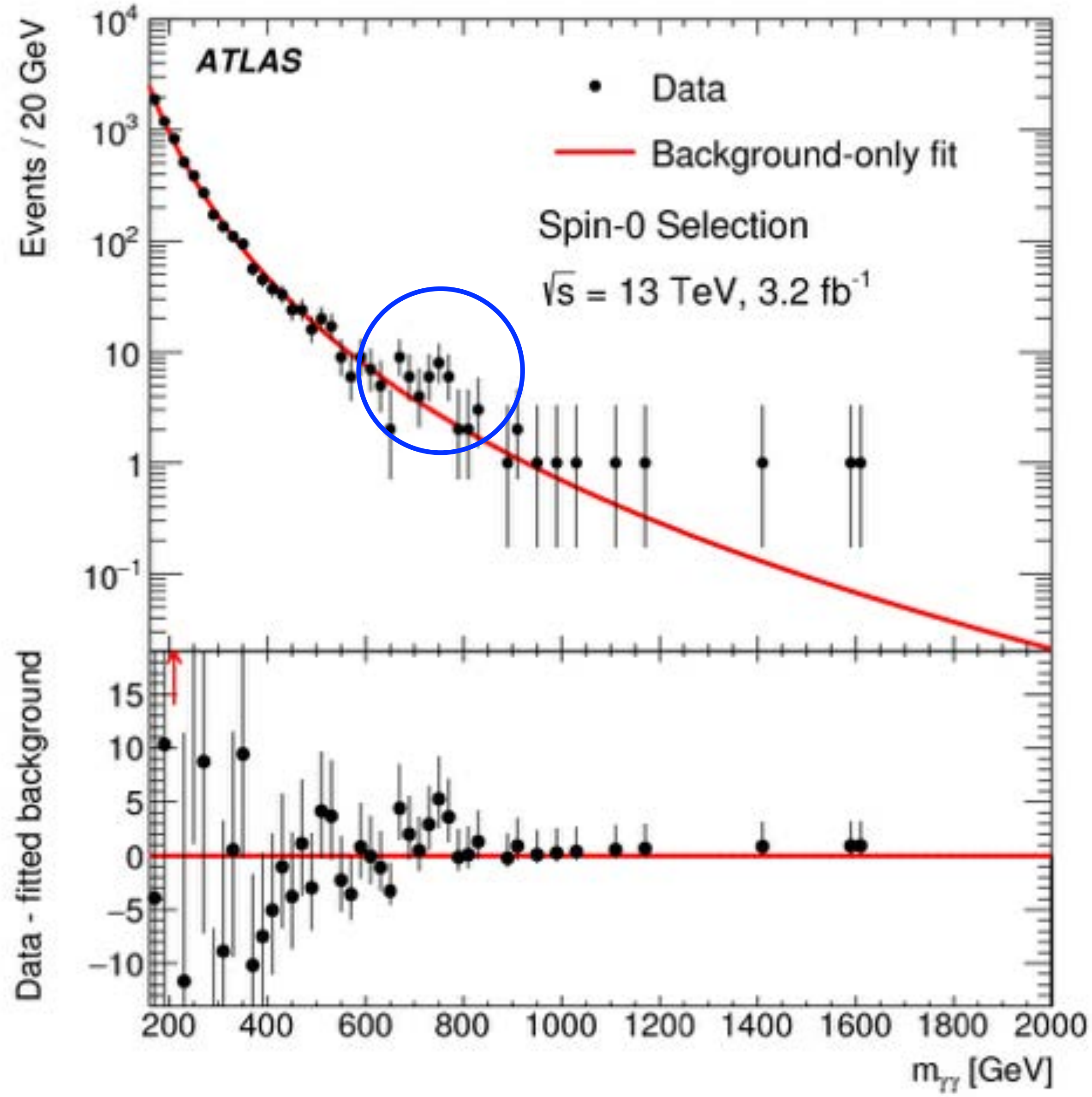


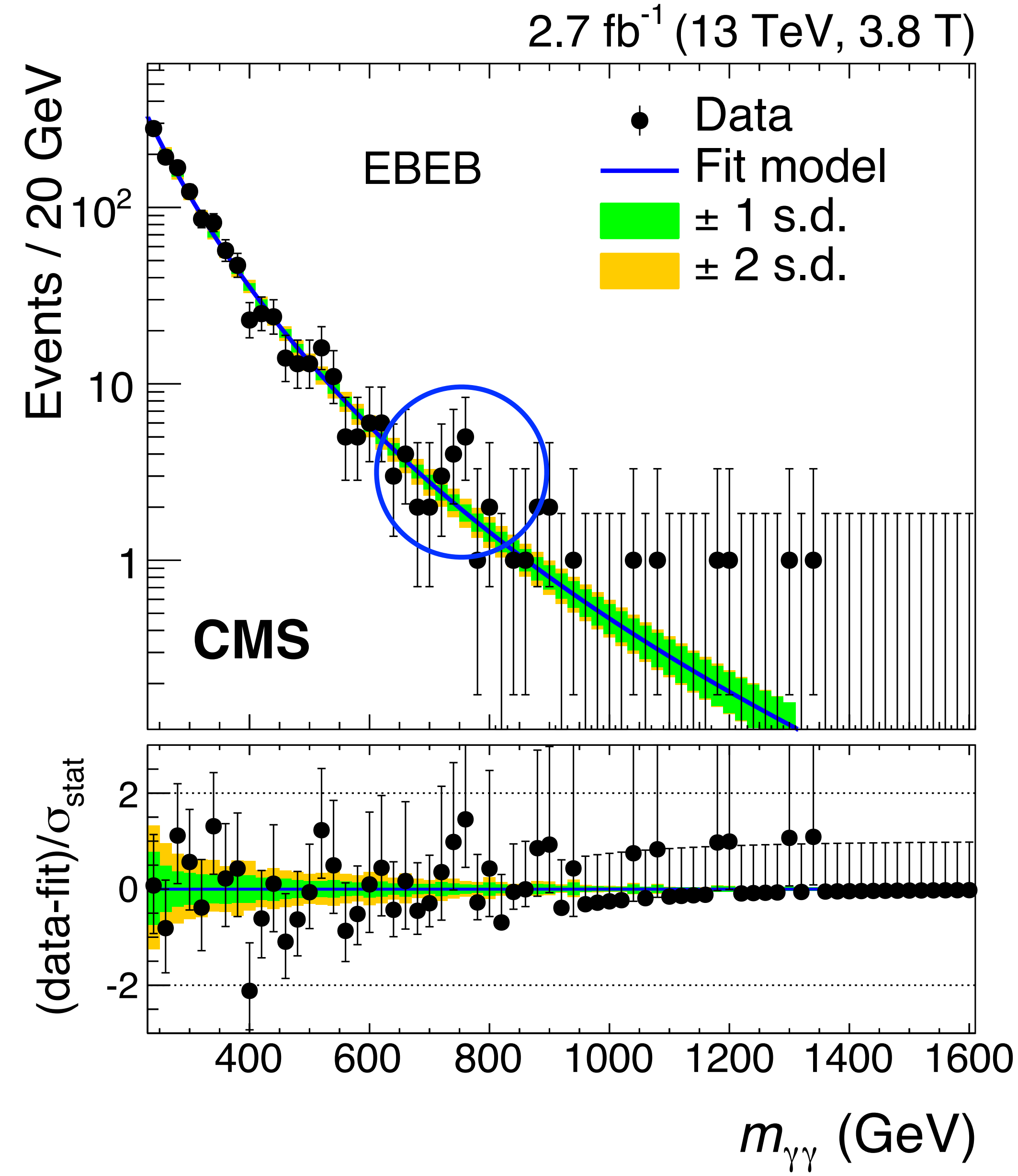
- ATLAS diboson excess: Rejection of QCD background by about 40~70. requiring two boson you gain lot
- boosted W (hadronic) is promising signature: idea started from 2007 Les Houches workshop (→ Butterworth et al 2008)
- Thing behind: IR& Collinear safe JET algorithm → Fastjet
  - N_{tr} used but being IR unsafe (still some kind of voodoo there)
- t-tbar resonance searches etc also on going→ better subjet understanding toward FCC





750 GeV Diphoton





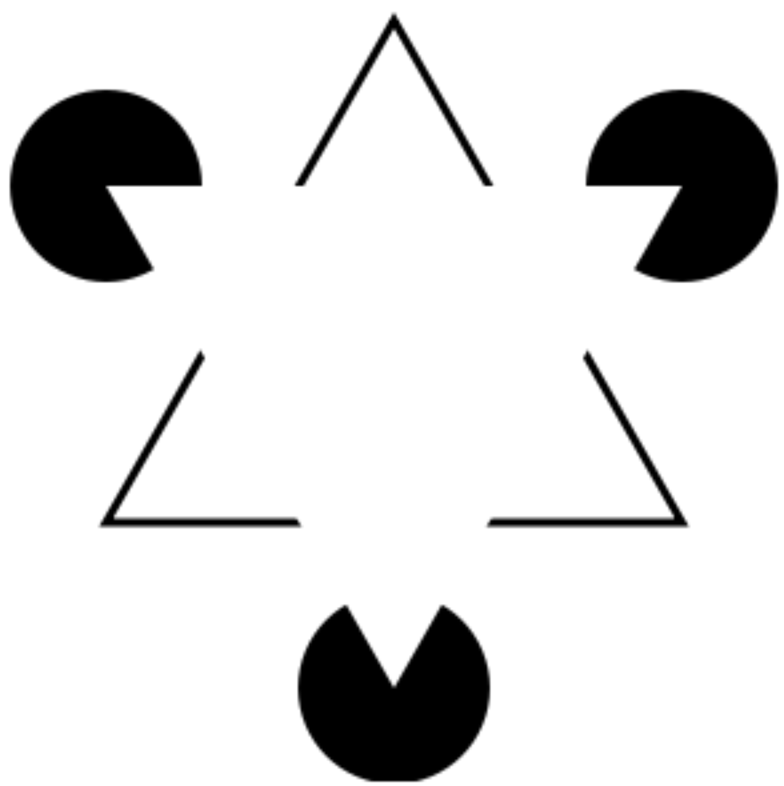
ATLAS: local 3.9σ, global 2.1σ

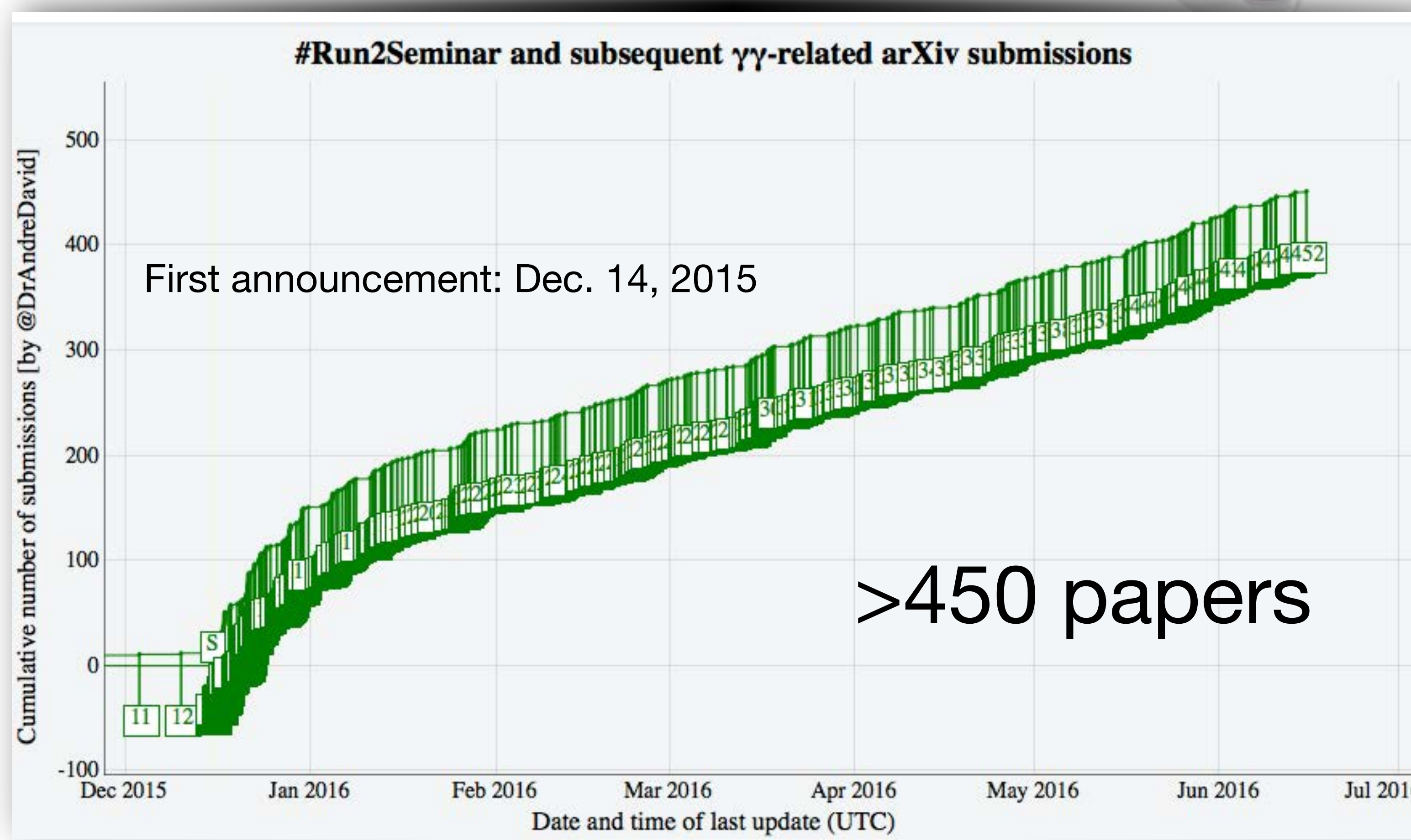
CMS: local 3.4σ, global 1.6σ

excitements… and more rumors

"human" tends to find structure and meaning in the structure but significance was not so great

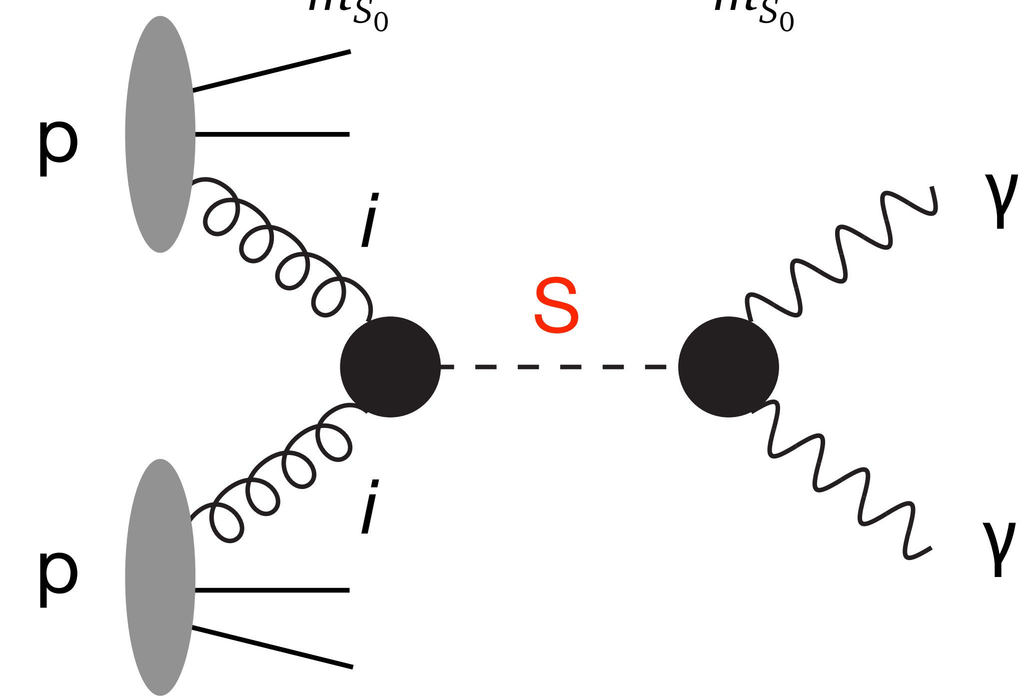
"**scientific subjective contour**"





baseline scenario

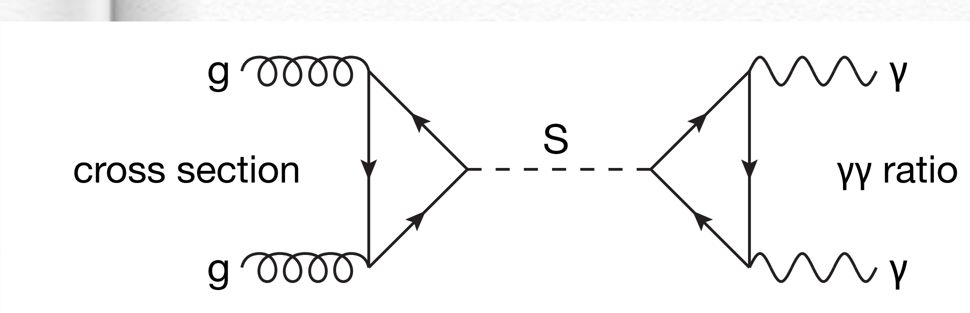
$$\mathscr{L}_{\rm eff} \supset \frac{C_{BB}}{m_{S_0}} S_0 B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{C_{gg}}{m_{S_0}} S_0 G^{a\mu\nu}\tilde{G}^{a}_{\mu\nu},$$

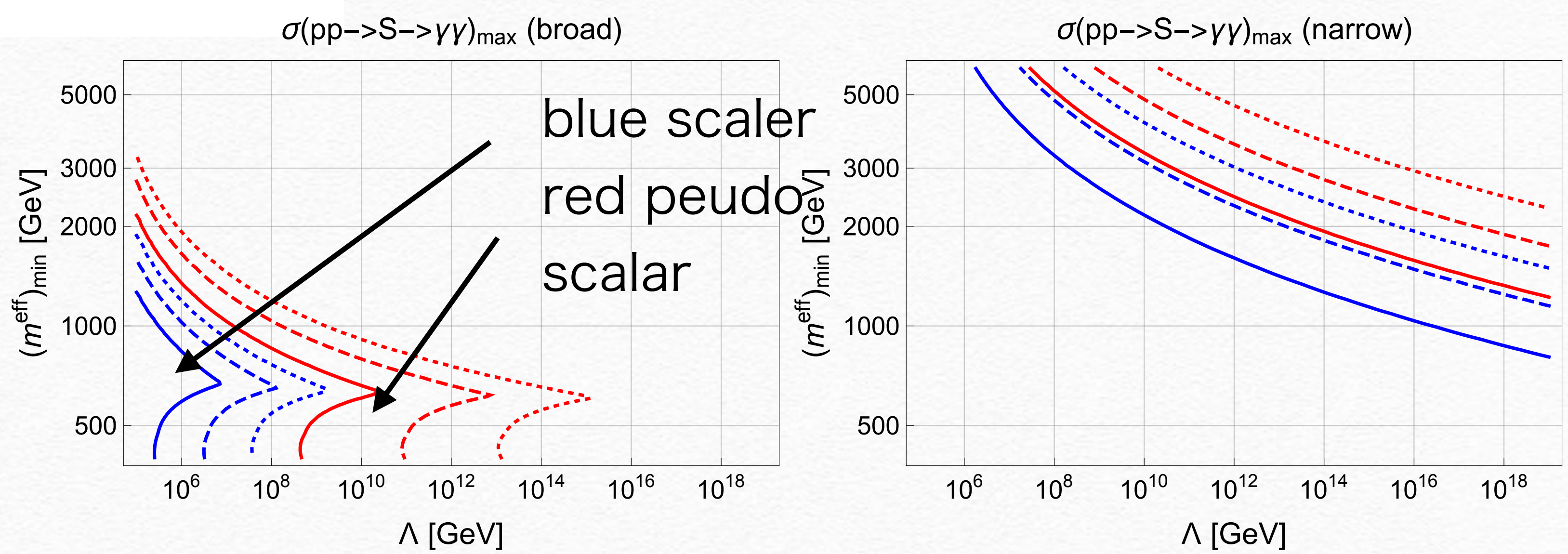


- Seen in early stage of LHC 13TeV

→must be generated from gg fusion then decay into two photonstwo photon final state spin 0 or 2

many papers on many particles in the loop …

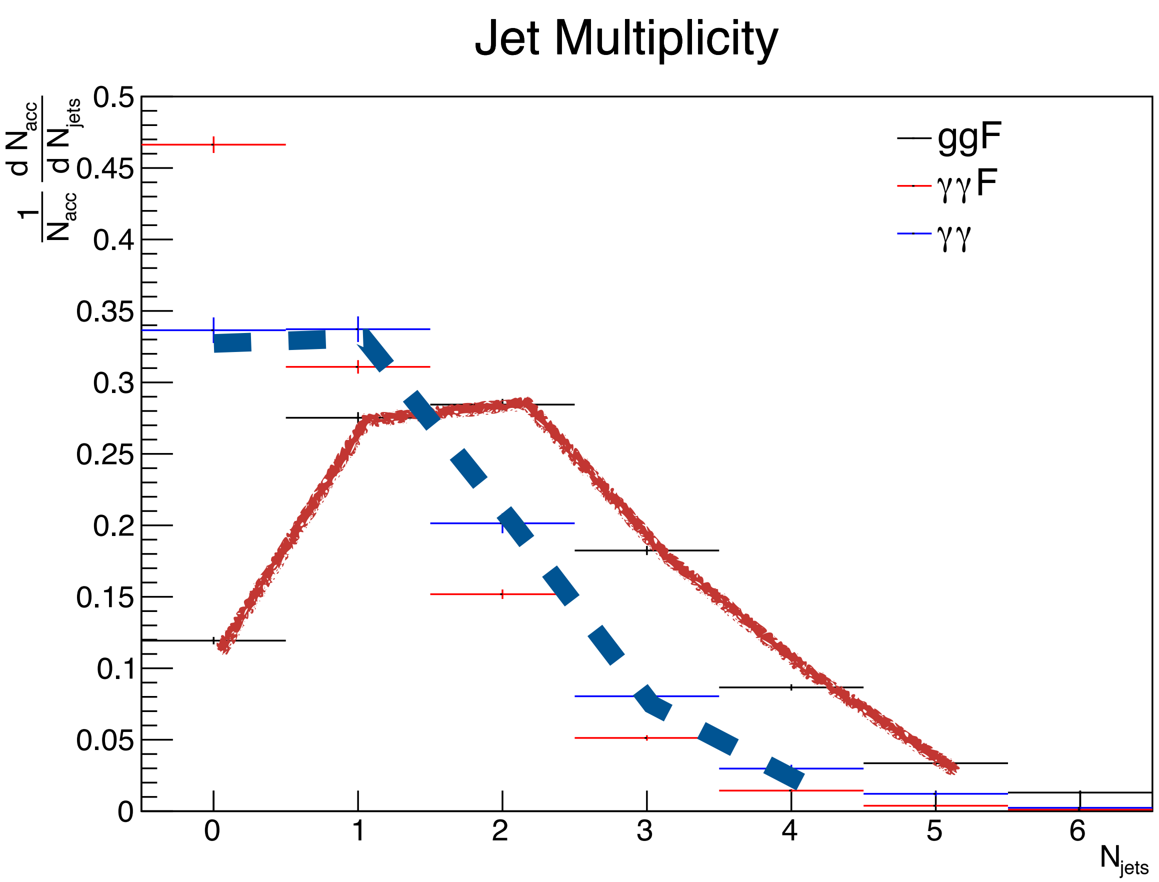


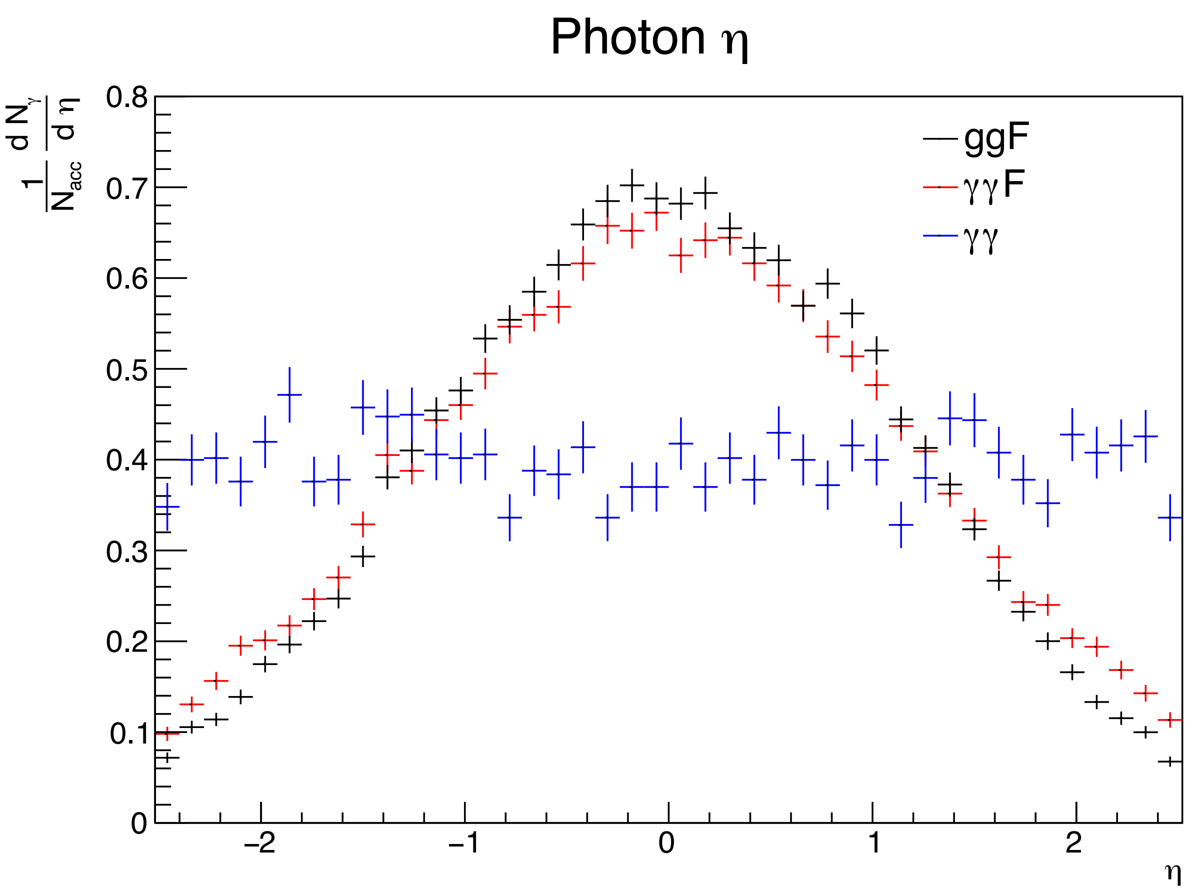


Bas,Endo, Hamaguchi, Moroi Phys Lett

FROM QCD TOOLBOX

- Angular distribution to discriminate spin 1 and spin 2
- number of additional jets , photon eta distribution to see initial state
- **Distributions of jets and photons of early data were rather skeptical…**





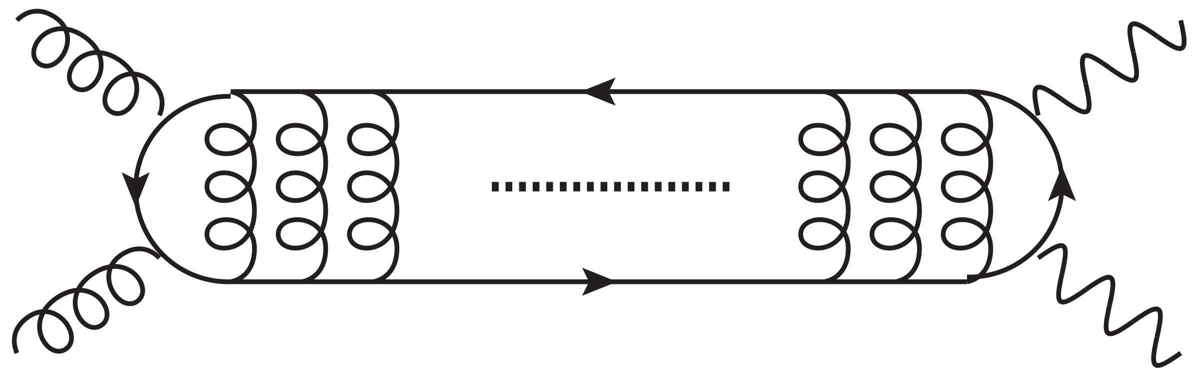
PRD 93.095020 Csaki, Hubisz, Lombardo, Terning

spin correlation of ISR is in principle sensitive to the CP of scalar

eta distribution and $\cos\theta^*$ of photon is sensitive to spin 0 or 2

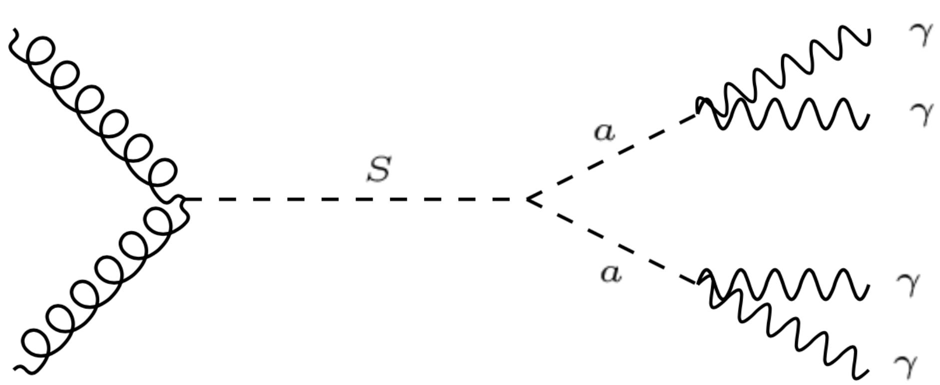
my favorite alternatives

Bound state of heavy particles



either new gauge interaction or QCD interaction form bound state

scalar decaying into peudoscalars. not photon but photon jet



- Model s+ axion with φ= s+ ia
- NMSSM with slightly broken R-symmetry s: CP even Higgs boson a: pseudo-NG boson
- mixing with η modify the branching ratio into 2 photons.
- Knapen et al, Ellwanger et al ,Dasguputa et al,

QCD bound state

- pp →X Xbar → S → gg, $\gamma\gamma$, ZZ

$$\Gamma_{\rm tot} = \Gamma_{\gamma\gamma}/c_W^4 + \Gamma_{gg} + 2\Gamma_X,$$

$$\sigma(pp \to S_0 \to \gamma\gamma) = \frac{K}{s\, m_{S_0}} \frac{\Gamma_{\gamma\gamma}\Gamma_{gg}}{\Gamma_{\rm tot}} \text{[PDF factor]}$$

$$\Gamma_{\gamma\gamma} = 48\pi Y_X^4 \alpha^2 |\psi_0(0)|^2/m_{S_0}^2,$$

$$\Gamma_{gg} = 32\pi\alpha_s^2 |\psi_0(0)|^2/(3m_{S_0}^2),$$

Only higher dim decay

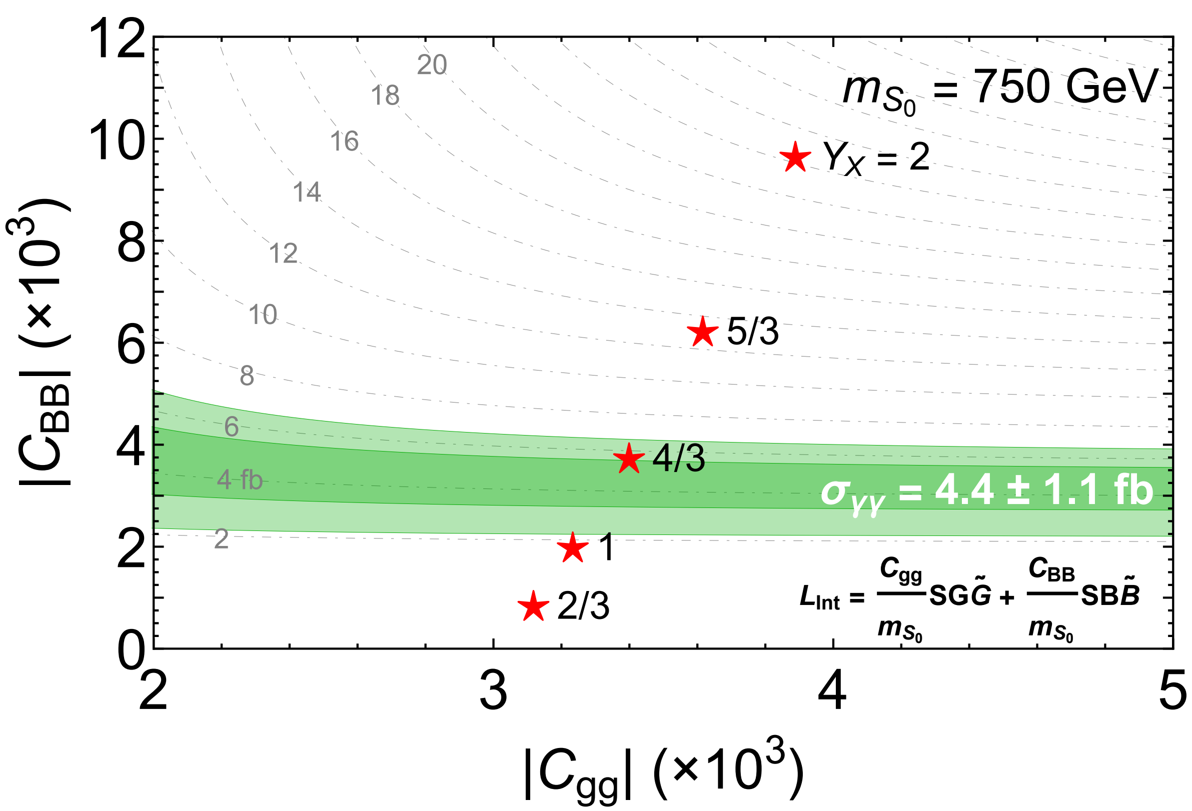


Figure 1: *Red stars are predictions of our model on the ($|C_{gg}|, |C_{BB}|$)-plane with Y_X being 2/3, 1, 4/3, 5/3 and 2, respectively. Contours of the diphoton cross section as a function of $|C_{gg}|$ and $|C_{BB}|$ are also shown by gray-dashed lines. Darker (lighter) green-shaded region corresponds to the cross section experimentally favored by the diphoton excess at 1σ (2σ) level [3].*

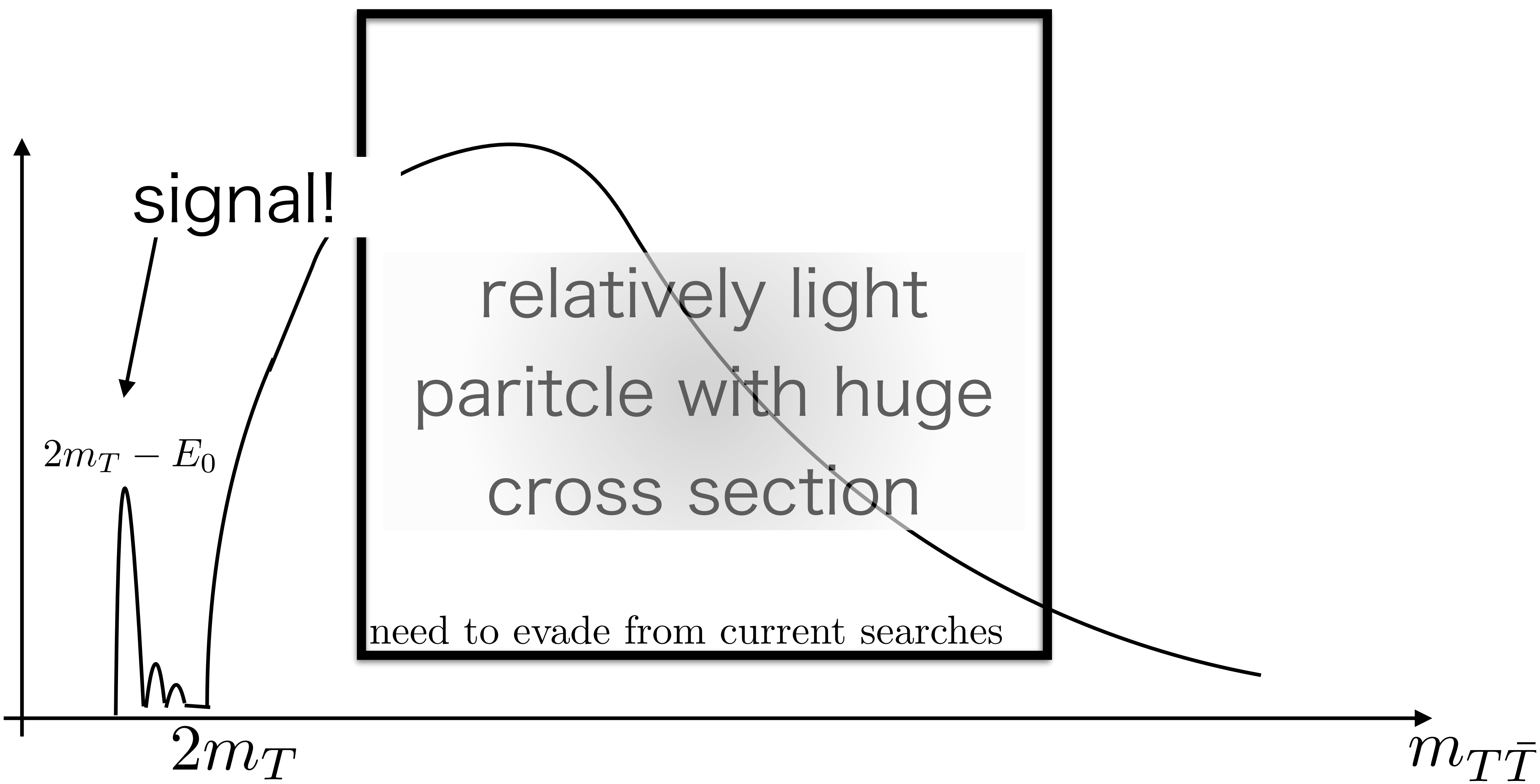
X →DM + jets (A New Class of simplified DM)

Han, Ishikawa, Matsumoto, Nojiri JHEP 04(2016) 159,mass density is almost independent of σv(DM DM) because of DM X coannihilaion: favoring mass difference around 40 GeV.

X-> 2j, 3j

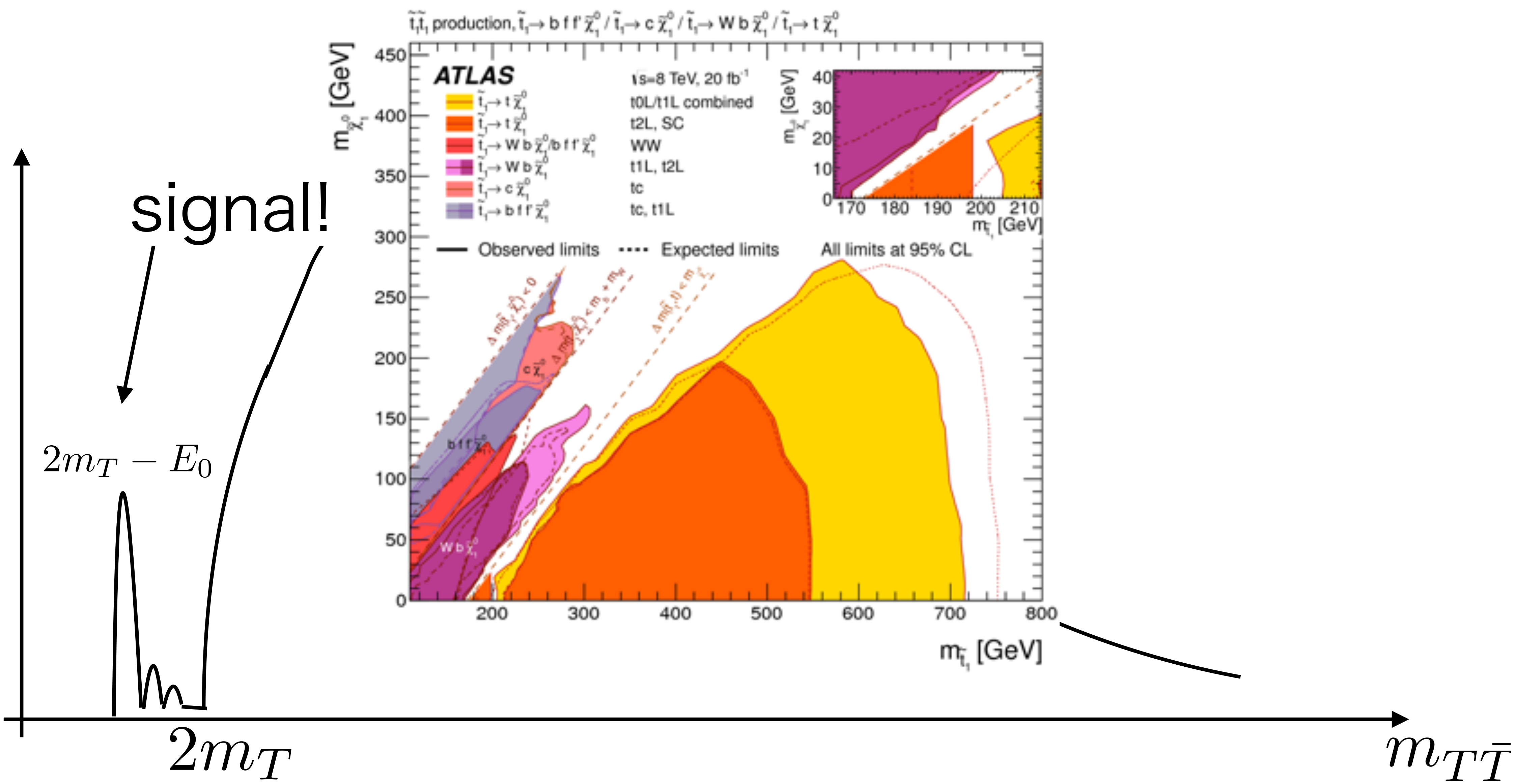
Kats and Strassler JHEP05(2016)092 weaker collider bound:

Collider Constraints



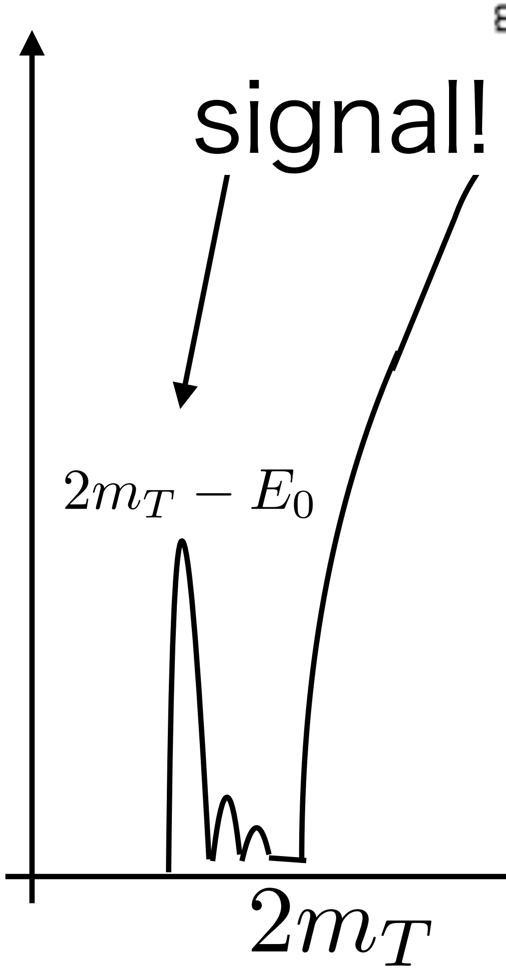
Collider Constraints

recast light squark search at LHC

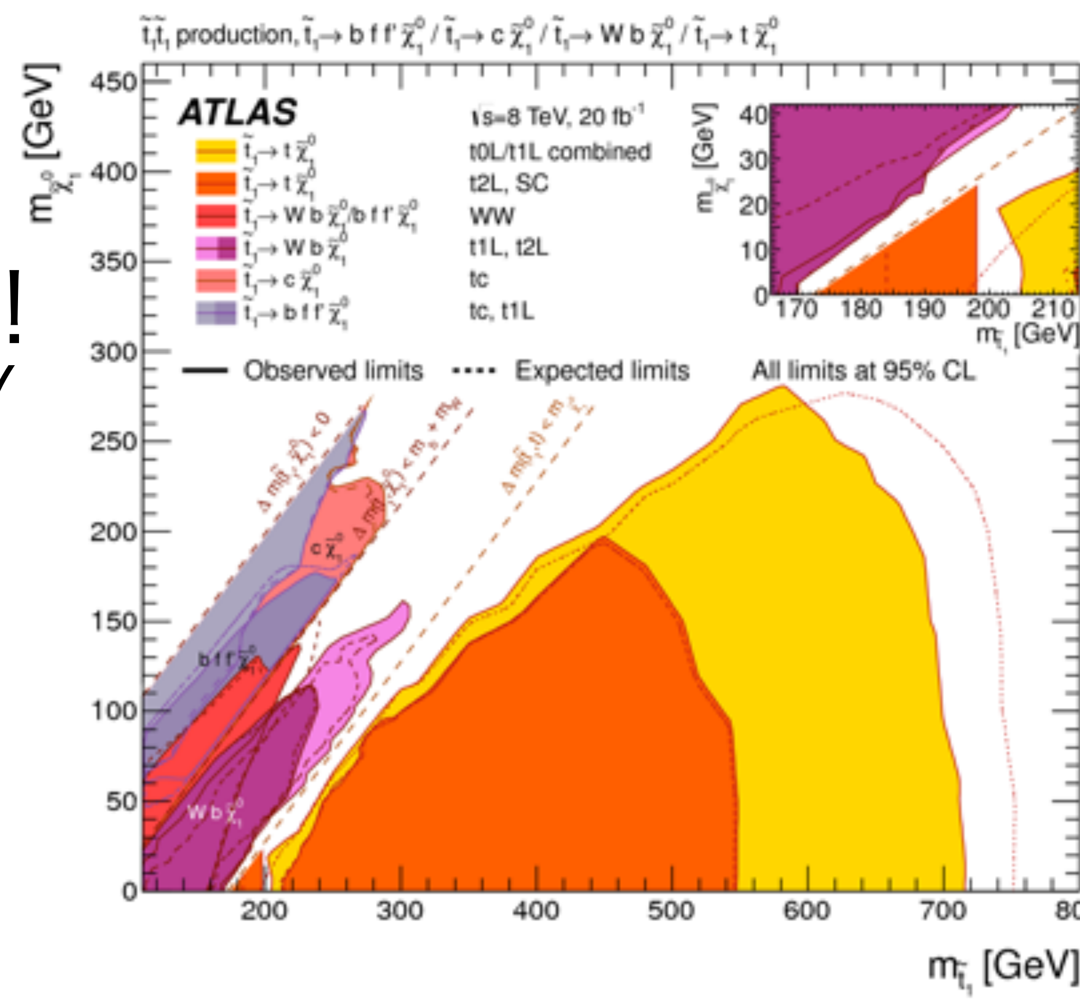


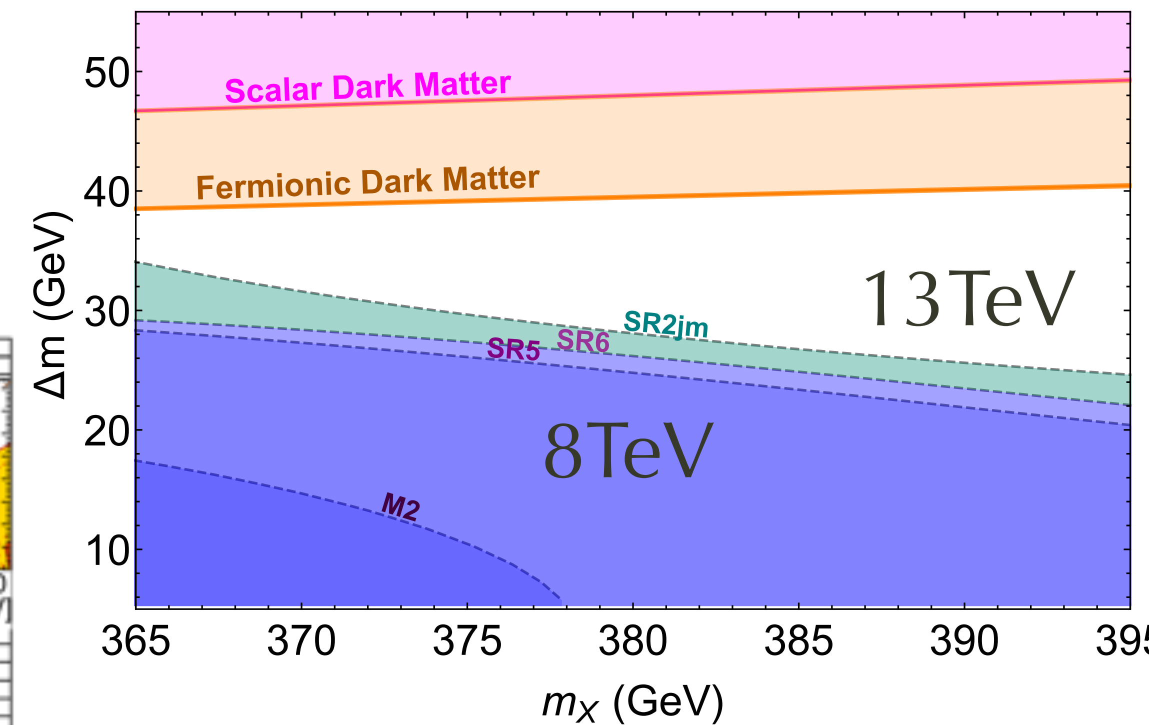
Collider Constraints

Mono jet search does not completely kill coannhilation window yet



recast light squark search at LHC

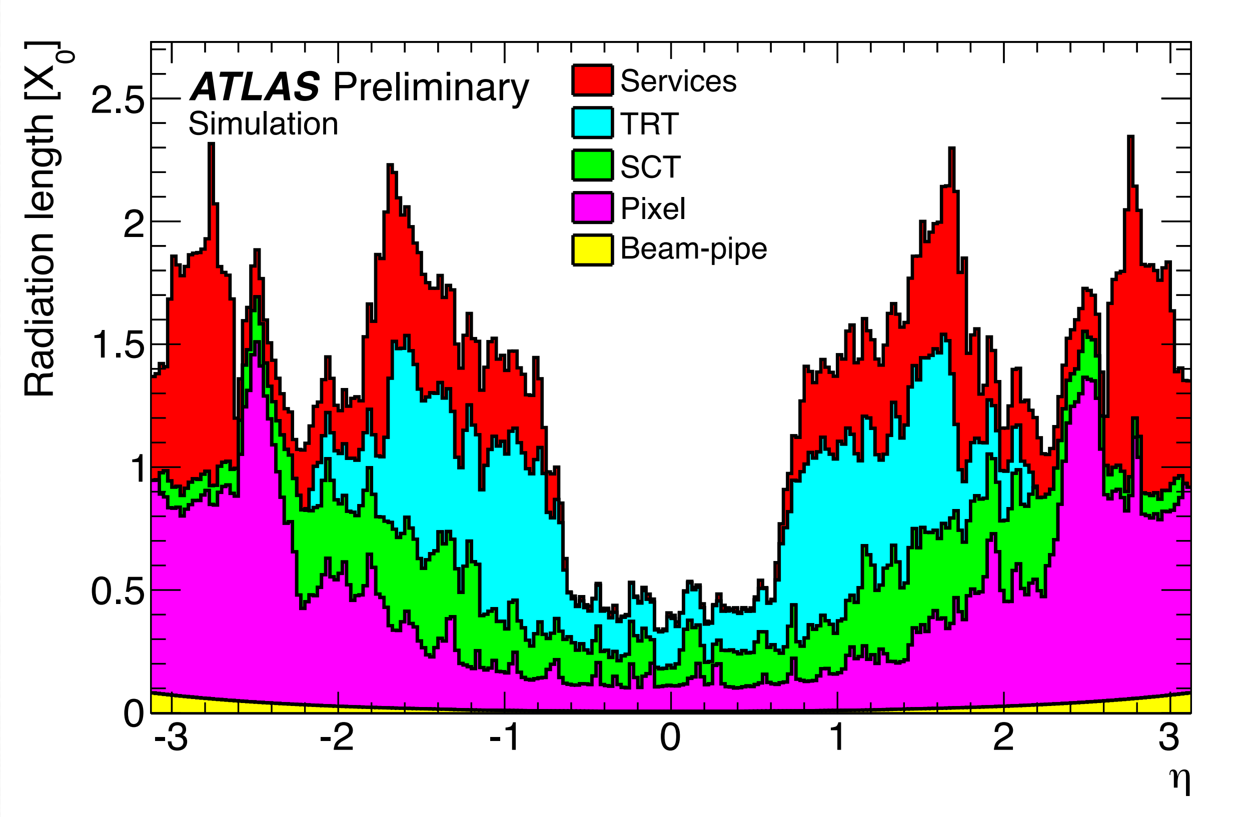


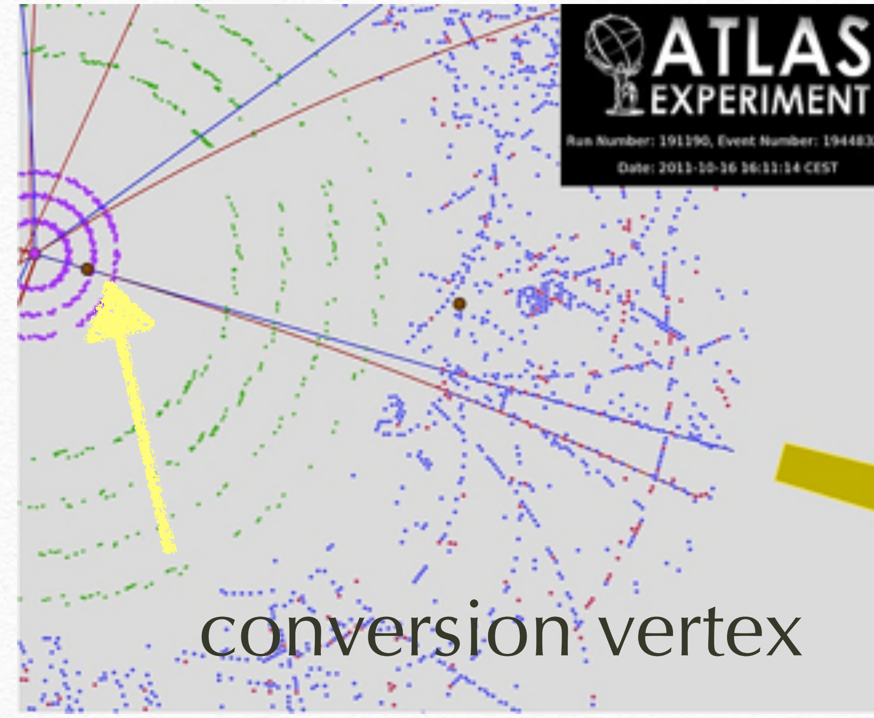


bound state signature may fill this gap (at least independently)

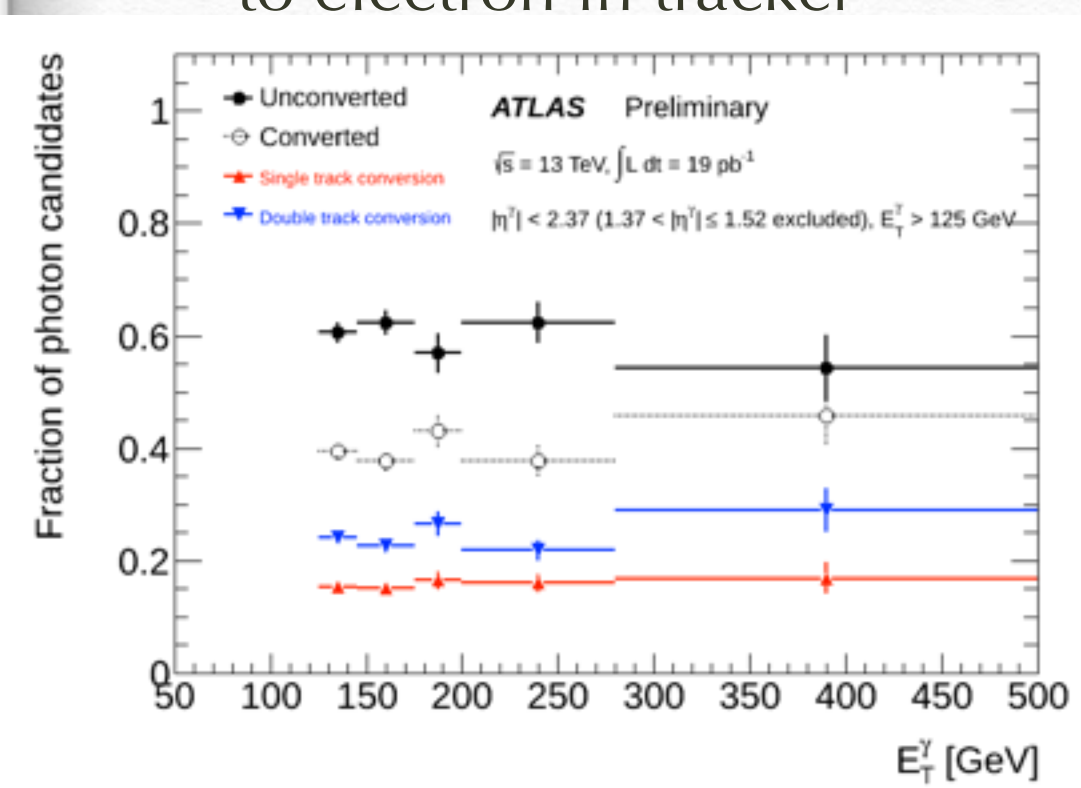
Note scale uncertainty of signal distribution is also important for the degenerate region

photon conversion and photon jet



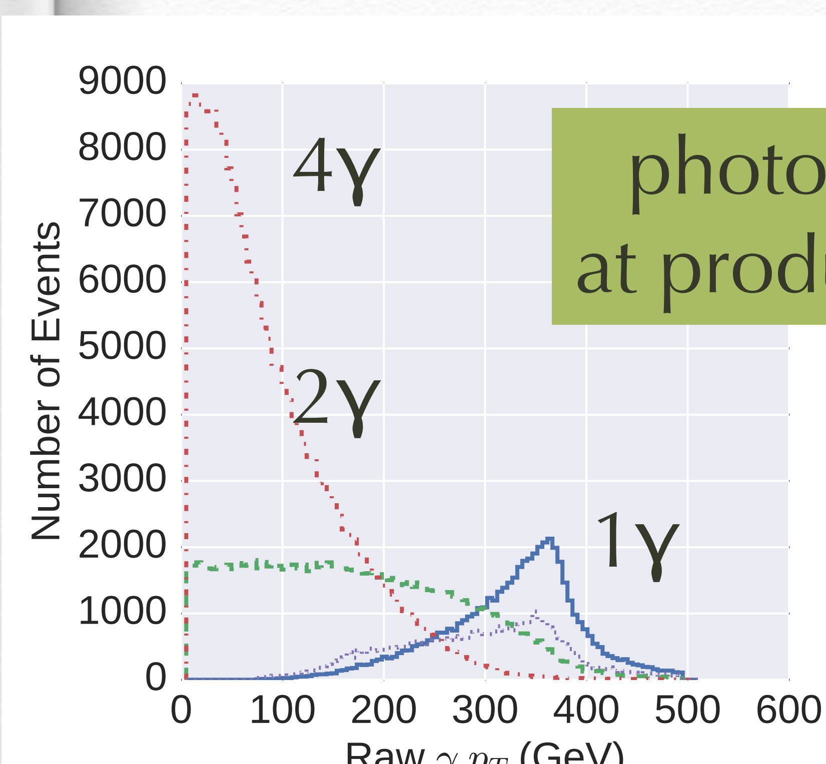


half of photon convert
to electron in tracker

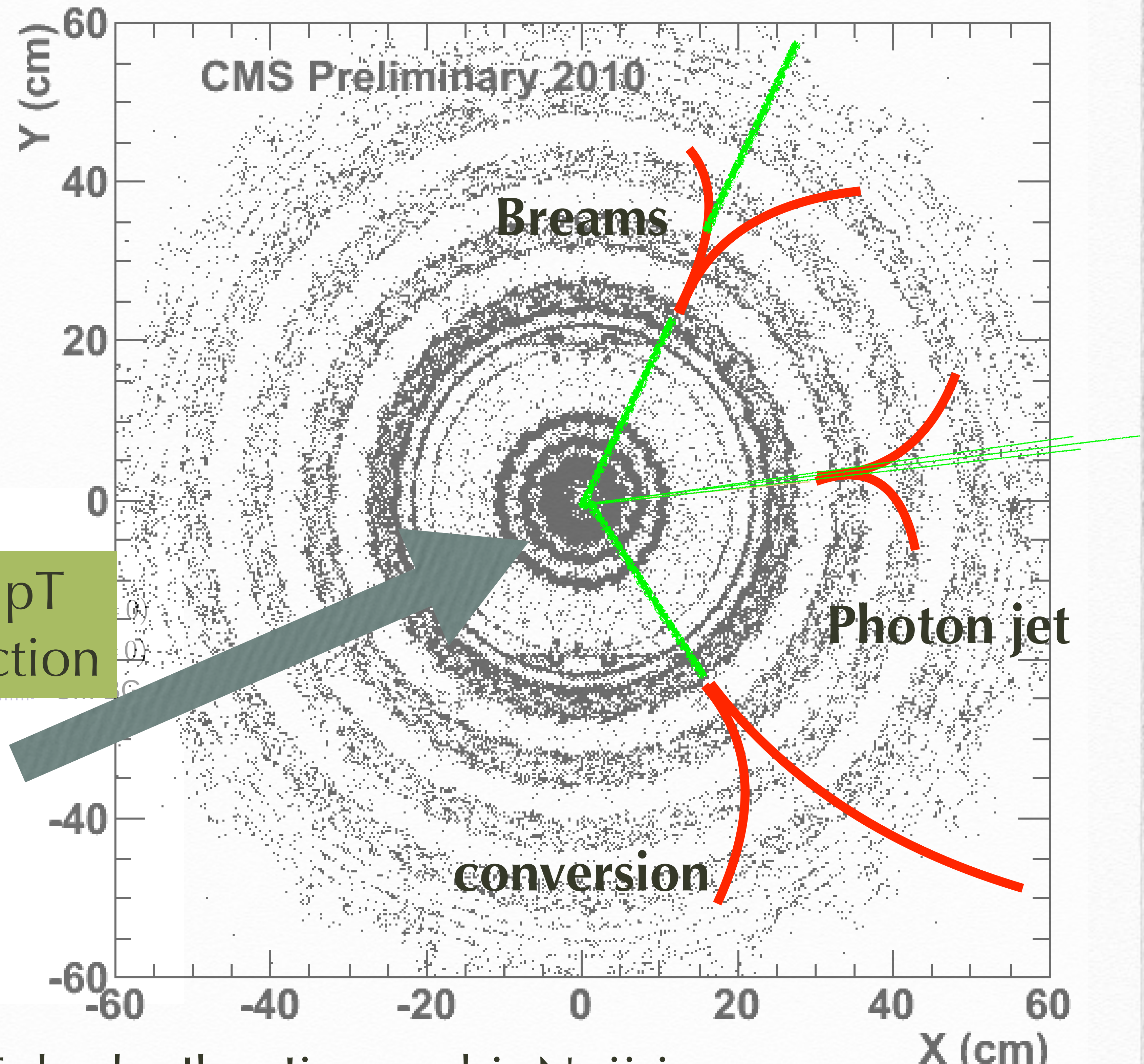


- Detector is photon target: photon converts to $e^+ e^-$.
- $P_{conv} \rightarrow N_\gamma \times P_{conv}$ PT of electron pair $E_\gamma \rightarrow E_\gamma / N\gamma$. different from BG photon and diphoton signature
- However, electron is not just a "charged track" in tracker, but **photon emitter.** It may lose half of its energy in the detector.

e+e- tracks in the detector

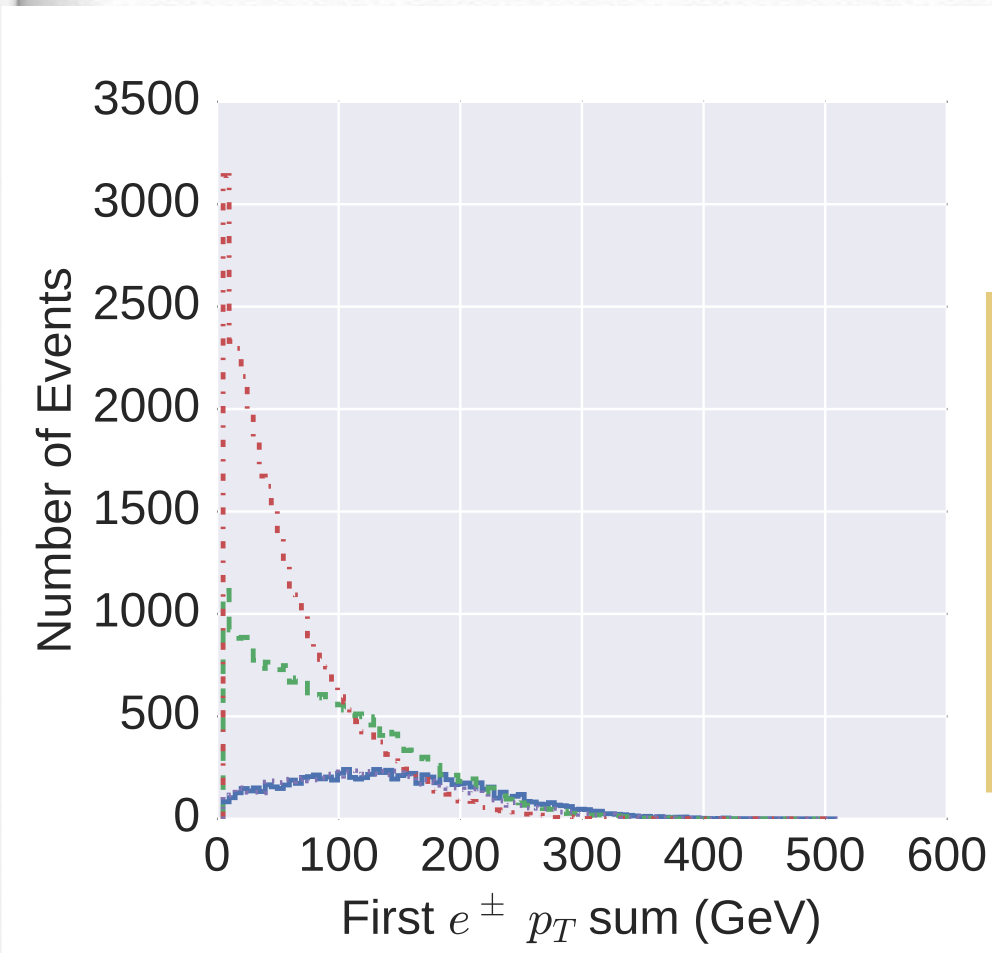


photon pT
at production

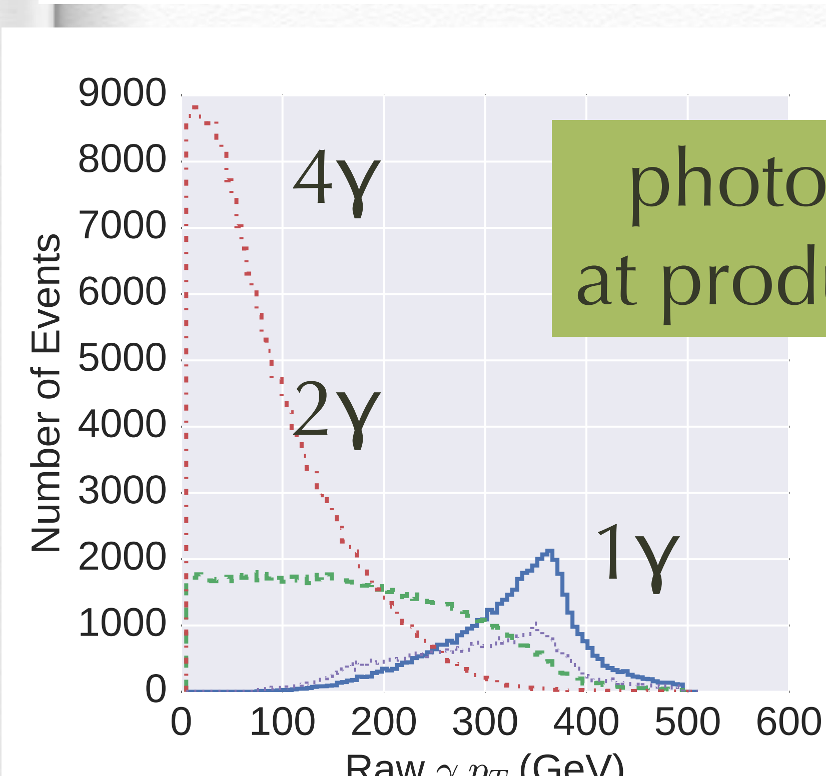


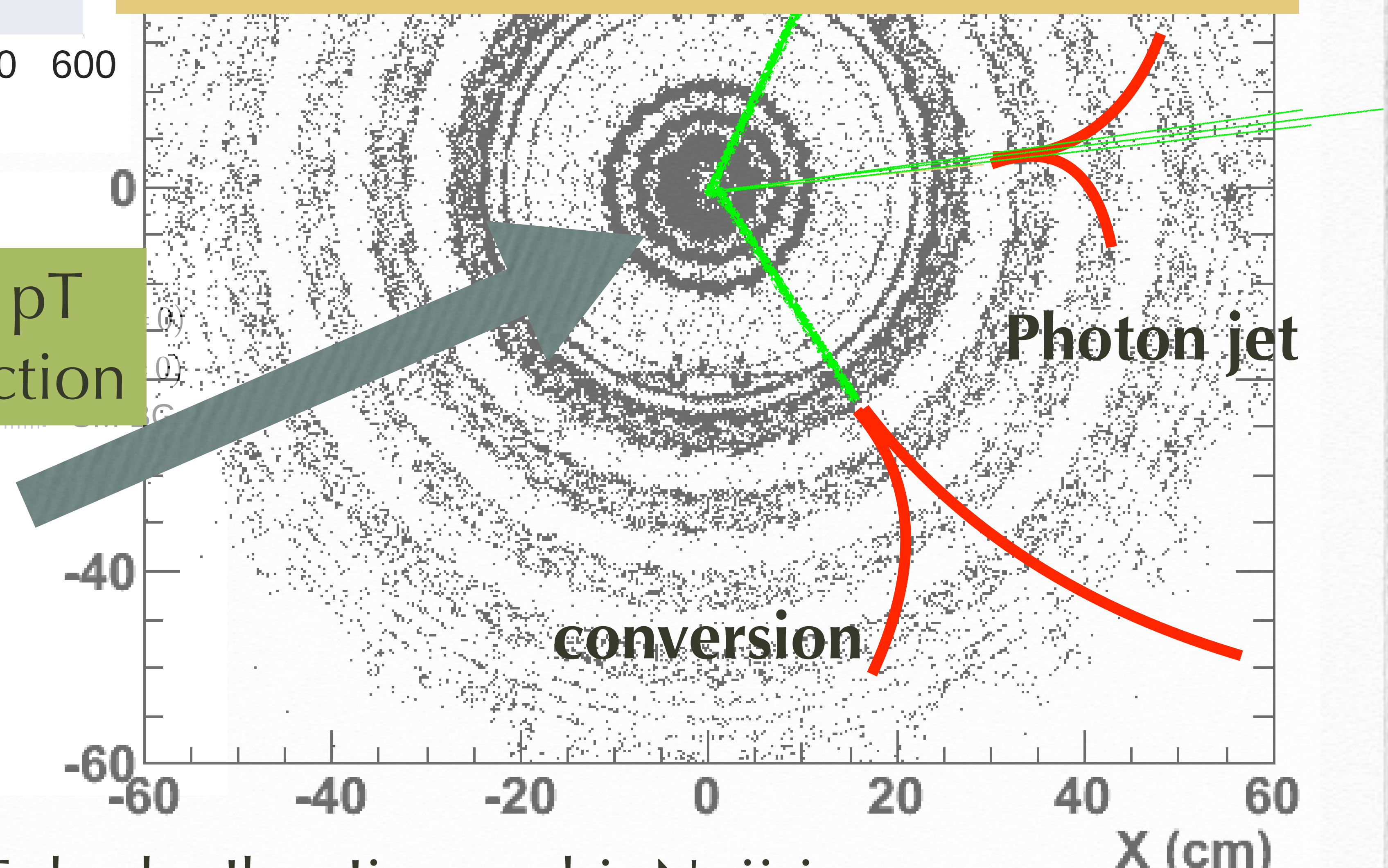
arXiv.1607.01936 Fukuda, Ibe, Jinnouchi, Nojiri e+e- tracks in the detector

smeared/measurable track pT sum
*soft electron from bremsstrahlung
**high pT track momentum cannot be measured by tracker

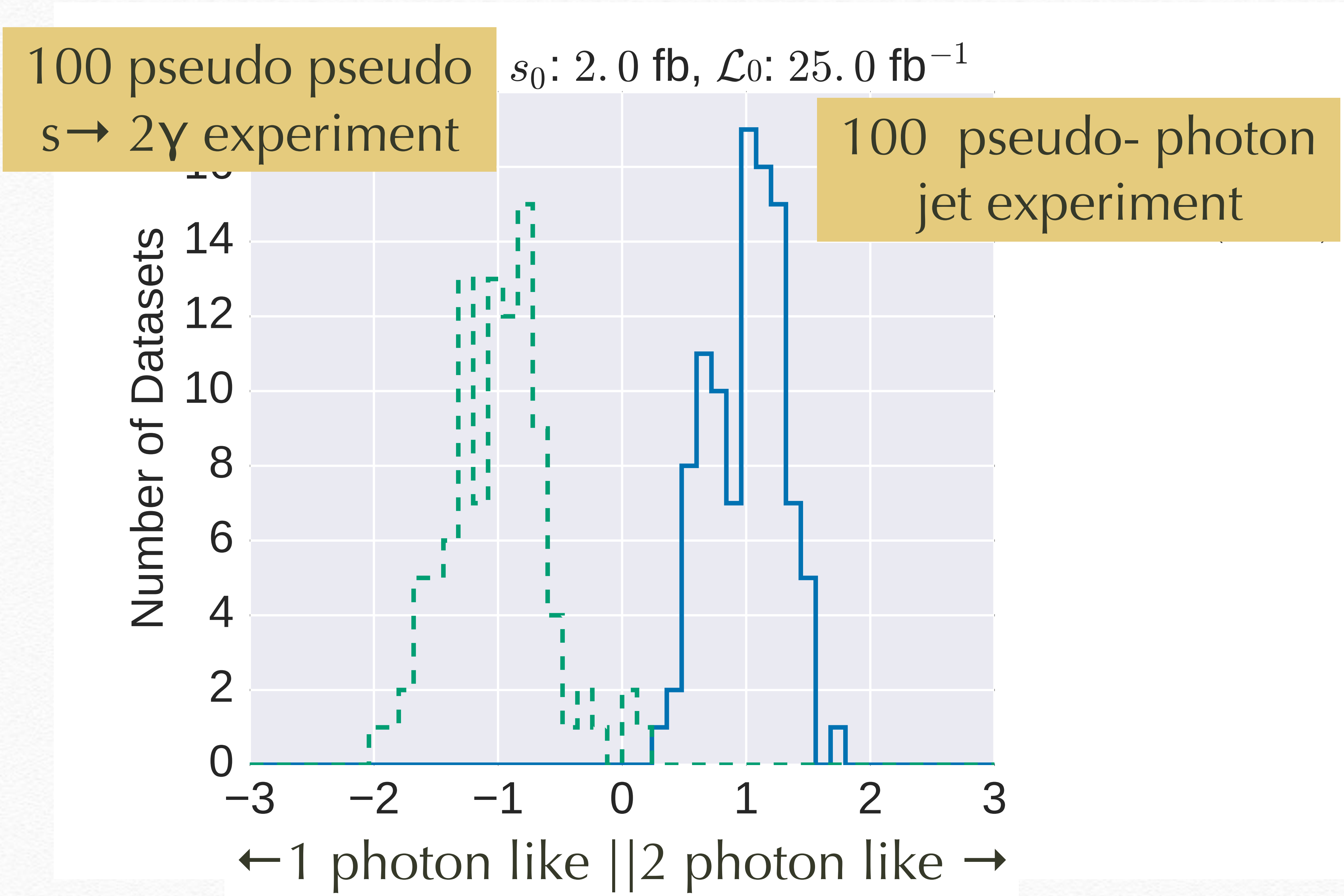


photon pT
at production





arXiv.1607.01936 Fukuda, Ibe, Jinnouchi, Nojiri



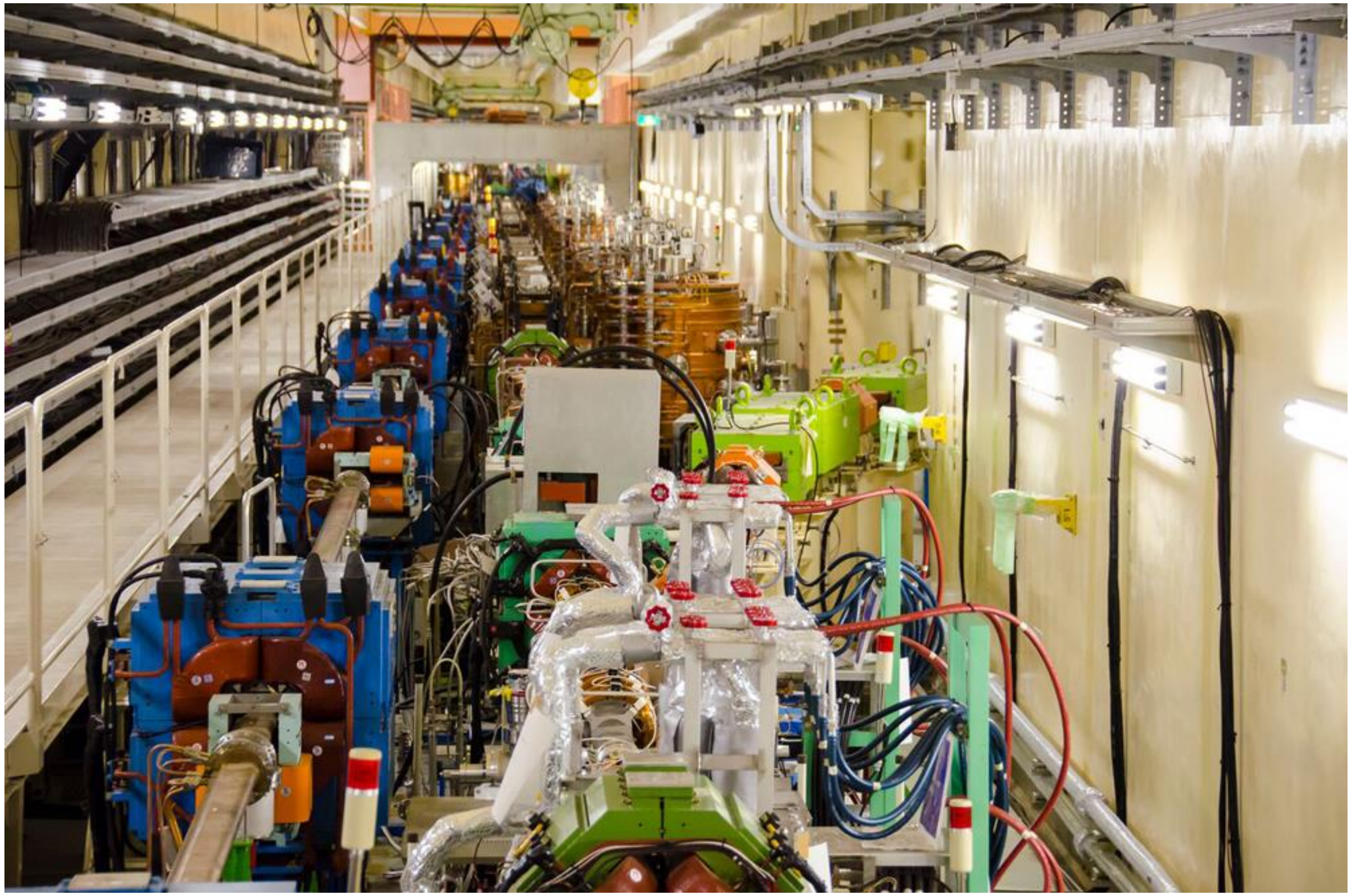
fit distributions of 100 prude-experiment to
expected pT distribution + #unconverted distribution

arXiv.1607.01936 Fukuda et al

4. Land of Flavor ?

Feb 2016: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)

NEWS



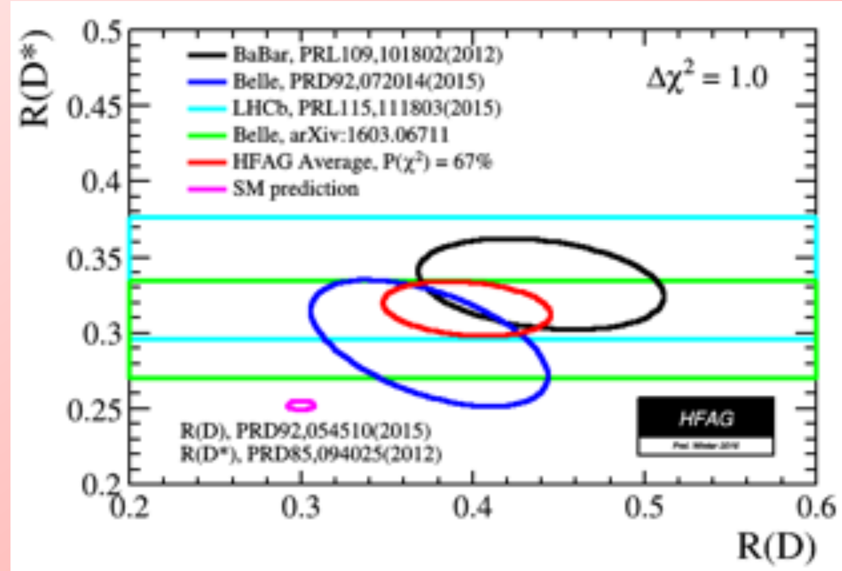
June 28, 2016 (LER beam current at 1000 mA, HER at 870 mA)

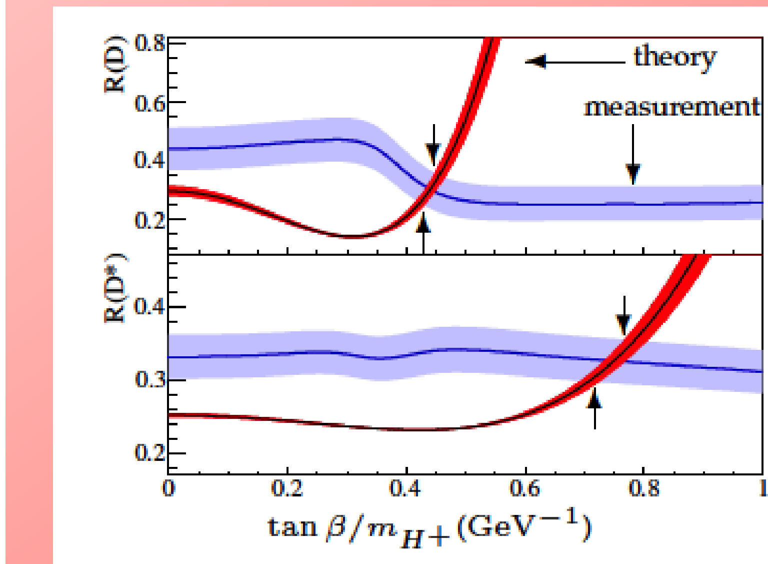
2017: Collisions at the Y(4S) will produce pairs of QM entangled (B-anti B) mesons

First new particle collider since the LHC (*intensity frontier* rather than energy frontier; $e^+ e^-$ rather than p p)

B →D(*) τ ν

deviation is 4 σ but inconsistent with Type II Higgs



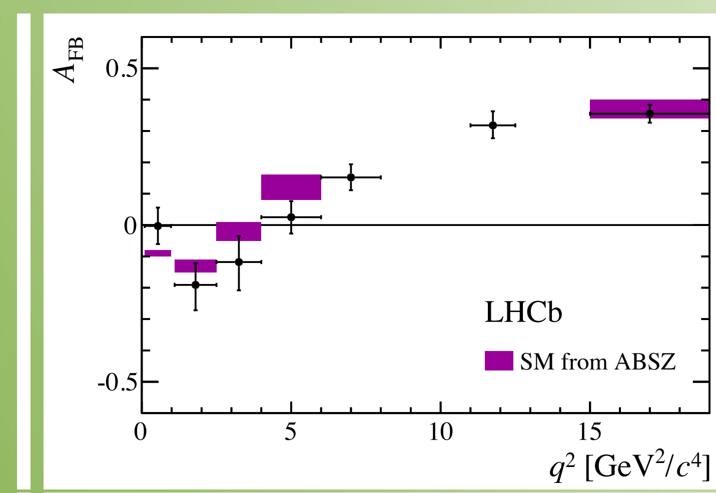


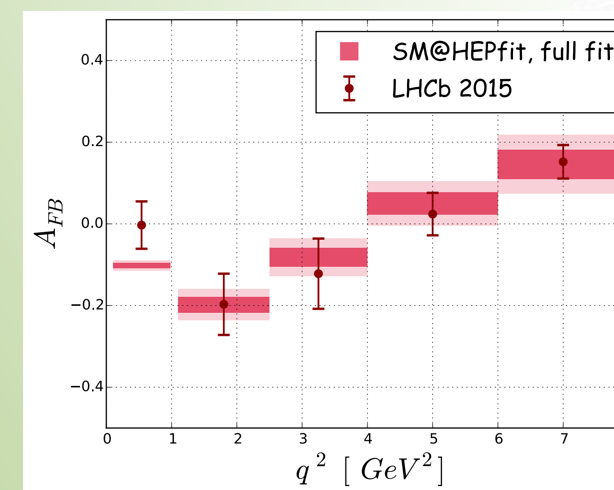
RK at LHCb 2.6 σ

$$R_K = \frac{Br(B^+ \to K^+\mu^+\mu^-)}{Br(B^+ \to K^+e^+e^-)}$$

$$\mathbf{R_K = 0.745\ ^{+0.090}_{-0.074}(stat) \pm 0.036(syst)}$$

angular analysis give 3.4 sigma fro B0-> K*0 μμ





Maybe charm effect

g-2(μ)

$\Delta a_\mu = a_\mu^{exp} - a_\mu^{the} = 288(80)10^{-11}$

3.6 σ

more anomaly and L_μ- L_τ model

K_0 K_0 bar mixing

$$(\varepsilon'/\varepsilon)_{\rm exp} = (16.6 \pm 2.3) \times 10^{-4}.$$

$$\varepsilon'/\varepsilon = (1.9 \pm 4.5) \times 10^{-4}.$$

$$\mathrm{Br}[h \to \mu\tau] = \left(0.89^{+0.40}_{-0.37}\right)\%$$

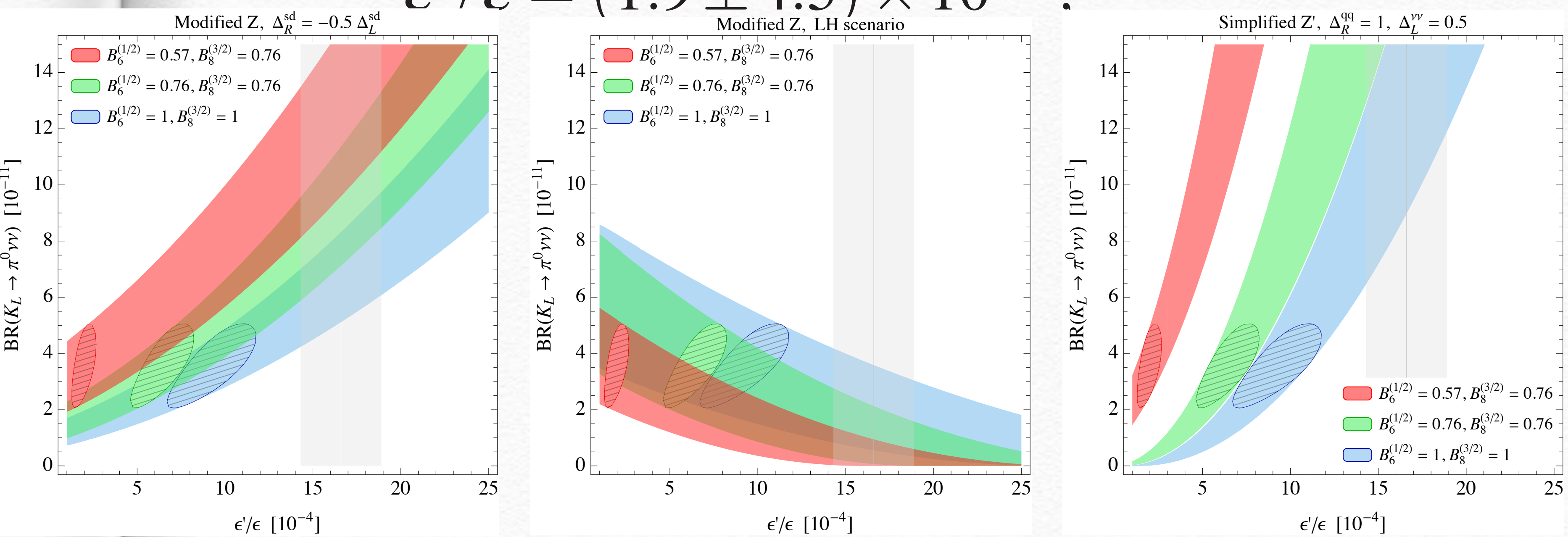
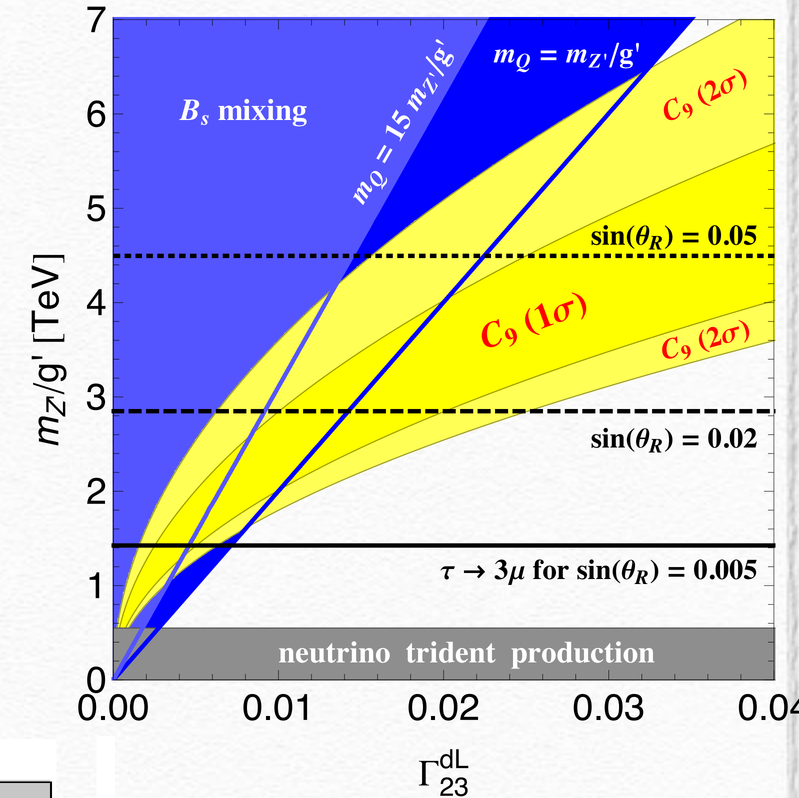
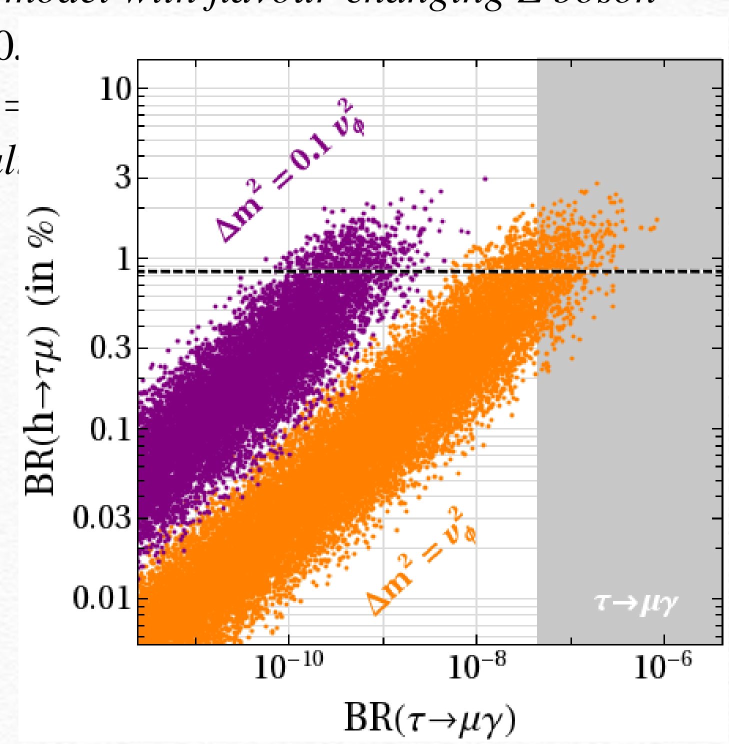


Figure 3: *95% C.L. allowed regions for ε'/ε and $K_L \to \pi^0\nu\bar{\nu}$. Left: model with flavour-changing Z boson couplings $\Delta_R^{sd} = -0.5\Delta_L^{sd}$. Center: modified Z, LH scenario $\Delta_R^{sd} = 0.$ $\Delta_L^{\nu\nu} = 0.5$. The plots are for $B_6 = 1$ (blue), $B_6 = 0.76$ (green), and $B_6 =$ the SM predictions at 2σ. The gray band shows the experimental resul*





U(1)Lμ-Lτ couple to vector li

1501.00993v2

1604.08221

correlation with

K rare decays?

Implication to τ decays

but "Who ordered this… "

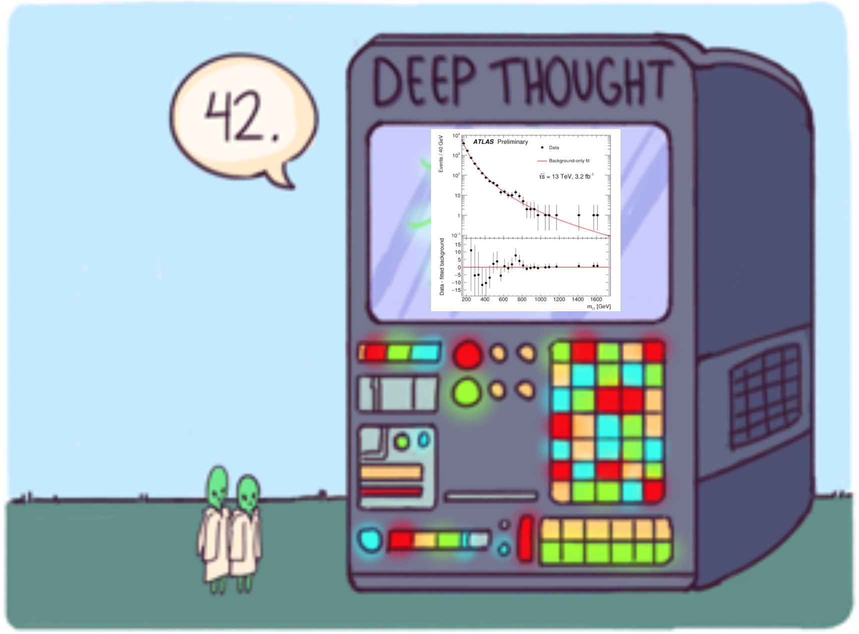
5.Summary

- Overall **LHC is successful**. It is based on solid science, especially, precision EW calculation, higher order QCD, development of MC tools. fantastic job compared with our expectations at 23 years ago(at the time of SSC cancellation) , really!

- Anomaly are more abundant in flavor physics now. Are there something more to be developed? Or are we in the “who ordered this” situation?

- **Is understanding good/excluded regions in effective/ simplified theory enough to justify the existence of HEP on the earth?**

Life and Universe and Everything $\neq$



- **Neither Deep thought without no data nor Low Energy Effective theory to fit data** brings the answer to "the big question"

- MOST IMPORTANTLY, we are here **on the earth** to think about **the question**, not the answer…

- I think BSM models still shining (though I have been always in the side of phenomenology)

- We should not give up chasing **true beauty of the nature**