

ヒッグス探索の展望など

SUSY/ED探索の現状も

大阪大学・花垣和則

ヒッグス探索

Lagrangian in the Standard Model

$$\begin{aligned}
 \mathcal{L} = & \bar{\nu}(i \not{\partial} - m_\nu)\nu + \bar{l}(i \not{\partial} - m_l)l + \frac{1}{2}(\partial_\mu \chi \partial^\mu \chi - \mu^2 \chi^2) \\
 & - \frac{1}{4}F_{\mu\nu}^i F^{i\mu\nu} + m_W^2 W_{+\mu}^* W_+^\mu - \frac{1}{4}G_{\mu\nu} G^{\mu\nu} + \frac{m_Z^2}{2} Z_\mu Z^\mu \\
 & + eA_\mu (\bar{l} \gamma^\mu l) - \frac{g}{\sqrt{2}} [W_+^\mu (\bar{\nu} \gamma^\mu P_L l) + c.c.] \\
 & - \bar{g} Z_\mu [\bar{\nu} \gamma^\mu (s_{\nu L} P_L + s_{\nu R} P_R)\nu + \bar{l} \gamma^\mu (s_{l L} P_L + s_{l R} P_R)l] \\
 & + \frac{2v\chi + \chi^2}{4} (g^2 W_{+\mu}^* W_+^\mu + \frac{\bar{g}^2}{2} Z_\mu Z^\mu) \\
 & - \frac{m_l}{v} \chi (\bar{l} l) - \frac{m_\nu}{v} \chi (\bar{\nu} \nu) \\
 & + \dots
 \end{aligned}$$

騙されないぞっ、と感じてしまうところ

$$\blacklozenge m^2 A^\mu A_\mu \rightarrow m^2 (A^\mu + \partial^\mu \Lambda)(A_\mu + \partial_\mu \Lambda) \neq m^2 A^\mu A_\mu$$

⇒ need to be massless

❖ Fermion mass term

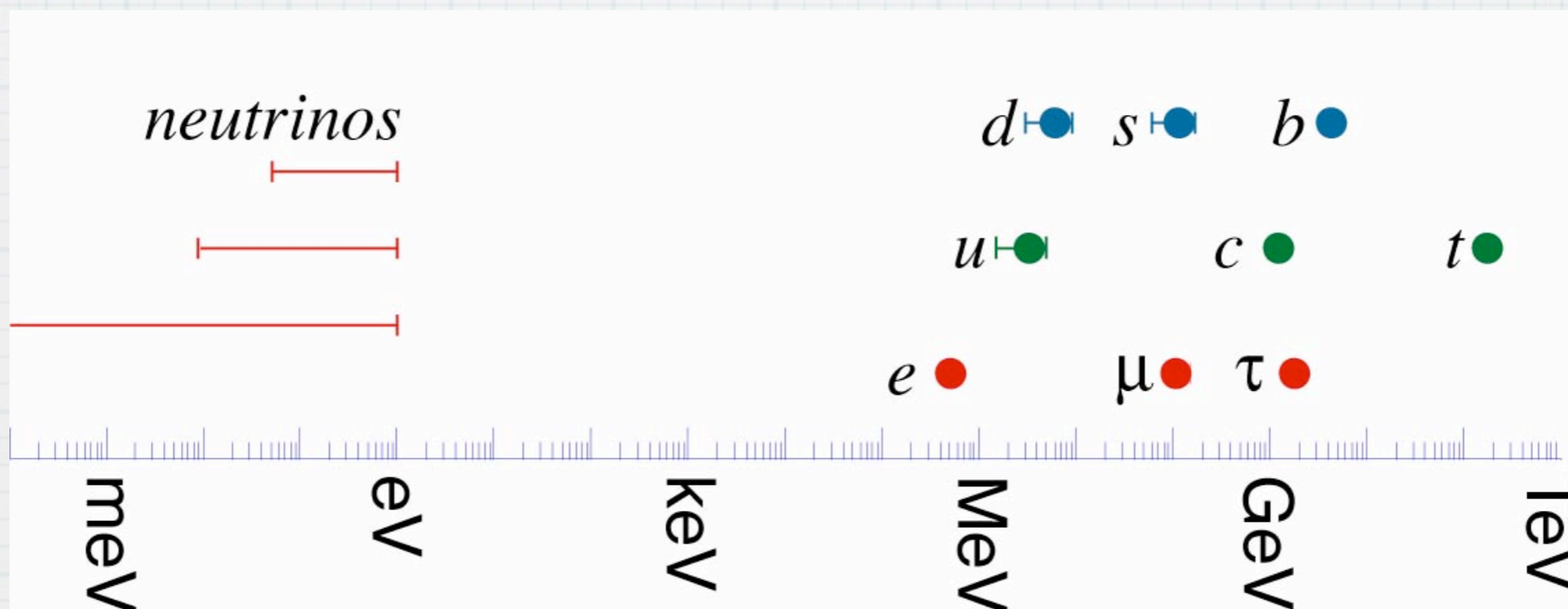
▶ Not necessarily massless

❖ 血の繋がっていない男女が一軒の家に住んでる
みたいに怪しい

質量の違い

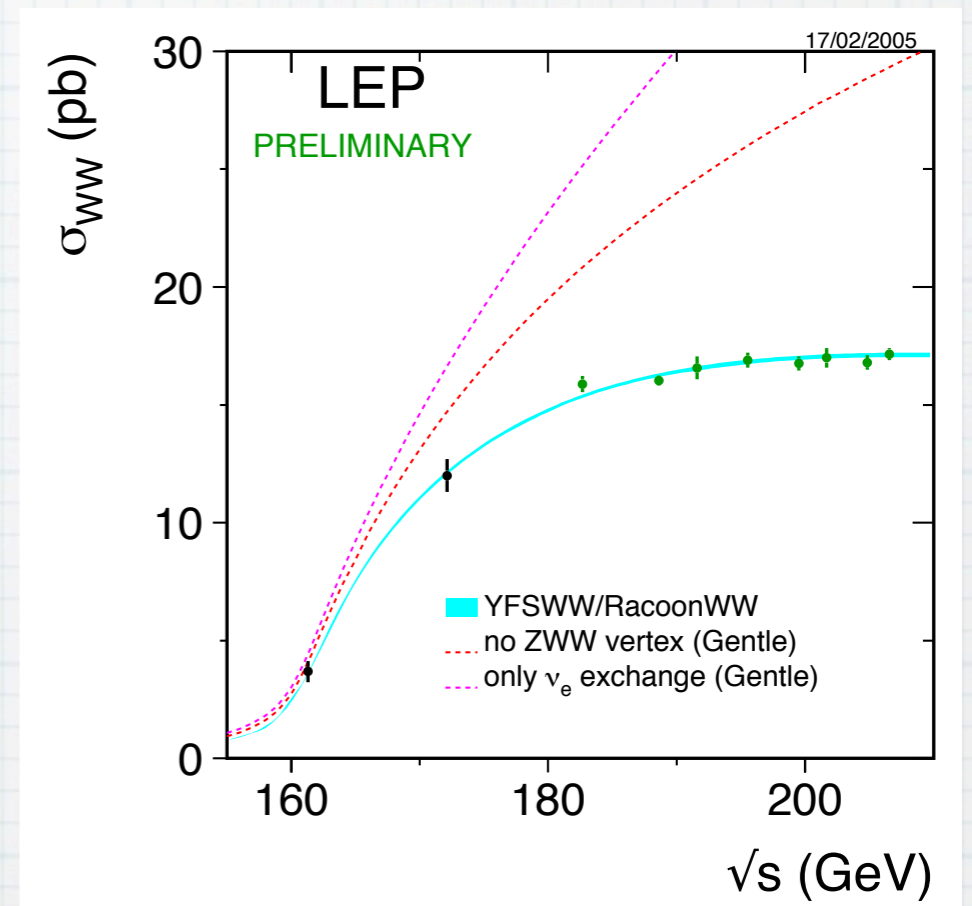
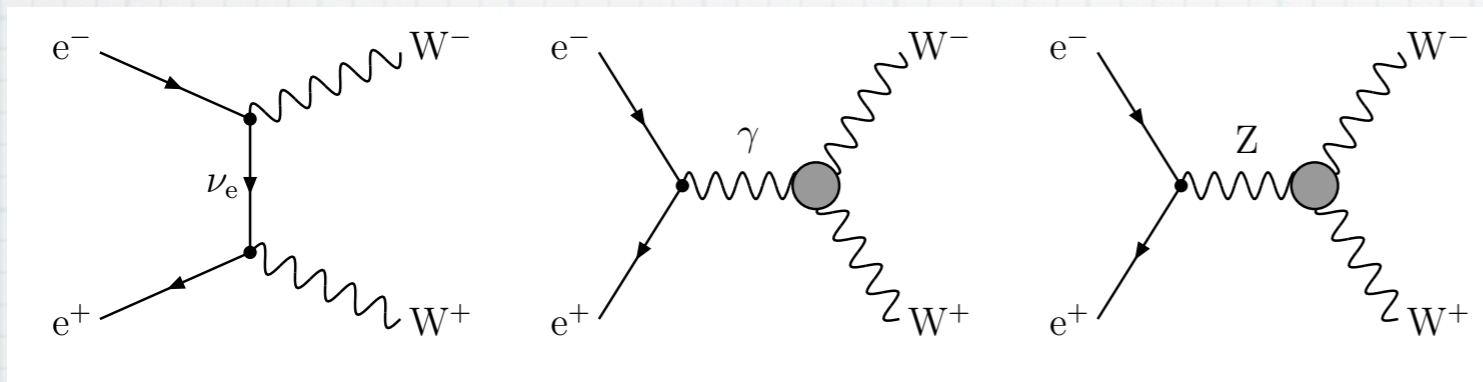
❖ 昆虫 0.7g vs 人間 70kg vs 象 7t
= 1 : 100,000 : 10,000,000

❖ Point-like (?) particle



GWS模型
不自然過ぎ
しかし...

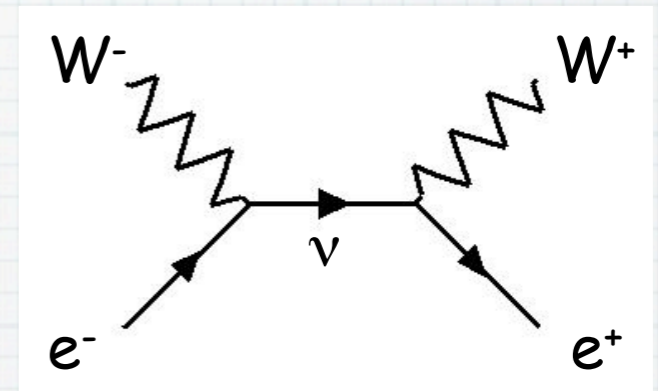
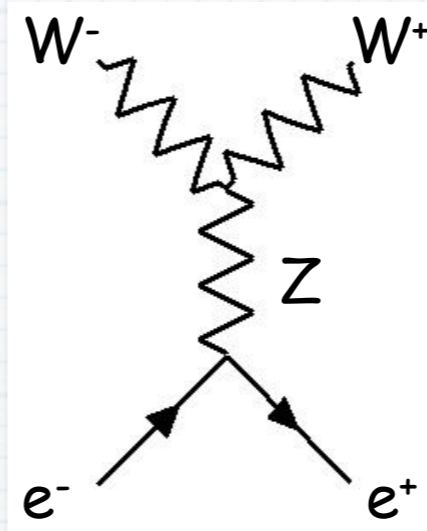
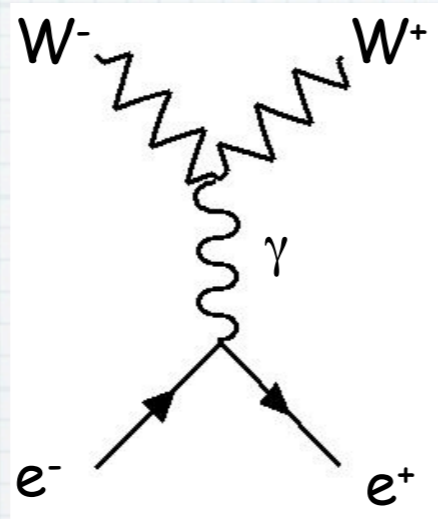
Gauge Cancellation



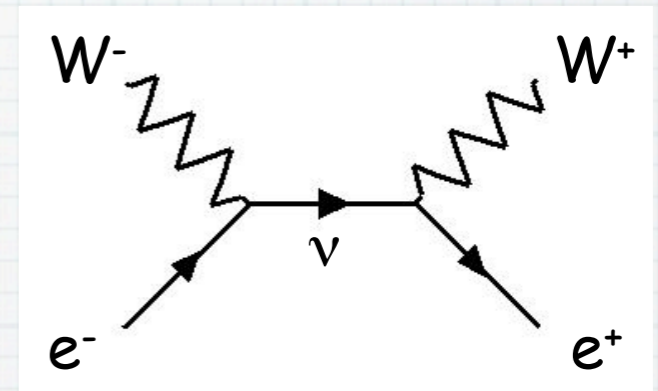
❖ ゲージ理論は正しいようだ

Another Gauge Cancellation

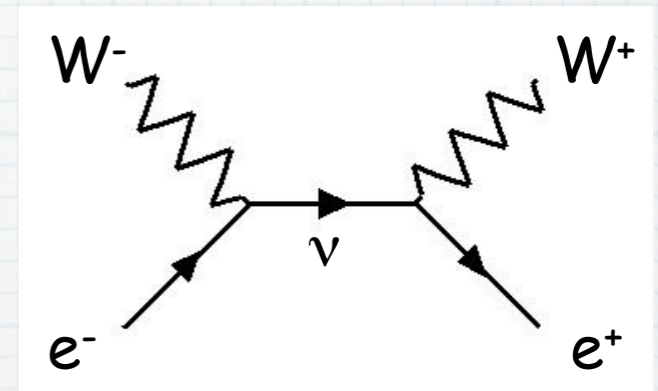
Spin 1



Another Gauge Cancellation

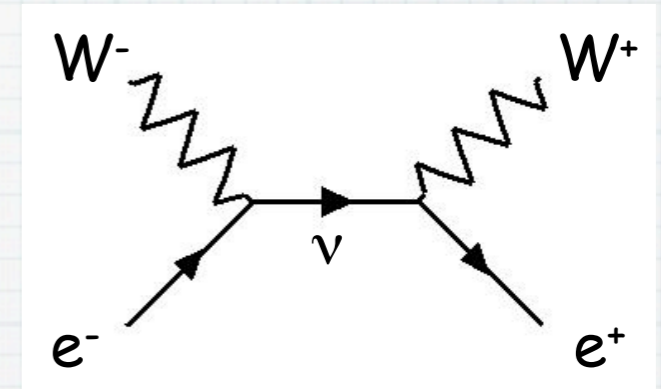
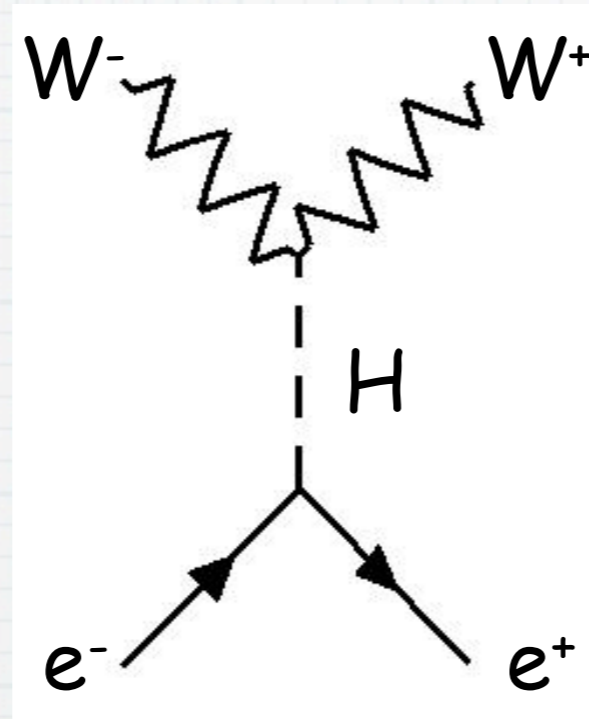


Another Gauge Cancellation



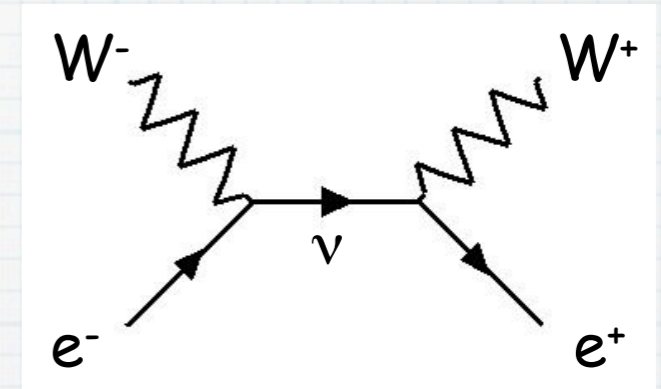
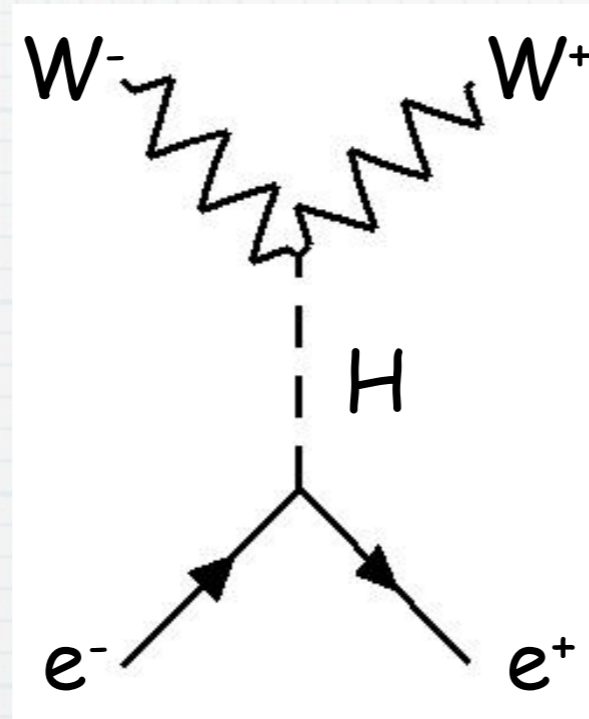
Spin 0
from wrong
helicity state

Another Gauge Cancellation



Spin 0
from wrong
helicity state

Another Gauge Cancellation



Spin 0
from wrong
helicity state

- ❖ Wrong helicity state $\propto m_e$
- ❖ eeH coupling $\propto m_e$
⇐ very well modeled? 出来過ぎ?

$$\begin{aligned}
\mathcal{L} = & \bar{\nu}(i \not{\partial} - m_\nu)\nu + \bar{l}(i \not{\partial} - m_l)l + \frac{1}{2}(\partial_\mu \chi \partial^\mu \chi - \mu^2 \chi^2) \\
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& + eA_\mu (\bar{l} \gamma^\mu l) - \frac{g}{\sqrt{2}} [W_+^\mu (\bar{\nu} \gamma^\mu P_L l) + c.c.] \\
& - \bar{g} Z_\mu [\bar{\nu} \gamma^\mu (s_{\nu L} P_L + s_{\nu R} P_R)\nu + \bar{l} \gamma^\mu (s_{l L} P_L + s_{l R} P_R)l] \\
& + \frac{2v\chi + \chi^2}{4} (g^2 W_{+\mu}^* W_+^\mu + \frac{\bar{g}^2}{2} Z_\mu Z^\mu) \\
& - \frac{m_l}{v} \chi (\bar{l} l) - \frac{m_\nu}{v} \chi (\bar{\nu} \nu) \\
& + \dots
\end{aligned}$$

実験が理論にインプットを与えたい

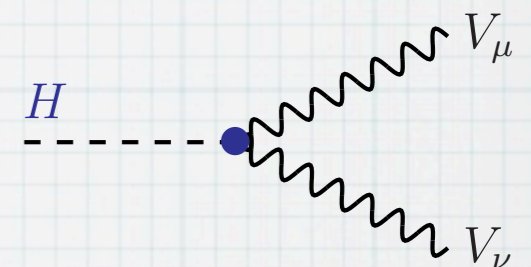
実験屋の観点から

Coupling to Higgs

❖ HWW

▶ Coupling

$$\frac{g^2}{2}v = gm_W = \frac{e}{\sin \theta_W} m_W$$



❖ HZZ

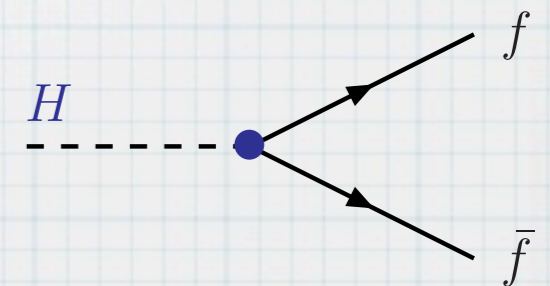
▶ Coupling

$$\frac{\bar{g}^2}{4}v = \frac{gm_Z}{\cos \theta_W} = \frac{2e}{\sin(2\theta_W)} m_Z$$

❖ Hff

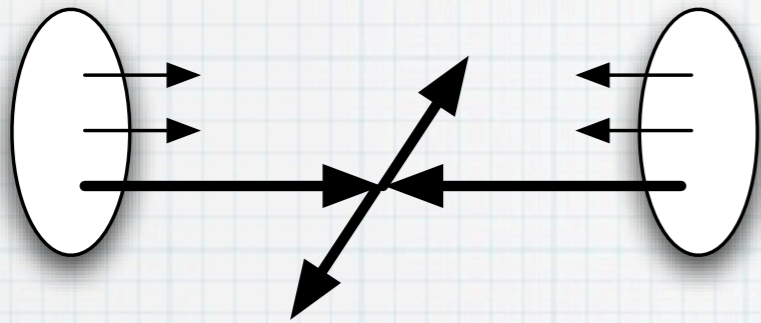
▶ Coupling = Yukawa (by definition)

$$Y_f \equiv \frac{\sqrt{2}}{v} m_f$$



In any case, coupling proportional to mass

ハドロンコライダーでの衝突物

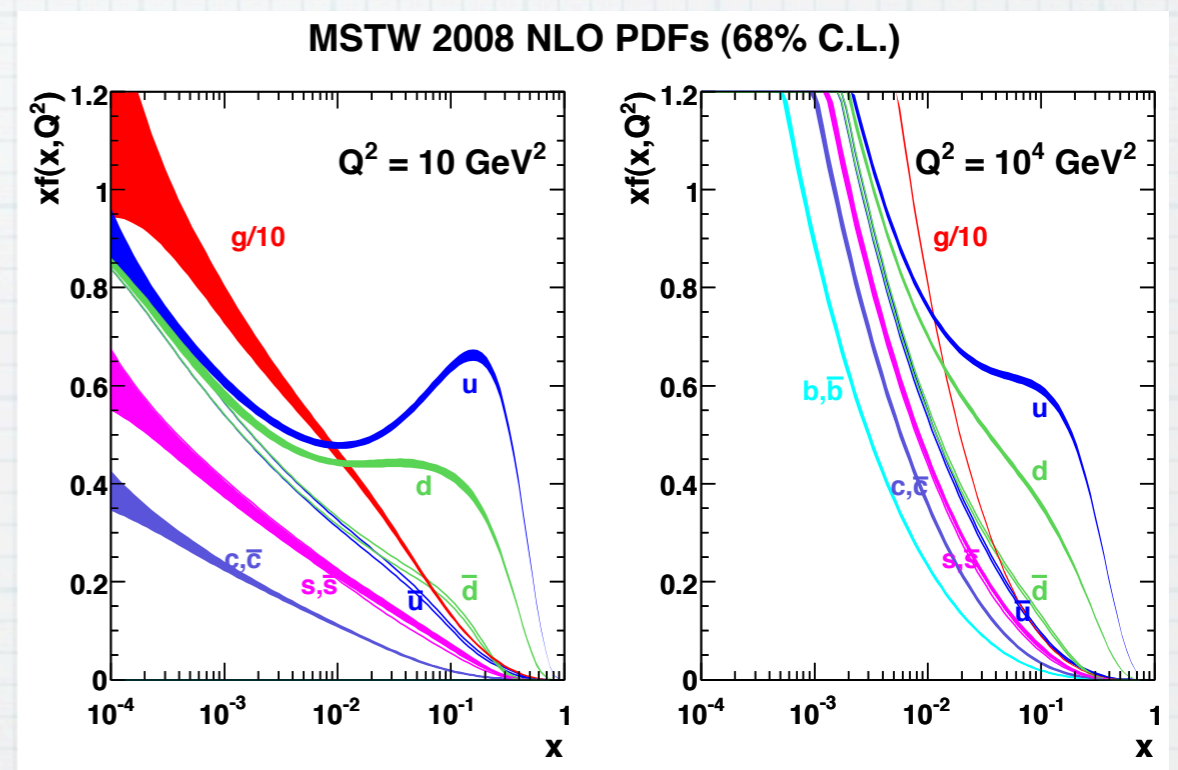


$$\hat{p}_1 = (x_1 E; 0, 0, x_1 E), \quad \hat{p}_2 = (x_2 E; 0, 0, -x_2 E),$$

$$\hat{s}^2 = (x_1 + x_2)^2 E^2 - (x_1 - x_2)^2 E^2 = 4x_1 x_2 E^2$$

$$\therefore \sqrt{\hat{s}} = \sqrt{x_1 x_2} \sqrt{s} \quad (\sqrt{s} = 2E)$$

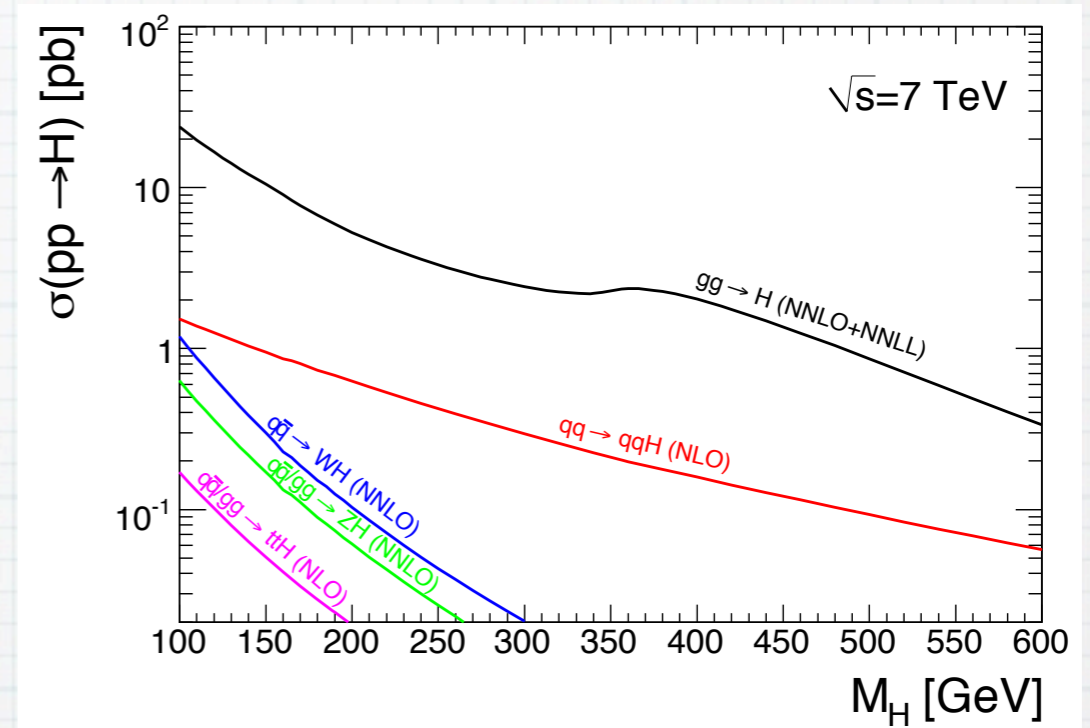
$$\sqrt{\hat{s}} \sim 100 \text{ GeV} \Rightarrow \sqrt{x_1 x_2} \sim 10^{-2}$$



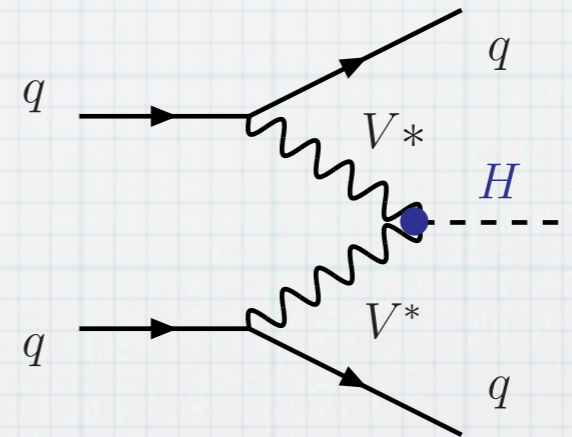
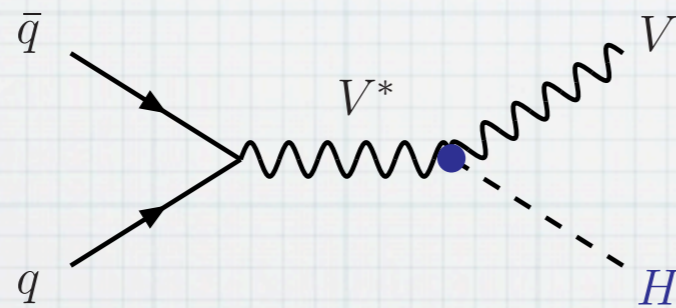
- ❖ 軽い粒子生成ではグルーオン衝突
- ❖ 重い粒子生成ではクォーク衝突

Higgs Production at LHC

- ❖ Coupling \propto mass
 - ▶ top the largest among fermions
- ❖ Gauge boson relatively larger

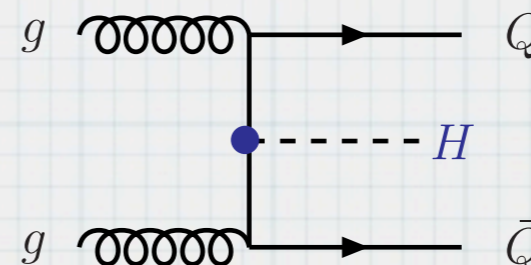
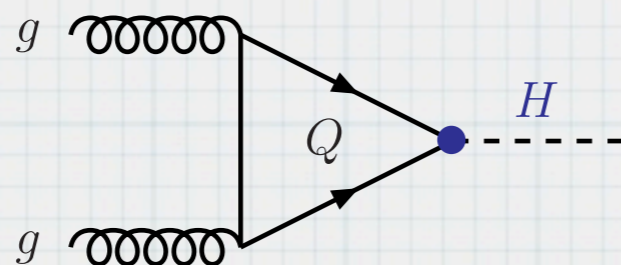


associated production of vector boson



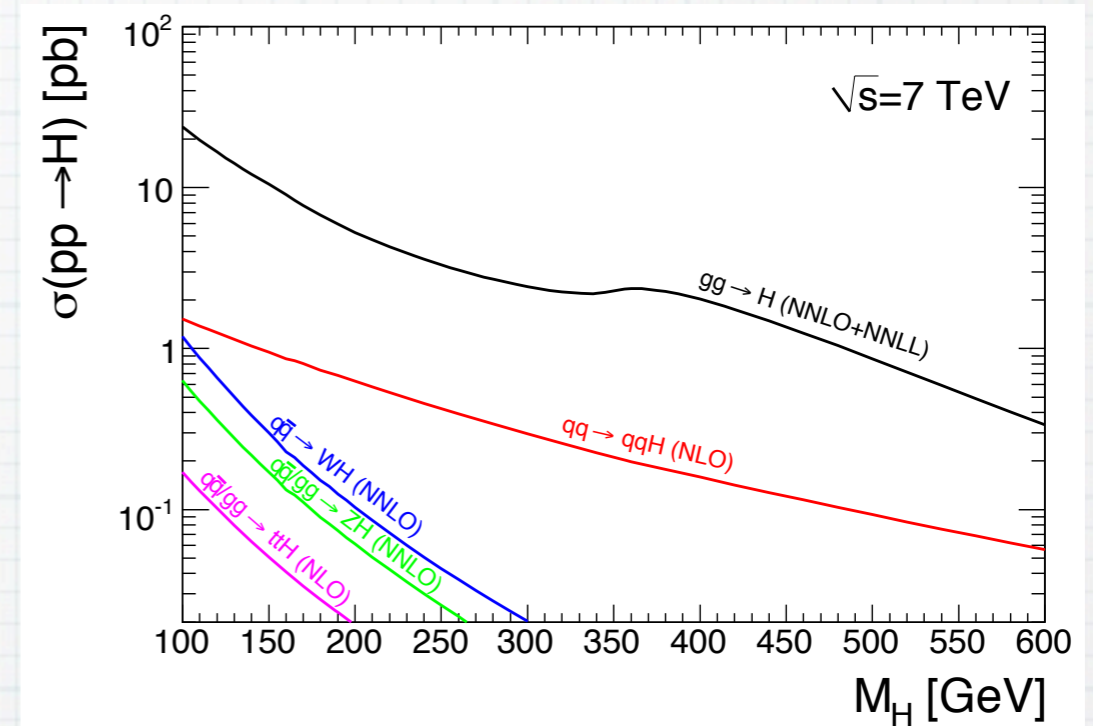
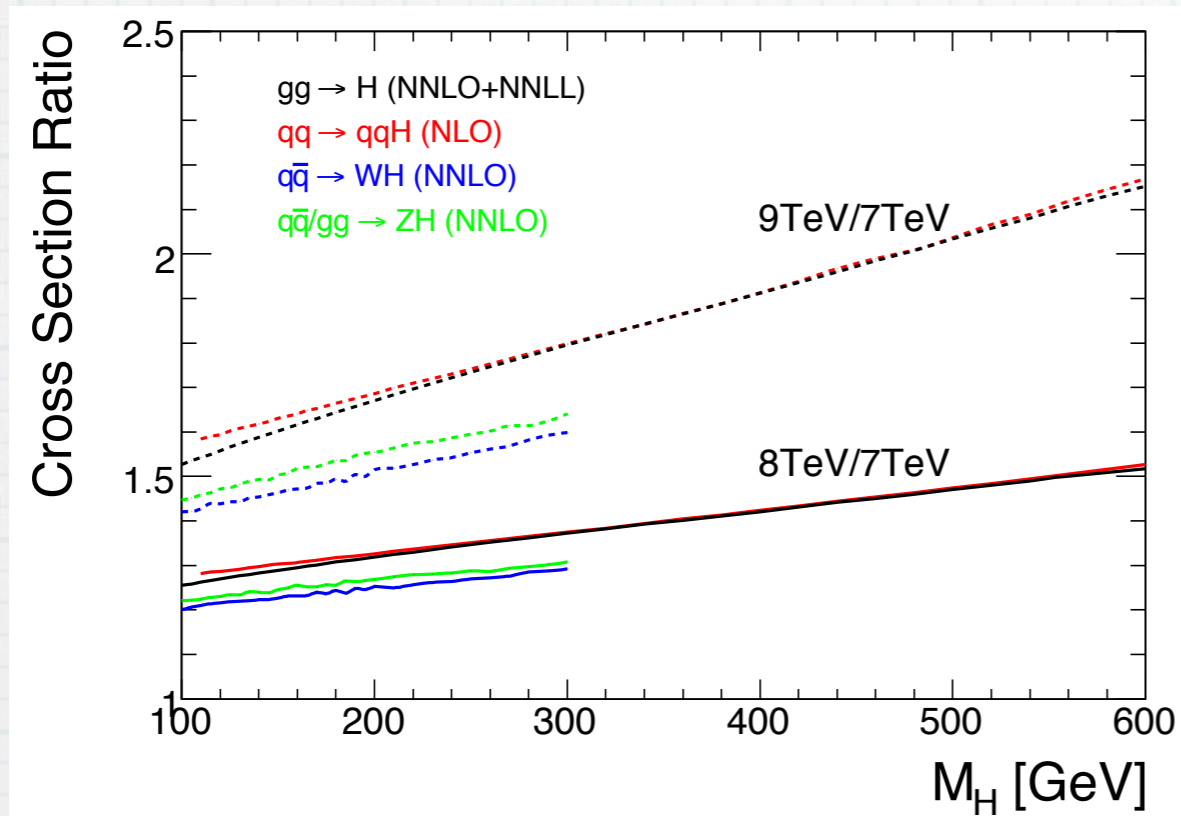
vector boson fusion (VBF)

gluon fusion (GF)

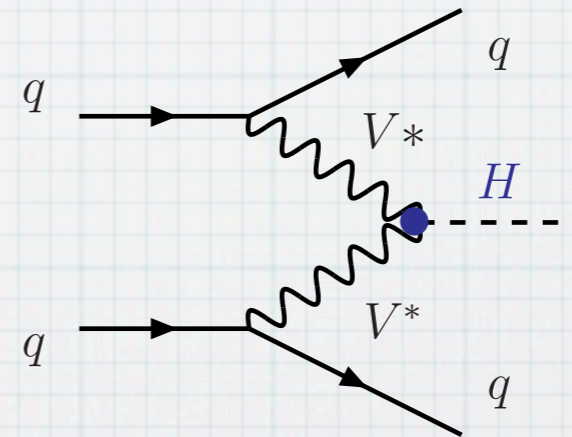
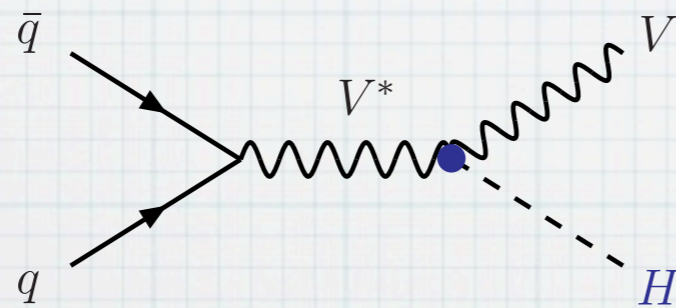


associated production of heavy quark (t, b)

Higgs Production at LHC

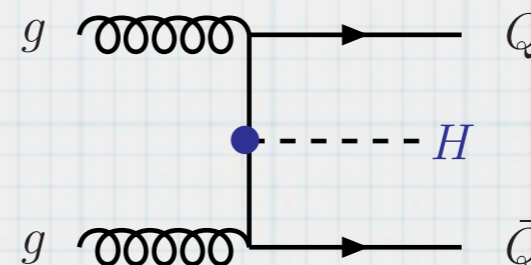
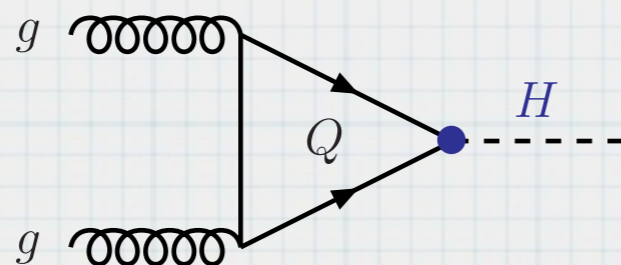


associated production of vector boson



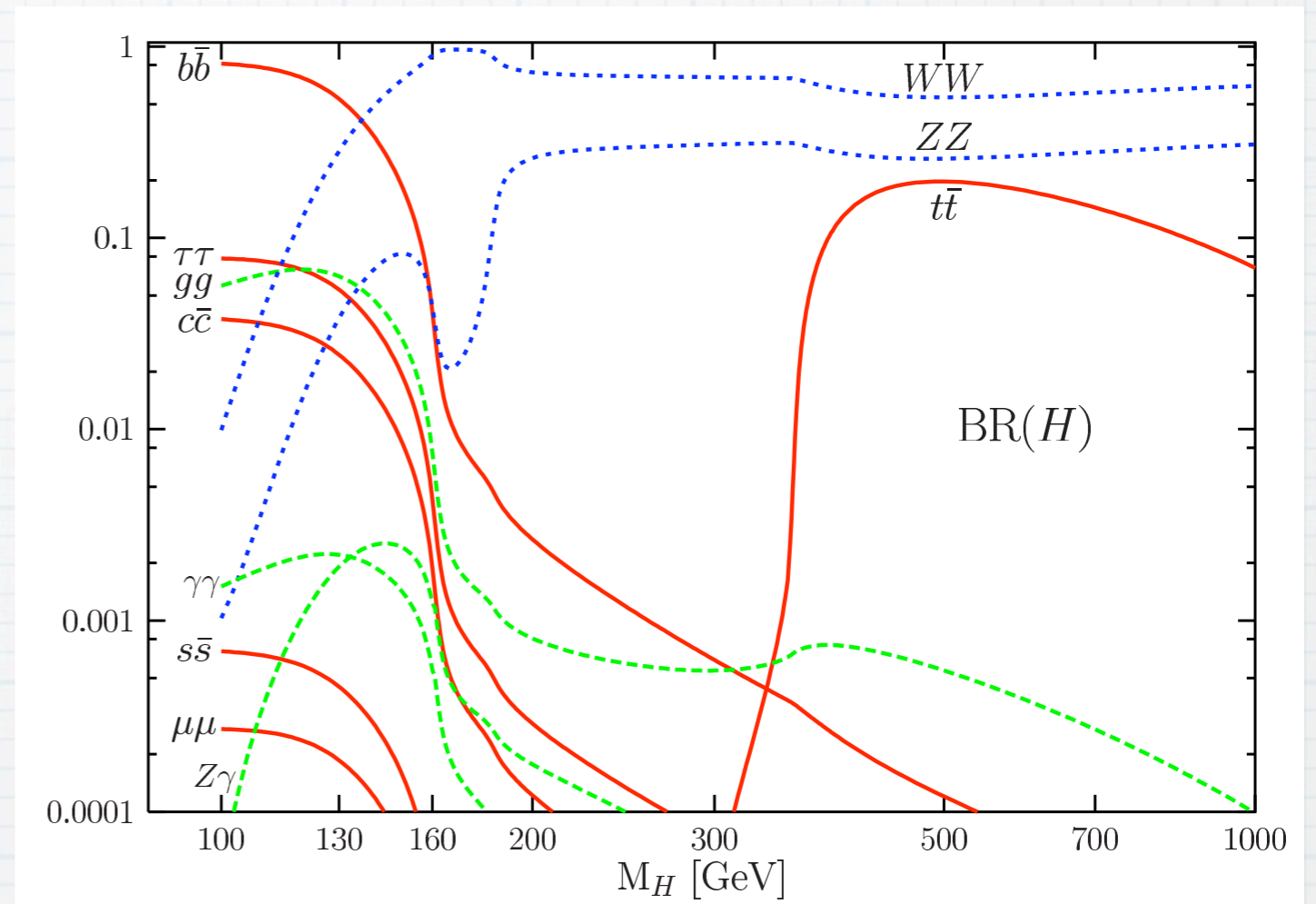
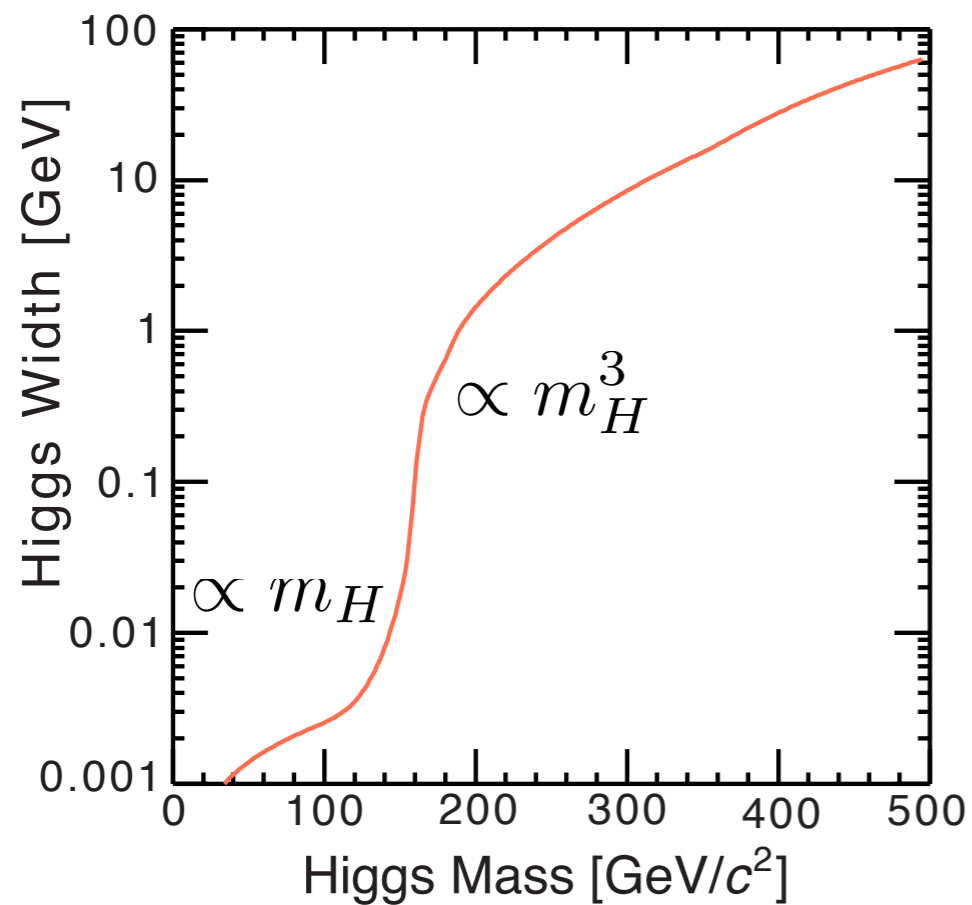
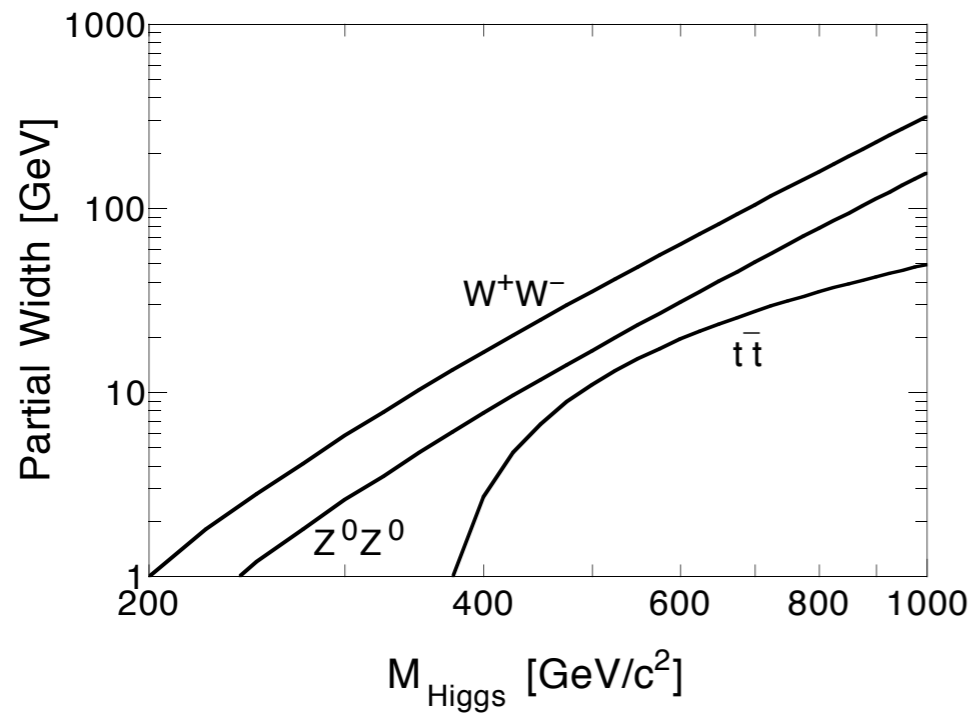
vector boson fusion (VBF)

gluon fusion (GF)



associated production of heavy quark (t, b)

Decay of Higgs

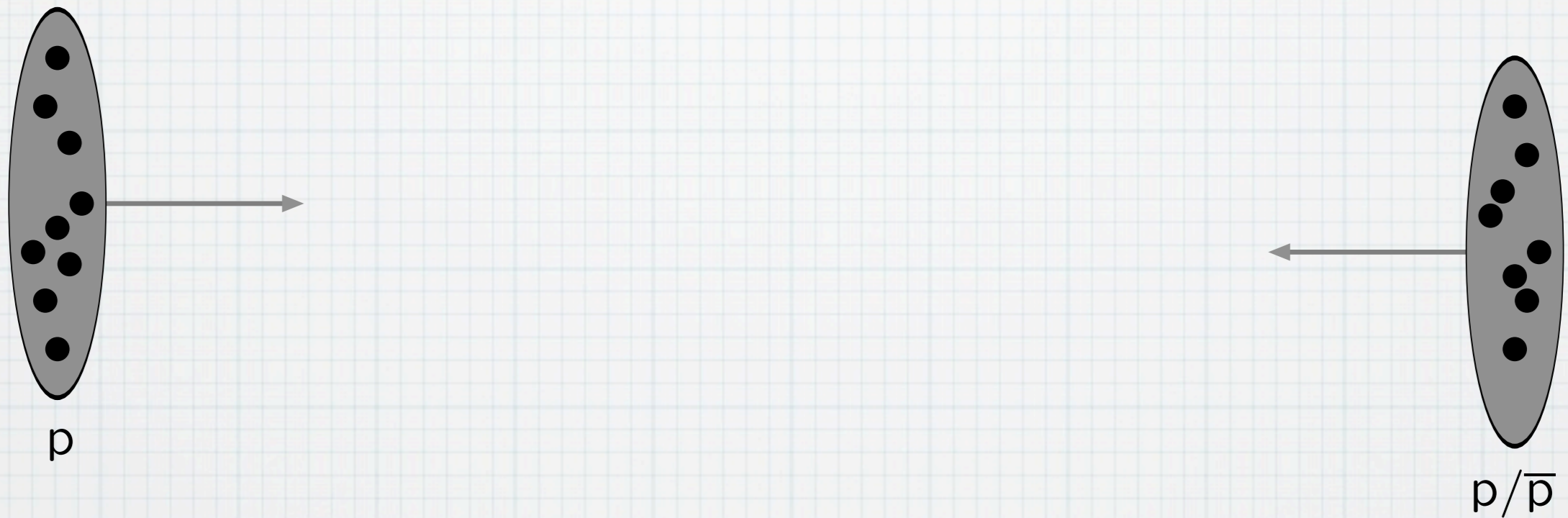


- ❖ Γ (vector boson) $\propto m_H^3$
- ❖ Γ (fermion) $\propto m_H$

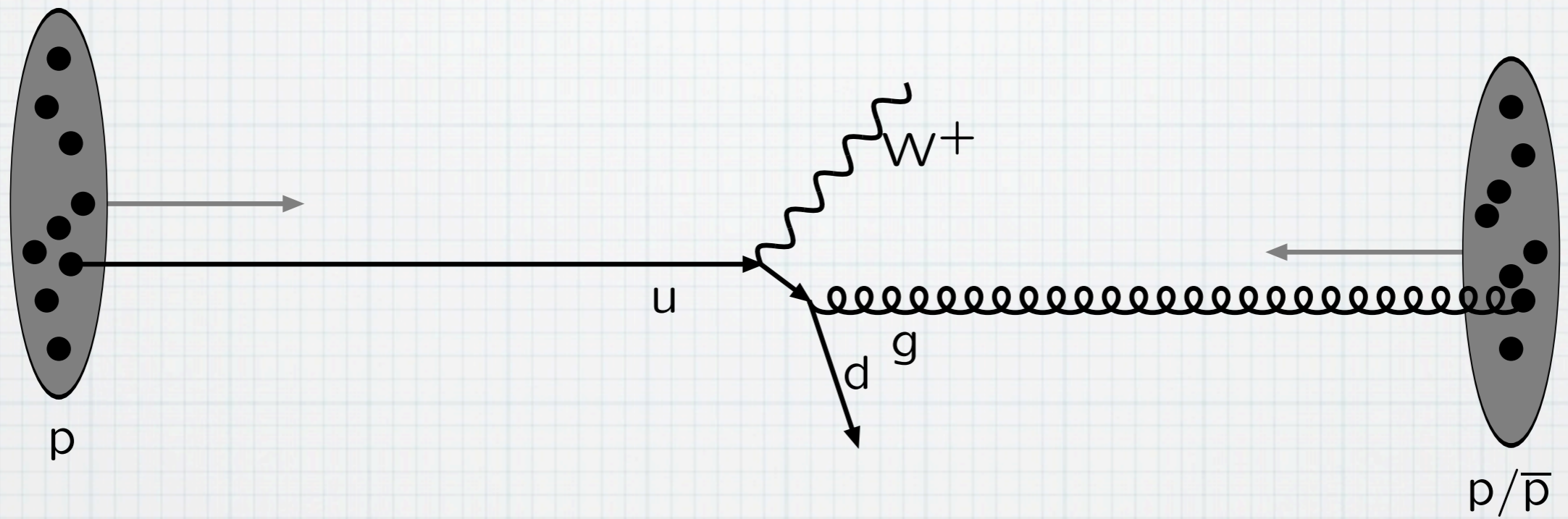
What actually happens
at hadron collider

The structure of an event

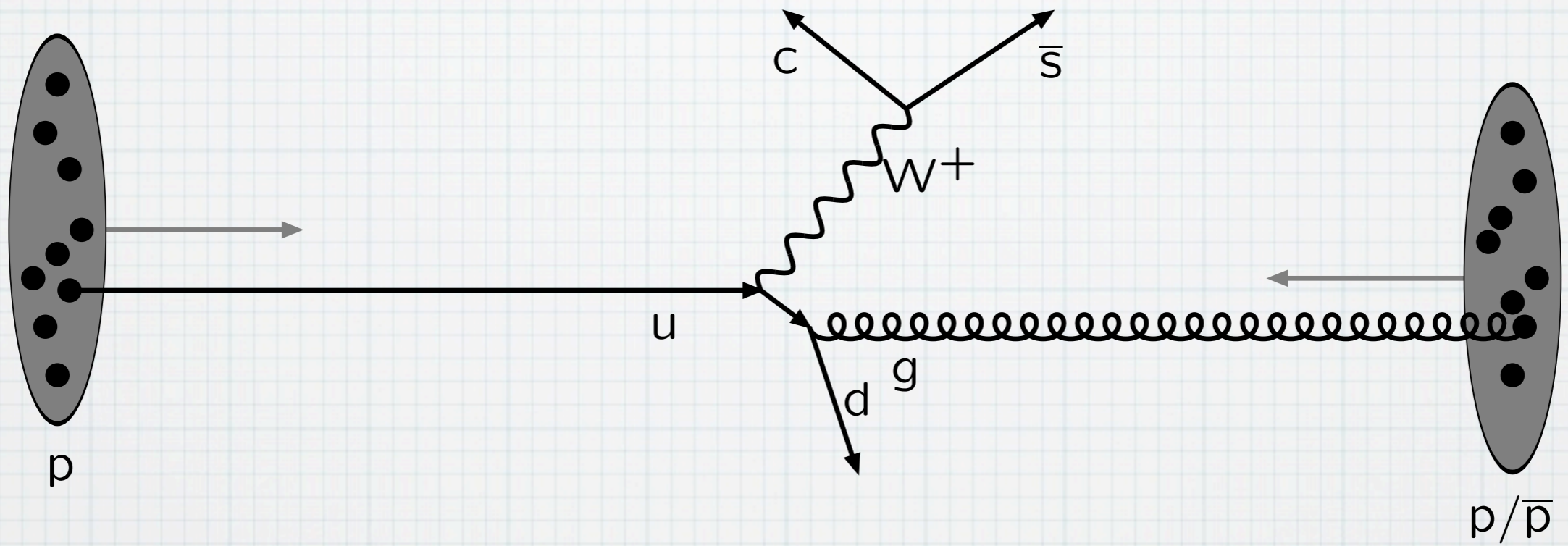
Warning: schematic only, everything simplified, nothing to scale, ...



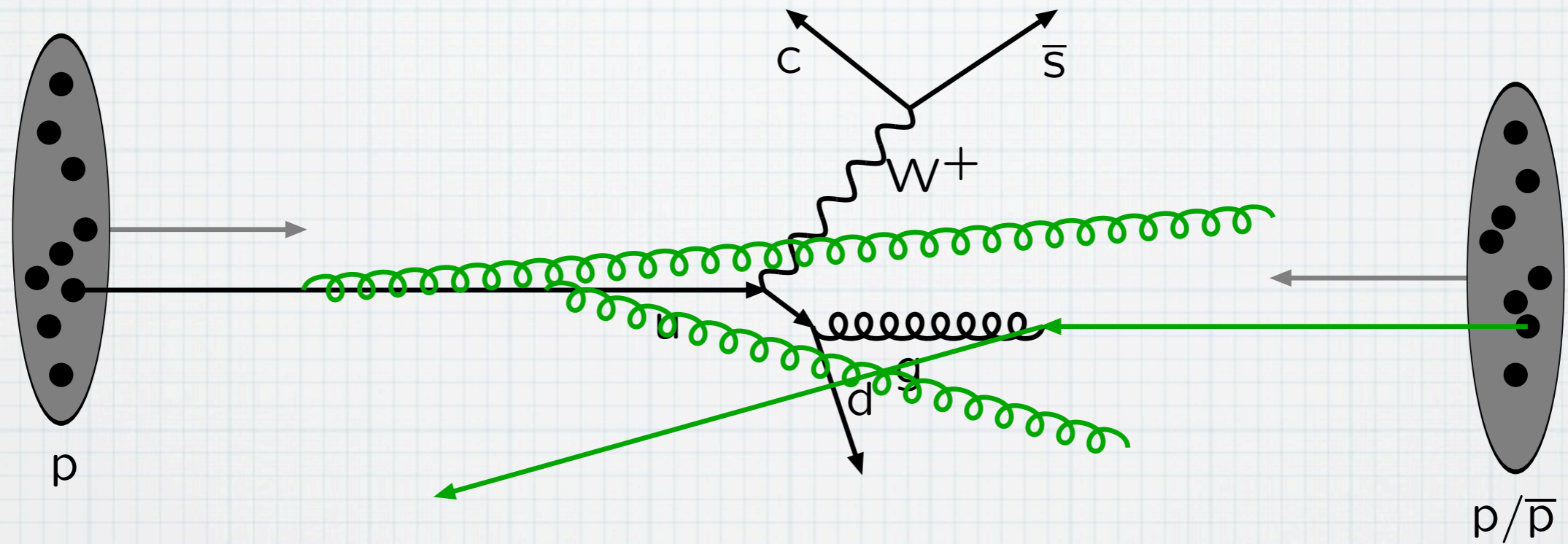
Incoming beams: parton densities



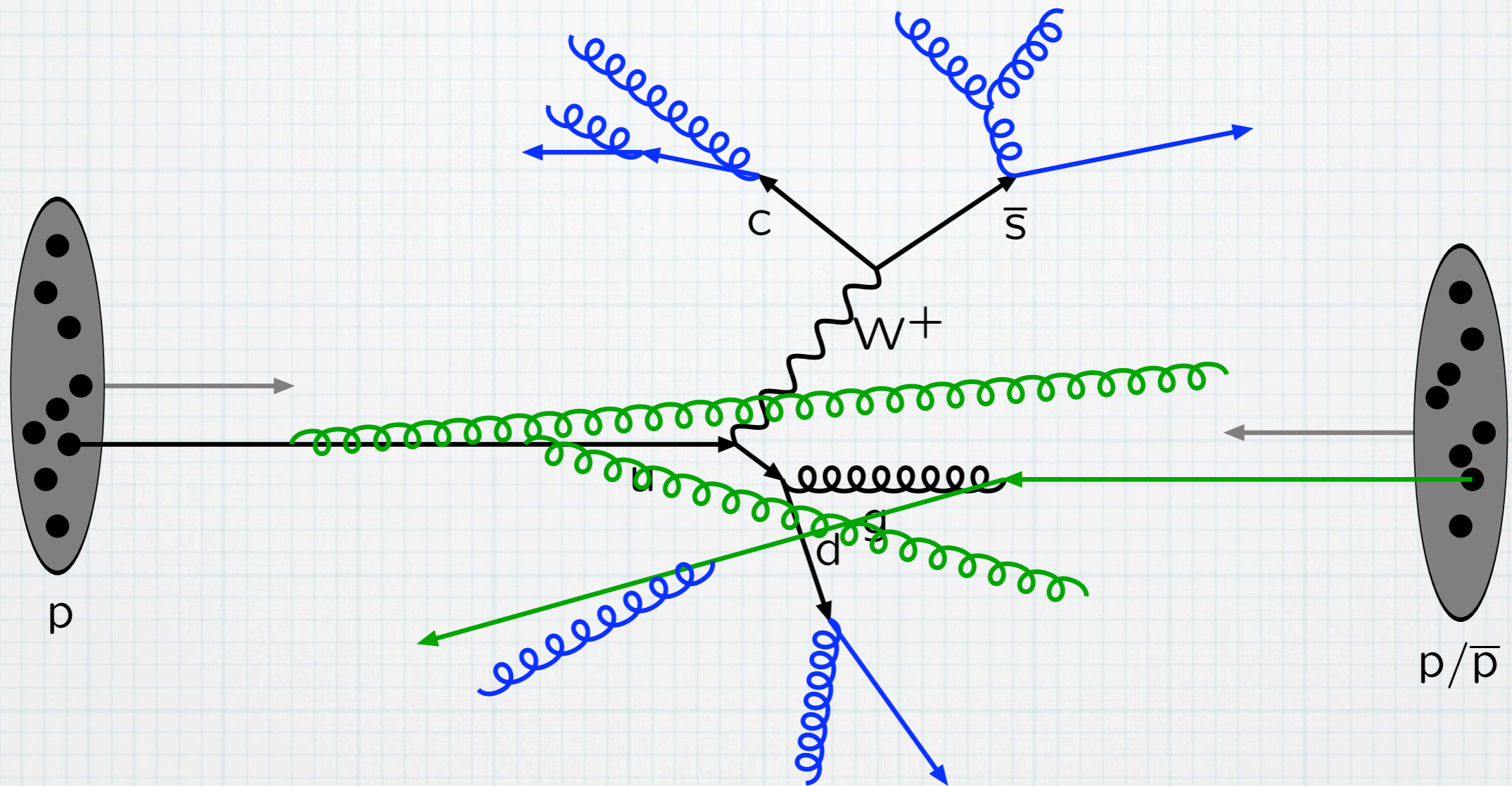
Hard subprocess: described by matrix elements



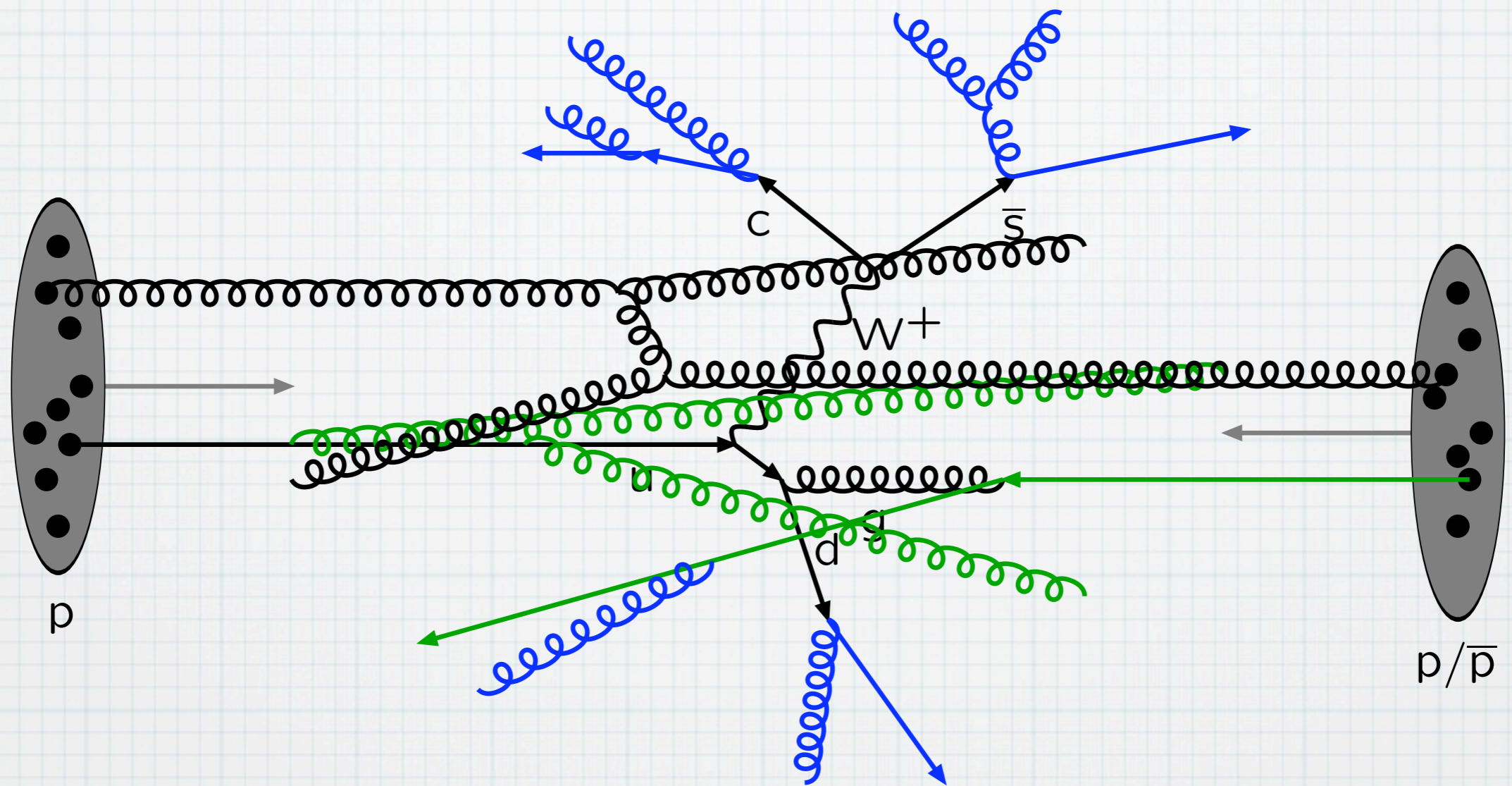
Resonance decays: correlated with hard subprocess



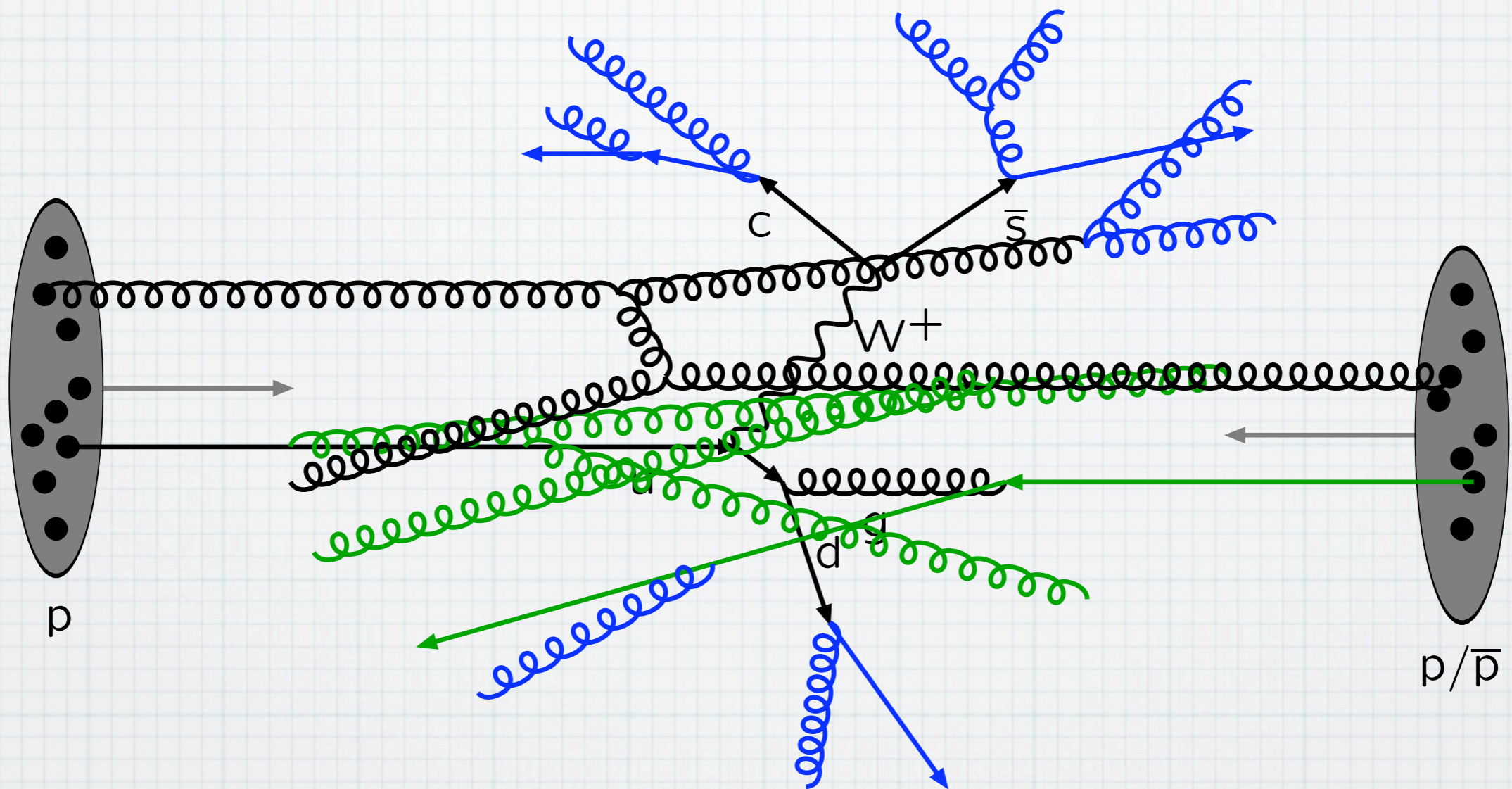
Initial-state radiation: spacelike parton showers



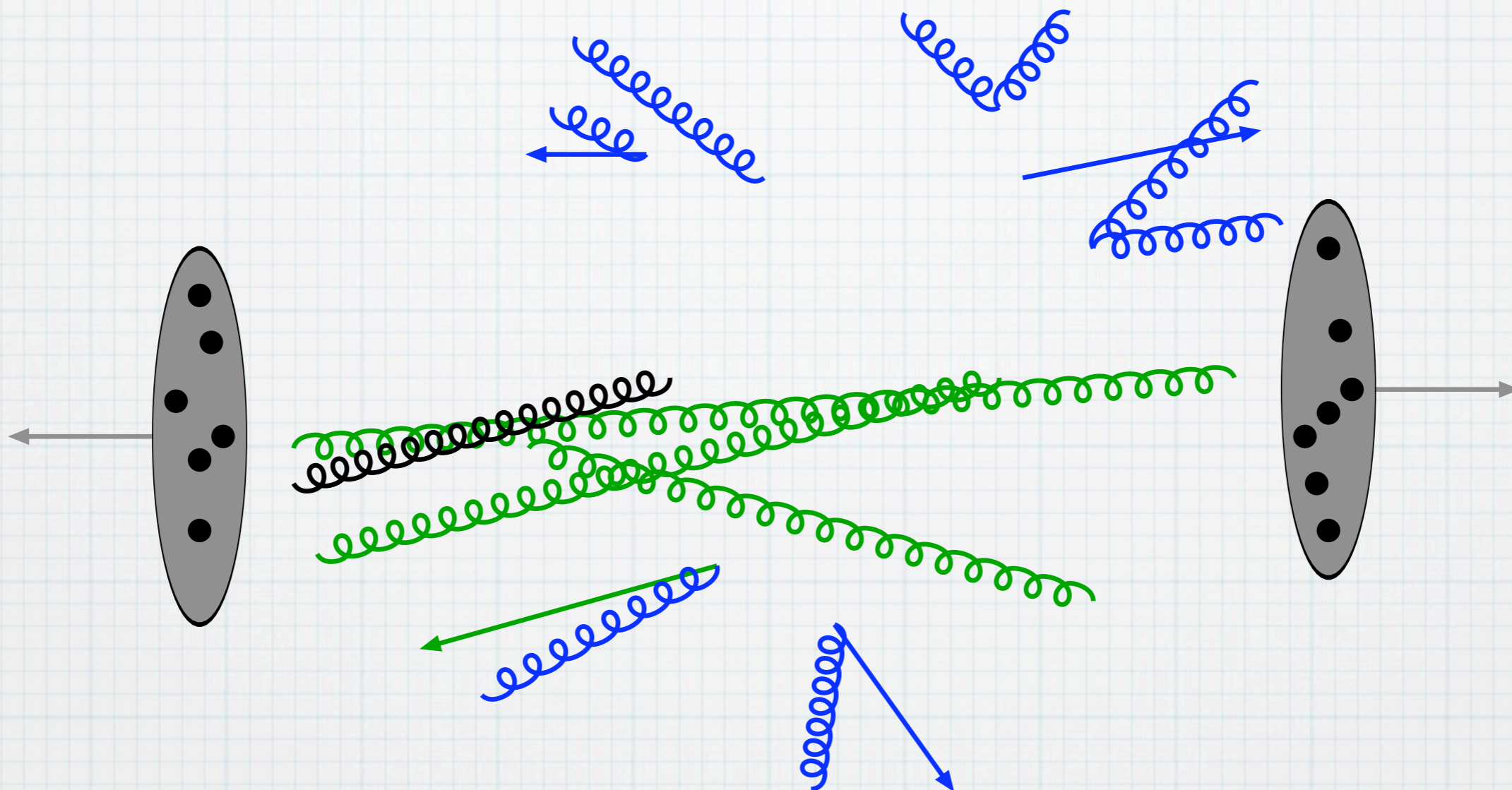
Final-state radiation: timelike parton showers



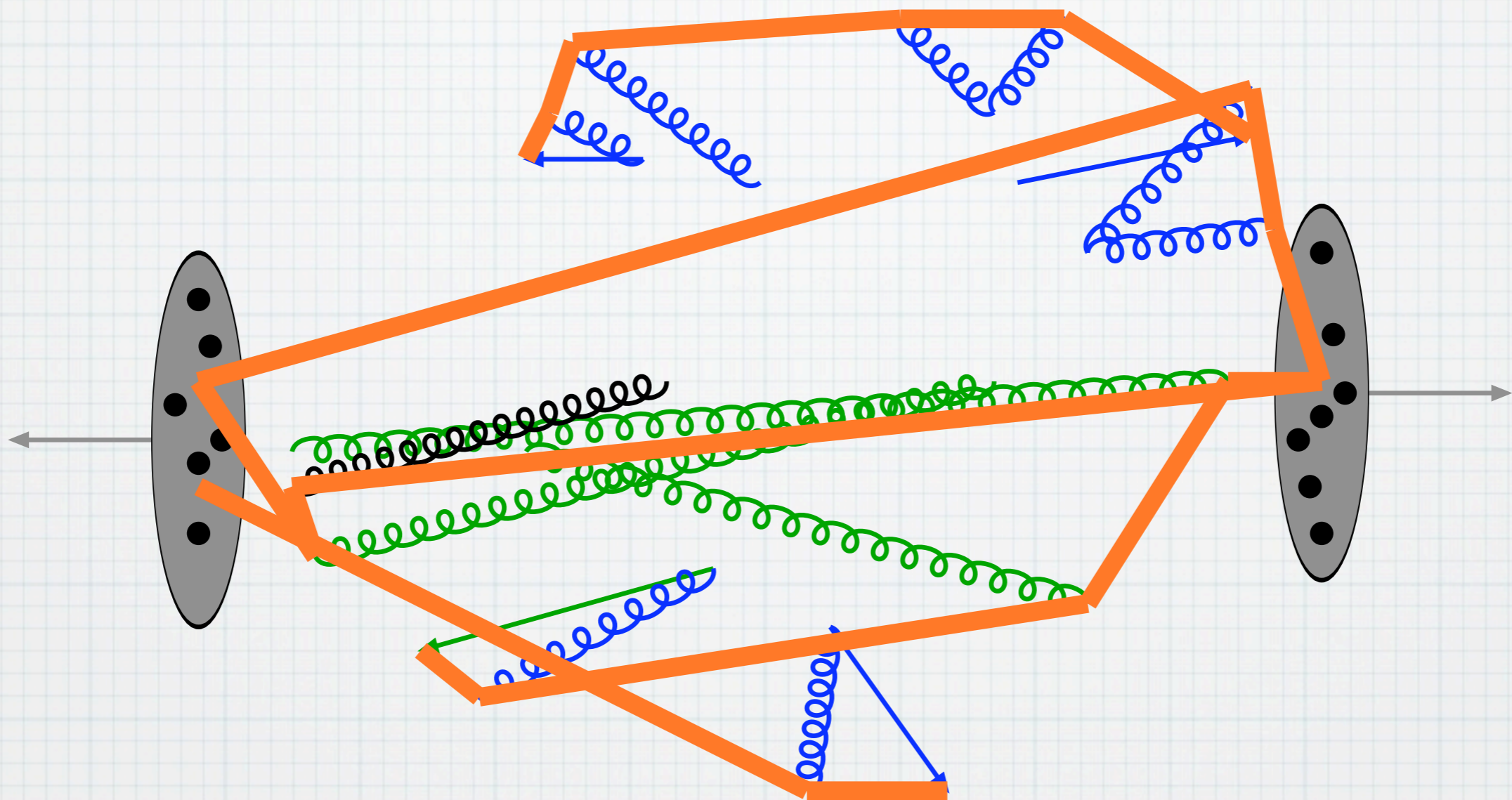
Multiple parton-parton interactions ...



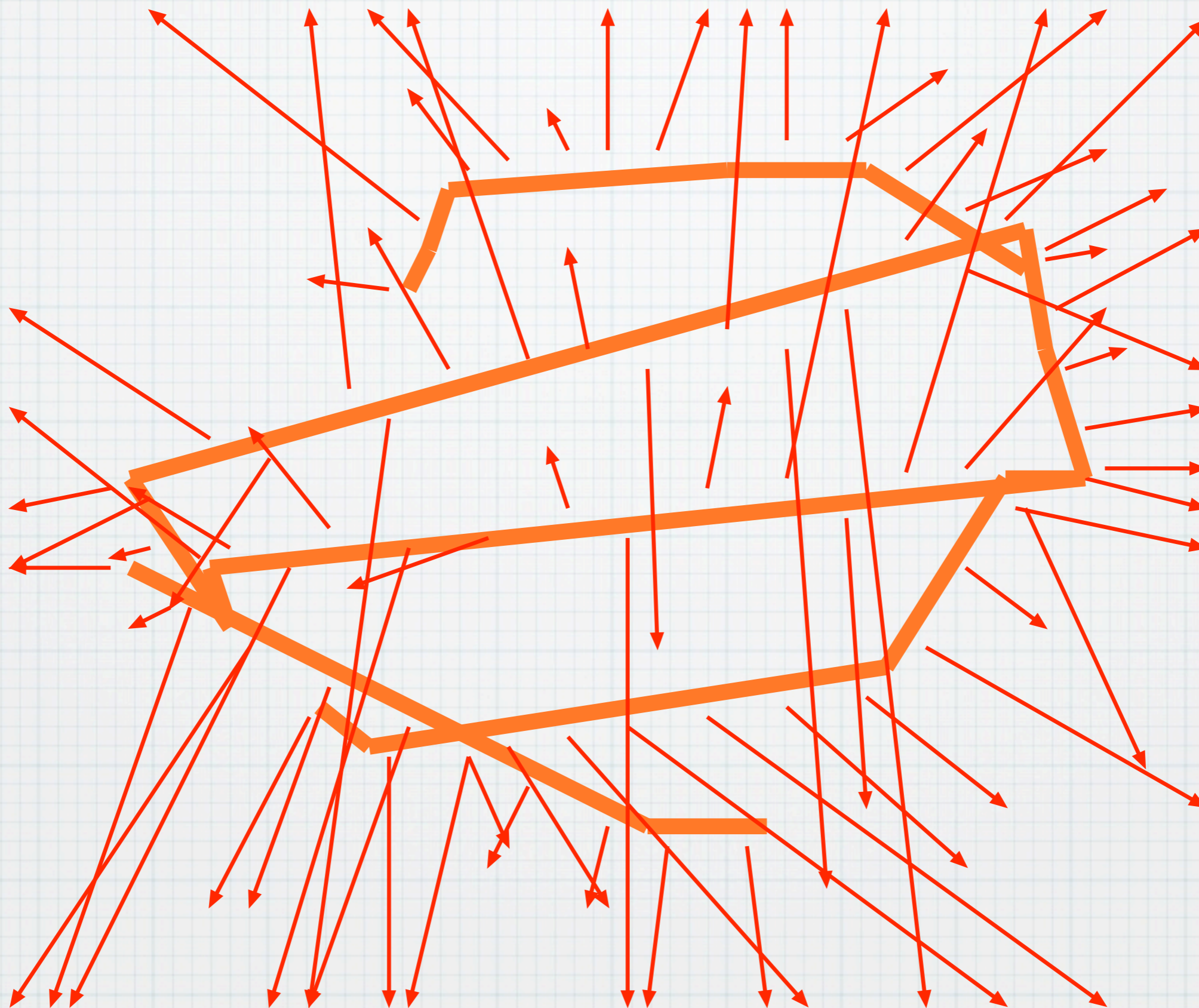
... with its **initial-** and **final-**state radiation



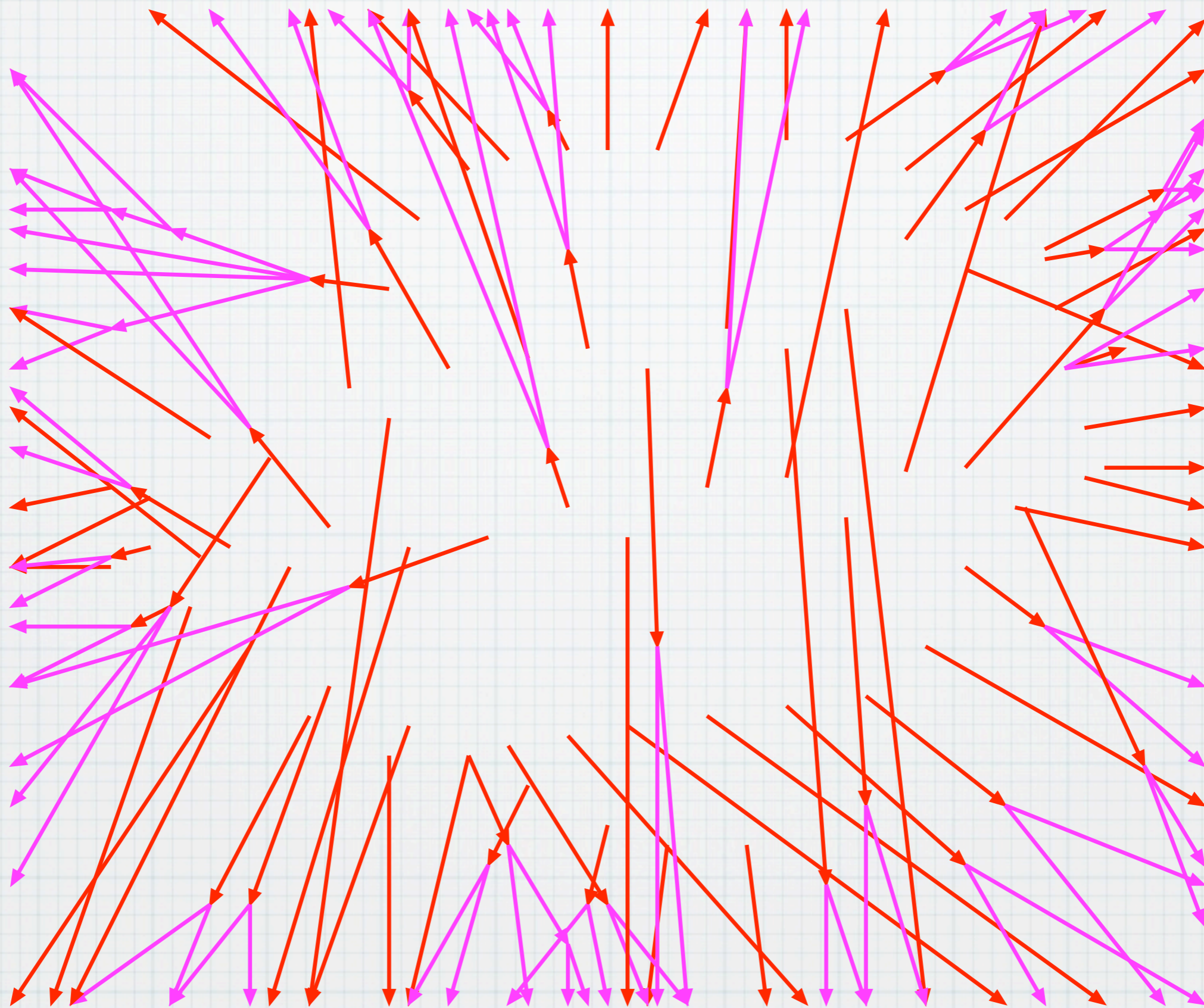
Beam remnants and other outgoing partons



Everything is connected by colour confinement strings
Recall! Not to scale: strings are of hadronic widths



The strings fragment to produce primary hadrons

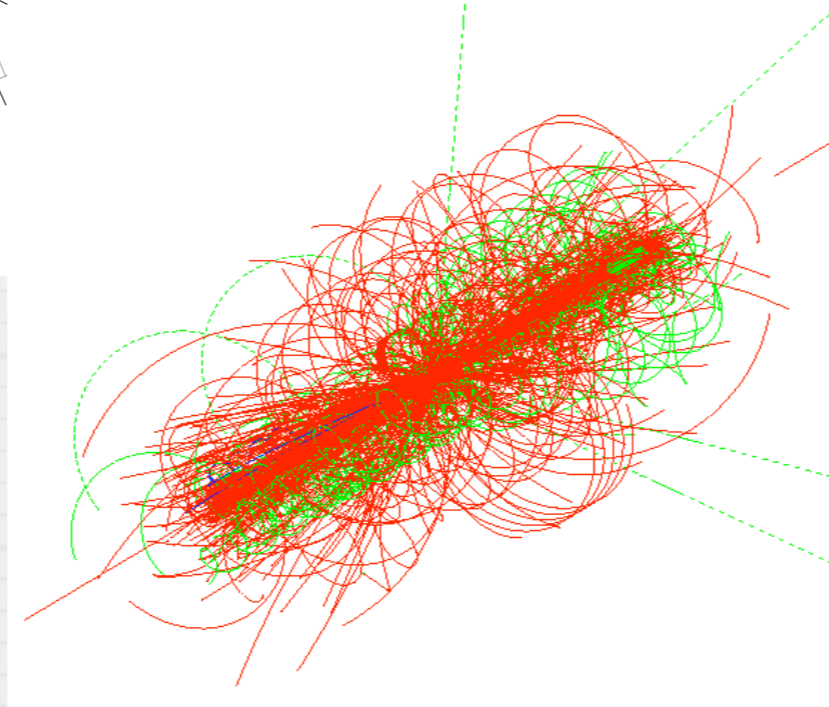
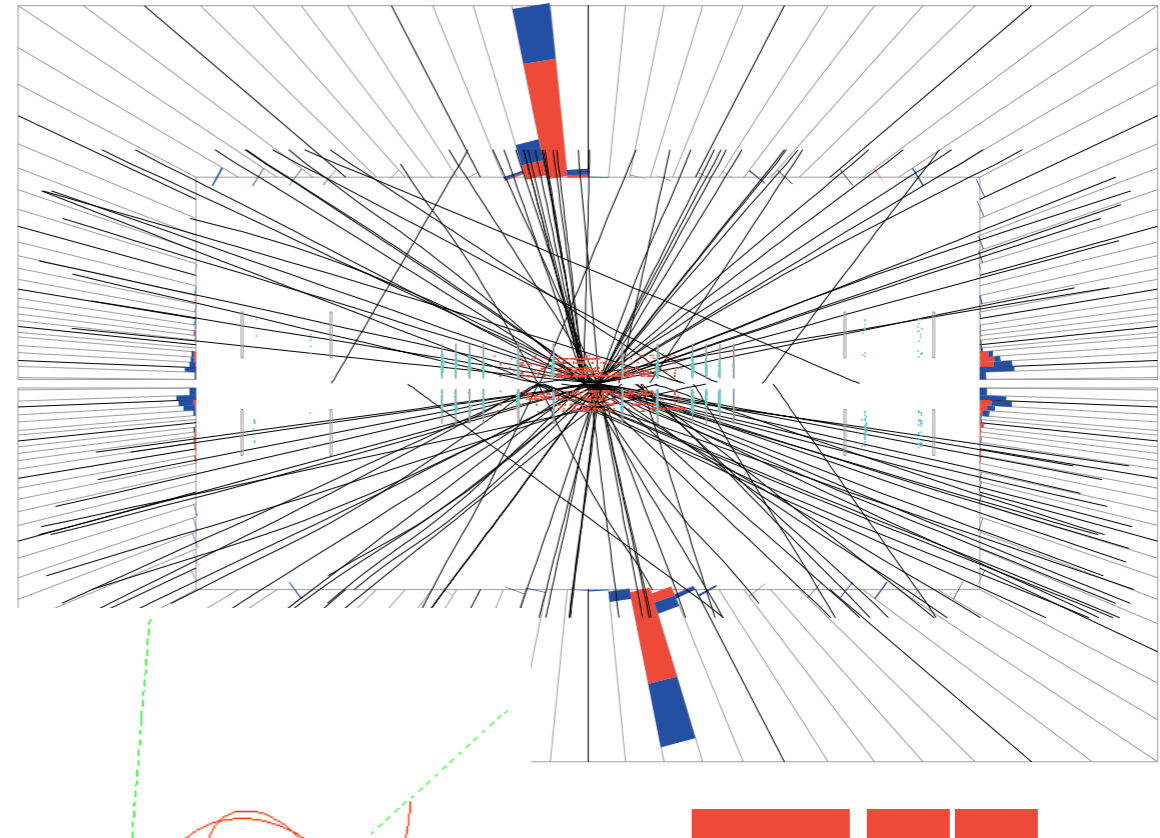
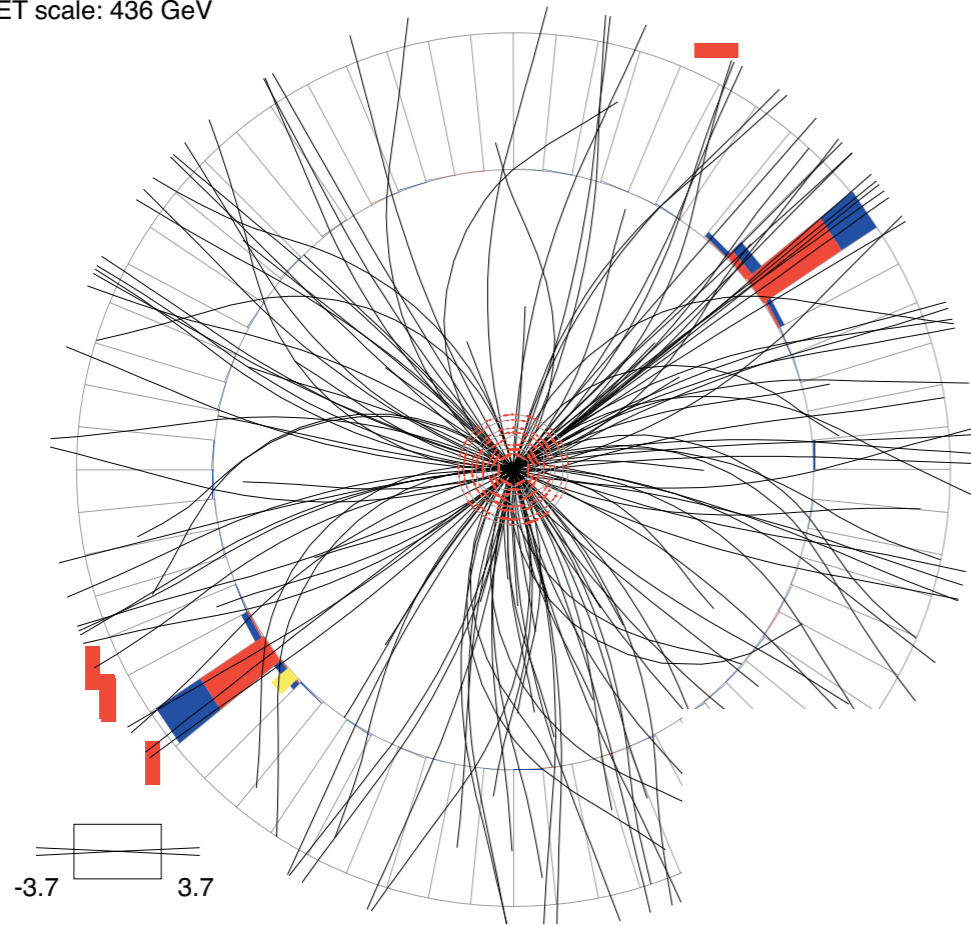


Many hadrons are unstable and decay further

Real Event at Dzero

E scale: 431 GeV

ET scale: 436 GeV



Experimental Difficulty

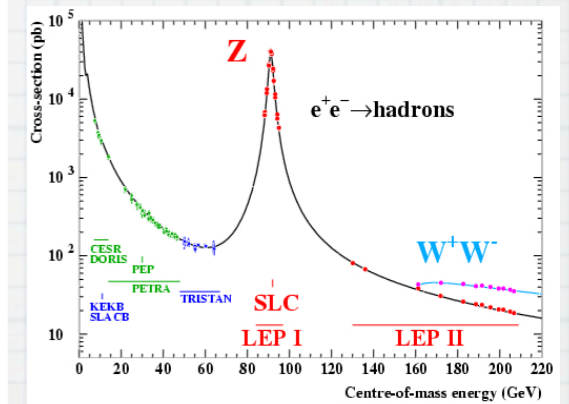
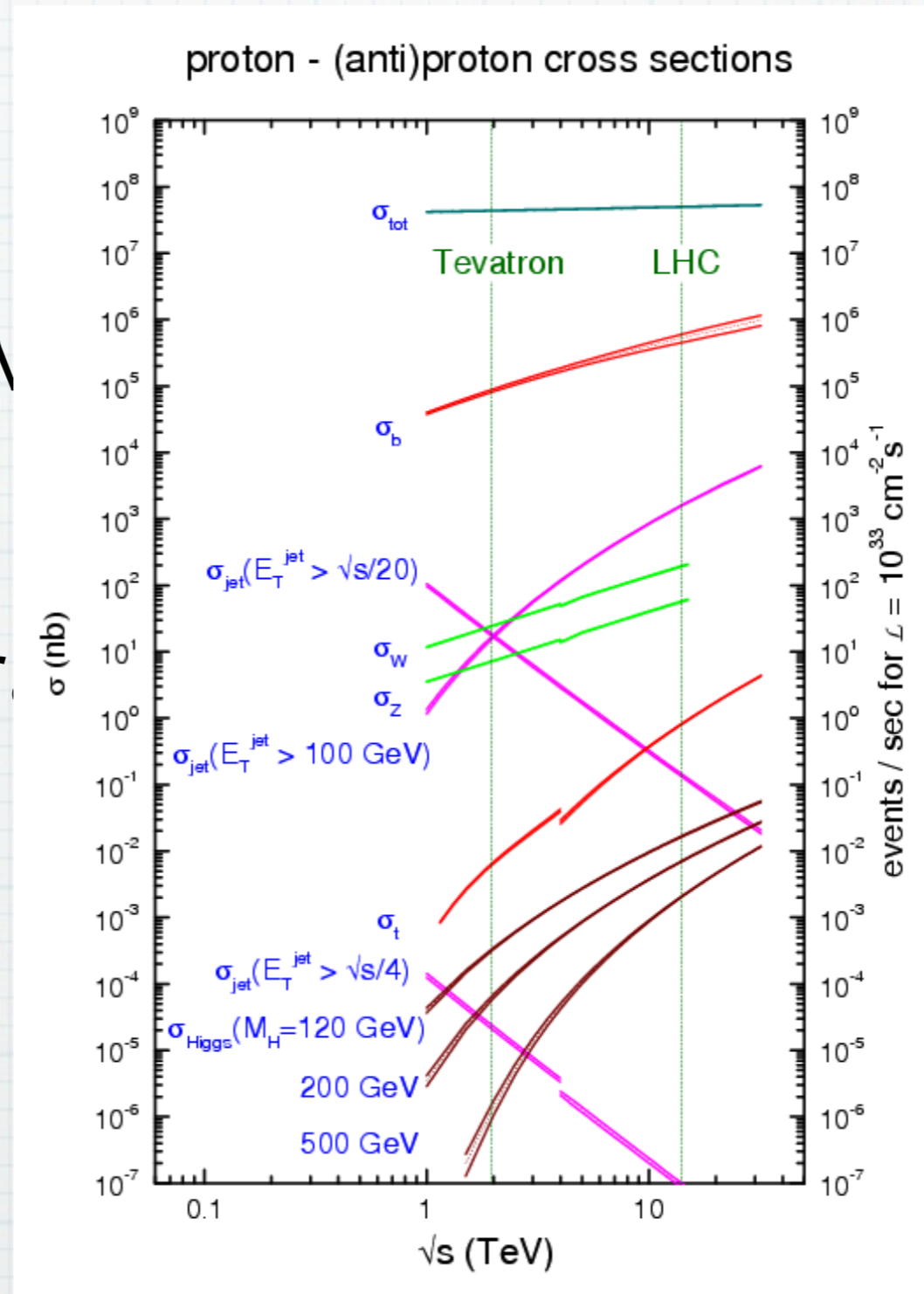
- ❖ Underlying Event
- ❖ Multiple Interactions

Experimental Difficulty

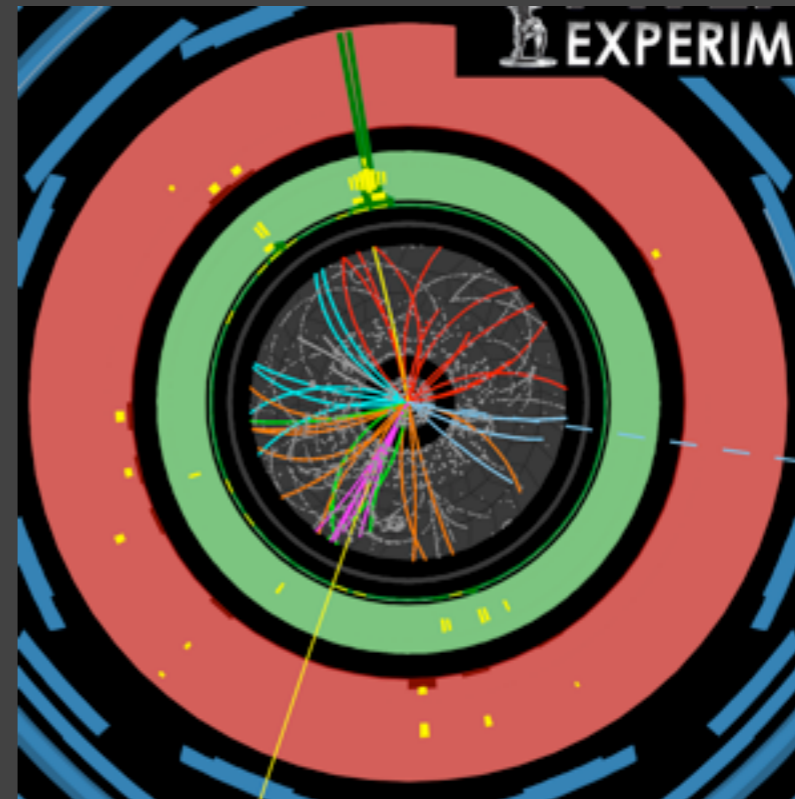
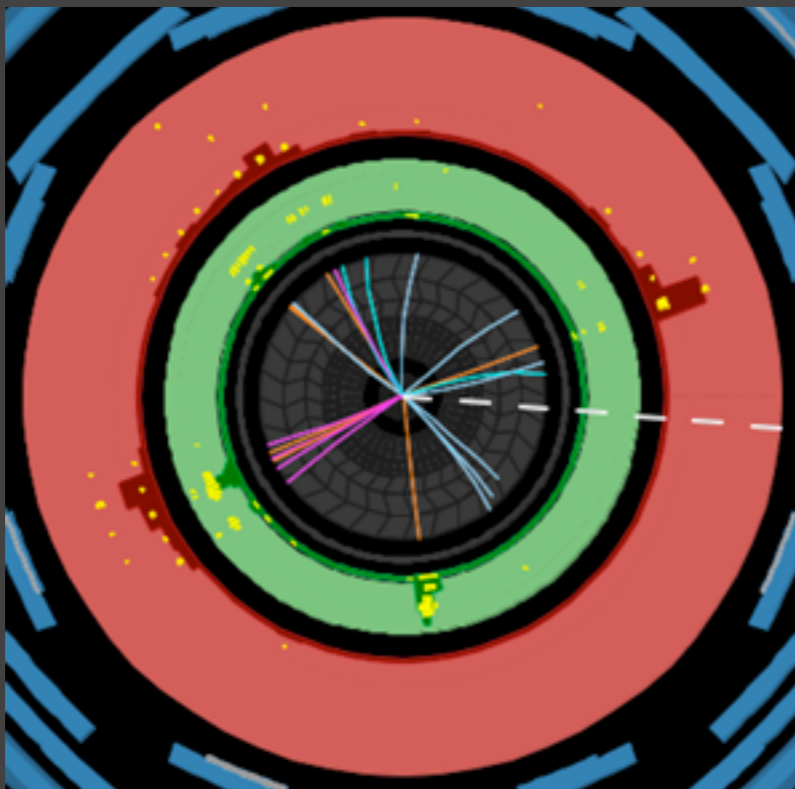
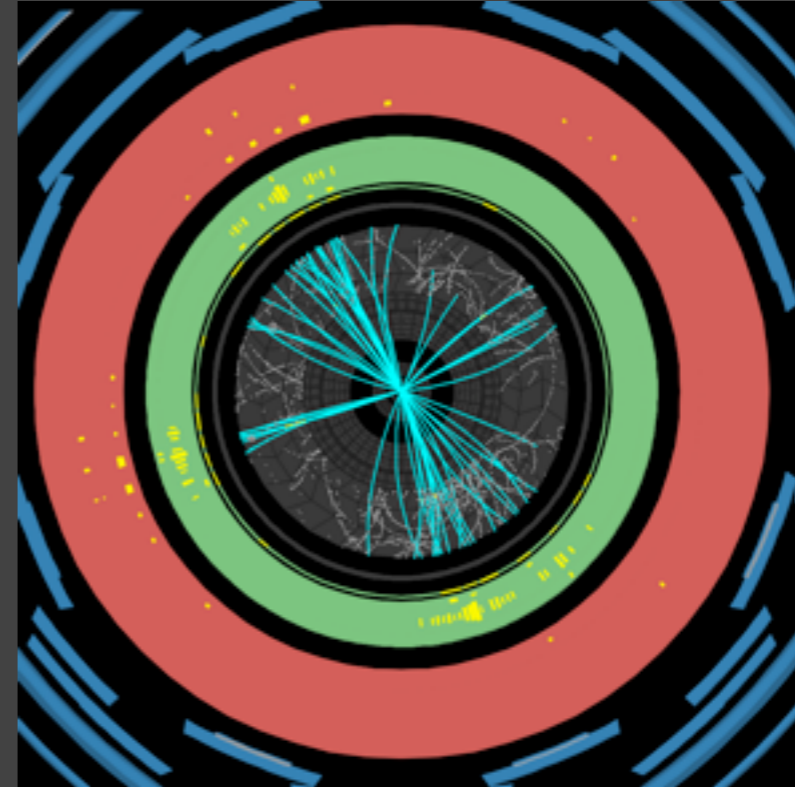
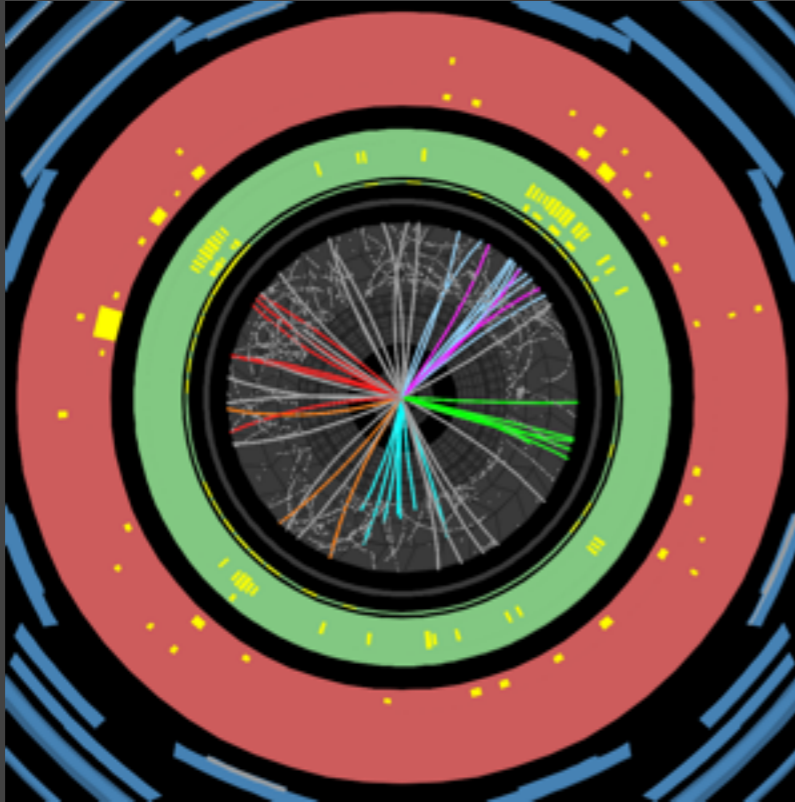
❖ Underlying Events

❖ Multiple Interactions

❖ Low S/N

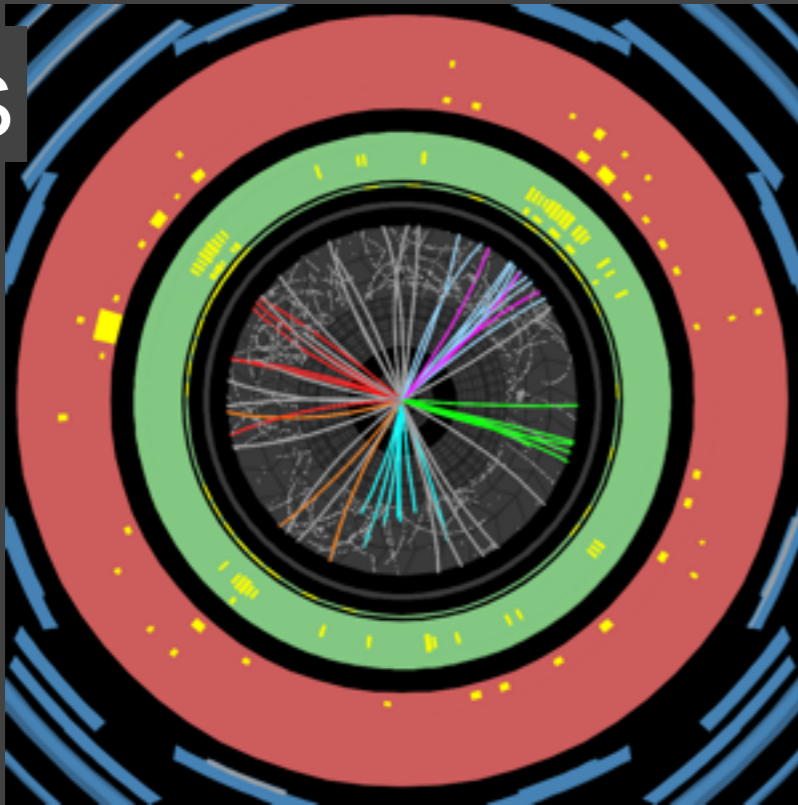


Can you distinguish?

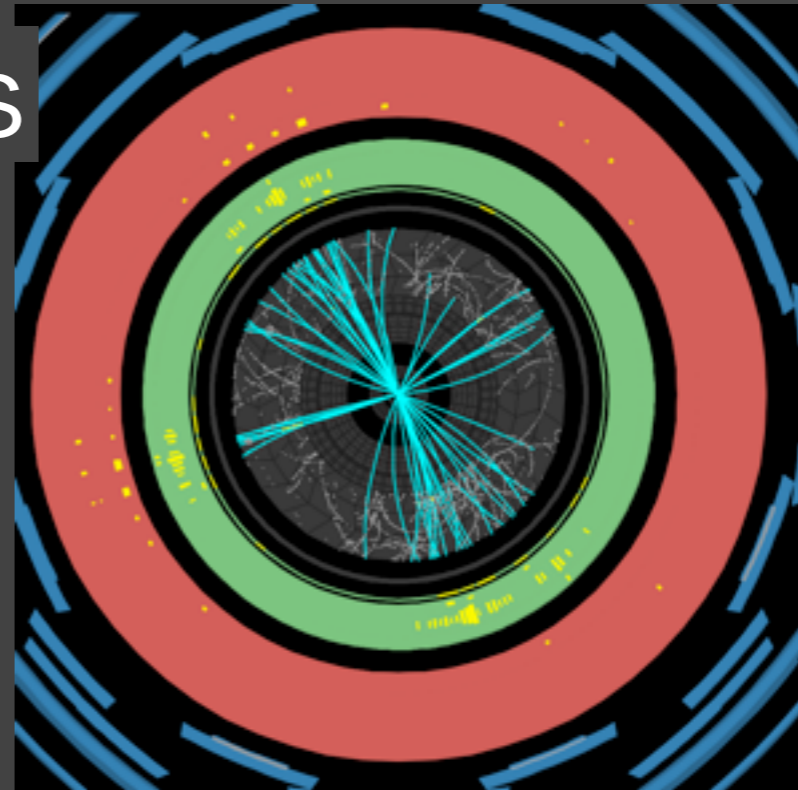


Can you distinguish?

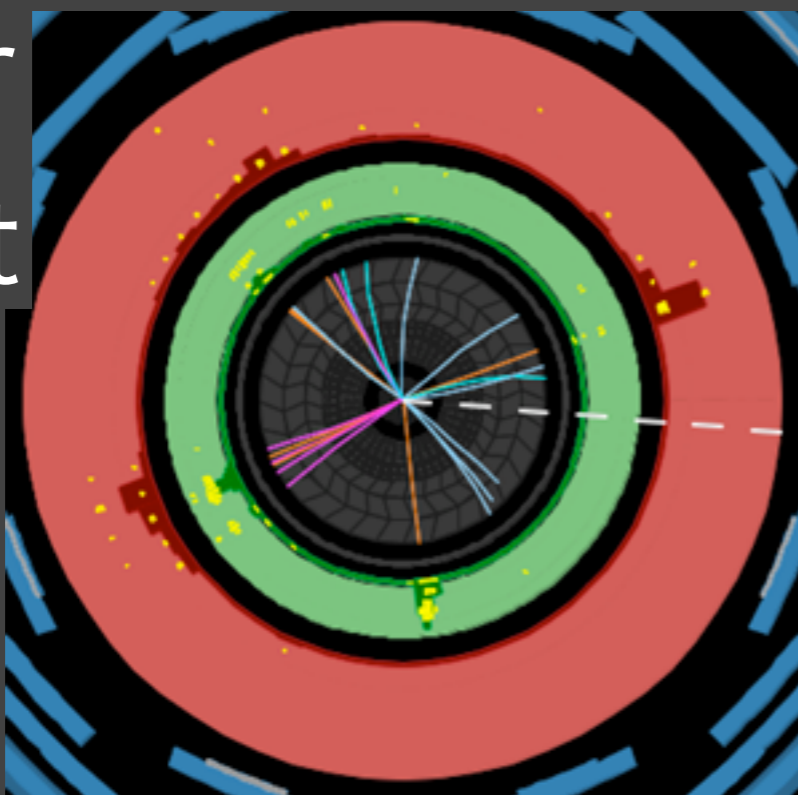
6jets



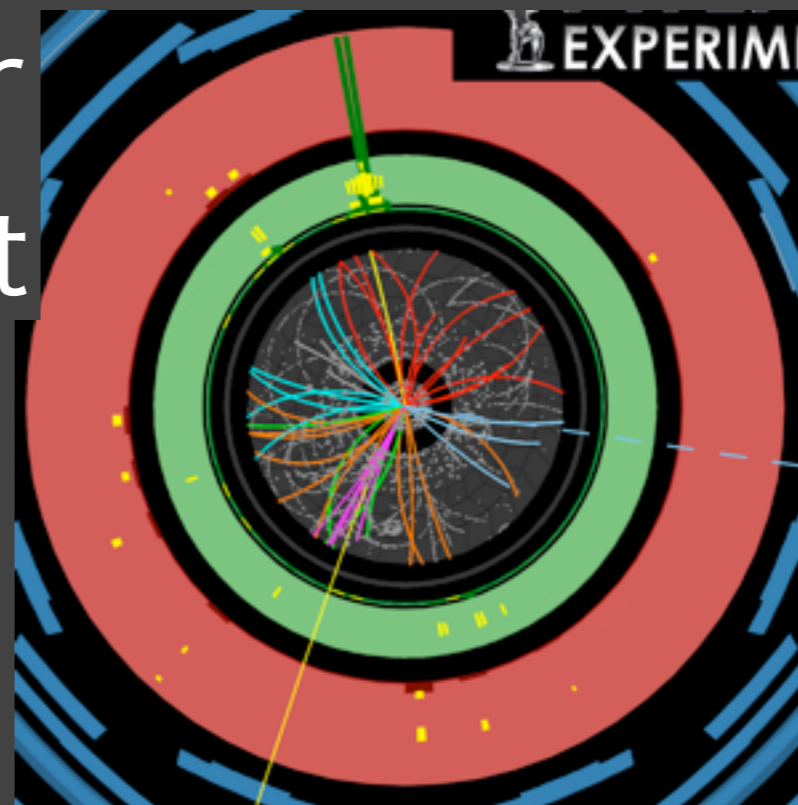
4jets



ttbar
e+jet



ttbar
e+jet

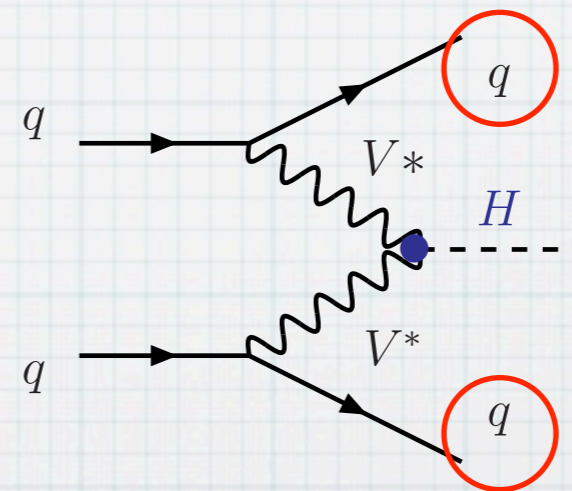
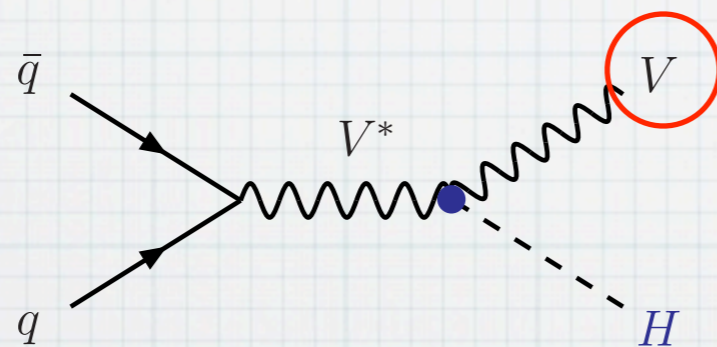


We have to fight for
huge backgrounds in
complicated event
structure

Clue Experimentalist Needs

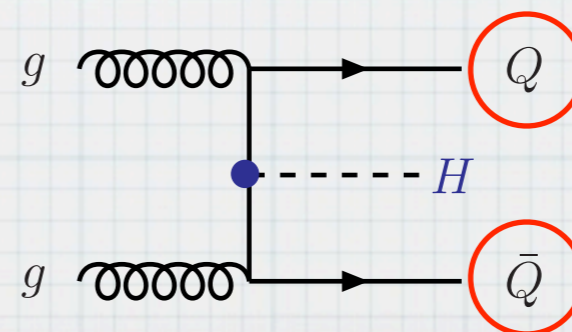
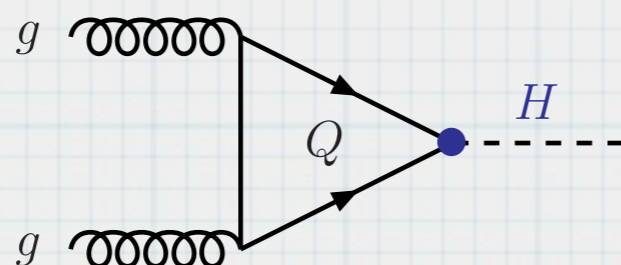
- ❖ Majority of backgrounds
 - ▶ quark/gluon (=jet) production
 - ⇒ we need something else
 - isolated lepton or special topology

associated production of vector boson



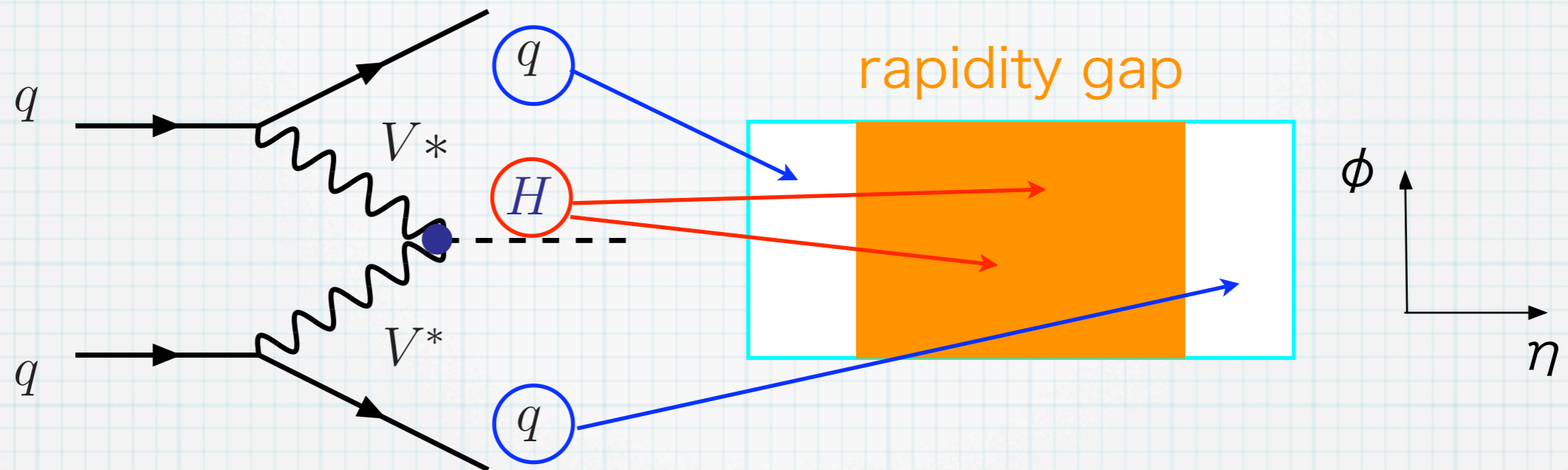
vector boson fusion (VBF)

gluon fusion (GF)

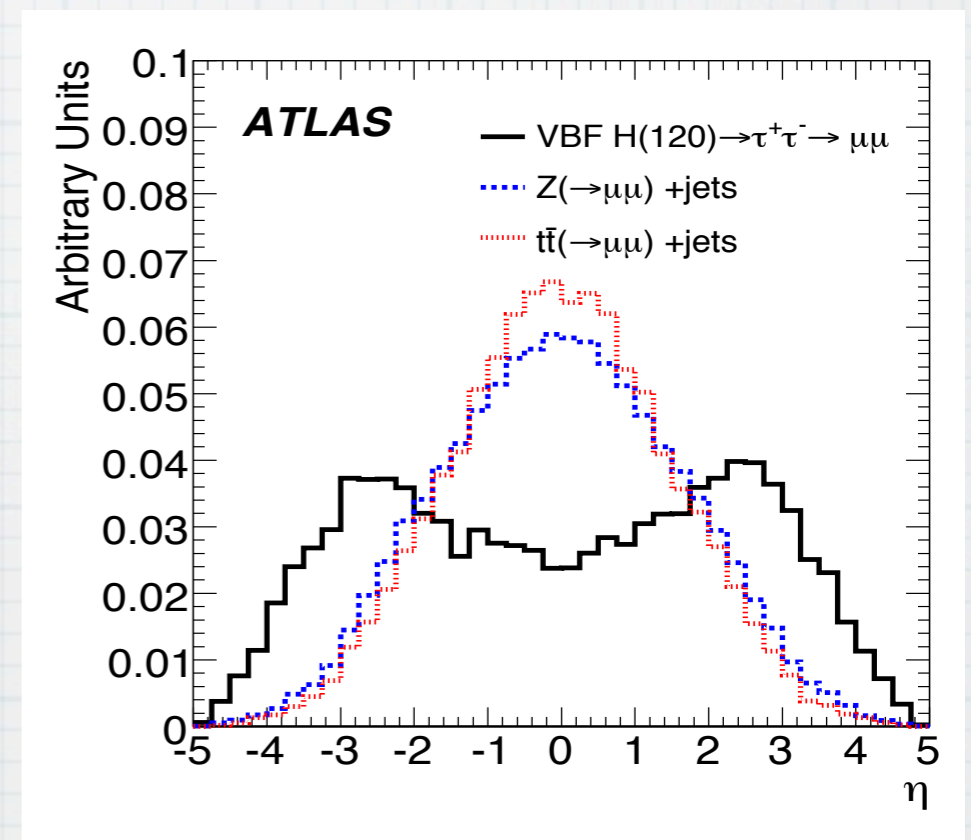


associated production of heavy quark (t, b)

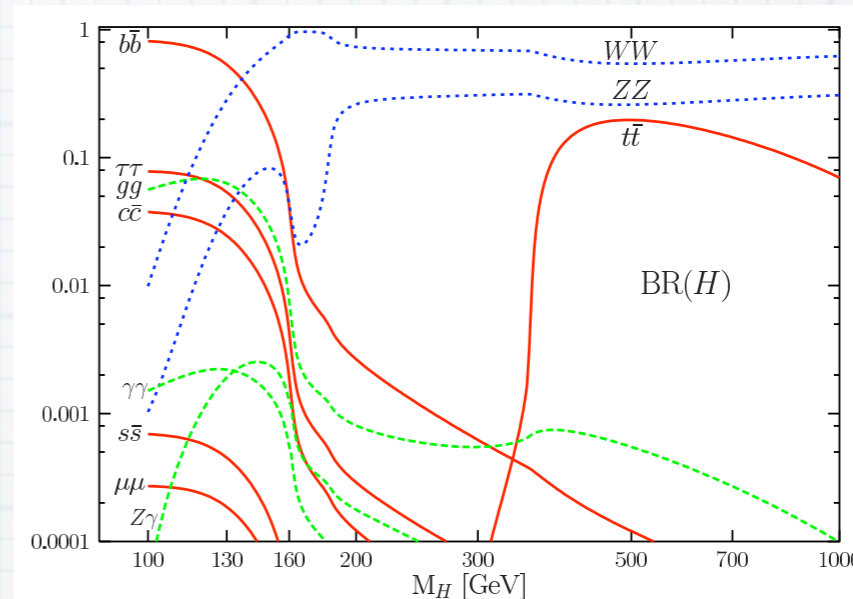
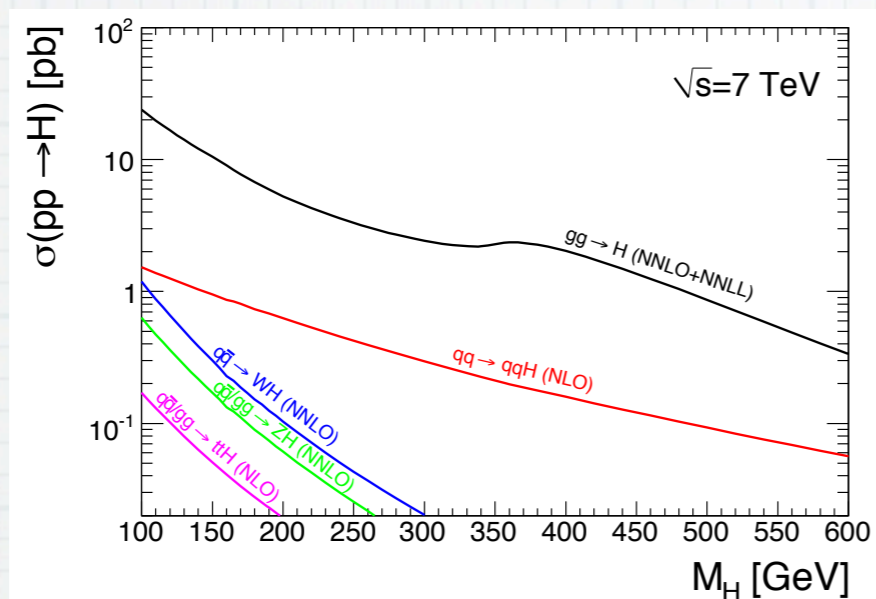
Vector Boson Fusion



- ❖ Two forward jets
 - ▶ propagator $\sim 1/(q^2 - m_V^2)$
- ❖ No jet activity in central
 - ▶ no color connection



Experimental Strategy



❖ Light

- ▶ GF (+VBF) $H \rightarrow \gamma \gamma$
- ▶ VBF $H \rightarrow \tau \tau$
- ▶ $W/Z + H \rightarrow bb$

Lepton
EM object
Special topology

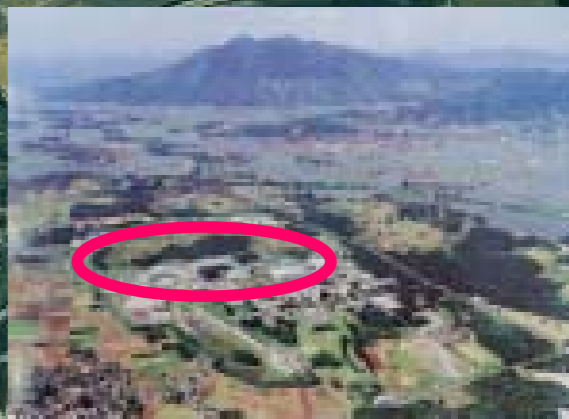
❖ Heavy or wide mass range

- ▶ GF (+VBF) $H \rightarrow WW(\rightarrow ll+X), ZZ(\rightarrow ll\bar{l}\bar{l})$

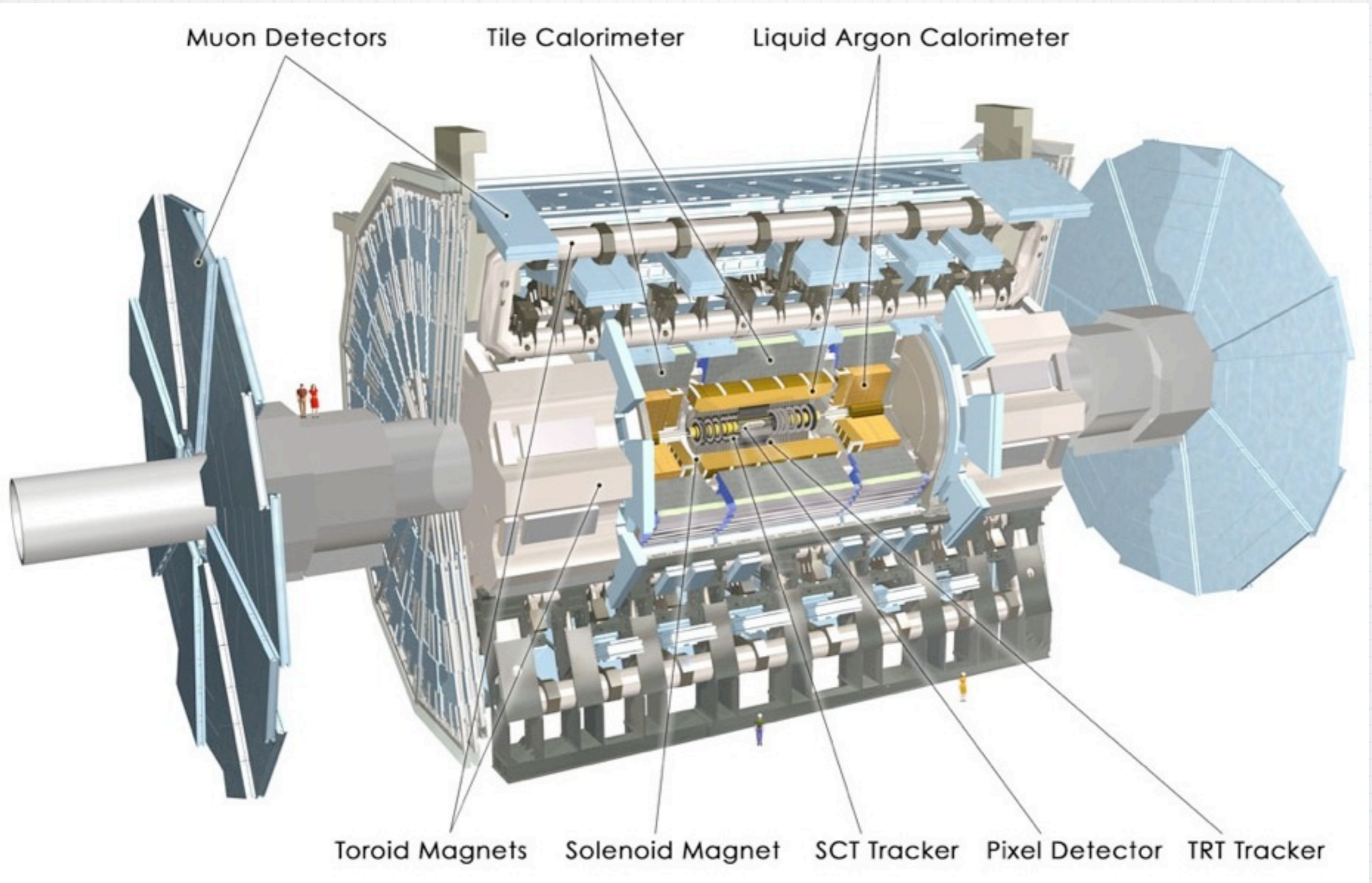
How well we are
(were) doing

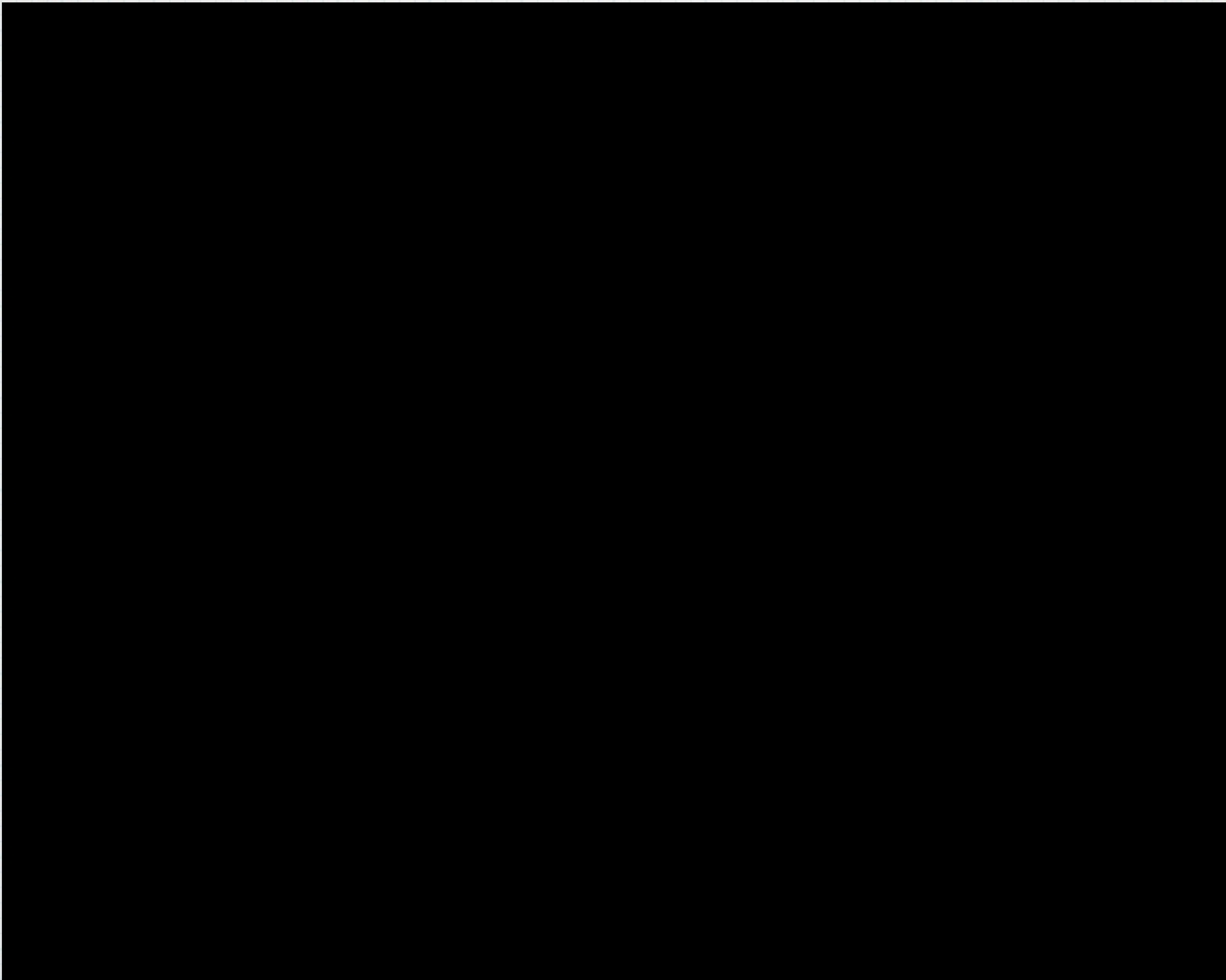


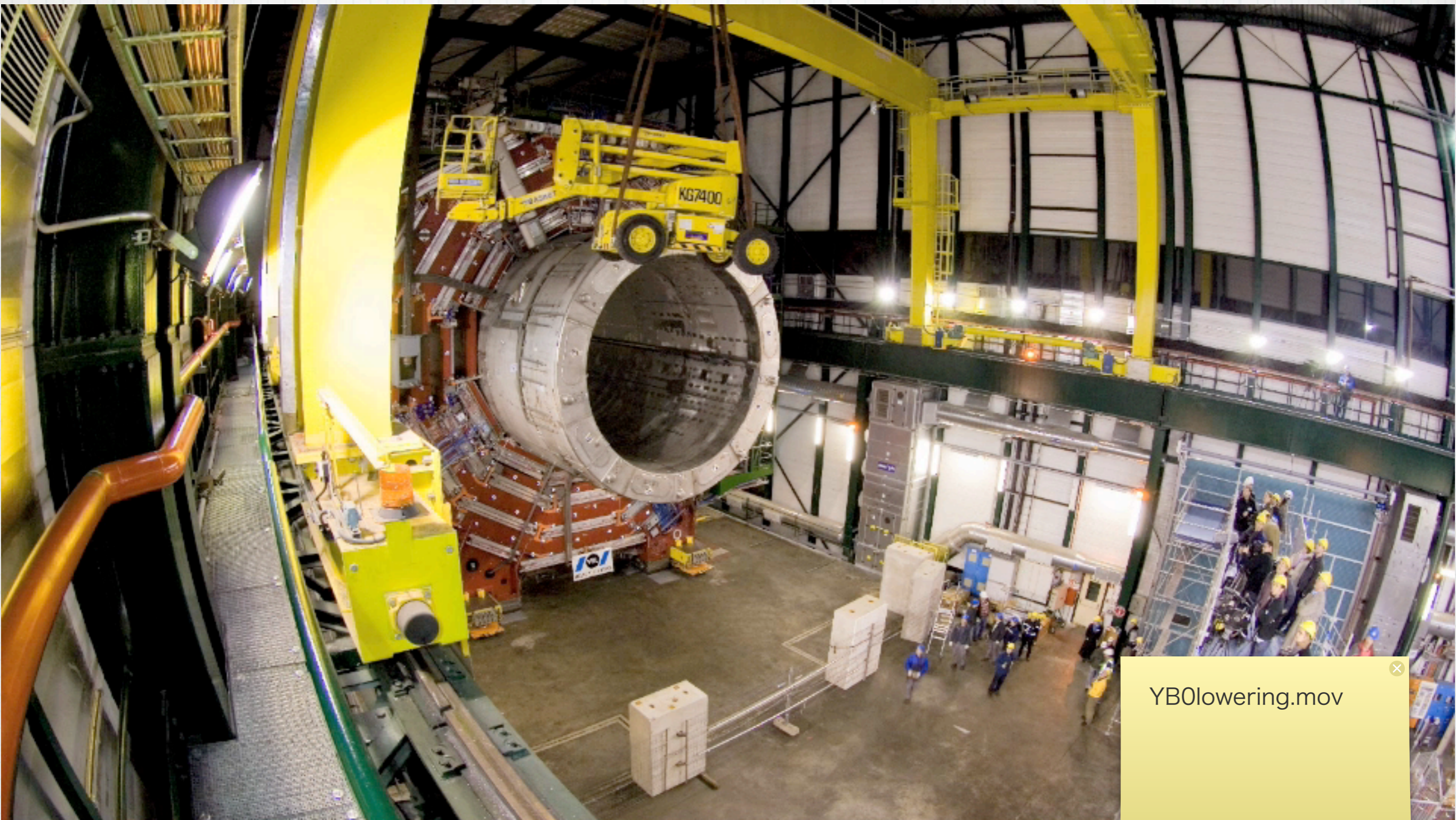
ATLAS



ATLAS Detector







YB0lowering.mov

LHCの現状

- ❖ 2010年から3.5+3.5TeVで物理データ収集
 - ▶ $>40\text{pb}^{-1}$ delivered ($\sim 35\text{pb}^{-1}$ for physics)
 - 陽子の速度 = $0.9999999964 \times$ 光速
- ❖ LHCが設計通りに動いた場合 (7TeV+7TeV)
 - ▶ 陽子の速度 = $0.9999999991 \times$ 光速
- ❖ これまでの世界最高 (米国フェルミ研究所)
 - ▶ 陽子の速度 = $0.9999999560 \times$ 光速

LHCの現状

- ❖ 2010年から3.5+3.5TeVで物理データ収集
 - ▶ $>40\text{pb}^{-1}$ delivered ($\sim 35\text{pb}^{-1}$ for physics)
 - 陽子の速度 = $0.9999999964 \times \text{光速}$
- ❖ LHCが設計通りに動いた場合 (7TeV+7TeV)
 - ▶ 陽子の速度 = $0.99999999991 \times \text{光速}$
= 光速 - 10km/h
- ❖ これまでの世界最高 (米国フェルミ研究所)
 - ▶ 陽子の速度 = $0.9999999560 \times \text{光速}$

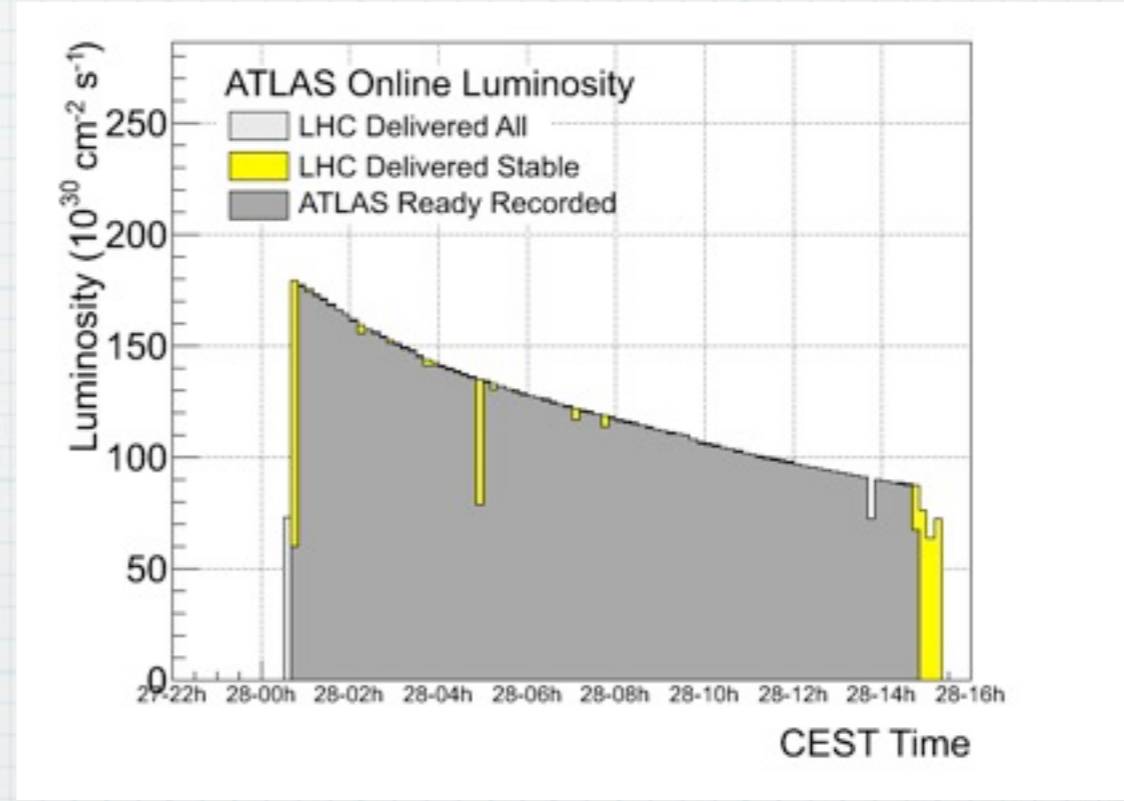
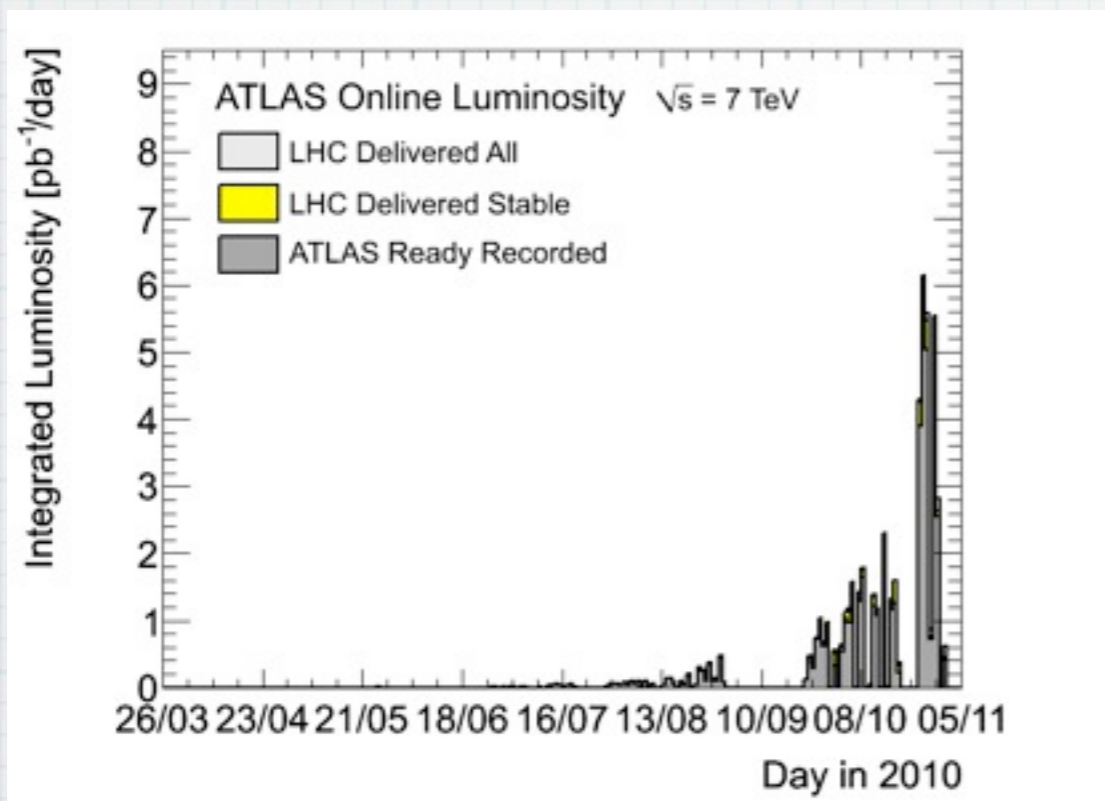
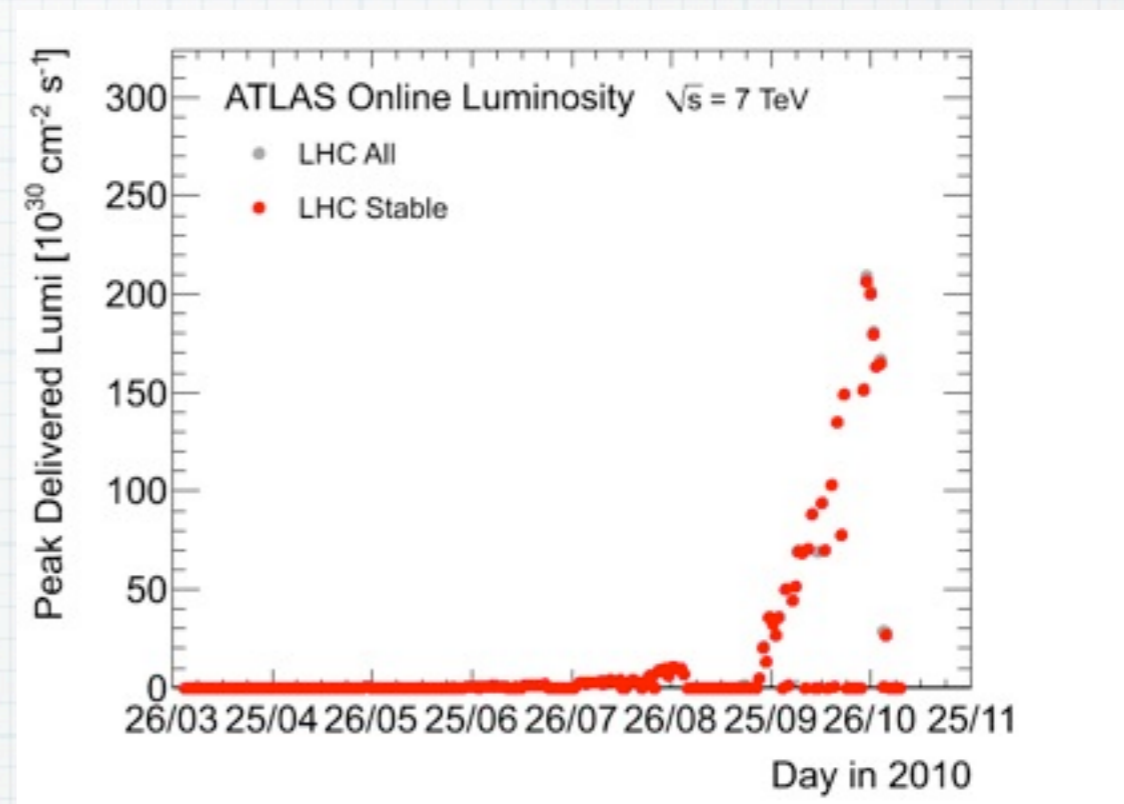
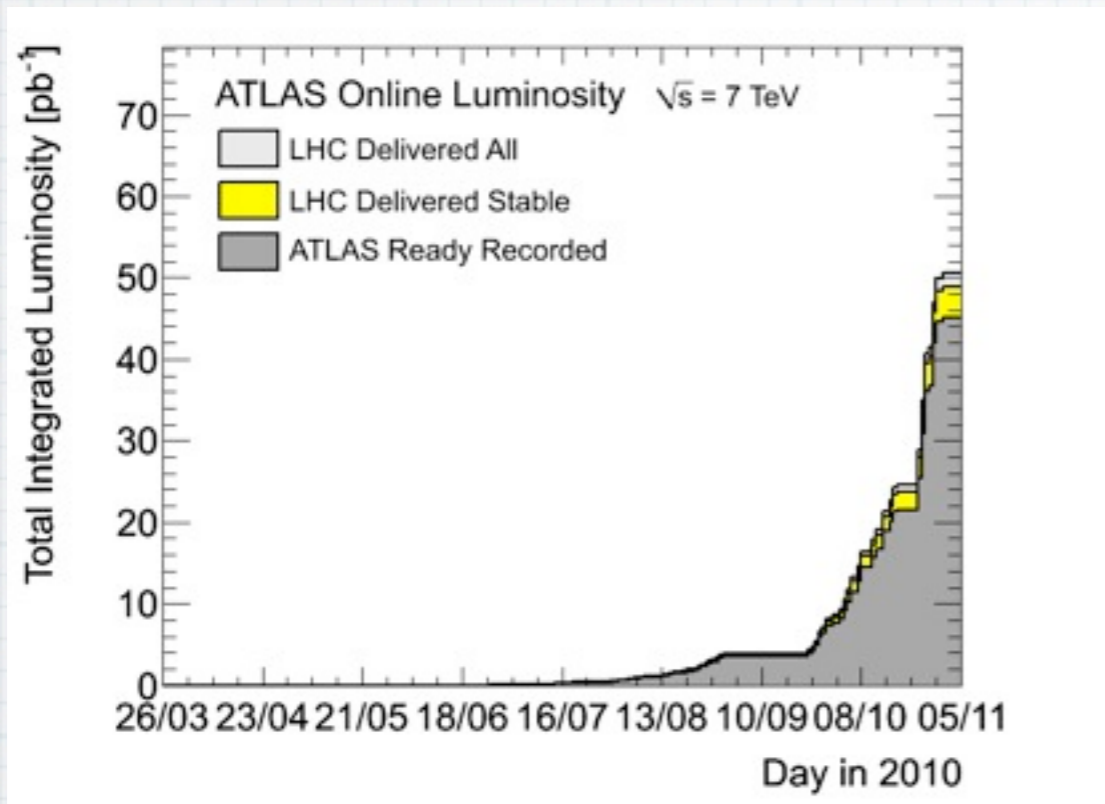
LHCの現状

- ❖ 2010年から3.5+3.5TeVで物理データ収集
 - ▶ $>40\text{pb}^{-1}$ delivered ($\sim 35\text{pb}^{-1}$ for physics)
 - 陽子の速度 = $0.9999999964 \times \text{光速}$
- ❖ LHCが設計通りに動いた場合 (7TeV+7TeV)
 - ▶ 陽子の速度 = $0.9999999991 \times \text{光速}$
= 光速 - 10km/h
- ❖ これまでの世界最高 (米国フェルミ研究所)
 - ▶ 陽子の速度 = $0.9999999560 \times \text{光速}$
= 光速 - 475km/h

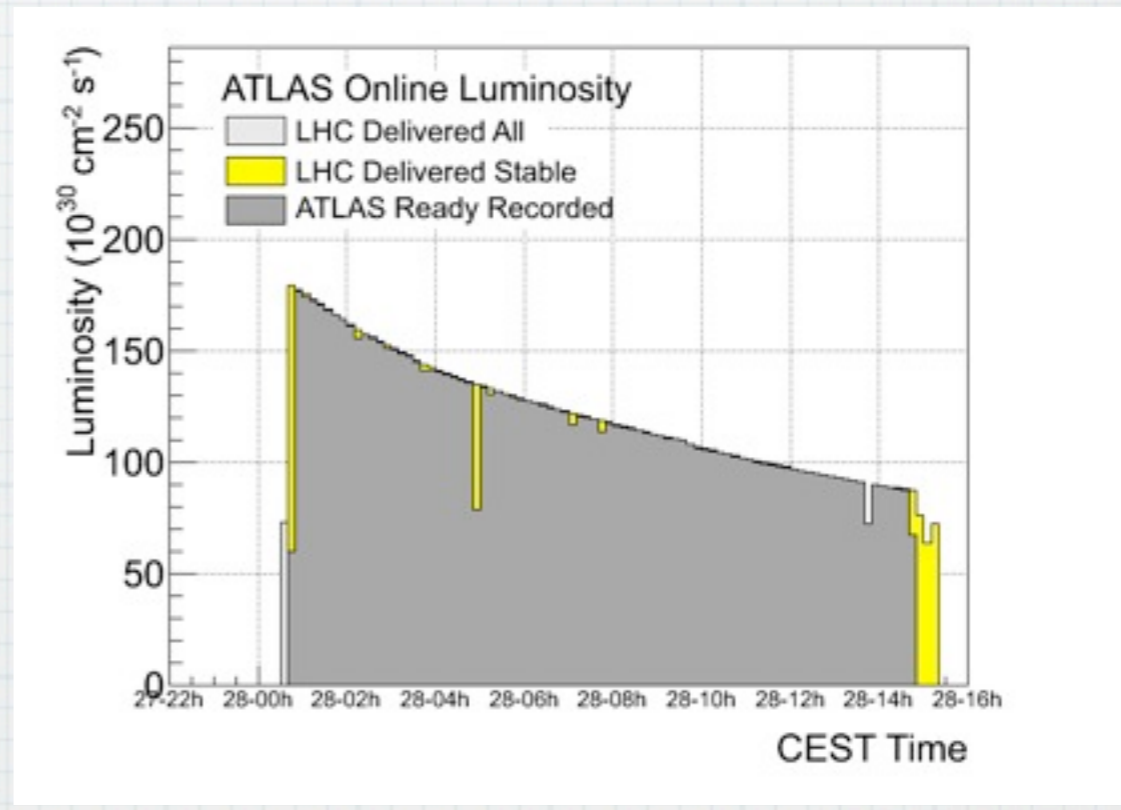
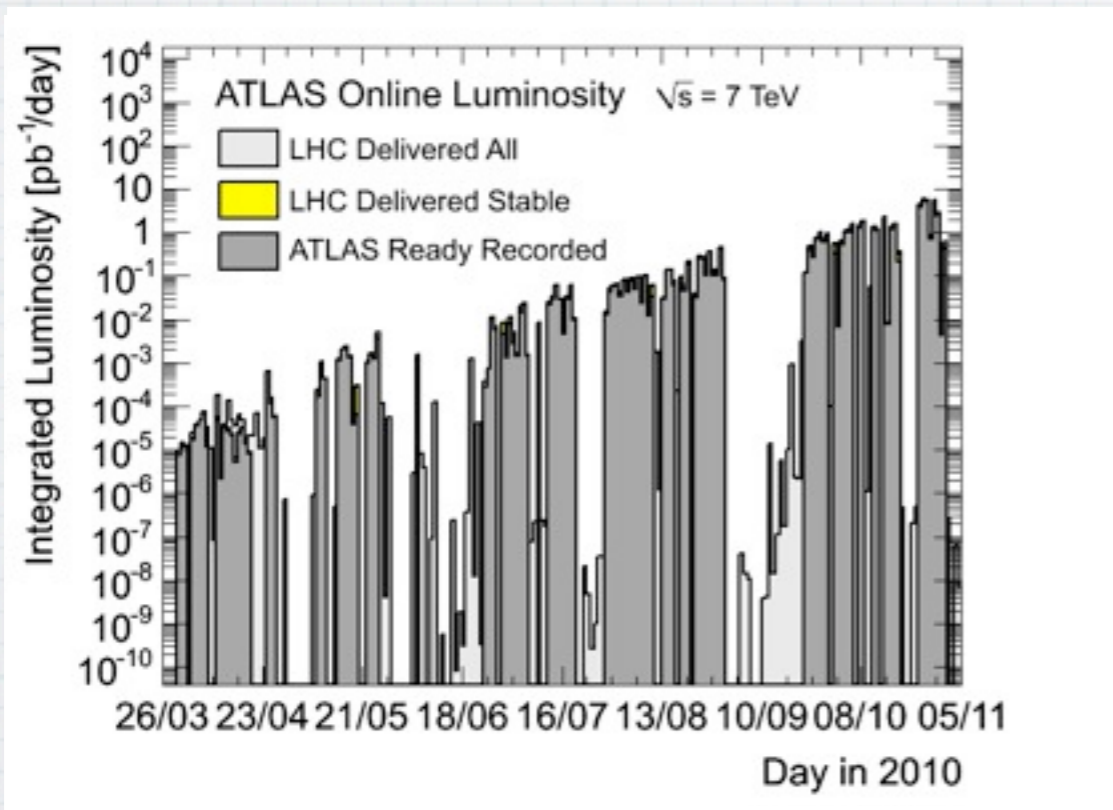
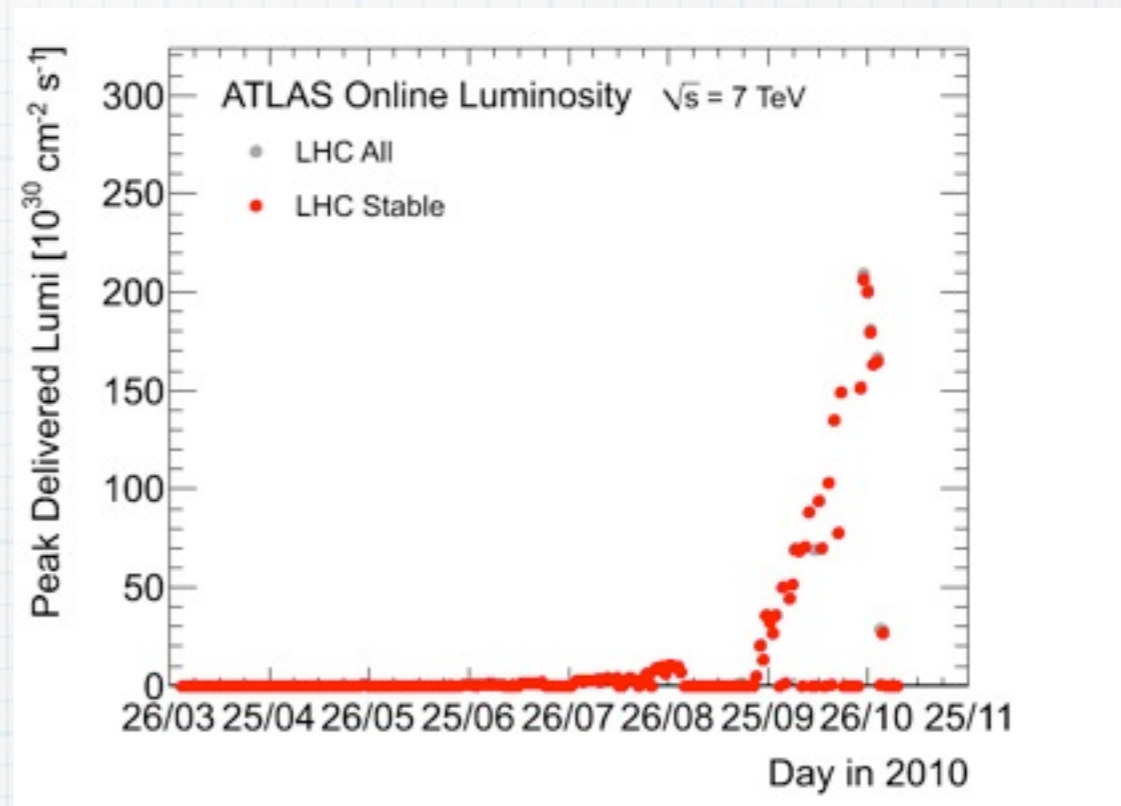
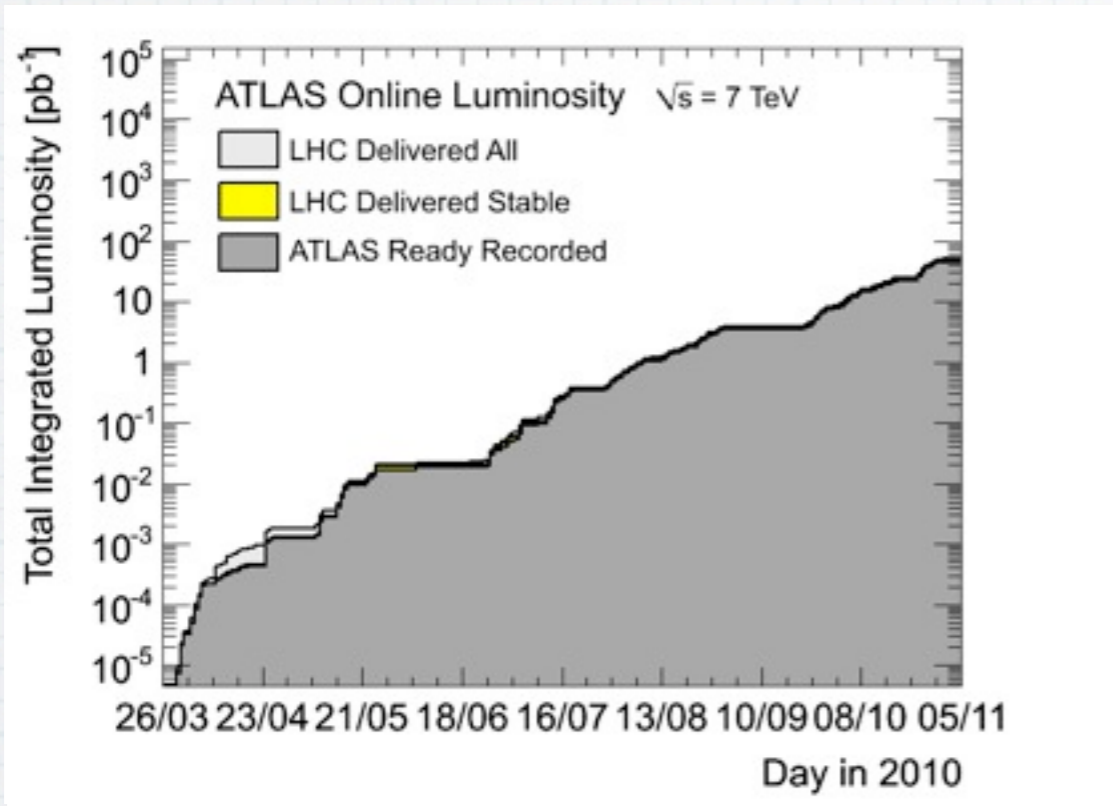
LHCの現状

- ❖ 2010年から3.5+3.5TeVで物理データ収集
 - ▶ $>40\text{pb}^{-1}$ delivered ($\sim 35\text{pb}^{-1}$ for physics)
 - ◎ 陽子の速度 = $0.9999999964 \times \text{光速}$
= 光速 - 39km/h
- ❖ LHCが設計通りに動いた場合 (7TeV+7TeV)
 - ▶ 陽子の速度 = $0.9999999991 \times \text{光速}$
= 光速 - 10km/h
- ❖ これまでの世界最高 (米国フェルミ研究所)
 - ▶ 陽子の速度 = $0.9999999560 \times \text{光速}$
= 光速 - 475km/h

Data Collection



Data Collection



運転計画

❖ 今までのデフォルト

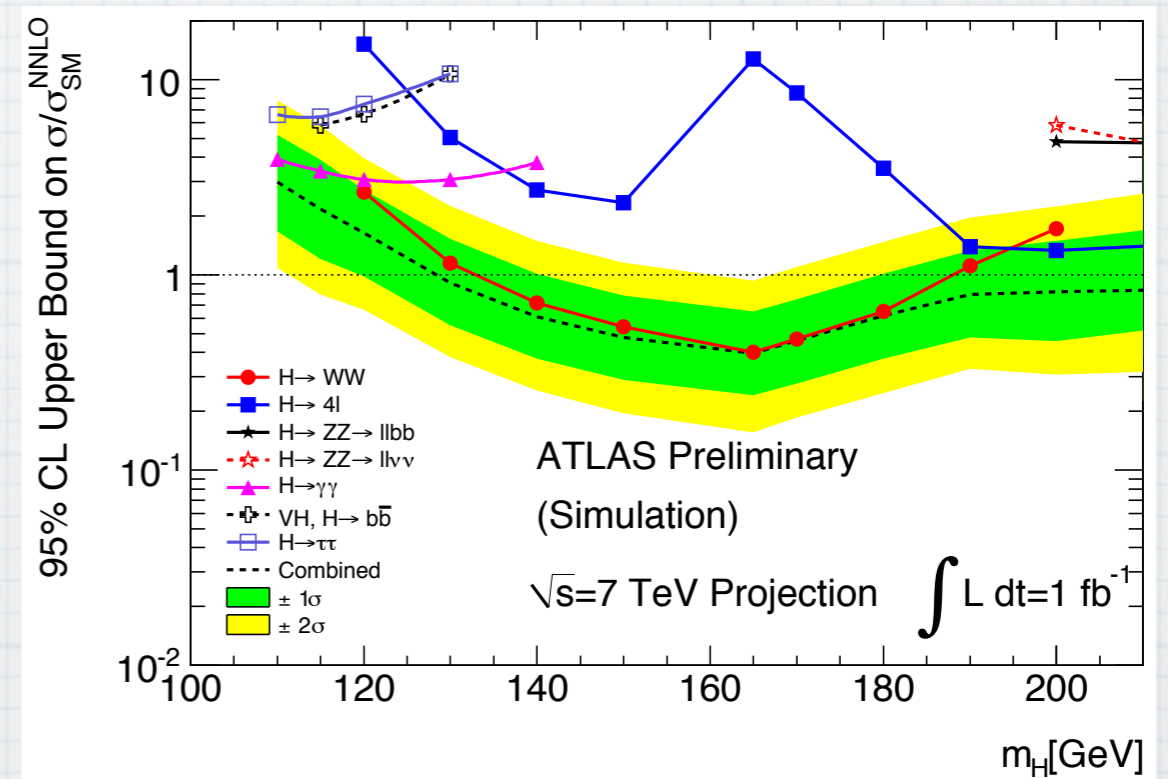
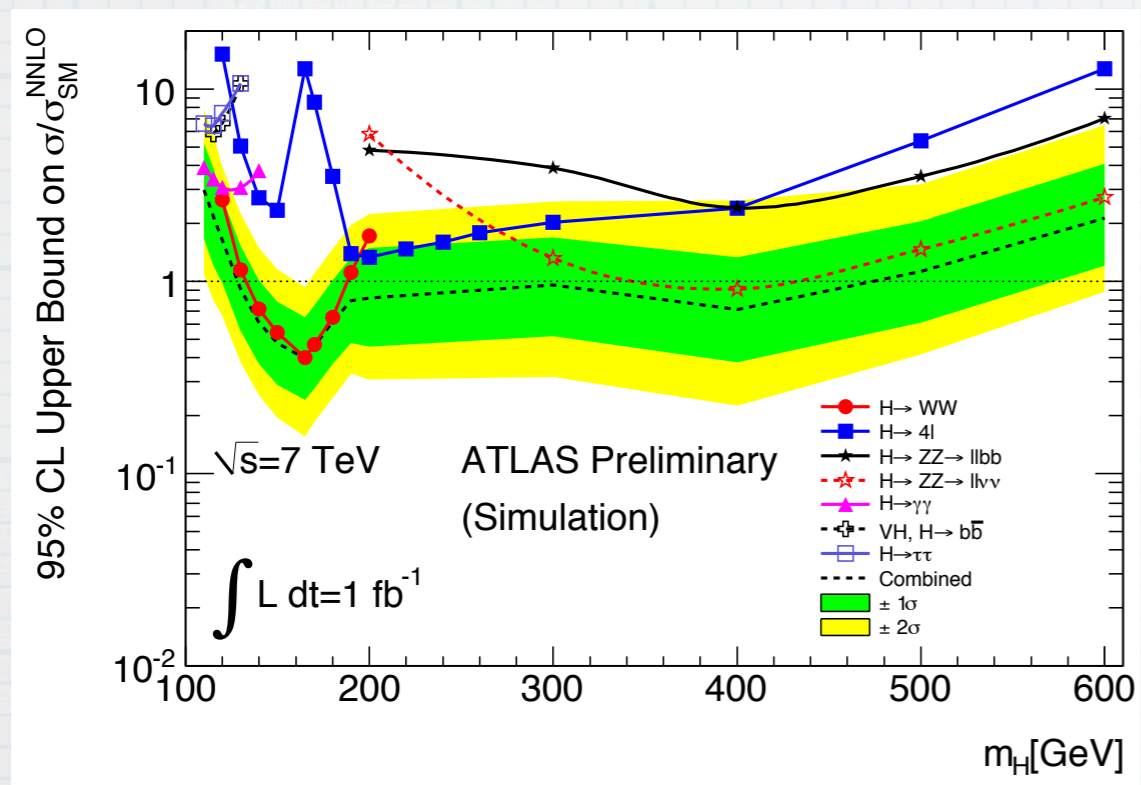
- ▶ 2011年は $\sqrt{s}=7\text{TeV}$ で $\sim 1\text{fb}^{-1}$ 貯める
2012年から2013年初めまでシャットダウン
(エネルギー増強のため)

❖ 有力なオプション

- ▶ 2012年まで走り続ける(8 or 9? TeV)
その後シャットダウン
- ▶ 今日からの会議で決定

Expected Sensitivity

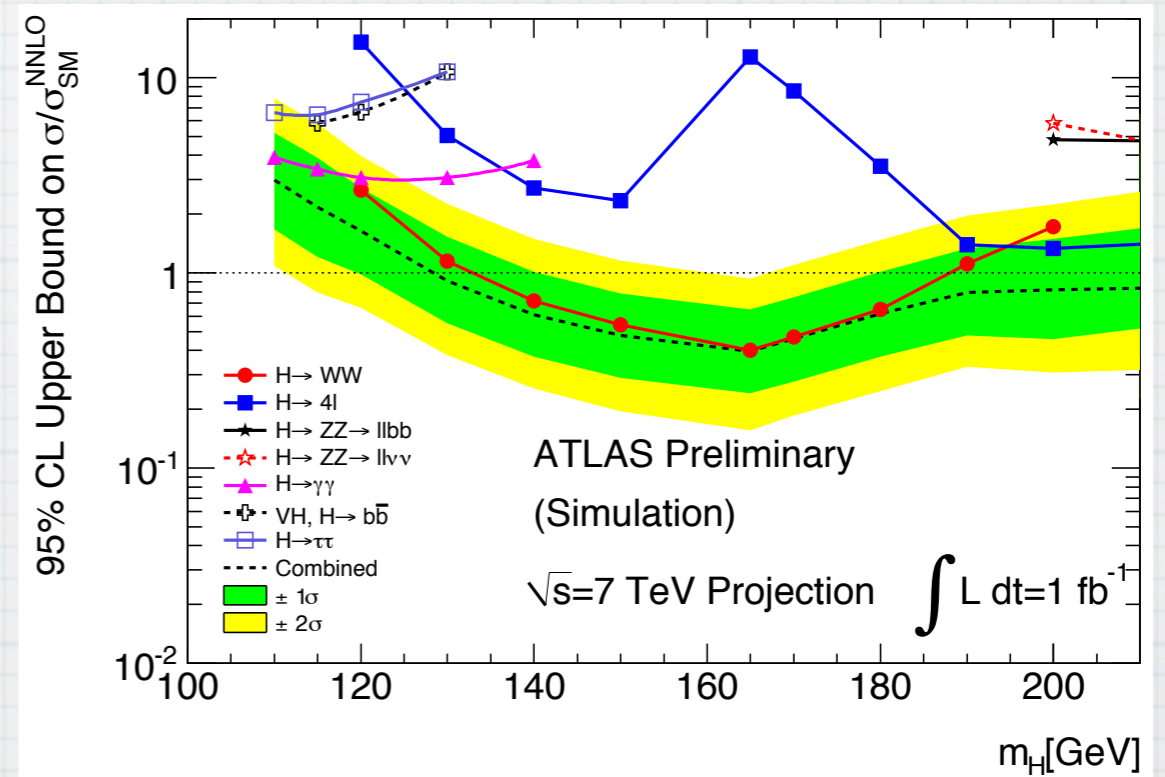
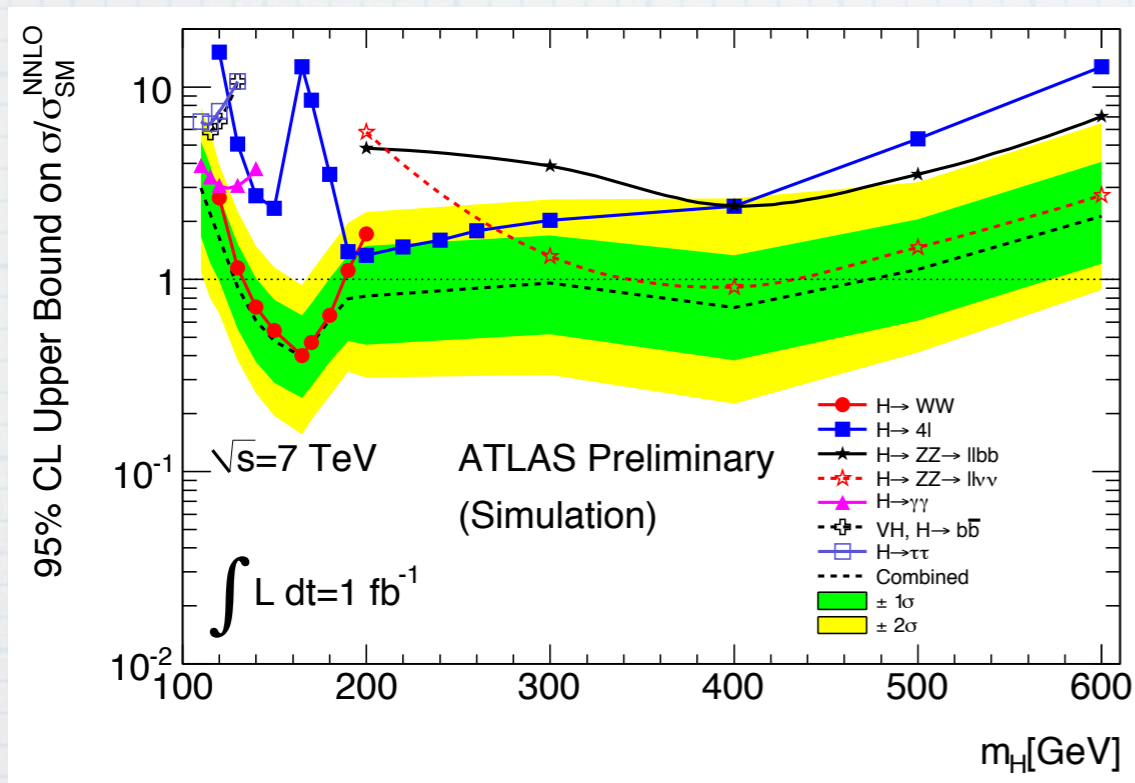
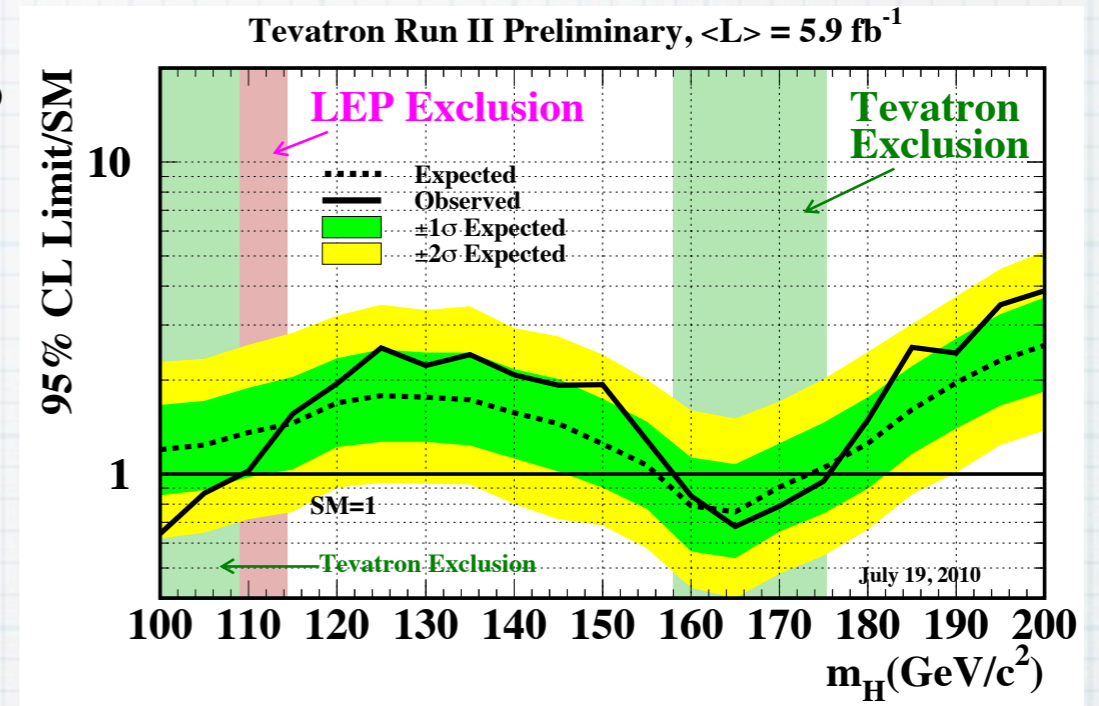
❖ $\sqrt{s} = 7\text{TeV}, 1\text{fb}^{-1}$



Expected Sensitivity

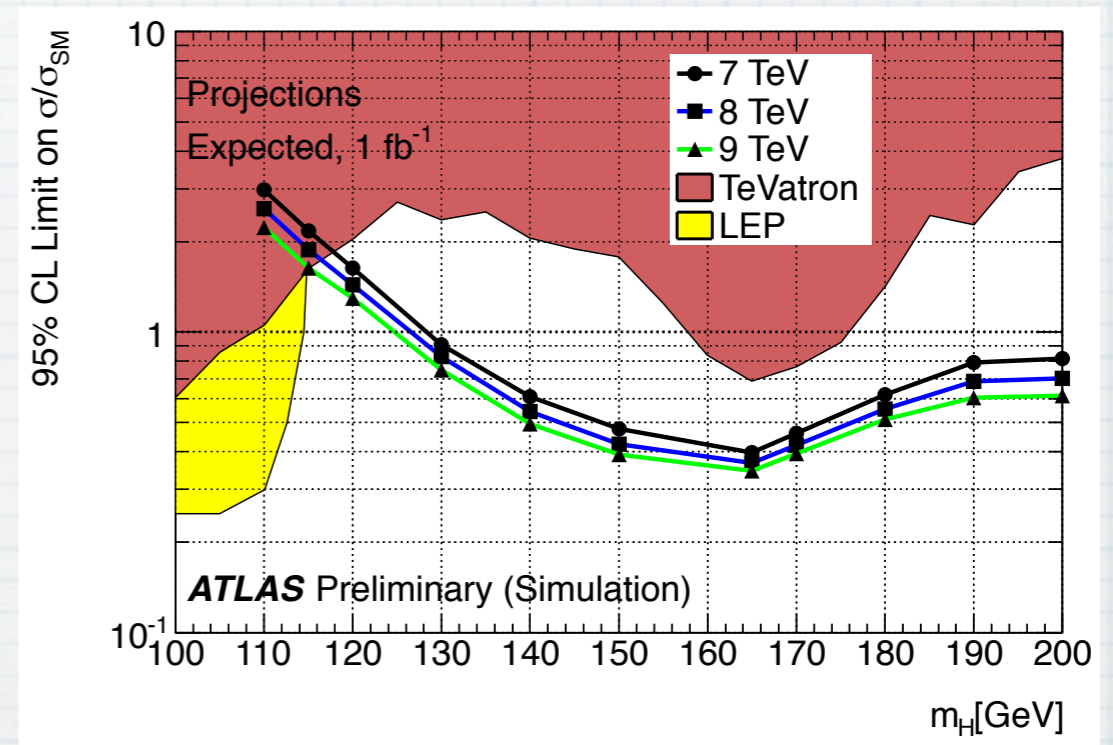
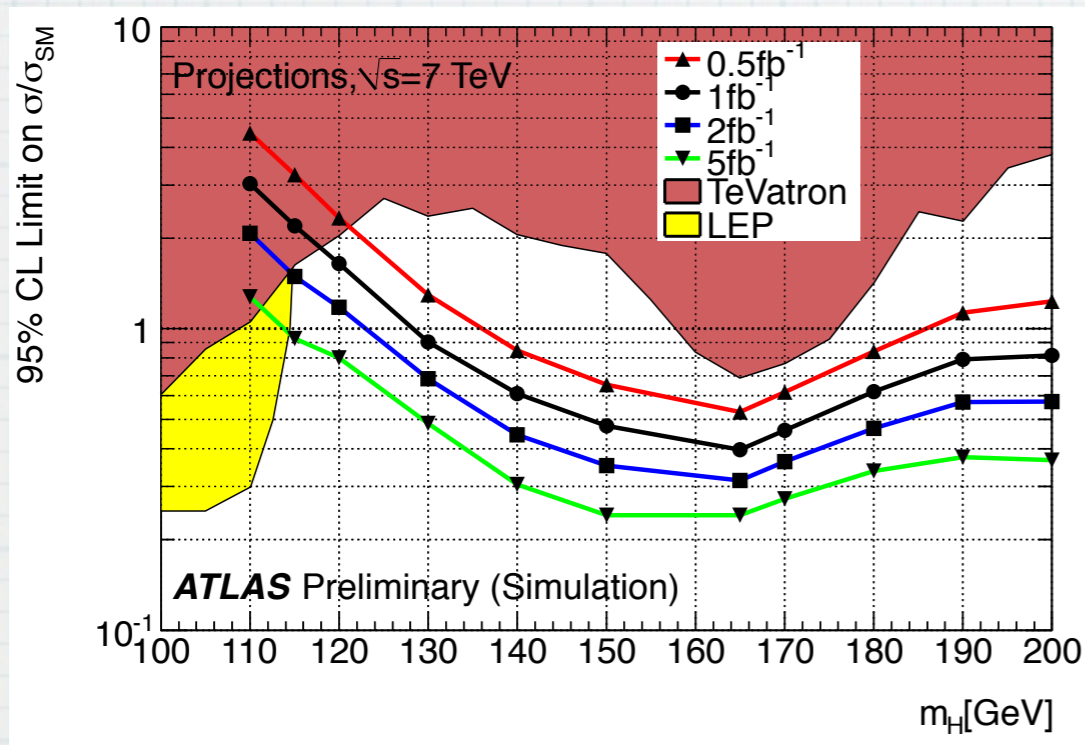
Tevatron status

❖ $\sqrt{s} = 7\text{TeV}, 1\text{fb}^{-1}$



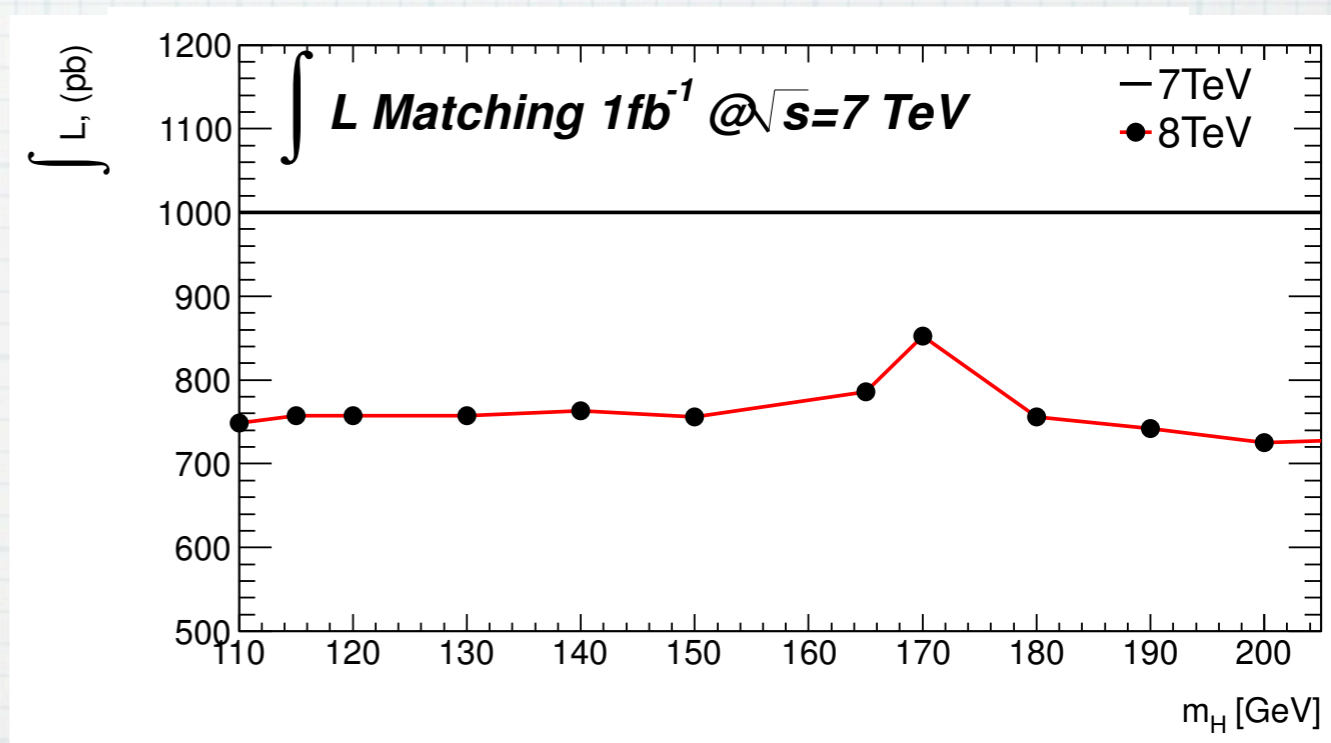
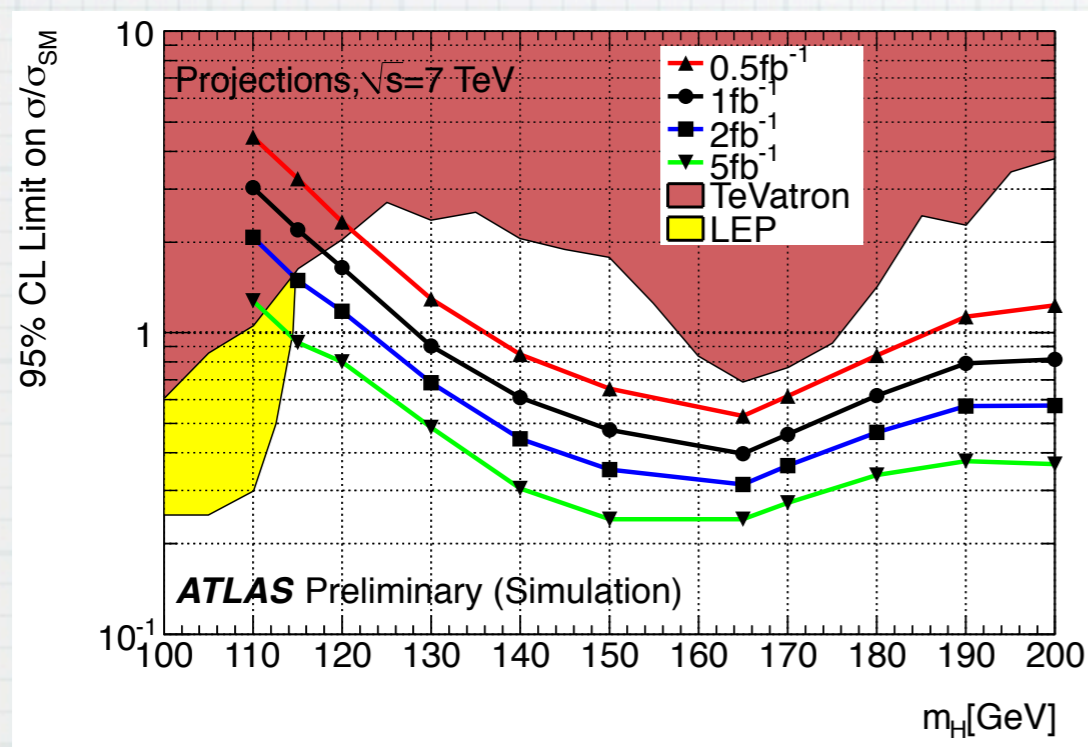
色々な運転シナリオ

- ❖ Different integrated luminosity
- ❖ Different beam energy



色々な運転シナリオ

- ❖ Different integrated luminosity
- ❖ Different beam energy



SUSY, Extra Dimension 探索の現状

見せられないものだらけです…

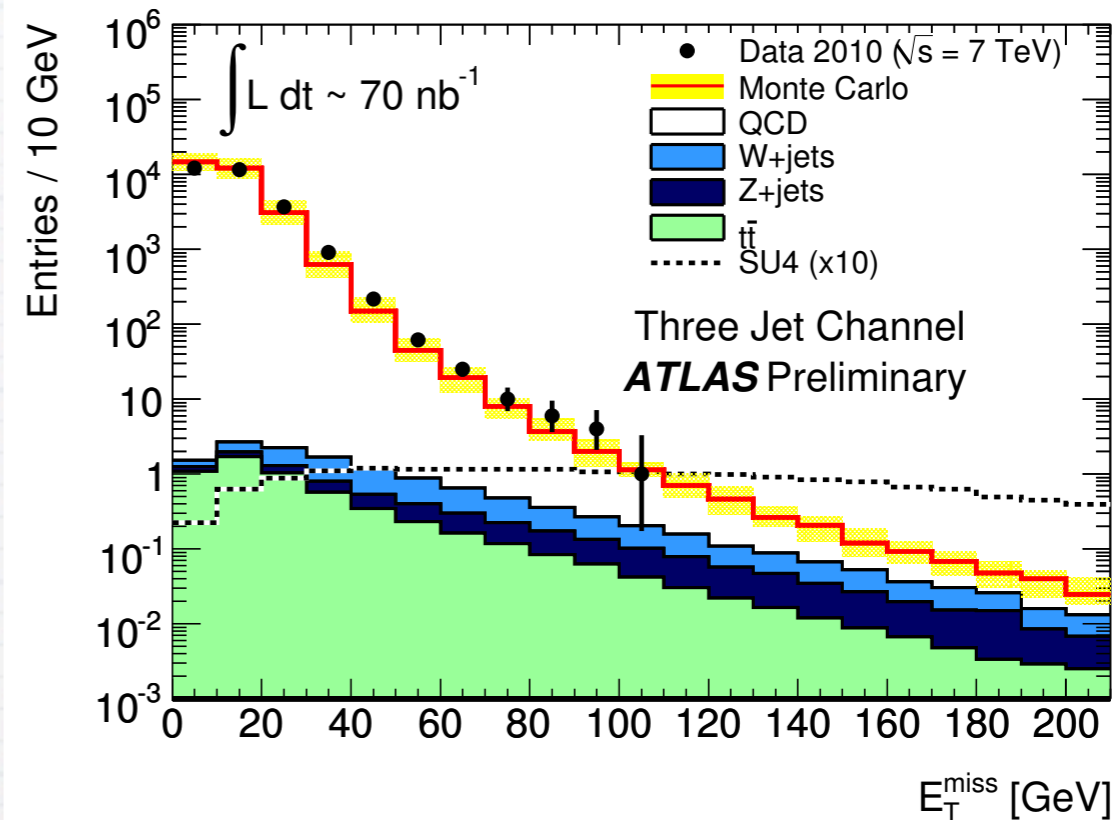
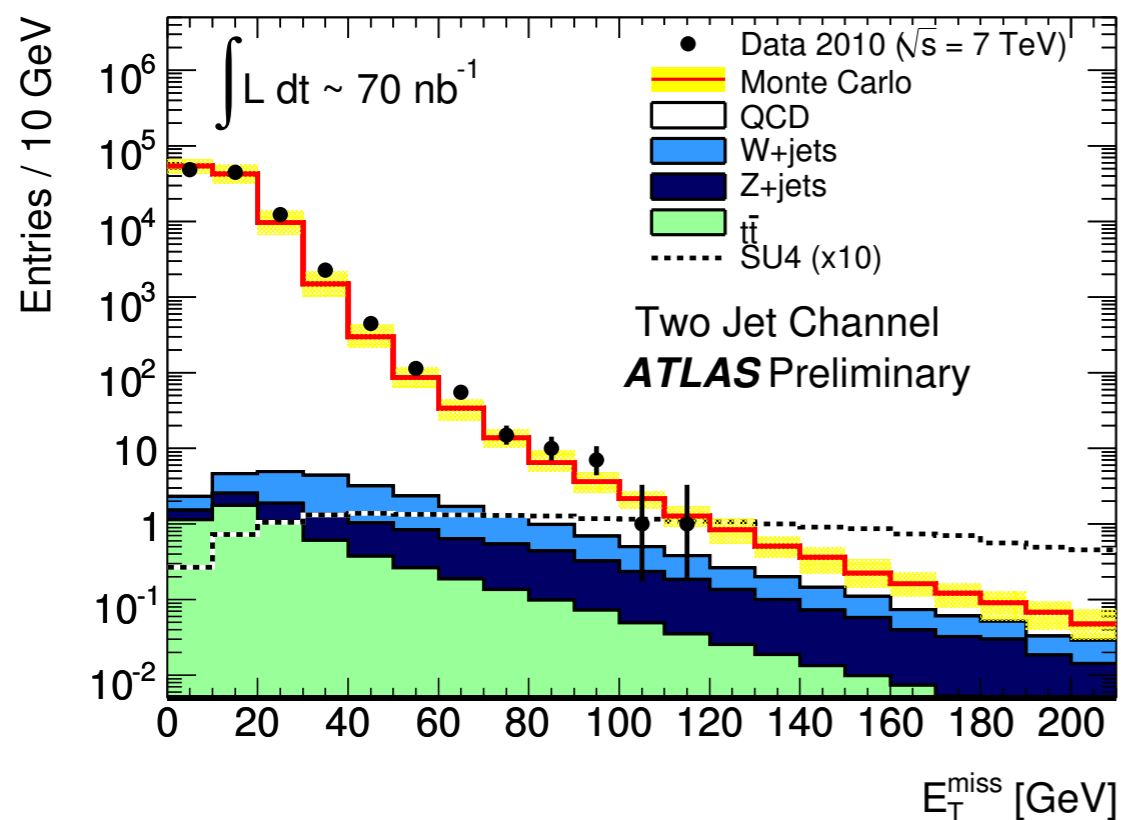
SUSY探索

- ❖ LSP探索 = Missing E_T のテールを見る
 - ▶ ピークを作らないので検出器を含めた事象 (underlying event含む) の理解が重要

missing E_T の図

オフィシャルな結果 (70nb^{-1})

去年の夏に見せたもの

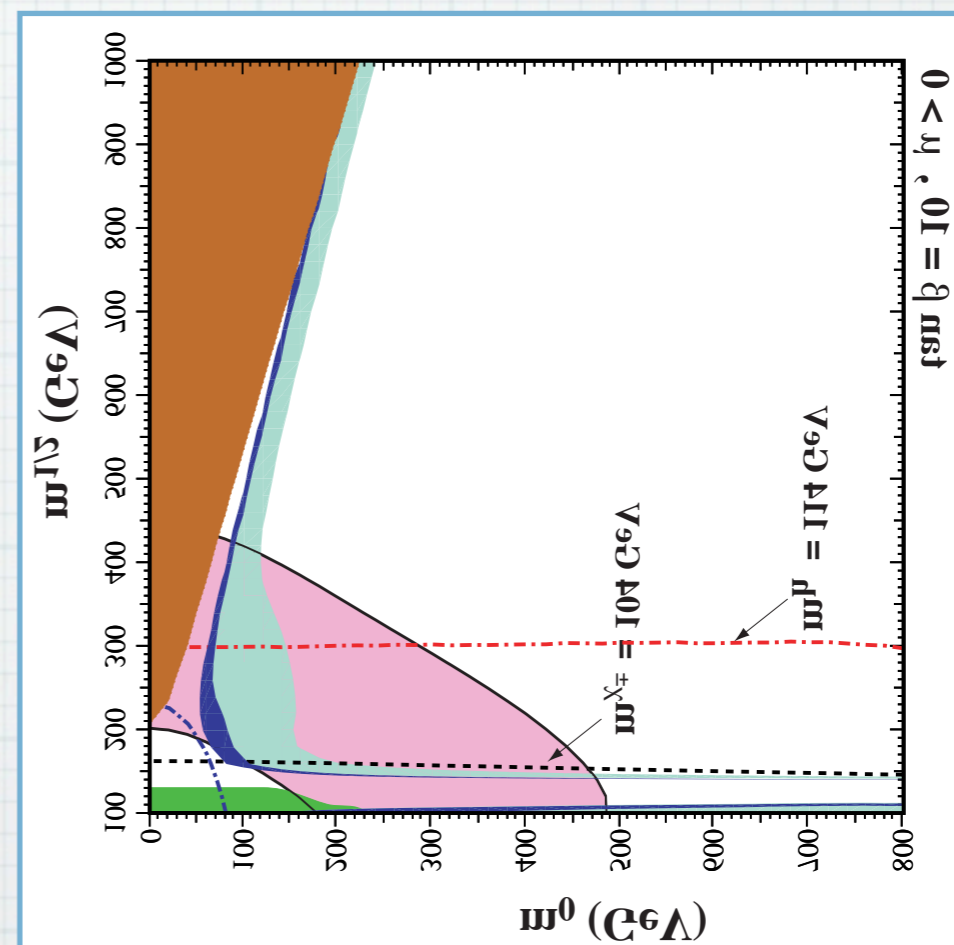
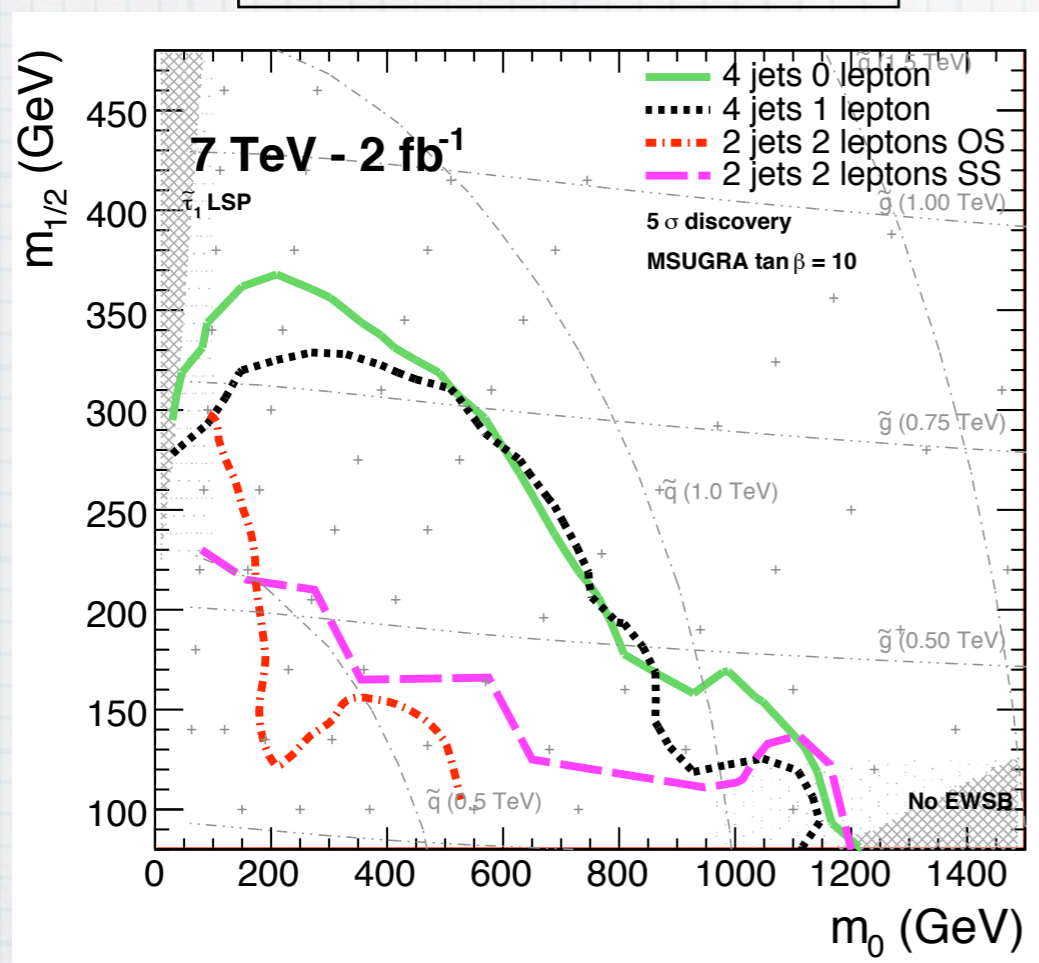


- ❖ Missing E_T の理解はまあまあ程度
- ❖ 今はもっと良くなりました

7TeV 2fb⁻¹ での感度予想

- ❖ 実験初期統計が少ない時はno leptonが優勢
 - ▶ O(1fb⁻¹)でlepton modeが優勢になる

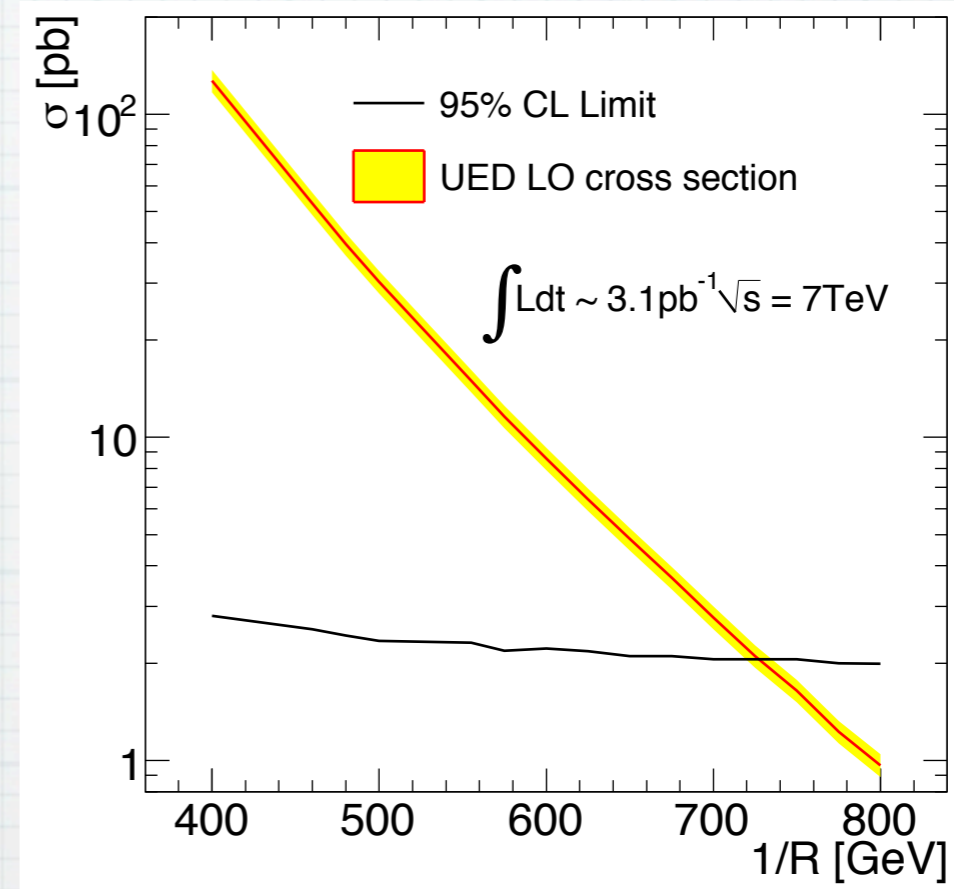
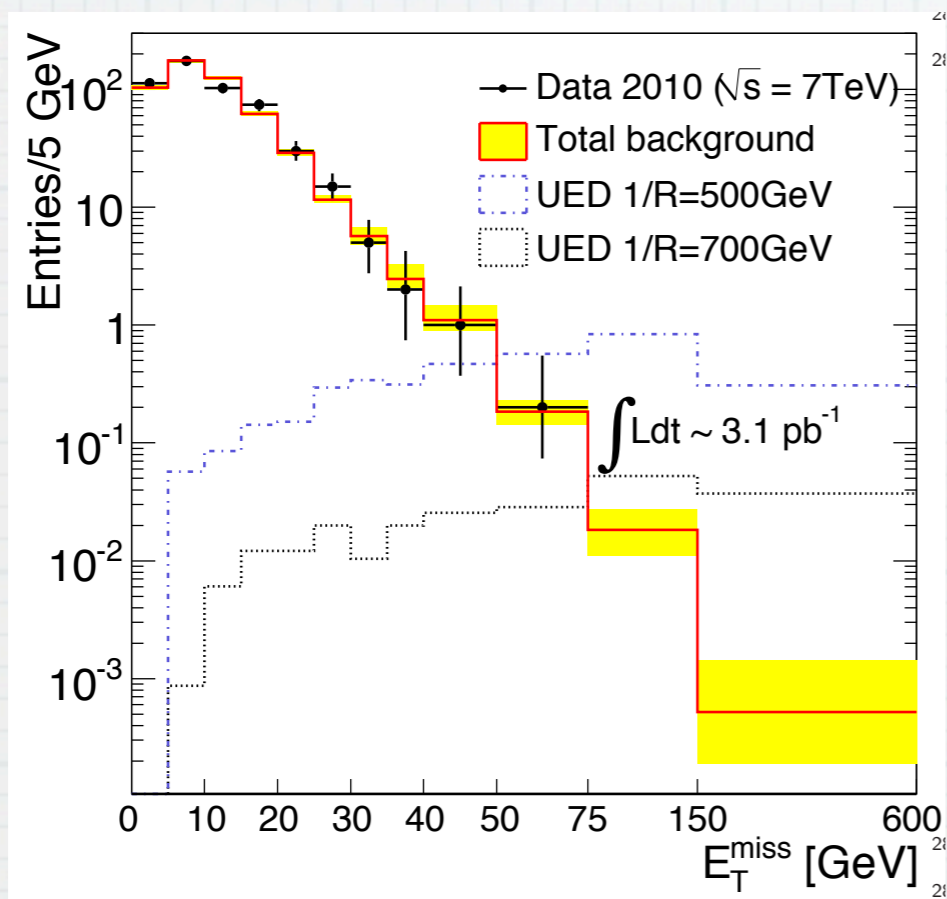
5σ discovery reach



UED探索

❖ $\gamma\gamma + \text{Missing } E_T$ (3.1 pb^{-1})

▶ 実験的にはSUSY探索とほぼ同じ



TeVスケール重力探索

- ❖ High q^2 事象を探す
 - ▶ 夏の結果はジェットのみ

2010年秋の学会
14aSL08
ICEPP 兼田さん

Dileptonの共鳴探索

- ❖ 解析は単純です
 - ▶ M_{ll} 分布上にピークがあるかどうか
 - ▶ Z' 探索などと共通
 - ▶ Drell-Yanとあっているかどうか

Conclusions

- ❖ ヒッグス発見（楽観的な）シナリオ
 - ▶ 2012年いっぱい走ることを仮定
 - ▶ 5σ discovery possible for $m_H > 130$ GeV
 - 5 fb^{-1} for both ATLAS & CMS
- ❖ SUSY, Extra Dimension 探索進行中