LHC Run2の現状と展望

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自己紹介

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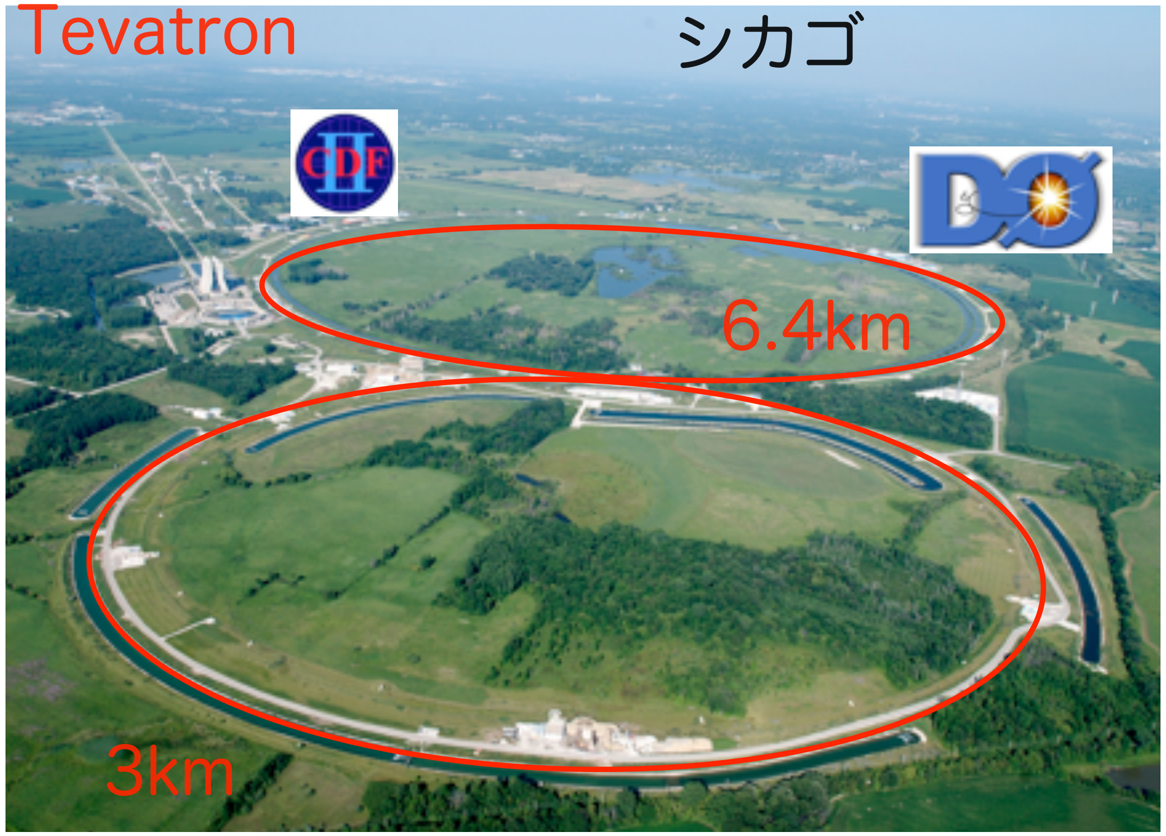
1971年　: 名古屋市中村区にて誕生。名古屋育ち

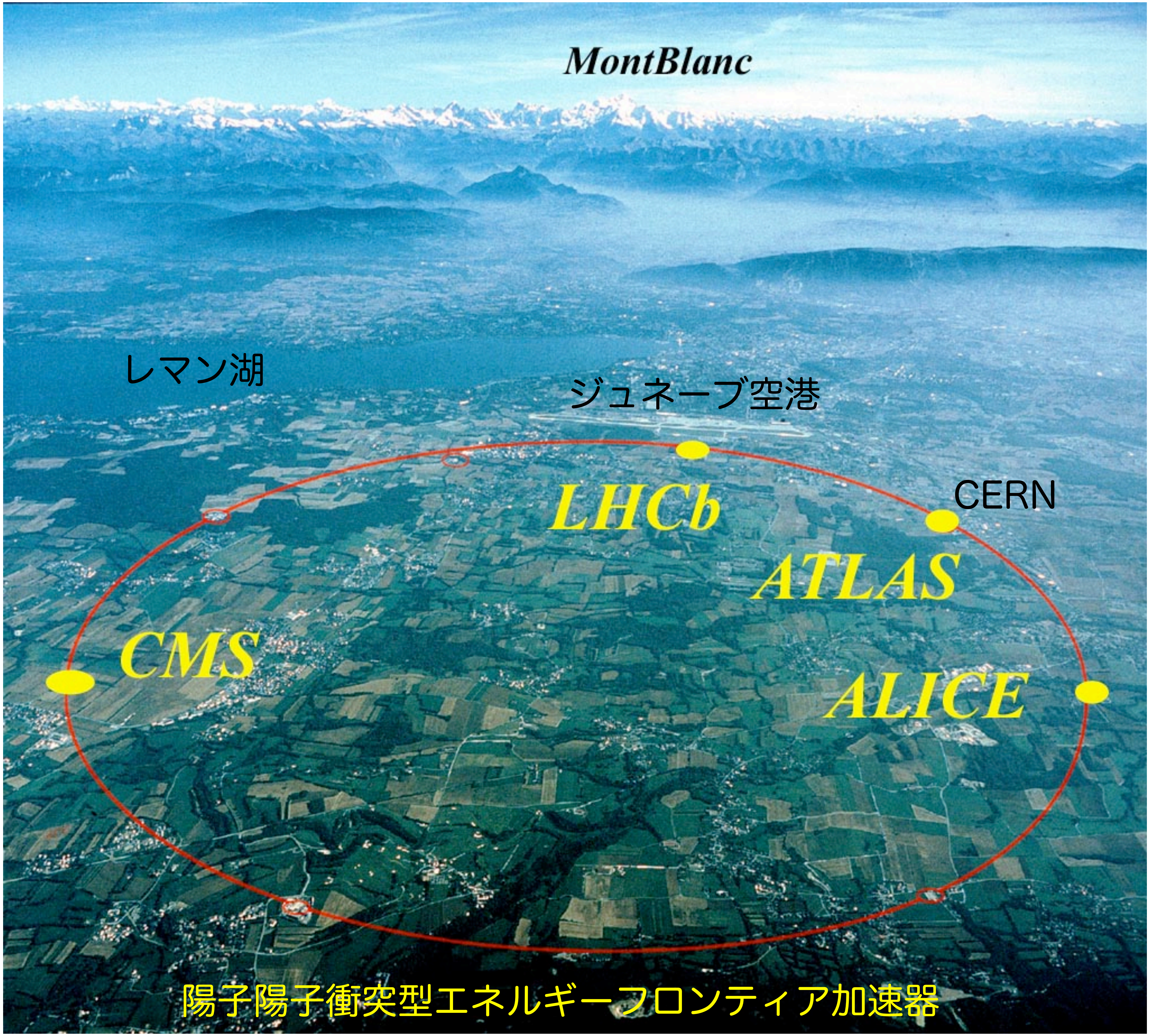
2000年　: 名古屋大学大学院理学研究科　博士(理学)取得
「Belle実験に於けるダイレプトン事象を用いた $B_d^0 \bar{B}_d^0$ 振動現象の測定」

2001年〜 : 米国Fermi研究所 Research Associate
Tevatron-D0実験でヒッグス粒子探索

2006年〜 : 現職
LHC-ATLAS実験でヒッグス物理、トップクォーク物理、新物理探索



Large Hadron Collider



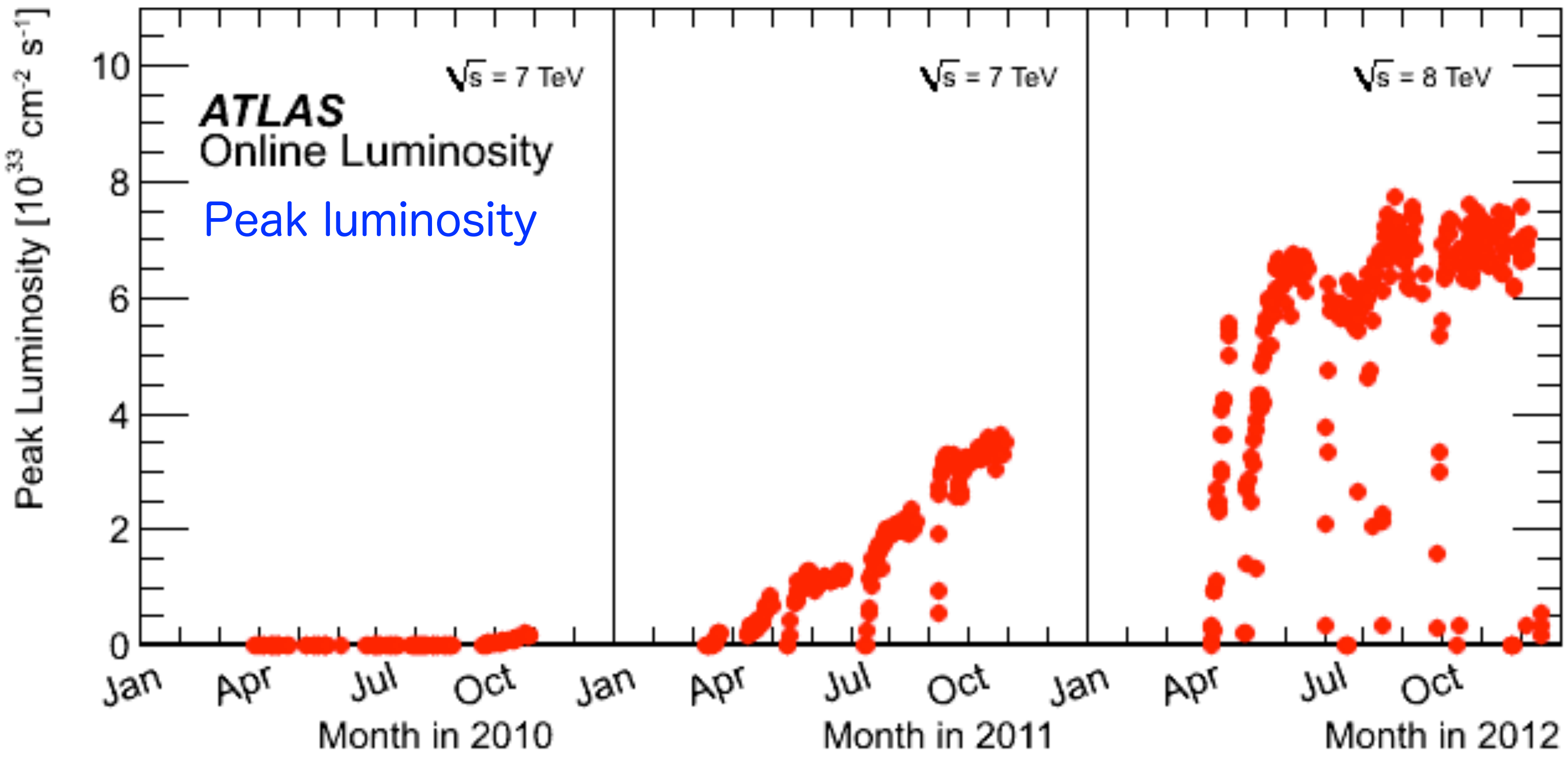
LHC実験のこれまでの歩み

～2009　：建設
2009　：加速器事故
2010　：Physics run開始
2011　：$\sqrt{s}=7$TeVの物理データ収集
2012　：$\sqrt{s}=8$TeVの物理データ収集
} Run 1
2012/7/4　：ヒッグス粒子の発見
2013-2015：Shutdown
2015　：$\sqrt{s}=13$TeVの物理データ収集　Run 2

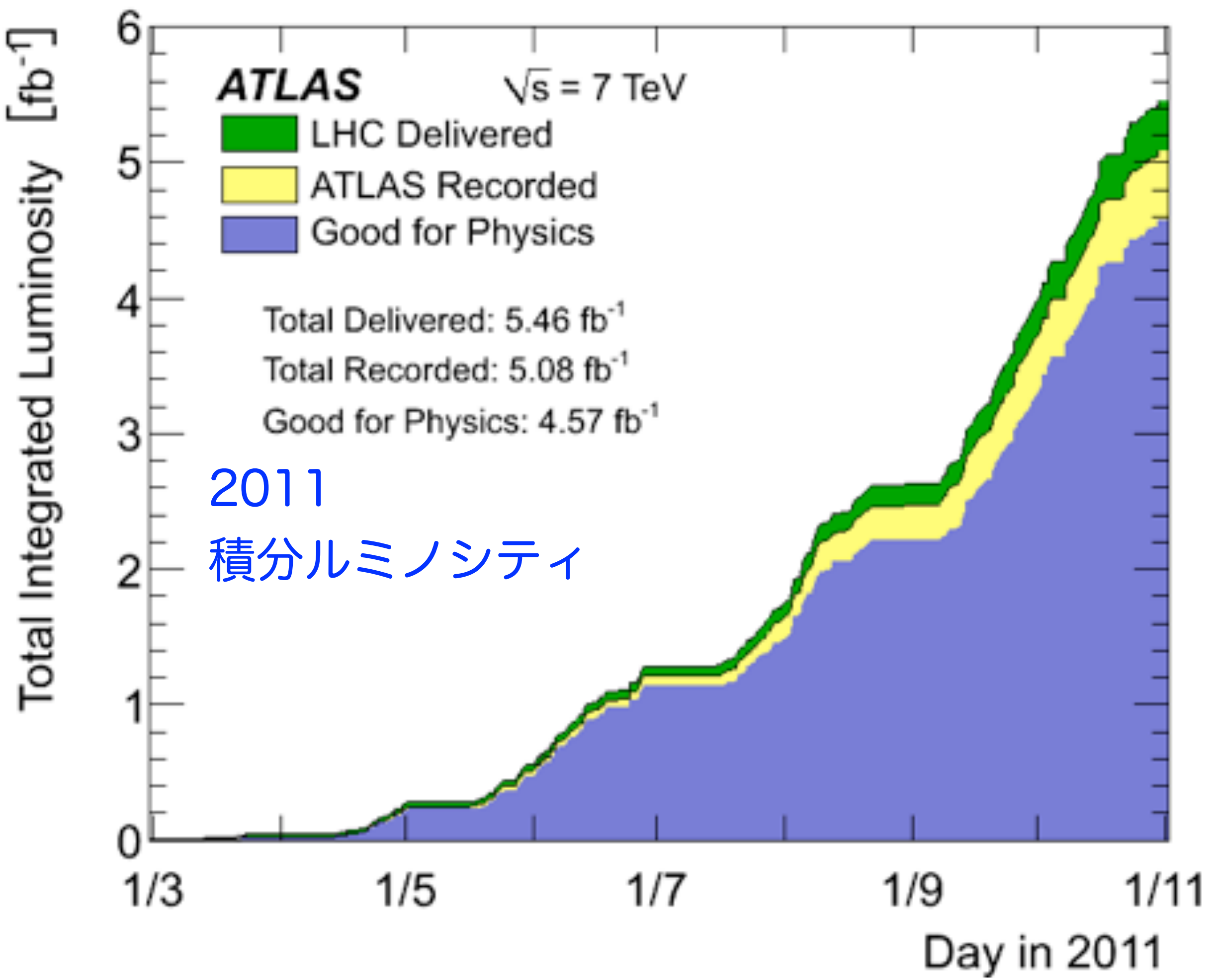
Publishされた論文数：434！
（2015年10月1日）

Run 1 : 2010 - 2012

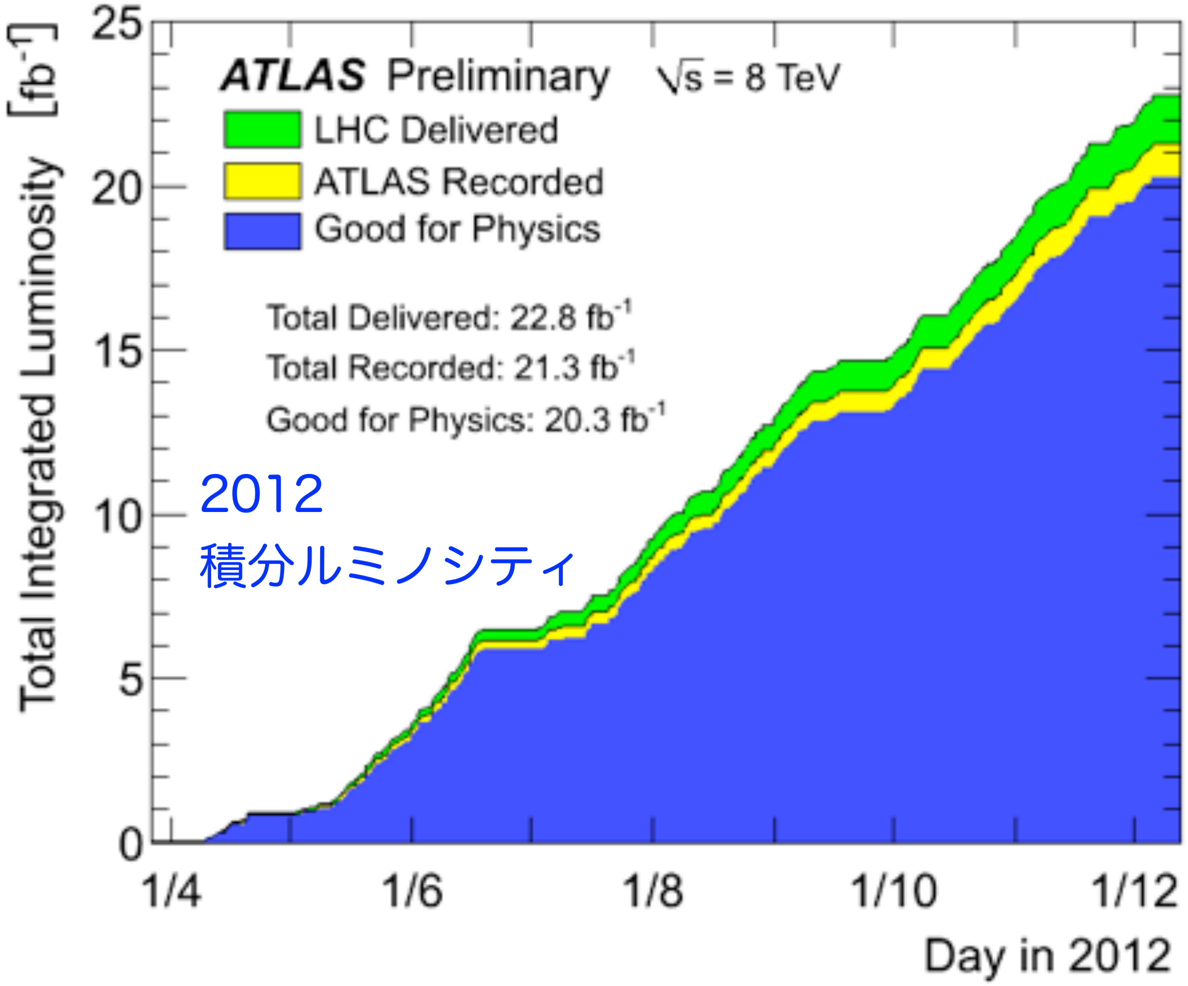
√s=7~8TeV
50ns bunch spacing
proton数/bunchなどは良かった
→ そこそこのルミノシティー
→パイルアップは多くなる



Peak luminosity



2011
積分ルミノシティ

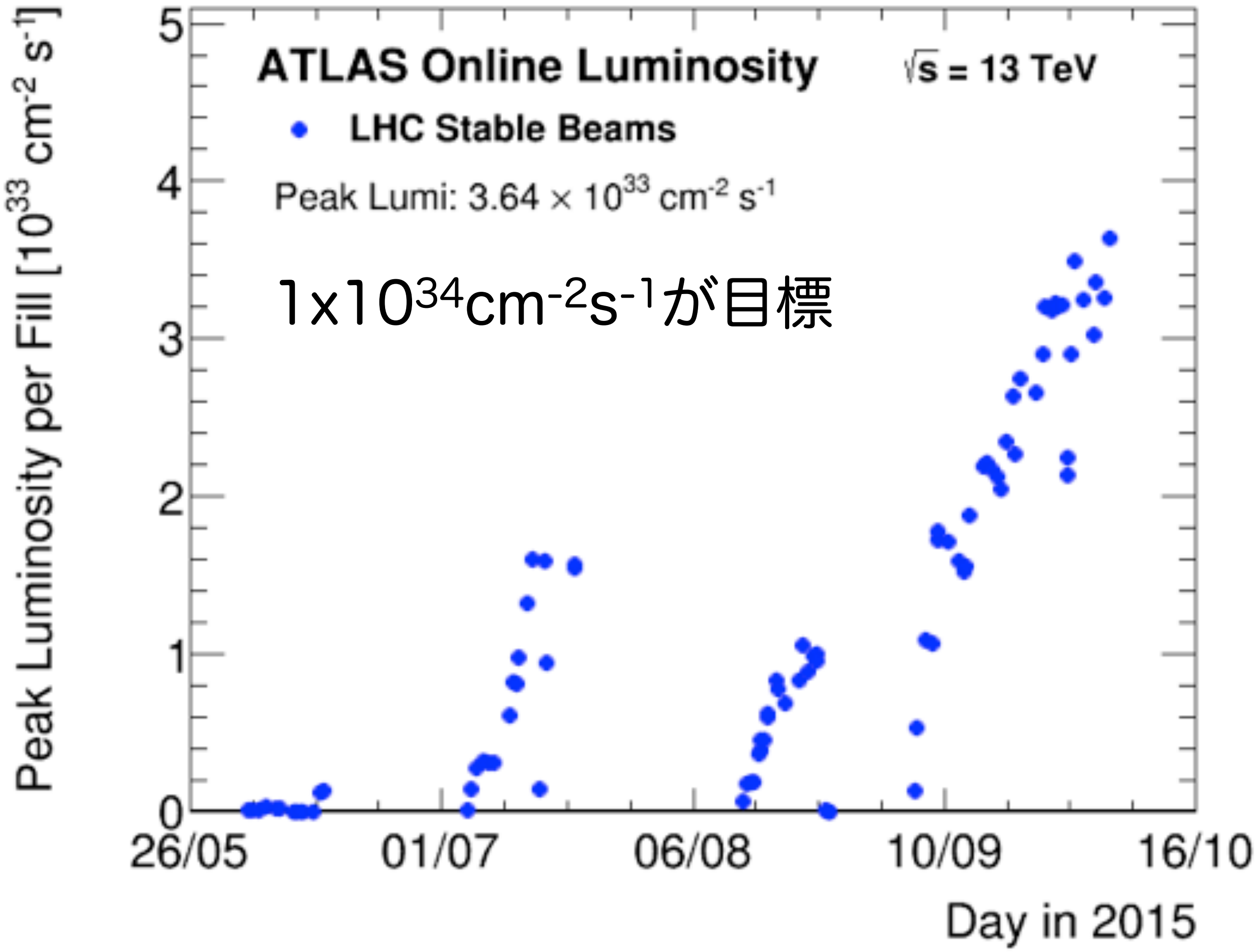


2012
積分ルミノシティ

Run 2 ：2015 -

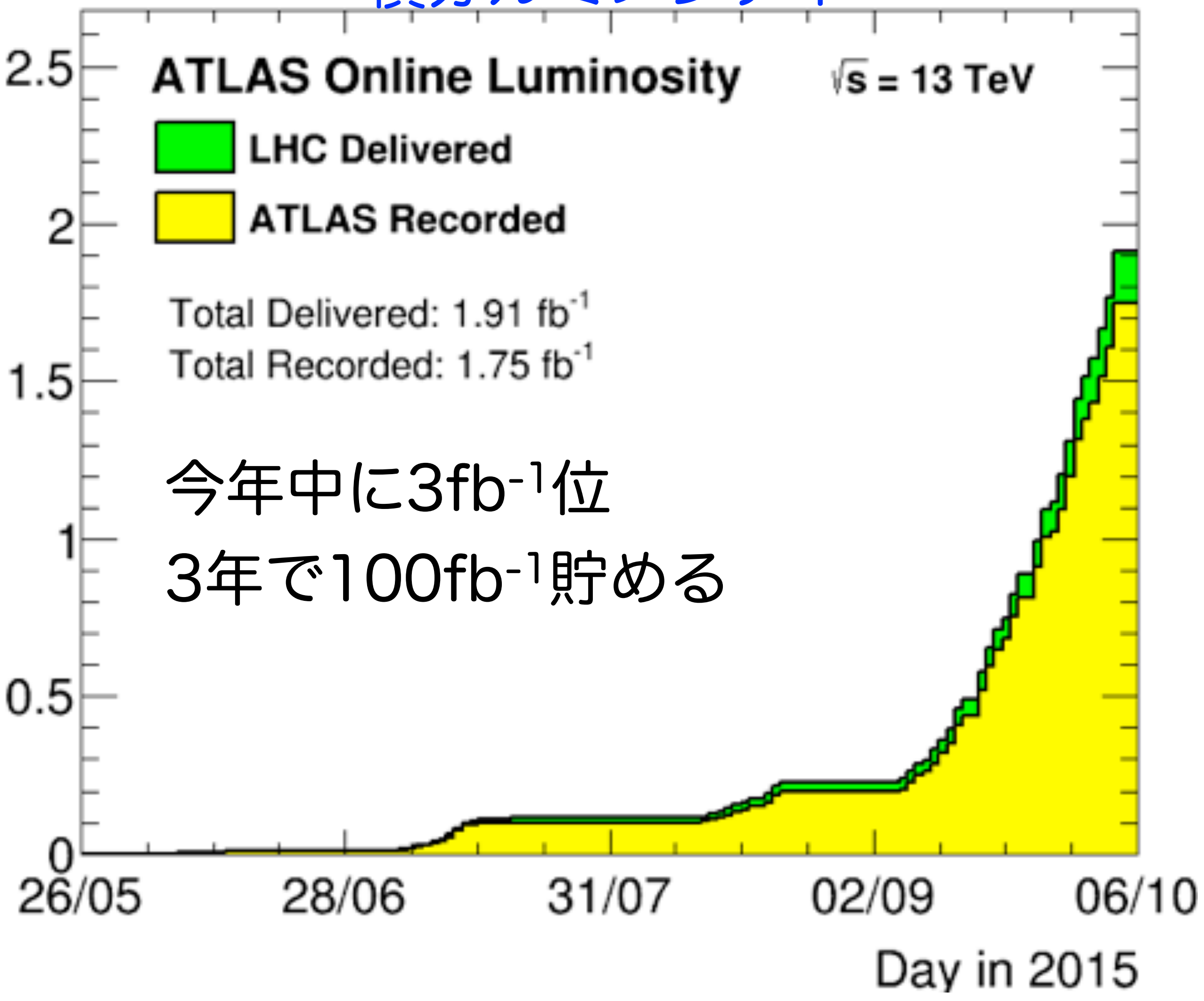
√s=13TeV
25ns bunch spacing
1464 bunch（design: 2808 bunch）まで入れることができた

Peak luminosity



$1\mathrm{x}10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$が目標

積分ルミノシティ



今年中に$3\mathrm{fb}^{-1}$位
3年で$100\mathrm{fb}^{-1}$貯める

今日のお話は、~$80\mathrm{pb}^{-1}$のデータ解析時による結果

はじめに

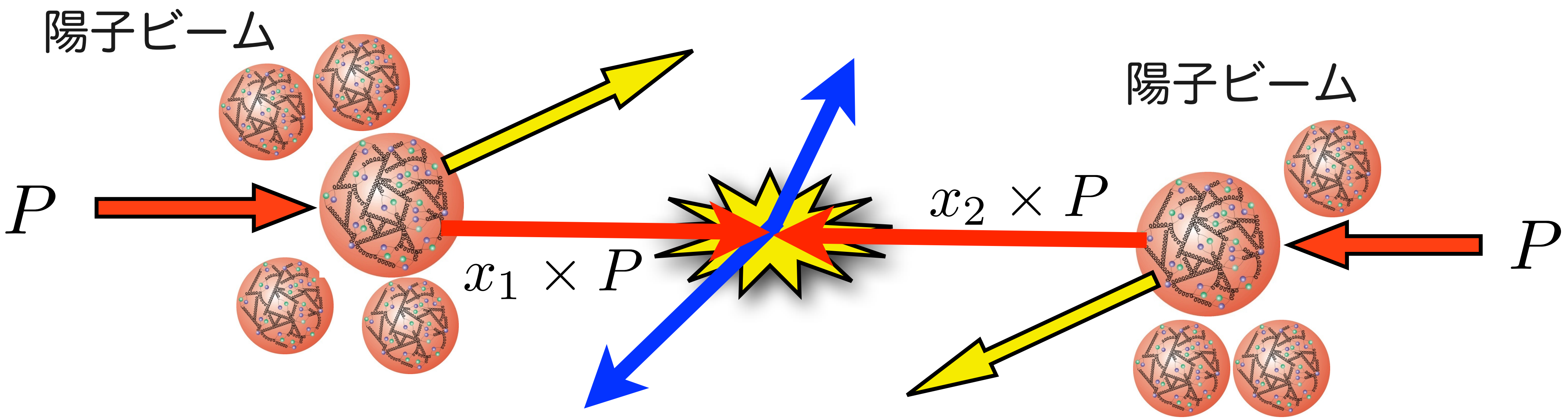
1. ハドロンコライダーの物理

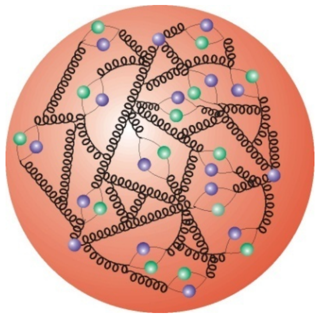
2. ATLAS検出器

3. ATLAS実験のこれまでの解析結果と展望
    - 3.1 標準模型
    - 3.2 Higgs物理
    - 3.3 新物理探索

ハドロンコライダーの物理

陽子陽子衝突

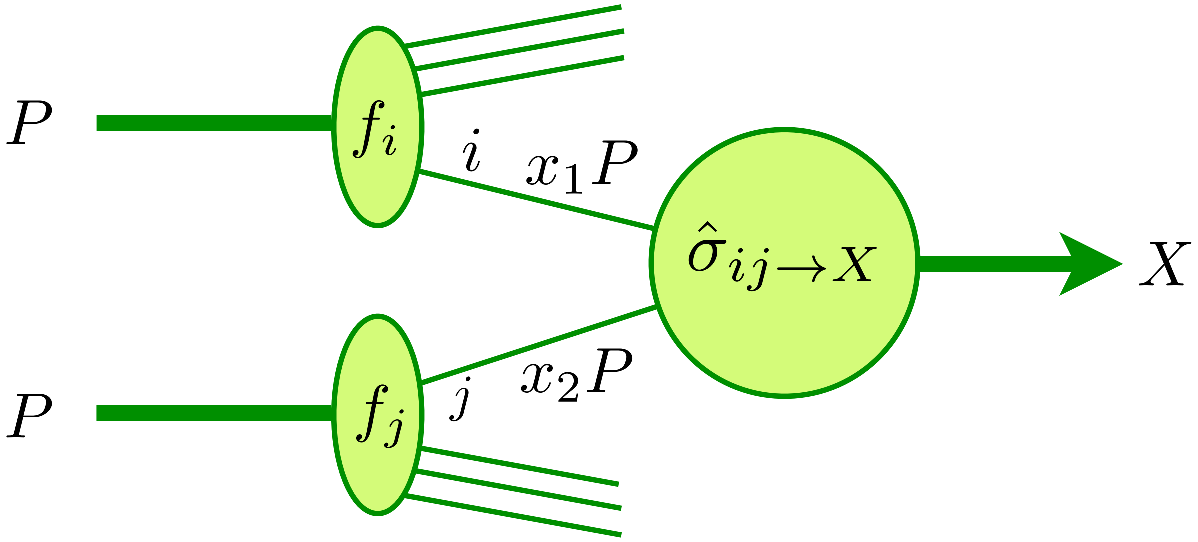




陽子の量子数を担うuud(valence quark)だけなく、
沢山のquark(sea quark)やgluon → parton
partonの存在割合がわからないと、生成断面積がわからない。

$$\sigma_{pp\to X} = \int \mathrm{d}x_1 \int \mathrm{d}x_2 \sum_{ij} \boxed{f_i(x_1,\mu_F)\, f_j(x_2,\mu_F)}\boxed{\hat{\sigma}_{ij\to X}(\hat{s})}$$

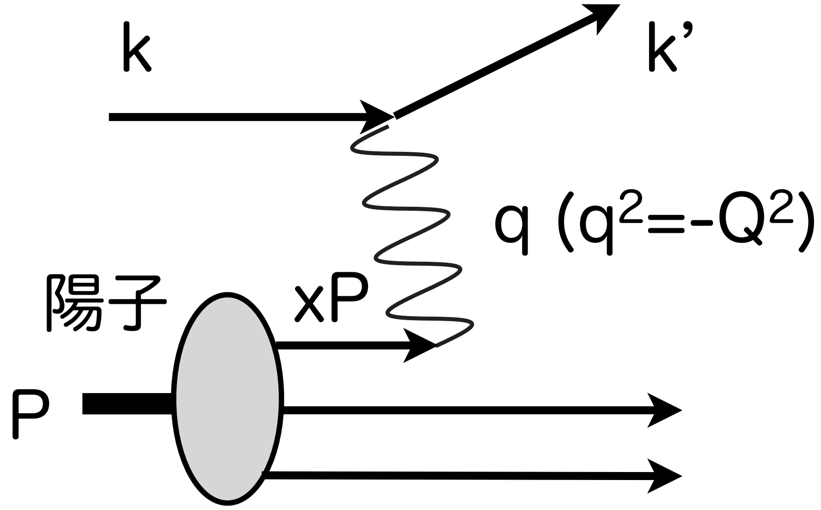
partonの存在割合　　素過程の断面積



partonとpartonの衝突による断面積 $\hat{\sigma}_{ij\to X}$
にparton分布で重み付け

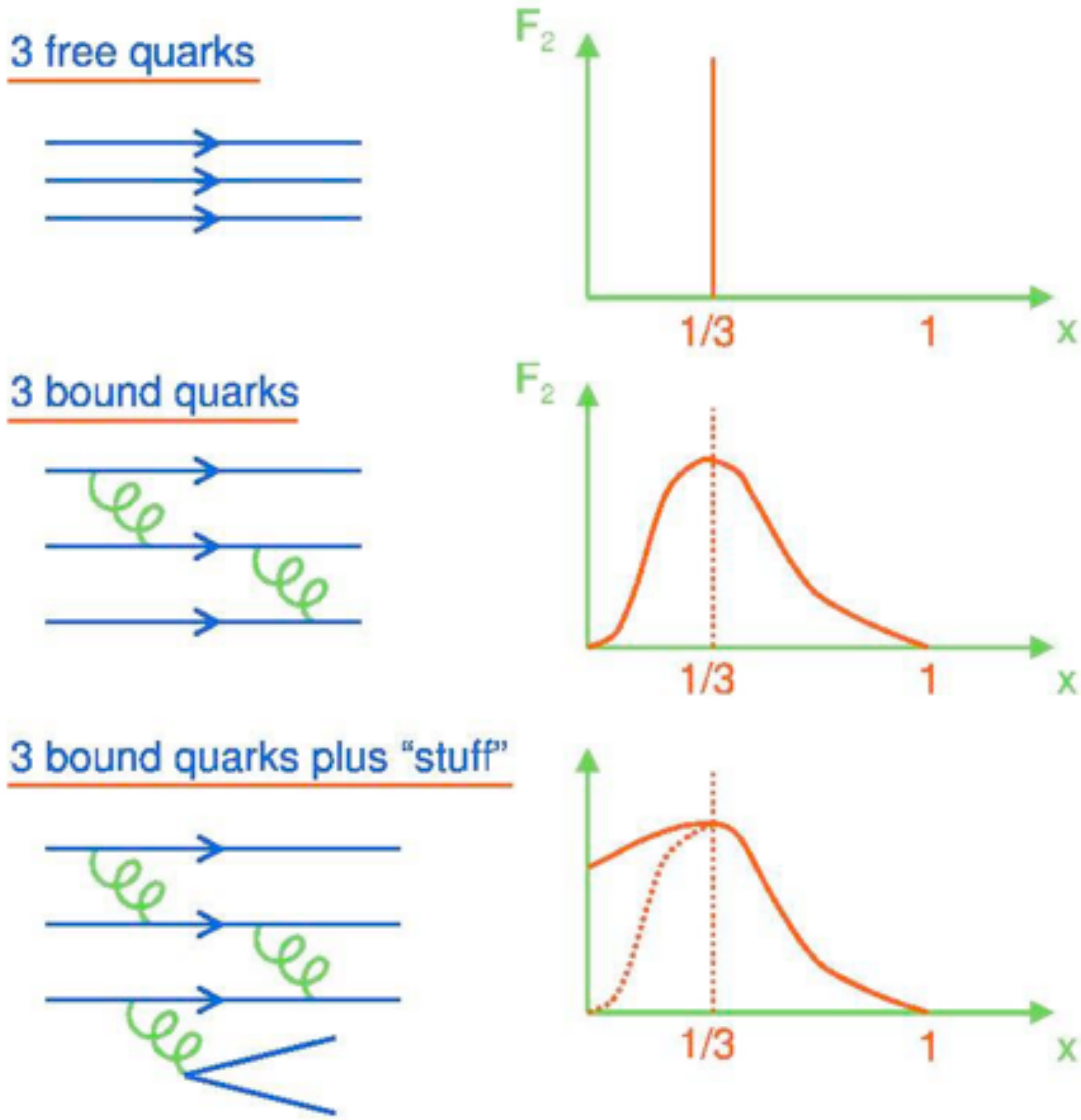
可能なparton全部足し算する

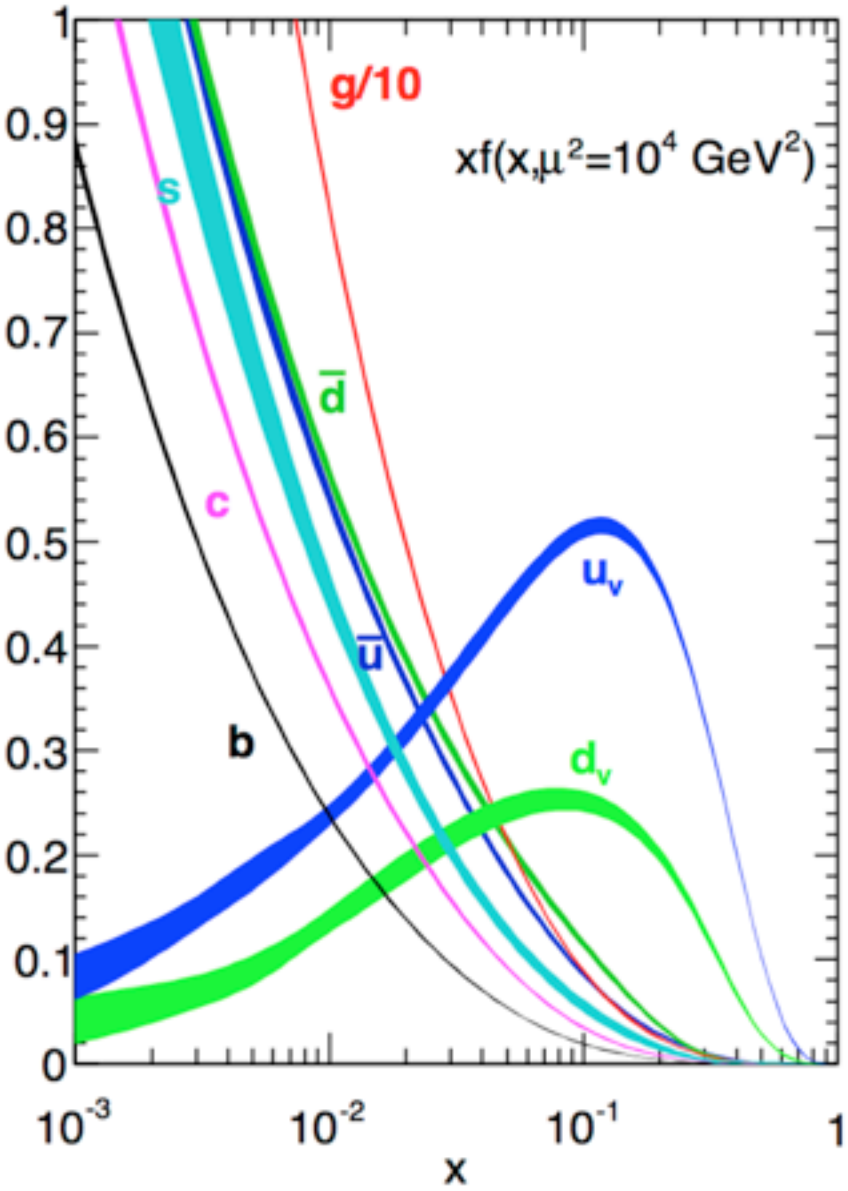
PDF: Parton Distribution Function



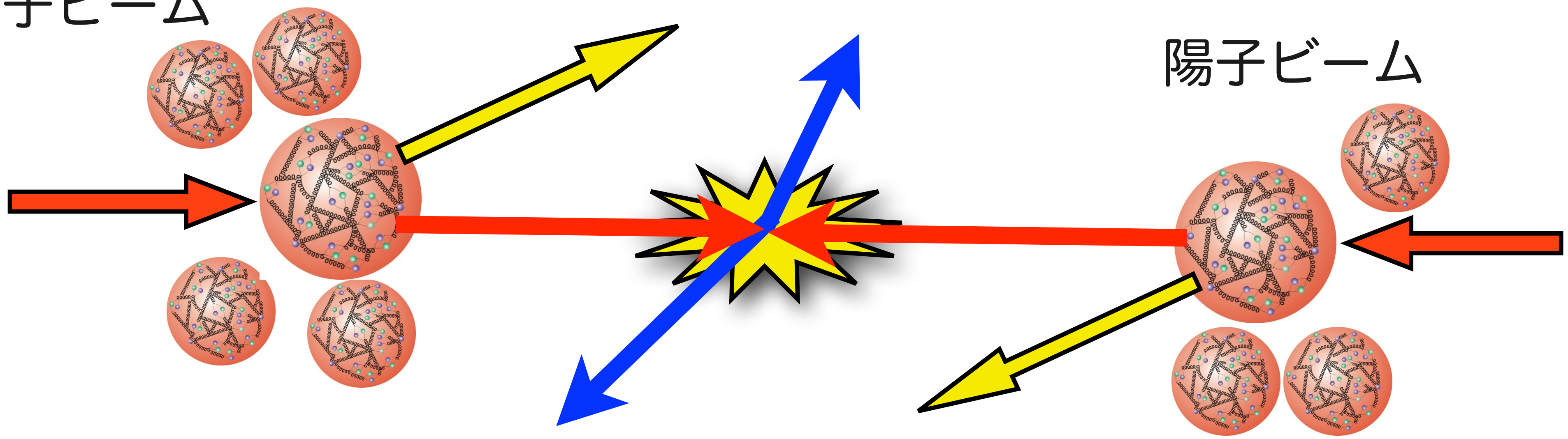
非摂動領域なので計算不能

どのpartonがどれ程のenergyを担うかは、
深非弾性散乱実験によって決定する





ハドロンコライダーの運動学



$P_1 = (x_1 P; 0, 0, x_1 P)$ $P_2 = (x_2 P; 0, 0, -x_2 P)$

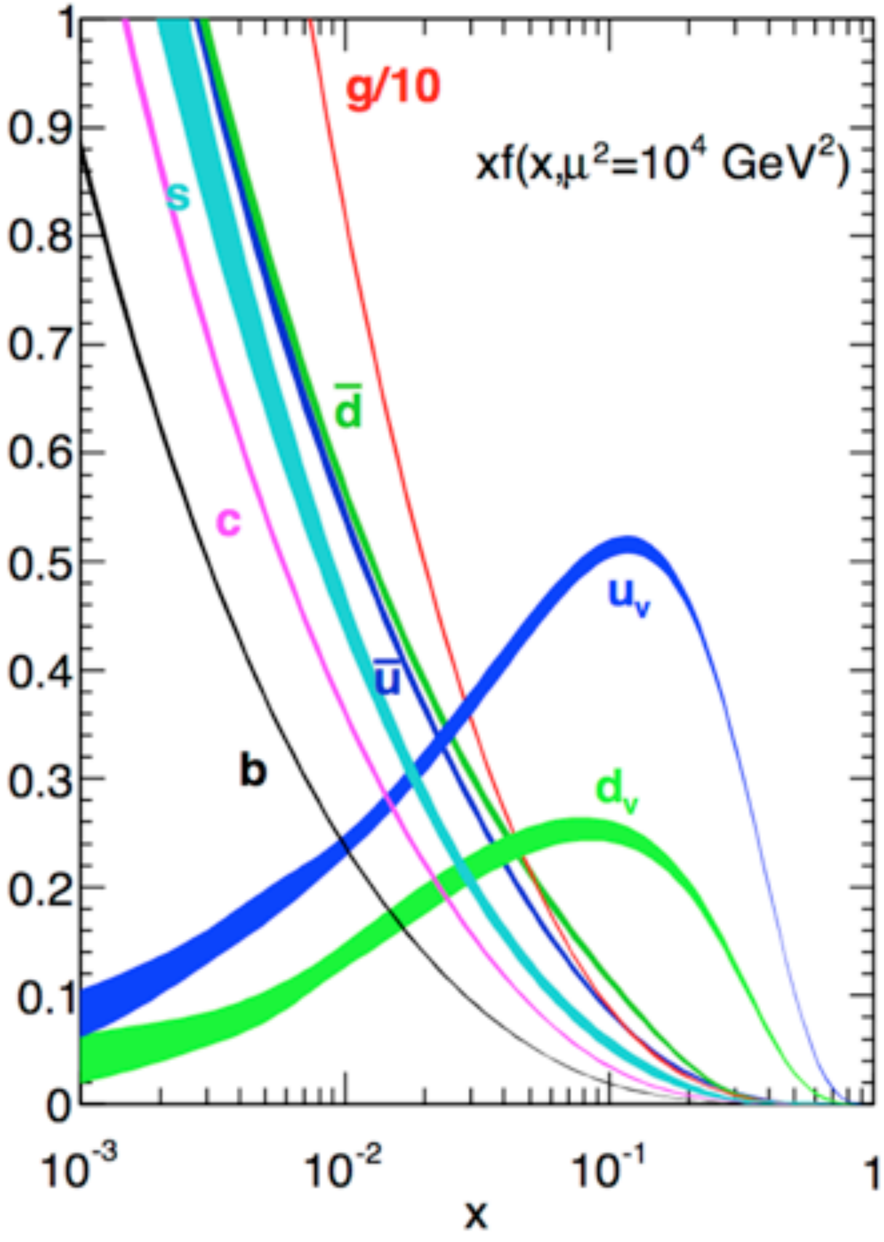
$((x_1 + x_2)P; 0, 0, (x_1 - x_2)P)$ → Asymmetric(衝突毎に違う)

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

実効エネルギー $\sqrt{\hat{s}} = \sqrt{x_1 x_2}\sqrt{s_{pp}}$ $(\sqrt{s} = 2P)$

物理過程によって x が決まる

$\sqrt{x_1 x_2}$	Tevatron 2TeV	LHC 8TeV	LHC 13TeV
$\sqrt{\hat{s}} = 100\ \mathrm{GeV}$	0.05	0.0125	0.007
$\sqrt{\hat{s}} = 1\ \mathrm{TeV}$	0.5	0.125	0.07

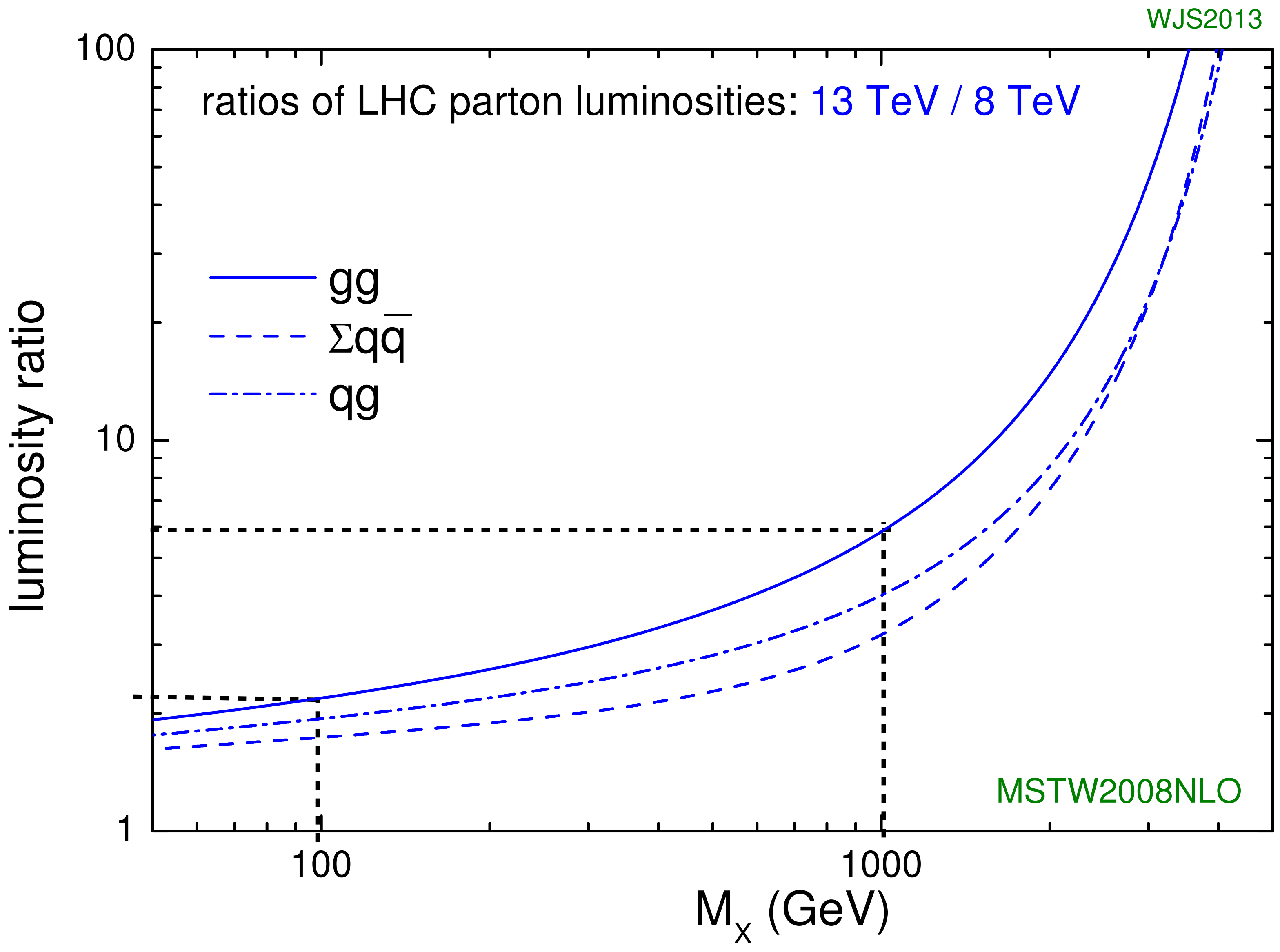


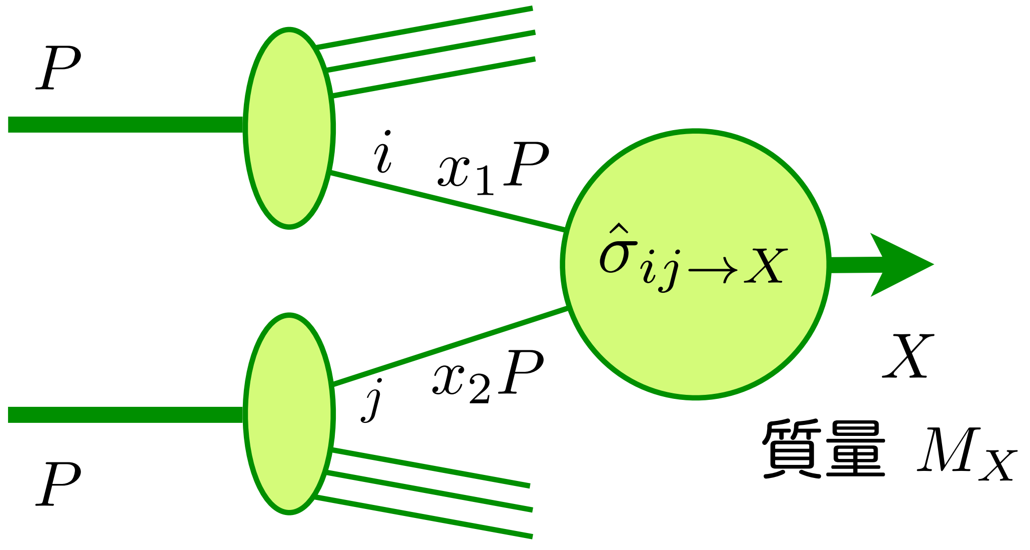
Tevatronはvalence quarkで勝負→陽子・反陽子

LHCはgluonやsea quarkが十分寄与できる→陽子・陽子

7TeV→8TeV→13TeVへのご利益

√sを高くすると、重い粒子の生成が特に増加する





13TeV / 8TeV

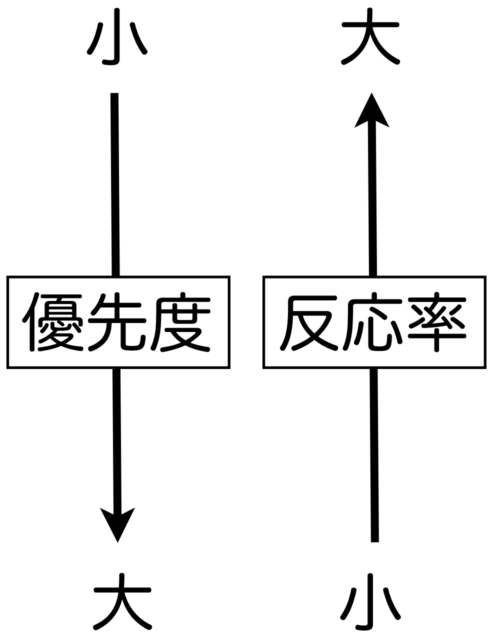
ヒッグス粒子（100GeV）生成 ： ~2倍

超対称性粒子（1TeV）生成 ： 5~6倍

陽子陽子衝突断面積

色々な物理を楽しめる

- QCD
- B-physics
- Electroweak
- top quark physics
- Higgs physics
- New physics



大抵の反応は興味のない事象

ヒッグス：10桁のリダクション

トリガーが重要

L1で100kHz、HLTで100Hzまで削減

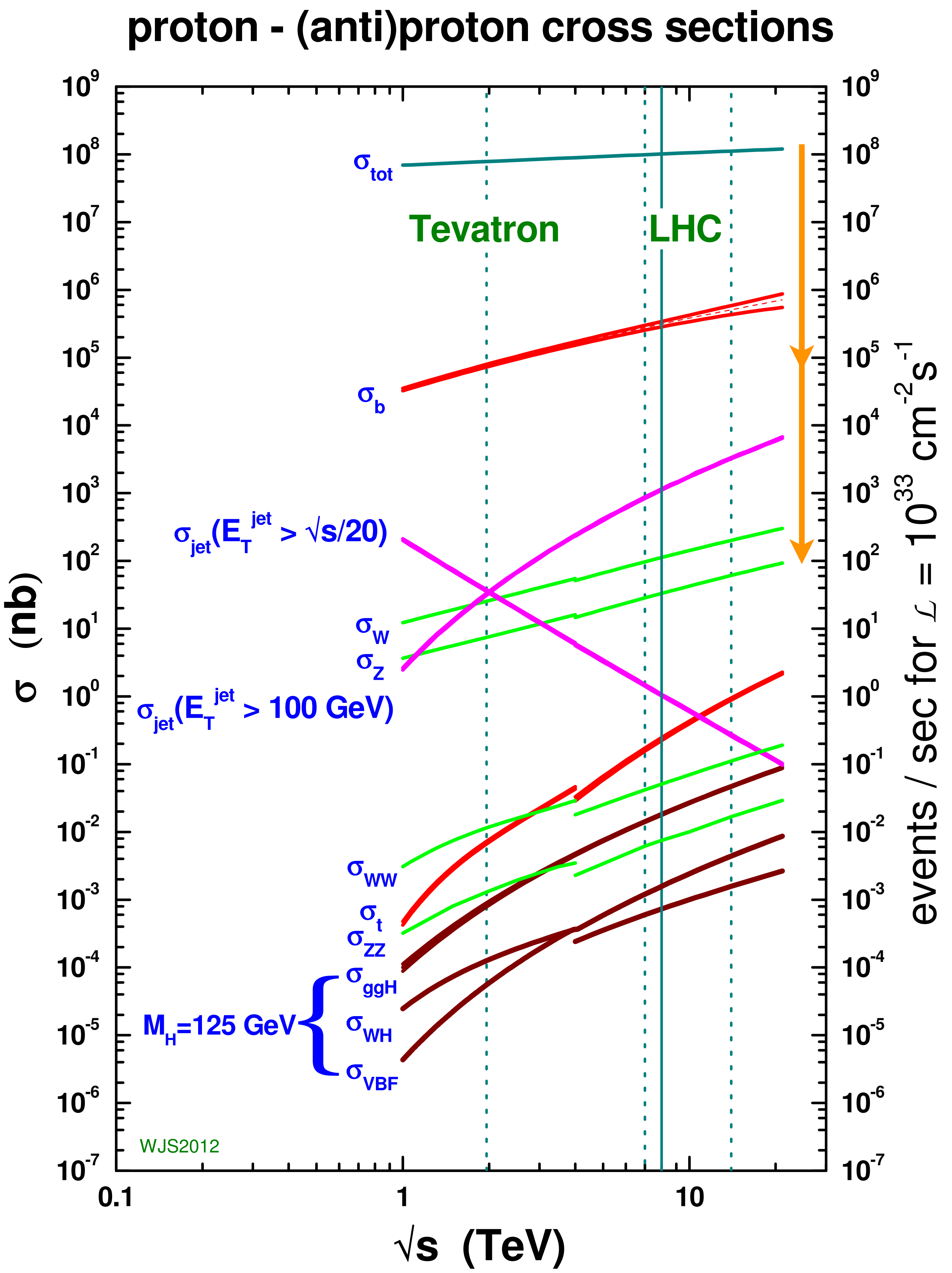
パイルアップ事象

反応頻度＝断面積 × ルミノシティー

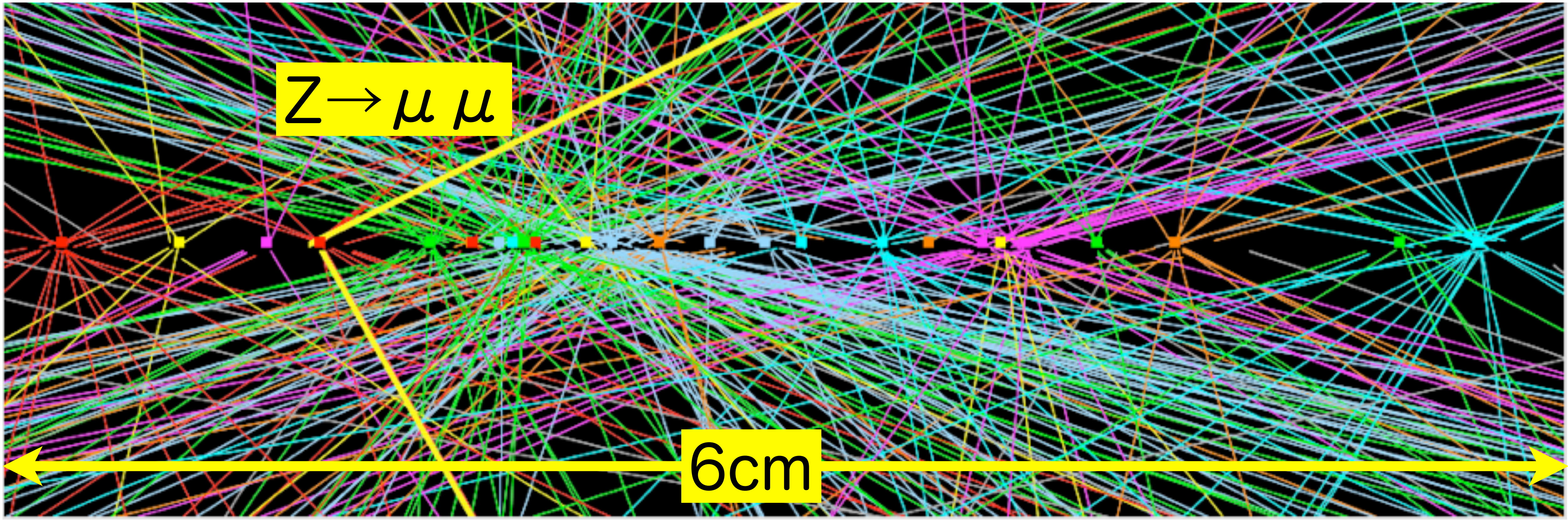
$\left.\begin{array}{l}\sigma_{\mathrm{tot}} \sim 100\,\mathrm{mb} \\ L \sim 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\end{array}\right\}$ →反応頻度 1GHz

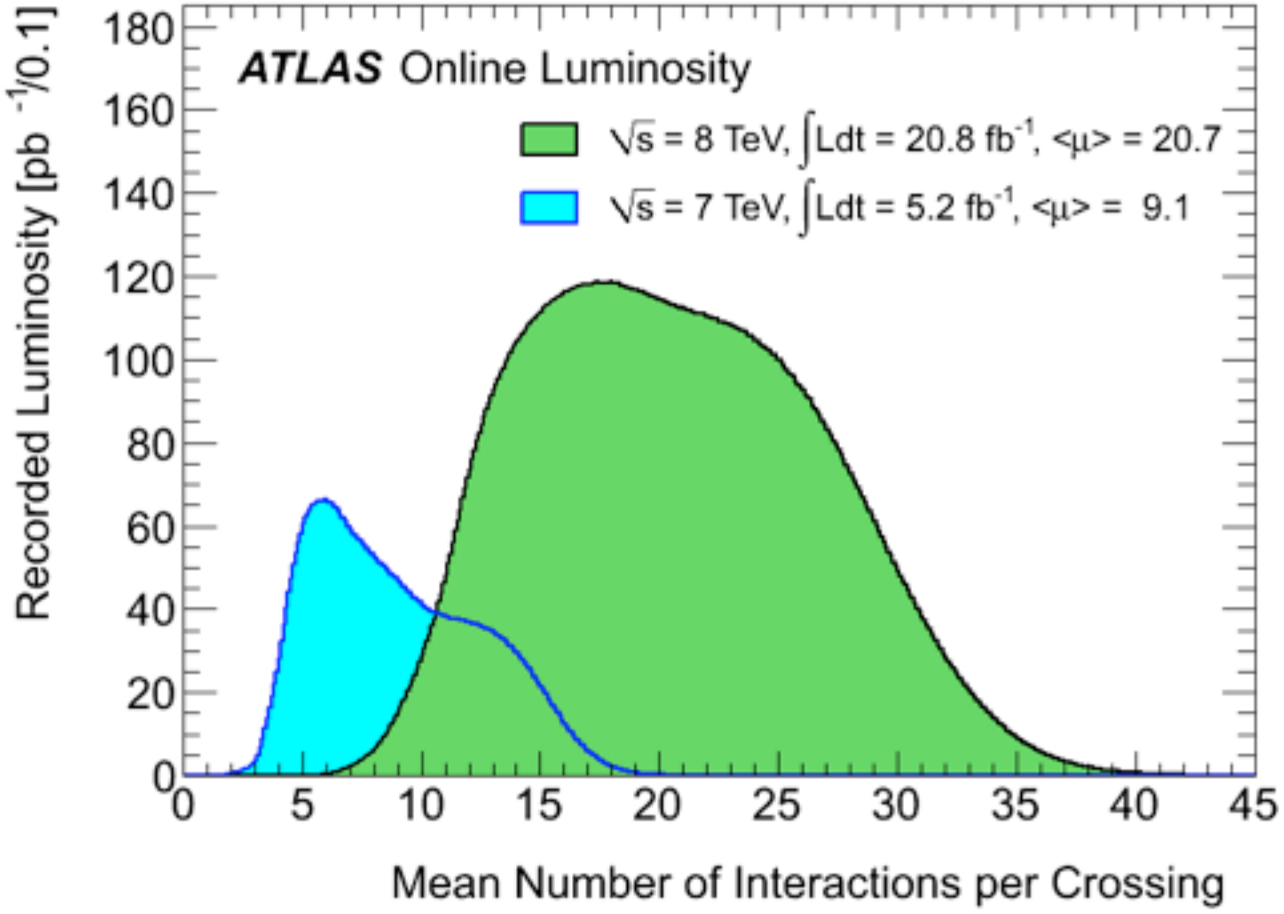
LHCの陽子衝突頻度＝40MHz

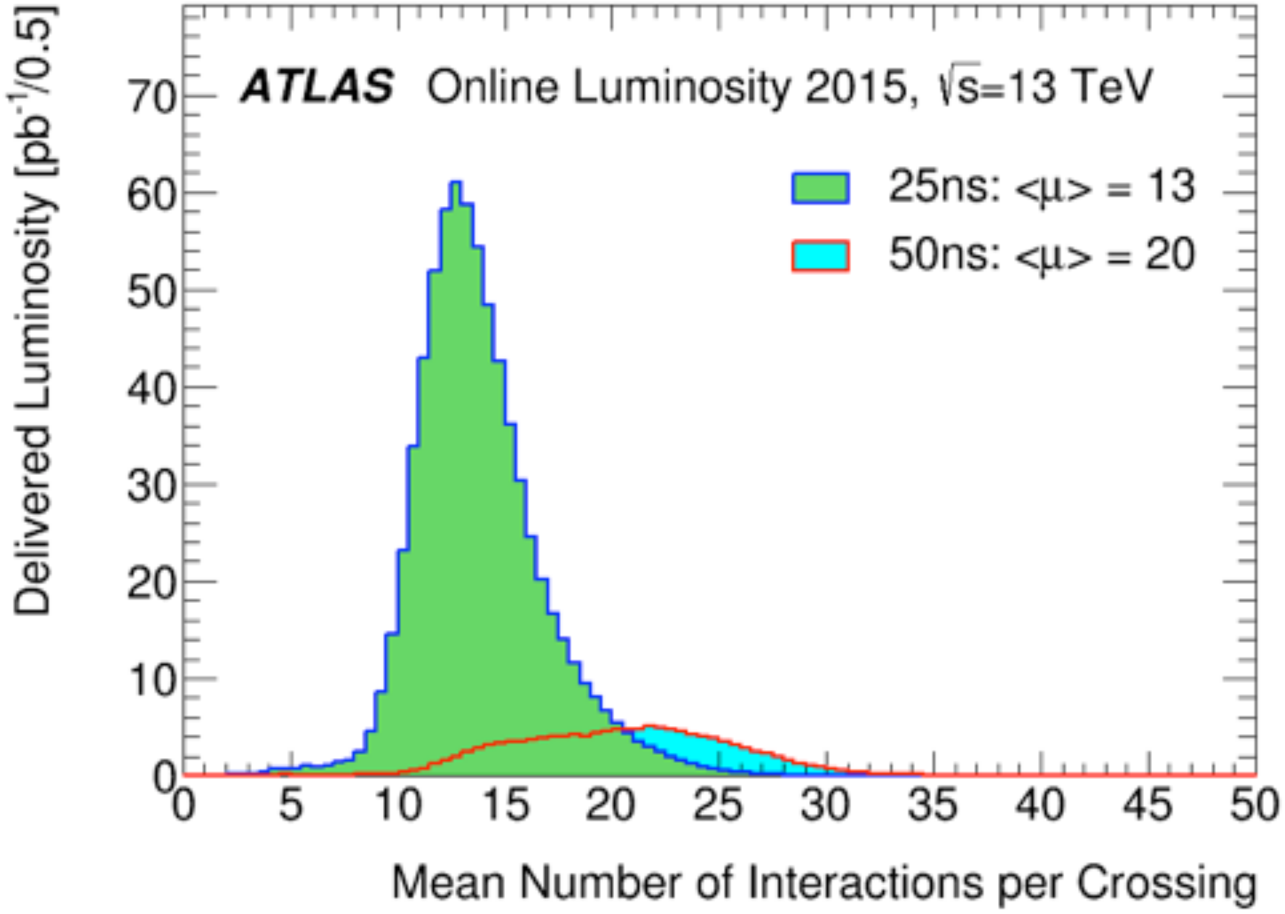
→1回の陽子交差で複数の陽子衝突



パイルアップ


Z→μ μ
6cm


ATLAS Online Luminosity
√s = 8 TeV, ∫Ldt = 20.8 fb⁻¹, <μ> = 20.7
√s = 7 TeV, ∫Ldt = 5.2 fb⁻¹, <μ> = 9.1
Recorded Luminosity [pb⁻¹/0.1]
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
Mean Number of Interactions per Crossing


ATLAS Online Luminosity 2015, √s=13 TeV
25ns: <μ> = 13
50ns: <μ> = 20
Delivered Luminosity [pb⁻¹/0.5]
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
Mean Number of Interactions per Crossing

ATLAS検出器
パフォーマンス

A Toroidal Lhc AppratuS

Calorimeters:
Tile & LAr

e/γ $\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} + 0.7\%$

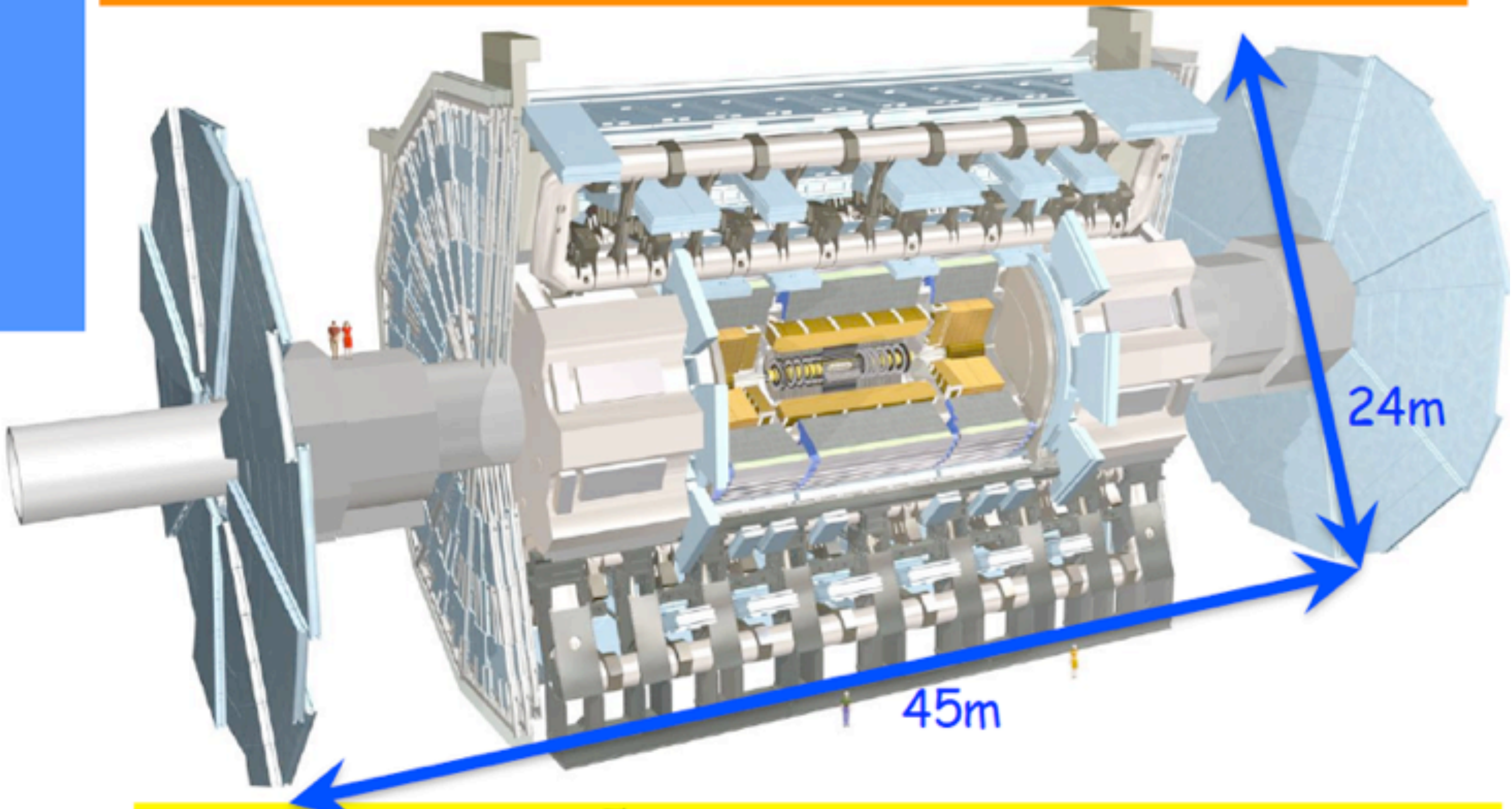
Hadron $\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} + 3\%$ |η|<3, $\frac{\sigma(E)}{E} = \frac{100\%}{\sqrt{E}} + 10\%$ |η|>3

Muons:

Trigger TGC 🇯🇵
RPC

Precision CSC
MDT

大きさ：24m × 45m
重量：7000 トン
読み出し：160M



Magnets:

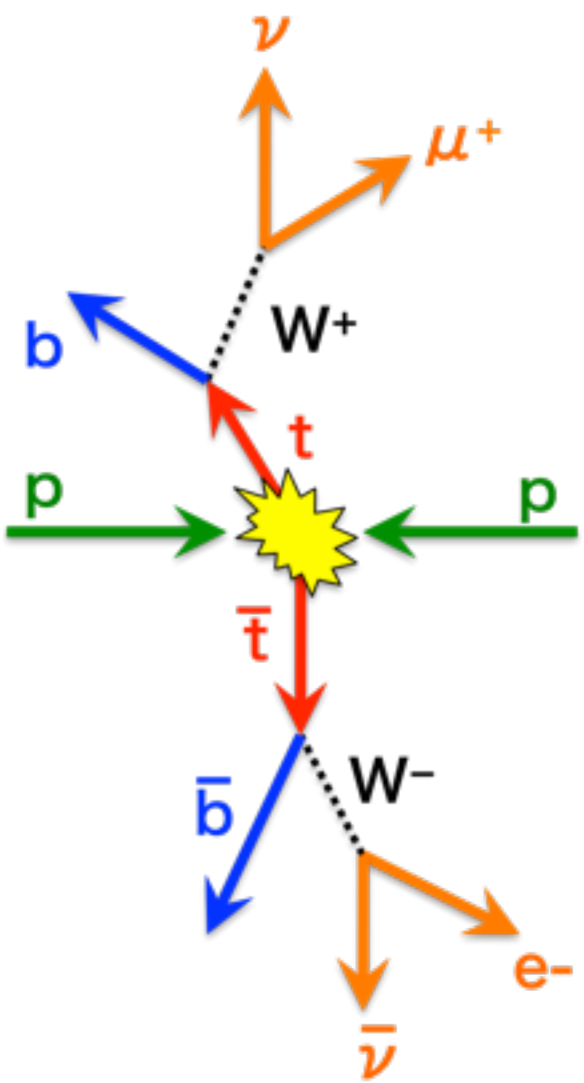
Solenoid : 2テスラ 🇯🇵

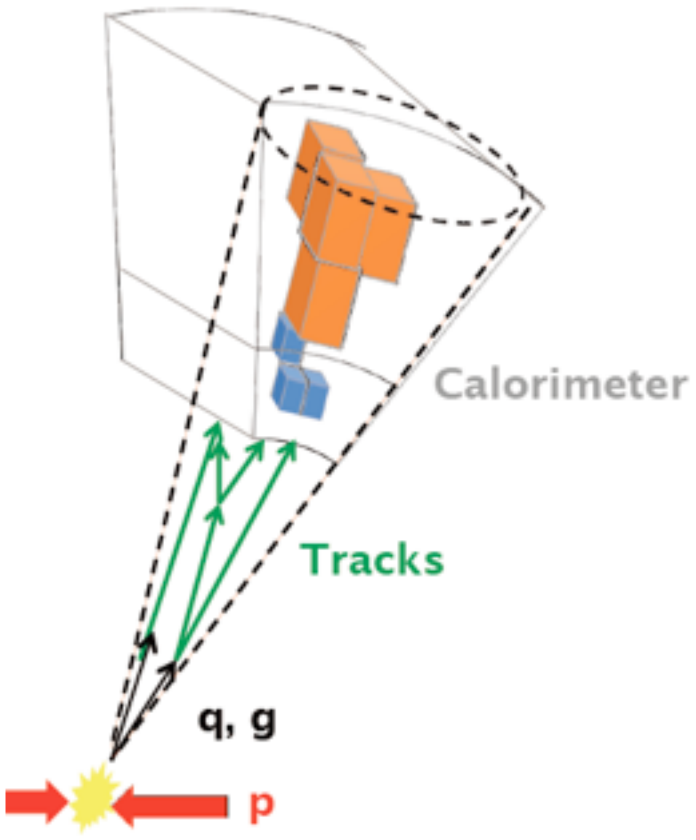
Toroidal :
$\int B \times d\ell$ = 2~6 (T×m)

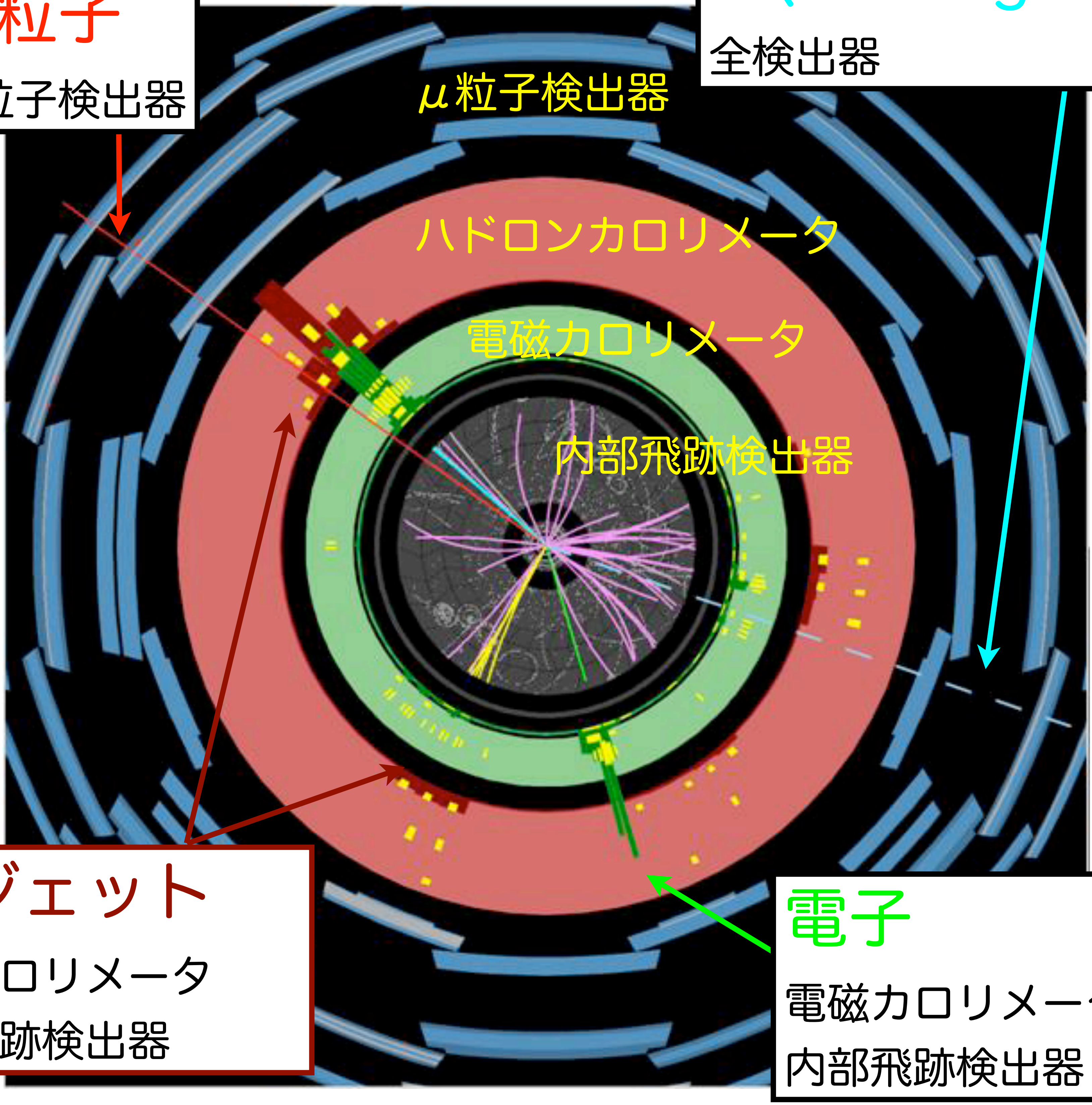
Inner Tracker: $\frac{\sigma}{P_T} = 0.05\% \times P_T + 1\%$ (2% @ 20GeV)

Pixel:	SCT: 🇯🇵	TRT:
50×400μm²	80μm × 6cm	4mm φ straw tube
80M channels	7M channels	350k channels

Object ID







μ粒子

μ粒子検出器

ν (missing E_T)

全検出器

ジェット

カロリメータ
飛跡検出器

電子

電磁カロリメータ
内部飛跡検出器

b-jet id & τ -id

b-jet id

jet内のmultiplicityが大

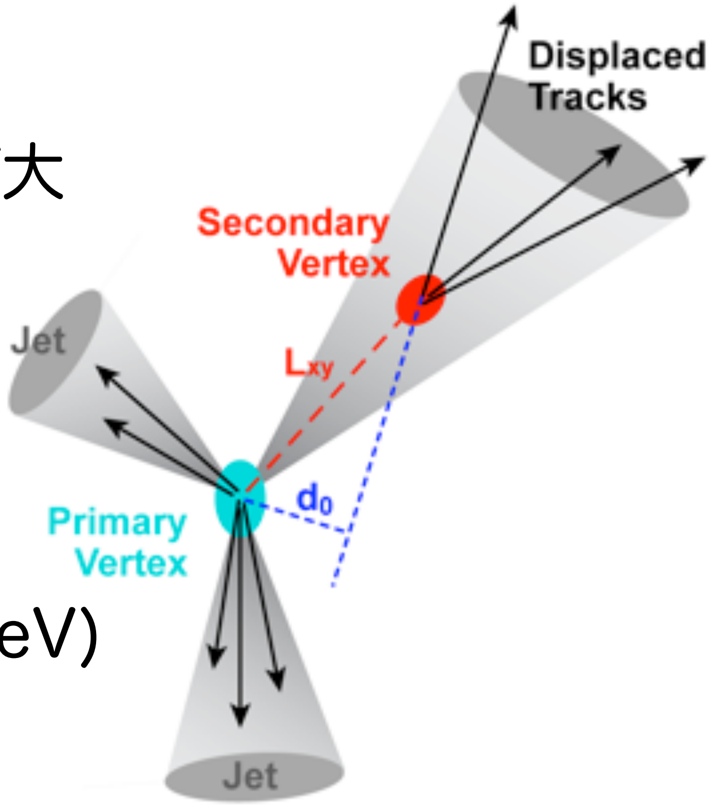
L_{xy}が大

jet内のd_0が大

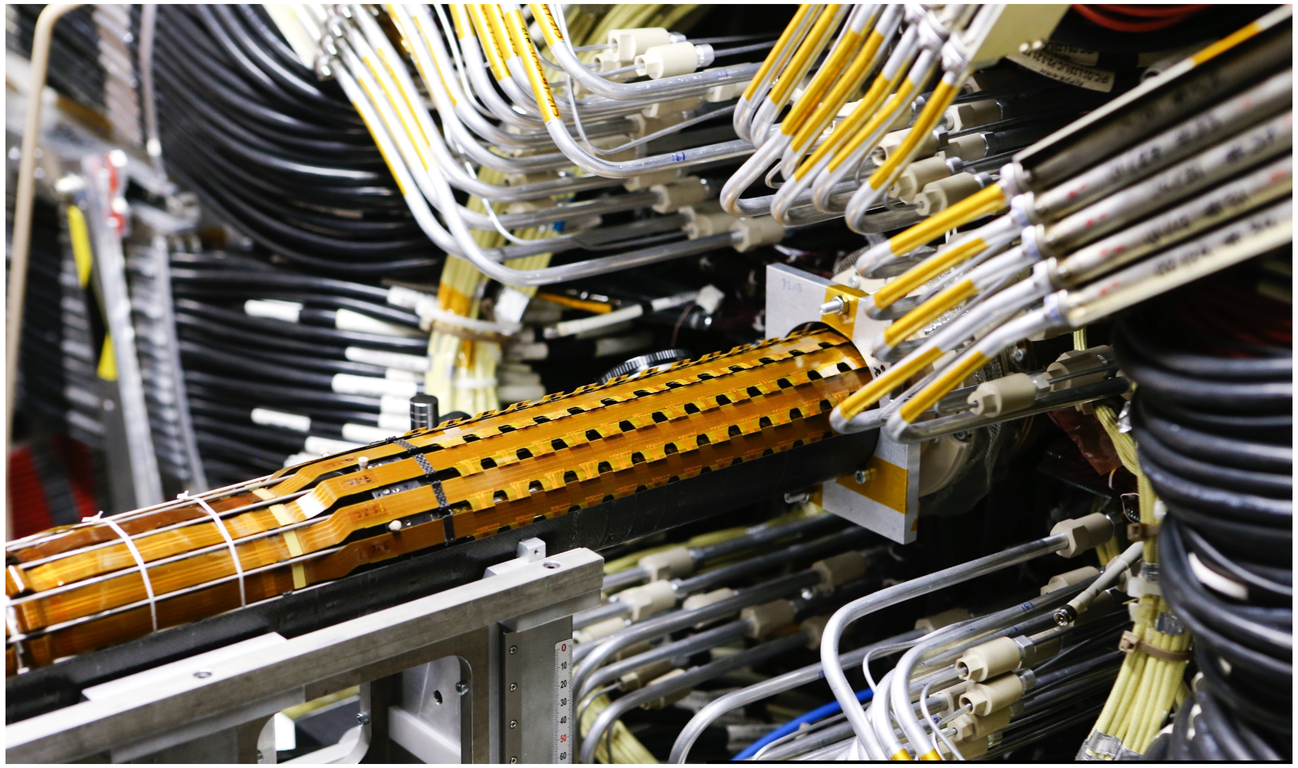
$c\tau$ ～500μm

$\beta\gamma$～10 (@P~50GeV)

→ 5 mm位走る



Run 2からInsertable B layer (IBL)を導入



τ -jet id

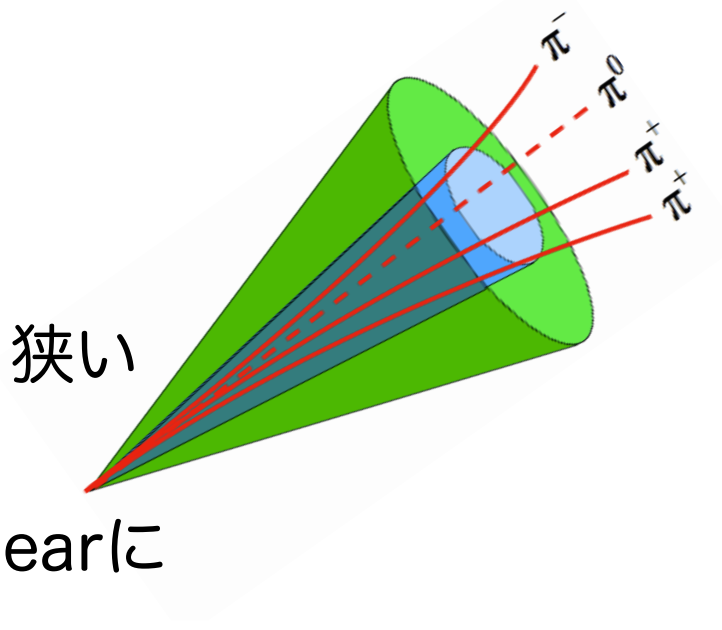
energyの広がり：

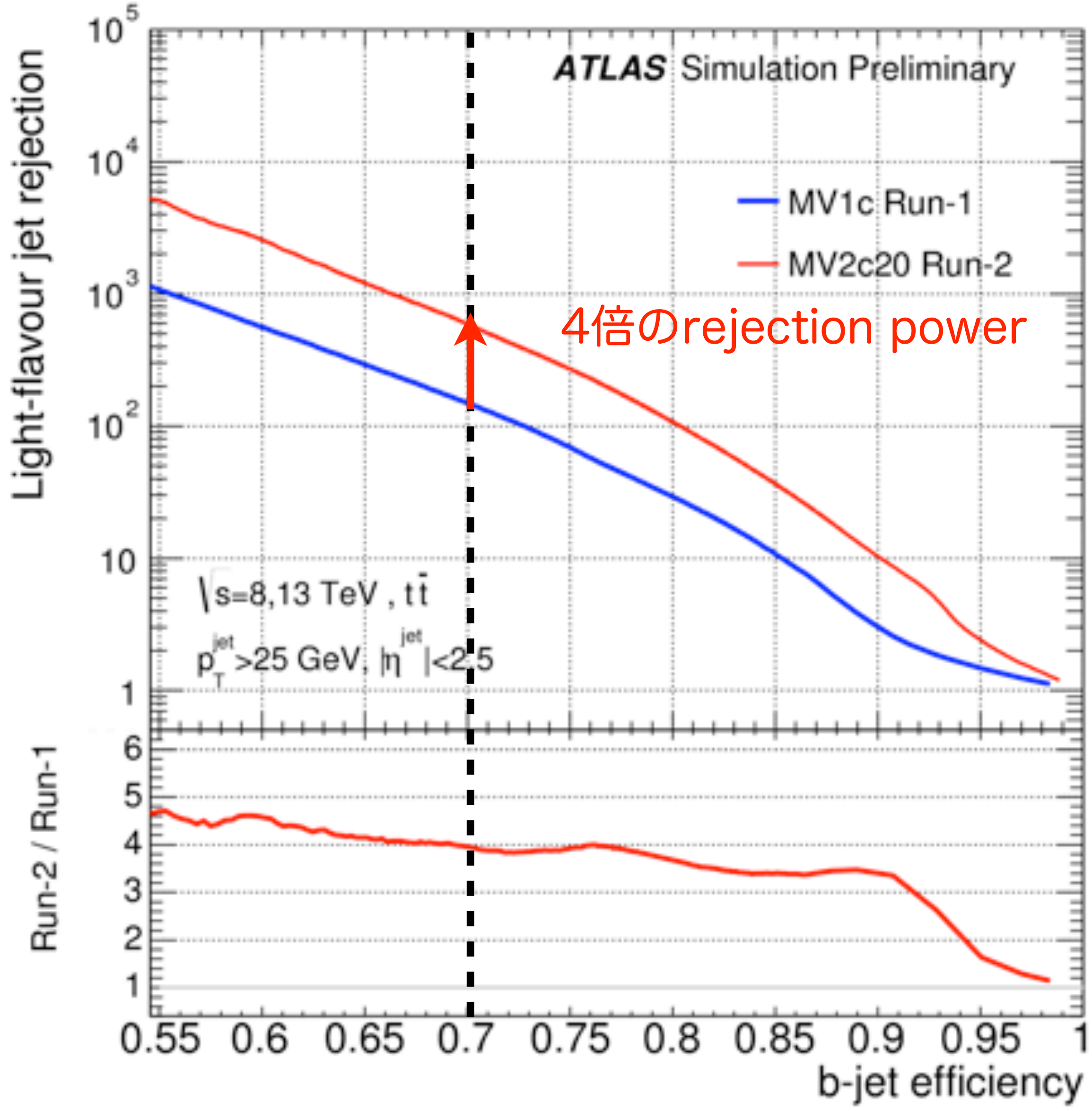
　e/γより広い

　quark/gluonより狭い

荷電粒子：

　1本か3本がcollinearに



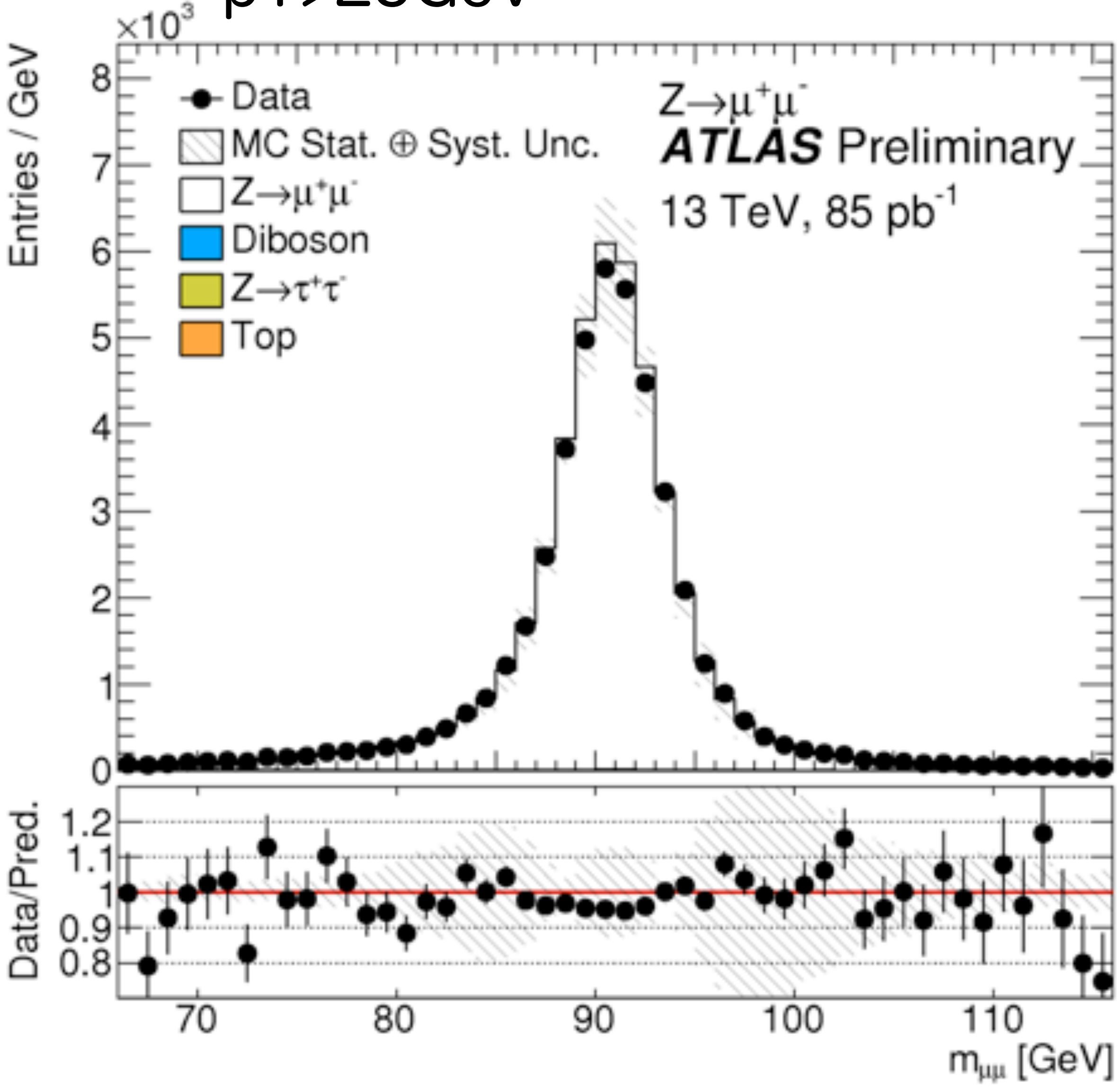


標準模型の検証

W, Z boson の測定

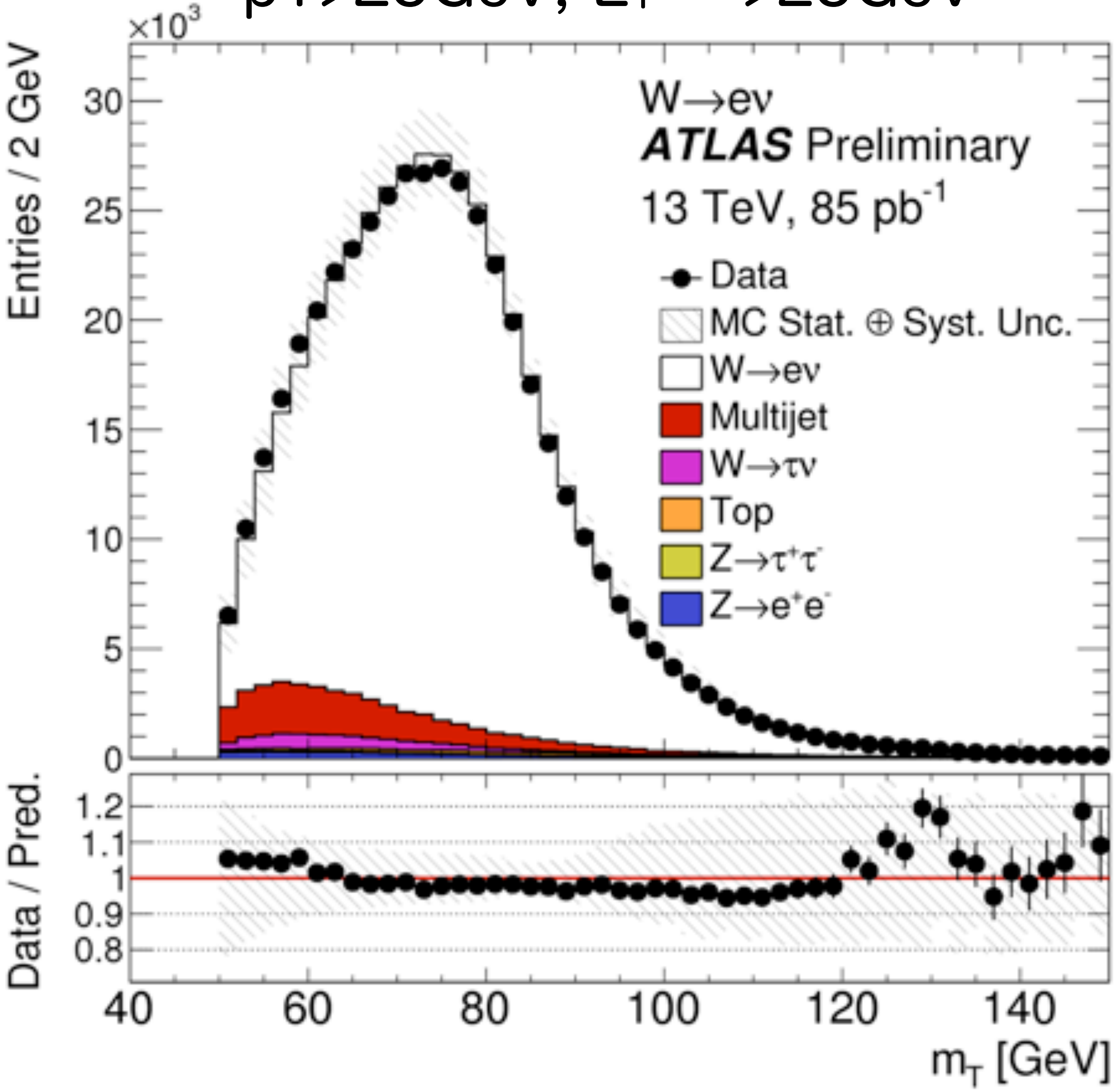
100k Z(90000) events

pT>25GeV



1M W events

pT>25GeV, E_T^{miss}>25GeV

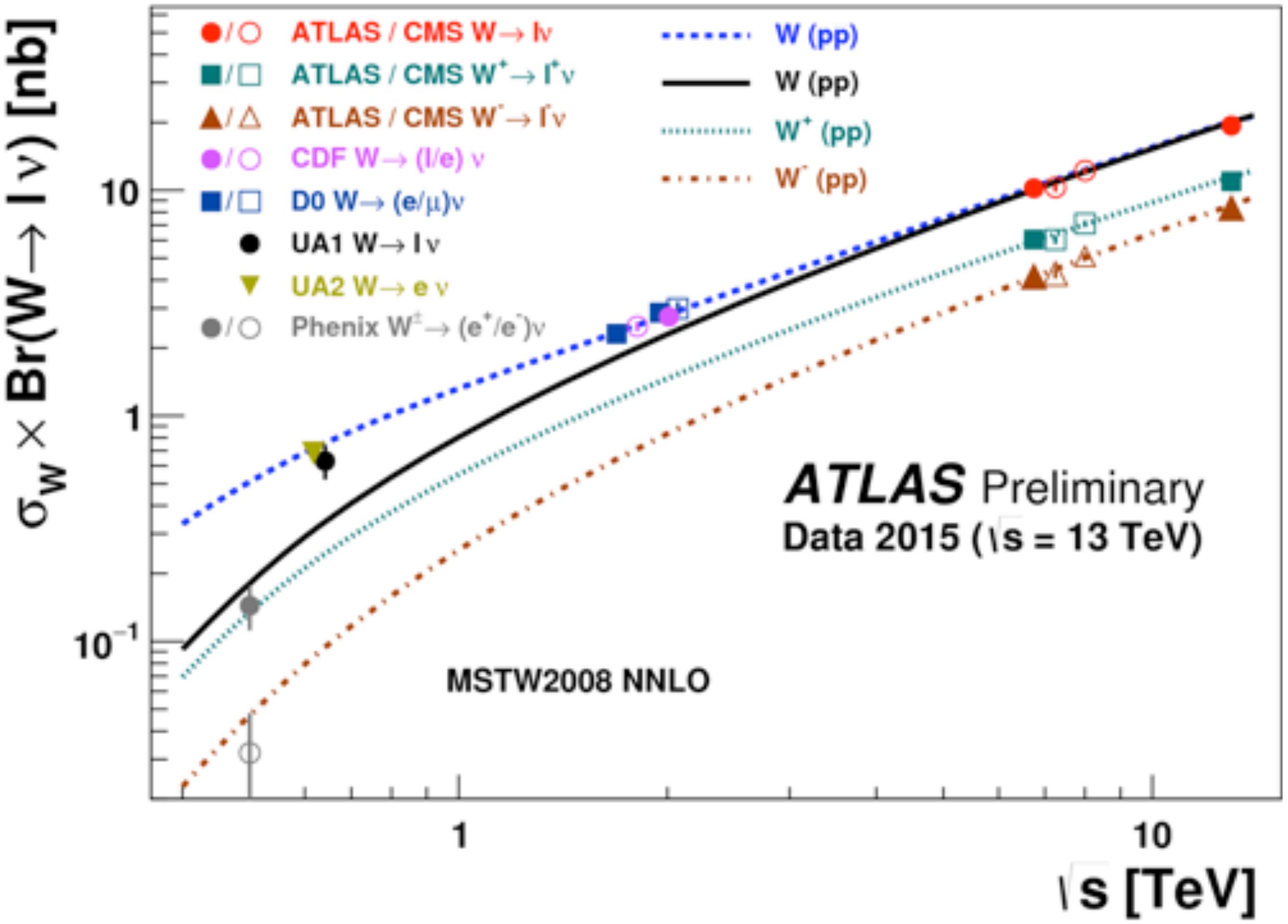


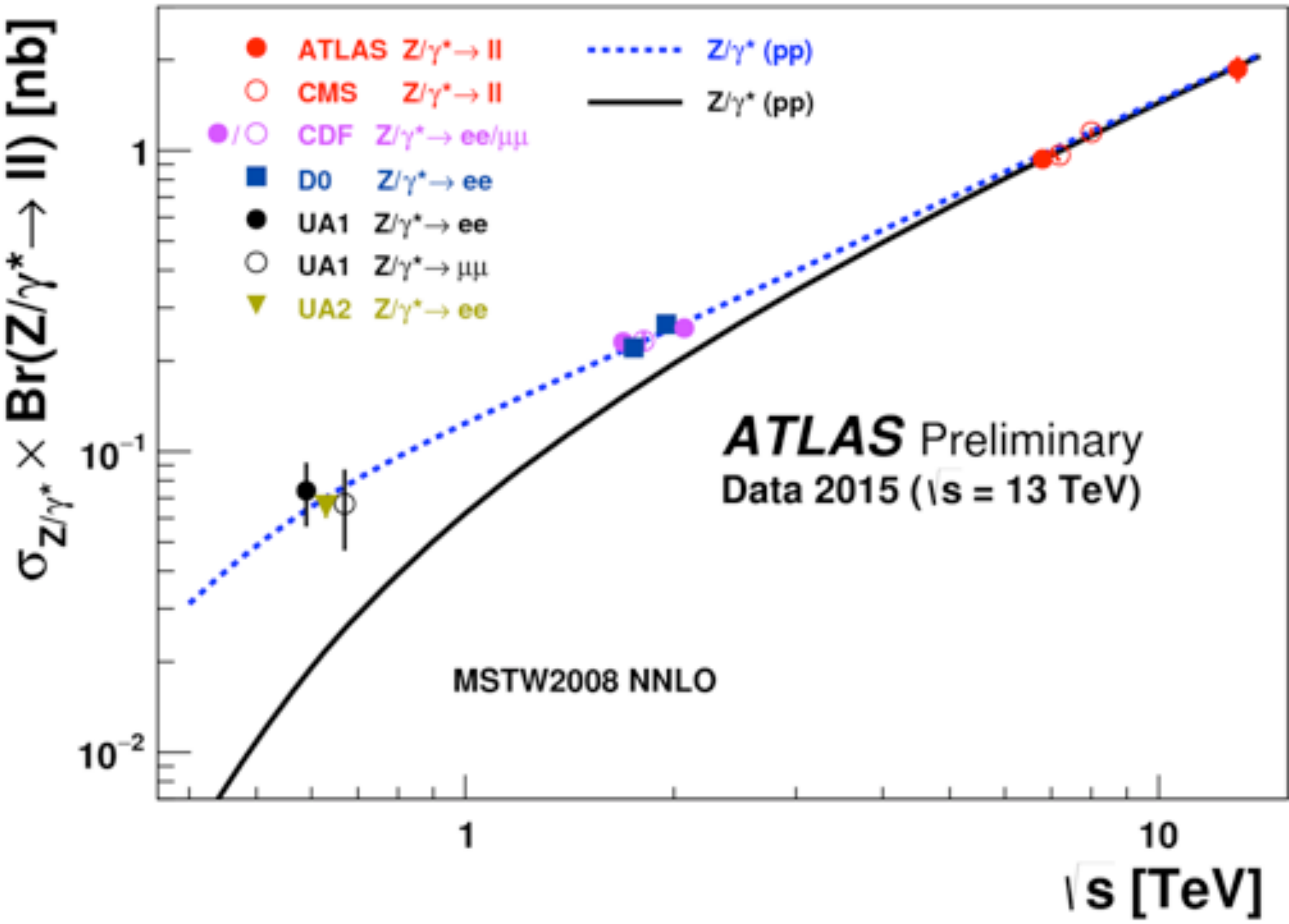
レプトン2つの4元運動量から不変質量

レプトンの(p_T^ℓ)とmissing E_T(E_T^{miss})から Transverse mass（m_T）

$$m_T = \sqrt{2 p_T^\ell E_T^{\mathrm{miss}} (1 - \cos \Delta\phi_{\ell\nu})}$$

W, Z 生成断面積

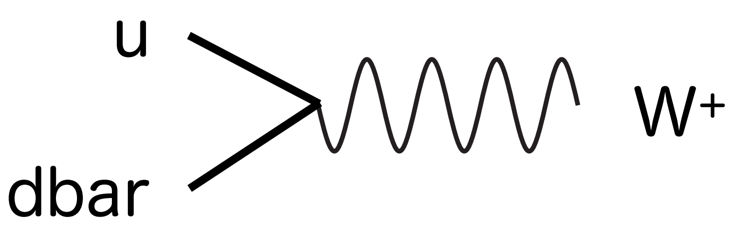


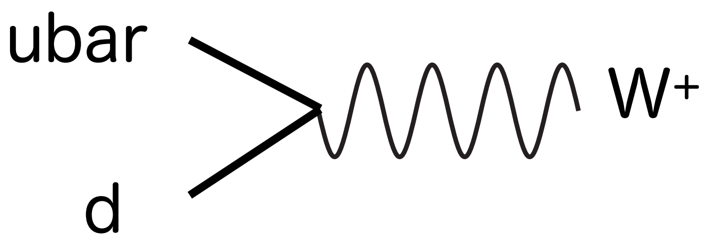


√sが小さいとppbar方が断面積大→valenceが寄与

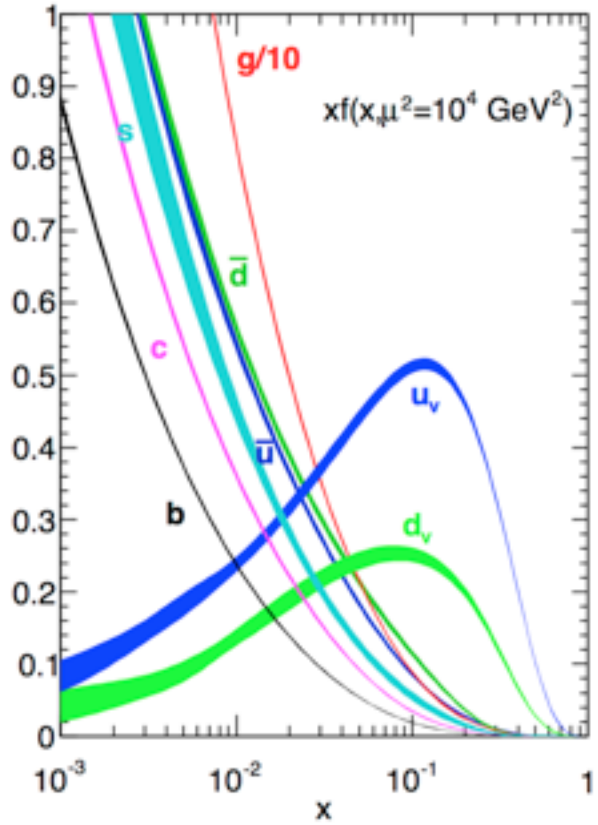
√sが大きいとsea quarkもW/Zの生成に関与できる

ppでW+とW-とで生成断面積が違う

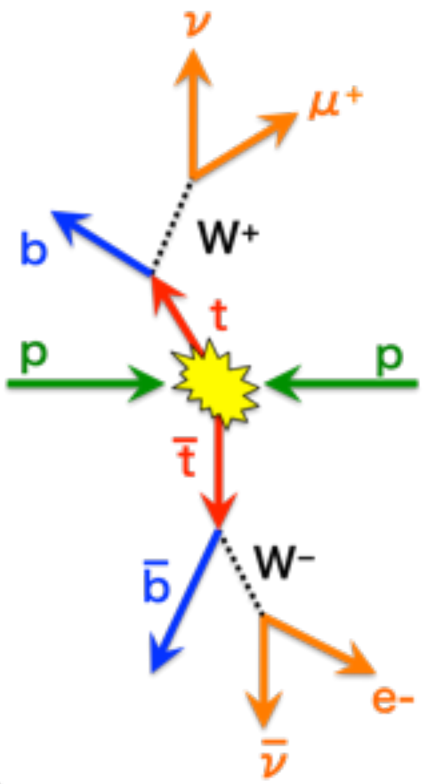




陽子内のuとdの分布で決まる

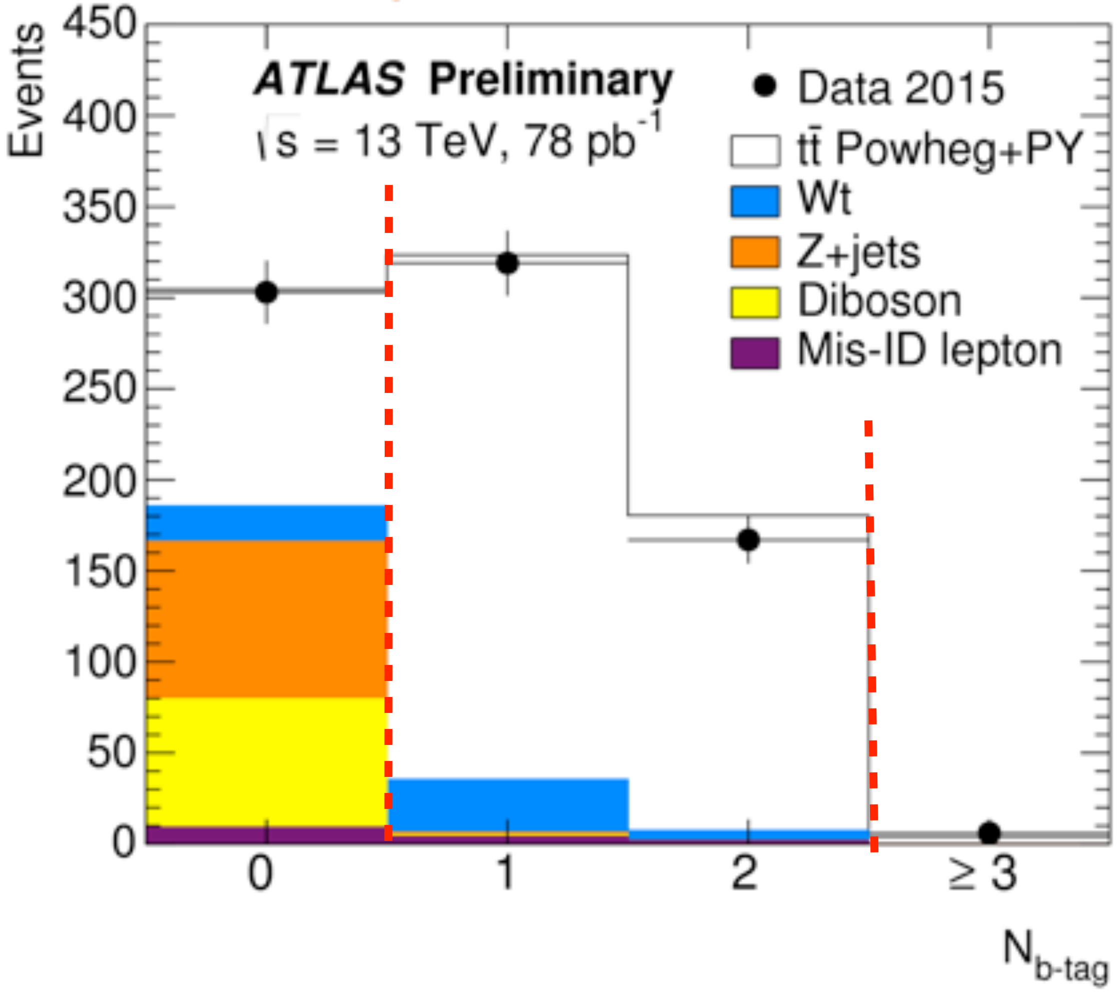


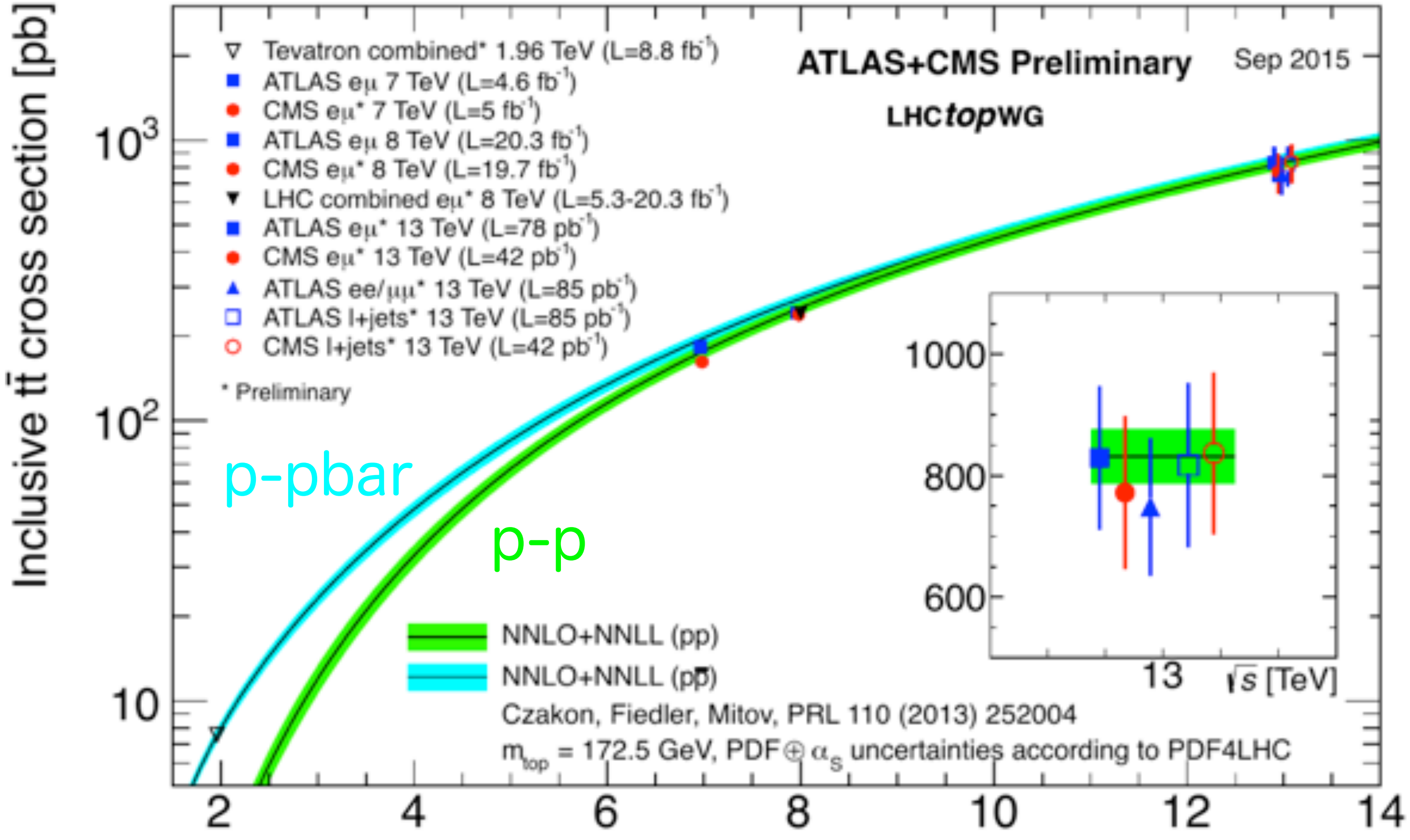
トップクォーク 生成断面積



LHCは、top quark factory

非常に高いエネルギーのp-p collision
2つのレプトンと1本か2本のb-jetを要求するだけで殆ど信号

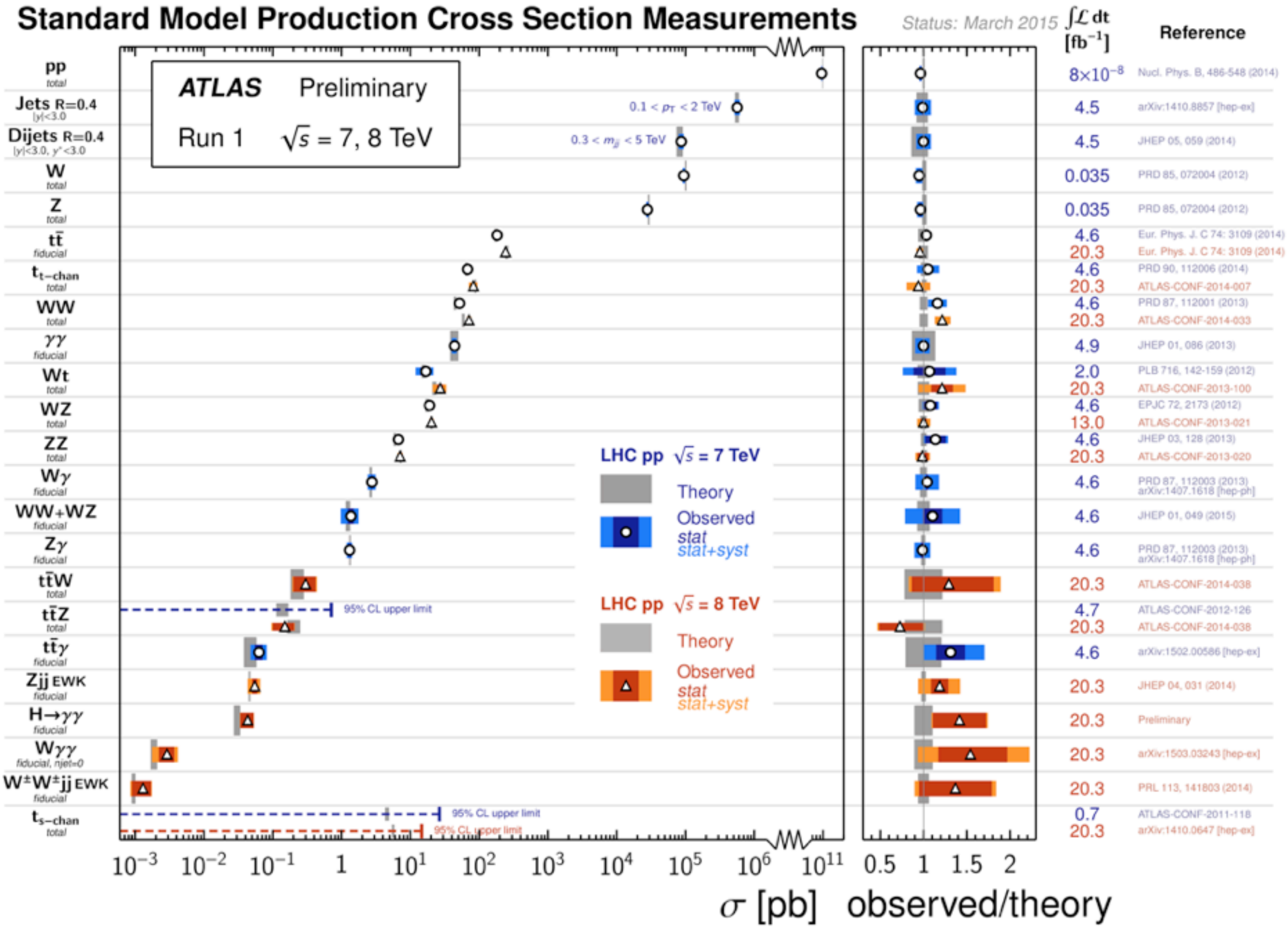




p-pとp-pbarでσ_{tt}が異なる理由は？ √s [TeV]

√s=2TeV ~ 13TeVまでQCDは非常に良い有効理論であることを立証

Run 1で測定した標準模型過程

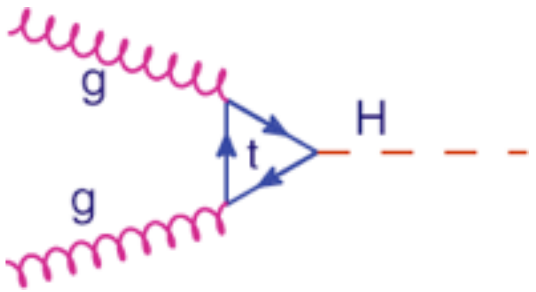


ヒッグス物理

発見からcoupling, mass, spinなどの測定へ
Run1の結果と展望

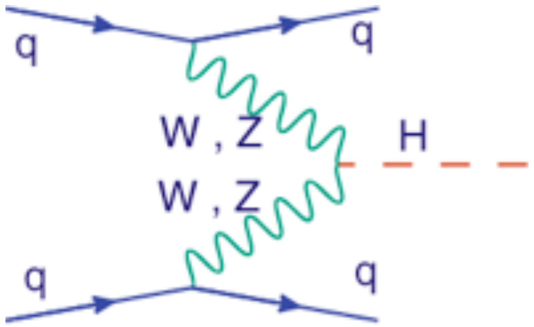
ヒッグス粒子生成過程

Gluon Fusion (ggF)



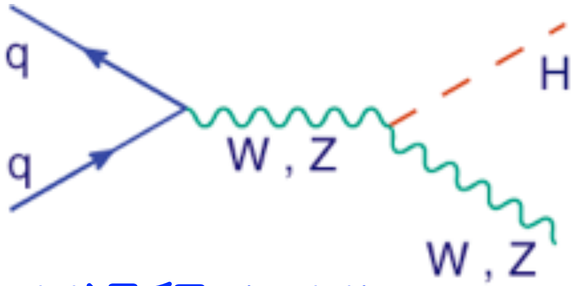
- 主にtop-quarkのループ
- top quarkとの湯川結合の間接的証拠
- gluonが多いのでσが大

Vector Boson Fusion (VBF)



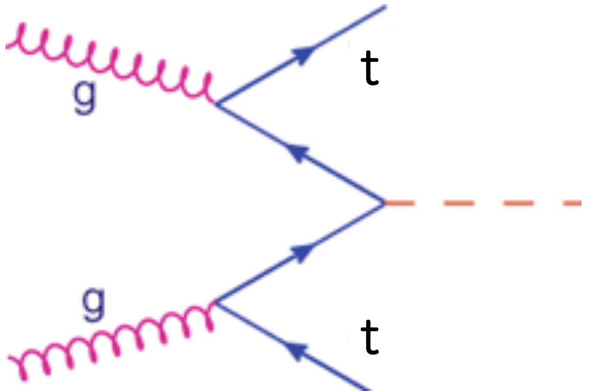
- ゲージ粒子との結合の直接測定
- 前後方向に出る2本のジェット

WH/ZH過程 (VH)

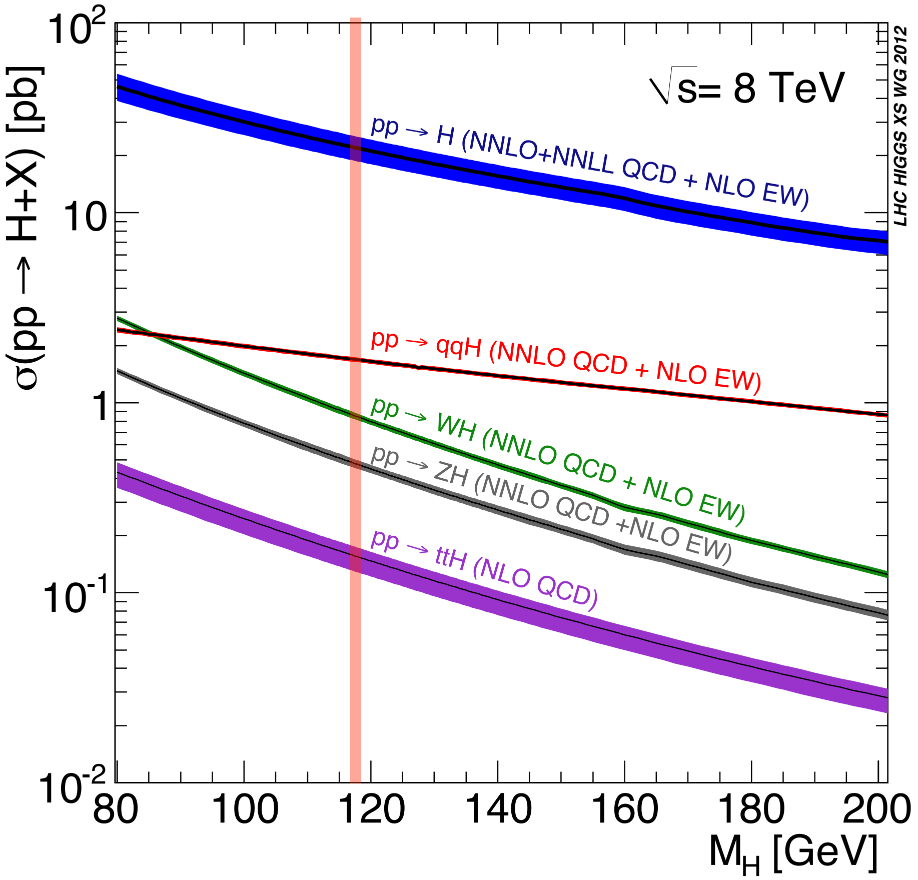


- ゲージ粒子との結合の直接測定
- W/Zからの高運動量レプトン

ttH過程 (ttH)

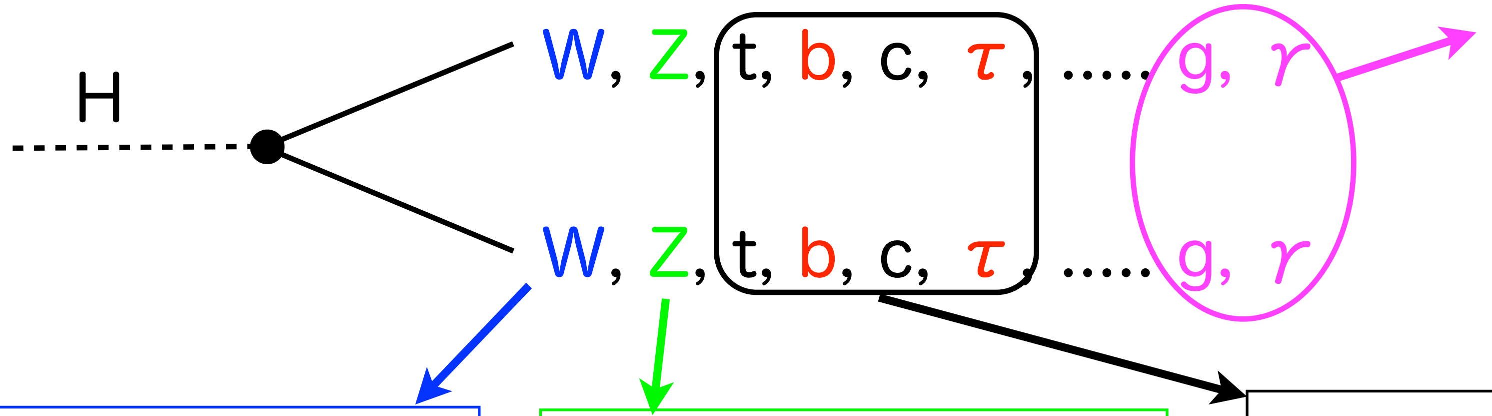


- top quarkとの湯川結合の直接的証拠

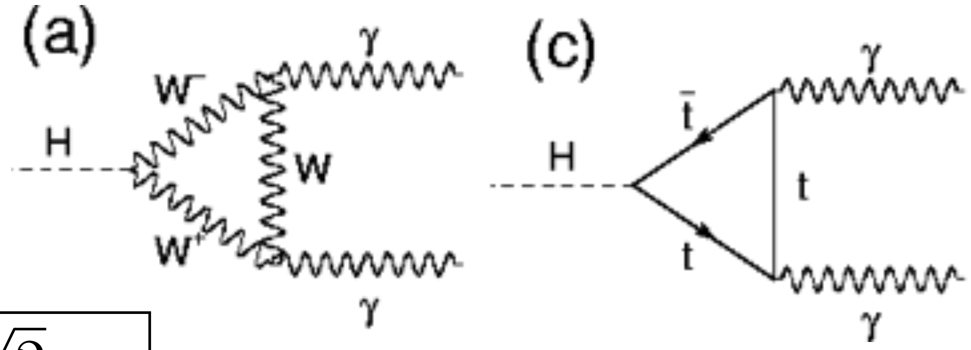


σ (pb)	8TeV	13TeV
ggF	19.3	43.9
VBF	1.6	3.7
WH	0.7	1.4
ZH	0.4	0.9
ttH	0.13	0.51

ヒッグス粒子崩壊過程



massless粒子への崩壊はloopを経由

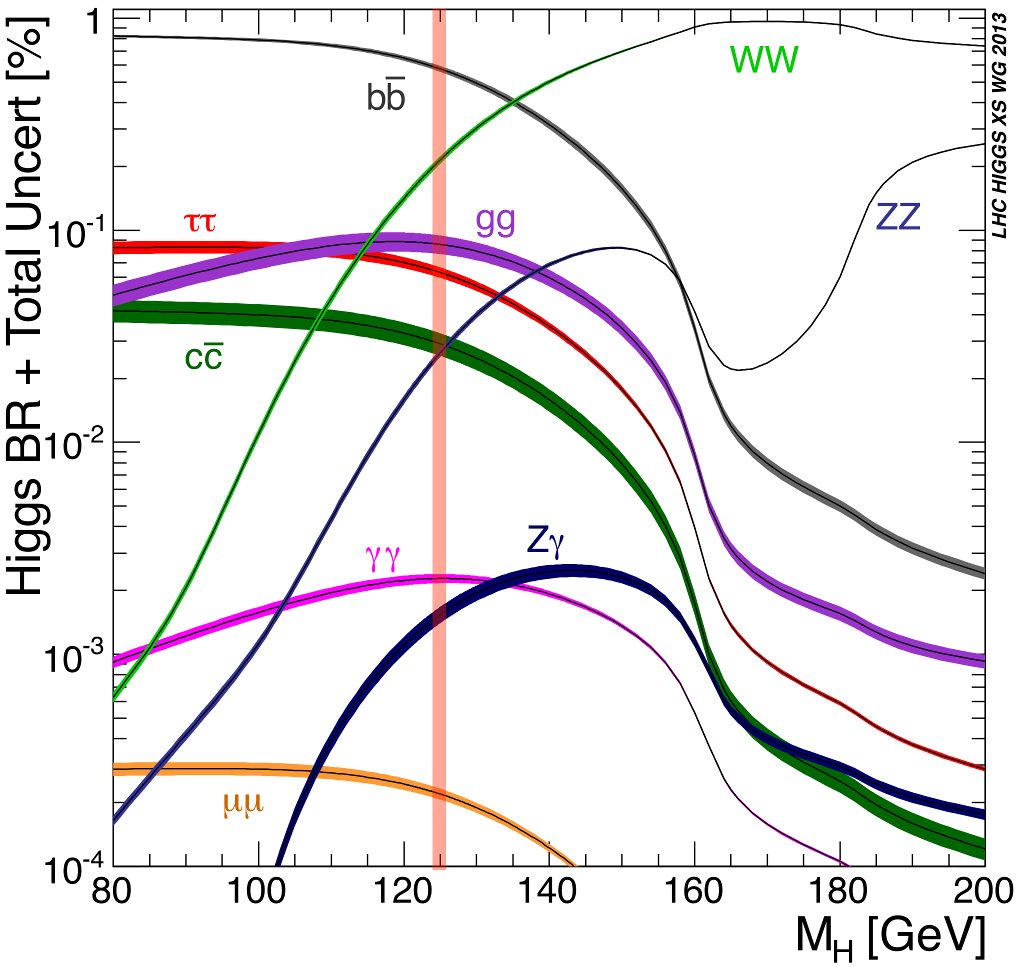


$$WWH = \frac{e}{\sin\theta} m_W = \frac{2m_W^2}{v}$$

$$ZZH = \frac{e}{\sin\theta\cos\theta} m_Z = \frac{2m_Z^2}{v}$$

$$f\bar{f}H = \frac{\sqrt{2}m_f}{v}$$

v=246GeV2



m_H=125.5GeV	BR(%)
H→γγ	0.23
H→ZZ	2.8
H→WW	22
H→ττ	6.2
H→bb	57

見つけやすさ

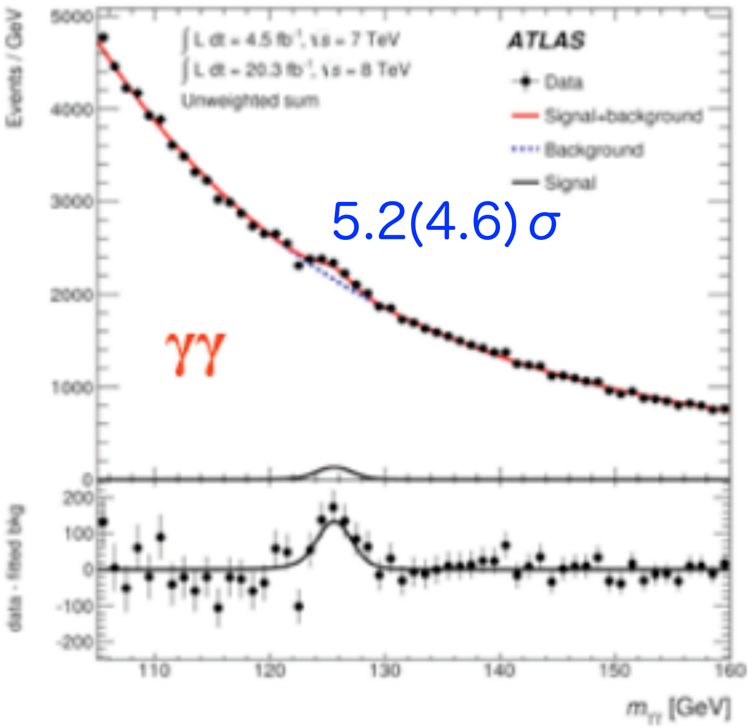
終状態にレプトンか光子があるものが発見チャンネル

H→γγ、ZZ(→4ℓ), WW(→ℓνℓν)

H→bb, H→ττ：膨大なQCD事象との分離が鍵

Run 1で観測したヒッグス粒子事象数

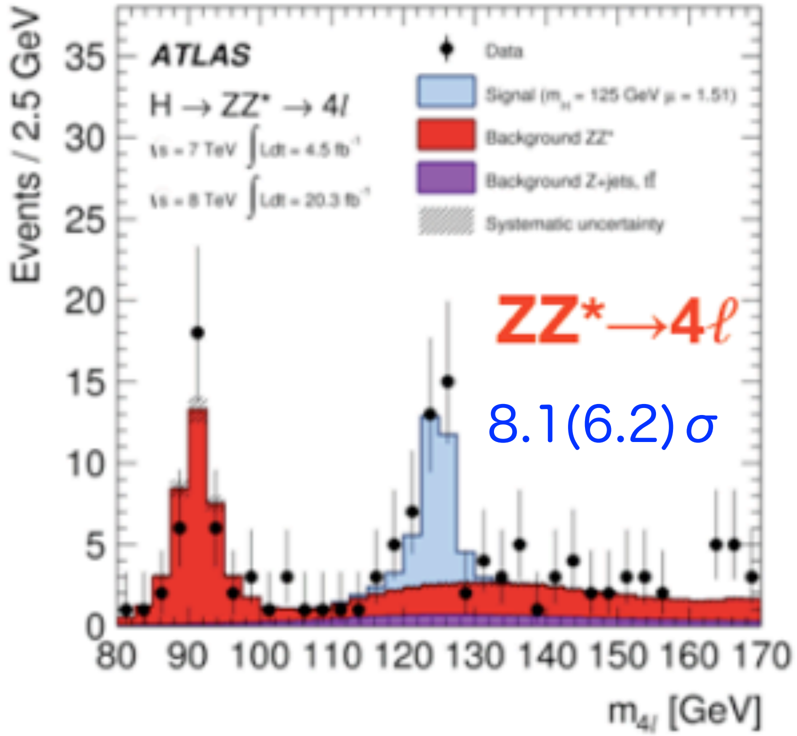
Phys. Rev. D90 (2014) 112015



γγ

5.2(4.6)σ

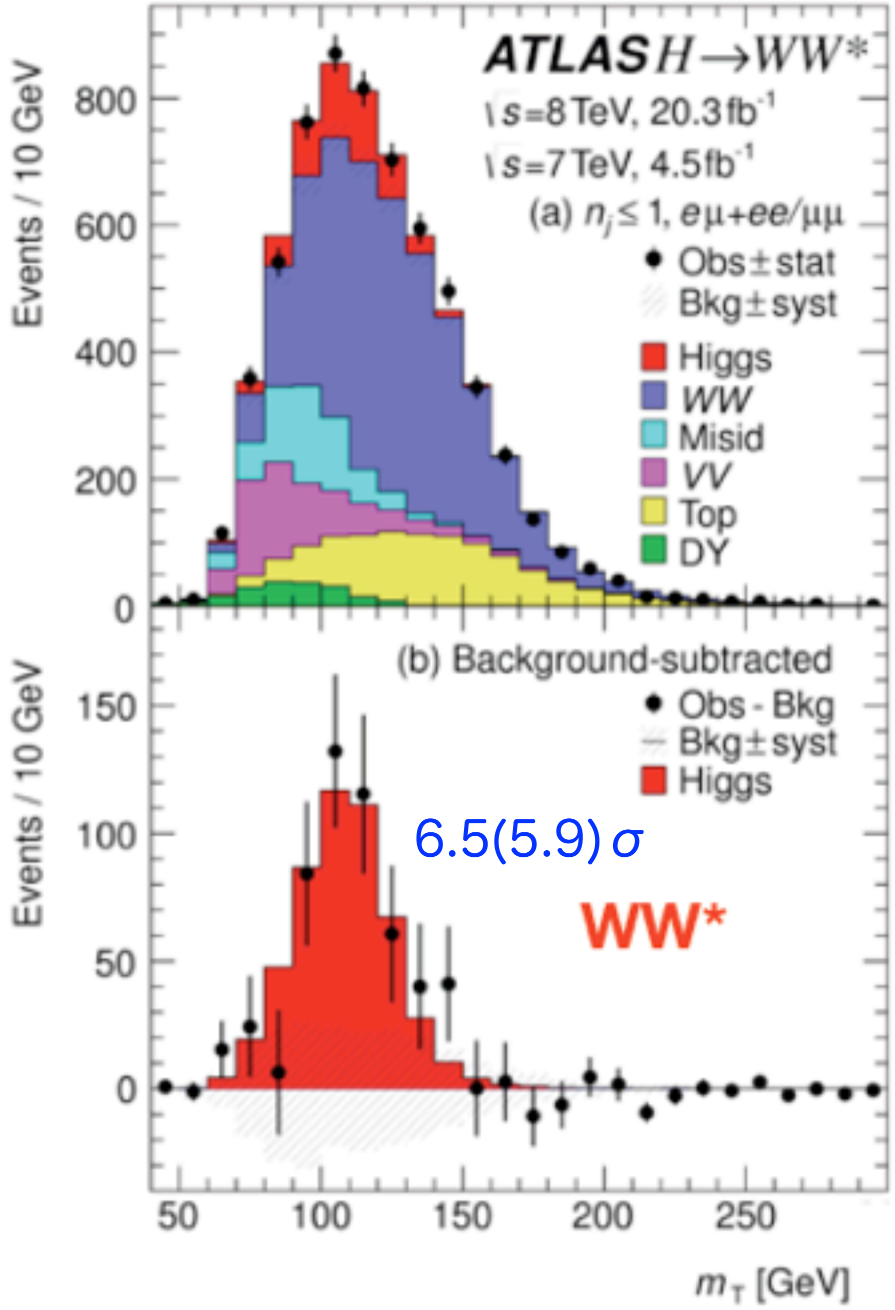
Phys. Rev. D91 (2015) 012006



ZZ*→4ℓ

8.1(6.2)σ

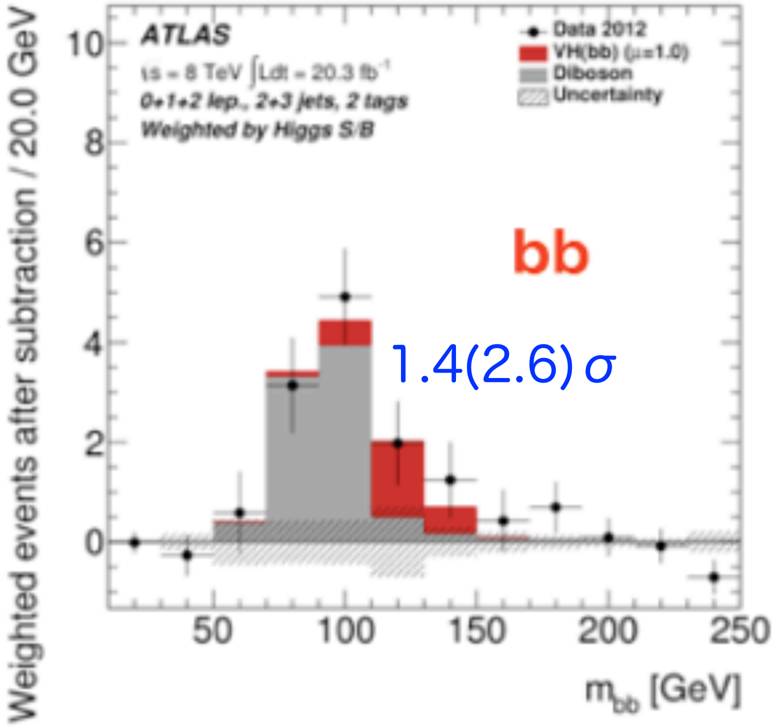
Phys. Rev. D92 (2015) 012006



6.5(5.9)σ

WW*

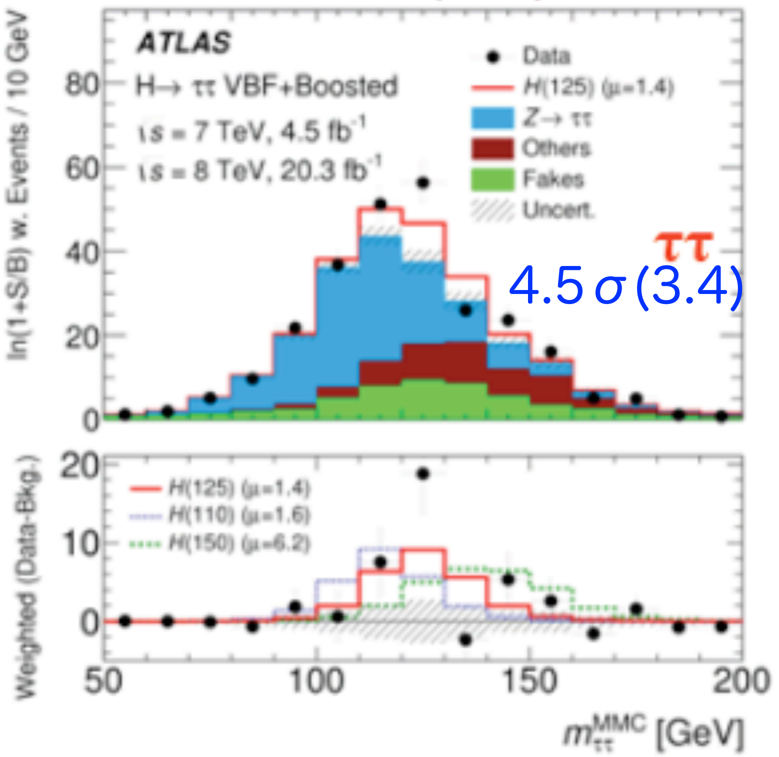
JHEP 01 (2015) 069



bb

1.4(2.6)σ

JHEP 04 (2015) 117



ττ

4.5σ(3.4)

まだ、測定感度が低いもの：
H→Zγ, H→μμ, ttH

signal strength

signal strength：理論予想の何倍観測されたか？

i→H 生成： $\mu_i = \dfrac{\sigma_i}{(\sigma_i)_{\mathrm{SM}}}$ ggF, VBF, VZ, ttH?

H→f 崩壊： $\mu_f = \dfrac{\mathrm{BR}_f}{(\mathrm{BR}_f)_{\mathrm{SM}}}$

i→H→fのsignal strength：

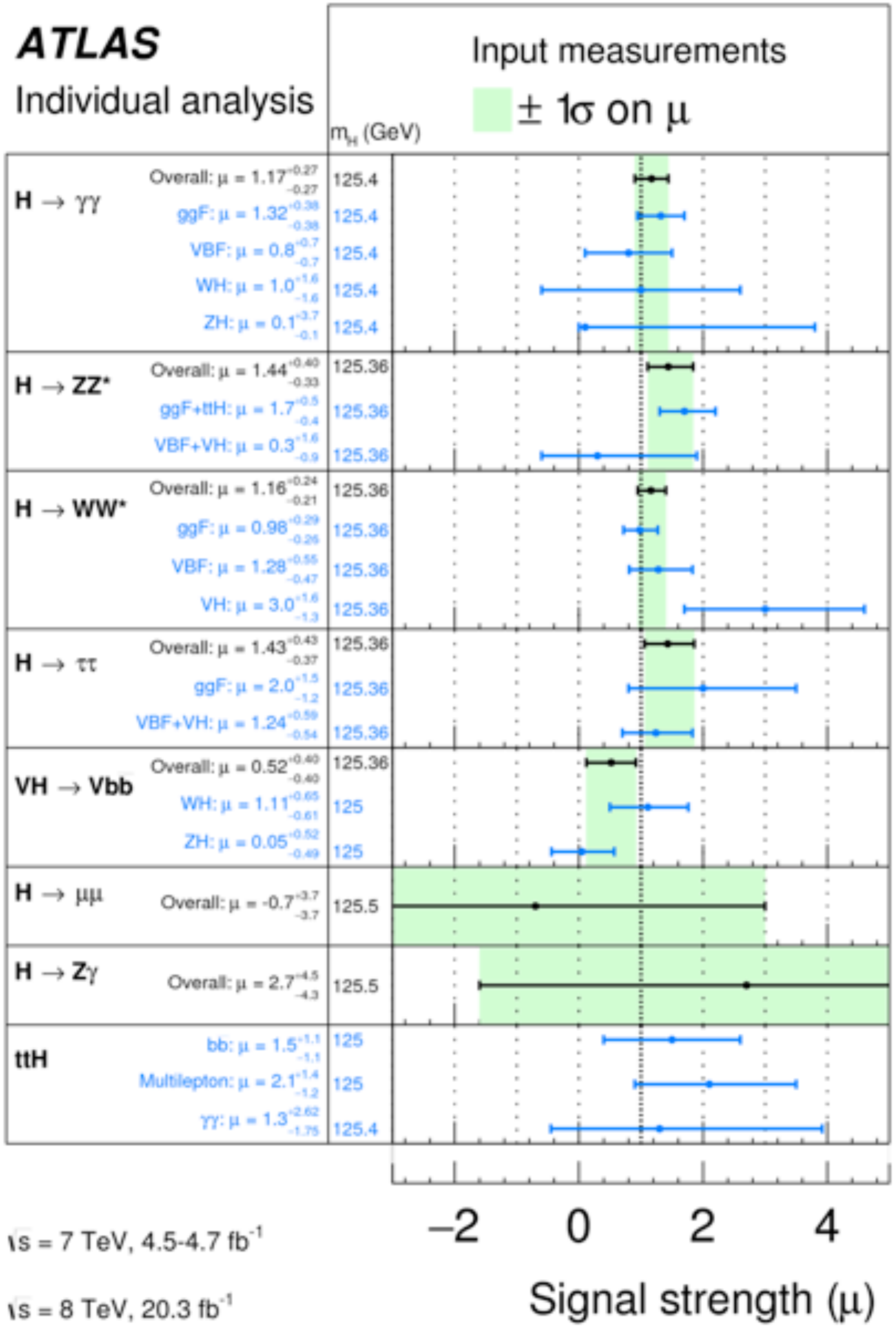
$$\mu = \mu_i \times \mu_f = \frac{\sigma_i \times \mathrm{BR}_f}{(\sigma_i \times \mathrm{BR}_f)_{\mathrm{SM}}}$$

信号数＝σ×BR×(acceptance)×(reco. effi.)：

$$n_S = \sum_i \sum_f \mu_i (\sigma_i)_{\mathrm{SM}} \times \mu_f (\mathrm{BR}_f)_{\mathrm{SM}} \times A_{if} \times \epsilon_{if} \times \mathcal{L}$$

測定　予想　見積　測定

arXiv:1507.04548



Higgs coupling

Hff coupling : $g_F^{\mathrm{SM}} = \sqrt{2}\frac{m_F}{v}$

HVV coupling : $g_V^{\mathrm{SM}} = 2\frac{m_V^2}{v}$

coupling strength(κ): SMの予想の何倍？

$$g_i = g_i^{\mathrm{SM}} \times \kappa_i$$

$$\Gamma_H = \Gamma_H^{\mathrm{SM}} \times \kappa_H^2$$

signal strengthはcoupling strengthで書ける

$$\sigma \cdot \mathrm{BR}(i \to H \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}$$

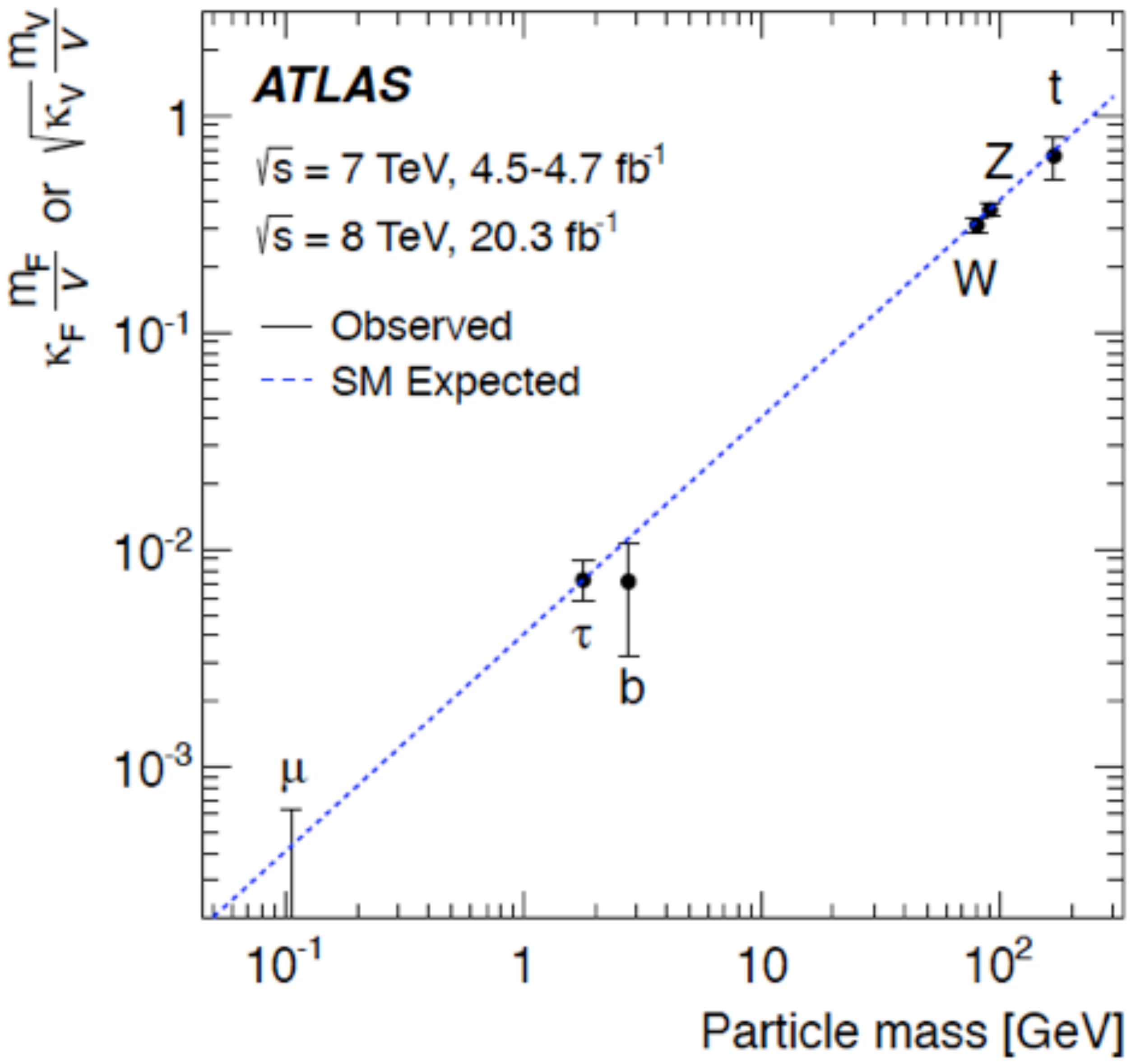
例：gg→H→γγ

$$\underline{\frac{\sigma \cdot \mathrm{BR}(gg \to H \to \gamma\gamma)}{\sigma_{\mathrm{SM}}(gg \to H) \cdot \mathrm{BR}_{\mathrm{SM}}(H \to \gamma\gamma)}} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

$$= \mu_i \times \mu_f$$

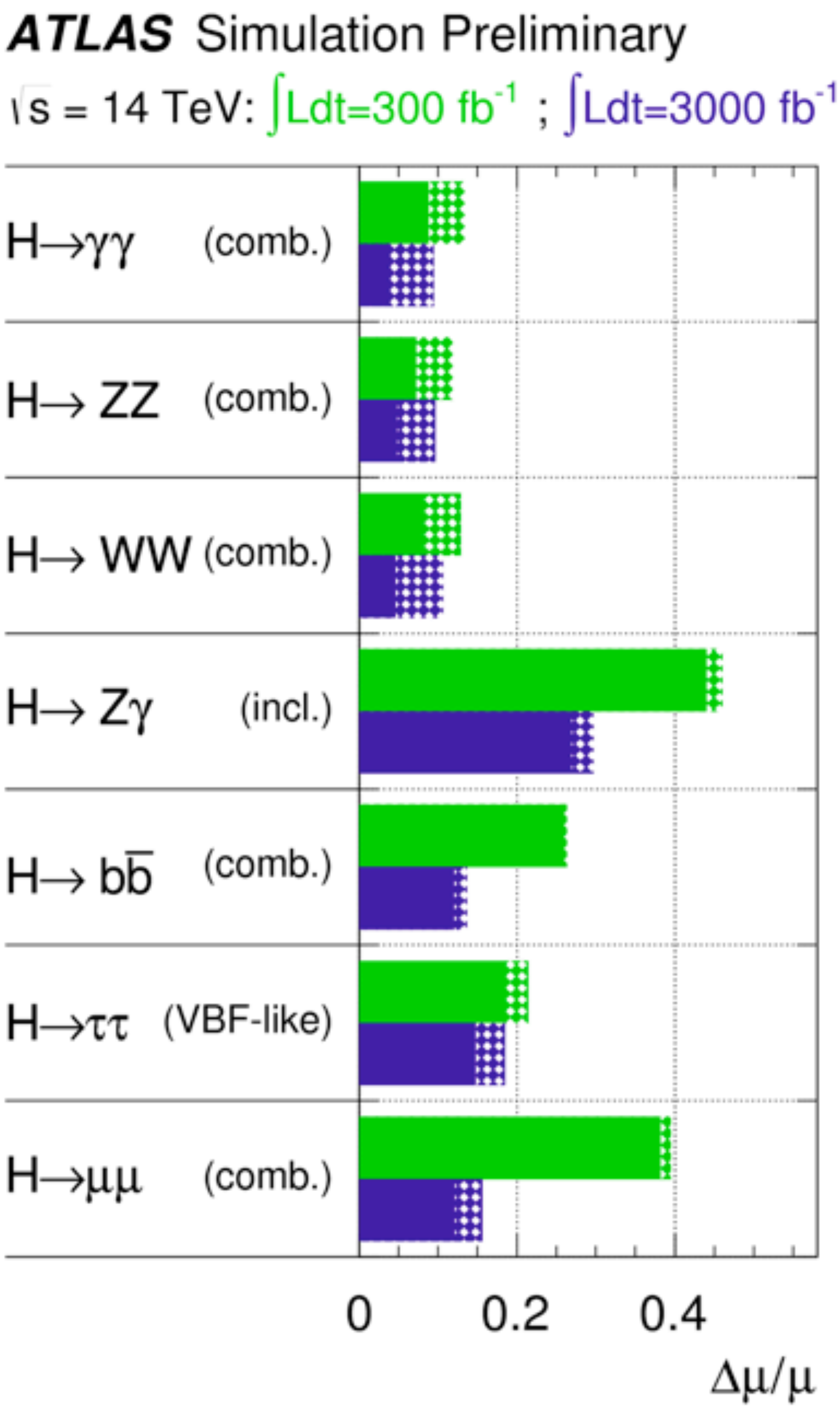
arXiv:1507.04548

κZ, κW, κt, κb, κτ, κμを測定

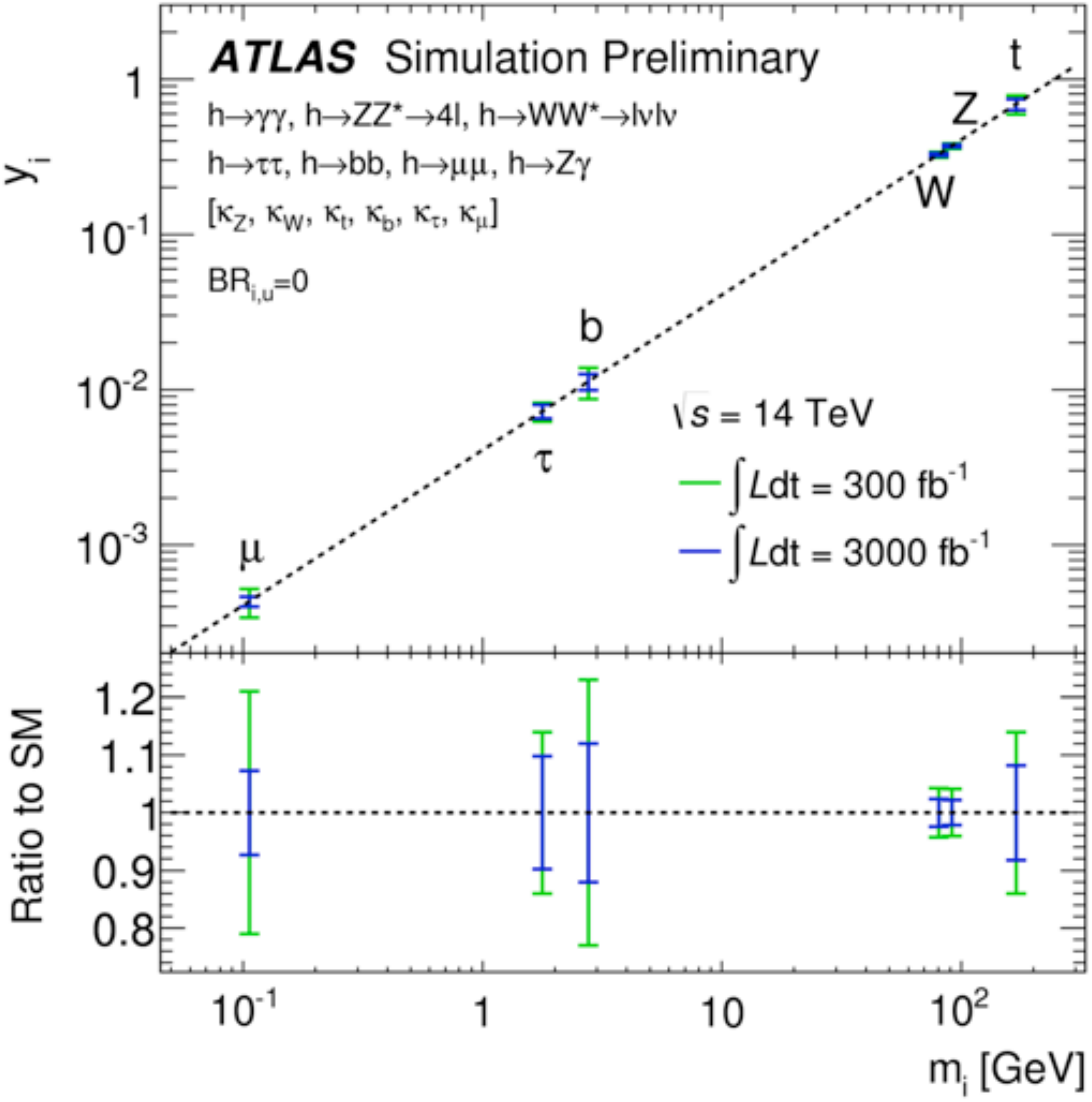


LoopやΓ_Hは、SMを仮定

Higgs coupling 展望



Run2 : L=100fb^{-1}

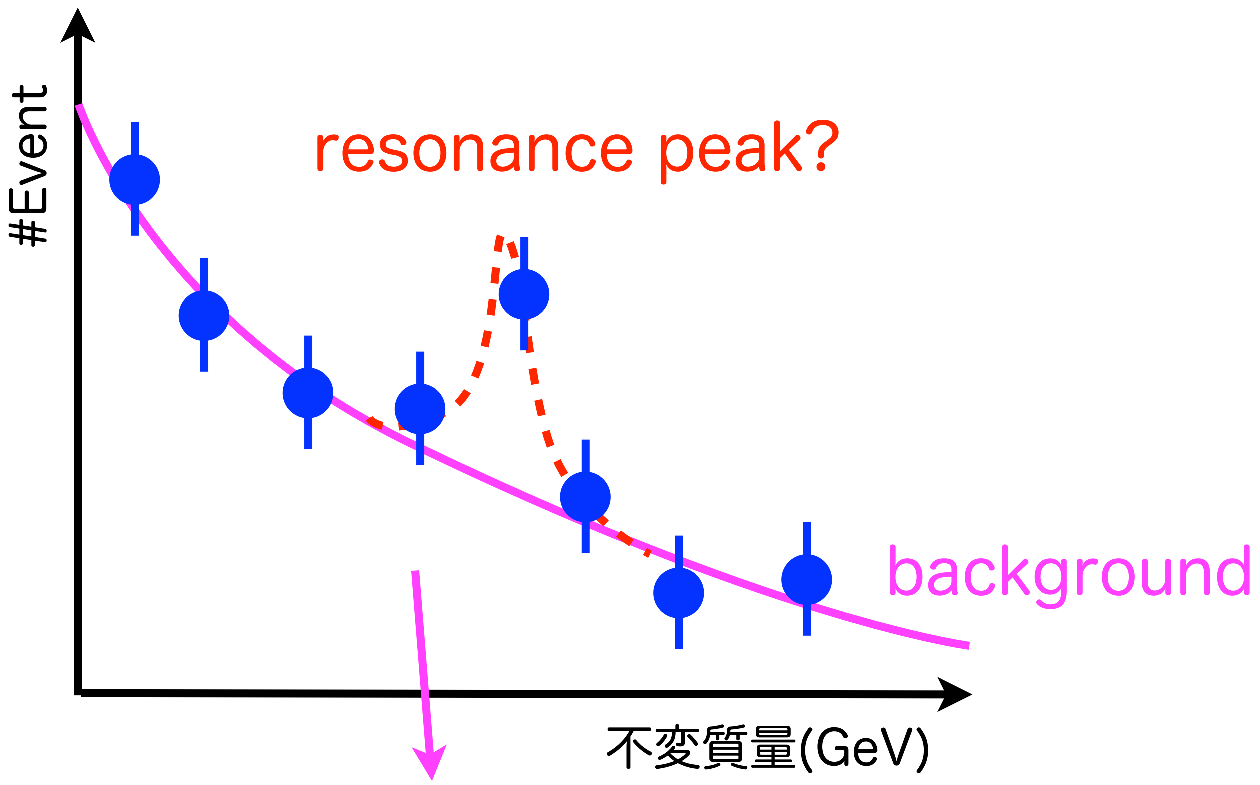


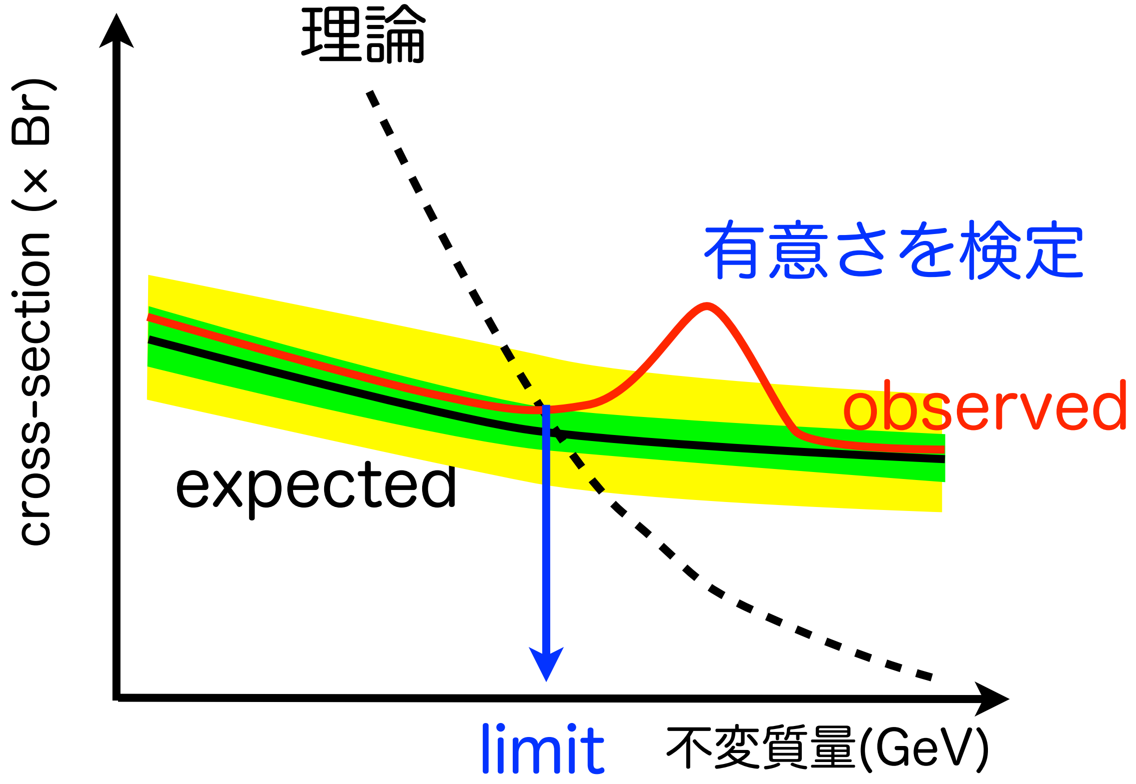
新物理探索

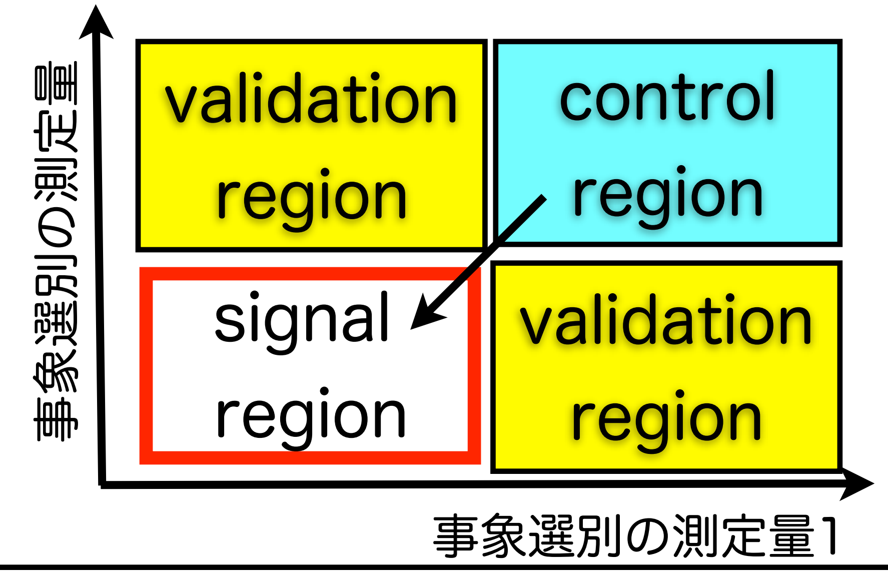
13TeV最新結果
SUSY探索の展望

直接探索のアプローチ

1. 信号と背景事象を区別する測定値を探す（不変質量など）
2. Simulation, data driven, 両方で背景事象の評価
3. 観測データと予想される背景事象との比較 (excess??)
4. 信号模型に対する制限を求める

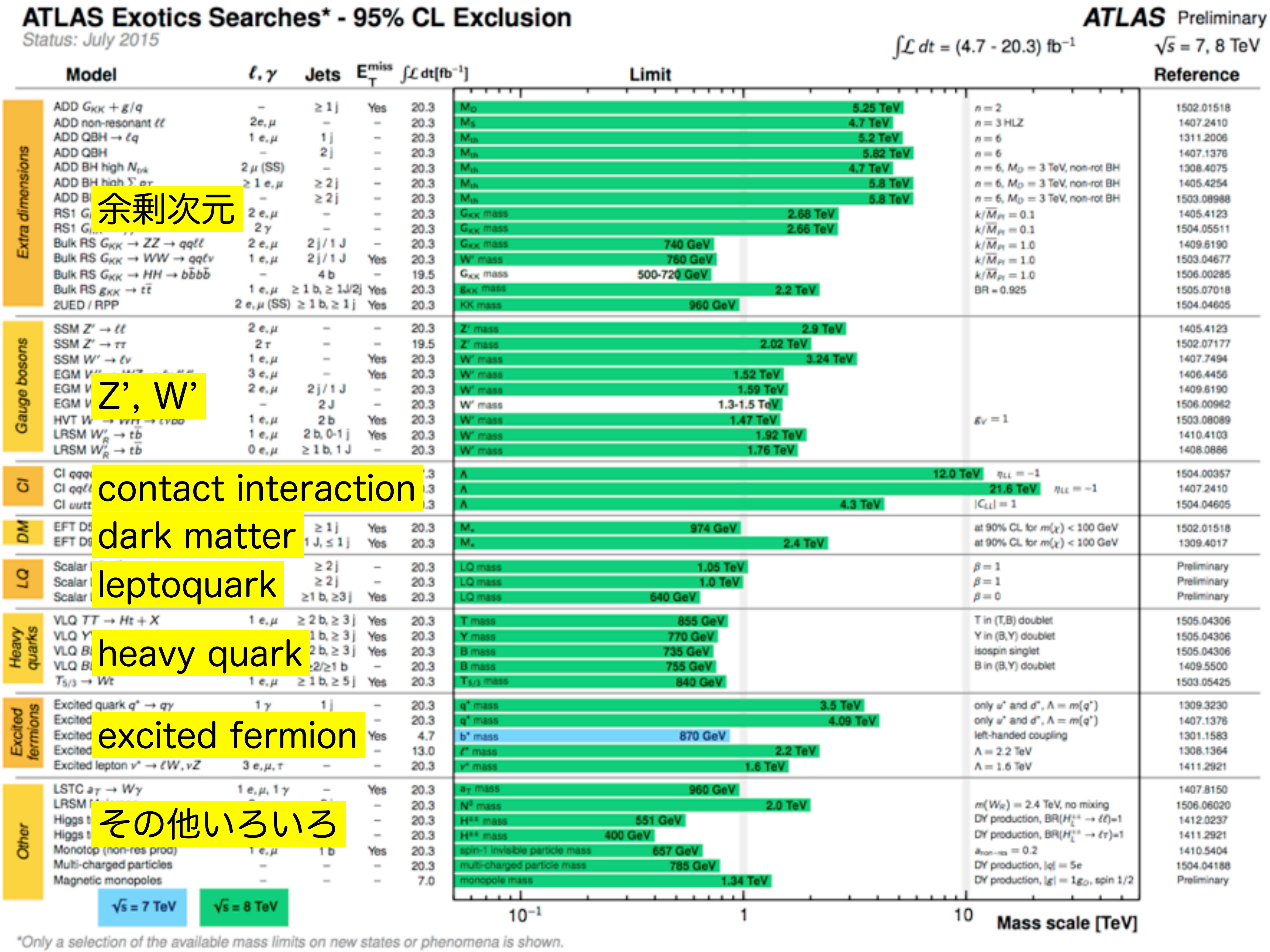






- control regionのデータ/MCをsignal regionへと外挿
- validation regionを使って外挿手法が適切か確認する

Run1：新粒子探索(SUSY以外)



ATLAS Exotics Searches* - 95% CL Exclusion
Status: July 2015

ATLAS Preliminary
$\int \mathcal{L}\,dt = (4.7 - 20.3)\ \mathrm{fb}^{-1}$
$\sqrt{s} = 7, 8$ TeV

	Model	ℓ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK}+g/q$	–	≥ 1 j	Yes	20.3	M_D 5.25 TeV	$n=2$	1502.01518
	ADD non-resonant $\ell\ell$	$2e,\mu$	–	–	20.3	M_S 4.7 TeV	$n=3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	1 e,μ	1 j	–	20.3	M_{th} 5.2 TeV	$n=6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n=6$	1407.1376
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 4.7 TeV	$n=6$, $M_D=3$ TeV, non-rot BH	1308.4075
	ADD BH high Σp_T	≥ 1 e,μ	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n=6$, $M_D=3$ TeV, non-rot BH	1405.4254
	ADD B[illegible]	–	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n=6$, $M_D=3$ TeV, non-rot BH	1503.08988
	RS1 G[illegible]	2 e,μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl}=0.1$	1405.4123
	RS1 G[illegible]	2 γ	–	–	20.3	G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl}=0.1$	1504.05511
	Bulk RS $G_{KK}\to ZZ\to qq\ell\ell$	2 e,μ	2 j / 1 J	–	20.3	G_{KK} mass 740 GeV	$k/\overline{M}_{Pl}=1.0$	1409.6190
	Bulk RS $G_{KK}\to WW\to qq\ell\nu$	1 e,μ	2 j / 1 J	Yes	20.3	W' mass 760 GeV	$k/\overline{M}_{Pl}=1.0$	1503.04677
	Bulk RS $G_{KK}\to HH\to b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 500-720 GeV	$k/\overline{M}_{Pl}=1.0$	1506.00285
	Bulk RS $g_{KK}\to t\bar{t}$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	2 e,μ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	KK mass 960 GeV		1504.04605
Gauge bosons	SSM $Z'\to\ell\ell$	2 e,μ	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z'\to\tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	SSM $W'\to\ell\nu$	1 e,μ	–	Yes	20.3	W' mass 3.24 TeV		1407.7494
	EGM W[illegible]	3 e,μ	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM W[illegible]	2 e,μ	2 j / 1 J	–	20.3	W' mass 1.59 TeV		1409.6190
	EGM W[illegible]	–	2 J	–	20.3	W' mass 1.3-1.5 TeV		1506.00962
	HVT $W'\to WH\to\ell\nu bb$	1 e,μ	2 b	Yes	20.3	W' mass 1.47 TeV	$g_V=1$	1503.08089
	LRSM $W'_R\to t\bar{b}$	1 e,μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R\to t\bar{b}$	0 e,μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI qqq[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Λ 12.0 TeV	$\eta_{LL}=-1$	1504.00357
	CI qqℓ[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Λ 21.6 TeV	$\eta_{LL}=-1$	1407.2410
	CI uutt	[illegible]	[illegible]	[illegible]	[illegible]	Λ 4.3 TeV	$\lvert C_{LL}\rvert=1$	1504.04605
DM	EFT D5[illegible]	[illegible]	≥ 1 j	Yes	20.3	M_* 974 GeV	at 90% CL for $m(\chi) < 100$ GeV	1502.01518
	EFT D9[illegible]	[illegible]	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar [illegible]	[illegible]	≥ 2 j	–	20.3	LQ mass 1.05 TeV	$\beta=1$	Preliminary
	Scalar [illegible]	[illegible]	≥ 2 j	–	20.3	LQ mass 1.0 TeV	$\beta=1$	Preliminary
	Scalar [illegible]	[illegible]	≥ 1 b, ≥ 3 j	Yes	20.3	LQ mass 640 GeV	$\beta=0$	Preliminary
Heavy quarks	VLQ $TT\to Ht+X$	1 e,μ	≥ 2 b, ≥ 3 j	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ Y[illegible]	[illegible]	[illegible]1 b, ≥ 3 j	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ B[illegible]	[illegible]	[illegible]2 b, ≥ 3 j	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ B[illegible]	[illegible]	[illegible]2/≥ 1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	$T_{5/3}\to Wt$	1 e,μ	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		1503.05425
Excited fermions	Excited quark $q^*\to q\gamma$	1 γ	1 j	–	20.3	q* mass 3.5 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1309.3230
	Excited [illegible]	[illegible]	[illegible]	–	20.3	q* mass 4.09 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1407.1376
	Excited [illegible]	[illegible]	[illegible]	Yes	4.7	b* mass 870 GeV	left-handed coupling	1301.1583
	Excited [illegible]	[illegible]	[illegible]	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda=2.2$ TeV	1308.1364
	Excited lepton $\nu^*\to\ell W,\nu Z$	3 e,μ,τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda=1.6$ TeV	1411.2921
Other	LSTC $a_T\to W\gamma$	1 e,μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM M[illegible]	[illegible]	[illegible]	–	20.3	N^0 mass 2.0 TeV	$m(W_R)=2.4$ TeV, no mixing	1506.06020
	Higgs t[illegible]	[illegible]	[illegible]	–	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm}\to\ell\ell$)=1	1412.0237
	Higgs t[illegible]	[illegible]	[illegible]	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm}\to\ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e,μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res}=0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert=5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert=1g_D$, spin 1/2	Preliminary

*Only a selection of the available mass limits on new states or phenomena is shown.

余剰次元

Z’, W’

contact interaction

dark matter

leptoquark

heavy quark

excited fermion

その他いろいろ

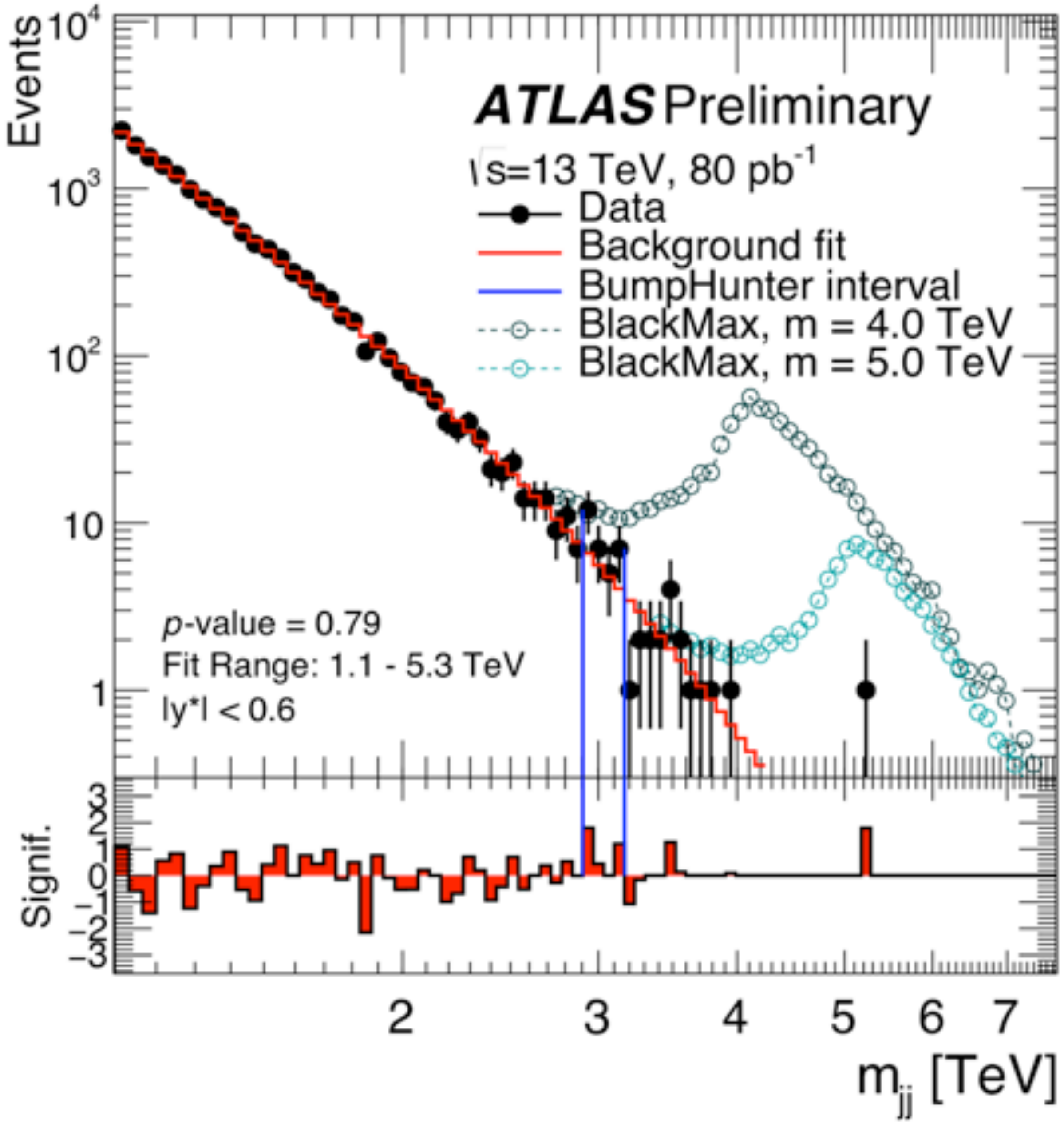
Run 2の探索：Dijet探索

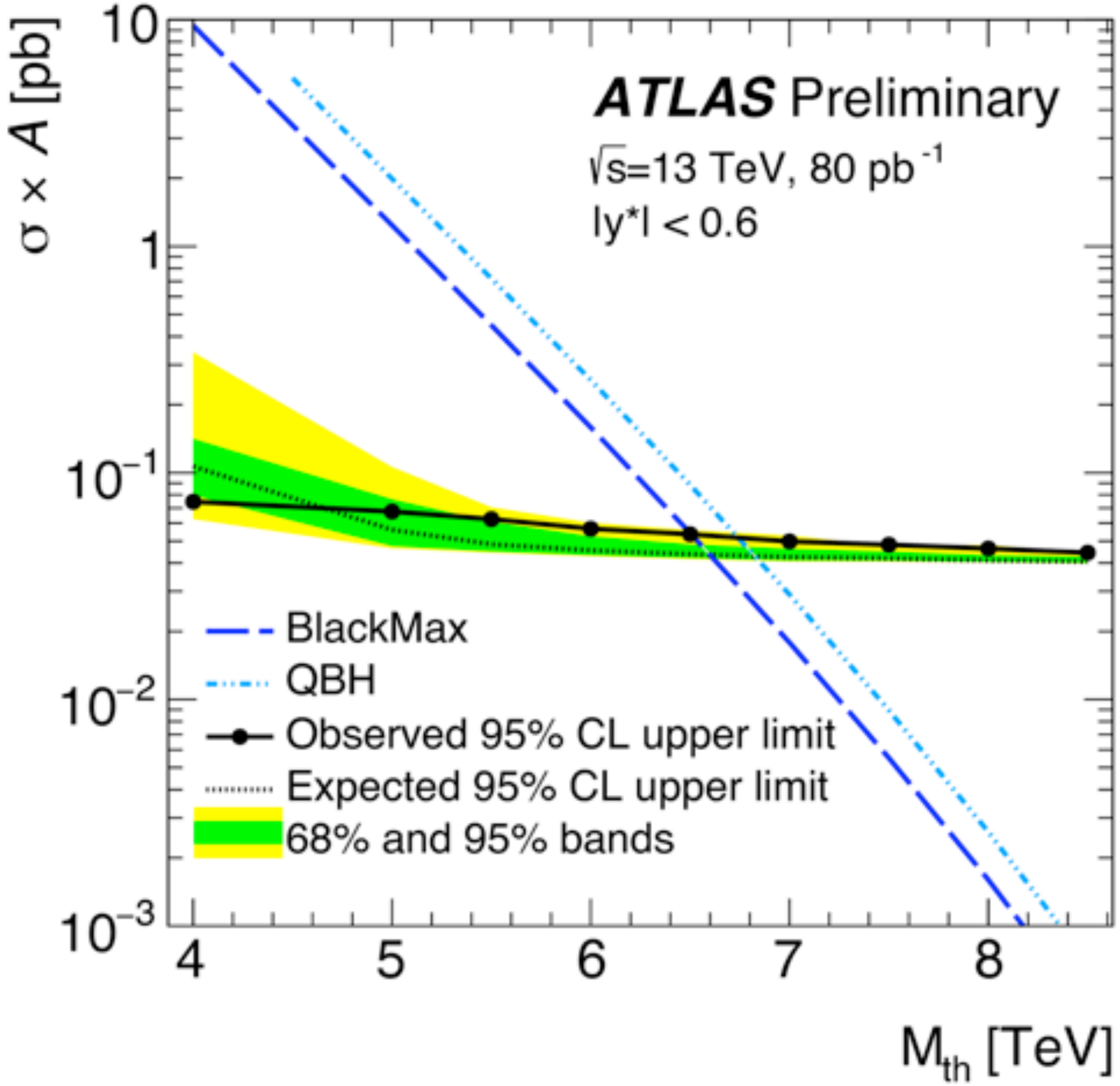
ATLAS-CONF-2015-042

pT>410GeV, 50GeVのdijet invariant mass

smooth関数で背景事象を評価

$$f(x) = p_1(1-x)^{p_2}x^{p_3} \qquad x = m_{jj}/\sqrt{s}$$

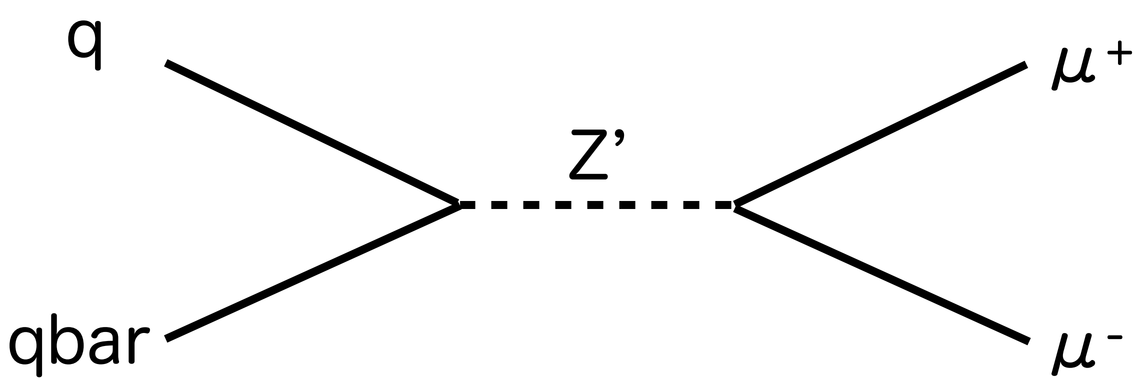


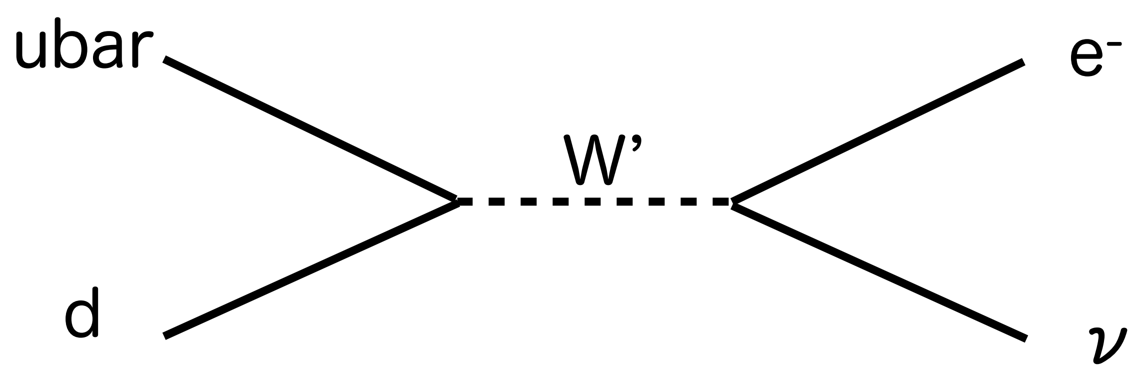


あるモデルの(ADD, n=6) の量子重力を~6.5TeVまで棄却

→ Run 1よりも1TeV位 improve

Run 2の探索：Z’, W’ search

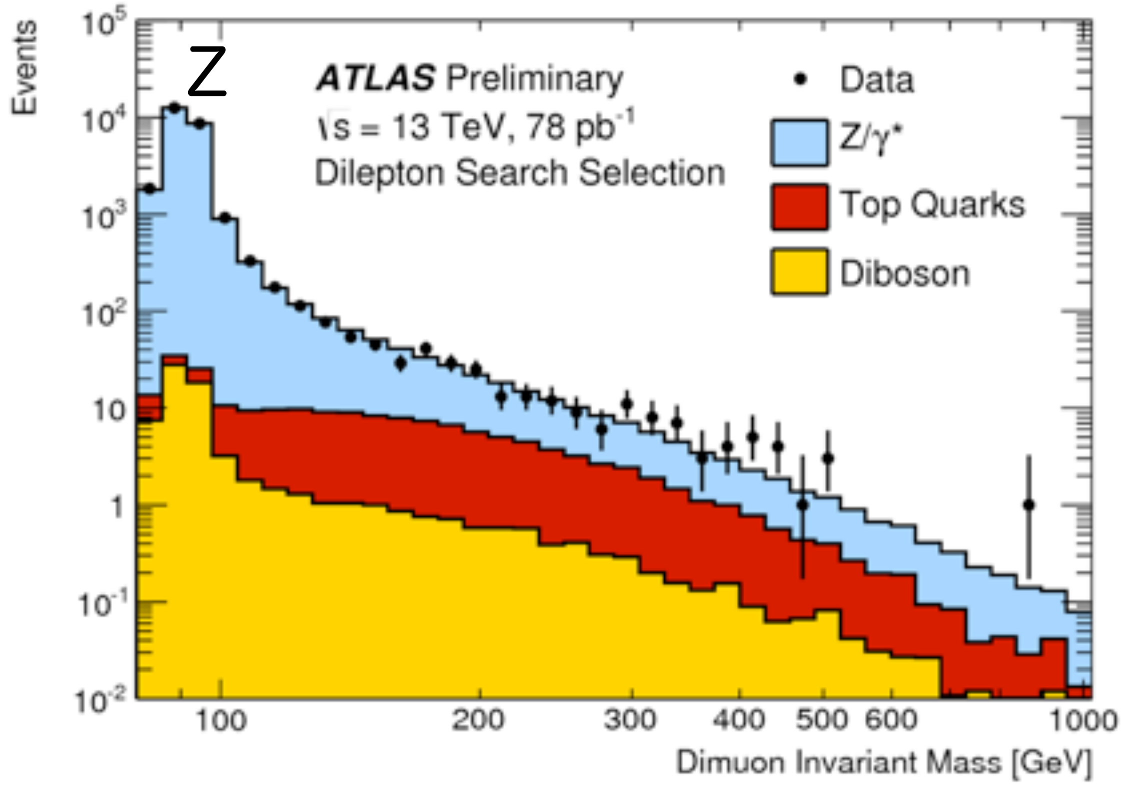


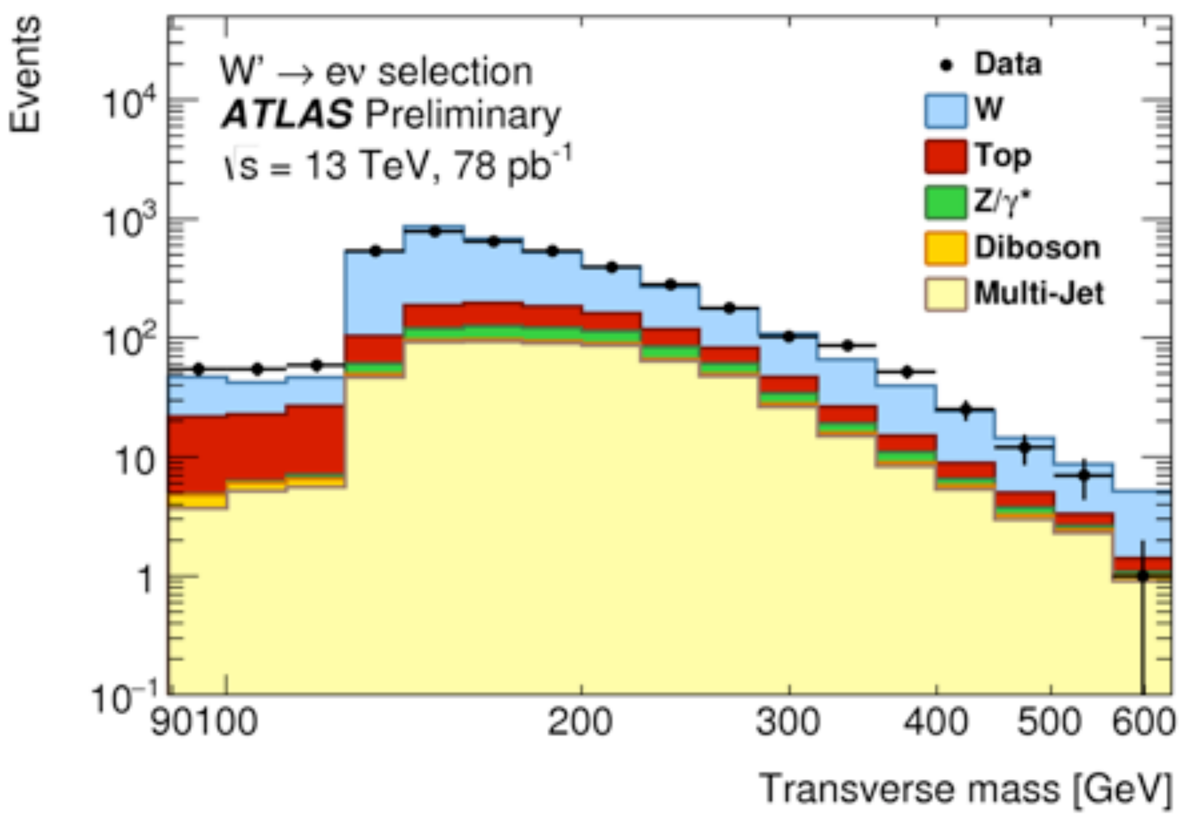


pT>30GeV

pT>65GeV

E_T^{miss}>65GeV



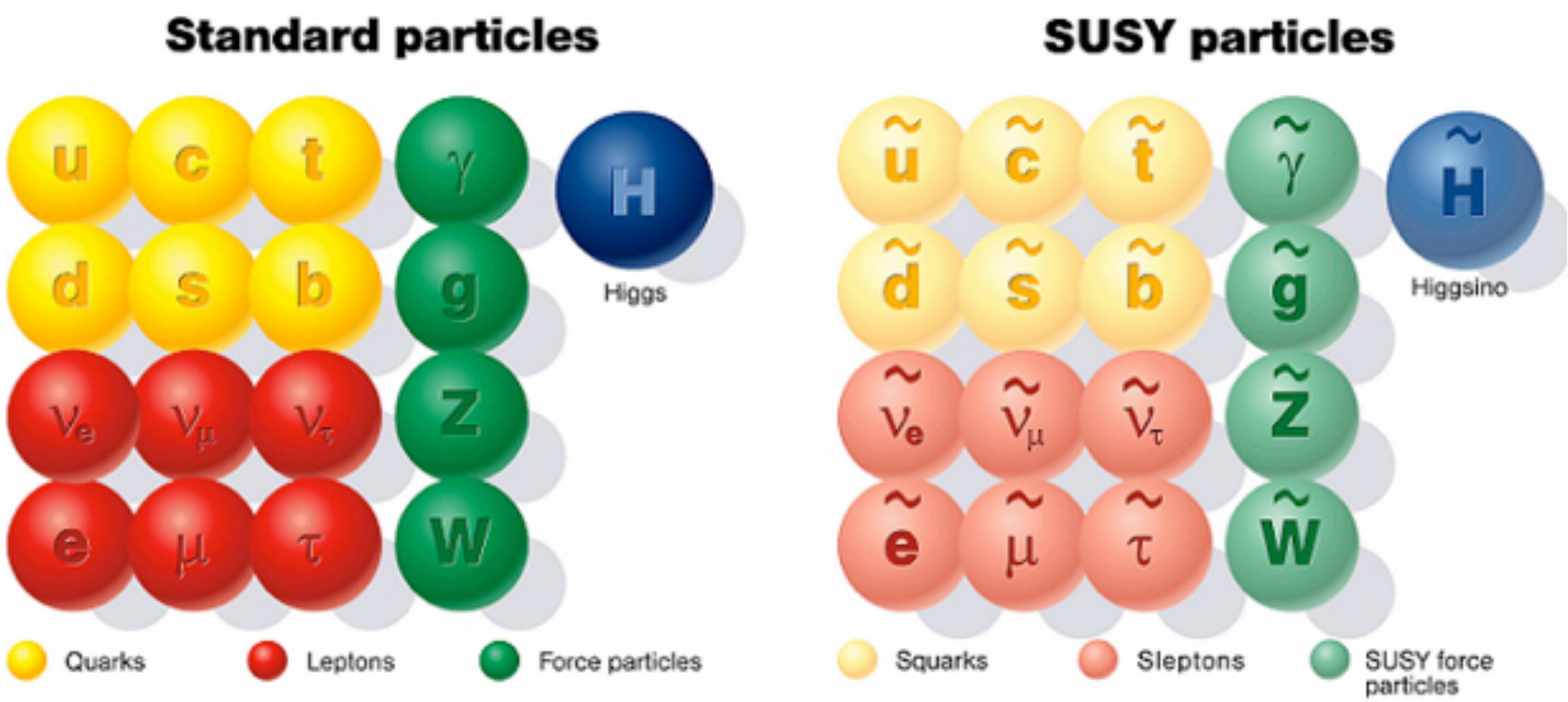


$$m_T = \sqrt{2 p_T^{\ell} E_T^{\text{miss}} (1 - \cos \Delta\phi_{\ell\nu})}$$

13TeV, 2~3fb-1のデータでRun1の感度を超える見込み

95% C.L. limit 約3TeV

SUSY



Neutralino($\tilde{\chi}^0$) :
bino, 中性wino, 中性higsino

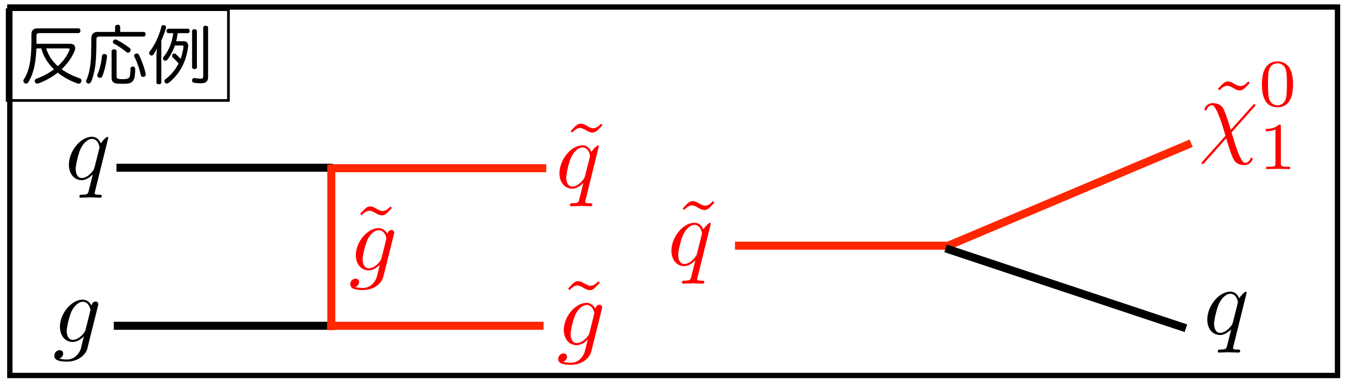
Chargino($\tilde{\chi}^\pm$) :
荷電wino, 荷電higsino

超対称性粒子の性質：

- フェルミオンとボゾンの入れ替え
  - SM粒子に対してspinが1/2違うSUSY
- spin以外の量子数 (電荷など) は同じ
  - SM粒子と同じ相互作用をする
- 超対称性は破れている
  - SUSYはSM粒子よりも重い
- 多くのモデルにRパリティ(≡$(-1)^{2S+3B-L}$)
  SM粒子は正、SUSYは負
  - SUSYはSM粒子から対生成で生成
  - SUSYはSUSYとSM粒子に崩壊
  - 最も軽いSUSYは安定→暗黒物質

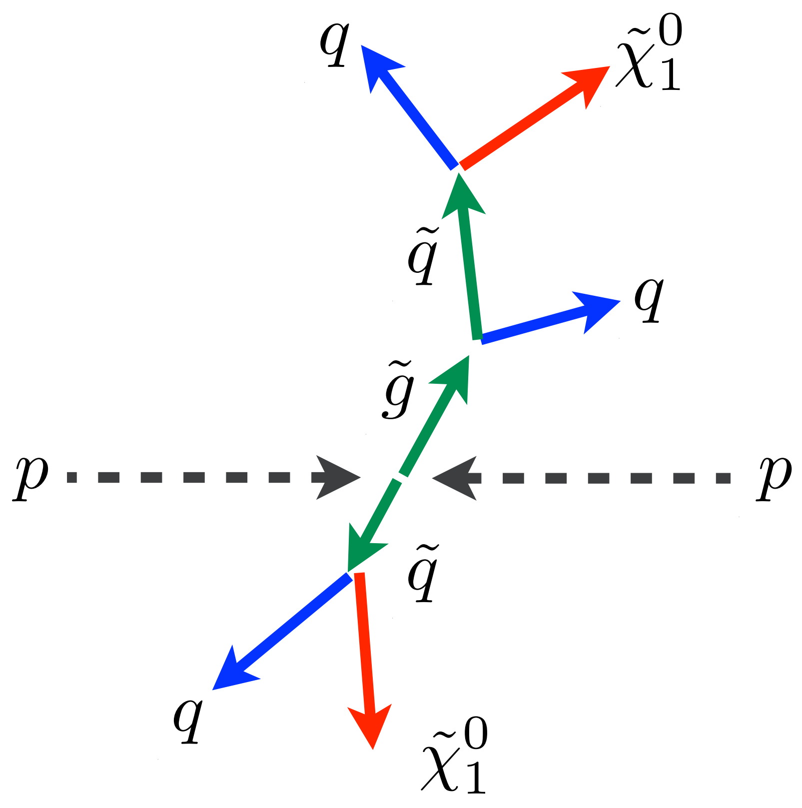
超対称性粒子のご利益：

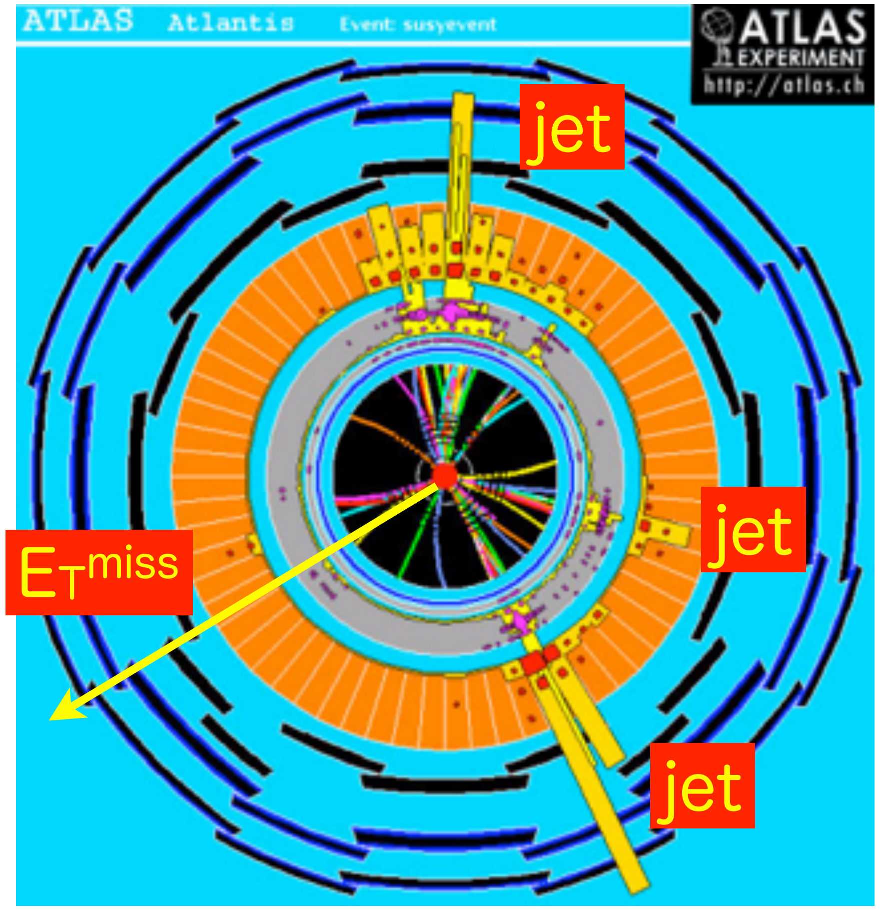
- 力の大統一の可能性
- 暗黒物質
- 階層性問題の解決



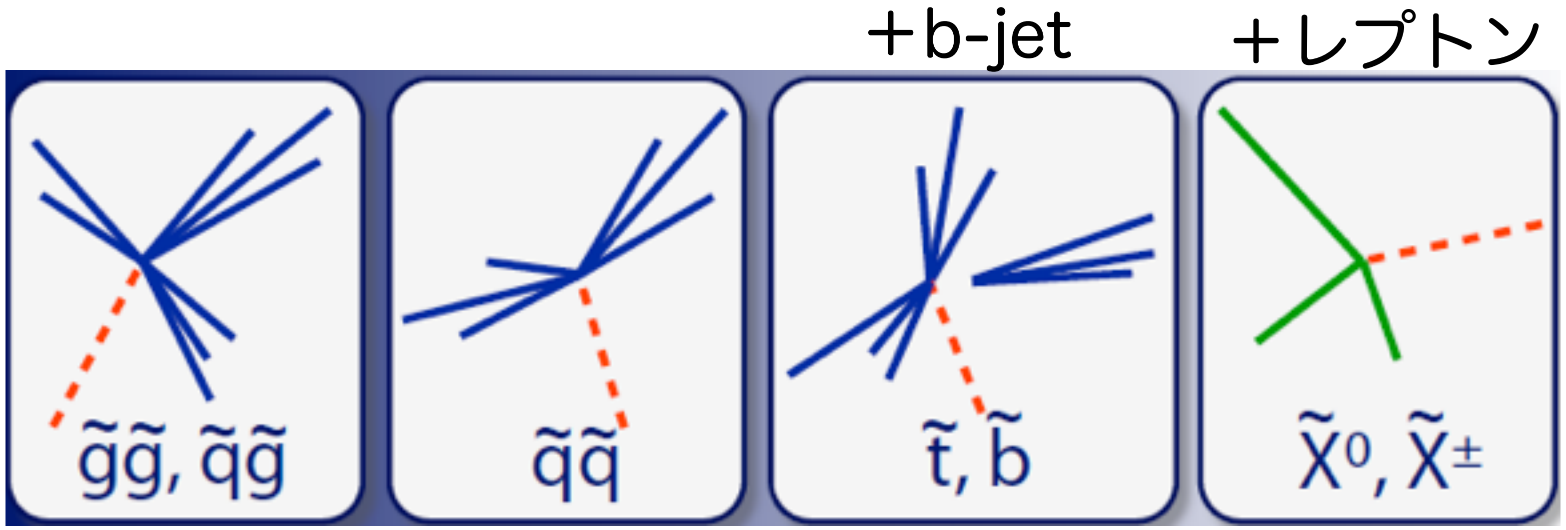
典型的なSUSYのsignature

陽子陽子衝突なのでカラーを持つSUSYの生成が主





様々な生成過程を考慮：signatureも変わる



Gluino　Squark　$\tilde{t}/\tilde{b}$ 直接　Gaugino直接

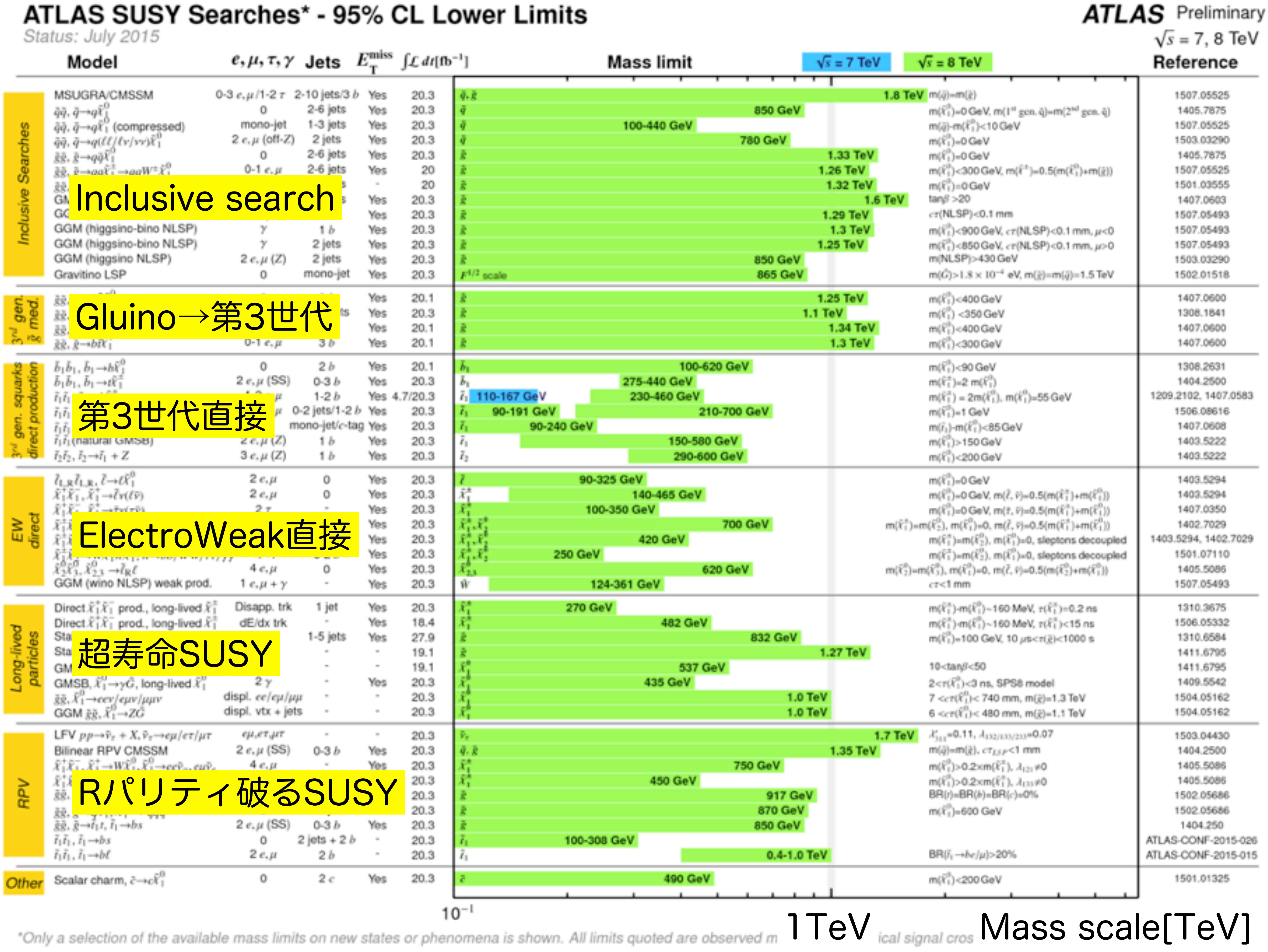
多 ← jet数 → 少

$$E_T^{miss} + \text{high } p_T \text{ jets} + \left(\begin{array}{l} \text{lepton} \\ \text{b-jet} \\ \tau\text{-jet} \end{array} \right.$$

信号と背景事象の分離：

$$m_{eff} = \sum_{\text{jets}} p_T + \sum_{\text{leptons}} p_T + E_T^{miss}$$

Run 1 SUSY探索



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

🟦 $\sqrt{s}$ = 7 TeV 🟩 $\sqrt{s}$ = 8 TeV

	Model	e,μ,τ,γ	Jets	$E_T^{\rm miss}$	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$	1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(1^{st}$ gen. $\tilde{q})=m(2^{nd}$ gen. $\tilde{q})$	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$	100-440 GeV	$m(\tilde{q})-m(\tilde{\chi}^0_1)$<10 GeV	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$	780 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1503.03290
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^{\pm}_1\to qqW^{\pm}\tilde{\chi}^0_1$	0-1 e,μ	2-6 jets	Yes	20	$\tilde{g}$	1.26 TeV	$m(\tilde{\chi}^0_1)$<300 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}^0_1)+m(\tilde{g}))$	1507.05525
	$\tilde{g}\tilde{g}$		s	-	20	$\tilde{g}$	1.32 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1501.03555
	GM		s	Yes	20.3	$\tilde{g}$	1.6 TeV	$\tan\beta$>20	1407.0603
	GG			Yes	20.3	$\tilde{g}$	1.29 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}^0_1)$<900 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}^0_1)$<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	850 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$			Yes	20.1	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}^0_1)$<400 GeV	1407.0600
	$\tilde{g}\tilde{g}$		ts	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}^0_1)$ <350 GeV	1308.1841
	$\tilde{g}\tilde{g}$			Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}^0_1)$<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}^0_1)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}^0_1)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}^{\pm}_1$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV	$m(\tilde{\chi}^{\pm}_1)=2\,m(\tilde{\chi}^0_1)$	1404.2500
	$\tilde{t}_1\tilde{t}_1$	μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$	110-167 GeV 230-460 GeV	$m(\tilde{\chi}^{\pm}_1)=2m(\tilde{\chi}^0_1)$, $m(\tilde{\chi}^0_1)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1$	μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$	90-191 GeV 210-700 GeV	$m(\tilde{\chi}^0_1)$=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1$		mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}^0_1)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}^0_1)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}^{\pm}_1$	140-465 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^{\pm}_1)+m(\tilde{\chi}^0_1))$	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}^{\pm}_1$	100-350 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}^{\pm}_1)+m(\tilde{\chi}^0_1))$	1407.0350
	$\tilde{\chi}^{\pm}_1\tilde{\chi}$			Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$	700 GeV	$m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^{\pm}_1)+m(\tilde{\chi}^0_1))$	1402.7029
	$\tilde{\chi}^{\pm}_1\tilde{\chi}$			Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$	420 GeV	$m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}^{\pm}_1\tilde{\chi}$			Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$	250 GeV	$m(\tilde{\chi}^{\pm}_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}^0_2\tilde{\chi}^0_3, \tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}^0_{2,3}$	620 GeV	$m(\tilde{\chi}^0_2)=m(\tilde{\chi}^0_3)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^0_2)+m(\tilde{\chi}^0_1))$	1405.5086
	GGM (wino NLSP) weak prod.	1 $e,\mu+\gamma$	-	Yes	20.3	$\tilde{W}$	124-361 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^{\pm}_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}^{\pm}_1$	270 GeV	$m(\tilde{\chi}^{\pm}_1)-m(\tilde{\chi}^0_1)$~160 MeV, $\tau(\tilde{\chi}^{\pm}_1)$=0.2 ns	1310.3675
	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^{\pm}_1$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}^{\pm}_1$	482 GeV	$m(\tilde{\chi}^{\pm}_1)-m(\tilde{\chi}^0_1)$~160 MeV, $\tau(\tilde{\chi}^{\pm}_1)$<15 ns	1506.05332
	Sta		1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}^0_1)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Sta		-	-	19.1	$\tilde{g}$	1.27 TeV		1411.6795
	GM		-	-	19.1	$\tilde{\chi}^0_1$	537 GeV	10<$\tan\beta$<50	1411.6795
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$	435 GeV	2<$\tau(\tilde{\chi}^0_1)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}^0_1\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}^0_1$	1.0 TeV	7 <$c\tau(\tilde{\chi}^0_1)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}^0_1\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}^0_1$	1.0 TeV	6 <$c\tau(\tilde{\chi}^0_1)$< 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$	1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$	1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to W\tilde{\chi}^0_1, \tilde{\chi}^0_1\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}^{\pm}_1$	750 GeV	$m(\tilde{\chi}^0_1)>0.2\times m(\tilde{\chi}^{\pm}_1)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}^+_1\tilde{\chi}$				20.3	$\tilde{\chi}^{\pm}_1$	450 GeV	$m(\tilde{\chi}^0_1)>0.2\times m(\tilde{\chi}^{\pm}_1)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$				20.3	$\tilde{g}$	917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}$				20.3	$\tilde{g}$	870 GeV	$m(\tilde{\chi}^0_1)$=600 GeV	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$	100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2 c	Yes	20.3	$\tilde{c}$	490 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1501.01325

1TeV

Mass scale[TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed m … ical signal cros

Inclusive search

Gluino→第3世代

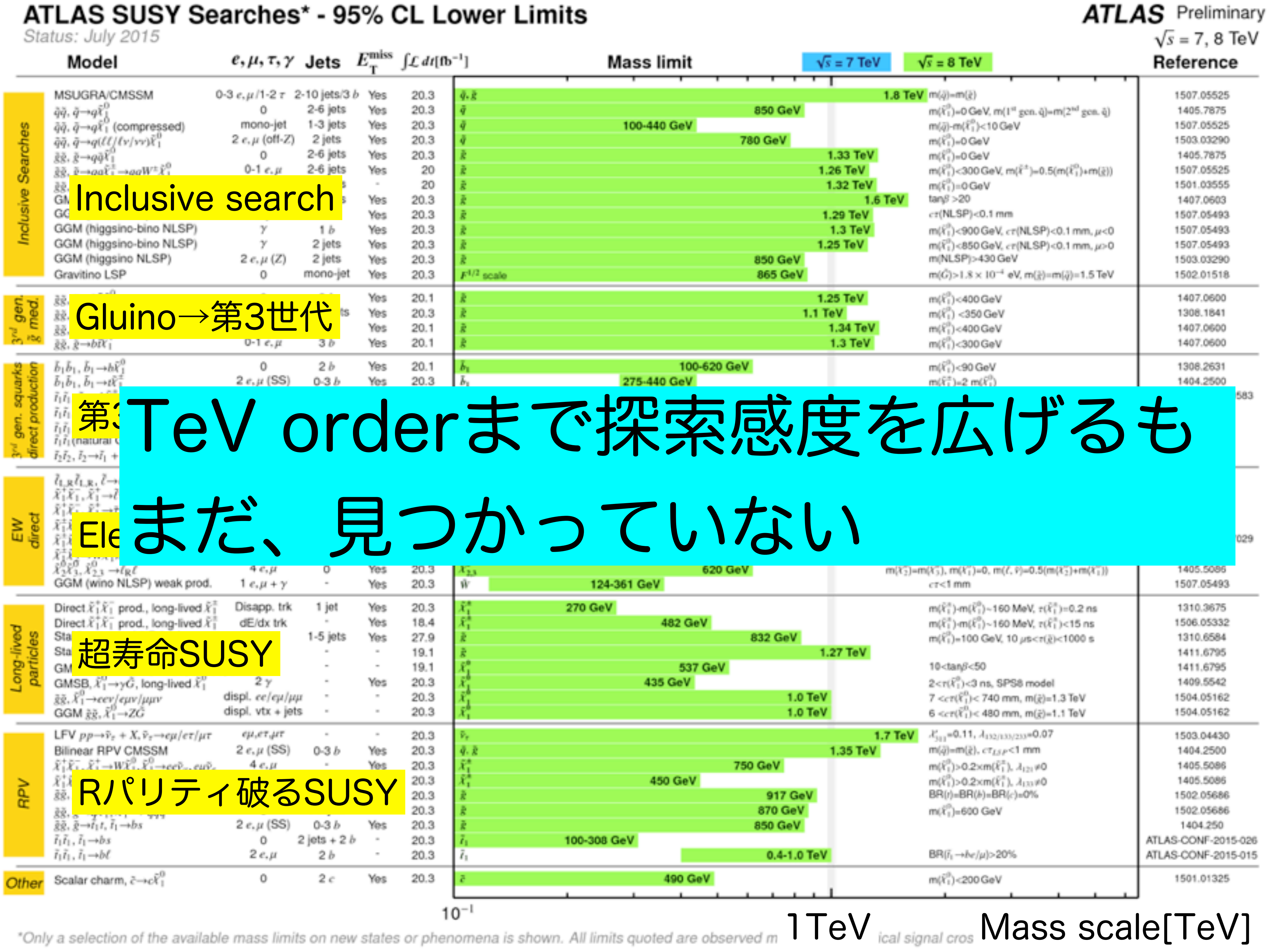
第3世代直接

ElectroWeak直接

超寿命SUSY

Rパリティ破るSUSY

Run 1 SUSY探索



*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed m

Inclusive search

Gluino→第3世代

第3

Ele

超寿命SUSY

Rパリティ破るSUSY

TeV orderまで探索感度を広げるも

まだ、見つかっていない

1TeV

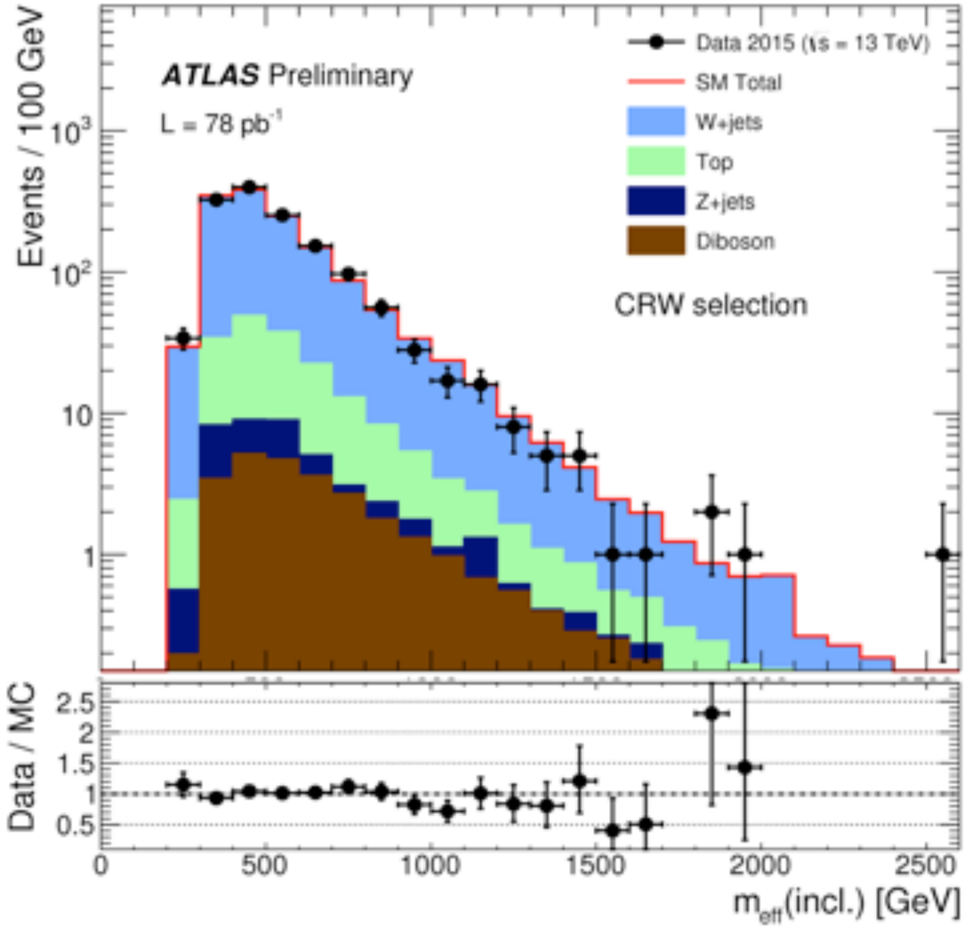
Mass scale[TeV]

Run 2のSUSY探索

2-6 jets + E_T^{miss}探索

1-lepton control region

- ==1 e/μ
- E_T^{miss}>100GeV, 30<m_T<100GeV
- ≧2 jets(100,60GeV), no b-jets

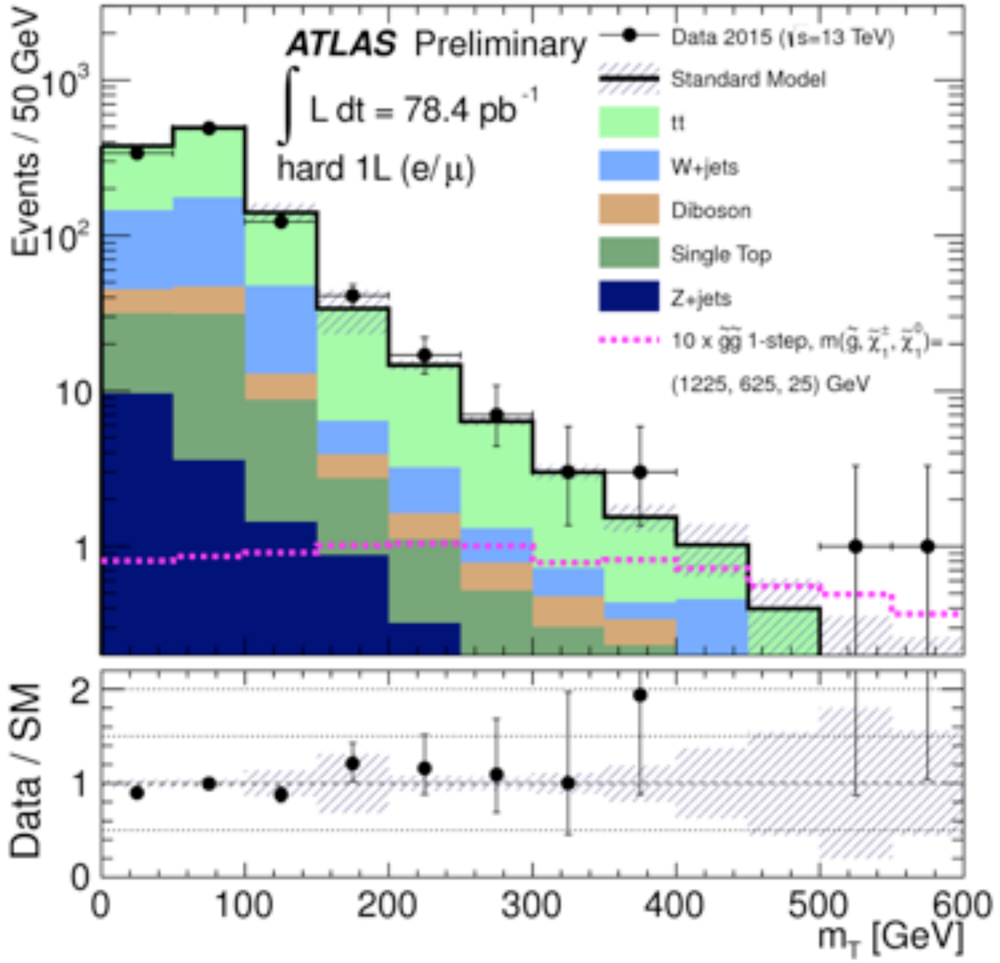


W+jets backgroundの理解

1-lepton+ ≧4 jets + E_T^{miss}探索

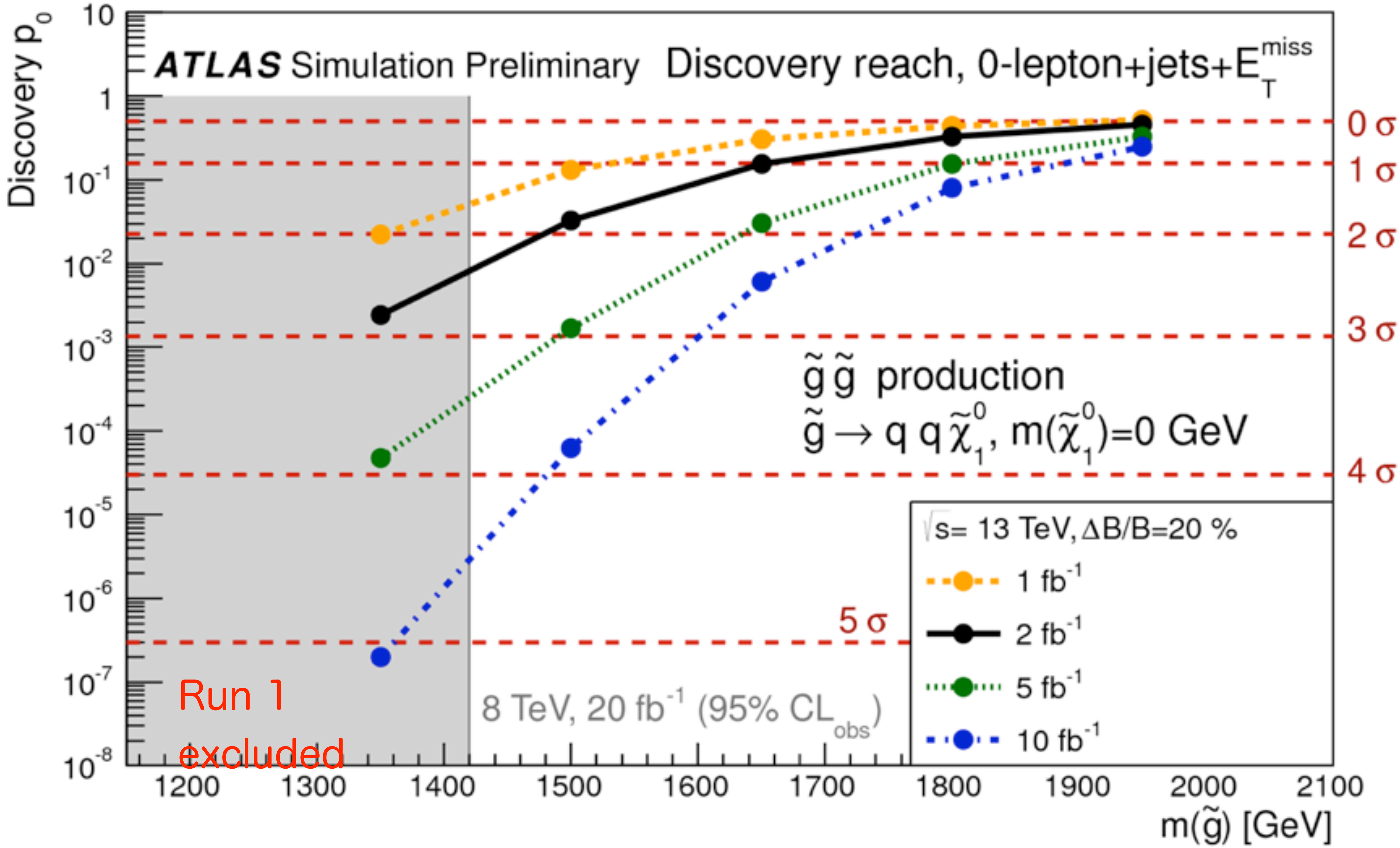
pre-selection

- ==1 e/μ
- E_T^{miss}>100GeV
- ≧4 jets(30GeV)



ttbar backgroundの理解

予想される探索感度



数fb-1のデータを用いれば、

Run1でexcludeできなかったgluinoを3σで観測できる

最後に

今年中に3fb^{-1}位は貯める予定

多くの新物理探索でRun1の感度を超え始める

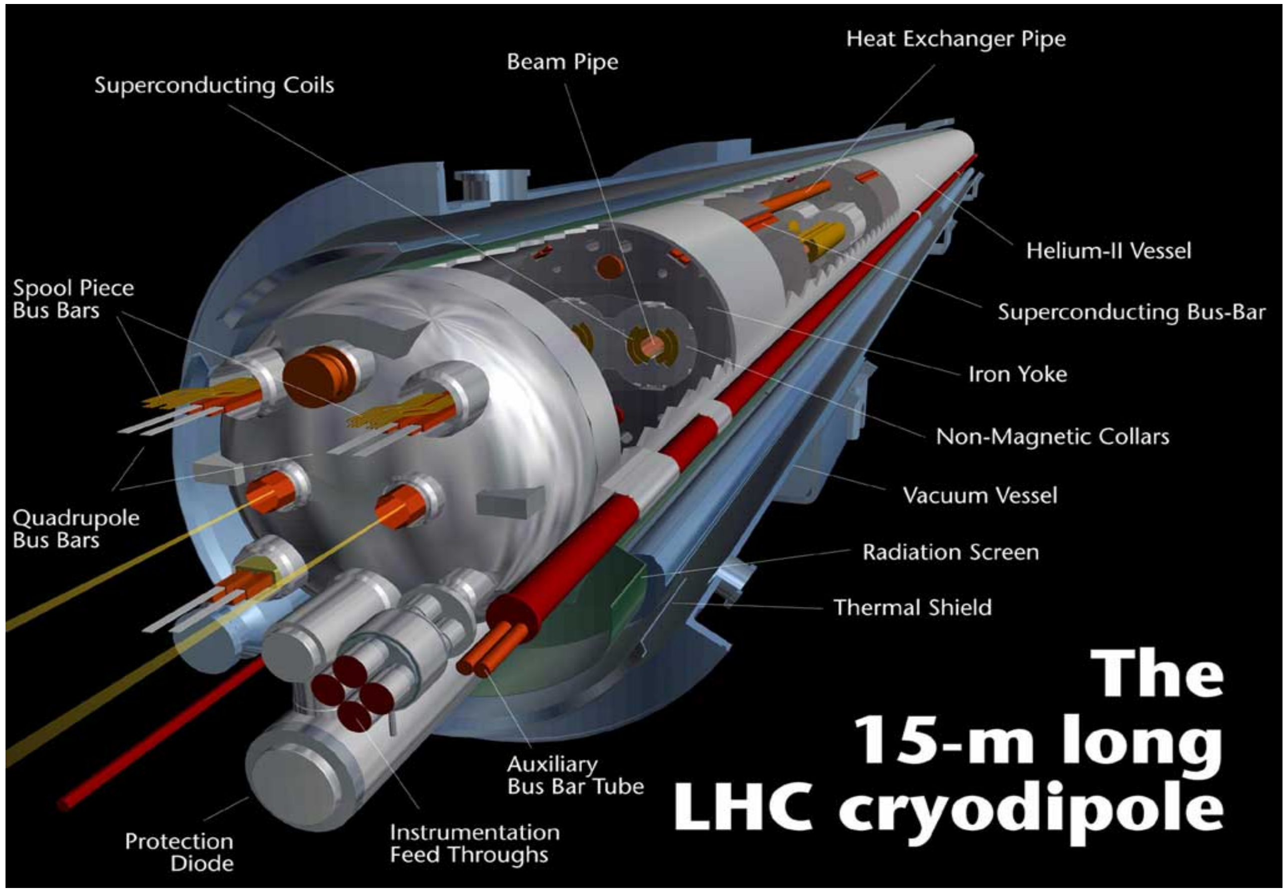
今年中に何が見えるか？
ご期待下さい！！

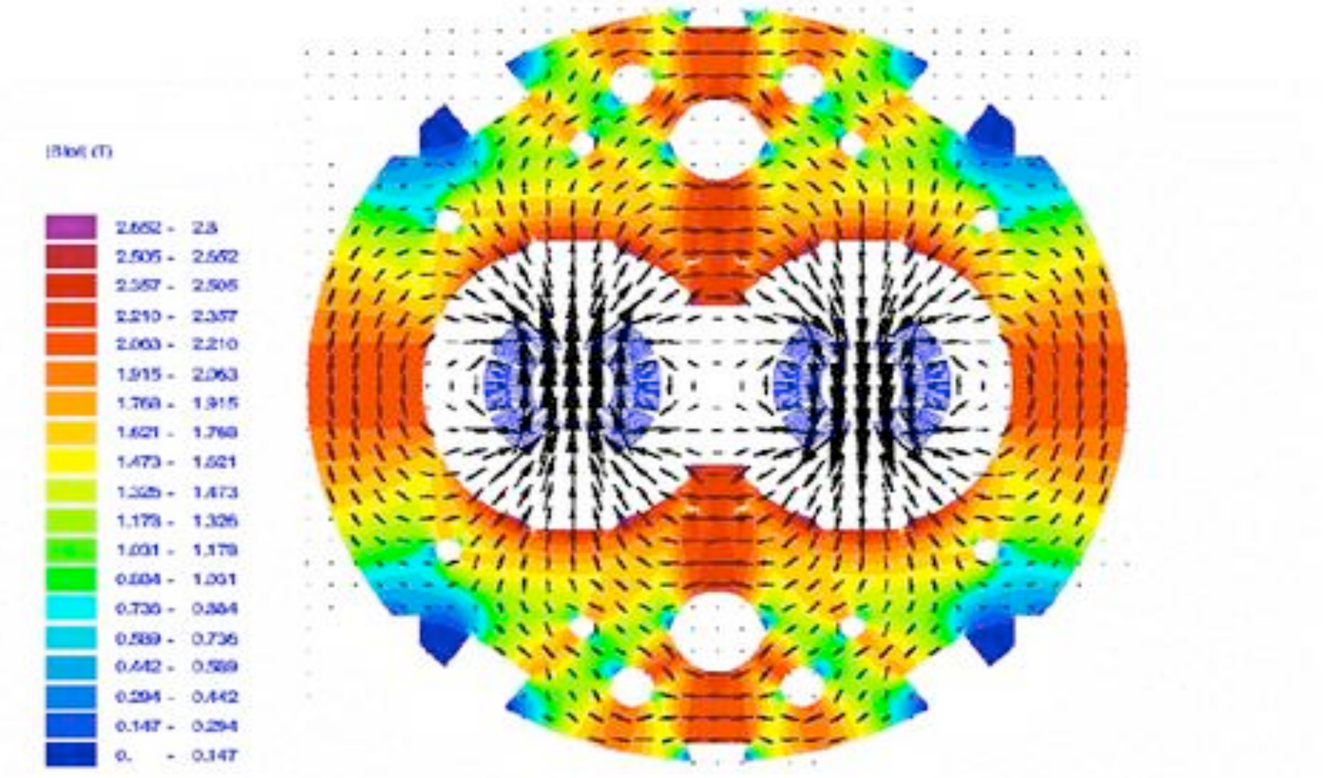
バックアップ

LHCのスペック

	Design	2015目標	現状
Beam Energy	7TeV	6.5TeV	6.5TeV
dipole磁場	8.33T	7.7T	7.7T
Peak Luminosity	10^{34}cm^{-2}s^{-1}	1.3×10^{34}cm^{-2}s^{-1}	0.3×10^{34}cm^{-2}s^{-1}
陽子数/Bunch	1.15×10^{11}	1.15×10^{11}	1.15×10^{11}
バンチ数/ビーム	2,808	2,802	1,321
バンチ間隔	25 ns	25 ns	25 ns
β^*	55 cm	40 cm	80cm

LHC加速器



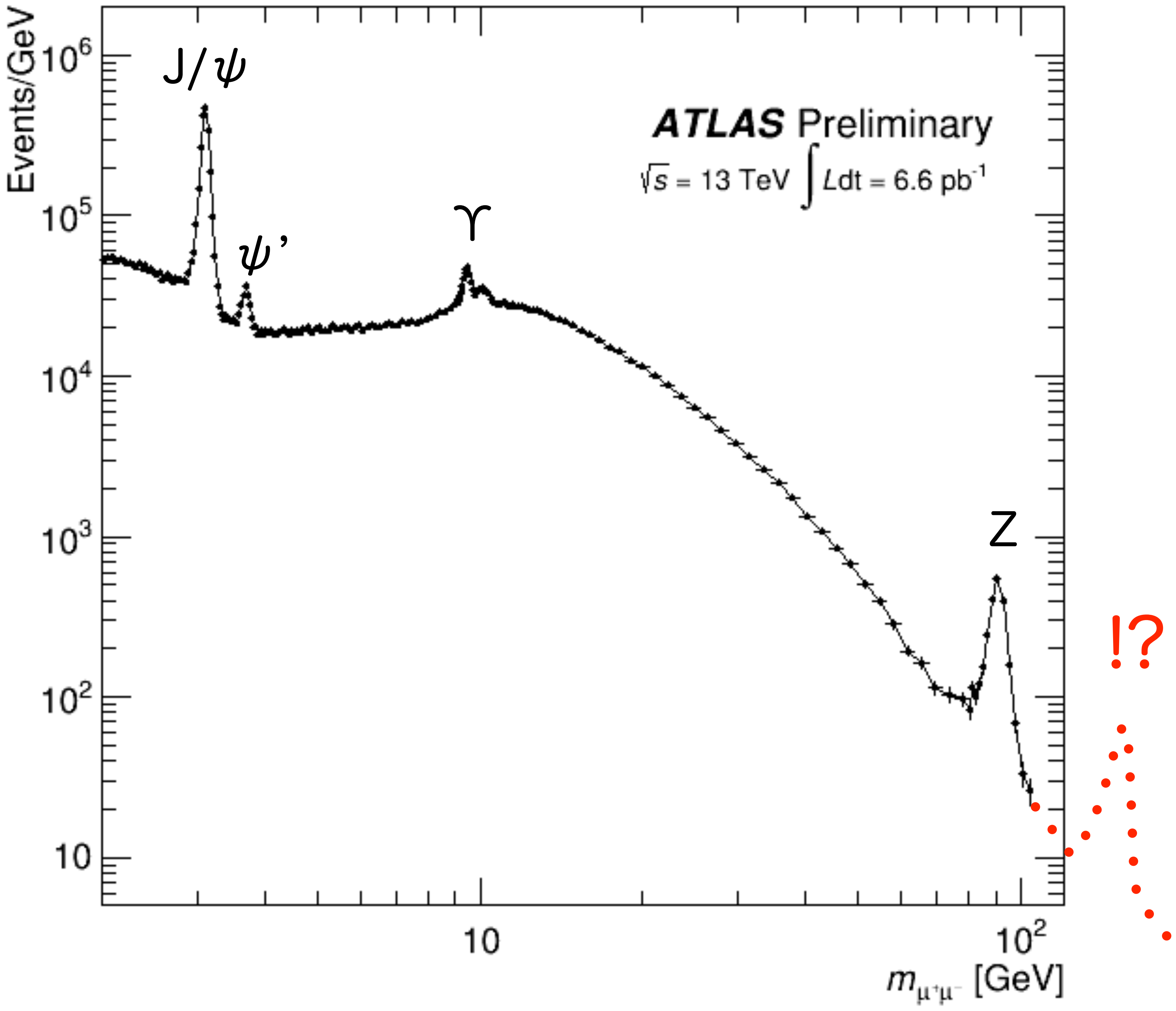


8.33テスラの超伝導磁石(1.9Kに冷却)

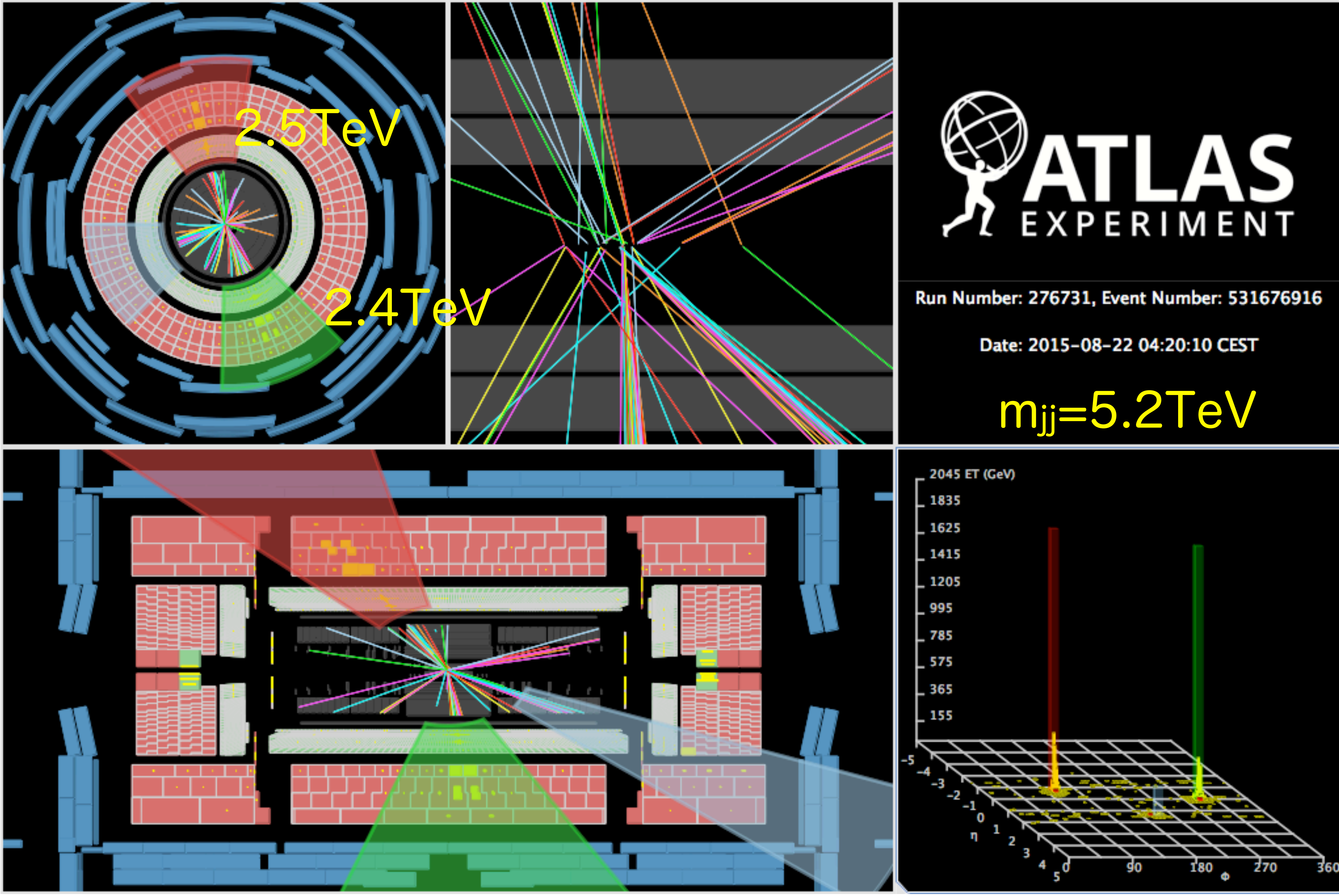
15m × 1232台=18km(27km中)

陽子を衝突させる為の磁石

新粒子探索


J/ψ
ψ'
Υ
Z
!?
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV $\int Ldt$ = 6.6 pb^{-1}
Events/GeV
10^6
10^5
10^4
10^3
10^2
10
10
10^2
$m_{\mu^+\mu^-}$ [GeV]

最もm_{jj}の高いdijet事象

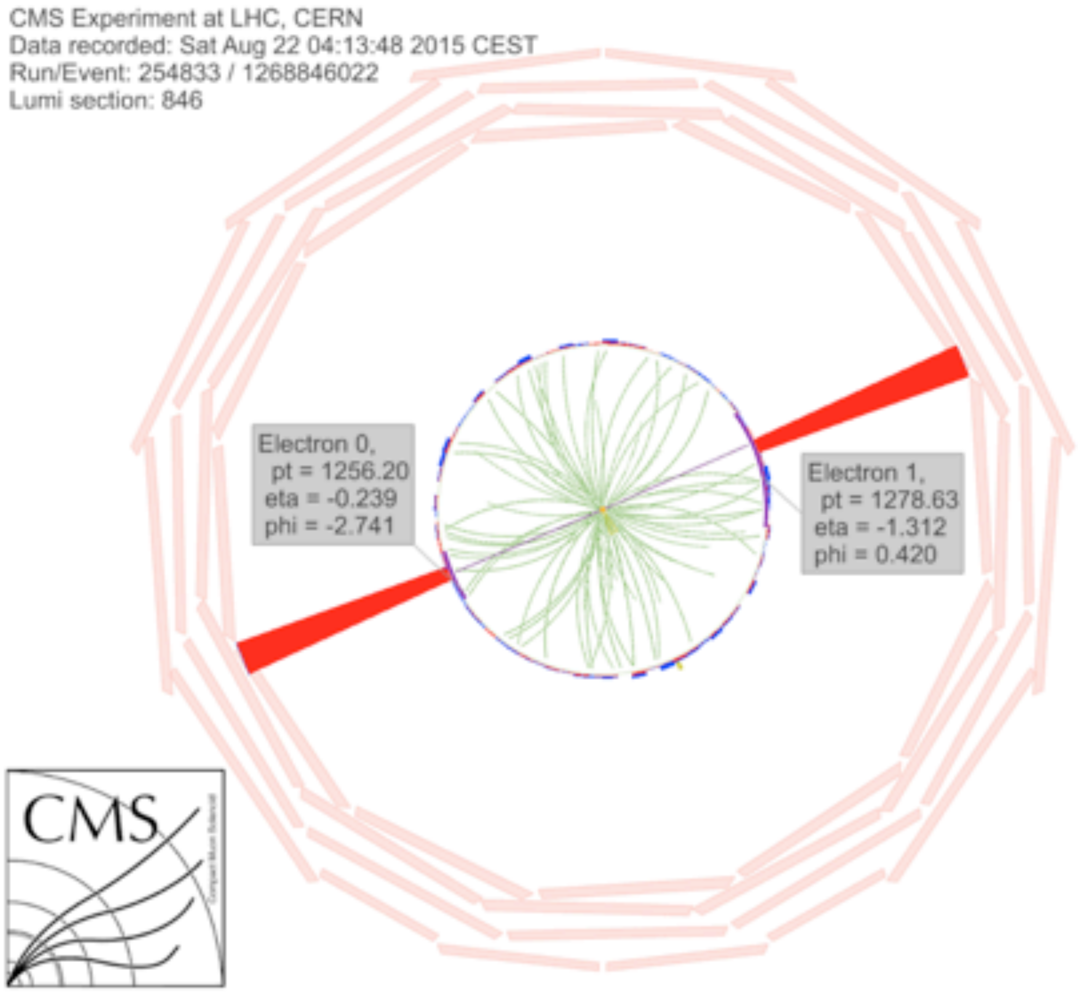


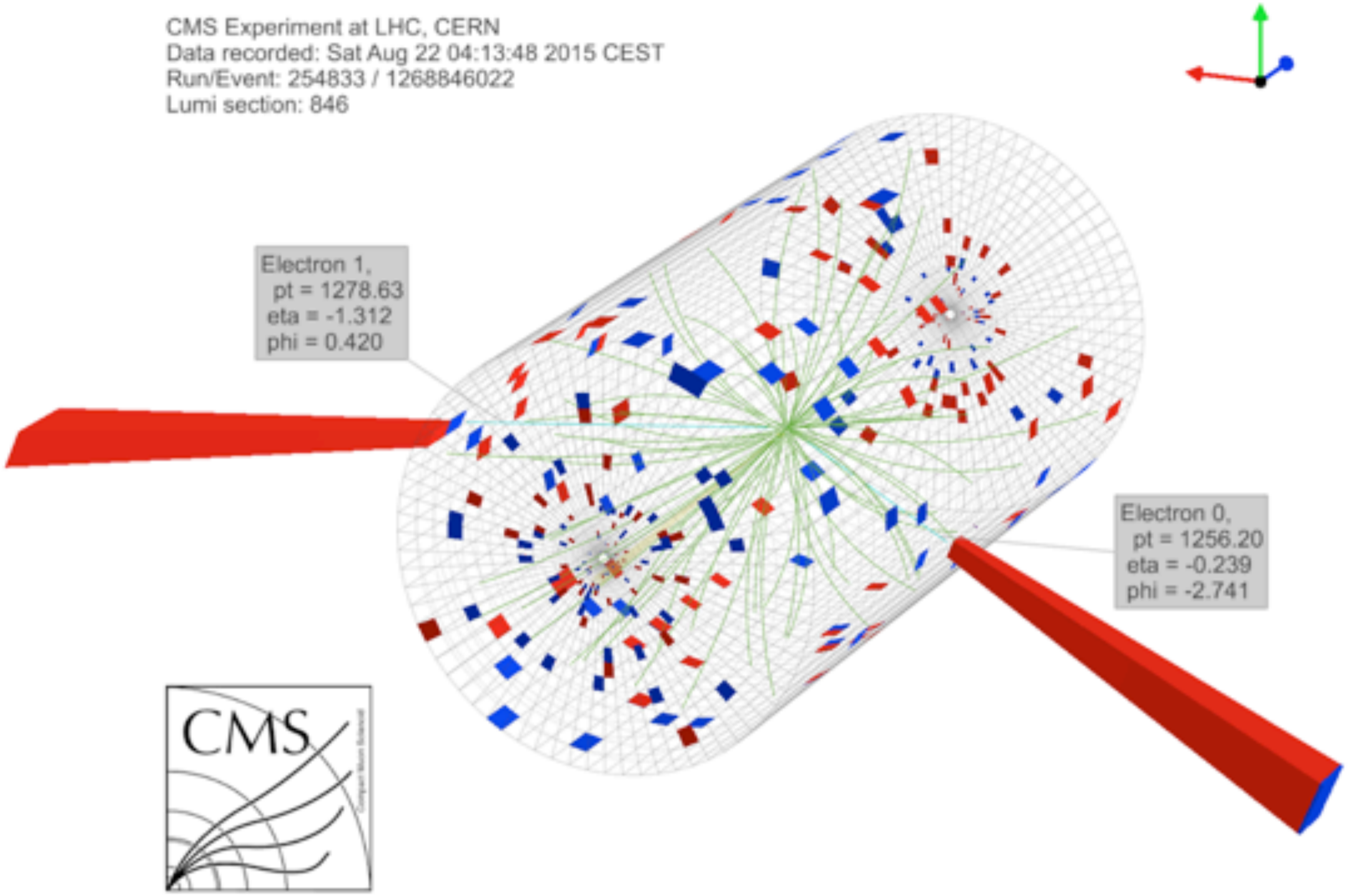
2.5TeV

2.4TeV

m_{jj}=5.2TeV

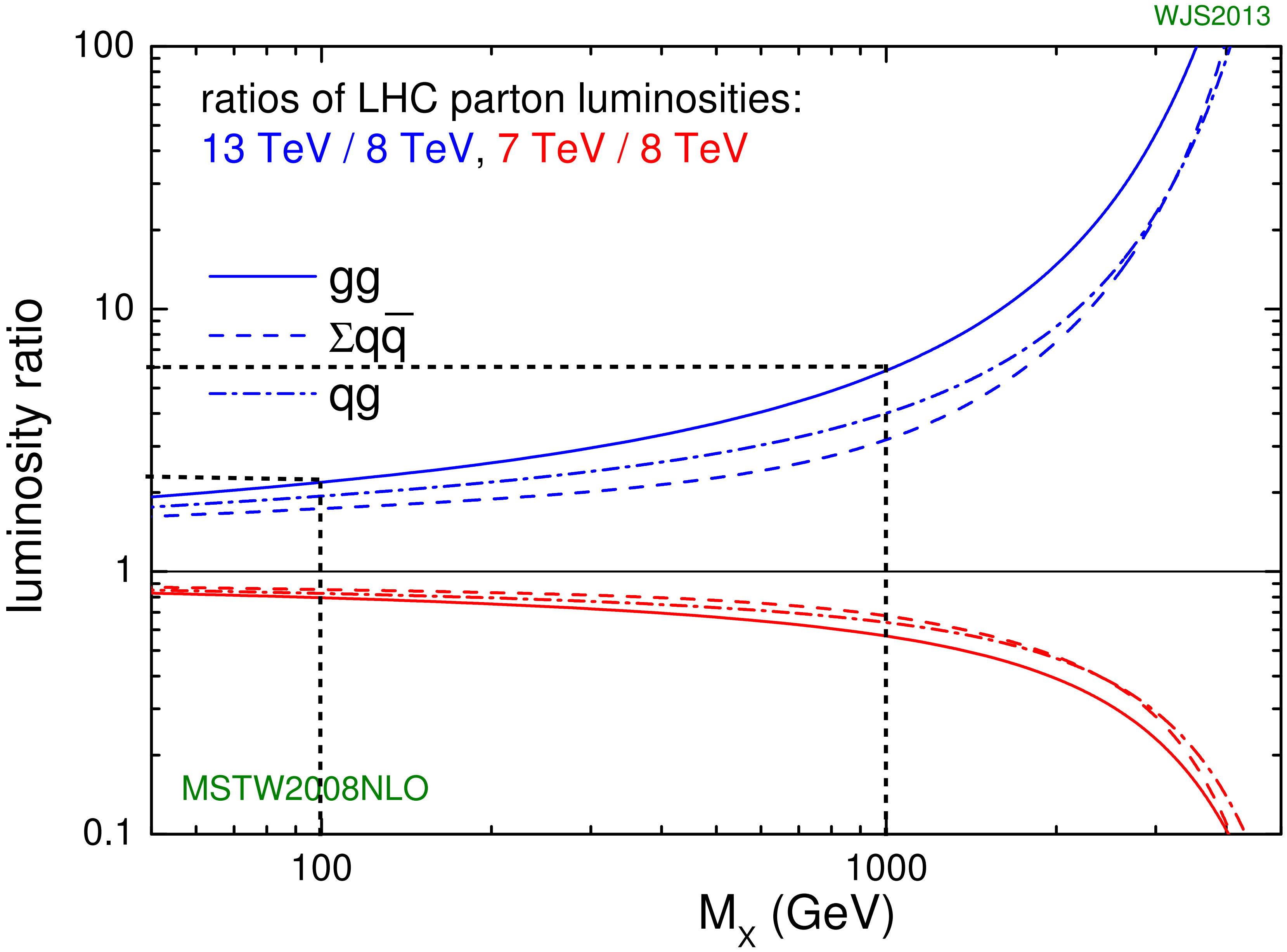
CMSの最も高いm_{ee}のdi-electron事象

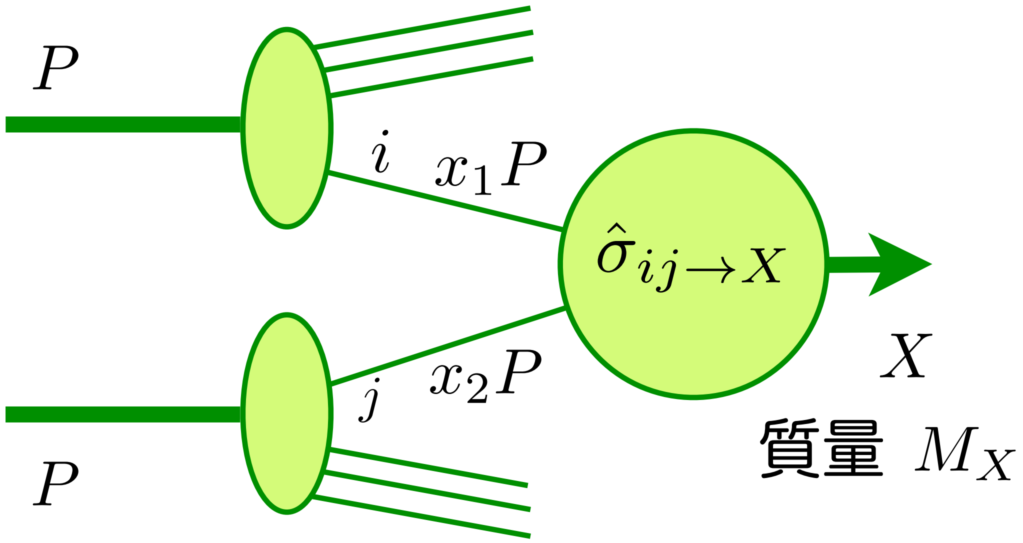




7TeV→8TeV→13TeVへのご利益

√sを高くすると、重い粒子の生成が特に増加する





13TeV / 8TeV

ヒッグス粒子（100GeV）生成　：~2倍

超対称性粒子（1TeV）生成　：~5倍