Prospettive per il Run2 a LHC

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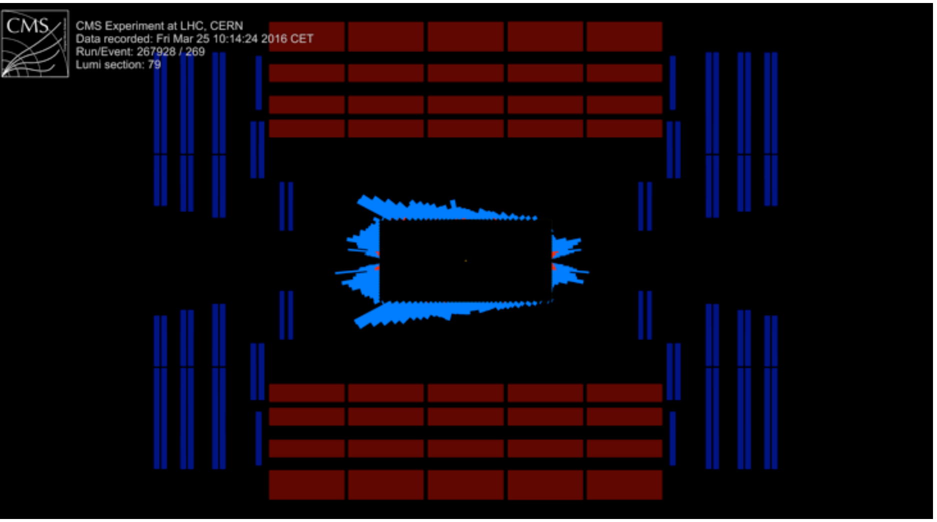
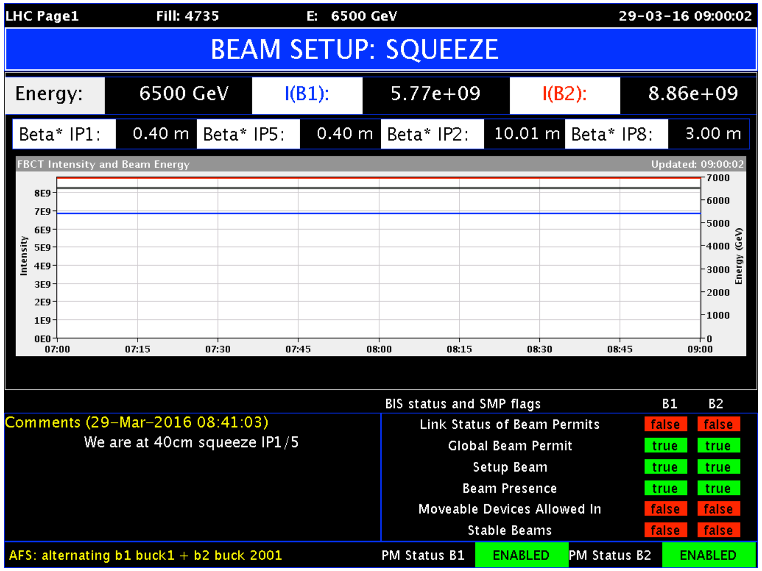
INFN TORINO

IFAE 2016 – Genova - 30 Marzo 2016

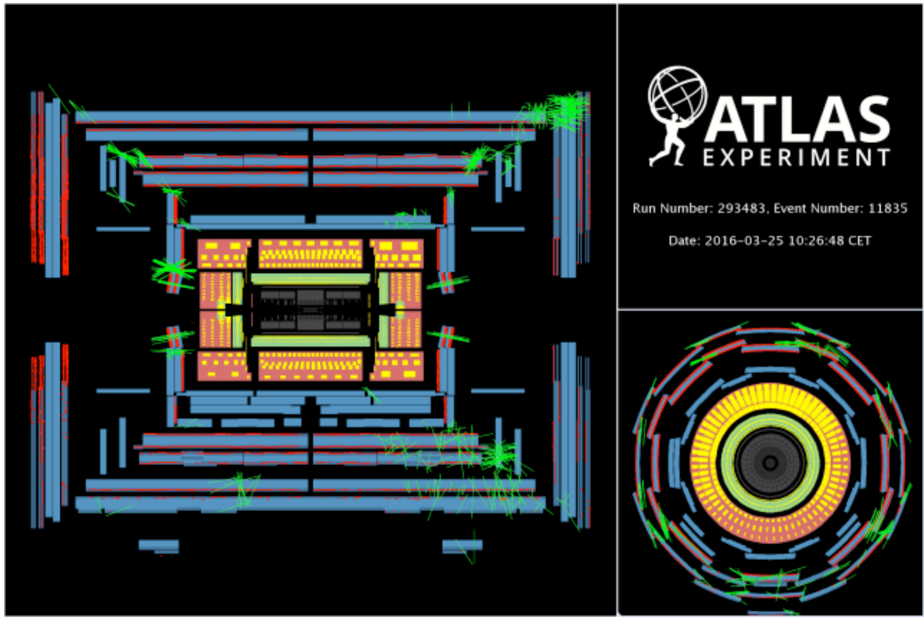


Sommario



- **LHC riparte @ 13 TeV:**

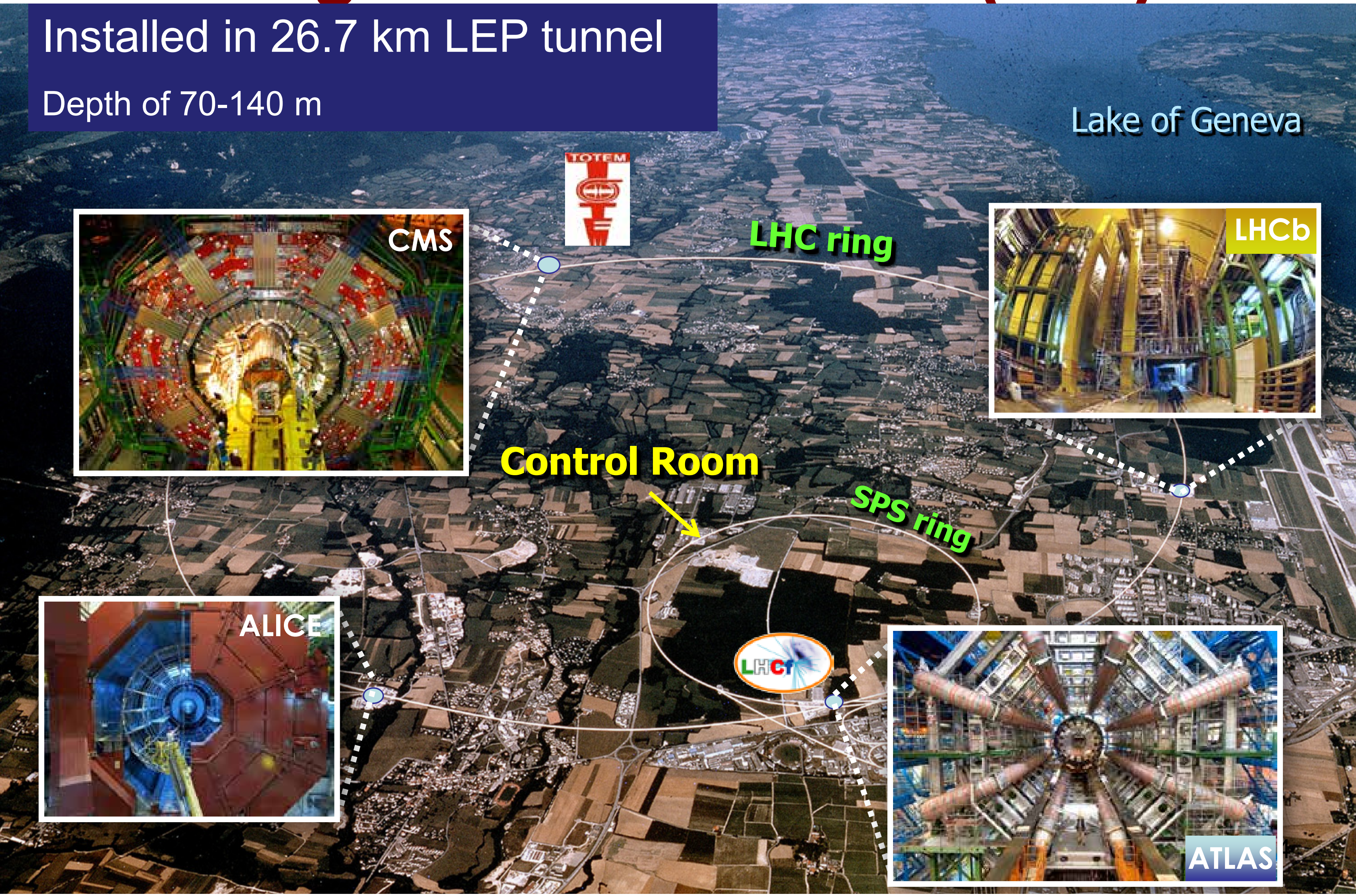
  primi splashes per IFAE 2016
- **Apparati sperimentali**
- **Risultati dai dati 2015**
- **Prospettive per il Run2**
- **Conclusioni**

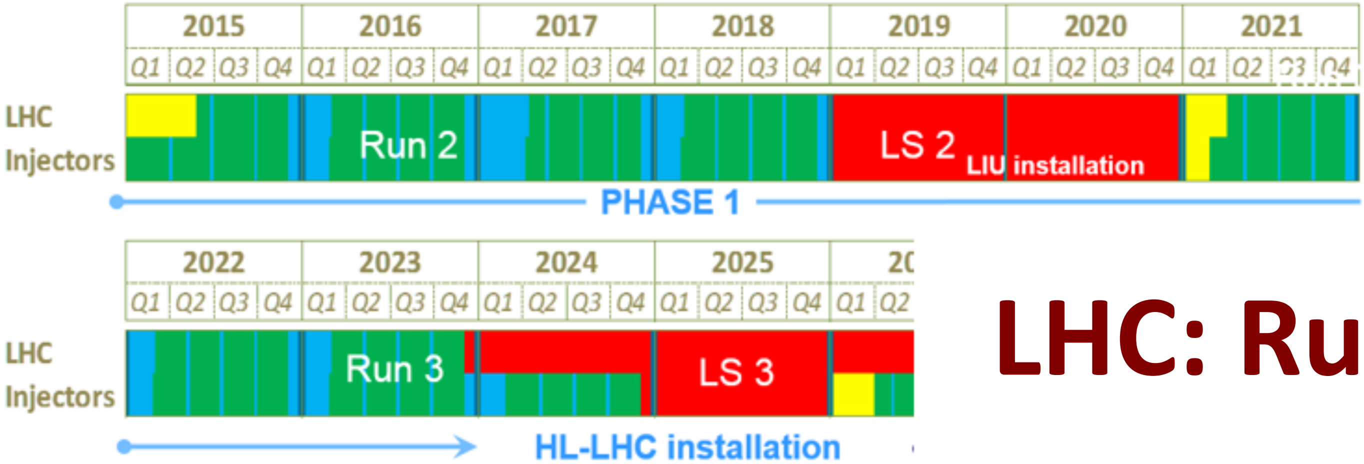


Large Hadron Collider (LHC)

Installed in 26.7 km LEP tunnel

Depth of 70-140 m





LHC: Run 2 e oltre

Goal luminosità integrata con 25 ns bunch crossing:

- **2015: ~ 4 fb^{-1} @ 13 TeV (2x2244 bunches nominali)**
- **2016: ~ 25 fb^{-1} @ 13 TeV**

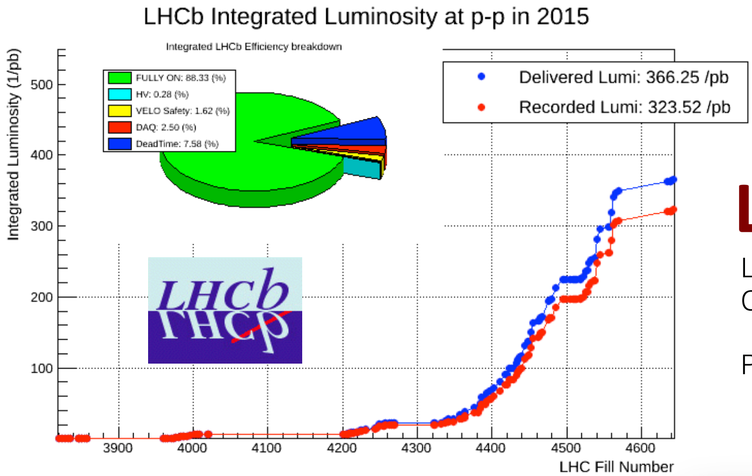
  β^* = 40 cm in ATLAS e CMS; 3 m in LHCb; 10 m in ALICE

  Ottimizzazione ramp-up/squeeze alta intensità e luminosità integrata
- **Run2: ~100 fb^{-1}**

  Preparazione per (o direttamente) operazione @ 14 TeV
- **300 fb^{-1} prima di LS3**

  LHC Injector Upgrade (LIU → LS2) e High Luminosity LHC (HL-LHC → LS3) ben definiti e in fase di costruzione

Dati pp nel 2015



LHCb Luminosità costante 0.36 (0.32) fb-1 (registrati)

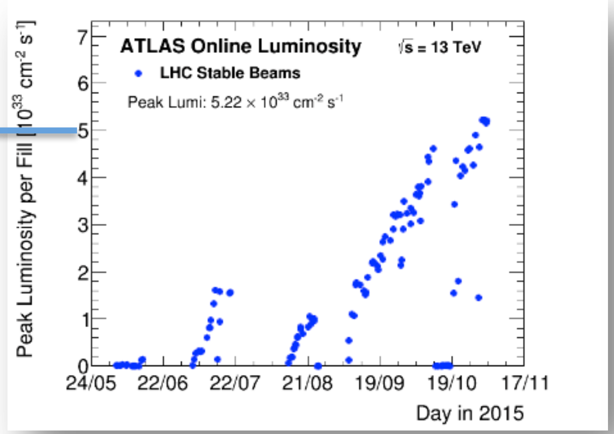
Luminosity monitors calibrated with beam-separation scans.
Current precisions: 5.0% (ATLAS), 2.7% (CMS), 3.8% (LHCb)

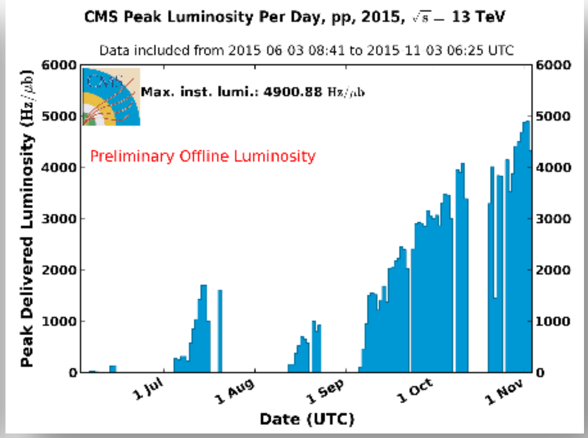
Pileup profiles: ATLAS/CMS: $\langle\mu\rangle_{50\,ns} = 20$, $\langle\mu\rangle_{25\,ns} = 13$ ($\langle\mu\rangle_{8TeV} = 21$), LHCb: $\langle\mu\rangle \sim 1.7$

ATLAS

CMS

5×10^{33} cm^{-1} s^{-1} **Picco**

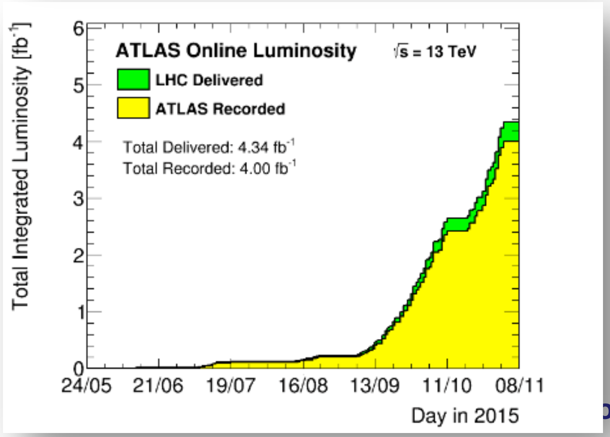


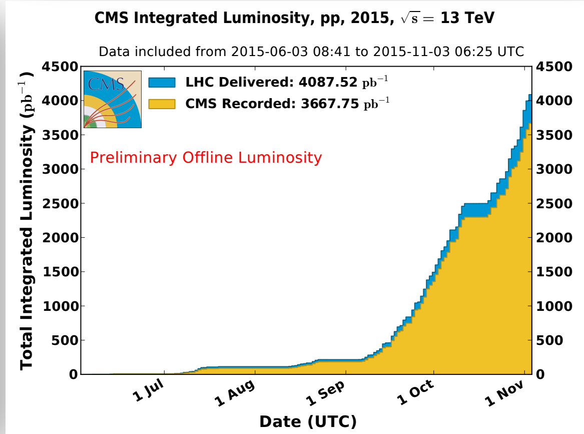


Disegno 10^{34} cm^{-1} s^{-1}

ATLAS:
efficienza presa dati 92.0%

Integrato

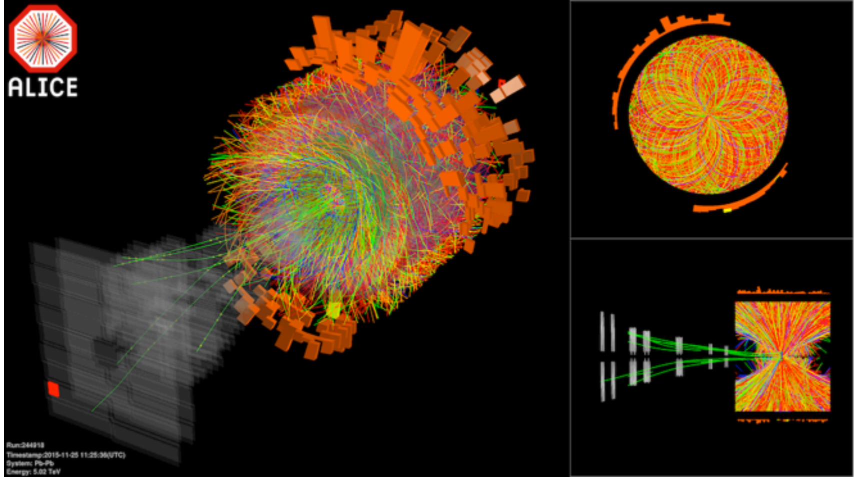




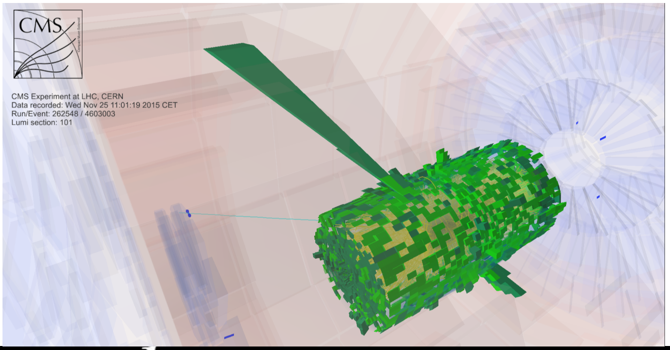
Registrati ~ 4.3 fb^{-1}
Ultima settimana > 1 fb^{-1}

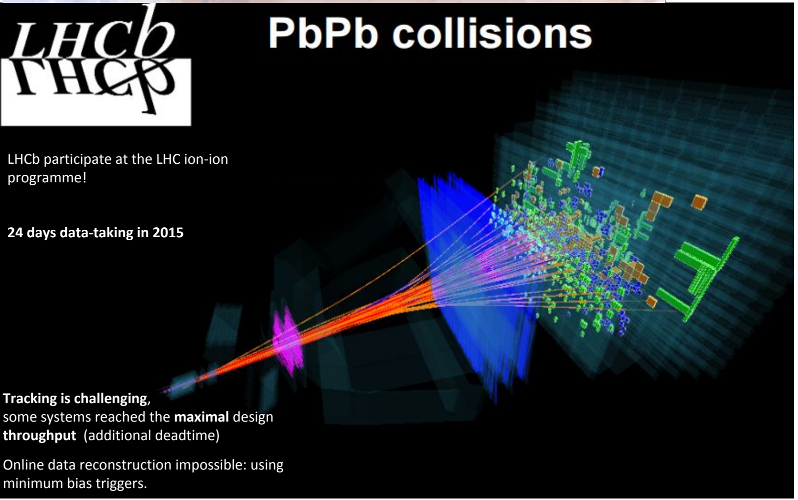
Pb Pb @ 2015

- Luminosità picco (disegno): 1×10^{27} cm^{-2}s^{-1}
  - *ALICE livellata a luminosità di disegno*
  - *ATLAS/CMS fino a un max $3.5\text{x}10^{27}$ cm^{-2}s^{-1}*



- Luminosità (3 settimane fisica):
  - *Goal ioni pesanti 2015 :300 - 500 μb^{-1}*
  - ***ALICE 430 μb^{-1};** ATLAS/CMS ~700/600 μb^{-1}; anche LHCb*





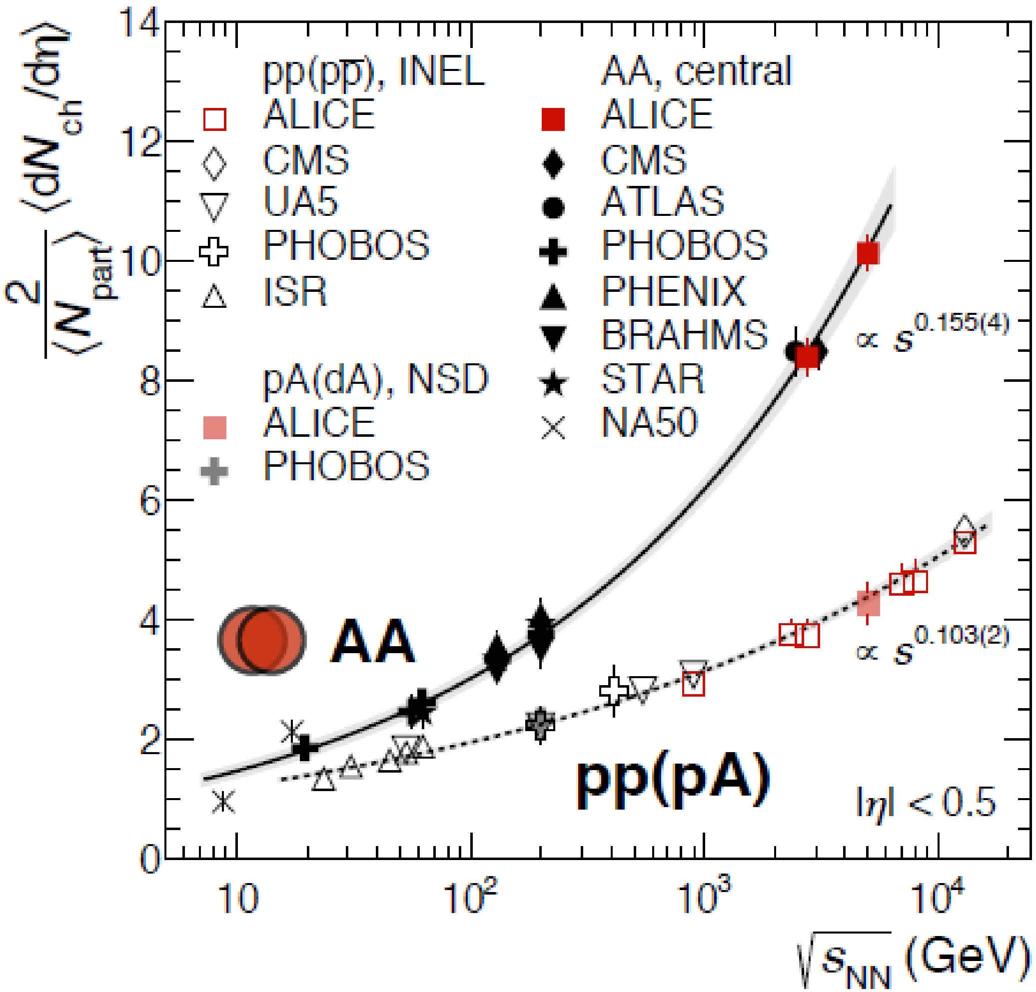
Piano di lavoro:

RUN2 (2015, 2016, 2018) : 1 nb^{-1} Pb-Pb con rivelatori migliorati e raddoppio energia (2015 e 2018), e un run p-Pb con statistica x10 nel 2016 (LoI LHCf)

Futuro:

RUN3 + RUN4 (2021, 22, 23 and 27, 28, 29): 10 nb^{-1} con ulteriori miglioramenti apparati e in aggiunta un run dedicato a basso campo e pPb

Collisioni Pb-Pb @5.02 TeV



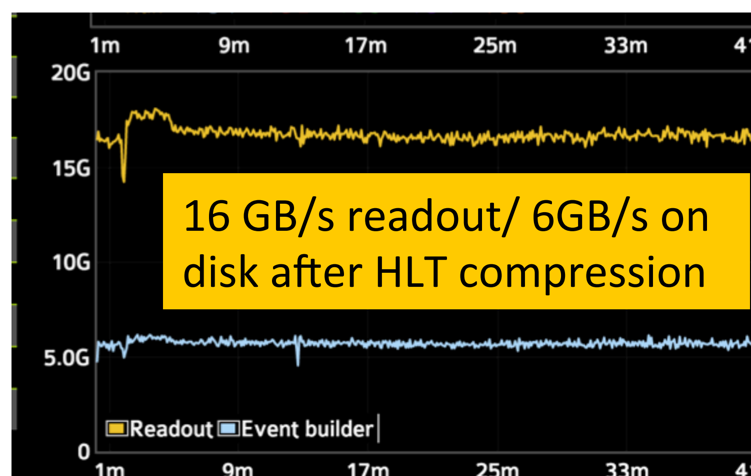
ALICE Pb-Pb Run 2: arXiv:1512.06104 [nucl-ex]

- **Densità di molteplicità di particelle cariche**

  A rapidità $|\eta| < 0.5$ raggiunge un valore di 1943 ± 54 nelle collisioni più centrali

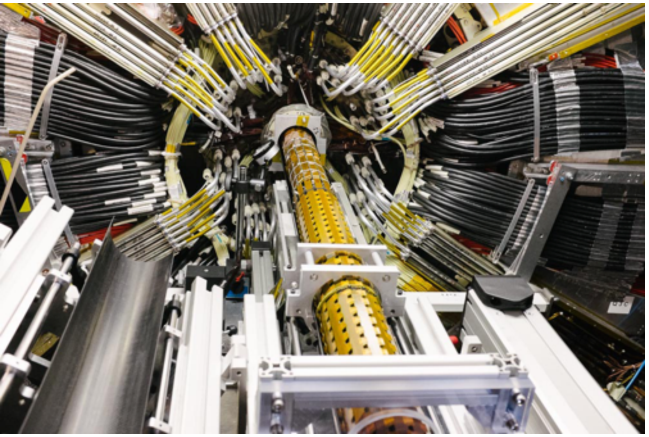
- **Più forte dipendenza da √s rispetto a pp**

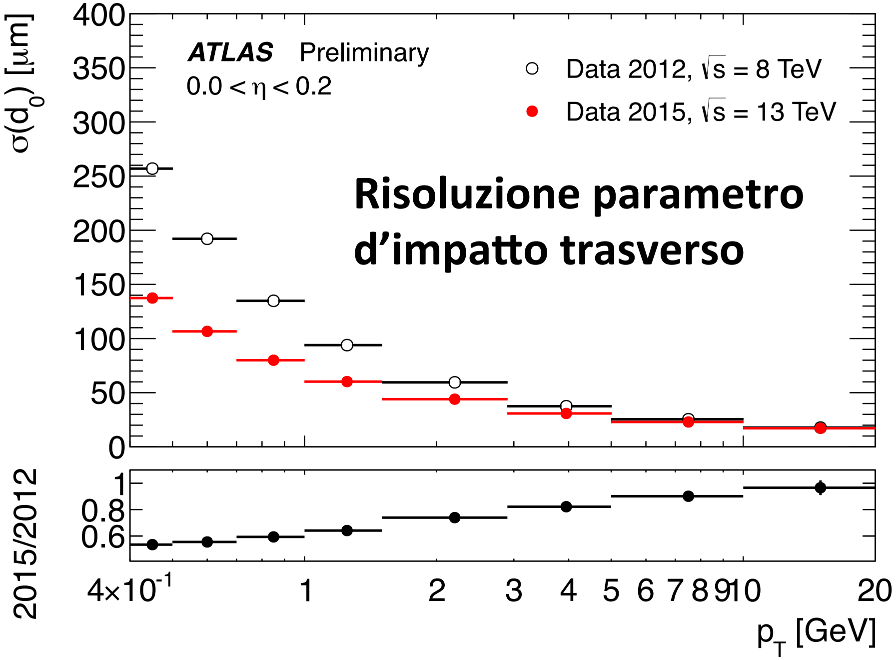
  Fattore 2.4x di molteplicità particelle cariche rispetto a p-Pb alla stessa energia scalata sul numero medio di coppie di nucleoni partecipanti $\langle N\text{part}\rangle/2$



Gli apparati per Run2

ATLAS Insertable B-Layer (IBL)





- **Long Shutdown 2013-14 (LS1)**
  - Nuovi tubi a vuoto Be zona collisione
  - Riparazioni e consolidamento camere muoni
  - Nuovi servizi, nuovi link ottici
  - Nuovi sistemi di monitor di fascio

ATLAS:
- IBL - Insertable B-Layer

CMS:
- Quarta stazione RPC Endcap

- **Prima del LS2 (2019-20)**

CMS:
- Nuovo rivelatore a pixel

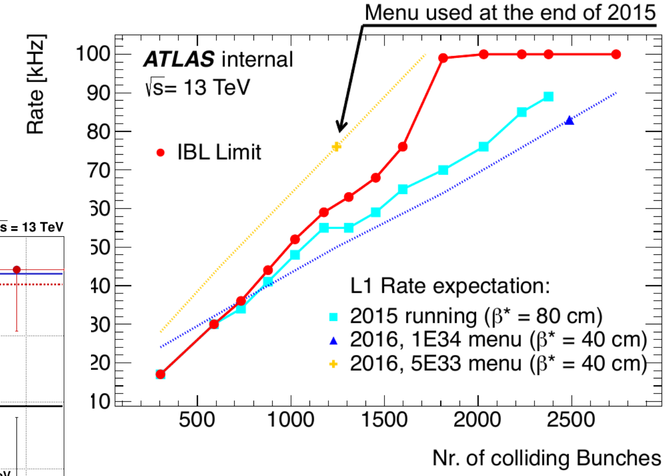
Trigger/DAQ per Run2

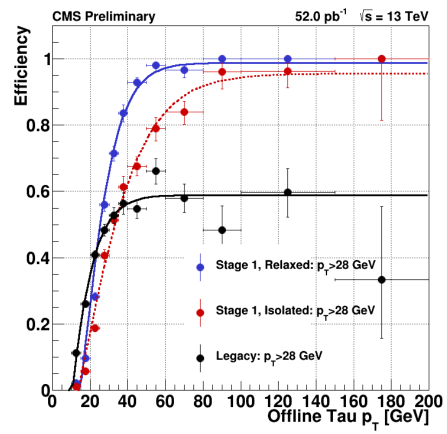
- **Long Shutdown 2013-14 (LS1)**

  Goal: L1 rate up to 100 kHz

  ATLAS:
  - Nuovo trigger topologico L1
  - Nuovo high-level trigger (HLT)
  - Nuovo Fast TracK Trigger (FTK)

  CMS:
  - Nuovo trigger calorimetrico
  - Nuovo DAQ/Nuove CPU per HLT
  - Calcolo multi-threading, multi-core

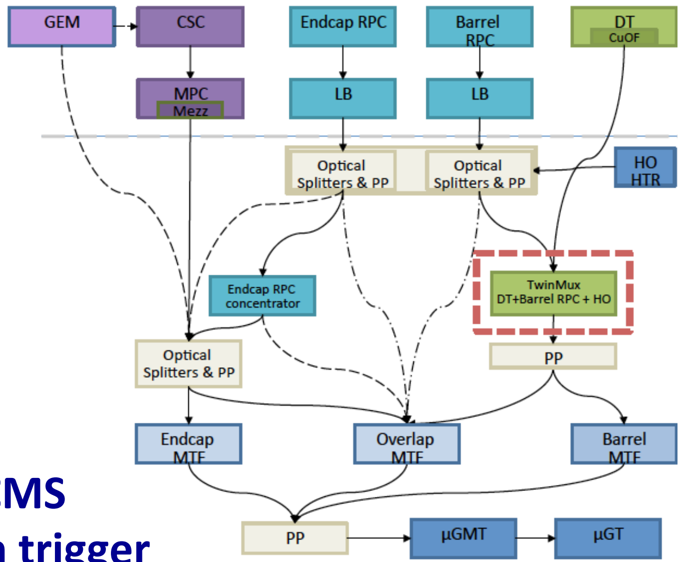




- **Prima del LS2 (2019-20)**

  ATLAS:
  - 2016-17: FTK completo

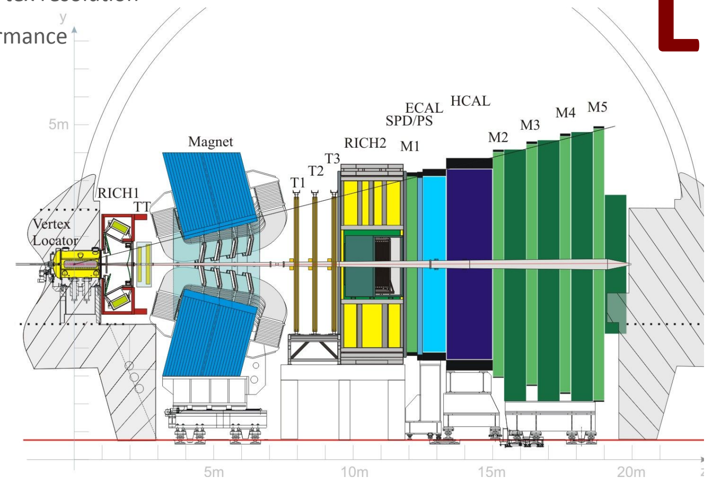
  CMS:
  - 2016: completamento nuovo trigger



CMS Muon trigger

LHCb: trigger

- ➔ unique geometrical coverage
- ➔ outstanding track momentum and vertex resolution
- ➔ excellent Particle Identification performance
- ➔ unique trigger strategy



Tracking efficiency	> 96 %
Decay time resolution	45 fs
Momentum resolution	0.5 - 1.0 %
Software trigger input	10^6 events / s

Turbo

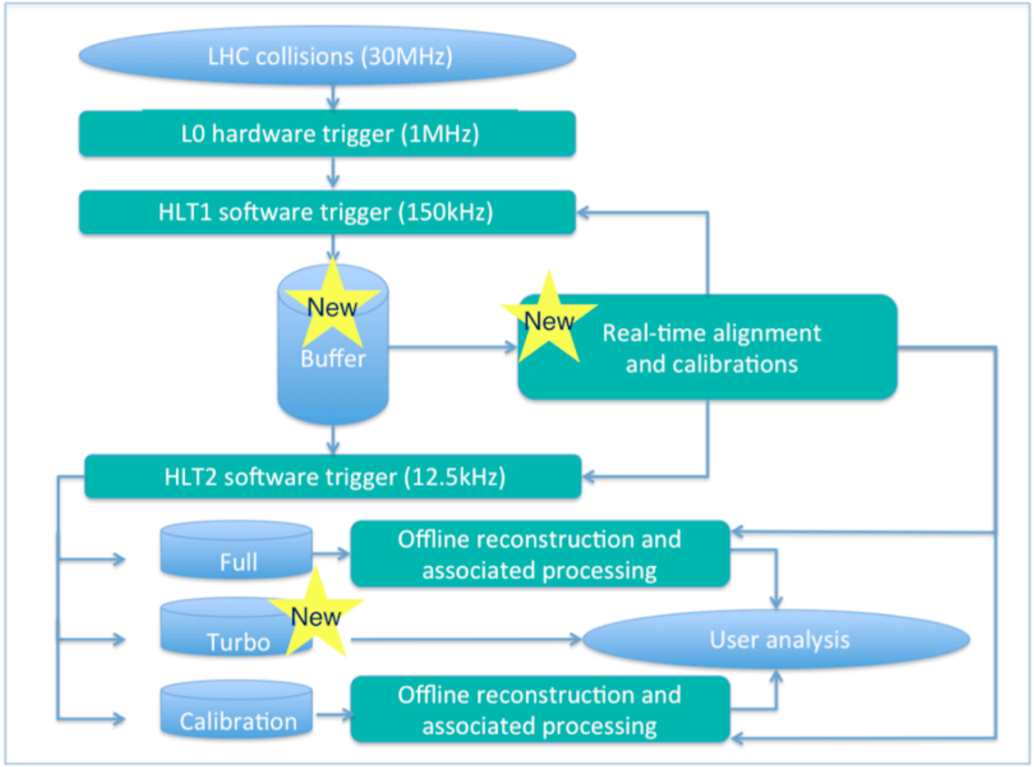
- Part of the physics programme needs **billions of recorded candidates** (e.g. charm measurements): but with no need for the rest of the event.

FULL

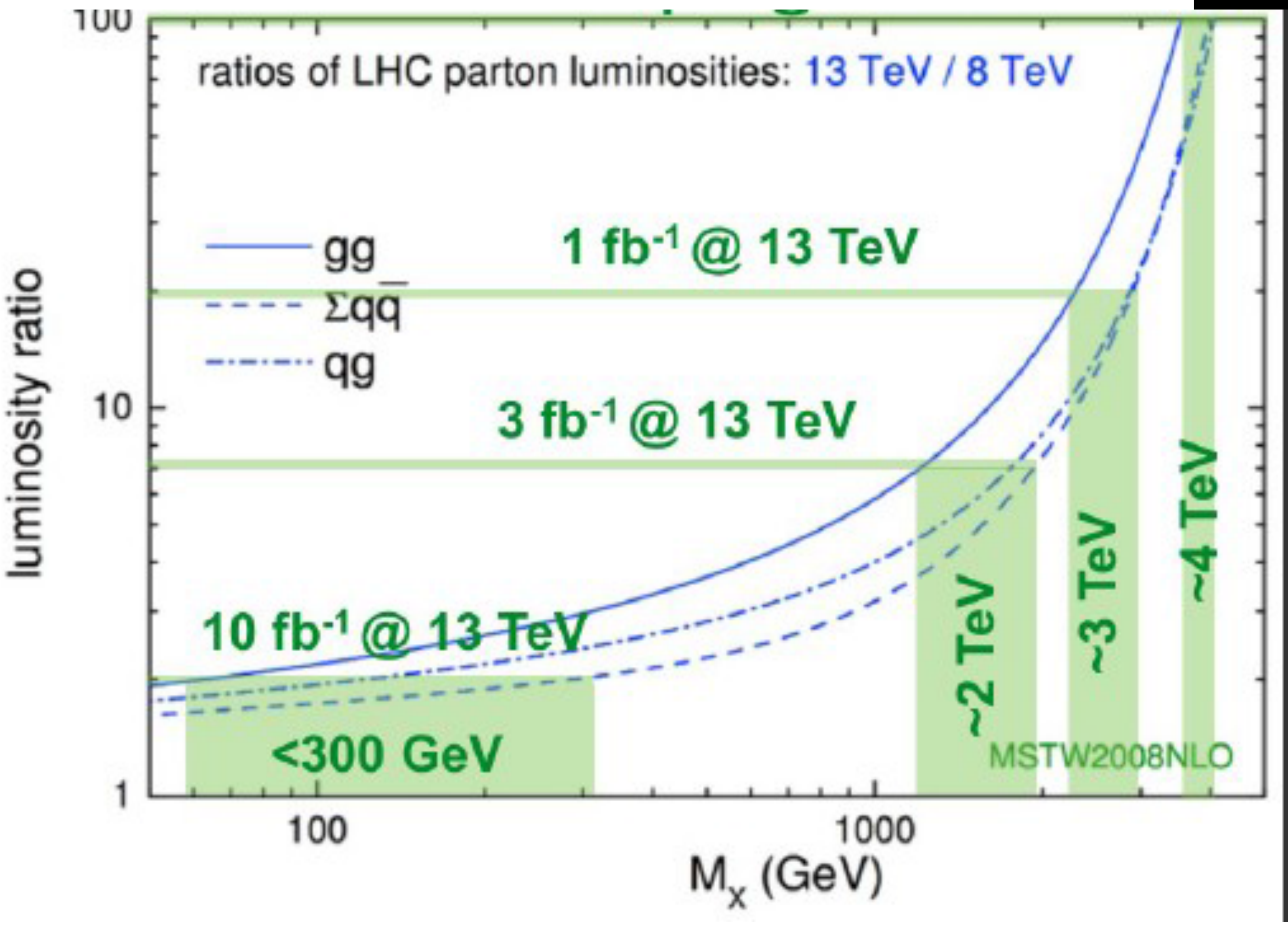
- Searches for rare states and rare decays still need the FULL event to take advantage of *new algorithms* (e.g. new MuonId)

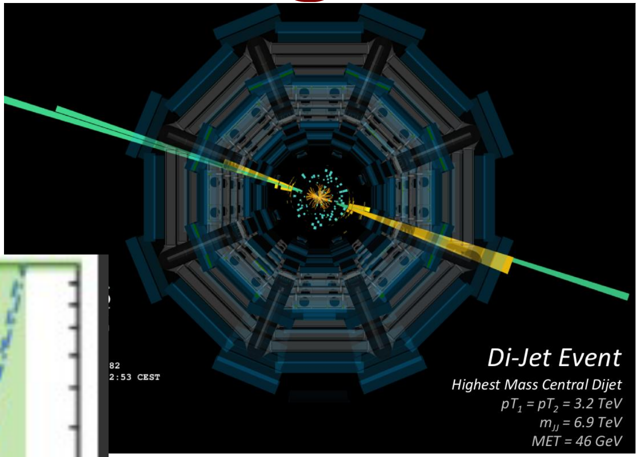
Calibration

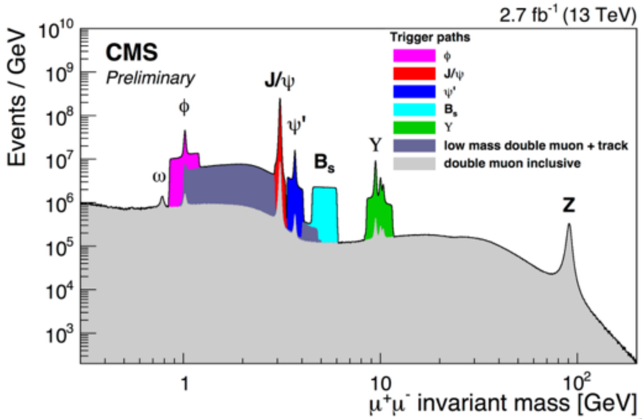
- New algorithms have to be **developed and calibrated**, online performance (efficiency, rejection power) has to be measured.



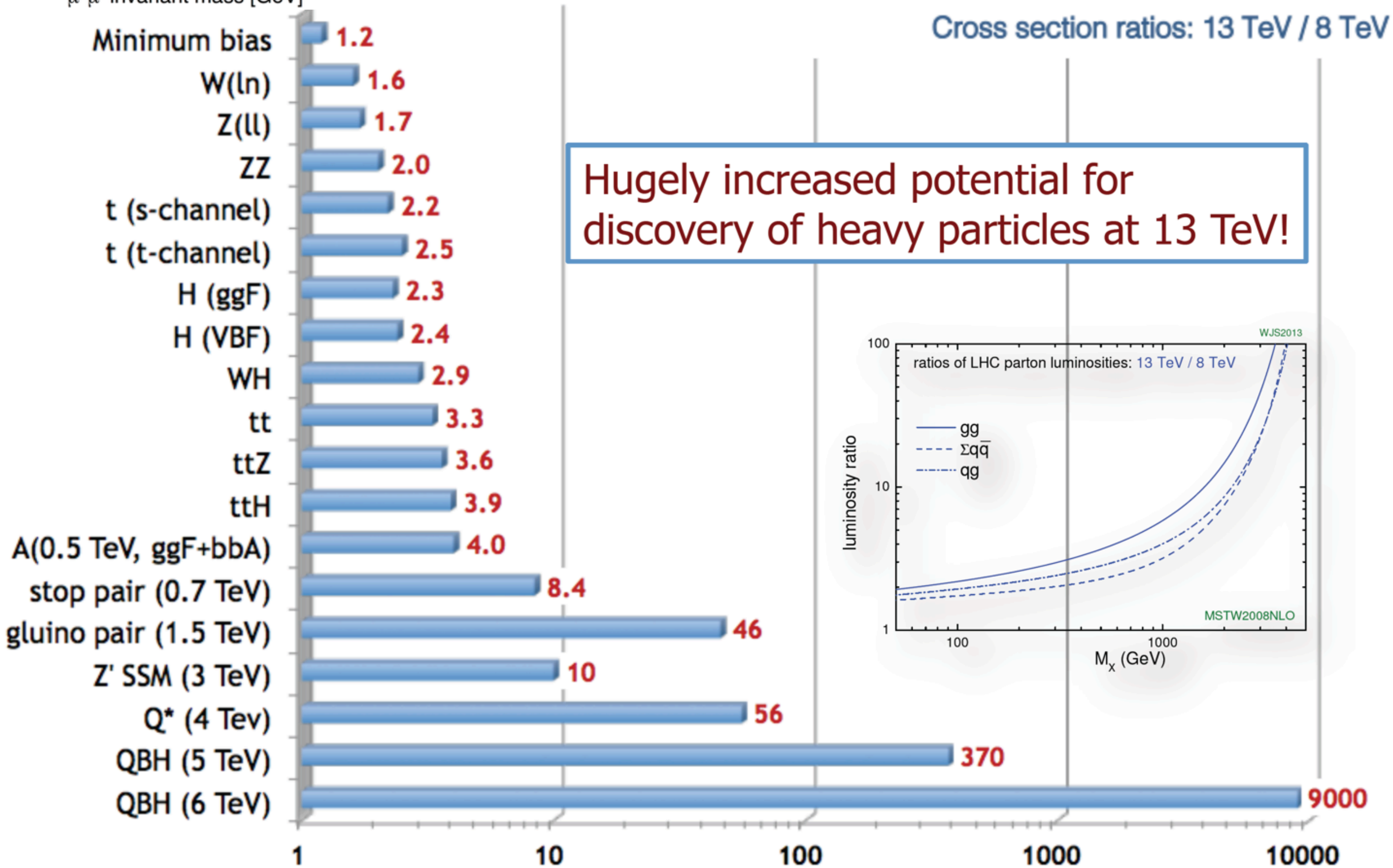
La nuova frontiera dell'energia





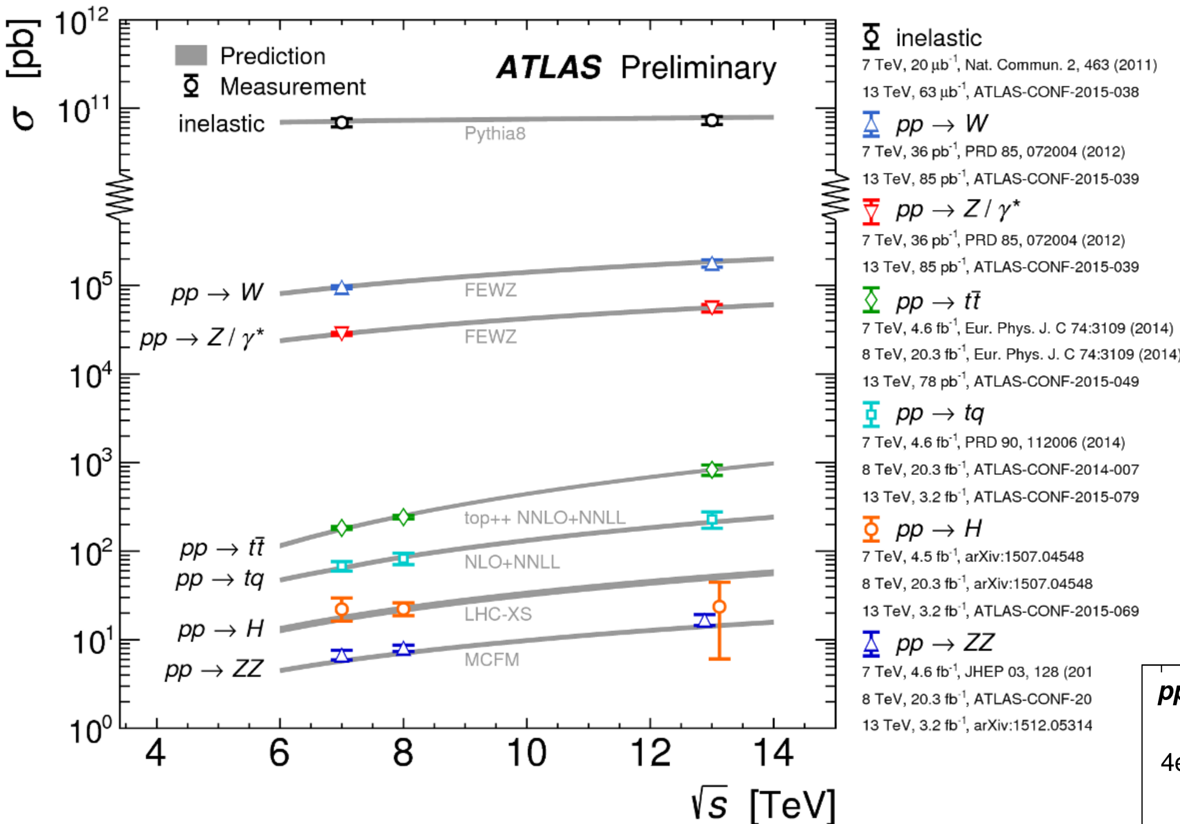


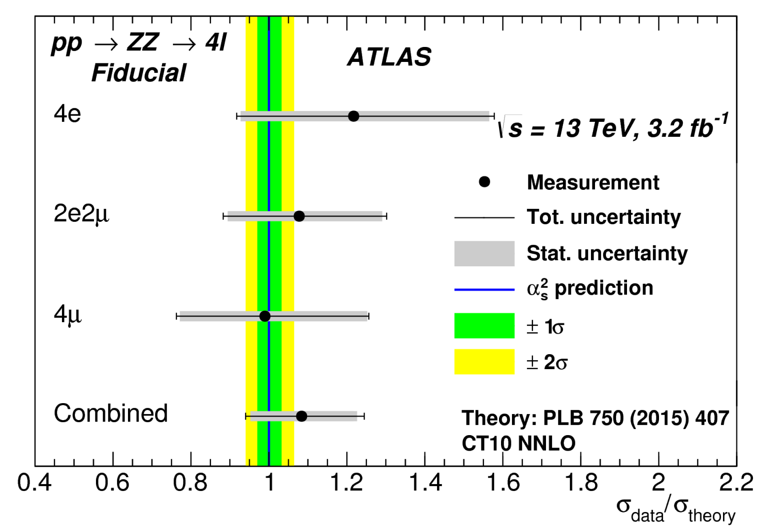
Quali potenzialità?



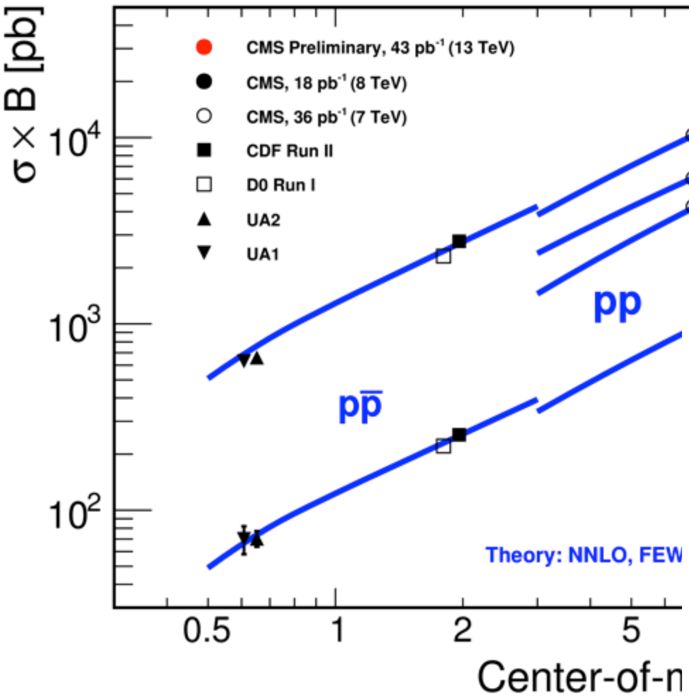
Hugely increased potential for discovery of heavy particles at 13 TeV!

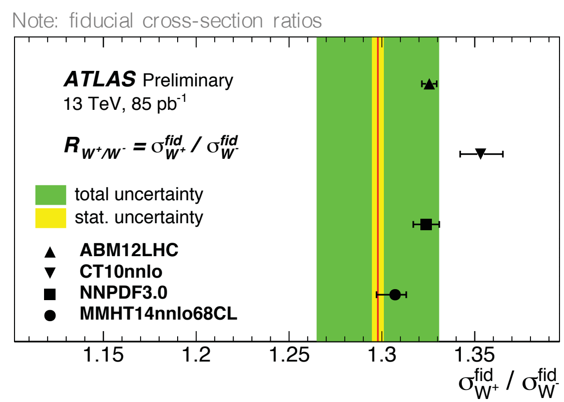
Sezioni d’urto inclusive

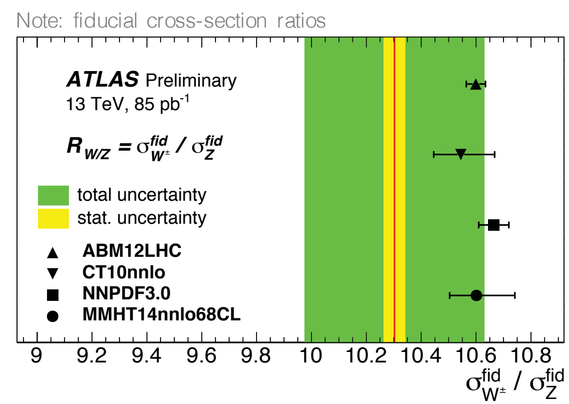


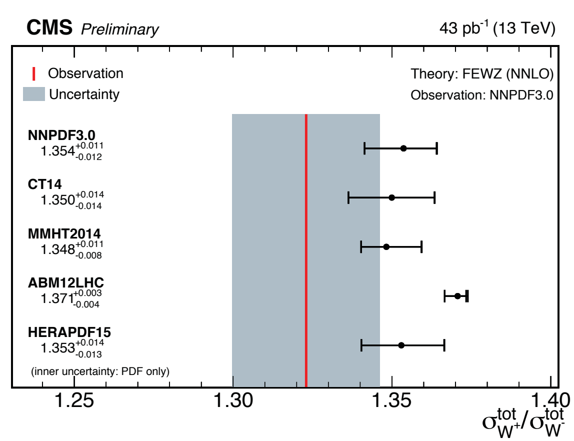


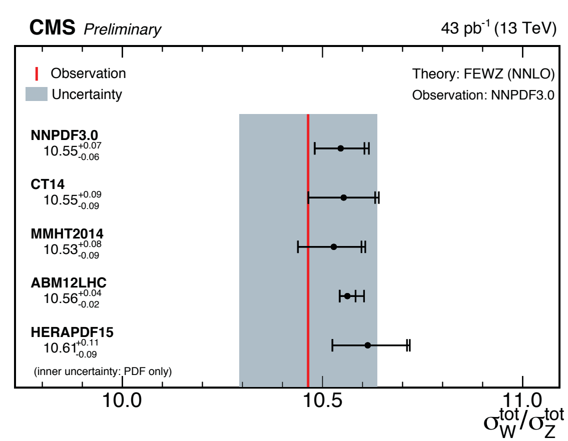
Produzione di bosoni singoli @ 13 TeV





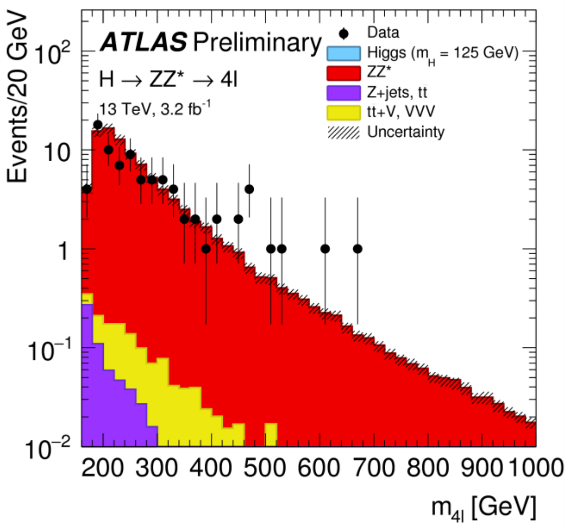


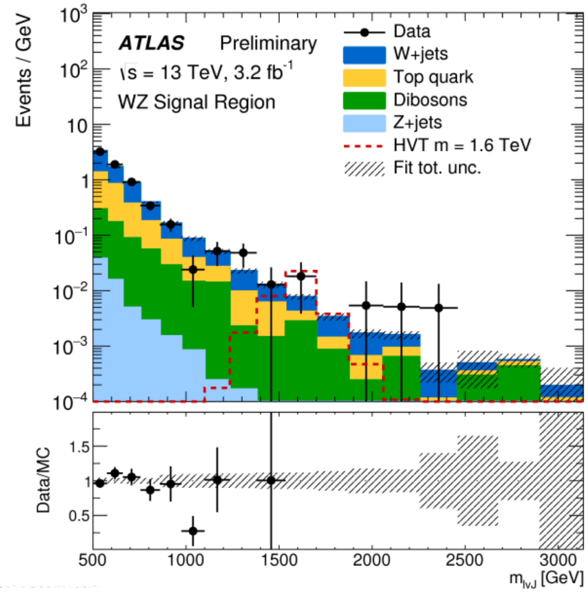


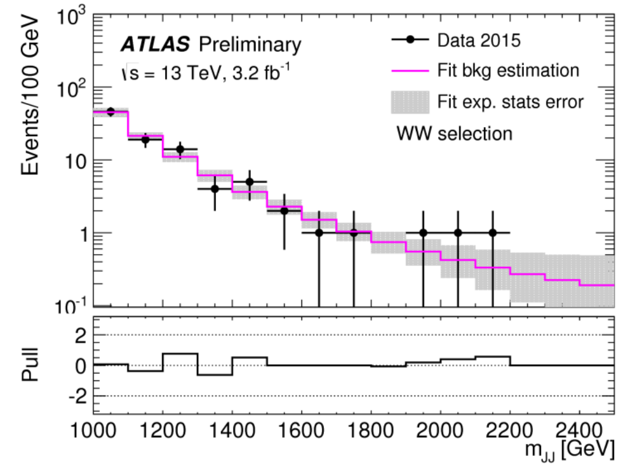


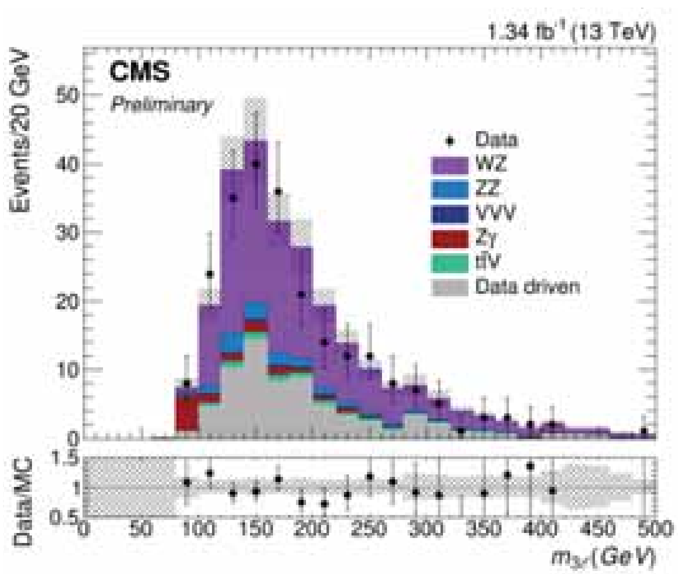
Also: LHCb σ_Z ($2.0 < \eta < 4.5$) in agreement with SM (PDFs)

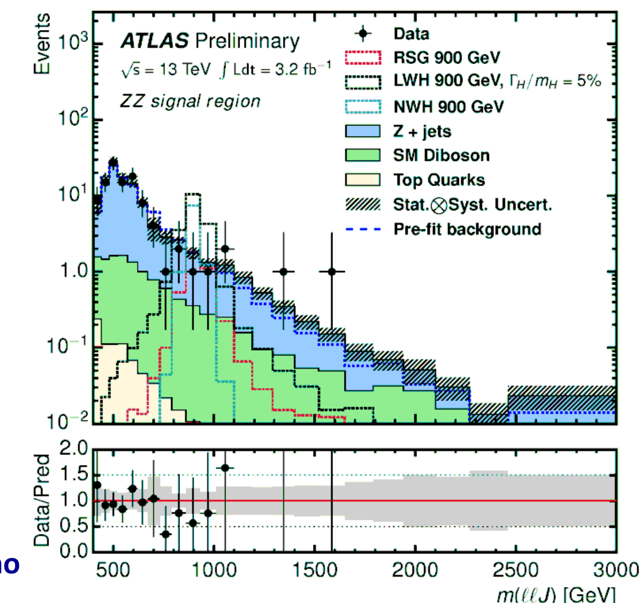
Produzione di di-bosoni @ 13 TeV



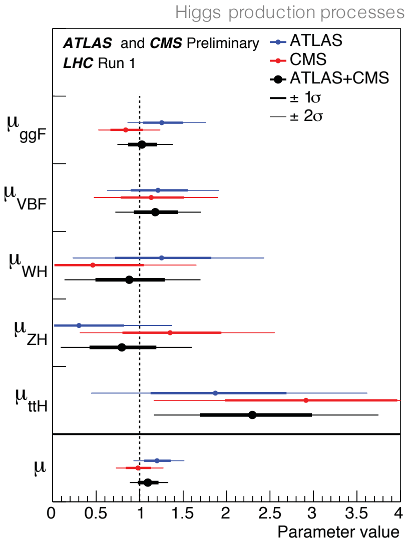




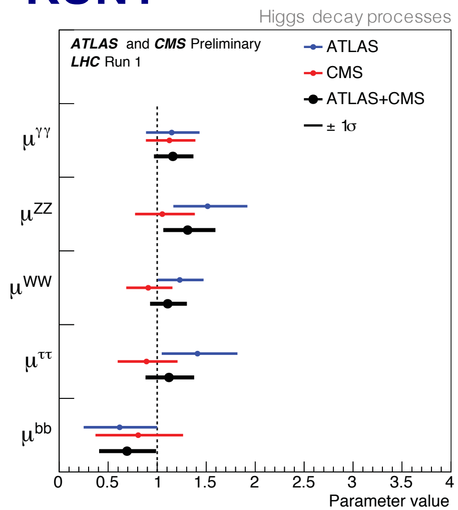




Higgs @ 13 TeV



RUN1



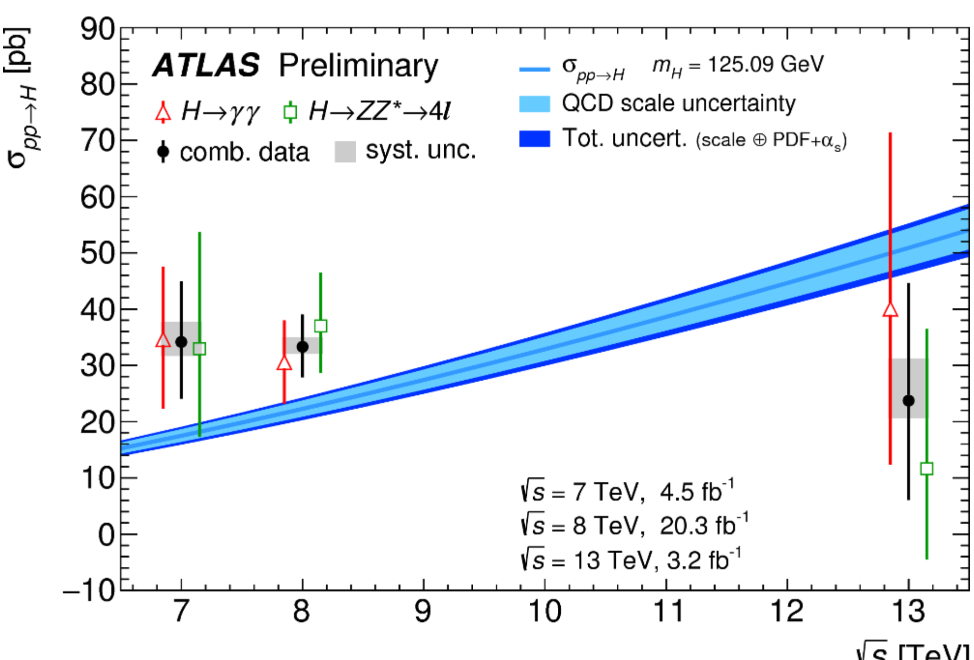
ATLAS

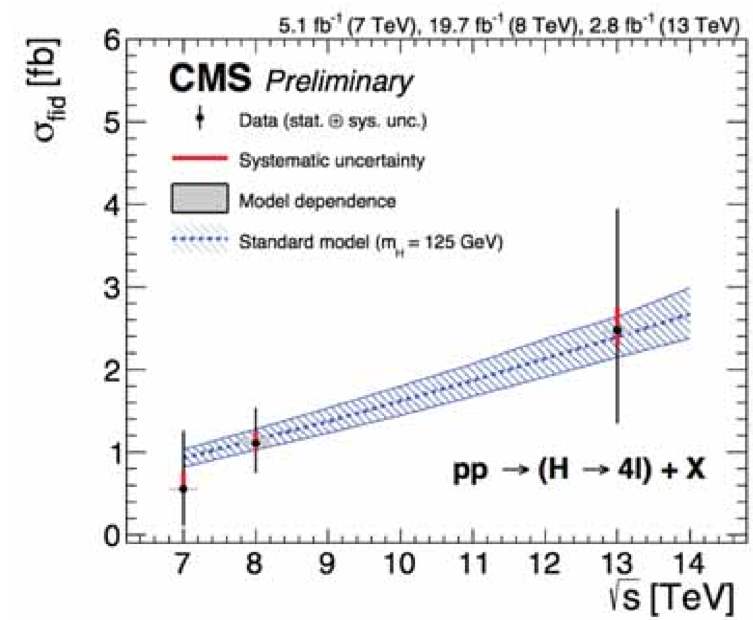
Canale γγ: osservata significanza 1.5σ attesa 1.9σ

Canale 4 leptoni: osservata significanza 0.7σ attesa 2.8σ

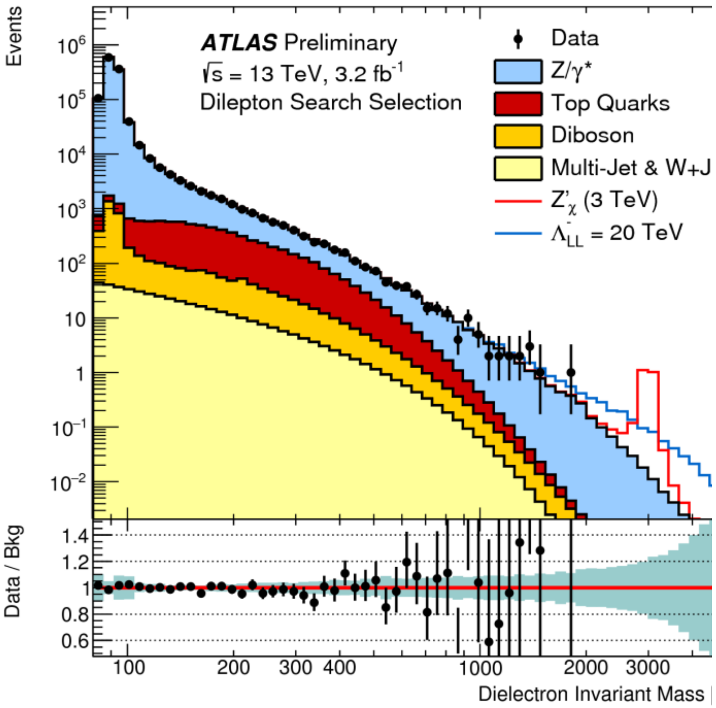
Compatinbilità combinata con SM 1.3σ

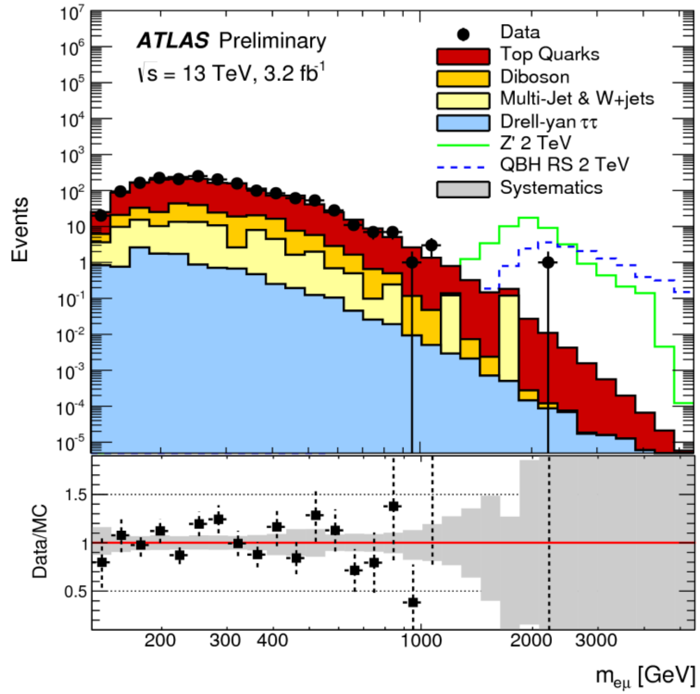
MANCA analisi *WW e altri dati !!!!*



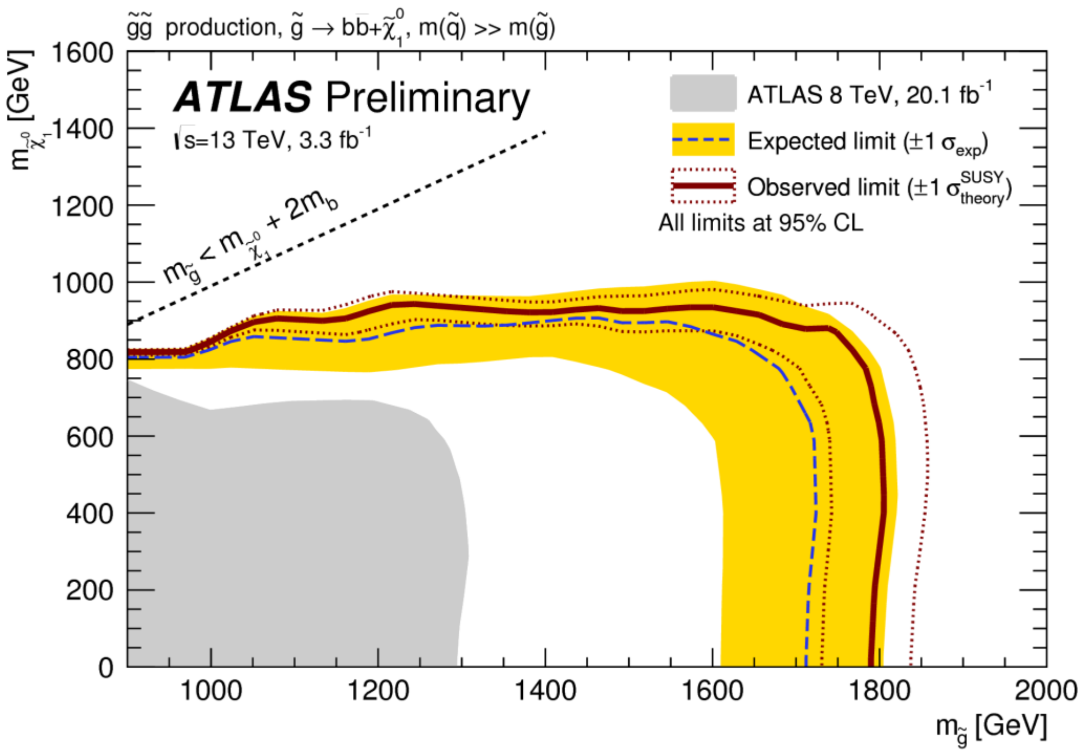


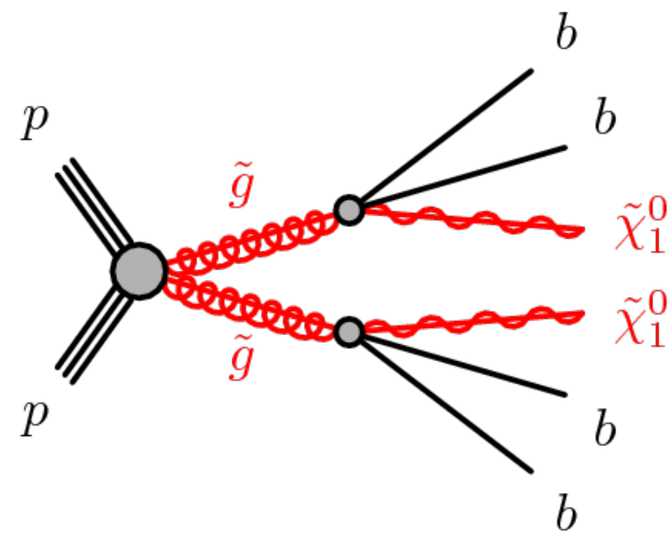
Ricerca nel canale di-leptoni @ 13 TeV

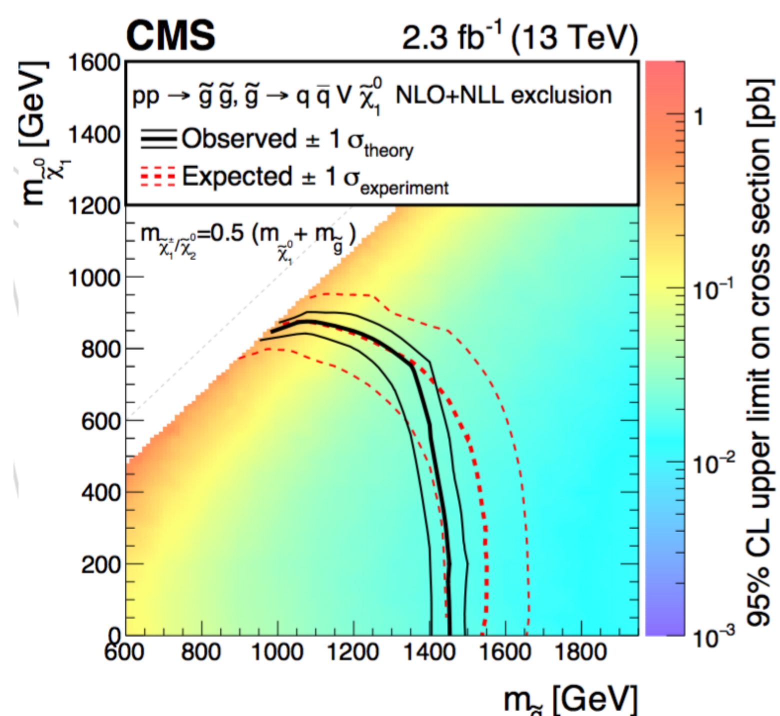




Ricerca: getti + massa mancante @ 13 TeV

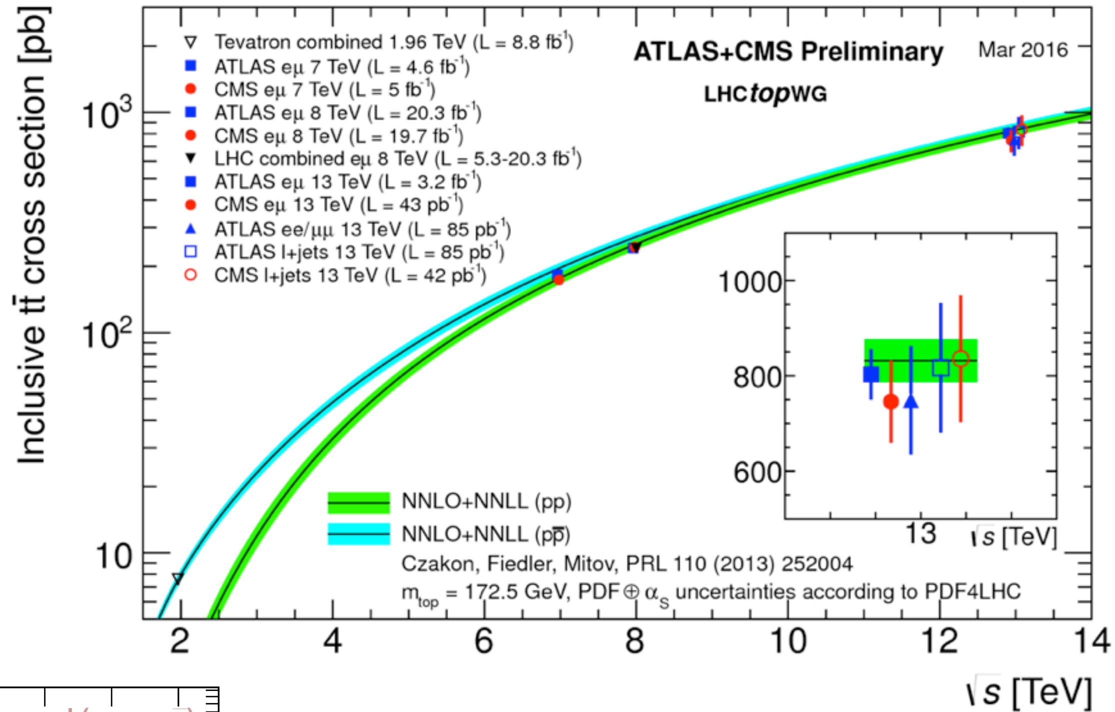


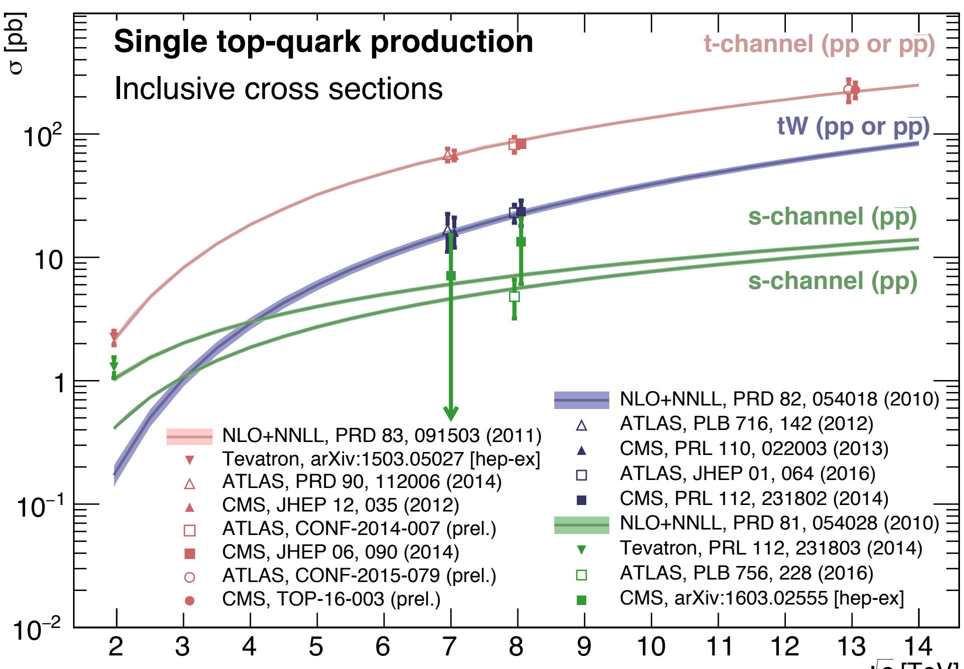


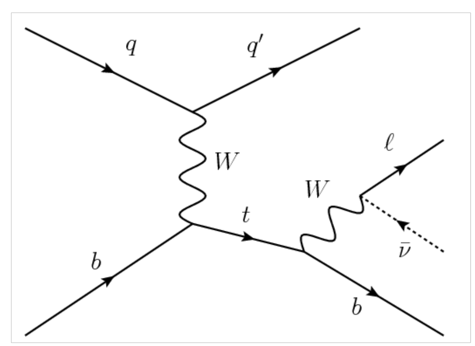


Top @ 13 TeV

Sezione d’urto inclusiva ttbar



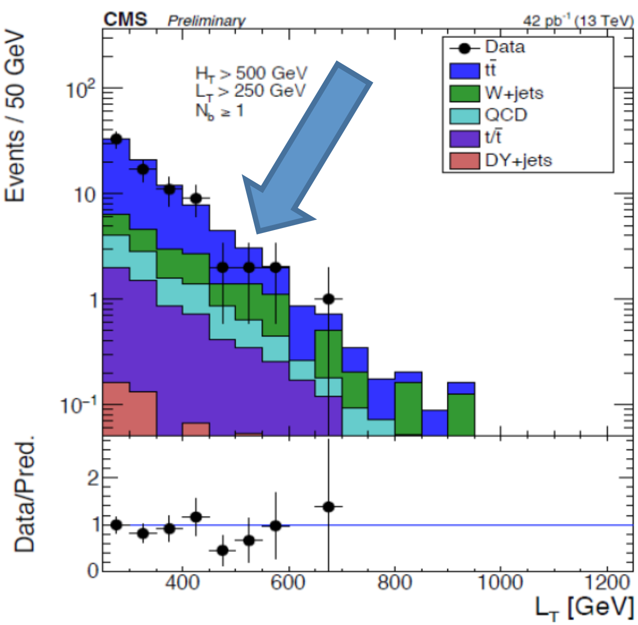


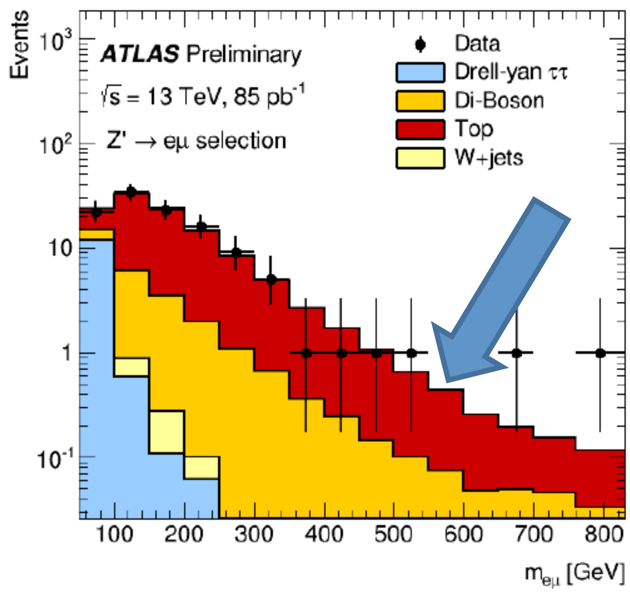


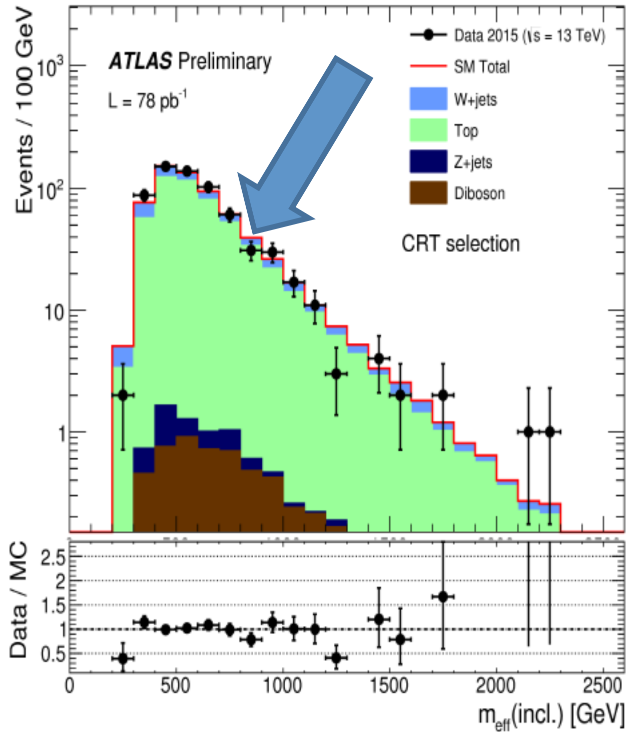
Courtesy Andrea Giammanco

Ricerche BSM @ 13 TeV

Tagli laschi per validare i dati



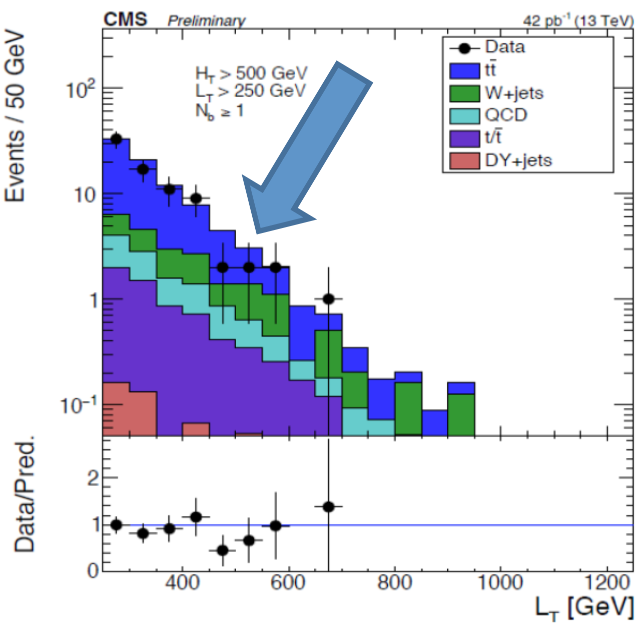


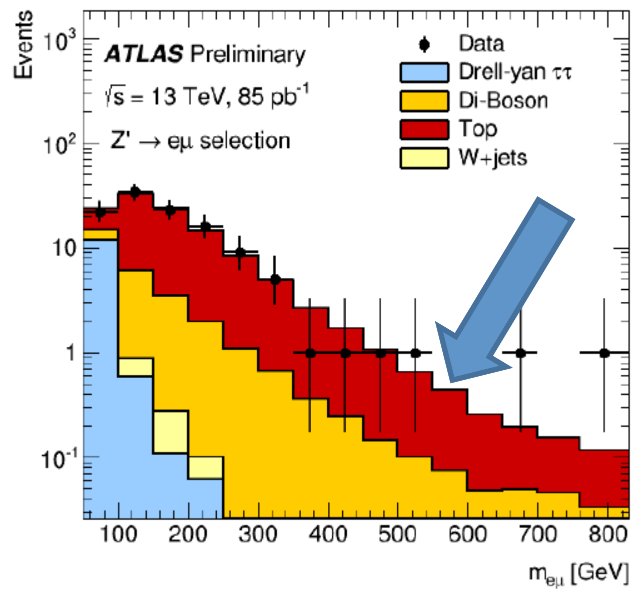


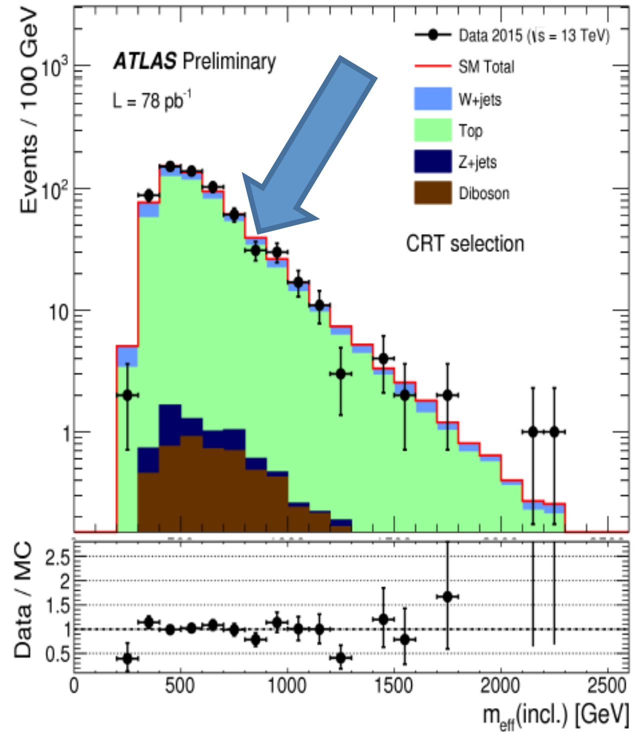
Top : importante fondo alle ricerche BSM

Ricerche BSM @ 13 TeV

Tagli laschi per validare i dati



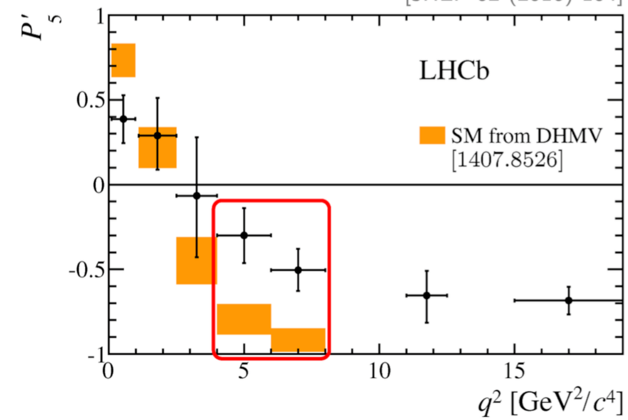




Top : importante fondo alle ricerche BSM

B mesons as search tool for NP

[JHEP 02 (2016) 104]



Where do we stand with K*μμ?

A small recap:

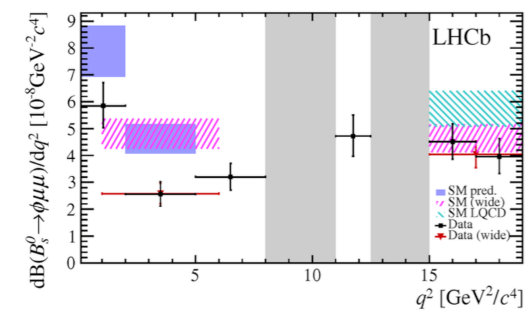
LHCb has a >3σ discrepancy in the P_5' variable (combination of spin amplitudes):

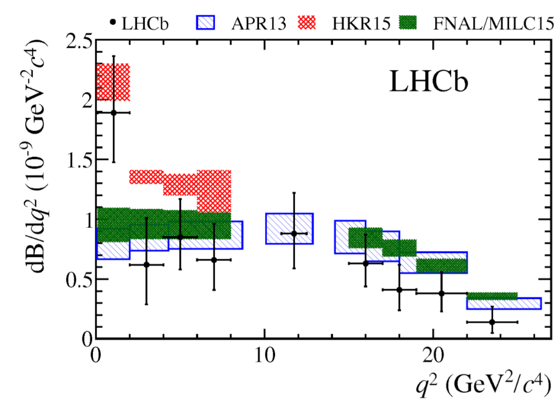
NP or imprecise calculations?

LHCb continued to look into close relatives to find any common sign:

- Φ(KK)μμ: accessible spin amplitudes compatible with SM, dB/dq^2 a bit low (but it's a general trend)
- πμμ: dB/dq^2 compatible sith SM, just a bit low (but it's a general trend)

[JHEP 09 (2015) 179]





Now waiting for:

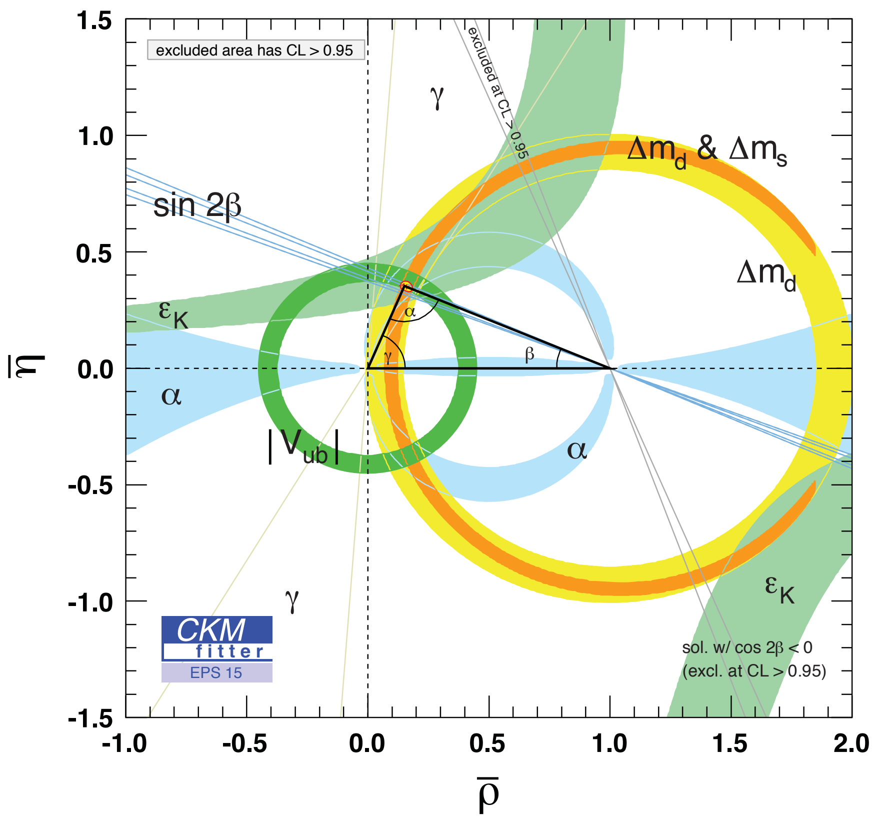
- CMS, ATLAS (promised to look into it)
- improved hadronic corrections in SM

Jeroen van Tilburg

The CKM matrix and more

Long-term effort to overconstrain CKM matrix continues. Huge contributions from LHCb

A precise measurement of γ (tree) together with sin(2β) (mix) or $|V_{ub}|$ (tree), fixes the unitarity triangle. All other measurements probe these two.

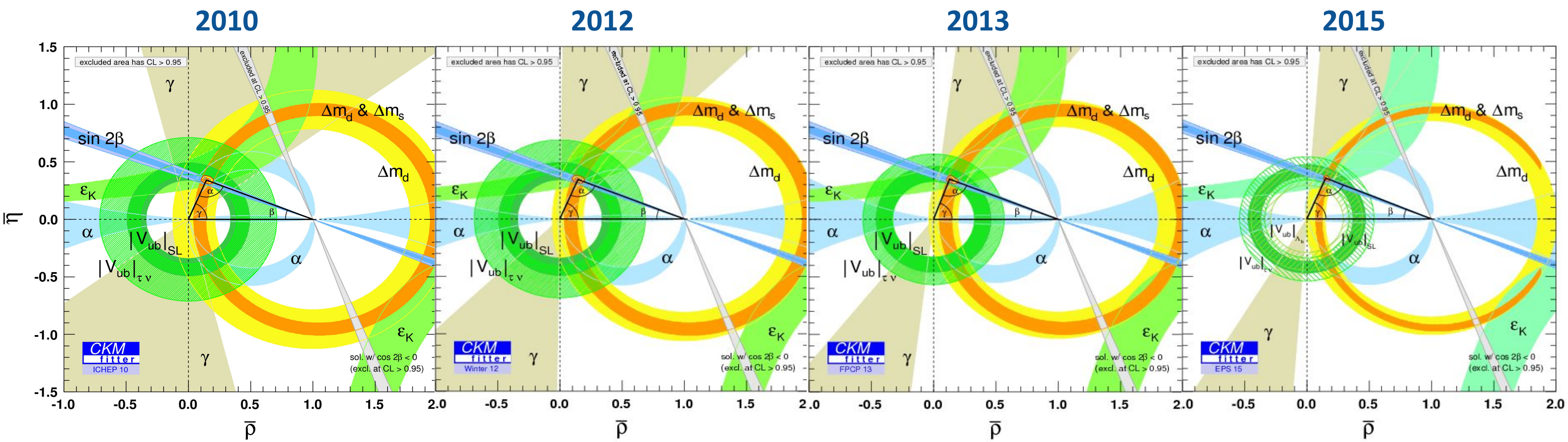


LHCb reported:

- $|V_{ub} / V_{cb}|$ from $\Lambda_b \to p\mu\nu$ at 5% precision (closer to exclusive B-factory result)
- World's best single Δm_d measurement: $0.5050 \pm 0.0021 \pm 0.0010$ ps^{-1} (B-factories: $\sigma_{ave} = 0.005$ ps^{-1})
- Precision on sin(2β) approaches that of B-factories: $0.73 \pm 0.04 \pm 0.02$
- World's best constraints on CP violation in $B^0_{(s)}$ mixing (a_{sl}^s, a_{sl}^d) in agreement with SM (D0 sees 3.6σ deviation)
- Search for CPT violation (difference in mass or width) in $B^0_{(s)}$ system, measurement of sidereal phase dependence of CPT violating parameter

Goal: dimezzare errore su γ

LHCb is among the major contributors (in the last few years) constraining the parameters, angles and sides, of the *bd*-triangle, as evident from the evolution of the global fit (taken here from CKM fitter)



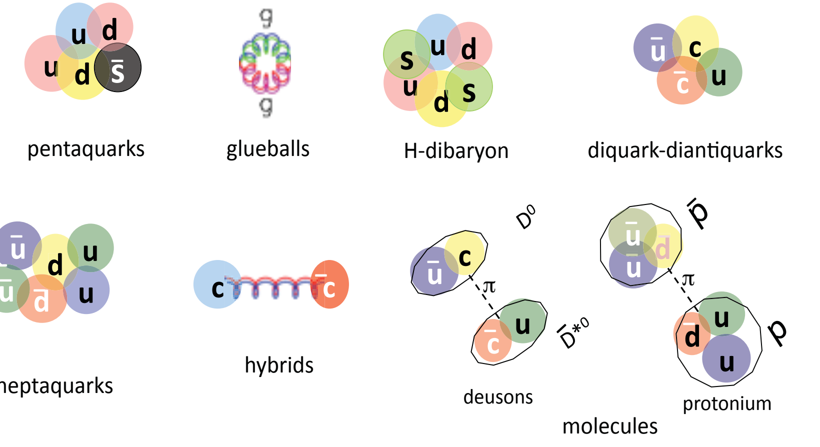
The constraint on the angle γ was improved significantly, but it is still the less stringent.

Jeroen van Tilburg

Hadron zoo: XYZ mesons

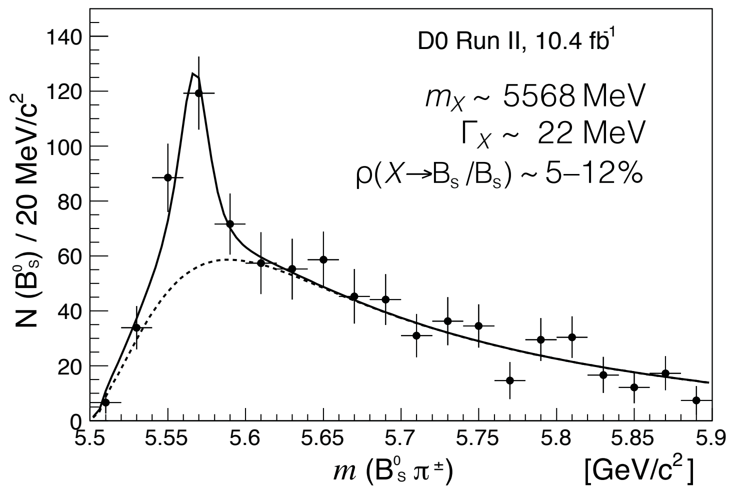
Topic of Moriond QCD, only this much…

non-$q\bar{q}$ & non-qqq color-singlet combinations

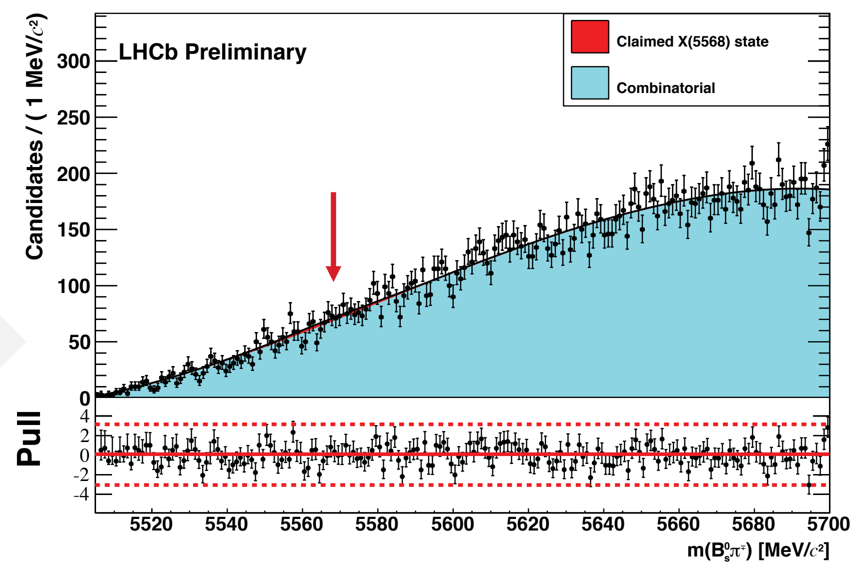


Picture from Stephen Lars Olsen, La Thuile 2016

D0 announced new state in $m(B_s(\to J/\psi\,\phi)\,\pi^{\pm})$ spectrum which may be a tetra-quark (*bsud*) [1602.07588, Feb 2016]



Prompt cross-check by LHCb did not confirm the observation in 20 times larger B_s sample. Upper limit on ρ ~ 1%, but this may depend on beam/energy/analysis. No public material yet, but more information expected this week.



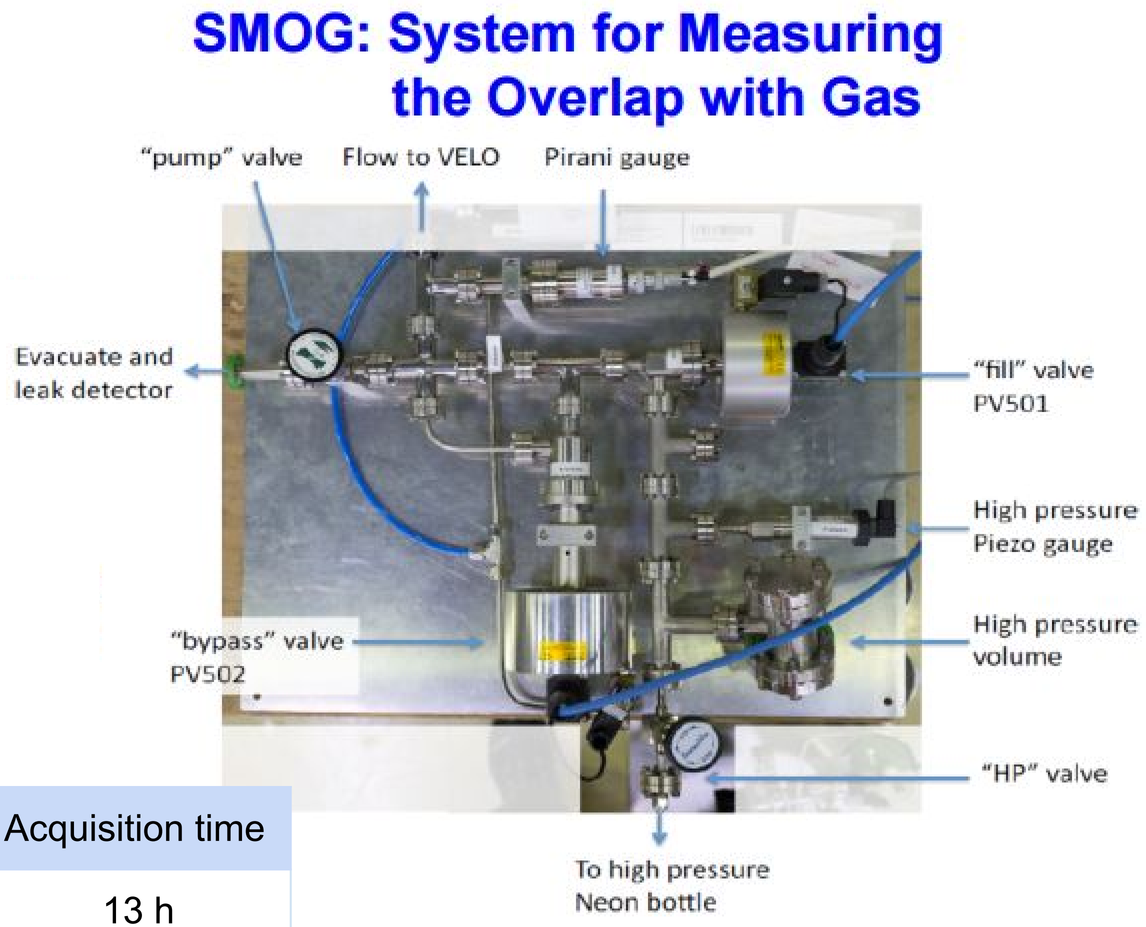
Other experiments are also looking

LHCb as fixed-target experiment: SMOG

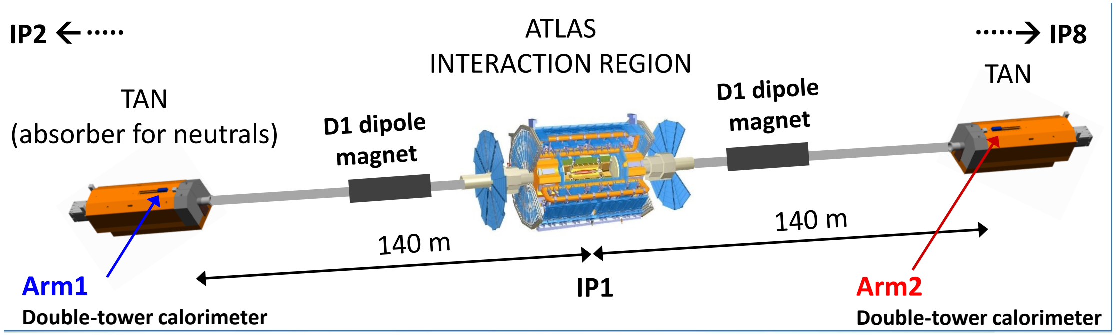
SMOG allows to inject gas in the beam-pipe close to the VELO region.

Scientific motivation:

- Sensitive probes of nuclear structure
- Cross-section measurement of $pHe \longrightarrow \bar{p}X$, dominant systematic uncertainty in dark matter searches with antimatter in cosmic rays.

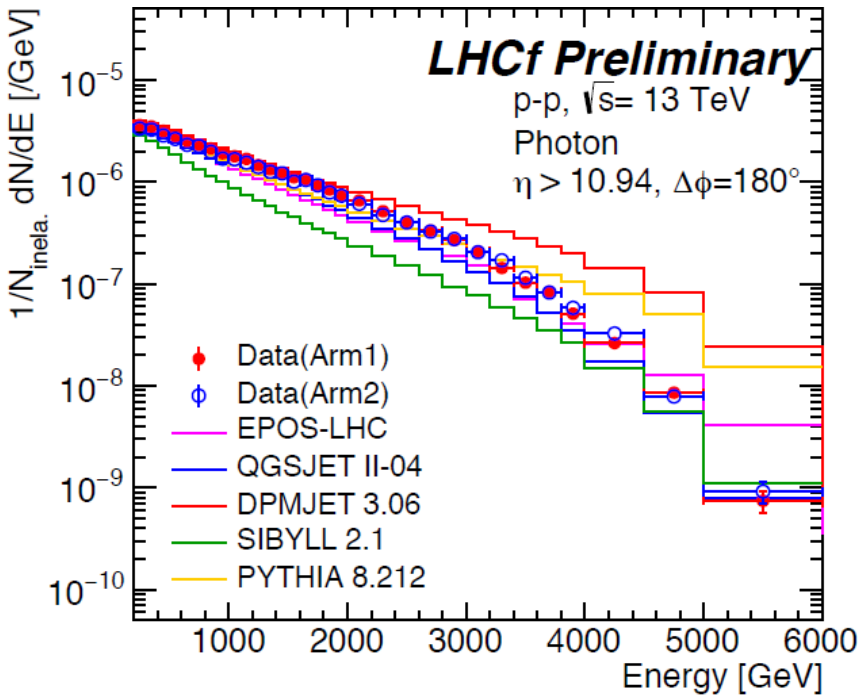


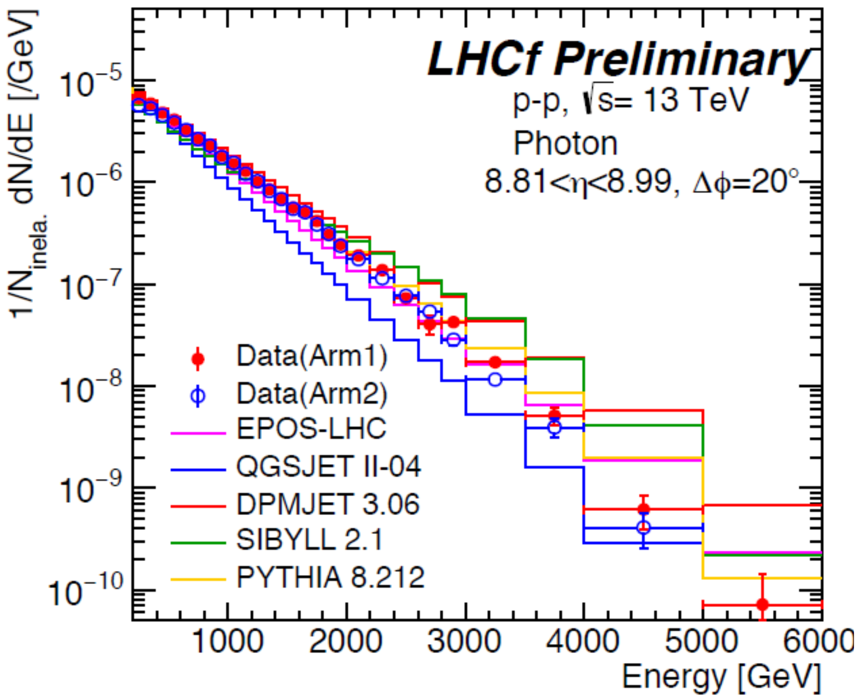
	$\sqrt{s}$ [GeV]	Date	Acquisition time
pNe	110.4	Aug. 25/26	13 h
pHe	110.4	Sept. 8	8 h
pAr	110.4	Oct. 15-18	29 h



LHCf

- Possibility to study particles in the **forward direction** at LHC (neutrals: γ, π^0, n)
  - Forward secondary particles carry a great fraction of the primary energy
- 6.5 TeV + 6.5 TeV in the LHC frame → **~10^{17} eV** in the laboratory frame (LAB)
- Calibration of **hadronic interaction models** used for the simulation of atmospheric showers





Error bars show only the statistical errors.

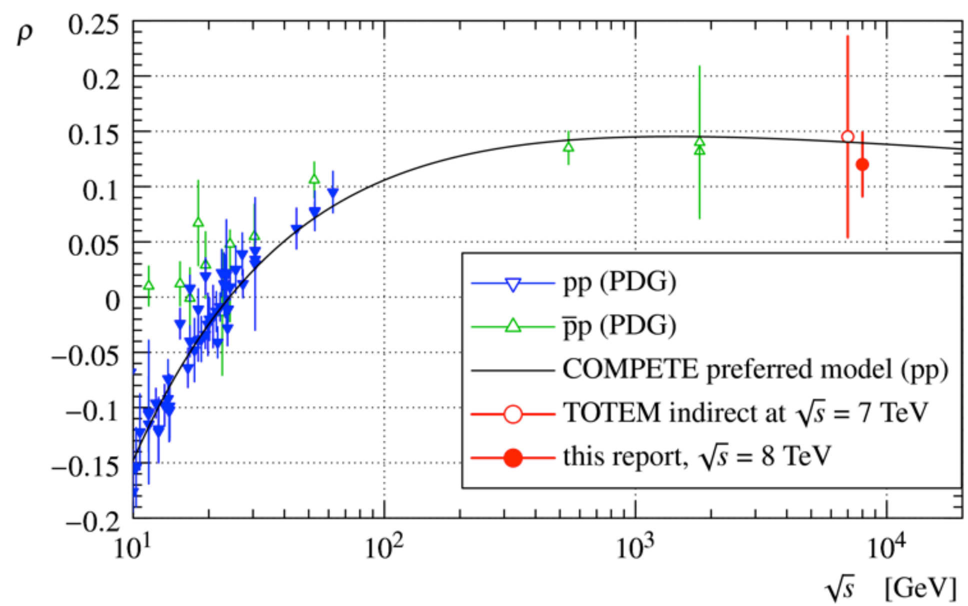
CMS-TOTEM @13 TeV (β^* = 90 m)

- ✓ Independent DAQ
  Level 1 Trigger exchange Offline merging
  - Totem LV1 Rate ~ 50kHz → recorded
    ~ $3 \cdot 10^9$ events collected!
  - CMS HLT Rate ~ 10kHz → recorded
- ✓ Elastic $>10^9$ (Totem standalone)
- ✓ Low Mass DPE ~$100 \cdot 10^6$ events (Totem-CMS)
  - Merged and analysis ongoing.
- ✓ Double arm Top-Top, Bottom-Bottom trigger ~$200 \cdot 10^6$ events, missing mass searches.
  - Merging ongoing
- ✓ Dijets pT~ 20 GeV – pT ~ 32 GeV, DiMuon, SingleMu & HF gap ~ $40 \cdot 10^6$ events
  - Merging ongoing

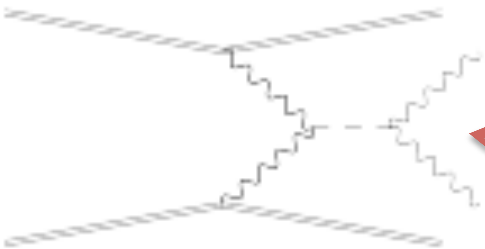
Totem β^*=2500m run speciale 2016

Measure elastic scattering in Nuclear-Coulomb interference region at 13TeV

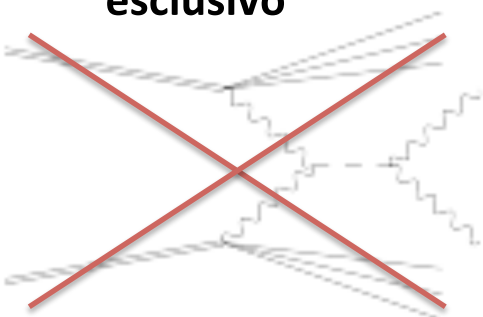
- ✓ Search for 3 gluon $J^{PC}=1^{--}$ state
- ✓ Already in the 8 TeV data we observed ~2-3 σ effect
  - Non exponential behavior at low |t|
  - Lower ρ value at higher energy.



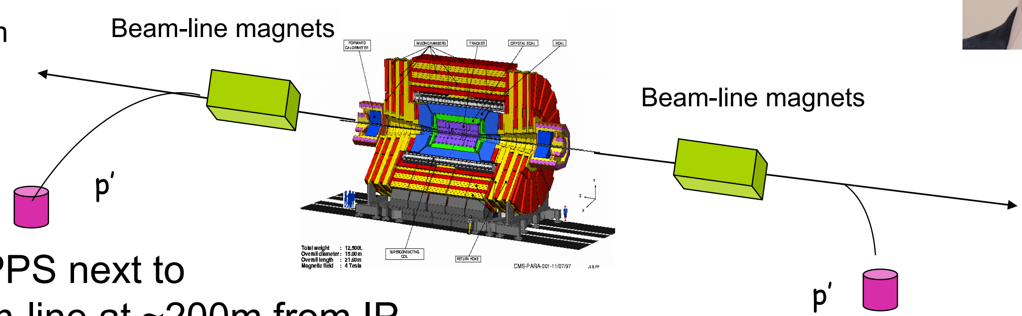
CMS-TOTEM
Precision Proton Spectrometer
(CT-PPS)



esclusivo



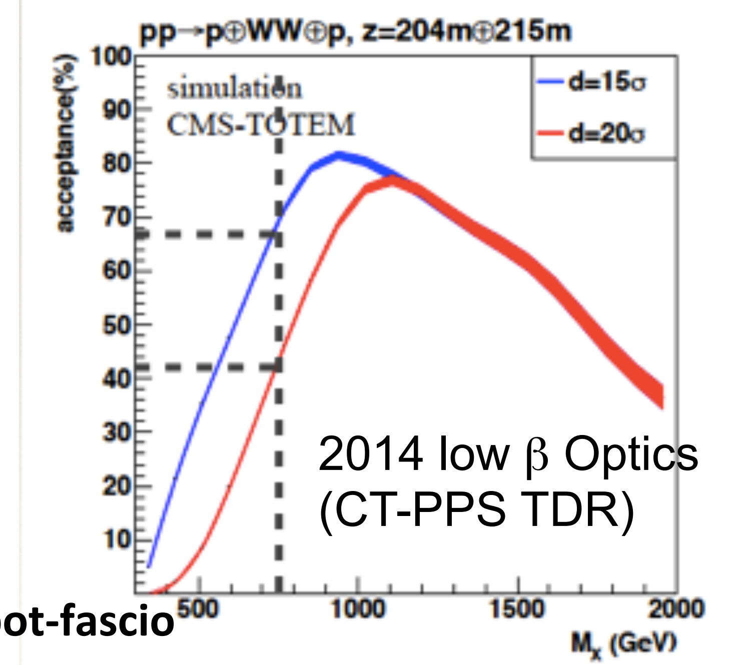
inelastico



CT-PPS next to
beam-line at ~200m from IP

CT-PPS next to
beam-line at ~200m from IP

- Si Strip Trigger da TOTEM a CMS
- Timing con diamanti in preparazione



- Possibile candidato γγ a 750 GeV può essere prodotto in modo esclusivo e visto in CT-PPS
  - Fichet, von Gersdorff, Royon (arXiv:1601.01712, arXiv:1512.05751)
  - Csaki, Hubisz, Terning (arXiv:1512.05776, arXiv:1601.00638)
  - Harland-Lang, Khoze, Ryskin (arXiv:1601.07187)

- Programma di fisica a CT-PPS:
  - di-Jet esclusivo
  - Coupling quartico anomalo

accettanza massa pp
in funzione distanza pot-fascio

First things first: the 750 GeV bump

Changes presented in the last two weeks

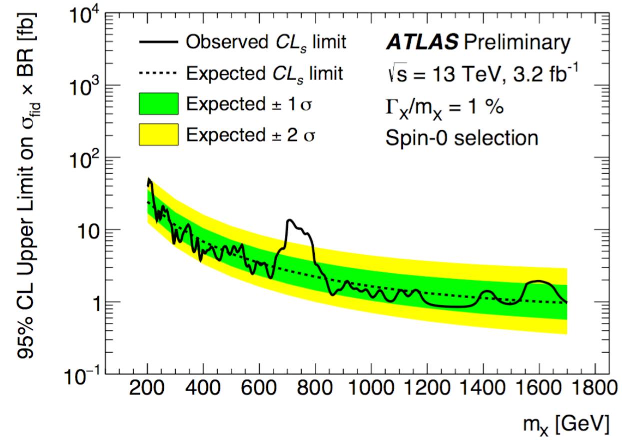
ATLAS:

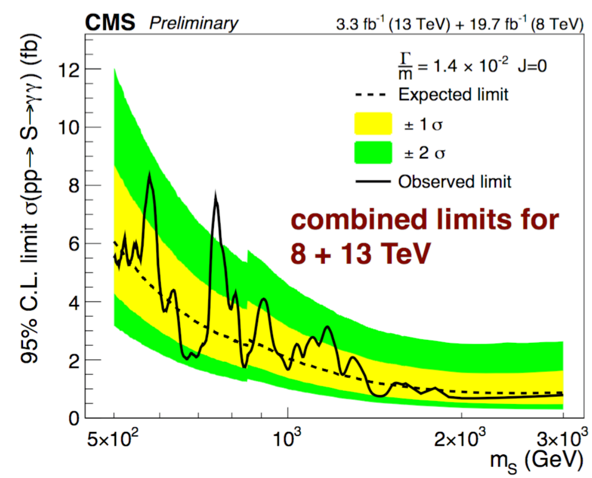
- new analyses (separate for spin-0,spin-2)
- new calibration (from final 2012)
- combination with Run1

CMS:

- re-reco with new calibrations (10% sensitivity increase)
- spin2 and spin0 hypotheses tested (same analysis)
- Added 25% statistics from BField-off

	spin 0 Local	spin 0 global	spin2 Local	spin 2 Global
Atlas (13 TeV only) - width 6%	3.9σ	2.0σ	3.6σ	1.8σ
CMS (13 TeV+8TeV) narrow width	3.4σ	1.6σ	~3.4σ	~1.5σ





The Gold Rush: [INSPIRES][list]

Date	papers
16 Dec	10
25 Dec	101
1 Jan	137
1 Feb	212
1 Mar	263
1 Apr	?

Conclusioni

- ATLAS e CMS hanno già pubblicato > 1000 lavori, LHCb > 300 lavori…
- La maggior parte delle misure finora sono in accordo con il Modello Standard ….
- …. si è appena aperto però un nuovo territorio di esplorazione

- Finalmente LHC si avvicina ai parametri di disegno in energia e luminosità
- Il Run2 è appena cominciato ….
  da 4 fb^{-1} nel 2015 si vogliono accumulare 100 fb^{-1} per fine 2018

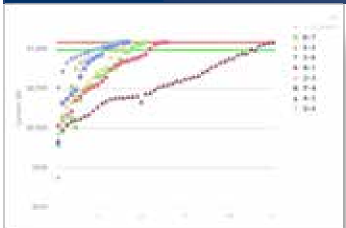
- LHC in fase di messa a punto, sara' pronto tra circa 4 settimane
- Anche gli esperimenti si preparano con cosmici, i primi splashes…
- Grande attività per migliorare gli apparati con i nuovi componenti di Fase1 e stesura TDR-Fase2 per HL-LHC
- Si comincia a discutere in vista della European Strategy per il 2019

- Periodo straordinario, di sfide tecnologiche, di intenso lavoro, di sforzi finanziari e umani... di grandissime aspettative!


Pronti?
VERSO UN NUOVO MONDO
Via!

Extra

2015 operation

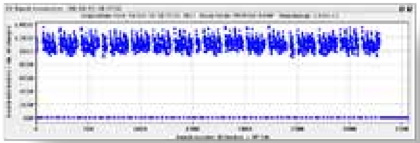


April 3,
End of powering tests – 150 quenches

April 10
First beam at

E: 6500 GeV

August 7,
Operation with 25 ns beam

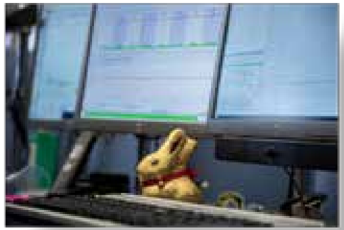


October 28,
Record no. bunches

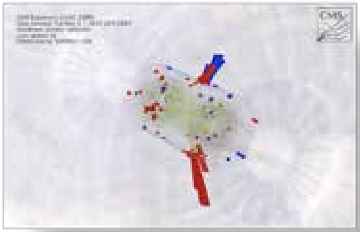
2244

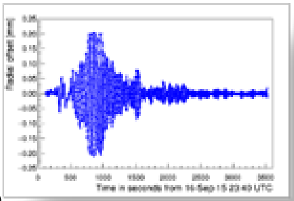
April | May | June | July | August | Sept | Oct | Nov | Dec

Easter,
Beam circulating



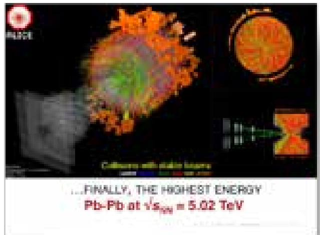
June 3,
Start of physics operation for run 2



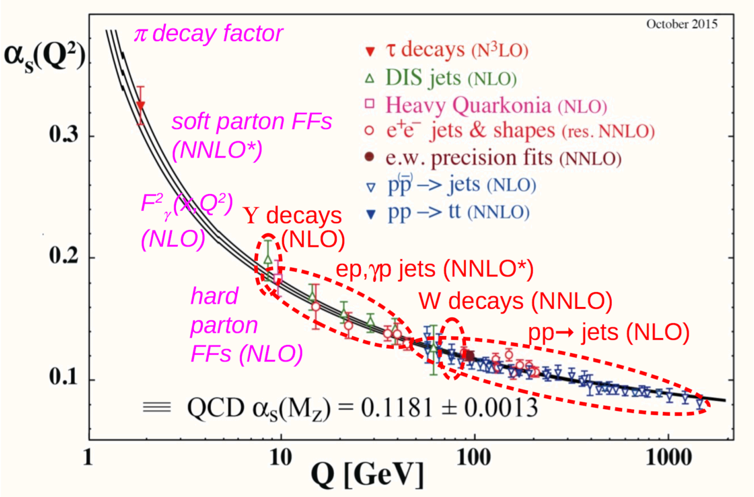


September 16,
Chili 8.3M earthquake shakes LHC rings

Nov-Dec,
Pb ion run



2. most of the uncertainties in searches for NP are related to precise determination of SM/QCD parameters:
   - α_S, PDFs, gluon content, MPI, V+jets distributions, single and di-boson productions,….

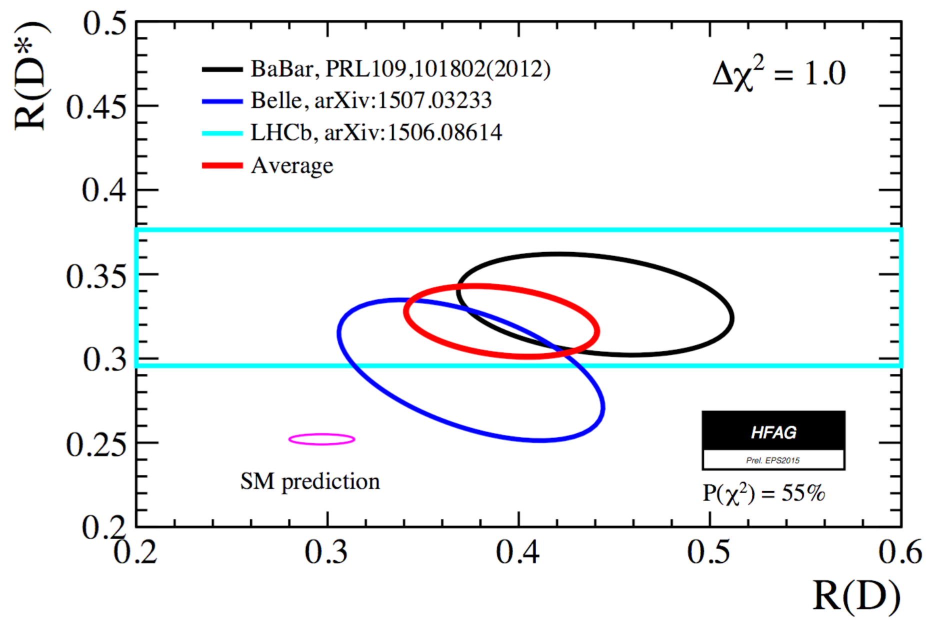


For details on α_S see Thomas' summary

LHCb

BABAR, Belle and LHCb observed excesses (>3σ) of B→ D(*)τν relative to B→ D(*)μν and B→D(*)eν.

$$R(X) = \frac{\Gamma(B \to X\tau\bar{\nu})}{\Gamma(B \to X(e/\mu)\bar{\nu})}$$



William James Barter

Inclusive W and Z production

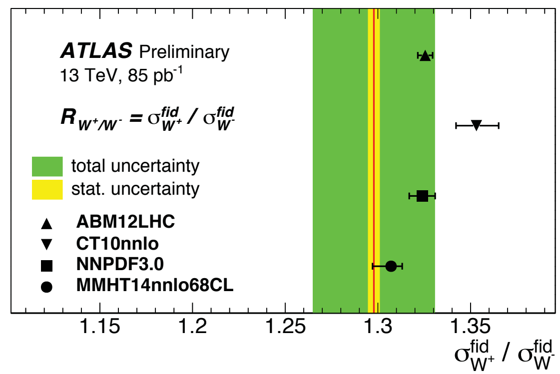
Very rich physics: strong PDF dependence, probes for QCD, precision electroweak physics

ATLAS, CMS & LHCb studied single gauge boson production at 7, 8, 13 TeV, LHCb covers complementary phase space in x, Q^2

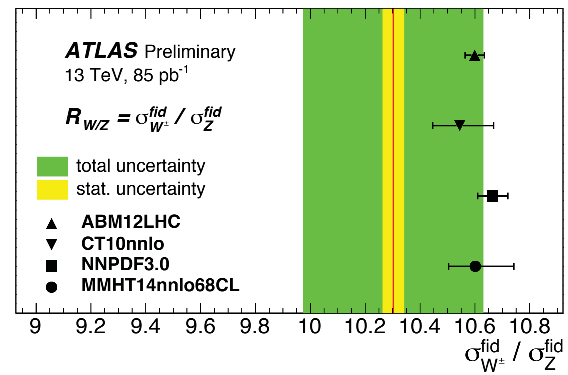
Leptonic decays of Z & W are also standard candles to verify and calibrate e/μ performance

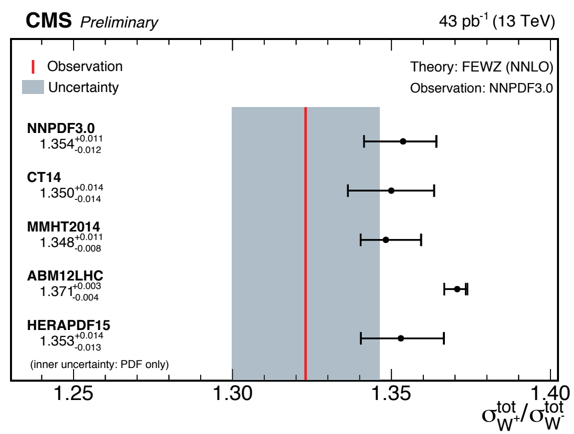
- 13 TeV W/Z cross section measurements (→ right plots)
- $p_T(Z)$ @ 8 TeV from ATLAS shows resummation needed at low p_T to describe data, NNLO below data at high p_T
- Charge asymmetry results by CMS and LHCb rather well predicted by theory
- LHCb high-rapidity cross sections well predicted with NNLO and PDFs
- 8 TeV Z → μμ angular analysis by CMS, sensitive to Z polarisation and decay structure

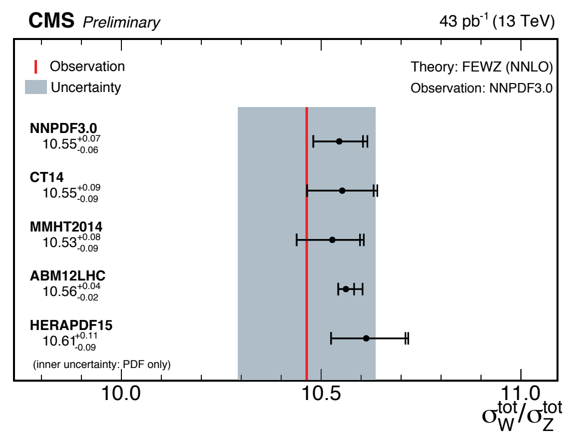
Note: fiducial cross-section ratios



Note: fiducial cross-section ratios







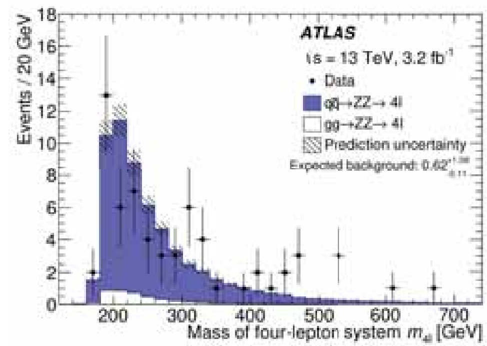
Also: LHCb σ_Z (2.0 < η < 4.5) in agreement with SM (PDFs)

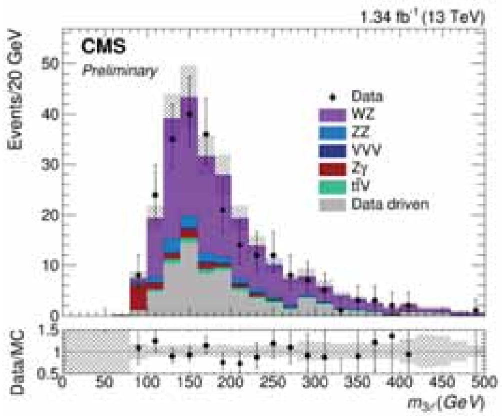
Diboson production

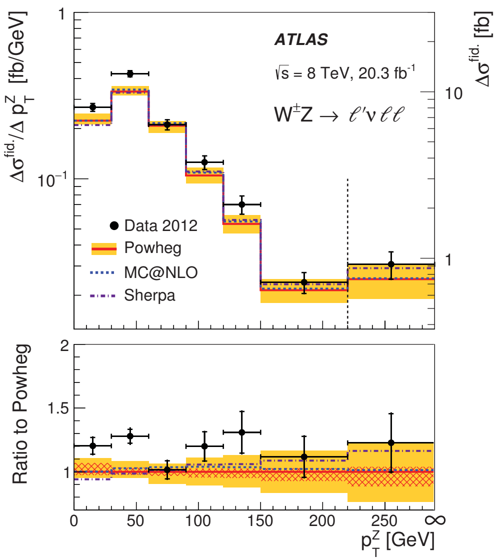
Highly important sector of LHC physics, intimately related to electroweak symmetry breaking

ATLAS & CMS studied diboson production at 7, 8, 13 TeV. Detailed inclusive, fiducial and differential cross-section analyses at 8 TeV. First 13 TeV results. Theoretical predictions at NNLO needed to match data.

- ZZ @ 13 TeV measured by ATLAS & CMS, WZ by CMS: all agree with SM
- WW @ 8 TeV cross-sections agree with SM NNLO + p_T resummation
- WZ @ 8 TeV by ATLAS shows deviations from SM (NLO only)
- Zγ @ 8 TeV by ATLAS & CMS, matched by NNLO SM predictions
- VBS: evidence in W^+W^+qq channel, new 8 TeV results on (W/Z)γqq (CMS), and WZqq (ATLAS), no observation yet
- Tri-boson process Wγγ & Zγγ observed by CMS, evidence for Wγγ by ATLAS
- Large set of anomalous coupling limits



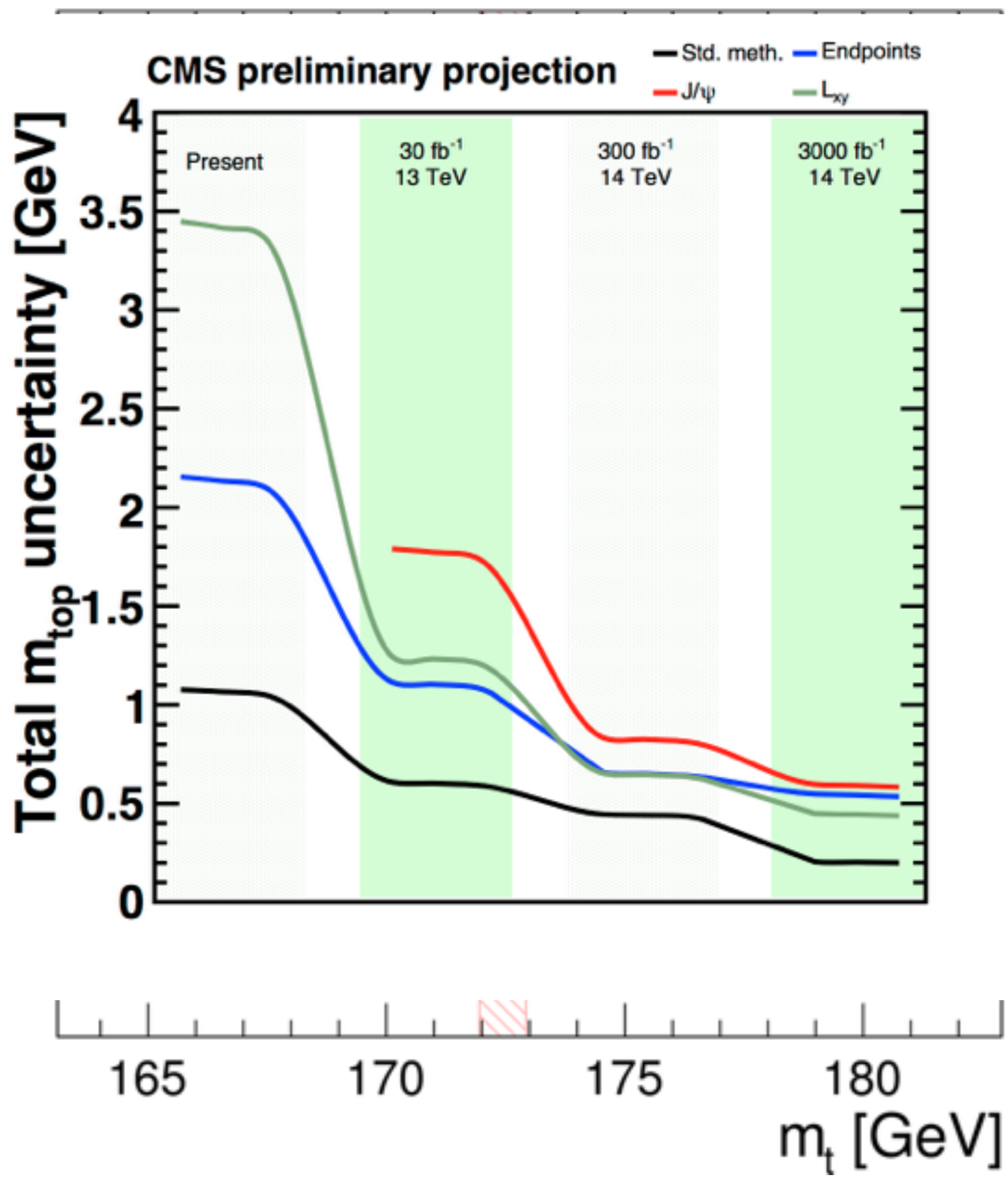




Each of these measurements in an experimental **tour de force**

Top mass
improving precision

- avoid double counting systematics
- re-calibrate in-situ (JES, …)
- minimize uncertainties by selecting (weighting) carefully the data



CMS, arXiv:1509.04044

500 MeV just crossed

Studies for the Muon Identification for the LHCb Upgrade

Exploring *Machine Learning* algorithms also in the reconstruction, already at trigger level,
combining in fast multivariate classifiers low-level detector quantities.

For example, a *Boosted Decision Tree* was developed for the muon identification combining

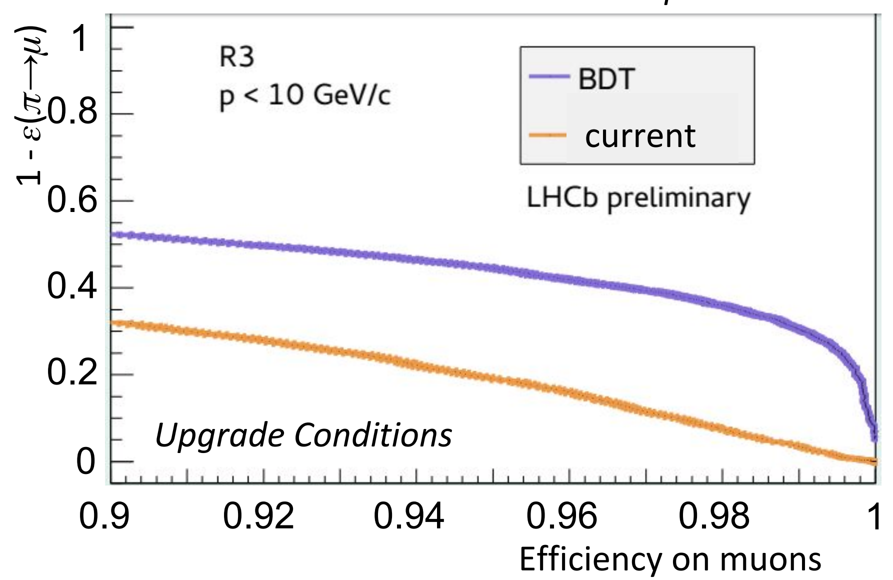
- discrepancy between measured hits and extrapolated tracks *(variable already used in current algorithms)*
- number of extrapolated tracks consistent with the hits relevant to the muon identification *(isolation)*
- **TDC of the electronic channels recording the hits** *(reject electronic noise)*

Algorithm designed to cope with the high-occupancy of the upgraded LHCb detector.

Under evaluation for Run2!

For details, refer to the LHCb Posters in the Students' Poster Session.

Results relative to muon preselection



Standard Model Production Cross Section Measurements