LHC and its Detectors: Marvel of Technology

Chicago, June 9th 2011
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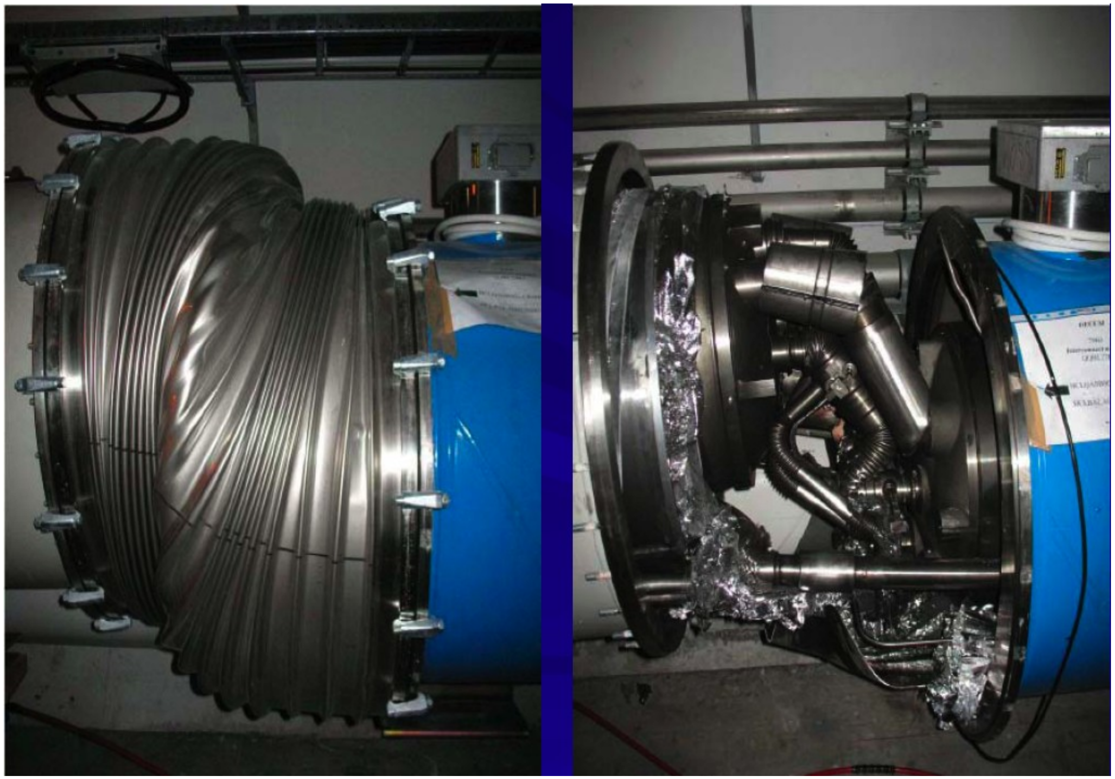
CERN

LHC and its Detectors @ TIPP 2011

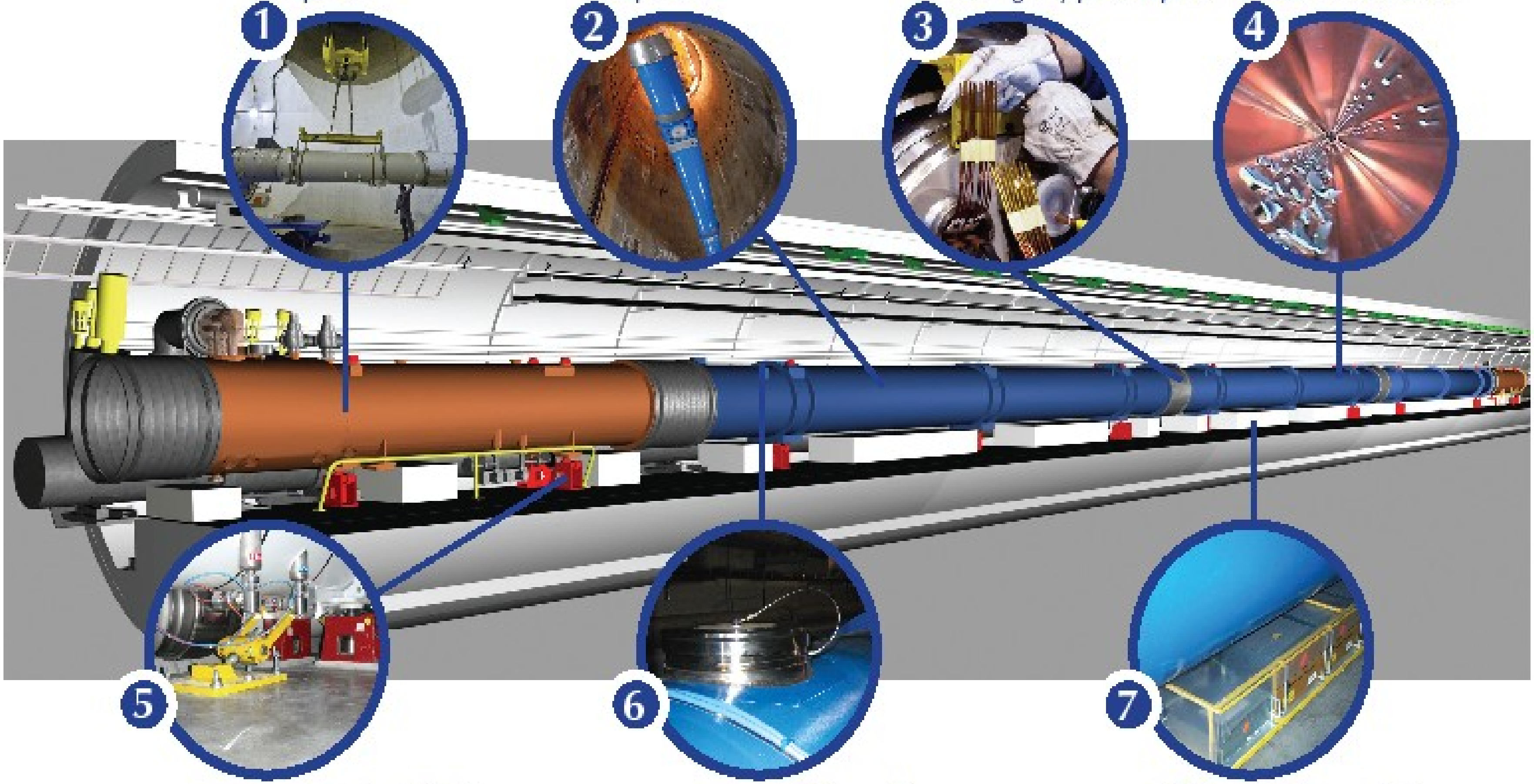
A timely occasion to:

- Evaluate the experiments performances as detector systems
- Assess the correctness of the design hypotheses
- Learn from the shortfalls
- Plan for the upgrades and necessary R&D

LHC shortly before TIPP09



The LHC repairs in detail

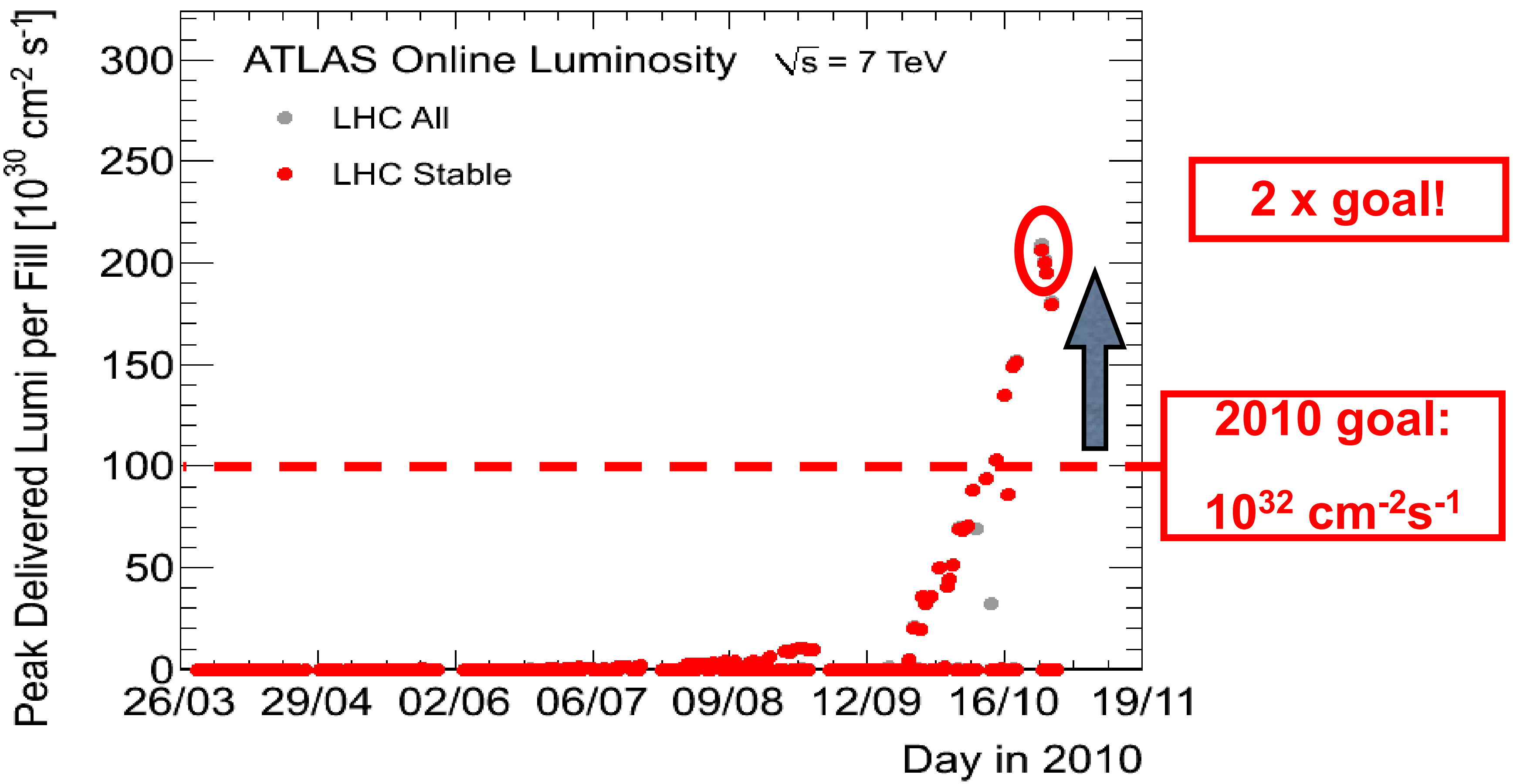


Good news from LHC commissioning 2010:

- Excellent single beam lifetime
- Ramp & squeeze essentially without loss
  - No quenches with beam above 450 GeV
  - Excellent performance of Machine Protection
- Optics close to model (and correctable)
- Excellent reproducibility
- Aperture (at least) as expected
- Better than nominal from injectors
  - Emittances, bunch intensity
- Beam-beam: can collide nominal bunch currents
  - With smaller that nominal emittances

And surprisingly good availability…

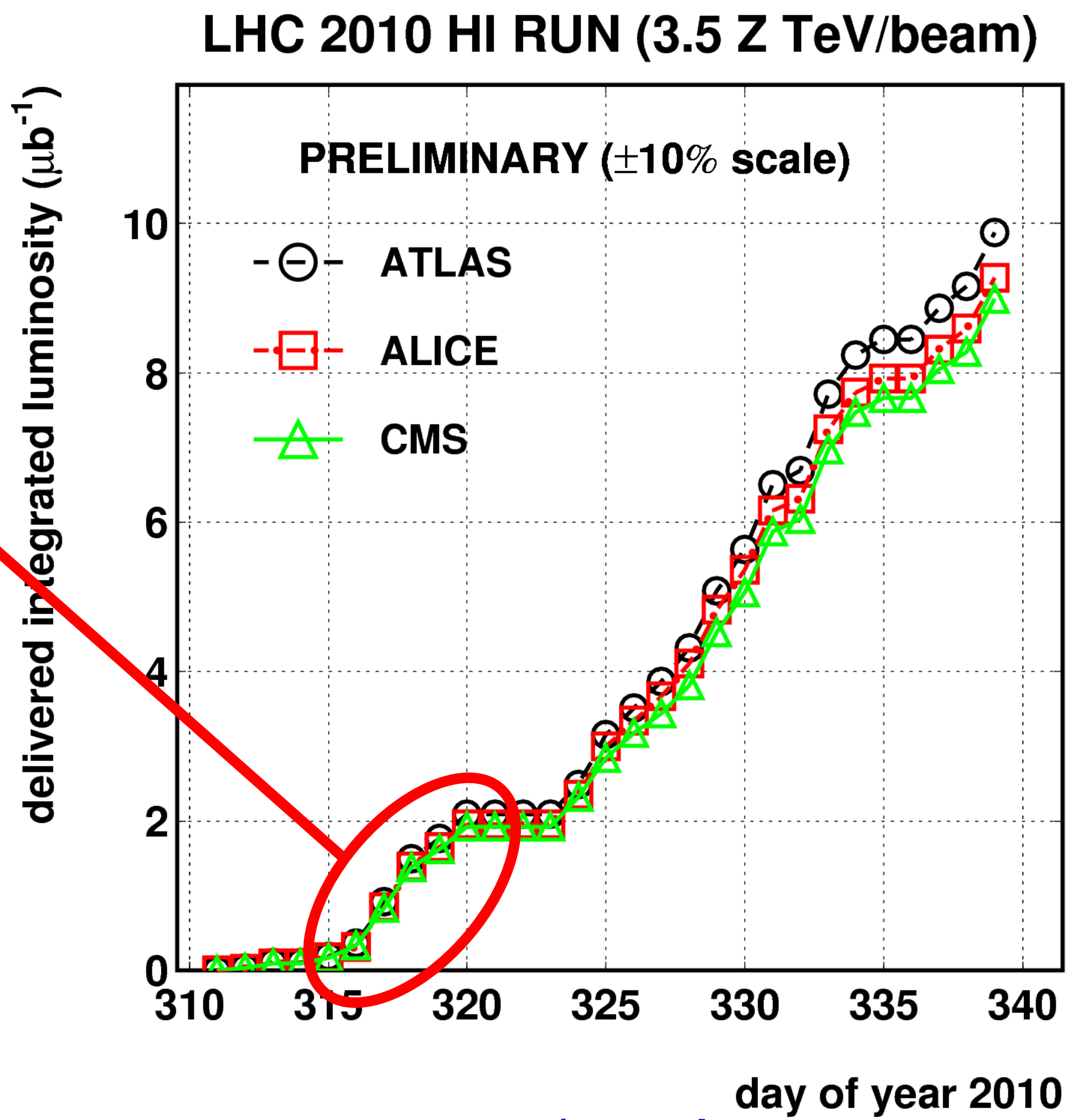
Peak luminosity performance



Main parameters: 368 bunches of 1.2 x 10^{11} protons.

Colliding beam sizes = 40 microns.

Ion luminosity performance



Gained a factor 100 of peak luminosity in 6 days!

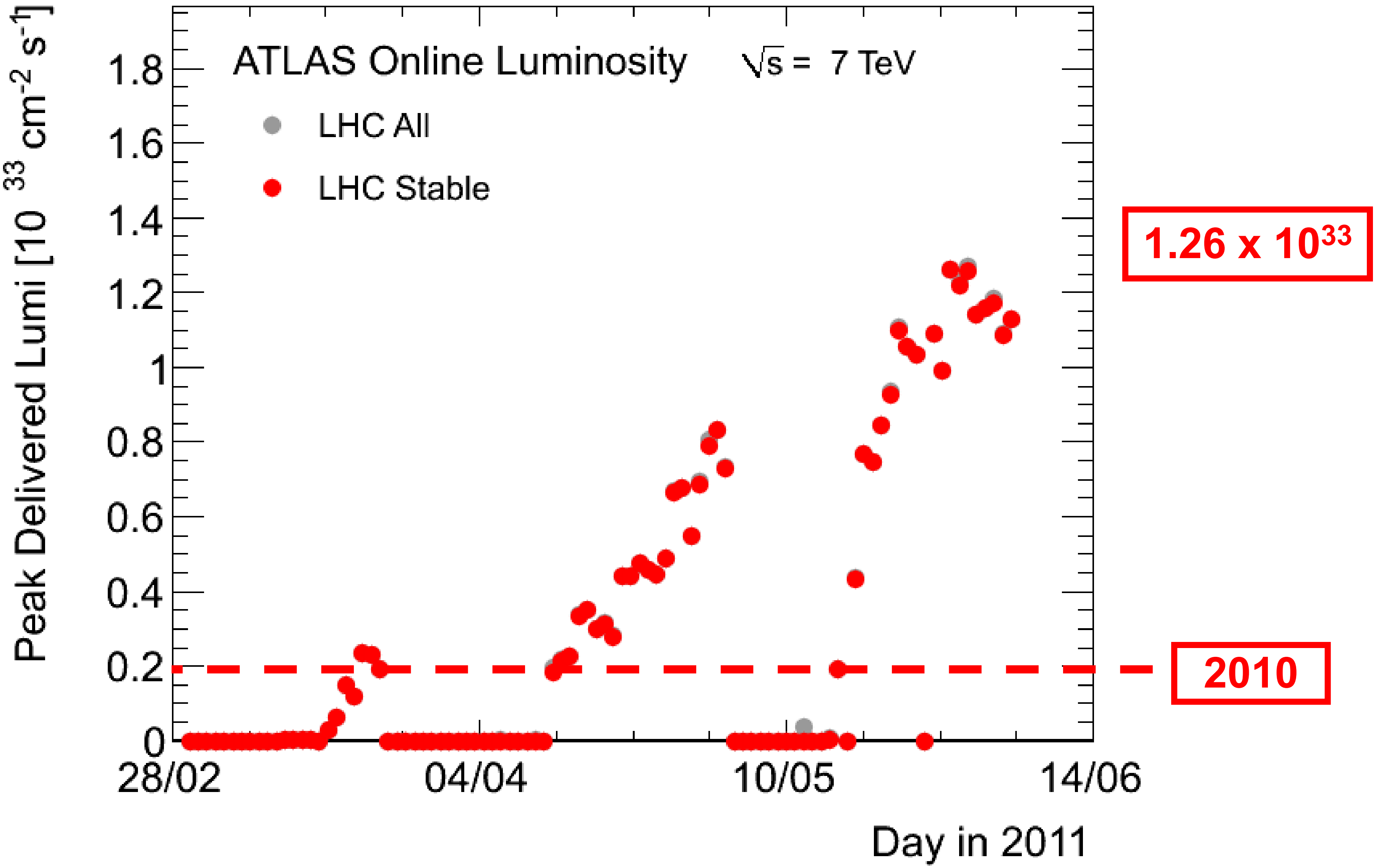
1 month

M. Ferro-Luzzi

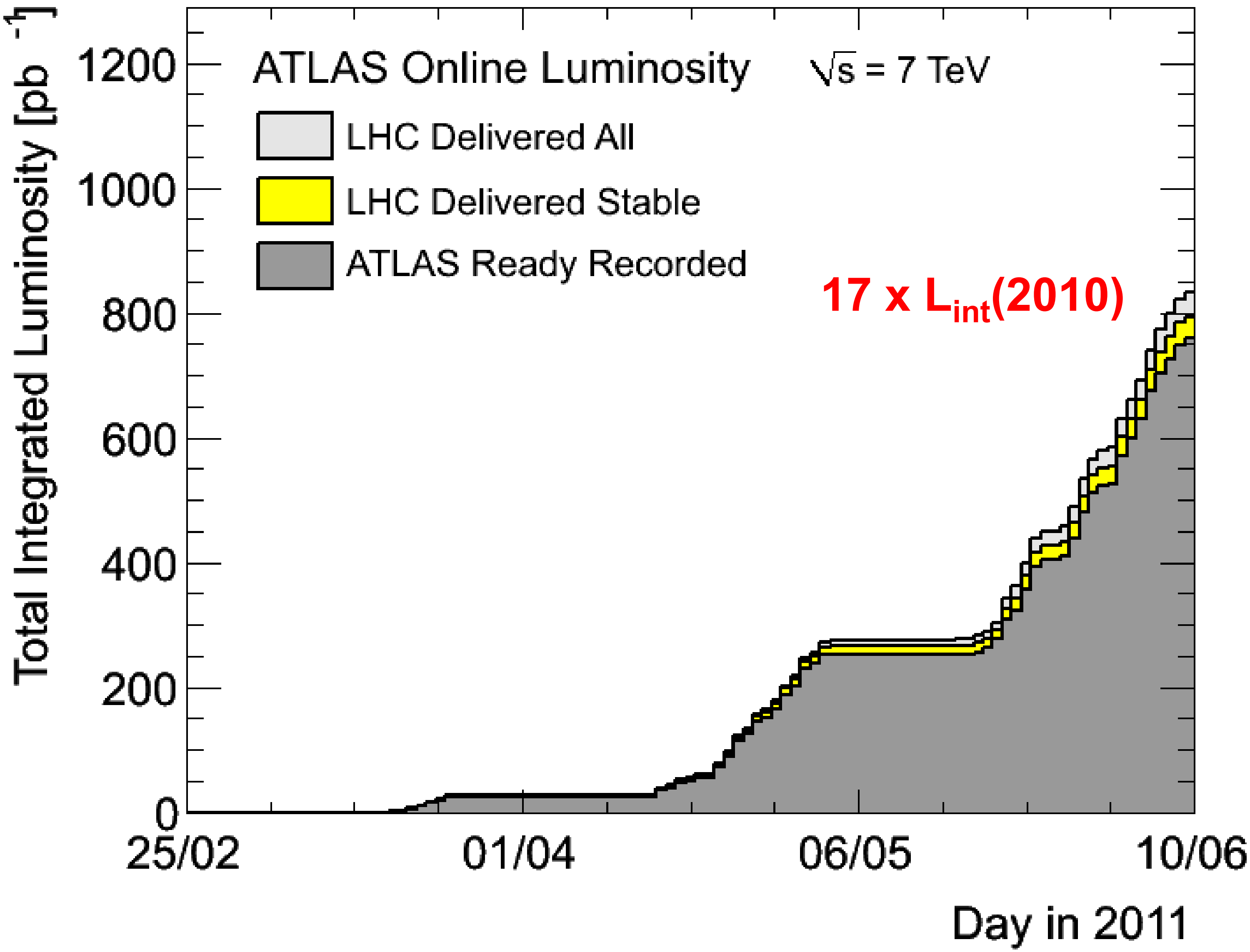
LHC in 2011 – so far

- Beam commissioning: 3 weeks ✓
  - Exit - stable beams with low number of bunches
- Ramp-up to ~200 bunches (75 ns): 2 weeks ✓
  - Multi-bunch injection commissioning continued
  - Stable beams
- Intermediate energy run: 4 days ✓
- Technical Stop: 4+1 days ✓
- **Scrubbing run: 10 days** ✓
- Decided to run at **50 ns** spacing ✓
- Resumed operation for physics and increase number of bunches: ✓
  - 300 – 400 – 600 – 800 – 900 – **1100** …1400

Peak luminosity 2011



…and integrated luminosity 2011



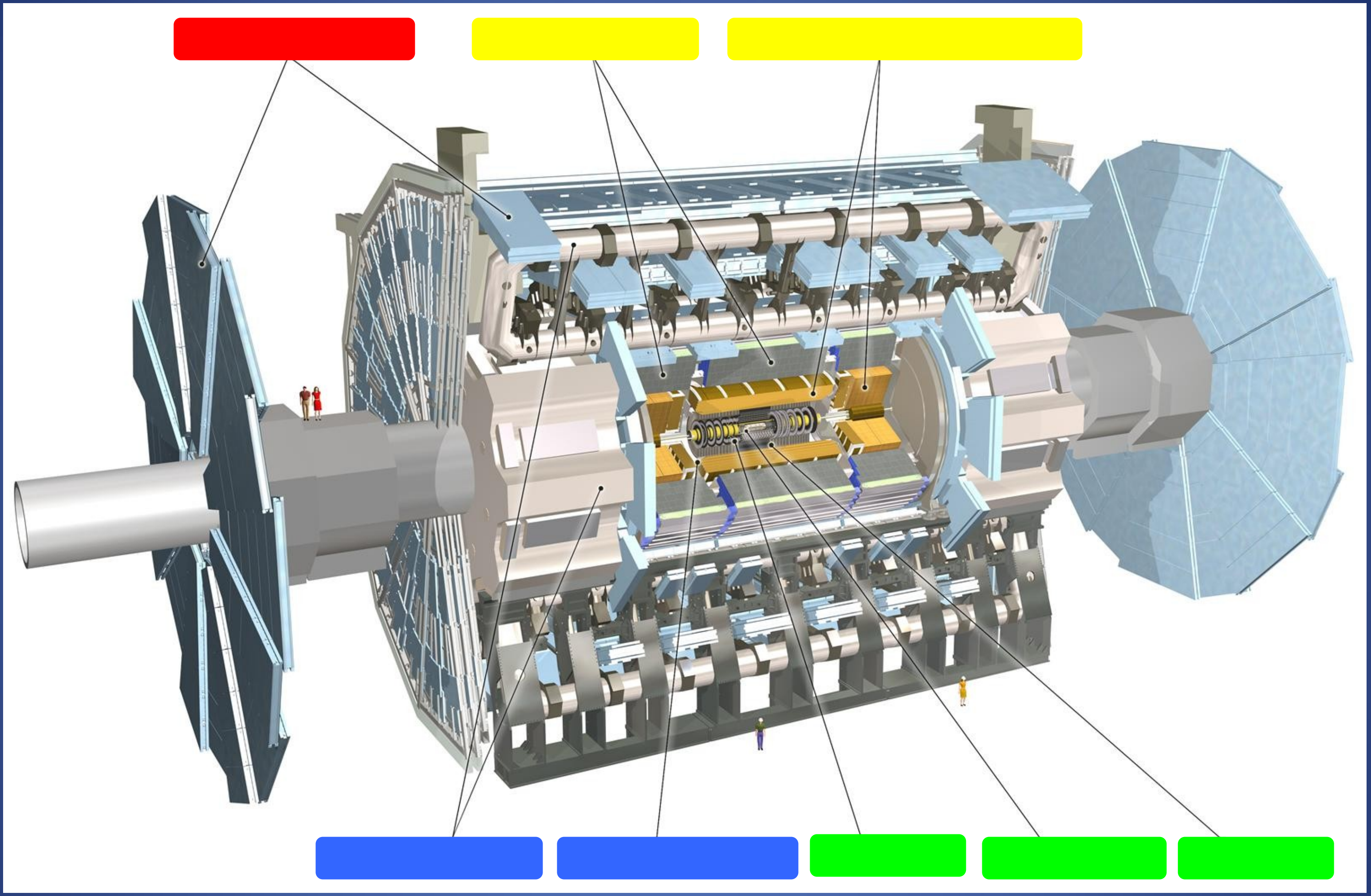
And the experiments?

Experiment have shown an astounding readiness in making use of the collected luminosity, due to:

- one year of cosmic rays (alignments, calibrations, people and systems training)
- excellent performances of the WLCG
- ~ 3000 greedy PhD students!

A very important discovery in 2010: experiments have an higher physics reach (for a given luminosity) than predicted by simulations!

The ATLAS Detector (in 1 Slide)



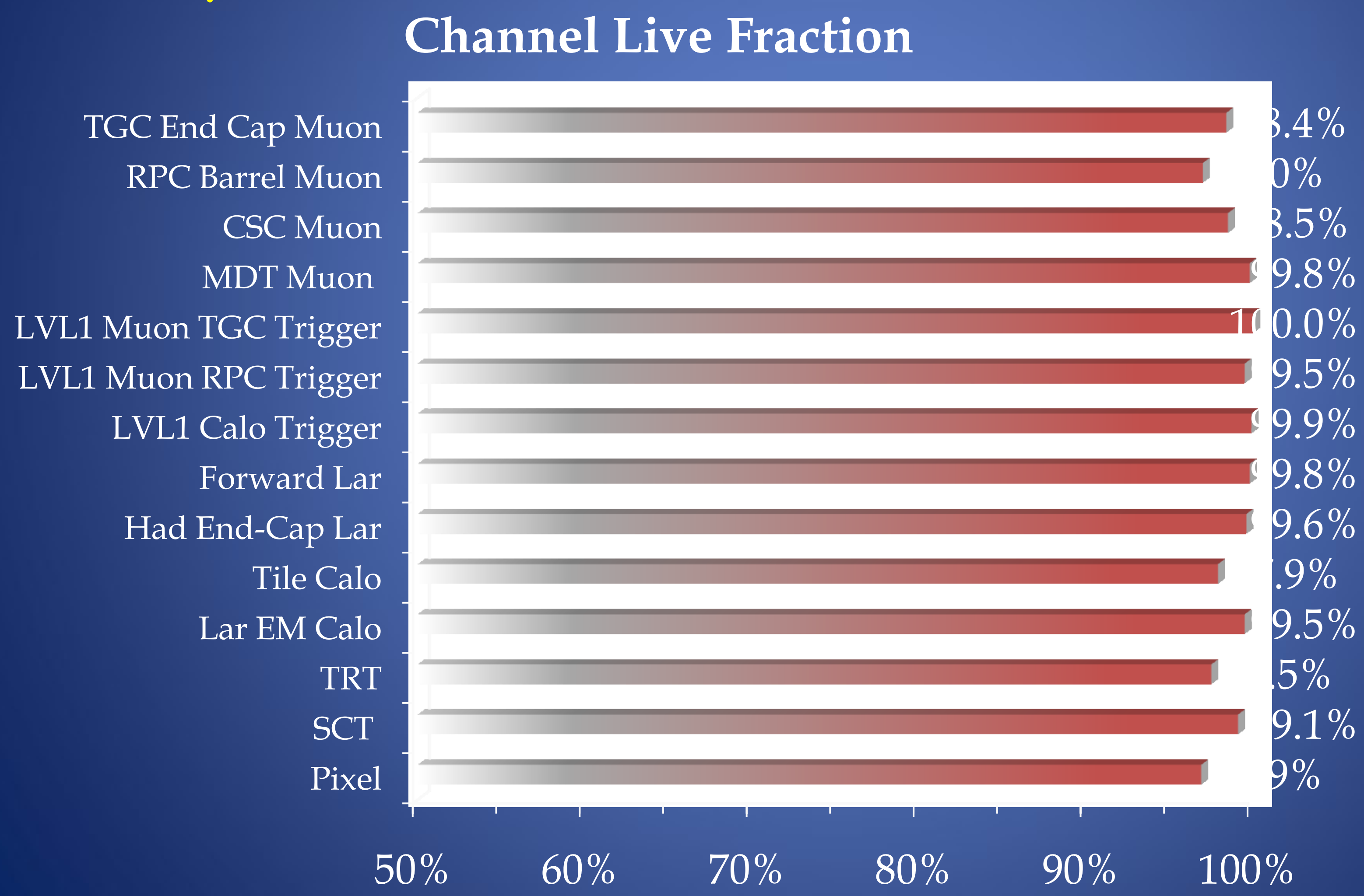
4 Superconducting magnets: Central Solenoid (B= 2T)

3 Air core Toroids

Inner detector | Calorimetry | Muon Spectrometer

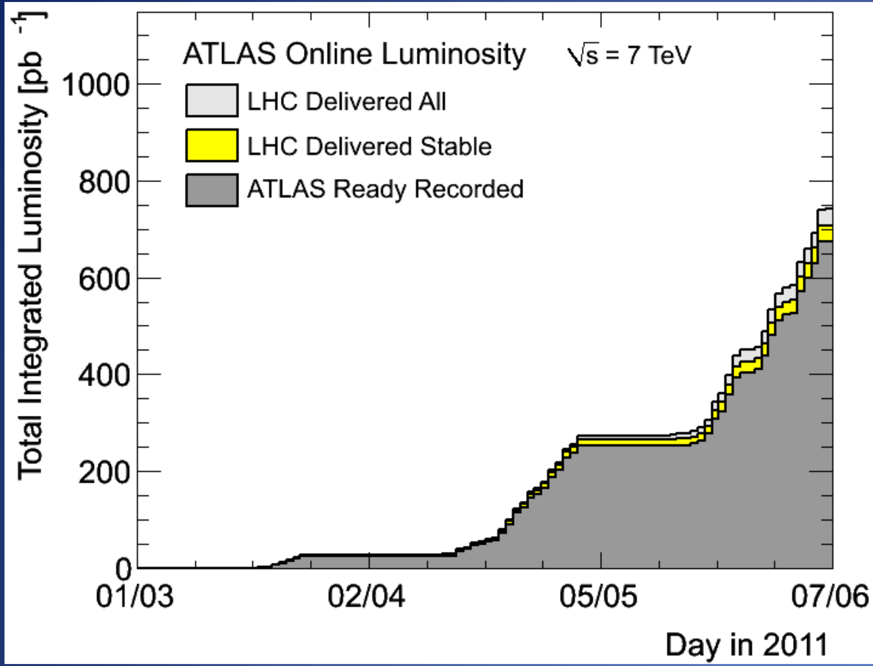
Detector Operations

- Fraction of operational channels close to 100 % for all systems



Number of Channels
320 K
370 K
31 K
350 K
320 K
370 K
7 K
3.5 K
5.6 K
9.8 K
170 K
350 K
6.3 M
80 M

Data taking efficiency



Max inst lumi. : 1.26×10^{33} cm^{-2} s^{-1}

Delivered luminosity: 709 pb^{-1}

ATLAS ready recorded: 676 pb^{-1}

Preliminary uncertainty on 2011 luminosity 4.5%

Data taking efficiency: >95%

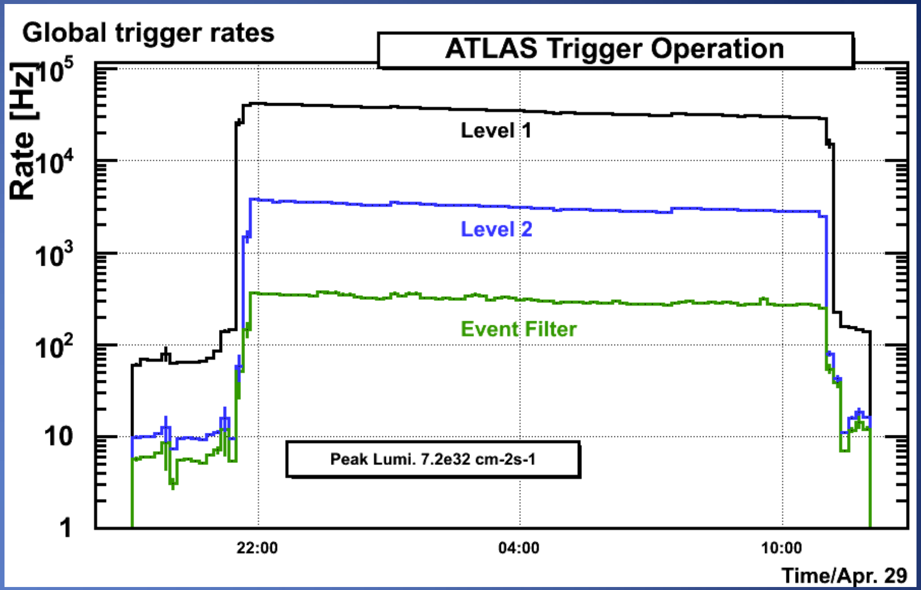
Fraction of good quality data per detector

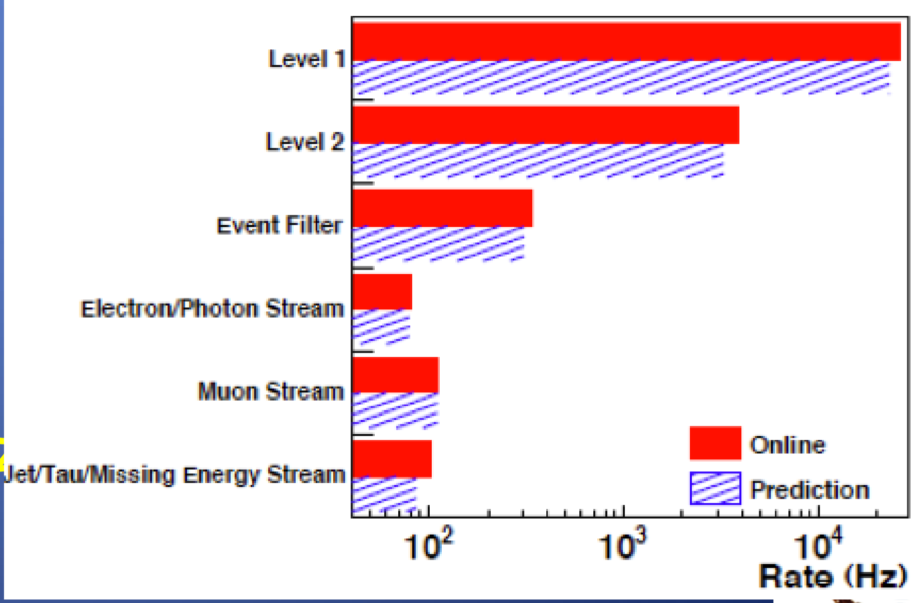
Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.5	99.4	100	87.5	92.4	94.5	100	100	99.0	99.9	99.8	96.8	95.1

Fraction of recorded data used for Top analysis : 83%

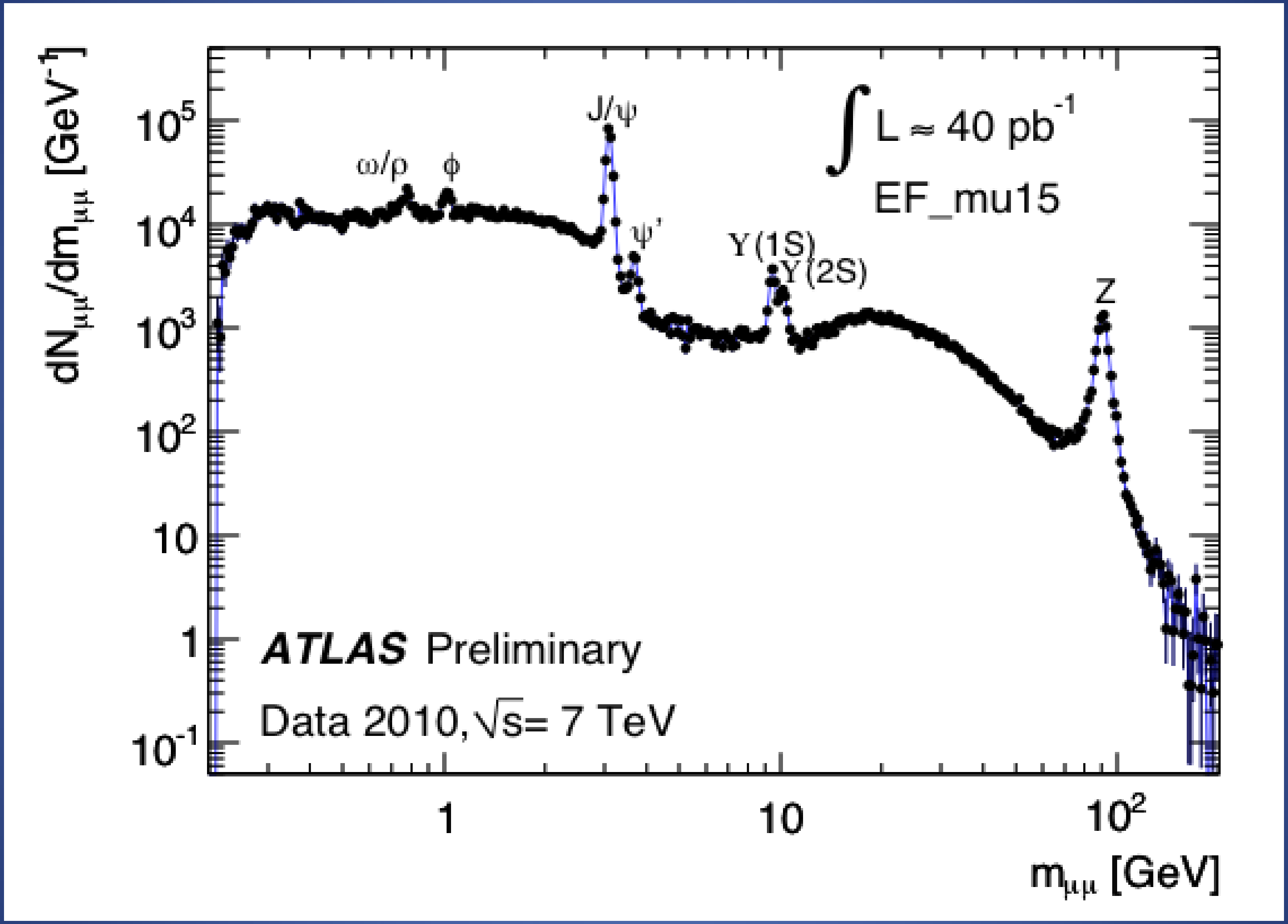
Trigger operations

- Trigger organized in 3 levels
  - LVL1 (50 KHz): Hardware
  - LVL2 (4 KHz): Software on reduced granularity (regions of interest)
  - EF (≈300 Hz): Based on Offline Reconstruction Full Granularity
- Rates of physics objects very well understood and under control.
- Recorded physics rate ≈300 Hz





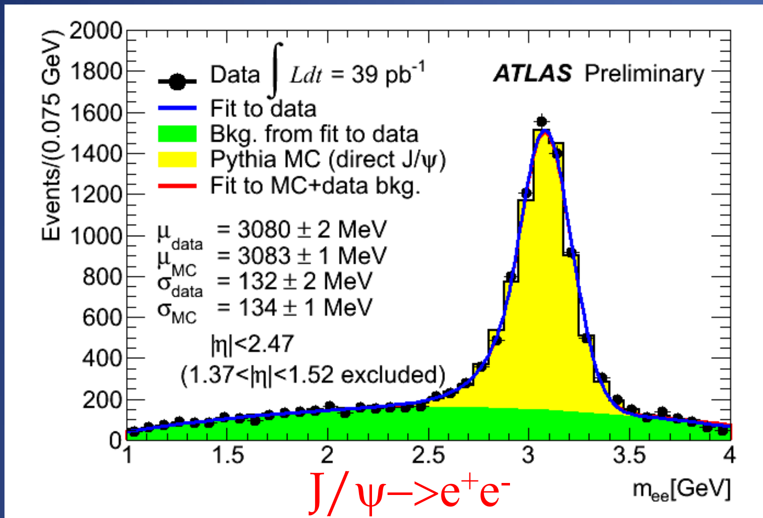
Performance

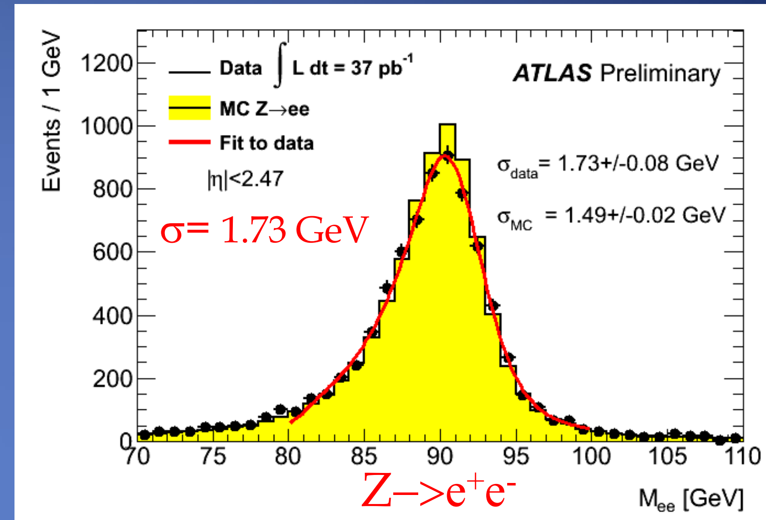


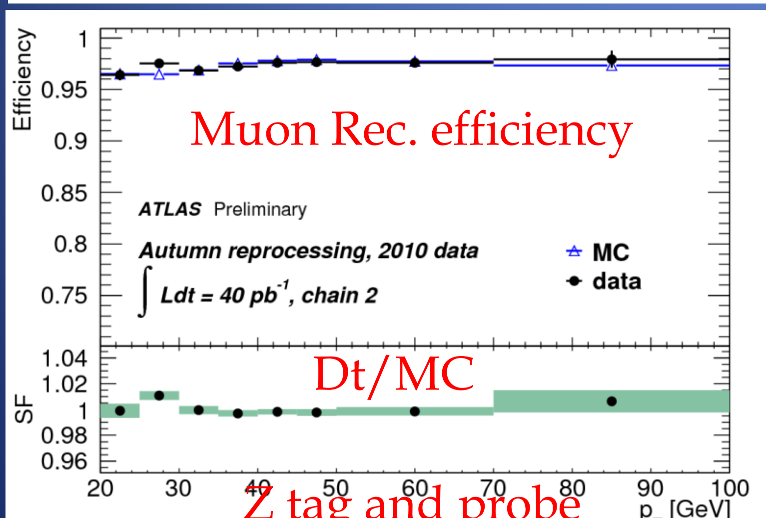
- Calibrating the detector performance with Nobel Prize winning particles

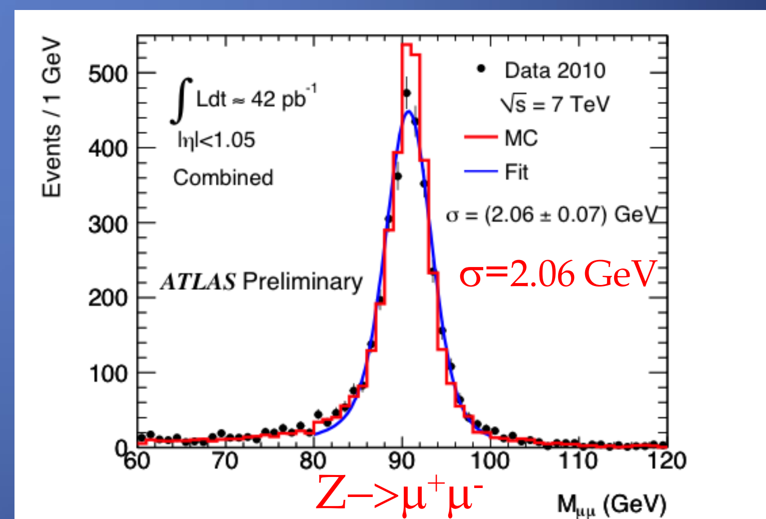
Electrons and Muons

Electrons: Excellent resolution (1.9% @ Z) and linearity down to very low Pt







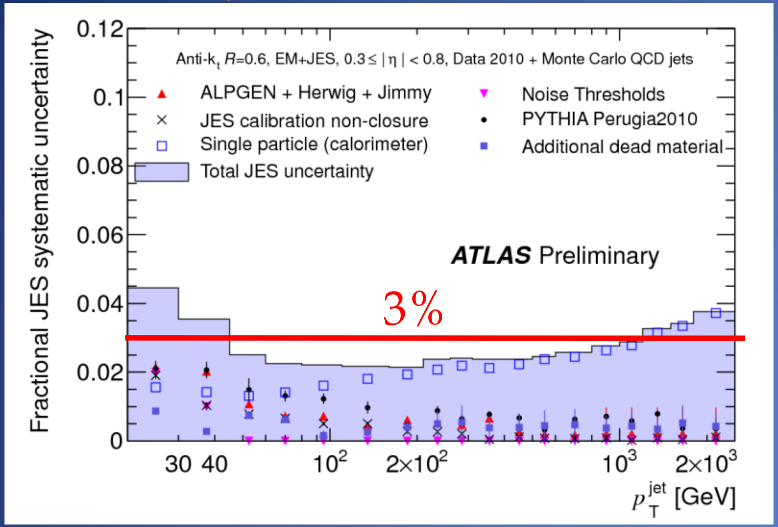


Muons: high and well understood reconstruction efficiency,

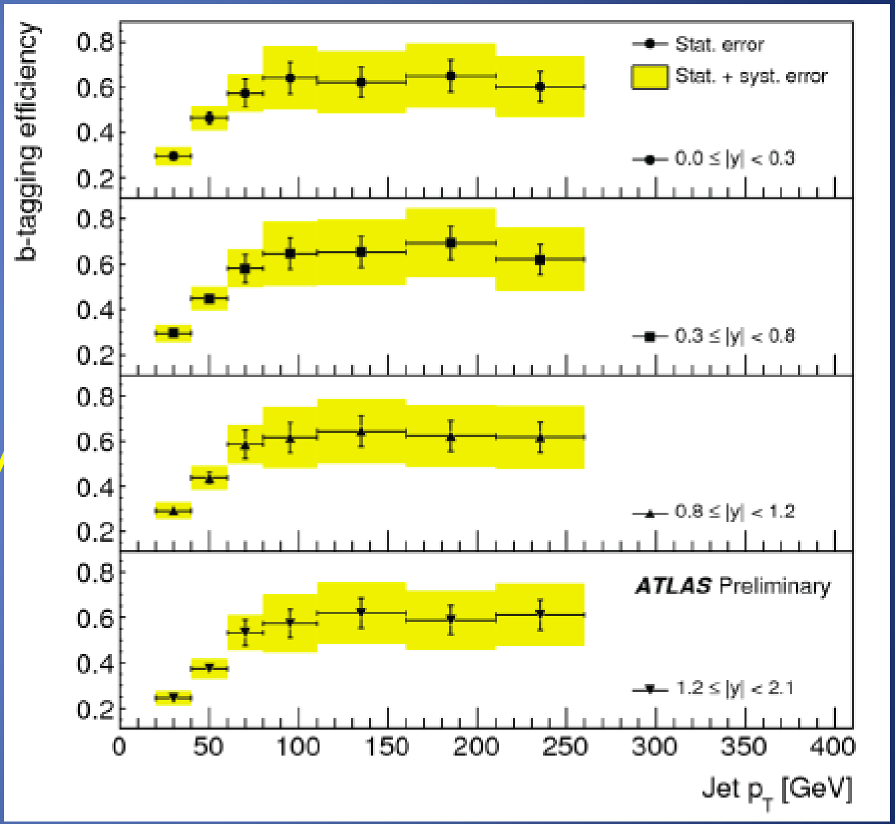
Excellent resolution: (@Z: 2 % in Barrel, 3% in EndCap) and scale <1%

Jets, E_T^{Miss} and B tagging

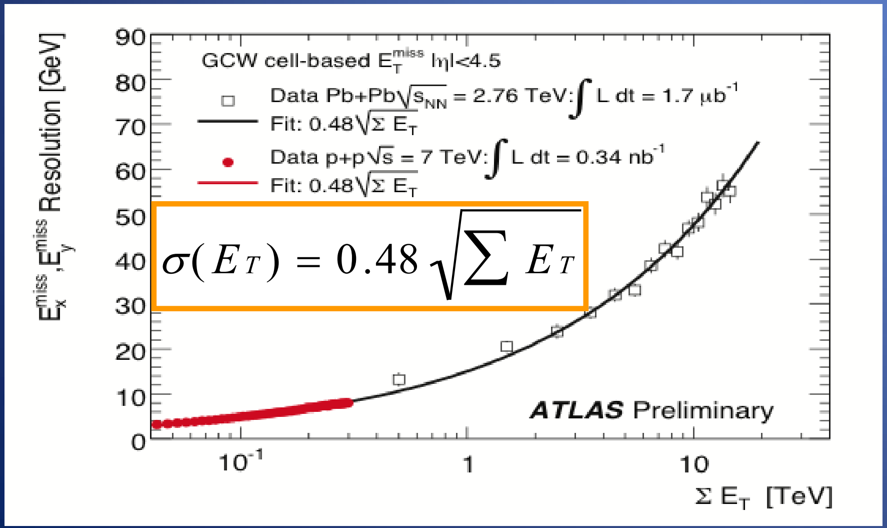
Jet Energy Scale: systematic uncertainty <3%
in a large pt range (2010 data no pile-up)



B tagging (SV0)

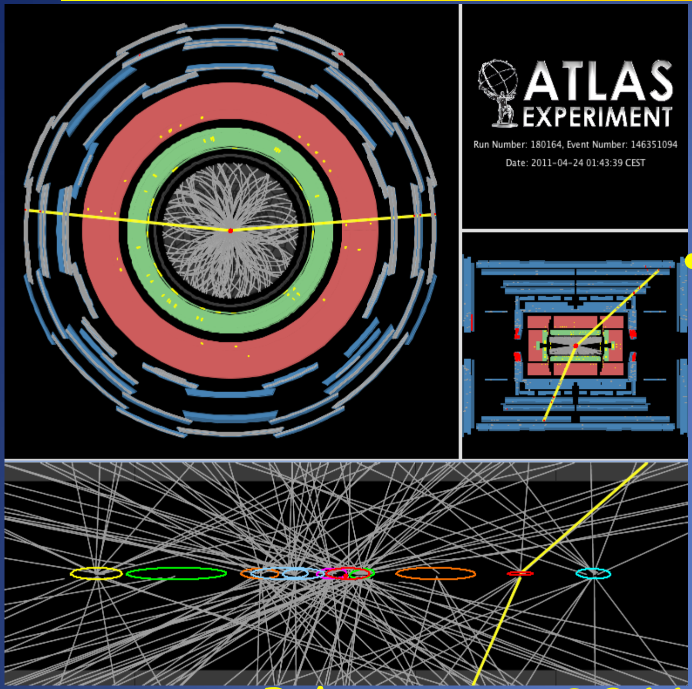


Missing Et Resolution : tested up to very high ΣE_T using Heavy Ions data



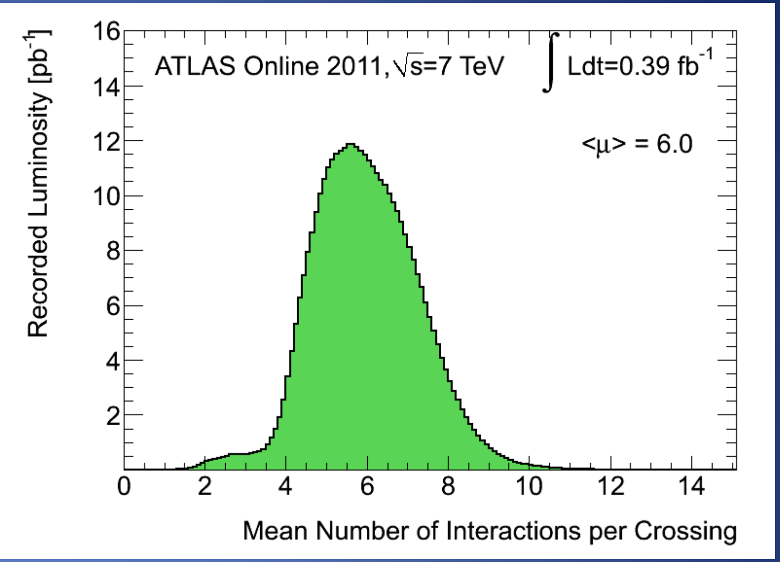
Efficiency 40-60%
Mis-tag rate : 0.2-1%

Pile Up



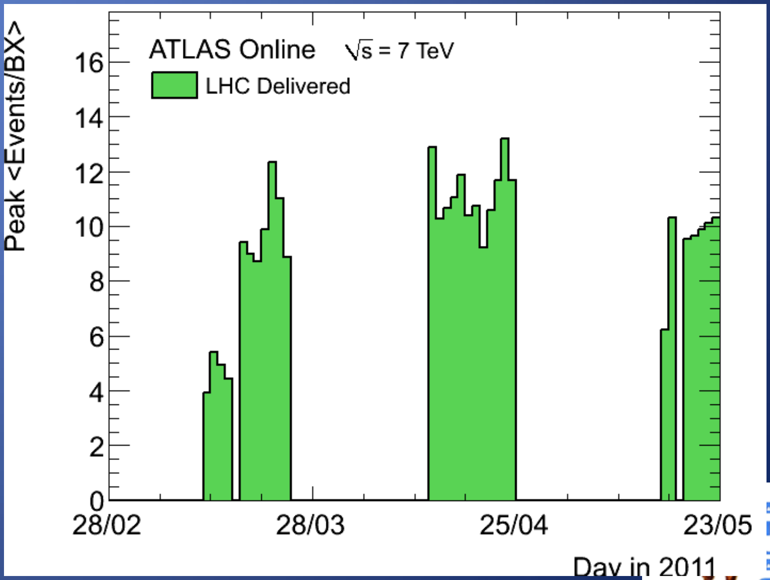
- Event with 11 vertices and 1 Z

Average # of interactions per crossing



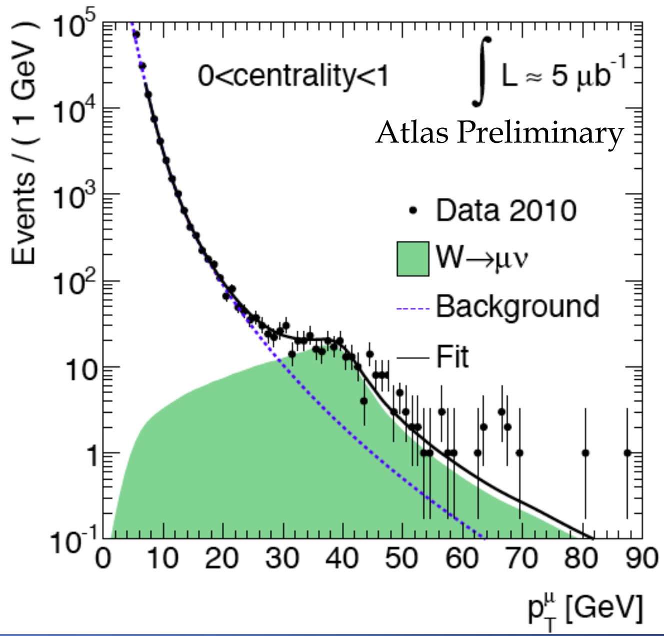
- Average Pile Up in 2011 : 6.0 Coll/BC
- Max Pile Up : 10-12 Collisions/BC
- Issue for:
  - Missing energy
  - Lepton Isolation (mainly calorimetric)
  - Jet Energy Scale and resolution
  - Vertexing
  - CPU time and event size

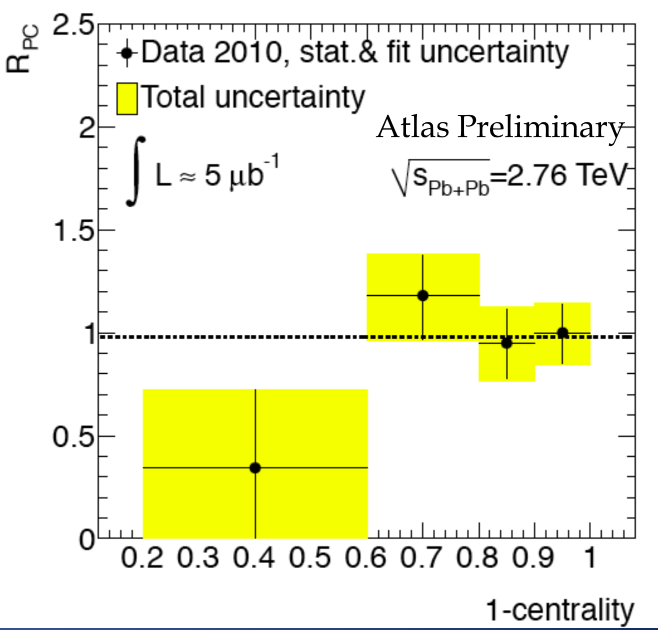
Max Pile up vs time



Selected Heavy Ions results

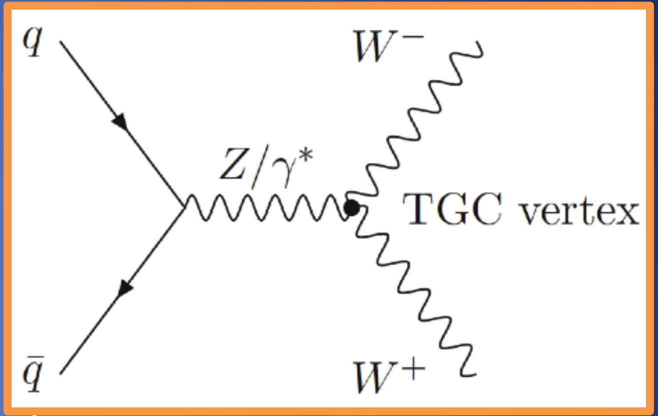
- First direct observation of Jet Quenching
- First publication on J/Psi suppression and Z production in HI at LHC.
  - Both papers sent to journals before Xmas 2010.
- New:
  - Measurement of relative yield (wrt most central bin) of W production in HI vs centrality
  - + many other new measurements (jet quenching, particle flow etc.)





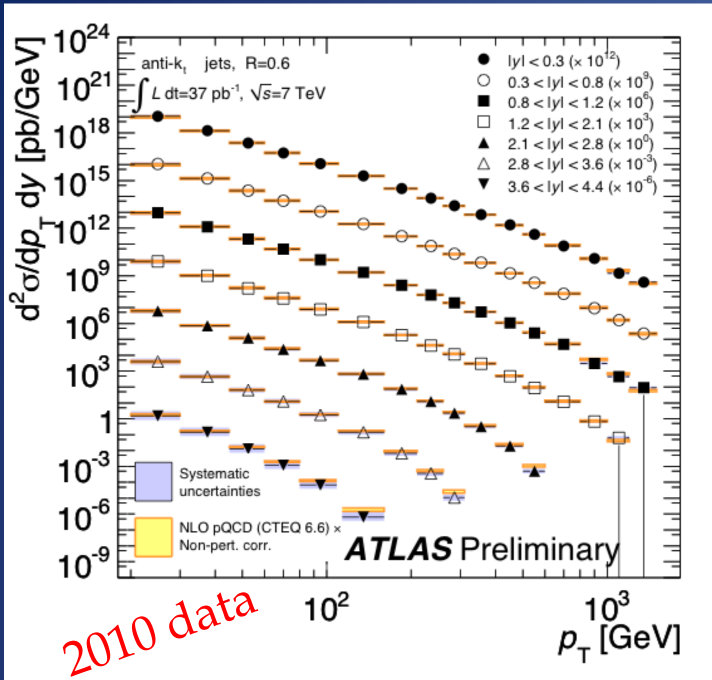
Standard Model highlights

- Measuring the SM processes at 7 TeV extends our knowledge of fundamental physics
  - QCD JET cross section
  - W, Z cross section
  - Di-bosons cross section
  - Top and single Top cross section

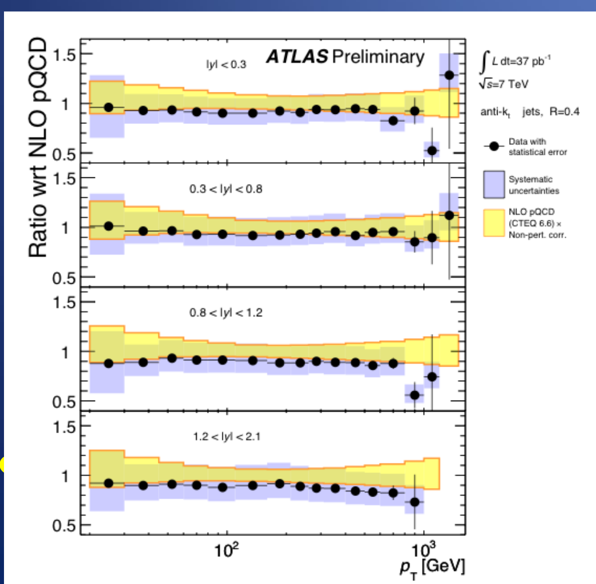


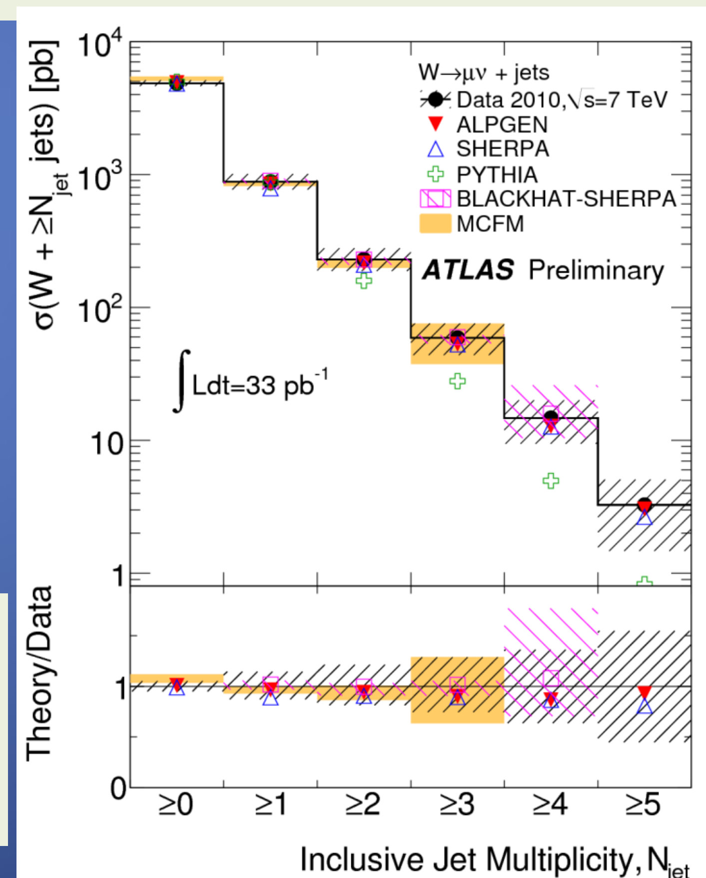
- The above processes are backgrounds for New Physics and Higgs searches
  - Understanding these processes is essential for the quest of New Physics
- Benchmark processes for the understanding of the detector

QCD: Jet results



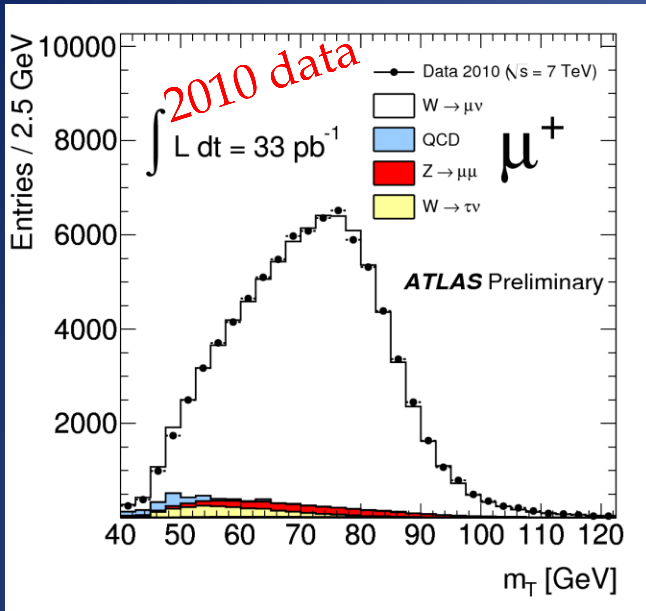
- •Double Differential Jet cross section vs Pt
- •7 rapidity bins, up to |y|=4.4 units
- •Pt range from 20 GeV to 1.5 TeV
- •~9 orders of magnitude in cross section
- •Total uncertainty, from 50% to 10%, dominated by JES





- •Jet Multiplicity in W+Jets events very well predicted by AlpGen and Sherpa

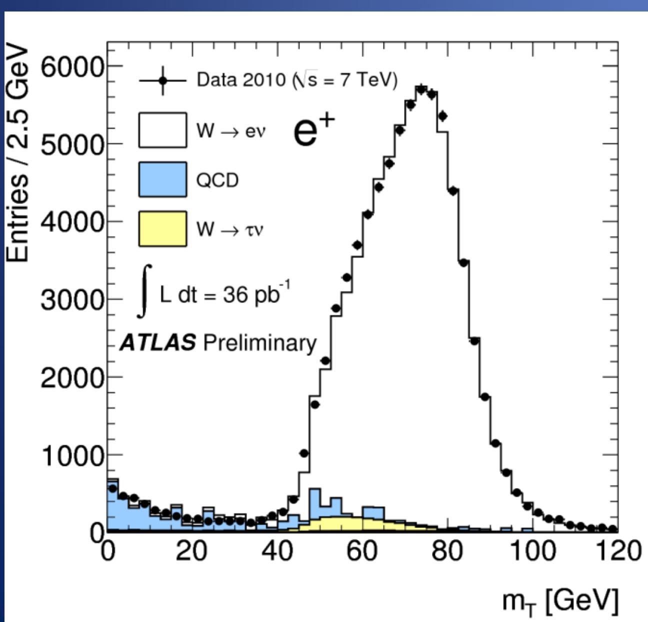
W/Z measurements

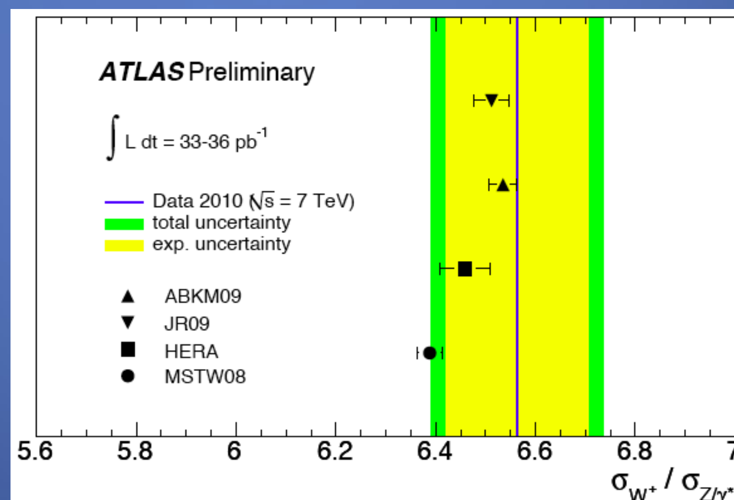


Kinematical distributions are well understood: good agreement Data/MC

Inclusive W-Z cross section and W+/Z cross section ratio

	$\sigma^{tot}_{W(\pm)} \cdot BR(W \to \ell\nu)$ [nb]
W^+	$6.257 \pm 0.017(sta) \pm 0.152(sys) \pm 0.213(lum) \pm 0.188(acc)$
W^-	$4.149 \pm 0.014(sta) \pm 0.102(sys) \pm 0.141(lum) \pm 0.124(acc)$
W	$10.391 \pm 0.022(sta) \pm 0.238(sys) \pm 0.353(lum) \pm 0.312(acc)$
	$\sigma^{tot}_{Z/\gamma^*} \cdot BR(Z/\gamma^* \to \ell\ell)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^*	$0.945 \pm 0.006(sta) \pm 0.011(sys) \pm 0.032(lum) \pm 0.038(acc)$





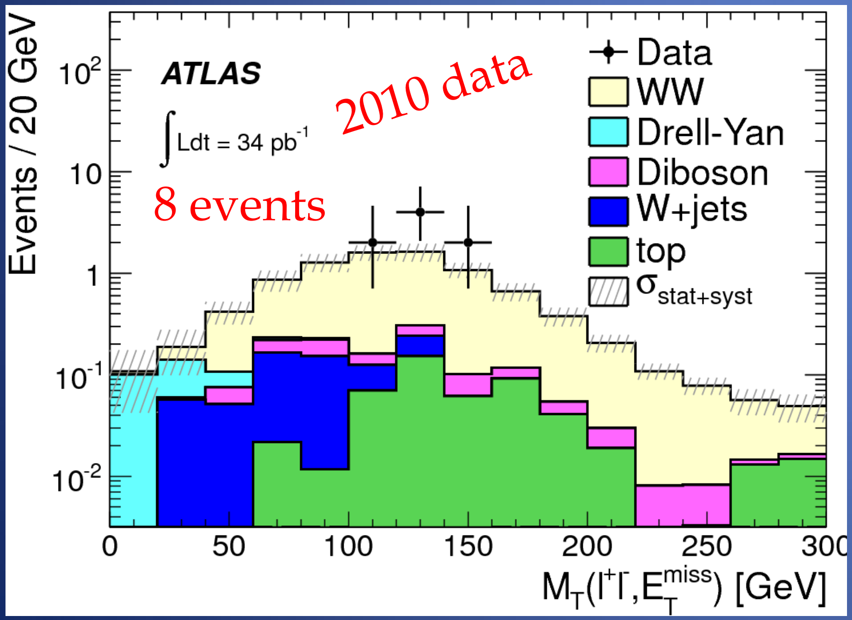
- NNLO predictions consistent with data
- Remarkable success of pQCD and PDFs

- QCD background always estimated with data driven techniques

Di-bosons cross section

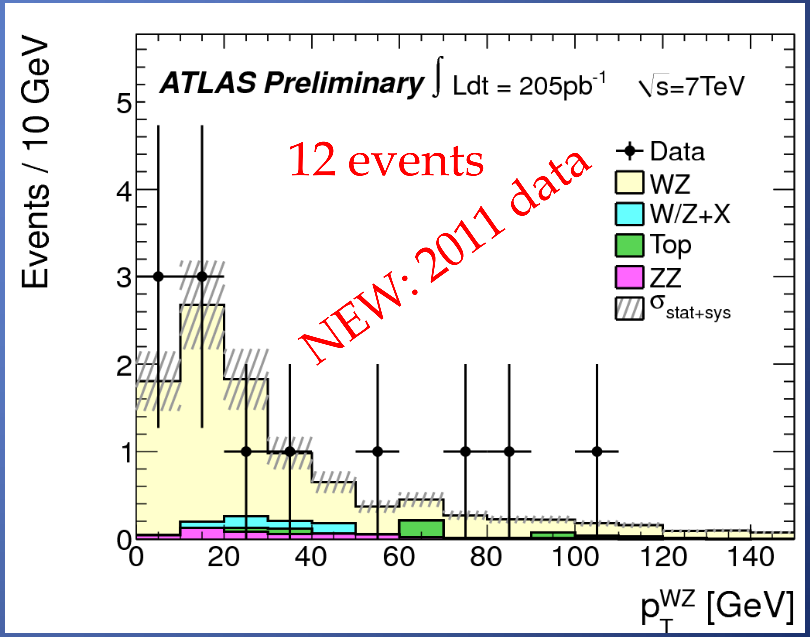
- Measurement of WW, WZ and Wγ, Zγ production cross section with 2010-11 data
- The goal is to test the non-Abelian nature of the Electro-Weak interaction: Triple Gauge Coupling
- Important background for Higgs and New Physics searches

Trans. Mass (l^+l^-, E_{tmiss}) for WW cand.



$$\sigma_{WW} = 40\,^{+20}_{-16}(stat) \pm 7(syst)\, pb$$

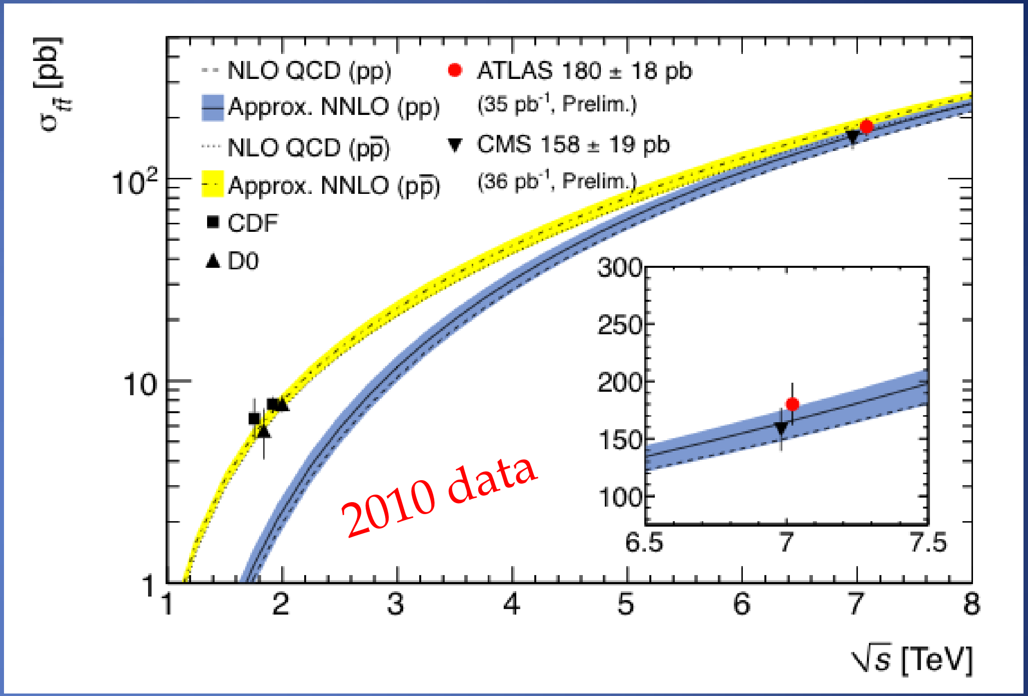
Pt distribution of WZ (lll,E_t^{miss}) Candidates



$$\sigma_{WZ} = 18\,^{+7}_{-6}(stat) \pm 3(syst) \pm 1(lumi)\, pb$$

Top Cross Section

- Top production cross section obtained combining 5 different analyses:
  - e+jets, with b-taging
  - μ+ jets, with b-tagging
  - ee+jets (w/o b-tagging)
  - μμ+jets (w/o b-tagging)
  - eμ+jets (w/o b-tagging)

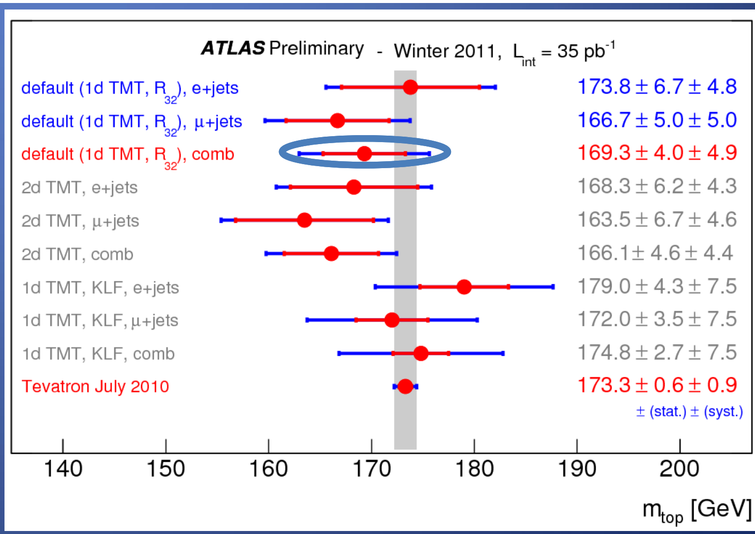


σ(tt) = 180 ± 9± 15 ± 6 pb

[~10% total uncertainty]]

- Top Quark Mass measured in the Lepton + Jets channel.

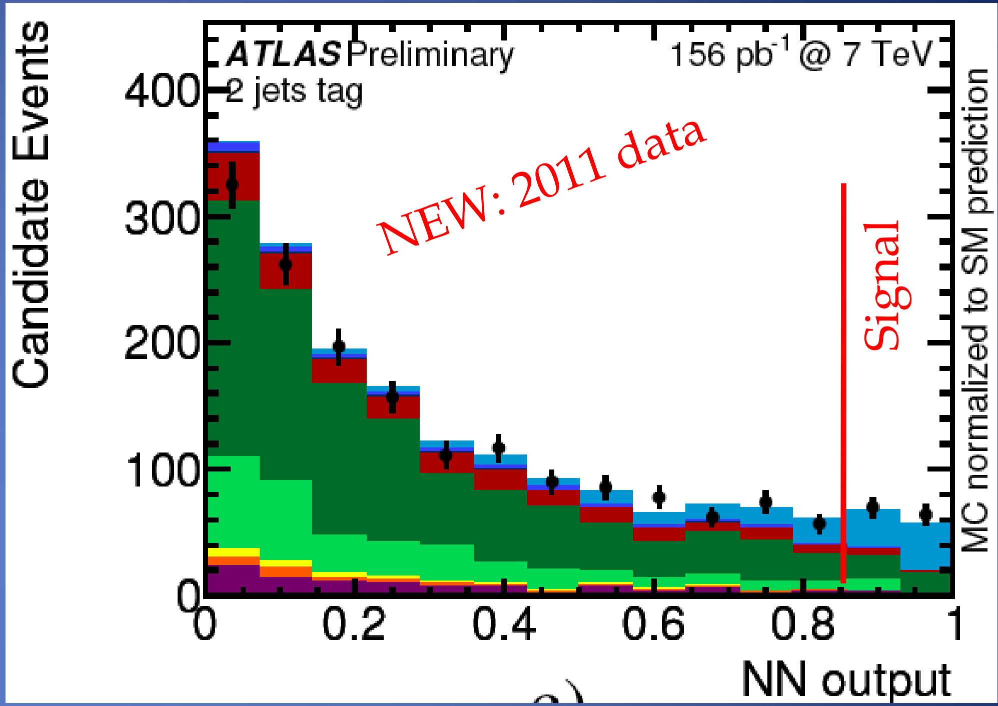
M_t = 169 ± 4.0± 4.9 GeV



Single Top Cross section

- Single Top production is a direct probe of the W-t-b coupling and is sensitive to New Physics
- Events selection: exactly 1 lepton, 2 jets (1 B-tagged) and E_t^{miss}>25 GeV
- Main backgrounds: MultiJet, W+ Jets, tt
- Two analyses:
  - Cut and Count (C-C)
  - Neural Network

Nb of candidate events in NN analysis



SM cross section for t-channel

$$\sigma_{t}{}^{SM} = 66.2\,pb$$

Neural Network result

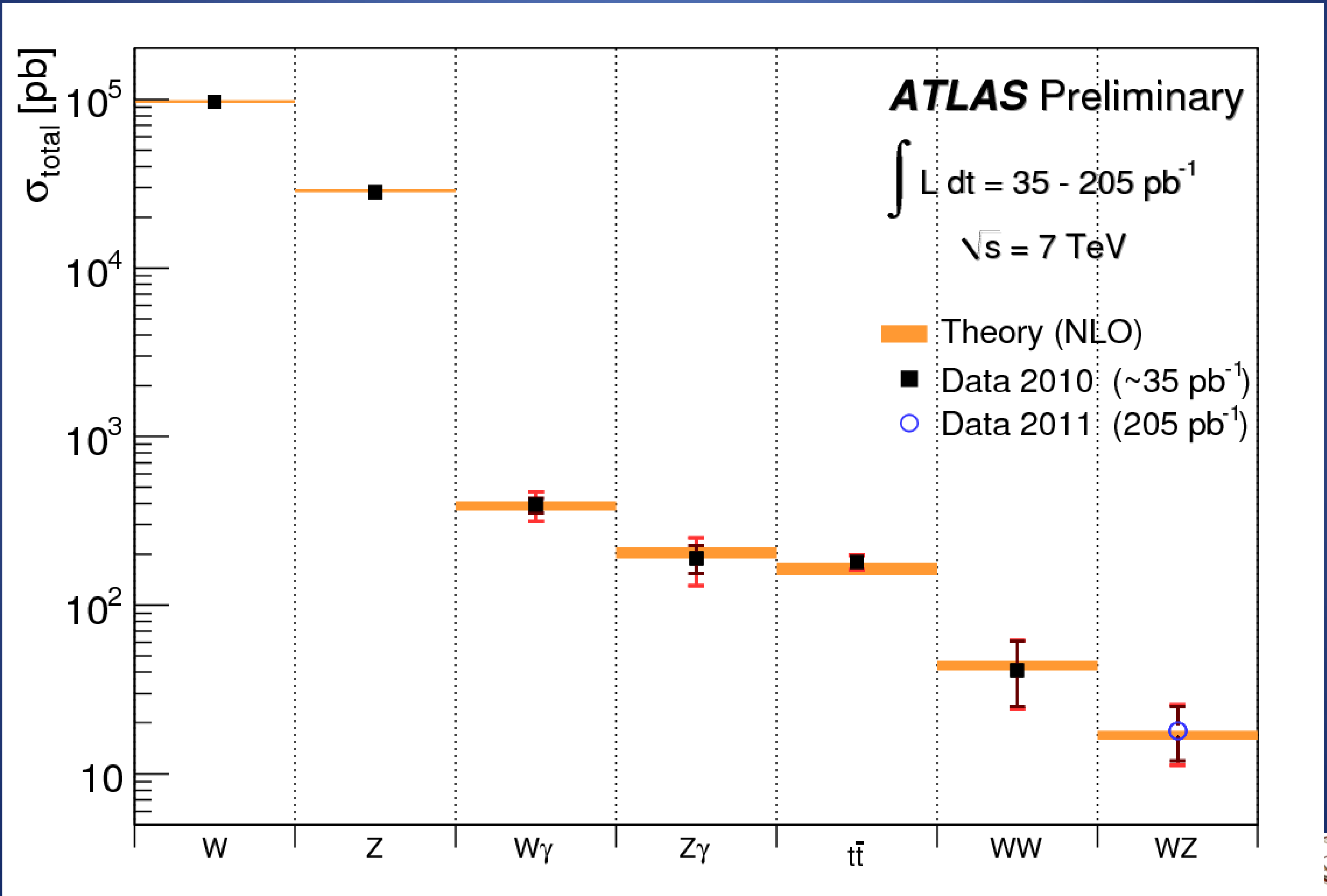
$$\sigma_{t} = 76\,^{+41}_{-21}\,pb$$

Significance

$$6.2\sigma$$

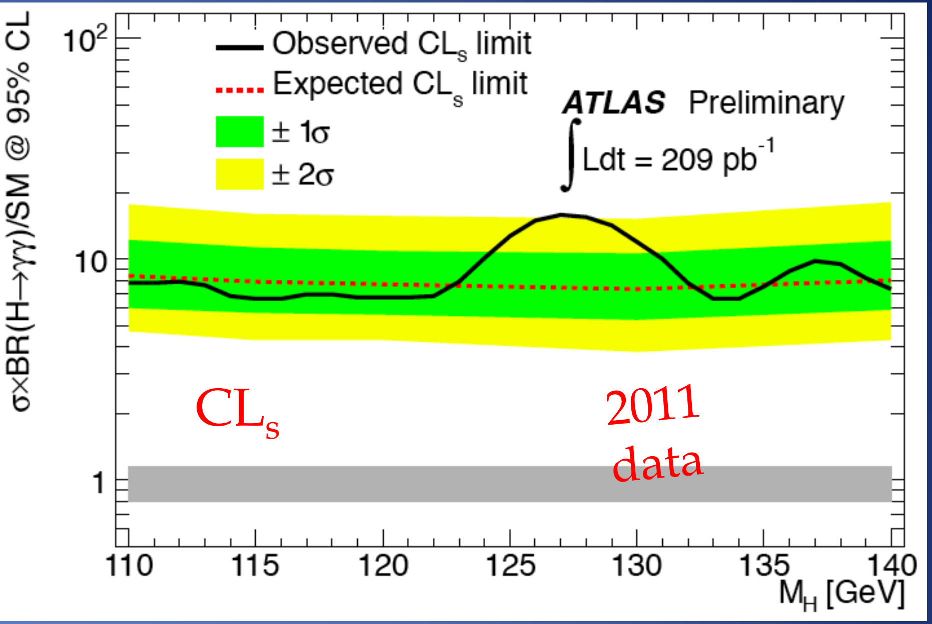
SM Cross-Section Summary

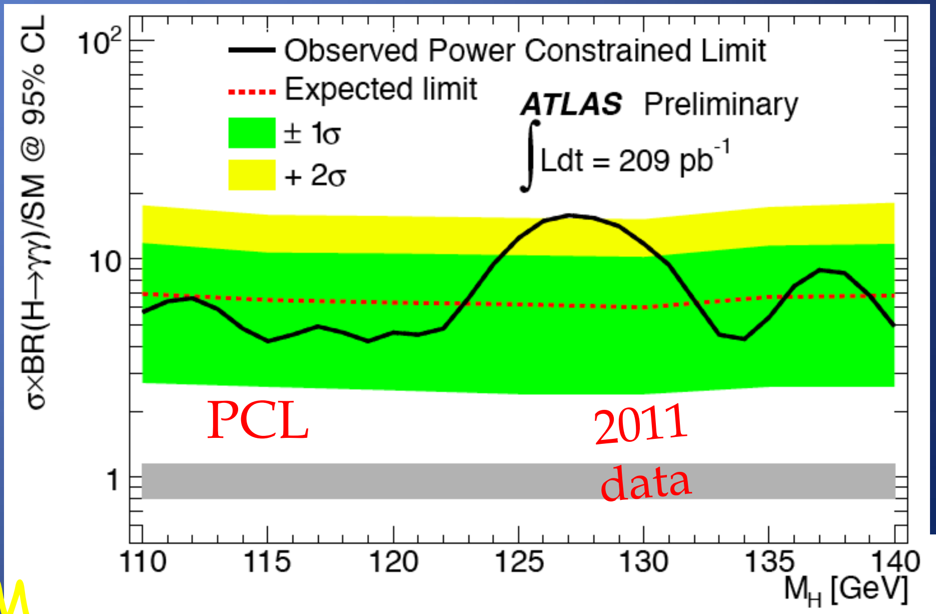
Main SM cross sections measured by ATLAS



H->γγ

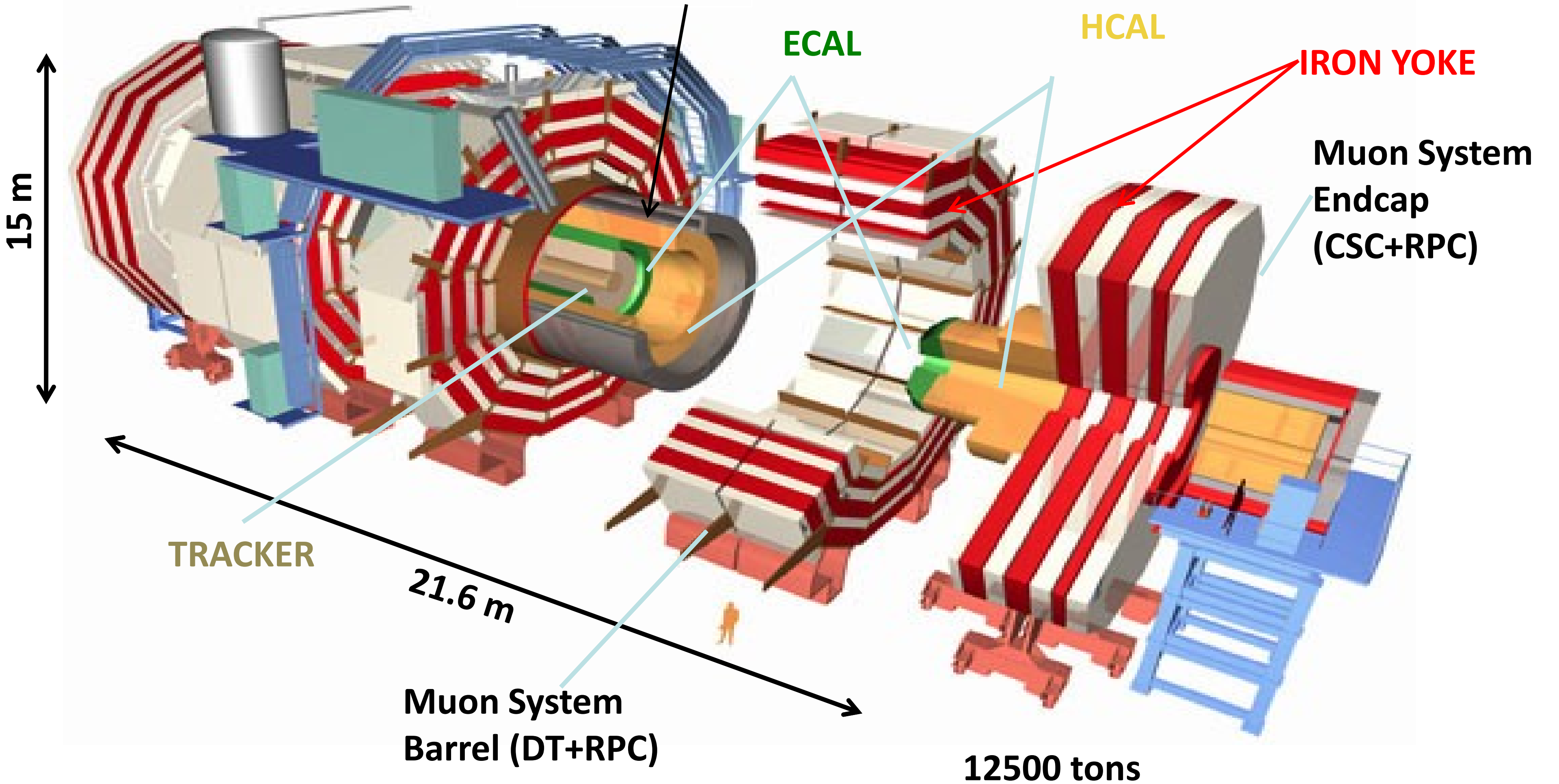
- Cleanest channels for very low Mass Higgs,
- Needs:
  - Good di-photon mass resolution
  - Determination of primary vertex
  - Good Photon Id.
  - γ/Jet, γ/π^0 discrimination
- Need to understand backgrounds with high precision with Data Driven techniques
  - QCD γγ production
  - γ-Jet and Jet-Jet production
- No significant excess seen
  - New Limit≈(4.2-15.8)× SM





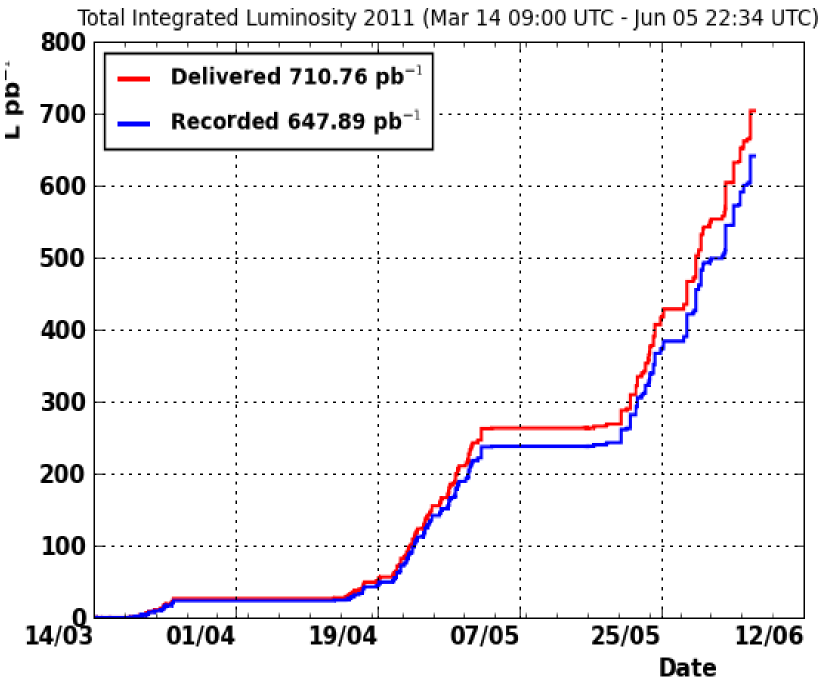
The CMS Detector

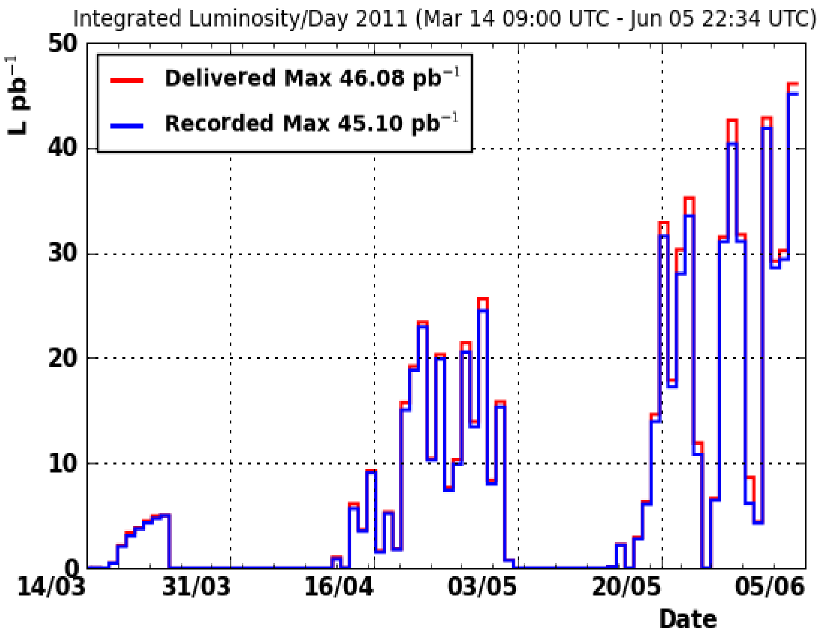
General purpose, hermetic experiment. Compact fully solenoidal design.
All central tracking and calorimetry inside a superconducting solenoid (B=3.8T)-> Large BL^2



LHC and CMS operations

~711pb^{-1} delivered by LHC and **~648pb^{-1}** collected by CMS. **CMS data taking efficiency >91%. We can now record more than 45pb^{-1}/day.**

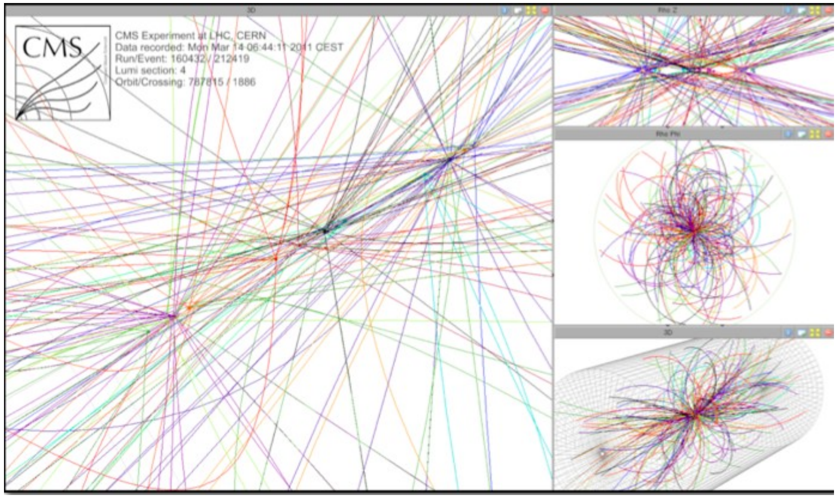




The goal of collecting 1fb^{-1} of data before the end of June is within reach.

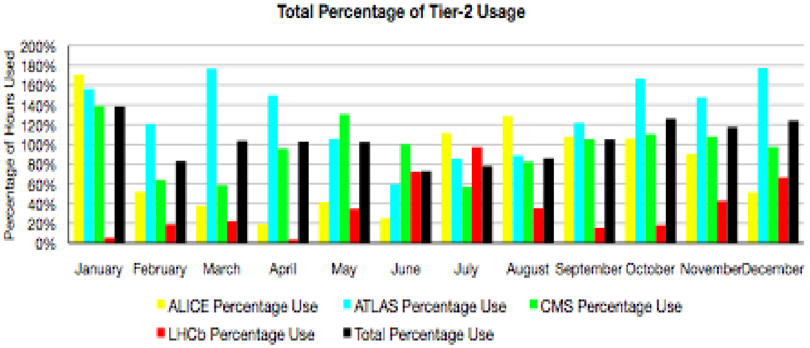
The challenge for Computing

- **Run in 2011: dataset+30%**
  - In 2010 we collected ~1.5B events. Expect more than 2B in 2011.
- **Events in 2011 are much more complicated**
  - At 10 interactions per crossing we have factors of 2-3 increase in RECO time. Factor of 2 in RECO size and AOD size
- **Resources**
  - Resource utilization for analysis was high in 2010 and increasing
  - Significant increases in Tier-1 and Tier-2 resources are available for 2011, but even with these we will have to prioritize activities



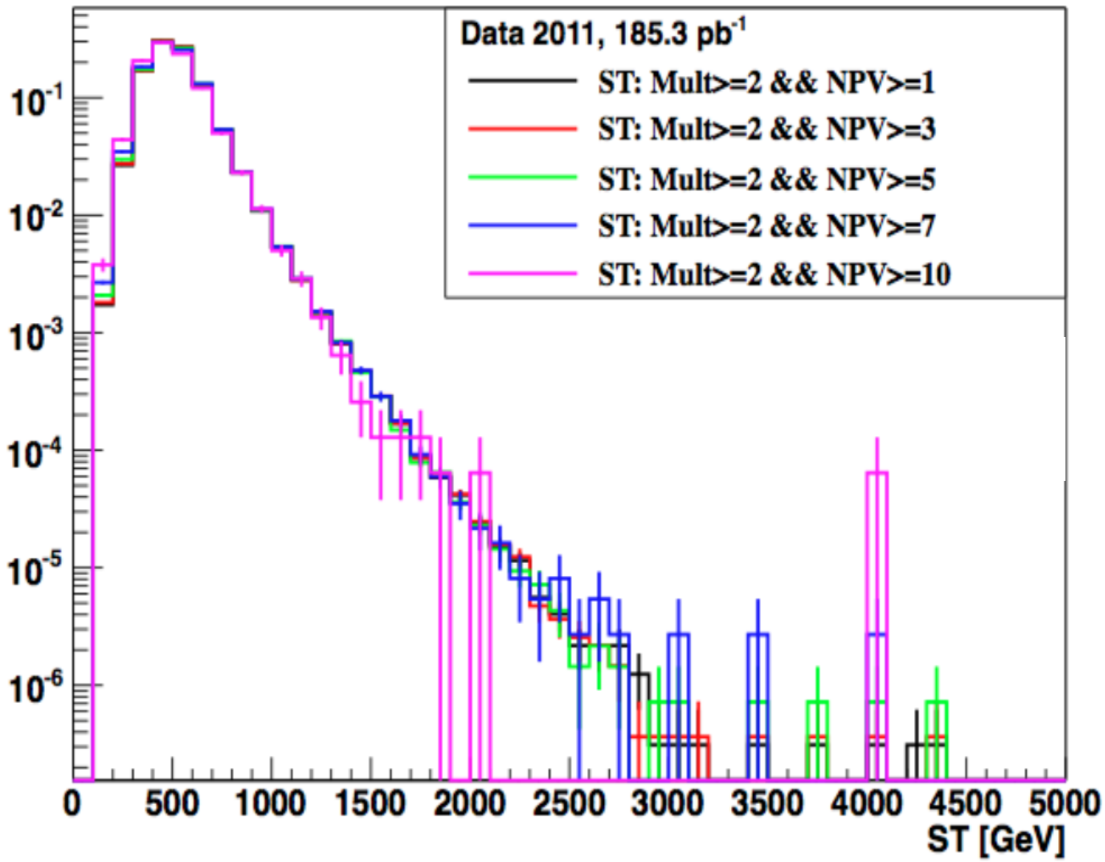
50% increase on Tier-2 resources for 2011
Larger increase in size and processing time from pile-up

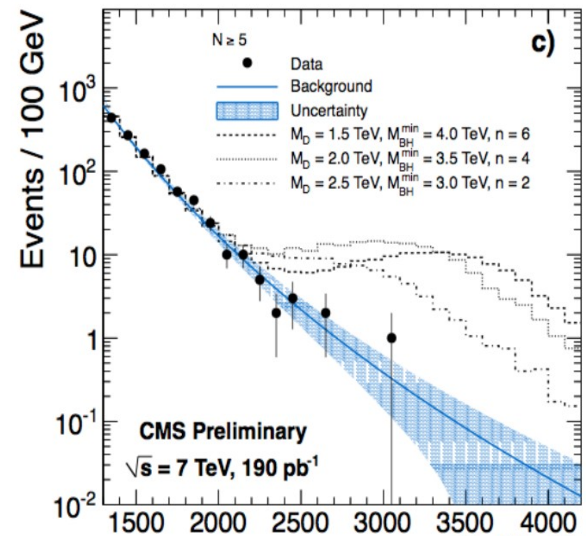
2010 T2 Usage by VO

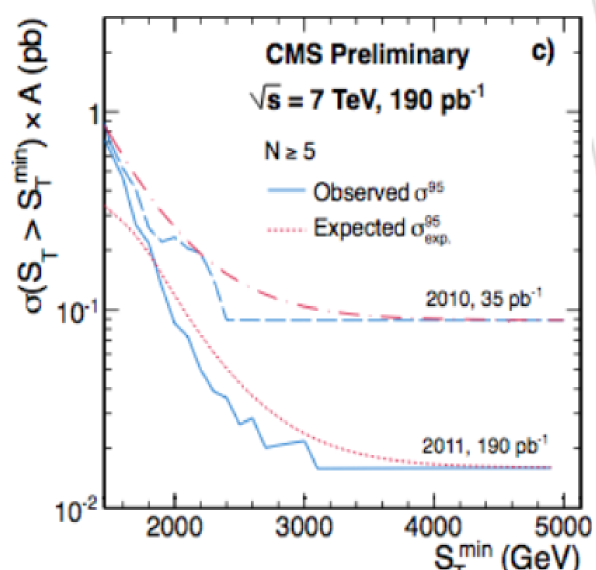


The challenge for Physics

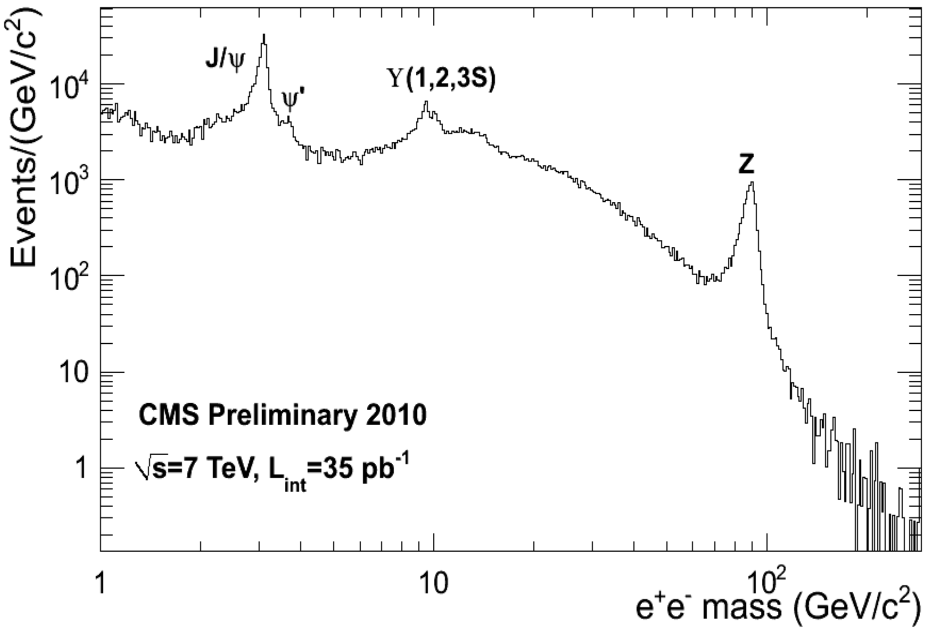
- Check carefully the effect on the pile-up on basic physics tool and selection criteria.
- An example: search for Black Holes.

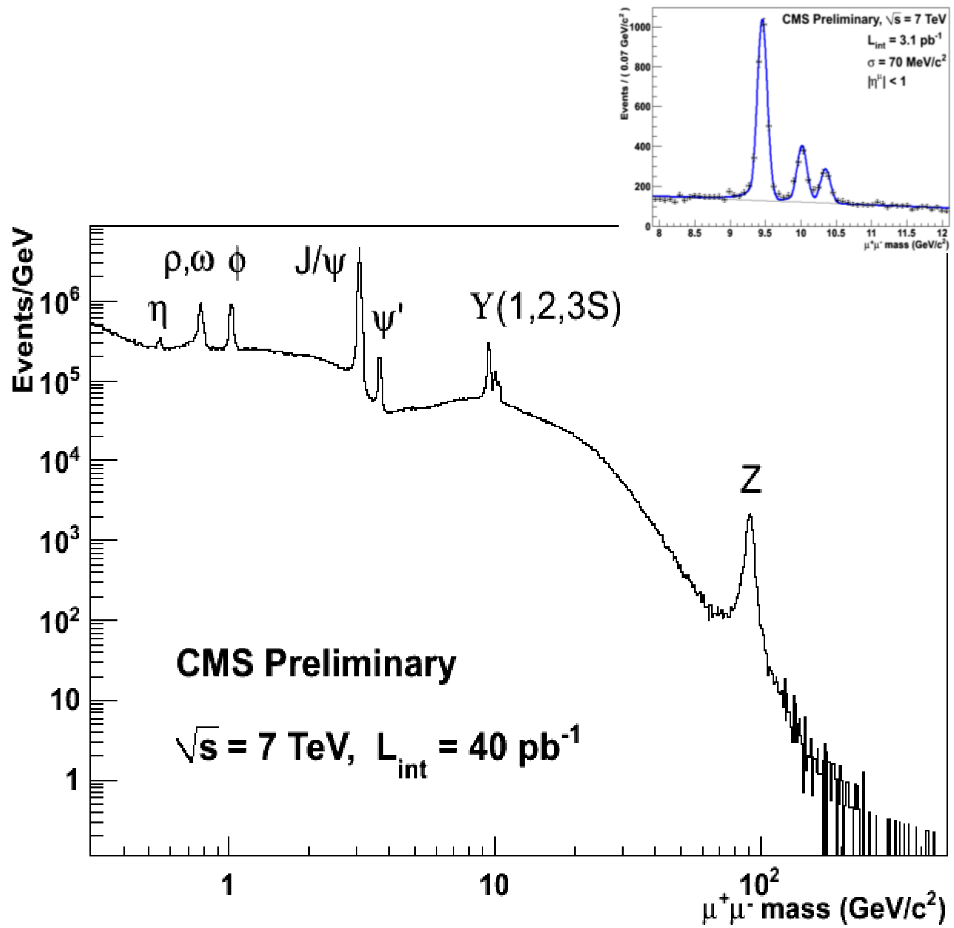




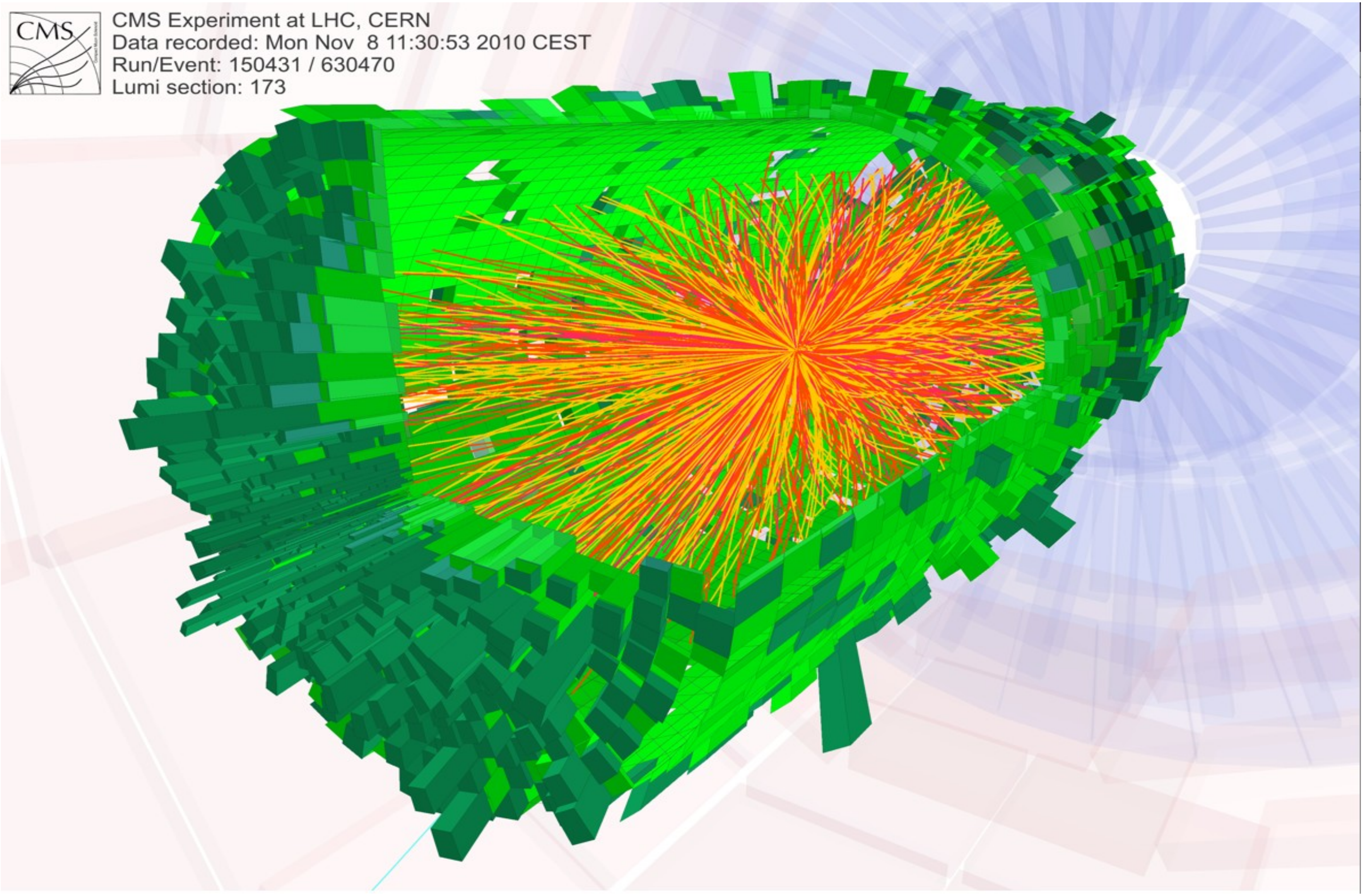


The Standard Model at 7TeV

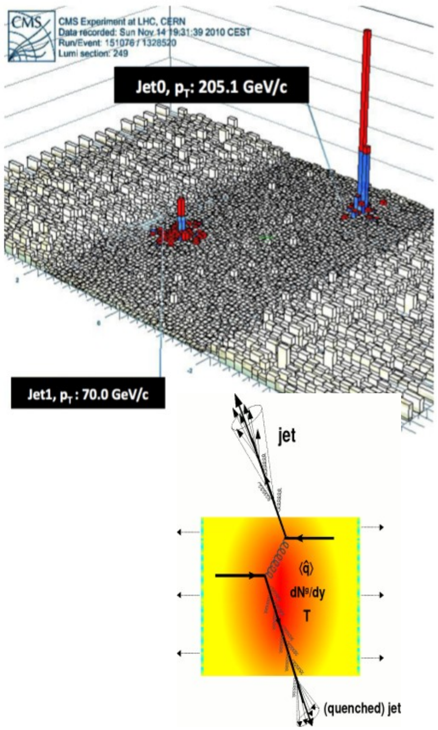


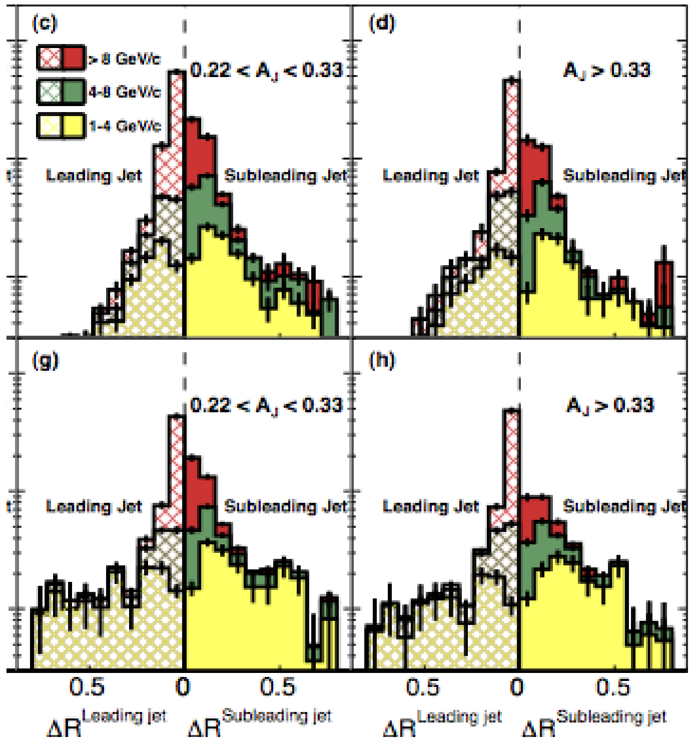


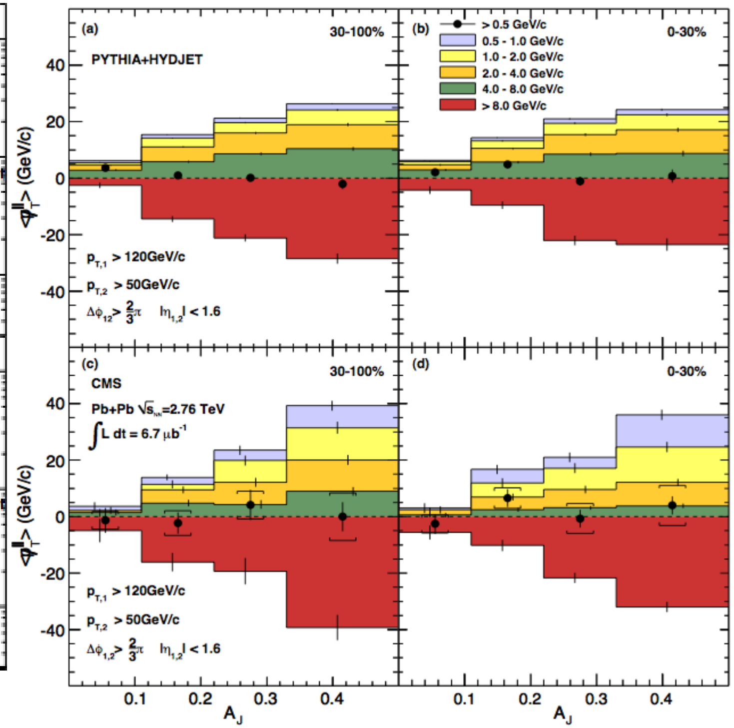
Pb-Pb collisions in CMS



Jet quenching: direct observation and detailed understanding



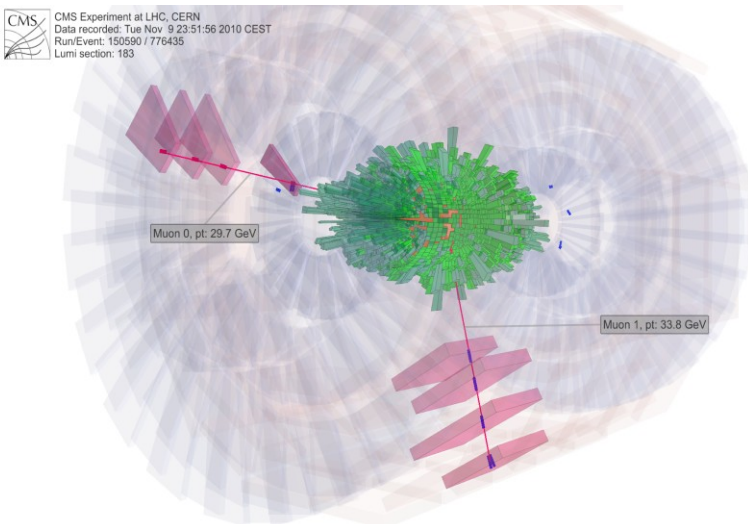




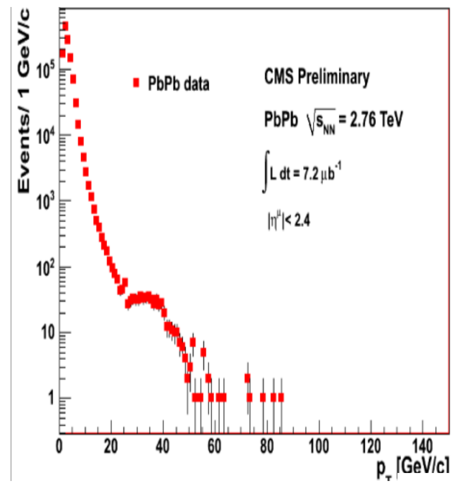
The phenomenon of jet quenching in Heavy-Ion collisions is now described in
detail and fully understood.

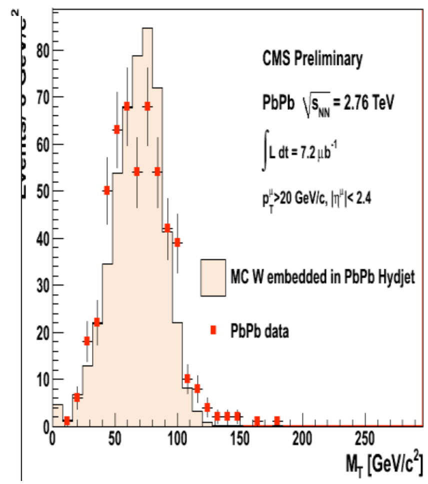
The di-jet momentum balance is fully recovered if we consider the low p_T tracks distributed over a wider angular range wrt the jet axis.

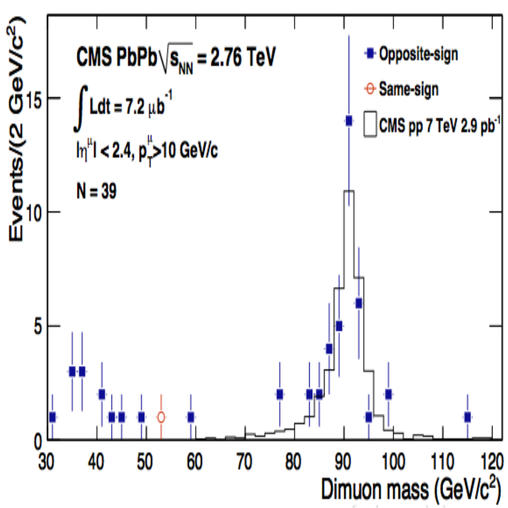
Observation of Z and W produced in HI collisions

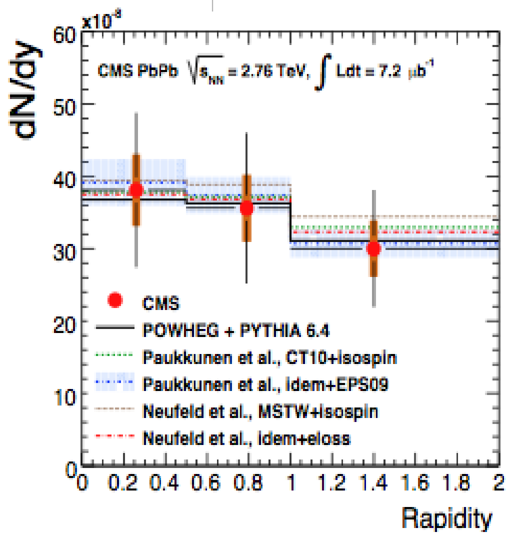


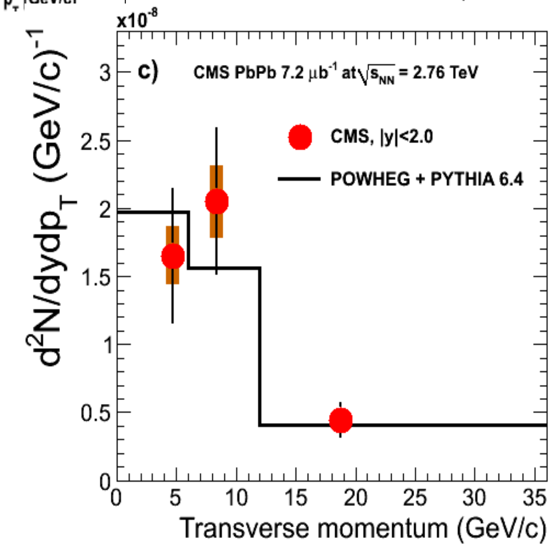
For the first time Electroweak probes accessible in HI collisions.





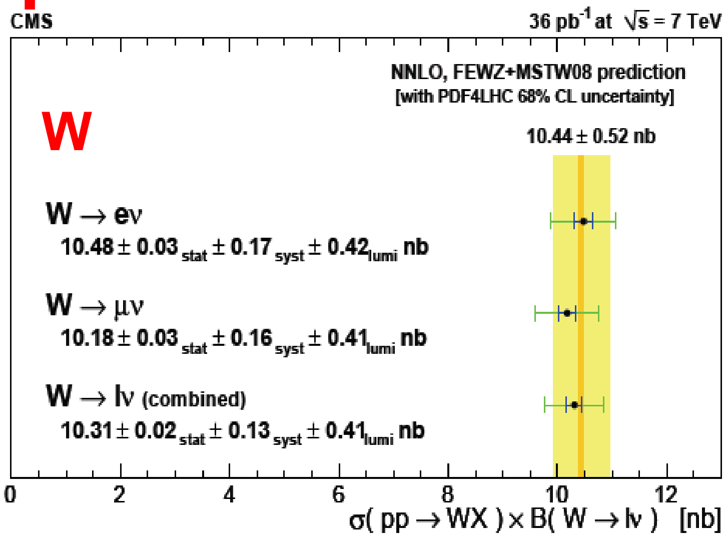


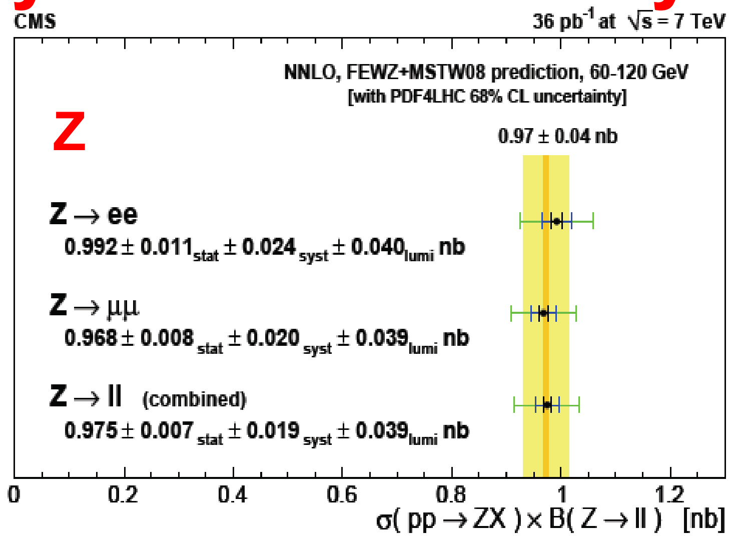


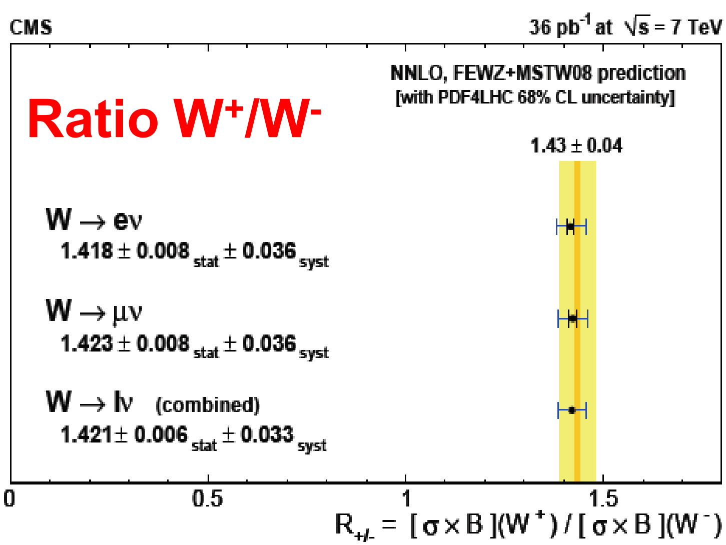


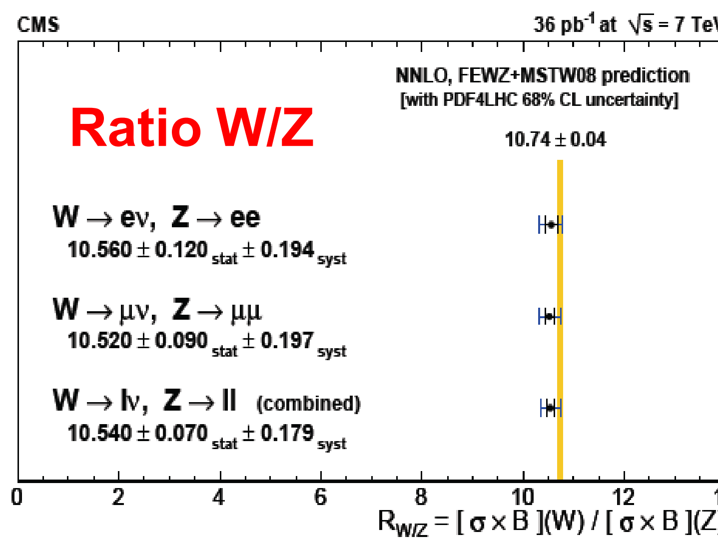
7TeV pp collisions: new EWK measurements

$36 pb^{-1}$ and 4% uncertainty on the luminosity



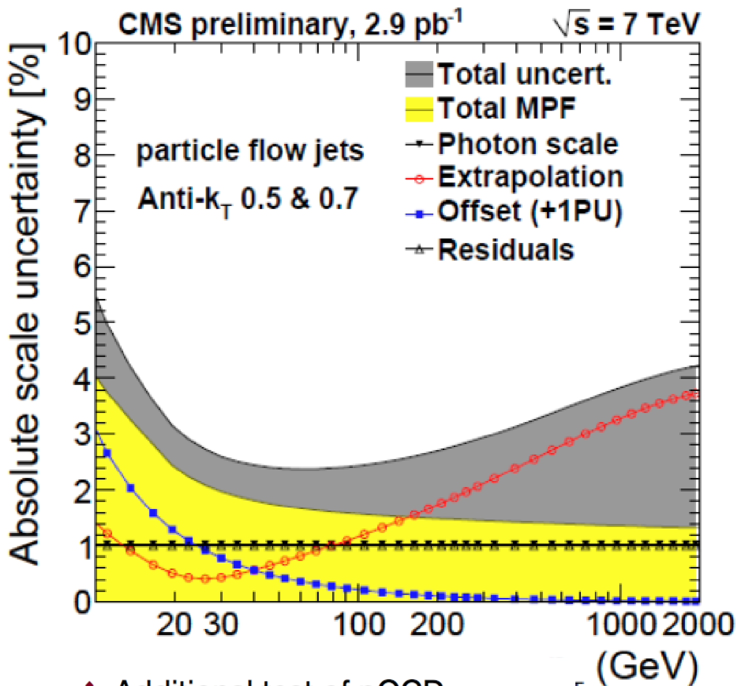


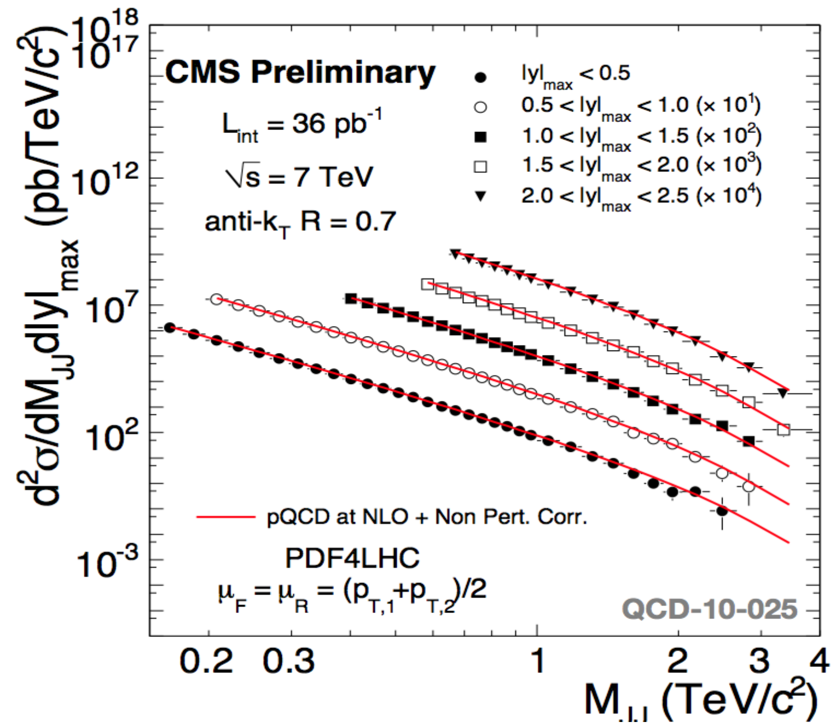


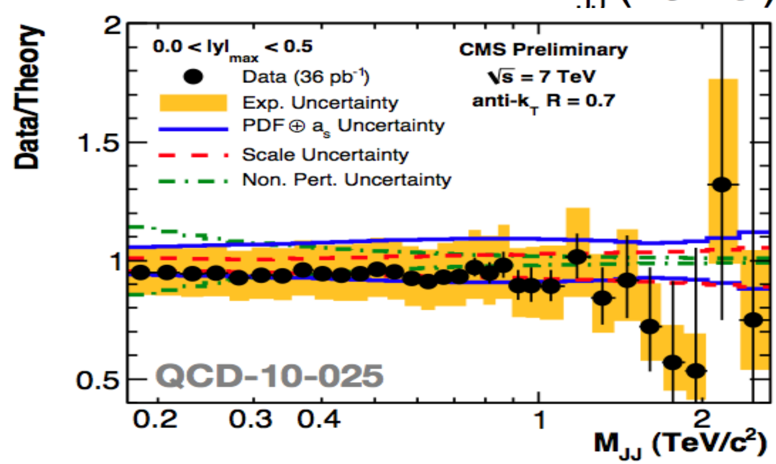


JEC; Di-jet Cross Section vs Mass.

Uncertainty on the energy scale depending on p_T and η: 3-5%





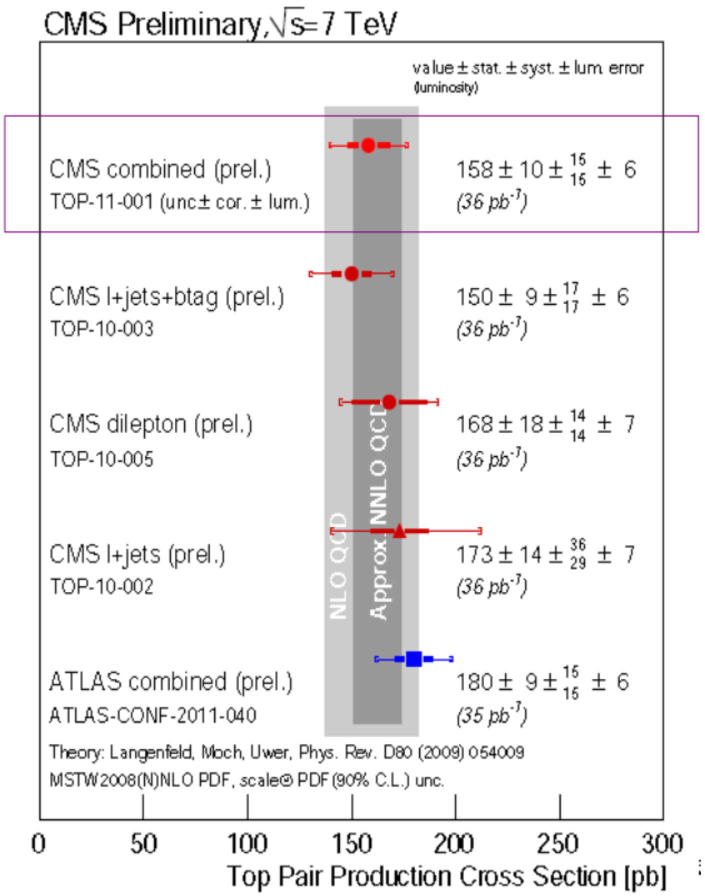


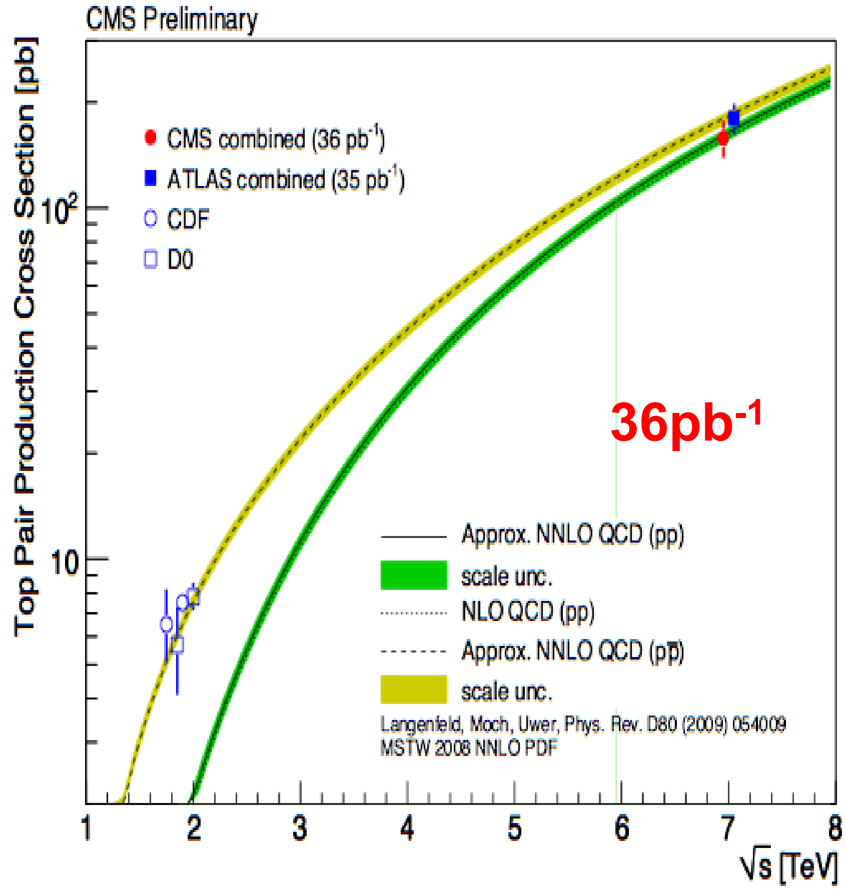
- Additional test of pQCD
- Background for 'bump hunting'
- Up to M_{JJ} = 3.5 TeV/c^2
- Data/theory compatible with inclusive jet measurement

Top cross section combined result

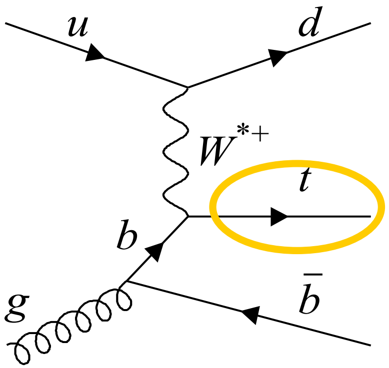
New measurements of the top cross section (leptons+jets with and without btag)

σ =158±10±16±6(lumi)pb

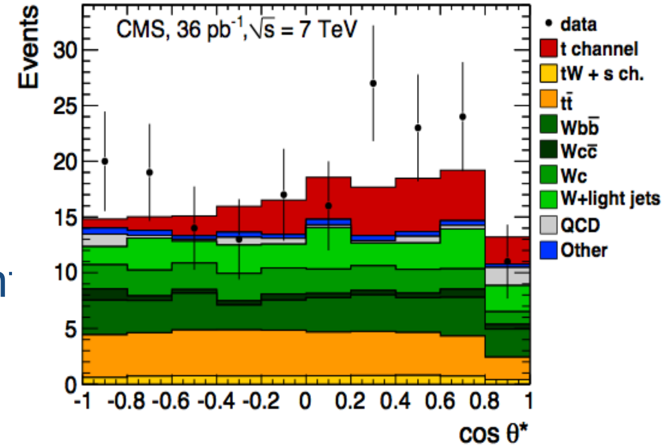


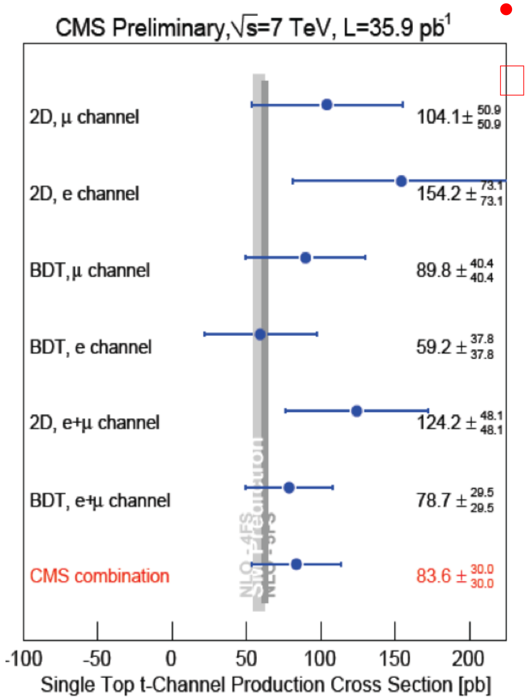


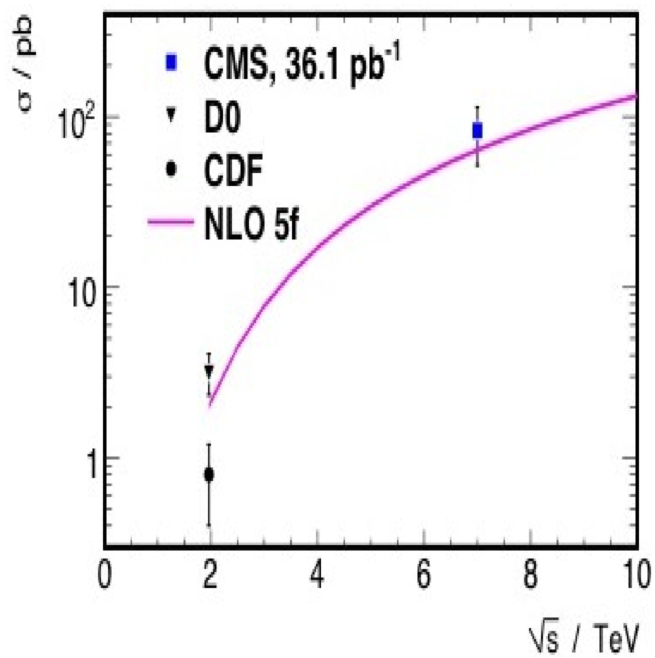
Single top @LHC: the challenge of tiny cross section over tough background.

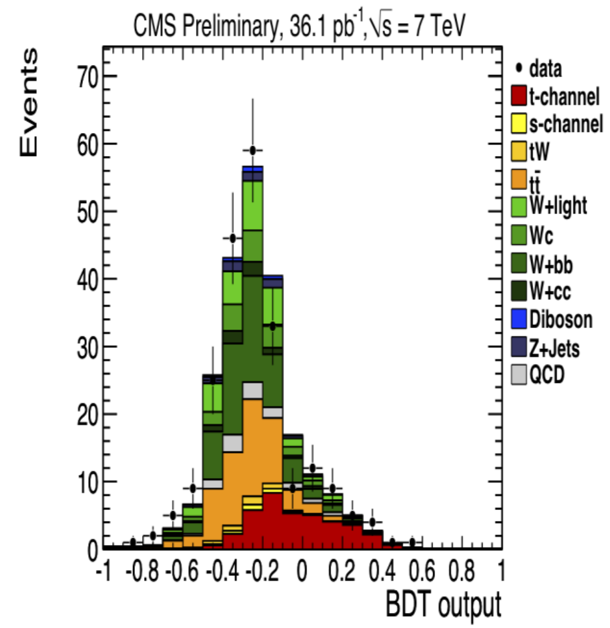


- Example of finding tiny signals with lepton, MET, b-tag and jets
- Two different analyses (cut based and BDT): three differen channels.
- **Very challenging analysis.**
- **σ =83.0±29.8±3.3(lumi)pb**

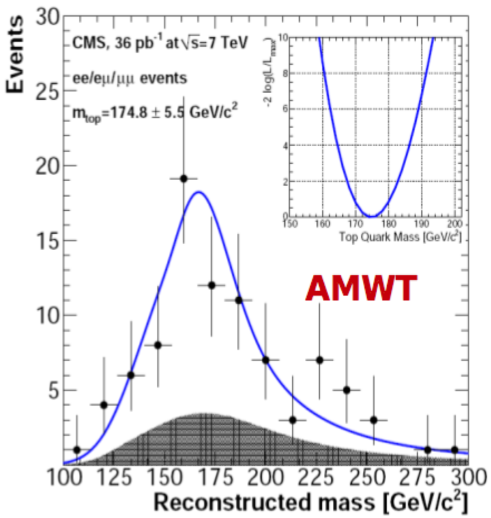


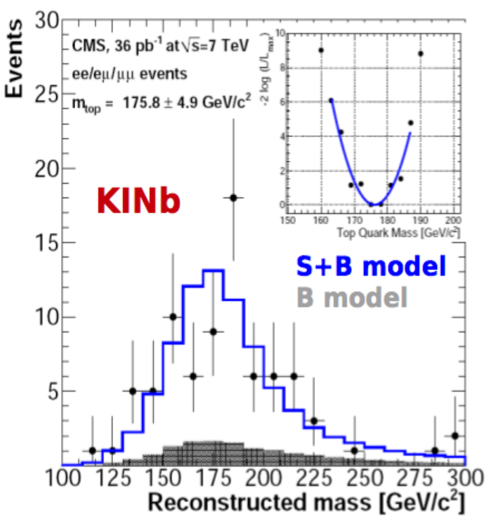






Top mass



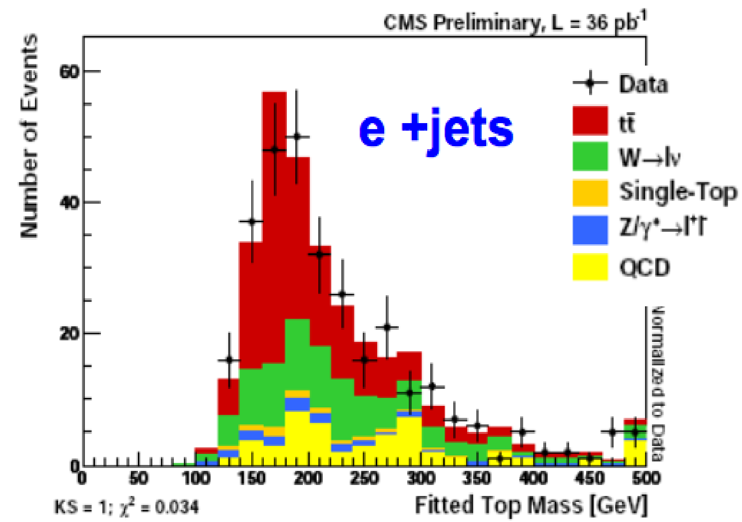


Dilepton channel

M_{top}=175.5±4.6±4.6 GeV/c^2

Lepton+jets channel

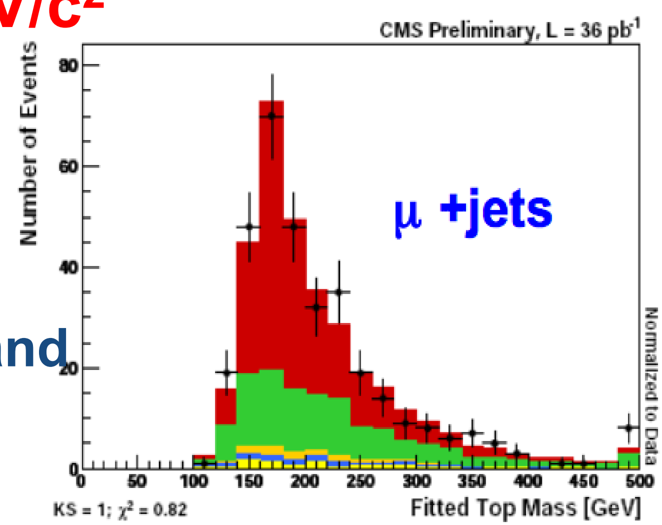
M_{top}=173.1±2.1±2.8 GeV/c^2



CMS combination

M_{top}=173.4±1.9±2.7GeV/c^2

2% precision

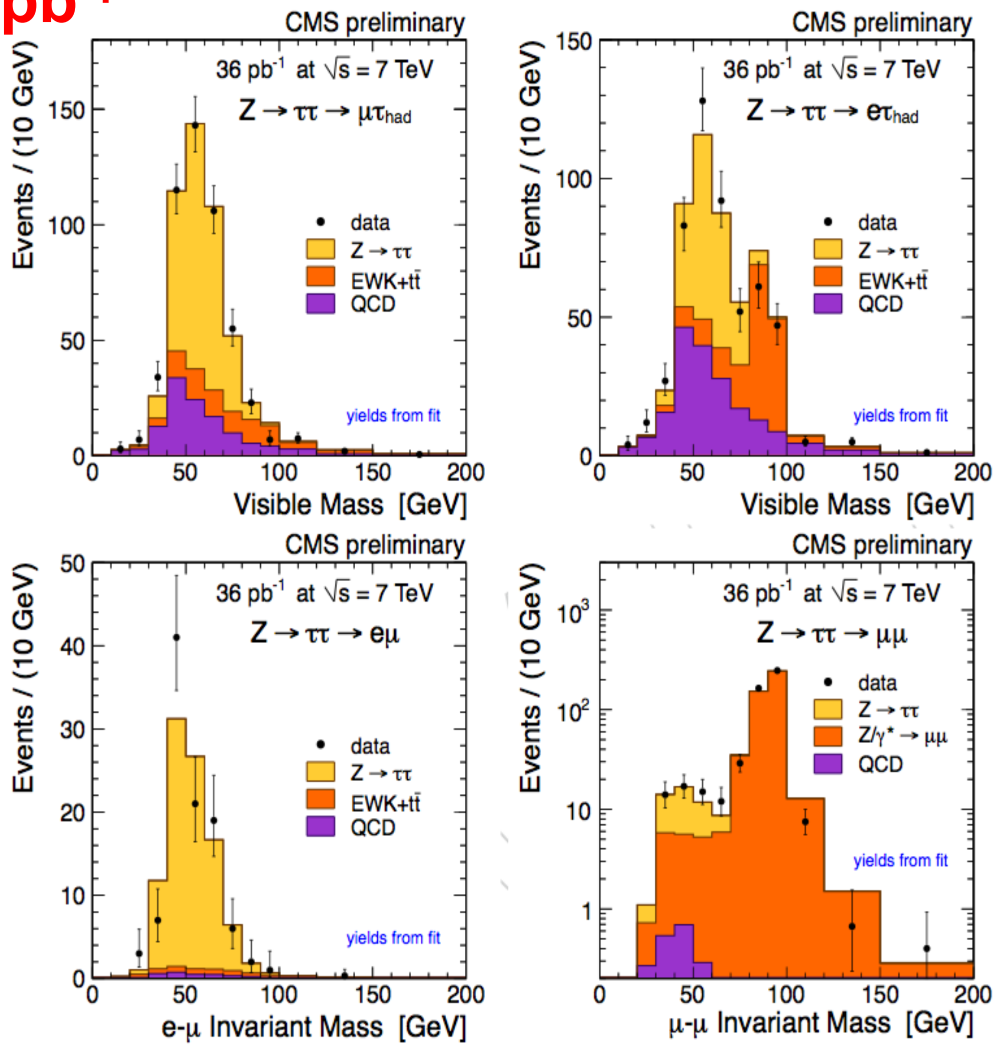


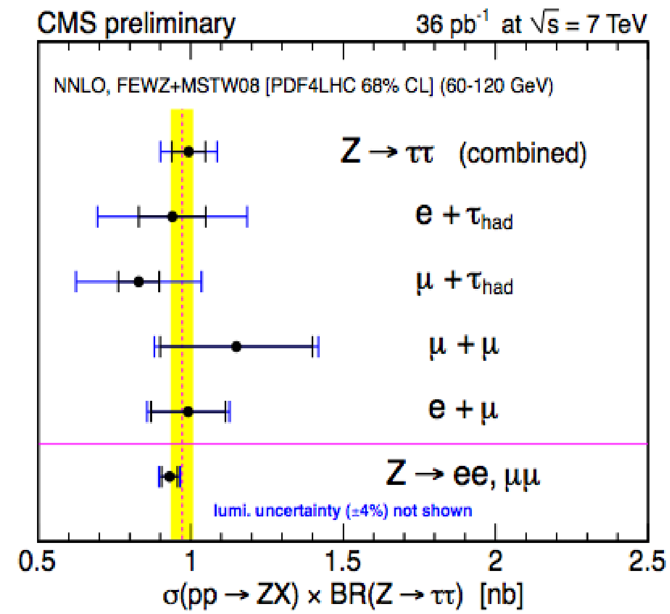
LHC is now a top factory and will allow soon detailed studies of top properties.

arXiv:1105.5661 ; CMS-TOP-11-002 ; CERN-PH-EP-2011-055

$Z \rightarrow \tau^+\tau^-$

36pb^{-1}

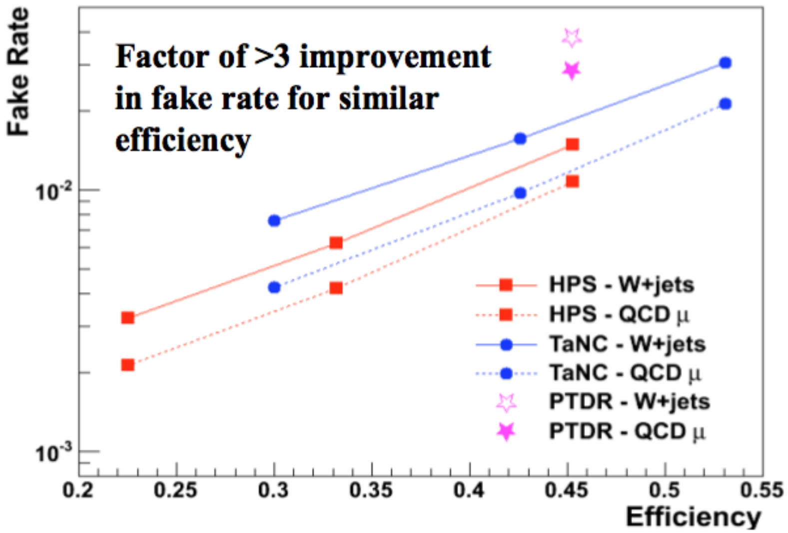


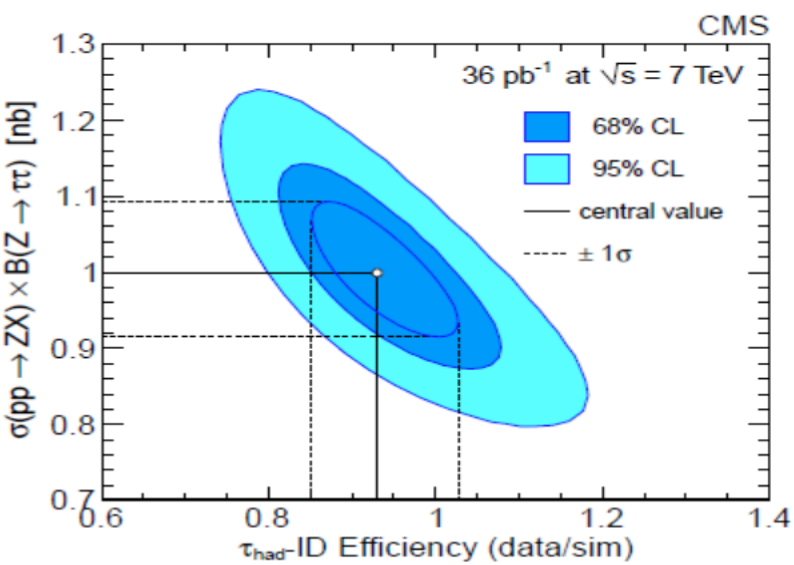


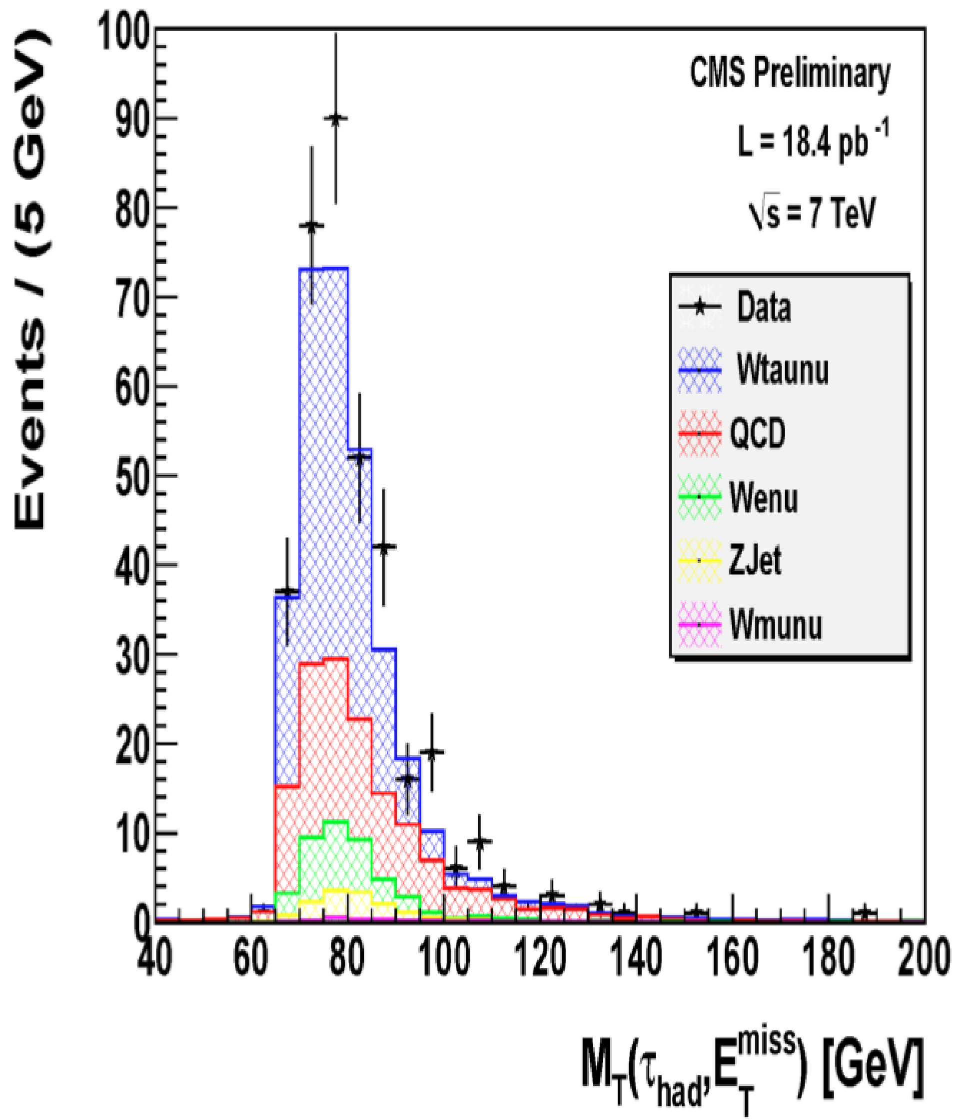
Measurement of the tau id efficiency → important to understand the tau as a discovery tool (Higgs, SUSY etc)

CMS-EWK-10-013; Submitted to the Journal of High Energy Physics

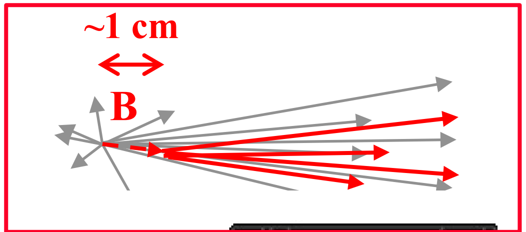
Detailed understanding of the τ lepton as a tool for discovery

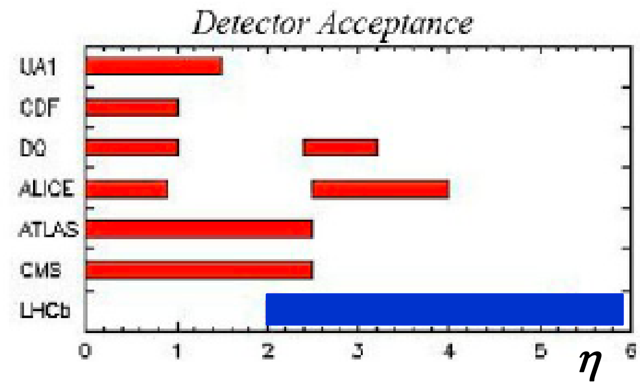


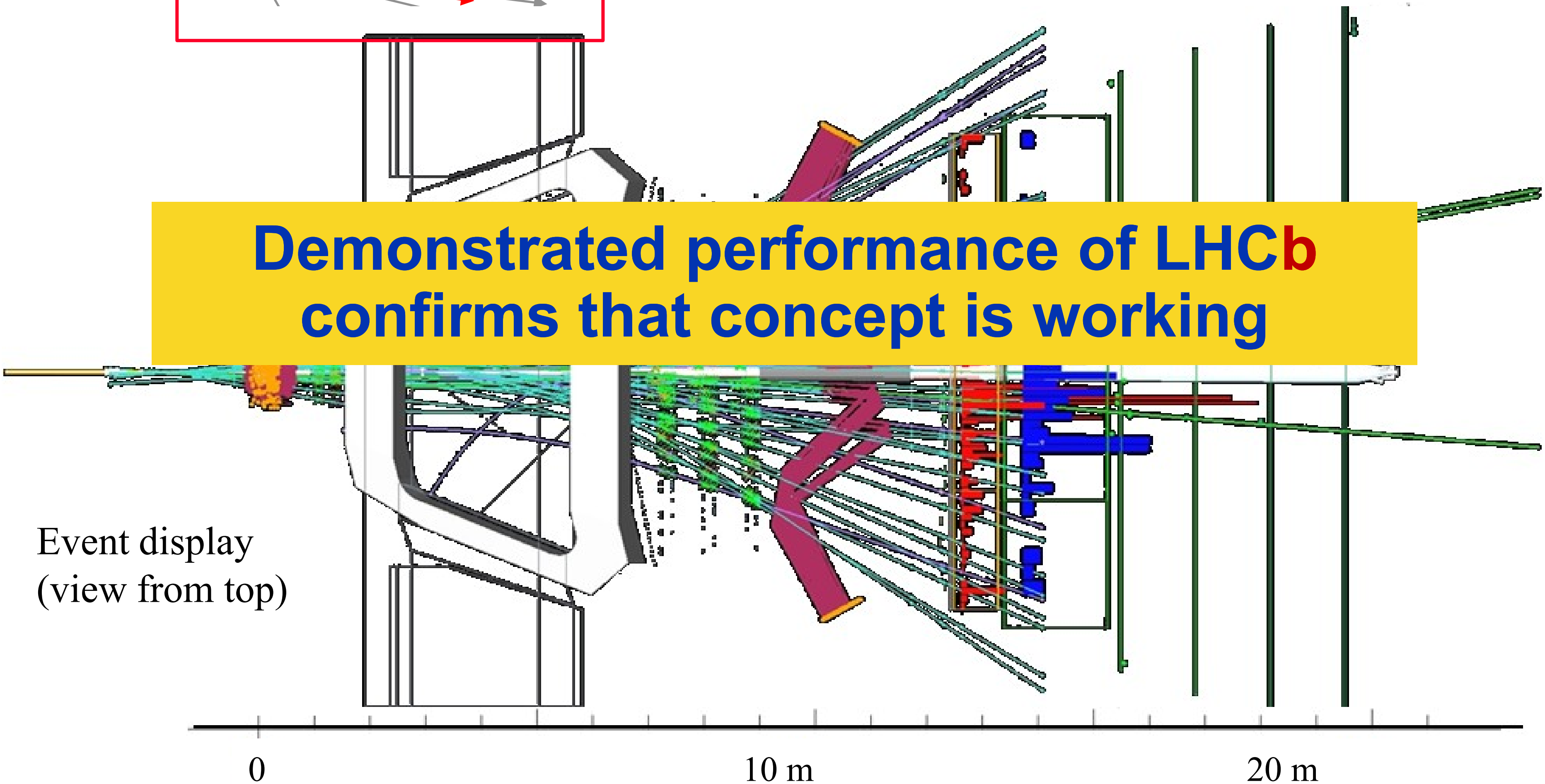




The LHCb Detector optimized for hadronic environment







Demonstrated performance of LHCb confirms that concept is working

Event display
(view from top)

LHC(b) operation in 2010

Evolution of average number of visible pp-collisions per bunch crossing:

$L = n_b \cdot L_b \propto n_b \cdot \mu$

LHCb design:

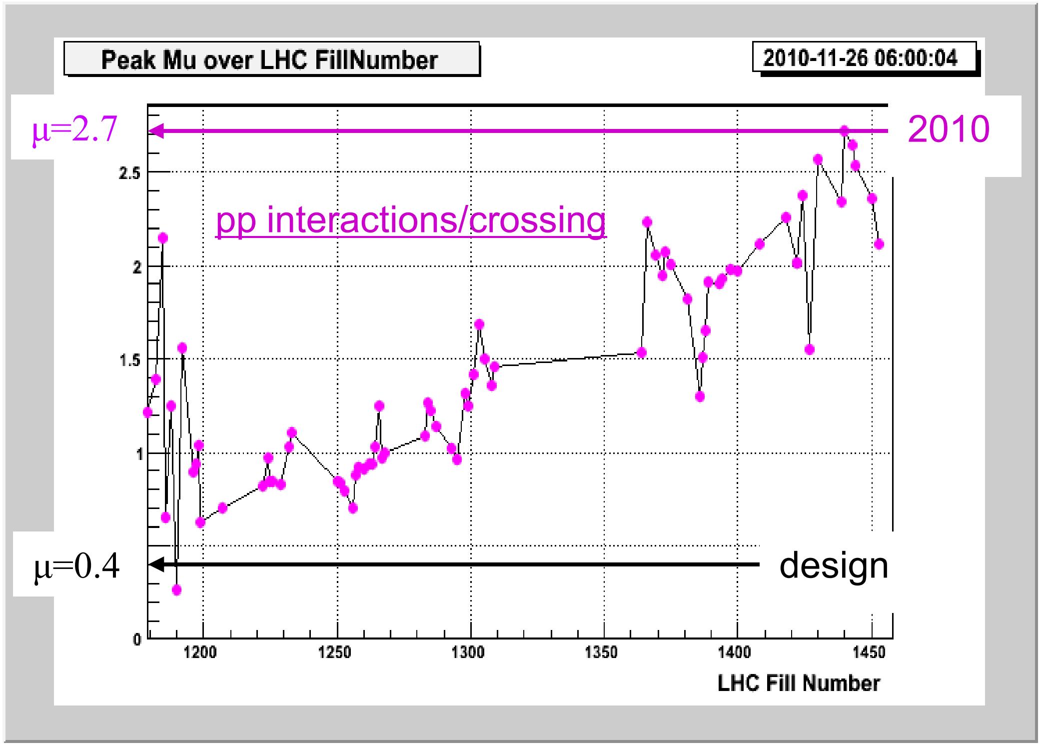
$L = 2 \cdot 10^{32}$; $n_b \sim 2600$ → $\langle\mu\rangle \sim 0.4$

- maximizes fraction of ***single interaction*** bunch crossings

2010 run:

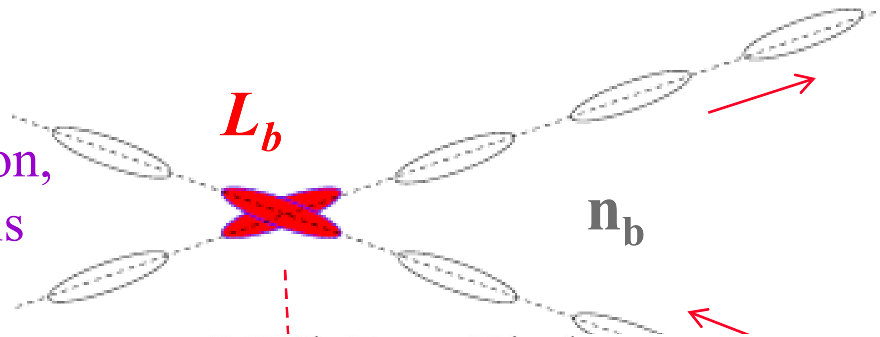
$L = 1.6 \cdot 10^{32}$; $n_b = 344$ → $\mu_{max} = 2.7$

- > 6 times nominal!

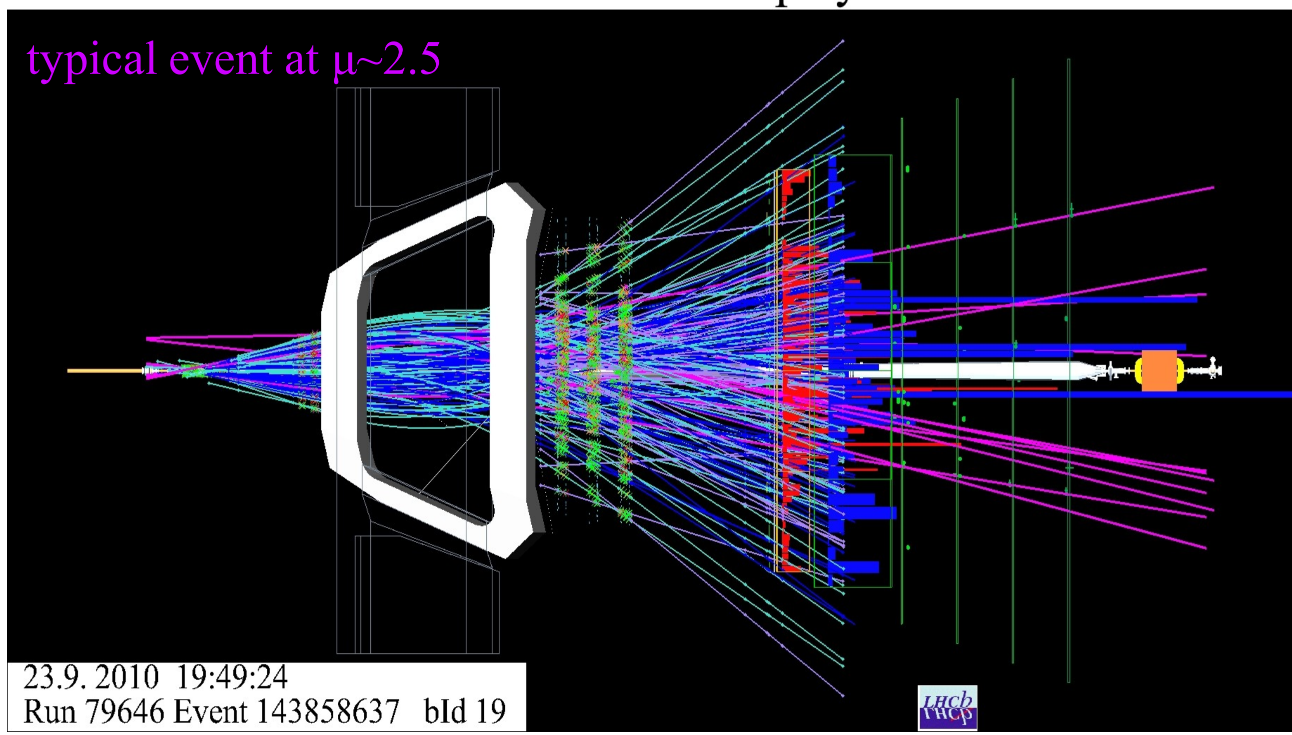


High multiplicity events

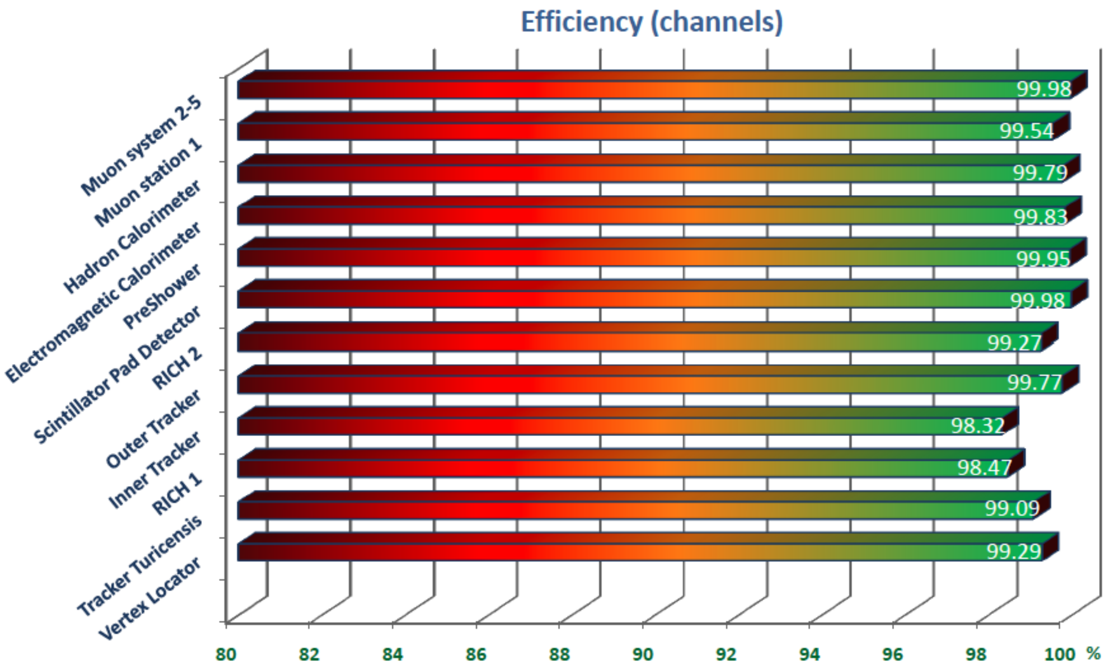
- ***high track multiplicity and many vertices*** in each collision event
- big challenge for detector operation, trigger, reconstruction and analysis



LHCb Event Display



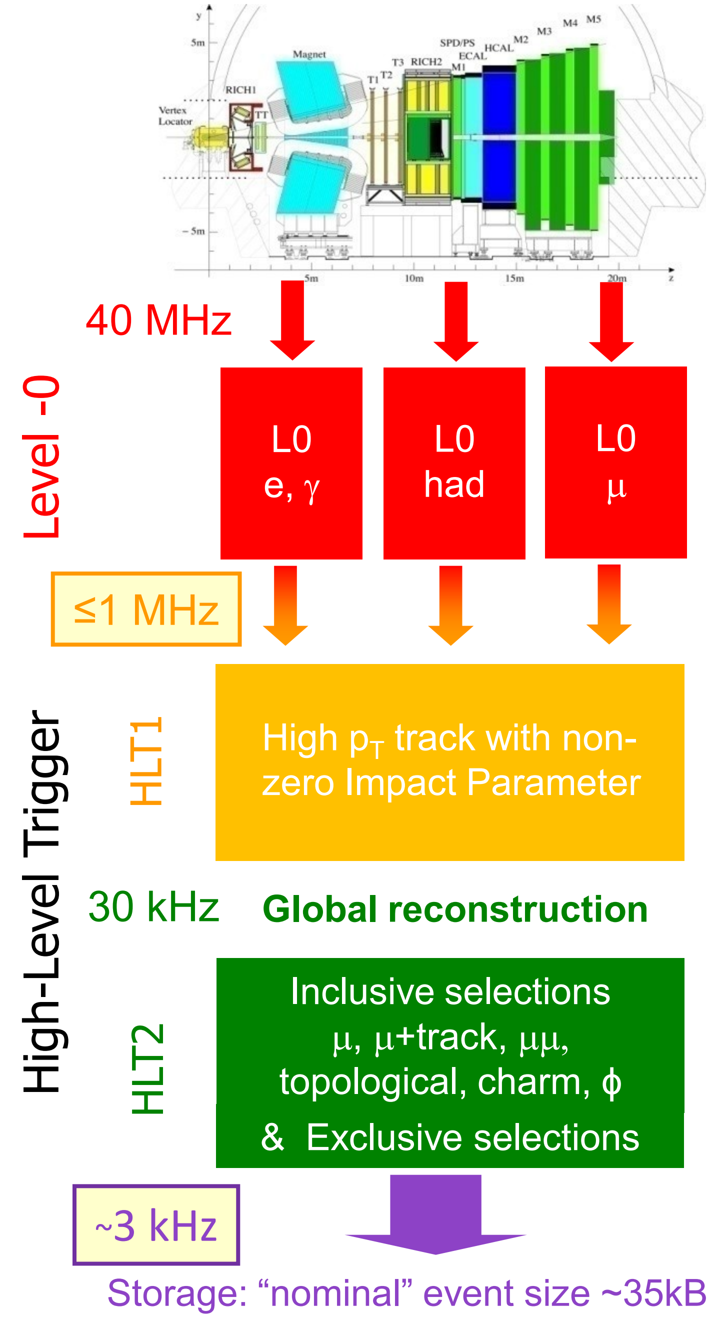
Detector & trigger efficiencies



→ all detector components ~ 99 % efficient!

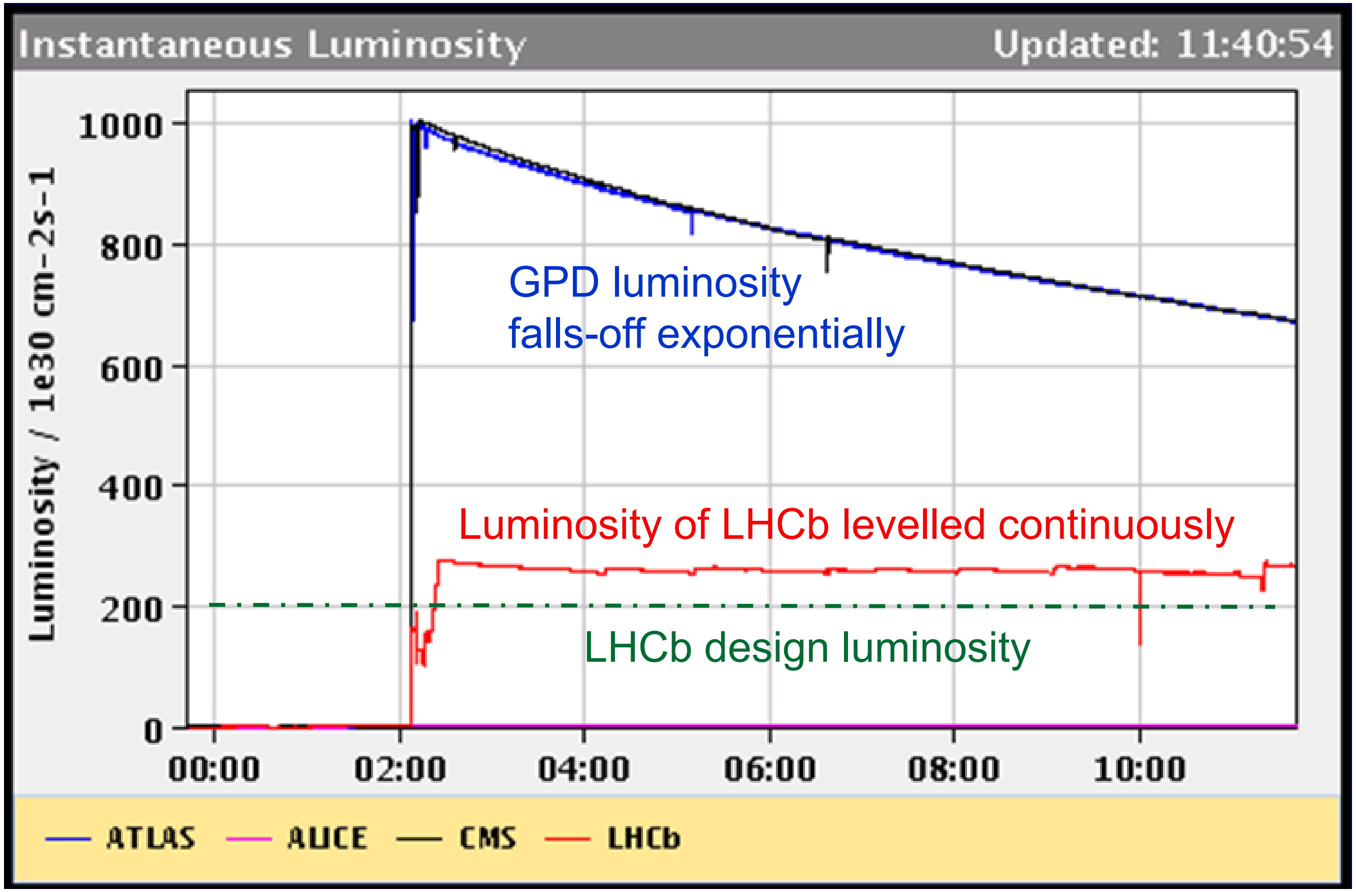
2010	Muon trigger (J/ψ)	Hadron trigger (D^0)
Data	94.9±0.2%	60±4%
MC	93.3±0.2%	66%

→ very high selection efficiencies!



Expected integrated luminosity for LHCb in 2011

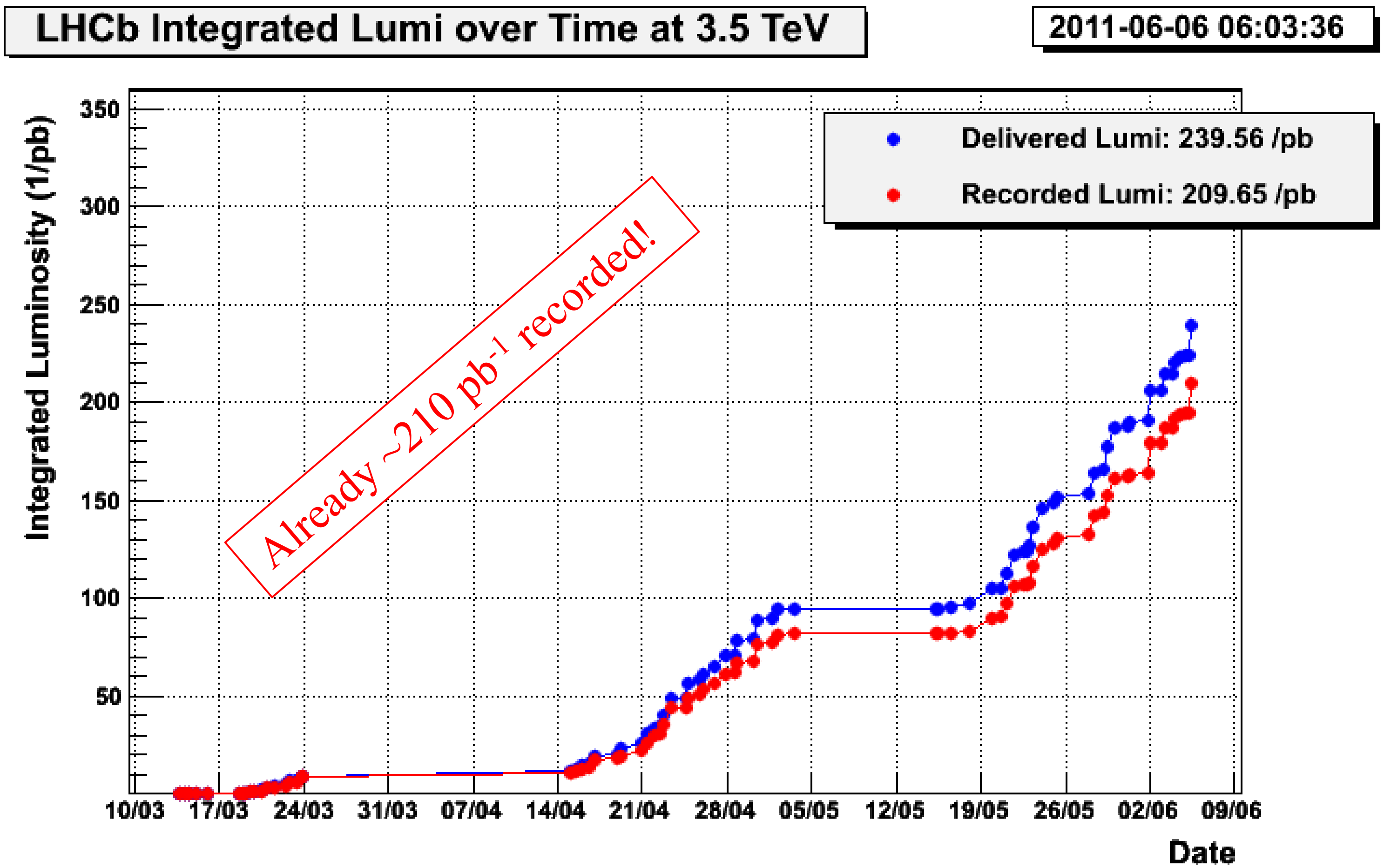
Introduced luminosity leveling for LHCb → can run at optimal μ and L_{max}



→ Since end of May running at constant $L \sim 3 \cdot 10^{32}$ $cm^{-2}s^{-1}$ with $\mu \sim 1.5$

Expected integrated luminosity for LHCb in 2011

Introduced luminosity leveling for LHCb → can run at optimal μ and L_{max}

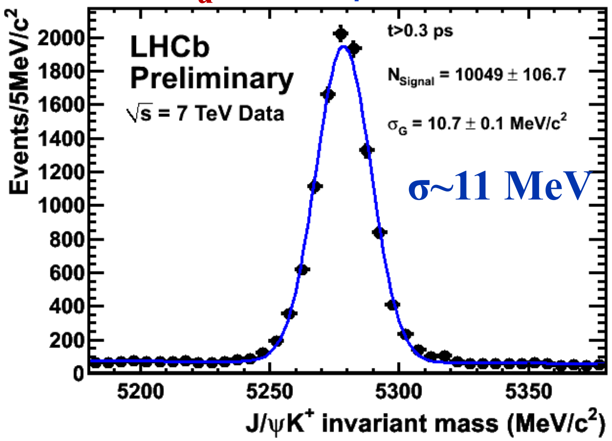


→ LHCb expects to collect ~1000 pb^{-1} in 2011 (and ≥ same in 2012)

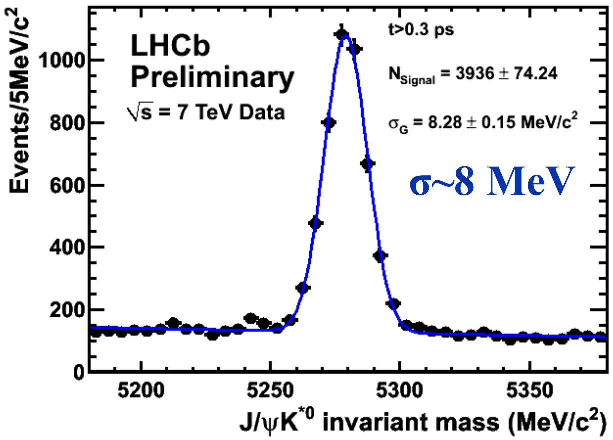
Detector performance: mass resolution

Detection of different B species: for $B \to J/\psi X$ with 34 pb^{-1} ~ full statistics of 2010

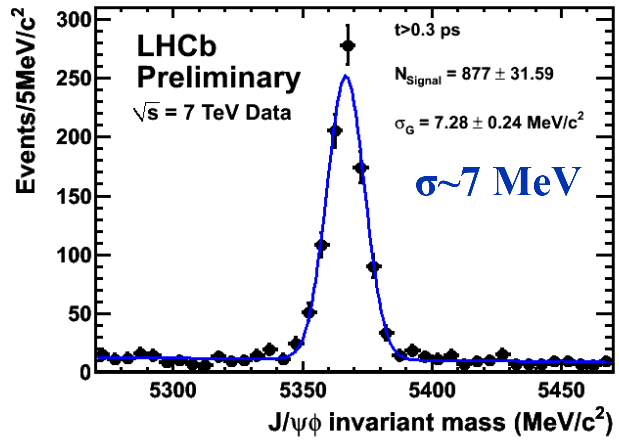
$B_u^+ \to J/\psi K^+$



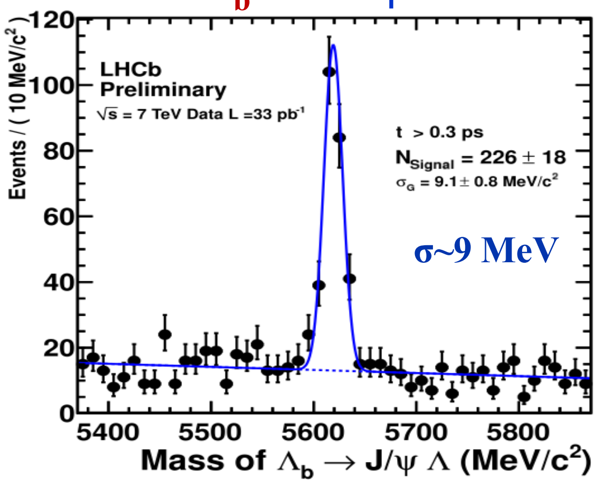
$B_d^0 \to J/\psi K^*$



$B_s^0 \to J/\psi \varphi$



$\Lambda_b^0 \to J/\psi \Lambda$



- very good mass resolution
- very low background (comparable to e^+e^- machines)
- ***worlds best*** mass measurements

Comparison GPDs:

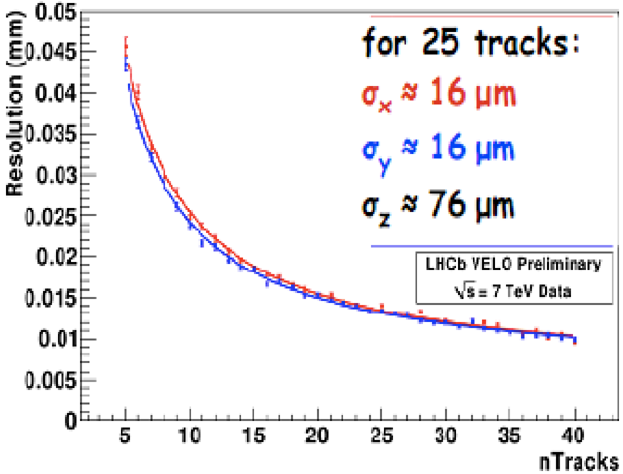
- CMS: σ~16 MeV
- ATLAS: σ~26 MeV

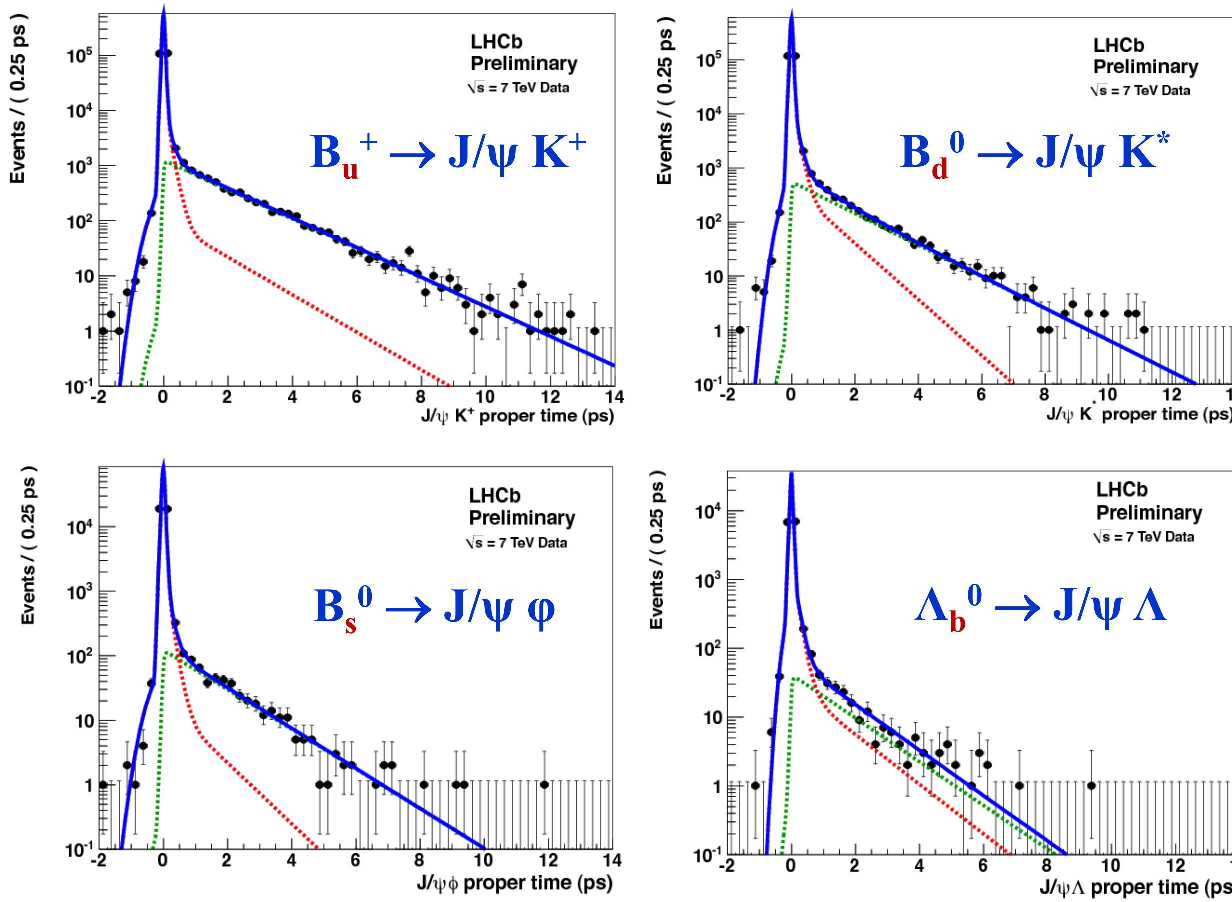
[LHCb-CONF-2011-027]

Channel		LHCb mass [MeV/c^2]	PDG [MeV/c^2]
$M(B^+ \to J/\psi K^+)$	=	5279.27 ± 0.11 (stat) ± 0.20 (syst)	5279.17 ± 0.29
$M(B^0 \to J/\psi K^{*0})$	=	5279.54 ± 0.15 (stat) ± 0.16 (syst)	5279.50 ± 0.30
$M(B^0 \to J/\psi K^0_S)$	=	5279.61 ± 0.29 (stat) ± 0.20 (syst)	5279.50 ± 0.30
$M(B^0_s \to J/\psi \phi)$	=	5366.60 ± 0.28 (stat) ± 0.21 (syst)	5366.30 ± 0.60
$M(\Lambda_b \to J/\psi \Lambda)$	=	5619.49 ± 0.70 (stat) ± 0.19 (syst)	5620.2 ± 1.6
$M(B^+_c \to J/\psi \pi^+)$	=	6268.0 ± 4.0 (stat) ± 0.6 (syst)	6277 ± 6

Detector performance: proper-time resolution

Vertex resolution
on primary vertex





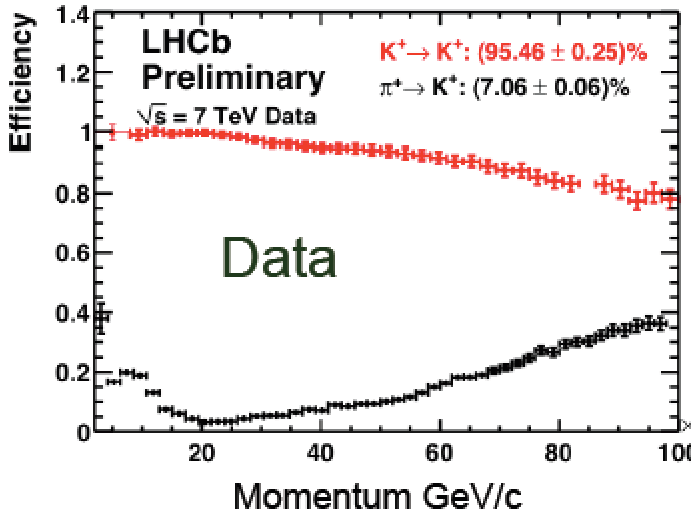
- excellent proper time resolution of ~50 ps

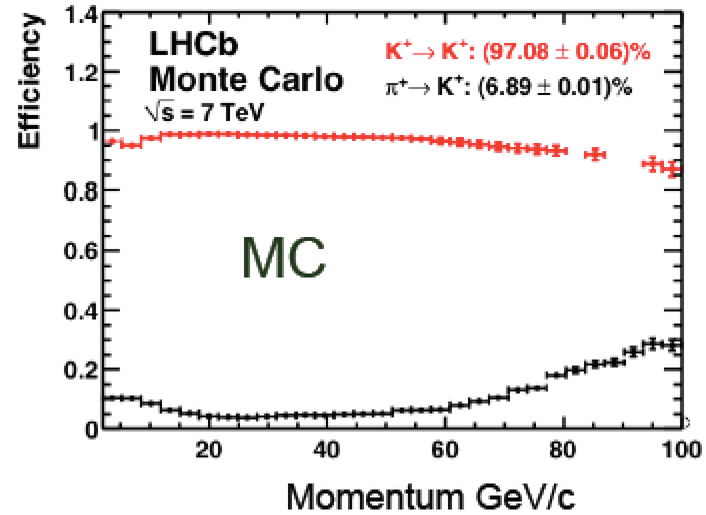
Channel		LHCb lifetime [ps]	PDG [ps]
$\tau(B^+ \to J/\psi K^+)$	=	1.689 ± 0.022 (stat.) ± 0.047 (syst.)	1.638 ± 0.011
$\tau(B^0 \to J/\psi K^{*0})$	=	1.512 ± 0.032 (stat.) ± 0.042 (syst.)	1.525 ± 0.009
$\tau(B^0 \to J/\psi K^0_S)$	=	1.558 ± 0.056 (stat.) ± 0.022 (syst.)	1.525 ± 0.009
$\tau^{\text{single}}(B^0_s \to J/\psi \phi)$	=	1.447 ± 0.064 (stat.) ± 0.056 (syst.)	1.477 ± 0.046
$\tau(\Lambda_b \to J/\psi \Lambda)$	=	1.353 ± 0.108 (stat.) ± 0.035 (syst.)	1.391 ± 0.038

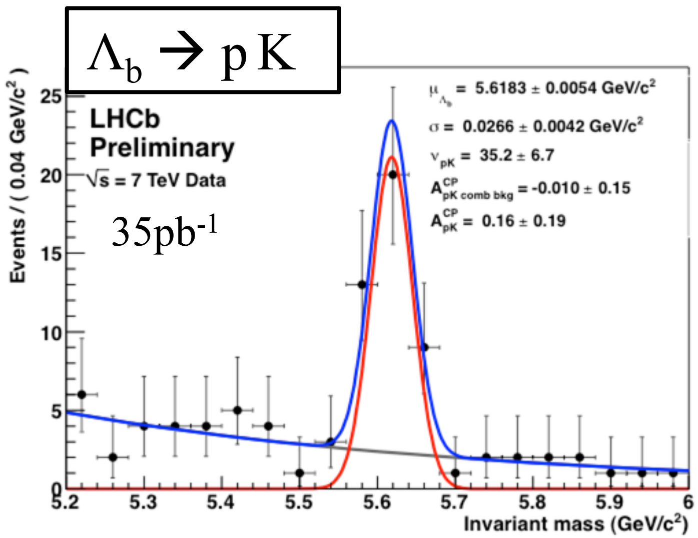
[LHCb-CONF-2011-001]

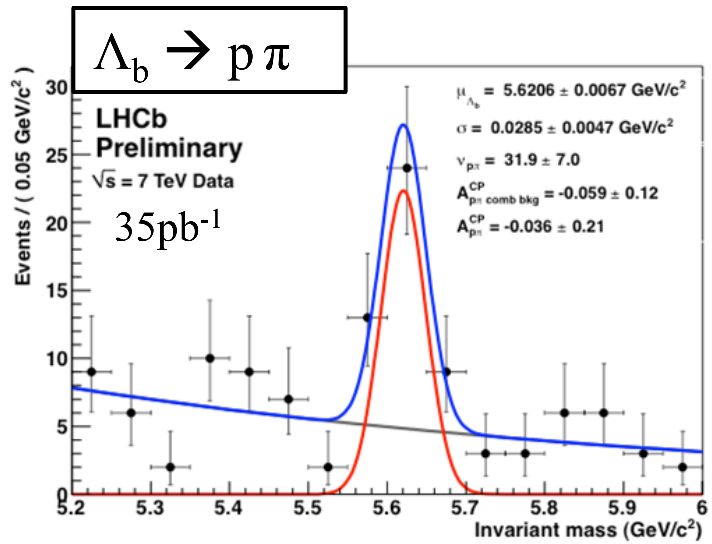
Detector performance: hadron PID performance

Kaon identification efficiency and miss-identification as function of momentum





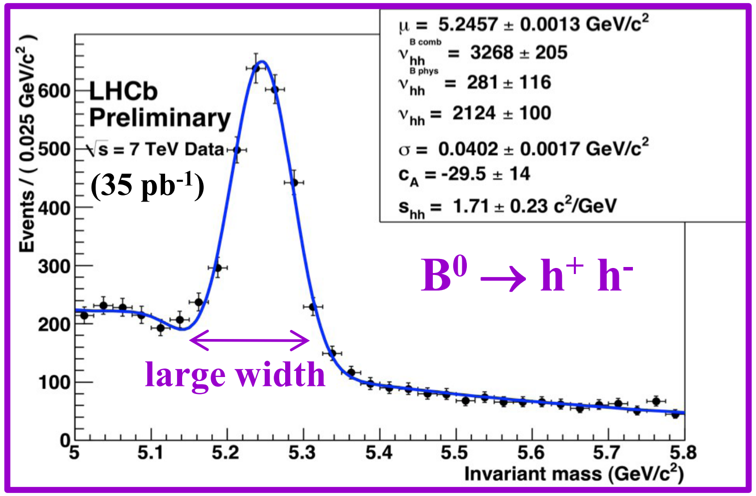




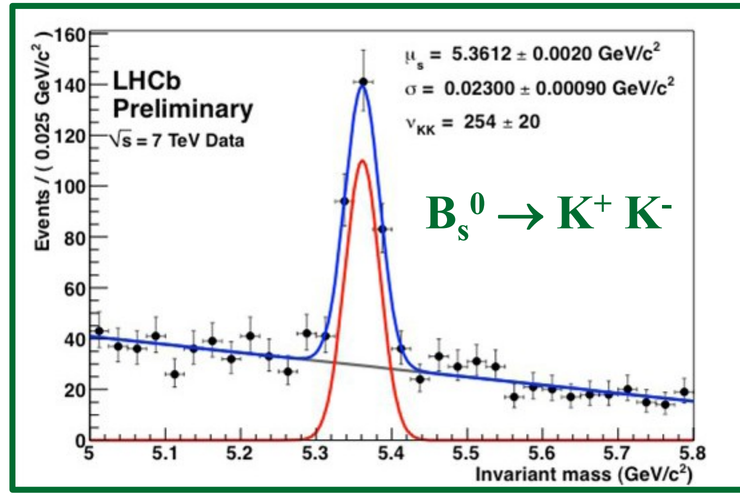
- excellent prospects for observation of CP violation with $L \sim 1\ \text{fb}^{-1}$

Detector performance:
Particle Identification on B→hh

No particle identification → any 2 hadrons!

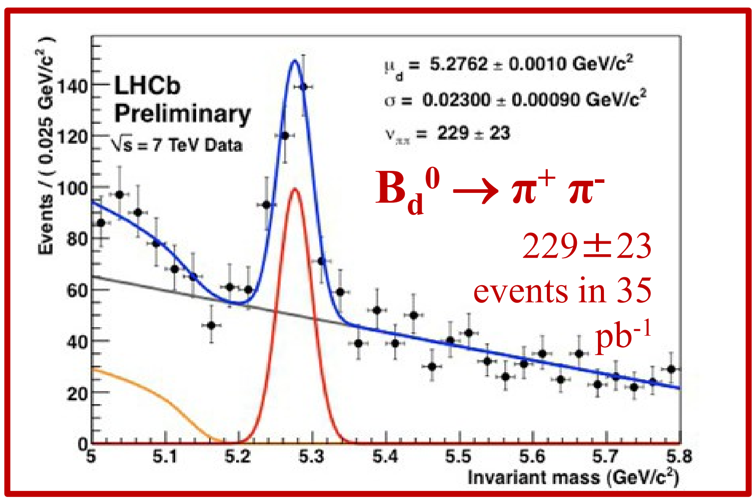


particle identification of 2 Kaons



particle identification of 2 π

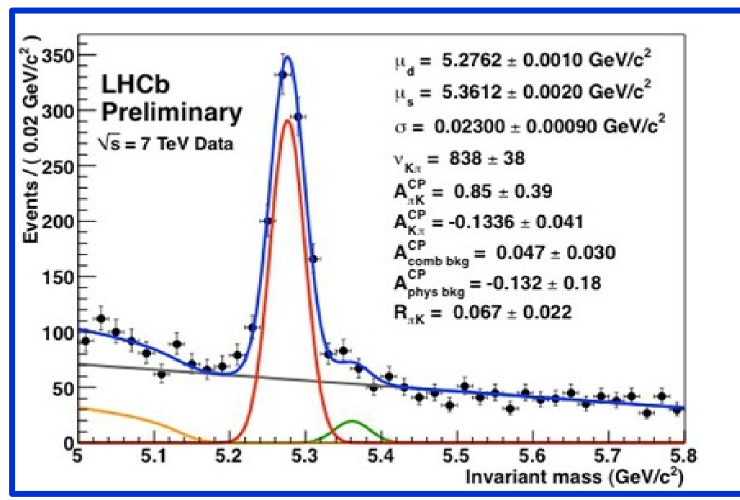
BR($B \to \pi^+\pi^-$) = 5 x 10^{-6} !



particle identification of 1 π and 1 K

$B_d^0 \to K\pi$ & $B_s^0 \to K\pi$

(will get as many Kπ in <1 fb^{-1} as Belle in 1000 fb^{-1})



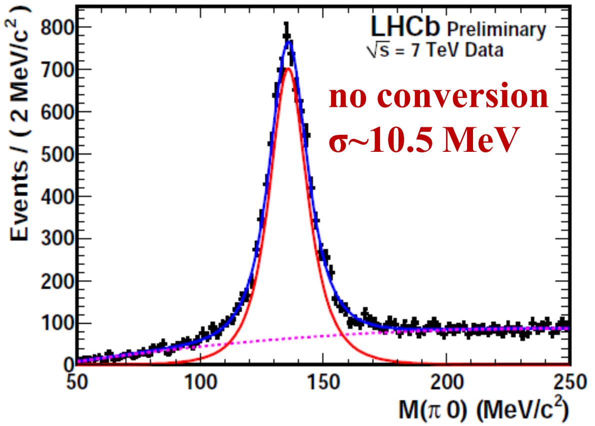
Expectations 2011:

LHCb: 6500 ev./fb^{-1}

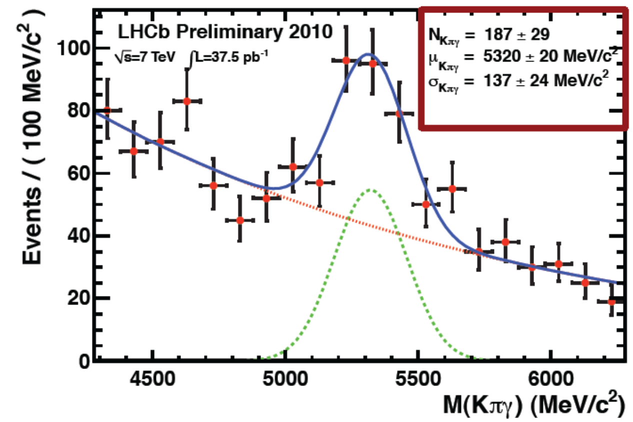
(CDF: 1100 ev./fb^{-1})

Detector performance: photon PID

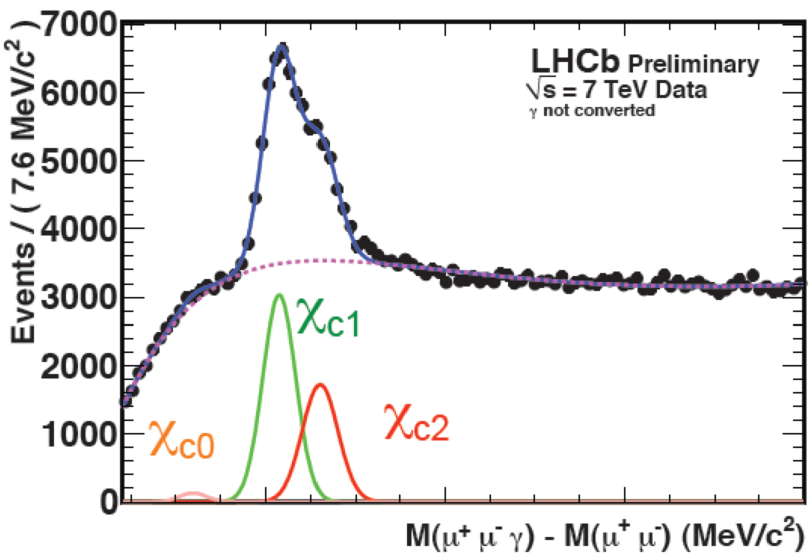
π^0 reconstruction performance



$B_d^0 \rightarrow K^*\gamma$

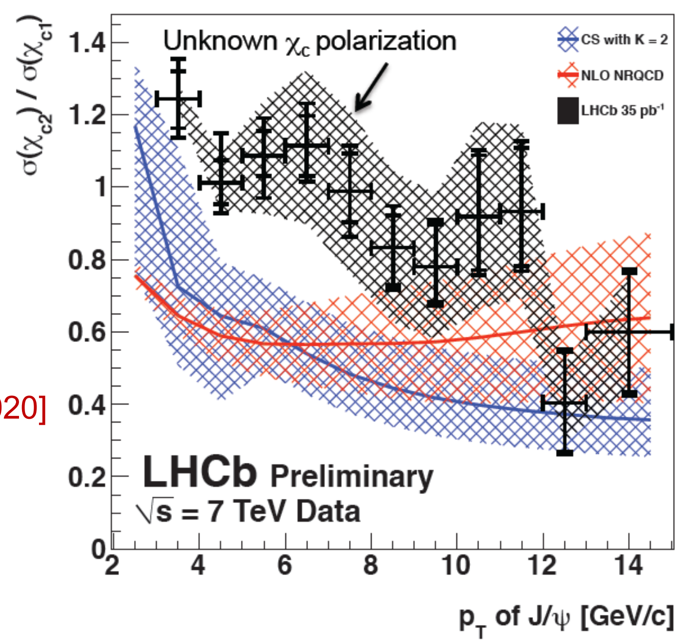


$\chi_c \rightarrow J/\psi\ \gamma$

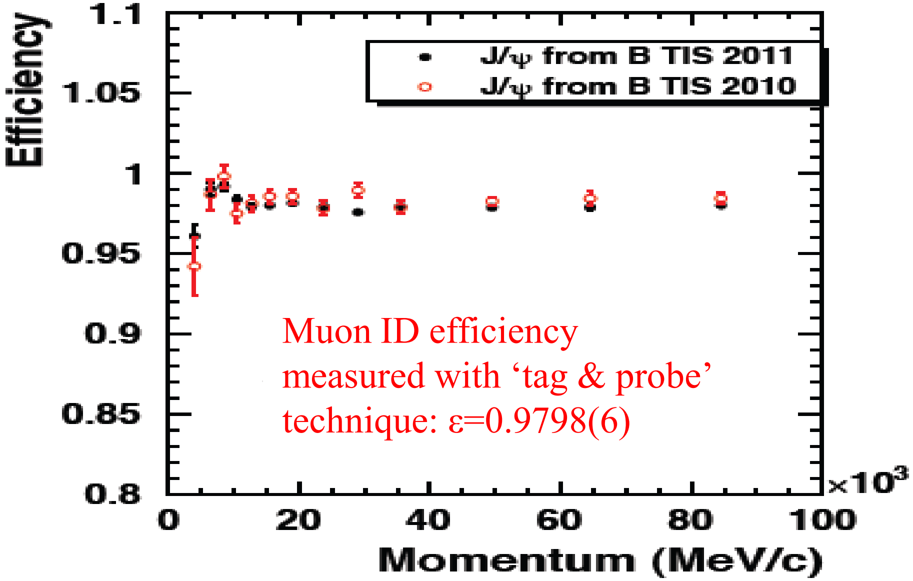


cross section ratio χ_{c2} / χ_{c1} for prompt χ_c production at $\sqrt{s}$ = 7 TeV

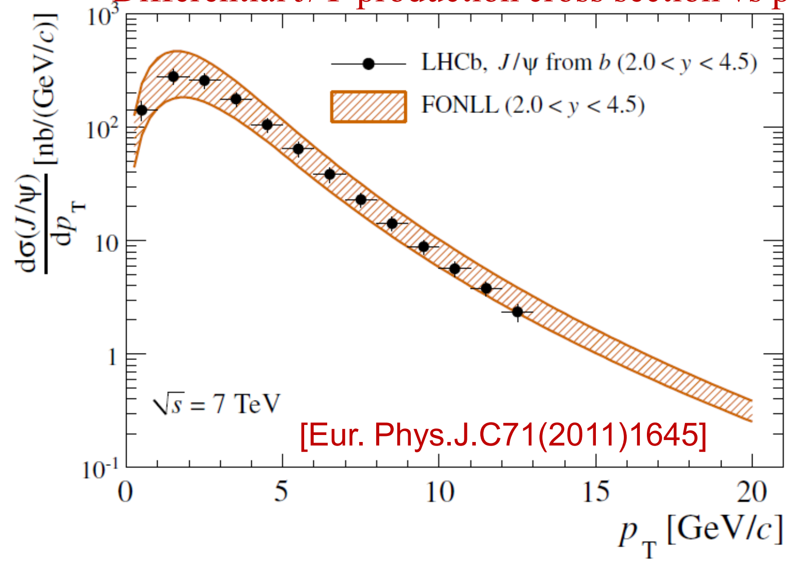
[LHCb-CONF-2011-020]

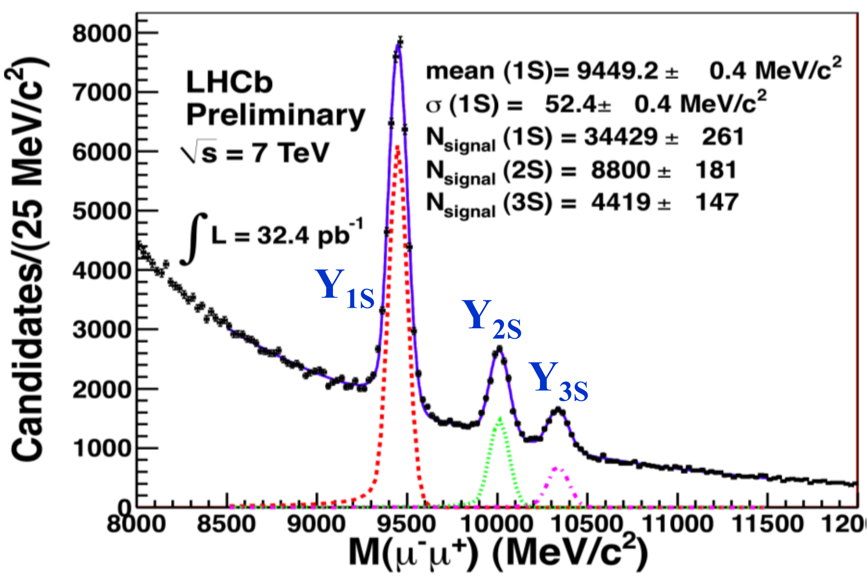


Detector performance: muon PID

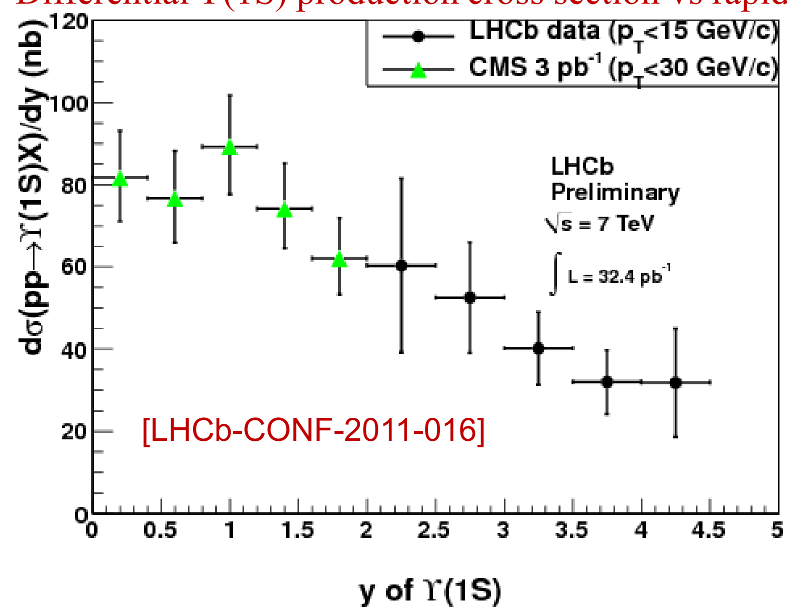


Differential J/Ψ production cross section vs p_T



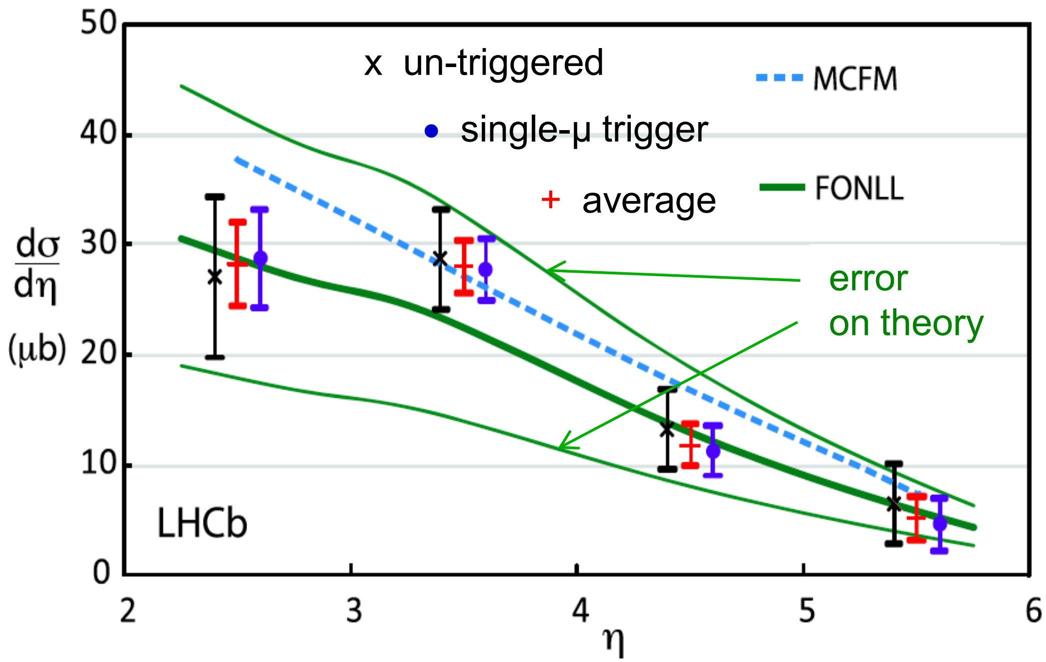


Differential Υ(1S) production cross section vs rapidity



High $b\bar{b}$-cross section confirmed

$b\bar{b}$-cross section at $\sqrt{s} = 7$ TeV from semileptonic B decays



From $B^0 \to D^0 X^+ \mu^- \nu$ with $D^0 \to K^- \pi^+$
total $b\bar{b}$ cross-section in 4π:

$$\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\ \mu b$$

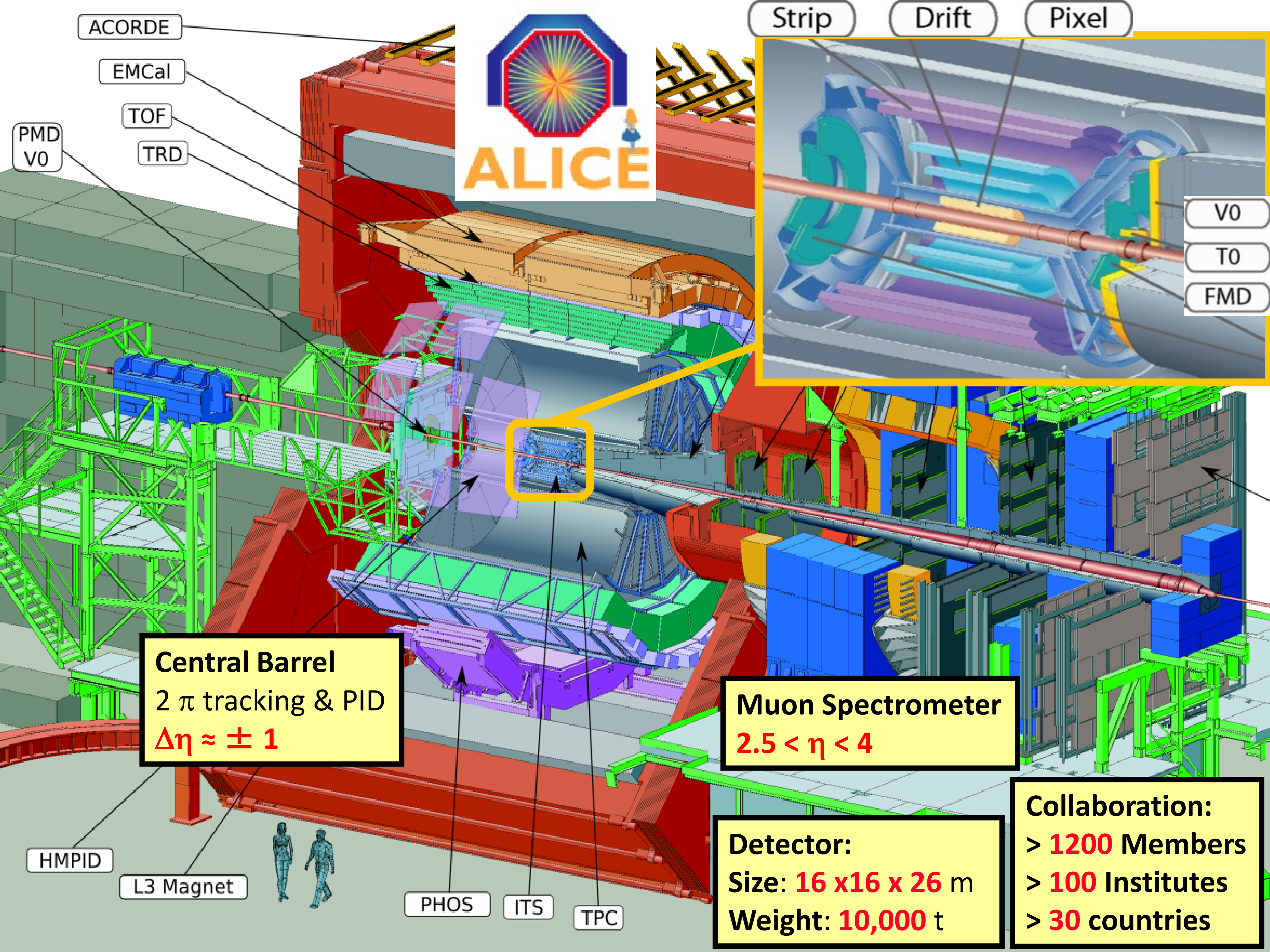
[Physics Letters B 694 (2010) 209]

In perfect agreement with result from $B \to J/\psi X$:

$$\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\ \mu b$$

[Eur. Phys. J. C 71 (2011) 1645]

Thanks to its excellent detector performance, with ~37 pb^{-1} LHCb is already competitive with Tevatron results based on 6000 pb^{-1}, even though $b\bar{b}$ cross-section only 3 times higher


ACORDE
EMCal
TOF
TRD
PMD
V0
ALICE
Strip
Drift
Pixel
V0
T0
FMD
Central Barrel
2 π tracking & PID
Δη ≈ ± 1
Muon Spectrometer
2.5 < η < 4
HMPID
L3 Magnet
PHOS
ITS
TPC
Detector:
Size: 16 x16 x 26 m
Weight: 10,000 t
Collaboration:
> 1200 Members
> 100 Institutes
> 30 countries

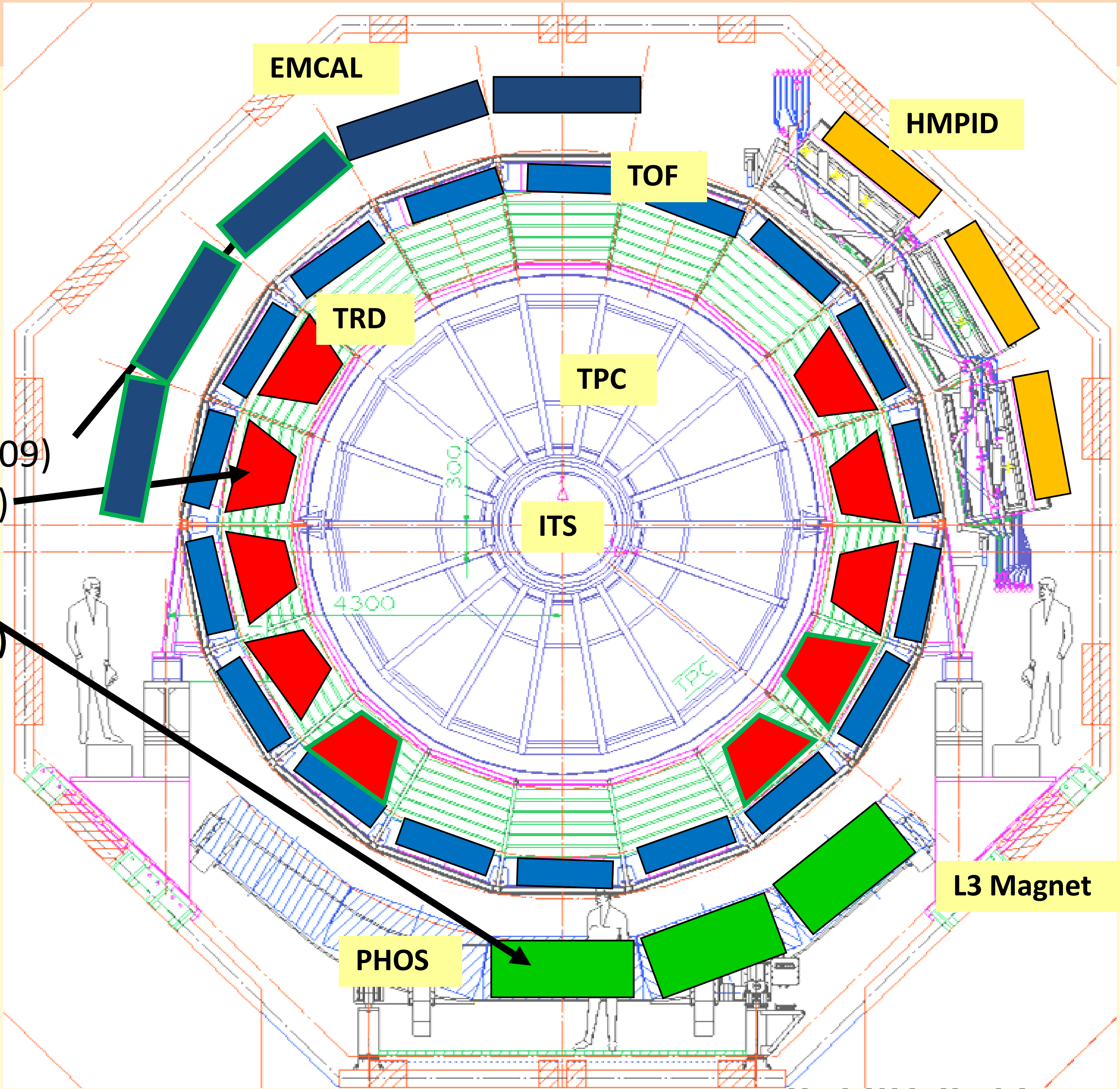
Detector Status

Complete since 2008:
ITS, TPC, TOF, HMPID, FMD, T0, V0, ZDC, Muon arm, Acorde PMD , DAQ

Partial installation (2010):
4/10 EMCAL* (approved 2009)
7/18 TRD* (approved 2002)
3/5 PHOS (funding)

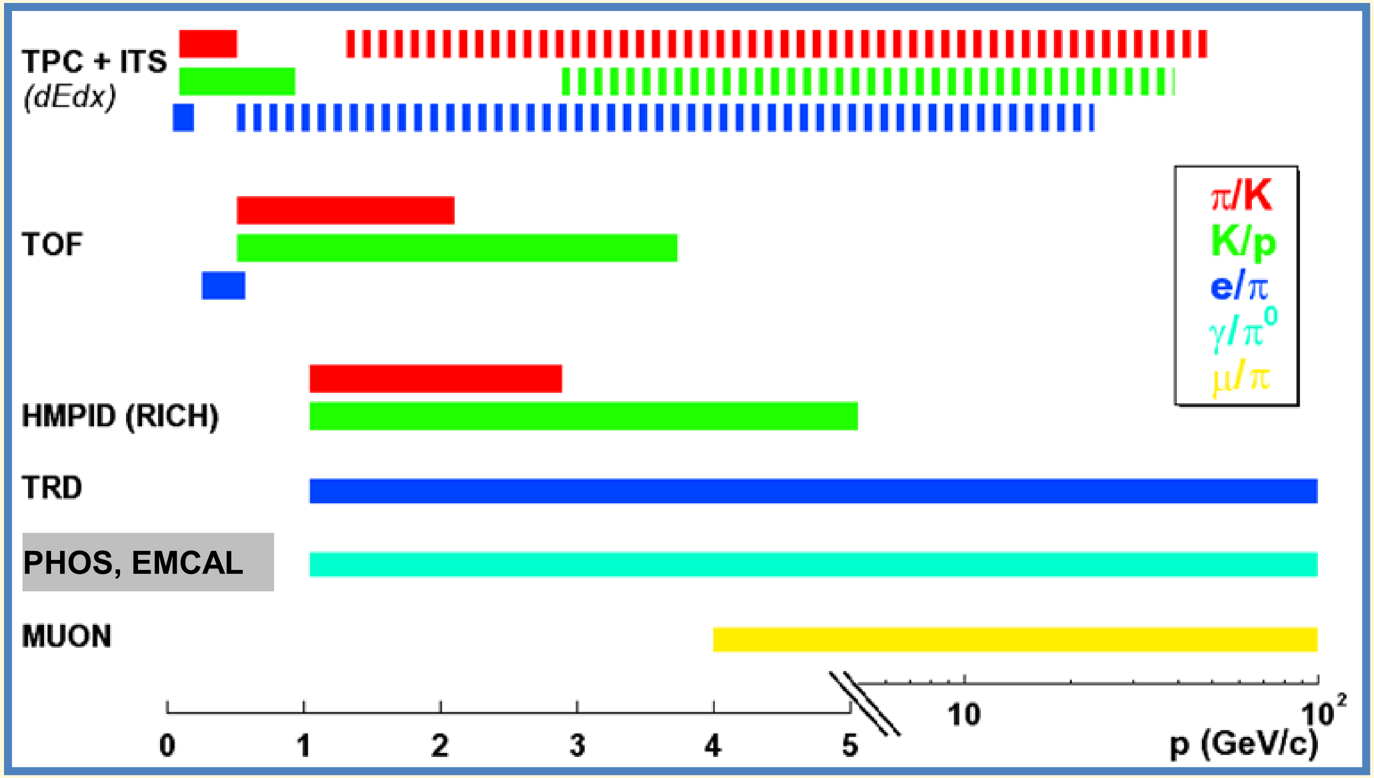
~ 60% HLT (High Level Trigger)

2011
10/10 EMCAL
10/18 TRD



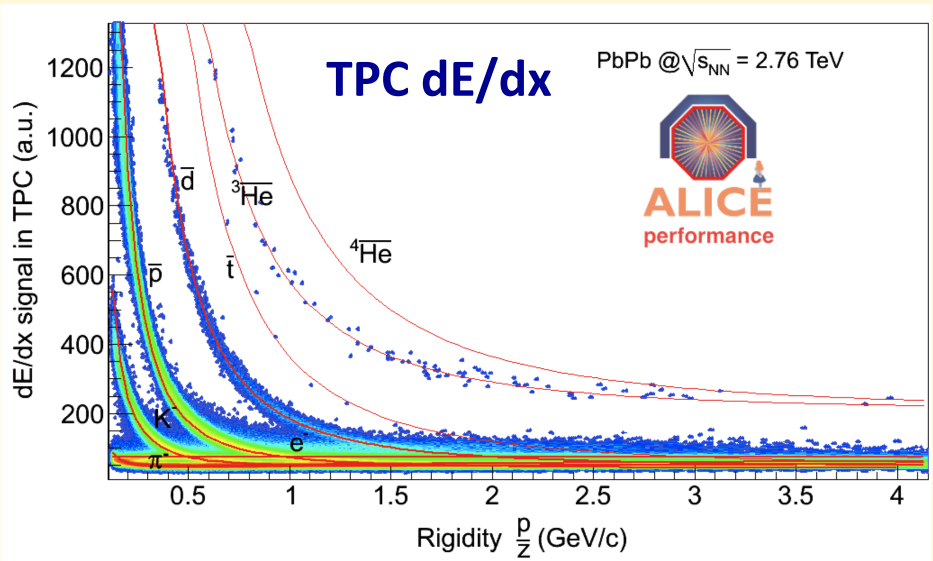
*upgrade to the original setup

Particle Identification in ALICE

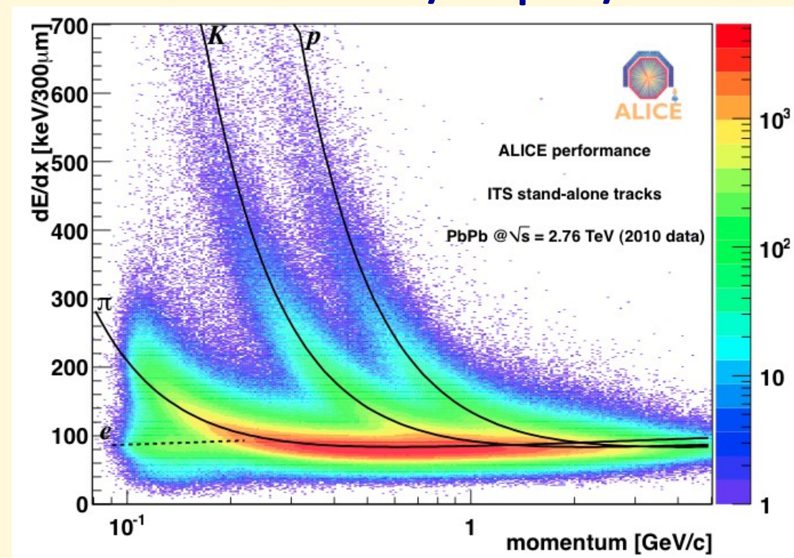


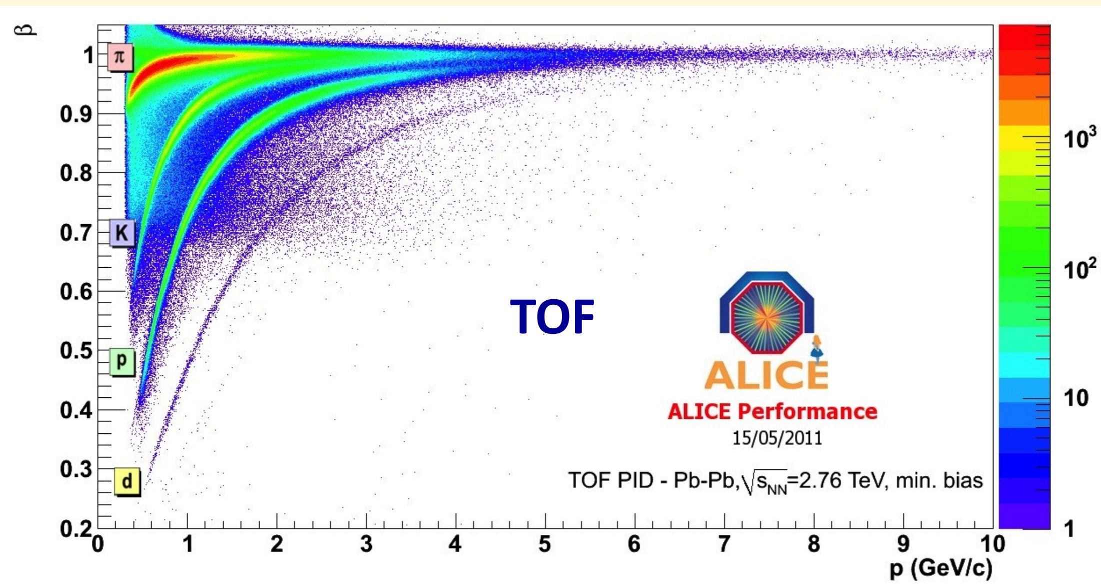
- 'stable' hadrons (π, K, p): 100 MeV < p < 5 GeV (several 10 GeV)
  - dE/dx in silicon (ITS) and gas (TPC) + time-of-flight (TOF) + Cherenkov (HMPID)
- decay topologies (K, Λ, ϕ, Ω, D)
  - K and Λ decays beyond 10 GeV
- leptons (e, μ), photons η,π^0
  - electrons TRD: p > 1 GeV, muons: p > 5 GeV, π^0 in PHOS, EMCAL: 1 < p < 80 GeV

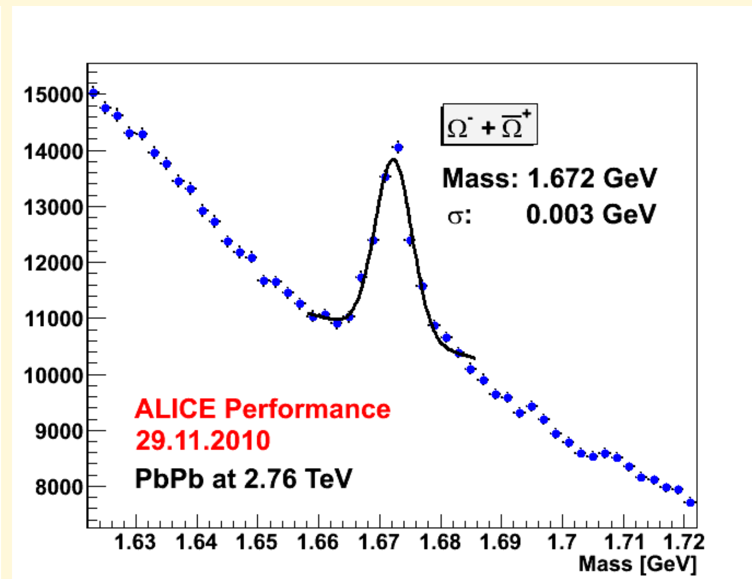
Particle Identification



ITS Silicon Drift/Strip dE/dx



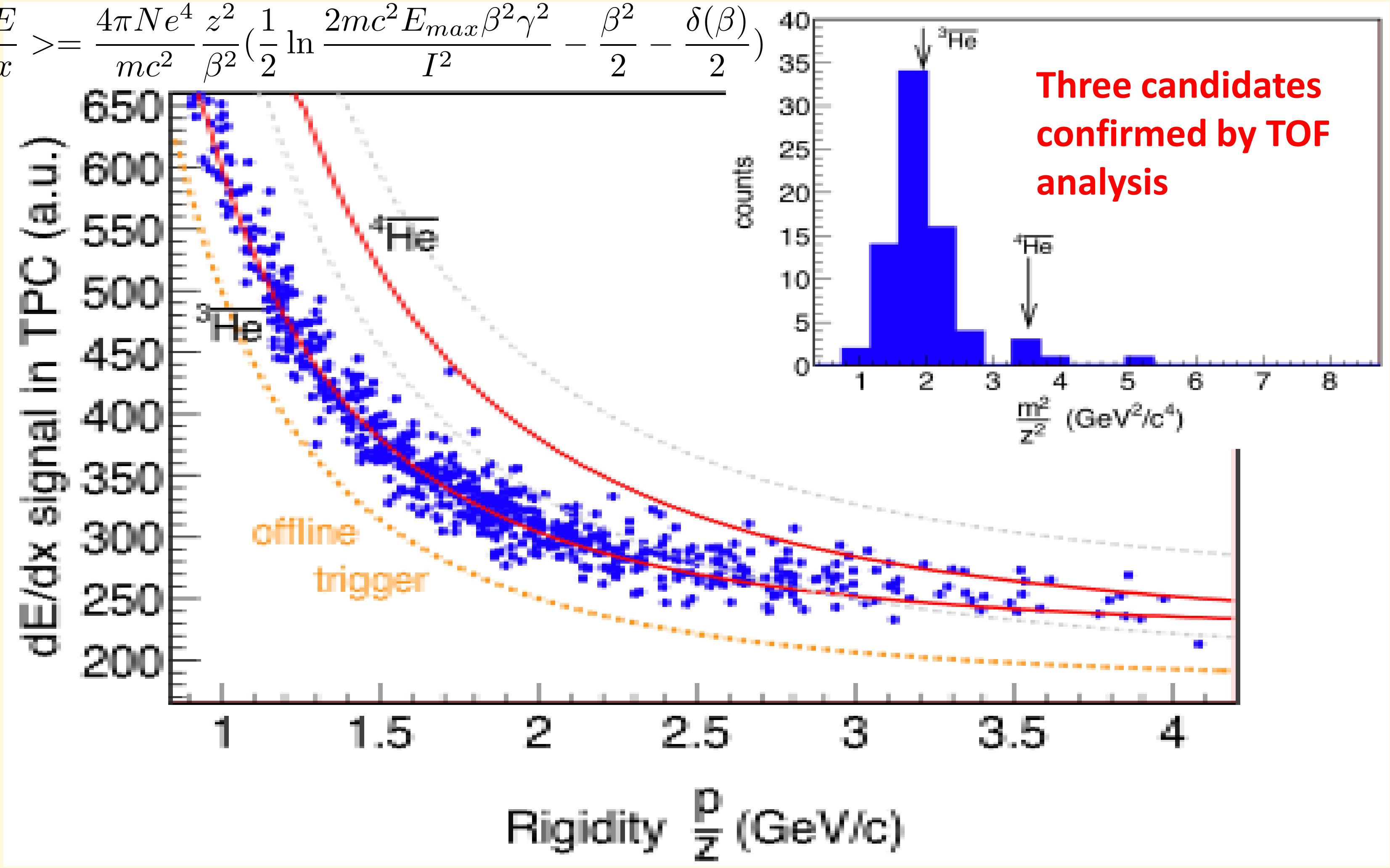




Anti-Alpha Candidates in Pb-Pb

Time of flight (sensitive to m/z-ratio): $m = \frac{z \cdot R}{\sqrt{\gamma^2 - 1}}$

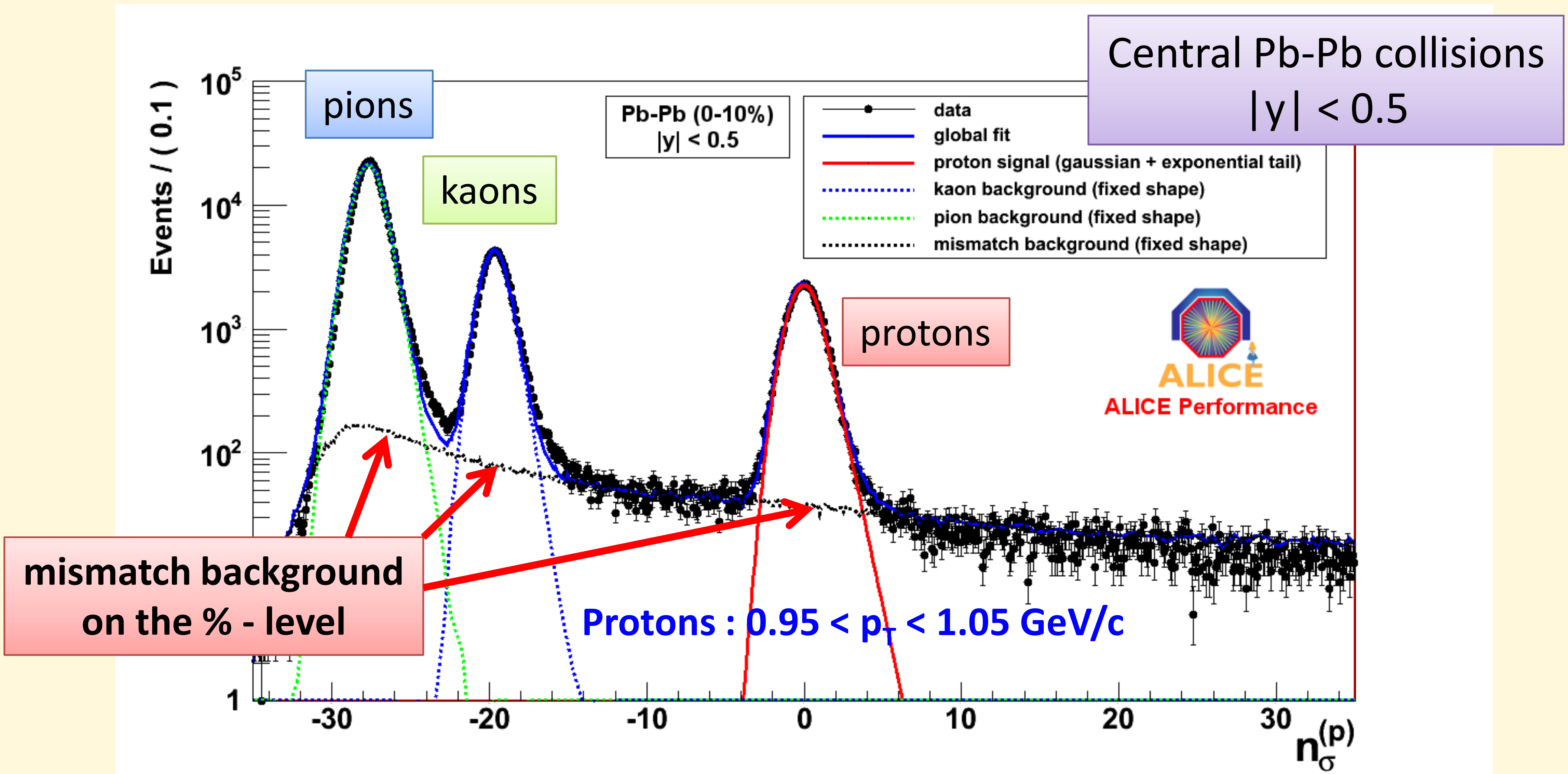
$$< \frac{dE}{dx} >= \frac{4\pi N e^4}{mc^2}\frac{z^2}{\beta^2}(\frac{1}{2}\ln\frac{2mc^2 E_{max}\beta^2\gamma^2}{I^2} - \frac{\beta^2}{2} - \frac{\delta(\beta)}{2})$$



Three candidates confirmed by TOF analysis

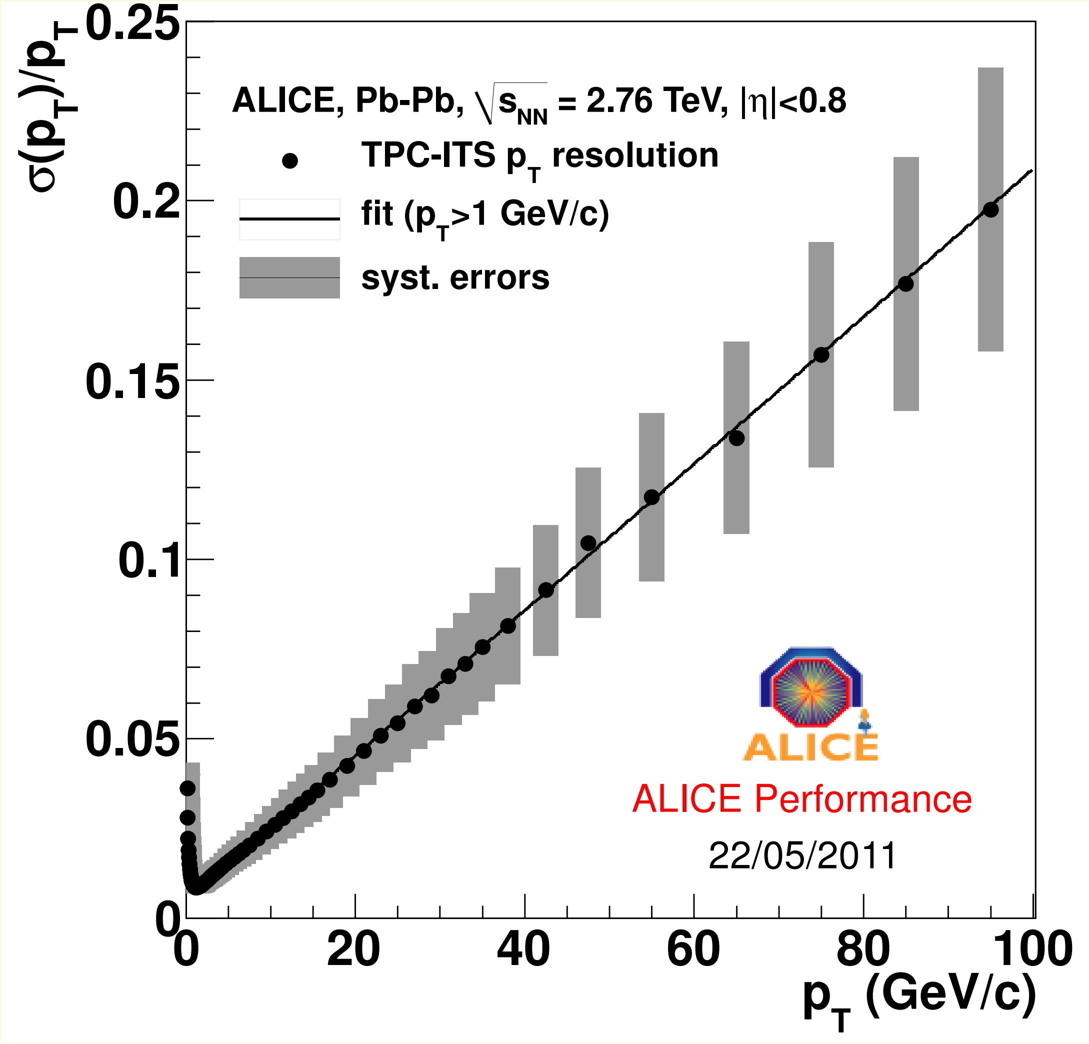
Particle Identification in Pb-Pb

Raw yields: a global fit of **Time-Of-Flight** signal - **mass hypotesis *i (π, K, p)*** constrains the integral of the fit to the total number of entries in the TOF PID



Momentum Resolution

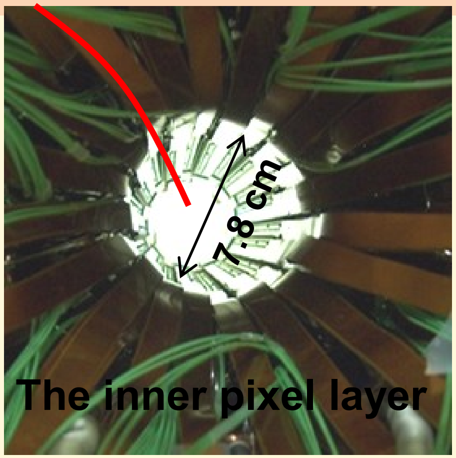
- Combined TPC + ITS tracks
- Background/weak decays excluded via DCA cut to primary vertex
- Tracks within |η| < 0.8
- Resolution determined from track residuals, verified with cosmics and reconstructed decay widhts (e.g. K_S^0)

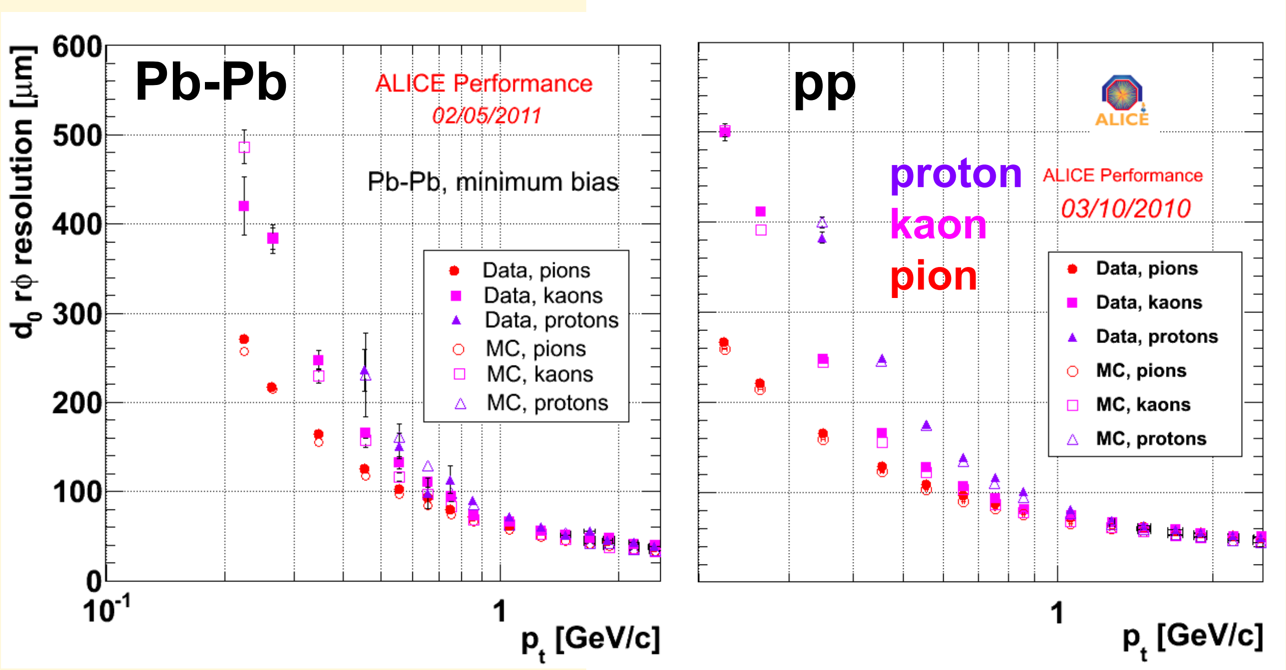


Good resolution already with early Pb+Pb calibration.

D Meson Reconstruction in ALICE

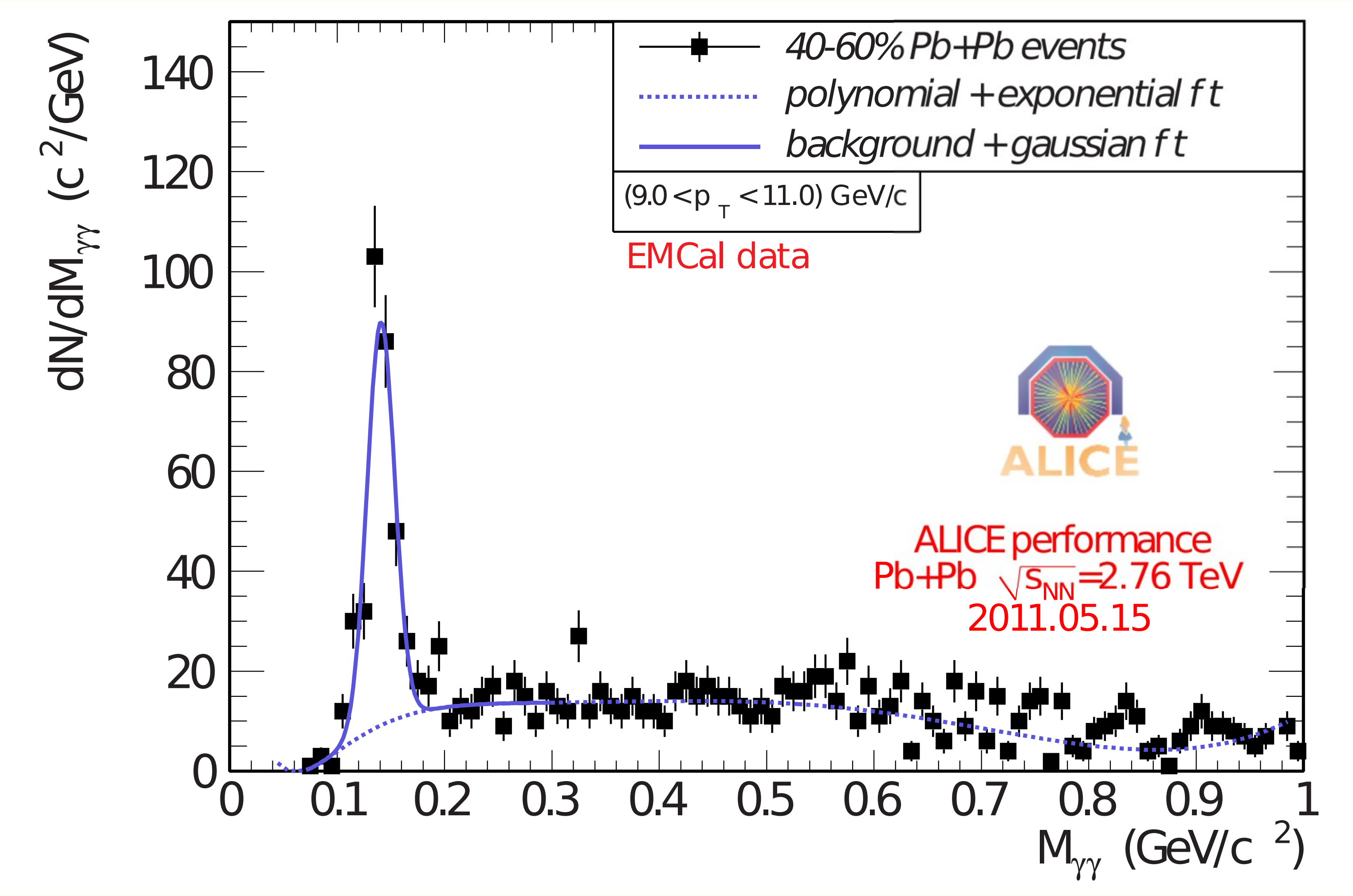
- Main selection: displaced-vertex topology
- Tracking and vertexing precision is crucial here
- Inner Tracking System (ITS) with 6 Si layers
  - two pixel layers at 3.9 cm (closest barrel layer at LHC!) and 7 cm
- The ITS was aligned using cosmics and collisions
  - current resolution for pixels: 14 μm (nominal: ≈11 μm)





Same tracking precision
in pp and Pb-Pb,
described in MC,
incl. mass dep.

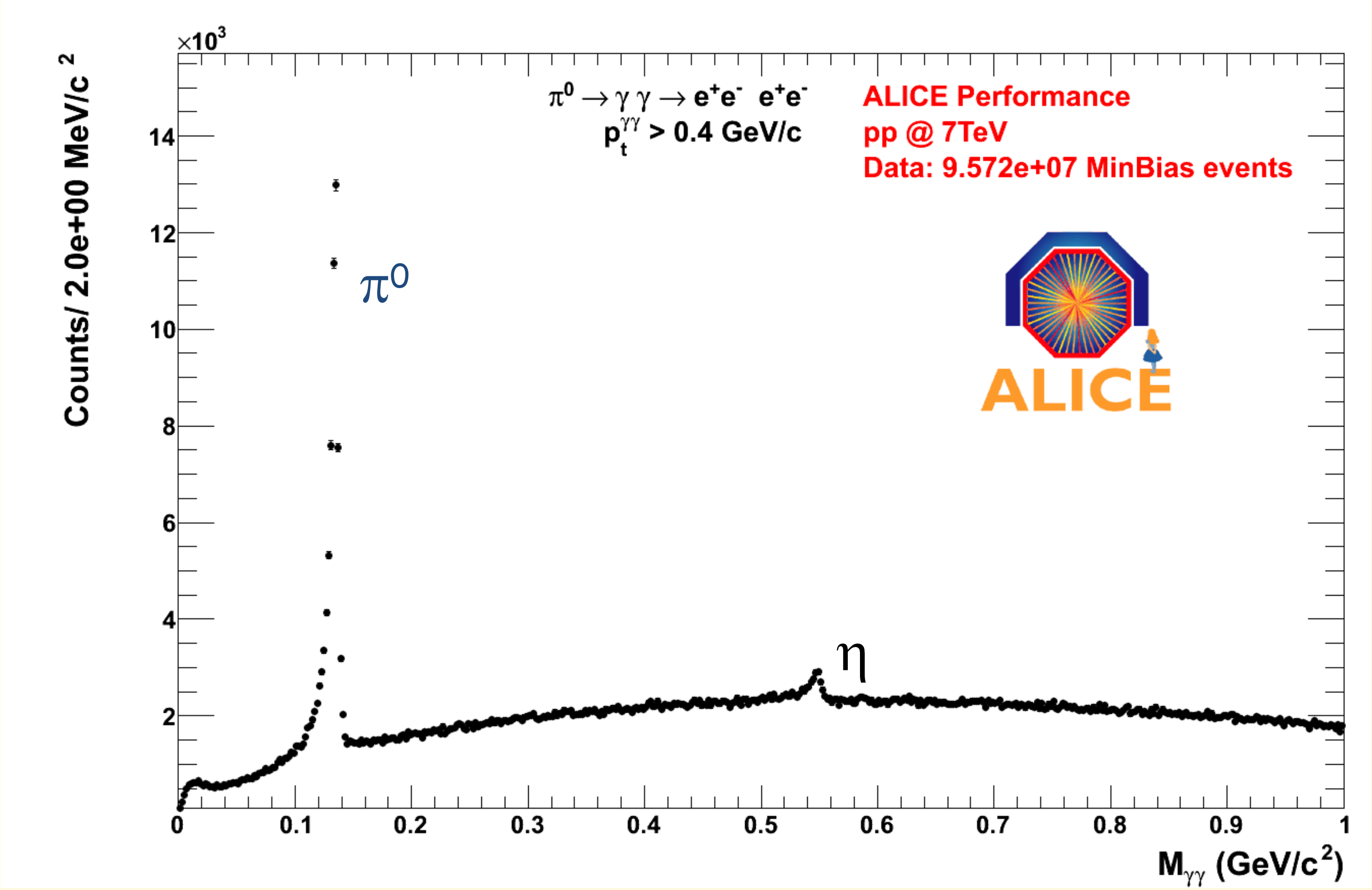
π^0 Reconstruction in EMCAL



Reconstruction of π^o invariant mass in semi-central Pb-Pb collisions

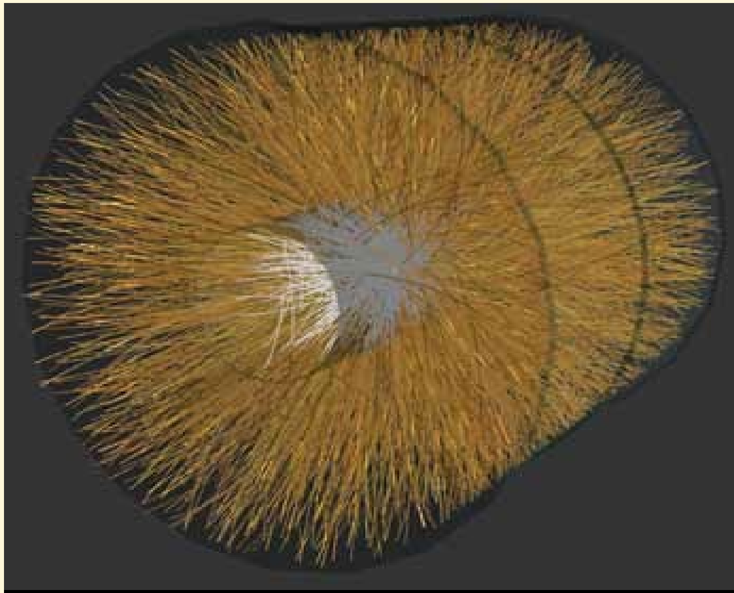
π^0 and η from Conversions

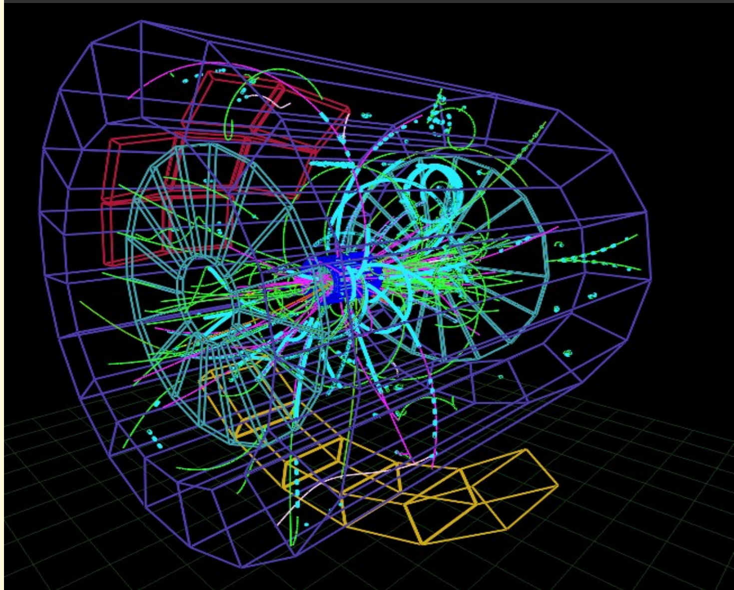
$$M_{\gamma_1\gamma_2} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma_1\gamma_2})}$$



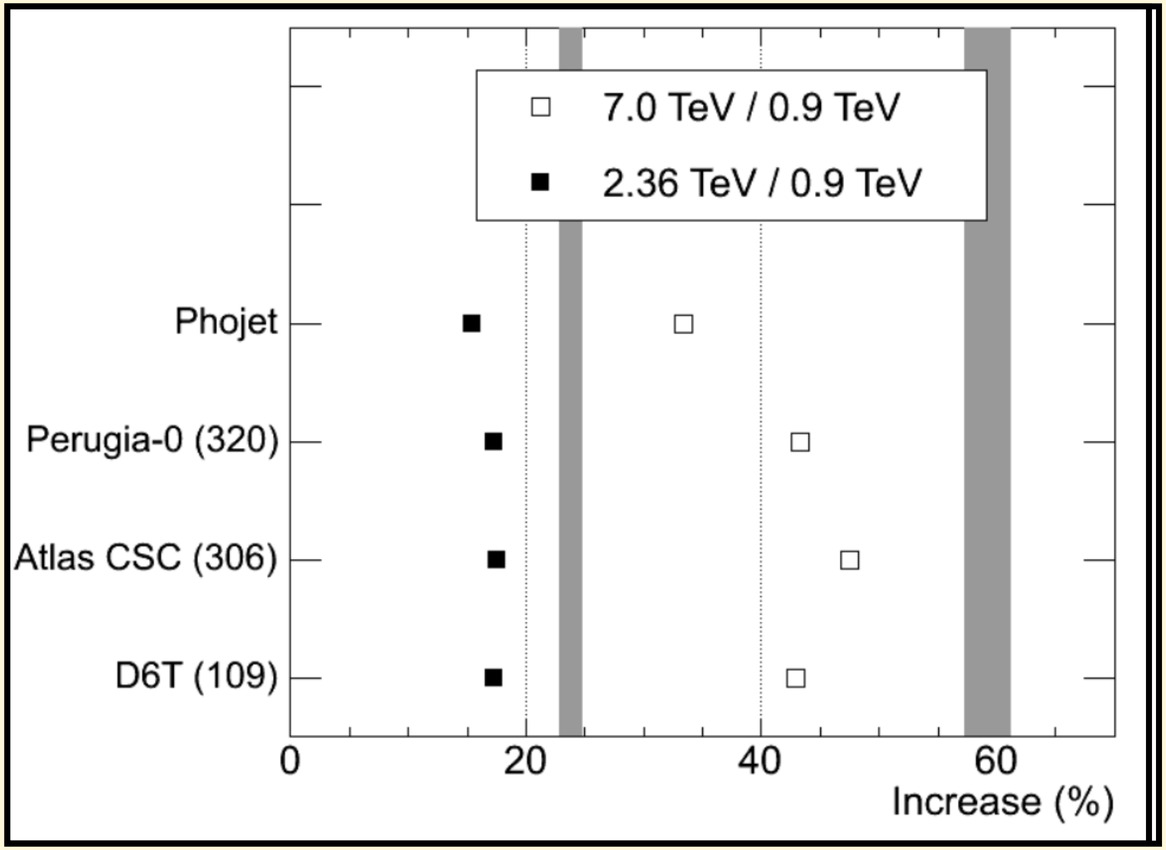
pp Physics in ALICE

- 'comparison data' for heavy ion program
  - many signals measured 'relative' to pp
- comprehensive study of MB@LHC
  - tuning of Monte Carlo generators (background to BSM)
  - complementary to other LHC expts
  - address specific issues of QCD
- very high multiplicity pp events
  - $dN_{ch}/d\eta$ comparable to HI => mini-plasma ?





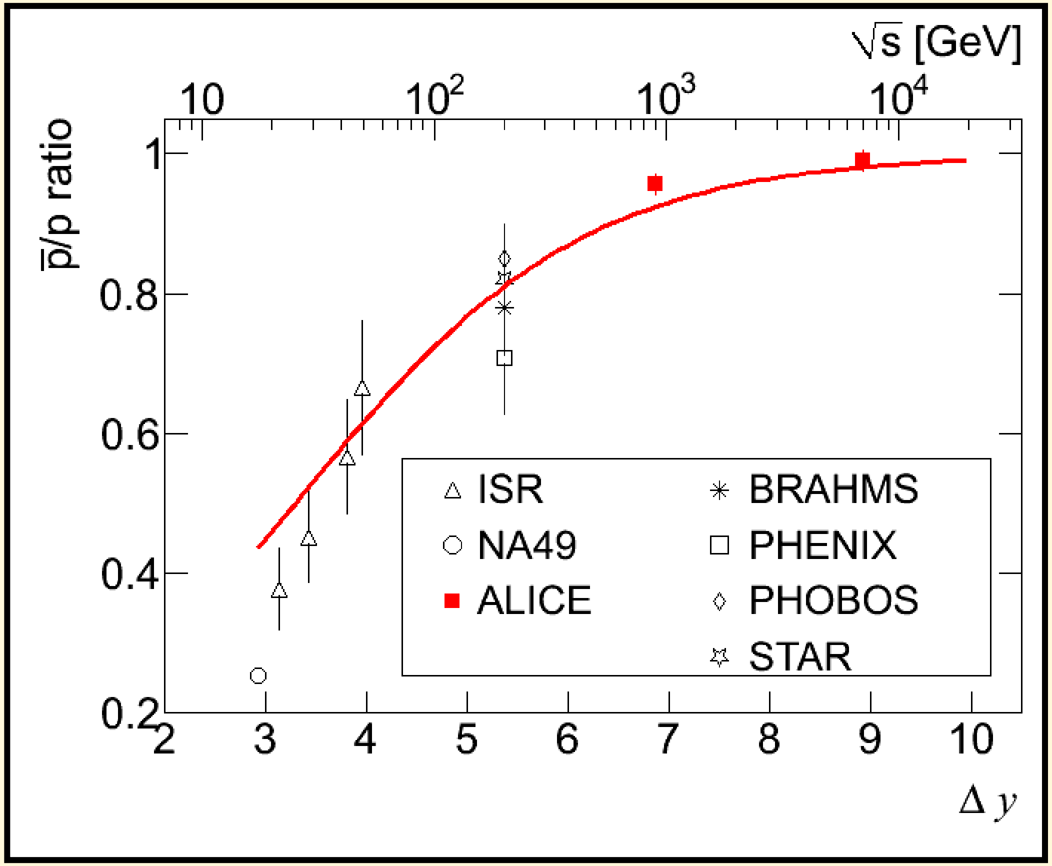
Charged Particle Pseudorapidity Density



ALICE 7 TeV:
Eur.Phys.J.C68:345-354,2010;
ALICE 0.9/2.36 TeV:
Eur.Phys.J.C68:89-108,2010.

- Multiplicity increases faster than predicted by models

(Anti)-Proton Production

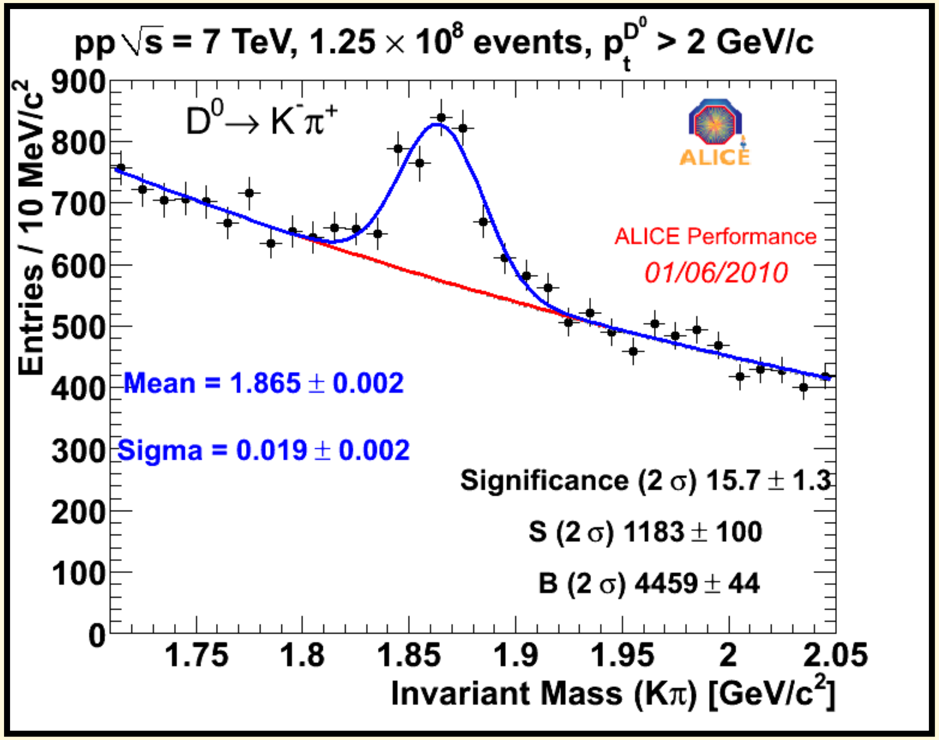


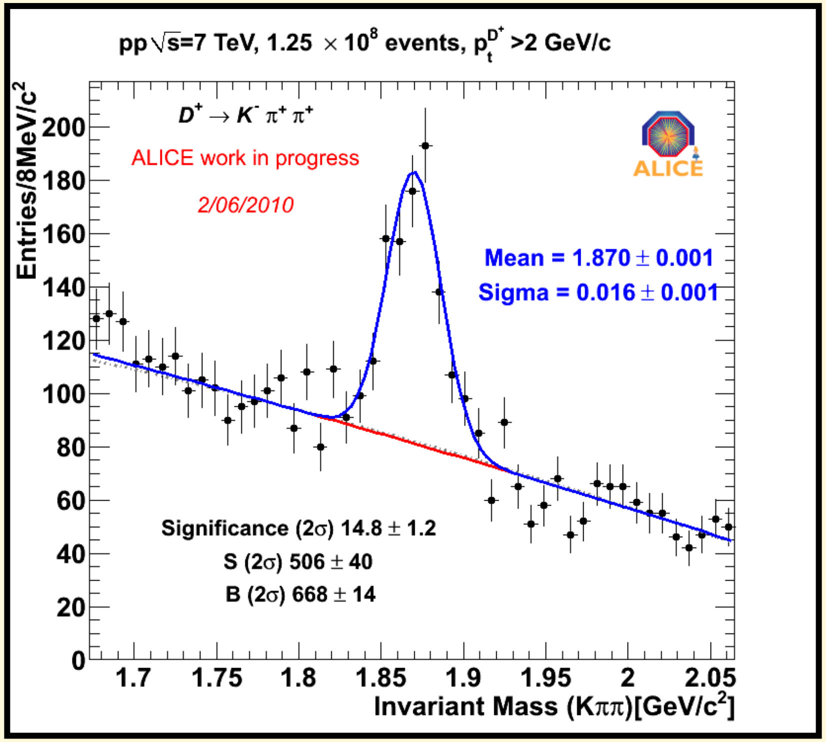
- **Excellent understanding of material budget is pre-requisite for $\overline{p}$/p-ratio measurement on the percent level**
- **Proton cannot be fully stopped at LHC**
- **Little room for baryon number transport over large rapidity gaps**

0.9 TeV: **0.957**±0.006(stat) ±0.014(syst)
7 TeV: **0.990**±0.006(stat) ±0.014(syst)

Details in talk of M. Broz, Tu, 15:15

Open Charm from ALICE





$D^0 \rightarrow K^-\pi^+$ $D^+ \rightarrow K^-\pi^+\pi^+$

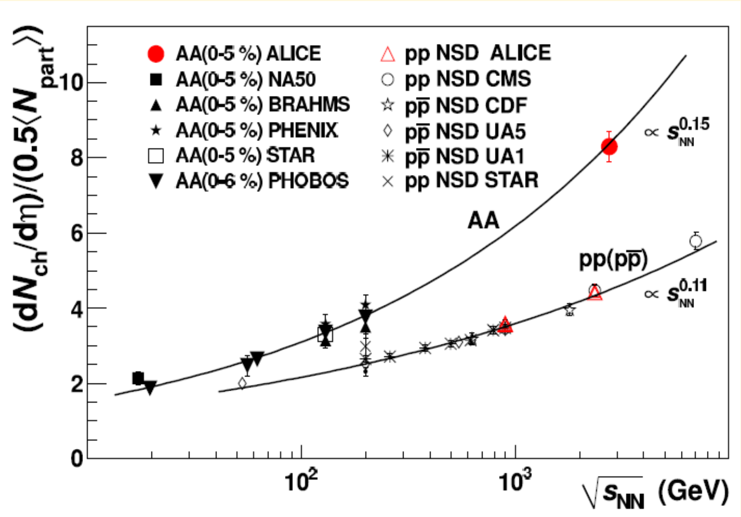
Study open charm production in as many channels as possible

First Measurements in Heavy-Ion Collisions at LHC

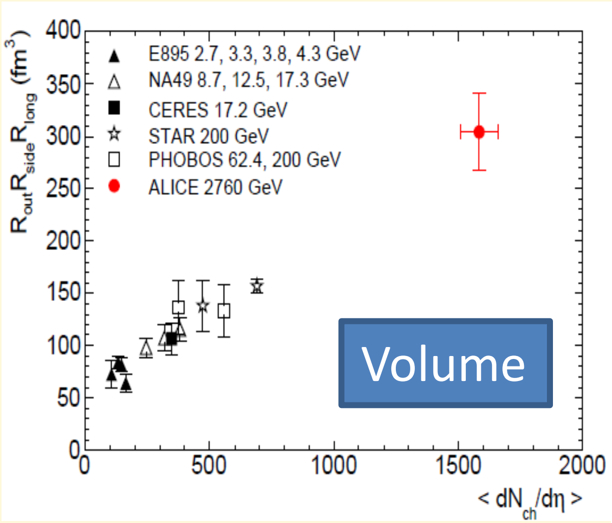
- Particle production
  - **Multiplicities – how does the particle production depend on energy and impact parameter of the collisions? Are we able to describe it?**
- Emission of particles – collectivity – dynamical evolution
  - **Azimuthal anisotropy – how the initial spatial anisotropy manifests itself in final momentum anisotropy? – Collective flow at LHC?**
  - **Collectivity? How do the source dimensions evolve with energy?**
- Parton energy loss
  - **Is QCD medium at LHC opaque to high energy partons?**
  - **Evolution of jet quenching with energy?**

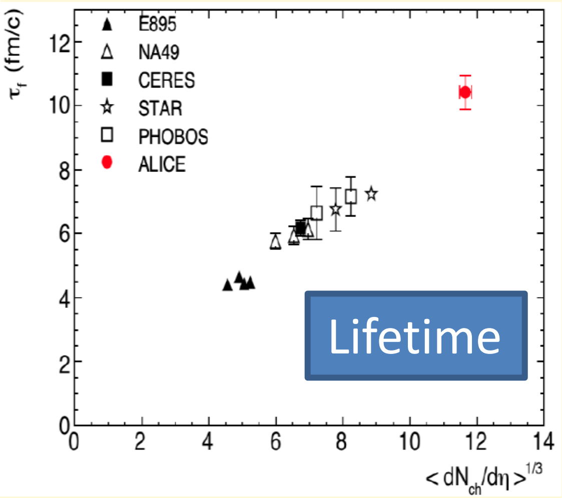
Characteristics of Central Pb+Pb Collisions at 2.76 TeV

- **Energy density from $dN_{ch}/d\eta$**
  - $dN_{ch}/d\eta$ = 1599 ± 4 (stat.) ± 80 (syst.)
  - constrains / rules out models
  - 100 times cold nuclear matter density
  - ~3 times the density reached at RHIC ($\varepsilon \approx 15$ GeV/fm^3)



- **Volume and lifetime from HBT interferometry**

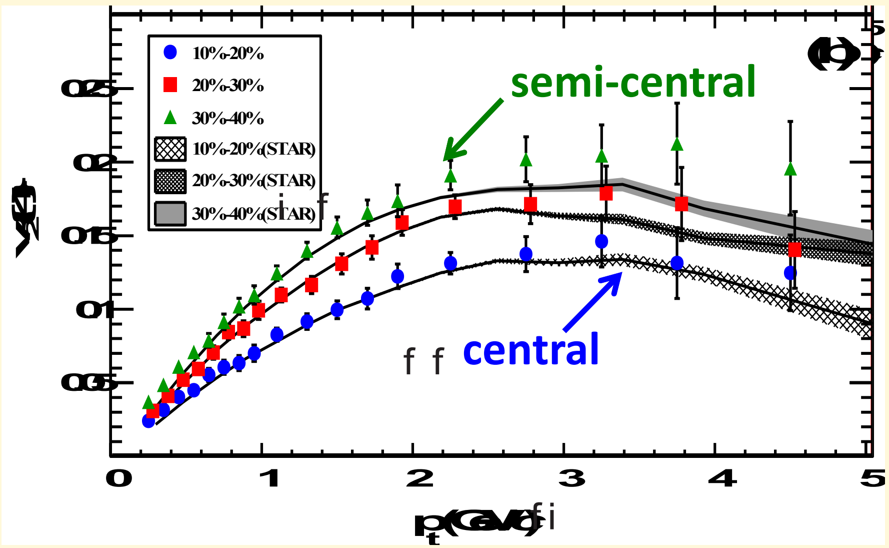


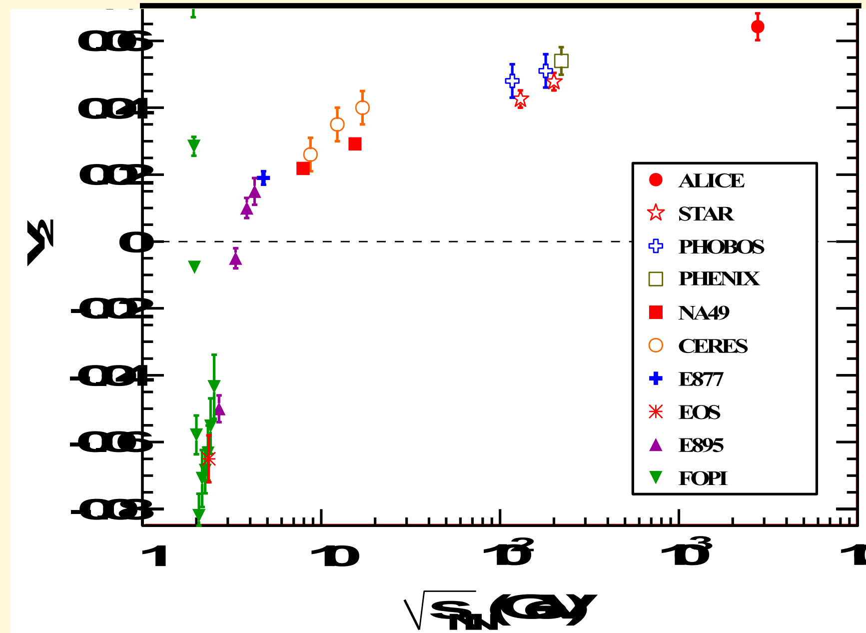


- Freeze-out volume ~ 300 fm^3
- ~ 2 times the volume measured at RHIC (AuAu@200 GeV)
- Lifetime until freeze-out ~ 10 fm/c

Particle Production in Pb-Pb: Elliptical Flow v2

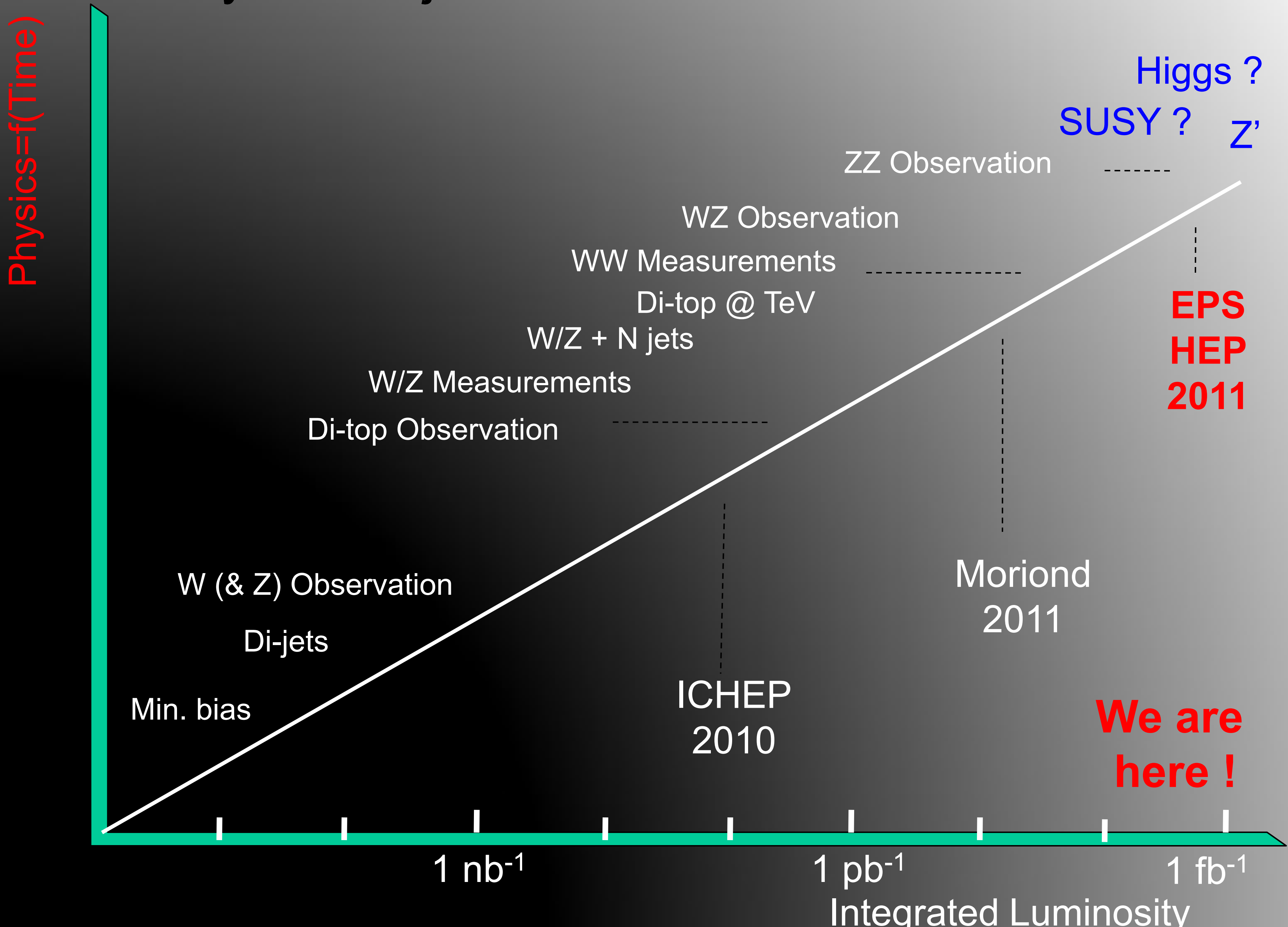
PRL 105, 252302 (2010)





- **Collective behavior observed in Pb-Pb collisions at LHC (+0.3 v_2^{RHIC}) –> ideal fluid behavior**
- **Testing hydrodynamical evolution**
- **Precision measurement for viscosity/entropy ratio**

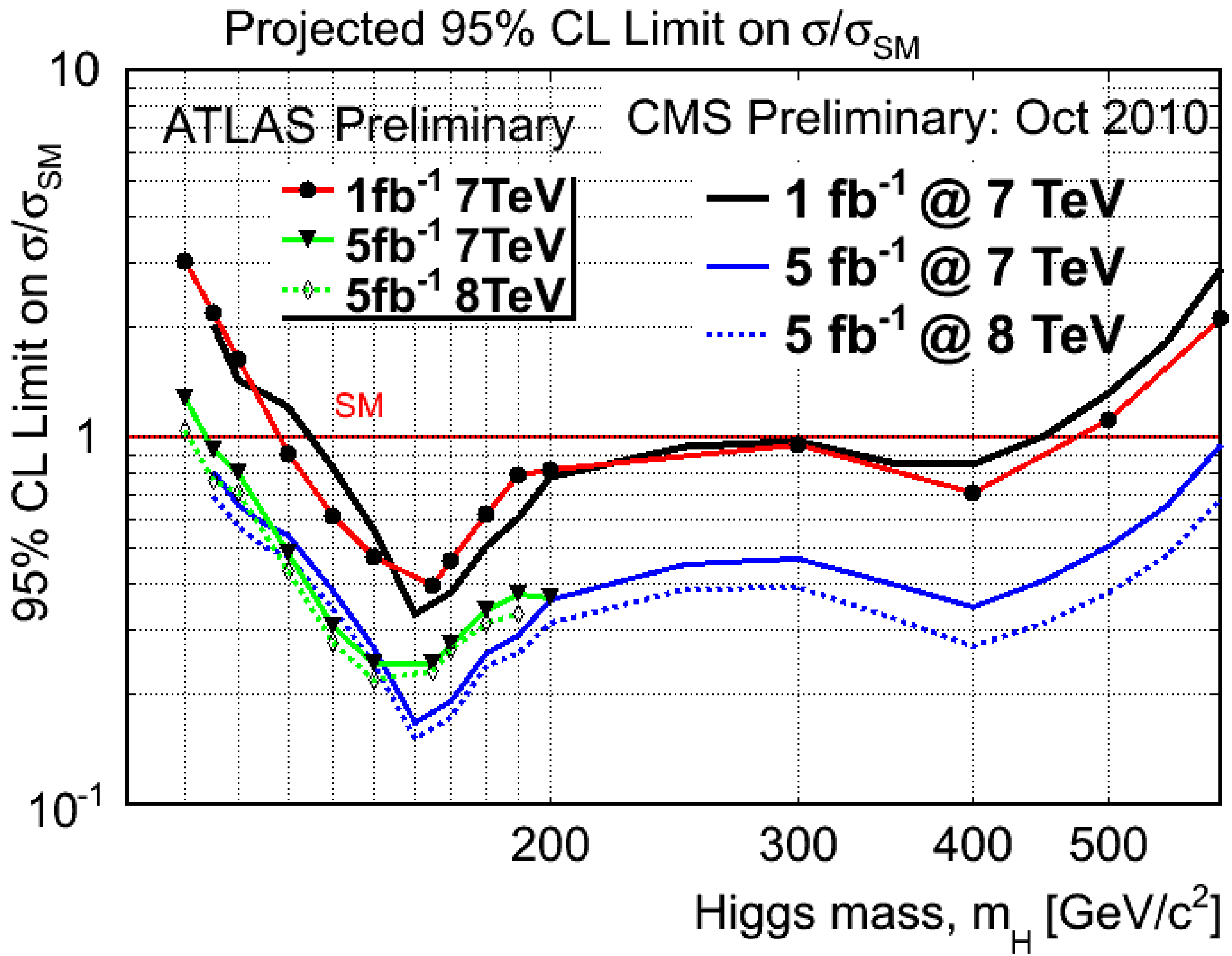
Physics Objectives for 2011-2012 LHC Run I



An example

Prospects for the Higgs Boson
at 7 TeV

CMS & ATLAS Projections Compared



- Experiments well prepared to exploit ALL decay channels accessible
- Experiments are cross-checking each other
- Experiments are preparing to combine their results

Summary of Prospects

Higgs Boson, if it exists between masses of (114 - 600 GeV) will either be discovered or ruled out in ≈ next two years

→ **Decided to run in 2011 and 2012**

SM Higgs Search Prospects (Mass in GeV)

ATLAS + CMS ≈ 2 x CMS	95% CL exclusion	3 σ sensitivity	5 σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535

…not only searches

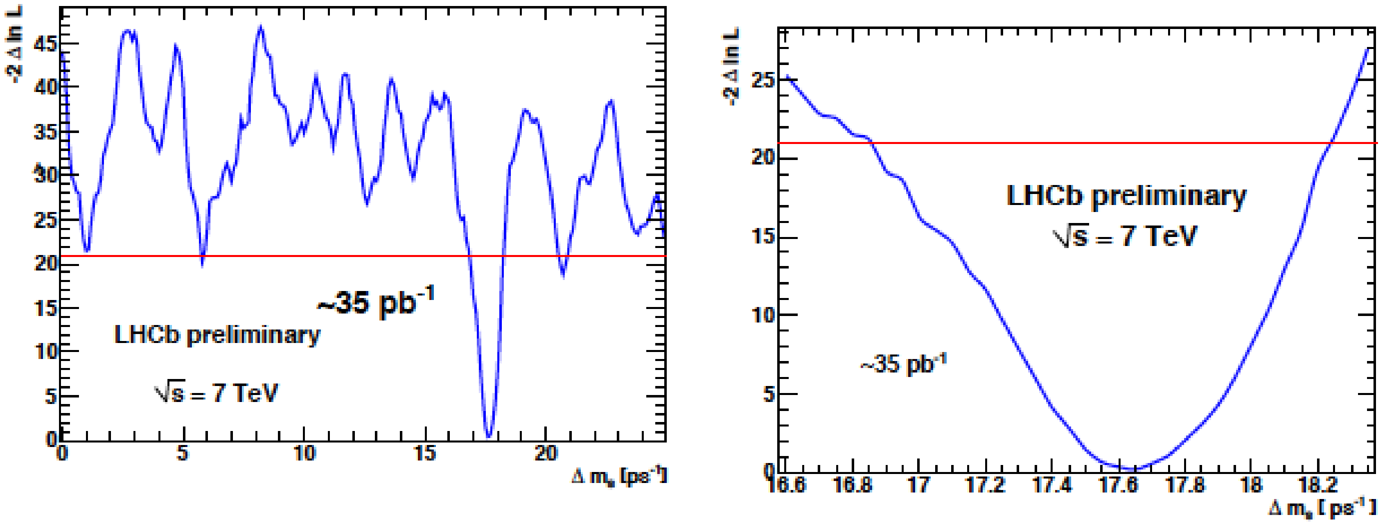
- 2010 LHCb results show exciting prospects for 2011-2012

B_s^0–$\overline{B}_s^0$ mixing frequency (2)

[LHCb-CONF-2011-005]

Use:

- per event proper time uncertainties, $\langle\sigma_t\rangle = 36 - 44\,\mathrm{fs}$
- per event mistag rate, $\varepsilon_{\mathrm{eff}} = 3.8 \pm 2.1\%$ (OS only)

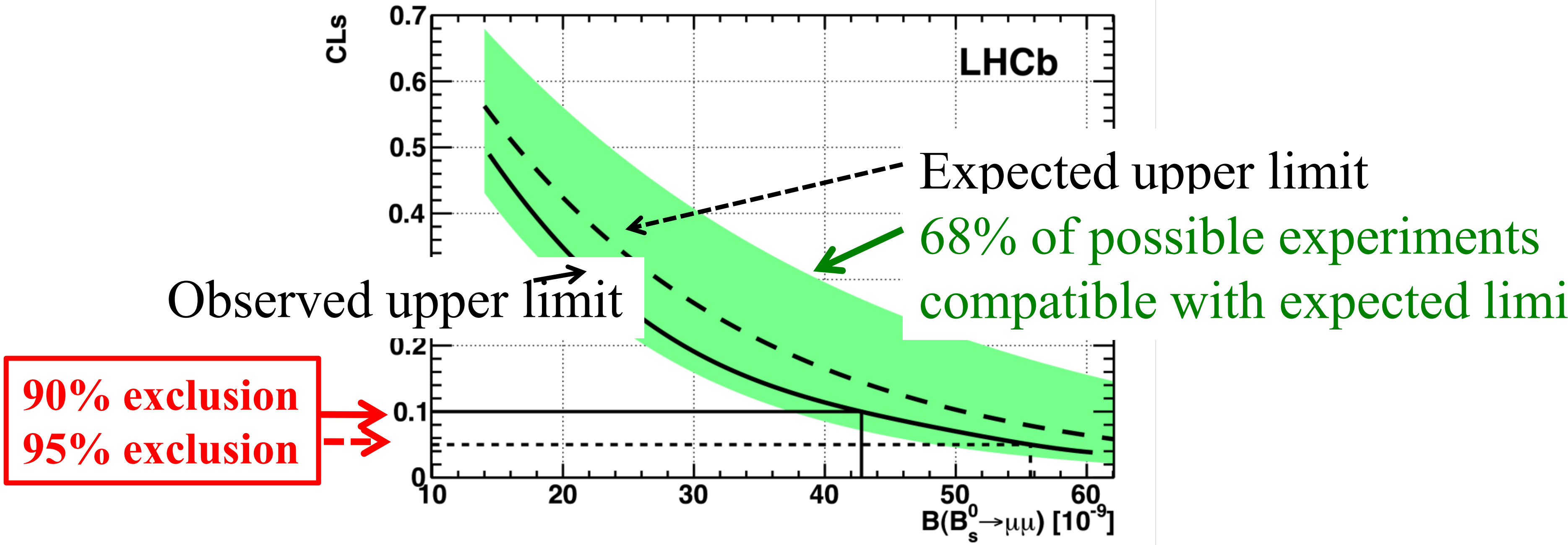


The line at 20.94 indicates the likelihood value evaluated in the limit of infinite mixing frequency

- $\Delta m_s = 17.63 \pm 0.11(\mathrm{stat}) \pm 0.04(\mathrm{sys})\,\mathrm{ps}^{-1}$ (4.6σ stat. significance)
- CDF: $\Delta m_s = 17.77 \pm 0.10$ (stat) $\pm\, 0.07$ (sys) ps^{-1}

Search for $B_s \to \mu\mu$

Paper submitted to Phys. Lett. B



		@ 90% CL	@ 95% CL
LHCb	Today, **37 pb^{-1}**	**< 43 $x10^{-9}$**	**< 56 $x10^{-9}$**
D0	World best, **6.1 fb^{-1}** PLB 693 539 (2010)	**< 42 $x10^{-9}$**	**< 51 $x10^{-9}$**
CDF	Preliminary, **3.7 fb^{-1}** Note 9892	**< 36 $x10^{-9}$**	**< 43 x 10^{-9}**

LHC Time-line

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

2030 — ILC, High energy LHC, ... ?

LHC experiments timeline

LHC schedule harmonized/agreed with the experiments

- Consolidation/incremental upgrades in 2013-2013, getting more substantial in 2017 (major upgrade for LHCb in 2017?)
- Major upgrades in 2021
- Upgrade proposals submitted/in submission to the LHCC

Working the schedule backwards, and considering realistic construction and commissioning times, all experiments are already on a very tight timeline for R&D and final choices!

Lessons learned (my biased view)

- Experiments did exceptionally well in term of
  - Performances
  - Reliability
  - Operations and ease of maintenance
- Measurement redundancy has proven to be a major asset for the physics performances
- Data and simulations have shown a remarkable agreement, at least in reproducing the bulk of the data
- We are still a bit optimistic in the way we account for passive material
- Our biggest problems mostly connected to the usual "low tech" stuff (cooling, LV power supplies, etc)

Lessons learned (my biased view)

- A lot of R&D work still needed in order to take decisions on the major upgrades, with a constant eye to physics (and the parallel LHC upgrade)
- Ancillary systems (cooling, power distribution, connections, data extractions, on detector data handling) need also a robust rethinking and the corresponding R&D

In summary

- So far so good, keep pushing!
- ..and hope on the gentleness of Nature, offering us some early discovery.

It will be fun to look in retrospective @ TIPP 2013!

Thank you!