First LHC Operation and Future Perspectives

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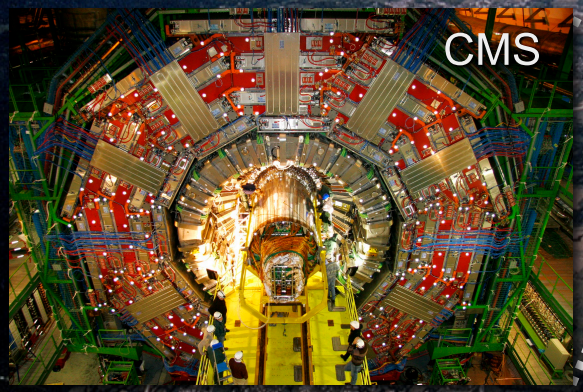
CERN and ETH Zurich

Enter a New Era in Fundamental Science

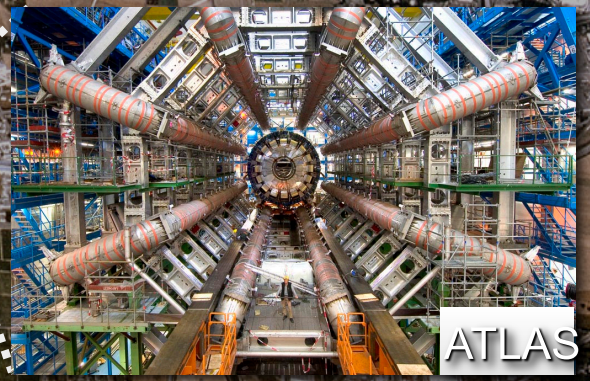
Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.



Exploration of a new energy frontier

Proton-proton Collisions at E_{CM} = 14 TeV

Heavy Ion Collisions: Energy/nucleon = 2.75 TeV/u



Chinese Involvement in LHC Experiments

Chinese Institutes are involved in all 4 LHC experiments

3 Institutes
Inst. of Atomic Energy, Beijing
Hua-Zhong Normal Univ., Wuhan
Hua-Zhong Univ., Wuhan
7 members

4 Institutes
IHEP Beijing
Nanjing Univ.
Shangdong Univ.
USTC Hefei
31 members

3 Institutes
IHEP Beijing
Peking Univ.
USTC Hefei
55 members

1 Institute
Tsinghua University, Beijing
14 members

Hardware contributions
Preparation for physics analysis
LCG: Tier-2 at IHEP

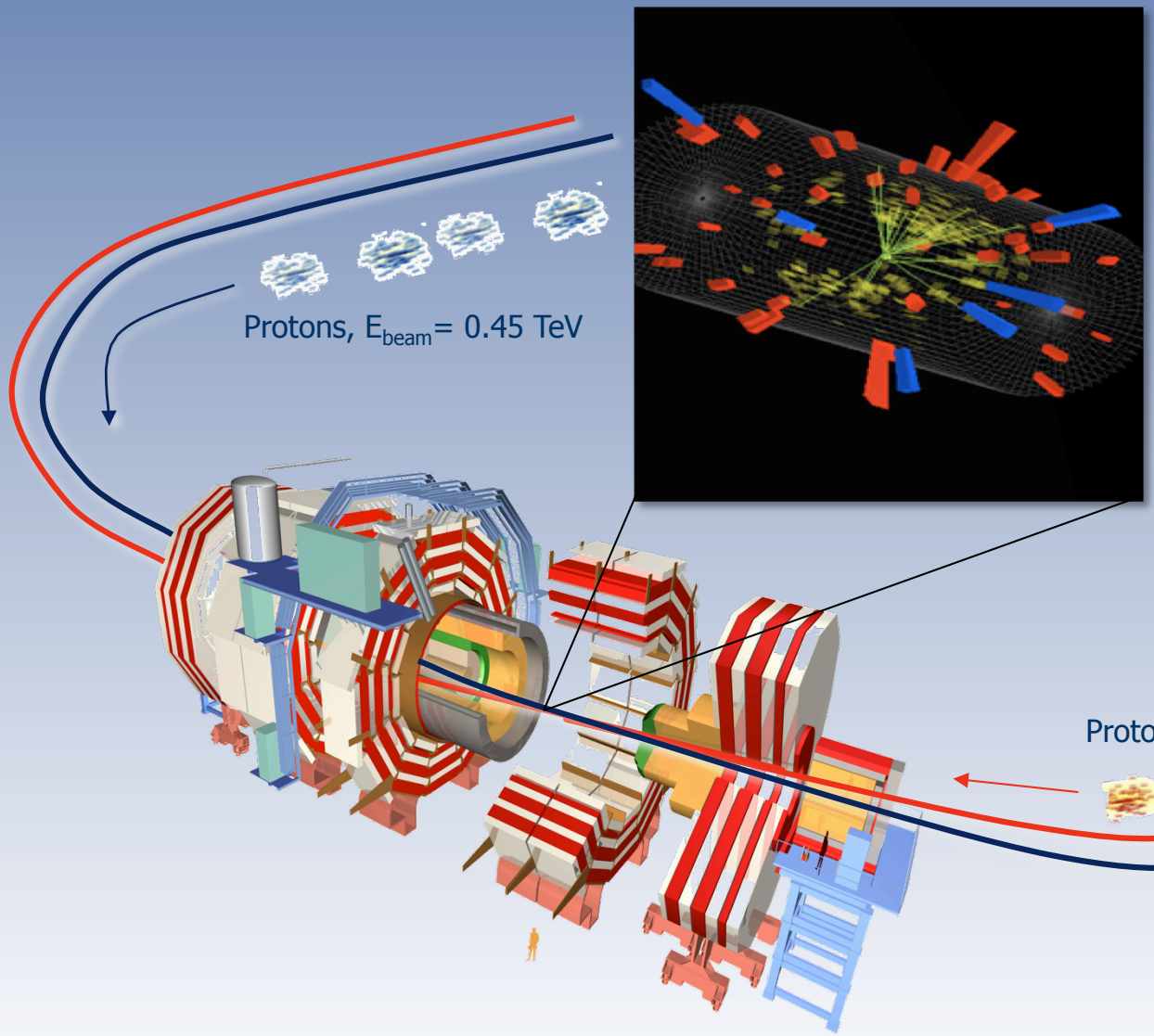
LHC: Exploration of a new energy frontier

Proton-proton collisions at E_{CM} = 14 TeV (design value)
Heavy Ions: Lead-lead collisions: Energy/nucleon = 2.76 TeV/u

The LHC will **illuminate a new landscape of physics**, possibly answering some of the most **fundamental questions in modern physics**, like e.g.

The origin of mass
Unification of fundamental forces
New forms of matter
Extra dimensions of spacetime

First Collisions at LHC on 23 November 2009 at E_{CM} = 900 GeV

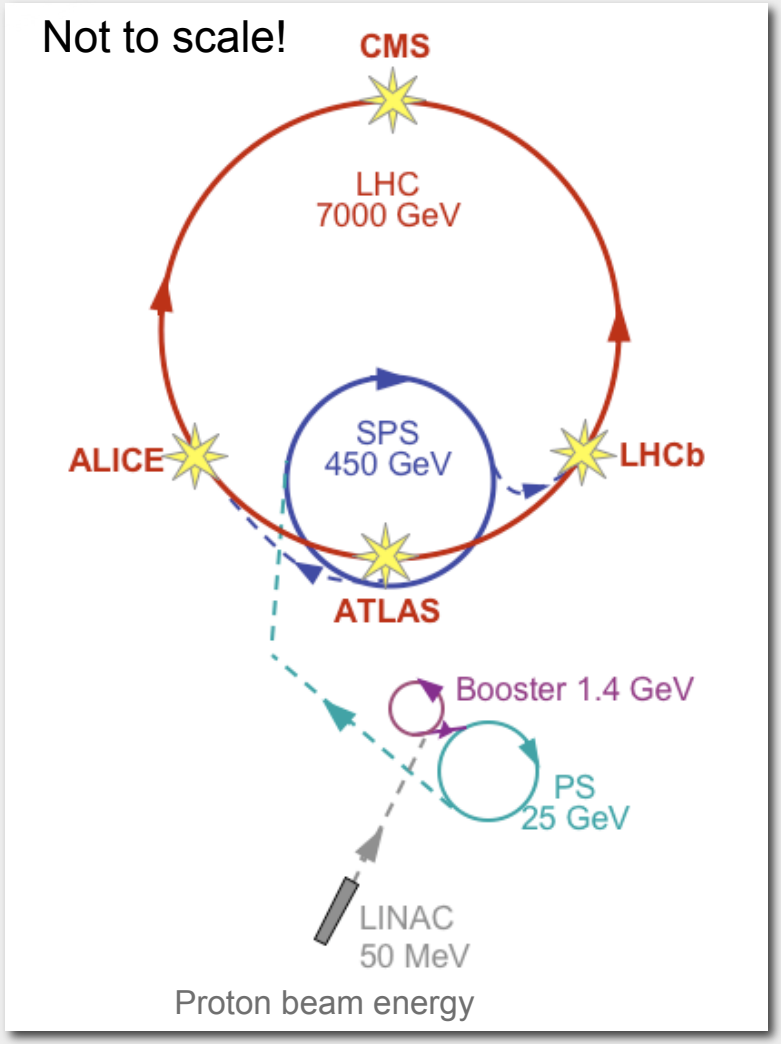


CMS Experiment at the LHC
Date Recorded: 2009-11-23 19:21 CET
Run/Event: 122314/1514552
Candidate Collision Event

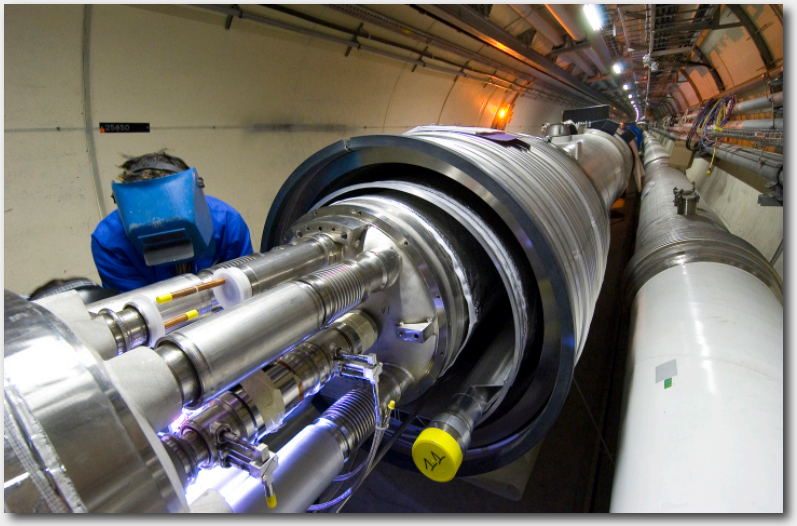
… after more than a year of repairs and improvements

Recall: LHC operation in September 2008

10 September 2008: first protons circulating in the LHC ring

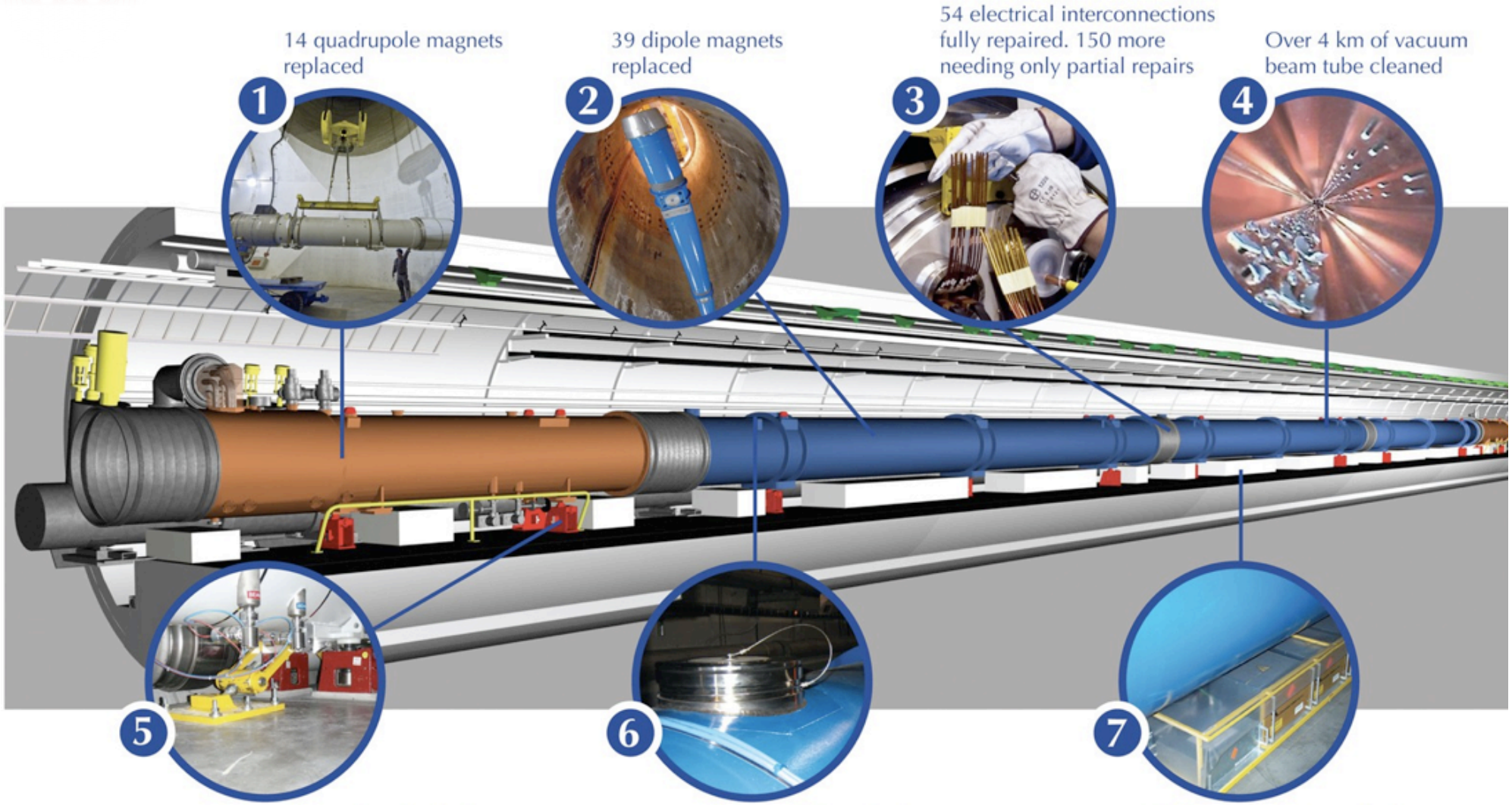


19 September: incident in sector 3-4



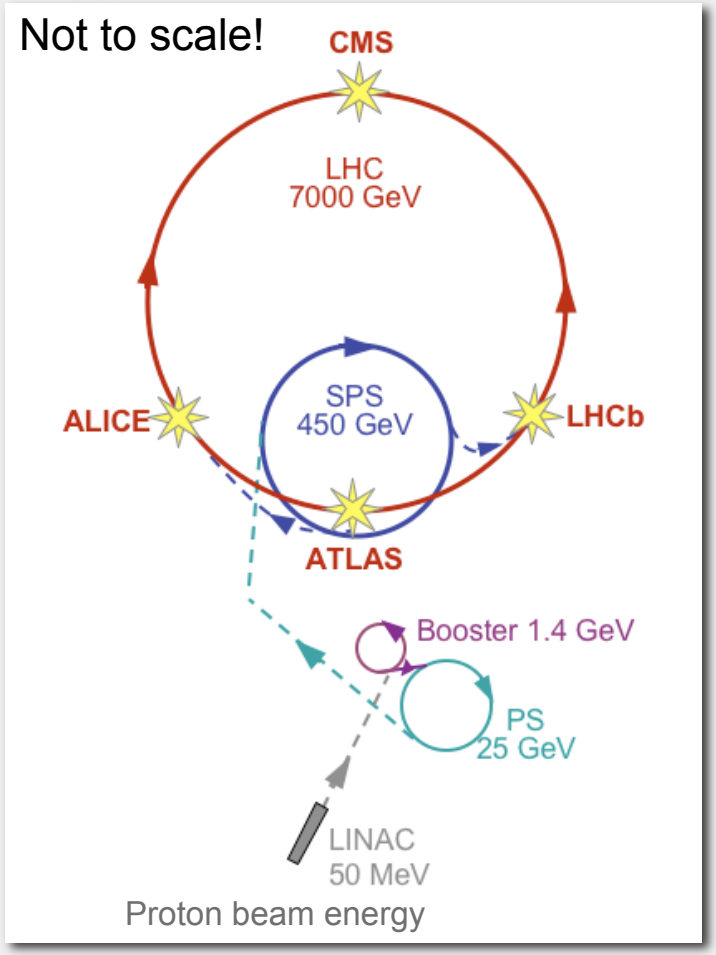
The incident was traced to a faulty electrical connection between segments of the LHC's superconducting cable
(busbars)
High impact was caused by collateral damage

The LHC repairs in detail



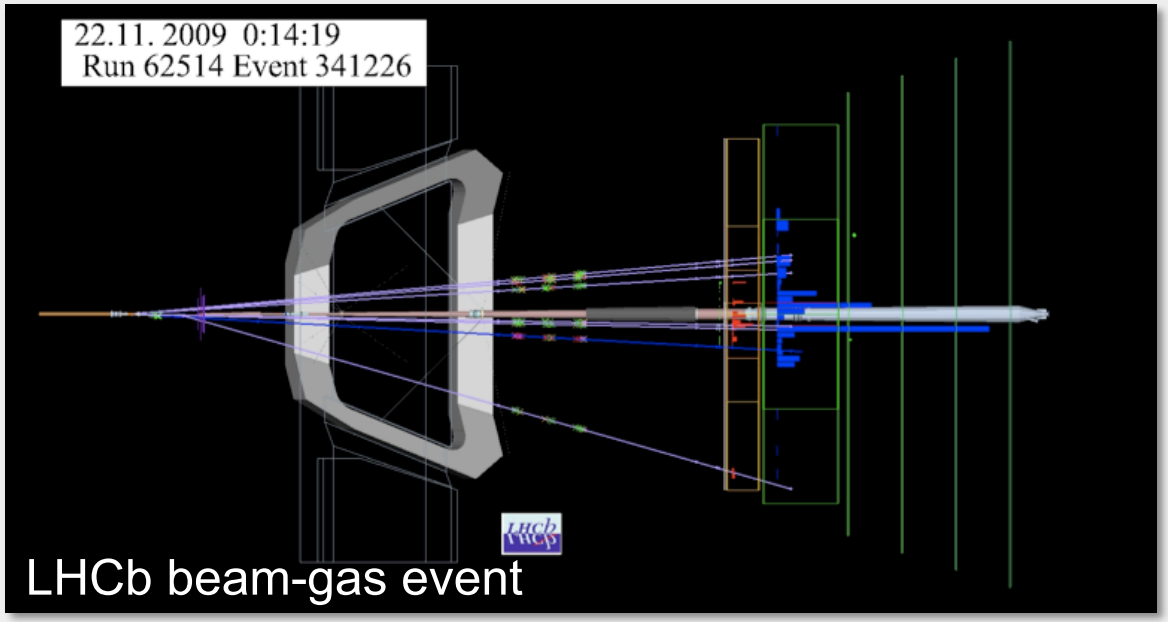
Location of LHC repairs in 2009

First LHC operation in 2009

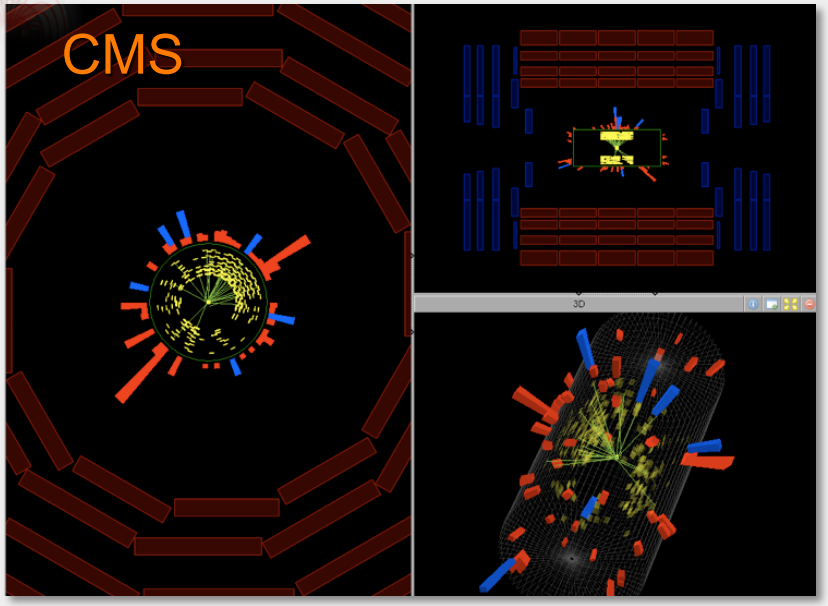


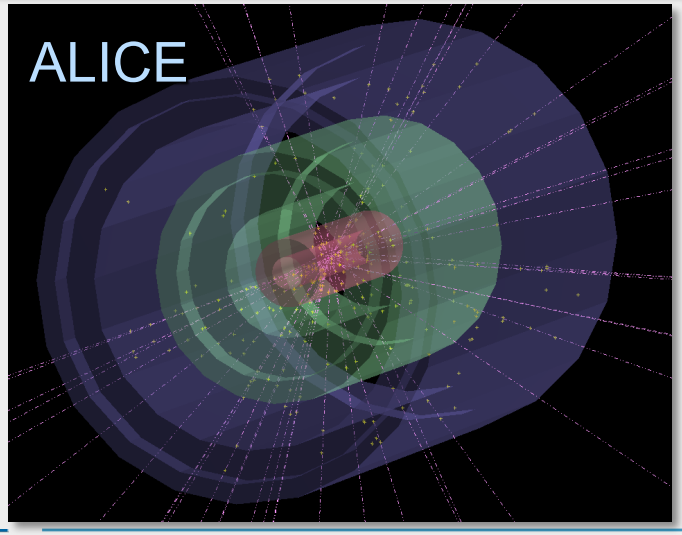
Friday, 20 November 2009:
First beam circulated in the LHC – a clockwise circulating beam was established at at 10:00 p.m., followed by a circulating beam in the other direction a few hours later

Monday, 23 November:
Both beams are circulating in LHC

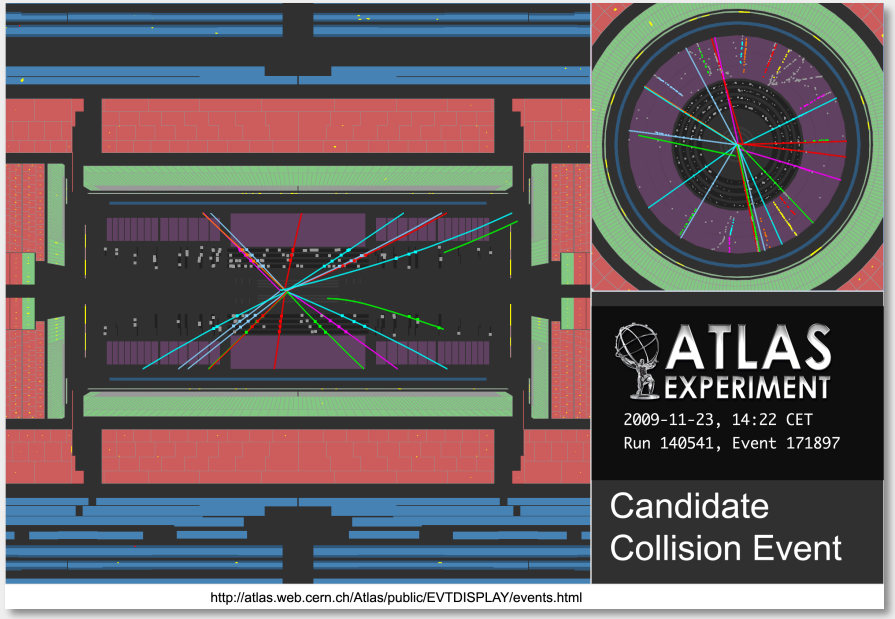


First LHC operation in 2009



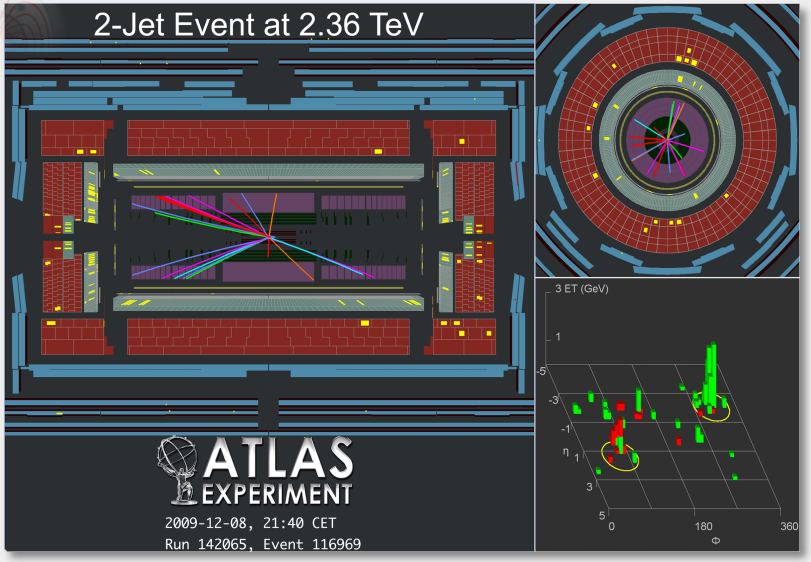


23 November 2009:
first 900 GeV Candidate Collision Events

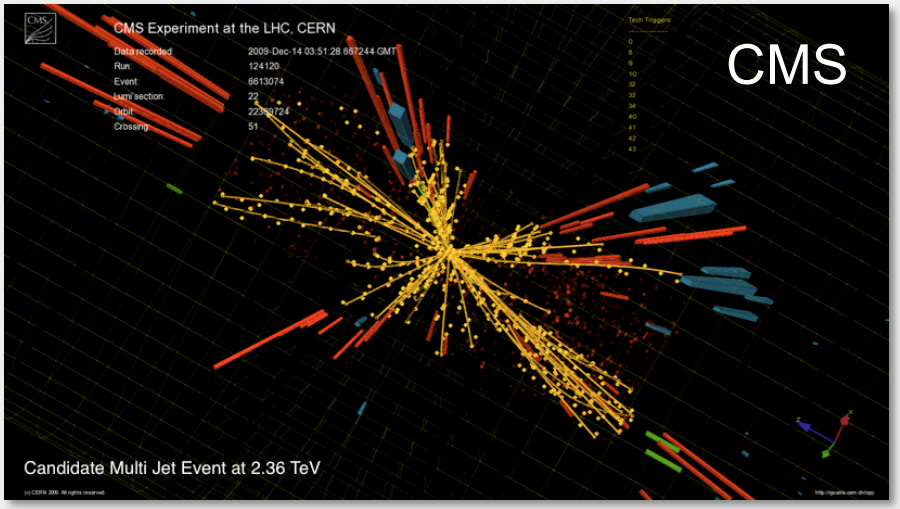


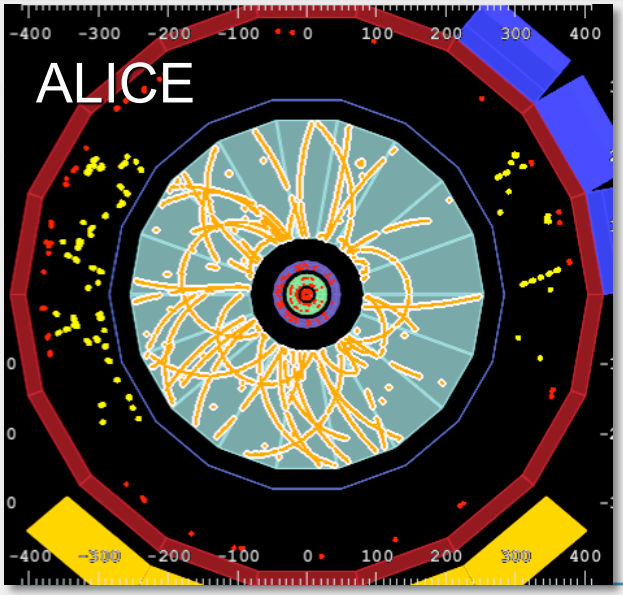
6 December 2009:
Machine protection system commissioned
➡ stable (safe) beams for first time

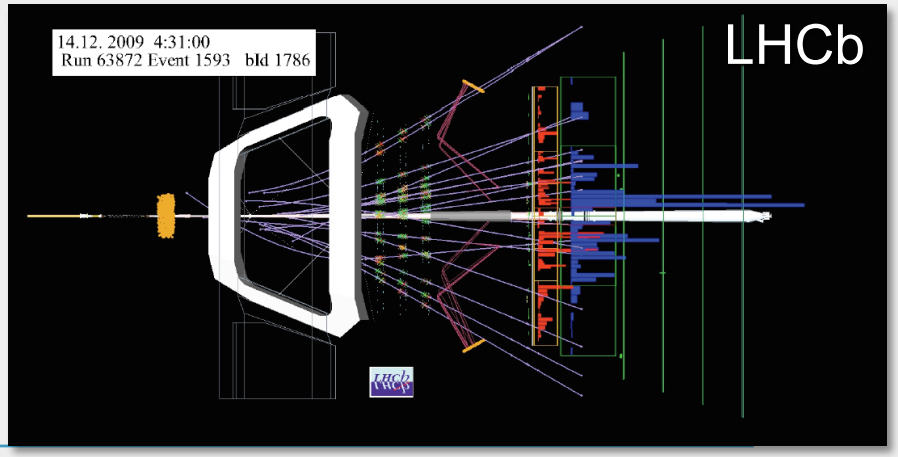
First LHC operation in 2009



8, 14, 16 December 2009: First collisions at 2.36 TeV



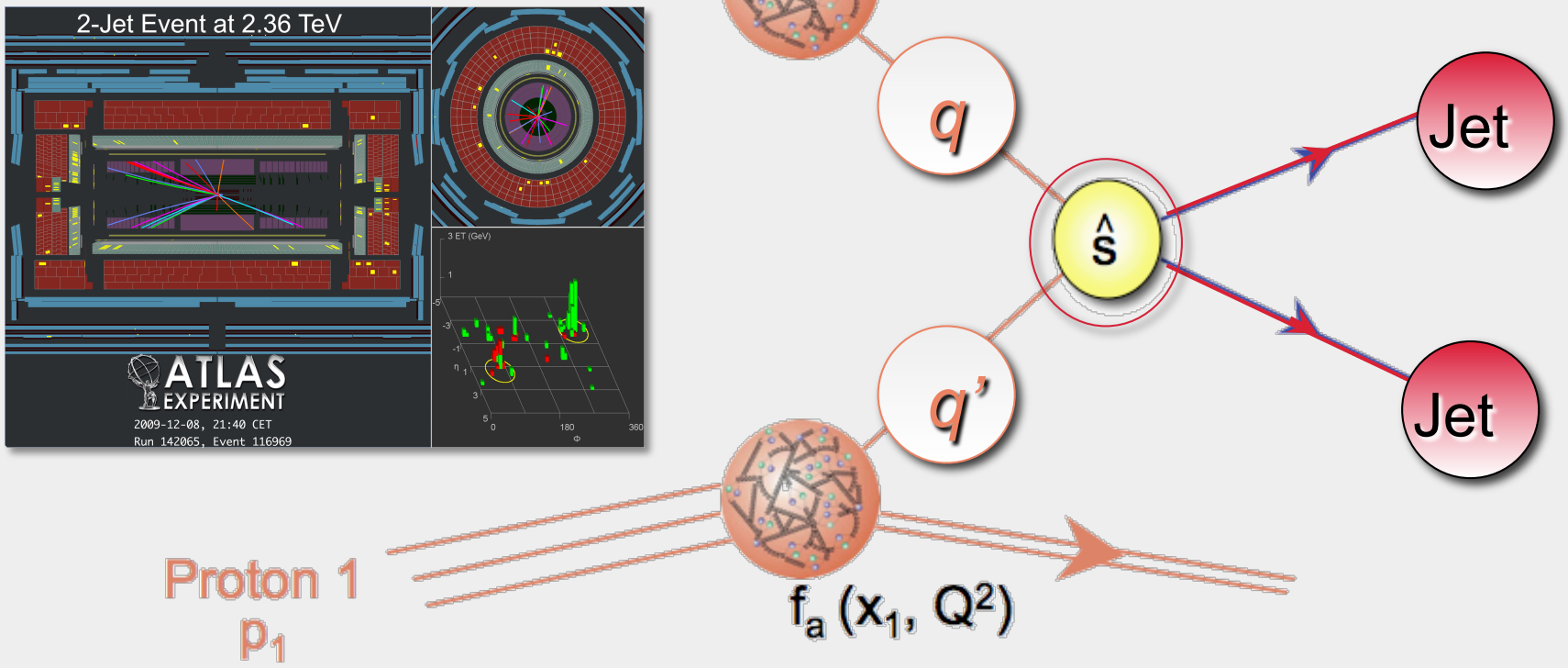




Summary LHC operation in 2009

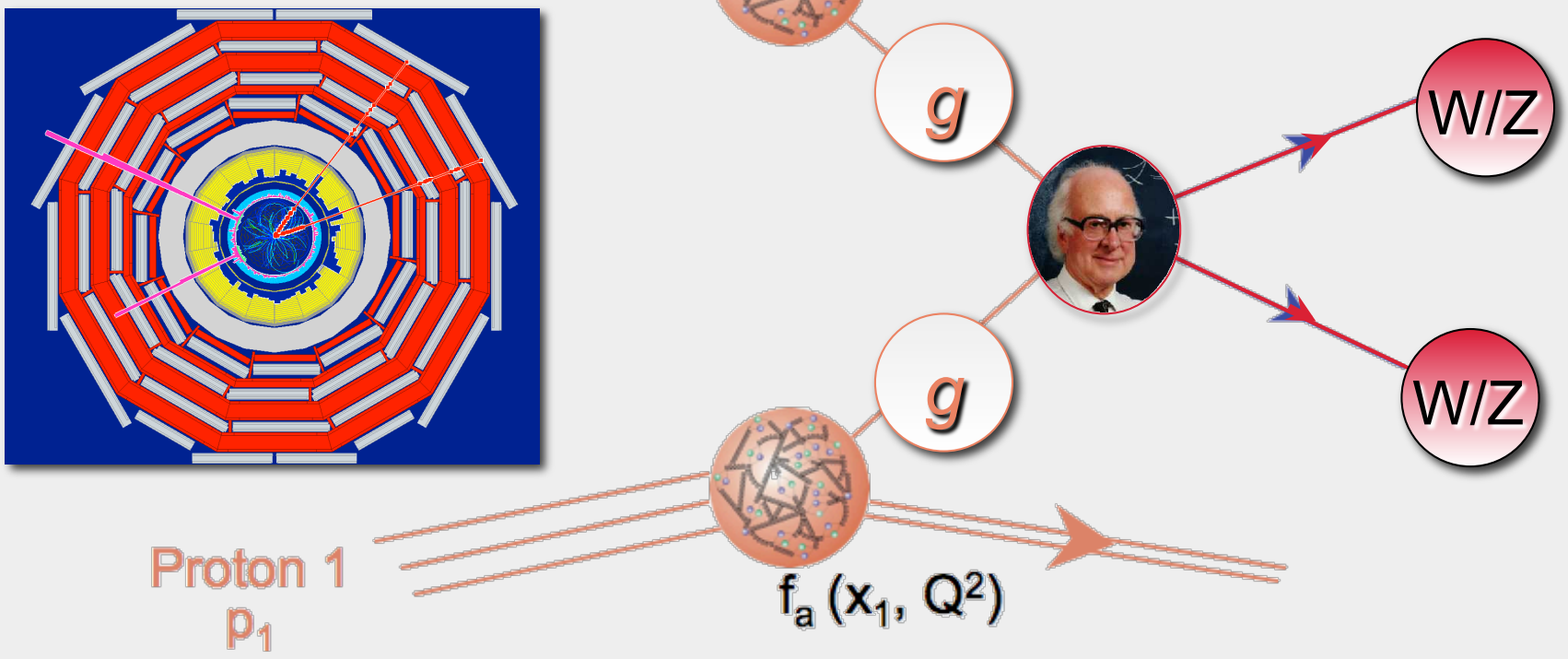
Date	Day	Milestones Achieved *(S. Myers, 18. Dec 2009)*
Nov 20	1	Each beam circulating. Key beam instrumentation working
Nov 23	4	First collisions at E_{beam} = 450 GeV. First ramp (reached 560 GeV)
Nov 26	7	Magnetic cycling established
Nov 27	8	Energy matching
Nov 29	10	Ramp to 1.18 TeV
Nov 30	11	Experiments solenoids on
Dec 04	15	Aperture measurement campaign finished. LHCb and ALICE dipoles on
Dec 05	16	Machine protection (injection, dump, collimators) ready for safe operation
Dec 06	17	First collisions with stable beams, 4 on 4 pilots at 450 GeV. Rates ~ 1Hz
Dec 08	19	Ramp colliding bunches to 1.18 TeV
Dec 11	22	Collisions with stable beams, 4 on 4 pilots at 450 GeV; >10^{10}/bunch; rates ~ 10Hz
Dec 13	24	Ramp 2 bunches/beam to 1.18 TeV. Collisions for 90 minutes
Dec 14	25	Collisions with stable beams, 16 on 16 at 450 GeV; >10^{10} /bunch.; rates ~ 50Hz
Dec 16	27	Ramp 4 on 4 to 1.18 TeV; squeeze to 7 m.

Basic processes at LHC

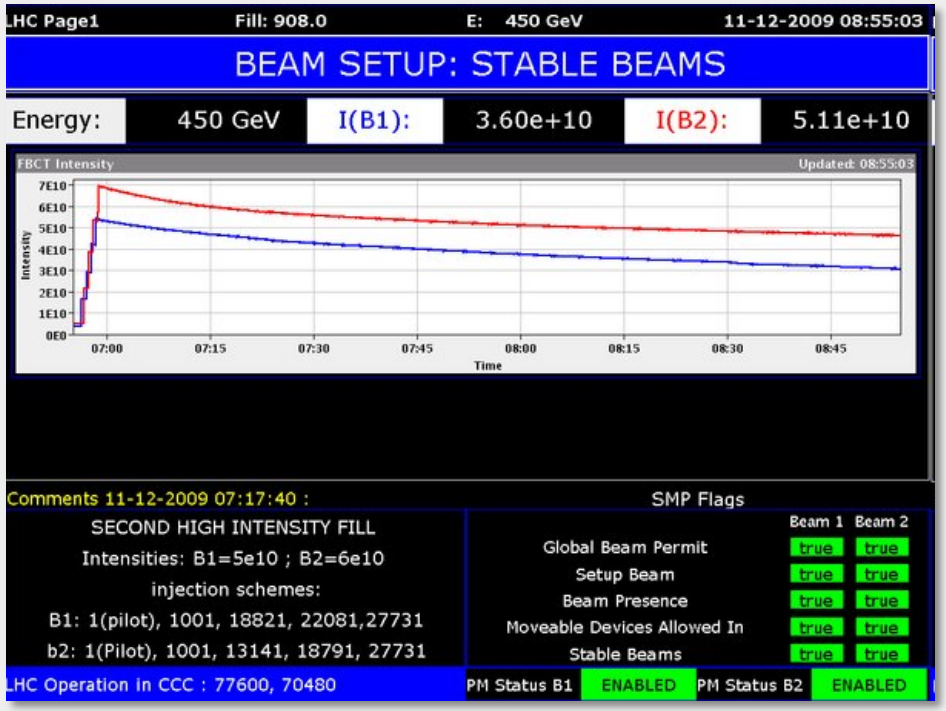


$$d\sigma(p_1 p_2 \rightarrow c\ d) = \int_0^1 dx_1 dx_2 \sum_{a,b} (f_a(x_1, Q^2)\, f_b(x_2, Q^2)\, d\hat{\sigma}^{ab \rightarrow cd})$$

Basic processes at LHC (not in 2009)



First collision data recorded at LHC



Status report on the progress of the LHC accelerator and of the experiments presented on 18 Dec 2009 at CERN

Some selected highlights from LHC and ATLAS, CMS, LHCb, ALICE

presented by

S. Myers (LHC)

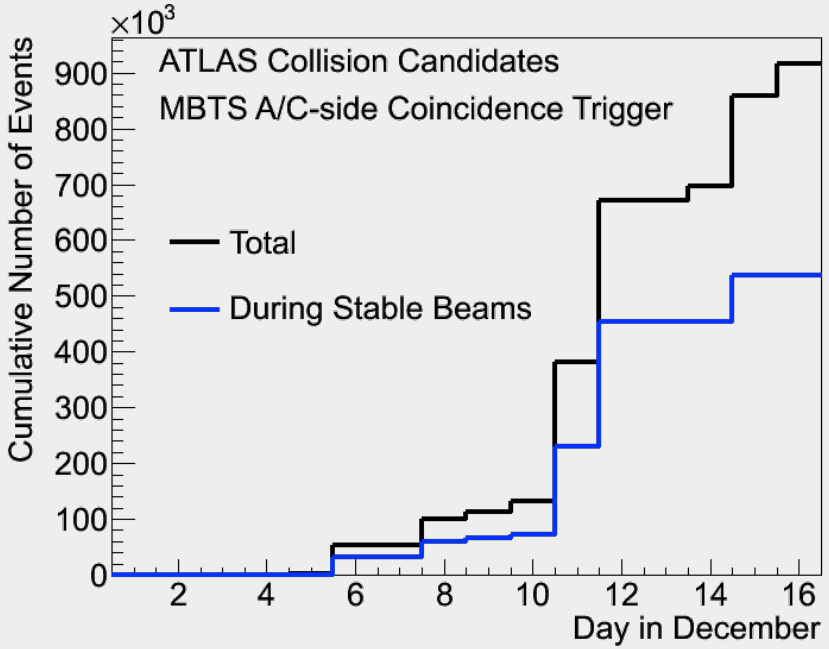
F. Gianotti (ATLAS)

T. Virdee (CMS)

A.Golutvin (LHCb)

J. Schukraft (ALICE)

First collision data: recorded data sample



Recorded data sample: ATLAS example

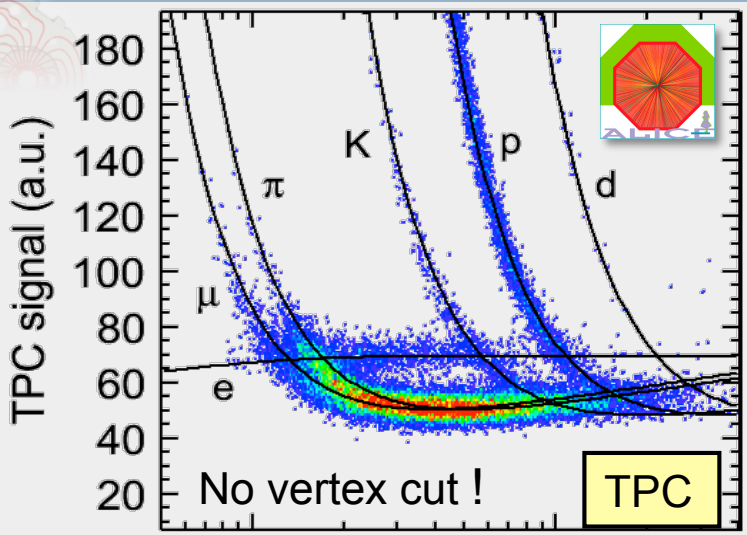
Max peak luminosity seen by ATLAS : ~ 7 x 10^{26} cm^{-2} s^{-1}

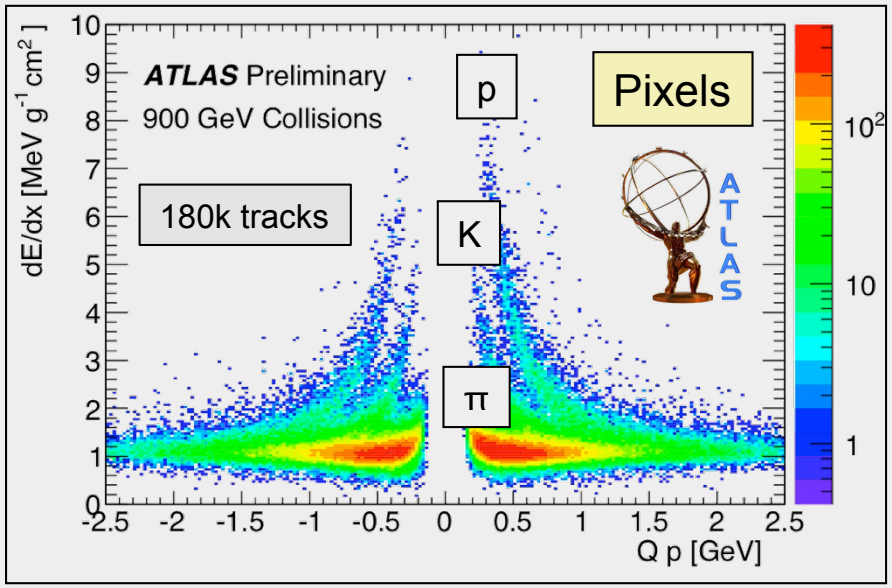
Average data-taking efficiency: ~ 90%

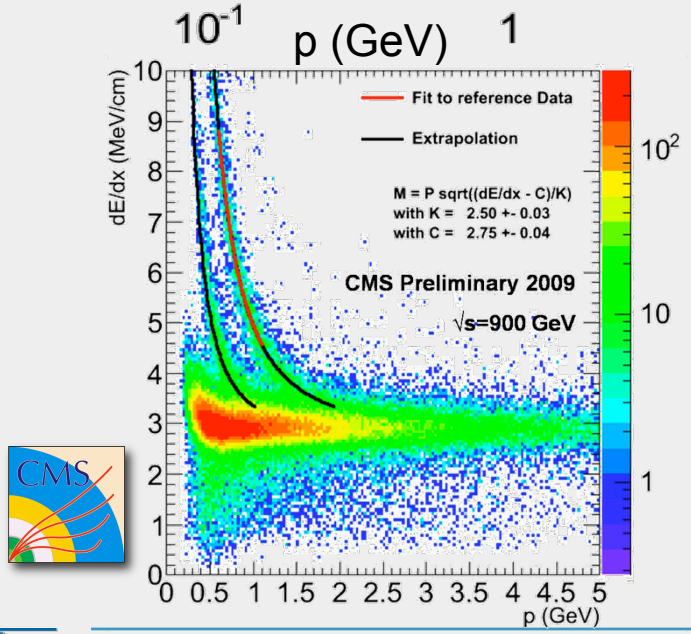
Recorded data samples in ATLAS	Number of events	Integrated luminosity (<30% uncertainty)
Total	~ 920k	~ 20 μb^{-1}
With stable beams (→ tracker fully on)	~ 540k	~ 12 μb^{-1}
At √s=2.36 TeV (flat top)	~ 34k	≈ 1 μb^{-1}

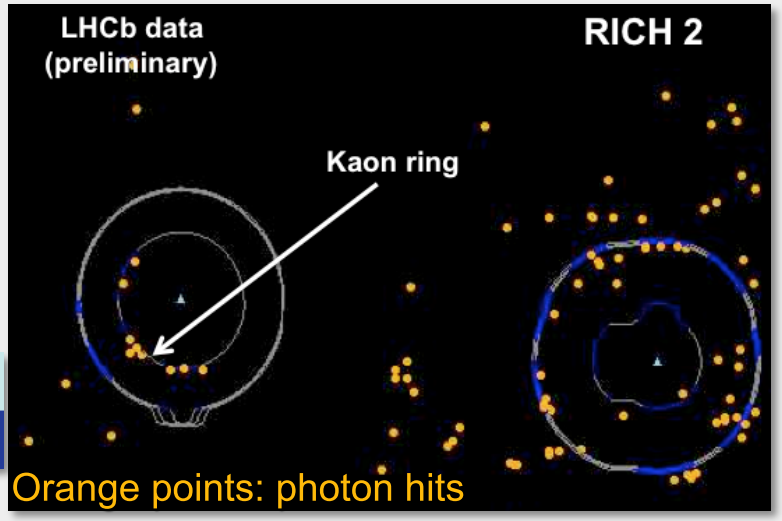
Similar numbers for other experiments

First collision data: particle identification

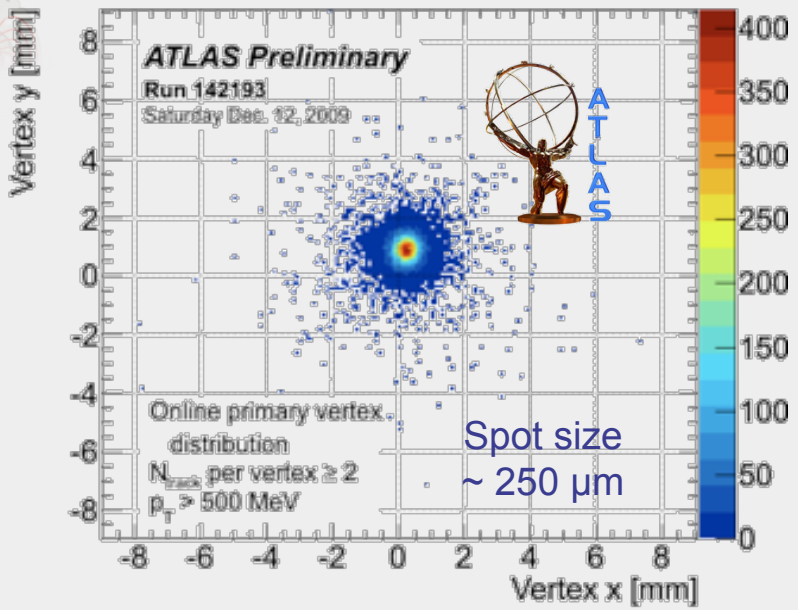


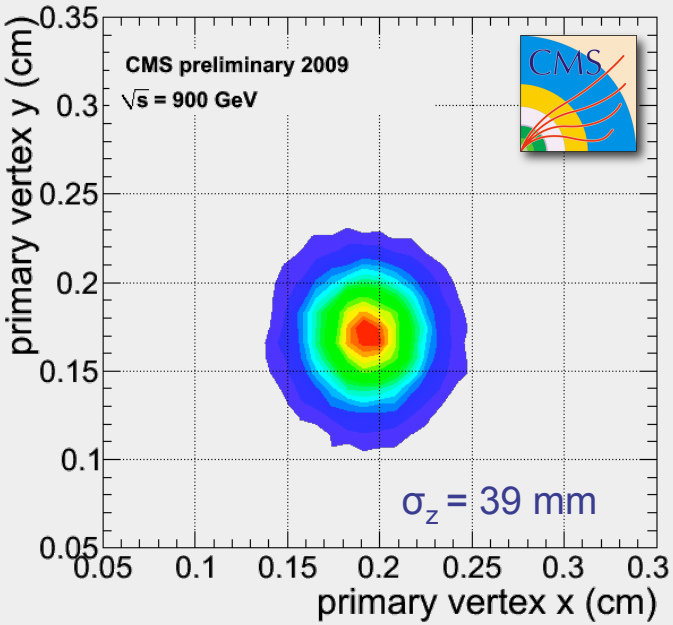


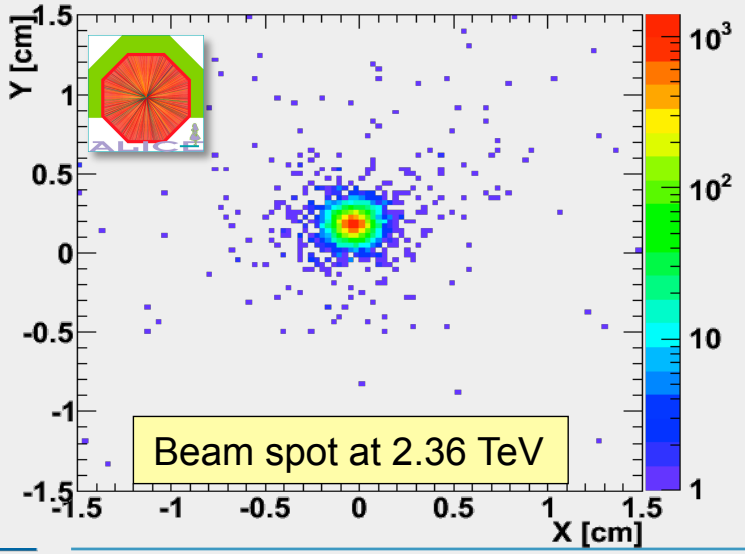


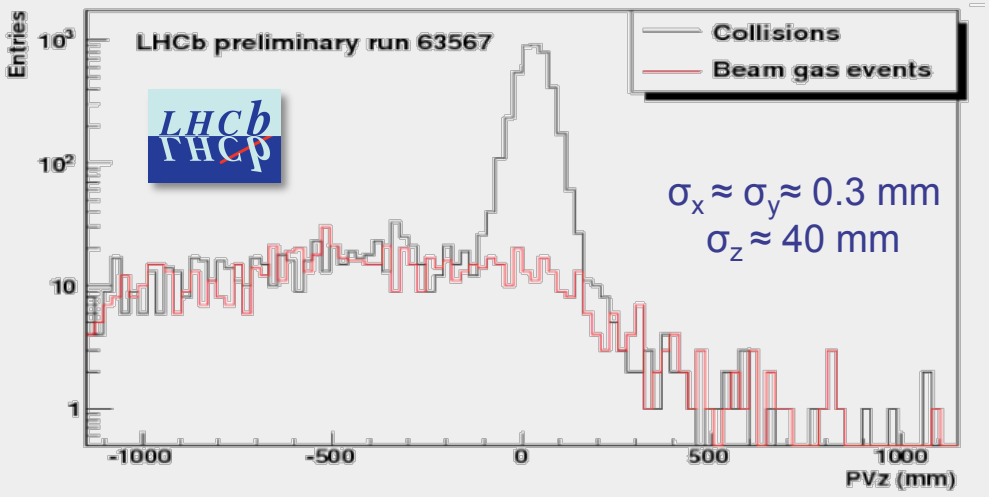


First collision data: primary vertex



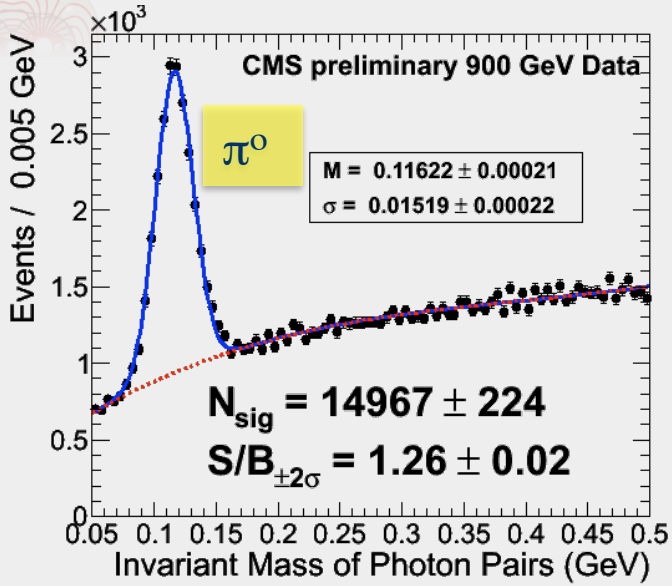


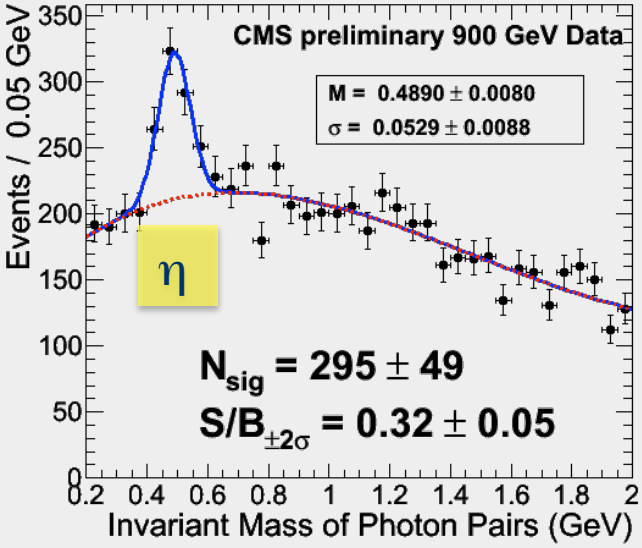




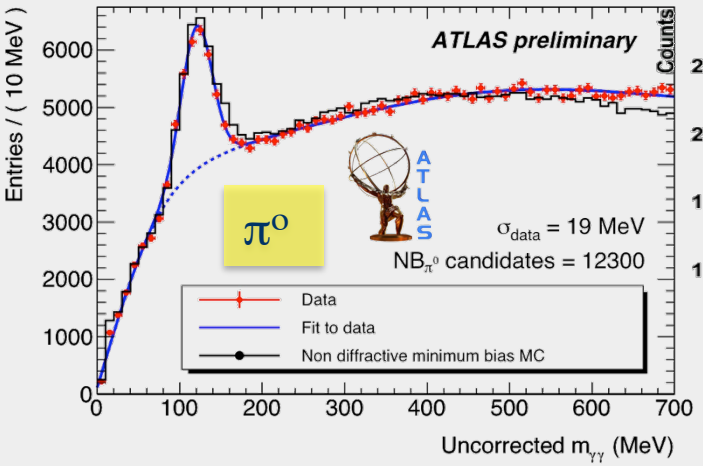
First collision data: π^0, η

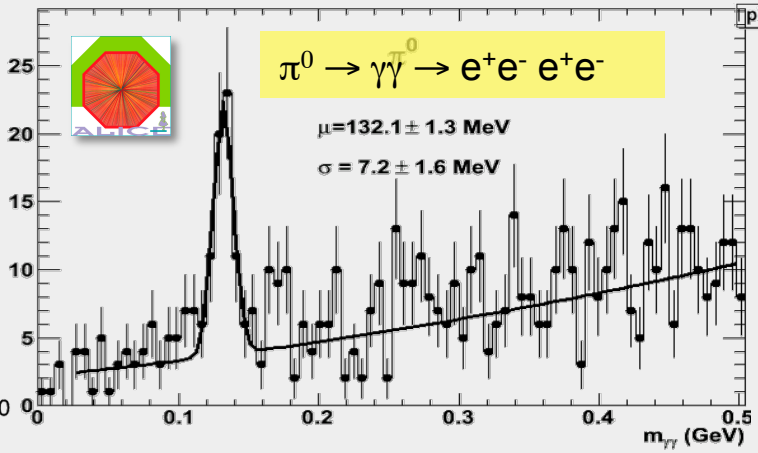
PDG:
$m(\pi^0) = 134.9$ MeV
$m(\eta) = 547.7$ MeV

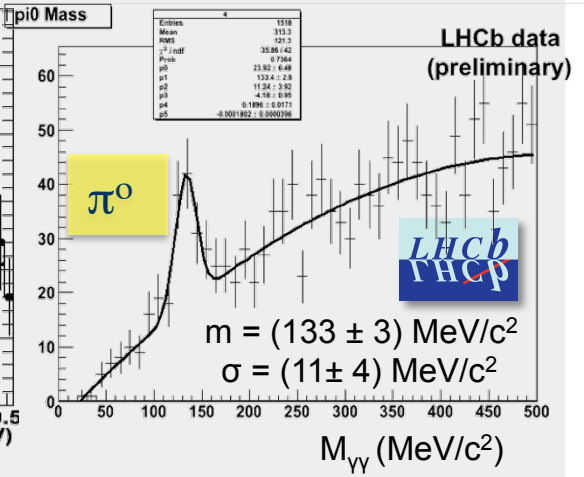




Data:
$N(\eta)/N(\pi^0) = 0.020 \pm 0.003$
MC:
$N(\eta)/N(\pi^0) = 0.021 \pm 0.003$

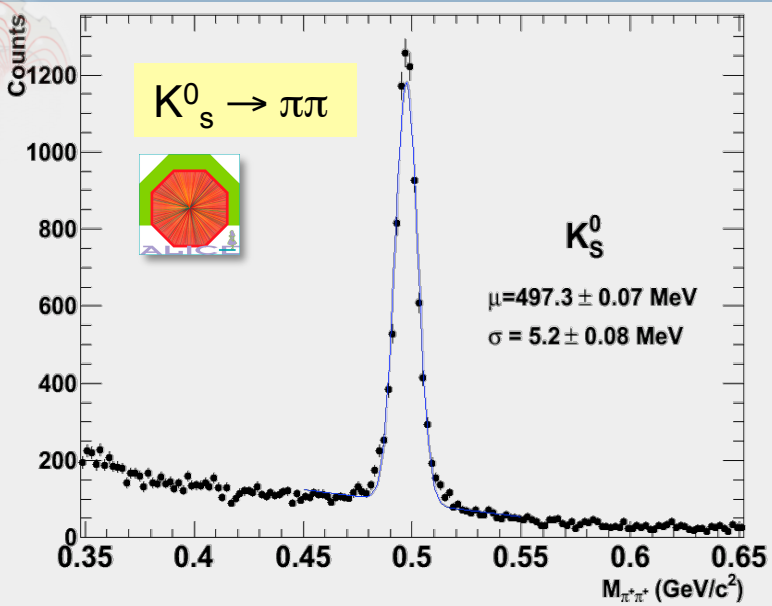


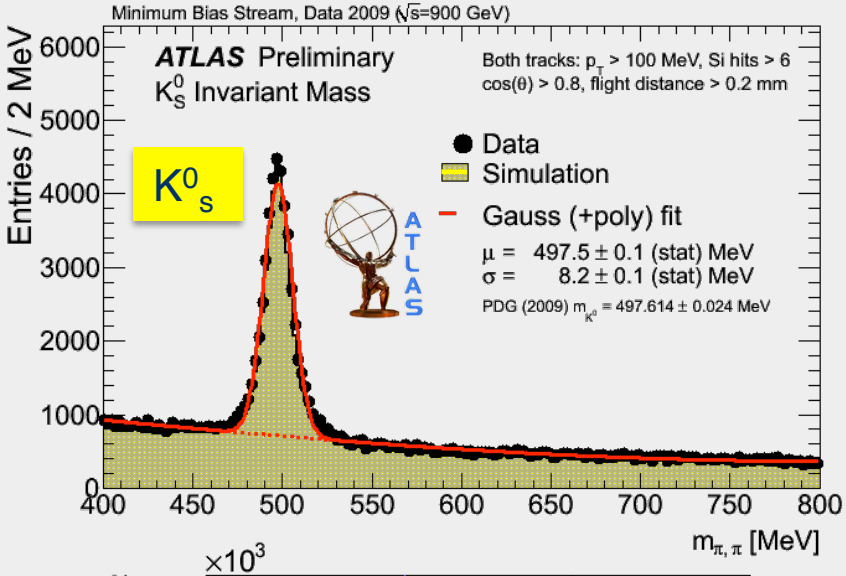


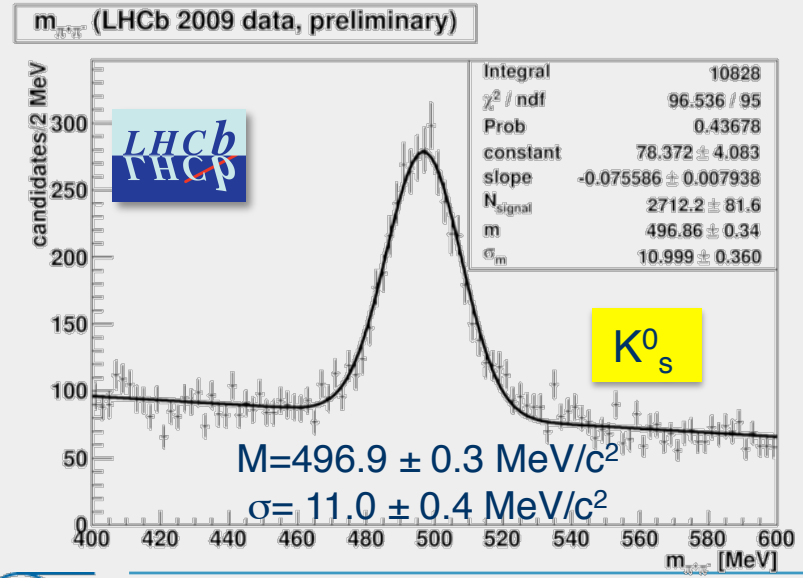


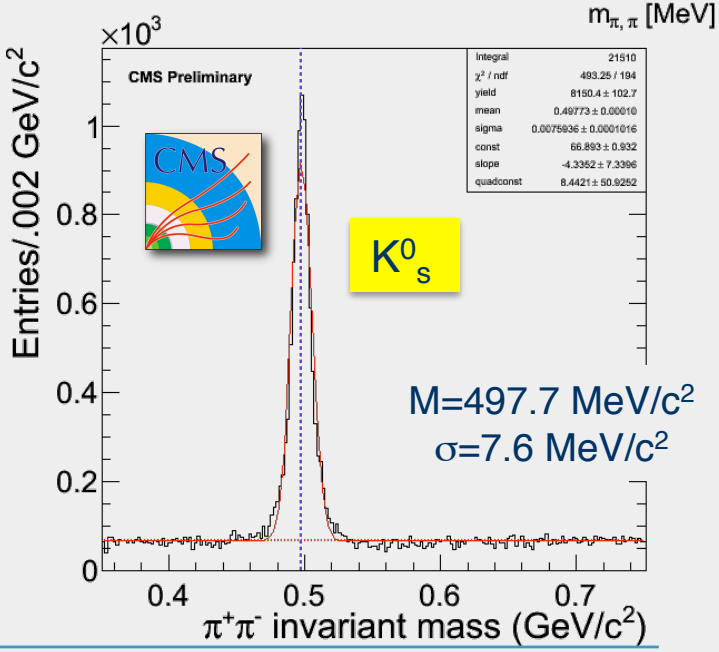
First collision data: $K^0_s \rightarrow \pi^+\pi^-$

PDG:
$m(K^0_s) = 497.6$ MeV



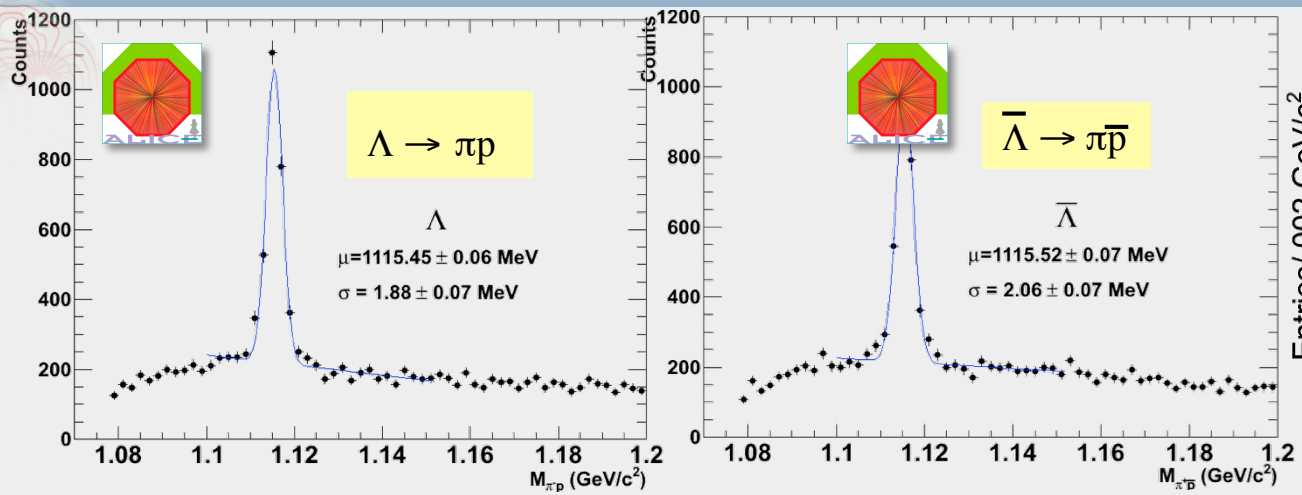


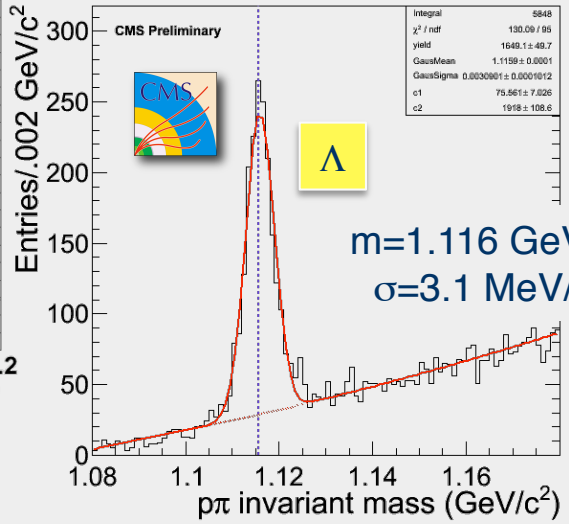




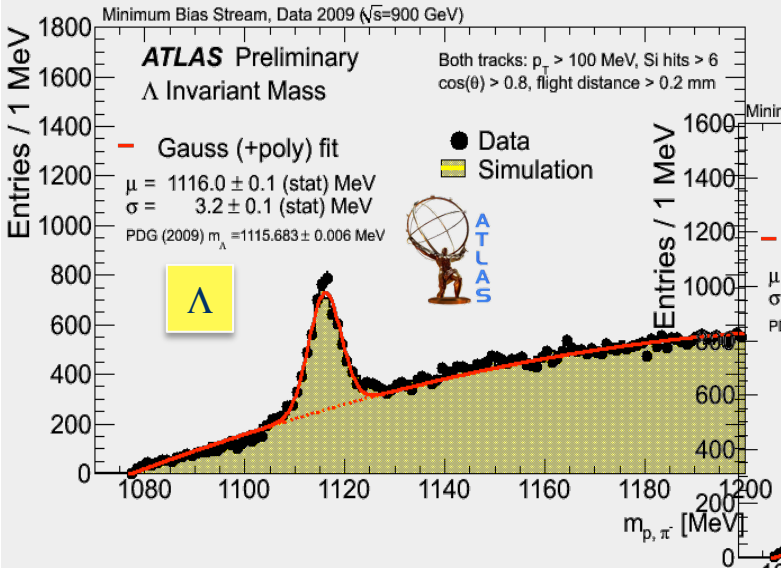
First collision data: $\Lambda \rightarrow p\pi^-$, $\bar{\Lambda} \rightarrow \bar{p}\pi^+$

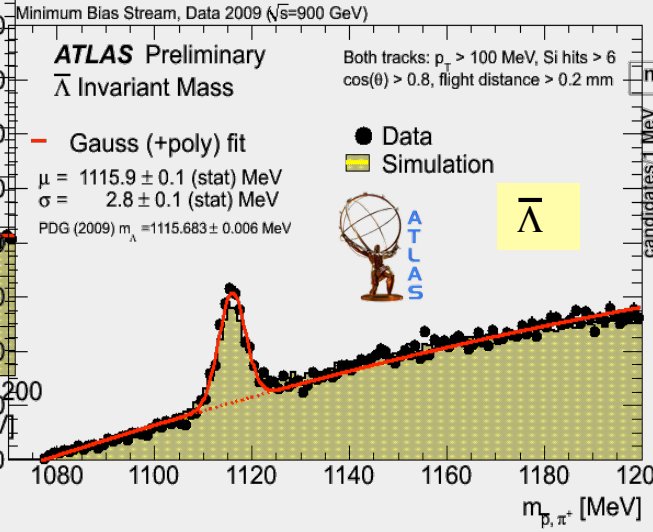
PDG:
M(Λ) = 1115.7 MeV

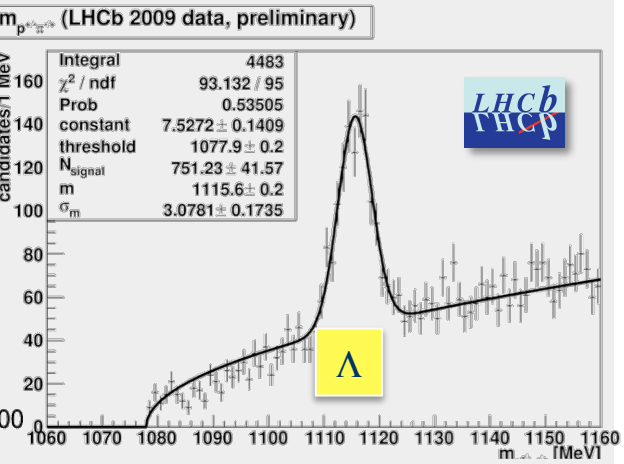




m=1.116 GeV/c²
σ=3.1 MeV/c²

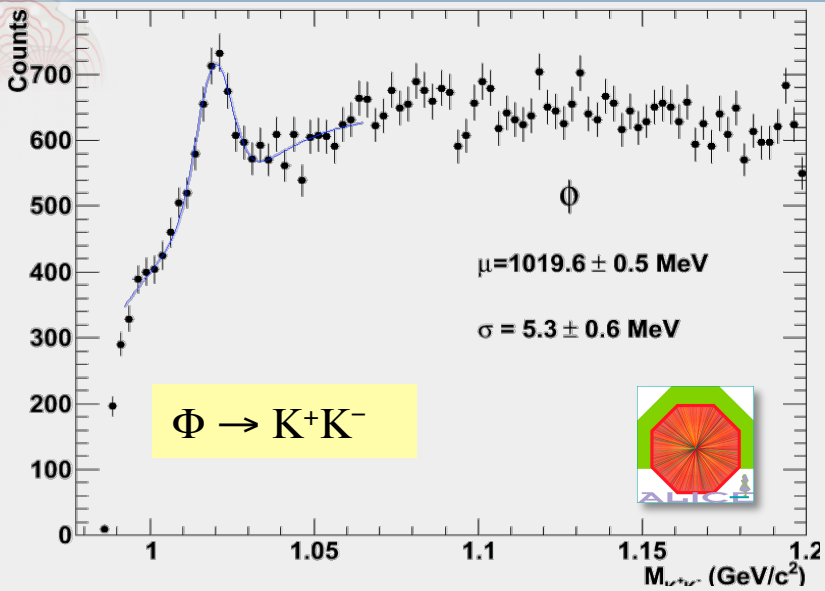




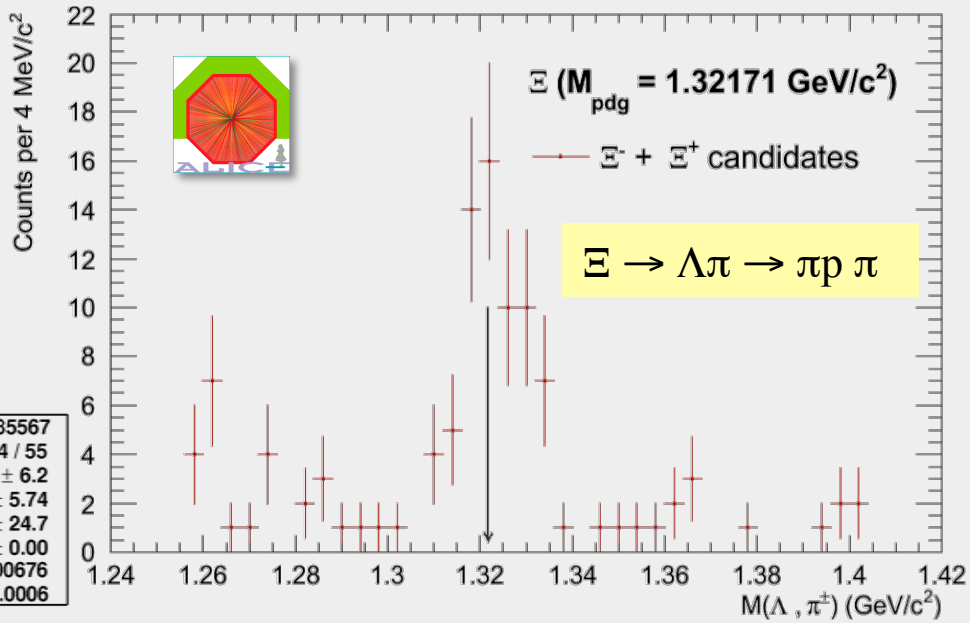


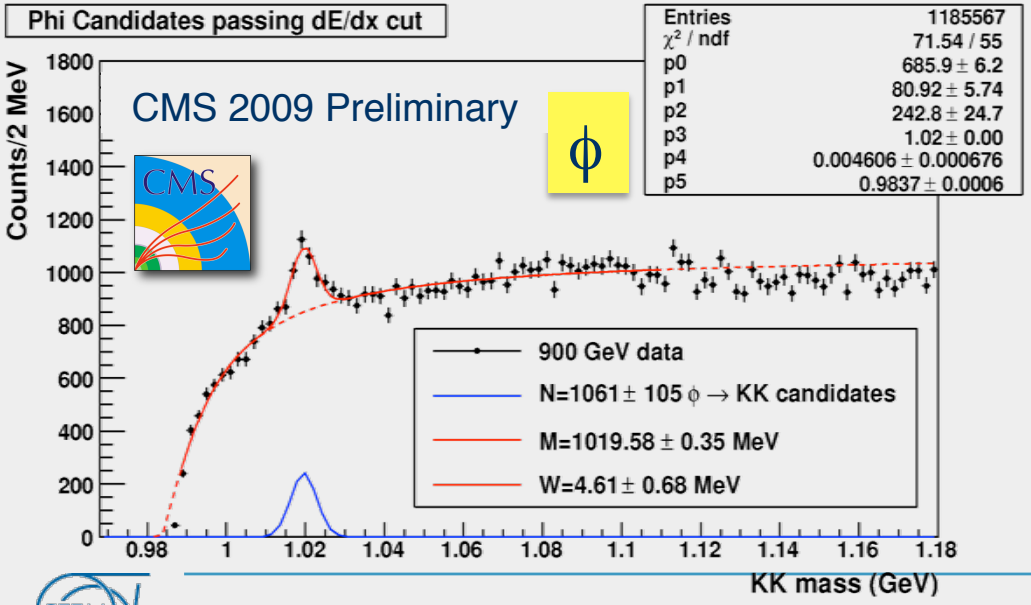
m=1115.6 ± 0.2 MeV/c²,
σ=3.1 ± 0.2 MeV/c²

First collision data: Φ → K⁺K⁻, Ξ → Λπ → πpπ



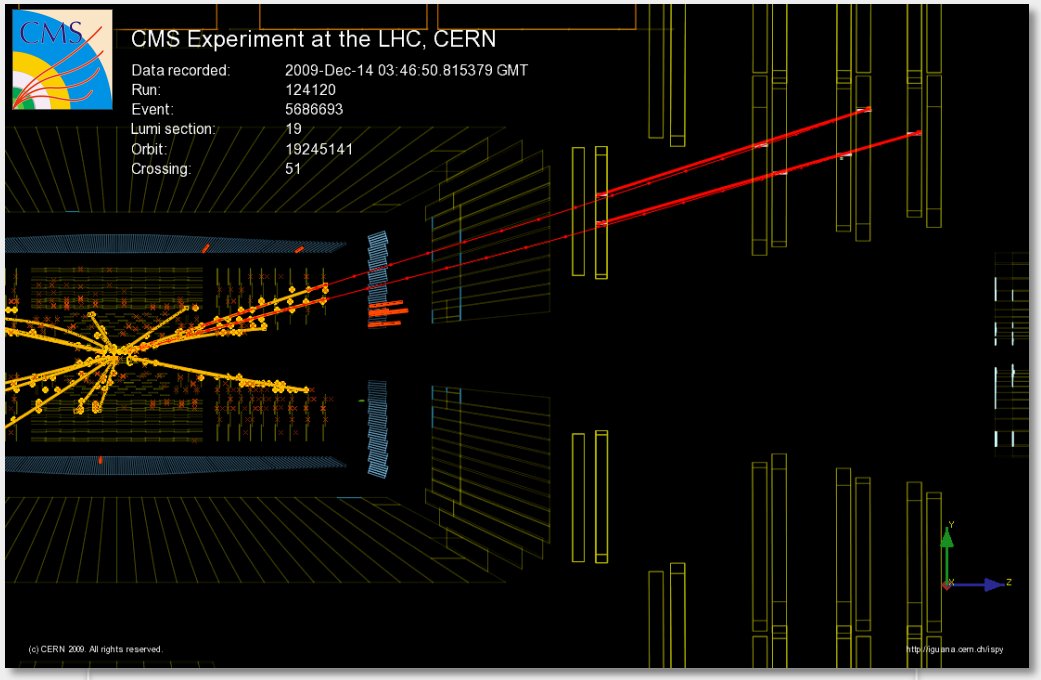
PDG:
M(Φ) = 1019.5 MeV
M(Ξ) = 1321.1 MeV





First collision data: Events with Dimuons

m (J/Ψ) = 3.096 GeV



CMS:

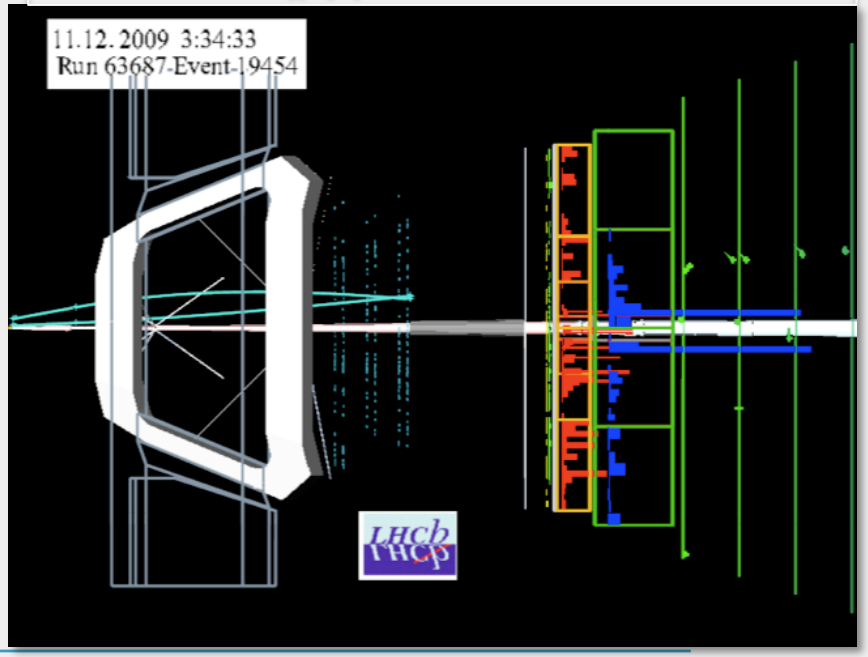
$p_T(\mu_1)$ = 3.6 GeV, $p_T(\mu_2)$ = 2.6 GeV

m(μμ)= 3.03 GeV

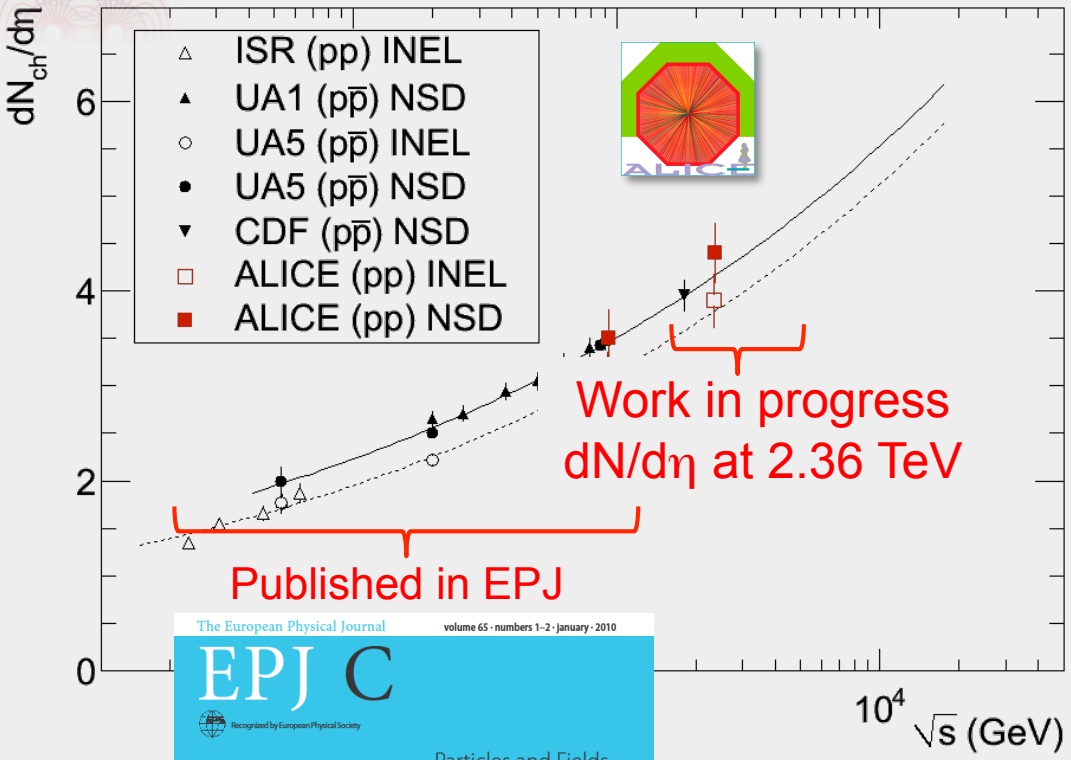
LHCb:

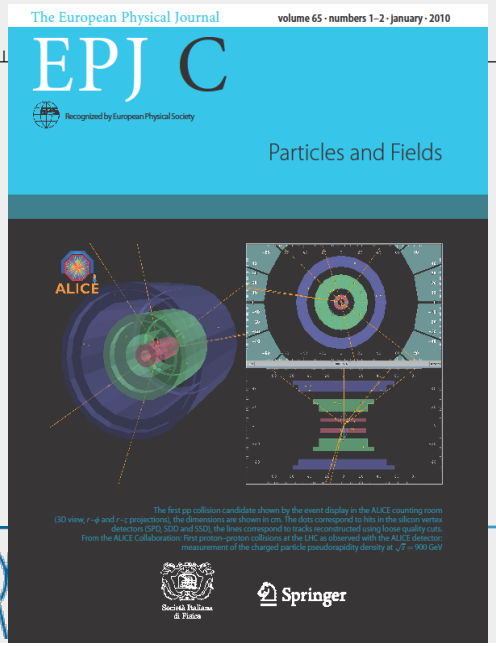
$p_T(\mu_1)$ = 2.2 GeV, $p_T(\mu_2)$ = 1.2 GeV

m(μμ)= 3.035 GeV

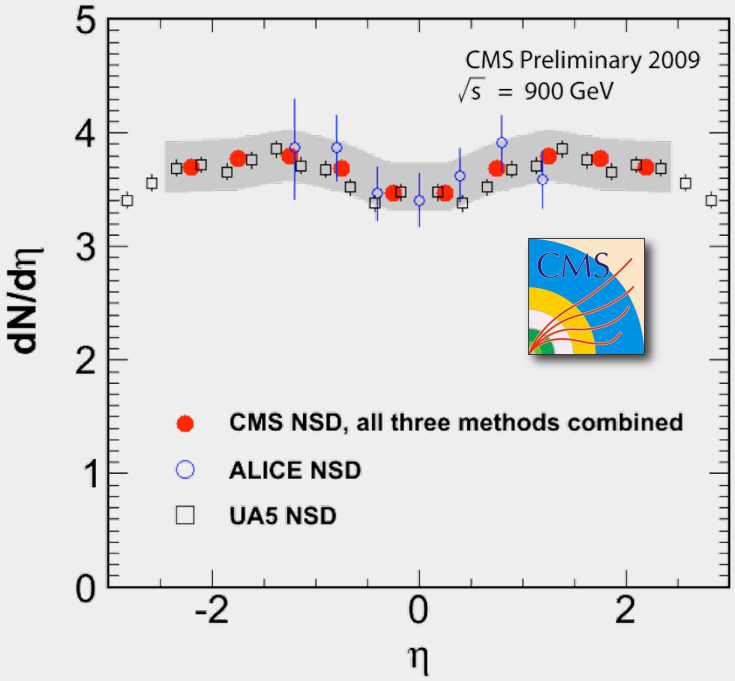


First collision data: first distributions





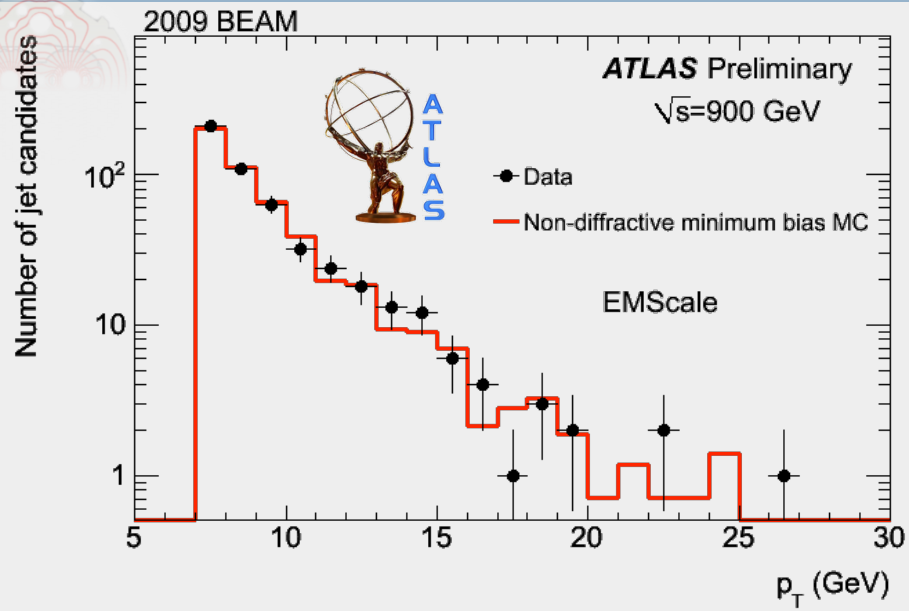
INEL= all inelastic interactions
NSD= non-single diffractive
(non-diffractive and double diffractive)



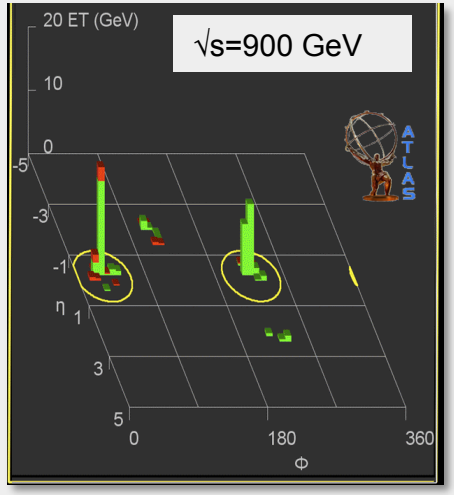
The average number of charged particles created perpendicular to the beam in pp collisions at 900 GeV is:
$dN/d\eta = 3.10 \pm 0.13\ (stat) \pm 0.22\ (syst)$

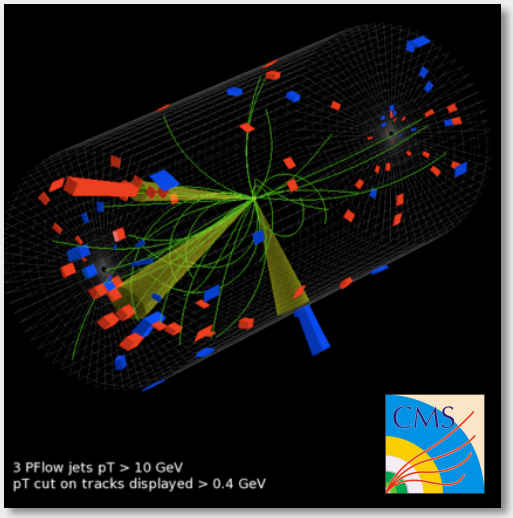
EPJ C vol 65, number 1-2 Jan 2010, Submitted to EPJC on 28 Nov 2009

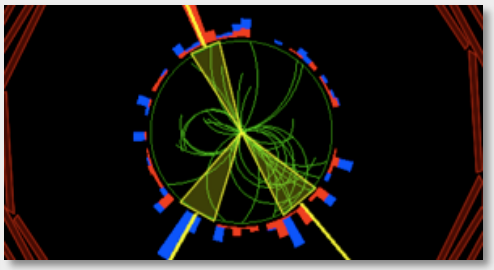
First collision data: jets

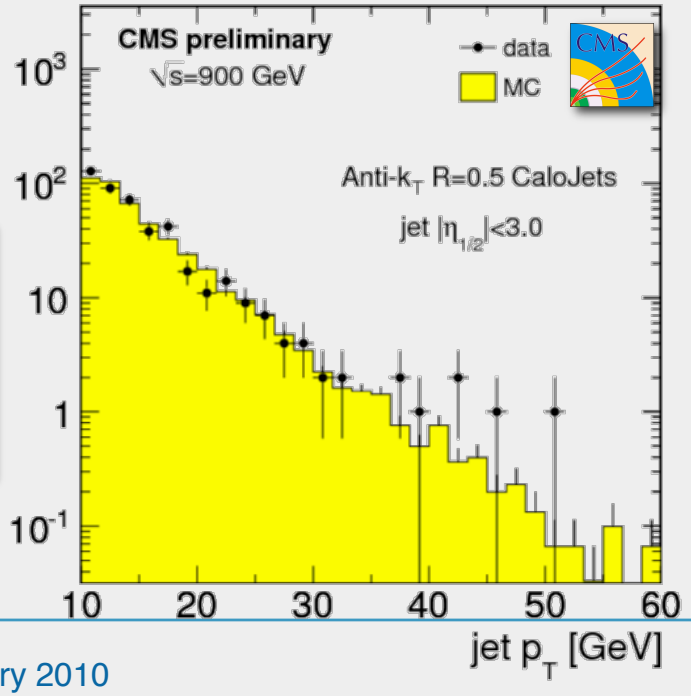


Un-calibrated EM scale MC normalized to number of jets or events in data





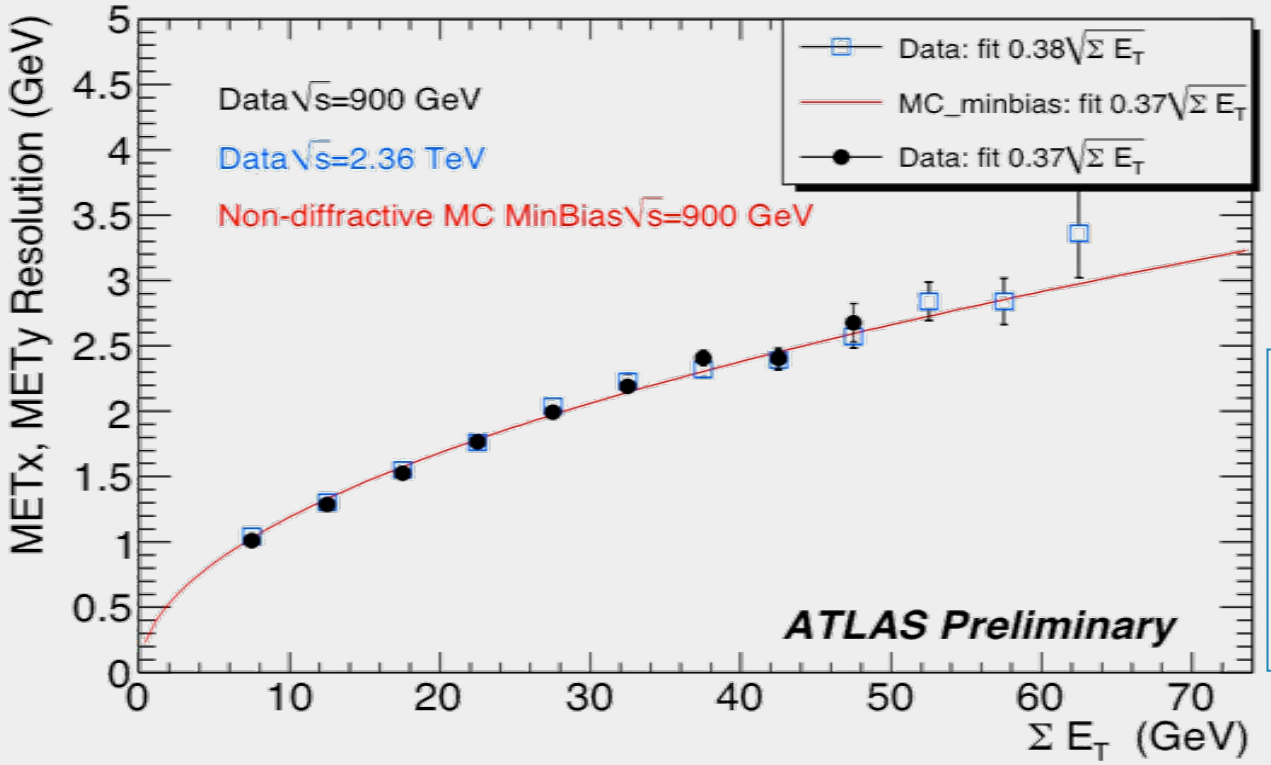




First collision data: Missing E_T

Missing transverse Energy (Missing E_T) is **important observable** for **many searches**

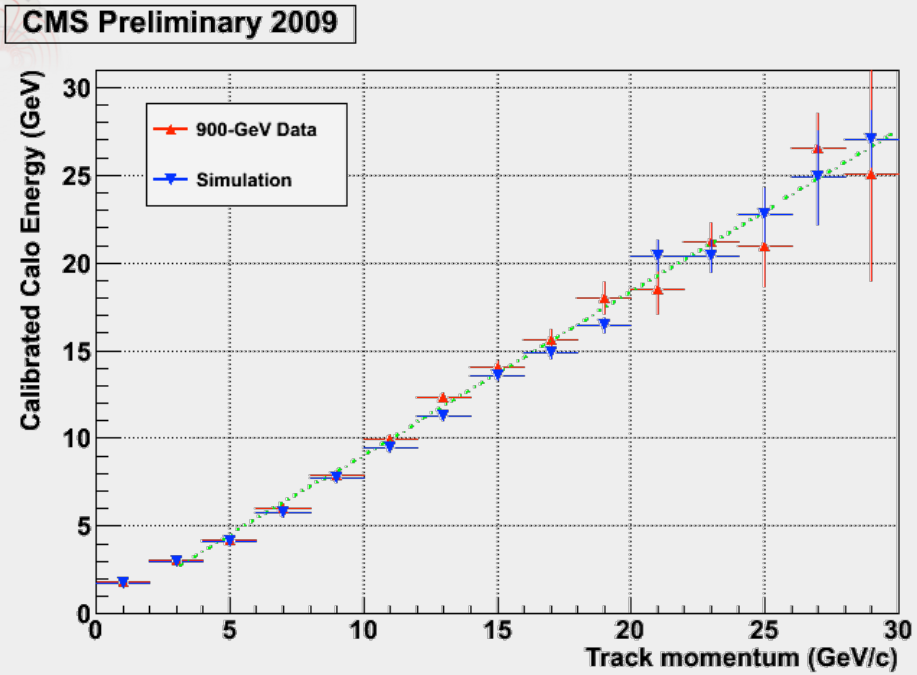
Missing E_T is **sensitive to detector performance** (noise, dead cells, mis-calibration, cracks, etc) and **background** from **cosmics** and **beams**

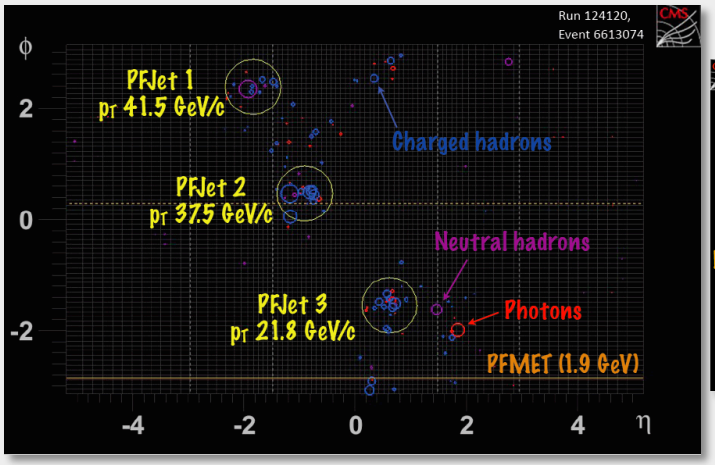


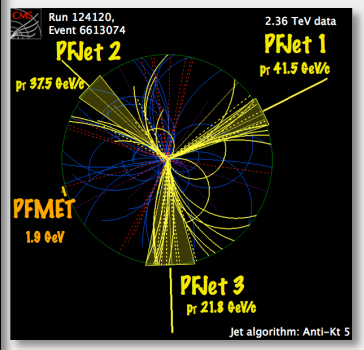
ATLAS: Measurement over full calorimeter coverage:
360^0 in φ, $|\eta| < 5$,
~ 200'000 cells

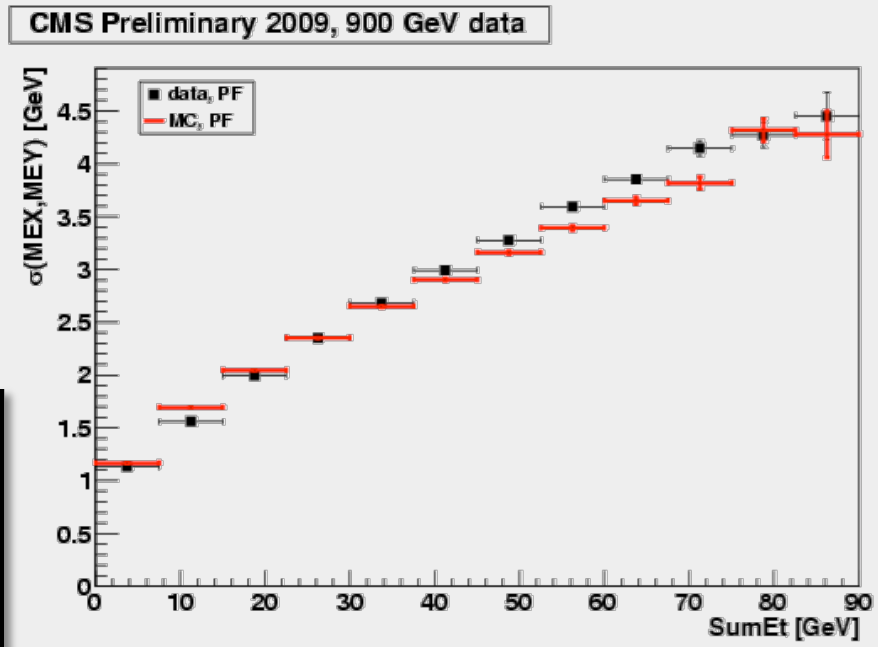
METx / METy indicate x/y components of missing E_T vector

First collision data: Missing E_T & particle flow

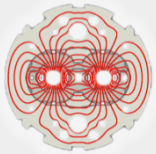








First collision data: summary



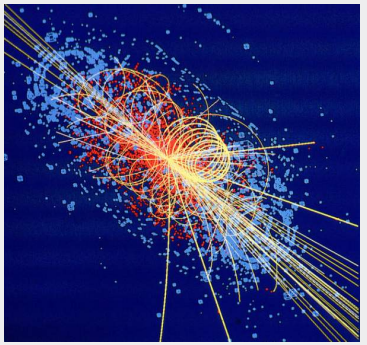
- Excellent performance of Collider:
  Highest p-p collisions ever produced

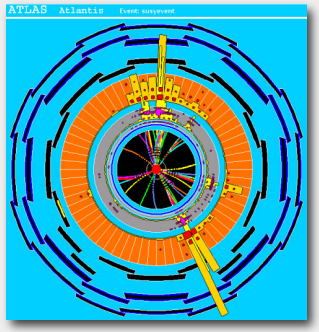
- Excellent readiness of experiments:
  High data taking efficiency, fast turn-around for results

- Impressive information already provided at the 18 December 2009 meeting at CERN
  (LHC stopped on 16 Dec)

- Collaborations preparing publications on first collisions observed at $\sqrt{s}$ = 0.9 TeV and 2.36 TeV

LHC Physics: next step





> 10 pb^{-1}: Standard Model processes

measure jet and lepton rates, observe W, Z bosons,
first top quark observation in Europe,
first look at possible **extraordinary signatures…**
integrated Luminosity: e.g.: L=10^{32} cm^{-2}s^{-1}, 10^5 s ➔ 10 pb^{-1}

30 pb^{-1} Measure Standard Model Processes (at 10TeV need ~ 30pb^{-1}):

~ 10^4 Z → e^+e^- (golden Z's for detector studies (1%))
~ 10^5 W → eν
~ 10^3 ttbar (measure σ to 10%)

} Background for new physics
Need to understand very well

Initial Higgs searches and searches for physics beyond the SM

> 200 pb^{-1} Entering Higgs discovery era and explore large part of SUSY and new resonances at ~ few TeV

Objectives for LHC Physics

In 2010:

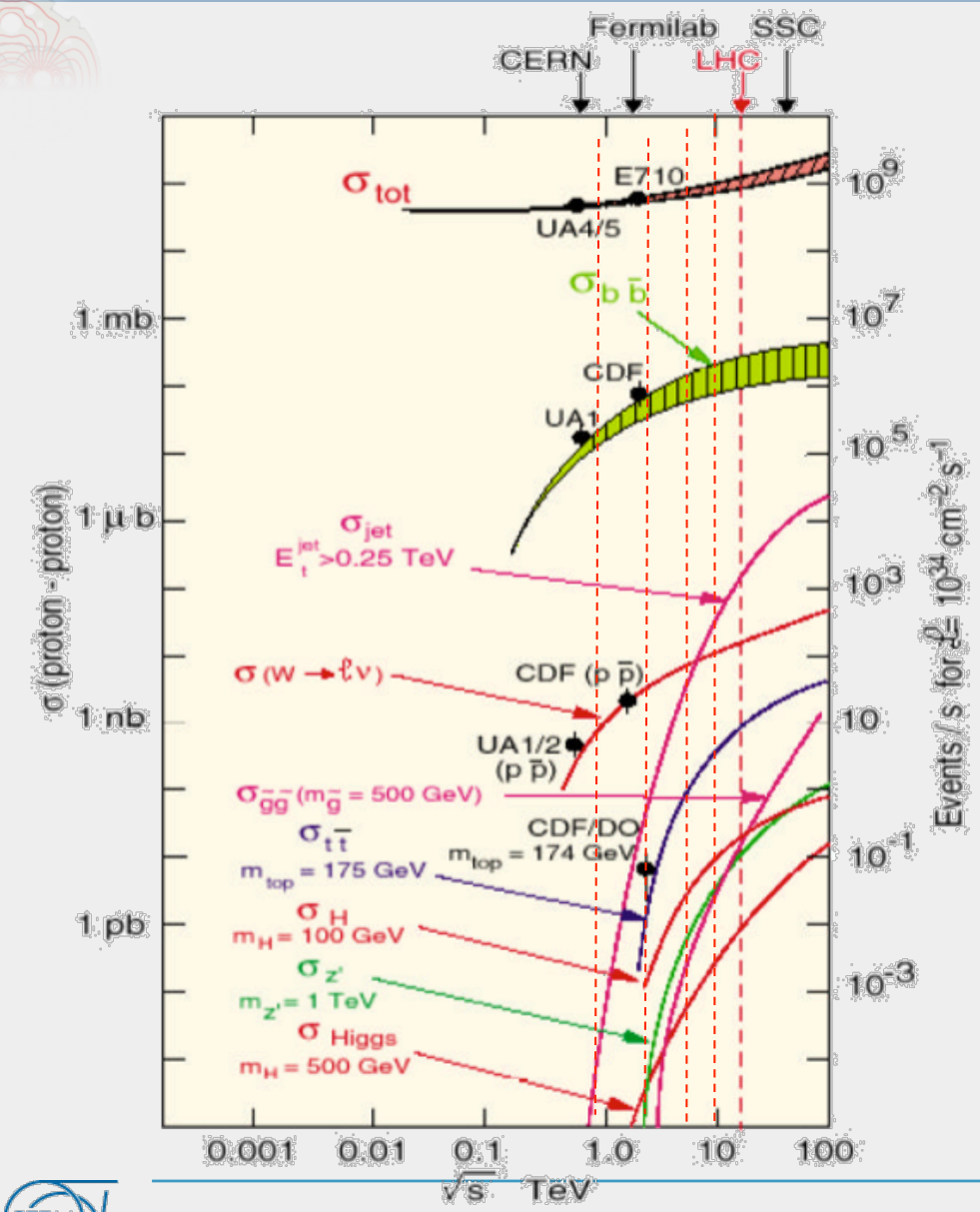
- LHC physics at E_{CM} = 7 TeV; higher energy will be decided during run; beam energy limit in 2010: E_{beam} = 5 TeV
- Towards end of year (2010) heavy ion run

Workshop in Chamonix end of January 2010

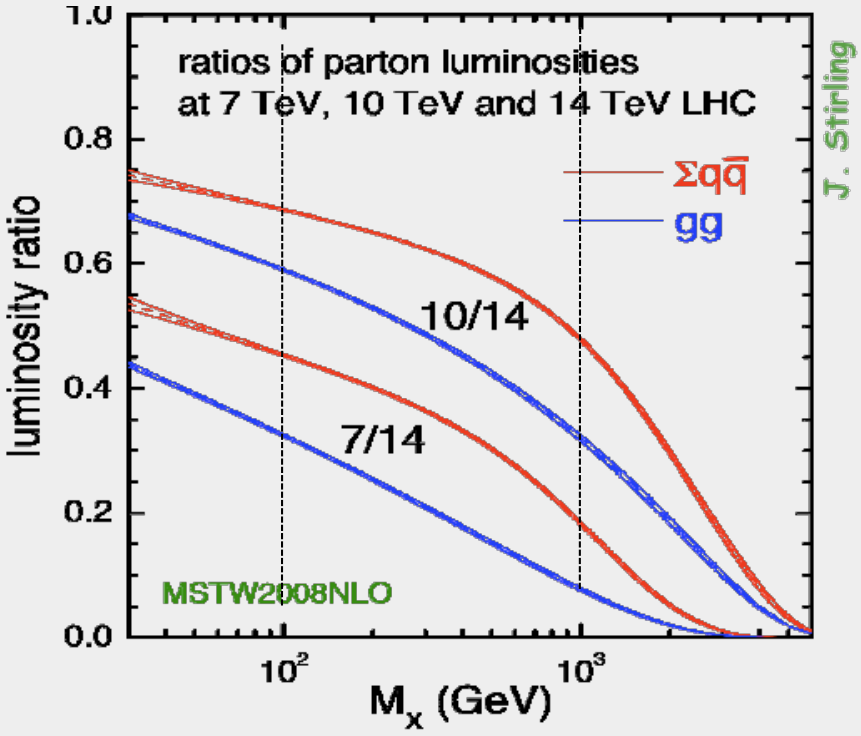
Beyond 2010

- LHC energy and luminosity increase
- Strategy: **maximize useable integrated luminosity for physics**
  - Key parameters: peak luminosity, luminosity lifetime, efficiency, pile-up , radiation dose, etc.
- Optimize running periods ➔ two years cycle

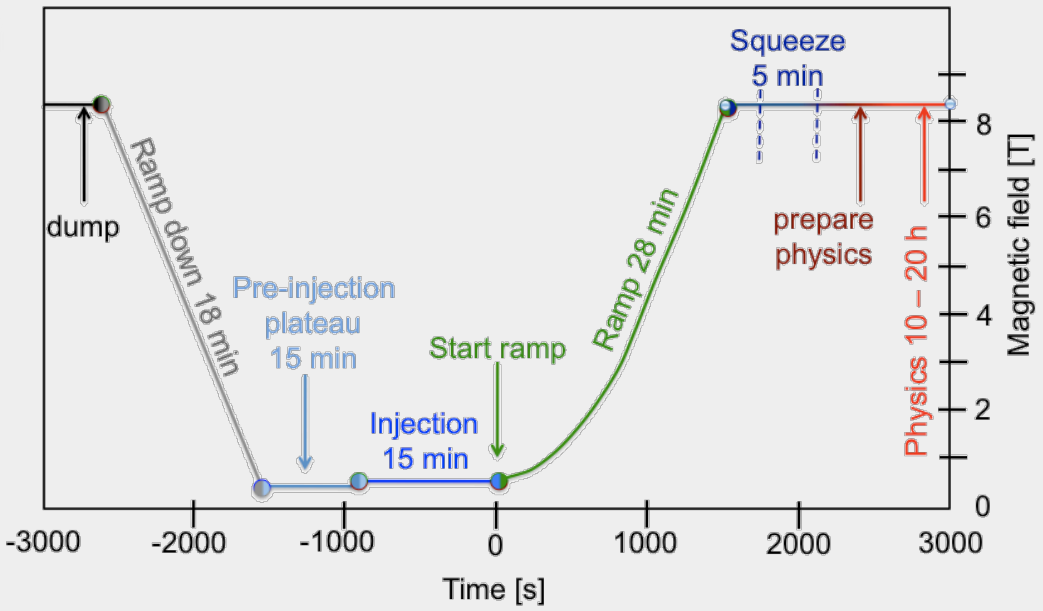
E_{CM} = .9 TeV → 2.36 → 7 → 10 → 14 TeV



Restart second half of February 2010



Objectives for LHC beyond 2010

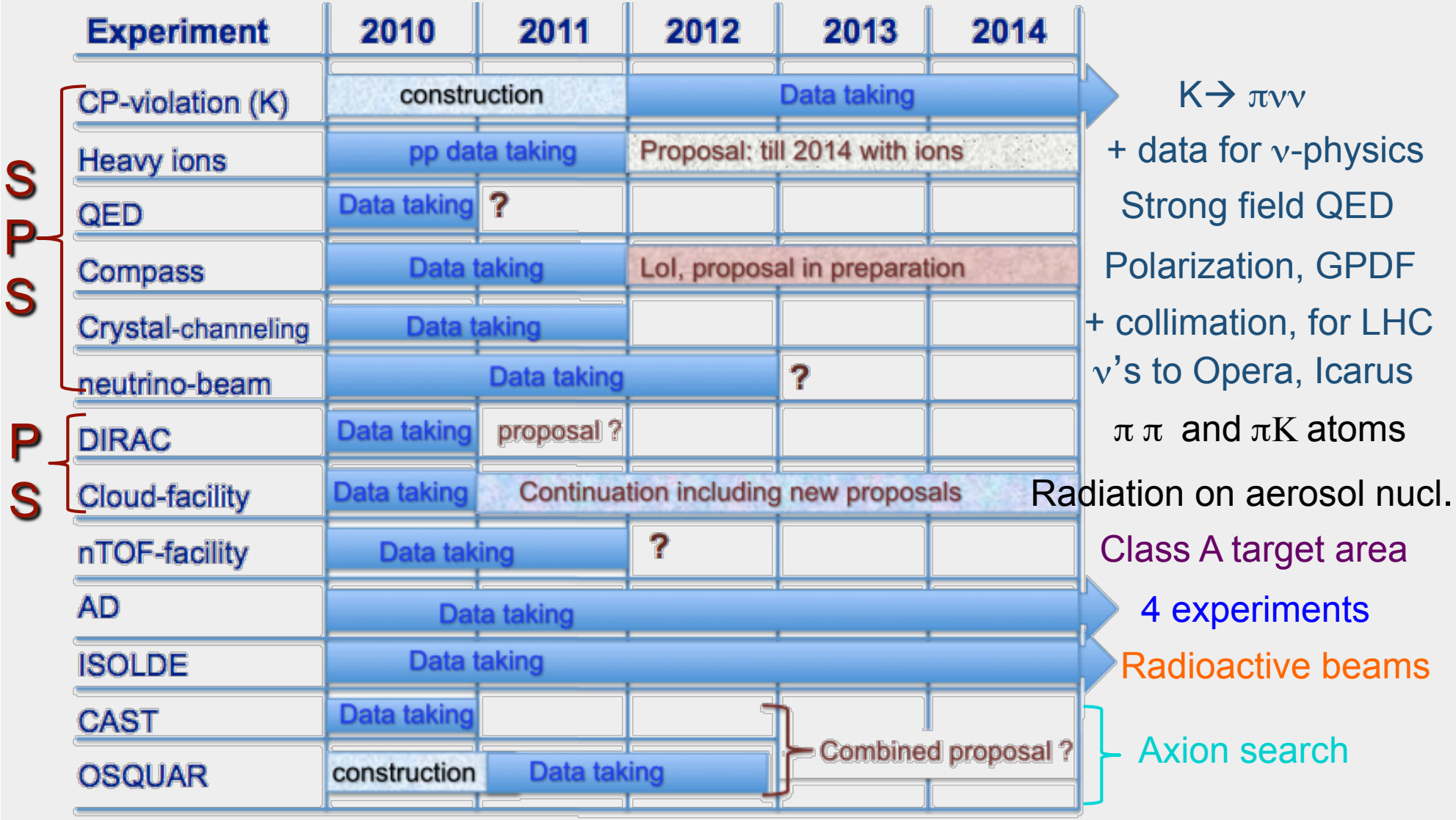


LHC (steady) operation: optimizing for physics

Workshop in Chamonix end of January 2010

- Expect **LHC operation** for at **least 15 years**
- **Upgrade Phase I:**
  - LINAC4 and Inner Triplet construction as foreseen, ready for earliest installation end 2014
- Upgrades for **beyond 2015:** several scenarios under discussion, **taking non-LHC programme into account**

Non-LHC Programme at CERN

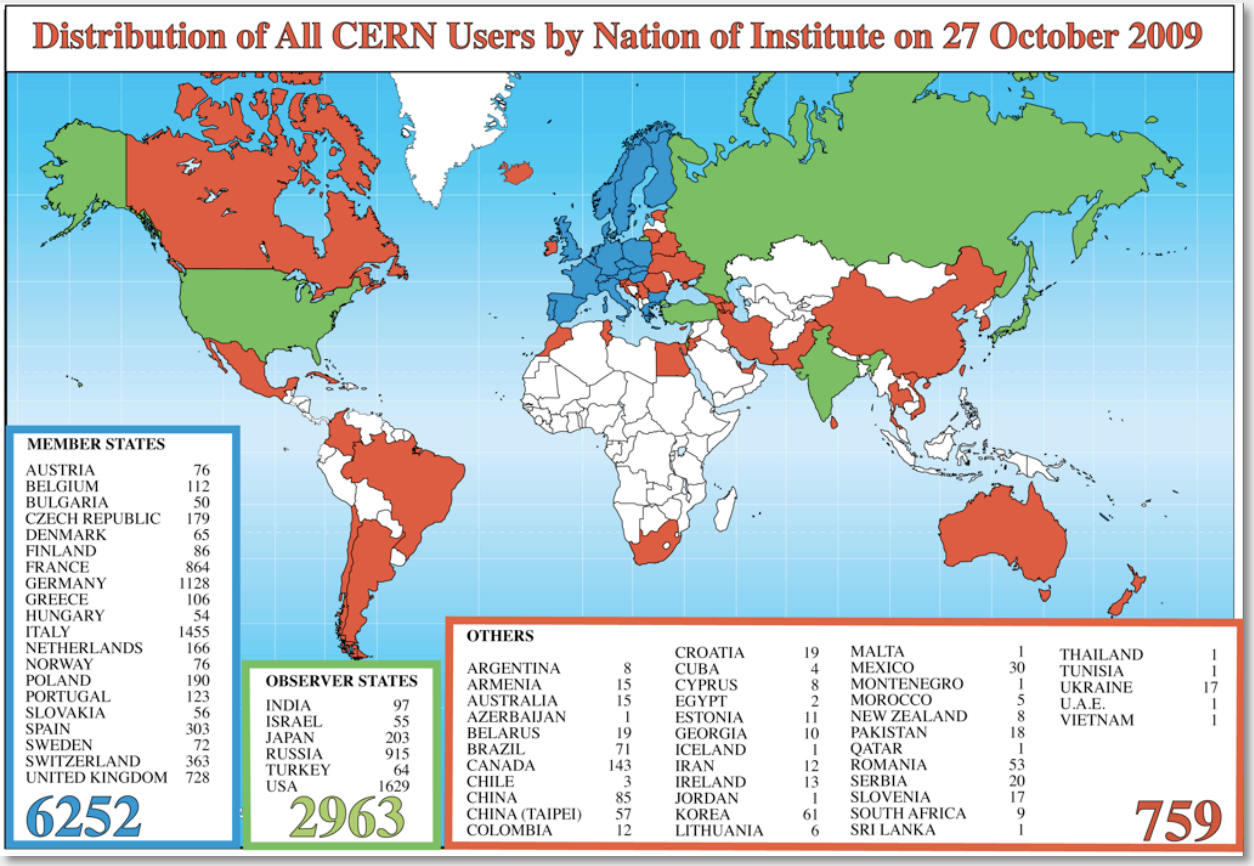


Strategy and Objectives for CERN

- **Full exploitation of physics potential offered by LHC:** LHC results will indicate the way to proceed at the **high-energy frontier**
- **Excellent non-LHC** accelerator based programme **beyond 2011:**
  - Outcome of strategy workshops decisive (FT, Neutrino)
- **Preparation for a Linear Collider:** CLIC study and increasing CLIC/ILC collaboration
- **Detector R&D** for energy frontier experiments (LHC/LC)
- Closer collaboration with Astroparticle physics

Important: International Collaboration

Future of High-Energy Frontier



CERN became a GLOBAL LABORATORY

Overall **increase** of CERN Users **since May 2001**: **~ 50%**

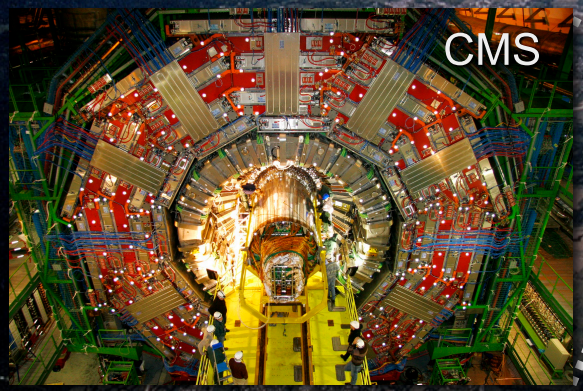
~30% Member States

~100% Observer States (India, Israel, Japan, Russia, Turkey, USA)

~ 125% Other States

} Due to LHC

Very exciting years are ahead of us



谢谢!