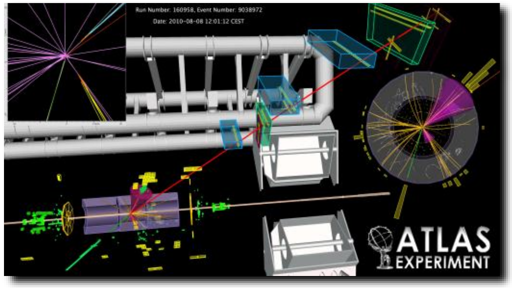
CERN
Status and Outlook

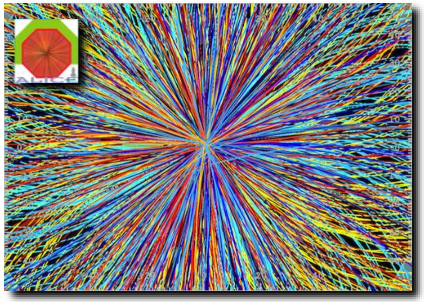
Astroparticle Roadmap
Paris, November 21, 2011
Sergio Bertolucci
Cern

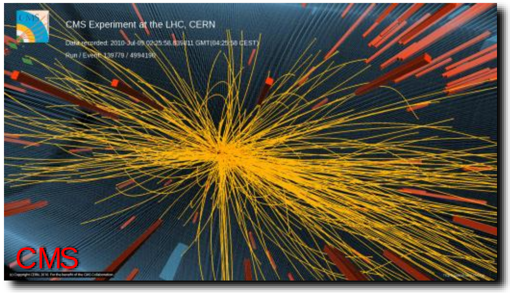
LHC: First collisions at 7 TeV on 30 March 2010

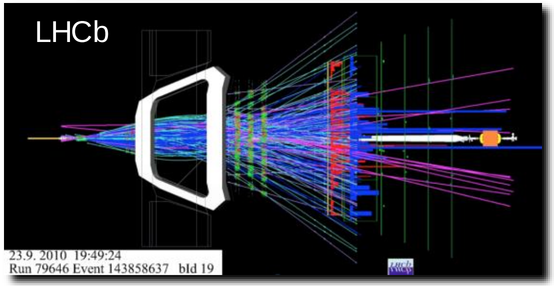
- LHC commissioning proceeding well beyond the most optimistic expectations, both in p-p an Pb-Pb modes.

- Experiments showed their readiness in exploiting the collected data with analyses proceeding very rapidly









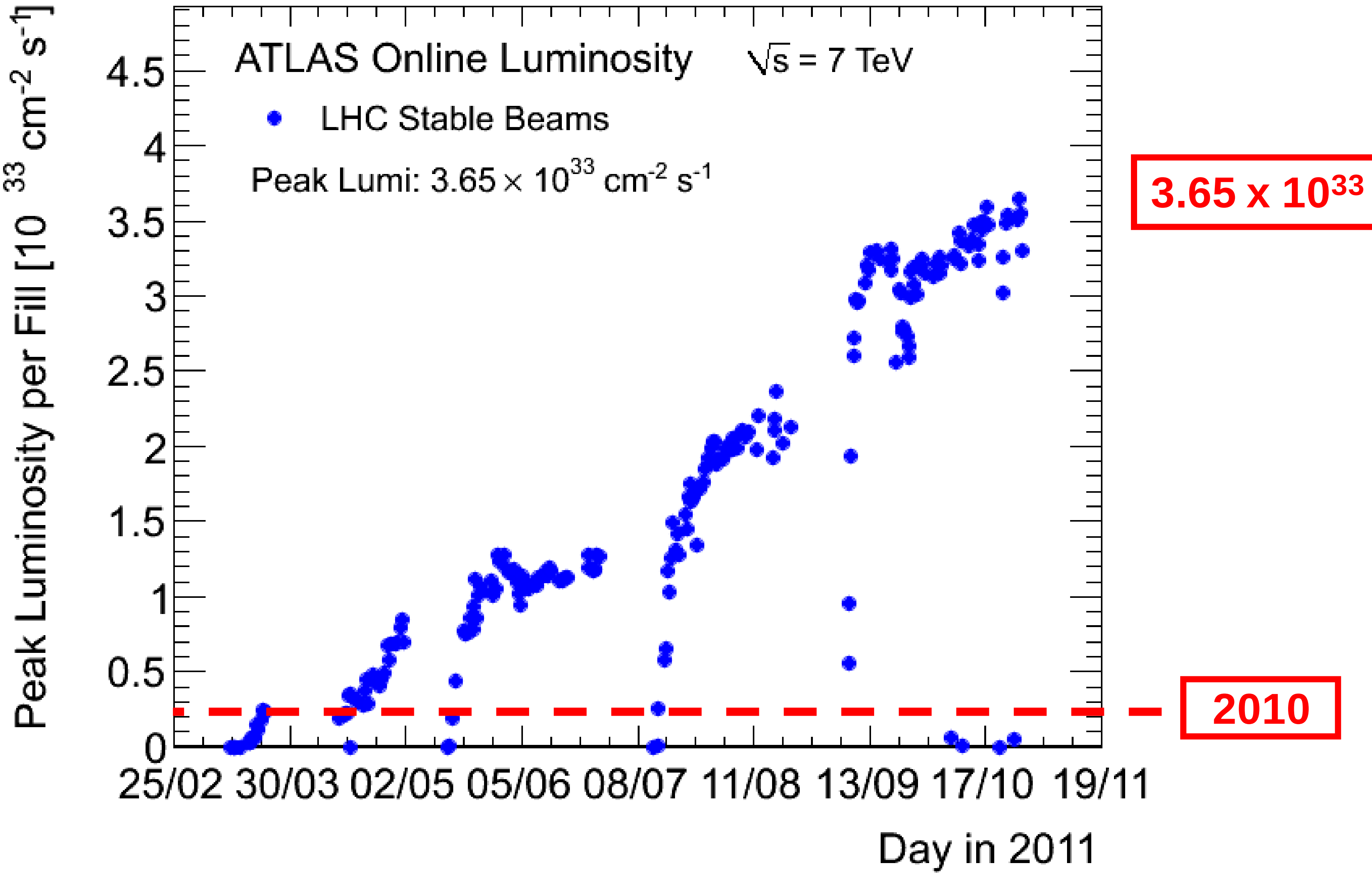
- Brilliant performances of the WLCG - a key factor in the spectacular startup

Good news from LHC commissioning 2010:

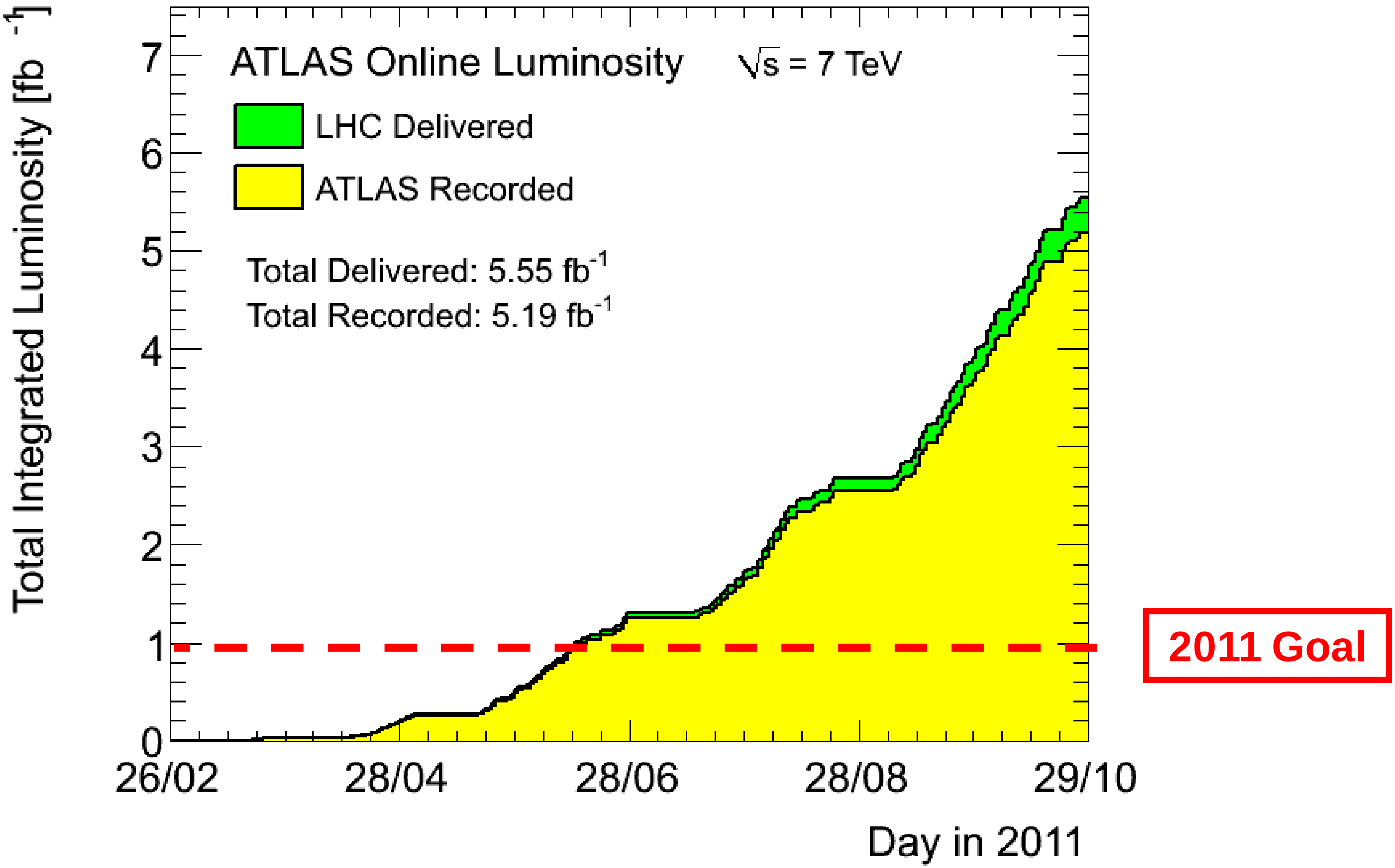
- Excellent single beam lifetime
- Ramp & squeeze essentially without loss
  - No quenches with beam above 450 GeV
  - Excellent performance of Machine Protection
- Optics close to model (and correctable)
- Excellent reproducibility
- Aperture bigger then expected
- Better than nominal from injectors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

And still going…

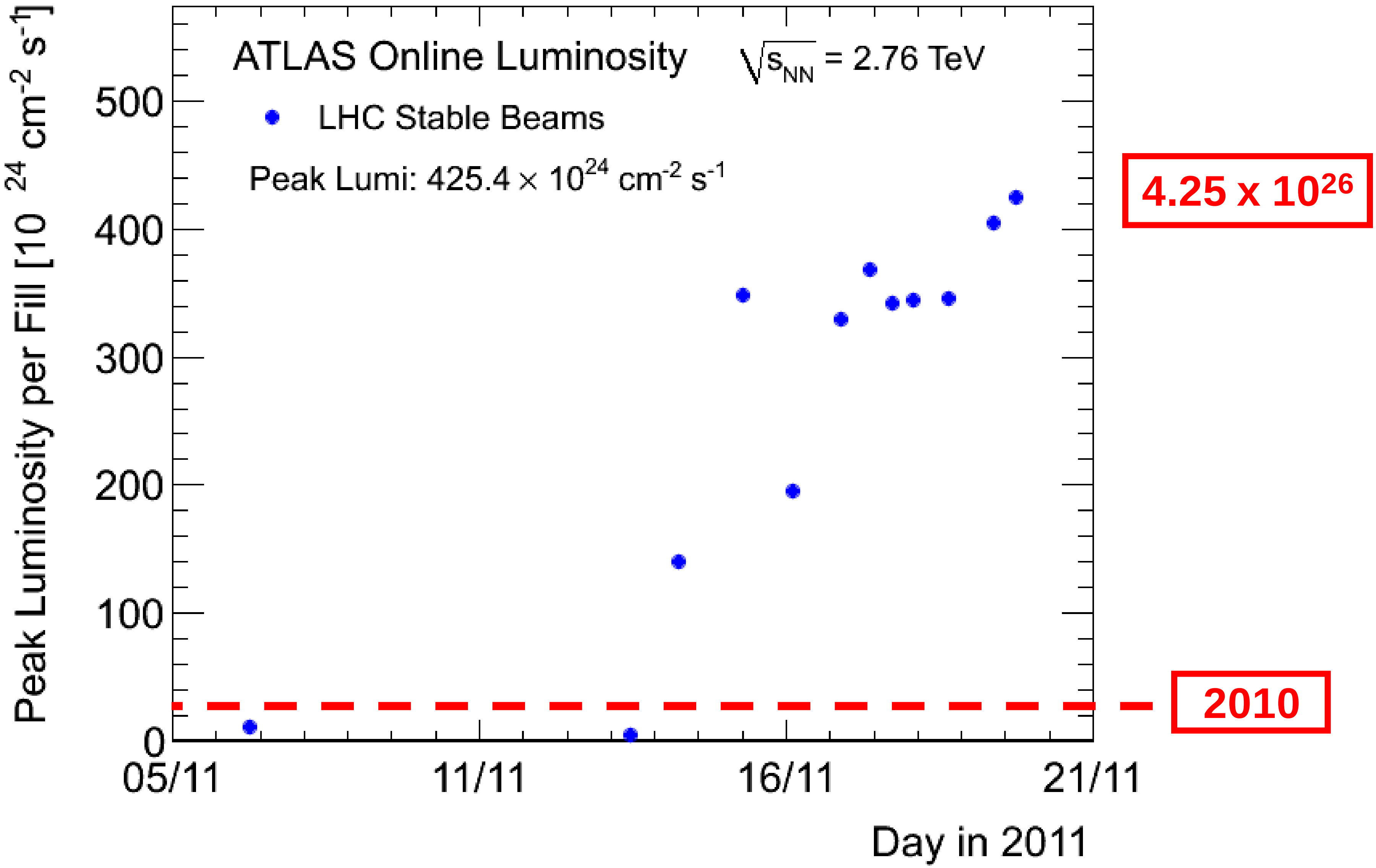
Peak luminosity 2011 - protons



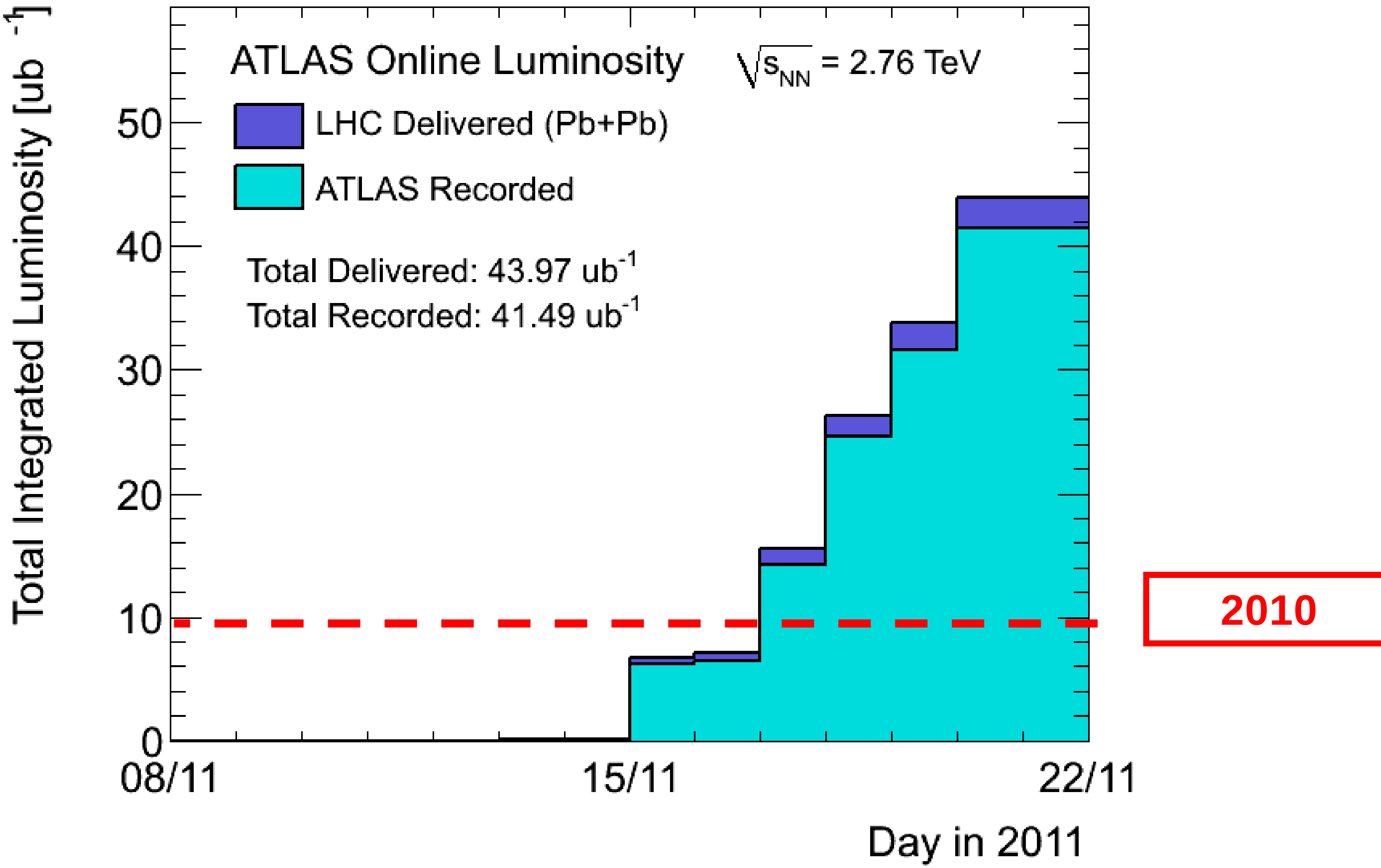
…and integrated luminosity 2011 - protons



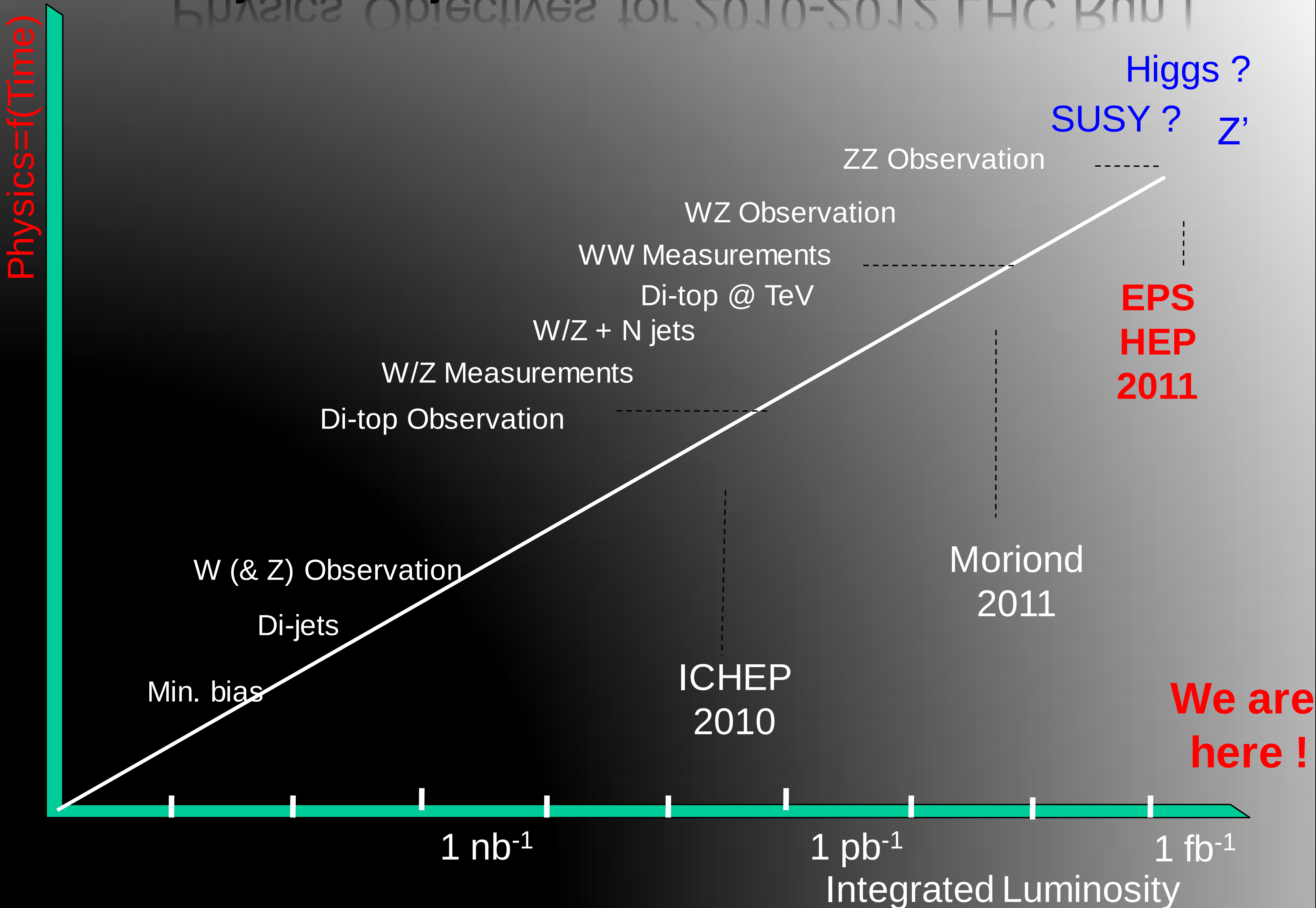
Peak luminosity 2011 – Pb ions

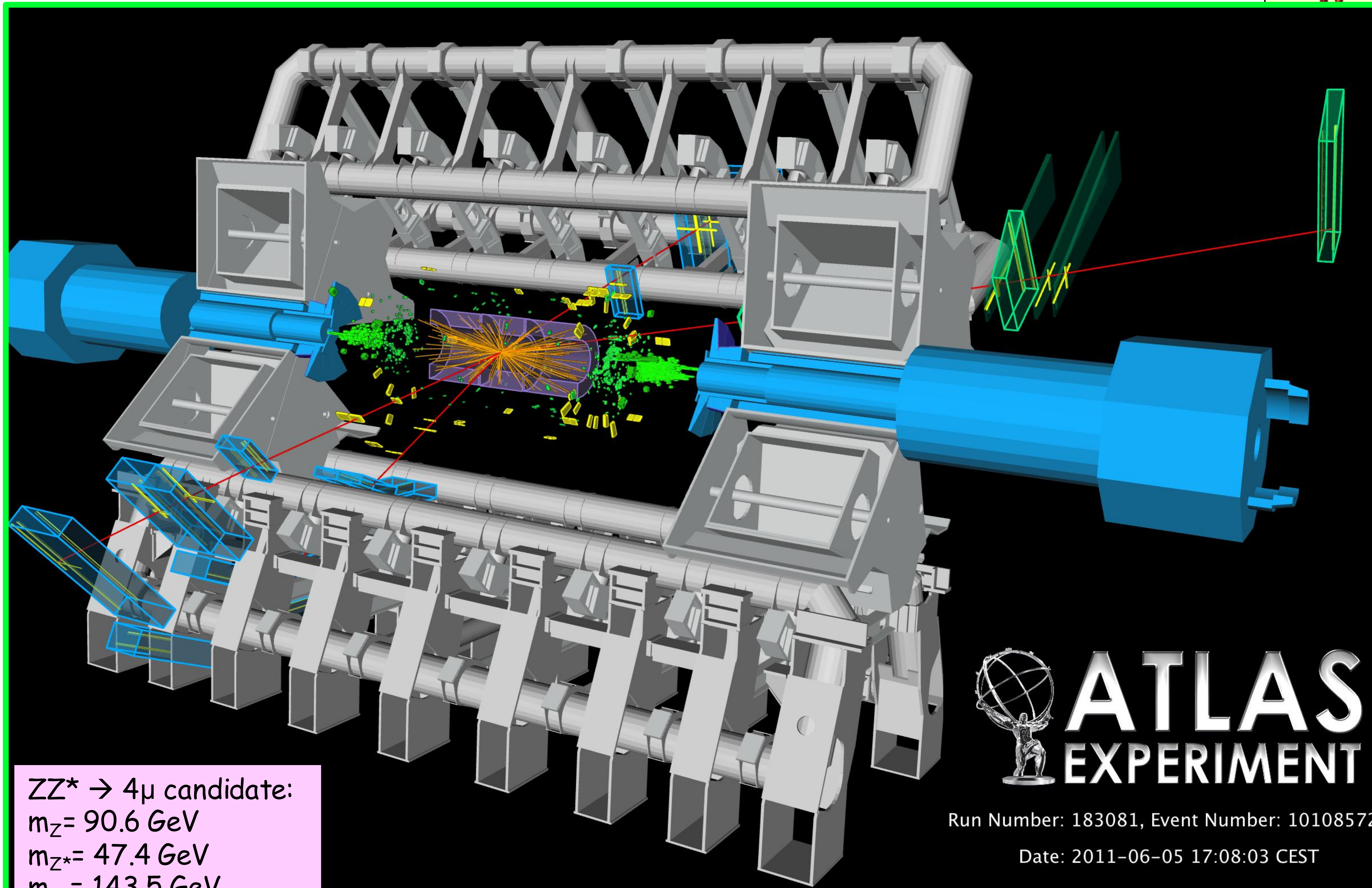


…and integrated luminosity 2011 – Pb ions



Physics Objectives for 2010-2012 LHC Run I





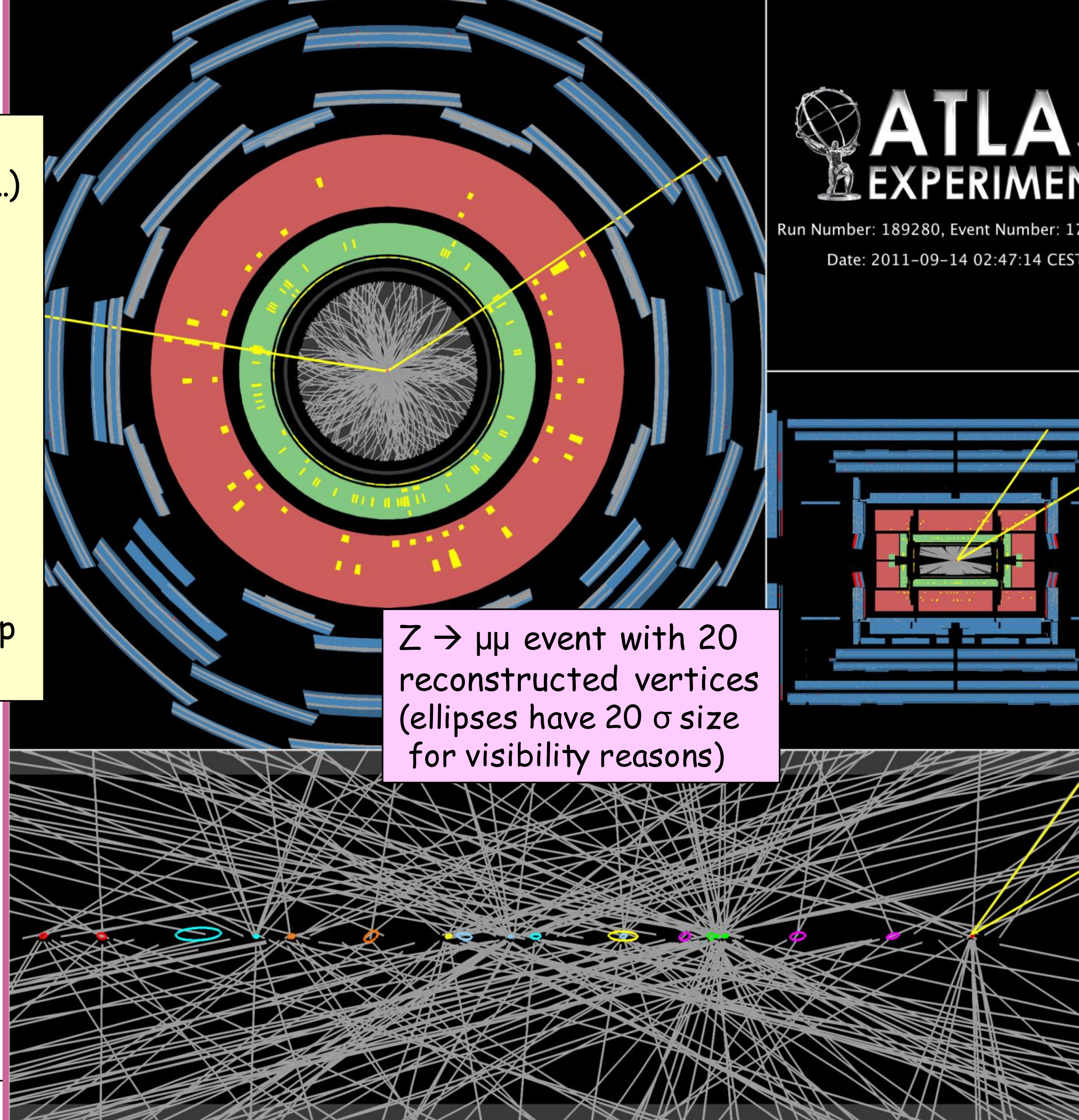
$ZZ^* \rightarrow 4\mu$ candidate:
m_Z= 90.6 GeV
m_{Z^*}= 47.4 GeV
$m_{4\mu}$= 143.5 GeV

Pile-up

Experiment (trigger, detector, reconstruction, ..) is coping well with larger than expected at this stage and increasing pile-up.

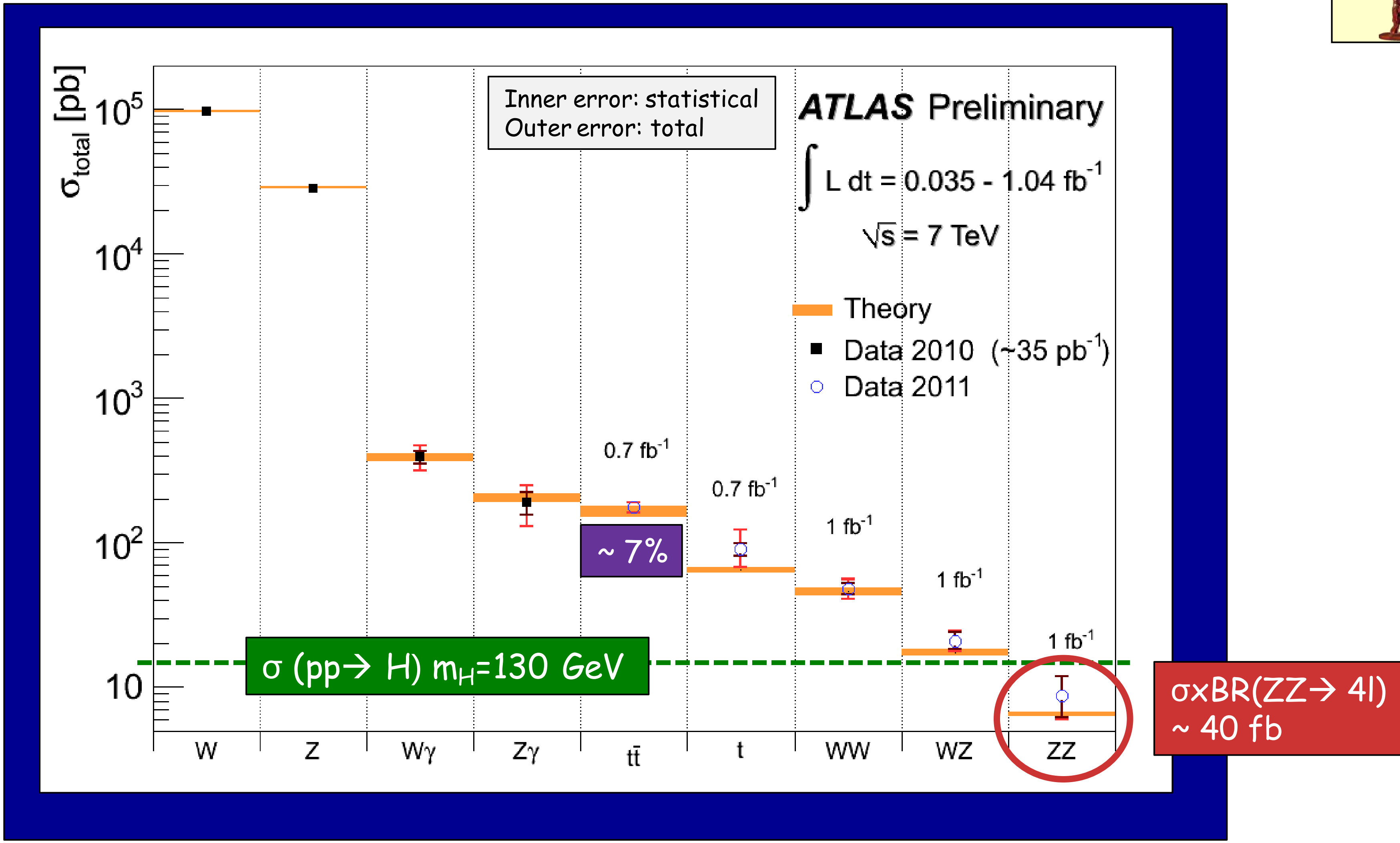
Today: average over a fill is ~12 interactions/x-ing (was ~ 6 in Spring), with tails up to ~20

Pile-up could increase by up to ~2 in 2012



Z → μμ event with 20 reconstructed vertices (ellipses have 20 σ size for visibility reasons)

Summary of main electroweak and top cross-section measurements

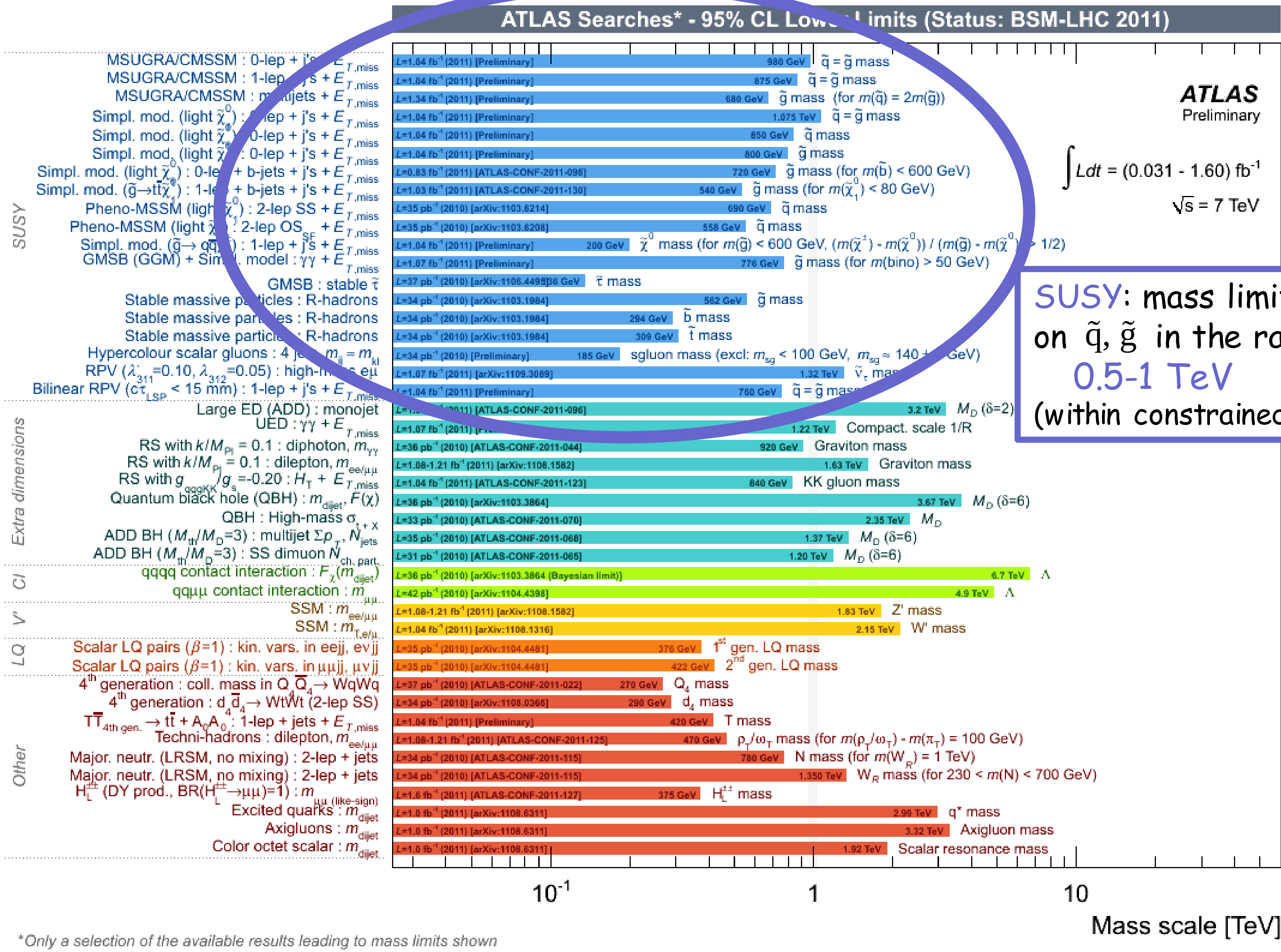


Good agreement with SM expectations (within present uncertainties)

Experimental precision starts to challenge theory for e.g. tt (background to most searches)

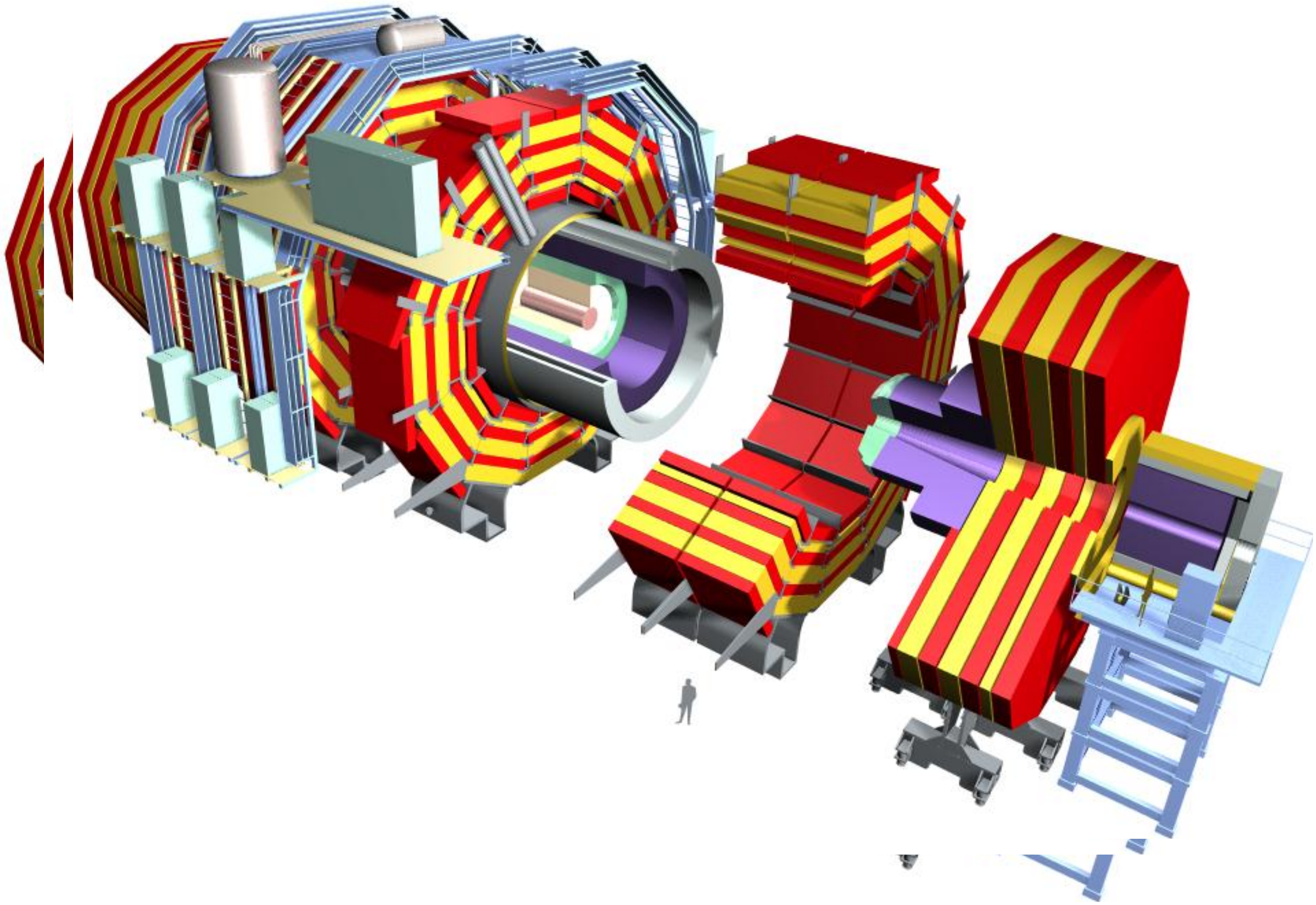
Measuring cross-sections down to few pb (~ 40 fb including leptonic branching ratios)

Results of main searches for New Physics

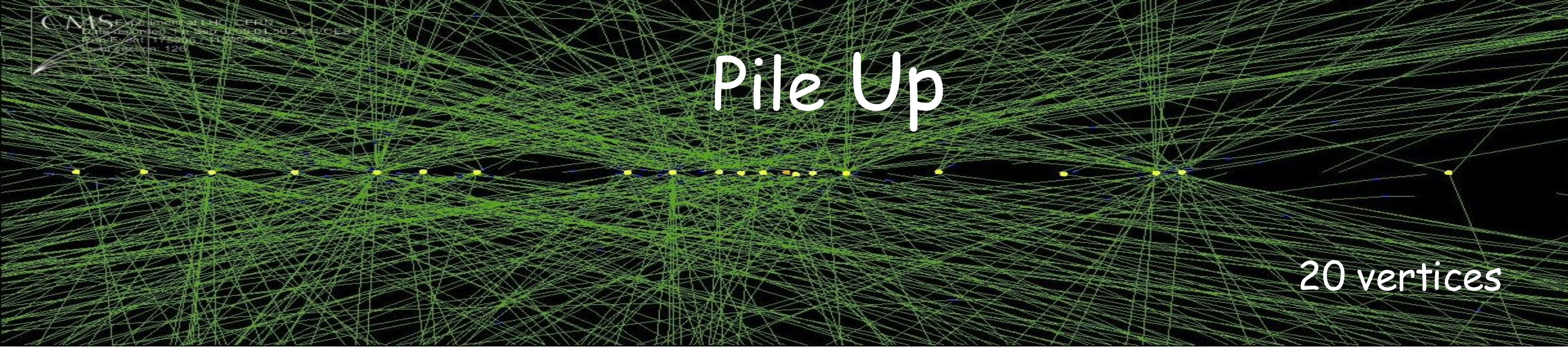


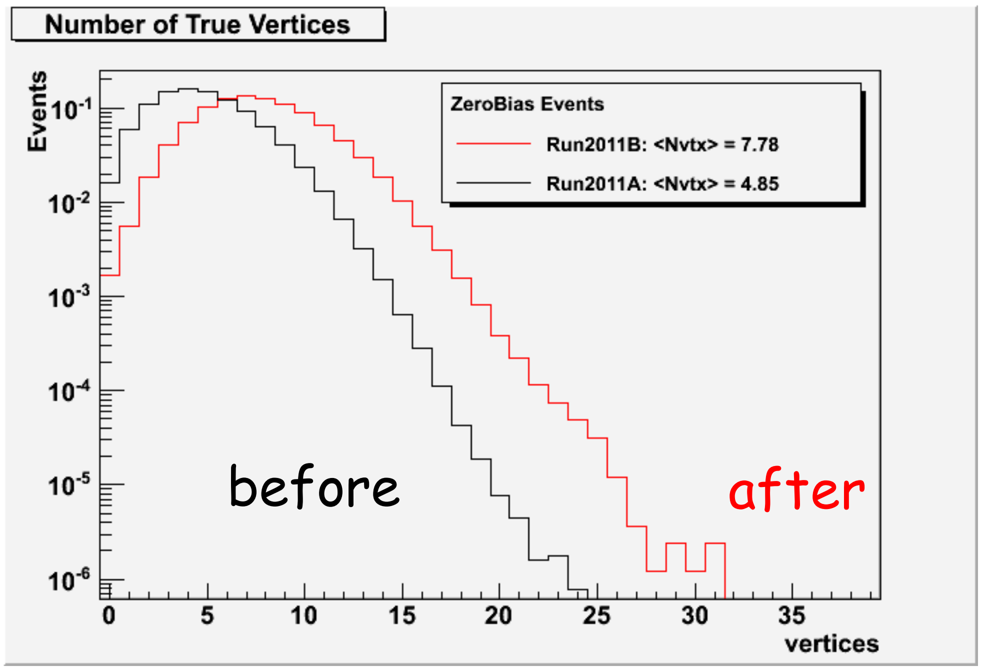
SUSY: mass limits on $\tilde{q}$, $\tilde{g}$ in the range **0.5-1 TeV** (within constrained models)

CMS



Pile Up





Averaged over fills.
$N_{rec} \sim 0.7 \times N_{pu}$

- The number of reconstructed vertices after the August Technical Stop increased by factor 1.5 (β^*=1.5m → 1m)
  - Fills start with ~15 pile-up interactions
  - Vertex reconstruction still quite linear with luminosity
- Total inelastic cross section also has been measured from pile-up
  - σ_{inel}(pp)= 68.0 ± 2.0 (Syst) ± 2.4 (Lum) ± 4 (Extrap.) mb.

Di-bosons: WW, WZ, ZZ.

With 2011 data updated measurement of the W^+W^- cross section and first measurements of the WZ, ZZ production cross sections at 7TeV.

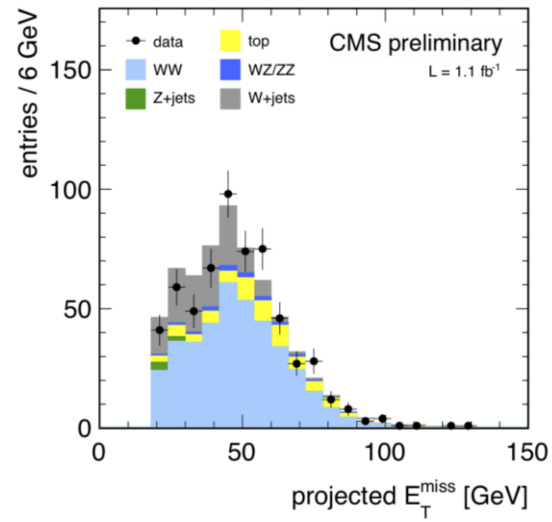
$\sigma(pp \rightarrow W^+W^- + X)$ = σ(NLO)=43±2pb
6.9 (syst.) ± 3.3 (lumi.) pb.

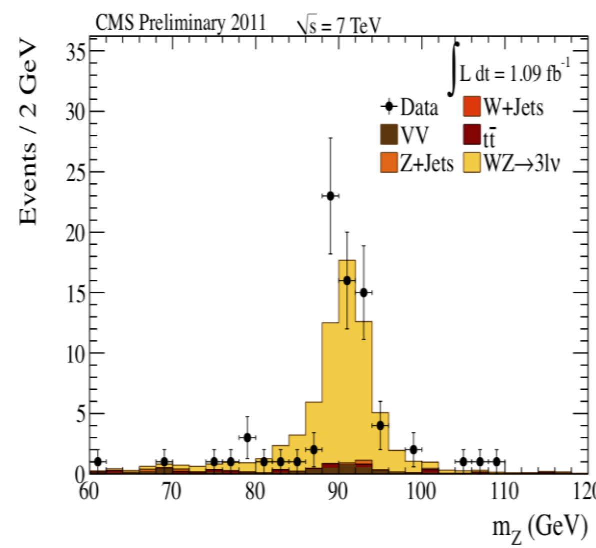
$\sigma(pp \rightarrow WZ + X)$ = 17 σ(NLO)=19.8±0.1pb
(syst.) ± 1.0 (lumi.) pb.

$\sigma(pp \rightarrow ZZ + X)$ = 3.8 σ(NLO)=6.4±0.6pb
(syst.) ± 0.2 (lumi.) pb.

All measured values are consistent with the standard model predictions.

Data driven methods are used to understand the background.

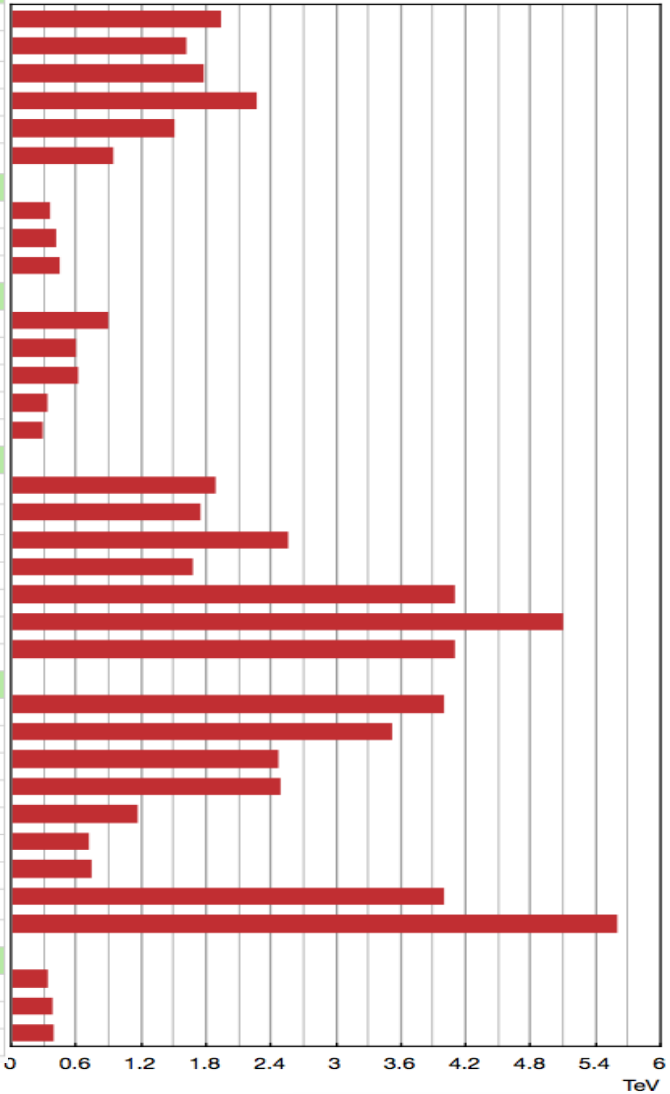




CMS PAS EWK-11-010

Summary of the searches in EXO

	Limits in TeV	
	Heavy Bosons	
Z'_{SSM} ll	1.94	2011
Z'_{Ψ} ll	1.62	2011
G_{KK} ll k/M = 0.1	1.78	2011
W' lv	2.27	2011
W' dijet	1.51	2011
G_{KK} $\gamma\gamma$ k/M = 0.1 (2010)	0.945	2010
	4th Generation	
$M_{b'}$, b' ⇒ tW (2010)	0.361	2010
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011
	Heavy Stable Particles	
M_{gluino}, HSCP	0.899	2011
M_{gluino}, Stopped Gluino	0.601	2011
M_{stop}, HSCP	0.620	2011
M_{stop}, Stopped Gluino	0.337	2011
M_{stau}, HSCP	0.293	2011
	Large Extra Dimensions	
M_s, $\gamma\gamma$, GRW (2010)	1.89	2010
M_s, $\mu\mu$, GRW (2010)	1.75	2010
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011
	Compositeness and Contact Interactions	
String Resonances	4.0	2011
E_6 diquarks	3.52	2011
Axigluon/Coloron	2.47	2011
q* , dijet	2.49	2011
q* , boosted Z	1.17	2010
e*, Λ = 2 TeV	0.720	2010
μ*, Λ = 2 TeV	0.745	2010
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010
C.I. Λ , X analysis	5.6	2010
	LeptoQuark	
LQ1, β=0.5 (2010)	0.340	2010
LQ1, β=1.0 (2010)	0.384	2010
LQ2, β=1.0 (2010)	0.394	2010



H Bachacou

Oversimplified summary

Unfortunately, no hint of New Physics in the LHC data (yet)

	Lower Limit (95% C.L.)
SUSY ($m_{\tilde{q}} = m_{\tilde{g}}$)	1 TeV
Gauge bosons (SSM)	2 TeV
Excited quark	3 TeV

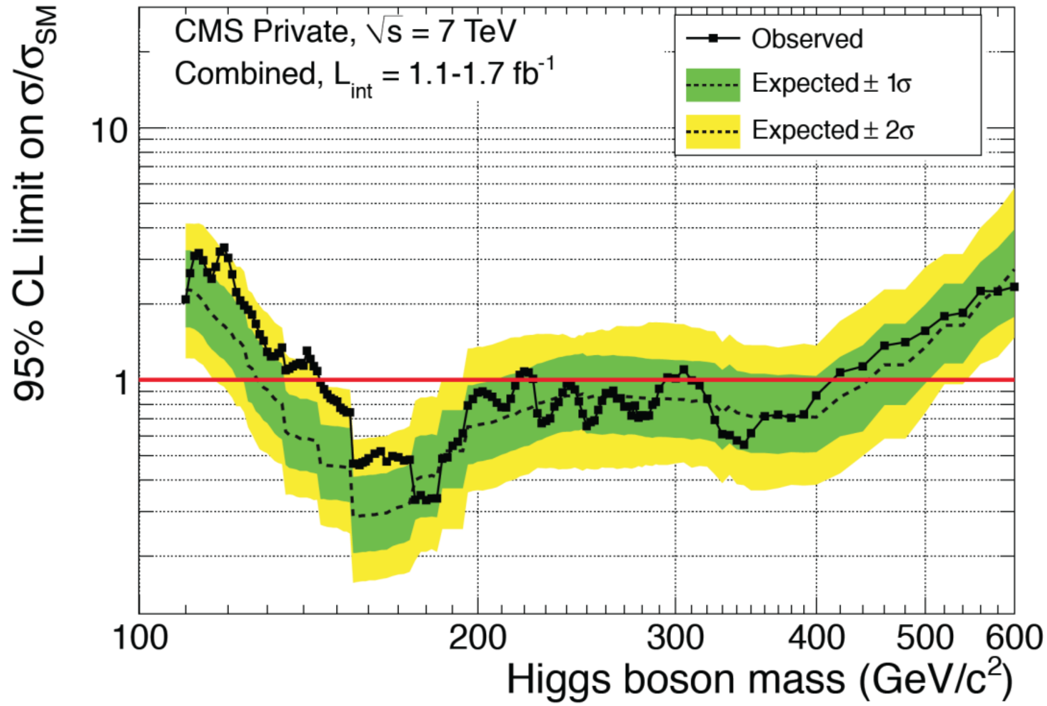
Principal goal for the 2011-2012 run:

Settle the question of the SM Higgs

The Search for the SM Higgs Boson

With $5fb^{-1}$ and the combination of the two major LHC experiments the discovery reach is almost everywhere in the range from 114 to 600GeV.

Alternatively, we could start ruling out the SM Higgs.

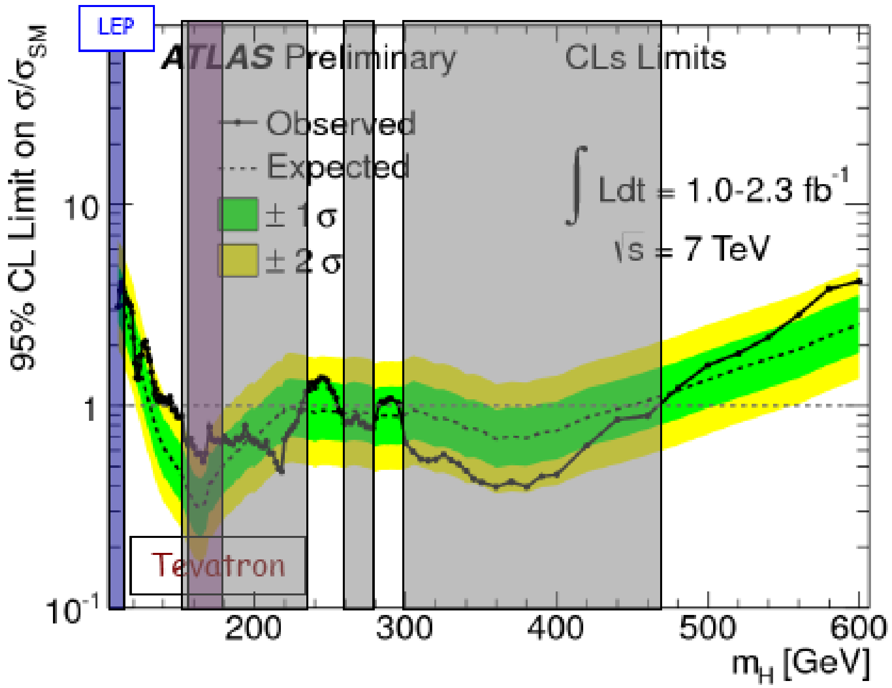


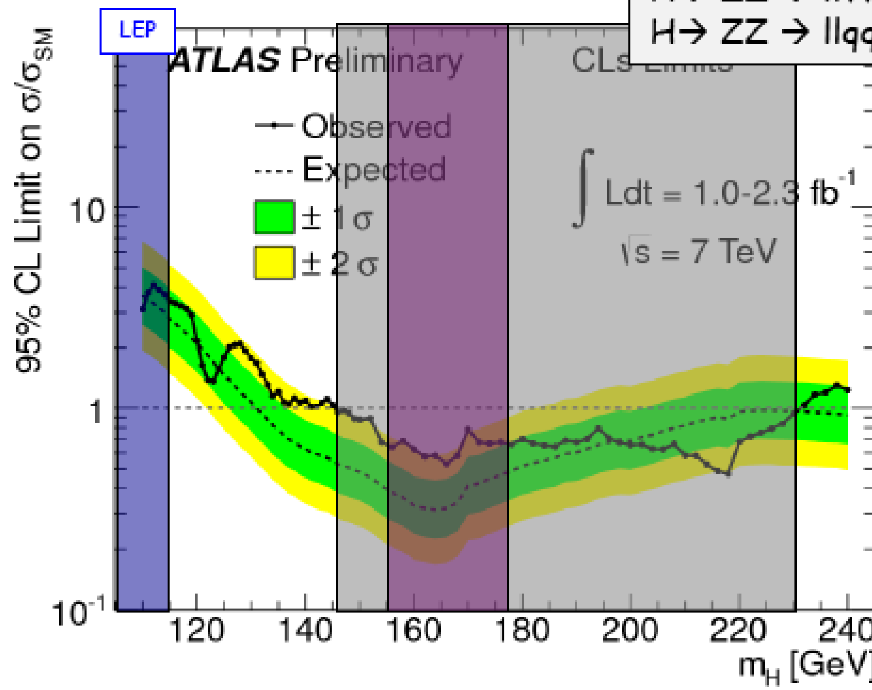
PAS HIG-11-022

SM Higgs Search Prospects (Mass in GeV)			
ATLAS + 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

All channels together → combined constraints

- H→γγ
- H→ ττ
- W/ZH→ lbb+X
- H→ WW(*)→ lνlν
- H→ ZZ(*) → 4l
- H→ ZZ → llνν
- H→ ZZ → llqq





Excluded by ATLAS at 95% CL : 146-466 GeV, except 232-256, 282-296 GeV
Expected if no signal at 95% CL : 131-447 GeV

- LHC provides first direct exclusion (95% CL) of a large mass range until now unexplored
- The best-motivated low-mass region (EW fit: m_H < 161 GeV 95% CL) still open to exploration
- Data are within ±2σ of expectation for no signal over full m_H range → no significant excess

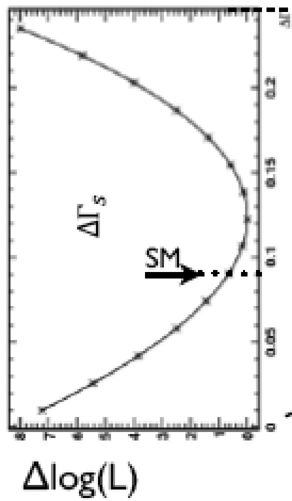
…not only searches

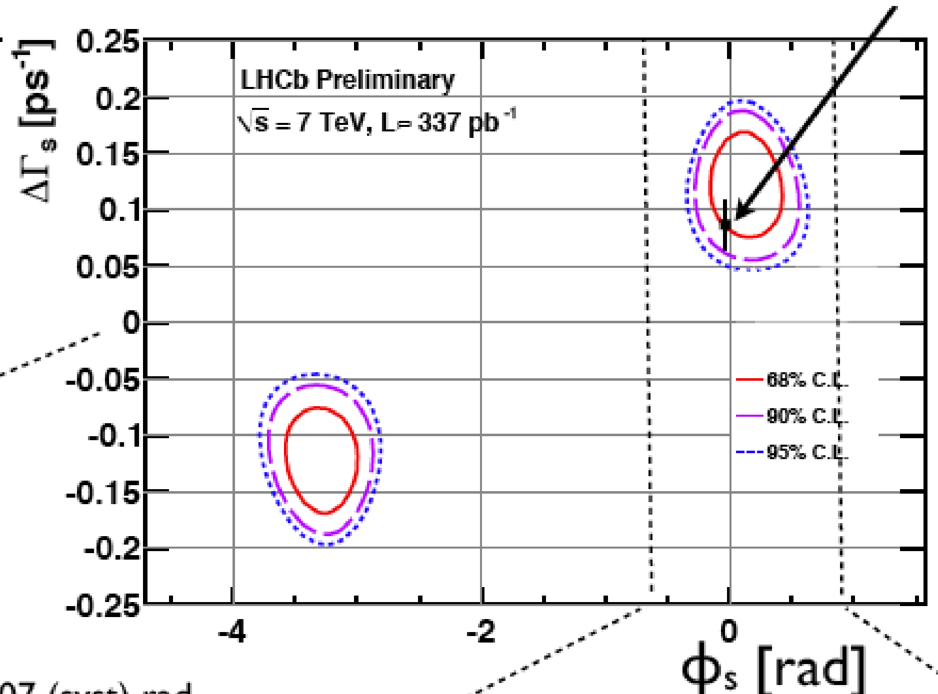
- LHCb results show exciting prospects for 2012

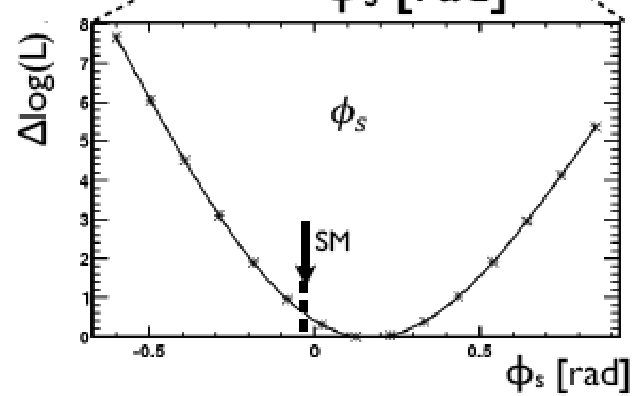
G Raven

LHCb result for $B_s \rightarrow J/\Psi\Phi$

LHCb-CONF-2011-49







Most precise measurement of ϕ_s

- $\phi_s = 0.13 \pm 0.18$ (stat) ± 0.07 (syst) rad
- Consistent with SM

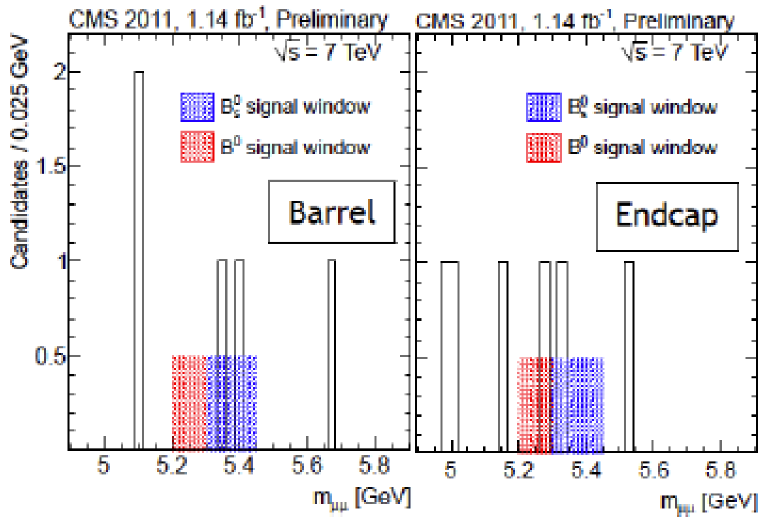
4 σ Evidence for $\Delta\Gamma_s \neq 0$:

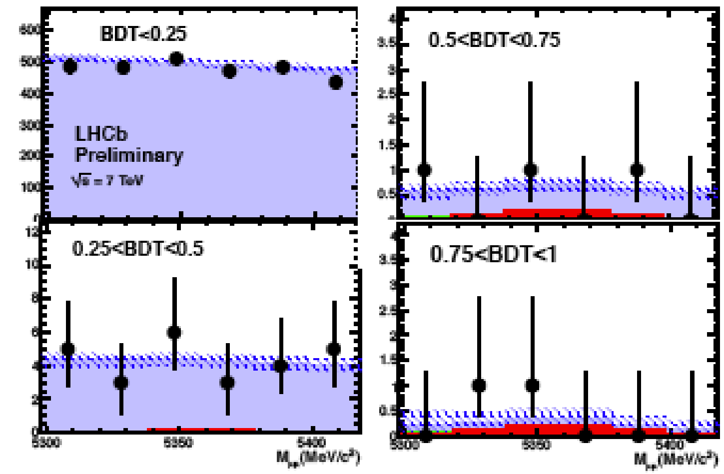
- $\Delta\Gamma s = 0.123 \pm 0.029$ (stat) ± 0.008 (syst) ps^{-1}
- $\Gamma_s = 0.656 \pm 0.009$ (stat) ± 0.008 (syst) ps^{-1}

CMS+LHC*b*: Combined $B_s \to \mu\mu$ Limit

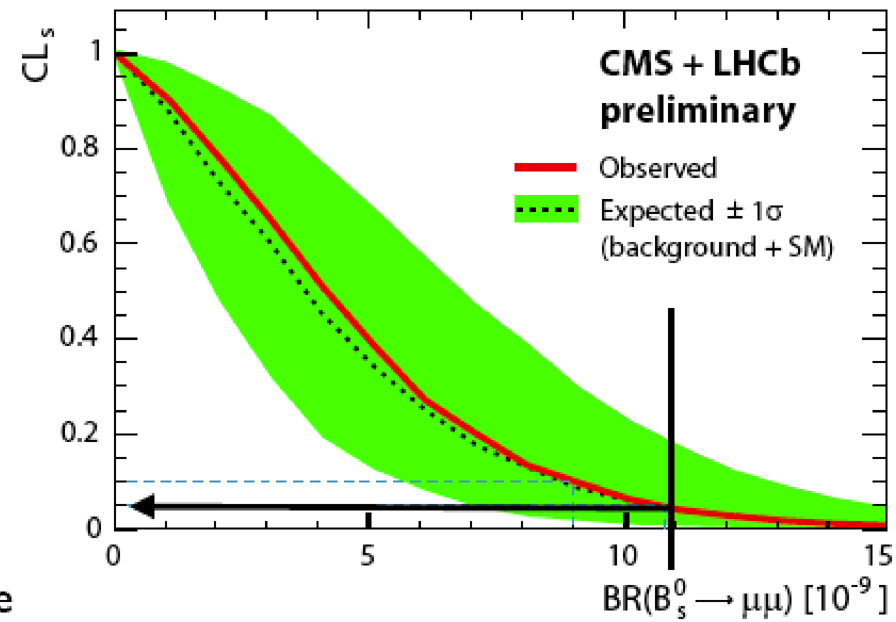
G Raven

LHCb-CONF-2011-047 = CMS-PAS-BPH-11-019





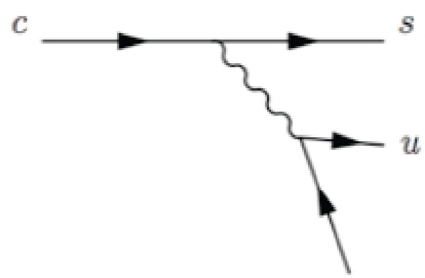
- Use $(f_s/f_d)_{LHCb} = 0.267^{+0.021}_{-0.020}$
- p-value background only: 8%
- p-value background + SM BR: 55%
- $Br(B_s \to \mu\mu) < 11 \times 10^{-9}$ @ 95% CL
- Given that the 95% CL is still 3.4 x SM, there remains plenty of room for NP, keep an eye in the near future!



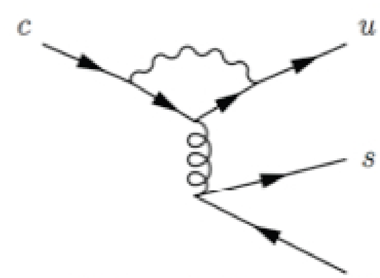
< 11x10^{-9} @ 95% CL

Direct CP Violation in the Charm Sector

M. Charles



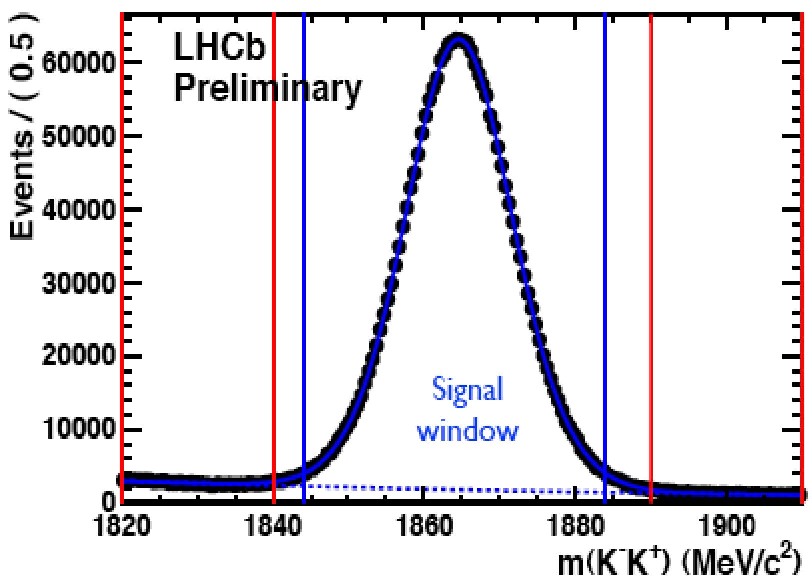
(a) *Tree diagram.*

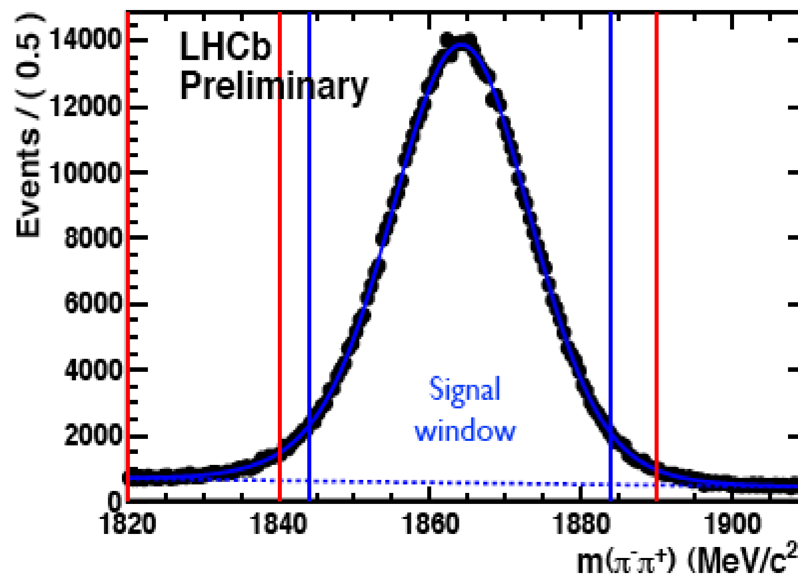


(b) *Penguin diagram.*

difference between $A_{CP}(D^0 \to K^+K^-)$, $A_{CP}(D^0 \to \pi^+\pi^-)$

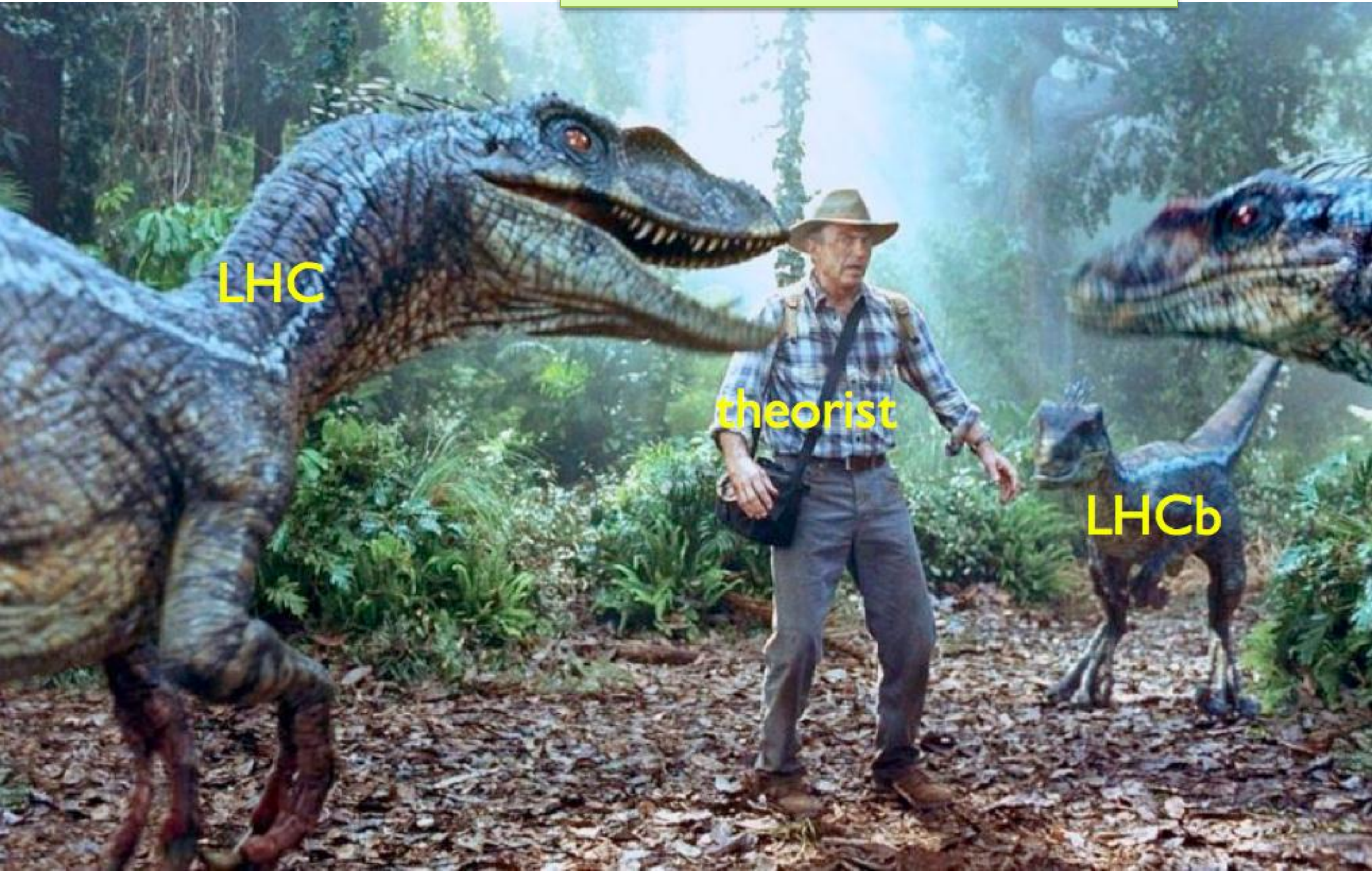
Showing D^0 candidate mass for D^{*+} candidates within $0<\delta m<15$ MeV/c²; $\delta m = m(D^0\,\pi^+) - m(D^0) - m(\pi^+)$





$$\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$

LHC and Theory…



The predictable future: 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, … ?

…and the corresponding experiments timeline

LHC schedule harmonized/agreed with the experiments

- Consolidation/incremental upgrades in 2012-2013, getting more substantial in 2017/2018 (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!

Without forgetting that CERN is not only LHC…..

Cern now and in the next 5-10 years

from the conclusions of SPSC and INTC chairs

High Energy Frontier
LHC

Hadronic Matter
deconfinement
hadron structure
non-perturbative QCD

Neutrino Oscillations

Low Energy
heavy flavours
rare decays
antiprotons

Non- Accelerator
Axions

Multidisciplinary
climate, medecine, …

n-ToF
s-processes, cross sections, fission, neutron-neutron int. high brightness

ISOLDE
isotopes He to Ra
10^{-6}eV – 3MeV/u
shell evolution, shapes, exotic nucl.,tests of SM

2011-2013: deciding years….

Experimental data will take the floor to drive the field to the next steps:

- LHC and Tevatron results
- θ_{13} (T2K, DChooz, etc..)
- ν masses (Cuore, Gerda, Nemo…)
- Dark Matter searches
- ….
- ...not to talk about the **speedy** ν!

Next decades

Road beyond Standard Model

At the energy frontier through synergy of

hadron - h **iders** (LHC, HE-LHC?)

n - hadron colliders (LHeC ??)

lepton - lepton colliders (LC (ILC or CLIC) ?)

(μ-collider ???)

LHC results crucial for decisions at the energy frontier

HLLHC and HELHC

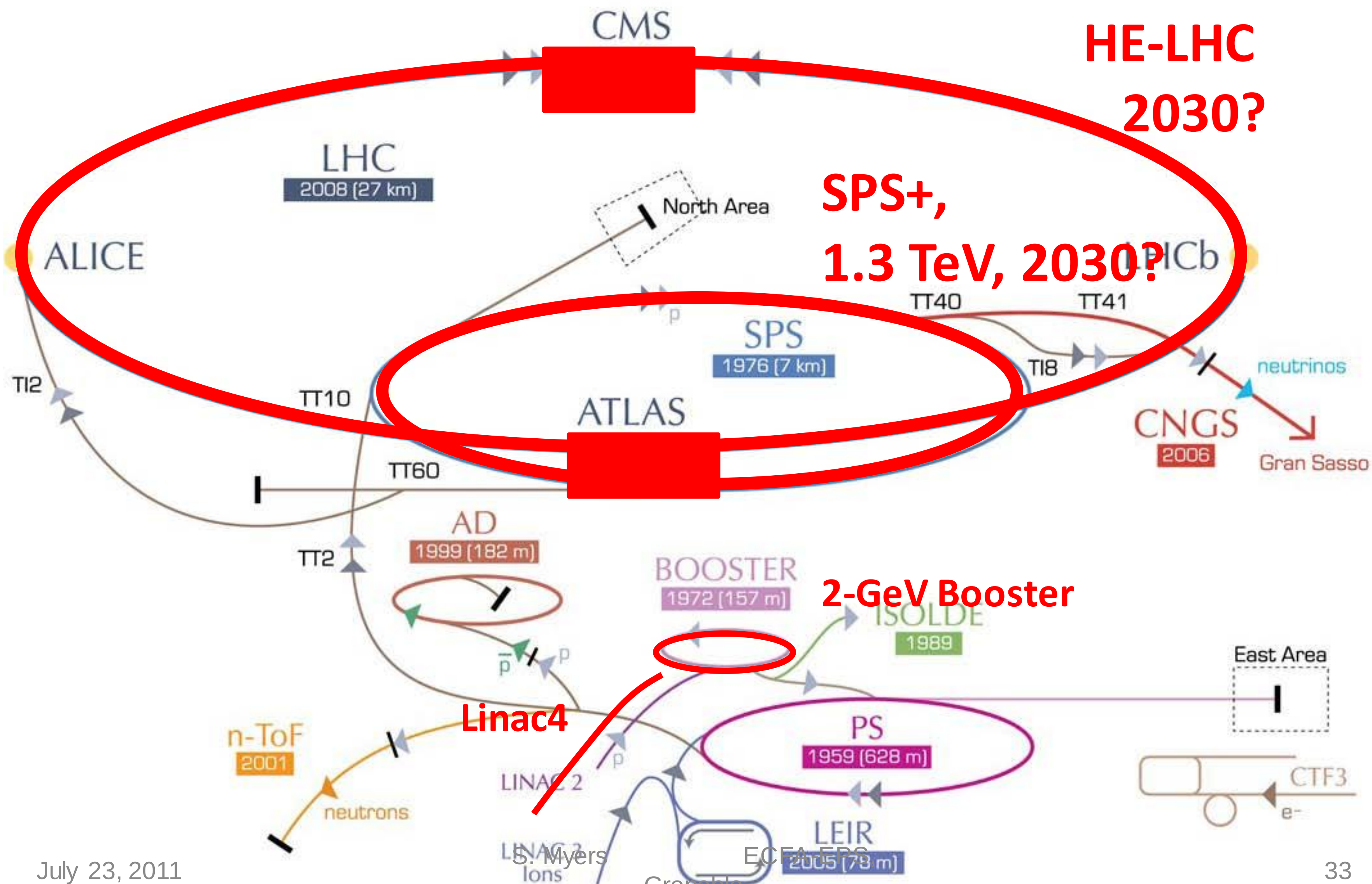
- High Luminosity LHC program in full swing

- High Energy LHC R&D started

Fri 18/11 — Print | Go back

09:00	**Welcome**	*MYERS, Steve*	*Main Auditorium, CERN*	09:00 - 09:10
	LHC physics results and long term perspectives	*MANGANO, Michelangelo*	*Main Auditorium, CERN*	09:10 - 09:35
	The CERN long term plan	*HEUER, Rolf*	*Main Auditorium, CERN*	09:35 - 10:00
10:00	**EU R&D for Accelerators**	*ALEKSAN, Roy*	*Main Auditorium, CERN*	10:00 - 10:25
	Coffee break		*Pas perdus - Not a meeting room -, CERN*	10:25 - 10:45
11:00	**The FP7-HiLumi Design Study and HL-LHC project**	*ROSSI, Lucio*	*Main Auditorium, CERN*	10:45 - 11:10
	The detector High Luminosity upgrade programme		*Main Auditorium, CERN*	11:10 - 11:35
	The USA contribution to HL-LHC	*STRAUSS, Bruce*	*Main Auditorium, CERN*	11:35 - 12:00
12:00	**The JP contribution to HL-LHC**	*YAMAMOTO, Akira*	*Main Auditorium, CERN*	12:00 - 12:25
13:00	**Lunch**		*Main Auditorium, CERN*	12:25 - 14:00
14:00	**Baseline scenario and options for 3000 fb-1**	*BRUNING, Oliver*	*Main Auditorium, CERN*	14:00 - 14:20
	IR Magnets	*TODESCO, Ezio*	*Main Auditorium, CERN*	14:20 - 14:40
	Crab Cavity	*JENSEN, Erk*	*Main Auditorium, CERN*	14:40 - 15:00
15:00	**Collimation**	*ASSMANN, Ralph Wolfgang*	*Main Auditorium, CERN*	15:00 - 15:20
	Cold Powering and SC links	*BALLARINO, Amalia*	*Main Auditorium, CERN*	15:20 - 15:40
	High Field Magnet program and HE-LHC	*BOTTURA, Luca et al.*	*Main Auditorium, CERN*	15:40 - 16:00
16:00	**Progress of other WPs and Conclusions**	*ROSSI, Lucio*	*Main Auditorium, CERN*	16:00 - 16:10
	2011 John Adams Lecture: LHC - Bold Beginning	*LAMONT, Mike*		

HE-LHC – LHC modifications



High Energy-LHC (HE-LHC)

CERN working group since April 2010

EuCARD AccNet workshop HE-LHC'10 ,

14-16 October 2010, Proc. CERN-2011-003

<u>key topics</u>

beam energy 16.5 TeV; 20-T magnets

cryogenics: **synchrotron-radiation heat**

radiation damping & emittance control

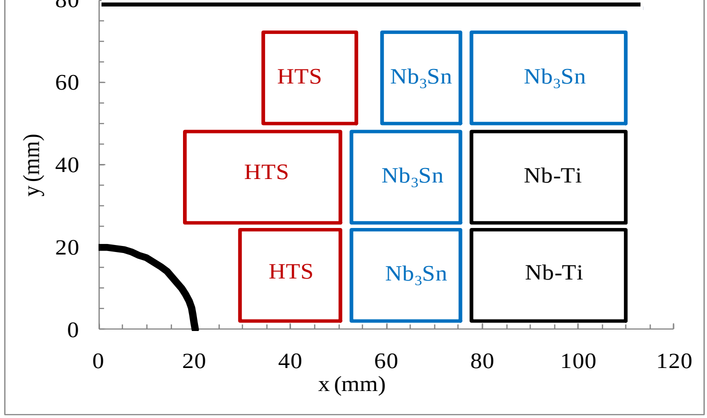
vacuum system: synchrotron radiation

new injector: energy > 1 TeV

parameters

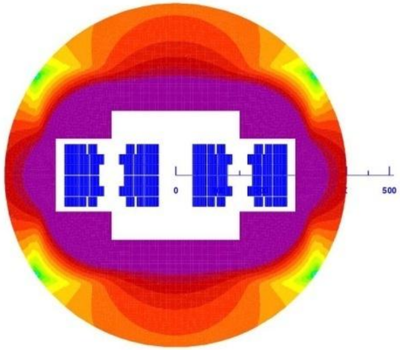
	LHC	HE-LHC
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40
#bunches	2808	1404
IP beta function [m]	0.55	1 (x), 0.43 (y)
number of IPs	3	2
beam current [A]	0.584	0.328
SR power per ring [kW]	3.6	65.7
arc SR heat load dW/ds [W/m/ap]	0.21	2.8
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0
events per crossing	19	76

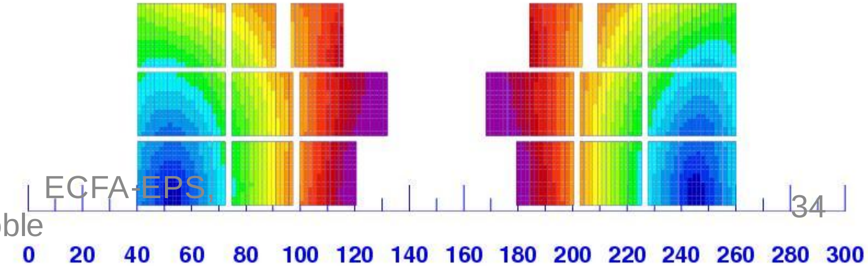
	Turns	%
Nb-Ti	40	28%
Nb_3Sn	58	41%
HTS	45	31%



E. Todesco

hybrid magnet





HE-LHC – main issues and R&D

- ***high-field 20-T dipole*** *magnets based on Nb_3Sn, Nb_3Al, and HTS*
- ***high-gradient quadrupole magnets*** *for arc and IR*
- ***fast cycling SC magnets*** *for 1-TeV injector*
- ***emittance control*** *in regime of strong SR damping and IBS*
- *cryogenic handling of* ***SR heat load*** *(first analysis; looks manageable)*
- *dynamic* ***vacuum***

Lepton – Hadron Collider

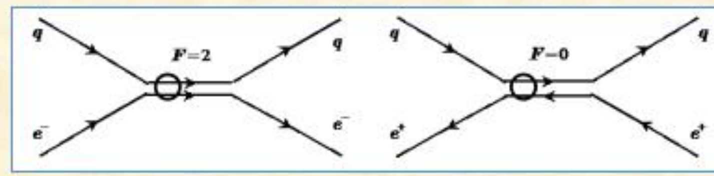
LHeC

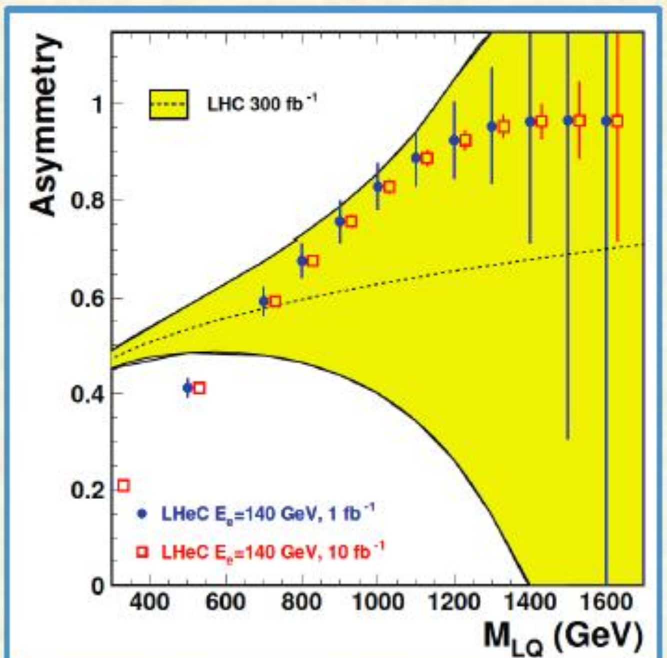
Determining Leptoquark Quantum Numbers

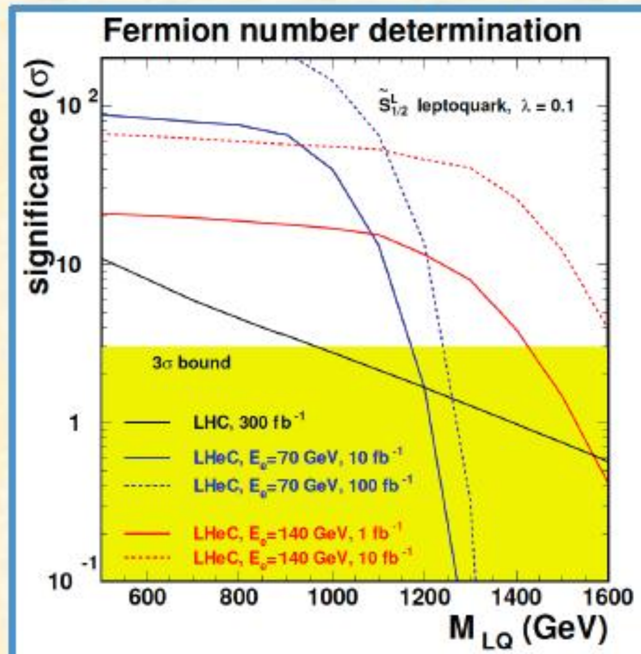
Single production gives access to quantum numbers:
- fermion number (below)   - spin (decay angular distributions)
- chiral couplings (beam lepton polarisation asymmetry)

- Fermion number *F* from asymmetry in e+/e-p cross sections
- Much cleaner accessible in DIS

$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 \text{ for F=2} \\ < 0 \text{ for F=0} \end{cases}$$

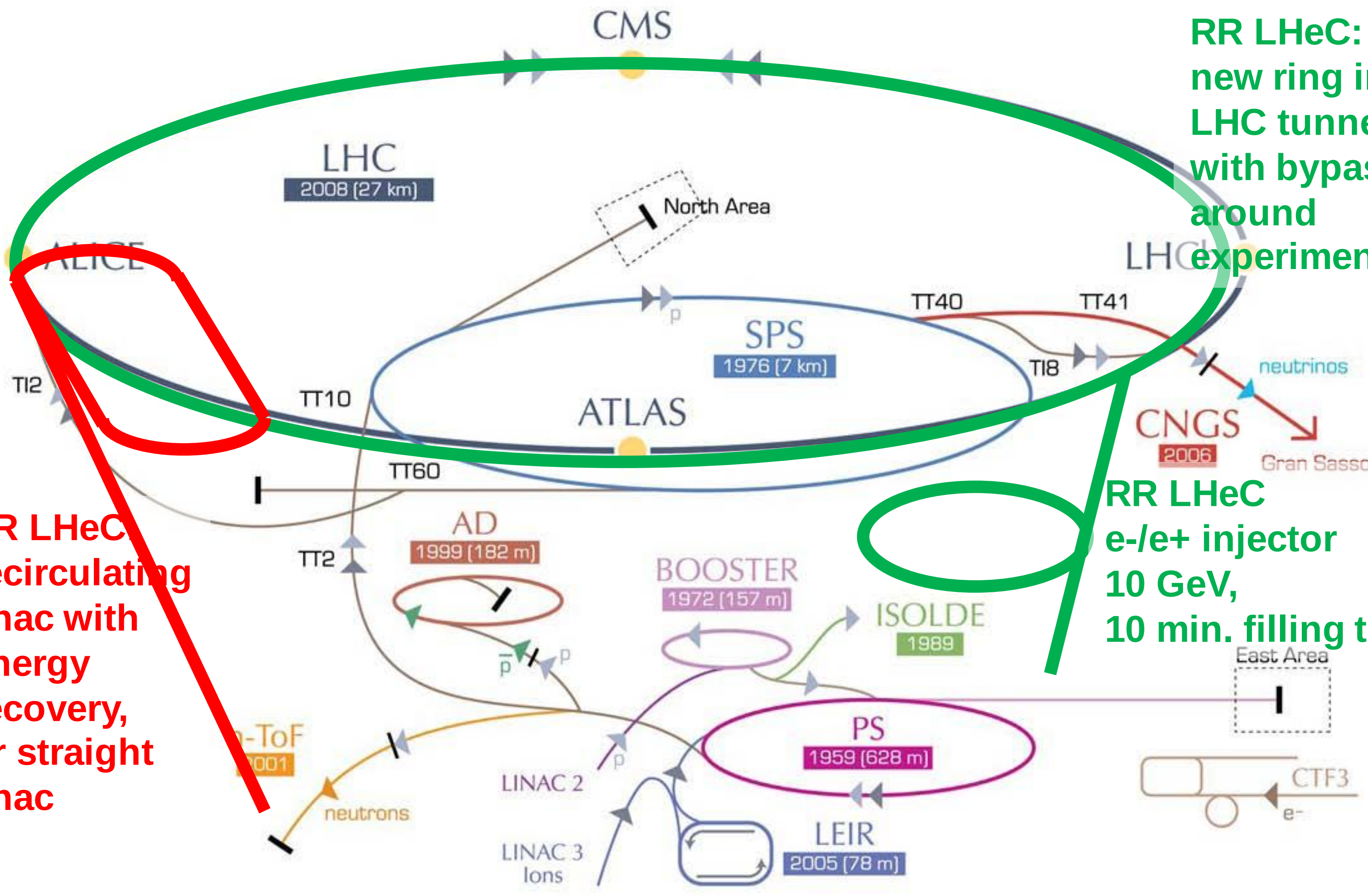






Studies for "low`` lumi assumptions for pp and ep

LHeC options: RR and LR



RR LHeC: new ring in LHC tunnel, with bypasses around experiments

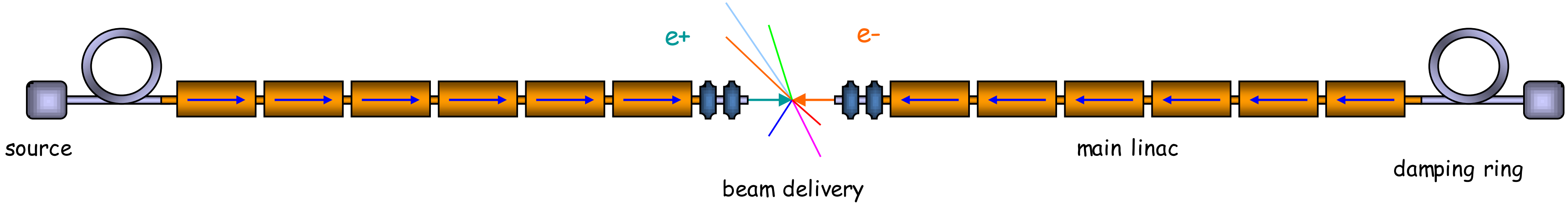
RR LHeC e-/e+ injector 10 GeV, 10 min. filling time

LR LHeC: recirculating linac with energy recovery, or straight linac

Frank Zimmermann, UPHUK4 Bodrum 2010

Lepton – Lepton Colliders

Multi-TeV Linear Colliders challenges



Energy reach $E_{cm} = 2\, F_{fill}\, L_{linac}\, G_{RF}$ ➡

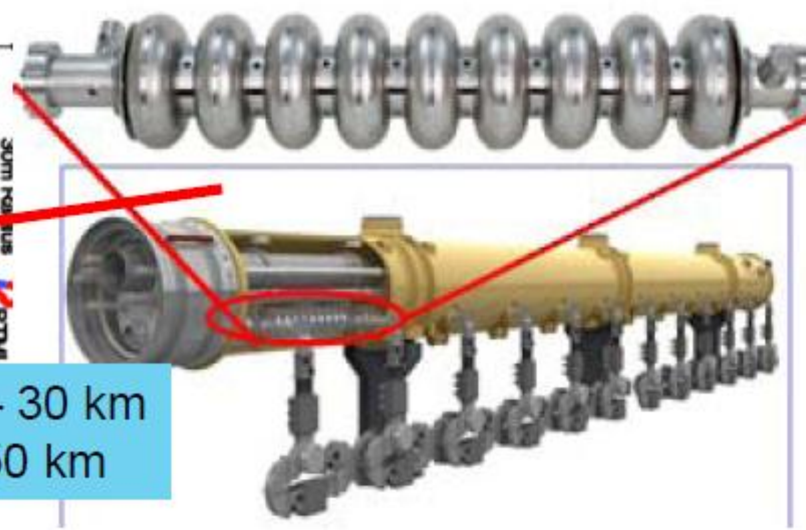
- Accelerating structures: large accelerating fields with low breakdown rate
- RF power source: high peak power with high efficiency

Luminosity $L = \frac{n_b N^2 f_{rep}}{4\pi\sigma_x^* \sigma_y^*} \times H_D \propto \frac{\eta_{beam}^{AC} P_{AC}}{\varepsilon_y^{1/2}} \frac{\delta_{BS}^{1/2}}{E_{cm}}$ ➡

- Beam acceleration: MW of beam power with high gradient and high efficiency
- Generation of ultra-low emittances: micron rad-m in H, nano rad-m in V
- Preservation of low emittances in strong wake field environment
  - Alignment (micron range)
  - Stability (nano-meter range)
- Small beam sizes at Interaction Point: Focusing to nm beam sizes
  - Stability to sub nano-meter

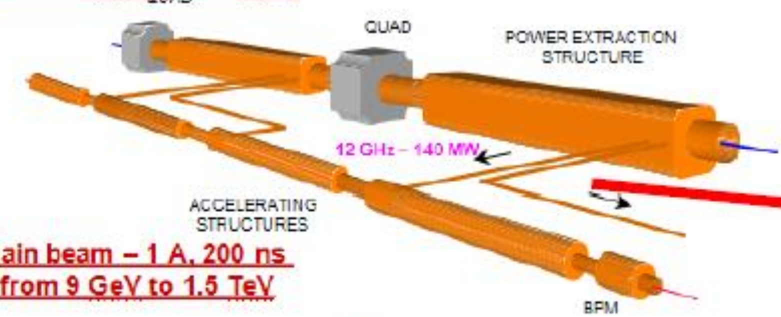
Linear Collider layouts

http://www.linearcollider.org/cms   http://clic-study.web.cern.ch/CLIC-Study/

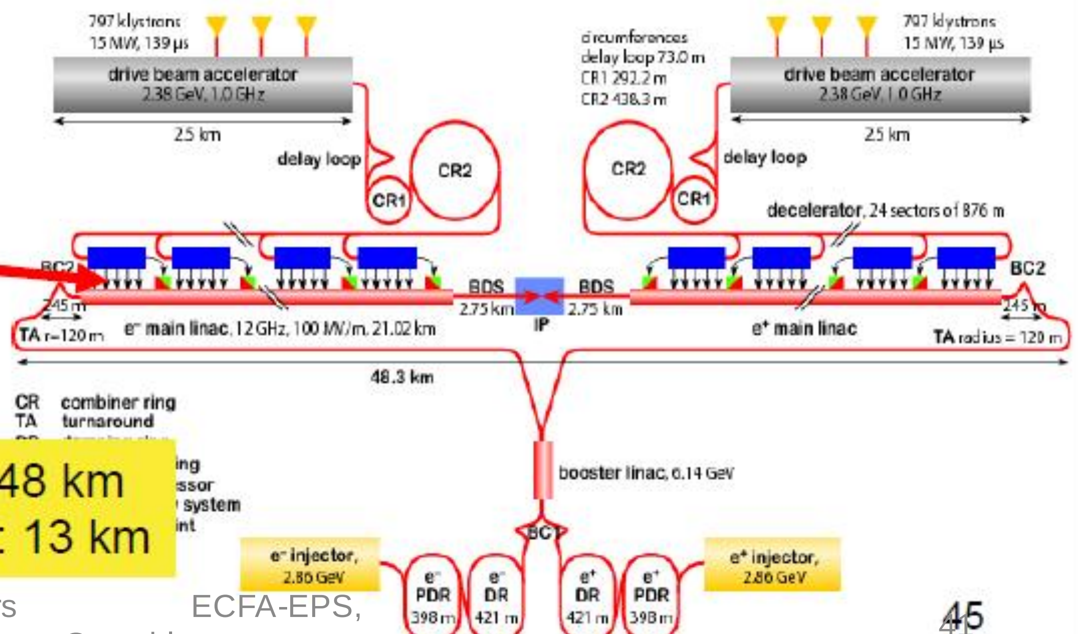


ILC 0.5 TeV – 30 km
ILC 1 TeV – 50 km

Drive beam - 95 A, 300 ns
from 2.4 GeV to 240 MeV



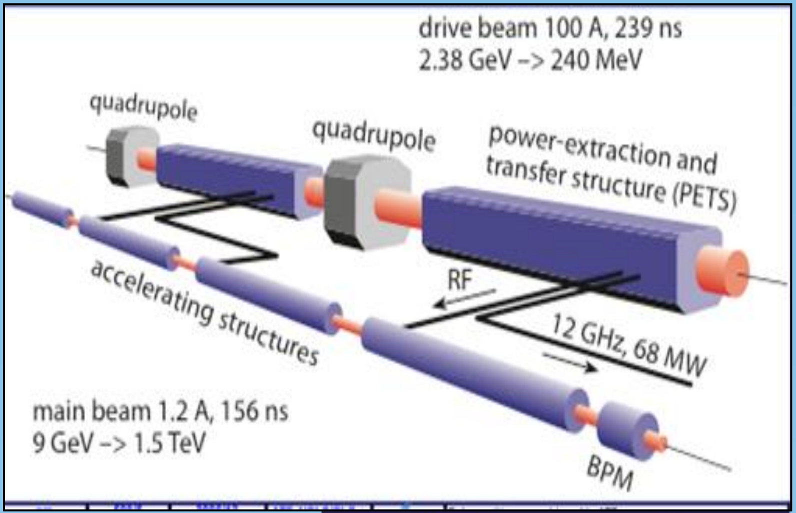
Main beam – 1 A, 200 ns
from 9 GeV to 1.5 TeV



CLIC 3 TeV: 48 km
CLIC 0.5 TeV: 13 km

Feasibility studies and the CDR

Feasibility issues:
- Drive beam generation
- Beam driven RF power generation
- Accelerating Structures
- Two Beam Acceleration
- Ultra low emittances and beam sizes
- Alignment
- Vertical stabilization
- Operation and Machine Protection System



CDRs:
- Vol 1: The CLIC accelerator and site facilities
  - CLIC concept with exploration over multi-TeV energy range up to 3 TeV
  - Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
  - Consider also 500 GeV, and intermediate energy ranges
- Vol 2: The CLIC physics and detectors
- Vol 3: CLIC study summary
  - Summary and input to the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
  - Proposing objectives and work plan of post CDR phase (2012-16)
- Timescales:
  - By end 2011: Vol 1 and 2 completed
  - Spring/mid 2012: Vol 3 ready for the European Strategy Open Meeting

High Priority Items for Linear Collider Projects

ILC and CLIC projects → LC project

Construction Cost

Power Consumption

Value Engineering

High Gradient Acceleration

- High gradient acceleration requires high peak power and structures that can sustain high fields
  - Beams and lasers can be generated with high peak power
  - Dielectrics and plasmas can withstand high fields

- Many paths towards high gradient acceleration
  - RF source driven superconducting structure ... 40 MV/m
  - RF source driven metallic structure ... MV/m
  - Beam-driven metallic stru
  - Laser-driven die ... ures
  - Beam ... ctric structures
    - ~1 GV/m (laser-driven and beam-driven dielectric structures)
  - La ... ven plasmas
  - Beam-driven plasmas
    - ~10 GV/m (laser-driven and beam-driven plasmas)

R&D on new technologies mandatory

From: T.Raubenheimer, EPS 2011

In summary

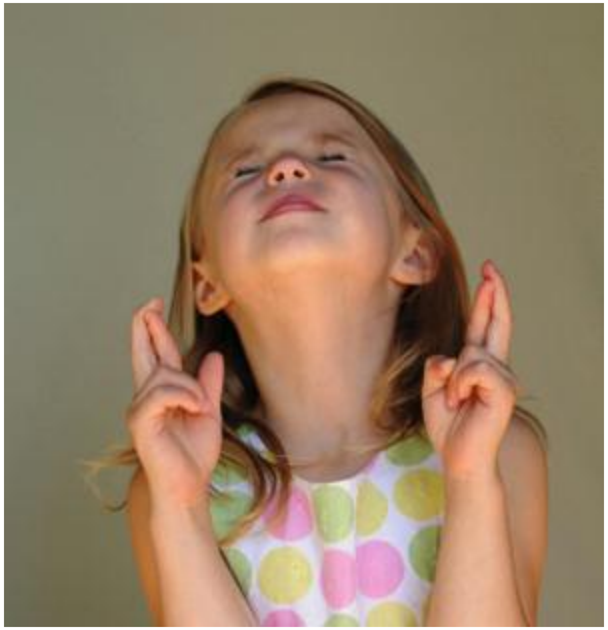
- By year 2013, **experimental results** will be dictating the agenda of the field.
- Early discoveries will greatly accelerate the case for the construction of the next facilities
- No time to idle: a lot of work has to be done in the meantime

In summary

We will need

- Flexibility
- Coordination
- Preparedness
- Visionary global policies

- ...and discoveries!



Thank you!