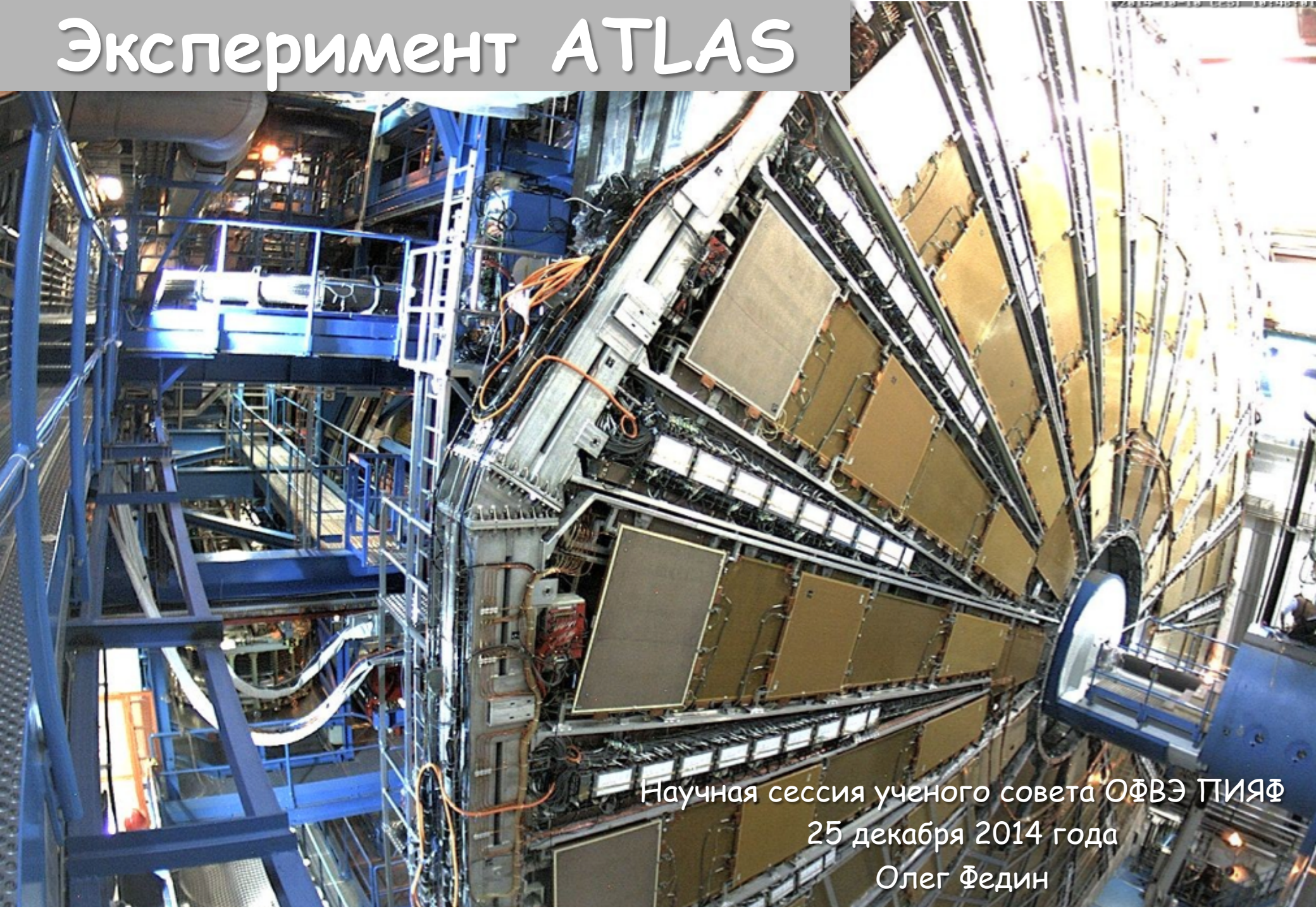
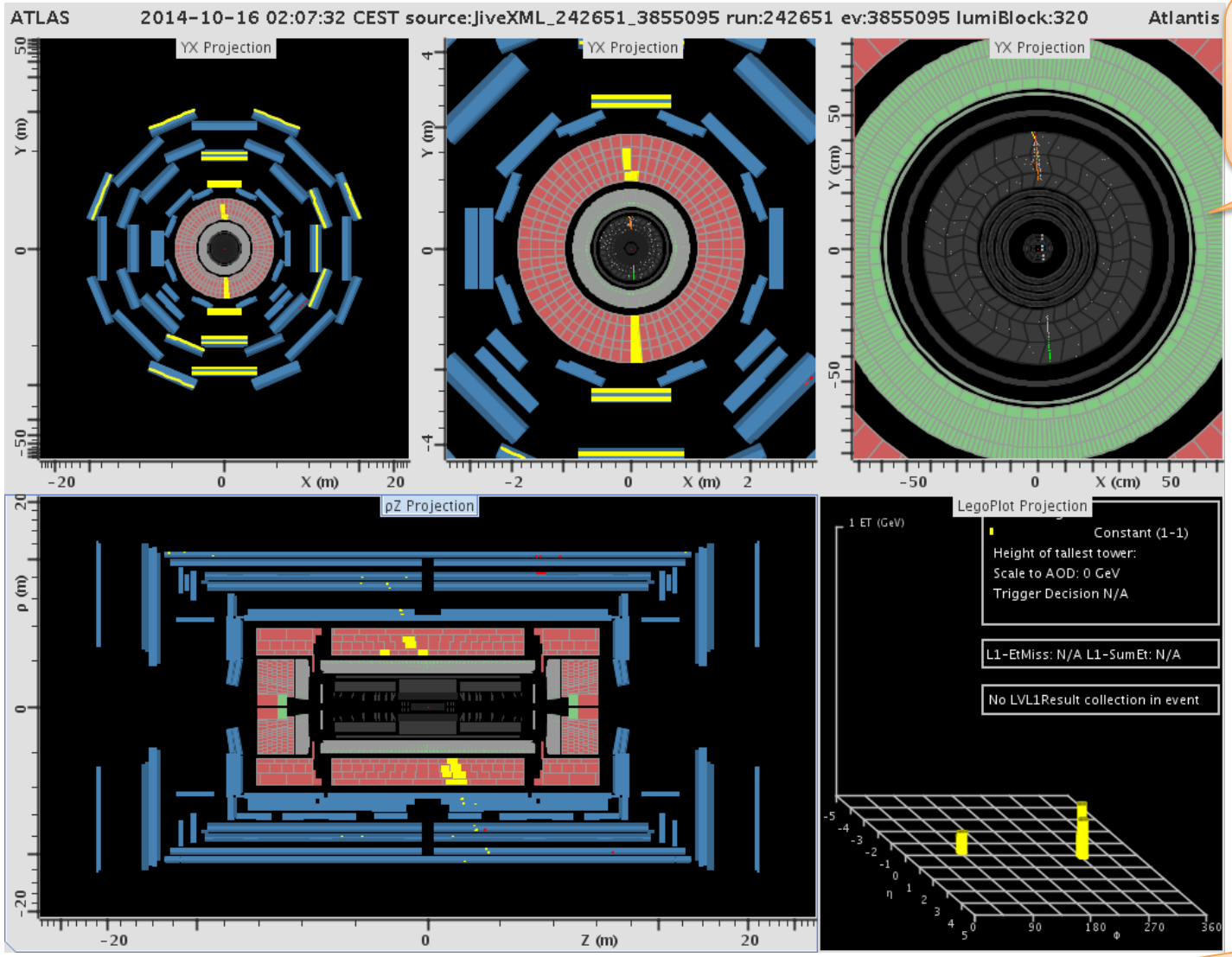
Эксперимент ATLAS



Научная сессия ученого совета ОФВЭ ПИЯФ
25 декабря 2014 года
Олег Федин

ATLAS M6 run (cosmic)



An event display
HLT ID Cosmics

→ IBL/PIX, ID data unambiguously seen

Run-2 Challenges

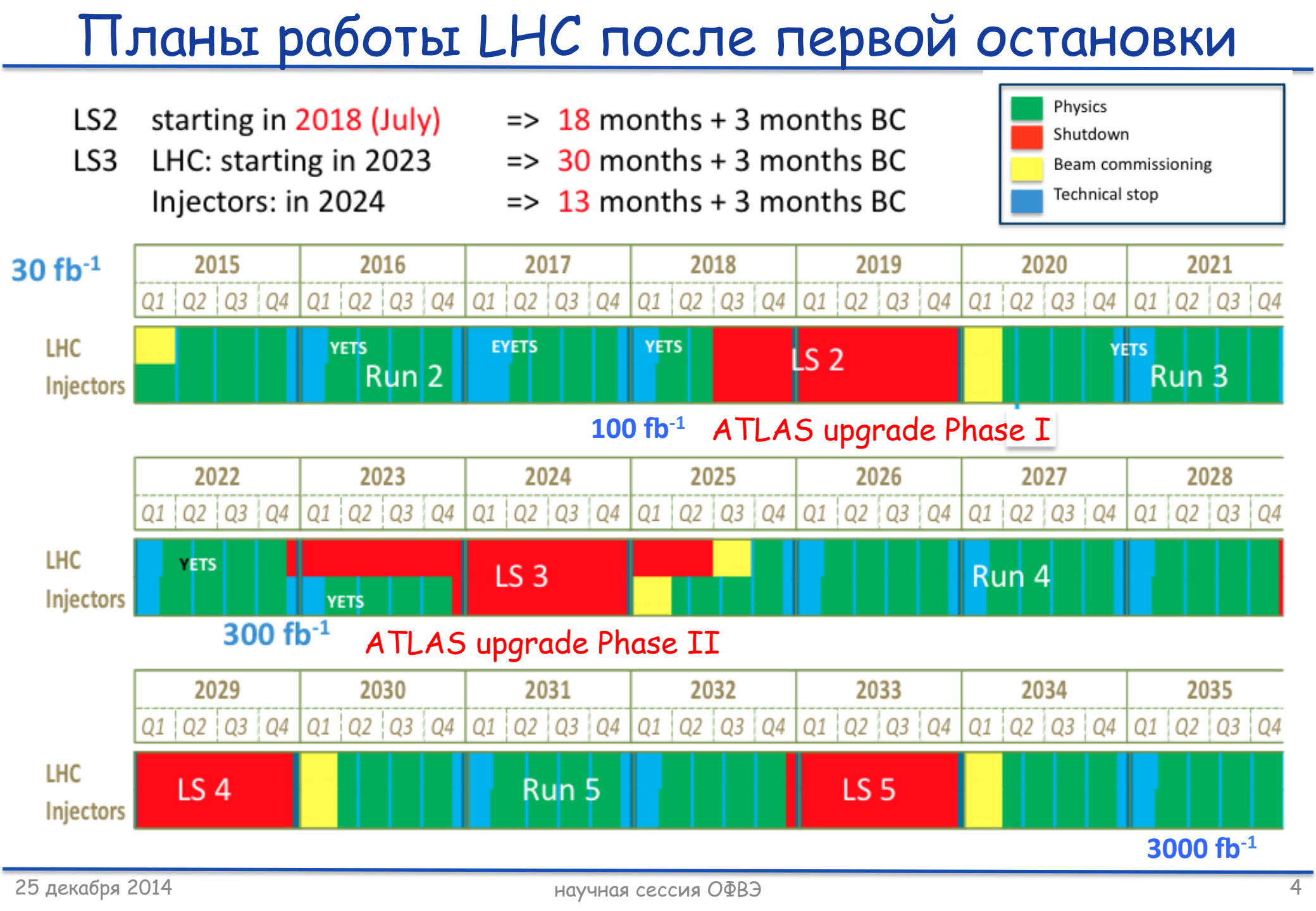
- The detector:
  - Several upgrades, improvements
  - refurbishments (IBL … etc. etc.)
  - repair (TRT… etc.)
- TDAQ:
  - New TDAQ architecture
  - New Triggers
  - Run at 100 kHz L1 rate (in Run-1 ~65 kHz)
  - New Gen III ROSes
  - Data compression
- LHC:
  - 8 => ~13 TeV c.m.s
  - 0.7 => (1.6) x 10^{34} $cm^{-2}s^{-1}$ inst. lum.
  - 50 =>25 ns bunch spacing

PNPI contribution :

- repair of TRT detector
- construction and assembly of the remote gas regulation system
- NSQP for the Pixel detector
- beam pipe geo model
- TRT s/w tuning

Планы работы LHC после первой остановки

LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023 => 30 months + 3 months BC
Injectors: in 2024 => 13 months + 3 months BC

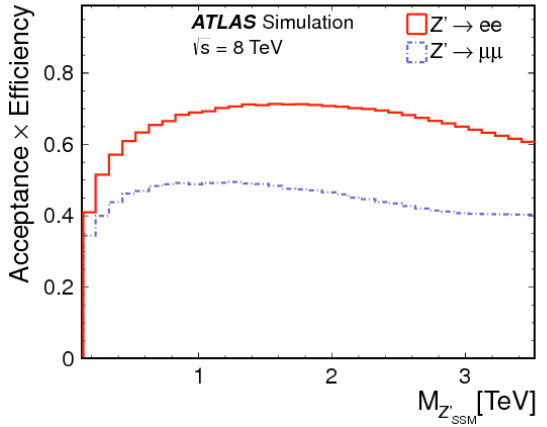


Search for high mass di-lepton resonances

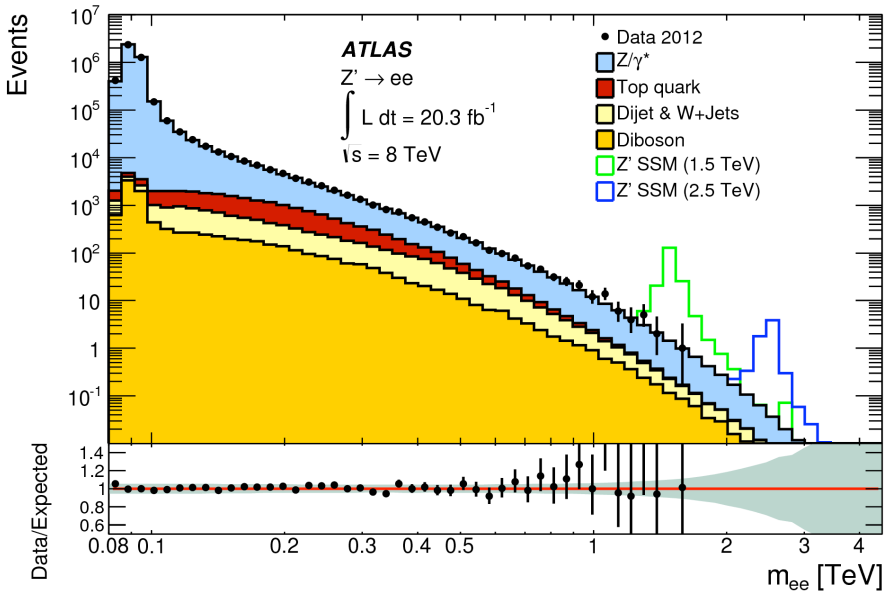
- Observable is mass of di-lepton pair
- Dominant background is $Z/\gamma^* \rightarrow ll$
- Backgrounds:
  - ✧ From simulation: Drell-Yan, diboson and ttbar
  - ✧ Data-driven estimation : W+jet and dijet
- Signals: From LO simulation

- Event selection:
  - ✧ 2 opposite-sign, electrons $|\eta|<2.47$, $pT>40$ (30) GeV
  - ✧ 2 opposite-sign muons, $|\eta|<2.4$, $pT>25$ GeV

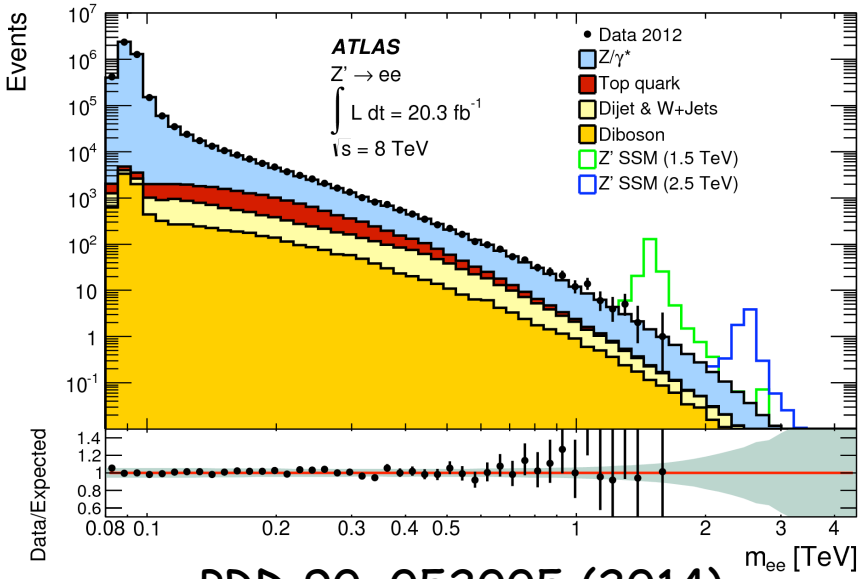
efficiency X acceptance



dielectrons



dimuons



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Search for high mass di-lepton resonances

- The numbers of expected and observed events in dielectron and dimuon channel in bins of the mll.
- The errors are the combined statistical and systematic uncertainties.

dielectrons

m_{ee} [GeV]	110–200	200–400	400–800	800–1200	1200–3000	3000–4500
Z/γ^*	122000 ± 7000	14000 ± 800	1320 ± 70	70 ± 5	10.0 ± 1.0	0.008 ± 0.004
Top	8200 ± 700	2900 ± 500	200 ± 80	3.1 ± 0.8	0.16 ± 0.08	< 0.001
Diboson	1880 ± 90	680 ± 40	94 ± 5	5.9 ± 0.4	1.03 ± 0.06	< 0.001
Dijet & W+jet	3900 ± 800	1290 ± 320	230 ± 70	9.0 ± 2.3	0.9 ± 0.5	0.002 ± 0.004
Total	136000 ± 7000	18800 ± 1000	1850 ± 120	88 ± 5	12.1 ± 1.1	0.011 ± 0.005
Observed	136200	18986	1862	99	9	0

dimuons

$m_{\mu\mu}$ [GeV]	110–200	200–400	400–800	800–1200	1200–3000	3000–4500
Z/γ^*	111000 ± 8000	11000 ± 1000	1000 ± 100	49 ± 5	7.3 ± 1.1	0.034 ± 0.022
Top	7100 ± 600	2300 ± 400	160 ± 80	3.0 ± 1.7	0.17 ± 0.15	< 0.001
Diboson	1530 ± 180	520 ± 130	64 ± 16	4.2 ± 2.1	0.69 ± 0.30	0.0024 ± 0.0019
Total	120000 ± 8000	13700 ± 1100	1180 ± 130	56 ± 6	8.2 ± 1.2	0.036 ± 0.023
Observed	120011	13479	1122	49	8	0

Search for high mass di-lepton resonances

In the absence of any significant signal 95% C.L. limits were set using Bayesian approach on cross section time branching ration

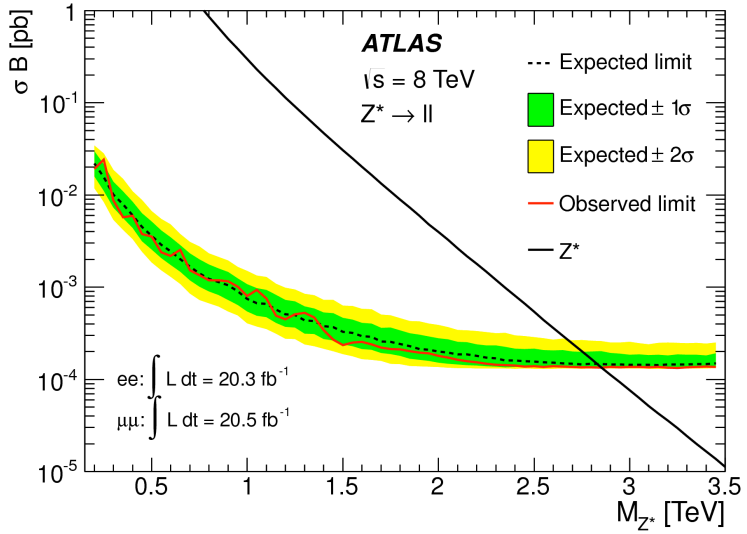
$$\mathcal{L}(\lambda,\boldsymbol{\nu}) = \prod_i^{N_{\text{bins}}} \frac{e^{-\bar{n}_i}\bar{n}^{d_i}}{d_i!} G(\boldsymbol{\nu}).$$

$$\text{LLR} = -2\ln\frac{\mathcal{L}(\text{data} \mid \hat{n}_{Z'}, \hat{M}_{Z'}, \hat{\boldsymbol{\nu}})}{\mathcal{L}(\text{data} \mid (\hat{n}_{Z'}=0), \hat{\boldsymbol{\nu}})},$$

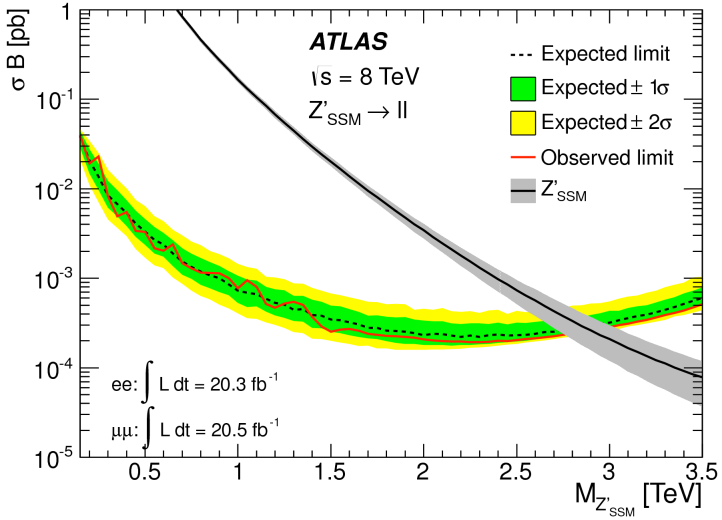
PNPI contribution :

- electron channel analysis: cut flow, QCD bkg. estimation, SF for electron efficiencies, Z* MC production and validation, CL for Z* channel.

Model	Z'		Z^*	
Year	Obs. [TeV]	Exp.[TeV]	Obs. [TeV]	Exp. [TeV]
2010	1.048	1.088	1.152	1.185
2011	2.22	2.25	2.20	2.22
2012	2.90	2.87	2.85	2.82



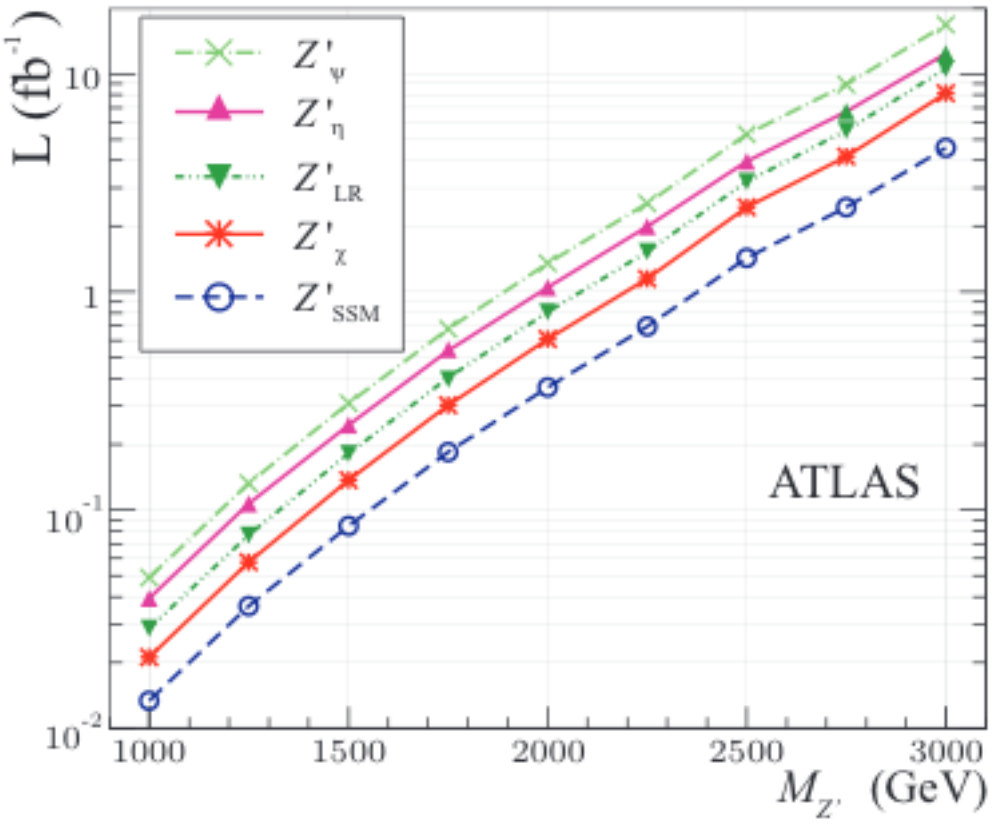
Z* observed limit: 2.85 TeV



Z' (SSM) observed limit: 2.90 TeV (20 fb-1 @ √s=8)
CMS: 2.59 TeV (5.3 fb-1 @ √s=7 && 4.1 fb-1 @ √s=8)

Search for Z'->ee @ 13 TeV

The integrated luminosity needed for a 5σ discovery of the usual benchmark Z' models as a function of the Z' mass.



- Only statistical uncertainties were taken into account.
- A fixed mass window of [500 GeV–4 TeV] was used to compute the significance:
  - less than 100 pb–1 are needed to discover a 1 TeV Z'
  - about 1 fb–1 are needed to discover a 2 TeV Z'
  - about 10 fb–1 are needed to discover a 3 TeV Z'

Search for heavy bosons decaying to lepton and neutrino

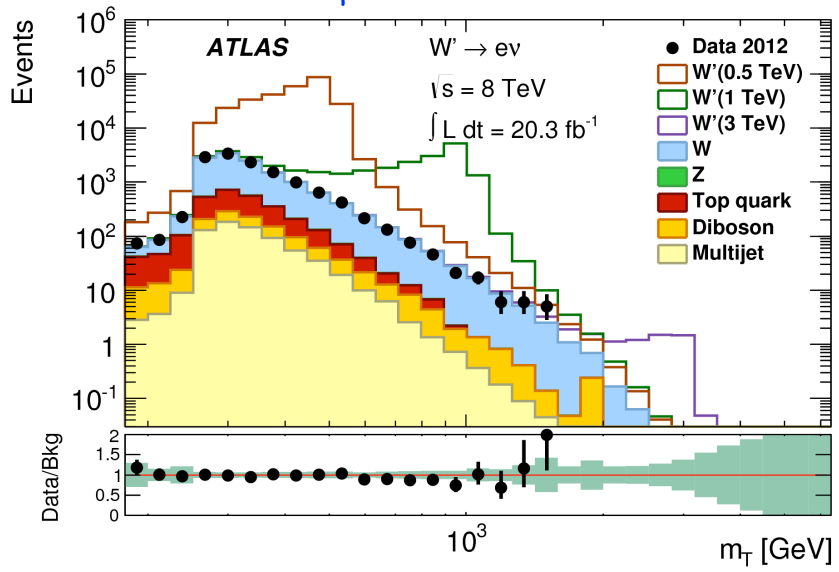
- Observable is transverse mass

$$m_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos\varphi_{l\nu})}$$

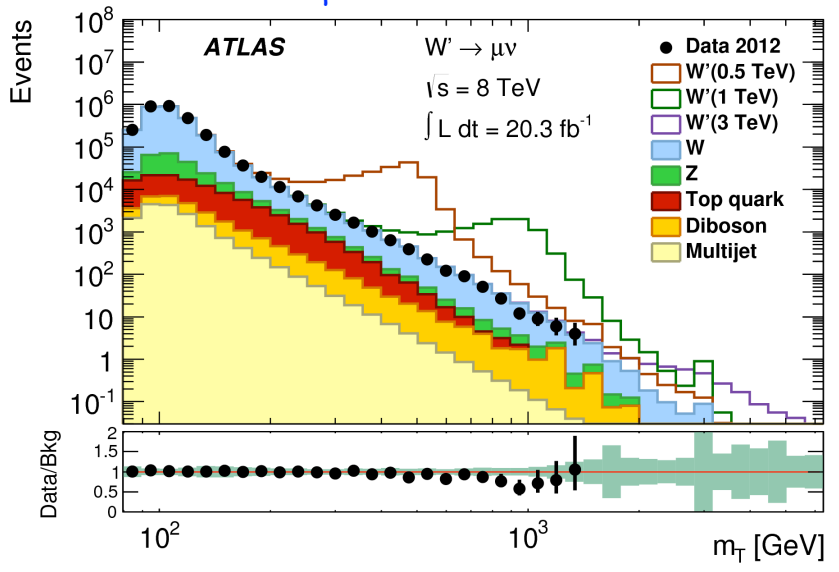
- Dominant background is $W/\gamma^* \rightarrow l\nu$
- Backgrounds:
  - ✧ From simulation: Drell-Yan, diboson and ttbar
  - ✧ Data-driven estimation - dijet

- Signature: $l\nu$ (with l=e,μ)
  - ✧ one electron $|\eta|<2.47$ $E_T>125$ GeV and missing $E_T>125$ GeV
  - ✧ one muon $|\eta|<2.4$ $E_T>45$ GeV and missing $E_T>45$ GeV

m_T electrons



m_T muons

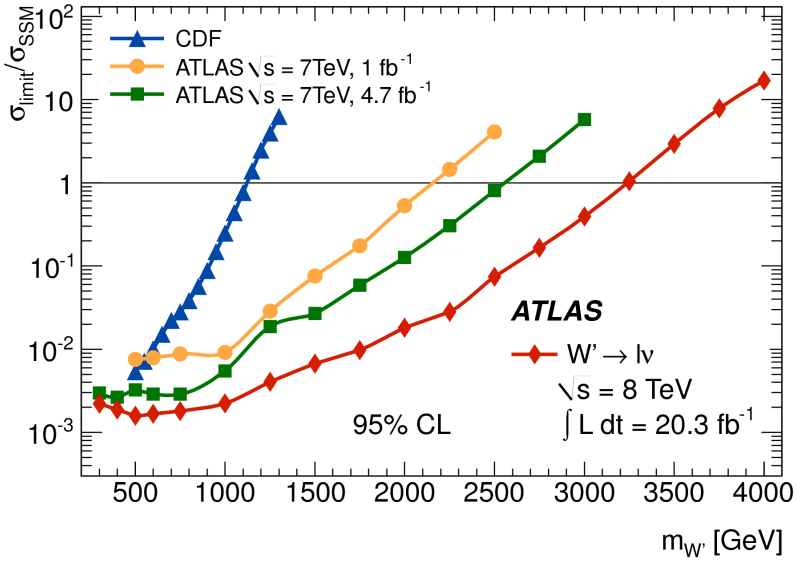


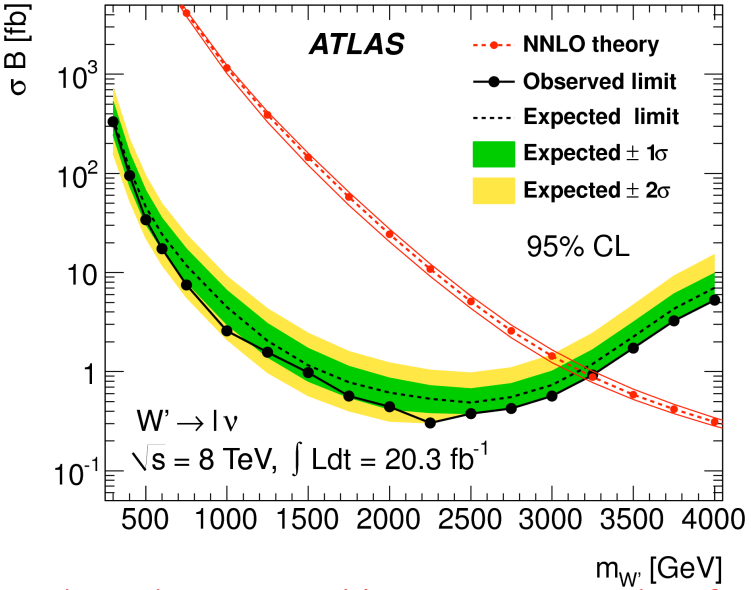
Search for heavy bosons decaying to lepton and neutrino

PNPI contribution :

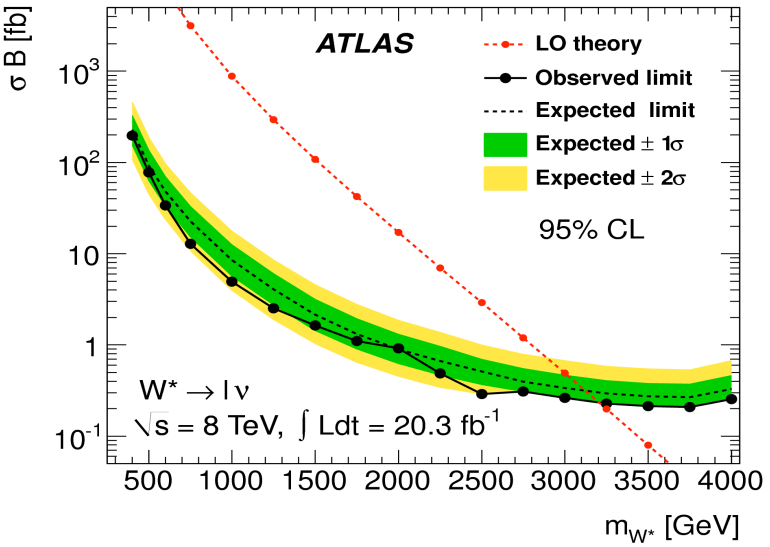
- electron channel analysis: cut flow, SF for electron efficiencies, W* MC production and validation, CL for W*/W'

Model	W'		W^*	
Year	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
2010	1.49	1.45	1.35	1.32
2011	2.55	2.55	2.42	2.42
2012	3.17	3.24	3.12	3.21





W' (SSM) observed limit: 3.24 TeV (20 fb-1 @ $\sqrt{s}$=8)
CMS: 3.28 TeV (19 fb-1 @ $\sqrt{s}$=8)



W* observed limit: 3.21 TeV

Z-boson polarization

Differential cross-section represented as of nine helicity cross-sections multiplied by harmonic polynomials in θ,φ angles of the Born lepton in the Z-boson rest frame:

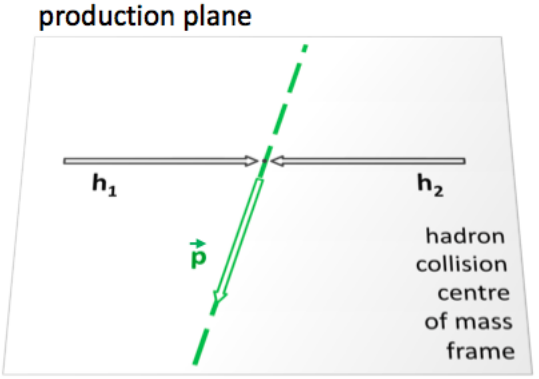
LO term

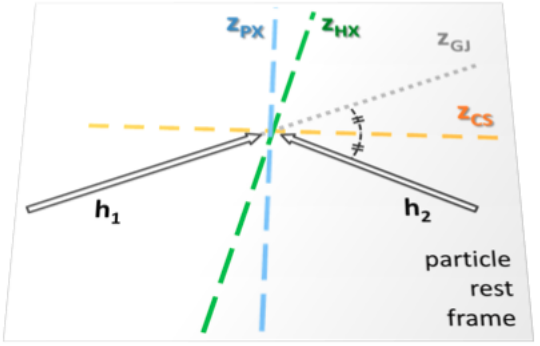
$$\frac{d\sigma}{dp_T^2 dy d\cos\vartheta d\varphi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T^2 dy d}\Big\{(1+\cos^2\vartheta)+\frac{1}{2}A_0(1-3\cos^2\vartheta)+\frac{1}{2}A_1\sin 2\vartheta\cos\varphi$$
$$+\frac{1}{2}A_2\sin^2\vartheta\cos 2\varphi + A_3\sin\vartheta\cos\varphi + A_4\cos\vartheta$$
$$+A_5\sin^2\vartheta\sin 2\varphi + A_6\sin 2\vartheta\sin\varphi + A_7\sin\vartheta\sin\varphi\Big\}$$

- Angular coefficients Ai are functions of lepton-pair kinematics: p_T^{ll}, y_{ll}, m_{ll}.
- Contain information about underlying QCD - dynamics, subject to modifications from higher order perturbative and non-perturbative corrections, structure functions, renormalisation/factorisation scale, underlying event, dependent on the subprocess type: annihilation or Compton scattering. => QCD dynamics can be probed.
- Aim is to measure all 8 coefficients A0 -A7 as the function of Z-boson pT (in several rapidity bins), which requires simultaneous 2D fitting in ($\cos\theta_{CS}$,φ_{CS}) parameter space.
- May be used to compare MC generator implementations of hard scatter/parton shower
- Not explored in TH papers since almost 20 years, last published results on NLO corrections for Tevatron from `94.

Z-boson rest frames

- Rest boson frames:
  - helicity (HX): Z-boson direction
  - Collins-Sopper (CS): average of the two beam direction
  - Gottfried-Jackson (GJ): direction of one or the other beam
  - Perpendicular helicity axis (PX): perpendicular to CS





$$< P_i(\vartheta,\varphi) > = \frac{\int d\sigma(p_T, y, \vartheta, \varphi) P_i(\vartheta,\varphi) d\cos\vartheta d\varphi}{\int d\sigma(p_T, y, \vartheta, \varphi) d\cos\vartheta\, d\varphi}$$

$$< \frac{1}{2}(1 - 3\cos^2\theta) > = \frac{3}{20}(A_0 - \frac{2}{3})$$

$$< \cos\theta > = \frac{1}{4}A_4$$

$$< \sin 2\theta \cos\phi > = \frac{1}{5}A_1$$

$$< \sin^2\theta \sin 2\phi > = \frac{1}{5}A_5$$

$$< \sin^2\theta \cos 2\phi > = \frac{1}{10}A_2$$

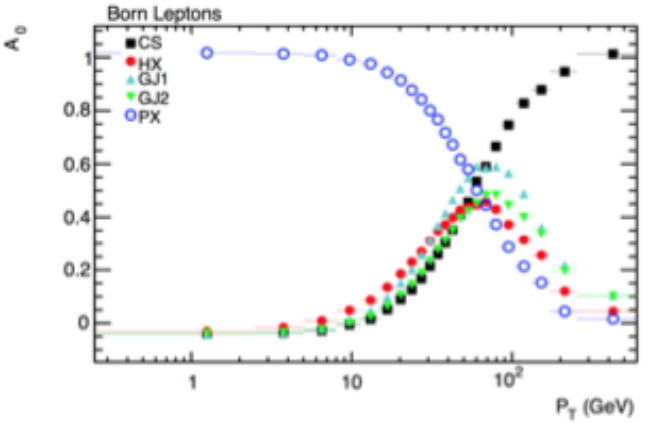
$$< \sin 2\theta \sin\phi > = \frac{1}{5}A_6$$

$$< \sin\theta \cos\phi > = \frac{1}{4}A_3$$

$$< \sin\theta \sin\phi > = \frac{1}{4}A_7$$

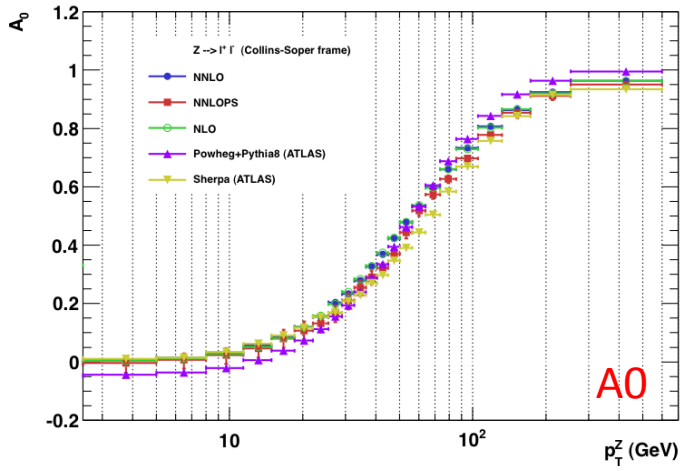
Ai can be extracted from MC via averages < Pi(cos θ, φ) > – Requires full phase space of truth to be available

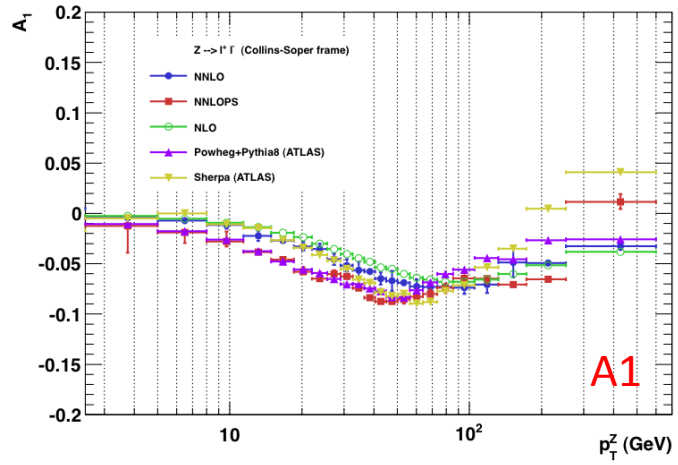
• Since Pi are orthogonal, the averages select out each coefficient from the differential cross section

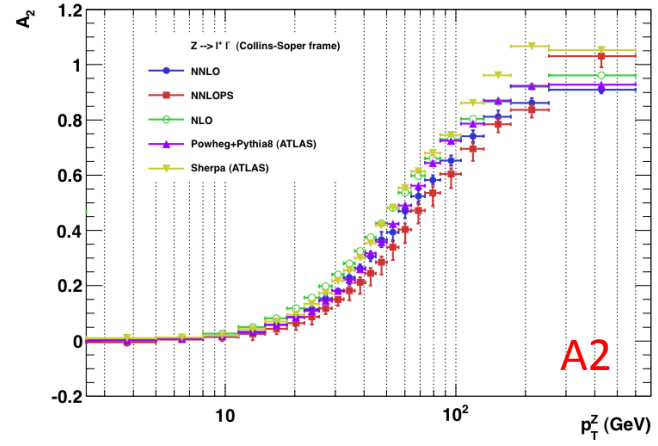


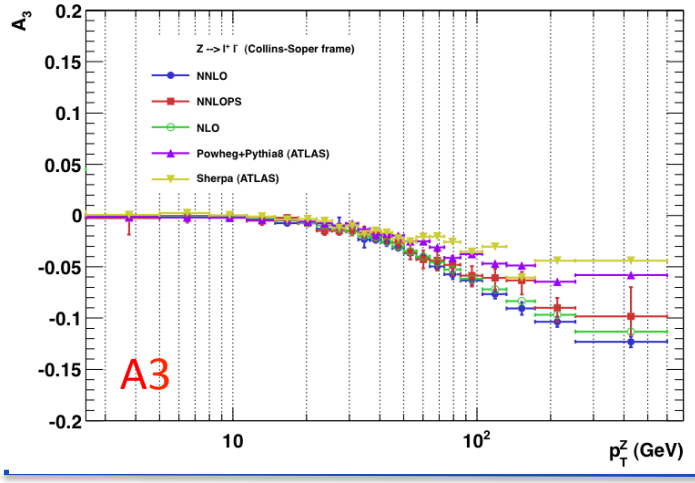
Coefficient behavior

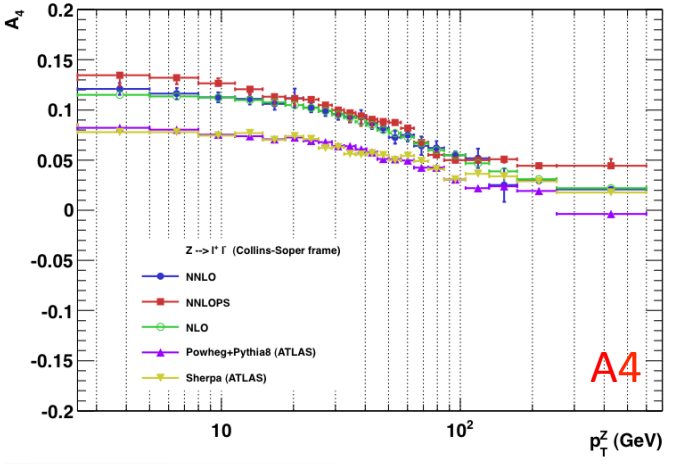
- NNLO and NLO from DYNNLO (qQCD), NNLOPS from Powheg+MiNLO
- A1 zero at low and ~-0.1 in intermediate pT
- A0 ~ A2 ~ for Compton (annihalation) processes. At NLO through Lam-Tung relationship (not true at NNLO) A0 = A2
- A3 zero at low pT and ~ -0.1 at high pT
- A4 has strong dependence on mll, with some weak dependence on p^Z_T. A4 = 8AFB and is sensitive to sin2 θW
- A5,6,7 ~0 at NLO

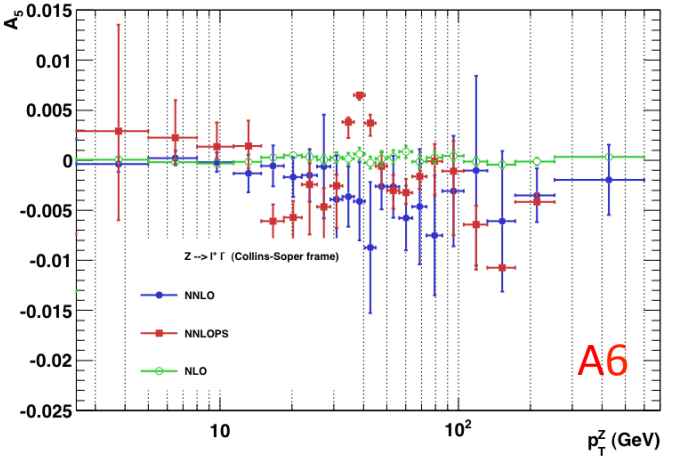






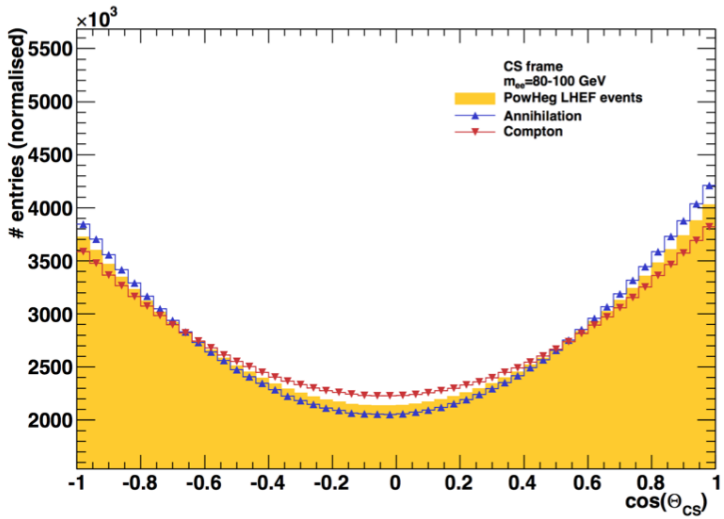


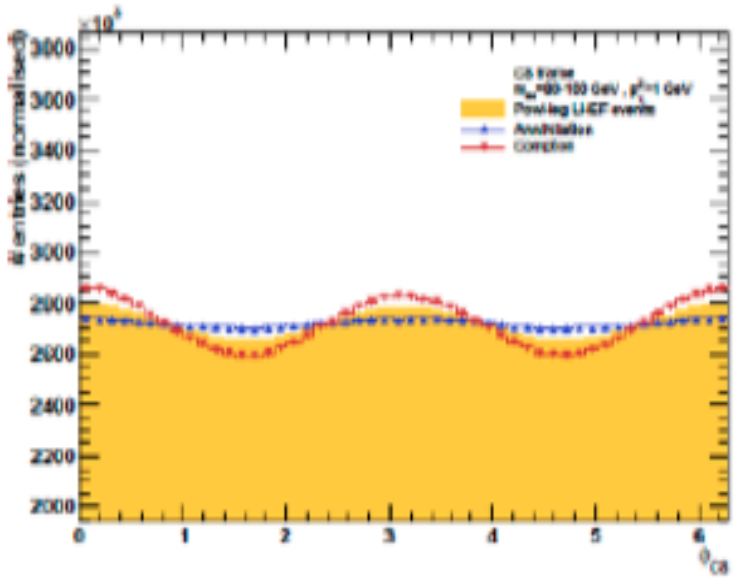




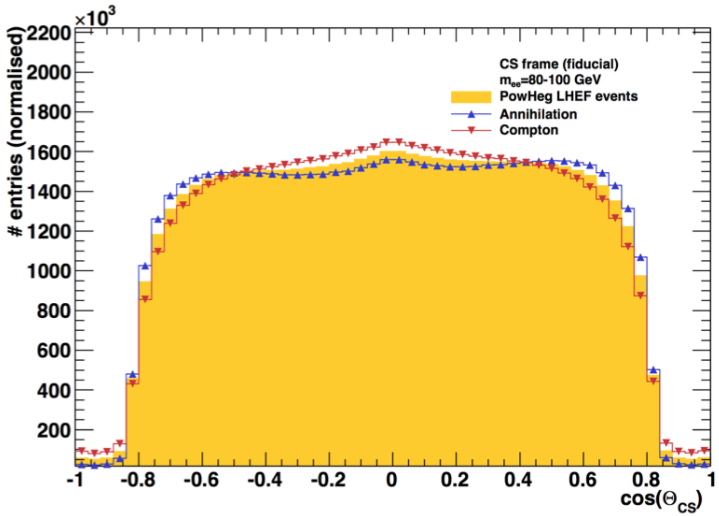
Z-boson polarization

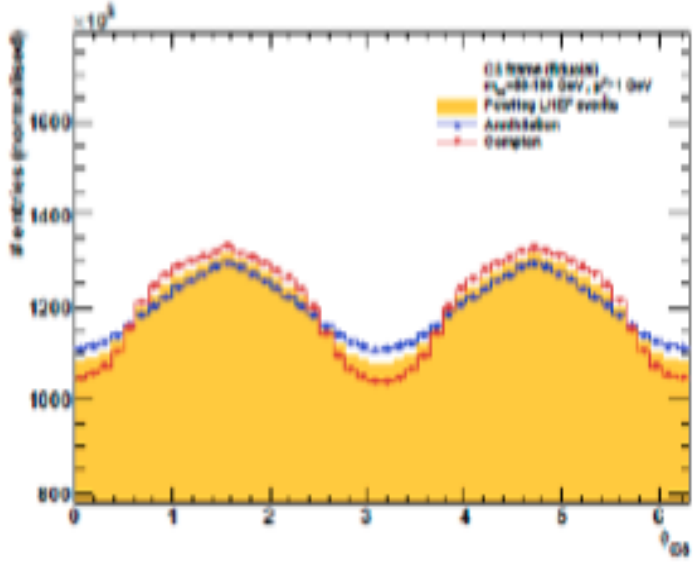
full phase-space





fiducial phase-space





Z-boson polarization

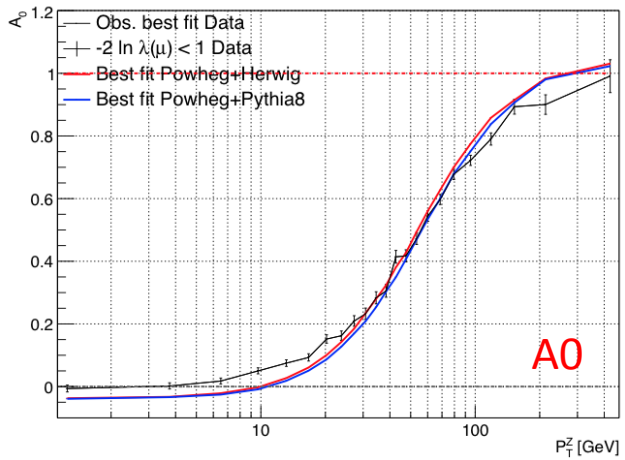
- Can write full likelihood as sum of all templates:

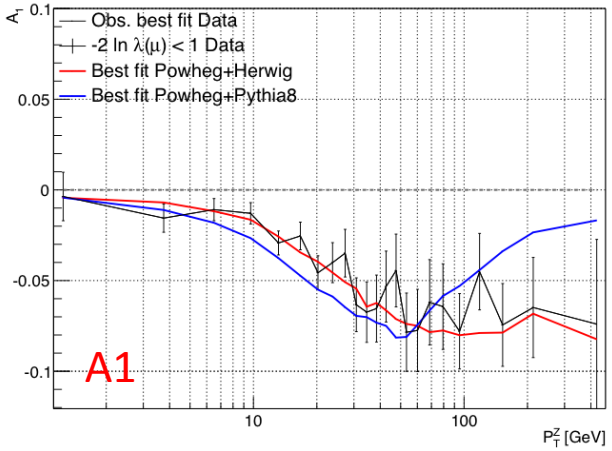
$$\mathcal{L}(A_{ij},\mu_j|N) = \prod_{bins}^{N}\left\{\sum_{j=1}^{23}\mu_j\left[T_{8,j}+\sum_{i=0}^{7}A_{ij}\times T_{ij}\right]+\sum_{B}^{bkgs}T_B+T_{Fakes}\right\}$$

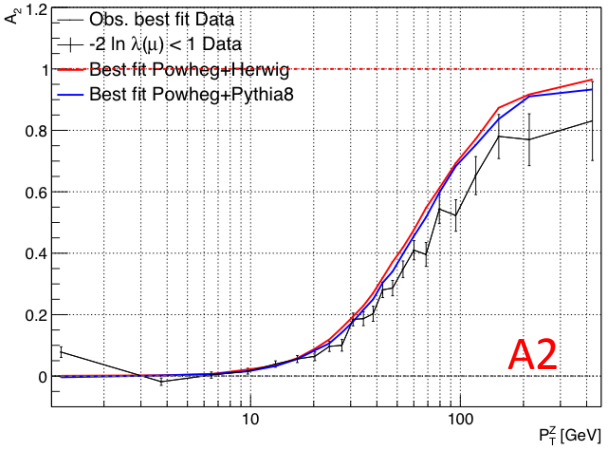
- Total 23 bins in p^Z_T , 9 polynomials→207 signal templates for each channel T_{ij}
- Background templates added in fit to account for other processes (~% level compared to signal)
  - T_B: QCD (data-driven), EW+ttbar (MC) backgrounds
  - T_{Fakes}: "Fakes": Z events outside fiducial truth volume, i.e. outside 80-100 GeV in mll, but pass reco cuts
- Extract Aij in each CC, CF, μμ separately, then combine:

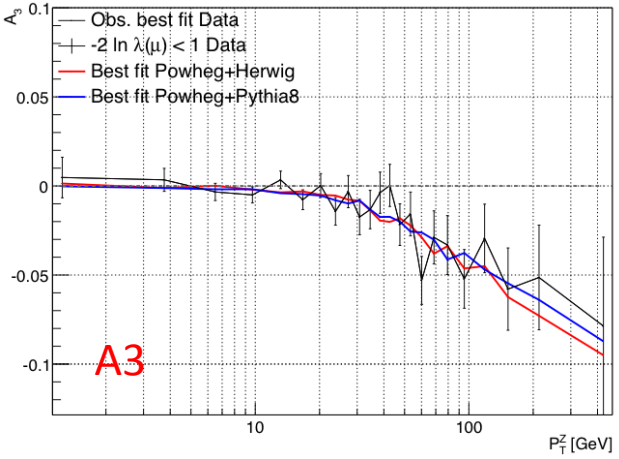
$$\mathcal{L}_{cb}(A_{ij},\mu_j) = \prod_{chan}\mathcal{L}_{chan}(A_{ij},\mu_j)$$

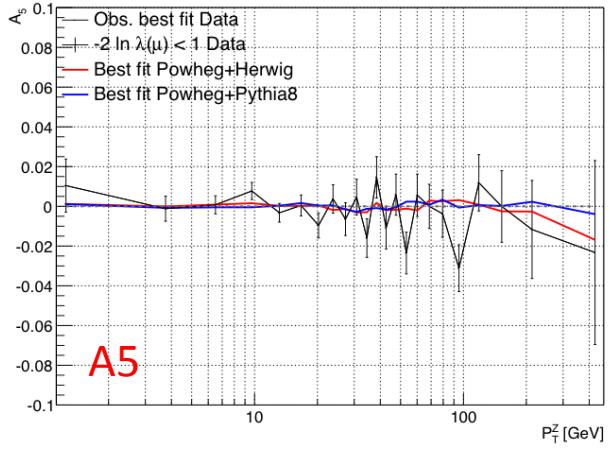
Preliminary results



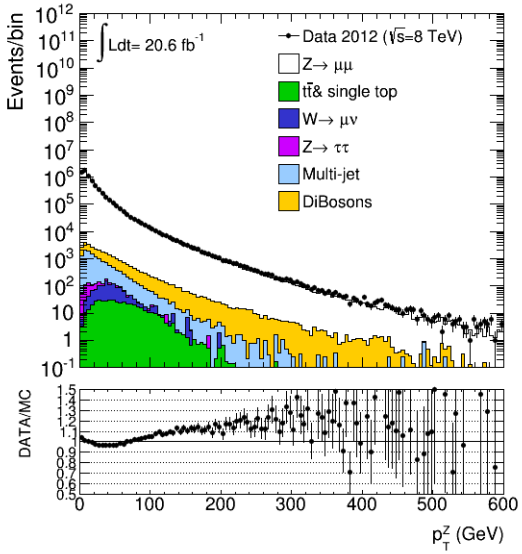


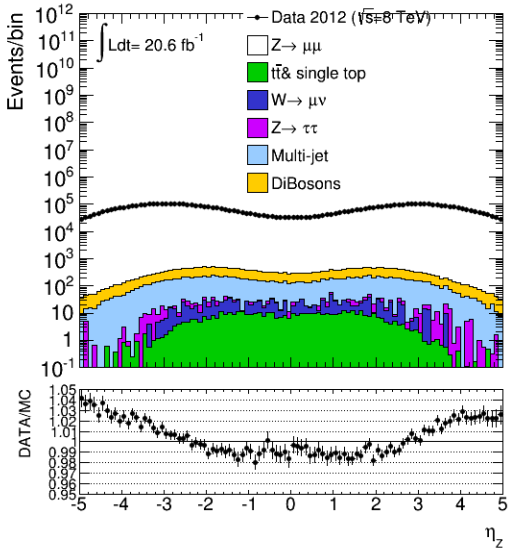


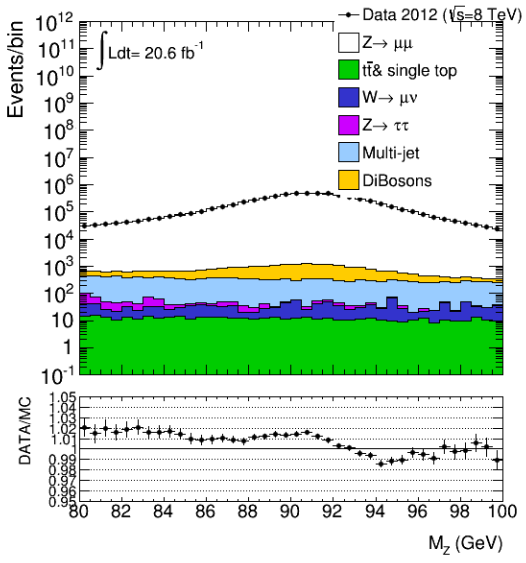


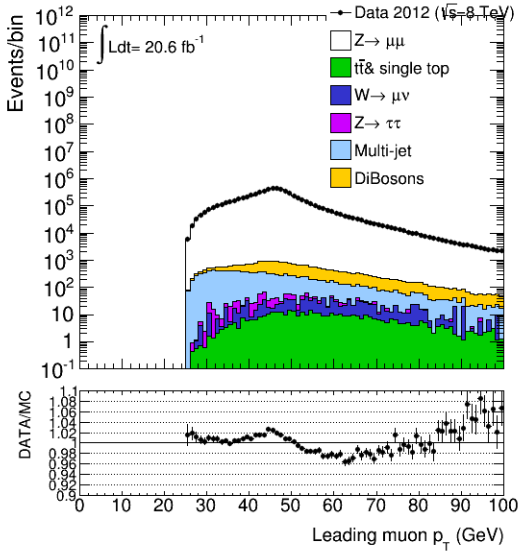


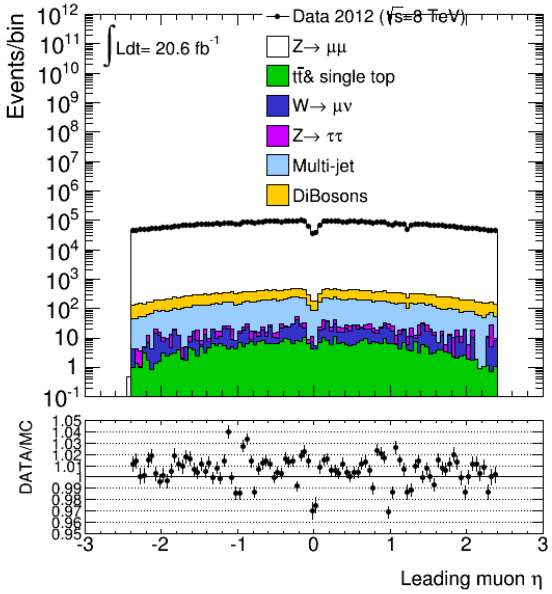
Control plots Z->μμ

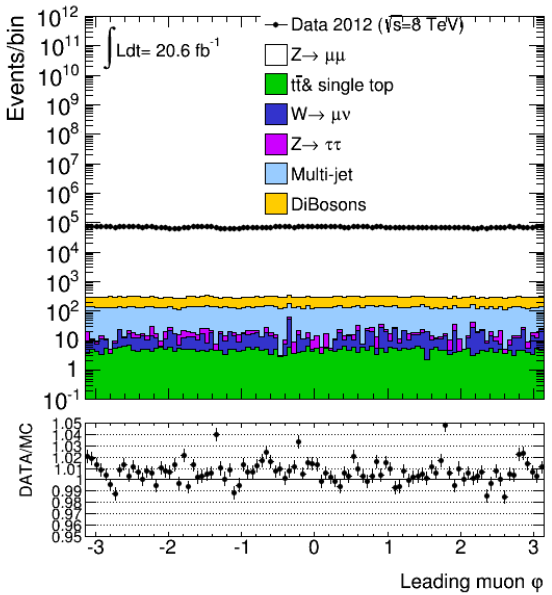








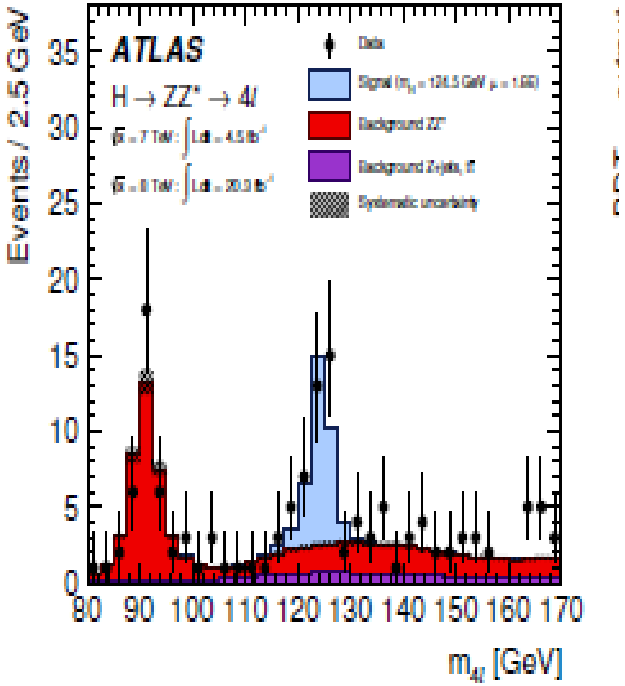




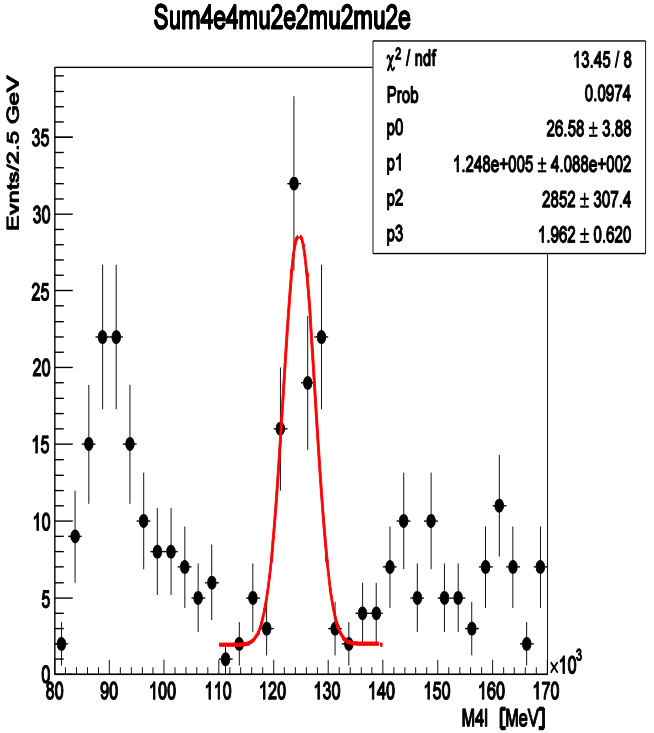
H->4l

Закончен анализ четырех-лептонных резонансов с низким порогом минимального Pt лептона (В.А. Щегельский + группа Новосибирска). Предварительные исследования представлены на сессиях УС ОФВЭ в 2012 и 2013 гг. Текущие результаты докладывались на заседаниях соответствующей рабочей группы АТЛАСа. Идет подготовка внутренней ноты

Официальный результат ATLAS
Nobs/Nth = 22.9/13.8
R=1.66±0.16±0.17



Nobs/Nth = 77/24.5
R=3.02±0.12±0.31



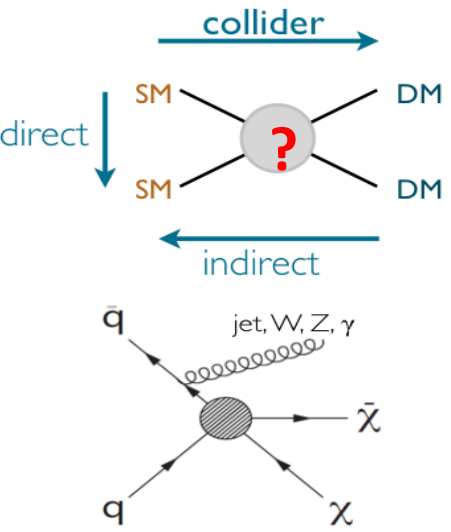
Significant deviation from SM theory predictions

Заключение

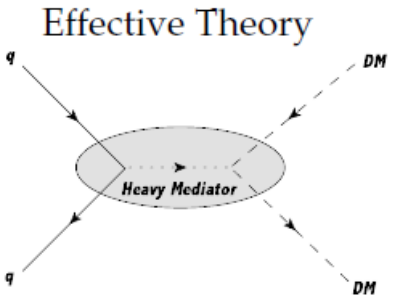
- Физическая программа в которой участвует ПИЯФ в ATLAS:
  - search W'/Z', mono-W, Z-boson polarization, H->4l
- Развитие и поддержка s/w эксперимента ATLAS:
  - validation of electron/photon reconstruction and identification s/w;
  - TRT digitization s/w;
  - ATLAS geo model;
  - ATLAS fast simulation – FATRAS;
  - MCTruthClassifier.
- Детекторы:
  - TRT - ремонт, модернизация газовой системы.
  - Pixel - сборка новых NSQ панелей, s/w для DCS
- ПИЯФ также участвует в TDAQ и DCS (группа проф. Ю.Ф.Рябова).

BACK UP SLIDES

Dark Matter search (WIMP) - mono-W



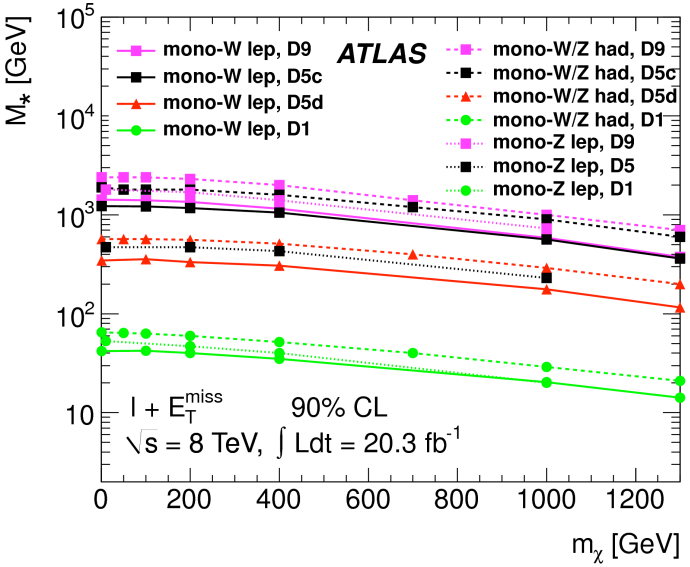
- DM itself invisible to detector
- Need something to tag/trigger on
- Unbalanced reconstructed object =>missing transverse energy (ETmiss)
- What is ?
  - assume: interaction mediated by a new particle too heavy to be directly produced @LHC
  - effective field theory approach (contact interaction)
  - suppression scale of effective theory: M*
- limits on M* can be translated into (upper) limits on WIMP-Nucleon scattering cross section

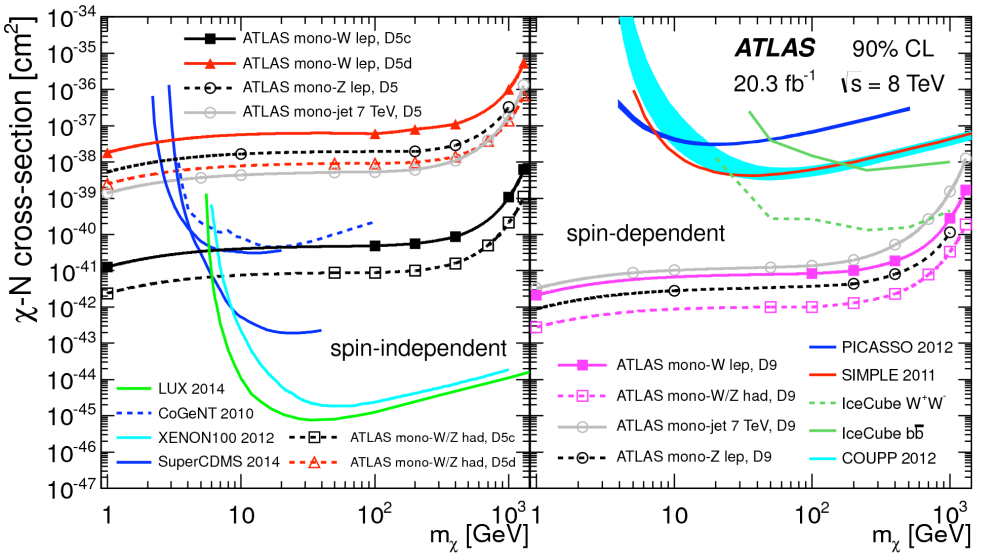


$$M_* \sim \frac{M}{\sqrt{g_\chi g_{SM}}}$$

spin-independent interaction: collider competitive at small masses

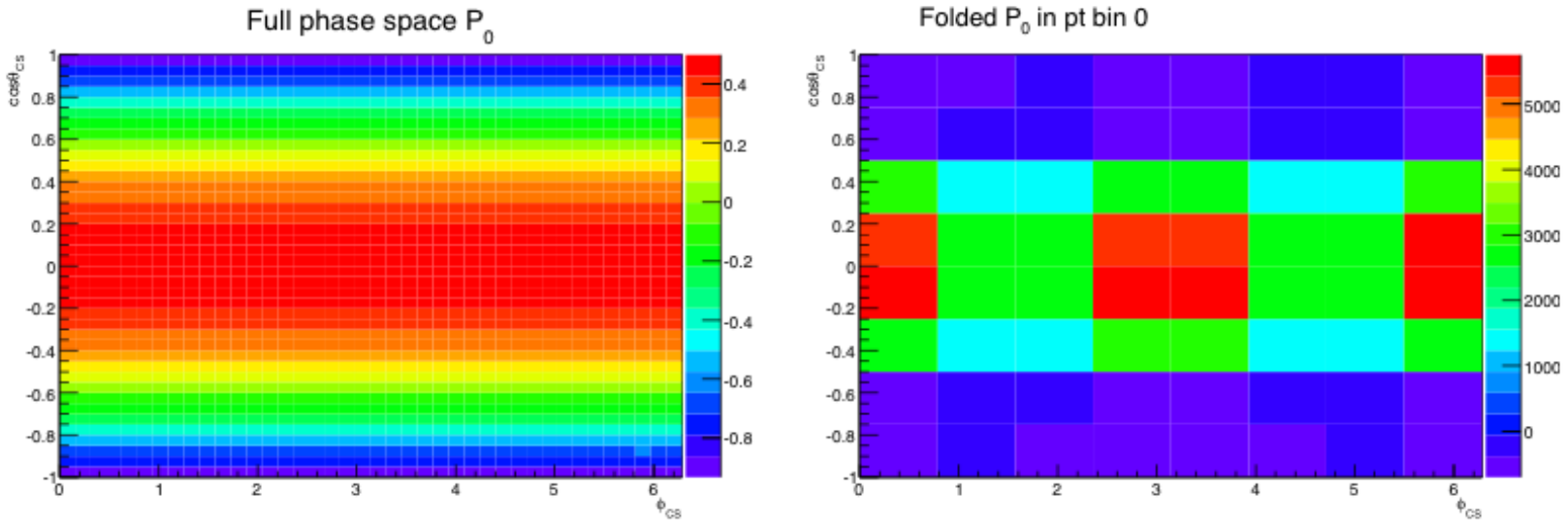
spin-dependent interaction: collider competitive over large mass region





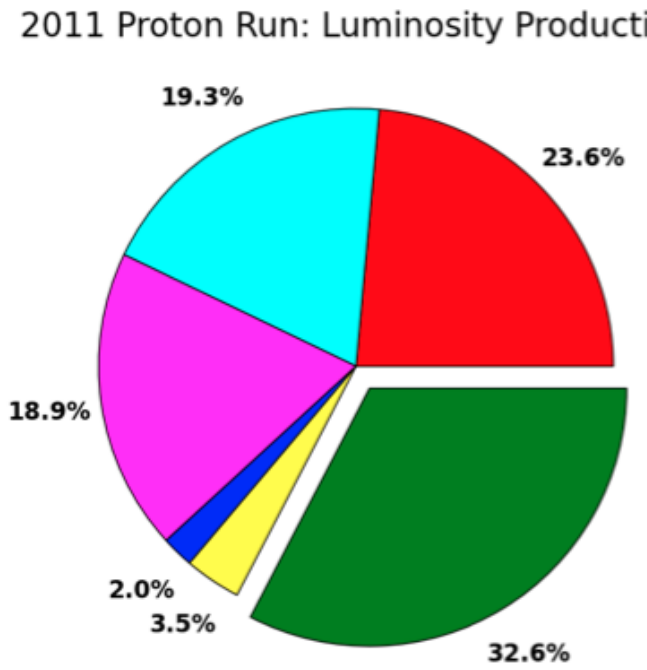
- D1: $\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
- D5(2): $\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
- D9: $\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$

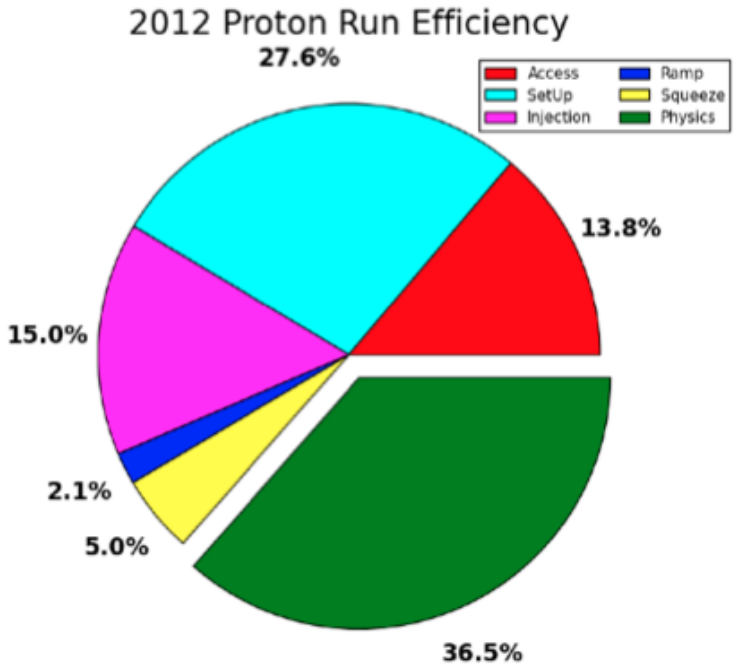
Measurement methodology



- Use MC to fold polynomials Pi from full phase space to reco distribution to obtain template signal histograms for each Pi in slices of p^Z_T
- Start by reweighting distribution to be flat in $\cos\theta_{CS}$, φ_{CS}, then weight this distribution by characteristic polynomials
  - $w_{ij}^{evt} = P_i w^{MC} / \left(P_8 + \sum_{k=0}^{7} A_{kj}^{ref} P_k\right)$ (diff weight for each p^Z_T bin j)
  - This convolutes Pi with acceptance, efficiency, and migration
- Templates T_{ij} ($\cos\theta_{Reco}$,φ_{Reco},$pZ_{,Reco}$) built from w^{evt}_{ij} are scaled by coefficient parameters A_{ij} , which are eventually fit in likelihood maximization

Эффективность работы LHC - Run I



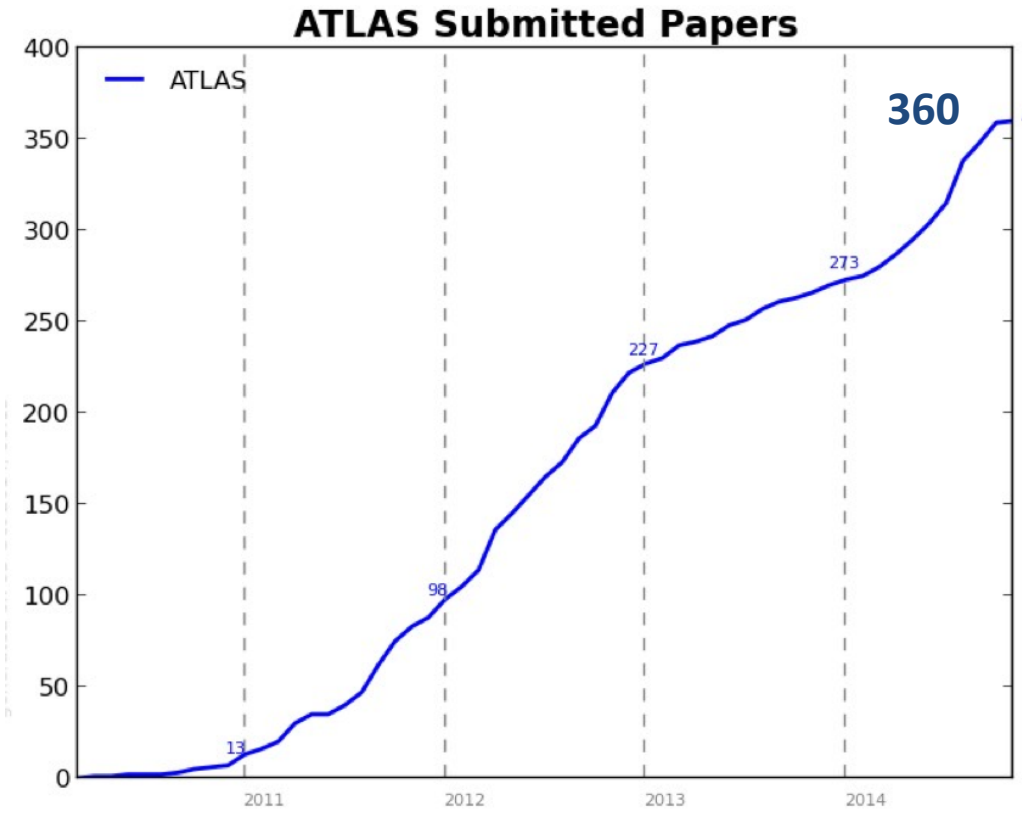


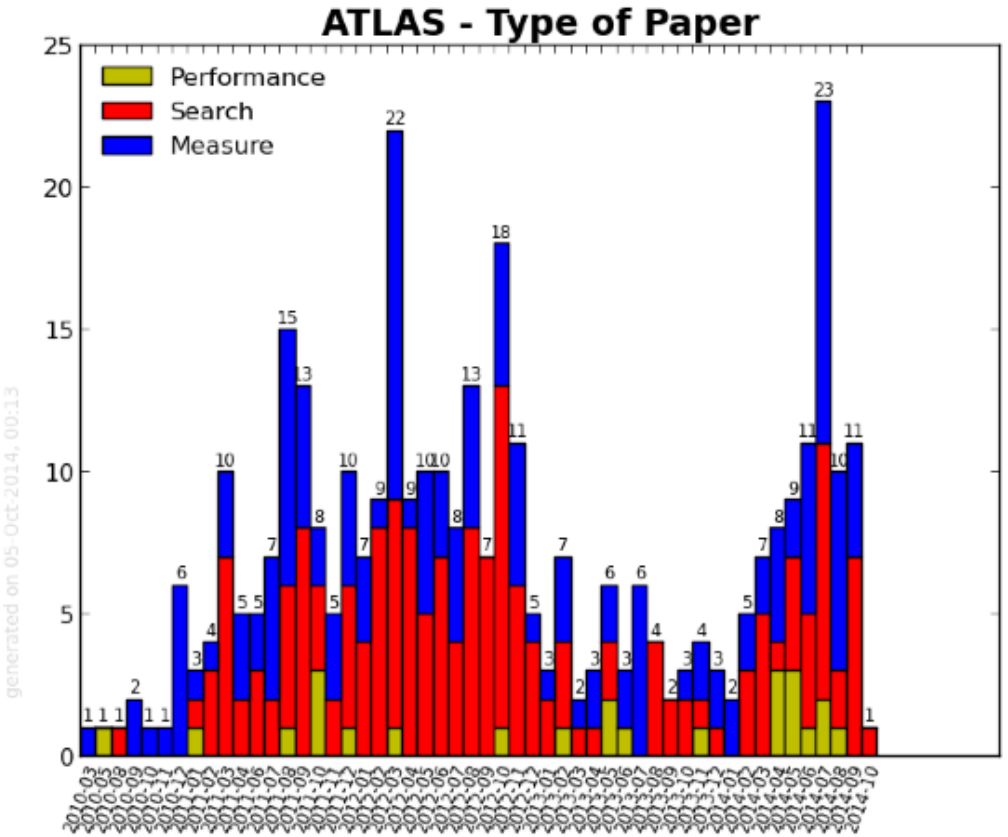
Полное время работы LHC: 81.4 дня
физика: 26.6 дня
Интегральная светимость: ~ 5 фб$^{-1}$

Полное время работы LHC: 200.5 дня
физика: 73.2 дня
Интегральная светимость: ~ 21 фб$^{-1}$

ATLAS publications

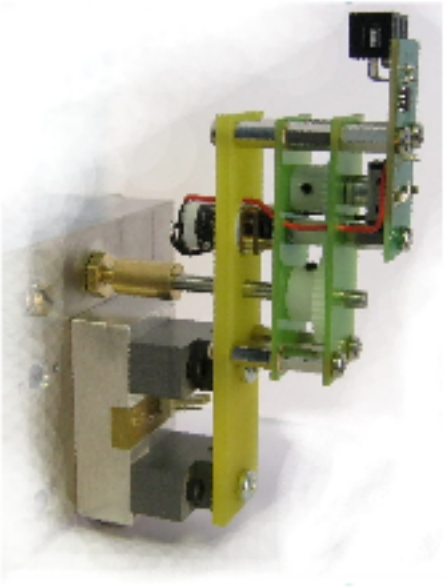
- ~200 more of remaining run-1 papers (~50 from the search groups)
- 689 conference talks allocated so far in 2014

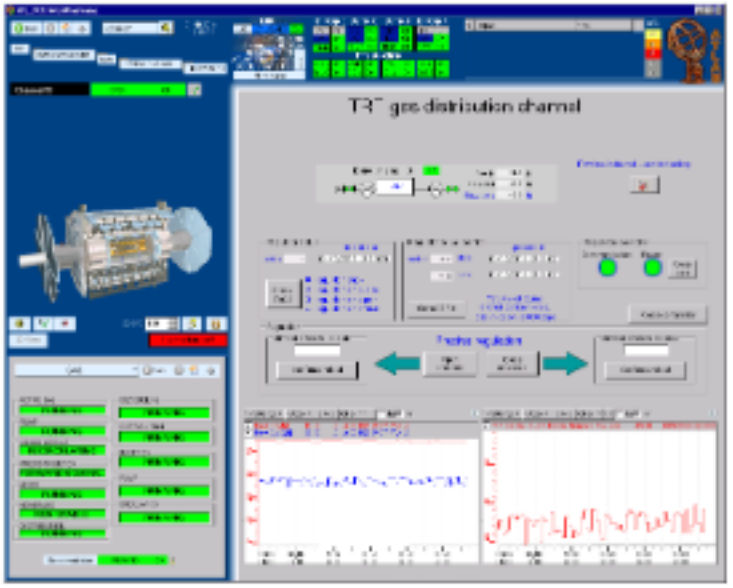




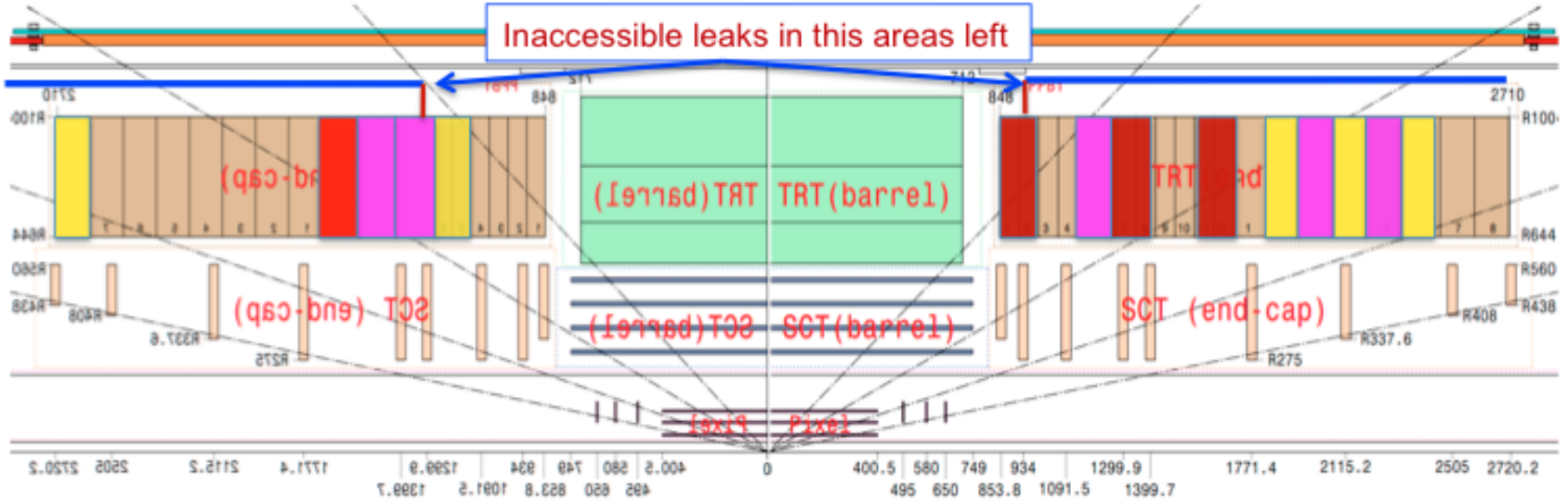
TRT remote gas regulation

- New system for remote gas flow regulation and DCS control deployed during LS1
- Production of regulators finished and installed in the distribution racks in UX15
- Cabling (power, ethernet) finished
- Remote control software developed, DCS FSM panel finished
- Tests for tuning/debugging ongoing: tests with CF4 (similar to Xe), calibration for zero loss (output flow=input flow) with Ar mixture, etc.





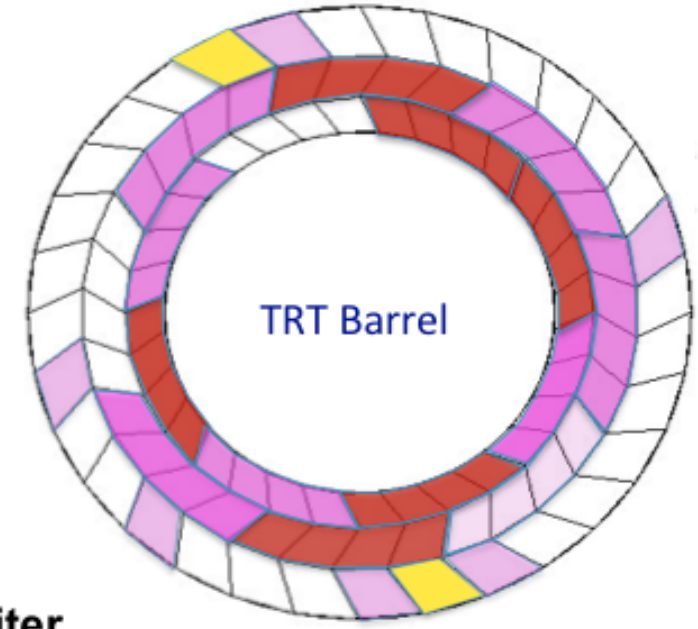
TRT gas leaks: status after LS1 repairs



Leaks at 8 mbar of overpressure

- 0.02-0.1 l/h
- 0.10-2 l/h
- 2-10 l/h
- >10 l/h

Xe cost ~16 CHF/liter



NOTE!

- **PINK** modules are the next candidates to become **RED.**
- **Barrel:** there are 8 PEEK pipes per gas supply line (layers 0 and 1) and any of them can develop leak.
- **Lines with very big leaks or with multiple leaks are not possible to control.**