JINR in CMS upgrade and physics programs

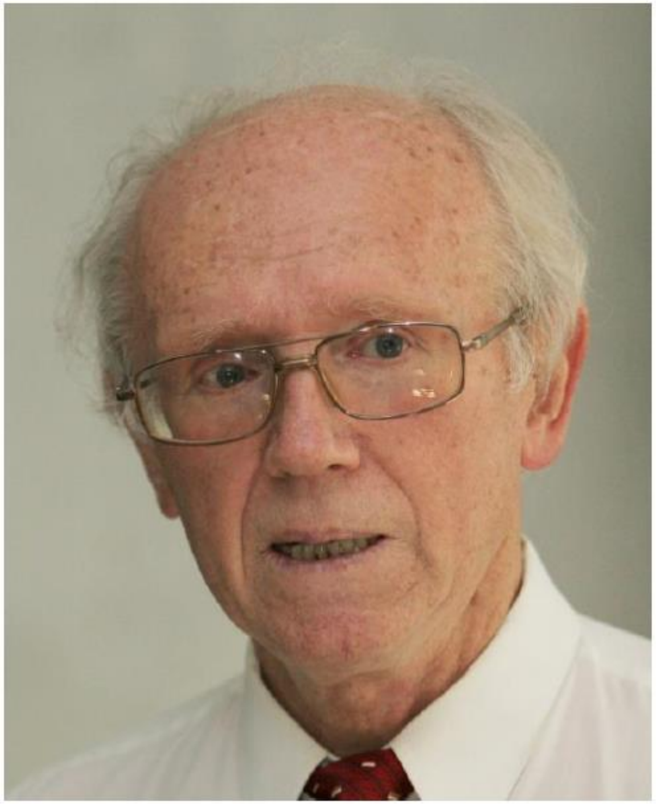
S. Shulga
on behalf of the JINR CMS group

JINR (Dubna, Russia)
on leave of GSU (Gomel, Belarus)

"LHC Days in Belarus 2018"
Institute for Nuclear Problems of Belarusian State University,
Minsk, Belarus,
26-28 February, 2018

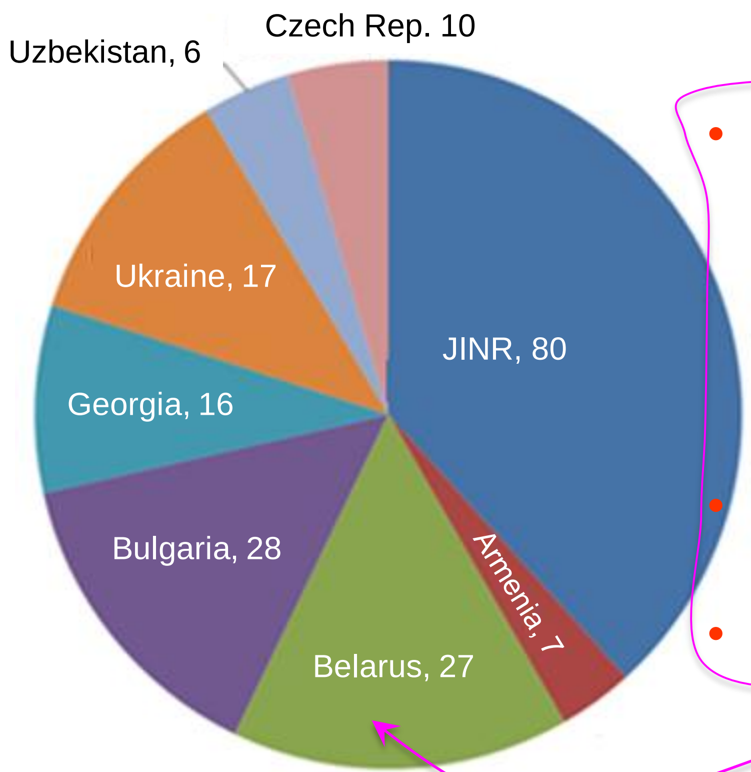
Contents

The report is dedicated to the memory of prof. N. M. Shumeiko, one of the founders of the CMS project, RDMS collaboration, one of the CMS constructors and developer of the CMS physics program.



See also seminar dedicated to the memory of prof. N.M. Shumeiko
and his 75th birthday, JINR (Dubna), September 20, 2017 http://rdms.jinr.ru/section.aspx?id=56

RDMS CMS collaboration - 2018



- Institute for Nuclear Problem, BSU, Minsk: Baryshevsky V., Budkovski D., Bugaevskaya M., Chekhovsky V., Drobychev G., Drugakov V., Dvornikov O., Dydyshka Y., Emeliantchik I. , Federov A. , Korzhik M., Litomin A., Lobko A., Makarenko V., Mechinsky V., Missevitch O., Mossolov V., Panov V., Stefanovich R., Suarez Gonzalez J., Yermak D., Yermolchyk E., Yevarovskaya U., Zuyeuski R.
- Research Institute for Applied Physical Problems, BSU, Minsk: Kuchinsky P.
- BSU, Minsk: Petrov V., Prosolovich V.

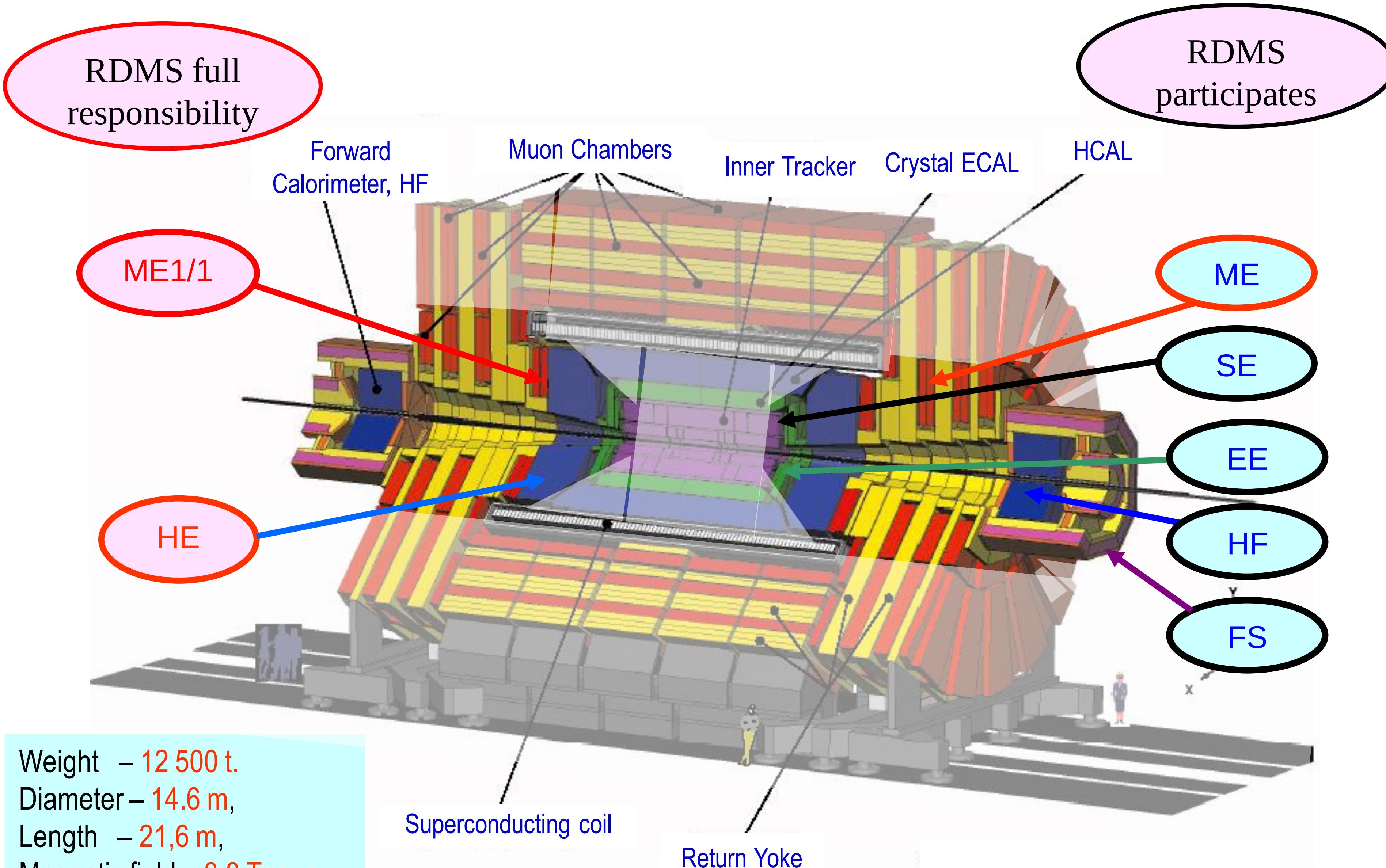
- 111 participants from Dubna Member States, including 27 from Belarus
- 80 participants from JINR, including 2 from Belarus
  Shulga S., Zykunov V.

- 14(10) paid authors and 4(1) unpaid authors (Ph.D.) from JINR(DMS)



RDMS in CMS Upgrade Program

RDMS in CMS Construction



Weight – 12 500 t.
Diameter – 14.6 m,
Length – 21,6 m,
Magnetic field – 3.8 Тесла

LHC/HL-LHC Plan

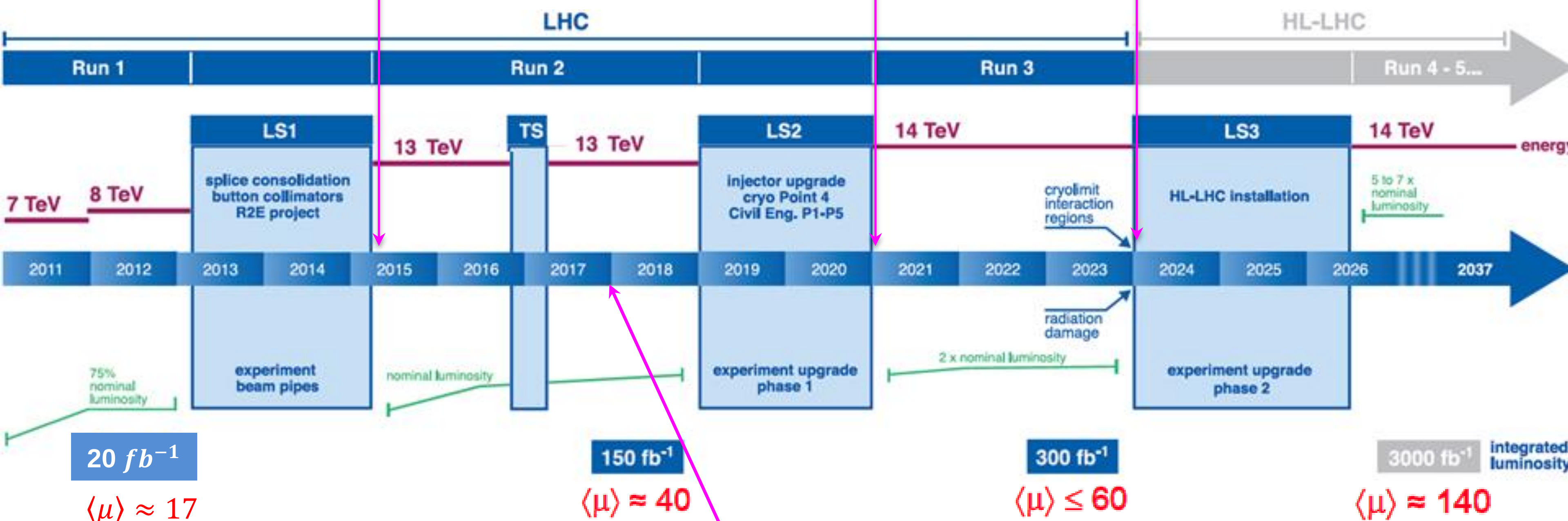
CMS Upgrade Phase 1

ME Upgrade

HE Upgrade

CMS Upgrade Phase 2

R&D for calorimetry



Total luminosity in Run-2:

2016 – $39\ fb^{-1}$

LHC delivered 2017 – $51\ fb^{-1}$

CMS Recorded – 90%

$L_{max} \approx 2.2 \cdot 10^{-34}\ cm^{-2}s^{-1}$

Operation efficiency:

HE – ~ 100%

ME – ~ 98.5%

$\langle\mu\rangle$ - mean pile-up

TS - Technical Stop

LS – Long Shutdown

RDMS in CMS Upgrade Phase I

❖ Endcap Muon stations

2015

- ❑ Readout electronics upgrade:
  72 chambers were extracted, re-instrumented, tested & reinstalled
  - recover trigger up to eta=2.4
  - minimize readout dead time and improve rate capabilities
  - readout robustness: optical readout instead of 50-pin scewclear cables
- ❑ Joint US-RDMS new electronics project
  - LV and interfaces (Dubna, Minsk)
  - Dubna, Minsk responsibility to re-install CSC with new electronics

❖ Endcap Hadron calorimeter

- ❑ Readout electronics upgrade – PDs replacement with SiPMs:
  36 sectors were fully reworked, tested & commissioned

2015

- RBX (readout boxes) are made in Minsk – for tests of new HCAL electronics in CERN
- RM (readout modules) are made in Minsk
- increase dynamic range, rate capability, sub-ns timing, muonID: SiPM instead of HPD

2019

- Update longitudinal segmentation to increase Particle Flow capability and 1-level HW trigger with new electronics
- Optimize ECAL/HCAL interface
- RDMS responsibility to install new phototransducers, front-end and back-end electronics

Preparation for the Phase II of CMS Upgrade

❖ Endcap Muon stations

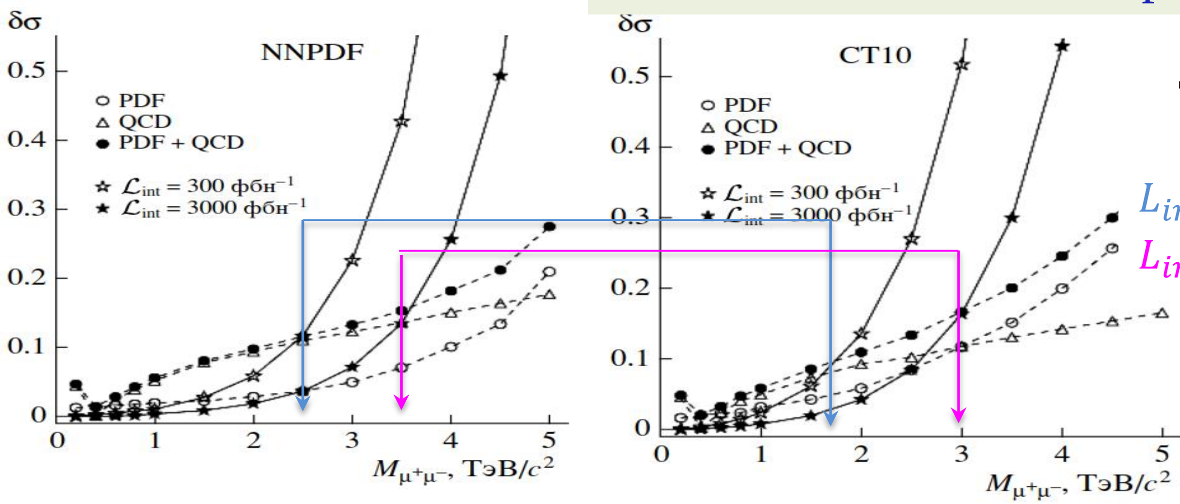
- Study of the aging of detectors was performed on the GIF++, CERN. ME1/1 station is capable to operate at HL LHC conditions. Only slightly decrease (by 8%) the spatial resolution of ME1/1.
- Radiation hardness of electronics was investigated at CHARM (CERN).
- New LVDB5 boards designed for MEx/1 (x=2,3,4), 2 prototypes tested
- New segment building algorithm for Cathode Strip Chambers was developed

❖ Endcap Hadron calorimeter

- Development of a finger-strip plastic scintillator option
- Study of the plastic scintillator damage caused by radiation on IREN
- Light yield measurements of "finger" structured and unstructured scintillators after gamma and neutron irradiation.
- Experimental study for possibility of using SiPM after hard neutron irradiation
- Measurement of absorbed dose by film dosimeters in two layers of the HE calorimeter.
- Determination of safe working conditions with irradiated megatile elements during its upgrading
- Development and construction of HGCAL

Preparation of Physics Program for HL-LHC

❖ Theoretical uncertainties of Drell-Yan muon pair production are examined

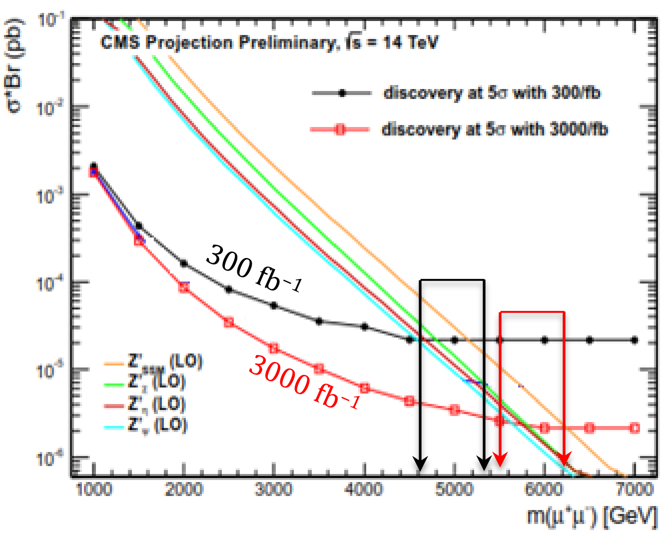


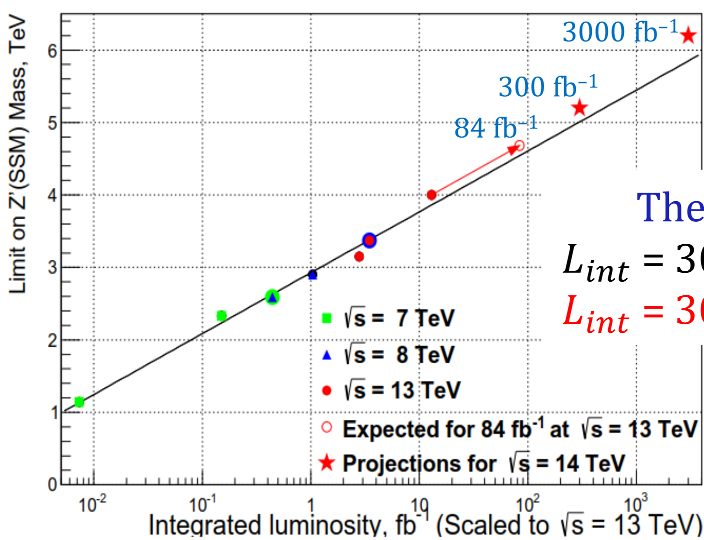
Theoretical uncertainty is more than statistical ones:

L_{int} = 300 fb^{-1} : $M_{\mu^+\mu^-} < 1.8 \div 2.5$ TeV

L_{int} = 3000 fb^{-1} : $M_{\mu^+\mu^-} < 3.0 \div 3.5$ TeV

❖ Observability of New Physics phenomena at the HL-LHC is studied



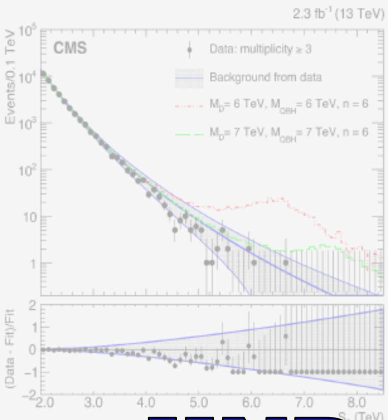


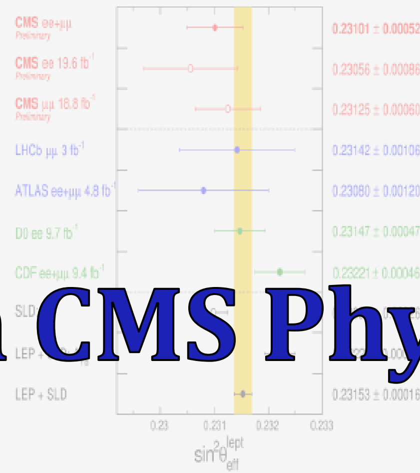
The expected Z'-mass limits:

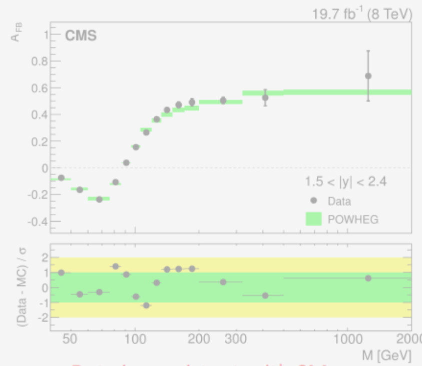
L_{int} = 300 fb^{-1} : 4.6 ÷ 5.2 TeV

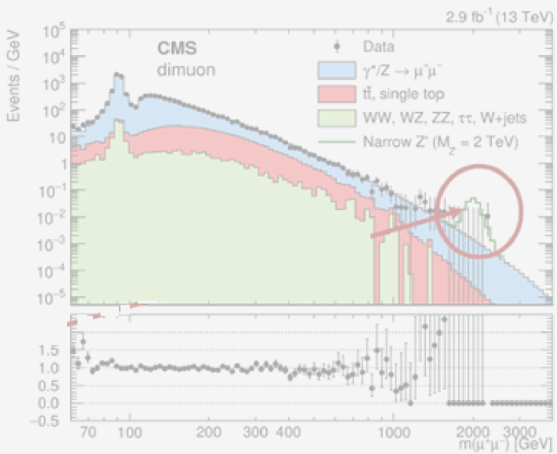
L_{int} = 3000 fb^{-1} : 5.6 ÷ 6.2 TeV

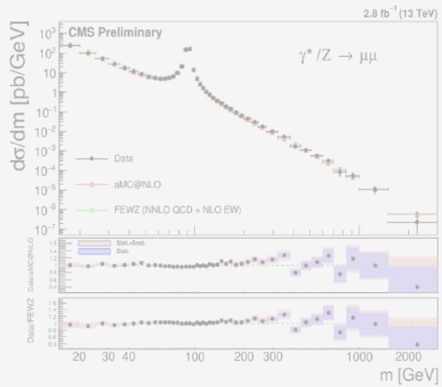
JINR in CMS Physics Program











Outline

❑ Standard Model Tests

- ✓ Physics with high-mass dimuons
  - [1] DY study in TeV energy region
  - [2] Forward-backward asymmetry
  - [3] Weinberg angle
- ✓ Jet physics
  - [4] Charged-particle multiplicity in jets & quark and gluon jet fractions

❑ Search for new physics beyond the SM

- [5] Physics with dimuons (Z’, KK modes of gravitons)
- [6] New physics in multijet channel (microscopic black holes, string balls)

Drell-Yan Study: Standard Model and Beyond

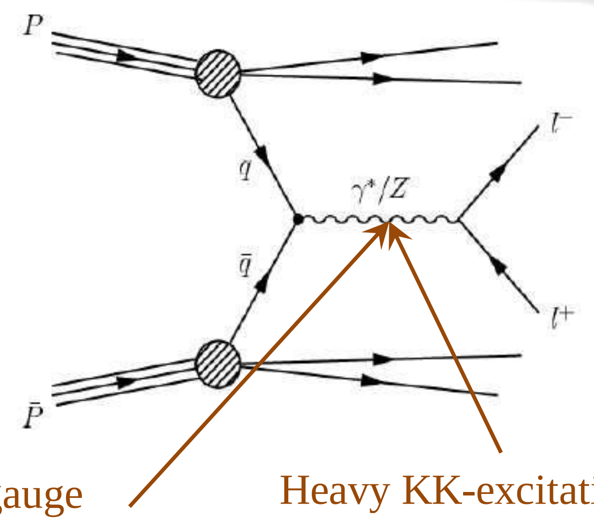
The history-steeped JINR group analyses direction for the CMS:
the long way from 2002 to 2018, from physics motivation through Physics TDR 2006 up to the newest results and papers of the Run II. The work is updating permanently.

- ❑ Study of DY process to verify the SM
  - ✓ Cross-sections vs invariant mass (including HO corrections, PDF etc.)
  - ✓ Angular distributions (helicity structure of processes)
  - ✓ Forward-backward asymmetry
  - ✓ Weak-mixing angle

- ❑ New Physics (NP) and new particles in virtual exchange channel – contributions to DY
  - ✓ Cross-sections (NP mass limits, energy scale limits, couplings, etc.)
  - ✓ Angular distributions (NP spin)
  - ✓ Asymmetry (NP models)

Young participants from JINR and Belarus

I. Gorbunov	(PostDoc, JINR)
U. Yevorovskaya	(PhD, Minsk)
Y. Dydyshka	(PhD, JINR/Minsk)
V. Yarmoltchik	(PhD, Minsk)
V. Shalaev	(MSc, JINR)
I. Zhizhin	(MSc, JINR)
M. Bugaevskaya	(BS, Minsk)



Extra gauge bosons Z' (spin-1 state)

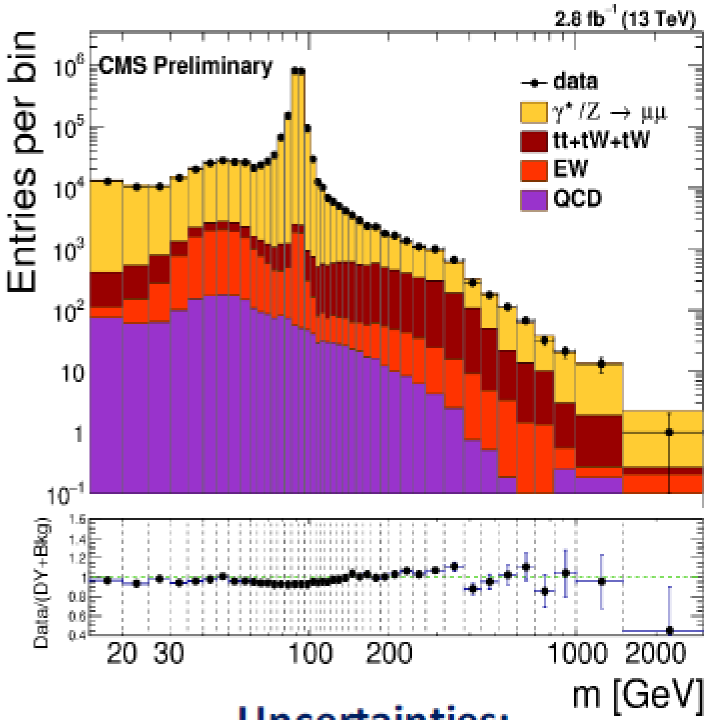
Heavy KK-excitations of gravitons (spin-2 state)

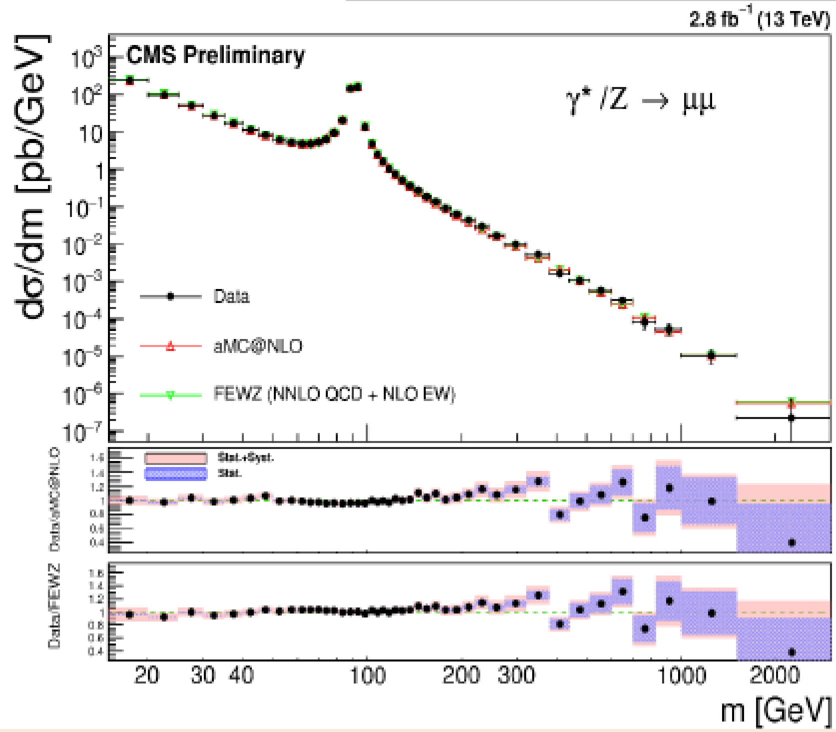
[1] Drell-Yan: Cross-Section @ 13 TeV

Background:
EWK – from MC
QCD – from MC + estimation from data

$15 < M_{\ell^+\ell^-} < 3000$ GeV

CMS-PAS-SMP-16-009,
CMS-PAS-SMP-17-001





Uncertainties:

efficiency (1.1-2.1%), background (K-factor and PDF) (3.6-10%), unfolding (up to 1.7 %), FSR (up to 2%), other (up to 3%), acceptance (up to 2.2 %)

Good agreement of the CMS Data and the SM predictions:
aMC@NLO and NNLO QCD + NNPDF3.0 (FEWZ) + MSTW08 PDF ->
aMC@NLO and FEWZ (NNLO QCD + NLO EW) + MSTW08 and NNPDF3.0 PDF

1 young PostDoc +1 MSc + 1 PhD St (from JINR)

Results for ~ 36 fb^{-1} is ready
Collaboration approval is in progress

[2] Drell-Yan: Forward-Backward Asymmetry

$$\frac{d\sigma}{d(\cos\theta^*)} = \frac{1}{2\left(1+\frac{b}{3}\right)}\left(1+b\cos^2\theta^*\right)+A_{FB}\cos\theta^*$$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3B}{8A}$$

$$\sigma_F = \int_0^1 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta)$$

$$\sigma_B = \int_{-1}^0 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta)$$

AFB value is sensitive to contribution both vector and axial-vector couplings

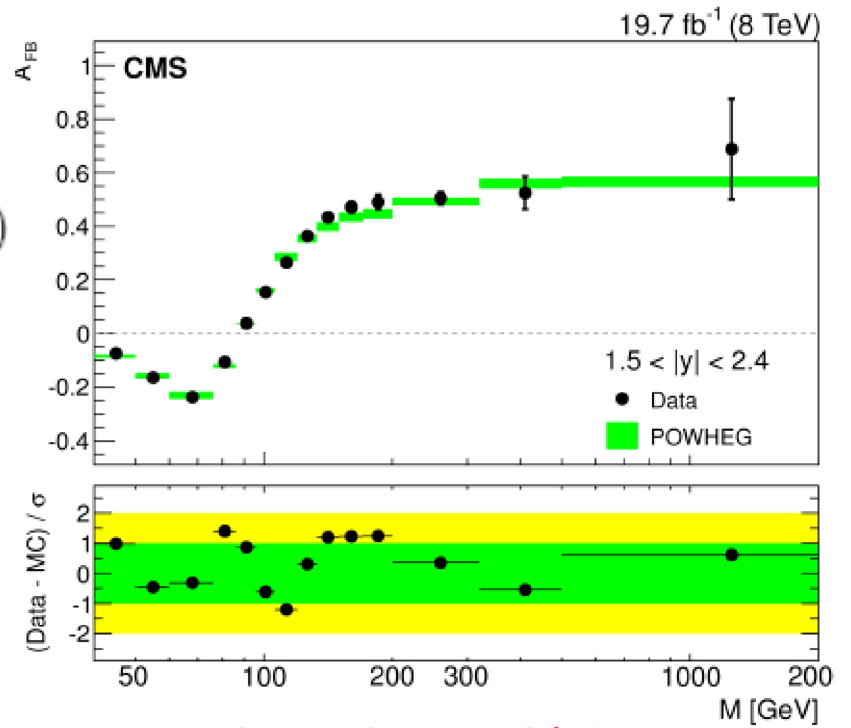
⇒ **Test of SM / new physics**

"Dilution" asymmetry measurements:

- bin-to-bin migration due to finite detector resolution
- Final-State-Radiation (FRS)
- acceptance cuts
- unknown quark/antiquark direction for the LHC

1 MSc + 1 PhD St (from JINR) and 1 MSc + 1 PhD St (from Minsk)

EPJ. C 76 (2016) 325, CMS AN-2017/155



Data is consistent with SM

Results for ~ 36 fb^{-1} at 13 TeV is coming soon

Special focus on development tools for EWK corrections (JINR + Minsk)
See talk V.Zykunov

[3] Drell-Yan: Extraction of Weak Mixing Angle

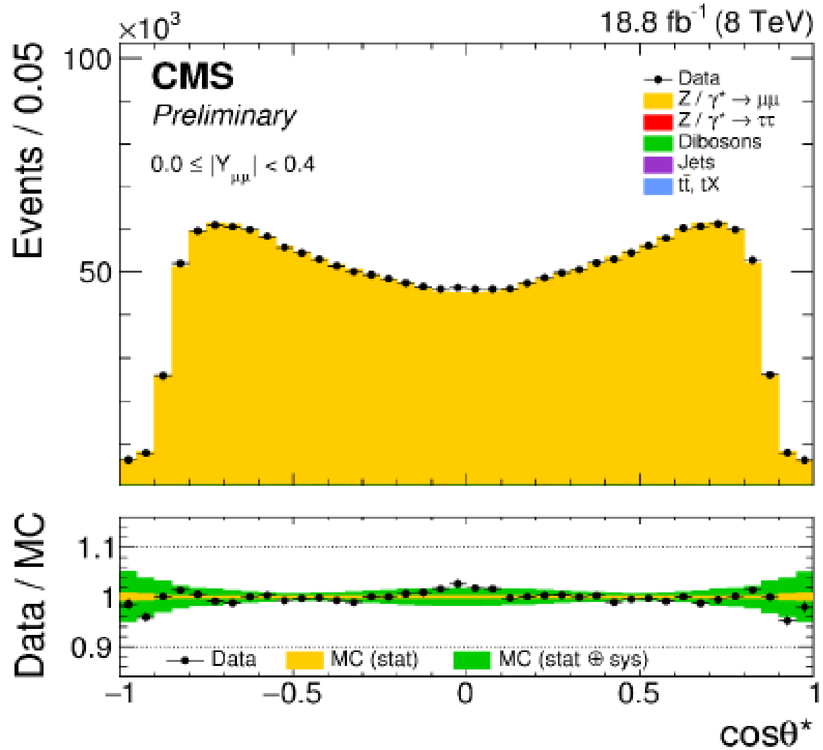
Drell-Yan yield = F [lepton angular ($\cos\theta_{CS}$), dilepton rapidity (Y), dilepton mass (s)]

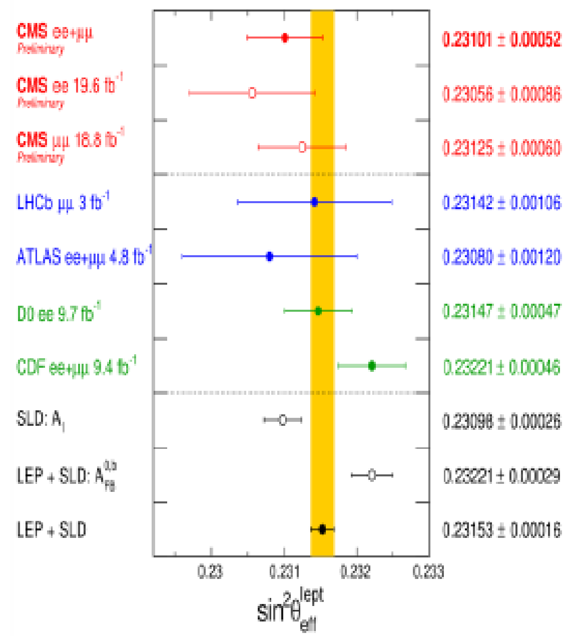
$$\frac{d\sigma_{pp\to l^+l^- X}(Y, s, \cos\theta^\star_{CS})}{dY\ ds\ d\cos\theta^\star_{CS}} \propto \sum_{q=u,d,s,c,b} [\hat{\sigma}^{even}_{q\bar{q}}(s, \cos^2\theta^\star_{CS}, \sin^2\theta_{eff}) +$$

$$D_{q\bar{q}}(s, Y) \times \hat{\sigma}^{odd}_{q\bar{q}}(s, \cos\theta^\star_{CS}, \sin^2\theta_{eff})] \times F_{q\bar{q}}(s, Y)$$

dilution factor
(reflects the fact that the quark direction is generally unknown and
is taken as the boost direction of the dilepton system)

parton factor
(takes into account flavour-dependence)





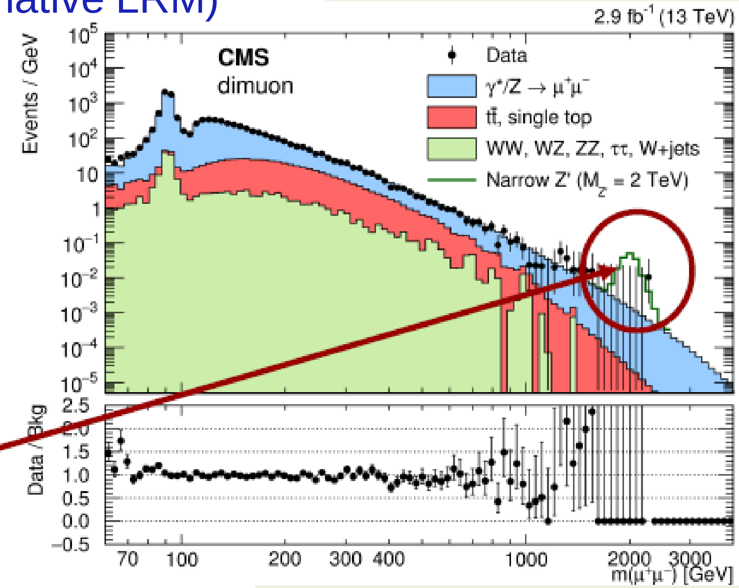
CMS-PAS-SMP-16-007

$$\sin^2\theta^{lept}_{eff} = 0.23101 \pm 0.00036(\text{stat}) \pm 0.00018(\text{syst}) \pm 0.00016(\text{theory}) \pm 0.00030(\text{pdf})$$

[5] Z' from Extended Gauge Sector @ 13 TeV

- Extended Gauge Sector (EGS) models based GUT E6 or SO(10)
- Left-Right Symmetric Models (LRM and ALRM - Alternative LRM)

CMS PAS EXO-16-031



Full interference with Z^0 at the amplitude level:

$$A_{ij} \equiv A(f\bar{f} \to l^+l^-) = -Qe^2 + \frac{\hat{s}}{\hat{s} - M_Z^2 + iM_Z\Gamma_Z} C_i^Z(f)C_j^Z(l) + \frac{\hat{s}}{\hat{s} - M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}} C_i^{Z'}(f)C_j^{Z'}$$

1. η, ψ and χ EGS models:

$$E_6 \to SO(10)\times U(1)_\psi \to SU(5)\times U(1)_\chi \times U(1)_\psi$$

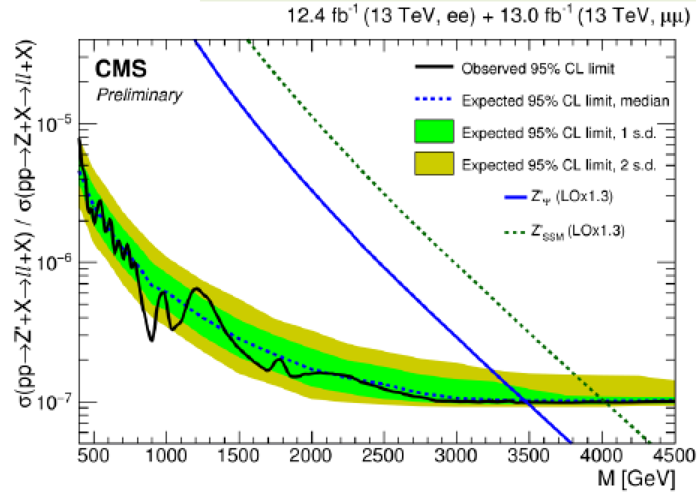
$$g_{Z^0}\left(\frac{g_{Z'}}{g_{Z^0}}\right)(Q_\chi \cos\theta_{E_6} + Q_\psi \sin\theta_{E_6}) \qquad -\frac{\pi}{2} \le \Theta_{E_6} \le \frac{\pi}{2}$$

2. LRM and ALRM EGS models:

$$SO(10) \to SU(3) \times SU(2)_L \times SU(1)_R \times U(1)_{B-L}$$

$$g_{Z^0}\frac{1}{\sqrt{1-(1+\kappa)\sin\theta_W}}[\sin\theta_W T_{3L} + \kappa(1-\sin\theta_W)T_{3R} - \sin\theta_W Q]$$

Phys. Lett. B 768 (2017) 57



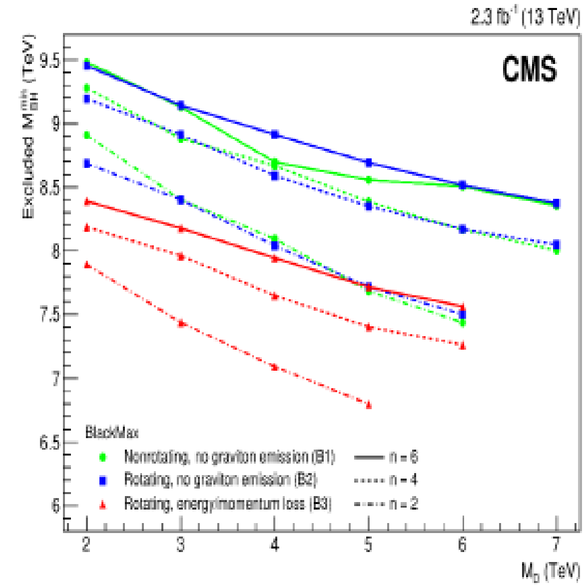
- Z' with SM-like couplings is excluded below 4.0 TeV
- The superstring-inspired Z' is excluded below 3.5 TeV

1 MSc (from JINR)

[6] Black Holes: New Limit @ 13 TeV

Phys. Lett. B 774 (2017) 279

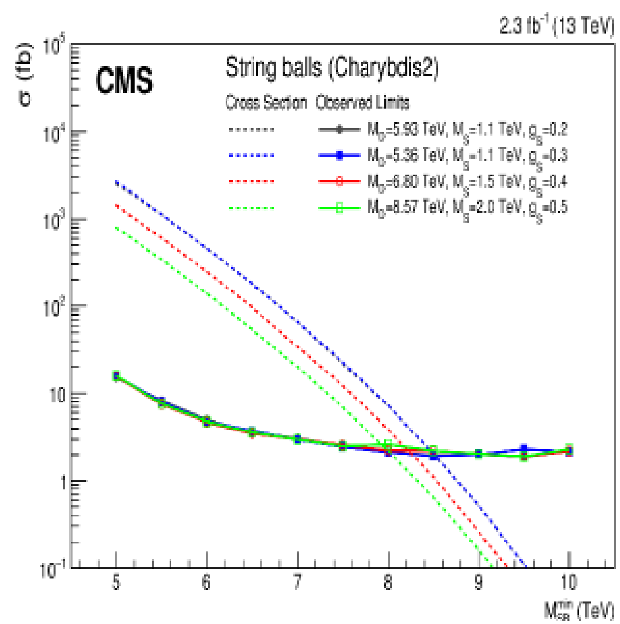
- ✓ we exclude minimum semiclassical BHs masses below 7.0–9.5 TeV
- ✓ lower limits on the minimum quantum BH mass span the 7.3–9.0 TeV range for the ADD (n >2) and 5.1–6.2 TeV range for the RS1 (n=1)
- ✓ for the case of the string balls, the mass exclusion limits reach 8.0–8.5 TeV

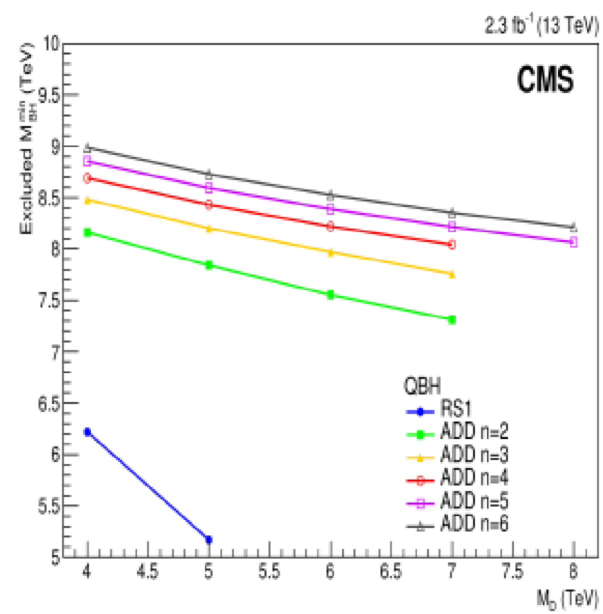


Use Charybdis, BlackMax, QBH generators to realize the different theoretical scenarios

Results (Black Holes and Sphaleron) for 35 .9 fb^{-1} is ready, collaboration approval is in progress

1 PhD + 1 MSc (from JINR)
+1 PhD + 1 MSc (from Erevan)





Jet physics
in CMS Dubna Group

This analysis was initiated in 2013 together with
Viktor Konoplianikov
(JINR, Dubna & GSU, Gomel, Belarus).

V.F. Konoplianikov
(1.01.1957-7.04.2014)

Observables

- We want to measure the **mean jet CPM** (Charged-Particle Multiplicity) for jet samples selected in different channels and selection conditions (kinematical regions)

- **Mean Jet CPM** in jet sample is defined by (in order of importance)
  - ✓ Gluon Jet fraction (because $r = \frac{\langle n^{(g)} \rangle}{\langle n^{(q)} \rangle} \approx 1.6 - 1.8$, parton level, *pQCD*)
  - ✓ *pQCD* evolution of parton shower
  - ✓ Factor K associated with the transition from the parton level to the hadron level $r^{parton} \approx K \cdot r^{hadron}$.

- Therefore, two ***correlated observables*** should be considered together for ***given jet sample***:

Gluon Jet Fraction and *Mean Jet CPM*

[1]**C**PM - **C**harged-**P**article **M**ultiplicity

Ratio $\frac{\langle n^{(g)} \rangle}{\langle n^{(q)} \rangle}$ at parton (pQCD) and hadron level (e^+e^-)

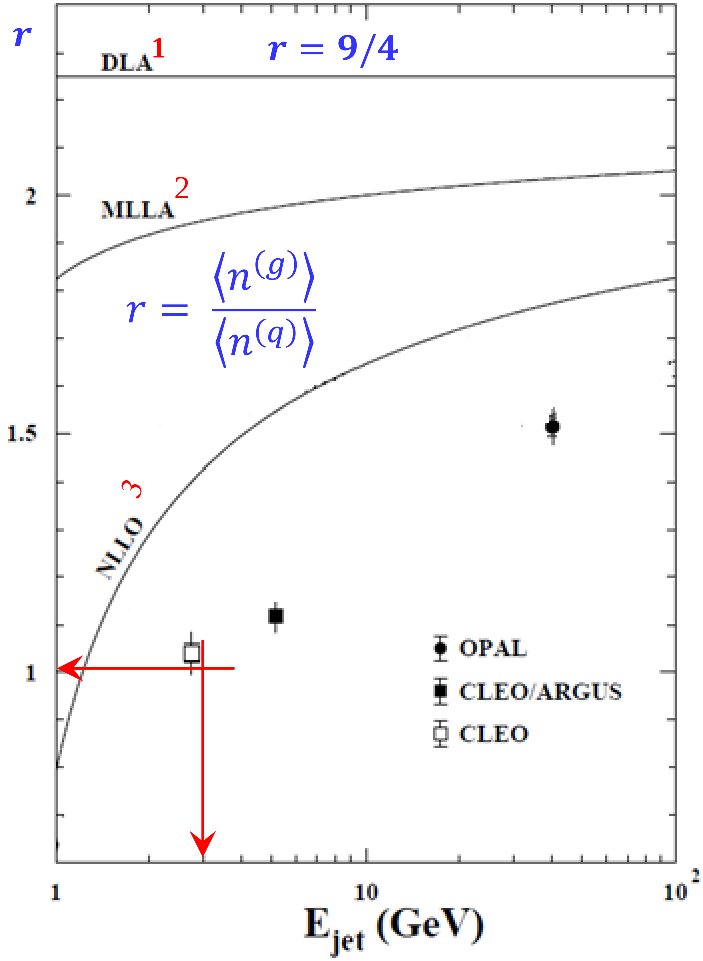


Fig.: QCD analytic predictions and e^+e^--experimental results for r. Results of HERWIG at parton and hadron level .

From I.M. Dremin, J.W. Gary, Phys. Rept. **349** (2001)

- The ratio r is of interest because the main *energy dependence* of the mean multiplicity in q/g-jets is *cancels*
- r is *sensitive to the order of pQCD approximation*

- In region $E_{jet} < E_{jet}^{min} = 3$ **GeV** quark and **gluon jets are unrecognizable** at hadron level: $r^{hadron} \sim 1$

❖ In pp collisions jets are reconstructed efficiently starting from $E_{jet} \sim 10$ GeV and **we expect** that in pp collisions we will have a **good recognition of gluon jets**…

[1]Double Logarithmic Approximation (**DLA**)
[2]Modified Leading-logarithmic Approximation (**MLLA**)
[3]Next-to-Next-to-Leading Oder Approximation (**NNLO**)

Ratio $\frac{\langle n^{(g)}\rangle}{\langle n^{(q)}\rangle}$ in $p\bar{p}$ and pp collisions

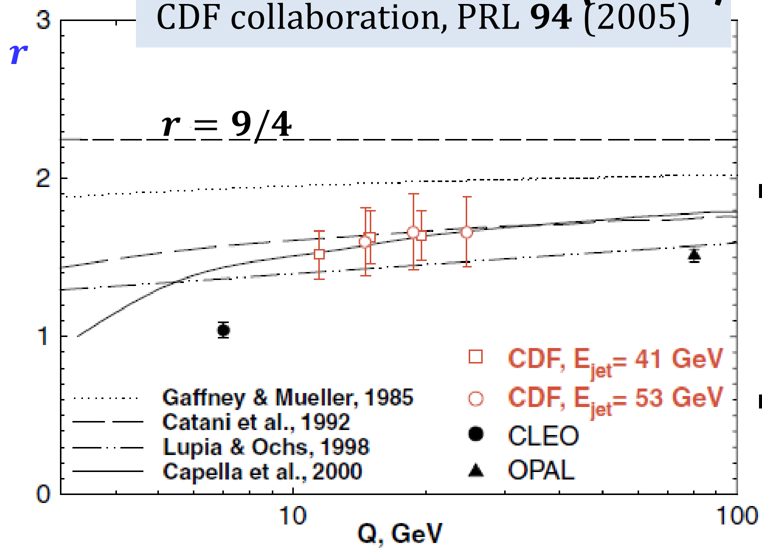


Fig.: CDF measurements of r as a function of jet hardness $Q = E_{jet}\Theta_c$: $E_{jet} = 41$ and $52.5\ GeV$, jet cone sizes $\Theta_c = 0.28, 0.36, 0.47$ rad). $p\bar{p}$-collisions, $\sqrt{s} = 1.8\ TeV$.

$$r = \frac{\langle n^{(g)}\rangle}{\langle n^{(q)}\rangle}$$

- In region $E_{jet} \in [40,50]$ GeV: very large r^{hadron}:

$$\Longrightarrow K \equiv \frac{r^{parton}}{r^{hadron}} \approx 1.$$

- It is not clear how to understand this result: "parton-hadron duality" is confirmed at E_{jet}~45 GeV?

To find q/g-jet CPM's two samples are used: *dijet* and $\gamma + jet$.

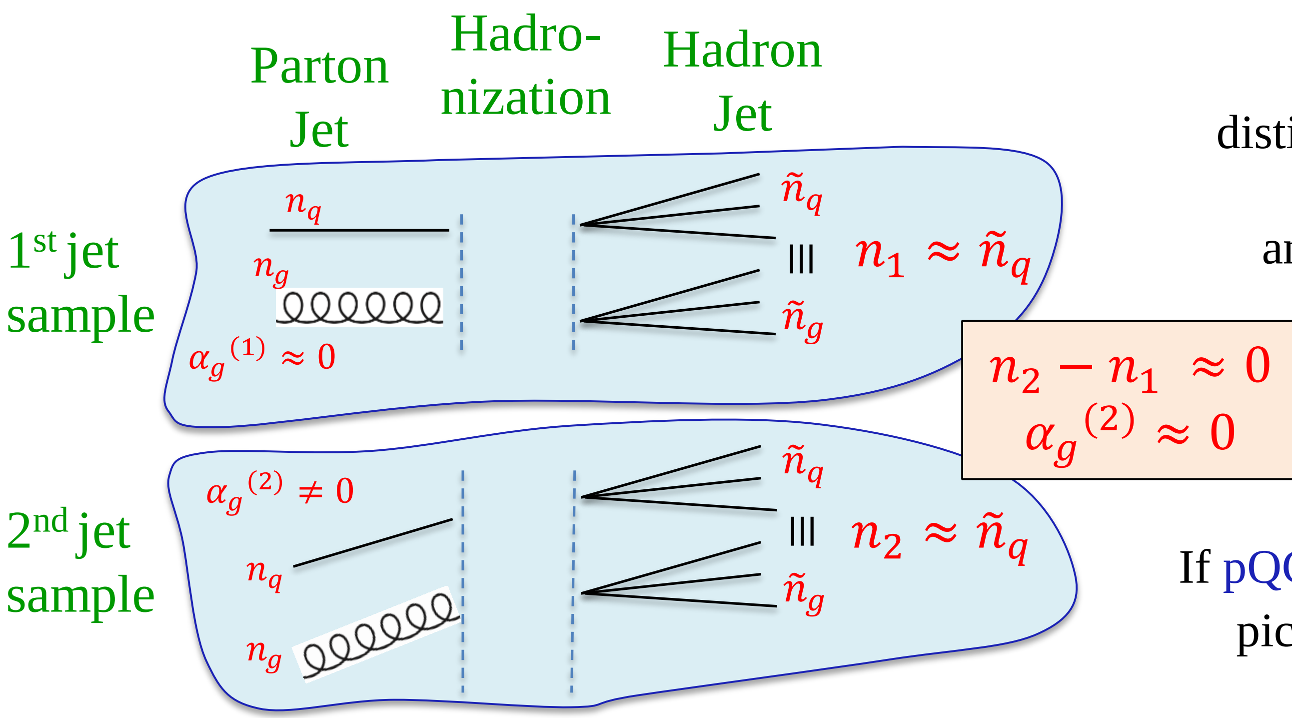
The first task of our analysis is precision measurement of *jet CPM's* in region $P_T{}^{jet} \in [30, 300]$ GeV. These region covers the region of CDF measurements.

Measurement of q/g-jet CPM ($P_T{}^{particle} < 0.5$ GeV) in region $P_T{}^{jet} \in [0.1, 1.2]$ TeV **(Run-I)**

ATLAS collaboration, arXiv:1602.00988v1 [hep-ex], Feb 2016

This analysis is outside of our study due to large $P_T{}^{jet}$ bins, large $P_T{}^{jet}$ interval and low precision

Suppression or non-recognition of gluon jets ?



In experiment we cannot distinguish two different pictures: suppression of g-jets and non-recognition of g-jets

If pQCD predict a large $\alpha_g^{(2)}$ then picture with non-recognition of g-jets is preferable

- The recognition of gluon jets is good for large P_T^{jet}.
  For small P_T^{jet} the gluon jet recognition may become difficult.
- We want to observe the boundary (in P_T^{jet}) of gluon jet recognition.
- For this we will measure independently :
  - (1) the difference $\Delta n = n_2 - n_1$
  - (2) gluon jet fractions $\alpha_g^{(1,2)}$

as a function of P_T^{jet}

How to measure g-jet fraction ?

To extract $\alpha^{(g)}$ we will minimize value $\boldsymbol{V}$ by MINUIT (ROOT):

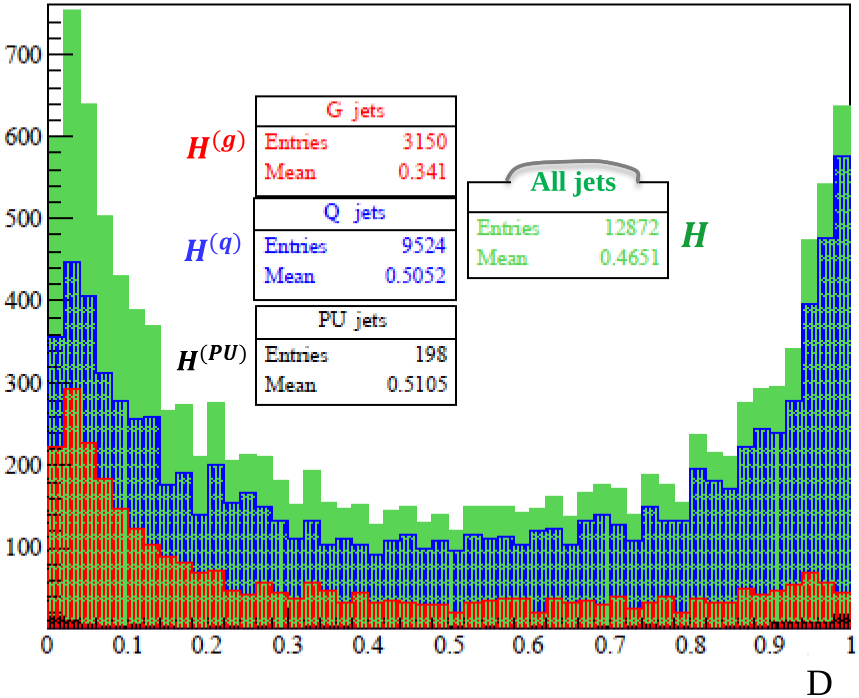
$$V = \sum_{i=1}^{N_{bins}} \left[\frac{Y_i}{\Delta Y_i}\right]^2 = minimum$$

where

$$\begin{cases} Y_i = \boldsymbol{H_i} - \alpha^{(g)}\boldsymbol{H_i}^{(g)} - \underbrace{(1-\alpha^{(g)})}_{\alpha^{(q)}}\boldsymbol{H_i}^{(q)} \\ \Delta Y_i = \sqrt{\Delta\boldsymbol{H_i}^2 + {\alpha^{(g)}}^2\Delta\boldsymbol{H_i}^{(g)2} + +(1-\alpha^{(g)})^2\Delta\boldsymbol{H_i}^{(q)2}} \end{cases} \quad (1)$$

"q" includes "u,d,s,c,b,x"
"x" – flavour misidentified jets

$$\boldsymbol{H} = \boldsymbol{H}^{(q)} + \boldsymbol{H}^{(g)} + \boldsymbol{H}^{(PU)}$$



D is q/g-discriminating variable

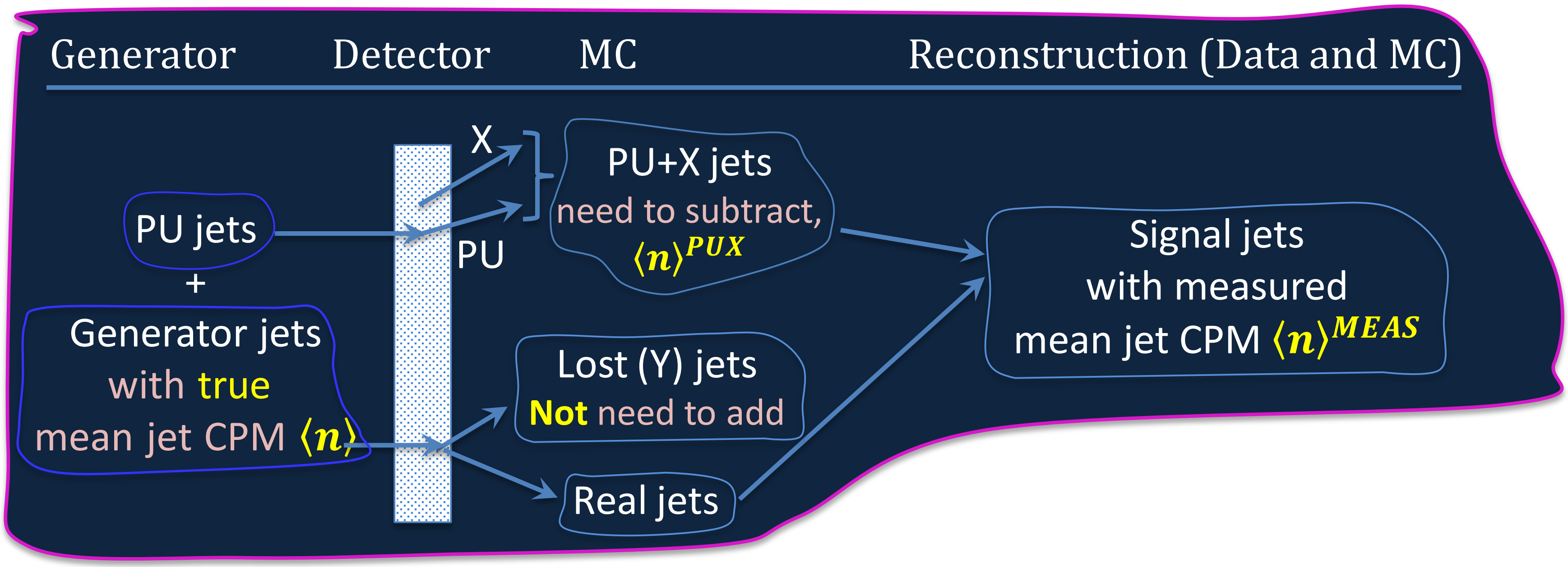
Systematical uncertainty:

We repeat the minimization N times with N clones of source triplet of histograms $[H,\ H^{(q)}$ and $H^{(g)}]$.

Uncertainty = dispersion of N quantities $\alpha^{(g)}$

❖ We propose the model independent method to measure g-jet fraction

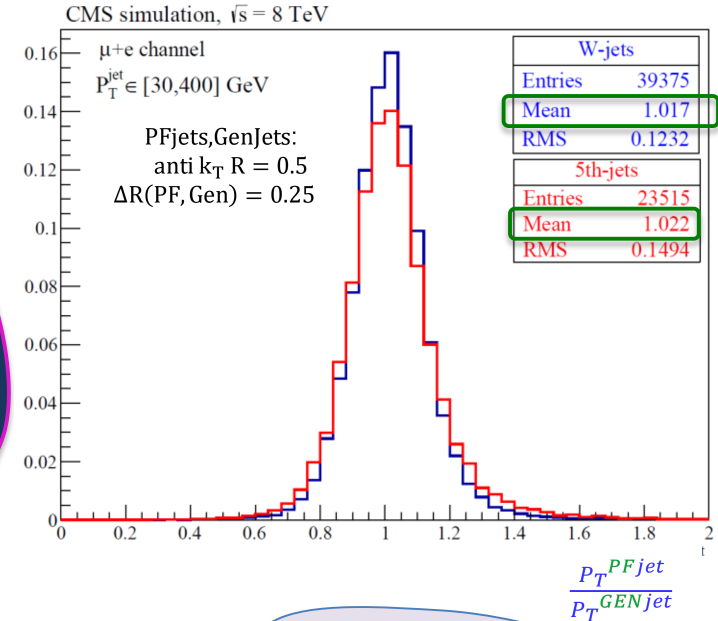
How to correct the measured mean jet CPM[1] ?



❖ We define the several possible sequences of corrections and propose the methods to find systematical uncertainties.

[1]**C**PM - **C**harged-**P**article **M**ultiplicity

Jet Energy Scale Correction and Uncertainty



We are going to measure two averaged observables:

$$\langle n \rangle_{TRUE} = f(\langle P_{T,}{}^{jet} \rangle),$$

for given $P_T{}^{jet}$-bin

$$\Delta_{JEC}(\langle n \rangle) \approx \frac{d\langle n \rangle}{d\langle \mathrm{P}_T{}^{jet} \rangle} \cdot \Delta_{JEC}\langle \mathrm{P}_T{}^{jet} \rangle)$$

If $\frac{d\langle n \rangle}{d\langle \mathrm{P}_T{}^{jet} \rangle} \approx 0$ then $\Delta_{JEC}(\langle n \rangle) \approx 0$

Calibration coefficient for JEC:

$$c^{jet} \equiv \frac{\langle \mathrm{P}_T{}^{GENjet} \rangle}{\langle \mathrm{P}_T{}^{\mathrm{PF}jet} \rangle}$$

❖We propose the method how to estimate the systematical JES uncertainty of mean jet CPM

Correction for jet flavour "non-universality"

$\langle n_1 \rangle$ - *1st jet sample*
$\langle n_2 \rangle$ - *2nd jet sample*
"*q*" includes "*u,d,s,c,b,x*"

- Jet CPM's are decomposed into flavour fractions:

$$\begin{cases} (1-\alpha_1{}^{(g)})\langle n^{(q)}{}_1\rangle + \alpha_1{}^{(g)}\langle n^{(g)}{}_1\rangle = \langle n_1\rangle \\ (1-\alpha_2{}^{(g)})\langle n^{(q)}{}_2\rangle + \alpha_2{}^{(g)}\langle n^{(g)}{}_2\rangle = \langle n_2\rangle \end{cases}$$

- Def.: "*Non-universality*" of jet flavours ⟺ dependence on index "*k*".

- Def.: "*universal*" mean q/g-jet CPM's ⟺ mean values over both jet samples *k=1,2*:

$$\langle n^{(q)}\rangle = \frac{\sum_{k=1,2}\sum_{qjet=1}^{N_{q,k}} n_k{}^{(qjet)}}{N_{q,1} + N_{q,2}} \equiv \rho_1{}^{(q)}\langle n^{(q)}{}_1\rangle + (1-\rho_1{}^{(q)})\langle n^{(q)}{}_2\rangle,$$

$$\langle n^{(g)}\rangle = \cdots .$$

- We define the notions
  - ✓ Jet flavour non-universality
  - ✓ Correction for jet flavour non-universality
  - ✓ And universal q/g-jet CPM's.
- *In region of q/g-jet non-recognition* we expect

$$\boldsymbol{\alpha_2{}^{(g)} \approx \alpha_1{}^{(g)} \approx 0}$$

$$\boldsymbol{\tilde{n}_2 - \tilde{n}_1 \approx 0}$$

$\boldsymbol{\tilde{n}_k}$ - jet CPM with correction for jet flavour non-universality

Correction of mean Jet CPM for UE

pp = hard parton interaction + [interaction of beam remnants + multiparticle interaction]

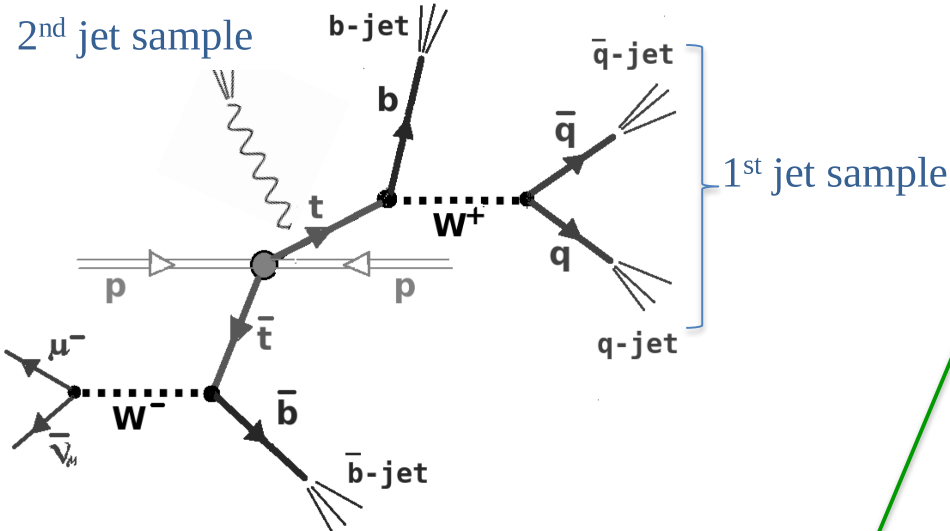
Underline Event (UE)

Track clusters = jets

Almost homogeneous distribution of tracks

- We propose to study simultaneously both the mean jet CPM as a function of P_T^{jet} and UE density as a function of η.
- It allows also to subtract the mean UE contribution from mean jet CPM and to answer the question:
  - ✓ does the UE-inhomogeneity inside $f-$jets represents the entire "non-universality" of the $f-$jet ?

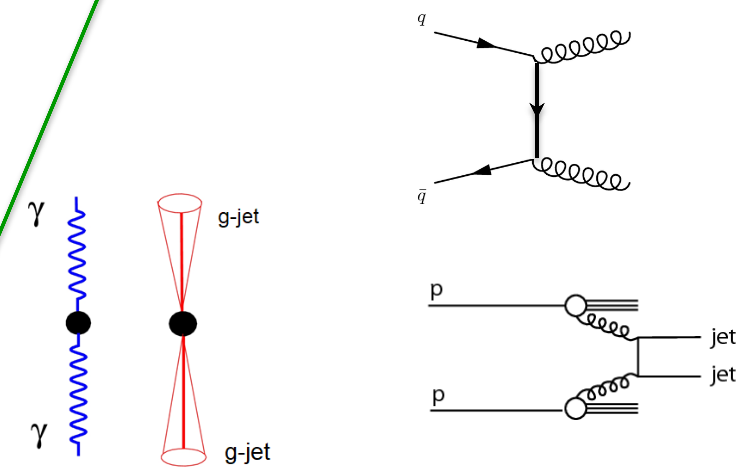
What was done and Plan for Future Data Analysis



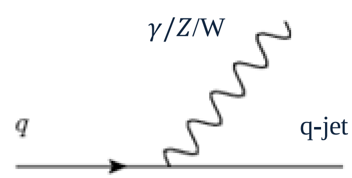
Semi-leptonic $t\bar{t}$-channel.

- Analysis with 8 TeV (Run-1, CMS) data was finished in 2017
- Collaboration approval is in progress

- Some issues are considered
  in talk of Dmitry Budkovsky



Dijets



$\gamma/Z/W$ + jet

Analysis with 13 TeV (Run-II, CMS) data will begin in the Summer of 2018

- The report outlines the priority tasks for the CMS experiment, which are performed by the RDMS CMS teams. Lots of described tasks are carried out with the participation of scientists from Belarus.

- Participation of the Belarus in the CMS project is highly appreciated and supported in JINR.

Particular mention deserves to be made of successful work of students and young scientists from Belarus:

Dydyshko Ya.,
Yevorovskaya U.,
Yarmoltchik V.,
Bugaevskaya M.,
Budkovsky D.