My research work at DESY, LAL and Fermilab

Olena Karacheban
Kyiv National University

Outline

Data analysis experience

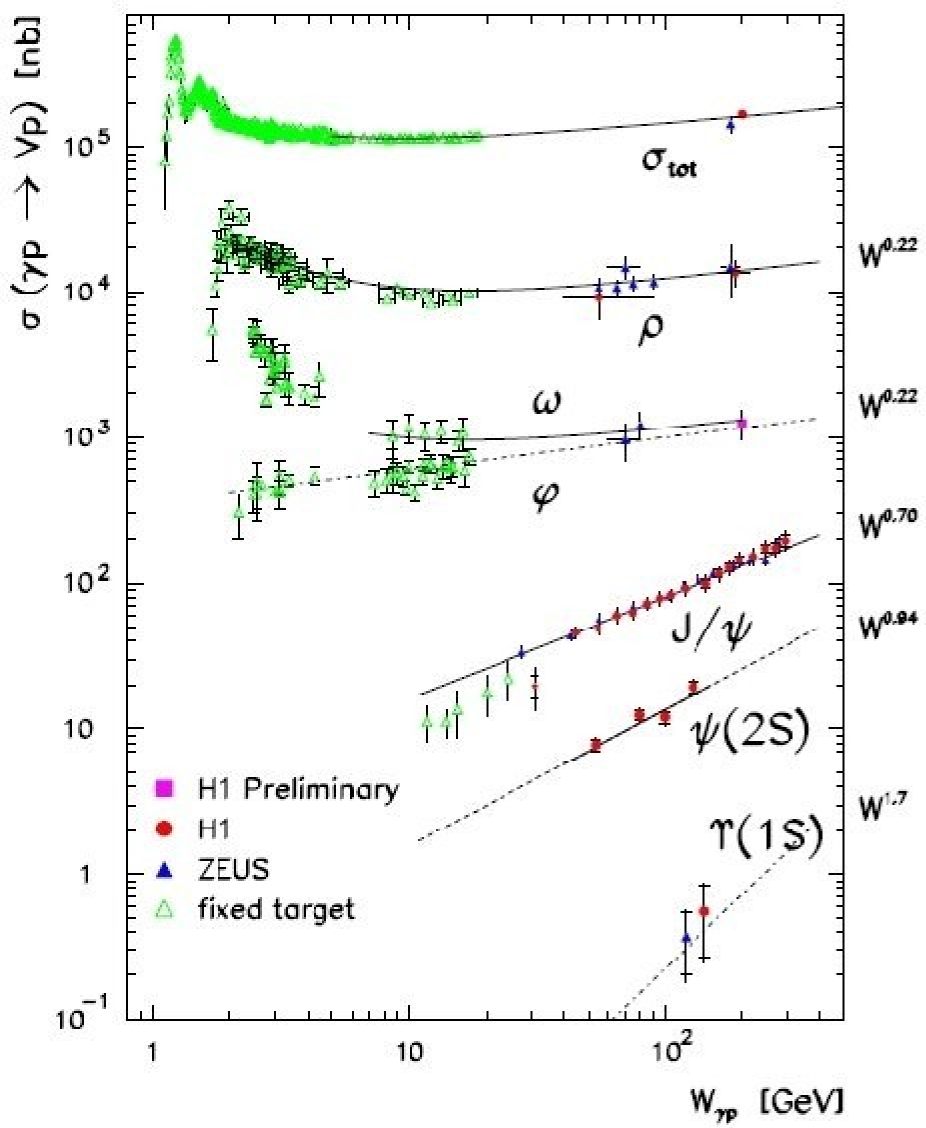
- Bachelor thesis (DESY, Hamburg, Germany)
  - *ψ(2S) mesons photoproduction at HERA collider.*
- Master Thesis (FERMILAB, Batavia, US)
  - *Top quark spin correlation measurement based on DZero data.*

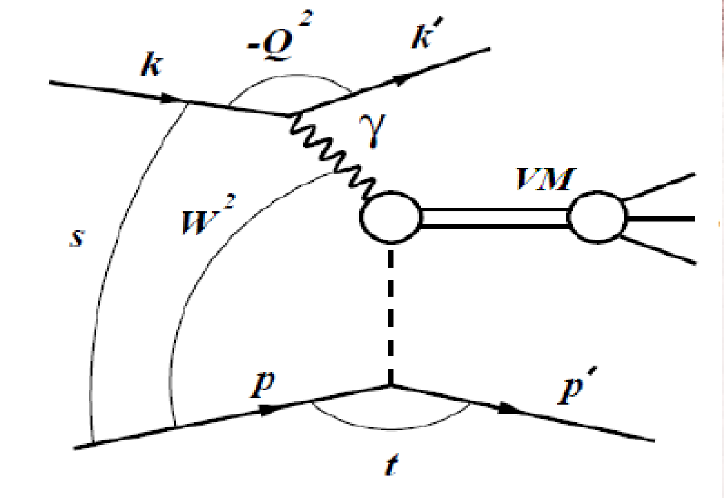
Work with hardware

- Practice at LAL (Orsay, France)
  - *Construction of plate for Smith-Purcell radiation polarisation measurement at SLAC.*

Bachelor thesis motivation

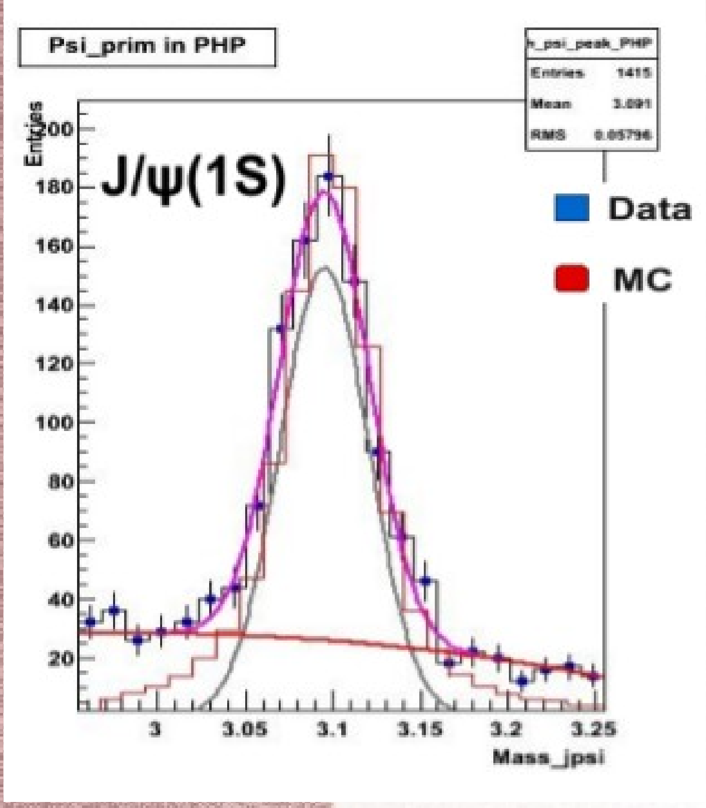
- Exclusive *ψ(2S) -> J/Ψ $\pi^+\pi^-$* decay channel – first measurement by ZEUS
- Separation of ψ(2S) meson production processes:
- PHP (Q^2 <1 GeV^2- JB method)
- DIS [Andrii Terliuk] (Q^2 >1 GeV^2 - electron method)
- Extension to the currently finished analysis on HERA I data with H1 detector.
- ψ(2S) cross section calculation.





Fit $m_{\psi(2S)}$ = 3.681 ± 0.001 GeV;

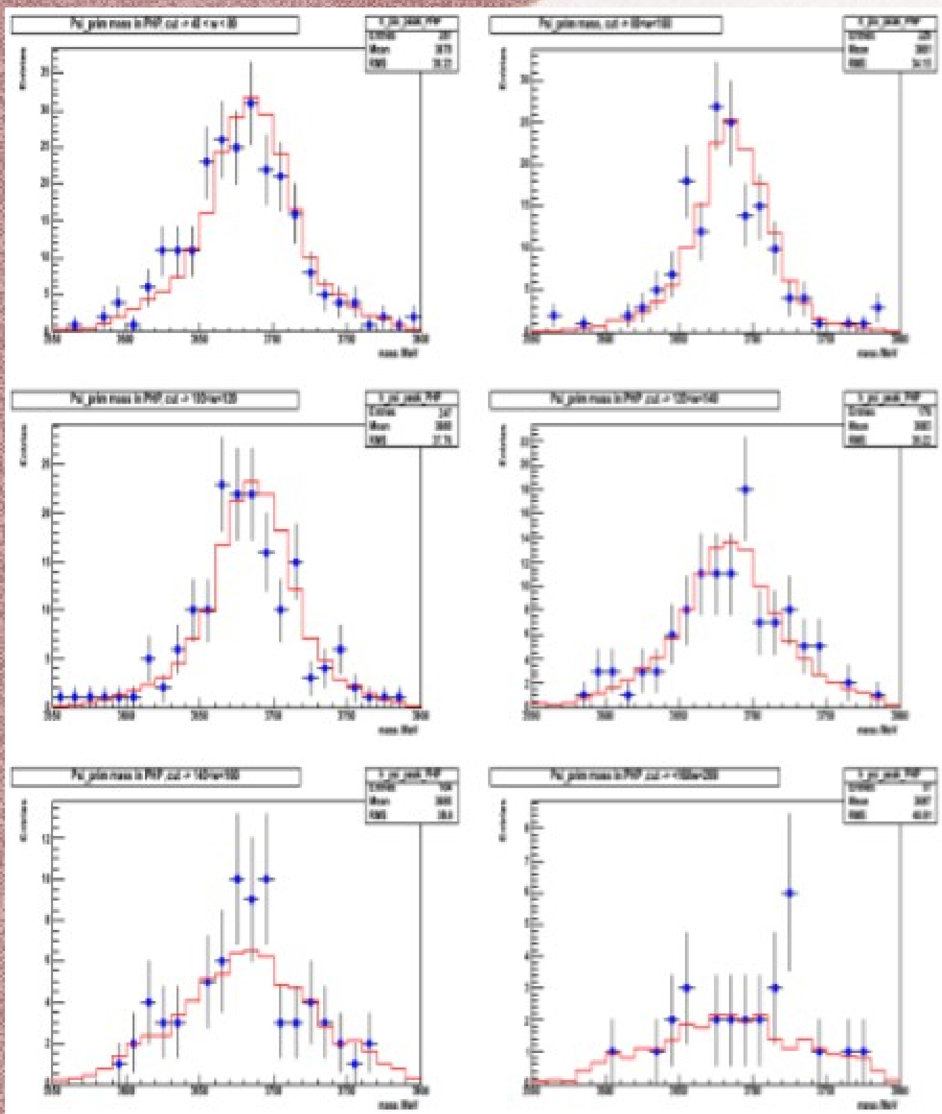
PDG $m_{\psi(2S)}$ = 3.686 GeV.



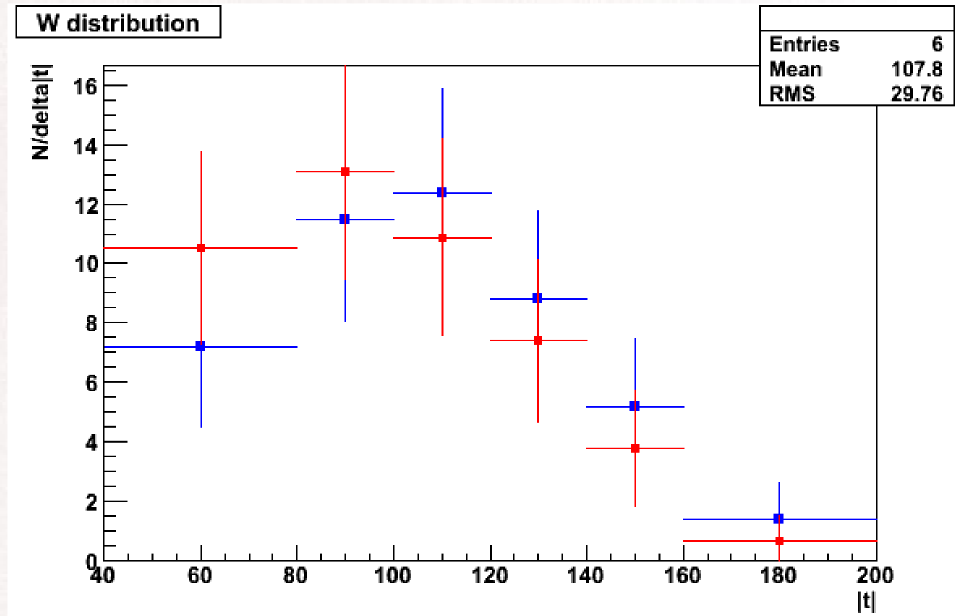
Main steps of analysis

- Using preselection code with special cuts ψ(2S) candidates in PHP serch;
- ψ(2S) and J/ψ(1S) mass distributions construction;
- Control plots for main kinematic variables;
- ψ(2S) yield, acceptance vs. W and cross section calculation in first glance.

Mass distribution in different ranges of W

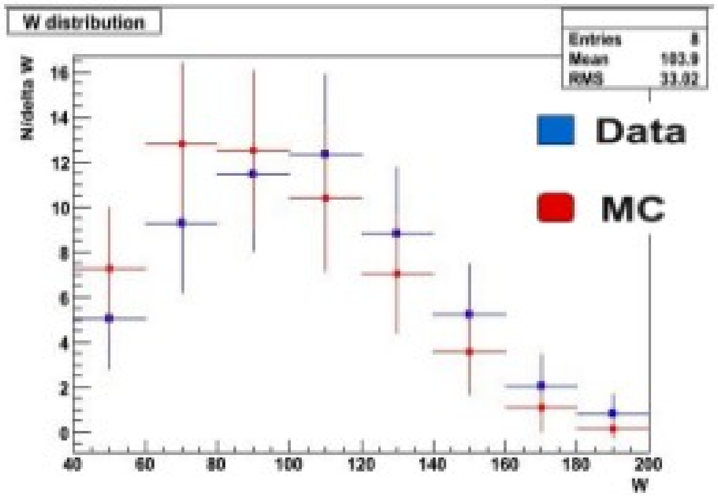


ψ(2S) yield vs. W

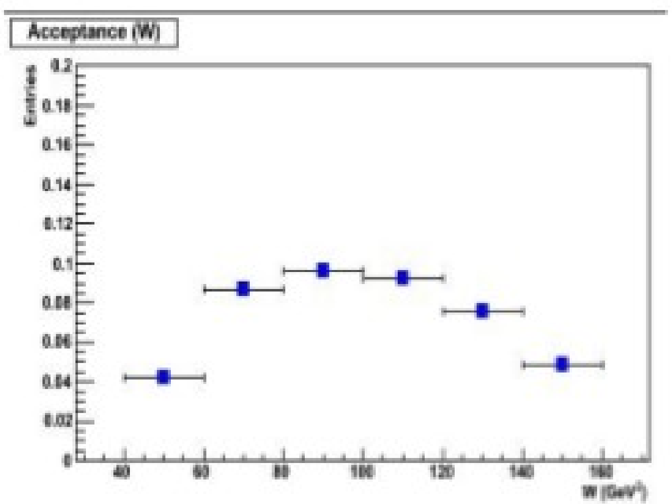


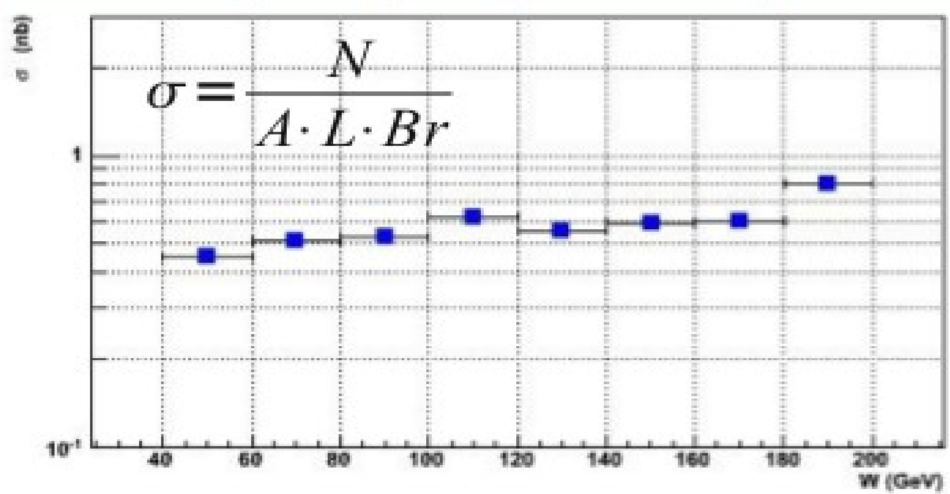
W bin	N evts. in RD	N evts. in MC
[40, 80]	7	11
[80, 100]	11	13
[100, 120]	12	11
[120. 140]	9	7
[140, 160]	5	4
[160, 200]	2	1

ψ(2S) yield vs.W, acceptance, diff.cross section



bin W	RD	MC	accept.	σ, nb
[40,60]	5	7	0.042	0.449
[60,80]	9	13	0.086	0.51
[80,100]	11	13	0.096	0.523
[100,120]	12	10	0.092	0.618
[120,140]	9	7	0.076	0.552
[140,160]	5	4	0.049	0.592
[160,180]	2	1	0.022	0.597
[180,200]	1	1	0.009	0.78





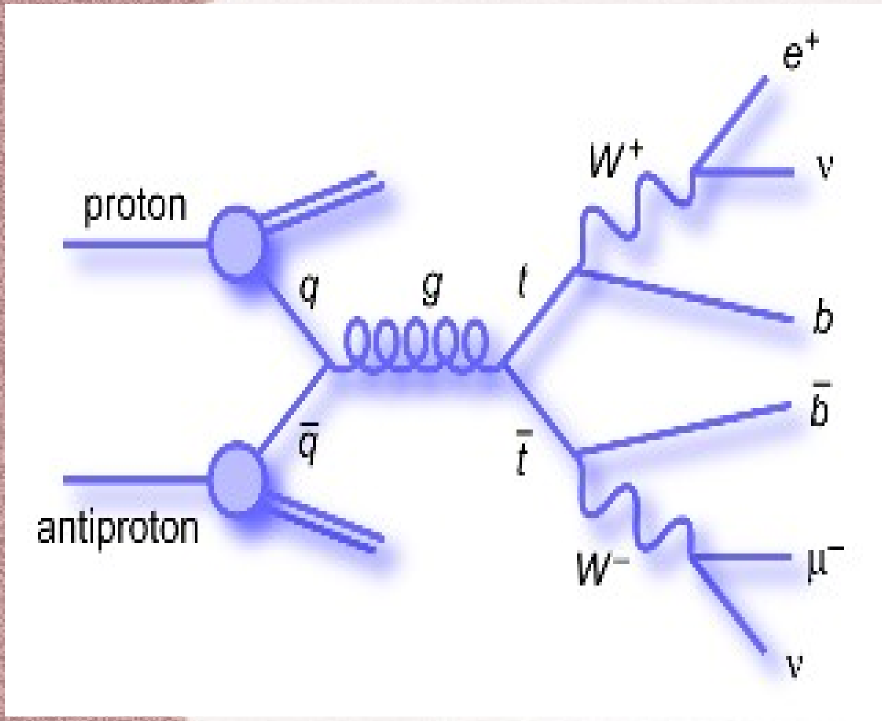
Conclusion for bachelor thesis

ψ(2S) mesons photoproduction at HERA collider

- ψ(2S) in PHP preselected
- Mass distribution of ψ(2S), J/ψ(1S) and control plots were presented for comparison data and MC.
- Kinematic variables were calculated and ψ(2S) yield vs. W presented.
- Acceptance and cross section vs. W were calculated (first glance).

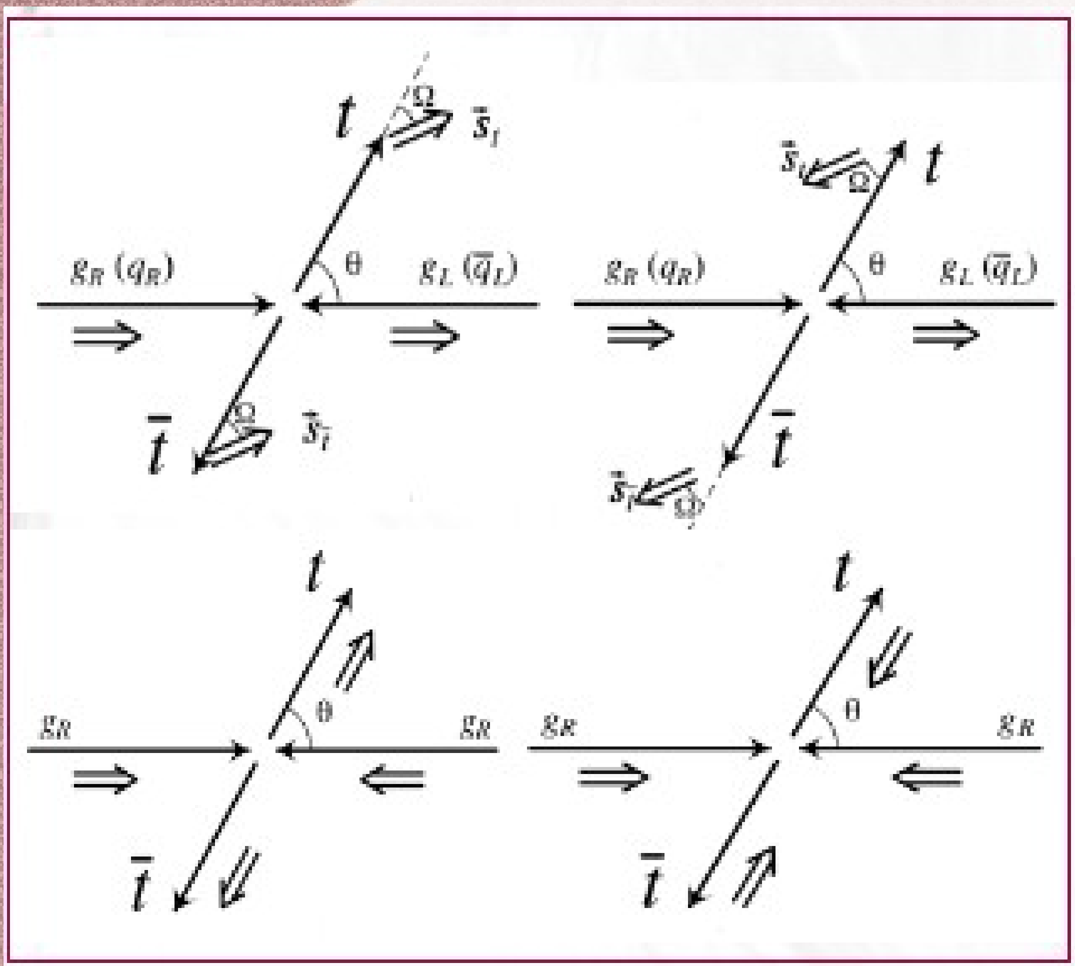
Master Thesis motivation

Channel: $t\bar{t} \rightarrow W^{+}W^{-}b\bar{b} \rightarrow ll\nu_{l}\bar{\nu}_{l}\,b\bar{b}$



- Why top quark? - *Its lifetime is short, so there is no top-quark hadronization. It allows to keep primary spin correlation.*
- Why dilepton channel? - *Top-quark spin orientation determinate angular distribution of decay products. Charged leptons are the most sensitive detectors, so dilepton channel is the most sensitive.*

Quarks produced by the strong interaction are un-polarized, but have correlated spins.



- Like configuration of top quarks' spins ← *from quark-antiquark annihilation or unlike helicity gluon fusion.*
- Unlike configuration of top quarks' spins← *from like helicity gluon fusion*.

At Tevatron it's big spin correlation effect because of domination of quark-antiquark annihilation.

Main steps of spin correlation analysis

- Comparison of data, preselected by Top-group and MC.
- Probability calculation for MC with spin correlation (H=c) and without spin correlation (H=u).
- Discriminant R construction for separation of two hypotheses.
- Cuts optimisation and estimation of precision.
- Measurement of spin correlation in data after *e-e* and *μ-μ* channels including.

Signal probability calculation using *matrix element method*

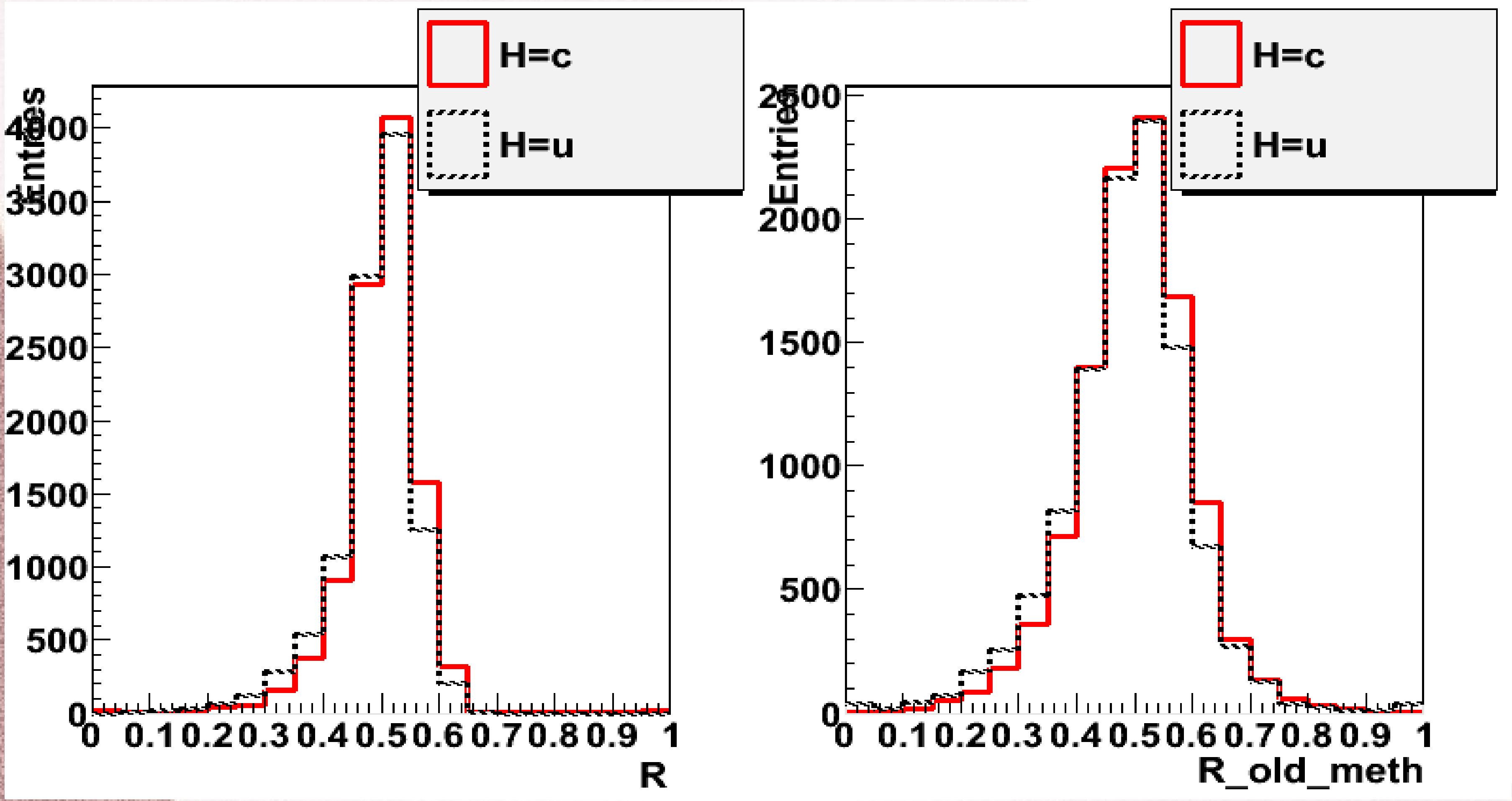
$$P_{\text{sgn}}(x;H)=\frac{1}{\sigma_{\text{obs}}}\int f_{\text{PDF}}(q_1)\ f_{\text{PDF}}(q_2)\mathrm{d}q_1\mathrm{d}q_2\frac{(2\pi)^4\,|\mathcal{M}(y,H)|^2}{q_1q_2s}\ W(x,y)\ \mathrm{d}\Phi_6$$

There is two hypotheses: H = c — spins are correlated, as predicted by the SM and H = u - spins are not correlated.

- q_1, q_2 - energies of colliding partons
- f_{PDF}*(q)* - partons distribution function
- σ_{obs} - $q\bar{q} \to t\bar{t}$ observed cross section of the t-quark
- $\mathcal{M}(y,H)$ - the matrix element
- $W(x,y)$ - the detector resolution function, which describes the probability for y to be measured as x
- $\mathrm{d}\Phi_6$ - an element of the 6-body phase space

Separation power of the discriminant variable R for two integration methods:

$$R = \frac{P_{\mathrm{sgn}}(x; H = c)}{P_{\mathrm{sgn}}(x; H = u) + P_{\mathrm{sgn}}(x; H = c)}$$



Start of spin correlation measurement

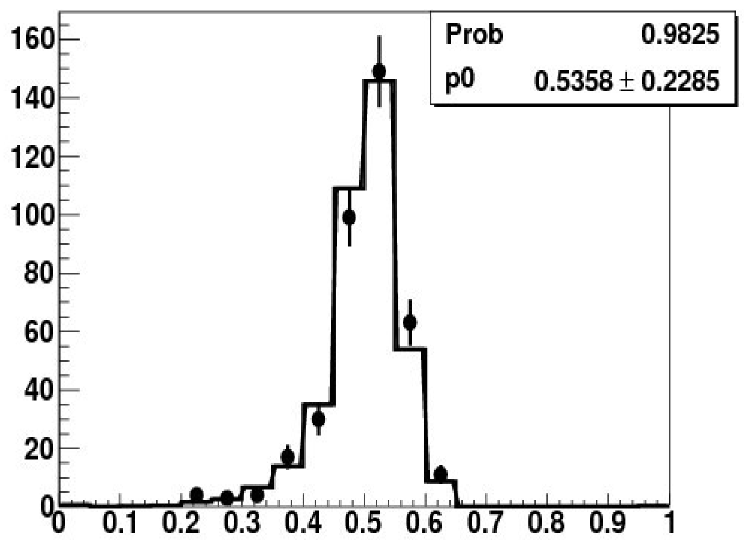
	New integration method		Old integration method	
	SM spin corr.	No spin corr.	SM spin corr.	No spin corr.
R mean value	0.50062	0.489872	0.498985	0.485291

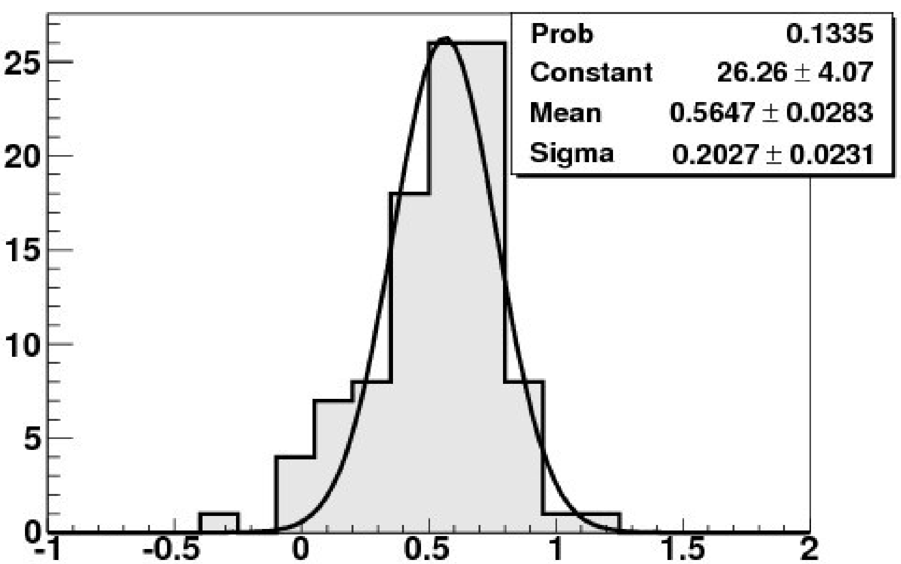
- It is necessary to extract the fraction *f* of events where the spin correlation of the $t\bar{t}$ production is preserved in the top decay over the total number of events
- To extract the fraction *f* we need to generate ensembles with 5 proportions of every type MC:
  - 100% MC with spin correlation
  - 25% MC with + 75% MC without spin correlation
  - 50% MC with + 50% MC without spin correlation
  - 75% MC with + 25% MC without spin correlation
  - 100% MC without spin correlation

Ensembles fitting

Ensembles is our pseudo data. We can do measurements as many times as we want. We need to fit each ensemble in corresponding proportion of templates (x% MC with corr. + y% MC without corr.)

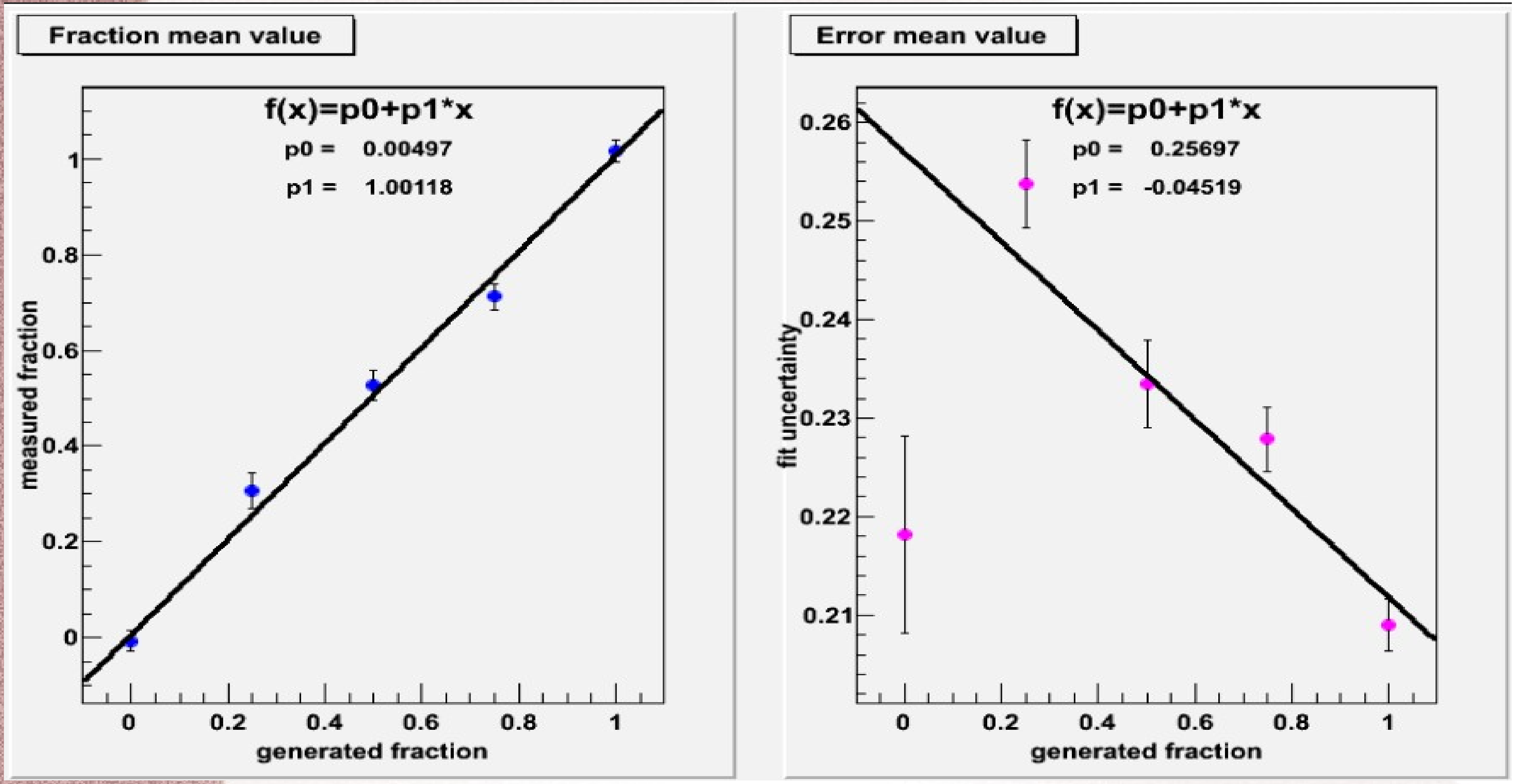
We have 100 ensembles for each proportion. Fitter answers we can describe with Gaussian distribution, is it our measured fraction.



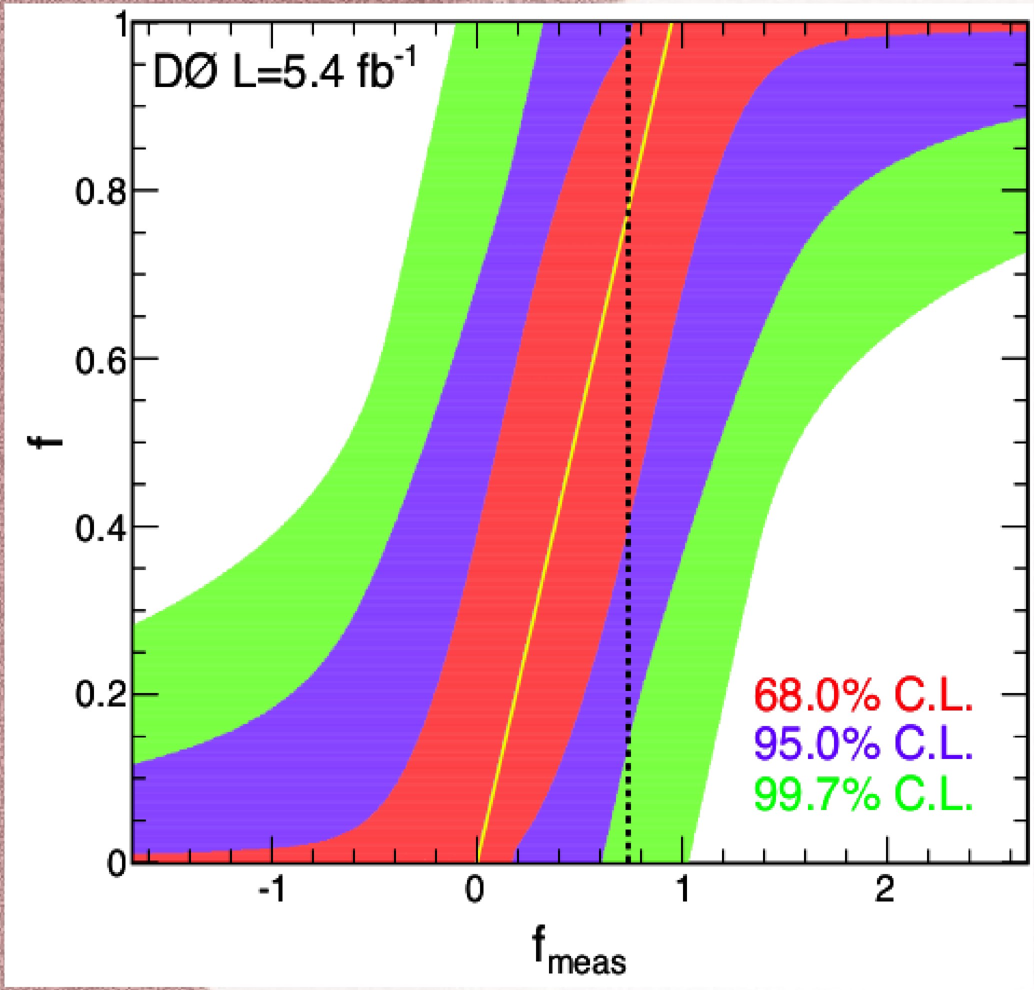


Calibration after all cuts and background including

For example for generated fraction 1.0 we can calculate measured value 1.00615 ± 0.21178.



Conclusions



- Work has been started on the ensembles testing procedure and fraction of events with correlation extraction.

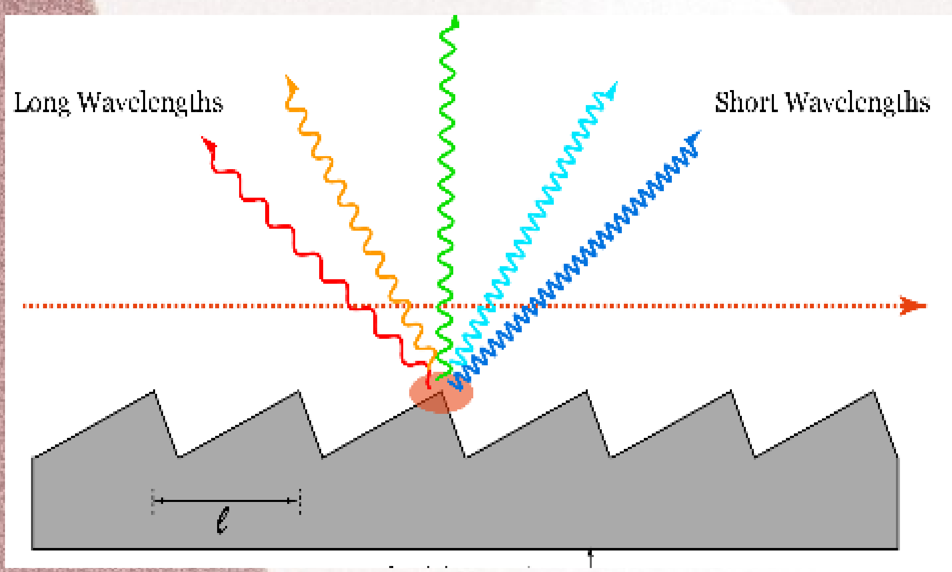
Future plans

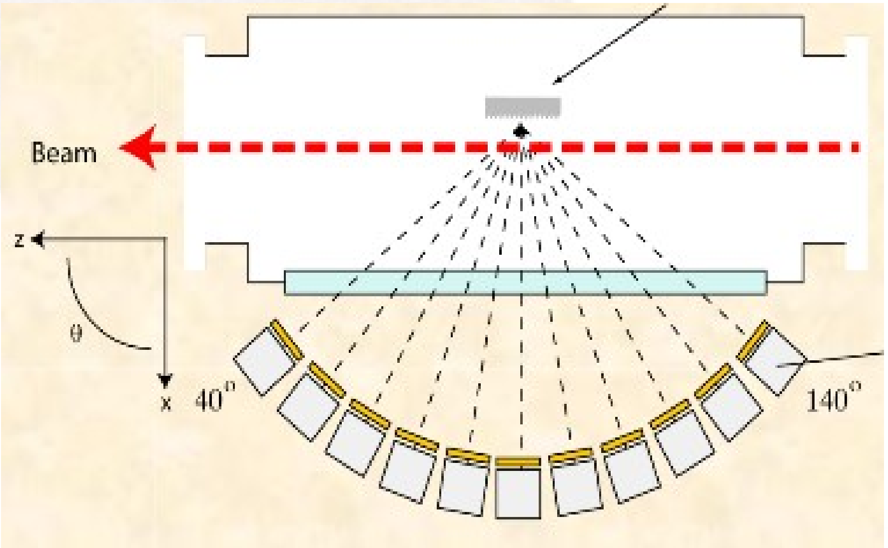
- After cuts optimisation, programs package modernisation and including of *e*-*e* and μ-μ channels we will do measurements in data.

This work will be continued during my stay at Fermilab next three month. In my plans there is to write note, master thesis and start preparing of publication during this time.

Practice at LAL

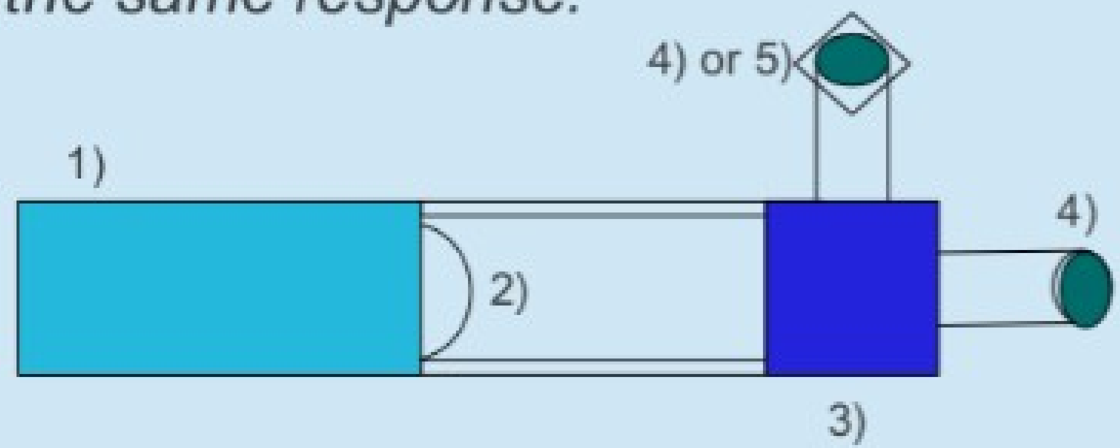
- Calibration system building
- Focussing of the light study
- Construction of plate for Smith-Purcell radiation polarisation measurement at SLAC
- Pyroelectric and thermopile detectors signal comparison
- Thermopile detectors sensitivity measurement





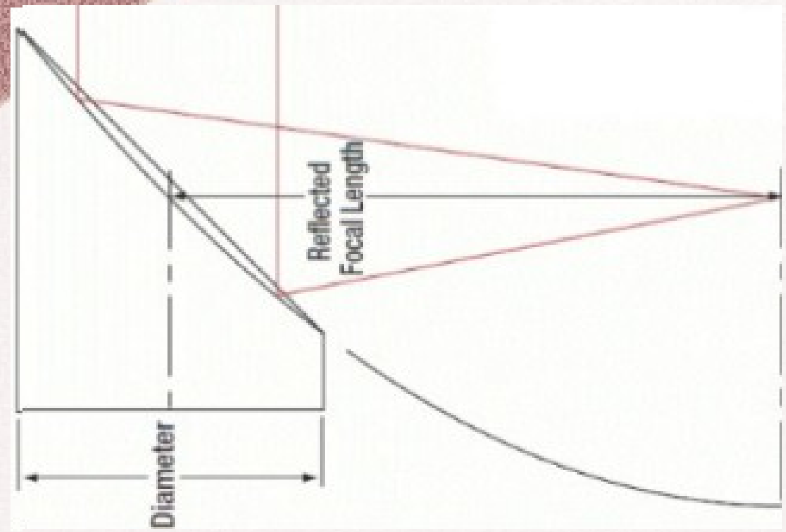
Calibration system

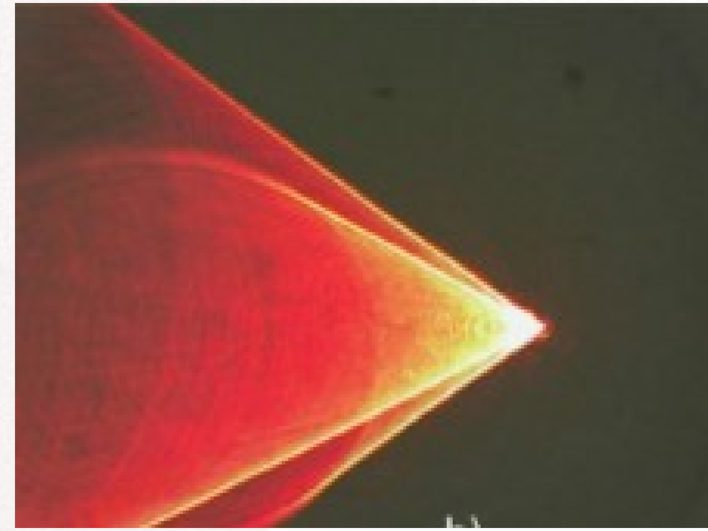
System was built using Thorlabs Elements to check if 2 detectors have the same response.



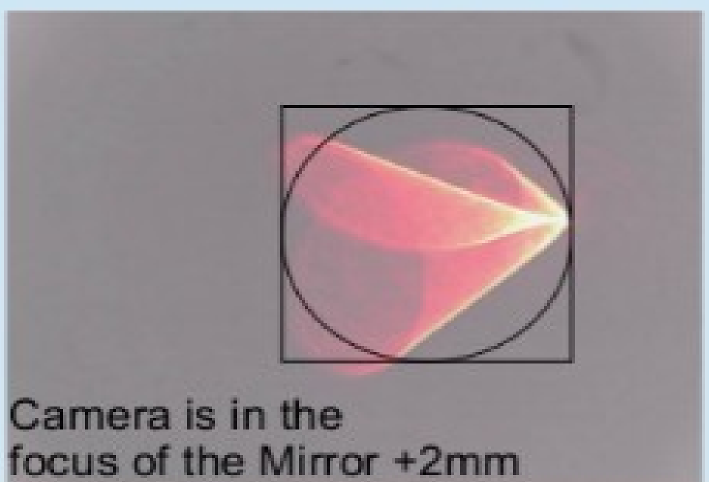
Main parts:
1) Laser Diode Module;
2) Plano-convex lens, f=150 mm;
3) Cube-Mounted Beamsplitter;
4) Detector in cover;
5) Photodiode - in quality of reference.

Off-Axis Parabolic Mirrors aberrations study



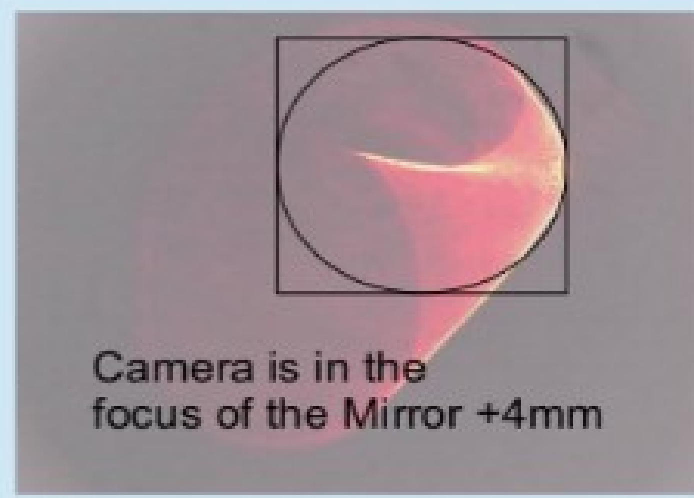


Form of aberrations changes if to move camera closer or further from mirror.



pyroelectr.
detect. size
(D=1,5mm)

thermopile
detect. size
(A=1,5mm)

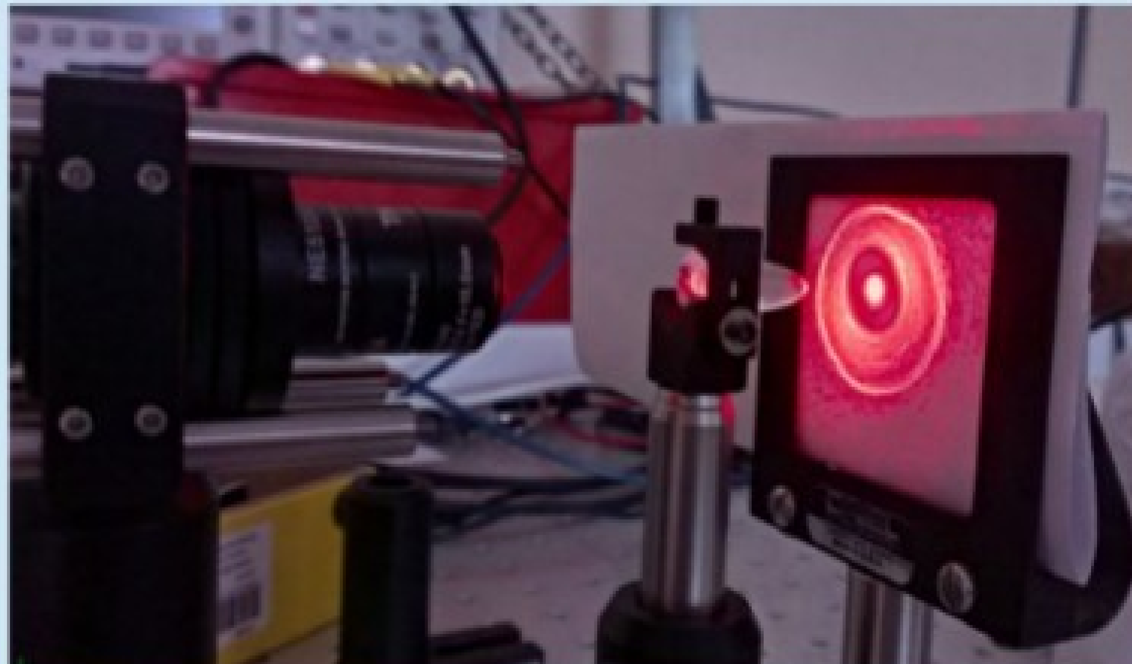


Compound Parabolic Concentrators focus study

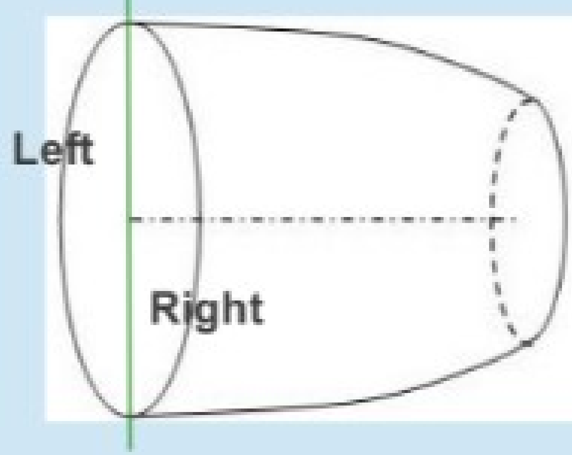
Output rays have two components:

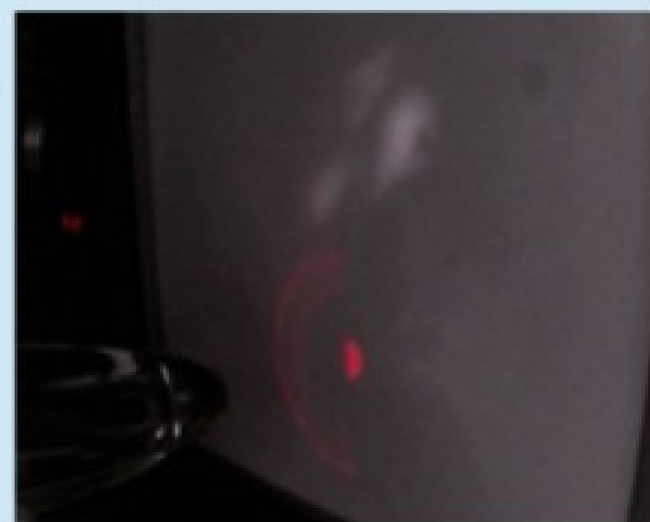
- not reflected rays — diameter 2.5mm circle in the centre like CPC exit diameter.
- reflected part - ring around small circle in the centre.

Moving the screen, we measured ring diameter and get value of diverging angle: φ=55,5˚.

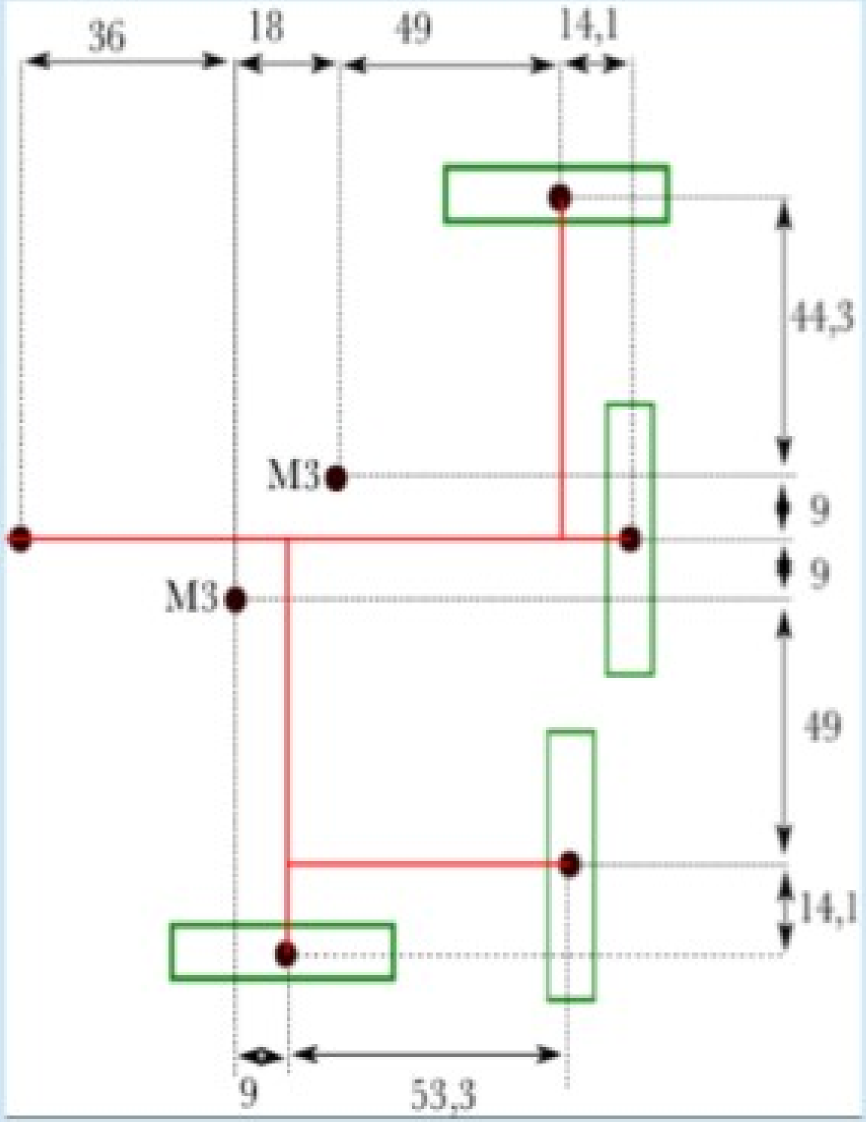


If to overshadow, for example, left part of the concentrator, we have on the screen :





Drawing of plate for polarisation measurement.

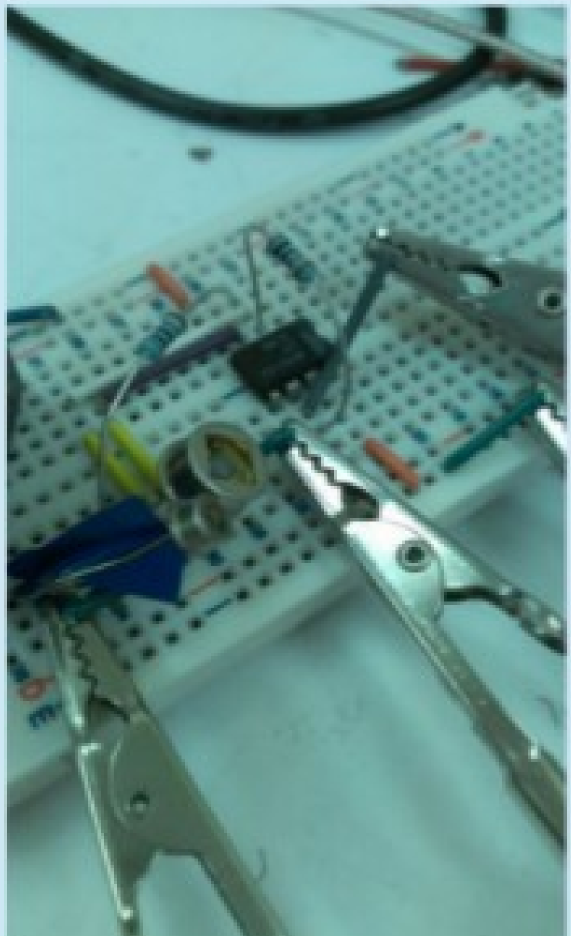


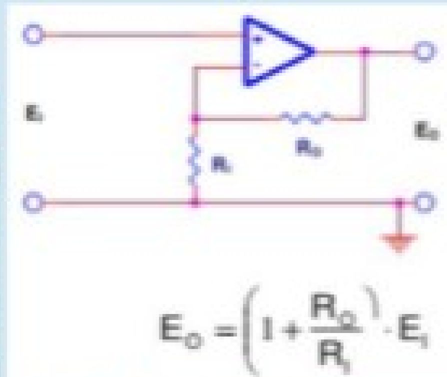
Final construction of plate but without tubes.

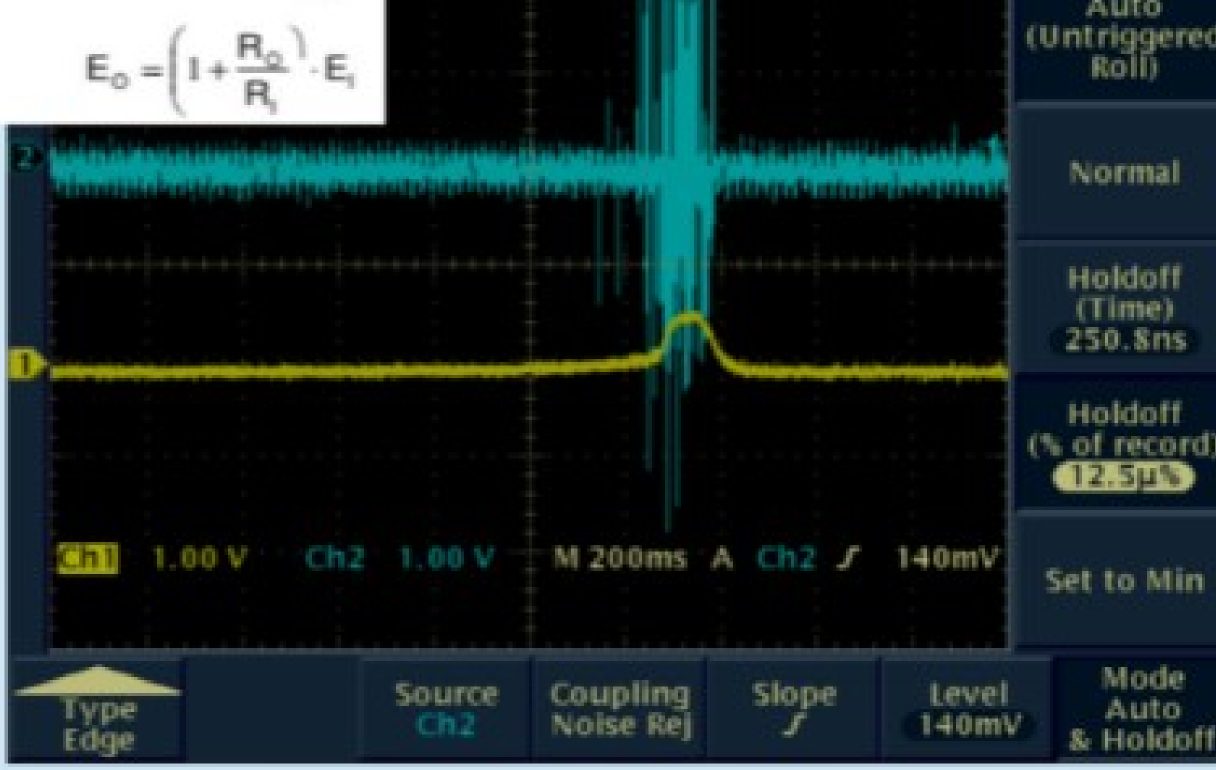
Expected price: 300 euro for mounting details + 260 euro mirrors + plate + polarizer.

We used pyroelectric and thermopile detectors.

Signal from thermopile detector is stronger and have less noise (yellow).
For pyroelectric detector we used operational amplifier (blue signal).

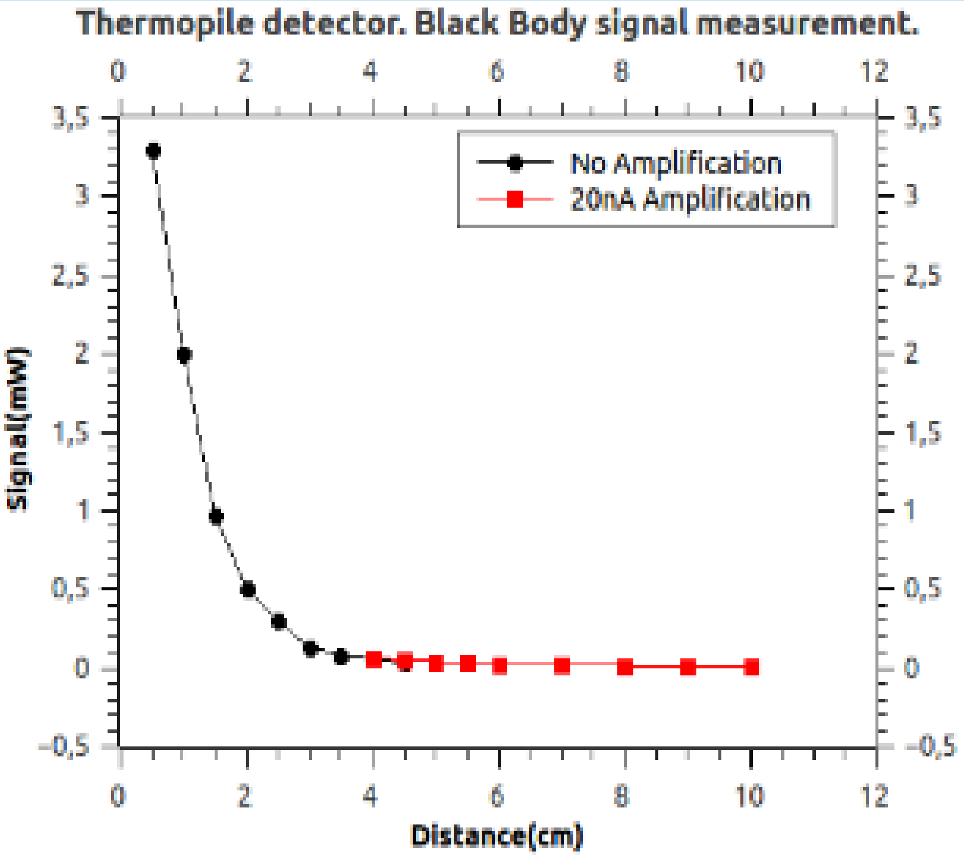


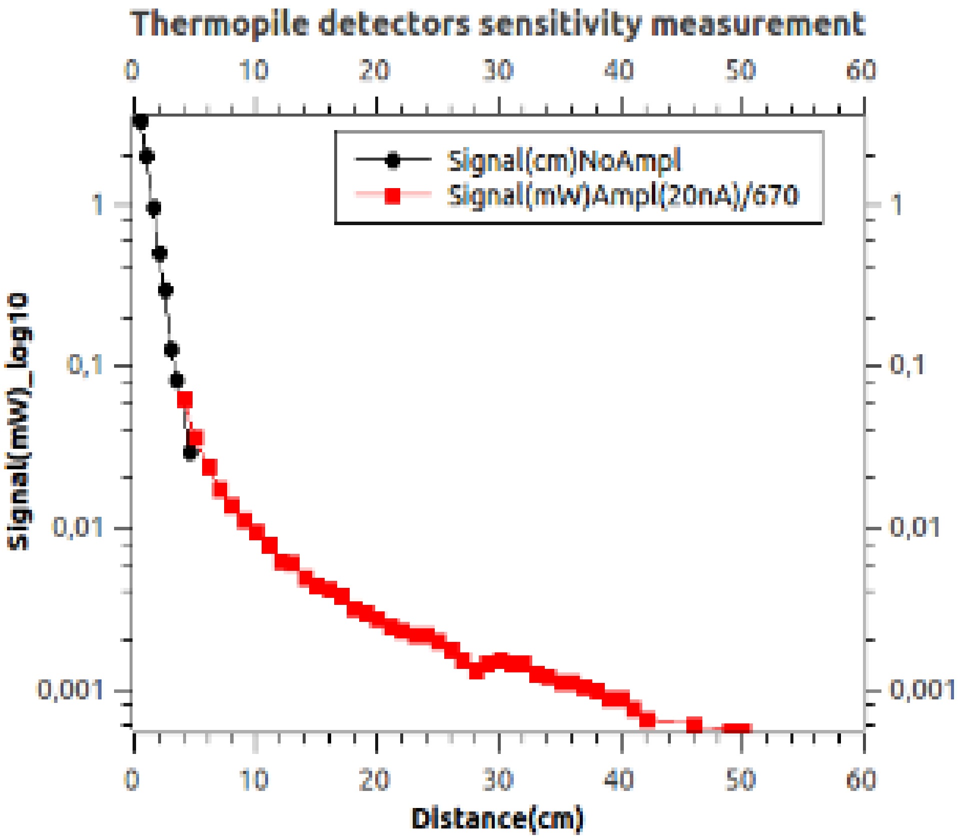




Thermopile detectors sensitivity measurement

To find how small signal we can detect with thermopile detector we used Black Body source. Smallest signal which we've detected is 0.55 µW, but we want to try go futher.





Important courses

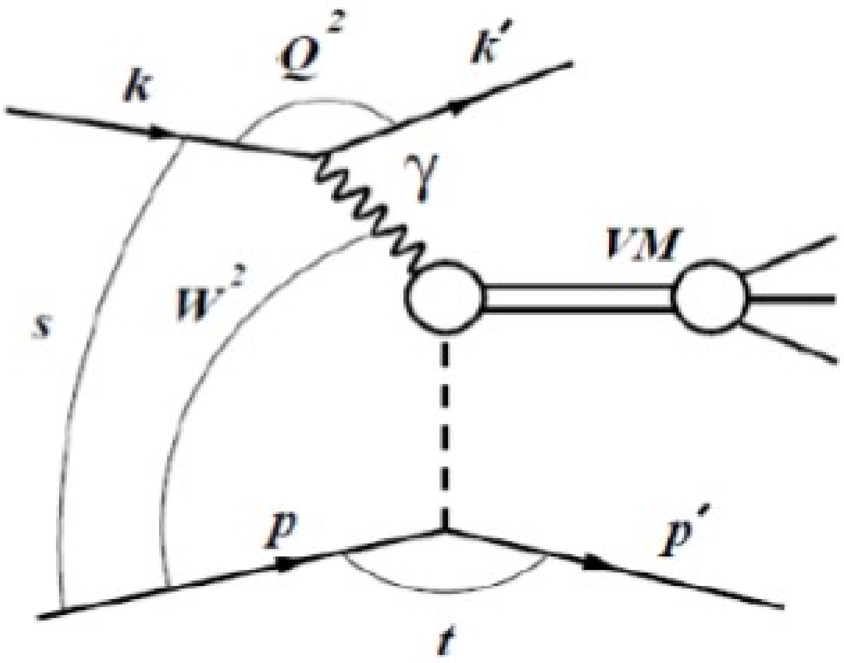
- Nuclear physics
- Interaction of radiation with matter
- Nuclear physics theory
- Methods of registration of nuclear radiation
- Quantum Mechanics
- Methods of the experimental data processing
- Scattering Theory
- Neutron Physics
- Quantum chromodynamics
- High energy physics
- Modern Problems of Nuclear Physics
- Advanced programming techniques in nuclear physics
- The use of programmable logic in high energy physics
- Theory of elementary particles
- MatLab modeling of charged particles penetration in matter

Interests

- DESY pays a lot of attention for new technologies and detection systems development, reconstruction of detectors.
- Research of FCAL Collaboration, related to creation of special calorimeters in the very forward region is very important for future detectors. New techniques will allow to receive data, with is not available for us now.
- I started work with hardware not so far, but I'm very interested in writing of PhD thesis related to high energy physics detection systems, I believe this work will be productive and will become a business card in my future work.

Backup slides

Introduction



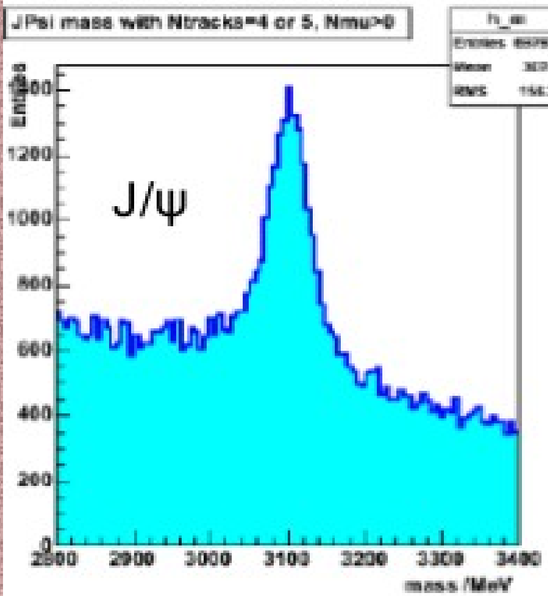
- Q^2 – the photon virtuality ($PHP – Q^2 = 0$)
- W – invariant mass of the γp system
- |t| - 4-momentum transfer squared at the proton vertex

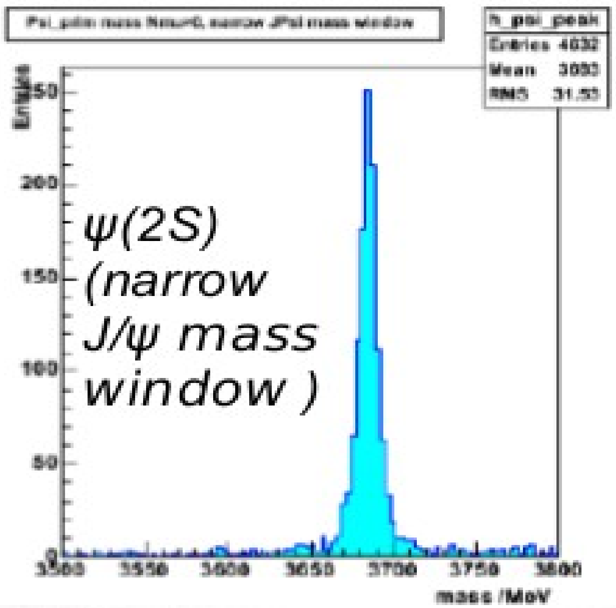
Q^2	=	$-q^2$	s	=	$(k+p)^2$
x	=	$\frac{Q^2}{2pq}$	W^2	=	$(q+p)^2$
y	=	$\frac{qp}{kp}$	t'	=	$\lvert t - t_{min} \rvert$
q	=	$k - k'$	t	=	$(p' - p)^2 = (v - q)^2$

Decay channel and mass distribution

Decay channel

- $\psi(2S) \rightarrow J/\psi(1S)\pi^+\pi^-$ BR $(33.6\pm0.4)\%$
- $J/\psi(1S) \rightarrow \mu^+\mu^-$ BR $(5.93\pm0.06)\%$
- Total decay probability : 1.99%



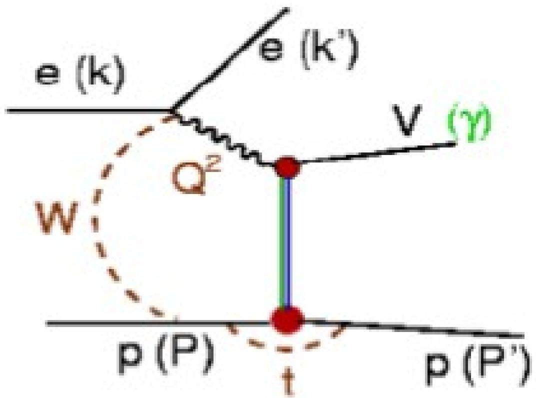


No PHP and DIS separation

PDG

- $m_{\psi(2S)}$ = 3.686 GeV
- $m_{J/\psi(1S)}$ = 3.096 GeV

Exclusive $\psi(2S) \to J/\psi(1S)\pi^+\pi^-$ in PHP



Cuts

- Tracks from primary vtx only.
- Trk_layouter > 3
- Ntracks=4 :
  - 2 tracks with charge "+" and 2 with "-"
- Empz_zu < 20 GeV
- |Zvtx|<30 cm
- *No electrons* : Sincand = 0 with Siprob > 0.9
- *Kinematic* : $Q^2 < 1$ GeV^2, $W < 200$ GeV

Data: CommonNtuple 03, 04, 05, 06e, 0607p
MonteCarlo: diffvm
Luminosity : 368,613 pb^{-1}

Data selection

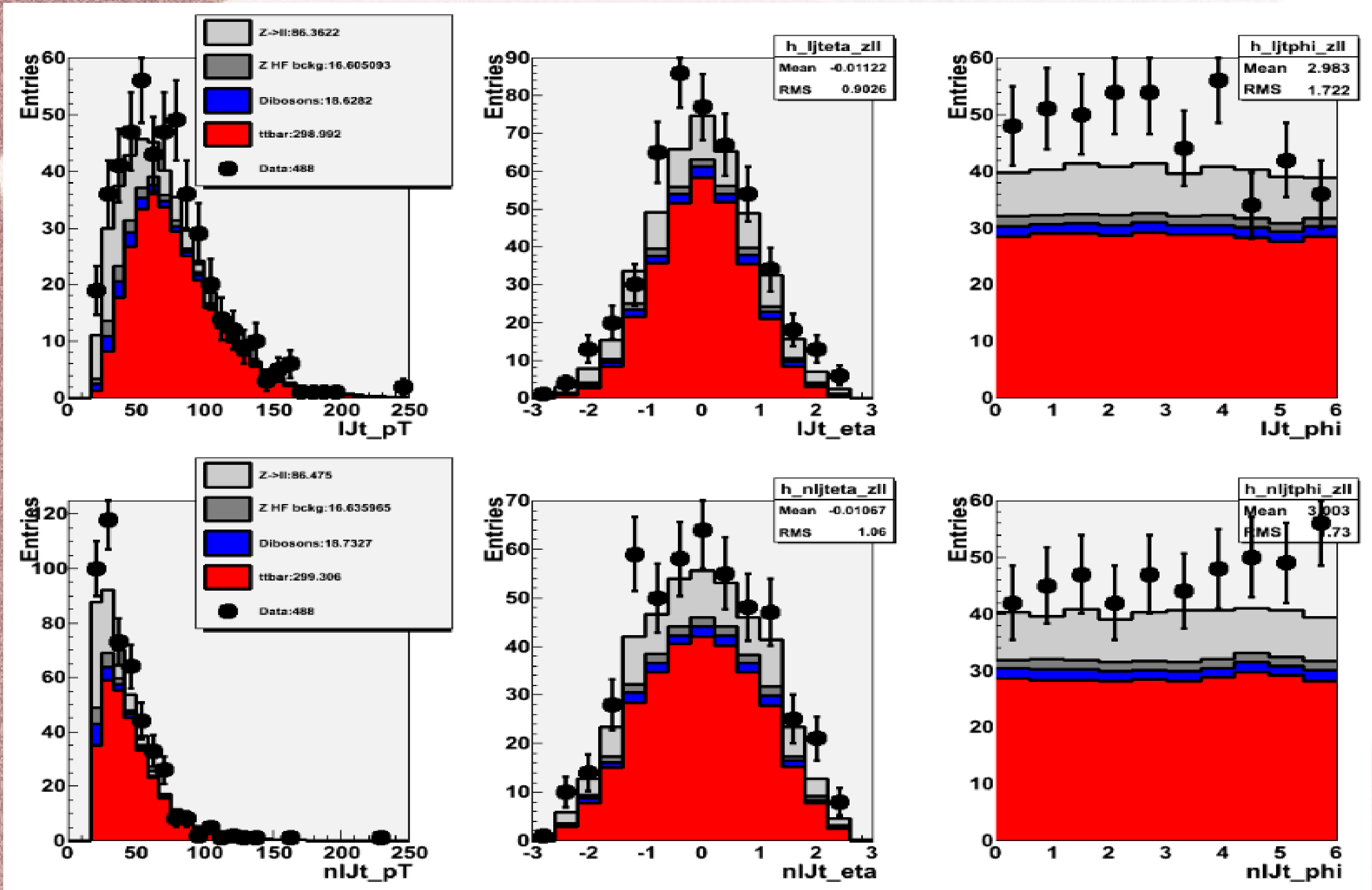
- Primary vertex is in the collision region: *| z | <60 cm;*
- At least 3 tracks are associated with primary vertex;
- At least two isolated *leptons* with p_T > *15GeV* and *opposite charges*;

For eμ channel:

- at least *one jet* with p_T > *20GeV*. To increase the purity of the signal also requires H_T > *110GeV*.

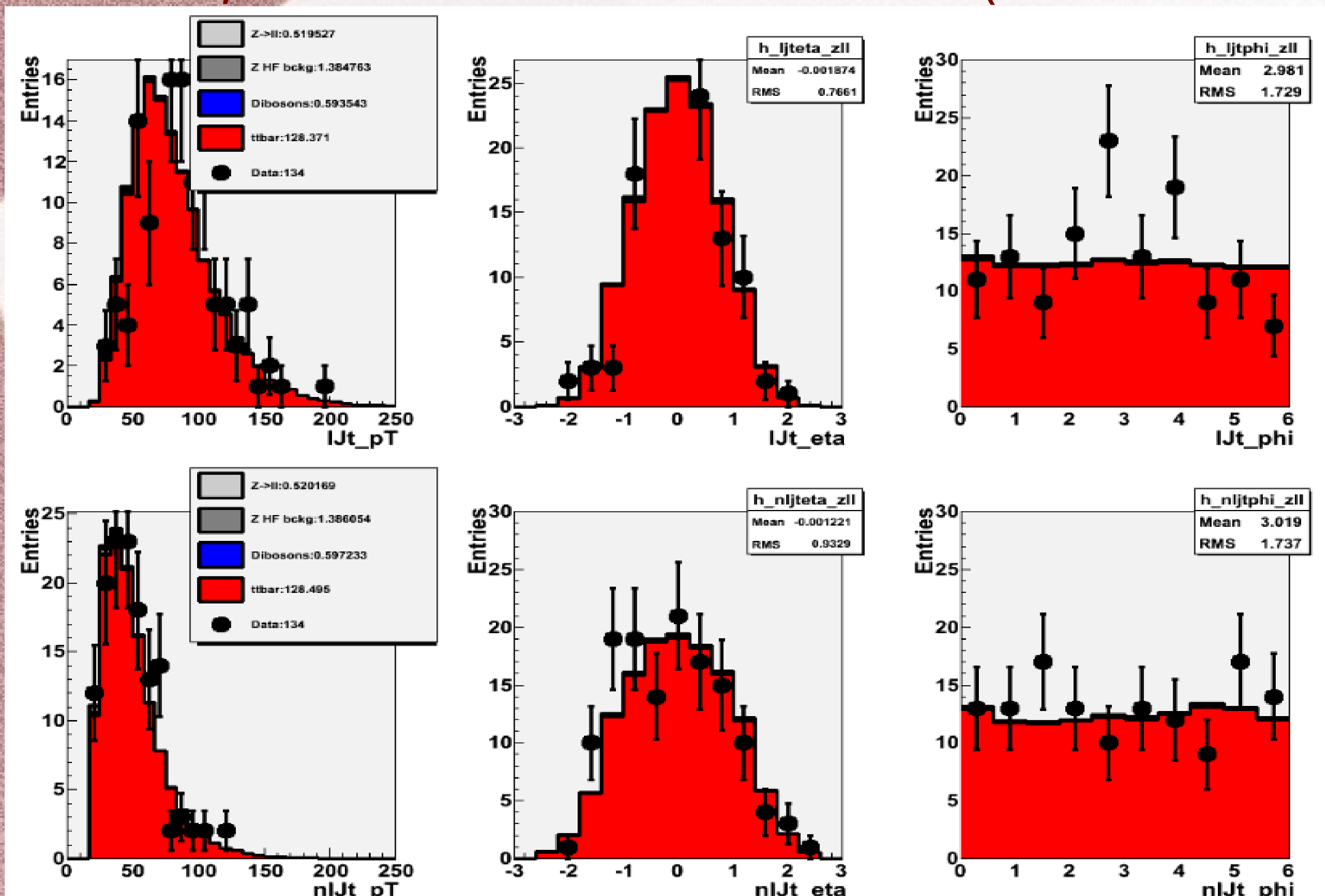
Control plots for jets.

In eμ channel 488 events $t\bar{t}$ selected.



Control plots for jets after b-taging.

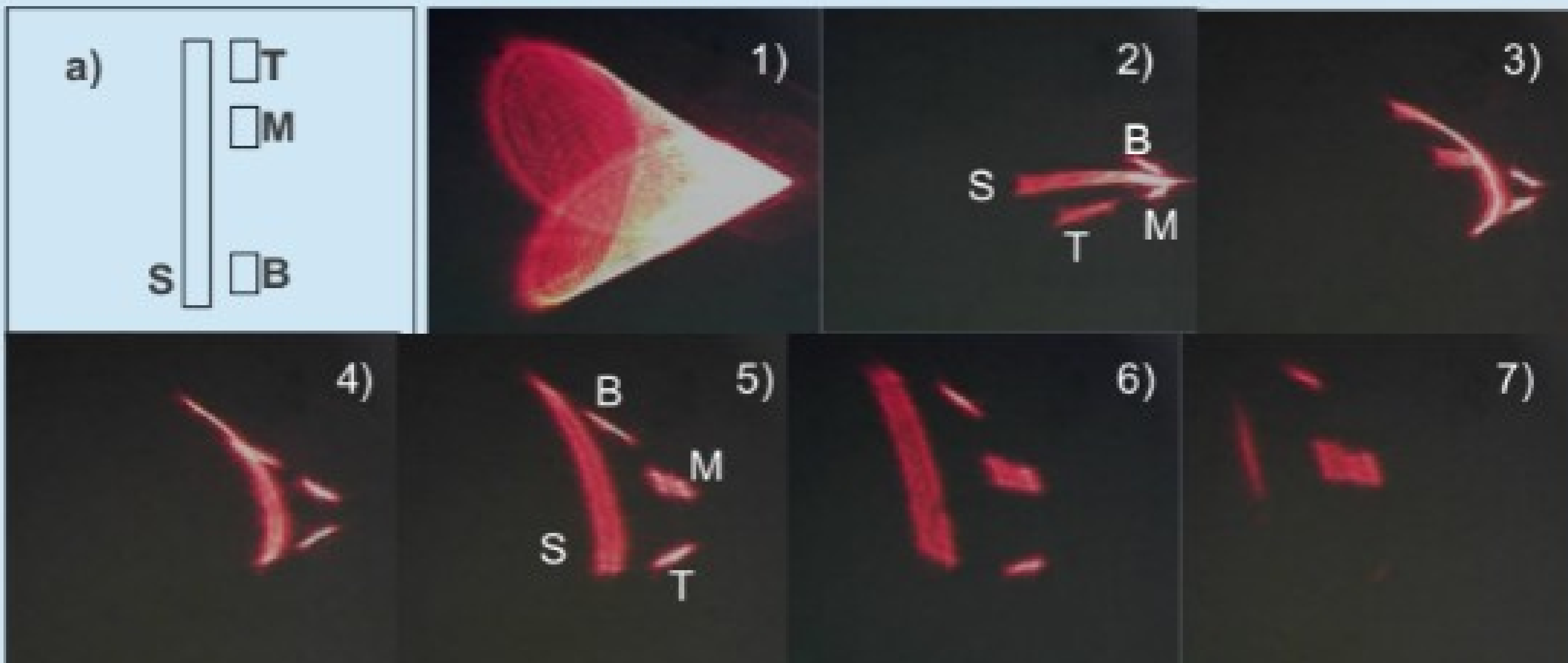
***In** eμ channel 134 $t\bar{t}$ events selected. (488 before b-taging)*



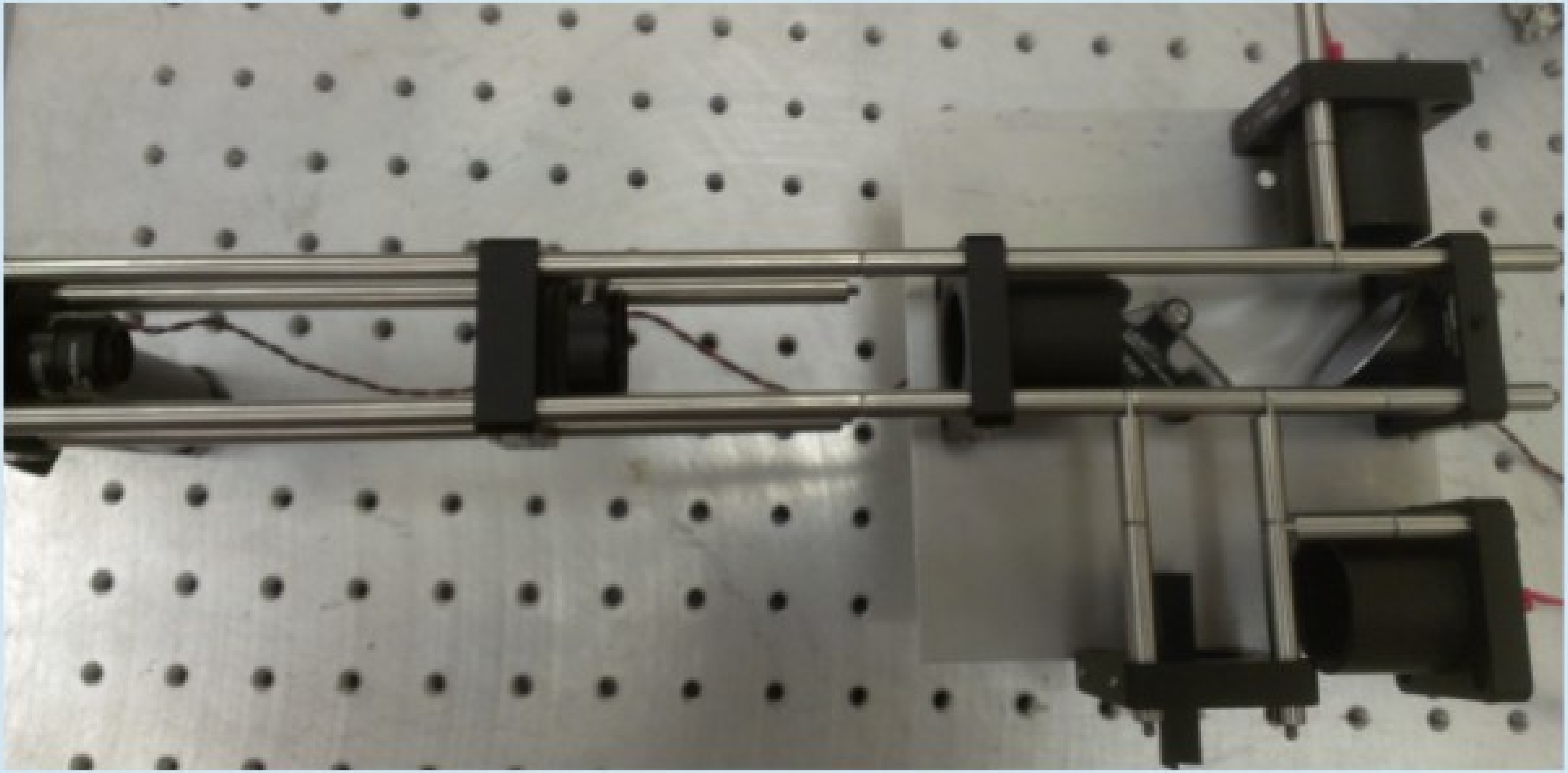
We considered jets associated with b-quark with a value of variable jt_mva_output > 0.02

Study of aberrations

We used special screen with narrow 1mm slit and 3 short separated slits lying on one line (a).
If to install the screen with slits in the center of the diverging beam before the mirror, only central rays could pass through slits, rest part of the beam will be overshadowed by screen. Then we start moving screen and discover changes of the aberrations.



Final construction of plate for Smith-Purcell radiation polarisation measurement at SLAC.



After OAP and CPC study we decided to use OAP for focussing, because in telescope system we can receive not divergent rays -> we have no comma; CPC focussing ability depends a lot from its position.