The drift chamber project for the Super Charm-Tau Factory detector

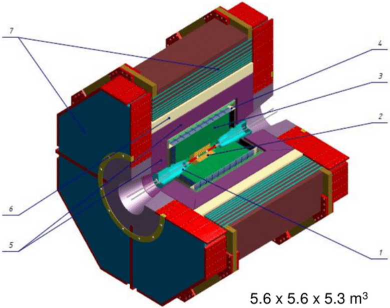
The drift chamber group of BINP

D.A. Kyshtymov

Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia

The outline

1. The drift chamber
2. Simulation in ANSYS
3. Optimization of cell structure
4. Momentum and dE/dx resolutions
5. The small prototype of DC
6. Summary



1. Vacuum pipe
2. Inner tracker
3. Drift chamber
4. PID
5. Calorimeter
6. SC magnet
7. Muon system

The Super c-tau factory

The main tool for researching the subatomic world is accelerators of charged particles

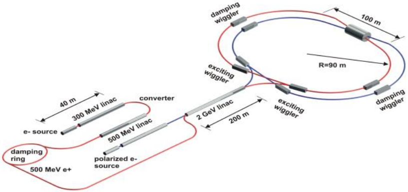
Currently, the project of Super C-Tau Factory is being developed at the BINP:

Provides opportunities:

- to study the c-quarks and τ-leptons birth processes;
- to search for exotic particles.

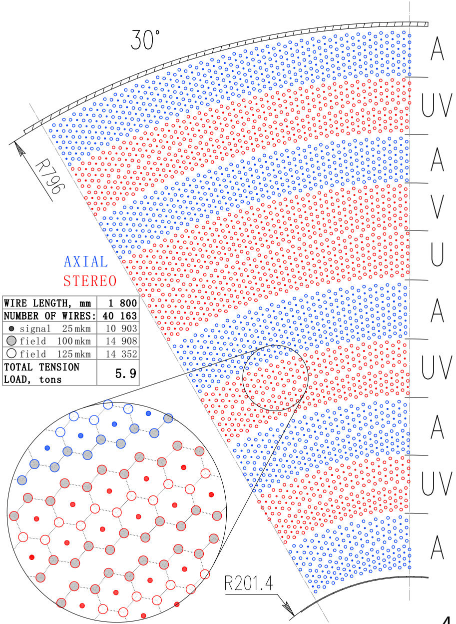
It will:

- work at energy range from 2 to 6 GeV ;
- have luminosity about $10^{35}\frac{1}{cm^2 \times s}$.



The drift chamber

- Shape - hexagonal
- 41 layer are divided into 10 superlayers
- Average radius $\sim$ 7 mm
- Gas mixture - $He/C_3H_8 - 60/40$
- Gas gain $\sim (5-7) \cdot 10^4$
- Voltage $\sim$ 2 kV
- Drift time $\sim$ 350 - 400 ns
- $\sigma \sim$ 100 μm
- $\frac{\sigma_{dE/dx}}{dE/dx} \sim$ 7 %



Characteristics of similar drift chambers

Characte-ristics	Detector				
	CLEOIII	BaBar	BESIII	BelleII	SCTF
B,T	1.5	1.5	1.0	1.5	1.5
N_{cells}	9796	7104	6796	14336	10903
Shape	Square	Hex.	Square	Square	Hex.
Anode wire d, mkm	W 20	W 20	W 25	W 30	W-Re(3 %) 25
Field wire d, mkm	Al 110	Al 120	Al 110	Al 126	Al 100, 125
Size mm × mm	14×14	18×12	12×12 16×16	7×7 10×10	$\sim 14 \times 14$
Gas mixture	He/C_3H_8 $60/40$	He/iC_4H_{10} $80/20$	He/C_3H_8 $60/40$	He/C_2H_6 $50/50$	He/C_3H_8 $60/40$
$V_{\textbf{anode}}$, B	1900	1930	2200	2300	~ 2000
T/D, ns/mm	$\sim 300/7$	$\sim 500/9$	$\sim 350/8$	$\sim 350/8$	$\sim 350/7$
σ_p/p, %	0.32	0.48	0.5	-	~ 0.35
$\sigma_{dE/dx}$, %	5.7	7.5	6.0	~ 6	~ 6.9
σ, μm	110	120	120	~ 100	~ 100

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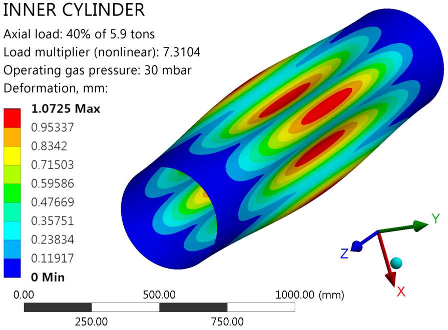
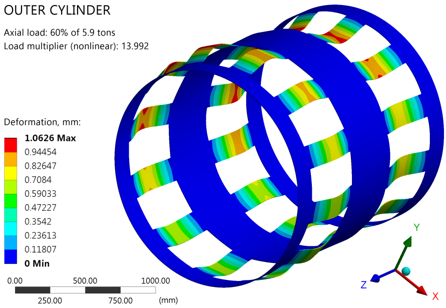
The inner/outer tube



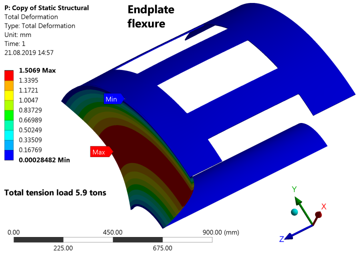
The inner tube simulated in ANSYS



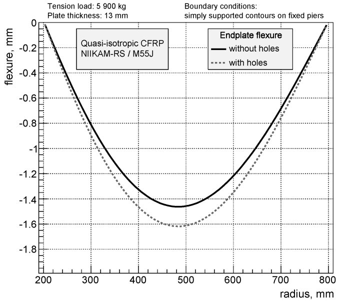
The outer tube simulated in ANSYS

- To facilitate the wiring the outer tube is provided with 24 windows
- The DC has a cylindrical shape (CFRP material)
- The wall thickness is 0.9 mm/4.5 mm ($X/X_0 = 0.46\%/2.1\%$)
- The load of wire tension 2.36 t/3.54 t (maximum deformation is about 20 μm/80 μm)
- Stability safety factor is about 7.3/14

The endplate



The endplate simulated in ANSYS



Endplate deformation as a function of radius

- Holes drilled in the endplate result in an increase in flexure of about 10%
- The endplate is flat
- The thickness is 13 mm (material CFRP, $X/X_0 = 5.9\%$)
- The full load is about 5.9 t (maximum deformation is about 1.6 mm)

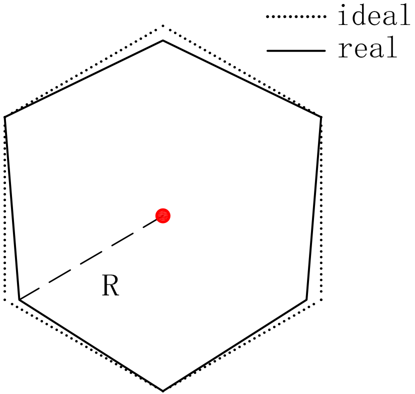
Gas mixtures

Gas mixture	Ratio	X_0, m	N_p, $\frac{1}{\text{cm}}$	V_{dr}, $\frac{\text{cm}}{\mu\text{s}}$	D_l, $\frac{\mu\text{m}}{\sqrt{\text{cm}}}$	Experiment
He/iC_4H_{10}	80/20	807	21.2	2.79	141	BaBar
He/iC_4H_{10}	90/10	1313	12.7	2.31	162	Kloe
He/C_3H_8	60/40	569	31	3.06	133	CLEOIII BESIII
He/C_2H_6	50/50	686	22.9	3.52	142	Belle BelleII
He/CH_4	80/20	3087	7	2.54	172	Kloe
Ar/C_2H_6	50/50	178	34	5.27	143	CLEOII
He/DME	70/30	678	21	1.12	123	-

Characteristics of different gas mixtures at B = 0 T, E = 1 kV/cm

Optimization of cell structure

- Due to imperfections of hexagonal shape ⇒ deviation of the electric field from cylindrical symmetry at the wire
- Solution ⇒ cells structure optimization

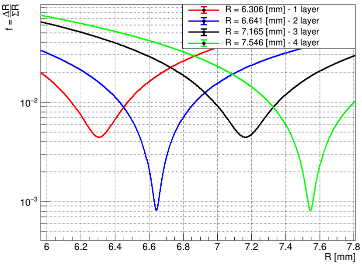


Distortion of cells from hexagonal shape

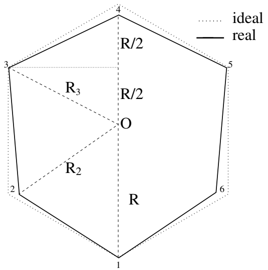
Optimization of cell structure

- The development of cell structure was carried out sequentially layer by layer. The wire positions in the cell were optimized for each layer:

$$f = \frac{\sqrt{(R - R_2)^2 + (R - R_3)^2 + (R_2 - R_3)^2}}{R + R_2 + R_3}$$

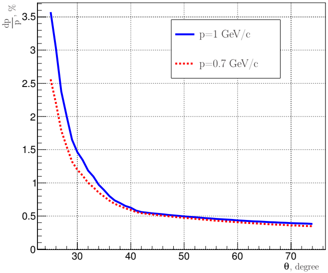


Dependence of f as a function of R for the first superlayer

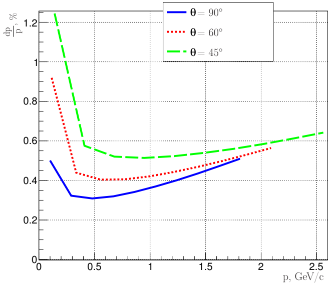


Definition R, R_2, R_3

The toy simulation of pions flight through DC was performed;



Momentum resolution as a function of polar angle

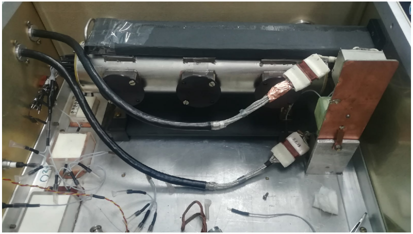


Momentum resolution as a function of full momentum

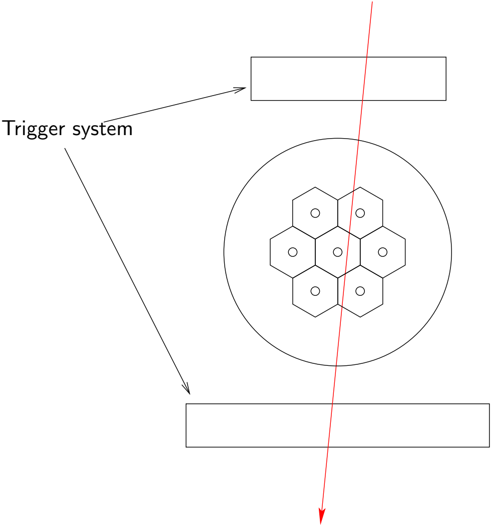
dE/dx resolution $\sigma_{dE/dx} \sim 7\%$ was estimated from CLEO dE/dx resolution and comparable with Belle(6.9%) and BaBar(7.5%)

The small prototype of DC

- Diameter - 70 mm
- Length - 300 mm
- 7 hexagonal cells
- The spatial resolution measurements have been performed at the $He/C_3H_8 - 60/40$ and $He/C_2H6 - 50/50$ gas mixtures at different gas gains



Prototype photo



Layout of cells in the prototype

Program of charged particles track reconstruction for the small DC prototype

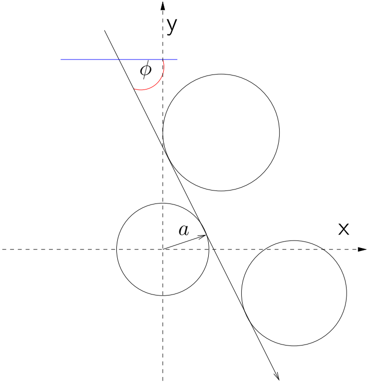
Track is parameterized: $xsin(\phi) + ycos(\phi) - a = 0$

All possible tangent tracks to isochrones are sorted out and the most suitable one is selected.

Next comes the numerical search:

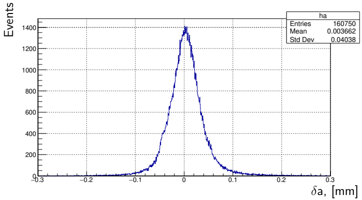
$$\chi^2(a, \phi) = \sum \frac{(R_i(a,\phi) - r_i)^2}{2\sigma_i^2},$$

где $R_i(a, \phi) = |x_i sin(\phi) + y_i cos(\phi) - a|$

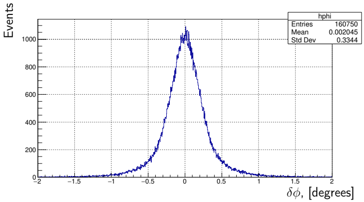


Tangents between circles

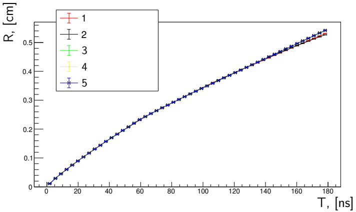
Simulation of the calibration procedure



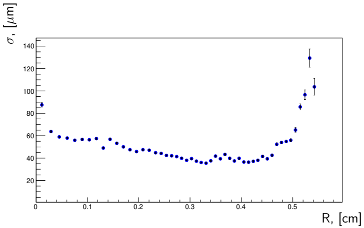
Deviation of a parameter



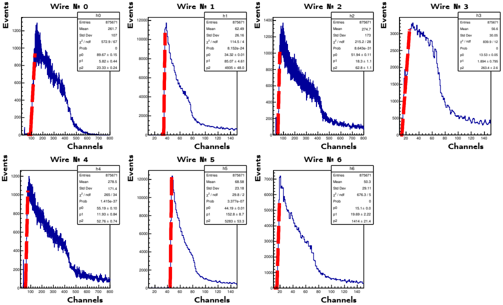
Deviation of ϕ parameter



R(t) dependence

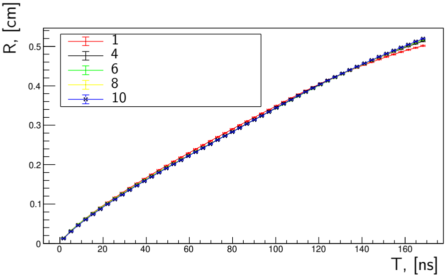


Spatial resolution without taking into account the diffusion of electrons and the constant component

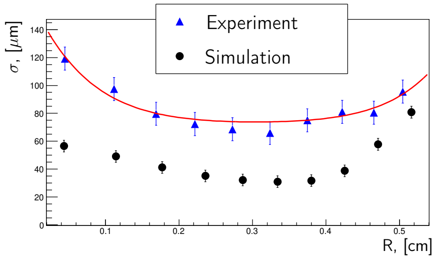


$\Longleftarrow$ Time spectrum from each wire at the $5 \cdot 10^4$ gain (He/C_3H_8, maximum drift time is around 170 ns)

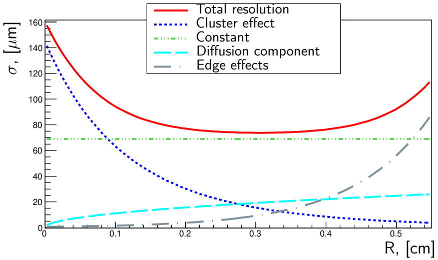
Dependence R(t) in experiment at the $7 \cdot 10^4$ gain (He/C_3H_8) $\Longrightarrow$



Spatial resolution measurements



Full spatial resolution for He/C3H8 mixture

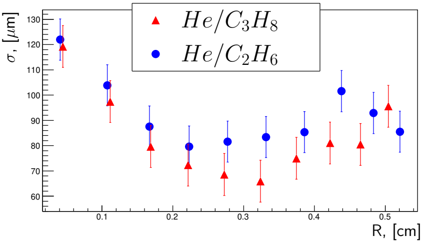


Contribution of each component to resolution

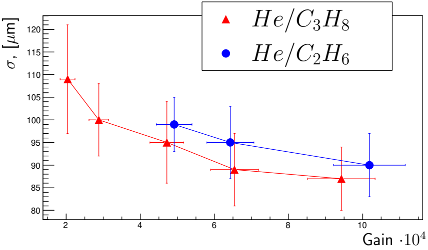
$$\sigma(r) = \sqrt{\sigma_{cl}^2 + \sigma_{dif}^2 + \sigma_{edge}^2 + \sigma_0^2}$$

σ_{cl} - cluster effect, σ_{dif} - diffusion component, σ_{edge} - edge effects, σ_0 - constant (contributions from electronics, wire arrangements, pressure, temperature)

Spatial resolution measurements



The spatial resolution comparison for He/C_3H_8 and He/C_2H_6 at $7 \cdot 10^4$



The average spatial resolution for He/C_3H_8 and He/C_2H_6 at the different gas gains

For He/C_3H_8:

$\bar{\sigma} = 109 \pm 12$ μm at $2 \cdot 10^4$

$\bar{\sigma} = 100 \pm 8$ μm at $3 \cdot 10^4$

$\bar{\sigma} = 95 \pm 9$ μm at $5 \cdot 10^4$

$\bar{\sigma} = 89 \pm 8$ μm at $7 \cdot 10^4$

$\bar{\sigma} = 87 \pm 7$ μm at 10^5

For He/C_2H_6:

$\bar{\sigma} = 99 \pm 6$ μm at $5 \cdot 10^4$

$\bar{\sigma} = 95 \pm 8$ μm at $7 \cdot 10^4$

$\bar{\sigma} = 90 \pm 7$ μm at 10^5

Summary

- A simple detector design with competitive characteristics is proposed
- The preliminary calculation of the DC construction has been completed in ANSYS
- Momentum resolution and dE/dX resolution have been simulated
- Measured the spatial resolution on the small DC prototype for He/C_3H_8 and He/C_2H_6 gas mixtures at different gas gains
- Our results show the possibility of achieving good accuracy measurements in a small hexagonal cell in a He/C_3H_8 gas mixture

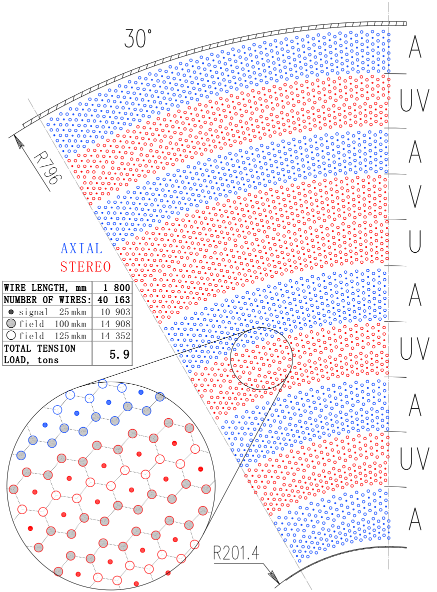
In the near future we plan to upgrade a prototype (increase amount of cells from 7 to 19)

THANK YOU FOR YOUR ATTENTION!

BACKUP

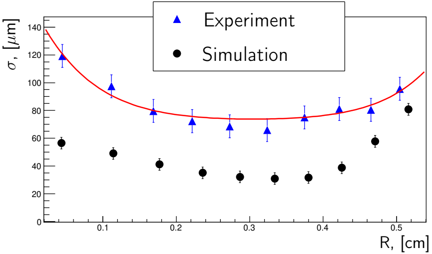
The drift chamber

SUPER LAYER NUMBER	NUMBER OF MONO-LAYERS	NUMBER OF CELLS IN MONOLAYER	NUMBER OF CELLS	STEREO ANGLE, mrad	CELL SIZE r ± Δr, mm		RADIUS OF ANODE WIRE LAYER, mm
1	4	125	500	0	6.306	0.034	217.306
					6.644	0.007	227.100
					7.165	0.039	246.906
					7.549	0.009	258.035
2	4	157	628	+ 33.8	6.473	0.028	280.154
					6.747	0.006	290.136
				− 34.2	7.182	0.031	310.863
					7.486	0.007	321.938
3	4	189	756	0	6.564	0.024	341.986
					6.794	0.005	352.060
					7.140	0.026	371.992
					7.388	0.005	382.950
4	4	223	892	+ 48.9	6.603	0.020	405.941
					6.799	0.004	416.040
				− 49.3	7.104	0.021	436.741
					7.314	0.005	447.606
5	5	255	1275	0	6.651	0.018	467.570
					6.823	0.003	477.718
					6.968	0.001	488.097
					7.120	0.001	498.701
					7.274	0.001	509.535
6	4	287	1148	+ 63.1	6.741	0.016	533.350
					6.895	0.004	543.615
					7.026	0.001	554.088
					7.161	0.001	564.762
7	4	313	1252	− 63.4	6.778	0.015	584.801
					6.919	0.003	595.108
					7.039	0.001	605.606
					7.163	0.001	616.289
8	4	341	1364	0	6.768	0.014	636.220
					6.898	0.003	646.501
					7.007	0.001	656.957
					7.121	0.001	667.581
9	4	371	1484	+ 64.7	6.746	0.013	689.948
					6.865	0.003	700.185
				− 65.0	7.041	0.013	720.090
					7.165	0.002	730.775
10	4	401	1604	0	6.791	0.012	750.730
					6.902	0.003	761.027
					6.995	0.001	771.472
					7.091	0.001	782.061
TOTAL	41		10903				

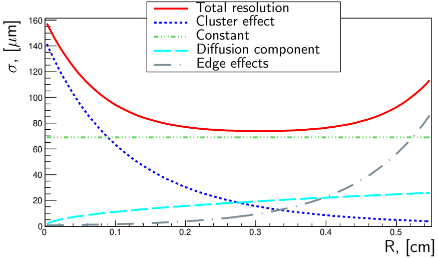


WIRE LENGTH, mm	1 800
NUMBER OF WIRES:	40 163
● signal 25 mkm	10 903
field 100 mkm	14 908
○ field 125 mkm	14 352
TOTAL TENSION LOAD, tons	5.9

Spatial resolution measurements



Full spatial resolution for He/C3H8 mixture



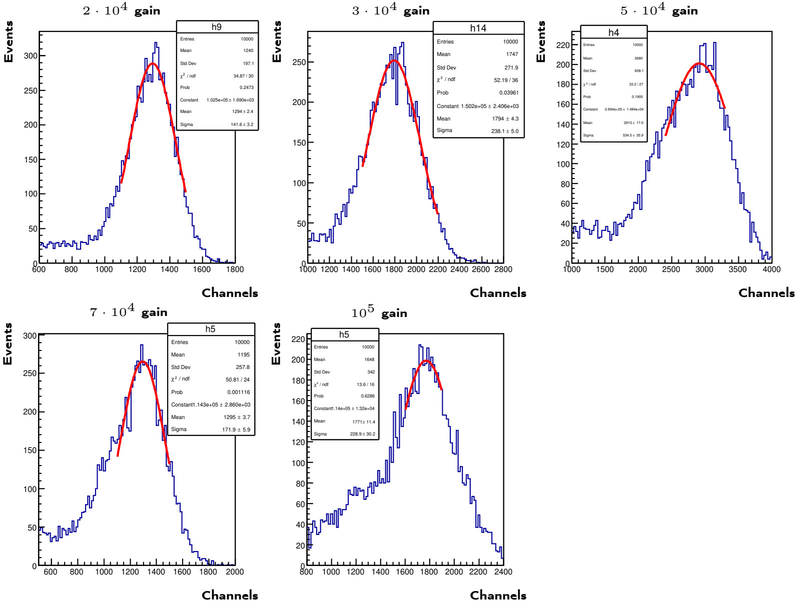
Contribution of each component to resolution

$$\sigma(r) = \sqrt{\left(\frac{p_0}{r+p_1}\right)^{p_2} + (p_3\sqrt{r})^2 + (p_4 e^{p_5 r})^2 + p_6^2}$$

$p_0 - p_5$ are free parameters

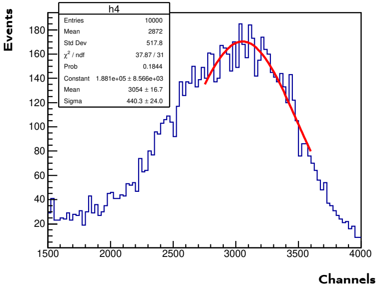
Parameter p_6 is a σ_0 associated with contributions from electronics, wire arrangements, pressure, temperature. It was found from quadratic difference between the experimental and simulated data

Gas gain in spatial resolution measurement (He/C_3H_8)

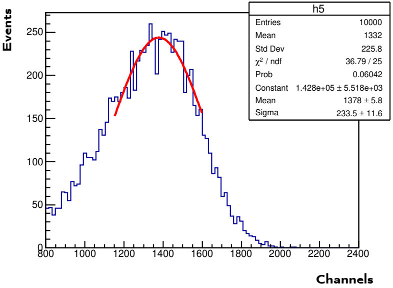


Gas gain in spatial resolution measurement (He/C_2H_6)

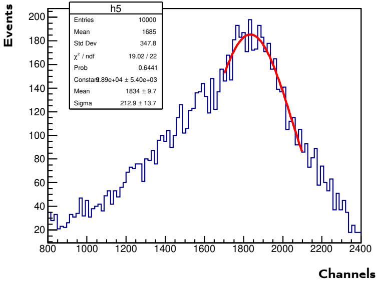
$5 \cdot 10^4$ **gain**



$7 \cdot 10^4$ **gain**



10^5 **gain**



Stereo layers

SCTF		BELLE II		BaBar		BES III	
R mm	α_{stereo} mrad	R mm	α_{stereo} mrad	R m	α_{stereo} mrad	R mm	α_{stereo} mrad
280.154	$+33.8$	257.0	$+45.4$	–	–	327.5	-30.68
290.136	-34.2	348.0	$+45.8$	318.5	$+44.9$	334.1	-31.31
405.941	$+48.9$	–	–	370.5	-52.3	402.1	$+31.41$
416.040	-49.3	476.9	-55.3	480.8	$+55.6$	415.5	$+32.46$
533.350	$+63.1$	566.9	-64.3	533.2	-62.8	531.7	-42.06
584.801	-63.4	–	–	–	–	583.0	$+40.37$
689.948	$+64.7$	695.3	$+63.1$	643.0	$+65.0$	676.3	-41.62
730.775	-65.0	785.3	$+70.0$	695.2	-72.1	–	–