图像预处理

GE_CCD-C@445eV弹性峰矫正算法

原始数据 → **Step 1** → 截取弹性峰附近区域 → **Step 2** → 中值滤波降噪 → **Step 3** → 线性背底扣除

2052*2048 16bit Data

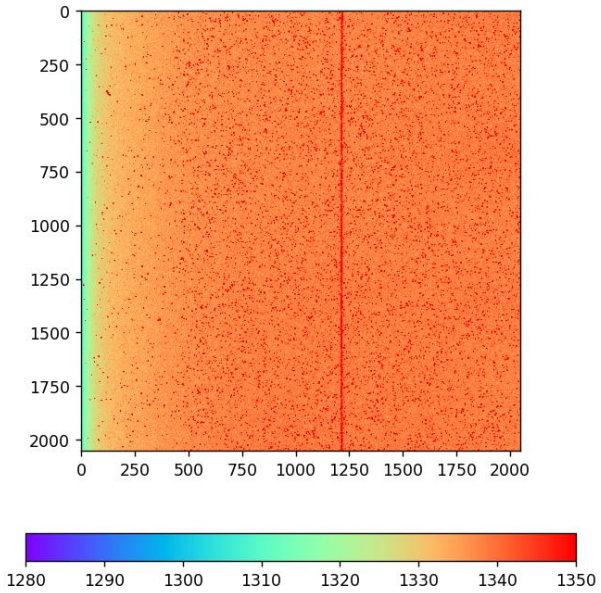
每列：2052像素
每行：2048像素
数据(16bit)：0-65535

截取弹性峰中心两边各200列
区域大小：2052*400 pixels

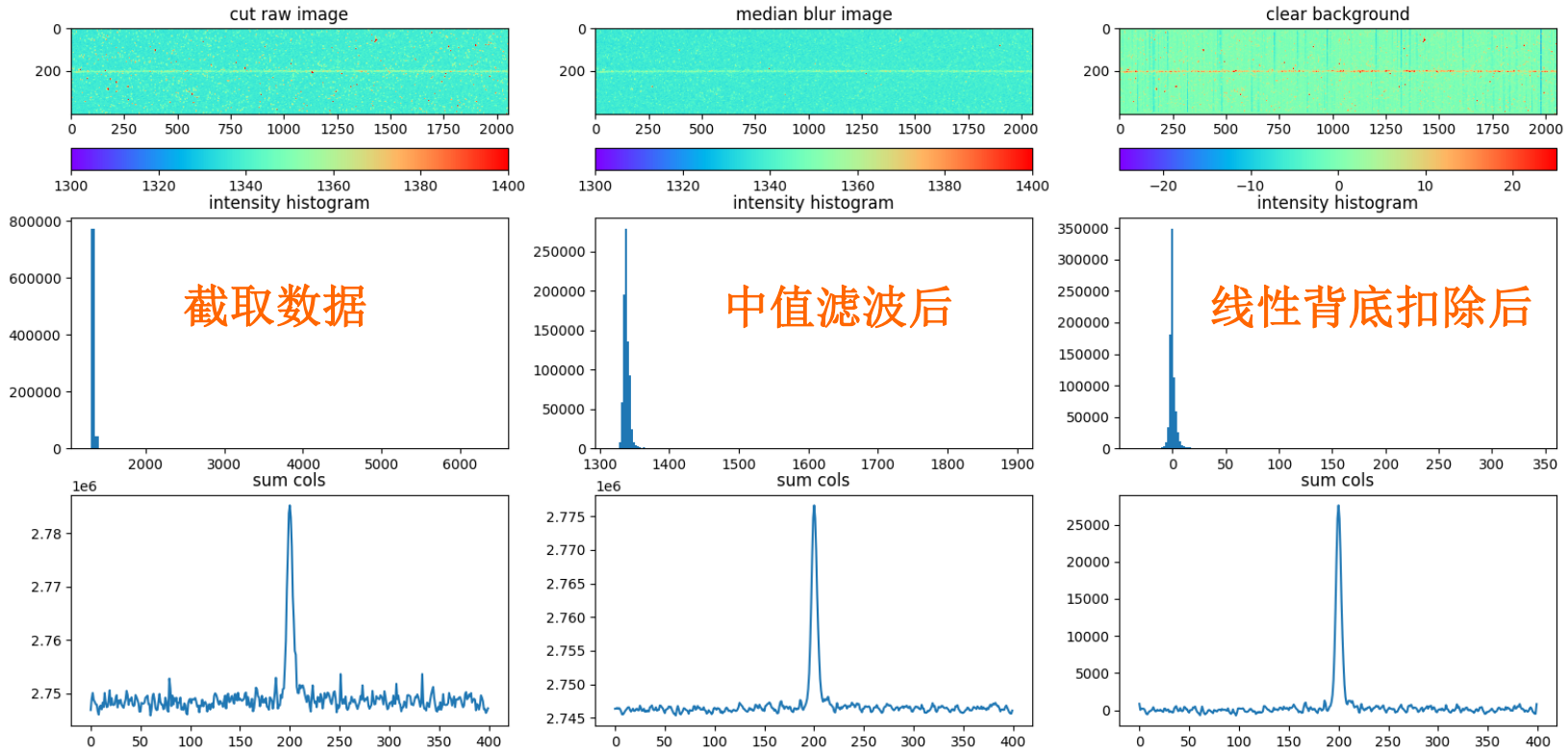
中值滤波：像素点周围3*3的共9个像素的数值按数值大小排序，修改为中间值。

每一列400个像素点数据，按照线性关系扣除背底，弹性峰两边拉平到0值。

目前测得的数据点范围：1300-1400



原始数据

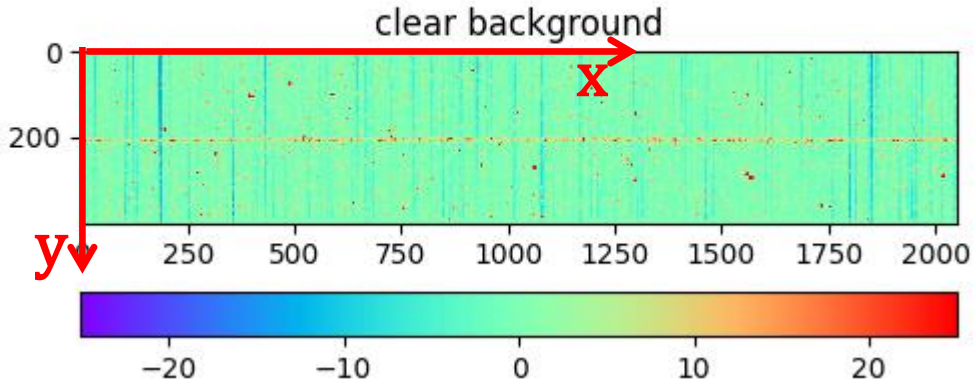


弹性峰偏移估算

GE_CCD-C@445eV弹性峰矫正算法

预处理后数据 → 算法实现

弹性峰在CCD幅面上分布满足二次曲线关系



$$shift\_pixels = a + bx + cx^2$$

x为每一列（400个像素）所在的像素位置

参数的物理含义：

1. a代表弹性峰整体沿着y方向平移，因为已经置于中心x=200位置，所以设置为0。
2. b代表弹性峰在每个x处线性平移，对应的谱线的倾斜
3. c代表弹性峰在每个x处按二次平移，对应与弯曲的弧度（与光栅常数相关：c=1e-7）

基本函数

```
def shift_pixel(index:int,j:int=1):
    #return round(0.005 + index*0.01+index**2*(1+j*0.1)*1e-7)
    #return round((0.001+0.005*j)*index+index**2*(1e-7))
    return round((0.015+0.0005*j)*index+index**2*(1e-7)) # best fit result
```

实现思路：

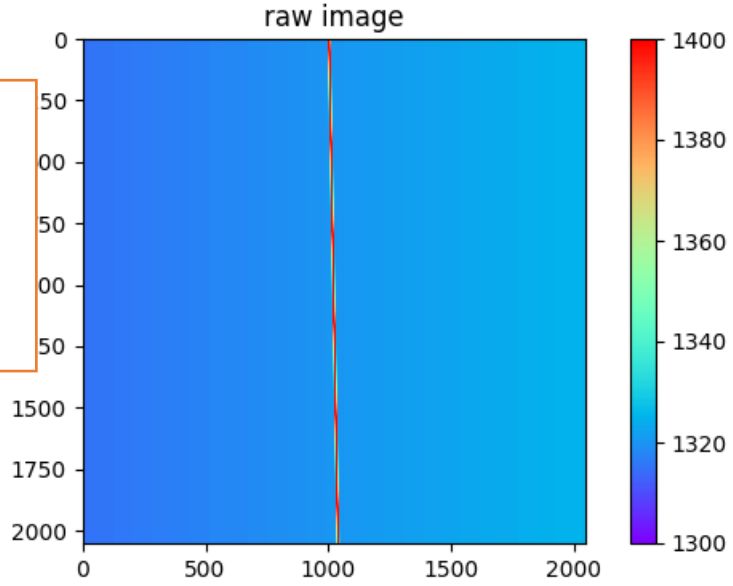
1. 对每一列（400个像素即0-399）按0.05的步长插值，得到400*20=8000个新点，取中间（2800~5200）段共2400个点来进行偏移，即对应于中间120个像素。
2. 对于每一列所对应的x即index，使用shift_pixel函数计算需要偏移的点数shift_N。（即最小偏移一个点，对应于0.05个像素）
3. 将该列的点2800- shift_N到点5200- shift_N，取出来进行叠加，相当于向上平移shift_N个点，向下则为+。
4. 将叠加后的数据（2400个点）插值后，输出为对应到原来120个像素的数据列。
5. 最后将所得到的120个像素的数据进行Gauss拟合得到半高宽FWHM。

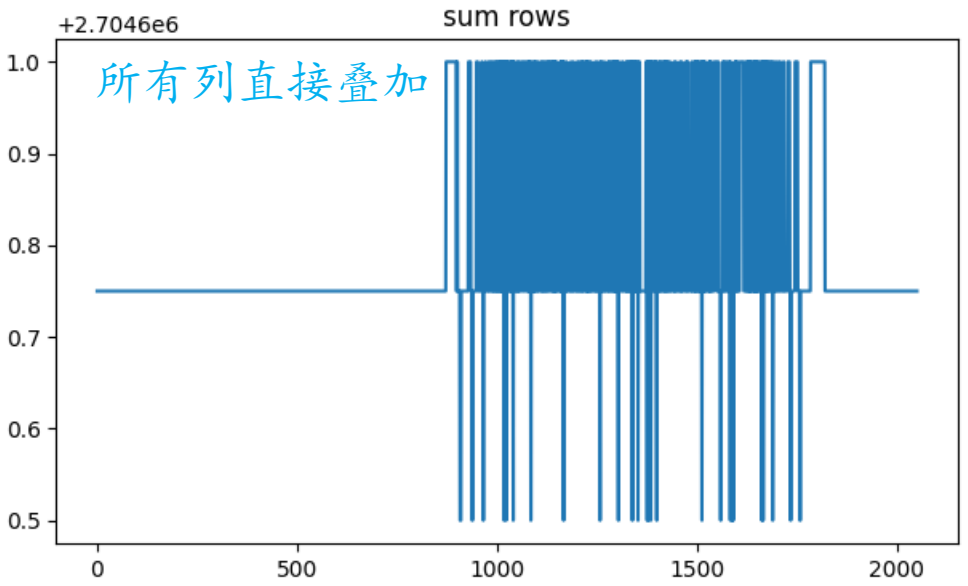
参数b优化：b=（0.0015+0.0005*j）通过遍历j逐步缩小b的数值范围，直至最小的半高宽。

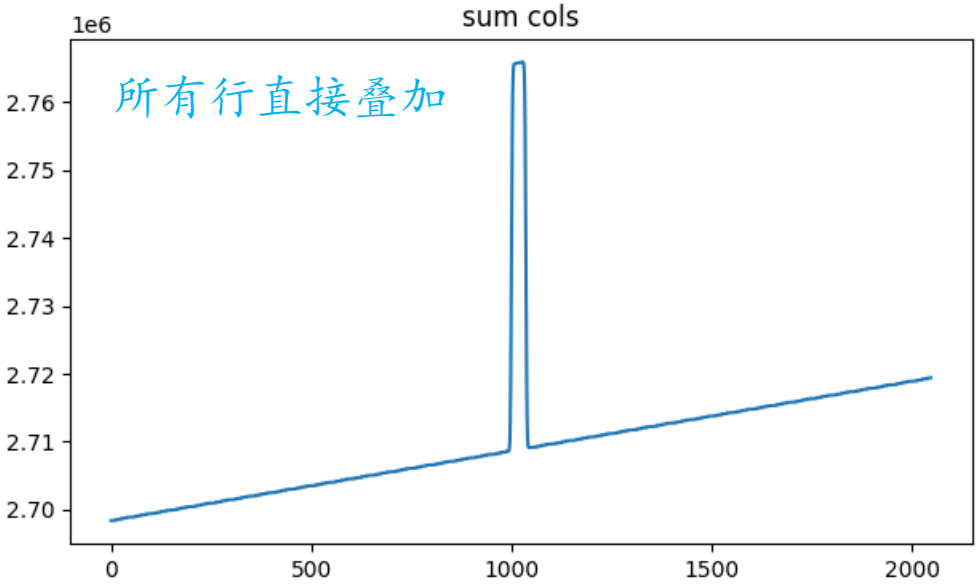
测试1:标准Gauss峰数据

GE_CCD-弹性峰矫正算法可靠性检验

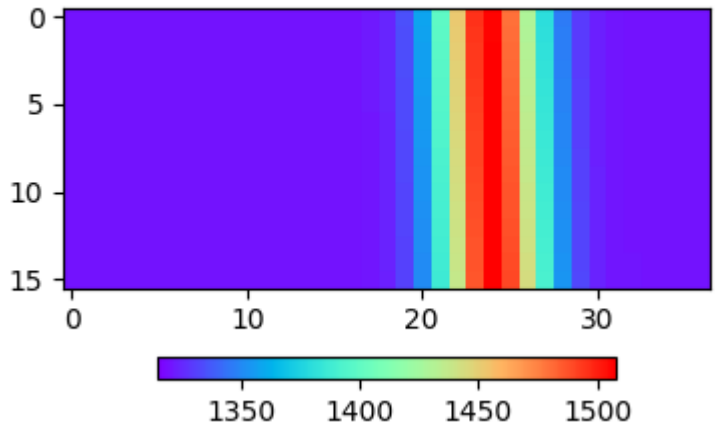
标准的高斯峰谱线
沿着斜线:
y=57*x-57000呈正态分布
高斯峰谱线半高宽FWHM=5
倾斜的背底
未添加随机噪声







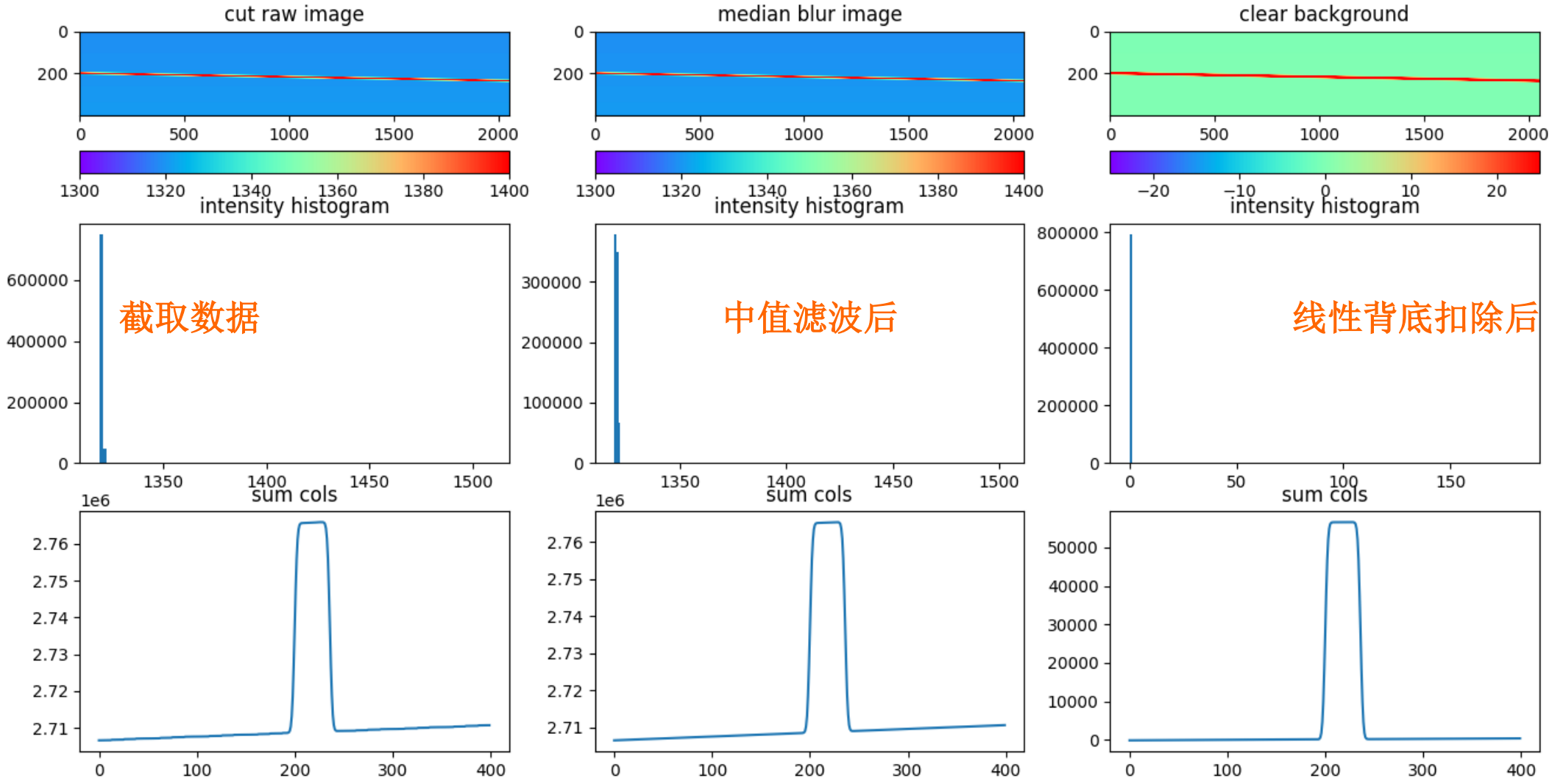
局部放大后的Gauss峰谱线



测试1:图像降噪和背底消除

GE_CCD-弹性峰矫正算法可靠性检验

高斯峰谱线半高宽FWHM=5



示例1:高斯峰矫正

GE_CCD-弹性峰矫正算法可靠性检验

高斯峰为倾斜的直线：y=57*x-57000

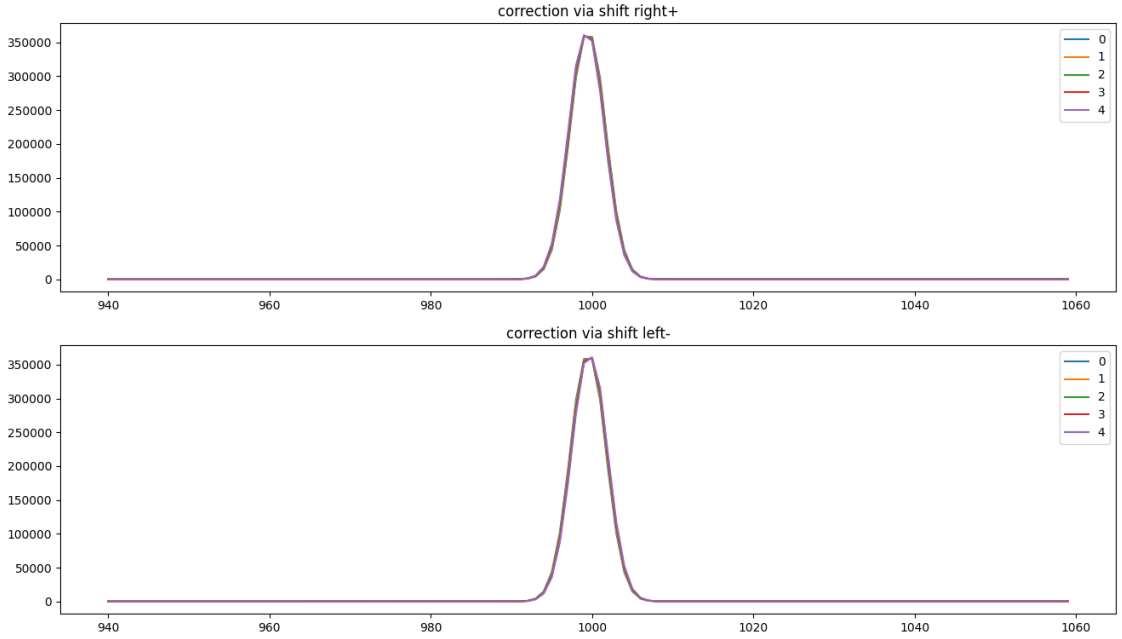
矫正只需要一次项

$$shift\_pixels = \mathrm{a} + \mathrm{bx}$$

（由于算法中x按照0.05的步长插值，所以b的标准值为1/57/0.05）

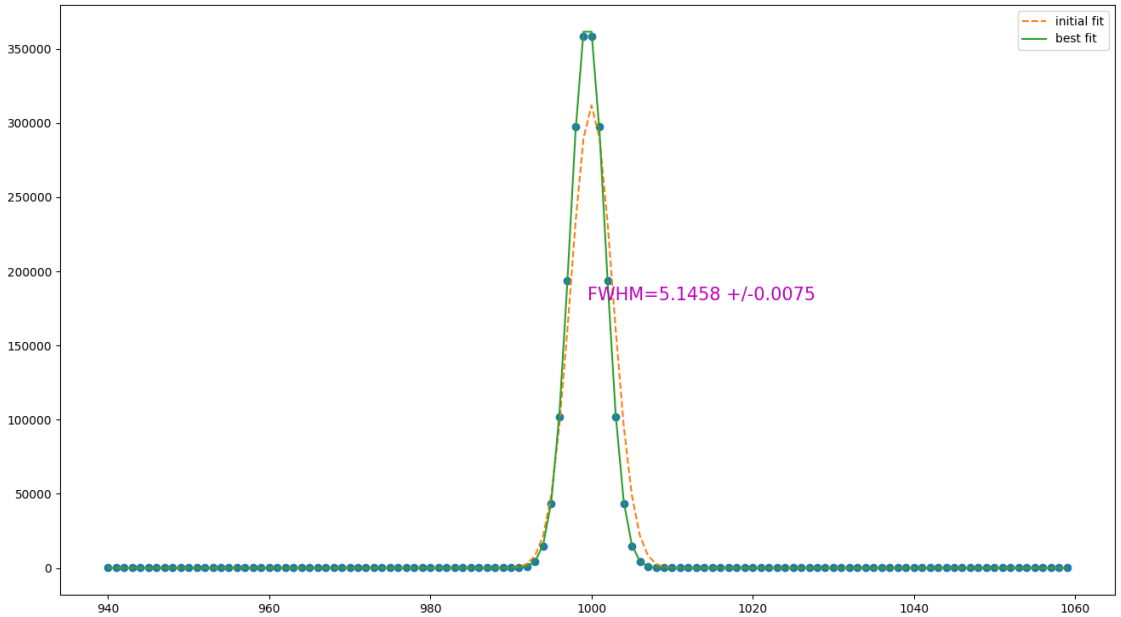
b=-(1/57/0.05+0.001*j)

j取值变化范围[-4, -3, -2, -1, 0, 1, 2, 3, 4]



算法拟合结果：$\mathrm{FWHM} = 5.14 \pm 0.0075\mathrm{pixels}$

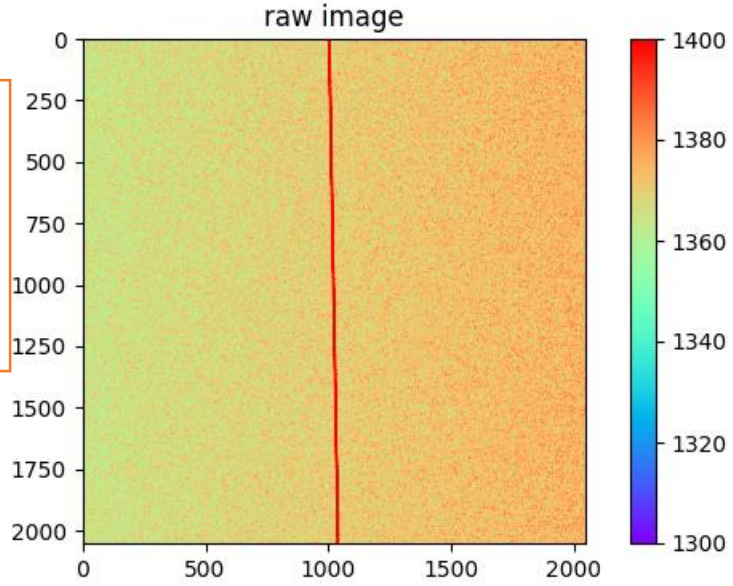
同标准值=5pixels的误差为2.8%

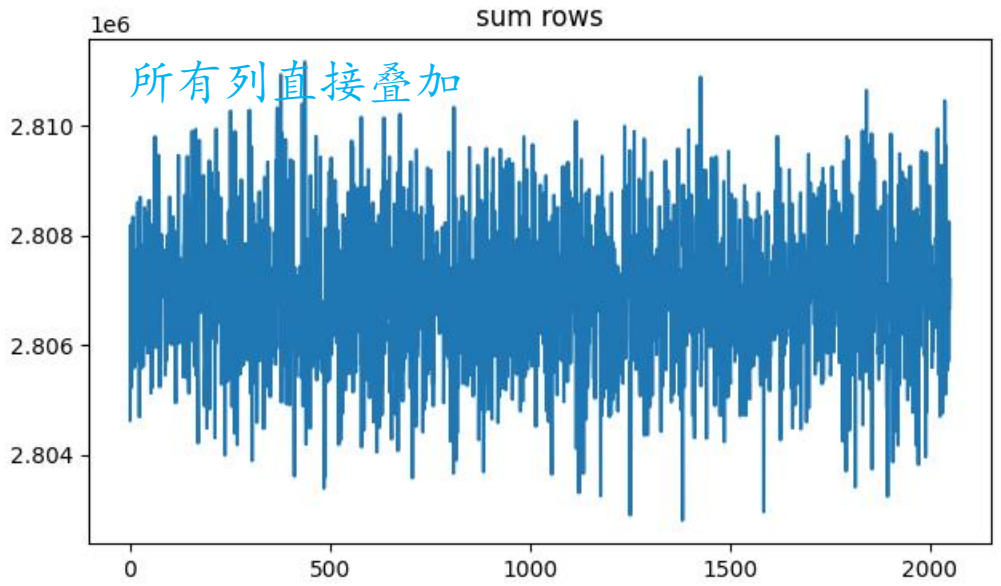


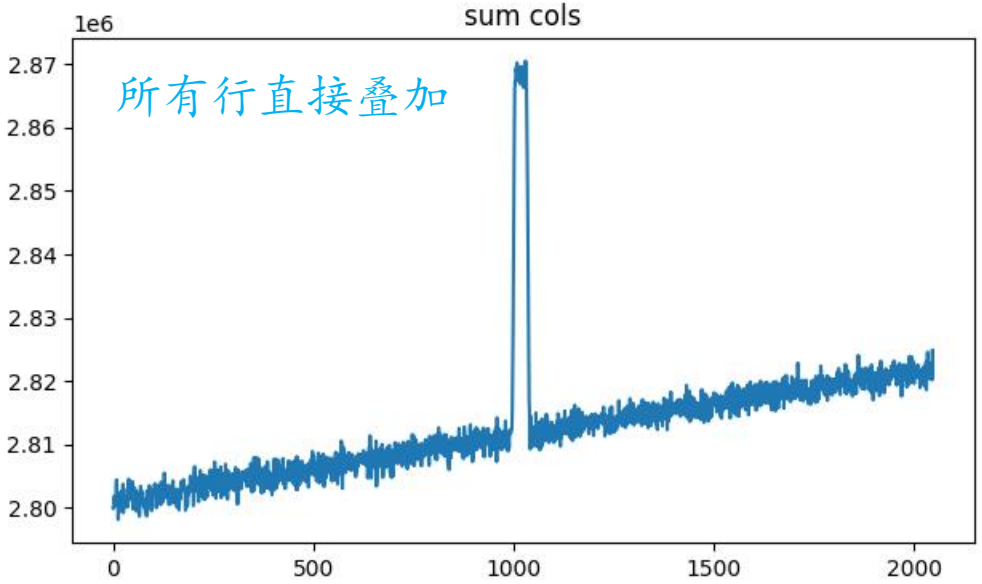
测试2:标准Gauss峰数据

GE_CCD-弹性峰拟合算法可靠性检验

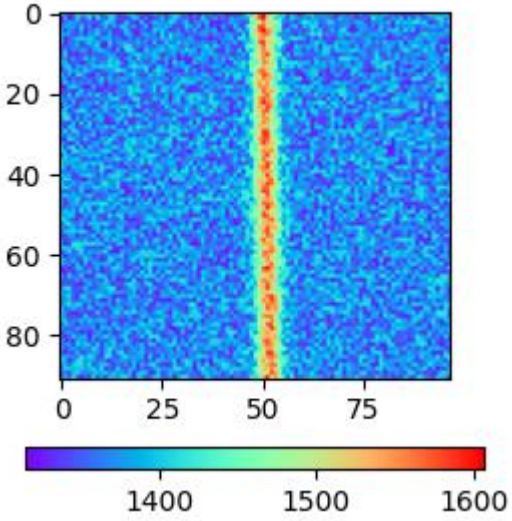
标准的高斯峰谱线
沿斜线:
y=57*x-57000呈正态分布
半高宽FWHM=5
倾斜的背底
添加了随机噪声(0~100)







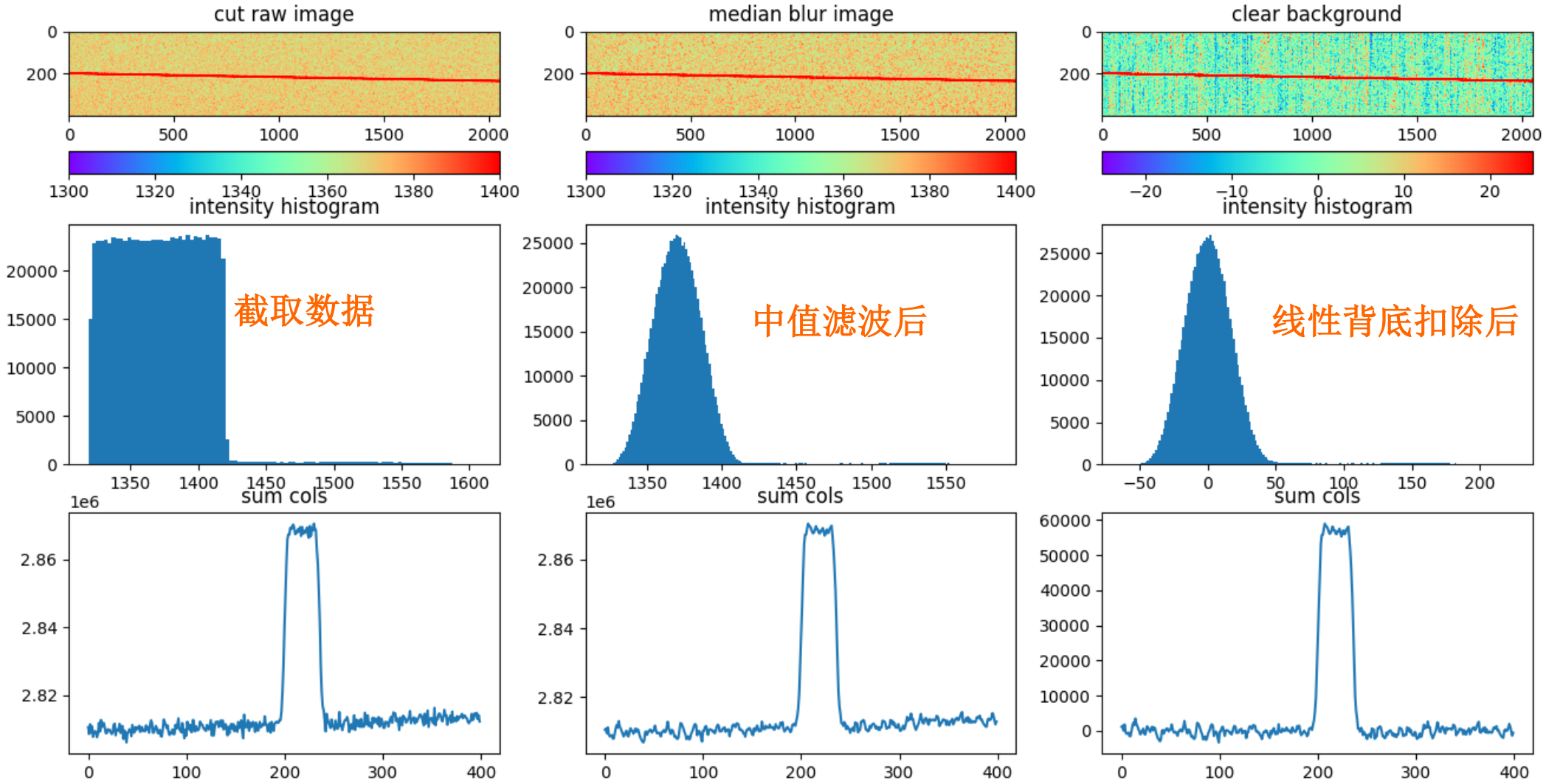
局部放大后的Gauss峰谱线



测试2:图像降噪和背底消除

GE_CCD-弹性峰矫正算法可靠性检验

高斯峰谱线半高宽FWHM=5



测试2:高斯峰矫正

GE_CCD-弹性峰矫正算法可靠性检验

高斯峰为倾斜的直线：y=57*x-57000

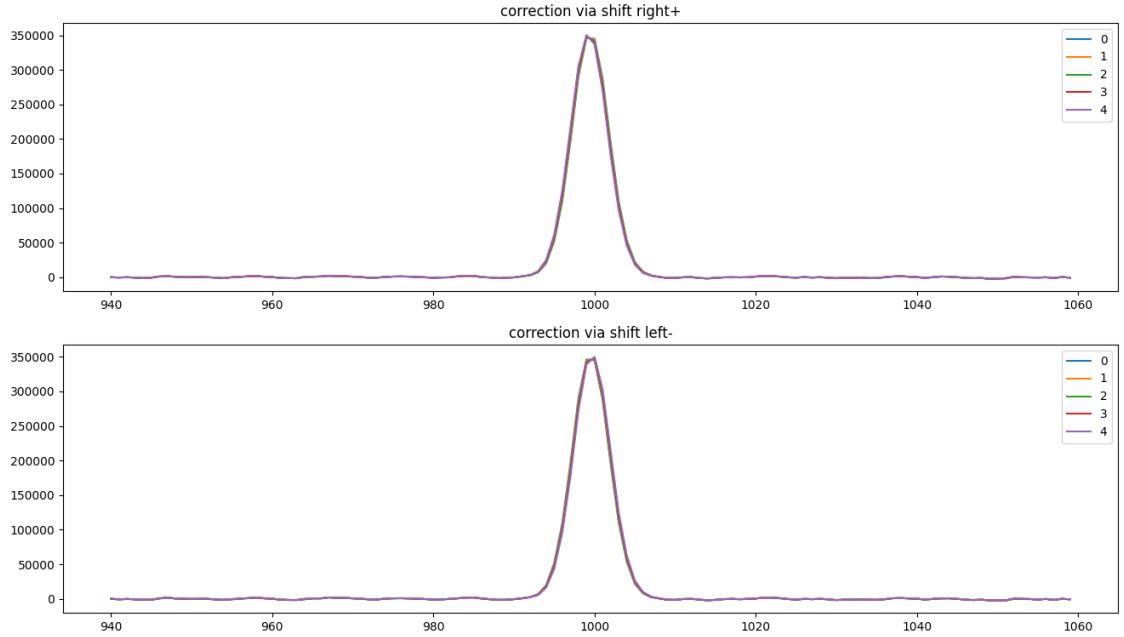
矫正只需要一次项

$$shift\_pixels = \mathrm{a} + \mathrm{bx}$$

（由于算法中x按照0.05的步长插值，所以b的标准值为1/57/0.05）

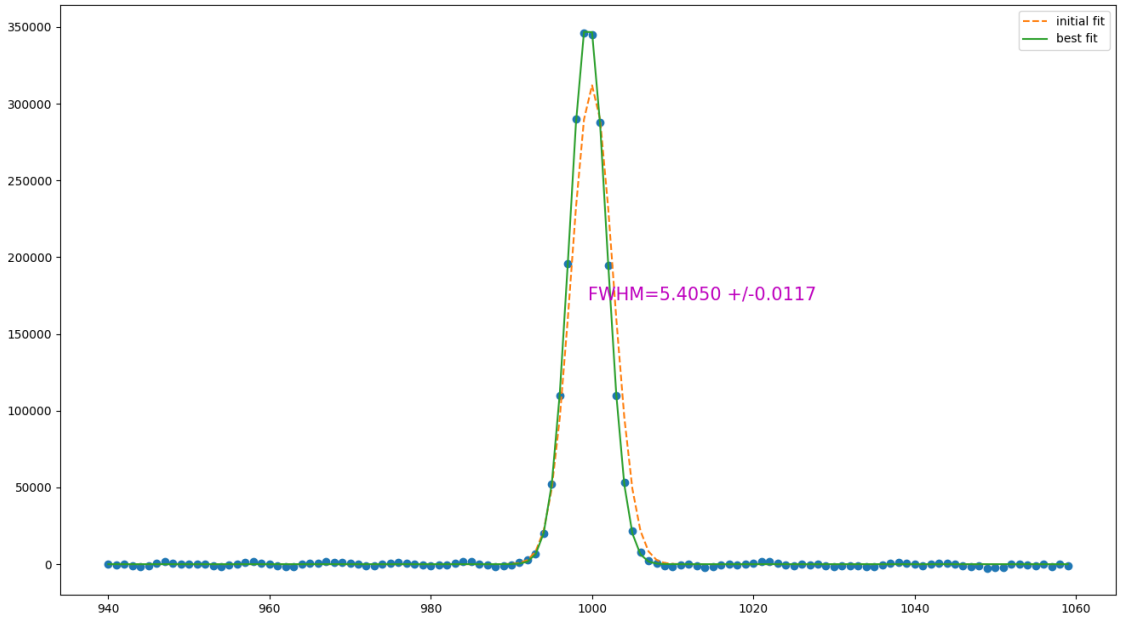
b=-(1/57/0.05+0.001*j)

j取值变化范围[-4, -3, -2, -1, 0, 1, 2, 3, 4]



算法拟合结果：$\mathrm{FWHM} = 5.40 \pm 0.01 \mathrm{pixels}$

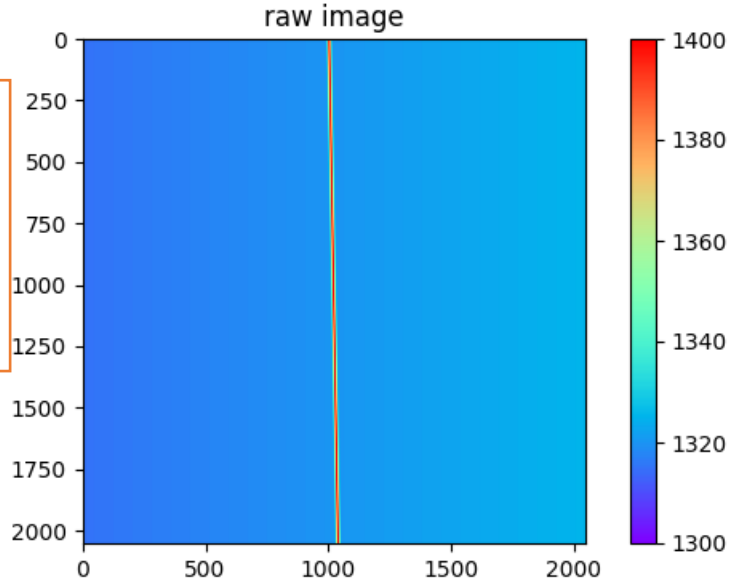
同标准值=5pixels的误差为8%

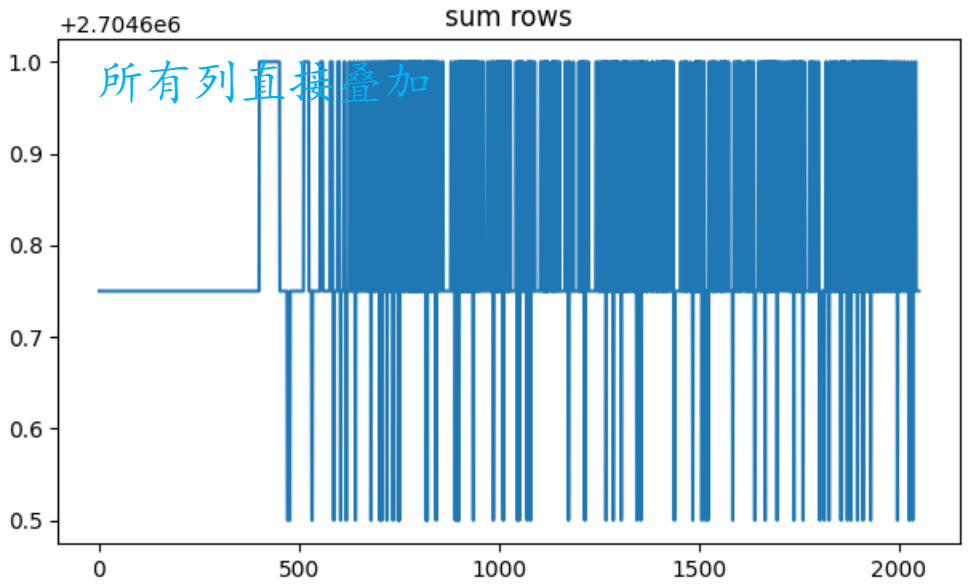


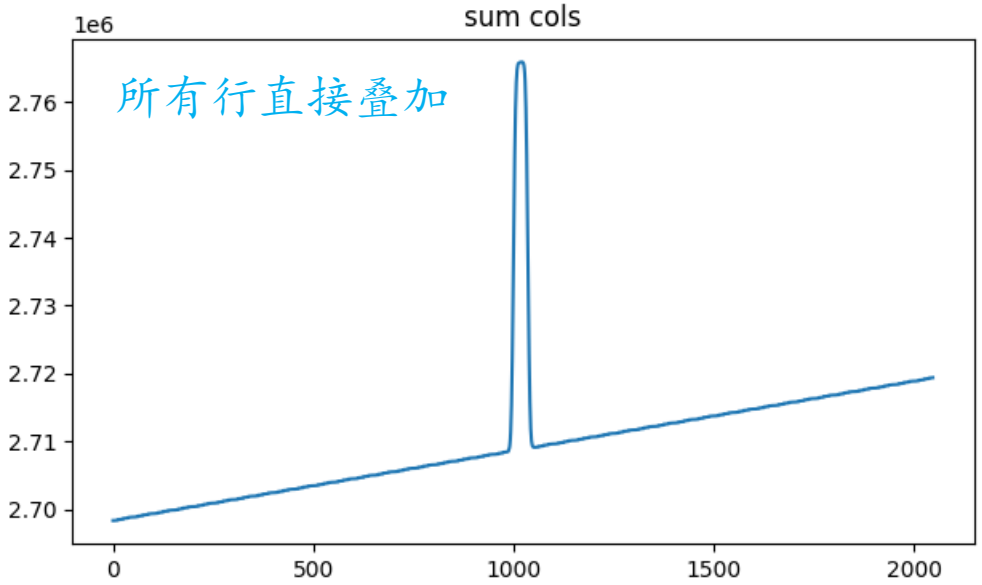
测试3:标准Gauss峰数据

GE_CCD-弹性峰矫正算法可靠性检验

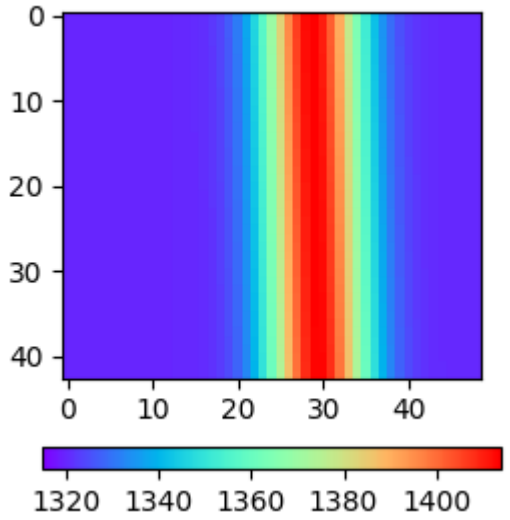
标准的高斯峰谱线
沿斜线:
y=57*x-57000呈正态分布
半高宽FWHM=10
倾斜的背底
未添加随机噪声







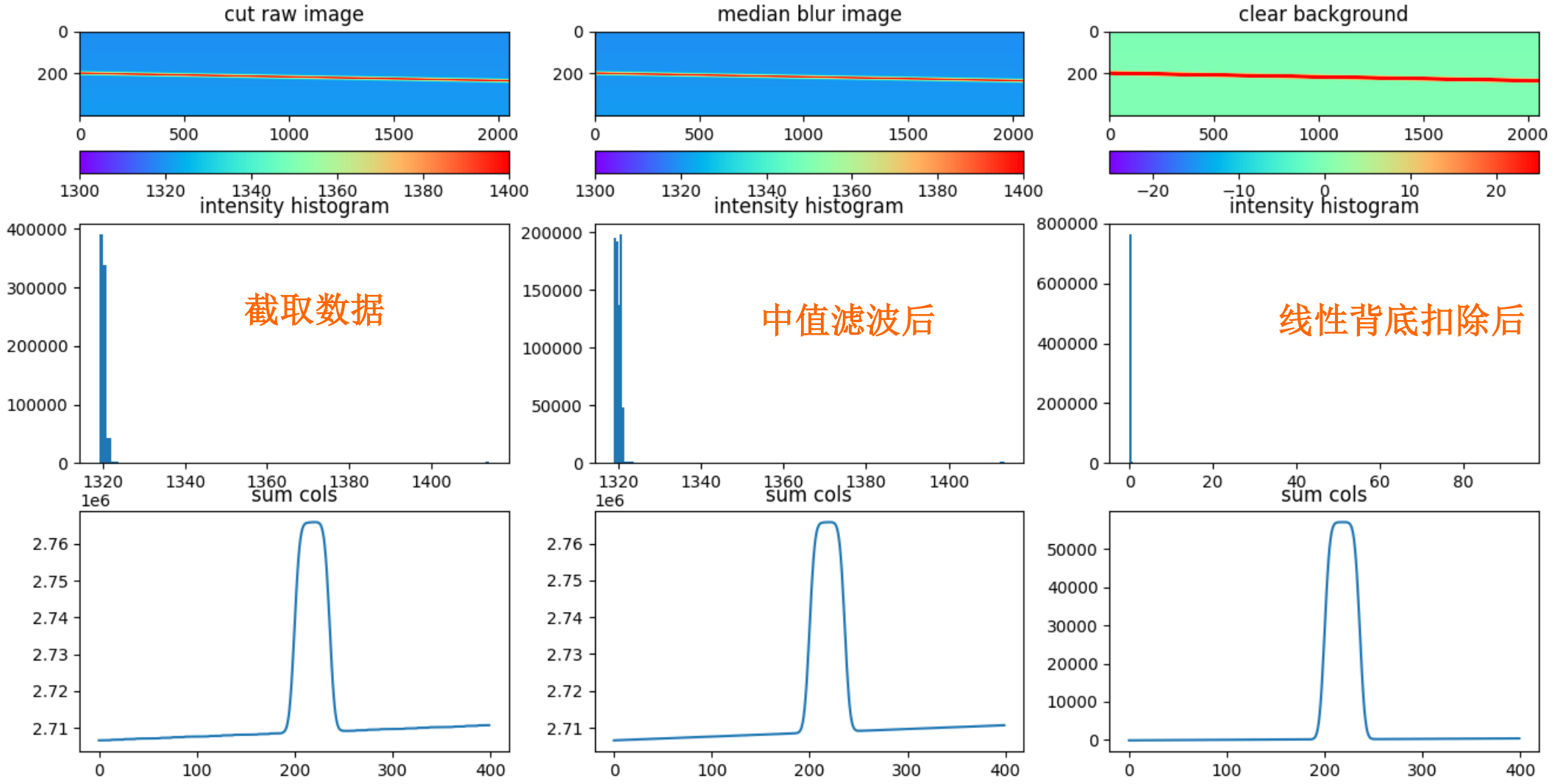
局部放大后的Gauss峰谱线



测试3:图像降噪和背底消除

GE_CCD-弹性峰矫正算法可靠性检验

高斯峰谱线半高宽FWHM=10



测试3:高斯峰矫正

GE_CCD-弹性峰矫正算法可靠性检验

高斯峰为倾斜的直线：y=57*x-57000

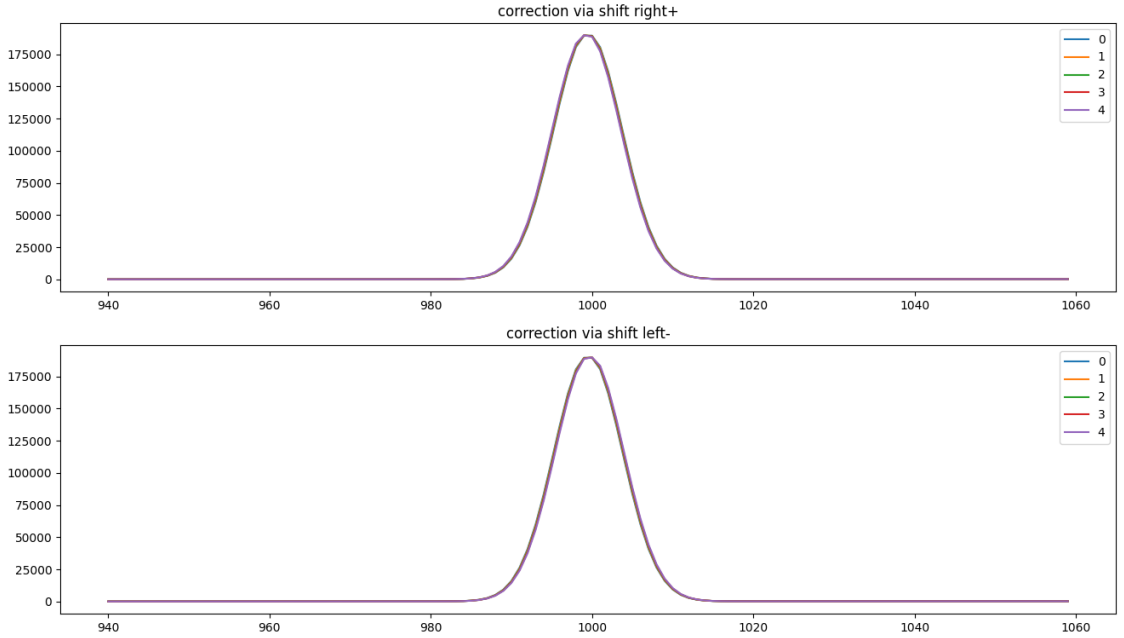
矫正只需要一次项

$$shift\_pixels = a + bx$$

（由于算法中x按照0.05的步长插值，所以b的标准值为1/57/0.05）

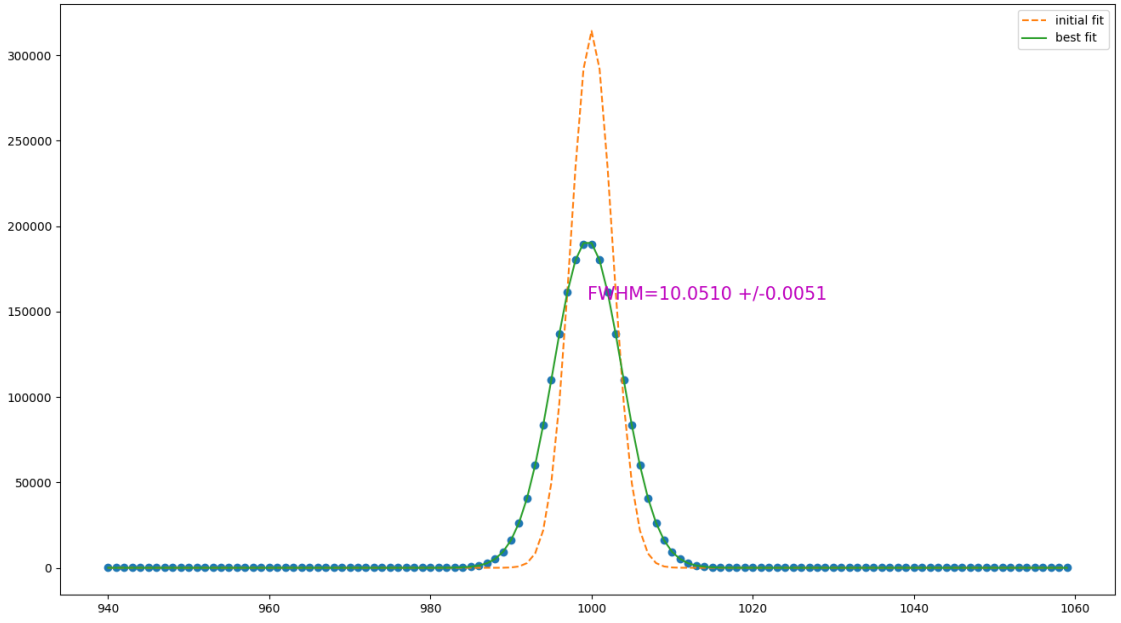
b=-(1/57/0.05+0.001*j)

j取值变化范围[-4, -3, -2, -1, 0, 1, 2, 3, 4]



算法拟合结果：$\mathrm{FWHM} = 10.05 \pm 0.005\mathrm{pixels}$

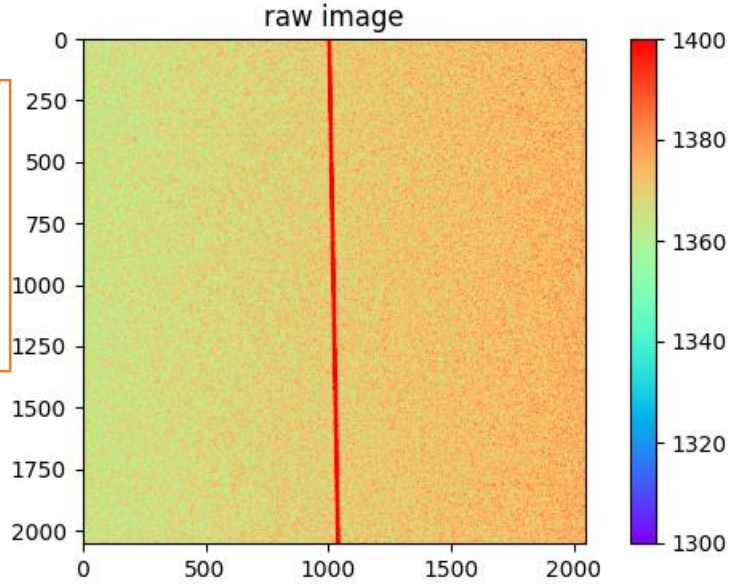
同标准值=10pixels的误差为0.5%

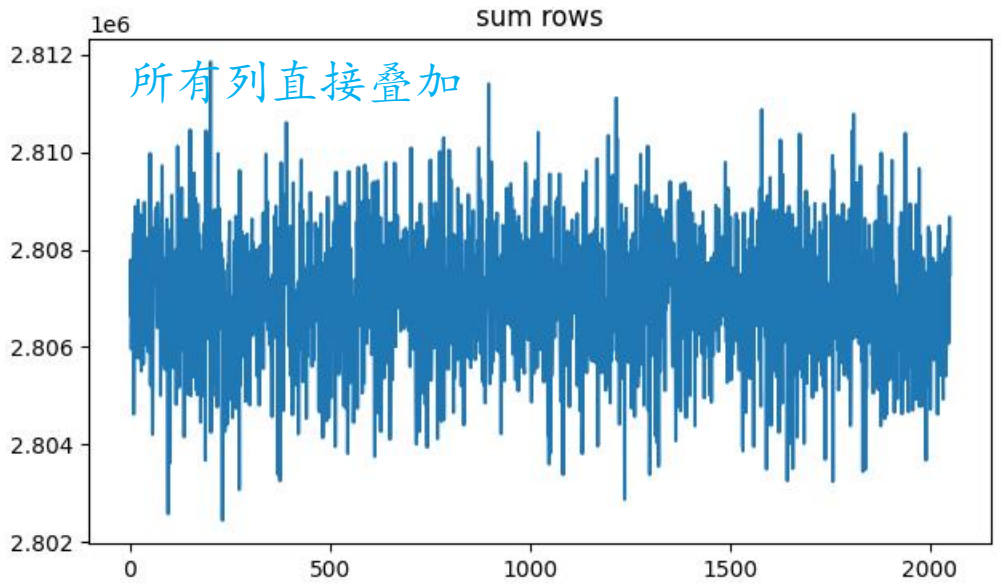


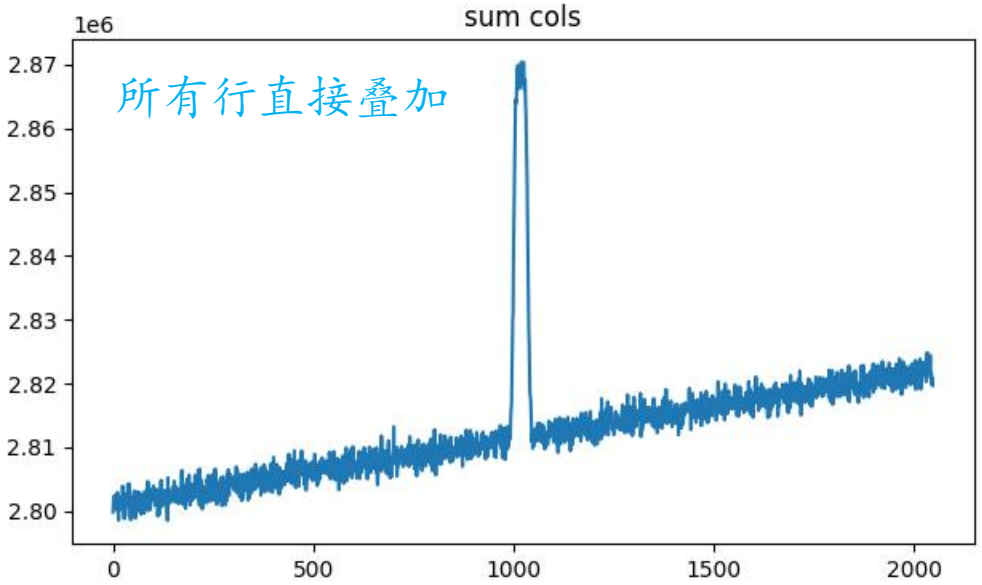
测试4:标准Gauss峰数据

GE_CCD-弹性峰矫正算法可靠性检验

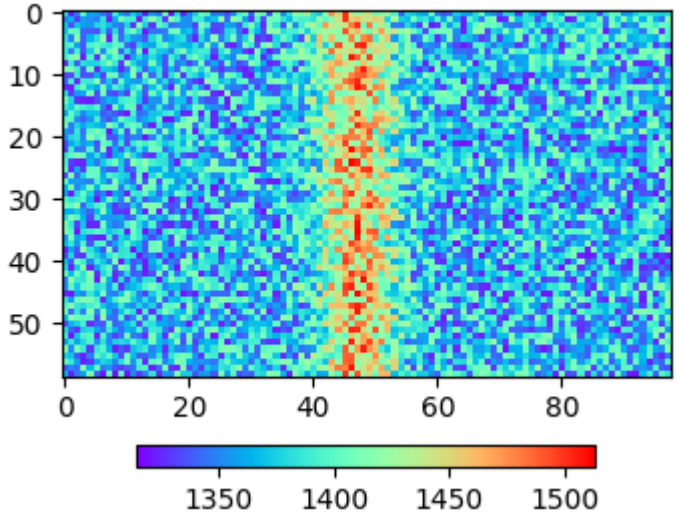
标准的高斯峰谱线
沿斜线:
y=57*x-57000呈正态分布
半高宽FWHM=10
倾斜的背底
添加了随机噪声(0~100)







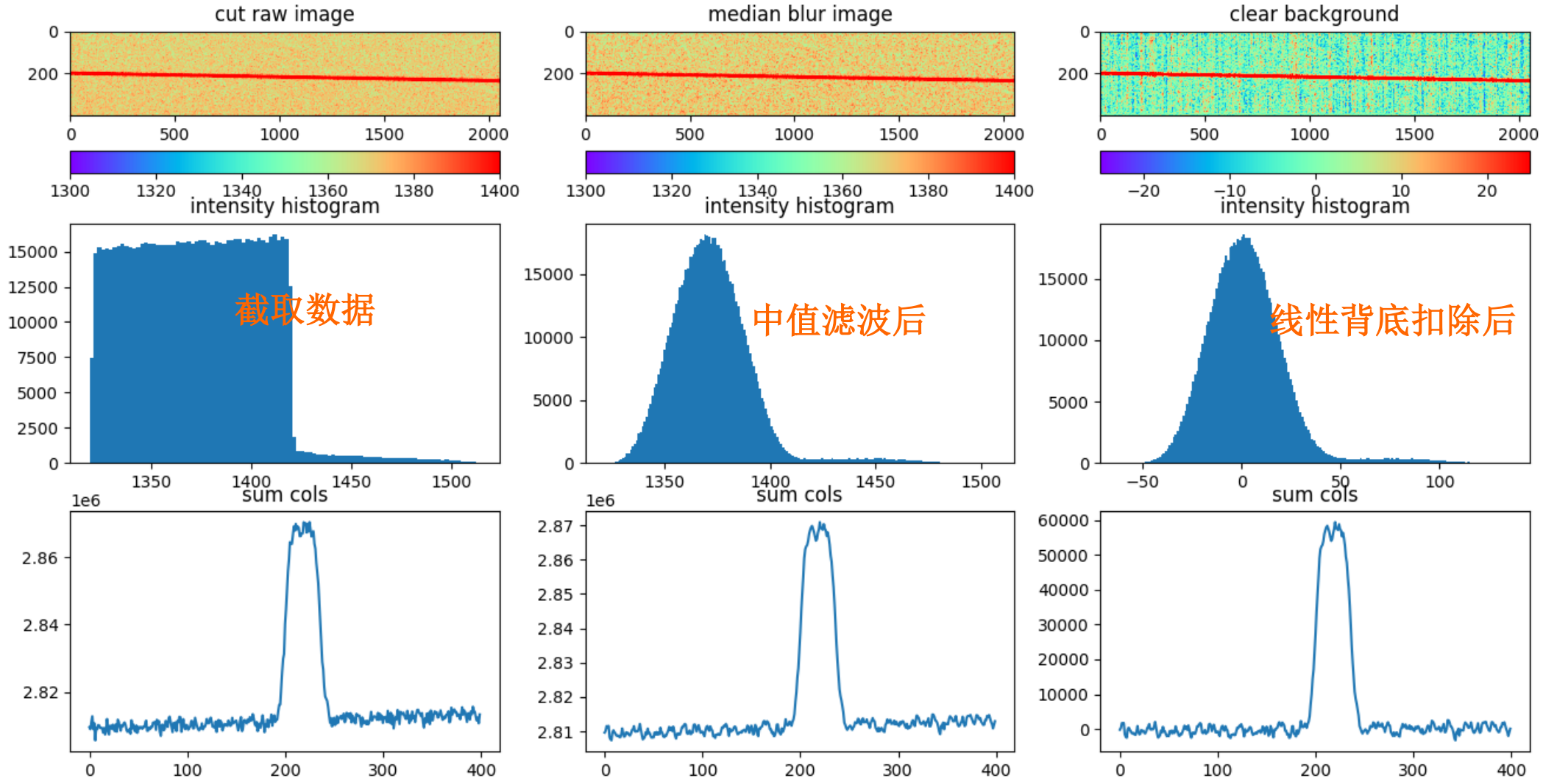
局部放大后的Gauss峰谱线



测试4:图像降噪和背底消除

GE_CCD-弹性峰拟合算法可靠性检验

高斯峰谱线半高宽FWHM=10



测试4:高斯峰矫正

GE_CCD-弹性峰拟合算法可靠性检验

高斯峰为倾斜的直线：y=57*x-57000

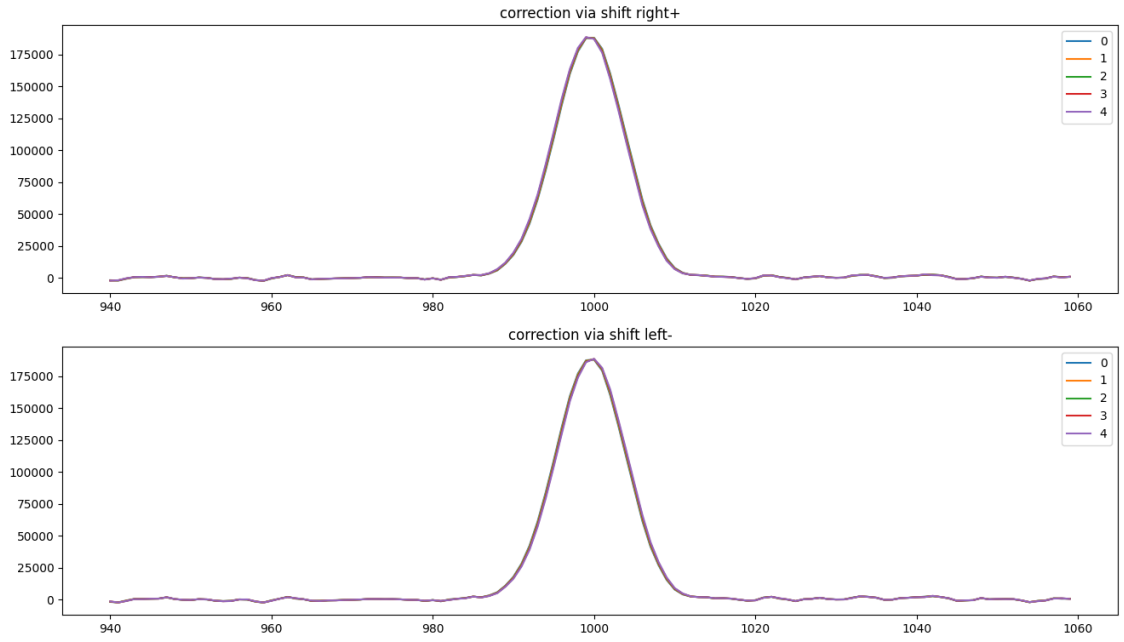
矫正只需要一次项

$$shift\_pixels = a + bx$$

（由于算法中x按照0.05的步长插值，所以b的标准值为1/57/0.05）

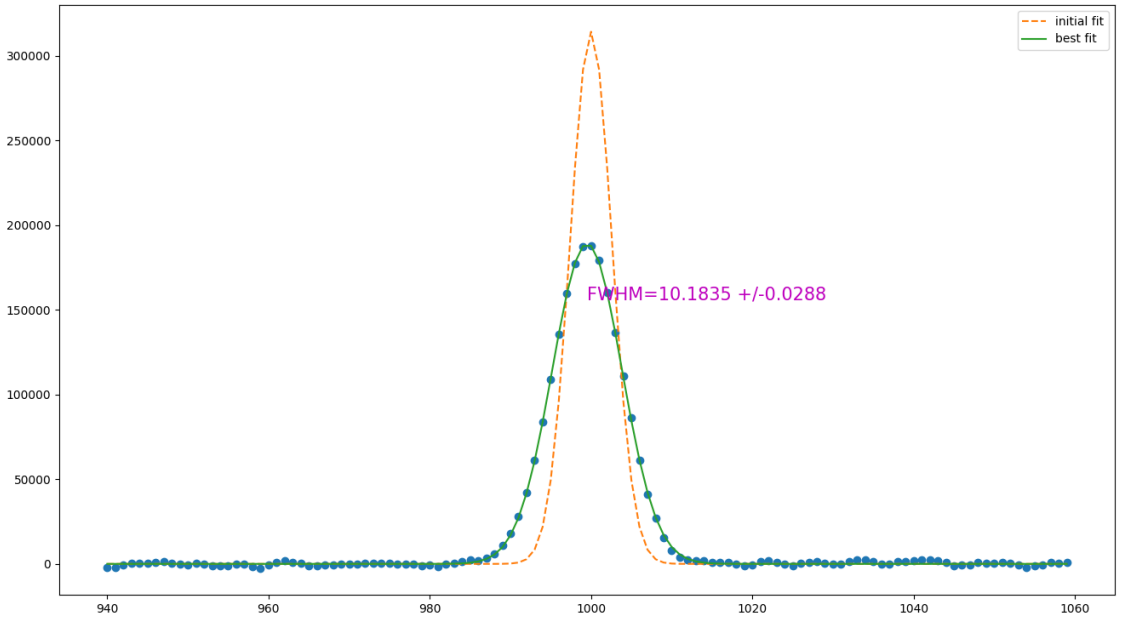
b=-(1/57/0.05+0.001*j)

j取值变化范围[-4, -3, -2, -1, 0, 1, 2, 3, 4]



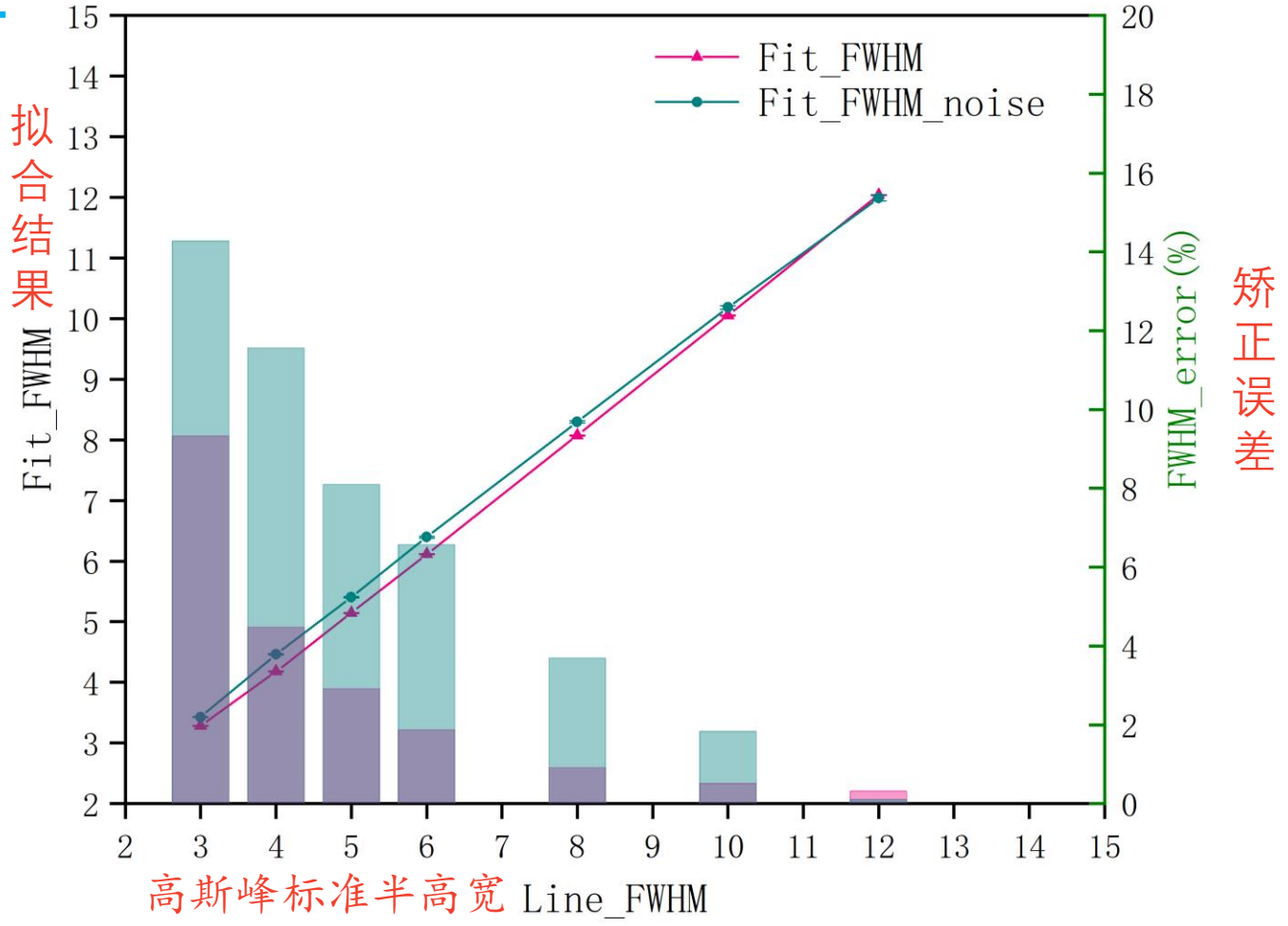
算法拟合结果：$\mathrm{FWHM} = 10.18 \pm 0.029\mathrm{pixels}$

同标准值=10pixels的误差为1.8%



标准Gauss峰矫正结果汇总

GE_CCD-弹性峰矫正算法可靠性检验

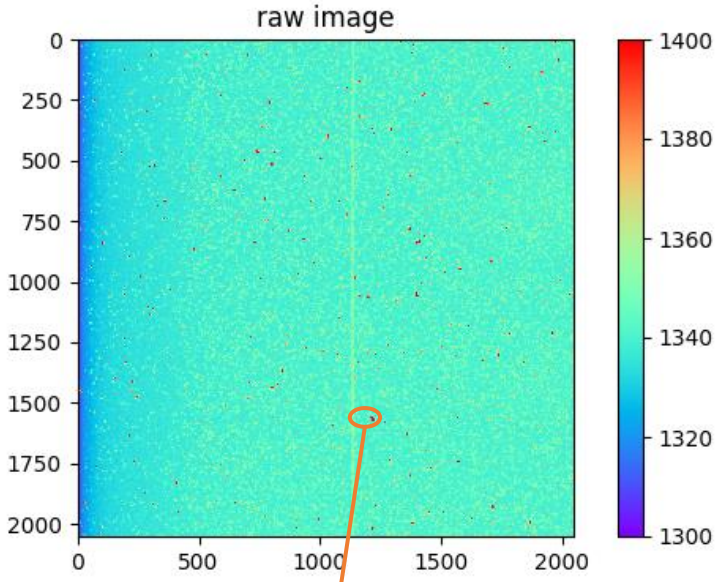


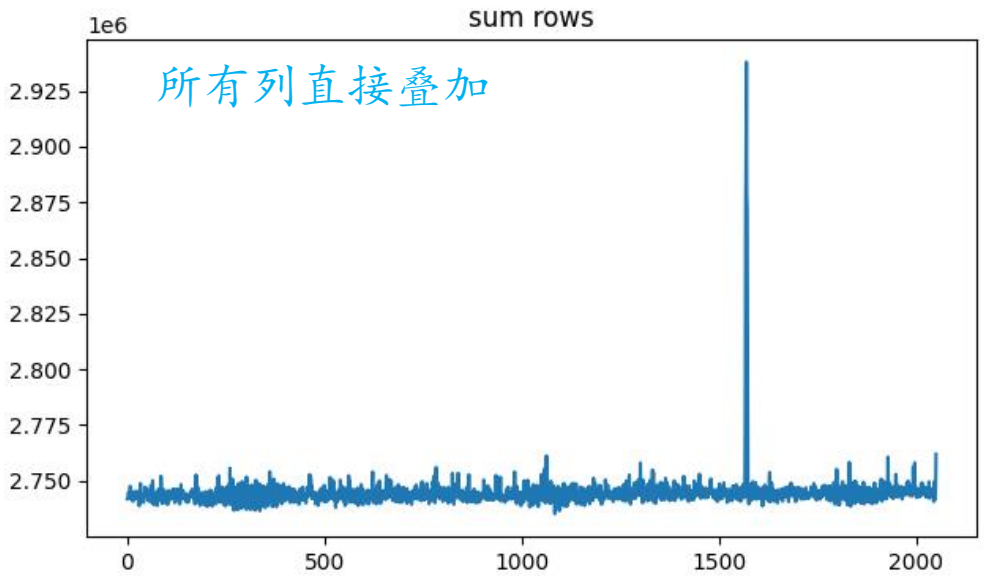
- ✓ 对于高斯峰半高宽在3-12pixels之间，矫正算法对于标准的Gauss分布峰的矫正误差要优于~10%
- ✓ 对高斯峰的背景增加噪声后，矫正算法会略高估半高宽，并且矫正误差会有明显上升，但最大误差仍优于~15%

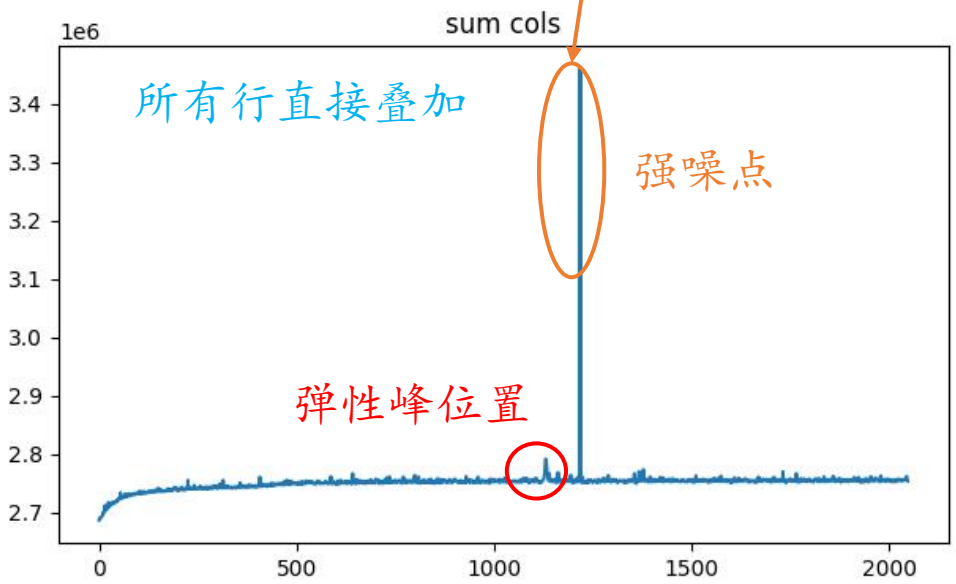
Line_FWHM	Fit_FWHM	FWHM_err	FWHM_err_percent	Fit_FWHM_noise	_FWHM_noise_err	FWHM_Noise_err_percent
3	3.2798	0.0088	9.326666667	3.4283	0.0094	14.27666667
4	4.1791	0.0085	4.4775	4.4625	0.0109	11.5625
5	5.1458	0.0075	2.916	5.405	0.01178	8.1
6	6.1124	0.0065	1.873333333	6.3943	0.0139	6.571666667
8	8.0728	0.0054	0.91	8.2952	0.0171	3.69
10	10.051	0.0051	0.51	10.1835	0.0288	1.835
12	12.038	0.0055	0.316666667	11.9879	0.0472	0.100833333

示例1:原始实验数据

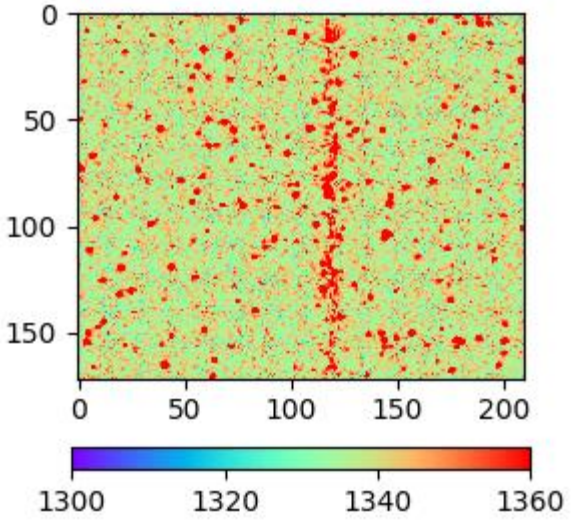
2022-09-18采集-数据11-C@448.5eV_CCDRX=32220_Slit2_100_T3600s



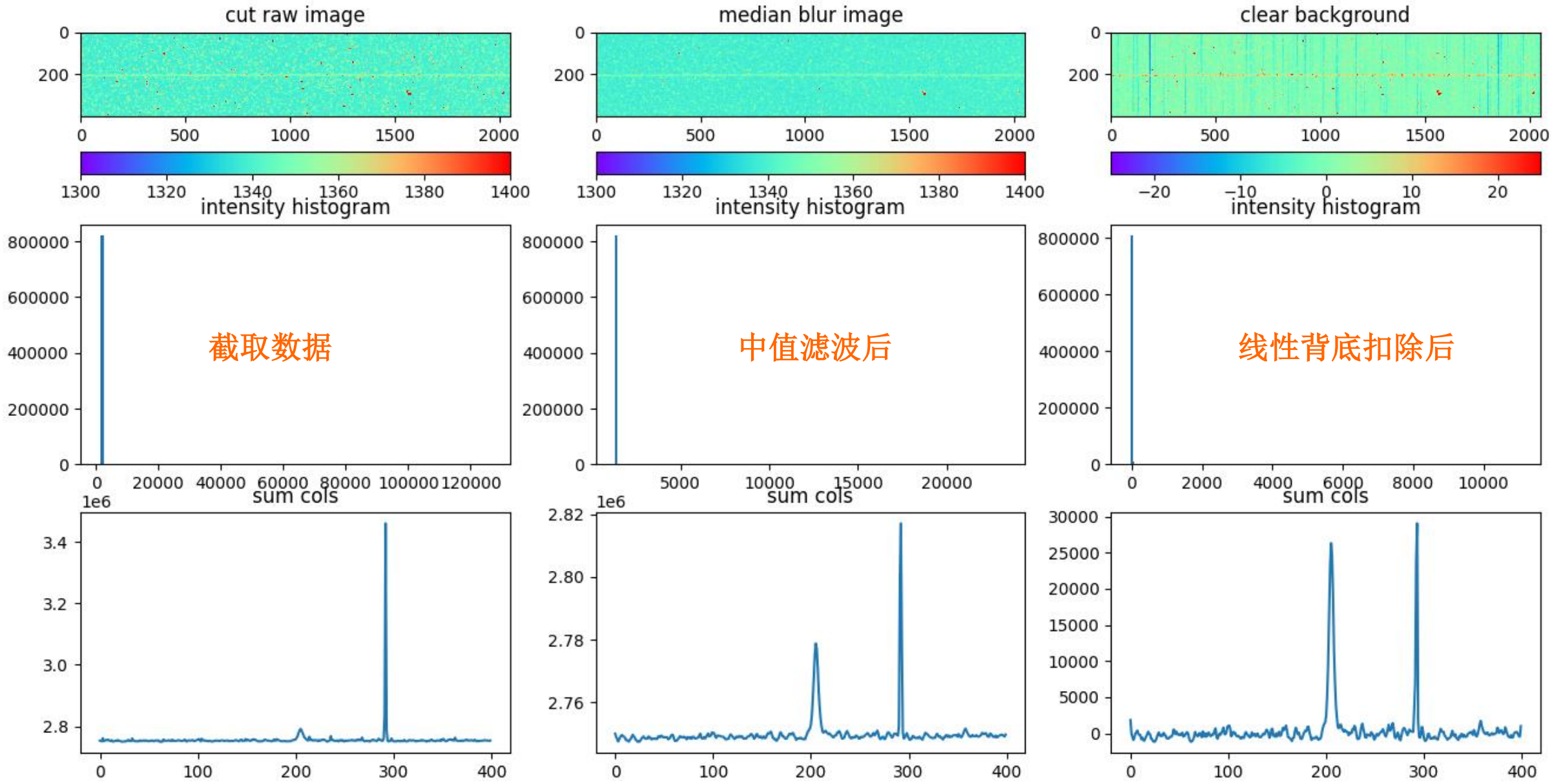




局部放大后的弹性峰谱线



示例1:图像降噪和背底消除

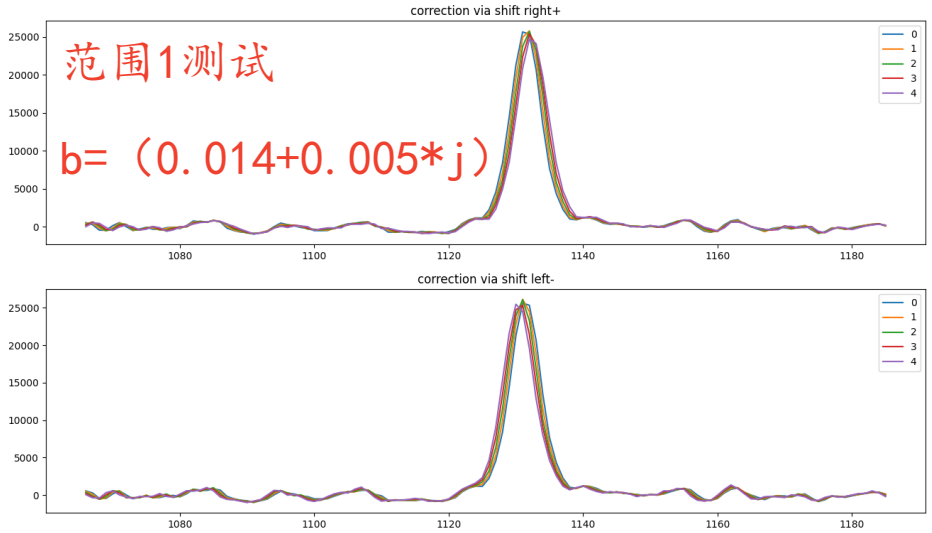


示例1:弹性峰矫正

j取值变化范围[−4, −3, −2, −1, 0, 1, 2, 3, 4]

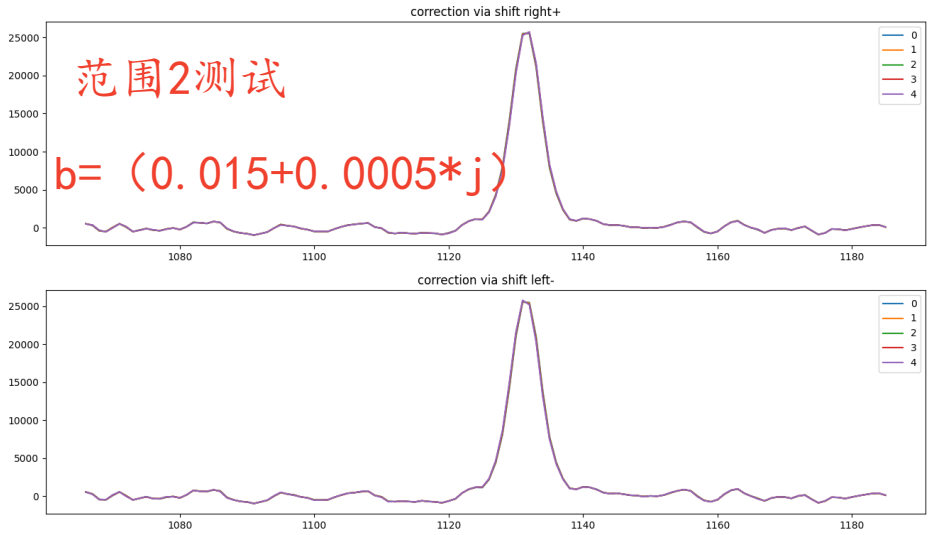
范围1测试

b=（0.014+0.005*j）

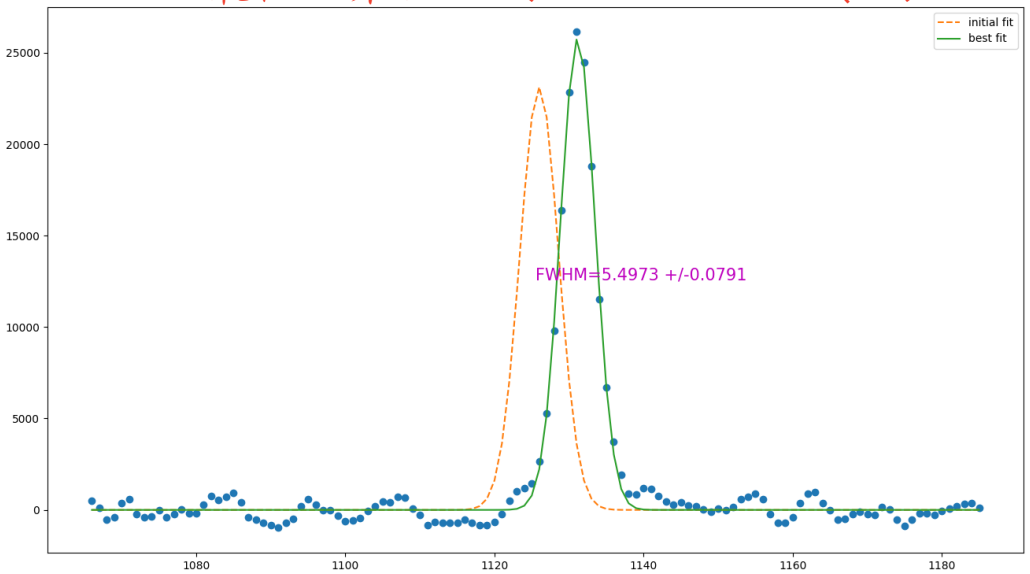


范围2测试

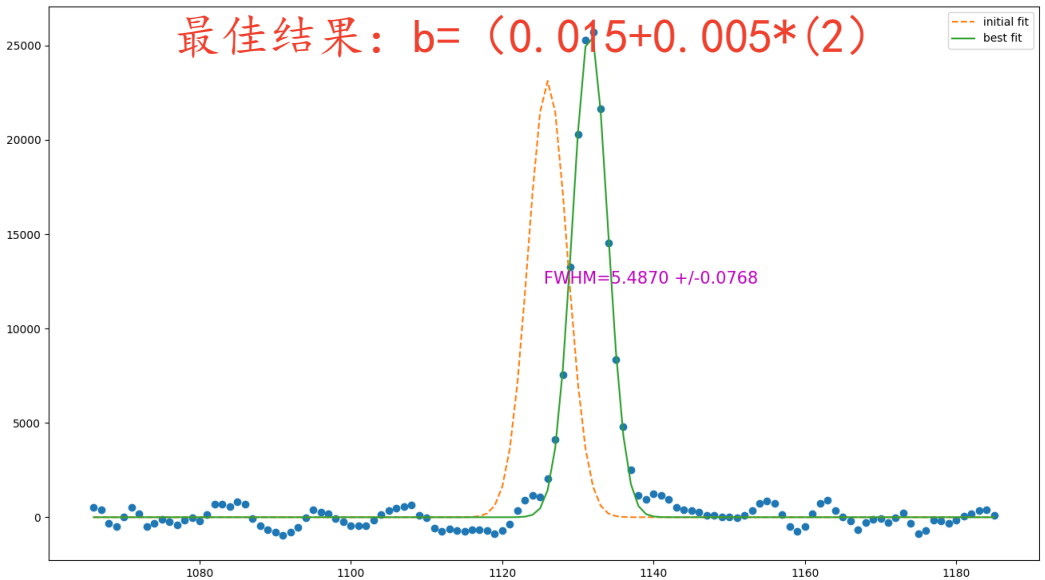
b=（0.015+0.0005*j）



最佳结果：b=（0.014+0.005*(−1）

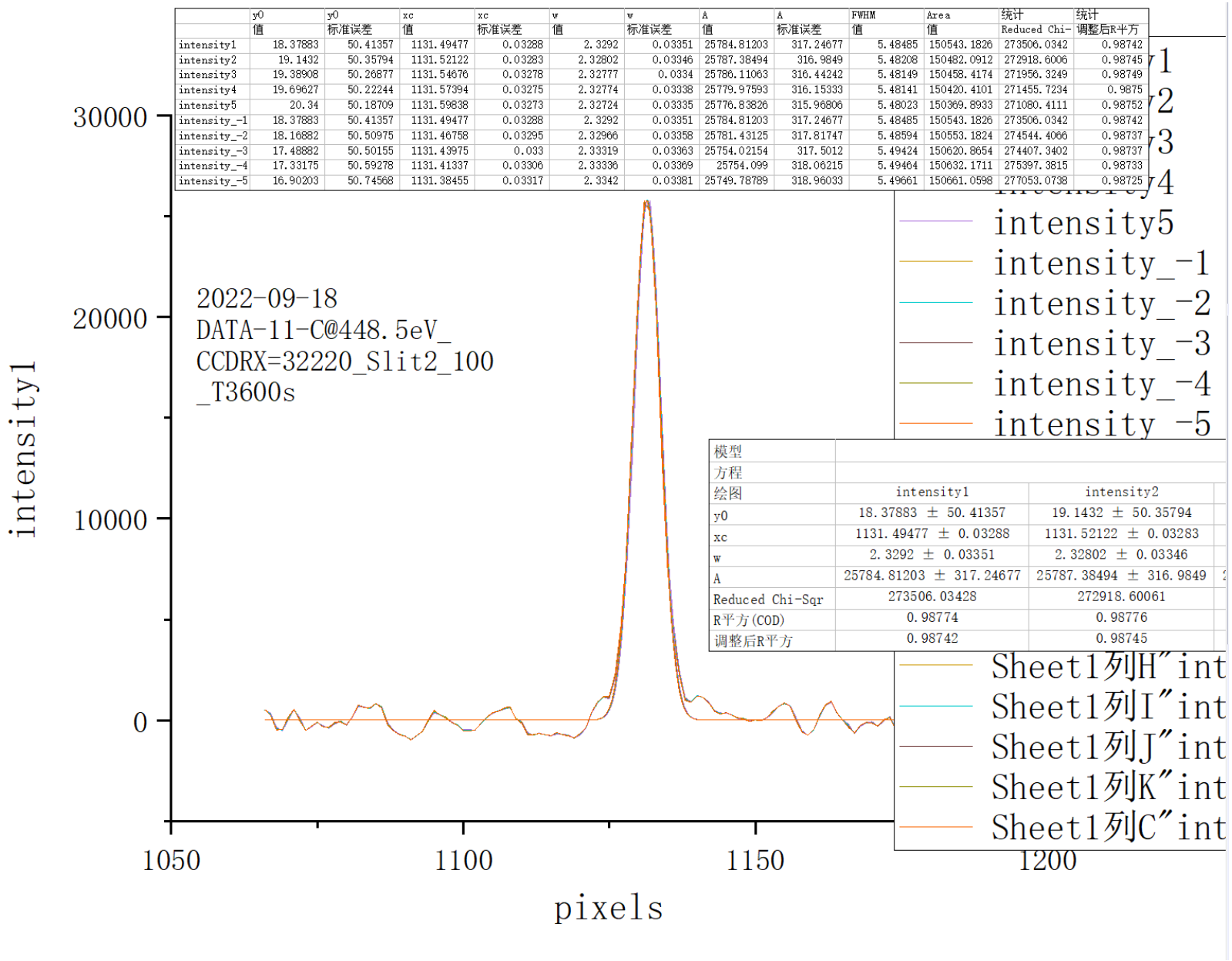


最佳结果：b=（0.015+0.005*(2）



示例1:origin Gauss拟合结果

	y0	y0	xc	xc	w	w	A	A	FWHM	Area	统计	统计
	值	标准误差	值	标准误差	值	标准误差	值	标准误差	值	值	Reduced Chi-	调整后R平方
intensity1	18.37883	50.41357	1131.49477	0.03288	2.3292	0.03351	25784.81203	317.24677	5.48485	150543.1826	273506.0342	0.98742
intensity2	19.1432	50.35794	1131.52122	0.03283	2.32802	0.03346	25787.38494	316.9849	5.48208	150482.0912	272918.6006	0.98745
intensity3	19.38908	50.26877	1131.54676	0.03278	2.32777	0.0334	25786.11063	316.44242	5.48149	150458.4174	271956.3249	0.98749
intensity4	19.69627	50.22244	1131.57394	0.03275	2.32774	0.03338	25779.97593	316.15333	5.48141	150420.4101	271455.7234	0.9875
intensity5	20.34	50.18709	1131.59838	0.03273	2.32724	0.03335	25776.83826	315.96806	5.48023	150369.8933	271080.4111	0.98752
intensity_-1	18.37883	50.41357	1131.49477	0.03288	2.3292	0.03351	25784.81203	317.24677	5.48485	150543.1826	273506.0342	0.98742
intensity_-2	18.16882	50.50975	1131.46758	0.03295	2.32966	0.03358	25781.43125	317.81747	5.48594	150553.1824	274544.4066	0.98737
intensity_-3	17.48882	50.50155	1131.43975	0.033	2.33319	0.03363	25754.02154	317.5012	5.49424	150620.8654	274407.3402	0.98737
intensity_-4	17.33175	50.59278	1131.41337	0.03306	2.33336	0.03369	25754.099	318.06215	5.49464	150632.1711	275397.3815	0.98733
intensity_-5	16.90203	50.74568	1131.38455	0.03317	2.3342	0.03381	25749.78789	318.96033	5.49661	150661.0598	277053.0738	0.98725



模型		
方程		
绘图	intensity1	intensity2
y0	18.37883 ± 50.41357	19.1432 ± 50.35794
xc	1131.49477 ± 0.03288	1131.52122 ± 0.03283
w	2.3292 ± 0.03351	2.32802 ± 0.03346
A	25784.81203 ± 317.24677	25787.38494 ± 316.9849
Reduced Chi-Sqr	273506.03428	272918.60061
R平方(COD)	0.98774	0.98776
调整后R平方	0.98742	0.98745

SciPy自带Gauss拟合算法:

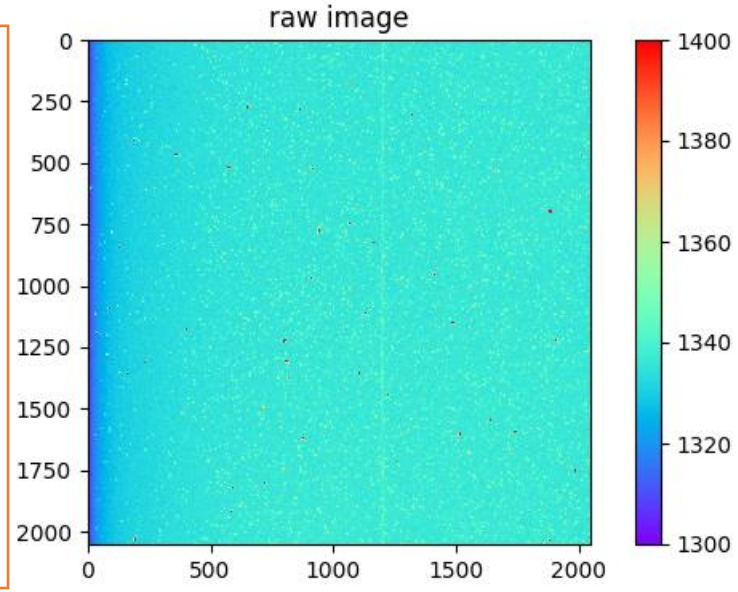
$$FWHM = 5.48 \pm 0.08 \text{pixels}$$

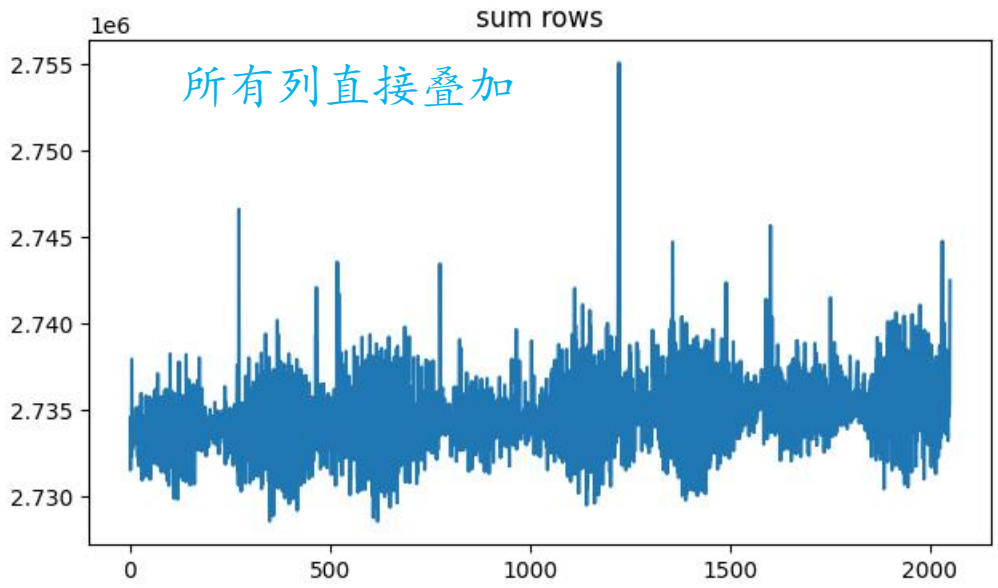
Origin Gauss拟合结果:

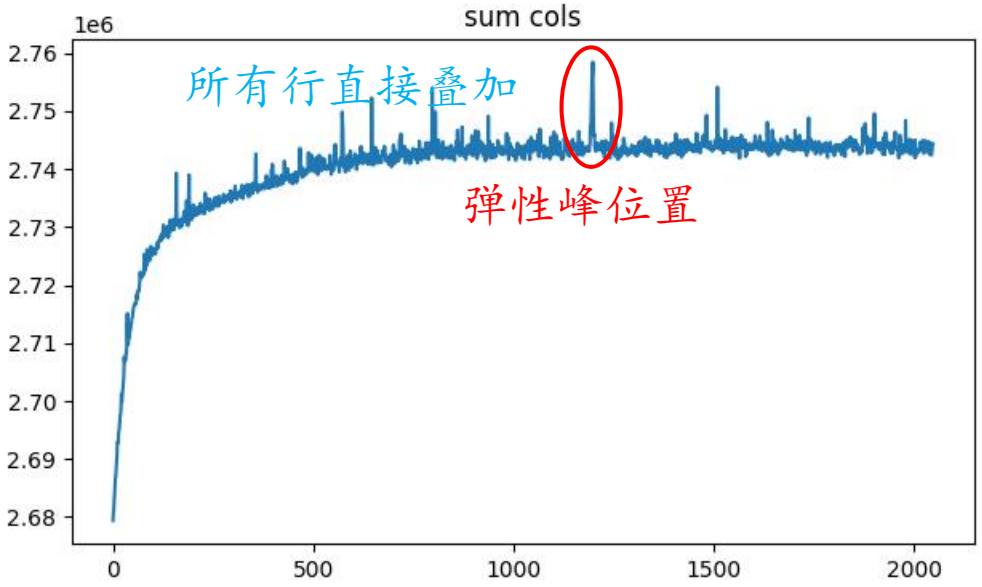
$$FWHM = 5.48 \pm 0.08 \text{pixels}$$

示例2:原始实验数据

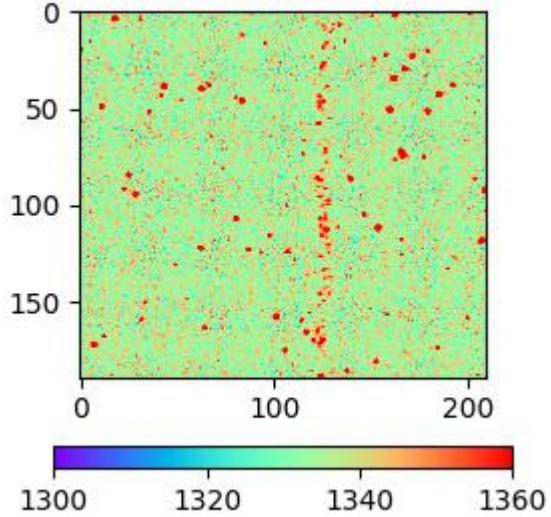
2022-09-05采集-数据12-C@445eV_SLIT1-1200X1500_SLIT2-100_sampleX=-2_sampleY-8_sampleZ=113_R1=11.6_CCDRx=36000_CCDY=-3340_CCDZ=-1000_FL=16mm_GrateX_1750_GrateR-X=-6680_T600s_SM6pitch_1.023_T1200s



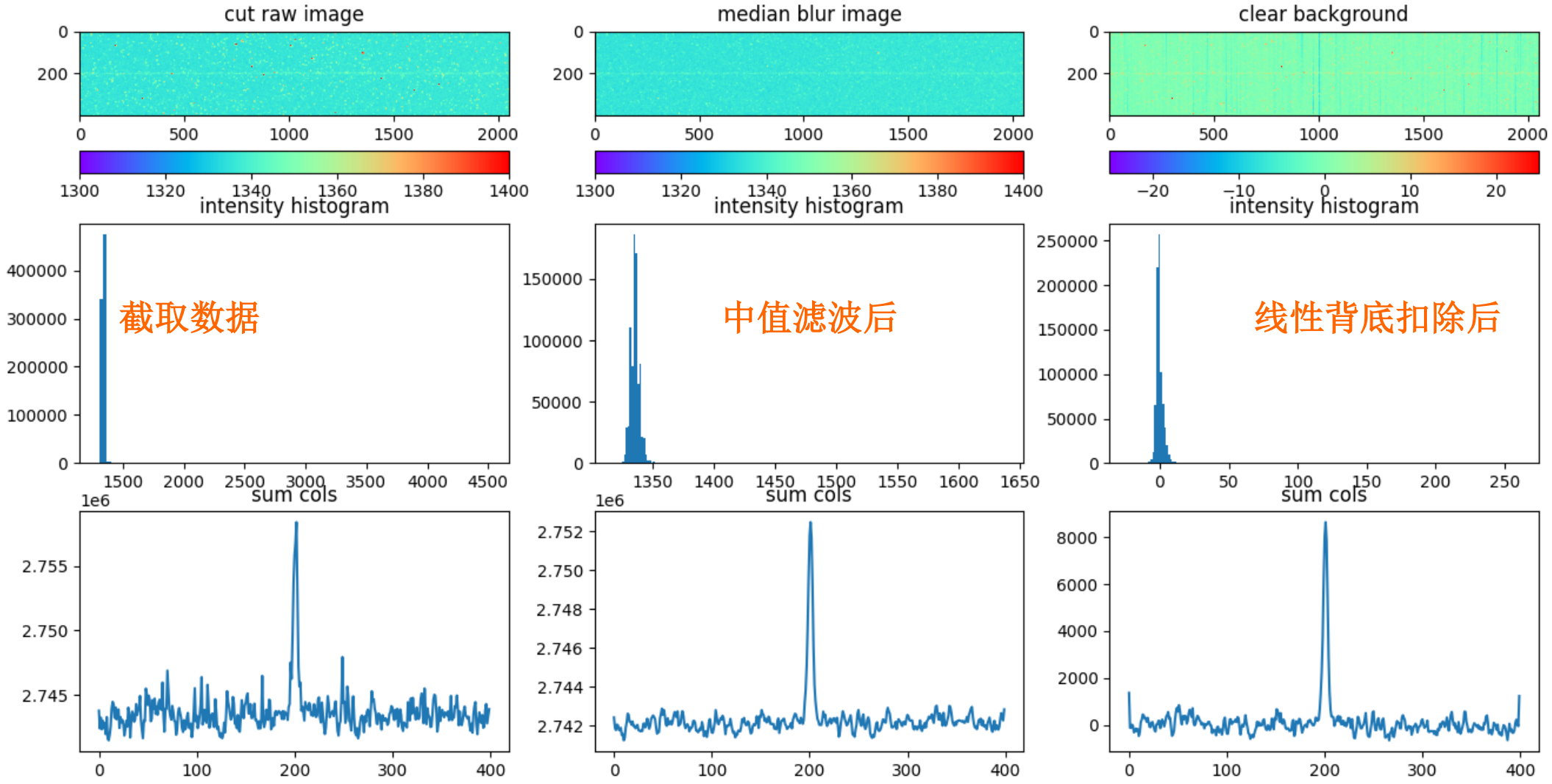




局部放大后的弹性峰谱线



示例2:图像降噪和背底消除

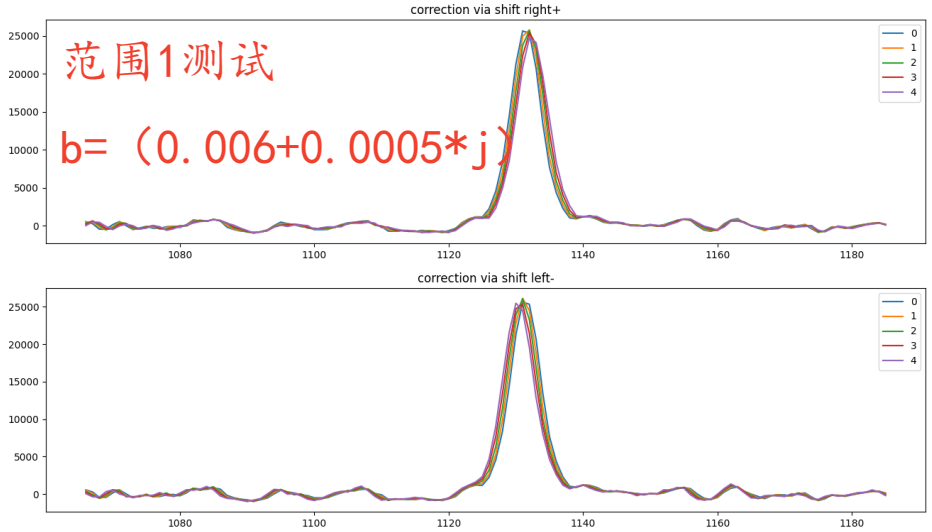


示例2:弹性峰矫正

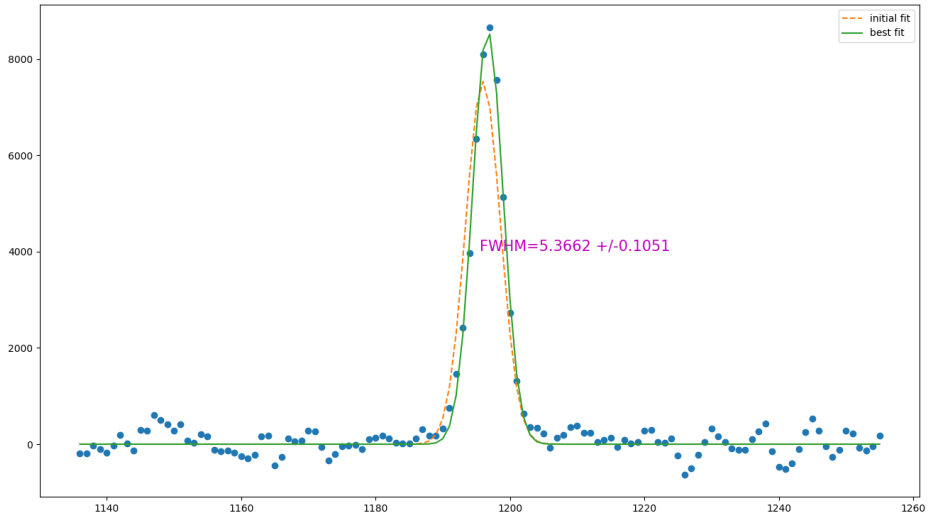
j取值变化范围[−4, −3, −2, −1, 0, 1, 2, 3, 4]

范围1测试

b=（0.006+0.0005*j）

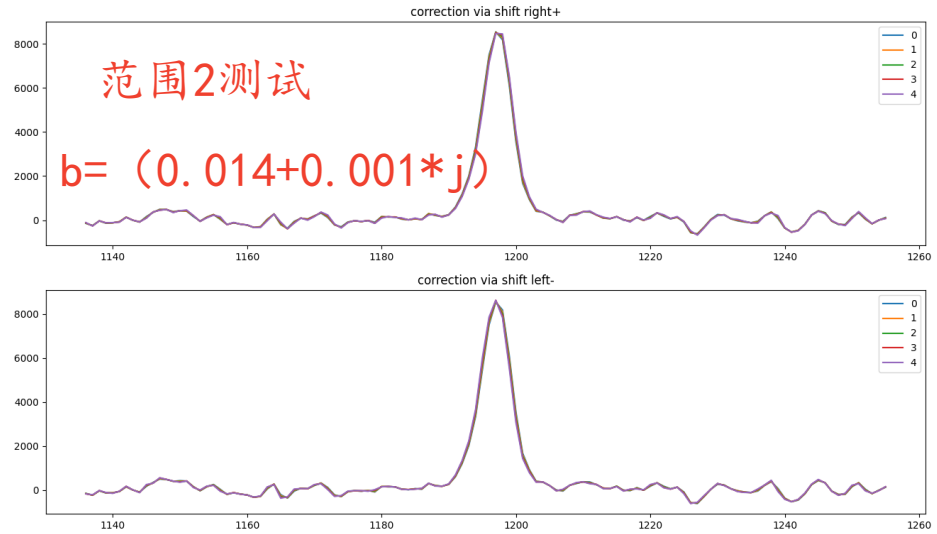


最佳结果：b=（0.006+0.0005*2）

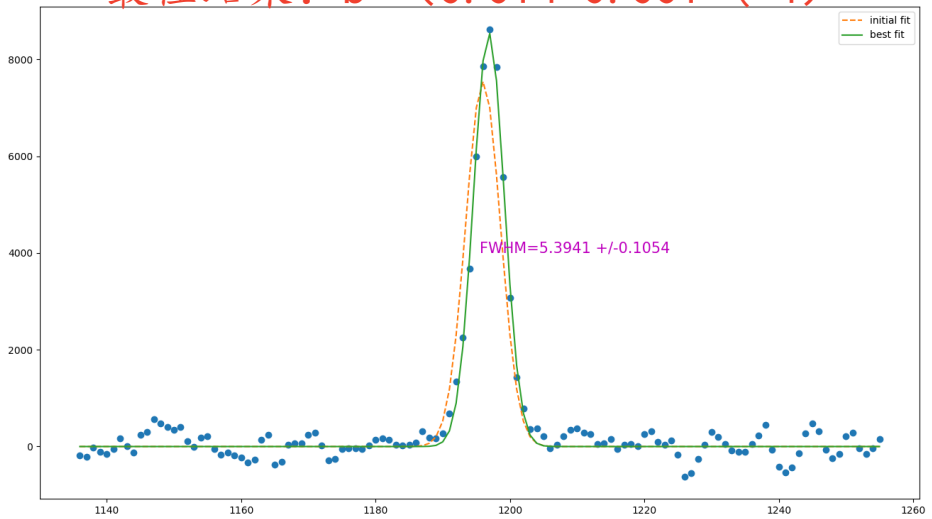


范围2测试

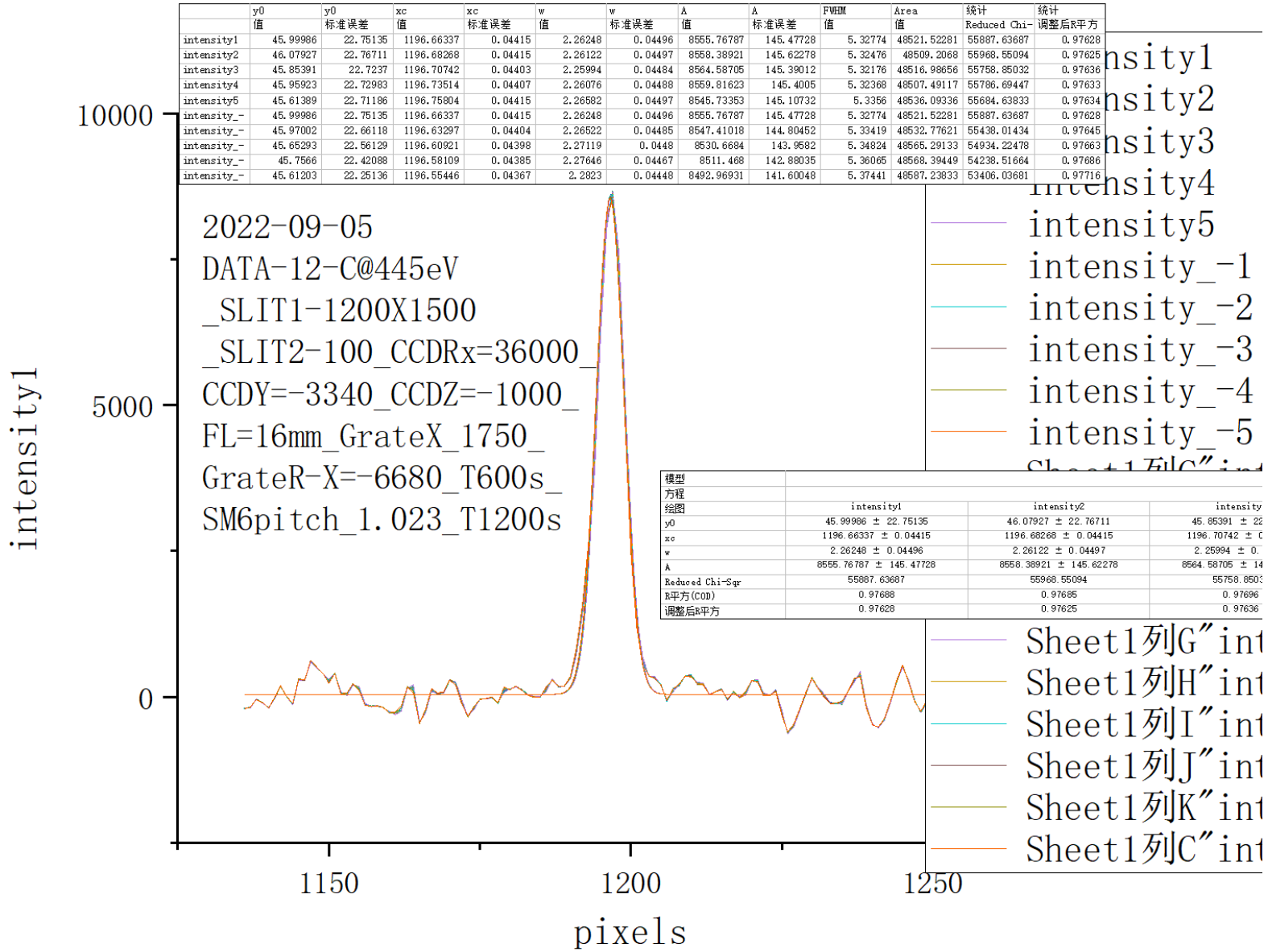
b=（0.014+0.001*j）



最佳结果：b=（0.014+0.001*(−4)



示例2:origin Gauss拟合结果



	y0	y0	xc	xc	w	w	A	A	FWHM	Area	统计	统计
	值	标准误差	值	标准误差	值	标准误差	值	标准误差	值	值	Reduced Chi-	调整后R平方
intensity1	45.99986	22.75135	1196.66337	0.04415	2.26248	0.04496	8555.76787	145.47728	5.32774	48521.52281	55887.63687	0.97628
intensity2	46.07927	22.76711	1196.68268	0.04415	2.26122	0.04497	8558.38921	145.62278	5.32476	48509.2068	55968.55094	0.97625
intensity3	45.85391	22.7237	1196.70742	0.04403	2.25994	0.04484	8564.58705	145.39012	5.32176	48516.98656	55758.85032	0.97636
intensity4	45.95923	22.72983	1196.73514	0.04407	2.26076	0.04488	8559.81623	145.4005	5.32368	48507.49117	55786.69447	0.97633
intensity5	45.61389	22.71186	1196.75804	0.04415	2.26582	0.04497	8545.73353	145.10732	5.3356	48536.09336	55684.63833	0.97634
intensity_-	45.99986	22.75135	1196.66337	0.04415	2.26248	0.04496	8555.76787	145.47728	5.32774	48521.52281	55887.63687	0.97628
intensity_-	45.97002	22.66118	1196.63297	0.04404	2.26522	0.04485	8547.41018	144.80452	5.33419	48532.77621	55438.01434	0.97645
intensity_-	45.65293	22.56129	1196.60921	0.04398	2.27119	0.0448	8530.6684	143.9582	5.34824	48565.29133	54934.22478	0.97663
intensity_-	45.7566	22.42088	1196.58109	0.04385	2.27646	0.04467	8511.468	142.88035	5.36065	48568.39449	54238.51664	0.97686
intensity_-	45.61203	22.25136	1196.55446	0.04367	2.2823	0.04448	8492.96931	141.60048	5.37441	48587.23833	53406.03681	0.97716

模型			
方程			
绘图	intensity1	intensity2	intensity
y0	45.99986 ± 22.75135	46.07927 ± 22.76711	45.85391 ± 22
xc	1196.66337 ± 0.04415	1196.68268 ± 0.04415	1196.70742 ± 0
w	2.26248 ± 0.04496	2.26122 ± 0.04497	2.25994 ± 0.
A	8555.76787 ± 145.47728	8558.38921 ± 145.62278	8564.58705 ± 14
Reduced Chi-Sqr	55887.63687	55968.55094	55758.8503
R平方(COD)	0.97688	0.97685	0.97696
调整后R平方	0.97628	0.97625	0.97636

SciPy自带Gauss拟合算法:

$$FWHM = 5.36 \pm 0.10 \text{pixels}$$

Origin Gauss拟合结果:

$$FWHM = 5.32 \pm 0.10 \text{pixels}$$