粒子物理与核物理实验中的数据分析

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第十三讲:分析实例
（盲分析，置信区间）

分析实例

- 稀有K介子衰变 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
- 避免人为干扰，忙分析
- 多区间泊松信号的联合分析

人为干扰与忙分析

有时候对一个优异结果的期待往往影响着人们的客观判断: (暗物质，Higgs，新技术)

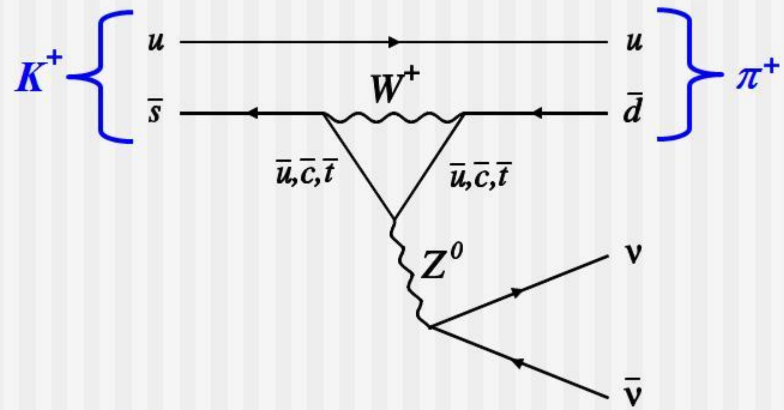
1.对稀有信号，主观上希望找到信号
2.对性能指标，主观上希望指标测量结果很好
3.有选择性的报道结果（主观性失明）
4.错误的误差处理（主观选择的有偏处理）

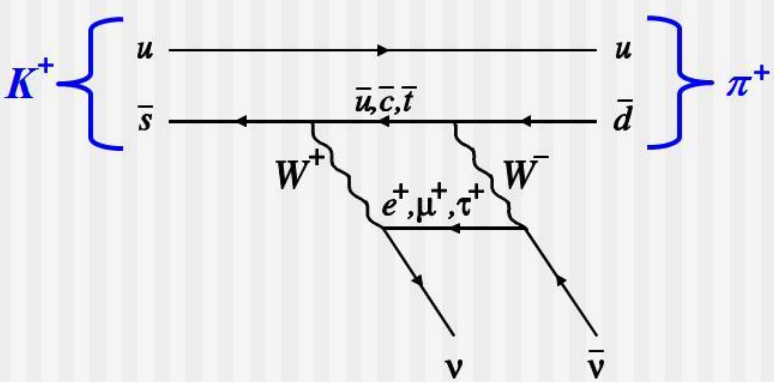
忙分析:

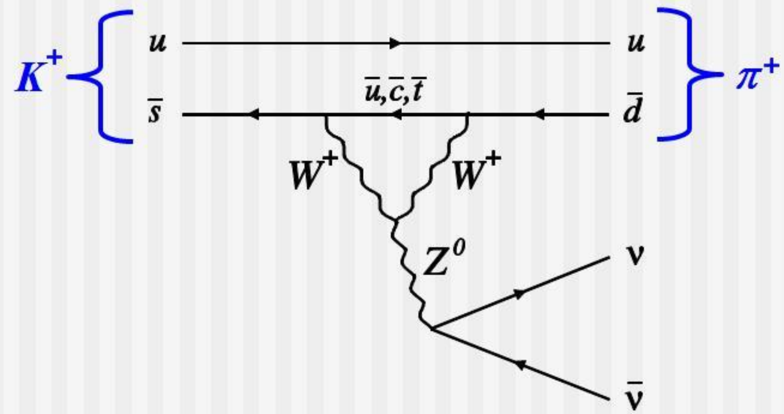
1.一种分析策略，分析条件等的确定不应依赖于分析结果，或者说，分析结果只有在最后一刻才知道。
2.具体的技术需要针对具体的实验设定

$K^+ \to \pi^+ \nu\bar{\nu}$ in standard model (SM)

	Quark contents	Mass (MeV/c^2)	Lifetime (ns)
K^+	$u\bar{s}$	493.7	12.4
π^+	$u\bar{d}$	139.6	26.0
ν	-	≈0	∞

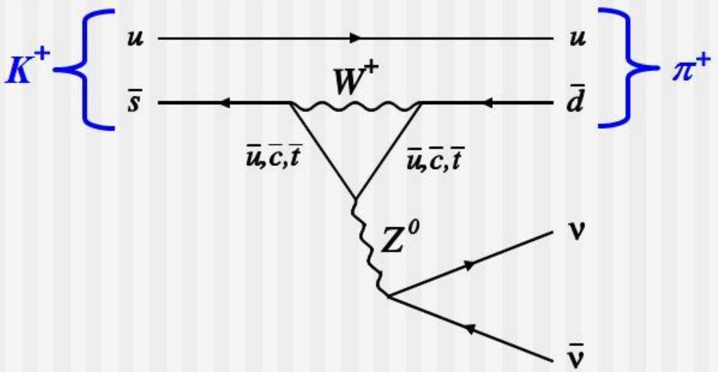






FCNC is permitted through loop diagrams, however it is highly suppressed.

Branching ratio prediction

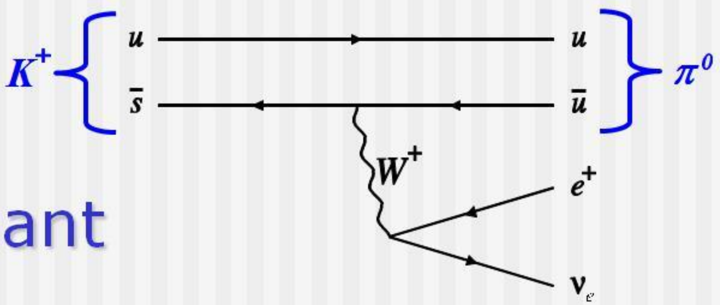


Effective Hamiltonian:

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \frac{\alpha}{2\pi \sin^2 \theta_W}$$

$$\cdot \sum_{l=e,\mu,\tau} [V_{cs}^* V_{cd} X_{NL}^l + V_{ts}^* V_{td} X(x_t)](\bar{s}d)_{V-A}(\bar{\nu}_l \nu_l)_{V-A}$$

X: Wilson coefficients



Short-distance interaction dominant

Relevant hadronic operator matrix element can be extracted from $K^+ \to \pi^0 e^+ \nu$

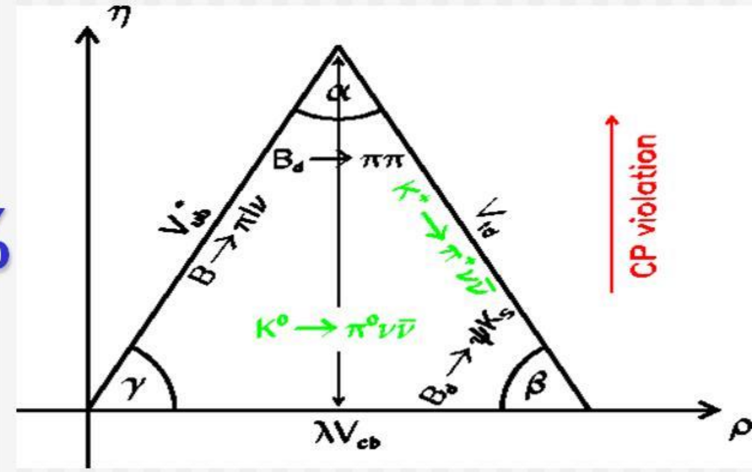
M.K. Gailard and Benjamin W. Lee 1974

稀有K介子衰变 $K^+ \to \pi^+ \nu \bar{\nu}$

Precise theory prediction: $(0.85 \pm 0.07) \times 10^{-10}$

(50% of the error is from CKM parameters)

arXiv: hep-ph/0405132 Andrzej J. Buras, et. al.



top quark contribution ~70%

(sensitive to V_{td})

Probe SM at quantum level, thereby allowing an indirect test of high-energy scales through a low-energy process

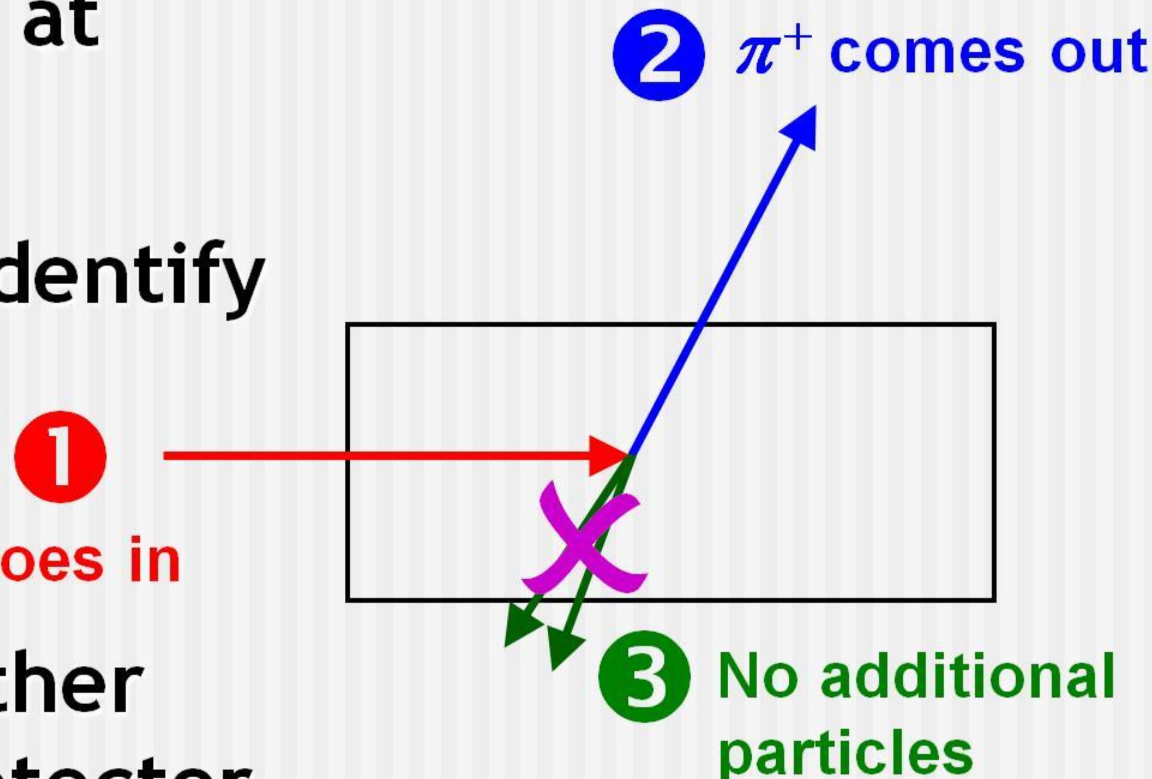
(sensitive to new physics)

Big picture for searching $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

1. K^+ stop in detector target and decay at rest

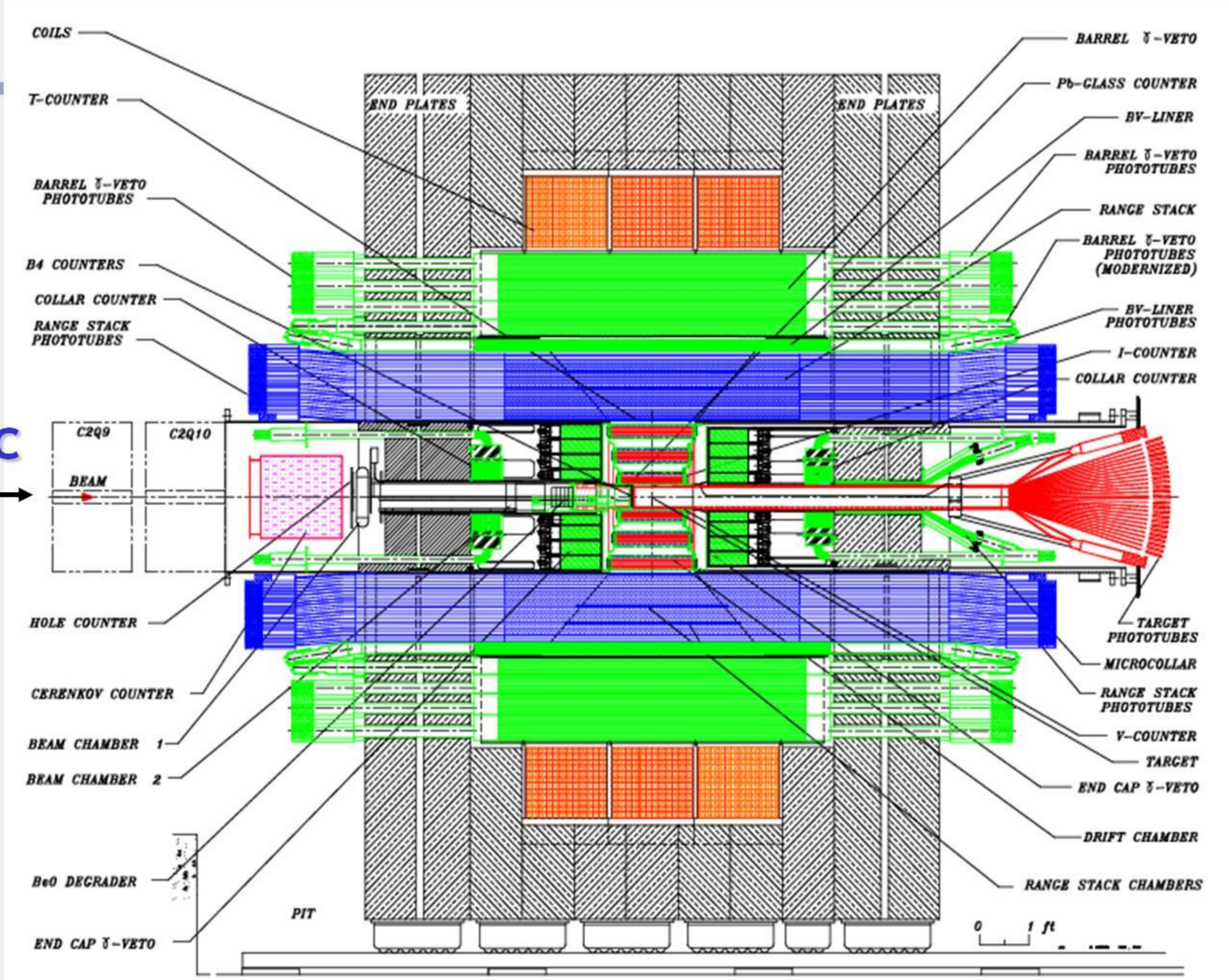
2. Measure and identify π^+

3. Veto on any other activity in the detector

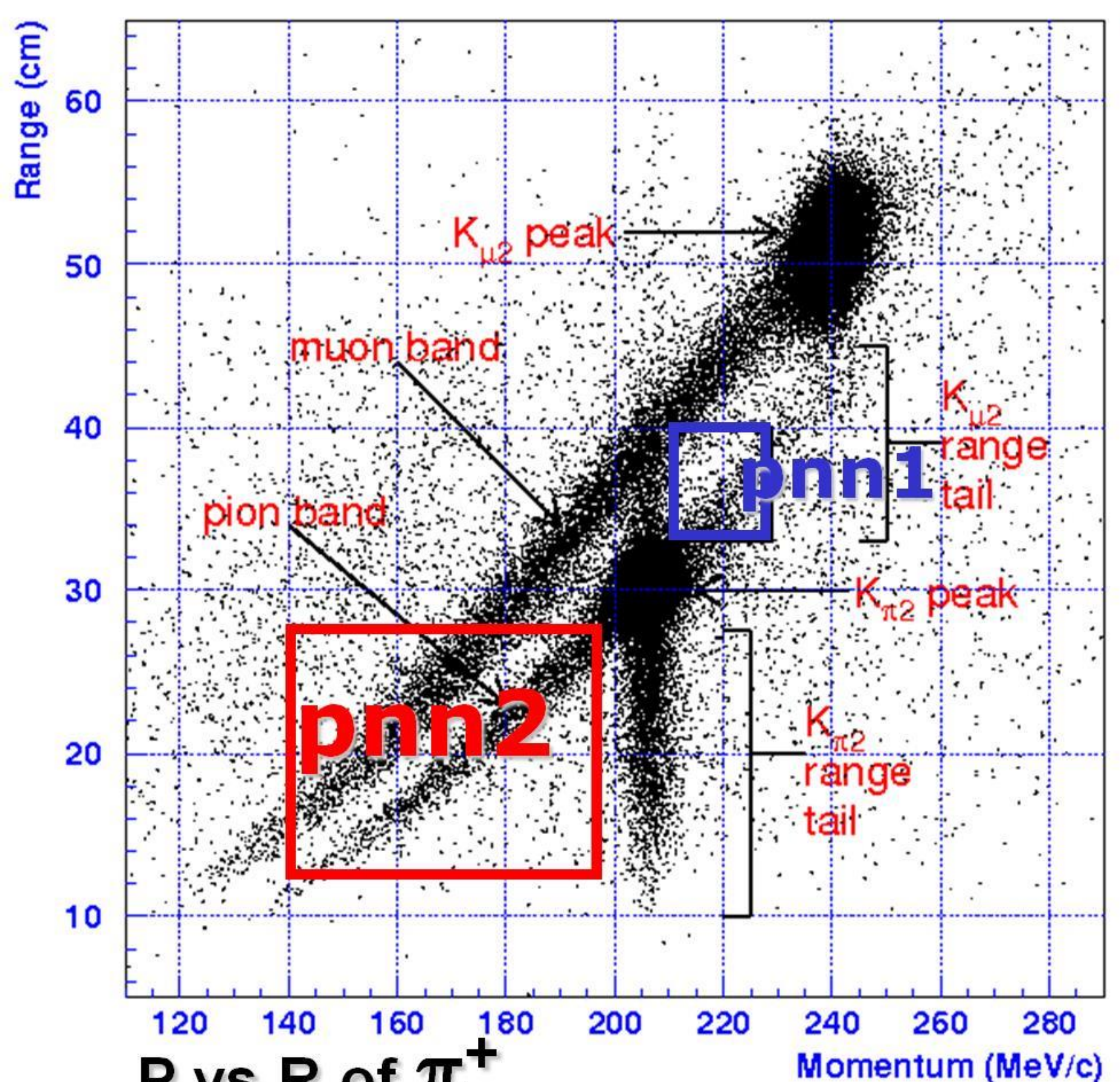


K⁺ beam

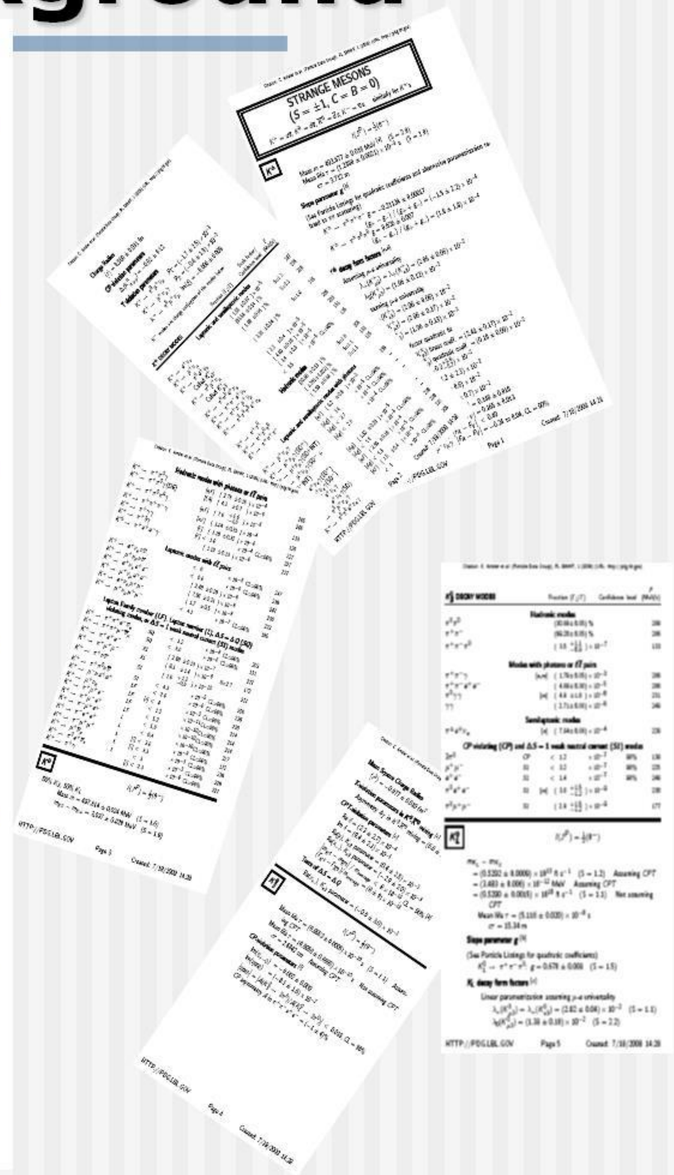
710 MeV/c



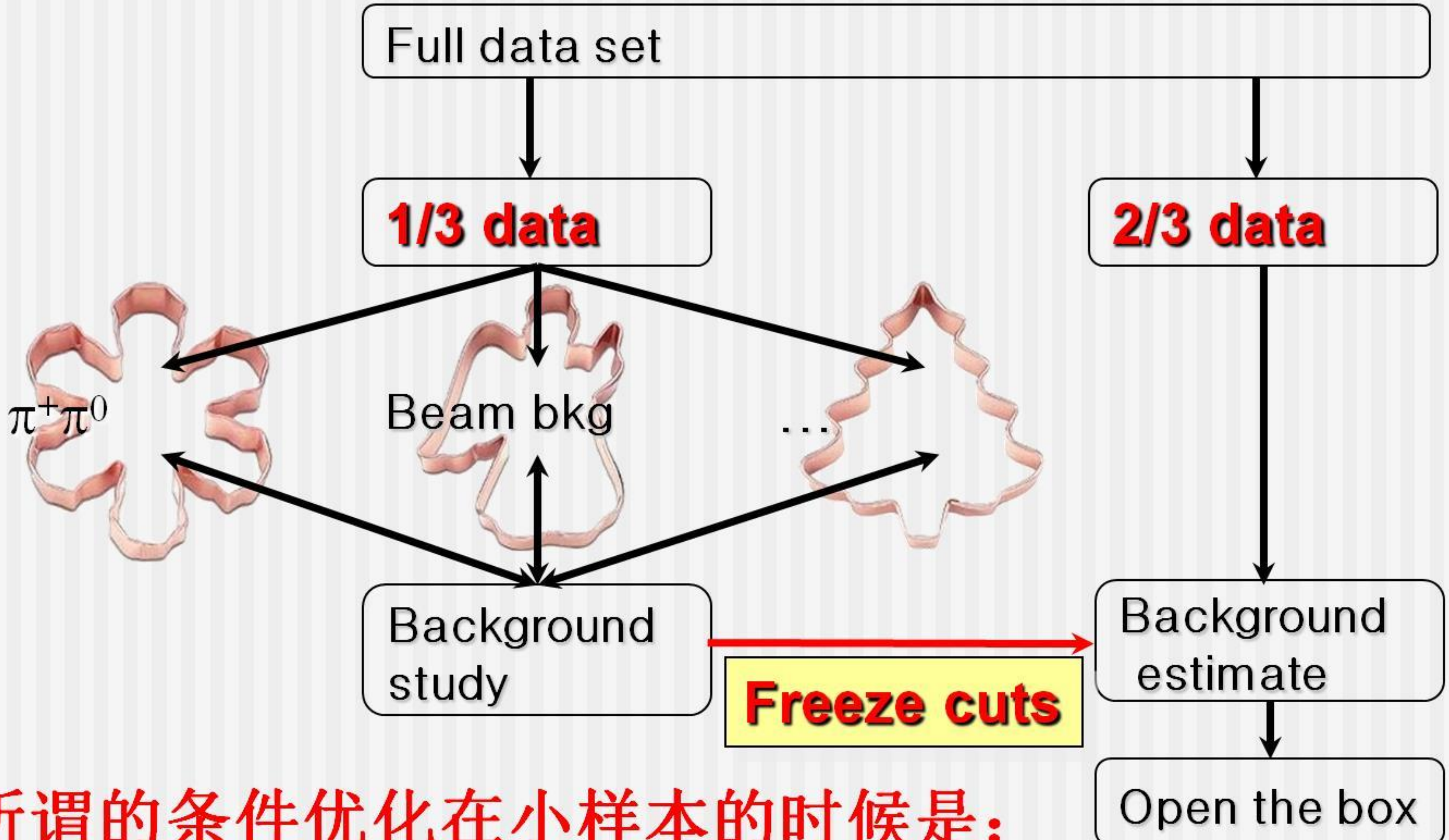
Signal box and background



P vs R of π^+



Strategy 1: avoid bias in cut tuning

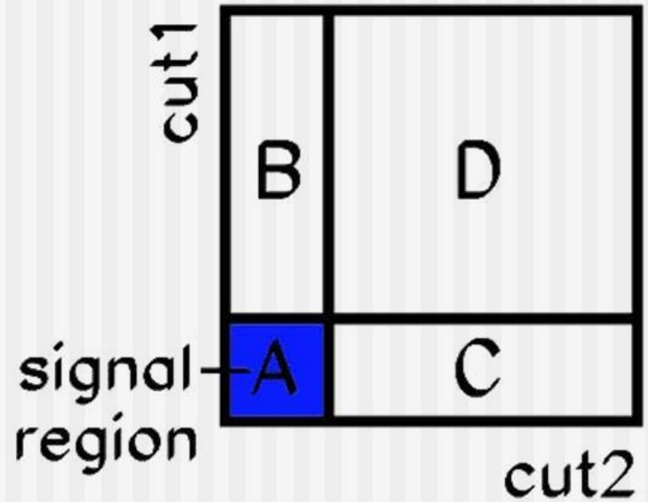


所谓的条件优化在小样本的时候是：
不稳定的，局域的，依赖于统计的。

Strategy 2: blind analysis - bifurcation

Step 1: Background isolation

Step 2: Suppress each background with two independent cuts



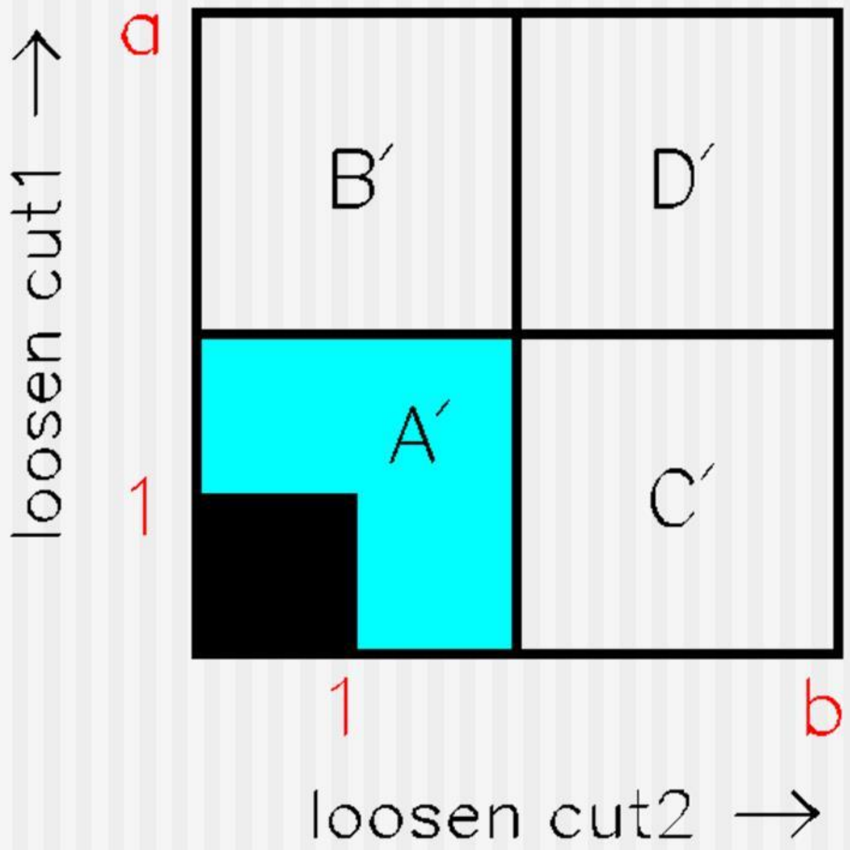
if cut1,cut2 uncorrelated,

$$A/B = C/D$$

$$A = BC/D$$

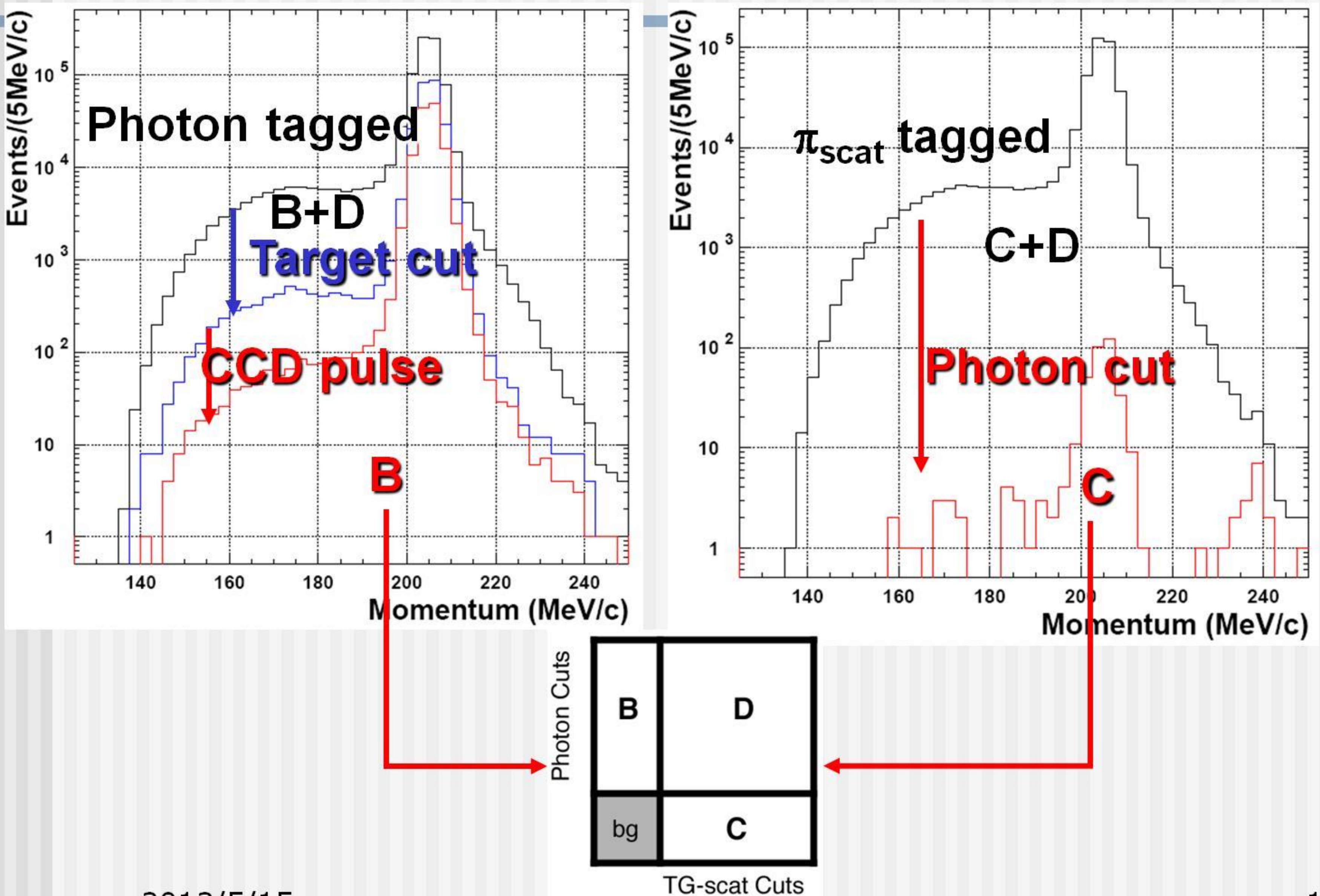
Strategy 2: blind analysis - bifurcation

Step 3: Check the correlation



$$bg' = bg(A') - bg(A) = B'C'/D' - BC/D$$

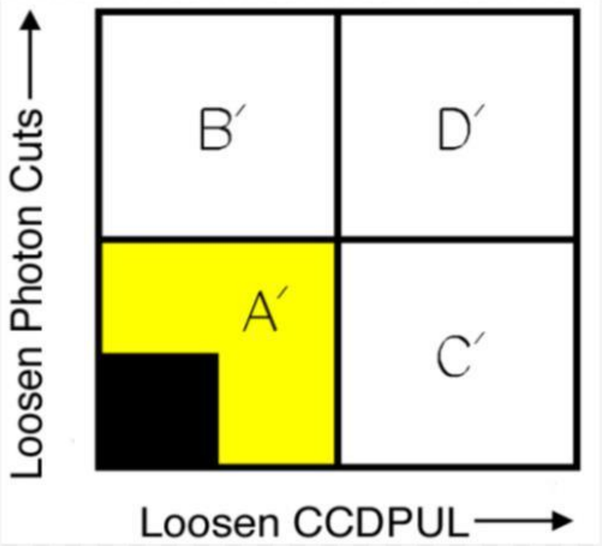
Measure $K^+ \to \pi^+ \pi^0$ background



Outside box study

- Keep signal region blinded
- Relax photon veto or ccd pulse cut
- Check the predicted events and observed events in the extended region A'

Region	N_{exp}	N_{obs}
CCD_L	$0.79^{+0.46}_{-0.51}$	0
PV_L	$9.09^{+1.53}_{-1.32}$	3
PV_{looser}	$32.4^{+12.3}_{-8.1}$	34



The probability to observe ≤ 3 events when $9.09^{+1.53}_{-1.32}$ are expected is 2%. The probability of the observation in regions CCD_1 and PV_1 given the expectation is 5%; the expectation is [2%,14%] when the uncertainty in N_{exp} is taken into account.

Cell information - 9 cells

Acc = 0.137%

Four cuts are tightened to define 9 cells

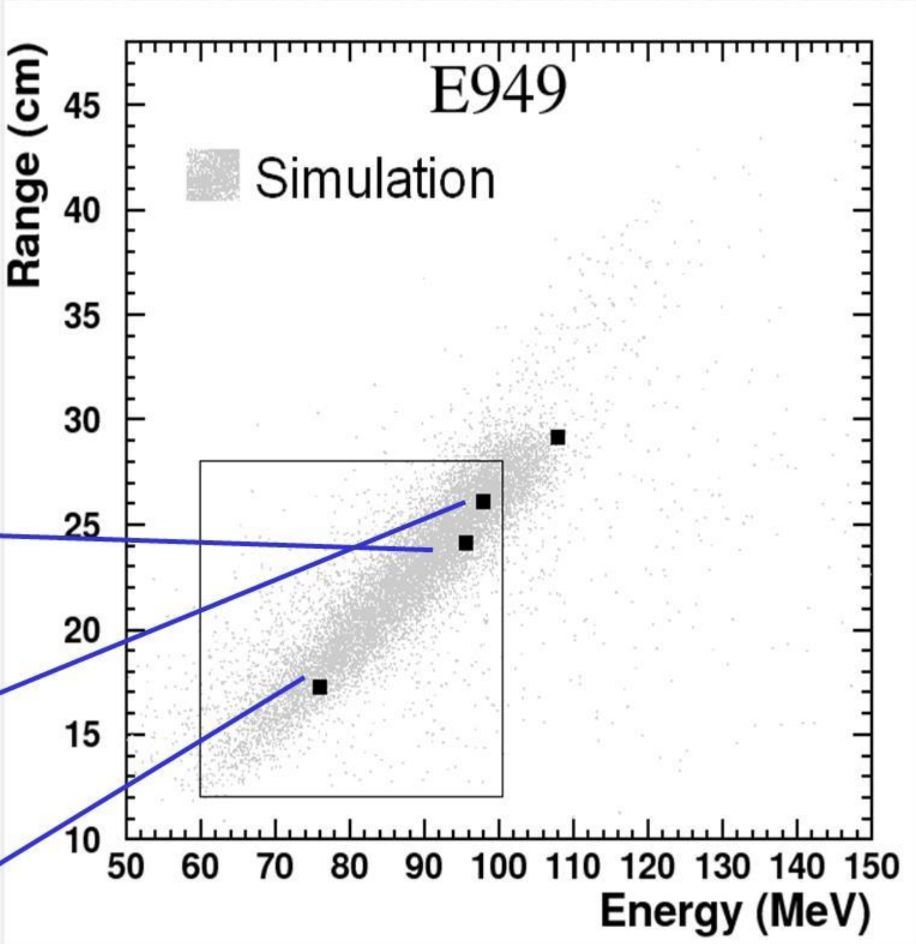
- **Kinematics box**
- **Photon veto**
- $\pi \rightarrow \mu \rightarrow e$
- **timing (delay coincidence)**

	rel. Acc	bkg	Acc/bkg
	0.314	0.152	2.065
	0.073	0.038	1.921
	0.031	0.019	1.653
	0.007	0.005	1.559
	0.287	0.243	1.183
	0.066	0.059	1.135
	0.028	0.027	1.036
	0.006	0.007	0.998
	0.188	0.379	0.496
sum	1	0.93	

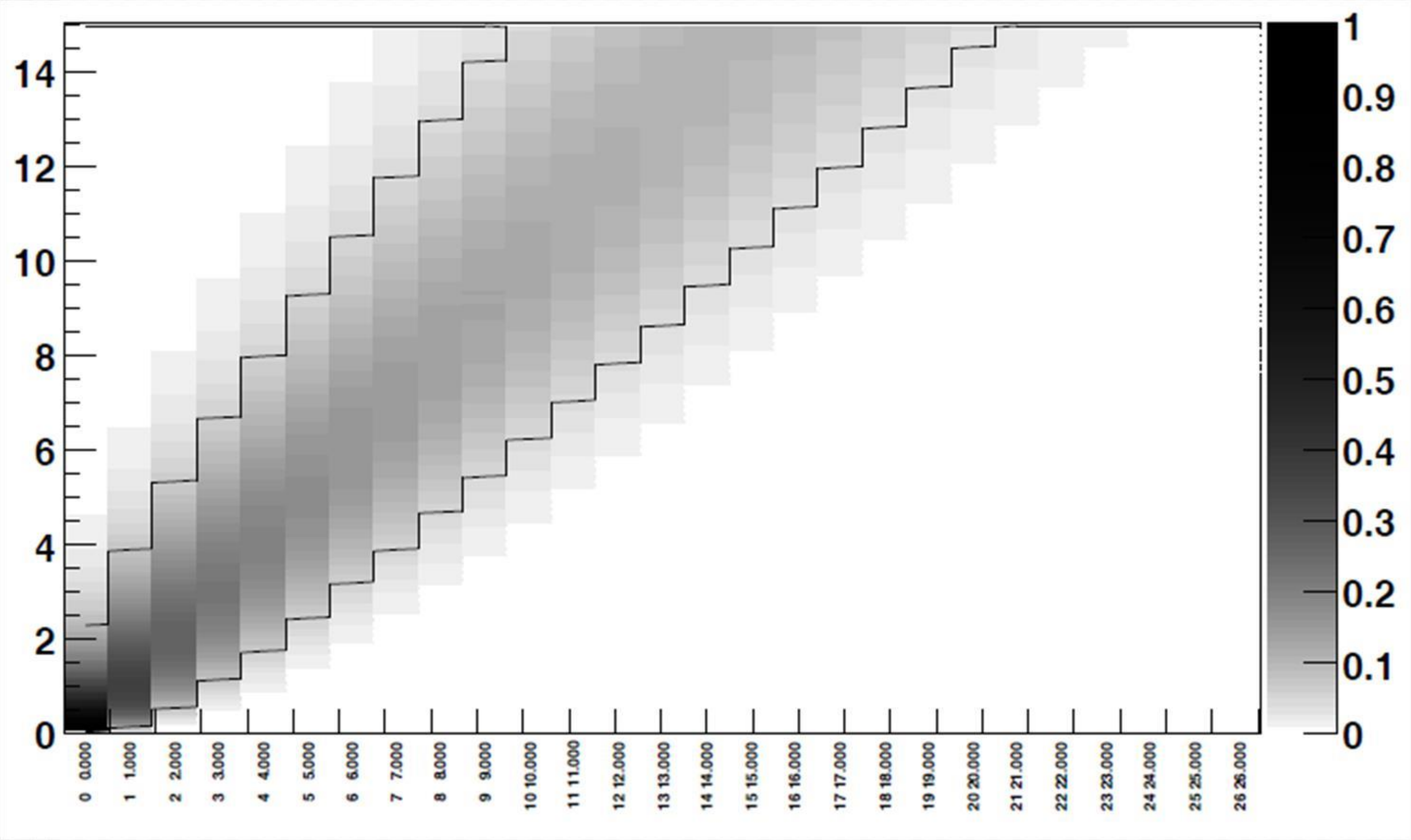
Three candidates are found

The nine cells

Bkgd	Events	S/B
0.152	0	0.84
0.038	0	0.78
0.019	0	0.66
0.005	0	0.57
0.243	1	0.47
0.059	0	0.45
0.027	1	0.42
0.007	0	0.35
0.379	1	0.20



求置信区间（single cell case）



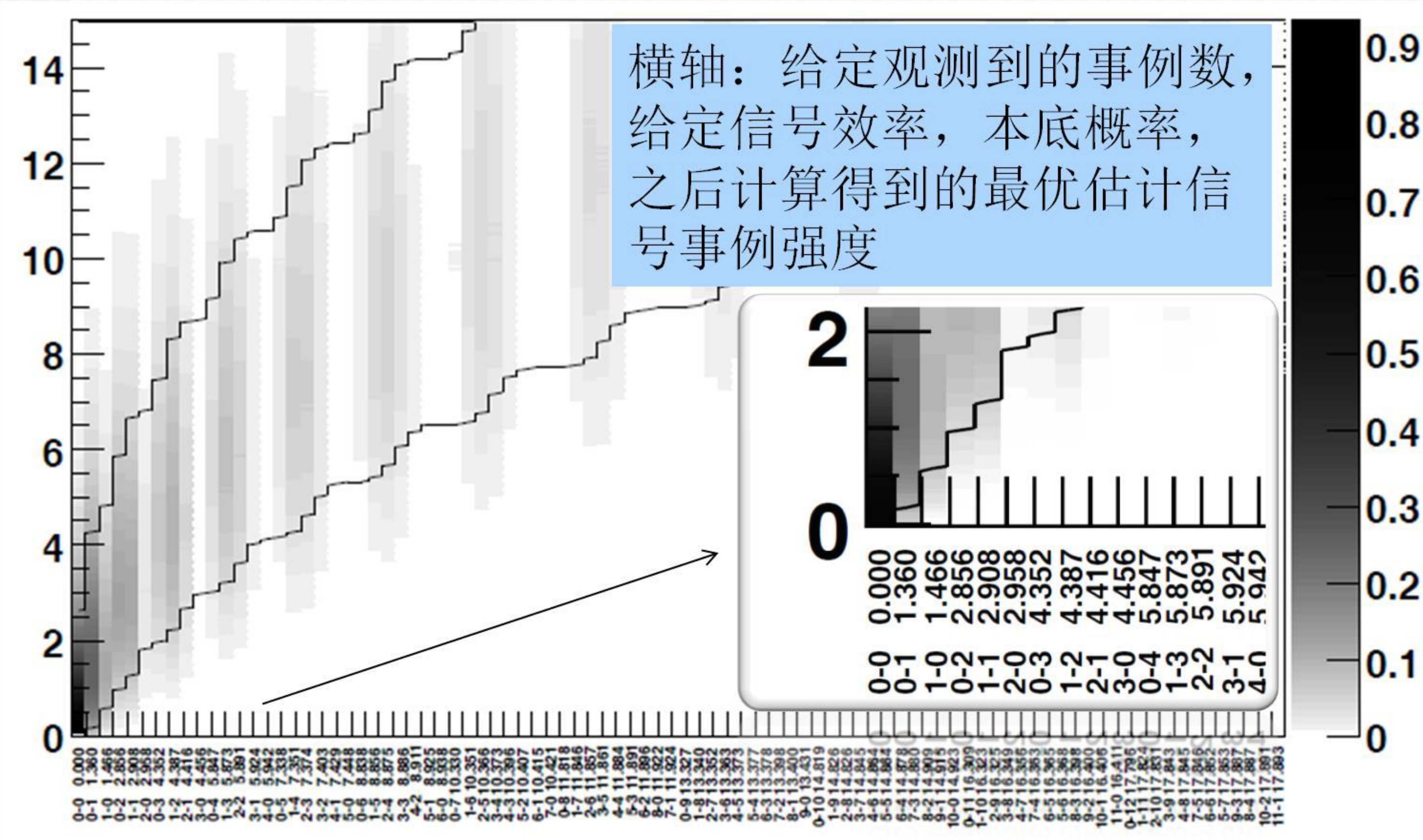
求置信区间（single cell case）

两个重要的参考文献：（必读）

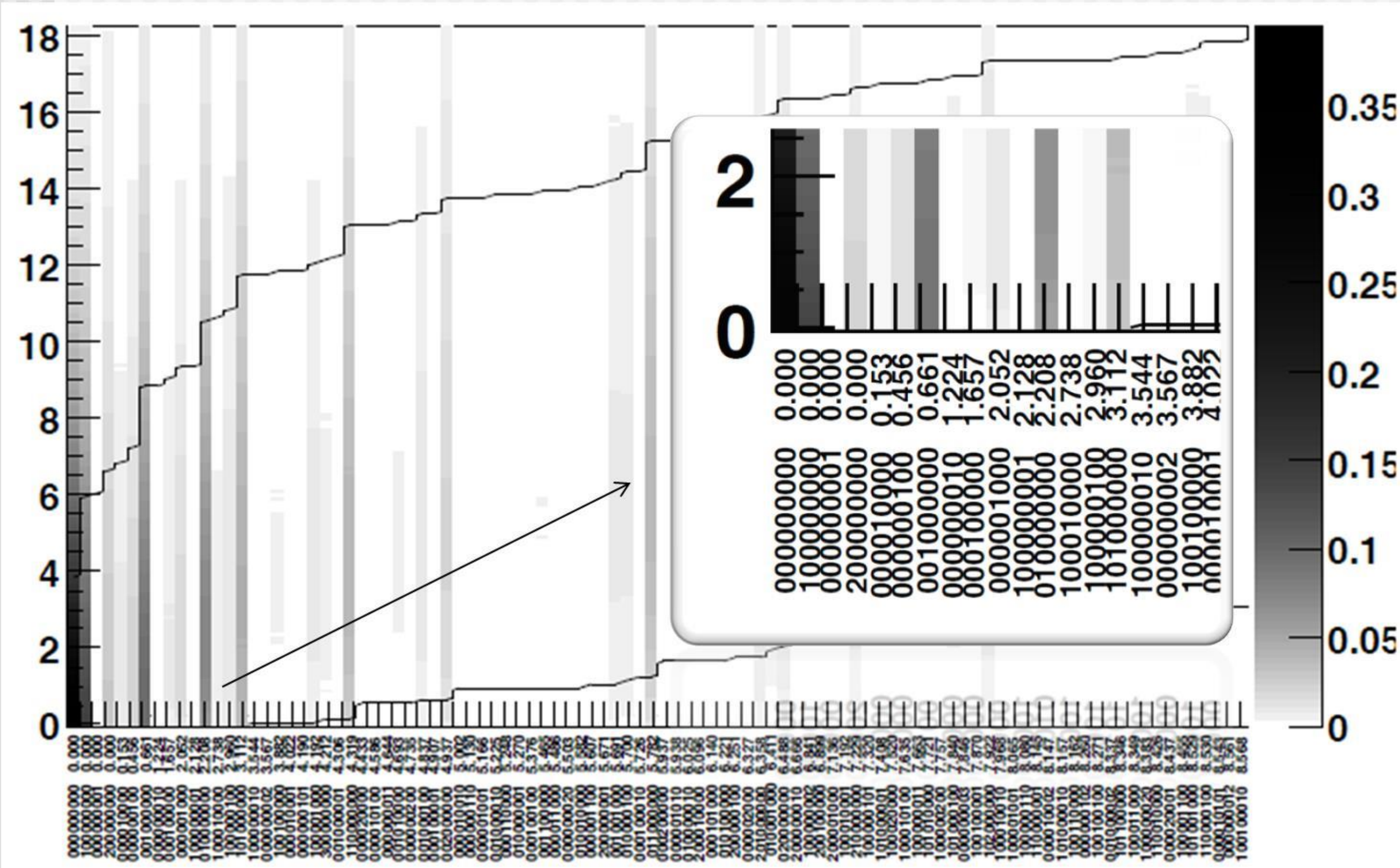
1. Glen Cowan，Statistical Data Analysis，Section 9.2

2. Gary J. Feldman，Robert D. Cousins，Unified approach to the classical statistical analysis of small signals，arXiv:physics/9711021，Phys. Rev. D 57, 3873
（使用了似然比求和）

求置信区间（double-cell case）



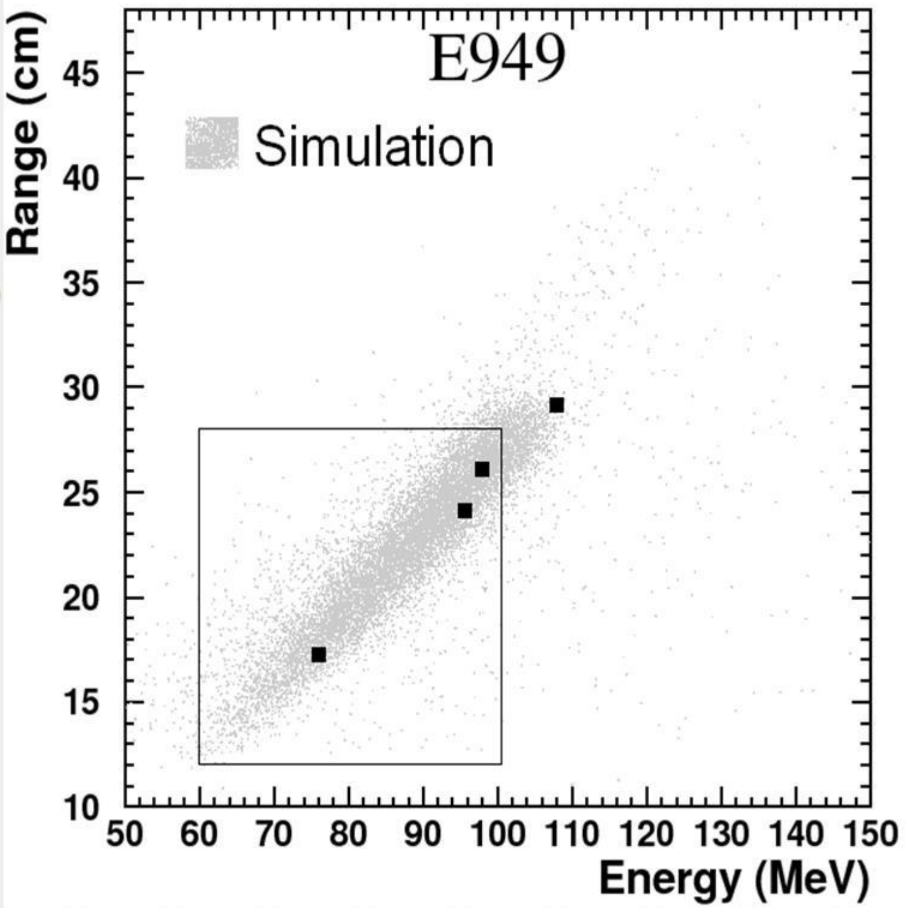
求置信区间（nine-cell case）



Measured $K^+ \to \pi^+ \nu \bar{\nu}$ BR of this analysis

- $BR = (7.89 \pm^{9.26}_{5.10}) \times 10^{-10}$
- The probability of all 3 events to be due to background alone is 0.037
- due to signal of SM prediction and background is 0.056
- SM prediction:

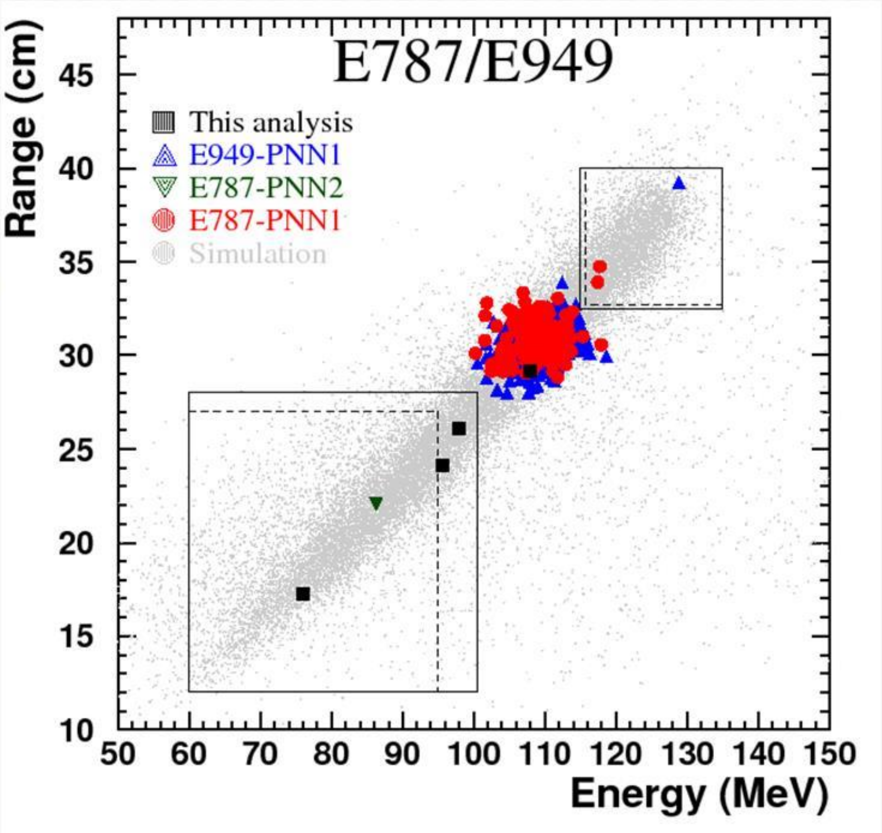
$BR = (0.85 \pm 0.07) \times 10^{-10}$



Combined with all E787/E949 result

- $BR=(1.73\pm^{1.15}_{1.05})\times10^{-10}$
- The probability of all 7 events to be due to background alone is 0.001
- due to signal of SM prediction and background is 0.07
- SM prediction:

$BR=(0.85\pm0.07)\times10^{-10}$



小结

- 稀有K介子衰变 $K^+ \to \pi^+ \nu\nu$
- 介绍了一个忙分析的实例
- 多区间泊松信号的联合分析的实例
- 期待客观的，诚实的“出色”结果。