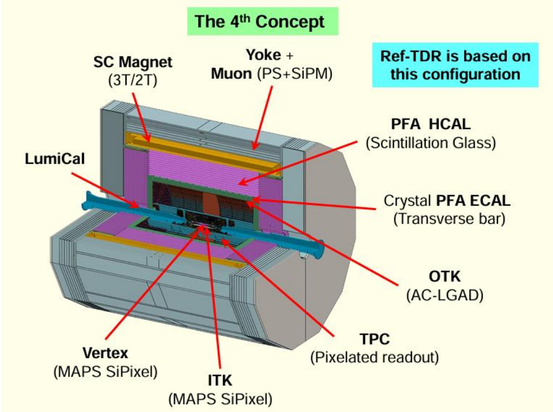
2024年度考核报告

软件组：赵光

2024年11月22日

报告内容

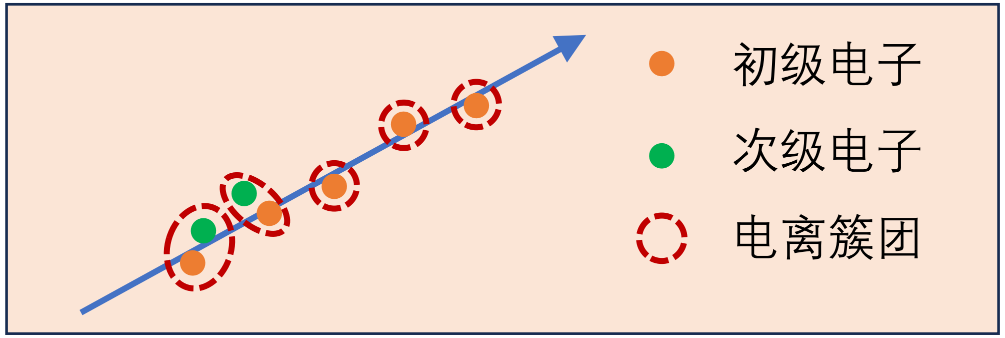
- **本年度工作情况**
  - CEPC 软件 (时间投影室和漂移室)
  - BESIII 数据分析
- **学术成果/科研项目/公共服务**
- **下年度工作计划**



CEPC 气体探测器 dN/dx 方法的研究

研究意义：

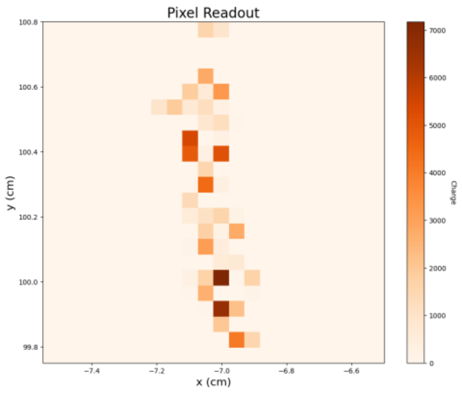
- **对新型探测器技术的探索。**从时间投影室和漂移室两个技术方案入手，深入研究 dN/dx 方法。对提升 CEPC 粒子鉴别能力和实验精度意义重大。



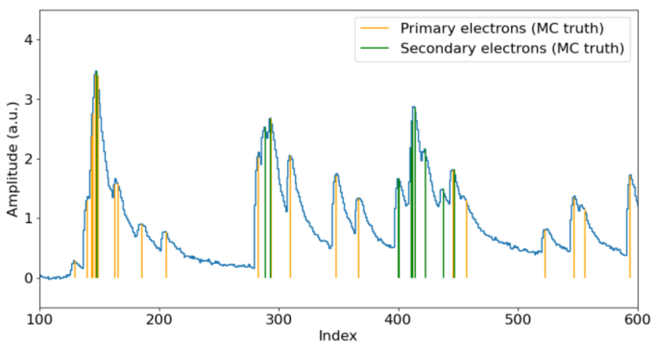
空间 时间

主要贡献：

- 主导时间投影室和漂移室 dN/dx 方法研究的**软件开发、关键算法研究、模拟性能研究和国际合作**



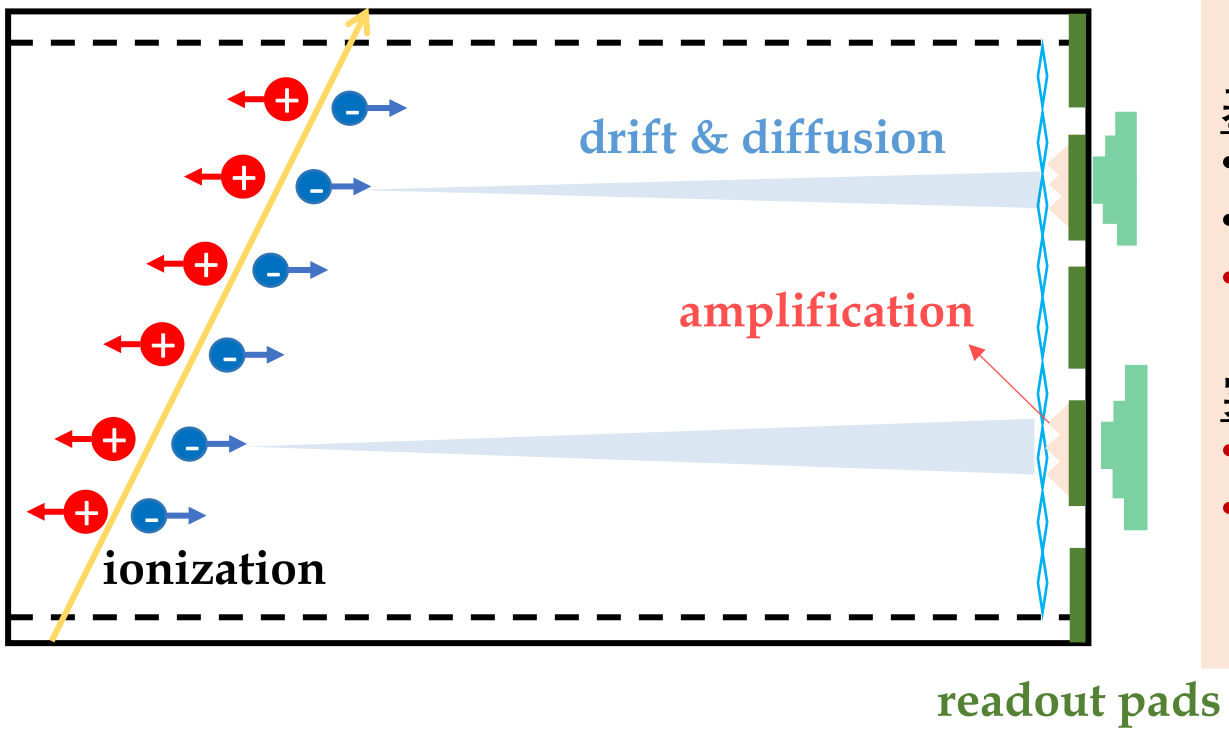
时间投影室



漂移室

时间投影室 dN/dx 方法的研究

工作重点： 新任务。完成精细模拟链条， 为 CEPC 物理提供关键粒子鉴别信息



全模拟框架

基于 Garfield++ 的模拟:

- 全尺寸 TPC
- 基于 Heed 的电离模拟
- 电子漂移扩散效应

实验驱动的数字化:

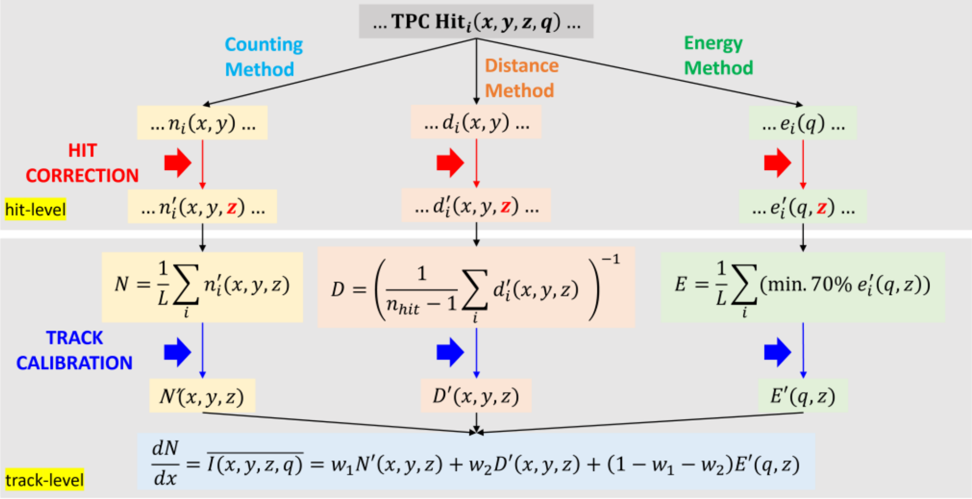
- 电子学噪声: 100 e-
- MicroMegas 放大:
  - 电子数增益: 2000
  - 电子空间展宽: 200 um (-3~+3 sigma)

时间投影室 dN/dx 方法的研究

重建算法:

- 基于像素计数的**基本算法**
- 基于三维位置和能量的四维信息的**新算法 (研究中)**

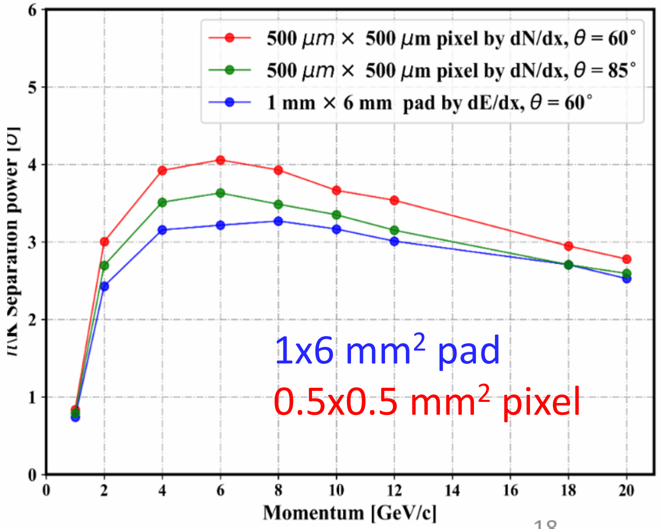
新算法 (考虑漂移距离、角度的修正和刻度)

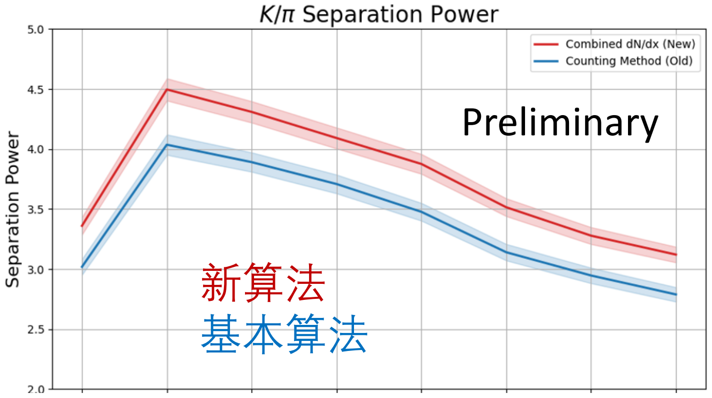


基于全模拟的粒子鉴别性能：

- **像素读出的粒子鉴别性能优于传统 pad 读出**
- 20 GeV/c 动量的 K/pi 粒子区分能力接近 3σ。**新算法有进一步提高性能的潜力**

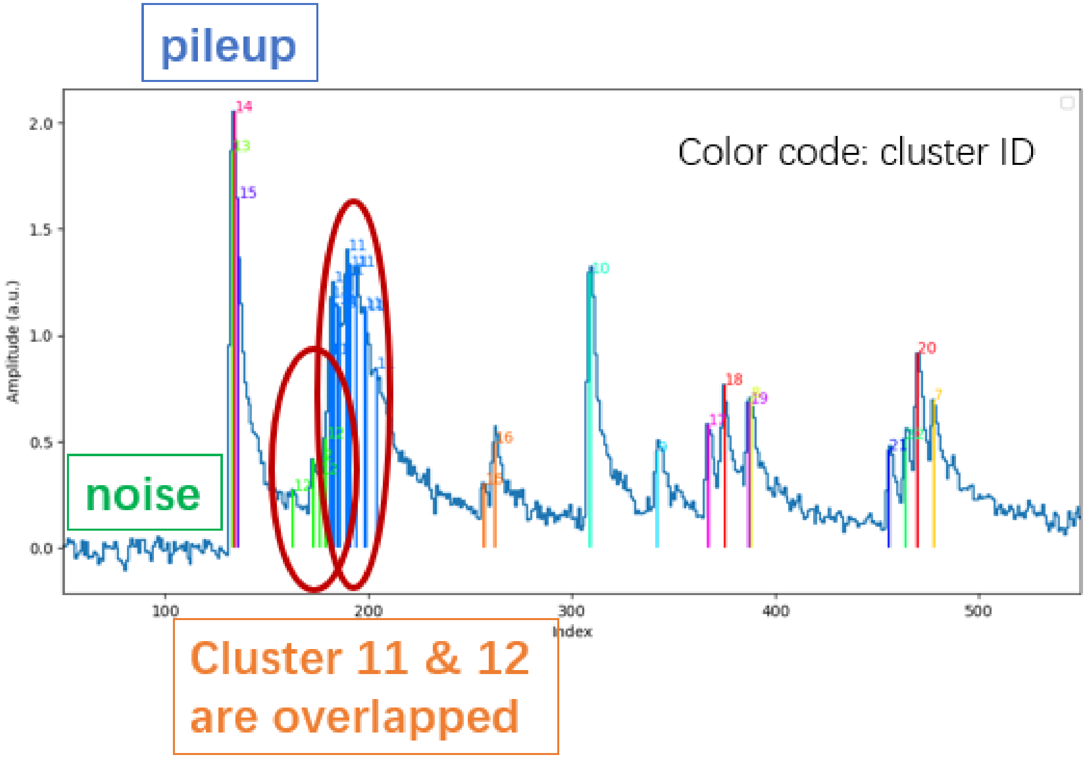
K/pi 粒子区分能力





漂移室 dN/dx 方法的研究

工作重点： 前期已开展了完整的模拟研究。今年重点解决重建算法的挑战。



dN/dx 重建存在巨大挑战，主要体现在：信号高堆积、高噪声污染和次级电子的干扰

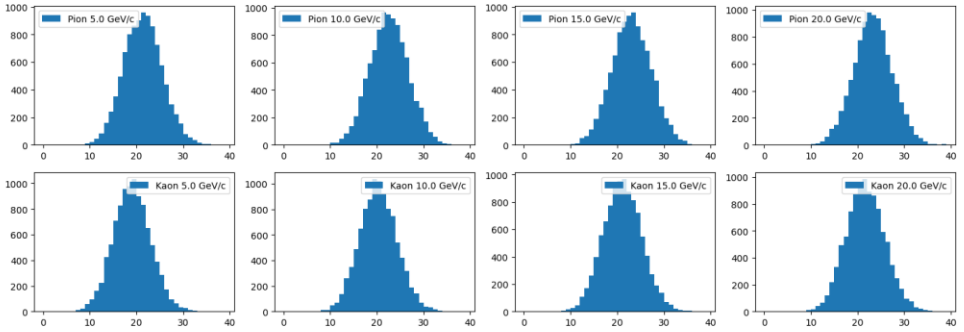
漂移室 dN/dx 方法的研究

关键机器学习算法的开发：

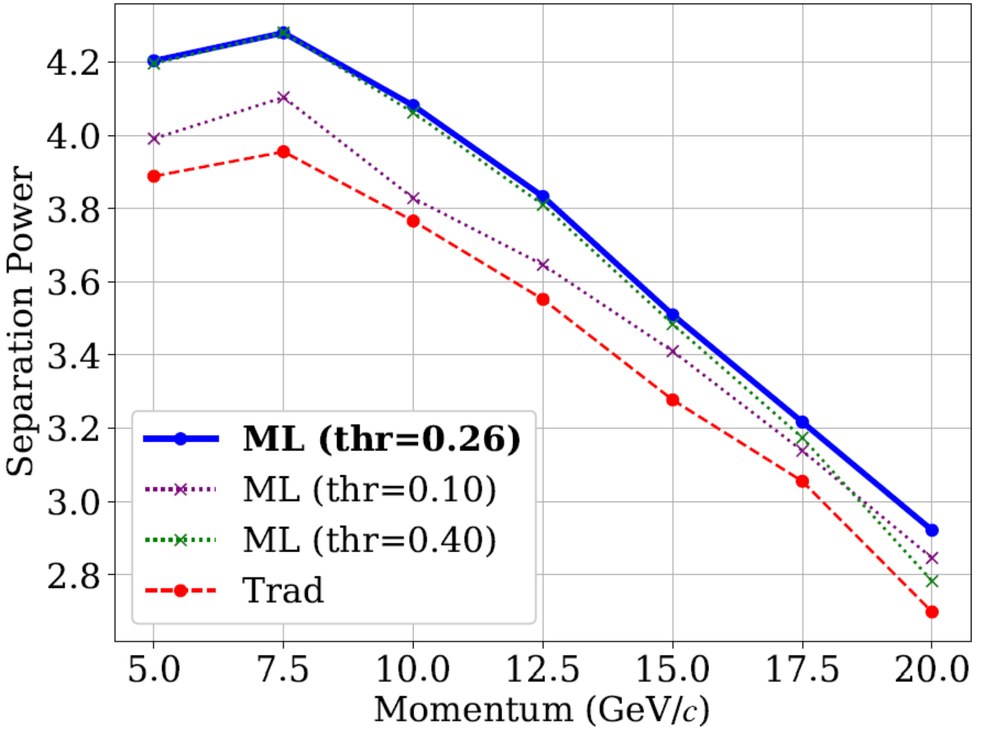
1. **针对模拟数据的监督学习算法**
   - 解决了信号堆积和噪声干扰的问题
   - 特别地，有效排除了次级电子的影响
   - 粒子鉴别性能比传统算法提高 10%
   - 文章已被 Nuclear Science and Techniques 接收

2. **针对实验数据的迁移学习算法**
   - 真实数据应用机器学习算法的深入思考和有效尝试
   - 文章已被 Computer Physics Communications 发表

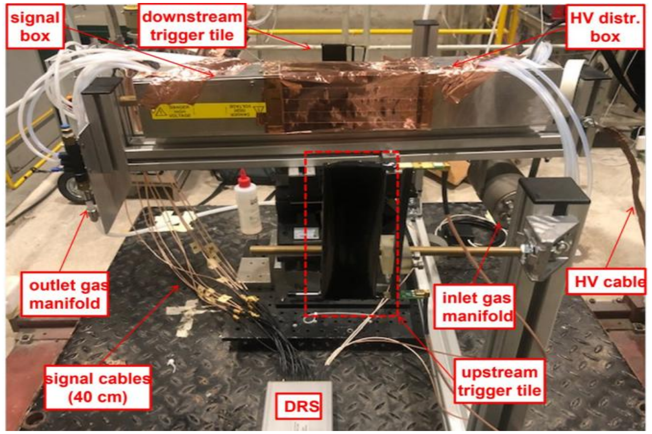
dN/dx分布：高斯分布➔有效排除了次级电离



机器学习算法提高了10%的粒子区分能力



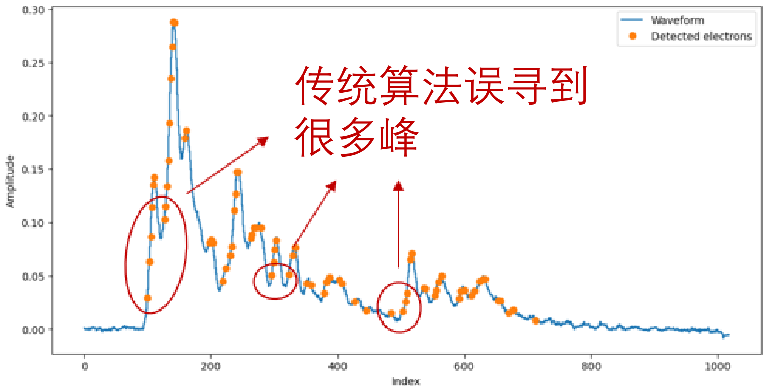
漂移室国际合作



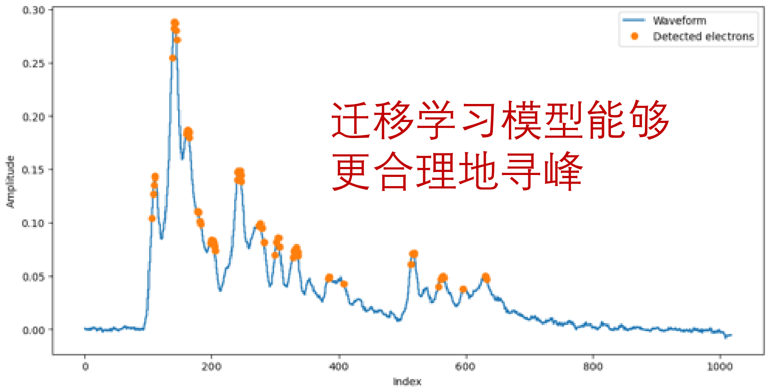
主导推动与 FCC-ee 探测器专家的合作：

- **通过在算法上的贡献，与 INFN 的 F. Grancagnolo/Nicola De Filippis 团队建立了深入合作的关系**
- 共同分析在 CERN 获取的束流实验数据，并共同发表一篇文章
- 指导 INFN 博士生 Muhammad 进行机器学习算法研究

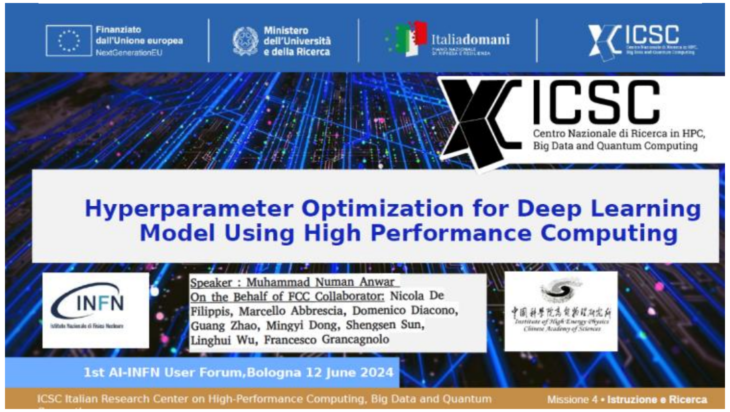
传统算法



迁移学习算法



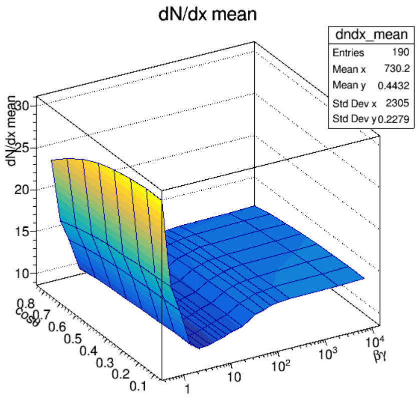
指导 INFN 博士生的国际会议报告



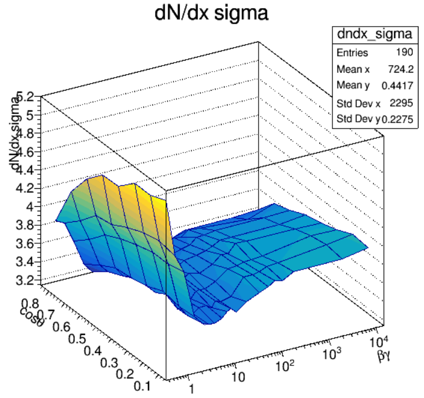
CEPCSW 实现及 Ref-TDR 撰写

- **CEPCSW 中实现了粒子鉴别功能，并为物理分析提供了完整粒子鉴别信息**
  - 基于Garfield++全模拟的参数化 TPC 模型
  - 基于参数化的 TOF 模型
- **正在撰写 Ref-TDR 中气体探测器和软件的章节**

CEPCSW中的参数化模型



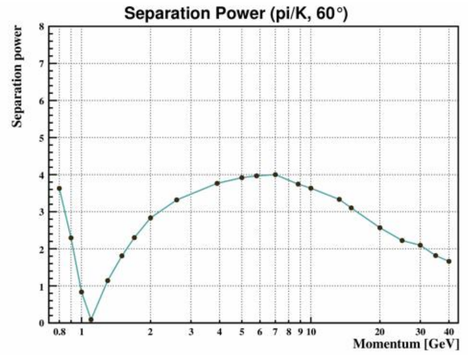
dN/dx mean

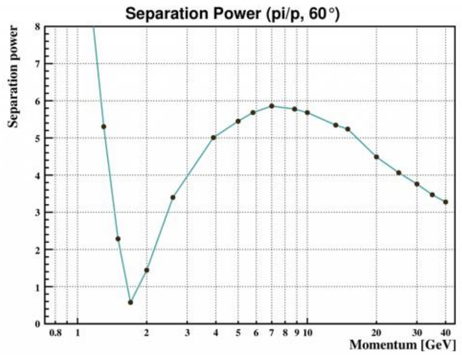


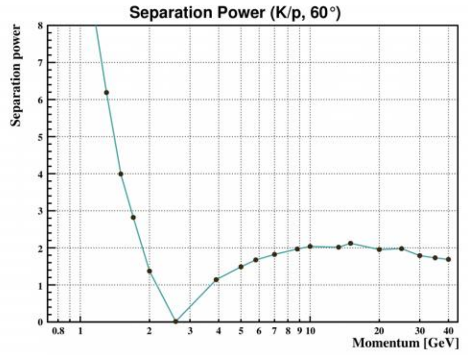
dN/dx sigma

Ref-TDR 章节

CEPCSW中的粒子鉴别性能 (TPC)







BESIII数据分析: $e^+e^- \to KK\eta_c$

研究意义：

- 寻找Z_c的奇特伴随态Z_{cs}，理解其产生机制，为理论提供实验信息
- 近年很多Z_c被实验上发现，其中：
  - LHCb: $Z_c(4100) \rightarrow \eta_c\pi^+$ (>3σ) [Phys.Rev.D 90 (2014) 11, 112009]
- 测量$e^+e^- \rightarrow KK\eta_c$过程，并通过$\eta_c K^+$寻找$Z_{cs}$

研究进展：

- 未观测到显著信号，给出了$e^+e^- \to KK\eta_c$及$Z_{cs}(3985) \to K\eta_c$的上限
- 回答 referee 4 轮次共 40 个问题，正在增加 4.0-4.6 GeV 能量数据的结果

进入Memo审核阶段：BAM-704

4.680 GeV 数据的K介子反冲质量谱

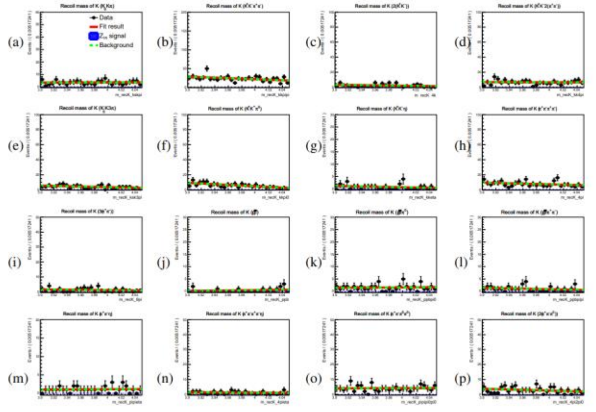


Figure 14: Nominal simultaneous fit to the recoil K mass for the decay mode (a) $K_S^0 K\pi$, (b) $K^+K^-\pi^+\pi^-$, (c) $4K$, (d) $K^+K^-2(\pi^+\pi^-)$, (e) $K_S^0 K3\pi$, (f) $K^+K^-\pi^0$, (g) $K^+K^-\eta$, (h) $2(\pi^+\pi^-)$, (i) $3(\pi^+\pi^-)$, (j) $p\bar{p}$, (k) $p\bar{p}\pi^0$, (l) $p\bar{p}\pi^+\pi^-$, (m) $\pi^+\pi^-\eta$, (n) $2(\pi^+\pi^-)\eta$, (o) $\pi^+\pi^-2\pi^0$, (p) $2(\pi^+\pi^-)2\pi^0$ in the range of (3.9, 4.05) GeV from data samples at 4680 energy point.

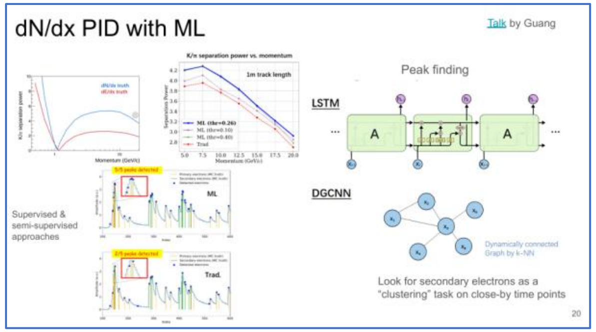
$Z_{cs}(3985) \to K\eta_c$截面上限的初步结果

Table 17: Upper limits of signal yield at the 90% confidential level before and after considering additive systematic uncertainty, luminosity of data samples, upper limit of dressed cross section, production of ISR factor, VP factor and the summation of $\mathcal{B}_i \cdot \varepsilon_i$, upper limit of Born cross section for each energy point.

Energy point	N_{UP}	N_{UP} after considering additive systematic uncertainties	$\mathcal{L}$ (pb^{-1})	$\sigma_{UP}^{dressed}$(pb)	$(1+\delta_{ISR})\cdot\delta_{VP}\cdot\sum_i \mathcal{B}_i\cdot\varepsilon_i$	σ_{UP}^{Born}(pb)
4600	29.1	38.8	586.90	6.8	7.27×10^{-3}	9.1
4630	21.1	28.0	521.53	5.5	7.19×10^{-3}	7.5
4640	13.2	20.8	551.65	3.8	7.30×10^{-3}	5.2
4660	25.1	42.8	529.43	7.9	7.45×10^{-3}	10.9
4680	25.9	32.3	1667.39	1.8	7.64×10^{-3}	2.5
4700	18.7	24.3	535.54	4.3	7.06×10^{-3}	6.4
4780	25.1	35.1	511.47	6.0	8.58×10^{-3}	8.0
4840	7.8	16.6	525.16	2.8	8.39×10^{-3}	3.8

学术会议与国际合作

CHEP 2024 Highlight (Track 3)



Summary talk by Davide Valsecchi

- **重要学术会议**
  - *DC for cluster counting for the CEPC 4^{th} concept*, **IAS program 2024**, Jan 8-26, Hong Kong (talk)
  - *Drift chamber developments for CEPC*, **1^{st} DRD1 Collaboration Meeting**, Jan 29-Feb 2, online (talk)
  - *dN/dx reconstruction with machine learning for drift chamber*, **CEPC Workshop (EU) 2024**, April 8-11, Marseille (talk)
  - *Drift chamber option for CEPC*, **LCTPC Collaboration Meeting**, May 12-13, online (talk)
  - *Drift chamber with cluster counting techniques for CEPC*, **International Workshop on Future Linear Colliders**, July 8-11, online (talk)
  - *dN/dx reconstruction with machine learning for cluster counting*, **the 42^{nd} International Conference on High Energy Physics (ICHEP 2024)**, July 18-24, Prague, Czech (poster)
  - *Drift chamber with cluster counting techniques for CEPC*, **Quantum Computing and Machine Learning Workshop 2024**, Aug 2-8, Changchun (talk)
  - *基于监督学习和迁移学习的电离计数重建方法研究*, **中国物理学会高能物理分会第十四届全国粒子物理学术会议 2024**, Aug 12-18, Tsingdao (talk)
  - *dN/dx reconstruction with supervised learning and transfer learning*, **Conference on Computer in High Energy and Nuclear Physics (CHEP 2024)**, Oct 21-25, Krakow, Poland (talk)

- **国际合作**
  - **DRD1:** CERN DRD1-WG2-WP2 "Inner and central tracking with PID capabilities with Drift Chambers"高能所联络人
  - **电离计数:** F. Grancagnolo/Nicola De Filippis INFN团队， 合作指导意方研究生Muhammad Numan Anwar

学术论文与科研项目

- **期刊论文**
  - Peak finding algorithm for cluster counting with domain adaptation, **Computer Physics Communications 300 (2004) 109208** (第一作者，通讯作者，**IF = 7.2**)
  - Cluster counting algorithm for the CEPC drift chamber using LSTM and DGCNN, **Nuclear Science and Techniques** (通讯作者，已接收，**IF = 3.6**)
  - High granularity readout TPC R&D for tera-z at the future e+e- collider, **Proceedings of Science** (合作作者)
  - Offline data processing system of the BESIII experiment, **European Physical Journal C** (合作作者)
  - Time calibration of barrel TOF system at BESIII, **Radiation Detection Technology and Methods** (合作作者)

- **科研项目**
  - **气体探测器电离计数方法的软件研究（国自然面上项目，主持）**
  - 粲强子的强子末态衰变机制研究（国自然重大项目，参加）
  - 利用粲强子含轻子衰变精确检验标准模型（国家重点研发项目，参加）

学生培养与公共服务

- **学生培养**
  - 研究生 (3名):
    - 田喆飞: DC电离计数方法的研究
    - 常悦: TPC电离计数方法的研究
    - 张锦闲: TPC电离计数方法的研究
  - 本科生 (3名):
    - 高旭: DC电离计数方法的研究
    - 王远瞻/何俊驰: TPC电离计数方法的研究
  - 合作博士后 (2名):
    - 曹宁: BESIII分析工作
    - 张辰光: TPC电离计数方法的研究

- **公共服务**
  - BESIII分析内部审阅人: BAM-769; BAM-874; BAM-917

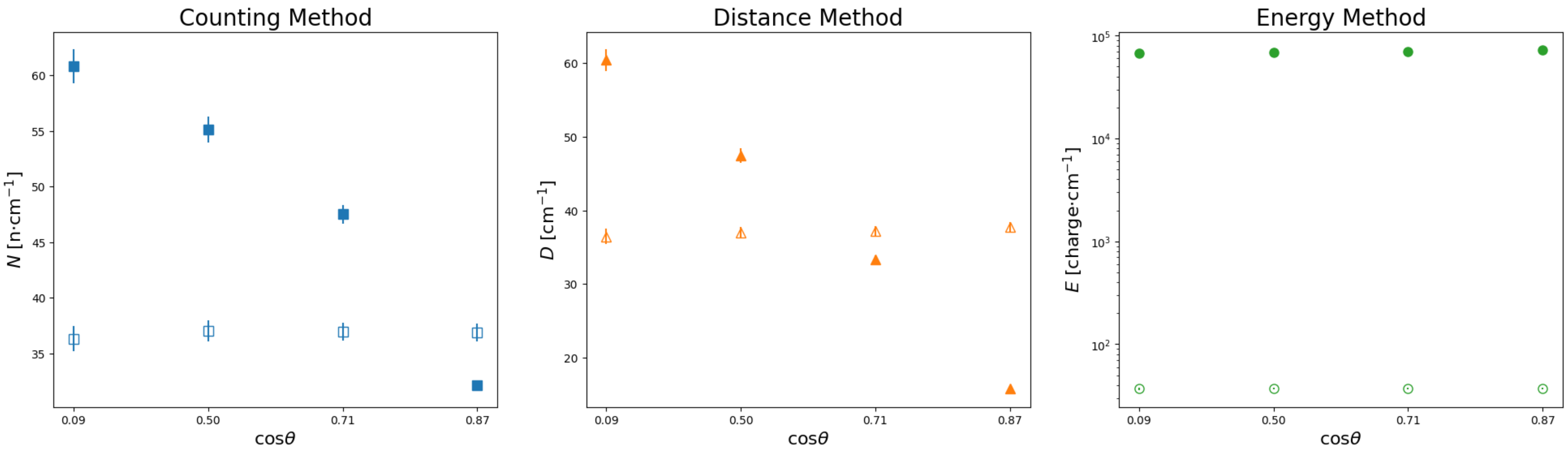
下年度工作计划

- **CEPC 气体探测器电离计数的研究**
  - 利用模拟研究优化 TPC 探测器设计
  - 开发复杂的 TPC PID 重建算法，以及 CEPCSW 下像素型读出 TPC 的实现
  - 加强国际合作，推动束流实验数据分析，验证模拟可靠性
- **BESIII 数据分析**
  - 继续完成$KK\eta_c$的分析

谢谢！

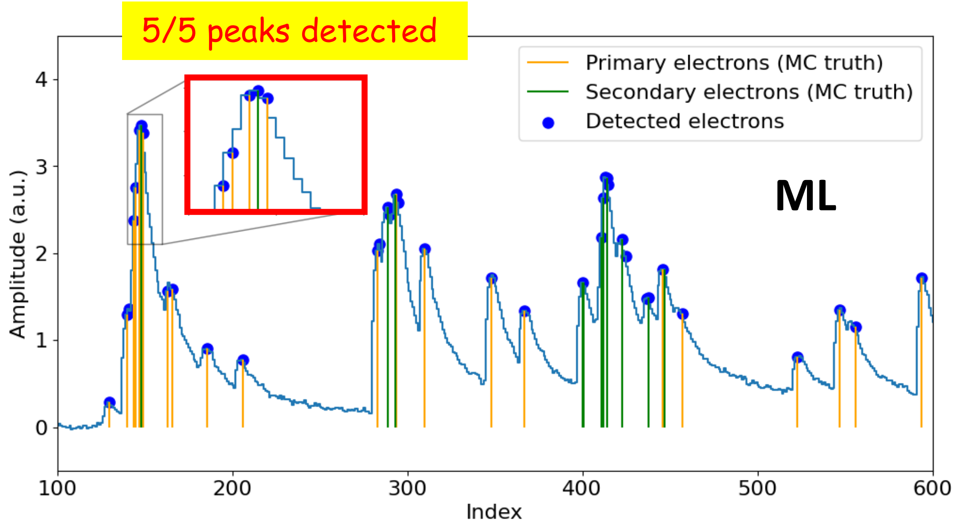
Backups

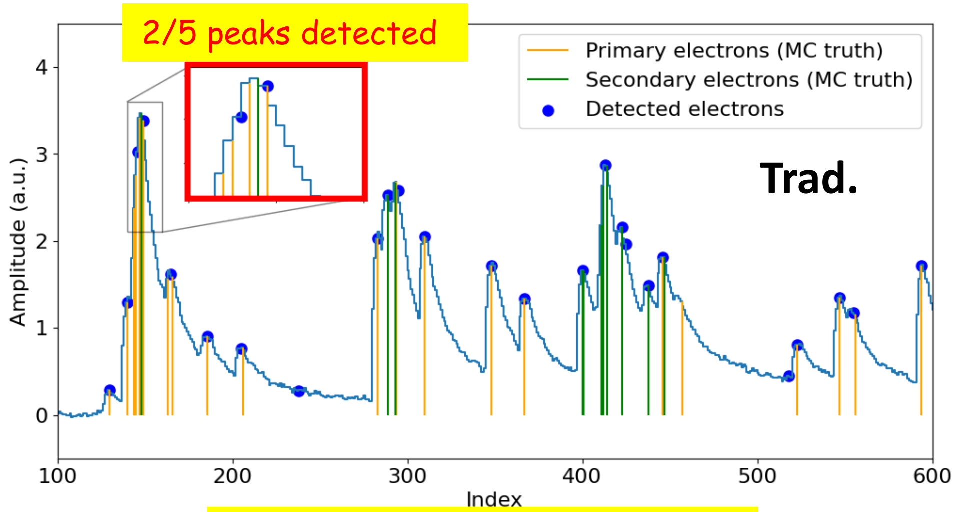
电离测量中的角度刻度



The cosine theta dependencies are vanished

Peak finding results





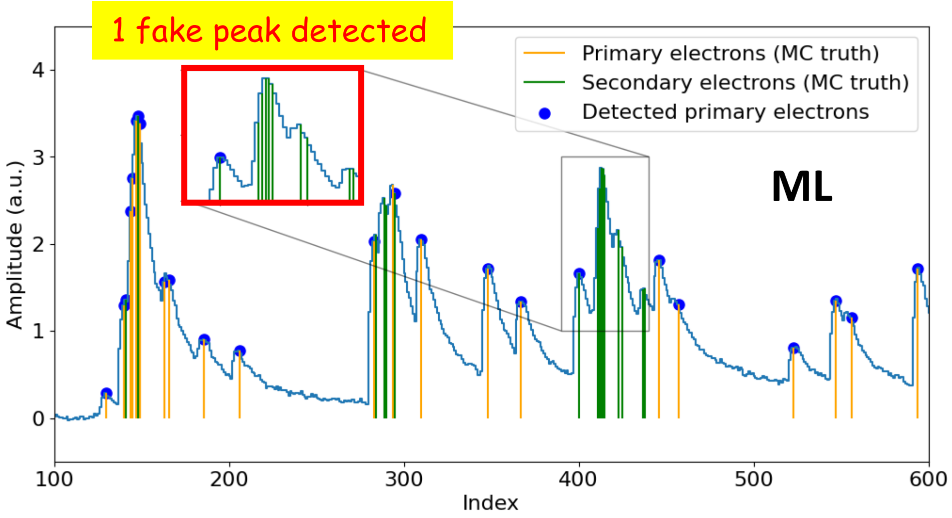
Traditional peak-finding: second derivative

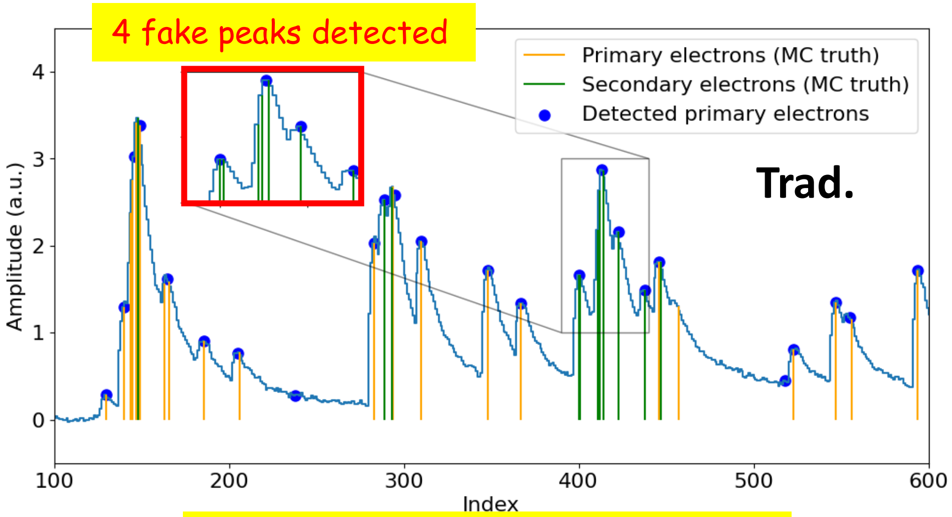
Table 2. The purity and efficiency comparison between LSTM-based algorithm and traditional D2 algorithm for peak-finding.

	Purity	Efficiency
LSTM algorithm	0.8986	0.8820
D2 algorithm	0.8986	0.6827

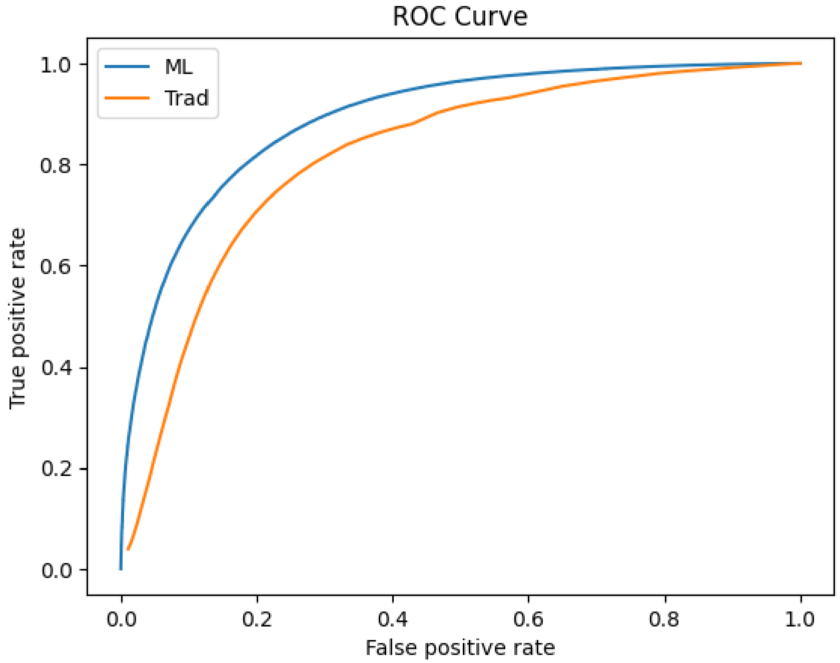
- The LSTM-based model is more powerful than the traditional derivative-based algorithm, especially for the pileup recovery

Clusterization results





Traditional clusterization: adjacent-peak merge

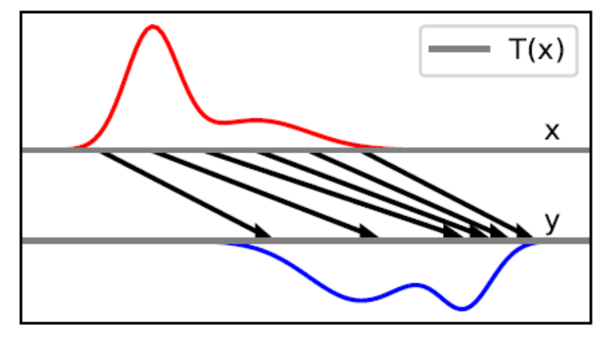


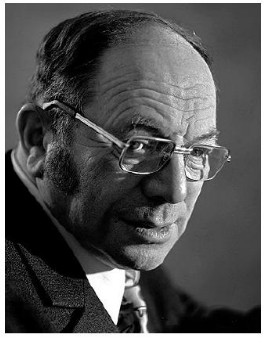
- The DGCNN-based model is more powerful than the traditional peak-merge algorithm, as it can remove the secondary electrons more accurate

Alg. 2: Transfer learning for real data

- **Challenges for real data**
  - Imperfect simulation
  - Incomplete labels in real data
- **Solution: Domain adaptation**
  - Transfer knowledge between simulation and real data via **optimal transport**

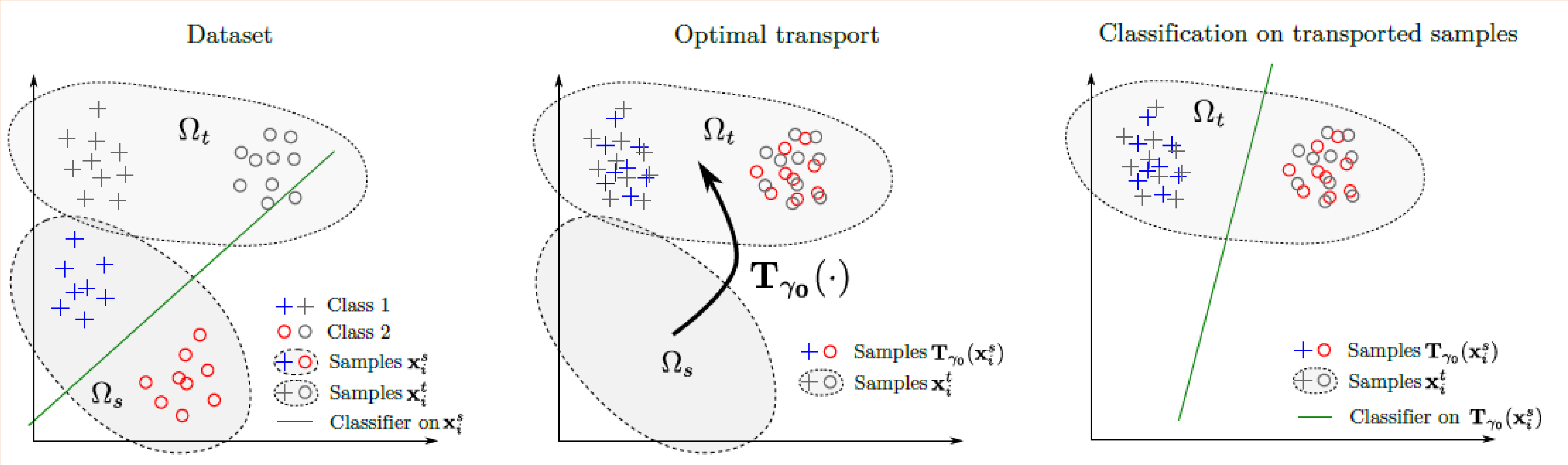
Optimal Transport





Kantorovich
(Economic Nobelist 1975)

Domain adaptation



Figures from Flamary's slides

Align data/MC samples with Optimal Transport