Particle identification in SPD: a Bayesian approach

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Outline

- set-up a 'framework' to support Bayesian approach within the SPD

Past talks connect to this topic
7 December 2021

- Ruslan Akhunzyanov "*dE/dx studies for particle*"
  https://indico.jinr.ru/event/2554/contributions/15153/attachments/11594/19132/Ruslan_dEdx_Dec7_2021.pdf

- Artem Ivanov "*Particle identification with TOF*"
  https://indico.jinr.ru/event/2554/contributions/15149/attachments/11593/19130/07.12.2021_Ivanov.A.V.pdf

Current talk based on following articles

- "*Bayesian approach for combined particle identification in ALICE experiment at LHC*"
  I. Belikov, P. Hristov, M. Ivanov, T. Kuhr, K. Safarik (2005) Contribution to: CHEP 2004, 423-426

- "*Particle identification in ALICE: a Bayesian approach*"
  ALICE Collaboration, Jaroslav Adam (Prague, Tech. U.) et al. (Feb 3, 2016) Published in: Eur.Phys.J.Plus 131 (2016) 5, 168

- "*Идентификация заряженных частиц по ионизационным потерям энергии во время-проекционной камере для экспериментов NICA/MPD*"
  С. П. Мерц, С. В. Разин, О. В. Рогачевский, Матем. моделирование, 2012, том 24, номер 12, 102–106

PID formalism

S - a raw signal from a detector
S(H_i) - expected average signal for a given species $H_i(\pi, K, p, \ldots)$

The Bayes theorem

probability that the particle is of species H_i, *given* $\vec{S}$

$$P(H_i|\vec{S}) = \frac{P(\vec{S}|H_i)\,C(H_i)}{\sum_{k=\pi,K,p} P(\vec{S}|H_k)\,C(H_k)}$$

a posterior probability

A priori probability for H_i

$$P(S|H_i) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(S-S(H_i))^2}{2\cdot\sigma^2}}$$

One detector

The conditional probability that a particle of species H_i produces a signal S (in this case expressed with a Gaussian response)

$$P(\vec{S}|H_i) = \prod_{\alpha=TOF,\,STAW,\,\ldots} P_\alpha(S_\alpha|H_i)$$

Many detectors

The conditional probability that a particle of species H_i produces the set of signals

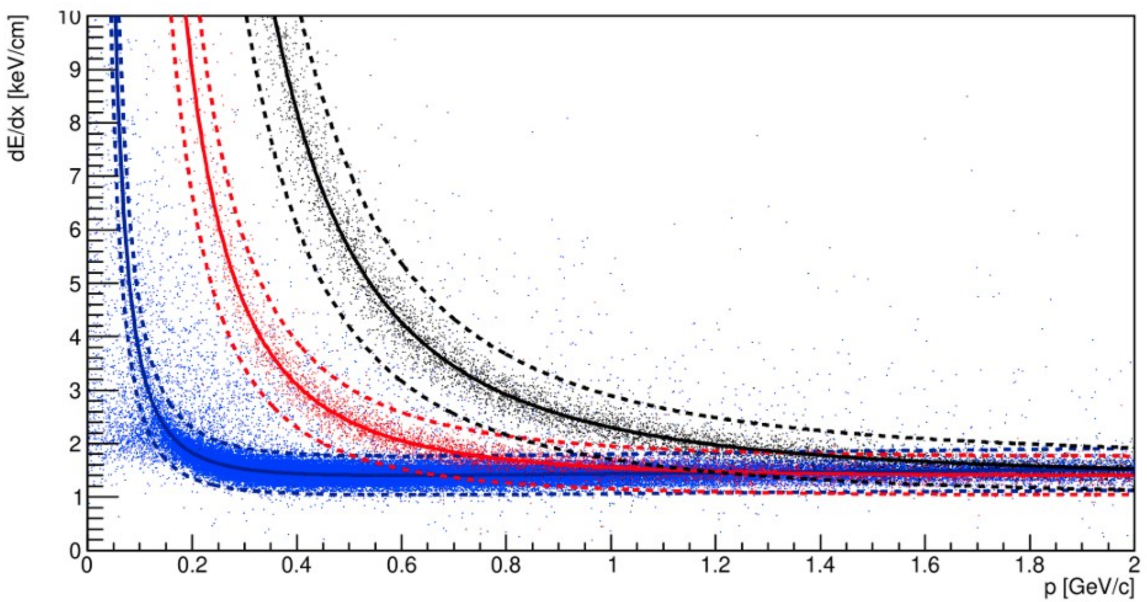
What is S raw signal

Detector	Signal
STRAW	dE/dx
TOF	m^2

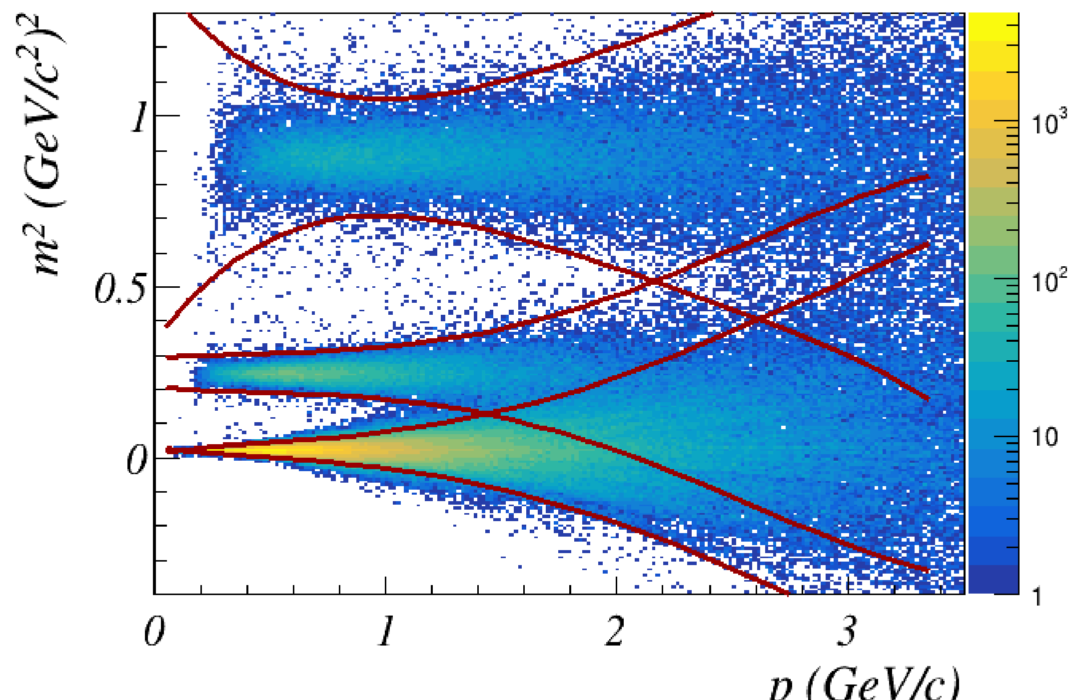
conditional probability

$$P(m^2) = \frac{1}{\sqrt{2\pi}\sigma(p)} e^{\frac{-(m_{TOF}^2 - m_{fit}^2)^2}{2\cdot\sigma(p)^2}}$$

STRAW



TOF



from talk of Ruslan Akhunzyanov "*dE/dx studies for particle*"

What is priors

Strategy to calculate

$$P(H_i|\vec{S}) = \frac{P(\vec{S}|H_i)C(H_i)}{\sum_{k=\pi,K,p} P(\vec{S}|H_k)C(H_k)}$$

Iterative procedure based on a set of unidentified tracks (raw yield $Y(p)$)

$$P(m^2) = \frac{1}{\sqrt{2\pi}\sigma(p)} e^{\frac{-(m_{TOF}^2 - m_{fit}^2)^2}{2\cdot\sigma(p)^2}}$$

1) Start with "flat" priors (i.e 1 for all species)

Priors obtained as a function of p

2) Bayesian posterior $P_n(H_i|S)$ at step n obtained from unidentified raw yield

$$Y_{n+1}(H_i, p) = \sum_S P_n(H_i|S)$$

3) Obtain identified raw yields at step $n+1$ using posteriors as weights

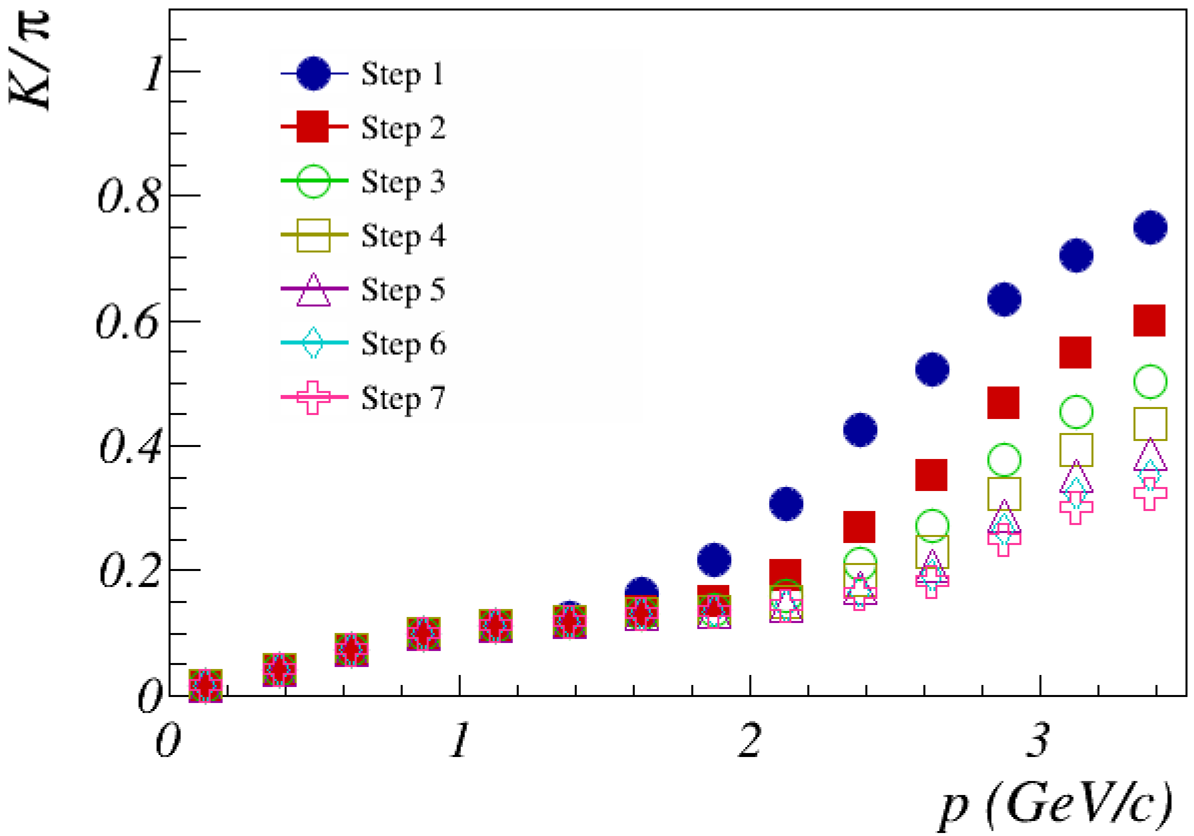
$$C_{n+1}(H_i, p) = \frac{Y_{n+1}(H_i, p)}{Y_{n+1}(H_\pi, p)}$$

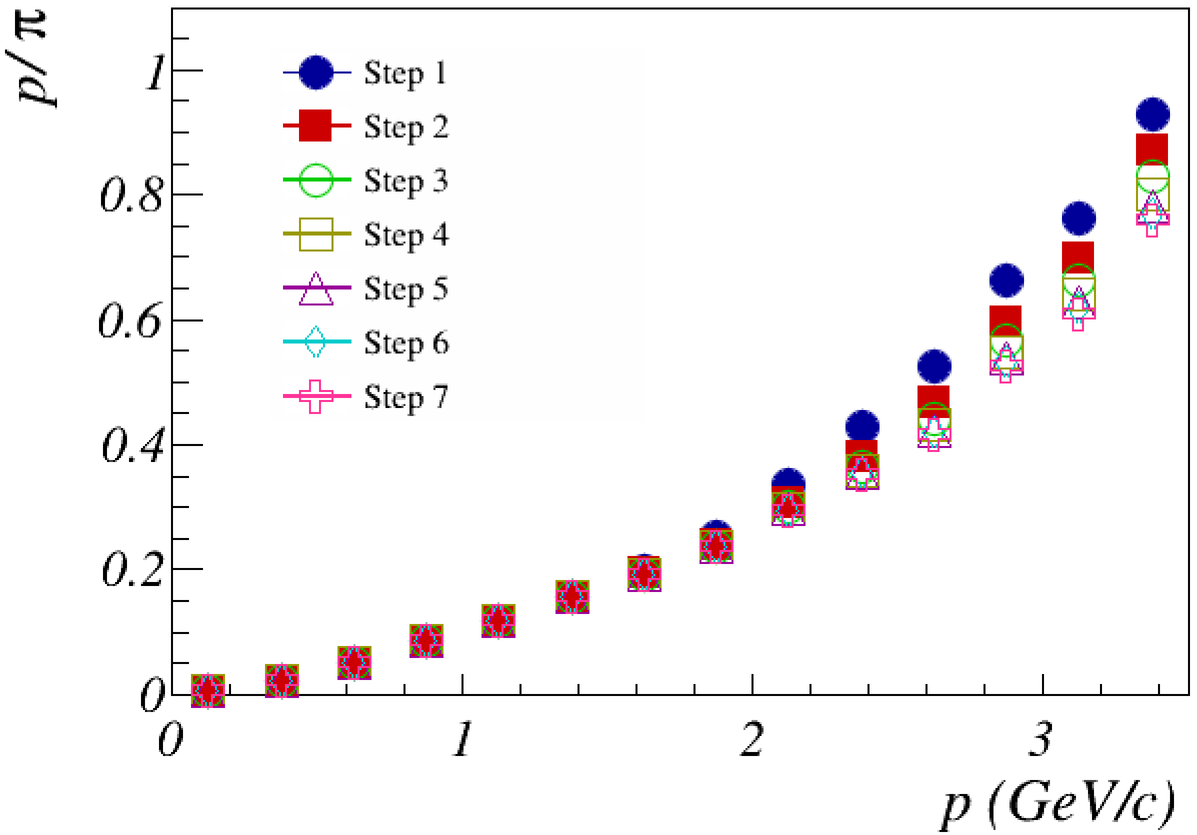
4) Obtain a new set of priors from the relative ratios of identified spectra

Separate sets of priors have to be evaluated for each collision system p-p, d-d, p-d and energies

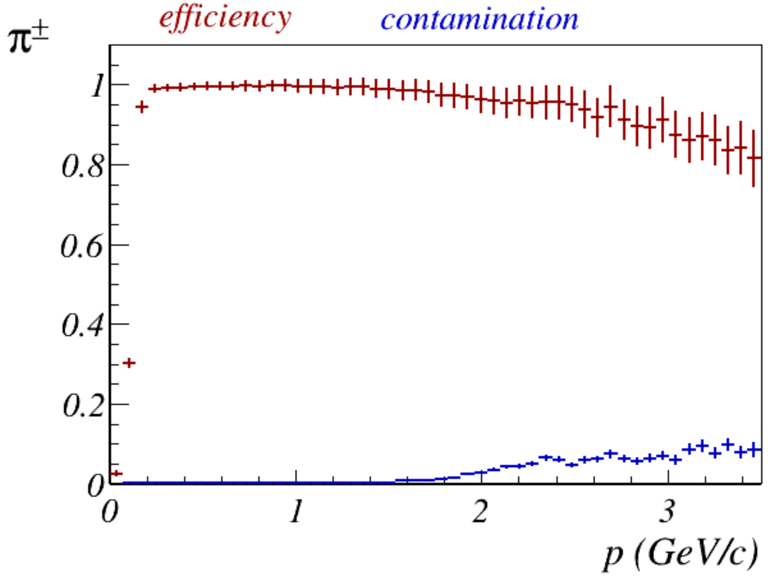
Calculation priors: only TOF

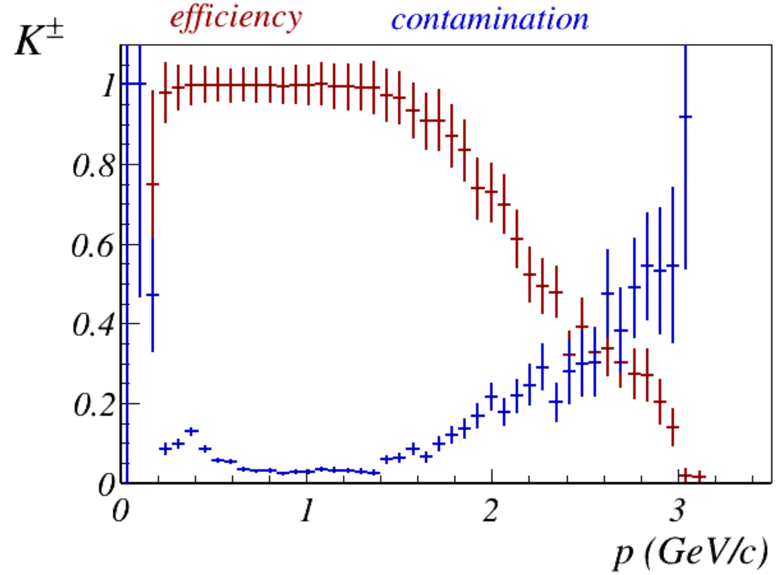
The extracted K/π and p/π ratio of the priors is shown as a function of *p* at each step of the iteration.

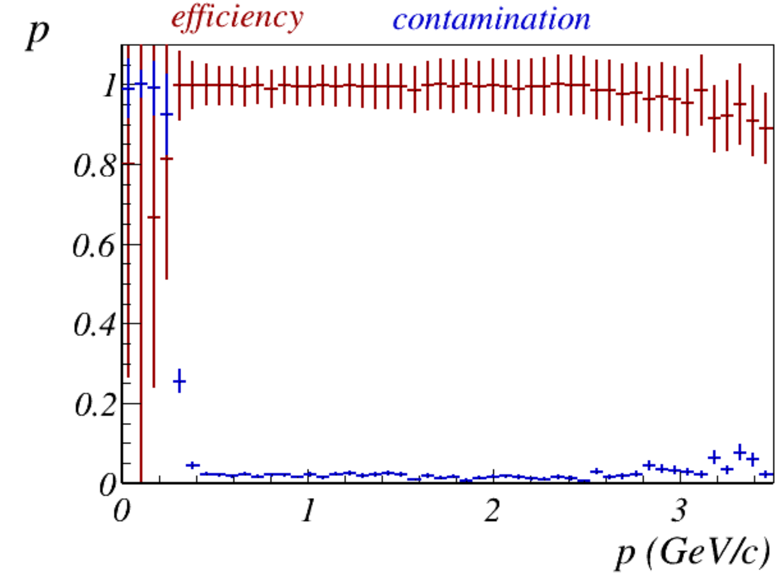


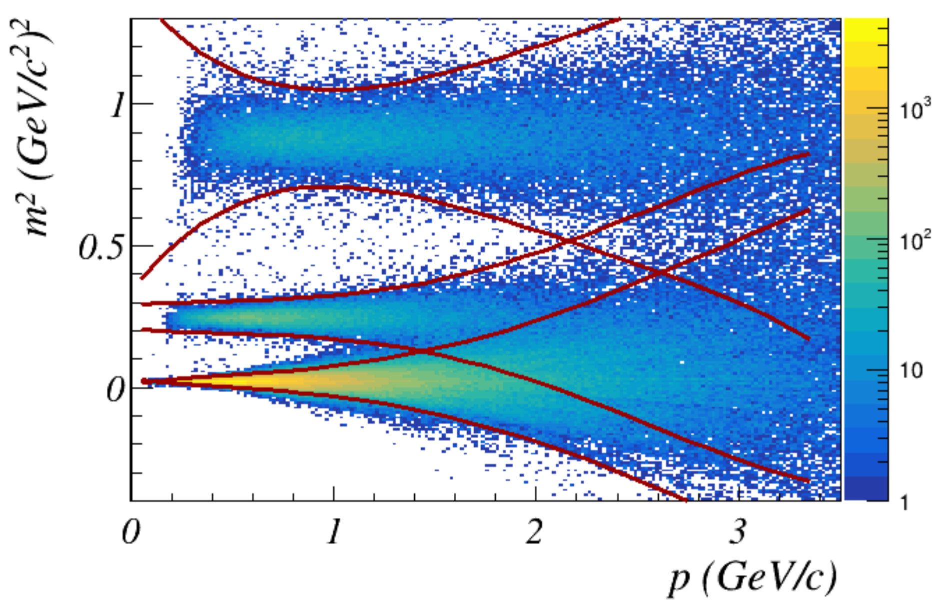


Efficiency and Contamination: only TOF









$$efficiency = \frac{N_{corr}}{N_{true}}$$

$$contamination = \frac{N_{incorr}}{(N_{incorr} + N_{corr})}$$

N_{corr} – the number of correctly identified particles of a certain type

N_{incorr} – number of misidentified particles a certain type

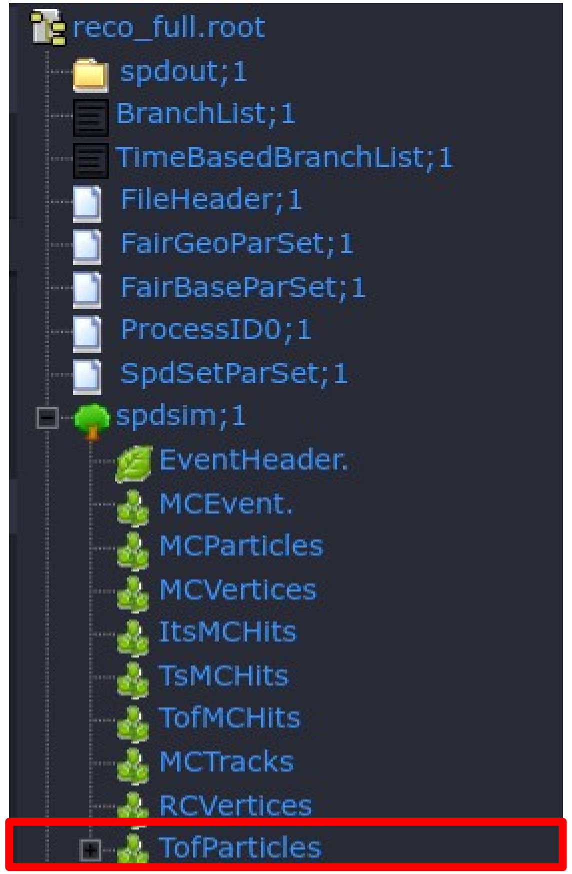
N_{true} – the true number of particles of a certain type.

Calculation TOF $P(H_i|S)$ probabity in SpdRoot

RecoEventFull.C

```
//   ///----------------------------------------------------------//
//   // [MC-PRODUCER FOR TOF-PARTICLES]
//   // Input: mc-event, mc-particles, mc-tracks(+ fit pars.), mc-tof-hits
//   // Output: tof-particles
//
  SpdMCTofParticleProducer* mctof_part = new SpdMCTofParticleProducer();
//
   //mctof_part->SaveParticles(false);
//
   mctof_part->SetVerboseLevel(1);
//
   Run->AddTask(mctof_part);
```

This code will create branch with name *"TofParticles"* which contains an information about probabilities of track to be pion, kaon, proton



Calculation TOF $P(H_i|S)$ probabity in SpdRoot

- spddata
  - hits
  - IdealTrackData
  - mcdata
  - params
  - reco
    - ecal
    - kfdata
    - rs
    - tof
      - SpdTofParticle.cxx
      - SpdTofParticle.h

Function from Class *SpdTofParticle*

```
std::vector<Double_t>   GetProb()          const  { return fprob; }
Double_t                GetProbPion()      const  { return fprob[0]; }    You, a month ago • added Tof probability
Double_t                GetProbKaon()      const  { return fprob[1]; }
Double_t                GetProbProton()    const  { return fprob[2]; }
Double_t                GetProbMax()       const  { return *std::max_element(fprob.begin(), fprob.end());};
```

<u>YourScriptForAnalysis.C</u>

```
Int_t IdhitTof = fparticle->GetTofParticleId();
if (IdhitTof < 0) continue;


SpdTofParticle *ftofparticle = (SpdTofParticle *)tofparticles->At(IdhitTof);
if (!ftofparticle)
    continue;


std::vector<Double_t> vprob = ftofparticle->GetProb();
```

Conclusion

- The ‘framework’ for Bayesian approach was added in my folk SpdRoot (https://git.jinr.ru/aivanov/spdroot)

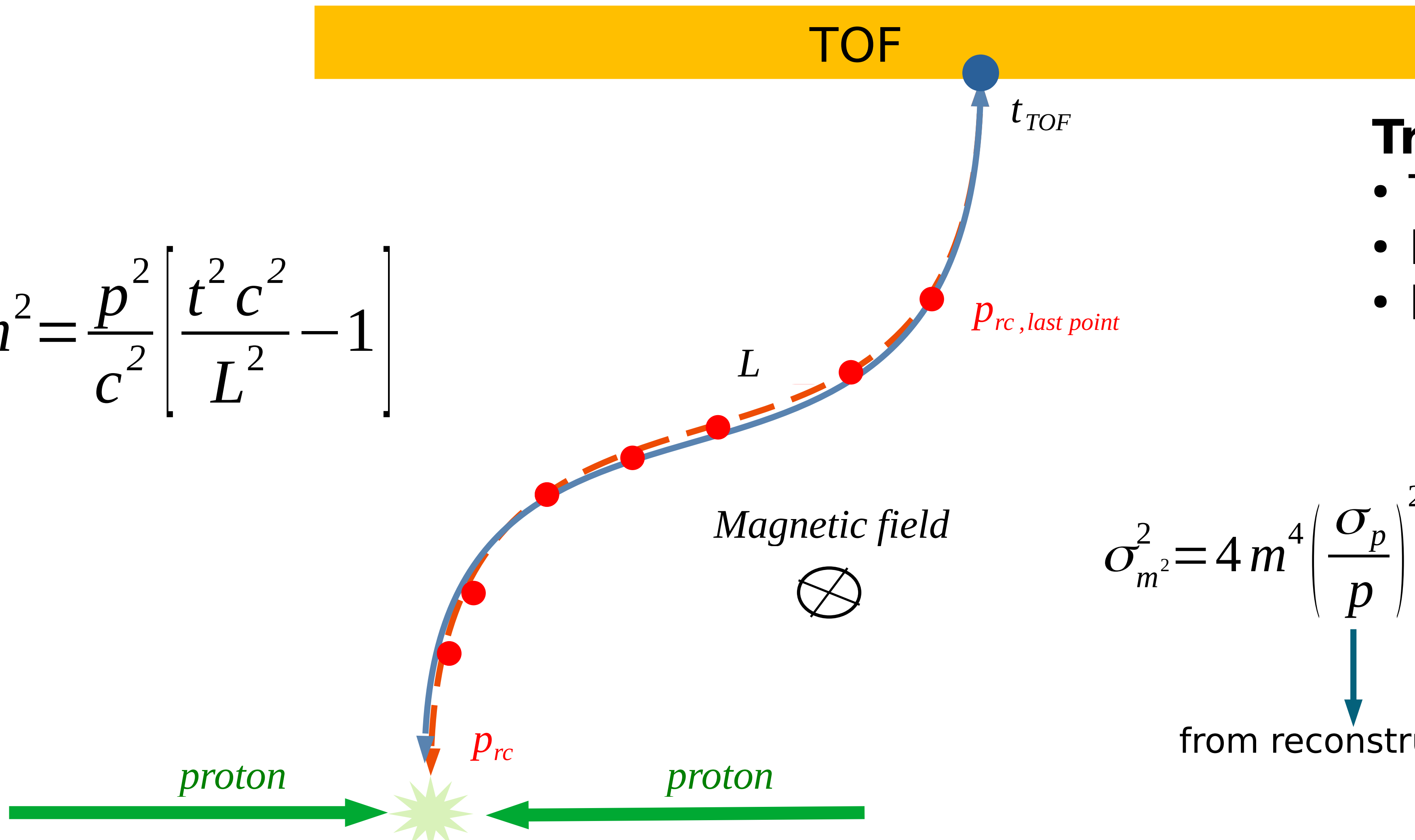
- To add in the official repository

- To combine results with STRAW

Backup

PID analysis with TOF in SpdRoot

$$m^2 = \frac{p^2}{c^2}\left[\frac{t^2 c^2}{L^2} - 1\right]$$



Track Selection:
- Track from PV
- Hit in TOF
- Fitted track is good

$$\sigma^2_{m^2} = 4m^4\left(\frac{\sigma_p}{p}\right)^2 + 4E^4\left(\frac{\sigma_t}{t}\right)^2 + \cancel{4E^4\left(\frac{\sigma_L}{L}\right)^2}$$

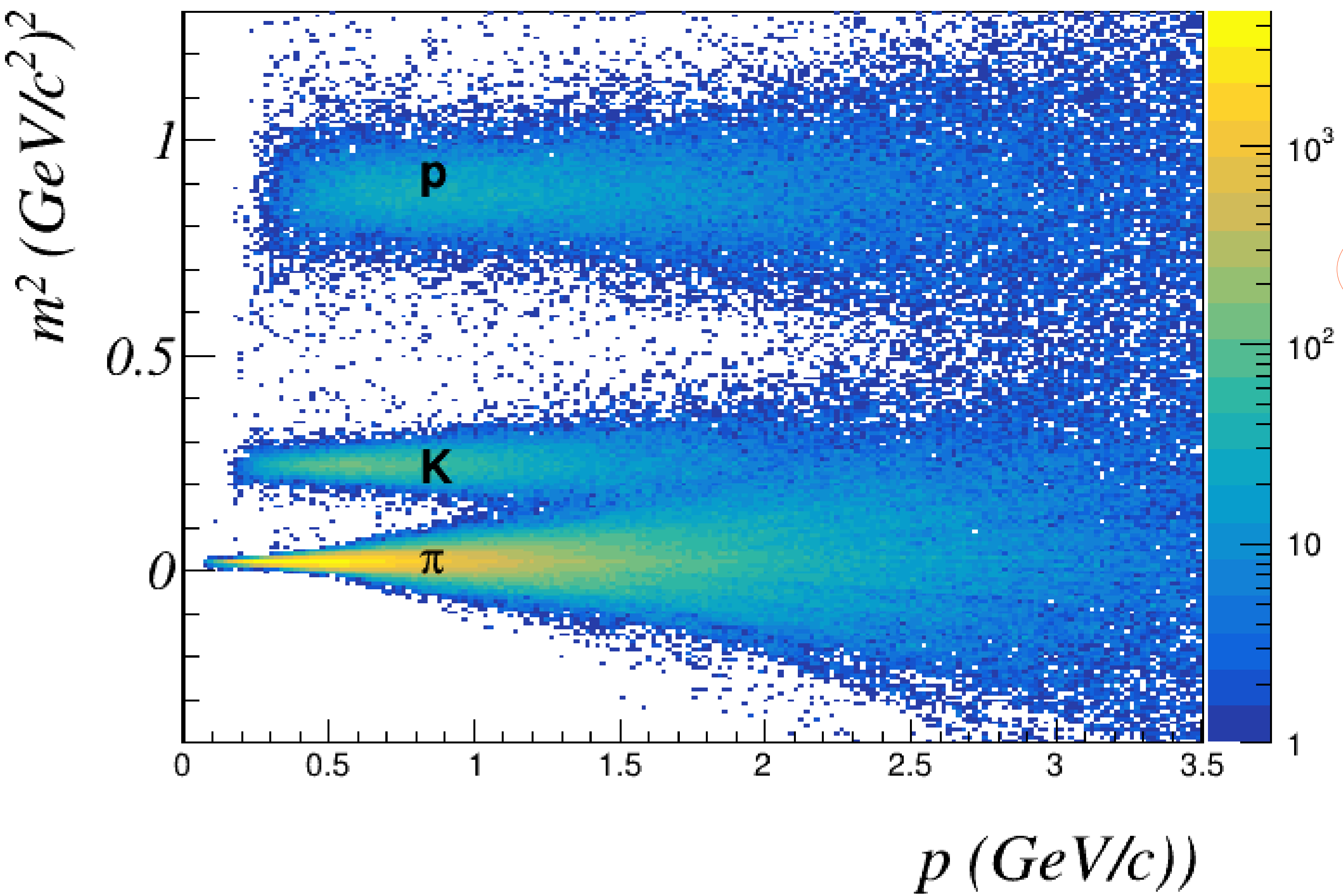
from reconstruction

$\sigma = \sigma_{TOF} = 60\,ns$

fixed

Minimum bias *pp* 27 *GeV* events were generated (SimuQslPy8.C)

Momentum dependence of m^2 distribution



$\frac{p_{rc} + p_{rc,\,last\ point}}{2}$

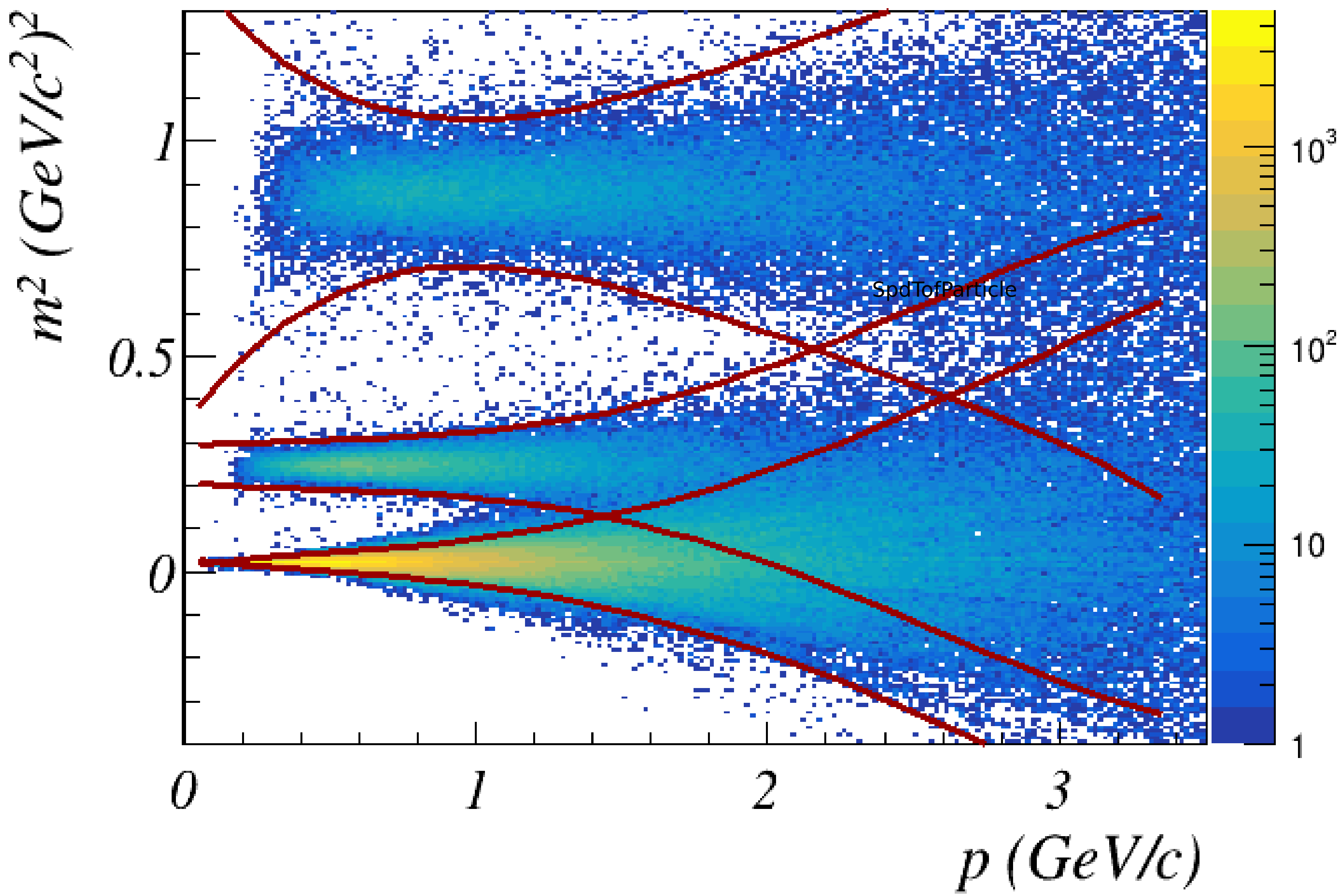
$t = gaus(t_{TOF}, 60)$

$$m^2 = \frac{p^2}{c^2}\left[\frac{t^2 c^2}{L^2} - 1\right]$$

Momentum dependence of m^2 distribution

Red lines depict 3σ bands

$$P(m^2) = \frac{1}{\sqrt{2\pi}\,\sigma(p)} e^{\frac{-(m^2_{TOF} - m^2_{fit})^2}{2\cdot\sigma(p)^2}}$$



Momentum dependence of m^2 *distribution*