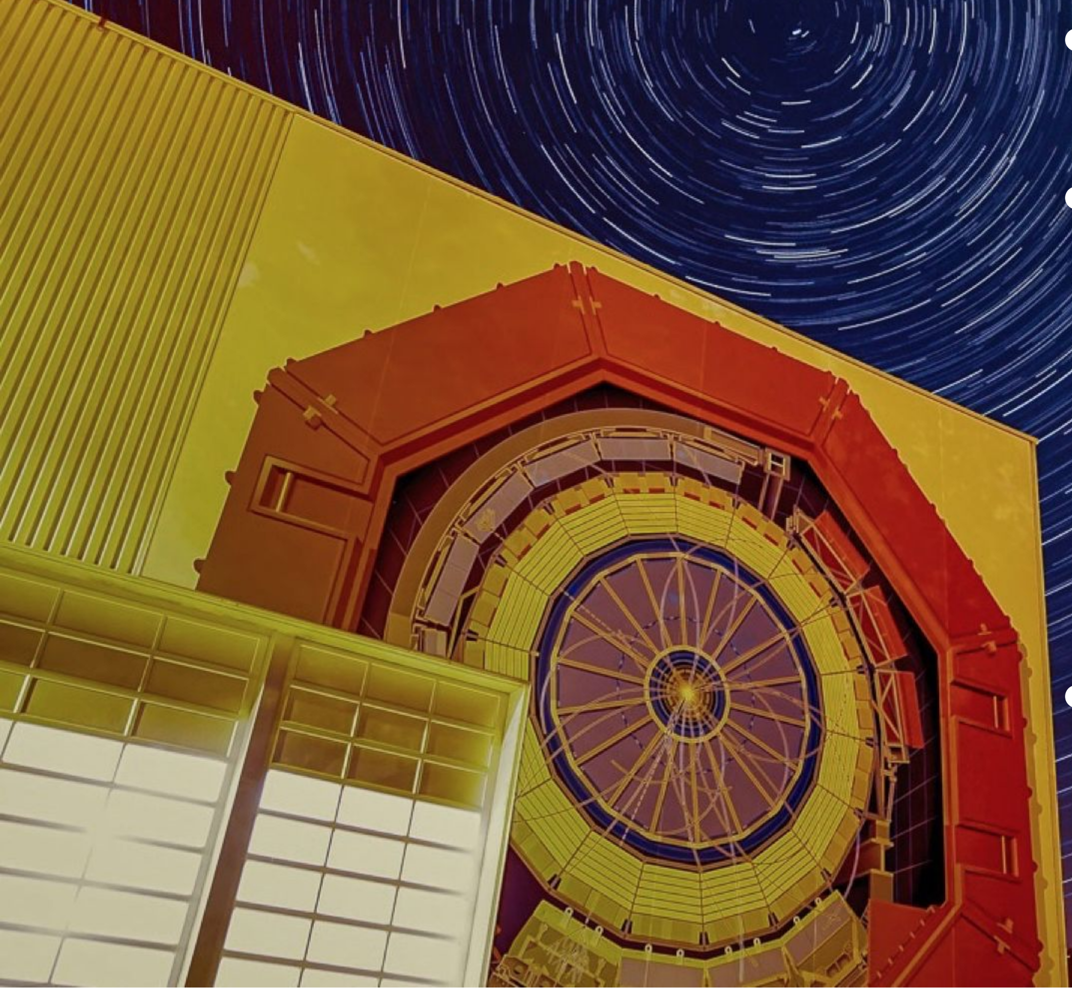
The ALICE experiment at the LHC

Cristiane Jahnke
for the ALICE Brazil group

Outline

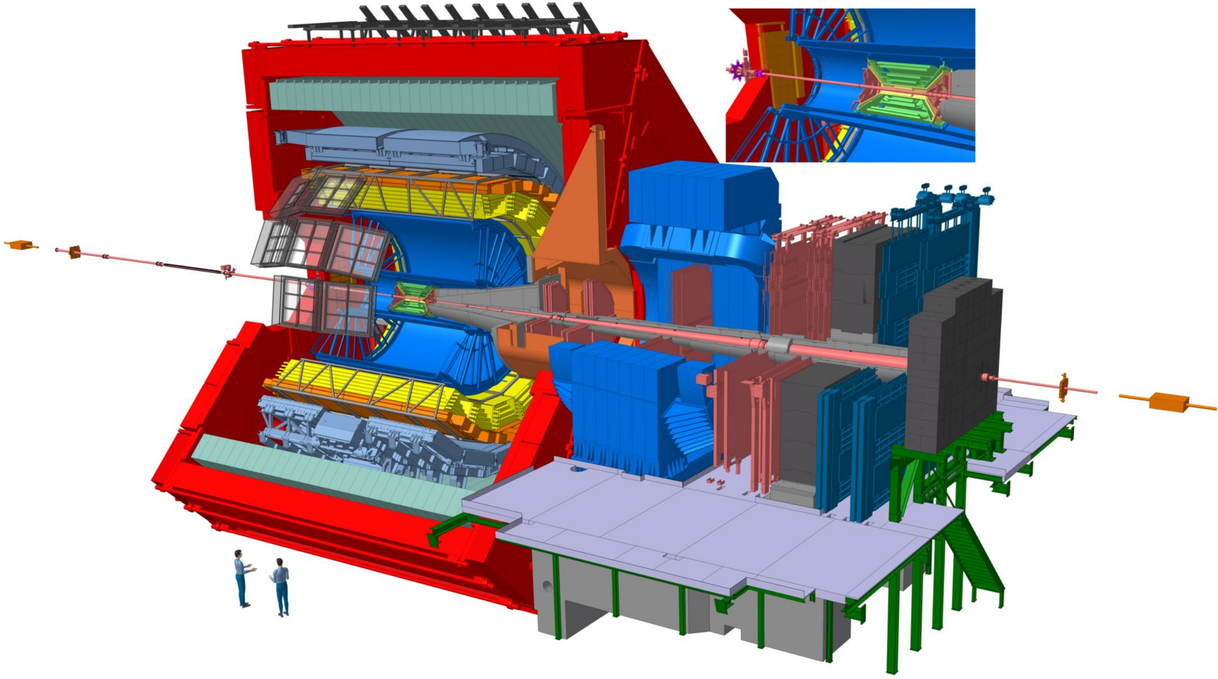


- ALICE
    - Collisions systems
    - Brazil in ALICE
- Highlights of scientific results
    - Jet quenching and heavy flavour
    - Anisotropic flow
    - Quarkonia
        - Cross section
        - Multiplicity dependence
        - Ultra-peripheral collisions
    - Machine learning
        - pile-up rejection
        - strangeness reconstruction
- ALICE future perspectives
    - Run 3 upgrades
    - Run 4 upgrades
    - ALICE 3

ALICE

- Optimized to study collisions of nuclei at ultra-relativistic energies
  - 40 countries
  - 170 institutes
  - 1972 members

- The study of matter under extreme conditions:
  - Quark-gluon plasma (QGP) characterization
  - Emergent QCD phenomena



Int. J. Mod. Phys. A 29 (2014) 1430044
JINST3 S08002

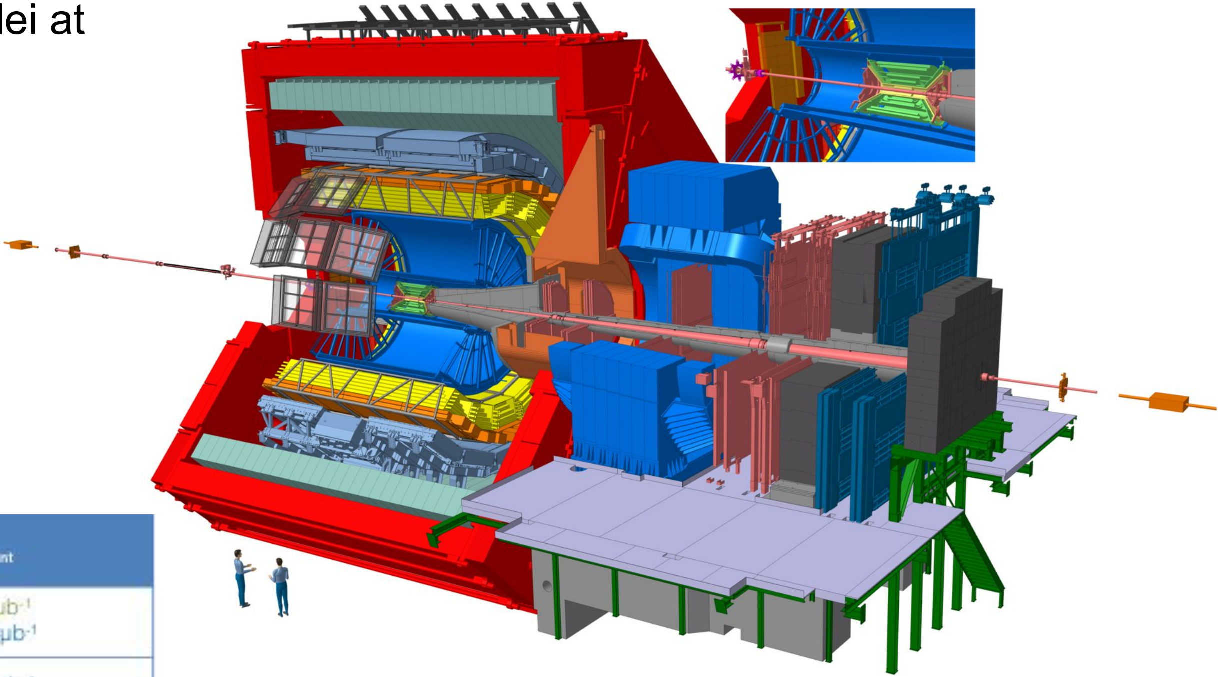
ALICE

Optimized to study collisions of nuclei at ultra-relativistic energies

Midrapidity ($|\eta| < 0.9$):

Electromagnetic Calorimeter
Time of Flight
Transition radiation detector
Time Projection Chamber
Inner Tracking System

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010, 2011 2015, 2018	2.76 5.02	75 μb^{-1} 800 μb^{-1}
Xe-Xe	2017	5.44	0.3 μb^{-1}
p-Pb	2013 2016	5.02 5.02, 8.16	15 nb^{-1} 3 nb^{-1}, 25 nb^{-1}
pp	2009-2013 2015, 2017 2015-2018	0.9, 2.76, 7, 8 5.02 13	200 μb^{-1}, 100 nb^{-1} 1.5 pb^{-1}, 2.5 pb^{-1} 1.3 pb^{-1} 36 pb^{-1}



Forward rapidity ($-4 < \eta < -2.5$)
Muon tracking and trigger

Int. J. Mod. Phys. A 29 (2014) 1430044
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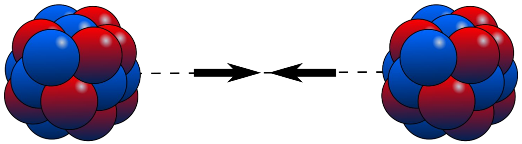
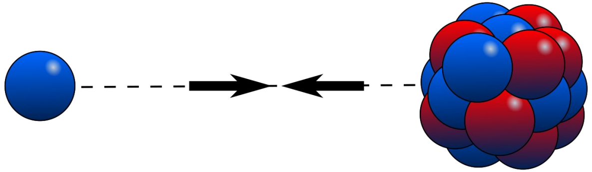
Collision systems



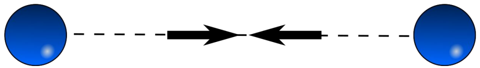
- Pb–Pb / Xe–Xe collisions:
  - QGP formation and its properties
    - Equation-of-state, transport coefficients...
  - In-medium energy loss
    - Colour-charge and quark-mass dependence / Thermalisation
    - Quarkonium dissociation and/or regeneration
  - Ultra-peripheral collisions

- p–Pb collisions:
  - Cold nuclear matter effects can be studied:
    - Nuclear modification of parton densities
    - Propagation in nucleus and in medium



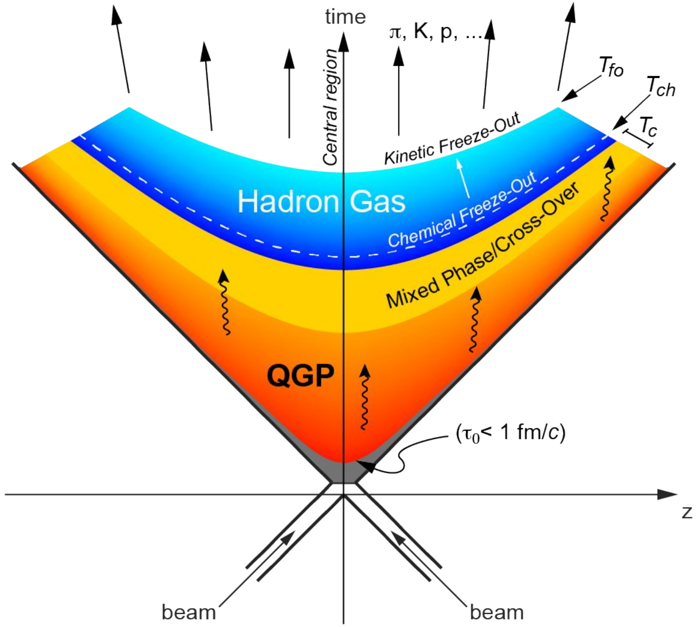
- pp collisions:
  - Reference for studies with p–Pb collisions and Pb–Pb/Xe–Xe collisions
  - Studies of several aspects of QCD

- pp and p–Pb collisions:
  - Look for possible collective behaviour in small systems



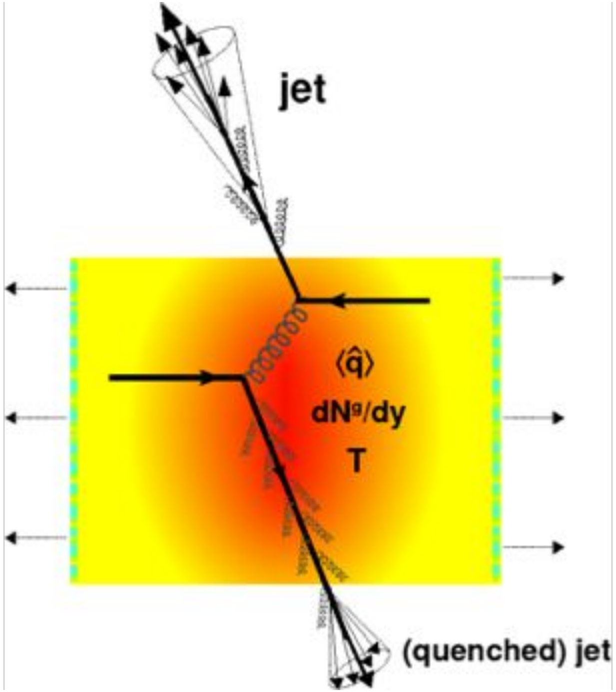
Brazil in ALICE

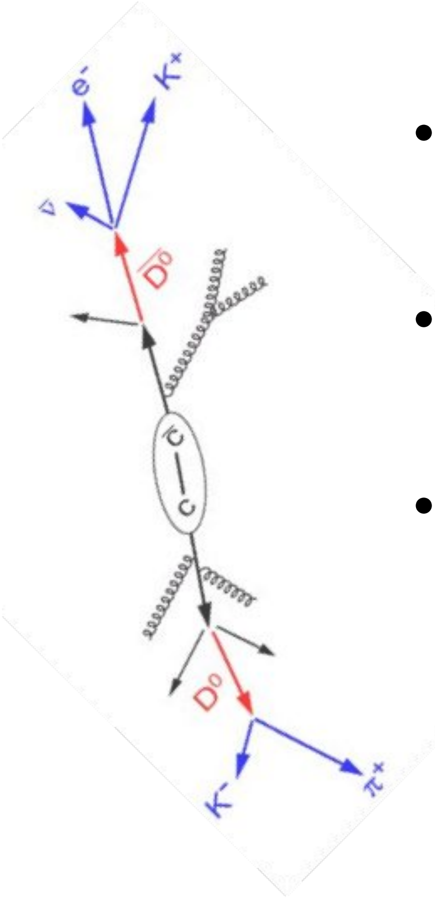
- Contribute to the study of the Quark-Gluon Plasma through a relevant participation in the **ALICE** experiment
  - Physics analysis
  - Development of state-of-the-art instrumentation
- Current Man power
  - 4 Institutes
  - 10 faculty researchers + 1 postdoc (1.75% of ALICE)
  - 12 PhD thesis defended + 6 PhD active students (1.4% of ALICE)



USP UNICAMP UFABC UFRGS

Jet Quenching and Heavy Flavour





- Hard scattering of partons during the collision
- Excellent probe of the medium properties due to energy loss
- Heavy quarks of special interest since they are produced at the early stages of the collision

Jet Quenching and Heavy Flavour

$$R_{\mathrm{AA}} = \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{AA}}\rangle \mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

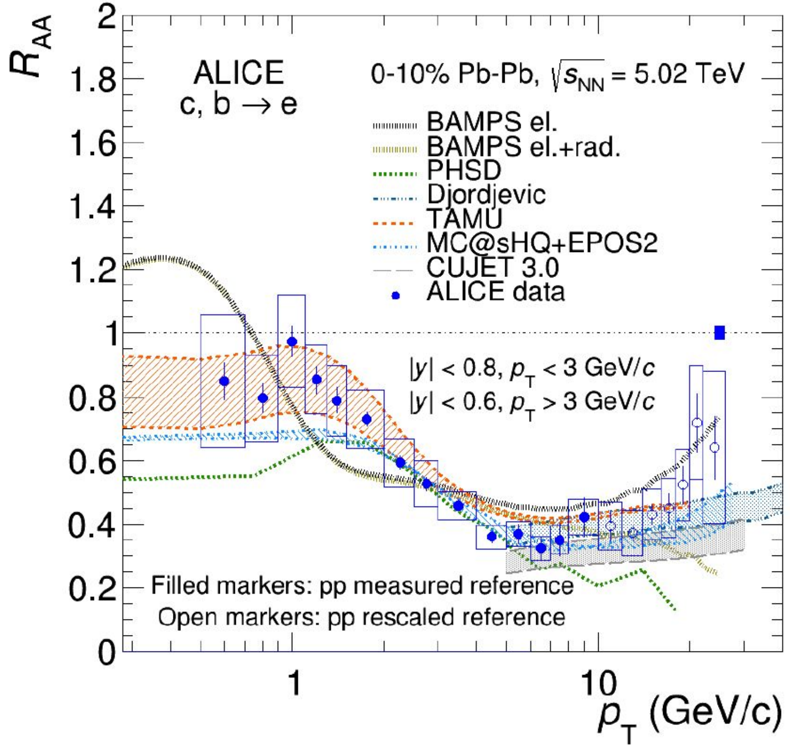
- If R_{AA} = 1 (at high p_T): no hot medium effects and no cold nuclear matter effects.
- If R_{AA} < 1 : hot or cold nuclear matter effects.

- The energy loss is expected to depend on the parton colour-charge, parton mass and path length.

ΔE(g,u,d,s) > ΔE(c) > ΔE(b)

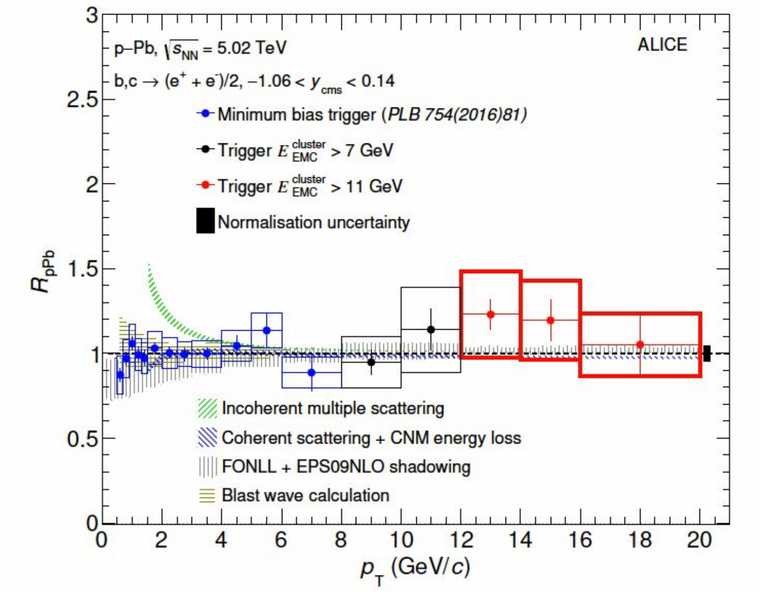
$R_{AA}(\pi)$ < R_{AA}(D) < R_{AA}(B)

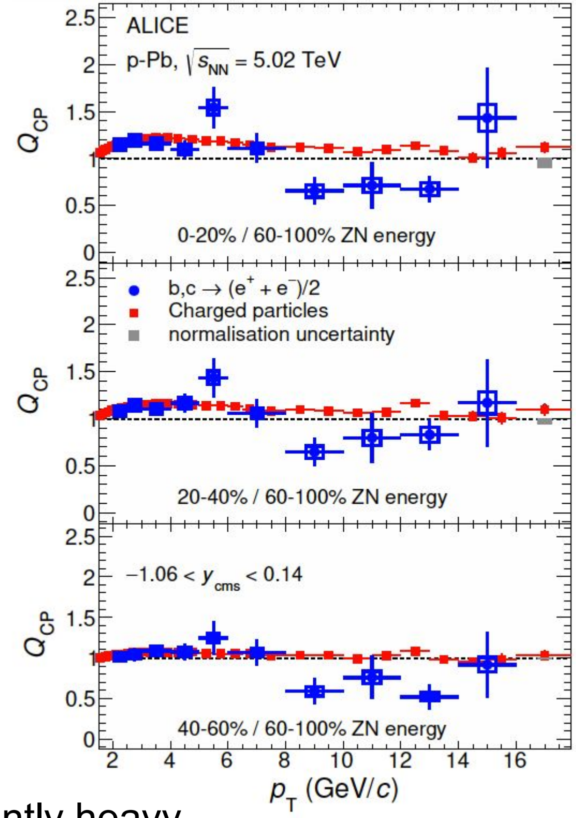
- Electrons from Heavy Flavor in **Pb-Pb collisions**
- Clear evidence of medium interaction
- Several models compatible with the results



PLB 804 (2020) 135377

Jet Quenching and Heavy Flavour





- Electrons from heavy quarks in **p-Pb collisions**
- Consistent with unity
  - binary scaling
- Cold Nuclear Matter effects do not modify significantly heavy quarks production at mid rapidity

JHEP02 (2020) 077

Anisotropic Flow

$$E\frac{d^3N}{dp_T^3} = \frac{d^3N}{p_T d\phi dp_T dy}\sum_{n=0}^{\infty} 2v_n cos[n(\phi - \Phi_R)]$$

- Anisotropic flow is caused by the initial asymmetries in the geometry of the system produced in a non-central collision.
  - Initial spatial anisotropy of the created particles is converted in momentum anisotropy due to the pressure gradients.
- v_2: indicates collective motion and thermalization
- v_3: event-by-event fluctuations

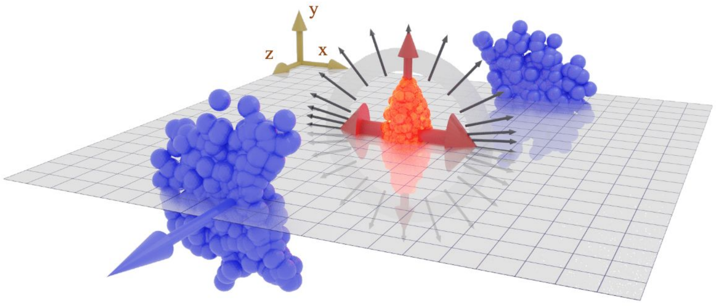
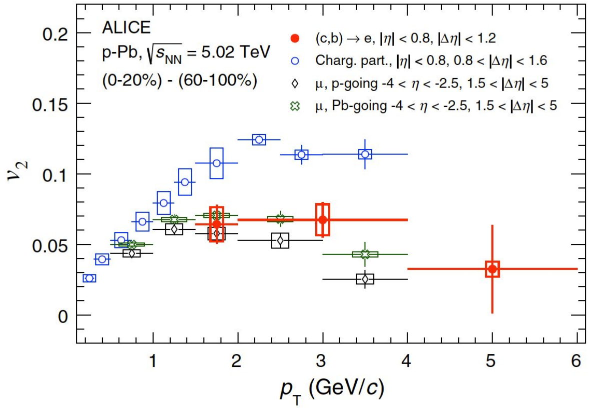


Figure from David Chinellato

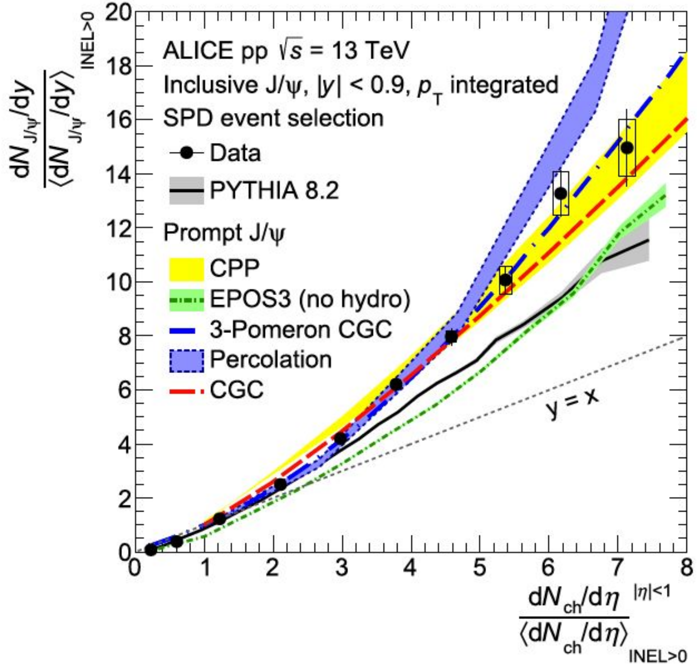


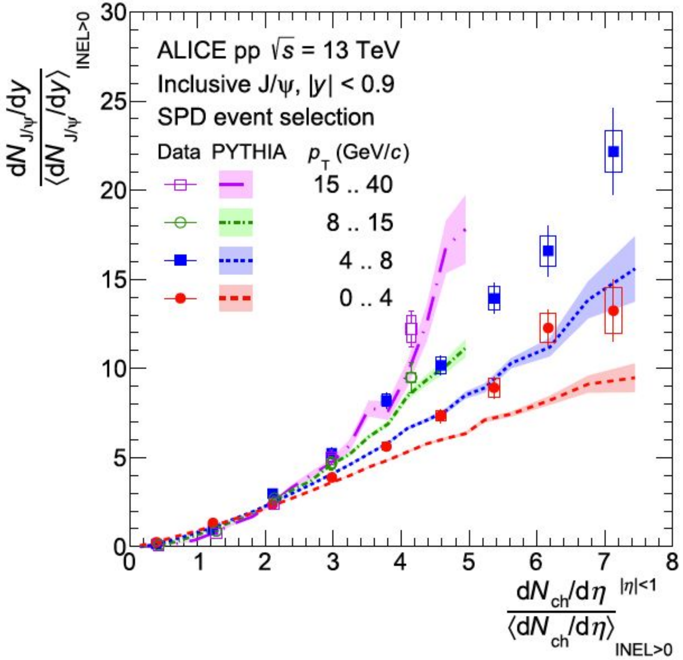
Phys. Rev. Lett. 122, 072301 (2019)

- Despite no evidence of suppression of heavy flavor in **p-Pb collisions**, v_2 of electrons from heavy flavor was measured in these collisions.
  - Effect is qualitatively similar to the one observed for light flavors
- Key to understand small systems.

J/ψ vs. multiplicity

Phys. Lett. B 810 (2020) 135758





- J/ψ self normalized yield
  - Increase faster than linear
    - Enhancement qualitatively described by several model calculations
      - Higher enhancement for higher p_T
      - PYTHIA8 which includes multi-parton interactions describes qualitatively the p_T dependence

J/ψ cross section

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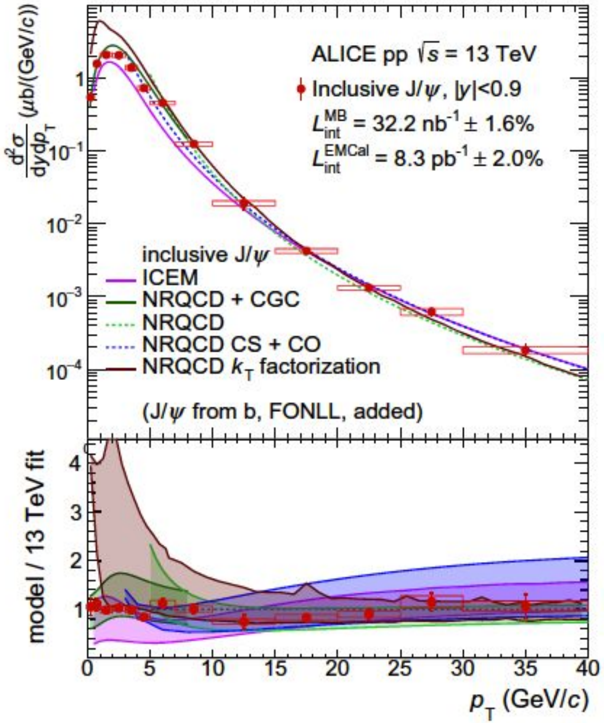
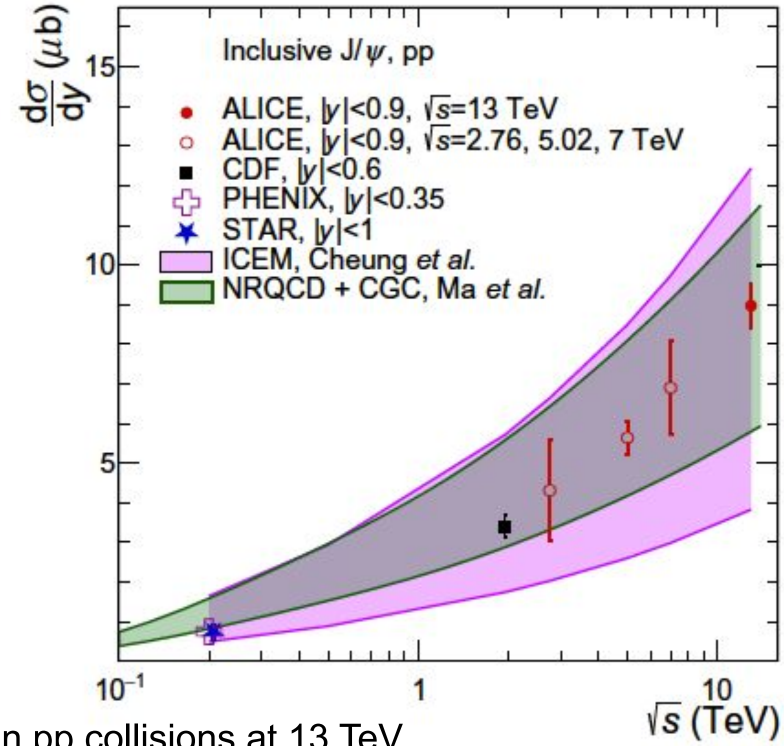
Eur. Phys. J. C 81 (2021) 1121





- Inclusive J/ψ production cross section in pp collisions at 13 TeV
- The p_T-integrated J/ψ production cross section at midrapidity was calculated;
  - An approximate logarithmic dependence with the collision energy is suggested in agreement with model predictions.

Ultra peripheral collisions

The Effective Photon Flow

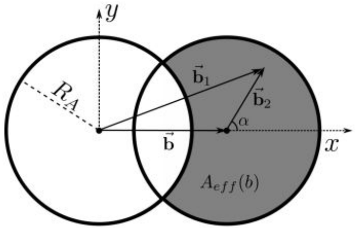
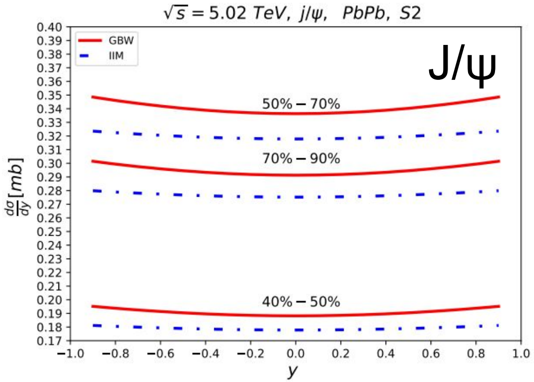
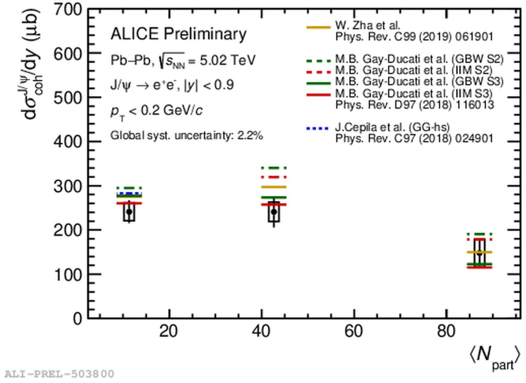


Fig. 1: Scheme of the interaction according to scenario 2.



- From the standard photon flux (N^{usual}) emitted by the projectile nucleus, only the photons that reach the geometric region of the target nucleus will be considered;
- Photons that reach the nuclear superposition region will be discarded (dominated by the strong interaction).



effective photon flow:

$$N^{eff}(\omega, b) = \int N^{usual}(\omega, b_1)\frac{\theta(b_1 - R_A)\theta(R_A - b_2)}{A_{eff}(b)} d^2 b_2$$

spectators area:

$$A_{eff}(b) = R_A^2\left[\pi - 2\cos^{-1}\left(\frac{b}{2R_A}\right)\right] + \frac{b}{2}\sqrt{4R_A^2 - b^2}$$

Ultra peripheral collisions

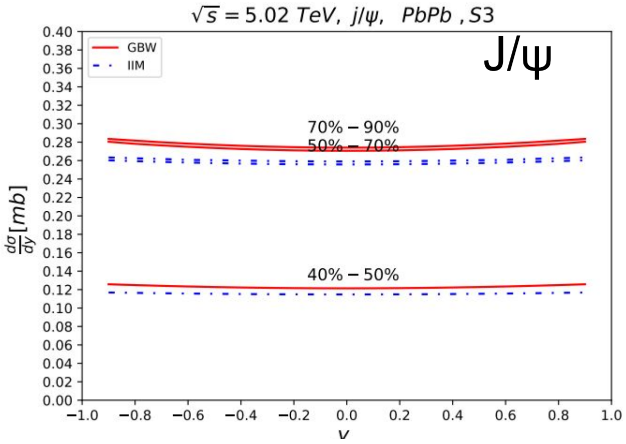
The effective photonuclear cross section

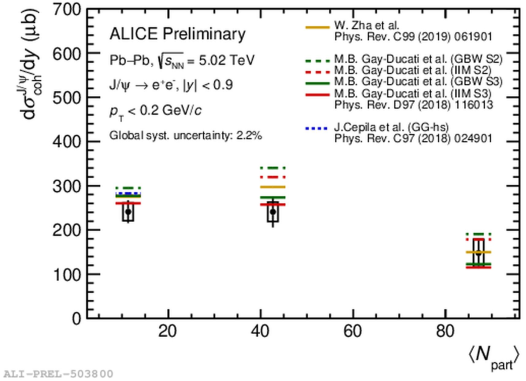
- Applying the same geometric constraint on the photonuclear cross section.
  - The dipole-core interaction will be restricted to only the dipole interaction with the part of the core that forms the spectator region

$$\sigma_{\rm dip}^{\rm nucleus}(x,r) = 2\int d^2b_2\Theta(b_1-R_A)\left\{1-\exp\left[-\frac{1}{2}T_A(b)\sigma_{\rm dip}^{\rm proton}(x,r)\right]\right\}$$

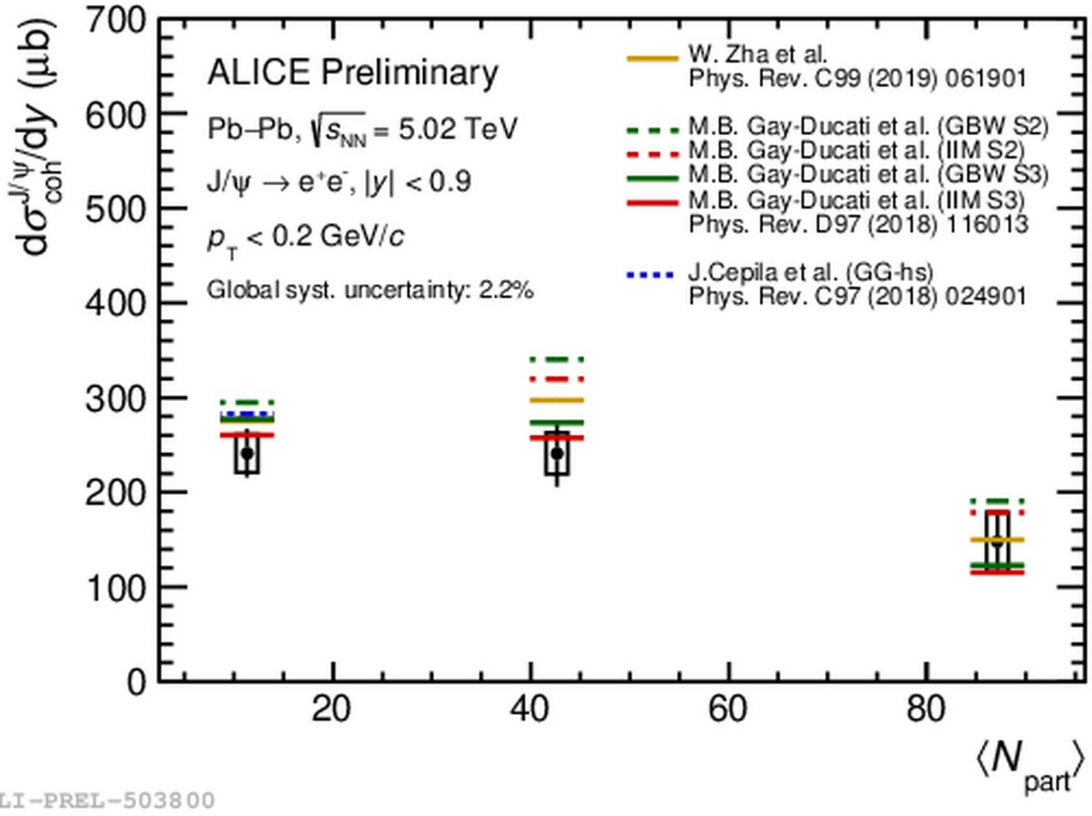
$$b_1^2 = b^2 + b_2^2 + 2bb_2\cos(\alpha)$$

➢ Effective photon flux and an effective photonuclear cross section





Ultra peripheral collisions



Results obtained the dipole cross section of

- Golec-Biernat Wüsthoff (GBW) and
- Iancu, Itakura e Munier (IIM)

Machine Learning applied to pileup rejection

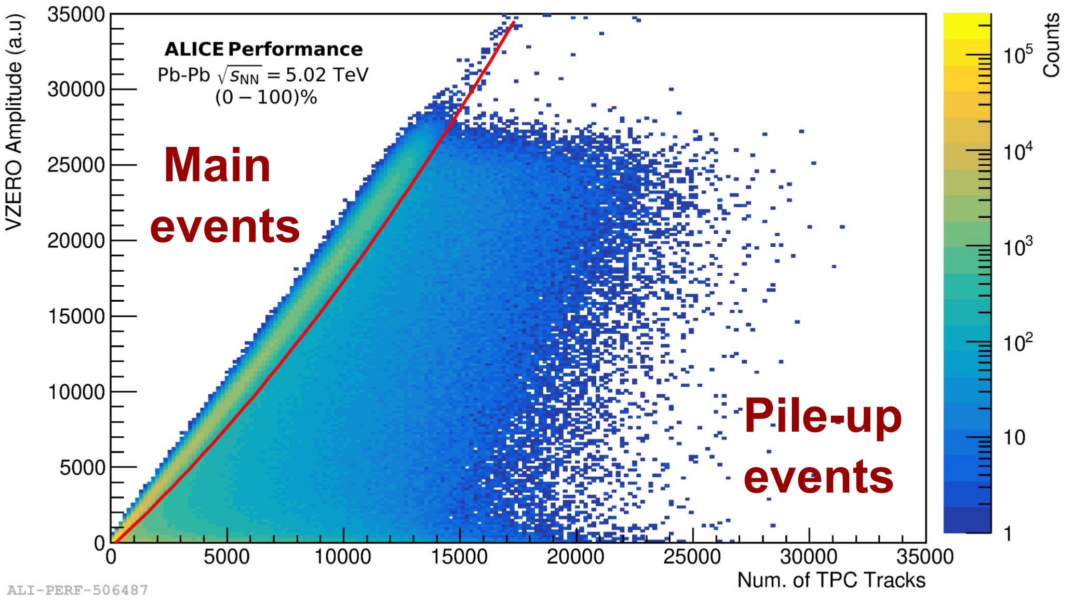
Standard Selection:

- **Cuts on correlations:**
  - TPC and V0 detectors
  - Quadratic polynomial
  - Rejects ~ 63% of pile-up events
  - Keeps ~ 100% of main events

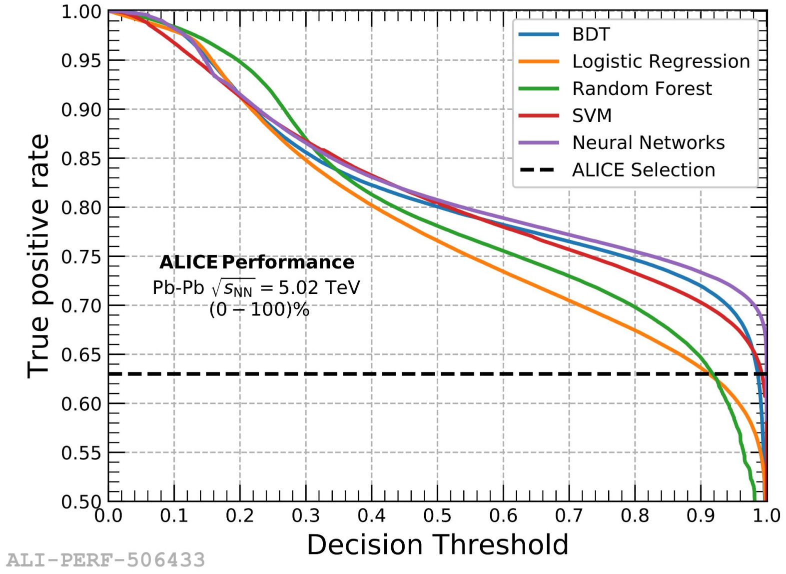
ML Analysis:

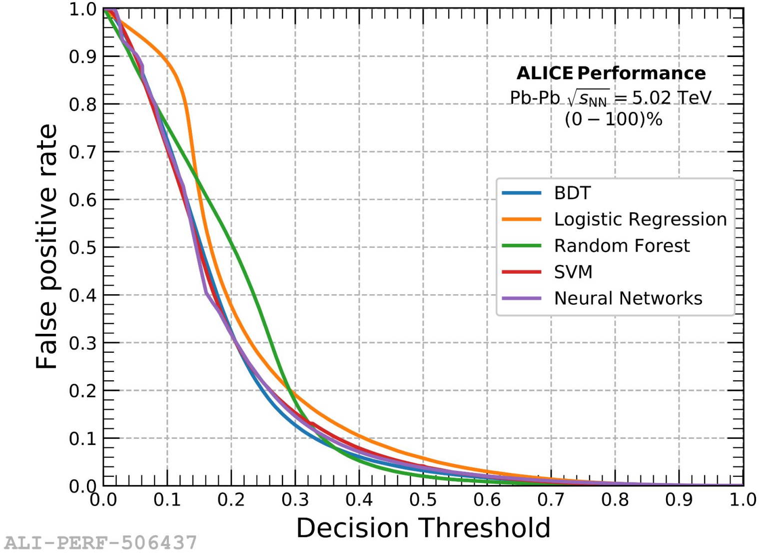
- ML techniques predict the probability of an event being a pile-up event
- Use signals from different detectors:
  - ITS, V0, and TPC

$3.4 \times 10^{-5}x^2 + 1.42x - 300$



Machine Learning applied to pileup rejection



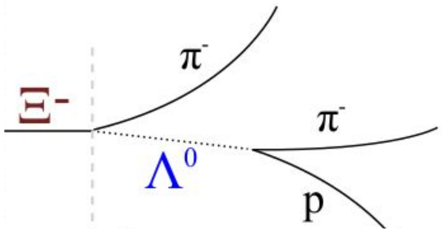


- True Positive Rate and the False Positive Rate as a function of the Decision Threshold.
- The standard event selection is presented as a constant line at 0.63.
- For a Decision Threshold value greater than 0.7:
  - All models show an improvement with relation to the standard selection
  - False Positive Rate tends to zero

Machine Learning applied to strangeness reconstruction

Standard Selection:

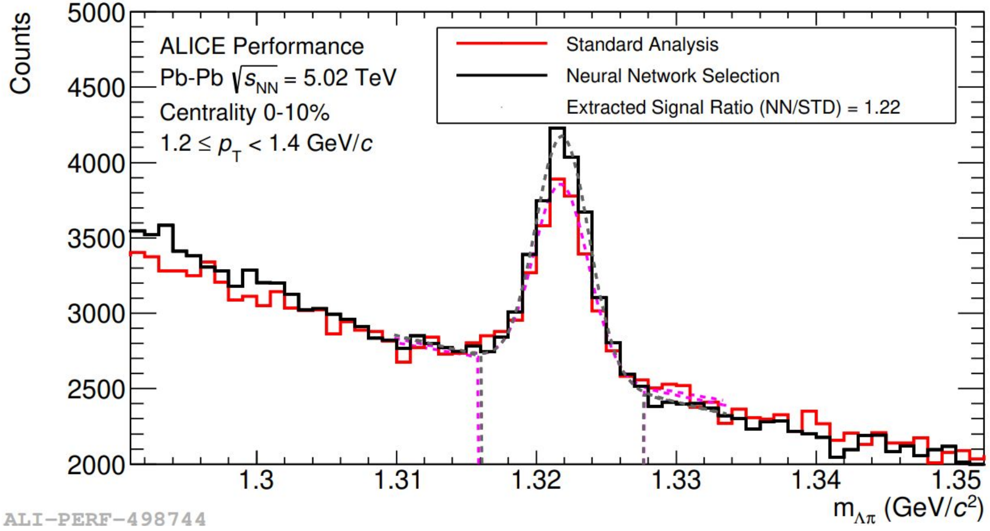
- **Topological cuts:**
  - Cascade decay



ML Analysis:

- Neural Network predicts the probability of three given candidate tracks being the product of a *Ξ* decay.

- Selection in a probability threshold indicates simultaneous gain in efficiency and significance.



ALICE future perspectives

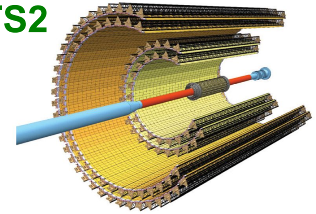
2021	LS2
2022	
2023	Run 3
2024	
2025	
2026	LS3
2027	
2028	
2029	Run 4
2030	
2031	LS4
2032	
2033	Run 5

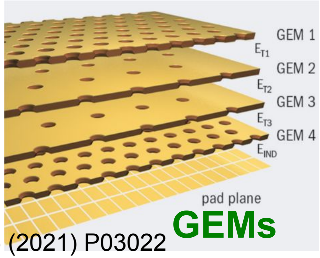
ALICE 2:

- new readout for all detectors
- new TPC readout (GEMs)
- new Fast Interaction Trigger (FIT)
- new silicon trackers (MFT & ITS2)
- new online/offline system (O^2)

J. Phys. G 41 (2014) 087002

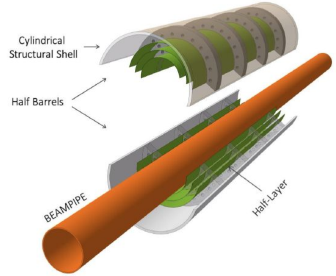
ITS2





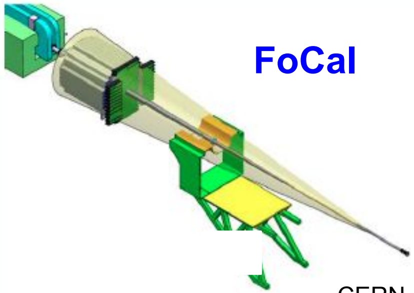
JINST 16 (2021) P03022

GEMs



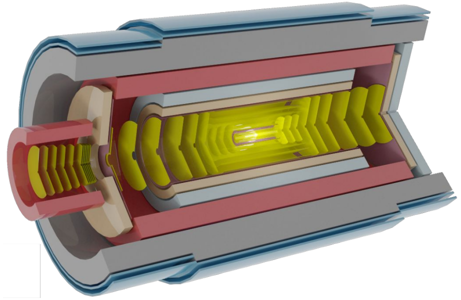
ITS3

ALICE-PUBLIC-2018-013



FoCal

CERN-LHCC-2020-009



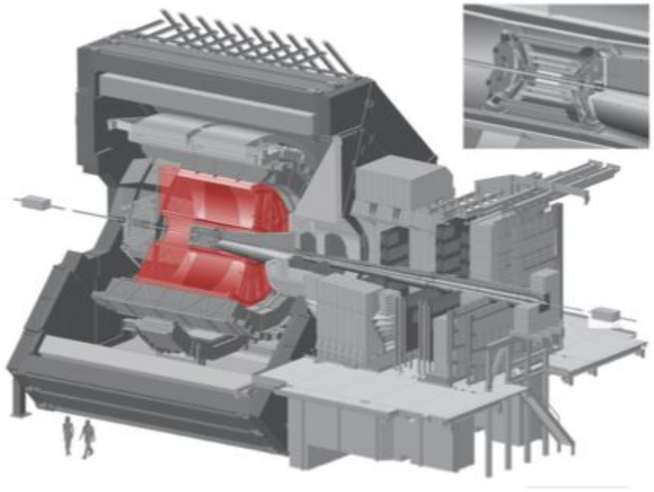
ALICE 3

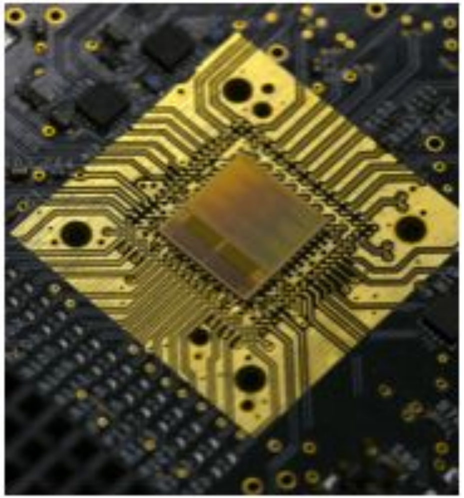
arXiv:1902.01211v2

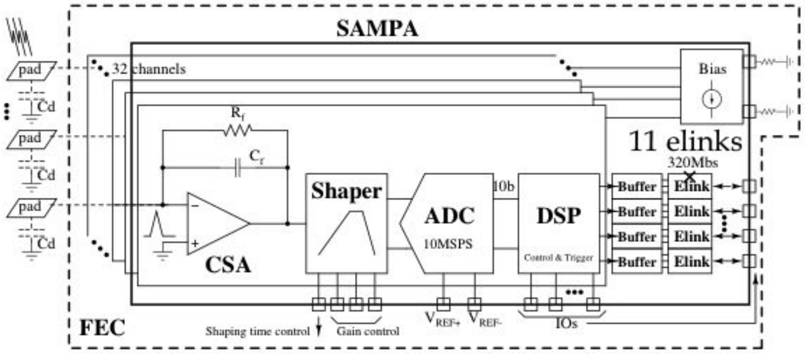
Letter of intent:
https://cds.cern.ch/record/2803563

ALICE upgrade: SAMPA chip

- Fully built in Brazil
- TPC and MCH readout
- A 32 input channels in 0.82 cm^2
- Combines analogic and digital functionalities in the same chip
- Continuous readout

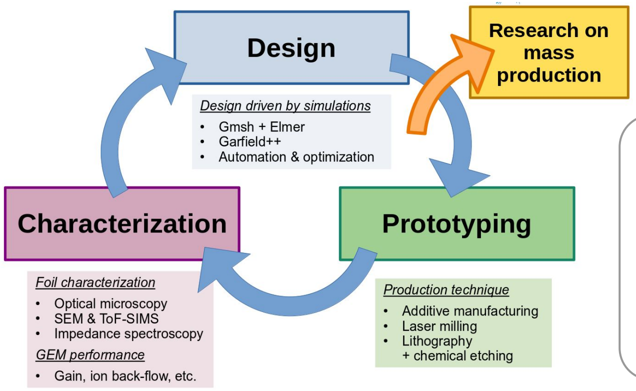


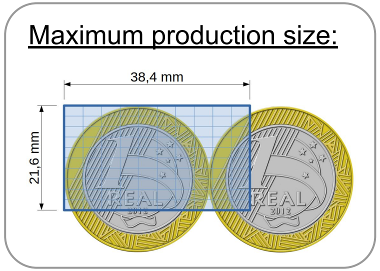


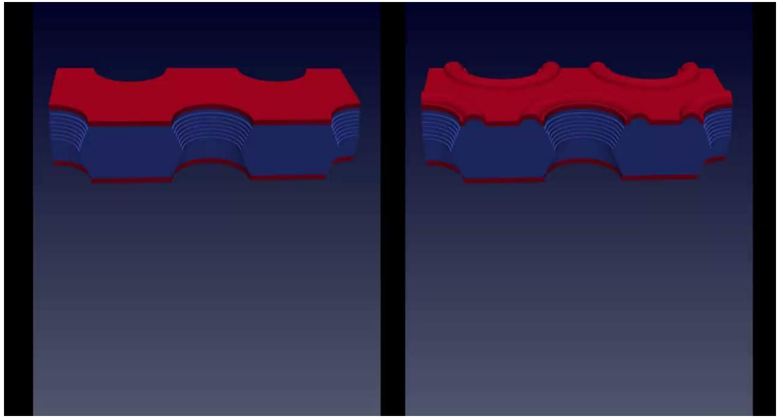


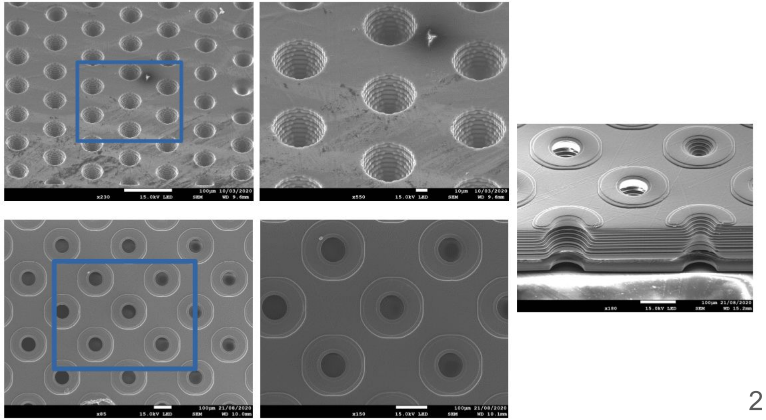
ALICE upgrade:
3D printing of MPGDs

Goal: Enable fast prototyping for tests of new geometries. Smooth integration between modeling and tests.









Challenges: Multi-material printing in high-resolution.

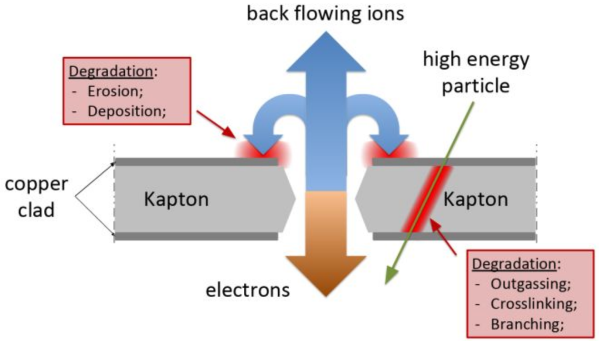
Partners: Univ. of Nottingham and NPL.

Motivation: Suppression of charging up, ion backflow and mitigation of degradation.

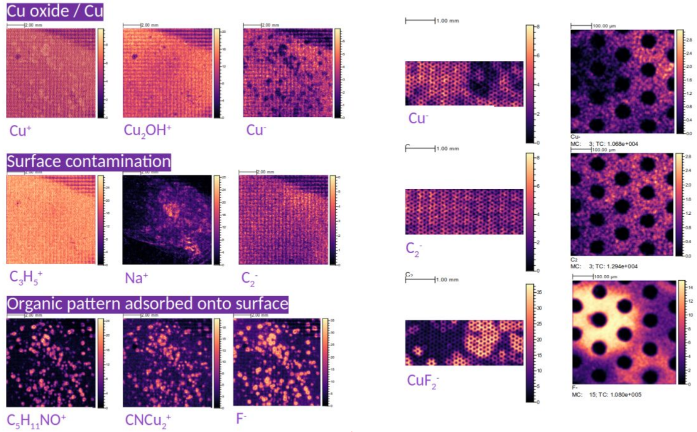
Research leader: Prof. Dr. Tiago F. da Silva

ALICE upgrade: GEM aging and degradation studies

Goal: Develop a deeper understanding on aging and degradation processes of Gas Electron Multipliers (GEMs).

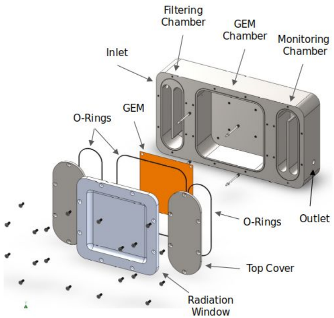


Challenges: Definition of controlled environment
Partners: Univ. of Nottingham and NPL.
Motivation: Enable longer lifetime and stability.
Innovation: Use of advanced surface analysis.
Research leader: Prof. Dr. Tiago F. da Silva

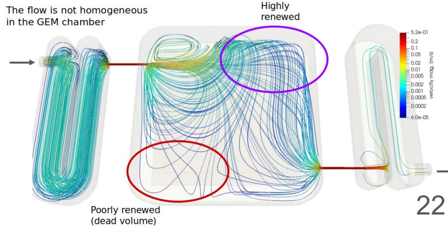


Evidence of kapton redeposition!

Design of degradation chamber:

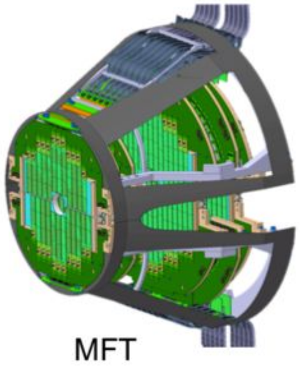


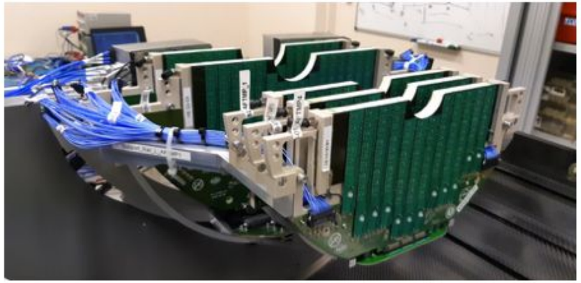
Gas flow simulation:

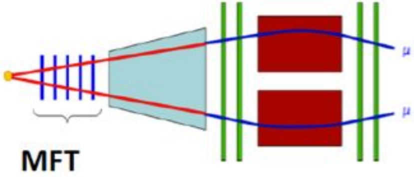


ALICE upgrade: Muon Forward Tracker

- Muon Forward Tracker (MFT)
  - A new high-resolution Si tracker (2.5 < η < 3.6)
  - Adds precise vertexing capabilities to muon tracking at forward rapidity
- Brazilian contribution:
  - Mechanical Infrastructure
  - Software development (O2)

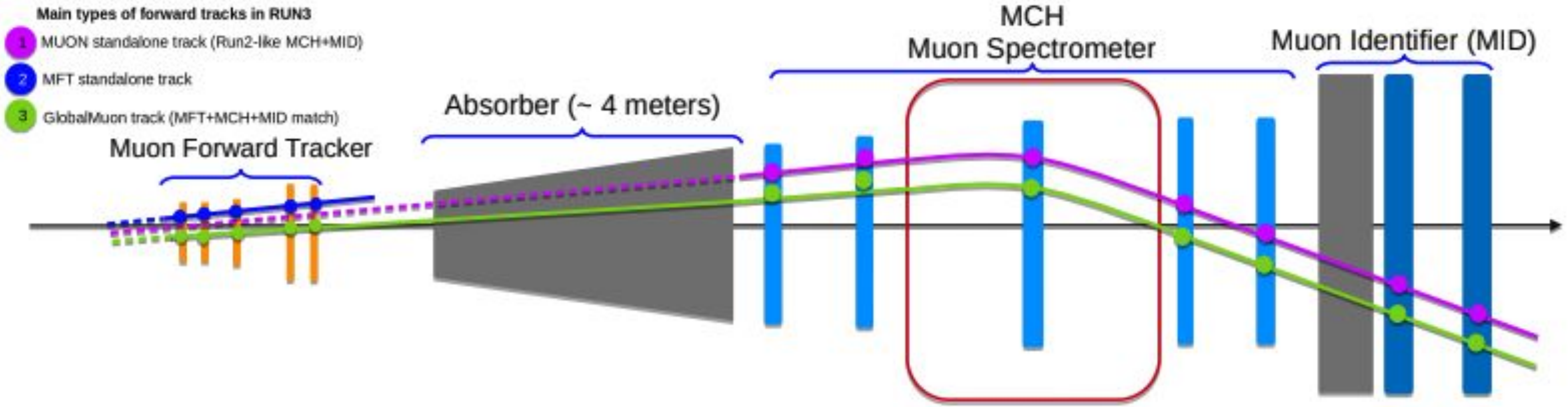






ALICE upgrade: Muon Forward Tracker

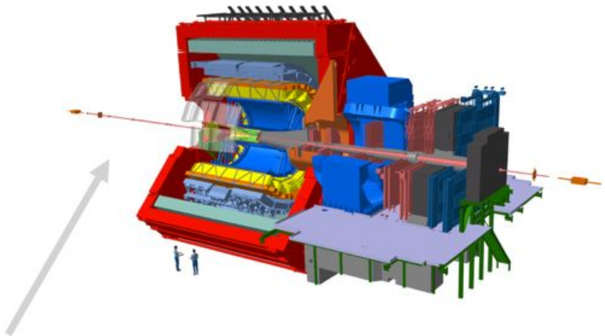
- MFT Standalone
  - Pre alignment geometry using pilot beam data
  - Reconstruction
- Global Forward Matching (MFT-MCH-MID)



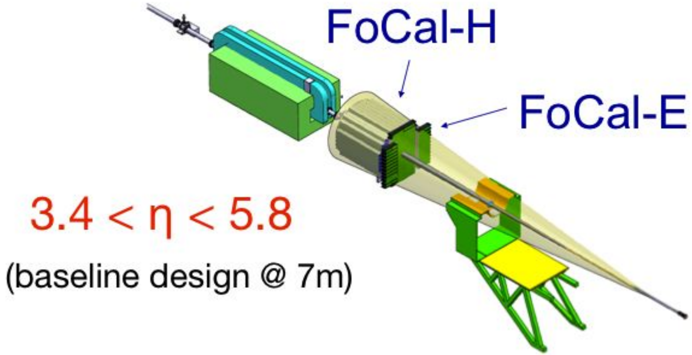
ALICE upgrade: FoCal (Run 4 - 2027)

FoCal: a highly granular Si+W electromagnetic calorimeter (FoCal-E: photons and π^0) combined with a conventional sampling hadronic calorimeter (FoCal-H : photon isolation)

- Unique capabilities to measure small-x gluon distributions via prompt photon production
- Measurements with mesons, photons, and jets to explore the dynamics of hadronic matter at small x down to $\sim 10^{-6}$



- Brazilian Hardware contribution:
  - Contribute to electronics of Pad Si layers
- First common project of all Brazilian groups in ALICE!



ALICE upgrade: ALICE 3 (Run 5 - 2032+)

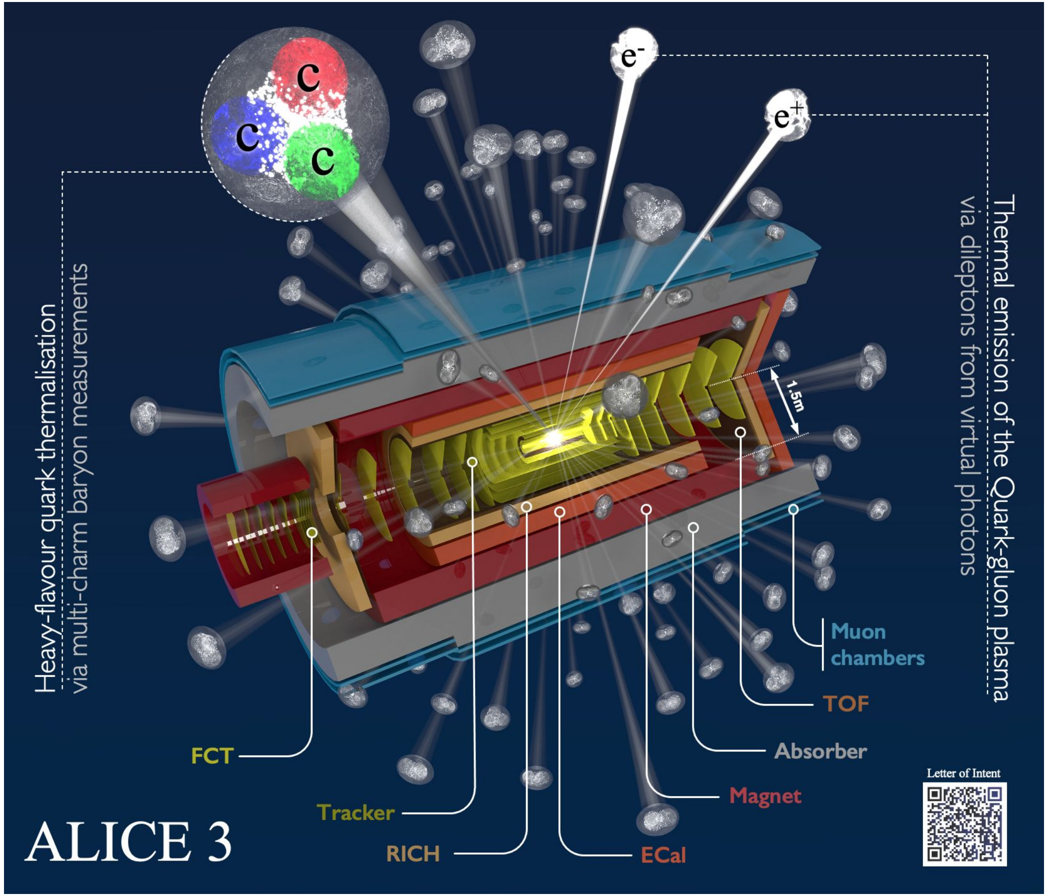


Figure from David Chinellato

- ➔ Compact all-silicon tracker with high-resolution vertex detector
- ➔ Superconducting magnet system
- ➔ Particle identification over large acceptance
- ➔ Fast readout and online processing

- Studies of A–A collisions at luminosities a factor of 5-10 times higher than possible now.

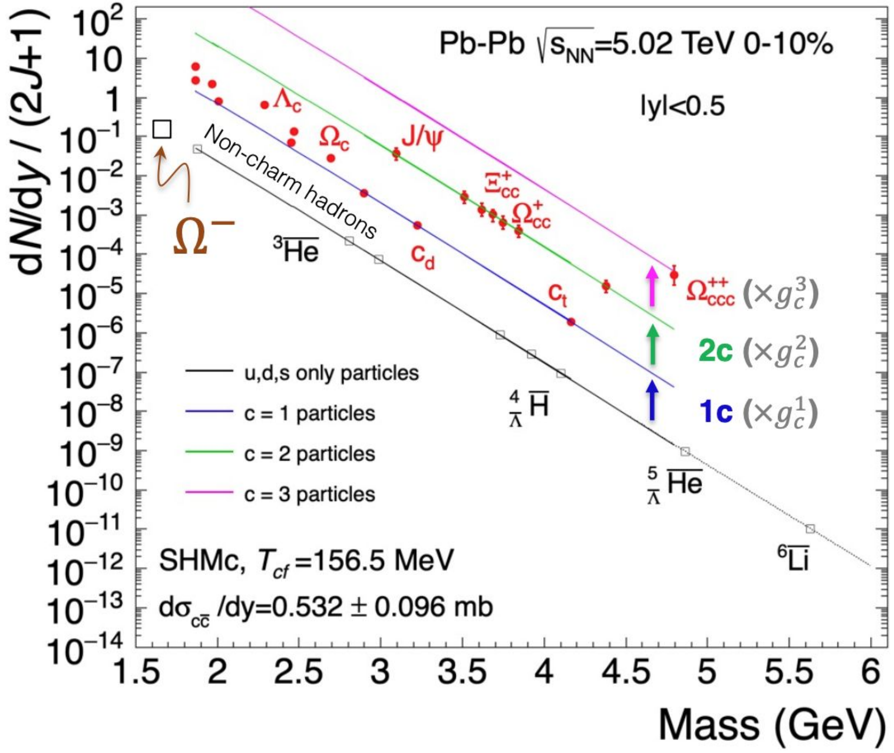
- The excellent timing resolution (≈ 20 ps) will provide particle identification information.

- Ultrasoft region of phase space
  - Production of very low transverse momentum lepton pairs, photons and hadrons.
  - Heavy-flavour, quarkonia, multi-charm hadrons
  - Low-mass dileptons
  - Soft and ultra-soft photons

Letter of intent:
https://cds.cern.ch/record/2803563

ALICE upgrade: ALICE 3 (Run 5 - 2032+)

Multi-charm baryons: key insight into charm production and hadronization

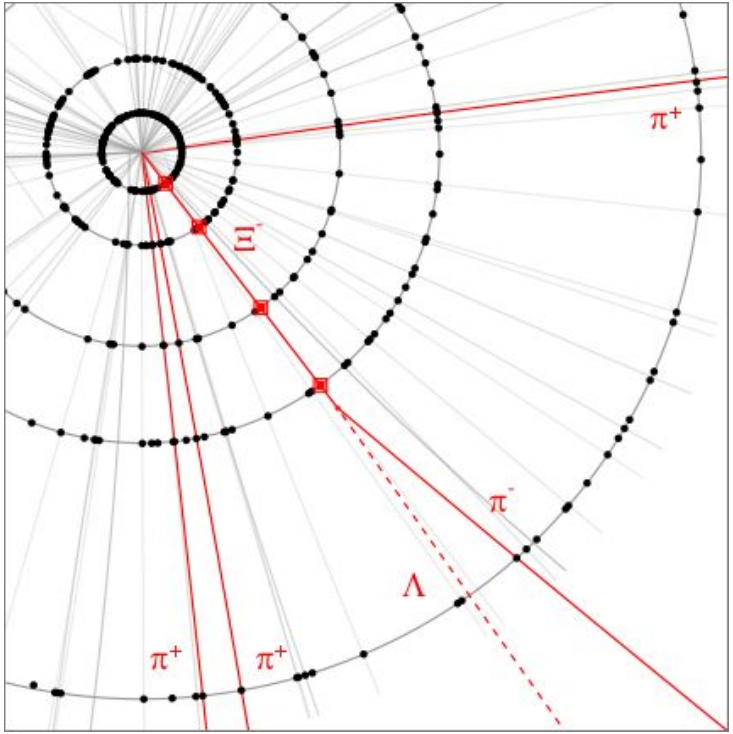


What is the advantage of multi-charm baryons measurements, compared with the measurements of multi-strange baryons?

- Non-charm: mass exponential hierarchy, dominated by quarks created at phase boundary (e.g. Ω^-)
- Charm: produced at the beginning of the collisions with fixed abundances
  - According to SHMc: still an exponential with mass but exponential displaced by g_c^n

ALICE upgrade: ALICE 3 (Run 5 - 2032+)

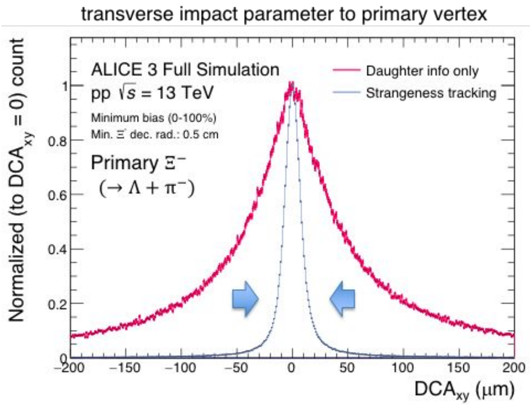
Multi-charm baryons: key insight into charm production and hadronization



Strangeness tracking:

- Decay products is used to determine momenta and decay point
- Ξ- hits used to determine the trajectory
  - backward propagation from daughters

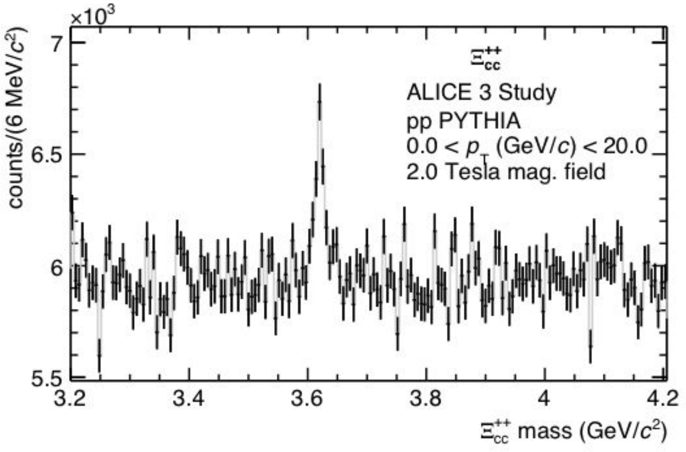
❖ Momentum precision from daughter tracks (~ 80 cm)
❖ Spatial precision from primary particle hits



Figures from David Chinellato

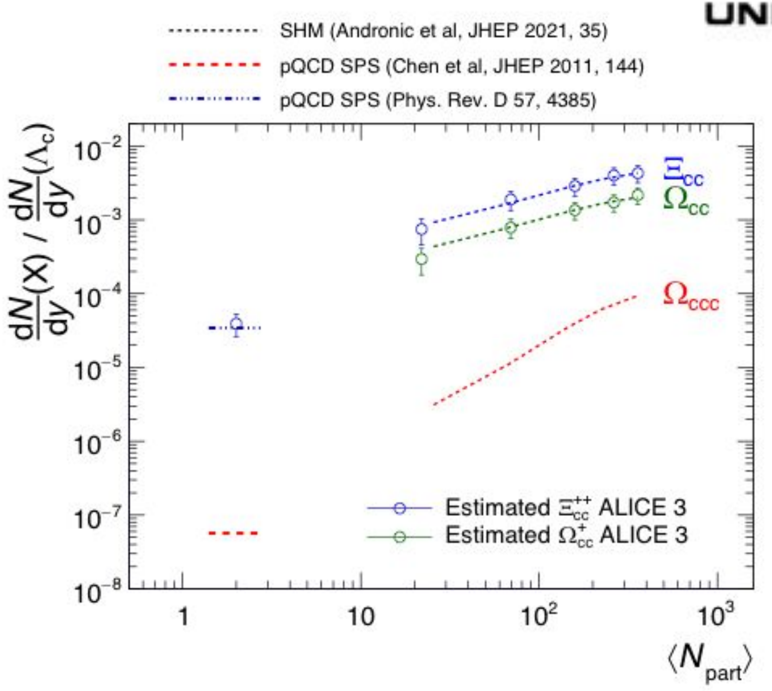
ALICE upgrade: ALICE 3 (Run 5 - 2032+)

Multi-charm baryons: key insight into charm production and hadronization



- Expected reconstruction performance for Ξ_{cc}^{++} in pp collisions

- Signal/background: 0.02
- Significance with 18 fb^{-1}: ~7.0



- Estimated ratios of multi-charm baryons to single-charm baryon yield as a function of multiplicity

Summary

- Brazilian group participated in several scientific results
- Brazil has a crucial role in the upgrade of ALICE
  - GEM's studies
  - SAMPA
  - MFT
  - FoCal
  - ALICE3
- Brazil is now a CERN Associate Member State
  - Unique opportunity for Brazilian Industry and Science
- Run 3, Run 4 and Run 5:
  - High precision data coming soon! Stay tuned!

UNICAMP

USP

UFABC

UFRGS

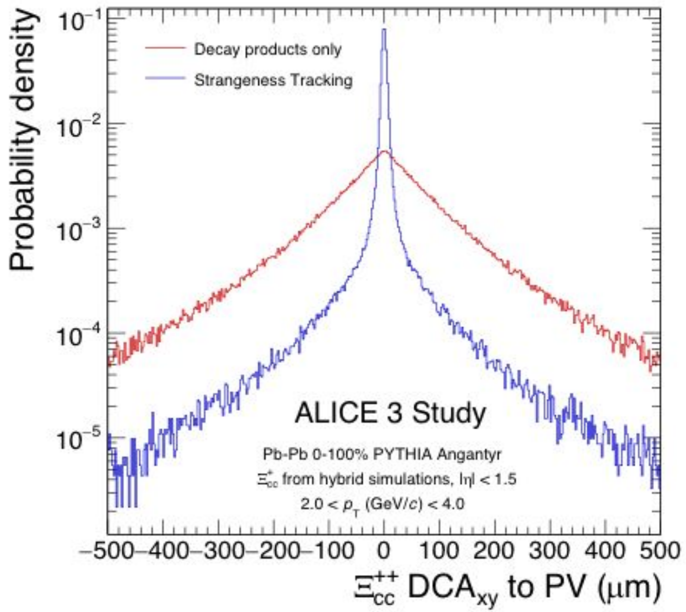
Thank you for your attention!

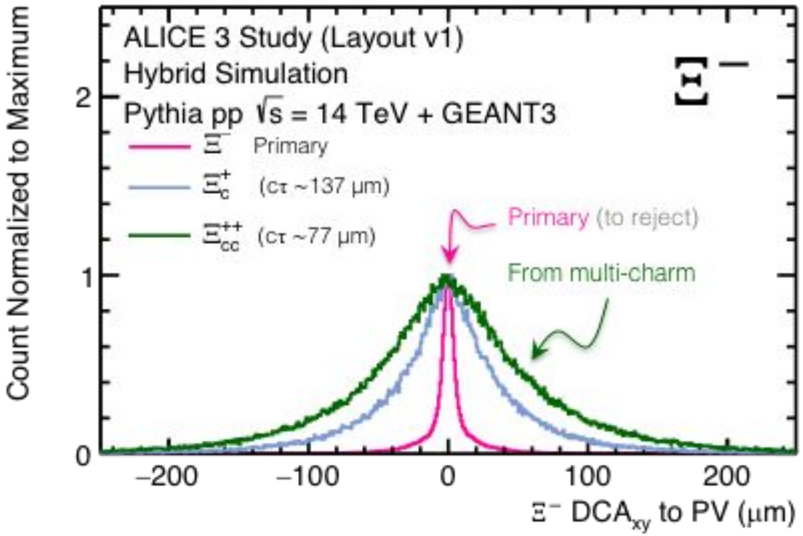
Backup

ALICE upgrade: ALICE 3 (Run 5 - 2032+)

Multi-charm baryons: key insight into charm production and hadronization

- Improves separation power between primary and secondary Ξ^-
  - Important to select Ξ^- from Ξ_{cc}^{++}



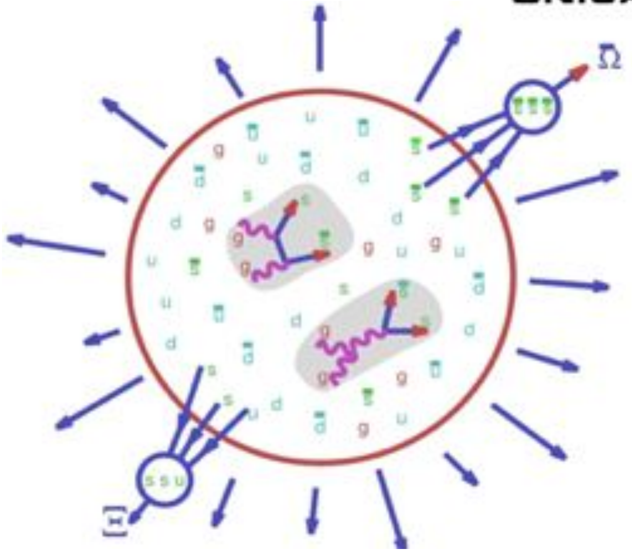


Strangeness Enhancement

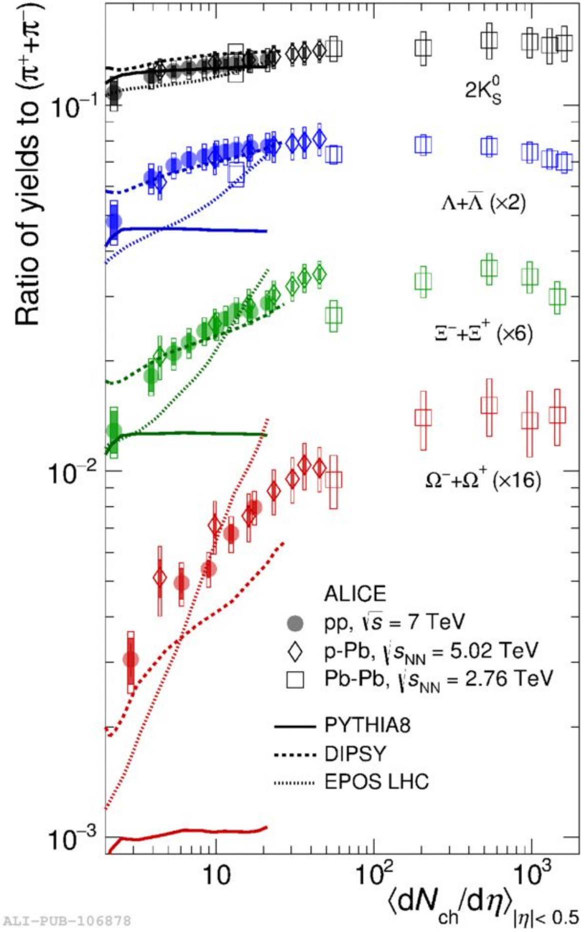
- Direct production of strange hadrons via color string breaking is suppressed
  - multi strange is even more suppressed

- Hadron reaction from single strange to multi strange is slow and kinetically disfavored

- **QGP scenario brings enhanced production of strange hadrons**

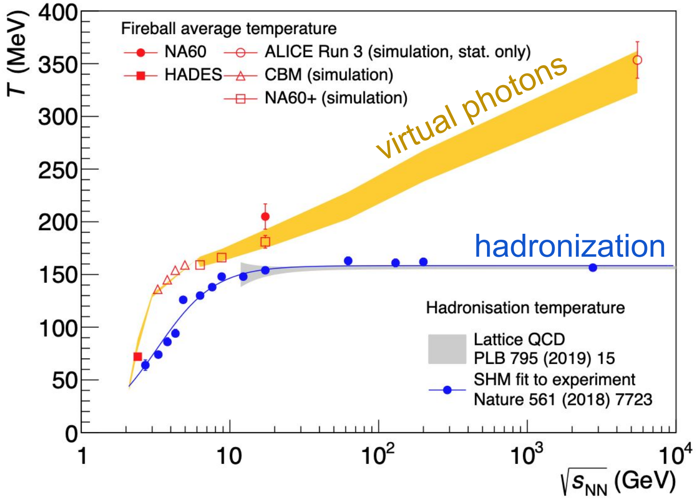


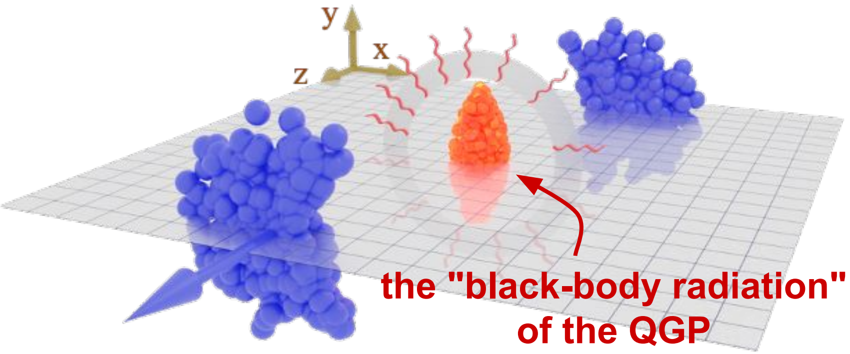
Strangeness Enhancement



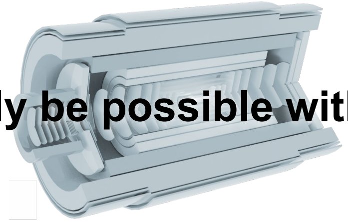
- Strangeness enhancement in pp data, where no QGP expected
- Models fail to describe observed enhancement
- Charged particle density scales strangeness enhancement measured in different systems and different energies

Dileptons: why are they interesting?





- QGP temperature can be measured in different ways
  - **thermal models**: temperature at hadronization
  - **virtual photons**: temperature before hadronization: larger, access to earlier stages!
- ALICE will do early measurements in Run 3 and 4
  - However, *differential measurements* are required to disentangle temperature value
  - from global average temperature …
    - …to *precise knowledge of system evolution*!

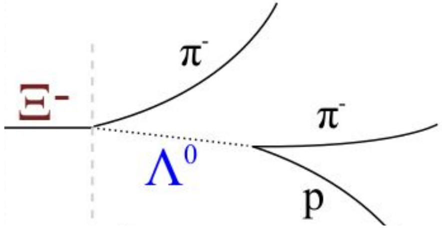


This will only be possible with ALICE 3!

Machine Learning applied to strangeness reconstruction

Standard Selection:

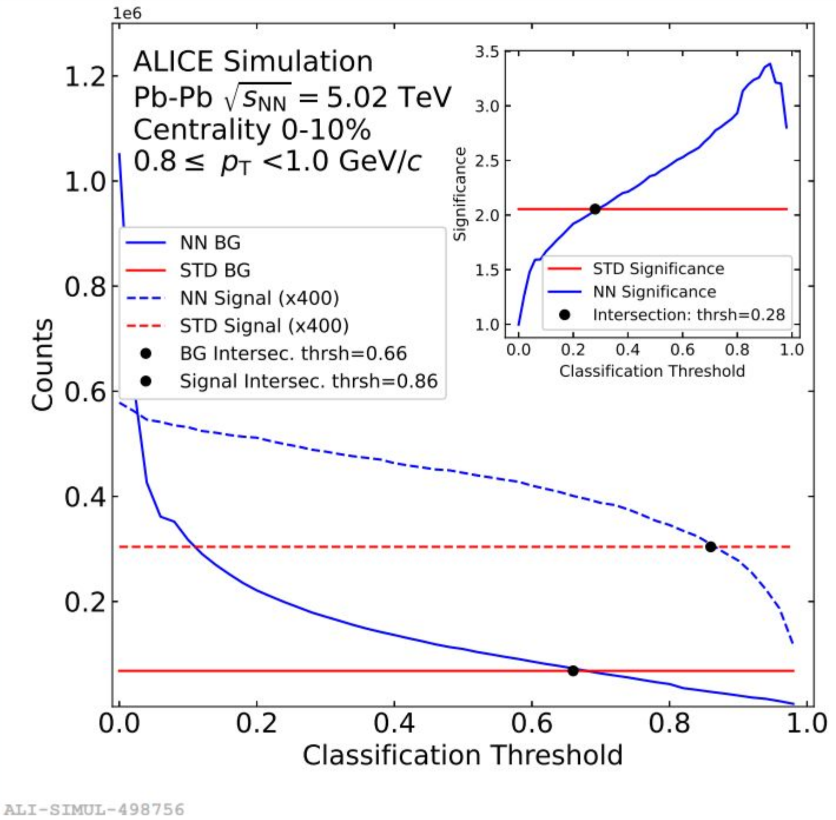
- **Topological cuts:**
  - Cascade decay



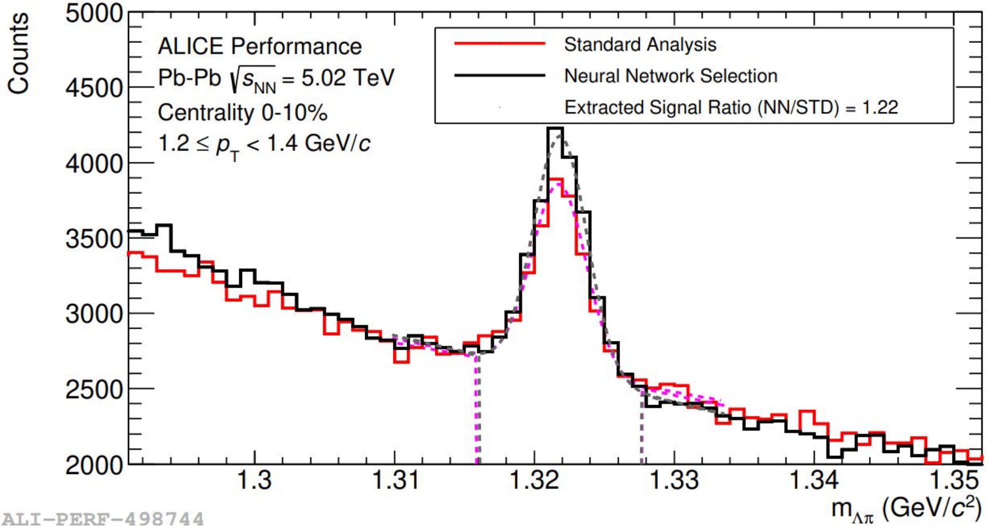
ML Analysis:

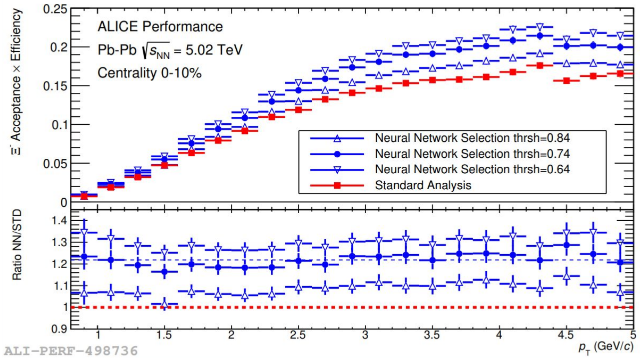
- Neural Network predicts the probability of three given candidate tracks being the product of a Ξ decay.

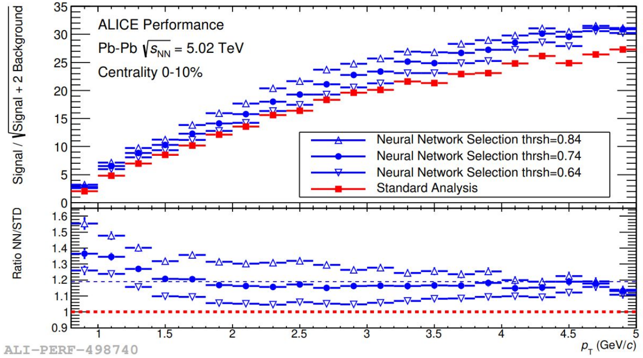
- Selection in a probability threshold indicates simultaneous gain in efficiency and significance.



Machine Learning applied to strangeness reconstruction



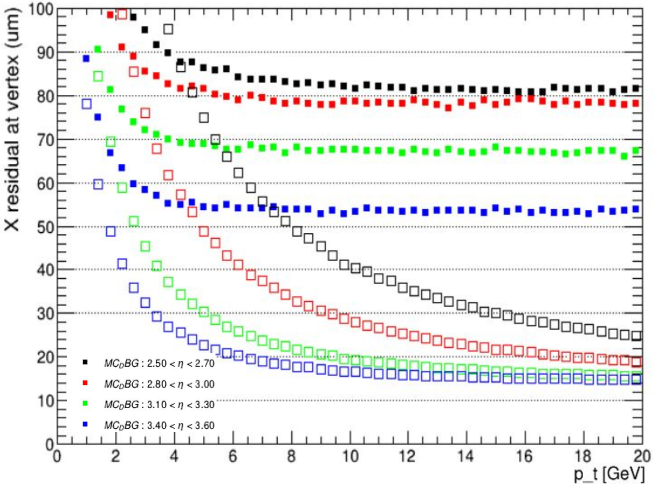




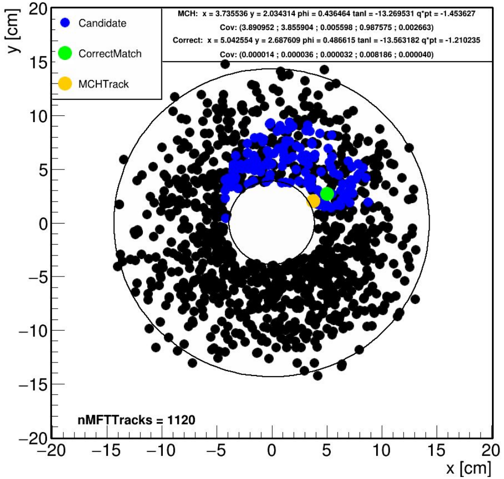
- Comparison of Invariant Mass spectra obtained with Neural Network and Standard Analysis: 22% gain in extracted signal
- Comparison of Efficiency obtained with Neural Network (±0.1 threshold) and Standard Analysis: 22% average gain
- Comparison of Significance obtained with Neural Network (±0.1 threshold) and Standard Analysis: 19% average gain 37% in the lowest p_T bin

ALICE upgrade: Muon Forward Tracker

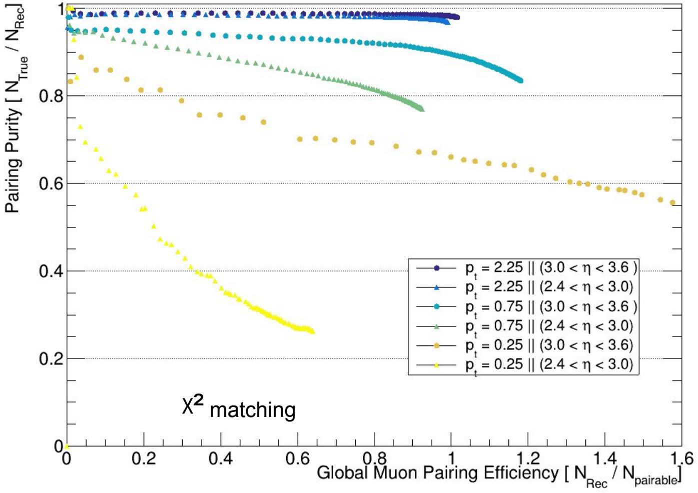
MFT standalone
performance assessment

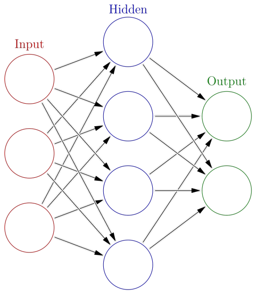


Track matching



Matching purity and efficiency:





Machine
learning
interface