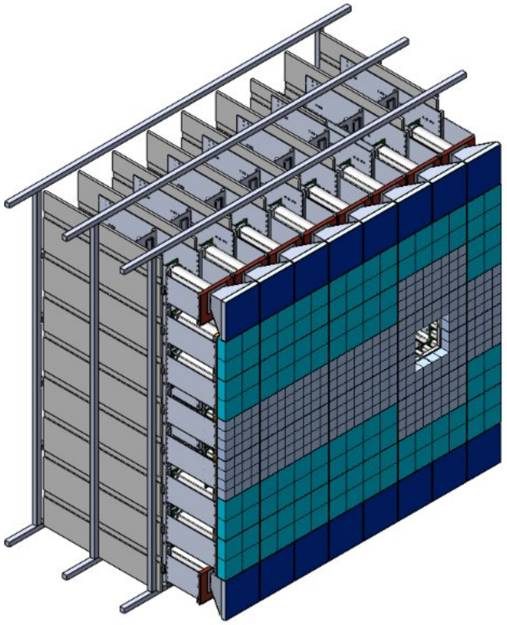
FSD - status

Petr Chaloupka

Czech Technical University in Prague



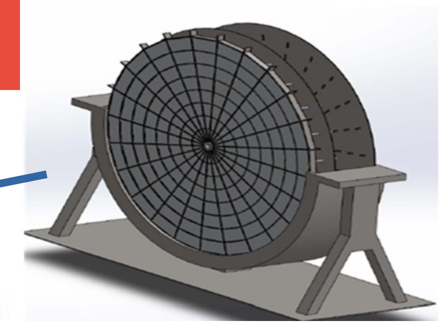
20.10.2025

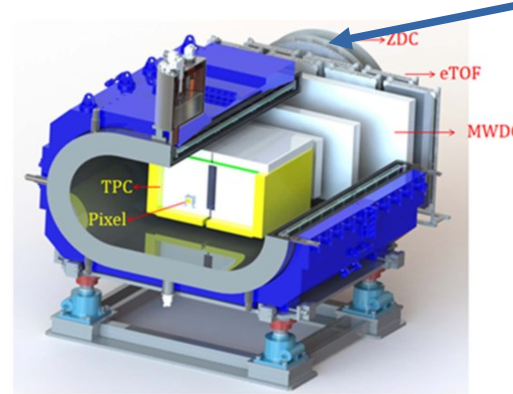
Forward Spectator Detector

Motivation:

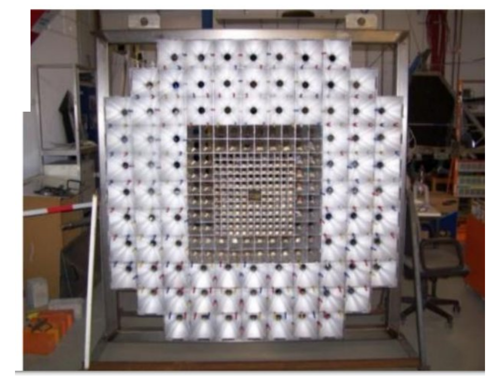
- Detect charged hadrons in forward rapidity
  - Protons and spectator fragments
- Centrality and event plane measurements
  - Independent of mid-rapidity
- similar in function to HADES FWALL or CEE- ZDC

CEE-ZDC



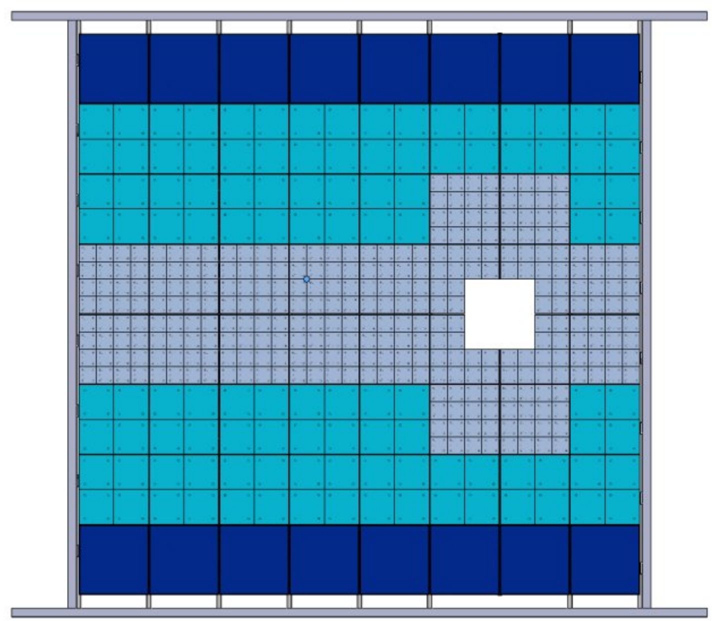


HADES hodoscope



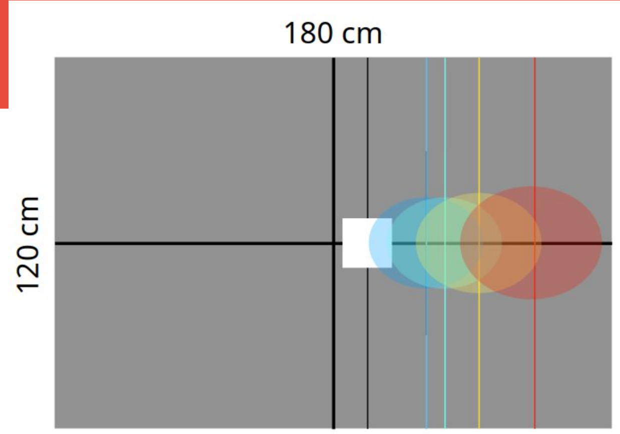
Scintillator hodoscope design

- Size 130x130cm
- Plastic scintillators pads
  - Varying sizes (4 – 16 cm wide)
- PMT + DiRICH readout
  - 1 and 2‘‘ PMT available from Juelich
  - too harsh for SiPM



CBM - FSD

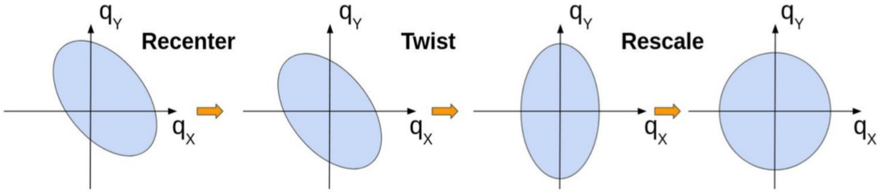
Flow with FSD



Non-trivial effects of magnetic field

- Different rapidities centered in different x position due to the magnetic field
- Mixing of rapidity, pt, phi
- Depends on charge/mass ratio
  - FSD - only dE/dx information

$$\mathbf{u}_n = \{\cos n\varphi,\ \sin n\varphi\}, \quad \mathbf{Q}_n = \sum_{i=1}^{N} w_i \mathbf{u}_{n,i},$$



Flow using Q_N vector framework

- Integrated with CBM Analysis framework
- 3 or 4 subevent correlations
- correction for non-uniform acceptance
  - Recentering, twist, rescaling
- Q vector (subevent selection) must be done carefully
  - correlated background can induce bias
  - no PID and tracking in forward direction

resolution:

$$R^A_{n,\alpha} = \sqrt{\frac{\langle Q^A_{n,\alpha} Q^B_{n,\alpha}\rangle \langle Q^A_{n,\alpha} Q^C_{n,\alpha}\rangle}{\langle Q^B_{n,\alpha} Q^C_{n,\alpha}\rangle}},$$

v_1:

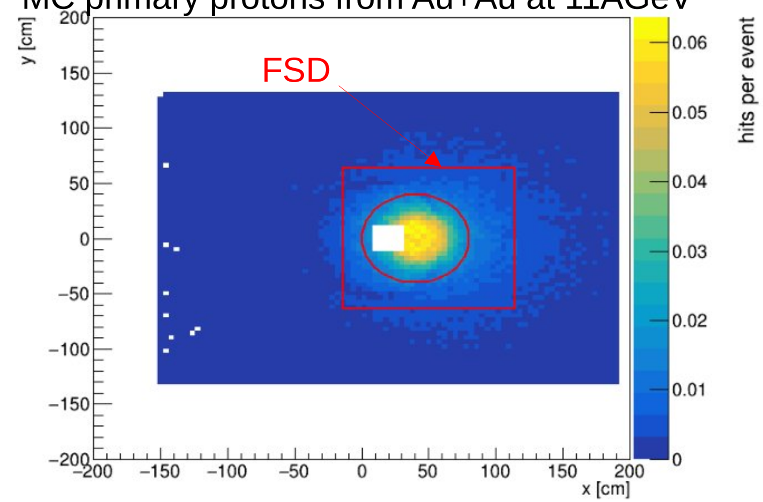
$$v_{n,\alpha} = \frac{2\langle q_{n,\alpha} Q_{n,\alpha}\rangle}{R_{n,\alpha}},$$

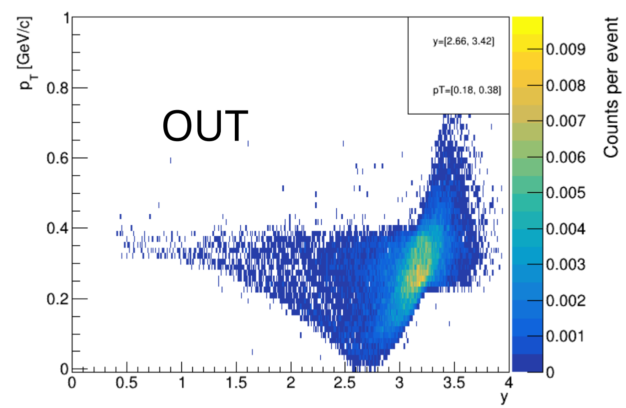
Flow with FSD

Eventplane information from primary protons (and fragments)

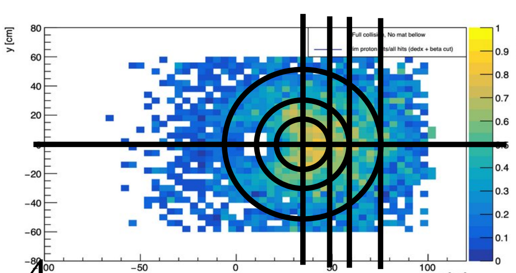
- Proton phi-angle calculated from hit position (not directly from momentum vector)
    - interplay of rapidity and pt
- Subevents centered at maximum of proton distribution
    - 3 subevents with different <pt>
    - for model comparision we use y & pt cut

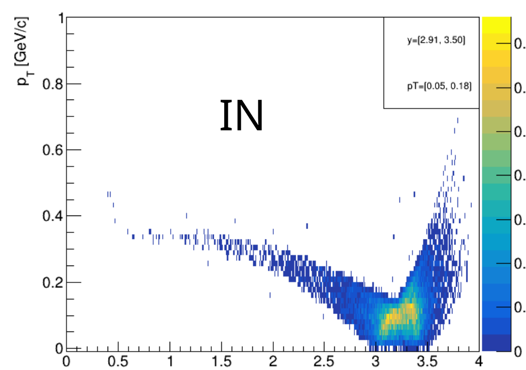
MC primary protons from Au+Au at 11AGeV

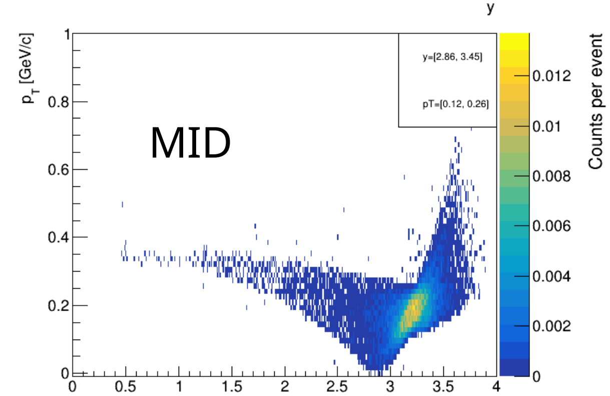




Subevent	R in FSD [cm]	MC y	MC p_T
IN	[0, 14]	[2.91, 3.50]	[0.05, 0.15]
MID	[14,24]	[2.86, 3.45]	[0.15, 0.22]
OUT	[24,40]	[2.66, 3.42]	[0.22, 0.38]







Comparing GEANT to pure MC

Using DCM-QGSM-SMM

Careful apple-to-apple comparison:

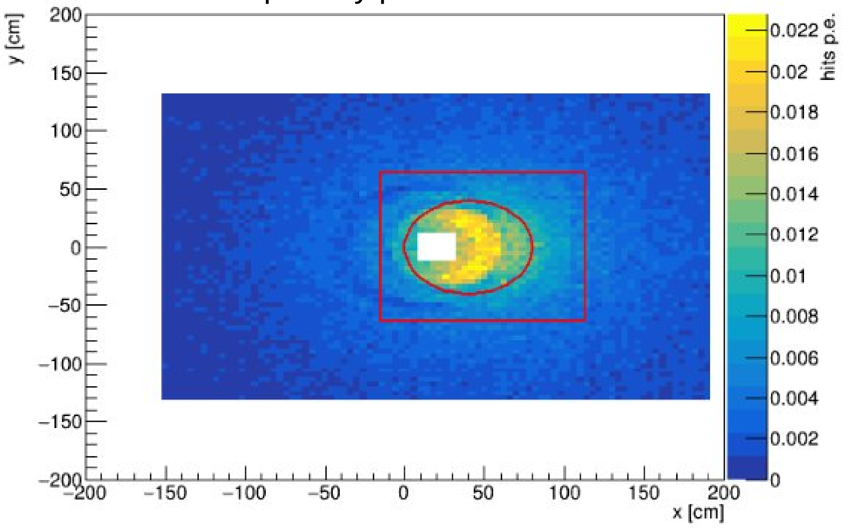
- same subevent definition

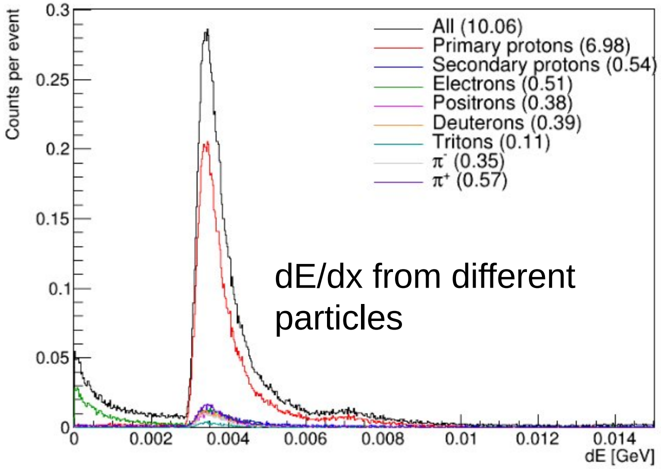
    - y, pt cut in MC, geometrical in GEANT sim.

- selection in FSD via dE/dx to select Z=>1
- the particle of which we measure flow are directly from MC

    - no effect of tracking, PID,

Simulated primary protons from Au+Au at 11AGeV





dE/dx from different particles

Comparing GEANT to pure MC

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Careful apple-to-apple comparison:

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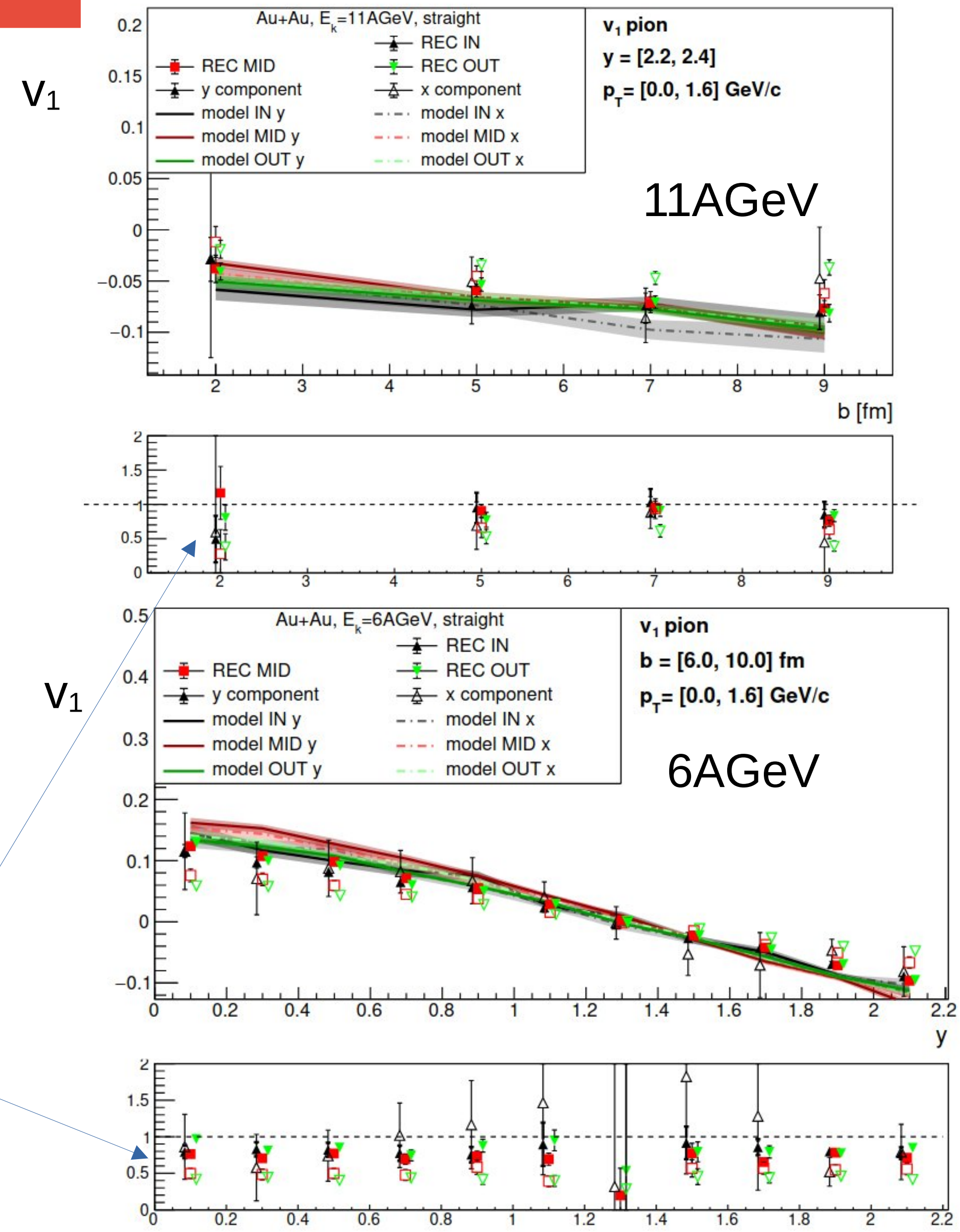
    - y, pt cut in MC, geometrical in GEANT sim.
- selection in FSD via dE/dx to select Z=>1
- the particle of which we measure flow are directly from MC
    - no effect of tracking, PID,

v_1 extracted from correlation with Qn vector separately using three subevents and x, y component

- 6 independent (technically) values
- Handle on systematics

Systematic difference between Geant and MC

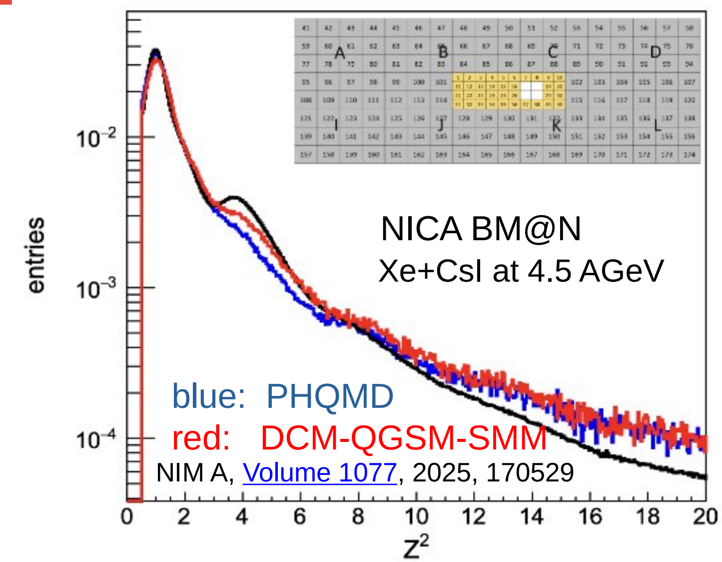
- More pronounced in x-direction (open points)
    - B field effect
- **Effect of correlated background**
    - traced to beam pipe



Centrality with FSD

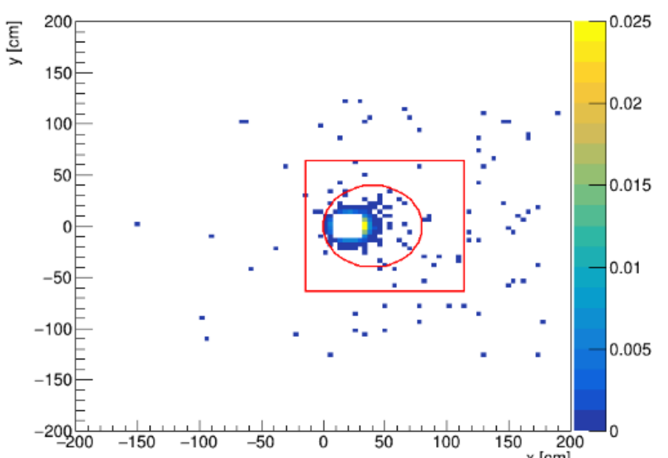
Deduced from charge deposition of spectators

- Insensitive to neutrons
- Effect of beam hole
  - missing fragments with charge/m close to beam
  - model dependent forward fragment production
- Effect of beam pipe material
  - loss of fragments

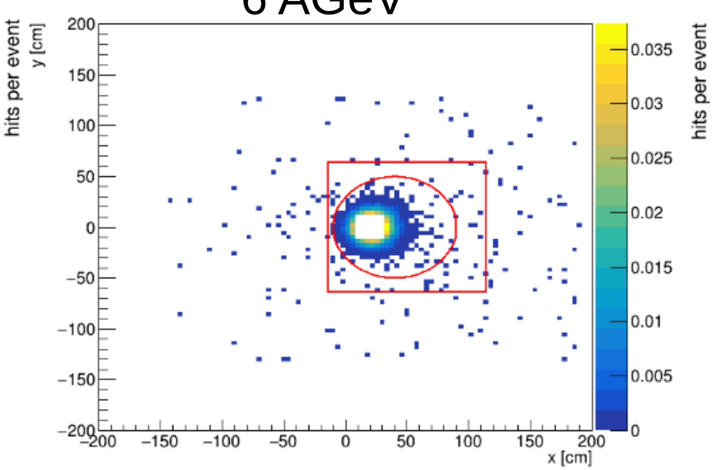


Fragments (Q>1) in FSD in Au+Au

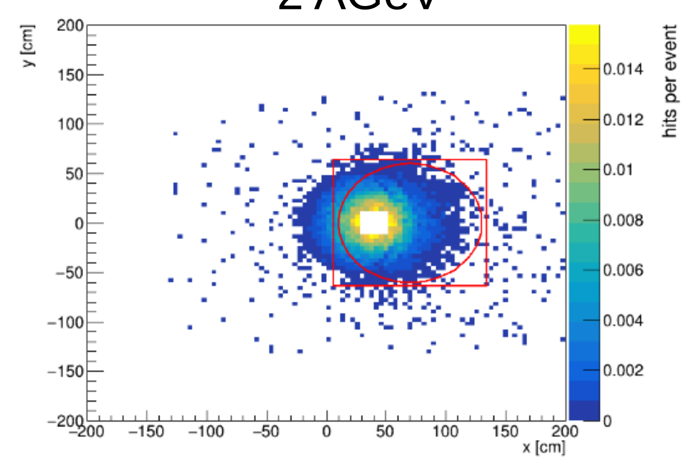
11AGeV



6 AGeV



2 AGeV



Centrality with FSD

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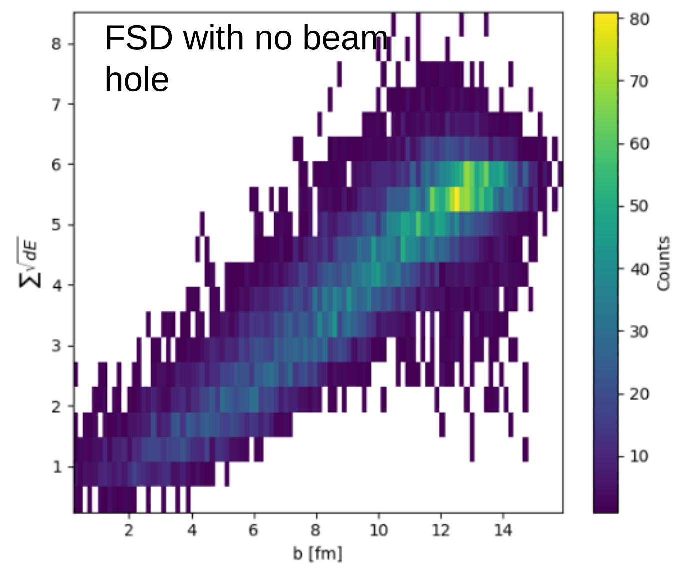
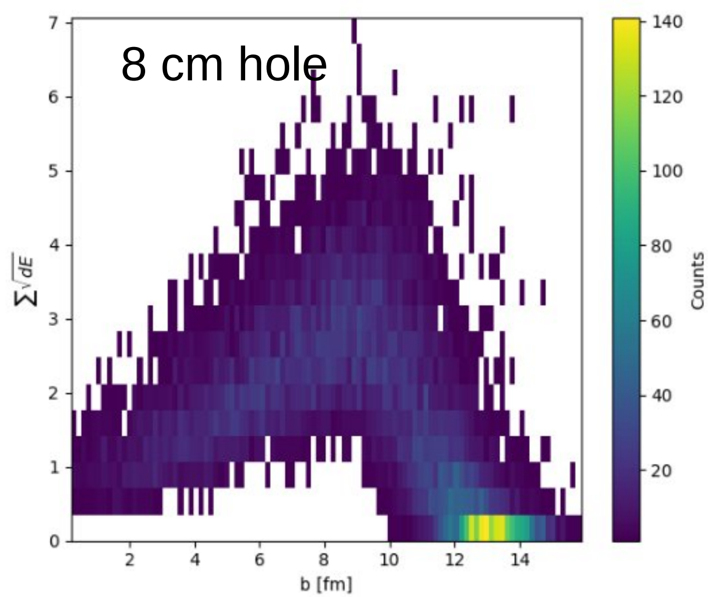
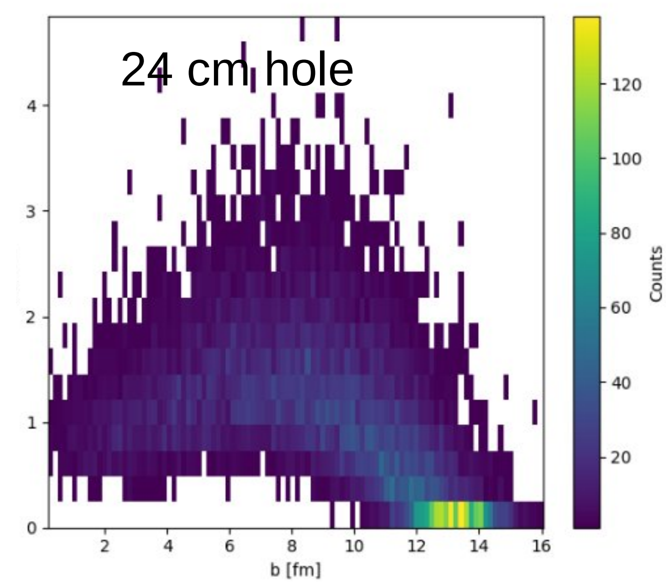


First studies by Radim Dvorak

- Using DCM-QGSM-SMM
- Summing sqrt of E-loss
- No beampipe and vacuum in the cave
- FSD is sensitive to centrality
- Significant effect of beam hole





Centrality with machine learning

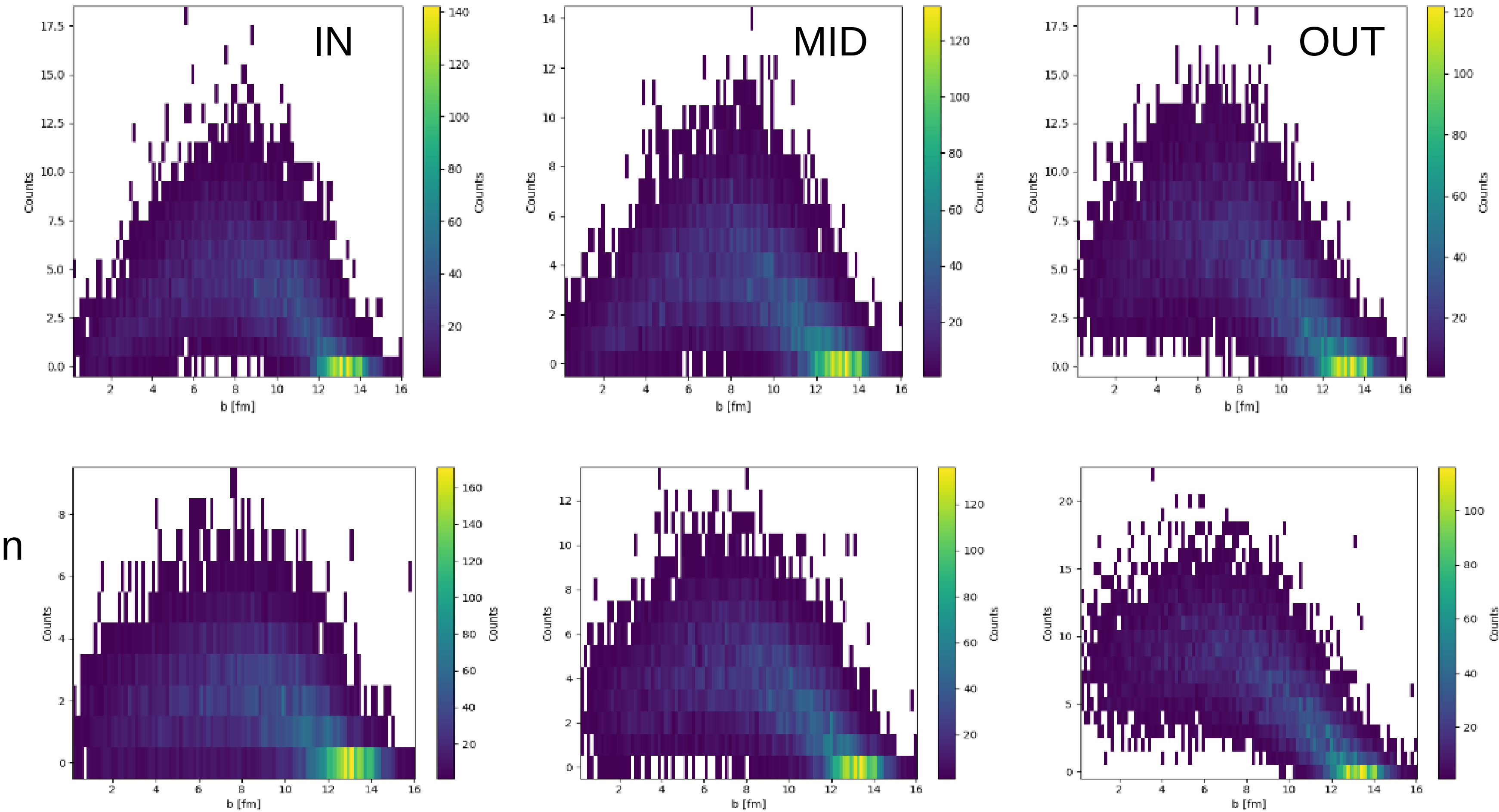
Centrality dependence of energy deposition differs for subevents

- Using BDT to reconstruct centrality
- Supervised learning – depends on model

number of protons, 11AGev, 8cm hole

MC model + acceptance

Geant sim + dE/dx selection



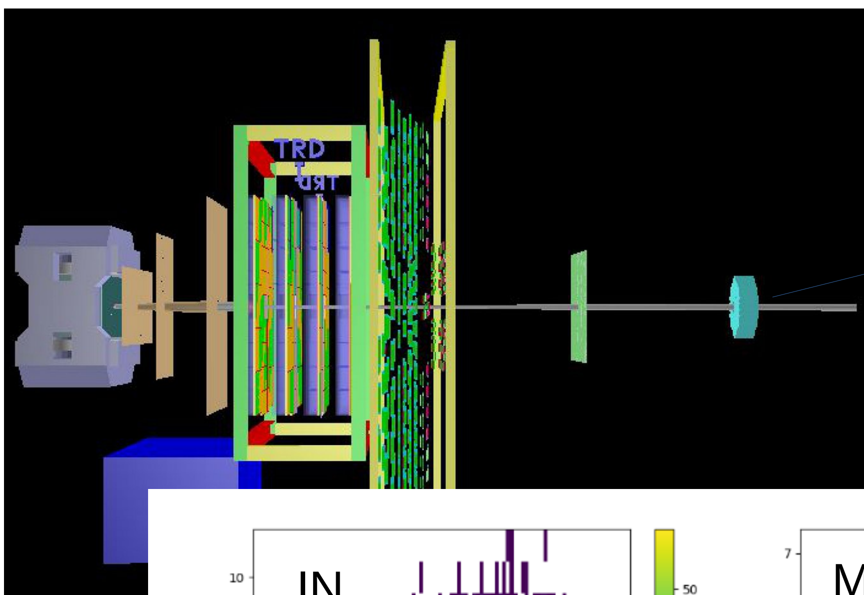
Centrality with machine learning

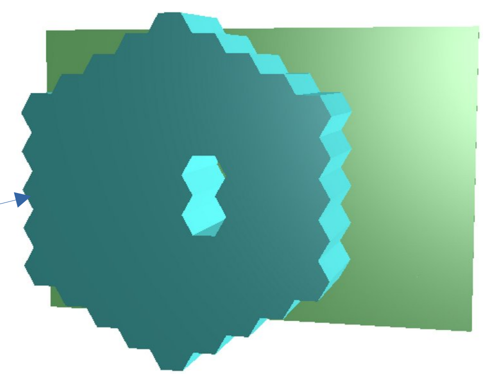
Centrality dependence of energy deposition differs for subevents

- Using BDT to reconstruct centrality
- Supervised learning – depends on model

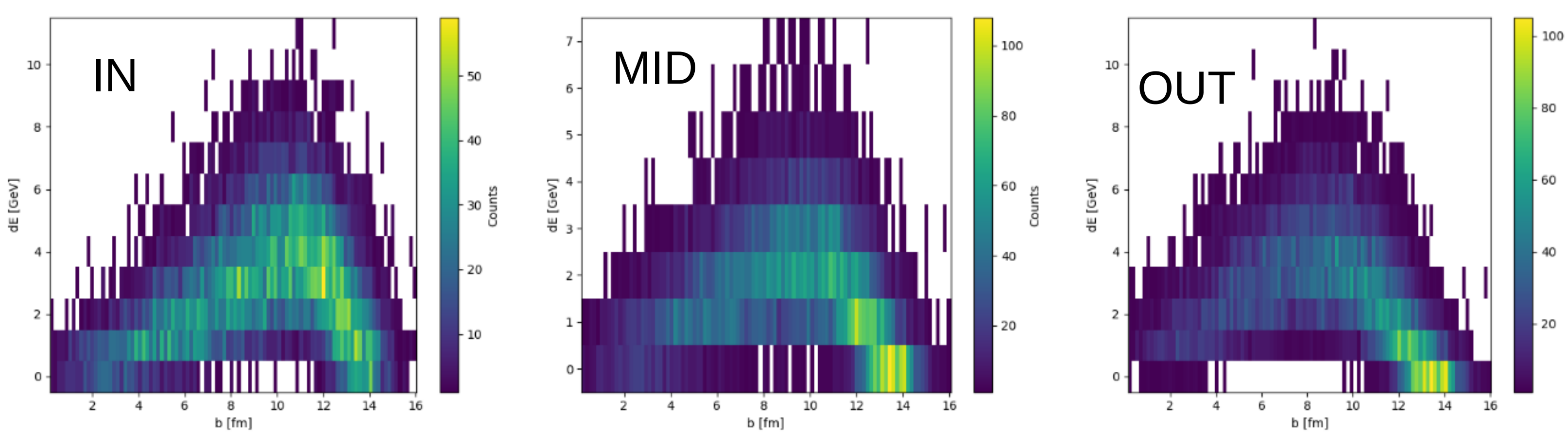
Inclusion of NCAL modules

- Expected ~ 30% efficiency for neutrons
- Large variations of deposited energy
  - separate subevent definition
- Simple Geant model





Energy depostion in NCAL



Centrality with machine learning

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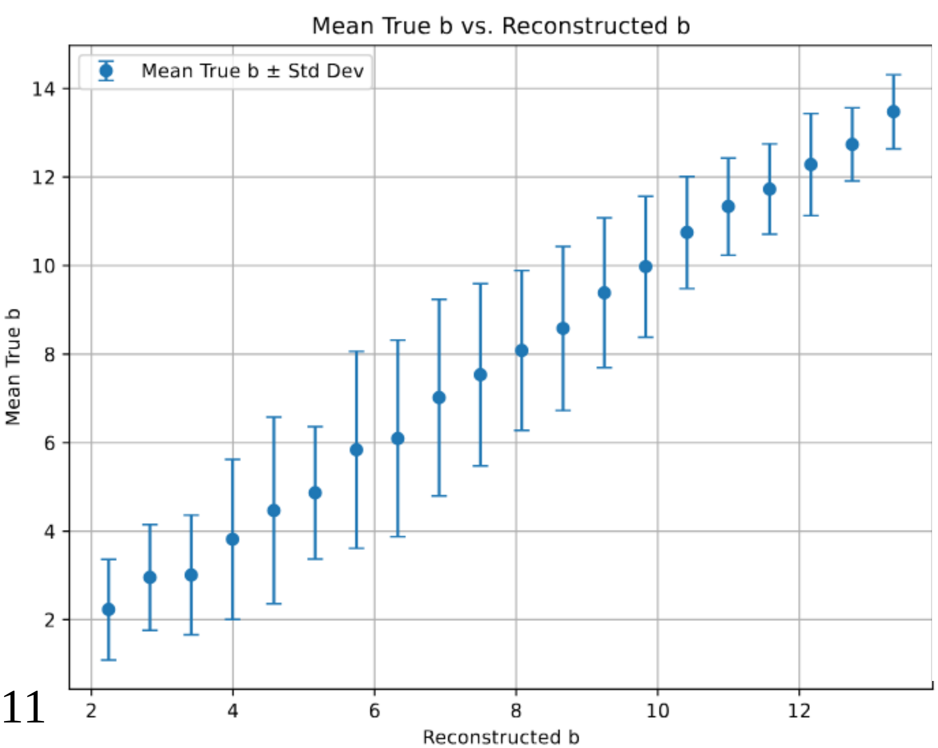
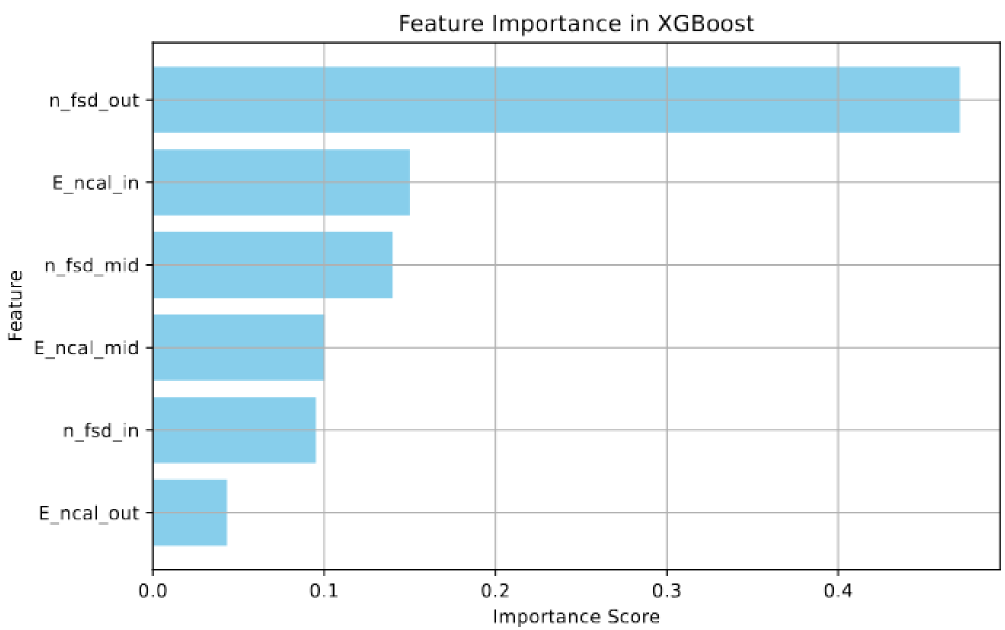
BDT results from combined FSD+NCAL signal

- works, but we need to understand better





Simulations for proton beam

Study of material effect on primary 12GeV protons

work by Ruijia Yang

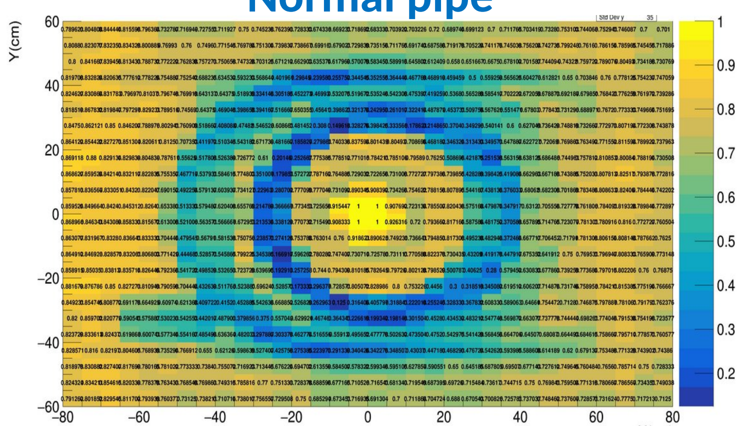
- Efficiency
- Momentum resolution
- Secondary particle production

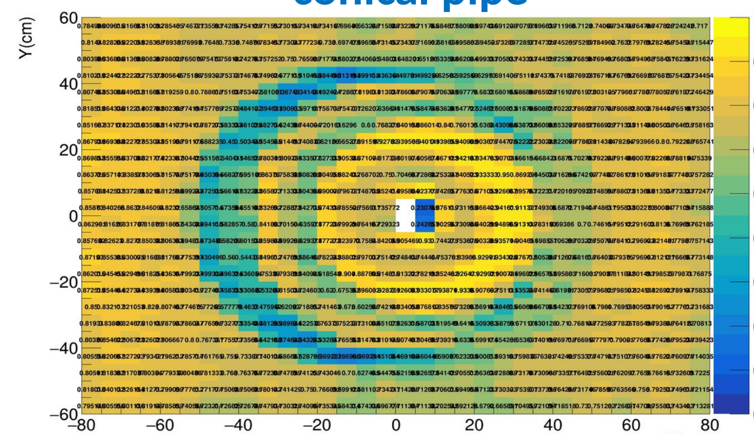
primary proton:

Normal pipe

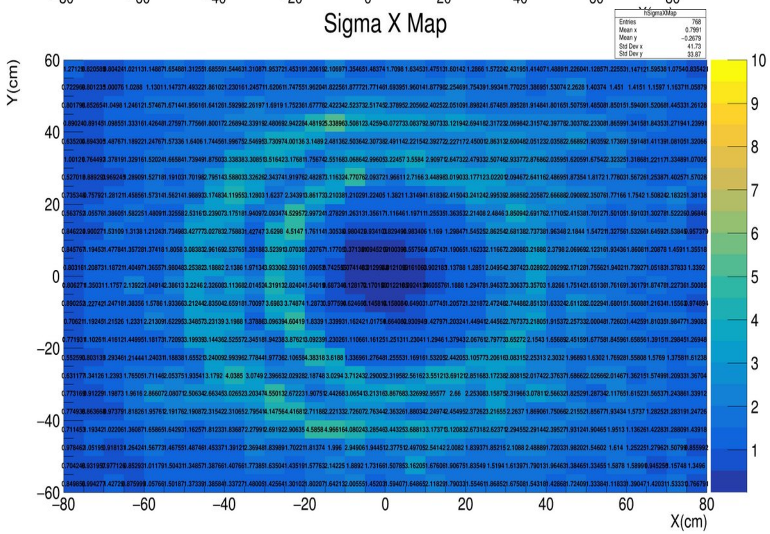
conical pipe

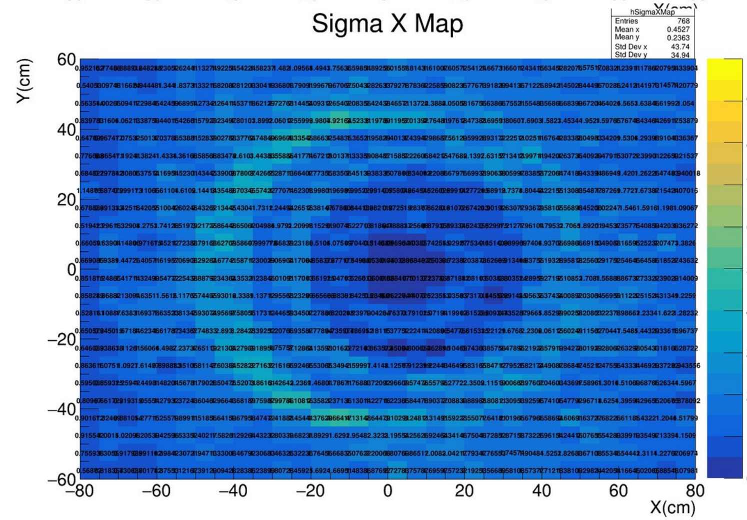
efficiency





hit resoluion

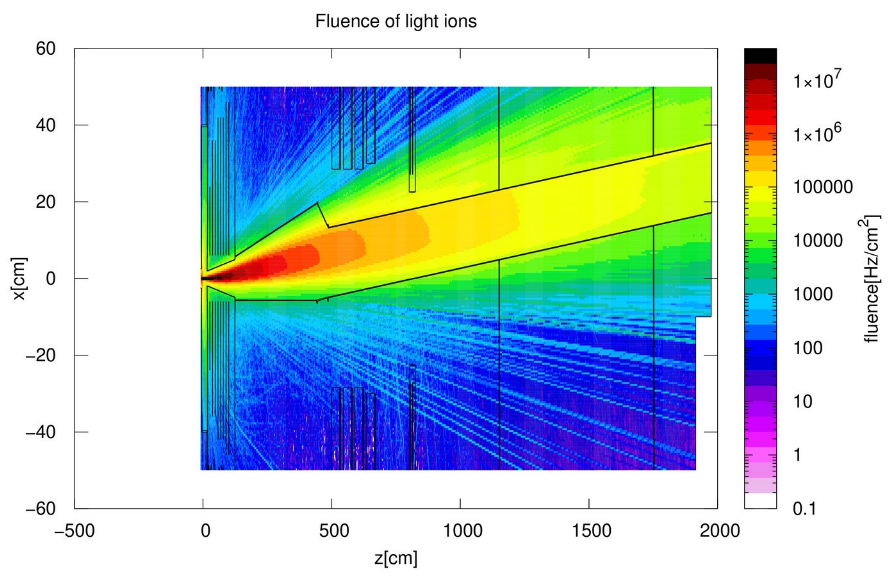




Beampipe-induced background

Interaction of spectators with beam pipe

- Effectively ~ 30 cm of carbon at very forward rapidity
- Rescattering of primary protons
- Loss of fragments passing through
  - Correlated background – interaction of fragments



Desirable to suppress background

- Different FSD position
- Two FSD planes
- Testing different downstream variants of beampipe
- Decrease effective material budget
  - Mechanical support
  - Vacuum pipes and inlets

Many paramters reduced to two options for detailed study

One FSD plane at ~12m with

1) Concentric (old) beampipe of 18 cm diameter
   - already produced and tested under vacuum
2) Beam pipe conical from bellow to FSD
   - 6m of pipe woudl have to be made

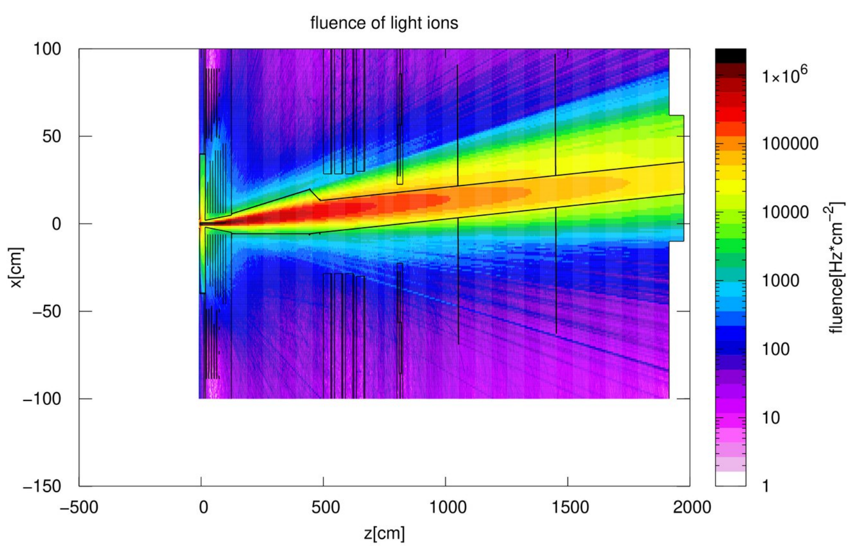
Fully conical beam pipe

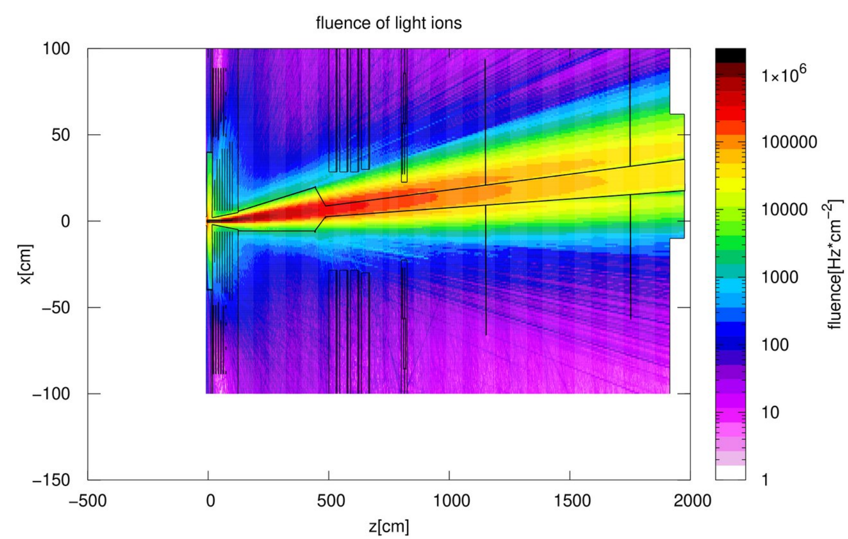
Study with completely conical beampipe from the below

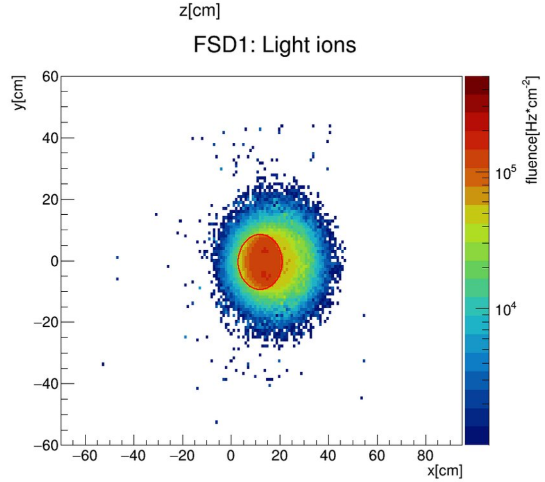
- Starting at 8cm diameter after RICH
- 13cm diameter at FSD at 12m

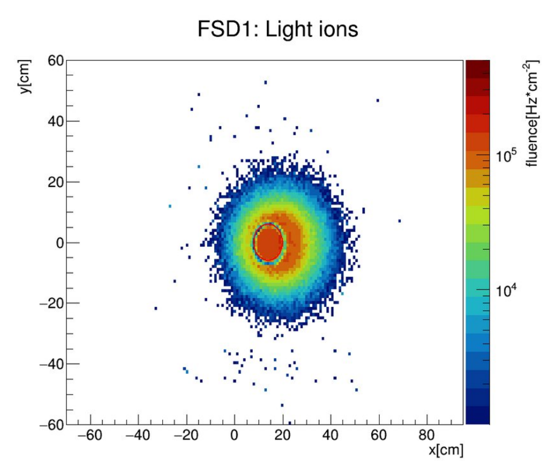
FLUKA

- clear improvements for light ions
- also material in neutron path









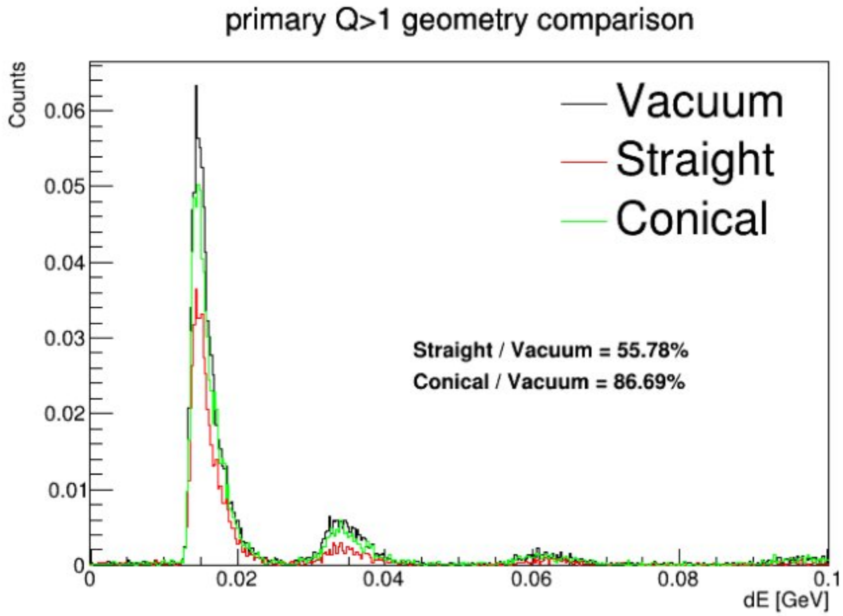
Geant BP simulations at 6AGeV

primary fragments:

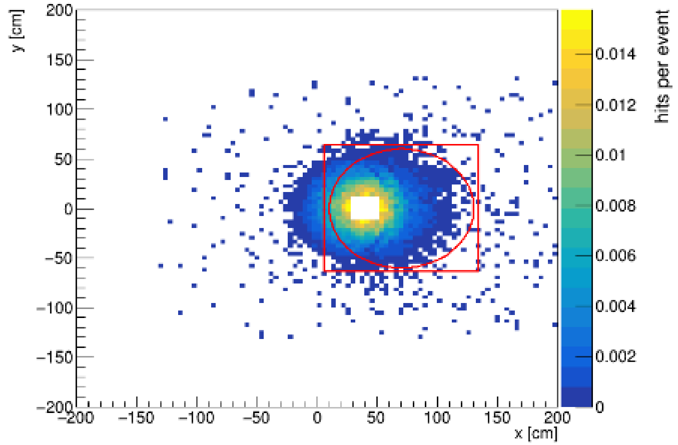
- about 50% fragments is lost in in concentric BP,
- only 14% in conical
- Note: with the same beam hole size

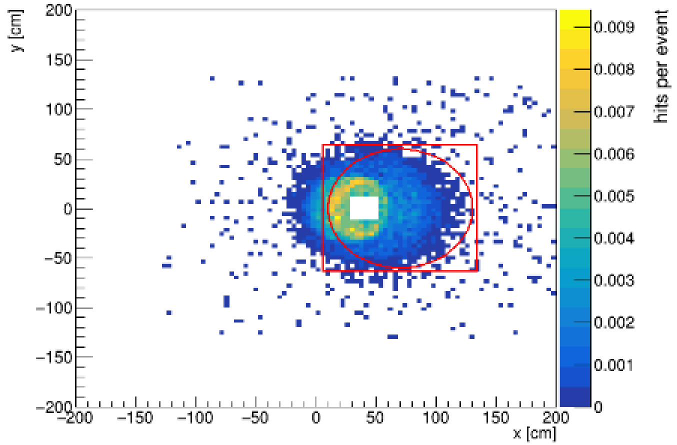
~ 50% higher background of secondary protons in concentric BP

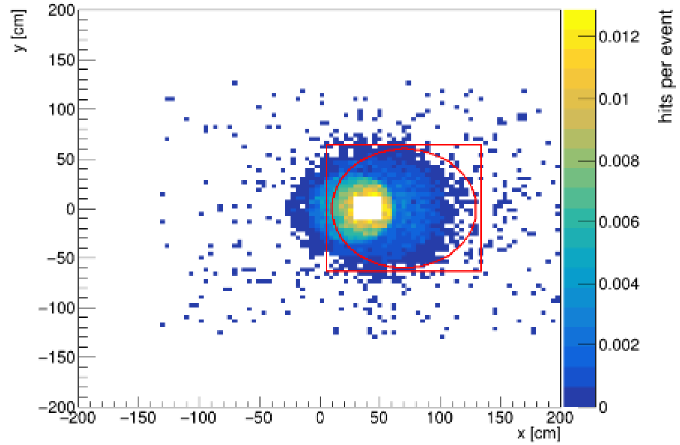
- correlated backround
- Effects on flow reconstruction



distributions of primary fragments in FSD in Au+Au at 6AGeV



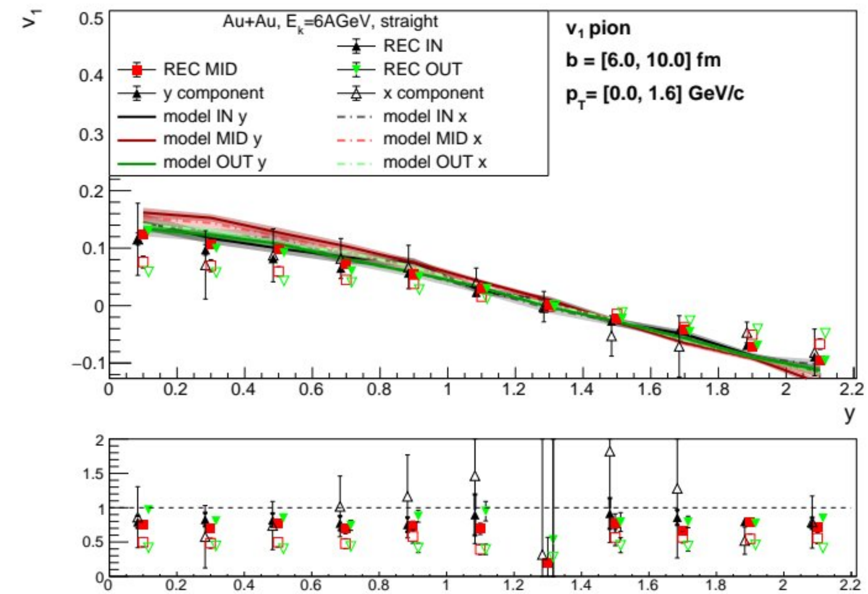


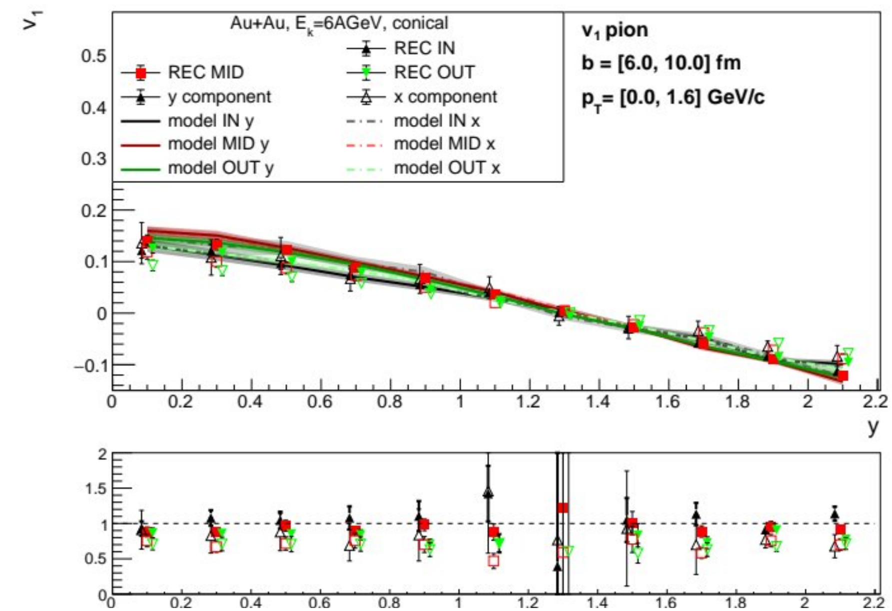


Effects on flow reconstruction

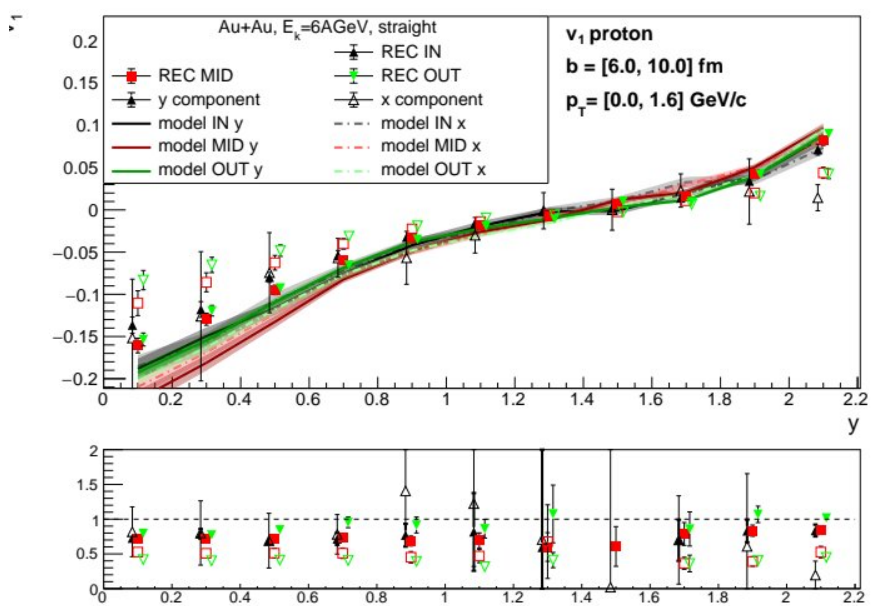
concentric BP | **conical BP**

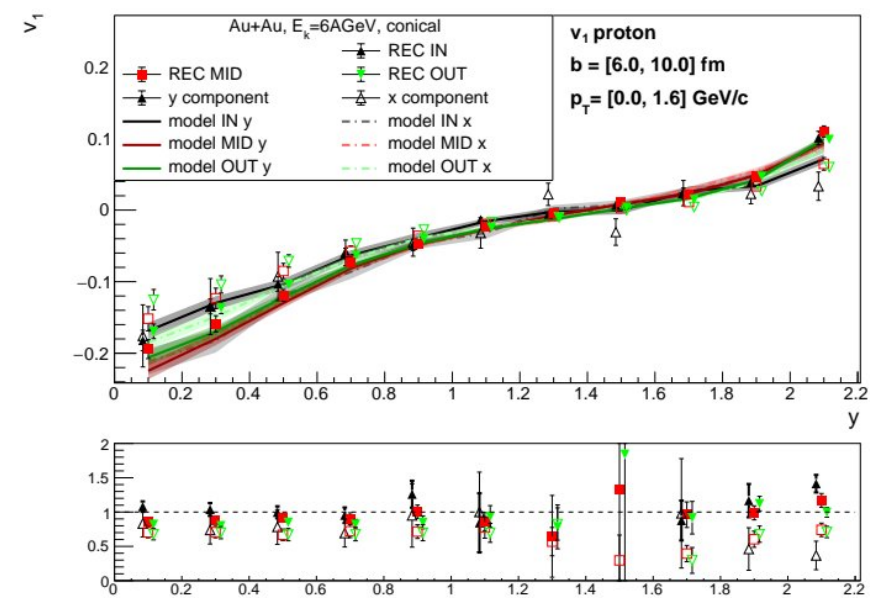
pion v_1





proton v_1

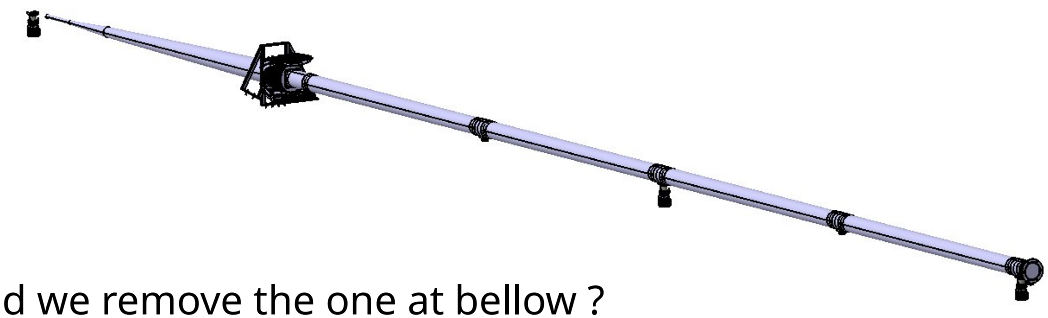




Beam pipe and vacuum

None of the simulations includes effect connect to vacuum and vacuum installations

- Flanges, hoses, vacuum pumps
- Beampipe support
- Background from beam-gas interaction

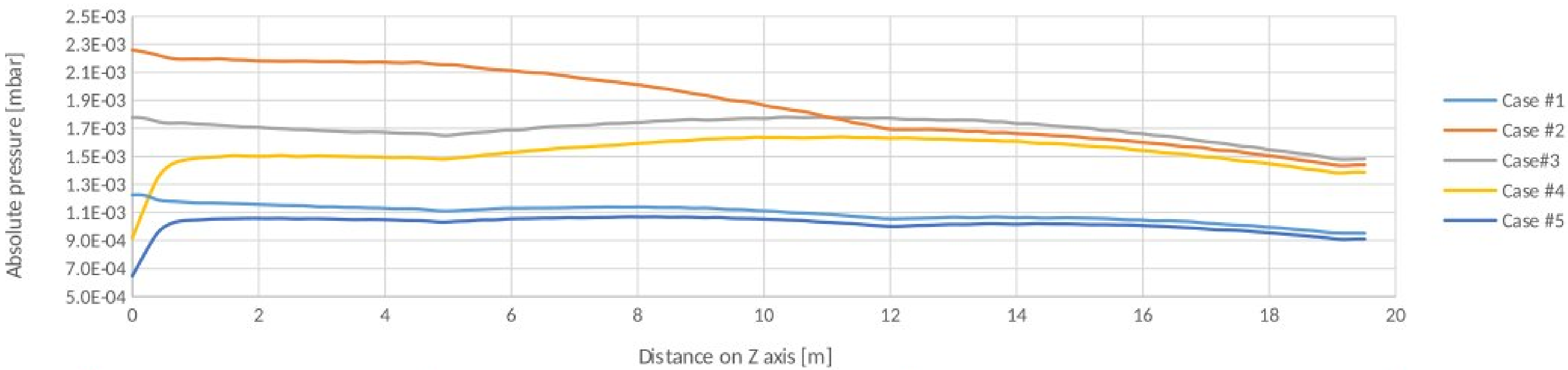


Potential 4 pumping stations

Could we remove the one at bellow ?

- less material in from of FSD

target bellow FSD beam dump

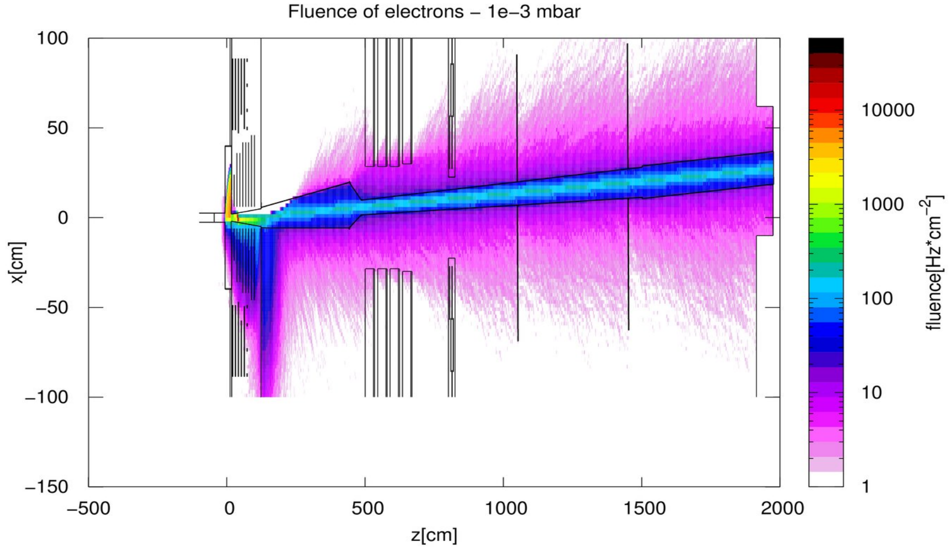


X	Case #1	√	Case #1	√	Case #1	√
X	Case #2	X	Case #2	√	Case #2	√
X	Case #3	√	Case #3	X	Case #3	√
√	Case #4	√	Case #4	X	Case #4	√
√	Case #5	√	Case #5	√	Case #5	√

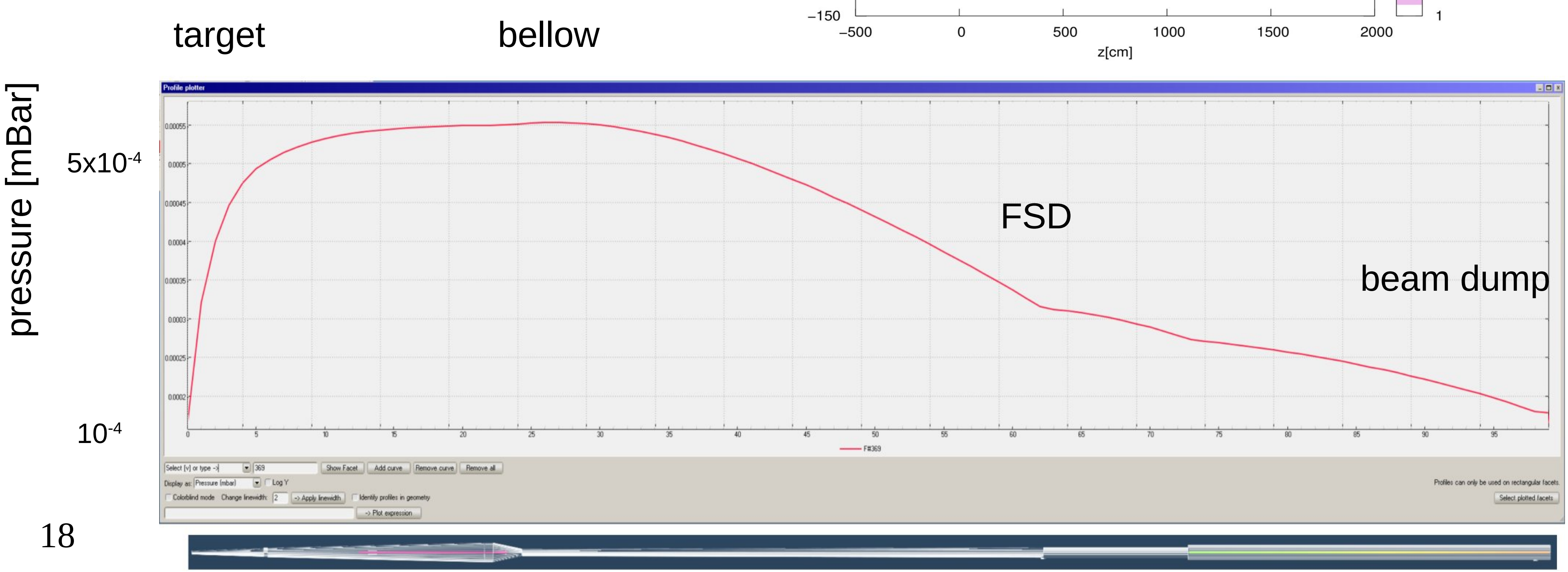
Beam pipe and vacuum

Simulations with three pumping stations

- assuming 10^{-4} mBar at target
- 5×10^{-4} mBar in RICH section should be OK
- Effect on background tested with FLUKA



Ongoing effort on beampipe mechanical design



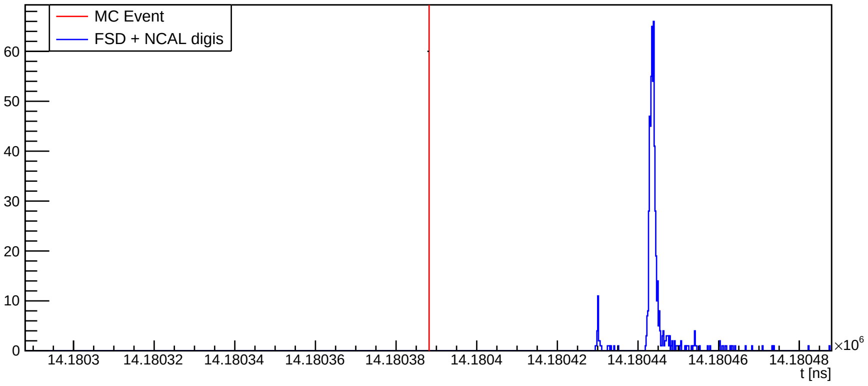
Towards FSD time-based simulations

work by Helena Dvorakova

Study effect of background from beam interaction with gas and beampipe

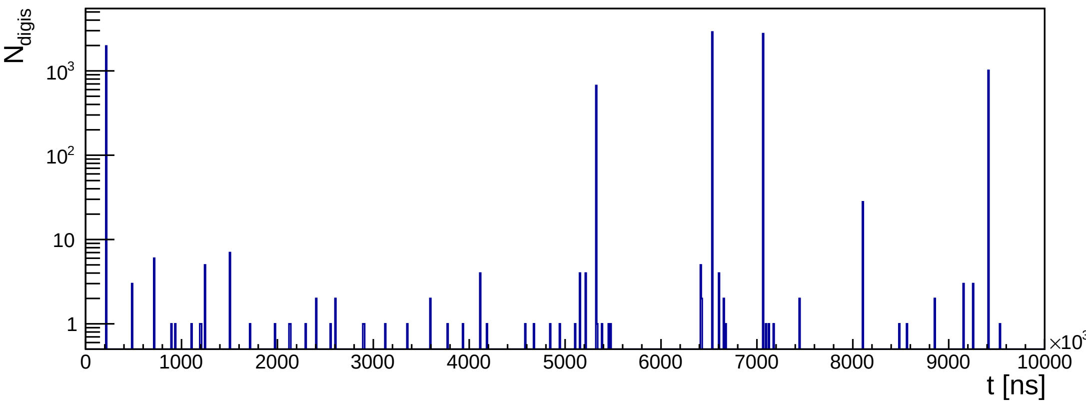
Trying to run time-based simulations

- Sliding window seed finder limited to lower rates
- Do not need tracking
- Do not need absolute event finding efficiency



Implementing simple seed finder

- Using MC event times as seed times
- Allowing event overlaps
- 100ns event window
- Some fixes needed in offline code
- First test with 1kHz event and 100kHz beam rate mixing



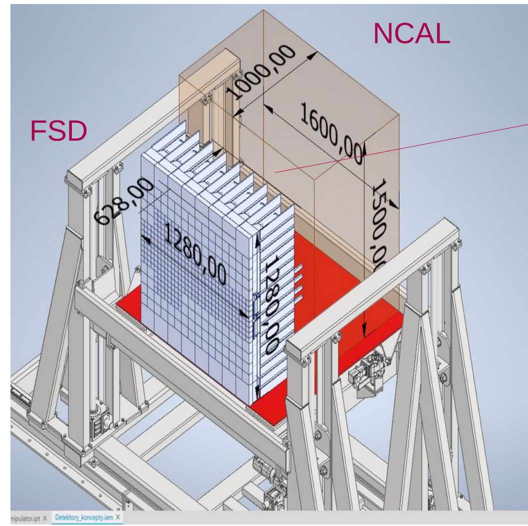
Signficant buildup of know-how

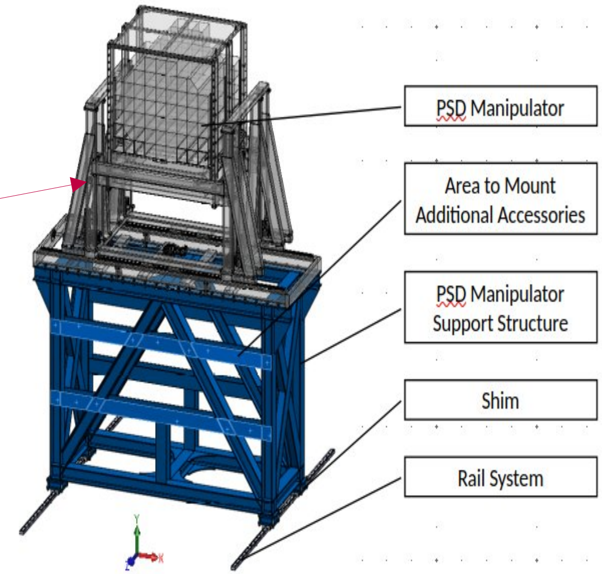
- Future improvement of digitizer

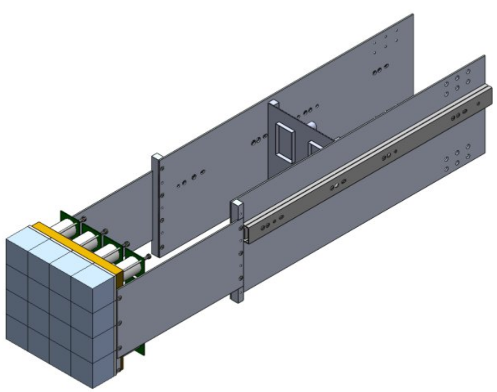
FSD mechanical design

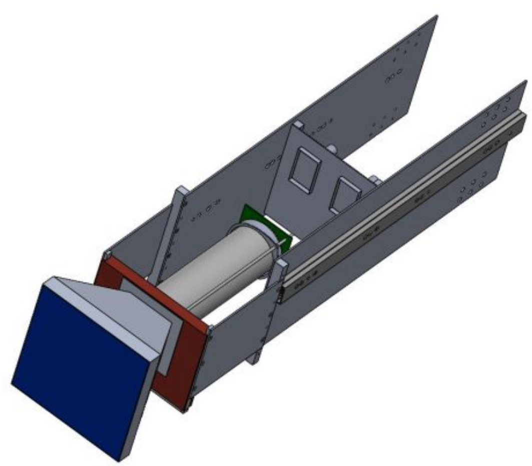
Work started on mechanical design

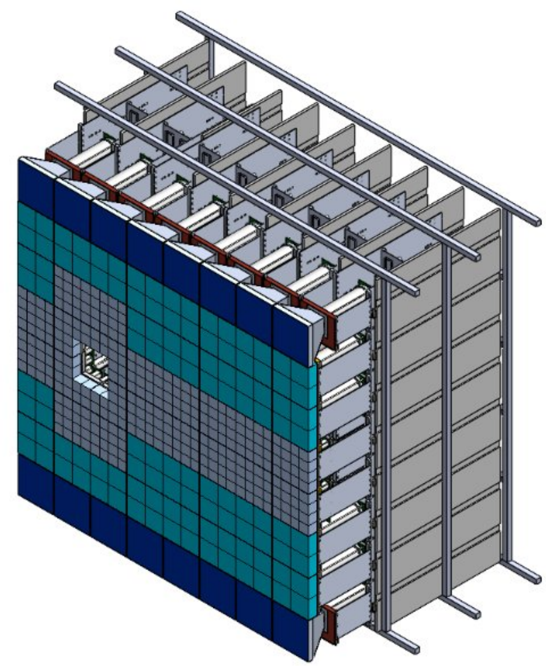
- Reusing the FSD manipulator
  - Reserved space for NCAL
  - New student to design the support stand
- Modular design
  - 6x6 up to 8x8 removable modules
  - Can be assembed, repaired and tested on the ground
  - Exchangable scintillator pads
    - 10kGy dose in 10Mhz run







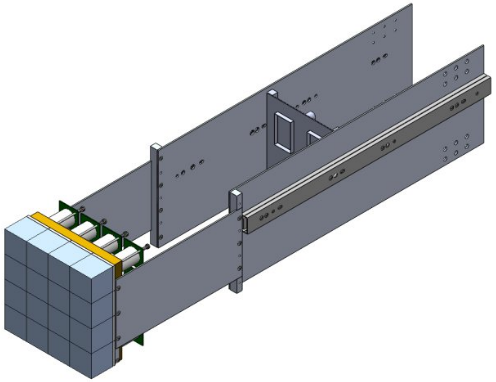


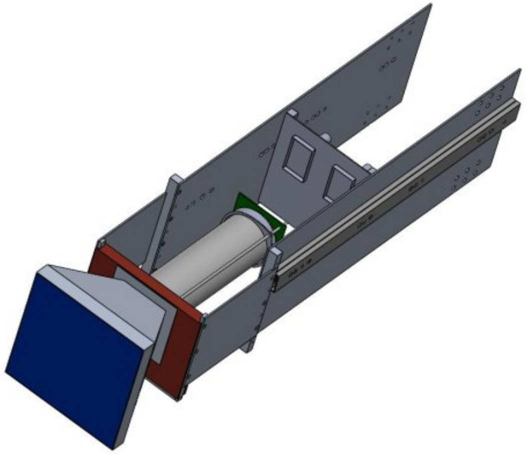


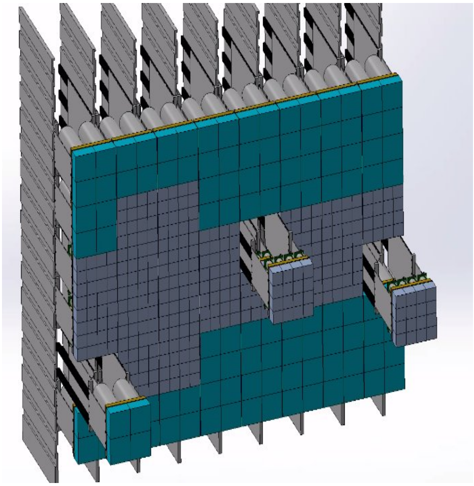
FSD mechanical design

Simple mechanical mockup

- working on improvements
- plan to make real module for test







Readout Electronics

Current status

- Use of the DiRICH readout boards
- Local setup with TRBNet
- Tested at mCBM in mRiCH DAQ

Placing DiRICHs in cave

- Planning for same or lower dose then RICH
- From Fluka simulations – must be on the ground level

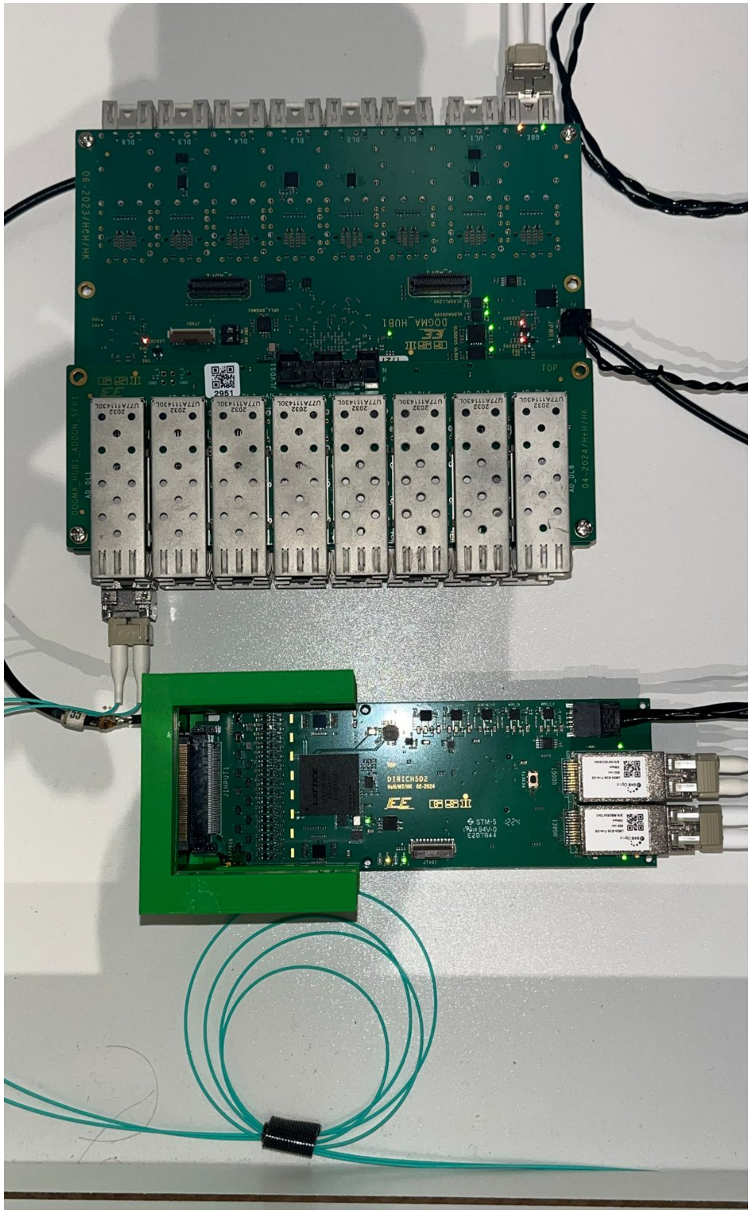
Dogma DAQ

- Radiation environment

  - DiRICH5D2 implements identification and self-recovery from single upset events

  - new version with rad hard FPGA

- High rate - new version also contains ethernet interface with capacity of 10 Gbps
- Integration to CBM DAQ being by implemented in Giessen
- Local test setup (P. Chudoba)



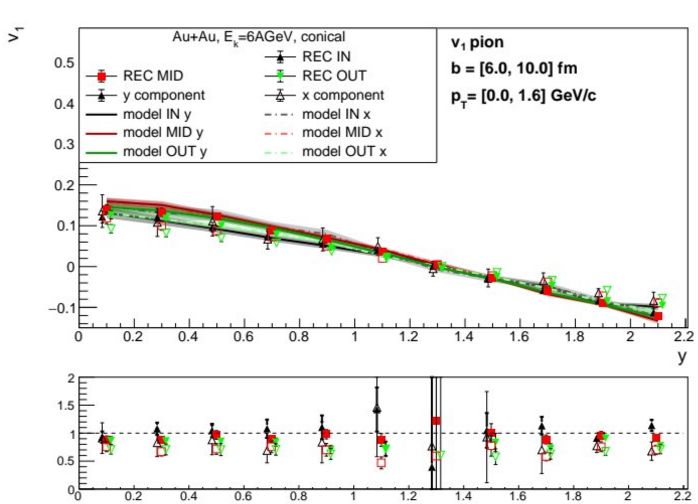
Summary and plans

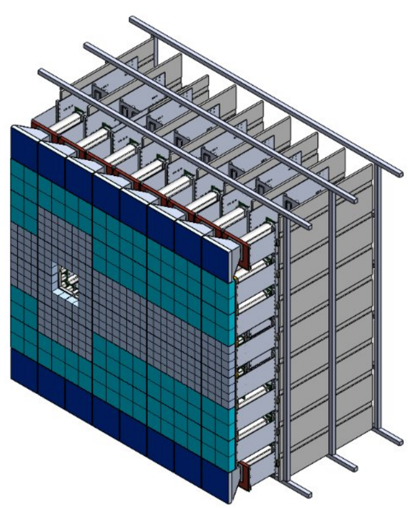
Simulations

- Finished study on event plane and flow reconstruction
  - Including effects of beam pipe material
- First results on centrality determination
  - Including NCAL
- Ongoing studies for p+p physics
- Work towards time-based simulations

Hardware

- Work to finalize beam pipe, support and vacuum
- Started work on FSD mechanical design
- Testing Dogma readout





Plans

- Finish study of centrality determination
- Finalize TDR

- Move to design of beampipe bellow
- Advance mechanical design
  - Connectors and cabling
  - Test module
  - Start work on FSD support
- DAQ - test Dogma
- Continue to analyze mCBM data
- Another NCAL module test in NPI Rez